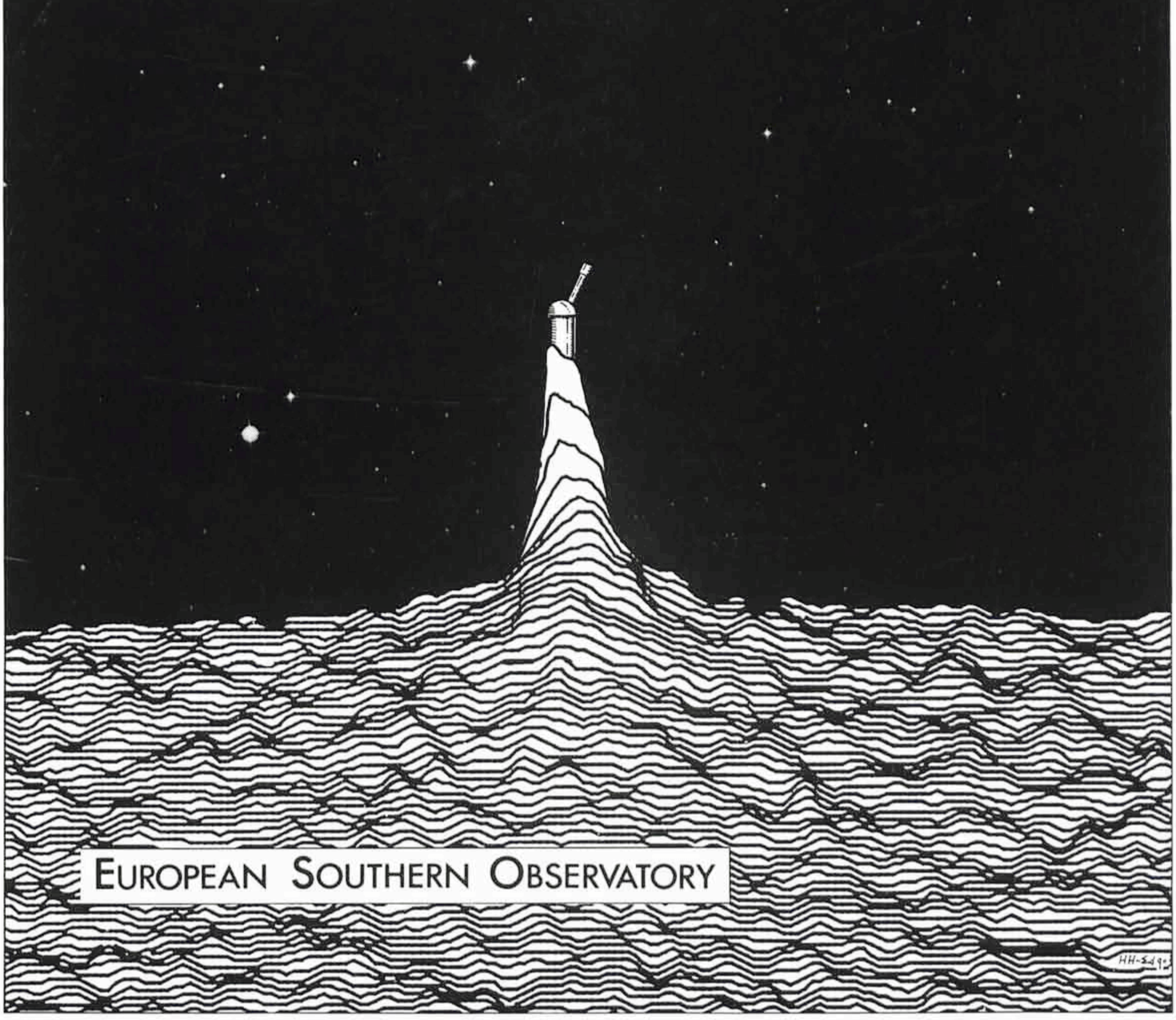
DISCOVERIES AT ESO

SCIENTIFIC AND TECHNOLOGICAL ACHIEVEMENTS SEEN THROUGH PRESS RELEASES (1985-1990)



EUROPEAN SOUTHERN OBSERVATORY

Discoveries at ESO

Scientific and technological

achievements seen through

Press Releases (1985 - 1990)

European Southern Observatory

January 1991

Discoveries at ESO

Scientific and technological achievements, seen through

ESO Press Releases (1985 - 1990)

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January 1991

Contents

Preface

Astronomers are explorers. Explorers aim to make discoveries. Discoveries cannot be kept to oneself, they must be revealed and shared.

The ESO community of astronomers is distributed all over Europe, in university institutes and in national research centres, in very small teams or in large, well funded groups. Tying this community together is the European Southern Observatory (ESO), which is their organization, their astronomical service centre, their exploration base. From this base, the La Silla Observatory, supported from the science- and technology centre at ESO Headquarters in Garching bei München, excursions proceed to regions of space-time far and near, from storms on Saturn via an exploding star in our nearest neighbour galaxy to the horizon of the Universe where galaxies are born and primordial violence goes by the poetic name of quasars.

News from ESO is sometimes of such a subtle astrophysical kind, so technically intricate that it does not lend itself for communication to a large public. Such developments may simply be left to publications in only the professional journal literature or be communicated to a small select group of science journalists of more general periodicals or newspapers. Some of the following press releases are of that type.

When ESO-community or ESO-in-house astronomers examine the results of their observational excursions, they sometimes recognize in the abundance of their data the contours of a breakthrough, the answer to an old question or the a strange proportions of a surprising phenomenon. More often than not, such astronomical discoveries do lend themselves for presentation to the public at large.

It has been said of scientists that 'if you cannot explain it to a twelve-year-old, you do not understand it'. It takes a master to simplify with integrity, to transmit the essence with clarity without dismissing or disturbing the intricacies which usually accompany vexing problems. Richard West is such a master. He has worked with his colleagues, the ESO astronomers-explorers, to explain their exciting findings to people in all walks of life. It is to his talent of linking astronomical insights and the public's eager curiosity that we owe this series of ESO Press Releases. We congratulate him and his team in the Information and Photographic Service for so successfully achieving one of ESO's prime responsibilities: having promoted good research, to share the results with as wide a public as can be reached by the media of our member states. This series testifies to expanding frontiers of a Universe whose exploration continues unabated.

Harry van der Laan
Director General

Introduction

This volume contains all ESO Press Releases which were issued between December 1985 and the end of 1990, arranged in ten chapters according to the subject. Because of the selective nature of communications to the Press - not all news is "newsworthy" - they highlight many of the astronomical and technological advances which have taken place at the European Southern Observatory, but it would certainly be wrong to pretend that they do full justice to all accomplishments during this period. The texts and figures are reprinted as they were published and the present document therefore also provides an interesting historical record.

The broad variety of information contained in the ESO Press Releases is reflected in the titles (*Contents* on pages 3 - 5) and the subjects discussed (*Chronological List* on pages 203 - 204). Among the astronomical themes, *Supernova 1987A* (the brightest since almost 400 years) and famous *Comet Halley* occupy prominent positions, while ESO's major telescope projects, the *New Technology Telescope* and the future *Very Large Telescope* represent two other natural centres of attention.

Although a few Press Releases were published by ESO on particular occasions in the past, it was only after the creation of the "*ESO Information and Photographic Service*" by the end of 1985, that the organization began to report to the media about its work in a more systematic way. This Service, also known to the outside under the shorter name *ESO Information Service*, is part of the Office of the Director General at the ESO Headquarters in Garching. It incorporates the earlier *Sky Atlas Laboratory* and is also responsible for the production of all ESO publications, including Scientific and Technical Preprints, Conference Proceedings and the quarterly house journal "The Messenger", as well as audio-visual material like slides, photographic prints, posters and video films.

The distribution list for ESO Press Releases currently encompasses about 600 addresses, mostly in the ESO member states but also beyond and on all continents. Most of the recipients are individuals at newspapers, broadcasting companies, popular journals, planetaria and museums, amateur societies, etc., who have a proven record of dissemination of science to the public at different levels. We are thankful that many of them regularly send copies of their ESO-related writings and videos to the Information Service; an evaluation of the available feed-back supports the impression that there is a satisfactory response. However, the wide geographical area and the many languages covered, virtually renders impossible a dedicated, active monitoring of the global impact of these Press Releases.

The preparations for the publication of an ESO Press Release normally begin when the Information Service learns about a news item, sometimes directly from the scientists or engineers involved, but not seldom as a rumour that "something" new has been discovered or is about to happen. When the contact to the appropriate persons has been established, an in-depth evaluation of the subject matter and its "newsworthiness" follows, in terms of expected public interest, originality, level of complexity, possibility of illustration, timing, etc. Once this hurdle is passed, the text is written in close consultation with the involved persons and the pictures are selected. The text of a Press Release differs quite dramatically from that of a scientific paper, in form as in content, and must therefore be the subject of extensive discussions among the parties, especially when simplified explanations of complicated scientific issues are necessary.

Once the text is ready and approved by the ESO management, in most cases within one or two days after the subject has first become known to the Information Service, the production begins. In addition to the preparation of the many envelopes this may also involve the printing of more than one thousand photos, each of which must be identified with an explanatory text imprinted on the rear side, and the laborious work must often be carried out at very late or early hours in order to be ready to mail the new Press Release the following afternoon. The absolute speed record is still held by PR 03/89 about the NTT "first light"; following an unsurpassed team effort in the early morning of Thursday March 23, 1989, all envelopes with this Press Release (with 3 figures), duly addressed and stamped, were deposited at the Garching post office, (and faxes sent to most of the major news agencies), just six hours after the original CCD images were obtained with the NTT at La Silla ! The remote control link was of course indispensible for this.

It is a pleasure to thank most cordially all scientists and engineers, at ESO and other institutes, who have contributed to these Press Releases. I hope that in return we have contributed to make their successes better known among their colleagues and the public. Moreover, it has been a special privilege to collaborate with so many dedicated colleagues at ESO; I herewith express my particular gratitude to Mrs. E. Völk, Mrs. O. Morath, Miss F. Buytendijk and Miss D. Miceli as well as Messrs. B. Dumoulin, H.-H. Heyer, C. Madsen, J. Quebatte, H. Zodet, K. Kjär, E. Janssen, H. Neumann and J. Kraus. Thanks to their combined efforts, it has been possible to ensure the prompt and efficient publication of the text and figures of the ESO Press Releases in this volume.

Richard M. West
Head of ESO Information Service

Chapter 1

Cosmology and Quasars

1.1 Is the Universe Younger than Previously Thought ?

(**PR 10/87**; 3 July 1987; For release on 9 July 1987)

The first observations of a long-lived radioactive isotope outside the Solar System indicate that the Universe may be younger than previously thought. Using one of the world's most powerful spectrometers, located at the ESO La Silla observatory in Chile, Professor Harvey R. Butcher of the University of Groningen, The Netherlands, has detected for the first time the radioactive element Thorium-232 in stars. A comparison of its abundance in old and young stars failed to show the expected differences. This means that the total age of Thorium-232 in these stars must be smaller than about 10 Gyr[1], instead of the previously estimated 16 - 18 Gyr.

Three "clocks" are used by scientists to estimate the minimum age of the Universe. The first of these relies on age-dating of certain stars by comparing their observed properties (temperature, luminosity, mass) with theoretical calculations; by this technique the oldest stars found to date, mostly in globular clusters, have been estimated to be over 16 Gyr old.

The second method is more straightforward. Galaxies are observed to be flying apart in the so-called Hubble expansion of the Universe; by extrapolating the observed velocities backwards, it is found that the galaxies would have been very near each other between 10 and 20 Gyr ago.

And third, the radioactive decay of certain isotopes in meteorites age-dates the chemical elements in the Solar System. The maximum age so derived depends on whether the elements were synthesized all at one time or more or less uniformly during a long time span. The resulting estimates range from 7 to 22 Gyr.

Given the substantial uncertainties in the latter two clocks, preference has been given to the stellar technique. A widely accepted minimum age of the Universe has therefore been around 16 - 18 Gyr.

The new observations of objects far outside the Solar System for the first time permit the radioactivity clock to be analyzed independently of the history of element synthesis. The half-life of the radioactive isotope Thorium-232 is 14 Gyr, making it sensitive to synthesis events over the whole of the age of the Universe. This Thorium isotope is the only one that occurs naturally and it decays by emitting an α-particle. Combining the meteoritic and the new stellar data now indicates that the observed Thorium-232 is very unlikely to be much older than about 10 Gyr. The unexpected, but unavoidable conclusion is therefore that the theoretical stellar age estimates must be in error.

The new analysis required measurement of exceedingly weak spectral absorption features of Thorium-232 in a sample of solar-type stars of different ages in the Milky Way Galaxy. The accuracy needed for this spectral study was substantially greater than what is generally attainable on faint stellar sources. The spectra were registered with the ESO-built Coudé Echelle Spectrometer which was fed by light collected at the 1.4 m Coudé Auxiliary Telescope on La Silla. In order to separate the features from the spectral lines of other elements, a very high spectral resolution had to be used, necessitating long integration times. In the end, data for twenty stars with widely different ages were obtained during two observing runs.

Professor Butcher adds: "These observations were only possible because of the superlative quality of the ESO spectrometer. I don't think it will be possible to improve on these data,

[1] 1 Gigayear (Gyr) = 1 billion years = 1000 million years

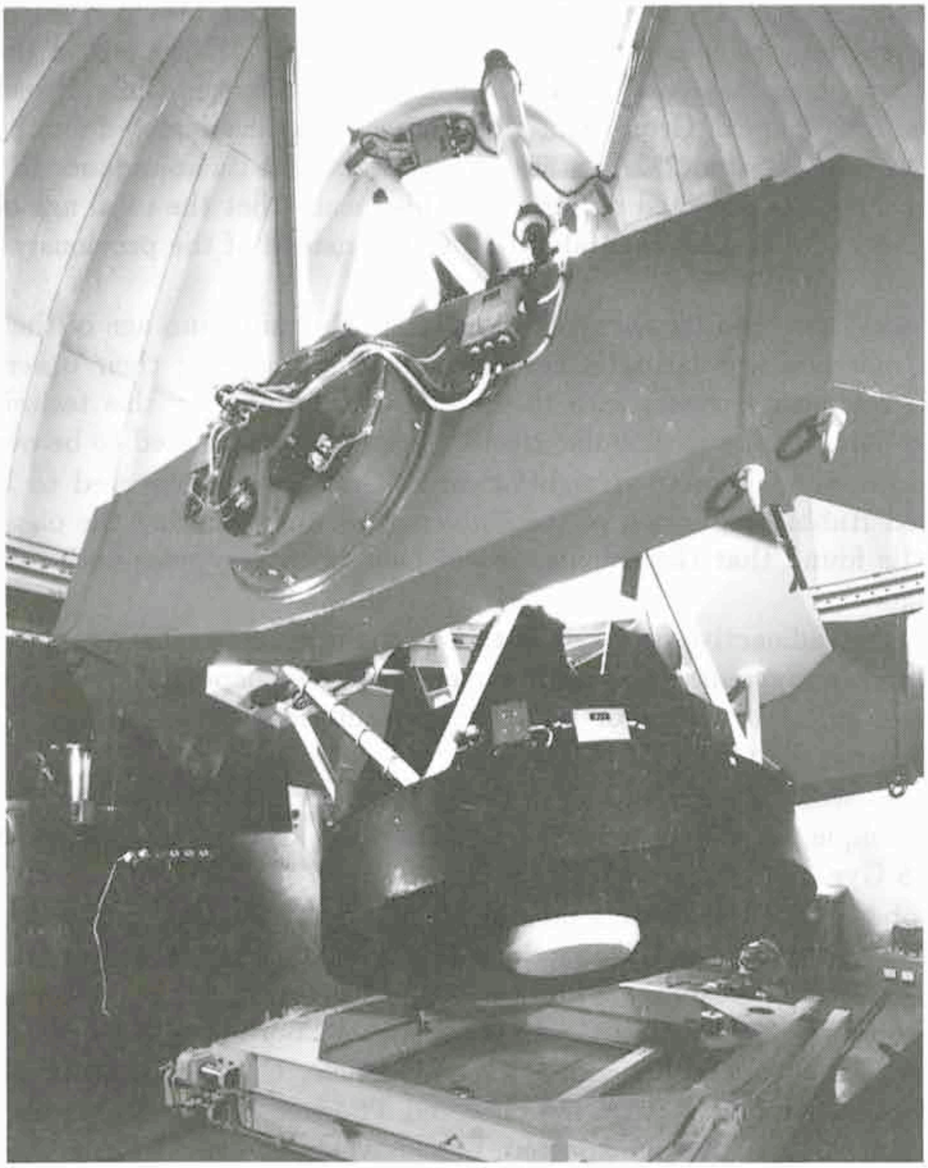


Figure 1.1: The **ESO Coudé Auxiliary Telescope (CAT)** has a 1.4 m primary mirror and is alt-alt mounted. It is housed in a smaller dome, adjacent to the 3.6 m telescope and feeds the 3.6 m Coudé Echelle Spectrometer through a light tunnel. The CAT is fully computer controlled. It has been used for many different types of astronomical observations, including millimetre radio mapping of CO clouds near the galactic centre. (PR 10/87; Colour)

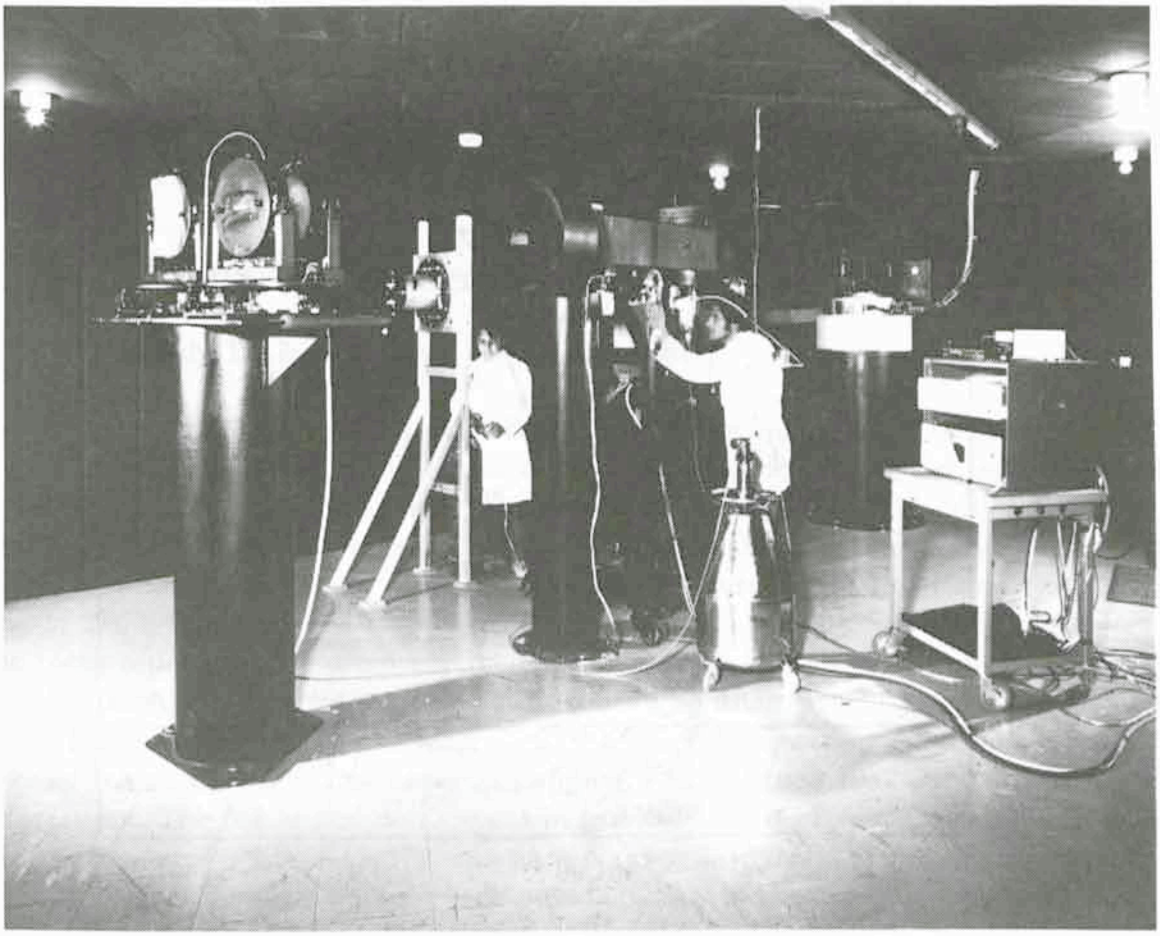


Figure 1.2: The **Coudé Echelle Spectrometer (CES)** is an advanced spectrograph that is housed in the 3.6 m building, just below the observing floor. It is mainly used in connection with the adjacent 1.4 m Coudé Auxiliary Telescope. Resolutions of the order of 100.000 are regularly employed to observe fine details in the spectra of stars and nebulae in the Milky Way. Recently it was also used to measure very faint, interstellar and intergalactic absorption lines in the spectrum of Supernova 1987A in the Large Magellanic Cloud. (PR 10/87; Colour)

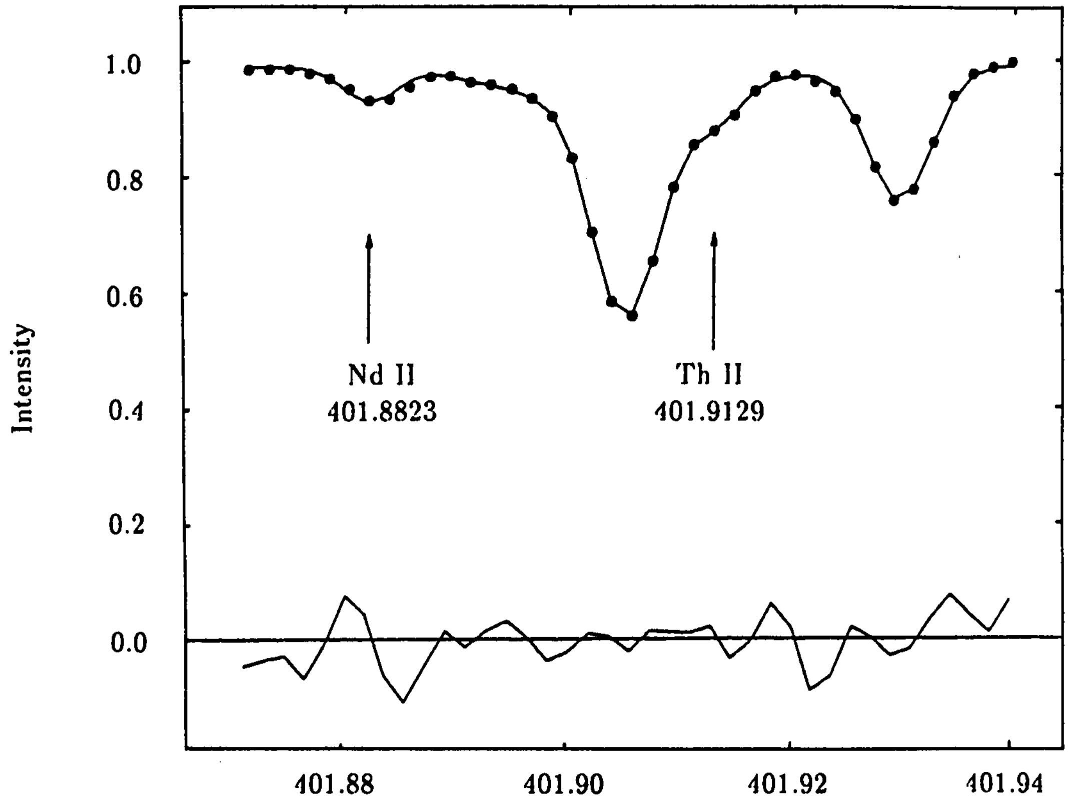


Figure 1.3: **Thorium and Neodymium in the Old Star HR 509.** The very weak absorption lines from the elements Thorium (Th II) and Neodymium (Nd II) in their singly ionized state, as observed in a very-high resolution spectrum of the old star HR 509. The filled circles represent spectral points observed with the ESO Coudé Echelle Spectrometer; the solid line is the fitted model spectrum, which is used to calculate the abundances of these elements. The line at the bottom is 10 times the difference between the data and the model. (PR 10/87)

and actually to measure an accurate history of element synthesis, until the new ESO Very Large Telescope is in operation, during the late 1990's."

This work will be published in the July 9, 1987 issue of the scientific journal *Nature*.

Three photos, which illustrate the subject of this Press Release, are available on request from the ESO Information and Photographic Service:

- Colour picture of the ESO 1.4 Coudé Auxiliary Telescope (CAT)
- Colour picture of the Coudé Echelle Spectrometer (CES)
- Graphic representation of a part of the spectrum of the old star HR 509, showing lines of ionized Thorium and Neodymium, near 401.90 nm.

1.2 Discovery of a Binary Quasar

(**PR 12/87**; 13 July 1987; For release on 15 July 1987[2])

The discovery of what may be the first true binary quasar has been reported by a European-American team of astronomers using a combination of optical, spectral, and radio observations. The pairs of nearly identical quasars, separated by only 4.2 arcseconds projection on the sky, have a redshift of 1.345, corresponding to a distance of some 12 billion light-years from Earth (according to the standard cosmological distance scale) and are apparently associated with the radio source PKS 1145-071 in the constellation Crater.

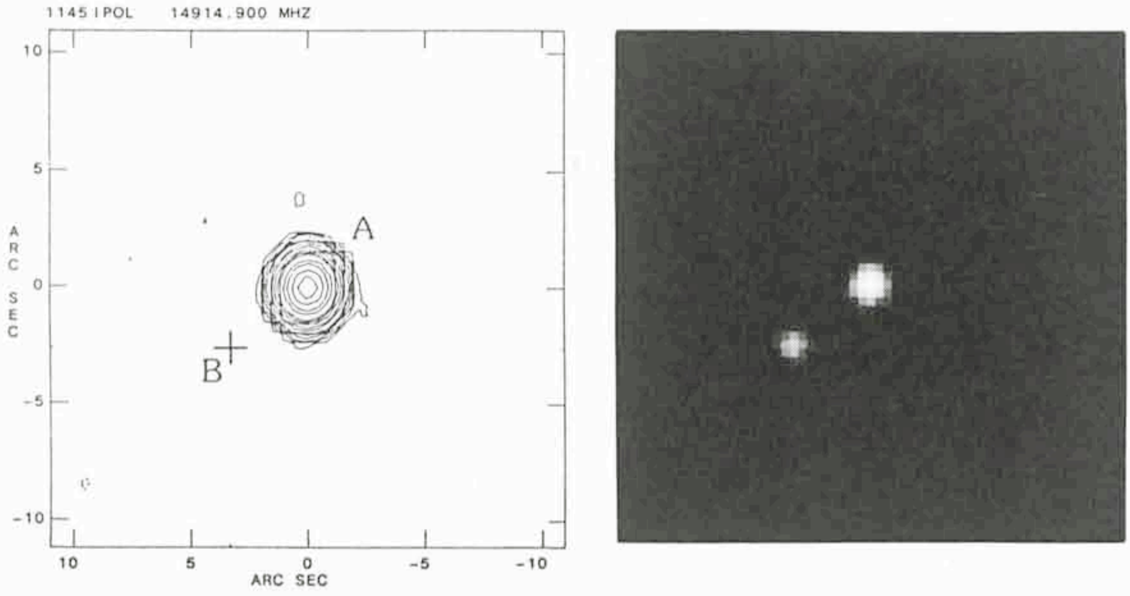
The team reporting this discovery includes S. George Djorgovski (Harvard-Smithsonian Center for Astrophysics), Georges Meylan (European Southern Observatory), Richard Perley (National Radio Astronomy Observatory), and Patrick McCarthy (University of California at Berkeley). A preliminary announcement appeared in the June 1987 issue of ESO's journal *The Messenger*. The full report will appear in the ***Astrophysical Journal Letters***.

The radio source PKS 1145-071 was known for many years to be associated with the quasar, but its binary nature had not been noted. Images of the object obtained 29 December 1986 at the European Southern Observatory's 2.2-meter telescope at La Silla, Chile, confirmed suspicions that the source was a double object. Spectroscopic observations to ascertain the nature of the two faint star-like components were obtained on 3 and 4 January 1987, at the Multiple Mirror Telescope Observatory in Arizona, operated by the Smithsonian Institution and the University of Arizona. The spectra confirmed that both objects (denoted A and B) were indeed quasars, very similar, and at essentially the same distance from Earth.

At first, the astronomers thought that the twin images might be another example of the so-called gravitational lens phenomenon: an image of a single distant quasar split in two by the gravitational field of a Galaxy or cluster of galaxies lying between the observer and the quasar. First predicted by Einstein's general theory of relativity some fifty years ago, several such gravitational lenses are currently known, the first one of which was, coincidentally, also confirmed by the Multiple Mirror Telescope in 1979.

Closer examination of the spectra of the two quasars revealed some subtle differences, reflecting slightly different physical conditions in the quasars themselves. Moreover, there appeared to be a small, but measurable relative velocity difference between them. This

[2]The text of this communication was released simultaneously by the Harvard-Smithsonian Center for Astrophysics, Boston, Mass., U.S.A.



The Binary Quasar QQ 1145-071

Figure 1.4: **Discovery of a Binary Quasar.** The radio map and visible-light image of the binary quasar QQ 1145-071. The two components are labeled as A and B. The right-hand picture, obtained with a charge-coupled device detector at the European Southern Observatory, La Silla, Chile, is the first observational evidence of the binary nature of the object. The picture to the left, showing radio emission in only the A component, allows astronomers to rule out the gravitational lens hypothesis in favour of the genuine binary character of the double source. (PR 12/87; BW)

suggested that the pair may be two distinct quasars, rather than lensed images of a single object. However, the gravitational lens hypothesis could not be discarded on the basis of such data alone. Quasars are relatively rare in the universe, and having two of them so close together would be unprecedented.

The crucial observations which confirmed the physical binary nature of the system involved radio-wave imaging of PKS 1145-071 with the Very Large Array (VLA) of radio telescopes near Socorro, New Mexico, on 9 January 1987. The data showed only one radio quasar in the field, corresponding to the optically brighter quasar. This result was contrary to the gravitational lens hypothesis since a lens should split images equally in both visible light and radio waves. The conclusion was that the two quasars represented a true physical pair, near each other in space and possibly interacting or even in a collision.

The discovery of quasars, about 25 years ago, was one of the most exciting events in the history of modern astronomy. Despite of the slow growth in understanding their physical nature, these objects, which are the most distant known, still provide the best available probe of the most remote observable regions of the universe.

A true binary quasar can offer astronomers important clues to the origin and the maintenance of quasar activity, which is often thought to be caused by collisions of galaxies. The light from the two quasars can be also used to measure the sizes of the intergalactic gas clouds lying between them and Earth.

From the measured velocity difference and projected separation of the two quasars, the astronomers estimated the pair may have a mass at least equal to that of some hundred billion solar masses. (Although commonly used for the binary stars in our galaxy, this is the first time such measurement has been possible for quasars). Such masses are typical for normal galaxies, and this measurement supports further the generally accepted interpretation of quasars as active nuclei of distant galaxies.

It is also possible that the two quasars are members of an extremely distant cluster of galaxies. Mere existence of rich clusters of galaxies at such large redshifts is an interesting constraint for the theories of large-scale structure formation, and the future studies of normal galaxies in this hypothetical cluster could be extremely valuable for the studies of galaxy evolution in the early universe.

This Press Release is accompanied by a photo showing the radio and visible-light images of QQ 1145–071.

1.3 Newly Discovered Quasar Is Most Distant Known Object in the Universe

(**PR 13/87**; 10 September 1987; For immediate release)

A newly discovered quasar[3] has been found to have a record redshift[4] of 4.11 and is therefore the *hitherto most distant known object* in the Universe.

This value of the redshift indicates that the quasar is receeding with 93 % of the speed of light and that we observe it as it was when the age of the Universe was only about one-tenth

[3]See also ESO Press Release 12/87 of July 13, 1987.

[4]In astronomy, the redshift denotes the shift of lines in the spectrum of a receding object towards longer wavelengths. The lines in the visible part of spectrum are shifted towards the red. The redshifts of galaxies and quasars are approximately proportional to their velocities and also to their distances.

of its present age. Detailed spectra of the quasar have been obtained at the ESO La Silla observatory which will permit the investigation of matter in the young Universe, at an *earlier time than ever before possible.*

This object, now designated Q0000-26, is seen as a star-like object of magnitude 17.5 near the border between the southern constellations of Sculptor and Cetus. It emerged as a bright candidate for a record redshift quasar during a programme by Cyril Hazard (University of Pittsburgh and Institute of Astronomy, Cambridge), Richard McMahon and Mike Irwin (Institute of Astronomy, Cambridge) to search for high-redshift quasars. Candidate objects were selected on the basis of an objective prism survey carried out with the UK 1.2 m Schmidt telescope at Siding Spring in New South Wales, Australia.

The high redshift was then confirmed and measured by John Webb (Leiden Observatory, The Netherlands) together with Bob Carswell and Helen Parnell (Institute of Astronomy, Cambridge) during an observing run in mid-August 1987 at the 3.9 m Anglo-Australian telescope, also at Siding Spring Mountain.

The astronomers became aware of the record redshift when they noted that a strong emission line of hydrogen, known as Lyman-alpha, was seen in the red region of the spectrum of Q0000-26, at a wavelength near 620 nanometres. During a subsequent observing run at the ESO La Silla observatory, John Webb was able to obtain very detailed spectra of this quasar. A preliminary analysis of these data has now shown that this quasar is of very particular interest and will yield invaluable information about the conditions in the Universe when it was much younger than now.

The La Silla observations were made on August 30 - September 1 with the ESO 3.6 m telescope, equipped with a powerful spectrograph (CASPEC). In order to see as many and as fine spectral details as possible, the spectral resolution was unusually high for an object of this magnitude (about 0.06 nm) and the total integration time during the two nights was in excess of 12 hours. The recorded spectrum covered the 480 - 660 nm spectral region and, in addition to the Lyman-alpha line, also showed lines of double and triple ionized carbon. The Lyman-beta and Lyman-gamma lines also fall in this spectral region.

Although the definitive data reduction is still in progress, several results have already emerged which are causing great excitement among astrophysicists. First, Q0000-26 is one of the intrinsically brightest objects in the Universe (as shown by its great distance and apparent magnitude). In particular, Q0000-26 is brighter than any other of the few quasars which have been detected so far at redshifts around 4.0.

A very large number of narrow absorption lines are seen in the spectrum. They originate when the quasar light passes through condensations of matter between the quasar and us. By measuring the redshift of these lines, the spatial distribution of the intervening matter can be determined. Additionally, the absorption line strengths and shapes supply more detailed physical information about the individual clouds.

Several absorption lines in the spectrum of Q0000-26 have the same redshift 4.13, that is even larger than the redshift of the quasar itself. They are believed to be caused by matter near the quasar, now falling towards it. Other absorption lines at slightly smaller redshifts now for the first time allow us to probe in detail the matter in the Universe beyond a distance corresponding to redshift 4.

It is most interesting that the spectrum also reveals strong absorption lines from a cloud with redshift 3.39. They probably originate when the quasar light passes through a disc of an intervening galaxy - herewith confirming the presence of galaxies at this very large distance and at the corresponding early time.

More information about this exciting discovery will become available in some weeks' time, when the reduction of the observations will be more complete.

1.4 Discovery of a New Gravitational Lens System

(**PR 14A/87**; 19 October 1987; For release on 22 October 1987)

The discovery of a new gravitational lens system in the southern constellation Cetus comes as a first exciting and fundamental result obtained by a group of European astronomers[5] in the frame of the systematic search program they are carrying out at the ESO La Silla observatory. Not only did they find that the image of the highly luminous quasar[6] UM673 is double, but they were also able to observe the distant galaxy that is responsible for this effect. Continued monitoring of this rare object may actually lead to cosmologically significant results about the size and the age of the Universe.

Quasars are known to be the most luminous as well as the most distant objects in the Universe. If a galaxy (or a cluster of galaxies) lies near the line of sight to a quasar, the result of gravitational bending of the light[7] may be such that more than one image of this single quasar will be seen by an observer on Earth. Such a phenomenon is referred to as gravitational lensing.

The relative positions and intensities of the multiple quasar images in the sky depend on the amount and d istribution of mass in the intervening object(s), as well as on the geometric configuration between quasar, deflector and observer. Therefore, accurate observations of such images may lead to a determination of the mass of the deflector as well as that of the relative size of the Universe.

Since the well known discovery in 1979 of the first gravitational lens system (Q0956+561 A and B), very few additional lensed quasars have been identified. Furthermore, not all reported candidates have been confirmed by subsequent, detailed observations. The present discovery at ESO is remarkable because, for the first time, a gravitational lens system has been identified by using a purely optical observational strategy, according to which the images of selected quasars are systematically obtained under the best possible seeing conditions.

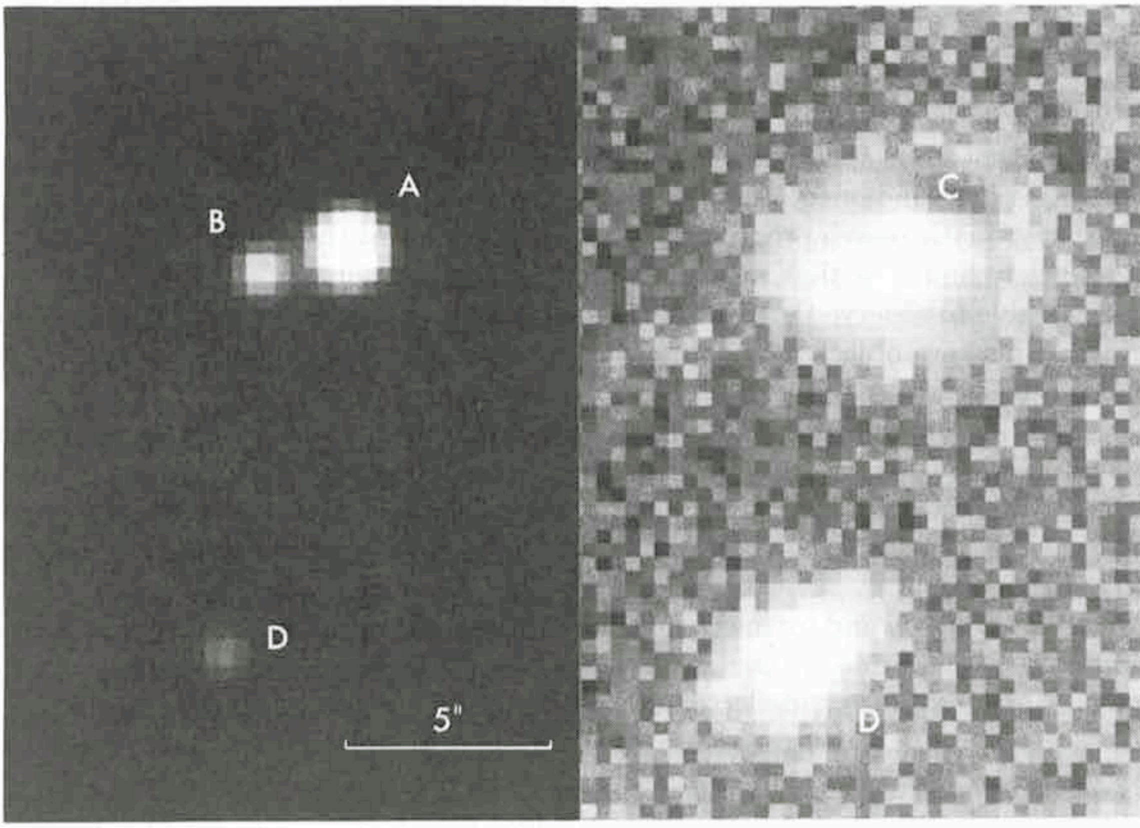
The observations were carried out with the ESO/MPI 2.2m and ESO 3.6m telescopes. The data show that the quasar UM673 (the 673th quasar catalogued during the University of Michigan survey) appears in the sky as a double object having a separation of 2.2 arcsec, and that a faint galaxy is superimposed over the two images (see accompanying photo). It is this galaxy that causes the gravitational lensing and it could only be seen after the two stellar-like images of the QSO (quasi-stellar object) had been removed by computer processing.

The conclusive evidence that the two images are of one single quasar comes from a detailed

[5]The group consists of J. Surdej and J.P. Swings (Institut d'Astrophysique, Université de Liège), P. Magain (formerly in Liège, presently at the European Southern Observatory, La Silla, Chile), T.J.-L. Courvoisier (Space Telescope European Coordinating Facility, Garching near Munich, F.R.Germany), H. Kuhr (Max Planck Institut für Astronomie, Heidelberg, F.R.Germany), S. Refsdal, U. Borgeest and R. Kayser (Hamburger Sternwarte, F.R.Germany) and K. Kellermann (National Radio Astronomy Observatory, Virginia).

[6]see also ESO PR 12/87 and 13/87

[7]Since the total solar eclipse of 1919, when astronomers observed for the first time an apparent displacement in the position of stars near the limb of the Sun, it is recognized that light beams can be bent, not only in optical systems, but also in gravitational fields. This effect was predicted by Einstein within his general theory of relativity.



A New Gravitational Lens: Quasar UM 673 and the Intervening Galaxy

Figure 1.5: **The Gravitational Lens System UM673.** This photo shows a newly discovered gravitational lens system and the galaxy that causes this effect. To the left are seen the two lensed stellar-like images of the quasar UM673; the magnitude of the brighter (A) is 17 and that of the fainter (B) is 19. The angular distance between A and B is 2.2 arcsec., i.e. approximately equal to one thousandth the angle under which we see the solar (or lunar) disk from Earth. The intervening galaxy (C) which is responsible for the gravitational bending of the quasar light, and thus for the formation of the two images of the same object, is seen on the right, together with another galaxy (D), possibly a member of the same cluster of galaxies. The right-hand picture was computer enhanced and the two images of the quasar have been removed in order to show better the faint lensing galaxy. This is why the background is rather uneven and the individual picture elements (pixels) are visible. The CCD frame was obtained with the EFOSC instrument attached to the Cassegrain focus of the ESO 3.6m telescope. One pixel = 0.338×0.338 arcsec^2. The scale is indicated. North is up and East to the left. (PR 14A/87; BW)

comparison of the spectra. A careful study shows that the two QSO images have exactly the same spectrum. The measured redshifts[8] are found to be identical, z(A) = z(B) = 2.72, corresponding to an apparent recession velocity of the order of 86 % the speed of light. Because of the enormous distance that separates us from the quasar, we see the latter today as it was ~ 13 billion years ago. It was also possible to determine the redshift of the intervening galaxy as z = 0.49, indicating that it lies between the quasar and us. With this information, the mass of the lensing galaxy has been estimated as ~ 240 billion times the mass of our Sun.

The discovery of gravitational lenses is important for at least three different reasons:

- The study of gravitational lens systems should lead to an independent estimate of the amount of hidden matter in the Universe. Indeed, several lines of arguments appear to indicate that the Universe may contain as much as 10 times more matter than can presently be directly observed (the "missing mass problem"). Since the quasar light is deflected by all the mass in an intervening object, a comparison with the visible mass deduced from other observations may lead to an estimate of the invisible mass.

- Another important cosmological measurement that is possible with gravitational lens systems is an independent verification of the distance scale in the Universe. This is feasible because the lengths of the light paths of the two quasar images are different. If, as expected in this type of objects, the brightness of the quasar changes with time, then the variation will first be seen in the image that corresponds to the shortest path, and later in the other. A measurement of the time delay, taken together with the known parameters of the lens, will determine the absolute size of the system, and therefore the value of the Hubble parameter H_0 which indicates the expansion rate of our Universe. For the quasar UM673, the time delay for a variation in the brightness of the two images is expected to be as small as a few months. Continued monitoring of the brightness of the two images is actually being carried out at La Silla. It is hoped that variations in the two images will soon be detected which will make it possible to accurately determine the time delay and thereby, for the first time, to make a reliable, independent determination of H_0 by this method.

- Finally, it should be mentioned that UM673 appears to be one of the most luminous quasars because its apparent luminosity has been amplified by gravitational lensing (approximately by a factor 10). In the systematic search for gravitational lens systems among a selected sample of the most highly luminous quasars, the present team of astronomers has now identified several additional promising candidates. Spectroscopic observations of these are under way at ESO. These findings naturally raise the following, very fundamental question: "To what extent is the observed, high luminosity of quasars really intrinsic ?". Since gravitational lensing may give rise to the formation of cosmic mirages, it may be that lensing effects also deform our own view of the entire Universe.

Detailed accounts of the observations and interpretation of the gravitational lens system UM673 are contained in two scientific papers to appear in the British journal *Nature* (on 22 October 1987) and in the European journal *Astronomy & Astrophysics*.

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[8]In astronomy, the redshift z denotes the fraction by which lines are shifted towards longer wavelengths in the spectrum of a distant galaxy or quasar receding from us with the expansion of the Universe. The observed redshift gives a direct estimate of the apparent recession velocity, which is itself a function (Hubble relation) of the distance of the object under study.

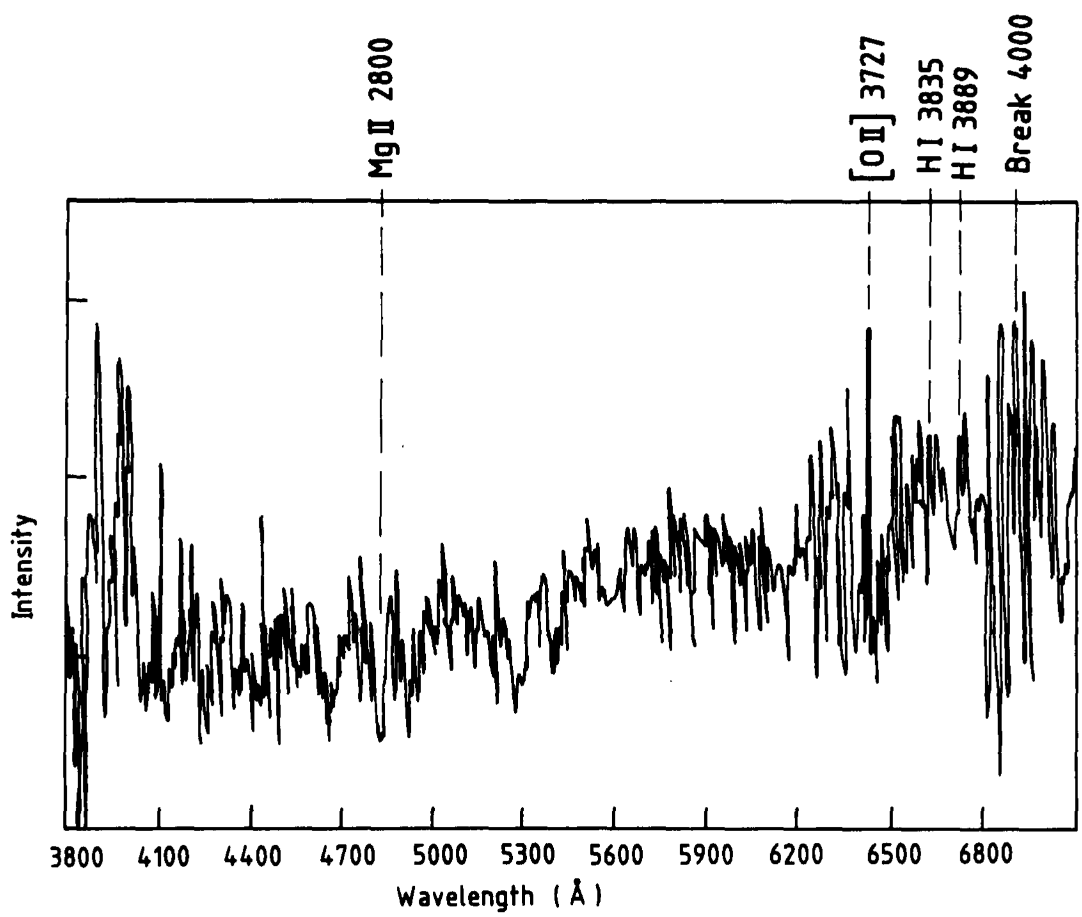

Figure 1.6: **Spectrum of the Giant Arc in Abell 370.** (PR 15/87)

1.5 The Nature of the Mysterious "Luminous Arc" Revealed: A Gravitational Einstein Ring

(**PR 15/87**; 5 November 1987; For immediate release)

The prototype of a new class of astrophysical phenomena has now been interpreted. Studies of other objects of the same type will open entirely new vistas in the exploration of the nature of distant galaxies.

The combination of a very dark sky at the ESO La Silla observatory, the large collecting area of the 3.6 m telescope and the high efficiency of the ESO Faint Object Spectrograph (EFOSC) has made it possible to obtain for the first time a convincing spectrum that reveals the true nature of a mysterious object, the prototype "Giant Luminous Arc" in the distant cluster of galaxies Abell 370.

Several atomic spectral lines have been unambiguously identified in the arc by a group of astronomers[9] from the Toulouse Observatory, France. They were able to show that the object is a "*gravitational ring*", a phenomenon predicted by Einstein, but never observed before. It is caused by the deflection of light from a background galaxy by the dense core of the cluster

[9]G. Soucail, Y.Mellier, B. Fort, G.Mathez and M. Cailloux

Abell 370. This exciting discovery opens an entirely new field of observational astronomy.

The giant arc was first recognized by the French group in September 1985, on direct images of Abell 370, obtained with the French-Canadian 3.6 m telescope on Mauna Kea, Hawaii[10]. The distance to this cluster of galaxies is about 4600 million light years (the redshift is z = 0.374) and the apparent size of the visible segment of the arc is at least 500 000 light years.

After the subsequent discovery of another arc in the cluster of galaxies Cl2244-02 by American astronomers later in 1986, several theories were advanced about their nature. One possibility was that the two arcs were the results of gravitational lensing by the dense cluster of galaxies (see also ESO Press Release 12/87). According to Einstein's Theory of Relativity, light rays can be bent by a gravitational field. An observer may then see multiple images or even an arc, depending on the relative positions of the foreground mass and the background object.

A determination of the true nature of the arcs had to await observations of their spectra, a task that had been viewed as almost impossible because of their faintness. However, for the first time, the French team has now been able to obtain spectra of the various segments of the giant arc in Abell 370. This shows that the spectrum is the same in different parts of the arc and also that it is the spectrum of a distant galaxy. Thus the arc is indeed a "gravitational ring".

The observations were made with the EFOSC/PUMA2 spectrograph at the Cassegrain focus of the ESO 3.6 m telescope, on October 18 - 22, 1987. Several 90 minutes exposures were made through a long and a curved slit, centered on the arc. In total, 6 hours of integration time was needed to bring out the rather noisy spectrum, attached to this Press Release. The spectrum shows several identifiable lines, including a comparably strong emission line from ionized oxygen, all shifted towards the red part of the spectrum. The measured redshift is 0.724 and the overall intensity profile of the spectrum is that of a galaxy at this redshift. This corresponds to a distance of about 7500 million light years; that is almost twice as distant as the galaxies in Abell 370.

The light of the distant galaxy is obviously deflected by the central core of the cluster Abell 370. It is confirmed that the central part of the arc, as well as a feature at the eastern end, both belong to the gravitational ring.

The creation of such a ring demands a rather specific geometric relationship between the background galaxy and the cluster, as well as a specific mass distribution within the cluster, of which studies of the ring's geometry and brightness will give detailed information. This kind of research is useful for verification of our understanding of gravitational theory and galaxy mass distributions. Since in certain configurations the arc-shaped image may be amplified, it is conceivable that distant clusters of galaxies may be used as "gravitational telescopes" to search for very distant objects in the Universe.

With the EFOSC instrument at the ESO 3.6 m telescope, it is possible to search efficiently for other gravitational rings, by obtaining direct images of other distant clusters of galaxies. Due to the highly efficient instrumentation, each exposure can be made in a few minutes only and several hundreds of clusters may be surveyed during a few nights.

The French astronomers have also made EFOSC observations of the only other known arc in the cluster Cl2244-02, now in the process of being reduced. The complete discussion of the exciting observations of the two arcs will be published in the European journal *Astronomy &*

[10]A picture of the arc has been reproduced in June 1987 (*48*, page 44) issue of the ESO Messenger. It is also available from the ESO Information Service upon request.

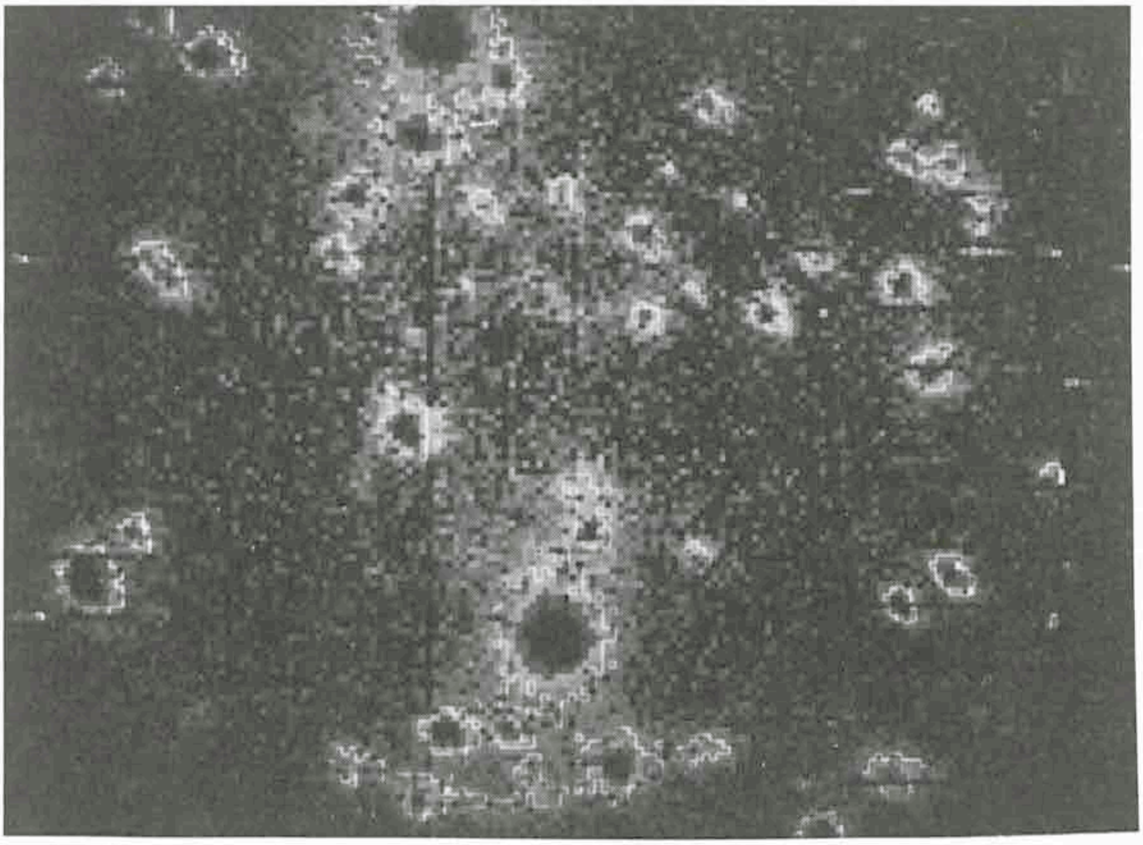

Figure 1.7: **Giant Luminous Arc in Abell 370.** This false-colour, computer processed image of the cluster of galaxies Abell 370 was obtained with the 3.6 m French-Canadian telescope on Mauna Kea, Hawaii by a group of astronomers from the Toulouse Observatory, France. It shows, in addition to the individual galaxies in the cluster, the "Giant Luminous Arc" near the lower edge. The arc is about 160 kpc (500.000 light years) long and $\sim$ 8 kpc (25 000 light years) wide. Spectra of this arc were obtained in October 1987 with the ESO 3.6 m telescope at the La Silla Observatory. They show that the arc is a "gravitational ring". This effect is due to the light from a background galaxy being bent in the gravitational field of the Abell 370 cluster. (PR 15/87; Colour)

Astrophysics.

This Press Release is accompanied by a graphic representation of the spectrum of the central part of the arc, as obtained with the EFOSC/PUMA2 instrument, attached to the ESO 3.6 m telescope. It shows the redshifted, strong emission line of singly ionized oxygen, as well as weaker absorption lines of hydrogen and ionized magnesium. The break at rest wavelength 4000 Å is near two strong absorption lines of single ionized calcium.

1.6 Discovery of a Cloverleaf Quasar in the Sky: (A Lot of Hard Work - and a Little Bit of Luck)

(**PR 06/88**; 28 July 1988; For immediate release)

Thanks to observations performed under near-perfect conditions at the La Silla observatory, it has been possible to show that the image of a distant quasar consists of no less than four components. Most appropriately, the object has now become known as the *cloverleaf quasar*. The peculiar image is due to the effect of "gravitational lensing", a phenomenon predicted by Einstein's General Theory of Relativity and explained at the end of this Press Release.

A rare gravitational lens

Quasars are known to be the most luminous objects in the Universe and can therefore be seen to distances greater than any other objects known. However, recent observations by a group of European astronomers[11] at the ESO La Silla Observatory seem to indicate that the most powerful quasars could in fact appear more luminous than they actually are since their light may be amplified by the effect of gravitational lensing. Having found earlier that the quasar UM 673[12] has a double image due to this effect, they have now discovered that the image of another highly luminous quasar, known as H 1413+117, is in reality four very close images, which look like a four-leaf clover in the sky.

The images were obtained under very good atmospheric conditions with the ESO/MPI 2.2m telescope and a high-resolution CCD camera and show clearly the quasar H 1413+117 as a quadruple object. All four images are about equally bright and they are separated by less than 1 arcsecond; see the accompanying photo.

It was possible to obtain individual spectra of two of these images with the ESO Faint Object Spectrograph and Camera (EFOSC) at the ESO 3.6m telescope. The spectra are identical, indicating that the images are indeed of of the same quasar. The common redshift[13] is measured as 2.55, corresponding to an apparent recession velocity of about 85% of the speed of light. Because of the enormous distance that separates us from the quasar, we see

[11]The group consists of P. Magain (formerly in Liège, now ESO, Garching), J. Surdej and J.P. Swings (Institut d'Astrophysique, Université de Liège), U. Borgeest, R. Kayser and S. Refsdal (Hamburger Sternwarte, F.R. Germany), H. Kühr (Max Planck Institut für Astronomie, Heidelberg, F.R. Germany) and M. Remy (formerly in Liège, now ESO, La Silla).

[12]See ESO Press Release 14A/87.

[13]In astronomy, the *redshift* denotes the fraction by which lines are shifted towards longer wavelengths in the spectrum of a distant galaxy or quasar receding from us with the expansion of the Universe. The observed redshift gives a direct estimate of the apparent recession velocity, which is itself a function (known as the Hubble relation) of the distance of the object under study.

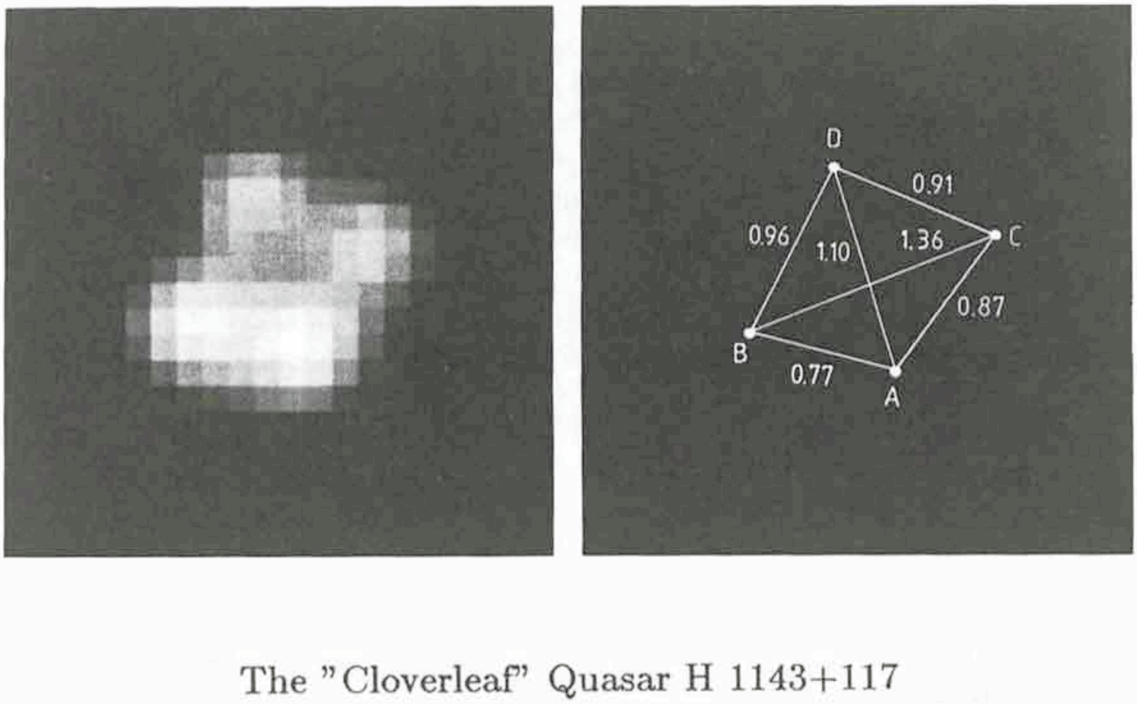

Figure 1.8: **The "Cloverleaf" Quasar H 1413+117.** Left: The central area of a CCD image of the quadruply lensed quasar H 1413+117 ("The Cloverleaf"), obtained in red light on 8 March 1988 at the ESO/MPI 2.2 m telescope. The four images are clearly separated; they all belong to the same object. Right: The geometry of the system. The four images of the quasar are called A, B, C and D, in order of decreasing brightness. The distances between them are indicated in arcseconds. (PR 06/88; BW)

it as is was ~13 billion years ago. In addition, several narrow absorption lines are seen in the spectrum of one of the quasar images. These lines are thought to originate in matter associated with the galaxy that causes the lensing effect.

A continued astrophysical study of this rare gravitational lens system will contribute to our knowledge about the dark matter content of the Universe. It may also lead to an independent determination of important cosmological parameters, for instance of the age of the Universe.

A detailed account of the observations and the interpretation of this gravitational lens system is contained in a scientific paper which will appear in the British journal *Nature* today (28 July 1988).

Gravitational lensing and amplification

Gravitational fields may act as optical systems of lenses and mirrors.

Since the total solar eclipse of 1919, when astronomers observed for the first time an apparent displacement in the positions of stars near the limb of the Sun, it is recognized that light beams can be bent, not only in optical systems, but also in gravitational fields. As a matter of fact, this effect was predicted by Einstein within his General Theory of Relativity.

Bending of light is also observed when the light from a distant quasar passes close by one or more massive objects on its way to us. Such objects may be individual galaxies or clusters of galaxies. The effect is referred to as a *gravitational lensing.*

Depending on the intensity and form of the gravitational field, that is on the mass and geometrical configuration of the objects in the gravitational lens, the light from the quasar may not only be bent into multiple images of the quasar, but some of these images may become brighter than the quasar itself would have appeared in the absence of the gravitational lens. This is referred to as *light amplification.*

Due to the amplification effect, we may be able to observe gravitationally lensed images of very distant quasars, which would otherwise have been too faint to detect with present telescopes. Gravitational lenses may therefore, at least in principle, allow us to investigate otherwise inaccessible, very remote regions of the Universe.

Chapter 2

Galaxies

2.1 Big Radio Galaxy is Nearer than Previously Thought

(**PR 07/86**; 13 May 1986; For immediate release)

Detailed observations of a bright supernova in the peculiar galaxy *NGC 5128 = Centaurus A*, have led astronomers at the European Southern Observatory to believe that this galaxy is much closer to us than previously thought. It is the nearest, strongly radio-emitting galaxy and is as such an object of crucial importance in modern astrophysical research. The revised distance is 7 - 10 million light years or only 3 - 4 times farther away than the Andromeda Nebula. Cen A may therefore even be an outlying member of the Local Group. The total radio emission energy corresponds to the conversion to pure energy (annihilation) of a mass equal to 10.000 suns.

