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The Role of ESO in European Astronomy

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Abstract

The evolution of ESO is briefly traced through its technical and managerial developments to today. Highlights of ESO activities in support of astronomical research by the member state community are given to emphasise the unique role of the Organisation in European astronomy, and the effectiveness with which it has carried out its mission, including the development of VLT/VLTI. This development is shown to be of crucial significance to permit forefront research in the global context. The need for continued support of this programme to permit full scientific exploitation is discussed. A continued role of ESO to support the study and the development of future facilities is advocated.

1. Introduction

The purpose of this paper is to clarify the context in which we are discussing the scope of ESO activities over the next several years. This appears both appropriate and necessary since by its recent accomplishments ESO's role has evolved significantly.

I do not wish to discuss ESO history in detail but I would like to distinguish (for the purpose of this paper) some different stages of its development.

1.1 The early years

The early years, 1962–1980, saw the development of the organisation and of its structure with the goal of establishing an observatory in the southern hemisphere. Particularly attractive was the possibility to study a region of

The Tarantula Nebula (30 Doradus) in the Large Magellanic Cloud as seen by SOFI, ESO's new 1–2.5 μm imager/spectrometer during its first test on the NTT telescope in December 1997 (see article on p. 9). The image is a colour composite of three ~ 5-min exposures made through narrow-band filters centred on the 2.166 μm Brγ hydrogen recombination; 1.644 μm [FeII] fine structure and 2.12 μm H_2 1-0 S(1) lines which have been coded blue, green and red respectively to reflect the ionisation state of the gas. Predominantly blue regions show where hydrogen is being photo-ionised by hot, massive, stars while red traces the sites of more recent and on-going star formation. The scale is 0.26″/pix. and the field is ~ 4.5′ × 4.5′ with N at the top and E to the left.

the sky not accessible to the major observatories in the north and containing the centre of our own galaxy and the Magellanic Clouds. The observatory did not compete directly with any member state facilities. The major technical accomplishment of this period was the construction of the 3.6-metre telescope, comparable in size to any of the generally available telescopes in the north and which achieved a performance equal to that of several telescopes in the world. More important in a sense was the development of an organisation with an identical structure to that of CERN for physics, which proved capable of constructing and operating substantial facilities.

1.2 The transition phase

A second phase (1980–1990) occurred with the design and construction of the New Technology Telescope (NTT). In this phase of its life ESO developed the technical capability which led to a new approach for telescope design. The actively controlled thin meniscus mirror was the prototype for the next generations of 8-metre telescopes such as the Very Large Telescope of ESO (VLT) and the American and Japanese 8-metre projects (GEMINI and SUBARU). Upon its completion, the NTT was the 4-metre telescope with the best optical performance in the world. It was fully competitive with any of the then existing telescopes, including Cerro Tololo, Kitt Peak, Palomar, AAT, CFHT, Calar Alto and WHT. Its observing capabilities when added to those of the 3.6-metre telescope made La Silla one of the major observatories in the world.

It should be noted that this major step was made possible, in part, by the strengthening of ESO resulting from the entrance of two new member states, Italy and Switzerland, in 1982.

ESO began in this period to carry out new functions in support of European astronomy. The development of MIDAS (a command language for scientific data analysis) was the only widely adopted European development of its kind. The creation of ECF (European Co-ordinating Facility) for the Hubble Space Telescope also gave ESO an additional responsibility for European astronomy. The major accomplishment of this period was, in addition to the completion of the NTT, the beginning of the VLT/VLTI project.

1.3 The current phase

A third phase is the current one (1990–2000). With the successful completion of VLT/VLTI, ESO's stature in the world scene changes from that of being one of the several European observing facilities of more or less comparable capabilities to (one of) the premier observatory(ies) in the world. **It is not just a Southern supplement to observatories by the member states in the north, but by far the most powerful observational capability available to European astronomers and the only one which permits them to compete in the world scene on a basis of parity in ground-based optical/IR astronomy.**

During this same period, ESO has undergone a major qualitative transformation. Its management structure, methodology and capabilities have greatly developed. Its engineering and contracting capabilities have been greatly strengthened. It has become an important focus of instrumentation and detector development for Europe. It has provided the European astronomical community with an institution capable of studying and elaborating future large-scale projects and to insure the participation of European astronomers in world-wide projects on a basis of parity with the USA and/or other countries.

1.4 The new role of ESO

The emergence of ESO as a European organisation capable to carry out in astronomy the role of leadership carried out by CERN in physics or by ESA in space science is a new development which is already widely recognised in the world.

VLT/VLTI is the only real competitor to Keck 1 + 2 (the twin ten metre telescopes in Hawaii).

The question which is implicit in many of the discussions about the future of ESO is whether this leading role in European astronomy should be continued in the future or whether the VLT/VLTI development should be considered a one-shot affair.

The Visiting Committee of ESO and its Science and Technology Committee have clearly taken the view that ESO should think about new missions well into the 2010–2020 time frame and have reaffirmed the ESO mission within the overall astronomical research programme of the member states. The mission of ESO is to "Provide facilities which will enable European astronomers to carry out outstanding science that can better be done in a global European context than nationally" (Report of the Visiting Committee and the Response of the Director General ESO/Cou-532 Conf.).

This view has been endorsed by Council and is in accordance with the Convention which assigns to ESO "projects that can only be accomplished through international co-operation".

In the last few years the VLT and VLTI projects and the development of the Paranal Observatory have been the clearest examples of what ESO as a unified force in European astronomy can do. These programmes are recognised to be beyond the capabilities of the individual national programmes in the member states.

It is clear that the need for large-ground based facilities in astronomy will continue to be present in the foreseeable future. Examples are the Large Millimetre Wave Array (LSA) and the new generation of Extremely Large Telescopes (single dishes > 50 m diameter or extended arrays with comparable or larger collecting areas). Access to such facilities in the future will be essential to maintain competitiveness of European astronomy in the global context and thus we foresee a continued role for ESO in providing this.

The issue therefore is not whether there is a need for ESO in the future but rather what is the proper balance in the community of member states between programmes carried out at the national level and programmes which require international co-operation. Of course each nation will make its own decisions in this matter.

From a scientific point of view this balance should be based on a **strategic scientific plan for European Astronomy** which unfortunately does not yet exist. Rather than adopting either consciously or by default the planning for astronomy carried out periodically in the United States by the National Academy of Sciences, the scientific committees of ESO (VC, STC, OPC and UC) in co-operation with the Executive have developed mid-term and long-range plans which take into account scientific developments world-wide and establish priorities for the Organisation.

I would like in this essay to underline the importance of ESO's major current projects for European astronomy and the unique role played by ESO in this context. Further I would like to highlight less obvious but equally important contributions which ESO has given and should continue to give to the development of astronomy in Europe. Finally, I would like to make clear the high effectiveness with which ESO is carrying out its tasks and the importance of its European character as an intergovernmental organisation in accomplishing them.

2. Highlights of ESO's Current Activities

2.1 VLT/VLTI

Although most European astronomers realise the great importance of the VLT/VLTI development to permit the study of the most interesting astrophysical problems of today on a competitive international basis, the true significance of the advent of the Paranal Observatory is often not fully appreciated.

The flourishing of astronomy in the last century has been mainly due to the development of physics which has enabled us to understand the physical processes occurring in the universe and of observational capabilities capable of studying fainter sources and finer details of their spectra. To a considerable extent only those astronomers who had access to the largest telescopes could carry out frontier science. Since the 19th century, the United States has had this advantage, with the Mt. Wilson and then the Mt. Palomar telescopes dominating cosmological research in the first part of the 20th century, and the 10-metre Keck telescope and the Hubble Space Telescope in the last decade.

The situation has remained largely the same until now. In the document "A strategy for ground-based optical and infrared astronomy" of the Commission on Physical Sciences, Mathematics and Applications of the NAS of the USA published in 1997, a Table is prominently shown which summarises the telescope areas available to US astronomers (Table 1). Upon completion of current plans (including GEMINI, LBT, Magellan, Keck 2 and the MMT upgrade) there will be available to US astronomers 110.3 m^2 in public observatories and 400.7 m^2 in private observatories. (The computation excludes telescopes of less than 2 metre aperture

TABLE 1.

	Public Observatories			**Independent Observatories**		
	Telescope	Aperture (m)	Area (m^2)	Telescope	Aperture (m)	Area (m^2)
	KPNO	4.0	12.6	Keck 1	10.0	78.5
	CTIO	4.0	12.6	Palomar	5.0	19.6
	0,4 × WIYN	3.5	9.6	MMT	4.5	15.9
	KPNO	2.1	3.5	ARC	3.5	9.6
	0,9 × IRTF	3.0	7.1	0,6 × WIYN	9.6	3.5
				Lick	3.0	7.1
				Texas	2.7	5.7
				Dupont	2.5	4.9
CURRENT				MDM	2.5	4.9
				WIRO	2.4	4.5
				Steward	2.3	4.2
				Hawaii	2.2	3.8
				Texas	2.1	3.5
	SUBTOTAL*	14.2	38.9		44.8	167.8
		24%	19%		76%	81%
	0.45 × Gemini N	0.45 × 8	50.3	0.9 × Keck2	10.0	78.5
	0.45 × Gemini S	0.45 × 8	50.3	0.5 × LBT	2×8.5	113.4
	1/3 × Keck 1	1/3 × 10	78.5	0.5 × HET	~ 8	35.2
				Magellan I	6.5	33.2
				Magellan II	6.5	33.2
PLANNED				MMT Upgrade	6.5	33.2
				SDSS	2.5	4.9
	SUBTOTAL*	10.5	71.4		42.8	248.7
		20%	22%		80%	78%
	TOTAL*	24.7	110.3		83.0	400.7
		23%	22%		77%	78%

*The actual telescope apertures or areas are listed, but these values are multiplied by the fractions of time allocated to US astronomers to calculate the subtotals and totals. The sums in the independent observatories column do not include the University of Hawaii shares of international telescopes on Mauna Kea, such as Gemini North, the CFHT, the United Kingdom Infrared Telescope, and the Subaru Telescope. The MMT upgrade replaces the MMT, whose contribution has been subtracted from the total.

Quoted from: http://www.nap.edu/readingroom/books/gboi/chap2.html

TABLE 2.

Nation	Telescope	Diameter	Area m²
Belgium	——	——	——
Denmark	NOT (30%)	2.5	1.47
France	OHP	2	3.14
	OPM	2	3.14
	CFH (42%)	3.6	4.28
Germany	Calar Alto	3.5	9.6
	Calar Alto	2.2	3.8
	La Silla (50%)	2.2	1.9
	HET (10%)	9	6.36
	LBT (12.5%)	11.3	12.3
Italy	Galileo	3.5	9.6
	LBT (25%)	11.3	24.6
Netherlands	WHT (10%)	4.2	1.5
Sweden	NOT (30%)	2.5	1.47
Switzerland	——	——	——
TOTAL			83.2 m²
ESO	La Silla 3.6	3.6	10.2
	NTT	3.6	10.2
	2.2 (50%)	2.2	1.9
	VLT	4x8	201
TOTAL			223.3 m²

and takes into account appropriate fractions given to international partners.)

If we carry out the same computation for the ESO member states and ESO (Table 2) we find that, without the VLT, the combined area available (including all fractional participations in non-member states programmes) only reaches 105.5 m^2. The VLT adds 201 m^2 of observing area to European astronomy.

Therefore approximately 3/4 of all telescope area available to European astronomers will be provided through ESO.

It is only through the construction of the VLT that Europe will (for the first time in this century) become competitive with the USA in optical ground-based astronomy. No single European nation can by itself compete with even single US astronomical institutions such as Caltech, Carnegie, CFA, Texas and Arizona. The concerted effort of European astronomy through ESO is therefore much more important to European astronomy than public facilities are to US astronomy.

VLT/VLTI, when completed, will not only be fully competitive but may in fact become the most advanced observing tool in ground-based astronomy in the world. It is a matter of some pride that it has already become the mark against which all other facilities are measured. This is particularly true for the VLTI capabilities which should be superior to any other currently planned.

2.2 Development of optics and materials

The construction of the VLT/VLTI could not have been undertaken in the 90's without the technical and engineering developments which ESO carried out in Garching in the 80's. Of crucial importance was the design, development and implementation of the New Technology Telescope. This superb 4-meter telescope which has been in full operation since 1990 embodied for the first time the mirror design concept of a single thin meniscus whose configuration is actively controlled by computer-driven actuators. It is this technique which is the foundation of the VLT design.

To emphasise the importance of this technological advance we should remember that, until active optics was introduced, the rule of thumb for a rigid optical telescope of sufficient accuracy was that the thickness of the mirror blank should be approximately 1/6 of the diameter. This would have required 133 cm of thickness for an 8-metre mirror. In contrast, the thin meniscus approach permits us to use 17 cm thickness. The current VLT primary mirror weight of 20 tons would have become 160 tons in the classical design. It should be noted that this particular approach has been adopted by the US Gemini as well as by the Japanese Subaru 8-metre projects. While alternative new technology approaches such as adopted by Keck and LBT do exist, Europe is now considered a leader in this field.

This entire development included optics design studies at ESO Headquarters, research in alternate mirror materials and technology with the European industry and pilot programmes to test basic technological approaches spread over many years. The development of large Zerodur blanks at Schott, the construction of a new mirror polishing laboratory at REOSC, the development of new mirror coating systems at Linde, of high-precision encoders at Heidenheim, the design and development at GIAT of a new type of mirror support structure, the construction at Dornier of the M-2 mirror cell and of the 480-ton structure at Ansaldo have not only provided the tools needed for VLT but have also given European industries a competitive edge in international procurements. It is clear that no single institution in the member states could have produced these results. ESO must continue to provide the European astronomical community with this kind of technological resources for future programmes.

2.3 System engineering and modelling

The design, operation and optimum scientific exploitation of complex optical systems such as those used in VLT/VLTI require a highly sophisticated degree of computer modelling. Among the major telescope facilities in the world, VLT is unique in having a fully developed end-to-end computer model. The model takes into account all mechanical and optical properties of the telescope and its control system to predict the distortions produced by a number of effects starting from design characteristics to variable environmental stimuli including wind, temperature, humidity, seismic and microseismic disturbances, etc. Furthermore, by modelling the physical characteristic of the detectors and using its calibrations, we can predict the expected output from a given input flux and spectrum of radiation.

These models have proven invaluable in permitting effective trade-offs between required scientific performance of VLT and engineering and contractual specifications. Beyond these practical benefits, however, even more important has been the use of modelling tools to assess the requirements placed on individual elements of the array by the exquisite precision needed for interferometry. During operations, the models are essential to respond to variable seeing conditions with appropriate tactics for telescope use. The complex nature of active and adaptive servo control loops would make it difficult to design and operate them without appropriate simulation through the model. This overall capability has already been used by the ESO engineering groups in the Large Southern Array programme study.

2.4 Development of instrumentation and detectors

The development of instrumentation for the VLT/VLTI has been carried out in Garching in close collaboration with institutions of member states. 9 out of 11 instruments in the first-generation VLT complement are primarily built in member states with a number of major components, especially detector systems, built at ESO (Table 3). In addition, ESO has carried out a monitoring function, instituted planned management reviews (CDR, PDR and FDR) established hardware/software standards when appropriate, suggested remedial technical action when required and insured that the scientific purposes for which the instrument was built could be achieved with the hardware planned for delivery. A formal acceptance phase, commissioning phase and science verification are planned for all instruments.

Is this rigor required and is the instrument construction being done effectively? Of course, the proof will occur after commissioning of the VLT, however, a recent study of the Scientific-Technical Committee of ESO (Instrumentation Study of the Scientific-Technical Committee ESO/STC-223, 14.11.1997) pointed out the risks of an unstructured approach as followed by Keck where only some out of five instruments built in the first generation were actually useful at the telescope. This committee also found that the prices of the first VLT instruments were normally in line with those in the US. Substantial cost reductions in the near future will be obtained from commonality of designs and parts. The success of a new infrared imager and spectrometer (SOFI) built very quickly and inexpensively utilising ISAAC designs gives us confidence that we are on the right track.

2.4.1 Detectors

ESO's contribution is particularly important in the detector area, which is usually the single most critical item for the competitiveness of any astronomical instrument.

Europe had traditionally lagged behind the US in the development of visible light and infrared solid-state detectors and of their associated low-noise fast controllers. In the last few years, through association with US institutions, as well as with independent procurement, we are now receiving detectors which are equal to the best in the world. We have completed two inhouse controllers, the FIERA system for visible CCDs, IRACE for infrared arrays, which are at the forefront of performances in terms of low noise and high speed. In response to perceived need and to the recommendation of the technical committees, the ESO management created a new detector group with a critical mass of dedicated engineers and scientists to carry out this task. We believe that this has been the key to success.

As a result of successful laboratory and field tests of these new detector systems, ESO has taken responsibility for all detector systems on VLT(except on VISIR) and all the La Silla instruments.

At the moment 17 FIERA systems are being constructed for delivery to the instrument teams. The quality of the devices is such as to have raised the interest of the environmental sciences and defence communities in France (Onera) and Germany (Zeiss).

