THE MESSENGER

EL MENSAJERO

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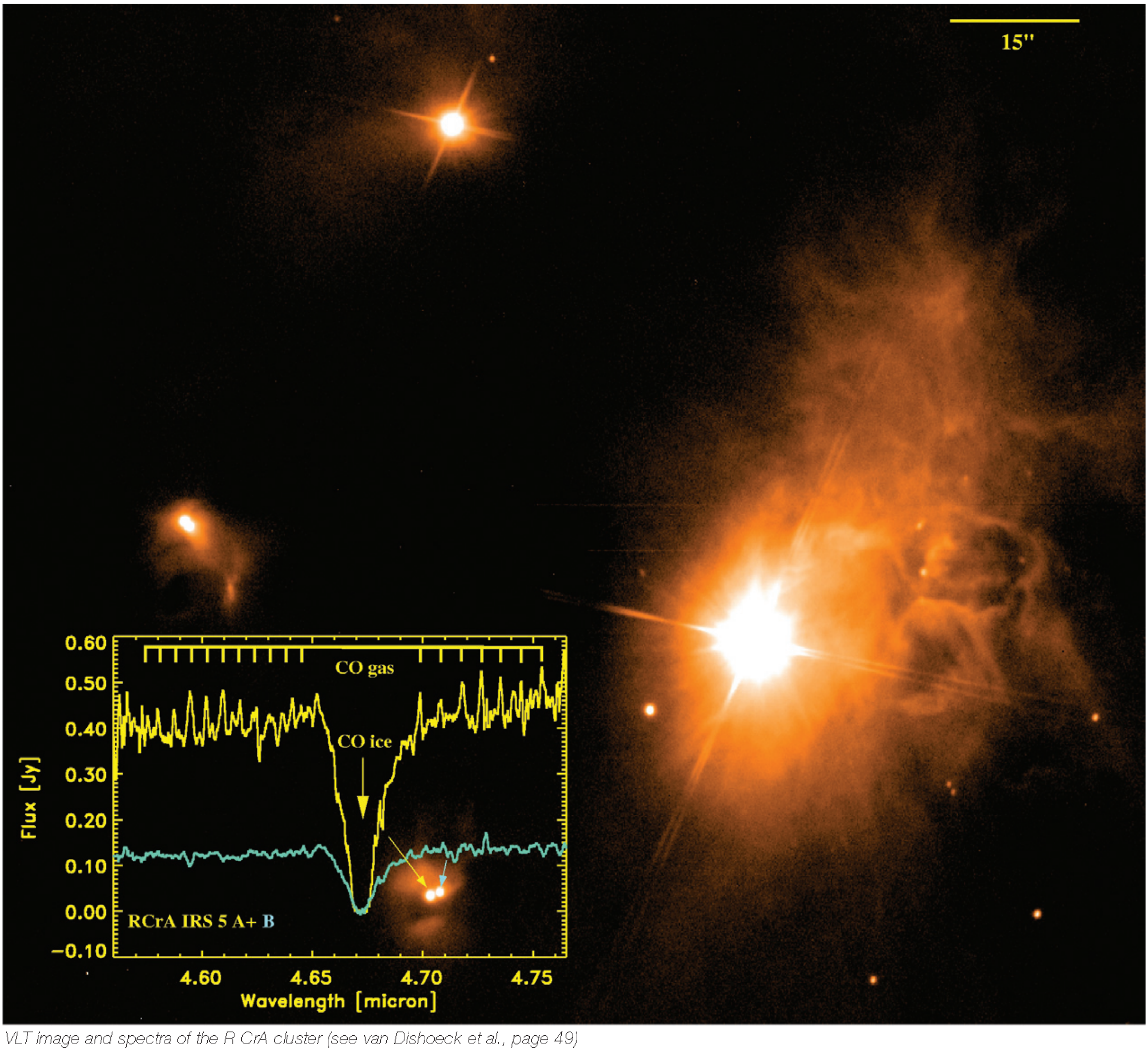


VLT image and spectra of the R CrA cluster (see van Dishoeck et al., page 49)

THE HISTORY AND DEVELOPMENT OF THE ESO ACTIVE OPTICS SYSTEM

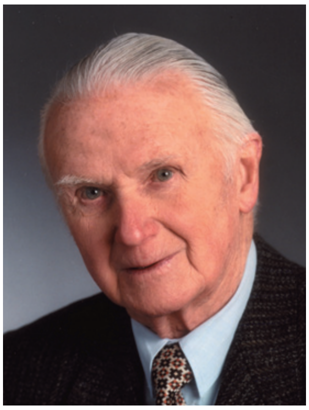
THE ACTIVE OPTICS SYSTEM IS THE FUNDAMENTAL OPTICAL CHARACTERISTIC OF THE ESO NEW TECHNOLOGY TELESCOPE (NTT) AND VERY LARGE TELESCOPE (VLT). THE NTT PIONEERED THIS SYSTEM. WITHOUT IT, THE VLT, WITH ITS THIN, VERY FLEXIBLE MIRROR, COULD NOT GIVE A USABLE OPTICAL IMAGE AT ALL.

R. N. WILSON

THE TERM "ACTIVE OPTICS" is normally, and I believe correctly, associated with the ESO system developed for telescopes with monolithic primaries and applied in the ESO NTT and VLT telescopes. Technical systems based on the same principles, also with thin meniscus primaries, are used in the other very large telescopes (8 m) of GEMINI (2x) and SUBARU (1x). Other important telescopes with monolithic primaries, but using stiffer lightweighted blanks, are also actively controlled, the most notable being the WIYN (3.5 m) telescope, the three 6.5 m telescopes of the MMT upgrade and the two Magellan telescopes, and the two 8.4 m telescopes of the Large Binocular Telescope (LBT). The other major branch of modern optical telescope development, that using segmented mirrors, was pioneered and exemplified by the two Keck 10 m telescopes. This has its own system of active control of the segmented primary. Although the aim is the same, the technologies involved in the control systems of monoliths and segmented mirrors are essentially different. This is the case because the flexure function of a monolith has no discontinuities, which are fundamental to the nature of segmented mirrors. The ESO active optics system is "closed loop" in the sense that correction is made by measurements in real time of the quality of a star image. This is not the case with the Keck telescopes which correct the primary with an internal active system. "Closed loop" in the ESO sense is also not necessarily used in the other active systems for monolithic primaries: some of them rely on "precalibration" of the flexure effects (see page 9).

In this article, I shall confine myself to active optics with monoliths. When was the idea of active optics for monoliths first conceived? We must remember that *all* "classical" telescopes had monolithic mirrors, normally made as thick and stiff as possible to avoid flexure. The idea of segmenting goes back to Lord Rosse in 1828, but was first realised in practice by Horn d'Arturo in the 1950s using a fixed primary. Keck I, finished in 1992, was the first such telescope with a normal 2-axis mounting. So it was logical that earlier ideas of active optics should have been limited to monoliths. The history of the development of mirror support systems and of active optics for monoliths is given in relatively complete form in my second book, Reflecting Telescope Optics II (Wilson 1999; W99 in the following). The present article is a simplified and much abbreviated version, with more emphasis on the personalities involved.

A friend of mine at ESO, who comes from the rich French tradition in telescope optics, recently suggested to me that active optics (and the Ritchey-Chrétien (RC) aplanatic telescope) might have been invented by one of my great French heroes in optics: Jean Bernard Léon Foucault. Reference is made in this connection to his largest – 80 cm– Newton telescope completed in 1862 (Wilson 1996). With all respect to the great genius Foucault, I believe that neither of these inventions would have been possible at that time. For active optics, no technology existed for *measuring* in a systematic way the errors in a star image, although Foucault's invention of the knife-edge test enabled a very sensitive *qualitative* assessment. The detector available, the eye, was sensitive but highly non-linear; photography was terribly slow and insensitive, and also non-linear. Third order aberration theory, due to Seidel, was only published in 1856 and existed only for spherical surfaces, not for a Newton parabolic primary. The complete theory for telescopes was only published in 1905 by Karl Schwarzschild. Lack of theory was also the reason Foucault could not have invented the *aplanatic* (RC) telescope. Both Schwarzschild (1905) and Chrétien (1910) used the Abbe "sine condition" (Wilson, 1996) as the basis for setting up aplanatic (i.e free not only of spherical aberration, but also of field coma) telescope forms, unknown to Foucault. No, realistically Foucault, a scientific and technical genius, conceived and adjusted his mirror supports to get the best image he could. But this was *not* active optics: it was a procedure which had been used throughout the history of the reflecting telescope. It had been used empirically by James Short, William Herschel, Lord Rosse and others before the invention of modern support forms by Lassell in 1842 (astatic lever) and T. Grubb, also about 1842 (whiffle tree) (see W99).



*I **should like** to dedicate this article to GERHARD SCHWESINGER (b. 08.01.1913 in Krappitz, Upper Silesia, d. 03.11.2001 in Heidenheim, Württemberg: see photo), who developed the first complete Fourier theory for the support of primary mirrors of telescopes and thereby also stimulated my thinking on active optics; and to LO WOLTJER whose vision and support led to the NTT and VLT based on my active optics concept.*

We must conclude that active optics was anyway a concept of the 20th century. I believe the first ideas of a systematic process came from the great French optician Couder in 1931 and (probably independently) from the great Russian optician Maksutov in 1948* (W99). Couder recognised the high sensitivity to the aberration astigmatism of mirrors which were inadequately supported and suggested that such "regular" errors might be corrected by "a system of forces suitably applied". He concluded that astigmatism left over from manufacture could be thus corrected. But as with Foucault, Couder had no means of *measuring* astigmatism in a star image. It could only be done *qualitatively*, off-line, in a slow process (effectively dc in modern terms of active optics). A rapid, repetitive, quantitative correction process was technically out of the question. Similarly, Maksutov proposed the adjustment of Lassell type astatic support levers to correct such errors observed with an ocular or a Foucault knife-edge, recognising too that the result was only valid for one zenith angle of the telescope. Since he had no mathematical algorithm for applying the correction, he suggested trial-and-error. Again, as with Couder, such a procedure was so cumbersome that its application could normally only be a once-off process at initial set-up (i.e trial-and-error, qualitative, dc active optics). Understandably, although these suggestions were highly perceptive, they never led to any practical results or to serious further thinking. The time was still technically not ripe!

In 1968 I was already working, at Carl Zeiss in Oberkochen, indirectly for ESO, on a study for the optics of the ESO 3.6 m telescope. This made me aware of the *centering problem* of such Cassegrain telescopes. A lateral decentering tolerance of the axis of the secondary mirror to that of the primary, in order to maintain the optical specification of this telescope, would have to be set at well under 1 mm. In discussions with my colleagues in mechanics, it was clear that this was virtually impossible in practice, bearing in mind exchange operations of the top-end units. It became clear to me why the aberration produced (decentering coma, a particularly unpleasant, asymmetrical degradation of the star images) was the main curse of the Cassegrain telescope in practice: I called it "Cassegrainitis". It struck me then that, *if one could measure its amount and direction*, its correction online would be a relatively simple mechanical operation requiring only a small lateral shift of the secondary to correct the error. This was the mental start of a complete system of correction, which later became the ESO active optics system. In the course of further discussions with Dr Gerhard Schwesinger, a brilliant engineer and mathematician who also had excellent knowledge of optical aberration theory, I became aware of his general Fourier theory of the flexure aberrations introduced by support errors in primary mirrors. I realised that the circular nature of the mirror led to polynomial functions which were completely equivalent to those defining optical aberrations, although the mathematical boundary conditions are not the same. A light went on in my head! It would be perfectly possible to interpret all the flexure effects in terms of the classical optical polynomials of Hamilton or Zernike. Again, *if one could measure their amount and direction*, one could correct all such flexure terms by appropriate force changes of the supports, calibrated from the Schwesinger theory. Above all, this would apply to the lowest order term, by far the most important as Couder had recognised, astigmatism. This was particularly interesting, as Schwesinger's calculations showed that maintenance of the absolute tolerances for the astigmatism specification was just as impossible in practice as the maintenance of an absolute decentering tolerance.

It followed that, when I formally joined ESO in September 1972, I had had the whole theoretical basis of active optics in my head for several years. However, not only the central problem of image measurement and analysis remained to be solved, it was also necessary to convince other colleagues and astronomers of the immense possibilities. In spite of the interest and vital information given by Schwesinger, Zeiss showed no interest in pursuing it. I think an industrial concern, however brilliant and engaged in the matter, would anyway have been too far removed from practical telescope use. In other words, an observatory concerned with practical telescope development for a functioning observing site was essential. Of course, I had this in mind when I joined ESO. However, I soon learned that ESO had other problems far more urgent: the successful realisation of the 3.6 m telescope, on which its reputation and, indeed, its future existence depended. This was a conventional telescope following the line of the "Bowen-class telescopes" (Wilson, 1996) and had no significant innovative features. Nevertheless, at its completion, the 3.6 m telescope gave me the opportunity, during its optical set-up, alignment and test in 1976, to simulate the whole theoretical basis of an active optics system. The test system used was "classical Hartmann". This was a painfully slow and exhausting process, measuring photographic Hartmann plates in a semi-automatic mode. But it enabled our team (essentially Francis Franza, Maurice Le Luyer and myself) to do a rigorous aberration analysis of the finished telescope. This led to my definition of the "Intrinsic Quality" (IQ) (see Fig. 1) of a telescope as that optical quality which would be achieved in principle if all the correctable terms measured could also be corrected in practice. In the 3.6 m telescope, there was no means of doing this: the primary mirror was too thick and rigid to allow it, even if a suitable support system had been available. Furthermore, a far simpler, rapid and on-line image analysis system than that used would be essential.

The essential elements of my active op-

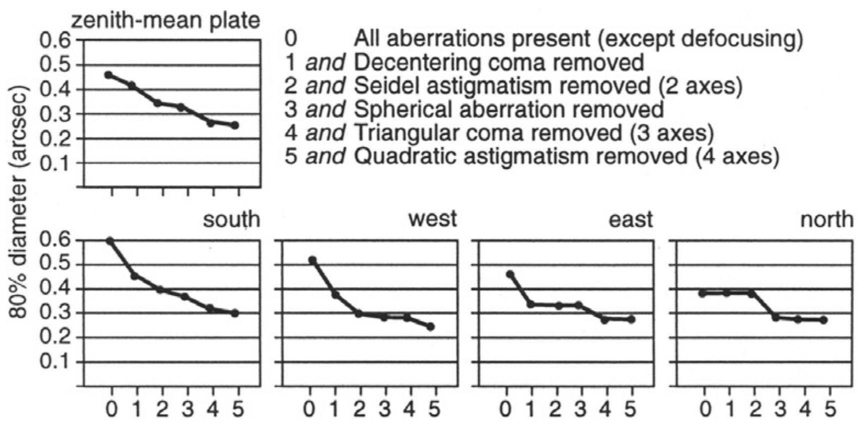


Figure 1: Results of classical Hartmann tests of the conventional ESO 3.6 m telescope in 1976, illustrating the theoretical improvement after successive removal of polynomial terms. The mean right-hand point of the functions gives the Intrinsic Quality (IQ) of the telescope. (W99)

*In W99, I expressed my gratitude to D. Enard and K. Bahner for drawing my attention to these proposals by Couder and Maksutov, respectively.

tics system were first published formally in Wilson (1977). At that time I called the concept a "feedback" telescope. The term "active optics" was used in a more explicit publication in Wilson (1982), which essentially gave the whole system of the NTT except for the practical details of the image detection and analysis. At the previous verbal presentation in 1981 at an optical conference in Graz, an American in the audience asked me at the end: "Have I understood you correctly, that you propose a telescope in which the optical system continuously checks itself and optimizes itself fully automatically?" I replied: "Yes, I congratulate you, you have understood it perfectly". He replied: "Well, my feeling is that such a system will never be realisable in practice". I hope he has since followed developments and registered what has emerged with the NTT and VLT.

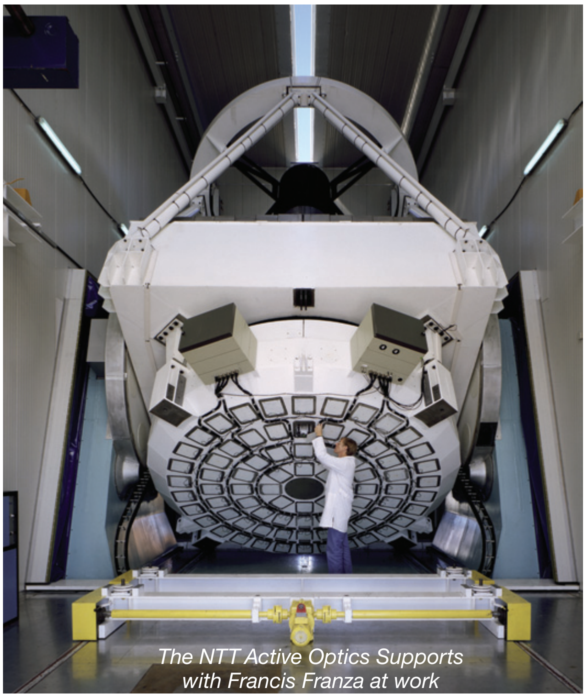
As is always the case with radically new developments, parallel thinking had been going on independently by other groups. In 1970, a paper was published by Creedon and Lindgren in the American journal "Automatica", a journal hardly known in the astronomical or optical communities. This work had been commissioned by NASA in connection with the 2.4 m Hubble Space Telescope (HST) and was reported in detail in secret NASA reports (W99). I only became aware of this work about 1985 through Oberto Citterio. The authors, who were brilliant control engineers but not versed in optical aberration theory, proposed a very complex mathematical scheme for the active control of the HST. In a (secret) NASA study of 1973, Howell and Creedon developed this approach further, improving it fundamentally by proposing a *modal* approach, also a fundamental feature of my own concept as thought out at Zeiss in 1968 with Schwesinger, from his own modal theory. However, Howell and Creedon's algorithm was extremely complex and required the optimization of the *support geometry* according to the errors measured. In contrast, the ESO system algorithm can be applied directly to *any* normal passive support, whatever its geometry. Since the Howell and Creedon proposal was completely impractical, it was rejected by NASA. Because the HST primary has a very stiff, lightweighted primary, the forces required for active optics correction of the initial spherical aberration error, discovered after launch in 1990, would have been unrealisable in practice. With a thin, relatively flexible primary similar to the NTT, the ESO active optics system could have corrected it immediately. Although unknown to the general telescope community at the time and not suitable for practical application, these studies had some valuable theoretical features, notably modal control with so-called "natural modes". The measurement system proposed was not "closed-loop" in the ESO system sense, using a natural star image in real time, but an experimental precalibration of deformations of the primary for given forces and determined by interferograms. In any event, the astronomical community in the United States, with a few exceptions such as Aden Meinel, showed little awareness or interest in the potential of active optics until the late 1980s when the ESO NTT produced its first results. Before the NTT development at ESO, the same was true in Europe. In the early 1970s, a very cheap low quality 4 m IR spectroscopic telescope was built in France by Connes, Chevillard et al. (1989). This used a primary with 36 square segments, similar in principle to the later Keck 10 m project. However, unlike the Keck, it used a closed-loop feedback control system based on measurements of a natural star image, in principle like the ESO system for monoliths. The detector was a circular aperture passing flux to a photo-multiplier for each segment. Image analysis in the ESO system sense would hardly have been possible with this detection system. The image quality aimed for was very low, 10 arcsec, but the segments were so poor that the image was more like 10 – 20 arcsecs. The project was apparently known to some ESO astronomers, but was not communicated to the engineers: apparently it generated no interest. Finally, it was abandoned in 1975 because of total lack of interest and support in the French astronomical community.

The Origins and Development of the ESO NTT and VLT

The ESO Technical report No. 8 in 1977, concerned with the image analysis of the newly set up 3.6 m telescope, gave the first account of the theoretical basis of an actively controlled telescope with a monolithic mirror with the ESO system. It was followed in the same year by the formal paper (Wilson, 1977) at the ESO Conference on "Optical Telescopes of the Future". At this conference, Prof. Woltjer also gave a paper assessing the great merits, above all for spectroscopy, of larger ground-based telescopes and thereby justifying astronomically the construction of a 16 m telescope. He left it open whether this should be a single 16 m telescope, or an array of smaller telescopes. Such forward thinking was legitimate and necessary for ESO at that time following the successful completion of the 3.6 m – indubitably essential for the future existence of the organisation. Immediately following the conference, Woltjer asked Richter, Chief Engineer in charge of the 3.6 m, to coordinate a study of three options: 1 x 16 m, 4 x 8 m, 16 x 4 m. Although Richter favoured the 1 x 16 m option, there was general agreement at ESO in favour of 4 x 8 m. I myself was strongly in favour of this option. A 16 m telescope was technologically too big a step in size, while 16 x 4 m represented *no* step in size and was politically too banal not to suffer reduction in the number of telescopes to save money. However, at that time, there was no clear idea what optical solution would be available for 8 m unit telescopes, let alone a 16 m. The concept of the 10 m Keck was just published, but design studies were only just starting. The Angel technology of lightweighted blanks (a further development of Palomar) had not then taken off, and the Multi-Mirror-Telescope (MMT) was only completed in 1979 and comprised only small telescopes. Already in these discussions on an ESO VLT, I had my active optics solution in mind. But a trial on a smaller-size telescope seemed to me essential. Shortly after these discussions, the extension of ESO by the membership applications of Italy and Switzerland provided a marvellous new perspective at just the right time: the entrance fees could perhaps fund a new test telescope to try out new technolgy. Woltjer asked Richter to make a cost estimate for such a 3.5 m New Technology Telescope (NTT). At that stage, the only "new technology feature" envisaged was an alt-az mounting, which had been pioneered by the Russian 6 m telescope completed in 1976, but no western project had had the courage to take this fundamental step. This cost estimate enabled political support for the NTT to be marshalled.

At this time, I was spending a most instructive year on La Silla, learning about the practical (maintenance) problems of the many (and varied) telescopes at our ESO observatory. Everything I saw convinced me further that active optics was the only answer to the problem of maintaining optimum optical quality with telescopes in practice. Back in Europe in the summer of 1980, the big event for ESO was the move from Geneva to Garching in Germany. Since Richter left ESO at this point, the position in charge of the Telescope Group was free and Woltjer asked me to fill it. I was happy to do this, for my central interest had always been the telescope optics side, although my final position in Geneva had been in charge of the Instrumentation Group. For the Telescope Group in Garching, although other tasks were not negligible (e.g. the building for the 2.2 m telescope of the MPIA or the achromatic plate for the Schmidt telescope), the NTT was the central project and was exactly the project I had longed for. I think I can truly claim that I determined every major characteristic of this telescope (the alt-az mount was taken over from Richter and was self-evident for a New Technology Telescope) – not always to the pleasure of all the astronomers. For example, I rejected not only a prime focus but also a Cassegrain focus, equipping the telescope only with two symmetrical Nasmyth foci. This meant that complex changes of foci as in the 3.6 m were totally avoided. With an act of great courage and expression of confidence in my knowledge of optics, Woltjer accepted my active optics concept, but imposed one entirely reasonable and prudent condition: that the NTT should work in the *passive mode* (i.e. without active optics) to the same specification as the classical (passive) 3.6 m telescope. This condition forced me to increase the thickness of the NTT primary from the 1:18 ratio I had envisaged to 1:15. This reduction in flexibility reduced the dynamic range of the active correction – see below concerning "First Light". With the proven success of the active optics, 1:18 would have been better, but I still accept Woltjer's imposed condition as correct at the time. The optics team was minimal in 1980 and consisted essentially of Francis Franza and myself with valuable assistance from Bernard Delabre on the optical design side. Quite early on I decided that it was too risky to go ahead with the final active optics system without a smaller scale experiment. This led to the 1 m-mirror experiment in the optics lab, in which Paul Giordano played a fundamental part. However, there was a serious lack in our optics group: a physicist to deal with the image analysis side and the necessary software development. This gap was filled by the engagement of Lothar Noethe, who came from Siemens. His application for the ESO job was one of the greatest pieces of good fortune in our whole active optics development. The presence of Francis Franza was the other essential pillar in the NTT development. Francis was engaged in 1973 in Geneva and from that time on we developed a perfect working symbiosis.

The 1 m-mirror experiment represented much work and was finally successful in demonstrating the practicability of the ESO active optics system. This was also our first trial of the image analyser based on the Shack-Hartmann principle. I had learned of this invention of Roland Shack (whom I had met at the Imperial College of London University in the early 1960s) about 1979, when he was a professor at the Optical Sciences Center in Tucson. I visited him with Francis and he was delighted at last to find someone who was deeply interested in his system of optical quality measurement and who wished to apply it immediately. The astronomical community in Tucson had shown no interest at all. Shack gave me an "S-H screen", a raster of lenslets, which he had made mechanically on a lathe. This had a serious phase defect, but was usable and enabled us to operate our image analyser. Initially, the detection was with photographic plates and, to get rapid results, I favoured doing the whole 1 m-experiment with plates. But Lothar Noethe wished to initiate CCD technology and worked also with a CCD which had just become available. The final results were only published in 1988 (Noethe et al. 1988, W99), but already earlier they had given us full confidence to complete the NTT active optics system. The CCD as detector was fundamental: there was no serious alternative for our closed-loop system working rapidly in real time. The 1 m-experiment was also fundamental for the VLT study, initiated by Woltjer in the 1980s after the financial approval of the VLT as an ESO project and technically led by Daniel Enard. He decided to follow completely the active optics, thin monolithic primary concept of the NTT. However, the VLT would require a much bolder approach than the (correctly) cautious approach of the NTT regarding the flexibility of the primary. The basic technical decisions on the VLT had therefore to be taken before the completion of the NTT First Light in March 1989. Essentially, the 1 m-experiment enabled those decisions to be taken with confidence.


The NTT Active Optics Supports with Francis Franza at work

Before the "Astronomical First Light" of the NTT we had what I called the "Technical First Light". This was the first time I saw a star image in the newly erected telescope. No adjustments had then been made: this phase of the operation was now starting and included the so-called "dc phase" of active optics, i.e. the fixed , once-off corrections – see pages 6-8. The star image I saw in a hand-held eyepiece did not please me. I looked at the defocused image inside and outside focus, a classical test procedure I had used for decades on many telescopes. The appearance indicated strong spherical aberration, a defect which became world famous two years later, when this aberration, indicating a "matching error" in the forms of the primary and secondary mirrors, was revealed in the Hubble Space Telescope. I hoped for the best, thinking perhaps there was a strong thermal effect in the local air of the building at that time. However, with the tests of the image that followed, my fears were confirmed: there was indeed a strong spherical aberration present. We were able to prove it was an error in the form of the primary. Exhaustive investigation, also with the manufacturer Carl Zeiss, showed that a spacer error had been made, as with the HST, in one of the so-called "null-test" systems. In fact, this error had been detected by a careful check of the system at Zeiss. However, owing to a misunderstanding of the sign of the spacer error, the error was corrected in the wrong direction, thereby doubling the resulting spherical aberration instead of eliminating it! The amount of spherical aberration was about the same as that found later in the HST. Our active optics system was able to correct it completely, although it used up about 80% of the dynamic range of correction available – see pages 8-9. This correction, saving a very costly reworking of the primary, was a marvellous demonstration of the power of active op-

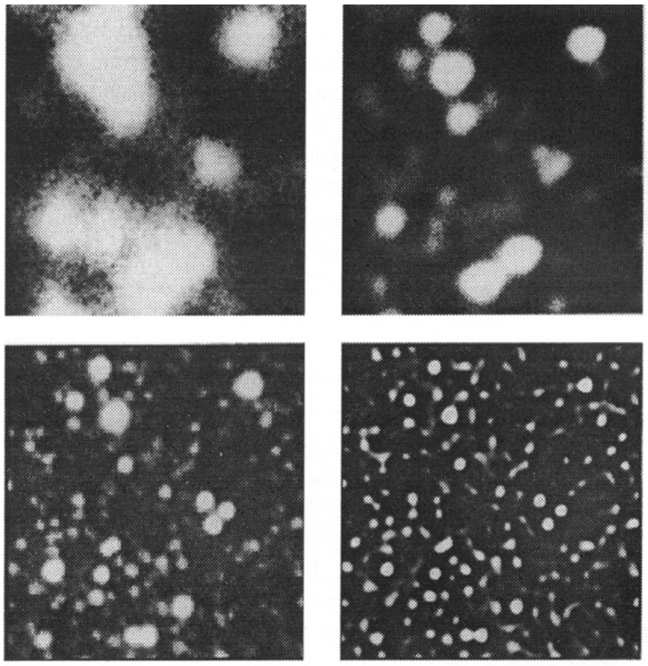


Figure 2: CCD pictures obtained at "First Light" with the ESO 3.5 m NTT in March 1989, compared with previous records of the same field (globular cluster ω Centauri). Upper left, ESO 1 m Schmidt; upper right, ESO 3.6 m telescope; lower left, ESO NTT raw image; lower right, NTT processed image. See text for details. From West, R. (1989).

tics to extend vastly the manufacturing tolerances of correctable aberrations.

The "Astronomical First Light" results of the NTT were so fantastic that they established it as optically the best telescope in the world at that time (1989). As is well documented (W99), the conditions were extraordinarily good both for external seeing and dome seeing: we were remarkably fortunate. This was also due to another new technology feature of the NTT, taken over and improved, from the MMT. This was the building concept, whereby the building rotates with the azimuth movement of the telescope. We improved the MMT building concept by removing the back wall, thereby allowing ventilation to pass laminarly through the whole building "slit" for the telescope. This feature has been very important for the excellent optical quality and, in somewhat modified form, has been taken over for the VLT.

Only one new technology feature which I envisaged was not realised. This was a second primary with an aluminium blank. This was finally abandoned for cost and time-scale reasons, but I believe that this decision was an error. The NTT would have been a perfect telescope to test the viability of aluminium as a blank option. Excellent and reasonable offers existed both for the manufacture of the blank and its "Canegen" coating and for the optical figuring. The existing blank in Zerodur is, of course, excellent: but the extreme zero expansion property of Zerodur (or ULE fused quartz) is no longer necessary for actively controlled telescope optics. The finite expansion coefficient of aluminium is largely compensated by its excellent thermal conductivity and active optics can easily handle residual expansion effects. Although interest in aluminium has since been shown, above all in France, no telescope of significant size has been equipped with an aluminium primary since the brilliant pioneer work of Mottoni for the Merate 1.37 m telescope (1969) in Italy (W99). This is unfortunate and demonstrates once again the inherent technical conservatism of the astronomical community: the refusal to abandon glass corresponds exactly to the inverse refusal to abandon metal (speculum) in the 1860s and to introduce chemically silvered glass! This led to the disaster of the Melbourne reflector, set up in 1869 (Wilson, 1996).

It follows from the above account that three very important aspects of the NTT technology came from the USA: the CCD detector, the Shack-Hartmann image analyser and the building concept. But the active optics concept for thin meniscus monoliths was a purely European development, which, apart from Roland Shack and Aden Meinel, was ignored or actively rejected in the USA until the "First Light" success in 1989.

The success of the ESO active optics concept has been wonderfully demonstrated by the best Full-Width-Half-Maximum (FWHM) star images recorded for the NTT and VLT. With "First Light" in March 1989, the NTT revealed a best star image for a CCD frame in the globular cluster Centauri of 0.33 arcsec FWHM – a world record at that time for a ground-based telescope. Richard West identified the field (only 12 x 12 arcsec because of the small size of the CCD used directly at the Cassegrain focus) and set up a beautiful comparison (West 1989, W99) which is reproduced here (Fig. 2). Upper left shows the field, suitably magnified, taken from a plate by the ESO 1 m Schmidt telescope in 1984 under modest seeing conditions (ca. 2 arcsec). Upper right is from a plate, considered excellent by normal standards, by the passive 3.6 m telescope with seeing about 1 arcsec. Already with this improvement, the "clumps of cotton wool" representing star images in the Schmidt plate have vastly improved. At the bottom left is the "First Light" frame with the NTT. The five separate images of the Schmidt became about 15 with the 3.6 m and number almost 100 with the NTT. (The bottom right frame shows further improvement by off-line processing; but this cannot be compared with the other three which are "raw images"). The enormous gain in resolution is striking and well-illustrated by the triple star right of centre. The Schmidt shows no resolution, with the 3.6 m the triple nature can be inferred without resolution, while the NTT resolves the three components completely. But at least as significant as the gain in resolution is the gain in *light concentration per star image*, giving a huge increase in depth penetration for the same exposure time.

Figure 3 reproduces the frontispiece of my second book (W99) and shows the UT No. 2 (Kueyen) of the VLT together with two beautiful photographs. The photo at the top right, a three-colour composite of the Spiral Galaxy NGC 2997, was taken with UT No. 1 (Antu) and the FORS 1 instrument on 5 March, 1999. In the near IR band, the FWHM of the best star images was 0.25 arcsec, a record at that time.

Some Basic Properties of the ESO Active Optics System

(a) Automatic optical Maintenance

As indicated in the first section, the ESO active optics system was conceived to remedy what seemed to me the most intractable problem of the "passive" telescopes built up till about 1980: the problem of optical maintenance of the finished telescope. The optical specifications of such telescopes (e.g. the ESO 3.6 m) were much inferior to those which have become normal for "active" telescopes, but they were still good. Furthermore, they were largely met by the manufacturers. The problem was that they could rarely be maintained in practical observatories. Often, they could be re-established

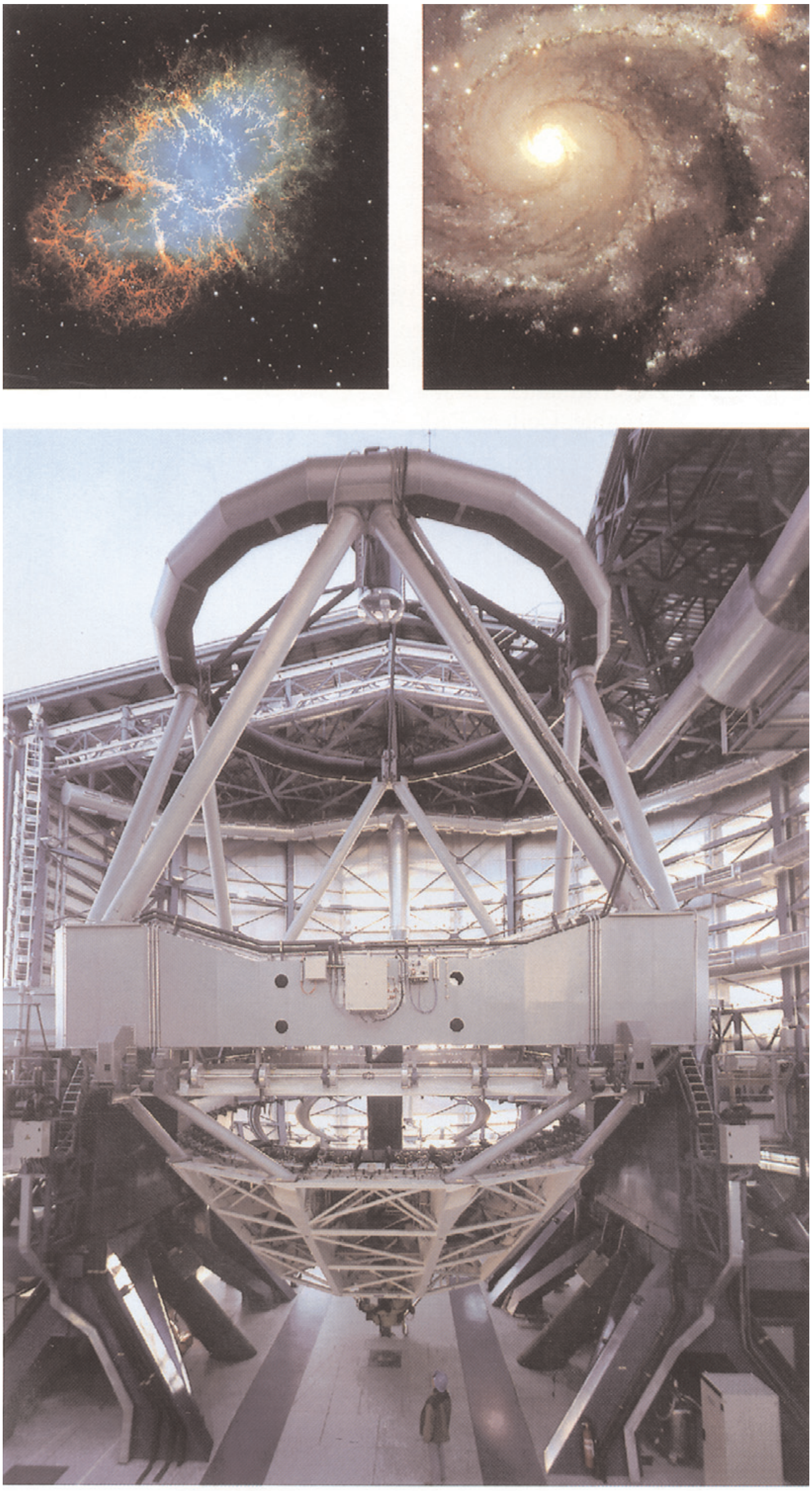


Figure 3: ESO VLT Unit Telescope No. 2 photographed in March 2000 by Hans-Hermann Heyer. The photo upper left shows the Crab Nebula taken with UT No. 2 and the FORS2 instrument on 10 November 1999. The photo upper right was taken with UT No. 1 and the FORS1 instrument on 5 March 1999 and shows the Spiral Galaxy NGC 2997. The best star image quality (in the near IR band) had a FWHM of 0.25 arcsec.

by careful adjustment in a complex off-line operation, but most frequently they declined again long before the next such operation. The aim of active optics was therefore to *automate* the whole optical maintenance procedure. In the NTT, the design aim was to re-optimize the quality automatically with a cycle time of *about 10 min*. This automation was never realised in my time (it was still initiated by hand). The NTT is very robust in its design (see previous section), and this manually initiated procedure could also ensure good quality. However, it depended on procedures being followed and, in the real world, this does not always happen. The VLT telescopes are not at all robust in this sense, because the primaries are about *50 times more flexible* than that of the NTT. Without its active optics, the VLT cannot produce a usable image. Fully automatic operation is thus essential, and optimization is performed *every 40 s*. Therefore, the period over which the optical performance can decline is reduced from what used normally to be weeks for a passive telescope to 40 s. Furthermore, the optimization is always complete, recovering fully the maximum potential of the telescope, whereas the old-fashioned, off-line procedures were rarely fully effective simply because the telescope was inevitably out of commission and there was always great time pressure. Also, the telescope designs were rarely "maintenance friendly" for the optics. The optimization cycle of the VLT means essentially that the optical quality must maintain itself for the change of zenith distances involved in tracking for 40 s.

Originally, the NTT software had no provision for automation of the active optics correction because we knew we had to learn from experience how this could best be realised. The initial huge success after First Light was therefore achieved by purely manual operation. By the end of 1990, we had sufficient practical experience to make an attempt at automation possible, but organisational changes prevented any further advance in practice. Finally, the wise decision was taken to use the NTT as a test bench for the new VLT software, which was installed about 1996. This included, of course, the fully automated active optics correction cycle. Recently, the VLT software for the active optics has been further improved to eliminate aberration effects of the air and to make the choice of reference star more flexible (i.e. easier) because the brightness and colour are less critical. This was from the start a problem with the NTT, for which the availability of sufficiently bright stars was uncertain. This problem was exacerbated by the raster of the Shack-Hartmann detector, which was laid out cautiously with 40 × 40 sub-apertures. With more experience, this was reduced to 20 × 20 sub-apertures for the VLT, which anyway gives more light because of the larger aperture. Although the S.-H. raster is unchanged, it has been possible (according to current information from Olivier Hainaut) to operate a partial automation of the NTT active optics for astronomical exposure times longer than ca. 2 – 3 minutes and under stable conditions for the residual aberrations. Typically, about 5 – 7 image analyses are averaged out, giving then a correction every 5 – 10 minutes. This procedure is therefore close in cycle time to my original proposal.

(b) Frequency bandpasses of active and adaptive optics

Table 1, taken from W99, shows the basis of all this thinking in terms of the "Bandpass" or frequency of all the sources of image degradation. The most important conclusion from this Table is that all the error sources are dc or of bandpass <10^{-2} Hz except (8), (9) and (10) and partly (7). This is of central importance, because it is roughly the frequency limit of *normal* active optics correction in *closed-loop* and implies that two thirds of all the errors listed are amenable to it. The definition of the *correction bandpass* is an essential feature of any control system. The situation with my definition is shown in Fig. 4.

The normal active optics bandpass A, as defined for the NTT, goes from dc to 1/30 Hz. The limit of 1/30 Hz simply corresponds to the well-known fact that, in the presence of good astronomical external seeing, an integration time of 30 s is sufficient to "integrate out" the external seeing completely, giving a round image corresponding to the external seeing quality, the classical definition of "seeing". (If the integration time is inadequate, the image analyser will give completely erratic and wrong results since random aberrations of the external seeing are included). For a frequency higher than 1/30 Hz (for inferior seeing at somewhat lower frequencies), we enter into the *adaptive optics bandpass* C, going to beyond 10^3 Hz, for the external seeing. In this bandpass, we are confronted with the phenomenon of the *isoplanatic angle* Θ (W99), that angle over which the phase of the error introduced by atmospheric seeing is essentially constant. Θ is a function of seeing quality, wavelength and the frequency. For visible light and an extended frequency band, the value of Θ is only a few arcsec and even at the lowest frequencies of bandpass C amounts to only one or two arcmin at most. For *closed-loop operation*, for which a reference star within the isoplanatic angle is required, this is a very serious limitation *compared with bandpass A for active optics*, for which there is no isoplanatic angle limitation at all and a reference star at any convenient point in the field can be used. The bandpass B, which I call the *extended active optics bandpass*, goes from 1/30 Hz to about 10 Hz. This is particularly important for Error 7 of Table 1, of which the higher frequency component can only be actively corrected within the limits of the isoplanatic angle. For the external seeing in general, unlimited correction will only be possible using artificial, laser-generated reference stars.

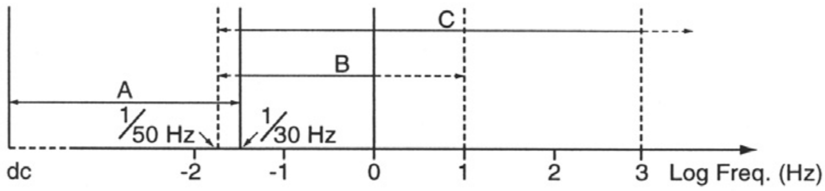


Figure 4: The bandpasses for active and adaptive optics correction. From original publication by Wilson and Noethe 1989 and W99.

(c) Modal control

A *modal* concept (i.e. successive terms of some polynomial with increasing powers of the parameters involved) has always been normal practice in optical design based on the theory of optical aberrations. As explained in the first section, I realised from discussions with Dr Schwesinger at Carl Zeiss in 1968 that the flexure terms in his theory of elastic flexure of circular mirrors could be interpreted in a similar way. The whole theoretical basis of active optics was already clear to me. A modal basis was thus clear from the start. It is a fundamental property of physics, linked to thermodynamics, that so-called "higher order terms", involving higher powers of the polynomial parameters (essentially the radius, the thickness and the azimuthal orientation in cylindrical mirrors) require more energy for their generation and are more stable than "lower order terms". This is embodied in the principle of St Venant, fundamental to this application of elasticity theory. The conclusion is of great importance for active optics: low order terms such as defocus and astigmatism can occur in telescopes readily and vary rapidly and require relatively low forces to generate them, such as the gravity effects due to telescope movement. Beyond a certain (high) order, conversely, gravity effects produce effects which are optically negligible. The corollary is a very simple basic axiom of active optics: if forces of the order of the gravity forces on the supports can produce an optical error of significance, then correcting forces *of the same order of magnitude* can correct it, if we can determine how and where to apply them! Conversely, a higher or-

Table 1: *The ten sources of error giving degradation of image quality in ground-based telescopes, and their corresponding bandpasses. Diffraction, which is inevitable and continuous, is excluded since (for a given signal wavelength) it cannot be influenced. In space, the three errors dependent on air vanish (W99).*

	Source of error	Bandpass (Hz)	
(1)	Optical design	dc	(fixed)
(2)	Optical manufacture	dc	(fixed)
(3)	Theoretical errors of:		
	- Mirror supports	dc → 10^{-3}	(fixed → minutes)
	- Structure (focus, centering)	10^{-3}	(minutes)
(4)	Maintenance errors of the structure and mirror supports	10^{-6} → 10^{-5}	(weeks → days)
(5)	Thermal distortions		
	- Mirrors	10^{-5} → 10^{-4}	(days → hours)
	- Structure	10^{-3}	(minutes)
(6)	Mechanical distortion of mirrors (warping)	10^{-7}	(years)
(7)	Thermal effects of ambient air (telescope, dome and site "seeing")	10^{-4} → 10^{2}	(hours → 0.01 s)
(8)	Mirror deformation from wind gusts	10^{-2} → 10^{1}	(minutes → 0.1 s)
(9)	Atmospheric turbulence (external "seeing")	2•10^{-2} → 10^{3}+	(50 s → < 10^{-3} s)
(10)	Tracking errors	5 → 10^{2}	(0.2 s → 10^{-2} s)

der error which cannot be corrected by forces of this magnitude will also not be generated, i.e. it will not be present. In other words, any error present which is due to elasticity and gravity can be corrected. Later, I realised that this modal approach is also mathematically essential for finding a practical solution. Mathematically, it would seem simple and elegant to measure the total aberration error at many points of a rectangular raster over the pupil. If calibrations exist for the aberrations produced by known force distributions, then a so-called matrix inversion would give a solution reducing the optical error at all the raster points to zero. However, this procedure would include *all* the aberration orders, including higher order effects which are negligible in practice, *but not zero*. These terms would only be correctable by impossibly high forces. The result would be a solution matrix with an inaccessible solution: mathematically a solution matrix with enormous eigenvalue ratios. The modal approach avoids all such problems, provided the modes are reasonably determined. In the NTT, because the primary was relatively stiff, seven modes were sufficient. In the VLT, with a primary about 50 times more flexible, 16 modes are corrected. Fig. 5 shows the nature of the deformations produced by these modes. The use of these so-called "natural vibration modes" is one of the great contributions of Lothar Noethe (Noethe 1991, W99). The obvious optical alternative of Zernike polynomial modes, orthogonal modes commonly used in optical design, is quite feasible. But the dynamic range of correction for a given range of forces is an optimum for the natural modes, a very important advantage.

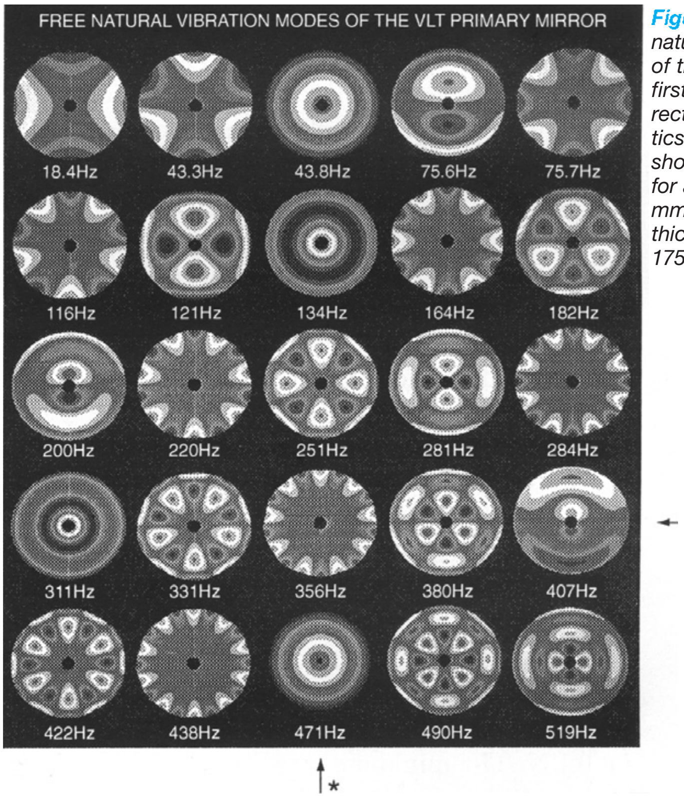


Figure 5: The first 25 natural vibration modes of the VLT primary. The first 16 of these are corrected by the active optics system. The modes shown were calculated for a thickness of 200 mm, whereas the final thickness of the mirror is 175 mm (W99).

(d) Closed-loop operation

Reference has been made several times above to the fact that the ESO active optics system is a *closed-loop* system performing corrections at frequent time intervals by measuring the errors in a star image in real time. The development of this image measurement system, based on the Shack-Hartmann detection principle, was not trivial, but has long been standard technology at ESO through the NTT and VLT. In a VLT unit telescope, up to 1000 image analyses might be made in a single winter night! In the first section, it was indicated that an alternative approach is by precalibration of aberrations as a function of zenith distance in an alt-az mounted telescope, and that this approach is used in some other projects. The ESO viewpoint is that precalibration can be a reasonable approximation in many cases, but can never rival the repeated direct measurement of the actual aberration in the telescope image. Since there is no isoplanatic angle problem and there is no unsolved practical problem of applying image analysis using CCDs in big telescopes, my view is that the *closed-loop* system with image analysis is the optimum way of performing active optics. This was my intention from the start of my complete theoretical concept of active optics in 1968, although I knew of no technical solution for real-time image analysis at that time.

Conclusion

As with all technical developments departing radically from accepted technology, it took a long time, 21 years, between my first theoretical basis of active optics in 1968 to its final practical confirmation with the NTT in 1989. Without the confidence and support of Prof. Woltjer for the NTT and VLT, who knows whether it would have been tried in practice to this day? The significance of active optics seems to me, in hindsight, greater today than in those early years. Together with the segmented technology of the Keck telescopes, it enabled the breakthrough of both the technological quality barrier and the cost barrier presented roughly by the 5 m Palomar telescope. Future huge telescope concepts, such as the 100 m OWL of ESO (Dierickx et al. 2003), would be inconceivable without these modern active optics technologies, both for their optical function and for their cost. Finally, for the reader interested in a full account of the current status of active optics, the best reference is a recent review article by Lothar Noethe (2002).

Acknowledgements

I am most grateful to Prof. Woltjer for discussions and clarification regarding the early years of the NTT and VLT developments, and to Lothar Noethe for technical discussions. Thanks are also due to Olivier Hainaut for information on the current status of the NTT. The editor of *The Messenger*, Peter Shaver, has also been most helpful regarding the content. My gratitude is due to him for suggesting the article in the first place.

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VLT/I Instrumentation: Lessons Learned FORUM

This paper is the result of a joint effort by ESO and its Scientific and Technical Committee (STC) to extract the main lessons from last April's "VLT/VLTI Instrumentation: Lessons learned" Forum and start applying them, in particular in the framework of the development of second generation VLT –and soon VLTI– instruments. This is but one step in a continuing effort to optimize these complex and challenging developments which involve a significant fraction of Europe's astronomical instrument builders in the near-UV to mid-IR range. With a major effort in the European radio community to build multiple receiver systems for ALMA now being pursued at an accelerated pace, it was also vital to revisit very quickly our whole procurement strategy in this area.

G. Monnet (*ESO*) and R. Bacon (*STC; CRAL*)

The Forum was held at ESO-Garching over three consecutive half-day sessions on 8–9 April. To ensure maximum feedback from the ESO user community, the event was sandwiched between the regular User's Committee (UC) and Scientific and Technical Committee (STC) spring meetings. The purpose was to review with the external Consortia how the first generation instrumentation has been developed and the lessons of its successes and failures. The main objectives were: *i*) to produce a better common understanding among the instrument builders both from the Community and from ESO and the members of the ESO Committees (UC, STC, Council); and *ii*) to get the necessary input to improve ESO's procedures and policies, in particular for second Generation VLT/I instrumentation development and ALMA.

