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ESO Turns 40

CATHERINE CESARSKY, Director General of ESO

1962 – 2002… Four decades that changed Europe – and forty years that changed European Astronomy. One full generation of scientists, a wonderful time during which many of our dreams, our hopes, and our goals have finally come true.

Our ancient science has always been characterized by broad international collaboration. However, it was only in the early 1950's that our illustrious predecessors, led by Jan Hendrick Oort and Walter Baade, embarked upon the arduous political process that ultimately gave birth to ESO. With great foresight and an equal measure of stubborn will, they paved the way for some of the world's best telescope and instrument facilities, the solid and durable ground for a strong and brilliant future of European Astronomy and Astrophysics.

From the construction of its first observatory at La Silla on a remote mountain top in the inhospitable Atacama desert, to the momentous Very Large Telescope at Paranal, with the construction of the ALMA project about to start and promising perspectives for a super-giant telescope, ESO has matured to become a major player on the world scene, offering to its community a unique complement of research facilities. Always a persistent driver of frontline research, it is now the prime service organization in its field on this continent, with thousands of scientists profiting from precious data obtained with telescopes at the ESO sites. In a steady and carefully planned process, new and extremely powerful instruments and telescopes are being developed for the ESO community in close collaboration with research institutes and the high-tech industry. Innovative concepts, like the Astronomical Virtual Observatory and associated data archives with tens of Terabytes contribute to the success of European Astronomy and Astrophysics.

The challenges ahead are commensurate with the achievements of today. To meet them, ESO, a dynamic organization, is committed to continuous progress and ever-increasing efficiency. I want to take this opportunity to pay tribute to those who have contributed to ESO's success. I must start with ESO's skillful and dedicated staff that brought these great projects to fruition. I also want to salute the commitment of the members of ESO Committees. I am in particular grateful for the active support over these past three years from the President of Council and from the Chairs of Finance Committee, Scientific and Technical Committee, VLTI Implementation Committee, Observing Programme Committee, Users Committee and Visiting Committee, as well as from so many influential members of these Committees. And, of course, above all, I wish to thank the member countries for their enthusiastic support of ESO throughout the years.

ESO Council Meeting in London, 8–9 July 2002

To mark the occasion of the the tenth member state joining ESO, the UK invited ESO to hold its 98th Council meeting in London on 8–9 July 2002. The hosts provided a wonderful venue for the meeting in Trinity House, overlooking the Tower of London. An excursion to the historic Greenwich Observatory and a banquet at Lancaster House helped to make it an especially memorable occasion. A landmark decision made at the meeting was the approval for the construction and operation of the Atacama Large Millimeter Array (ALMA).

The speeches given at the banquet by Lord Sainsbury, A. Freytag and C. Cesarsky are printed below, followed by an article by Prof. Gerry Gilmore on the British astronomers' perspective.

Speeches to Mark the Accession of the UK to ESO

Lord Sainsbury, UK Science Minister

Good evening Ladies and Gentlemen and welcome to you all. It is a great pleasure for me to act as host tonight for this dinner, which is held to celebrate the UK's accession to the European Southern Observatory (ESO). I am delighted too, that we have the opportunity to host this ESO Council meeting, and that we have the ESO Council Members and the principal officials of ESO present here tonight.

I am sure I speak for the entire UK astronomy community when I say how much we are looking forward to participating in ESO and taking advantage of its marvellous facilities. I also hope very much the UK's participation will lead to a strengthening of ESO and a widening of its capabilities for astronomical research.

As Minister for Science, I see my role as the provider of access to World-class facilities for UK scientists rather than the provider of all the facilities themselves. For this reason, the Science and Innovation White Paper 'Excellence and Opportunity', which we produced two years ago, undertook to develop a ten-year rolling plan for future large-scale facilities, taking account of developments in Europe and elsewhere, to ensure that UK researchers have access to the best facilities in the world.

The Large Facilities Strategic Roadmap, which we produced, represents the first attempt at a ten to fifteen year map of future facility requirements. The aim of the document is to provide a longer-term vision of future requirements of the UK Science and Engineering Base. It reflects the context of future European, or in some cases global, requirements for large-scale facilities in order to assess the most effective approach for satisfying UK needs.

International collaboration is a key part of this strategy because the characteristics of these large-scale facilities often make collaboration the most effective means of provision: They are expensive to build and operate; they frequently serve national and international users; and they tend to be multidisciplinary.

The UK astronomy community was also asked, a few years ago, to examine their science priorities for the next ten to fifteen years, and also to identify the facilities required to address those priorities. The message received was clear – joining ESO was the top priority for astronomy.

Our astronomers recognized that the current generation of World-leading telescope facilities are on a scale that can only be achieved through international partnerships. This of course has been an increasing trend for some years and

Gathered in the historic Octagon Room of the Royal Greenwich Observatory, London, Ian Halliday (CEO, Particle Physics and Astronomy Research Council) stresses the benefits to British astronomers of belonging to the European Southern Observatory. The Panel consisted of (left to right) Roy Clare (Director of the National Maritime Museum), Arno Freytag (President of the ESO Council), Lord Sainsbury (Science Minister), Gerry Gilmore (Cambridge University), Ian Halliday, Catherine Cesarsky (Director General of ESO) and Pat Roche (Oxford University). Courtesy PPARC.

will no doubt become more pronounced for future telescopes under consideration.

The Government responded to the wishes of the astronomy community in the Government's 2000 Spending Review, when it made a special contribution to PPARC of £100 m over the next 10 years specifically to allow the UK to join ESO. We are of course very pleased that the UK is now at last a member of ESO. The UK has joined probably the World's leading observatory and UK astronomers will gain access to some of the World's most advanced telescopes including ESO's Very Large Telescope. Joining ESO also integrates the UK astronomical community with that of continental Europe.

The UK now embarks on a new journey with the joining of ESO. There are some exciting opportunities ahead and I am aware in particular of the ALMA project.

This global project, with Europe, North America, and possibly Japan, all working together, promises, once completed, hopefully in 2009, to be the largest ground-based astronomy facility ever constructed. The UK is very enthusiastic about becoming involved in ALMA. I know ESO Council has been considering this subject carefully and we look forward to its decision on participation.

The UK currently funds about 5% of World science. This means that over 95% of science is funded elsewhere. We believe, therefore, that strong international relationships are essential; any society that is closed, inward looking and defensive will not long remain at the forefront of science because it cannot take part in global collaboration. I believe that the UK is stronger when it collaborates internationally and I want the UK to be a key player in European and global science.

The message I want to convey to you is very simple. We are very pleased that the UK has finally joined ESO, we are excited by the opportunities that lie ahead, and we hope UK participation will serve to strengthen this renowned international organization.

Thank you.

Dr. Arno Freytag, President of the ESO Council

Lord Sainsbury, distinguished guests, ladies and gentlemen;

Thank you for your warm words of welcome and for inviting us to dinner in these magnificent surroundings, which I must say compare rather favourably with the facilities in Garching!

This is a historic occasion. We are all privileged to be a part of it, no-one more than me. It is indeed an honour to be President of ESO Council, and, on behalf of all the member states and the staff of ESO, to welcome the United Kingdom into our midst.

We have had a most enjoyable afternoon which has served to remind us of Britain's long and distinguished contribution to astronomy. So now the nation of Newton and Herschel joins the nations of Galileo, Kepler, Brahe, Cassini, Messier, and many others who paved the way to where we are now.

But today, of all days, we look to the future. World astronomy has made enormous progress in the past few decades. The outstanding recent telescopes in space and on the ground are allowing us to accelerate the pace of that progress. Europe has to work together in astronomy – as it has demonstrated it can do in other fields, such as particle physics – if it is to exploit these wonderful instruments. But it is even more important that we work together to prepare for what is to follow.

That is why today is so significant.

For today the ESO Council discussed European participation in ALMA. This is a truly international project with a good prospect of turning into a global project. We know that ALMA was a major force behind the United Kingdom decision to join ESO, and we recognize the mutual benefit, for, without the United Kingdom, ESO could not take up a half share. That would have been a disaster for European astronomy. We also look forward to the contribution of Vista, a uniquely powerful infrared survey telescope that will considerably enhance the already exceptional capabilities of our Paranal observatory.

I can say, without any false modesty, that ESO has become the leading astronomical observatory in the world. This is due to our clarity of vision, the dedication and skill of our staff, the strength of our community, and the support of our member states. Now that the United Kingdom has joined, we will be stronger and better prepared for the future. We know you share our vision, we know of your skills and dedication, we never doubted the strength of your community, and we now know we can count on your support. I look forward confidently to an outstanding future for ESO and for European astronomy.

I turn once again to you, Lord Sainsbury, and thank you, and everyone else in the United Kingdom who made it possible.

Dr. Catherine Cesarsky, ESO Director General

I would like to thank you, Lord Sainsbury, for your hospitality here and for your kind words.

Forty years ago many of us were still in school or at the beginning of our careers – not able to imagine the incredible developments going to happen to us – to science – to Europe – to the world. But what is 40 years in astronomical terms? 40 revolutions of the Earth around the Sun – a little more than half a revolution of Comet Halley – the orbit first calculated by famous British astronomer Edmond Halley in 1705 – a little less than half a revolution of planet Uranus, discovered in 1783 by British astronomer William Herschel. One 100 millionth of the age of the solar system. But on Earth, a *full* generation of astronomers.

It is also the *age* of ESO this year. And the time needed for us to prove that we are the best in the world in our field, good enough for the UK to join after 40 years of hesitation!

Astronomy is *the* international science, since the earliest times. The heavens know no borders. There are megalithic observatories in your country and also in my country; surely the master builders talked to each other also in those ancient days.

Astronomy demonstrates to all of Europe the benefit of pooling forces – by doing so, we can do better than anybody else. Let us be honest and proud of what has been and what can be achieved by working together. So what happens in the next 40 years? Our flagship projects – VLT – ALMA – OWL...

We cannot promise to find that first exoplanet with exo-life, but we will have the means to look for it. We cannot promise that we will understand what the enormous amount of dark matter and dark energy in the Universe is made of, but we will search for it. We cannot promise to discover the ultimate secret of the world in which we live, but we will certainly know much more about it and our own position.

Astronomy has an enormous potential for exciting discoveries that will fascinate the public and it will continue to attract the most clever minds among future generations.

The UK has a long and successful history in our science, with many trailblazing results by theoreticians and observers, and we are proud and happy to welcome it to ESO. Together we have an enormous potential for new breakthroughs.

Minister Sainsbury, we would be very happy to welcome you at Paranal. Do come and experience that unique atmosphere. Do sit down at the telescope controls and let us look together towards the end of the universe and the beginnings of time!

ESO AND THE UK

Why Does the UK Need More Astronomy?

GERRY GILMORE, Professor of Experimental Philosophy, Institute of Astronomy, Cambridge University, UK

"What was God doing before he made heaven and earth? … He was preparing hell for those who would pry into such profound mysteries."[1] This joke was already venerable when quoted by Augustine, in his analysis of the ancient and still modern problem, time.

Understanding the origin(s), meaning(s), future(s), and significance(s) of time, space, existence, mass, matter, geometry, of origins and endings, of what and where, remains one of the greatest intellectual endeavours of the human mind. From the caves of Lascaux, through the megaliths of Stonehenge to the dreamtime of Australia, mankind has striven to understand his origins and future. Our generation has the exceptional good fortune to be living through the greatest increase in knowledge relevant to these fundamental questions since someone first looked up at night. We are also increasing understanding, while realizing how much more there is in the Universe still be learned and understood.

Even more wonderful (*sic*) for us, our rate of progress in knowledge is accelerating, as the technological advances resulting from research into basic science feed back positively in turn to advance basic knowledge more rapidly. This is truly a golden age of discovery in astronomy, with almost every class of object we study having been discovered in our working lifetimes.

Why is it so? There are two dominant reasons: technology and people, but only one explanation: efficiency. The astronomical community is at most one order of magnitude larger by number than it was a generation ago: a significant, but not huge advance. Astronomical telescopes today provide the real advance, with not only a very considerable increase in mirror collecting area, but a vast increase in detector area, detector quantum efficiency/sensitivity, and image quality. Each modern large telescope is both vastly more sensitive, and vastly more efficient, than were 4-metre-class telescopes 20 years ago.

It is this huge increase in generation of high-quality data which drives current progress in astronomy. Consequently, the community with the best technology has the best opportunity to discover the new, and has a head-start in attracting bright young people to science. But it is not just a question of wealth buying power: the huge technological investment of Tycho and Kepler reached its scientific fruition with Newton. Real scientific progress, as that example reminds us, requires both technology and people, complementary approaches, and trans-national collaborations. And it works best with a spice of competition.

Considerations like those above led to the formation of ESO (cf. *ESO's Early History*. A. Blaauw) and the formation of La Silla Observatory, and led the UK to found collaborative observatories in Australia, South Africa, the Canary Islands, Hawaii and Chile. (Radio and space astronomy have their own history and set of personalities, and are not considered in this article.)

A significant motivation in development of these observatories was an attempt to regain international research leadership in astronomy. For whatever mix of reasons, Europe, including the UK, fared much less well relative to the US in astrophysics research in the early 20th century than it did in, for example, quantum theory and relativity.

UK and European astronomy: a micro-history

I am not aware of the factors considered when the UK decided to develop its astronomy independently from ESO, through bilateral partnerships, but by 1980, when I arrived in the UK, it was obviously a successful policy. The Anglo-Australian telescope, with its marvellous IPCS photon-counting system, the UK Schmidt Telescope, complemented by the APM (Cambridge) and COSMOS (Edinburgh) measuring machines, the UK InfraRed Telescope (UKIRT) and the beginnings of the JCMT sub-mm telescope on Hawaii, and the Isaac Newton Group on La Palma were world-quality facilities quite sufficient to challenge those of us fortunate enough to be let loose on them.

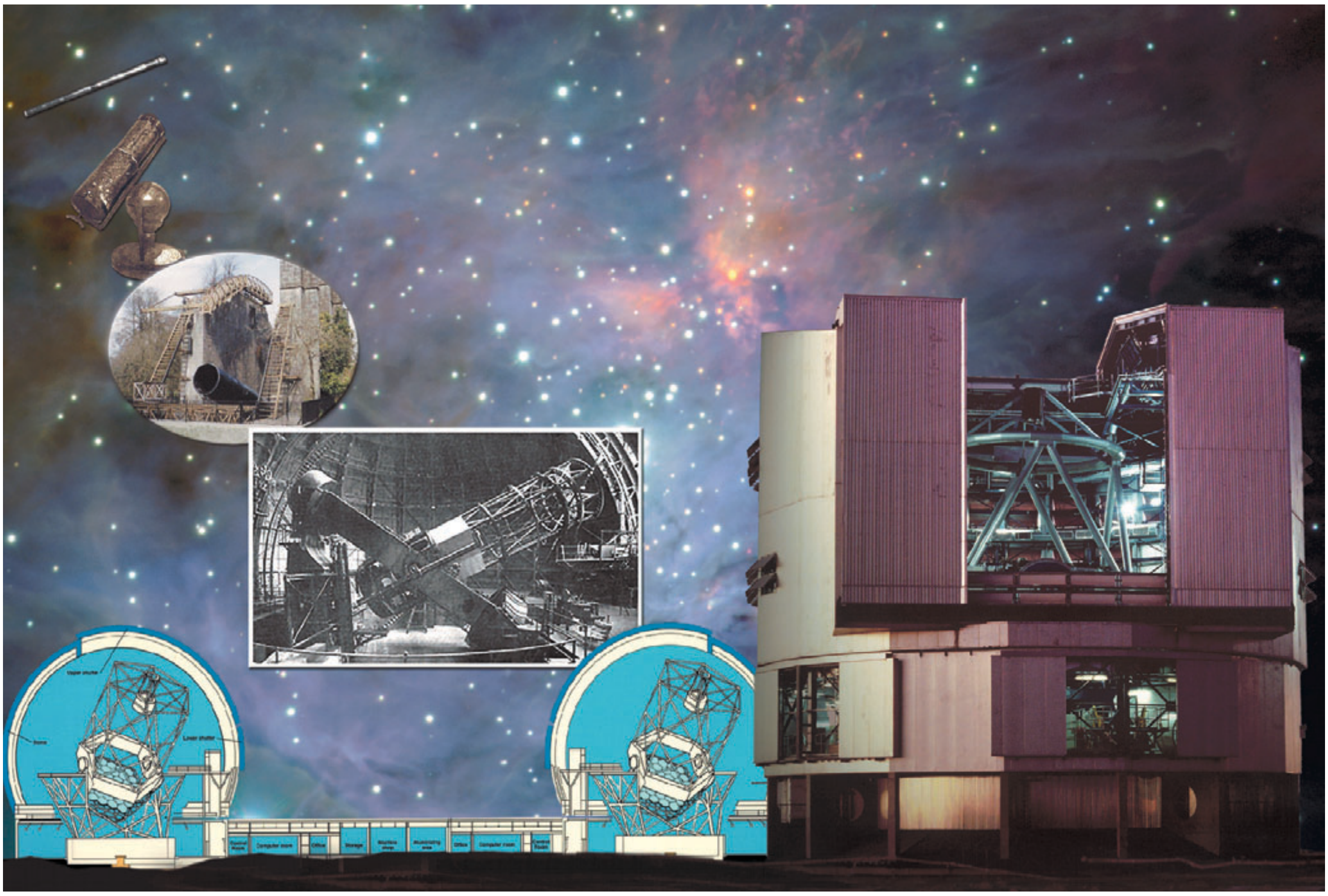
These observatories were (mostly) international partnerships, with the UK the largest partner. Next came Gemini, two superb 8-m telescopes, with the UK as a 25 per cent partner. And most recently ALMA, with the UK as (roughly) 20 per cent partner inside the European-wide 50 per cent share. Why the systematic decrease in share? Why is Gemini on-line so long after Keck? Simple: money.

Sometime around 1990 optical/IR astronomy became too expensive for one country, even one as large as the UK. But something else more fundamental changed too. 'International astronomy' began to mean more to UK astronomers than 'astronomy in the former British Empire', or 'trans-atlantic astronomy'. Routine collaboration between institutes in the UK and in continental Europe was less common than was collaboration with the US. But this began to change.

Of course, many European countries besides the UK had close scientific links across the Atlantic: the effect of the Netherlands on US astronomy is a famous exemplum. The European (largely Italian) *diaspora* who made the Space Telescope Science Institute in Baltimore so much more than just another NASA center is a major example of the happy internationalization of astronomy. Cheap and easy travel was of course another factor. As was the lesson from space science and radio astronomy, which had much earlier crossed the 'unaffordable by one country' barrier. All these factors changed the assumption, and encouraged UK astronomers to look more widely for competition, and for colleagues.

And what did we see happening in

[1] *'Quod faciebat Deus, antequam faceret caelum et terram?' Respondeo non illud quod quidam respondisse perhibetur, iocolariter eludens quaestionis violentiam: 'Alta' inquit 'scrutantibus gehennas parabat'*. Augustine, *Confessions* XI xii 14.



An illustrative view of the development of astronomical telescopes. From the top left, the telescopes of Galileo, Newton and Birr Castle, reflecting European technological innovation and dominance in astronomy until the twentieth century. Mt Wilson and the two Keck telescopes are typical of the dominance of telescope technology by the private US observatories through the twentieth century. Finally, the VLT sets the standard of excellence at the start of the 21st century.

continental Europe: by the late 1990s European astronomy was not only not ignorable, it was seriously good, and about to become outstanding. This was only in part a technological change. There was one other structural change, still only in its earliest stages in some countries, which perhaps had the largest positive effect: the move away from tenured positions on completion of a PhD to an assumption of a postdoctoral position, or several, in different institutes and countries, between degree and job. It is postdocs who really move around, who naturally, through re-location, become part of multi-Institute collaborations, and who really link communities.

Also important was the effort made by key individuals: for example, Simon White (then in Cambridge), Alain Omont and George Miley founded EARA, the European Association for Research in Astronomy, a formal link between Cambridge, Paris and Leiden (now extended to include MPA Garching and IAC Tenerife). Specific initiatives such as EARA, together with the sociological change which forced young astronomers to move around, had a big and positive impact. The Institute of Astronomy in Cambridge provides one very clear illustration of the changed balance between the UK and continental Europe. In 1992, the IoA had 50 postdoctoral fellows, about one-half from outside the UK, of whom 4 were from Western Europe (one each from Greece, Italy, Norway and Spain). In 2002 the IoA has 70 postdoctoral fellows, of whom 22 are from Western Europe. In addition, 6 European-registered PhD students (on an EARA/Marie Curie EU-funded programme) are visiting. The change is dramatic, from 8 per cent to 30 per cent, and UK astronomy is very much better for it.

With this background, one can now answer the question: why did the UK join ESO. As shown above, over a decade close and real scientific partnerships were developed. The unknown was replaced by mutual respect. This was a necessary but not sufficient condition. Then something much more important happened: the VLT.

The VLT changed everything

As it became clear that ESO really was delivering the world's finest large telescopes, UK astronomers realized they needed to be part of ESO. This unfunded ambition was complemented by development of ALMA, in which the UK was an active participant. It was always clear that ALMA would be a world-scale facility, and that ESO was the natural Europe-wide organization to build and operate it, so that some sort of a partnership between the UK and ESO would happen. Fortunately, the UK is currently in a period of relative wealth, and has a government supportive of all of excellence, science, and Europe. The conditions came into phase ideally, and here we are in ESO!

Will the UK change ESO?

This question has been raised a few times! My answer is purely personal. I think the UK will change ESO: the last big European country is in, this is the biggest change ESO will experience in the forseeable future. Much of the change will be cultural. UK astronomers have a somewhat more aggressive attitude to publishing than do some other communities. There is in the UK a significantly larger bias than in some countries towards studies of the poorly known: dark matter, inflation, galaxy formation… rather than more detailed studies of known objects. UK astronomers tend to question extant structures and priorities rather more than do some other communities. For example, some have asked if VLTI developments are proceeding on a timescale and scientific cost-benefit basis which is maximally appropriate to today's financial and facility situation. I know many UK astronomers want the next-generation European Large Telescope sooner rather than later, even at the cost of other priorities. "We didn't join ESO to let the US leave us behind again", is a common refrain. ALMA must be made a success. But, most of all, the astounding VLT must be used to deliver the exciting science for which it was built. On that, I am sure all of us in ESO agree.

What does Europe get from the UK

In the preface to his translation of St Gregory's 'Pastoral Care', King Alfred (c. 890) commented "Learning had declined so thoroughly in England that there were few men on this side of the Humber who [could] even translate a single letter from Latin into English. There were so few [men of learning] that I cannot recollect even a single one south of the Thames… I recollected how – before everything was ransacked and burned – the churches throughout England stood filled with treasures and books. … And they derived very little benefit from them because they could understand nothing of them, since they were not written in their own language. I wondered exceedingly why the good wise men who were formerly found throughout England, and who had thoroughly studied all those books, did not wish to translate any part of them into their own language. But I immediately answered myself, and said: 'they did not think that men would ever become so careless, and that learning would decay like this.'" [Ref. King Alfred's Preface to Gregory's 'Pastoral Care', tr. M. Lapidge and S. Keynes.]

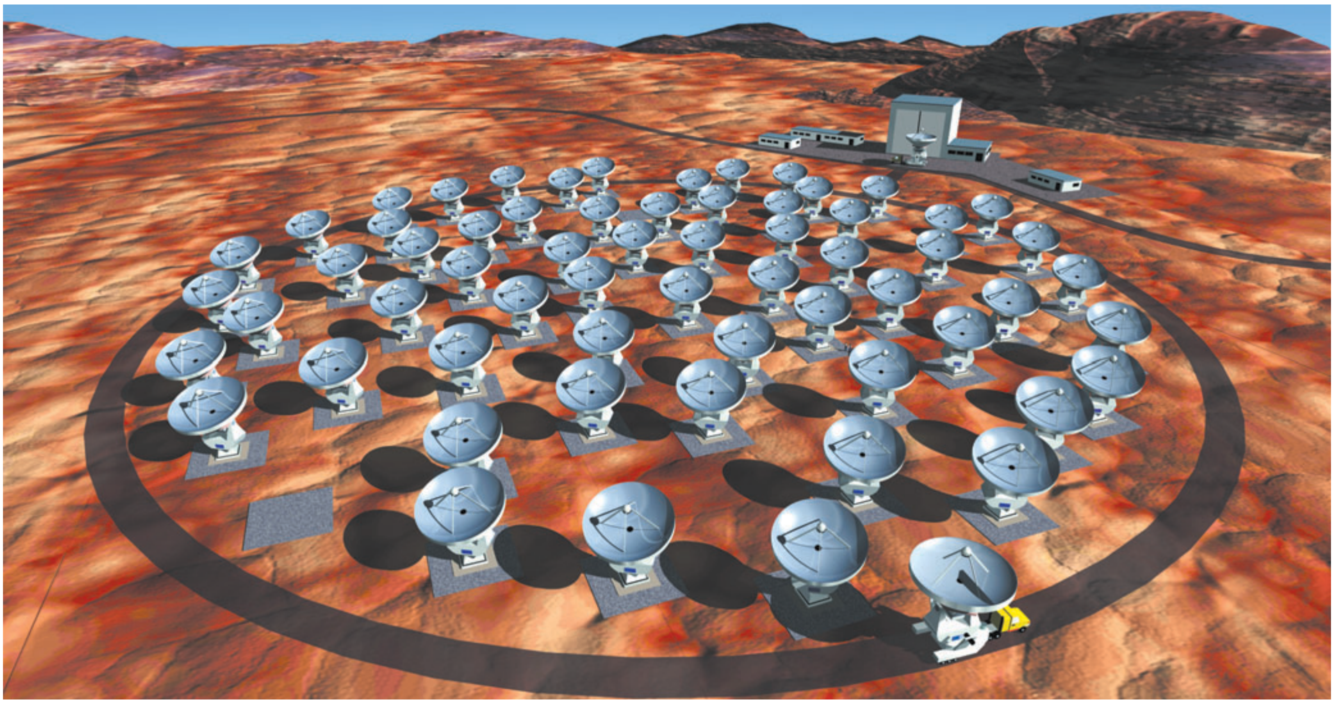
There is a school of thought which asserts that Britain's occasional drifts into barbarity and ignorance correspond to isolation from Europe: Romans civilizing, post Roman Dark Ages; Vikings exciting, later Alfred's lament; Normans enlivening, medieval black death. Even the quintessential British hero, King Arthur, is associated with Saxon and Angle introductions of new ideas. Gildas, in his subtly-titled *De Excidio Britanniae* (On the ruin of Britain), writing c. 540, at the time Arthur is frequently supposed to have existed, describes the coexistence of Saxons and Britons, leading to the rise of Anglo-Saxon England.

We look forward to the next stage of coexistence: astronomers across Europe, now including the UK, uniting in progress, and working together for the future across a whole continent.

***TABLE: Who does astronomy in the UK**. Astronomy research groups exist in many UK universities. An approximate identification list, with a crude indicator of size, can be found by noting which groups are supported by PPARC (the sole national UK funding agency for astronomy). The table lists all groups funded by PPARC at present, and the number of associated grants. The number of grants is a very crude indicator of group size, but it must be noted that this list includes space hardware groups, solar system research, and some upper-atmospheric physics. More specific information can usually be found on www pages.*

Organization	Number of grants	Organization	Number of grants
Armagh Observatory	6	Nottingham University	10
Bath University	1	Open University	9
Birmingham University	12	Oxford University	12
Bristol University	7	Portsmouth University	2
Cambridge University	35	Queen Mary and Westfield College	12
CCLRC (Rutherford Laboratories)	2	Queen's University of Belfast	8
Durham University	17	Reading University	1
Edinburgh University	10	Sheffield University	8
Exeter University	4	Sheffield Hallam University	1
Glasgow University	5	Southampton University	15
Hertfordshire University	5	St Andrews University	15
Imperial College	20	Surrey University	1
Keele University	2	Sussex University	3
Kent University	7	UK Astronomy Technology Centre	3
Lancaster University	4	UMIST	4
Leeds University	9	Univ of Central Lancashire	5
Leicester University	19	University College London	40
Liverpool John Moores Univ	8	University of Wales Cardiff	17
Manchester University	8	Univ of Wales, Aberystwyth	2
Natural History Museum	2	Warwick University	2
Newcastle University	1	York University	3

Note: 'Number' is the number of current grants at the institution; taken from the PPARC webpage http://www.pparc.ac.uk



ALMA: the next major ESO project.

Perspectives from the Directors General, Past and Present

ADRIAAN BLAAUW, ESO Director General, 1970–1974

Reflections on ESO, 1957–2002

Nearly half a century ago, I witnessed Walter Baade and Jan Oort dreaming of a joint enterprise which would lift observational astronomy in Europe from the level of their modest national efforts to that of the leading observatories in the United States. I have been privileged to see, and to have been able to contribute to, the realization of that dream. This half century has left a wealth of recollections and sentiments from which it is difficult to select for this occasion.

My direct involvement with ESO began in 1958, upon my return from the US where I had lived in the years 1953–1957. Seventeen years later, in December 1974, I concluded my five-year term as Director General. I was slightly involved as a Council member for the Netherlands in the late 1970's and early 1980's, but became pretty deeply involved again when I started writing ESO's history, which first appeared as installments in the *Messenger* in the years 1988–1991 and then as my book *ESO's Early History* of 1991.

When, in 1953, I left for the States, I had earlier that year witnessed the first moves toward establishing a joint European observatory at the occasion of IAU Symposium No.1. This led to the "declaration of intent" signed in January 1954 by astronomers from Belgium, France, Germany, Sweden, and the United Kingdom (it has been reproduced on pages 2 and 3 of my book). However, by 1957, little progress had been made, mainly due to the great difficulties encountered in obtaining the governments' agreement and financial support. These efforts continued and led to the signing of the Convention in September 1962. (By that time the UK had dropped out, Denmark was about to join.) But, behind this simple statement lie that immense patience and perseverance of ESO's founding fathers. It should not be forgotten by today's students of astronomy.

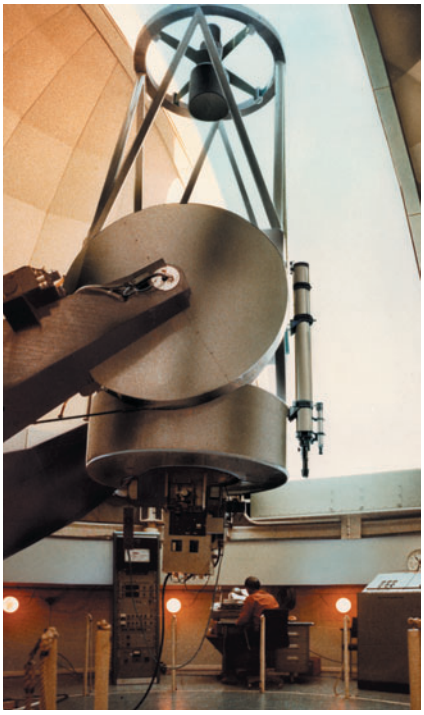
In search of a site, 1963.

Meanwhile, I had become a sort of Executive Secretary of the ESO Committee (the precursor of Council) and in this capacity became deeply involved in the organization of ESO's site testing expeditions, first for several years in the South African desert, and then briefly in Chile until, in November 1963, ESO resolved to settle in the Andes. Satisfaction about this excellent choice by ESO is mixed with the recollection of the devotion to the cause of ESO on the part of all those who in South Africa, so remote from home and European culture, devoted years of effort and time to our cause.

My involvement was renewed when, from January 1968, I became Scientific

La Silla before…

… and after.

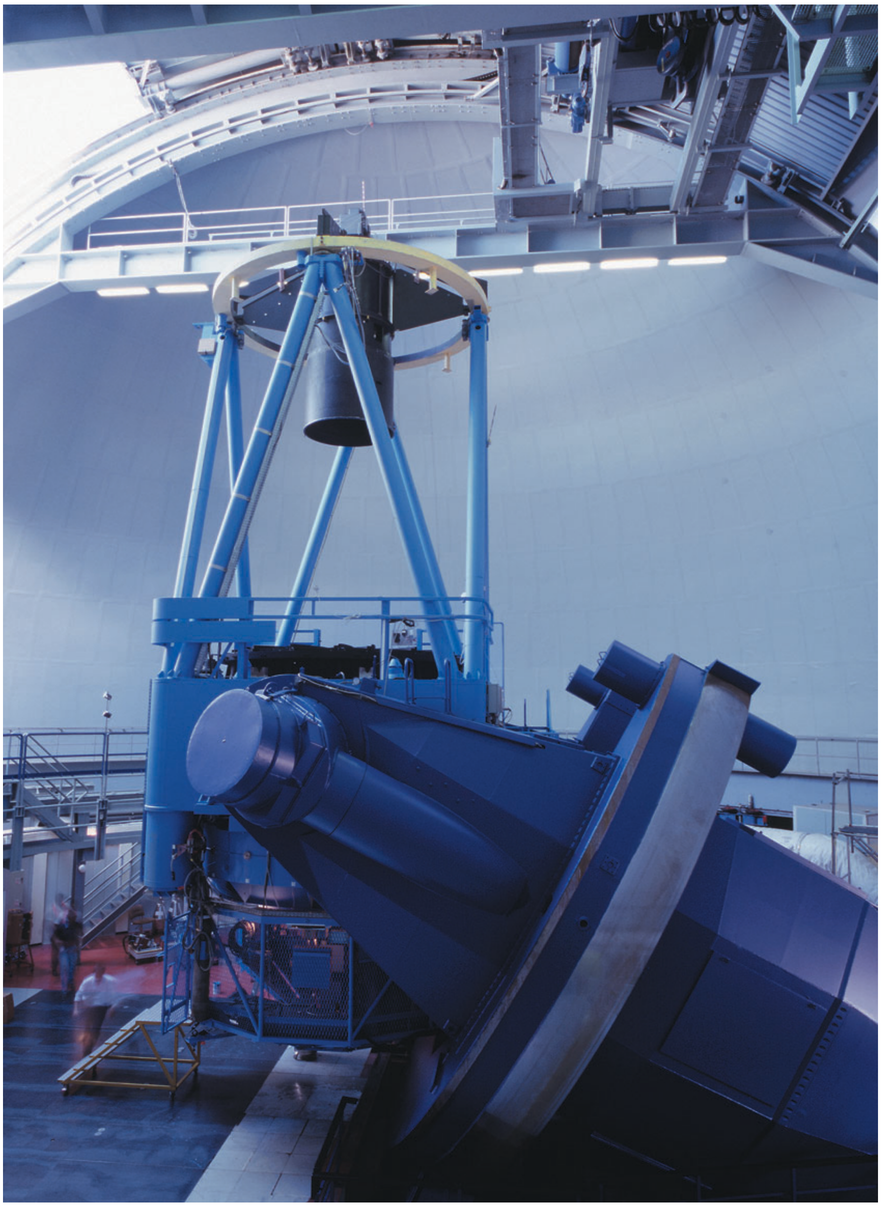


The 1-metre Photometric Telescope started operating in 1966.

Director of ESO, formally for half of my time, but in practice soon for a larger share. While ESO's first General Director, Otto Heckmann continued his efforts to complete ESO's instrumentation programme as outlined in the Convention and with administrative and personnel matters, my task was to initiate the scientific work, i.e. the observational programmes with the telescopes that had become operational. Principal among these were the 1,52-m "Spectrographic telescope" and the 1-m "Photometric Telescope". In March, 1969 ESO dedicated, on La Silla, the completion of this "First Phase". It crowned an effort to which both Chilean and European staff in Chile had essentially contributed, for some of them not without considerable personal sacrifice under very demanding conditions.

When, two years later, Heckmann retired, I was appointed his successor for a term of five years. There was no mistake about my principal assignment: realizing the main telescope project and the Schmidt telescope. These two projects, unfortunately, had been lagging far behind schedule. Whereas Heckmann had admirably and successfully laid the foundations for ESO with all its political and logistic aspects, he had not succeeded on these two topics, and serious doubts had begun to arise among the supporting governments. In retrospect, we know that the scope of a project of this size was far beyond what collective experience of European astronomy had learned to handle. We had to call on those scientists and engineers used to tackling projects of a size comparable to our big telescope in costs and engineering challenge, whatever the nature of the instrument. When I reflect on my years as DG, I realize how fortunate we were to be able to engage in a collaboration with CERN for our Telescope Project, on the CERN premises near Geneva. By the time I handed ESO over to my successor Lodewijk Woltjer, the 3.6-m telescope was nearing completion. In another respect our collaboration with CERN was equally successful. After ESO's Schmidt telescope project had also been reorganized and successfully put into operation – an accomplishment inconceivable without the perseverance and patience of some of my close collaborators – we could establish on CERN premises our unique Photographic Laboratory, capable of undertaking the extremely demanding job of producing the Sky Atlas for ESO and for the UK Schmidt. It is, to me, a source of great satisfaction that these two essential parts of the ESO programme made such excellent progress during my directorate. But perhaps even more fundamental, I believe that by the end of my term, those gnawing doubts that marked its beginning had been removed and ESO had won the full confidence of the funding governments.

Of course, many more recollections come to my mind, too many to dwell upon within this limited space. I feel happy to have contributed, through ESO's status and its administrative services, to the creation of *Astronomy and Astrophysics*, a European Journal, in 1969. And last, but not least, I feel proud to have initiated half a year before my retirement as DG, the *ESO Messenger* – at that time meant as a means to promote communication between ESO's various departments – now serving the astronomical community at large.



The 3.6-metre telecope, completed in 1976.

LODEWIJK WOLTJER, ESO Director General, 1975–1987

Reflecting on my thirteen years as Director General, what gives me most satisfaction are the following:

The enlargement of ESO membership with Italy and Switzerland, which put it on track to be a pan-European organization – now still more fully realized with the adhesion of Portugal and the UK.

The realization of the NTT which showed that ESO had developed the capability of technological innovation and the organizational structure for handling larger projects.

The idea of the VLT and the completion of its planning phase and approval, as well as the discovery and acquisition of Paranal as the best site world-wide for optical astronomy.

The extension of ESO's mandate to include the ST-ECF in cooperation with ESA, and SEST in cooperation with Sweden. Some discussion was needed in Council about the fact that HST would also look at the southern sky and that, after all, radio photons were not fundamentally different from optical ones. So both projects could be fitted in by appropriate interpretation of the ESO Convention. And following SEST, ESO's participation in ALMA appears now entirely natural.

The immediate future of ESO is clear: Adaptive optics at the VLT and the VLT interferometer, the ECF/NGST +Astrovirtel, ALMA. But what comes thereafter? A Very Very Large Telescope? A very large interferometer? And what is very large, in metres and in euros? Since ultimately all euros come from the same sources, what other European projects have to be financed? As one example, many European radio astronomers would wish to participate not only in ALMA, but also in another worldwide project, SKA – the square kilometre array. So it is not clear that budgets for optical facilities can be increased much further. And finally, will optical astronomy have a long-term future on the ground or will most innovative instrumentation move into space some two or three decades from now? Answers to such questions are far from obvious, but perhaps they should receive more attention in a broader circle than they have until now.

Also through its closer collaboration with ESA, ESO is now more than ever at the centre of European Astronomy. Its future looks very bright, indeed.

ESO Headquarters in Garching.

The ESO Council in session on December 8, 1987, when the VLT project was approved.

HARRY VAN DER LAAN, ESO Director General, 1988–1992

From SEST to ALMA, from NTT to OWL: Of Vision, Dreams and Realities

ESO has come a long way since in 1987 the first rocks were blasted at the NTT site on La Silla. Those were exciting days, when SEST came online and soon after the VLT programme was getting up to speed upon its approval in December 1987. It was not an easy time for staff or management: taking up the role of main contractor for its own design and construction programme rather than finding an industrial consultant to do so was an enormous challenge. It was not obvious that it could be done, for more than ninety per cent of ESO's staff capacity was occupied with running La Silla, operating Headquarter services and constructing the NTT. The VLT Blue Book and the bag of money Council had allocated to its realization were necessary but by no means sufficient. For the new, formidable task, manpower had to be found and trained, manpower both reassigned and newly recruited.

Change inevitably meets resistance in both staff and community. For astronomers in member states the VLT was a faraway dream that could not help current Ph.D. projects or further institute ambitions within their normal timeframe. Reductions, of services, of instrumentation and of telescopes were therefore opposed, now and then vehemently. For staff, ends of contracts or reassignments often seemed unfair and misconceived: was their current work not valuable, their normal effort not in demand? The NTT proved crucial for both sorts of objections. It enabled me to introduce the La Silla Key Programmes very early in my term, providing unparalleled opportunities for trailblazing research of a scope until then not possible in Europe. The very positive response to this initiative made inevitable economies on La Silla more palatable; the resistance faded.