2.4.2 Operation of the instruments and calibration

A great deal of attention has been given to the maintainability and operability of the instrumentation associated with VLT/VLTI especially with systematic hardware and software standardisation. It should be remembered that our plan for operation on Paranal foresees a number of people comparable to those employed on La Silla. This goal would make Paranal perhaps the most effective facility in ground-based astronomy in the world. On the other hand, this requires strict planning, assembly and integration of instruments, the development of commissioning and verification plans, a plan for instrument maintenance and calibration which maximises scientific return within hard budgetary constraints. These stringent requirements have been made part of the deliverable items by individual institutions. Here ESO carries out a unique function in ensuring across the board uniformity to enable reliable high-level operation of the instruments.

2.5 Operations and data flow

The purpose of constructing the VLT/VLTI is to achieve scientific results which will be at the forefront of astronomical research in the world. To this end, particular attention has been given to the possibilities of new forms of observing such as service observing, variable queue and remote observing. All of these modes are intended to maximise the opportunity for the observer to carry out his/her observations under the optimum conditions. Extensive use of the modelling tools, mentioned above, is made to predict performance and modify telescope parameters to optimise its output, finally to ensure that the most suitable programmes for these conditions are carried out. This implies a great deal of attention to how the initial proposals are written, how they are further detailed after OPC approval, their division in observing blocks (the standard high level command unit to the VLT system) and the transfer of this information to the operators. Quick look data monitor capabilities are also provided.

The use of calibration data for the first cut reduction of the observed data permits the translation of signals in physical quantities which are then made available to the observers and stored in a long-term research archive. The development of this Data Flow System and of the VLT Archive will be one of the outstanding achievements of ESO and provide the European astronomer with the basis for further scientific elaboration of the data in a prompt and effective manner. I cannot more strongly emphasise the importance of this unique ESO contribution to ground-based astronomy in Europe.

2.6 The La Silla Observatory

La Silla was developed in the 70's and 80's to the point that it had become one of the important observatories in the world. It had a full complement of 15 telescopes (including two 4-metres) and it was thus fully competitive with Cerro Tololo, KPNO, Hawaii, etc. La Silla has provided for many European as-

TABLE 3.

In order to reduce as much as feasible the load on the in-house instrumentation staff and to profit from the available technical competence in the European astronomical community at large, ESO has adopted the policy of relying as much as possible on external national institutes in the member states for the construction of instruments.

At the moment only two instruments ISAAC (4.8 MDM 1996) and UVES (7.1 MDM 1996) are fully developed by ESO. Under the UVES programme there is a small contract (Only reimbursement of travel expenses) to the Osservatorio di Trieste for software developments. The other instruments currently under development are listed below with the responsible institutes and the ESO contract amounts. The leading Institute is underlined. It should be noted that in almost all cases ESO is providing the detector system, as well as a number of major subunits, e.g. motor controls, Real Time Display, etc.

FORS 1 and FORS 2
Institutes: Heidelberg Observatory, München Observatory, Karlsberg University (FRG)
Contract Value: 4.78 MDM (1997)

CONICA
Institutes: MPI-A Heidelberg, MPI-E Garching (FRG)
Contract Value: 2.57 MDM (1997)

NAOS
Institutes: ONERA, Meudon Observatory, Grenoble Observatory (France)
Contract Value: 7.61 MDM (1997)

VISIR
Institutes: CEA Saclay (France), ASTRON (The Netherlands)
Contract Value: 5.32 MDM (1997)

VIRMOS
Institutes: LAS Marseilles, OHP St Michel, OMP Toulouse (France), IRA Bologna, Observatories of Bologna, Milano and Napoli (Italy)
Contract Value: 10.22 MDM (1997)

FUEGOS
Institutes: Meudon Observatory, OMP Toulouse (France), Geneva Observatory (Switzerland), A.A.O. Sydney (Australia)
Contract Value: 4.4 MDM (1997)

Two new instruments, CRIRES and SINFONI, have been recently recommended by the STC, to fully equip the VLT with its first generation of instruments. We are currently exploring possible collaborations with the ESO member states in order to decrease the costs involved.

tronomers the major observational capability they could use.

Nearly 600 programmes of research on a vast range of scientific topics are carried out every year. The residence of astronomers from all member states at the observatory gives unique opportunity for fruitful interactions. Many young scientists have received their initial training in observing and data reduction through their involvement in the support functions. A vigorous Fellowship Programme (20–24 Fellows/year, ESO wide) has made this possible. La Silla also became the site of a number of national telescopes either fully funded and used by national groups or in a shared mode with ESO. Joint projects with Danish, French, German, Swiss and Swedish institutions are embodied in a variety of telescopes currently in use.

La Silla hosts a number of national experiments, such as CORALIE to search for exosolar-planets, EROS for the microlensing, DENIS for the IR survey of the southern sky. Also, individual institutes are providing additional money for specific projects (example: the 8k camera at the 2.2, SUSI2, etc.). La Silla was the site where Come-on-Plus and Adonis (the first adaptive-optics instruments) were offered to the community.

La Silla played a vital role during the development of the VLT as a site for early testing of technology and methodology. The VLT control software was implemented and tested on the NTT prior to its use on Paranal. The control consoles, operator stations, data-flow systems, etc., were also prototyped on the NTT. The SOFI infrared imager spectrometer for the NTT is a derivative of ISAAC for the VLT reduced in size as appropriate. It has already been commissioned with truly outstanding results on the NTT at the end of 1997. This will greatly facilitate the integration of ISAAC (planned for mid-1998) on the VLT. Finally, operational concepts such as service observing and calibration methodology were tested on the NTT.

The role of all smaller telescopes in the world after the arrival on the scene of the new generation of 8–10 metres has had to be reassessed. The ESO Scientific-Technical committee carried out a study which established priorities and was translated into an operation plan by the ESO Management (Scientific Priorities for La Silla in the VLT Era, ESO/STC-174 rev. 20.11.1995).

The resulting plan, approved by Council, detailed first the scientific priorities for medium-class telescopes operated along side an 8-m-class facility. Then a number of instrument upgrades were defined which were considered essential to support VLT programmes. These upgrades have been carried out with substantial long-term investment by ESO and several member states. Third, facilities and services that would not remain essential and competitive were identified for near- or medium-term closure. Finally, it was pointed out that space for medium-class facilities on or near Paranal is limited and expensive to develop. Furthermore the cost benefit of operating a given telescope on Paranal rather than on La Silla is doubtful at best.

By the year 2003, it is foreseen that only the two 4-metre-class telescopes would be offered to the astronomical community of the member states instead of the 15 utilised in 1993. It is clear that the 3.6-metre telescope and the NTT will continue to be important in conjunction with the VLT. Some programmes can be more effectively carried out with these telescopes, whose cost of operation is 1/10 of that of the VLT.

For some programmes the 4-metre telescopes may also be more suited. For example, a strategically important programme such as the search for extrasolar planets with high-precision (1m/sec) measurements of stellar radial velocities can best be done by the use of a dedicated 4-m-class telescope with the appropriate spectrometer. Similarly, wide-field surveys required to find targets for the VLT are most efficiently done at smaller telescopes with a wider field of view. Operational costs of such dedicated facilities will be appreciably lower than the multipurpose use of the same telescope.

We are currently reassessing the science role and operating plan for La Silla in light of the experience gained in the last few years and a new report will be presented to STC and Council. We foresee the possibility of further optimisation resulting in additional savings.

At reduced cost La Silla can continue to play a vital role in the ESO activities. Primarily its functions should be as follows:

(a) Continued use of upgraded, properly instrumented NTT and 3.6-m telescopes.

(b) Continued use during a transition period of the 2.2-m and 1.5-m telescopes and SEST.

(c) Infrastructure support for National Telescopes on a cost-reimbursement basis.

(d) A site for experimentation and tests of new instrumentation and technologies.

2.7 ESO-ESA collaboration

ESO Garching is the site of the HST European Co-ordinating Facility and its operation is jointly sponsored by ESO and ESA to support the Hubble Space Telescope Project and in particular to facilitate access by European astronomers to its data. ECF staff consists of a mixed team of ESO and ESA personnel. ECF is the only site in Europe where a full copy of the Hubble archive exists and is offered to the community with a unique set of tools for the recalibration and interpretation of its data.

The ECF staff was deeply involved in the design and execution of the Hubble data archive in collaboration with STScI and CADC. It also played major roles in the development of instrument calibration methodology. ECF has been recognised as one of the leaders in the techniques of image reconstruction and deconvolution, which were particularly important during the initial period of HST operation, when the telescope was affected by spherical aberration.

The expertise of ECF will continue to be used during the execution and later operations of the Next Generation Space Telescope (NGST). The expertise of ECF has been applied in the design of the VLT archive and in many other aspects of the data-flow system development. ECF plays a particular role in providing a synergism between ground-based and space-based astronomy programmes and between ESO and ESA, an activity clearly outside the scope of national institutions.

2.8 The role of ESO in international collaborations

ESO, as the largest single European Observatory, has acquired a stature which is recognised world-wide. Non member states are interested in entering in collaborative agreements with ESO or even to become members. Through these activities new concepts and technologies can be introduced into ESO for the benefit of European astronomers at a minimum cost.

Even more important for the future, however, may be the role of ESO in representing European interests in negotiations with the US or Japan. Just like ESA represents the European Community interests in its negotiations with NASA, ESO plays a similar role in negotiations with non member states consortia or institutions. Examples of such interactions which have already occurred are with NRAO, NOAO, STScI, and NASA in the US and with the Australian Research Council.

ESO provides a focus for discussions and agreements among European scientists about the proposed European roles in international ventures. It provides also the managerial and engineering support to support technical interactions with potential partners. It permits Europe to deal with the US institutions on a basis of parity rather than as perpetual minority partners. This is particularly important to allow European interests and points of view to influence in a positive manner the early conceptual phases of the programmes. It is clear that in the future the even larger facilities that will be needed in astronomy will require transcontinental scientific collaborations and ESO can play a unique role in these developments.

3. Future Programmes and the Balance between National and International Activities in Member States

From the above it should be clear that ESO should not be considered as simply an institution to construct VLT/VLTI and operate La Silla and Paranal on a one-shot basis but as an institution which will provide an important, continued contribution to European astronomy in providing technology and ground-based facilities beyond the reach of national groups.

Given the continued need for these facilities, the need for a continued role by ESO seems clear. The issue is then what would be an appropriate balance between national programmes and programmes done through ESO.

In order to successfully accomplish its task, **ESO's activities must reach the critical mass required to carry out those programmes which are beyond the capability of single nations but that are essential to maintain a competitive research level in the international context.** Among such programmes one can clearly include NTT, VLT/VLTI, a large millimetre/submillimetre array (beyond 2005) and any future large-scale optical telescopes (beyond 2015). One could also include many of the activities listed in the Highlights. Without these programmes European astronomy could not achieve the level of excellence required to place it in the forefront of research. The execution of these programmes would require an ESO budget which remains at least constant in purchasing power over the next decade, preferably with a few percent increase. This view is hard to reconcile with the current decline in funding for basic research in Europe but I hope that this crisis is temporary and will disappear as economic conditions improve.

What now of the balance between national and international enterprises? The level of this balance at this moment is very difficult to assess and it is certainly a prerogative of each member state. For some of the ESO member states the issue may be between the construction of major national facilities and the scientific utilisation of ESO facilities. For the majority of the ESO member states the issue is moot because they have chosen to make their investment in large facilities through ESO rather than nationally.

It would still be useful to compare expenditures from the point of view of scientific priorities. Unfortunately there are no complete figures to describe the national efforts in astronomy which can be directly used. Often the comparison is made between the expenditures for ESO and those for the discretionary part of the astronomy budgets in the nations. This of course ignores in the national programmes the cost of the institutional infrastructure and of the personnel salaries which constitute typically 80% to 90% of the expenditures in these disciplines. The ESO budget includes all expenditures. Also part of the ESO funds are returned for direct support of research and instrument development to the member states.

The only reasonable comparisons in absence of this financial material is for us to consider if ESO funding is too high for the tasks it is required to do in comparison with other known projects, in other words whether ESO is effective. We have compared the costs of development of VLT/VLTI with those of GEMINI, Keck and Subaru. Our costs are very close to American costs and a factor 3 below Japanese costs. Similarly with regard to operations we have compared our costs of operating our observatories and we find that they are quite competitive for a given level of performance. These findings have been reported to Council in the ESO document "Operation Plan/A Blueprint for ESO/CHILE in the 21st Century" (ESO/COU-534, 23.11.1994). We have already mentioned the instrument cost comparison which has been recently carried out by STC and has shown that ESO and the member states institutes are producing excellent quality instruments at reasonable costs. Thus ESO is fulfilling its role with a high level of competence and effectiveness. A detailed report was presented to Council in 1996 in the document "Management Approach, Policies and Cost Controls at ESO", (ESO/COU-601 conf., July 12, 1996).

I would like to conclude this section by mentioning the role of science at ESO. ESO has provided the forum for the early studies and scientific debates by the community which have led to NTT, VLT, VLTI and may lead to the LSA. Both during these studies and in the conception, design, development and operation of the facilities, ESO has relied on its in-house scientific staff to draw upon the best expertise available in the community in order to define and direct its programmes. **The community of member states counts approximately 2000 astronomers; of these only 40 occupy positions at ESO** which are defined as requiring active research astronomers to fulfil ESO's tasks. This represents only 2% of the European Astronomical Community dedicated to the service of the major facilities required by all of the community to succeed. It is clear that **ESO does not compete but complements national programmes** and will continue to do so in the future.

In order to accomplish its mission, however, ESO requires a strategic plan which is not subject to continued erosion. We carried out a full audit of ESO operations in 1993. We prepared a **long-range plan 1996 to 2003 in 1995** (ESO/COU-582 to 588, May 1996). This plan has been discussed extensively at STC, FC and Council and provides the technical basis of our activities. This plan has been reduced in cost three times in the last two years with overall cost decreases of more than 5% without any changes in scope. **We will still be able to complete VLT and VLTI within schedule and specifications**. **However we are now in great danger of diminishing the resources which are required both to fully utilise these wonderful new facilities and properly provide for the future.**

Over the next few years several 8–10-metre-class telescopes will enter in operation. The competition among them for new discoveries will be fierce. There is widespread perception that with this generation of big telescopes the basic tools are now in hand to map in great detail the formation and evolution of galaxies, clusters and large scale structures all the way to $z = 5$, i.e. back to when the universe was more than ten times younger than now. Several of the main open questions of observational cosmology may be closed within a few years. Leading ahead or lagging behind others in this effort, especially the US, will depend for Europe essentially on the quality and diversity of the VLT instrumentation, on the efficiency of its operations and data flow, and especially on their timely deployment. In all this ESO is now striving for the best, and we are confident we can actually lead. **A cut in the budget at this point in the project would impact inevitably the instrument plan and/or the operation efficiency, with the result of losing the margin of advantage over the competitors that we are trying to secure for the community, that will make the difference between being first in doing fundamental discoveries, or just confirm the results of others.**

Europe has made the capital investment to reach parity with the other major astronomical enterprises of the world. It would be a blow to European science if this effort was jeopardised now when success seems within reach.

4. Conclusions and Recommendations

Only through collaboration between nations can Europe hold its own in the arena of international scientific facilities.

ESO's programmes are a necessary complement to national programmes and do not compete with them. National programmes benefit from access to ESO facilities, from opportunities for development of advanced technology in collaboration with ESO and from use of ESO infrastructure.

The successful completion of VLT/VLTI is providing European scientists with the only facility in ground-based optical and IR astronomy fully competitive on a world scale.

VLT/VLTI will provide most (75% in area alone) of all observational facilities available to member states in this field.

The continued support of a vigorous programme of instrumentation development, operation and data utilisation of the VLT/VLTI will be essential to achieve scientific success.

Continued operation of La Silla with a restricted number of high-quality telescopes will provide a low-cost but essential complement to the VLT/VLTI.

The on-going process of assessment of the role of La Silla should continue. This will include the utilisation of the infrastructure for national projects and the hand over of facilities to partners (in and out of ESO member states).

ESO has an important role to play in future large programmes starting from the leadership and co-ordination of early studies by the community to programme execution. ESO is uniquely qualified to carry out these programmes because of its technical and management experience and expertise and because of its effectiveness and cost competitiveness.

ESO-Garching should continue to study the conceptual definition, feasibility and implementation of the Large Millimetre Array (LSA). One of the aims of this study is to participate in discussions with the US and Japan to determine a possible basis for co-operation. New forms of co-operation with institutes in member states and non member states will also be considered.

ESO Headquarters should begin the study of scientific drivers and technology assessment for future ground-based optical telescopes of extremely large aperture which may come in existence in 2010 and beyond.

ESO can carry out its tasks within a budget constant in purchasing power or with small increases over the next decade. It is important, however, that a degree of stability should be achieved. The continued cuts over the last few years have gone as far as one can go without seriously jeopardising scientific success.