The supernova in Cen A, which has received the official designation *1986G* by the International Astronomical Union, was discovered on May 3.5 UT by Reverend R. Evans, an amateur astronomer in Australia, who has more than a dozen earlier discoveries to his credit. It appeared as a "new star", southeast of the center of Cen A and almost in the middle of the broad dust band that girdles this unusual galaxy (see attached picture). The magnitude was estimated as 12. No supernovae have been detected in this galaxy before. This event is of particular interest, because bright supernovae are rather rare and also because of the peculiar nature of the parent galaxy. The most recent supernova of a similar magnitude was in 1980, in the northern, spiral galaxy NGC 6946[1].

Observations at ESO with the 1 m and 50 cm photometric telescopes have shown that supernova 1986G was still brightening at a rate of about 0.05 mag/day on May 11.2 UT. On this date, the V-magnitude was 11.4 and colour index (B-V) was 1.1 mag. CCD images were exposed at the Danish 1.5 m telescope. Low-dispersion IDS and CCD spectra have been obtained with the ESO 1.5 m spectroscopic telescope and with the 2.2 m telescope. They show a typical Type I supernova spectrum before maximum, significantly reddened by absorption in Cen A. Of special interest are very high dispersion spectral observations, obtained with the CASPEC spectrograph at the ESO 3.6 m telescope. The Calcium and Sodium spectral lines show a complicated structure with no less than six very deep absorption components, four of which originate in rapidly moving interstellar clouds in Cen A.

These observations, and the position near the middle of the dust band, indicate that the supernova is situated well inside the galaxy and that its light is dimmed by about 4 mag due to obscuring dust. Had it been situated in an unobscured region, its magnitude would have been about 7.5, making it the brightest supernova in this century. Due to Cen A's peculiar structure (some astronomers consider it to be the result of a collision among two galaxies), it has not yet been possible to measure an accurate distance to this galaxy. However, if the

[1] *Supernovae* are believed to represent a late evolutionary stage of massive stars in which the star runs out of atomic fuel. It can no longer support its own weight and collapses. Immediately thereafter follows a dramatic thermonuclear explosion during which the outer layers are blown into the surrounding space. A small and very compact object may remain at the center. The best known historical supernova was seen in the year 1054, giving birth to the Crab Nebula and an associated neutron star, which was detected as a radio pulsar in 1967. Most, if not all heavy elements in the universe have been generated in the exceedingly hot interiors of stars in the supernova phase. Supernovae are very rarely discovered before they reach their maximal brightness and little is known about the early phases. Currently, about 20 - 25 supernovae are detected per year in exterior galaxies; the last one in our own galaxy, the Milky Way, appears to be the one found by *Kepler* in the constellation Ophiocus in 1604.

Figure 2.1: This picture of the newly discovered **supernova 1986 G in the peculiar, southern galaxy Centaurus A (= NGC 5128)** was obtained on 1986 May 8.0 UT with the ESO 40-cm double astrograph (GPO) on La Silla. Exposure: 90 minutes on blue-sensitive IIa-O emulsion. Observer: H.Duerbeck, visiting astronomer from Astronomisches Institut, Münster, FRG. The 11.5 mag supernova (indicated with an arrow) is situated in the extensive dust band that surrounds the galaxy. (PR 07/86; BW)

intrinsic brightness of 1986G is that of a normal Type I supernova, then the distance to Cen A would be only 2 - 3 Megaparsecs (7 - 10 million light years). Assuming the upper figure, the total radio energy is at least 10^{58} erg, that is the equivalent of 10^4 solar masses. Obviously, Cen A was the site of a most energetic event not so long ago - the velocities of the interstellar clouds may be relicts of this.

The ESO observations are continuing. The following ESO staff and visiting astronomers have participated so far: *I. Bues, P.R. Christensen, S. di Serego Alighieri, H. Duerbeck, G. Galletta, P. Magain, P.E. Nissen, D. Reimers, P. Schulte Ladbeck and J. Sommer-Larsen.*

2.2 Quasar-like Activity in the Outskirts of an Elliptical Galaxy

(**PR 02/87**; 29 January 1987; For release on 5 February 1987[2])

A European group of astronomers has discovered an extreme example of 'quasar-like' activity in an otherwise normal radio galaxy. What is most remarkable in this case is that the activity occurs not at the galaxy's centre, but in its halo at a distance of about 30000 light years from the centre. This important result, which is based on observations at the ESO La Silla observatory, opens new and exciting lines in galaxy research. The members of the group are C.N.Tadhunter (Royal Greenwich Observatory, Hailsham, UK), R.A.E.Fosbury (Space Telescope - European Coordinating Facility, Garching, FRG) and L.Binette, I.J.Danziger and A.Robinson (ESO).

Although *quasars* are seen as star-like objects in optical telescopes, they are believed by most astronomers to be extremely energetic sources of radiation, situated in the centres of galaxies. They far outshine the emission from surrounding stars and gas in these galaxies. Quasars emit not only optical light but also radio, infrared, ultraviolet and X-ray radiation and because of their brightness, they can be detected at very large distances. Somewhat less luminous examples of the quasar phenomenon are known closer to our Galaxy. They are called *Active Galactic Nuclei (AGN)* and are seen typically in what are known as *Seyfert galaxies* and sometimes in *radio galaxies.*

Radio galaxies are most often of the elliptical type with very smooth images on ordinary photographs. Some of them also exhibit the AGN phenomenon. It is believed that such galaxies have powerful sources of energy in their nuclei that create oppositely directed *jets* of energetic particles. The jets escape the visible galaxy to fill huge areas (*lobes*) with highly energetic atomic particles. It is these lobes that can be 'seen' with radio telescopes as a classical 'double' radio source. In some radio galaxies, the jets themselves can be seen clearly at radio wavelengths. There are also several cases known where regions of interstellar gas are being impacted by jets, thereby creating glowing clouds or 'blobs' which are visible in optical light.

One such galaxy is PKS 2152-69, situated in the southern constellation Indus. It is a relatively nearby radio galaxy; its distance is estimated to be around 500 million light years. It has a double-lobed radio structure but, being so far south, it is beyond the reach of present high-resolution radio telescopes. Recently, the astronomers observed this galaxy through special optical filters in front of a very sensitive CCD (Charge-Coupled Device) detector at the 2.2 m telescope at La Silla. These filters isolate the light emitted by hydrogen and nitrogen and, after computer processing, the recorded images clearly show the glowing clouds of gas in this galaxy (see attached photo). A large cloud, which appears to be at least 30,000 light years from the galaxy's centre, was studied in detail using spectrographic equipment with a similar detector on the ESO 3.6 m telescope. Surprisingly, the observed spectra revealed emission lines which are characteristic of some very highly ionized ions. For instance, the presence in this gas cloud of Ca^{+4}, Fe^{+6} and Fe^{+9} ions (calcium atoms with four electrons missing, iron atoms with six and nine electrons missing) was demonstrated. Spectral lines from these ions are characteristic of only the most extremely excited of active nuclei of galaxies or quasars and they testify to the extraordinarily high energies in the gas cloud.

[2] A B/W photo is attached to this Press Release; a false-colour photo is available on request.

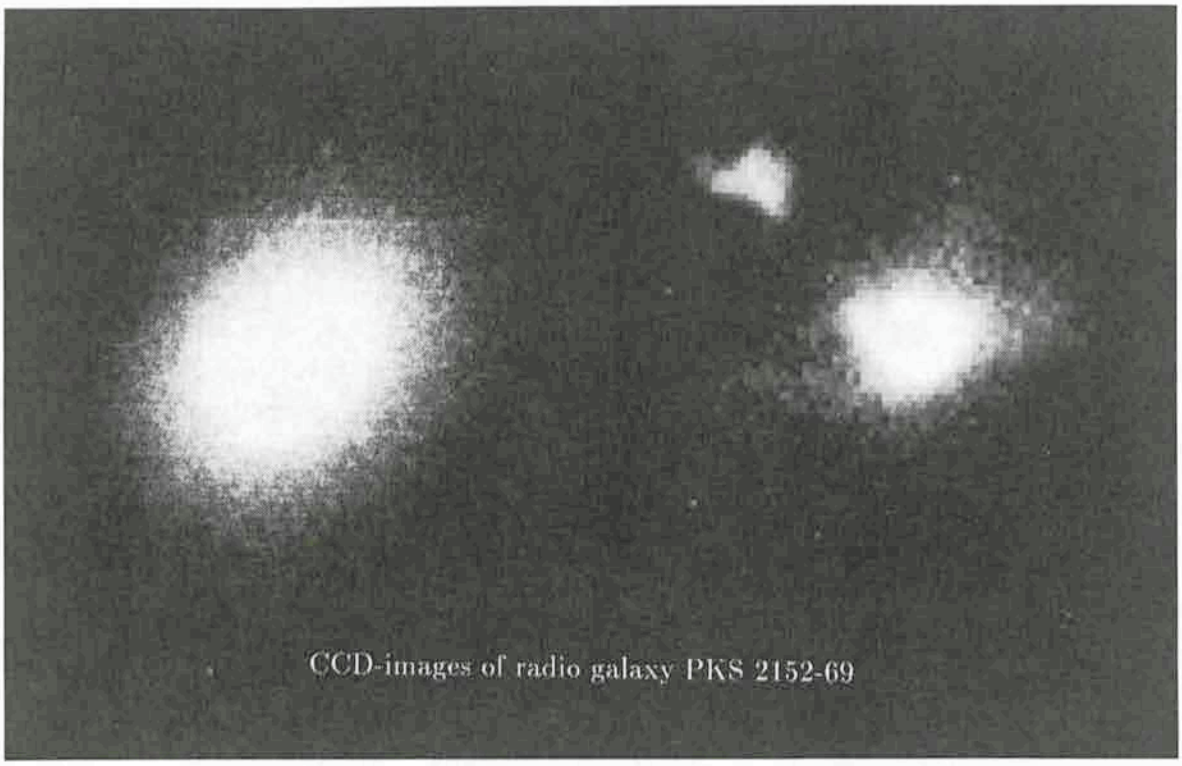

Figure 2.2: These CCD images of the southern radio galaxy **PKS 2152-69** show the gas cloud in which quasar-like activity has been discovered. The frame to the left was obtained in integrated light (continuum) and demonstrates the smooth distribution of stars in this seemingly normal elliptical galaxy. However, a highly energetic gas cloud is clearly seen to the upper left in the right frame, which was obtained by subtracting the continuum image from an image made in the red light of hydrogen and nitrogen. The two frames have the same scale. The frames were exposed with a CCD camera at the 2.2 m telescope at the ESO La Silla observatory. The projected distance from the centre of the galaxy to the cloud is about 10 arcseconds, or about 30,000 light years. North is up and east is to the left. (PR 02/87; BW)

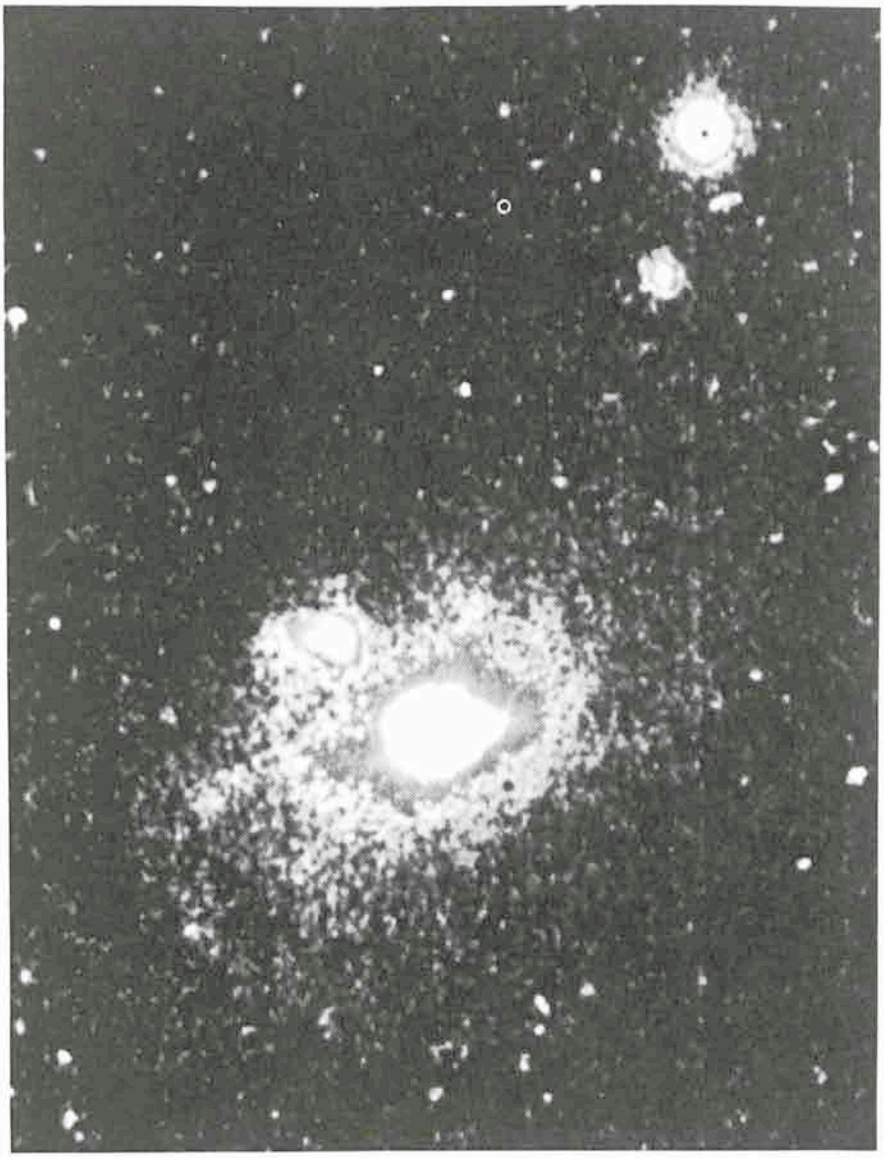

Figure 2.3: This **false-colour CCD-image of the southern radio galaxy PKS 2152-69** shows the gas cloud in which quasar-like activity has been discovered. The highly energetic cloud is seen to the upper left of the bright centre in the otherwise normal radio galaxy. The image was obtained by subtracting a continuum image from another made in the red light of hydrogen and nitrogen. They were exposed with a CCD camera at the 2.2 m telescope at the ESO La Silla observatory. The projected distance from the centre of the galaxy to the cloud is about 10 arcseconds, or about 30,000 light years. North is up and east is to the left. The round images of two stars (in our Galaxy) are seen in the upper right part of this picture. (PR 02/87; Colour)

By comparing the intensity of emission in different spectral lines with theoretical calculations, the astronomers were able to show that the energy source exciting the gas cloud must be very similar in character to that responsible for the activity seen in many AGN's. This gives an important clue to the nature of the source and suggests that it is associated with jets of energetic particles that push their way through the material composing the galaxy. Because these jets are so highly 'collimated' (parallel, non-diverging flow) they constitute a very efficient way of transporting a large amount of the energy which is generated in the nucleus and depositing it thousands of light years away. One of the most important aspects of this study is that, by seeing the 'nuclear' activity well outside the crowded and complex region of the nucleus, it is possible to get a clearer view of some of the exotic mechanisms which operate there.

In addition, understanding the physical state and chemical composition of the interstellar gas in elliptical galaxies is of great and topical importance to astronomers since only in the last decade has it been realised that these galaxies contain any significant quantity of gas at all. Firstly, cool hydrogen gas in some ellipticals was detected by radio observations and, more recently, X-ray observations revealed massive amounts of hot (ten million or more degrees) gas around these galaxies. If the origin and evolution of such halos can be determined, astronomers will come closer to solving the long-standing puzzle of why some galaxies have spiral and others have elliptical shape.

Optical observations like those referred to also provide detailed information about the composition and state of motion of galaxy halos. The work reported here is part of an extensive programme at the European Southern Observatory and the Space Telescope-European Coordinating Facility to observe the interstellar gas in elliptical galaxies using both ground-based and orbiting telescopes. The Hubble Space Telescope, now scheduled for launch late in 1988, will provide an unprecedentedly clear view of objects such as PKS 2152–69 and, by opening up the ultraviolet part of the spectrum to scrutiny, will make a giant step in the study of galactic nuclei and the way in which their enormous energy output influences the surrounding galaxy.

A report about this work will appear in the *February 5, 1987* issue of the scientific journal *Nature*. The full text of this article is also available as ESO Scientific Preprint no. 482 (January 1987).

The *Space Telescope-European Coordinating Facility* is housed at the ESO Headquarters and is operated jointly by the European Space Agency (ESA) and the European Southern Observatory.

2.3 Hunting the Black Hole

(**PR 09/87**; 16 June 1987; For immediate release)

Of all exotic objects predicted by current theories, none are as elusive as the *Black Holes*. Despite great efforts, their existence has never been unambiguously proven by astronomical observations.

However, a team of French astronomers have now obtained strong evidence in favour of the presence of a black hole at the centre of a peculiar galaxy. Based on observations at the European Southern Observatory, Danielle Alloin, Catherine Boisson and Didier Pelat of the Paris Observatory (Meudon) find that a mass of about 70 million times that of the Sun is contained within a very small volume at the centre of the active galaxy *Arakelian 120*[3]. The centre is surrounded by a rapidly spinning, gaseous disk.

Black holes are thought to be created when matter coalesces into a vanishingly small volume. For instance, if a mass equal to that of the Earth were to form a black hole, its diameter would be less than 2 centimetres. A black hole is exceedingly dense and its gravitational pull is so great that even light cannot escape from its surface. It is therefore completely dark and it only manifests its presence by the gravitational attraction which it exerts on nearby objects.

According to recent theories, the matter around a black hole will arrange itself in a rapidly rotating disk. Enormous amounts of energy are liberated when matter at the inner edge of the disk falls into the black hole and disappears from sight.

Since black holes are invisible, their existence must be deduced by observing the phenomena that take place around them. Looking for likely sites, astronomers have been particularly interested in X-ray emitting binary stars in which a large amount of energy is liberated from a very small volume in space. There is growing evidence (but so far no definite proof) that black holes with masses a few times that of the Sun may exist in some binary star systems.

Black holes may also be expected to form in the nuclei of galaxies. For instance, recent radio and infrared observations of the innermost regions of the Milky Way Galaxy indicate the presence of a heavy black hole at the very centre. Furthermore, the nuclei of some galaxies, *Active Galaxy Nuclei*[4] or AGN's, emit prodigious amounts of energy. The same phenomenon, but on a still larger scale, is found in quasars, now thought to be the extremely bright and energetic centres of very distant galaxies. The hypothetical black holes in quasars would be millions of times heavier than the Sun.

But even if the nucleus in a galaxy emits large amounts of energy, how do you prove that this energy comes from matter falling into a black hole ? As the black hole cannot be observed directly, the proof must necessarily be indirect. In specific terms, it must be shown that there is *so much mass inside such a small volume*, in other words that *the density is so high*, that a black hole is the only possible explanation. The observational problem is therefore to measure the mass in the smallest possible volume that can be distinguished at the centre of the galaxy.

This is exactly what the French team has done. First, they noted that the energy output from the nucleus in the AGN galaxy *Arakelian 120* is variable on a relatively short time scale, alternating between states of "high" and "low" activity. It was an Armenian astronomer, M.A. Arakelian at the Bjurakan Observatory, who first found this peculiar galaxy in 1975. It is situated in the constellation Orion, just south of the celestial equator. From the measured radial velocity, 10000 km/sec, the distance is estimated at $\sim$ 500 million light-years.

The spectrum of Arakelian 120 shows bright lines of various elements, including hydrogen and iron. The shapes (profiles) of some of these lines depend on whether the nucleus is in the "high" or the "low" state. By subtracting spectra, which were obtained with the ESO 1.52 m telescope with an IDS spectrograph when the galaxy was in "high" state and with the Anglo-Australian 4 metre telescope when it was in "low" state, respectively, the astronomers were able to prove that the excess light at "high" state in some of the hydrogen lines comes from a rotating disk around the nucleus. The rotational velocity at the edge of this disk is about 2100 km/sec, and the disk appears to be inclined by 60° to the line of sight. Outside the disk there are many hydrogen clouds.

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[3]This Press Release is accompanied by a photo of Arakelian 120.

[4]see also ESO PR 02/87 of 29 January 1987.

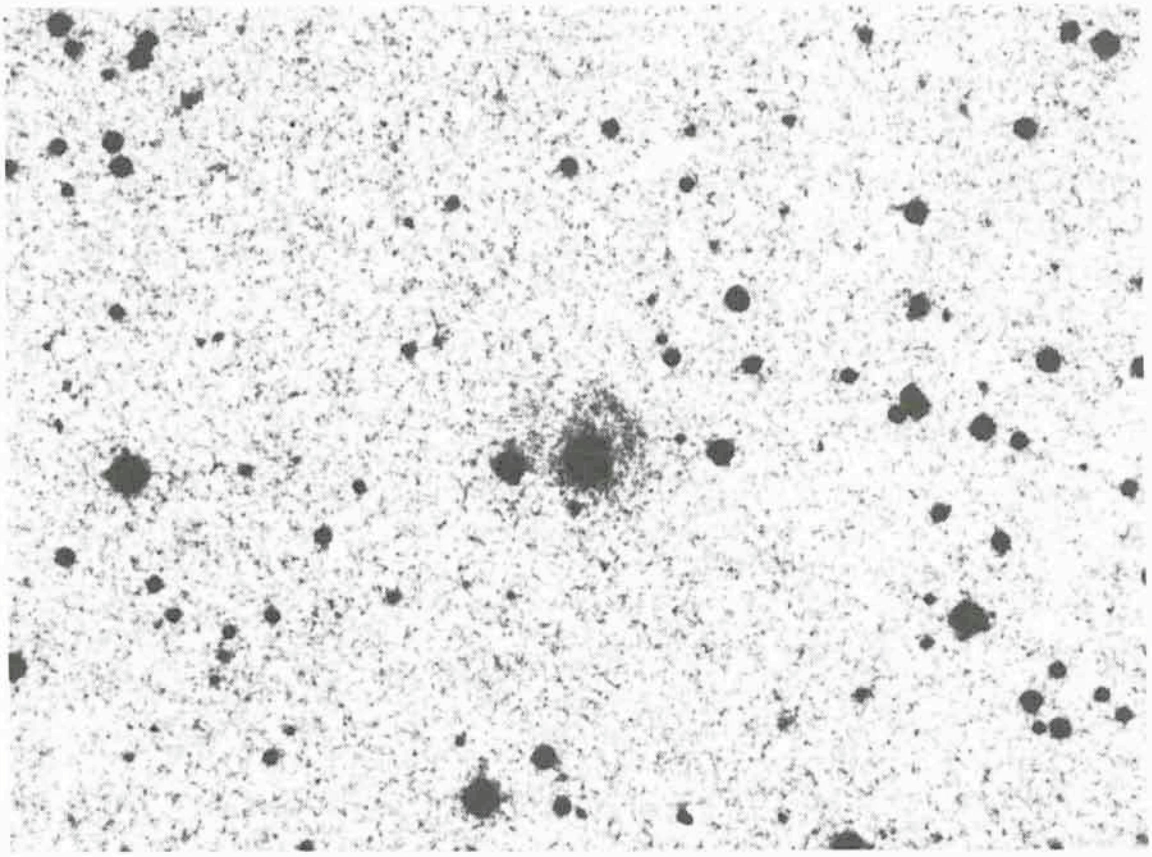

Figure 2.4: **Is there a black hole in this galaxy ?** This is a photo of *Arakelian 120*, an AGN galaxy which may contain a massive black hole at its centre, cf. ESO Press Release 09/87. The bright nucleus is overexposed and the underlying galaxy is only faintly visible. Most of the other objects in this field are stars in the Milky Way Galaxy. This photographic print was prepared at the ESO Photographic Laboratory from the Palomar Observatory Sky Survey (©National Geographic Society and California Institute of Technology). (PR 09/87; BW)

From continued monitoring, they noted a time delay of about 2 months between the moment when the nucleus changes from one state to the other and when the profiles of certain spectral lines that originate in the surrounding clouds begin to change. This delay therefore corresponds to the time it takes the light to traverse the disk and the radius of the disk cannot be larger than 2 light-months, or $\sim$ 10.000 Astronomical Units. One Astronomical Unit = 150 million kilometres, i.e. the distance from the Sun to the Earth. Note also that 2 light-months at the distance of Arakelian 120 only subtend an angle of about 60 microarcseconds, too small to be directly resolved with existing interferometric techniques. (An object measuring 12 cm and placed on the surface of the Moon, would be seen under the same angle.)

From the size of the disk and its rotational velocity, the mass inside the disk can now be calculated as $\sim$ 70 million solar masses. (The mass of the Sun is calculated in a similar way from the radius of the Earth's orbit and its velocity in this orbit.) This observation therefore shows that the density is very high at the centre of Arakelian 120. In fact, if the total mass were spherically distributed and belonged to individual stars, each with a mass like that of the Sun, then the mean distance between two stars would only be about equal to the distance between the Sun and Pluto.

Such an enormous stellar density is highly unlikely since a system like this would suffer from stellar collisions and would not be very stable. Thus, from the measured density and the total amount of energy emitted from the small volume, a much more plausible explanation is the presence of a black hole. Its mass may be a significant fraction of the total mass inside the perimeter of the disk and the radius is perhaps $\sim$0.5 Astronomical Units.

The three astronomers describe their detailed findings in an article which has been accepted for publication in the European journal *Astronomy & Astrophysics*.

2.4 No "Missing Mass" in Opaque Spiral Galaxies ?

(**PR 07/90**; 7 September 1990; For immediate release)

A long-term astronomical study of spiral galaxies, initiated almost a decade ago at the European Southern Observatory, has recently produced intriguing results about the presence of cold matter in the Universe. They have a direct bearing on the socalled "missing mass" problem, one of the major unsolved riddles in astronomy.

The ESO Atlas

In 1972, ESO embarked on the production of the first modern, photographic atlas of the southern sky. More than 1200 large, blue-sensitive photographic plates were obtained with the 1-m ESO Schmidt telescope on La Silla; the 606 best of these formed the basis for the "ESO Quick Blue Atlas of the Southern Sky" which was ready in 1980. This Atlas showed celestial objects up to 100 times fainter than recorded in earlier southern atlasses and, not unexpectedly, many new and interesting discoveries were made on it.

A comprehensive catalogue of more than 16,000 bright galaxies, stellar clusters and galactic nebulae was compiled by Swedish astronomer Andris Lauberts as a result of a careful, visual inspection of the Atlas photographs. It was published by ESO in 1982 and included the first systematic classification by type (elliptical, spiral, irregular) of southern galaxies.

Accurate measurements of 15,000 southern galaxies

In 1982, Andris Lauberts and the Dutch astronomer Edwin Valentijn embarked upon an even more ambitious project. With a fast, high-precision microphotometer at the ESO Headquarters in Garching, they scanned the images of 15,467 galaxies in this Catalogue, first on the blue-sensitive Atlas plates, and then on red-sensitive plates, also obtained with the ESO Schmidt telescope. In this way, the photographic images were registered as arrays of numbers which could be stored in a computer. In the end the immense database comprised more than 4 Gigabytes. It has been stored on optical disks, making it possible to display the blue and red images of all of these galaxies instantaneously, a very efficient tool for many astronomical investigations.

By means of sophisticated computer programmes, each galaxy was automatically analyzed and classified according to type, brightness, colour, size, the angle from which it is viewed, etc. In all, each galaxy was characterized by about 200 different parameters.

Opaque spiral galaxies

New and exciting results have now been obtained by Edwin Valentijn, following an extremely detailed computer analysis of 9,381 southern spiral galaxies, identified as such in the above mentioned database.

His investigation began with a comprehensive study of the surface brightness of these galaxies (that is, the way the brightness varies over the galaxies' surface) in relation to the angle under which they are seen (spiral galaxies seen face-on ressemble pinwheels, while they look like compass needles when they are seen from the side). The dependance of the surface brightness on the viewing angle, statistically spoken, makes it possible to estimate the opaqueness of these galaxies, that is how strongly light passing through them is absorbed.

To his great surprise, and contrary to the conventional view that spiral galaxies are rather transparent, Valentijn found that these galaxies are quite opaque and therefore contain many more clouds of interstellar matter than thought before, also in their outer regions. Like the dimly visible headlights of cars on a foggy morning, the light from many of the stars within these galaxies barely penetrates these clouds.

Most important, a comparison with infrared measurements from the IRAS satellite indicates that this matter must be very cold; the temperature is less than 20 degrees above the absolute zero ($T < 20$ K). It is most likely to consist of molecular clouds, such as those known since some time in our own galaxy, the Milky Way.

The clouds are too cold and dark to be seen directly, but from our own galaxy it is known that much of the mass of molecular clouds is made up of molecular hydrogen gas, H_2, which is extremely difficult to observe.

The missing mass ?

The mass of a spiral galaxy can be determined by accurate measurements of the motions of its stars and atomic hydrogen gas (H I); this is done by means of optical and radio doppler spectroscopy. The more rapid the motions are, the heavier is the spiral galaxy. Previously, in virtually all cases the mass of a galaxy determined this way, has been found to be significantly larger than the combined mass of all the stars and interstellar matter actually visible within the confines of that galaxy. Thus, a large fraction of the mass must be "invisible" - this is known as the problem of the "missing mass".

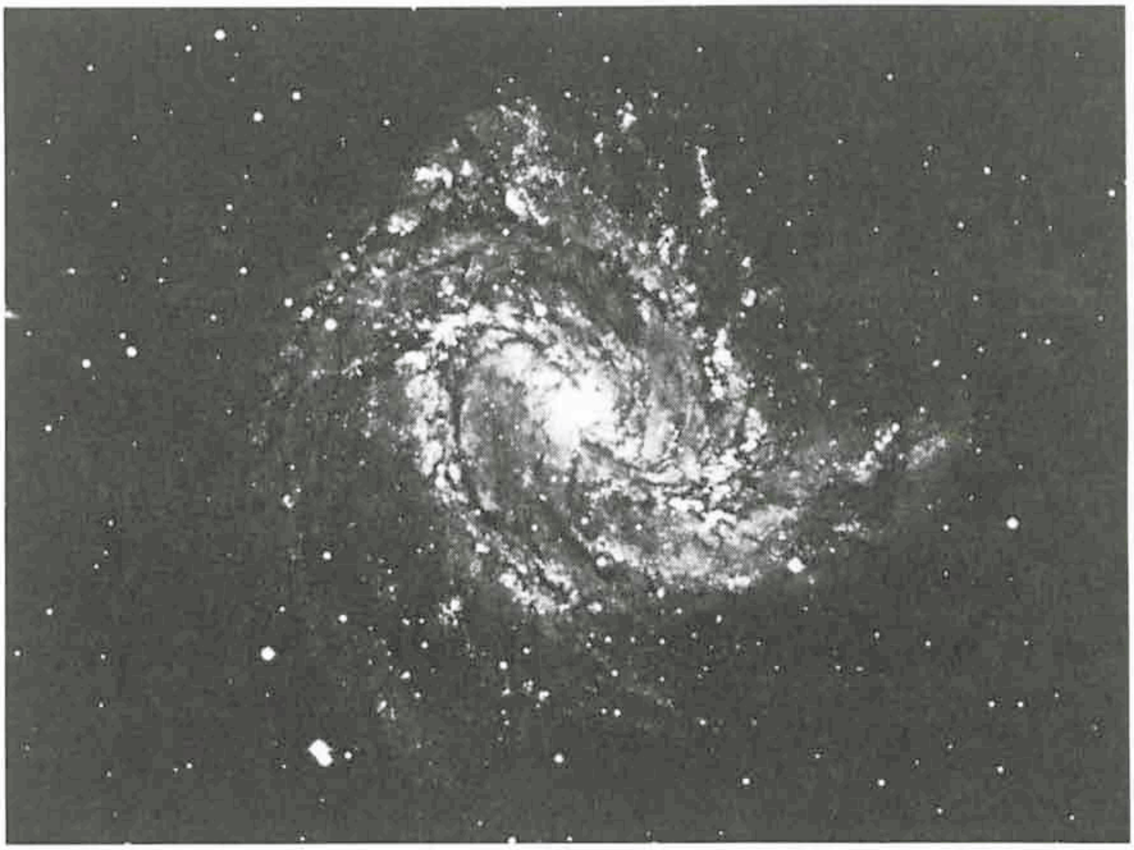

Figure 2.5: This is an image of the **bright, southern spiral galaxy NGC 5236**, also known as Messier 83, one of the 9381 spiral galaxies studied by Andris Lauberts and Edwin Valentijn. It is the nearest galaxy of type Sbc in the study, for which the new results indicate that it contains more light absorbing dust than previously thought. Although many dark patches of dust can be seen along the spiral arms, and even in the outer regions, the new study suggests that there are actually many more opaque clouds all over this galaxy. (PR 07/90; BW)

There have been many attempts to explain this. Some scientists believe that galaxies may have large haloes of hot gas, not visible with present astronomical instruments. Others have invoked the presence of large numbers of exotic elementary particles, including neutrinoes, or massive "cosmic strings".

However, if the spiral galaxies contain many more interstellar, molecular clouds than detected before, then perhaps the mass of these clouds makes up for the "missing" amount ?

To look into this, Valentijn and the Spanish astronomer Ignacio González-Serrano have studied half a dozen of the most "mass-missing" spiral galaxies, for which extensive doppler spectroscopy has been made. In all cases, the astronomers find that the mass of the molecular clouds inferred from the opaqueness corresponds exactly to the amount that was "missing". Thus, for these "classical missing-mass" galaxies at least, there is no longer any need to invoke the presence of any exotic "missing mass".

This, of course, does not mean that the "missing mass" problem has now been definitively solved. More observations are needed to provide more knowledge about the molecular clouds in these spiral galaxies, in particular difficult measurements of the radio emission from some of the other molecules expected to be present in the clouds, for instance carbon monoxide (CO). It is important, however, that Valentijn's findings offer a natural explanation of the "missing mass", which is in agreement with all available observations and which would eliminate the need for additional, exotic ingredients.

There is also "missing mass" in elliptical galaxies and in clusters of galaxies, but such objects were not included in the present study.

The Milky Way

Our own galaxy, the Milky Way, is a typical spiral galaxy, so how opaque is it, and what about the "missing mass" thought to exist here in our immediate neighbourhood ?

Hoping to cast new light also on this problem, Edwin Valentijn again turned to the computerized database. He noted that about 60,000 additional, faint galaxies, situated much further out in space, are seen in almost the same direction as the nearly 16,000 galaxies for which computerized images are available. Counts of the nearby as well as of the more distant galaxies revealed that there are 60 % more of these objects "above" the Milky Way plane (in the Northern Galactic Hemisphere) than in the opposite direction.

There are two possible explanations for this phenomenon. In the first case the distribution in space of these galaxies is not uniform, but this would require that the Universe is non-uniform on a scale of 1000 - 2000 million lightyears which is not very probable according to current cosmological research.

The more likely explanation is that it reflects the position of our Sun in the Milky Way, which has been shown by accurate measurements to be about 40 lightyears above ("North" of) the galactic plane. Indeed, if our Milky Way were as opaque as the spiral galaxies of the same class in the computer database were found to be, then the interstellar absorption in the Milky Way should be significantly larger towards the South (looking through the central plane where most of the absorbing material is) than towards the North (looking through less absorbing regions, high above the plane). Hence more galaxies would be seen in the North than in the South.

In summary, the discovery that spiral galaxies are more opaque than thought before may therefore also apply to our own Galaxy. Again more observations, particularly in the southern hemisphere (for instance with the SEST telescope on La Silla) will be needed to clarify the situation.

Note that, as in the spiral galaxies in the study, the presence of cold and opaque molecular clouds near the galactic plane would not show up in conventional studies of interstellar absorption which rely on the reddening of starlight. This is because these opaque clouds simply block all light from objects located behind them.

Literature

A preliminary account by Valentijn of the opaqueness of spiral galaxies has just appeared in the science journal *Nature* (**346**, p.153). More detailed accounts, also including a discussion about the "missing mass" will appear in papers being published in the Proceedings of IAU Symposium 144 (Kluwer, Dordrecht) and (with Ignacio González-Serrano) in the European journal *Astronomy and Astrophysics*.

2.5 Discovery of the Most Distant "Normal" Galaxy Known

(**PR 08/90**; 24 October 1990; For immediate release)

Astronomers working at the ESO La Silla observatory have just discovered the most distant "normal" galaxy known so far. It has been given the designation **G 0102–190** and its distance is so great that the light we observe from it was emitted when the Universe was only one third as old as now[5].

Why is it so important to observe "normal" galaxies ?

Looking back through time towards the depths of the Universe in a way is similar to reading ancient chronicles from our own past: while we hear much about spectacular events like wars and the ascension of kings and emperors, the inconspicuous life of the common man only rarely emerges from the shadows. And so it is when we search for objects in the distant realms of space: there we first of all find the brightest quasars and the most energetic radiogalaxies which, because of their prodigious output of energy, can be detected at immense distances.

However, while these objects are of course highly interesting in themselves, they most certainly only represent a very small fraction of the objects located out there. As is the case in our immediate surroundings, it is believed that the spectacular, energetic objects are greatly outnumbered by much less bright "normal" galaxies, also far out in space. The problem is that at these large distances the light we receive from them is so faint that they can hardly be observed, even with the largest astronomical telescopes.

And yet, it is exactly these galaxies which we must study in order to progress in one of the most central subjects in modern astrophysics: the evolution of the Universe. At the present epoch, virtually all matter in the Universe is concentrated in "normal" galaxies, such as our own Milky Way and its neighbour, the Andromeda galaxy, neither of which - and that is

[5] According to the best estimates, the age of the Universe is 15 -20 000 million years, i.e. the distance to G 0102–190 is at least 10 000 million light years.

good for us - shows any particularly strong activity. It is therefore of crucial importance to understand how "normal" galaxies have developed and what they were like, a long time ago.

We can do so by observing "normal" galaxies at very large distances, so great that their light has been underway to us during a significant fraction of the age of the Universe. Indeed, unless we are able to observe such very distant objects and compare them with similar nearby galaxies (which we see as they are "now"), it would be impossible to discuss the evolution and formation of galaxies in the early Universe and also the evolution of the Universe itself.

Detection of distant galaxies by means of quasar light

Galaxies which are so distant that they are observed as they were when the age of the Universe was about one third or less of its present age, i.e. galaxies with redshifts[6] above 1, are very difficult to detect directly since the light we receive from them is extremely faint. Moreover, it is not sufficient just to detect such galaxies as faint nebulous spots on an astronomical image; supplementary observations of their spectra are needed to estimate distances and physical properties. Spectral observations are even more difficult and have so far only been possible for the brightest of the very distant objects, i.e. for the very luminous quasars and a small number of bright radio-galaxies.

That very distant "normal" galaxies actually exist has been inferred from the presence of absorption lines in the spectra of extremely distant quasars. When the light from one of these ultraluminous objects on its way to us happens to pass through the interstellar gas in a "normal" galaxy on the same line of sight, part of the light is absorbed at particular wavelengths which is a measure of the redshift and therefore the distance of the intervening galaxy. Absorption features of hydrogen atoms and heavier elements have been detected in various studies, during which quasars are used as background "candles" to probe all the intervening matter between us and them[7].

The first observations at ESO

By means of such observations in 1985 at the 3.6-m telescope at La Silla, Jacqueline Bergeron, astronomer at the Institut d'Astrophysique de Paris (CNRS, France) was able to detect the image of a "normal" galaxy at a redshift $z \sim 0.4$, i.e. at an epoch corresponding to about two thirds of the age of the Universe ($\frac{2}{3} \cdot t_H$). The existence of this galaxy had first been inferred from the presence of absorption lines in the spectrum of a quasar, situated much further away. This first identification was soon followed by about a dozen others at similar redshifts (i.e. distances) during a survey carried out in collaboration with another French astronomer, Patrick Boissé of the Ecole Normale Superieur in Paris.

The French astronomers found that all of these galaxies appear to be single; they are not members of galaxy clusters and are therefore referred to as "field" galaxies. Their spectra and luminosities (i.e. the amount of energy emitted) were typical of nearby "normal" galaxies.

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[6]In astronomy, the redshift z denotes the fraction by which the lines are shifted towards longer wavelengths in the spectrum of a distant galaxy or quasar receding from us with the expansion velocity of the Universe. The observed redshift gives a direct estimate of the apparent recession velocity, which is itself a function (the Hubble relation) of the distance to the object under study. If we denote the age of the Universe as t_H and the time the light we observe from a galaxy was emitted as t_g, then a galaxy redshift of $z_g \sim 1$ corresponds to a look-back to $t_g \sim \frac{1}{3} \cdot t_H$, i.e. we see the galaxy as it was when the age of the Universe was only one third of what it is now.

[7]For an example, see ESO Press Release 13/87 of 10 September 1987. Also Supernova 1987A in the Large Magellanic Cloud was used as a background light source to study interstellar clouds along the line of sight.

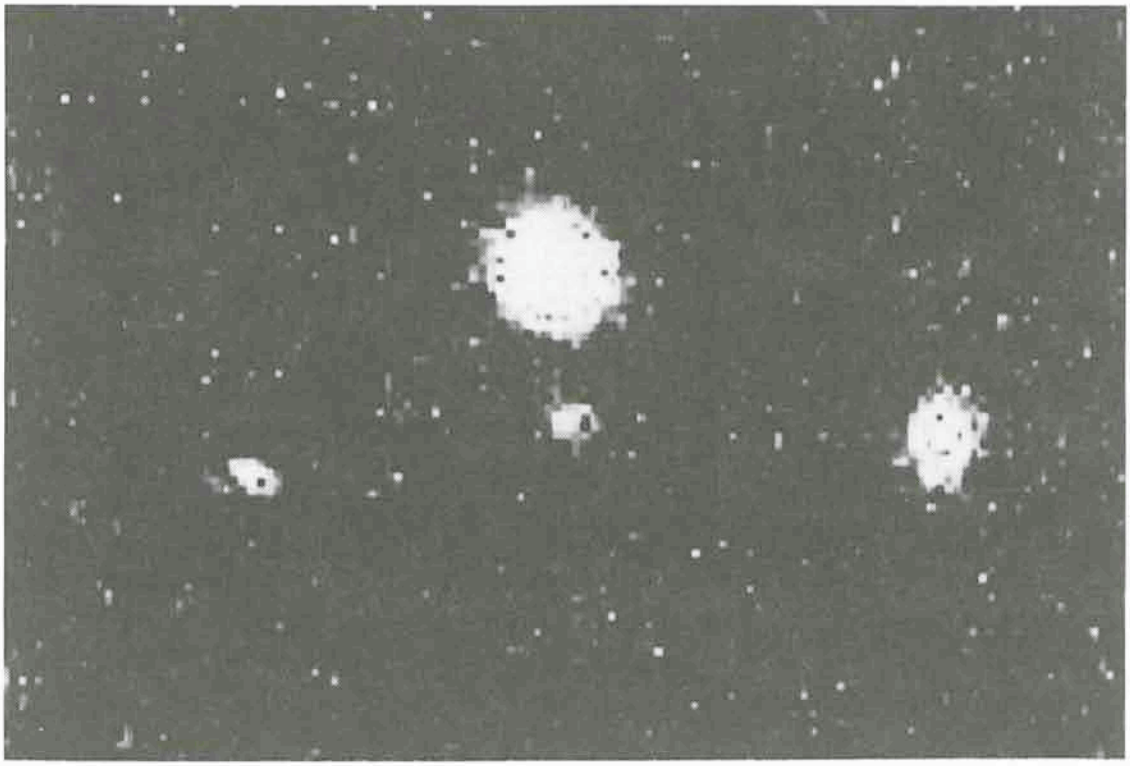


Figure 2.6: This is an image of the **most distant "normal" galaxy known, G 0102−190**, as seen on a CCD exposure obtained with the EFOSC II instrument at the ESO New Technology Telescope. The field measures 39 × 26 arcsec; the brightest object is the quasar UM 669, whose image is strongly overexposed. G 0102−190 is the faint resolved object 4.8 arcsec south of the quasar image. Only the stellar component of the galaxy is seen; the continuum emission of the gaseous halo is much too faint to be detectable. The other two faint resolved objects, 12 arcsec south–east and 14 arcsec south–west of the quasar image, are galaxies with smaller redshifts, ∼ 0.9 and 0.6, respectively. North is at the top and East is at the left. Broad-band red filter. (PR 08/90; BW)

The observations showed that these distant galaxies are surrounded by huge gaseous halos, with diameters roughly three times larger than those of the inner regions occupied by the stars. This is demonstrated by the fact that even though the centres of these galaxies are separated from the quasar images by 5 to 10 arcsec, the quasar light still passes through the gaseous halos so that absorption lines are visible in the quasar spectra.

Thus the study showed that most, if not all field galaxies at the earlier epoch that corresponds to redshift $z_g \sim 0.4$ (i.e. $t_g \sim \frac{2}{3} \cdot t_H$), have extended gaseous halos. Since galaxies today ($t = t_H$) do not appear to possess such extended gaseous halos (for instance, the Milky Way has no big, spherical halo), this suggests that there has been a strong evolution in more recent times. The observed halos around the distant galaxies are most likely the remnants of the huge gaseous clouds in the early Universe whose collapse led to formation of galaxies.

Now, a "normal" galaxy at redshift 1 !

Encouraged by this successful search for "absorbing" galaxies at $z \sim 0.4$, Jacqueline Bergeron continued this work in collaboration with Stefano Cristiani (Osservatorio di Asiago, near Padova, Italy) and Peter Shaver (ESO), searching for "normal" galaxies at even larger distances, corresponding to redshifts $z \sim$ 1.0 to 1.5.

Observations were conducted in March and September 1990 at the ESO New Technology Telescope and resulted in the identification in late September of the first "absorbing" galaxy at z $\sim$ 1. The galaxy, now designated G 0102−190, has a redshift $z_g = 1.025 \pm 0.001$; this was measured from a strong emission line of ionized oxygen atoms, which was detected in a spectrum of total exposure time of 4.5 hours. The redshift of the absorption in the spectrum of the quasar (UM 669, $z_Q = 3.035$) was measured as $z_a = 1.026$ and, given the accuracy of the redshift determination, $z_g = z_a$; this proves beyond any doubt that it is indeed this galaxy that causes the absorption.

As seen in the picture, accompanying this Press Release, the absorbing galaxy lies 4.8 arcsec south of the quasar. This corresponds to a linear separation between the centre of the galaxy and the line of sight to the quasar of about 160 000 light years, meaning that G 0129−190 must possess a gaseous halo of at least this size.

The difficulty of this spectral observation is illustrated by the fact that the observed brightness of this galaxy is only r = 23.2 mag, i.e. no more than 2% of that of the background emission from the Earth's atmosphere. At the same time this brightness, together with the measured distance, indicates that the galaxy is "normal" in the sense that its luminosity (energy emission) is at the most double that of the Milky Way Galaxy. It is more than thirty times fainter than typical radio-galaxies and one-thousand times fainter than typical quasars, observed earlier in the distant Universe.

A first glimpse of the "common inhabitants" of the early Universe ?

This first identification of a "normal" galaxy at redshift z $\sim$ 1 suggests that gaseous halos of galaxies were at least as extended at the corresponding epoch, $t \sim \frac{1}{3} \cdot t_H$, as later at $t \sim \frac{2}{3} \cdot t_H$. The present galaxy is also in other respects very similar to those which were earlier found at redshifts near 0.4; in particular it has about the same luminosity.

The initial success gives reason to hope that this observational approach will soon lead to the detection of further, "normal" galaxies at even larger redshifts and earlier epochs. The observational programme now continues and the images of a number of other distant and supposedly "normal" galaxies, seen in almost the same directions as quasars, have already been identified; their spectra will soon be observed. If also they are found to be situated at the distances measured from the absorption lines seen in the quasar spectra, then they will not be intrinsically much brighter either, and it would appear that there has been no substantial change of the luminosity of galaxies during this long interval of time.

Earlier surveys of extremely faint galaxies indicate that either the local density or the luminosity of "normal" galaxies increase with redshift. The present observational programme will undoubtedly contribute to the solution of this central problem in the evolutionary history of the Universe.

The detailed results of this investigation will be reported in a Letter to the Editor in the European journal *Astronomy & Astrophysics*.

2.6 At Last: the Enigmatic Centre of the Milky Way Sighted !

(**PR 09/90**; 31 October 1990; For immediate release)

Observing with the ESO New Technology Telescope, three European astronomers[8] have discovered two previously unknown celestial objects which are seen in the direction of the mysterious centre of our galaxy, the Milky Way. One of the new objects has a comparatively blue colour and appears to be the actual Galactic Centre, at a distance of about 28 000 light-years. It has required a telescope with the penetrating power of the NTT to see through the dense, interstellar dust clouds (which effectively hide the central area from our view) in order to obtain the first optical image of the Galactic Centre.

The newly found objects, provisionally designated **GZ-A** and **GZ-B**, will now be studied with all available means in order to unravel the true nature of the Galactic Centre. In particular, it may become possible to learn whether it is a compact cluster of hot, young stars, or rather a *black hole.*

How to look through the interstellar clouds

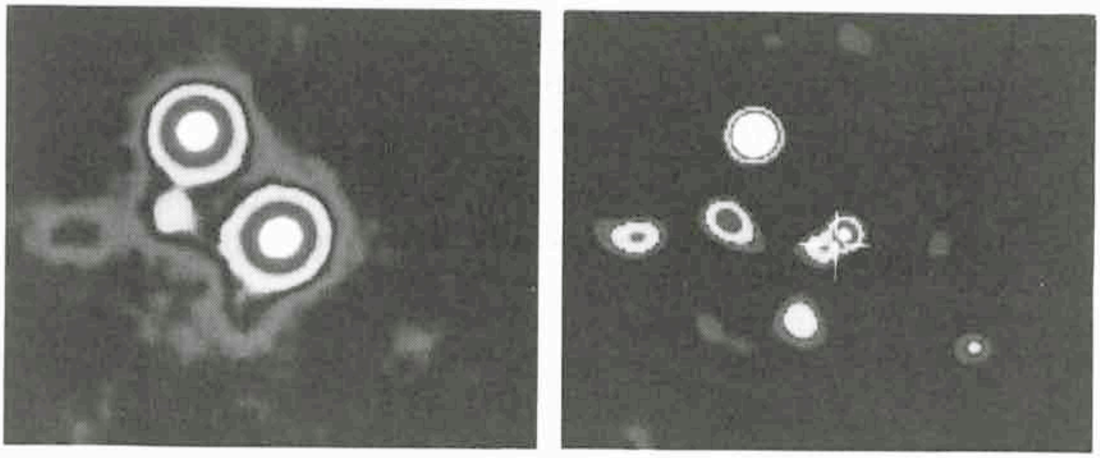
Although we receive much infrared radiation from the general area surrounding it, the very Centre of the Milky Way Galaxy has so far only been detected by means of observations of its radio emission. Some years ago, radioastronomers established that the radio-source **Sgr A*** in the southern constellation of Sagittarius is connected to this centre. However, until now all observations in other wavebands (infrared, optical, ultraviolet, X-ray and gamma-rays) did not reveal any object at the exact position of the radio source; this is mainly because the very dense interstellar clouds of dust and gas in front of the Galactic Centre absorb most of the radiation at the shorter wavelengths.

Another observational problem is the great number of foreground objects like stars and nebulae, which are located in the space between us and the Galactic Centre. In particular, there is one comparatively bright star which is seen very near the line of sight to the Centre and partly obstructs the view. For some time this star was even thought to be the Centre itself, but this has since been disproved.

To obtain the present image of the Galactic Centre, the astronomers resorted to a clever observational approach. Assuming that the Galactic Centre (as other energy-rich regions) has a blue colour, it would be natural to attempt to register the blue light from this direction. However, blue light is particularly strongly absorbed in the interstellar clouds and less than one million millionth of what is emitted at the Centre actually gets through. For this reason there is not enough blue light to be registered, even with the NTT. In the infrared spectral region, the interstellar absorption is much less and relatively more infrared light can therefore pass through the clouds. But if the Centre is blue, it may not emit much infrared radiation and accordingly, it would not be observable at these wavelengths either.

Thus the astronomers reasoned that the best chance to see the image of the Galactic Centre is by observing at wavelengths, intermediate between blue and infrared. The present observations were therefore made in the spectral interval 850 - 1100 nm, just outside the red

[8]Hans Zinnecker (Institut für Astronomie und Astrophysik, Universität Würzburg, Fed. Rep. Germany), Michael R. Rosa (ST-ECF, ESO-Garching) and Andrea Moneti (ESO La Silla Observatory).



The Galactic Centre

Figure 2.7: This photo shows the **first optical image of the Galactic Centre**, the enigmatic region at the centre of our galaxy, the Milky Way. It was obtained with the EFOSC II instrument at the ESO New Technology Telescope (NTT). The left frame is the direct combination of five 40-min CCD exposures, showing two bright objects, as well as several fainter ones. The bright object at the centre is the star IRR1/CCD2. The right frame shows the the same area, but after computer processing and removal of the image of IRR1/CCD2. At its place, two fainter objects are now seen which were previously hidden in the glare of IRR1/CCD2. They have been designated GZ-A (lower left) and GZ-B (upper right); the distance between them is 0.7 arcsecond. The position of the radio-source at the Galactic Centre, Sgr A*, is indicated with a cross. The apparently blue object GZ-A is only 0.3 arcsec from Sgr A*, well within the uncertainty of the radio-position, and is thought to be the optical image of the very Centre. Technical details: Gunn-z filter (850 - 1100 nm); mediocre seeing: 1.0 arcsecond. Field size: 12 $\times$ 11 arcsecond. North is up and East to the left. (PR 09/90; BW and Colour)

spectral region. At these wavelengths, one millionth of the light gets through. As will be seen, this strategy bore fruit !

What was hidden behind the bright star

A total of five 40-min exposures of the sky area in the direction of the Galactic Centre was obtained with the NTT and further image processing was done with the MIDAS software, developed by ESO. To begin, the five exposures were added together to produce the "deepest" optical image[9] ever produced of this region, showing a wealth of very faint objects. Among those identified in the picture are virtually all of the infrared-emitting sources, which have been detected in earlier infrared surveys, but which are not directly connected to the Galactic Centre.

In the next step, the NTT picture was "computer-sharpened" (by means of a powerful algorithm developed by ESO astronomer Leon Lucy) so that the diameters of the stellar images in the field were reduced to 0.4 arcseconds. Because of the very low "noise" in this picture (due to the very large number of photons registered with the large NTT during a long exposure time), the images are extremely "clean" and well-defined. This permitted the astronomers to detect that the image of one of the two relatively bright stars in the picture is slightly elongated, a clear indication of the presence of other fainter images, nearly coincident with that of the bright star.

When the perfectly round image of the other bright star in the field was "subtracted" from that of the elongated star (whereby the image of the latter is removed from the picture), two previously unknown star-like objects emerged on the computer screen. Comparing their positions with that of the radiosource Sgr A*, the objects (designated **GZ-A** and **GZ-B**) were found to lie within 0.3 and 0.5 arcseconds of the Galactic Centre, respectively; this is well within the uncertainty of the radio position. The distance between the two objects is only 0.7 arcseconds. The very close positional coincidence of GZ-A with SgrA*, and the fact that no infrared radiation has been detected from GZ-A, which therefore presumably has a blue colour, strongly indicates that this object is indeed identical with the optical image of the Galactic Centre.

The presence of these two objects, until now hidden in the glare of the bright star, has in the meantime been confirmed by means of another, shorter NTT exposure, obtained under very good observing conditions by ESO astronomer Jorge Melnick.

Is there a black hole at the Galactic Centre ?

The astronomers have measured the brightness of GZ-A as seen on the computer-processed picture and they have also estimated how much its light is weakened during the passage to us. This makes it possible to calculate the amount of light emitted by GZ-A. They find that GZ-A shines with an intensity that is a few million times larger than that of the Sun and that it could be a very compact cluster of several hot stars (of spectral class O7). Such clusters have been found at the centres of some star-forming regions in the Milky Way and also in the Tarantula Nebula (30 Doradus) in the Large Magellanic Cloud.

However, it is also possible that one or both of the two new objects are related to a black hole at the Galactic Centre. It would be surrounded by hot gas which emits strong

[9]This Press Release is accompanied by a B/W picture; a false-colour rendering is available on request.

radiation from ionized atoms and from electrons moving at very high (relativistic) velocities in a magnetic field.

It should be feasible to ascertain which of the two possibilities is the correct one by means of spectroscopic observations. They will be attempted with the NTT as soon as possible, but will require extraordinarily favourable observing conditions in order to succeed.

This important discovery is creating much excitement in the astronomical community and has significantly increased our chances of finally being able to unravel the true nature of the enigmatic Galactic Centre.

A preliminary, scientific account of this investigation has been given on IAU Circulars nos. 5125-6, issued by the Telegram Bureau of the International Astronomical Union on October 30, 1990.

Chapter 3

Supernova 1987A in the LMC

3.1 Brightest Supernova since Four Hundred Years Explodes in Large Magellanic Cloud

(**PR 04/87**; 25 February 1987; For immediate release)

Astronomers all over the world are highly excited about the sudden explosion of a *supernova* in the Large Magellanic Cloud (LMC), a small satellite galaxy to our own Milky Way Galaxy. The LMC is the nearest, external galaxy; its distance is only about 180.000 light years.

Almost at magnitude 4, this supernova is easily visible with the naked eye to observers in the southern hemisphere. It has been given the designation ***1987A*** and is the brightest to be observed since the 1604 supernova in our own Galaxy, observed by Johannes Kepler. In 1885, a magnitude 7 supernova was seen in the Andromeda Nebula, another neighbour galaxy. The current event is therefore a most unique, once-in-a-lifetime opportunity for astronomers.

The supernova was seen first during the night between February 23 and 24, apparently almost simultaneously by observers in South America, Australia and New Zealand. According to professional astronomers in Chile and Australia, it had risen very rapidly in brightness, becoming at least 1500 times brighter within the previous 24 hours.

An emergency programme was immediately put into action at the ESO La Silla observatory. At least eight ESO telescopes have been observing the supernova during the past night (February 24 - 25). The following is a brief summary of the information which was transmitted this morning from La Silla to the ESO Headquarters:

The supernova was nearly constant in brightness, during 5 hours of accurate photometric observations; the visual magnitude is found to be 4.60. There is a slight indication of further brightening, so perhaps it has not yet reached maximum brightness. The colour is very blue. Spectra were obtained at medium resolution which show very broad features, as normally seen in a Type I supernova. High resolution spectra (resolution 100.000, Calcium ion lines at 393 and 397 nm) show narrow absorption lines from at least 12 intergalactic clouds, situated between the LMC and our Galaxy, and most of which were not known before.

By chance, colour photographs were obtained at ESO of the LMC, a few days before the supernova explosion. More colour photos were made last night, now showing the bright supernova. It is expected that they will become available from the ESO Information and Photographic Service early next week.

Some general information about supernovae:

Supernovae are believed to represent a late evolutionary stage of massive stars in which the star runs out of atomic fuel. It can no longer support its own weight and collapses. Immediately thereafter follows a dramatic thermonuclear explosion during which the outer layers are blown into the surrounding space. A small and very compact object may remain at the center. The best known historical supernova was seen in the year 1054, giving birth to the Crab Nebula and an associated neutron star, which was detected as a radio pulsar in 1967. Most, if not all heavy elements in the universe have been generated in the exceedingly hot interiors of stars in the supernova phase. Supernovae are very rarely discovered before they reach their maximal brightness and little is known about the early phases. Currently, about 20 - 25 supernovae are detected per year in exterior galaxies; the last one in our own galaxy, the Milky Way, appears to be the one found by Kepler in the constellation Ophiocus in 1604. A 12 mag supernova was observed last May in the peculiar galaxy NGC 5128 (Centaurus A), see ESO Press Release 07/86 of 13 May 1986. It was about 1500 times fainter than the present one in LMC.

3.2 Supernova in Large Magellanic Cloud: Overview of First Results

(**PR 05/87**; 3 March 1987; For immediate release)

One week after the explosion of a bright supernova (1987A) in the Large Magellanic Cloud[1], and after intensive observations at the European Southern Observatory and elsewhere in the southern hemisphere, it is now possible to draw several important conclusions about this unique event.

The supernova is located about 20 arcminutes (2/3 of the diameter of the Moon), southwest of the well-known Tarantula Nebula, a bright gaseous nebula in the Large Magellanic Cloud. It was first seen early on February 24 by I. Shelton at the University of Toronto station at the Las Campanas Observatory in Chile. Subsequent inspection of a colour photo, by chance obtained at the European Southern Observatory on February 23, 01:00 Universal Time (UT) did not show the supernova, but it is clearly seen on photos taken 8 hours later in Australia. The explosion must therefore have taken place during this time interval.

The star that exploded (the supernova *progenitor*) has been provisionally identified with a 12th magnitude, hot supergiant star with the designation *Sanduleak -69 202*. Close examination of earlier photographs have revealed that this star has two very close companions. From positional measurements, it is seen that one of these (2.5 arcseconds northwest of the main star) cannot be the progenitor. However, the other companion is less than 1 arcsecond from the main star and it is not yet possible to decide which of the two became the supernova.

The *brightness* of the supernova continued to rise for several days after the initial, rapid phase. On February 25, the visual magnitude was 4.5, and two days later, it had reached 4.3. But accurate photometric measurements from the last days indicate stagnation or even a slight decrease, so that it appears that the maximum in visual light may have been reached around February 28. This would imply a total increase of about 8 - 9 magnitudes, or that the supernova is about 2000 times brighter in visual light than its progenitor. This may seem much, but is nevertheless unexpectedly little for a supernova of Type II. As a matter of fact, had this supernova behaved as other Type II supernovae, it would have been expected to reach magnitude +1, about as much as the brightest stars. This has already led to theoretical speculations and again demonstrates that the supernova phenomenon is far from being fully understood.

The *colour* of 1987A has become significantly redder since it was first observed. From the time of discovery until now, there has been a continuous, rather rapid decrease of the ultraviolet radiation, and somewhat less of the blue. Contrarily, the object has brightened

[1] cf. ESO Press Release 04/87 of 25 February 1987.