Technically and contractually the NTT proved a great learning process for the job, thirty times or so bigger, of designing and constructing the VLT and the Paranal Observatory. The entire process of generating the engineering specifications, the contractual conditions and the financial arrangements was developed to a very professional level that withstood critical tests in very competitive circumstances. When we signed the contract for mirror blanks with Schott in September 1988, I was confident that we were up to the challenge. Of course, the troubles ahead, managerial, technical, financial and above all political, were not all anticipated, but they were resolved as they came along. An example is the summer of 1991. From several directions concerted actions tried to break up the main structure contract into at least three pieces. Summer weeks were spent in design reviews of the main structure tenders, an operation whose motive was to meet political objections in a technical guise. The exercise was well worth it, as the performance of the unit telescopes has by now amply demonstrated: the affordable Italian bid for realizing the ESO double-track design prevailed in the end.

Such troubles are, I believe, a normal and inevitable feature of major international projects, although they have a peculiar flavour in European organizations.

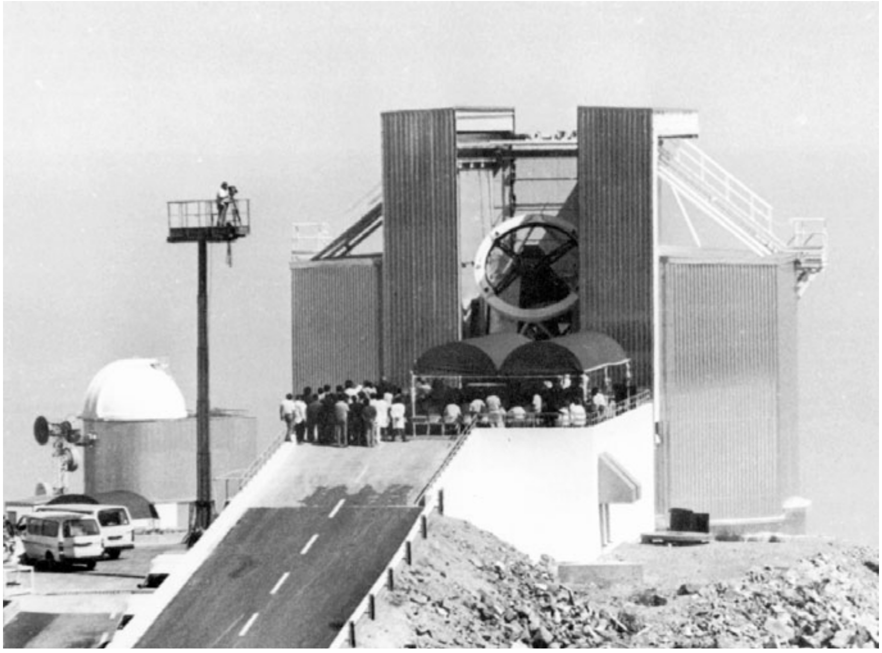
The site decision was of major significance and did not come lightly. Before coming to ESO, I chaired the Site Selection Working Group and was convinced that the Paranal area, in the heart of the Atacama Desert, was much superior to the La Silla region. Both Paranal's number of clear nights and the amount of superb seeing, ground-based optical astronomy's most precious asset, were without precedent. That building the VLT on ESO's La Silla territory had countless logistic, operational and hence financial advantages was as clear to me as it was to administrative Council- and Finance Committee members. But unlike them, I could assess the science-added value of going North and it far exceeded the extra costs and trouble. All powers of persuasion had to be mustered but in the end science won over short-term economy and convenience.

Today the Paranal Observatory is a towering witness to astronomical persistence, engineering skills and ESO staff dedication. Europe will be in the lead for many decades to come in exploring the Universe from there, the finest cosmic discovery base yet devised by man.

The 15-m Swedish-ESO Submillimetre Telescope (SEST) at La Silla.

The VLT, even its VLTI-mode, is not the end of ESO's journey; rather their quality brightens the prospects for further ambitions that reach for the stars. A key role in ALMA is called for and is bound to unfold in the next twenty years. OWL is a dream as the VLT was twenty years ago. Twenty years from now it shall, in some rendition reminiscent of the current dream, amaze the world once more. Because '*A vision is a dream with a deadline'*.

ESO was Jan Oort's vision fifty years ago. This vision had great power and has propelled our community to a sequence of extraordinary achievements. With ESO, Europe is first to reach for ultimate frontiers. It's what our political leaders in a recent Lisbon summit called for.



On February 6, 1990, the ESO NTT was officially inaugurated.

RICCARDO GIACCONI, ESO Director General, 1993–1999

I feel privileged in having had the opportunity to lead ESO during a period of great innovation and expansion. Building on thirty years of heritage, working together with an extremely competent staff and with the full support and cooperation of the ESO member states, we were successful in many endeavours. They include the construction of the Very Large Telescope and the development of Paranal, the modernization of the La Silla Telescopes, the introduction of new managerial and scientific methodology, the expansion of the Education and Public Outreach programmes and the start of the VLT interferometry development. By achieving success in all these areas we established ESO as a model for optical ground-based facilities around the world and redefined the role of ESO in European astronomy.

Today ESO is busily proceeding in the scientific exploitation of the VLT, in completing development of VLTI and is cooperating on a 50/50 basis with the US and Canada on the Atacama Large Millimeter Array, the largest ground-based astronomy programme yet undertaken. I am confident that ESO can lead an international cooperative effort on the next-generation overwhelmingly large telescope (OWL).

CATHERINE CESARSKY, Present ESO Director General

I arrived at ESO at a very interesting time. I had the privilege of witnessing the first light of Melipal and Yepun, of overseeing the installation of UVES, NACO, VIMOS and FLAMES at the focus of VLT telescopes, and of celebrating the first fringes of VLTI, first with siderostats and then with 8-m telescopes. The harvest of scientific results with the two FORS, ISAAC and UVES is already impressive, and the efficiency of the Paranal Observatory is astounding. ISAAC and UVES both have features unequalled at any other telescope; with NACO, we have the best adaptive optics instrument ever, nearly ready to be offered to our community, while VIMOS and FLAMES are showing their promise in the current commissioning activities. The VLT archive is open and attracts more and more users, a good omen for the Astrophysical Virtual Observatory. Meanwhile, the La Silla Observatory has also been very productive and has undergone huge improvements, coming closer and closer to VLT standards.

In parallel, these three years have been filled with work and meetings in preparation for the next large project, ALMA. Wide collaboration with the European millimetre and submillimetre wave observatories and laboratories, use of all the available expertise and pooling of the forces, and a well coordinated sharing of tasks with our American colleagues, have brought about considerable progress of the project during Phase 1. Now, Phase 2 is about to be launched. Negotiations with the USA and Canada, Chile, Spain and Japan are all converging on time.

Also, faithful to its original purpose, ESO is preparing the long-term future in ground optical/infrared astronomy, with the conceptual study of the OWL 100-m telescope. All these developments – from VLT instruments to VLTI to ALMA and in the future studies for Extremely Large Telescopes – require and foster an ever-growing involvement of other European groups, who are no longer just users but also full fledged collaborators.

The past three years have seen the emergence of ESO as a major player on the European scientific scene, in which role it is actively contributing to the establishment of the European Research Area advocated by Commissioner Busquin. The organization has acquired two new member states, Portugal and the United Kingdom. Council has unanimously endorsed a long-range plan allowing continuing the deployment of VLT and VLTI while starting the construction of ALMA on an equal partnership with North America. Several other countries are considering or negotiating adhesion to ESO, and in the mean time Spain is participating in ALMA with the ESO member states. Contacts and exchanges with six scientific European organizations and with the European Union have been strengthened through the creation of EIROFORUM; with ESA in particular the cooperation has been greatly enhanced in the perspective of a tighter coordination of space- and ground-based astronomical research.

Some Snippets of History

Richard West (ESO): Memories of early times at ESO

My first encounter with ESO was a meeting for young European astronomers, organized in Nijenrode Castle (north of Utrecht, The Netherlands) in the summer of 1963. Here, about thirty future astronomers had a wonderful opportunity to meet some of ESO's famous founding fathers and – the real aim of this event – to become acquainted with each other. I was one of three from Denmark, as a student at the Copenhagen University Observatory at that time. With the conference programme running late, I had to speak about my work (computer studies of light curves of eclipsing binary stars) in the evening session, just before Prof. Marcel Minneart's closing lecture. It was the first such speech I had ever given in English and I remember being suitably nervous, but surviving. The meeting indeed brought together many of those young scientists who later became involved in ESO and many of us still recall this initiation to European cooperation with great pleasure. Thanks above all to the persistent efforts of my Professor in Copenhagen, Anders Reiz, Denmark was able to join ESO in 1967.

I myself came to ESO at the beginning of 1970 as Assistant to the Director General, Prof. Adriaan Blaauw. I often travelled to La Silla to perform observations with the various telescopes there during the following years. In November 1970, John Graham at Tololo found a nova in the LMC. With the ESO Director in Chile, Prof. Bengt Westerlund and another ESO astronomer there, Bob Havlen, we decided to obtain slit spectra of the fading 13th magnitude object; as far as I recall, it was only the second time this was done on an LMC nova. I spent three nights at the "Chilicass" spectrograph on the ESO 1.52-m telescope, exposing continuously for 4, 5, and 7.5 hours, respectively. To do the visual guiding properly – each photon really counted! – I had to balance most of the time in total darkness, high up on a ladder at the edge of the floor platforms. It was indeed a rewarding feeling when I finally saw a usable spectrum on the small plate in the dim darkroom light at the end of the night. Ten years later, we started using CCD's and such heroic efforts are now ancient history.

Jacques Breysacher (ESO): Early days of the OPC

The history of the OPC goes back to June 1967 when the ESO Council decided to establish a Scientific Programmes Committee (SPC) meant to advise the Directorate and the Council on general scientific policy matters, and to evaluate the observing proposals submitted by the visiting astronomers. The SPC held its first meeting in May 1968 at the Bergedorf office of the ESO Directorate, in Germany.

The SPC proposed rules of procedure which were formally adopted by the ESO Council in July 1968: telescope time allocation was to be arranged for periods of six months; observing proposals had to be submitted 6 months before the beginning of these periods; final allocation was done by the Directorate following the recommendations of the SPC. One third of the observing time was to be allocated to the ESO staff. According to the ESO numbering system of the observing semesters, in which October 1, 2002 – April 1, 2003, corresponds to Period 70, the first observing semester (Period 1) was November 1, 1968 – May 1, 1969.

In these early days potential applicants were informed that "Observing periods granted may range from several weeks to several months", a somewhat unusual length for a run nowadays ..., but were also warned that "Defrayal of travel expenses of accompanying wives is foreseen to a limited extent and that only in the case the observers will have to stay in Chile for a period of at least six months." This last statement reveals an interesting sociological fact: in the early 1970's a visiting astronomer was by definition a man!

Svend Laustsen (ESO, ret.): How ESO got its Optics Group

In 1970, at a time when ESO still had its European seat in Hamburg, I was given the task to build up technical groups and to install these at CERN in Geneva. Thanks to splendid help from CERN we soon succeeded to set up groups for mechanics and electronics and for site, buildings and domes. These groups worked for the design and construction of the 3.6-m telescope and other projects in Europe and at La Silla.

In the optical field, however, CERN was not of much help, and we had not succeeded otherwise in attracting optical technicians. Finally Alfred Behr and I agreed to ask Ray Wilson at the Zeiss Works, whether he new of any young man he could recommend to us. He replied: "No, I do not know of any technician for that job, but I can offer myself to ESO as an optician." A new situation indeed. After consultation with Adriaan Blaauw, we invited Ray for a dinner – in confidence of course – at the restaurant Mövenpick in Geneva. It was a long-lasting dinner, which resulted in the agreement on his appointment.

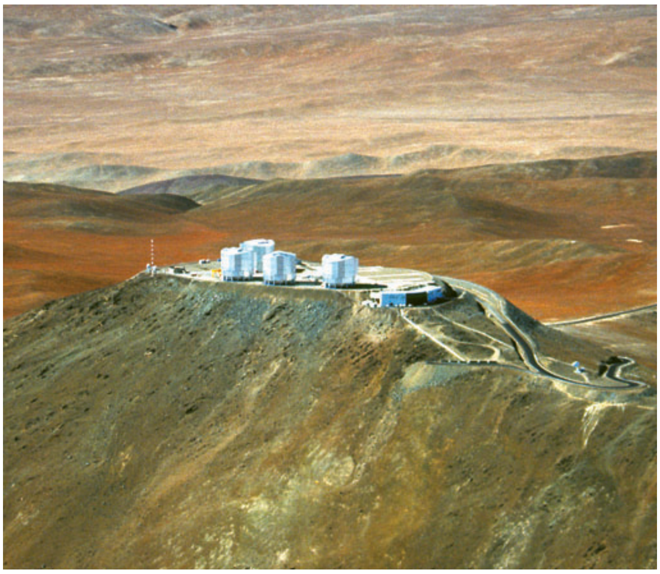
Shortly after taking up his duties Ray presented plans for an Optics Group, and according to this Francis Franza, Maurice Le Luyer, Daniel Enard, and some others for shorter periods, were engaged. Still at the time when the 3.6-m telescope was under construction and installation, they started their development of new methods for the support of big mirrors. The positive impact this group and their work has had for the NNT, the VLT and for ESO in general is well known to everybody in and around the organization.

Daniel Hofstadt (ESO): Renata Scotto at La Silla

Twenty years ago Renata Scotto sang Madame Butterfly at the Santiago Opera House and later on visited La

Construction of the building for the 3.6-m telescope at La Silla in 1975.

Paranal before ...



... and after construction of the VLT .

Silla. Most of us were somewhat stiff in our welcome in view of her Prima Donna reputation. An incident was to break the ice in a most unexpected manner. Our colleague the “Dottore”, a great opera fan, came to see the Diva and asked her to sign a music record. For a moment she acted very surprised and then signed a dedicatory with grace and smiles. The “Dottore” had approached her with a María Callas record! Such an achievement is most likely to remain a world premiere.

Daniel Hofstadt (ESO): La Silla vaut bien une Messe

Newcomers at La Silla had to learn and face the peculiarities of a world and culture which had developed at La Silla over the years. Ingenuousness was not part of that culture. Newcomers would be quickly baptized with nicknames reflecting their physical or psychological traits. Practical jokes were not absent either and most of the beginners would be sent to the telescopes to attend weird issues or support important visitors who had not shown up. Probably the most striking welcome was staged for a young technician who enquired if Mass was celebrated at La Silla. His colleagues immediately reassured him and invited him for his first Sunday Mass, a Mass which was properly and seriously officiated by a member of Team and with extensive attendance from the staff.

Jean-Pierre Swings (IAP, Liège): First experience at La Silla, and some activities for the VLT

Thirty years ago (January–February 1972) I had my first observing run on La Silla, a “luxurious outfit” after 10 nights on Las Campanas. (On Las Campanas the night assistant had been hired just when I arrived, neither he nor I knew anything about the 1-metre telescope, and we had no common language... not to mention the lodging and eating “facilities”!). I was allocated 8 or so nights at the ESO 1.52-m coudé to do spectroscopy of B[e] stars. Having observed (± discovered) some interesting objects with IR excess at Las Campanas, I requested to use the Cassegrain spectrograph to take low-dispersion spectra of those objects... but this was refused by the ESO Director for Chile: I had to do my “approved programme”, period. So I did, but in “retaliation” I decided to end my fruitful run by observing HD 45677 at 3 Å mm^{-1}, which required a 3-night exposure. This enabled one to show that, contrary to the sharp-single [FeII] lines, those of FeII exhibit a double structure, qualitatively explained as originating from a ring around the star... and not from an earthquake that occurred during the second night of exposure!

I later became involved with the VLT, as successively chairman of the VLT Study Group, the VLT Advisory Committee, and the Site Selection Working Group. The Workshop on ESO’s Very Large Telescope (Cargèse, May 1983, in which an ESO VLT was presented for the first time to a number of scientists from the ESO countries, showed full unanimity about the definite need for a 16-m (equivalent) telescope to be located on an excellent site. Five working groups and a VLT Advisory Committee were set up after the Cargèse meeting in order to “define realistic objectives” and to “assess the implication of the specifications (and thereby the cost!) of a VLT”. Their reports were presented in Venice (2nd VLT Workshop, Sept. 1986) and received an overwhelmingly positive echo. The VLT proposal was then elaborated into the “Blue Book” that was endorsed by the ESO Council in 1987. The VLT was going to become a reality; interferometry was going to evolve from a bonus to a driver, and we now start to see its fantastic potentialities through the VLTI.

The conclusion of the VLT Site Selection Working Group (SSWG) (VLT report n° 62, p. 159, Nov. 14, 1990, edited by Marc Sarazin) stated: “On the basis of scientific considerations, the SSWG unanimously recommends that the Paranal area be chosen for the location of ESO’s Very Large Telescope”. As chairman of that SSWG I had to defend this at the next Council meeting, and then came the truncation of a beautiful conical mountain in order to accommodate the VLTI on what was, and hopefully will remain, an excellent site. Once in a while I shiver a bit about all the consequences of the SSWG recommendation!

Daniel Enard (EGO, Pisa): The early days of instrumentation at ESO

To younger people born in the age of Megapixels and computer control, a narration of the (not so) old ESO times may sound like a medieval tale. Yet, the experience acquired in this period largely contributed to the present extensive ESO expertise.

In the early 1970s, the largest telescopes built in Europe were between 1 and 2 metres diameter. Several 3- to 4-m telescopes were being developed (3.6-m, CFH, Calar Alto, AAT) all much inspired by the 5-m Palomar telescope which was still a reference model. Astronomical instrumentation consisted largely of conventional spectrographs, with images recorded on photographic plates in which sensitivity was boosted through a complex alchemy. The forefront detectors of the time were image intensifiers, with images recorded on photographic film, and electronographic cameras that recorded photoelectrons directly on fine grain emulsions. These “electronic cameras”, as they were called, resulted largely from the pioneering work of Lallemand and were the most sensitive and most linear of the time. But operation of the early models also required much delicate and complex manipulation as the photographic emulsion was placed inside the vacuum and a new photocathode had to be installed before each operation! Later electronic cameras – the Spectracon and McMullan cameras – avoided these problems but it was still a challenging task to extract the data afterwards.

I joined ESO in February 1975, by coincidence on the same date as Lo Woltjer, the newly-appointed DG. My initial position was within the optics group led by Ray Wilson which, with the arrival of Guy Ratier, Maurice LeLuyer and Bernard Delabre grew suddenly from 2 (Ray Wilson and Francis Franza) to 6 people. The ESO 3.6-metre was under test in Europe and well on its way to completion. Its instrumentation programme however did not go beyond talks and minutes of meetings. Faced with the prospect of the largest European telescope deprived of instrumentation, a crash programme was set up by the new DG. As a “first-aid” solution, a single aspheric plate corrector was developed and arrived just on time for the telescope first light in 1977. Waiting for better instruments able to fully exploit the capabilities of the telescope, in particular the large field of view of the prime focus, a number of beautiful pictures were recorded by Svend Laustsen while the telescope was being commissioned. This first experience with the 3.6-m was also our first direct encounter with a subtle and devastating devil: seeing degradation.

As part of the initial programme there was a 1-degree field triplet corrector for the prime focus that was put into operation in 1979, and a Boller and Chivens spectrograph, which had the immense advantage of being commercially available. A Cassegrain adapter, providing field acquisition, guiding and calibration facilities, already under development in 1975, was completed and installed in 1977.

The ESO Council at Ansaldo, with the mechanical structure of one of the VLT 8.2-m telescopes.

An episode will give a hint on the mood of the time. Around the Cassegrain adapter and instruments arose a fierce debate, in particular on whether the astronomer should sit in the Cassegrain cage to guide the telescope through an eyepiece or whether it was at all thinkable to trust a TV camera and perform the control from the control room! Although an eyepiece was included, the “modern” school eventually won, but not before making three prototypes of the “Cassegrain chair”, an improbable object somewhere between a middle-age torture device and a dentist chair for cosmonauts.

More pragmatically, Martin Cullum meanwhile dealt with the adaptation of electronographic and electronic detectors for imaging (Spectracon in 1978 and 40-mm McMullan camera in 1979) and for spectroscopy (two Image Dissector Scanners in 1978 and 1979).

With the first set of basic instruments under way, there was more time to think about more ambitious projects. Simultaneously, the designs of the CES (Coudé Echelle Spectrometer), CASPEC (Cassegrain Echelle spectrometer) and, somewhat later, IRSPEC (IR spectrometer) were initiated, while the CAT (1.4-m Coudé Auxiliary Telescope) was being built. This first generation of modern instruments was put into operation in the early 1980s together with the first solid-state detectors (Reticons and CCDs).

The realization of this instrumentation programme within a few years by the small and somewhat novice group in Geneva was not only a great achievement but also a defining experience for many of us. Working on the Boller and Chivens spectrograph, I realized the significant light losses occurring within instruments, in particular in the popular solid-Schmidt cameras, due to vignetting, the large central obstruction and mirror reflections. High efficiency coatings were already available, yet relatively little used in astronomy because of their limited spectral bandwidth. A rather obvious idea was to split the spectrum into blue and red channels within the same instrument so that high efficiency coatings could be used. This not only provided an important throughput gain but also allowed the use of many more optical surfaces without significant losses, hence opening the path to more complex optical solutions. In particular, with the new fluorine glasses then available, it became possible to design high-quality and efficient transmission optics instead of mirror combinations. This allowed instruments to be designed that could satisfy both imaging and spectrographic requirements by simply removing or exchanging the dispersive element. On the logistic side, one of the many lessons learned by the 3.6-m experience

The ESO Council at Paranal Observatory, December 1996.

was that frequent change-over of instruments and of telescope configurations (Prime, Cassegrain, IR secondary, etc.) was a major contributor to telescope down time.

From all these considerations, the idea progressively emerged of a *high-productivity* telescope having a single configuration and several focal stations equipped with fixed multimode instruments. This idea inspired first the NTT and became fully mature with the VLT, which was conceived around this concept. As a forerunner, the multimode instrument EFOSC was developed in 1982 and put into operation in 1983 with great success. The multimode concept was then fully developed with EMMI, then used in several VLT and other large-telescope instruments. Another conceptual idea which directly emerged from the 3.6-m experience was the use of natural ventilation to eliminate dome seeing, a concept fully validated with the NTT and the VLT.

This quick glance at the past would not be complete without mentioning the gigantic progress made in detectors in about two decades. Up to the late seventies, image recording was still essentially done with photographic plates, and solid-state arrays were very much laboratory curiosities. The first solid-state detector at ESO was installed on the CES in 1981; this was a then state-of-the-art Reticon array with a read-out noise of 1000 electrons! Our first CCD put into operation in 1982 had about 300 × 500 pixels and a read-out noise of some 80 electrons (plus a lot of fringing). Today, when megapixel image formats and quasi photon-counting performance are routine, it is difficult to appreciate just how significant an advance these early electronic detectors represented.

The completion of the 3.6-m telescope and the development of the first modern instruments has been an extraordinary learning period and contributed to the creation of a core team of instrument builders fully familiar with the problems of astronomical observation as well as with the latest technical advances. Capitalizing on the progresses in detectors, optics and computer control technologies, several highly advanced and successful instruments and telescopes were built in the early 80's that moved ESO to the forefront of astronomical instrumentation. The international recognition of this competence, and the confidence this generated, contributed greatly to the enthusiastic endorsement of the VLT programme in 1987. It belongs now to the new generation of instrumental developers to maintain and further develop this capital.

Alan Moorwood (ESO): The early days of infrared instrumentation at ESO

ESO's commitment to infrared astronomy was expanded in 1977 by the creation of a new staff position for an Infrared Astronomer to advise the Director General on the development of infrared instrumentation. I actually only became aware of the advertisement via a letter from Franco Pacini, then Head of the ESO Scientific Division, with a request that I let him know of any suitable candidates. The surprising end result, despite having felt protected by my non-member state nationality, was that I found myself leaving ESA to take up duty at ESO in Geneva on October 1st, 1978!

As it happens, I was fortunate to have had been preceded by Piero Salinari, who had worked with me to build a balloon-borne IR spectrometer at ESTEC but had then been hijacked to Geneva by Franco on his way back to Italy. As I was to do later, Piero had already discovered that 'advise on infrared instrumentation' could be loosely translated as 'build infrared instrumentation'. He had thus already commandeered a somewhat dilapidated container on wheels, reminiscent of a gypsy caravan but converted into an authentic looking infrared laboratory by installing the golden looking cryostats and pumps associated with infrared astronomers in those days. (His later attempt to improve the container by painting it was less successful, at least the idea of drying it by leaving a powerful heater on all night which considerably changed its shape). Despite that, the first ESO-developed infrared photometer system was finished and installed at the 3.6-m on La Silla in 1979 (and tested with software written by Daniel Hofstadt).

In parallel, we had been developing the idea of building a cryogenic infrared array spectrometer for the 3.6-m telescope (IRSPEC, later transferred to the NTT) which was subsequently enthusiastically approved by Lo Woltjer and the STC. Unfortunately, this did not win me many friends amongst the majority of ESO astronomers who were members of a committee still deliberating on the choice of the next visible spectrograph! Being a relatively major undertaking I was also subjected to more management control, starting with a summons to appear before Lo Woltjer, Ray Wilson and Wolfgang Richter to outline the resources I would need. For a young man on a short-term contract this was a somewhat awe-inspiring event but one which I believed to have mastered with bravado by replying that I wished first to absorb their wisdom as to how best to develop such an instrument at ESO. The answer of ' if only we knew' was unexpected but at least an honest admission that these were still pioneering days in the adventure of instrument (as opposed to telescope) building at ESO. I therefore decided to concentrate first on the problem of finding a larger caravan which was solved surprisingly quickly – albeit with the additional work involved in transporting our golden cryostats and pumps from Geneva to Munich.

Walter Nees (ESO):
ESO's first step into the world of minicomputers

In today's world of automation, computerization, data-processing, etc., it is rather difficult to imagine how it all started. The story goes back to early 1970, nearly 33 years ago. I had just joined ESO in the Hamburg-Bergedorf office when I became witness to a major ESO event, synonymous to setting the cornerstone of automation technology at ESO. Unknown to most people at ESO today, it was the exciting moment (at least for most ESO staff at the time) when ESO acquired and introduced its very first digital minicomputer, a Hewlett Packard HP-2114B system. This "workhorse" computer had a core memory of 16 kbytes (interesting to compare with today's computers!).

The ESO Grant machine.

The NTT at La Silla.

In order to close a technological gap, ESO committed itself to employ leading-edge technology for acquisition, process control, and reduction of astronomical data. This first computer system was selected to serve as the central control for the "Grant Machine", an automated photographic-plate measuring and scanning facility for stellar-line radial-velocity determinations, and for microdensitometry recordings of stellar spectrograms.

Before this so-called automated mode of operation was feasible, a significant number of technical modifications and extensions became necessary to the original Grant Machine, initially conceived for manual operation: the incorporation of an analogue to digital data-acquisition system, the attachment of precision rotary digital encoders for Grant table X and Y position decoding, and the integration of the computer with all peripherals and I/O-interfaces. The main tasks of the minicomputer were automatic scan control of the table, table position recording, as well as digitization and recording of the density or intensity data from the spectral photographic plate. The required electrical and electronics hardware adaptation on overall system controls had been contracted by ESO Bergedorf to a specialist electronics company in Stockholm, Sweden.

The initial installation of the Grant machine and its dedicated computer system at ESO Headquarters in Santiago was in July 1970. In spite of the positive acceptance tests in Stockholm, significant technical work was necessary until all problems had been resolved. The data-acquisition and control software (all written in awkward Assembler and Fortran code) was designed and implemented by ESO's chief programmer, Mr. Frank Middelburg (deceased November 1985), in collaboration with a few of the leading staff astronomers (Dr. J. Rickard, Dr. A. Ardeberg, and others) from the ESO Santiago Vitacura office. At the end a reliable and successful product was produced. The "ESO Grant machine" became for many years a well-known tool in astronomical data reduction and was used extensively by many ESO and visiting astronomers. Eventually it was transferred to ESO's Headquarters in Garching were it served until its retirement some years ago.

Ray Wilson (ESO, ret.):
First Astronomical Light at the NTT

The night beginning on 23rd March 1989 was the culmination of my career at ESO and indeed of my work on telescope optics, which started as an amateur when I was six and continued professionally at Zeiss in 1963.

Intensive work by many colleagues in Garching and La Silla had preceded this great night of first light at the NTT: above all I would mention Francis Franza, Paul Giordano and Lothar Noethe on the optics and Krister Wirenstrand on the pointing. The active optics was working only in open loop, as we had "borrowed" its CCD to record the test object I had chosen, the globular cluster ω Centauri. The night was perfect, a light laminar wind giving excellent ventilation and seeing. The results started to come in and were evaluated by the astronomers. The best one was evaluated by Jorge Melnick, but he checked it a second time because he couldn't believe the result, but then confirmed it: FWHM = 0.33 arcsec. Jubilation and amazement in La Silla, also in Garching as expressed by Richard West. A journalist was also present with us: he absolutely wanted to record that this result had occurred on my birthday (23rd March), but it actually occurred about 02.00 hours on 24th March. I didn't mind this at all, but the journalist did! This best frame of our test night was shown in a beautiful comparison set-up by Richard West, with blown-up sections of photos from the ESO 1-m Schmidt and 3.6-m telescopes, in the next *Messenger* and is reproduced in my RTO II (p. 293).

The foundations of the incredibly successful active optics system of the VLT, based on identical principles, had been laid.

The first of the VLT 8.2-m telescopes (Antu) saw "First Light" in 1998, the last of the giant telescopes (Yepun) on September 3, 2000.

Piero Benvenuti (ST-ECF): Recovery of a historical document

While clearing his office of over a decade of accumulated papers recently, in preparation for an extended stay at the ST ScI in Baltimore, Richard Hook knocked on my door and, smiling, handed over a paper with an handwritten note on the front page: "An excellent idea! Sorry it took 13 years for me to reply! Richard".

The "historical" document was entitled "A proposal for the astrophysical classification of HST targets" and was drafted by me in March 1989, in a final attempt to convince the HST Project to implement a classification scheme of the observed targets that would facilitate the browsing through the HST Archive. At the time the proposal was received with interest, but was never implemented.

Perusing the paper today, it still makes a lot of sense, although one would implement its concept differently. Indeed its scientific goal would be better achieved today as a functionality of the Virtual Observatory environment, correlating data from more than a single instrument together with direct link to the existing literature. Nonetheless, it shows some kind of coherence (stubborn-mindedness?) in the ECF!

Catherine Cesarsky (ESO): First Light of UT4

(from *The Messenger* No. 101, Sept. 2000)

At 21:44 hours on the night of September 3, 2000, the test camera at the Cassegrain focus was opened for 30 seconds, and the fourth VLT Unit Telescope, Yepun, saw First Light. A historic event in the life of ESO; this first light marked the successful conclusion of the important period which started with the approval of the VLT project by the ESO Council in December 1987. Exceptionally for such a complex and expensive project, the four VLT telescopes came into operation ahead of schedule. The VLT was no longer only a project, it was now also an Observatory.

By virtue of becoming ESO's Director General at the right time, I had the privilege of actually being in the observing hut of Yepun at the crucial moment, sharing the excitement of the VLT Manager, Massimo Tarenghi, of the Director of Paranal Observatory, Roberto Gilmozzi, and of the members of the commissioning team, Jason Spyromilio, Krister Wirenstrand and Rodrigo Amestica. It was a cold night, appropriate to the late Chilean winter, and we could hear the wind howling outside. We had chosen our first light target in advance: the planetary nebula He 2-428. In a few minutes, the guide star was acquired, the position and shape of the mirrors were actively corrected, and we could see on the computer screen the unmistakable shape of the source, with an image quality limited only by the atmospheric seeing (0.9 arcsec at the time). The rest of the evening was spent in the VLT Control room in the appropriate celebratory manner, taking more images, attending to the PR requirements, and drinking champagne with the teams observing on the other telescopes.

Everyone present felt the sense of accomplishment, triumph and elation that always accompanies the culmination of a great human adventure.

Andreas Glindemann (ESO) et al.: First Fringes with ANTU and MELIPAL

(from *The Messenger* No. 106, Dec. 2001)

On October 30, 2001 at about 1 a.m., the two 8-m Unit Telescopes ANTU and MELIPAL of Paranal Observatory were combined for the first time as a stellar interferometer observing fringes on the star Achernar, only seven months and twelve days after the VLTI produced the first fringes with two siderostats. This was the first time that the VLTI was operated as a truly Very Large Telescope Interferometer.

The night started with tests of the Coudé Optical Trains and the Relay Optics, converting the light from the Coudé focus to a parallel beam in the Delay Line Tunnel. Around midnight, when the UT team finished the tests and the search for fringes could start, not everybody on the mountain would have bet how quickly the search was successful.

Barely one hour after we had started, the automatic fringe search routine in VINCI reported 'flecos en el cielo', and the fringes appeared on the screen. We found that the baseline of 102.5 m between ANTU and MELIPAL differed by only 28 mm from their nominal length. After refinement, fringes were subsequently found within 0.4 mm of their calculated position.

With the experience that we had gathered over the last six months of commissioning, 'routine operation' with the 8-m telescopes started almost immediately.

APEX – The Atacama Pathfinder Experiment

L.-Å. NYMAN[1,2], *P. SCHILKE*[3] and *R.S. BOOTH*[2]

[1]*ESO/SEST, La Silla, Chile*
[2]*Onsala Space Observatory, Onsala, Sweden*
[3]*Max-Planck-Institut für Radioastronomie, Bonn, Germany*

1. Introduction

APEX is a collaboration between the Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn (together with Astronomisches Institut Ruhr-Universität Bochum, AIRUB), ESO and Onsala Space Observatory in Sweden (OSO). The idea is to construct and operate a 12-m diameter submillimetre telescope on the ALMA site of Llano de Chajnantor in Chile at an altitude of 5000 m. APEX will operate at submillimetre wavelengths as well as in the far infrared (at THz frequencies), which is possible because of the excellent atmospheric transparency that exists on the site at these wavelengths; it might be the best site in the world for sub-millimetre astronomy.

APEX will explore the southern sky, which is virtually unexplored at submillimetre wavelengths, and also serve as a pathfinder for ALMA, both by performing wide-field surveys for later follow-up by ALMA, and by obtaining experience in operations of telescopes at the site.

The project is shared between the partners in the ratio 50% MPIfR/AIRUB, 27% ESO and 23% OSO. 10% of the observing time will be dedicated to Chilean astronomy. The antenna is being purchased by MPIfR, OSO and MPIfR will provide instrumentation and ESO operations.

2. Science

APEX will be able to make significant contributions to the solution of a number of current astronomical problems that cannot be, or are insufficiently addressed with currently available telescopes: constraining cosmological models, studying star formation in the early and local universe, stellar evolution, interstellar chemistry at high frequencies, and the exploration of the southern submillimetre sky. At submillimetre wavelengths APEX will have a better spatial resolution than space or balloon borne instruments, by virtue of the larger dish size. Additionally, it will serve as a pathfinder for ALMA in all of its wavelength ranges. Surveys with APEX will be an outstandingly efficient means of finding target sources for ALMA, and for their line and continuum exploration prior to their detailed interferometric study with greater spatial resolution.

Figure 1: An artist's impression of the APEX antenna.

2.1 Exploring the star-formation history of the Universe

Among the fundamental cosmological questions being asked today are: when did galaxies and massive black holes form in the early universe, and how did they subsequently evolve? Modern telescopes are now detecting galaxies out to redshifts beyond 6, close to the “dark ages” where the first stars and galaxies may have formed. Because much of the stellar light emerging from massive star-formation regions is immediately absorbed by the surrounding dusty clouds, even the most luminous starburst galaxies are difficult to observe at optical and even NIR wavelengths. The absorbed radiation is re-emitted by the dust as long-wavelength infrared radiation which can easily escape the star forming regions – but cannot cross the Earth's atmosphere. However, for very distant objects this radiation is red-shifted to submillimetre wavelengths. This makes it accessible from the ground, at a very few places such as Chajnantor. The large 870-micron bolometer array (LABOCA, see below) at APEX will be ideally suited to detect and map the distribution of the earliest, most distant star-forming galaxies in the Universe. Follow-up observations at 350 micron will provide data on their distance and nature. The unprecedented size of its bolometer arrays and the ideal observing conditions all year round will make APEX the most powerful ground-based instrument to explore the star formation history of the Universe.

2.2 Constraining the Universe: the Sunyaev-Zel'dovich effect

Galaxy clusters are the largest collapsed structures in the Universe. Measuring their distribution and structure provides crucial information on the history and structure of our Universe. Galaxy clusters are embedded in vast amounts of hot, ionized gas. This gas scatters the passing photons of the Cosmic Microwave Background (CMB) and increases their average energy. The resulting distortion in the CMB is called the Sunyaev-Zel'dovich (SZ) Effect and can be used as a sensitive probe of cosmological models and cluster physics. Planned 2-mm bolometer arrays at APEX will have an ideal spatial resolution and sensitivity to measure the SZ effect toward distant clusters.

2.3 Unbiased searches for protostars

Another important scientific objective APEX will pursue is a search for protostars in heavily obscured star-formation regions in our Galaxy. Understanding the very earliest stages of star-formation ranks as one of the most important questions in astrophysics.

Stars and their surrounding planetary systems form from dense condensations within molecular clouds. Before and during their collapse, these dense gas cores, or protostars, remain very cold (10–30 K), and therefore escape detection with infrared instruments such as ISO, IRAS and MSX. APEX on the other hand will detect these objects in the submillimetre continuum and in molecular lines to study the kinematics of the collapsing objects, deepening our understanding of the sources discovered.

Figure 2: The APEX antenna seen from the back. Note the Cassegrain focus cabin and the two Nasmyth focus cabins. The container below and behind the focus cabins will contain the spectrometers and other electronics.

2.4 Submillimetre spectroscopy of the Milky Way and external galaxies

The frequency bands between 600 GHz and 1.5 THz are relatively poorly explored, especially in the southern hemisphere, but the spectral windows in this range contain low-lying transitions of many molecules that are known, or expected to be abundant in interstellar clouds, protostars, the circumstellar envelopes of evolved stars, and comets. Important lines are those of the light hydrides, of particular interest in astrochemistry, and some fine

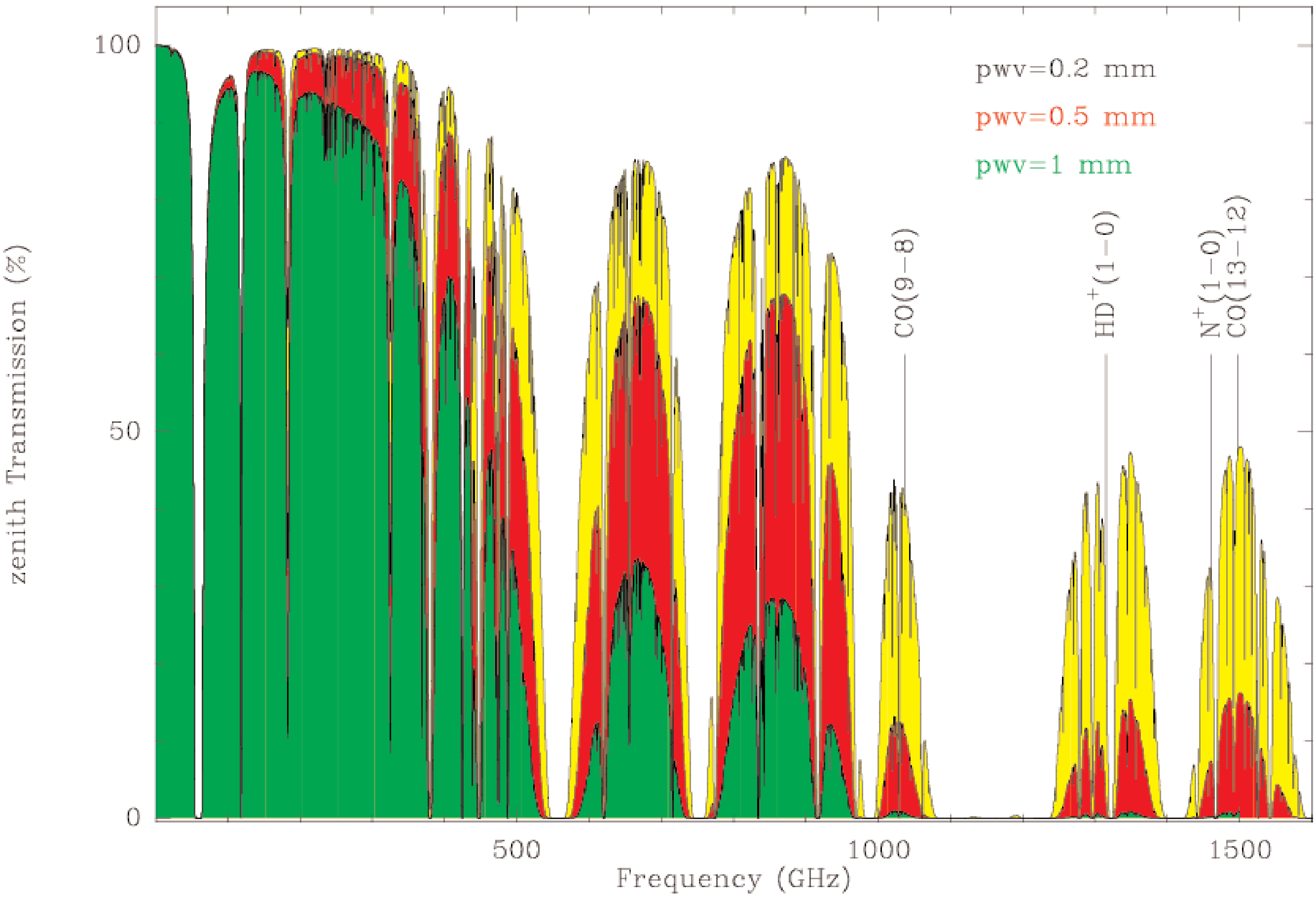


Figure 3: The atmospheric transmission curve for Chajnantor with different amounts of precipitable water vapour (PWV). The THz windows open at PWV levels below 0.5 mm.