The Forum embraced both analytic and synthetic approaches. The analytic approach featured individual presentations by the external PIs on the instruments developed in the last decade for Paranal and La Silla, supplemented by two presentations by ESO on its experience. The synthetic approach included two panel discussions, one on "Procedures" (Contracts, Design Reviews, Progress Meetings, Reporting, PAE, Commissioning, GTO, ESO roles) and one on "Science Operations" (Observing modes, Templates, Quality Control, Pipelines, Data Access), followed by concluding presentations on behalf of the UC, STC and ESO executive.

Invitations were extended to the Consortia that were involved in first generation instrument projects and their ESO counterparts, the potential PIs of second generation instruments, the STC/UC/Council representatives, the panel members and a number of ALMA representatives. Attendance was high with more than sixty non-ESO staff participants. All external Consortia were duly represented, except for the Australian Oz-Poz Team, which unfortunately could not attend the Forum but sent comments in advance.

Membership for the Panels was as follows:

-*Panel #1* (Procedures): S. D'Odorico, ESO (moderator); A. Blécha, Observatoire de Genève; W. Boland, NOVA-Leiden; F. Casoli, INSU; J. G. Cuby, ESO;

Forum Agenda

Instrument Procurement History & Evolution	C. Cesarsky	ESO
Lessons learned: FORS 1 & 2	I. Appenzeller	LSW-Heidelberg
Lessons learned: CONICA	R. Lenzen	MPIA-Heidelberg
Lessons learned: NAOS	G. Rousset	ONERA
Lessons learned: VIMOS & NIRMOS	O. LeFèvre	LAM-Marseille
Lessons learned: Giraffe	F. Hammer	Obs. Paris
Lessons learned: SPIFFI	F. Eisenhauer	MPE-Garching
Lessons learned: VISIR	P.O. Lagage	CEA-Saclay
Lessons learned: OmegaCAM	K. Kuijken	Leiden SW
Lessons learned: HARPS	M. Mayor	Obs. Genève
Lessons learned: MIDI	U. Graser	MPIA-Heidelberg
Lessons learned: AMBER	R. Petrov	Nice University
What went right and What went wrong?	G. Monnet	ESO
Panel #1: Instrument development Procedures	Panel #1	
Perspective from the Users	H. van Winckel	UC
Panel #2: Science Operations	Panel #2	
What Shall We Change? ESO Perspective	G. Monnet	ESO
What Shall We Change? STC Perspective	R. Bacon	STC
General Discussion & Conclusions	All	

F. Eisenhauer, MPE-Garching; A. Russell, ATC-Edinburgh; P. Vettolani, INAF.

-*Panel #2* (Science Operations): P. Quinn, ESO (moderator); M. Bremer (Bristol University); C. Cacciari, (Bologna); B. Garilli, (IASF-Milano); D. Minniti, Chile; D. Silva, ESO.

Forum Agenda

The Forum Agenda is given in the Table on the previous page. All Presentations are accessible from the Web at *http://www.eso.org/~gmonnet/llforum* (username: *llforum*; password: *UR32Cthem!*).

Lessons Learned and Applied

We received considerable feedback both from the Principal Investigators of some twelve instrumental projects led by external groups and from ESO project managers from Garching, La Silla and Paranal. As expected, no complete consensus could be reached from such a diverse set of individual experiences, but a number of common threads clearly appeared during the Meeting. All steps of instrument development were addressed, from the initial evaluation and decision process through instrument design, fabrication and integration and finally reintegration and commissioning in Chile. Most of these points were related to contractual and management aspects, but there were also some important technical issues. All require a closer look on how instrument projects are handled at ESO and how we can improve.

Management and Contractual Aspects

Schedule, Performance & Cost: revisiting the "fast-track" approach

"Schedule, performance, cost: pick any two". The extensive instrument programs for the present generation of Very Large Telescopes certainly offer a good opportunity to check the validity of this Dilbert-like saying. In ESO's case, experience so far shows that: *i*) hardware costs are as a rule accurately predicted; *ii*) manpower predictions are less accurate, with systematic underestimation factors ranging from slightly larger than 1 to 1.5; *iii*) performance specifications are mostly met, with the painful exception of (mechanical) reliability for many projects and *iv*) schedules consistently tend not to be met, with typical 1 to 2 year delays. Overall, both Gemini and Keck found similar patterns in spite of large differences in their respective procurement policies.

Thus, schedule is the main "free" parameter in the equation. This would appear therefore to put into question the usefulness of the so-called "fast-track" approach, used with varying degrees of success in recent years for numerous ESO projects (NAOS, VIMOS, FLAMES, SPIFFI, HARPS). In retrospect, however, it appears to have been a useful tool, especially for faster contracting, early purchases and relatively quick design. On the other hand, time pressure generated during the crucial Assembly, Integration and Testing phases has been sometimes detrimental, e.g. for NACO and especially VIMOS. However, as counterexamples, the complex FLAMES facility was "only" a year late on an extremely challenging original schedule. The technically complex, if operationally simpler, SPIFFI spectrometer was even closer to meeting its original schedule. The HARPS Planet Searcher project for the La Silla 3.6 m telescope even succeeded in making its original 3-year schedule to the day. Based on our experience, developing a full-fledged VLT facility would "normally" take about 5 years. This can be significantly accelerated, but with a special concerted effort and then only if in addition all eventual R&D issues have been solved upfront, a lesson certainly learned *a contrario* on some first generation instruments, e.g. VISIR and NIRMOS.

Consortium-ESO relationship

Almost fifteen years ago, when the VLT first generation instruments effort was launched, a simple and neat model was adopted with, basically, a customer (ESO) to industrial-like supplier (Consortium) relationship. A more complex situation evolved in the following years as the need to apply rigorous hardware and software standards was recognized – at first rather reluctantly on both sides, and, ultimately, fully embraced by both sides. The *quid pro quo*, however, was that the corresponding systems, in particular instrument control and detector assemblies, were delivered, documented and maintained by ESO for the vast majority of the instruments. This played a large role in the evolution towards the present, sometimes confusing, situation in which ESO increasingly plays the dual role of a "subcontractor" to the Consortium – required to deliver goods within time, cost & performance – and of the "client", monitoring the instrument contract. In some cases, the ESO contributions have been seen as outsiders compared to the "real" Consortia. This too has led to problems in understanding the implications of resource limitations within ESO and in evaluating the rate of progress in some areas.

Perhaps even more importantly, with the delivery so far of the first seven VLT instruments, it has become clear that, at the end of the day, ESO bears the ultimate responsibility for operating these scientifically competitive new facilities for its community. The relationship with Consortia has thus evolved quite naturally towards a partnership with a common single goal, rather than the previous client to customer model. This remains a somewhat entangled scheme as, at the same time, ESO is responsible to its own community for the guaranteed time granted to external Consortia in exchange for manpower and, possibly, cash (e.g. OmegaCAM, MIDI, AMBER), assuming the instruments are delivered on time, within budget, and according to performance specifications. This aspect necessarily retains a contractual nature.

The Gemini Observatory is engaged in similar soul-searching. However, in its case, there is much less technical contribution to the projects on the part of the Observatory and, in particular, little standardization. Moreover, in contrast to ESO, it bears the full cost (hardware plus manpower) of the instruments. One year ago, their "lessons-learned" solution was to adopt from now on a full partnership model until Critical Design Review (relatively close to ESO Preliminary Design Review), followed by the usual client role until full delivery of the instrument. In the case of ESO, we should distinguish between instrument building, which is inherently done in partnership, and the contractual aspect, whose *raison d'être* is to cover the guaranteed time allocation in exchange for the Consortia contributions.

Above all, both the ESO and the community instrument builders recognize the need to continue applying proper project management tools, in particular, Instrument Specifications and Statements of Work, Progress Reports and Reviews, as well as maintaining a living Management Plan for every project. This view, which started at a very early phase of the VLT project, is now shared by virtually all instrument teams at every large telescope.

Analysis and Decision Phase

First generation instrument definitions and procurement schemes ranged over the whole gamut, from competing proposals (e.g. the two FORS, CONICA and VIMOS) to single source procurements (e.g. ISAAC and UVES for internal ESO instruments, VISIR after an extensive, competitively selected Phase A study and FLAMES for external procurements). With the present second generation start, there is a clear demand for a more unified scheme. We are thus instituting systematic Phase A studies to establish the instruments' top level scientific goals, their technical feasibility and the aptitude of the teams – including the possible ESO contributions. These studies are conducted in partnership and, ideally, we are already able to build at this early phase a full ESO project team covering all instrumentation and operational aspects, including a Paranal contribution.

The Phase A studies will lead to Reviews by ESO, with the help of external reviewers, in which the project concepts, performance and feasibility are covered, as well as results of critical R&D and provisional contributors, to conduct the projects within acceptable schedules, cost and management plans, costs and schedules. This phase is also crucial to recognize any further R&D effort, which should be completed before any project enters into an "irreversible" state. It is worth noting that there are currently two cases, viz., KMOS and the Planet Finder, with two teams in direct competition with each other during this phase, and ESO will make every effort to treat them on an equal footing.

These Phase A Reviews will be the basis for ESO evaluations transmitted to the Consortia for comments. These elements, together with the Review documents, will be communicated to the STC for recommendations on the individual projects, for resolving cases of competing projects, and on the relative scientific priorities of the different instrumental avenues explored. This scheme should make the decision making process more transparent to our community.

Recently, steps have been taken to strengthen the final decision phase for the launch of instrument projects. In parallel with the Forum, we have established within ESO a "Project Definition & Approval" (PDA) Committee, composed of representatives of Instrumentation & Systems Development and Paranal & Garching Operations, which endorses proposals to the Executive for all new projects, including instrument upgrades. This integrated approach is essential to ensure that all project aspects are addressed in a coordinated way and to develop full project "ownership" inside ESO.

It should be noted that so far the second generation Phase A studies have been handled through formal Contracts with the Consortia. This is a slow and time-consuming process, somewhat disproportionate to the relatively small sums involved in each of the cases (50 to 150 k), and even more so with respect to their short timescales (1 to 2 years). We are looking to implement a much simpler procedure, e.g. through direct purchase orders issued by ESO, at least below a certain financial cap.

Development phase: Design; Fabrication; Assembly, Integration & Testing

Both Gemini and ESO have expended huge efforts to establish proper contracts with external Consortia in order to start the development phase. There is relatively little we can do about the efforts required, given the usually large number of actors involved, but we could save time by starting actual design (and when appropriate, initiating some time-critical procurements) right after selection while, in parallel, negotiating the contract for guaranteed time allocation, which requires approval by the ESO Council. We would obviously then run a (small) risk on both sides by investing in a project that could eventually be cancelled some 6 to 9 months later. This is however more than counter-balanced by the certainty otherwise of losing momentum, including, at the very least, a full semester delay in every schedule, as was experienced on first generation projects with some damaging impact on ESO competitiveness.

During all this development phase, the key management tools are the progress meetings, which involve the whole Consortium, including of course the relevant ESO team. Building this combined team approach, involving not only ESO "hardware" divisions but also operational ones (Paranal & DMD), is crucial to the success of the partnership model.

As originally put into place for the VIRMOS contract, all instrument contracts should be framed in two successive steps: First, instrument design up to the project Final Design Review (FDR) and second, fabrication up to the instrument reintegration and Commissioning in Chile. The FDR is a crucial event whose purpose is to firmly establish the technical, financial and human capacity to actually develop the facility within schedule, performance and cost or, barring that, to terminate the project in an efficient and amicable way (with some contractual guaranteed time attached to the Consortium efforts up to FDR). There has been some lively discussion on the Review process carried out by ESO on more than 20 instrumental projects. Some Consortia have found the ESO approach too formal and occasionally inefficient. There has been a rather large consensus that the fundamental approach looks right, but also that we must revisit the issue, in particular, to give clearer definitions of the objectives of the various reviews and that we must ensure that these reviews remain conducted in a professional way, but at the same time within a fully cooperative atmosphere.

Many of the instrument delays occurred between FDR and Preliminary Acceptance in Europe (PAE), and closer involvement of ESO staff and improved communication would be of great benefit in this phase. The instrument development phase ends with the PAE, another crucial event, which requires stepping up Paranal involvement, ideally months before the actual acceptance tests. In the last two years, we have experienced some rather painful PAE, where an instrument finally got a go-ahead to Paranal (partly) out of desperation from all actors involved. This, however, did not appear to be directly connected to a major management or procedure failure, but to sheer technical complexity instead (see below).

Commissioning and Start of Operations

Even with due allowance for the finite capability of Paranal compared to the present avalanche of instrument and telescope systems installations, the current commissioning scheme appears sub-optimal, both practically and psychologically, due to the complex and sometimes confusing responsibility sharing between the Consortium P.I., the ESO-Garching project manager and instrument scientist, and the Paranal responsible. Granted, partly because some instruments were not fully completed before moving to Paranal, we sometimes went through protracted commissioning extending over 3-4 periods instead of the canonical two phases: Commissioning I, devoted to instrument technical evaluation, and Commissioning II for integration in the VLT operation flow. This is an experience that neither the Consortia nor ESO would like to repeat.

We need to move to a clearer scheme, strictly linked to the absolute first priority goal to characterize the instruments and finalize the deployment of their observing modes. The intent is to retain an overall Paranal-led commissioning under plans drafted by the combined Consortium-ESO team, with the goal of sticking to the two-phase model. Early involvement of Paranal staff in the program definition should help reduce the sense of "Them" and "Us" that has developed. In addition, for the subsidiary but nevertheless important goal of early scientific evaluation of the instrument capabilities, a separate short observing program should be carried out jointly by the Instrument PI and the Instrument Scientist(s) under the supervision of the VLT Program Scientist. The observational data will immediately become public. At the same time, we will continue with the recent practice of allowing Consortia to make use of some of their Guaranteed Time very early in the deployment of the instrument.

Technical Aspects

Instrument Complexity

In the fully integrated "operation flow" concept of the Paranal Observatory, operational complexity has been a limiting factor in our capacity to put a given facility on the air. In this respect, the multimode first generation instrumentation, with many different "internal states" (in other words, a very high instrumental entropy) to be integrated, commissioned, evaluated, documented and calibrated, has presented an enormous burden. In retrospect, we all have largely underestimated this kind of complexity and at the same time overestimated the capabilities of the Consortia and of ESO. In parallel, this operational complexity is linked to an equally large technical complexity, with many moving functions and all too often serious reliability problems that are exacerbated by the particularly demanding Paranal observation scheme, especially in service mode.

For second generation instruments, the crucial time window to avoid repeating this mistake is right now, when projects are still at the conceptual level. The fine point is to balance the scientific usefulness of adding another sub-mode or another function to a given instrument to the additional burden it would create. Such a pruning is essential to avoid revisiting the *Via Crucis*, viz. the painful phase from PAE to Commissioning in Chile that has been walked through too often in the recent past.

The VLT standards

Once (almost) a dirty 12 letter expletive, the concept of "VLT standards", which has applied across the board, and in particular to all instrument control HW/SW and detector systems, has now gained respectability as these standards have matured and are now systematically provided by ESO to the Consortia. While there were growing pains in that process, ESO is now able to deliver a number of building blocks that speed up and simplify the development efforts of the Consortia. We are considering possible extensions e.g., providing a common Real-Time Computer platform for the Adaptive Optics systems as well as providing all Observing Software (OS) top layers.

We should not be blind to the shortcomings of this approach. Standards are notoriously difficult to maintain and especially to upgrade in a fully backward compatible way, and they usually carry significant penalties in volume, weight, heat dissipation and production cost, albeit with big savings in spares and maintenance costs. On the Consortia side, there is also a clear risk of loss of competence in strategic instrumental domains for the Laboratories across Europe. However, all this pales in comparison to the sheer chaos we would be in if we were to operate and maintain dozens of incompatible systems in the Chile Observatories.

Instrument Pipelines

During the first generation phase, ESO has built a common data flow infrastructure that addresses basic end-to-end needs for data acquisition and archiving. Observatory pipelines have so far been mainly restricted to the operational needs of quick-look and quality control, which are vital to the VLT operational model. Evolution of this infrastructure has sometimes been painful for external Consortia but this should be largely avoided in the near future with the ongoing development of a Common Pipeline Library.

There is an urgent need to move now in the direction of pipelines that provide more science-ready products to the users; i.e., with the astronomical objects automatically extracted and the instrumental signature removed from the data. In that sense, the UVES pipeline is a precursor that has largely contributed to the scientific success of the instrument. We plan to move steadily in that direction. The first step will be to cover multi-slit spectrometry, with the even bigger challenge ahead of integral field spectroscopy. In this endeavour, external Consortia have much to provide in terms of algorithms, as does Paranal (and La Silla) Observatory in terms of observing procedures. These contributions will have to be integrated, under the control of the corresponding instrument scientists, and within the ESO common infrastructure, in order to maintain reliability, scalability and predictability – admittedly, at the expense of flexibility and responsiveness.

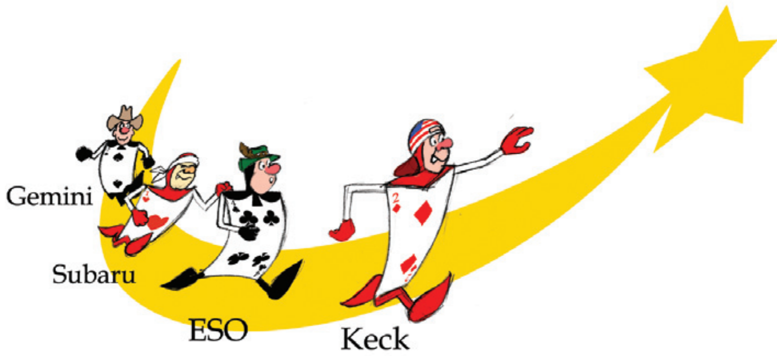
There is a much larger issue on the horizon, viz., eventually going beyond science-ready products to scientifically led, full data analysis pipelines. It is presently unclear if and how the numerous efforts in the ESO community, in particular from the various national data centres, could –or even should – be coordinated with the goal to increase our scientific productivity. This needs to be addressed in the near future.

Conclusions and Perspectives

The deluge of self-criticism above should not obscure the bright silver lining. ESO and its community, through dedicated and competent Consortia, have produced a challenging instrumentation complement in roughly one decade, at an affordable cost, with state of the art performance at the cutting edge of present technology and offering a staggering variety of observing modes. This instrumentation has been integrated end-to-end into the powerful VLT -and VLTI- Machine. In parallel, La Silla instrumentation and telescopes have been modernized and their operation increasingly brought under the VLT paradigm. Global success can be measured objectively: technically, from the low rate of downtime and the high shutter open efficiency, and scientifically, from the high publication rate and citation index of the ESO Observatories. As a result of this whole effort, and for the first time in a century, the observational capabilities of European ground-based astronomy have overtaken the other side of the Atlantic.

At first sight, our common challenge ahead with second generation instrumentation may appear somewhat less formidable than it has been for the first instrument complement. In a couple of years, the VLT/I Infrastructure should be largely complete, from the Telescopes themselves to the instrument standard HW & SW sub-systems, to data handling and analysis pipelines. This will ease the instrument builders' work, whether at ESO or in external Consortia. We certainly should not repeat the painful stories of the early VLT instruments, e.g. the two FORS for which the Consortium had to go repeatedly through vastly different versions of the Instrument Control System! This, hopefully, will also translate into somewhat easier instrument handovers to the Operation Divisions. However, the burden of the remaining infrastructure tasks – in particular VISTA and PRIMA – as well as putting the VLTI facility into full operation, should not be underestimated. We are now largely free from the panic mode in which some first generation instruments were installed in order to provide a long-needed, sorely-lacking capability (e.g. Adaptive Optics with NACO) and/or to be able to fully use a Unit Telescope (again the case of NACO for bright time periods at UT4). Finally, there is now an extensive knowledge base in Europe on how to build – and how not to build – instruments for 8-10 m class telescopes.

This does not mean, however, too much of a free lunch ahead. In this era of fully



This cartoon illustrates the race between present builders of large telescopes and their instrumentation, put in order of first light on the sky. It may also help to remind us of the point made by the red Queen to Alice: 'HERE, you see, it takes all the running YOU can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that.' (Lewis Carroll; Through the Looking Glass)

international competition, delivering facilities tuned to urgent new scientific drivers in a timely way through brand-new instruments or upgrades of existing ones, or using a "friendly" visitor focus in order to keep at the frontier of astrophysical research, remains crucial. Also, while the second generation projects so far tend to feature "almost" single mode instruments with fewer mechanisms, they nonetheless present some formidable technical challenges such as the KMOS multiple cryo-mechanisms, the MUSE 24 (!) spectrometers *cum* image slicers, and the extreme Adaptive Optics system required for the Planet Finder. Some of the suggestions above in our global approach for instrument procuring have already been transformed into policy. We will be working on more in the coming months to improve the overall process. It is clear that every attention should be given to ultimately make the second generation developments an unqualified scientific success. In that respect, the Forum has been both timely and useful.

As for ALMA, many of the lessons learned with the first generation VLT/I instruments apply. Institutions or Consortia of institutions in the community are responsible for major ALMA work packages in the areas of front-end and back-end electronics. While these are integral components of the overall facility, rather than instruments in the VLT/I sense, the relationship between ESO and the institutions is very similar, and the approach to ALMA largely derived from this instrumental experience. Two distinct differences are that ALMA will bear the full costs including labour, and that no guaranteed time will be granted to the contributing institutions. The relationship between ESO and the participating European institutions during design and development (the so-called ALMA Phase I) was essentially the full partnership model. As we move now into construction and series production to equip the 64 antennae, it is shifting to the customer–supplier model with correspondingly more formal contracts and active monitoring and management by ESO. In all these contractual aspects, the ALMA project is in fact much closer to the Gemini Observatory approach than the ESO one; it may be interesting to note that Gemini has however recently introduced a relatively small amount of guaranteed time observing to better motivate the instrument Consortia. Extensive "ALMA standards" are applied across the project, especially in software. Integration and Commissioning is an overall project responsibility with support to be provided by the sub-systems suppliers. Hence, any confusion due to shared responsibilities should be avoided.

Finally, we would like to extend warm thanks to the speakers, the panel members, and all participants from ESO and its Community. Such an event is not an easy one to tackle and could have easily degraded into a blame storming session. *Au contraire*, the maturity of all actors was impressive and reflects the increasing professionalism that is key to successfully developing ever more powerful scientific facilities.

NEWS FROM THE LA SILLA SITE

L. GERMANY, *SciOps*

3.6M CONTROL ROOM HAS MOVED!

Finally, those who dwelt at the very top of La Silla have come to join the rest of us in the common control room of the RITZ. On June 19, the 3.6 m control room was moved into the RITZ and has been operating successfully from there ever since. Congratulations to all those involved in the move, all of the careful preparation and planning paid off with no time lost at all! 3.6 m observers can now enjoy the community atmosphere of the RITZ along with observers at the 2.2 m and NTT.

HARPS 2ND COMMISSIONING

This was scheduled for between the 5th and 21st of June but was unfortunately severely hampered by bad weather (eleven nights lost out of sixteen). Although we were not able to fully characterise the instrument due to lack of time, we were extremely happy with how the instrument performed, with *P*-modes from a pulsating star clearly observed. More tests will be conducted before the instrument is offered to the community at the start of Period 72.

NEW IR STAFF ASTRONOMER

We welcome Ivo Saviane as the new IR staff astronomer on La Silla. Ivo has been a La Silla fellow for the past two years working within the 2p2 team and assumed his new role for the observatory on July 1st.

First Images with the ARGUS Mode of FLAMES

The commissioning of the large Integral Field Unit ARGUS of the VLT instrument FLAMES has successfully been completed. The capabilities of this new instrument mode together with some first scientific test images are presented.

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[1]ESO Paranal, Chile; [2]ESO Garching, Germany

An increasing number of the current and future instruments of the VLT are equipped with Integral Field Units (IFUs). FLAMES, the multi-fibre facility at the VLT (Pasquini et al. 2002), is no exception and provides two different types of IFUs. Each of the two plates of the Fibre Positioner OzPOz hosts 15 deployable mini-IFUs of 2×3 arcsec^2 aperture, while a larger, stationary IFU named ARGUS is mounted at the centre of Plate 2.

All FLAMES IFUs have been developed in collaboration with the Observatoire de Paris-Meudon (Jocou et al. 2000). For technical reasons, the commissioning of ARGUS was postponed from Period 70 to Period 71 and the facility will be offered to the community starting on October 2003. While all potential users are invited to read the public Commissioning Report[1] which includes a detailed technical description of ARGUS, in this *Messenger* article we would like to share some of the spectacular test images of the Homunculus nebula around the Luminous Blue Variable η Carinae, obtained during the ARGUS commissioning nights in July 2003.

The ARGUS Integral Field Unit

With ARGUS in the focal plane of the VLT, the light of the astronomical target is collected by a rectangular array of 22×14 square microlenses, each of 0.52×0.52 arcsec^2 in size. The light from the microlenses is re-arranged along the GIRAFFE spectrograph slit through optical fibres, so that on the GIRAFFE detector, 300 separate fibre spectra are formed, grouped into 15 subslits of 20 fibres each. The microlens output has been organised on the GIRAFFE slit in such a way so that two adjacent microlenses on the sky correspond to adjacent fibre spectra on the detector. With respect to other integral field units existing or planned at the VLT, ARGUS has the unique capability of coupling spatial resolution with a fairly high spectral resolving power of about 11,000 and 33,000 with the low and high resolution gratings of GIRAFFE, respectively.

The First Spectra

Figure 1 shows a portion of a spectacular ARGUS spectrum of one equatorial region of the η Carinae Homunculus nebula, taken using the GIRAFFE high-resolution setting around the Hα line (HR14, which has a resolving power of R=47,000 and a wavelength coverage of 638–663 nm). The dispersion is along the horizontal axis, with the wavelength increasing from left to right; the 300 single fibre spectra are displaced along the vertical axis. The three nebular emission lines of [NII]6548, Hα, and [NII]6583 are clearly visible.

This raw frame already contains quite a lot of information: in particular the elliptical and cross-shaped outlines of the three emission lines on the CCD are striking. The particular shapes are caused by two effects: first we can clearly see for the

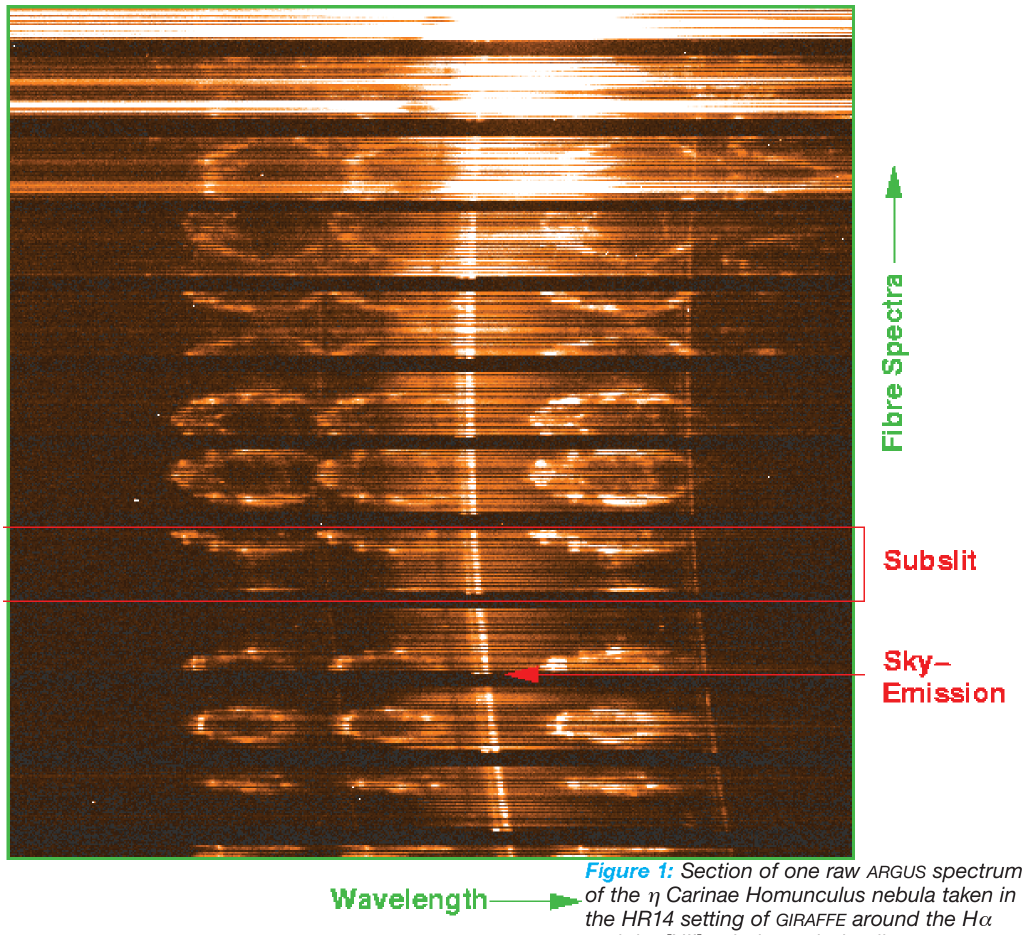

Figure 1: Section of one raw ARGUS spectrum of the η Carinae Homunculus nebula taken in the HR14 setting of GIRAFFE around the Hα and the [NII] nebular emission lines.

[1]http://www.eso.org/instruments/flames/manuals/ArgusCommissioning.pdf

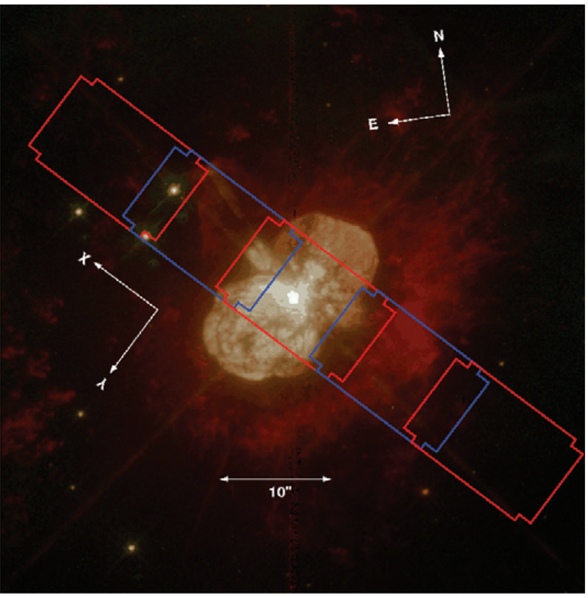

Figure 2: *Position of the five ARGUS pointings on the η Carinae Homunculus nebula superimposed on a HST WFPC-2 image (from HST press release STSCI-1994-09).*

same spatial point one gas component receding and one approaching: in fact, for a given fibre spectrum, two emission lines per ionisation stage are present, one red and one blue shifted with respect to the unshifted position of the line; this observation indicates that we are looking at an expanding thin shell of the nebula. The second effect, which causes the roundish shape, is that within one subslit, adjacent fibre spectra also correspond to adjacent spatial regions. Their continuity on the sky and on the detector results in a smooth transition from one spectrum to the next. However, this continuity is not provided from subslit to subslit because some subslits have been mounted with the fibres in reverse order on the GIRAFFE ARGUS slit.

Spectra from five overlapping pointings were acquired along the equatorial axis of the η Carinae Homunculus nebula. A superposition of the ARGUS apertures and their orientations onto an HST image of the Homunculus is shown in Figure 2. All spectra were taken in the HR14 setup with an exposure time of 300 seconds each, except for the pointing on the central (brightest) region of the nebula where the exposure time had to be reduced to 1 second to avoid saturation of the Hα line. Like all FLAMES commissioning data, these first ARGUS observations will be made publicly available to the ESO community through the ESO archive.

Each of the ARGUS frames contains both spectral and spatial information which is best stored in a data cube with one spectral and two spatial dimensions. Two-dimensional slices can easily be extracted from such a data cube for presentation and data analyses. An example of such a data cube is given in Figure 3, where all five η Carinae frames have been assembled to form one data cube. The data cube is organised in such a way that the axis at the base of the cube is in wavelength, while the second is along the X direction as indicated in Figure 2 (i.e., the long side of the mosaic). The height of the cube is along the Y-axis. Therefore, looking at each wavelength X-plane is equivalent to a longslit spectrum of 40 arcsec length with a spatial resolution of 0.52 arcsecs. A total of 14 of these planes exist along the Y axis, each corresponding to one microlens row along the short side of ARGUS. Out of the 14 slices, only four are shown in Figure 3. The discontinuity in the middle of each plane is caused by the fact that the central part is created from the shorter 1 second exposure. The four slices presented cover a small spatial area of 6 arcsec in the Y direction and reveal the complex spatial and dynamical structure of this part of the Homunculus nebula. At the same time, the simultaneous observation of three different nebular emission lines will allow the study of the physical conditions in great detail.

From our first experience with the ARGUS integral field mode of FLAMES at the VLT, we conclude that the comparatively large field of view and the spatial sampling of the ARGUS-IFU, paired with the high resolution of the GIRAFFE spectrograph, indeed provides the ESO community with a unique facility that will lead to many new exciting observing opportunities.

Acknowledgements

We would like to thank the OzPoz team at the Anglo Australian Observatory and Gerardo Avila at ESO-Garching for their active support during the ARGUS commissioning. We further thank all those at ESO and at the different consortia who contributed to the development of FLAMES.

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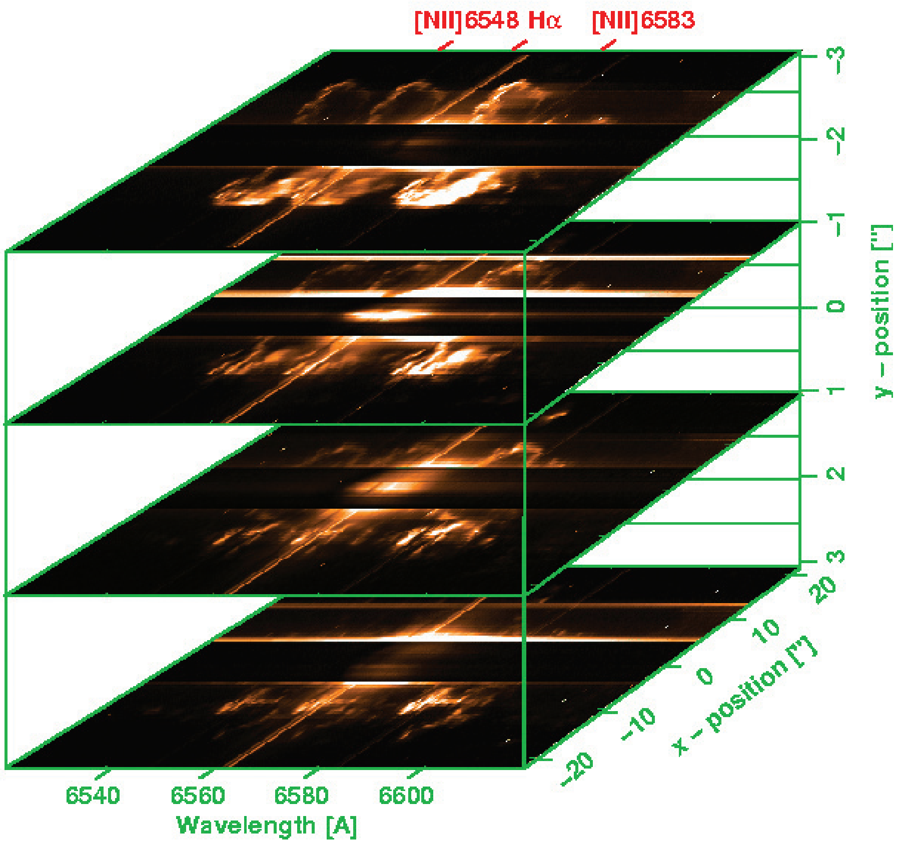

Figure 3: *Four out of 14 slices from the η Carinae ARGUS data cube around the Hα and the [NII] lines. The horizontal lines at the back indicate the positions of the 10 slices which could not be shown.*

THE UNIVERSE IN 3D

FIRST OBSERVATIONS WITH SPIFFI, THE INFRARED INTEGRAL FIELD SPECTROMETER FOR THE VLT

SPIFFI IS THE INFRARED INTEGRAL FIELD SPECTROMETER FOR THE VLT. HERE WE REPORT ON EARLY RESULTS FROM OUR FIRST OBSERVATIONS IN 2003. THIS SELECTION INCLUDES THE STELLAR CONTENT AND DYNAMICS OF THE GALACTIC CENTRE AND ITS GEOMETRIC DISTANCE MEASUREMENT, THE DYNAMICS AND MOLECULAR EMISSION OF THE ULTRA LUMINOUS INFRARED GALAXY NGC 6240, AND THE PORTRAIT OF THE HIGH-RED-SHIFT SUBMILLIMETER GALAXY SMM 14011+0252, INDICATING THAT SUBMILLIMETER GALAXIES ARE THE PRECURSORS OF MASSIVE LOCAL BULGES AND ELLIPTICALS.

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SPIFFI (SPECTROMETER FOR *Infrared Faint Field Imaging*) is the new near-infrared field spectrometer for the VLT, developed at the Max-Planck-Institute for Extraterrestrial Physics (MPE, Eisenhauer et al. 2000). Here we report on the results of its first observing runs as a 'guest instrument' at the VLT in the February to April 2003 period. As of 2004 on, SPIFFI will be coupled to an adaptive optics module developed at ESO (Bonnet et al. 2003) to provide the SINFONI (SINgle Faint Object Near-IR Investigation) facility. SPIFFI offers imaging spectroscopy of a contiguous, two-dimensional field of 32 × 32 spatial pixels in the 1.1 – 2.45 μm wavelength range and a resolving power of 1300-3500. As a result, the instrument delivers a simultaneous, three-dimensional data-cube with two spatial dimensions and one spectral dimension. SPIFFI is the successor to the MPE integral field spectrometer 3D, the world's first infrared integral field spectrometer developed in the early 1990s.

When the new generation of 1024^2 pixels, near-infrared detectors became available in the mid-1990's, we started the development of SPIFFI, for an order of magnitude increase in the number of spatial and spectral elements over 3D. Even more importantly, because of its fully cryogenic image slicer and high throughput optics, along with OH airglow suppression and smaller pixels, SPIFFI at the VLT delivers a factor of 20 to 50 improvement in point source sensitivity over 3D. This development attracted the attention of ESO, specifically because of its major advantages over long slit spectroscopy when operated together with adaptive optics. Simultaneous observation of a two-dimensional field is the best way to reach the full diffraction limited resolution in imaging spectroscopy, while in addition minimizing slit losses. The development of such an adaptive optics assisted integral field spectrometer was subsequently recommended by the ESO Scientific and Technical Committee (STC) in 1997, and finally formalized in 2001 with a contract between ESO and MPE. Because the research and development program for SPIFFI had been launched long before the official start of the full project, we took advantage of this head start and brought SPIFFI to the VLT as a guest instrument for seeing limited observations, while integration of the adaptive optics module was starting at ESO-Garching.

THE INSTRUMENT: EVERY PHOTON, EVERY PIXEL

The primary goal of SPIFFI was to get a maximum number of spectra of a two-dimensional field in a single exposure, each spectrum covering a full near-infrared atmospheric wavelength band, J (1.1 – 1.4 μm), H (1.45 – 1.85 μm) or K (1.95 – 2.45 μm), with sufficiently high spectral resolution (~3000) to observe between the night sky emission lines. However, the format of infrared detectors is still rather limited when compared to optical CCDs, and the largest detector available at the start of the SPIFFI project had only 1024 × 1024 pixels. We thus decided to use every single detector pixel, simultaneously observing 32 × 32 (1024) spectra with 1024 spectral channels each. The second design criterion for SPIFFI was to provide small pixel scales (~25 mas) for diffraction limited observations, and in addition to allow seeing limited observations with as large as possible a field of view. In practice, the pixel size on the sky is limited by the minimum feasible *f*-number of the spectrometer camera. We finally pushed the camera design to a *f*-number of 1.45, so that SPIFFI can deliver a pixel

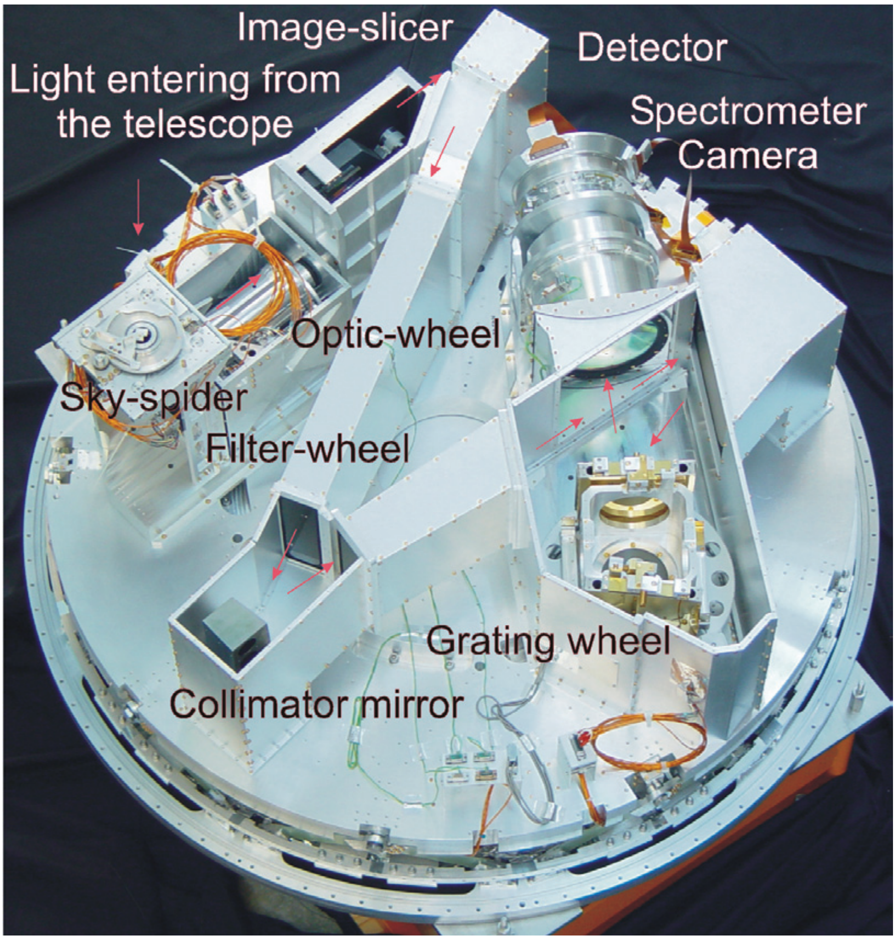

Figure 1: *An inside view of SPIFFI: The light enters from the top, and passes the sky-spider. The pre-optics with a filter-wheel and interchangeable lenses provides three different image scales. The image slicer rearranges the two-dimensional field into a pseudo-long slit, which is perpendicular to the base plate. Three diamond turned mirrors collimate the light on one of the four gratings. A multiple-lens system then focuses the spectra on a Rockwell HAWAII array. The diameter of the instrument is 1.3 m.*

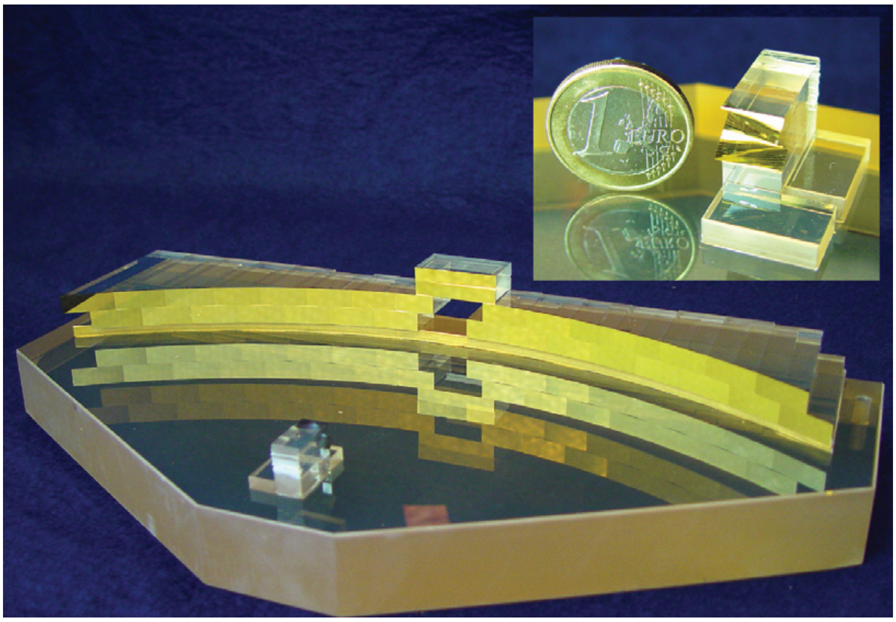

Figure 2: *SPIFFI image slicer: The light enters through the hole in the big slicer. A stack of 32 small mirrors 'the' small' slicer – slices the image and redirects the light towards the 32 mirrors of the 'big' slicer, which rearranges the slitlets to a 31 cm long pseudo-long-slit. The small inset shows an enlargement of the small slicer.*

size of 0.25″, corresponding to a total field of view of 8″ x 8″. To make optimal use of the excellent seeing conditions in Paranal, and for partial correction of atmospheric turbulence with faint reference stars, SPIFFI also provides an intermediate image scale of 0.1″/pixel. In addition to spectroscopy of the J, H, and K-bands individually, the combined H and K bands (1.45 – 2.45 μm) can be observed at a lower spectral resolution.

Figure 1 shows the opto-mechanical components of SPIFFI. The entire instrument is cooled in a bath cryostat to the temperature of liquid nitrogen. Light enters SPIFFI from the top, and first passes the sky-spider. This device contains three motorized pairs of mirrors, which reflect the light from an off axis sky field up to 45″ away from the object onto the image slicer field of view for simultaneous measurement of the sky background. Below the sky-spider, a motorized pre-optics provides three different image scales, the filters, and a cold stop for the suppression of the thermal background. The focus of the pre-optics is located at the 'small slicer' (Figure 2). This part of the image slicer consists of a stack of 32 plane mirrors, which slices the image into slitlets sent in different directions. A second set of 32 mirrors, the 'big slicer', collects the light and forms a pseudo-long-slit (Fig.2). To avoid differential thermal contraction, the unit is made completely from zero expansion glass. All parts (approximately 70 in number) are optically contacted.

After the image has been sliced and rearranged to the pseudo slit, three diamond turned mirrors collimate the light onto the gratings. The gratings are directly ruled in gold on an aluminium substrate and blazed to the centre of their bandpass for optimum efficiency. The spectrometer camera is a six-lens system with an aperture of 160 mm. When operated at adaptive optics pixel scales, the demands on the instrument flexure are very stringent. We have thus implemented an inductive metrology system, which measures the relative motion of the cold structure with respect to the cryostat lid, and provides the input for the secondary guiding.

Commissioning: Never Waste a Minute of Telescope Time

After its final tests at the VLT Cassegrain focus simulator in Garching in December 2002, the instrument arrived on Paranal on 9 January, 2003. After one week of integration, the SPIFFI team (Fig.3) cooled down the instrument successfully. On 6 February 2003, SPIFFI was transported to the VLT observatory platform.

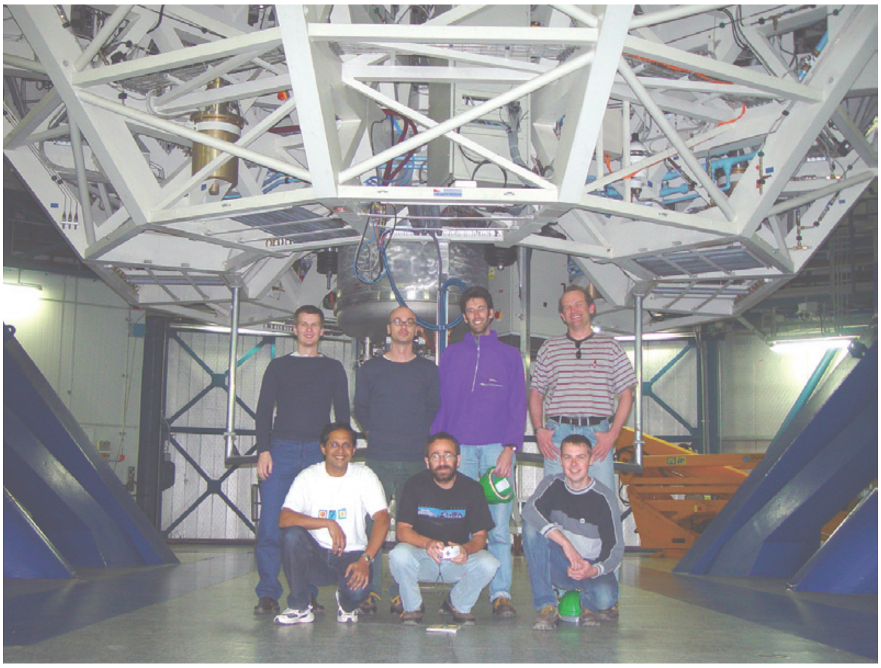

Figure 3: SPIFFI at the telescope: The picture shows members of the SPIFFI team after the successful installation of the instrument at the Cassegrain focus of Kueyen: From left to right: C. Iserlohe, N. Thatte, J. Schreiber, R. Abuter, F. Eisenhauer, S. Huber, M. Tecza. Not shown but present during commissioning or observing: R. Genzel, M. Horrobin, C. Röhrle, D. Lutz, A. Schegerer.

During the nights from February 8 through 13, SPIFFI was commissioned. Thanks to careful definition and verification of the telescope-instrument interface, the first target HD23561 immediately appeared within a few arcseconds of the SPIFFI field centre. The best images taken with the 0.1″/pixel scale during science operation in March and April had a FWHM of approximately 0.25″ in K-band. More than 30% of all photons in H- and K-Band arriving at the telescope are eventually detected. The total efficiency in J-Band is approximately 20%. The average optical transmission of SPIFFI including pre-optics, filter, image-slicer, spectrometer-optics, and grating is approximately 37%, 47%, and 42%, for the J-, H-, and K-band, respectively. With this overall transmission, SPIFFI significantly outperforms competing integral field spectrometers. The spectral resolving power as measured on night-sky emission-lines is approximately 3500 in K-Band, 2500 in H-Band, 2000 in J-Band and 1300 in the combined H&K band.

SPIFFI's operation is straightforward, and requires no in-depth knowledge of integral field spectroscopy. A quick-look image reconstruction allows the instantaneous display of the reconstructed image during acquisition and observing. The normal mode of observing is nodding between the science field and blank sky, which allows accurate subtraction of the night sky emission and the thermal emission of the telescope. Alternatively, SPIFFI was operated in a 'stare'-mode, in which no separate sky-field is observed, but in which the night-sky contribution to the source spectrum is subtracted from a measurement within the instrument field of view. For a small object, which fills only part of the SPIFFI field of view, the night-sky spectrum can be extracted directly from its surroundings. Larger objects, which fill the whole SPIFFI field of view, are observed with the sky-spider. While this stare-mode doubles the on-source observing time, the quality of the sky-subtraction is limited by the accuracy of the instrument calibration, specifically the flat field, and detector instabilities. In practice, the noise in the stare-mode observations is presently a factor of a few above the photon noise. We are currently investigating improved data-reduction techniques based on a Bezier-Spline representation of the night-sky emission to optimally recover the sky-free spectrum of the object of interest.

Because of the various peculiarities of the raw data from integral field spectroscopy SPIFFI has its own data reduction software. This package provides all tools for the calibration and reduction of SPIFFI data, including wavelength calibration and image reconstruction. The final data format is a three-dimensional data cube with 32 × 32 spatial pixels, and up to 2560 spectral elements.