First Light at the VLT UT1 is now rapidly approaching. For the latest news about the various activities that will accompany this important event, please consult: http://www.eso.org/outreach/info-events/ut1fl/

SOFI Sees First Light at the NTT

A. MOORWOOD, J.-G. CUBY and C. LIDMAN, ESO

SOFI, ESO's new 1–2.5 μm infrared imager/spectrometer, was installed at the NTT on La Silla in early December 1997 and saw first light as planned on the 6th. The acronym stands for Son OF ISAAC, the larger and more complex infrared instrument being built by ESO for the VLT (see Moorwood, 1992, *The Messenger*, 70, 10, and Lizon, 1996, *The Messenger*, 86, 11), which is now undergoing final tests in Garching prior to shipment to Paranal. By copying some of its technology and using a large subset of its software, the ISAAC Team has managed to build and test SOFI in less than two years since the start of its detailed design and in parallel with the on-going ISAAC and other work. In addition to significantly enhancing the infrared observing capabilities on La Silla, SOFI has also provided valuable experience within the 'VLT environment' now existing at the upgraded NTT telescope in advance of the more complicated installation of ISAAC at the VLT later this year. In addition to the opportunity for testing some of the purely instrumental aspects, this includes some of the new operational features being introduced to ground-based astronomy at the VLT such as automatic

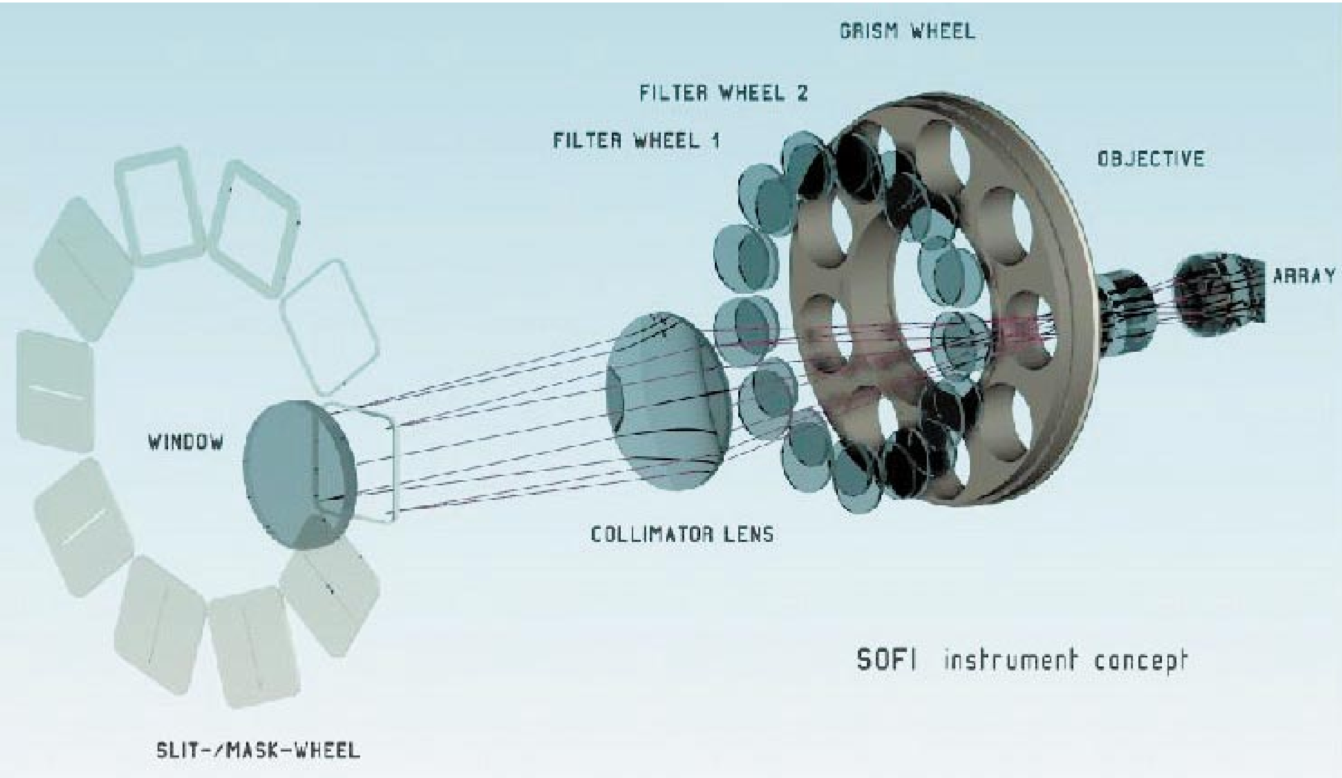


Figure 1: Optical layout of SOFI (see text for description).

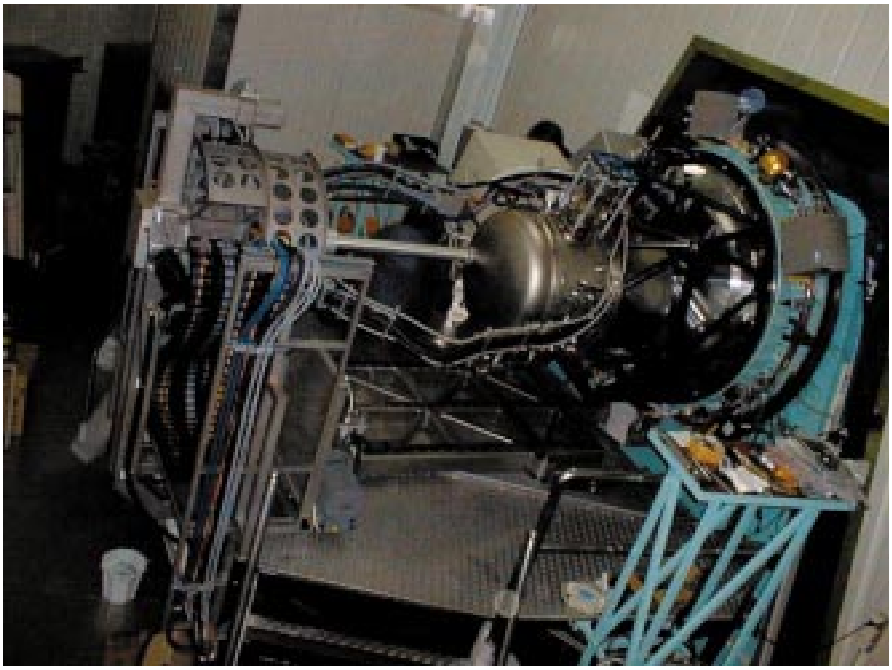


Figure 2: SOFI mounted at the NTT. One of the complications is the need for the co-rotator at the left which carries electrical cables, cooling liquid and gas hoses for the closed-cycle cooler to the instrument and is slaved to rotate with it. (Photograph by J. Brynnel.)

Figure 3: Composite of three 1-min narrow-band-filter exposures of the Orion nebula centred on the 2.166 μm Brγ atomic hydrogen line (blue), the 2.12 μm 1-0 S(1) line of molecular hydrogen (red) and the 1.257 μm [FeII] line (green). Brγ traces hydrogen gas ionised by the well-known Trapezium and other, young, hot stars in the region; the molecular hydrogen emission shows hollow filaments which have been shock heated by matter ejected during the birth of new stars within the OMC1 molecular cloud and the [FeII] emission (only clearly visible here at the end of one of the NW filaments) is emitted by the high velocity fragments impacting the interstellar medium. Pixel scale is 0.29″ and the field is ~ 5′ × 5′ with N at the top and E to the left. Seeing was ~ 0.5″.

execution of observing sequences via pre-prepared Observation Blocks and pipeline reduction and calibration of the data (see D. Silva and P. Quinn, 1997, *The Messenger,* 90, 12).

Why SOFI?

SOFI was conceived within the framework of the NTT Upgrade Plan as a means of providing La Silla with new and greatly enhanced capabilities for near-infrared astronomy which would remain competitive into the VLT era. Science drivers for its design, discussed within the Scientific Priorities for La Silla WG and included in the proposal to the STC, included deep 'wide'-field surveys for high *z* galaxies and low-mass stars plus spectroscopy of galaxy nuclei, supernovae and sources detected by the DENIS infrared sky survey. The first test results reported here show that SOFI, as built, can be a factor ~ 50 faster or reach ~ 2 magnitudes fainter than IRAC2 at the 2.2-m telescope for survey work and can provide low-resolution spectral coverage of the complete 1–2.5 μm region more than 1000 times faster than the, now decommissioned, IRSPEC at the NTT. It also provides superior spatial resolution plus a new polarimetric capability and is still planned

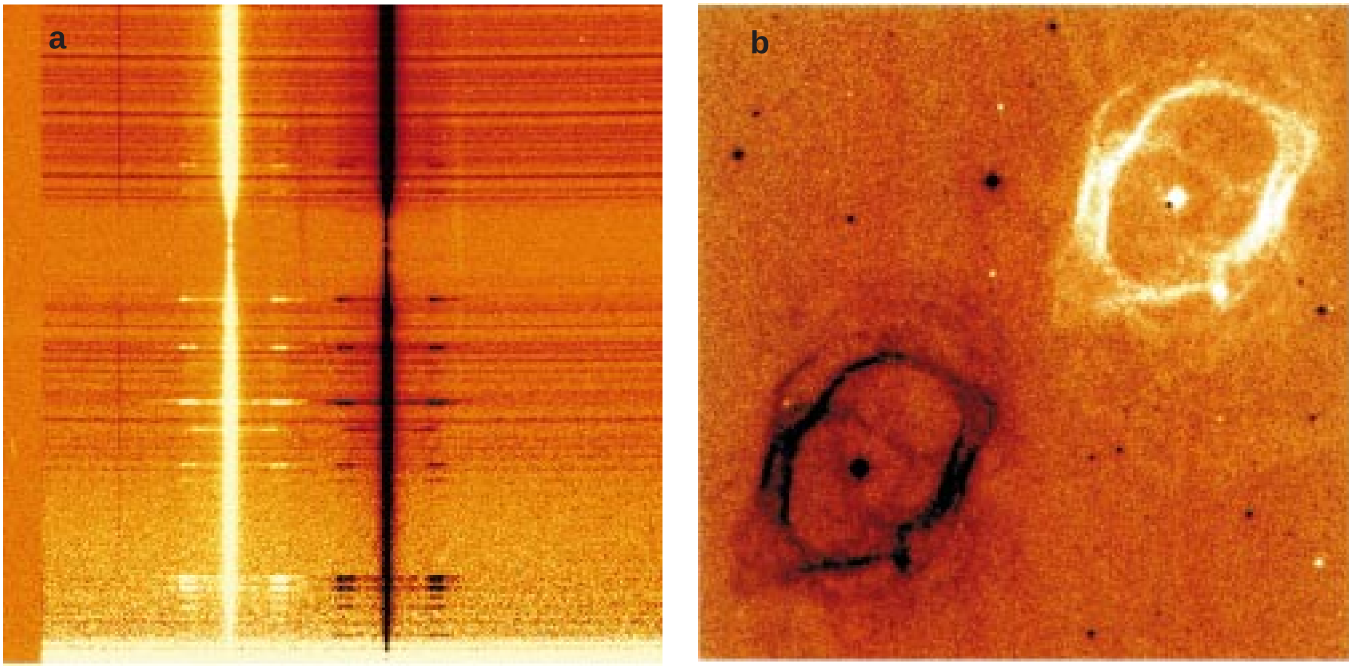
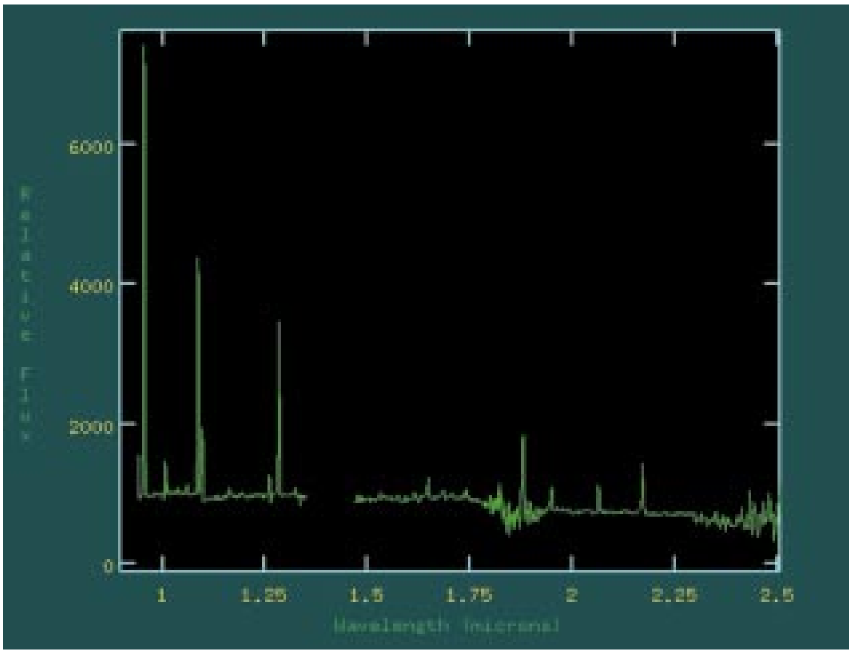


Figure 4a: Red grism 'image' of the planetary nebula NGC 3132. Two 5-min exposures obtained with the object at different positions along the slit have been subtracted to yield 'positive' and 'negative' spectra. Residual sky emission lines (mostly OH) extending across the complete frame are due to their variation between exposures. Several of the lines in the PN spectrum are emitted by molecular hydrogen and are seen to be brightest in a narrow region at some distance from the central star, indicative of a ring-like structure.
Figure 4b: Difference of two 1-min narrow-band 2.12 μm 1-0 S(1) H_2 line exposures with NGC 3132 centred at different parts of the array yielding positive and negative images and showing clearly the molecular ring..

Figure 5: 0.95–2.5 µm spectrum of the dwarf HII galaxy He2–10 obtained using the two grisms. In each case, two 5-min exposures with the galaxy at different positions along the slit have been subtracted. The slit width was 1″, corresponding to 3.4 pixels or 24–34 Å across the spectrum. The region around 1.35 µm suffers from strong atmospheric absorption and has been removed. Atmospheric absorption is also responsible for the increased noise around the Pa (1.875 µm) line. The brightest emission features are the [SIII] 0.953 µm doublet; several H and HeI recombination lines; [FeII] (1.257 and 1.644 µm). CO stellar absorption features are just visible around 2.3 µm.



to be equipped with a medium resolution echelle mode providing that the current problems in developing the required grisms can be overcome. Applications for this new instrument are therefore expected to extend far beyond its primary science objectives. The gains in field and sensitivity, however, are obviously most critical for the deep surveys and open up qualitatively new areas of science which could only be partially addressed with the previous generation of instruments. For many infrared survey programmes, SOFI is also likely to remain competitive with the VLT for some time because its larger field of view compared with ISAAC essentially offsets the smaller telescope diameter. Indeed, many of the programmes already awarded time by the OPC in Period 61 do fully exploit the combination of field and sensitivity e.g. for galaxy and cluster surveys, the use of clusters as gravitational telescopes to detect more distant galaxies and narrow-band searches for [OII] and Hα line emitting galaxies to determine the star-formation density at $z \sim 2$. Follow-up observations e.g. to determine redshifts require complementary optical images or spectroscopy which, for the important $z \sim$ 1–3 range (where the usual optical features are shifted into the infrared), means either with SOFI itself or ISAAC at the VLT. Some of the test results shown here, although obtained with relatively short exposures, have been selected to illustrate SOFI's potential to meet its prime scientific objectives on faint objects while others highlight the additional possibilities offered for detailed studies of brighter, extended, sources.

Instrument Design

Figure 1 shows the layout of SOFI whose optics were designed by B. Delabre and procured and tested with the support of A. van Dijsseldonk. The first wheel carries field masks; various slits for the spectroscopic modes and a special mask for polarimetric observations using the Wollaston prism. Re-imaging of the telescope pupil at the 25 mm diameter Lyot stop is made by the 12 cm diameter, diamond turned, BaF_2 collimator lens which also produces a parallel beam passing through the three wheels carrying broad- and narrow-band filters; grisms; a Wollaston prism and a focal elongator. The final wheel carries three objectives providing a maximum field of 5′ × 5′ and scales of 0.29″/pix, 0.26″/pix (mainly for spectroscopy), and 0.14″/pix (or 0.075″/pix in combination with the focal elongator). The two directly ruled KRS5 grisms currently installed provide coverage of the 0.95–2.5 µm range at R ∼ 300–1000 depending on which of the 2, 1 or 0.6″ wide slits is used. A cross-dispersed mode yielding R ∼ 3500 is

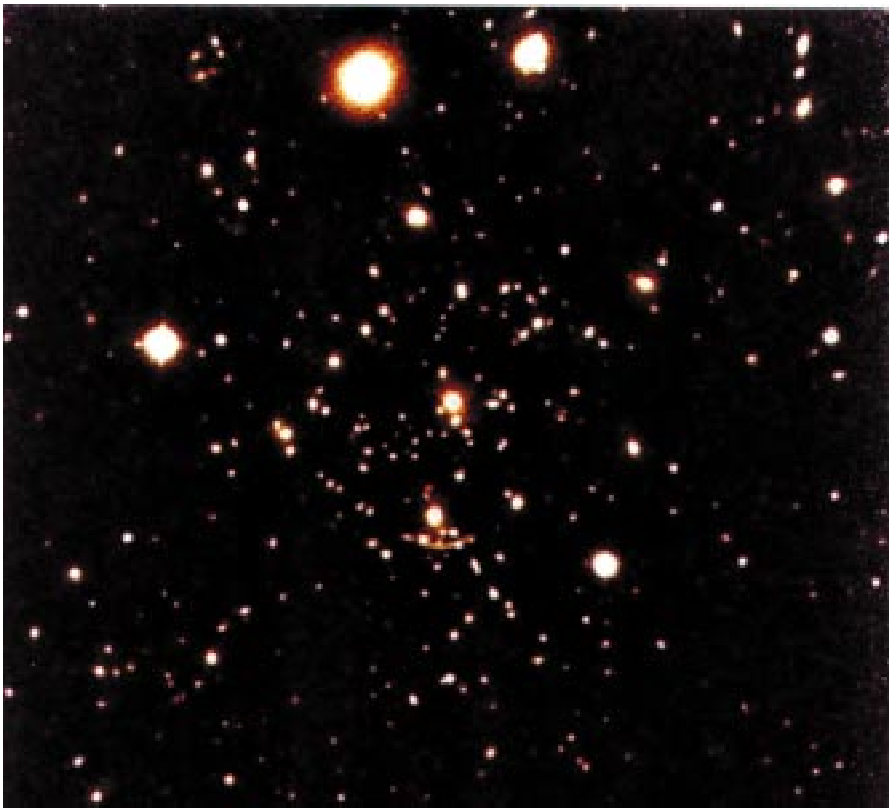


Figure 6: J(1.25 µm) band image of the z = 0.375 galaxy cluster A370, obtained in 'jitter' mode and showing the famous gravitational arc just below the centre. The observations consisted of 24 exposures of 2 minutes each made on randomly-generated telescope positions constrained within a region of 30″ × 30″. The individual exposures have been sky subtracted using a running average determined from the same data and then re-centred and combined. Pixel scale is 0.29″ and the field is ∼ 5′ × 5′ with N at the top and E to the left. The seeing was rather poor (∼ 1.2″). A J = 22 mag. point source yields s/n = 5 within a 2.5″ diameter aperture.