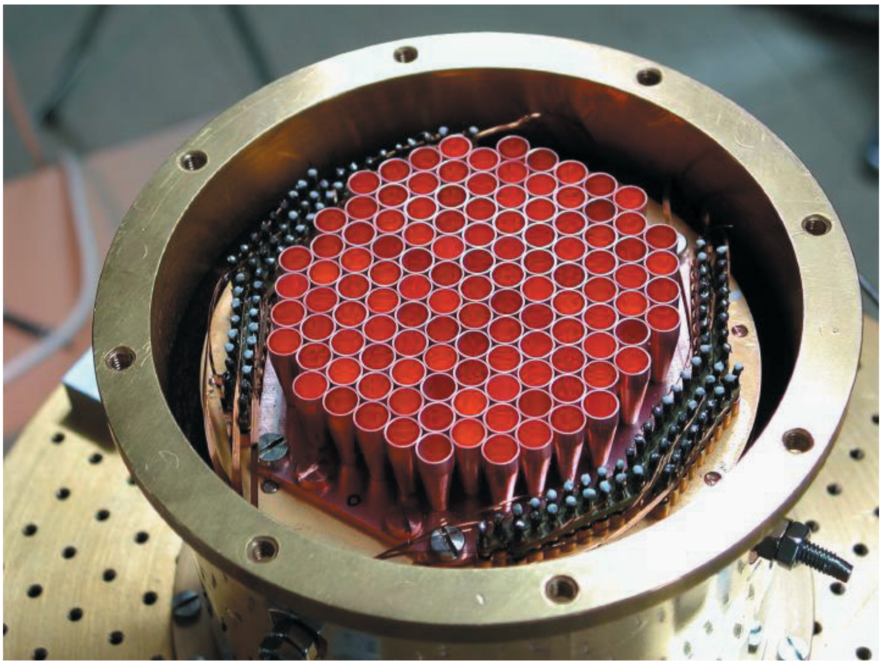


Figure 4: An example of a bolometer array: MAMBO2, the 117-channel bolometer array built by the Max-Planck-Institut für Radio-Astronomie for the IRAM 30-m telescope.

structure atomic lines like the CI lines at 809 GHz and 492 GHz as well as the excited nitrogen line [NII] at 1.46 THz, which is very common in the ISM. The excitation requirements of most atomic and molecular transitions at THz frequencies select the densest gas nearest to a young stellar object. As a result it is expected that the most intense radiation will be concentrated in regions with angular scales of a few arcseconds, corresponding to the beam size of APEX at these frequencies. The luminous star bursts in interacting galaxies also produce intense emission at THz frequencies, also on angular scales of a few arcsec in the nearest regions. Thus, the highest (THz) observing bands which may be reached through the combination of the superior Chajnantor site and the excellent performance of the APEX antenna are ideally suited to the study of chemical evolution, energetics and dynamics of star-forming regions.

2.5. Objects of special interest

APEX will be able to completely map unique objects at submillimetre wavelengths. Some of the most interesting sources in the sky can best (or only) be studied from the southern hemisphere. These include four out of five of the nearest sites of low-mass star formation (within about 150 pc), the Galactic centre (an important prerequisite study for the future understanding of the central regions of other galaxies), the Magellanic Clouds (the nearest galaxies to our own and prototypes of metal-poor galaxies in an earlier stage of evolution), and Centaurus A (the nearest galaxy with an active nucleus).

3. Telescope

The APEX antenna, built by VERTEX Antennentechnik in Germany, is a modified copy of the ALMA-US prototype antenna. It has a diameter of 12 metres, and the reflector surface will be set to an accuracy of 18 micrometer or better in order to observe beyond 1 THz. The telescope is designed to give precision performance even with wind speeds up to 9 m/s, and the pointing accuracy is specified to be better than 2 arcsec (absolute). The main modifications to the original ALMA antenna design are the incorporation of Nasmyth focus cabins and a chopping secondary mirror. These modifications are required for single-dish operations of array receivers and bolometers. The antenna will have in total three focus cabins, one at the Cassegrain focus and two at the Nasmyth foci.

4. Instruments

APEX instrumentation will include both wide-band bolometer array receivers for continuum observations and heterodyne receivers for spectral line observations. Some of the instruments will be specifically designed and custom-built for APEX. Instruments in use at other sites may be transferred to APEX, where they are expected to provide better data than at their current home.

APEX will initially operate with a 300-element bolometer array at 870 microns, the ideal wavelength to search for high-redshift dust emission. It is called LABOCA (LArge BOlometer CAmera) and is being built through a Bonn/ Bochum/Jena collaboration. Additionally, a 37-element array at 350 microns will be constructed to determine the spectral index of the radiation and to study sources with higher angular resolution over smaller fields.

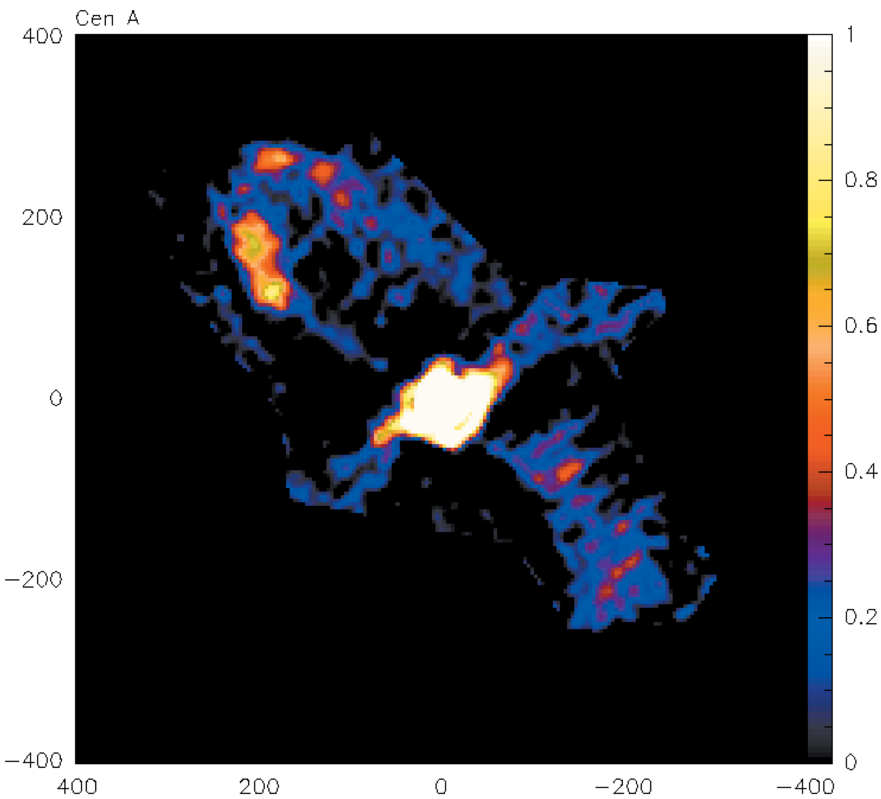


Figure 5: Centaurus A, the most nearby active galaxy, observed with the 37-channel bolometer array SIMBA (SEST IMaging Bolometer Array) at SEST. Note the emission from the dust lanes as well as the curved jets perpendicular to the dust lanes.

Heterodyne instruments will play an important role for observations from Chajnantor: APEX will be equipped with receivers covering all atmospheric windows from 200 GHz to 1 THz. In addition, several experimental receivers covering selected windows above 1 THz – uniquely observable from Chajnantor – will be provided. APEX will be equipped with autocorrelation spectrometers.

5. Site

The greatest problem for ground-based submillimetre astronomy is the absorption of incoming radiation by atmospheric lines, mainly by water vapour. This is why the submillimetre region of the spectrum is still relatively unexplored. Ground-based submillimetre astronomy can only be done from sites with extremely dry atmospheres, such as high mountain tops and in Antarctica.

Llano de Chajnantor is most likely the best place for submillimetre astronomy on Earth (possibly rivalled only by the far more inaccessible sites in Antarctica), because of its high altitude at 5000 m and also because of its location in the dry Chilean Atacama desert. Long-range monitoring to characterize the site for the ALMA project has been carried out since 1995, showing that the excellent atmospheric conditions on Cerro Chajnantor will allow observations in all submillimetre windows close to 50% of the time.

6. Infrastructure and operations

APEX will be operated as part of the La Silla Observatory. The staff of 18 will include astronomers, operators and engineers/technicians. There will be a base in San Pedro de Atacama (the nearest village at an altitude of 2500 m), which will consist of offices, laboratories, control room, cafeteria and dormitories, and the staff will sleep at the base. On the high site, APEX will be operated and maintained from a set of oxygenized and heated containers. Diesel generators will provide power, both at the base and at the high site. There will be a high-speed microwave link between the San Pedro base and the telescope, allowing APEX to be operated remotely from San Pedro in service mode and with flexible scheduling. There may also be a visitor mode with observations being done remotely from San Pedro. Part of the observing time will be dedicated to more experimental observations with PI instruments at THz frequencies.

7. Time scales

The antenna will be erected on the site in April 2003 by VERTEX Antennentechnik. At this time receivers operating at 90 GHz will be installed in order to do holography and to set the surface to 18 microns rms. First-light receivers will be installed soon after this, consisting of the SEST 1.3-mm receiver and perhaps also a single pixel bolometer. The first heterodyne receivers are expected to arrive at the end of 2003, and LABOCA, the 300 pixel bolometer array, in the beginning of 2004. APEX operations are expected to start in the beginning of 2004.

8. SEST and APEX

ESO and OSO are presently operating SEST on La Silla. In order to provide operational funds for APEX, SEST operations are expected to stop at the end of June 2003 and SEST will be closed. There is however a possibility that SEST may continue to be used after June 2003, by dedicated groups doing survey work.

More information on APEX can be found at: http://www.mpifr-bonn.mpg.de/div/mm/apex.html and http://www.oso.chalmers.se/oso/apex/index.html

VIMOS Commissioning on VLT-Melipal

O. LE FÈVRE[1], D. MANCINI[2], M. SAÏSSE[1], S. BRAU-NOGUÉ[3], O. CAPUTI[2], L. CASTINEL[1], S. D'ODORICO[4], B. GARILLI[5], M. KISSLER[4], C. LUCUIX[3], G. MANCINI[2], A. PAUGET[1], G. SCIARRETTA[2], M. SCODEGGIO[5], L. TRESSE[1], D. MACCAGNI[5], J.-P. PICAT[3], G. VETTOLANI[6]

[1]Laboratoire d'Astrophysique de Marseille, France; [2]Osservatorio Astronomico di Capodimonte, Naples, Italy; [3]Observatoire Midi-Pyrénées, Tarbes, France; [4]European Southern Observatory, Garching, Germany; [5]Istituto di Fisica Cosmica e Tecnologie Relative, Milan, Italy; [6]Istituto di Radio Astronomia, Bologna, Italy

Introduction

In the mid-80s, multi-object spectroscopy (MOS) appeared as a new and powerful technique to perform the spectroscopy of many objects simultaneously. The idea is simple: instead of using a single slit as the input to a spectrograph, masks are manufactured with slits positioned facing the images of targets of interest in the entrance focal plane of the spectrograph. The technical implementation turned out to be more tricky, but the first successful experiments were conducted with punching machines, in particular at ESO and CFHT with the PUMA concept [1].

MOS was then quickly identified as the tool of choice to conduct deep galaxy surveys. Multi-object spectrographs on 4-m-class telescopes have been very powerful tools to quantify the evolution of galaxies over more than half of the age of the universe, up to redshifts ~1 [2][3]. This because the density of galaxies to I ~ 22 (reaching redshifts ~1 or about half the current age of the universe) projected on the sky is high enough that very efficient spectrographs with high-quality CCDs [4] can efficiently assemble samples of several hundreds of measured spectra and redshifts. The technique was then applied on the first 10-m Keck with the LRIS spectrograph [5] and produced most of the Lyman-break galaxies at redshifts 3–4 known today [6].

However, the study of galaxy evolution and of their space distribution over most of the age of the universe requires much more than the few thousand galaxies measured today, all surveys included. The need to study the distribution of galaxies in the local universe has prompted two major science and instrumentation programmes: the Sloan Digital Sky Survey (SDSS), and the 2dF Galaxy Redshift Survey. Both are acquiring several hundred thousands of galaxy spectra with dedicated MOS facilities [7][8]. Similarly, the need to acquire large numbers of spectra/redshifts over a redshift range 0–5 covering 90% of the current age of the universe, has been identified. This is required by the necessity to cover several time/redshift steps, study the evolution of various classes of galaxies in a wide range of environments, ranging from the low density of voids to very

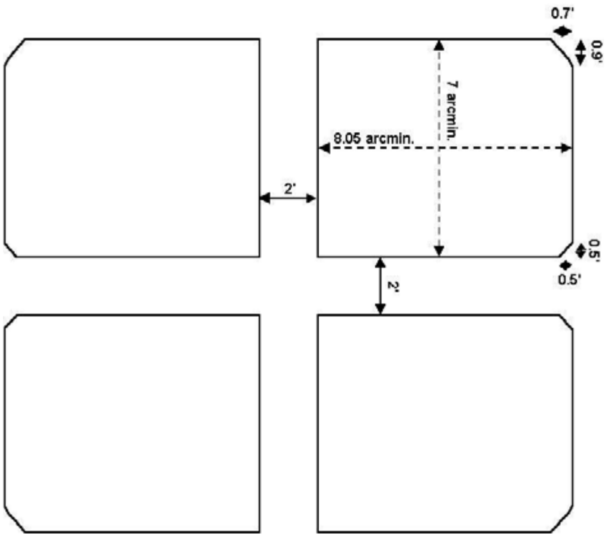


Figure 1: VIMOS field as projected on the sky, each quadrant has a field 7 × 8 arcmin^2, for a total field of 224 arcmin^2.

dense cluster cores. As an example, the measurement of the evolution of the luminosity function of galaxies or of the star-formation rate requires 50 galaxies per measured magnitude bin, over 10 magnitudes, for three basic types (colours) of galaxies, in three types of environments. Adding the necessity to probe several fields (i.e. 4) to minimize the impact of cosmic variance, and 7 time steps leads to a total galaxy sample of 50 × 10 × 3 × 3 × 4 × 7 = 126,000 galaxies. Very efficient MOS instruments are therefore needed.

In 1994, ESO convened a workshop to canvass the community in defining the full instrument complement for all unit telescopes of the VLT. A wide-field multi-object spectrograph appeared as the most important missing instrument in a poll of the community present at the meeting. Our team presented the baseline specifications and a tentative concept [9], the result of discussions across the community, in particular including the WFIS concept developed at ESO. A feasibility study was then commissioned by ESO to our consortium of French and Italian institutes, and conducted over 9 months in 1995–1996. ESO then issued a call for proposals to build a facility instrument, based on a wide-field MOS. The proposal presented by our consortium was selected by the ESO-STC in October 1996. A contract between ESO and the Centre National de la Recherche Scientifique of France represented by the then Laboratoire d'Astronomie Spatiale in Marseille (now Laboratoire d'Astrophysique de Marseille) was signed in July 1997, to construct VIMOS, the Visible Multi-Object Spectrograph, NIRMOS, the Near-IR Multi-Object Spectrograph, and the MMU, the Mask Manufacturing Machine.

After the successful completion of the Preliminary Acceptance Europe, VIMOS was shipped and reassembled in Paranal. We describe here the results of the main tests carried out during the first commissioning periods and present the general performance of VIMOS. This article is also intended to prepare the community to the arrival of this powerful facility.

VIMOS concept

VIMOS was designed from the outset to maximize the number of spectra observed with spectral resolutions R = 200–2500 (1 arcsec slits) [10]. The 4-channel concept allows one to maximize the multiplex gain: the field of view of each channel is 7 × 8 arcmin^2 in both imaging and MOS, projected on the central 2048 × 2350 pixels of a 2048 × 4096 pixels thin EEV CCD, while the full detector is used to record spectra. The slit sampling is set to allow Nyquist sampling for a 0.5 arcsec slit, with a plate scale of 0.205 arcsec/pix. In addition, the Integral Field Unit (IFU) covers a field 54 × 54 arcesc^2, with 6400 resolution elements 0.67 × 0.67 arcsec^2, each leading to a spectrum.

In all, it is really 4 instruments in one, with a total field of view of 224 arcmin^2, each channel being the equivalent of a complete FORS instrument. For each channel, a mask exchange unit (MEU), a filter exchange unit (FEU), and a grism exchange unit (GEU) permits configuration of the instrument in the imaging or MOS modes. Furthermore, special masks can be positioned at the entrance focal plane to configure the instrument in IFU mode.

To produce the masks placed at the VIMOS focal plane, a dedicated mask manufacturing unit (MMU) is available to cut masks with slits at any location, with any size and shape. It is fully described elsewhere [11]. The powerful laser machine is capable of cutting ~200 typical slits 1 × 12 arcsec each in less than 15 min. The MMU is also used to cut masks for the FORS2 MXU mode.

VIMOS observing modes

VIMOS has three main observing modes: direct imaging, multi-object spectroscopy with multi-slit masks, and integral field spectroscopy. The main characteristics of these modes are listed in Table 1.

Table 1: VIMOS observing modes

Imaging mode	
Field of view	4 × 7 × 8 arcmin^2
Wavelength range	0.37–1 micron
Filters	U′ BVRIz
Spatial sampling	0.205 arcsec/pixel
Multi-Object Spectroscopy mode	
Field of view	4 × 7 × 8 arcmin^2
Spatial sampling	0.205 arcsec/pixel
Low resolution R ~ 200 (1 arcsec slit)	Grisms: LRBlue
Number of slits ~1000 of length ~8 arcsec	LROra
	LRRed
Medium resolution R ~1000 (1 arcsec slit)	Grisms: MR
Number of slits ~400 of length ~8 arcsec	
High resolution (1 arcsec slit)	Grisms: HRBlue
Number of slits ~200 of length ~8 arcsec	HROra
	HRRed
Integral Field Spectroscopy mode	
Field of view	54 × 54 arcsec^2
Wavelength range	0.37–1 micron
Spatial sampling	0.67 arcsec / fiber
Number of resolution elements / spectra	6400
Spectral resolution	R ~ 200–2500

Figure 2: Installation of VIMOS on the VLT-UT3. From upper left, clockwise: (a) transportation of VIMOS from the Paranal Observatory integration facility to the telescope, (b) VIMOS being hoisted inside the dome of Melipal to reach the Nasmyth platform, (c) installation on the Nasmyth rotator, (d) VIMOS after cabling and co-rotator installation.

VIMOS integration and tests

After completing integration and testing at the European integration facility at Observatoire de Haute-Provence, France, VIMOS was completely disassembled and shipped in more than 50 crates (a total of 15 tons) at the end of 2001. The reassembly took place in the integration facility of the Paranal Observatory in January-February 2002. Optical alignment was checked, all mechanical motions were tuned and verified over hundreds of cycles, and all software components were implemented prior to the installation at the telescope. The instrument was moved to Melipal on February 23rd (Figure 2). VIMOS is now attached to the Nasmyth focus B of the “Melipal” – UT3 telescope of the ESO Very Large Telescope (Figure 2).

The weight of the instrument turned out to be significantly larger than foreseen in the original design. At a total weight of 4 tons, VIMOS is about 1 ton overweight with respect to the Nasmyth rotator-adapter specification. It was necessary to implement a support structure at the back end of the instrument to relieve the adapter from the extra weight as seen in Figure 3.

In a first commissioning run in February 2002, the first 2 channels were extensively tested on the sky. While the internal image quality was measured to conform to specifications during integration, images on the sky have demonstrated the excellent overall image quality of the combined telescope + instrument. Images as good as 0.4 arcsec FWHM have been recorded. The complex sequence necessary to place slits at the focal plane in coincidence with selected targets, involving a transformation matrix from sky to mask focal plane to detector, has been tested and validated.

In a second technical commissioning in May 2002, the support structure to compensate the extra weight was installed, and the 4 channels completely integrated. Due to bad weather, many calibration tests were obtained on the complete 4-channel configuration but no sky observations could be obtained. Image and spectral quality have been confirmed to be within specifications.

After technical activities in July 2002, completing the work on the support leg and on flexures adjustment, VIMOS will have its third and last commissioning on the sky in September 2002.

VIMOS performance

Image quality

The image quality of the optical train was measured for each channel. A grid with pinholes 100 microns in diameter was produced with the Mask Manufacturing Unit and placed at the entrance focal plane. The optical alignment was perfected by means of a relative X,Y adjustment of the last element of the optical train coupled to the detector assembly. All channels are fully in specification, with 90% of the field with images better than 0.5 arcsec at 80% encircled energy as shown in Figure 4.

Flexure

Flexure control for a 4-ton instrument has been a concern from the start of the project. The main VIMOS structure was designed to minimize flexure defined as

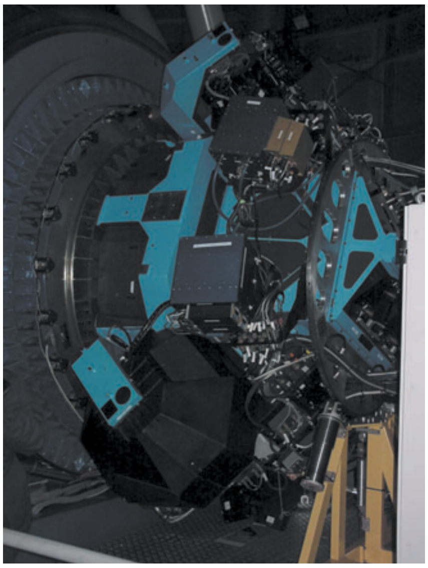
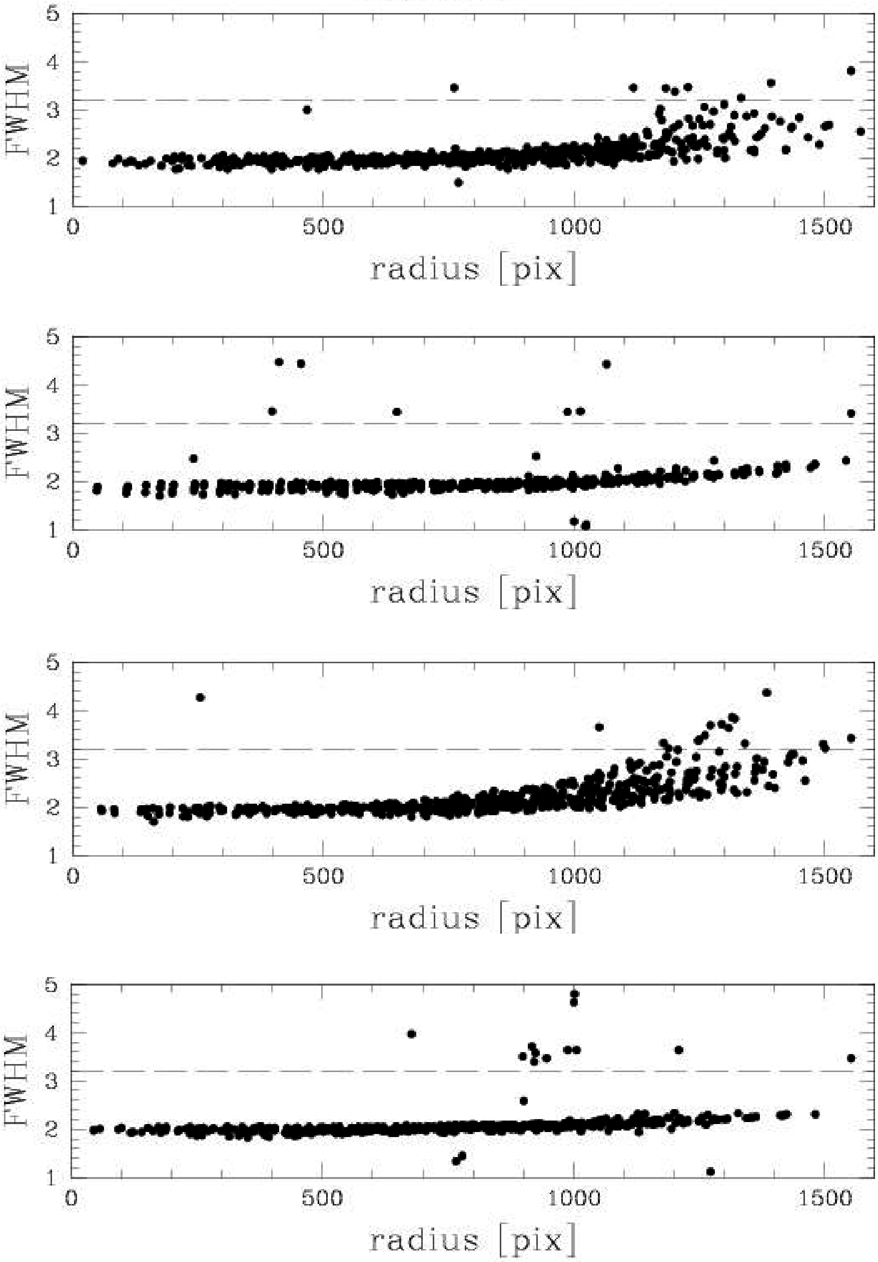


Figure 3: The fully integrated instrument on the Nasmyth focus, including its dedicated support structure to the right.



motion on the CCDs of a light spot produced at the entrance focal plane. A mechanical support system was implemented at the back of the folding mirrors on the optical train to allow for passive flexure compensation by means of astatic levers. This support system can also be upgraded to an active support using piezo-actuators to apply motion on the folding mirrors to compensate for flexure.

▶

Figure 4: image quality as a function of radius from the field centre, measured for channels 1 to 4 (top to bottom) on a grid of pinholes 300 microns in diameter. The image quality is better than the specification identified by the dashed line.

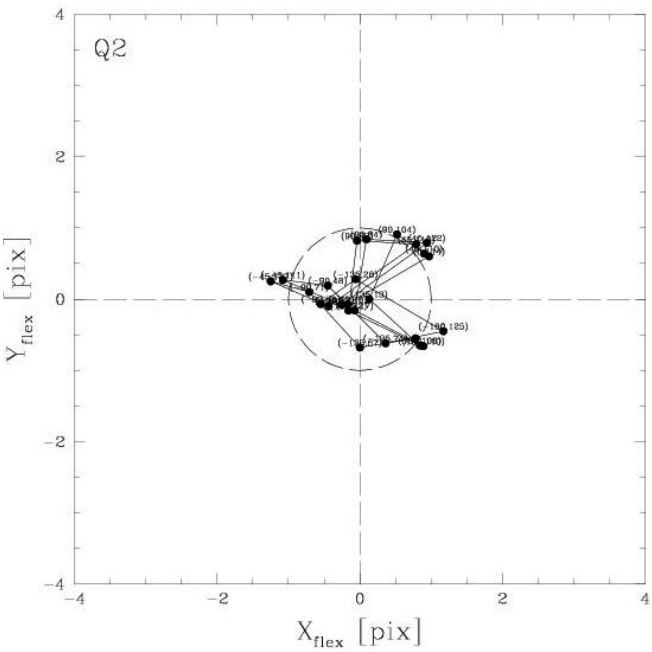


Figure 5: Flexure measurement on channel 2. The points represent the position of a reference spot of light on the detector, as a function of the rotation angle of the Nasmyth rotator over 360°. The dashed circle represents a 1-arcsec radius motion of the reference spot.

Uncompensated flexure is measured to be on order ± 2.5 pixels in both X (along slit) and Y (dispersion) for a full 360° rotation of the instrument. Astatic levers have been installed and are being adjusted at the time of this writing. They are expected to cut the flexure by a factor 3, as based on previous measurements taken during integration at Haute-Provence Observatory. This is shown on the current corrected flexure behaviour for channel 2, showing flexure contained within a one-pixel radius (Figure 5). Optimization of the other channels is under way.

VIMOS first light

First light was achieved on February 26, 2002, with VIMOS in 2-channel mode. Images with excellent image quality were recorded right away (see e.g. Figure 6 to Figure 8, and images on http://www.astrsp-mrs.fr/virmos

Table 2: Photometric zero points

Filter	Zero point (preliminary, average of 2 channels) Mag = zero point –2.5 log (flux) in ADU) –2.5 log (CCD gain) +2.5 log (exposure time)-kc.sec (air mass)
U	26.3
B	28.0
V	27.7
R	27.8
I	27.0

Imaging performance

The overall throughput of the instrument can be measured in terms of the photometric zero points used to transform the observed CCD counts to magnitudes as listed in Table 2. This is better in the UV and blue than the comparable FORS instrument on the VLT and shows equivalent sensitivity in the visual-red, when the additional reflection in the telescope is taken into account.

Multi-object spectroscopy performance

Masks have been produced from images taken with the instrument. The transformation matrix from CCD to mask was computed using images from a uniformly distributed grid of pinholes. This transformation proved to be very accurate: from the first try onward, slits and reference apertures on masks have been successfully positioned directly on top of astronomical objects.

Examples of masks observed are shown in Figure 9. This demonstrates the great multiplex capability of VIMOS, with several hundred objects being observed simultaneously. The details presented in Figure 10 show the high accuracy of the slit profile, thanks to the high precision of the laser-based mask manufacturing unit [11].

Figure 6: Image of the "Antennae" taken during the first night of VIMOS on the sky. Composite of V, R, and I images, 60 seconds each. The image quality measured on stars is 0.6 arcsec FWHM.

The mask design interface allows one to define a mask in an automated fashion from a "pre-image" taken with VIMOS. Slits can be placed either on targets selected from a catalogue of objects detected on the pre-image, or on objects from a user imported catalogue. The software cross correlates the brightest objects detected in the pre-image with objects in the user catalogue to define a transformation matrix. This allows one for instance to use very deep images taken with VIMOS or another facility to place slits on objects not visible on the short-exposure pre-images. Slits are placed in an automated fashion in order to maximize the number of objects, and to minimize the effect of overlap between orders when working with several banks of spectra along the dispersion direction.

Performance in spectroscopy mode is as expected, and follows the computations from the Exposure Time Calculator (see ESO web page referred to below). Spectra of extended $I_{AB} \leq 22.5$ galaxies have been recorded in 3×15 min exposures, with S/N ~ 5–10 on the continuum (Figure 14).

Spectra with the integral field unit have also been obtained as shown in Figure 11.

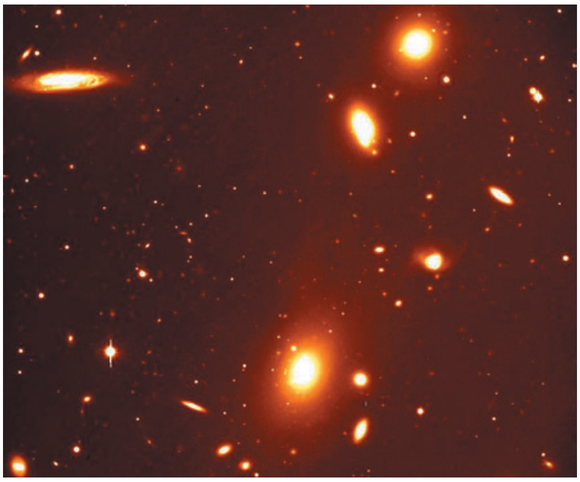


Figure 7: image of the cluster of galaxies ACO 3341.

Figure 8: Central part of the cluster Cl 1008-12. Composite of V, R, and I band exposures, 5 minutes each.

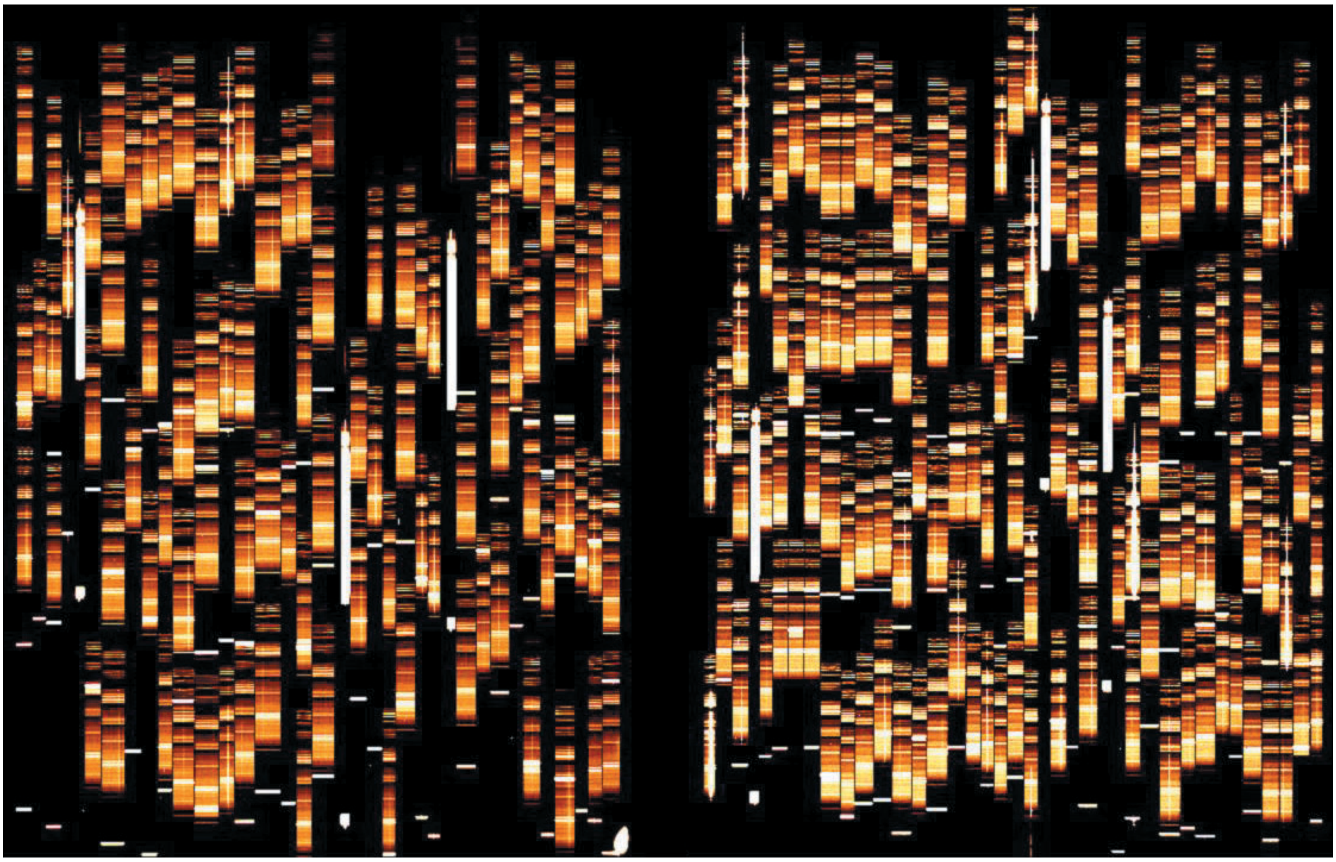


Figure 9: Example of multi-slit data taken with VIMOS during the first light in February 2002. In these masks on 2 channels, more than 220 objects were observed simultaneously with a spectral resolution R ~ 250.

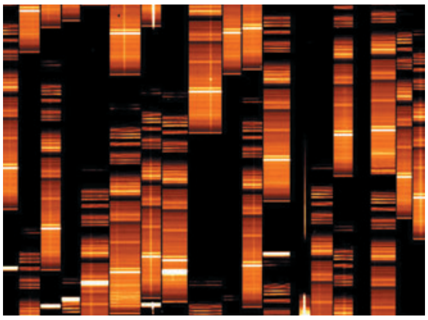


Figure 10: Detail of a raw MOS spectra frame. One can identify the trace of the continuum of galaxies in each slit. The slit profile is extremely accurate thanks to the high precision of the MMU. Fringing from the detector is visible in the red part of the spectra (towards the top).

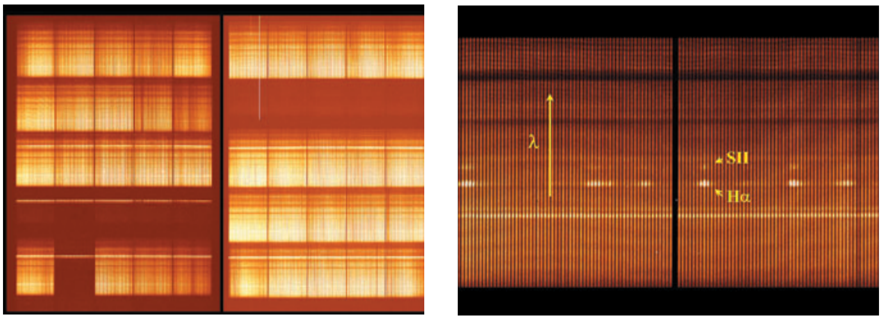


Figure 11: Spectra taken with the VIMOS-IFU. Left: 3200 spectra obtained with 2 channels in February 2002. Right: enlarged portion of the IFU spectra showing the emission lines from a planetary nebula observed during tests.

Data processing

Spectra have been processed using dedicated Data Reduction Software (DRS). The spectra are corrected for the detector response and the sky lines are subtracted before the 2D spectra are summed. The 1D extraction then follows, with wavelength and flux calibration. Because of the thin substrate of the EEV detectors, fringing from the strong sky OH emission appears above ~ 8200 Å. This fringing can be efficiently removed using a sequence of shifts of objects along slits, as shown in Figures 12 and 13. Spectra of extended

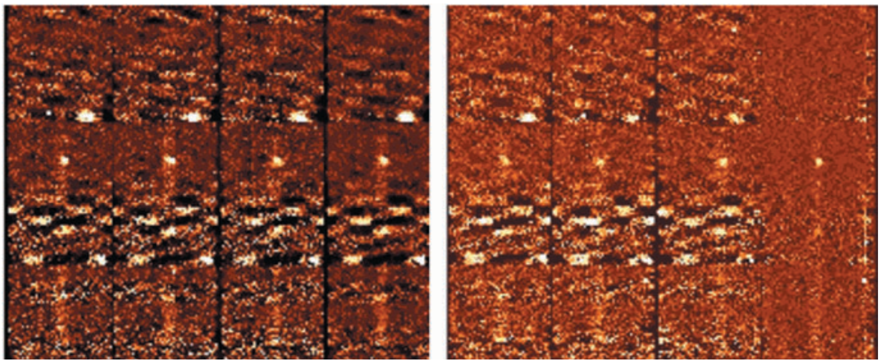


Figure 12: Processing of the VIMOS MOS data. Left panel: *sequence of 3 spectra taken while the object was maintained at the same position in the slit. Three sky-subtracted spectra are shown from left to right (about 200 Å around 8200 Å; wavelength increases towards the top), together with the combined average of the three spectra on the right. Significant fringing residuals are present.* Right panel: *in this set of observations, the object was moved along the slit at positions –1, 0, +1 arcsec; the combined average shows that fringes can be corrected to a high level of accuracy.*

galaxies with $I_{AB} \leq 22.5$ are shown in Figure 14.