First results

In the following we will discuss some of the scientific results obtained during the guest instrument runs in March and April 2003. To give the readers a feel for the kind of science that can be obtained with an integral field instrument we present here three highlights in different areas – our own Galactic Centre, a z=0.024 infrared luminous merger and a z=2.5 submillimeter galaxy - rather than making a broad sweep of all the observations that were carried out during the 15 observing nights. These results are also discussed in greater detail in several papers that are submitted/in press (e.g. Genzel et al. 2003b, Eisenhauer et al. 2003).

Stellar populations and dynamics of the Galactic Centre star cluster

The Centre of the Milky Way is a unique laboratory for studying physical processes that are thought to occur generally in galactic nuclei (see Ott et al. 2003). High resolution, near-IR integral field spectroscopy offers a unique opportunity for exploring in detail the properties, dynamics and evolution of the nuclear star cluster in the immediate vicinity of a supermassive black hole. We observed the central parsec region with SPIFFI during two nights (for about an hour each) and created two mosaics of the central region, one covering the central parsec with 0.25″ pixel resolution (FWHM~0.75″) at R~1300 in the combined H&K mode, and one of the central ~6″ with 0.1″ pixels at R~3500 in K (Fig. 4). In the latter case, the effective spatial resolution was a remarkable 0.27″ FWHM, providing us with the by far deepest (K~15-16) and highest resolution imaging spectroscopy data set obtained up to this time.

With this new data set, it is possible to probe in more detail the stellar composition of the central parsec. We found about 40 massive early type stars in the region mapped, mostly from stellar emission lines, thereby almost doubling the number of spectroscopically identified early type stars (mostly of type WN9-10, Ofpe or luminous blue variables LBVs). Our new data also clearly detect, for the first time, an early, hot WN star (WN5/6: T_{eff}~40–45 kK, Figure 5), as well as a large number of WC stars (Fig. 4, 5). The ratio of WC to WN stars is about 1, and the ra-

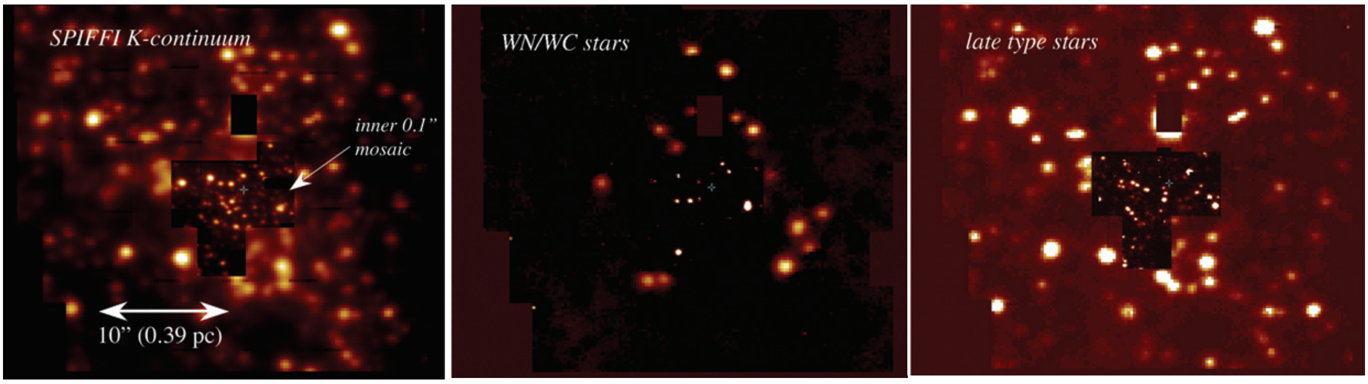

Figure 4: SPIFFI continuum and line images of the Galactic Centre. The light blue asterisk marks the position of the supermassive black hole/SgrA*. Left: K-band image constructed from an outer mosaic of 0.25" pixel data cubes (~0.75" resolution), as well as an inner mosaic of the central ~10" at a pixel scale of 0.1" and FWHM 0.27". Middle: continuum subtracted line image near HeI 2.113mm, marking the positions of the Wolf-Rayet (WN, WC) stars. Right: continuum subtracted CO 0-2 absorption line flux, marking the positions of late type stars.

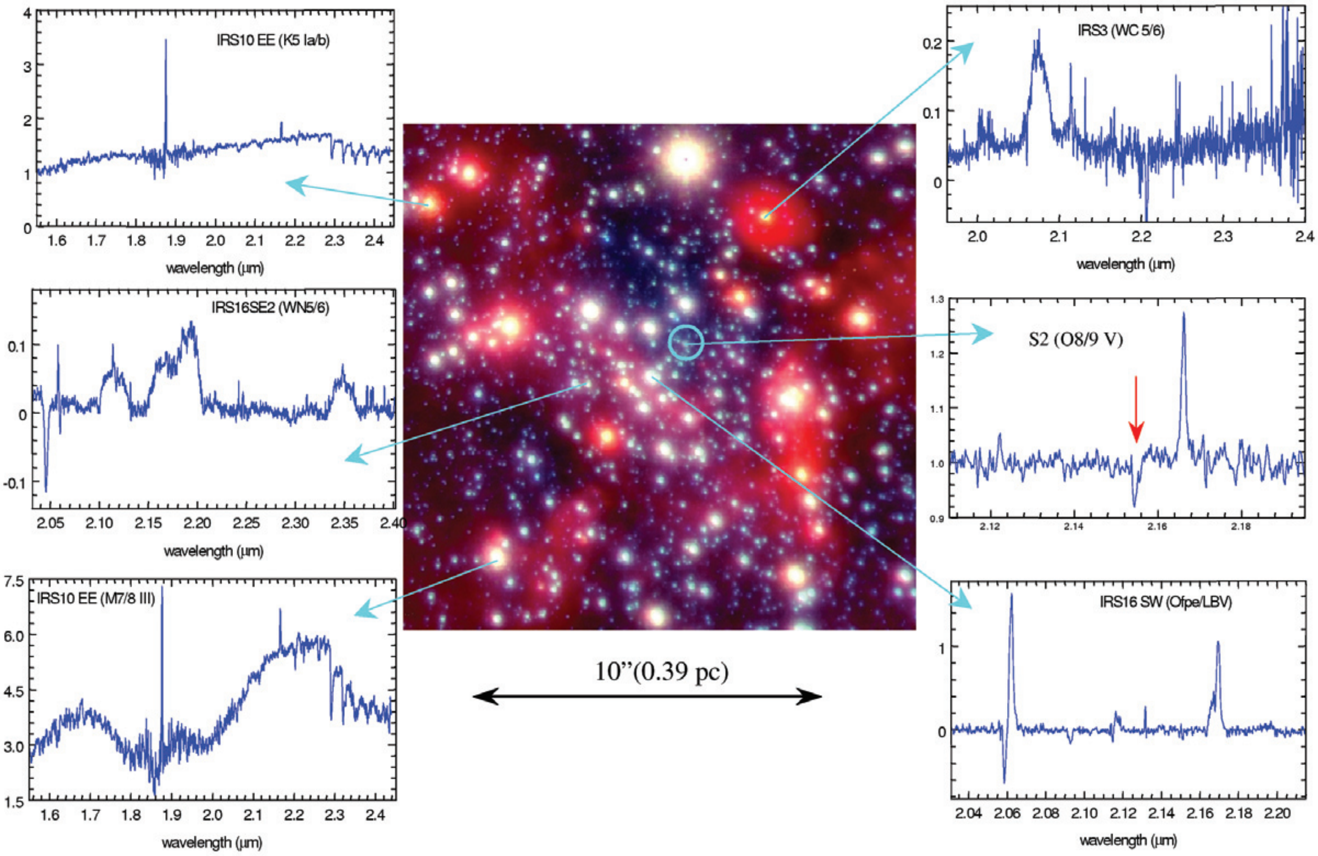

Figure 5: Selected SPIFFI spectra superposed on a NACO H/K/L' colour composite image of the central region. The spectra display the wide range of stellar types found in the cluster, ranging from late type main sequence O stars (the star S2 near SgrA*, oval in image), to luminous blue variables (IRS16SW, lower right), early WN (middle left) and WC (top right) Wolf-Rayet stars, to red supergiants (the brightest star IRS7 at the top/middle of the image), bright asymptotic giant branch stars (IRS9, lower left) and normal red giants (top left). Note that in the case of the dusty WC5/6 star IRS 3 (top right) we first subtracted a strong featureless power-law to emphasize the characteristic carbon-features.

tio of (narrow-line) LBVs, such as IRS16C, NW and SW, to WN stars is about 0.5. Despite the much superior high resolution, inner cube (much less susceptible to veiling of stellar Brγ absorption by the diffuse Brγ emission from the SgrA West HII region), there is (still) no evidence for main sequence O-stars, with the exception of the innermost arcsecond. The WR/O star ratio in the nuclear star cluster thus appears to be greater than about 20. Several of the mid-IR excess stars in the central region (very red color in Fig. 5), including the brightest 10 μm source in the central parsec, IRS 3, are WC stars. As a WCE (WC5/6) star IRS3 may be a prime candidate for exploding as a supernova in the next few 10^4 years. Other such dusty sources can now be shown from their spatial distribution and proper motions to be luminous early type stars that happen to move into and strongly heat the dust in the HII region (Genzel et al. 2003b).

The unique simultaneous H&K capability allows to unambiguously distinguish moderately late type (K2-5) supergiants from AGB stars. Both types have equivalent near-IR flux densities. The much later type (M4-9 III) AGB stars, however, exhibit deep water vapour, steam troughs between the H and K-bands that can be easily recognized in our

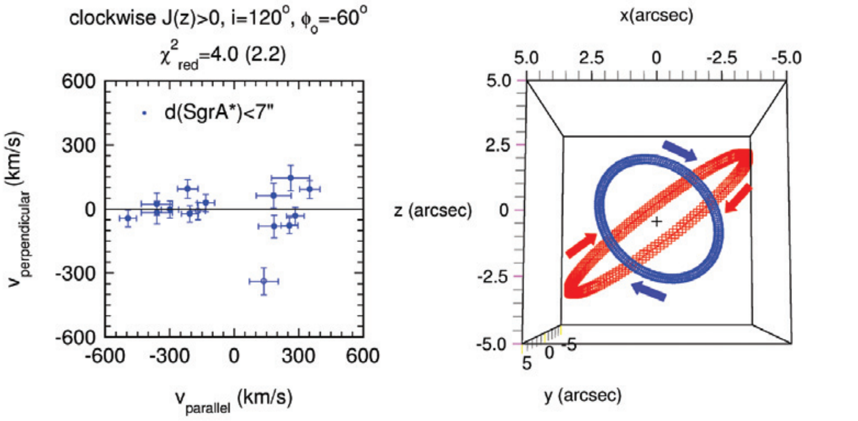

Figure 6: Dynamical properties of early type stars in the Galactic Centre. Left: projection of 3D space velocities of clockwise (on the sky) rotating stars, perpendicular to the best fitting plane, at inclination 120° with respect to the sky, and –60° of the line of nodes, east of north. 14 of the 15 stars with three space velocities adhere to rotation in a fairly thin plane in this orientation. Likewise most of the counter-clockwise stars largely also follow a disc rotation pattern. Right: Orientation of the two young star discs. East-west on the sky is left-right, and the line of sight direction is up-down (the observer sits at z=-∞). The two discs counter-rotate with respect to each other, but both exhibit rotation that is counter to Galactic rotation.

data (source IRS9 in the lower left inset of Fig. 5). This finally settles a long debate about the properties of the brightest late type stars in the central parsec: of the dozen or so K<10.5 late type stars (M(K)<–7.2), a maximum of two are supergiants, the rest are clearly AGB stars.

The large ratio of Wolf-Rayet stars to O-stars, the large WC/WN ratio, and the large blue to red supergiant ratio, in comparison with recent star cluster models, indicate that the young stars in the Galactic Centre originated in a high metallicity starburst about 5 Myr ago. The unusually large number of luminous LBV stars, most of them in the central IRS16 cluster, suggests that this burst had a duration of several Myr and that the massive stars may be fast rotators, thereby allowing the presence of very massive (≥100 $M_\odot$) stars near the Humphreys-Davidson limit of stability.

The combination of proper motions and radial velocities of the massive stars allows a detailed analysis of their dynamical properties. The surprising result (Genzel et al. 2003b) is that essentially all young stars in the central 10″ belong to one of two well defined, rotating stellar rings/discs. The two young star discs are at fairly large angles with respect to each other but share a common, counter-Galactic rotation (Fig. 6). Combined with the fact (see above) that both discs have essentially the same stellar content these data offer valuable constraints on one of the most perplexing current riddles in Galactic Centre research: how can the central 0.1-10″ host so many young, massive stars? The environment and the presence of strong tidal forces from the black hole make star formation from cloud collapse extremely difficult, if not impossible, and mass segregation of the massive stars from further out is excluded because of their short lifetimes. The presence of two, coeval stellar discs suggests that a highly dissipative and sudden event was at play in the formation of the massive stars. One possibility is the collision of two infalling clouds, followed by the settling of the remaining debris into two separate discs orbiting the central black hole, and subsequent star formation.

A Geometric Determination of the Distance to the Galactic Centre

The distance between the Sun and the Galactic Centre (R_o) is a fundamental parameter for determining the structure of the Milky Way. Through its impact on the calibration of the basic parameters of standard candles, such as RR Lyrae stars, Cepheids and giants the Galactic Centre distance also holds an important role in establishing the extragalactic distance scale. Ten years ago Reid (1993) summarized the state of our knowledge on R_o. At that time the only primary (geometric) distance indicator to the Galactic Centre came from the "expanding cluster parallax' ' method" applied to two H_2O masers in SgrB2, resulting in values of 7.1 and 6.5 kpc for the distances, with a combined statistical and systematic (1σ) uncertainty of ±1.5 kpc. In addition there was a number of secondary (standard candle) determinations, based on RR-Lyrae stars, Cepheids, globular clusters and giants, as well some tertiary indicators, derived from theoretical constraints (e.g. Eddington luminosity of X-ray sources, Galaxy structure models). Since then Hipparcos data have improved the uncertainties of

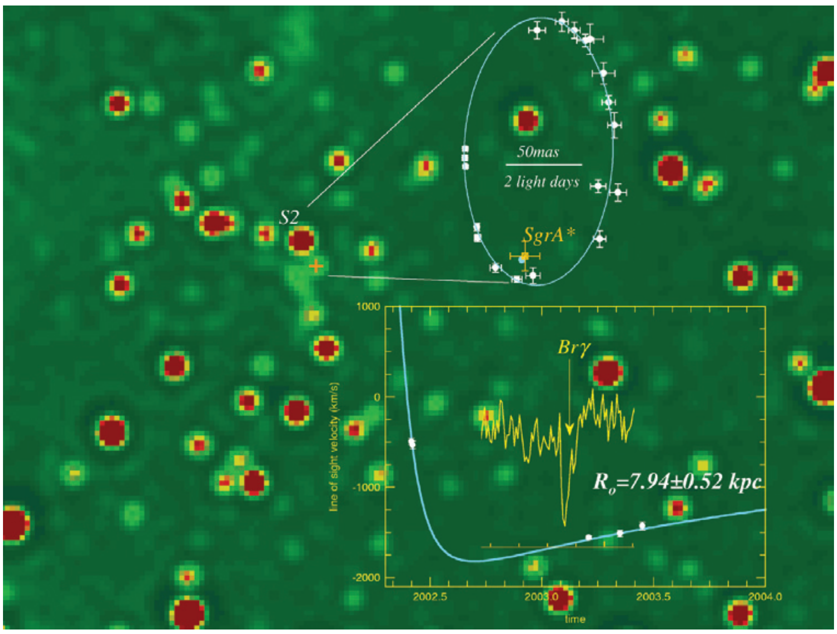

Figure 7: Geometric determination of the Sun-Galactic Centre distance R_o from a precision measurement of the orbital parameters of the star S2 that is orbiting the central supermassive black hole. The star's line-of-sight motion is measured via the Doppler shift of the Brγ line in terms of an absolute velocity (SPIFFI data as well as spectroscopic data from NIRSPEC (Keck, Ghez et al. (2003) and from NACO), whereas its proper motion is measured in terms of an angular velocity (data from SHARP/NTT and NACO). The orbital solution ties the angular and absolute velocities, thereby yielding the distance to the S2/SgrA binary system.*

the secondary determinations. The best present value of R_o is ~ 8 kpc, with a combined statistical and systematic uncertainty of ±0.5 to ±1 kpc.

The SPIFFI observations allowed us to derive a primary distance measurement to the Galactic Centre with an uncertainty of only 5%. This determination has become possible through the advent of precision measurements of proper motions and line-of-sight velocities of the star S2. This star is orbiting the massive black hole and compact radio source SgrA*, and the classical 'orbiting binary' technique can then be applied to obtain an accurate determination of R_o that is essentially free of systematic uncertainties in the astrophysical modelling. The essence of the method is that the star's line-of-sight motion is measured via the Doppler shift of its spectral features in terms of an absolute velocity, whereas its proper motion is measured in terms of an angular velocity. The orbital solution ties the angular and absolute velocities, thereby yielding the distance to the binary. For the analysis of our measurements, we fitted the positional and line-of-sight velocity data to a Kepler orbit, including the Galactic Centre distance as an additional fit parameter. Taking the first two radial velocity data of S2 obtained by Ghez et al. (2003), the SPIFFI data, the two NACO spectroscopy points, and the 19 positions from SHARP and NACO, our measurements deliver 43 data points to robustly fit 9 parameters of the S2 orbit as well as the Galactic Centre distance, resulting in R_o=7.94 ± 0.42 kpc (Eisenhauer et al. 2003). This result confirms and significantly improves the earlier primary distance measurements and gives confidence in the quality and robustness of the standard candle methods that are at the key of the second rung of the extragalactic distance ladder.

A Galactic Shock in the Merger NGC6240

The infrared luminous galaxy NGC6240 (D=97 Mpc, L_{IR}= 6 • $10^{11} L_\odot$) is in many ways a prototype for the class of gas rich, infrared (ultra-) luminous mergers that dominate the upper end of the local luminosity function of IRAS galaxies. The NGC6240 system has two rapidly rotating, massive bulges/nuclei at a projected separation of 1.6″ (750 pc, upper left inset in Fig. 8), each of which contains a powerful starburst and a luminous, highly absorbed, X-ray active AGN (Tecza et al. 2000, Komossa et al. 2003, Lutz et al. 2003). As such, NGC6240 is probably a local template for the population of dust and gas rich, merger/AGN systems at high redshift that likely contribute about half of the energy density at z~2.5 (see the section on SMMJ14011+0252). About $2•10^9 L_\odot$, or 0.3% of the infrared luminosity emerges in H2 infrared line emission, and the origin and excitation of this spectacular line emission has been subject of many studies. The K-band spectrum is full of vibrationally excited H2 lines with excitation potentials up to about 20,000 K above the ground state (right inset, Fig. 9).

We observed NGC6240 with SPIFFI in K-band in excellent seeing (0.27″ FWHM) with the 0.1″/pixel scale. Figure 8 compares the distribution of the stellar light with that of the ionized gas (bottom

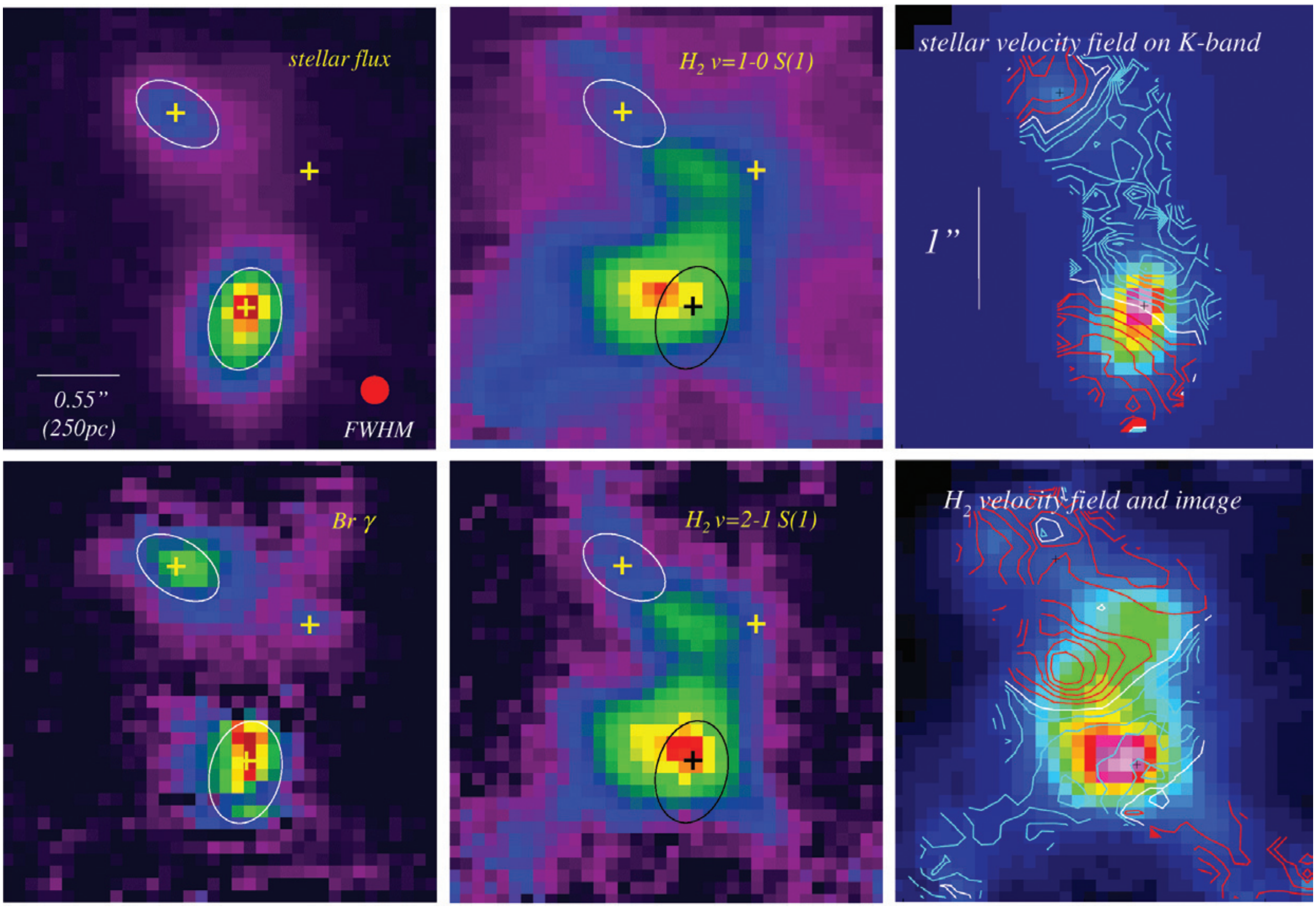

Figure 8: SPIFFI images, stellar and H_2 kinematics of the infrared luminous merger NGC6240. Stellar light (upper left, from CO 0-2 absorption flux), Brγ flux (bottom left), H_2 v=1-0 S(1) and v=2-1 S(1) flux distributions (middle insets). In all images the position of the two nuclei and their outer contours and of an extra-nuclear Brγ source are marked. Top right: stellar velocity field (contours) superposed on K-band image. The contour lines are in steps of 50 km/s, red and blue of the systemic velocity at 7300 km/s (white line). Bottom right: H_2 v=1-0 S(1) velocity contours (same units as for stars) on H_2 image.

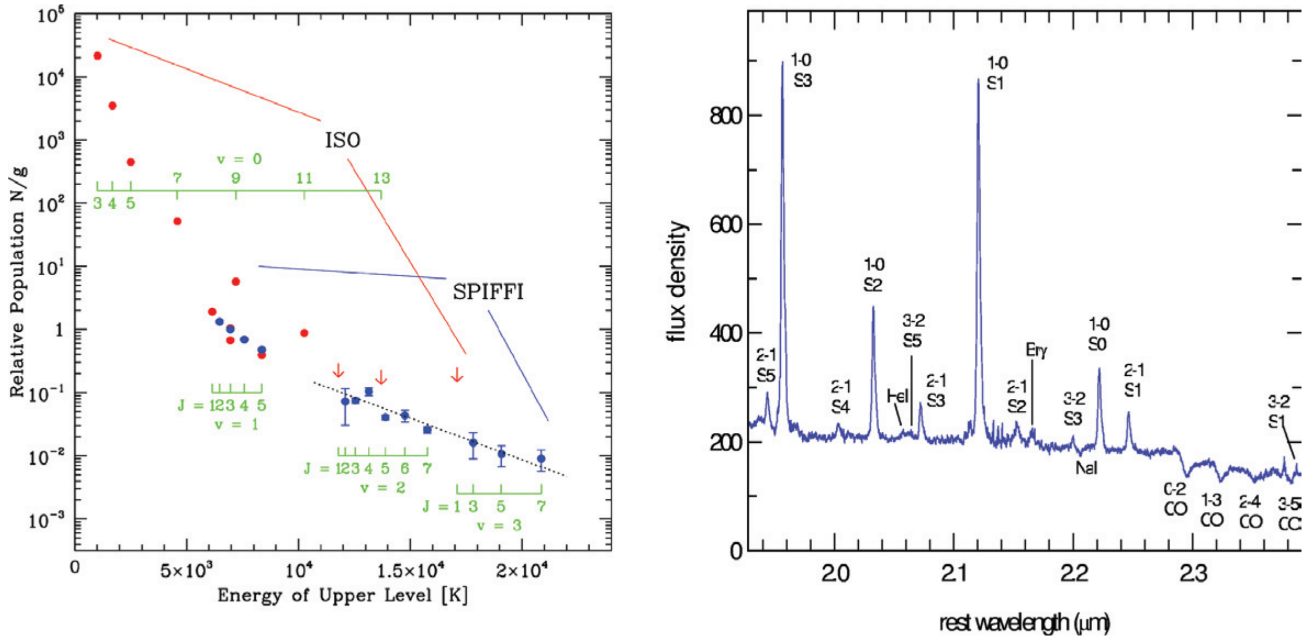

Figure 9: K-band spectrum (right, 0.5″ aperture near southern nucleus) and level diagram (left) of H_2 rotationally excited and ro-vibrationally excited states (blue: SPIFFI, red: ISO SWS, Lutz et al. 2003). A constant temperature distribution is a straight line in this diagram, with a slope inversely proportional to temperature. The NGC6240 data indicate the presence of a wide range of excitation temperatures up to about 3300K (dotted black line fitting the v=2 and v=3 data). The offset between v=0 and v>0 data may either be due to extinction, or due to an additional component of somewhat cooler material. The distribution can be fit by a combination of J- and C-shock models, or by a bow-shock model.

left) and vibrationally excited molecular hydrogen (middle insets). Most of the starburst activity (as traced by Brγ) occurs in the two nuclei on scales of 200 pc, although there appears to be one extra-nuclear Brγ source in the gas bridge between the two nuclei, suggestive of star formation there. The vibrationally excited H_2 is very different and follows a complex spatial and dynamical pattern (lower right inset of Fig. 8) with several extended streamers. The high-resolution SPIFFI data now permit us to follow the H_2 distribution, excitation and kinematics on $\leq 10^2$ pc scales. The two middle insets show that v=2–1 and v=1–0 emission lines exhibit very similar large-scale distributions. The only difference occurs in the most prominent H_2 peak, where the higher excitation v=2–1 S(1) line is located closer to but still off the southern nucleus. The H_2 kinematics is extremely complex (lower right inset in Fig. 8) and very different from the relatively simple counter-rotation pattern of the stars (top right, Fig. 8).

The gas bridging the two nuclei is redshifted relative to the northern and southern nucleus and exhibits a very steep velocity gradient of 500 km/s over 0.7″ as it curves around toward the southern nucleus. There it appears to 'crash' into the nuclear regions approximately at right angles relative to the stellar rotation pattern and with a velocity of 150 to 200 km/s relative to the stars. From the bright H_2 peak just NE of the southern nucleus two gas streamers emerge and envelop the southern galaxy. This kinematic pattern resembles the gas bridges found in simulations of gas rich mergers after the first peri-approach. We may be observing the two galaxies after the first 'hang out' phase in the process of falling back in for the second peri-approach. In the process, they are strongly interacting with and shock exciting the tidally swept out gas bridge between the nuclei.

Figure 9 shows an excitation diagram of the H_2 emission, where we have combined the SPIFFI data with ISO SWS measurements of the rotational line emission (Lutz et al. 2003). The H_2 level populations follow a smooth distribution with local excitation temperature steadily increasing with level energy (the slope of the local level distribution is inversely proportional to excitation temperature). The highest excitation lines we observe require an excitation temperature of about 3300 K. With the possible exception of the region very near the southern nucleus, the H_2 spatial distribution, kinematics and level populations thus strongly favor a 'galactic shock' model as the origin of the spectacular H_2 emission. The high temperature and turbulence also explains why little star formation as of yet has occurred in the dense molecular gas bridge between the two nuclei. The cooling time of that gas is $\leq 10^7$ years, comparable to the time to the second peri-approach of the two nuclei. At this point NGC6240 will probably experience an even stronger star formation episode that will turn the system into a true 'ultra'-luminous galaxy.

Portrait of a z=2.5 Submillimeter Galaxy

The strength of the extragalactic mid- and far-IR/submillimeter background indicates that about half of the cosmic energy density (excluding the microwave background) comes from distant, dusty starbursts and AGN. Surveys with ISOCAM at 15 μm, SCUBA at 850 μm, and MAMBO at 1200 μm suggest that this background is dominated by luminous and ultra-luminous infrared galaxies (LIRGs/ULIRGs: $L_{IR} \sim 10^{11.5..13}\ L_{\odot}$) at $z \geq 1$ (e.g. Genzel & Cesarsky 2000). Little is known yet about the physical properties of this important 'submillimeter' galaxy population since they are very faint in the rest wavelength UV/visible range. Half a dozen SCUBA sources presently have mm-confirmed spectroscopic redshifts near $z \sim 2.5$ (e.g. Genzel et al. 2003b, Downes & Solomon 2003), close to the redshift of the peak of cosmic star formation and QSO activity. The submillimeter population may trace the formation of massive/luminous AGN/starburst systems that may evolve into massive local early type and bulge galaxies.

One of the brightest SCUBA galaxies is the source SMMJ14011+0252 at z=2.565, which is gravitationally lensed by the foreground z=0.25 cluster Abell 1835

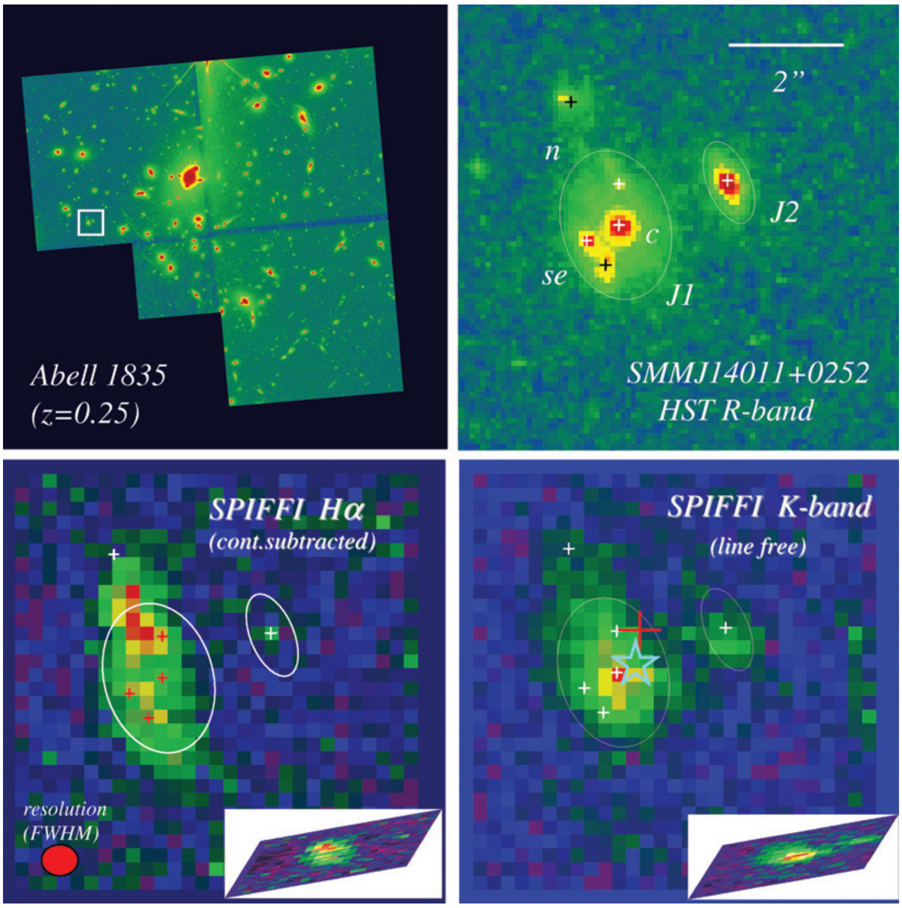

Figure 10: The SCUBA galaxy SMMJ14011+0252 (z=2.565). Top left: R-band HST WFPC2 image of the z=0.25 cluster Abell 1835, which gravitationally lenses the background submm galaxy SMMJ14011+0252 by about a factor of 4 to 6. Top right: HST R-band image of the central few arcseconds of the source with a log-scale color stretch (white square in left inset, from Ivison, priv. comm.). Bottom right: Line free K-band continuum image obtained with SPIFFI. The red cross is the position of the 1.4GHz radio emission (Ivison et al. 2001), and the blue asterisk marks the position of the CO mm line and continuum emission (Downes & Solomon 2003). Bottom left: Continuum subtracted SPIFFI Hα map. At the bottom right of the lower insets we show the morphologies of the Hα and K-band maps when correcting for a lensing magnification of 5 along p.a. 10°.

(Fig. 8, Ivison et al. 2001). HST imaging shows that the system consists of several sub-components (J1 (c, se, n), J2) spread over about 3″ (Fig.10, 24 kpc without correction for lensing). We observed SMMJ14011 with SPIFFI in J, H and K-bands at the 0.25″ pixel scale for a total of 15 hours on-source integration. The effective resolution in the different data sets is between 0.5 and 0.75″. The lower right inset of Fig. 10 shows the line free K-band continuum distribution. In comparison to the HST image (Ivison et al. 2001, appropriately smoothed to the same resolution as the SPIFFI data), the rest-frame optical (~R-band) distribution is dominated by the extended J1 complex (white oval in Fig. 8), with a significant extension to the NNE. The blue knots J2 and J1se are not as prominent in the K-band data. The continuum subtracted Hα distribution (bottom left inset) is very different from either of the continuum maps. The Hα emission comes from an elongated feature (4″×1.6″) along p.a. 10-15°, approximately centreed on J1c but peaking on either side of the continuum peak.

Figure 11 shows the near-IR spectra obtained with SPIFFI and integrated over the central J1 complex. As already found by Ivison et al. (2001), the rest-frame optical/UV emission line spectrum is dominated by a starburst (HII region) spectrum without much evidence for AGN activity. The Ha and [NII] line profiles exhibit blue wings with velocities of several hundred km/s and a [NII]/Ha line ratio of about 1 (indicated by the yellow line in the lower spectrum of Fig. 11).

These values are characteristic of shock-heated superwinds seen at low redshift. The J/H/K spectral energy distribution exhibits a break between the J and H bands that can be well fit by an A-star continuum model at redshift z~2.5 (thick yellow line, age a few 10^2 Myrs). We interpret this emission as coming mainly from J1c and its extended surroundings (oval in Fig. 10), and conclude that J1c is a post-starburst stellar component at the same redshift as the young starburst and possibly part of the central bulge/disc of the submm source. The position of the powerful submm starburst, as marked by the mm CO line and continuum emission (Downes & Solomon 2003) is ~0.5″ (±0.4″) NW of J1, somewhat offset from but still consistent with the location of the K-band peak. The Hα line emission has a remarkably narrow profile (~130 km/s) and exhibits a systematic velocity gradient mainly in east-west direction, perpendicular to it spatial elongation. J2 also shows Hα emission, which is about 170 km/s offset from the systemic velocity of J1.

We can place the optical starburst features on the classical diagnostic diagrams. All diagnostic ratios ([OIII]/Hβ vs [NII]/Hα, or [OI]/Hα or [SII]/Hα) put the system firmly in the region of low excitation, low extinction (E(B-V)~0.4) but high Hα equivalent width, local starbursts. The density sensitive [SII] line ratio also indicates a very typical electron density of about 10^2 cm^{-3}. Perhaps most importantly we deduce a super-solar oxygen abundance (12+log(O/H)~9) from the classical (I([OIII]) +I([OII]))/I(Hβ) ratio. In addition, and somewhat surprisingly, the relatively strong [NII] emission relative to [OII] indicates that SMM 14011+0252 has relatively large nitrogen enrichment. These results are very significant since they pertain, in contrast to high-redshift QSO emission line regions, to large regions in the galaxy and imply that star formation has been proceeding in this system for a considerable period of time.

The morphology of the Hα emission, its kinematics, the likely identification of J1c with a post-starburst component at the same redshift and the similar but not identical redshifts of J1 and J2 all can be explained in a simple lensing model where J1 and J2 are two physically associated background galaxies located behind the central cD of Abell 1835 that are magnified by about a factor of 4 to 6. The corresponding de-magnified images J1 (Fig.10 bottom insets) are fairly circular and point to a central dusty starburst (the submm source) surrounded by a low inclination and low extinction star forming disc (Ha and optical continuum) of diameter about 8 kpc. The intrinsic luminosity

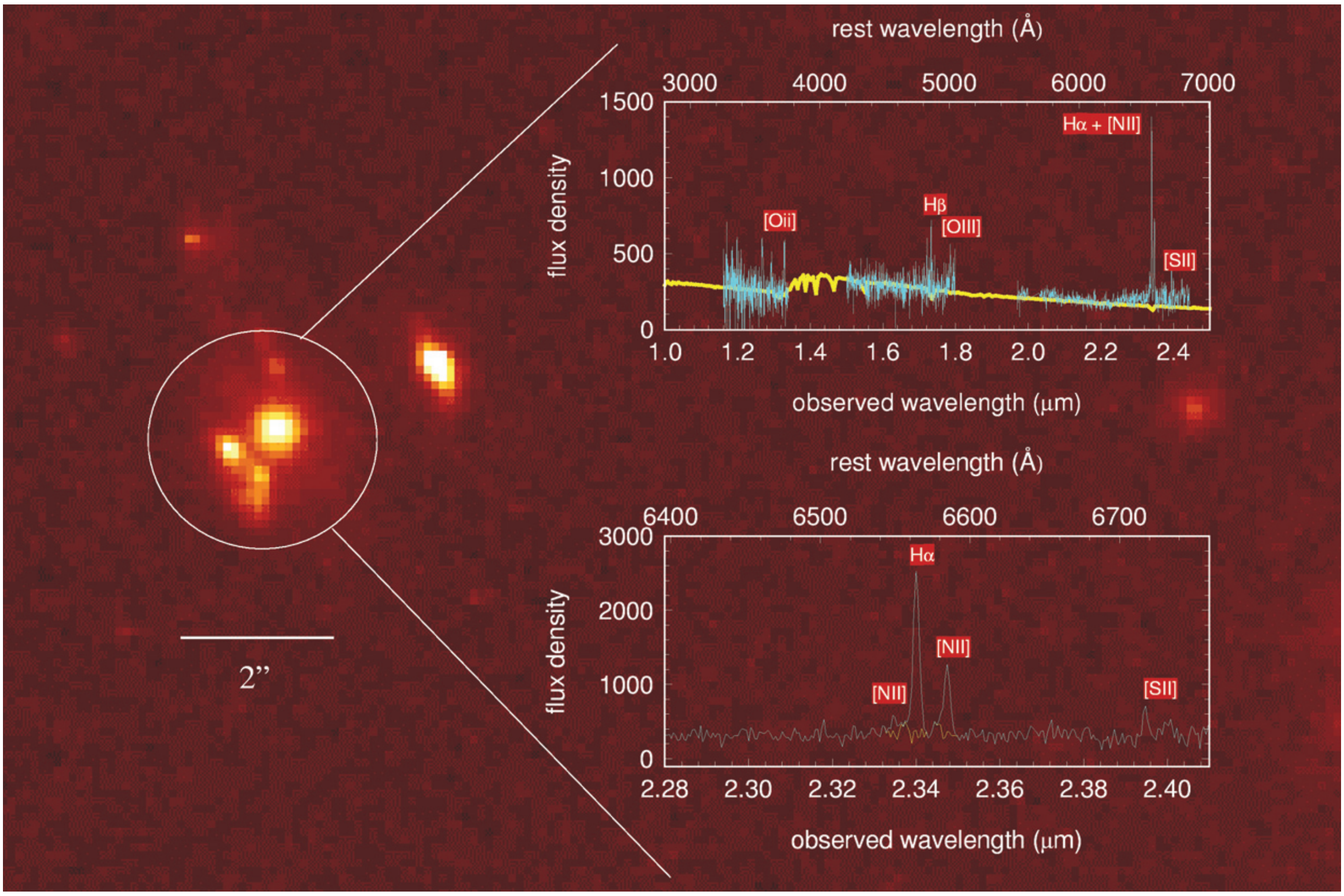

Figure 11: *SPIFFI spectra of the central 2.5″ centred on J1c. The top right J/H/K spectrum shows a typical starburst emission line spectrum, plus a continuum with a spectral break between J and H that can be well fit by a few 10^2 Myr starburst (A-star spectrum) at redshift 2.5 (thick yellow curve). The bottom right zoom into the region around Hα emission shows the narrow line widths, with a blueshifted residual wing that is probably due to a superwind (yellow curve).*

of SMMJ14011+0252 then is about $4{\bullet}10^{12}$ $L_\odot$, corresponding to a current star formation rate of ~300 to 700 $M_\odot$/yr, depending on the IMF chosen. Assuming that this burst has been proceeding for the last 100 Myr – the minimum age derived from the continuum break – the inferred stellar mass formed in this burst is about 3–$7{\bullet}10^{10}$ $M_\odot$. For comparison the present (molecular) gas mass is about $2{\bullet}10^{10}$ $M_\odot$ and the virial mass of the J1/J2 system is about $6{\bullet}10^{10}$ $M_\odot$. While these numbers are obviously quite uncertain, they imply that SMMJ14011+0252 is a massive (~m*) system forming in a major starburst event at z~2.5, possibly triggered by the interaction of the J1/J2 components. Its luminosity is similar to those of very luminous local starbursts, such as the ULIRG mergers. Our conclusion is very much strengthened by the high metallicity of SMMJ14011+0252. The only low-z systems with such high a metallicity are massive (≥m*) early type galaxies. As our knowledge about the high-z submillimeter population increases, the evidence becomes firmer that these systems indeed must be precursors of massive local bulges and ellipticals. This is in contrast to the Lyman break population whose evolutionary endpoint seems less clear.

Outlook for SINFONI

SPIFFI is presently back in Europe for final tests and upgrades before mating with the ESO-delivered adaptive optics module for the full SINFONI instrument, which is based on MACAO, the Multiple Application Curvature Adaptive Optics toolbox (Bonnet et al. 2002). The present schedule foresees the acceptance tests of SINFONI early 2004. After shipment to Paranal, we expect first light at the telescope in April 2004. In addition to its seeing limited modes presented here, SINFONI will then be the world's first adaptive optics assisted near-IR integral field spectrometer. We hope that the instrument will be available to the general user community starting in fall 2004. In 2004, SPIFFI will also be retrofitted with a next generation $2K^2$ detector including its camera, presently under development by NOVA, ESO and MPE. Mating of SINFONI with the laser guide star facility (Bonaccini et al. 2003) is planned for spring 2005.

Acknowledgments

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VIMOS IN OPERATION AT THE VLT

The performance of VIMOS, the powerful large field imager, multiobject spectrograph at the VLT, is critically assessed after the first four months of operation and the current activities for its upgrade are presented.

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VIMOS IS THE LARGE FIELD (4 times 6′.7 × 7′.7, approximately) imager and multi-object spectrograph built for the Nasmyth focus of the VLT MELIPAL. Its field size (diagonal ~24″) matches the full unvignetted field of a Nasmyth focus of the VLT. The combination of the large field, good image quality, high slit multiplexing (masks with up to 1000 short slits can be inserted in the focal plane for low-resolution spectroscopy) makes the instrument the most powerful MOS spectrograph available at telescopes of the 8-10 m class. A detailed description of the instrument can be found at *http://www.eso.org/instruments/ vimos*.

The instrument (and the associated Mask Manufacturing machine) was built by a Consortium of French and Italian institutes (*http://www.astrsp-mrs/virmos*) with Olivier Le Fèvre of LAM, France and Paolo Vettolani of IRA-CNR, Italy, as P.I. and co-P.I. respectively. ESO provided the detector systems and support in other areas of the project.

VIMOS had its first commissioning on the sky in its full configuration in September 2002, only ~5 years after the signature of the contract between ESO and the Consortium. Results from the commissioning and from a first allocation of guaranteed nights received by the Consortium have been presented by Le Fèvre et al. (2002 and 2003, respectively). The instrument has been offered to the ESO users in service mode as of the start of Period 71, on April 1st 2003.

Instrument Performance and Tips on the Preparation of the OBs

Imaging

VIMOS offers a number of advantages but also draw-backs with respect to the other two optical imagers at the VLT, FORS1 and FORS2. Among the advantages, clearly the wide field (~4 times the FORS field) ranks top and makes it an unique instrument for imaging surveys at any very large telescope. Since the field of view of the instrument takes almost all of the Nasmyth unvignetted field, the arm used to pick up the guide star do mask in most cases a small part of one quadrant. The observers are requested to choose the guide star using a special tool, *GuideCam*, made available by ESO for the preparation of the observations.

Although the VIMOS Nasmyth location implies the additional M3 reflection, the VIMOS efficiency of a single channel is higher than that of the two FORS at UV and blue wavelengths, comparable in *V*, and lower than FORS2 in the Red and *I* band (by factors 1.5 and 1.9 respectively) mainly due to differences in the CCD QE curves. The different efficiencies have been well estimated from the zero points measurements for the three instruments reported in the ESO Quality Control pages*. One has however to keep in mind that VIMOS uses non-standard broad-band filters and the color corrections have not yet been introduced.

The image quality (FWHM of the stellar images) in the VIMOS quadrants reported in the same web pages is fairly good lying in the range 0.5 – 1.0 arcsec FWHM during the first four months of observations (Fig. 1 and 2). The difference between quadrants is below 20%. We estimate that there is still room to improve the quality in some of the quadrants by optical realignement. Clearly VIMOS image quality cannot reach the unique performance of the FORS when used in the high resolution mode in very good seeing condition because of the larger field and coarser sampling but it is on the other hand fully adequate for deep photometry of compact sources much fainter than the sky.

One VIMOS limitation is a significant variation of the Point Spread Function (PSF) across the four quadrants, mainly due to the difficult optimization of the optics over the large field. Furthermore, the field being so large, the telescope guide probe (used for the active optics correction in the telescope optics) is often forced to pick a star in a region where the telescope pupil is slightly vignetted and the resulting active optics correction not

*The ESO Quality Control pages can be found on http://www.eso.org/observing/dfo/quality

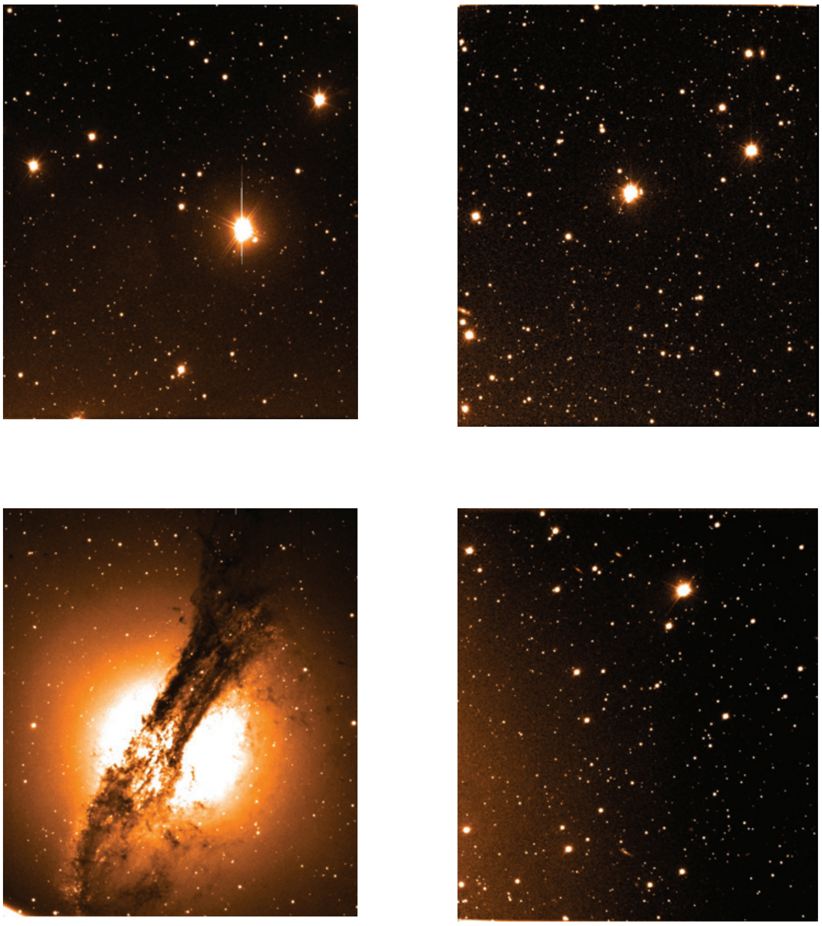


Figure 1: The NGC 5128 (Cen A) field in a V exposure (30s) with the four channel of VIMOS taken in Feb. 2003. North is to the top, East to right. Each of four channels covers 6′.7 × 7′.7 approximately, the gaps in the X- and Y-directions ~ 2′. The average FWHMs of the stellar images in the four quadrants in this exposure vary between 0.69 and 0.77.

optimal. The image deformations highly depend on the location of the guiding star.

Programmes heavily relying on excellent and consistent image quality (e.g. to measure accurate object shapes) are probably best performed with FORS. If the large field is needed and VIMOS is the choice, in the selection of the guide star it is better to accept some obscuration of one quadrant by the guide probe rather than to use a guide star in the vignetted telescope field of view or to have to change the guiding star during the observations because this will modify the PSF.

Two other points must be taken into account in the planning of the observations. Sky emission lines do cause relatively strong fringing (at the 10% background level) in the *I* and *Z* bands, and thus dithered exposures to build a night flat field are strongly recommended when deep photometry is the main scientific goal. Bright stars (< 8th mag) in/around the middle of the field can cause reflections at a few percent of the typical background light at specific orientations of the instrument. We are investigating systematically the effect to identify the best orientation to be used as default for imaging.

Multi-Object Spectroscopy

There are two spectroscopic modes of VIMOS: MOS (Multi-Object Spectroscopy with four field-specific, laser-cut masks remotely inserted in the focal planes) and IFU (area spectroscopy of a field covered by a fibre head). The absolute performance of MOS is consistent with the efficiencies observed in imaging with respect to the two FORS. The two low resolution and the intermediate VIMOS grisms have transmissions which are comparable to the best FORS grisms, while the high resolution grisms have significantly lower efficiencies. Of course, the actual gain in spectroscopic survey depends on the density and overall distribution of the program targets. If the sources are numerous and uniformly distributed in the VIMOS field, the number of targets acquired in one exposure can be between 4 and 10 times larger than with FORS2.

Absolute depth limits in MOS spectroscopy are not easily pinpointed as they depend on many factors: the accuracy in matching the masks to the targets, the strategy of the observations, the flexures of the instrument during exposures and the accuracy with which fringing (more than 30% peak to valley past 850 nm) in the spectra are corrected. The preliminary results from the first GTO allocation (Le Fèvre et al., 2003) suggest that the limiting magnitudes in *V* and *R* are close to the ones with FORS1 or FORS2.