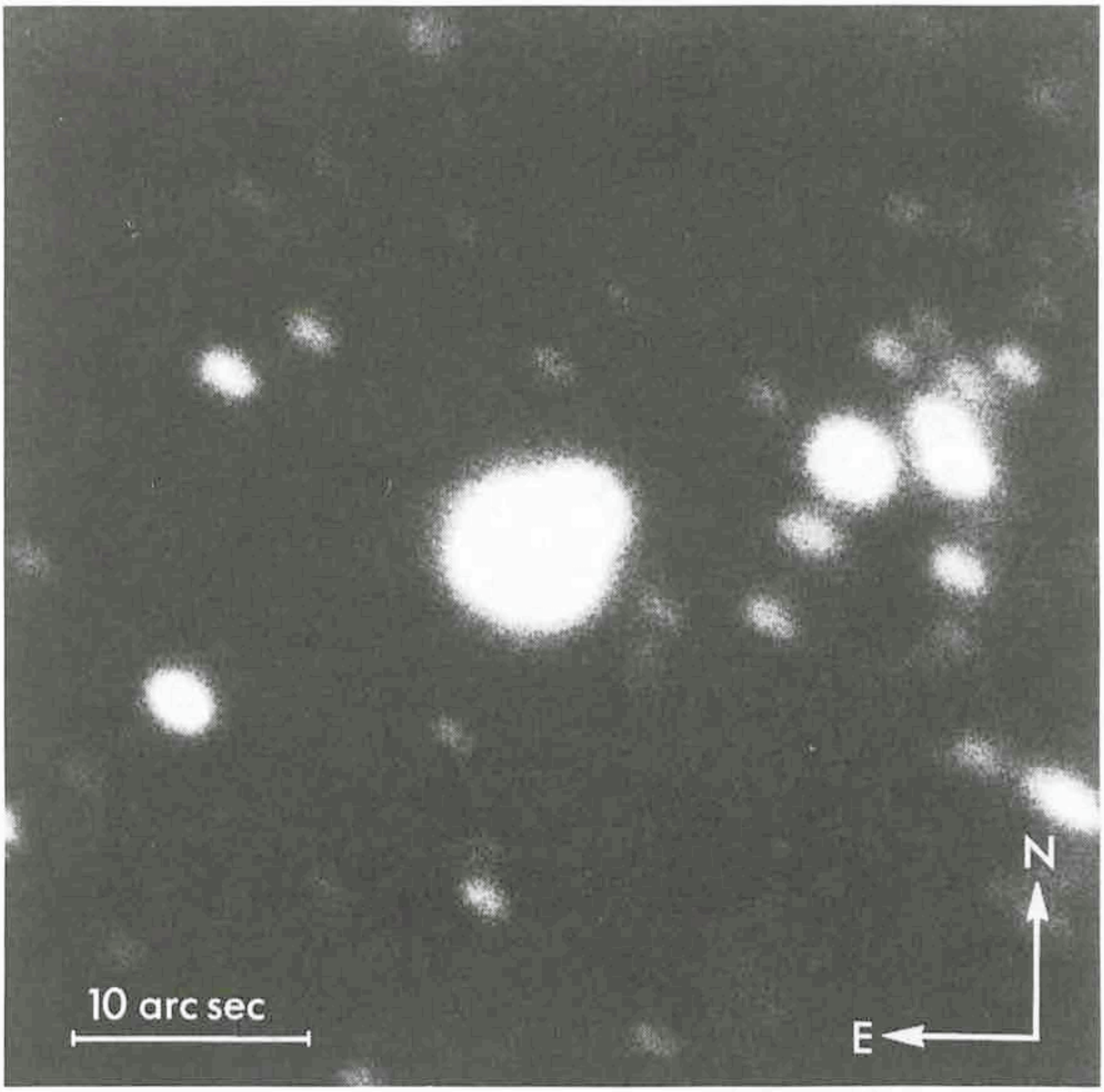


Figure 3.1: **The star that exploded on February 23 in the Large Magellanic Cloud** (the *progenitor* of supernova 1987A) has now been identified. It was catalogued in 1969 as an OB star of 12th magnitude and given the designation *Sanduleak -69 202*. Observations at the European Southern Observatory in the mid-1970's allowed to classify it as of spectral type *B3 I*, that is a very hot, supergiant star. It is here shown on a photograph, obtained with the ESO 3.6 m telescope in red light on December 6, 1979. Closer inspection has now revealed that two other stars are seen very near to this star. On this photo, one of the companions is clearly seen (as a prominent bulge) to the northwest at a distance of only 2.6 arcseconds. This companion cannot be the progenitor, since its position does not coincide with that of the supernova. However, there is a third star within 1 arcsecond, just southeast of the main star. It cannot be seen on this photo. Further investigations are needed to ascertain which of the two became the supernova. Photo: ESO 3.6 m telescope, 60 min exposure on 098-04 emulsion behind a RG630 optical filter (630 - 700 nm). The stellar images are very close to the edge of the plate and are somewhat elongated, due to less than optimal optical adjustment. (PR 05/87; BW)

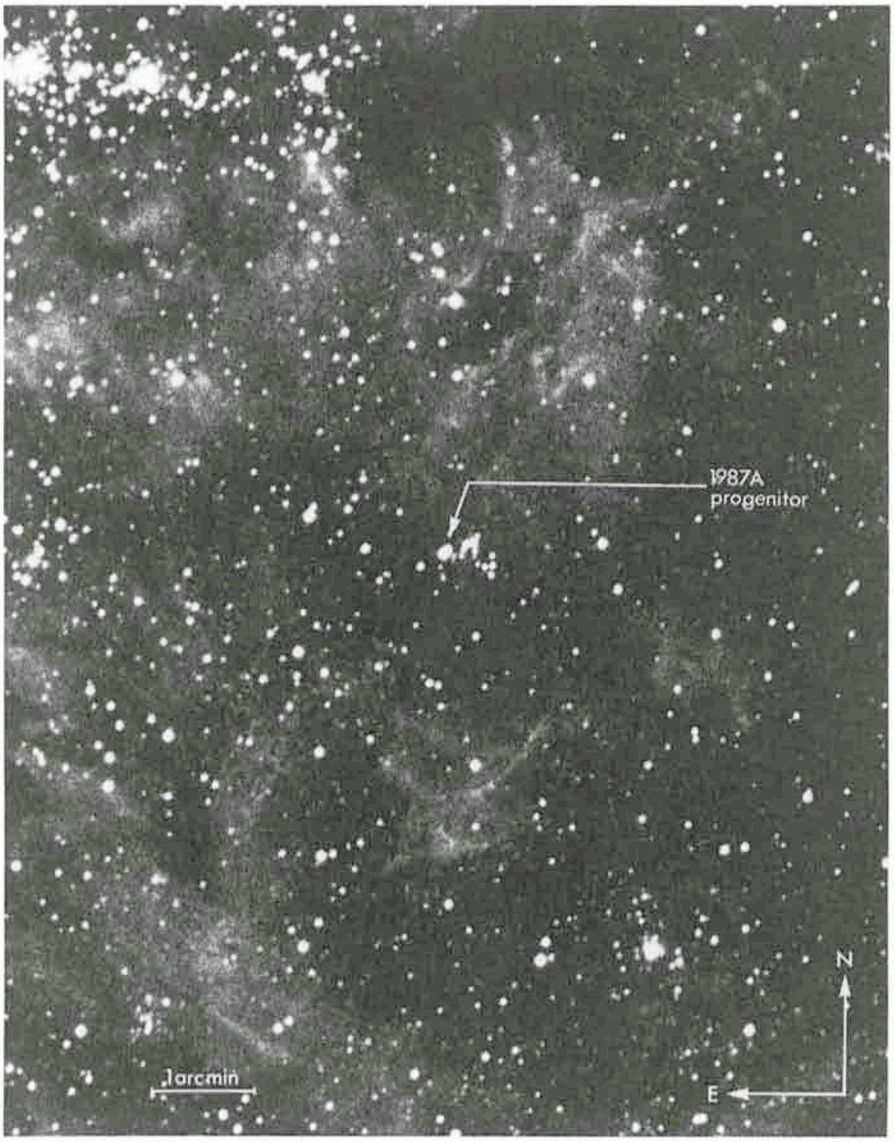


Figure 3.2: **The star that exploded on February 23 in the Large Magellanic Cloud** (the *progenitor* of supernova 1987A) has now been identified. It was catalogued by in 1969 as an OB star of 12th magnitude and given the designation *Sanduleak -69 202*. Observations at the European Southern Observatory in the mid-1970's allowed to classify it as of spectral type *B3 I*, that is a very hot, supergiant star. It is here shown on a photograph, obtained with the ESO Schmidt telescope in ultraviolet light on December 9, 1977. Closer inspection has now revealed that two other stars are seen very close to this star. On this photo, the image of Sanduleak -69 202 is somewhat elongated towards northwest, since one of the companions lies in this direction at a distance of only 2.6 arcseconds. This companion cannot be the progenitor, since its position does not coincide with that of the supernova. However, there is a third star within 1 arcsecond, just southeast of the main star. Further investigations are needed to ascertain which of the two became the supernova. Photo: ESO 1m Schmidt telescope, 60 min exposure on IIa-O emulsion behind a UG1 optical filter (300 - 380 nm). (PR 05/87; BW)

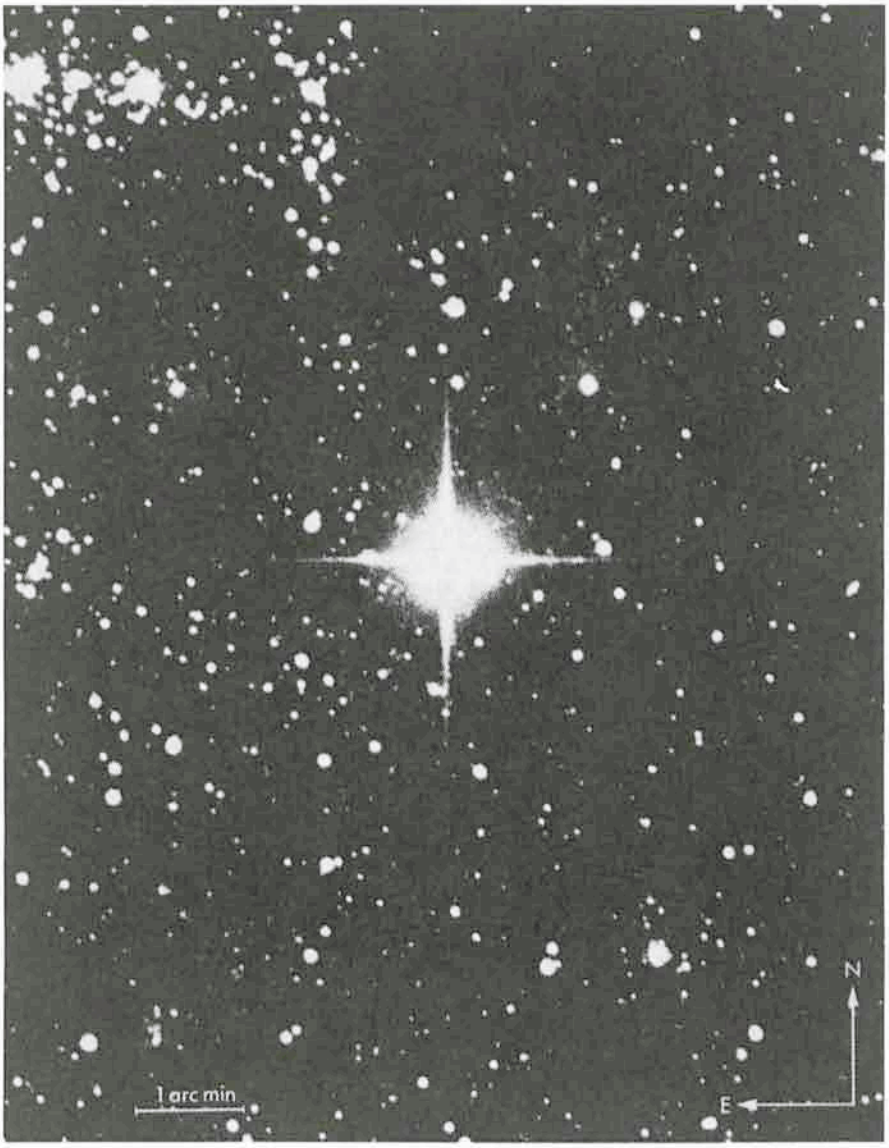


Figure 3.3: This photo of the **bright supernova in the LMC** was obtained with the ESO 1m Schmidt telescope on February 26 at 01:25 UT. On this date, the supernova had reached visual magnitude 4.4. The photo should be compared with the ultraviolet photo showing the supernova progenitor which was taken with the same telescope in 1977. The enormous increase in brightness, around 2000 times, is evident. The background nebulosity emits strongly in the ultraviolet and is therefore better visible on the ultraviolet photo. Otherwise more or less the same stars are seen on both photos. The "cross" around the supernova is an optical effect in the telescope which is caused by the support of the plateholder. Photo: ESO 1m Schmidt telescope, 15 min exposure on IIa-O emulsion behind a GG385 optical filter (spectral range 390 - 480 nm). (PR 05/87; BW)

Figure 3.4: **Last colour photo before the supernova explosion in LMC.** This colour photo of the Large Magellanic Cloud (LMC) was obtained with a 6 x 6 camera mounted piggy-back on a large telescope at the ESO La Silla Observatory, on February 23 at UT 01:00, a few hours before the supernova exploded. It is the last colour photo obtained before this event. Comparing this photo with a similar one obtained two days later, and which shows the supernova reveals a faint star at the position of the supernova; it is the progenitor Sanduleak -69 202, a 12th magnitude B3 I star. Photo: 20 min exposure on Agfachrome 1000 RS emulsion with a Hasselblad camera attached to the 40 cm GPO astrograph on La Silla. (PR 05/87; Colour)

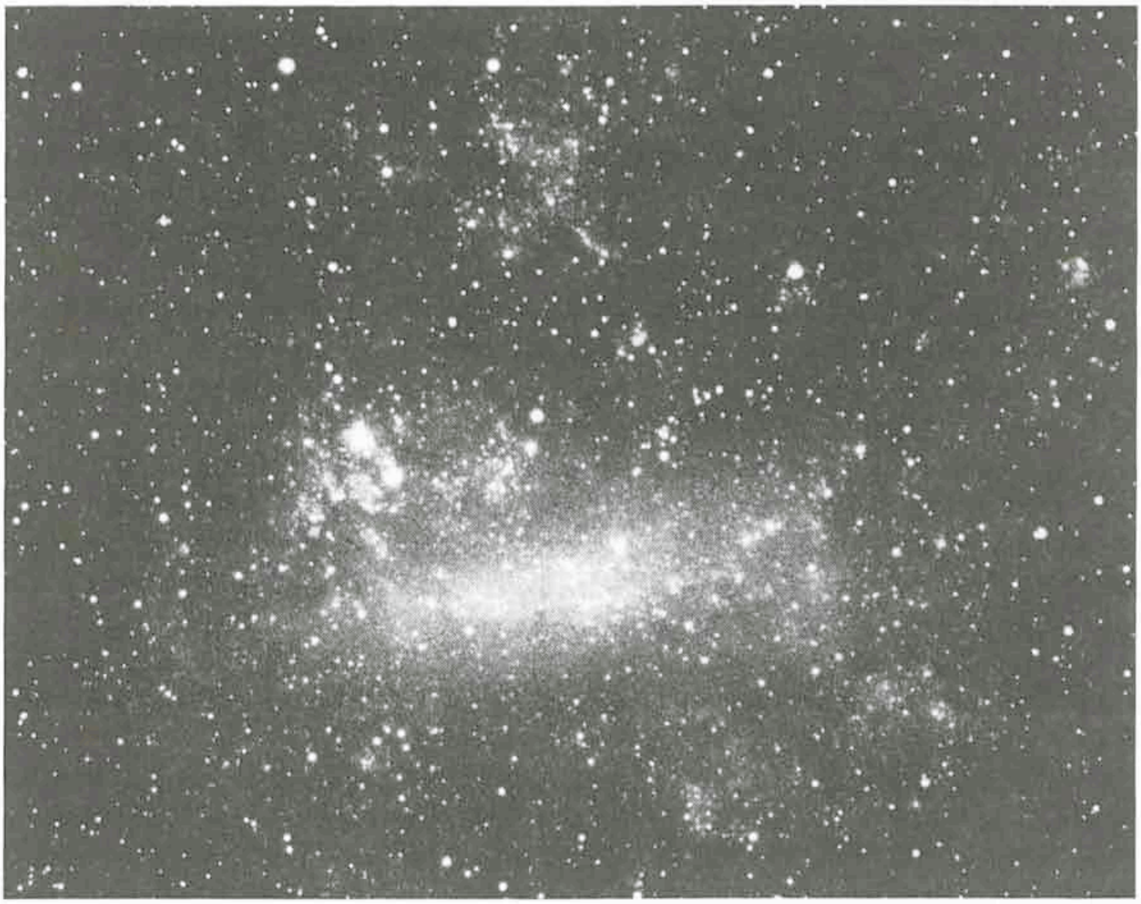


Figure 3.5: This colour photo of the **bright supernova in the Large Magellanic Cloud (LMC)** was obtained with a 6 x 6 camera mounted piggy-back on a large telescope at the ESO La Silla Observatory, on February 25 at UT 01:00, two days after the supernova exploded. On this date, the supernova had reached visual magnitude 4.5. It is well visible, left of the centre and above the LMC main body as the lower right (round) of the two bright objects. The other object, which is extended and more diffuse, is the Tarantula Nebula. The distance to the LMC is about 180.000 light years and it is a satellite galaxy to our own, the Milky Way. This supernova is the brightest to be recorded since the galactic supernova in 1604 that was observed by Johannes Kepler. It reached its visual maximum around February 28 and is now declining in brightness. Photo: 20 min exposure on Agfachrome 1000 RS emulsion with a Hasselblad camera attached to the Danish 1.5m telescope on La Silla. (PR 05/87; Colour)

in the red and infrared. This effect is explained by the decreasing temperature. Infrared photometry on March 2 shows that the temperature of the emitting material at this time was about 6000 degrees.

Immediately after discovery, *spectra of medium resolution* were rather featureless and showed no identifiable spectral lines, but later several broad spectral features have become visible. They are first of all the Balmer lines of hydrogen, which exhibit blue-shifted absorption and red-shifted emission features. This is typical for a Type II supernova and is due to emission from a rapidly expanding shell of material around the exploding star. The expansion velocity is around 17.400 km/sec. Rapid changes of this spectrum have been observed at ESO, probably reflecting violent motions in the surrounding gas.

Infrared spectra were obtained on March 1 with the ESO 1m photometric telescope. This is the first time that such spectra of a supernova have ever become available. Many emission lines are seen, including those of hydrogen and helium and the time-consuming interpretation of these spectra has now started at ESO.

Very high dispersion spectra were obtained with the ESO Coudé Echelle Spectrograph at the CAT telescope. They show - also for the first time - a large number of narrow absorption lines, which originate in interstellar clouds in the LMC and in our Galaxy (the Milky Way), and also in intergalactic clouds between the two galaxies. More than 20 such lines belong to ionized Calcium, around 13 to neutral Sodium and 2 to neutral Potassium. This unique observation will allow a study, for instance of the chemical composition of these clouds.

A search was made for very rapid variations in brightness (*flickering*) to see whether a rapidly rotating neutron star could be detected. It is known that such stars are left-overs by other supernovae and they are observed as pulsars. These objects are extremely dense; a mass similar to that of the Sun is contained within a diameter of 20 kilometres or less. Ultra-fast photometry at ESO of supernova 1987A has not yet detected such variations, but as the envelope expands, the possibilities for a successful search become larger.

In view of this extraordinary event, the telescope schedules at ESO La Silla were changed and all observers switched over to the supernova with great enthusiasm. Preliminary reports with more details than those given in the present Press Release will be published in the March issue of ESO's journal *The Messenger*. It is also expected that several articles will appear shortly in the scientific journals. A scientific Workshop on "Supernova 1987A in the LMC" (Observations and Theory) will be held at the ESO Headquarters in Garching during early September 1987.

In the last decades, supernovae have been observed in other galaxies which were always more than one hundred times fainter than this one in the LMC. While studies made with large telescopes at ESO La Silla and elsewhere have yielded interesting data, no very high resolution studies were possible due to lack of light. However, with the full light gathering power of the future 16 m ESO Very Large Telescope[2], now being planned, fainter supernova in other galaxies, as well as some stars in the LMC will be observed with the same spectroscopic resolution as has been possible for supernova 1987A in LMC. This supernova thereby gives us a preview of the discoveries that can be made with the Very Large Telescope.

This Press Release is accompanied by three pictures:

- B/W photo from 1977 showing the sky area of the supernova event, with the progenitor indicated,

[2]cf. ESO Press Release 08/86 of 4 October 1986.

- B/W photo from 25 February 1987 of the same area and with the same scale, now showing the very bright supernova, and
- Colour picture of the LMC, obtained on 25 February 1987, and clearly showing the entire LMC galaxy and the supernova near the Tarantula Nebula.

Additional pictures may become available from ESO at a later date. Copies of the March 1987 Messenger issue will be sent on request after March 15.

3.3 The Unusual Behavior of Supernova 1987A in LMC

(**PR 06/87**; 31 March 1987; For immediate release)

"This supernova is different from all others observed so far".
That is the unanimous conclusion of astronomers who have observed supernova 1987A in the Large Magellanic Cloud (LMC) with ESO telescopes since the explosion in late February[3]. The collective results from the ESO La Silla observatory of no less than 38 astronomers have now been submitted to the European journal *Astronomy & Astrophysics* where they will appear in six "Letters to the Editor" in the May(I) 1987 issue. These articles cover astrometry, optical and infrared photometry, polarimetry, optical and infrared spectroscopy and high-resolution spectroscopy; they are immediately available in ESO Preprint no. 500 (March 30, 1987) which can be obtained by request to the ESO Information and Photographic Service.

More than one month of intensive observations have now been made of SN 1987A. Measurements of its brightness showed an initial increase to a maximum near visual magnitude 4.5[4] on February 28. During the next few days, the brightness dropped slightly, but since March 5, it has increased again, reaching visual magnitude 3.96 on March 28. Except for the ultraviolet light, which has been nearly constant since March 10, the intensity has increased in all other spectral regions. In the infrared, the present rate of brightening is about 5 % per day. It is not possible to predict which brightness SN 1987A will ultimately reach, but it is still more than 2 magnitudes ($\sim$ 6 times) fainter than a normal Type II supernova would have been expected to be.

Fast photometry has not yet shown the existence of a pulsar in SN 1987A, that is a rapidly spinning neutron star, supposed to be created in a supernova explosion of Type II. If there is such an object at the centre of SN 1987A, its light must still be obscured by the surrounding, rapidly expanding envelope of material. Infrared observations showed that the temperature of this envelope was 5800 K ($\sim$ 5500 C°) on March 1; on this day, the diameter was 5600 times the diameter of the Sun, that is almost equal to the size of the orbit of planet Neptune. Ten days later, the temperature had dropped to 5200 K and the diameter of the envelope had grown to 9100 times that of the Sun. The expansion velocity has dropped from initially 18.000 km/sec to about 10.000 km/sec in late March. The total luminosity is now about equal to 100 million Suns. Some days ago, there were signs of some extra light in the far

[3]see ESO Press Releases 04/87 and 05/87.

[4]In the astronomical magnitude scale, smaller numbers signify brighter stars. The brightest stars have magnitudes near 0. The star *Polaris* near the celestial North Pole has magnitude 2. A star of magnitude 4.5 is about 10 times fainter than Polaris.

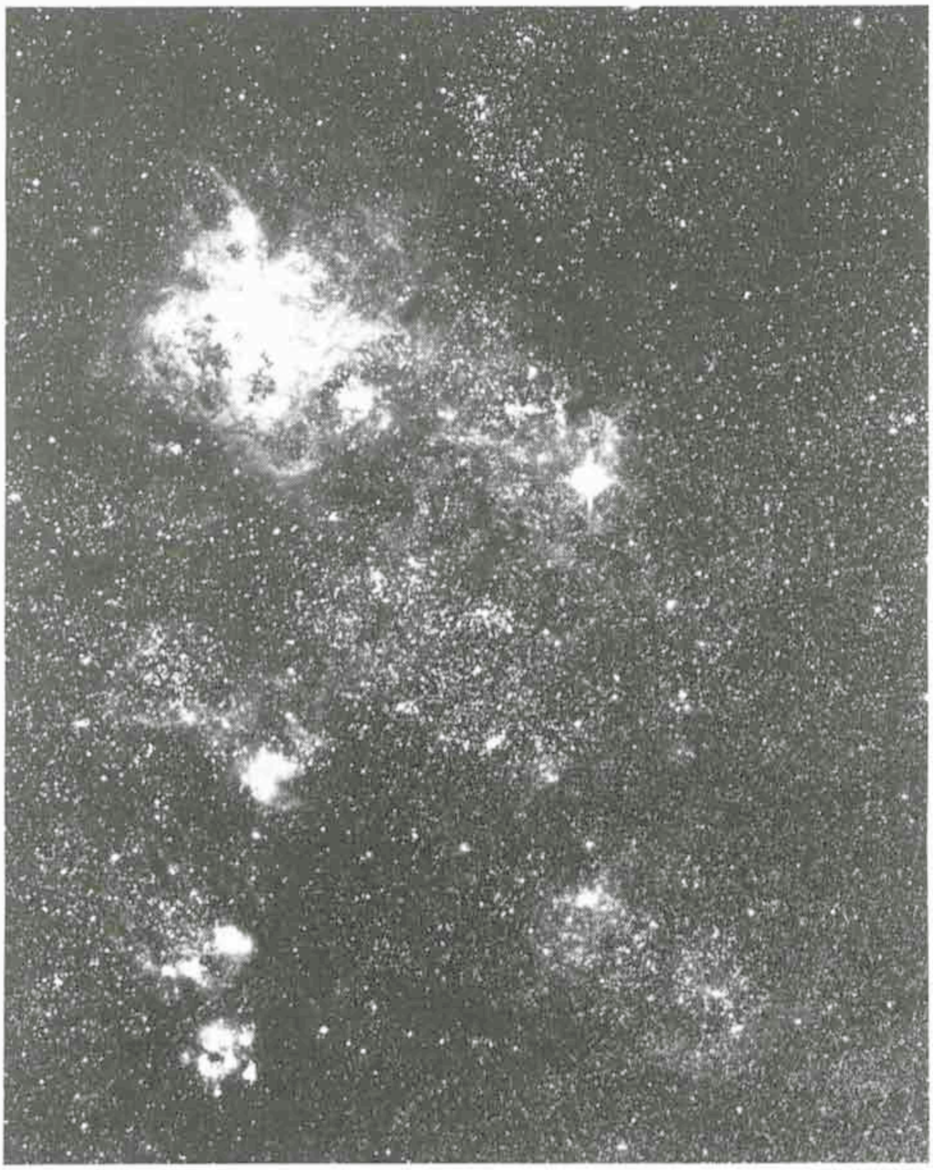


Figure 3.6: **Supernova 1987A and the Tarantula Nebula.** (PR 06/87; Colour)

infrared (12 μm), maybe because the strong light from the supernova was being reradiated by surrounding interstellar dust ("infrared echo").

The spectrum has changed rapidly, in fact much more rapidly than any other supernova known so far. Only 20 days past maximum, the optical spectrum already resembled that of a Type II supernova, 100 days after maximum light. But some astronomers express doubt whether SN 1987A can be classified as Type II, or whether it perhaps belongs to a different, hitherto unknown type. The spectra which were obtained during the past few days show more and more features, possibly suggesting that the surrounding envelope is breaking up into smaller pieces and filaments.

Accurate astrometry indicates that SN 1987A's position in the sky is less than 0.1 arcsecond from where a 12th magnitude, warm and heavy star, Sanduleak -69 202, was seen before the explosion. It is still not clear whether it was this star that blew up, or whether the supernova originated in a very close companion star. Measurements of earlier photographic plates seem to indicate that this hypothetical companion could not have been a bright, cool supergiant. Until now, most theories predicted that such a star (a socalled M supergiant) should be the progenitor of Type II supernova.

No less than 24 narrow absorption line systems have been detected in very-high resolution spectra of SN 1987A. They originate when the light from the supernova passes through interstellar clouds in the LMC and in our Galaxy, and also through clouds in intergalactic space between them. The presence of Calcium, Sodium and Potassium has been observed and also Lithium-7. This is the first time ever that neutral Lithium, Calcium and Potassium have been detected in interstellar space outside the Galaxy.

This Press Release is accompanied by a colour picture of SN 1987A and the Tarantula Nebula in LMC. It is based on three B/W photos obtained by the ESO 1 m Schmidt telescope.

3.4 Important Events in the Southern Sky

(**PR 07/87**; 14 May 1987; For immediate release)

In these days, northern astronomers have reason to envy their colleagues in the south. By chance, the two main events in observational astronomy at this moment both occur deep in the southern sky and they can therefore not be observed from the astronomical centres in the northern hemisphere.

These are the occurence of the brightest supernova since 383 years, SN 1987A in the Large Magellanic Cloud (LMC)[5] and the relatively close approach to the earth of naked-eye Comet Wilson on May 2, 1987. By a curious coincidence, the two objects were seen only 5 degrees apart on May 3, when the comet moved rapidly across the sky, southeast of the LMC. However, while SN 1987A is situated at a distance of about 180.000 light years, Comet Wilson was only 93.5 million kilometres from the earth.

SN 1987A

The brightness has continued to increase and by mid-May it attained magnitude 2.8, that is about half the intensity of the Polar Star. The rate of increase by mid-April was about 3 % per day, slowing to 1.5 % per day in early May. It would appear that a plateau has now been

[5]see ESO Press Releases 04/87, 05/87 and 06/87.

reached. Whether or not this is the maximum still remains to be seen. The time from the initial rise to the present plateau, almost 3 months, is unexpectedly long and has never been observed for any other supernova.

An new reduction of the IUE (International Ultraviolet Explorer) satellite data indicates that the central star of Sanduleak -69 202 has disappeared. It is therefore very likely that it was this star that exploded. Its spectral type was measured at ESO in the mid 1970s and showed it to be a hot supergiant star, which according to current evolutionary theories should not yet have reached the critical phase. Theoretical astrophysicists are now confronted with the problems of why and how this star blew up at this stage of its evolution.

The expansion velocity of the matter which was ejected into interstellar space at the explosion has now decreased to about 5000 km/sec. Despite continuous monitoring by fast photometry at ESO La Silla, no brightness fluctuations have yet been observed, which could be ascribed to a rapidly rotating neutron star (pulsar) at the centre of the supernova. (Some astronomers think that the pulsar was transformed into a black hole within a few hours after the explosion). Infrared speckle interferometry with the ESO 3.6 m telescope on May 8 and 9 did not show any extended emission around the supernova as might be expected from an infrared echo in surrounding dust, but the weather conditions were not optimal during these observations.

The observations at La Silla continue. Meanwhile ESO is preparing for the first full-scale international meeting about "SN 1987A in the LMC", which will take place at the ESO Headquarters in Garching bei München, on July 6 - 8, 1987. More than 100 supernova specialists from all continents intend to participate. The topics will include all aspects of supernova research, from the precursor star to the evolution of the envelope and interaction with the surrounding interstellar medium.

Members of the Press who would like to participate in this meeting, are kindly requested to contact the ESO Information and Photographic Service soonest possible. A Press Conference may be organized at ESO on July 8, immediately following the meeting.

Comet Wilson

This part of the PR 07/87 is printed on page 108.

3.5 Supernova 1987A Passes Maximum

(**PR 09/87 (Addendum)**; 16 June 1987; For immediate release)

Supernova 1987A in the Large Magellanic Cloud reached a maximum near magnitude 2.8 around May 20. A few days later, the brightness began to decrease, at first rather slowly, but then somewhat faster. On June 15, the magnitude was about 3.5, i.e. the supernova was only half as bright as it was at maximum. Ultraviolet spectra, obtained with the International Ultraviolet Explorer showed the development of emission lines on the 120 - 190 nm spectral region, probably indicating that the ejected shell of matter is becoming thinner.

3.6 Astronomers and Physicists Meet at ESO at the First Full-Scale International Conference on Supernova 1987A

(**PR 11/87**; 8 July 1987; For immediate release)

The first full-scale, international meeting about the bright Supernova 1987A in the Large Magellanic Cloud (LMC) was held at the European Southern Observatory in Garching near Munich on July 6 - 8, 1987. ESO was a natural meeting place in view of the many different observational studies of SN 1987A which have been carried out at the ESO La Silla observatory.

After three days of detailed discussions and long working sessions, the two hundred participants from all over the world concluded that much new and exciting knowledge has been gained from 4 1/2 months of intensive observational and theoretical studies of this unique object. Nobody doubted, however, that a major effort is still required to solve the many outstanding questions and in addition to providing an up-to-date review of current supernova research, the meeting also served to initiate future collaboration in the most urgent problem areas.

It was a historical occasion: for the first time satellite-, rocket-, balloon- and ground-based astronomical observations of an object outside the solar system were supplemented by the measurement of antineutrinos in several huge particle detectors, deep underground. Astronomers and physicists met on common ground to the mutual benefit, and it was obvious that both parties were pleased to learn from each other.

Summarizing the main results of this conference this afternoon, Professor Sidney van den Bergh of the Dominion Astrophysical Observatory, Victoria, Canada, was impressed by the width and accuracy of the presented data, and he added: "It has been tremendously exciting for all of us and we have experienced a textbook example of how the observational and organizational problems, associated with such a sudden event, can be overcome when all involved scientists join their forces within an open and extensive, international collaboration. We can be proud of what was achieved around SN 1987A and the efficient way in which it was done should serve as an enlightening example to people in other fields of human endeavour."

What have we learned so far from this supernova ?

In general, there are four fields of astrophysics which are directly related to the interpretation of a supernova explosion:

- *stellar evolution theories* which explain how a star reaches a stage of instability,
- *collapse physics* which deals with the implosion of the inner parts of the star at which moment great quantities of neutrinos are emitted, and the creation of an extremely compact object (neutron star or black hole) at the centre,
- *explosion physics* that trace the collision of the rapidly expanding, inner layers with the outer layers and the ejection of a shell of material into surrounding space, and
- *nucleosynthesis*, the creation of heavy elements during the brief moment of extreme physical conditions which do not exist anywhere else in the Universe.

In all of these fields, some problems have now been solved, thanks to the availability of accurate, observational data from SN 1987A and one of the speakers commented that the theoretical interpretations have "taken a giant step forward". Nevertheless, there are still many unexplained features, which it is hoped to solve by continued interaction between observers and theoreticians.

There was general agreement that it was the star Sanduleak -69 202 which exploded. Stellar model calculations have shown that this star with a mass of 15 - 20 times that of the Sun may previously have developed into a red supergiant star, but also that shortly before the explosion, it would have lost a significant amount of mass and became a blue supergiant. The relatively low metallicity in the LMC may have contributed to this. It was reported that there is a relative overabundance of the elements helium and nitrogen in similar blue stars in the LMC. This points towards an advanced evolutionary state where carbon burning is taking place.

Supernova 1987A can be classified as of Type II, because its electromagnetic spectrum now (130 days after the explosion) rather closely ressembles a typical Type II spectrum; because of its very blue colour, immediately after the explosion and because of the overall shape of its lightcurve. However, it is not a typical Type II, since the brightness increased much slower than a normal Type II; since the colour very rapidly changed from blue to deep red; since the initial expansion velocity of the shell was extremely high, more than 30.000 km/s in some UV spectral lines, and also because the light maximum in mid-May is at least 1.5 magnitude fainter than what a normal Type II supernova would have reached.

From statistics in other galaxies, it is estimated that the supernova-rate in the LMC is about 1 per 500 years. We have therefore been very lucky to observe SN 1987A.

From polarimetric measurements and also recent IUE (International Ultraviolet Explorer, a joint NASA-ESA satellite) spectral data in the ultraviolet, it appears that the expanding envelope is now breaking into smaller fragments. This raises the hope that it shall soon become possible to learn what was left over at the centre of the explosion. From a comparison with the Crab Nebula and its associated pulsar (the remnants of a supernova explosion in the year 1054), as well as with other pulsars, it is estimated that a possible pulsar in SN 1987A may have a rotation period of about 10 milliseconds, but the apparent magnitude may not be brighter than 17. It is therefore necessary to wait until SN 1987A fades significantly, before optical observations of the pulsar may become feasible. It is quite likely that such a pulsar will manifest itself earlier in other wavelengths, like X-rays or radio.

High spatial resolution optical and infrared observations have given the first direct images of the expanding envelope and also a "mystery spot", an unidentified point-like object, at a distance of about 20 light-days from the supernova. It appears to be moving away from the supernova, but the nature of this object is still unknown. It must be related to the supernova since it is only $\sim$ 10 times fainter, i.e. at magnitude 5 or 6. If it had been there before the explosion, it would have been 100 times brighter than any other object in the LMC and would therefore have been discovered long ago.

An interesting prediction made at the meeting was that a very strong electro-magnetic pulse, released at the moment of the explosion, would have deposited enough energy ($\sim$ 1 erg cm^{-2}) in the so-called E-layer in the Earth's atmosphere that its effects should be observable. Atmospheric physicists have therefore begun to study the data recorded on February 23, 1987.

The undisputed highlight of the meeting was the presentation of detections of antineutrinos from SN 1987A which were made with particle detectors, located in the Mount Blanc tunnel between France and Italy, and also in Japan, USA and USSR. Never before has it been possible to observe directly the core collapse during a supernova explosion and it may be a long time before another supernova explodes sufficiently close to us to permit similar measurements.

It was not yet possible to decide definitively which of these events refer to the core collapse, but the exact coincidence in time between Japanese and US detections at 7:36 UT is taken as evidence in favour of these. The USSR detection is some 20 seconds later, but this might be due to a timing problem. But then, what does the Mont Blanc detection at 02:52 UT signify ? Is it possible that there are other, dramatic events which produce neutrinos before the core collapse ? Or does, after all, the Mount Blanc event correspond to the initial core collapse and the others to the transformation of a short-lived neutron star into a black hole ?

Upper limits for the mass of the neutrino of the order of 15 to 20 eV were reported from an analysis of the arrival times of the individual particles; a zero mass can not be excluded.

Although the spectrum of SN 1987A is complicated, new computations of synthetic supernova spectra show reasonable agreement with what is actually observed. It has been possible to identify many atomic species, some of them highly ionized. Following an intensive exchange of experience, theoretical groups in several places announced that they will soon improve their computer programmes and that a fuller understanding of the violent events in the expanding envelope is within reach.

Up to 40 individual interstellar and intergalactic clouds have now been observed along the line of sight to the supernova and according to one group of astronomers, these unique observations indicate the existence of a "bridge of matter" between the LMC and the Milky Way Galaxy. It is also possible that some of the narrow absorption lines seen in the SN spectrum belong to the expanding shell of matter or even to the matter that may have been expelled during a phase of rapid mass loss, soon before the supernova explosion.

Scientists with access to X-ray and γ-ray detectors on satellites and balloons are on stand-by, waiting for the moment when the envelope becomes transparent. So far, attempts to observe the supernova in these wavelength regions have failed. Radio-observations were made during the first few days after the explosion, but then the signal faded. A new, possible radio-detection in Brazil in late June has not yet been confirmed, but Very-Long-Baseline-Interferometry (VLBI) observations will start in Australia as soon as the supernova again begins to radiate strongly at radio wavelengths. According to theory, this may happen any moment. These radio measurements, when compared with optical observations, will allow an accurate determination of the distance to the supernova. This distance, in turn, will be of great importance in correctly estimating the overall cosmical distance scale.

The ESO Conference has undoubtedly brought us a long way towards the unraveling of the secrets of supernova explosions, but as one of the participants said: "We leave this meeting in a great air of inspiration, but I also know that there is a lot of hard work to be done during the next many years!"

SN 1987A is still visible with the unaided eye. The magnitude is now 4.5.

3.7 Light Echoes from Supernova 1987A in the LMC: Snapshots of Interstellar Clouds

(**PR 02/88**; 16 March 1988; For immediate release)

New and exciting observations at the European Southern Observatory have probed the interstellar space around last year's bright supernova SN 1987A in the Large Magellanic Cloud (LMC)[6].

On images obtained with the ESO 3.6 m telescope in mid-February 1988, *light echoes*[7] have been unambiguously detected, which arise from the reflection of the bright supernova light in interstellar clouds surrounding the exploded star.

Light echoes from SN 1987A

When, on February 23, 1987, observations were first made of the exploding supernova SN 1987A in the LMC, the initial, very bright light-flash of the first few seconds was already past. But some of this light, travelling away from the supernova in other directions, may be reflected from dust clouds in the vicinity of the supernova. A small part of that reflected light will be directed towards the Earth and can be seen after some time as a faint "light echo" of the original flash.

Astronomers have been searching for this phenomenon since last year. A detection on March 3, 1988, was announced by A. Crotts from McDonald Observatory, Texas, U.S.A.. Earlier images were made at the European Southern Observatory on January 25 by H. Pedersen with the Danish 1.5 m telescope and on February 13, by M. Rosa with the ESO 3.6 m telescope. In particular the latter observations unambiguously show a double light echo (see attached photo).

For these exposures of SN 1987A with the EFOSC instrument at the ESO 3.6 m telescope, the bright light from the supernova itself was dimmed by the insertion of a small, obscuring disk into the instrument. Two almost concentric rings are clearly visible with radii of 32 and 51 arcseconds. The rings are brighter towards North (top of photo), probably because there is more interstellar matter in this direction. The intensity of the light echo is more than 10,000 times fainter than the current brightness of the supernova and is in agreement with the predicted intensity.

From the time delay of about one year and the angular dimensions of these rings, it can be inferred that the reflecting clouds are at distances of approximately 400 and 1000 light years in front of the supernova, respectively.

Continued observations of these light echoes will allow to determine the three-dimensional structure of the interstellar clouds near the line-of-sight to the supernova. The rings are expected to expand by about 5% of their present diameter per month and variations in the brightness along the periphery will indicate variations in the density of the reflecting material.

For this reason, direct and spectral observations of the light echoes have been initiated at ESO. Pictures in different colours were obtained last night with the 3.6 m telescope by Chr. Gouiffes (ESO) and M. T. Ruiz (Universidad de Chile). A quick check of some photographic

[6]See also ESO Press Releases 04/87, 05/87, 06/87 and 07/87.

[7]This Press Release is accompanied by a B/W photo, showing a double light echo

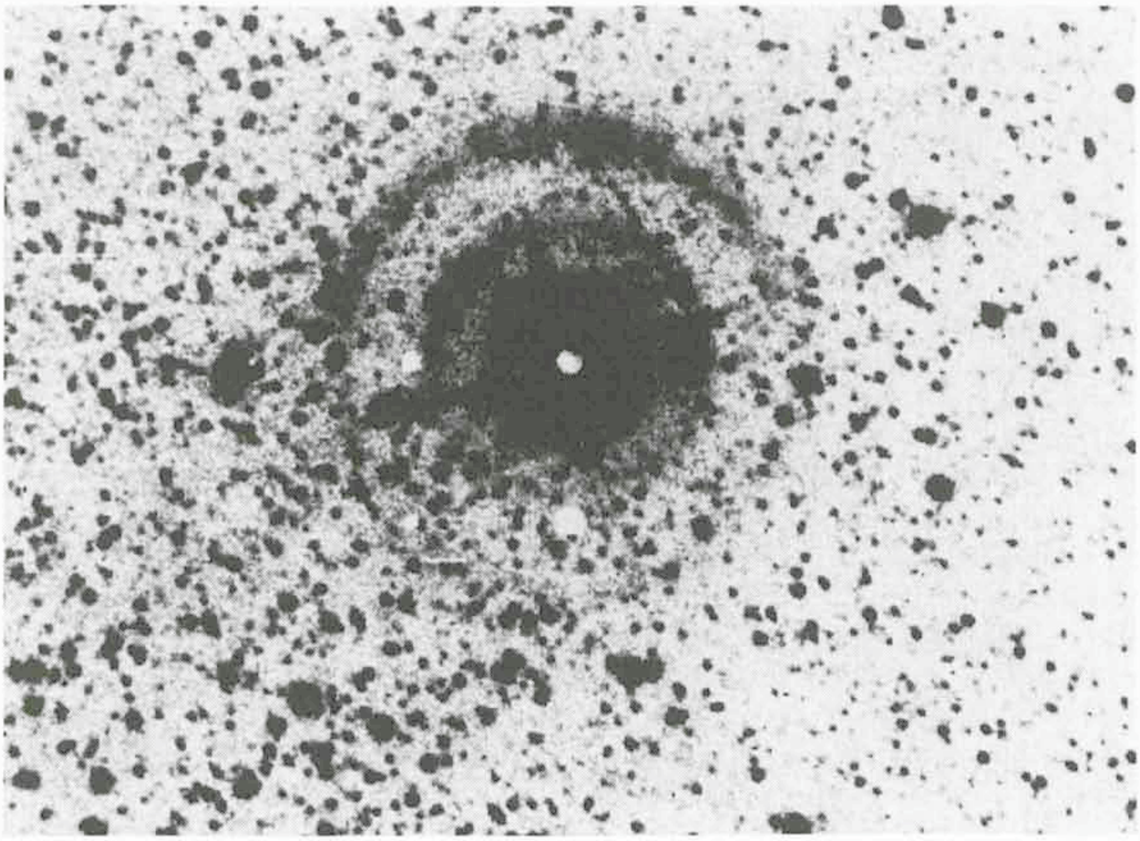


Figure 3.7: **Light echo from Supernova 1987A.** A double *light echo* from Supernova 1987A in the Large Magellanic Cloud (LMC) was observed on February 13, 1988 with the ESO 3.6 m telescope and the EFOSC instrument (observer: Dr. Michael Rosa). The light echoes are reflections in interstellar clouds in the LMC of the light from the bright supernova explosion, first observed on February 23, 1987. The light echoes are seen as two concentric rings around the overexposed image of the supernova itself. The outer ring, which has a radius of ~ 50 arcseconds, is strongest towards North, but can be followed all the way round. The inner ring has a radius of ~ 30 arcseconds. Note that the "cross" extending from the image of the supernova is an artifact from the telescope optics. In order to see the very faint light echoes, the light from the supernova was dimmed by a small obscuring disk, here seen as a lighter spot at the centre of the image. (The shadows of three other disks are also seen). This computer-enhanced photo was obtained by a CCD detector behind a narrow optical filter at a wavelength near 470 nm, thereby suppressing the light from interstellar nebulae in the LMC in order to improve the visibility of the light echoes. For the same reason, the photo is here reproduced as a negative (black stars on a light sky). (PR 02/88; BW)

plates, obtained with the ESO Schmidt telescope towards the end of 1987, appears to indicate that it will become possible to follow the development of the echoes further back in time.

The reductions of these observations are rather time consuming and further results will be reported as soon as they become available.

3.8 Is There a Pulsar in Supernova 1987A ?

(**PR 02/89**; 24 February 1989; For immediate release)

A recent announcement of the discovery of a pulsar in Supernova 1987A in the Large Magellanic Cloud has excited the world-wide astronomical community. New observations at the La Silla Observatory by a group of European astronomers[8] from the Max Planck Institute for Extraterrestrial Physics and the European Southern Observatory, however, do not confirm the reality of this object. More observations are now needed to settle this important question.

Searching for the pulsar in Supernova 1987A

Since the explosion of the now famous supernova in the Large Magellanic Cloud on February 23, 1987, astronomers have been eagerly waiting for the emergence of a newborn *pulsar*. Current theories predict that the explosion of a heavy star as a supernova will result in most of its mass being blown out into surrounding space, but also that some of it will be compressed into an extremely dense and rapidly rotating *neutron star* at the centre. Such an object would later manifest its presence in the supernova by the emission of regular light pulses (hence the name "pulsar"). Neutron stars measure no more than 10 -15 kilometres across, but they weigh as much as our Sun which is about 100,000 times as large.

Of half a dozen pulsars known in supernova remnants, the most famous are those in the Crab Nebula and the Vela Nebula. The detection of a pulsar inside SN 1987A, the first naked-eye supernova in nearly four centuries, would provide the definitive confirmation of the creation of pulsars in supernova explosions. Extensive searches for such a pulsar have therefore been made at some southern observatories since the explosion was first recorded, almost exactly two years ago. This is done by observing the supernova light with a "rapid" photometer, capable of measuring the light intensity many times each second. A pulsar would reveal itself by the presence of brief "flashes" of extra light, regularly spaced in time.

Immediately after the explosion, the dense cloud around the supernova did not allow a look at its centre, but as the clouds become thinner, light from the new pulsar should eventually become visible. Many astronomers have been waiting for this exciting moment.

First detection ?

On 8 February 1989, a group of American astronomers[9] announced the discovery of a very fast pulsar in SN 1987A, flashing no less than 1969 times per second. This is referred to

[8]The group consists of Hakki Ögelman, Günther Hasinger and Wolfgang Pietsch (Max Planck Institut für Extraterrestrische Physik, Garching bei München, F.R.Germany), Christian Gouiffes, Jorge Melnick, Thomas Augusteijn, Flavio Gutierrez, Preben Grosbøl and Christian Santini (ESO) and Holger Pedersen (formerly ESO, now Nordic Optical Telescope Scientific Association).

[9]This group is headed by John Middleditch, Los Alamos National Laboratory; the announcement was made on Circular 4735 of the International Astronomical Union (IAU).

as 1969 cycles/second and supposedly corresponds to the number of rotations per second by the pulsar. No other pulsar has ever been found to rotate this fast. These observations were made on January 18, 1989 at the Cerro Tololo Interamerican Observatory, situated about 100 km south of La Silla. Surprisingly, the American group did not see any pulsations when the observations were continued 12 days later with another telescope.

At the European Southern Observatory, the light of the supernova has been monitored with a special, rapid photometer at the 3.6 m telescope at regular intervals during the past year. The intensity of the supernova light was measured 1000 times per second, a rate which was determined from theoretical considerations about how fast the predicted pulsar in SN 1987A might rotate. However, it is too slow to show variations at the rate observed at Tololo.

New observations fail to provide confirmation

In order to confirm the presence of a pulsar with the higher pulsation rate, the ESO instrument was modified immediately after the announcement by the American group, so that it can now measure the supernova light up to 10,000 times per second. On February 14 and 15, observations were performed at the 3.6 m telescope during a total of 8 hours. The data tapes were rushed to the ESO Headquarters in Garching near Munich. The detailed results of a careful analysis at the Max Institute for Extraterrestrial Physics have today been transmitted to the IAU Telegramme Bureau for publication on the next IAU Circular.

The European team finds that no pulsating signal is present in the ESO data near 1969 cycles/second, to a limit of 1/4000th of the intensity of the supernova light. Nor is there any obvious signal at any other frequency in the interval from 1 to 5000 cycles/sec. These observations therefore do not provide confirmation of the presence of a pulsar.

If there is a pulsar in SN 1987A, then the absence of observed pulsations in the measurements obtained after January 18, both by the American and the European groups, possibly indicate that the pulsar is being intermittently obscured by dust clouds around the supernova.

Further observations will therefore be needed to definitively demonstrate the reality of a pulsar in Supernova 1987A.

3.9 The Elusive Pulsar in Supernova 1987A

(**PR 01/90**; 5 January 1990; For immediate release)

Is there - or is there not - a pulsar in Supernova 1987A ? This is one of the main enigmas in current astrophysical research, and nearly three years after the explosion of the first naked-eye supernova[10] in four hundred years, the answer is still not known.

In early February 1989, observations of rapid light fluctuations during a single night were reported[11], tantalizingly hinting at the presence of a blinking pulsar amidst the supernova debris. But, unfortunately, they could not be confirmed and some doubts have been expressed about the reality of these results[12].

However, recent observations by staff astronomers at the European Southern Observatory present new, strong evidence of a pulsar inside the expanding envelope which was blown off by the supernova when it exploded in February 1987. Although the pulsar cannot be seen

[10] See ESO Press Releases 04/87, 05/87, 06/87, 11/87 and 02/88.

[11] Circular 4735 of the International Astronomical Union (8 February 1989).

[12] See ESO Press Release 02/89 of 24 February 1989.

directly because it is still deeply imbedded in thick dust clouds, its fierce radiation heats these clouds so that they in turn emit strong infrared radiation. The new measurements show that the intensity of this infrared radiation has been constant during the past four months; this is a clear indication of the presence of a central energy source.

The ESO astronomers have alerted the worldwide astronomical community, suggesting that the search for the elusive pulsar should now be intensified[13].

What is a pulsar ?

Current theories predict that the explosion of a heavy star as a supernova will result in most of its mass being blown out into surrounding space, but also that some of it will collapse and be compressed into an extremely dense and rapidly rotating ***neutron star*** at the centre. Such an object will later manifest its presence in the supernova by the emission of regular light pulses (hence the name *"pulsar"*). The pulses are due to the star's very rapid rotation, similar to the intermittent light beam from a lighthouse.

Neutron stars measure no more than 10 - 15 kilometres across, but they weigh as much as our Sun which is about 100,000 times as large. Their densities are correspondingly enormous; one cubic centimetre of neutron star matter weighs one thousand million tons !

Of half a dozen pulsars known within the remnants of old supernovae, the most famous are those in the Crab Nebula and the Vela Nebula, which exploded in the year 1054 and about 10,000 years ago, respectively. The detection of a pulsar inside SN 1987A, the first naked-eye supernova since 1604, would provide definitive confirmation of the creation of pulsars in supernova explosions.

But according to the theory, at early phases the dense gas in the inner regions of the supernova would make it opaque to radiation from a central pulsar and later, the formation of dust clouds would achieve the same effect. Nevertheless, as these clouds expand and become thinner, the light from the presumed new pulsar should eventually penetrate the dust storm and become visible to earthbound observers.

A first glimpse of the new pulsar?

The actual presence of dust in the envelope of SN 1987A was first detected by ESO astronomers in late 1988, by means of accurate observations of emission lines in the supernova spectrum. These dust particles have been created by condensation in the gaseous envelope as it slowly cools. It was found that there is enough dust to hide any pulsar from view and it appeared to be merely a question of time, before the pulsar could be detected through the "thinning smog".

And indeed, in early February 1989 a group of American astronomers reported the discovery of a very fast pulsar in SN 1987A, flashing nearly 2000 times per second. But when observations were performed at ESO a week later, no pulsating light could be seen. This negative result did not necessarily disprove the existence of the purported pulsar; a possible explanation was that the dust around the pulsar was distributed in a clumpy way, and that the pulsar light was therefore being intermittently obscured by dense dust clouds, passing directly in front of the pulsar, as seen from the earth.

Still, the lack of definitive observational proof made many astronomers rather sceptical about the reality of the pulsar.

[13]IAU Circular 4933, issued on 29 december 1989.

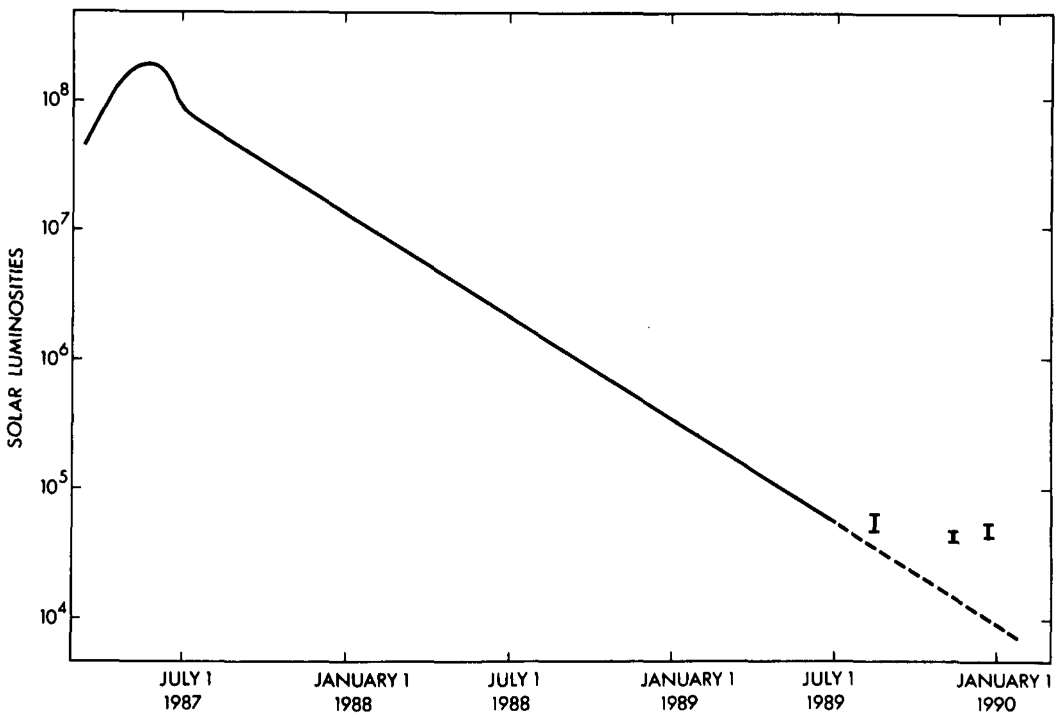


Figure 3.8: **The lightcurve of Supernova 1987A.** This schematic diagramme shows the "light curve" of Supernova 1987A in the Large Magellanic Cloud, that is the change of brightness with time. It represents the total energy of radiation emitted per second at all wavelengths by the expanding envelope (the so-called *bolometric lightcurve*) from the moment of discovery (February 24, 1987) until the end of 1989. The ordinate is calibrated in "solar luminosities"; one solar luminosity is equal to the total energy emitted per second by the Sun ($3.9 \cdot 10^{26}$ Watts). After an initial increase, the supernova brightness peaked in May 1987 at about 200 million times the luminosity of the Sun. Then followed a rapid decrease due to the cooling of the envelope. After mid-1987 the light curve becomes a straight line; during this phase, the released energy is provided by radioactive decay of Cobalt-56 isotopes. Three ESO observations in the second half of 1989, each representing several hours of observation (the bars show the accuracy), are significantly above the extrapolated brightness, shown by a dashed line. These measurements therefore demonstrate that the brightness has levelled off after mid-August 1989 and has remained nearly constant since then. Most of the energy is now radiated in the far infrared spectral region. This is indicative of a central energy source, probably a pulsar, within the supernova envelope. (PR 01/90)

Infrared observations reveal central energy source

At the present time, almost three years after the explosion, the expanding gas and dust cloud has cooled and is now more than 10,000 times fainter than at the moment of maximum brightness in May 1987. With decreasing temperature, the colour of the cloud has become redder and more than 80 % of its light is now emitted at wavelengths longer than 5 μm, that is in the far-infrared spectral region.

It is therefore necessary to perform infrared photometry (i.e. measuring the intensity of the infrared radiation), in order to evaluate the total energy output from the supernova envelope. Due to the overall faintness of the object and the rather low sensitivity of current infrared detectors, the largest available telescopes are needed for such measurements.

In fact, the only telescope in the southern hemisphere which is equipped to continue such infrared measurements at this time is the ESO 3.6 m telescope. Northern telescopes cannot observe SN 1987A in the Large Magellanic Cloud near the southern celestial pole. The ESO telescope has been used to monitor the supernova almost every month since the explosion.

Three long-time ESO staff astronomers, Patrice Bouchet, John Danziger and Leon Lucy, now report that the amount of infrared radiation from the cloud has levelled off and has in fact been nearly constant since mid-August 1989. A definitive confirmation of this new phenomenon was obtained during several nights in late December 1989, from observations in the 5 - 20 μm spectral region; see the graphic representation of the light-curve, accompanying this Press Release.

These observations show that the temperature of the dust cloud is now 160 K (degrees above absolute zero), or $-110°$C. The levelling-off of the far-infrared radiation implies that a hitherto-undetected energy source must now be contributing significantly to the total energy output.

Is it a pulsar ?

But what is the nature of this energy source ? Is it really a pulsar ?

One other possibility is radioactive decay of the Cobalt-57 isotope, created during the supernova explosion[14]. However, to account for the infrared intensity now observed, the original amount of Cobalt-57 would have had to be 20 - 25 times larger than the theoretically anticipated amount (about 0.0017 solar mass), and this is in direct contradiction to the observed strength of a spectral emission line from Cobalt ions. Cobalt-57 is therefore excluded as the new energy source.

Could it perhaps be an infrared light echo from dust further out, due to energy emitted earlier from the supernova being absorbed and re-emitted by the dust ? Apparently not, since in that case the radiated light from dust external to the supernova envelope would need coincidentally to have a temperature that closely imitates that of the cooling supernova envelope, and that is highly unlikely. Moreover, a corresponding visible light echo (truly reflected light) is not seen in photometric measurements at shorter wavelengths.

The only other possibility is the powerful emission from a hidden pulsar. Its emitted energy will be absorbed and re-radiated by the dust clouds in the supernova envelope which then shines at nearly constant brightness in infrared light. Weighing all the evidence, the ESO astronomers are convinced that this is the most likely explanation.

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[14]Cobalt-56 was the primary energy source during almost two years, while the brightness of the supernova decreased at a rate that closely followed the half-time life of Cobalt-56 atoms. Cobalt-57 decays 3.5 times slower than Cobalt-56 and would therefore be expected to play a more important role at a later stage.

They have therefore alerted their colleagues at other observatories to check periodically for the emergence of the pulsar from behind the dust clouds. Nobody knows when that may happen; educated guesses range from a few months to a few years. In addition to rapid light pulses, the pulsar may also manifest its presence by the sudden appearance of certain (high-excitation) emission lines in the supernova spectrum.

The visual magnitude of SN 1987A is now about V = 15.2 and is still decreasing.

Chapter 4

Stars and Nebulae

4.1 Possible Planetary System Photographed Around Nearby Star

(**PR 01/87**; 31 December 1986; For release on 5 January 1987[1])

Based on observations obtained at the European Southern Observatory (ESO), astronomers at the Space Telescope Science Institute (STScI) have uncovered the strongest evidence yet for the presence of a giant planetary or protoplanetary system accompanying a nearby star.

Using special observational and image analysis techniques, Francesco Paresce and Christopher Burrows, of STScI and the European Space Agency (ESA), have made the first visible light images of a large disc of material closely bound to the star Beta Pictoris. The disc is at least 80.000 million kilometres across, or more than three times the diameter of our solar system.

The observations were made at the ESO La Silla observatory in the Atacama desert in Chile. The astronomers will present their findings at the 169th meeting of the American Astronomical Society in Pasadena, California on January 5th.

An unusual excess of infrared radiation, indicative of circumstellar matter, was initially detected around Beta Pictoris by the Infrared Astronomy Satellite (IRAS) in 1983. Subsequent ground-based observations revealed the presence of a disc-like feature at near-infrared wavelengths.

When Paresce and Burrows made detailed observations of the disc at several regions of the visible light spectrum, they found that the reflectivity of the disc material was neutral, or wavelength independent. This means that the colour and spectral characteristics of light reflected from the disc almost exactly matched the spectrum of light emitted from the star itself.

This observation offers the strongest indications yet that the disc is made up of relatively large solid particles. If it were extremely fine dust, which is commonly found in interstellar space, it would scatter only the bluer wavelengths of starlight. The observational data alone cannot establish the true size of the reflecting particles but does set a lower limit of about 0.001 millimetre (1 micron). At this diametre or greater, the particles found around Beta Pictoris are at least ten times larger than material normally observed in interstellar space.

"The observations show unequivocally that an agglomeration process is in an advanced state, where fine interstellar grains stuck together to form larger clumps", reports Dr. Paresce. It is believed that as such a 'snowballing' process continues, the disc material may eventually accrete into planet-sized objects, if they have not done so already. Our solar system may have condensed or accreted out of thick dust grains which formed a circumstellar nebula that accompanied the birth of our sun, approximately 4600 million years ago.

The presently available observational data cannot determine the composition of the particles, though they likely contain silicates, carbonaceous materials, and water ice - common elements abundant within our own solar system.

The evidence for planetary formation is also supported by the fact that the large dust particles are arranged in a flattened disc. The disc likely formed out of an immense, protostellar nebula that contracted and collapsed into the feature seen today. Most of the nebula's gas and dust concentrated at the centre of the disc to form the star Beta Pictoris. The remaining

[1]The text of this Press Release is published simultaneously by STScI and ESO. A B/W picture is available on request from both organisations.