Summary

The wide-field survey instrument VIMOS is now being commissioned at the VLT. In each of the three operational modes (imaging, multi-slit spectroscopy and integral-field spectroscopy), VIMOS offers an unprecedented field of view. In multi-slit spectroscopy mode, several hundred spectra can be recorded simultaneously, while in integral-field mode, 6400 spectra are recorded in a field 54 × 54 arcsec². It is expected that VIMOS guest observations will start in April 2003. Information needed to prepare observing proposals is available on the web pages http://www.eso.org/instruments/vimos/index.html

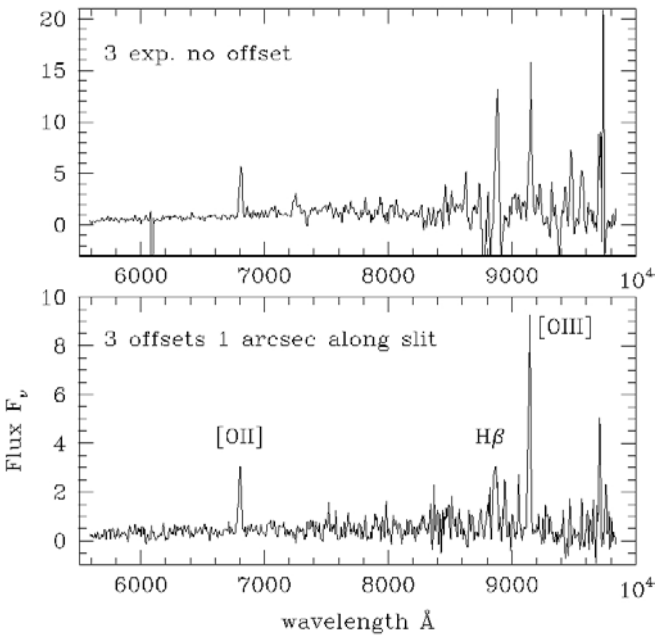


Figure 13: Effect of sky and fringe subtraction with (bottom) and without (top) shifting objects along the slit as described in Figure 12.

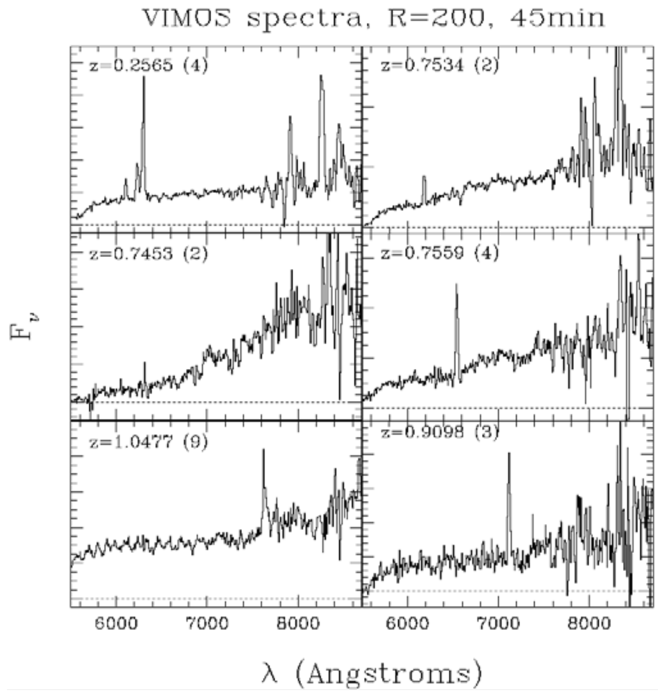


Figure 14: Examples of spectra taken with VIMOS during the first commissioning in February 2002. The redshift is indicated in the upper left corner of each panel. These spectra are the average of 5 exposures 10 minutes each with the LR grism (R ~ 200).

References

[1] Fort, B., Mellier, Y., Picat, J.P., Rio, Y., Lelièvre, G., 1986, *SPIE*, **627**, 339.
[2] Ellis, R.S., Colless, M.M., Broadhurst, et al., 1996, *MNRAS*, **280**, 235.
[3] Lilly, S.J., Le Fèvre, O., Crampton, D., Hammer, F., Tresse L., 1995, *Ap.J.*, **455**, 50.
[4] Le Fèvre, O., Crampton, D., Felenbok, P., Monnet, G., 1994, *A&A.*, **282**, 325.
[5] Oke, J.B. et al., 1995, *PASP*, **107**, 3750.
[6] Steidel, C.C., Giavalisco, M., Pettini, M., et al., 1996 *ApJ*, **462**, 17.
[7] Gunn, G.E., and Weinberg, D.H., 1995, in "Wide field spectroscopy and the distant universe", ed. S. Maddox & Aragon Salamanca, World Scientific Singapore, 3.
[8] Colless, M.M., et al., 1999, proc. 2nd Igrap conference "Clustering at high redshifts, June 1999, Mazure, Le Fèvre, Le Brun Eds, ASP series.
[9] Le Fèvre, O., et al., 1994, proceedings of the meeting Science with the VLT", J. Walsh, I. Danziger Eds., Springer, p. 367.
[10] Le Fèvre, O., et al., 2000, Proc. SPIE Vol. 4008, p. 546–557, Optical and IR Telescope Instrumentation and Detectors, Masanori Iye; Alan F. Moorwood; Eds.
[11] Conti, G., Mattaini, E., Maccagni, D., Sant'Ambrogio, E., Bottini, D., Garilli, B., Le Fèvre, O., Saïsse, M., Voët, C., et al., 2001, *PASP*, **113**, 452.

2.2-m Team

L. GERMANY

Welcome to the last (very short) installment of 2p2team news from La Silla. This is mostly just a farewell message, as in October we cease to operate as a separate entity and join with the old NTT and 3.6 teams under the new guise of Sci-Ops. Never fear though, the next *Messenger* will see this section expanded to include all the telescopes and instruments on La Silla.

The folding of the 2p2team heralds the end of ESO time at both the ESO 1.52 and Danish 1.54-m telescopes. The Boller and Chivens spectrograph is only available in Brazilian time until the end of 2002, after which time the instrument will be mothballed and the telescope decomissioned. FEROS is moving to the 2.2-m telescope at the end of Period 69 and we expect it to be up and running in its new home by November 2002. The Danish telescope will continue to operate after October 2002, but only in Danish time.

So farewell from the 2p2team and we'll see you next time as Sci-Ops.

Standing on the Shoulder of a Giant: ISAAC, Antu, and Star Formation

M. McCAUGHREAN, H. ZINNECKER, M. ANDERSEN, G. MEEUS, and N. LODIEU

Astrophysikalisches Institut Potsdam

If I have seen further, it is by standing on the shoulders of giants.
Isaac Newton, in a letter to Robert Hooke, 1676

In the Beginning

Today's astronomers spend much of their time staring into regions where stars are forming, whether deep out in extragalactic space and far back in time, to watch as the first galaxies are assembled, or nearer to home, witnessing the fiery creation of new stars and planetary systems within our own Milky Way.

Crucial to these endeavours are the new 8–10-m diameter telescopic leviathans, equipped with powerful eyes sensitive to near-infrared light. For the high-redshift surveyors, the justification is straightforward: wavelengths grow as $(1 + z)$ and surface brightness drops as $(1 + z)^4$, making newly-born galaxies extremely faint, infrared sources. On the other hand, the nearest regions of ongoing star formation are "only" a few hundred parsecs away, yet the rationale is equally compelling. Stars are born from, and shrouded in, dense clouds of dust and molecular gas, out of whose obscuration visible light can barely escape. The same physics also yields substellar objects, the brown dwarfs, with masses perhaps as little as 1% of the Sun, feebly emitting their excess gravitational warmth as they cool and contract forever, never able to initiate nuclear hydrogen fusion. Young stars are encircled by disks of barely warm dust and gas, where swirling vortices gather mass to form planets, and the stars and disks conspire to generate immense supersonic jets of outflowing gas blasting out of the cocoon, lighting up great shocks glowing in the light of molecular hydrogen. Very often, all of this is going on at once, as stars are born in dense, crowded clusters, all interacting and competing with each other for survival.

All of which calls for the largest telescopes operated with sensitive infrared cameras and spectrographs. Wide field coverage is necessary to capture the whole story in a given region, but simultaneously with enough spatial resolution and dynamic range to disentangle the interactions between the many sources, and to ensure that we can detect even the faintest companions, disks, and planets immediately adjacent to their much brighter parents. Fortunately, all of these demanding specifications are being well satisfied by the new large telescopes, optimized for infrared observing, equipped with state-of-the-art infrared array instruments, and situated on sites with excellent intrinsic atmospheric qualities.

In this article, we hope to illustrate the great qualitative and quantitative strides that star-formation studies have taken in the past few years, by looking at three highlights from our own work using the ESO Very Large Telescope UT1, Antu, and its facility near-infrared camera/spectrograph, ISAAC. In particular, we have chosen examples which illustrate a key theme running through our work, namely that of environmental impact, both in the effects that the birthplace of a star can have on its evolution, and in the back reaction that star formation can have on its surroundings. These are just a selection from the sample of young clusters and protostellar objects we are studying with the VLT (see also, e.g., Brandl et al. 1998; Zinnecker et al. 1999, 2002), and, of course, only a small subset of the work being carried out by the broad and active European star- and planet-formation community (Alves & McCaughrean 2002).

A momentary digression: the infrared Moore's law

We are by now all very familiar with the current generation of large telescopes, perhaps pre-eminent among which are the four 8.2-m diameter units of the VLT: this story could certainly not be told without them. However, photons must not only be collected but also detected, and an equally important issue in the present context is the huge parallel progress made in infrared detector technology over the 25 years or so since telescopes like the VLT were first proposed (Woltjer 1978).

At that time, the first purpose-built large infrared telescopes, such as the 3.8-m UKIRT on Mauna Kea, were about to go online, with instruments that focussed all of the primary mirror's light onto a single element detector. For much of the following decade, infrared astronomy continued in the same vein, carrying out photometry or spectroscopy with single apertures, or laboriously mapping out extended regions one pixel at a time. Of course, many pioneering discoveries and advances were made, but the great sea change came in 1986, when infrared-sensitive detector arrays made their way out from behind the dark curtains of military secrecy and into open use on those large astronomical telescopes. With only 62 × 58 pixels, these arrays seem pitifully small in hindsight, and yet an instantaneous increase of almost 4,000 in the number of detectors in the focal plane of a telescope inspired the community and incited a true revolution.

It is a revolution that continues today. In the 1960s, Gordon Moore formulated his now-famous law that the number of transitors on semiconductor chips doubles every 12–24 months (Moore 1965): the same exponential growth in processor "power" has continued into the new millennium (Intel 2002). Interestingly, Alan Hoffman of Raytheon/SBRC has found that a similar scaling relation has tracked the introduction of progressively larger infrared detector arrays into common astronomical circulation, with a doubling of the number of pixels roughly every 18 months (see Fig. 1). Following SBRC's InSb 62 × 58 pixel arrays in 1986, the widespread adoption of the Rockwell NICMOS3 HgCdTe and SBRC InSb 256 × 256 pixel arrays occurred circa 1992, and that of the presently common generation of Rockwell HAWAII HgCdTe and SBRC Aladdin InSb 1024 × 1024 pixel arrays circa 1998. Indeed, ISAAC was commissioned in late 1998, and can switch between one or other of a HAWAII or Aladdin 1024 × 1024 pixel array.

So, while the VLT has "only" about five times the collecting area of UKIRT, ISAAC has a million times the number of pixels of any of UKIRT's first-generation instruments. This combined factor of five million improvement in the throughput (used in a deliberately loose sense here) available to infrared astronomers over just 20 years is quite dramatic, and has driven our understanding of star formation and early stellar evolution forward in leaps and bounds.

The Trapezium Cluster: towards a lower mass limit

It is well known that the entire life history of a star is almost uniquely determined by its mass, and yet it remains quite unclear how a star arrives at that mass in the first place. In a more general sense, we do not know how to predict the distribution of masses of a population of stars recently born from a molecular cloud, as found in a young cluster, for example, the so-called initial mass function (IMF).

In the broadest possible sense, the IMF has two important components: its form and its limits, that is, the shape of the IMF and where it cuts off at high and low mass. By measuring these parameters as a function of environment, including metallicity, cluster density, the presence of massive stars, for example, we can hope to place important constraints on any general theory of star formation that aims to predict the IMF and its variations. The single power-law form of the upper IMF in our galaxy has been known for many years (Salpeter 1955), but at lower masses, things become more interesting, with a turndown and peak in the IMF typically seen somewhere in the range 0.1–0.5 $M_\odot$, that is, just above the stellar/substellar break (Kroupa 2001). While it seems self-evident that the processes of star formation know nothing about the nuclear fusion that later so brutally separates the fates of stars and brown dwarfs, the form of the IMF over this peak and down into the brown dwarf regime must nevertheless encode important physics. As a result, considerable effort has been invested in examining the substellar IMF in young clusters, searching for and investigating proto-brown dwarfs.

Most recently, several groups have been pursuing the IMF downwards in search of a possible lower cut-off. The theory of hierarchical fragmentation predicts that a collapsing molecular cloud will continue to break into ever smaller clumps as long they are able to radiate away their excess energy in less than the free-fall time for local collapse. However, opacity rises with density, and at some point the gas cannot cool quickly enough, becomes adiabatic and pressure-supported, and fragmentation ceases (Hoyle 1953). Traditionally, this lower cut-off is predicted to lie at 0.005–0.015 $M_\odot$ or 5–15 Jupiter masses (1 M_{Jup} = 0.001 $M_\odot$) (Lynden-Bell & Low 1976; Rees 1976; Silk 1977), although more recent calculations suggest that it may be modified by the inclusion of magnetic fields, down to perhaps as little as 1 M_{Jup} (Boss 2001). More importantly, however, the whole fragmentation scenario down at low masses may have to be replaced by a more complex model involving a wide range of physical processes, including supersonic turbulence (Padoan & Nordlund 2002), dynamical interactions between protostars (Bate, Bonnell, & Bromm 2002), and feedback due, for example, to strong bipolar outflows (Adams & Fatuzzo 1996) and ionizing radiation from massive stars (Palla & Stahler 2000). In addition, the existence of such objects with just a few Jupiter masses would be interesting in itself, as they could provide important insights into the very early evolution of giant planets, even if most astronomers would agree that free-floating objects formed directly from a molecular cloud core are not true planets like those formed in a circumstellar disk, and thus do not deserve that special name (cf. McCaughrean et al. 2001).

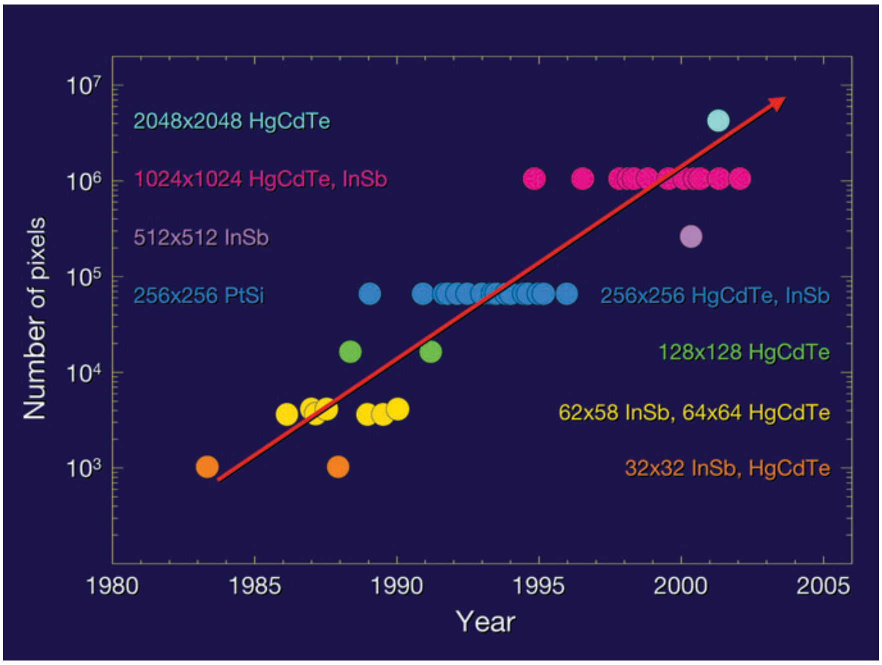


Figure 1: The growth of astronomical near-infrared array detectors, illustrated using a sample of 41 infrared cameras and plotting the year they were introduced into service against the number of pixels (rows × columns) in their main detector. The dates have been randomised within the year of commissioning in order to provide a little horizontal separation. Some systems include more than one array, but typically with the same unit size: just the unit size is plotted for these. A wide range of telescope sizes is implicitly represented, from 1 to 10-m diameter, although there is no obvious tendency for the newest arrays to be introduced at either the smallest or largest telescopes. The red line represents Hoffman's version of Moore's Law, showing a doubling in pixel count roughly every 18 months over the past 20 years. Extrapolation points to 4096 × 4096 pixel arrays or mosaics (1.7 × 10^7 pixels) being the workhorse imaging systems by 2006.

In any case, can we find such objects and any related mass cut-off directly, via observations? Although it might at first seem futile to think of searching for objects with just a few Jupiter masses at distances of a few hundred parsecs, they are remarkably warm and bright when young, and deep infrared imaging with large telescopes can now be used to go in search of them. One of the obvious targets for such a hunt is the Trapezium Cluster in Orion, probably the most populous and densest of the nearby young stellar clusters, with more than a thousand members crammed into its inner cubic parsec. The cluster has proven an excellent site for probing the stellar initial mass function (Hillenbrand 1997), and is known to include many brown dwarfs (McCaughrean et al. 1995; Luhman et al. 2000; Hillenbrand & Carpenter 2000; Muench et al. 2001), and recent studies have suggested there may be sources down to as low as ~10 M_{Jup} (Lucas & Roche 2000; Lucas et al. 2001). However, an even deeper wide-field survey was needed to test this finding and to search for any lower mass limit.

We have carried out such a survey using ISAAC over a 7 × 7 arcminute field centred on the well-known Trapezium OB stars, as shown in Figure 2, a true-colour J_s, H, K_s composite made from our initial data taken in 1999 (see McCaughrean et al. 2001). Adding data from 2000 and 2002, the final survey has 900 seconds integration time pixel per filter, and a mean seeing of 0.5 arcsec FWHM. These data go significantly deeper over a wide field than any previous infrared survey, with 3σ peak-pixel point source detection limits of J_s, H, and K_s of $21\overset{m}{.}3$, $20\overset{m}{.}0$, and $19\overset{m}{.}6$, respectively, limits ultimately set by the bright emission from the Orion Nebula. In the K_s band, these limits correspond roughly to 3 M_{Jup} at 450 pc, assuming an age of 1 Myr and a typical intracluster reddening of A_V ~ 7^m, using the DUSTY pre-main-sequence models of Chabrier et al. (2000).

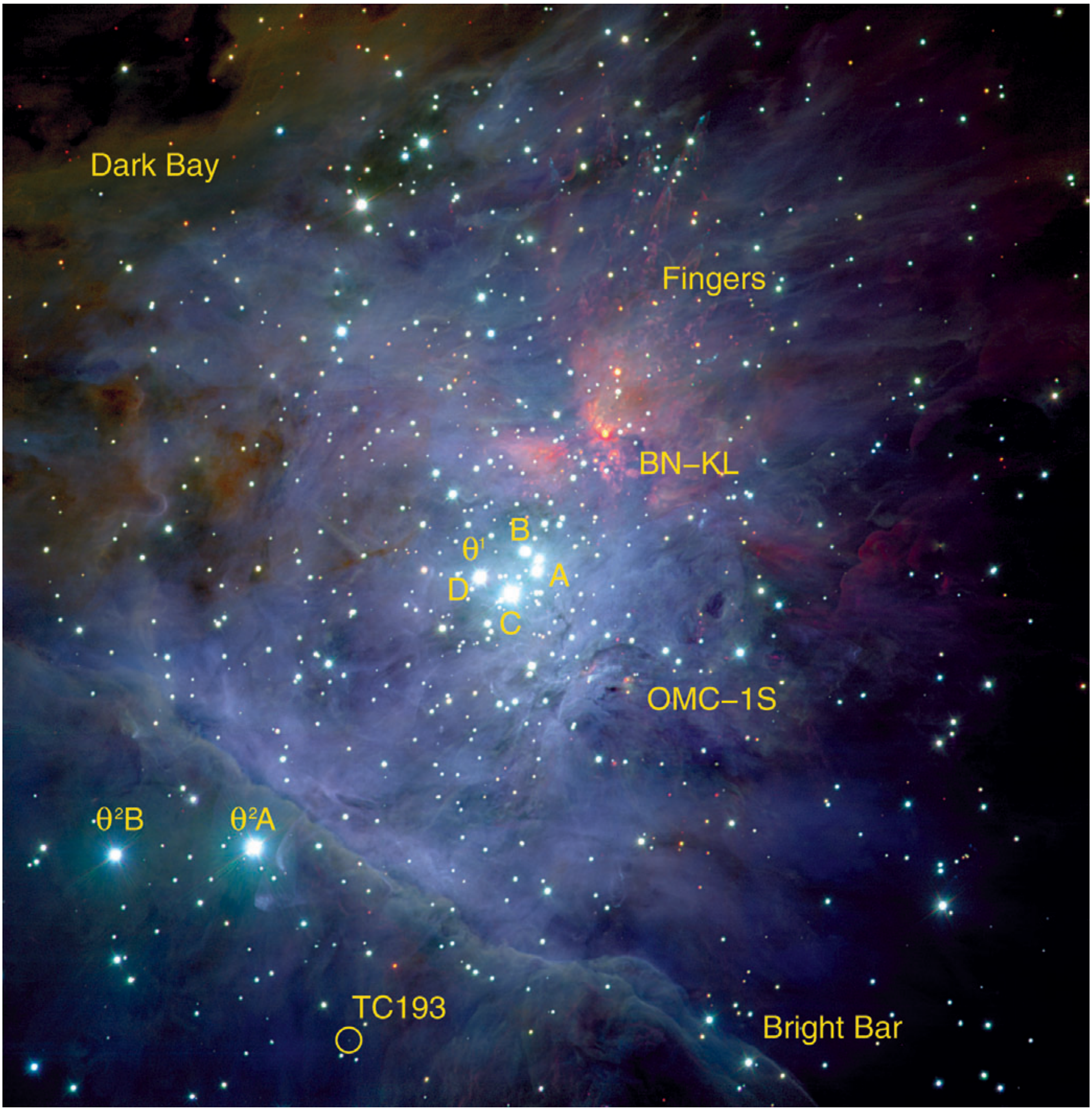


Figure 2: A true-colour near-infrared (1–2.5 μm) image of the Orion Nebula and Trapezium Cluster made using ISAAC on Antu in December 1999. The J_s data are shown as blue, H as green, and K_s as red. In this representation, cube root intensities and unsharp masking were used to compress the dynamic range and emphasise point sources, at a cost of some enhancement in the noise. The original version can be seen in McCaughrean et al. (2001). The image covers 7 × 7 arcmin, or 0.9 × 0.9 pc at the 450 pc distance to the nebula. North is up, east left. Total integration time in this subset of our data is 270 seconds per filter, and the seeing is 0.5 arcsec FWHM. For orientation, we have labelled the eponymous Trapezium OB stars at the centre of the image (θ^1 Ori A, B, C, & D); the two other well-known OB stars (θ^2 Ori A & B) just the south-east of the Bright Bar ionisation front; active star-formation centres embedded in the background molecular cloud, OMC-1S and BN-KL, the latter also being the origin of a massive outflow and the associated broad fan of shocked emission-line fingers to the north-west; and the Dark Bay, a region of high extinction in visible images that is penetrated here at infrared wavelengths. Also marked with a circle is TC193, a member of the Trapezium Cluster. With J_s, H, K_s magnitudes of $18^{\rm m}\!.4$, $17^{\rm m}\!.7$, and $17^{\rm m}\!.2$, respectively, this source is roughly 13 magnitudes fainter than θ^1 Ori C, illustrating the huge dynamic range that must be faced in such studies. TC193 is part of a sample for which we already have ISAAC spectroscopy: a preliminary estimate of its spectral type is L2, which would yield a mass of roughly 6 M_{Jup} assuming an age of 1 Myr, according to the models of Chabrier et al. (2000). Dereddening the near-infrared magnitudes back to the same isochrone would suggest a mass nearer 10 M_{Jup}. Keep in mind also that it lies 2–3 magnitudes above our detection limits, and there are a significant number of potentially lower-mass sources to be studied in detail.

There are roughly 1200 sources in the survey region, 700 of which are fainter than the saturation limit of $K_s \sim 13^{\rm m}$, and the $(J_s - H)$ vs. H colour-magnitude diagram is shown in Figure 3. Without the aid of spectroscopy, it can be notoriously difficult to convert a colour-magnitude diagram for a young, embedded cluster such as this into a mass function, and a discussion of the details and caveats of the methods used would fill an article in itself. To investigate how close we may get to our goal of finding a lower limit to the IMF, however, we can carry out a simple analysis. In Figure 3, we start by assuming that the cluster is 1 Myr old, taking a pre-main-sequence model isochrone for that age and plotting it in the colour-magnitude diagram. The large and variable extinction in the cluster means a source must be individually dereddened back to that isochrone in order to determine its approximate mass, with care taken to ensure that a suitably complete extinction-limited sample is chosen before a mass function is derived. Next, we displace the 1 Myr isochrone by the median cluster reddening of $A_V \sim 7^m$, noting that the reddened 5 M_{Jup} point lies more or less at our observational completeness limit. Thus in principle, we can now derive an extinction-limited sample down to that 5 M_{Jup} limit. Finally, we divide the brown dwarf regime into just two equally-spaced logarithmic mass bins spanning the brown dwarf regime, from 5–20 M_{Jup} and from 20–80 M_{Jup}. Between the unreddened and reddened isochrones, there are roughly 120 sources in the higher mass bin, compared to 30 in the lower bin. These numbers can be converted into a crude two-point mass function for brown dwarfs, with $dN/d \log M \propto M^{+1}$; this should be contrasted with the classical Salpeter mass function in the stellar domain which goes as $\propto M^{-1.35}$.

Thus, the mass function is falling steeply through the brown dwarf regime, a general result known previously for the Trapezium Cluster (see, e.g., McCaughrean et al. 1995; Hillenbrand & Carpenter 2000; Muench et al. 2002), but now extended all the way down well below the so-called deuterium-burning limit at 13 M_{Jup}. Indeed, a more detailed analysis of the K_s data reveals that there are very few sources below 5 M_{Jup}. Is this evidence for a lower mass cut-off? Such a claim would be premature: better mass determinations are required using spectroscopy to derive temperatures and surface gravities, and thus eliminate uncertainties due to differential reddening and non-coevality: we have begun this work using ISAAC, but much larger samples will be required. Second, a comprehensive comparison of the data against the wide range of available pre-main-sequence evolutionary and atmosphere models is required in order to test the robustness of the mass estimates. Third, it is clear that yet deeper imaging is required to probe well below the present limits, to ensure that we have delineated any such boundary on a statistically sound basis.

At first sight, this last point might appear trivial, since the present data only have 15 minutes integration time per filter. However, in practice, accumulating those 15 minutes was an onerous task. First multiply by three filters, then by nine on-source and four sky positions, a factor of two for detector readout, telescope offset, and standard star overheads, and a total of ~ 20 hours of clear conditions with excellent seeing were

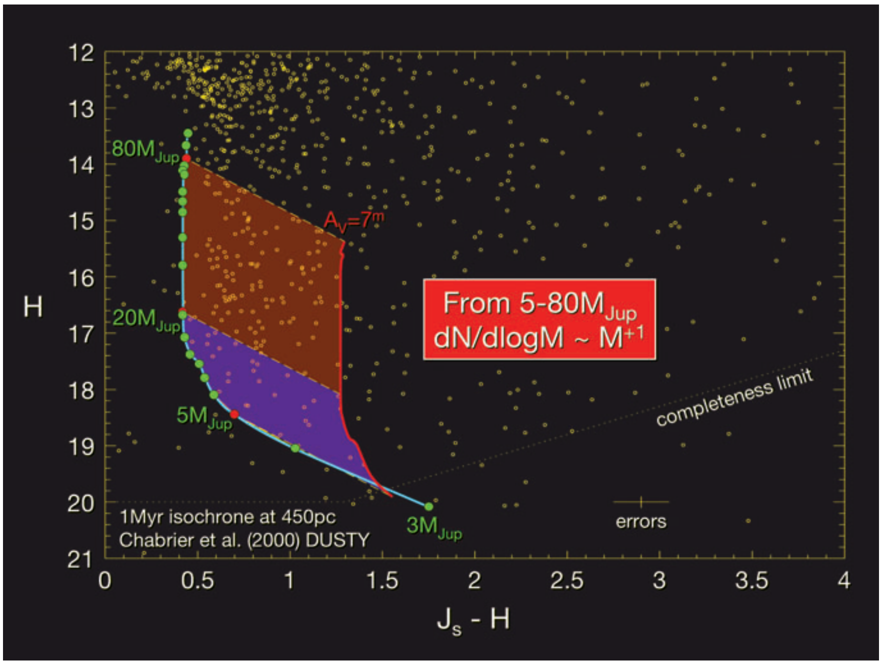


Figure 3: The (J_s–H) vs. H colour-magnitude diagram derived from our ISAAC imaging survey of the Trapezium Cluster (see Fig. 2). The completeness limit and typical photometric errors for sources just above this limit are shown. The 1 Myr isochrone from the pre-main sequence (DUSTY) models of Chabrier et al. (2000) is plotted assuming a distance of 450 pc. The great majority of the sources lie redwards of the isochrone due to intracluster dust extinction of up to ~ 20^m and greater. There is a pile-up of sources at $H = 12^m$–13^m due to the effects of deuterium burning, although sources brighter than this saturated within the 10 second on-chip integration time used for the survey. The number of potential brown dwarfs is large, but not dominant. As described in the text, we have also plotted the 0.005–0.08 $M_\odot$ (5–80 M_{Jup}) segment of the isochrone reddened by $A_V \sim 7^m$: by counting sources in the 5–20 and 20–80 M_{Jup} bins, we can see that the brown dwarf end of the IMF is clearly falling, as crudely characterised by the form $dN/d \log M \propto M^{+1}$.

needed. Also, as there are very bright stars in the field, the observations had to be made in visitor mode to avoid possible persistence effects impacting others in service mode. While trips to Paranal are always interesting, it unfortunately suffers relatively poor weather in peak Orion season, at the height of austral summer, and in the end, it has taken eight nights over three years to complete the survey to the present depth.

How much longer would be needed to get down from our current limit in the K_s band of ~ 3 M_{Jup} to 1 M_{Jup}, where, for example, the magnetically-mediated fragmentation limit may lie? Pre-main-sequence models can be used to assess this, although there are many uncertainties and differences between various models in this low-mass, low-temperature domain. For illustration, we use the well-known COND and DUSTY models of Isabelle Baraffe, Gilles Chabrier, France Allard, and collaborators, and in these models, a 1 M_{Jup} source at 1 Myr is predicted to be at least 2.8 magnitudes fainter than its 3 M_{Jup} counterpart in the K_s band. At least one infrared colour is required in order to provide a reddening estimate, and taking the H band, the most optimistic models predict that our 1 M_{Jup} source should again be 2.8 magnitudes fainter than the 3 M_{Jup} source. Thus even in the best case, we would require integration times roughly 175 times longer than we presently have, i.e., almost 44 hours on-source integration time per filter per field of view.

A wide field is necessary in order to obtain enough sources to ensure a statistically robust result, and using ISAAC to mosaic the cluster would obviously be prohibitive. A wide-field imaging system covering the whole cluster in one shot would improve matters greatly, but even then, once the two filters necessary plus sky and other overheads are accounted for, at least a month of clear observing nights on Orion would be required. Ultimately then, getting to the very bottom of this crucial question will require the NGST, as discussed briefly below.

The Eagle's EGGs: fertile or sterile?

At the opposite end of the mass spectrum from the sub-10 M_{Jup} objects we have been searching for in the Trapezium Cluster, the eponymous OB stars at its heart pose a problem for their lower-mass neighbours. The massive stars yield a prodigious output of ultraviolet photons which not only sculpt and illuminate the Orion Nebula HII region, but also heat and ionise the dense disks of dust and gas which surround the neighbouring young stars (O'Dell, Wen, & Hu 1993; Bally, O'Dell, & McCaughrean 2000). Are planetary systems able to form under this onslaught? As most stars form in clusters, this poses a major quandary in our attempts to understand the birth statistics of the galactic planetary population. However, massive stars can have an impact even earlier in the star formation process. When they first ignite, their ionising photons and strong winds collide with any nearby molecular cloud material, first compressing dense cores and then ripping them apart. Can new stars form via radiative implosion before the cores are destroyed (Larosa 1983; Bertoldi 1989; Lefloch & Lazareff 1994)? How are the properties of any pre-existing protostars affected by having their parental cores blown away before accretion has ended?

A case in point is M 16, the Eagle Nebula, where the famous HST images of Hester et al. (1996) delineated in exquisite detail three so-called elephant trunks, parsec-long columns of gas and dust being ionised by OB stars of the adjacent NGC 6611 cluster. Around the fringes of the trunks, Hester et al. resolved a population of small, dense knots, which they named EGGs for evaporating gaseous globules. As strictly correct as the acronym may have been, it also encapsulated a less obvious proposition, namely that the EGGs are also eggs, the birthplaces of new stars. Based on a couple of plausible associations between EGGs and stars, Hester et al. hypothesised that the full population of 73 EGGs identified in their images might harbour a plethora of young stars about to be exposed by the ionizing flux of the OB stars, thus terminating accretion and helping to define their final masses. Indeed, Hester et al. went further, and suggested that if most stars form in such an environment, perhaps the form of the IMF is determined by the impact of OB stars.

This far-reaching hypothesis needed testing. The optical HST images were unable to probe the interiors of most of the dense EGGs, to assess how many of them truly contained young stars, and deep infrared observations are called for in order to penetrate the extinction and make a detailed census. In addition, these observations must be at high spatial resolution, as the median EGG diameter is just 1000 AU or 0.5 arcsec at 2 kpc, and have to span a wide field of view, in order to cover the whole elephant-trunk system and make a detailed statistical study of contamination by the dense field star population seen towards and beyond M 16. Early attempts either had inadequate resolution (McCaughrean 1997) or too limited a field (Currie et al. 1997), and only the combination of the VLT, ISAAC, and service mode observations was able to deliver the deep, wide-field images with superb seeing necessary to carry out the definitive survey of this astronomical icon. Our data were obtained in 2001, covering a wide field (10 × 10 arcmin) with excellent seeing-limited resolution (0.35 arcsec FWHM), yielding 3σ peak pixel point source detections at J_s. H, and K_s of $22\overset{m}{.}6$, $21\overset{m}{.}3$, and $20\overset{m}{.}4$, respectively. Assuming an age of 1 Myr, these limits correspond to the detection of a 0.08 $M_\odot$ source embedded in 30^m of visual extinction, and even brown dwarfs should be visible through less extinction (McCaughrean & Andersen 2002).

The resulting colour composite image covering just the elephant trunks is shown in Figure 4: the full field of view can be seen in McCaughrean & Andersen (2001). A detailed examination of the 73 EGGs shows that just 11 appear to harbour infrared sources, as marked in Figure 4. Four of these appear to be low-mass stars, while the other seven may be brown dwarfs, several of which cluster near the tip of the largest elephant trunk, close to a massive (4–10 $M_\odot$) young protostar (YSO1; see also Sugitani et al. 2002; Thompson, Smith, & Hester 2002). Although selection effects and uncertainties abound, there does indeed appear to be some limited star formation going on in the elephant trunks. However, a major question remains completely unanswered. Did these objects already exist in the trunks, only to be revealed now by the passage of the NGC 6611 ionisation front, or was their formation indeed initiated by that front triggering the radiative implosion of dense cores? If the former model holds, then we might expect to find a distribution of young stars and brown dwarfs embedded within the densest parts of the trunks, not just at the ionised periphery: due to the extinction however, this is also an experiment which will probably have to await a combined thermal-infrared and millimetre survey by the NGST and ALMA, respectively.

And finally, we must be careful not to develop tunnel vision, mistaking the single HST WFPC-2 field of view version of M 16 for a detached, isolated object, as the makers of the film version of Carl Sagan's "Cosmos" did in their otherwise bravura opening sequence. The real action in the region appears to have taken place in NGC 6611, where a cluster of thousands of stars has formed within the past few million years, apparently with a rather normal IMF (Hillenbrand et al. 1993). The ongoing destruction of the adjacent elephant trunks and the limited star formation taking place within them may ultimately prove to be a sideshow in the grander scheme of things, albeit a beautiful one.

HH212: the prototypical protostellar jet

In M 16, we have seen the impact massive stars can have on their environment. However, even low-mass stars can play an important part in the feedback loop, as we see in our last example, an enigmatic protostellar source near Orion's belt. In the mid-1980s, one of us (HZ) had become interested in very young binary systems, very few of which were known at the time. A newly-discovered cold, dense molecular cloud core, however, IRAS 05413-0104, appeared to be an ideal target in which to go looking for a low-mass protobinary system. The opportunity came in 1987, during the commissioning of the original IRCAM on UKIRT. With only a 62 × 58 pixel array, there was an inevitable trade-off in IRCAM between field of view and spatial resolution, the former generally favoured over the latter. This was in part because of the lure of finally being able to map large regions, in part because the typical seeing at UKIRT was not thought to be that great, and in part because the received wisdom from single-element detectors was that small, noisy pixels would make it impossible to detect low-surface-brightness emission, forgetting however that one only had to integrate long enough to become background limited. In any case, the IRCAM field of view in its 0.6 arcsec/pixel mode was just 37 × 35 arcsec, and in retrospect, these parameters conspired to lead us completely astray for several years. A single K-band image was taken, revealing two, apparently point sources separated by 7 arcsec. Without further ado, we took this to confirm all of our expectations and preconceptions, and as a consequence, IRAS 05413-0104 was written up as a young binary system (Zinnecker 1989; Zinnecker et al. 1992).

Everything changed a few years later during an observing run at the 3-m IRTF on Mauna Kea. While defining macros to observe one target, a brief opening in the proceedings made it possible to slew to IRAS 05413-0104 for follow-up imaging using the facility camera, NSFCAM. With its 256 × 256 pixel array, NSFCAM had improved sampling and field compared to IRCAM, 0.3 arcsec/pixel and 77 × 77 arcsec, respectively. As soon as the first image arrived, it was clear this was something other than a simple binary system: the original two sources were now seen to be extended, not point-like, and they appeared to be just the innermost pair of a long, linear trail of faint nebular knots. Guessing that this was in fact a young jet, not a protobinary, we switched to a narrow-band filter at 2.12 μm designed to trace emission from hot molecular hydrogen and after some mosaicing, a spectacular large outflow was revealed, later to be named HH

Figure 4: A true-colour near-infrared (1–2.5 µm) image of the well-known elephant trunks (or columns, C1, C2, C3) in M 16, the Eagle Nebula, made with data taken with ISAAC on Antu in April–May 2001. The J_s data are shown as blue, H as green, and K_s as red. The cube root of the intensities was taken to compress the dynamic range before normalizing and combining the three mosaics. The main image covers 2.6 × 3.6 arcmin or 1.5 × 2.0 pc assuming a distance of 1.9 kpc to M 16, and is a subsection of the full 9 × 9 arcmin data set that can be seen in McCaughrean & Andersen (2001). North is up, east left. Total integration time is 1200 seconds in J_s, and 300 seconds in each of H and K_s. The seeing is 0.35 arcsec FWHM. The small subimages have been magnified by a factor of 2.9 and each covers 18.5 × 18.5 arcsec (0.17 × 0.17 pc). Labels mark evaporating gaseous globules (EGGs) identified in the optical HST data of Hester et al. (1996) which we find to be associated with low-mass stars and brown dwarfs as described in the text. Also shown are E23, an EGG with no near-infrared point source, but thought to contain an embedded protostar driving a collimated jet; YSO1 and YSO2, massive sources in the tips of C1 and C2, respectively; and HH 216, an optically-visible Herbig-Haro object (Andersen et al. 2002). Due to the large dynamic range, some of the very faintest sources are not easily seen in the subimages, but can be seen in the original data. From McCaughrean & Andersen (2002).