There is an additional effect to be taken into account in MOS observations. When multiple spectra in the dispersion direction are taken (mostly in low-resolution spectroscopy) each 1st order spectra is contaminated at a few percent by the 0th, –1st, or 2nd order spectra of the aligned slitlets (see also Fig. 4).

VIMOS is installed at the Nasmyth focus of UT3 and rotates around a horizontal axis during observations. There are no flexures or thermal effects in the focal plane (in particular due to masks made of Invar). This, together with a good mechanical positioning of the masks, ensures a stable positioning in the focal plane. However, there are significant flexures between the detector plane and the telescope focal plane through rotation of the instrument, smaller than ± 1 pixel (0.2 arcsec) in quadrant 2 (Q2) and less than ± 1.5 pixel in Q1, Q3 and Q4. These motions are reproducible, and low enough that they guarantee an effect below 0.5 pixel at maximum through a typical exposure even at maximum field rotation close to zenith. However, flexures are annoying for mask preparation. The positions of the slits are determined from pre-images and from a mask to CCD transformation matrix. If the matrix and the pre-images are obtained at different rotation angles of the instrument, there will be a systematic error in the derived slit positions. The final differential effect between the flexures of the 4 quadrants will typically amount to ~ 1–2 pixels positioning errors in 1–2 quadrants. The component of relative motion across the slits will imply some light losses: their amplitude depend on slit width and object size, and/ or seeing conditions.

As it is the case for imaging, users are required to use the *GuideCam* tool to

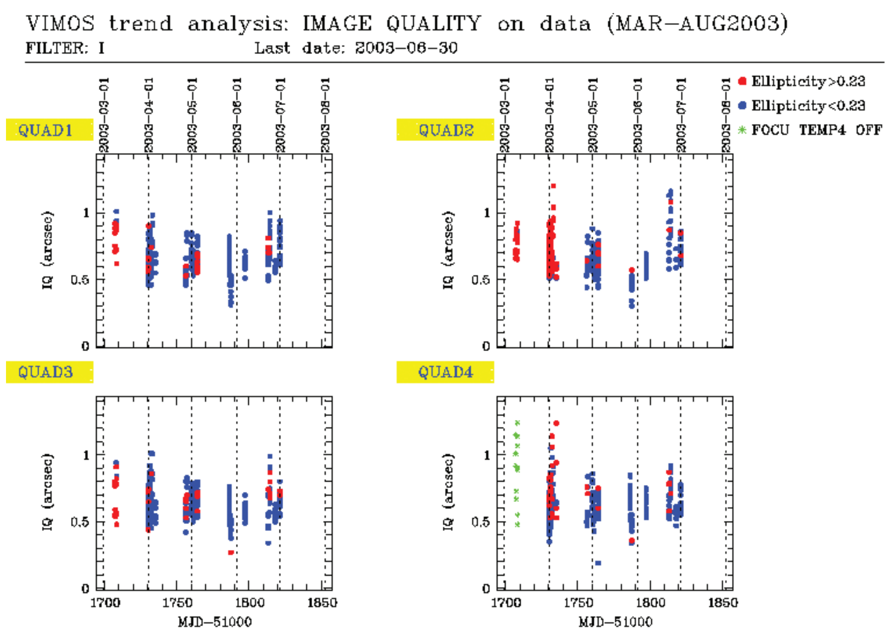


Figure 2: Image quality of the four VIMOS quadrants from I-band observations taken during four months of service operations. Monitoring of these parameters is a task of the DFO group of the Data Management Division.

prepare their pre-imaging observations*. The telescope guide star is carried along in the header and later in the aperture definition file, so that the same guide star is eventually used during the spectroscopic observations. Here also, allowing some vignetting of the field by the Guide Probe might be better than picking a guide star outside the unvignetted telescope field of view.

IFU

IFU is one of the most used mode in VIMOS in the first period. In low resolution it is the largest IFU currently offered at any observatory (54″ × 54″), in medium to high spectral resolution it still offers a fantastic 27″ × 27″ field. Its throughput is below the original expectations and lies on average at 50–60% of the MOS transmission value.

Among the known caveats figures the image quality. The current PSF is elongated and shows chromatic effects. These can be observed when spectra from single spatial resolution elements (along the CCDs Y-direction) are compared: only when all spectra forming a PSF are combined (typically from 3-4 fibres in 0.8″ seeing) the energy distribution is properly reconstructed.

The individual fibres coming from the IFU head are packed at their output such that spectra from contiguous fibres on the detector are spaced by 5 pixels, comparable to their FWHM. A significant overlap/crosstalk is thus present.

Given the tight space between spectra, the instrument flexures of 1–2 pixels (plus an additional, comparable contribution from the IFU slit masks itself) amplify the problem. To be able to cope with these shifts in the data reduction, we are currently adding a night time calibration to each OB taken at the same rotator position of the science exposure, but clearly this reduces the overall time efficiency of the instrument for collecting scientific data.

Finally, we can currently only verify the right pointing after the first exposure (and only when at least two bright objects lie in the field). The astronomers are required to use the *GuideCam* tool in preparing Phase 2 of the observations and to select a guide star taking care to specify accurate pointing coordinates in the coordinate system of that guide star. Following that recipe will typically lead to a 1–2″ pointing accuracy.

The First 4 Months of Operation in Service Mode

The first months of operation have been marred by reliability problems, most of them of mechanical nature. Problems were particularly encountered with the Mask Exchange Units (MEU) and the Grism Exchange Units (GEU). Admittedly, these units are complex: the MEUs select the masks in the 15-slot cabinets, grip, translate and clamp them into the focal plane with high accuracy ; the GEUs select from a 6-position carousel the grisms (up to 15 kg a piece for the high resolution grisms) and insert them in the pupil plane. All these motions are to work under any orientation of the instrument. Because each function exists in the four units, the probability of a failure to happen is multiplied accordingly. In total there are 64 functions in VIMOS, each of them associated with its set of sensors. The overall instrument design appears sound and most of the reliability problems have originated from insufficient workmanship, e.g. inappropriate quality of many components: screws, linear guides, clamps around axes, sensors, etc.

From January to April, the instrumentation group on Paranal had to spend alone 200 hrs of technical work to keep the instrument into operation. The next months were followed by alternate periods of satisfactory reliability followed by intensive periods of troubleshooting, often requiring interventions at night from technical staff and support astronomers. Special operation procedures were implemented to e.g. setup the instrument at particular rotator positions known to generate less problems, change programmes when one mode was not available, etc. In parallel, and as part of the so-called “Paranalisation”, extensive efforts were

Table 1: Status of approved programs in Period 71 as of July 28, 2003

Type of observing run	Number of completed runs	Number of ongoing and pending runs (degree of completion, in % of the allocated hours)
Preimaging (for MOS preparation)	7	3 (0%)
Imaging	6	5 (38%)
IFU	15	12 (33%)
MOS	3	7 (10%)

*see the instructions at http://www.eso.org/observing/p2pp/VIMOS/VIMOS-P2PP.html also devoted to improve the software operation of the instrument, in particular for mask operation and configuration control of the instrument calibrations which are operation critical, e.g. the mask to CCD calibrations etc.

In view of the shaky status of the instrument prior to beginning of operations, the decision was made to transfer all P71 runs, and subsequently also those of P72, to service mode, so as to ensure as high a completion rate as possible for the highest ranked programmes.

The technical downtime attributable to VIMOS was limited to approximately 15% during the period April-July 2003. Although already high on its own (Paranal standards for technical downtime are, all included, at the level of 3–4%), this performance could only be achieved due to the hard work by the technicians, engineers and astronomers who concentrated their efforts on this instrument during this period and by the flexibility offered by service observations. Part of the negative impact of the technical downtime on the completion of scientific programmes was absorbed by performing additional VIMOS observations outside the formal time allocation.

Table 1 summarizes the status of advancement. A total of 374 hrs of observations have been successfully completed, 320 remain to be executed.

An unfortunate side effect of these operational difficulties is that the characterization of the instrument, in particular of the IFU mode, could not be carried out as desired because the resources were mainly directed towards maintaining the instrument operational.

Status of Data Reduction Pipelines

The VIMOS Pipeline is operational on Paranal since April 1st 2003 and is used to process VIMOS service mode data. The pipeline recipes are based on the data reduction software ESO obtained from the VIRMOS consortium, which have been upgraded during the commissioning phase to fulfill the requirements set by Paranal Science Operation group and the Data Flow Operation (DFO) in terms of operations and data quality.

The current version of the pipeline supports the imaging and multi-object spectroscopy modes of VIMOS .

Imaging Pipeline

The VIMOS imaging pipeline provides recipes to create a complete set of master calibrations needed for the processing of scientific observations. Scientific observations are bias subtracted, flat field corrected and photometrically calibrated. Optionally the images may be dark subtracted and corrected for bad pixels and cosmic ray hits. In case of a jitter observation the individual observations can also be co-added. With the current algorithm used for the image combination residual offset are sometimes present in the combined image, depending on the step size. An algorithm with improved accuracy will be available in the course of Period 72.

For the photometric calibration standard star fields are regularly observed and processed and serve to monitor the zero point trends of the instrument.

Software routines are used by the Observatory staff to create bad pixel maps and to compute the coordinate transformations from CCD to mask plane and a model of residual geometrical distortions which is used to compute an improved world coordinate system. The CCD to mask transformation is crucial to the preparation of masks used for MOS observations. The RMS of the residuals of this transformation typically is about 5 10^{-3} mm in the focal plane where the masks are inserted, while the RMS of the inverse transformation is about 0.04 pixels at the detector.

MOS Pipeline

The existing MOS pipeline provides recipes to create a normalized flat field from a set of individual flat fields, to compute the inverse dispersion solution and to process scientific observations taken in stare or jitter mode. Science observations are bias and, optionally, dark subtracted and flat field corrected. The spectra are corrected for curvature and optical distortion effects. Residual shifts of the slit positions (due e.g. to instrument flexure between the scientific and the calibration exposures) are corrected using the position of sky lines. The dispersion solution is applied re-sampling the spectra to a constant wavelength step, and the spectra are sky subtracted. If the observation was in jitter mode, the images can be co-added using offsets computed from the positions of the brighter objects detected on the individual images. Objects are detected and extracted using either a simple sum, or a Horne extraction (Horne K., 1986, *PASP* 98, 609).

The MOS pipeline relies on the presence of models in the FITS header describing the spectral curvature, the optical distortions and the inverse dispersion solution. These models are used in two ways. For the pipeline on Paranal, which runs unattended, these models are used to process science data because the full set of required calibrations for the mask used is typically not available when the data is processed. When the scientific data is processed in Garching, DFO uses the calibrations specifically created for the science mask. In this case the model is just used as a “first guess”. In particular the inverse dispersion solution is then computed for each individual slit of a mask.

Table 2 shows the RMS of the wavelength calibration for the different grisms averaged over the four quadrants using a global dispersion solution and a solution computed locally on the CCD. The two approaches give very similar results

The large RMS value for the low resolution grisms (especially LR_blue, with RMS values up to 2 pixels in worse cases) is probably due to the –1 and 0 order contamination of neighboring spectra along the same CCD columns, an adverse effect of the multiplexing. This contamination can be removed from the calibration spectra by using the built-in instrument mask shutters, whose implementation in the calibration procedure is expected in the last quarter of 2003.

Table 2: RMS of Inverse Dispersion Solutions (pixels-Å)

GRISM	Model	Single slit procedure
LR blue	1.4 – 7.4	1.4 – 7.4
LR red	0.9 – 6.4	0.8 – 5.7
MR	0.5 – 1.3	0.4 – 1
HR blue	0.6 – 0.36	0.4 – 0.24
HR orange	0.4 – 0.38	0.4 – 0.38
HR red	0.4 – 0.26	0.4 – 0.26

IFU Pipeline

The complete set of software modules needed for the IFU data reduction was received just recently from the VIRMOS Consortium and it has been tested on the low resolution data only. It is currently being checked and validated at ESO and will be available in one of the next pipeline releases (for availability dates please have a look at: *http://www.eso.org/qc/pipeline-status.html*).

At the Paranal Observatory there is so far just a quick-look IFU image reconstruction tool developed by ESO to allow the quick verification of the telescope pointing.

Quality Control, Processing and Delivery of VIMOS data

The VIMOS data will go eventually through a Garching-based full quality control process as it is customary for VLT instruments (Hanuschik & Silva 2002). Given the large number of subsystems of the instrument such a QC process is critical for ensuring that useful data with a consistent quality are being delivered to VIMOS users.

At this time, most QC parameters which are extracted from the observations of the first four months of service observing are related to detector and/or imaging performance. For each detector, fundamental properties such as bias level, read noise, gain, flat-field stability, image quality (Fig. 2) and photometric zero-points are measured and compared to nominal values on a regular basis. In time, parameters related to MOS and IFU observations will also be regularly monitored. Various QC reports and trending diagrams for VIMOS are available from the ESO Data Flow Operations Quality Control Web pages: *http://www.eso.org/qc/*.

As for all other VLT instruments, all VIMOS data obtained for Service Mode programmes are processed and distributed to the appropriate Principal Investigators (PIs). Basic processing consists of organising all incoming raw science data by observing run and associated them with appropriate raw calibration data. All PIs receive these basic data plus a variety of file listings when their observing run is completed.

In addition to these basic data, imaging and MOS mode users receive both calibration and science data products created by the VIMOS pipeline. Detailed information about production and nature of these science and calibration products is provided to the users and is available from the DFO QC Web pages mentioned above.

The data from all four VIMOS quadrants are organized and processed separately. Imaging mode users receive bias-corrected, flat-fielded science frames as well as the master bias and master flat-field frames used to process the science frames. Whenever appropriate, they also receive processed standard star frames and zero-point tables. For normal imaging, the most recent calibration data is used to process the science data. Pre-imaging data, however, are processed using archival calibration data to facilitate rapid delivery.

MOS users receive the following science products: an image containing all the 1D extracted spectra, an image containing the two-dimensional (2D) extracted spectra (Fig. 3), and an image containing the 2D extracted sky spectra (Fig.4). Tables containing identification information for each extracted spectrum as well as their individual dispersion solutions are also provided together with the master calibration frames used to process the science data (e.g. bias, flat-field, and arc-lamps).

These spectra have been corrected to a linear dispersion and aligned in wavelength. They have not been divided by the flat-field. Division by the master FF does not yet provide good results and the procedure is being refined and tested. The use of the uncorrected data has little effect below ~8000 Å because the cosmetics of the CCDs is excellent but it is more serious above that wavelength because of the CCD fringing. The problem is partly resolved by the combination of jittered spectra as discussed in Le Fèvre et al. (2002).

The distributed data do not yet include the spectrophotometric correction.

As mentioned above, the IFU pipeline is still under development. Only a basic re-constructed image of the central 27 × 27 arcsec and a IFU sky-slit comparison table are provided to help the user correlating the fibre spectra with the fibre position in the IFU head.

Per standard ESO procedure, the goal is to deliver VIMOS data packages to the users within one month after the completion of the final OB for an observing run. By the end of Period 72, this goal should be met on a regular basis. In the special case of MOS pre-imaging, processed images are already being made available to users within 2 – 3 working days of pre-image acquisition using an ESO Science Archive based process.

Instrument Repair and Upgrading Plans

As reported above, the operational experience with VIMOS has consistently shown relatively high failure rates for some key functions, during commission-

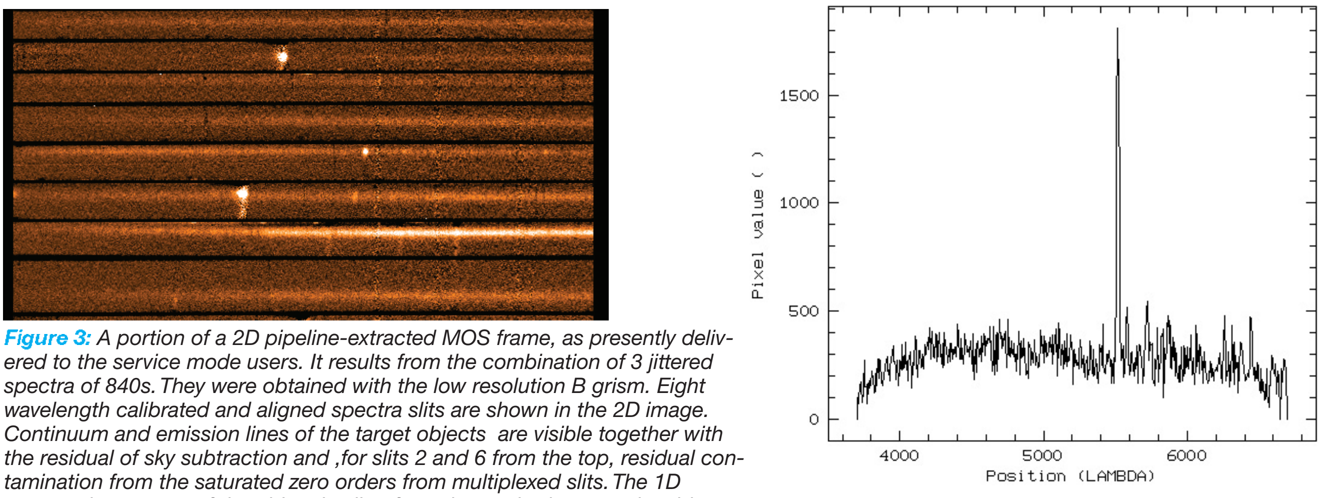


Figure 3: A portion of a 2D pipeline-extracted MOS frame, as presently delivered to the service mode users. It results from the combination of 3 jittered spectra of 840s. They were obtained with the low resolution B grism. Eight wavelength calibrated and aligned spectra slits are shown in the 2D image. Continuum and emission lines of the target objects are visible together with the residual of sky subtraction and ,for slits 2 and 6 from the top, residual contamination from the saturated zero orders from multiplexed slits. The 1D extracted spectrum of the object in slit 5 from the top is shown to the side.

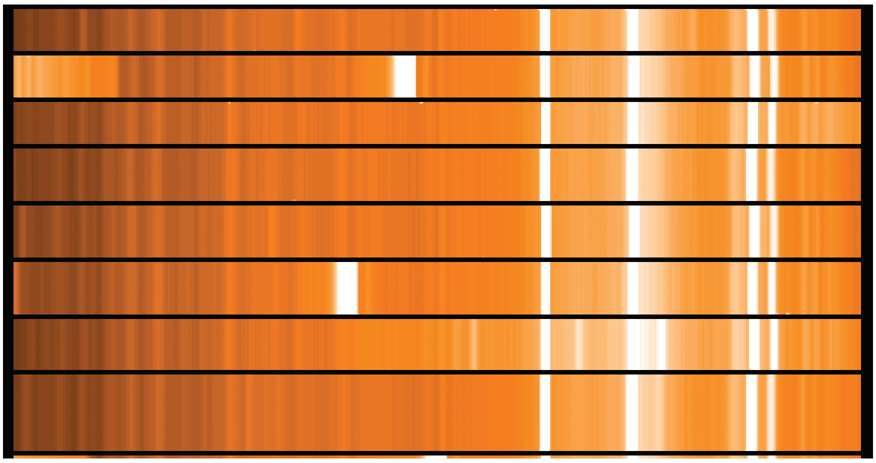


Figure 4: A portion of the sky spectrum for the 8 slits shown in Figure 3. The spectra have been calibrated and aligned in wavelength. The strong sky emission line close to the centre is the 5577.4 Å [O I] line, followed at longer wavelength by the blended doublet of Na I at 5893 Å and the 6300 and 6364 Å lines of [OI]. Some other features of the VIMOS low-resolution spectral data format are also visible. In the slit #2 and #6 from the top the strongest line is the zero order from contiguous multiplexed spectra. In slit #2 from the above, the contamination from the slit in the lower part of the mask is visible on the left. In the slit #7 from above, the –1 order contamination is visible, overlapping the right part of the spectrum.

ing time last year, test runs between November 2002 and March 2003 and the first four months of regular operation in service mode since April 2003. Periods of acceptable reliability following a major tuning of the instrument by the Consortium technical team did not prove to last long. If left unchecked, we fear that the instrument could progressively degrade to a level where its regular operation would become impossible.

With the instrument taken over by ESO from June of this year, we have decided to launch a major repair/upgrade plan, based on two extended interventions by the Instrumentation Division and the Paranal Observatory within the next 12 months.

Although the time when the instrument is off the telescope is concentrated around full moon, the interventions will still result in some loss of useful observing time and they imply some additional cost and manpower to the project. It is however a good investment considering the total value of the project and its scientific capability.

This first, 6 week-long, intervention is taking place in August-September of this year. We are in particular going through extensive verification and refurbishing of the instrument focal plane assembly (including the Mask Exchange Units and the IFU) to improve its reliability and possibly reduce the IFU flexures. The time will also be used to investigate the changes required by the Grism Exchange Units. The instrument is expected to come back into regular operation in the second half of September.

The second intervention is planned for the spring of 2004. The main objective will then be the full refurbishing of the complex GEUs. We now plan also to use this occasion to replace eight high-resolution classical grisms (four blue and four red) with Volume Phase Holographic ones, which are now available in the large size (160 mm) required for VIMOS. The new sets have been just ordered. Besides a substantial reduction in weight, hopefully beneficial to the reliability of the exchange mechanism, they will boost the VIMOS efficiency in these sub-modes by almost a factor 2. The start of P 73, 1st April 2004, should find VIMOS in a much more robust state and able to deliver efficiently the unique science for which this complex machine has been developed.

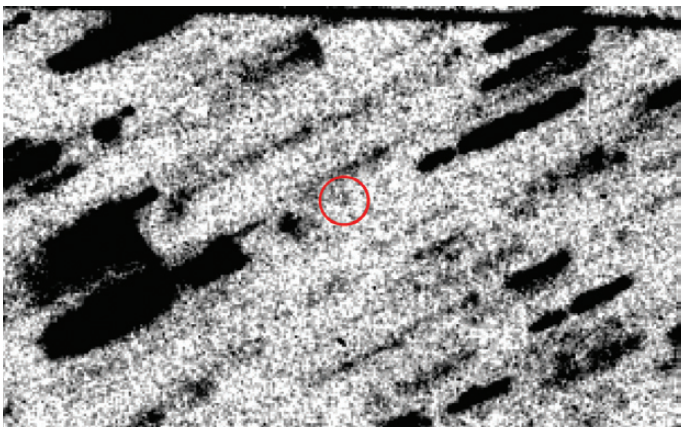
References

Le Fèvre O. et al., 2002, *ESO Messenger*, 109, 21

Le Fèvre O. et al., 2003, *ESO Messenger*, 111, 18

Hanuschik H. & Silva D., 2002, *ESO Messenger*, 108, 4

VLT Observes Comet Halley at Record Distance



Sky field in which Comet Halley was observed with the ESO Very Large Telescope (VLT) at the Paranal Observatory on March 6-8, 2003. 81 individual exposures with a total exposure time of 32284 sec (almost 9 hours) from three of the four 8.2-m telescopes were cleaned and added while shifting their positions according to the motion of the comet. The faint, star-like image of Comet Halley is visible (in circle, at centre); all other objects (stars, galaxies) in the field are "trailed". A satellite trail is visible at the very top. The field measures 60 x 40 arcsec^2; North is up and East is left. ESO Press Photo 27c/03

Seventeen years after the last passage of Comet Halley, the ESO VLT has captured a unique image of this famous object as it cruises through the outer solar system. It is completely inactive in this cold environment. No other comet has ever been observed this far (28.06 AU heliocentric distance) or that faint (V = 28.2). The image of Halley was obtained by combining a series of exposures obtained simultaneously with three of the 8.2-m telescopes during 3 consecutive nights with the main goal to count the number of small icy bodies orbiting the Sun beyond Neptune, known as Transneptunian Objects (TNOs). The combination of the images from three 8.2-m telescopes obtained during three consecutive nights is not straightforward. The individual characteristics of the imaging instruments (FORS1 on ANTU, VIMOS on MELIPAL and FORS2 on YEPUN) must be taken into account and corrected. Moreover, the motion of the very faint moving objects has to be compensated for, even though they are too faint to be seen on individual exposures; they only reveal themselves when many frames are combined during the final steps of the process. It is for this reason that the presence of a known, faint object like Comet Halley in the field-of-view provides a powerful control of the data processing. If Halley is visible at the end, it has been done properly. The extensive data processing is now under way and the intensive search for new Transneptunian objects has started. (*see ESO PR Photo 27/03*)

Four years of Service Mode observing at the VLT

performance and user feedback

On the night of 3rd April 1999 the ESO Very Large Telescope (VLT) started regular science operations with Service Mode (SM) observations using ISAAC at Antu, the first Unit Telescope. Nineteen days later, SM observations were executed for the first time with FORS1. Over the four years following that date, three more Unit Telescopes have joined Antu, five more instruments (FORS2, UVES, NACO, FLAMES and VIMOS) have joined ISAAC and FORS1, and SM observations are now being carried out during more than 50% of the observing time available on Paranal.

It thus seems timely to present an overview of the performance of SM at the VLT, and how it is judged by its users. In this article we provide such an overview, discuss some lessons learned during the last four years, and present a summary of the main results collected from the VLT SM users community through the extensive questionnaire that ESO released in September 2002, where a broad range of the aspects of SM observing, from the Phase 1 proposal preparation to the scientific evaluation of the results obtained, is covered.

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[4]ESO, Paranal Science Operations

Service Mode (SM) observing has been perceived by ESO since the early days of VLT operations planning as a key component in optimizing the scientific return and the operational efficiency of the VLT. It is a concept deeply embedded in the VLT end-to-end science operations model (Quinn et al. 1998, 2002; Mathys et al. 2002). Experience with SM was already gained in February 1997 at the NTT, as soon as that telescope entered into operations again after the "*Big Bang*" (Wallander and Spyromilio 1997) that provided a field testing both for the VLT control system and for much of the VLT end-to-end system.

The current effort invested in SM operations at the VLT can be illustrated by some recent operational statistics. A total of 2909 SM Observation Blocks (OBs), corresponding to 200 observing runs submitted for execution by the five instruments in operation during Period 70 (1st October 2002 - 31st March 2003), were completed within or nearly within the user-specified constraints, amounting to 1685 hours of execution time, without counting the time spent in calibration observations provided by the observatory or the time used in the execution of OBs that turned out to be outside specifications. In the ongoing Period 71, with VIMOS and FLAMES now also in operations, 2043 OBs for 1559 hours of execution time have already been completed under or near user-specified conditions at the time of this writing (mid July 2003).

SM is the most requested observing mode at the VLT, as Figure 1 illustrates. After a steady increase in the SM vs. Visitor Mode (VM) demand ratio over the first two years of VLT operations, the pressure has now stabilized at a ratio of about 15.5 hours requested in SM for each night in VM, or a ratio of 1.7:1 if we take an average duration of 9 hours per night. Although this would directly translate into a community demand of approximately 63% in SM vs. 37% in VM, constraints and limitations resulting from the current Garching-based staff available for support of the front and back ends of the operations has forced ESO to move towards a 50%-50% share, which is mostly achieved by moving selected SM programs to VM. Such a share also ensures that Paranal staff astronomers and fellows keep in direct contact with the astronomical community, that ESO receives external feedback based on first-hand experience of visiting astronomers about the Paranal instrumentation and operations, and that a certain level of know-how about the actual observation process and about observatory operations is maintained in the community.

How Service Mode works: Long-, Medium-, and Short-Term Schedules

The Long-Term Schedule combines the VM observing runs and the SM periods in the best possible way for every observing semester. The main goal of SM planning at the VLT is to make possible the realization of the rationale behind flexible scheduling: to adjust to the prevailing external conditions by executing those programmes that can make the best use of them, and to ensure that each programme is carried out under the conditions that best suit it following a priority scheme that gives precedence to those programmes that received the highest scientific rating by the Observing Programmes Committee (OPC). This leads to the separation of SM runs into the three priority classes A, B, and C, the last one corresponding to low priority runs that can be executed under relatively poor conditions. The allocation of the priority classes is made by the Visiting Astronomers Section in strict accordance with the OPC scientific ratings, taking also into account technical feasibility, target distribution on the sky, and user-specified constraints on the execution conditions, as has been described in detail by Silva (2001).

The outcome of this process is the SM Long Term Schedule (hereafter LTS). Once it is ready and the list of scheduled runs is finalized, the Visiting Astronomers Section notifies the Principal Investigators via e-mail, giving them access to password-protected webpages where detailed information on the time allocated to each of their runs, as well as possible OPC comments, are given. This marks the beginning of the Phase 2 process. Users have to provide at Phase 2 the set of OBs fully defining their observations, prepared with the Phase 2 Preparation Program (P2PP) produced by the Data Flow Systems group of the Data Management Division, and with instrument-specific preparation software maintained by Paranal Observatory. Ancillary information, such as specific execution instructions, internal priorities, and finding charts, must also be submitted at this time. Detailed information on the Phase 2 Preparation Process can be found at *http://www.eso.org/observing/p2pp/ServiceMode.html*. The Phase 2 packages are reviewed by the User Support Group for compliance with SM policies, technical correctness, and consistency with the Phase 1 information as approved by the OPC. Once certified, the runs are included in the Medium Term Schedule queues that are provided daily to Paranal Science Operations, and which form the basis for the Short Term Schedule (STS). The STS is the actual sequence of observations carried out on a given night, and is prepared by the astronomer in charge of SM observing based on target visibility, external conditions, run priority, and possibly other factors such as instrument mode availability or timing constraints.

Once an observing run is completed, the Data Flow Operations group prepares a data package containing all the science data obtained for the run, the corresponding calibration data and, for most instrument modes, also pipeline-reduced data useful for a quality assessment of the science data and, to a limited extent, for their scientific analysis. The Science Archive Facility produces the media (normally, CD-ROMs or DVDs) containing the data package and sends it to the Principal Investigator. Data packages are also produced for non-completed runs at the end of the period. Fast-track procedures for the early delivery of data have been set up to deal with Target of Opportunity runs and for pre-imaging runs to be followed by multi-object spectroscopy. Under special circumstances, it is also possible for Principal Investigators to retrieve raw data from the archive while the observing run is still being carried out if strong scientific reasons require it.

SOME RECENT RUN COMPLETION STATISTICS

All the time in principle available for Service Mode observations during a given semester is distributed among the priority A and B runs. This time would be really available for scientific observations only under ideal conditions, including no technical and weather downtime. The unavoidable deviations between such ideal conditions and the reality, which we describe in more detail below, naturally lead to a certain level of oversubscription of the actually available time. The goal of ESO at the time of executing the priority A and B runs is thus that all the runs in class A, and a large fraction of those in class B, are completed at the end of an observing semester. Indeed, as far as class A runs are concerned the completion fraction is virtually 100%, both due to their higher scheduling priority and to the fact that non-completed priority A runs are eligible to be carried over to the next period unless they can be considered as essentially completed. In the recently completed Period 70, 17 runs out of 71 obtained carryover status. While this is 24% in number of runs, it is actually less than 5% of the time initially allocated to them, since a large fraction of the observations for the runs to be carried over had been already completed by the end of the Period.

The lower scheduling priority of class B runs, designed to make them absorb the impact of the deviations between the ideal assumptions used in preparing the LTS and the reality encountered during the observing semester, implies that a certain number of runs in this class cannot be completed the end of that period, as we have said above. On the other hand, the occurrence of less-than-ideal observing conditions, or the occasional completion of all class A and B runs with targets at a given right ascension interval, gives a chance for the execution of observations of priority C runs.

The statistics on the completion of class B and C runs for the most recently completed Period, given in Figure 2, show that the goal of completing a substantial fraction of priority B runs is being met. An interesting feature visible in Figure 2 is the large fraction of completed class B runs followed by a tail of incomplete runs, whose number actually increases towards the lowest completion fractions. The rea-

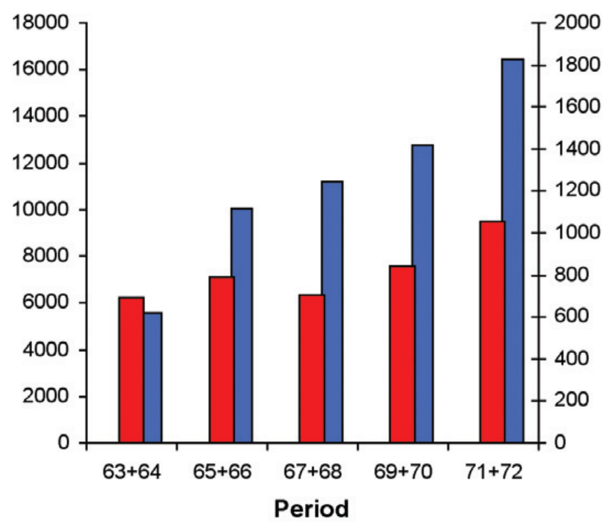

Figure 1: User demand of Visitor Mode (in nights, red bars) and Service Mode (in hours, blue bars) since the beginning of VLT operations. The periods have been binned in couples to remove seasonal differences in the hours/nights equivalence. The right and left vertical scales are directly comparable if we assume a night length of nine hours averaged over the year. After a steady increase of the SM/VM ratio over the first four periods, the ratio has kept roughly constant at 15.5 hours in SM requested for each night in VM since Period 67.

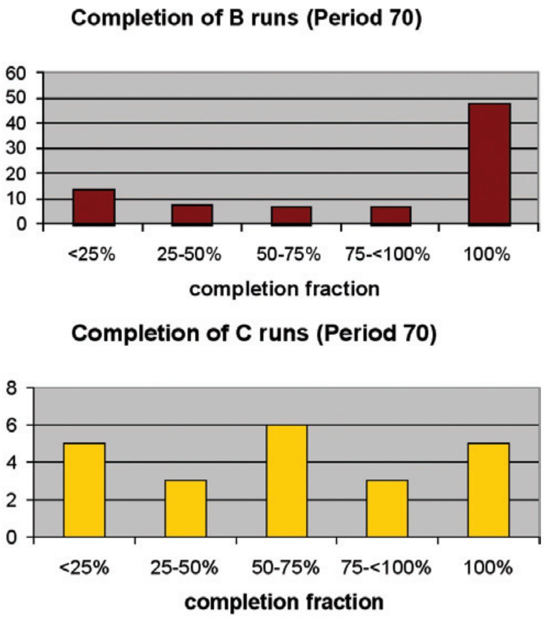

Figure 2: Degree of completion of class B and C runs at the end of Period 70. The priority given in the STS to completing entire runs as opposed to uniformly distributing time over all runs results in a large number of completed runs at the expense of a fairly large number of runs with completion fractions below 50%. Such priority cannot be applied to the "filler" runs of class C

son lies in the practical application of the principle that the scientific objectives of an observing run are most likely to be achieved only if all its observations are completed. Therefore, at the time of building up the STS, priority is given to completing as many class B runs as possible, rather than to obtaining observations for runs likely to be left incomplete, thus explaining the existence of class B runs that were either not started or obtained less than 25% of their observations in Period 70 (such priority is harder to apply to class C runs given their "filler" character, explaining why such a trend is not visible in the lower panel of Figure 2). In terms of the time devoted to priority B runs, 642 hours were allocated in priority B; 421 hours (66%) were actually spent on priority B OBs executed within constraints; 251 h (39%) corresponded to runs that were completed at the end of the Period (since short runs are easier to complete, the fraction of completed B runs is 57%).

Let us recall that the LTS is a forecast on the scheduling of the observing semester based on the Phase 1 information given in the proposals, coupled with a model of the observing conditions during the semester. In practice, a variety of factors contribute to create differences between the LTS and the actual outcome at the end of the period. Most of these factors tend to decrease the time actually available for the execution of scientifically valuable SM observations:

A) Weather and technical downtime are not factored into the LTS preparation process. On Paranal, the total amount of downtime ranges typically between 10 and 15% of the available time, and is largely dominated by weather losses.

B) The actual pressure on each right ascension interval is known only at the end of Phase 2, i.e., after the LTS has been prepared. Deviations from the right ascension distribution assumed at the time of preparing the LTS can be due to a variety of reasons:

① The time allocated is sometimes reduced at the time of reviewing the proposal, leaving to the user the choice of a subset of the proposed targets to observe out of those listed in the Phase 1 proposal.

② The actual time that users planned to spend on each target is often not known in detail at Phase 1 time. Furthermore, users occasionally underestimate overheads or overestimate instrument performance at Phase 1, and thus have to drop targets at Phase 2 to keep within the allocated time and intended S/N.

③ Target change requests at Phase 2 may be approved, as long as they are based on convincing scientific arguments, are consistent with the goals of the project, no conflicts with other runs exist, and the impact on the schedule is small or moderate.

C) Director's Discretionary Time (DDT) and Target of Opportunity (ToO) runs are needed to give the VLT the capacity to react to sudden or unpredictable astronomical events or to very recent scientific developments, and have a random impact on the schedule.

D) The amount of time that will need to be devoted to carryover of runs into the upcoming semester, and the distribution on the sky of the targets of these runs, are not known when preparing the LTS, as this happens long before the current period concludes.

E) The completion of highly rated runs with very demanding observing conditions constraints is usually very expensive in terms of excellent weather conditions, and involves a "hidden" overhead that can greatly increase the actual time needed to complete a highly rated run within constraints. Observations started within constraints are sometimes finished outside, for example because the seeing or the transparency worsened during the execution. According to the current ESO policy of considering an OB as completed only if the user-specified constraints were fulfilled, such OBs need to be repeated, but the time that was spent on them (generally still in reasonably good conditions) is lost to other runs. The difficulty in satisfying demanding constraints over a long period of time is one of the main motivations for imposing a maximum duration of SM OBs to one hour, a limitation that often increases the execution overheads for individual programmes but that greatly increases the overall efficiency of VLT science operations.

F) Finally, and related to the previous item, extremely good observing conditions occur rather rarely, and therefore the relative fluctuations on the amount of time in which they occur are large. When we enter the range of conditions that occurs in only a very small number of nights on a given semester, small number statistics come into play and the risk that a large fraction of the allocated time under those conditions may actually be unavailable becomes very real.

User Feedback

As we have noted above, the preferential choice of SM over VM at the VLT can be taken as a direct indicator of user satisfaction with current ESO Service Mode execution. Feedback from SM users over these last years, either by direct communication with ESO or via the Users Comittee, has been essential to prioritize improvements in the system, such as the major reengineering of the P2PP software or the constant upgrading of the user support tools. In addition, the extensive VLT SM web-based questionnaire made available to the community in September 2002 provides a way to collect comprehensive feedback on the rating that the community makes of the whole SM mode process, covering the proposal preparation, the Phase 2 preparation, the programme execution, the evaluation of the data obtained, and the fulfilment of the science

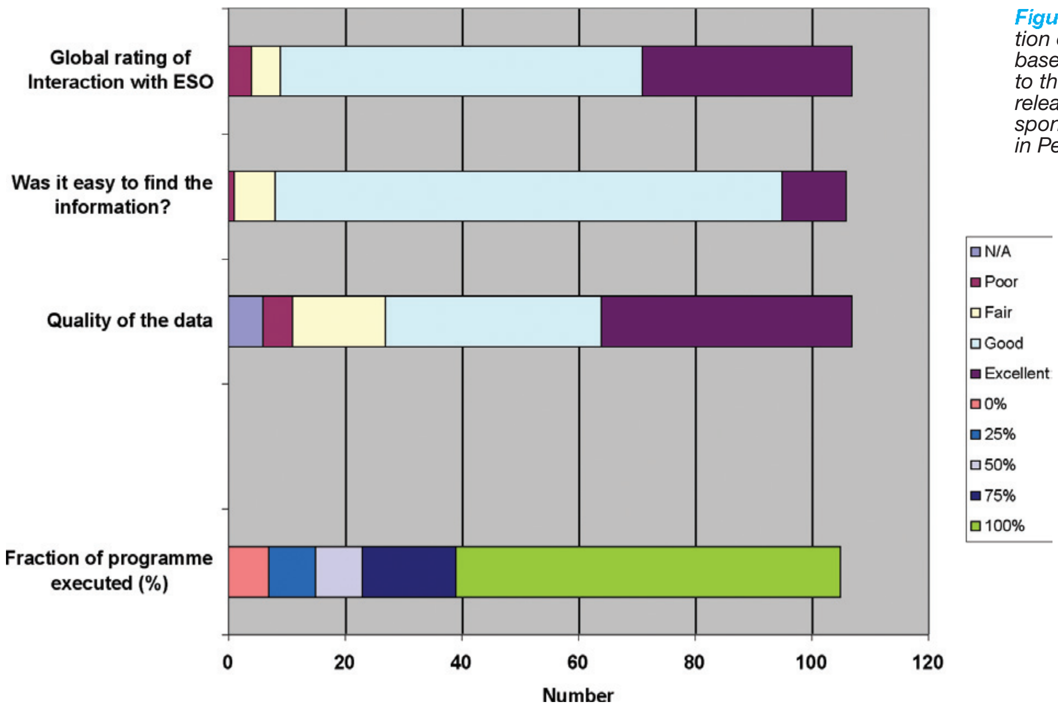

Figure 3: Summary of the evaluation of Service Mode performance based on the 117 answers received to the Service Mode questionnaire released in September 2002 corresponding to runs that obtained time in Periods 63 through 68.

goals. Feedback via this questionnaire was directly requested from the Principal Investigators of runs having obtained SM time in Periods 63 to 68, i.e., covering the entire first three years of VLT operations. The questionnaire can be found at *http://www.eso.org/org/dmd/usg/survey/sm_questionnaire.htm*, and all SM users are encouraged to fill it in. In particular, the note sent to the PIs of SM runs near the end of their proprietary data period reminds them to fill in the questionnaire, as this is the time when a complete scientific evaluation of the data obtained is most likely to have taken place, and when feedback is most valuable to ESO.

A complete report on the results collected from users who had approved SM runs in Periods 63-68 and completed the questionnaire can be downloaded from *http://www.eso.org/org/dmd/usg/reading/smquest_report.doc*. Here we summarize the main points of interests of those results, based on the responses that have been received from 74 unique users on 117 runs, out of the 371 users to which time was awarded in 886 runs between Periods 63 through 68. Most of the responses received (55%) concern runs that obtained time in Periods 67 and 68 (April 2001 to March 2002), and only 14% refer to runs corresponding to the first year of VLT operations. Thus, the results presented here mostly represent a recent evaluation of VLT SM.

The results providing an overall rating of the process (Figure 3) yield a percentage of 92% of runs in which the interaction with ESO is qualified as good or excellent. Concerning data quality, the most frequent rating of the data is "excellent" (40% of the runs), with a rating of "good" in another 35% of the runs, although room for improvement is demonstrated by the 20% of runs for which data were deemed to be of poor or fair quality.

It is interesting to review also the responses given on specific areas of the SM process:

A) Phase 1 receives a very positive global consideration. The Call for Proposals was found to be good or excellent by all the users who replied with one single exception, and the Proposal submission process was considered as good or excellent in 86% of the responses. The web-based documentation provided at Phase 1 on the call for proposals, on the ESOFORM package preparation, and on the instruments (by means of the instrument User Manual) receives over 85% of good-to-excellent marks. At the time of preparing their proposals, 72% of the users find it clear how to compute the overheads on the basis of the documentation provided, and 80% consider the Exposure Time Calculators to be good or excellent.

B) On Phase 2 preparation, 30% of the users found the time between the notification of the time allocation and the Phase 2 package submission deadline too short. Although this time has generally been four to five weeks, it has been possible to extend it to six weeks in Period 72, and we thus believe that this point has been mostly addressed now. The Phase 2 instruction webpages, both general and instrument-specific, and the instrument manuals, receive similar approval rates with 86%–90% of responses giving ratings of good to excellent. However, the still relatively low percentage (8%–12%) of the responses giving a rating of "excellent" are a good reason to continue the sustained effort to improve the documentation.

C) P2PP, one of the most visible software products currently provided by ESO to its user community, is now rated as good or excellent in between 75% and 78% of the cases regarding its installation, user manual, usability, and functionality. Its installation receives the highest marks, being considered "excellent" by 22% of the response. Improvements in both functionality and documentation introduced over the last year will hopefully increase these marks in the near future.

Among other tools used for Phase 2 preparation, *Skycat* receives a very positive consideration: 58% of the users consider its functionality as good, and 35% as excellent. Over half of users (55%) use it to produce their finding charts.

At the time when the survey was released, the FORS Instrumental Mask Simulator (FIMS) was the only auxiliary, instrument-specific tool that had been released for use in the preparation of Phase 2. Its usability and functionality were considered as good or excellent by 55% and 58% of the FORS users, respectively. Several other auxiliary preparation tools

(*NAOS PS* for NACO, *VMMPS* and *Guidecam* for VIMOS, and *FPOSS* for FLAMES) have been released in the last year.

D) The assistance of the User Support Group astronomers in preparing the Phase 2 package has been considered good in 42% of the cases and excellent in another 37%. The Phase 2 review process, also carried out by the User Support Group, is rated as excellent in 36% of the responses and good in another 53%. Overall, the phase 2 process is considered as good or excellent in 89% of the answers.

E) Most of the users (88%) check the progress of their SM observations during the period through the webpages, and a similar percentage find the information clear, up-to-date, and complete. However, almost half (46%) of the users who answered the survey complained that the run progress information was not easy to find. This is one of the cases in which the questionnaire allowed us to identify a shortcoming perceived by many users that had passed unnoticed to us! We have tried to make this information more visible now by including links to it from more ESO webpages.

F) The SM data package, prepared once a run has been completed or terminated, is globally considered as good in a wide majority (81%) of the cases, with an additional 11% that rate it as excellent. The amount of data seems adequate to 92% of users, and the data volume is unanimously considered to be manageable. The typical delay of four weeks between the completion and the delivery of the data is found to be acceptable for 88% of users, although ESO is studying ways to speed up the process for users who need earlier access to the data.

G) The quick-look science data are mostly found to be of good (55%) or excellent (8%) quality. The pipeline products are generally considered as useful (71% of responses), but were directly used for science in only 18% of cases. Shortcomings identified in this area thanks to the SM questionnaire are a perceived insufficiency of information on the reduction process (72% of responses) and the limited usability of the quality control parameters. Slightly more than half of the users (53%) visited the Quality Control webpages, where they generally found the information to be useful (94%) and up-to-date (79%). Also in this area, the Data Flow Operations group has made a considerable effort in making data reduction and quality control documentation available through its Web pages (*http://www.eso.org/qc*; see also Hanuschik and Silva, 2002, and Hanuschik et al., 2002) in order to increase the usefulness of processed data products to the end users.

H) Finally, most of the answers received to the questionnaire (53%) corresponded to runs for which the data analysis was completed, while it was still in progress in another 38% of the cases. A major concern in this respect is that only for 10% of the runs are the calibration plan data considered as good: by far the dominant rating is fair, with 78% of the answers. Also, the information on the calibration plan is rated as only fair by 91% of the answers, and none of them gives the rating "good" or "excellent". Nevertheless, the data quality was rated as excellent regarding the fulfilment of the scientific goals in 49% of the cases, and good in another 28% (note that these percentages include runs that were only partially completed, thus preventing the full achievement of their scientific goals).

Concluding Remarks

In summary, although there is still room for improvement in a number of areas, the users' satisfaction with the large majority of the services that ESO provides in Service Mode observing is high. Needless to say, a fair measurement of the performance of Service Mode and its perception among the users community relies on a continued and abundant feedback to ESO; we thus encourage SM users to continue providing ESO with such feedback through the Service Mode questionnaire at *http://www.eso.org/dmd/usg/survey/ sm_questionnaire.htm.*

On ESO's side, much has changed and improved since Service Mode observations were started in 1997 at the NTT and in 1999 at the VLT: new and better tools are available, more experienced and skilled staff are in charge of planning and executing the observations, policies and procedures leading to an efficient use of the Service Mode time have been defined and evolved over time, a clearer picture of the advantages and limitations of Service Mode observing has emerged, and many lessons have been learned, both obvious and subtle. On the users community side, the principles underlying Service Mode observing have become better appreciated and increasingly used to the advantage of the scientific goals of the projects, while new projects with new demands keep pushing the boundaries of its possibilities. The high standards expected by the community, its sustained high demand for Service Mode, and the valuable feedback received from it, together with the challenges set by new and more complex instruments recently entered into operations or soon to do it, drive Service Mode as an evolving process at the VLT and as an essential ingredient in maintaining its high scientific productivity, at the same time that it explores operations paradigms that will be essential to the success of ALMA and OWL in the coming decades.

Acknowledgements

The success of Service Mode operations at the VLT owes much to many individuals who are or have been involved in multiple aspects on both sides of the Ocean: the software engineers who develop tools; the staff astronomers and fellows who carry out the observations and sometimes provide lessons learned the hard way; the telescope and instrument operators; the user support astronomers; the scientists in charge of scheduling, maintenance of reporting tools, quality control and data distribution; the people who have developed and refined its underlying concepts with time; and, last but not least, the broad community of Service Mode users.

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THE ALCATEL/EIE ALMA ANTENNA PROTOTYPE APPROACHES COMPLETION IN NEW MEXICO

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AT THE TIME OF WRITING the French-Italian Consortium responsible for one of the two ALMA Antenna prototypes is completing the assembly phase of the antenna at the ALMA test facility (ATF) located at the site of the Very Large Array (VLA) in New Mexico.

The ALCATEL/EIE antenna in the final phase of assembly at the ATF.

The assembly activities are performed by a team led by ALCATEL Space of France, including engineers of European Industrial Engineering (EIE) of Italy, the other member of the Consortium, and responsible for the antenna design.

ALCATEL Space Industries joined the original Italian Consortium, formed by EIE and Costamasnaga in December 2001, when an amendment to the original Contract was signed by ESO allowing the enlargement of the Consortium. With the amendment ALCATEL Space became the Consortium leader.

In the months following the signature of the Contract amendment, the existing antenna design was brought to the manufacturing stage. This process was the occasion for further optimising a design that had been considered to be very promising since the beginning of the project. Direct drives (similar to those used on the VLT main structure) are used on both elevation and azimuth axes. The receiver cabin is entirely manufactured of Carbon Fiber Reinforced Plastic (CFRP). This allows considerable mass saving compared to a steel cabin. Together with the primary reflector backup structure (BUS), also made of CFRP, it provides a thermally stable elevation structure. Both the direct drives and the CFRP cabin are expected to be advantageous for the dynamical performance demanded of the ALMA antennas.

Another new design feature was the use for the reflector surface of replicated Nickel panels developed by Media Lario under a Contract from the European Space Agency (ESA) and ESO. The replica technique has allowed a fast production process and may prove to be advantageous for the serial production of the 64 ALMA antennas.

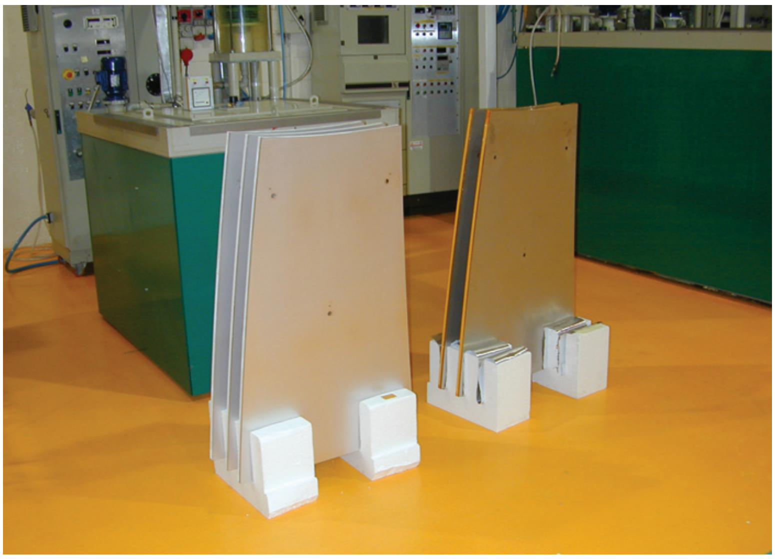
The replicated panels are Rhodium coated for protection against the harsh Chajnantor environment. The performance of these panels for the ALMA antenna has been the object of extensive studies and tests. One major test has made use of a setup constituted by one panel, mounted by its adjusters on a CFRP slice of the BUS in a climatic chamber to prove some elements of the surface stability budget of the reflecting surface.