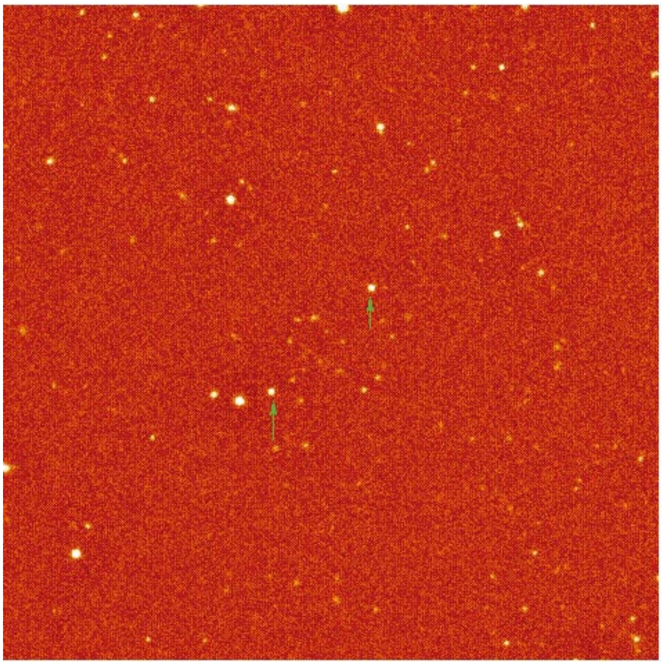


Figure 7a: A 90-min Ks (2.16 µm) 'jittered' image of the field containing the z ~ 2.1 quasar pair 0307–195A,B (marked by the arrows) plus a possible galaxy cluster of unknown redshift located between them. Pixel scale is 0.29″ and the field is ~ 5′×5′ with N at the top and E to the left. Image FWHM is about 1″ and a Ks = 21 mag. point source yields s/n = 4 within a 2″ diameter aperture. Point source FWHM ~ 0.6″ were obtained in a J image of the same field obtained under superior seeing conditions.

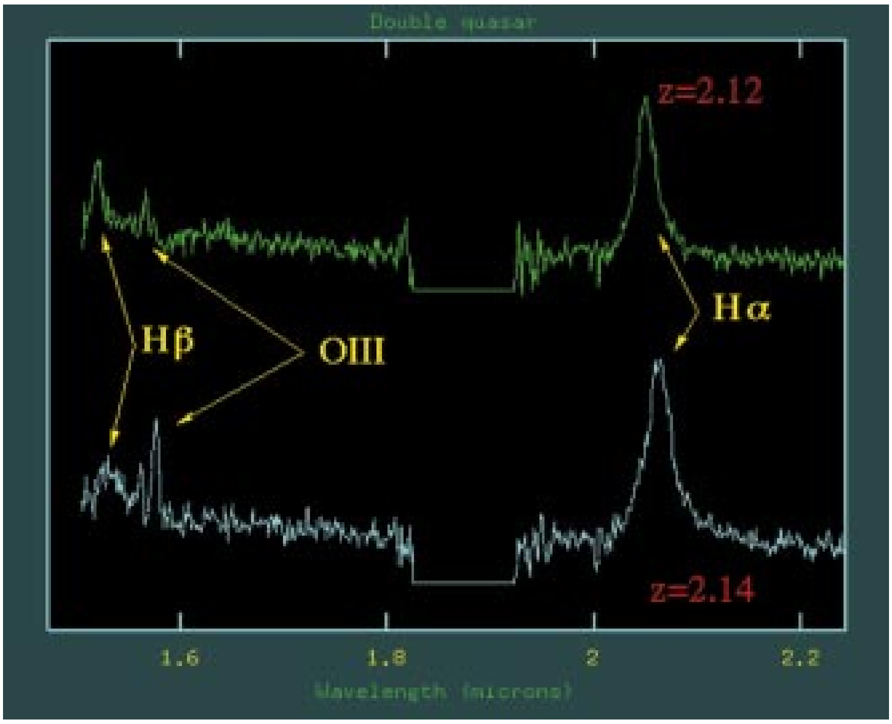


Figure 7b: Spectra of the two quasars in 7a obtained with the red grism. A short imaging exposure was first made to align and centre the objects in the 2″ slit (~ 70 Å). The spectra were then obtained by 'nodding' between two positions along the slit (for sky subtraction) for a total of 80 minutes.

also foreseen in the design but has been delayed due to problems, encountered by the manufacturer, in bonding etched Si wafer gratings to Si prisms to produce the special echelle grisms required. Although the approach is similar to that used successfully for the 10 µm TIMMI grisms (H.-U. Käufl, 1994, *The Messenger*, 78, 4) optical contacting rather than bonding was sufficient in that case due to the longer wavelength.

At the heart of SOFI is a Rockwell 1024 × 1024 pixel Hg:Cd:Te infrared array detector which exhibits fewer than 900 (< 0.1%) bad pixels, extremely low dark current and a read noise of only a few electrons as measured both in the laboratory and on the telescope by G. Finger using the ESO IRACE acquisition system (see Meyer et al., 1997, *The Messenger*, 86, 14).

The optics and detector of SOFI are enclosed within a vacuum vessel and maintained at temperatures of around 77 K by a closed-cycle cooler, assisted by a liquid-nitrogen circuit during the initial cool-down phase. The surrounding cryo-mechanical system, drives, vacuum vessel and external maintenance equipment were largely designed by G. Huster who adopted or adapted ISAAC solutions where possible. Whereas major parts such as the vacuum vessel and maintenance platform were sub-contracted to industry, R. Büttinghaus produced most of the cryogenic functions at ESO using machines controlled by the CAD system used for the design. All the moving functions are driven by gear systems and 5-phase stepper motors as used in ISAAC and adapted at ESO for cryogenic operation by J.-L. Lizon who was also responsible for the overall cryogenic system and integration of the complete instrument with the assistance of A. Silber.

The electronics required to monitor and control the moving functions; vacuum and cryogenic systems; co-rotator system and safety systems is a derivative of the VLT standard ISAAC system and was developed and built by J. Brynnel with the help of E. Pomaroli. Amongst its advanced features are automatic cool-down and warm-up sequences; local fault diagnosis and logging of temperature and pressure data which can be monitored in Garching.

The control software is a large subset of that written for ISAAC under the supervision of P. Biereichel. It includes the Instrument Control (ICS) and Observing (OS) Software developed by T. Herlin and the Detector Control Software (DCS) of J. Knudstrup who also helped J.-G. Cuby to develop the instrument templates used to execute observation and test sequences. The detector acquisition and pre-processing software was developed by J. Stegmeier.

Installation and Test at the NTT

The re-integration and installation of SOFI on the NTT was completed within the 1 week planned with the result that first light was achieved at the beginning of the first test night on December 6th. Figure 2 shows SOFI installed at the Nasmyth focus previously occupied by IRSPEC and SUSI (which is being replaced by SUSI2). Overall, the telescope tests also went extremely well with little night-time lost due to hardware or software problems. Basic tests performed included optical alignment; calibration of the focus pyramid; measurements of scale and distortion; ZP's; backgrounds; flat fielding, etc. Images and spectra were also obtained to test both the instrument performance and the operation of various software templates developed for automatic execution of the main observational and calibration modes. Two examples are the 'jitter' template, which generates random telescope offsets within a defined range between exposures and one for automatic slit centring of objects identified by mouse click on the Real Time Display (RTD) images.

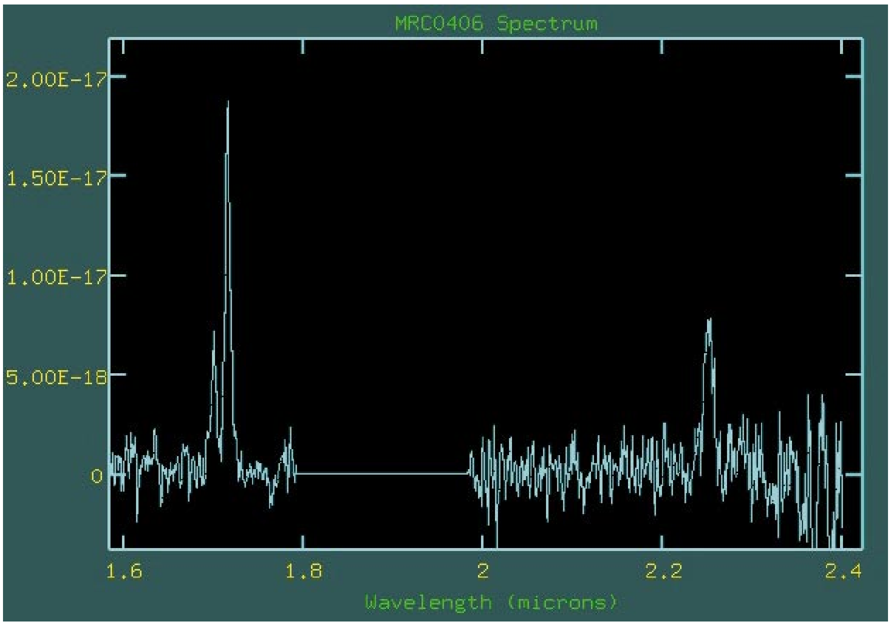


Figure 8: 1.6–2.5 μm 'red' grism spectrum of the z = 2.4 radio galaxy MRC0406-244 showing the redshifted 'visible' [OIII](5000 Å) doublet and Hα emission lines. The 1.8–2.0 micron region suffers from strong atmospheric absorption and has been removed. After identifying the Ks ~ 18 galaxy in a 1-min. imaging exposure and centring it in the 2″ slit (~ 70 Å), spectra were obtained by 'nodding' between two positions along the slit (for sky subtraction) for a total of 60 minutes. A provisional calibration yields fluxes of 7 and 9.10^{-16} erg/s/cm^2 for the [OIII] and Hα lines respectively.

Performance

Figures 3–9 show some of the test images and spectra which illustrate the new capabilities now offered by SOFI. (Some of these plus some not reproduced here can be viewed on the Web at http://www.eso.org/outreach/press-rel/pr-1998/pr-03-98.html). Details are given in the individual figure captions. Overall, the raw images are found to be flat to about 5% before and 1% after flat fielding and the derived point source magnitude limits of J ~ 22.9, H ~ 21.9 and Ks ~ 20.9 (s/n = 5 in 1 hr with 0.75 seeing) are consistent with or somewhat better than those predicted. Under the best seeing conditions experienced, the final images obtained after re-centring and stacking ~ 40 'jittered' exposures have FWHM around 0.6″ (with the 0.29″ pixel scale). Combined with the larger telescope and field plus somewhat higher instrumental efficiency this means that it should be possible to image a 5′ × 5′ field to a given depth up to about 50 times faster with SOFI than with IRAC2 at the 2.2-m telescope. Particularly pleasing is the fact that the Ks (2.16 μm) background is both slightly lower than and appears to be free of the low level, time variable, gradients experienced with IRAC2 at the 2.2-m telescope.

Given the excellent performance achieved overall, it is a pity to have to report the development of some coma in two corners of the large field when using the 0.29 arcsec/pixel LF objective. This has appeared since the first cryogenic tests made with the star simulator in Garching and is most probably due to decentring of one or more of the four, relatively heavy, spring-loaded lenses during temperature cycling. The possibility of replacing it is still being studied. In the meantime, the 0.26 arcsec/pixel 'spectroscopic' objective, used for the 30 Dor image on the front cover, may actually be preferred for some imaging programmes. This and the small field (SF) objective are also largely free of the unexpected appearance, also when using the LF, of extremely faint shadow 'images' of the telescope pupil which could be caused by dust and/or small scratches on the lens surface nearest to the detector (although this cannot be confirmed without opening the instrument). It is doubtful that these would have even been seen on an equatorially mounted telescope. Because of the pupil rotation in an alt-az telescope, however, 'images' of the spider can appear in sky subtracted images although, in practice, they were only seen in the Ks filter and are at or below the shot noise limit in all the 'jittered' images.

Future Plans

Despite this early success, SOFI still has to be fully commissioned during runs scheduled for March and May when it is planned to test the DMD supplied P2PP tool (for generating Observation Blocks) and imaging pipeline and to conduct Science Verification observations. These latter will include deep, follow-up infrared images of the 'NTT Deep Field' (see S. D'Odorico, 1997, *The Messenger*, 90, 1) which will be made generally available for scientific use by the community.

Acknowledgements

In addition to the ISAAC/SOFI Garching Team members mentioned in the article, we wish to thank the La Silla Infrared Team led by U. Weilenmann and the NTT Team led by G. Mathys for their excellent support during the SOFI installation and test. We are also grateful to N. Devillard of DMD for making the colour composite of Orion during his visit to prepare for the pipeline installation and to F. Selman in Santiago for making the one of 30 Dor.

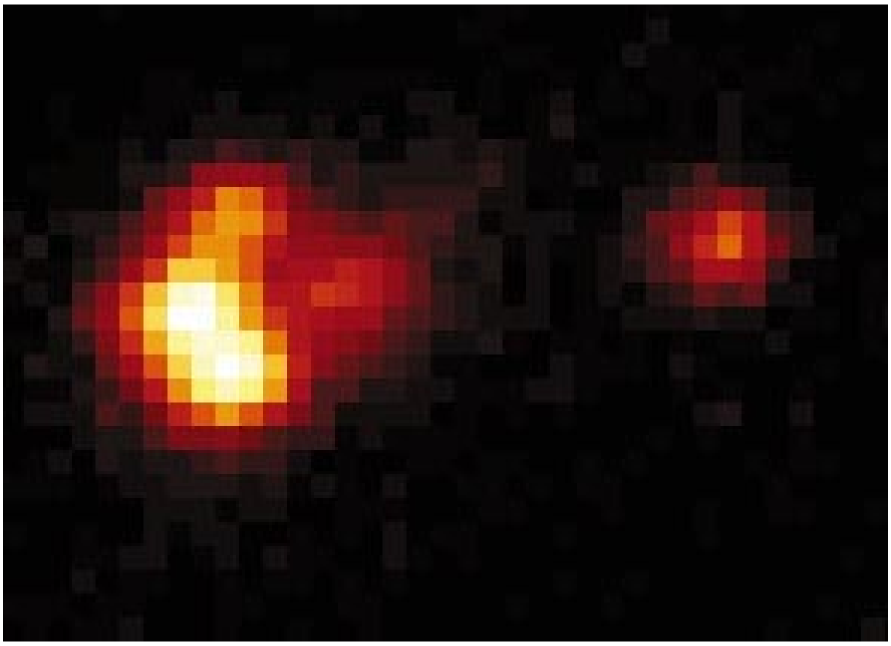


Figure 9: Ks (2.16 μm) 'jittered' (7 × 2 min.) image of the gravitationally lensed quasar RXJ 0911 obtained with the 0.14″/pixel objective. Visible in this small extract of the full image are the lensing galaxy plus three images of the quasar immediately to the left and one to the right.

The New Direct CCD Imaging Camera at the NTT

SUSI2 gets the first FIERA CCD controller and a mosaic of two 2k × 4k, 15 μm pixel, thinned, anti-reflection coated EEV chips

S. D'ODORICO, ESO

SUSI2: A Summary View

In 1995, the ESO Instrumentation Division got the green light for a two-step upgrade of the instrumentation at the NTT, in preparation to the key role that this telescope will have to complement and enhance the scientific output of the VLT Observatory. The first and major step was the infrared imager-spectrometer SOFI whose first observations in the sky are described in this Messenger issue. The second part of the upgrade concerned the direct CCD imager SUSI at the same telescope focus. In December 1995, ESO reached an agreement with the Osservatorio di Roma which provided approximately 40% of the instrument budget and supported the effort with 1 FTE, mainly in the CCD technical area and in the commission of the instrument at the telescope, in exchange for guaranteed observing time. The financial support of Rome permitted the project to proceed with an accelerated schedule without limitations from the ESO yearly budget.