212, not at all coincidentally after the wavelength at which it was emitting. Subsequent deeper observations a year later using the 256 × 256 pixel MAGIC camera on the Calar Alto 3.5-m telescope fully delineated the extreme bipolar symmetry of the flow, with a series of compact knots and bowshocks equidistantly spaced on either side of the centre. It is highly unlikely that inhomogeneities in the surrounding ambient medium would give rise to such symmetry. Rather, the symmetric sequence of features appears to represent a ticker-tape record of the accretion history of the very young central protostars, with variations in the infall onto the protostar being reflected in sequences of knots and bowshocks in the corresponding outflow (Zinnecker, McCaughrean, & Rayner 1998).

However, the unknown parameter in this chart recorder is how quickly the paper is moving, i.e., the timescales involved. How often are new knots emitted? How fast are they moving when emitted? How do they decelerate when they interact with the ambient medium? What is their time-averaged impact on the surrounding medium? High-resolution spectroscopy of the two inner knots in the 2.12-μm line shows almost identical radial velocities, indicating that the jet must lie very close to the plane of the sky (Zinnecker et al. 1998), and thus proper motion measurements are required to reveal the velocity structure of the jet. Typical peak outflow speeds measured in young jets are of the order of 100–200 km s^{-1}, equivalent to just 0.05–0.1 arcsec/yr at 400 pc. But while two images separated by 10 years might appear to be sufficient, it is important to measure the motions as rapidly as possible, as shocked molecular hydrogen cools on timescales of 1–2 years, and thus over longer timescales, there is no guarantee that it is the same packet of gas that is glowing. In addition, it is important to measure lower velocities where the outflowing jet decelerates into the surrounding gas.

Thus we require deep, high spatial resolution imaging separated by reasonably short intervals. We are observing HH 212 in the 2.12-μm line with ISAAC once per year over a five-year period. Service mode observing almost guarantees that we will obtain the desired excellent seeing (< 0.4 arcsec) for the annual two hours of integration time, and the relatively large ISAAC field means that only a two-position mosaic is required to cover the whole jet, which in turn ensures reasonably accurate proper-motion determinations. Adaptive optics imaging is not an option in this region given the lack of a suitably bright guide star, and distortion problems introduced by AO over wide fields might also be a concern. To date, we have imaged the jet three times over a 16-month period, and are already able to identify velocities in the inner knots of 100–200 km s^{-1}, although the observations must be continued in order to extend the sensitivity down to 20 km s^{-1} or so, where the outer bow shocks sweep up the ambient medium.

In the meantime, however, we have combined the extant data to make a single extremely deep image as shown in Figure 5, which has a total integration time of 282 minutes in the central half, and 141 minutes in the outer parts. This is by far the deepest infrared image obtained of a young protostellar jet, with 4.7 hours on an 8.2-m telescope to be compared to the typical longest observations of any other system of 30 minutes on a 4-m-class telescope. In addition, the coadded spatial resolution is an excellent 0.34 arcsec FWHM, with one data set having 0.2–0.25 arcsec resolution over its full two hour span, equal to the diffraction-limited spatial resolution of the HST at the same wavelength. Finally, even though the jet is indeed seen to move over the 16-month baseline, the maximum shifts are on the order of a single ISAAC pixel (0.148 arcsec), and thus any blurring introduced is invisible at the scale shown here.

While the basic symmetry of the jet is obviously maintained, the greatly improved sensitivity and resolution reveal important new details. The innermost knots are all resolved into bowshocks, small counterparts to the larger bows further out, and overall, the flow appears very similar to simulations made of so-called “hammer jets” (Suttner et al. 1997; Volker et al. 1999), where a time-variable jet sends out a series of pulses of dense gas leading to small bowshocks: these subsequently merge into a larger bowshock plowing its way through the ambient medium. However, the image reveals almost continuous emission between the knots following apparently sinuous channels, and the origin of this emission is not entirely clear: why are there continuous shocks between the bows?

Near the base of the jet, there is a pair of diffuse nebulae that broadly resemble the parabolic reflection nebulae associated with circumstellar disks around young stellar objects, as seen in HH 30, IRAS 04302+2247, and Orion 114–426 (McCaughrean, Stapelfeldt, & Close 2000). However, the HH 212 nebulae are separated by roughly 5.5 arcsec or 2200 AU, and comparison with continuum data shows that these nebulae are in fact emitting almost exclusively in the 2.12-μm line, which apparently rules out the central YSO as the source of illumination. Finally, the deep data show that these nebulae extend up and along the jet. It seems likely that the two brightest, innermost knots of the jet are acting as huge spotlights hanging in space, their light being reflected off the uppermost surfaces of the large flattened, rotating molecular cloud core associated with the central protostar (Lee et al. 2000; Wiseman et al. 2001), as well as the inner edges of the cavity being excavated by the outflow in the larger parent core. Alternatively, it may be that gas along the edge of the cavity is being lightly shocked and that the emission is *in situ*, not reflected.

Finally, close inspection of the VLT image reveals that a substantial fraction of the sources in the surrounding field are in fact background galaxies, confirming that the parent core is very compact and quite detached from the nearby Orion B molecular cloud complex. This is especially evident at the north-east end, where the outer bowshock appears to pass close to a cluster of galaxies, and begs the question of how there can be any ambient medium in the region to be shocked. Conversely, in one of the largest departures from symmetry, there is an additional large bowshock at the south-west end, probably formed as the jet prows into another cloud core, as signposted by the presence of a bright source surrounded by nebulosity and an apparently edge-on disk system. This interaction between one low-mass protostar and a dense core apparently containing another reminds us again that the cumulative effects of feedback cannot be neglected when trying to understand the formation of a population of young stars, whether they be in a dense cluster or more distributed over a larger molecular cloud.

A look to the near future

The first few years of VLT operation have been a great success, and ISAAC has been an outstanding workhorse instrument, as hopefully witnessed by the data shown in this article and elsewhere. However, there is a fly in the ointment: all of the projects described in this article relied on mosaicing to cover the desired field, which is not only inefficient, but also compromises accuracy when it comes to PSF-fitting photometry, proper-motion monitoring, and detection of very extended low-surface-brightness emission. As a result, it is worth taking a brief look at the future of wide-field near-infrared imaging at ESO, and thus by extension, how our studies may be further improved.

The standard answer is VISTA, the 4-m survey telescope which will feed a huge infrared camera covering the equivalent of 42 × 42 arcmin at 0.31 arcsec/pixel with 16 2048 × 2048 pixel arrays. It is argued that VISTA eliminates the need for a wide-field camera on the VLT, since for large-area surveys, it will make up with field of view what it lacks in collecting area. But there are caveats. First, the VISTA camera

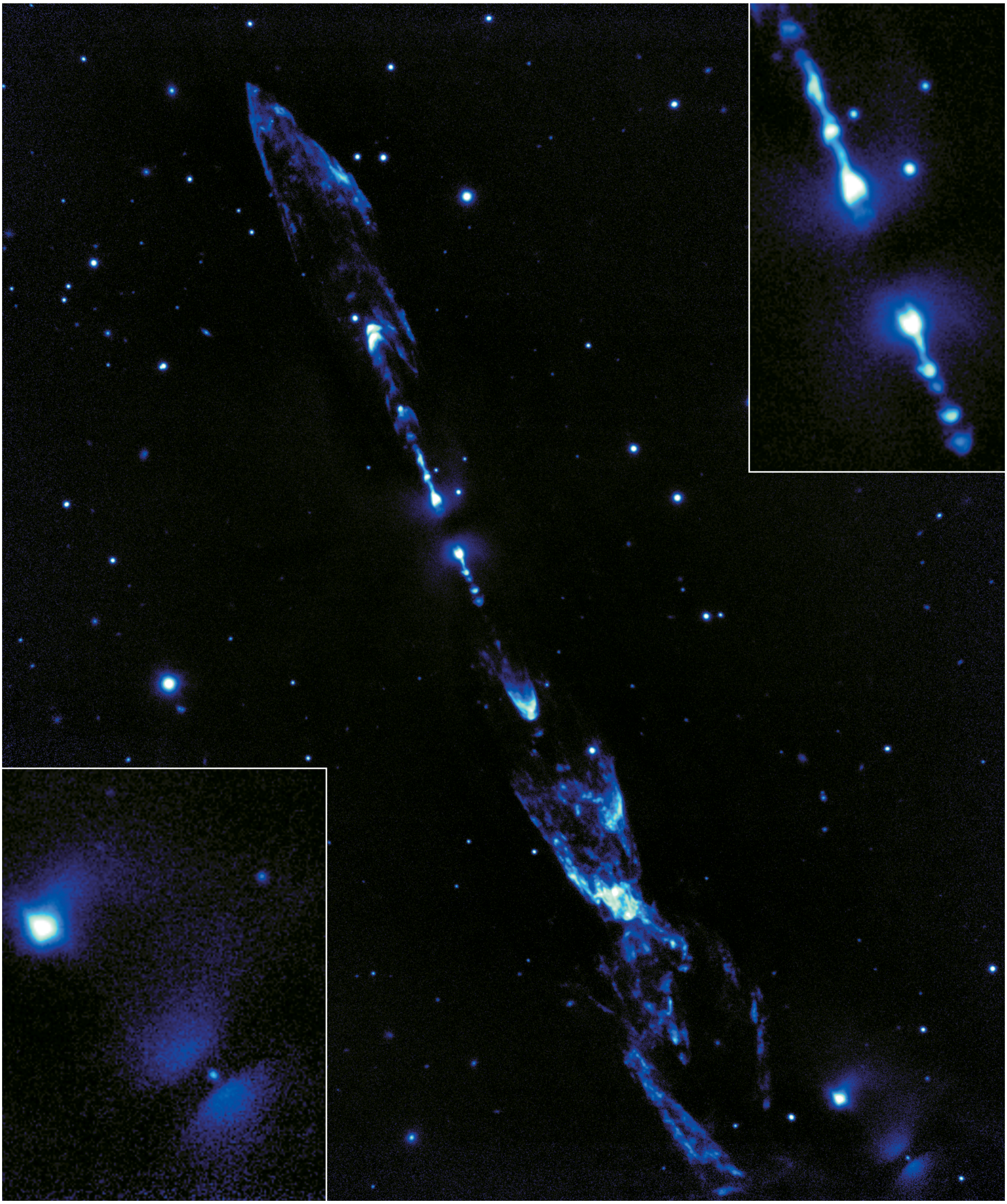


Figure 5: A deep image of the protostellar jet, HH212, in the 2.122 μm v = 1–0 S(1) line of molecular hydrogen, made using ISAAC on Antu, with data from October 2000, October 2001, and January 2002. North is up, east left. Total integration time in the central half is 282 minutes, yielding a 3σ per pixel limiting surface brightness sensitivity there of 1.2×10^{-19} W m^{-2} $arcsec^{-2}$. The image covers 3.2 × 3.9 arcmin or 0.37 × 0.45 pc assuming a distance of 400 pc to HH212. The resolution is seeing limited at 0.34 arcsec FWHM. Intensities have been scaled logarithmically. Continuum emission has not been subtracted as the jet is known to be emitting almost exclusively in the S(1) line: however, continuum sources such as field stars and galaxies remain visible. As discussed in the text, the nebulosity surrounding the base of HH212 is line emission, while the bipolar nebula at the south-west end of the image is seen in continuum emission, and is most likely a large circumstellar disk. Judging from broad-band data, the point source at the centre of the southwest nebula appears to be an unrelated field star. The two subimages in the corners have been expanded by a factor of 2.5, and show the south-west bipolar nebula (lower left) and the inner knots of HH 212 (upper right) in more detail. From McCaughrean et al., in preparation.

will not have the contiguous field which is often so important for star-formation targets: mosaicing will still be required. Second, for observations of a single field trying to reach a given faint flux limit, the VLT will be four times quicker than VISTA. Third, the infrared seeing is frequently excellent on the VLT, and the VISTA image scale will not take proper advantage of it: a camera with an image scale similar to ISAAC's would make it quicker yet for point sources, as well as yielding superior resolving power for extended sources, and reducing confusion in crowded fields.

On the VLT itself, NAOS/CONICA delivers excellent spatial resolution, but over a smaller field than even ISAAC. NIRMOS should include an imaging mode covering roughly 16 × 14 arcmin at 0.2 arcsec/pixel, but again not contiguous, and only covering 1–1.8 μm, making it of limited utility for studies of low-mass or deeply embedded, cool sources, or shocked H_2 emission associated with outflows. Among the VLT second-generation instruments under consideration, there is a near-infrared multiobject spectrograph, KMOS, which would extend to 2.5 μm, but which may or may not include an imaging mode. In any event, according to present planning, it does not appear that any wide-field imager covering the whole 1–2.5 μm region would be in operation on Paranal before 2007.

Hoffman's version of Moore's law suggests that we should have already had a 2048 × 2048 pixel infrared array camera available in 2001, and indeed, Gemini-South commissioned such a camera (FLAMINGOS) at that time. In the 2004–2006 timeframe, 4096 × 4096 pixel cameras should be shouldering most of the load, and indeed, several ESO member states are developing such cameras for their 4-m-class telescopes, including WFCAM for UKIRT and WIRCAM for the CFHT. Thus it seems reasonable to explore the options for developing a wide-field imager for the VLT. A straightforward direct imager with a 2 × 2 mosaic of 2048 × 2048 pixel arrays would cover a 10 × 10 arcmin field at the same 0.15 arcsec/pixel scale as ISAAC, sampling the kind of excellent infrared seeing seen in this article, and would be very well suited to deep pointed imaging of embedded star clusters, and outflows, as well as nearby galaxies and distant galaxy clusters.

Looking even further ahead, the joint NASA/ESA/CSA Next Generation Space Telescope will combine a large primary mirror (in this case, 6.5 m in diameter), with diffraction-limited resolution (0.08 arcsec at 2 μm) over a field of more than 3 × 3 arcmin, and a location at the Sun-Earth L2 point where passive cooling to 50 K will avoid the scourge of OH airglow and thermal background fought from the ground. Together, these features will yield extraordinary gains in sensitivity from 0.6 to 28 μm for both imaging and spectroscopy. As examples in the context of this article, consider a survey for point sources at 2 μm: the NGST should go more than 6 magnitudes deeper than ISAAC in the same integration time, and folding in all factors, the NGST will be roughly 10^4 times faster than a present-day 8-m telescope, completing in just one hour what would take literally years of ground-based observing time.

Thus, when the NGST is launched in 2010, we will take yet another giant leap in the ongoing revolution that is infrared astronomy, less than 25 years after the first infrared arrays were brought to UKIRT and 12 years after the opening of the VLT. In tandem with the wide-field, high spatial resolution millimetre and submillimetre imaging to be enabled by ALMA in the same timeframe, the future for star-formation studies looks very rosy indeed. Given what we have seen in the past decade, who knows what surprises lie ahead?

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References

Adams, F.C. & Fatuzzo, M. 1996, *ApJ*, **464**, 256.
Alves, J. & McCaughrean, M.J. 2002, eds. The Origins of Stars and Planets: The VLT View (Berlin: Springer Verlag).
Andersen, M., Reipurth, B., Knude, J. et al. 2002, *A&A*, in press.
Bally, J., O'Dell, C.R., & McCaughrean, M.J. 2000, *AJ*, **119**, 2919.
Bate, M.R., Bonnell, I., & Bromm, V. 2002, *MNRAS*, **332**, L65.
Bertoldi, F. 1989, *ApJ*, **346**, 735.
Boss, A.P. 2001, *ApJ*, 551, L167.
Brandl, B., Brandner, W., Eisenhauer, F., Moffat, A.F.J., Palla, F., & Zinnecker, H. 1999, *A&A*, **352**, L69.
Chabrier, G., Baraffe, I., Allard, F., & Hauschildt, P. 2000, *ApJ*, **542**, 464.
Currie, D., Kissell, K., Shaya, E. et al. 1996, *The Messenger*, **86**, 31.
Hester, J.J., Scowen, P.A., Sankrit, R. et al. 1996, *AJ*, **111**, 2349.
Hillenbrand, L.A. 1997, *AJ*, **113**, 1733.
Hillenbrand, L.A. & Carpenter, J.M. 2000, *ApJ*, **540**, 236.
Hillenbrand, L.A., Massey, P., Strom, S.E., & Merrill, K.M. 1993, *AJ*, **106**, 1906.
Hoyle, F. 1953, *ApJ*, **118**, 513.
Intel 2002, http://www.intel.com/research/silicon/mooreslaw.htm
Larosa, T.N. 1983, *ApJ*, **274**, 815.
Lee, C.-F., Mundy, L.G., Reipurth, B., Ostriker, E.C., & Stone, J.M. 2000, *ApJ*, **542**, 925.
Lefloch, B. & Lazareff, B. 1994, *A&A*, **289**, 559.
Lucas, P.W. & Roche, P.F. 2000, *MNRAS*, **314**, 858.
Lucas, P.W., Roche, P.F., Allard, F., & Hauschildt, P. 2001, *MNRAS*, **326**, 695.
Luhman, K.L., Rieke, G.H., Young, E.T. et al. 2000, *ApJ*, **540**, 1016.
Low, C. & Lynden-Bell, D. 1976, *MNRAS*, **176**, 367.
McCaughrean, M.J. 1997, in *Herbig-Haro Flows and the Birth of Low Mass Stars*, eds. B. Reipurth & C. Bertout, IAU Symp. 182, 551.
McCaughrean, M.J., Alves, J., Zinnecker, H., & Palla, F. 2001, ESO press release (http://www.eso.org/outreach/press-rel/pr-2001/phot-03-01.html).
McCaughrean, M.J. & Andersen, M. 2001, ESO press release (http://www.eso.org/outreach/press-rel/pr-2001/phot-37-01.html)
McCaughrean, M.J. & Andersen, M. 2002, *A&A*, **389**, 513.
McCaughrean, M.J., Reid, I.N., Tinney, C.G. et al., 2001, *Science* (Letters), **291**, 1487.
McCaughrean, M.J., Stapelfeldt, K.R. & Close, L.M. 2000, in *Protostars & Planets IV*, eds. V. Mannings, A.P. Boss, & S.S. Russell (Tucson: Univ. Arizona Press), p. 485.
McCaughrean, M.J., Zinnecker, H., Rayner, J.T., & Stauffer, J.R. 1995, in *The Bottom of the Main Sequence and Beyond*, ed. C.G. Tinney, (Berlin: Springer Verlag), p. 209.
Moore, G.E. 1965, *Electronics*, **38**, 8.
Muench, A.A., Lada, E.A., Lada, C.J., & Alves, J. 2002, *ApJ*, **573**, 366.
O'Dell, C.R., Wen, Z., & Hu, X. 1993, *ApJ*, **410**, 696.
Padoan, P. & Nordlund, Å. 2002, *ApJ*, submitted (astro-ph/0205019).
Palla, F. & Stahler, S.W. 2000, *ApJ*, **540**, 255.
Rees, M.J. 1976, *MNRAS*, **176**, 483.
Salpeter, E.P. 1955, *ApJ*, **121**, 161.
Silk, J. 1977, *ApJ*, **214**, 152.
Sugitani, K., Tamura, M., Nakajima, Y. et al. 2002, *ApJ*, **565**, L25.
Suttner, G., Smith, M.D., Yorke, H.W., & Zinnecker, H. 1997, *A&A*, **318**, 595.
Thompson, R.I., Smith, B.A., & Hester, J.J. 2002, *ApJ*, **570**, 749.
Völker, R., Smith, M.D., Suttner, G., & Yorke, H.W. 1999, *A&A*, **343**, 953.
Wiseman, J., Wootten, A., Zinnecker, H., & McCaughrean, M.J. 2001, *ApJ*, **550**, L87.
Woltjer, L. 1978, in *Optical Telescopes of the Future*, eds. F. Pacini, W. Richter, & R.N. Wilson (Geneva: ESO), p. 5.
Zinnecker, H. 1989, in *Low Mass Star Formation and Pre-main Sequence Objects*, ed. B. Reipurth, (Garching: ESO), p. 447.
Zinnecker, H., Andersen, M., Brandl, B. et al. 2002, in *Extragalactic Star Formation*, eds. E. Grebel, D. Geisler, & D. Minniti, IAU Symposium 207, in press.
Zinnecker, H., Bastien, P., Acoragi, J.-P., & Yorke, H.W. 1992, *A&A*, **265**, 726.
Zinnecker, H., Krabbe, A., McCaughrean, M.J. et al. 1999, *A&A*, **352**, L73.
Zinnecker, H., McCaughrean, M.J., & Rayner, J.T. 1998, *Nature*, **394**, 862.

Gamma-Ray Bursts: the Most Powerful Cosmic Explosions

L. KAPER[1], A. CASTRO-TIRADO[2], A. FRUCHTER[3], J. GREINER[4], J. HJORTH[5], E. PIAN[6], M. ANDERSEN[7], K. BEUERMANN[8], M. BOER[9], I. BURUD[3], A. JAUNSEN[5], B. JENSEN[5], J.M. CASTRO CERÓN[10], S. ELLISON[11], F. FRONTERA[12], J. FYNBO[13], N. GEHRELS[14], J. GOROSABEL[2], J. HEISE[15], F. HESSMAN[16], K. HURLEY[17], S. KLOSE[16], C. KOUVELIOTOU[18], N. MASETTI[12], P. MØLLER[13], E. PALAZZI[12], H. PEDERSEN[5], L. PIRO[19], K. REINSCH[8], J. RHOADS[3], E. ROL[1], I. SALAMANCA[1], N. TANVIR[20], P.M. VREESWIJK[1], R.A.M.J. WIJERS[1], T. WIKLIND[21], A. ZEH[16], E.P.J. VAN DEN HEUVEL[1]

[1]Astronomical Institute "Anton Pannekoek", Amsterdam, The Netherlands; [2]IAA-CSIC, Granada, Spain; [3]STScI, Baltimore, USA; [4]MPE Garching, Germany; [5]Copenhagen University Observatory, Denmark; [6]Trieste, Italy; [7]Potsdam, Germany; [8]Universitäts Sternwarte, Göttingen, Germany; [9]CESR/CNRS, Toulouse, France; [10]Real Instituto y Observatorio de la Armada, Cádiz, Spain; [11]ESO Paranal, Chile; [12]Bologna, Italy; [13]ESO Garching, Germany; [14]NASA/GSFC, Greenbelt, USA; [15]SRON Utrecht, The Netherlands; [16]Thüringer Landessternwarte (Tautenburg, Germany); [17]UC Berkeley, Space Sciences Laboratory, USA; [18]NASA/MSFC, Huntsville, USA; [19]Rome, Italy; [20]Hertfordshire, United Kingdom; [21]Onsala, Sweden

1. Introduction

Gamma-ray bursts (GRBs) are brief flashes of cosmic γ-rays, first detected in data from the US military *Vela* satellites in 1967 that were launched to verify the Nuclear Test Ban Treaty (Klebesadel et al. 1973). Lacking a distance scale, the physical nature of GRBs remained a mystery for thirty years. Their cosmological origin was suggested by their isotropic sky distribution, demonstrated in the early 1990s by the BATSE experiment onboard the *Compton Gamma-Ray Observatory* (Fig. 1).

However, the definite proof of their distant, extragalactic nature came from the discovery of their rapidly fading *afterglows* at X-ray, optical, and radio wavelengths in 1997, thanks to the alerts of the Italian-Dutch *BeppoSAX* satellite. Absorption and emission lines in the afterglow spectra provided redshifts in the range z = 0.1–4.5, corresponding to distances of several billion light-years out to the edge of the visible universe. This made it clear that GRBs represent the most powerful explosions in the universe since the Big Bang.

There are strong indications that GRBs are caused by highly relativistic, collimated outflows powered by the collapse of a massive star or by the merger of two compact objects. Their enormous brightness make GRBs powerful probes of the distant and early universe, yielding information on the properties of their host galaxies and the cosmic star-formation history.

2. The GRACE consortium

Since the discovery of the first GRB afterglow on 28 February 1997 (Costa et al. 1997, Van Paradijs et al. 1997, Metzger et al. 1997), active collaborations between many observatories around the world has resulted in a timely and detailed study of several dozen GRBs. From the start ESO has played a very important role in the identification and analysis of the optical and infrared afterglows. Gamma-ray detectors onboard spacecraft orbiting the Earth or exploring the solar system provide the GRB alerts, which are promptly announced on the *Gamma-ray burst Circular Network* (GCN); these trigger immediate follow-up observations at ground-based observatories. By building up a network of astronomers at observatories all around the world, it becomes possible to quickly (within hours) respond to a GRB alert (from one or both hemispheres) and to locate and monitor the afterglow.

Here we report on behalf of the GRACE consortium, the *Gamma-Ray burst Afterglow Collaboration at ESO*[1]. The GRACE consortium was awarded an ESO Large Programme that started in April 2000 and ended in March 2002. So far, the GRACE collaboration has identified most of the known GRB optical counterparts and has measured about two thirds of all known GRB redshifts. Currently, ESO observing time is allocated to GRACE through normal Target of Opportunity one-semester programmes. Our collaboration is also involved in GRB follow-up programmes awarded observing time on the *Hubble Space Telescope* (HST), the *Chandra* X-ray observatory, and INTEGRAL.

GRACE consists of teams of astronomers ("nodes") based in Denmark, Germany, Italy, Spain, the Netherlands, the United Kingdom and the United States of America. The nodes take turns for being "on duty" for periods of two weeks. Starting September 2002 our collaboration will be supported by a Research and Training Network funded by the European Commission for a period of four years.

[1]http://zon.wins.uva.nl/grb/grace/

3. GRBs and their afterglows

GRBs are short flashes of γ-rays, with a duration ranging from several milliseconds to tens of minutes, and in most cases an observed peak energy around 100 keV. The daily rate of GRBs, detectable from Earth, is about two (Paciesas et al. 1999). The γ-ray light curves are extremely diverse, some very smooth, others with numerous spikes. BATSE data showed that there are two distinct classes of GRBs: a class with a short duration (less than 2 seconds) and relatively hard spectra, and a class of long-duration bursts with softer spectra. It is important to note that only afterglows of the latter population have been observed so far: it is not known whether short bursts produce afterglows at all. The best limit obtained so far is for the short/hard HETE-II burst GRB 020531, for which Salamanca et al. (2002) did not detect any afterglow candidate brighter than V ~ 25, just 20 hours after the alert.

In a previous *Messenger* paper (Pedersen et al. 2000) the first scientific break-throughs in this field were reported. The Italian-Dutch *BeppoSAX* satellite played a crucial role in these discoveries by rapidly determining the position of a GRB with arcminute precision. Arcminute-sized error boxes match the typical field size of modern (optical) detectors, so that it became feasible to detect the GRB afterglows,

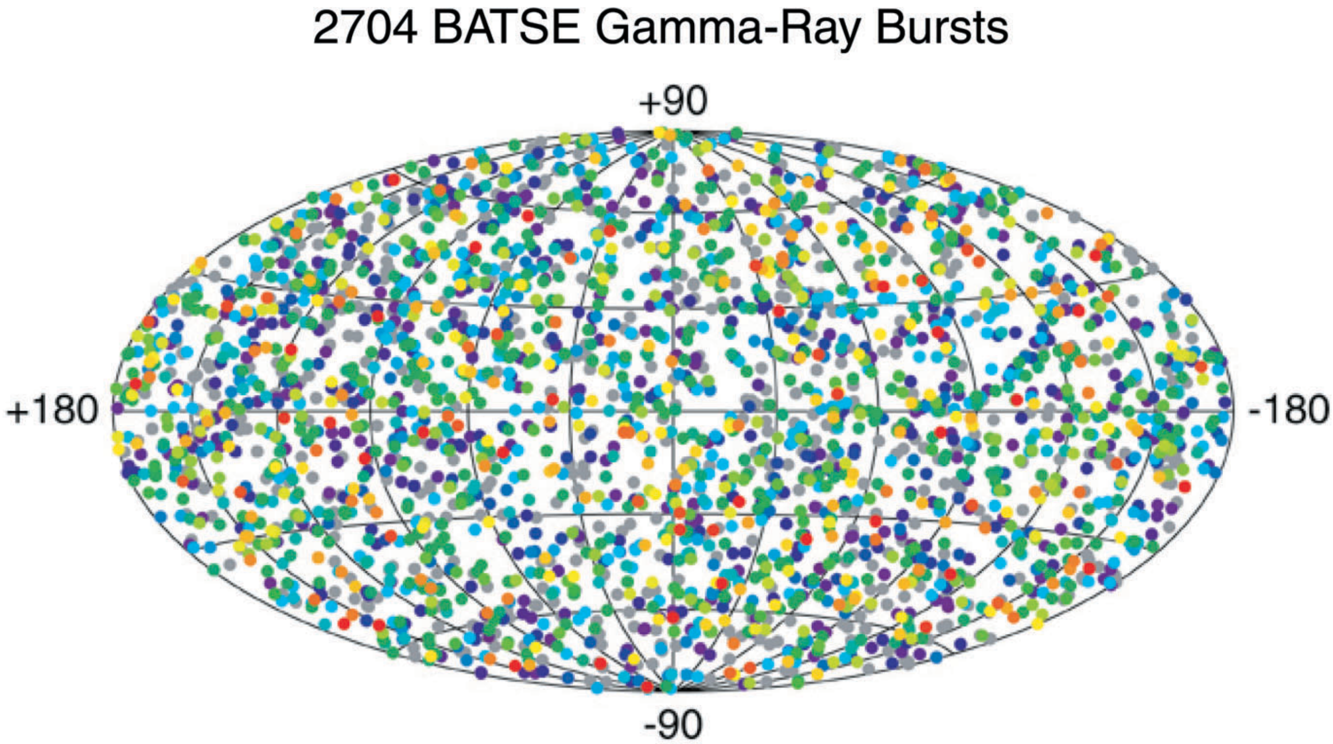

Figure 1: This map shows the locations of a total of 2704 GRBs recorded with BATSE on board NASA's Compton Gamma-Ray Observatory *during its nine-year mission. The projection is in galactic coordinates; the plane of the Milky Way Galaxy is along the horizontal line at the middle of the figure. The burst locations are colour-coded based on the fluence, which is the energy flux of the burst integrated over the total duration of the event. Long-duration, bright bursts appear in red, and short-duration, weak bursts appear in purple (credit BATSE team).*

which fade quickly, on a timescale of only a few days (the typical time profiles are $t^{-\alpha}$, with $\alpha \sim 1–2$).

The *High Energy Transient Explorer II* (HETE-II), launched in October 2000, was designed to provide very rapid (< 1 minute) and very precise positions (error boxes down to arcseconds) of both long- and short-duration bursts. This mission has been one of the main drivers of our ESO Large Programme, but so far only few accurate HETE-II positions have become available. Besides HETE-II, satellites in the *Interplanetary Network* (IPN) provide burst positions, though at a low rate. The *BeppoSAX* mission was terminated on April 30, 2002, exactly 6 years after its launch.

With *Integral* (launch October 2002) and *Swift* (2003) the rate of GRB alerts will definitely increase again. In preparation for these missions, robotic telescopes are installed at ESO La Silla to perform prompt follow-up of GRB alerts. Given the expected high data rate, a fast afterglow identification pipeline is necessary. Our consortium has developed such a pipeline using colour-colour discrimination techniques. The efficiency of this procedure was demonstrated by the discovery, at ESO, of the optical and near-infrared counterpart of GRB 001011 (Gorosabel et al. 2002a).

Since the advent of rapid (within a few hours to days) GRB locations[2], 39 alerts resulted in the detection of an

[2]http://www.aip.de/People/Greiner/grbgen.html

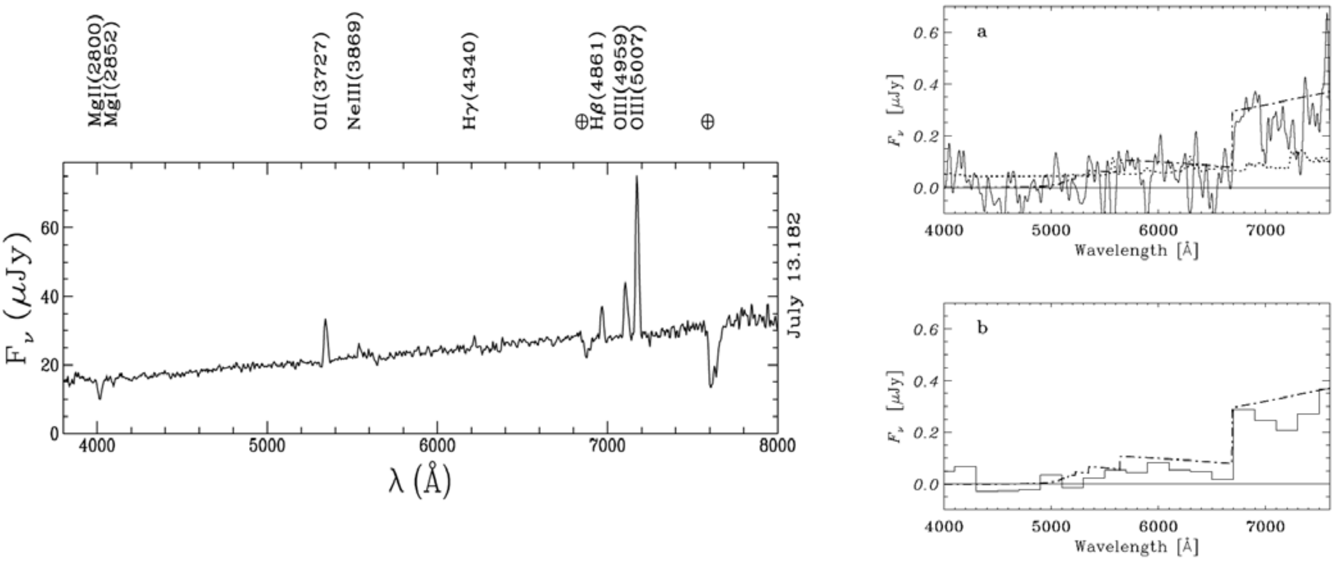

Figure 2: Left: VLT spectrum of GRB 990712 taken 12 hours after the burst. Absorption lines of Mg I and Mg II are detected, as well as several emission lines from the underlying bright (V ~ 22) host galaxy (from Vreeswijk et al. 2001). The redshift of the galaxy is z = 0.43. Right: A low-resolution FORS spectrum of the currently most-distant GRB 000131 at z = 4.5 (from Andersen et al. 2000). The redshift is determined from the Lyman break.

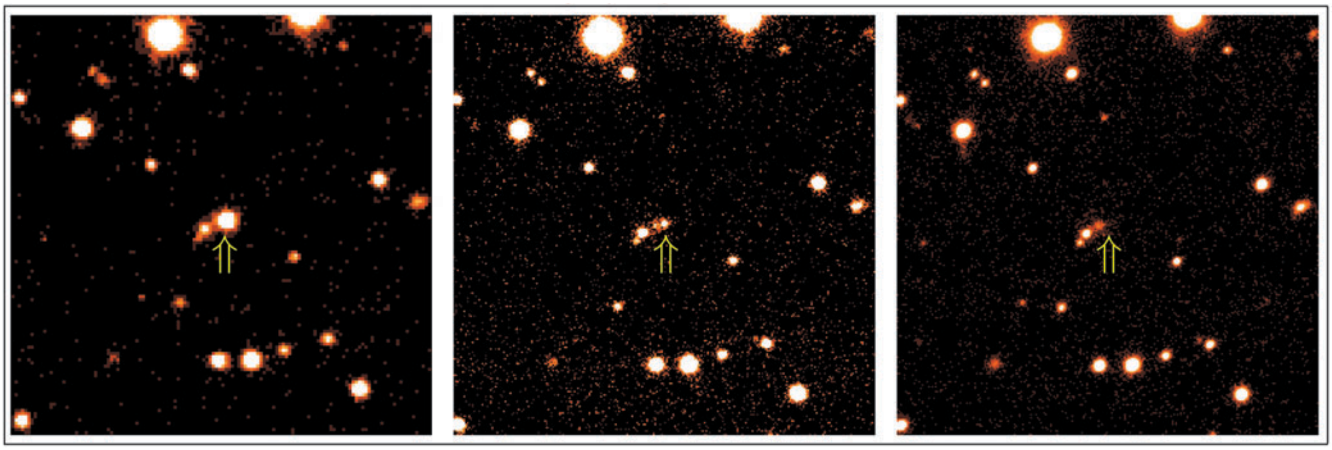

Figure 3: The fading afterglow of GRB 011121 at near-infrared wavelengths (1.2 µm, J band, Greiner et al. 2002). The field size is 40 × 40 arcseconds, North is up and East is to the left. On November 22, 2001, the afterglow is detected by NTT/SOFI at J = 17.5; 2 days later the afterglow has faded to J = 20.9. On February 9, 2002, the afterglow is not detected anymore (J > 24) in this superb VLT/ISAAC image (seeing 0.4 arcsecond). The light sources near the position of GRB 011121 might represent some bright regions in the host galaxy.

X-ray afterglow; 32 optical afterglows have been found (of which more than half were discovered by our collaboration), and 20 radio afterglows (status July 1, 2002). For many GRBs no afterglow is found. Adverse observing conditions can explain many of these non-detections. For example, the optical afterglow of GRB 000630 had faded to an R-band magnitude of 23 just 21 hours after the burst (Fynbo et al. 2001), and would certainly have remained undetected in searches initiated a bit later. In some cases, however, another explanation is needed. For example, the extinction by gas and dust in the circumburst environment might hinder the detection of an afterglow at rest-frame UV and optical wavelengths, or it may be too faint or even absent. The nature of these *dark* bursts remains to be resolved.

For 24 GRBs the distance has been determined. The GRB spectrum itself is featureless (consistent with optically thin synchrotron emission), but absorption and/or emission lines formed in the GRB host galaxy, or the position of the Lyman break (912 Å), provide the redshift (Fig. 2). The majority of redshifts are in the range between 0.5 and 1.5. The current record holder, achieved with the VLT, is GRB 000131 with z = 4.5, corresponding to a "distance" (look-back time) of 13 billion light-years (Andersen et al. 2000, ESO press release 20/00).

That GRBs can potentially probe the very distant universe was demonstrated by the impressive burst detected in January 1999: GRB 990123 (Akerlof et al. 1999). Within the first minutes following the burst, its optical afterglow reached visual magnitude V = 9, i.e. observable with a pair of binoculars. It was briefly one million times brighter than a supernova. This particular burst, at z = 1.6, would have been detectable (at its maximum, in the K band) with the *Very Large Telescope* up to a redshift of about 15. With *Swift,* which will provide accurate burst positions within a few minutes, many such bright early afterglows become detectable.

4. Evidence for collimation

Assuming isotropic emission, the measured distances imply peak luminosities of 10^{52} erg/s (10^{45} Watt). Thus the peak luminosity of each event corresponds to about 1% of the luminosity of the visible universe! The resulting energy budget is about 10^{53} erg, which is actually comparable to the total amount of energy released during a stellar collapse (supernova). The measured rate of GRBs corresponds to about one per million year per galaxy.

There is mounting evidence, however, that γ-ray bursts are collimated into jets, with opening angles of a few degrees only. This evidence comes from the interpretation of the occurrence of a kink in the slope of the afterglow light curves, and from the detection (in a few cases) of polarization (see ESO press release 08/99). Also, the total isotropic energy inferred for GRB 990123 is uncomfortably high (to be explained by a stellar-collapse model), but would be reduced by a factor of 500 if the energy were emitted into a cone with an opening angle of 5 degrees.

Frail et al. (2001) determine the jet opening angle of several GRB afterglows and show that the spread in the output energy distribution of their sample becomes much narrower when taking the collimation into account, with a mean energy output of 2×10^{51} erg. They suggest that this may be the standard energy reservoir for all GRBs. Though speculative, the implications of this finding are great if these intrinsically bright GRBs can be used as standard candles at high redshifts, e.g. to measure the expansion rate of the Universe. Another consequence of the collimation is that the GRB rate also increases by a factor of 500, and that the vast majority of bursts are not visible.