In the tradition of ESO all new design characteristics were subjected to a formal review process by the team in charge of the follow-up of the Contract[1]. This re-

[1]The "core" team is composed of J. Baars, F. Biancat Marchet, C. Dichirico, B. Gustafsson, F. Koch, M. Kraus, J. Strasser, A. van Kesteren and the author.

The machining of the CFRP cabin interfaces at the Galbiati factory. The machining head is working on the elevation motor attachment point.

The BUS being assembled at the Galbiati factory.



View of the replicated Nickel Panel at the Media Lario factory. The panels at the left have been coated with Rhodium and have a brighter appearance than those on the right (bare Nickel).

view process was also applied to the new design of the internal metrology system of the antenna. Such a system will be used to guarantee the very demanding pointing and stability performances in the open conditions of the Chajnantor site, characterized by strong winds, significant temperature gradients, and strong solar radiation.

The pre-erection activities in Europe were limited by the short time available to the Consortium and by the default, in May 2002, of one of the Consortium members (Costamasnaga), whose original scope of work within the Consortium had been the mechanical manufacturing and pre-assembly. A replacement mechanical shop (Galbiati) was found for those activities, and EIE took over the tasks linked to the antenna mount manufacturing (antenna base, yoke, motors, electrical subsystems etc.). At the Galbiati assembly hall the major parts of the antenna mount were installed and checked in November 2002, to be finally shipped to the ATF in January 2003.

The assembly of the CFRP cabin and BUS, performed in parallel, and extending up to spring 2003, proved to be a delicate task, given the dimensions of the parts to be joined together and the strict dimensional tolerances on the final assemblies. The cabin and BUS were manufactured by two specialized Italian CFRP manufacturers (Plyform and ATR) based on the EIE design, under contract from ALCATEL. The various sub-assemblies had to be glued and bolted together under dimensional control by means of a laser tracker. For this task ALCATEL made use of a French subcontractor (SETAT) specialized in the measurement of large structures[2]. A setback was encountered when two of the sixteen sectors of the BUS structure were damaged in a road accident while being transported from ATR to the Galbiati integration hall. Nevertheless in April 2003 the cabin and BUS were finished, painted, specially packed and shipped by air cargo to the testing site. (See *ESO Messenger* No. 112. p. 2) .

In the meantime, in order to be able to work in the difficult conditions of the ATF (strong winds in late spring, burning sun and thunderstorms in summer) the Consortium had erected a temporary shelter for the assembly of the antenna. This shelter has proven valuable for the

[2]The company is known to ESO for having performed the dimensional measurement of the primary mirror cells of the VLT.

delicate task of mounting and aligning the antenna. All major mounting operations were performed under control of the laser tracker. In June the cabin was positioned and aligned onto the antenna mount, and on 11 July the important operation of mounting the BUS on the antenna was performed without major difficulties. All major interfaces, although not tested at the factory, mated correctly.

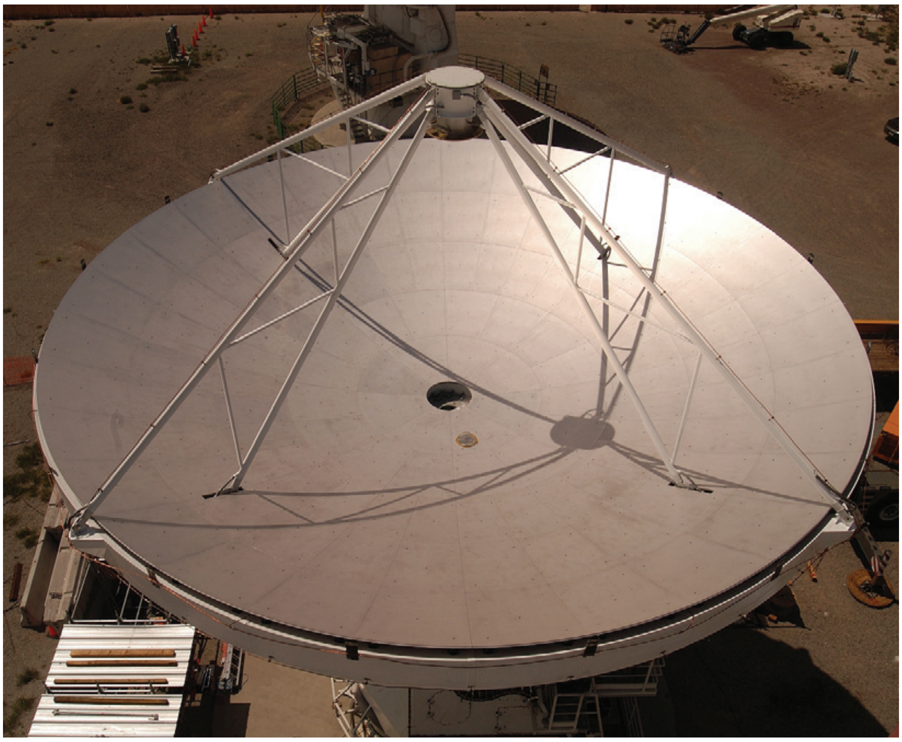
In the following weeks the 600 panels adjusters and the 120 replicated panels were mounted and aligned on the BUS. A verification of the surface accuracy with the laser tracker has resulted in a panel map with the excellent accuracy of 40 micrometers. (It will be a later task of the joint ESO-NRAO Antenna Evaluation Group (AEG) to obtain the final specified accuracy of 25 micrometers.)

On 18 August the roof of the shelter was removed and the quadrupod with the sub-reflector and its mechanism were installed. A branch of a tree (later removed) had been put on top of the antenna to respect an old French building tradition. The long-awaited dismounting of the shelter walls revealed for the first time the antenna in its entirety and final configuration.

In the entire manufacturing and assembly process the close collaboration between the ALCATEL integration team, and the EIE engineering team, author of the ALMA antenna design, has been fundamental for solving the unexpected problems and various glitches typical of a prototype. At the ATF site even minor problems can impact the schedule due to the transport and import time. Close communication between the site team and the design office is essential.

At the time of writing the technical commissioning of the antenna has started, in parallel with the finishing activities. The team on site is working round the clock to give the final touches to the antenna and to start the verification phase with ESO. Part of the verification activities is linked to the commissioning of the metrology system, involving a set of delicate performance measurements, some of which will be performed on the sky. Following acceptance of the antenna by ESO, the final evaluation of the antenna characteristics will be done by the Antenna Evaluation Group of the ALMA project after equipping the antenna with a receiver.

The mounting of the BUS onto the antenna at the ATF site.



View of the top of the antenna, after completion of the reflecting surface and installation of quadripod and subreflector.

THE LAST BORN AT LA SILLA: REM, THE RAPID EYE MOUNT

CERRO LA SILLA IN JUNE WELCOMED A NEW SMALL TELESCOPE ON ITS TOP: THE RAPID EYE MOUNT (REM) ITALIAN TELESCOPE: A TELESCOPE WHICH HAS BEEN CONCEIVED AND DESIGNED TO IMMEDIATELY POINT AND OBSERVE THE GAMMA-RAY BURSTS DETECTED BY SATELLITES. ITS IMMEDIATE DATA GATHERING CAPABILITY AND ITS ACCURATE ASTROMETRY IN THE OPTICAL AND IN THE NEAR-INFRARED WILL ALSO ALLOW AN EARLY ALERT AND POINTING OF THE VERY LARGE TELESCOPE.

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IN THE LATE NINETEEN SIXTIES, the Vela satellites, designed and flown to monitor the outer space in agreement with the "Outer Space Treaty" that forbade nuclear explosion in space, detected quite accidentally the presence of bursts of high energy photons. Their energy was in the range of 100 KeV – 1 MeV and they would last for a few tens of seconds. Klebesadel, Strong and Olson announced the discovery in 1973 and since then the attention of the astronomical community became focused on these highly energetic and completely unknown wonders of the sky.

A Gamma-Ray telescope does not allow the estimate of the position of a source on the Celestial Sphere with good accuracy. At the same time the scarcity of the events detected by the satellites launched before the nineties did not allow astronomers to know their distribution on the sky. These uncertainties led to two different schools of thought. Many astronomers were defending the galactic origin of these sources while others were sustaining their extragalactic origin. The launch of the Compton Gamma Ray Observatory (GRO) in 1991 with the BATSE detector aboard revolutionized our understanding not only by providing detailed temporal and spectral information but also by showing that these sources are uniformly distributed on the Sky. This made a convincing case for their extragalactic origin. But it is thanks to the Italian Dutch satellite Beppo SAX that the extragalactic origin was confirmed beyond any doubt. The scientists of this mission were able to discover the X-ray counterparts and consequently achieve accurate astrometry, which finally led to the identification of the host galaxy and redshift measurements.

Since the GRBs are at cosmological distances, the observed fluence (~10^{-7} ergs/cm^2), that is the total flux received during the burst, indicated that the emitted energy had to be extremely high and of the order of 10^{51}–10^{52} ergs/s under the model of a beamed source. We are thus witnessing one of the most spectacular emission of energy in the Universe. Such energy corresponds to the annihilation of a very significant fraction of a solar mass in a few seconds and corresponds to the luminosity we have when summing up the light of all the galaxies in the nearby universe.

While the phenomenon is rather rare assuming an isotropic emission, roughly one event per year per million galaxies, the frequency considerably increases if we consider we are seeing only those bursts for which the line of sight is within the emission cone of the relativistic beaming jet and we miss all the rest.

The generic model we have at present is simple and fascinating. A fireball of very hot radiation, possibly contaminated by some baryonic matter, at some point appears and expands at ultra-relativistic velocity. That the velocity is extremely close to the velocity of light is demonstrated by the fact that the spectrum we observe is not thermal that is, we do not observe the equivalent of an opaque expanding photosphere. The optical depth for radiation is smaller than one. On the other hand the rapid variations that have been observed at high energies would call for a very small volume of the source with the production of copious electron positron pairs. That is we should have high opacity, and therefore optical depth larger than one, and expanding near blackbody photosphere. However if the ball is moving at high relativistic speed, with a Lorentz factor of about 100, the volume of the source at its rest frame becomes larger, the photon energy involved much smaller and, as a consequence, the number of electron pairs produced highly reduced causing a much smaller optical depth. The expanding shells are transparent to radiation.

A beautiful confirmation of this super relativistic velocity came from the radio observations of GRB970508 by Frail et al. About a week after the detection of the burst (both BATSE and Beppo-SAX detected it in gamma-rays and Beppo-SAX localized it with the X-ray camera) the radio emission was optically thick and showed intensive oscillations that disappeared after about three weeks. Interpreting the oscillations as due to scintillation it became feasible to estimate the size of the fireball at this phase to be about 10^{17} cm and in agreement with the theoretical considerations described above.

The ultra relativistic beamed shells moving outward slow down and are hit by the following shells causing internal shocks with the emission of high energy photons while the impact of the shells with the interstellar medium of the host galaxy causes what are known as the external shocks and produce the X-ray and optical emissions, the afterglow phase of the burst. The observed flux decays as a power law with exponent which in general is between –2 and –1. But while all of the bursts detected in the γ-rays have been also detected at X-ray frequencies, a large percentage of these, about 50 to 60%, are not detectable at optical wavelengths.

The success of the Beppo-SAX satellite and the knowledge gained on the GRBs both observationally and theoretically, clearly pointed to the information needed if we wanted to make any progress in this field of endeavour. The opportunity to make a satellite capable of procuring the needed data was caught by US scientists who proposed, in collaboration with Italy and the United Kingdom, a NASA MIDEX Mission, Swift, to carry out the research. As spelled out in the international logo, with Swift we are ready for "catching the bursts on the fly". The Mission is scheduled for launch in Spring 2004.

The planned satellite had to be able to detect GRBs over a large fraction of the sky with a good sensitivity, measuring the afterglow at the X-ray and optical wavelengths. Indeed Swift after detecting the Bursts with the BAT (Burst Alert Telescope) instrument points the spacecraft in about 10 – 70 s so that the Narrow Field Instruments, XRT (X-Ray Telescope) and UVOT (Ultraviolet Optical Telescope) follow the event. UVOT is sensitive in the range 170 – 600 nm. Soon after each instrument onboard the spacecraft detects the burst, the position of the source is communicated to Earth so that the Ground Based Telescopes can point in that direction and get the complementary observations.

Fast and quick is the mandatory priority since the phenomenon evolves very quickly and the emission due to the physical events occurring at the very outset may be the most revealing about the physics at work. The multi-wavelength coverage is crucial since the complex phenomenon, and its interaction with the environment, radiates at all wavelengths. For instance, it will be essential to estimate the time lag between the emission peaks at different frequencies.

The Swift instrumentation does not provide any coverage in the red and infrared bands, which is instead critical, given that 50 to 60% of the bursts have no detected optical afterglow, let alone the importance of monitoring the temporal decay in the infrared. We must find out whether this fact is due to dust (from the centre of the Galaxy we easily receive γ-radiation and we observe in the X-ray but we suffer about 30 magnitudes extinction in the optical) or a percentage of bursts are missed in the optical simply because of their very high redshift. This second possibility, the detection of very high redshift sources with $z > 6$, is an extremely exciting challenge and fundamental to cosmology.

« Fiat lux et lux fuit »

The end of the "Dark Age" in the cosmic history of the Universe occurs with the generation of the first light and the subsequent re-ionisation of the hydrogen that had been formed at recombination. This epoch, that according to theoretical consideration and numerical simulation is located in the range $6 < z < 20$, is at present under intense theoretical investigation and close to our observing capabilities as demonstrated by the observations of the quasar detected by the Sloan Digital Sky Survey at $z \sim 6.43$. But light and re-ionisation are only part of the story. Assuming population III stars and nuclear reactions create light, it is during this epoch that we start forming heavy elements in the Universe and spread them around. It is the beginning of the chemical evolution. It would be a different story if at the very beginning the creation of light was related to accretion of matter into massive black holes. This non nuclear mechanism is highly efficient in producing light, however the lack of significant star formation would imply a delay in the chemical evolution of the Universe. The high-z very bright GRBs could be the objects giving us the fundamental information about this epoch and using them as beacons they will tell us the details of the intergalactic medium (IGM) and therefore the history of the Universe. But to do that we have to detect them fast, measure accurately their position and quickly point the very large telescopes in order to get the information we need before they fade away. These considerations guided the conceptual design of the REM telescope.

With an estimated frequency of bursts detected by Swift of about 150 per year on the average from any ground based facility, due to the location and to the day and night alternation, we will be able to observe about 40 bursts a year. REM is located in the Southern hemisphere . While soon after alert the telescope will be observing the burst for as long as possible uninterruptedly, after a while the main players will be the large telescopes and REM will only make a few observations on each given burst. That is REM will be free to observe other targets, and to perform a secondary science program, for

Figure 1: *"Notre Dome de La Silla". The Dome hosting the REM telescope.*

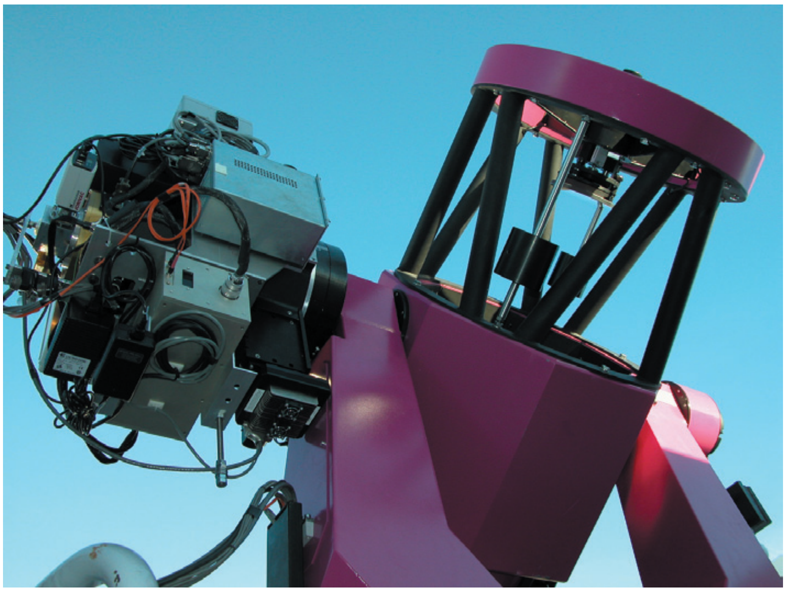

Figure 2: The telescope with its instrumentation.

more than 40% of the time. To this end we already planned a set of observational programs and later on REM will also be open to observing proposals.

The Rapid Eye Mount Telescope (REM)

The specifications for REM were very simple even if very demanding on both the hardware and software. The science drive demanded an instrumentation that had to be sensitive also to the near infrared and that had to be sensitive to all wavelengths up to 2300 nm, the K' band. The science needs dictated the telescope had to go immediately, and without human interference, on target after Swift, or any other satellite, sent a burst trigger deciding automatically, and, according to a priority tree designed in the software (Figure of Merit – FOM) and regularly updated, what to do. The quick look automatic software had to be capable of identifying right away, and measuring accurately, the position of the burst and its magnitude as to immediately alert the community and all the major telescopes, the ESO VLT in particular. Furthermore the combination of the two instruments described below, and the related software, had to allow the estimate of the redshift of the cosmic events via the Lyman-α line and the drop out technique.

The specifications as dictated by the science drive suggested immediately the choice of an alt-azimuth mounting in order to minimize the momentum of the instrumentation during slew. Our interest in using the VLT Unit Telescopes suggested either Cerro Paranal or Cerro La Silla as suitable sites. When such idea was illustrated and documented to the Director General Catherine Cesarsky, even before approval of our proposal for funds in Italy, we were extremely pleased to see interest and excitement toward the proposal and to be encouraged to proceed. Later on, and after many interactions with the ESO staff, Cerro La Silla (Figure 1) was selected as the most convenient location for REM.

The telescope uses a Ritchey – Chretien configuration with a 60 cm f/2.2 primary mirror and two Nasmyth f/8 focal stations (Figure 2). The telescope has been manufactured by Teleskoptechnik Halfmann Gmbh in Augsburg (Germany) and the optics by Carl Zeiss AG (Germany). To optimise the response in the near infrared the telescope optics were coated with silver and protected by a special overcoating. Accurate pointing, fast slewing and precise tracking are achieved using azimuth and elevation motors made by ETEL which allow a maximum speed of 12 deg/s and Heidenain encoders with 237 steps per arcsec.

The instrumentation has been attached, together with the field de-rotator, in one of the Nasmyth foci (Figure 3). A beam splitter (dichroic) manufactured by ZAOT (Italy) according to our design leaves the Infrared beam (950 – 2300 nm) to continue along the optical axis where the IR Camera (REM-IR) is installed while it deflects the optical beam (450 – 950 nm) to an orthogonal axis where the optical instrument (ROSS) is installed (Figure 4).

The Infrared Camera

At present the camera is working with 4 filters (Z, J, H and K'). However the filter wheel, located in the parallel beam, hosts 8 positions so that provision has been made for further filters and grisms. The camera optics convert the telescope f/8 beam into a f/5.3 beam allowing a scale on the focal plane of 64.4 arcsec/mm. This allows us to have a 9.9′ × 9.9′ field of view on a 512×512 (1800 nm pitch) HgCdTe array produced by Rockwell. We are using 1 quadrant of a Rockwell Hawaii II

Figure 3: The telescope during operations and pointing the sky, Courtesy of P. Aniol.

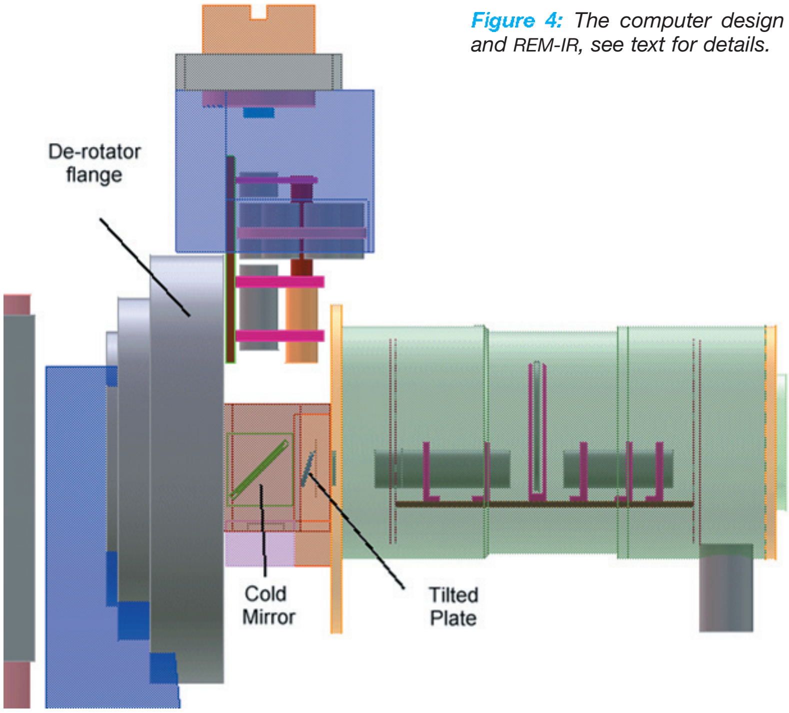

Figure 4: The computer design of ROSS and REM-IR, see text for details.

1024×1024 chip so that in case of deterioration of the quadrant we are now operating we can switch to another 512×512 quadrant. The IR array uses a Leach Controller with a read-out speed of 1.64 microsecond per pixel.

The collimator and the camera (Silica – CaF2 and CaF2 – Silica) focus the image on the CCD after passing through the Cryostat window. The whole camera is mounted in a dewar manufactured by the Infrared Laboratories in Tucson (Arizona) so as to operate in a cold environment and is kept at a working temperature of about 77 K. The working temperature of the IR array is 77 K as well. The cryogenics are supported by a Stirling – Cycle cryo-pump made by Leybold AG (Germany).

The ROSS spectrograph

The optics of ROSS, also designed by us, consist of separated doublets made of ZKN7 – FPL53. The filter wheel accommodates the V-, R-, and I-filters and an Amici prism 66 mm long. The prism is made of Silica, BAF2 and CAF2 and the spectral range from 450 to 950 nm is displayed over 60 pixels. In order to match the optical thickness of the Amici prism and to avoid refocusing while passing from the imaging mode to the spectroscopy mode, the filters were glued on properly designed cylinders of optical glass. The detector head is a commercial Apogee AP47 camera hosting a Marconi 47-10 1K×1K 13 μm pitch CCD.

Software and Operation Conceptual Design

When the telescope was conceived, the idea was that it had to go on target according to built-in decisional software and according to a trigger given directly by the Swift satellite or any other satellite for that matter. Conversely, the telescope and related science software had to be capable of immediately evaluating the observations and be capable of communicating them immediately and eventually trigger large ground based telescopes like the VLT or any Space Borne Observatory. This has been accomplished.

The REM Observing Software (REMOS) after receiving the alert message via a socket connection from the GCN (*http://gcn.gsfc.nasa.gov/gcn/*) will also check the status of the telescope, the on-going observations and any other activity including its meteorological environment. If the priority tree built into the software commands the telescope to move to the new alert, the telescope is on target in less than 60 seconds and starts the observation with both instruments according to the instructions that are listed in the Figure of Merit. At this point the astrometry and photometry of the Transient is done immediately by an automatic routine and the information passed via Internet to all the relevant parties, astronomers and observatories. At all time we will have a person remotely supervising the performance of the facility.

Installation at La Silla and First Light

In June 2003 everything started to move quickly. After a long journey over the Atlantic Ocean and Panama and a trip through the Chilean land, the telescope arrived at Cerro La Silla. Here the very efficient and competent staff at ESO Observatory had already constructed a simple, but very neat and complete with all the needed connection, dome: "Notre-Dome de La Silla".

The Telescope was mounted in about a week and soon after we mounted the instrument on the Nasmyth focus. For the first time we had on the mountain a bunch of young – and not so young - Italians, trying to get things working. Indeed some were busy with the hardware, some with the instrument software and others in making the whole network connection active. At the same time Mr. Aniol from Halfmann was busy in setting up the telescope and, in collaboration with the software subcontractors, was working on the telescope pointing software, pointing model and de-rotator software. Indeed the space inside this small dome was packed with persons working on different tasks without interfering with each other and each one with a very high capability of understanding the relevant information from the cross talking in different languages: Italian, German, English and Spanish.

Soon after the equipment had been turned on we were able to point the telescope, even if not very accurately yet, and get the first images. By Tuesday June 24th we had the first fairly good images (Figure 5) and standard stars both with the infrared camera (REM-IR) and the ROSS instrument.

Preliminary data reduction of the standard stars without correcting for flat fielding in the NIR, gives the following limiting magnitudes for 1 second integration and S/N=5: V=17.2, R=17.2, I=16.0, J=14.5, H=13.5, K'=13.0. These observations show that the sensitivity of the instrument already matches (or is even better in K') the sensitivity we expected as estimated in the original proposal. That also means that by a proper reduction of the data and after fine-tuning of the observing, and data analysis software, the system will exceed the expectations.

As it is very clear to all astronomers, as for the roof of an house, the first light is a milestone in the making of a telescope

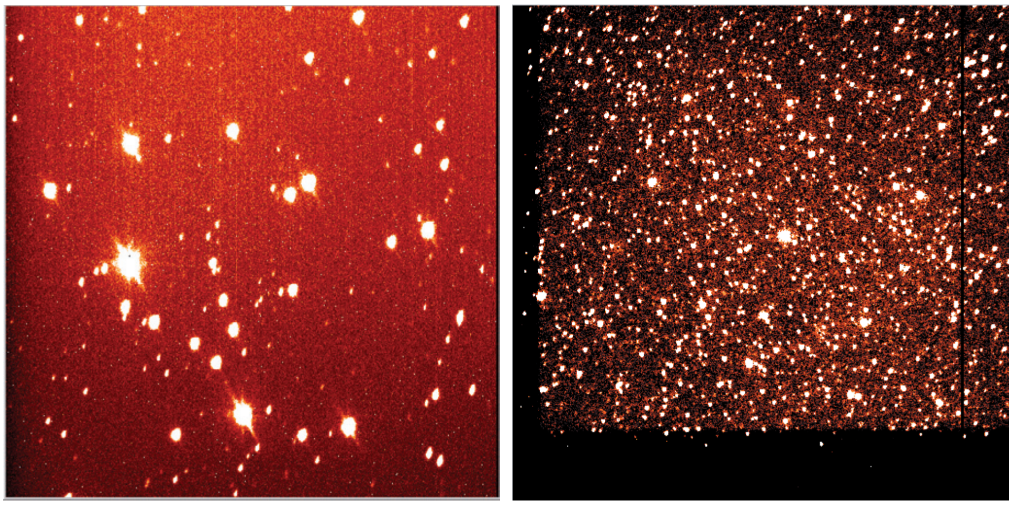

Figure 5: *First images, showing the open star cluster M6, taken with the ROSS in the V-band (left) and with the REM in the K'-band (right). Note the striking difference between the images, showing the strong role played by the dust absorption along the galactic plane.*

and the related instrumentation but, at the same time, it is only the very beginning of the commissioning period, during which time the telescope will be adjusted, the instrument tuned up and the whole software assembled to work properly. We are in this phase with all the small problems that need to be solved and with the software to be fine-tuned. The issues that need to be very carefully fine-tuned are: the alignment of the optical axis of the telescope with the axis of the de-rotator, the synchronization of the de-rotator with the telescope tracking and the pointing (we need a very accurate model) of the telescope. We will have a few months to do all of this together with the science verification program that, to some extent, already started. All of the above, mounting of the telescope, instruments and first tests took about 10 days. At the time of writing (June 26) we were already able to send to the telescopes commands from a remote computer.

On June 25th, and thanks to the Director of La Silla, we celebrated the first light with the staff of the Observatory. For us it has been an emotional moment and we are very grateful to the staff for the warmth of that evening. Indeed REM is the first telescope an Italian group of its own put on ESO ground. It was about time. The only regret is that we could not build an even fancier Dome. We will do better next time when we will get more support in Italy.

This endeavour we undertook is very important for the research we plan to carry out in the GRBs and also for the secondary science program. It is also the first fully automatic infrared telescope ever built and while its aperture is very small but suited to the science goal, its control and various automatisms in the observing procedures and data analysis make REM a very advanced astronomical tool.

But even more important we feel is the fact that it will not only further strengthen the collaboration with the ESO staff, and in particular with the staff in La Silla, but above all it will be an open gate for the youngest scientists and graduate students who will interact both remotely and in loco, youngsters will like to travel to Chile, during maintenance or other programmed activities. We hope it is the beginning of something very interesting.

Acknowledgments

The Swift mission triggered the idea of REM and many of its members, especially Prof. Alan Wells, encouraged enthusiastically the REM project. Naturally we are very grateful to Catherine Cesarsky for the encouragement she gave since the very beginning when we proposed to locate the telescope at ESO in Chile and for her openness toward the GRBs research. Alvio Renzini acted as our reference point for ESO and Jorge Melnick, to whom we are deeply indebted, did everything possible to make our work at La Silla comfortable and pleasant and for the building of "Notre-Dome". Needless to say we could not operate without the help of the La Silla staff, the vice Director G. Andreoni in particular, to which we are very grateful and without the expertise of G. Crimi (OAB) who helped in the operation of mounting the telescope and of Giuseppe Malaspina whose expertise allowed us to communicate among our computers and with the rest of the world. Fundamental has been the collaboration of: M. Bagaglia, C. Campeggi, R. Cunnife, D. Fugazza, G. Gentile, E. Martinetti, A. Melandri, G. Nucciarelli, S. Sardone. The financial support came from the Italian Ministry of the University and Research (MIUR) through the COFIN organization. The ROSS instrument has been financed by an ASI grant and the CNAA helped us with "Notre-Dome at La Silla". Finally we would like to thank AMD for providing part of the computer hardware.

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The Gamma-Ray Burst Hunt at La Silla
the TAROT-S Very Fast Moving Telescope

The study of cosmic Gamma-Ray Bursts (GRBs) is an important challenge for the understanding of the formation of black holes and for the star formation and evolution in the early universe. GRBs are also an invaluable cosmological probe. ESO has agreed to install a set of robotic telescopes at La Silla, TAROT-S and REM (Chincarini et al., see page 40). TAROT-South is a very fast moving (1s) optical robotic observatory able to observe from the beginning of the explosion. The spacecraft fleet detecting GRBs will send timely signals to TAROT, which in turn will be able to give a sub-arc second position to the community. The data from TAROT-S will also be useful to study the evolution of GRBs, the physics of the fireball and of the surrounding material.

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Since the late seventies, ESO has pioneered the study of Gamma-Ray Burst (hereafter GRB) sources. Deep searches of GRB error boxes have been performed at the 3.6 m and many other telescopes at La Silla. At that time, they were localized by the first interplanetary network (IPN), and getting a position could take months. However, European groups were among the first involved in the GRB optical and infrared counterpart hunts. One of the first systematic surveys of GRB error boxes was aimed at searching for events recurring in four error boxes. The GRB Monitoring System (GMS) was approved in 1982, and installed in a small building lying down the hill from the 3.6 m. Now time has passed over the GMS, some of these telescopes have been reused by ESO for education and public outreach purposes, and, at La Silla, the building is known as the "Sarcofago" (figure 1).

While no mummy has awakened, the Sarcofago will soon reopen every night to resume its former activity as a GRB optical counterpart spotter: a duplication of TAROT (Télescope à Action Rapide pour les Objets Transitoires – Rapid Action Telescope for Transient Objects; figure 2), already in operation at the Calern Observatory in France, will be installed by the next Chilean summer. Able to start an observation within a second, TAROT-South will observe GRB sources in the optical range, while the event may be still active in Gamma-Rays. TAROT-S will be a wide field, very fast companion of the Rapid Eye Mount (REM – Chincharini et al., this issue), more specialized in the study of the infrared range and broad-band spectroscopy. Both experiments form the Fast Robotic Observatory System for Transients (FROST).

Advances and Questions

Since the results of the BATSE experiment onboard the Compton-GRO spacecraft and of the Beppo-SAX satel-

Figure 1: The GMS building, alias the "Sarcofago", located down the hill of the 3.6m telescope, in front of the new La Silla control room. It will host the TAROT-S experiment (photography M. Lopez / CNRS).

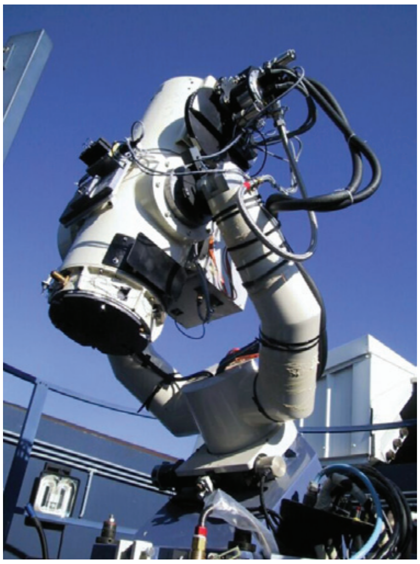

Figure 2: The TAROT telescope at the Calern Observatory (France) has already given results from the observation of sources detected by the BATSE, HETE and INTEGRAL experiments. TAROT-S is a duplication of this robotic observatory (photography M. Boër / CNRS).

lite, many advances have been made in the field of cosmic Gamma-Ray Burst sources (see companion paper in this issue, Chincharini et al.). It is now known that they lie at cosmological distances and that they reach a tremendous luminosity, about 10^{51} – 10^{52} ergs per event. This happens in two steps: first a powerful burst of hard radiation, the prompt GRB, is emitted, and may last from tenths to hundreds of seconds; at some point, a much fainter decaying emission takes over from the prompt emission, and is called the afterglow. Finally, in several cases, a supernova has appeared, confirming the association of a large part of the bursters with the final stages of massive star evolution.

Because of opacity problems, what we see is not the initial release of energy, but most probably the result of the shocks produced by the ultrarelativistic ($\Gamma \geq 100$) fireball. We are in a position to observe the result of the blast wave produced by the explosion of the bomb, but the initial event is not directly accessible to us. Though the "standard fireball model" has been a powerful tool to understand the physics of GRBs and their panchromatic emission both prompt and delayed (the afterglow), many questions still remain to be answered, and a full picture of GRBs as a whole remains to be drawn. As an example little is known about the so-called short-hard class of bursts: they last about a second or less, have a spectrum harder, on average, than the longer GRBs, and have not been seen at long wavelengths.

Another problem is why half of the GRBs are not displaying an afterglow (the so-called "dark GRBs")? Are dark GRBs only "optically dark"? While the data from the REM experiment will give hints at IR wavelengths within a minute after the GRB alert, it is important to get the full picture in order to determine, from the first seconds of every event, the reason of the absence of long wavelength emission: is it due to the redshift of the source? to its location inside a high density environment? Is it connected to the way the GRB machinery works or how it is seen by the observer? Does dark GRBs emit at all, or does the afterglow decays so fast that it quickly becomes invisible to any telescope? On that last point, data acquired by the existing TAROT system (Calern – France), give a tight constraint on the light curve of several afterglows (figure 3).

One important milestone is the transition between the prompt emission and the afterglow. It is a direct measure of the beginning of the external shock, and of the medium surrounding the GRB source itself. These observations, not only requires a telescope able to react quickly to an alert, but also a fast sampling of the signal, i.e. a rapid image acquisition rate. With a dead time of only one second, TAROT is able to acquire a seventeenth magnitude, four million pixels image every ten seconds. After the SWIFT launch TAROT and REM will observe a GRB source location every ten days: this will allow a precise light curve to be obtained from the prompt event to the afterglow, and the determination of the precise point when the decaying emission starts.

One of the major roles of TAROT-S will be to quickly detect the source (within one second after the alert), and to derive a precise position. At present, with TAROT-Calern, we reach routinely accuracy better than one arc-second after a standard processing time of one minute. This position will be transmitted in real time via the net, and will be available to other instruments at ESO. This means that within about a quarter of an hour, while the source is still bright, high or medium resolution spectroscopy may be performed on, deriving not only an accurate redshift, but also physical quantities. Equally important is the acquisition of polarimetric data, providing an insight in the geometry and emission processes of the fireball. It should be noted that evidence has been seen for strong evolution of the source polarisation, though this point still lacks confirmation. The conjunction of the data from TAROT-S and REM will allow optimising the choice of the instrument configuration on large telescopes.

We note also that the data on GRB afterglows have been acquired by a number of telescopes with various accuracy and calibration procedures. Since these sources are highly variable, and that variability contains information on the source physics, on its environment, on the host galaxy, and eventually on the line of sight, it is of paramount importance to have a consistent set of data well calibrated with standard procedures. For the first hours of the GRB, TAROT will give a precise relative photometry. Since it is expected that larger telescopes at ESO will take over to relay from TAROT and REM after that time, a set of combined measures will be available, giving for the first time an accurate picture of a GRB light curve from the first seconds to several tens of hours at least.

The TAROT-South Robotic Observatory

The "first" TAROT (figure 2) is in operation at the Calern observatory (Observatoire de la Côte d'Azur) since 1999, and has observed GRB source locations from BATSE, HETE and INTEGRAL. We decided to keep for TAROT-S the same characteristics, i.e. a very fast moving (80°/s), wide-field (2° - figure 4) telescope: not only this eases the duplication,

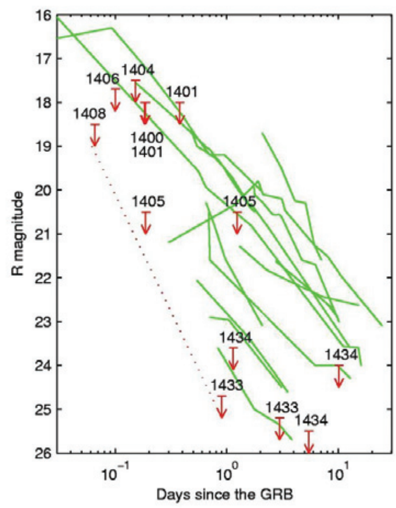

Figure 3: Dotted line: upper limit on the light curve of the GRB 020531 afterglow. The arrows are the upper limits from individual measurements with the GCN Circular number (1408 for TAROT). For comparison, the continuous green lines are the light curves of other events: the GRB 020531 light curve has the tightest limit for a "dark" GRB.

Table 1: Summary of the main technical features of TAROT.

Optical configuration	Newton hyperbolic
Telescope aperture	25 cm
Speed ratio	f/3.5
Pointing speed	Up to 80°/s
Acceleration	Up to 120°/s^2
Pointing time	1 – 1.5s
Filter wheel	Clear, B, V, R, I, custom
CCD device	Thomson THX 7899 MCRH
CCD size	2048 x 2048 pixels, 29 x 29 mm
Pixel size	14 µm, i.e. 3.5″
Field of view	2°x2°
CCD operating temperature	-45°C
Limiting magnitude in 10s	R = 17
Limiting magnitude reached	R = 20 (Calern)
Readout speed	2 – 0.5s (full frame)
Readout noise	Prototype 14e$^-$, expected final 10e$^-$
Actual image processing time	1 minute average

but also TAROT-S will still be able to work with SWIFT, INTEGRAL and HETE, as well as with the forthcoming GLAST, AGILE and many satellites which may be launched during its operational life. Apart from the precision in coordinates, the requirements on an automatic observatory aimed at the study of GRBs have not much evolved: it should react as quickly as possible, and give deep images of the sky at the fastest possible rate. This is still challenging, and the compromise made for TAROT was to have a compact, fast telescope. The telescope is usually on target within one second, whatever its position actually is, probably the shortest time for a telescope dedicated to the observation of GRBs, and quite important for the study of the early behaviour of these sources. Table 1 displays the main technical features of TAROT.

The overall software architecture will be the same at Calern and ESO. The advantage is that the cost and development times are drastically reduced, while the instrument which will arrive at La Silla will be fully operational. Additionally, any change may be tested at Calern, where we have easy access before implementation at ESO, reducing the risk and the load on the teams, both in Europe and at ESO. Any software change may be remotely implemented at no risk, and with no operational interruption.

The software chain is detailed in figure 5: a first software, the AUTOMATE takes care of the housekeeping, of the observatory status and health (telescope, building, temperatures, coolers, roof, weather…), sends orders to move the telescope and drives the camera through a socket connection with the CAMERA software. This later software plays an identical role for the camera, but can be operated alone via a remote interface. The MAJORDOME makes the interface with the outside world, first with the GCN, and other satellite alert systems, but also with the request system through a web interface. In routine mode, i.e. between alerts (about 80% of the time), the MAJORDOME schedules observations in an optimal way. In other words, apart from specific constraints, the user chooses only the observation parameters (coordinates, exposure time, filters, repetition factor, eventually time constraint…), and an efficient algorithm produces the telescope time line: a priori, the user does not know when the observation will be performed, but the MAJORDOME schedules it in a way that most observations are performed in the best astronomical conditions (e.g. at minimal airmass), and the whole telescope efficiency is maximised.

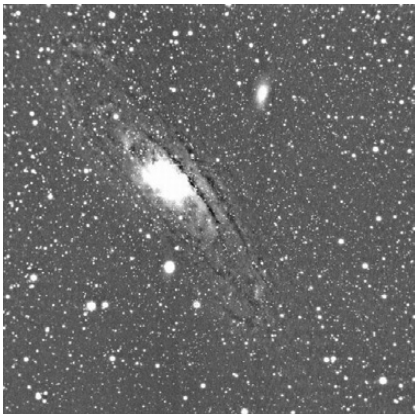

Figure 4: The M 31 Andromeda galaxy, as seen by TAROT (image TAROT/CNRS).

As soon as an image is taken, the processing software (the GRENOUILLE) proceeds with calibration, removal of cosmic-ray hits, normalization, searches for sources, computes the astrometry, and ends-up with a complete catalogue of the sources in the image. This frame and the products are archived on a disk, and sent later to Europe. Both the image (in compressed FITS and/or jpeg) and its catalogue are available on the web interactively. The page allows the superposition of the USNO-A2.0 catalogue extract on the displayed image, retrieving source coordinates via the mouse, requesting an extract of the Digital Sky Survey around any position, or getting a chart of the asteroids found in the field. Additionally the catalogue gives all unidentified sources in the field, and an algorithm able to derive the possible optical transient candidates among a set of images according to various criteria will be implemented. All these features have proven to be very useful for the GRB counterpart searches at Calern, as well as for other programs. All the software components are independent from each other, and the dialog is performed through standard socket connections. This way, the actual location of a module has no relevance, provided that the INTERNET connection is reliable. As an example, the MAJORDOME has been developed in Toulouse, and has for months scheduled TAROT from the CESR. Each module has also its own interface, accessible either on site or remotely. The whole system can be maintained and monitored remotely, and the failure of one component does not lock the access to the TAROT observatory.

The telescope, together with its immediate hardware will be installed in the "Sarcofago" GMS building (figure 1). In order to ease both the installation and operations, all the computers and auxiliary hardware are currently being implemented in a specialized, climate controlled, container. The telescope hardware is under construction, and will be assembled by the fall of 2003. At that time we will have a fully operational telescope which

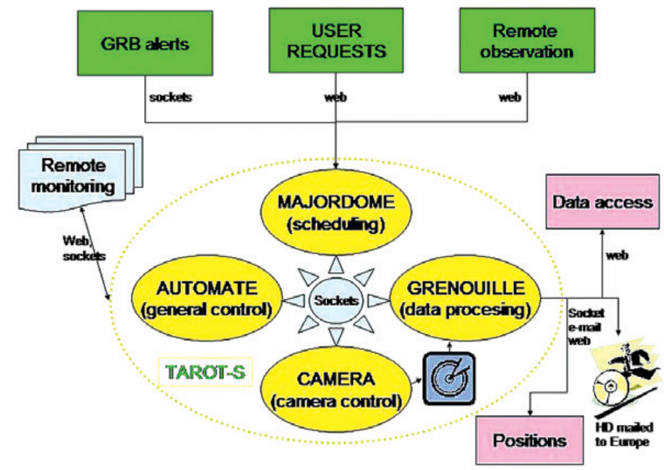

Figure 5: Software configuration of the TAROT observatory.

will be thoroughly tested before shipping at La Silla. Hence installation time will be reduced to a minimum, and the telescope will be quickly fully operational.

A Multi-Purpose, Multi-Satellite Observatory

With TAROT and REM united together within the FROST consortium (Fast Robotic Observatory System for Transients), ESO will be equipped with a fully automated, scientifically consistent set of instrument spanning the IR and optical range, able to detect and analyse quickly the data from GRB counterparts. One of the major challenges which may be addressed by FROST is the measure and understanding of the relative emission in IR and visible band, and, moreover, why this emission may be suppressed in the visible, and/or infrared.

The data obtained with small telescopes have proven to be extremely useful: though small, these telescopes are able to "see" sources at cosmological distances, and to probe the extragalactic line of sight, as well as to get information on the host galaxy. The detection of the supernova rise and the systematic monitoring of the light curve by small telescopes are also an aid to understanding the fate of massive stars, the making of black holes, and the last stages of stellar evolution across the universe at its various epochs. As shown above, the upper limits obtained, within seconds, by TAROT already compete with the data from large telescopes, thanks to its very quick response (1s), much quicker than other telescopes. Moreover, the combination of data actually gives the tightest limits on the "dark" afterglows. The rapid analysis of the image and the immediate dissemination of the sub-arc second position may be rapidly exploited by large telescopes, such as the VLT. With this accuracy, a spectrometer slit can be almost blind-positioned, giving data within the first ten minutes of the event, e.g. with the VLT, and why not later ALMA. Able to work with the accuracy provided by any spacecraft, HETE, INTEGRAL, SWIFT, and later GLAST and AGILE, TAROT will provide unique data during the very first seconds of the event at visible wavelengths, giving hints on the central engine release of energy, on the forward and reverse shocks, and on the transition between the prompt phase and the afterglow. Systematic investigations will be performed with REM, providing a deep insight in the broad band early afterglow. With its wide field of view, combined with a good sensitivity, TAROT-S is also able to start a systematic search for orphan afterglows, and to provide hints toward direct evidence of the focussing of the fireball.

More generally, the secondary program of TAROT-S will be mainly devoted to the study of variable sources, such as active galactic nuclei, or a census of variable stars. Thanks to its ability to sample a wide fraction of the sky with a good sensitivity, given by its field-of-view / duty cycle combination, TAROT will be also able to detect extrasolar planets using the occultation method. Though the scheduling of observations is optimally performed without any human intervention, TAROT features a mode in which it can be remotely controlled. Our experience (with TAROT-Calern) with users around the world shows that TAROT is also a very powerful tool for education and public outreach.

TAROT-Calern has proven its reliability and efficiency for its scientific objective. Building upon our experience, TAROT-South will enhance the prompt optical coverage of Gamma-Ray Burst sources and will gain from a darker sky and better weather. With the dramatic increase in GRB alerts expected next year with SWIFT, TAROT-S, together with its companion REM, will contribute to maintaining the leading role in GRB observation and science that ESO and European astronomy have gained since the afterglows have been discovered.

Acknowledgements

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Origin and Evolution of Ices in Star-Forming Regions

A VLT-ISAAC 3–5 μm Spectroscopic Survey

THE VLT HAS OPENED UP THE POSSIBILITY TO PERFORM SPECTROSCOPIC SURVEYS OF LARGE NUMBERS OF YOUNG LOW-MASS STARS WHICH ARE STILL DEEPLY EMBEDDED IN THEIR PARENTAL CLOUDS. OUR INFRARED SPECTRA SHOW A RICH VARIETY OF FEATURES DUE TO ICES AND GAS-PHASE MOLECULES, EACH OF WHICH TRACE DIFFERENT ASPECTS OF THE PHYSICAL AND CHEMICAL STATE OF THE OBJECTS. HIGHLIGHTS INCLUDE FUNDAMENTAL NEW INSIGHT INTO THE STRUCTURE OF INTERSTELLAR ICES; THE FIRST DETECTION OF SOLID METHANOL IN LOW-MASS PROTOSTARS, A KEY INGREDIENT FOR BUILDING MORE COMPLEX ORGANIC MOLECULES; DIRECT EVIDENCE FOR SIGNIFICANT FREEZE-OUT IN EDGE-ON CIRCUMSTELLAR DISKS; AND SENSITIVE LIMITS ON MINOR ICE COMPONENTS SUCH AS AMMONIA AND DEUTERATED WATER.

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When stars form deep inside dense molecular clouds, the surrounding gas and dust become part of the infalling envelope feeding the central object. In the earliest stages, the nascent protostars are extinguished by hundreds to thousands of magnitudes, so that only the circumstellar gas and dust can give a glimpse of what is happening inside. A study of their evolution is therefore key to understanding solar origins. Part of this gas and dust ends up in the rotating discs surrounding the young stars, and forms the basic material from which icy planetesimals, and ultimately planets, are formed. A spectroscopic survey of a set of embedded young low-mass stars, such as that performed by our team with VLT-ISAAC, thus also provides quantitative information on the chemical building blocks available during planet formation.

Due to the high dust obscuration, star birth is best studied at long wavelengths. Most young stellar objects (YSO's) have been found through IRAS and ground-based infrared surveys, and have the peak of their spectral energy distribution at far-infrared wavelengths. The spectra of the coldest protostellar objects (ages of ~10^4 yr since collapse began) peak around 100 μm and such sources are best studied with submillimeter telescopes. Once the dense envelopes start to dissipate due to the effects of outflows, the objects become detectable at infrared wavelengths, around ages of ~10^5 yr. Both regions have their advantages for studying circumstellar material. In the submillimeter, thermal continuum emission from cold ($T_{dust} \approx 10$ – 50 K) dust is seen, as well as spectral lines from a plethora of gas-phase molecules. Owing to the heterodyne technique, the spectral resolving power of these data is intrinsically extremely high, $R=\lambda/\Delta\lambda>10^6$ or $\Delta V < 0.1$ km/s, so that the detailed kinematics of the region can be studied. Until the advent of large millimeter interferometers such as ALMA, however, the spatial resolution of these data remains poor.

Mid-infrared spectroscopy has the advantage that the composition of both the gas and the dust can be studied. Solid-state material has characteristic broad vibrational transitions in the infrared, but no strong bands at millimeter wavelengths. In this case, the features are often seen in absorption against the hot ($T_{dust} >$ 300 K) dust in the immediate surroundings of the young star (Fig. 1). At R > 2000, the gas-phase lines – which are intrinsically much narrower – also become visible, albeit only for the most abundant molecules.

The earliest mid-infrared spectra of YSO's were obtained in the 1970's and 1980's, mostly with the Kuiper Airborne Observatory and UKIRT (see van Dishoeck & Tielens 2001 for a historical

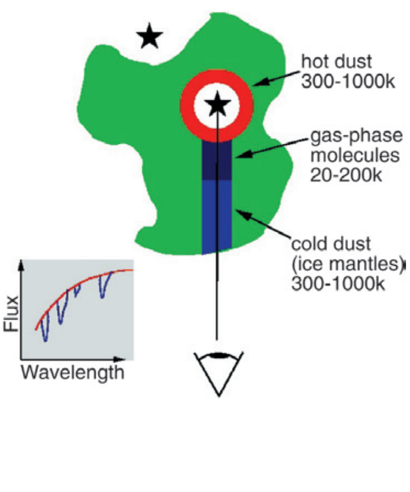

Figure 1: Schematic illustration of infrared absorption line observations of gas and dust toward embedded or background sources. The infrared continuum (red color) is provided by the hot dust at 300–1000 K very close to the YSO (region not drawn to scale) against which cooler material (blue color) along the line-of-sight is seen in absorption.