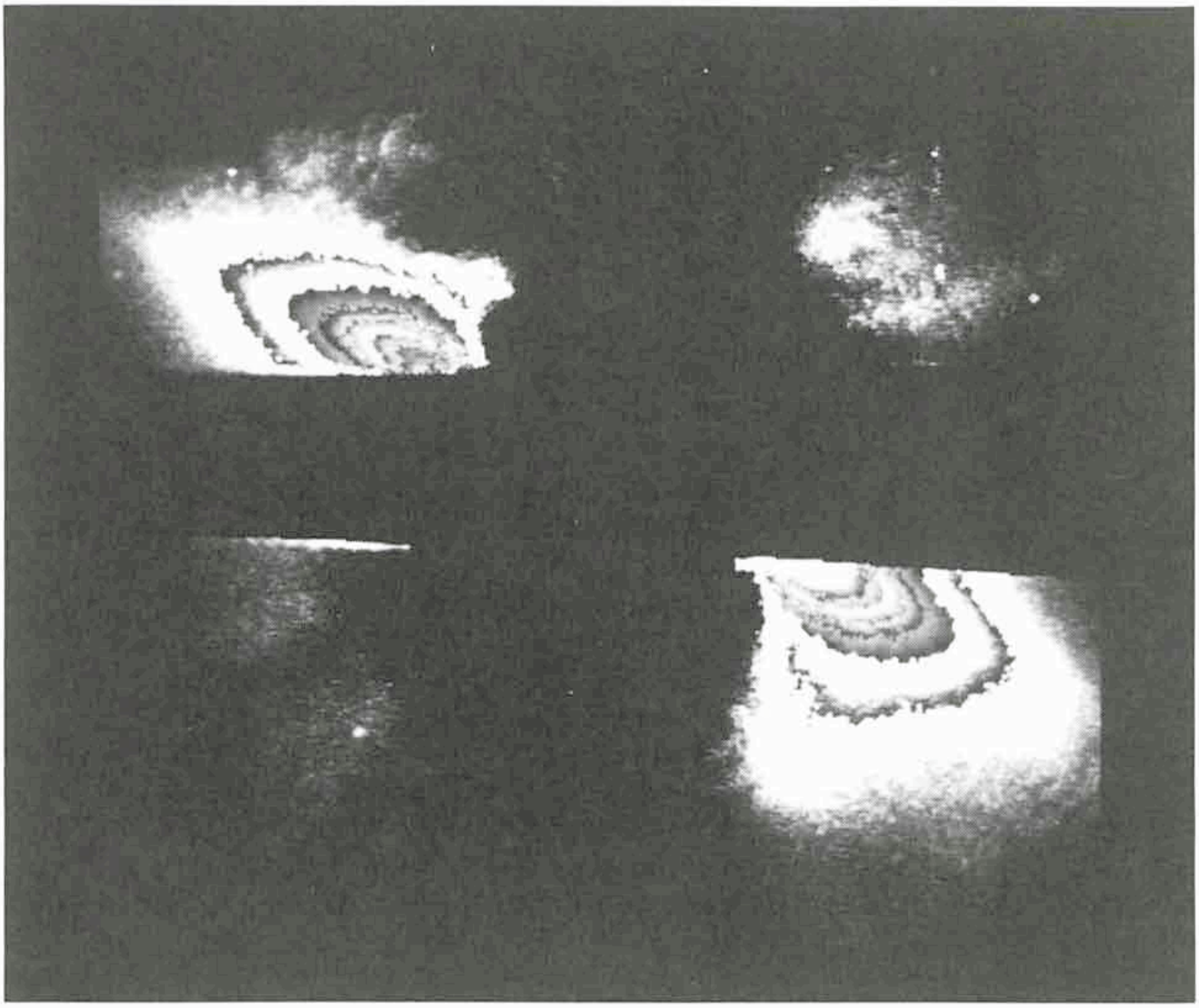


Figure 4.1: This is an image of a **possible planetary or protoplanetary disc around the star Beta Pictoris.** It is the first visible light image ever taken of a compact disc of solid material located within such close proximity to a star. The disc is estimated to be 80.000 million kilometres across. This image is the result of observations made by astronomers Francesco Paresce and Christopher Burrows, using the 2.2 metre telescope of the European Southern Observatory at La Silla, Chile. Using special data analysis techniques the astronomers were able to construct a photometrically accurate picture of the disc, which reveals the true light reflection properties of the particles comprising it. The contours correspond to different intensities of light reflected by the disc particles. The symmetry of the image and concentric distribution of increasingly brighter material is indicative of a broad flattened disc surrounding the star. The star itself is blocked out by an occulting finger which crosses the picture horizontally. Credit: Francesco Paresce, Christopher Burrows (Space Telescope Science Institut). (PR 01/87; BW and Colour)

material now continues to orbit the star.

At present it is not known if planets already formed within the disc or if it is still in a protoplanetary stage. "All that can be said for sure is that the disc has progressed from a 'fine sand' stage into at least a 'pebble' stage", says Dr. Paresce.

Beta Pictoris is a relatively young star estimated to be no older than 1000 million years, or about one fifth the age of our sun. Approximately 50 light years away, it is a socalled 'main-sequence dwarf', like our sun.

Paresce and Burrows made their observations of Beta Pictoris, which is visible as a fourth magnitude star in the southern hemisphere, with the ESO 2.2 metre telescope. Attaching a coronograph of their own design and fabrication, the researchers blocked out the brilliant image of the star, so that the faint circumstellar features could be photographed with a CCD (Charge Coupled Device) detector. To allow analysis of the disc at various wavelengths of light, a series of exposures were then taken through bandpass filters across the visible spectrum. These difficult observations were facilitated by the excellent atmospheric conditions at the ESO La Silla observatory.

As a control, an identical observing sequence was performed on the stars Delta Hydrus and Alpha Pictoris which are not expected to have prominent circumstellar disc features visible from Earth.

Through special data analysis techniques developed by Paresce and Burrows, the two stellar images were corrected for known instrumental effects, precisely registered, and differences between the two images were evaluated. This was an especially challenging task since the researchers were probing the near vicinity of Beta Pictoris and had to contend with intense scattered light from the star itself. They also had to be sure that they were seeing reflected light from a true disc feature and not contamination produced by the instrument optics.

Their resulting data yields the first true, photometrically accurate image of the Beta Pictoris disc, down to about four arcseconds from the star. Never before has such a relatively faint feature been photographed within such close proximity to such a bright star.

The resulting images reveal a highly flattened disc which extends symmetrically outward from Beta Pictoris, into a northeast and southwest direction on the sky. The disc's apparent angular width may indicate that it is slightly tilted to our line of sight. The disc dramatically increases in brightness toward its center, though its structure closer to Beta Pictoris is not visible due to the occulting finger which blocks out most of the light from the star.

Astronomers are eager to find evidence of extrasolar planetary systems to learn whether our own solar system was created out of very unique conditions, or whether it is the result of common and fundamental processes that accompany stellar formation. These questions can not be satisfactorily answered until astronomers have carefully studied examples of planetary formation other than our own solar system.

Paresce and Burrows have images of planetary or protoplanetary around other stars to analyze. They also plan to make detailed observations of Beta Pictoris with the NASA/ESA Hubble Space Telescope, which is now scheduled for launch in late 1988. With its significant increase in resolution over present ground-based instruments, the Space Telescope will have the capability to provide a far more detailed view of the disc's structure, closer to the star. It will also have the potential for detecting the extremely faint glow of planets which may accompany the star. It is also expected that this fascinating area of astronomical research will greatly benefit from future, giant telescopes on the ground, such as the ESO 16 metre Very Large Telescope (VLT), now in the final planning stage.

The *Hubble Space Telescope* is a project of international collaboration between NASA and ESA. The *Space Telescope Science Institute* is operated for NASA by the Association of Universities for Research in Astronomy (AURA). It is located on the Johns Hopkins University Campus in Baltimore, Maryland, U.S.A.

The *European Southern Observatory* is an international organisation, supported by eight countries (Belgium, Denmark, France, the Federal Republic of Germany, Italy, the Netherlands, Sweden and Switzerland). Its headquarters are located in Garching near Munich, F.R.Germany, and the observatory is at La Silla, 600 kilometres north of Santiago de Chile, South America.

4.2 Bubbles from a Dying Star

(**PR 03/87**; 20 February 1987; For release on 26 February 1987)

Stars do not live forever - they are born and they die.

All stars are born by contraction of matter in large interstellar clouds of gas and dust, but they do not all die in the same way. *Heavy stars* appear to end their active lives in gigantic supernova explosions[2], while *less massive stars* (like our Sun) follow another path.

For instance, once the Sun - perhaps 5 billion years from now - has exhausted its nuclear fuel, it will increase more than a hundredfold in size and become a *red giant star*. Thereafter it is expected to very rapidly shred its outer layers, leaving only a shrunken core behind. This core is a *white dwarf star*, that is a very small and dense object which slowly cools and ultimately fades away from sight as it loses the little energy left.

Although this scenario appears plausible to most astronomers, nobody had ever directly witnessed how a solar-like star, towards the end of its life, undergoes the dramatic transformation from a red giant star to a white dwarf.

Now, however, observations at the European Southern Observatory for the first time show a dying star at this crucial evolutionary stage.

Using four different telescopes at the La Silla observatory, ESO staff astronomer Bo Reipurth has just concluded a detailed study of the peculiar star OH231.8+4.2 which is visible as a faint object in the southern constellation of Puppis, inside the Milky Way band. The distance is about 4000 light years. This object is known to have rather strong radio emission from OH molecules (hydroxyle) and it is also a source of infrared radiation, as observed with the satellite IRAS. With the Danish 1.5 m telescope, Reipurth obtained deep CCD (Charged-Coupled Device) pictures of OH231.8+4.2 in the red light of hydrogen, nitrogen and sulphur and discovered a most unusual, complicated structure (see attached photograph). The interpretation of this picture, supported by spectroscopic and infrared observations with the ESO 3.6 m, 2.2 m and 1 m telescopes, now shows that we are here watching the rapid transformation of a red giant star at the end of its active life.

The star itself cannot be seen on the picture; it is embedded in and obscured by dense matter. The 'bubble' *nebula* (shaped like a 'figure 8' or an 'hourglass') consists of matter which has been ejected from the star. The dark band around the 'waist' is the shadow of an extremely dense *disk* of dust particles, rotating around the central star. The matter in the nebula has been ejected in directions perpendicular to the disk. The light received from the innermost part of the nebula is reflected light from the star, but the light from the outer

[2] cf. ESO Press Release 07/86 of May 13, 1986.

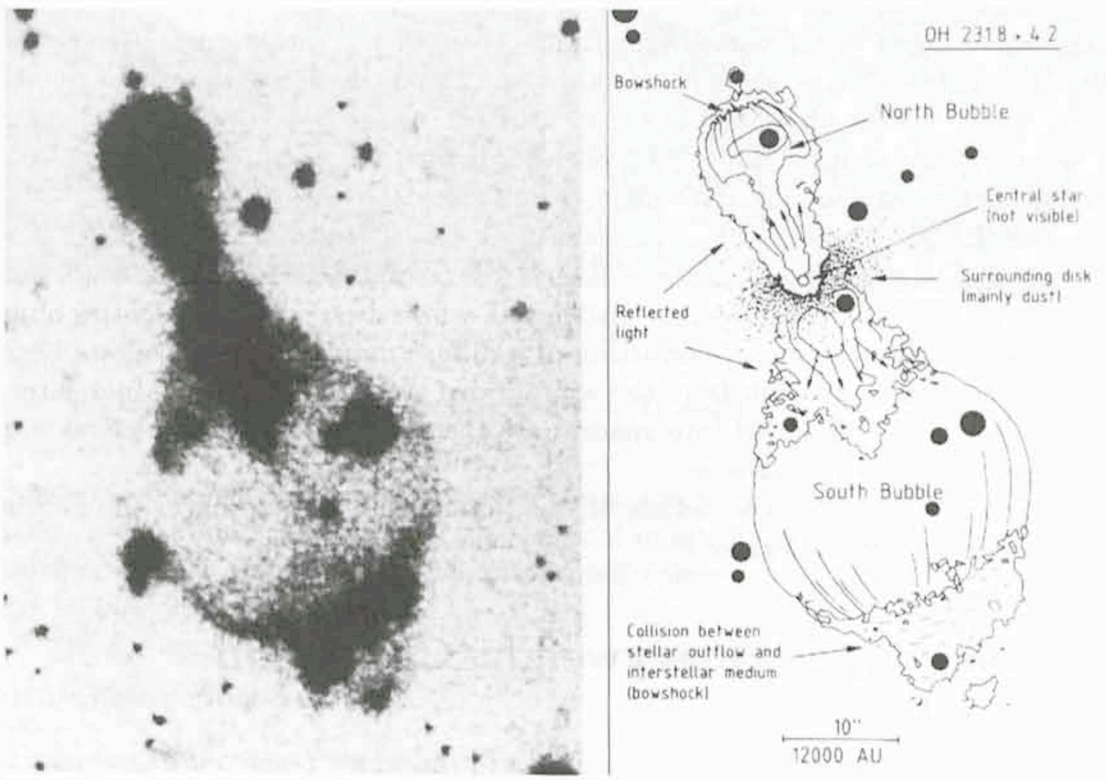


Figure 4.2: **Bubbles around the dying star OH231.8+4.2.** This red CCD-image (left) of the peculiar object OH231.8+4.2 shows for the first time a star during the rapid transition from a red giant to a white dwarf (cf. ESO Press Release 03/87). A schematic interpretation of the picture is shown at the right. The star is embedded in a dense dust disk and material is ejected into two 'bubbles'. Shocked regions indicate where high-speed stellar material collides with interstellar gas and dust. The dark points are stars in the Milky Way which have no connection with this object. The scale is indicated; North is up and East to the left. (PR 03/87; BW)

part (the *'bubbles'*) is emitted from 'shocked' regions where the rapidly moving stellar matter rams into the surrounding interstellar gas.

It is obvious that the star is losing mass very fast. Since the size of the southern part of the nebula is about 50000 Astronomical Units ($\sim$ 0.8 light years) and the outward velocity is about 140 km/sec, the ejection must have started very recently (in astronomical terms). Together with similar data for the northern part of the nebula, this leads to an estimated age of only 1400 years. At the end of this short-lived process, the star which was originally rather similar to our Sun, will have lost much of its material and will have been transformed into a very small and dense object.

Since normal stars live billions of years and the mass-loss phase only lasts a few thousand years, our chances of observing a dying star in this phase are very slim indeed; this readily explains why such observations have never been done before. The present observation is therefore of the greatest importance for our understanding of the late stages of stellar evolution; it constitutes a long-sought 'missing link'.

When OH231.8+4.2 sometime in the near future has shred a large part of its mass, the surrounding nebula becomes less and less dense as it slowly expands. Soon the remaining, inner parts of the star (the core) become visible as a white dwarf star. The entire object will then appear as a *planetary nebula*, consisting of a diffuse mass of gas that glows because of the irradiation by ultraviolet light from the white dwarf star at the centre. Much later, when the surrounding gas has dispersed into space, only the white dwarf will be left as a ghostly memorial to the once so brilliant star.

An article, which describes the details of this discovery, is appearing in the February 26 issue of the scientific journal *Nature*.

4.3 Stellar Super Heavyweight Champion Disqualified

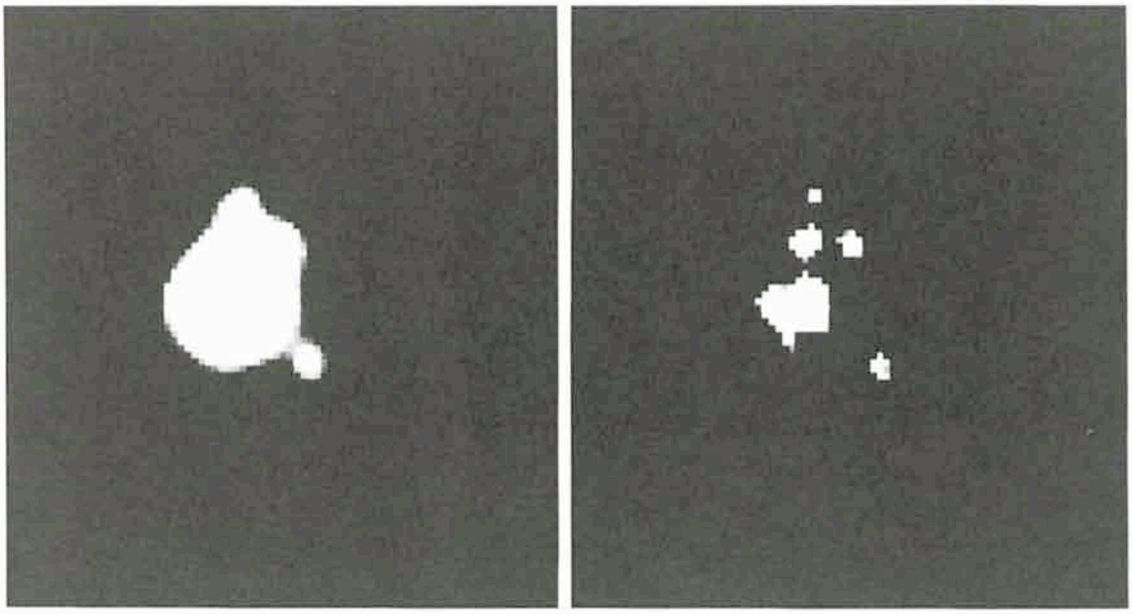
(**PR 03/88**; 19 May 1988; For immediate release)

The most massive stars may be less heavy than thought before. Recent observations with two telescopes at the ESO La Silla observatory have now shown that a star in the Large Magellanic Cloud, long believed to be one of the most massive in existence, is in fact multiple and consists of a very compact cluster of hot, young stars. This discovery may have important implications for the theory of stellar birth and the determination of distances in the Universe.

Sanduleak -66°41 resolved

From earlier observations, a mass of more than 120 times that of the Sun was estimated for the bright blue star Sanduleak -66°41 in the Large Magellanic Cloud. This high value was difficult to reconcile with theoretical calculations, which showed that stars with masses well above $\sim$60 times that of the Sun should be unstable.

However, observations with the 3.6 m and 2.2 m telescopes at the ESO observatory were carried out in March 1988, under very good conditions. Extremely sharp images of this star were obtained by a group of three ESO astronomers, M. Heydari-Malayeri (on leave from Observatoire de Paris), P. Magain and M. Remy. They showed for the first time that Sanduleak -66°41 is not a single star, but a very compact cluster of hot, blue stars.



Sanduleak -66°41 Resolved Into 6 Components

Figure 4.3: **The "Star" Sanduleak −66°41 resolved.** (PR 03/88; BW)

With advanced image processing methods, the astronomers were able to further "sharpen" the images. This allowed them to split the original image into no less than six components, each corresponding to a single star. There are indications that the central star (see figure) may itself be double or even multiple.

The birth of star clusters

Other, apparently very heavy stars have been found to be double or triple. Thus, there is now some evidence that most of these objects may indeed consist of several stars which are very close in space. Stars in such clusters are born at the same time by condensation out of dense, interstellar clouds of gas and dust. The evolution of the individual stars depends on their mass; the heavier ones evolve faster than those with less mass.

The star Sanduleak -69°202 that exploded as Supernova 1987A on February 23 last year, was the most massive member of a group of a few stars, similar to the cluster now found at Sanduleak -66°41. However, the exploding star was already at a late stage of its evolution, whereas Sanduleak -66°41 is at an early stage. Still, it will not live very long, when compared to stars like the Sun. Whereas the Sun will remain stable during another 5000 million years or more, very heavy stars use their hydrogen fuel at a prodigious rate and become unstable after a few million years at most.

The new observations support the suggestion by theoreticians that very massive stars cannot exist.

Distances in the universe

There is another implication of this discovery. Since the heaviest stars are also the brightest, such objects can be seen over great distances, also in galaxies far out in space. It is usually assumed that they are similar to heavy stars in the Milky Way Galaxy and its satellite galaxies, the Magellanic Clouds, and therefore radiate the same, known amount of light. Light is dimmed by the square of the distance, so from the observed brightness of such stars it is possible to determine the distances to the galaxies in which they reside. This method is an important tool to establish the scale of distances in the Universe.

However, if these objects are not individual, massive stars, but rather clusters of stars, then this assumption is no longer valid. At the great distances of galaxies, a compact cluster could not be resolved into individual stars and would look exactly like a single star. But the combined cluster stars emit more light than a single star.

At a given observed brightness in the sky, the cluster is farther away than the star. This means that if the brightest "stars" in other galaxies are not stars, but clusters of stars, then the distances to these galaxies are larger than previously thought.

This question is therefore of great cosmological interest and must now be investigated in detail.

The detailed findings of the ESO astronomers have been submitted for publication in the European journal *Astronomy & Astrophysics.*

4.4 Most Distant *Star* Ever Seen: Supernova Explodes 5 Billion Years Ago

(**PR 07/88**; 9 September 1988; For immediate release)

The most distant, individual star ever recorded was detected with a telescope at the ESO La Silla observatory on August 9, 1988. The object is an exploding star, a *supernova*, and is situated in an inconspicuous galaxy, itself a member of a distant cluster of galaxies. Additional observations indicate that the cluster, known as AC118, is at a distance of about 5 billion light-years (1 billion = 1000 million). Thus this supernova explosion occurred 5 billion years ago, or about the time when the Sun and the planets were born. Ever since then, the light emitted by this event has been travelling towards us, only arriving here now. It is the most distant supernova[3] observed so far.

The discovery was made by Danish astronomer Hans Ulrik Nørgaard-Nielsen, working with the Danish 1.5 m telescope at La Silla. It is the successful outcome of a dedicated search programme for supernovae in very distant galaxies, which has been carried out during the past few years by a group of astronomers[4] with this telescope.

The explosion of a star as a supernova is an extremely powerful event and during a short time it may shine brighter than the entire galaxy in which it is located (and which consists of several hundred billion stars). But due to the enormous distance, the light we receive from this supernova event is 4 million times fainter than what can be seen with the unaided eye. It is therefore difficult to detect such an object.

The present detection technique is based on the comparison of two images of the same cluster of galaxies, obtained at different times. "Subtracting" the two images from each other in principle allows to distinguish any object which is present in one of the images, but not

[3]For information about the very bright and relatively nearby Supernova 1987A, see f.inst. ESO PR 02/88 of 16 March 1988 and earlier ESO Press Releases.

[4]The group includes Hans Ulrik Nørgaard-Nielsen (Danish Space Research Institute, Lyngby, Denmark), Leif Hansen and Henning E. Jørgensen (University Observatory, Copenhagen, Denmark), Richard S. Ellis (University of Durham, U.K.) and Warrick J. Couch (Anglo-Australian Observatory, Epping, NSW, Australia)

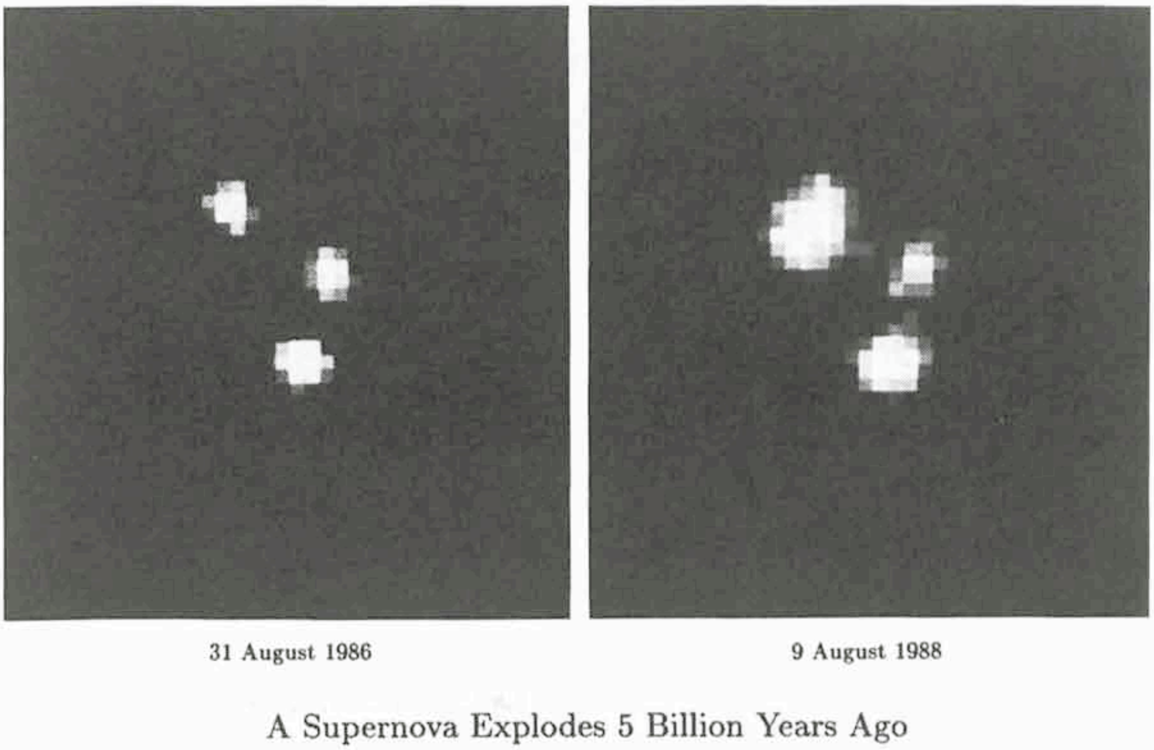


Figure 4.4: **A supernova explodes 5 billion years ago.** The figure shows a small field with three galaxies in the cluster AC 118, as observed with a CCD camera at the Danish 1.5 m telescope at La Silla on 31 August 1986 and 9 August 1988, respectively, under slightly different observing conditions. The image of the upper-left galaxy is extended downwards in 1988, due to the superposition of the supernova image, about 0.8 arcseconds southeast of the centre of the galaxy. The magnitude of the supernova is $V \sim 22.3$; the redshift of the galaxy cluster is $z = 0.31$, corresponding to a recession velocity of $\sim 79,000$ km/sec. The supernova faded to ~ 23.1 on 16 August 1988. North is up and East is to the left. 1 pixel = 0.47 arcseconds. (PR 07/88; BW)

in the other. A supernova will show up as an additional spot of light in an image obtained soon after the light from the explosion reaches us, when compared to an earlier image. This is clearly illustrated in the photo which accompanies this Press Release.

A supernova only remains at its brightest during a short time. For a distant supernova this implies that it must be detected as soon as possible after the explosion, so that additional observations can be made before it becomes too faint to observe. By good luck, the detection of the present supernova appears to have been made less than one week after the explosion became visible. Further images were obtained until August 16, when it had faded to half of its brightness at discovery, unusually fast for a supernova. On September 6, the supernova was too faint to be seen.

Still, by concerted action, it was possible to obtain spectra with the EFOSC instrument at the ESO 3.6 m telescope and, a few days later, with the Anglo-Australian 4 m telescope at Siding Spring, NSW, Australia. These spectra are now in the process of being interpreted, a difficult task due to the faintness of the object.

The present supernova is apparently of Type I, and many supernovae of this type have been observed in nearby galaxies. (Type II supernovae are generally fainter than Type I). It is therefore of great interest to compare this very distant supernova - which we now observe as it was 5 billion years ago - with those in our neighborhood. If it behaves identically to the nearby Type I supernovae, then we may hope to use these objects for cosmological investigations, also in distant regions of the universe.

For instance, if the intrinsic brightness of all Type I supernovae is the same everywhere, then they may serve as independent distance indicators, allowing us to verify distance determinations based on the Hubble expansion. Moreover, distant supernovae may be used as "clocks" to check the time dilation predicted by the General Theory of Relativity. This implies an apparent slow-down of events observed at great distances. The fact that this supernova apparently faded *more rapidly* than most other known Type I supernovae is not necessarily in contradiction to relativity; it is probably inherent to the supernova itself.

By now, this supernova has become too faint to observe with existing telescopes. However, this event has convincingly demonstrated our ability to detect very distant supernovae. When the Hubble Space Telescope and the ESO Very Large Telescope become available in the 1990's, we shall be able to study these important objects in much more detail, thereby opening a new line in our investigations of the distant regions of the universe.

4.5 The Vanishing Star

(**PR 09/88**; 8 December 1988; For immediate release)

Reinhold Häfner[5], visiting astronomer at the ESO La Silla Observatory, got his life's surprise when the star on the screen in front of him suddenly was gone. All the other stars were still visible, but this particular one had simply vanished.

Now, stars are big gaseous spheres like our Sun, and they cannot disappear just like that. Dr. Häfner concluded that the star was being eclipsed by an unseen companion star and that it would therefore reappear after some time. He got his next surprise when this happened only a few minutes later. In fact, he had just discovered the most complete and probably also the fastest stellar eclipse ever seen.

This happened during the night of July 1-2, 1988, in the control room of the Danish 1.5 m telescope. Two more eclipses were observed during this and the following night. After a thorough analysis of all data, this interesting phenomenon can now be fully explained.

The mysterious, 17 magnitude star (in the constellation Ophiuchus) has the designation PG 1550+131 and was first observed at the Palomar Observatory in the mid-seventies. At that time, it was found to have an unusual blue colour. Later observations indicated that its brightness varies somewhat, and Dr. Häfner had therefore decided to have a closer look at it. He thought that it might belong to a relatively rare type of stars, known as *"cataclysmic variables"*.

"Cataclysmic variables" are double (binary) stars in which one of the two components has already gone through its entire evolution and has now become a small, compact object. The other star in the system is still in the main phase of its life, burning hydrogen into helium. The two stars orbit around each other, and there is a steady stream of gas from the larger star to the smaller one. This phenomenon sometimes gives rise to an abrupt increase in brightness; hence the term "cataclysmic variable".

Less than two dozen binary stars are known which are presently in the state that immediately precedes the "cataclysmic" phase. They are known as *"pre-cataclysmic binaries"*. In

[5]Home Institute: Munich University Observatory, Fed. Rep. Germany.

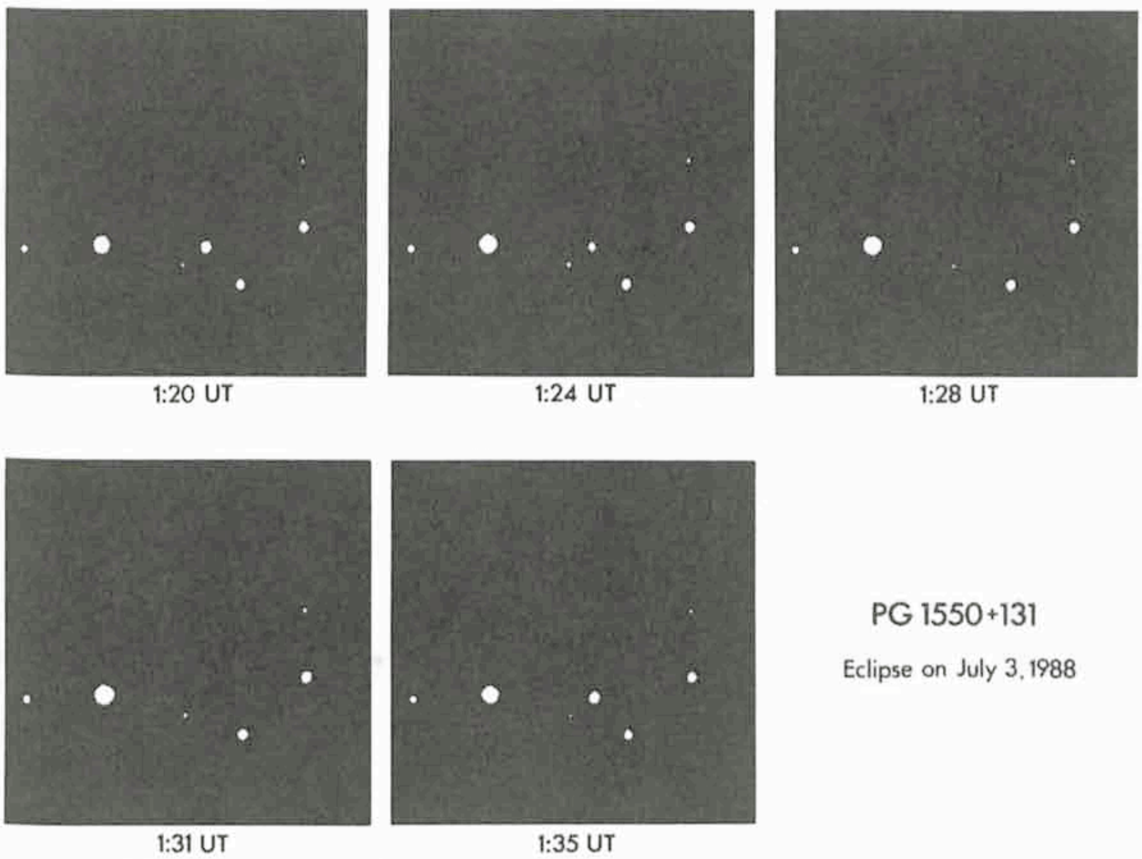


Figure 4.5: **An eclipse of PG 1550+131.** This sequence of five CCD images was obtained by Reinhold Häfner of the Universitäts-Sternwarte München with the Danish 1.5 m telescope at the ESO La Silla observatory. They show a fast and total eclipse of the pre-cataclysmic binary star PG 1550+131 in the constellation Ophiuchus, in the early morning of July 3, 1988. Whereas all other stars in the field remain unchanged, this star disappears entirely from the view during a short moment. At 1:20 Universal Time, the eclipse has not yet begun; at 1:24 the star has dimmed notably; at 1:28, it is completely eclipsed; it weakly reappears at 1:31 and again shines at normal brightness at 1:35. For all frames, the exposure time was 3 minutes. No filter was used, and the main spectral response is therefore in the red region. (PR 09/88; BW)

this phase, there is not yet a gas stream from the larger component. However, due to scarcity of accurate data, relatively little is known about binary stars in this transitory phase, for instance about the sizes of the stars, their temperatures, masses, orbital periods, etc. But the exact nature of "pre-cataclysmic binaries" must be known in order to fully understand the violent processes during the unstable "cataclysmic" phase.

Thanks to the occurence of pronounced eclipses of PG 1550+131, it may now become possible to learn more about this important "missing link" in the evolution of binary stars. The analysis of exactly how the light changes during an eclipse, allows to determine the physical properties of the system, e.g. the size of the components, the size and shape of the orbit, the distribution of light on the surfaces of the components, their temperatures, etc. These numbers then place constraints on the corresponding values for "cataclysmic variables".

The eclipses in PG 1550+131 obviously happen when the smaller and brighter of the two stars in the system (the one which is more evolved) during its orbital motion passes behind the other star, as seen from the Earth.

The "depth" of the eclipse, i.e. the amount of light lost, is a record 99%, or even more[6]. This means that the secondary component - whose light is the only light left during the eclipse - is more than 100 times fainter than the star which it eclipses. Moreover, the very short duration of the eclipse - another record - indicates that the faint star is also very small; it is termed a "red dwarf" and its temperature is "only" about 3000 degrees.

Contrarily, the brighter of the two stars is of the "white dwarf" type with a surface temperature of $\sim 18,000$ degrees. Interestingly, that hemisphere of the fainter "red dwarf" which faces the "white dwarf" is heated to about 6000 degrees. The orbital period in the system is only 187 minutes and the distance between the two components is about 700,000 kilometres. That means that the entire binary system could be contained within the space filled by our Sun.

Immediately after the discovery of the eclipses, spectra were obtained of PG 1550+131 with the ESO 3.6 m telescope, and they support this interpretation. More observations are planned for mid-1989, which will hopefully lead to a refinement of the photometric and spectroscopic data. In the meantime, Dr. Häfner has submitted the preliminary findings for publication in the European journal *Astronomy & Astrophysics.*

4.6 The "Southern Crab" Nebula

(**PR 01/89**; 30 January 1989; For immediate release)

Celestial Crabs

Everybody knows the *Crab Nebula* - that famous object in the northern constellation Taurus (The Bull). It is the remnant of a supernova explosion in the year 1054 and has been studied with all available astronomical techniques.

But this nebula does not really ressemble the animal whose name it carries ! Whoever attached this name to it by the middle of the last century must have had a well developed imagination.

[6] In astronomical terms, the eclipse has a central depth of at least 5 magnitudes; the duration is less than 12 minutes.

Now a "real crab" has been discovered, a nebula in the southern constellation of Centaurus (The Centaur), which from its appearance on recent pictures made with telescopes at the La Silla Observatory would seem to have more right to associate with crustaceans. To avoid confusion, astronomers now refer to the new object as the *"Southern Crab"*.

The new observations

The prosaic name of this object is *He 2-104*, meaning that it was first catalogued as no. 104 in the second list of emission-line stars, compiled by American astronomer-astronaut Karl Henize in 1967. At that time, it was thought to be starlike, and nothing was known about the extended nebula around it until recently, when ESO astronomer Hugo E. Schwarz, together with Colin Aspin (UK Joint Astronomy Centre, Hawaii) and Julie H. Lutz (Washington State University, Seattle), obtained direct CCD images with the 2.2 m telescope at La Silla. By means of suitable optical filters, pictures were made in various colours, corresponding to the emitted light from several elements, e.g. hydrogen, sulphur, nitrogen and oxygen. Because different physical conditions prevail in the various parts of the object, the apparent shape of the nebula depends on the colour in which it is observed.

The attached B/W photo[7] shows what the astronomers saw on the monitor screen in the light of ionized nitrogen ([NII] λ6584Å), once the image had been computed processed to remove all detector induced effects. No wonder that the object quickly received its present name !

The astrophysical background

It is one thing is to obtain pretty pictures, but quite another to explain what they mean. The "Southern Crab" is not easy to understand, and the explanation below is only a first attempt.

Symbiotic stars are binaries in which a small hot star (white dwarf or main sequence star) orbits around a red giant star. These systems are often surrounded by an envelope of gas or dust; those with gas are known as *S-types* and those with dust as *D-types*.

Their spectra show strong emission lines, and their brightness varies in an irregular way, reflecting the energetic processes that take place in and near these unusual objects. Especially the D-type symbiotic stars emit strongly in the infrared part of the spectrum.

There is mounting evidence that the D-type symbiotics, of which no more than about 20 systems are known, are on their way to becoming *planetary nebulae* (PNe), a late evolutionary stage for stars of medium mass. Such objects are seen in the sky as gaseous nebulae, surrounding small hot stars. (Despite their name, planetary nebula have nothing to do with the planets in our solar system; it refers to the fact that some of the brightest of them are seen in telescopes as small disks.)

Some D-type symbiotic stars are expected to be in a very rapid phase of their evolution, lasting only a few thousand years. Since the normal stellar lifetime is of the order of 100 million to 1000 million years, this transitory phase lasts only a very small fraction of the star's lifetime, and the phenomenon must therefore be quite rare among the stars we see in the sky. (In comparison, this would correspond to a single hour only during the entire life of a human being !)

[7] A false-colour, computer enhanced picture is available on request.

The "Southern Crab" Nebula (He2-104)

Figure 4.6: **The "Southern Crab" Nebula (He2-104).** This CCD image of the proto-planetary symbiotic star He2-104, also known as the "Southern Crab", was obtained with the 2.2 metre telescope at La Silla by Hugo Schwarz and collaborators; the exposure time was 30 min. It shows the unusual object in the light of nitrogen ions ([N II] λ6584 Å). The visual magnitude of the central part is 14.6. The astrophysical interpretation of this image is described in ESO Press Release 01/89 of January 30, 1989. North is up and East is to the right. The field shown on this photo measures ~ 80 × 80 arcseconds square (1 cm = 4.7 arcsec). (PR 01/88; BW and Colour)

He 2-104 is possibly one of these few D-type symbiotic stars, and the present observations were made during a search for ***proto-planetary nebulae*** (PPNe), that is objects which are in the transition phase and on the verge of becoming planetary nebulae.

Interpretation of the Southern Crab

Against this background, it is now possible to interpret provisionally the crab-like appearance of He2-104.

The central, hot and small star in the binary system has recently formed a disk of material in its equatorial plane, which is made up of gas and dust that has been transfered by rapid mass loss from its companion, a red giant star. When a fast, stellar wind (mainly energetic atoms and ions) some time ago started to "blow" from the central star, the surrounding disk prevented this material to flow in the equatorial direction. It was, however, able to escape in the polar directions and soon gave rise to the two "bubbles" which can now be seen as the "legs of the Crab". Since we are looking through these bubbles, they appear brighter at the edges than in the central parts - this is refered to as "limb brightening".

Then a highly collimated and very fast wind started to blow (like a "jet stream") and produced the two "blobs" which we see somewhat further out in the same general directions as the bubbles. These "legs" and blobs are likely to be the places where the fast wind "hits" the surrounding interstellar gas and dust, or possibly material which was earlier lost by the red giant star. The collision results in rapid heating (the socalled "shock process"), so that the "shocked" regions start to shine in the light of various ionized elements; they are similar to the "Herbig-Haro" objects.

Confirming the scenario

This general scenario was confirmed by spectra which were obtained of the two blobs. The astronomers found that they are moving away from the central object with speeds of the order of $\sim$ 100 kms^{-1}. Their velocities in space must actually be higher, because we only observe them as projected on the line-of-sight. This clearly fits the above explanation very well.

Photometry in the visible and infrared regions of the spectrum with other telescopes (3.6 m, 1 m and 0.9 m Dutch) at La Silla, and using the IRAS database, has enabled the astronomers to determine the overall energy distribution of He2-104. When compared with that of another object which is apparently in the similar evolutionary phase, OH231.8+4.2[8], it would appear that the temperature of He2-104 is higher, thereby implying a somewhat later evolutionary stage for this object. The surrounding dust would have been heated more. This idea is also supported by the crab-like structure: the bubbles are more expanded and the Herbig-Haro "blobs" are at a larger distance from the central star(s) than in OH231.8+4.2.

It has not yet been possible to make an accurate determination of the distance to the "Southern Crab"; this is mainly because the amount of absorbing, interstellar material along the line-of-sight is not well known. The visual magnitude of the starlike center is about 14.6; it is therefore $\sim$ 3000 times fainter than what can seen with the unaided eye.

[8]See also ESO Press Release 03/87 of 20 February 1987.

The future of the Southern Crab

It therefore looks as if the "Southern Crab" is indeed a binary star which is just about to become a planetary nebula. By good luck, this phenomenon, which in astronomical terms lasts only a very short time and is therefore extremely rare, can here been studied in detail. Changes in the spectrum and brightness may take place in the future, and the object will therefore be kept under regular surveillance during the coming years. The velocities of the various components will also be determined in more detail.

The astronomers have written two articles which describe this interesting object; they will appear in the scientific journals *Astrophysical Journal* and *Publications of the Astronomical Society of the Pacific.*

4.7 Witnessing the Violent Birth of a Solar-type Star

(**PR 04/89**; 30 June 1989; For release on 6 July 1989)

Recent studies at the European Southern Observatory indicate that the formation of a new star is a dramatic process which may be more complex than most astronomers believed only a few years ago.

Earlier this year, observations with telescopes at the ESO La Silla observatory led to the discovery of an exceptionally interesting newborn star, situated within the confines of the giant interstellar cloud complex to which also the well-known Orion Nebula belongs. This particular object displays in a spectacular way the violent phenomena which accompany starbirth. We here witness a modern replay of energetic events which took place during the formation of our own solar system, approximately 4,700 million years ago.

The new observations were made by ESO astronomer Bo Reipurth. Searching for the signatures of newly born stars on wide-field photographs obtained with the ESO Schmidt telescope, he discovered a most unusual object in the constellation of Orion, near the celestial equator. A detailed analysis has shown that this object, now officially designated *HH-111*[9], displays virtually all of the phenomena known to be associated with starbirth, in particular an intense stream of outflowing material (a "jet"), more prominently than in any other known object of this type[10].

Because of its great importance for our understanding of how stars are born, HH-111 will now be further investigated with all available observational methods. A first analysis by Dr. Reipurth appears in an article in the July 6 issue of the scientific journal *Nature*.

How stars are formed

In order to understand the importance of HH-111, let us briefly summarize the current picture of the formation of stars like our Sun.

[9]The designation means "Herbig-Haro type object no. 111". The astronomers George Herbig (USA) and Guillermo Haro (Mexico) discovered the first objects of this class in the early 1950's, although the underlying astrophysical phenomena have only recently become more fully understood. On celestial photographs they are seen as small, bright nebulae, always in front of large interstellar clouds. The Herbig-Haro nebulae emit light mainly from excited hydrogen, nitrogen, oxygen and sulphur atoms.

[10]This Press Release is accompanied by a B/W photo showing the newly discovered HH-111 jet and also a contour plot of the entire system. A colour version of the B/W photo is available on request.

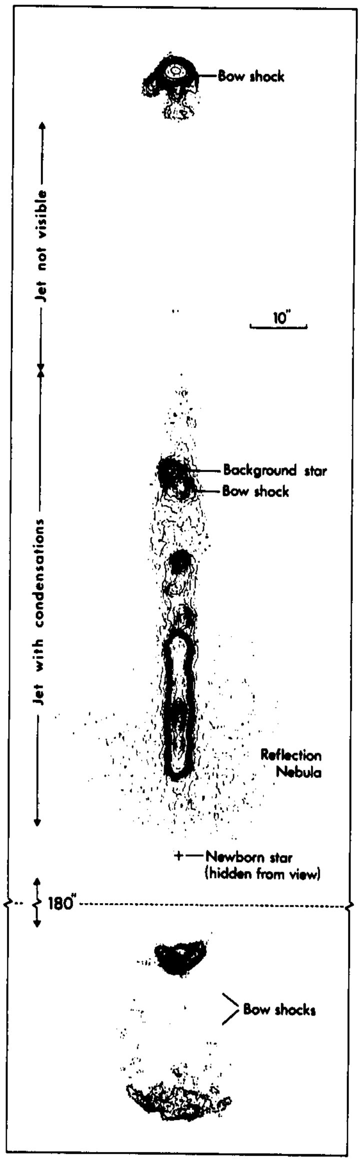


Figure 4.7: **The large jet in the HH-111 complex.** This drawing shows contours of equal brightness (isophotes) of the newly discovered, large jet from a newborn star. With the exception of one background star, all stellar images have been removed by means of image processing. In order to show the bow-shocks on the opposite side of the main jet within the same picture, an empty section, 180 arcseconds long, has been "cut out". The upper part of the picture may be compared with the B/W photograph which also accompanies the Press Release. The newborn star and its surrounding accretion disk cannot be seen in visual light, but its position is known from infrared measurements; it is here indicated with a cross (+). The associated jet emerges from the surrounding cloud, about 9 arcseconds from the star, within an extended reflection nebula that is illuminated by the star. There are numerous condensations in this jet and two bow-shocks (indicated), where it rams into the surrounding interstellar material, producing highly excited nebulae. The drawing is based on a composite of five CCD exposures, each of 1 hour duration, obtained at the Danish 1.5 m telescope at La Silla. The angular scale is indicated by a 10 arcsecond bar. (PR 04/89)

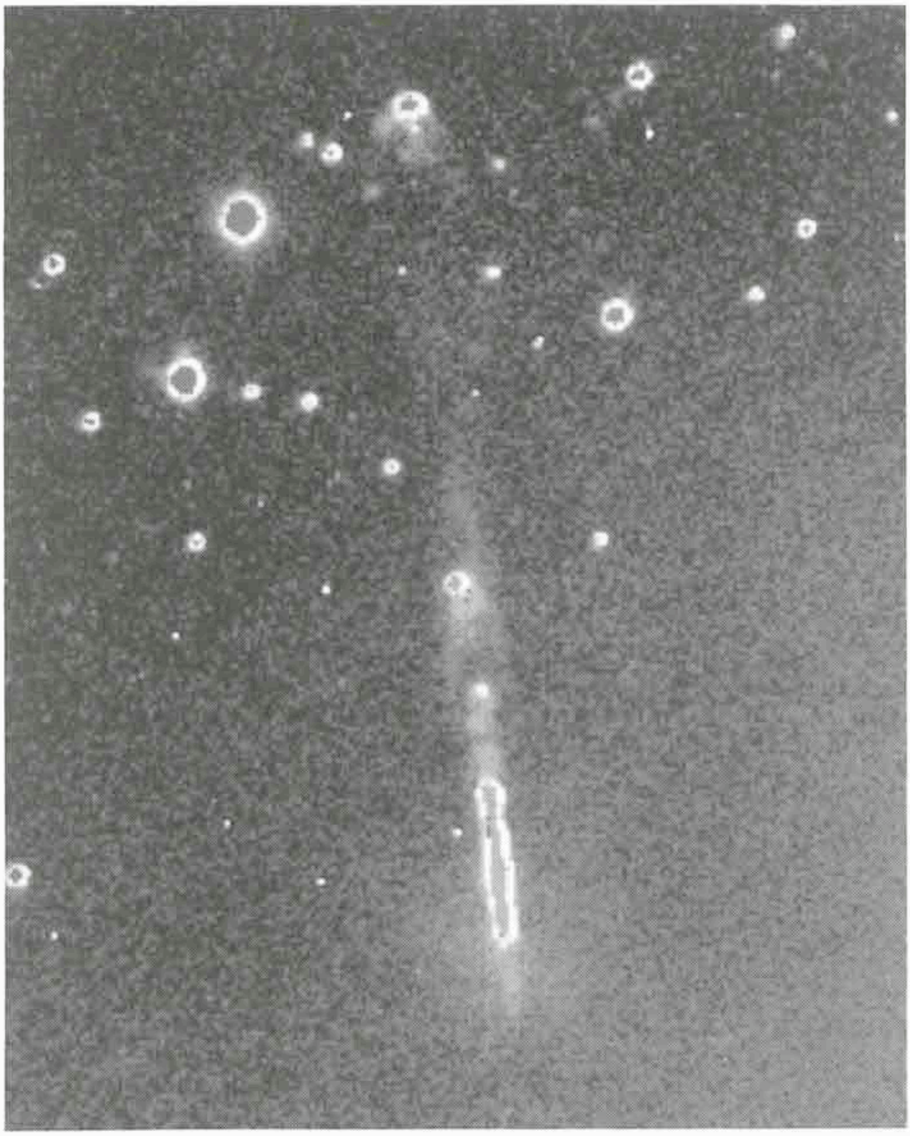


Figure 4.8: This photo shows the **newly discovered large jet in the HH-111 complex.** The straight jet emerges from the surrounding interstellar cloud in the lower part of the picture. The outline of the cloud is vaguely visible by the brighter background near the right edge of the picture. Also seen is a diffuse reflection nebula around the lower part of the jet. This nebula is illuminated by the light from the newborn star, hidden deep within the cloud. Because of the heavy obscuration, the star itself is not visible on this photo. The jet produces a "bow-shock" nebula; this is the bright, mushroom-shaped nebula in the upper part of the picture. The round points are background stars in the Milky Way. Compare this image with the graphic representation of the jet isophotes, also accompanying this Press Release. The picture was produced as a composite of four 1 hour CCD exposures, obtained with the Danish 1.5 m telescope at La Silla through a narrow optical filter. The light seen here from the jet is emitted by singly ionised sulphur atoms. This photo is available in a B/W and a false-colour version. (PR 04/89; BW and Colour)

There is general agreement that stars are born by contraction in large, interstellar clouds of gas and dust. Many such clouds are known in the Milky Way Galaxy and some of them contain vast amounts of complex molecules.

The star-forming process starts when for some reason, perhaps the blast from a nearby exploding star (a supernova), a small part of the cloud is compressed and begins to contract further because of the mutual gravitational attraction of the individual particles.

After some time, the gas and dust in this volume fall freely towards a growing central condensation, whose density steadily increases. In astronomical terms, this phase does not last very long, in some cases shorter than 10,000 years. All of this takes place deep inside the cloud which is completely opaque to visual light. These early stages of star formation can therefore only be observed by infrared and radio techniques.

The process releases a lot of energy and the central condensation becomes warmer and warmer. Since the "parental" cloud rotates, some of the material does not fall directly towards the centre; a substantial part collects in a dense disk around the central condensation. Material feeds into this *accretion disk* from the surrounding cloud and eventually spirals down towards the centre.

From the inside edge of the disk, material steadily "rains" down on the central condensation, now termed a *proto-star*. By this process the protostar gradually becomes heavier. There is no exact moment when it can be said that the protostar has become a "real" star, but one might say that the new star has been "born" when it has acquired at least half of its final mass.

Jets from proto-stars

The matter near the protostar and its accretion disk "boils" and is in violent motion. From time to time, some of it is ejected towards surrounding space, mostly in the form of highly excited atoms (ions). There is no way in which the ejected material can pass through the dense accretion disk, and it is therefore forced out in the directions perpendicular to the disk. Intense magnetic fields may also play a role in this connection.

Thus the young object sends out relatively narrow, high-speed *"jets"* in opposite directions. These supersonic jets penetrate far into the surrounding cloud before they are eventually brought to a halt by collision with the particles in the cloud. Luckily for the observer, the jets in a few systems reach beyond the surface of the parental cloud so that they are much less obscured than the protostar. Such jets may therefore be studied in detail by means of *optical* observations.

Jets from stars in the process of being born were only recognized in 1982, when better observational techniques, in particular highly sensitive Charged Coupled Detectors (CCD's) became available. By astronomical standards, the "jet phase" lasts very briefly, probably less than a few hundred thousand years. It appears that the more material there is still in the accretion disk, the larger are the chances that jets will be ejected. It is also thought that the jets switch on and off; maybe they are only active when particularly large chunks of matter fall inwards from the inside of the accretion disk.

Interestingly enough, jets are also observed in certain double star systems and from old stars, which are about to die. On a much larger scale, jets also emerge from the centres of "active" galaxies, as well as from many quasars.

It is apparent that jets with a vast range of sizes and energies occur in many different types of objects. Jets are clearly a fundamental phenomenon in the Universe.

The magnificent jet in the HH-111 complex

HH-111 was first seen by Dr. Reipurth as a small nebula on a long-exposure photographic plate, obtained with the ESO 1 metre Schmidt telescope in red light.

The significance of HH-111 became clear when the ESO astronomer studied the object in more detail. CCD images, obtained with the Danish 1.5 m telescope in the light of excited hydrogen and sulphur atoms immediately revealed one of the largest and most perfect, narrow stellar jet systems ever seen. Spectra of this jet were observed with the 2.2 m ESO/MPI telescope and show the rapid motion (several hundred km/sec) of the particles in the jet, from a point very near the hidden newborn star to where they ram into the surrounding interstellar medium and produce several spectacular mushroom shaped "bow-shock" nebulae. These nebulae emit light from atoms excited by the energy released in the braking process.

Even better, two more bow-shock nebulae were found exactly in the opposite direction, indicating the action of another jet, opposite to the one first seen. However, it is not visible even on the deepest exposures. Although it is most likely that this is due to heavy obscuration, it may also be that it is less active at the present moment.

Infrared observations have shown that the young star at the centre has a total luminosity of about 25 times that of the Sun. This is a rather high value for such an object and suggests that material is currently spiralling down through the accretion disk onto the star. In addition, deep CCD exposures show the presence of a faint reflection nebula around this object, illuminated by the light of the deeply embedded new star.

Radio-observations with the Swedish-ESO Submillimetre Telescope (SEST) at La Silla, also show that there is a major outflow of CO-molecules in the same direction as the jet.

In other words, virtually all known characteristics of a newborn star are here combined in a single object, HH-111.

Witnessing the birth of a star

Since it is situated within the Orion clouds, the distance to HH-111 is estimated as 1500 lightyears. The size of the visible jet is about $3.4 \cdot 10^{12}$ kilometres, or 23,000 times the mean distance from the Sun to the Earth. The total extent of the object, as measured between the outermost bow-shock nebulae, is 6 arcminutes, or more than 2 lightyears.

From the outflow velocity and the known size of the system, it is possible to calculate that it would take a particle only about 1000 years to move from the newborn star to the bow-shock.

HH-111 is obviously in a crucial phase of the starbirth process and it may be expected to show important changes on quite a short timescale. Monitoring the jet will indirectly tell us what is going on at its origin, near the young star and its associated accretion disk.

Although Dr. Reipurth is hesitant to qualify HH-111 as the "Rosetta-stone" to solar-type formation, it is clearly an object that deserves much observational and theoretical attention during the coming years. It will undoubtedly help us to improve our knowledge about the birth of our own solar system.

Chapter 5

The Solar System

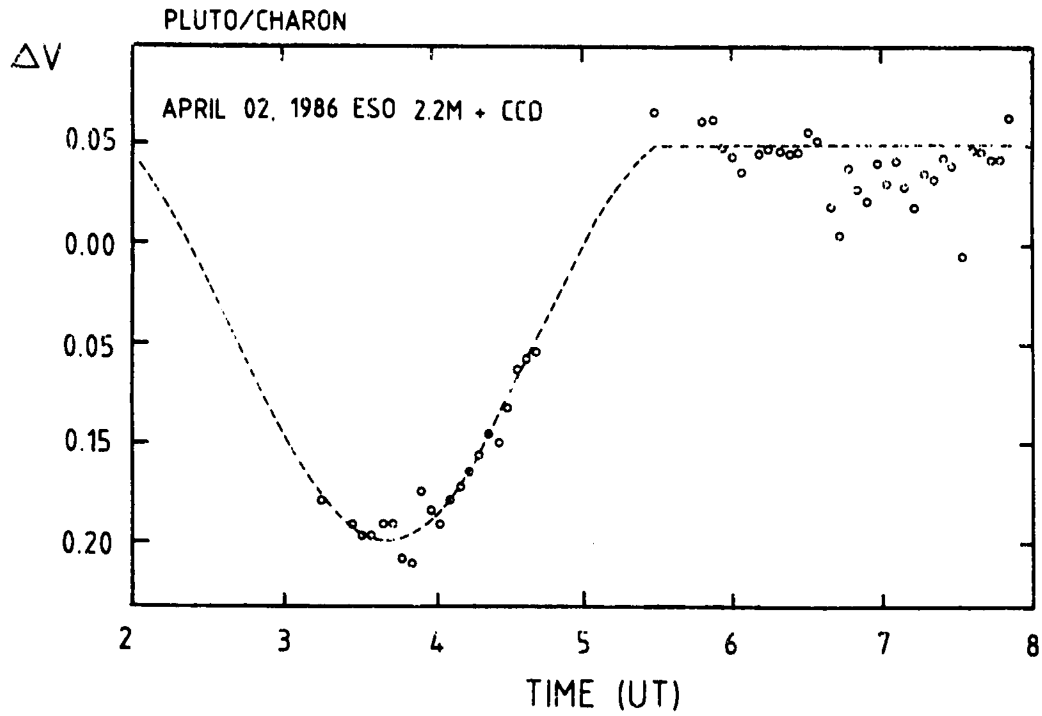


Figure 5.1: **Eclipse of Pluto on April 2, 1986.** The figure shows the light curve (time vrs. magnitude (logarithmic intensity)), as observed during an eclipse when Charon passed in front of Pluto on April 2, 1986. The dashed curve shows the light variation predicted by the best fitting geometric and photometric parameters, that is those mentioned in the text. (PR 09/86)

5.1 First Accurate Determination of the Sizes of Pluto and its Moon

(**PR 09/86**; 5 November 1986; For immediate release)

For the first time, an accurate and direct determination of the diameters of the outermost planet Pluto and its moon, Charon, has been made. On the basis of measurements of light changes during eclipses, Pluto was found to have a diameter of 2200 ± 140 km. Charon is approximately half the size; the diameter is 1160 ± 100 km. Charon moves in an almost perfectly circular orbit around Pluto; the orbital period is 6.38 days and the mean distance is 19400 km.

The fundamental observations were made by astronomers Manfred Pakull and Klaus Reinsch from the Institute for Astronomy and Astrophysics of the Technical University, West Berlin, with telescopes at the ESO La Silla observatory. In April 1985, they used a 90 cm telescope to show the absence of eclipses, but one year later, they observed two well-defined eclipses with a 1.5 m and a 2.2 m telescope. On April 2, 1986, Charon passed in front of Pluto (see the figure), and on April 18, Pluto passed in front of Charon. After careful evaluation of the data, the results have now become available. At the time of the observations, Pluto and Charon were about 4300 million km distant from the Earth.

The shapes of the light curves reflect the geometry of the Pluto/Charon system. For instance, with the orbit of Charon accurately known, the total duration of an eclipse is a measure of the sizes of the two bodies. The "solution" of light curves in order to learn the underlying properties of a double system is a well known problem in astronomy, mainly in connection with the study of double stars.

The opportunity to perform these measurements occurs only once every 124 years, when the Earth is near the plane that is defined by Charon's orbit around Pluto. From the presently derived sizes, it is estimated that further observations of eclipses will be possible until 1989. Earlier estimates of Pluto's diameter were significantly larger; soon after its discovery in 1930, a diameter around 6600 km (only a little less than Mars) was surmised. Before the observations of Pakull and Reinsch, the best estimate (from speckle interferometry) was in the 2600 - 4000 km range. Thus, the new determination puts Pluto at a smaller size, but still at least twice as big as the largest known minor planet, but smaller than the Earth's Moon and also than some of the moons of the outer planets.

With the currently accepted mass of Pluto, about 450 times less than that of the Earth, the mean density derived from the measured diameter is 2.1 ± 0.5 g·cm^{-3}, similar to some of the icy moons of the outer planets, including the Neptunian moon Triton. Some astronomers think that Pluto may be an escaped Neptunian moon. The "albedo", that is the reflectivity of the surfaces of Pluto and Charon, is now of the order of 0.5 for both objects.

A summary of the results obtained by Drs. Pakull and Reinsch is being published in the *Circulars of the International Astronomical Union* and a more detailed paper is being submitted to a professional journal.

5.2 Long Lost Planet Found Again

(**PR 10/86**; 4 December 1986; For immediate release)

An unusual "astro-detective" investigation came to a successful conclusion today, when a long lost planet in the solar system was finally found again. This planet which carries the name "MALLY" and the number "1179" had been missing for 55 years, and was last seen in 1931. Its faint image was now identified on photographic plates obtained with the ESO Schmidt telescope during a dedicated search programme. The accurate orbit of MALLY in the solar system[1] has now been determined, ensuring that MALLY will never be lost again. This work was carried out by Drs. Lutz Schmadel of the Astronomisches Rechen-Institut in Heidelberg, FRG, and Richard M. West of the European Southern Observatory.

In addition to the nine *major planets* in the solar system (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto), there are numerous *minor planets (asteroids)*, most of which move in elliptical orbits well outside the Earth's orbit. A few cross the Earth's orbit and may possibly collide with the Earth in a distant future. By late 1986, more than 3500 minor planets, with diametres from a few hundred metres to several hundred kilometres, have been registered and given a number. Their orbits have been determined with great precision, so that their positions in the sky are well known at all times. Most of them have also received a name by the astronomers who discovered them.

Unfortunately, a few of these planets have "disappeared" in the meantime. Minor planet "(1179) MALLY" is one of these. It was discovered on March 19, 1931 by Karl Reinmuth, Staff Astronomer at the Landessternwarte Heidelberg. He first saw the image of MALLY on

[1] MALLY's main data: Approx. diametre: 7 kilometres; Approx. weight: $5 \cdot 10^{11}$ tons; Mean distance from the Sun: 390 million kilometres; Orbital period around the Sun: 4 years and 84 days. Its orbit lies between the planets Mars and Jupiter.

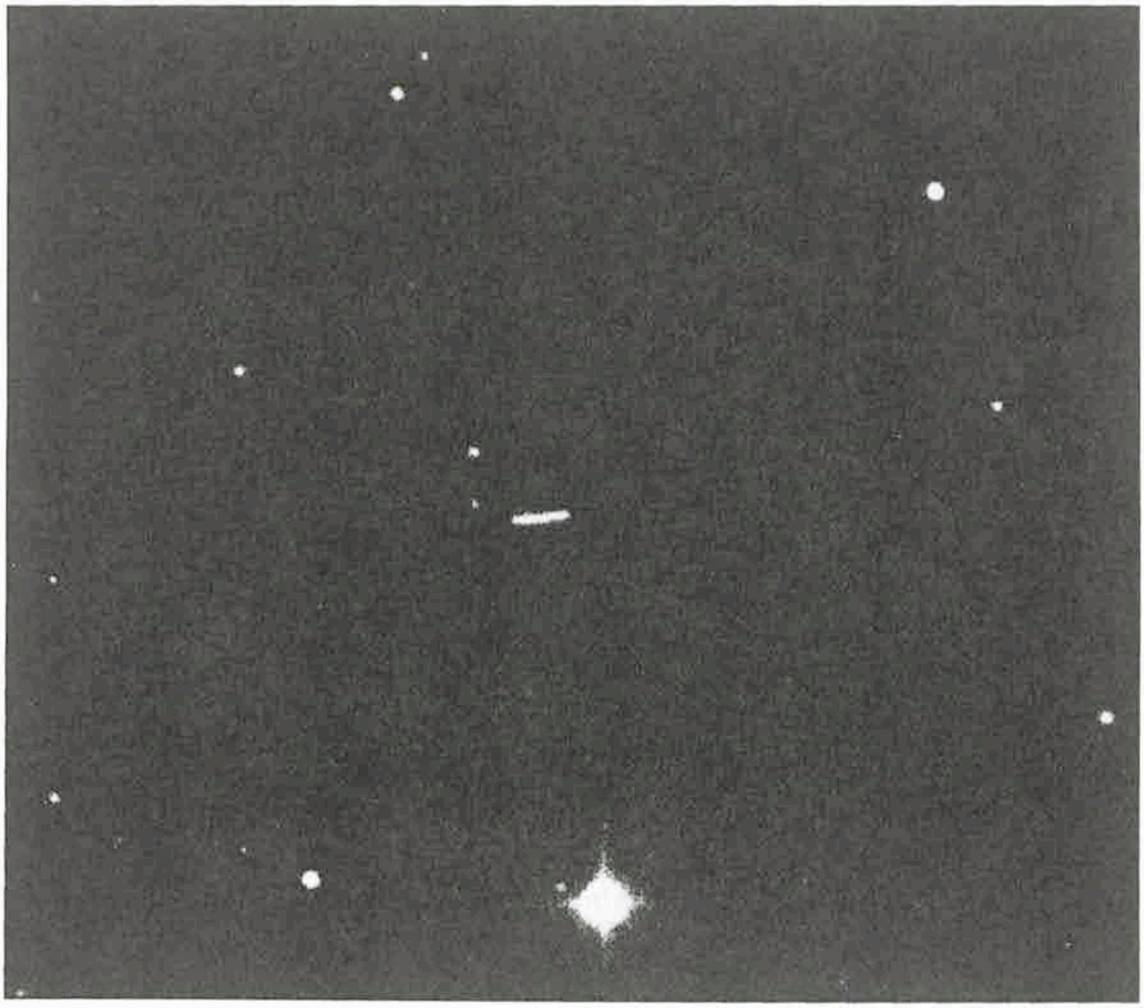


Figure 5.2: The trail of **Minor Planet (1179) Mally**, as seen on a 30-min. blue ESO Schmidt plate obtained on March 12, 1986. (PR 10/86; BW)

a photographic plate, exposed at the 72 cm reflecting telescope and showing a sky field in the constellation Virgo (the Virgin). He measured MALLY's positions on this and some other plates which were obtained until May 13, 1931. From these measurements, it became possible to compute MALLY's orbit in the solar system; it then received a number and Reinmuth gave it its current name (the meaning is not clear).