5. The origin of GRBs: possible progenitors

From a variety of arguments, such as their total energy and the evidence for collimation, the general expectation is that a system consisting of a black hole and a surrounding accretion torus is powering the GRB. Such a setting, just before the GRB goes off, can occur in several ways. One way is the merging of a binary neutron-star system, like the Hulse-Taylor binary pulsar, or a neutron star and a black hole (e.g. Lattimer & Schramm 1974, Eichler et al. 1989). Another popular model involves the core collapse of a rapidly rotating massive star, the "collapsar" model (Woosley 1993, Paczynski 1998, MacFadyen & Woosley 1999).

There are several indications that the observed population of GRB afterglows, i.e. the long-duration bursts, is best explained by the latter model. The first indication comes from the models themselves. The collapsar model naturally produces bursts that have a duration longer than a few seconds, but cannot make short bursts. On the other hand, the merger model can produce short bursts, but has problems keeping the engine on for longer than a couple of seconds. The clear distinction between short- and long-duration bursts suggests that both progenitor models may be at work in nature.

6. The supernova connection

Another indication that long-duration GRBs are related to the core collapse of a massive star is that some GRBs seem to be associated with a supernova (SN). The first evidence for a supernova connection came from GRB 980425/SN1998bw (Galama et al. 1998; ESO Press Release 15/98). This supernova, approximately coincident in time and position with GRB 980425, was of the rare type Ic, and at radio wavelengths the brightest supernova ever detected. Interpretation of the light curve indicated that during this supernova a black hole was formed (Iwamoto et al. 1998). However, the amount of prompt γ-ray emission was very modest, which makes GRB 980425, the closest GRB at a redshift of $z = 0.0085$, a peculiar event.

In the mean time, evidence has been found that several GRB afterglow light curves show a so-called supernova bump, i.e. a bump in the light curve at a time interval compatible with the rise time of a SN, assuming it has gone off simultaneously with the GRB. The bump would thus represent the SN maximum light. Amongst them is the recent burst GRB 011121 (Fig. 3), which was followed up by our collaboration with ESO telescopes in several wavelength bands (Fig. 4, Greiner et al. 2002). Emission lines produced by the host galaxy indicate a redshift of 0.36. The late-time light curve shows a bump, some 10 days after the burst when the GRB afterglow has faded by a factor of 250. After correcting for the flux contribution and extinction due to the host galaxy, the late-epoch light curve is consistent with a SN similar to SN1998bw (taking into account the difference in redshift).

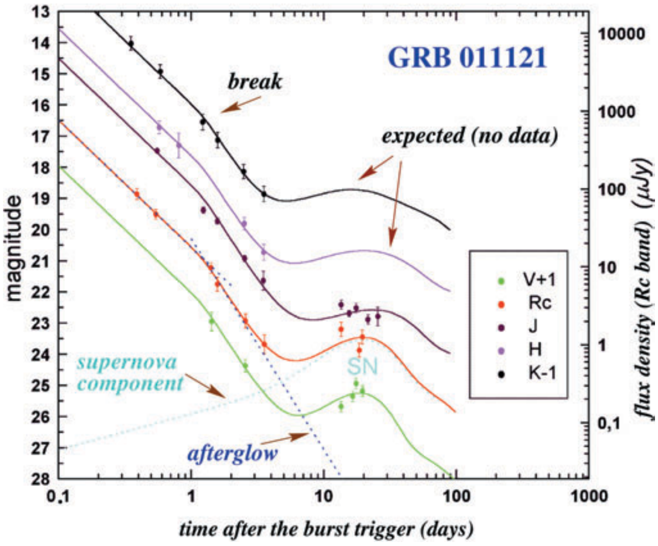

Figure 4: The light curve of GRB 011121 at optical and near-infrared wavelengths. The blue dotted line represents the contribution to the light of the GRB afterglow. About 10 days after the burst the light curve shows a bump, indicative of an accompanying supernova,shown in magenta (Greiner et al. 2002).

7. GRB host galaxies

For practically all GRB afterglows with an accurate location, a host galaxy has been detected. In nearly all cases the burst is located within the optical (rest frame UV) extent of the galaxy. This, in combination with the blue colours of the galaxies, suggests that GRBs originate in galaxies with a relatively high star-formation rate. The collapsar model predicts that GRBs will occur in regions where active star formation is taking place (see, e.g., the VLT observations of the host of GRB 001007, Castro Cerón et al. 2002). Neutron-star binaries do not necessarily reside in star-forming regions. Due to the kick velocities received during the two supernova explosions forming the neutron stars, such binaries are high-velocity objects. As the merging process of the binary, driven by the emission of gravitational radiation, can take up to a billion years, the binary may have travelled several thousand light-years before producing a GRB.

With the *Hubble Space Telescope* (HST) the morphology of the GRB host galaxies is studied in detail. Figure 5 shows an HST/STIS image of the galaxy hosting GRB 990705 (Andersen et al. 2002). It is a giant grand-design spiral at a distance of about 8 billion light-years with a diameter in excess of 150,000 light-years. Apparently, the GRB went off in the outskirts of one of the spiral arms.

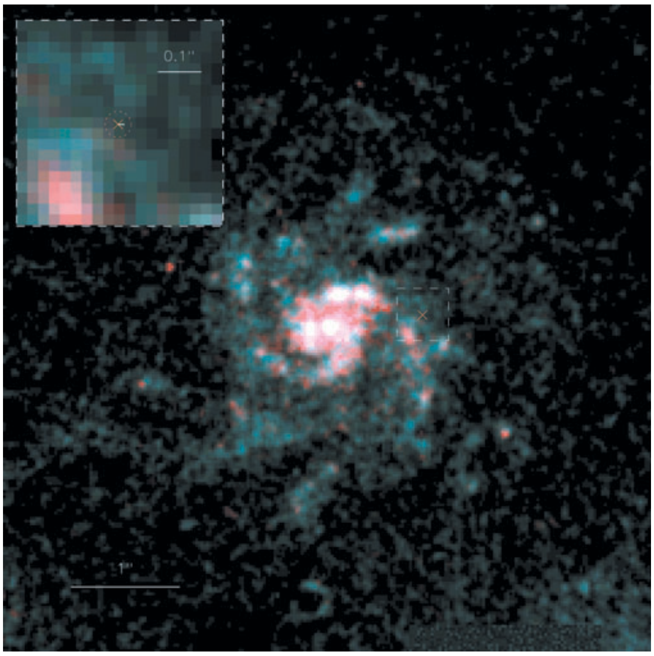

Figure 5: HST/STIS image of the host galaxy of GRB 990705. It is a grand-design spiral at a distance of 7.6 billion light-years. North is up and East is to the right. The location of the GRB is marked with a cross; the red circle gives the 3σ error on its position. Note that, due to the redshift, the image shows the rest-frame UV light emitted by the galaxy (Andersen et al. 2002).

For several host galaxies the star-formation rate has been determined. The emission lines in the VLT spectrum of the host galaxy of GRB 990712 (Fig. 2) are produced by H II regions in that galaxy. The strengths of these lines indicate an (extinction-corrected) star-formation rate of about 35 $M_\odot$ yr^{-1} (Vreeswijk et al. 2001). For some host galaxies even higher rates of star formation are claimed, up to 1000 $M_\odot$ yr^{-1} (e.g. Berger et al. 2001). These observations show that at least some of the GRB host galaxies belong to the class of *starburst* galaxies.

Thus, the observations of GRB host galaxies support the collapsar model. Since these galaxies, due to their distance, are often very faint, the bright GRB afterglow provides a unique opportunity to study the gas and dust content of the host galaxy. The metallicity and star-formation rate of these relatively young galaxies can be measured. As part of our host-galaxy programme, the spectral energy distribution (SED) of the host galaxy of GRB 000210 has been determined. Fitting the observed SED with a grid of synthetic templates, the age (0.2 Gyr) of the dominant stellar population and the galaxy's photometric redshift ($z = 0.84$) is determined (Gorosabel et al. 2002b). If the collapsar model is right, the GRB rate is a direct measure of the formation rate of massive stars in the early universe, an important quantity for the study of the star-formation rate as a function of redshift.

8. Remaining fundamental questions

Much progress has been made in understanding the GRB phenomenon. However, many fundamental questions remain to be addressed. What is the origin and nature of the short-duration bursts? Do they produce afterglows, like the long bursts? Are all GRBs associated with a supernova, and if so, why do we rarely observe it? Is this related to the difference in collimation of the γ-rays with respect to the optical light? Are GRBs preferentially found in galaxies undergoing a starburst?

The number of GRBs with optical counterparts roughly corresponds to the number of supernovae observed before 1934, when Baade and Zwicky suggested that supernovae might be powered by the gravitational collapse to a neutron star. The collapsar model, a massive star collapsing to a black hole, has now become widely accepted to explain GRBs. But, just as Baade and Zwicky failed to anticipate Type Ia supernovae, the collapsar model, even if correct, may be incomplete. A challenging future lies ahead.

We would like to acknowledge the support which our collaboration has received from the staff at several observatories.

References

Akerlof, C., Balsano, R., Berthelemy, S., et al. 1999, *Nature* **398**, 400.
Andersen, M.I., Hjorth, J., Pedersen, H., et al. 2000, *A&A* **364**, L54.
Andersen, M.I., Hjorth, J., Gorosabel, J., et al. 2002, *A&A*, submitted.
Berger, E., Kulkarni, S.R., Frail, D.A. 2001, *ApJ* **560**, 652.
Castro Cerón, J.M., Castro-Tirado, A.J., Gorosabel, J., et al. 2002, *A&A*, in press.
Costa, E., Frontera, F., Heise, J., et al. 1997, *Nature* **387**, 783.
Eichler, D., Livio, M., Piran, T., et al. 1989, *Nature* **340**, 126.
Fynbo, J.U., Jensen, B.L., Gorosabel, J., et al. 2001, *A&A* **369**, 373.
Frail, D.A., Kulkarni, S.R., Sari, R., et al. 2001, *ApJ* **562**, L55.
Galama, T.J., Vreeswijk, P.M., Van Paradijs, J., et al. 1998, *Nature* **395**, 670.
Gorosabel, J., et al. 2002a, *A&A* **384**, 11.
Gorosabel, J., et al. 2002b, in preparation.
Greiner, J., Klose, S., Zeh, A., et al. 2001, *GCN* **1166**.
Iwamoto, K., Mazzali, P.A., Nomoto, K., et al. 1998, *Nature* **395**, 672.
Lattimer, J.M., Schramm, D.N. 1974, *ApJ* **192**, L145.
Klebesadel, R.W., Strong, I.B., Olson, R.A. 1973, *ApJ* **182**, L85.
Kouveliotou, C., Meegan, C.A., Fishman, G.J., et al. 1993, *ApJ* **413**, L101.
MacFadyen, A.I., Woosley, S.E. 1999, *ApJ* **524**, 262.
Meegan, C.A., Fishman, G.J., Wilson, R.B., et al. 1992, *Nature* **355**, 143.
Metzger, M.R., Djorgovski, S.G., Kulkarni, S.R., et al. 1997, *Nature* **387**, 878.
Paciesas, W.S., Meegan, C.A., Pendleton, G.N., et al. 1999, *ApJS* **122**, 465.
Paczynski, B. 1998, *ApJ* **454**, L45.
Pedersen, H., et al. 2000, *The Messenger* **100**, p. 32.
Salamanca, I., et al. 2002, *GCN* **1443**.
Van Paradijs, J.A., Groot, P.J., Galama, T., et al. 1997, *Nature* **386**, 686.
Vreeswijk, P.M., Fruchter, A.S., Kaper, L., et al. 2001, *ApJ* **546**, 672.
Woosley, S.E. 1993, *ApJ* **405**, 273.

Cataclysmic Variables: Gladiators in the Arena

R.E. MENNICKENT[1], C. TAPPERT[1], M. DIAZ[2]

[1]Departamento de Física, Universidad de Concepción, Chile
[2]Instituto Astronomico e Geofisico, Universidade de São Paulo, Brazil

1. Warriors and weapons

Life can be different for individuals growing up alone or closely interacting with members of their community. The same is true for stars, which present interesting phenomena when they are forced to evolve together in close interaction. This is the case for cataclysmic variables (CVs, Fig. 1), consisting of a red dwarf filling its Roche lobe and transferring matter onto a white-dwarf (WD) companion. If the white dwarf is a non-magnetic one, the orbiting gas interacts with itself dissipating energy by viscous forces, forming a luminous accretion disc around the white dwarf. The WD reacts by emitting X-rays and UV radiation from the region where the inner disc reaches its surface. As a result, part of the red dwarf atmosphere is irradiated and mildly heated, and possibly the upper accretion disc layers evaporated. It has been suggested that after a long-time of having accreted matter, the outer layers of the white dwarf eventually undergo a thermonuclear runaway in a so-called nova explosion.

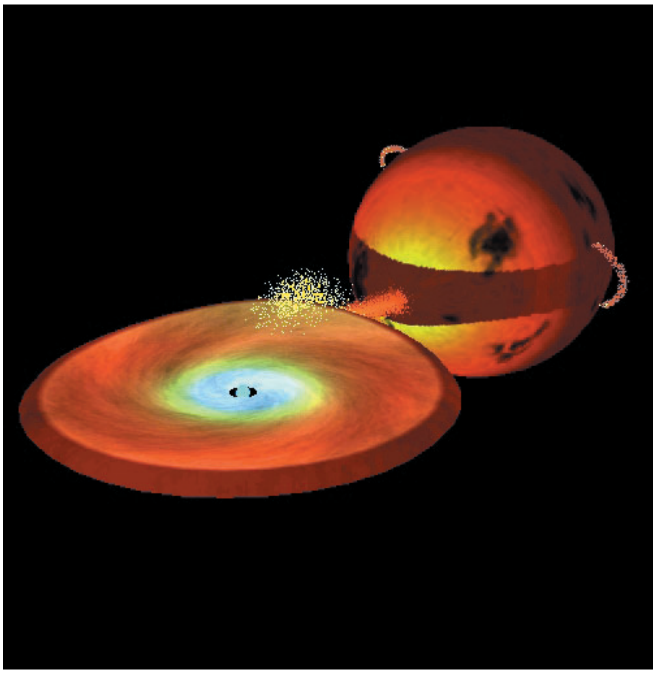

Figure 1: Computer-generated view of a cataclysmic variable star by Andrew Beardmore. The donor, usually a M-type star, transfers matter onto a white dwarf. Due to viscous forces, an accretion disc is formed. Colours represent different temperatures, from the higher (white) to the lower ones (red-black). Irradiation of the donor by the white dwarf and disc shading are also shown, as well as the hotspot in the region where the gas stream impacts the disc.

Here we present some results of our recent research in the area of dwarf novae, a subclass of cataclysmic variables showing semi-regular outbursts in time scales of days to years with typical amplitudes of 2–6 mags. The origin of these dwarf-nova outbursts is not a thermonuclear runaway as in the case of a nova outburst, but a sudden jump in disc viscosity and mass transfer rate as a result of the hydrogen ionization. In this article we do not go into deep details. Instead, we will illustrate the application of some standard techniques in the field of CVs aimed to explore disc dynamics and also to reveal the nature of the donor star. The latter point is especially important to constrain theories of CV evolution.

A typical spectrum of a dwarf nova in quiescence is shown in Figure 2. It is

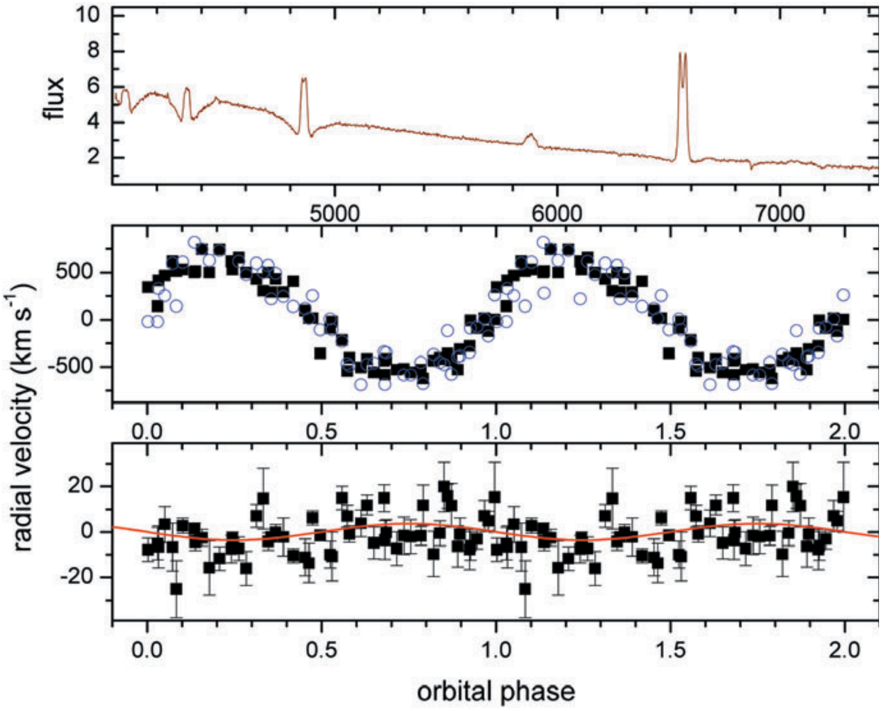

Figure 2: Upper panel: Spectrum of 1RXSJ105010.3-140431, a cataclysmic variable with a low mass accretion rate (Mennickent et al. 2001). The double emission lines in the Balmer series are formed in the accretion disc and hotspot. The flux is given in units of 10^{-16} erg s^{-1} cm^{-2} Å^{-1}, the horizontal units are in Å. Middle panel: The Hβ (squares) and Hγ (circles) hotspot velocity folded with the ephemeris given by Mennickent et al. (2001). Bottom panel: The Hγ absorption line velocity (squares) obtained by cross correlation and the best sine fit. Note the different amplitude for the emission and absorption components.

characterized by H I and He I emission lines. Flanking the strong Balmer emission lines we observe the gravity broadened absorption profiles typical of a white dwarf. The Hα emission is double peaked, reflecting an origin in a rotating disc, with an equivalent width of –110 Å and half peak separation 560 km s^{-1}, whereas their full width at zero intensity is 2950 km s^{-1}. These velocities are typical for dwarf nova accretion discs and reflect the rotation of the outer and inner disc regions, respectively. The steep emission decrement suggests an origin in an optically thin accretion disc. The fact that we can observe the WD in this system suggests that the disc has a low luminosity, which should be related to a low-mass accretion rate. There is evidence that radial velocities (RVs) of the emission lines in CVs do not reflect the orbital motion too well, so most of the mass determinations for short orbital period dwarf novae available in the literature could be heavily biased. Therefore, the possibility of measuring the WD absorption RVs is very interesting, since it could be the only source of reliable stellar masses for these systems. As an example, we show in Figure 2 the radial velocities for the emission and absorption components of 1RXSJ105010.3-140431. It is clear that, whereas the emission RV reflects the large amplitude motion of the hotspot around the centre of mass, the white dwarf RVs have almost zero amplitude. This result has been interpreted as evidence for an undermassive donor star, likely in the realm of brown dwarf stars (Mennickent et al. 2001). Figure 2 also illustrates that high resolution spectrography is needed to measure the subtle motion of a white dwarf gravitationally linked to an undermassive secondary star. According to the standard CV evolution scenario (see below), we should expect many short orbital period CVs hosting brown-dwarf like secondaries. We are currently conducting a project aimed to determine the secondary mass of a sample of short orbital period CVs showing white dwarf absorptions. We will obtain radial velocities using cross-correlation in high-resolution UVES spectra.

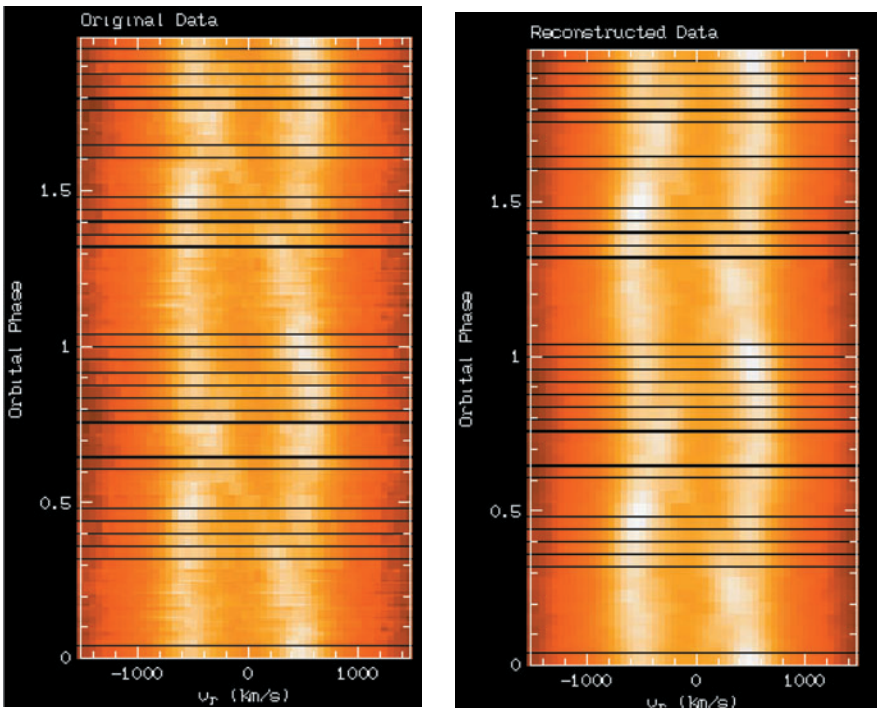

Figure 3: Left: Hα trailed spectra of the cataclysmic variable VW Hyi. The sinusoids followed by the double emission peaks reflect the orbital motion of the disc around the binary centre of mass. The s-wave indicates the presence of an additional emission component in the system. Right: Reconstructed data from the Doppler map of Figure 4.

2. Imaging the invisible arena

In CVs, accretion onto a white dwarf releases a considerable amount of energy. This makes the accretion discs luminous, and visible at large astronomical distances, and they can be studied in some detail. CVs are ideal laboratories to study accretion-related phenomena, since their binarity and the time scales involved (much shorter than in other astronomical objects), make it possible to obtain insights into the accretion processes that drive some of the most energetic objects in the Universe.

The angular diameter of a typical CV accretion disc as seen from Earth is of the order of 10^{-4} arcseconds, too small to be resolved from Earth even with modern interferometers. It is possible however, to use indirect imaging techniques to image the accretion disc and the processes taking place in the CV.

The technique of Doppler tomography was introduced by Marsh & Horne (1988) to the realm of interacting binaries. A nice analogy useful to understand Doppler imaging as applied in CVs comes from the field of medical diagnostics. In computer tomography, a 3-D image is reconstructed from 2-D slices obtained at different angular positions around the body. In astronomy, we cannot move the telescope around the CV, but the spinning binary does the job for us. We simply take spectra of the system at several binary phases, and then combine them in a 2-D image of the emitting region in velocity space. This can be done since optically thin accretion discs are strong line emitters, and the emission line contains information on disc emissivity projected into the line of sight. Doppler maps can be obtained for different spectral lines, yielding useful probes for the physical conditions inside the accretion disc. Doppler tomography has been successfully applied to a large number of CVs (e.g. Kaitchuck et al., 1994), and now is widely used in the area of CVs, Algols, X-ray binaries and isolated rotating stars (see a recent review in Marsh 2001). As a reminder, we list the facts regarding the interpretation of the resulting maps:

• The coordinates of the white dwarf in the map are $(v_x, v_y) = (0, -K_1)$, those of the secondary $(0, -K_2)$, with K_1 and K_2 being the respective semi-amplitudes of the radial velocity curves.

• The velocity image of the accretion disc is inverted with respect to the spatial one, as the material near the primary has high rotational velocities, and material at the outer parts of the disc rotates with lower velocities.

• A transformation of the resulting map into a spatial coordinate system is only possible if the valid velocity law is known. This is not necessarily always the case, since also emission from non-Keplerian sources is possible.

In this work, the implementation of Spruit (astro-ph/9806141) has been used to perform the Doppler tomography. We have replaced the original IDL routines by a corresponding MIDAS interface, but still use the FORTRAN core program (version 2.3.1), to run the computation on a Linux PC.

We show in Figure 3 the Hα trailed spectra of the cataclysmic variable VW Hyi. This is a rather bright southern SU UMa star with a large photometric database. However, the spectroscopic record is rather poor. The outburst recurrence time is about 27 d. We obtained 44 spectra with the EMMI spectrograph mounted at the ESO 3.5-m NTT at La Silla Observatory, on August 29, 1998. The spectra had a wavelength range of 4475–7040 Å and a spectral resolution of 2.5 Å. The sinusoids traced by the Hα double emission peaks reflect the orbital motion of the disc around the binary centre of mass. The s-wave indicates the presence of an additional emission component in the system. In Figure 4 we show the

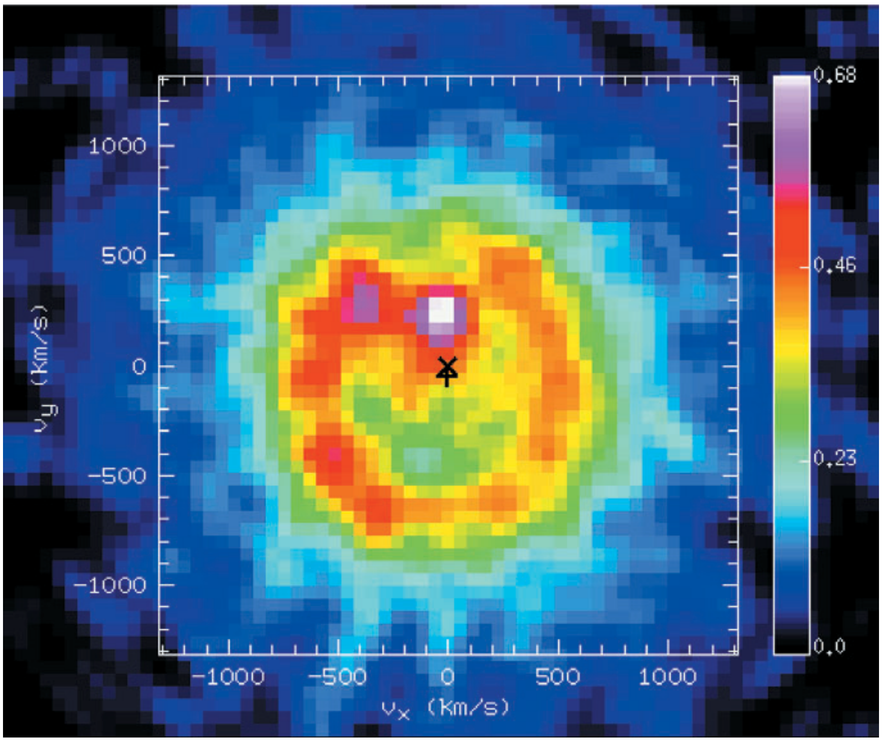

Figure 4: Doppler map of VW Hyi obtained from the data shown in Figure 3. The cross and the plus signs indicate the position of the white dwarf and the system centre of mass, respectively. The accretion disc is revealed in the donut-shaped emissivity region. The central bright spot in the upper region represents emission from the secondary star. The hotspot is also revealed in the upper left quadrant, as well as the gas stream connecting the donor and the hotspot.

Doppler map of VW Hyi obtained from the data shown in Figure 3. The accretion disc is revealed in the donut-shaped emissivity region. The central bright spot in the upper region represents emission from the secondary star. The hotspot is detected as the second maximum in the upper left quadrant, as well as the gas stream connecting the donor and the hotspot. This is one of the few maps showing emission from all of these four components. We must keep in mind, however, that these emissions are highly variable, and different components may be visible at different times, depending on the luminosity state of the CV.

Figure 5 shows the Doppler map of another cataclysmic variable star of the dwarf nova type, RZ Leo, which is characterized by a relatively long recurrence time and short orbital period. The data presented here have been discussed by Mennickent & Tappert (2001) in the context of a search for the orbital period, but they did not construct Doppler maps from these data. Contrary to that seen in VW Hyi, the map reveals the existence of two isolated emission maxima on roughly opposite sides of the disc. The feature in the $(-v_x, \pm v_y)$ quadrant is the more dominant one and could be related to the classical hotspot. Up to now, no convincing theory can explain isolated emission-line sources like the one observed in the $(+v_x, +v_y)$ quadrant of RZ Leo, although emission in this quadrant has been observed in roughly 32% of the CVs (Tappert & Hanuschik 2001).

Doppler imaging is already well established, but it has an even more promising future in CV research. The method is being improved in several ways. Steeghs (2001) describes a modification which allows orbital variability to be included in Doppler reconstructions. Bobinger et al. (1999) describe a method to simultaneously fit spectra and light-curves of emission lines. Skidmore et al. (2000) introduced the method of ratio maps between reconstructions obtained at different wavelengths. Using this method, Mennickent et al. (2001) determined a steady-state ($T \sim r^{-3/4}$) accretion disk mainly emitting in Hα and an optically thicker hotspot with a strong contribution to the higher-order Balmer lines and He I 5875 in 1RXSJ105010.3-140431.

3. Looking for signatures of the red warrior

The determination of the secondary mass in CVs is the key to understanding the secular evolution of these objects. Cataclysmic variables are found with orbital periods between 78 minutes and 10 hours, with an abrupt drop in the number of systems in the range 2–3 hours, the so-called "period gap". Current theories state that the process of mass transfer becomes linked with the loss of orbital momentum, so the bi-

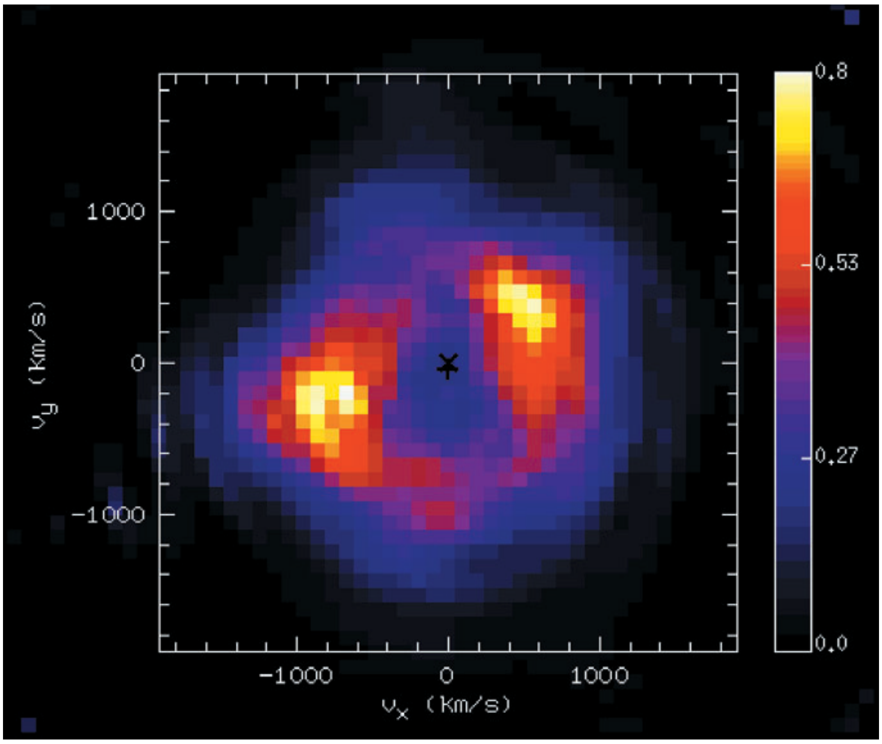

Figure 5: Doppler map of RZ Leo. The spot on the left side could be associated with the disc-stream interacting region.

nary spins faster whereas the secondary becomes less and less massive, eventually being eroded by the process, resulting in a kind of brown dwarf star when the orbital period approaches 80 minutes (e.g. Howell et al. 2001), which is consistent with our finding for 1RXSJ105010.3-140431 (see above). While above the gap CV evolution is likely driven by loss of angular momentum due to magnetic-braking (MB), below the gap the responsible mechanism is thought to be gravitational radiation (GR). Since the efficiency for removing angular momentum by GR is much smaller than for MB, a pile-up of systems is expected below the orbital period gap. Some of them should be systems with normal secondary stars approaching the orbital period minimum at 80 minutes, others should be systems which have "bounced" near P_{min} and now are receding towards the longer period area. These systems should have degenerated secondaries. The period gap is understood as an interruption of the mass transfer rate when the secondary becomes detached from its Roche-lobe, probably due to the onset of convection at $M_2 \sim 0.3\ M_\odot$.

At present, four methods have been used to search for undermassive secondary stars in cataclysmic variable stars: (1) analysis of the spectral energy distribution using multi-wave-band observations through the ultraviolet, optical, and infrared spectral regions (Ciardi et al. 1998; Mason 2001), (2) looking for signatures of the secondary star (Steeghs et al. 2001, Littlefair et al. 2000, Dhillon & Marsh 1995), (3) "weighting" the secondary star, possible in systems which develop an elliptical accretion disc during certain luminosity states (e.g., Patterson 2001), and (4) by spectroscopic diagnostic of the stellar masses in systems where the white dwarf is revealed through its optical absorption wings (Mennickent et al. 2001).

While the IR spectra of bright CVs have been measured and modelled in the past years, there are only a few spectrophotometric observations of low-luminosity systems in J, H and K band. In order to investigate the relatively unexplored infrared region of short period CVs, we have initiated a programme with ISAAC aimed to find evidence for undermassive secondary stars.

VY Aqr is a cataclysmic variable showing one of the largest outburst amplitudes among dwarf novae (Downes et al. 2001). Accordingly to current models for dwarf nova outburst (Osaki 1996), this is consistent with a very low mass transfer rate system. Spectroscopic studies in the optical region have revealed the orbital period (0.06309(4) d, Thorstensen 1997), but not the stellar masses, likely due to the distorted nature of the emission-line radial velocities (e.g. Augusteijn 1994). J-band spectroscopy by Littlefair et al. (2000) revealed spectral features of the secondary star, but too weak to make an estimate of the spectral type. According to the current CV evolution scenario (e.g. Howell et al. 2001), the orbital period and the low mass transfer rate of VY Aqr should suggest a system beyond the orbital period minimum, probably containing an undermassive secondary star. This has also been supported by the application of Method 3 (Patterson 2001). We have found direct evidence for this scenario, based on the unambiguous detection of the secondary star in the spectrum of VY Aqr (Mennickent & Diaz 2002).

The ISAAC infrared spectrum of VY Aqr shown in Figure 6 reveals Bracket and Paschen emission lines. We also observe the K I doublets at 1.169-1.177 and 1.244-1.253 and the Na I line at 1.141, which are signatures of a cool secondary star, confirming previous indications found by Littlefair et al. (2000).

When fitting the spectral energy distribution (SED) we observed that spectral types earlier than M7 fail to reproduce the depth of K I lines in the J band and the continuum in the K band. On the other hand, spectral types later than L3 do not fit well the H and K band continuum shape. These cool types present a well-defined CO band head at 2.29 μm which is not seen in our data. Our fit with a M9.5 type secondary plus power-law continuum is slightly better than that for M7 and L3 type templates, giving a χ^2 parameter about 15% lower. If such a spectral contribution is in fact due to the emission of the secondary star in the system one may estimate its temperature. Using the effective temperatures for L type dwarfs derived by Leggett et al. (2001) using structural models, we find $T_2 = 2300 \pm 100\ K$ for the secondary star in VY Aqr. The best fit with a M9.5 companion is shown for illustration in Figure 7. Representative fits using types between M7 and L3 indicate that the secondary star may contribute with 45% to 55% to the flux at 2.17 μm, depending on the spectral type. Later types yield better fits for smaller flux fractions. Using the distance values for our templates from M7 to L2 (LHS3003 and LHS429 by van Altena et al. 1995 and Kelu-1 from Dahn et al. 2000) and the flux fractions derived from the spectral fitting we were able to derive a distance estimate for the system between 80 and 120 pc, with a most likely value of 100 ± 10 pc. The spectroscopic parallax given above is in agreement with the distance of 110 pc found by Augusteijn (1994) using the average absolute magnitude value for dwarf novae in outburst.

We have applied the method outlined above to a sample of cataclysmic variables which are candidates to host brown-dwarf like secondaries (Mennickent & Diaz, 2002). The SED fitting for RZ Leo and CU Vel suggests M5 type dwarf companions, and distances of 340 ± 110 and 150 ± 50 pc, respectively. We find no evidence of a secondary star in the IR spectra of WZ Sge and 1RXSJ105010.3-140431. The infrared SED in these objects is dominated by the accretion disc, and it can be well modelled by a simple power-law continuum.

Figure 8 shows a comparison of the $T_{eff} - P_{orb}$ CV evolutionary tracks near the orbital period minimum with our data and some additional data taken from the literature. From this figure we conclude the following: (1) HV Vir, WZ Sge, EF Eri, WX Cet, LL And and SW UMa seem to be post-orbital period minimum systems. (2) It is difficult to reconcile the positions of VY Aqr in the diagram with the code's predictions. (3) In the same context, RZ Leo and CU Vel should be evolving toward the orbital period minimum.

The fact that the predicted density of short orbital period CVs is at least a factor 10 higher than observed (e.g. Patterson 1998) and that the observed orbital period minimum is slightly, but significantly longer than the theoretical one, has motivated the entrance of two new theoretical models. Both explain the absence of the spike at P_{min} as an age effect, i.e. that CVs have not yet evolved down to P_{min}. While Taam & Spruit (2001) invoke a circumbinary disc as braking mechanism for the evolutionary process, King & Schenker (2002) propose a reduced duration of the CE phase, leading to a much longer lifetime of the pre-CV state. This approach additionally solves the space density problem. In this picture, most systems around the orbital period minimum in Figure 8 could be systems born with this mass-period configuration, not the remnants of the evolution of longer-period systems born with more massive secondaries.

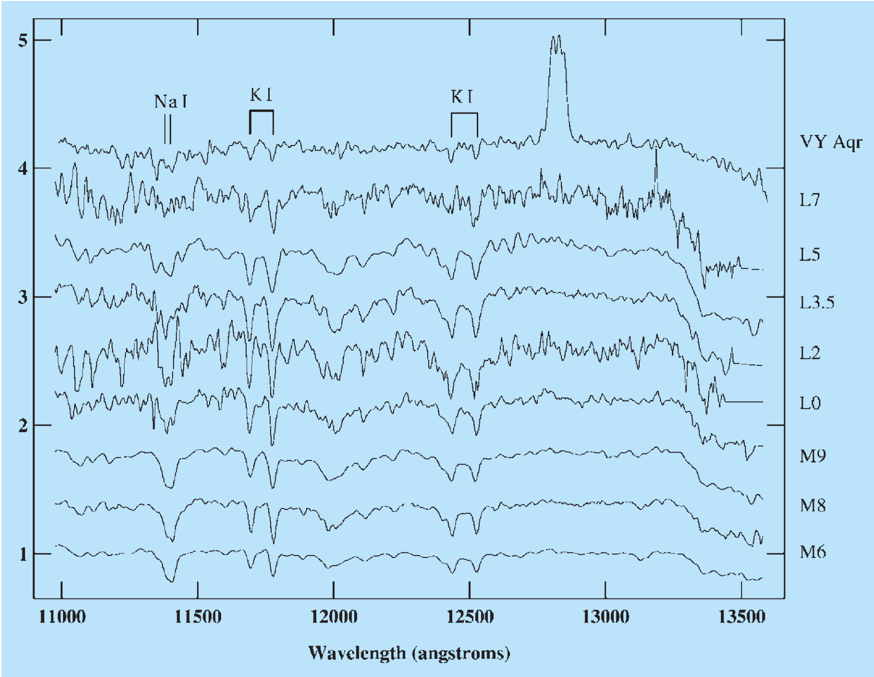

Figure 6: Comparison of the normalized spectrum of VY Aqr with late-type templates.

The results from the application of the spectral fitting procedure described above suggests that the infrared continuum shape in short-period cataclysmic variables may be a useful indicator of the companion spectral type. This point is especially important if we consider that, due to the limitation imposed by the spectrum S/N in such faint systems, it is not always possible to detect the individual lines of the secondary star, but nevertheless to determine the shape of its continuum. Also, the method has the advantage of avoiding the uncertainties associated with non-simultaneous multi-wavelength observations, although their predictive power clearly is inferior to the ideal case of modelling of simultaneous multi-waveband observations. We are currently analyzing ISAAC data of a larger sample of CVs which are candidates for harbouring brown dwarf like secondaries in order to provide constraints on the proposed evolutionary models.