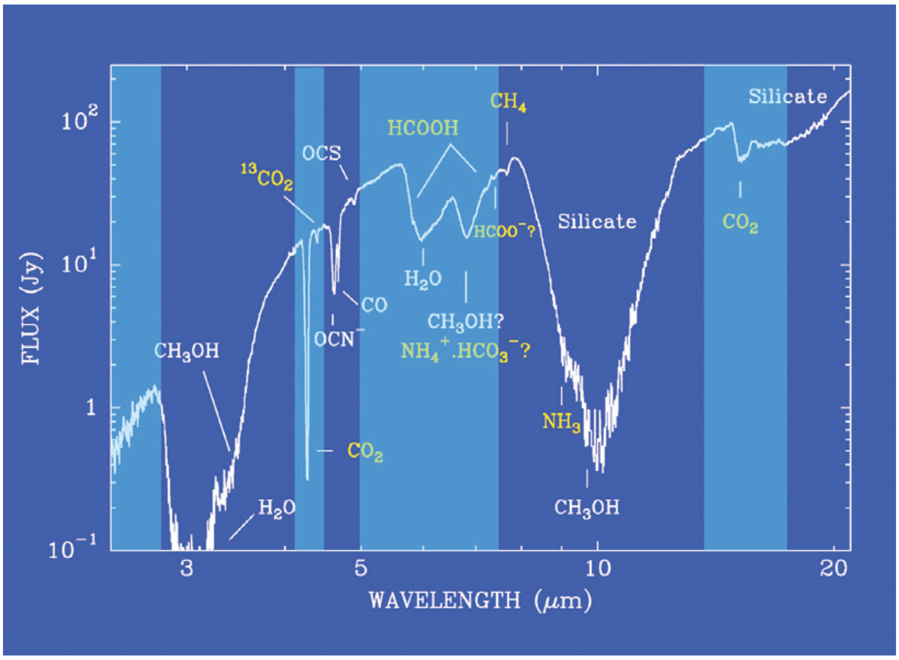

Figure 2: ISO–SWS spectrum of the deeply embedded massive YSO W 33A (Gibb et al. 2000, ApJ 536, 347). Various absorption features due to silicate grain cores and icy mantles are indicated. Regions which cannot be observed from the ground are shaded. Our large programme covered the 2.85–4.1 μm (L-band) and 4.5–5.1 μm (M-band) windows.

review). At the low spectral resolution of those data, only solid-state bands were detected, but the spectra of some massive protostars already revealed a surprising wealth of features. These included not only the anticipated bands of the silicate grain cores at 9.7 and 18 μm due to the Si-O stretching and bending modes, but also other broad features. Thanks to detailed interaction with laboratory astrophysicists (including some of the authors at that time!), these could soon be ascribed to ice mantles, in particular H_2O ice and CO ice.

The big step forward came in 1995 with the launch of the Infrared Space Observatory (ISO). The Short Wavelength Spectrometer (SWS) on ISO provided the first opportunity to obtain mid-infrared spectra over the entire 2.5–20 μm range unhindered by the Earth's atmosphere. High quality data were obtained for about a dozen YSO's, revealing several new features and allowing a much more reliable identification of other species (Fig. 2). Several important ingredients of ices, such as CO_2, CH_4 and CH_3OH, were firmly established with abundances ranging from < 1% up to 30% of that of H_2O ice. However, the ISO-SWS only had the sensitivity to observe sources forming massive O or B stars with luminosities >10^4 $L_\odot$.

The advent of 8–10 m class telescopes equipped with infrared spectrometers with large-format arrays has opened up the possibility to study low-mass protostars with luminosities comparable to that of our Sun. Although hampered by the atmosphere, the sensitivity of these facilities is such that a large sample of objects can be surveyed in a relatively short time. Accordingly, we proposed in 1999 a large VLT-ISAAC programme to perform a spectroscopic 3–5 μm survey of YSO's in the southern hemisphere. The main goals were to: (i) obtain an inventory of the major and minor ice components in a large set of low- and intermediate-mass YSO's (< 10^3 $L_\odot$) and some circumstellar discs, and study evolutionary and environmental effects by comparison with high-mass sources and comets; (ii) use gaseous and solid-state features to probe the physical conditions and thermal history of the protostellar environment; and (iii) constrain the basic ice structure through comparison with experimental data obtained in our laboratories in Leiden and Paris.

Our VLT-ISAAC Large Programme

In mid-1999, we were alloted 14 nights to survey 30–50 southern YSO's, but due to a long string of technical difficulties, our first observing run did not take place until January 2001. At that time, ISAAC had been upgraded with a 1024×1024 Aladdin array improving the efficiency of our observations, so that the programme could be finished in May 2002. Because our team was the first to use the long-wavelength spectroscopic mode of ISAAC, we had to build up much of the experience on how to use the instrument ourselves. Also, there was no pipeline data reduction at the time, so we had to develop codes for quick-look at the telescope and more detailed off-line data reduction. Several observing runs in visitor mode were crucial to gain familiarity with the instrument and devise an optimal observing strategy.

The L-band window from 2.85–4.1 μm was surveyed in the low spectral resolution mode (1 spectral setting), whereas the M-band window from 4.5–5.1 μm was

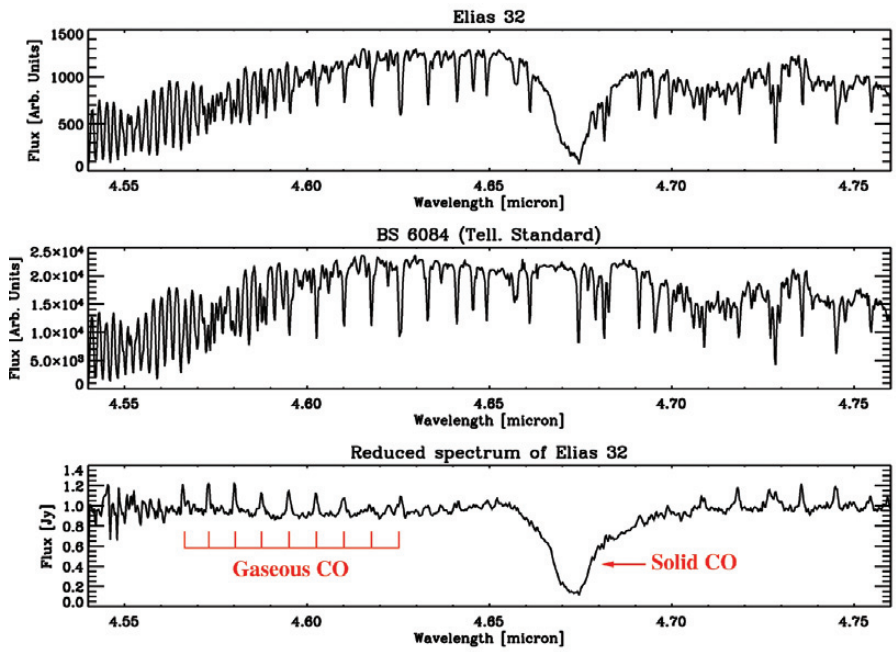

Figure 3: Raw spectrum of the source Elias 32 (top) and a standard star (middle), illustrating the forest of telluric features at M-band. The bottom spectrum shows the source spectrum with the atmospheric lines divided out. These features are best removed by observing at the highest spectral resolution.

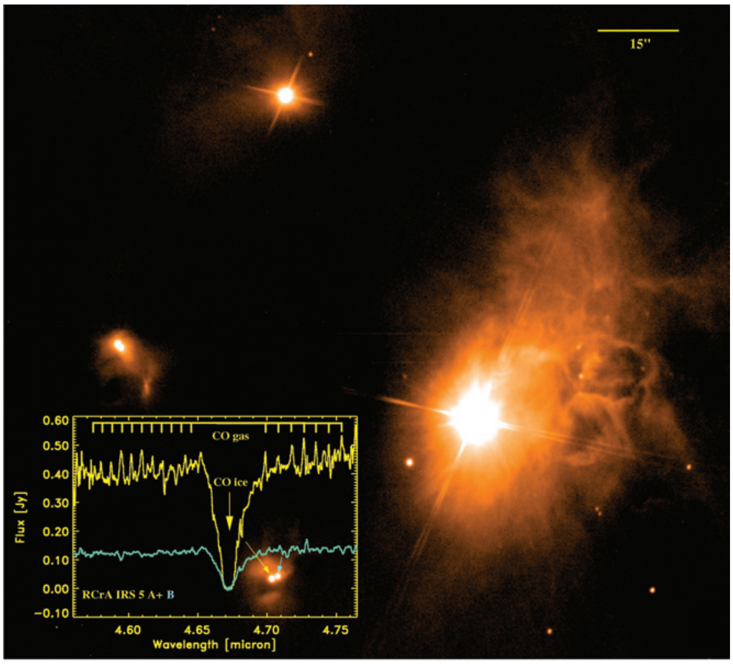

Figure 4: *VLT-ISAAC K' image of the R CrA cluster, with several of our targets indicated. The spectra of the 5A and 5B binary (few hundred AU separation) are shown, illustrating similarities and differences on small scales.*

from Chile, the agreement between the two spectra is excellent and the shape of the solid CO band is well reproduced, confirming Paranal as a good mid-infrared site in spite of its lower altitude than Mauna Kea. As expected, the gas-phase CO absorptions are deeper in the higher resolution R≈25,000 Keck spectra.

As Fig. 2 shows, the L- and M-band windows include only a limited number of features and are dominated by the H_2O ice at 3 μm and CO gas and ice bands at 4.67 μm, respectively (see also Fig. 6). At R > 2000, CO ice can be readily distinguished from CO gas as it consists of a single broad vibrational band: because the molecule is trapped in the ice matrix, it cannot freely rotate. In contrast, CO gas shows a number of narrow lines due to the simultaneous vibration and rotation of the molecule. H_2O and CO ice were detected in more than 90% of our sources. The abundances of H_2O ice are typically 10^{-5}–10^{-4} with respect to H_2, making it the third most abundant molecule after gaseous H_2 and CO.

observed in medium resolution mode (2 spectral settings required to cover the entire band; often only a single setting from 4.55–4.75 μm was taken). After the first observing run, it became clear that the S/N was dominated by our ability to remove atmospheric features (Fig. 3) and that the best strategy was to observe at the highest spectral resolution, i.e., smallest slit width. Accordingly, all subsequent spectra were obtained with the 0.3″ slit, resulting in R≈1200 at L-band and R≈10,000 at M-band. Slit losses due to seeing were found to be minimal, even when the optical seeing was close to 1″. Standard spectra of bright unreddened early-type stars were obtained immediately before or after each source, as close as possible in airmass (< 0.1 difference).

The sources were chosen from infrared surveys of southern star-forming clouds, including Ophiuchus, Chamaeleon, Corona Australis, Vela, Orion, and Serpens. Although 2.5 of the 14 nights were lost due to bad weather, 60 sources at L-band and 45 at M-band were observed. We were able to survey more objects than envisaged in the original proposal because several new sources were picked up in the acquisition images at 2–15″ distance from the main target. By rotating the slit, the spectrum of the weaker, second component could be obtained simultaneously and was often of good enough quality for analysis. This also gives interesting information on the small-scale structure of the clouds, on scales down to a few hundred AU (Fig. 4). Typical integration times were 20 minutes on source, with the longest integration being 2 hr. This gave S/N > 30 on sources with L~9 mag (0.07 Jy) and M~8 mag (0.1 Jy).

Since the detailed line shapes are crucial for our analysis, extensive checks were done to explore the reproduceability. Spectra obtained on different nights and with different standard stars were compared, as were low- versus medium-resolution spectra. More revealing is the comparison with spectra obtained at other facilities, in particular ISO, UKIRT and Keck. Figure 5 shows the spectra of a northern YSO, L1489 in Taurus, obtained with both VLT-ISAAC and Keck-NIRSPEC. In spite of the large airmass

Other weaker features at L-band include the 3.54 μm CH_3OH ice band, the 3.47 μm feature likely due to ammonia-water hydrates, the 3.3 μm PAH feature, and potentially the 4.1 μm HDO band. In the M-band, a weak feature around 4.62 μm assigned to OCN^- within the ice is sometimes seen. In the remainder of this article, we discuss a few of the scientific highlights of our programme. More details can be found in the papers by the authors: several of them have been published, whereas others are still in preparation. The reduced spectra will be made available in due course through the Web site *http://www.strw.leidenuniv.nl/~vltchem*

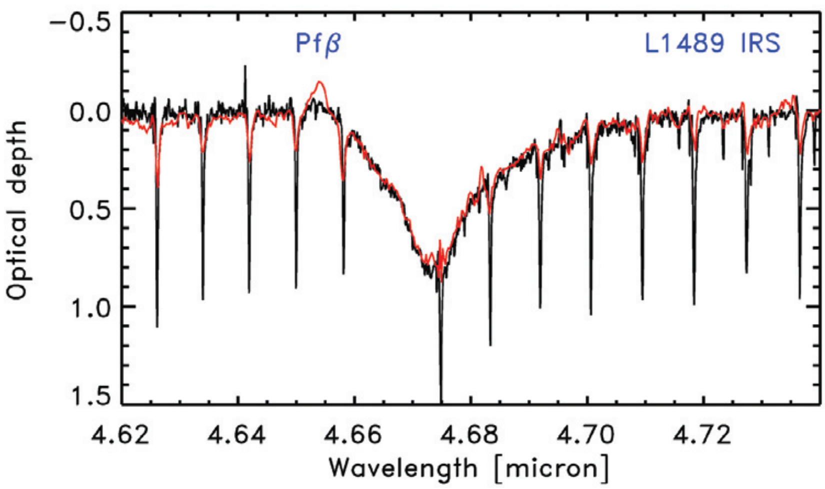

Figure 5: *Comparison of the VLT-ISAAC (red) and Keck-NIRSPEC (black, Boogert et al. 2002) spectra of L1489 in Taurus. Note the excellent agreement in the shape of the solid CO feature. The gas-phase absorptions are deeper in the Keck spectrum due to its higher resolving power (R≈25,000 vs 10,000), which also aids in removing the telluric features.*

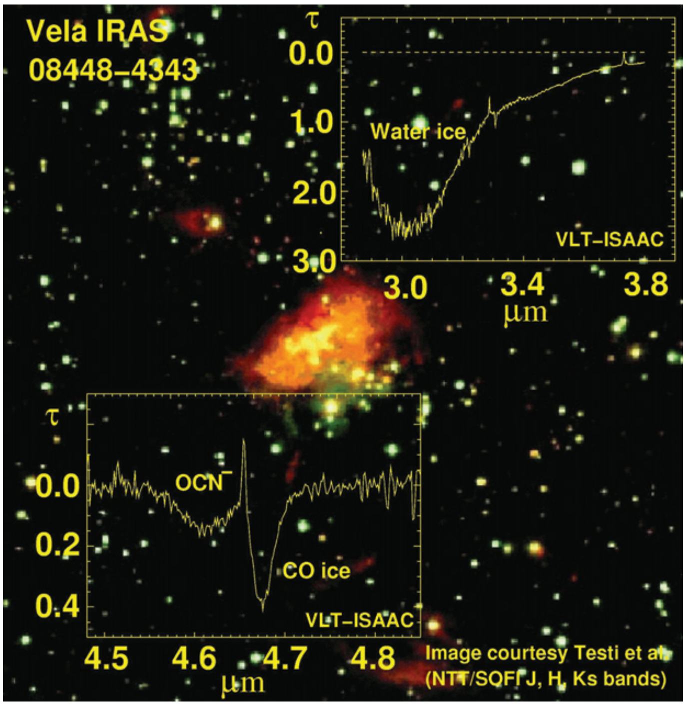

Figure 6: VLT-ISAAC L- and M-band spectra toward the intermediate mass YSO IRAS 08448-4343 in Vela. The spectra are on an optical depth scale and are superposed on a NTT-SOFI H-Ks band image provided by L. Testi.

is correct, the shape of the CO profiles can be used as a temperature indicator.

In some sources, the ^{12}CO ice feature is so strong that its isotopic counterparts can be searched for. In our sample, ^{13}CO ice has been seen toward IRS 51 in Ophiuchus, the first detection toward a low-mass YSO. Since ^{13}CO is only a minor component of the ice, its line shape does not depend on the grain shape and allows further constraints to be placed on the CO ice environment. Its profile is indeed consistent with pure CO ice. Finally, a new weak feature at 2175 cm^{-1} (4.61 μm) is found in several sources, distinctly offset from the OCN^- band at 2165 cm^{-1} (4.62 μm). Since its strength correlates with that of one of the CO components, it is natural to ascribe it to solid CO as well. A feasible match with CO directly bound to the silicate surface has been found in laboratory experiments.

Abundant solid CO in discs

A few of our targets are edge-on discs, for which near-infrared images show nebulosities separated by a dark lane. For inclinations of ~10-20°, the young star is not completely obscured and the line of sight intercepts a significant fraction of the disc (Fig. 8). One such object is CRBR 2422.8-3423, discovered with VLT imaging. This spectrum shows the deepest solid CO absorption observed to date (Fig. 9) (Thi et al. 2002). Absorption by foreground cloud material likely accounts for only a small fraction of the total solid CO. Gas-phase ro-vibrational CO absorption lines are also detected with a mean temperature of

CO ice structure

One of the major advantages of our sample is the unprecedented combination of high S/N, high spectral resolution, and the large number of sources studied. Indeed, these data show that the solid CO profile is intrinsically very narrow (~3 cm^{-1} or 0.007 μm) and was often not fully resolved in previous observations. Thus, similarities and differences in the profiles for different lines-of-sight can be systematically studied for the first time (Pontoppidan et al. 2003a). In earlier analyses, often a 'mix-and-match' procedure was followed to fit profiles for individual sources with a variety of laboratory ice mixtures, often leading to degenerate results. Surprisingly, it is found that excellent fits to *all* our spectra can be obtained using a phenomenological decomposition into just three components (Fig. 7). The relative strengths of these components vary from source to source, but their positions and widths are fixed. Only three linear parameters are thus required to fit all CO ice bands ever observed.

This leads to the important conclusion that the CO ice has the same fundamental structure along all lines of sight and that there are at most three different environments for CO on, or in, the ice. Previously, the number of sites was thought to be much larger depending on whether the CO molecule is surrounded by H_2O, CO_2, CH_3OH, O_2, CO itself, or any other molecule. Using a simple physical model, it can be shown that for the majority of the lines of sight, 60–90% of the CO ice is in a nearly pure form. This result has significant consequences for our understanding of the formation and structure of interstellar ice mantles: either the segregation of the CO and other species has occurred prior or during freeze-out, or subsequent processing of the ice and selective desorption and recondensation have resulted in separation of the components. Figure 7 includes one possible scenario based on recent laboratory experiments where CO is deposited on top of a porous H_2O ice and gradually diffuses into the pores upon heating. If this picture

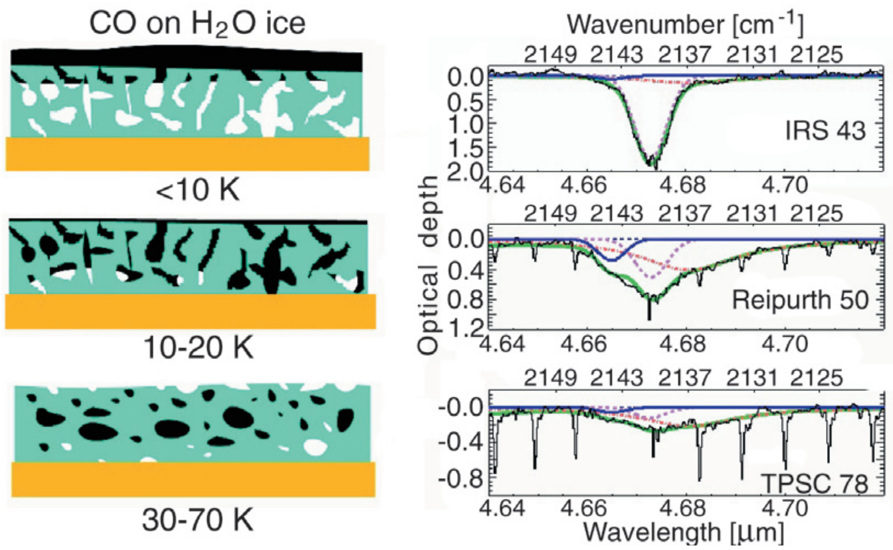

Figure 7: Right: VLT-ISAAC M-band spectra of three sources, showing the decomposition of the solid CO profile into three basic components (blue, purple and orange curves). The green curves indicate the sum of the three components. Left: Sketch of the adsorption, diffusion and desorption behaviour of CO (black) on a porous amorphous H_2O ice (green) as a function of temperature derived from laboratory simulations under pseudo interstellar conditions (Collings et al. 2003, ApJ 583, 1058). A one-to-one correspondence of each of these situations with the astronomical spectra can be made.

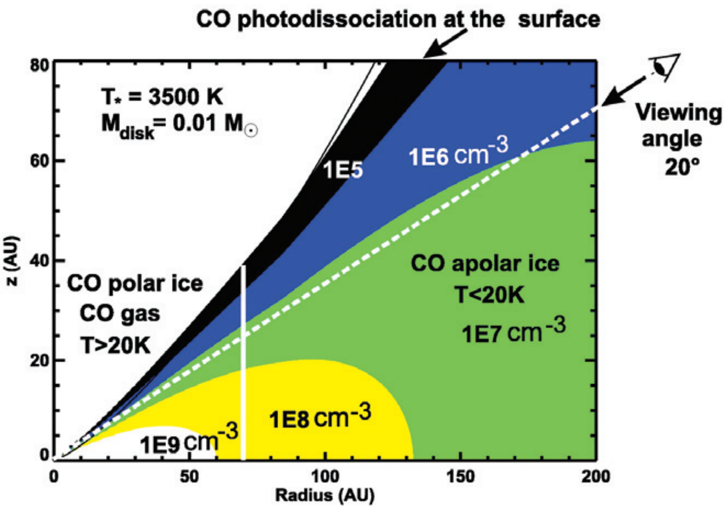

Figure 8: Sketch of a flaring disc, with different temperature and density zones indicated. The line of sight for the case of CRBR 2422.8 -3423 is indicated. CO ice can exist in water-rich ('polar') and water-poor ('apolar') environments depending on temperature.

50 ±10 K and an average gas/solid CO ratio of ~1 along the line of sight. Such temperatures and ratios are consistent with the flaring disc model sketched in Fig.8.

Another example is L1489 (Fig. 4), which has a much larger 2000 AU radius disc and is in a transitional state to the T Tauri phase. The high resolution Keck spectra show red-shifted wings on the gaseous CO absorption lines, indicative of infalling motions down to the 0.1 AU scale (Boogert et al. 2002). This illustrates the power of high spectral resolution data to obtain additional kinematic information.

Strong gaseous CO emission: probing the accretion shock?

Many M-band spectra reveal gas-phase CO absorptions in addition to CO ice. A few sources, however, unexpectedly show CO lines in emission (see Fig. 3 and 4). In some cases, these lines are narrow, in other cases they are broad, fully resolved and have a double-peak structure characteristic of rotation in a disc. A spectacular example is provided by the embedded source GSS30 IRS1 in Ophiuchus, where even emission from ^{13}CO and from higher excited ^{12}CO levels is detected (Fig. 10) (Pontoppidan et al. 2002). Analysis of the lines shows that the emission originates in a reservoir with 10-100 M_{Earth} of thermalized gas at a well-determined single temperature of ~515 K. Although not conclusive, evidence suggests that the gas is associated with an accretion shock in the disc at 10–100 AU distance, rather than with an outflow.

Abundant CH_3OH: key ingredient for building complex molecules

Another highlight of our program is the first detection of solid methanol towards solar-mass YSO's, thought to be a necessary ingredient for making even larger organic molecules. Gas-phase species like dimethyl-ether (CH_3OCH_3) and methylformate (CH_3OCHO) have been known in massive YSO's for decades, but their high abundances have been a puzzle to astrochemists, since traditional low-temperature ion-molecule chemistry falls short by orders of magnitude. The currently favored explanation is that evaporation of methanol-rich ices can trigger a high-temperature gas-phase chemistry which can produce complex organic species with abundances close to those observed.

One of the easiest transitions of solid CH_3OH to observe from the ground is at 3.54 μm, superposed on the wing of the water ice band (Fig. 11). Up to now, this feature has only been seen along lines of sight toward high-mass YSO's, but our large programme, together with some follow-up observations, shows detection in at least five low-mass objects, four of them in a small cluster in Serpens (Pontoppidan et al. 2003b). The inferred abundances are as high as 25% of H_2O ice, comparable to the highest solid CH_3OH abundances found toward high-mass YSO's. For other sources, the CH_3OH limits are less than a few % of H_2O ice, consistent with previous limits. This large variation in the solid CH_3OH abundance is not yet understood.

The elusive ammonia ice

Another key molecule to identify in the ice is ammonia, NH_3, which is thought to be one of the main nitrogen carriers. Its presence has important consequences, since NH_3 is a strong base and can produce ions through acid-base chemistry, potentially explaining the presence of OCN^-. Also, experiments in our laborato-

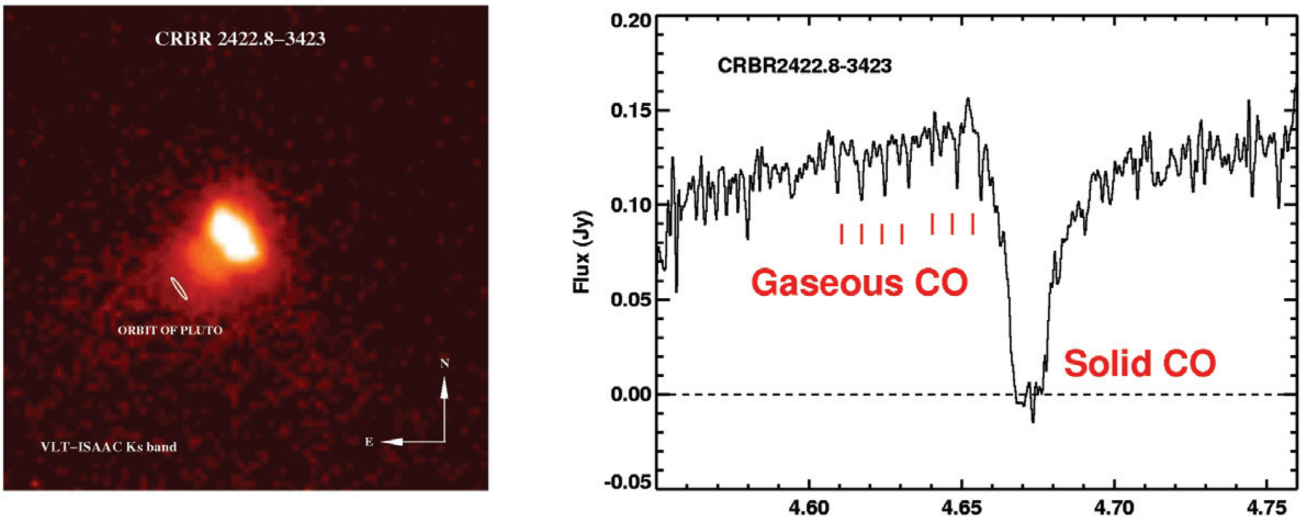

Figure 9: Detection of strong solid CO absorption in the edge-on protoplanetary disk around the solar-mass young star CRBR 2422.8–3423, providing direct evidence for significant freeze-out of CO in the cold layers of the disk. The amount of solid CO is comparable to that of gaseous CO. The VLT-ISAAC Ks archival image of the source shows the dark lane due to the disk crossing the nebulosity.

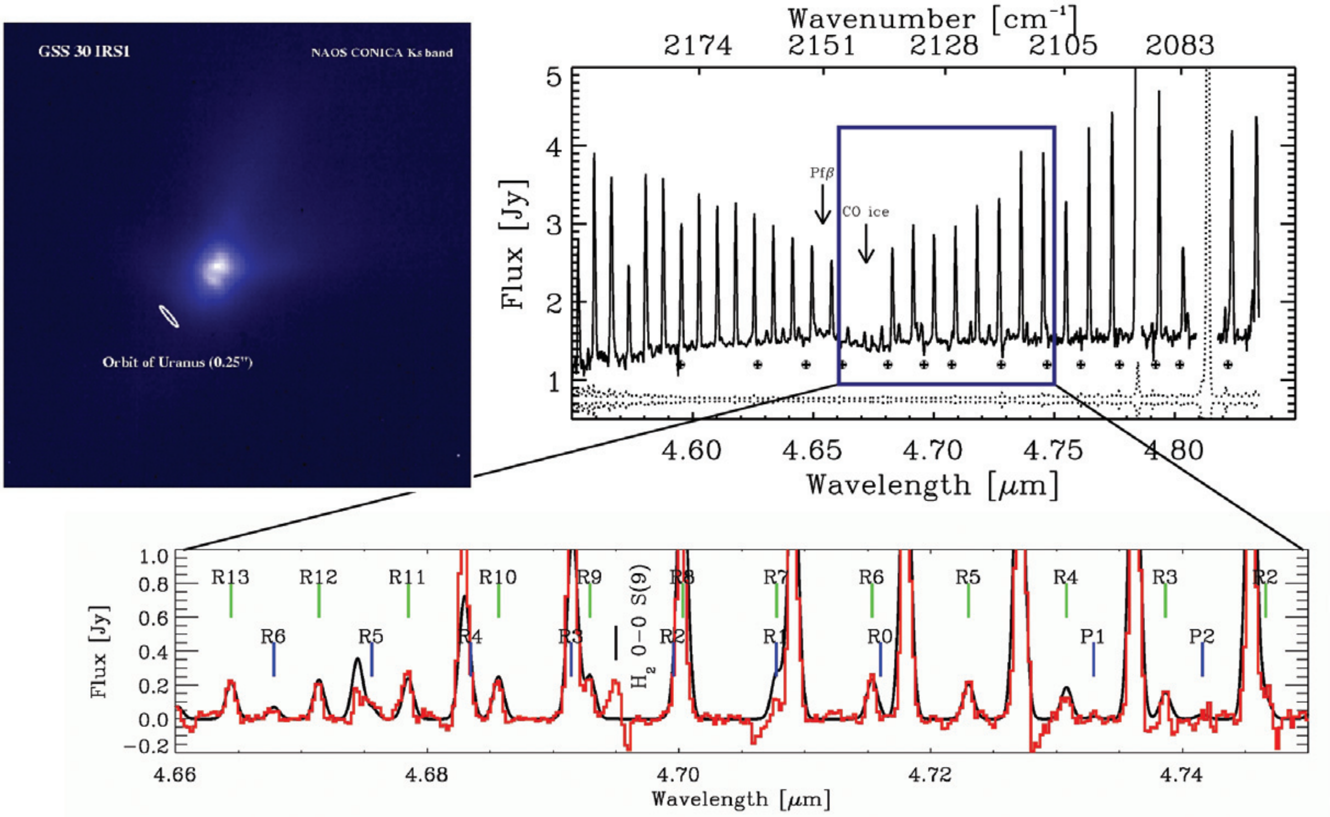

Figure 10: Strong gas-phase CO emission lines found toward the embedded YSO GSS30 originating in ~500 K gas within 100 AU from the source. Scattering in the surrounding reflection nebula boosts the strength of the lines. A NAOS-CONICA K-band image, taken in one of our follow-up programmes, is shown as well.

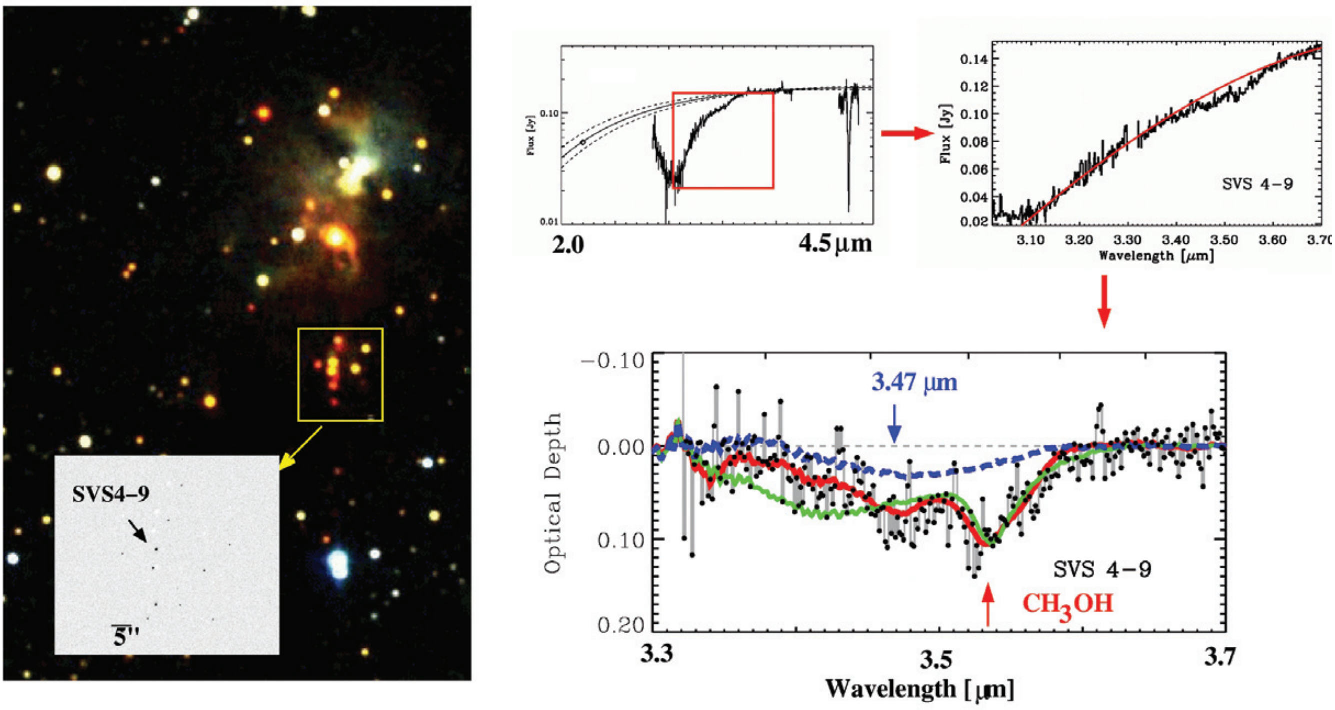

Figure 11: Right: VLT-ISAAC L-band spectra of SVS 4-9 in Serpens, showing the detection of solid CH_3OH in the wing of the solid H_2O band. The 3.47 μm feature is also seen. The red and green lines indicate laboratory spectra of solid CH_3OH, either in pure form or mixed with H_2O. Left: 2MASS infrared image of the Serpens core (color), with the VLT acquisition image of the small cluster indicated. Note the excellent VLT image quality (0.25" seeing) resolving the cluster.

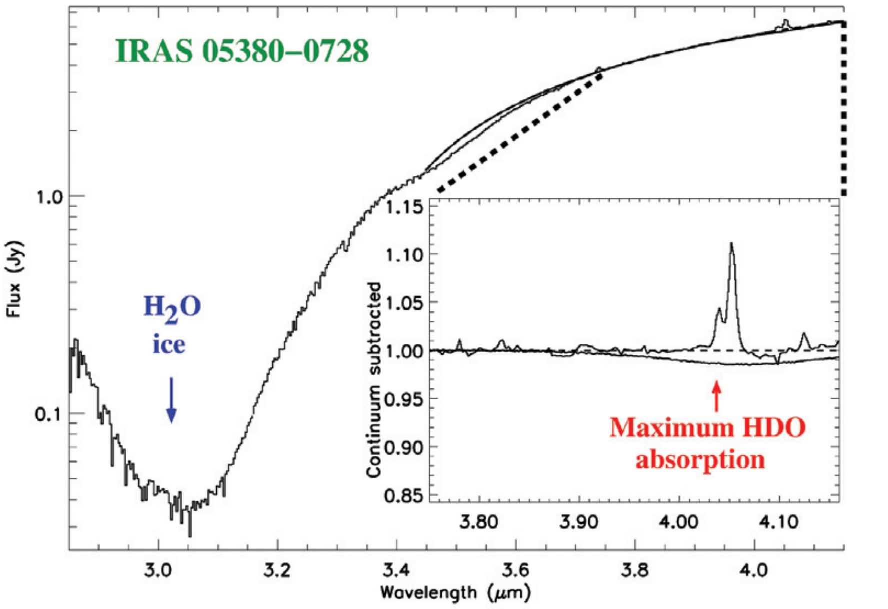

Figure 12: *L-band spectrum of IRAS 05380-0728 in Orion, showing the absence of any HDO ice feature at 4.07 μm.*

ries and at NASA-Ames have shown that energetic processing of ices containing NH_3 gives rise to complex organic molecules, some of which could be of pre-biological significance, e.g. amino acids. Unfortunately, all of the strong bands of NH_3 overlap with very deep absorptions by H_2O, silicate and other species. A weak NH_3 signature can be obtained from a feature at 3.47 μm, ascribed on the basis of laboratory experiments to a NH_3-H_2O hydrate. This 3.47 μm band is detected in a large fraction of our sources (see Fig. 11 for example) and indicates an amount of NH_3 ice equal to or less than 7% of H_2O ice (Dartois et al. 2002).

Another weak, overtone band of NH_3 occurs at 2.21 μm. Although our heavily obscured sources have very low fluxes in the K-band, we attempted one deep spectrum on the massive YSO W 33A. Earlier analyses of the 9 μm band had inferred a NH_3 abundance of 15% for this source, but our K-band spectrum gives an upper limit of only 5%. This shows the importance of observing more than one band to firmly identify minor species in ices.

Heavy water ice: link with comets?

Deuterated molecules have long fascinated astrochemists because of the enormous fractionation observed in cold clouds, where the D/H ratios in molecules can be as large as 0.1, more than four orders of magnitude above the overall [D]/[H] abundance ratio of ~1.6×10^{-5}. Two main explanations have been put forward for these large enhancements: (i) low-temperature gas-phase chemistry, aided by significant CO freeze-out; and (ii) gas-grain interactions. Detection of deuterated molecules in ice mantles could distinguish between these two scenarios. Heavy water, HDO ice, is the obvious candidate to observe because most of the ice consists of water. It has a feature at 4.07 μm, just at the edge of the atmospheric L-band. As Fig. 12 shows, the feature is not detected, giving typical upper limits HDO/H_2O ice < 0.002–0.01 in various sources (Dartois et al. 2003). These limits are lower than those of gas-phase molecules such as DCN/HCN or HDCO/H_2CO, but are consistent with the HDO/H_2O ratios of ~$3 \cdot 10^{-4}$ found in comets. This favors a scenario in which water is indeed formed on grains and is directly incorporated into (proto-)planetesimals, without participating in the low-temperature gas-phase chemistry.

Outlook

Our large programme summarized here illustrates the power of the VLT and other 8-10 m class telescopes in two areas. First, it has enabled us to obtain high spectral resolution, high quality data on a much larger sample of objects than previously accessible. Second, deeper integrations on selected objects and specific settings have been used to search for minor species or to observe weaker sources. Indeed, weak extragalactic sources are now also within reach and recent VLT-ISAAC M-band spectra of NGC 4945 by Spoon et al. (2003) show very similar features as those found in our sources. Together with the modern surface science, solid-state and gas-phase techniques studied in our laboratories, we have begun to address several puzzles in astrochemistry. Without access to laboratory work and associated theory, however, these beautiful spectra would constitute an impressive technological accomplishment, but would shed little light on our basic understanding of the physical and chemical processes during star- and planet formation.

Our data base of 3–5 μm spectra will form a valuable reference for future observations of southern YSO's. Many of our sources are part of the SIRTF Legacy '*Cores to Disks*' programme (Evans et al. 2003), for which complementary IRS 10–38 μm spectra will be obtained in the coming year. VISIR will be well suited to look for various weak ice bands at longer wavelengths in the same sample, e.g. CH_4 at 7.7 μm and CH_3OH at 9.7 μm. For the gas-phase molecules, the highest spectral resolution modes of VISIR and CRIRES will allow searches for molecules other than CO, both in absorption and emission, opening up new regimes of chemical studies. CRIRES also has the necessary spectral resolution to trace the kinematics.

As emphasized in the introduction, infrared and submillimeter data go hand-in-hand in unravelling the structure of the envelopes and discs around low-mass YSO's. We can hardly wait for ALMA to come on-line and start mapping the millimeter molecular lines in these objects at subarcsec resolution!

Acknowledgments

We are grateful to the builders of ISAAC for providing such a fine instrument, and to the ESO staff in Garching and at Paranal, in particular F. Comerón, C. Lidman and O. Marco, for their expert support of our programme. We also thank S. Bisschop, I. Taban and W. Alsindi for important contributions.

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Deep Infrared Surveys and their Cosmological Implications

SINCE THE RECENT DISCOVERY BY THE COBE MISSION OF A COSMIC BACKGROUND IN THE INFRARED CONTAINING ROUGHLY HALF OF THE GLOBAL COSMIC RADIATIVE BUDGET, ONE OF THE IMPORTANT THEMES IN COSMOLOGY HAS BEEN THE DETECTION AND CHARACTERIZATION OF ITS SOURCES. WE REPORT HERE ON THE FIRST ATTEMPTS IN THIS SENSE CARRIED OUT THROUGH DEEP MID- AND FAR-IR SURVEYS WITH THE INFRARED SPACE OBSERVATORY, AND WE DETAIL ON THE OBSERVATIONAL CAMPAIGNS OF OPTICAL FOLLOW-UP USING VARIOUS ESO TELESCOPES. THIS RESULTED IN THE IDENTIFICATION OF A POPULATION OF LUMINOUS AND ULTRA-LUMINOUS MASSIVE STAR-FORMING GALAXIES, STRONGLY EVOLVING IN COSMIC TIME. THESE RESULTS SET THE SCENE FOR THE FORTHCOMING DEEPER EXPLORATIONS USING THE SIRTF OBSERVATORY AND THE LATEST GENERATION OF ESO INSTRUMENTS.

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ONE OF THE KEY THEMES for observational cosmology is the study of the build up with cosmic time of stellar populations and the progressive assembly of galaxies, a fundamental process from the primordial diffuse plasma to the highly structured present-day universe. These investigations are usually performed through observations in the UV/optical/near-IR with large ground-based optical telescopes. In the last couple of decades, however, it has become more and more evident that a lot of further independent information may be obtained from selecting faint galaxies at longer infrared wavelengths. By these means not only are the effects of dust extinction minimized (dust absorption is a strongly decreasing function of wavelength), but also the dust re-radiation in the mid- and far-infrared and the sub-millimeter (between $\lambda \sim 10$ and 1000 μm) can be detected.

While only ~30% of the light from normal galaxies is absorbed by dust, this fraction becomes much higher when we consider the most active star-forming regions in galaxies and phases of enhanced generations of stars which are episodically triggered in galaxies.

There is also evidence that these active phases in galactic evolution were quite more frequent in the past, not strange if we consider the much larger fractions of diffuse gas and dust in galaxies during the early evolutionary phases, hence the more abundant fuel available to form stars. A spectacular achievement for cosmology during the 1990s was the discovery by the COBE mission of a diffuse airglow with peak emission at $\lambda \approx 200$ μm (the Cosmic IR Background, CIRB) attributed to the integrated emissions by primeval galaxies and Active Galactic Nuclei (Puget et al. 1996; Hauser et al. 1998).

Unfortunately, the IR and sub-millimeter domain is very difficult to access by astronomical observations, possible from ground only in a few narrow spectral windows, between 2.5 and 30 μm (the VISIR instrument on VLT will soon exploit some of these windows) and at $\lambda > 300$ μm (accessible by large millimetric telescopes). Observations from space platforms are then mostly required. The combined use of deep observations from space by the ESA Infrared Space Observatory (ISO) for selecting high-z active galaxies (both starbursts and AGNs) and the VLT for high-resolution optical studies to physically characterize them turned out to be particularly powerful.

Another important step is being achieved with the infrared observatory SIRTF successfully launched by NASA on August 25. ESO is currently involved in systematic campaigns (mentioned later in this paper) of complementary optical imaging and spectroscopic observations for a best exploitation of the data from space. We summarize in this paper results of some exploratory long-wavelength surveys and optical follow-up studies that have involved the use of ESO telescopes.

The Main Infrared Surveys

The Infrared Space Observatory (ISO, Kessler et al 1996), operative from 1995 to 1998, included two focal-plane instruments of cosmological interest: a mid-IR array camera (ISOCAM), and a far-IR imaging photometer from 60 to 200 μm

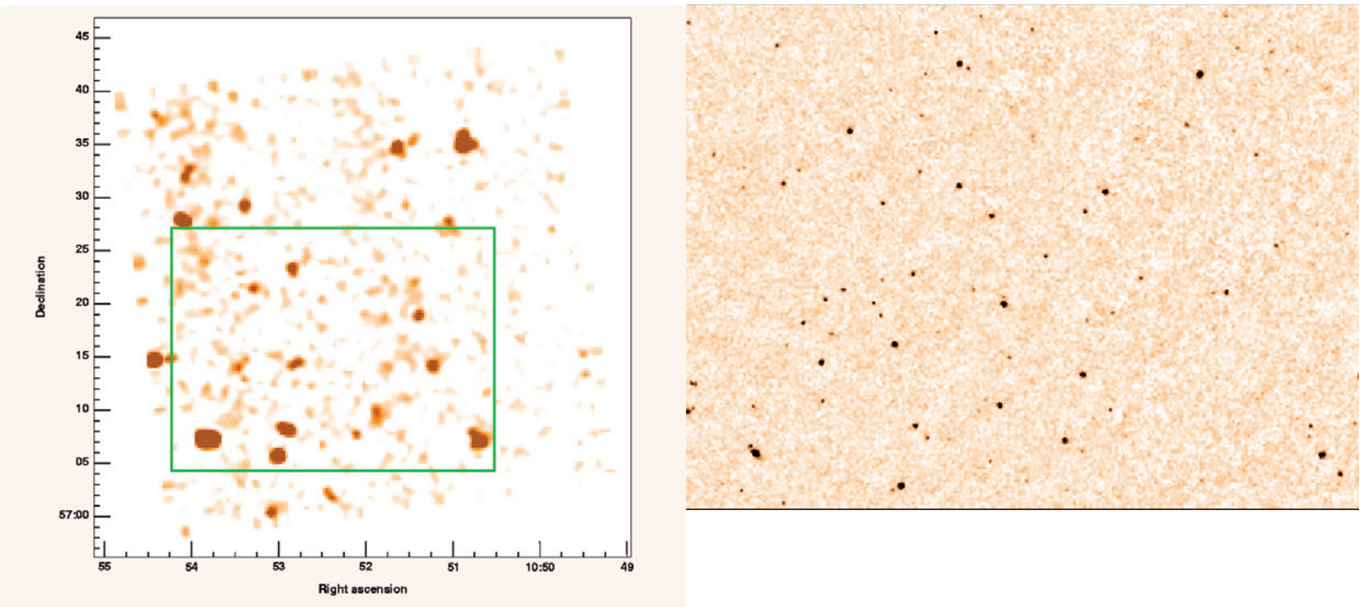


Figure 1: Left panel: ISOPHOT 90 μm map in the Lockman Hole region (Rodighiero et al. 2003). This is likely the deepest far-IR image ever obtained and contains sources with fluxes down to ~20 mJy. The area within the green box is expanded in the right panel, as seen by ISOCAM at 15 μm (Fadda et al., 2003, in preparation).

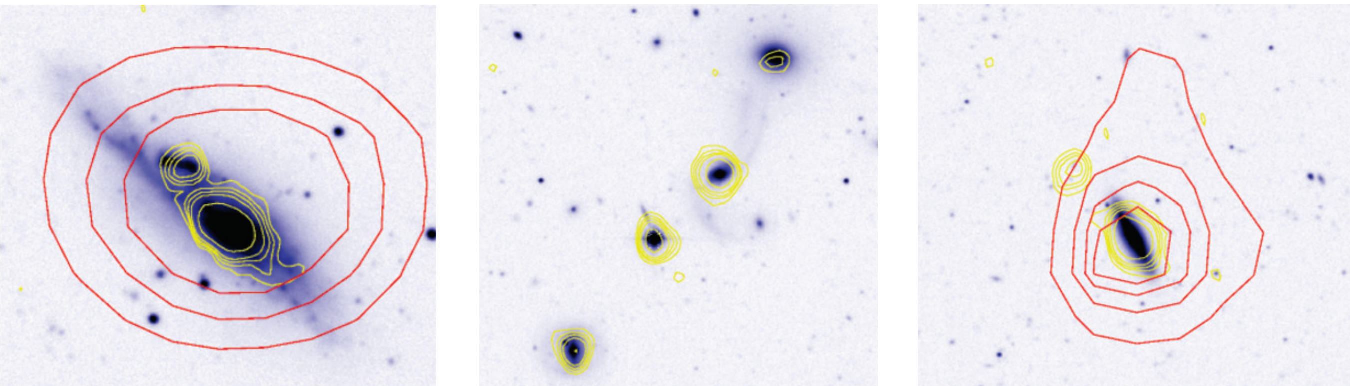


Figure 2: Optical R-band images of IR sources in the Lockman Hole (taken from Rodighiero et al. 2003 and Fadda et al. 2003 in preparation). Yellow contours are the 15 μm detections, red contours are from the 90 μm map.

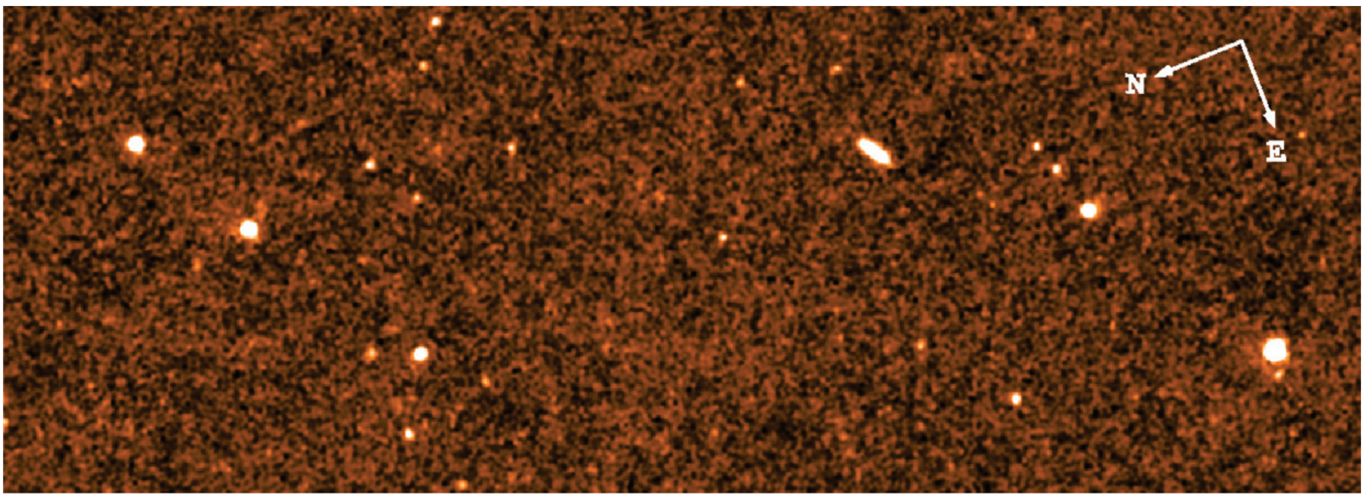


Figure 3: An ISO 30′ × 10′ region at 15 μm of the ELAIS N2 field (Vaccari et al., 2003, in preparation).

(ISOPHOT). The main extragalactic results from the 30-month ISO mission have been summarized by Genzel & Cesarsky (2000). The most important ISO surveys have been performed with a wide-band filter at 12-18 μm and two far-IR (λ=90 and 170 μm) channels. Due to the different diffraction-limited spatial resolution, ~4.6 arcsec FWHM at 15 μm and ~50 arcsec at 100 μm, ISO sensitivity limits in the mid-IR are three orders of magnitude deeper in flux than at the long wavelengths (0.1 mJy versus 100 mJy). Illustrative examples of deep images at 15 and 90 μm are reported in Figs. 1 to 4.