By chance, nobody observed MALLY during the following years and when an attempt was finally made in 1936, MALLY could no longer be found. Apparently, the orbit which was computed in 1931 was not very accurate and, as an exceptional measure, the International Astronomical Union officially had to declare MALLY as "lost".

In order to solve this long-standing problem and to find MALLY again, Schmadel and West first remeasured Reinmuth's photographic plates with modern techniques, achieving a higher accuracy than what was possible in 1931. A new, more accurate orbit was computed and MALLY's predicted positions in the sky from 1931 to 1986 were determined. Due to the unavoidable, great uncertainty in this prediction, MALLY could still be anywhere within a large sky area by 1986. A substantial number of photographic plates that had been obtained with various telescopes during recent years, were therefore searched, but no images of minor planets were found which could be identified with MALLY. The catalogue of all registered observations of minor planets (more than 400.000) was checked but none belonged to MALLY. Finally, it was decided to obtain new photographic plates of the sky region in which MALLY was expected to be seen in early 1986. These plates were obtained by Hans-Emil Schuster, ESO Staff Astronomer, with the ESO Schmidt telescope in March 1986. Almost 100 images of minor planets were identified on each of these plates.

Extensive computations showed that one of these images might be MALLY. A new orbit was computed, based on the positions from 1931 and the assumed one from 1986. This new orbit indicated that images of MALLY should be visible on three other ESO Schmidt photographs, obtained for another astronomical research programme in December 1979. And indeed, such images were found at the expected places. Finally, Schmadel and West also found MALLY images on two plates taken with the Schmidt telescope on Mount Palomar, California, USA, in 1952 and on one plate obtained with the SERC Schmidt telescope at Siding Spring, Australia in 1983. All this evidence definitely proves that MALLY has been found again, after having been missing for no less than 55 years.

With the recovery of MALLY, only five minor planets are still "lost". They are "(473) NOLLI" (last seen in the year 1901), "(719) ALBERT" (1911), "(724) HAPAG" (1911), "(878) MILDRED" (1916) and "(1026) INGRID" (1923).

5.3 Important Events in the Southern Sky

(**PR 07/87**; 14 May 1987; For immediate release)

In these days, northern astronomers have reason to envy their colleagues in the south. By chance, the two main events in observational astronomy at this moment both occur deep in the southern sky and they can therefore not be observed from the astronomical centres in the northern hemisphere.

These are the occurence of the brightest supernova since 383 years, SN 1987A in the Large Magellanic Cloud (LMC)[2] and the relatively close approach to the earth of naked-eye

[2] see ESO Press Releases 04/87, 05/87 and 06/87.

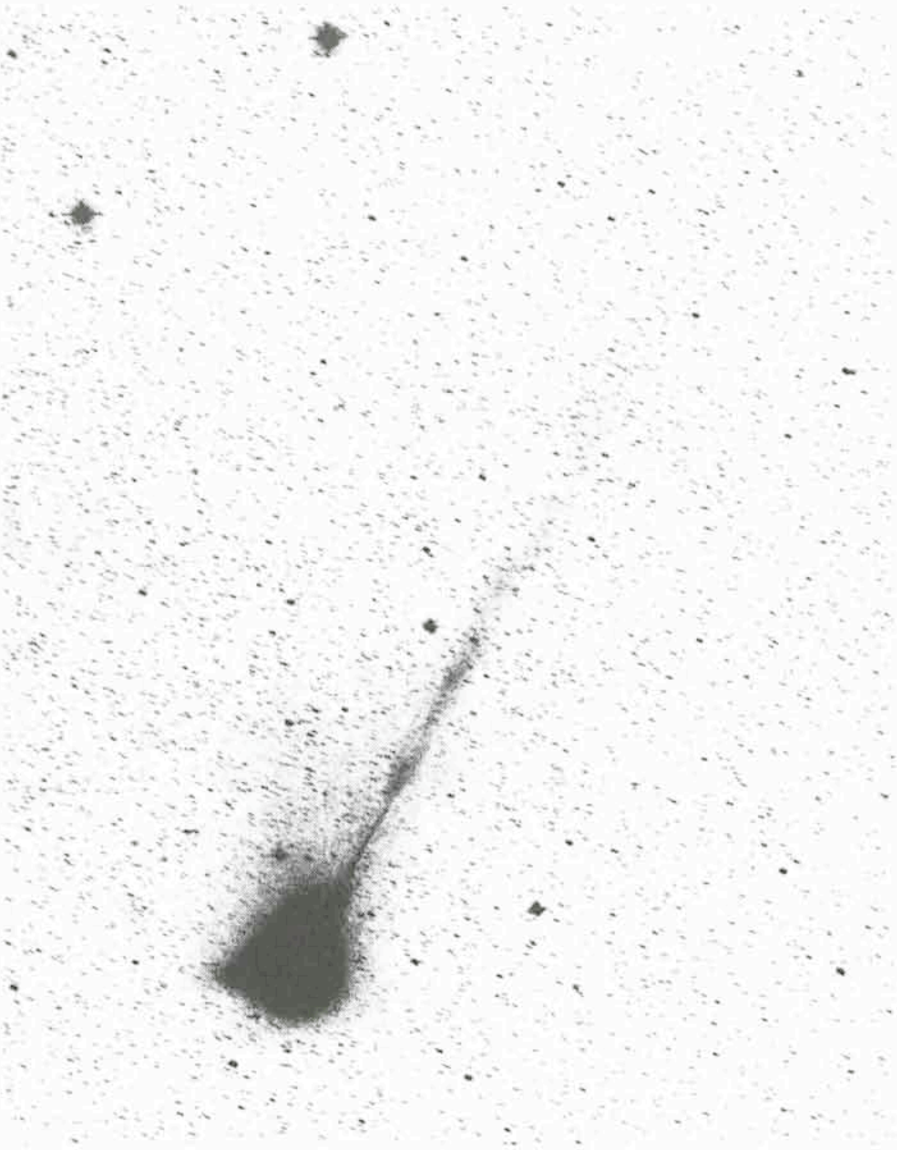


Figure 5.3: **The long ion tail of Comet Wilson.** This photo of Comet Wilson was obtained with the ESO 1 m Schmidt telescope on March 28, 1987, three weeks before its closest approach to the Sun (perihelion). It shows the development of a long, weak ion tail, consisting of ionized atoms and molecules which are pushed away from the coma (comet head) by action of the solar wind. This straight ion tail measures about 3 degrees, corresponding to about 11 million km (projected) and points towards southwest. Note also the streamers near the coma. A short, stubby dust tail is seen towards north (to the left in this picture). On this day, the distance to the earth was 210 million kilometres. The comet was situated in the constellation Sagittarius and moving rapidly south while approaching the earth. The magnitude of the comet was estimated at about 6.5, that is just too faint to be seen with the naked eye. The stars on this photo are trailed, since the telescope was set to follow the motion of the comet during the exposure. Technical information: 30 min exposure on Kodak IIa-O emulsion behind a GG385 filter (spectral range 385 - 500 nm). Contrast enhanced at the ESO photographic laboratory and printed as negative (black stars on white sky) in order to better show the faint details. (PR 07/87; BW)

Comet Wilson on May 2, 1987. By a curious coincidence, the two objects were seen only 5 degrees apart on May 3, when the comet moved rapidly across the sky, southeast of the LMC. However, while SN 1987A is situated at a distance of about 180.000 light years, Comet Wilson was only 93.5 million kilometres from the earth.

SN 1987A

This part of the Press Release is printed on page 65.

Comet Wilson

Observations have commenced at La Silla of this comet, which was discovered last year by Christine Wilson at the Palomar Observatory. It would appear that the cautious magnitude predictions were essentially correct and by early May, when it was closest to the earth, the comet reached magnitude 5. Photos are being obtained with the ESO 1 m Schmidt telescope (one accompanies this Press Release) and spectral observations are carried out with the ESO 1.5 m telescope. Moderate tail emissions of CO^+ and H_2O^+ are seen, extending up to about 2 arcminutes from the center.

The observations of Comet Wilson are of particular interest because of the possibility of direct comparison of this "new" comet, which moves in a hyperbolic (open) orbit and therefore never before has been near the Sun, with "old", periodical Comet Halley, an object of much observational attention last year.

5.4 First Picture of New Periodic Comet West-Hartley

(**Photo 01/89**; 30 May 1989; For immediate release)

On May 11, 1989, Richard M. West at the ESO Headquarters in Garching, Fed.Rep.Germany, found a new comet in a photographic plate obtained on March 14 by night assistant Guido Pizarro with the 1-m Schmidt at the ESO La Silla Observatory. The blue-sensitive plate was exposed during 60 minutes and was centered in the southern constellation of Libra.

This "negative" photo is a reproduction from that plate. The comet's head (lower left) of magnitude 17.5 is seen as a condensation in a diffuse halo. Due to the comet's motion during the exposure, it appears as a short trail. A very faint, broad tail stretches across the picture. The round images are stars in our galaxy. The dark, vertical line in the upper left part is an artificial edge mark on the plate. The picture measures 7.9 × 6.4 arcminutes square and North is up and East is to the left.

Since only a single plate was available, it was not possible to determine with certainty whether the direction of the motion was North-East or South-West. The failure to find the comet on a plate taken in late April with the U.K. Schmidt at the Siding Spring Observatory, Australia, at first seemed to indicate that the South-West possibility was less probable.

However, on May 28 Malcolm Hartley accidentally discovered a comet on a survey plate taken by S. M. Hughes with the U.K. Schmidt, about 15° West-South-West of the sky field shown on the photo. It was quickly realized that this object was identical with the comet seen earlier by West. A preliminary orbital computation by Brian Marsden of the IAU Central Bureau for Astronomical Telegrams indicated that it moves in an elliptical orbit with a period

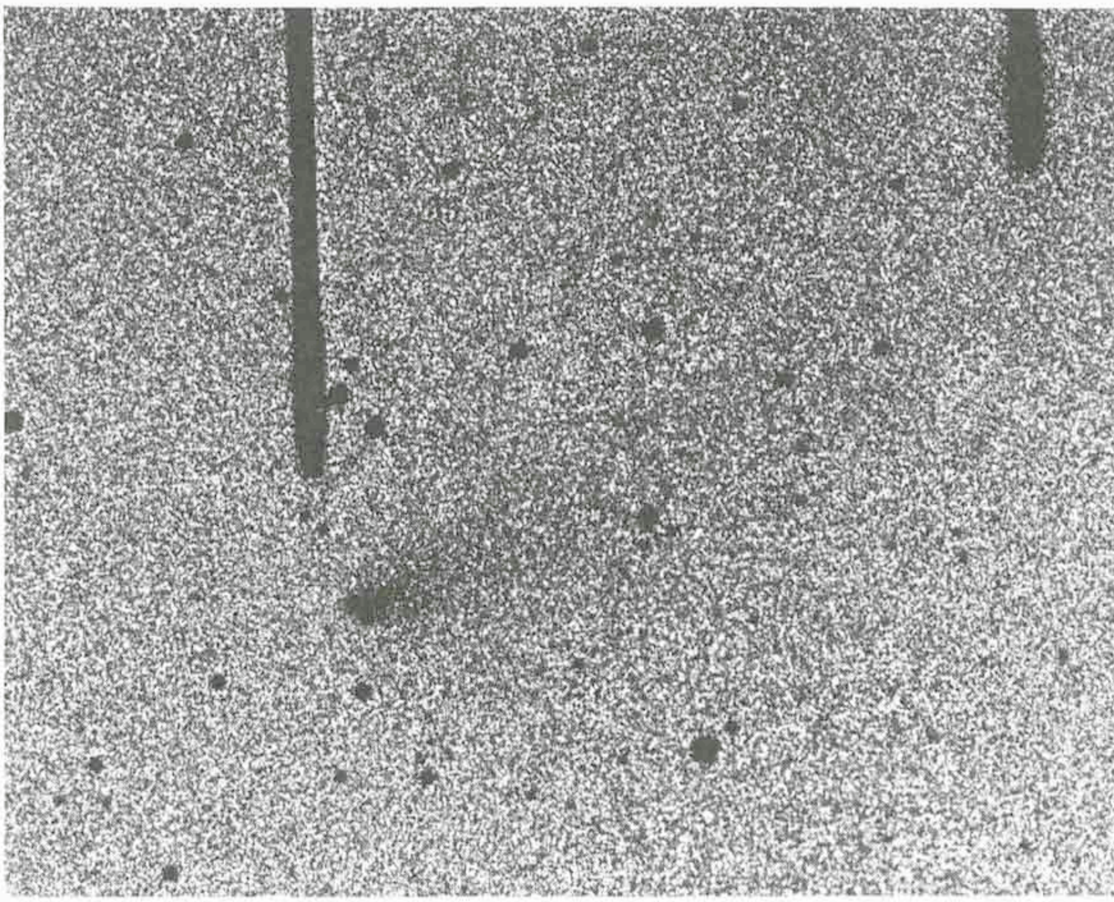


Figure 5.4: **Discovery image of comet "P/West-Hartley (1989k)".** (Photo 01/89; BW)

of about 6.6 years. It passed its perihelion (the point nearest to the Sun) in early October 1988 at a distance of about 360 million kilometres.

According to astronomical custom it was named after the two astronomers who discovered it independently. It has also received the preliminary designation "1989k", indicating that it is the eleventh comet which was discovered or recovered since the beginning of this year.

From the preliminary orbit it is now known that the comet was about 280 million kilometres distant from the Earth when this photo was obtained. The projected tail length was about 4 arcminutes, or $\sim 300,000$ kilometres.

5.5 Comet Austin Develops a Long Tail

(**PR 04/90**; 2 March 1990; For immediate release)

Professional and amateur astronomers all over the world are excited about the prospects of seeing a really bright comet during the coming months. A newly discovered comet, known by the name of the amateur who first saw it, is now getting brighter each day. Observations are made almost every night at the ESO La Silla Observatory and elsewhere in order to follow the development of the comet and also to try to predict the maximum brightness which the comet will reach by mid-April this year.

Comet Austin - a very large comet

When Comet Austin was discovered by New Zealand amateur Rodney R.D. Austin on December 6, 1989, it was already obvious that it must be an unusually large object. At that time the comet was still more than 350 million kilometres from the Sun and yet it was so bright that it was seen as an 11th magnitude object (that is, 100 times fainter than what can be perceived with the unaided eye).

More observations were soon made, establishing the comet's orbit and it was found that it will pass through its perihelion (the point of its orbit where it is closest to the Sun) on April 9, at a distance of about 53 million kilometres, inside the orbit of Mercury, the planet closest to the Sun.

Thereafter it will move outwards again and, by good luck, it will come within 38 million kilometres of the Earth on May 25. It will be well situated in the sky for observation from the northern hemisphere after April 20, when it can be seen low above the NW horizon, just after sunset, and even better above the NE horizon, shortly before sunrise. It is expected that Comet Austin will then have developed a tail which should be easily observable and provide spectators with a grand celestial view.

How bright will Austin become ?

One important question worries the astronomers. How bright will Austin actually become ? Will it - according to the most optimistic predictions - become as bright as the brightest stars in the sky ? Or will it "stall", much short of this goal, like the ill-famed Kohoutek comet in 1974 ?

At the centre of a comet is a "nucleus", a big chunk of ice and dust, with a diameter from a few hundred metres to several tens of kilometres. The diameter of the nucleus of Comet Halley was about 15 kilometres and that of Austin appears to be even larger. When cometary nuclei come close to the Sun, their surface ices evaporate due to the intense solar light. A surrounding cloud is formed - it is known as the "coma" - and also a tail that points away from the Sun.

A comet's brightness is determined by the amount of gas and dust in this cloud which in turn depends on the rate of evaporation from the nucleus. This rate is very unpredictable and accordingly, so is the comet's brightness. When theoretical predictions are uncertain, only observations can (perhaps) yield an answer.

Observations at ESO

For this reason, observations of Comet Austin have been carried out by ESO staff astronomers at the La Silla Observatory during the past months.

In concordance with observations elsewhere, a preliminary conclusion is that Comet Austin does have a good potential to become bright, but also that its current brightening, as it comes closer to the Sun, is "running slightly behind schedule". This is based on accurate photometric observations, carried out with the automatic Danish-SAT 50 cm telescope, accurately measuring the rate of brightening from night to night.

On the other hand, spectra of Comet Austin, obtained with the 1.52 m spectrographic telescope at ESO in mid-February, already show the strong emission of many different gas molecules in the coma cloud around the nucleus. Direct images from the 3.5 m New Technology Telescope in late January also showed a strong jet of dust particles, emanating from the nucleus. These observations clearly indicate that the evaporation process is well under way.

Finally, and rather significant, is the recent detection of a long tail of ions (electrically charged atoms) stretching more than 2 degrees in the direction away from the Sun. It was first seen on a photographic plate obtained with the ESO 1 m Schmidt telescope on February 25 under difficult observing conditions in the evening twilight, low above the horizon. A reproduction of this plate accompanies this Press Release.

However, another Schmidt photograph, obtained the day after, showed a much shorter tail. Thus the one seen on the photo was of brief duration and was probably caused by momentary interaction with a burst of rapid particles in the solar wind, not unusual at this time of maximum solar activity.

Predictions

The orbital computations indicate that Comet Austin appears to be a "new" comet, now approaching the Sun for the first time ever. The behaviour of "new" comets is much more difficult to predict than that of "periodic" comets who move in closed orbits and regularly pass near the Sun, like Comet Halley.

It is believed that new comets are covered by a thin layer of ices which begins to evaporate, already at a large distance from the Sun. Some of them may therefore be rather bright while still far from the Sun. However, when the deposit of ice is all gone, the brightness stalls; this is the most likely explanation for Comet Kohoutek's performance.

It remains to be seen how Comet Austin will behave. In the best case it could reach magnitude -1 to -2 and rival the last bright comet, Comet West in 1976. It is perhaps more likely that it will reach magnitude 0, that is the same brightness as the brightest stars. In late April, when it is best visible from the northern hemisphere, it would then have magnitude 2, about as bright as the Polar Star. Presently, the most pessimistic predictions would put it at magnitude 2 at maximum, and 3.5 in late April.

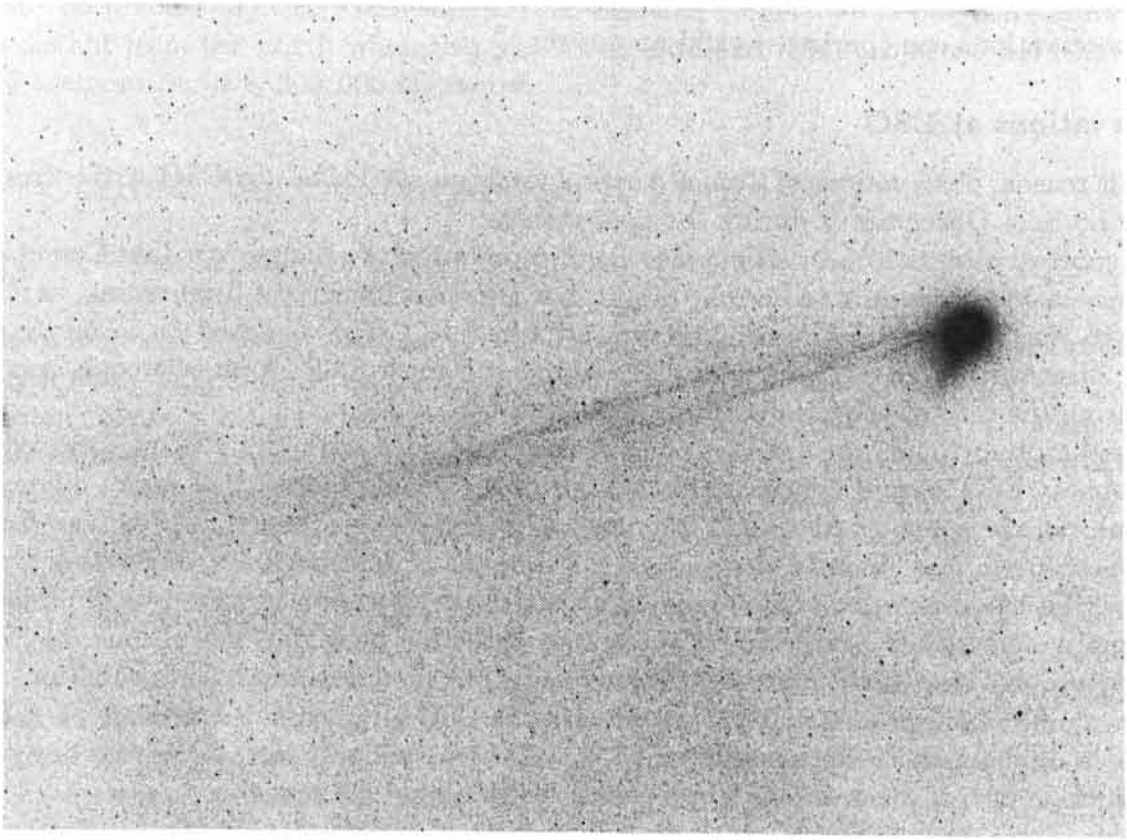


Figure 5.5: **Comet Austin develops an ion tail.** This photo is a reproduction of a photographic plate, obtained with the ESO Schmidt telescope at La Silla in the evening of February 24, 1990 (Feb. 25.0 Universal Time). It was made on blue-sensitive emulsion during evening twilight, only 15° above the horizon. The telescope was set to follow the comet's motion; this is why the images of stars are trailed. The reproduction has been photographically amplified to bring out better the details in the faint tails. There are two tails. The short, stubby one consists of dust particles reflecting the light from the Sun; it measures about 20 arcmin. The narrow ion tail mostly shines in the light of CN and CO_2 molecules; it is more than 2° long. It has the appearance of a double helix with at least two cross-over points and several wiggles. The shape is determined by the deflection of the elctrically charged ions in the interplanetary magnetic field which is in turn influenced by the intensity of the solar wind. Technical information: 6 min. exposure on IIa-O + GG 385 emulsion; observers: Hans-Emil Schuster and Guido Pizarro; photographic work by Herbert Zodet. (PR 04/90; BW)

Figure 5.6: **An unusual view of Comet Austin.** (Photo 01/90; BW)

The best guess, based on the recent ESO observations, is the middle way. If that holds true, Comet Austin will indeed become a grand spectacle with a fine tail on the morning sky in late April. Since it approaches the Earth it will only fade slowly and we should be able to enjoy it all through the month of May.

But, of course, comets are notoriously unpredictable...!

5.6 An Unusual View of Comet Austin

(**Photo 01/90**; 13 June 1990; For immediate release)

This photograph presents an unusual view of the tail structure of Comet Austin.

Most of the dust that is ejected from a comet's nucleus (i.e. the "dirty snowball" at its centre) assembles in a thin "sheet" near the orbital plane in which the comet moves around the sun. This sheet is very thin and is difficult to observe unless it is viewed directly from the side. On June 6, 1990, the Earth crossed the orbital plane of Comet Austin, allowing such a unique, side-on view.

A 10 minute exposure in blue light of Comet Austin was obtained by Guido Pizarro with the 1 m ESO Schmidt telescope at 09:20 hours UT in the morning of June 5, 1990. The image shown here is a photographically enhanced, "negative" reproduction of the original plate by Hans-Hermann Heyer at the ESO Headquarters in Garching. On this date, the comet was seen in front of a rich star field with many dark nebulae, near the galactic centre in the southern constellation of Sagittarius. The stars are trailed since the telescope was set to follow the comet's relatively rapid motion. At this time, Comet Austin was about 51 million km from the Earth and 203 million km from the Sun.

The photo shows clearly the so-called "neck-line" structure, a narrow and very straight feature that stretches at least 2.6 deg (to the plate border) within a broader, diffuse and rather faint envelope. This is sunlight reflected in the thin dust sheet in the comet's orbital plane, here seen almost exactly from the side.

There is also a much weaker sunward spike which can be followed in the opposite direction to about 30 arcmin distance from the nucleus. This unusual feature also represents sunlight reflected in dust particles ejected from the comet, most probably shortly before the perihelion passage in early April.

This ESO photo provides observational confirmation of a theoretical prediction about the brightness and structure of these dust features, made by Italian astronomers M.Fulle (Trieste) and L.Pansecchi (Bologna) in April 1990 and published on IAU Circular 4991. Similar features were seen in Comet Bennett in 1970 and Comet Halley in 1986.

5.7 Comet Levy Observed with the ESO Schmidt Telescope

(**Photos 03/90 and 04/90**; 25 September 1990; For immediate release)

These impressive photos of Comet Levy (1990c), one of the brightest comets in recent years, were obtained with the ESO 1-metre Schmidt telescope at the ESO La Silla Observatory, on September 12 and 14, 1990. On these dates, the comet was 104 and 111 million kilometres from the Earth and 179 and 176 million kilometres from the Sun, respectively. It will reach its perihelion (the point in the orbit which is closest to the Sun) on October 24.

On September 12, a 50 minute exposure was made on a blue-sensitive emulsion and shows an impressive tail, here reproduced in negative, so that the fainter details are better brought out. It measures about 4 degrees and is seen on the background of stars and nebulae of the Milky Way in the southern constellation of Scorpius. Two days later, on September 14, a 32 minute exposure was made, also on a blue-sensitive emulsion. The stars are here seen as small trails, since the telescope was set to follow the comet's motion during the exposure.

Observer: Oscar Pizarro (ESO/La Silla); Photographic work: Hans-Hermann Heyer (ESO/Garching).

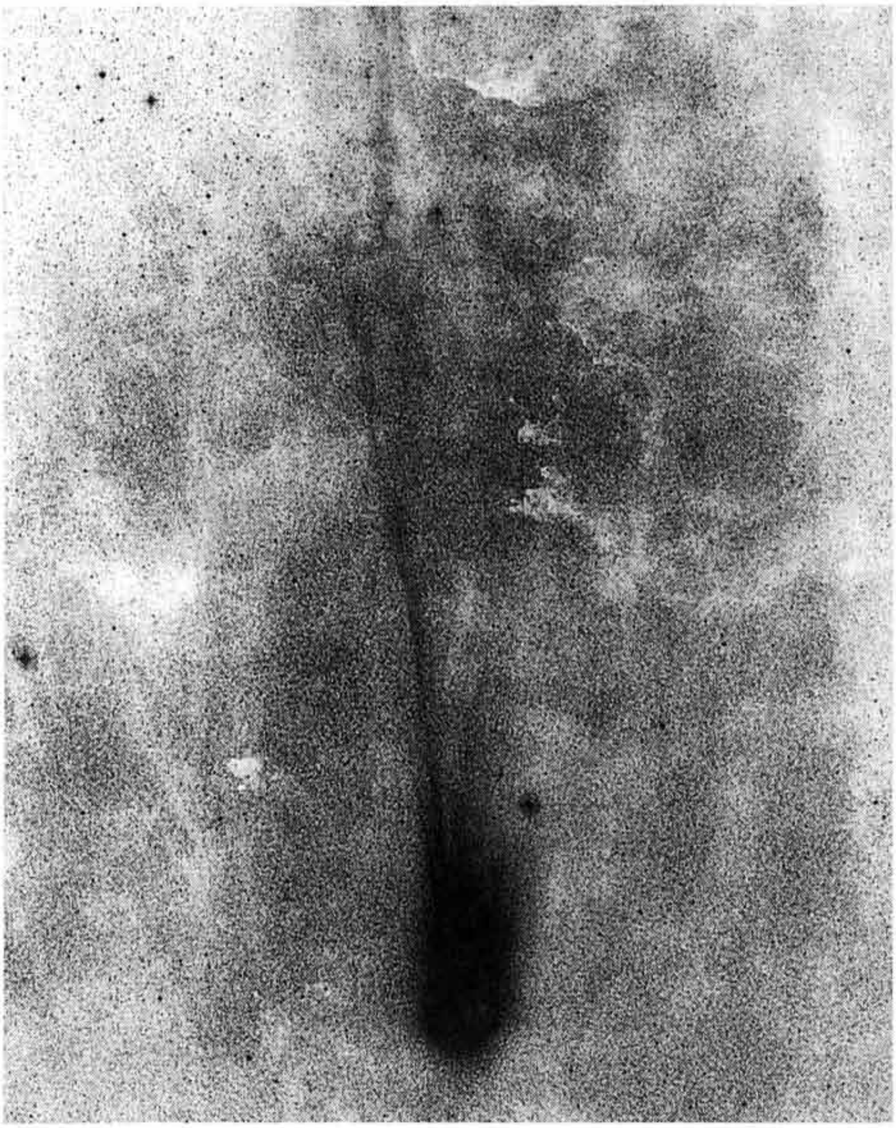


Figure 5.7: **Comet Levy on 12 September 1990.** (Photo 03/90; BW)

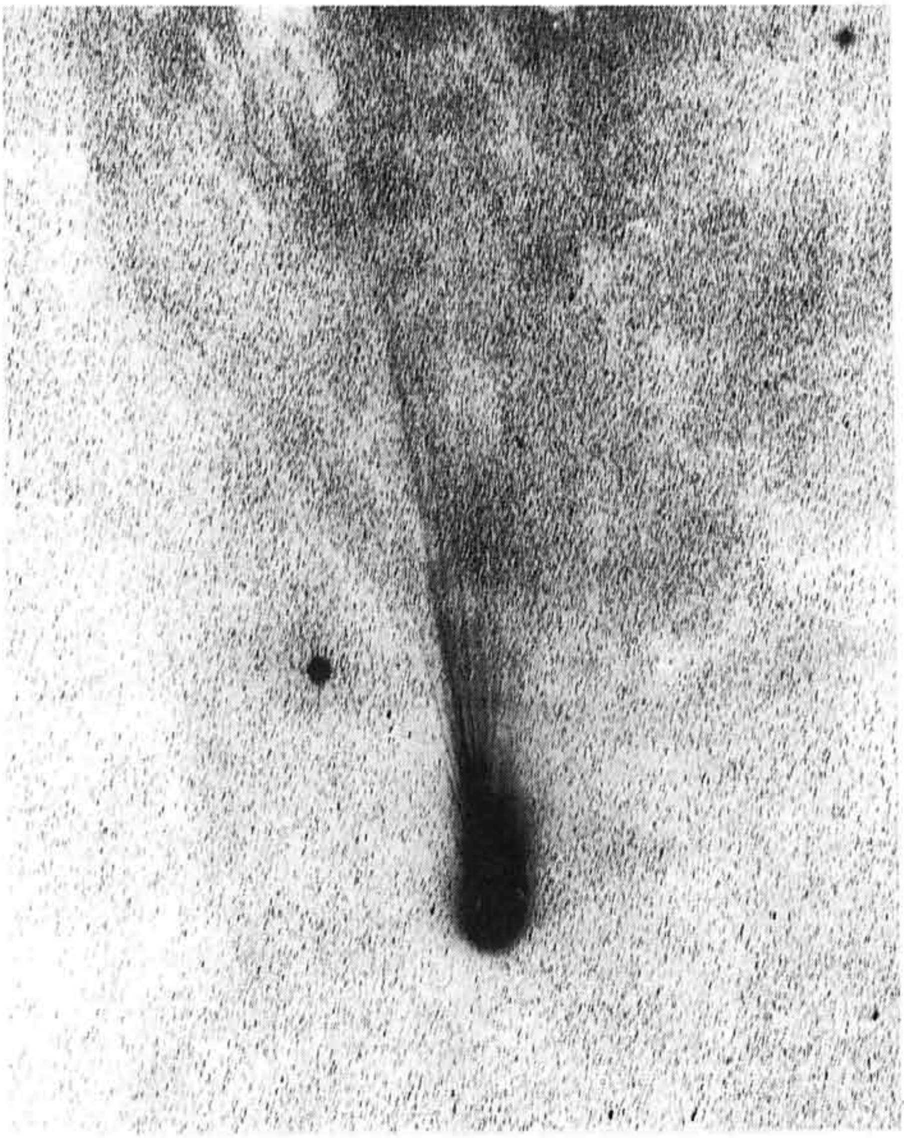


Figure 5.8: **Comet Levy on 14 September 1988.** (Photo 04/90; BW)

5.8 Newly Discovered Minor Planet Named "Portugal"

(**PR 07A/90**; 29 September 1990; For immediate release)

Minor Planet 3933: Portugal

By decree of the International Astronomical Union, a newly discovered minor planet (asteroid) in the solar system, has been given the name **Portugal**, honouring this European country.

The minor planet was first discovered on photographical plates, obtained with the 1-metre ESO Schmidt Telescope, at ESO's La Silla Observatory in the Chilean Atacama desert. It was detected by an ESO astronomer as a short trail among the point-like images of stars; see the attached photo.

The official dedication, which will appear in the *IAU Minor Planet Circulars* on October 4, 1990, reads as follows:

(3933) Portugal = 1986 EN4

Discovered 1986 March 12 by R.M.West at the European Southern Observatory.

Named in honour of the European country whose famous navigators studied the skies with great skill and discovered many new routes to distant shores under southern stars. Its recent association with ESO now opens new, exciting celestial paths for its modern astronomers.

"Portugal" moves in a nearly circular orbit between the planets Mars and Jupiter at a distance of about 485 million kilometres from the Sun, that is about three times further away than the Earth. Its size is about 10 kilometres and one revolution around the Sun takes 2137 days, or nearly 6 years.

The agreement between Portugal and ESO

On July 10, 1990 in Lisbon, the Republic of Portugal and the European Southern Observatory signed a Cooperation Agreement which is aimed at *full membership of Portugal in ESO within the next ten years.*

During this period, the Portuguese Government "will allocate an amount equivalent to a percentage of the annual contribution Portugal would have to pay, if it was already a member of ESO, to the development of research in the field of contemporary Astronomy, so as to permit a future efficient usage of ESO's facilities by Portuguese astronomers". This amount will be spent on a number of infrastructures necessary for the development of Astronomy in Portugal and on technological and scientific training actions related to ESO's activities.

In return, Portuguese astronomers will have access to ESO's facilities during the pre-accession period under scientific conditions similar to those of Member Countries. It is expected that the first proposal(s) will soon be received from Portugal, and that some joint programmes with astronomers from ESO member countries will be worked out before the end of the year.

A Joint Portuguese/ESO Advisory Body is being set up to monitor the development of Portuguese astronomy and its interaction with ESO.

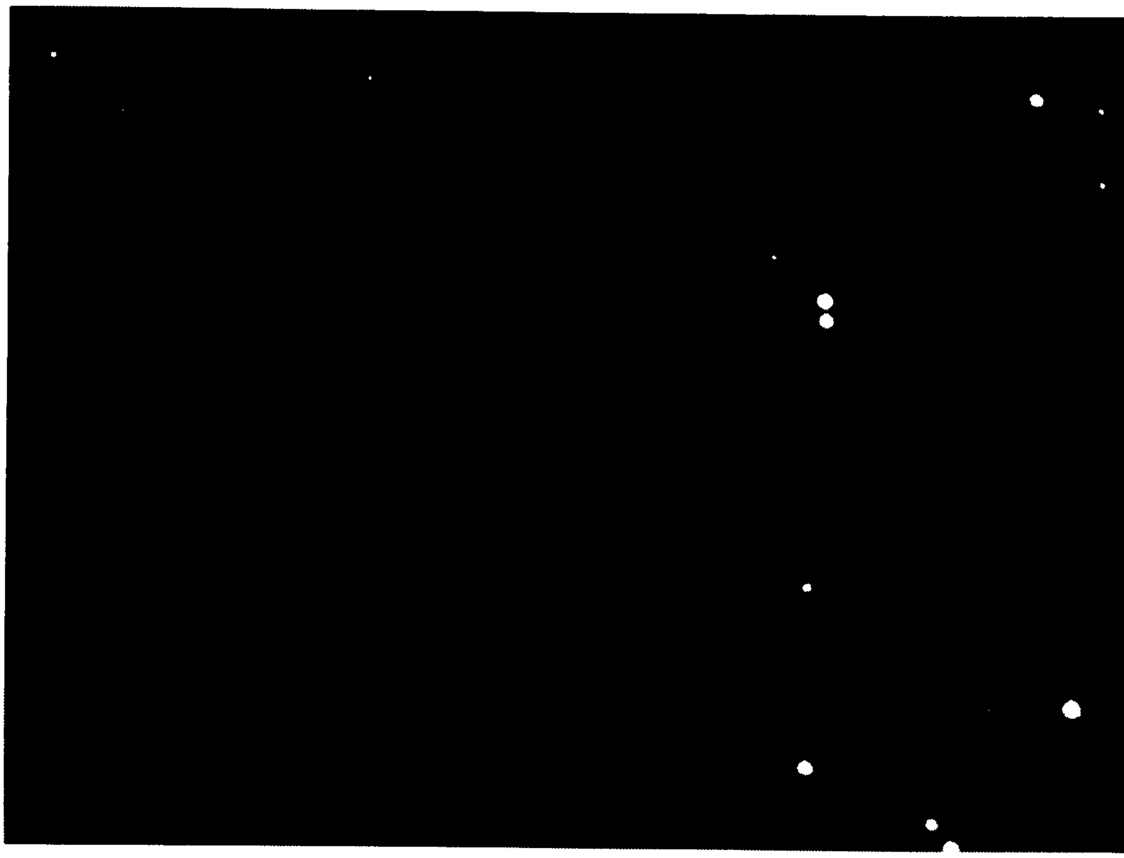


Figure 5.9: This is a reproduction of a small area of the photographic plate on which **Minor Planet (3933) Portugal** was discovered. Due to its orbital motion around the Sun, "Portugal" is seen as a short trail, while the fixed stars in the background are point-like.
The photo was made with the 1-metre ESO Schmidt telescope at the La Silla Observatory on March 12, 1986. The exposure lasted 30 minutes. On this date "Portugal" was seen in the direction of the constellation of Virgo as an object of 17th magnitude, near the celestial equator. The distance to the Earth was 344 million kilometres. (PR 07A/90; BW)

Portuguese astronomy is in a phase of rapid and well considered expansion. With access to the ESO telescopes, more young astronomers in this country will be drawn towards observational studies and their possibilities for fruitful interaction with astronomers in other places will increase.

5.9 The White Eye of Saturn

(**PR 10/90**; 9 November 1990; For immediate release)

A very large, white spot has recently appeared on the giant planet Saturn[3]. It is probably a great storm in the planet's atmosphere, which has been initiated by upwelling of clouds from the lower layers into the uppermost regions. The spot began as a small, white feature in Saturn's northern hemisphere and has since developed rapidly so that it now appears to completely encircle the planet's equatorial regions. "Great White Spots" have been seen on Saturn in 1876, 1903, 1933 and 1960 (see below), but the present one seems to be the biggest of them all.

At this moment Saturn is situated in the southern constellation of Sagittarius and is therefore best observed with southern telescopes. It has been monitored at the ESO La Silla Observatory since early October by Belgian astronomer Olivier Hainaut (on temporary assignment to ESO from Institut d'Astrophysique, Liège, Belgium), together with several other astronomers. Most of the observations have been made with the ESO New Technology Telescope (NTT) and ESO/MPI 2.2 m telescope.

Development of the spot

The new phenomenon was first reported on 25 September 1990 by astronomers at the Las Cruces Observatory in New Mexico, USA, as a white spot at northern latitude +12°. It was watched by many amateur astronomers in various countries as it slowly grew in size to about 20 000 km on October 2. Further observations determined the spot's rotation period to about 10 hrs 17 min, that is somewhat slower than the surrounding atmosphere.

During the next days the spot became longer and longer and by October 10, its length was approximately half of Saturn's visible diameter. After that it continued to expand and on exposures made at ESO from October 23 onwards it encircles the entire planet as a

[3]**Saturn** is the fifth planet from the Sun and the outermost planet known before the advent of the telescope. It moves in a nearly circular orbit around the Sun at a mean distance of 1430 million km; one revolution lasts 29.5 years. Saturn's equatorial diameter is about 120 000 km (9.5 times larger than that of the Earth) and it is significantly flattened towards the poles. The rotation period depends on the latitude; it is more rapid at the equator (about 10 hrs 14 min) than near the poles. Its polar axis is inclined by 29°, i.e. somewhat more than is the case for the Earth (23.5°), and it therefore has pronounced seasons. The surface we observe is not solid, but merely represents the upper layer of a very deep atmosphere, mostly consisting of hydrogen and helium; there are also small amounts of methane and ammonium and possibly other organic substances. Saturn may have a solid core of silicates and other minerals, possibly surrounded by a mantle of metallic hydrogen. The planet emits more energy than it receives from the Sun and must therefore have an unknown source of energy in its interior. It also has a strong magnetic field. Saturn has at least 17 satellites (moons), ranging in size from Titan (diameter 5150 km) to the small Calypso and Telesto (~ 35 km). However, Saturn is perhaps most famous because of its ring system which consists of small particles that orbit the planet in many hundreds of well defined rings, whose thickness is probably only a few tens of metres. The largest, dark gap in the rings is known as "Cassini's division", after the French astronomer who first saw it in 1675.

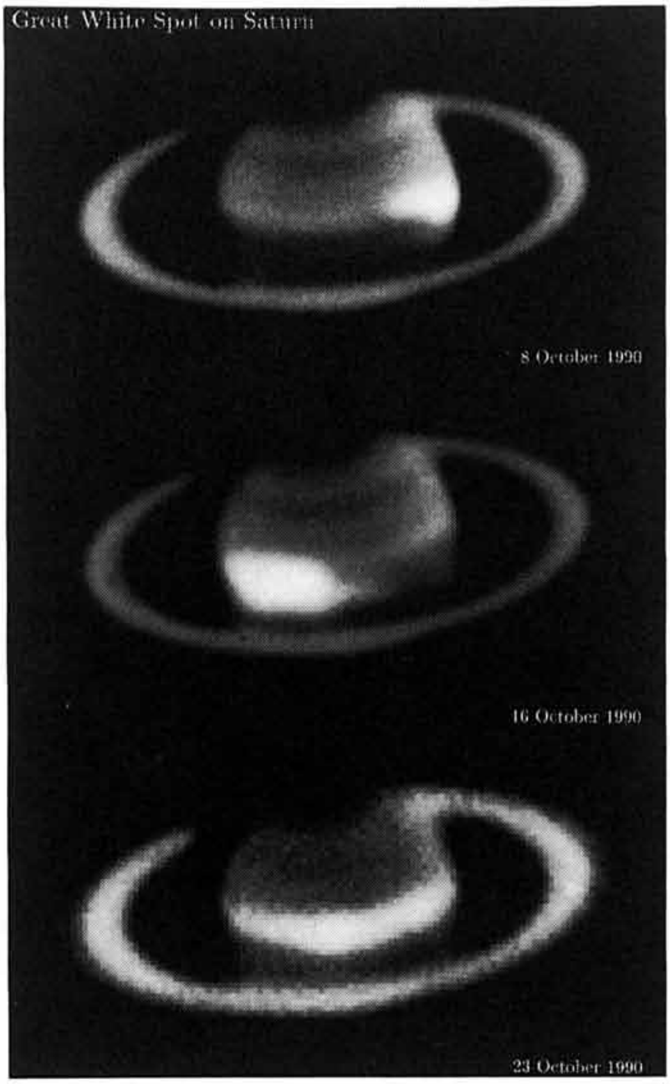


Figure 5.10: **The Great White Spot on Saturn.** This series of three exposures from the ESO La Silla Observatory was made in the course of the study of the newly detected spot in the northern hemisphere of the giant planet Saturn. It shows the development of the spot over a period of two weeks. Between October 8 and 16, the spot grew significantly in size; it became longer and probably also brighter. After October 16, it rapidly expanded to reach all the way around the equator of the planet. The images were made in blue light in mediocre seeing conditions with three different instruments, all equipped with CCD detectors. A computer enhanced version of the October 16 image is available in B/W or in false-colour on request. Technical information: October 8: UT 0 hrs 0 min; ESO NTT + EFOSC II, Johnson-U filter, exposure 1 sec; October 16: UT 0 hrs 0 min; ESO NTT + EMMI, 468 nm filter, 6 nm wide, exposure 1 sec; October 23: UT 0 hrs 1 min; ESO/MPI 2.2m + CCD camera; 388 nm filter, 3 nm wide, exposure 10 sec; observers O. Hainaut and S. D'Odorico, both ESO. Saturns disk measures about 16 arcseconds across. (PR 10/90; BW)

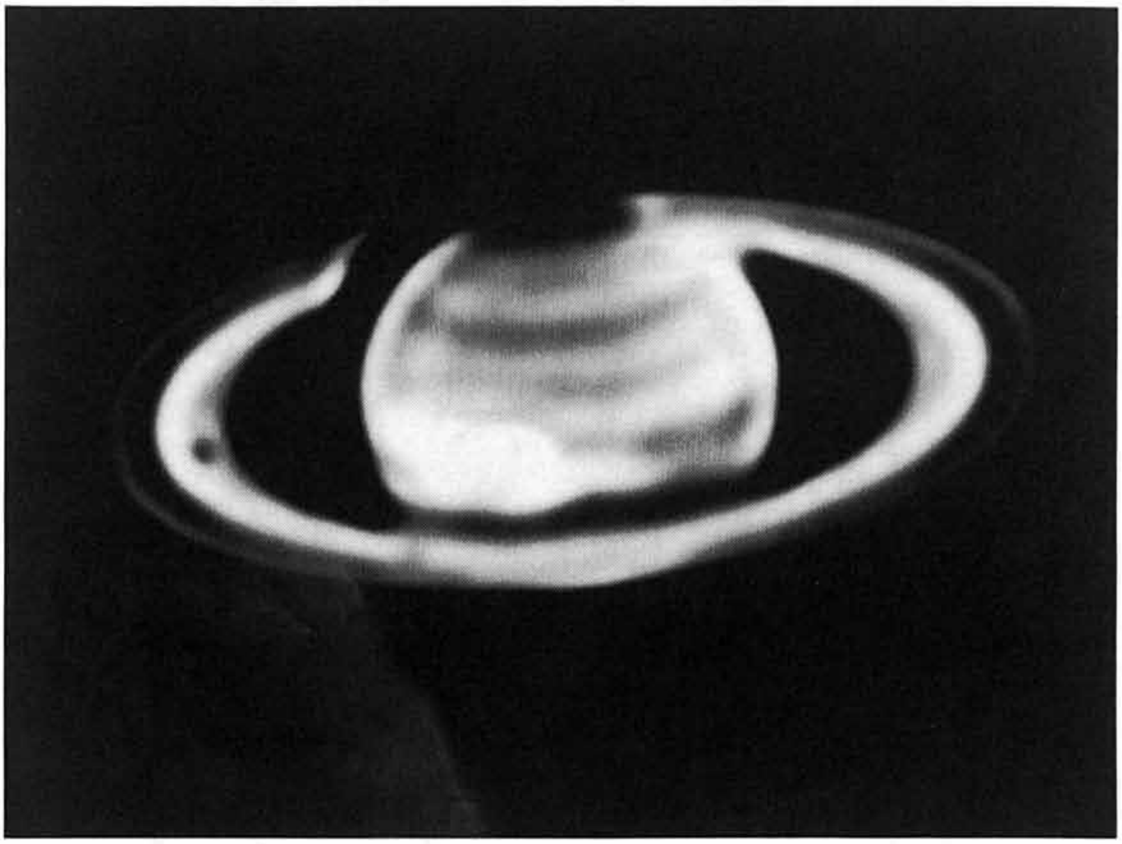


Figure 5.11: This picture of **Saturn and the Giant White Spot** which was recently detected on its surface was obtained by O. Hainaut and S. D'Odorico with the ESO New Technology Telescope on October 16, 1990 at UT 0 hrs 0 min. It is a 1 sec exposure through a 6 nm wide filter, centered in the blue spectral region at 468 nm. North is approximately up and East is to the left. The seeing conditions were mediocre (about 1.1 arcsecond), and the reproduction shown here was subjected to computer processing by D. Baade at the ESO Headquarters, according to an advanced algoritm, developed by L. Lucy; this has resulted in a sharpening to about 0.4 arcseconds. It shows the structure of the spot which on this day extended to the equator and had already grown significantly in length. The various bands are also well visible. The round spot on the rings to the left is a CCD artifact. (PR 10/90; BW)

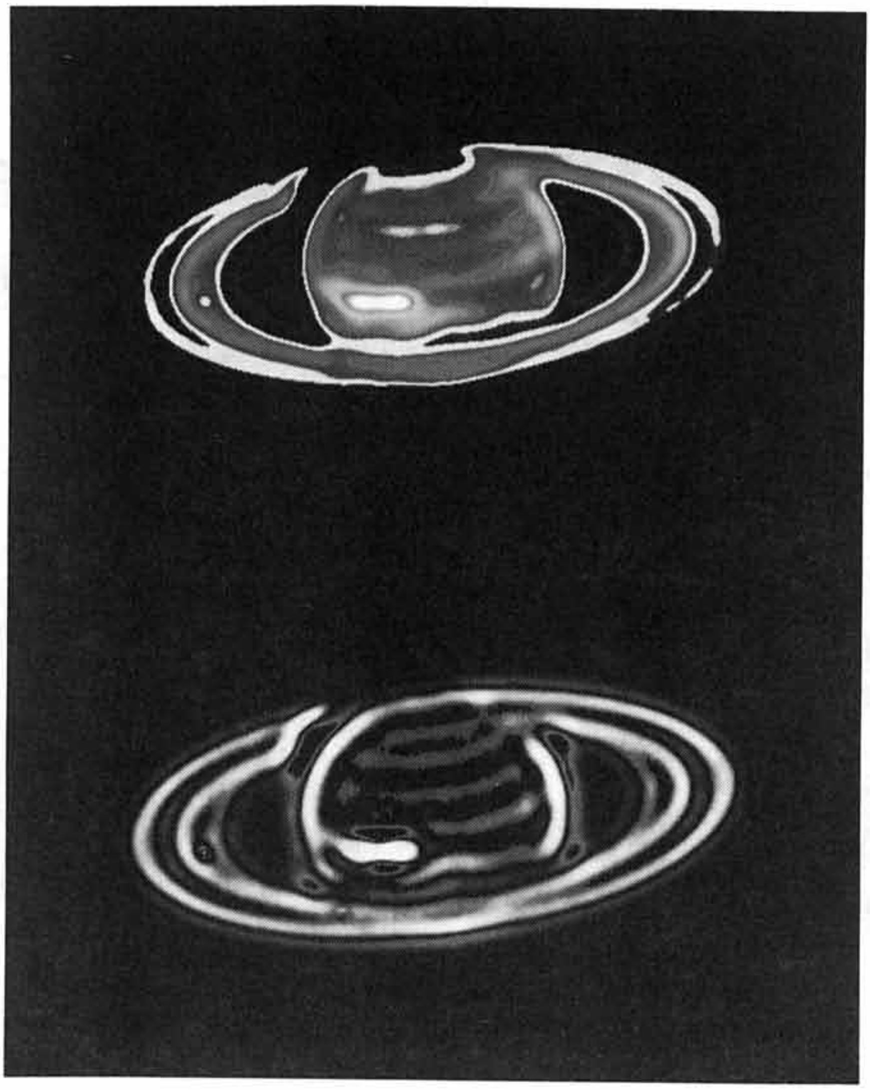


Figure 5.12: This picture of **Saturn and the Giant White Spot** was obtained with the ESO New Technology Telescope on October 16, 1990 at UT 0 hrs 0 min. It is a 1 sec exposure through a 6 nm wide filter, centered in the blue spectral region at 468 nm. North is approximately up and East is to the left. The seeing conditions were mediocre (~ 1.1 arcsecond), and the false-colour reproductions shown here have been subjected to computer processing by D. Baade at the ESO Headquarters, according to an advanced algoritm, developed by L. Lucy; this has resulted in a sharpening to about 0.4 arcseconds. The upper image shows the sharpened image, while the lower one has been further "flattened" by subtraction of the original image from the "sharpened". It is seen that the spot has a double structure. It extends to the equator and has already grown significantly in length. The various atmospheric bands are also well visible. (PR 10/90; Colour)

bright equatorial band. At the same time, several new, intensively bright spots have been sighted inside the larger feature; they are now being followed with great interest. There is no indication yet that the phenomenon has started to fade away.

Earlier spots

There are less than two dozen reports about spots on Saturn during the past 200 years, but only four of these were "Great White Spots" which lasted more than a couple of weeks and none appears to have approached the enormous size of the present spot. We are therefore witnessing a very rare event.

The first known Great White Spot was detected in December 1876 by American astronomer Asaph Hall in Washington D.C. and the next one was found in June 1903 by E.E. Barnard with the 40-inch refractor at Yerkes Observatory, near Williams Bay, Wisconsin. The third and fourth were both found by eagle-eyed amateurs; in August 1933 by Will Hay in England, and in March 1960 by J.H. Botham in South Africa. All of these spots were seen in the northern hemisphere of Saturn: those in 1876 and 1933 at about the same latitude as the present one, while the two others were further north at +40° (1903) and +58° (1960).

What is a "Great White Spot" ?

Detailed observations of the giant planets Jupiter and Saturn have been made since the invention of the astronomical telescope in the early 17th century. The "meteorological" studies of their atmospheres took a great stride forward during the flybys of the Pioneer and Voyager spacecraft, from which accurate measurements were made at close distance.

It has long been known that the "surface" of Jupiter shows many more bands and whirls than that of Saturn; this is now explained by the presence in the Saturnian atmosphere of a high layer of aerosols (small solid particles) and haze (liquid drops) which hide the view of the patterns of streams and turbulence below.

The five Great White Spots have appeared with amazing regularity, about once every thirty years, that is with the same period as the orbital revolution around the Sun. Moreover, these spots have all developed near the moment of Saturnian "mid-summer" in the northern hemisphere, when the insolation (amount of solar energy received) is the greatest possible here. It is therefore obvious that there the emergence of large spots in the north must be triggered by some mechanism that is related to heating of the atmosphere.

Most planetary astronomers agree that the Great White Spots are upwellings from the lower atmosphere, whereby large clouds move upwards and become visible when they penetrate the uppermost, hazy layers. They resemble the towering cumulonimbus clouds often seen in the Earth's atmosphere. However, the lifting mechanism is not yet known; one possibility is that their upward motion is due to the release of heat by water condensation, perhaps in combination with strong updrafts from sublimating ammonia grains.

The spots become longer, as the clouds are carried along by strong winds in the upper atmosphere. Eddies and whirl patterns undoubtedly develop because of the different wind velocities at different latitudes, but due to their smaller size they are very difficult to observe from the Earth. This may imply that the spots, perhaps in particular those which have emerged more recently, are actually gigantic storm centres, just like the Giant Red Spot on Jupiter, that has now been visible for almost 400 years.

Since the Great White Spots on Saturn last much shorter, in the past cases at the most a few months, it will now be very interesting to follow the new one during some time to learn exactly how it disappears. Observations are therefore continuing at ESO as well as at other observatories.

This Press Release is accompanied by two B/W pictures. One shows the development of the 1990 Great White Spot over a two-week period (October 8 to 23); the other is a computer enhanced version of an NTT image, obtained in blue light on October 16; this image is also available on request in a false-colour version (in which the internal structure of the spot is better seen than on the B/W photo).

Chapter 6

Comet Halley

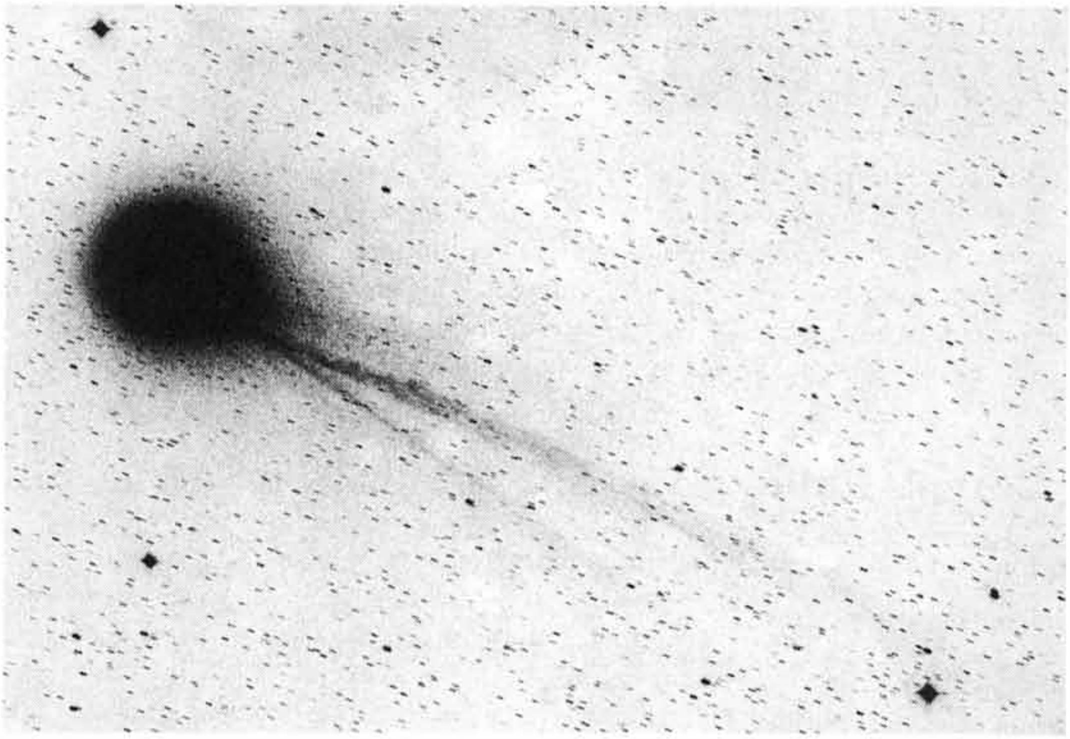


Figure 6.1: **Comet Halley's ion tails** were photographed with the ESO Schmidt telescope on 9 December 1985. (Original scale of the photograph: 1 degree = 12 cm.) (PR 01/85; BW)

6.1 Comet Halley Develops a Tail

(**PR 01/85**; 17 December 1985; For immediate release)

Comet HALLEY was photographed with the ESO 1 metre Schmidt telescope at La Silla on 1985 December 9. The exposure was 10 min on a blue-sensitive emulsion. The telescope was guided on the moving comet. The stars in the field are therefore seen as short trails.

Although Comet HALLEY is somewhat brighter (magnitude 4 on December 12) than originally predicted, it has been slow in developing a tail. This negative picture, which has been somewhat enhanced for clarity, shows two tails pointed towards East (away from the Sun). The thin, very straight tail (the northernmost) is a typical ion-tail, consisting of charged particles, which are pushed away from the comet by the solar wind (charged particles travelling away from the Sun at high speeds). The other ion tail, which is slightly bent and broader, can be followed to a distance of about 2.5 degrees (more than 5 million kilometres) from the comet's head. The bend ("kink") is due to a change in the solar wind direction. Both tails are enveloped in a very faint cloud of dust particles, also released from the comet.

When the picture was taken, Comet HALLEY was about 200 million kilometres from the Sun and 110 million kilometres from the Earth. It is moving south in the sky and is becoming more and more difficult to view from Europe. In early February, it disappears from view, when it passes behind the Sun. It is expected that it can be seen again around February 15.

Many of the ESO telescopes will be used for observations of Comet HALLEY during early 1986.

6.2 Comet Halley Recovered at ESO

(**PR 03/86**; 16 February 1986; For immediate release)

The first observation of Comet Halley after its passage behind the Sun was made at ESO La Silla by ESO Staff Astronomer R.M. West and Belgian astronomer H. Debehogne.

The comet was observed just above the eastern horizon, against a bright sky. The magnitude was around 3, approximately as predicted. This early recovery observation is of great importance for the navigation of the five spacecrafts (from ESA, USSR, Japan) which are now heading towards an encounter with Halley in early March.

6.3 Comet Halley Status; Observations at La Silla

(**PR 04/86**; 18 February 1986; For immediate release)

After the successful recovery of Comet Halley on February 15, at the European Southern Observatory (ESO), observations have been made at the ESO La Silla Observatory every morning since. Accurate positions of the comet continue to be measured and transmitted within a few hours to the spacecraft centers in Darmstadt, Moscow, Tokyo and Pasadena. This is an important contribution to the accurate navigation of the five spacecrafts, including the European Space Agency's GIOTTO, now heading towards an encounter with Halley in early March.

In the morning of February 18, it became apparent that an outburst from the comet nucleus must have taken place within the past 24 hours. On photographic plates from the ESO Double Astrograph, the nucleus was very bright and there were three jets emanating from it. Also bolometric measurements with the ESO 1 metre telescope showed that the comet was unusually bright in the infrared region of the spectrum.

Until now, the comet has only been visible low in the bright morning sky, just above the eastern horizon. It has therefore been difficult to observe the tail. Still, the presence of a one degree tail was seen on February 17 and today observations with the new ESO wide angle CCD Camera, which was specially designed to follow the development of Comet Halley, showed two tails pointed in the direction opposite to the sun.

A group of astronomers from the Ruhr University in Bochum, F.R. Germany, started observations of Halley in different colours with a multi-camera mounting.

The astronomers involved in this major observing effort at ESO observatory are R.M. West, H. Debehogne, T.H. Le Bertre, H. Pedersen, P. Monderen, R. Schultz, W. Celnik, and K. Weisssbauer.

More information and the first pictures can be expected from ESO in a few days' time.