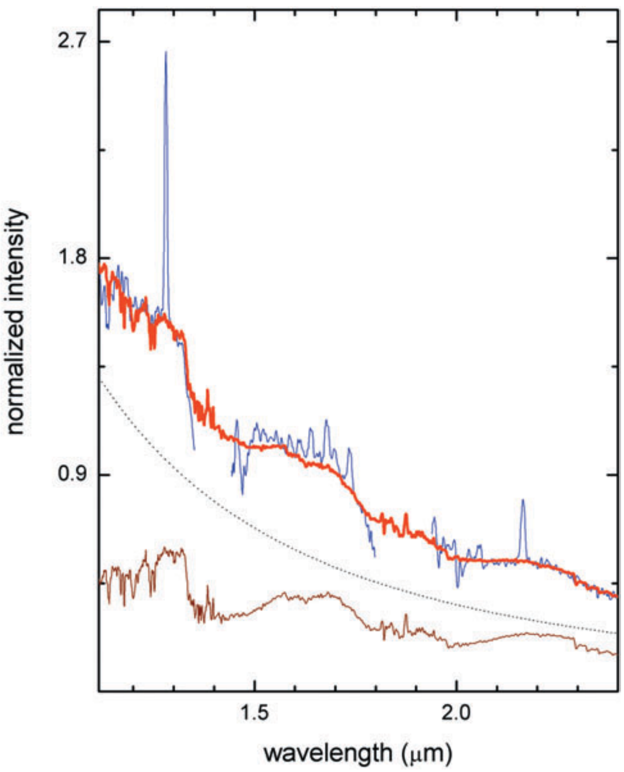

Figure 7: ISAAC spectrum of VY Aqr and the best composite SED fit (red line). The individual M 9.5 type template spectrum and power law continuum are shown. The spectra are normalized to 29.7 × 10^{-17} erg cm^{-2} s^{-1} Å^{-1}.

Acknowledgements

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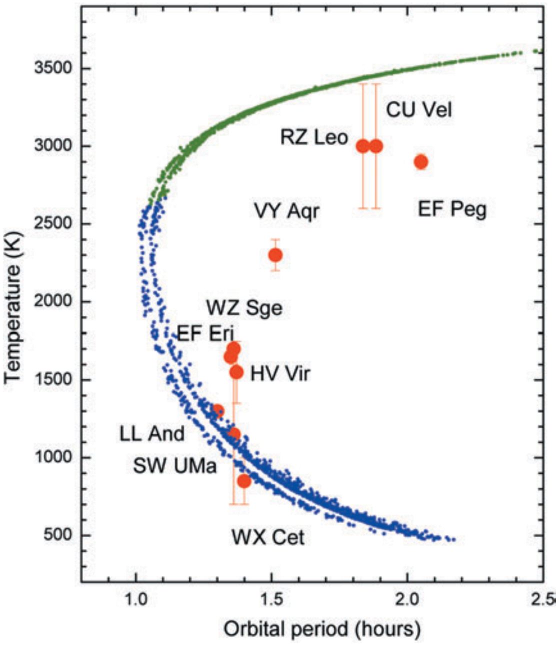
References

Allen 2000, *Allens Astrophysical Quantities*, Arthur N. Cox (ed), AIP Press, Springer.
Augusteijn, T., 1994, *A&A* **292**, 481.
Bobinger, A. et al., 1999, *A&A* **348**, 145.
Ciardi, D.R., Howell, S.B., Hauschildt, P.H., & Allard, F., 1998, *ApJ* **504**, 450.
Dahn, C. et al., 2000, Giant Planets to Cool Stars, ASP Conf. Ser. C. Griffith and M. Marley eds.
Dhillon, V.S., Littlefair, S.P., Howell, S.B., Ciardi, D.R., Harrop-Allin, M.K., & Marsh, T.R., 2000, *MNRAS* **314**, 826.
Dhillon, V.S., Marsh, T.R., 1995, *MNRAS* **275**, 89.
Downes, R.A., Webbink, R.F., Shara, M.M., et al.,2001 astro-ph/0102302 (see also http://icarus.stsci.edu/ downes/cvcat
Howell, S.B., Nelson, L.A., & Rappaport, S., 2001, *ApJ* **550**, 897.
Howell, S.B., Ciardi, D.R., 2001, *ApJ* 550, L57.
Ishioka, R.et al. 2001, *PASJ* **53**, 905.
Kaitchuck, R.H., Schlegel, E.M., Honeycutt, R.K., et al., 1994, *ApJS* **93**, 519.
King, A.R., Schenker, K., 2002, in *The Physics of Cataclysmic Variables and Related Objects*, Gansicke et al. eds. ASP Conf. Ser., Vol. **261**, p. 233.

Figure 8: Cataclysmic variables close to the orbital period minimum. Observations are compared with results of the CV population synthesis code by Howell et al. (2001). Normal and degenerate stars are represented by green and blue dots respectively. The evolution of a particular system is from longer periods to shorter periods, eventually passing by the minimum around 80 minutes. We have used spectral type – temperature calibrations based on data of M-L dwarfs by Leggett et. al. (2000, 2001). Data for LL And and EF Eri are from Howell & Ciardi (2001), for WX Cet, EF Peg and SW UMa from Mason (2001) and for WZ Sge (a temperature upper limit) from Ciardi et al. (1998). All others are from Mennickent & Diaz (2002).



Leggett, S.K., Allard, F., Dahn, C., Hauschildt, P.H., Kerr, T.H., & Ryner, J. 2000, *ApJ* **535**, 965.
Leggett, S.K., Allard, F., Geballe, T.R., Hauschildt, P.H., & Schweitzer, A. 2001, *ApJ* **548**, 908.
Littlefair, S.P., Dhillon, V.S., Howell, S.B., & Ciardi, D.R., 2000, *MNRAS*, **313**, 117.
Marsh, T.R., 2001, in "Astrotomography", *Lect. Notes on Phys*. **573**, Eds. H.M.J. Boffin, D. Steeghs and J. Cuypers, Springer, p. 1.
Marsh, T.R., Home, K., 1988, *MNRAS* **235**, 269.
Mason, E., 2001, PhD thesis, Department of Physics & Astronomy, University of Wyoming.
Mennickent, R.E., & Diaz, M., 2002, *MNRAS*, in press (astro-ph/0206343).
Mennickent, R.E., Tappert, C., 2001, *A&A* **372**, 563.
Mennickent, R.E., Diaz, M., Skidmore, W., Sterken, C., 2001, *A&A*, **376**, 448.
Osaki, Y., 1996, *PASP*, **108**, 39.
Patterson, J., 1998, *PASP*, **110**, 1132.
Patterson, J., 2001, ***PASP***, 113, 736.
Skidmore, W., Mason, E., Howell, S.B., Ciardi, D.R., Littlefair, S., & Dhillon, V.S., 2000, *MNRAS*, **318**, 429.
Steeghs, D., Marsh, T., Knigge, C., Maxted, P.F.L., Kuulkers, E., & Skidmore, W., 2001, *ApJ*, **562**L, 145.
Steeghs, D., 2001, in "Astrotomography", *Lect. Notes on Phys*. **573**, Eds. H.M.J. Boffin, D. Steeghs and J. Cuypers, Springer, p. 45.
Taam, R.E., Spruit, H.C., 2001, *ApJ* **561**, 329.
Tappert, C., Hanuschik, R.W., 2001, in "Astrotomography", *Lect. Notes on Phys.* **573**, Eds. H.M.J. Boffin, D. Steeghs and J. Cuypers, Springer, p. 119.
Thorstensen, J.R., & Taylor, C.J., 1997, *PASP*, **109**, 1359.
van Altena, W.F., Lee, J.T., & Hoffleit, E.D., 1994, The General Catalogue of Trigonometric Parallaxes (New Haven: Yale University Observatory).

Reproduction of a colour-composite image of the nearby spiral galaxy NGC 300, obtained in 1999 and 2000 with the Wide-Field Imager on the MPG/ESO 2.2-m telescope at the La Silla Observatory. For more details see http://www.eso.org/outreach/press-rel/pr-2002/phot-18-02.html

Supernova Polarimetry with the VLT: Lessons from Asymmetry

L. WANG[1], D. BAADE[2], P. HÖFLICH[3], J.C. WHEELER[3]

[1]Lawrence Berkeley National Laboratory, California, USA
[2]European Southern Observatory, Garching, Germany
[3]Department of Astronomy and McDonald Observatory, The University of Texas at Austin, Austin, USA

1. Introduction

Picture a 55-year-old telescope of modest two-metre aperture and the need to take multiple spectral exposures of the same object to elicit any signal from the noise with an inexpensive spectrograph jury rigged to do polarimetry, an effort requiring integrations on a single object lasting a whole long winter night with a single observer and no night assistant, if any transient target is available during the scheduled time. Contrast that with ordering up queue-scheduled target-of-opportunity observations by a dedicated professional staff on an 8 metre telescope with a state-of-the-art spectrograph and polarimeter. That is the leap that has occurred in our programme to obtain spectropolarimetry of all accessible supernovae. The spectropolarimetry obtained in a brief exposure on the VLT with the FORS1 spectrograph is comparable to the total flux spectrum obtained on those long nights on the 2.1-m Struve Telescope at McDonald Observatory where this programme began. While the data obtained at McDonald pointed the way to a revolution in the way we think about supernovae, it is the quality of the data from the VLT that has led the programme to flourish.

Supernovae have been studied with modern scientific methods for nearly a century. During this time, it has been traditional to assume that these catastrophic stellar explosions are, for all practical purposes, spherically symmetric. There were observational reasons for this. The Sun is essentially spherically symmetric and most stars are thought to be. The assumption that stars are round is quite reasonable. Self-gravity will tend to pull any large body into a sphere which is the minimum-energy configuration. There were also practical reasons. Theoretical study of stellar explosions has been difficult enough even with the assumption of spherical symmetry. There has been no commanding observational need to abandon that simplifying assumption. Now there is.

The evidence that supernovae may depart a little or even drastically from spherical symmetry has been growing for years. Neutron stars were predicted to form and to power supernovae by Fritz Zwicky shortly after the discovery of the neutron in 1932. When the first neutron stars were discovered by Jocelyn Bell they were manifested as rapidly rotating pulsars with intense magnetic fields. Pulsars have space velocities that average several hundred kilometres per second. This indicates that they are somehow "kicked" at birth in a manner that requires a departure from both spherical and up/down symmetry. More recently, NTT and then Hubble Space Telescope images of Supernova 1987A in the Large Magellanic Cloud showed rings of gas that had been ejected by the progenitor star before it exploded. This means either the progenitor star or its surroundings possessed some sort of asymmetry. Further observations showed that the debris of the explosion were also asymmetric. The supernova remnant Cassiopeia A shows signs of a jet and counterjet that have punched holes in the expanding shell of debris and there are numerous other asymmetric supernova remnants. Each of these things has been known. The question has been: are they merely incidental or a vital clue to how supernovae work?

The previous discussion pertained to core-collapse supernovae. These come in a variety of spectral classifications, Type II, Type Ib or Type Ic, depending on whether there is abundant hydrogen, helium or neither in the outer layers. There is another kind of supernova known as Type Ia. These are thought to be the result of the thermonuclear explosion of a white-dwarf star composed of carbon and oxygen. When the mass of the white dwarf closely approaches the Chandrasekhar limit of about 1.4 solar masses, the carbon ignites. The resulting thermonuclear explosion is thought to completely disrupt the star, leaving no compact remnant. This sort of explosion has received prominence recently because they have been the tool to discover the accelerating Universe and the dark energy that drives the expansion. The progenitor white dwarf has long been treated as basically spherically symmetric even though the popular model is that the explosion must take place in a binary system where the white dwarf grows to the critical mass by accretion of mass and, inevitably, angular momentum. There could be asymmetries in this sort of supernova resulting from the spin of the white dwarf, the motion of the orbit, a surrounding accretion disk, or the presence of the companion star. As for the case of core-collapse supernovae, this was known, but there was no compelling observational reason to consider departures from spherical symmetry. This, too, is changing.

2. Polarization of Supernovae

The question of the shape of supernovae has undergone a revolution in the last decade. The driving force has been a new type of observation: measurement of the polarization of the light from supernovae.

Light consists of oscillating electric and magnetic fields. An ordinary beam of light is a mix of photons with all orientations equally present, a state that leaves the light unpolarized on average. Some processes of producing or scattering light favour certain orientations of the electric and magnetic fields over others. One such process is the reflection of light. When light scatters through the expanding debris of a supernova, it retains information about the orientation of the scattering layers. If the supernova is spherically symmetric, all orientations will be present equally and will average out, so there will be no net polarization. If, however, the gas shell is not round, a slight net polarization will be imprinted on the light.

Since we cannot spatially resolve the average extragalactic supernova, polarization is the most powerful tool we have to judge the shape of the ejecta. The method used is called spectropolarimetry. This technique both spreads the light out into its spectrum of colours and determines the net orientation of the electric field at each wavelength. This way both the overall shape of the emitting region and the shape of regions composed of particular chemical elements can be determined. We note that the effective spatial resolution attained by polarimetry of a supernova of radius 10^{15} cm at 10 Mpc is 10 microarcsec. This is a factor of 100 better resolution than VLTI or other comparable optical interferometer installations – and at a tiny fraction of the cost.

There were systematic and stimulating observations of the polarization of the light of SN 1987A that are still being studied and interpreted. Another event that was modestly well studied was the hydrogen-depleted event SN 1993J in M81. These two events just illustrated how poor the overall data base of supernova spectropolarimetry was. In 1994 we began a programme to obtain spectropolarimetry of as many supernovae as possible that were visible from McDonald Observatory. At the time, only a handful of events had been examined at all and there were virtually no statistics. The data reduction was tricky, if only because the intervening interstellar medium can impose a polarization signal that has nothing to do with the supernova.

The data were also difficult to interpret. There are, in principle, many reasons why the light from a supernova could be polarized. The supernova could be aspherical, it could be spherical but have off-centre sources of light, or other matter in the vicinity could be asymmetrically distributed, blocking part of the scattering surface and yielding a net polarization signal from even a spherical surface. To make matters worse, the first few supernovae our group studied (and those in the previous sparse record like SN 1987A and SN 1993J) were classified as "peculiar" in some way, so we did not know whether we were seeing incidental peculiarities or something truly significant.

As data accumulated, however, this uncertainty was removed, and significant new insights were revealed. With more data and better statistics, we identified the first key trend. In 1996, we realized that the data were bi-modal. Type Ia supernovae showed little or no polarization signal (we will talk about some significant exceptions below). Supernovae thought to arise by core collapse in massive stars – Types II, Ib, and Ic – were, by contrast, all significantly polarized. So far there has been no exception. Every core-collapse supernova for which we or other groups have obtained adequate data has been substantially polarized. Core-collapse supernovae are definitely not spherically symmetric. The question is, why? As data continued to mount, new trends appeared that give critical clues to address that question.

Normal Type II supernovae explode in red-giant stars that retain large, massive outer envelopes of hydrogen. Types Ib and Ic are thought to happen in stars that have already shed much or all of their outer hydrogen layers, so they allow us to see deeper into the heart of the exploding star. We noticed that the Type II supernovae, with their large blankets of hydrogen, showed relatively less polarization. The Type Ib and Ic that allowed us to peer deeper into the exploding matter had higher polarization. In addition, as a given supernova expands, the debris thins out and allows us a view deeper inside. We found that even in a Type II supernova, the longer we watched and the deeper inside we could see, the larger the polarization became. This was illustrated by our VLT observations of the classic Type II supernova, SN 1999em, that was characterized by an especially long plateau, suggesting an especially massive outer hydrogen envelope. Observations were obtained around optical maximum and about 2 months past optical maximum. The polarization rose from 0.1 per cent in the early observations to about 1 per cent in the later data. Figure 1 shows the data for SN 1999em on a "Q-U" plot where Q and U represent different projections of the polarization vector. The striking feature of the SN 1999em data presented in this way is that all the data points fall on a single line. This suggests a well-defined symmetry axis throughout the ejecta and independent of wavelength. The explosion of SN 1999em is asymmetric, but aligned in a significant way. Figure 2 shows data from another Type II event, SN 2001dh, that also shows this tendency to follow a fixed orientation in space.

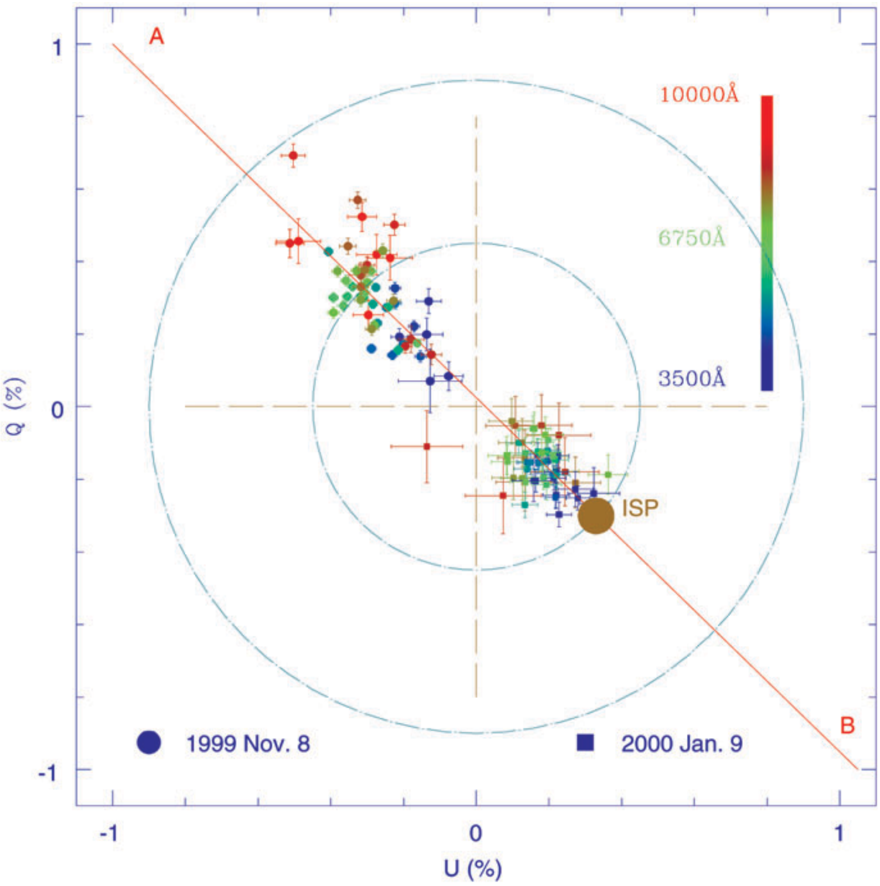


Figure 1: Polarimetry of the Type II SN 1999em on the Q-U plane. The wavelength of different data points are colour encoded. The data points are rebinned to 100 Å for clarity. The 1999 Nov 8 data (clustered in the lower-right quadrant) are clearly separated from the 2000 Jan. 9 data (clustered in the upper-right quadrant), suggesting strong polarization evolution. The data points of both epochs fall roughly on the line denoted AB. Line AB defines the axis of symmetry if the object is axially symmetric. Note that the blue and red dots are well separated for each epoch with the blue points preferentially located at the lower-right of the data cluster of each observations. The circles are the upper limits to the interstellar polarization assuming E(B-V) toward the supernova to be 0.05 (inner circle) and 0.1 (outer circle). The approximate location of the component due to interstellar dust is shown as a solid circle.

These observations of core-collapse supernovae taken together tell us that the closer we see to the centre, the larger is the asymmetry. The asymmetry is not some incidental aspect of the progenitor's surrounding environment that is causing the polarization, but something deep in the heart of the explosion. The implication is that the explosion mechanism itself is asymmetric.

3. The Cause of Asymmetry in Core Collapse

The fact that the asymmetry of many core-collapse supernovae is aligned in one direction provides an important clue to the engine of the explosion. The explosion mechanism must impose some axial symmetry. There must be some sustained bi-polar influence because otherwise, as the supernova expands, pressure gradients will tend to heal irregularities and the ejecta will tend to become more spherical rather

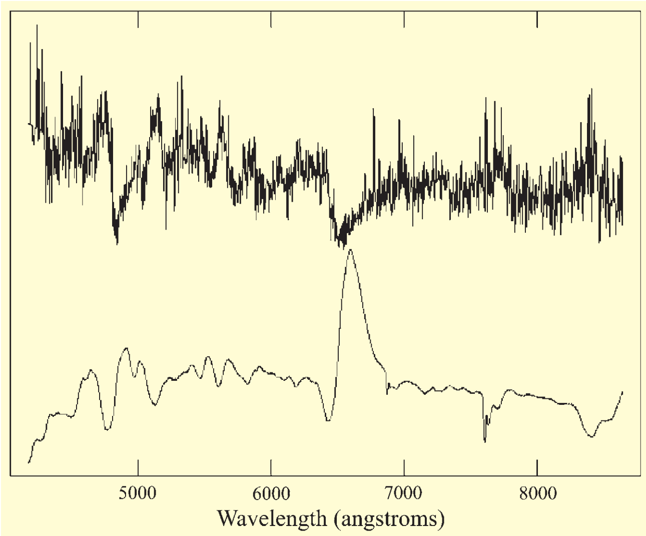


Figure 2: A total flux spectrum (bottom) and polarization spectrum (top) of the Type II SN 2001dh, obtained on August 8, 2001 with the VLT. In the top panel the locations of the prominent lines of hydrogen and other elements can be identified by the emission peaks at these wavelengths. To the short wavelength side of the emission peaks are Doppler blue-shifted absorption troughs corresponding to absorption in the expanding atmosphere of the supernova. The average polarization at the epoch of these data (a week or so after discovery) was about 1 to 2 per cent. The peaks and troughs in the polarization spectrum prove that the polarization comes from the supernova, not the intervening interstellar matter. Some of the features correspond to those in the total flux spectrum, but others correspond to features that are only clearly revealed by the polarization.

than less. To do what we see, the mechanism that drives the supernova must produce energy and momentum asymmetrically from the start, then hold that special orientation long enough for its imprint to be permanently frozen into the expanding matter. Appropriate outflows might be caused by MHD jets, by accretion flow around the central neutron star, by asymmetric neutrino emission, or by some combination of those mechanisms.

The light we see from a supernova comes substantially from the decay of short-lived radioactive elements, nickel-56, cobalt-56 and later titanium-44 in the debris. If this material is ejected in a bi-polar fashion, then the overall debris shell could be nearly spherical, while the asymmetric source of illumination leads to a net polarization. This mechanism may be at work in the early phases of Type II supernovae such as SN 1999em and SN 2001dh.

By injecting jets of mass and energy up and down along a common axis deep within a model of an evolved star, we have shown that typical asymmetric configurations emerge. As shown in Figure 3, bow shocks form at the heads of the jets as they plow through the core, and a significant portion of the star's matter bursts through the core along the jet axis. The bow shocks also drive "transverse" shocks sideways through the star. These shocks proceed away from the axis, converge toward the star's equator, and collide in the equatorial plane. From there, matter is compressed and ejected in an equatorial torus perpendicular to the jets. These models have shown that sufficiently energetic jets can both cause the explosion and imprint the observed asymmetries. Whether this process can alone explain the explosion or whether it merely supplements the standard neutrino-driven explosion remains to be seen. If the jets up and down the symmetry axes are somewhat unequal, they might also account for the runaway velocities of pulsars.

If such jets produce the asymmetries, the most likely cause of the jets are the fast rotation and magnetic fields that are intrinsic to pulsars. Progress in understanding the origin of jets from magnetized disks around black holes makes us optimistic that similar processes will form jets from a newborn pulsar in a stellar core. Recent work in Austin has shown that the magnetorotational instability may play a significant role to produce strong magnetic fields in a fraction of a second after core bounce. These fields may, in turn, promote the flow of energy up the rotation axis by a combination of hoop stresses and other pressure anisotropies.

4. SN 2002ap – Not a Hypernova?

This work may also shed light on the supernova/gamma-ray burst connection. Several supernovae have been identified as "hypernovae" since they show excessive velocities and luminosity. The most famous example, SN 1998bw, was apparently associated with the gamma-ray burst of April 25, 1998. We have been concerned that asymmetric explosions could mimic some of the effects of "hypernova" activity as interpreted by spherical models. In particular, asymmetric models could give especially high velocities in some directions, the directions of axial jets, and be brighter in some directions than others because of the resulting asymmetric flux distribution. This could

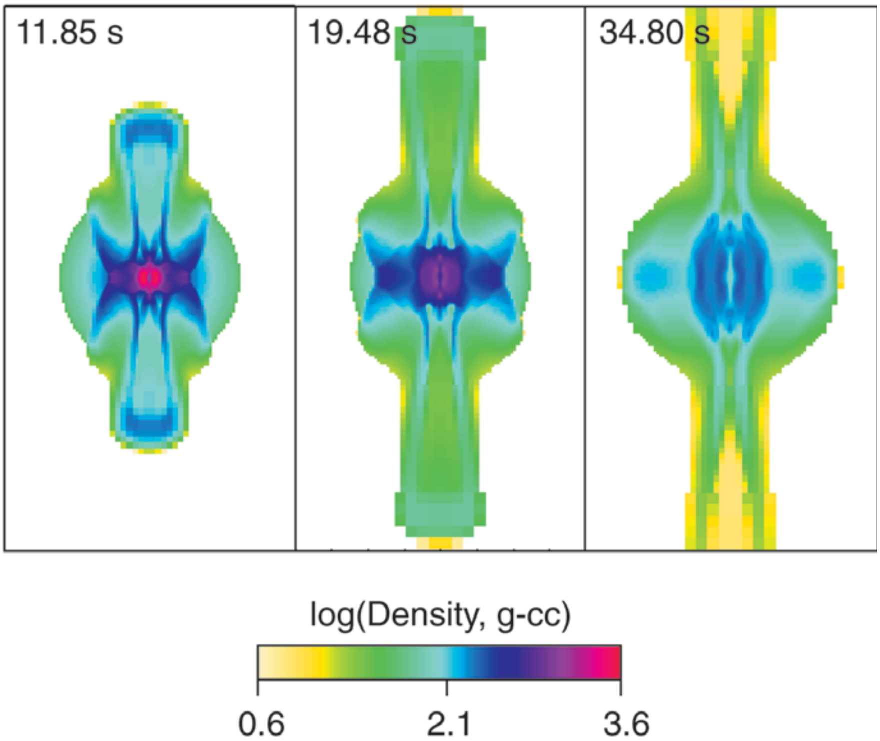


Figure 3: Three-dimensional computation of a jet-induced supernova explosion in a helium core. The frames show the density in the plane parallel to the jet axis that passes through the centre of computational domain. The time since the beginning of the simulation is given in the upper left corner of each frame. The scale expands in each frame with the left frame being about 10^{10} cm, the middle frame about 5×10^{10} cm and the right frame about 10^{11} cm. Note the transverse shock waves that converge on the equator. From Khokhlov et al. 1999, Astrophys. J., 524, L107.

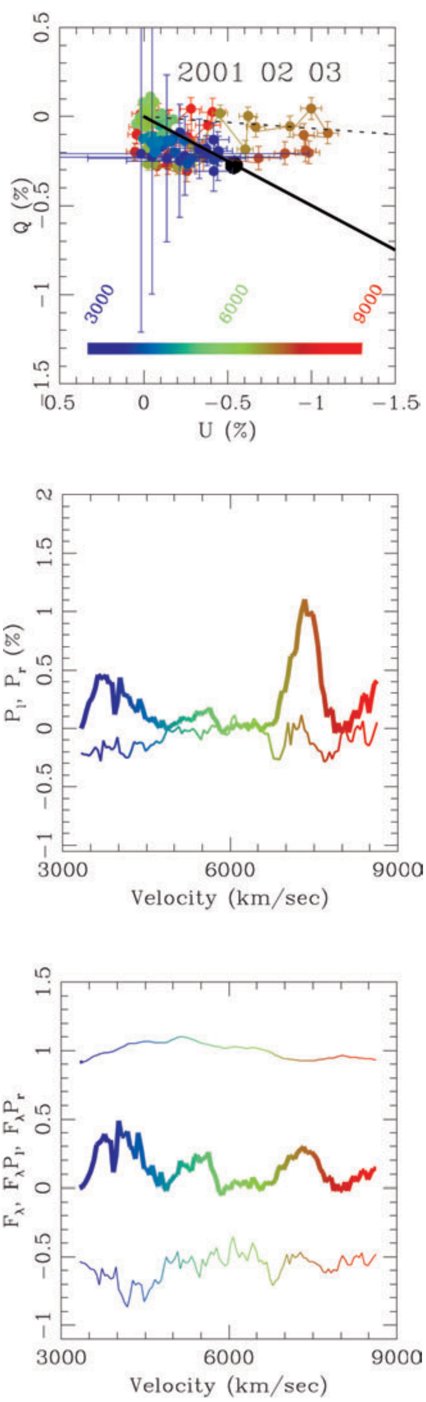


Figure 4: Spectropolarimetry of the Type Ic SN 2002ap on 2002 3 Feb, 6 days before V maximum. The Stokes parameters Q and U are rebinned into 15 Å bins. An interstellar polarization component is subtracted from the observed Stokes parameters so that the data points represent intrinsic polarization due to the supernova. The assumed interstellar polarization is shown as the solid dot in the Q–U plot (top panel). Without subtraction of the interstellar component, the origin of the coordinates would be centred at this solid dot. The solid line represents the axis from the origin through the value of the ISP. The dashed line illustrates the locus of the O I feature in the Q–U plot. The polarization spectra (middle panel) and polarized flux (bottom panel) show conspicuously polarized spectral features corresponding to Fe II, Na I D, and O I 777.4 nm. The wavelength colour code is presented at the bottom of the top panel.

be especially true for Type Ic events where the lack of hydrogen and helium envelopes give a close view of the asymmetries of the inner explosion.

A particular case in point is the recent Type Ic event SN 2002ap. This event showed high velocities, but none of the other characteristics of a "hypernova," neither a strong relativistic radio source, nor excessive brightness. High-quality spectropolarimetric data of SN 2002ap were obtained with the VLT Melipal and the FORS1 spectrograph at 3 epochs that correspond to –6, –2, and +1 days for a V maximum of 9 Feb 2002. A sample of the data is presented in Figure 4. The polarization spectra show three distinct broad (~ 100 nm) features at ~ 400, 550, and 750 nm that evolve in shape, amplitude and orientation in the Q-U plane. The continuum polarization grows from nearly zero to ~ 0.2 per cent. The 750 nm feature is polarized at a level $\gtrsim$ 1 per cent. We identify the 550 and 750 nm features as Na I D and OI λ 777.4 moving at about 20,000 km s^{-1}. The blue feature may be Fe II.

We interpret the polarization evolution in terms of the impact of a bi-polar flow from the core that is stopped within the outer envelope of a carbon/oxygen core. Although the symmetry axis remains fixed, as the photosphere retreats by different amounts in different directions due to the asymmetric velocity flow and density distribution, geometrical blocking effects in deeper, Ca-rich layers can lead to a different dominant axis in the Q-U plane. The features that characterize SN 2002ap, specifically its high velocity, can be accounted for in an asymmetric model with a larger ejecta mass than the well-studied Type Ic SN 1994I such that the photosphere remains longer in higher velocity material.

We conclude that the characteristics of "hypernovae" may be the result of orientation effects in a mildly inhomogeneous set of progenitors, rather than requiring an excessive total energy or luminosity. In the analysis of asymmetric events with spherically symmetric models, it is probably advisable to refer to "isotropic equivalent" energy, luminosity, ejected mass, and nickel mass.

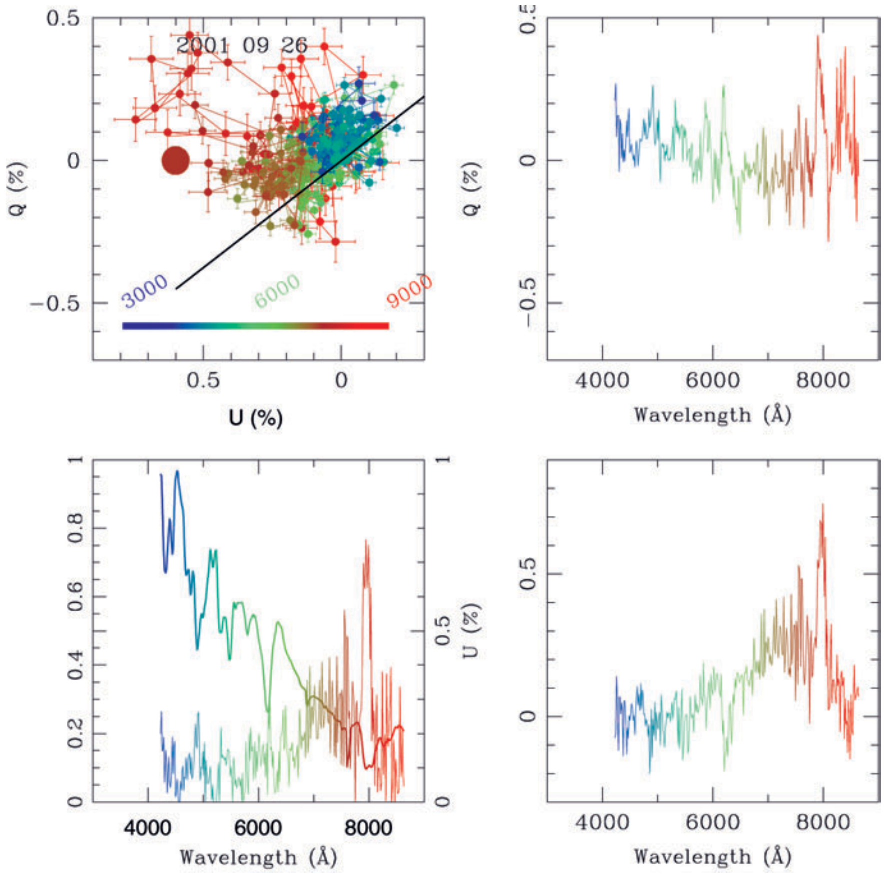


Figure 5: Spectropolarimetry of the Type Ia SN 2001el on 2001 Sept. 26, 7 days before maximum. The Stokes parameters Q and U are rebinned into 15 Å bins. An interstellar polarization component is subtracted from the observed Stokes parameters so that the data points represent intrinsic polarization due to the supernova. The assumed interstellar polarization is shown as a solid dot in the Q–U plot (panel a, upper left). Without subtraction of the interstellar component, the origin of the coordinates would be centred at this solid dot. The straight line illustrates the dominant axis shifted to the origin of the Q–U plot. The Q (panel b, upper right) and U (panel d, lower right) spectra show conspicuously polarized spectral features. The degree of polarization is shown as the thin line in panel c (lower left) with the flux spectrum (panel c, lower left, thick line) overplotted to show the correlations of the degree of polarization and the spectral features. The wavelength colour code is presented at the bottom of panel a.

5. Asymmetries in Type Ia Supernovae

Most Type Ia supernovae are not substantially polarized at the epochs that have been observed. This suggests that, despite occurring in binary systems, the explosions are essentially spherically symmetric. There are some interesting exceptions to this, however. SN 1999by was one of the class of subluminous, rapidly declining Type Ia events. It was substantially polarized and hence asymmetric in some way. We do not yet know whether this was characteristic of subluminous Type Ia, or whether SN 1999by was odd in this regard.

In this context, it is important to obtain spectropolarimetry of "normal" Type Ia supernovae. A step in this direction was taken with our observations of the Type Ia SN 2001el. High-quality spectropolarimetry of the SN 2001el was also obtained with VLT Melipal and FORS1 at 5 epochs. Some of these data are shown in Figure 5. The spectra a week before and around maximum indicate photospheric expansion velocities of about 10,000 km s^{-1}. Prior to optical maximum, the linear polarization of the continuum was $\approx$ 0.2–0.3% with a constant position angle, showing that SN 2001el has a well-defined axis of symmetry. The polarization was nearly undetectable a week after optical maximum.

The spectra of SN 2001el are similar to those of the normally-bright SN 1994D with the exception of a strong double-troughed absorption feature seen around 800 nm (FWHM about 22 nm). The 800 nm feature is probably due to the Ca II IR triplet at very high velocities (20,000–26,000 kms^{-1}). The 800 nm feature is distinct in velocity space from the photospheric Ca II IR triplet and has a significantly higher degree of polarization (= 0.7%), and different polarization angle than the continuum. Taken together, these aspects suggest that this high velocity calcium is a kinematically distinct feature with the matter distributed in a filament, torus, or array of "blobs" almost edge-on to the line of sight. This feature could thus be an important clue to the binary nature of SN Ia, perhaps associated with an accretion disk, or to the nature of the thermonuclear burning, perhaps representing a stream of material ballistically ejected from the site of the deflagration to detonation transition.

If modelled in terms of an oblate spheroid, the continuum polarization implies a minor to major axis ratio of around 0.9 if seen equator-on; this level of asymmetry would produce an absolute luminosity dispersion of about 0.1 mag when viewed at different viewing angles. If typical for SNe Ia, this would create an RMS scatter of several hundredths of a magnitude around the mean brightness-decline relation. This scatter might have implications for the high precision measurements required to determine the cosmological equation of state of the "dark energy."

6. Conclusions

The acquisition of systematic supernova polarization data has led to remarkable new insights. It seems likely that all core-collapse supernovae are substantially asymmetric. They explode by means of bi-polar flow associated with the newborn neutron stars. This discovery may, in turn, give new insights into more exotic jet-induced events like gamma-ray bursts. While most Type Ia supernovae have been found to be little polarized, the number of exceptions is growing. The asymmetries observed in Type Ia may finally yield direct observational evidence that they occur in binary systems, as long assumed, and clues to the combustion mechanism. Understanding these asymmetries may be necessary to properly interpret future data on cosmologically distant Type Ia's.

The authors are grateful to the European Southern Observatory for the generous allocation of observing time. We are also anxious to acknowledge that, contrary to the impression perhaps given in the Introduction, requests for service-mode observations with the VLT are much different than orders to a pizza home-delivery service: The Paranal Science Operations staff and the User Support Group in Garching have gone to considerable effort to augment our proposal with their full range of expertise. We recognize that accommodating our target-of-opportunity observations in an already busy observing and work schedule often poses a special extra challenge. Only this symbiosis enables the ongoing success of this project. We are especially grateful for that. This work was supported in part by NASA Grant NAG5-7937 to PAH and NSF Grant AST 0098644 to JCW.

OTHER ASTRONOMICAL NEWS

An Exciting Working Session on Cataclysmic Variables at ESO/Santiago

E. MASON (ESO/Chile, fellow) and S. HOWELL (ESO/Chile, visiting scientist)

An intensive working session on Cataclysmic Variables (CVs) was held at ESO/Santiago on August 14, 2002. The workshop was organized on the occasion of the presence in Santiago of Dr. S. Howell, from the Planetary Science Institute in Tucson, thanks to the ESO/Chile visiting scientist programme.

The goal of the workshop was to gather all astronomers in Chile working on CVs, for exchanges and fruitful discussions. The participants were from the University of Concepción and from ESO/Chile, and we could also welcome Dr. N. Vogt, from Heidelberg, who had organized the first workshop on CVs ever held in Chile (Viña del Mar, 1992). We hope that the wealth of ideas and projects discussed during the working session, will trigger regular CV workshops here in Chile, possibly involving a larger number of participants and invited speakers. The workshop was organized in a morning review session on CVs, both on observations and on theory, and an afternoon discussion session.

Reviews were about: (i) the photometric behaviour of dwarf novae (DNs) during cycles and super-cycles, (ii) the spectroscopic characteristics of CVs in the wavelength range UV-IR, (iii) the evolution of CVs – theory vs. observations, (iv) radial velocity measurements as a diagnostic for the binary system geometry and (v) the CVs accretion disks and current analysis of their emission lines.

The afternoon talks were more specifically focused on the observation of particular objects or on some aspects of theoretical modelling.

The participants really benefited from being in a fairly small but highly motivated group and could present, discuss, and confront various problems and results of their current research programmes. In particular, the discussion of unsolved problems turned out to be important and fruitful as it triggered the submission of new proposals (on ESO telescopes!), as well as the development of new research projects and collaborations.

CONFERENCE SUMMARY

From Twilight to Highlight: the Physics of Supernovae

ESO/MPA/MPE Summer Workshop 2002

(http://www.mpa-garching.mpg.de/~supnov/)

W. HILLEBRANDT (MPA) and B. LEIBUNDGUT (ESO)

This year's joint workshop between ESO, the Max-Planck-Institut für Astrophysik and the Max-Planck Institut für Extraterrestrische Physik, already the fifth in this series, was dedicated to the physics of supernovae. With active groups at all three institutions (and at both of ESO's scientific centres in Garching and Vitacura) this topic was ideal. Over 100 experts came to Garching during the last three days of July to discuss the progress made in the explosion physics, the current observational status, the astrophysical relation of supernovae and their environment, and the most energetic explosions known.