Source counts analyses

Faint IR-selected sources show extremely high rates of evolution with redshift, exceeding those measured for galaxies at other wavelengths and comparable to, or larger than, those of quasars (Elbaz et al. 2002, Franceschini et al. 2001). This is shown by the differential counts of extragalactic sources at 15 μm based on seven independent datasets, displaying a strong departure from an Euclidean law characteristic of a local non-evolving population (see Fig. 5).

An attempt to reproduce these source counts through modelling (but also involving data on the z-distributions, luminosity functions, and data at other IR and sub-mm wavelengths) was described in Franceschini et al. (2001). The model assumes the existence of two basic source populations with different physical and evolutionary properties: quiescent spirals (long dashed line in Fig. 5) and a population of fast evolving sources (dotted line, including starburst galaxies and type-II AGNs). The local fraction of the evolving starburst population is ~10% of the total. In this scenario, the active starbursts and the quiescent galaxies belong to the same population. Each galaxy is expected to spend most of its lifetime in the quiescent state, but occasionally interactions or merger events with other galaxies trigger a short-lived (few to several 10^7 years) active starbursting phase. The inferred cosmological evolution for the latter may be interpreted as an increased chance to detect a galaxy during the active phase back in the past, following the higher probability of interactions during the past denser epochs, and the larger gas masses available to form stars at higher z increasing the rate of star formation (SFR) and the starburst's luminosity. By exploiting the observed correlations of mid-IR, far-IR and radio luminosities, Elbaz et al. (2002) have found that the galaxies detected in the ISOCAM deepest 15 μm surveys are responsible for about two-thirds of the in-

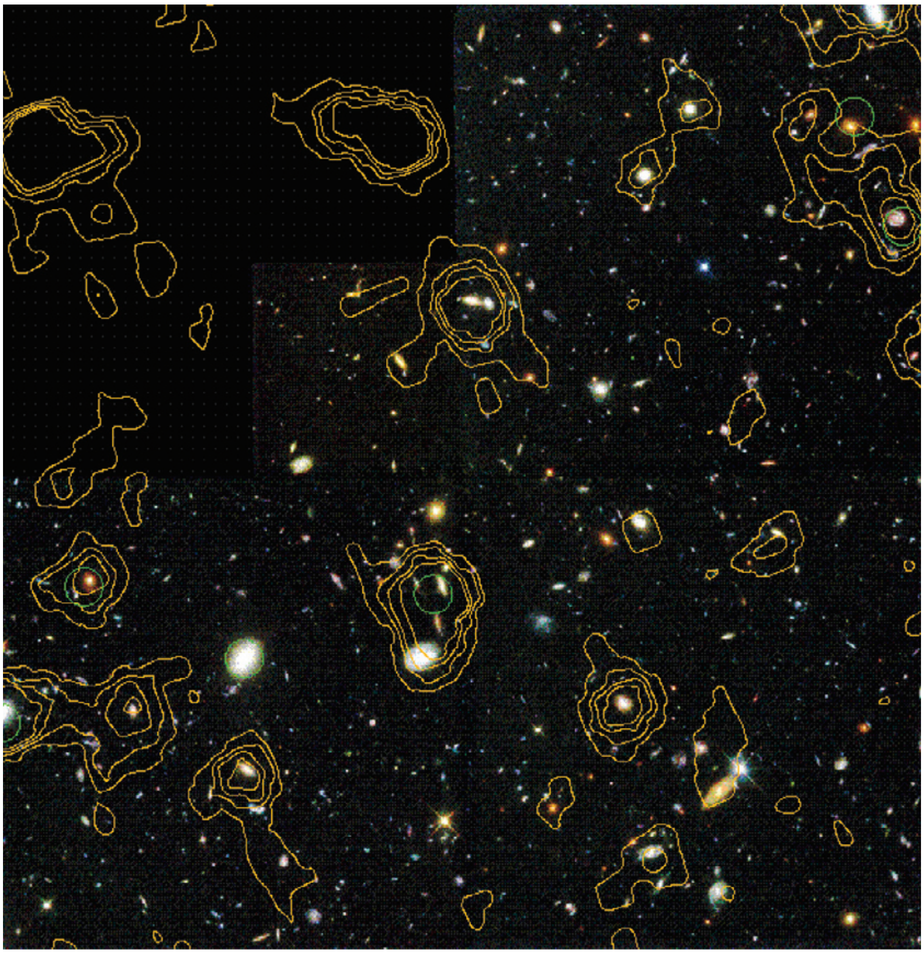


Figure 4: ISO 15 μm contours (yellow) overlayed on the WFPC2 HST image of the HDF North (Aussel et al., 1999).

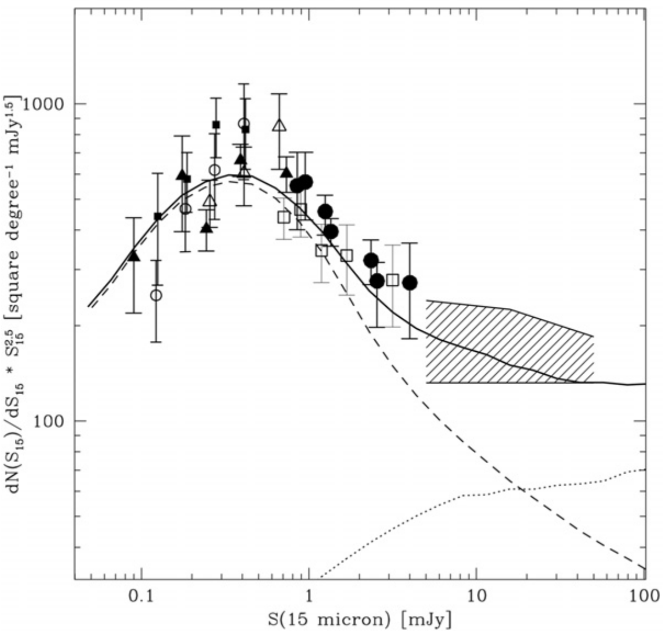


Figure 5: Differential counts at λ_{eff}=15 μm normalized to the Euclidean law ($N[S] \propto S^{-2.5}$). The dotted line are the expected counts for a population of non-evolving spirals. The short dashed line comes from our model population of strongly evolving starburst galaxies. See Franceschini et al. (2001) for more details.

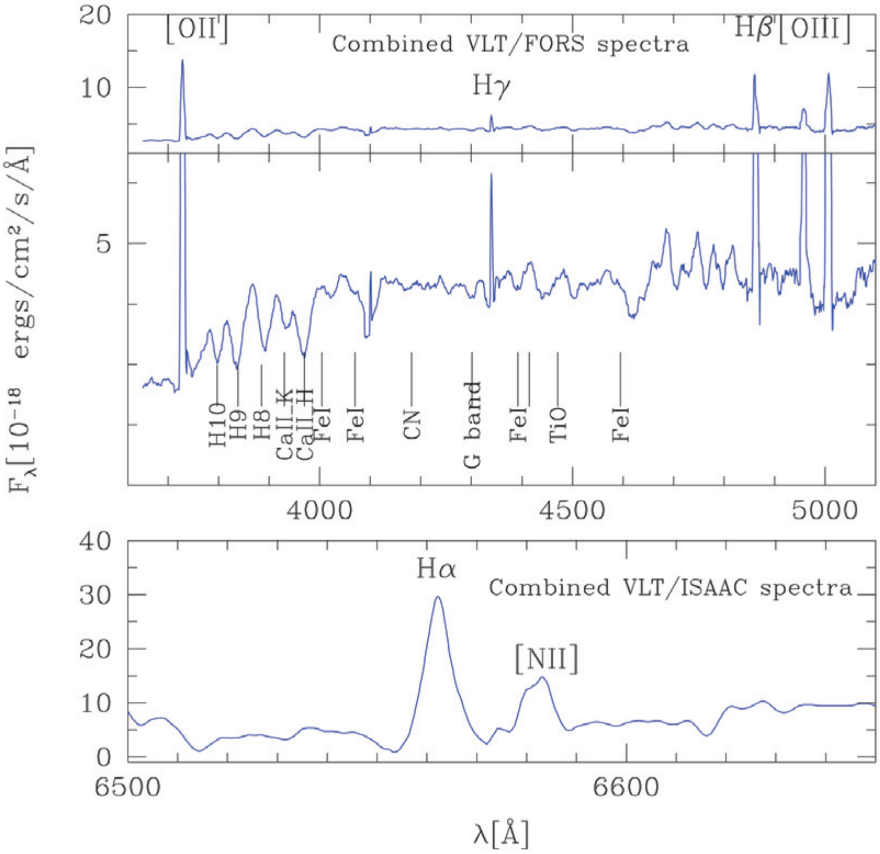
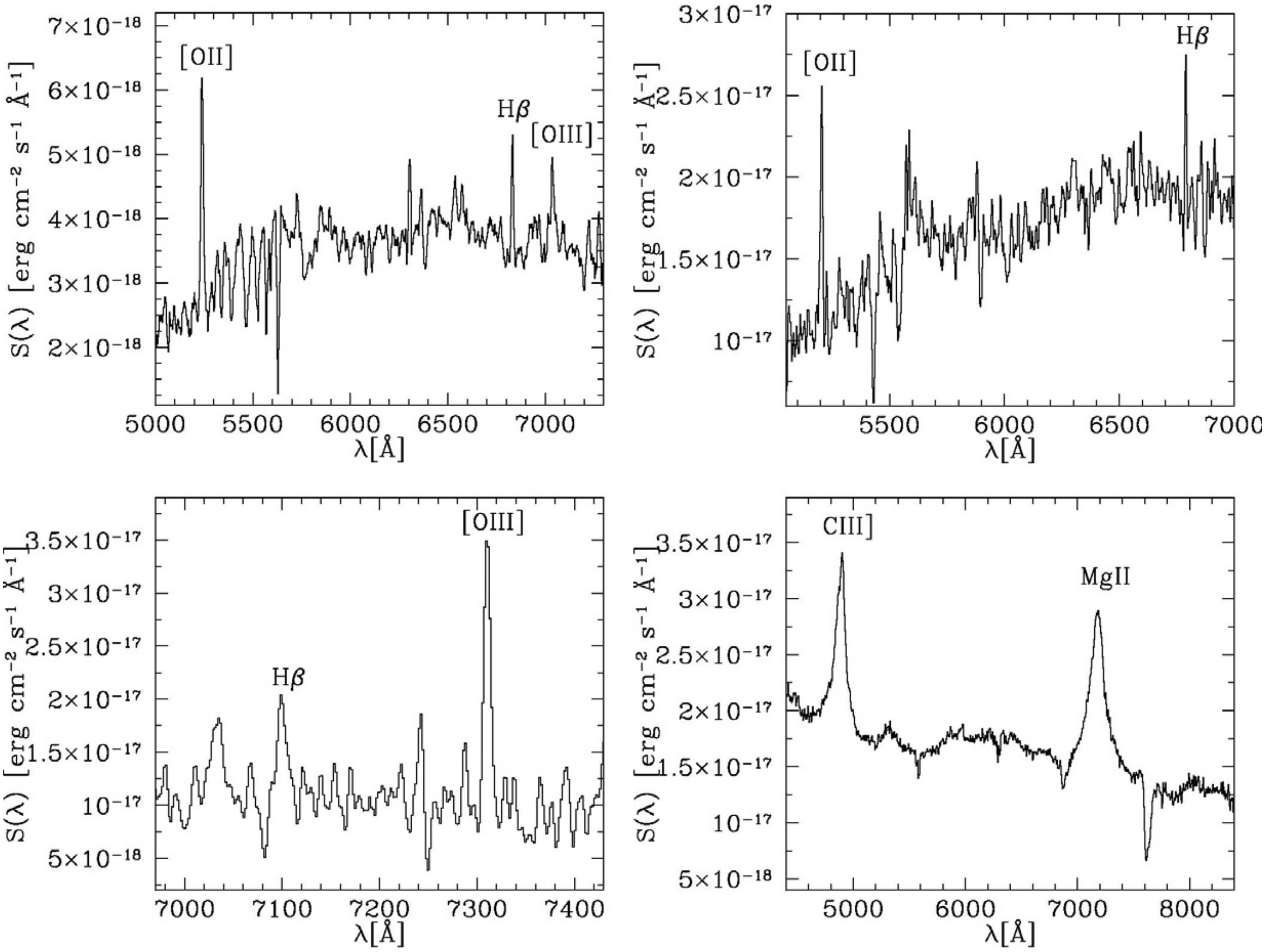


Figure 6: *Combined VLT FORS+ISAAC spectra of eight distant LIRGs (z~0.7) detected in the CFRS 03hr field. A zoom of the spectra revealing metallic and Balmer absorption lines combined with intense emission lines is shown in the central panel (the main absorption lines are indicated, Flores et al., 2003 in press).*

▼ Figure 7: *Observed optical spectra: panels (a) to (c) show 15 μm sources observed with NTT/EMMI. Panel (d) represents the QSO s19 from a FORS1/VLT spectrum. The spectra are taken from Franceschini et al. (2003)*



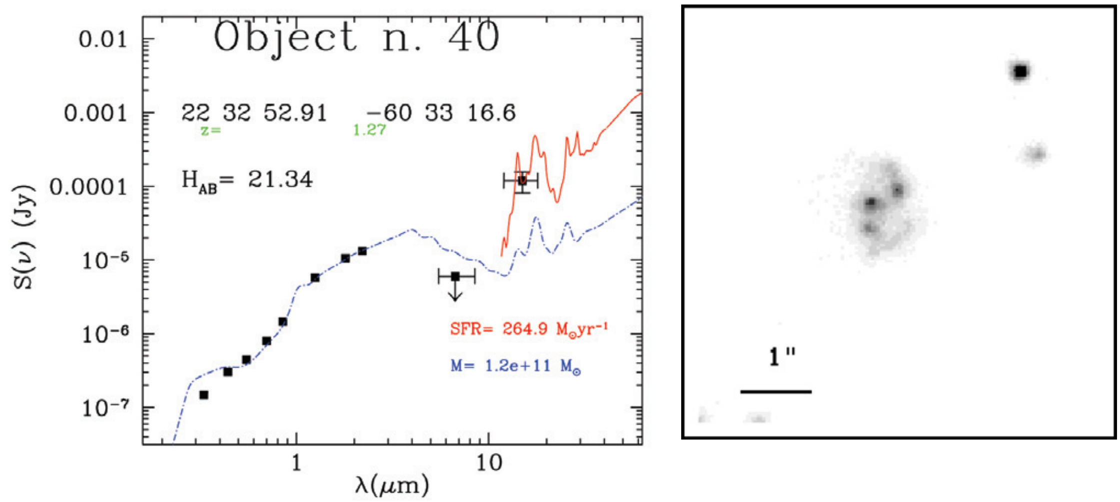


Figure 8: HDFS source S40. Left panel: the observed spectral energy distribution (square dots) compared with the best fit spectrophotometric model (dot-dash blue line) and the template SEDs of M82 (thick solid red line). Right panel: the WFPC-2 F814W image of S40 reveals a very complex and disturbed structure, possibly characterized by different regions of ongoing star formation or multiple nuclei (Franceschini et al. 2003).

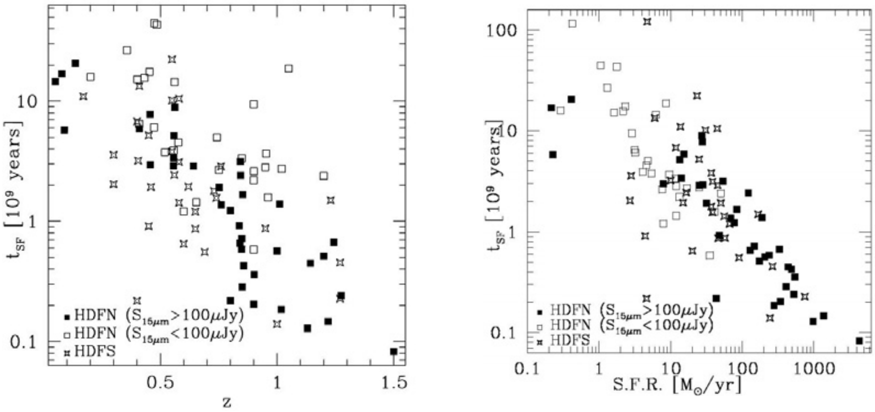


Figure 9: The timescale of star formation t_{SF}=M/SFR [in units of 10^9 yrs] of faint 15 μm ISO sources as a function of redshift (panel a) and star formation rate SFR (panel b). An Ω_m=0.3, Ω_Λ=0.7 cosmology is assumed.

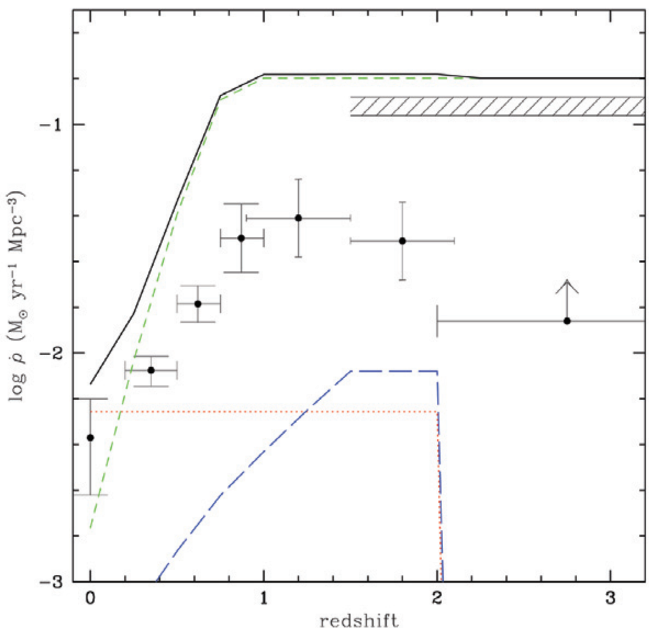


Figure 10: Evolution of the comoving SFR density for the IR-selected population based on our model of IR evolution, compared with data coming from optical observations. Dotted line: quiescent non-evolving population. Short-dash line: evolving starbursts. Long dashes: type-I AGNs. The shaded horizontal region is an evaluation of the average SFR in spheroidal galaxies to reproduce the observed metal abundance in clusters.

tegrated intensity of the CIRB at the peak wavelength of 140 μm.

ESO FOLLOW-UP OF IR-SELECTED SOURCES

The faint ISO-selected sources display various distinct features compared with other optically selected galaxy populations. They are very luminous on average ($L_{bol} \geq 10^{11}$ $L_\odot$), with the bulk of their emission coming out in the far-IR, in a similar way as the IRAS-selected galaxies include the most luminous systems in the local universe. Their areal density (a few sources/square arcmin at the faintest limits detectable by ISO) is much lower than found for faint galaxies in the optical. We have investigated the characters of IR emission in galaxies between z~0.2 and 1.5 detected by ISO in the Hubble Deep Fields North and South (HDFN and HDFS) and in the CFRS 03hr fields. We have in particular exploited the mid-IR flux as a most reliable tracer of star-formation. This study made use in particular of the near-infrared ISAAC and optical FORS spectrographs on VLT for a representative and unbiased subsample of 21 objects selected in HDFS (Franceschini et al. 2003).

Fairly intense redshifted Hα+[NII] emission is detected by ISAAC in virtually all the observed sources. The comparison with the Hβ, Hγ and [OII] line emissions observed with FORS2 (see Figs. 6 and 7), as well as the analysis of the spectral energy distributions of these sources, indicate typically high extinction values between 1.5 and almost 3 magnitudes in V, much larger than found for local normal spirals. The intrinsic (de-reddened) Hα flux then comes out to be strong in these objects. The SFR values estimated from the Hα measurements are fairly consistent with those based on the IR bolometric flux, if care is taken to appropriately correct the former for the large dust extinction. However, the latter is very difficult to assess based on slit spectroscopy: sensitive Integral Field IR spectrographs, like SPIFFI and SINFONI on VLT, will be needed to measure it more reliably. Typical values of SFR turn out to be ~10 – 300 $M_{\odot}$/yr for the IR-selected galaxies.

The analysis of VLT spectra show that distant LIRGs detected by ISO have solar or higher metallicities, revealing metallic and Balmer absorption lines combined with intense emission lines (Fig. 7), indicating a particularly complex star formation history.

Figure 8 shows the spectral energy distribution of the ISO-selected HDFS source S40 and its HST WFPC-2 I-band image. This object has been identified as a ULIRG at z=1.27, showing very strong Hα emission and mid-IR excess. Its optical SED has been fitted through a spectrophotometric synthesis code (dot-dashed line), while the mid-IR flux has been reproduced with an M82 template (thick red line).

Details on another ISO galaxy in the HDFS, source S27, can be found in an ESO 2000 Press Release by Rigopoulou et al.; observed with the ISAAC mid-resolution spectrograph, it turned out to be one of the most massive galaxies known, with a mass of $M \approx 10^{12}$ $M_{\odot}$.

We have looked for the evidence of the presence of Active Galactic Nuclei, as possibly responsible for the enhanced IR luminosities, by looking at the broadness of the Balmer lines, the low- to high-ionization line ratios, the HST morphologies, the slopes of the mid-IR spectra, and the ratio of the radio to IR fluxes. Clear evidence for nuclear activity has been found in 2 objects out of 21, while for two other objects the presence of AGN contributions is suspected. This AGN fraction is consistent with that estimated by Fadda et al. (2002) by combining deep mid-IR ISOCAM and Chandra and XMM-Newton X-ray observations in HDFN and the Lockman Hole: (17 ± 7)% of the mid-IR

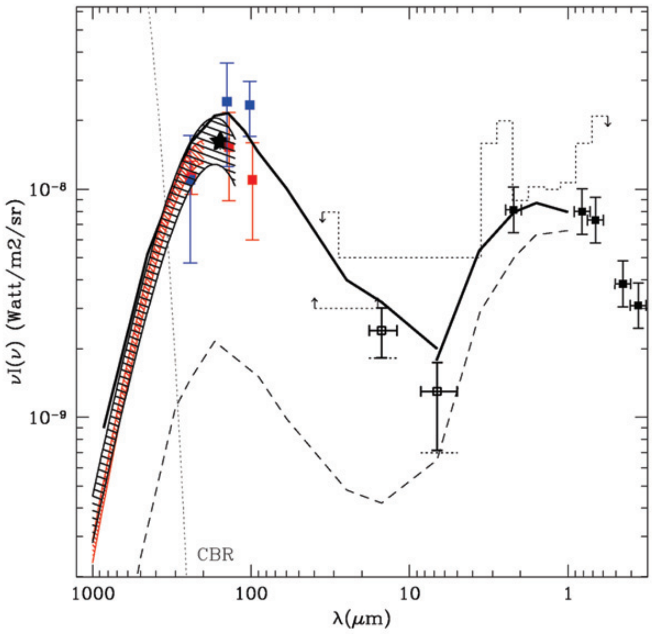


Figure 11: *The Cosmic Infrared Background spectrum compared with estimates of the integrated optical light of faint galaxies in the HDF. The star marks the expected contribution of faint ISOCAM sources by Elbaz et al. (2002). The two mid-IR points are the resolved fraction of the CIRB by the deep ISO surveys IGTES (see Franceschini et al. 2001 for more details).*

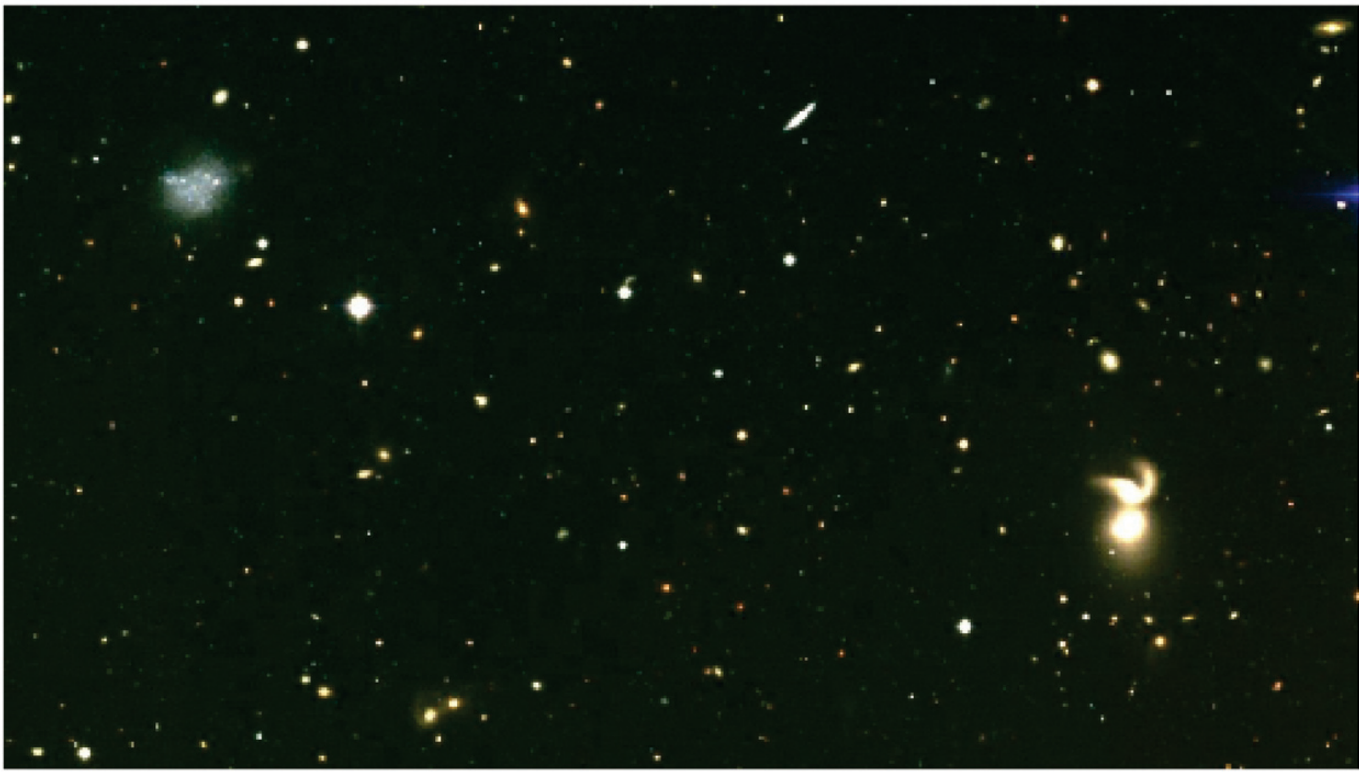


Figure 12: *Combined BVR image of a 8×5 arcmin region in the ELAIS S1 region from the ESIS survey (Berta et al. 2003, in preparation). In the spirit of "Legacy Projects", all these data will have short proprietary periods and will become available to the community soon after the data reduction is completed.*

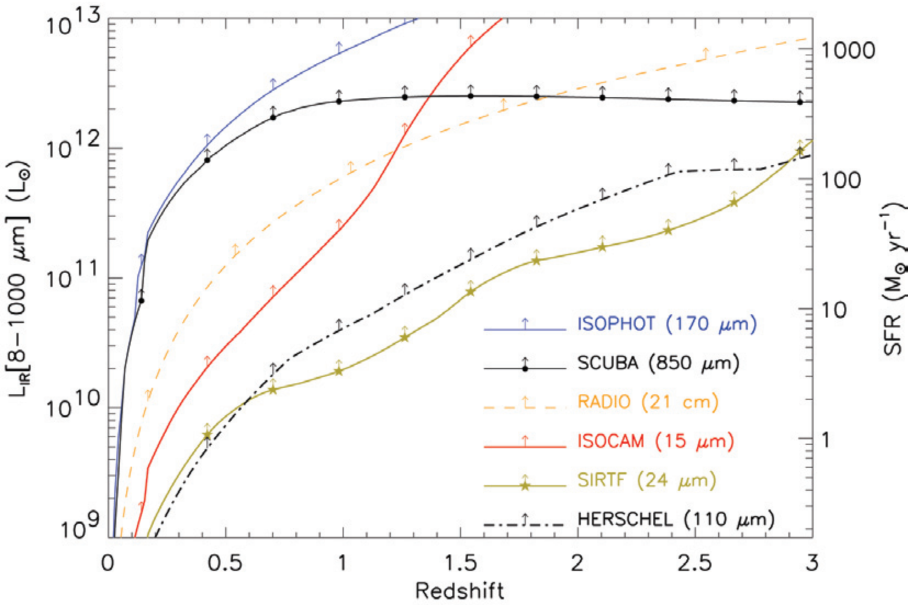


Figure 13: IR luminosity (left axis) and star formation rate (right axis) as a function of redshift corresponding to the 5-σ sensitivity (S) limits at different wavelengths: ISOCAM (λ = 15 μm, S = 0.1 mJy), VLA (λ = 21 cm, S = 40 μJy), ISOPHOT (λ = 170 μm, confusion limit S = 120 mJy), SCUBA (λ = 850 μm, confusion limit S = 2 mJy), the MIPS camera on board SIRTF (λ= 24 μm, S = 22 μJy) and HERSCHEL-PACS (λ = 110 μm, S = 5.1 mJy). [Figure taken from Elbaz and Cesarsky 2003]

sources are found to be AGNs. We estimate that the contribution of AGNs to the total extragalactic mid-IR background is of this same order.

To complement the dynamical mass estimates for faint IR galaxies based on ISAAC spectroscopy, we have estimated the stellar mass M by fitting the optical/near-IR photometric data with a detailed spectrophotometric model combining stellar populations with different ages and extinction (dot-dash line in Fig. 8). This analysis shows that the faint IR sources with fluxes $S_{15} > 100$ μJy are hosted by massive galaxies ($M \approx 10^{11}$ $M_\odot$). We have then estimated the timescale for the formation of stars in these galaxies as the ratio t_{SF} between the stellar mass M and the observed rate of SF. By these means t_{SF} has been found to span a very wide range of values between 0.1 and 10 Gyrs or more (see Fig. 9). When compared with the typical starburst duration (~10^8 yrs), this implies that the ongoing event of star formation can typically generate only a fraction of the stellar content in these galaxies, many of such repeated episodes during a protracted SF history being required for the whole galactic build-up. A trend towards a reduced level of star-formation activity in galaxies at decreasing redshifts is also apparent in the data (Fig. 9a). In summary, the 15 μm selection appears to emphasize sites of enhanced star formation inside massive galaxies, which are typically the brightest members of galaxy groups. These sources probably trace evolutionary phases, involving strong dynamical interactions and mergers, bringing to the formation of massive current-day galaxies.

The faint 15 μm selected galaxies in context

While ISO surveys do not allow sampling the optically-hidden SF at z>1.3 (emissions by small dust grains and PAH molecules are redshifted outside the ISO filters), constraints on higher-z sources come from ground-based sub-millimeter surveys with SCUBA and MAMBO on the JCMT and IRAM telescopes. Figure 10 shows an evolutionary model for the SFR density as a function of redshift based on ISO and SCUBA surveys. The contribution of IR-selected sources to the SFR significantly exceeds those based on optically selected sources. However the fast evolution inferred from the IR observations should level off at z>1, to allow consistency with the observed z-distributions for faint ISOCAM sources and with the observed CIRB spectrum (see Fig. 11).

As suggested by several authors (e.g. Lilly et al. 1999; see also Franceschini et al. 1994), the similar properties (bolometric luminosities, SEDs) between the SCUBA high-z population and local ultra-luminous IR galaxies argues in favour of the idea that these represent the long-sought "primeval galaxies", those in particular leading to the local massive elliptical and S0 galaxies. The less extreme starbursts discovered by ISO at lower z may instead be related to the assembly of lower mass spheroids and spheroidal components in spirals.

The currently available data suggest an evolutionary scheme where star formation in galaxies has proceeded in two phases: a quiescent one taking place during most of the Hubble time, slowly building stars with standard IMF from the regular flow of gas in rotationally supported disks, and a transient actively starbursting phase, recurrently triggered by galaxy mergers and interactions. During the merger, violent relaxation likely redistributes old stars, producing de Vaucouleur profiles typical of galaxy spheroids. During this active phase, Franceschini et al. (2001) argue that young stars may be generated with a top-heavy IMF to allow consistency between the energy in the CIRB and optical backgrounds and the local stellar mass density in galaxies.

The SIRTF Legacy Surveys and the ESO Large Program ESIS

Relevant developments in this field are soon expected by the NASA Great Observatory SIRTF, with a primary mirror larger than ISO (85 vs. 60 cm) and superior detector assemblies. As part of its policy for the exploitation of the mission, NASA has promoted a set of six observing campaigns, the so-called SIRTF Legacy Program. Two of these are dedicated to deep cosmological surveys, the Great Observatory Origins Deep Survey (GOODS, a survey of 300 sq.arcmin in the HFD-North and Chandra Deep Field South) and the SIRTF Wide-Area In-

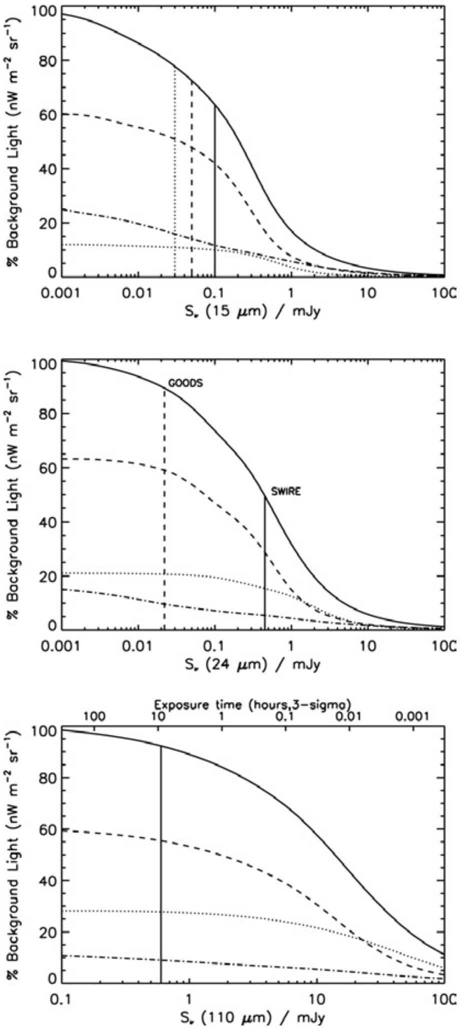


Figure 14: The fraction of the extragalactic background light resolved into individual galaxies at 15, 24 and 110 μm by ISOCAM, SIRTF and HERSCHEL respectively down to the corresponding confusion limits. In the middle panel the two cosmological Legacy Programmes of SIRTF, GOODS and SWIRE, are indicated.

frared Extragalactic (SWIRE) survey. The latter will observe a sky region of 67 sq.degrees split into 7 contiguous areas, 4 in the Northern and 3 in the Southern sky. In a formal letter issued by the Director General in 2001, ESO has committed itself to systematic optical/near-IR observing campaigns to complement the SIRTF observations, one of which (the Large Program ESO/SIRTF Imaging Survey, ESIS, P. I. A. Franceschini) has already started. The combined BVR image in Fig. 12 illustrates the imaging quality that we achieved with the ESO/MPG 2.2 m WFI in the area ELAIS-S1 (Berta et al. 2003, in preparation). The final ESIS survey will cover ~5.5 sq.deg. in BVR with WFI and in I with VIMOS, while a smaller overlapping area is being observed in Z. SIRTF SWIRE will observe this field in four mid-IR channels at 3.6, 4.5, 5.6, 8 μm and three far-IR channels at 24, 70 and 160 μm. Particularly the 24 μm channel promises to break the z~1.3 limit imposed on the ISO surveys.

Prospects for the long-term

Deep IR and sub-millimeter surveys have already demonstrated that a large fraction of present-day stars must have formed during one, and more probably several, dusty starburst events. As we have illustrated, the physics ruling IR emission of galaxies is extremely complex, and based on current observations we can just claim to have identified a new important area for cosmology. New instrumentation, both in space and on ground, will be needed to characterize these astrophysical and cosmogonical processes. Particularly the direct detection of the FIR emission is still missing and a detailed description of the evolution at $z > 1$ is missing. Also the origin of the infrared emission of these strong starbursts remains an issue: are they triggered by galaxy interactions? Are these interactions major mergers, minor mergers or simply tidal effets?

The challenge for future long wavelength surveys will be:

1. to increase the redshift range in which dusty starbursts can be detected in order to determine whether the cosmic density of star formation in the universe flattens, increases or decreases above redshift one;

2. to quantify the level of clustering of dusty starbursts;

3. to detect directly the far infrared emission of distant galaxies;

4. to study their morphology not only in the optical but also in the dust emission regime, thereby precisely quantifying the role of interactions in triggering these starbursts.

All these issues will be addressed in a complementary way by forthcoming infrared instrumentation, i.e. SIRTF, Herschel, ALMA and the JWST. SIRTF, and in particular the Legacy Program GOODS (Great Observatories Origins Deep Survey, Dickinson and Giavalisco 2001) will detect luminous IR galaxies up to z ~ 3 by pushing the IRAC and MIPS 24 μm instruments to their limits (see Fig. 13).

With its large field of view of 70 square degrees, the Legacy Program SWIRE (SIRTF Wide-area Infrared Extragalactic Survey), will quantify the level of clustering of these galaxies up to z~ 1. Later on, Herschel will allow for the first time the direct detection of the FIR luminosity of the distant dusty starbursts responsible for the CIRB (see Fig. 14), while SIRTF will be limited by confusion in this wavelength range. Large surveys with Herschel will also permit us to study the connection between the build up of large-scale structures and galaxy formation and evolution (see Elbaz and Cesarsky 2003). Finally, the James Webb Space Telescope (JWST) and the Atacama Large Millimeter Array (ALMA) will allow us for the first time to study the morphology of these galaxies directly in the infrared regime where they emit the bulk of their light.

Given the spatial complexity and optical faintness of these cosmic sources, an essential complement to the long-wavelength observations will be offered by the high-sensitivity integral-field spectrographs on VLT in the optical (GIRAFFE, VIMOS) and near-IR (SPIFFI, SINFONI). During the next decade our understanding of galaxy formation and evolution will see a decisive improvement.

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The CORALS Survey

A Review and Progress Report on The Search for Dust Obscured Quasar Absorption Line Systems

Distant, luminous quasars can be used to study intervening gas-rich galaxies - a potentially powerful tool for tracing galaxy evolution over most of the age of the universe. Here we describe the CORALS quasar survey which aims to quantify whether dust in such galaxies could hide a significant fraction of background quasars from view and bias our view of early galaxy formation.

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The existence of microscopic dust grains in interstellar space represents a perennial problem in many fields of astrophysics. Solid grains of dust in a galaxy's interstellar medium (ISM) can mop up certain chemical elements from the gas phase, complicating attempts to measure ISM abundances. In addition, the presence of dust acts as an obsuring veil that dims and reddens background objects, hiding them from the view of optical telescopes. However, dust is very much a necessary evil since it regulates the temperature of the ISM, as well as acting as a shield against harsh UV radiation and providing nucleation sites for the formation of molecular hydrogen. Despite its ubiquitous astrophysical impacts, the formation of dust, and even its composition, remain poorly understood. Nonetheless, the widespread evidence for significant amounts of dust, even in the very early universe, means that it is hard to escape the possible consequences of depletion and extinction effects on astronomical observations.

The study of quasar (or QSO) absorption line systems is a field in which dust continually plagues our interpretation of the data. This technique uses relatively bright, yet distant, quasars as background sources to study intervening gas clouds (like galaxies), which imprint their signatures on the quasar spectrum. Echelle spectrographs such as UVES on the VLT are now, almost routinely, providing exquisite data that permit accurate measurements of gas phase abundances in galaxies and the intergalactic medium out to very high redshifts. Identifying galaxies at high redshifts through their absorption signatures has provided astronomers with a powerful probe of galaxy evolution by tracing objects that are generally too faint to study with more direct methods. Despite the high quality data, however, there has been concern for many years that surveys for absorption line galaxies may be affected by dust. That is, if the internal extinction of absorption galaxies is sufficiently large, then optical searches will miss quasars located behind them; this would seriously bias our surveys and skew our view of how galaxies evolve. Indeed, theoretical calculations have estimated that between 30 and 70% of QSOs (and, consequently, the absorption galaxies aligned in front of them) could be missed in present surveys due to this very effect.

Seeing Beyond the Smoke Screen

The Complete Optical Radio Absorption Line System (CORALS) survey was designed to provide a quantitative answer to concerns about absorption line survey dust bias. The aim, simply put, was to compile a sample of QSOs selected at radio wavelengths (where dust does not have an effect) with *no optical magnitude limit* from which absorption line statistics could be determined. The parent sample for this survey is the Parkes quarter-Jansky (PQJ) sample (Jackson et al. 2002) which contains 878 flat spectrum radio sources observed at 2.7 and 5.0 GHz. An important feature of the PQJ sample is the extensive follow-up imaging campaigns that have resulted in optical identifications and classifications for essentially all of the sources. Although a large spectroscopic campaign was undertaken for much of the PQJ sample, these data were obtained at low spectral resolution for the purpose of object classification and redshift determination and are not suitable for absorption system studies. Therefore, over the last five years, we have been pursuing an active observing campaign that has so far logged some 30 nights on telescopes over four continents to address issues associated with obscuration bias.

The First CORALS Survey

The initial goal of the CORALS survey was to assess the possible bias in samples of high redshift damped Lyman α systems

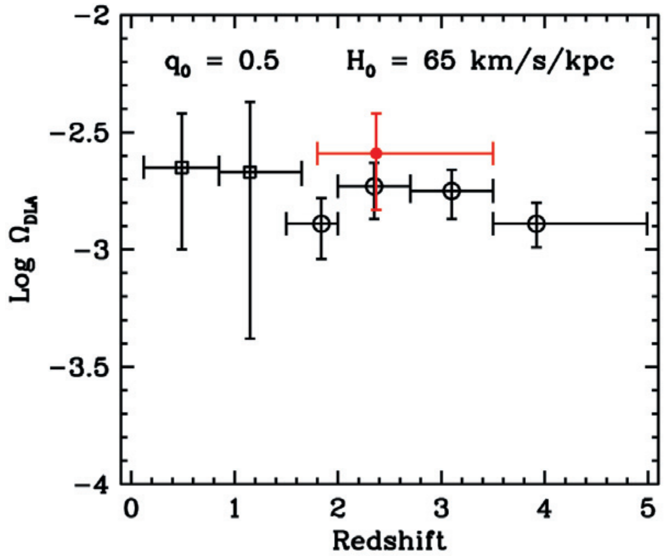


Figure 1: The mass density of neutral gas, Ω_{DLA}, in DLAs. Open circles and squares are measurements from the latest compilations by Péroux et al. (2001) and Rao & Turnshek (2000) respectively. The solid red circle is the value from the CORALS I survey presented here for the redshift interval $1.8 < z_{abs} < 3.5$. These results show that, for $z > 2$, dust bias can only cause an under-estimate of Ω_{DLA} by at most a factor of two.

(DLAs), the highest column density absorbers associated with galaxy scale systems. The sample for this survey consisted of the 66 $z_{em} > 2.2$ QSOs from the PQJ survey which had magnitudes as faint as B=23.5. In order to determine whether dust had played a significant role in previous DLA surveys, we quantified both the number of absorption systems ($n(z)$), and the amount of neutral gas (Ω_{DLA}), that they contained. The main result of the first CORALS survey (whose results have been published in full by Ellison et al. 2001) is that these quantities ($n(z)$ and Ω_{DLA}) have only been slightly under-estimated in the past, i.e. that dust obscuration does not play a major role in hiding absorption galaxies. For example, in Figure 1 it can be seen that the amount of gas measured in the CORALS survey is at most a factor of about two more than previous magnitude limited samples. Nonetheless, fewer DLAs are found towards brighter QSOs than fainter subsets, and the total gas content is also somewhat lower, although the error bars remain large. Such a trend is supported by the DLA survey conducted using the Hamburg-ESO (HE) sample of bright QSOs, in which Ω_{DLA} is an order of magnitude lower than for CORALS (Smette et al., in preparation). The precise dependence of DLA statistics on survey magnitude limit not only has an important application in the design of future surveys, but also has implications for the large datasets being reaped from surveys such as 2dF and the Sloan Digital Sky Survey (SDSS). These surveys are sufficiently large that error bars will be much less dominated by redshift coverage, so that observational biases, even subtle ones, will be important.

CORALS II: Extension to Lower Redshift

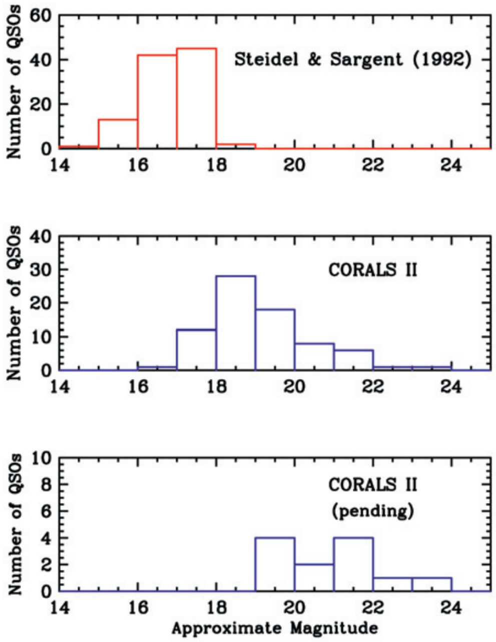
The preliminary results from CORALS I indicate that at $2 < z < 3$, dust does not seem to play a significant role in hiding DLAs from previous surveys, at least when QSOs with magnitudes V~20 can be reached. However, it might be expected that biasing becomes more severe towards lower redshifts, since the bulk of star formation takes place by z ~1. With most of the star formation completed, we may expect the ISM of galaxies to exhibit pronounced chemical (and therefore, plausibly, dust) evolution at low z.

Observationally, it is challenging to extend CORALS to $z < 1.5$, due to the onset of the atmospheric cut-off which renders detection of low redshift Lyα at λ=1216 Å impossible from the ground. Although large DLA surveys have been conducted with the Hubble Space Telescope (HST), these are very expensive in terms of resources. Moreover, current HST instrumentation restricts surveys to bright magnitudes, but it is the faintest QSOs that may be most affected by dust. Therefore, we have designed CORALS II to select absorption galaxies via Mg II and Fe II lines – strong metal features associated with galaxy halos that have transitions observable in the optical regime down to z ~ 0.3. By selecting systems with strong Mg II and Fe II absorption, we can efficiently pre-select likely DLAs.

CORALS II, a complete survey for Mg II absorbers with $0.5 < z < 1.5$, is currently nearing completion; out of 75 QSOs, we have so far observed some 60 targets, the rest pending observation (mostly with FORS on the VLT) in Period 71. The QSO sample is again based on the PQJ flat spectrum quasar sample, although we have now preferentially selected $z_{em} < 2.5$ targets so that Mg II will fall redwards of the Lyα forest. In the majority of cases, we also cover Fe II λ2600 and usually also Mg I λ2853. Our aim is to be complete down to an observed 3σ equivalent width threshold of 0.5 Å for Mg II, although in most cases we achieve limits significantly beyond this. Up to this point, we have a redshift path coverage Δz ~50 for a rest frame equivalent width limit of 0.5 Å, which will increase to approximately 60 by the end of the survey. We have so far detected 28 Mg II absorbers with EW(Mg II λ2796) ≥0.5 Å and a further 10 with EW(Mg II λ2796) ≥0.3 Å. We can compare these statistics with the landmark survey of Steidel & Sargent (1992, hereafter SS92) performed with the Palomar 5-m telescope on a sample of QSOs with 15 < V < 18. We determine a number density of absorbers that is, considering the error bars, marginally lower than SS92: for an equivalant width threshold of EW>0.6 Å (the limit used by SS92) we determine $n(z)$=0.46±0.10 (at $\langle z_{abs} \rangle$ = 1.08) compared with 0.65±0.07 at a similar mean redshift for SS92. *This is the opposite to what we would expect if a dust bias is at work!* Therefore, the preliminary results of this lower redshift survey paint the same picture as at high redshift: dust is not responsible for hiding a large number of absorption systems.

In Figure 2 we show the distribution of optical magnitudes for the SS92 survey compared with CORALS II as it currently stands, as well as the complete sample which is still pending completion. Although these magnitudes have error bars which may exceed 0.3 mags (and the CORALS radio-loud QSOs are expected to be highly variable), the basic picture is that the Steidel & Sargent (1992) sample occupy a locus of brighter magnitudes than CORALS. In the context of dust bias, the possible surfeit of absorbers towards bright QSO samples at intermediate redshift seems puzzling. One way to explain this is with a lensing bias, whereby intrinsically fainter QSOs are boosted by intervening galaxies and are included in brighter flux limited samples (e.g. Smette et al 1997). If we split the CORALS sample in half by emission redshift, the number density for $z_{em} > 2.1$ is $n(z)$=0.52±0.17 and 0.41±0.13 for lower

Figure 2: Comparison of the QSO magnitudes for the Steidel & Sargent (1992) Mg II survey and CORALS II. The bottom panel shows the final targets that are still pending observation. The SS92 survey is effectively a 'bright' QSO sample, whereas CORALS II is optically complete and includes QSOs up to 250 times fainter than the SS92 limit.



redshifts (for $\langle z_{abs} \rangle \sim 1.1$ in both cases). Although these values are consistent within the large error bars, the marginally higher $n(z)$ towards higher redshift QSOs is again suggestive of lensing. This is because the lensing efficiency (by intermediate redshift galaxies) is higher for more distant QSOs. Larger samples, such as the SDSS and 2dF surveys will be able to confirm this trend of $n(z)$ versus emission redshift, even though they are confined to brighter samples. We note that this is probably not an issue for high redshift ($z_{abs} > 2$) DLA surveys because of the low lensing probability in this configuration. Indeed, Smette et al. (in preparation) find less neutral gas in DLAs towards the bright HE quasars, compared to CORALS.

Confirming the N(HI) of our complete Mg II sample, and thereby determining Ω_{DLA}, will be an important test of whether a bright magnitude cut-off induces a bias in the determination of the neutral gas density in DLAs at low z. Such a bias is predicted to overestimate Ω_{DLA} (Smette et al. 1997) because the line of sight preferentially passes through the inner part of the lensing galaxy.

Along the Way...

Sizeable surveys of any kind often produce spin-off projects which either focus on a few unusual objects, or can exploit large datasets to study the properties of subsets of the data. We briefly review two such spin-offs from the CORALS survey.

Traditional DLA surveys have excluded DLAs within ~3000 km/s of the QSO due to proximity effects and the possibility that the absorber may be associated with the QSO itself. However, it has been argued that, at least in some cases, proximate DLAs (PDLAs) are likely to be the same beast as intervening absorbers, based on their typical metallicities and lack of high ionization lines. If correct, we can use PDLAs as a probe of galaxies that are clustered around QSOs at high redshift. By calculating the $n(z)$ for PDLAs in the radio-loud quasar CORALS sample, Ellison et al. (2002) found four times as many systems in CORALS I than in the radio-quiet sample of Peroux et al (2001). Although this result is only significant at the 2σ level, it supports the suggestion that galaxies cluster preferentially near radio-loud QSOs.

A second spin-off to have been born of CORALS is the study of multiple DLAs (MDLAs). Lopez & Ellison (2003) define an MDLA as two or more absorbers with log N(HI) > 20.0 with velocity separations $500 < \Delta v < 10000$ km/s. One of the DLAs discovered during the CORALS I campaign, Q2314-409, conforms to this definition and was the first to be studied at high resolution (Ellison & Lopez 2001). The abundances determined from a UVES spectrum show a propensity towards low α/Fe (where α elements include such metals as Ca, Si, S and O) for MDLAs compared with single absorbers, a result more recently backed up by Lopez & Ellison (2003), see Figure 3. Having ruled out systematic effects such as ionisation or atypically low dust depletion, we have suggested that this abundance pattern could be due to low star formation efficiencies, possibly linked with environment (assuming that MDLAs are not just chance alignments, as indicated by the low statistical probability of such an event). To confirm this hypothesis will require a larger abundance study of MDLAs, as well as imaging campaigns to determine whether galaxy excesses exist in these fields.