The new CCD imager had the requirement of a substantially larger field (at least a factor of 4 improvement in area with respect to the SUSI 2.3 × 2.3 arcmin) and of a CCD camera of enhanced performance, both in terms of speed of readout and of QE in the UV-blue region. The larger field is needed to make studies of gravitational shearing over angular scales which are statistically significant and for survey work which can identify targets (e.g. high redshift galaxy candidates) for spectroscopy with the FORS instrument at the VLT in an efficient way. The higher QE in the UV-blue will make feasible very deep observations in these bands in affordable integration times. The measurements at the shortest wavelengths are essential to derive the overall spectral energy distribution of both galaxies and stars which is the key to understand their physical properties.

The opto-mechanical design was constrained by the need to fit in the 50-cm space between the adapter/rotator and the SOFI vessel (see Fig. 2 in the SOFI article in this issue). In the adopted configuration, a 45° mirror, which can be inserted in the optical beam, feeds, through the filter wheel, a mosaic of two new EEV 44-82, 2k × 4k, 15 μm pixel, thinned, anti-reflection coated chips. The resulting field is 5.5 × 5.5 arcmin with a pixel scale of 0.08 arcsec. The CCDs are driven by the new ESO-developed controller FIERA (for a description see 1998, Proceedings of the ESO Workshop on Optical Detectors, J.W. Beletic & P. Amico eds, Kluwer Academic Publ., p. 103). Other novel features of the instrument are a 8 cm × 8 cm sliding curtain shutter which permits exposures down to 0.3 seconds without vignetting and a special cryostat designed to operate on a rotating Nasmyth adapter.

SUSI2's opto-mechanical layout includes a second, off-axis, red optimised CCD channel which can be used in parallel to the first one. The implementation of this option in the year 1999 is under study.

SUSI2 has become operative at the telescope in a little more than two years

Figure 1: This colour picture of the galaxy NGC 2613 (estimated distance 19.8 Mpc) prepared by F. Pedichini (Rome Observatory) is the combination of 9 SUSI2 exposures in the I, V and B bands for a total of 12 minutes integration. North at the top, East to the left. The CCD mosaic gap of 8 arcsec aligned in the N-S direction has been filled in this combined image by the averaging of 3 dithered exposures in each band.

since the formal go-ahead of the project. This has been made possible by the extraordinary efforts of the project team at a time in which our resources go with first priority to the VLT and the successful development of the new format chips by EEV. With a field of view which is very similar to the one of SOFI, the instrument appears ideally suited to multi-colour studies which will complement and support the programmes carried out with the ISAAC and FORS instruments at the VLT. The instrument total cost was 750 kDM and 4 FTEs (ESO) +1 (Roma).

The First Test Results in the Lab and at the NTT

SUSI2 was first integrated at the telescope with an engineering CCD system in December 1997. The science grade CCDs arrived at ESO in December 1997 and January 1998. The average QEs for the two chips have been measured as: 350/76, 450/90, 550/82, 650/ 74, 750/58, 850/35 where the first number is the wavelength in nm and the second is the % QE. The other properties were in agreement or very close to the original specifications: CTE $>$ 0.999999, linearity within $\pm$ 0.2% over pixel full well of 145000 e^-.

Although severely affected by the bizarre "El Niño" weather of this year in Chile, the commission period just concluded at the end of February could be used to optimise the operation parameters of the CCD system at the telescope, to verify the operability of the instrument in the NTT environment and to measure the basic astronomical parameters of the instrument, such as scale, throughput, colour term and image quality.

FIERA at the NTT is presently reading the two chips in parallel, at 200000 pixels/port, second with a read-out noise of 4.6 e^-/pixel. This is limited by the speed of the Ethernet link between FIERA and the instrument WS: there are plans to upgrade this by the beginning of 1999 with the installation of an ATM connection as it is foreseen for the VLT instruments.

The total time from the end of an integration to the display of the image on the RTD monitor is 56 and 16 seconds for the full format 4k $\times$ 4k and the binned 2k $\times$ 2k format respectively. When compared with the readout times of other 2k $\times$ 2k chips in other La Silla instruments (EMMI, EFOSC2) the gain for equivalent sizes is more than 1 min per exposure, or between 1 and 2 hours in a typical night. The amount of data collected in a clear night (between 3 and 12 Gbytes, depending on the format used and the length of the typical exposure) required an upgrading of the disk memory at the telescope and will call for an upgrading of most of the data reduction facilities operating in the community.

The instrument throughput benefits from the higher QE of the CCDs and the higher efficiency of M4 and the cryostat window. The gain in speed of SUSI2 with respect to SUSI is larger than a factor of 5 in the UV and a factor of $\sim$ 1.5 in the B, V and R bands. The measured count rates for a star of 15 mag in the different bands are reported together with other relevant information on the instrument in the SUSI2 page of the NTT web site. The counts are in good agreement (better than 10%) with the values predicted by the instrument simulator available at the ESO web site for the purpose of proposal preparation. The image quality over the field of view could not be tested extensively due to lack of nights with very good seeing. The first data which have been analysed (see Fig. 2), point to an homogeneous image quality over the whole SUSI2 field down to at least 0.5 arcsec FWHM.

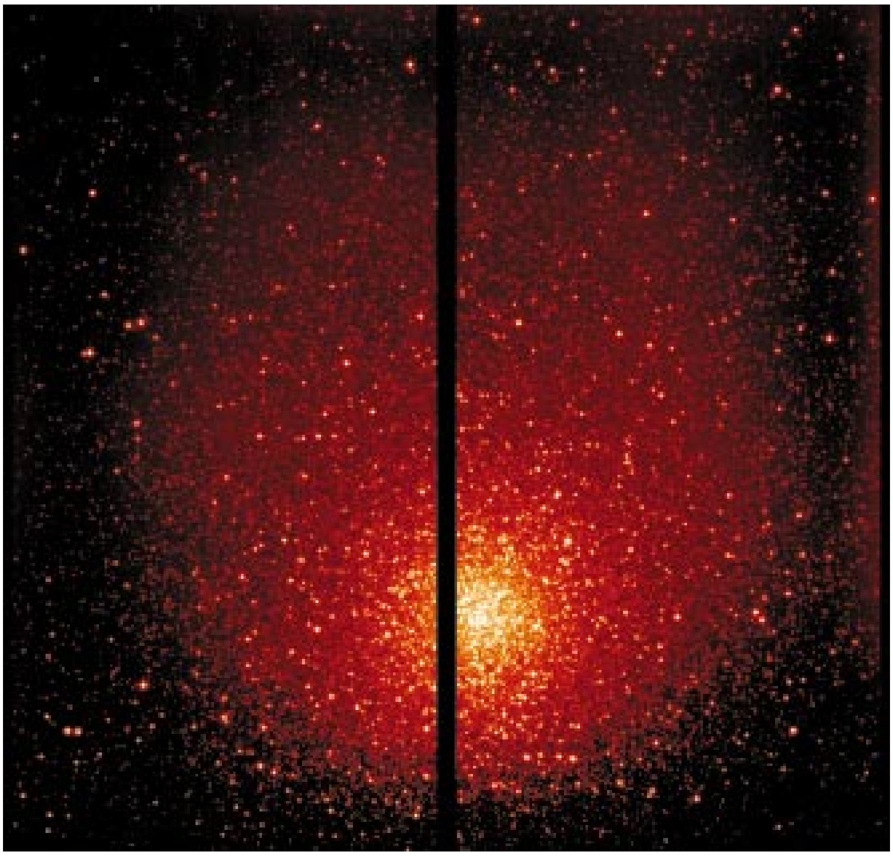


Figure 2: A 30 seconds, flat-fielded, unguided I band exposure of the globular cluster NGC 5286 which illustrates the format of the data from SUSI2. In the unbinned mode, in the x direction there is the prescan region, 2048 active pixels of the first CCD, 46 of overscan, 50 of prescan, 2048 active pixels of the second CCD and the overscan region. In the y direction there are 4096 pixels. The active CCD field corresponds to 5.5′ × 5.5′. This image was obtained in 2 × 2 binned format (0.161 arcsec/pixel). The number of overscan and prescan pixels (96) in the central region is chosen to match the physical gap between the two chips, which correspond to 8 arcsec approximately. The image quality measurement over the field gives an average FWHM of the gaussian fits of the stellar images of 0.48 arcsec. The ellipticity is less than 10%, homogeneous over the field and with a constant orientation.

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VIMOS and NIRMOS: Status Report

J.-G. CUBY and R. GILMOZZI, ESO

At its meeting in Milan in October 1996, the STC recommended the procurement of 2 instruments for imaging and massive multi-object spectroscopy, VIMOS and NIRMOS, as conceptually designed by the VIRMOS consortium. The STC further recommended that ESO reduce the overall development time to ensure that these new instruments are competitive, with respect to e.g. DEIMOS on the Keck telescope and GMOS on the Gemini Telescope.

Consortium

The VIRMOS consortium has accepted with enthusiasm the challenge of building these two instruments on a fast track. The consortium is made of French and Italian institutes, and is headed by Laboratoire d'Astronomie Spatiale (LAS), Marseille, France. The other institutes are:

• in France: Observatoire Midi-Pyrénées (OMP, Toulouse) and Observatoire de Haute-Provence (OHP);

• in Italy: Istituto di Fisica Cosmica del CNR and Osservatorio Astronomico di Brera (IFCTR-OABr, Milano), Osservatorio Astronomico di Capodimonte (Napoli) and Istituto di Radioastronomia CNR and Osservatorio Astronomico di Bologna (IRA-OABo, Bologna).

The VIRMOS consortium is led by Olivier Le Fèvre (P.I.), and Paolo Vettolani (Co-P.I.).

Science Objectives

The main objective of these instruments is the study, through massive deep surveys, of the early universe, when it was 10 to 20% of its current age. VIMOS will mostly observe objects of redshifts below 1 and above ~ 3 (when the Lyman discontinuity is redshifted into the B band), whereas NIRMOS will observe objects in the intermediate range of redshifts (for which there is virtually no spectral signature in the visible).

The main science objectives are:

• Evolution of field galaxies (primeval galaxies, galaxy formation and evolution, influence of merging and of environment)

• Evolution of large-scale structure (formation of structures, evolution, clustering, distribution of visible and dark matter)

• Evolution of galaxies in clusters

• Evolution of QSO absorption systems

In addition, these instruments are of high interest for many Galactic programmes, such as:

• Search / study of sub-stellar objects (brown dwarfs)

• Abundances and ages of stars in clusters and obscured regions

Instrument Concept and Capabilities

VIMOS and NIRMOS are four quadrant spectro-imager. Multi-object spec-

	VIMOS	NIRMOS
Field of view	$4 \times 7' \times 7'$	$4 \times 6' \times 8'$
Spectral range	370 –1000 nm	1100 –1800 nm (J & H)
Spectral resolutions	200 & 2000	2500
Multiplex gain	800 @ R = 300, 170 @ R = 2500	170
Detection limit range in spectroscopy:	V = 24–25	J = 21–22
Detectors	$4 \times 2k \times 4k$ CCDs	$4 \times 2k \times 2k$ IR arrays
Integral Field Unit (~ 5000 fibres)	$1' \times 1'$ / 0.8″ sampling, R = 200 30″ × 30″ / 0.8″ sampling, R = 2000 30″ × 30″ / 0.4″ sampling, R = 200 15″× 15″ / 0.4″ sampling, R = 2000	TBD

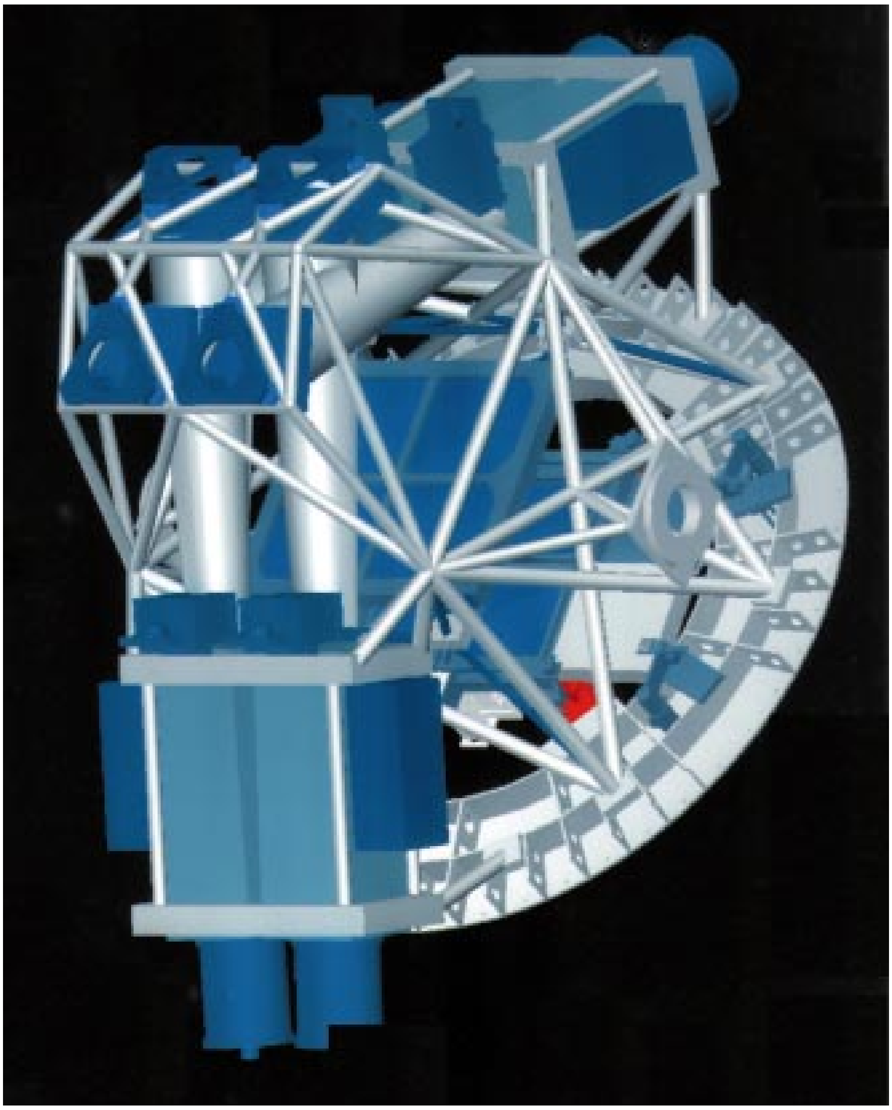
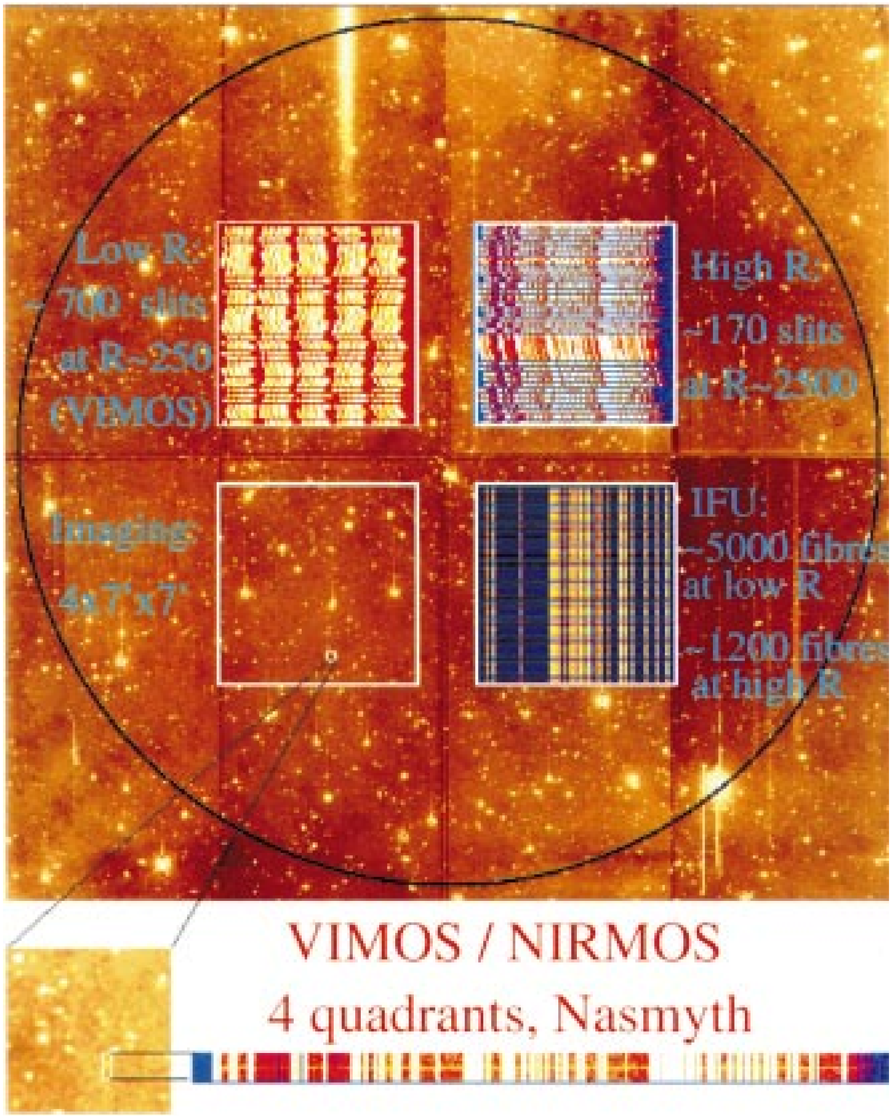


Figure 1: Preliminary VIMOS optomechanical layout. The four cameras, two on each side are clearly visible. The telescope focal plane is corrected and split in four quadrants. Four collimators provide images of the telescope pupil, after folding by flat mirrors, at the entrance of the cameras where the filter exchange units are (in blue on the figure at the entrance side of the four cameras). On the top of the four cameras are the grism exchange units. (Figure courtesy D. Mancini.) ▶

Figure 2: Illustration of the VIMOS and NIRMOS capabilities. The circle represents the Nasmyth field of view. The four squares are the instrument fields of view of the four channels. The four modes are represented: Imaging, low-resolution spectroscopy (VIMOS only), high-resolution spectroscopy, Integral Field Spectroscopy (tbd on NIRMOS). (Background image: courtesy Y. Mellier.) ▶



troscopy is achieved with masks, and the two instruments are complemented by the MMU (Mask Manufacturing Unit), to be located in the VLT buildings. Masks are inserted in cabinets holding up to 15 masks. The cabinets are manually installed in the instruments during daytime. VIMOS has in addition an Integral Field Unit providing contiguous low resolution spectroscopy with fibres in a field of view up to 1 arcmin × 1 arcmin.