With increased attention to supernovae for their cosmological application and their possible connection to the Gamma-Ray Bursts (GRB) during the past few years these stellar explosions have entered into the limelight of the astronomical stage. However, our understanding of the underlying physics advances more slowly and its progress has to be evaluated regularly. It was the goal of this meeting to focus on the basics of the explosions and the current knowledge of these cosmic highlights.

The meeting was structured with reviews opening the sessions on the individual topics. The first day started with the evolution of stars towards the final core collapse or the ignition of a thermonuclear flame. The outcome of massive star evolution depends on the initial metallicity, which governs the stellar mass loss and hence the mass at the explosion, and during the early universe even very massive stars (up to 250 $M_\odot$) can explode as supernovae (Heger). Direct observational evidence of the progenitor stars of core-collapse supernovae is still hard to come by and, with the notable exceptions of SN 1987A and SN 1993J, only upper limits can be set on the progenitor luminosity and initial mass (Smartt). The finer details of the progenitor evolution for SN 1987A still have to be worked out. Almost everybody agrees that there must have been a binary system (Podsiadlowski). The binary may have fully merged shortly (10^4 years) before the explosion. The many constraints on the progenitors of thermonuclear supernovae (Type Ia Supernovae) and their evolution to explosion were presented in a coherent picture (Nomoto). This has also implications on the relative supernova rates as a function of look-back time, i.e. redshift. Nevertheless, there remain many open questions and the debate whether double-degenerate models (a binary consisting of two white dwarfs) or the single-degenerates (a white dwarf with a main sequence or giant star as companion) are the progenitor systems was continued at this conference. From the cosmic SN Ia rate the double-degenerate systems appear less favoured due to their long evolutionary time (Canal) and the recurrent novae, in particular in super-soft X-ray sources, appear more promising candidates (Starrfield). An especially attractive feature of the super-soft sources is that the measured white-dwarf masses are already very close to the Chandrasekhar limits.

A systematic survey of white dwarfs for radial velocity changes with UVES has so far yielded quite a high fraction of binary white dwarfs (16%). Among the best candidates are three objects with a combined mass very close to the Chandrasekhar limit and two of these will merge in about 4 Gyr (Napiwotzki). The search for the companion stars after they have lived through the violent explosion in their vicinity has so far not yielded positive detections (Ruiz-Lapuente). In particular, Tycho's supernova (SN 1572) and SN 1006 have been investigated. The physics of the core collapse in massive stars was beautifully introduced (Janka). There might be light at the end of the tunnel with the first multi-dimensional calculations yielding explosions when general relativity and new neutrino opacities are used in the models. The treatment of the neutrino transport is key in these models, a view also echoed by other experts (Burrows, Mezzacappa) but even more sophisticated models may be needed to confirm the first positive results. Gross asymmetries appear in some model calculations. The copious production of neutrinos in the core collapse might be observable with a suitable supernova in the Milky Way. Neutrino oscillations can be measured from these supernovae and will provide important diagnostics for neutrino physics and the neutrino masses (Sato). The models of thermonuclear supernovae have progressed tremendously during the past decade as well. 3-dimensional calculations of the turbulent nuclear flames in deflagration models appear now to solidly produce explosions and about the right masses of ^{56}Ni. With increasing resolution in the simulations more energy is released and explanations for regular SN Ia dynamics appear within reach even with pure deflagration, i.e. subsonic, explosions (Niemeyer). Should a transition to detonations occur then the explosion can be further strengthened (Garcia-Senz).

There is a bonanza of new observations being assembled on supernovae. Most of the second day of the workshop was dedicated to presentations of new data. The Berkeley group is not only currently finding most of the nearby supernovae, they are also assembling a large sample of light curves and spectra (Filippenko). Among the recent supernovae there are many peculiar ones and with SN 2002cx a truly strange SN Ia has been added to the zoo. The latest news on SN 1987A was presented in two presentations. The shock interaction with the inner ring has become quite apparent during the last few years in HST imaging (Kirschner). The light curve is dominated by the ring emission and extracting the fading ejecta requires HST imaging (Suntzeff). The supernova itself is fading now very slowly. The first tentative spectral identification of a supernova (SN 2001ek) in a Gamma-Ray Burst afterglow (GRB 011121) triggered some discussion on data quality and wishes for longer integration times (Kirschner). Densely sampled light curves in UBVRI and the infrared JHK bands for several nearby supernovae are now becoming available. With these excellent observations the construction of bolometric light curves becomes a lot easier and the global properties of SNe Ia can be assessed (Suntzeff). Core-collapse supernovae with very weak explosions are observed more often and their general appearance can be investigated (Turatto, Pastorello). The ejecta mass of the weak explosions is still debated, but higher masses appear to be favoured (Zampieri). For these weak objects, it might be possible to directly see emission from the infall of matter into a black hole at very late phases.

With large telescopes, including the VLT, some supernovae can now be followed for over a decade enabling one to look deep into the ejecta and explore the heating mechanisms working in these cinders (Turatto). An interesting transition object between the subclasses Ib and Ic has been observed in a Large Programme at the VLT (Hamuy). The early adiabatic cooling from the shock breakout and the exquisite IR spectroscopy firmly establish the core-collapse nature of this object. The infrared wavelength regime will draw much more attention in the near future. It offers the possibility to observe supernovae with much less influence from host galaxy absorption. The possibility of an H-band Hubble diagram of SNe Ia would make this fundamental measurement less dependent on assumptions about absorption in the host galaxies (Phillips). At the same time, many new SNe Ia show light curves and spectral evolutions that can not be fit into the one-parameter relations used in the past. The infrared also provides access to phenomena which are not easily observable in the optical. The core-collapse supernova SN 1998S is an intriguing case where the careful optical and infrared monitoring not only revealed very strong interaction with circumstellar material, i.e. the remnant of the wind of the progenitor star, but also an infrared excess (Meikle). Dust formation in the cool shell between forward and reverse shock has been deduced from these observations.

To bridge the gap from explosion models to the observations the radiation transport has to be calculated. The comparison of the latest explosion models from the group at the MPA with observed light curves are very encouraging (Blinnikov). Indeed there appears to be enough energy in the deflagration models to explain the ejecta velocity of the Tycho supernova remnant. During a poster session the 28 posters on a wide range of topics were discussed. Supernova searches and recent observations of specific objects were presented. The latest ideas and details on modelling the explosions were displayed as well as plans for future projects.

The last day was devoted to the interactions between other astronomical fields and supernovae. Not all supernovae explode in isolation. Some of them strongly interact with their close environment. The radio and X-ray emission are the most direct tracers of this circumstellar interaction of the supernova shock, but optical spectroscopy can reveal the emission sites through line shapes as well (Chevalier). Most regular SNe IIP show very little sign of interaction consistent with progenitor masses in the range of 10 to 20 $M_\odot$. Many other objects, especially stripped core-collapse supernovae (IIL, Ib/c), are enshrouded in a dense environment, which most likely resulted from the evolution in a close binary system.

To date only 15 supernovae have been observed in X-rays (Aschenbach). All of them are core-collapse supernovae interacting with their circumstellar material. Recently the first X-ray spectra have been obtained showing high ionization lines of oxygen through iron. The flux from SN 1987A is increasing as the shock is interacting inside the ring with dense, ionized material. SNe Ia, on the other hand, are postulated to explode in a rarefied environment and no interaction is expected. However, in some progenitor models the presence of hydrogen or helium has to be expected. Finding the traces of such material has been the goal of a UVES programme (Lundqvist). So far, only upper limits for the mass loss can be derived from the absence of any detection of hydrogen or helium lines. On a grander scale, the supernova light can scatter off dust grains between the explosion and the observer. There are now two SNe Ia and two core-collapse SNe (SN 1987A and SN 1993J) with observed light echos (Patat). Since supernovae are the main producers of heavy elements, they are of special interest for models of the chemical evolution of the Galaxy (Thielemann).

The relative contributions of thermonuclear and core-collapse supernovae should sum up to the abundances measured in the Sun. The dependences on various parameters in the explosions (density, temperature, and metallicity) are still not fully explored. It has been claimed recently that the chemical composition of the most metal-poor stars could be dominated by a single supernova. Hence, these most pristine stars are of particular interest for the explosion models. The comparison of the evolution of individual elements in stars yields hints about the contribution of different supernova types (Primas). Some of these stars may be the first ones formed in the galaxy, the putative Population III. But also celestial objects picked up from the ground can provide information on supernova enrichment. Inclusions in meteorites give hints on the composition of the early solar system and material ejected from nearby supernovae (Ott).

A discussion on the nomenclature of the most energetic explosions was the guiding theme of the following presentations. The very first massive stars should explode in truly gigantic explosions even on the supernova scale. The chemical composition of the metal-poor stars might be dominated by these explosions of the first generation of stars (Limongi). The observed abundances cannot be matched with the current models, but progress could be reported. The nucleosynthesis can also be altered, if the explosion is asymmetric as the conditions for the burning are not isotropic any longer (Maeda). Direct detection of the γ radiation from the radioactive decays would constraint the explosion models considerably. With the past satellites this has been very difficult but the situation will improve after the launch of *INTEGRAL* this fall (Diehl). Decay lines from ^{56}Ni and ^{57}Co were observed from SN 1987A and a tentative detection of the ^{56}Co decay in the SN Ia SN 1991T was reported. Other decays have been observed in supernova remnants (^{44}Ti in Cas A) and distributed throughout the Galaxy (^{26}Al). The connection of Gamma-Ray Bursts and supernovae may be intimate, it certainly is intricate (Woosley). With sufficient angular momentum the formation of a black hole can trigger the formation of a disc formed of nucleons, which can reverse the infall along the poles into a strong jet explosion. Depending on the viewing angle the observer will see a GRB, an intermediate object like GRB 980425/SN 1998bw or an unusual supernova. Depending on the conditions outside the disc the nucleons can form nuclei up to Ni and hence trigger a supernova (MacFadyen). The disc itself could be the site of an reprocess. The problem of this scenario is to produce stellar cores with sufficient angular momentum for these models. A possibility is to have either a merger event or mass accretion onto a massive star (Joss). The observational parameters of some of these energetic explosions can vary from object to object (Mazzali). A range of explosion energies and masses has been observed until now. The spectral signatures of wide, high-velocity lines of what otherwise might appear as a SN Ic are quite obvious.

Despite an intense programme there was plenty of time for discussions. The workshop was opened with a buffet dinner and a speech by the Mayor of Garching in the town hall. The first day ended with a relaxed ‘Beer and Bretzen’ party outside the MPA. The conference dinner took place at a typical Bavarian *Biergarten* outside Munich during a wonderful summer evening. All occasions to informally catch up on the latest news and developments.

The proceedings of this conference will appear in the ESO Astrophysics Symposia Series published by Springer Verlag.

Developing 3D Spectroscopy in Europe

J.R. WALSH, ESO
M.M. ROTH, Astrophysikalisches Institut Potsdam

1. Background

One of the inherent preoccupations of astronomy is to obtain a three-dimensional view of the Universe and its components. Except for Solar System objects, we are always presented with a two-dimensional view of celestial objects. Spiral galaxies for example could be considered only as flat structures if it were not for the rotational velocity which shows them to be spinning three-dimensional entities. The distance scale is another fundamental aspect of this question – placing astronomical sources in the third dimension. Once their distance is determined, physical parameters can follow such as luminosity, radius and mass. In order to determine this information one could ideally imagine a "maximal spectrograph" which produced the spectrum of the whole sky at some desired spectral resolution and spatial sampling on the sky. The complexity of such an instrument is obviously beyond current technological means and the sheer size of the resulting data set would be prohibitively large. Nevertheless, a small, but significant, step towards this goal is to obtain the spectrum of an area of sky and this is what 3D spectroscopy achieves. With advances in technology the sampled area is becoming bigger.

3D spectroscopy is called integral field (IFS) or area spectroscopy and the principle is summarized in Figure 1. The resulting data have three dimensions – two spatial and one spectral. The spectrum at a spatial pixel (dubbed a "spaxel"), or in an aperture of any desired shape over a substructure of interest, can be extracted or an image over a spectral range can be formed by summing in the spectral direction. A long-slit spectrum can be formed by slicing the 3D data in one spatial and the spectral direction. Such data have very powerful advantages over aperture or long-slit spectra which sample pre-defined spatial regions. With 3D spectroscopy not only can spectra of a whole extended object be obtained, such as a nearby elliptical galaxy to investigate its velocity field, but areas of the sky can be searched for objects which are difficult to detect in wide-band imaging, such as emission line sources with a few, even only one, visible line over the wavelength range of the instrument (such as a search for Lyman-alpha emission from very high-redshift galaxies).

Since there is no slit in the conventional sense, there are neither slit losses nor the problems associated with atmospheric refraction which plague conventional spectroscopy. Most importantly, there is, by definition, no prejudice as to the selection of the region of interest: thus a particular slit pointing and orientation may easily miss a physically important structure which appears to be unassuming on a broad-band image. Integral-field observation can unveil the complete spectroscopic signature within the 2-dimensional field of view of the wavelength coverage of the 3D instrument. A good example is the 3D observations of the stellar kinematics of the nuclear region of the nearby galaxy M31. Whilst the distribution of light shows a double nucleus, the velocity map reveals a structure that is not aligned with the two nuclei and the peak in the velocity dispersion, assumed to mark the location of the supermassive black hole, is also offset from one of the peaks (Bacon et al. 2001a). Orientation of a long slit over the obviously visible features would have missed the essentials of the velocity structure.

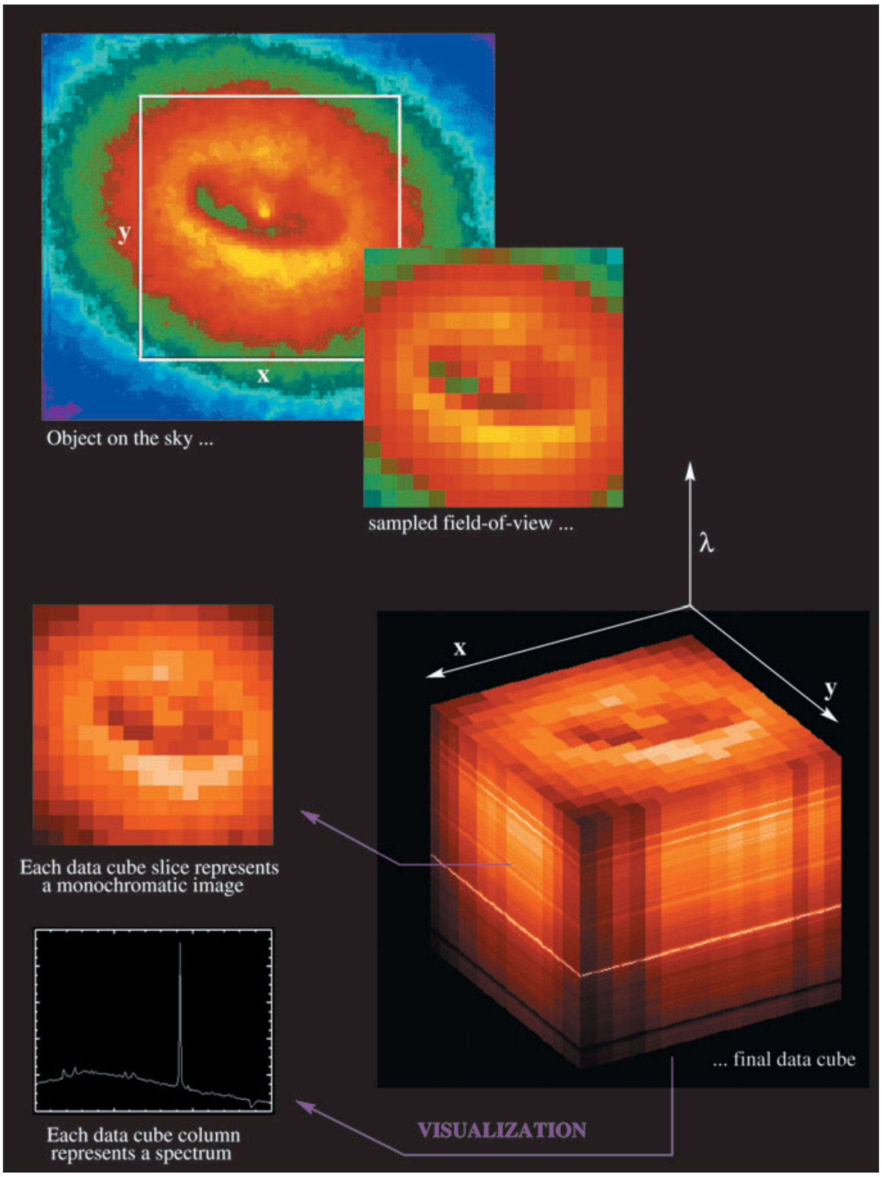


Figure 1: The principle of 3D spectroscopy is illustrated. An area of interest on the sky is sampled on a discrete grid of spatial elements, using techniques such as a fibre bundle, lenslet array, slicer, etc. The light collected in each spatial element is dispersed into a spectrum. After extracting the family of individual spectra from the detector image, they can be rearranged to form a data cube. Spectra of individual spatial elements, or defined regions on the sky, can be extracted from the data cube. Slicing the data cube over a range of wavelengths allows a narrow-band or broad-band image of the sky to be formed.

The process of data-taking sounds simple – point at a target of interest (high-precision pointing is not required), obtain spectra at many spatial positions (currently hundreds to thousands). The removal of the instrument signature and the assembly of the data into a 3D data cube proceeds similarly to spectroscopic reduction with long slits except for the much larger volume of data. However, it is the analysis of those thousands of spectra which provides the greatest hurdle. Integral-field spectrometers in various forms have been available for decades but the publications resulting have in no way been proportional to their data volume, or allocated telescope time. The sheer scale of the data analysis and the need to do justice to the quantity of spectra has deterred many, and even the 3D spectroscopy pundits have to admit that they cannot analyse their data cubes fast enough. The lack of adequate data-analysis tools is becoming more acute with the installation of new common-user instruments offering IFS modes on 8–10-m-class telescopes, such as VIMOS, FLAMES and SINFONI at the VLT, and GMOS at GEMINI.

In order to try to ease this “data jam”, all the European groups working in 3D spectroscopy came together in a working group launched by OPTICON – the Optical and Infrared Coordination Network for Astronomy. A proposal for a Research Training Network (RTN) in the 5th Framework of the European Commission was made in which young post-docs would be enabled to work on science projects with 3D spectroscopy. User tools would be developed and shared to increase the scientific exploitation and productivity of the data. The RTN, entitled “Promoting 3D Spectroscopy in Europe” was awarded and began on 2002 July 1. Post-docs are now being sought in ten European institutes. This article provides a brief overview of the 3D spectroscopy and a flavour of what can be expected from the RTN over the next few years.

2. Growth of 3D Spectroscopy

The first attempts at imaging spectroscopy used scanned Fabry-Perot interferometers to observe the velocity fields of emission lines in gaseous nebulae. Groups at Marseille and Manchester used photographic and image-tube recorders to obtain multiple narrow spectral band maps which, when stacked, allow the line profiles over an area to be mapped. With the advent of piezo-scanning Fabry-Perot spectrometers coupled with photon-counting detectors, rapid sampling of the spectral range could be achieved. The effect of transparency variations in the atmosphere would be reduced by the fast scanning and many scans could be averaged. The TAURUS instrument, used at many 4-m telescopes, was the most advanced realization (Atherton et al., 1982) and emission line maps of many extended targets were observed.

Photon-counting detectors could also be employed in rapid slit-scanning techniques where the positioning of a long slit on the sky was synchronized with the readout of the detector. The ASPECT system at the AAT (Clark et al. 1984) using the IPCS (Boksenberg & Burgess 1973) was successfully used for a number of projects from kinematic mapping of elliptical galaxies to spatial abundance mapping of spiral and starburst galaxies. The data volumes were modest with typically ten long slit positions. Scanning techniques suffer from changing seeing and transparency, which also produce line profile variations for Fabry-Perot spectrometers.

The first attempts to measure simultaneously spectra over a 2-dimensional field were made in the 1980’s with fibre bundles packed into an area at the telescope focal plane and aligned onto a common “pseudo-slit” of a conventional spectrometer. Each fibre generated a single spectrum on the detector of one position on the sky. Several prototype instruments have been developed, and some of them are still in use today. The application of microlens arrays to astronomy brought a revolution in this field. An area of sky could be divided up by a monolithic microlens array. The beams from the microlenses could then be fed to a spectrometer and many spectra recorded on the same detector. The spectrometer design can ensure that the many individual spectra are packed on the detector so that there is minimal overlap. The Tiger, subsequently Oasis, instruments used for many years on the CFHT was the most successful example of this design principle and much science was achieved from resolving the kinematic components of galaxy nuclei to the jet structure of PMS stars (Bacon et al., 1995). Using the micropupil principle, the coupling of lens arrays with fibre bundles allowed more flexible designs even with several spectrometers. The integral field mode of the Gemini GMOS instrument uses this design, as does the VLT FLAMES facility; in VIMOS, currently the largest IFU unit in operation (80 × 80 elements), the fibres feed four spectrometers. There is no reason in principle for not extending the number of spatial elements towards that of the maximal spectrometer and two propos-

OBITUARY GUILLERMO DELGADO (1961–2002)

Guillermo started his career in radio astronomy in 1983 when he participated in the activities and development of the Maipu Radio Astronomy Observatory.

In 1986, at the time when Onsala Space Observatory and ESO embarked on the SEST project, Guillermo went to Sweden to become involved in the project. Upon his return to Chile he took an active part in the commissioning of the SEST. His contribution helped greatly in the early readiness of the SEST operations. Later on, he was responsible for the instrument maintenance and upgrades, including the installation of receivers and the design of their control system.

In 1989 Guillermo graduated as Electrical Engineer from the Universidad de Chile. In 1992 he went to Sweden to work on his doctorate at Chalmers University of Technology. He returned to Chile and the SEST in 1995 where he completed his Ph.D. thesis.

In 1997, health problems obliged him to be based in Santiago, where he was, essentially, dedicated to support the ALMA site testing and development campaign, including the maintenance of its equipment, the interpretation of the atmospheric transparency data from Chajnantor and the modelling of phase correction methods. His efficient work under difficult health conditions was impressive. Above all, Guillermo had an extraordinary capacity to handle a large spectrum of skills, ranging from electronic designs and opto-mechanics to software development and data analysis. He taught at the Universidad de Chile and encouraged students towards the world of astronomy. ESO and Onsala Space Observatory are deeply grateful for his contribution to ALMA and the SEST.

Guillermo was a first-rate colleague whose generosity and dedication was highly appreciated by all who worked with him. Until his very last weeks at the hospital he was actively involved in his tasks with an energy and will power only to be defeated by his physical condition.

Our expression of condolence goes to his wife, Alejandra, and their sons.

DANIEL HOFSTADT
LARS-ÅKE NYMAN

als for VLT wide-field (1 × 1′) 3D optical spectrometers are under consideration (see Monnet, 2002).

One other technique has found application for dividing up the field subsequent to feeding the spatial elements to a spectrometer and that is a development of the image slicer. Originally image slicers were used to increase the throughput of slit spectrometers for a point source by stacking slices along a narrow slit. Applied in two dimensions mirrors can be used to reformat a square field onto a long slit which is then packed on to the detector (e.g. for the MPA instrument 3D, Weitzel et al., 1996, which is the fore-runner of the VLT instrument SPIFFI). In common with all methods the limitation is detector area, and as CCDs have grown larger so have the areas encompassed by 3D instruments, whilst the sampled size on the sky has remained relatively constant. A survey of the commissioned and planned 3D instruments, or instruments with an integral-field capability, around the world showed the astonishing number of 26. Truly, this is a burgeoning field and many integral field instruments are planned for the large telescopes, and for NGST. Within two years there will be three IFU-capable instruments on the VLT – VIMOS, FLAMES and SINFONI.

3. The Euro3D RTN

Europe currently has the lead in the development of integral-field devices and many of the instruments currently in use, or planned, are for telescopes in which European institutes, including ESO, have strong participation. The need to foster good communication and interchange between these groups, which represent all the different 3D methods sketched above, led to the formation of an OPTICON 3D Spectroscopy Working Group. This group identified that, whilst individual instruments are diverse and the responsibility for removal of the instrument signature must rest with the instrument builders, there existed a lack of instrument-independent data analysis software. The Euro3D RTN was proposed and planned by this group.

A 3D data format for the exchange of 3D data and a software platform for the development of analysis tools form two of the cornerstones of the Euro3D effort. A draft format for a Euro3D format has been issued and the essence of the format, which is FITS, is a stacked spectrum image with a table to reference each spectrum to its position on the sky plane. For the data analysis tools, it was decided to write individual applications in C and to use a scripting language such as Python, Tcl/Tk or IDL for analysis scripts. The I/O library would be adapted from the extensive Lyon Oasis libraries for the Euro3D format.

The RTN consists of a network of eleven institutes – Astrophysikalisches Institut Potsdam, Institute of Astronomy Cambridge, University of Durham, Max-Planck-Institut für Extraterrestrische Physik, Garching, Leiden Observatory, CRAL Observatoire de Lyon, Laboratoire d’Astrophysique de Marseille, Istituto de Fisica Cosmica “G. Occhialini” of the Italian CNR in Milan, Observatoire de Paris section de Meudon, Instituto de Astrofísica de Canarias, ESO – all of which have active involvement in 3D spectroscopy projects. Full details of the RTN are available on the Web at: http://www.aip.de/Euro3D/ and there are also links to detailed descriptions of the 11 3D instruments with which the RTN members are involved. The coordinator of the network is Martin Roth at AIP Potsdam (mmroth@aip.de) and questions about participation or interest in the scientific or software activities should be directed to him.

References

Atherton, P.D., Taylor, K., Pike, C.D. et al., 1982, *MNRAS*, **201**, 661.
Bacon, R., Emsellem, E., Combes, F., et al., 2001a, *A&A*, **371**, 409.
Bacon, R., Copin, Y., Monnet, G., et al. (The Sauron Project), 2001b, *MNRAS*, **326**, 23.
Bacon, R., Adam, G., Baranne, A., et al., 1995, *A&AS*, **113**, 347.
Boksenberg, A. Burgess, D. E., 1973, in Proc. Symp. TV type sensors, eds. Glaspey, J. W., Walker, G.A.H., 21.
Clark, D., Wallace, P., Fosbury, R. F., Wood, R., 1984, *QJRAS*, **25**, 114.
Monnet, G., 2002. *The Messenger*, No. **108**, 2.
Weitzel, L., Krabbe, A., Kroker, H., et al., 1996, *A&AS*, **119**, 531.

Forty Years ESO – Public Anniversary Activities

C. MADSEN, ESO

Readers of *The Messenger* will be well aware of ESO’s 40th anniversary in October this year. This is most certainly a reason for ESO’s friends to celebrate. Beyond the professional astronomers, engineers and other people with direct links to the organization, this includes many people all over Europe, e.g. amateur astronomers, science teachers, and people with a general interest in science. At the same time, the European Intergovernmental Research Organizations constitute fine examples of how, through collaboration, European countries can interact and achieve ambitious goals. Thus the success of ESO reaches beyond the confines of professional Astronomy.

Taking account of this, ESO’s Education and Public Relations Department has worked intensively with partners in the publishing world and planetaria to ensure that the 40th anniversary will also become a visible event in the public arena.

Among the activities and products that will be ready in the autumn are a major book, a CD-ROM, a video and a planetarium show.

Geheimnisvolles Universum – Europas Astronomen entschleiern das Weltall is the title of an ‘anniversary book’, published by the German Kosmos Verlag. Comprising 208 large-format pages with more than 150 colour pictures, the book is written by science journalist Dirk Lorenzen, known from German Radio and author of *Deep Space* and *Raumsonde Galileo*. The original version of the book is published in German, but other language versions are planned.

Although published on the occasion of the 40th anniversary of ESO, the book

is a forward-looking book, dealing with some of the hottest topics of contemporary astronomy. It looks at the technology and, by means of interviews with both ESO staff and visiting observers, offers a very human account of the people now engaged in front-line astronomical research. A chapter describes an observing night at Paranal and provides an outlook to the future, in particular the ALMA and the OWL projects.

For readers who are interested in the past, the book includes a chapter with some historical aspects and milestones in ESO’s development, and a fascinat-

ing description of the early search for sites by the German astronomer Jürgen Stock, whose work played a key role as the ESO Council took its initial decision about where to locate the observatory.

Dirk Lorenzen is also the author of the CD-ROM entitled *3D Atlas of the Universe*, which is produced in a collaboration between ESO, USM (Munich) and Planetary Visions (University College, London). Apart from audio and video clips from Paranal, the CD-ROM also contains spectacular 3D images of astronomical objects, thanks to a unique rendering software developed by Planetary Visions.

The CD-ROM will initially be available in English and German, with a French version under preparation.

On the background of the status of post-World War II astronomy in Europe, the video *Europe Reaches for the Stars – Forty Years ESO* traces the evolution of ESO, from the humble beginnings until today – with the VLT in full scientific operation and VLTI in the development stage – and projects the current successes into the future.

The 50-minute film includes rich historic footage not shown before and interviews with the past directors general. Scientific highlights are exposed, both in the context of the general development of Astronomy and the research activities at ESO.

The film is produced by ESO's EPR department and will initially be available with English narration.

Finally, a planetarium show with the title *Les mystères du ciel austral* has been developed in collaboration with APLF, the association of French-language planetaria and with the help of its sister association in the German-speaking countries (ADP). Prof. Agnès Acker from the Louis Pasteur University of Strasbourg and Marc Moutin, head of the planetarium at the Cité de l'Espace in Toulouse, have been the driving forces behind the project, with the technical preparation of the show being executed by Master Image Group of France.

This show, which focuses strongly on the VLT and the recent scientific results, is initially produced in two versions, customized for France and Germany, and other language versions may be produced.

First Teachers Training Course at ESO HQ was a Great Success

A. BACHER, R.M. WEST, ESO

On August 20–24, 2002, School Teachers from a dozen different European countries (including eastern countries) came to ESO HQ to learn about recent developments at ESO. The training course called FAST2002 (**Fron**tline **A**strophysics for **S**chool **T**eachers) consisted of several lectures and workshops.

The lectures were given by ESO astronomers and dealt with ESO in general, VLTI, OWL, and Science at ESO.

During the first three workshops, the teachers went through three of the four ESA/ESO Astronomy Exercise Series (see *The Messenger* No. 107, March 2002), trying out different methods of determining astronomical distances.

The fourth, major workshop aimed at creating new exercises. Two different topics were discussed in great detail. One was to determine properties of a Transneptunian Object using six different images, kindly provided by Olivier Hainaut (ESO La Silla).

The other topic was about Extrasolar Planets. Results taken at the Leonhard Euler Swiss Telescope at La Silla by the group of Michel Mayor were elaborated in ways that students of different ages can understand. This included the determination of planetary parameters and how to judge if life would be possible on the planet (concept of "habitable zone").

In addition there was a poster session, where the participants presented projects about their own educational work.

Veselka Radeva from Bulgaria made the following statement, when she was asked about her impression of this course: "Excellent organization, wonderful presentation of the observational possibilities of ESO, excellent work on the existing exercises and efficient creative work for the invention of new exercises by an excellent group of teachers. Thank you very much!"

After this good start, the ESO Educational Office now looks forward to organizing more teacher training courses in the next years.

Participants in front of the ESO Headquarters building in Garching. Photo taken by Gian Nicola Cabizza.

ANNOUNCEMENTS

STRUCTURE EVOLUTION AND COSMOLOGY:

New synergy between ground-based observations, space observations and theory

An international workshop to be held at ESO/Santiago, Chile, on October 28–31, 2002

Sponsoring Organizations:

European Southern Observatory (ESO); Centre National d'Etudes Spatiales (CNES); Commissariat a l'Energie Atomique CEA); DAPNIA/Service d'Astrophysique (SAp)

Scientific Rationale:

With the upcoming of the new generation of powerful wide-field instruments (XMM, Megacam, VIRMOS, Integral, SIRTF, GALEX, VLA, Omegacam/VST, VISTA...), the first decade of the XXIst century is to open a decisive era in the study of large-scale structure formation.

These observational developments are being complemented by considerable numerical and semi-analytical advances. The workshop aims to bring together groups closely involved in carrying out and coordinating ground-based and space surveys with efforts made in modeling the formation of structures. An important point will be the optimization of observing strategies and science returns in the context of th forthcoming Virtual Observatory. First results from various on-going programmes will be presented. Attendance by young researchers (students and postdocs) is most welcome. In this respect, a half-day cosmology introductory session will be given.

Scientific Organizing Committee:

M. Birkinshaw (Bristol), R. Ellis (Caltech), M. Kamionkowski (Caltech), C. Lonsdale (Caltech/IPAC), M. Pierre (CEA), A. Refregier (Cambridge), J. Silk (Oxford), S. White (MPA).

Local Organizing Committee:

D. Alloin (ESO), R. Cabanac (ESO), H. Quintana (PUC), J. Willis (PUC).
More details are available at: http://www.eso.org/cosmology2002

STELLAR CANDLES FOR THE EXTRAGALACTIC DISTANCE SCALE

An international Workshop to be held at the Universidad de Concepción, Chile, on December 9–11, 2002

Sponsoring Organizations:

CONICYT/FONDAP Institute for Astrophysics, Chile; European Southern Observatory; Fundación Andes; Universidad de Concepción, Chile

Organizing Committee:

D. Alloin, ESO (Co-chair); P. Fouqué, Paris;
D. Geisler, Concepción; W. Gieren, Concepción (Co-chair);
G. Pietrzynski, Concepción; T. Richtler, Concepción

Rationale of the workshop:

The past decade has seen a huge effort to improve the calibration of the extragalactic distance scale. Stellar methods of distance determination are used to measure the distances to nearby galaxies, setting the zero point of the extragalactic distance scale. Yet, comparison of the results from a variety of stellar standard candles shows that there are significant systematic uncertainties attached to most, if not all stellar methods of distance measurement, preventing a truly accurate calibration of the distance scale. This workshop will bring together leading experts on the most prominent stellar standard candles including Cepheid variables, RR Lyrae stars, Type Ia supernovae, blue supergiants, planetary nebulae, novae and globular clusters to explore their current usefulness for the calibration of the distance scale, and for putting constraints on the Hubble constant as a fundamental cosmological parameter. Special attention will be given to improve our understanding of systematic uncertainties in the various methods of distance measurement, and in designing strategies to reduce these uncertainties in the near future.

More details can be found at: workshop@coma.cfm.udec.cl
http://cluster.cfm.udec.cl

A meeting on

Science Operations with the Atacama Large Millimeter Array

will take place at ESO, Garching bei München, on Friday, November 8, 2002, from 9 a.m. to 4 p.m.

The Atacama Large Millimeter Array (ALMA) project is an international collaboration between Europe and North America to build an array of telescopes that will operate at millimetre and submillimetre wavelengths at the high-altitude (5000 m) Chajnantor site in Chile. It reached a critical milestone this summer when on July 9, the ESO Council approved the European participation through ESO in the bilateral project. On August 16, the US National Science Board authorized the US share of the ALMA construction.

The aim of this one-day meeting is to provide an overview and update to the European astronomy community of the ALMA project as it enters the construction phase, and to solicit input from the community on science operations and user support for ALMA. Topics will include:

- Overview of project and project status;
- Major science drivers; ALMA as a complement to facilities at other wavelengths;
- Science operations plan;
- Regional Support Centres: core and additional functions;
- Toward a European Regional Support Centre;
- Open discussion

More details on ALMA can be found in the March 2002 issue of *The Messenger*, see http://www.eso.org/projects/alma/info/brochure.pdf, and the ALMA web site http://www.eso.org/projects/alma/

To register for the meeting and obtain further information, please send a message to Samantha Milligan (smilliga@eso.org) by October 5. There will be no registration fee. A second announcement will be distributed to participants in October.

Organizing Committee:

R. Bachiller, A. Benz, R. Booth, P. Cox, E.F. van Dishoeck, S. Guilloteau, R. Kurz, J. Richer, P. Schilke, P. Shaver, M. Walmsley.

PERSONNEL MOVEMENTS

International Staff

(1 July 2002 – 30 September 2002)

ARRIVALS

EUROPE

BLONDIN, Stéphane (F), Student
ESCHBAUMER, Siegfried (D), Infrared Laboratory Technician
IVANESCU, Liviu (R), Assembly Integration and Testing Engineer
LEONI, Marco (I), Astrophysical Virtual Obs. Archive Software Engineer
MENGEL, Sabine (D), User Support Astronomer
MOTTINI, Marta (I), Student
SCALES, Kevin (USA), Optical/Electrical Engineer
THILLERUP, Jesper (DK), Electronics Technician
VAN DEN ANCKER, Mario (NL), User Support Astronomer
WEGERER, Stefan (D), Mechanics Technician
WERNER, Daniela (D), Associate

CHILE

DALL, Thomas (DK), Fellow
NÜRNBERGER, Dieter (D), Fellow

DEPARTURES

EUROPE

BRANDNER, Wolfgang (D), AO Instrument Scientist
CHADID, Merieme (MA), Fellow
DEVILLARD, Nicolas (F), Astronomical Data Reduction Specialist
GRAZIAN, Andrea (I), Student
KIM, Tae-Sun (ROK), Fellow
PANCINO, Elena (I), Student
RIVINIUS, Thomas (D), Fellow
STOLTE, Andrea (D), Associate

CHILE

ATHREYA, Ramana (IND), Fellow
BÖHNHARDT, Hermann (D), Data Flow Operations Astronomer
HUTSEMEKERS, Damien (B). Operations Staff Astronomer
JONES, David Heath (AUS), Fellow
RABELING, David (NL), Associate
RATHBORNE, Jill (AUS) Associate SEST

Local Staff

(1 June 2002 – 30 June 2002)

ARRIVALS

CERDA HERNANDEZ, Susana, Telescope Instrument Operator
PREMINGER HEYUM, Daisy, Data Handling Administrator

CORRIGENDUM

The Horsehead Nebula on page 34 of the June 2002 issue of *The Messenger* (No. 108) was erroneously attributed to the ESO/MPG 2.2-m Telescope.

The photo was produced from three images, obtained with the FORS2 multi-mode instrument at the 8.2-m KUEYEN telescope at Paranal. The images were prepared by Cyril Cavadore (ESO-ODT), by means of Prism software.

ESO, the European Southern Observatory, was created in 1962 to "... establish and operate an astronomical observatory in the southern hemisphere, equipped with powerful instruments, with the aim of furthering and organising collaboration in astronomy..." It is supported by ten countries: Belgium, Denmark, France, Germany, Italy, the Netherlands, Portugal, Sweden, Switzerland and the United Kingdom. ESO operates at two sites in the Atacama desert region of Chile. The new Very Large Telescope (VLT), the largest in the world, is located on Paranal, a 2,600 m high mountain approximately 130 km south of Antofagasta, in the driest part of the Atacama desert where the conditions are excellent for astronomical observations. The VLT consists of four 8.2-metre diameter telescopes. These telescopes can be used separately, or in combination as a giant interferometer (VLTI). At La Silla, 600 km north of Santiago de Chile at 2,400 m altitude, ESO operates several optical telescopes with diameters up to 3.6 m and a submillimetre radio telescope (SEST). Over 1300 proposals are made each year for the use of the ESO telescopes. The ESO headquarters are located in Garching, near Munich, Germany. This is the scientific, technical and administrative centre of ESO where technical development programmes are carried out to provide the Paranal and La Silla observatories with the most advanced instruments. There are also extensive astronomical data facilities. ESO employs about 320 international staff members, Fellows and Associates in Europe and Chile, and about 160 local staff members in Chile.

The ESO MESSENGER is published four times a year: normally in March, June, September and December. ESO also publishes Conference Proceedings, Preprints, Technical Notes and other material connected to its activities. Press Releases inform the media about particular events. For further information, contact the ESO Education and Public Relations Department at the following address:

EUROPEAN
SOUTHERN OBSERVATORY
Karl-Schwarzschild-Str. 2
D-85748 Garching bei München
Germany
Tel. (089) 320 06-0
Telefax (089) 3202362
ips@eso.org (internet)
URL: http://www.eso.org
http://www.eso.org/gen-fac/pubs/messenger/

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