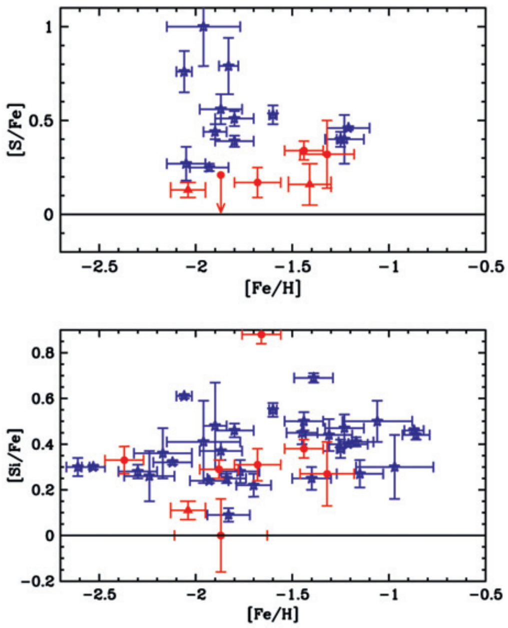


Figure 3: α/Fe ratios for MDLAs (solid red circles), DLAs in fields with known galaxy neighbours (solid red triangles) and single DLAs taken from the literature (open blue stars). DLAs with nearby galaxies both in the field, and seen in absorption (MDLAs) have systematically lower α/Fe, a trend particularly obvious in the [S/Fe] ratio. See Lopez & Ellison (2003) for further discussion.

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IC 5063: AGN DRIVEN OUTFLOW OF WARM AND COLD GAS

THE SOUTHERN SEYFERT GALAXY IC 5063 WAS THE FIRST AGN WHERE A FAST OUTFLOW OF NEUTRAL HYDROGEN WAS DETECTED. HERE WE PRESENT NEW OPTICAL SPECTRA THAT WERE TAKEN WITH THE ESO-NTT TO COMPARE THE KINEMATICS OF THE IONISED GAS WITH THAT OF THE NEUTRAL HYDROGEN COMPONENT IN ORDER TO STUDY THE MECHANISM THAT COULD DRIVE THIS OUTFLOW. THE DATA REVEAL EXTREMELY COMPLEX GAS KINEMATICS, INCLUDING THE PRESENCE OF AN OUTFLOW OF IONISED GAS (WITH SPEEDS OF SEVERAL HUNDRED KM/S) AT THE LOCATION OF THE BRIGHTER RADIO LOBE. THIS OUTFLOW IS STRIKINGLY SIMILAR TO THAT OF THE HI. WE CONSIDER THE INTERACTION BETWEEN THE RADIO JET AND THE ISM TO BE THE MOST LIKELY MECHANISM FOR THE EXTREME KINEMATICS AND A POSSIBLE SCENARIO IS DESCRIBED.

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HUGE AMOUNTS OF ENERGY are produced through the accretion of material onto the super-massive black hole situated in the centre of an Active Galactic Nucleus (AGN). This energy is released into the surrounding medium in a number of different ways, ranging from collimated radio-plasma jets to UV and X-ray emission. The regions around the AGN are, therefore, highly complex and host a wealth of physical processes. Gas in different phases (atomic, molecular and ionised) is observed in this very hostile environment and the highly energetic processes related to the presence of the AGN are likely to have a *profound influence on the physical and kinematical properties of this gas*. Thus, the study of the gas provides ideal diagnostics to trace the relative importance of the various processes and the effect that the AGN has on the surrounding medium.

The energy released from the nucleus can produce gas outflows at very high velocities (thousands of km/s) as seen in many AGN, ranging from Seyfert galaxies to quasars. Gas outflows are detected as blueshifted absorption or emission line wings in optical, UV and X-ray spectra, (see e.g. Crenshaw 2001 and refs therein).

A number of mechanisms can be considered for the origin of such outflows. In radio-loud objects, they could be driven by the interaction of the radio plasma with the (rich) gaseous medium in the direct vicinity of the active nucleus. This effect is, for example, particularly evident in young radio sources where the newly born radio jet is making its way out of the galaxy. In high-*z* radio galaxies, such jet-cloud interactions are believed to be a mechanism for triggering star formation and indirectly explaining, e.g., the alignment between the rest frame optical continuum and their associated radio sources (van Breugel 2000).

However, a complication is that fast gas outflows have also been found in radio quiet AGNs. This has led some investigators to suggest that other mechanisms are at work and that some of these outflows are more likely driven by radiation- or wind pressure from the regions near the active super-massive black hole (i.e. a quasar wind).

A very interesting and surprising aspect of these outflows is that, despite the high energies involved, they are not only seen in ionised gas but also in *neutral* gas. A few examples of this phenomenon are now known. The first case where such a fast outflow of neutral gas was detected is the Seyfert galaxy IC 5063. Using the Australia Telescope Compact Array, we detected HI absorption up to 700 km/s blueshifted with respect to the nucleus in this galaxy, indicating an outflow of neutral hydrogen with at least these velocities (see below). More recently, using the Westerbork Synthesis Radio Telescope, we have found even faster outflows of HI (up to 2000 km/s) in the radio galaxies 3C293 and 4C12.50. These observations raise the interesting question of which mechanism can drive these fast neutral outflows. Large amounts of energy are needed to push the gas out at these high velocities, but despite these high energies, some fraction of the outflowing gas remains, or becomes, neutral.

The study of the ionised gas can provide a key complement to the neutral hydrogen and help in solving this puzzle. For this reason we have made a detailed optical follow-up study of the Seyfert galaxy IC 5063 using EMMI on the NTT. In general, Seyfert galaxies are particularly interesting objects for investigating the effects described above. They have strong emission lines coming from the ionised gas. Their narrow-line regions (NLRs, regions of highly ionised gas immediately surrounding the active nucleus) can be extremely complicated kine-

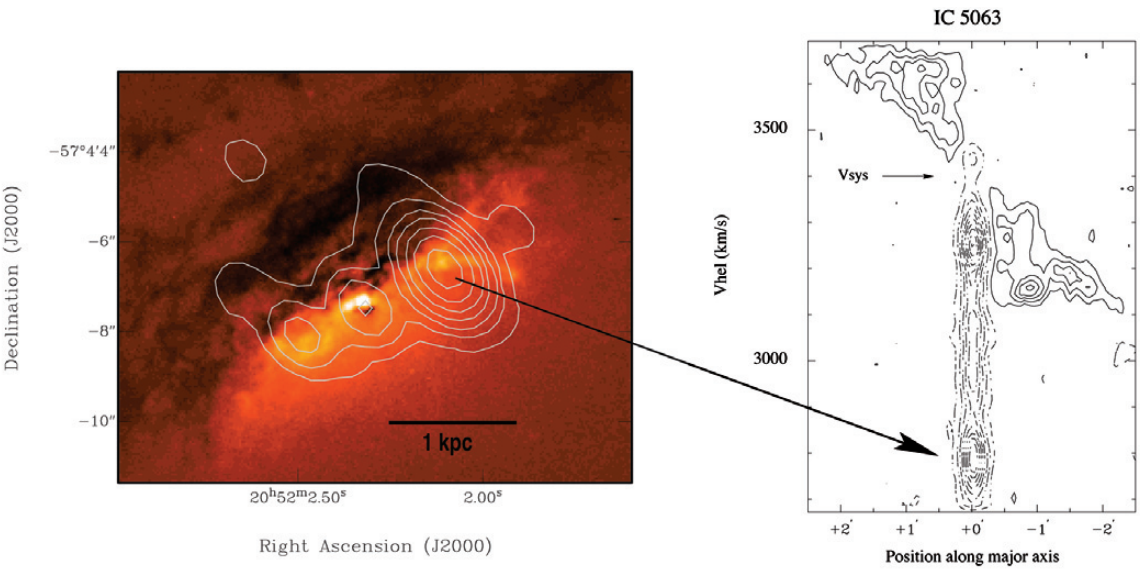

Figure 1: *HST image with superimposed the radio continuum (from ATCA at 8 GHz). The radio shows three components, of which the middle one is the core. On the right is the position-velocity diagram of the HI showing the broad, blueshifted absorption (dashed). The location in the continuum image where the broad HI absorption occurs is indicated.*

matically. Some of them are believed to represent the best examples of regions where interactions between the local interstellar medium (ISM) and radio plasma occur (Wilson 1997, Capetti et al. 1999). However, recent results based on HST observations (e.g. NGC 4151 and NGC 1068) have indicated that instead quasar winds may play a major role. They therefore represent ideal objects to study the importance of the impact of the AGN on its surrounding ISM. IC 5063 is, given its proximity and its characteristics, a perfect candidate for such a study. Apart from being an interesting case by itself, the results from this galaxy can shed light on what is going on in AGNs that are more distant, i.e. objects that cannot be studied in the same detail, such as radio galaxies and quasars.

The intriguing Seyfert galaxy IC 5063

The southern Seyfert galaxy IC 5063 (z = 0.0110) is classified as a Seyfert 2. According to the unified schemes for AGNs, this means that the broad-line regions (lines coming from ionised gas in close proximity to the AGN) are obscured from our direct view by the nuclear torus, but that it can be seen indirectly in scattered/polarized light. Strong and broad polarized Hα emission has indeed been observed in IC 5063.

IC 5063 is an early-type galaxy – not very common among Seyfert galaxies – that shows a complicated system of dust lanes. This is clearly seen from the HST image in Figure 1. The extended (about 15 kpc in radius) ionised gas has a very peculiar X-shaped morphology shown in Figure 2. This gas is ionised by photons from the AGN and the interesting shape is probably due to the obscuration of the AGN by the large-scale warped gas disc that is visible as the system of dust lanes.

The most intriguing characteristic of this object is seen in the radio (see Morganti et al. 1998 and Oosterloo et al. 2000 for details). IC 5063 is among the most radio-loud Seyfert galaxies known. In the radio continuum, it shows triple structure (Figure 1) of about 4 arcsec in size (about 1.3 kpc). Two very asymmetric lobes are situated at each side of the radio core. Despite being an early-type, the host galaxy is very rich in neutral hydrogen (almost 10^{10} $M_{\odot}$). A large, regularly rotating HI disc (of about 30 kpc in radius) is observed (Figure 2). Because of the strong radio continuum source, we were able to detect HI gas in absorption at very low optical depth. This absorption is indicated by the dashed contours in Figure 1, while the solid contours indicate the emission from the large HI disc. The absorption is highly blueshifted with respect to the centre of the galaxy. The systemic velocity can be accurately derived from the HI emission, and the absorption is unambiguously blueshifted. Follow-up VLBI observations showed that the broad blueshifted absorption occurs against the western and brighter radio lobe and not against the core (Oosterloo et al. 2000).

The obvious question is: what mechanism can produce such a fast outflow of gas, allowing it to remain, or become again, (partly) neutral? As mentioned above to better understand what is going on, the radio study needs to be complemented by a detailed study of the ionised gas. In particular, the kinematics and the ionisation level of the gas can shed light on whether a strong jet/cloud interaction is responsible for the outflow, or whether other processes must be invoked. This was the goal of our NTT observations.

The complex optical spectrum

IC 5063 was observed (in service mode) with EMMI on the NTT in the medium resolution spectral mode. The 0.8 arcsec-

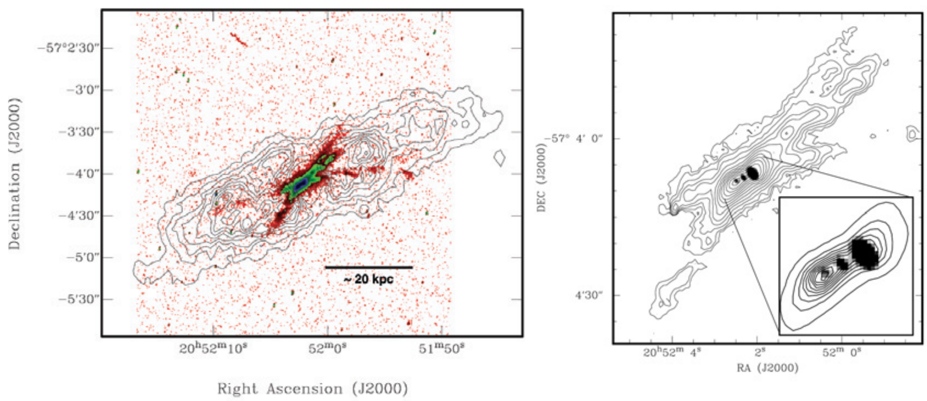

Figure 2: *Left: the HI disk (contours) superimposed onto the image of the ionised gas ([OIII] 5007Å). Right: ionised gas (contours) superimposed onto the radio continuum (grey scale). In the central regions, there is an evident correspondence between the two.*

wide slit was positioned along the radio axis. Spectra were taken in the blue and the red arm simultaneously. Gratings 12 and 7 were used, giving a spectral resolution of 0.92 and 0.66 Å/pix in the blue and in the red respectively. Therefore, we cover the wavelength range from [OII] 3727Å to [SII].

The spectrum shows a wealth of information with many emission lines, up to very high ionisation – in particular high ionisation Fe lines (as found by Colina et al. 1991). Most of the lines are spatially extended and because of the sub-arcsecond seeing of the observations, we can clearly separate the ionised gas at the location of the radio core from the location of the lobes, as illustrated in Figure 3. This is crucial for the success of the study. In fact, it allows us to investigate how the kinematics of the ionised gas relates with the radio structure. The extremely complex kinematics can clearly be seen in Figure 3. Different components are evident, with emission both from the disturbed gas as well as from the quieter and regularly rotating gas (i.e. the gas that follows the galaxy rotation as shown by the large scale HI emission). The region of highly disturbed kinematics extends almost 6 arcsec (almost 2 kpc), mostly in coincidence with the region where the radio emission is also present. Indeed, Figure 3 already shows an important result of this study, namely that the most extreme kinematics are detected *in the region between* the radio core and the bright radio lobe, and that, as for the neutral gas, a large blueshifted wing is clearly present near the western radio lobe. The *first order* similarity between the kinematics of the blueshifted wing of ionised gas and that of the HI is illustrated in Figure 4, where a direct comparison of the two can be made.

One interesting point to note is that the most extreme blueshifted velocities are displaced compared to the peak of the radio lobe and they appear to be located closer to the nucleus. The velocities become progressively less blueshifted as one approaches the peak of the radio lobe, producing a sort of "comma"-like shape. This can naively be interpreted as an indication of a decelerated flow: the flow gets slower as it approaches the position of the radio lobe where perhaps some "obstructing" material is present. This is, in fact, consistent with the detection of molecular gas (H_2) from NICMOS observations (Kulkarni et al. 1998) in the western region near the radio lobe.

In addition to the blueshifted wing, a very broad component is observed only in the region between the core and the western (stronger) radio lobe. This very broad component of ionised gas, however, does not appear to have a counterpart in the neutral gas. This may represent a component of highly shocked gas that is only seen as ionised.

Taken all together, these properties clearly indicate that the interaction between the radio plasma with the ISM is responsible for the extreme kinematics observed both in the ionised and in the neutral gas.

Apart from the complex kinematics detected in the western region, the ionised gas in the eastern side also shows complex kinematics, in particular line splitting. Interestingly, this seems to extend *beyond* the radio emission (see below). It is clear that the gas kinematics on the two sides of the radio core are completely different, possibly reflecting some major differences in the properties of the ISM and/or that there are two different mechanisms acting.

Although it is obvious from Figure 3 that the kinematics are very complex, a quantitative analysis is required to fully identify the various kinematical components and to study their characteristics. As a starting point, we have used the strong [OIII] 4959, 5007Å doublet. A good description of each line typically requires between two and four Gaussian components. The same components were used to fit other emission lines (e.g. Hβ, [SII], Hα+[NII]) where only the relative amplitudes of the various components were allowed to change. These restricted fits gave good results in almost all cases.

Using the components found from the Gaussian fits, one can study the ionisation of the gas by, for example, looking at the ratio (for each component) of the [OIII] 5007Å and the Hβ emission lines. Although the extreme kinematics near the western lobe appear to be due to a jet/cloud interaction, that does not necessarily mean that all the gas is ionised through this mechanism. The ratio [OIII]/Hβ is found to be very high (> 10) for the narrow components close to the centre (up to a few hundred parsec from the nucleus). This component, being narrow, is likely not to be influenced at all by the interaction with the radio plasma and therefore the high ionisation is likely to be due to the UV radiation from the nucleus. In the remaining regions/components, the [OIII]/Hβ ratio is between 5 and 10, without any clear difference between the regions with extreme kinematics or the broad components. This suggests that the shocks, produced in the interaction between the radio plasma and the ISM, are not the dominant ionisation mechanism (even in the NW region).

This confirms what was derived from the energy budget argument (Morganti et al. 1998) and also what has been found from similar studies of radio galaxies, e.g. Cygnus A.

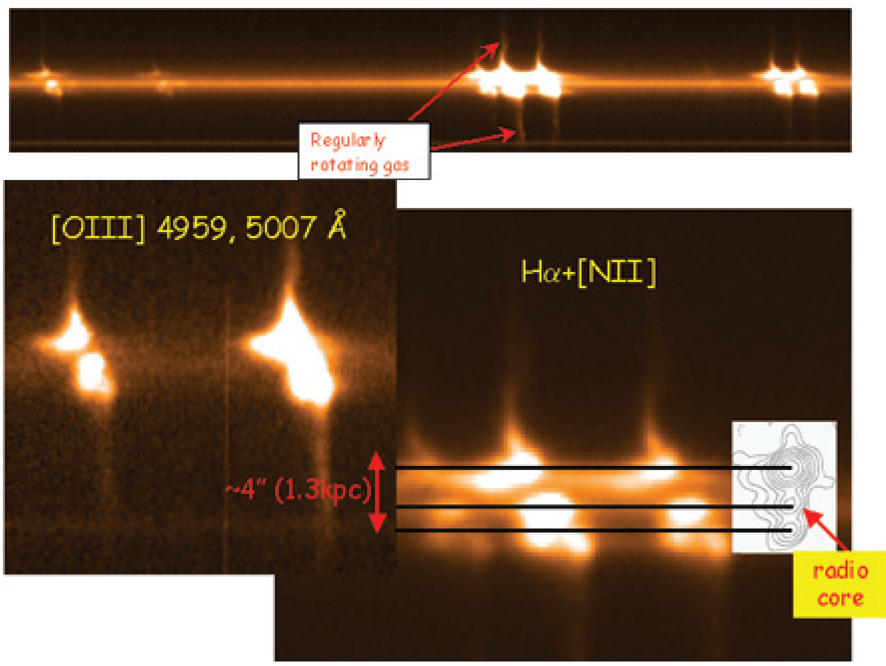

Figure 3: *(Top) The spectral region from [OI] 6300Å to [SII], including the Hα+[NII] lines. With the contrast used, the different intensity of the lines allows to see different features: from the regular galaxy rotation at larger distance from the centre to the complex kinematics clearly seen especially from the [OI] lines. (Bottom) A zoom-in of the [OIII] lines. The radio image on similar scale is also shown. This allows a direct comparison between the structures observed in the radio and the kinematics of the ionised gas.*

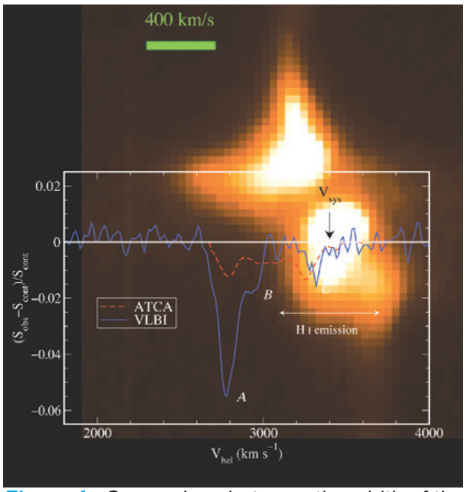

Figure 4: Comparison between the width of the HI absorption (white profile) and that of the ionised gas (from the [OIII]5007Å). The first order similarity between the amplitude of the blueshifted component is clearly seen.

Finally, the density can be measured using the ratio of the [SII] 6717/6731Å lines. The narrow component traces a decrease in the density going from almost 1000 particles cm^{-3} close to the nucleus to the low-density limit (<100 particles cm^{-3}) in the outer regions. Part of the reason for the decline of the [OIII]5007Å /Hβ can be the result of this density decrease.

A possible scenario

The kinematics of the ionised gas and the similarities compared to that of the neutral hydrogen, support the idea that we are observing a gas outflow in the region of the stronger radio lobe due to interaction between the radio jet and the ISM. This situation is conceivable because in IC 5063, the radio jet appears to be expanding in the galactic disc, therefore moving through a rich medium, as evidenced e.g. by the large-scale HI disc seen in emission, as well as by the presence of molecular gas from NICMOS observations (Kulkarni et al. 1998) detected in the western region near the radio lobe.

However, the question remains: *why, in such a hostile environment, is some fraction of the gas neutral?*

A possible scenario, illustrated in Figure 5, is that the radio plasma jet is interacting strongly with a molecular cloud in the ISM. Part of the gas is kinematically disturbed by the shock that is produced by the interaction. Once the shock has passed, some fraction of this gas may have the chance to recombine and become neutral, showing up as neutral gas at high velocities. To understand whether such a scenario is feasible, it is worth considering the model proposed for the evolution of clouds in radio galaxy cocoons when they are overtaken by a strong shockwave (Mellema, Kurk & Röttgering 2002). This model predicts that, as the shock runs over a cloud, a compression phase starts (as the cloud gets embedded in an overpressured cocoon) and the shock waves start travelling *into* the cloud and the cloud fragments. By taking cooling into account, they derived that the excess of energy is radiated away on a time scale much shorter (a few hundred years) than the typical lifetime of a radio source (10^{6-7} yr). This process results in the formation of *dense, cool and fragmented structures at high velocities*. These clouds can contain neutral gas that can be seen in absorption, if located in front of the radio source. Whatever the details of the processes involved, the observations of IC 5063 show that neutral and ionised gas outflows co-exist and that the interaction between the radio plasma and the ISM is likely to produce both. This puts strong constraints on the physical processes in the centre of this galaxy.

What is the situation on the other side (i.e. the *SE* side) of the nucleus? Apart from the emission associated with the regularly rotating large-scale gas disc, a second component is seen, blueshifted compared to the quiescent gas and extending *beyond* the radio emission. It is hard to explain this component only by a jet-cloud interaction and the line split is perhaps more reminiscent of an expanding cocoon. It is worth noting that in other Seyfert galaxies radiation pressure from the nuclear emission has been proposed as the dominant acceleration mechanism. In addition to this, the clear asymmetry between the two sides of the radio source suggests that the conditions of the medium around the AGN are actually very inhomogeneous. This is likely to strongly affect the evolution of the radio plasma and its effect on the environment.

The detailed study of the nearby Seyfert IC5063 has a number of implications for other objects that cannot be studied with the same detail as IC 5063. In particular, we are now also finding broad blueshifted HI absorption in more distant *powerful radio galaxies* (the best examples so far are 3C293 and 4C12.50, Morganti et al. 2003). Moreover, in the high redshift universe, radio galaxies appear to live in very gas rich environments. Strong interaction between the radio plasma and this medium is likely to be even more common. What we learn from the study of nearby objects can therefore be of great help in interpreting what happens in their faraway cousins.

Acknowledgments

JH acknowledges a PPARC PhD studentship and a NOVA-Marie Curie Fellowship. She also wishes to thank the Kapteyn Institute, Groningen, for its hospitality where most of this work was done.

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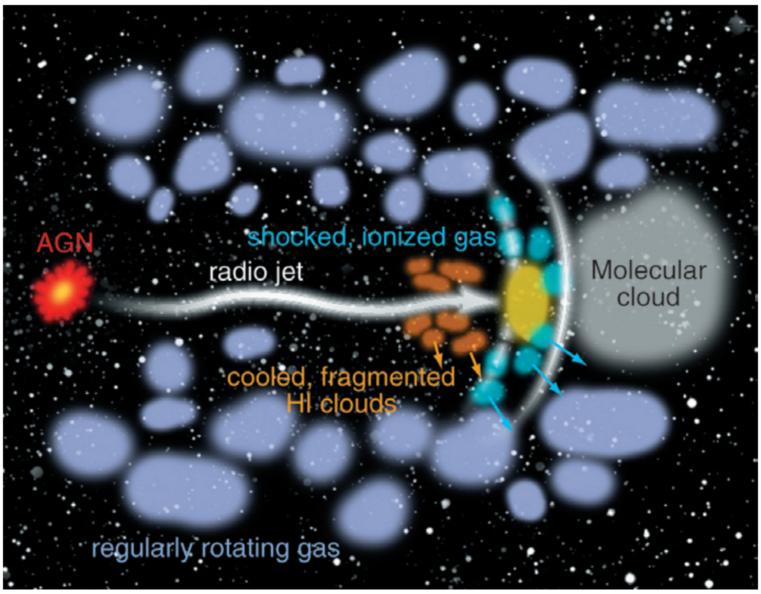

Figure 5: A schematic diagram illustrating the proposed scenario (as described in the text) and a possible geometric arrangement of the various emitting components in IC 5063.

ESO AT THE IAU GENERAL ASSEMBLY

THE 25TH GENERAL ASSEMBLY OF THE International Astronomical Union was held in Sydney, Australia, from 13-24 July 2003. For two weeks the world of professional astronomy descended on Darling Harbour. In the early days it was used for receiving fresh produce and timber from Parramatta and the north coast, but with time had become a somewhat derelict dock area. Following massive redevelopment of the old wharves in the course of the 1980s, it now constitutes a spectacular example of contemporary urban renovation, with shopping malls, hotels, restaurants, museums and other leisure facilities, as well as the magnificent Sydney Convention and Exhibition Centre (SCEC).

With more than 2000 participants, six symposia, three invited discourses, 21 joint discussions, four special sessions and numerous working group, division and commission meetings, participating IAU members seemed to agree that the meeting was highly successful. But also the public was well looked after, with a large public astronomy exhibition with an 'industry day' and a 'school day' as well as numerous public lectures and activities organised by Sydney's community of amateur astronomers as part of the Australian Festival of Astronomy, in itself a month-long activity.

The exhibition was organised in Hall 5 of the SCEC. As at the previous IAU General Assemblies, ESO was represented with an information stand. Not surprisingly, the main features were the ALMA and OWL projects, but other ESO activities were shown as well. A model of the OWL telescope drew the attention of many visitors, with comments revealing almost all aspects of human reactions, from awe to excitement and enthusiasm. The enthusiasm was not confined to the professional audience. Thus the weekend edition of the *Australian*, one of the main broadsheet newspapers, featured a full-page article about OWL and ELTs. The ESO stand also served as backdrop for several TV interviews and, as has become tradition, also functioned as meeting point both for ESO astronomers and for many visitors.

On separate stands, projects with ESO participation were shown: the ALMA project, the stand of which was situated vis-à-vis the ESO stand, and the Astrophysical Virtual Observatory. ESO staff took turns at all three stands, talking to astronomers, amateurs and to media representatives.

Through the many talks given by ESO astronomers, articles in the *Magellanic Times* (the conference newspaper), press releases and the information stands, ESO maintained a high visibility, as justified by the exciting programmes and activities that keep this organisation busy during these years.

CLAUS MADSEN

Esteban Illanes from ESO Chile explaining the ALMA project during the school day.

ESO Director General appointed President-Elect of the International Astronomical Union

Dr. Catherine Cesarsky, the new President-Elect of the IAU, and Prof. Ron Ekers, the new President, in front of the ESO stand at the General Assembly of the International Astronomical Union in Sydney.

The General Assembly of the International Astronomical Union (IAU), meeting in Sydney (Australia) in July, has appointed the ESO Director General, Dr. Catherine Cesarsky, as President-Elect for the three-year period 2003-2006. The IAU is the world's foremost organisation for astronomy, uniting almost 9000 professional scientists on all continents.

The IAU General Assembly also elected Prof. Ron Ekers (Australia) as President (2003 - 2006). Dr. Cesarsky will become President of the IAU in 2006, when the General Assembly next meets in Prague (The Czech Republic). Dr. Cesarsky is the first woman scientist to receive this high distinction.

"*The election of Catherine Cesarsky as President-Elect of the IAU is an important recognition for a scientist who has made impressive contributions to various areas of modern astrophysics, from cosmic rays to the interstellar medium and cosmology*", commented the outgoing IAU President, Prof. Franco Pacini. "*It is also an honour and an important accolade for the European astronomical community in general and ESO in particular*."

(see ESO Press Release 21/03 for more information)

Philippe Busquin Visits Paranal

European Commissioner for Research at the ESO Very Large Telescope

The European Commissioner for Research, Mr. Philippe Busquin, who was visiting the Republic of Chile, arrived at the ESO Paranal Observatory on July 29, 2003.

The Commissioner was accompanied, among others, by the EU Ambassador to Chile, Mr. Wolfgang Plasa, and Ms. Christina Lazo, Executive Director of the Chilean Science and Technology Agency (CONICYT).

The distinguished visitors were able to acquaint themselves with one of the foremost European research facilities, the ESO Very Large Telescope (VLT), during an overnight stay at this remote site. Arriving after the long flight from Europe in Antofagasta, capital of the II Chilean region, the Commissioner continued along the desert road to Paranal, some 130 km south of Antofasta and site of the world's largest and most efficient optical/infrared astronomical telescope facility.

The guests were welcomed by the ESO Director General, Dr. Catherine Cesarsky, and the ESO Representative in Chile, Mr. Daniel Hofstadt, as well as ESO staff members.

The visitors were shown the various high-tech installations at the observatory, including many of the large, front-line VLT astronomical instruments that have been built in collaboration between ESO and European research institutes. Explanations were given by ESO astronomers and engineers and the Commissioner gained a good impression of the wide range of exciting research programmes that are carried out with the VLT.

Having enjoyed the spectacular sunset over the Pacific Ocean from the KUEYEN telescope, one of the four 8.2 m telescopes that form the VLT array, the Commissioner visited the VLT Control Room from where the four 8.2 m Unit Telescopes and the VLT Interferometer (VLTI) are operated. Here, the Commissioner was invited to follow an observing sequence at the console of the KUEYEN telescope.

“*This is a tribute to the human genius*”, commented the Commissioner. “ *It is an extraordinary contribution to the development of knowledge, and as Commissioner for Research, I am proud that this is a European achievement.*”

“*It is a great pleasure to receive Commissioner Busquin, whose actions towards European research we admire, and to share with him the excitement about the wonders of the Universe and the advanced technology that allows us to probe them*”, said the Director General of ESO.

ESO Press Release 22/03

ESO astronomers demonstrate an observation sequence to Commissioner Busquin.

The Commissioner visits the VLT Interferometric Laboratory with the VINCI instrument.

Fellows at ESO

Malvina Billeres

When I had my interview for an ESO fellowship in Chile, the committee asked me where I would like to work: Paranal or La Silla. I have to confess that I had never been to either of the ESO observatories before, and I thought that my tiny amount of experience wouldn't be enough to work at Paranal, so I answered la Silla.

After two and a half years of the la Silla routine, I know that my argument was completely wrong! The fellows at la Silla do exactly the same job as the staff, with a lot of responsibilities, freedom and interesting challenges.

I think that the most exciting thing at la Silla is that I can touch everything: be part of the difficult task of opening SOFI, pilot the New Technology Telescope with its active optics, do a turn as a Telescope and Instrument Operator (TiO), make tests with the instruments to do my science etc... With all these possibilities, I feel really lucky to be at la Silla!

Before coming to Chile, I spent almost 6 years in Montreal (Canada) where I did part of my thesis. I had the chance to work in a really good team at the University de Montreal, on pulsating stars: white dwarfs and mainly subdwarf B stars. During my thesis, I did a lot of fast photometry observations with the Montreal 3-channel portable photometer, LAPOUNE. I went to the CFHT several times, and spent weeks at the Mount Bigelow station in Arizona (amazing to see that observatories are always localized at such beautiful places).

Today, although my science is still centred on the study of variable evolved stars (EC14026 and ZZ Ceti), I have broadened my scientific interests: the search for LPsdBV (a new class of pulsating sdB discovered last year) in the southern skies, the search for luminosity variations in young brown dwarfs, determining the influence of magnetic cycles on measured radial-velocity with HARPS. ESO is a perfect place to start new projects thanks to the interaction with all the visiting astronomers.

In addition, the mountains in Chile are almost as beautiful as the mountains in the French alps where I came from.

VALENTIN D. IVANOV

I STARTED WORKING for ESO in April 2001, after spending seven years in the US where I got my PhD. This was a new beginning as the ESO fellowships are different than most other academic positions. Besides the research, we are engaged in duties, and mine are with the Paranal Science Operations. It is a challenge and a blessing. The work requires attention, quick understanding of problems in a broad range of astronomy topics, good knowledge of the instrumentation and observing techniques, interaction with visitors in various situations. But the work also gives back a lot - the very same things, and they do enrich the great experience of being an astronomer.

When people ask me what I do, I answer - I am a craftsman and a general purpose infrared astronomer. After spending the last two years and a half at ESO, it is even more so. Still, my science interest is concentrated mostly on: (i) Stellar populations in star burst and active galaxies. Since these object often boast 10 or more magnitudes of visual extinction, I have assembled a stellar library and a population model for the near-infrared. The absorption features in the H-band turned out to be an excellent metallicity indicator. (ii) I lead a collaboration to search for hidden globular and massive clusters in the Milky Way. We are currently engaged on detailed follow up observations from various telescopes around the world.

Ending on a more personal note: back in my home country, Bulgaria, I am more (in)famous as a science fiction writer. I have published some stories, and they have even brought me some literary awards.

CLAUDIO MELO

MY INTEREST IN Astronomy started at the end of my under-graduate years when I had to choose a topic for my masters degree. Among the options I had, Astronomy was by far the most exciting. After that, I went to Geneva where I had the privilege to do my Ph.D. thesis with Prof. Mayor on some aspects of pre-main sequence spectroscopic binaries such as, binary frequency, orbital evolution and angular momentum evolution. This long-term study (4 years) took me many times to the Swiss Telescope at La Silla Observatory where I (like Linda in the last Messenger) fell in love with the place, making my application to ESO quite a natural step after my Ph.D.

I started as an ESO Fellow in May 2002 with duties at Paranal Observatory. It has been an amazing experience to work on Paranal – having contact with the new instruments, talking to and assisting visitor astronomers, performing operations, etc. Of course, the real world is certainly more stressful than what you imagined in your dreams. In spite of this, I am glad to be able to find in Paranal that magic that I experienced in La Silla during my first run in the Swiss Telescope. Another key change in contrast to my thesis years where I spent most of my time working alone, it is the need for team work. Learning how to work as a team on Paranal with people from many different countries and backgrounds has been a hard, but doubtless, an enriching process that I'm glad to be undertaking.

From the scientific point of view I'm also very happy with the ESO fellowship since we still have plenty of time for our research. Currently, I'm still interested on the evolution of angular momentum in both young stars in the pre-main sequence phase and more evolved stars in clusters. In the same direction, myself together with a few collaborators in different places have been working on the connection between the angular momentum evolution and the light element abundances. I'm also participating in a common project along with the star-forming people in Vitacura (led by Michael Sterzik) aimed to understand how spectroscopic binaries form.

One thing that I missed during my years in Geneva and that I still do miss here in Santiago is the Sea. Being from a coastal city of Natal (Brazil) makes the Ocean not only a place where you go to have some beers or to get tanned, but also makes it your friend. I'm patiently waiting for the day I'll be able to spend more time at the sea again, either watching it or in my sailing boat (for the greatest happiness of my inner Popeye!).

CHRIS MULLIS

I HAD THE PLEASURE to join ESO Garching in September 2001 directly after completing my PhD at the University of Hawaii. This global shift meant distinct changes in scientific and living environments, but I have found both to be very stimulating and very enjoyable.

Galaxy clusters lie at the heart of my research interests. More specifically, I use X-ray selected groups and clusters of galaxies to study the distribution and evolution of large-scale structure in the universe. X-ray selection is currently the optimal procedure for building cluster samples with minimum bias and maximum statistical completeness. Working with colleagues in several fruitful collaborations, we have discovered hundreds of clusters largely based on ROSAT data, and we are following these up with dedicated observations with *XMM* and *Chandra*.

We probe different redshift, luminosity/mass, and spatial regimes using several independent surveys. For example, in an on-going observing campaign at La Silla and Mauna Kea, we are completing the first comprehensive X-ray survey for galaxy clusters behind the Milky Way (nearly 200 systems located so far of which ~75% are new discoveries). This sample is crucial for making an unbiased census of the mass distribution of material in the nearby universe. On a different front, we are using deep, multi-color VLT+VIMOS imaging for a sample of high-redshift, high-X-ray luminosity clusters ($z \sim 0.6$) to investigate the transformation of galaxies as they are accreted along filamentary conduits from the field to the cluster environment.

The exceptional quality of the science community at ESO and the supporting technical resources (hardware, software, and most importantly, people) is very beneficial to my research. Thus I'm very happy to contribute to the observatory's mission through my functional duties. During my first year at ESO, I had the opportunity to work in the Paranal Science Operations group. After spending many quiet nights observing at Keck with only the telescope operator's company, I was initially overwhelmed by the magnitude of the VLT operation.

However, I soon learned this large footprint is necessary to keep ESO's fantastic array of cutting-edge telescopes and instrumentation running smoothly and continuing to grow. The Paranal experience broadened my technical knowledge and continues to help maximize the effectiveness of my observing programs.

Now completing my second year at ESO, my functional duties are much closer to home (and to a much happier wife) with the Astrophysical Virtual Observatory group at Garching. I am developing a system that will allow astronomers to pursue innovative research made possible by efficiently leveraging the ESO Science Archive with processed X-ray data from the XMM and Chandra archives. In addition to these responsibilities, I have also served on various committees, organized weekly science discussions, and administered computers to our fellows and students.

With all the exciting work to be done, it's a supreme challenge to marshal free time. On the rare occasions that I succeed, my wife and I enjoy hiking and climbing in the Alps and exploring Europe.

First Advanced Chilean School on

"EXTRASOLAR PLANETS AND BROWN DWARFS"

Santiago, Chile, 15-19 December 2003

The Advanced School on "Extrasolar Planets and Brown Dwarfs" is organized by: Catolica/Princeton, European Southern Observatory, and FONDAP Center for Astrophysics.

Local and Scientific Organizing Committee members are:
Dante Minniti (Universidad Catolica)
Danielle Alloin (European Southern Observatory)
Maria Teresa Ruiz (Universidad de Chile)
Grzegorz Pietrzynski (Universidad de Concepcion)

Sponsors are:
ESO, UChile, PU/PUC, Fundacion Andes,
FONDAP, NRAO, and SOCHIAS.

The main lecturers will be:
France Allard (ENS Lyon)
Gillian Knapp (Princeton University)
Michel Mayor (Geneva Observatory)
Scott Tremaine (Princeton University)

The lectures will cover the following themes:
Models of brown dwarfs and giant planet atmospheres, predictions.
Observations of brown dwarfs, searches, classification, main properties.
Search for extrasolar planets, main discoveries, future prospects.
Theory of extrasolar planetary systems, formation, dynamical models.

In addition, a number of short invited talks are planned on the topic of the School, and participants are welcome to present posters.
The Advanced School lectures will be aimed at graduate students of Astronomy. Interested participants will find information on the School webpage, *http://www.astro.puc.cl/school* and should fill in an expression of interest form to be emailed back to *school@astro.puc.cl* before **September 30, 2003**. Financial aid is available upon request. A Second announcement will be sent shortly thereafter.

International Workshop jointly organized by
ESO/Chile, FONDAP-Chile
and Universidad de Chile

PHYSICS of ACTIVE GALACTIC NUCLEI at ALL SCALES

at ESO/Santiago Headquarters, Chile
December 3 to 6, 2003

Invited speakers: Omar Almaini (tbc), Roger Blandford (tbc), Niel Brandt, Bob Fosbury, Jack Gallimore, Shardha Jogee, Hagai Netzer, Brad Peterson
Organizing committee: Danielle Alloin (ESO), Poshak Gandhi (ESO), Rachel Johnson (ESO), Paulina Lira (UChile), Sebastian Lopez (UChile), Jose Maza (UChile)
Aim & scope: FONDAP-Chile, ESO-Chile and Universidad de Chile jointly announce an international workshop on the study of physical processes in AGN environments. One of the goals of the workshop is to train young researchers in the field.
International experts will review a wide range of topics and attendees are invited to present individual contributions. A wealth of new observational constraints on AGN are available thanks to recent key space missions and large ground-based telescopes. Therefore, it is exciting and timely to see how these fit in with model predictions and to explore the new perspectives they bring to the field. A general overview of all related issues, in the form of a tutorial, will introduce the workshop. Then, starting with the theory of BHs and accretion disks, the discussion will focus on the physics of the material in the vicinity of the central source and related radiative processes. Moving to larger scales, interactions with the surrounding stellar environment will be considered before concentrating on the inferred evolution of luminosity functions with redshift and AGN-galaxy formation scenarios. While the emphasis will be on providing a solid theoretical base, appropriate results from recent observations across the electromagnetic spectrum will be discussed.
Chile is a particularly apt venue for this workshop. Its current and planned world-class observational facilities, with their increase in sensitivity (Magellan, Gemini, VLT) and high angular resolution (adaptive optics, VLTI, ALMA), are crucial for AGN research.

PERSONNEL MOVEMENTS

International Staff

(1 June 2003 - 31 August 2003)

ARRIVALS

EUROPE

ANWUNAH, Judith (GB), Associate
CASTRO, Sandra (BR), Astronomical Data Analysis Specialist
DOBRZYCKA, Danuta (PL), Astronomical Data Quality Control Scientist
DOBRZYCKI, Adam (PL), Data Interface Control Scientist
HEIN, Priya (GB/MS), Administrative Support/Assistant DG Secretariat
KORKIAKOSKI, Visa (SF), Student
McKAY, Derek (AUS) on 04.12.2002, Associate
MIGNANO, Arturo (I), Associate EIS
MUÑOZ, Samuel (RCH), Student
OLIVIER, Nathalie (F), Associate
PETR-GOTZENS, Monika (D), User Support Astronomer
WEIDINGER, Michael (DK), Student

CHILE

GALLIANO, Emmanuel (F), Fellow
HARTUNG, Markus (A), Fellow
HUMMEL, Christian (D), VLTI Astronomer
ROEHRLE, Claudia (D), Student
SAVIANE, Ivo (I), Staff Astronomer
VANNIER, Martin (F), Fellow

DEPARTURES

EUROPE

BOXHORN, Andreas (D), Associate
HOMEIER, Nicole (USA), Student
NORMAN, Colin (AUS), Associate
SIKKEMA, Geert (NL), Associate EIS
ZOCCALI, Manuela (I), Fellow

CHILE

ANDERSSON, Andreas (S), Associate SEST
BROOKS, Kate (AUS), Fellow
CABANAC, Rémi (F/CDN), Fellow
COUTURES, Christian (F), Associate Eros II
ELLISON, Sara (GB), Fellow
HAIKALA, Lauri (SF), Operations Staff Astronomer
LERNER, Mikael (S), Microwave Engineer
MAURY, Alain (F), Associate Eros II
NIELBOCK, Markus (D), Fellow
WILLIS, Jon (GB), Fellow

Local Staff

(1 June 2003 – 31 August 2003)

ARRIVALS

AGUILAR URREA, Luis, Safety Engineer
BENDEK SELMAN, Eduardo, Instrumentation Engineer
CARCAMO URIBE, Ruben, Maintenance Mechanical Technician
CARRASCO PEREZ, Oscar, Safety Engineer
CORREA GUTIERREZ, Alex, Data Handling Administrator
JIMENEZ ROJAS, Jorge, Instrumentation Maintenance Technician
MADRAZO ROSALES, Maria, Accounting Clerk
PEREZ BEAUPUITS, Juan Pablo, Electronic Engineer ALMA
ROA FIGUEROA, Mauricio, Software Engineer
SANHUEZA SLATER, Roberto, Data Handling Administrator
SICLARI BORDONES, Waldo, Maintenance Mechanical Technician

DEPARTURES

HERRERA MOLINOS, Gabriel, Maintenance Mechanical Technician
MCKINSTRY, Christopher, Telescope Instrument Operator
MORNHINWEG KROHMER, Manfred, Electronician
PEÑAFIEL BARRERA, Juan, Safety Engineer
VARAS CUBILLOS, Humberto, Safety Engineer

Applications are invited for a Staff Astronomer position at APEX (the Atacama Pathfinder EXperiment) located on Chajnantor near San Pedro de Atacama, Chile.

Staff Astronomer (CSO111)

CAREER PATH: V

Assignment: APEX is a sub-mm telescope presently being erected at the ALMA site of Chajnantor in Chile through a collaboration between the MPIfR, ESO and Sweden. The site is excellent for sub-mm observations, and the telescope will be equipped with bolometer arrays and heterodyne receivers for observations at sub-mm wavelengths as well as in the THz band. We seek two staff astronomers for APEX. They will join a team of scientists, engineers, and technicians, in total 20 people, responsible for the operation and maintenance of the antenna and its instrumentation. Astronomers will be part of the science operations group responsible to support observations, both in visitor mode and service mode, to develop calibration and quality control procedures for the instruments, to control the configuration of the system, and to develop operational procedures for the telescope including pointing models. The Science Operations team will consist of staff astronomers, fellows and telescope operators.
As an astronomer and member of the ESO Science Faculty, the successful candidate will be expected and encouraged to actively conduct astronomical research up to 50% of the time using APEX and other facilities. The APEX astronomers spend 105 nights per year carrying out functional duties in the APEX base in San Pedro de Atacama and at the telescope, which is located on Chajnantor at an altitude of 5000 m, usually in a shift of 8 days in San Pedro with trips to Chajnantor, followed by 6 days off. The rest of their time is spent in the Santiago office. Scientific trips and stays at other institutions, also in Europe are foreseen.

Education: Ph.D. in Astronomy, Physics or equivalent
Experience and knowledge: APEX is seeking active staff astronomers with a solid publication record in observational astronomy. Observational experience with (sub)mm telescopes will be an asset. At least three years of post-doctoral experience as well as excellent communication skills and a good command of the English language (spoken and written) will be required.
Duty station: San Pedro de Atacama, La Silla and Santiago, Chile
Starting date: As soon as possible
Contract: The initial contract is for a period of three years with the possibility of a fixed-term extension. Promotions will be based on scientific as well as functional achievements. It is necessary to take a high altitude medical examination before taking up the post.
Remuneration: We offer an attractive remuneration package including a competitive salary (tax-free) and comprehensive social benefits. Furthermore, an expatriation allowance as well as some other allowances may be added. Either the title or the grade may be subject to change according to education and the number of years of experience.

Applications consisting of your CV (in English language) and the ESO Application Form (to be obtained from the ESO Home Page at *http://www.eso.org/*) and four letters of reference should be submitted by **15 October 2003**.
For further information, please consult the ESO Home Page or contact Mrs. Nathalie Kastelyn

ESO Fellowship Programme 2003/2004

THE EUROPEAN SOUTHERN OBSERVATORY AWARDS SEVERAL POSTDOCTORAL FELLOWSHIPS to provide young scientists opportunities and facilities to enhance their research programmes. Its goal is to bring them into close contact with the instruments, activities, and people at one of the world's foremost observatories. For more information about ESO's astronomical research activities please consult *http://www.eso.org/science/*
Fellows have ample opportunities for scientific collaborations, a list of the ESO staff and fellows, and their research interest can be found at *http://www.eso.org/science/sci-pers.html* and *http://www.sc.eso.org/santiago/science/person.html*. The ESO Headquarters in Munich, Germany host the Space Telescope European Coordinating Facility and are situated in the immediate neighbourhood of the Max-Planck-Institutes for Astrophysics and for Extraterrestrial Physics and are only a few kilometres away from the Observatory of the Ludwig-Maximilian University. In Chile, fellows have the opportunity to collaborate with the rapidly expanding Chilean astronomical community in a growing partnership between ESO and the host country's academic community.

In Garching, fellows spend beside their personal research up to 25% of their time on support or development activities of their choice in the area of e.g. instrumentation, user support, archive, VLTI, ALMA, public relations or science operations at the Paranal Observatory. Fellowships in Garching start with an initial contract of one year followed by a two-year extension.

In Chile, the fellowships are granted for one year initially with an extension of three additional years. During the first three years, the fellows are assigned to either the Paranal or La Silla operations groups. They support the astronomers in charge of operational tasks at a level of 50% of their time (split into 80 nights per year up on the mountain and 35 days per year at the Santiago Office). During the fourth year there is no functional work and several options are provided. The fellow may be hosted by a Chilean institution and will thus be eligible to apply for Chilean observing time on all telescopes in Chile. The other options are to spend the fourth year either at ESO's Astronomy Centres in Santiago, Chile, or the ESO Headquarters in Garching, or any institute of astronomy/astrophysics in an ESO member state.

Starting in 2004 three APEX Fellow positions are becoming available within the ESO Fellowship programme in Chile. Applications for these positions are especially encouraged.

We offer an attractive remuneration package including a competitive salary (tax-free), comprehensive social benefits, and provide financial support in relocating families. Furthermore, an expatriation allowance as well as some other allowances may be added. The Outline of the Terms of Service for Fellows at *http://www.eso.org/gen-fac*/adm/pers/fellows.html provides some more details on employment conditions/benefits.
Candidates will be notified of the results of the selection process in December 2003/January 2004. Fellowships begin between April and October of the year in which they are awarded. Selected fellows can join ESO only after having completed their doctorate.

The closing date for applications is October 15, 2003.
Information on how to apply can be found at *http://www.eso.org/gen-fac/adm/pers/vacant/fellows2003-4.html*

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 three sites in the Atacama desert region of Chile. The Very Large Telescope (VLT), is located on Paranal, a 2,600 m high mountain approximately 130 km south of Antofagasta. 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. The third site is the 5,000 m high Llano de Chajnantor, near San Pedro de Atacama. Here a new submillimetre telescope (APEX) is being completed, and a large submillimetre-wave array of 64 antennas (ALMA) is under development. 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. 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:

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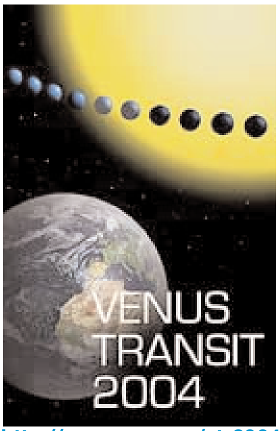
Venus Rendezvous with the Sun

An invitation to planetariums, public observatories, amateur astronomy associations, etc. to participate in a unique public educational programme



http://www.eso.org/vt-2004

On June 8, 2004, Venus passes in front of the Sun. This is a very rare event: the last one occurred in 1882! The founding members of the "**VT-2004 consortium**", the European Southern Observatory, the European Association for Astronomy Education, the Observatoire de Paris, and the Astronomical Institute of the Academy of Sciences of the Czech Republic, have decided to take advantage of this unique opportunity to launch an *ambitious educational programme aimed at stimulating and activating the broad public and introducing into Europe's schools the subject of the Venus 2004 transit* with its multiple historical, cultural, scientific and technological aspects. A provisional overview of the main goals and means of this programme is given at the VT-2004 website, now in the process of being set up.

We cordially invite your planetarium, public observatory or association to join this exceptional programme by becoming an institutional member of this international network! You may do so by sending an email to *vt-2004@eso.org*. Please state in this email which (kind of) activities (if any) you are planning in connection with the Venus Transit 2004.

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