Figure 1 shows the opto-mechanical layout of VIMOS.

In the IR (NIRMOS), only medium-resolution spectroscopy will be provided, as this is the most efficient way of observing faint targets between the OH sky emission lines.

VIMOS will reach very high multiplex gains at low spectral resolution, while NIRMOS will be a genuinely unique instrument world-wide.

Figure 2 illustrates the instrument capabilities.

Status

The contract between ESO and the VIRMOS consortium was signed in August 1997. The Preliminary Design Review of VIMOS and of the Mask Manufacturing Unit (MMU) took place in November. The Final Design Review will take place in July 1998.

The planning is the following:

Instrument	UT	Preliminary Acceptance in Chile
VIMOS & MMU	#3	May 2000
NIRMOS	#4	April 2001

Under discussion at the time of writing are the choice for the Mask Manufacturing Unit (milling machine or laser), and the material of the Focal Plane Corrector for NIRMOS.

ESO is responsible for the development and procurement of the four CCD cryostats of VIMOS, and of the 4 IR cryostats of NIRMOS. For VIMOS, continuous-flow cryostats with rotating feed-through are under consideration. For NIRMOS, it is expected to use 2k × 2k IR arrays currently under development at Rockwell. ESO is participating in the development contract, and expects to receive the first science grade array by the end of 1999.

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VISIR at PDR

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In 1995, we were reporting in this journal about the phase A study of VISIR, the VLT Imager and Spectrometer for the mid InfraRed [1]. Since then, the status of the instrument has evolved a lot. In November 1996, the contract to build VISIR was signed [2]. VISIR is built by a French-Dutch consortium of institutes led by the Service d’Astrophysique (SAp) of Commissariat à l’Energie Atomique (CEA, Saclay, France). The Dutch partner is the Netherlands Foundation for Research in Astronomy (NFRA, Dwingeloo, the Netherlands). Other contributing institutes are the Institut d’Astrophysique Spatiale (Orsay, France) and the Netherlands Foundation for Space Research (SRON, Gro-

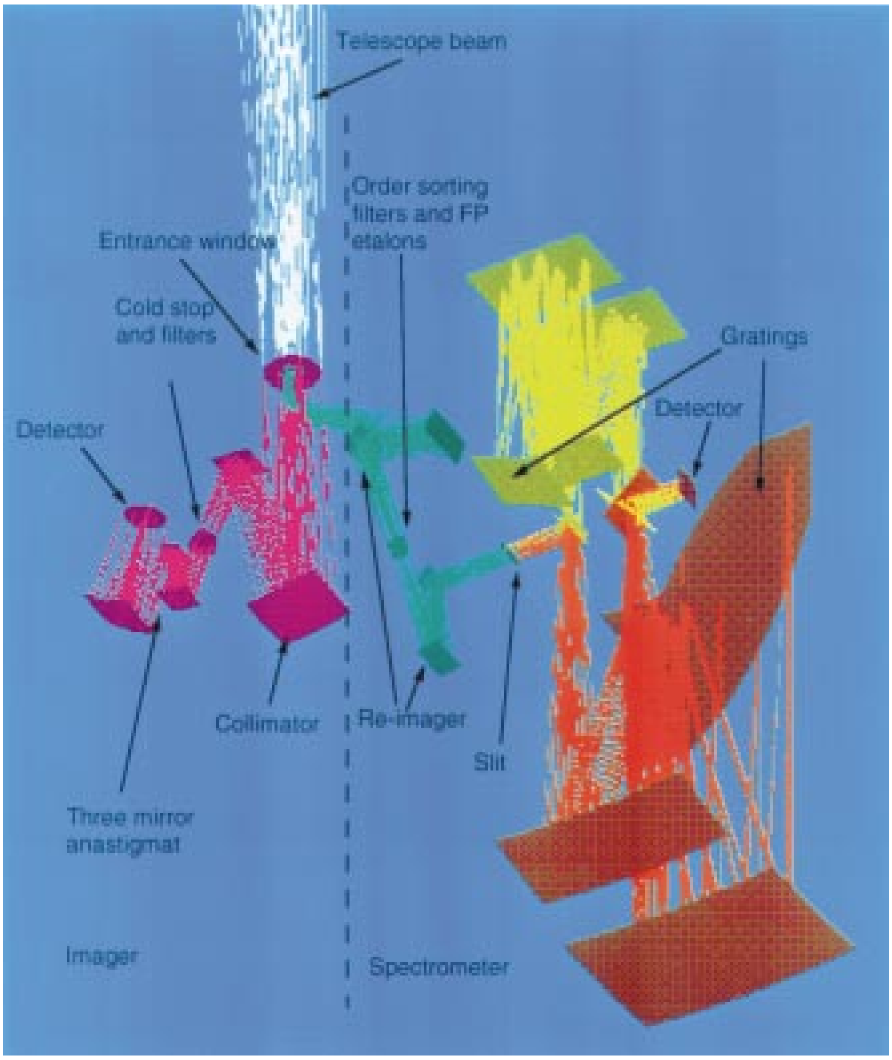

Figure 1: Overview of the optical layout of VISIR. The beam from the telescope is coming from the top. The imager, in pink, is on the left side of the diagram; the spectrometer is on the right side of the diagram. One can see the re-imager unit of the spectrometer in green, the low- and medium-resolution arm in yellow, and the high-resolution arm of the spectrometer in red. The re-imaging unit of the spectrometer was not shown in [1], because we had presented the option where the imager was used as re-imaging unit. This option was no longer viable with the new optical design. The spectrometer re-imaging unit consists of two concave off-axis paraboloids, two folding flats and a cold stop. The order selection filter wheel and the Fabry-Pérot wheel are located immediately behind the cold stop.

ningen, the Netherlands). One year after the signature of the contract, VISIR has reached the Preliminary Design Review (PDR) level. An abundant documentation has been written for this review (5 kilograms of papers!)[1]. A (25-gram) summary of the results of the preliminary design studies is given hereafter.

1. Scientific Aspects

1.1 Observing modes

As VISIR is the only VLT instrument working in the mid-infrared atmospheric windows (the N band, between 8 and 13 μm, and the Q band, between 16 and 24 μm), it has to cover a large range of observing modes. Those modes are:

[1]The full package can be obtained upon request to Lagage@CEA.fr

• imaging over a field up to about 1 arcmin with a choice among three scales (0.075, 0.127, 0.200 arcseconds per pixel) and with a choice among 40 narrow- and broad-band filters.

• long-slit ($> 30''$) grating spectroscopy with various spectral resolutions (350, 3200, 25000 at 10 μm; 1600, 12500 at 20 μm).

1.2 Comparison with ISO

VISIR will naturally be an ideal instrument for ISO follow-up observations. The great success of ISO ensures that a large community will use VISIR. The main advantage of VISIR over ISO will be the much higher angular resolution that can be obtained with the 8-metre VLT mirrors, which are expected to be diffraction-limited in the superb Paranal seeing. The diffraction airy disk of ISO (FWHM of 3.5″ at 10 μm) will be resolved into more than 100 elements with VISIR. The situation is even more favourable for the VISIR spectrometer, whose spatial resolution of $0.5'' \times 0.25''$ has to be compared to the $14'' \times 20''$ entrance aperture of the ISO Short Wavelength Spectrometer (SWS).

The comparison of the expected sensitivity of VISIR with the measured sensitivity of SWS (see Table 1) shows that VISIR should beat ISO, especially at high spectral resolution (of course in the limited wavelength range accessible from the ground). The same is true when we consider the wavelength range covered in one setting of the grating.

At low spectral resolution, ground-based telescopes cannot compete with space facilities in terms of sensitivity, because of the large photon background generated by the atmosphere and the telescope. However, with an expected VISIR sensitivity in its imaging mode around 1 mJy (10 sigma 1 hour) in the N band, follow-up observations of many ISO objects will be possible. Note also that the observing time needed to reach a given signal over noise ratio on a point source from the ground is inversely proportional to the telescope diameter to the fourth power (D^4). Thus 1 hour of point source observations with VISIR will be equivalent to 2 nights of observations with a Mid-IR instrument on a 3.6-m telescope.

Apart from ISO follow-up programmes, key programmes such as the study of “post planetary” dust disks around main or pre-main sequence stars, with as best example the 41-Pictoris dust disk [3], will profit greatly from VISIR.

1.3 Operation plan

Astronomers familiar with ISO observations (or more generally with observations from space facilities) will not be surprised by the scientific operations of VISIR (and other VLT instruments). Given the complexity of VLT instruments, those instruments can only be used efficiently through well-defined Astronomical Observing Templates (AOTs). A preliminary set of three basic AOTs has been identified for VISIR. One template is devoted to imaging observations with the classical chopping and nodding technique. To account for the huge flux difference received by the spectrometer depending on the spectral resolution, two templates have been reserved for spectroscopic observations. One template corresponds to observations at low spectral resolution in the N-band and at medium spectral resolution in the Q-band with chopping and nodding. The second template corresponds to observations at medium spectral resolution in the N band and at high spectral resolution in the N and Q bands with only nodding. These templates are not supposed to cover all the observing possibilities, but are expected to cover a large fraction of the observer's needs. A discussion of these templates with the VISIR science team appointed by ESO and chaired by M. Rosa has been initiated.

A key element in the successful use of an instrument is its calibration. Various calibration tools have been incorporated in the VISIR design; for example, a wheel with fixed Fabry-Pérot etalons has been included in the spectrometer in order to calibrate accurately the wavelength. A preliminary calibration plan has been written. The basic idea of this plan is to ensure that each observing template will always be associated with a corresponding calibration.

The data reduction will be part of the general data-flow system developed by ESO [4]. Specific VISIR data reduction algorithms will be provided by the consortium to the data flow division.

2. Instrument

2.1 Detectors and associated electronics

Two potential suppliers of large-format detector arrays for mid-IR ground-based instruments exist: Santa Barbara Research Center (SBRC), Santa Barbara (US) and Boeing (previously Rockwell), Anaheim (US). The arrays for ground-based use are characterised by a large storage capacity ($> 10^7$ electrons), needed to "absorb" the huge photon background generated by the atmosphere and the telescope. In the mid-IR domain, large format means 256 $\times$ 256 pixels for Boeing and 320 $\times$ 240 for SBRC. This is not yet large enough to have a field of one arcmin with an adequate sampling of the telescope diffraction pattern (0.127″ per pixel at 10 µm). That is why the imager needs to have several magnifications.

The development of these arrays has taken much more time than expected. Even if the first arrays now exist, optimisations are still needed, for example in terms of noise. Our aim is to be able to test these arrays at Saclay, in the operating conditions of VISIR. We are setting agreements with each of the two suppliers to this purpose. Those BIB (Blocked Impurity Band) Si:As detectors are convenient both for 10- and 20-µm observations. The figure of merit of a given detector in an imaging mode or in a spectroscopic mode is not the same. For example, dark current is much more crucial for a spectrometer than for an imager. Each of the two subsystems of VISIR, imager and spectrometer, will therefore have its own detector array.

The electronics associated with the detector should provide the clock drivers and biases to control the detector and the 16-bits analogue-to-digital conversion of the detector output signals. Even with the large storage capacity of the detectors, the frame rate can be up to 500 images per second. A data cruncher is thus needed. We have developed a preliminary design of the detector electronics largely based on commercial cards. For operational reasons, ESO would prefer us to use the ESO IRACE system [5]. We are presently investigating this possibility.

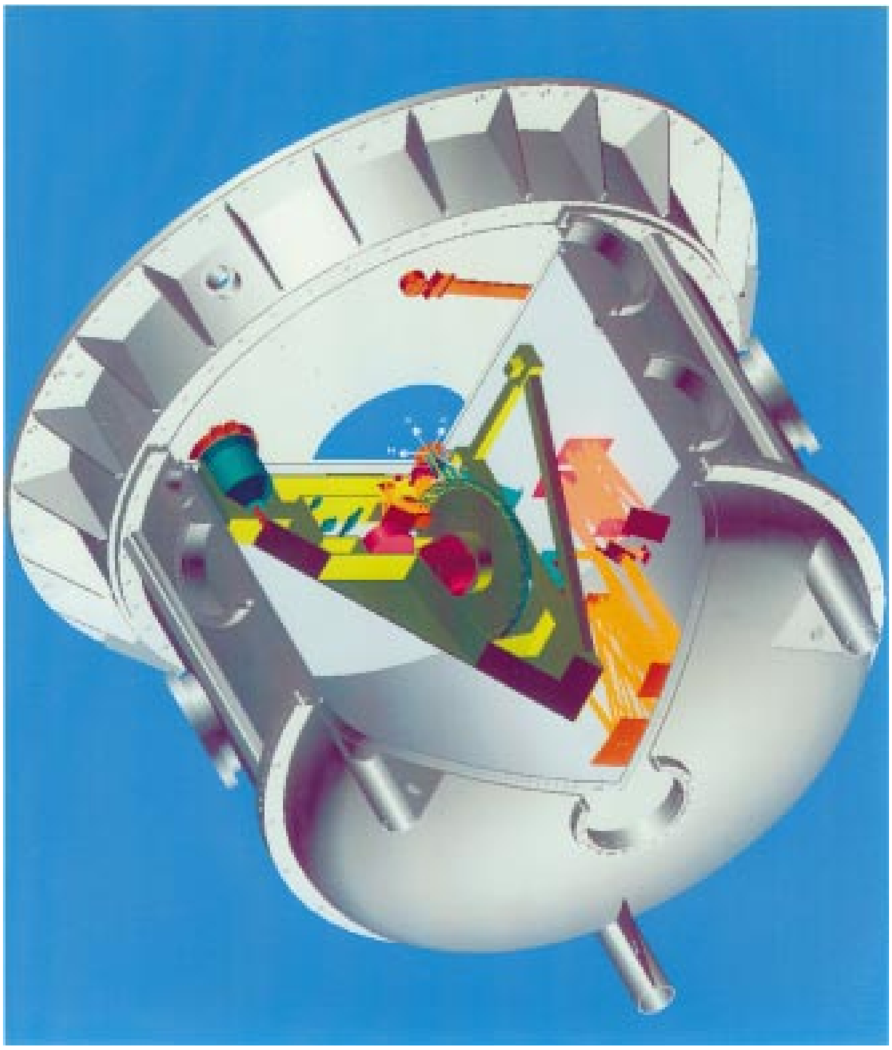

Figure 2: Drawing of the VISIR enclosure, "opened" to show a schematic drawing of the imager mechanical structure. The cryostat is a cylinder of length 0.7 m and diameter 1.2 m. The weight of the cryostat and of the enclosed optical bench is 1 ton. When we consider the total weight of VISIR (cryostat, pumps, cable wrap, electronics boxes ...), we are only 10% below the limit of the VLT unit (2.5 tons).

TABLE 1: VISIR Spectrograph sensitivity versus ISO-SWS sensitivity, as well as the wavelength coverage in one shot.

	Spectral Resolution		Signal/Noise for 1 Jy point source		Wavelength Coverage (km/s)	
	VISIR	SWS	VISIR	SWS	VISIR	SWS
N band	3200	1500	24	20	6500	2000
	25,000	20,000	14	0.14	850	100
Q band	1600	1100	5	40	6500	2750
	12500	25000	3	0.3	850	100

2.2 Optical design

A general sketch of the optical design of VISIR is shown in Figure 1.

2.2.1 Imager

The optical design of the imager has been completely changed since the Phase A report [1]. Because of bad experiences when testing the material considered for the optics at 20 µm (CdTe), we have moved from a lens design to a mirror design. Five mirrors are on the optical path (see Fig. 1). The first mirror

Figure 3: Test equipments of VISIR. One can see the test cryostat mounted on its integration support, which allows to simulate the telescope position and to measure the mechanical flexure.

is a concave aspherical collimator mirror, which provides an 18-mm cold stop pupil in parallel light (as usual for infrared instruments, the pupil of the telescope is imaged on a cold stop mask to avoid straylight). The second mirror is just a folding flat mirror which eases the mechanical implementation, especially of the two filter wheels immediately behind the cold stop. The last three mirrors form a Three Mirror Anastigmat (TMA) configuration, similar to the TMA systems used in the VISIR spectrometer. They ensure the re-imaging of the field onto the detector. The three magnifications required for the imager are obtained by three sets of TMA mirrors mounted on a wheel. The optical calculations have shown that the image quality of the system is excellent (well below the telescope diffraction limit).