6.4 Observations of Comet Halley at ESO Continue

(**PR 05/86**; 26 February 1986; For immediate release)

February 23 was the last morning when Comet Halley could be seen in a dark sky. During the next two weeks, the moonshine will hamper further detailed observations of the incredibly

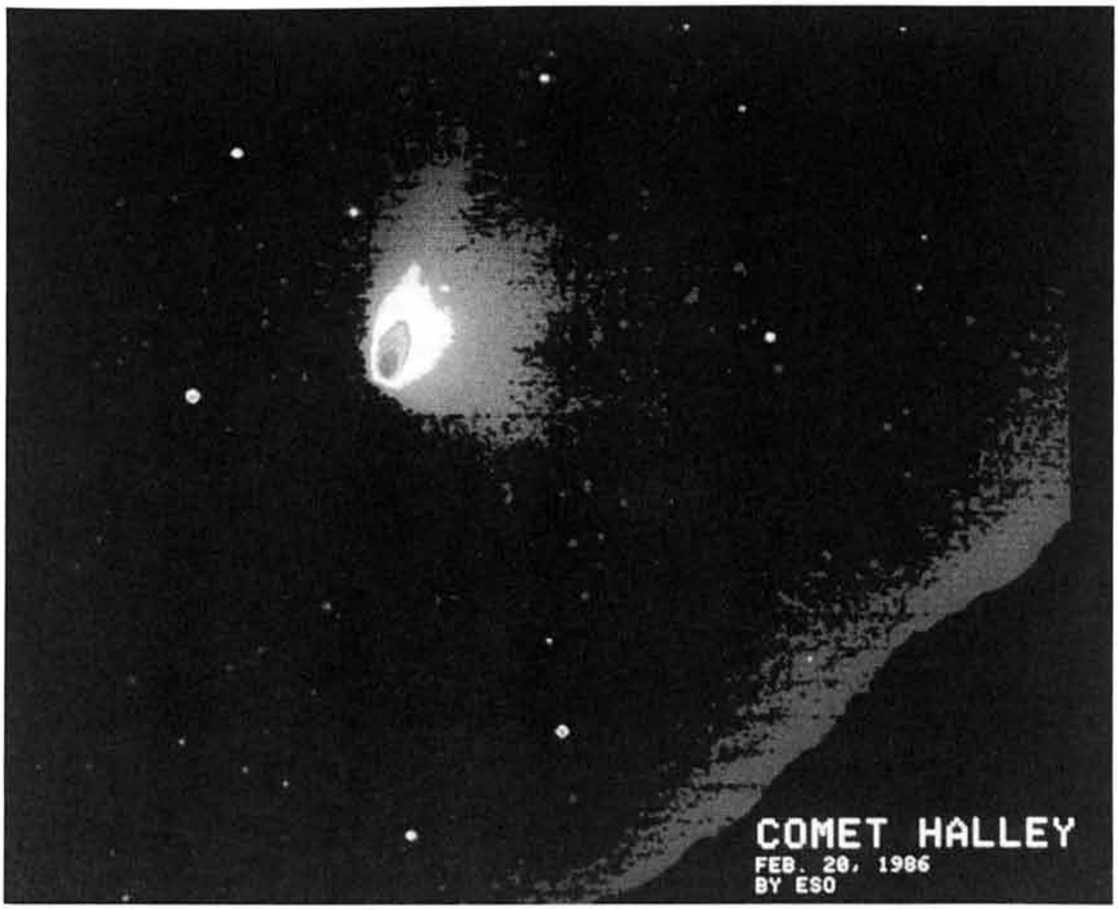


Figure 6.2: **Halley's multiple dust tail.** This false-colour wide-field CCD Picture of Comet Halley was obtained with the ESO special camera sensitive to the 500-1100 nm spectral region. The exposure time was 45 seconds. This is the first picture to show clearly multiple tails of Comet Halley. The ion tails point towards the top of the picture and those to the right (north) are dust tails. Note also the structure in the north-east direction, that is towards the sun. (PR 05/86; Colour)

complicated tail structure which was recently detected at the European Southern Observatory on La Silla.

As a matter of fact, whereas normal photographic equipment has only been able to show two tails, four tails were detected with special equipment at La Silla already last Wednesday, 19 February. Seven tails were identified on Thursday, 20 February and an eighth tail was seen on Saturday, 22 February.

These observations were made with two telescopes, one belonging to the Ruhr University of Bochum, German Federal Republic and the other, which was specially designed for observations of Halley, to ESO.

ESO scientists believe that the additional tails, which point to north and north-east consist of dust which was released from the 6 km nucleus some days ago. The additional tails have a very red colour, indicating that they shine by reflected sunlight. The two major tails towards west are blue and must therefore consist of ions, that is electrically charged particles which are pushed away by the solar wind.

Observations on Sunday morning (23 February) at La Silla indicated that important changes are taking place in the comet. Four tails could be easily recognized even through small telescopes and the appearance of the comet to the naked eye was definitely more impressive than on Saturday morning.

The observations from La Silla have been transmitted daily to the Central Bureau of the International Astronomical Union in Cambridge, Mass., USA. The ESO scientists learned from the Bureau yesterday that, due to unfortunate cloudy weather in most other parts of the world, observations at La Silla during the past nine mornings are among the only ones available which provide full coverage of the important post-perihelion activities of Comet Halley. In particular, the Bureau informed that accurate positions have only been registered from ESO so far and that therefore the navigation of the five spacecrafts on way to Halley has been highly dependent on the ESO data.

Although this passage of Halley will be the faintest one in the 2000 years this famous object has been observed, it appears that the comet is putting on an unexpected display of tails, for the benefit of the many millions of people who are now eagerly awaiting Comet Halley. In the southern hemisphere the best time to see it will be in about 14 days from now, at the time of the New Moon, when the moonlight no longer interferes.

6.5 Comet Halley's Tails

(**Photos 01/86, 02/86 and 03/86**; 6 March 1986; For immediate release)

Comet Halley's multiple tails (February 22)

This spectacular image of Comet Halley, rising above the eastern horizon, was obtained at the La Silla observatory during the morning of February 22. It was made by superposing 6 exposures (total 9 min.) with the wide-field CCD camera which was specially designed for the study of Comet Halley. The image measures 5.5 x 9 degrees across and covers the 500 - 1100 nm spectral region (green near infrared). Each pixel (image element) measures 31 x 31 arc-seconds.

On this date the comet was 99 million kilometres from the sun and 209 million kilometres from the earth. At least seven tails can be discerned. Two ion tails point straight up (towards west). The other tails, pointing toward north and northeast, are rather red and are thought to consist mainly of dust. It was released from the small nucleus which is invisible in this picture. The length of the ion tail is at least 6 degrees, or 22 million kilometres. The very complex tail system was discovered at ESO a few days earlier.

The bright stars at the top are Alpha and Beta Capricorni (the vertical lines are caused by saturation of the detector).

Comet Halley develops 15-degree tail (February 27)

Three days past full moon, when it was difficult to see Comet Halley in the bright sky, this picture was obtained on February 27 at the ESO La Silla Observatory by means of a special wide-field camera. It shows the famous comet as imaged by a CCD detector through an optical filter that suppresses the moonlight in order to make the comet's 15 degree tail visible.

The image was obtained in violet light at 426 nm (half-width 7 nm), centered on the spectral emission of CO+ ions. It therefore shows the distribution of these ions in the tail, as they are pushed away from the comet by the solar wind. Near the comet head several

Figure 6.3: **Comet Halley's multiple tails (February 22).** (Photo 01/86; Colour)

streamers are visible - further upstream the tail broadens and becomes less dense as the ions disperse in interplanetary space. On this date, Comet Halley was at a distance of 196 million kilometres from earth and the length of the tail was at least 50 million kilometres.

Observations continue at ESO to study the evolution of the tail.

Comet Halley's CO^+ tails (March 3 - 5)

These images of Comet Halley's ion tails were obtained on March 3, 4 and 5 by means of the Wide-Field CCD camera, specially installed at La Silla for the purpose of monitoring the spectral emission of CO^+ ions in the tail of this comet. The images were obtained through a narrow filter, centred at 426 nm in the violet region of the spectrum.

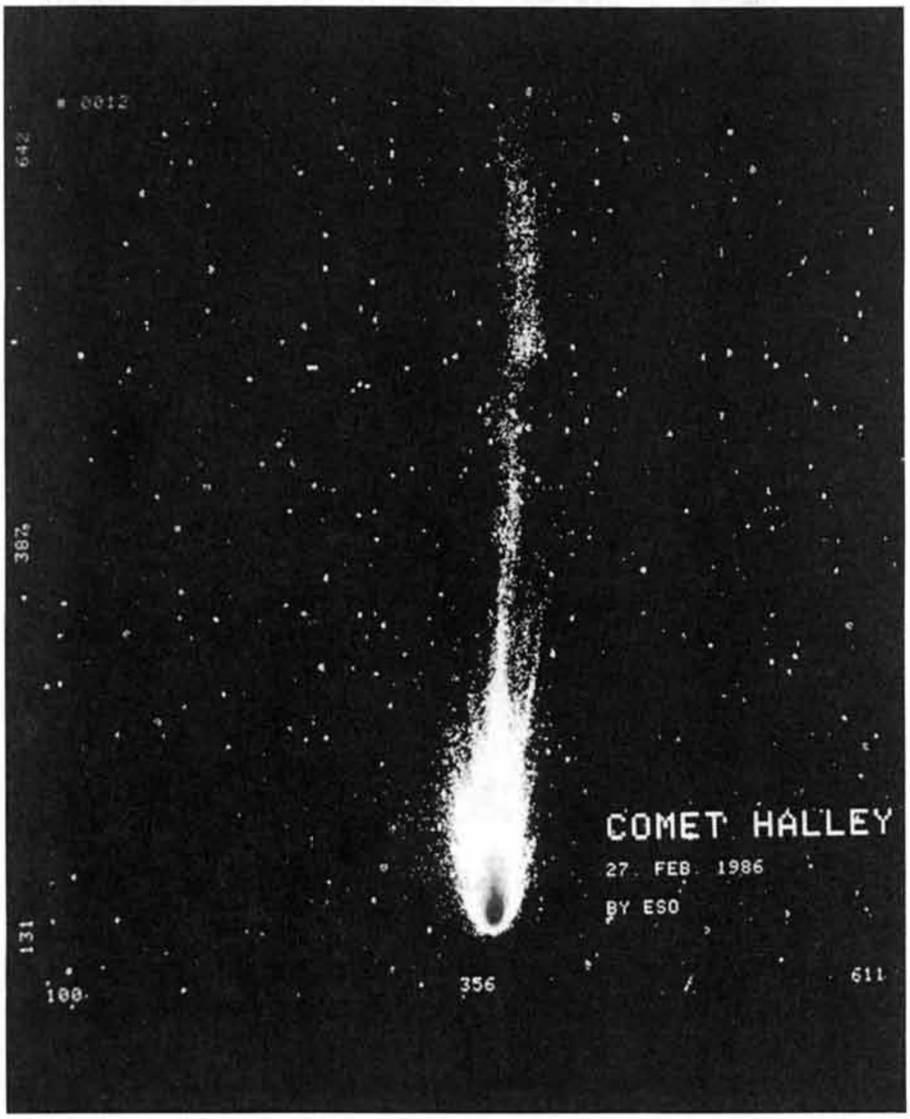


Figure 6.4: **Comet Halley develops 15-degree tail (February 27).** (Photo 02/86; Colour)

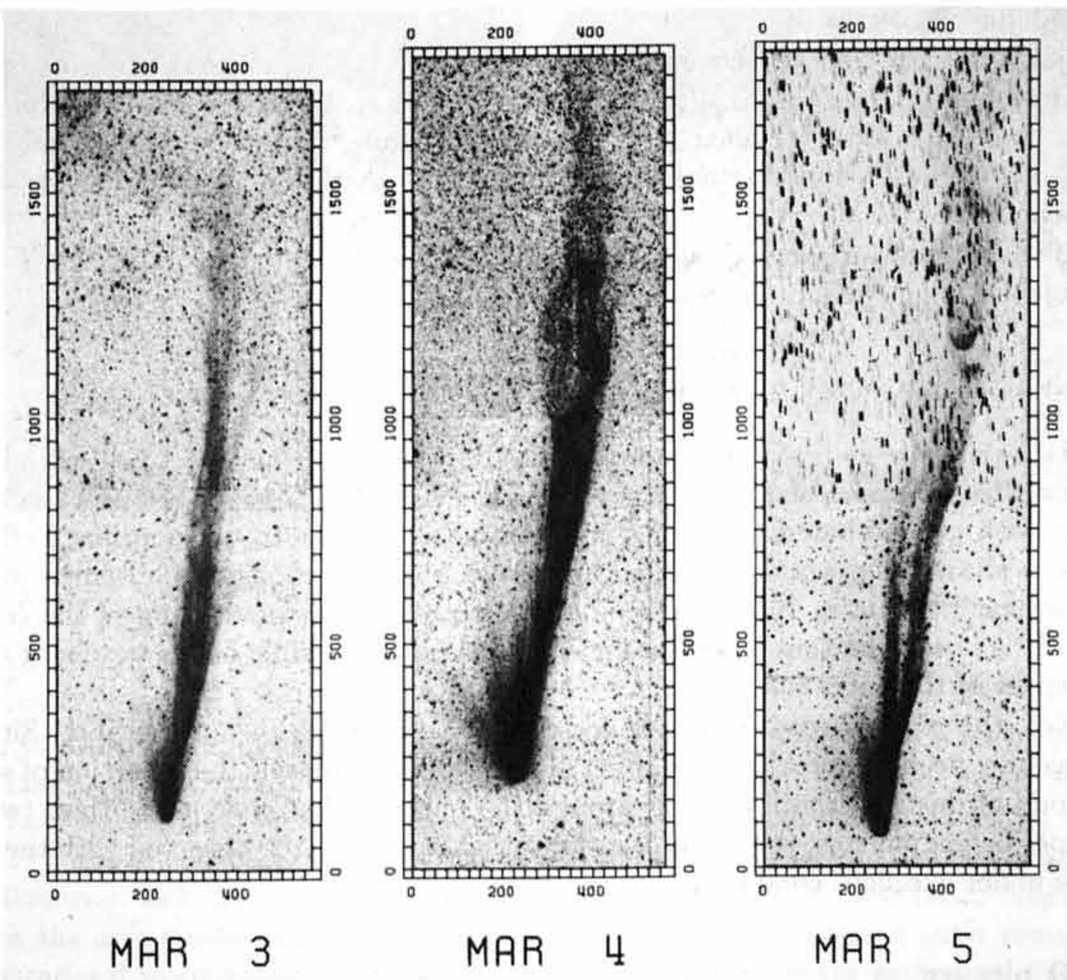


Figure 6.5: **Comet Halley's CO^+ tails (March 3 - 5).** (Photo 03/86; BW)

6.6 A Picture of Comet Halley at 1250 Million Kilometres

(**PR 04/88**; 8 July 1988; For immediate release)

A unique picture of Comet Halley has just been obtained by three astronomers[1] with a telescope at the ESO La Silla observatory. An exposure time of almost 12 hours was necessary to show the structure of the famous comet in some detail at the present, very large distance of 1250 million kilometres.

The point-like image of the comet's nucleus is clearly visible, although it is more than 6 million times fainter than what can be seen with the unaided eye. For the first time, it has also been possible to get a detailed view of a large, asymmetric dust cloud around a comet so far from the Sun. It appears that Comet Halley is still actively dispensing dust into the surrounding space.

A B/W version of the picture, suitable for reproduction, accompanies this Press Release. A false-colour version with more details is available on request.

Ground-based observations continue

Comet Halley made headlines when it was visited by no less than five spacecraft in March 1986. But whereas the space-based studies of Comet Halley lasted a few weeks only, observations with ground-based telescopes still continue. Thanks to extraordinary efforts by astronomers all over the world, an incredible wealth of observations was obtained when the comet was near the Sun in 1985-86. For the fullest possible understanding of the cometary processes, it is now important to follow the comet as far as possible on its way back towards the icy depths of the outer solar system.

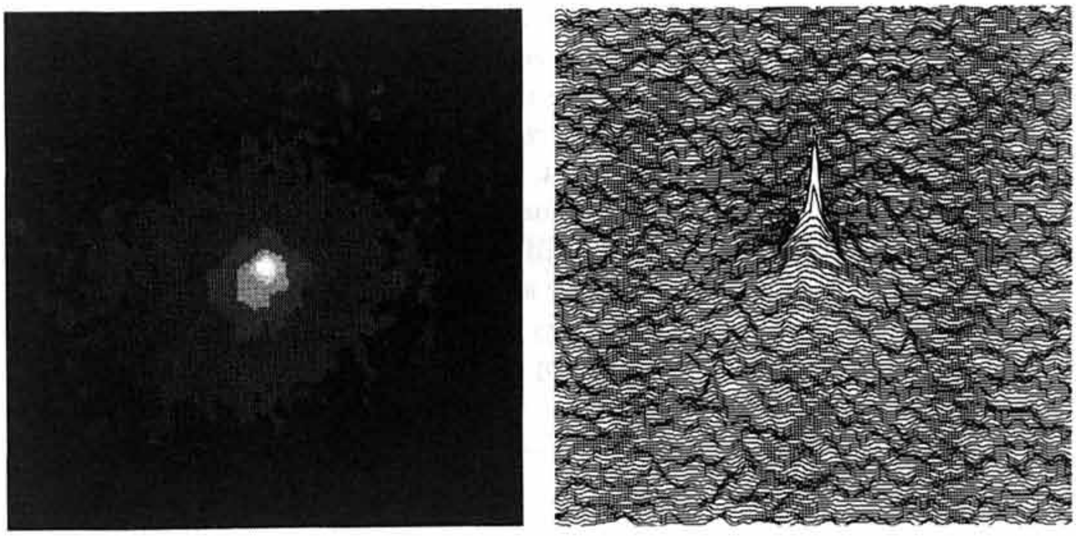
However, the comet becomes fainter and fainter as it recedes from the Sun. Since late 1986 it has only been visible as a fuzzy point of light. What we see is the reflection of sunlight from a cloud of dust, that still remains around the nucleus. And now, more than two years after the perihelion passage, the comet is so faint that it can only be observed with the largest telescopes under excellent conditions.

The ESO picture

Comet Halley was observed during 19 nights in April and May 1988 with the Danish 1.5 m telescope at the ESO La Silla observatory. A highly sensitive CCD-camera was used to obtain more than 60 images of the comet. In order to detect the faint light from the moving comet, the telescope was set to follow the comet's motion. Fortunately, the observations benefitted from very good atmospheric conditions throughout this period.

Extensive image processing was carried out with the ESO IHAP system, including "removal" of stars and galaxies in all frames. By coadding about 50 exposures, with a total exposure time of 11 hours 35 minutes, it is now possible to present a picture of the Comet Halley as it appears at a distance of 1250 million kilometres from the Sun (almost as far away as the planet Saturn). No picture with so much detail has ever been obtained of any comet so far from the Sun.

[1] H.E.Jørgensen and P.Kjærgaard (Copenhagen University Observatory); R.M.West (ESO).



Comet Halley at 1250 Million Kilometres

Figure 6.6: **Comet Halley at 1250 million kilometres.** This picture of famous Comet Halley was obtained with the Danish 1.5 m telescope at the ESO La Silla observatory during April-May 1988. It has been produced by the combination of about 50 CCD frames, obtained during 19 nights, totalling 11 hours 35 minutes exposure. It shows the comet in visual light at a distance of about 1250 million kilometres. Left: Smoothed picture with 6 light levels, in order to show the 23-mag cometary nucleus in the asymmetric, inner coma and also the much larger, elongated outer coma. Right: Three-dimensional representation, illustrating the relative brightness of the nucleus, as compared to the coma. The field of the picture measures 75 arcsec × 75 arcsec; North is up and East is to the left. The direction to the Sun is WNW. Technical information: Pixel size: 0.47 arcsec = 2800 km. Johnson V filter. Bias-subtracted, flat-fielded, cleaned for cosmic events, stars and galaxies removed, 3 pix × 3 pix gaussian smoothed. (PR 04/88; BW and Colour)

The *nucleus* (which is too small to be resolved at this distance) is clearly seen as a small, bright point. The visual magnitude was determined as 23.1 with variations from night to night by a factor of 2, reflecting the rotation of the avocado-shaped nucleus. It is located off-center in a relatively bright, asymmetric region, called the *"inner coma"*; it measures about 20 arseconds across, corresponding to 120.000 kilometres. Further out, a larger, *"outer coma"* of elliptical shape can be distinguished; it measures at least 45 arcseconds (300.000 kilometres) across and is possibly significantly larger. The faintest contour shown is about 27 mag per square arcsecond, or 100 times fainter than the light from the night sky. Summing all of the light, the comet's total magnitude is found to be around 17.

From the shape and density of the inner coma, it would appear that dust is still being released from the nucleus, even at this large distance. By the action of the solar wind, it is pushed away from the nucleus and slowly dissipates into the surrounding interplanetary space. The presence of such a large and faint, outer coma around a comet at this distance has not been detected before; this was only possible because of the very long exposure time.

It is expected that further observations will be made at ESO in early 1989, when Comet Halley will be more than 1500 million km away and also in 1990 (1900 million km) with the 3.6 m telescope or the new 3.5 m New Technology Telescope. However, at that time the comet will be significantly fainter than now and any future picture will show less detail. Halley crosses the orbit of Uranus in April 1994, that of Neptune in February 2006 and reaches the most distant point in its orbit in April 2024, 5300 million km from the Sun.

6.7 Sweet Dreams, Halley !

(**Photo 02/90**; 26 July 1990; For immediate release)

Famous Comet Halley, now receding from the Sun after its perihelion passage in early 1986, has recently entered into a state of hibernation which will last until shortly before the next passage in 2061.

This is main result of an extensive series of observations at the European Southern Observatory in late February 1990, during which the comet was imaged with an extremely sensitive CCD camera attached to the Danish 1.5 m telescope at La Silla. At this time Halley was 11.6 AU (1735 million km) and 12.5 AU (1870 million km) from the Earth and the Sun, respectively, that is well outside the orbit of the giant planet Saturn.

To see the faint light from the distant object, exposures totalling 980 min (16 hrs 20 min) were obtained. The "negative" picture shown here is a composite of 23 frames, each individually cleaned. The image of Halley at the centre is pointlike; the straight lines are trails of stars and galaxies in the field, because the telescope was set to follow the comet's motion. The mean, visual brightness of Halley during the observing period was 24.4 magnitude and brightness variations of 1.3 magnitude were seen.

The measured magnitude is about 0.3 mag brighter than what would be expected from Halley's nucleus alone, an avocado-shaped, 15 km long "dirty snowball", consisting of a variety of ices and dust. The brightness variations are caused by the tumbling motion of this nucleus, whereby the amount of reflected sunlight depends on the changing profile seen from the Earth.

Of particular interest is the fact that the extended coma (i.e. the dust cloud around the nucleus), which was observed with the same telescope in 1989 at heliocentric distance 10.1

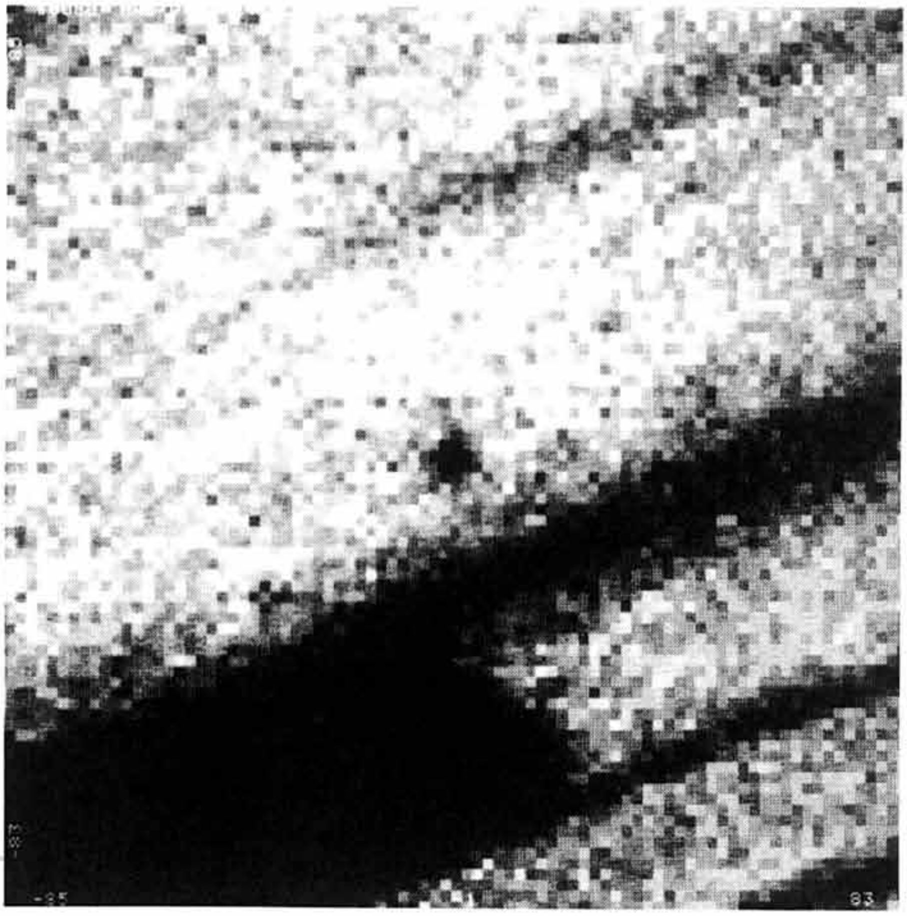


Figure 6.7: **Comet Halley in February 1990.** (Photo 02/90; BW)

AU, has now completely disappeared. In fact, no coma is visible at the 29 mag/sq.arcsec surface brightness level (this level corresponds to 1500 times less than the sky background emission !).

It is therefore fairly certain that the release of dust from the nucleus must have ceased somewhere between 10.1 and 12.5 AU heliocentric distance. The former coma has now dispersed into the surrounding space and it is no longer being replenished by dust from the nucleus. In order words, Halley seems to have entered a long period of hibernation which is likely to last until early 2061 when it again comes within about 5 AU from the Sun and will again be awakened by the sunlight.

Still, an accurate evaluation of the seemingly point-like image seen on this picture indicates that it is somewhat elongated in the direction opposite to the Sun. Together with the extra light observed, this could mean that a very low level of activity is still present and that there may still be some dust in the immediate neighbourhood of the nucleus.

Technical information: Composite frame of 23 individual exposures in Johnson-V, obtained during Feb. 21 - 24, 1990. Mean seeing: 1.3 arcsec. Frame size 84×84 pix^2, or 39×39 arcsec. Image processing with the IHAP system at the ESO Headquarters. North is up and East is to the left. Observer: R.M.West (ESO).

Chapter 7

The New Technology Telescope (NTT)

7.1 ESO Signs Major Contract with INNSE for the Technologically Most Advanced Astronomical Telescope in the World

(**PR 02/86**; 21 January 1986; For release on 23 January 1986, 14:00 MET)

An important contract was signed today in Milan, Italy between the European Southern Observatory and INNSE Innocenti Santeustacchio. It concerns the construction of a large astronomical telescope which will become the technologically most advanced in the world when it enters into operation in 1988.

The contract covers the fabrication of the main mechanical structure of the 25 million DM ESO New Technology Telescope (NTT), the preassembly in Europe and the disassembly and packing in late 1987. The NTT will then be shipped to the ESO La Silla observatory in Chile and the first astronomical observations will start during September/October 1988.

It is the first large telescope project for INNSE, part of ITALIMPIANTI (IRI-Finsider group), which has experience with the manufacture of large items for European science.

The ESO NTT will be the seventh-largest optical telescope in the world and the second-largest on La Silla, next to the ESO 3.6 metre telescope, installed in 1976. Its foremost advantages lie in a number of innovative technical solutions, which will facilitate operation, increase efficiency and reliability and, not the least, reduce the total cost to about one-third of what a classical telescope of this size would have cost.

The NTT is extremely compact (5 x 6 x 12 metre) and weighs only 120 tonnes (40 to the use of a "lightweight" (6 tonnes) main mirror which measures 3.58 m in diameter, but is only 24 centimetres thick. Since the mirror is lighter, the entire telescope structure can also be correspondingly reduced in weight.

However, such a thin mirror will become deformed by its own weight when the telescope moves. To overcome this, a system has been developed at ESO by which an "image analyzer" continuously monitors the shape of a stellar image in the focal plane and the deviation from the ideal shape. Corrective signals are generated for the main (primary) and the secondary mirror supporting structures, so that optical perfection is guaranteed. Part of this system is the active support of the primary mirror which has 75 active axial pads and 3 fixed supports.

This system represents a major breakthrough in telescope technology and will also be used in ESO's Very Large Telescope project (VLT), a 16 metre equivalent aperture instrument, planned for the 1990's. Similarly, it is expected that several other technical features, once tested at the NTT, can also be taken over by the VLT.

The NTT will be housed in a 250 tonnes octogonal building, 16 metres wide and 16 metres high, which will turn with the telescope around a common vertical axis. The design of the building emphasizes the need to exploit optimally the exceptional atmospheric conditions at La Silla, one of the best astronomical sites in the world with more than 300 clear nights per year.

Remote control of the NTT via satellite from the European Headquarters of ESO is planned. In this way, the observers will not have to travel to La Silla in order to use the NTT, resulting in important savings in time and money.

The NTT will be built by European firms according to overall ESO design. The 3.5 metre mirror of ZERODUR glass ceramics was successfully cast by Schott Glaswerke (Mainz, FRG) in July 1984 and will be polished by Zeiss (Oberkochen, FRG). A call for tender for the

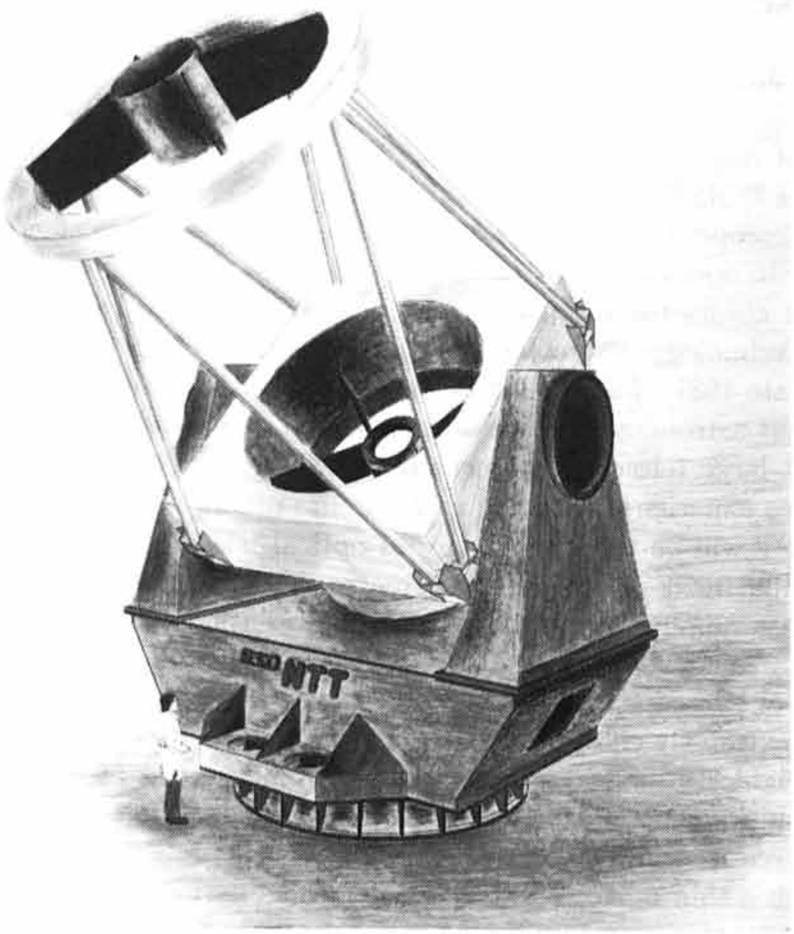


Figure 7.1: **A model of the New Technology Telescope.** (PR 02/86; Colour)

building is about to be issued by ESO.

The figure shows the alt-azimuthally mounted 3.5 metre ESO NTT.

7.2 Strange Building for the ESO New Technology Telescope Arrives at the La Silla Observatory

(**PR 01/88**; 9 February 1988; For immediate release)

Last week, M/S "Cervo" arrived in the harbour of Valparaiso, Chile, with the packaged parts for the building which will house the ESO New Technology Telescope (NTT). Soon thereafter, the 350 ton load was hauled by road to the ESO La Silla observatory in the Atacama desert, some 600 km north of Santiago de Chile. Here, at one of the best astronomical sites on earth, the giant mechanical puzzle will now be put together to form one of the strangest telescope domes ever seen.

The 3.5 m New Technology Telescope is the forerunner of the ESO Very Large Telescope

(VLT)[1]. When the NTT is ready later this year, it will be the technologically most advanced telescope in the world.

The NTT project

With a prime mirror of almost the same size as that of the ESO 3.6 m telescope (in operation since 1976), the NTT will take full advantage of the excellent observing conditions at La Silla. It will allow observations of very faint and distant objects in the Universe, as well as very detailed studies of the brighter ones. At the same time, it incorporates a large number of technical innovations which will now be tested under realistic conditions. In this way, much valuable experience will be gained for the design and construction of the 16 m VLT.

The realization of the NTT Project started in 1982, at the time when Switzerland and Italy joined ESO. With the entrance fee from these two countries, ESO decided to build the prototype of a new telescope generation, taking full advantage of the most advanced technology in the fields of optics, mechanics and computer science. The goal was to construct the best telescope in the 4 m class, but at only a third of the usual cost. The project would try out new ideas which could later be implemented in more ambitious projects, like the VLT.

The rotating building

The NTT will be mounted in a rotating building with an unusual octagonal shape. It has been designed to ensure maximum exposure of the telescope to the external environment during observation, while protecting the structure from strong winds and dust. Furthermore, the floor of the building is actively cooled and the temperature in the telescope room and in the instrument rooms is maintained at the level of the outside temperature at night. These features will improve the NTT performance, as compared to other telescopes, since there will be less turbulence in the surrounding air and the images of astronomical objects will therefore be sharper.

The exact shape of the building was determined by wind tunnel tests at the Technical University of Aachen.

The building was conceived at ESO and designed and manufactured by a consortium of Italian companies (MECNAFER, Mestre, ZOLLET, Belluno and ANSALDO Componenti, Genova) in close cooperation with a number of European industries. One of these is RKS France who manufactured an extremely precise roller bearing with diameter of no less than 7 m, a key component of the rotating system.

It will take almost six months to complete the erection of the rotating building at La Silla.

Active optics and remote control

The diameter of the prime mirror is 3.58 m and it is only 24 cm thick. It is therefore quite flexible and its form must be controlled by computer-activated supports. This is the concept of active optics, here used for the first time on a real telescope. This technique was developed at ESO and will ensure that the NTT will have the best possible image quality in every position.

The NTT control system consists of a number of microprocessors connected to the central computer and is also characterized by advanced software, developed at ESO. It includes the

[1]See ESO PR 02/86 of 21 January 1986 and PR 16/87 of 8 December 1987.

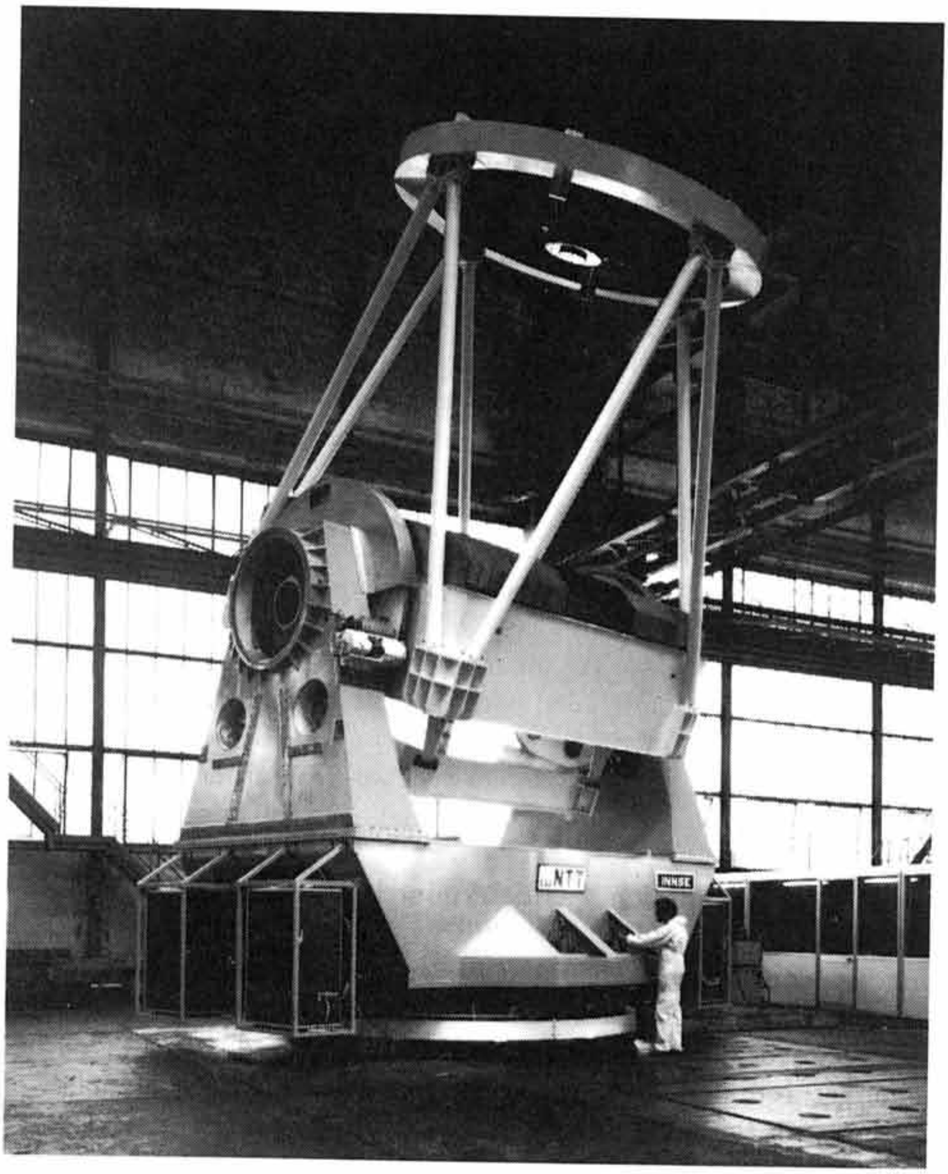


Figure 7.2: **The ESO New Technology Telescope (NTT) at INNSE** in Brescia, Italy in mid-August 1987. This telescope, which incorporates the latest innovations in telescope design, will be erected at La Silla in mid-1988 and is expected to enter into operation before the end of 1988. The mirror diameter is 3.58 m. (PR 01/88; Colour)

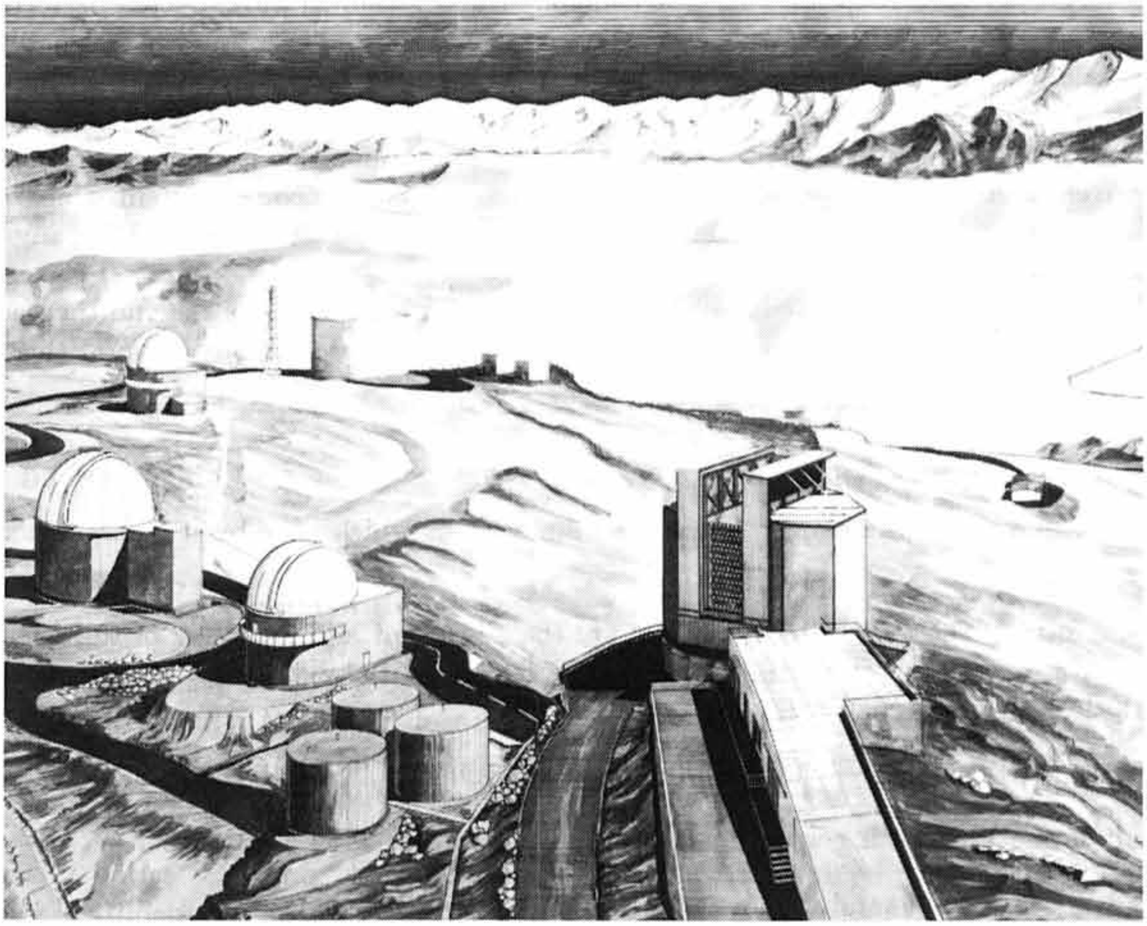


Figure 7.3: This is an **architect's view of the new NTT building on La Silla.** The foundations for this unusual structure have already been laid at the secondary summit of the La Silla mountain. The building design will ensure the best possible "seeing" , that is the best possible observing conditions, for the NTT. (PR 01/88; Colour)

possibility to have a remote control station in Europe. This concept is already used at ESO in connection with two existing telescopes at La Silla[2].

An unusual mechanical structure

The telescope structure has an alt/az mounting and rotates around one vertical and one horizontal axis, the new trend for optical telescopes. It was mechanically completed in the course of 1987 and after implementation of the electronic hardware and software, it was tested extensively at INNSE, Brescia. This gave complete confirmation of the expected performance. The moving structure of the telescope weighs about 110 tons and is supported by a multi-pad hydrostatic bearing, designed by INNSE to guarantee extremely high rigidity with minimum friction. It is thermally controlled in order not to introduce air disturbances which might degrade the optical quality. The axes of the telescope are guided by a group of water-cooled servodrives, and the absolute position of the telescope by an encoder system which allows pointing on the sky with an accuracy of 1 arcsecond, a figure unsurpassed by any other existing telescope of this size.

The NTT will be dismounted and shipped to Chile within a few months and then erected inside the rotating building. It is expected that the first sky observations begin at the end of 1988.

Technological innovations

Here is a summary of the main technological innovations which have been incorporated into the NTT:

- the form of the thin primary mirror and the alignment and focussing of the secondary mirror are computer controlled so that the telescope is always in optimal shape (active optics)
- fast switching of the light beam between two different auxiliary instruments
- alt-azimuth mounting with very high pointing and tracking accuracy
- advanced, flexible and very user-friendly control system
- possibility of remote control from Garching
- open dome structure so that the telescope is fully exposed to the external environment during observation
- rotating compact building

Some figures

Estimated price of the NTT project: 25 million DM
Size of NTT building: 18 m (high) × 17 m × 17 m
Weight of Building: 250 tons
Length of telescope tube: 8 m
Weight of telescope: 125 tons

[2]See ESO PR 14/87 of 29 September 1987.

Main mirror material: Zerodur
Size of main mirror: Diameter 3.58 m; Thickness 24 cm; f/2.2
Weight of main mirror: 6 tons
Foci: 2 Nasmyth platforms, f/11, with fixed infrared and visual multi-function instruments

Illustrations

This Press Release is accompanied by two illustrations:

- The NTT at the factory of INNSE after integration of the mechanical parts
- The NTT building on La Silla (Architect's drawing)

7.3 Completion of the 3.58 m NTT Optical System Inaugurates New Era in Telescope Technology

(**PR 05/88**; 8 July 1988; For Release on 14 July 1988)

On the occasion of the successful completion of the optical figuring of the 3.58 m primary NTT mirror, the European Southern Observatory and Carl Zeiss, FRG, organize a **Press Conference on Wednesday, July 13, 14.00 hours, at the Zeiss works in Oberkochen,** near Stuttgart, FRG. There will be an opportunity to see the finished mirror on its computer controlled support system and information will be provided about the successful tests of the world's first, large active optics telescope. Further information may be obtained from Mr. S. Hildebrand at Zeiss; telephone (0)7364-203846.

A break-through in astronomical telescope technology

Three recent dates are of great importance for the completion of the ESO New Technology Telescope (NTT)[3]. They are also milestones in the long and fascinating history of the reflecting telescope.

On May 11, 1988, the complete optical system for the NTT (primary, secondary and Nasmyth mirrors) was accepted on the basis of results for the primary mirror on the manufactoring support. On June 30, excellent agreement was achieved with the primary mirror mounted in its final cell and axial support. And today, July 8, the most important new technology aspect, the *Active Optics* control and optimisation of image quality was tested in function and found to give virtually perfect agreement with mathematically simulated results performed for the Carl Zeiss and ESO tests.

[3]See also ESO Press Release 01/88 of February 9, 1988.

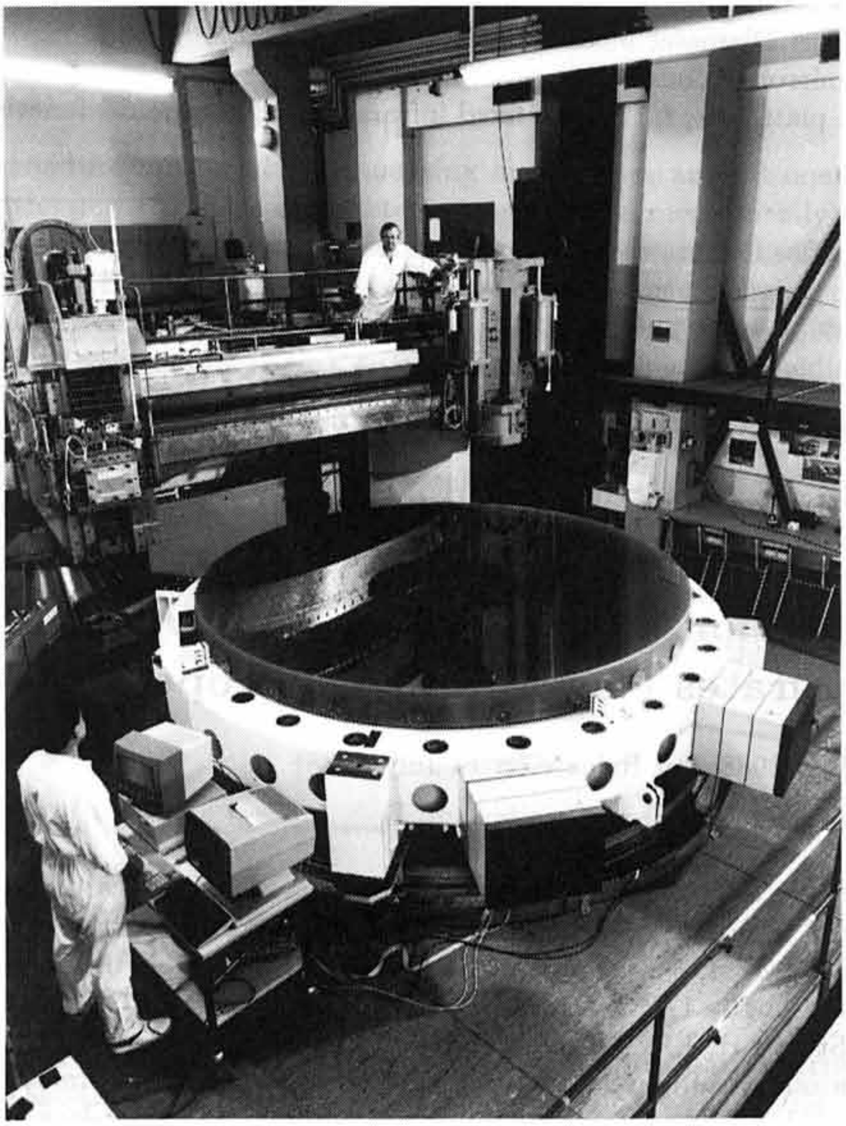


Figure 7.4: Early July 1988, the **3.58 meter mirror for the New Technology Telescope (NTT)** rests on its active support system during the final tests at the Carl Zeiss (Federal Republic of Germany) works in Oberkochen, FRG. The 6 ton mirror blank is made of Zerodur, a glass ceramic, and was produced by Schott in Mainz, FRG. The polishing of the mirror by Zeiss has taken two years in order to obtain an unsurpassed optical quality. The exceedingly smooth surface has residual errors of no more than 25 nanometers (1 nanometer = 1 millionth of a millimeter). This superb surface will be fully utilized, thanks to the new idea of *active optics* developed by ESO. This means that the NTT will be able to observe fainter and more distant objects in the Universe than any other telescope of the same size. The signals from an "image analyser", which monitors a stellar image, are elaborated by a computer and electronics developed by ESO (in two racks visible in the foreground of the picture). Thereby the forces on the 75 supports of the mirror are modified and the form of the mirror is optimised so that the light of the star is concentrated within the smallest possible area. The combination of the extremely high optical quality of the NTT mirror, the innovative support system and the new design of telescope and building signals a revolution in astronomical telescope technology. (PR 05/88; BW and Colour)

First active optics system confirms expectations

To understand the significance of these results, we must consider the nature of the technical specification given by ESO to Carl Zeiss. This required an exceptionally smooth form of the reflecting surface over small areas (i.e. for high frequency effects) but reduced certain low frequency error tolerances which are corrected afterwards by *Active Optics*, that is by slightly bending the primary in a controlled way through variations of its axial support forces. In this way, not only can an image quality be achieved which surpasses by a factor of about 3 the best previously achieved; but, even more important, this quality can be always maintained during operation. **Effectively, the NTT telescope monitors its performance continually and optimizes itself automatically.**

This *Active Optics* control system has been developed at ESO over the last 10 years and its application for the first time in the NTT represents a revolution in telescope technology, since it also allows thinner and lighter, and therefore more flexible, mirror blanks.

This successful result is the consequence of an admirable cooperation between ESO and the two firms of the Zeiss Foundation, Schott and Carl Zeiss. The primary mirror blank for the primary was delivered by Schott to Carl Zeiss in June 1986. The blank, 2 1/2 times thinner than a conventional blank, itself represents a great technical achievement in zero-expansion glass ceramic, Zerodur. Two years of intensive work at Carl Zeiss followed and have now been successfully completed. Both the Carl Zeiss and ESO tests have confirmed that the specification has been met with appreciable reserve, a remarkable technical achievement. In the course of the work, Carl Zeiss has developed its test and polishing technology to a hitherto unsurpassed level of perfection.

NTT to become operational in late 1988

The NTT mirror will now be carefully packed and transported to the ESO observatory at La Silla in Chile. After aluminisation in October and "first light" at the end of 1988, the NTT will go into normal operation in early 1989. The ESO engineers and scientists are confident that its performance will fulfill all expectations. **As the first "active" telescope, the ESO NTT will easily surpass in optical quality all other telescopes ever built** with the possible exception of the 2.4 m Hubble Space Telescope, awaiting launch in late 1989.

This Press Release is accompanied by a photo of the NTT primary mirror at the Zeiss works. Photos of the NTT mechanical structure and the NTT building, now erected at La Silla, are available on request.

7.4 "First Light" for ESO's New Technology Telescope

(**PR 03/89**; 23 March 1989; For immediate release)

Early this morning, and during superb atmospheric conditions, the 3.5 m ESO New Technology Telescope (NTT) produced its first astronomical images. They completely satisfy the high expectations towards this revolutionary high-tech telescope, the first of its kind in the world. This important milestone was passed less than seven years after the start of the NTT

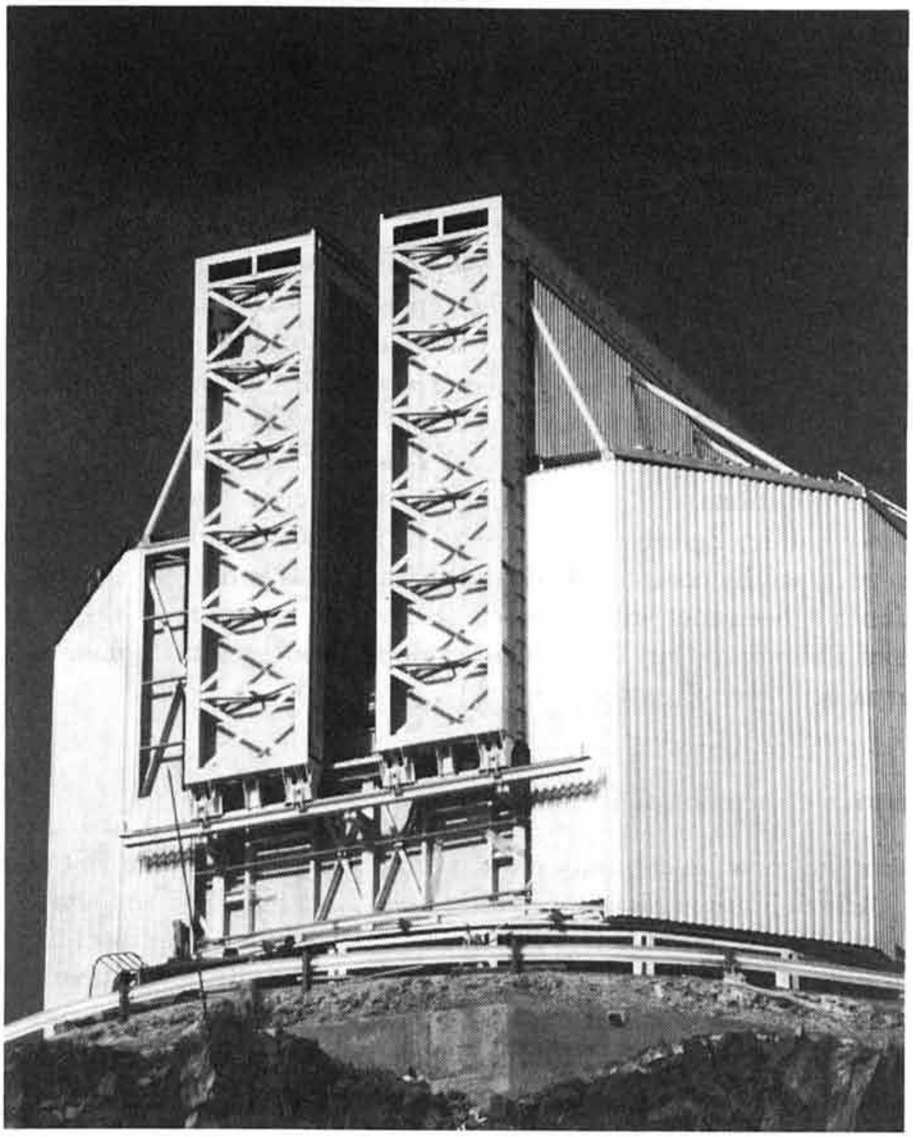


Figure 7.5: **The New Technology Telescope on La Silla.** The revolutionary 3.6 m ESO New Technology Telescope (NTT) has entered into operation in its unusual dome at the La Silla Observatory. The entire dome rotates synchronously with the telescope during the observations. The peculiar shape of the dome resulted from extensive wind-tunnel tests and ensures that there is a minimum of turbulence in the air around the telescope. Together with the actively controlled optics, this guarantees the sharpest possible images. (PR 03/89; Colour)

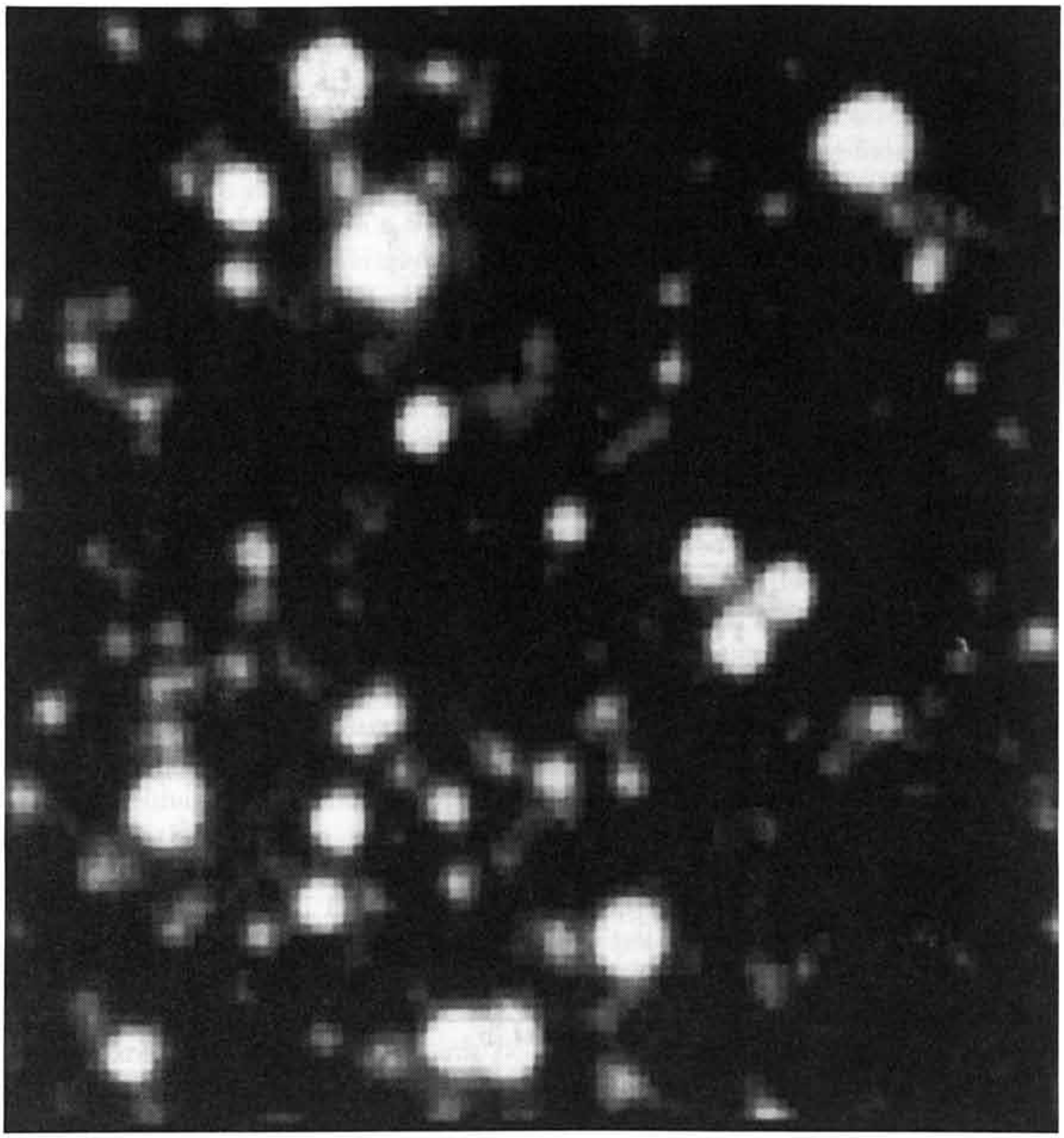


Figure 7.6: **Globular cluster ω Centauri observed with the ESO NTT.** This is one of the first astronomical images obtained with the ESO New Technology Telescope, during the night of "first light" (March 22 - 23, 1989). The CCD image was immediately transfered via a satellite link to the ESO Headquarters in Garching. It shows a small field (47×47 arcsec^2) near the centre of the well-known southern globular cluster Omega Centauri. At the time of this exposure, the "seeing" (smearing of the stellar images due to atmospheric turbulence) was only 0.39 arcseconds, one of the smallest values ever recorded with a ground-based optical telescope. Thanks to its superior optics, the NTT was able to fully exploit these excellent observing conditions, and the resolution of this picture is unequalled. The stellar images are extremely sharp, by all standards in optical astronomy. The pixel size is 23μm, or 0.123 arcseconds. The numbers along the axes indicate pixels. The observations were made in bright moonlight and the exposure time was limited to 10 seconds. (PR 03/89; BW)

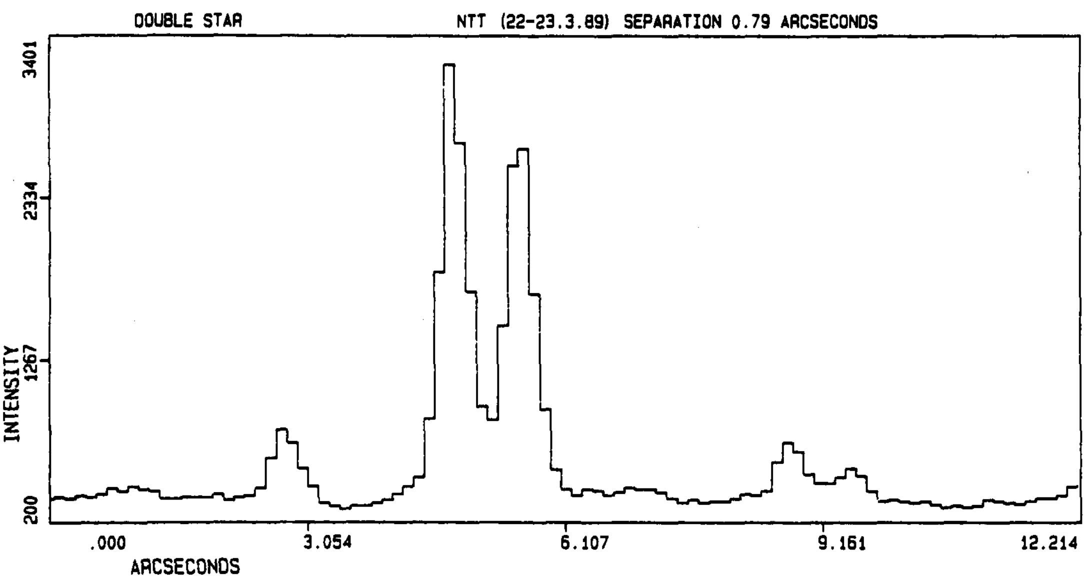


Figure 7.7: **Very sharp images with the ESO NTT at "first light".** On the night of "first light" for the ESO New Technology Telescope on La Silla (March 22 - 23, 1989), its excellent performance was impressively demonstrated. The "seeing" (smearing of the stellar images due to atmospheric turbulence) was about the best ever recorded with a ground-based optical telescope; it varied between 0.36 and 0.50 arcseconds. The CCD images were immediately transmitted by satellite link to the ESO Headquarters in Garching. Thanks to its superior optics, the NTT was able to fully exploit these excellent observing conditions, as shown by the example in this figure. A double star in which the two components of about equal brightness are separated by only 0.79 arcseconds, was fully resolved. The Full Width at Half Maximum (FWHM) of the intensity profile of each component, seen at the centre of the drawing below, is measured as 0.36 arcseconds; this is also the measured value of the seeing. By all standards in optical astronomy, the images are therefore extremely sharp. The pixel size is 23μm, or 0.123 arcseconds. The exposure time was 10 seconds. (PR 03/89; BW)

project in 1982 and at the end of a four-year construction phase[4].

Following a three month period of intensive optical, mechanical and electronic tests and adjustments, a CCD camera was mounted at the focal point on one of the instrumental platforms. "First light" was achieved during the night of March 22 - 23, 1989, when numerous exposures of various astronomical objects were made under very good atmospheric conditions (seeing between 0.36 and 0.50 arcseconds). The pictures were immediately transmitted via a permanent satellite link to the ESO Headquarters in Garching. This Press Release is accompanied by one that shows a field in the well-known southern globular cluster Omega Centauri. The impressive performance is also demonstrated by the profile of a double star in which the components, at an angular distance of only 0.79 arcseconds, are completely separated. On La Silla, Ray Wilson, Head of the ESO optics team responsible for the fine tuning of the NTT optical system, was pleased to announce that: "The NTT performance fully confirms our predictions[5]".

Thanks to major technological innovations in several areas, the NTT can give sharper images than any other existing ground-based optical telescope. First of all, its *active optics system* maintains the optimal shape and alignment of the primary and secondary mirrors by means of closed-loop computer control. Secondly, the turbulence of the air around the telescope is minimized by *active thermal control*; all sources of heat in the dome have been eliminated by water or air cooling and the telescope building itself has been designed in accordance with the results from detailed wind-tunnel experiments. Thirdly, the NTT control system allows a *very high pointing and tracking accuracy*, ensuring that the images of astronomical objects are not smeared by the telescope motion during exposure; the NTT has already been remotely controlled from the ESO Headquarters via the satellite link.

Its sharper images will enable the NTT to observe fainter and more distant objects and the manager of the NTT project, ESO astronomer Massimo Tarenghi, "looks forward to a rich harvest of scientific discoveries, beyond the horizon of other telescopes now in operation".

With the moment of NTT "first light" sucessfully passed, ESO has now two large telescopes at La Silla. The first of these, the ESO 3.6 m telescope which is a typical representative of the classical 4-m class of large optical telescopes, became operational in 1976. The NTT illustrates the great advances that have taken place in astronomical technology in the meantime. Compared with the "old" 3.6 m, the NTT is capable of giving three times sharper images; its improved aperture ratio (f/2.2) makes it three times "faster"; its main mirror weighs only half as much and the entire telescope is three times lighter than its predecessor.

Last, but not least, the NTT was constructed well within the budget frame set in 1982. Financed by the entrance fees from Italy and Switzerland, who joined ESO that year, the NTT has cost 25 million DM, or only one third of the earlier ESO 3.6 m.

[4]Various aspects of the New Technology Telescope have been described in ESO Press Releases 01/88 of 9 February 1988 and 05/88 of 8 July 1988.

[5]On another night with 0.5 arcsec seeing, the NTT optics were actually measured to concentrate 80% of the light within a diameter of less than 0.26 arcseconds. However, comparison with the laboratory tests proves that, without measuring noise, the real quality of the optics as now working is *between 0.15 and 0.20 arcseconds*, so that even the best possible seeing conditions can be fully exploited whenever they occur.

7.5 A Revolution in Ground-Based Direct-Imaging Resolution

(**PR 03A/89**; 11 May 1989; For immediate release)

"First Light" with the ESO New Technology Telescope (NTT) was obtained on March 23, 1989[6] during conditions of exceptionally good "seeing" and the first images are probably the sharpest ever obtained with a large, ground-based telescope. A full account of the associated events will appear in the June 1989 issue of the *ESO Messenger*.

In the meantime, the best CCD frame of the bright southern cluster Omega Centauri has been subjected to advanced image processing, further sharpening the stellar images. As an illustration of the importance of achieving the highest possible resolution, this Press Release is accompanied by four photos, which also demonstrate the great potential of the ESO New Technology Telescope (NTT), in terms of finer detail and fainter limiting magnitude, as compared to existing telescopes:

- (A) Overall view of the Omega Centauri Globular Cluster (ESO Schmidt telescope), with the NTT field indicated,
- (B) Reproduction of one of the best plates obtained with the ESO 3.6 m telescope, at the same scale as the NTT field,
- (C) False colour reproduction of best NTT exposure with 0.33 arcsecond resolution, and
- (D) Comparison between a) ESO Schmidt plate ($\sim$ 2 arcsecond resolution), b) 3.6 m plate ($\sim$ 1 arcsecond) , c) "raw" NTT CCD frame (0.33 arcsecond), and d) deconvolved NTT CCD frame (0.18 arcsecond).

General information about the photos is given in the figure captions and further technical details about photo (D) follow below:

The field shown in photo (D) is near the centre of the bright southern globular cluster Omega Centauri. It measures 12×12 arcseconds square and covers about 1/16 of the area of a CCD frame, obtained with the NTT on the night of "First Light". It can easily be identified near the left edge of photo (C).

The first (upper left) picture is an enlargement of a photographic plate obtained in 1984 with the ESO Schmidt telescope under seeing conditions mediocre by La Silla standards ($\sim$ 2 arcsec). The exposure time was 10 min on unsensitized, blue-sensitive IIIa-J emulsion behind a GG495 filter (spectral range 500 - 540 nm). The original image scale is 67.5 arcsec/mm; i.e. the field shown corresponds to 0.18×0.18 mm^2 on the original 30×30 cm^2 plate. In other words, about 2.6 million fields of this size are contained on the Schmidt plate; see also the indication of the field on photo (A) !

Next (upper right) follows an excellent photographic plate obtained at the Cassegrain focus of the ESO 3.6 m telescope in 1977. The exposure lasted 6 min 15 sec and the seeing was $\sim$ 1 arcsecond. The emulsion was IIIa-J and no filter was used (spectral range 300 - 540 nm). The image scale is 7.2 arcsec/mm; on the original 6×6 cm^2 plate this field measures 1.7×1.7 mm^2.

[6]See ESO Press Release 03/89 of March 23, 1989.

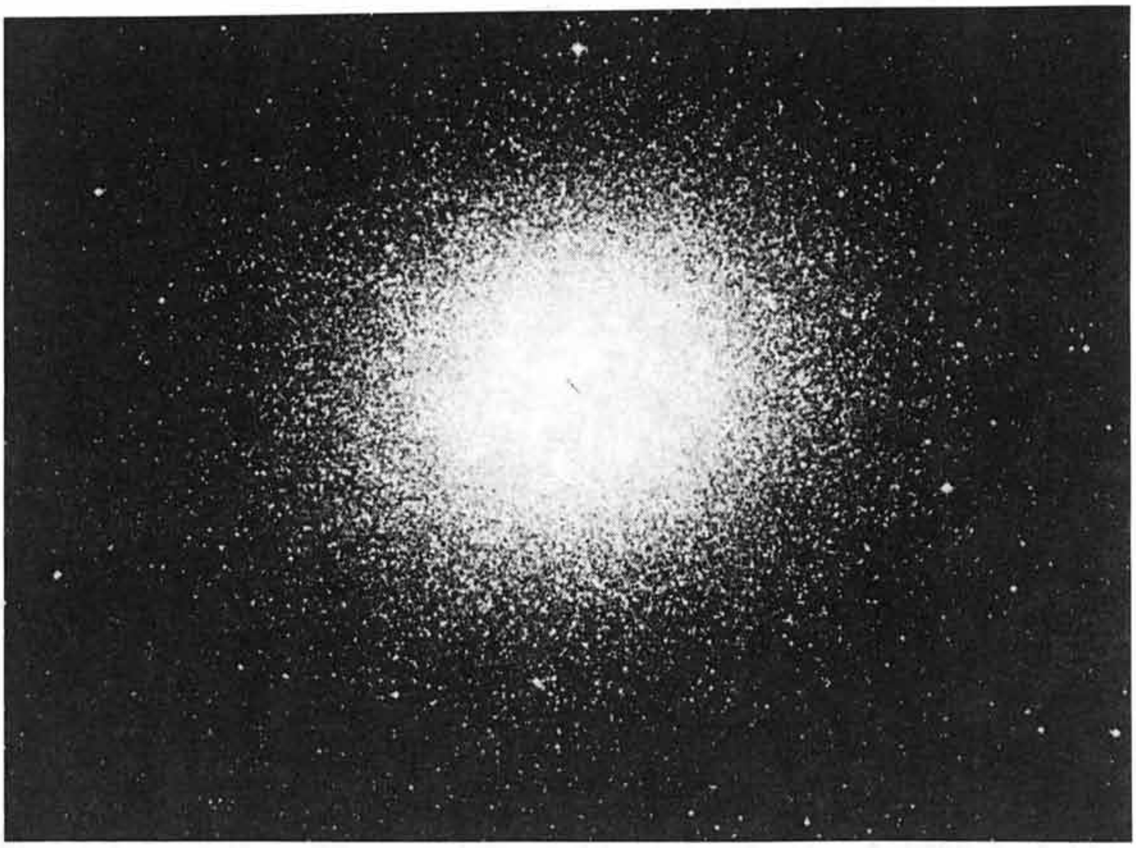


Figure 7.8: **A. The Omega Centauri globular cluster of stars** is the brightest of its type in the sky and contains several millions of stars. It is here reproduced from a photographic plate obtained with the ESO 1 m Schmidt telescope. The exposure time was 15 minutes on a blue-sensitive emulsion. The field shown is approximately 1.5×1.1 square degrees. The small square near the centre (arrow) indicates the 12×12 square arcsecond field shown in photo (D); the 47×47 square arcsecond field in photo (C) is four times larger. North is up and East is to the left. (PR 03A/89; BW)

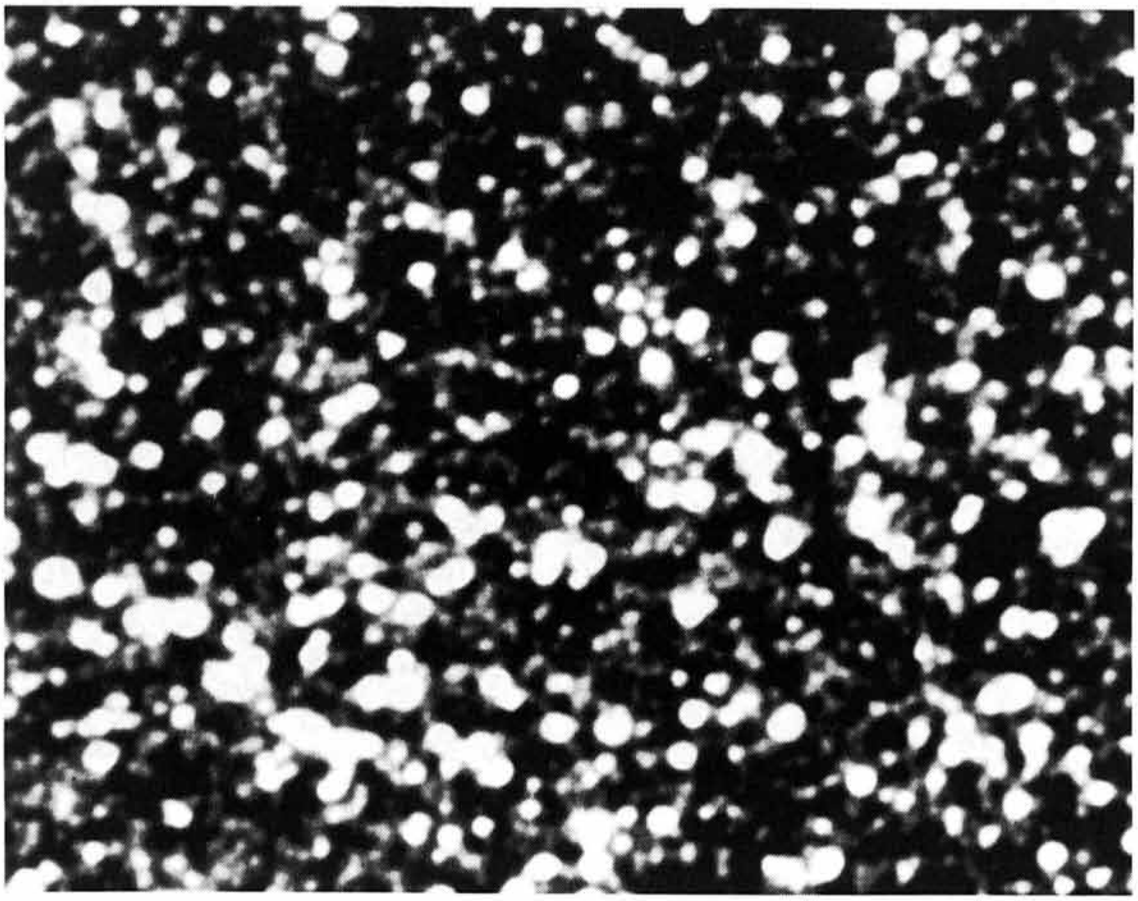


Figure 7.9: **B. Small field near centre of Omega Centauri (3.6m).** This photo has been reproduced from one of the best photographic plates of the globular cluster Omega Centauri obtained with the ESO 3.6 m telescope. It shows a field near the centre; the size is approximately 62 × 47 square arcsecond. The exposure lasted 6 min 15 sec and was made on blue-sensitive emulsion. North is up and East is to the left. The atmospheric "seeing" was very good, about 1 arcsecond, and the size of the stellar images is correspondingly small. This photo is a good example of the "state of art" photography with a classical astronomical telescope of the 4 metre class. (PR 03A/89; BW)

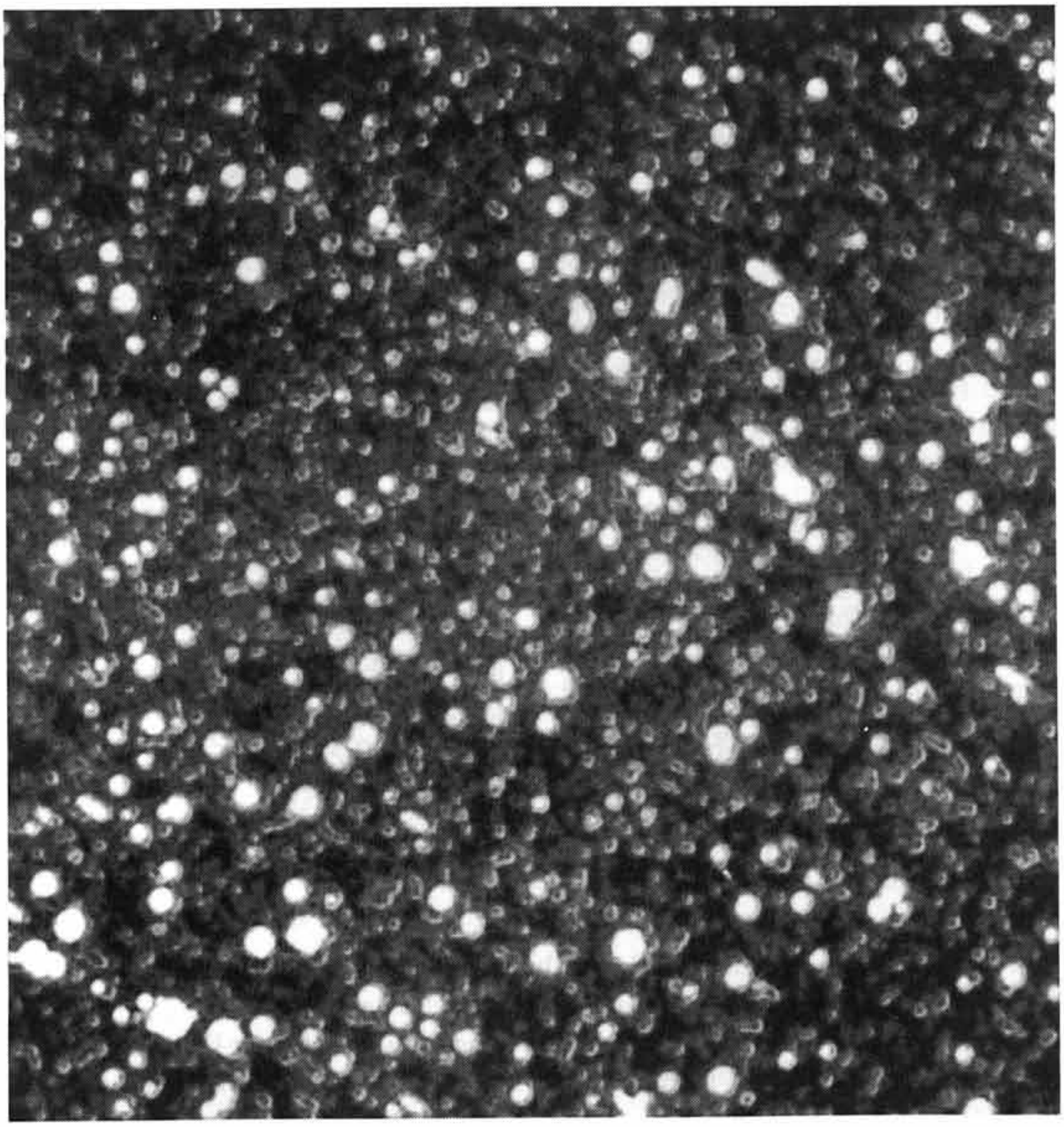


Figure 7.10: **C. Small field near centre of Omega Centauri (NTT).** This false-colour photo has been reproduced directly from the best CCD frame obtained with the ESO New Techonology Telescope during the night of "first light" on March 23, 1989. It shows a field near the centre of the bright southern globular cluster Omega Centauri; the size is approximately 47×47 square arcsecond. The atmospheric "seeing" was extremely good, and the diameter of the stellar images (at half of the maximum intensity) is measured as 0.33 arcseconds. The exposure lasted 10 seconds. North is up and East is to the left. (PR 03A/89; Colour)

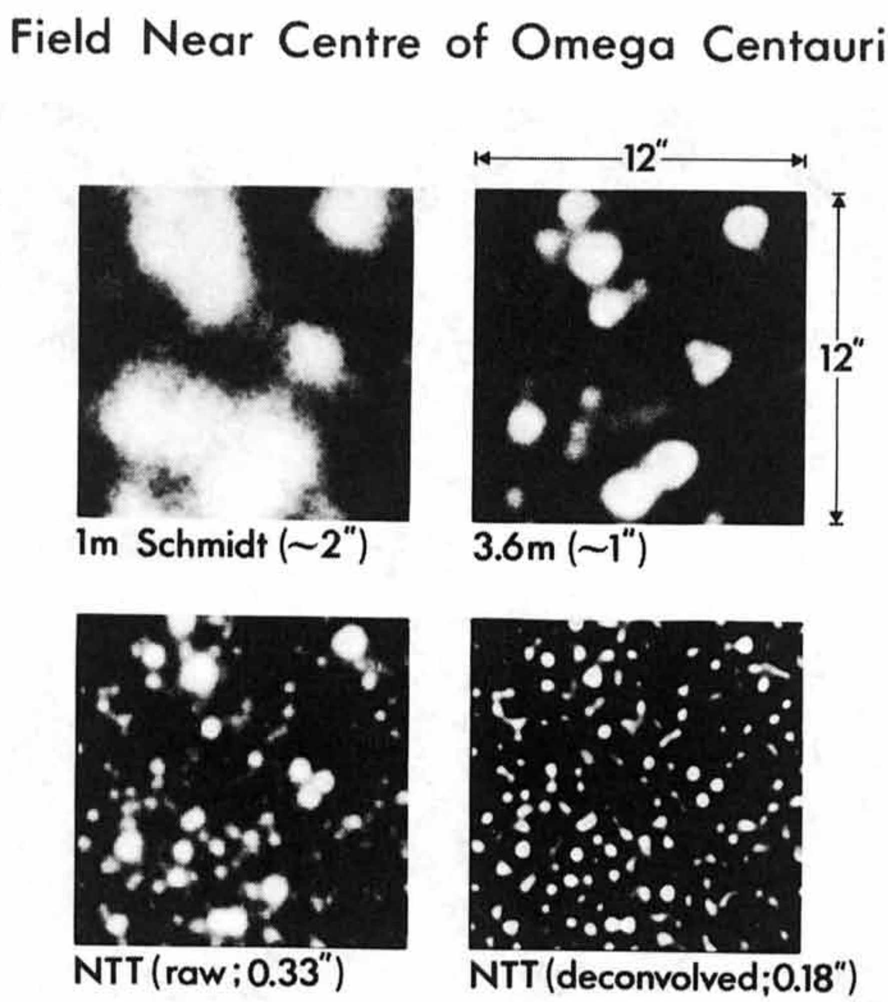


Figure 7.11: **D. The importance of high resolution.** These four images illustrate the importance of improving the resolution of astronomical images. They also demonstrate the great potential of the ESO New Technology Telescope (NTT), in terms of finer detail and fainter limiting magnitude. The field shown is near the centre of the bright southern globular cluster ω Centauri. It measures 12×12 arcseconds square and covers about 1/16 of the area of the CCD frame, shown on photo (C); it is also indicated on photo (A). The upper left picture is an enlargement of a photographic plate obtained in 1984 with the ESO Schmidt telescope under atmospheric seeing conditions mediocre by La Silla standards ($\sim$ 2 arcsec). Next (upper right) follows an excellent photographic plate obtained at the Cassegrain focus of the ESO 3.6 m telescope in 1977 with seeing $\sim$ 1 arcsecond. A 10 sec unfiltered CCD exposure was made with the NTT at the moment of "First Light" on March 23, 1989. Part of it is shown below; to the lower left in the "raw" version in which the width of the stellar images (at half maximum intensity) is 0.33 arcseconds, a value never before achieved with a large, ground-based telescope. To the lower right, the same frame is shown after "sharpening" by advanced image processing; the resolution is now improved to 0.18 arcseconds. The stellar images are noticeably sharper and faint stars are much better visible. (PR 03A/89; BW)

A 10 sec unfiltered CCD exposure was made with the NTT at the moment of "First Light" on March 23, 1989; a small part of it is shown here in two versions. The first (lower left) is the "raw" 100 × 100 pixel^2 image (pixel size 0.123 arcseconds). The Full Width at Half Maximum (FWHM), as measured directly on the stellar images in the frame is 0.33 arcseconds. To this value, the NTT optics contributed perhaps 0.15 arcseconds, so that the actual, atmospherically induced seeing may have been better than 0.3 arcseconds, a spectacular value, even by La Silla standards.

At the lower right, the same frame is shown after "sharpening" by advanced image processing. For this, the frame was subjected to deconvolution with a point spread function, which was empirically constructed from 50 profiles of uncontaminated stellar images and at the same time resampled at 1/5 of the pixel size in both directions. The FWHM is now improved to 0.18 arcseconds; the stellar images are noticeably sharper and faint stars are much better visible. To facilitate the comparison, the intensity scale is the same in both NTT frames.

The image processing was made by Dietrich Baade at the ESO MIDAS facility in Garching with an algorithm developed by Leon Lucy. About 3 hours VAX 8600 CPU time was needed to perform 20 iterations; this time can of course be significantly reduced with other computers, optimized for "number-crunching".

The improvement in resolution is dramatic, as illustrated for instance by the triple star, just right of the field centre. The distance between the two components which are closest to each other, is only 0.79 arcseconds. The Schmidt picture does not indicate any multiplicity, the 3.6 m barely resolves the system, while the NTT shows the three components, well detached from each other. Note also the resolution of the double system near the lower border, here the distance is 0.59 arcseconds.

Since the light is better concentrated on the detector, the higher resolution also leads to fainter limiting magnitudes. The 10 second NTT exposure reaches about magnitude 20. A simple extrapolation then predicts that a limiting magnitude well beyond 27 mag may be reached with the NTT within a reasonable exposure time. The actually achievable value will of course also depend on other factors, like the sky background and the accuracy of the tracking.

7.6 ESO Celebrates its New Technology Telescope

(**PR 03/90**; 5 February 1990; For release on 6 February 1990)

In the presence of a distinguished audience of ministers and high-ranking officials, as well as representatives of European industry and scientists from the member states, the European Southern Observatory today officially inaugurates its revolutionary 3.5-metre New Technology Telescope (NTT).

The festive act takes place simultaneously at ESO's Headquarters in Garching near Munich, F.R.Germany, and at the La Silla observatory in the Atacama desert, Chile. The two ESO sites, 12,000 kilometres apart, will be connected with a transatlantic TV link. During the ceremony, which commences at 14:15 MET (10:15 Chilean time), the NTT at La Silla will be remotely controlled from Europe via a satellite link.

Official speeches will be delivered by Dr. Antonio Ruberti, Minister of Research and Technology, Rome, Italy; Ambassador Jean-Pierre Keusch, Director of the Directorate of

International Organizations, Bern, Switzerland; Dr. Heinz Riesenhuber, Federal Minister of Research and Technology, Bonn, Federal Republic of Germany; Professor Hubert Curien, Minister of Science and Technology, Paris, France. On behalf of ESO, interventions will be made by the Professor Per-Olof Lindblad, President of the ESO Council; Professor Harry van der Laan, ESO Director General; Professor Massimo Tarenghi, Manager of the NTT project; Dr. Raymond Wilson, ESO Senior Optical Scientist; Daniel Hofstadt, Chairman of the La Silla Management Team. The Bishop of La Serena, the capital of the IV Region in Chile, in which La Silla is located, will pronounce a blessing of the new instrument.

At the inaugural ceremony, a 25-minute BBC-made film about ESO will be shown for the first time. The most recent astronomical images from the NTT will also be presented.

The inauguration will be followed by a scientific session with talks by three distinguished European astrophysicists, Professors G. Miley (Leiden, The Netherlands), F. Pacini (Florence, Italy) and G. Tammann (Basel, Switzerland).

The ESO NTT is a telescope of the 21st century and incorporates many new technologies, in particular within optics, mechanics and electronics. Moreover, the NTT building has been especially conceived to ensure a minimal influence on the observations.

Already during the night of "first light"[7], the NTT has demonstrated its enormous observational possibilities[8]. This has been fully confirmed by a great variety of astronomical observations, carried out by ESO staff astronomers in the course of the start-up phase. Unprecedentedly sharp images have been obtained (down to 0.33 arcseconds FWHM) and extremely faint objects have been recorded (under seeing conditions not unusual at La Silla, stars fainter than 25th magnitude are registered in 10-minute CCD exposures).

The first visiting astronomers from ESO member countries to the NTT were received at La Silla on January 17, 1990. The first programme was dedicated to Supernova 1987A in the Large Magellanic Cloud.

The NTT, while an excellent telescope in its own right, is also the forerunner of ESO's next telescope project, the 16-metre Very Large Telescope, which is expected to be ready in 1999. Consisting of four 8.2-metre telescopes, it will become the largest ground-based telescope in the world.

List of available NTT photos

This Press Release is accompanied by the following thirty-one photos, most of which are astronomical exposures obtained with the NTT.[9] "BW" and "C" indicate that the photo is available in BW and Colour, respectively.

- NTT image C01: The ESO New Technology Telescope Building
- NTT image BW01: The ESO New Technology Telescope Building
- NTT image C02: The ESO New Technology Telescope
- NTT image C03: The NTT 3.58-metre Main Mirror

[7]cf. ESO Press Release 03/89 of 23 March 1989.

[8]This Press Release is accompanied by a new brochure and a compendium with background information which summarizes the main features of the NTT. Further NTT images are available from the ESO Information Service upon request, cf. the attached list

[9]**Editor's note:** Only a few of these photos are shown here. Many of the images have been reproduced in a colour brochure, which was also available at the NTT Inauguration.

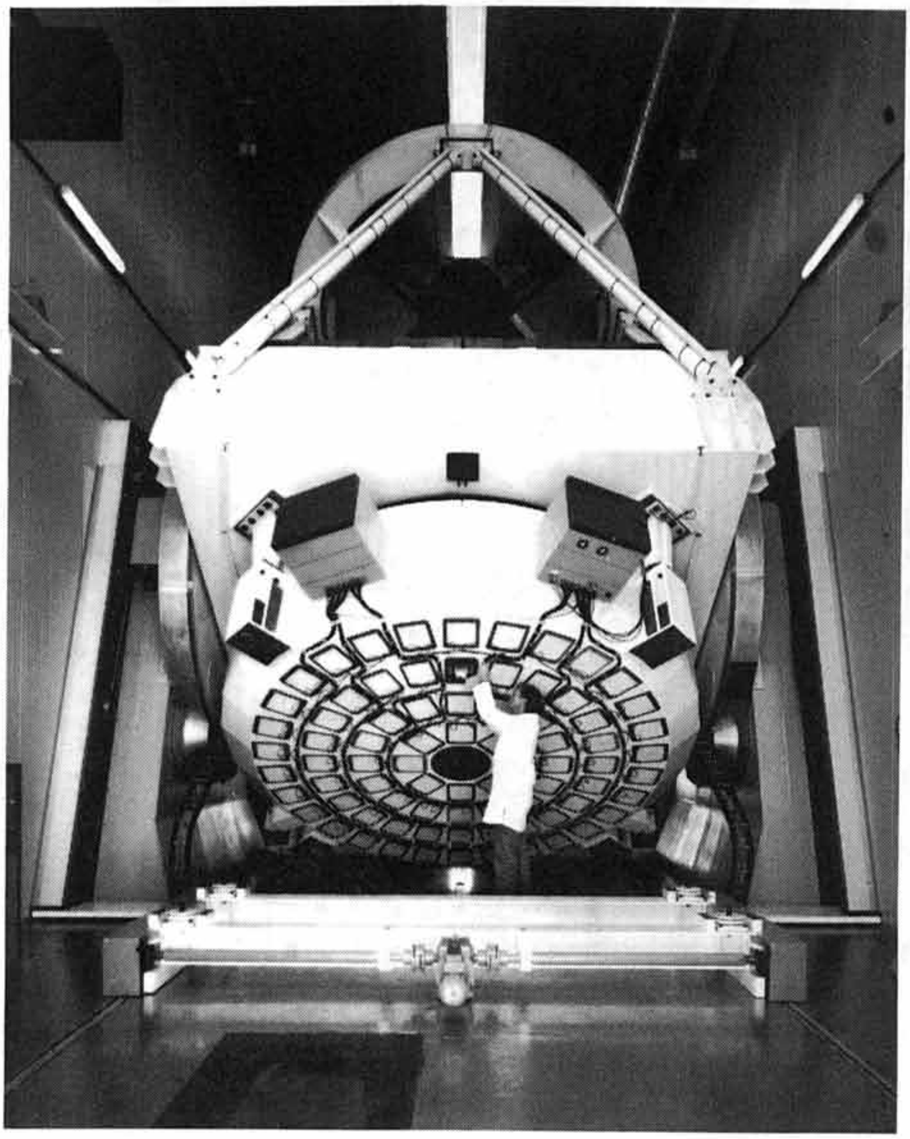


Figure 7.12: **The NTT mirror support system.** The 3.58-m main mirror of the ESO New Technology Telescope (NTT) rests on 78 "active" supports which are controlled by a computer. The system is refered to as "active optics" and was first developed at ESO for the NTT. In this view from below the main mirror, the arrangement of the support compartments in four concentric circles is seen. (PR 03/90: NTT image C04).

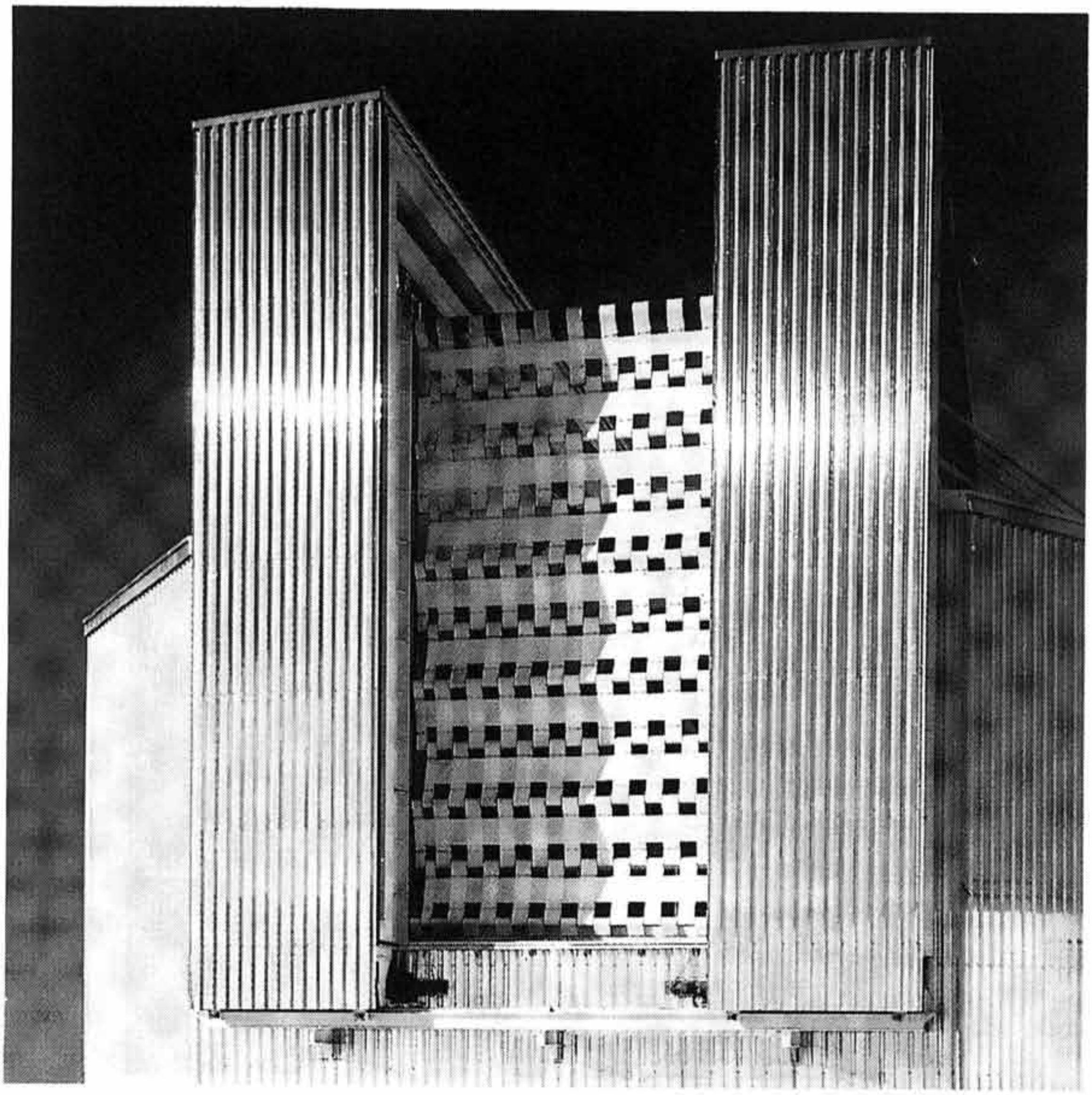


Figure 7.13: **The NTT windscreen.** During periods of high winds, the ESO New Technology Telescope is protected by a windscreen. It is elevated in front of the telescope to an appropriate height so that it does not impede the observations. In this way wind buffeting of the telescope structure is avoided and the NTT remains stable, even during wind speeds up to 70 km/h. (PR 03/90: NTT image C05).

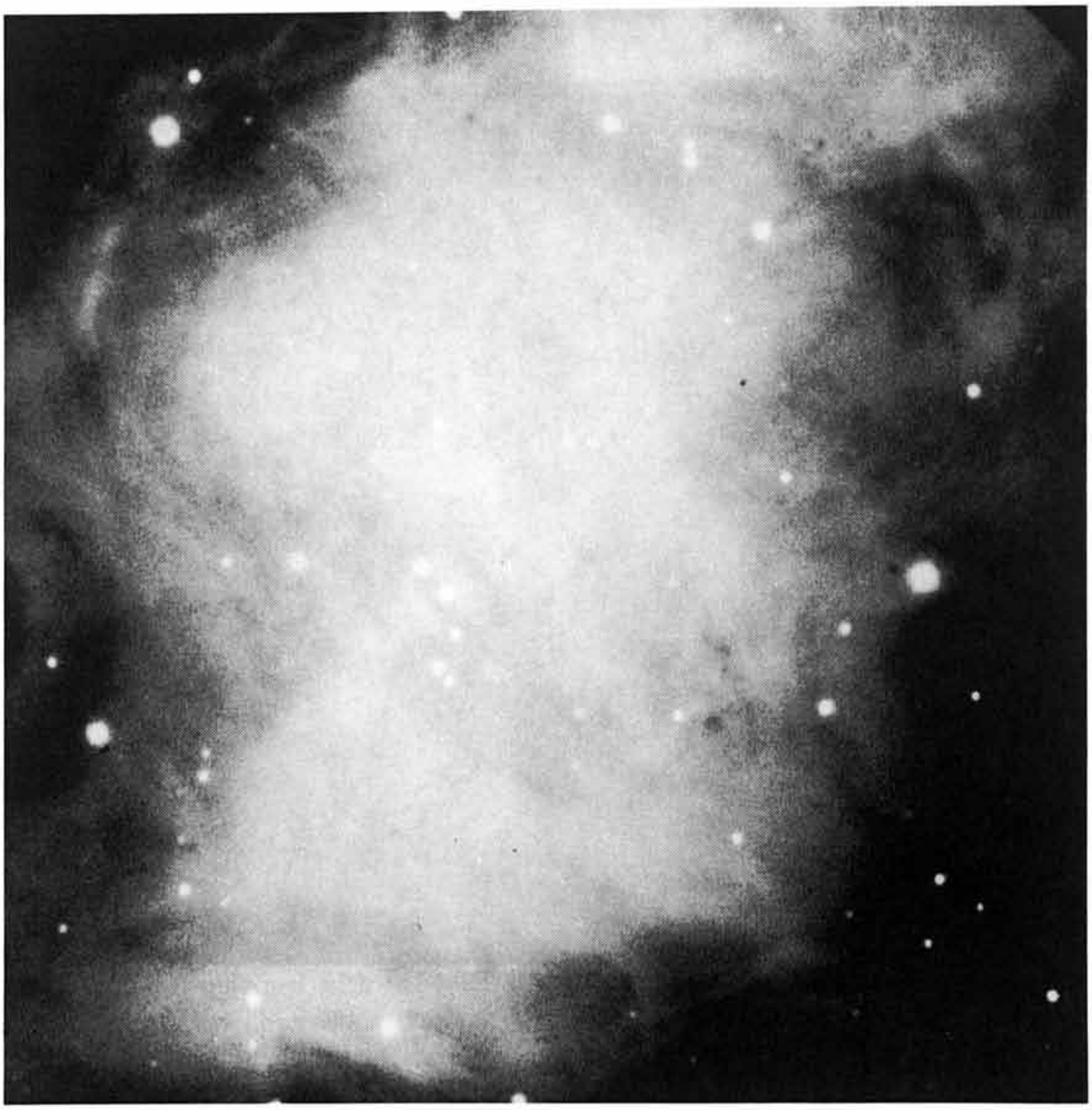


Figure 7.14: **The central area of the Crab Nebula.** The Crab Nebula, one of the most famous objects in the northern sky, was observed rather low above the La Silla horizon (altitude $\sim 35°$) with the NTT. Despite this adverse condition, the picture shows in great detail the complex structure. The Crab Nebula is the remnant of a supernova which exploded in the year 1054. This view of the central area was obtained with a CCD camera through a red broad-band filter. It depicts both the filamentary structure mainly emitting in the light of hydrogen atoms, as well as the diffuse background light from electrons being accelerated in the magnetic field in the nebula (the synchrotron process). The central pulsar is the lower right one of the two brighter stars near the centre. The "Wisp Nebula" lies to the right of the pulsar. *Technical data:* Exposure: 3 minutes; Filter: R; Seeing: 0.70 arcsec; Field: $\sim 140 \times 145$ arcsec^2; Date: 18 December 1989; Observer: Massimo Tarenghi. (PR 03/90: NTT image BW09).

Figure 7.15: **The peculiar galaxy ESO 060-IG26.** Far down in the southern sky, on the border betwenn the constellations of Volans and Carina, lies this small group of galaxies. It was first discovered at ESO in 1974. The central galaxy is visibly disturbed and now carries the designation "ESO 060-IG26". The less disturbed galaxy of elliptical shape is "ESO 060-G27". The distance to the system has not yet been measured, but is probably in excess of 150 million light-years. This excellent NTT exposure shows in hitherto unknown clarity the peculiar structure of the galaxies in this group. The strange forms are the result of a "recent" galaxy encounter, during which the mutual gravitational attraction pulled out stars and interstellar from ESO 060-IG26. Two fainter galaxies both have ringformed structures. It is not known whether the fainter of these really belongs to the group or is perhaps a background object. *Technical data:* Exposure: 10 minutes; Filter: R; Seeing: 0.54 arcsec; Field : 150 × 115 $arcsec^2$; Date: 24 December 1989; Observer: Massimo Tarenghi. (PR 03/90: NTT image BW24).

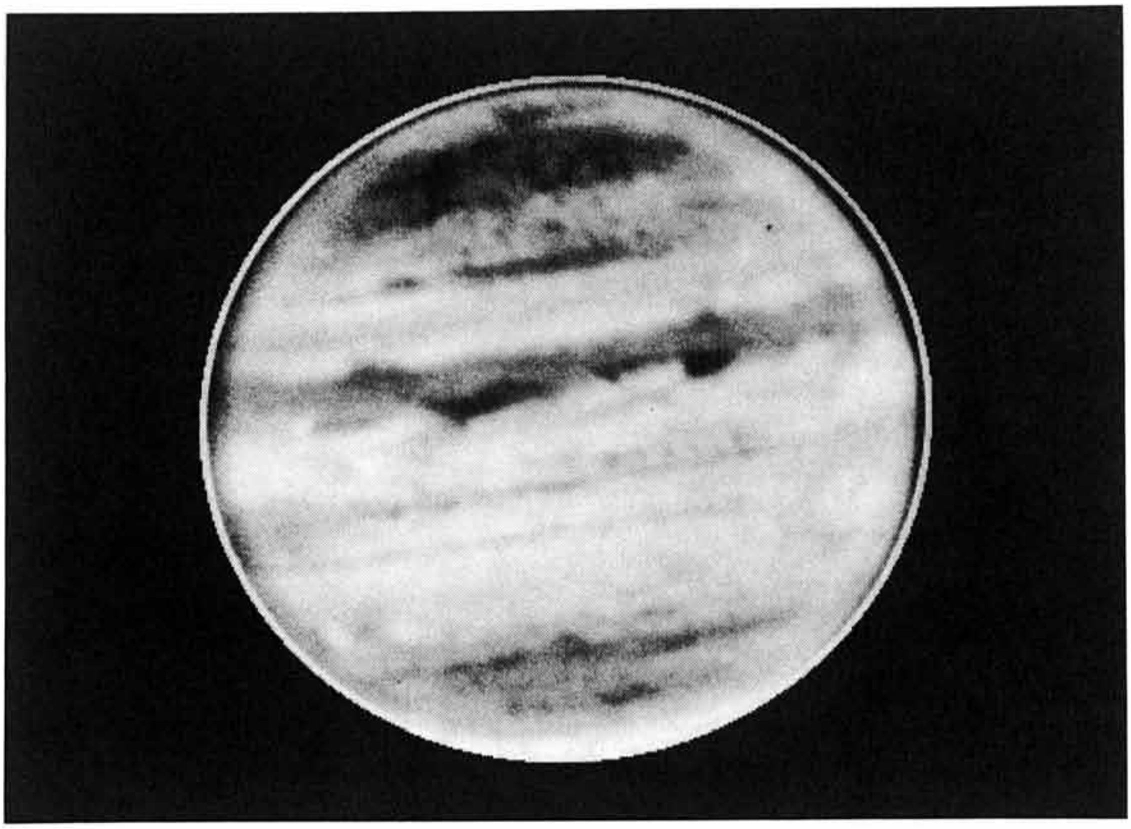


Figure 7.16: **Infrared image of giant planet Jupiter.** This a very-short CCD exposure of the giant planet Jupiter, obtained with the NTT through an infrared filter with a passband near 1000 nm. At the time of the observation, Jupiter was only 35° above the northern horizon at La Silla. The image has been subjected to moderate image processing: the intensity over the surface has been flattened to bring out small intensity variations over the entire surface. The image shows many of the bands in the Jovian atmosphere, and also some of the whirls in these bands. The Great Red Spot in the south is not very prominent in this spectral band, but is still faintly visible near the western rim. None of the satellites were in transit at the moment of observation. This is an excellent image by a ground-based telescope; the smallest features which can be perceived (that is the linear resolution) on Jupiter's disk measure about 2000 kilometres. *Technical data:* Exposure: 0.03 second; Filter: Gunn-z; Diameter of Jupiter's disk: 47 arcsec (equator); Seeing: 0.6 arcsecond; Date: UT January 6.174, 1990; Observer: J. Melnick; Image processing at ESO Headquarters with IHAP/MIDAS. (PR 03/90: NTT image BW28).

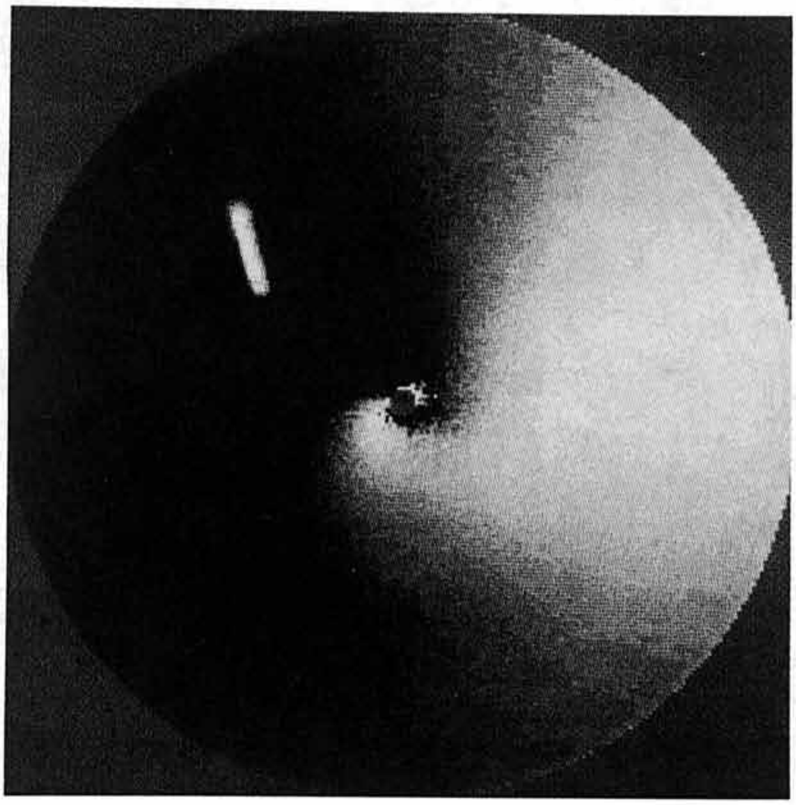


Figure 7.17: **A dust jet from Comet Austin (1989 c1).** This a computer-enhanced NTT image of the newly discovered Comet Austin (1989 c1) which may become comparatively bright during mid-April 1990 when it approaches the Sun to within 50 million kilometres. On May 25, it will be only 36 million kilometres from the Earth. After mid-April, it will be well visible from the northern hemisphere in the early evening. The image shows the presence of a comparatively bright, anticlockwise jet, emanating from the overexposed nucleus. It begins on the side which is facing the Sun and consists of dust particles which are released from the surface of the nucleus into space due to the heating effect of the Sun. The dust jet reflects the sunlight and can therefore be seen. On the date of exposure, the comet had not yet developed a real tail. At this time, the comet was nearly 300 million kilometres from the Earth and 255 million kilometres from the Sun, still outside the orbit of planet Mars. The magnitude was about 9. *Technical data:* Exposure: 5 minutes; Filter: R; Diameter of the field : 55 arcsec; Seeing: 1.2 arcsec; Date: January 23, 1990; Observer: P. Bouchet, J. Melnick, L. Pasquiri and Ch. Gouiffes. (PR 03/90: NTT image BW31).

- NTT image C04: The NTT Mirror Support System
- NTT image C05: The NTT Windscreen
- NTT image BW06: Herbig-Haro Object No. 34
- NTT image BW07: Herbig-Haro Object no. 46/47 in the Gum Nebula
- NTT image C08: The Butterfly Nebula
- NTT image BW09: The Central Area of The Crab Nebula (R)
- NTT image BW10: A Very Distant Globular Cluster
- NTT image BW11: Globular Cluster in the Fornax Dwarf Galaxy
- NTT image BW12: The Centre of the Tarantula Nebula
- NTT image BW13: Supernova Remnant N 49 in the LMC
- NTT image BW14: Light Echo Around SN 1987A
- NTT image C15: The Surroundings of Supernova 1987A in the LMC
- NTT image C16: Supernova 1987A in the LMC
- NTT image C17: The Antique Nebula Around SN 1987A
- NTT image BW18: Dwarf Galaxy NGC 625
- NTT image BW19: The Centre of NGC 1365
- NTT image BW20: Filaments Near the Centre of Messier 87
- NTT image BW21: The Seyfert Galaxy NGC 1068
- NTT image BW22: Violent Motion in NGC 1808
- NTT image BW23: The Dusty Galaxy NGC 6300
- NTT image BW24: The Peculiar Galaxy ESO 060-IG26
- NTT image BW25: Distant cluster of galaxies
- NTT image BW26: The "Einstein Cross" Quasar
- NTT image BW27: Blue Image of Giant Planet Jupiter
- NTT image BW28: Infrared Image of Giant Planet Jupiter
- NTT image BW29: Ultraviolet Image of Giant Planet Jupiter
- NTT image BW30: Comet Austin (1989 c1)
- NTT image BW31: A Dust Jet From Comet Austin (1989 c1)

Chapter 8

The Very Large Telescope (VLT)

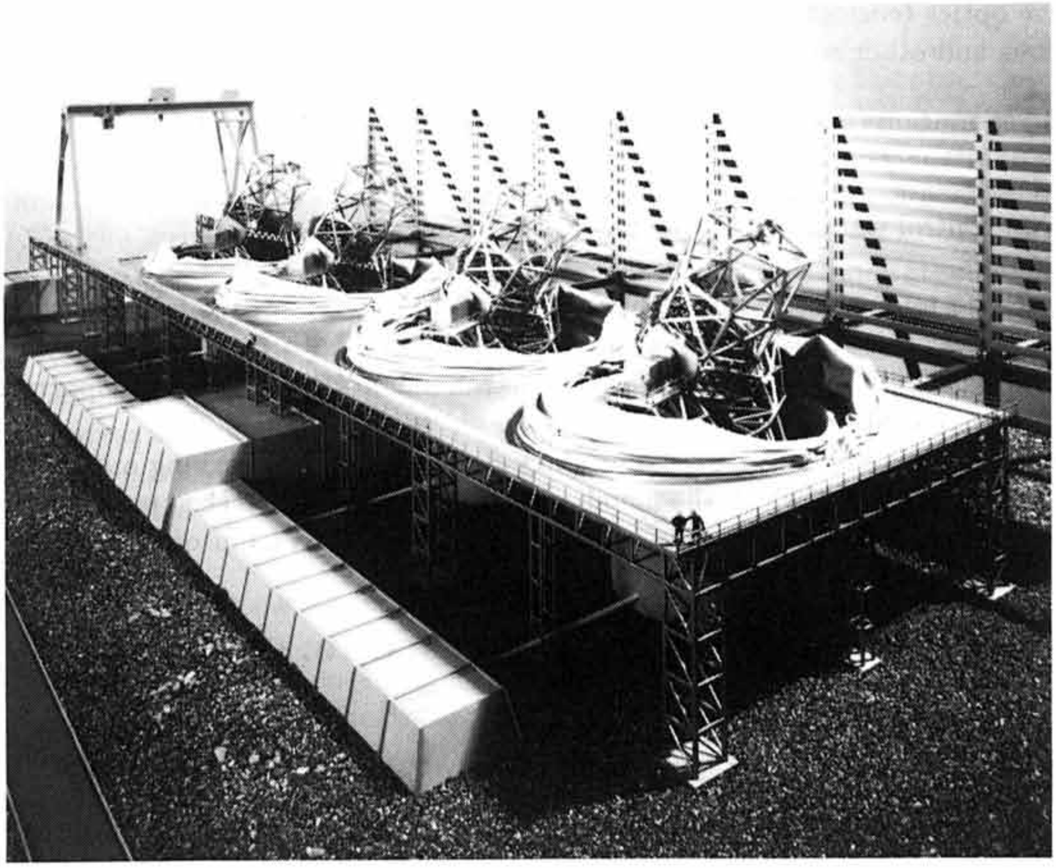


Figure 8.1: **Model of the ESO Very Large Telescope.** (PR 06/86; Colour)

8.1 ESO Presents the VLT: A 16 Metre Optical Telescope Project

(**PR 06/86**; 3 March 1986; For immediate release)

Note also PRESS CONFERENCE at ESO on 19 March 1986, 10:30 am

After several years of intensive studies, the European Southern Observatory now releases information to the public about its 16 metre telescope project. The concept here shown is the result of an extensive collaboration between European science and industry.

This major astronomical project, which aims at the construction of one of the world's largest optical telescopes by the 1990's will be further defined during forthcoming meetings of the various ESO technical committees. It will thereafter be submitted to the ESO member countries and it is hoped that funding at the level of 300 million DM can be ensured by late 1987. The realization of the project may start soon thereafter.

Since no optical telescope this large has ever been constructed, it is evident that new ground will be broken in several areas. Technologically, the VLT will profit from experience with ESO's 3.5 metre New Technology Telescope (see ESO Press Release 02/86 of 13 January 1986). Significant advances and industrial spin-off are expected, among others, in the fields of

- optical technologies (mirror materials, polishing techniques),

- active optics (correction in real time of image degradation due to atmospheric perturbations and other sources),
- instrumentation (extremely large holographic gratings and very large solid state detectors, data analysis), and
- remote control (monitoring, robots, telecommunications).

The 16 metre telescope will allow optical and IR observations of the faintest, most remote and oldest objects known in the universe. When equipped with the state-of-art instrumentation of the 1990's, it will provide European astronomers with unrivalled opportunities for front-line astronomical research.

A Press Conference will be held at the ESO Headquarters in Garching on Wednesday 19 March at 10:30 am, during which the members of the press will have the opportunity to meet the key scientific and technical people who are involved in the VLT project.

8.2 The ESO Very Large Telescope: One More Step Towards Reality

(**PR 08/86**; 4 October 1986; For immediate release)

The ESO Very Large Telescope (VLT) project[1] has passed an important milestone on its way towards realization. This week, more than 80 leading scientists and engineers from the ESO member countries (and beyond) made a detailed assessment of this ambitious project, which aims at the construction of the world's largest optical telescope. There was unanimous agreement that the present concept is near the optimal, that it is technologically feasible and can be realized within approximately 10 years after funding has been decided upon, and that it will allow European astronomers to perform new and spectacular investigations of the universe, unparalleled elsewhere. Completion is aimed at in 1997 but part of the VLT may become operational already in 1993.

The "Workshop on ESO's Very Large Telescope II" was held on the premises of the Giorgio Cini Foundation, Venice, Italy, from September 29 - October 2, 1986. The four days of discussion were appropriately closed with a very positive appraisal of the VLT project by Mr. Luigi Granelli, Italian Minister for Coordination of Scientific Research and Technology. The minister emphasized the important impact of the project on European science and technology and also stressed the leading role of Europe in this field.

During its meeting on October 3, 1986, the ESO Scientific and Technical Committee (STC), decided to recommend that the VLT project, in its present stage, be provisionally accepted by the ESO Council. It is expected that the definitive, detailed project will be presented to the Council in June 1987 and that a final decision, including the financing by member states, may be taken later in 1987. The cost of the VLT proper is estimated at 310 million DM plus 50-60 million DM for auxiliary instrumentation.

The VLT project consists of an array of 4 telescopes, each of which has a single-blank mirror with a diametre of 8 metres, resulting in a total, equivalent aperture of 16 metres.

[1]See also ESO Press Release 06/86 of March 3, 1986. Pictures of a model of the VLT and a colour brochure about the VLT are available upon request.

The telescopes can be used individually or combined, depending on the type of observations, giving an unprecedented degree of flexibility and greatly enhancing the observing efficiency. During the past two years, several specialized Working Groups have evaluated the scientific programmes which can be envisaged with the ESO VLT. Among these, observations of the faintest and most distant quasars and galaxies will have a profound impact on cosmology, the study of the structure and evolution of the universe in which we live. High-resolution spectral observations will allow a detailed chemical analysis of individual stars in our own and in other galaxies, contributing to our knowledge of the evolution of galaxies and the genesis of elements. When used in the interferometric mode, the VLT will achieve angular resolutions in the milliarcsecond range and permit observations of the innermost regions of for instance starforming areas and galaxy nuclei which may have black holes near their centres. These are but a few of the many, extremely interesting observational possibilities with the ESO VLT which were identified by the Working Groups and discussed in Venice.

The technologically most advanced, auxiliary instrumentation is needed to perform these observations and much time was dedicated to this central subject. A great variety of instruments, like photometers and spectrophotometers, visual as well as infrared, were proposed. Based on these suggestions, a preliminary list of fundamental instrumentation for the VLT will now be established and circulated for further discussion in the user community. It was stressed that it is the intention to involve national laboratories in the member countries in the construction of these complicated, high-technology instruments, although a major part of the necessary funds will have to come through ESO.

Among the still unresolved questions is the choice of site for the VLT. Detailed meteorological observations have confirmed the excellency of the La Silla site, but even better observing conditions may possibly be found on the top of mountains further north in the Atacama desert. Following local investigations, a promising site has been identified at Cerro Paranal, about 150 kilometres south of the town of Antofagasta. There is a clear consensus that the "seeing" (a measure of the atmospheric turbulence which degrades the sharpness of astronomical images) will play a decisive role in the choice of the VLT site. However, other considerations like cost of development of a new site and increased cost of operation outside La Silla must also be taken into account. In this context, a reduction in operating costs may be obtained by extended use of remote control of the VLT, for instance from Europe. This is now thought feasible, in particular after a very successful experiment earlier this year, during which a 2.2 m telescope on La Silla was controlled via a computer-to-computer satellite link by astronomers at the ESO Headquarters in Garching.

In order to keep to the tight VLT schedule, ESO intends to issue a call for tenders for the first 8 metre mirror blank, already in 1987. The first 8 m telescope could become operational in 1993 and the other three within the following 4 years. Whereas the first mirror will be made of conventional material, on-going tests at ESO of other materials, like aluminium and steel, may influence the choice for the remaining three blanks. All mirrors will be exceptionally thin in order to reduce weight and thereby significantly save cost. ESO has recently successfully tested the principle of "active" optics, by computer controlling the surface of a thin 1 metre mirror. This new concept will play a decisive role in the VLT, so that it can achieve a superior performance when it enters into operation.

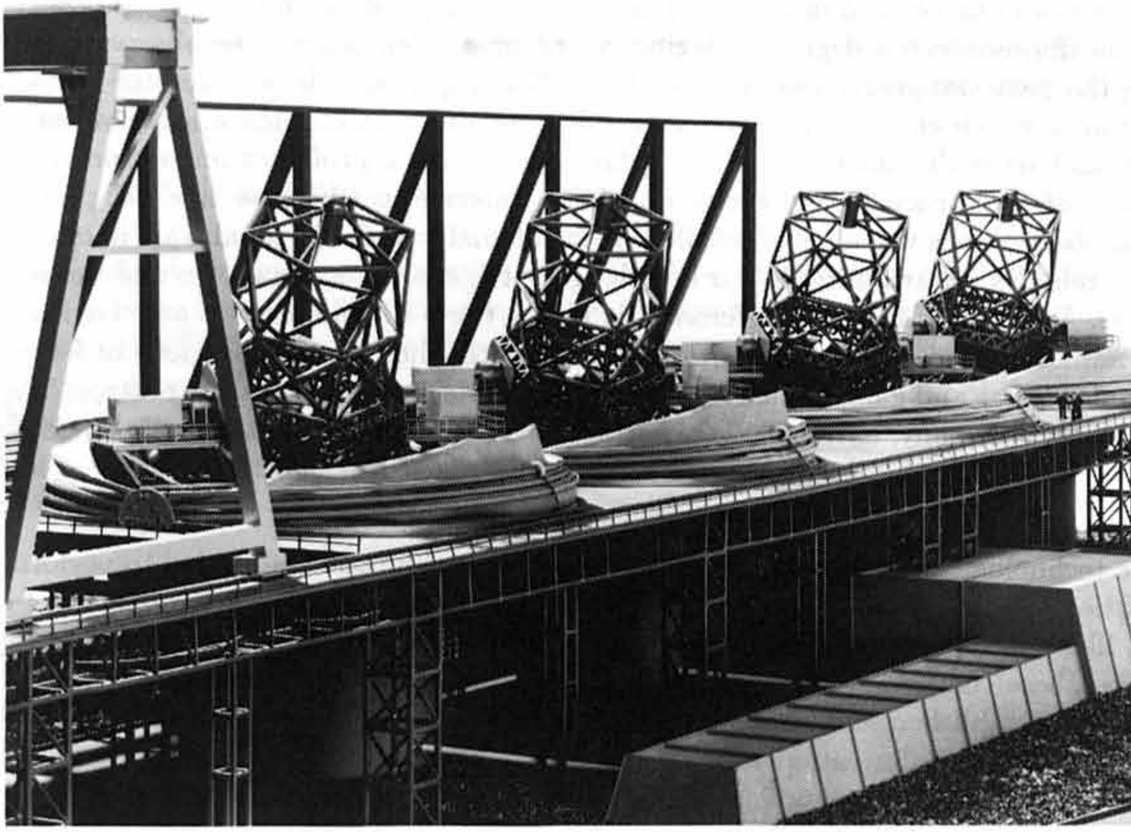


Figure 8.2: **The ESO 16 m Very Large Telescope (VLT).** The ESO VLT (here a model) consists of four connected telescopes, each with an 8 metre main mirror. They will operate in the open air and can be protected by inflatable shelters. They are served by a crane (left) that moves on a supporting platform with a length of about 120 metres. (PR 16/87; BW)

8.3 Europe Decides To Build The World's Largest Optical Telescope

(**PR 16/87**; 8 December 1987; For immediate release)

The ESO Council today gave the green light to the ESO Very Large Telescope (VLT)[2], an extraordinary astronomers' dream and an amazing engineering challenge. The VLT is to be the largest telescope in the world and Europe's superior eye to the Universe of planets, stars and galaxies, an eye so sharp and sensitive that new wonders will be revealed in the remotest regions of space and time.

An ambitious project for European science and industry

The representatives of the eight member states (Belgium, Denmark, the Federal Republic of Germany, France, Italy, the Netherlands, Sweden and Switzerland) agreed that the European Southern Observatory shall embark upon the realization of this marvellous instrument. This

[2]See also ESO PR 08/86 of 4 October 1986. A colour brochure about the VLT is available upon request. This Press Release is accompanied by a B/W photo of a model of the VLT. (Ed. note: The photo of the ESO Council in session at the moment of this historical decision was made available the following day.)

Figure 8.3: **The ESO Council in session on 8 December 1987, at the moment of the historical decision to construct the Very Large Telescope (VLT).** (PR 16/87; BW)

decision expresses Europe's confidence in the ambition of her astronomical community and the ingenuity of her high-tech industry; together they will ensure that Europe will be second to none in the exploration of the Universe for a long time to come. The VLT is an essential complement of Europe's astronomical research activities from space vehicles.

Following detailed project studies (1984 - 87), it is now expected that it will take about 10 years to complete the construction, but that part of the VLT may become operational already in 1994-95. The total cost is around 382 million DM, of which 309 million is for the telescope proper and 48 million for the attached instrumentation. The rest is for the site preparation.

Exciting research opportunities

Under ESO management, and in collaboration with scientific institutions in the member countries, it is the intention that the high-tech VLT shall be constructed by European industry. Considerable technological spin-off is expected in various fields, including optics, mechanics and electronics. Once ready, the enormous telescope will be installed in the Atacama desert, at one of the best observing sites in the world, allowing European astronomers to perform new and spectacular investigations of the Universe, unparalleled elsewhere.

To mention but a few, these include the search for planets around nearby stars, the study of stars being born in interstellar clouds, and a look into the innermost regions of active galaxies which may harbour black holes at their centres. As the world's largest optical telescope, the VLT will enable scientists to probe hitherto unexplored, extremely distant regions in the Universe. Above all, its unique combination of light-gathering power and very high angular resolution will undoubtedly lead to wholly unexpected discoveries.

A new technological concept

The ESO VLT will consist of an array of 4 telescopes, each of which has a single-blank mirror with a diametre of 8 metres, resulting in a total, equivalent aperture of 16 metres. The telescopes can be used individually or combined, depending on the type of observations, giving an unprecedented degree of flexibility and greatly enhancing the observing efficiency.