2.2.2 Spectrometer

The optical design of the spectrometer has not changed very significantly since the completion of the Phase A study, and the reader is referred to [1] for details on the design. We only recall that, like the ISAAC instrument [6], it is a long-slit grating spectrometer based on TMA systems in double pass, (pass 1: collimator, pass 2: camera). The spectrometer has two arms, one for the low- and medium-resolution modes; the other for the high-resolution mode, which is based on the ‘duo-echelle’ concept: two large echelle gratings mounted back-to-back on one 350 × 130 mm blank. The opto-mechanical design allows for the implementation of an array with up to 512 × 512 50 μm pixels in the focal plane of the spectrometer. The implementation of two 256 × 256 arrays along the wavelength axis would double the efficiency of the instrument for many observations; but at the moment only one detector array is funded.

2.3 Mechanical and cryogenic design

2.3.1 Cryogeny aspects

To avoid prohibitive dark currents, mid-IR detector arrays need to be operated at a temperature around 6–8 K, much lower than near-IR or visible arrays. The optics and associated mechanical structure has also to be cooled, so that the amount of background photons radiated by these elements becomes negligible compared to background photons generated by the telescope and the atmosphere. A temperature lower than 35 K is required for the spectrometer optical bench. To avoid thermal gradients, the imager will be at the same temperature, even if a temperature up to 60 K could be accepted for this subsystem. A lot of intelligence will still be invested in the detailed studies to prevent “hot” photons from penetrating the heart of VISIR, e.g. via cables. That is the real difficulty of VISIR compared to instruments operating at shorter wavelengths.

The cooling of detectors down to 6–8 K with two-stage closed-cycle coolers was a problem at the end of the phase A study. The use of three-stage cryocoolers or even of liquid helium was considered. Such solutions were a pain in terms of technical operations and maintenance, which are crucial aspects in the VLT context. Recent developments on two-stage commercial cryocoolers allow now cooling power of 1 W at 4.2 K, which fulfils VISIR detector requirements.

Three cryocoolers are needed, one for the imager (detector 6–8 K, structure 35 K), one for the spectrometer (detector 6–8 K, structure 35 K) and one for the radiation screens (100 K) and the detector baffles (15 K).

A pre-cooling system based on the circulation of liquid nitrogen will be implemented in order to reduce the time to cool the instrument from room temperature down to 80 K to 8 hours, instead of 60 hours with only the cryocoolers.

2.3.2 Mechanical implementation

The mechanical structure of VISIR is made of two autonomous substructures: the imager optical bench and the spectrometer optical bench. Typical dimensions of the subsystem are 0.85 × 0.6 × 0.3 m for the spectrometer and 0.6 × 0.6 × 0.14 m for the imager. These two structures are connected isostatically in three points and together form a rigid unit, which in turn is connected isostatically in three points to the main structure inside the VISIR cryostat (see Fig. 2).

Given that VISIR is a cryogenic instrument, leading design criteria are: high stiffness-to-weight ratio, low mass and high thermal stability. It appears that the design goals of 40 kg for the imager and of 80 kg for the spectrometer can be achieved. A special effort has been done at Dwingeloo to lightweight the aluminium blanks of the duo-echelle and the TMA mirrors. Weight reductions of 70–80% with respect to solid blanks have been achieved without degrading the optical performances.

2.3.3 Flexure analysis

The instrument has to be stiff enough in order not to perturb the observations. The specification is a shift of the image on the detector by less than a pixel (50 μm) in one hour of observations. The analysis of the first mechanical structures has shown that we were able to fulfil the specifications. The results of finite element mechanical calculations have been injected into the optical model in order to compute the impact of mechanical deformations on the optical quality. Such a coupling between an optical model and a mechanical model has been done both at Saclay and Dwingeloo. Further optimisations of the mechanical structure will be done during the detailed study of VISIR.

2.4 Motorisation

There are a lot (16) of mechanisms in the cold part of VISIR. All the mechanisms, except those for the fine setting of grating positions, will use the same motor unit. This unit is a novel development, which combines in a very compact manner (outer diameter 100 mm, inner diameter 32 mm, thickness 37 mm), a space qualified stepper motor used in direct drive, a “dog” (tooth clutch) system which locks the mechanism in accurate discrete positions and bearings.

The power is down when the movable part is in position. Typical duration for movements will be 2 seconds and repeatability accuracy is expected to be 1 micron at 10 cm from the axis, as demonstrated with our warm dog prototype.

The grating scanner mechanisms are close copies of the scanners applied in the SWS and LWS spectrometers of ISO. These scanners are servo systems with linear motors as actuators and high-resolution LVDTs (Linear Variable Differential Transformers) as encoders. Adaptations of the SWS/LWS scanners for VISIR are being developed by SRON, (Groningen, the Netherlands).

2. 5 Control/software

The Control and associated software represent a heavy load. This work was not our priority during the predesign studies. Our group is well used to this aspect of an instrument and a lot of work has already been done for ISAAC, which will be used as a model.

3. Tools and Test Equipments

Final integration and tests of the instrument, which are the latest phase of a project, generally suffer from the cumulative delays which have happened in the earlier phases of the project. Then those tests are done under heavy time pressure. In order to avoid such a situation, we have decided to start very early in the project the construction of all the test and handling equipments and to prototype in full size many parts of VISIR. The VISIR test cryostat and integration support are already available, as can be seen on Figure 3. The installation of the test equipment has prompted the safety analysis of VISIR. We have the approval of the CEA internal safety panel to operate VISIR and its handling equipments at SAp.

Our early intensive test approach should prevent us from bad surprises during the final integration and tests, and help us to meet the contractual delivery date of VISIR at Paranal, beginning of 2001. The ESO decision to move VISIR from telescope unit 2 to telescope unit 3 should not prevent us from starting the commissioning of VISIR on telescope soon after arrival on site. Scientific observations are expected to start shortly after the commissioning, in the second semester 2001.

Acknowledgements

We wish to thank our VISIR colleagues who contributed so much to a very promising VISIR design and who are too numerous (23) to be quoted here. We also thank the members of the ESO infrared group and the PDR review panel for their numerous constructive comments. Our special thanks go to the panel chairman, Jason Spyromilio, who conducted the review with maestria. We use this occasion to salute Anton van Dijsseldonk, who is leaving ESO and will be missed by the VISIR team.

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[5] M. Meyer et al., 1996, *The Messenger*, **86**, p. 14.
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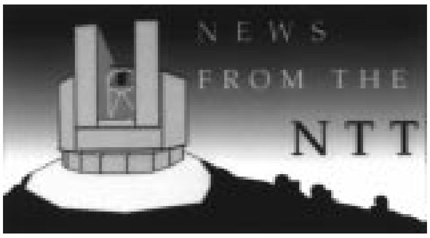

NEWS FROM THE NTT

G. MATHYS, ESO

The relatively quiet situation that had prevailed at the NTT since the return into operations (see the News from the NTT of *The Messenger* No. 90) has come to an abrupt end beginning of December. Since then, the NTT has been the scene of a quick succession of events, which will be reported below in chronological order of occurrence.

SOFI

The installation of SOFI was the first major technical intervention scheduled at the NTT since the end of the big bang. The readers of *The Messenger* have already had various opportunities to get acquainted with this instrument, the first one of the VLT generation. Indeed, the acronym SOFI stands for Son OF ISAAC. It may not be necessary to recall that ISAAC, an IR imaging spectrograph, will be one of the first two instruments to be mounted on UT1 of the VLT. As suggested by its name, SOFI is essentially a scaled-down version of ISAAC. There are many similarities between the two instruments, all the way from the opto-mechanical design down to the control software, which is common to both.

At the NTT, SOFI takes the place on the Nasmyth focus A that has been left vacant by the decommissioning of IRSPEC at the end of June 1996. IRSPEC had already been dismounted during the big bang year. By end of November 1997, SUSI, which had been sharing adapter A with IRSPEC, was, in turn, decommissioned. This was needed because the adapter flange on which SUSI was mounted had to be replaced by a new one, required by SOFI. This new adapter flange furthermore bears SUSI2 (of which more below). As soon as SUSI had been removed from the telescope, the installation of SOFI started. This installation proceeded very smoothly, and the performance of the instrument turned out from the first moment to be very promising.

SOFI is operated from a dedicated workstation, *wsofi,* whose dual-screen console has taken place in the EMMI control room. Another sign of the presence of SOFI which is perceived immediately by the visitor entering the NTT building is the SOFI “heartbeat”, that is, the sound of the Closed Cycle Cooler, which is permanently heard throughout the building and has already become one of its landmarks.

The reader will find more details about the installation of SOFI and SUSI2 at the NTT and preliminary information about the instruments’ performance in separate, dedicated articles in this issue of *The Messenger*.

A New Release of the VLT Common Software

The VLT common software, which is the cornerstone of the NTT control system, keeps being developed. At regular intervals (6 months, for the time being), a new “official” package of this software is released, which contains the most recent versions of the various modules that have been fully tested and debugged off-line by the developers. This new release is then ported to the telescope. This is true not only in the current period of pre-VLT development: it is foreseen to apply the same scheme once the VLT has come into operations. Indeed the software will keep being updated then, to fix problems, to improve performance, and to expand functionality.

During the first six months of operations, the NTT has been running the May 97 release of the VLT Common Software. In January 1998, this version was replaced by the one of November 1997 (in short, VLTSW NOV97). The implementation of the latter took place during a suspension of the operations scheduled from January 8 to January 20 (the last 3 days were devoted to tests of SOFI, in parallel with the final checks and bug fixes of the new software release). The step from VLTSW MAY97 to VLTSW NOV97 was a major one, because it also involved an upgrade of the operating systems of the HP workstations (from HP-UX 10.10 to HP-UX 10.20) and of the LCUs (Local Control Units, on which Tornado was installed). The change affected the telescope and all of its subsystems as well as the EMMI and SUSI (or SUSI2) instruments, but SOFI, which has not been commissioned yet, was left aside for later intervention. The installation was performed by the NTT Team with the support of the La Silla Software & Communication Team and of members of the VLT Division sent from Garching to La Silla to this effect.

The newly installed version includes many changes with respect to the previous one which are almost invisible for the casual user, and which were made e.g. to improve the overall robustness of the system or to provide a better platform for implementation of some VLT specific applications. However, the impact of some modifications can be perceived right away. For instance, overheads in the executions of observation templates have been drastically reduced thanks to the combination of improvements made at the level of the EMMI/SUSI Observation Software and in the templates themselves. Also changes made on the autoguider and image analysis modules have allowed the ranges of magnitude of the stars to be used for guiding and for analysis of the wavefront to be better matched, so that executions of image analysis in parallel with scientific observations, hence closed-loop active optics operation, have become possible. This possibility has now started to be exploited in regular operations, where it is expected to contribute effectively to the achievement of optimal image quality.

Regrettably (but probably not quite unexpectedly, given the magnitude of the change performed), some new problems have appeared with the installation of VLTSW NOV97, which may either be bugs of this release or already existing weaknesses that surface or are emphasised by differences in the use of the system with respect to the previous software version. These problems are currently under study, and one can reasonably hope that it will be possible to fix them within the next few weeks. The most prominent ones are:

– most LCUs from time to time reboot themselves spontaneously, without obvious reason;

– the technical CCDs (autoguiders, EMMI slit viewer, image analysis cameras) fail unpredictably at irregular time intervals (typically a few times per night);

– read-out of the EMMI CCDs hangs infrequently.

In spite of those newly introduced difficulties, the installation of VLTSW NOV97 has to a large extent been successful. This is an extremely positive result for the VLT, since the software version that will be initially installed on UT1 should be very close to the current NTT version. Also, for the longer term, the work that has just been done at the NTT gives confidence that it will be possible to perform similar upgrades at the VLT on a regular basis, as planned. Of course, lessons will be drawn from the analysis of the difficulties encountered this time, in order to make future interventions of this kind smoother and safer.

Data Flow

Some of the readers of this column will remember that the NTT has been, since its return into operation, running a temporary application for file transfer between different workstations, and that transfer of the data taken at the NTT to the archive group in Garching was made through DDS tapes (see the News from the NTT in *The Messenger* No. 89). This somewhat primitive mode of operations had had to be adopted because it had been impossible to bring the data transfer chain to a sufficiently stable state on time for the beginning of NTT operations. The time elapsed since has been taken advantage of to modify the archive chain in order to increase its reliability. As a result, a new version of this chain was released, and it was installed at the NTT in parallel with the new version of the VLT common software. The new transfer chain has proved much more robust than the one tested in June 1997: accordingly, it has been decided to bring it into operations.

At the front end of the data flow, the use of the Phase 2 Proposal Preparation (P2PP) tool, of the Observing Tool (OT), and of the High-Level Observing Software (HOS, aka BOB – Broker of Observation Blocks) to handle the Observation Blocks (OBs) has been described in some detail in the News from the NTT of *The Messenger* No. 90. These tools worked very well, but their use, initially intended for and well suited to service observing, proved rather awkward in classical observation, and many visiting astronomers have expressed their wishes for an improvement at that level. They have been heard, and a visitor mode of P2PP (referred to as P2PP/VM) has been implemented. Major improvements of this upgraded tool are enhanced facilities for edition and modification of OBs, and the fact that P2PP/VM talks directly to BOB without need for explicit communication with the OB database and for passage through the OT (database handling is still done but is fully transparent for the astronomer).

On the other hand, new developments have been made for service observing too, with the installation, at the end of January, of the prototype version of a Short-Term Scheduler (STS). The STS handles a list, established by the Medium-Term Scheduler (for the time being, a human being), of OBs to be executed during a given time interval (series of nights – typically a service observing run of a few nights), and determines an optimal time of executions of each observations according to some pre-defined criteria. The output of the STS is updated in real time according to the current meteorological conditions and to the history of the observations already performed, so that at any given moment, the service observer sees in the short-term schedule which is the OB best suited for execution. The first version of this tool which has been installed at the NTT is still preliminary in many respects, but its first tests during the service observing period of January 30 to February 5 have been quite promising and have yielded a large number of indications that will be exploited for the development of an improved version. The STS will continue to be used during the remaining service observing runs of Period 60 to gain more feedback for future developments.

The NTT Team has taken advantage of the installation of VLTSW NOV97 and of new versions of P2PP and OT to introduce a new release of the observation templates, which features increased functionalities of the already existing templates as well as a set of brand new templates (e.g. for observations in the dichroic medium-dispersion mode of EMMI).

Furthermore, in the new template release, the cryptic keywords that were displayed on the P2PP user interface were replaced by more explicit “labels”: for instance, WIN1.UIT1 has become “Exposure time”. This should make the use of the P2PP tool and templates more user-friendly.

SUSI2

Beginning of February, the installation of SUSI2 at the NTT started. Let us recall that SUSI2 is an imager, which uses as a detector a mosaic of 2 CCDs of 2k × 4k, with a pixel size of 15 µm. The resulting field of view is approximately 5′ × 5′ (about 6 times as large as the field of view of SUSI), with a sampling of 0.08″ per pixel. As a matter of fact, the opto-mechanical part of SUSI2, which is attached to the adapter flange, had already been on the telescope since the SOFI installation in December. But a major step remained to be done in February with the arrival of the CCD and of its controller. At that level, SUSI2 features two premieres: the first new ESO controller FIERA to come into operations and the first new-generation EEV CCDs. FIERA is the controller that will be used for the VLT scientific CCDs, and EEV CCDs will be used in various instruments at the VLT, starting with the test cameras to be used for first light and during commissioning, and later on in FORS and UVES; they will also be found in the Wide-Field Imager on the 2.2-m telescope on La Silla. Hence the test represented by the installation of SUSI2 at the NTT is a critical one for the future of CCD-based instrumentation at ESO.

This is written just before the beginning of the SUSI2 commissioning period. Accordingly, it is too early to present definitive conclusions. However, it can already be mentioned that the preliminary tests carried out during the installation period yielded quite promising results, both with respect to the performance of the EEV CCD mosaic and of the FIERA controller, and with respect to the image quality achieved. The reader can find a more detailed report in a separate article in this issue of *The Messenger*.

On the control system side, SUSI2 presents a lot of similarities to SUSI, and the Observation Software of the new instrument derives directly from that of its predecessor. In particular, the astronomers interact with the system through a set of templates bearing the same names and having essentially the same functionalities as the old SUSI templates (even though the adaptation of the templates to SUSI2 has been accompanied with an almost complete re-coding in order to improve their performance and robustness).

Telescope News

In the News from the NTT in *The Messenger* No. 87, J. Spyromilio had described in some detail the optical realignment of the telescope that had been performed as part of the big bang. In particular, he had noted that, although the intervention had been mostly successful, it had not been possible to adjust optimally the secondary mirror (M2), which was only marginally within the specified limits. The practical impact of this was an extreme sensitivity of image quality towards the edge of the EMMI field of view to the configuration of the primary mirror and to the telescope focusing. With time, this had proved critical, since small changes of the telescope conditions during an integration (such as, e.g., a drift of the temperature of the Serrurier structure by 0.5°) could yield unacceptable image degradation (elongations of several tens of percent) away from the EMMI field centre.