All VLT mirrors will be exceptionally thin in order to reduce weight and thereby significantly save cost. ESO has recently successfully tested the principle of "active" optics, by computer controlling the surface of a thin 1 metre mirror, and this principle has also been incorporated into ESO's 3.5 m New Technology Telescope (NTT)[3], which will enter into operation at the ESO La Silla observatory in late 1988. This revolutionary concept will play a decisive role in the VLT, and will permit it to achieve a superior performance.

The technologically most advanced, auxiliary instrumentation is needed for the VLT, and a great variety of instruments will be built. Among the fields which are high on the list of priorities, one may mention: infrared imaging and spectroscopy, low resolution spectroscopy and imaging, high resolution spectroscopy and interferometry.

Site still to be chosen

The future site for the VLT has not yet been chosen. Detailed meteorological observations have confirmed the excellence of the La Silla site, but even better observing conditions may

[3]Colour photos of the NTT at the factory are available upon request. See also the *ESO Messenger*, No. 49, p. 36.

possibly be found on the top of mountains further north in the Atacama desert. Following local investigations, a promising site has been identified at Cerro Paranal, about 100 kilometres south of the town of Antofagasta. The final decision about the site is expected to be made about 3 years from now.

Remote control

Traditionally optical telescopes are used by astronomers who travel to the mountain to carry out their observations. Computer control and the latest means of satellite-borne telecommunications enable entirely new and flexible methods of telescope use. In the future, astronomers in Europe will control the VLT, with all its science options and technical possibilities at the distant South American site, from a console at the ESO Headquarters or perhaps at their home institute. ESO has already demonstrated that it is feasible to operate a telescope at a distance, and remote observing with a 1.4 m and a 2.2 m telescope on La Silla is regularly done from the ESO Headquarters in Garching near Munich, via a satellite link[4].

8.4 ESO Places Contract for World's Largest Mirror Blanks

(**PR 08/88**; 12 September 1988; For release on 12 September 1988, 12.00 hours)

After a period of intense negotiation, the European Southern Observatory and Schott Glaswerke, Mainz (F.R.Germany) reached agreement about the delivery of four giant mirror blanks for the ESO Very Large Telescope (VLT)[5]. The blanks will be made of Zerodur, a glass ceramic material. Each will have a diameter of 8.2 metres, an area of more than 50 square metres and a thickness of only 17.5 centimetres.

These optical mirrors are far larger than any others ever made for any purpose, requiring radically new, technological procedures.

In 1984, Schott performed the preliminary design study for these blanks. Since then, while the VLT design progressed at ESO, Schott undertook a technical development programme which culminated in the successful manufacture of spin-cast Zerodur blanks with diameters up to 4 metres.

The same technique will be used for the VLT blanks; it consists of pouring the molten material into a rotating, concave form. Due to the centrifugal force, the surface of the spinning blank takes on the desired concave shape, thereby minimizing the amount of material to be removed during the subsequent grinding phase. The use of the heat-insensitive Zerodur material will also allow fast testing during polishing.

The contract was signed this morning at the ESO Headquarters in Garching bei München, by Professor Harry van der Laan, Director General of ESO, and Mr. Erich Schuster, Member of the Board of Directors of Schott Glaswerke.

The decision to grant this important contract to Schott represents a crucial milestone in the VLT project and a major step forward in European optical technology.

[4]See ESO PR 14/87 of 29 September 1987.

[5]See ESO Press Release 16/87 of 8 December 1987 about the decision to build the VLT.

Figure 8.4: **ESO and Schott sign contract for world's largest mirror blanks.** After a period of intense negotiation, the European Southern Observatory and Schott Glaswerke, Mainz (F.R.Germany) reached agreement about the delivery of four giant mirror blanks for the ESO Very Large Telescope (VLT). The blanks will be made of Zerodur, a glass ceramic material. Each will have a diameter of 8.2 metres, an area of more than 50 square metres and a thickness of only 17.5 centimetres. These optical mirrors are far larger than any others ever made for any purpose, requiring radically new, technological procedures. The contract was signed on September 12, 1988 at the ESO Headquarters in Garching bei München, by Professor Harry van der Laan (right), Director General of ESO, and Mr. Erich Schuster (left), Member of the Board of Directors of Schott Glaswerke. The decision to grant this important contract to Schott represents a crucial milestone in the VLT project and a major step forward in European optical technology. (PR 08/88; BW)

8.5 ESO Contract for Polishing of VLT Mirror Blanks Goes to R.E.O.S.C.

(**PR 05/89**; 21 July 1989; For release on 25 July 1989 at 12.00 hours)

The European Southern Observatory and R.E.O.S.C. Optique (Recherches et études d'optique et de sciences connexes), located at Ballainvilliers near Paris, France, have reached agreement on a contract for the polishing of four giant mirror blanks for the ESO Very Large Telescope (VLT)[6].

The four blanks will be made at Schott Glaswerke, Mainz, F.R.Germany. They will be the largest ever produced and will be made of Zerodur, a glass ceramic material. Each will have a diameter of 8.2 metres, an area of more than 50 square metres and a thickness of only 17.5 centimetres.

The first blank is expected to be ready in 1993 and will then be transported from Schott to R.E.O.S.C. by road and water in a specially constructed case.

At R.E.O.S.C., it will first be coarsely figured on a giant grinding machine. When the surface of the mirror approaches the desired form, the mirror will be transferred to a second machine with which the final, highly delicate polishing will be performed. Both of these very complex machines will be constructed on the R.E.O.S.C. premises during the next years.

After thorough testing, the mirror will be packed for transport to the VLT observatory in Chile. It is expected to arrive there in 1995, soon after completion of the mechanical structure of the first of the VLT's four unit telescopes.

The polishing schedule of the other three mirrors aims at delivery in Chile at one year intervals, i.e. in 1996, 1997 and 1998, so that the entire VLT array of four telescopes can be assembled in 1998.

When ready, the VLT mirrors will have the best possible figure of all large ground-based telescopes. The optical performance will rival that of the recently installed ESO New Technology Telescope (NTT)[7].

As is the case for the NTT, the optimal shape of the large and flexible VLT mirrors will be ensured by "active optics". In the VLT system about 200 computer controlled precision actuators will support each of the 8-m mirrors.

R.E.O.S.C. and ESO have collaborated on earlier projects. In 1975, this firm successfully polished the large fused-silica mirror for the ESO 3.6 m telescope that entered into operation the following year. With its excellent optical quality, this "classical" 3.6 m telescope has since been a rich source of important observational data for European astronomers.

R.E.O.S.C. has also polished a very thin 1-metre mirror (thickness 18 mm) of Zerodur for ESO. It was used at the ESO Headquarters in the prototype "active optics" system on which the highly successful New Technology Telescope is based.

The contract for the polishing of the four VLT mirrors was signed this morning at the ESO Headquarters in Garching bei München, by Professor Harry van der Laan, Director General of ESO, and Mr. Dominique Ruffi de Ponteves, Chairman and General Manager of R.E.O.S.C..

The decision to entrust R.E.O.S.C. with this important task is a key event in the VLT

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[6]See ESO Press Releases 16/87 of 8 December 1987 (Decision to build the VLT) and 08/88 of 12 September 1988 (Manufacture of the blanks).

[7]See ESO Press Release 03/89 of 23 March 1989 (and 03A/89).

Figure 8.5: **Polishing of VLT mirrors: ESO and R.E.O.S.C. sign contract.** The European Southern Observatory and R.E.O.S.C. Optique (Recherches et études d'optique et de sciences connexes), located at Ballainvilliers near Paris, France, have reached agreement on a contract for the polishing of four giant mirror blanks for the ESO Very Large Telescope (VLT). The contract was signed on July 25, 1989, at the ESO Headquarters by Professor Harry van der Laan, Director General of ESO and Mr. Dominique Ruffi de Ponteves, Chairman and General Manager of R.E.O.S.C.. In short speeches, both parties expressed satisfaction about the conclusion of this important contract. The photo shows Mr. D. Ruffi de Ponteves (centre), Dr. D.Enard (ESO, right of centre) and the ESO Director General (right) after the signing ceremony. The decision to entrust R.E.O.S.C. with this important task is a key event in the VLT project. It also means that this enormous project, a flagship of European science and technology and soon to become the largest optical telescope in the world, is keeping to its original time schedule. (PR 05/89; BW)

project. It also means that this enormous project, a flagship of European science and technology and soon to become the largest optical telescope in the world, is keeping to its original time schedule.

8.6 The Best Site for the Biggest Telescope: The VLT Goes to Paranal

(PR 11/90; 4 December 1990; For immediate release)

ESO's Council chooses Cerro Paranal for the VLT Observatory

The Council of the European Southern Observatory, in session today at the ESO Headquarters in Garching near Munich, unanimously decided that the world's largest optical telescope, the 16-metre equivalent Very Large Telescope, shall be placed on *Cerro Paranal*[8], an isolated mountain top at 2664 m altitude in the central part of Chile's Atacama desert, some 130 kilometres south of the town of Antofagasta and 12 kilometres from the Pacific coast.

This decision by the delegates from ESO's eight member states is based on the most extensive, comparative meteorological investigation that has ever been carried out in connection with the selection of an observatory site. For more than six years, continuous, accurate measurements have shown that Paranal is the best continental site known in the world for optical astronomical observations, both in terms of number of clear nights and stability of the atmosphere above.

In anticipation of the choice of Cerro Paranal as the future site of the VLT Observatory, the Chilean Government has donated a 725 km^2 area around Paranal to ESO in order to ensure the continued protection of the site against all adverse influences, in particular light pollution and mining activities.

The advantages of Paranal

The meteorological and climatological investigation incorporated a detailed comparison between Paranal and the present site of ESO's telescopes, La Silla, by means of identical measuring equipment. Despite La Silla's world-wide reputation for excellent observing conditions, Paranal was found to be even better, mainly because of its location in a more stable and drier climate in the most arid part of the Atacama desert.

Interestingly, in terms of atmospheric stability La Silla was found to be better than previously thought, with a measured median "seeing"[9] of 0.76 arcsec. Paranal is better with a mean of 0.66 arcseconds, but of even greater importance is the fact that the number of clear nights of exceptional quality (seeing better than 0.5 arcsecond) is about 2.4 times higher on Paranal (16% of all nights) than on La Silla (7 %). Indeed, during one night in September

[8]This Press Release is accompanied by a geographical map showing the location of Paranal, and an aerial view of the mountain.

[9]Astronomical "seeing" is a measure of the sharpness of stellar images as seen in a telescope, introduced by the turbulence in the atmosphere above; the smaller it is, the sharper are the images. With sharper images, more details can be seen in celestial objects and the fainter and more remote are the objects that can be seen at all. A typical seeing in Europe is 2 - 3 arcseonds. For observations in the infrared region of the spectrum, the adverse effects of the seeing can be overcome by "adaptive optics", cf. ESO Press Release 05/90 of 23 May 1990.

Figure 8.6: **Cerro Paranal**, 2664 metres above sea level, is one of the highest summits in the coastal Cordillera of the Atacama desert. It is located in one of the driest regions of the world, about 130 kilometres south of the city of Antofagasta. It will become the site of the largest optical telescope in the world, the ESO 16-metre equivalent Very Large Telescope (VLT). The preparations will start in 1991 and it is expected that the installation of the four 8.2 metre unit telescopes of the VLT on Paranal will have been completed in 1999. This aerial picture was taken in late 1990 from the South; the Pacific coast is to the left, at a distance of 12 km. The constructions at the left are the living quarters for the site survey team, in place since 1983. On the top of the mountain various instruments are installed which permanently monitor the atmospheric quality and perform meteorological measurements. There are several other, slightly lower summits in this area, for instance to the right, which are also very suitable for high-quality astronomical work. (PR 11/90; Colour)

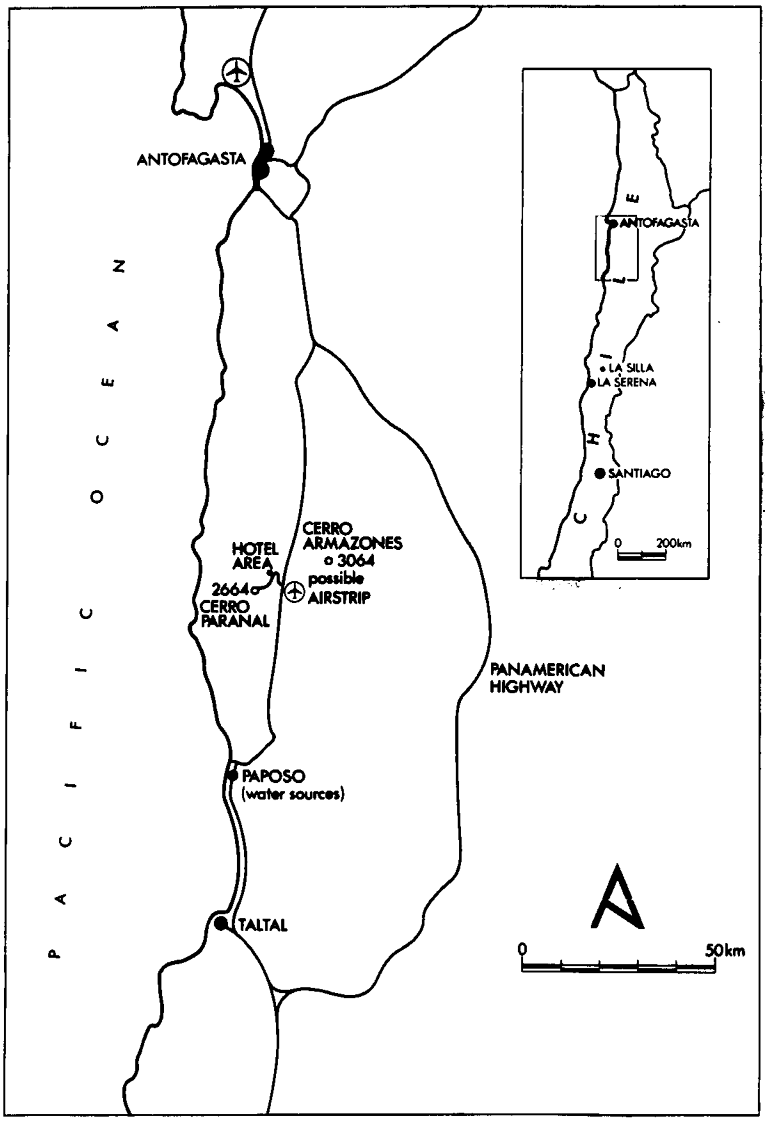

Figure 8.7: **A map of northern Chile, with the location of Cerro Paranal indicated.** (PR 11/90)

1990, the mean seeing at Paranal (over 10 hours) was measured with a "seeing monitor" as only 0.32 arcsecond, reaching the incredibly good value of 0.25 arcseconds during three consecutive hours.

The atmospheric conditions on Paranal will allow the VLT to take full advantage of its unique imaging and spectroscopic capabilities so that fainter and more distant objects can be observed than with any other telescope in the world. Moreover, when the VLT is supported by "adaptive optics", it will produce images that are almost as sharp as if it were in space. In the "interferometric" mode, when the light from the four 8.2-m telescopes is combined coherently (in the same phase), the resolving power of the VLT is further increased, so that even finer details can be seen. Under optimal circumstances, it should be possible to achieve a resolution of 0.0005 arcseconds. This would correspond to imaging 1 metre objects on the surface of the Moon.

Because of the extremely low atmospheric water vapour content in the Paranal region, probably the driest area on the surface of the Earth, this site is also highly suited for astronomical observations in the infrared and submillimetre wavelength regions.

Organizational issues

The decision to place the VLT Observatory at Paranal implies that some years from now ESO will operate two geographically separate observatories in Chile. In order to ensure the optimal functioning of both units, it will be necessary to adjust ESO's set-up in Chile.

The efficient running of the La Silla Observatory, on which so many European astronomers are dependent, will of course continue to have high priority, but it is expected that a certain streamlining will have to be made of the operations there. The ESO management is now looking into how this can best be done and will, in agreement with the ESO Council, implement the necessary changes over the coming years.

Next steps

ESO is proceeding with the detailed planning of the VLT Observatory. The next step will be to decide about the exact configuration of the four 8.2-metre telescopes and their enclosures. Several major contracts will be signed with European industry during the coming year, for instance for the construction of the mechanical structure of the giant telescopes and also the buildings which will be erected on Paranal. The first of the 8.2-m telescopes will be ready on Paranal in 1995.

Chapter 9

Auxiliary Technology

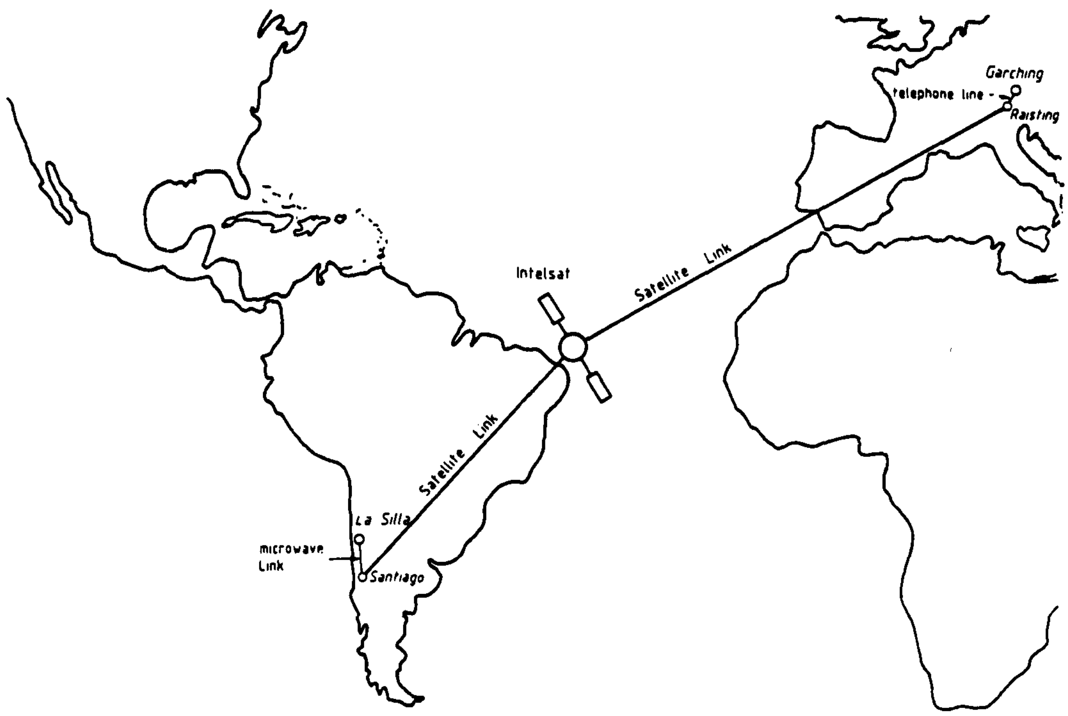

Figure 9.1: **The link between Garching and La Silla.** (PR 14/87)

9.1 Intercontinental Remote Control: Observing with La Silla Telescopes from Garching

(**PR 14/87**; 29 September 1987; For immediate release)

ESO announces the establishment of the world's first system for interactive remote control of ground-based telescopes on another continent.

Since July 1st, 1987, European astronomers can perform astronomical observations with a telescope at the ESO La Silla observatory in Chile, while remaining at the ESO Headquarters in Garching bei München. This is made possible by a computer-to-computer connection via a satellite link between the ESO installations in Europe and South America.

From the "Remote Control Room" in Garching, the astronomer controls his telescope almost 12000 km away, at the ESO La Silla observatory in the Atacama desert, about 600 km north of Santiago de Chile. The results of the observations, for instance direct images or spectra, are sent back via the same link in digital form. The astronomer can immediately inspect his data and decide about how to best continue his observations.

The system currently works on the 2.2 m telescope. It will be extended to the 1.4 m CAT in early October 1987 and later to other telescopes on La Silla. It is expected that more and more astronomers will prefer to stay in Europe and perform their observations at La Silla by remote control, avoiding the long and expensive trip to South America.

The remote control system includes transfer of TV-images of the focal field of the telescope, in order to center correctly the objects which shall be observed. There is also voice and telex connection between the observer in Europe and the night assistant in Chile, who is present in case of technical failure. The computer-to-computer data transfer takes place at 12000 baud. About 25 seconds are needed to transfer a TV picture. Spectra of astronomical objects are transmitted in less than 4 minutes and it takes 7 minutes to send a full CCD frame with about 164.000 image elements (320 x 512 pixels).

A major advantage is the possibility of very flexible scheduling of telescope time and short term reservation. Shorter observing programmes which do not justify the expense of travel to Chile, have now become possible. Recovery of lost observing time may also become feasible.

In the future, the leased line will also be used for other ESO communications during the daytime, ensuring even closer cooperation between the observatory and the Headquarters.

The operation of the present system is providing valuable experience for the remote control of the next large telescope on La Silla, the New Technology Telescope (NTT), which will become available towards the end of 1988. It is also expected that most observations with the ESO Very Large Telescope (VLT) will be performed by remote control from Europe. The VLT will consist of four individual telescopes with 8-metre mirrors, giving it the equivalent aperture of a 16-metre telescope. When ready in the late 1990's, it will be the world's largest optical telescope.

9.2 Catching a Twinkling Star: Successful Tests of Adaptive Optics Herald New Era

(**PR 06/89**; 24 October 1989; For release on 26 October)

An old dream of ground-based astronomers has finally come true, thanks to the joint development of a revolutionary new technique, *adaptive optics*, by ESO and ONERA[1], LdM[2] and Observatoire de Paris in France.

It effectively eliminates the adverse influence of atmospheric turbulence on images of astronomical objects, yielding images almost as sharp as if the telescope were situated in space. An editorial appraisal of this important break-through appears in today's issue of the scientific journal *Nature*.

Why adaptive optics ?

Ever since the invention of the telescope in the early 17th century, astronomers have had to accept that the sharpness of astronomical images obtained with ground-based instruments is severely limited by a factor which is beyond their control, that is the turbulence in the Earth's atmosphere.

This turbulence is perceived by the eye as the twinkling of stars. High above the observer, mostly at altitudes between 5 and 10 kilometres, there are many small, moving cells of air, each of which produces a "sub-image" of the same star; the result is a swarm of moving sub-images. (Compare with the air above a toaster or a hot radiator.)

To a naked-eye observer, the number of sub-images which fall within the periphery of his eye pupil changes all the time. The perceived intensity of the star varies; the star twinkles.

In a telescope, the size (that is, the sharpness) of a stellar image, is equal to the area within which this swarm of sub-images moves. The greater the air turbulence, the larger is

[1]Office National d'Etudes et de Recherches Aérospatiales.

[2]Laboratoires de Marcoussis (formerly CGE, now Aérospatiale).

this area and the less sharp are the resulting images. Because of this effect, an increase of the size of a telescope does not improve its ability to resolve details of astronomical objects, once the aperture of the telescope exceeds 10 or 20 cm; the best achievable image sharpness, even by high-quality, large astronomical telescopes, is effectively determined by the state of the atmosphere, and is referred to as "astronomical seeing" during the exposure. For this reason, large telescopes are placed at sites where the atmospheric turbulence is as small as possible, for instance La Silla.

For a long time it was thought impossible to avoid this natural limit. Now, for the first time, this old problem has been demonstrably solved.

A break-through in optical technology

In a major technological break-through in ground-based astronomy, a new device, known as the *VLT Adaptive Optics Prototype*[3], has now proved its ability to overcome this natural barrier during a series of successful tests in the period 12 - 23 October 1989. They were performed at the coudé focus of the 1.52 m telescope at the Observatoire de Haute Provence (OHP), France (see photo).

The extensive tests showed that it was possible effectively to "neutralize" the atmospherically induced smearing of a stellar image by continuously monitoring the motion of the sharp sub-images and then focussing them into one spot by means of a deformable mirror. In this way stellar images were obtained at infrared wavelengths whose sharpness was only limited by the telescope aperture (this is referred to as *diffraction limited imaging*).

On each of ten nights, exposures were made of about 10 bright stars through 4 or 5 infrared filters. Several integrations were made through each filter without the adaptive device, immediately followed by an equal number with the device activated. Depending on the brightness of the observed star, each exposure lasted between 10 and 100 seconds. For wavelengths of 3.5 μm and longer, the diffraction limit was always reached, irrespective of the atmospheric turbulence; it was often reached at 2.2 μm (see the figure) and a noticeable improvement was seen at 1.2 μm.

How does it work ?

The adaptive optics technique can also be described in terms of correcting the atmospherically introduced distortions of the light wavefront from the star.

It is based on a feed-back loop, and the optical system contains a deformable mirror which can change its surface profile in a way that exactly compensates for the distortions of the light wavefront after it has passed through the atmosphere. The information about how to deform the mirror comes from a wavefront sensor which allows to measure the shape of the distorted light wavefront. It requires a very fast and powerful computer to calculate how the actuators located behind the deformable mirror have to push and pull the mirror surface.

The present prototype system has a mirror with 19 actuators. The mirror is deformed, hence the wavefront is corrected, 100 times per second.

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[3]For more information about the ESO Very Large Telescope Project, cf. ESO Press Releases 16/87, 08/88 and 05/89.

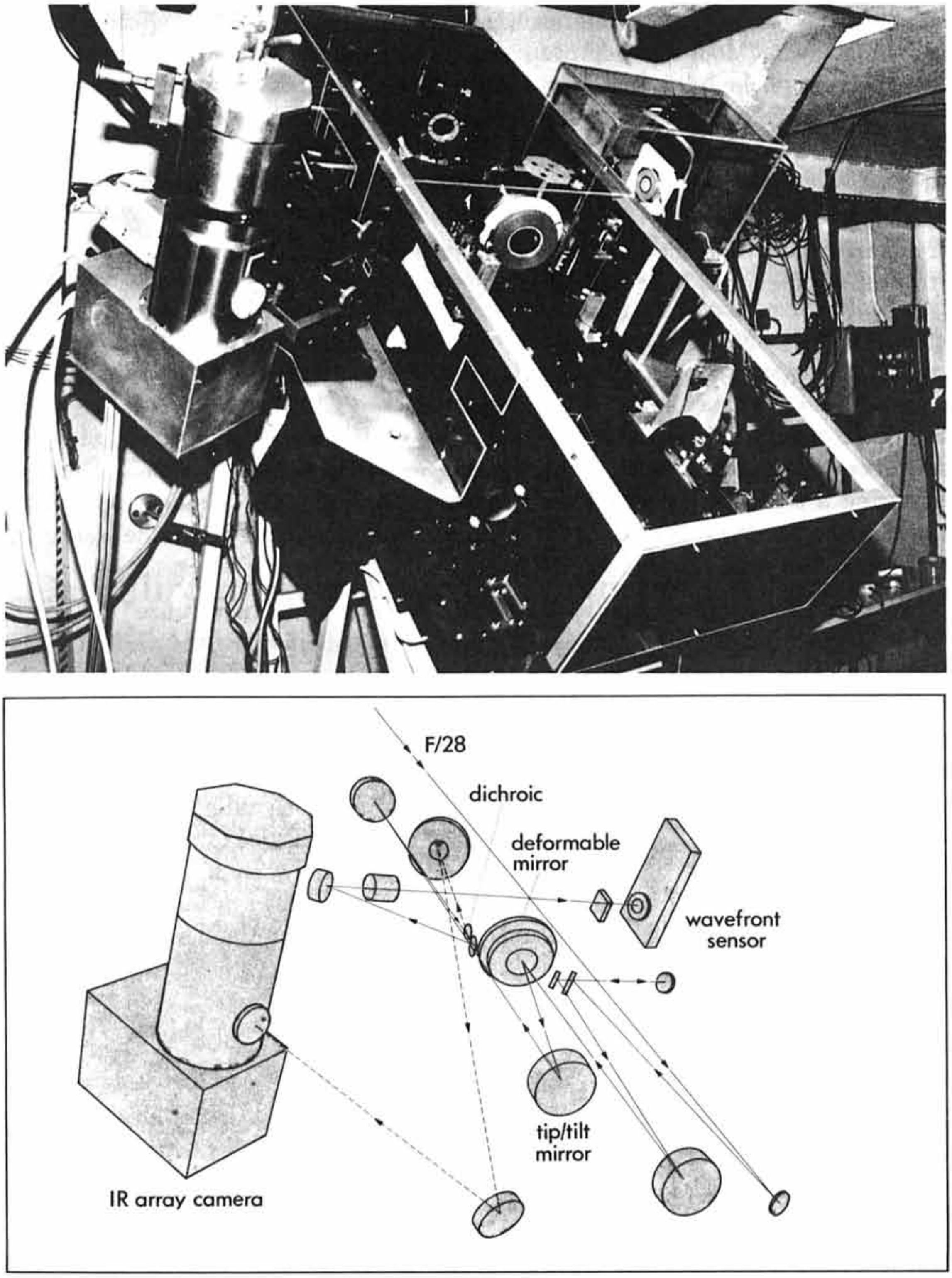

Figure 9.2: **The VLT Adaptive Optics Prototype System.** The picture shows the VLT Adaptive Optics Prototype System, installed during the first test at the coudé focus of the 1.52 m telescope at the Observatoire de Haute Provence (France). The light from a star enters the system from the top. The round element at the centre is the deformable mirror. The wavefront sensor is in the upper right part of the instrument. The large vessel at the left houses the cooled, infrared camera. (PR 06/89; BW)

Adaptive Optics Test

Uncorrected

Corrected

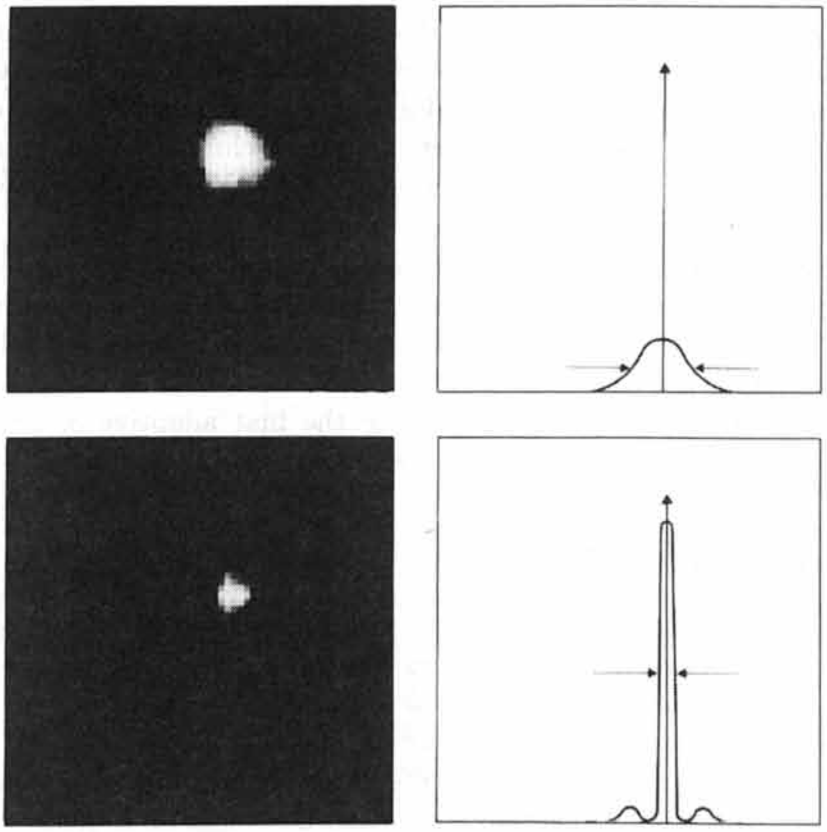

Figure 9.3: **Deneb observed with the VLT Adaptive Optics Prototype System.** The picture shows the dramatic improvement of the infrared image of the star Alpha Cygni (Deneb), by means of the VLT Adaptive Optics Prototype System. The images were photographed directly from the monitor screen during the observations at the coudé focus of the 1.52 m telescope at the Observatoire de Haute Provence (France). These images were obtained through a K-filter (wavelength 2.2 μm). Each image was exposed during 50 seconds. The upper left picture shows the uncorrected image with the corresponding, schematic intensity profile to the right. The atmospherically induced image smear results in a rather broad profile with comparatively low, central intensity; the measured FWHM (Full Width at Half Intensity; indicated by the arrows) corresponds to about 1.2 arcseconds. Below, the image has been corrected by the adaptive optics system. The great improvement in sharpness is obvious; the profile has become very narrow and the central intensity is much higher, i.e. the light is much better concentrated. The measured FWHM is now three times smaller, about 0.4 arcseconds. This corresponds to the diffraction limit of the telescope optics at this wavelength and demonstrates that the atmospheric influence has been fully eliminated. This is also indicated by the presence of a weak "diffraction ring" around the central image. It is best seen in the intensity profile as two adjacent maxima. In addition to providing finer details, sharper images also means that more of the starlight is concentrated in a smaller area and that therefore fainter stars can be observed with the same telescope and detector. (PR 06/89; BW)

Future plans

This prototype system will soon be installed at the ESO 3.6 m telescope at La Silla. The encouraging results represent a first, major step on the way towards an adaptive system for the 16 m Very Large Telescope (VLT).

The new technology makes it possible to achieve the theoretical limits for optical imaging in the infrared wavelength range by means of a medium-sized telescope. Further developments will aim at perfecting the technique for larger telescopes and at shorter wavelengths. Not only will present day telescopes benefit, but this technique will revolutionize the exploitation of the next generation telescopes, such as the ESO VLT, and, in many cases, compete with observations carried out by telescopes deployed in space.

Note that the technique of *adaptive optics*, as described here, is complementary to *active optics*, a system that allows to keep large astronomical mirrors in optimal shape when gravity, wind and heat distort them, and which has recently been successfully installed at the ESO New Technology Telescope[4].

A scientific-technical paper, describing the first adaptive optics results, is expected to appear soon in the European journal *Astronomy & Astrophysics*.

Acknowledgements

The design and construction of this system is the product of a three year effort, involving a collaboration between the European Southern Observatory (ESO), the Office National d'Etudes et de Recherches Aérospatiales, the Laboratories de Marcoussis (formerly CGE, now Aérospatiale) and the Observatoire de Paris.

The project received support from ESO, the Ministère de la Recherche et de la Technologie (France), Ministère de l'Education Nationale, Direction de la Recherche (France), Université Paris VII, Centre National de la Recherche Scientifique (CNRS) and Institut National des Sciences de l'Univers (INSU).

The early development of critical optical components of the system has been independently supported by La Direction des Recherches et Etudes Techniques (DRET), Ministère de la Défense, France.

9.3 Adaptive Optics at the ESO 3.6-m Telescope: Space-Sharp Images

(**PR 05/90**; 23 May 1990; For immediate release)

With the help of "adaptive optics", a revolutionary optical concept[5], infrared astronomical images have been obtained with the ESO 3.6 m telescope at the La Silla observatory which are as sharp as they would be if the telescope were situated in space. This is the first time in astronomy that a ground-based telescope of this size has been able to directly register during long time periods stellar images with a sharpness that corresponds to the theoretically possible limit.

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[4]See ESO Press Release 03/89.

[5]See also ESO Press Release 06/89 (24 October 1989).

Producing four times sharper images than possible before, the 3.6-m telescope is now able to register images up to sixteen times fainter than before. With the new technique its observational potential in the infrared spectral region is unsurpassed by any other ground- or space-based telescope.

The observations were made by an astronomer/engineer team[6] with a new device, the *VLT Adaptive Optics Prototype System*, developed in a collaboration between ESO, the Office National d'Etudes et de Recherches Aérospatiales (ONERA), LASERDOT (formerly Laboratoires de Marcoussis) and the Observatoire de Paris-Meudon in France. The principle of adaptive optics is based on a computer-controlled, small deformable mirror which counteracts the smearing effect of the atmospheric turbulence. More details may be found in the Appendix at the end of this Press Release.

Eliminating the atmospherical turbulence

During a period of good observing conditions, images were obtained in various wavebands in the infrared region of the spectrum, ranging from the J-band (at wavelength 1.2 μm) to the M-band (4.8 μm). The atmospherically induced "seeing", i.e. the diameter of stellar images registered by the telescope, was around 0.8 arcsec; the actuation of the adaptive optical system reduced this by a factor of four in the L-band (3.5 μm), to the theoretically smallest possible value, 0.22 arcsec. The picture accompanying this Press Release illustrates the dramatic improvement in image sharpness[7]. With the adaptive optics, the telescope easily separates the components of a double star which are at a distance of only 0.38 arcseconds.

This achievement implies that the image-smearing effect of the turbulence in the atmosphere above the telescope was almost completely eliminated. It no longer has any influence on the image sharpness and for observations at this wavelength, the *3.6 m telescope therefore functioned as if it were situated in space.*

The present prototype adaptive optics system is optimized for this wavelength region, but a substantial improvement was also seen at shorter wavelengths. For instance, the image diameter in the K-band (2.2 μm) was measured as 0.18 arcseconds. This is the smallest image size ever obtained continuously and in real-time at a large ground-based telescope and it is only slightly above the theoretical limit in this waveband, 0.13 arcseconds.

Future developments

Following the successful demonstration of the adaptive optics principle at the 3.6-m telescope, the team of astronomers and engineers at ESO and in France now aims at the rapid implementation of further technological refinements in a second-generation adaptive optics instrument.

By increasing the number of computer-controlled supports ("actuators") for the deformable mirror from 19 to 52 and improving the speed of computation of the mirror corrections by a factor of 2.5 or more, it is expected that it will become possible to achieve the theoretical sharpness limit at shorter wavelengths, e.g. in the H-band (1.65 μm). This would also further improve the performance at even shorter wavelengths; the present configuration already

[6]Members: Gerard Rousset (ONERA); Fritz Merkle and Georg Gehring (ESO); Francois Rigaut, Pierre Kern and Pierre Gigan (Observatoire de Paris); Corinne Boyer (LASERDOT).

[7]In B/W; also available in false-colour on request.

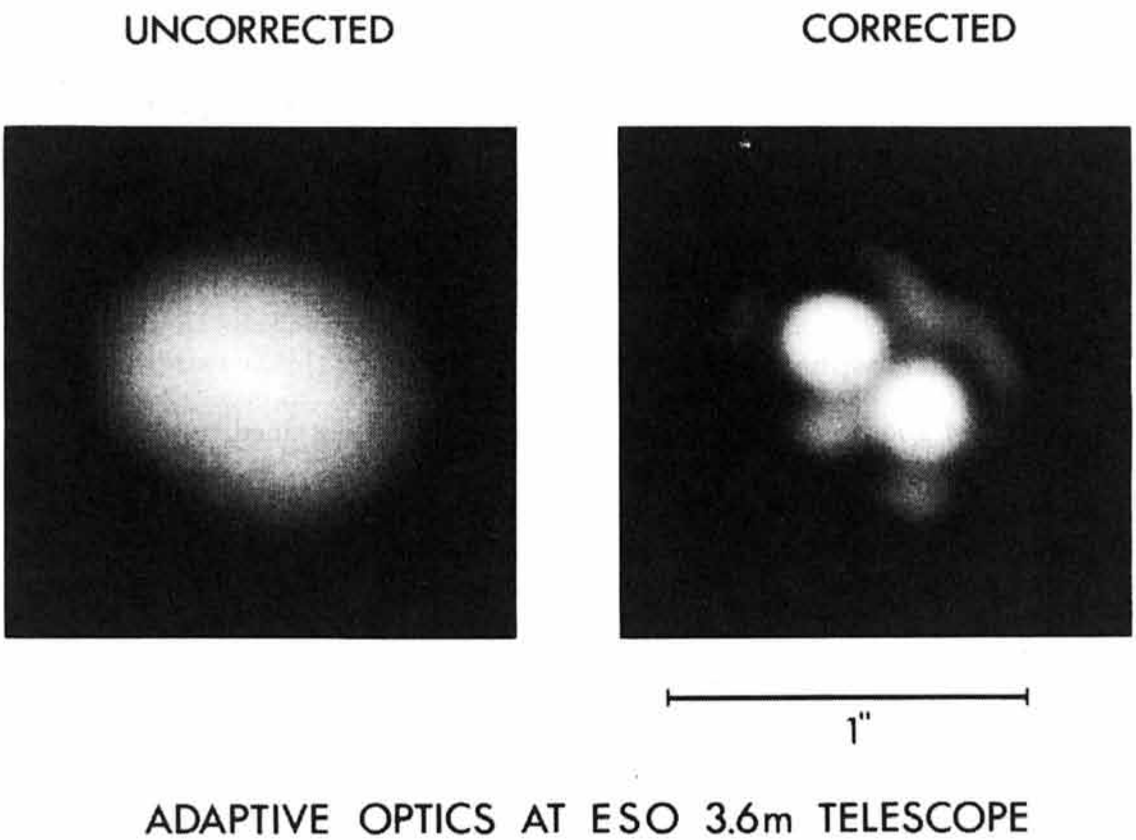

Figure 9.4: **Adaptive optics at the ESO 3.6 m telescope.** This B/W photo illustrates the dramatic improvement in image sharpness which is obtained with adaptive optics at the ESO 3.6 m telescope. It shows the 5.5 magnitude star HR 6658 in the galactic cluster Messier 7 (NGC 6475), as observed in the infrared L-band (wavelength 3.5 μm), without ("uncorrected", left) and with ("corrected", right) the "VLT adaptive optics prototype" switched on. The diameter of the uncorrected image is about 0.8 arcseconds, corresponding to the instantaneous "seeing" disk, i.e. the image smearing introduced by the turbulence in the air around and above the telescope. When corrected, the image sharpness increases fourfold; the image diameter is now only 0.22 arcsec. The improved sharpness reveals that the star is double; the angular distance between the two components is 0.38 arcseconds (compare with the 1 arcsecond bar). It moreover brings out the "diffraction rings" around the image, a natural optical phenomenon which also proves that the theoretical resolution limit has indeed been reached. Note that the central intensity of the corrected image is much higher than that of the uncorrected. By concentrating the light better, the efficiency of the telescope is correspondingly increased. This means that shorter exposure times are possible or that fanter objects can be observed than before. (PR 05/90; BW and Colour

reduces the image diameters in the J-band (1.2 μm) by a factor of about three, to 0.31 arcseconds, while the theoretical limit at this waveband is 0.07 arcseconds. It is expected that the new developments will require about 18 months.

Not only does adaptive optics increase the image sharpness, it also concentrates the light better (see the picture). This is of great importance in order to increase the efficiency of the modern detectors at the telescope.

There is little doubt that adaptive optics will play an increasingly important role in ground-based astronomy. The elimination of the adverse effects of atmospheric turbulence enables a ground-based telescope to approach - in the restricted wavelength range where the Earth's atmosphere is transparent, i.e. mostly at near-infrared wavelengths - the limits of a space-based one, but at a much smaller cost. This technique is therefore entirely complementary to the Hubble Space Telescope concept.

Adaptive optics will provide a decisive advantage for the interferometric mode of ESO's 16-m Very Large Telescope (VLT), a unique feature of this project that combines several telescopes.

But are there limitations ? Yes, the adaptive optics principle only works on a small sky field around a comparatively bright reference star. The light from this star gives the information that is needed to control the deformable mirror.

Appendix: what is adaptive optics ?

Ever since the invention of the telescope in the early 17th century, astronomers have had to accept that the sharpness of astronomical images obtained with ground-based instruments is severely limited by a factor which is beyond their control, that is the turbulence in the Earth's atmosphere.

This turbulence is perceived by the eye as the twinkling of stars. High above the observer, mostly at altitudes between 5 and 10 kilometres, there are many small, moving cells of air, each of which produces a "sub-image" of the same star; the result is a swarm of moving sub-images. (Compare with the air above a toaster or a hot radiator.)

To a naked-eye observer, the number of sub-images which fall within the periphery of his eye pupil changes all the time. The perceived intensity of the star varies; the star twinkles.

In a telescope, the size (that is, the sharpness) of a stellar image, is equal to the area within which this swarm of sub-images moves. The greater the air turbulence, the larger is this area and the less sharp are the resulting images. Because of this effect, an increase of the size of a telescope does not improve its ability to resolve details of astronomical objects, once the aperture of the telescope exceeds 10 or 20 cm; the best achievable image sharpness, even by high-quality, large astronomical telescopes, is effectively determined by the state of the atmosphere, and is referred to as "astronomical seeing" during the exposure. For this reason, large telescopes are placed at sites where the atmospheric turbulence is as small as possible, for instance La Silla.

The technique of "adaptive optics" overcomes this natural limit. Expressed in simple terms, it enables the telescope to "catch" all of the subimages by means of a small, deformable mirror which "focuses" these images into one, sharp image. It can also be described in terms of correcting the atmospherically introduced distortions of the light wavefront from the star.

It is based on a feed-back loop, and the optical system contains a deformable mirror which can change its surface profile in a way that exactly compensates for the distortions of the light wavefront after it has passed through the atmosphere. The information about how to deform the mirror comes from a wavefront sensor which allows to measure the shape of the distorted light wavefront. It requires a very fast and powerful computer to calculate how the actuators located behind the deformable mirror have to push and pull the mirror surface.

The present prototype system has a mirror with 19 actuators. The mirror is deformed, hence the wavefront is corrected, 100 times per second.

Note that the technique of ***adaptive optics***, as described here, is complementary to ***active optics***, a system that allows to keep large astronomical mirrors in optimal shape when gravity, wind and heat distort them, and which has been so successfully implemented at the ESO New Technology Telescope, cf. ESO Press Releases 03/89 (23 March 1989), 03A/89 (11 May 1989) and 03/90 (5 February 1990).

Chapter 10

Miscellaneous

10.1 ESO Information and Photographic Service

(**PR 01/86**; 13 January 1986; For immediate use)

ESO has established a new service, which will from now on handle all public relations matters. It is located at the ESO Headquarters in Garching, FRG and can be reached as indicated below.

The ESO Information and Photographic Service will inform the media and interested persons about events at ESO of general interest. These will include results of scientific research (in particular new discoveries) made at ESO's La Silla observatory (see overleaf), as well as technical matters in connection with ongoing telescope projects and auxiliary astronomical instrumentation. Major scientific meetings at ESO will also be covered.

The information will become available in the form of press releases and through ESO's own journal "The Messenger" (published in March, June, September and December). It is also expected that press conferences will be arranged from time to time; members of the press will receive invitations well in advance. Archival and current pictures, related to astronomical and other activities at ESO will be made available upon request (catalogue in preparation).

Major news items during the coming months are likely to include:

- Comet Halley (extensive observations will be made from La Silla by many European astronomers after February 15, 1986 - ESO/ESA cooperation around the Giotto spacecraft - selected photographs and digital pictures obtained at ESO will be available at very short delays),
- ESO 3.5 metre New Technology Telescope (NTT), now being built in collaboration with European industry,
- ESO 16 metre Very Large Telescope project (VLT), which will be formally presented to the public later this year, and
- ESO/CERN Symposium on Cosmology, Astronomy and Fundamental Physics, which will be held at ESO in mid-March 1986 with participation of some of the world's foremost scientists in these fields.

Members of the press, who desire to visit the ESO Headquarters in Garching, must contact Mrs. E. Voelk (tel: (089) 320-06-276) at least one week in advance.

The Head of the ESO Information and Photographic Service is Dr. Richard M. West, a Danish astronomer who has been with ESO since 1970. He was General Secretary of the International Astronomical Union (1982-1985) and is currently a member of the Executive Board of the International Council of Scientific Unions (ICSU).

10.2 ESO Exhibition at the Heysel Planetarium in Brussels

(**PR 08/87**; 25 May 1987; For immediate release)

***** Press Conference on June 5, 1987 *****

An exhibition about the European Southern Observatory will be open to the public at the Heysel Planetarium, Brussels, Belgium, on June 6 - 15, 1987 (all days, also during the weekends, from 10:00 to 16:30). It has been organized in a collaboration between ESO, the Brussels Planetarium and the Belgian National ESO Committee.

The exhibition will be opened by the Belgian Ministers of Education, Messrs. D. Coens and A. Duquesne, on Friday, June 5, at 15:00, in the presence of the members of the ESO Council. The brief ceremony, with presentations by the ministers, the Director-General of ESO, Prof. L. Woltjer, and the President of the Belgian National ESO Committee, Prof. C. de Loore, will be followed by a *Press Conference*, also at the Planetarium.

More than 100 large colour photos (including many beautiful exposures of nebulae, galaxies, etc.) illustrate the scientific and technical activities of ESO. They are accompanied by comprehensive texts. Recent results are shown, for instance about the bright supernova in the Large Magellanic Cloud. The exhibition also features large-scale models of ESO's Very Large Telescope project, which aims at the construction of the largest optical telescope in the world, before the end of the next decade.

This year marks the 25th anniversary of the European Southern Observatory, a European scientific organization with eight member countries: Belgium, Denmark, the Federal Republic of Germany, France, Italy, the Netherlands, Sweden and Switzerland. Its Headquarters are located in Garching bei München, its Observatory at La Silla in the Atacama desert, about 600 kilometres north of Santiago de Chile. ESO was founded in 1962 to foster cooperation in astronomy and to provide European scientists with a major modern observatory.

At the La Silla Observatory, seven optical telescopes with diameters between 1.0 and 3.6 metres are in operation, as well as six smaller ones. A 3.5 m New Technology Telescope (NTT) is being constructed and will enter into operation by the end of 1988. A 15 m submillimetre radio telescope (SEST) was recently installed. A Very Large Telescope (VLT), consisting of four 8 m telescopes (equivalent aperture 16 m) is being planned for the 1990's. Some of the telescopes on La Silla belong partly to particular ESO member countries. Six hundred scientists make proposals each year for the use of the telescopes at La Silla.

At the European Headquarters, technical development programmes are carried out to provide the La Silla Observatory with the newest instruments. While the design of instruments is made at ESO, their construction is largely contracted to European industry. Also in the Headquarters there is the scientific and administrative centre of ESO, where extensive facilities are available which enable European scientists to analyze their data. In addition, the European Space Agency (ESA) and ESO here jointly operate the "Space Telescope European Coordinating Facility".

ESO publishes the ESO Messenger, a quarterly journal with information about the latest news in astronomy and especially about the results of observations at La Silla. Other ESO publications include Conference Proceedings, Preprints and Technical Notes. An Atlas of the Southern Sky, consisting of 1200 deep photographical copies of original plates obtained with the ESO and UK Schmidt telescopes, and showing the faintest and most distant objects, is now almost ready.

In Europe ESO employs about 150 international Staff members, Fellows and Associates; at La Silla about 40 and, in addition, 150 local Staff members.

Further information about ESO may be obtained from:

ESO Information and Photographic Service
D-8046 Garching bei München
Federal Republic of Germany

For information about the Press Conference on June 5, please contact:

Professor C. de Loore
Astrophysical Institut, Free University of Brussels
B-1050 Brussels
Belgium
Tel: (32-2) 6413496

10.3 Caltech and ESO Join Forces to Produce Sky Atlas

(**PR 02/90**; 26 January 1990; For immediate release)

The California Institute of Technology (Caltech) of Pasadena, California, U.S.A. and the European Southern Observatory have concluded an agreement by which ESO will undertake the responsibility of producing high-quality copies of photographic sky survey plates obtained with the Palomar 40-inch Oschin Telescope and to distribute the resulting photographic atlas[1].

The second Palomar Observatory Sky Survey is a mammoth decade-long project to photograph the entire northern sky using sensitive new photographic techniques. The new atlas of the heavens, contained on 2,682 glass plates or film transparencies, will serve as the basic astronomical guide to the northern skies for decades to come. It will be known as the **Palomar Observatory - European Southern Observatory Atlas of the Northern Sky**.

"We are delighted that ESO will be copying and distributing the results of the Palomar Sky Survey", says Robert J. Brucato, assistant director of Palomar Obervatory. "ESO has considerable experience from their work on the southern sky surveys conducted by ESO and by the United Kingdom Schmidt Telescope in Australia and the results were excellent. We had been planning on doing the copying and distributing at Caltech, but we decided to have the work done at ESO in the interest of making high-quality copies available to the astronomical community at the minimum price possible".

The photographic work at ESO will be carried out by a team of experienced photographers, headed by staff astronomer Richard M. West. The laboratory employs highly specialized techniques, many of which were invented at ESO, and which guarantee a minimal loss of information in the copying process. The laboratory staff has more than 15 years of practice with survey and atlas work in the southern sky. Comments the ESO astronomer:

[1]Caltech issues simultaneously a Press Release about this collaboration.

"Our laboratory facilities and copying methods are unique in the astronomical world and we have until now produced more than 300,000 absolutely faithful photographic copies of large Schmidt telescope plates. Each original plate exposed at the telescope contains several millions of images of stars and galaxies and we do not want to remove any real images or add any false images during the copying process."

Able to record celestial objects several million times fainter than can be detected with the naked eye, the plates of the Palomar Sky Survey will become a standard reference in the libraries of every major observatory around the world. Astronomers will use the data from the new survey to:

- discover new quasars, galaxies, stars, asteroids and comets;
- map the structure and circulation of our Milky Way galaxy by comparing the positions of stars with those in the last major survey 30 years ago;
- serve as a celestial road map for the NASA/ESA Hubble Space Telescope, scheduled for launch on the Space Shuttle this year; the joint ESA/ESO European Coordinating Facility for the HST is located at the ESO Headquarters in Garching;
- identify at visible and near-infrared wavelengths, objects discovered with telescopes that see in the radio, x-ray, or infrared regions of the spectrum.

The multi-million dollar Palomar Observatory Sky Survey is funded by grants from the Eastman Kodak Company, the National Geographic Society, the Samuel Oschin Foundation, and the Alfred Sloan Foundation, with additional funding from NASA and the National Science Foundation. Begun in 1986, the survey is scheduled for completion in the mid-1990s. ESO expects to terminate the copying a few years later, having then distributed the entire atlas to astronomical institutes all over the world.

Caltech took its first step in the business of sky surveys in 1948, when Institute astronomers and technicians began the eight-year task of mapping the northern sky for the first Palomar Sky Survey. This proved to be one of the most important developments in 20th century astronomy, because it provided astronomers with an unprecedented wealth of information about the heavens. ESO carried out similar surveys of the southern sky after the erection of the ESO Schmidt telescope at La Silla, in 1972. Part of this work was done in collaboration with the UK Schmidt telescope in Australia.

In 1980, Caltech astronomers began planning for a new, northern survey because of advances in photographic and telescope technology and the changes in the heavens over the ensuing three decades. The Oschin Telescope was substantially refurbished before the second sky survey was begun. This included a new, $380,000 lens that enables the telescope to focus a wide range of wavelengths. In addition, advances in photographic technology have led to the development of photographic plates that are far more sensitive than those available in 1948.

Each glass plate is 14 inches square, and photographs a segment of the sky about 6.5 degrees across, about 13 times the diameter of the full moon. It would take 894 such segments to cover the entire northern hemisphere of the sky, but since each segment is photographed at three wavelengths, the survey will finally comprise 2,682 plates. Because of the trails of overflying airplanes, plate defects, or other observational problems, the Caltech astronomers expect that they will have to expose two plates for every one that is finally accepted for the survey.

10.4 Discoveries in the Southern Sky: ESO Exhibition now at "Microcosm"

(**PR 04A/90**; 9 April 1990; For immediate release)

Paris, Brussels, Vienna and Copenhagen were some of the stations for ESO's travelling astronomy exhibition. Now this exhibition can be seen for the first time in Switzerland, where CERN's MICROCOSM exhibition has opened its doors for a detailed view at the World of stars and galaxies.

In 1980, two divisions of the European Southern Observatory (ESO), the Telescope Project Division and the Science Division, left the CERN premises and Switzerland to join ESO's administration at the new ESO Headquarters building in Garching near Munich.

Now, a decade later, ESO "returns" to Geneva and CERN with its beautiful exhibition "Discoveries in the Southern Sky". It has been installed in the MICROCOSM building at CERN in which CERN is setting up its new, permanent exhibition. It is planned to show here a series of special exhibitions; the first of these is the ESO exhibition.

Like CERN, its sister Organisation, ESO is a European organisation. At this time ESO has eight member countries, including Switzerland; more countries have expressed interest in joining. ESO operates the La Silla Observatory, one of the largest in the world. It is located 600 km north of Santiago de Chile in the dry Atacama desert. Here, between the Pacific Ocean and the majestic Andes mountain range, ESO operates 14 optical telescopes up to 3.6 metres diameter and also a 15 m sub-millimeter radio telescope.

The telescope park includes the newly commissioned 3.5 metre New Technology Telescope (NTT), which is considered the world's best optical telescope. It was built during the past eight years, and it was financed through the entry fee paid by Switzerland and Italy as they joined ESO in 1982. La Silla is also the home of a 0.7-metre telescope owned by Observatoire de Geneve.

Large photographs, models and videos show this remote but fascinating research base and also present some of the most exciting discoveries made at ESO. Examples are the violent birth of a new star in our own Galaxy, the glimpse of a giant star-explosion in a galaxy 5000 million light years away and unprecedented views of the mysterious quasars.

The exhibition features an eight metre long photographic panorama of the Milky Way Galaxy. It shows many well-known celestial objects and configurations, like the famous Southern Cross, the dark Coalsack Nebula, the huge Summer Triangle, the bright Andromeda Galaxy and the complex Magellanic Clouds.

ESO's new 16-metre Very Large Telescope project is presented in some detail. When this 400 million DM super telescope goes into operation by the end of the current decade, Europe's astronomers will have at their disposal the largest optical telescope in the world. It will enable them to make important discoveries and to write new chapters in the history of astronomy.

The ESO exhibition is jointly organised by ESO, CERN and the Observatoire de Geneve and will remain open until the end of the summer.

ESO Press Releases (1985 - 1990)

No.	Release Date	Subject	Fig.	Lang.	Sect.	Page
PR 01/85	17 Dec 1985	Comet Halley Ion Tail	1	E	6.1	127
PR 01/86	13 Jan 1986	ESO Information Service	-	E	10.1	199
PR 02/86	23 Jan 1986	NTT Contract with INNSE	1	E	7.1	141
PR 03/86	16 Feb 1986	Comet Halley Recovered	-	E	6.2	128
PR 04/86	18 Feb 1986	Comet Halley Status	-	E	6.3	128
PR 05/86	26 Feb 1986	Observations of Comet Halley	1	E	6.4	128
PR 06/86	03 Mar 1986	VLT Presentation	1	E	8.1	171
Photo 01/86	06 Mar 1986	Halley's Multiple Tails	1	E	6.5	130
Photo 02/86	06 Mar 1986	Halley Develops Long Tail	1	E	6.5	130
Photo 03/86	06 Mar 1986	Halley's CO^+ Tails	1	E	6.5	130
PR 07/86	13 May 1986	Supernova in Centaurus A	1	E	2.1	33
PR 08/86	04 Oct 1986	VLT Nearer Reality	1	E	8.2	172
PR 09/86	05 Nov 1986	Sizes of Pluto and Charon	1	E	5.1	103
PR 10/86	04 Dec 1986	"Mally" Found Again	1	E	5.2	104
PR 01/87	05 Jan 1987	Possible Planetary System (β Pic)	1	E	4.1	81
PR 02/87	05 Feb 1987	Activity in PKS 2152-69	2	E	2.2	35
PR 03/87	26 Feb 1987	Bubbles from OH231.8+4.2	1	E	4.2	84
PR 04/87	25 Feb 1987	SN 1987A Explodes	-	E	3.1	55
PR 05/87	03 Mar 1987	SN 1987A: First Results	5	E	3.2	56
PR 06/87	31 Mar 1987	SN 1987A: Unusual Behavior	1	E	3.3	63
PR 07/87	14 May 1987	Important Events: SN 1987A	-	E	3.4	65
		Important Events: Comet Wilson	1	E	5.3	106
PR 08/87	25 May 1987	ESO Exhibition in Brussels	-	E	10.2	200
PR 09/87	16 Jun 1987	Black Hole in Arakelian 120 ?	1	E	2.3	38
PR 10/87	09 Jul 1987	Age of the Universe	3	E	1.1	13
PR 11/87	08 Jul 1987	SN 1987A Conference	-	E	3.6	67
PR 12/87	13 Jul 1987	Binary Quasar QQ 1145-071	1	E	1.2	17
PR 13/87	10 Sep 1987	Most Distant Quasar Q0000-26	-	E	1.3	19
PR 14/87	29 Sep 1987	Intercontinental Remote Control	1	E	9.1	187
PR 14A/87	19 Oct 1987	Gravitational Lens UM 673	1	E	1.4	21
PR 15/87	05 Nov 1987	Luminous Arc in Abell 370	2	E	1.5	24
PR 16/87	08 Dec 1987	Decision to Build the VLT	1	EFD	8.3	174

No.	Release Date	Subject	Fig.	Lang.	Sect.	Page
PR 01/88	09 Feb 1988	NTT Building at La Silla	2	E	7.2	142
PR 02/88	16 Mar 1988	SN 1987A: Light Echoes	1	E	3.7	70
PR 03/88	19 May 1988	Sk -66°41 in LMC is Multiple	1	E	4.3	86
PR 04/88	08 Jul 1988	Comet Halley at 1250 mill. km	1	E	6.6	134
PR 05/88	14 Jul 1988	NTT Optical System Ready	1	E	7.3	147
PR 06/88	28 Jul 1988	Cloverleaf Quasar H 1413+117	1	E	1.6	27
PR 07/88	09 Sep 1988	Supernova at 5 billion light years	1	E	4.4	88
PR 08/88	12 Sep 1988	VLT Contract with Schott	1	E	8.4	177
PR 09/88	08 Dec 1988	Eclipsing Binary PG 1550+131	1	E	4.5	90
PR 01/89	30 Jan 1989	The Southern Crab (He 2-104)	1	E	4.6	92
PR 02/89	24 Feb 1989	A Pulsar in SN 1987A ?	-	E	3.8	72
PR 03/89	23 Mar 1989	First Light for the NTT	3	E	7.4	149
PR 03A/89	11 May 1989	Very Sharp NTT Images	4	E	7.5	154
Photo 01/89	30 May 1989	Comet West/Hartley	1	E	5.4	108
PR 04/89	30 Jun 1989	Jet in HH-111	2	E	4.7	96
PR 05/89	25 Jul 1989	VLT Contract Goes to R.E.O.S.C.	1	E	8.5	179
PR 06/89	24 Oct 1989	First Test of Adaptive Optics	2	E	9.2	188
PR 01/90	05 Jan 1990	Elusive Pulsar in SN 1987A	1	E	3.9	73
PR 02/90	26 Jan 1990	Caltech and ESO to Produce Atlas	-	E	10.3	201
PR 03/90	06 Feb 1990	NTT Inauguration	31	EFDI	7.6	159
PR 04/90	02 Mar 1990	Comet Austin Develops Long Tail	1	E	5.5	110
PR 04A/90	09 Apr 1990	ESO Exhibition at CERN	-	EF	10.4	203
PR 05/90	23 May 1990	Adaptive Optics at 3.6-m Telescope	1	E	9.3	192
Photo 01/90	13 Jun 1990	Unusual View of Comet Austin	1	E	5.6	113
Photo 02/90	26 Jul 1990	Comet Halley at 12.5 A.U.	1	E	6.7	136
Photo 03/90	25 Sep 1990	Comet Levy (12 Sep 1990)	1	E	5.7	114
Photo 04/90	25 Sep 1990	Comet Levy (14 Sep 1990)	1	E	5.7	114
PR 07/90	07 Sep 1990	Opaque Spiral Galaxies	1	E	2.4	41
PR 07A/90	29 Sep 1990	Minor Planet "Portugal"	1	EP	5.8	117
PR 08/90	24 Oct 1990	Distant Normal Galaxy G0102-190	1	E	2.5	45
PR 09/90	31 Oct 1990	Galactic Centre Sighted	1	E	2.6	49
PR 10/90	09 Nov 1990	Great White Spot on Saturn	3	E	5.9	119
PR 11/90	04 Dec 1990	The VLT Goes to Paranal	1	ES	8.6	181

Notes: Some Press Releases (marked with "A") were of a more special nature and were given a limited distribution. PR 07/87 contained information about SN 1987A and Comet Wilson; the corresponding sections have been included in the appropriate chapters. PR 06/90 was not issued. The "Photos" were issued with figure texts only.

Languages: English (E), French (F), German (D), Italian (I), Portuguese (P), Spanish (S).

List of Figures