The problem was followed up, and further analysis, based in particular on mappings of the astigmatism with the image analysis system throughout the field reachable with the guide probes, allowed us to understand better its origin and to devise a corrective action. The latter was executed in the beginning of February. Its outcome was a spectacular reduction of the amount of field astigmatism by a factor of approximately 6, which reflects the fact that M2 is now very well aligned.

On the other hand, study of the problem of telescope pointing degradation reported in these pages in the last issue of *The Messenger* has continued. In particular, telescope pointing performance has been put under regular monitoring. As part of this monitoring, a large pointing jump, of the order of 30″, has been observed at the time of the earthquake of October 14, which with its epicentre close to Ovalle, has been the strongest one affecting La Silla in a long period of time. Since then, the NTT pointing has behaved very well, showing no other large sudden variation and achieving a performance close to specifications. This is somewhat surprising, since before October 14, pointing errors of up to 20″ were appearing on timescales of a few days. The much improved behaviour of the telescope pointing over the last few months is, of course, welcome, but not understood yet. One can, for the time being, only speculate about possible causes of the degradations previously occurring: for instance, unrecognised seismic activity or seasonal effects (e.g., some unexpected sensitivity to temperature below a certain threshold). This lack of understanding is unsatisfactory, especially because the reappearance of the problem at any time cannot be ruled out. Accordingly, the NTT Team keeps actively studying and monitoring this issue.

Staff Movements

The last three months have seen an unusually large number of changes in the composition of the NTT Team. This is partly due to the facts that the NTT upgrade project is nearing completion and that the integration of the first unit telescope of the VLT is well under way.

In the middle of December, José Parra became the NTT Team's second Data Handling Administrator. He is one of the two Data Management Division members undergoing a training in the area of VLT Data Flow Operations at the NTT before being transferred to the VLT. His main tasks are the preparation of the CD-roms for data archiving and the maintenance of the databases.

End of December, Percy Glaves and Roberto Rojas left the NTT Team to go back to the La Silla Software & Communication Support Team, which they had left temporarily to participate in the NTT upgrade. Percy is taking up new duties, becoming one of the La Silla System Administrators. Roberto's assignment is a genuine continuation of his work at the NTT: he is one of the VLT Software programmers participating in the upgrade of the 3.6-m telescope (in particular, he is developing the control software of EFOSC2). He will also continue to give occasional support to the NTT when required.

End of January, two more software engineers, Marco Chiesa and Thanh Phan, left the NTT Team. They had joined it early in the upgrade project, first in Garching and then on La Silla, and had accordingly participated in most of the developments of the new control system. This involvement had from the start been intended as a preparation for the VLT, and along this line, Marco and Thanh have now moved to Paranal to participate in the integration of the first Unit telescope. The vast experience that Marco and Thanh have acquired through work at the NTT will undoubtedly be extremely beneficial for the VLT.

Finally, end of January was also the time of departure for Griet Van de Steene, after three years of fellowship at ESO. During that time, Griet had been the astronomer in charge of monitoring the performance of the NTT CCDs and of co-ordinating maintenance and corrective actions in this area with the Optical Detector Team. The dedication and the commitment to excellence that she showed in the execution of these tasks served the astronomical community even better than the many introductions that she gave to visiting astronomers, which have always been highly appreciated by the latter. Griet has now joined Mount Stromlo and Siding Spring Observatories, in Australia. She will soon be replaced by a new fellow.

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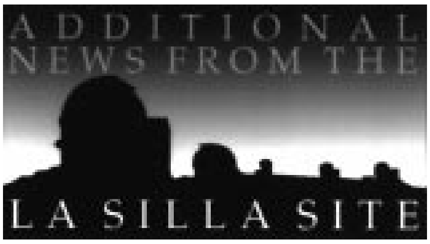

The La Silla News Page

The editors of the La SillaNews Page would like to welcome readers of the nineth edition of a page devoted to reporting on technical updates and observational achievements at La Silla. We would like this page to inform the astronomical community of changes made to telescopes, instruments, operations, and of instrumental performances that cannot be reported conveniently elsewhere. Contributions and inquiries to this page from the community are most welcome. *(R. Gredel, C. Lidman)*

Image Quality of the 3.6-m Telescope (Part VIII) New Seeing Record of 0.47″

S. GUISARD, ESO

The bad behaviour of the lateral pneumatic support of the main mirror (M1) has already been put forward several times to explain the bad image quality of the telescope at large zenith distance. In order to check this assumption, several adjustments were done on the primary mirror support during the technical time last December. We decided to start by recentring the mirror axis on the rotator axis. This was done successfully and we found that the old position of the mirror was about 2 mm away from the rotator axis position. All the lateral pads supports were modified, and it is now possible to adjust them radially to match the new mirror position.

The lateral support system of the primary mirror is composed of 18 lateral pneumatic pads and 3 fixed pads. The pressure in the pneumatic pads is controlled via a mechanical computer, commonly called the “REOSC system” which provides a certain theoretical pressure to each pad according to the position of the telescope, the system therefore has 18 pressure controllers. For each pad, the pressure is a function of the declination of the telescope and hour angle. The problem of the system is that it can only be adjusted for a single position of the telescope and that it does not follow accurately the theoretical law of pressure to be applied on the mirror edge. Furthermore even if that was the case, we proved that a pressure regulation of the air in the pneumatic pads is not sufficient. The reason for this is that because of flexures of the cell and small mirror motions, the distance between the pads and the mirror changes and modifies the contact area between the air cushion and the mirror. The direct consequence is that the force applied to the mirror is not the correct one.

The installation of load cells on all the lateral supports in April 1997, allowed us to do the following test adjustment for the telescope pointing at 45 degrees of zenith distance towards the South. The pressure into the pneumatic pads was adjusted on the REOSC system; then the distances between the pads and the mirror were adjusted until the correct lateral forces distribution could be read on the load cells.

During the following test nights we first tilted the secondary mirror (M2) to compensate for the coma introduced by the recentring of M1 and we measured the aberrations of the telescope for several zenith distances. The position of the telescope for which the Optical Quality (OQ) was the best was between 30 and 45 degrees of zenith distance to the South, position for which the lateral adjustment of the forces was performed. The OQ at this position was around 0.27″ d80% which corresponds to the polishing errors of the mirrors. However for any other position of the telescope, including zenith, the OQ degraded for the reason explained above. To confirm the aberration measurements we also made several direct images at 30 degrees of zenith distance to the South and 15 second unguided exposures (the mirror ventilation was on). The FWHM measured on the star is 0.47″ d80% which breaks down the old record of 0.56″ obtained one year earlier. It must also be noticed that this new value has been obtained at 30 degrees of zenith distance and the old one at zenith. This new seeing record is very close now to the limit we can obtain with this telescope.

This year a new control system of the pressure will be installed. It works in closed loop with the force values read on the load cells, and it should enable us to get an excellent optical quality all over the sky.

EFOSC2 and VLT Autoguider Commissioned at the 3.6-m Telescope

R. GREDEL and P. LEISY, ESO

During three weeks of technical time in December 1997, EFOSC2 and the VLT autoguider were commissioned at the 3.6-m telescope. EFOSC2 is no longer offered at the 2.2-m telescope and replaces EFOSC1 on a permanent basis.

EFOSC2 is equipped with a 2048 × 2048 LORAL CCD and comes with a sampling of 0.16 arcsec per pixel. It thus takes full advantage of the improved image quality of the 3.6-m telescope (see previous articles in *The Messenger* by

Stephane Guisard). During the December run, an overall image quality of 0.7–0.8 arcsec was routinely achieved, while the outside seeing was about 0.5 arcsec.

The standard filter set for EFOSC2 is that of SUSI, that is, Bessel U, B, V, R, Gunn g, r, i, z, and a number of narrow-band filters. The presently available grism set is the one which was previously offered at the 2.2-m. A number of new grisms have been ordered, which should be available for period 61 (see our web page for details, http://www.ls.eso.org/lasilla/Telescopes/360cat). In period 61, MOS shall be available as well. A second EMMI punching unit shall be used to prepare the MOS plates. The quality of the slits punched with the EMMI unit is superior to that available with the old EFOSC1 PUMA machine.

An important aspect of the December technical time concerns the installation of the new VLT autoguider at the 3.6-m telescope. Two new VLT technical CCDs were installed in the Cassegrain adapter, one of which is used for the autoguider. The Cassegrain adapter functions and the autoguider are now controlled by dedicated local control units. The error vectors calculated by the software are fed back directly to the position loop of the telescope control system (TCS). This is a significant improvement over the old autoguider, where constant offsets were applied to correct for tracking errors. Thus, the new autoguider provides a faster response to large tracking errors, and ensures a smoother tracking when the errors are random.

With the commissioning of EFOSC2 at the 3.6-m telescope, a major milestone of the 3.6-m upgrade project is concluded. Our main effort now goes into the replacement of all HP1000 computers. Next milestones include the adaptation of the NTT software modules to replace the TCS, and the adaptation of the EMMI instrument software for EFOSC2.

Signing of Contract for the Delivery of the Delay Line of the VLTI

At a ceremony in Leiden, the Netherlands, on March 12, a contract was signed between Fokker Space B.V. and ESO for the delivery of the Delay Line of the VLTI.

Fokker Space B.V. is the largest company in the Dutch space industry. It is based in Leiden. Fokker Space is mainly active in the field of solar arrays, launcher structures, thermal products, instruments and simulators. It also plays a key role in the development of robotics and is responsible as a prime contractor for the European Robotics Arm (ERA) to be used on the International Space Station.

Fokker Space is well embedded in the Dutch aerospace infrastructure, thanks to close relations with the Dutch Space Agency (NIVR), the National Aerospace Laboratory (NLR), the Delft University of Technology and other Dutch space industries and institutes like TNO-TPD (Netherlands Organisation for Applied Scientific Research - Institute of Applied Physics).

The VLTI Delay Line programme will be realised in collaboration with TNO-TPD.

P.G. Winters, president of Fokker Space B.V., and R. Giacconi, ESO Director General, signing the contract.

Prof. E.P.J. van den Heuvel, Dutch delegate to the ESO Council, speaking at the ceremony. ▼

The Large Southern Array

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There is great interest around the world in the possibility of a large millimetre and submillimetre wavelength array in the southern hemisphere. Europe, the US, and Japan are all working in this direction, and these projects may well merge into one global collaboration. For Europe such a facility will be of particular importance because of the strong synergy with the VLT.

1. Introduction

One of the highest-priority items in astronomy today is a large millimetre array. It will be a millimetre counterpart to the VLT and the HST, with similar scientific objectives and comparable high angular resolution and sensitivity but unhindered by dust opacity. It will be highly complementary to FIRST, SOFIA, and single-aperture ground-based telescopes. It will be sensitive to the cool dust emission and the dense forest of molecular lines unique to the millimetre wavebands, as well as the synchrotron emission extending from the radio and thermal emission from the optical/infrared. With a capability of seeing star-forming galaxies across the Universe and star-forming regions across the Galaxy, it will open new horizons in science.

Such an array should provide high angular resolution, about 0.1 arcsec at 3 mm, both for the science objectives and for compatibility with the VLT and HST. This in turn requires very high sensitivity, hence a total collecting area of about 10,000 m^2 (receivers are already reaching fundamental limits and bandwidths for spectral line observations are fixed, so larger collecting area becomes the only way to greater sensitivity). Such a collecting area implies an array with many antennas and baselines, which give the added advantage of fast, high-quality images. The site must be high, dry, large, and flat – a high plateau in the Atacama desert is ideal, and has the great advantage of being in the southern hemisphere, important for compatibility with the VLT. Thus, discussion has focused on a "Large Southern Array", or LSA.

2. Science with a Large Southern Array

The scientific case for this revolutionary telescope is overwhelming. The main science drivers are the origins of galaxies and stars: the epoch of first galaxy formation and the evolution of galaxies at later stages including the dust-obscured star-forming galaxies that the HST and VLT cannot see, and all phases of star formation hidden away in dusty molecular clouds. But the LSA will go far beyond these main science drivers – it will have a major impact on virtually all areas of astronomy, and make millimetre astronomy accessible to all astronomers. It may well have as big a user community as the VLT itself. A taste of the scientific potential of the LSA is given in the following paragraphs.

The Early Universe. Star-forming galaxies will be detectable out to $z = 20$ because of the large negative *K*-correction in the far-infrared dust emission peak. This may be the best way to find the first galaxies in the "dark ages" beyond $z = 5$, and the star-forming galaxies invisible to HST and VLT because of dust obscuration. (Sub)millimetre observations are essential to our understanding of the star-formation history of the Universe. The "ladder" of molecular transitions essentially guarantees that a redshifted line will appear in one of the observing bands. Millimetre continuum and line emission has already been detected in some of the most distant objects known, at redshifts near 5.

Gravitational Lenses. Many gravitational lenses may be found – possibly more numerous and at higher redshifts than in the optical or radio wavebands because of the very steep source count. Gravitational arcs will be mapped in molecular lines.

Quasar Absorption Lines. Quasar molecular absorption lines will be observed in the spectra of many sources. This is a new field with great potential, which was recently pioneered at the SEST. Over 30 molecular transitions have already been detected in individual absorption systems up to $z = 0.9$. In such systems one can study detailed chemistry at cosmological distances, the microwave background temperature *vs.* redshift, and gravitational lens time delays. The high sensitivity of the LSA will make a large number of distant sources accessible.

Active Galactic Nuclei. AGN can be studied "in depth", because of the low synchrotron and dust opacity and the unprecedented angular resolution of millimetre VLBI. The LSA will provide millijansky VLBI sensitivity, corresponding to brightness temperatures as low as 10^2–10^4 K. The optically-obscured molecular tori and the circumnuclear starbursts of nearby galaxies can be resolved. The presence of central black holes can be studied kinematically in a large number of galaxies.

Normal Galaxies. The LSA will make observations of normal galaxies at $z = 1$–2 with the same detail as is presently possible in nearby galaxies. The main dynamical features of nearby spirals will be resolved with enough resolution and sensitivity to constrain theoretical scenarios of galaxy evolution. The mass spectrum of molecular clouds in galaxies of different types will be determined.

Magellanic Clouds. In the Magellanic Clouds, large statistical samples of many types of objects at essentially the same distance can be studied and compared in detail with the corresponding objects in the Galaxy: molecular clouds, star-forming regions, SiO masers, circumstellar shells, supernova remnants.

The Galaxy and the Interstellar Medium. The galactic centre and its environs can be observed free of obscuration. High resolution is essential to distinguish SgrA* from confusion in this crowded region. Interstellar molecular absorption lines will be studied along a great many sight-lines towards extragalactic sources. An interferometer is essential to resolve out contaminating extended emission, and the sight-lines are guaranteed to sample random (unperturbed) clouds, as the background sources are extragalactic.

Astrochemistry. Galactic molecular clouds and astrochemistry will of course be major targets for the LSA. It will be used to study the conditions at the start of cloud collapse near star-formation regions and the interactions of newly-born stars with nearby molecular clouds. It will allow vastly improved chemical abundance analysis, limited only by intrinsic line blending. Observations of Galactic and extragalactic molecular clouds will provide comparative studies of chemistry and abundance variations.

Protostars and Young Stellar Objects. The elusive protostars may best be found by virtue of their cold dust emission at millimetre wavelengths. High angular resolution is required to distinguish objects at different evolutionary phases within the same star-forming region: the collapsing cloud cores, cool dust envelopes, hot dust cocoons, hot molecular cores, bipolar flows, ultra-compact HII regions, etc. The LSA will reveal the dynamics of the dust-obscured protostellar accretion disks, the rate of accretion and infall from the molecular clouds, and the mass distribution over the disk. Indirect evidence for planet formation may be provided by the presence of gaps cleared by large bodies condensing around the stars. The molecular outflows will be observed in unprecedented detail; masers (both molecular and atomic) might make it possible to study the innermost regions, and could reveal the velocity structure of the accretion disk.

Stellar Evolution. The LSA will detect tens of thousands of stars over the entire H-R diagram, and allow major advances in virtually all fields of stellar astronomy. Millimetre emission has already been detected from O and B stars, W-R stars, hot stars with shells, pre-main sequence stars, late-type giants and supergiants, and optically variable stars. Circumstellar shells around evolved stars, observed at millimetre wavelengths, provide a unique probe of time-dependent chemistry. The LSA will resolve thousands of such shells, and reach across the Galaxy, so that dependence on stellar type, local environment, and galactocentric distance can be studied.

Planetary Nebulae and Supernova Remnants. The LSA will provide detailed line and continuum images of planetary nebulae and supernova remnants. Radio supernovae are first seen at high frequencies, and the LSA will detect them out to large distances; VLBI can be used for absolute distance determination. SN 1987A in the Large Magellanic Cloud will be a prime target for the LSA. Evidence of a central source may require millimetre-wave observations because of possible free-free and dust absorption. The shock wave will hit the [OIII] ring in 2005 $\pm$ 3, providing an incentive for early operation of at least part of the array!

Planets. Combined observations using the LSA in conjunction with spacecraft will greatly enhance studies of the planets and their satellites. Millimetre continuum observations probe the deep atmospheres of the giant planets or the surface layers of the terrestrial planets. Millimetre heterodyne spectroscopy allows the detection of narrow spectral lines and measurement of small molecular abundances. Temporal monitoring reveals composition changes as a function of season and climate. The LSA will also detect and resolve the atmospheres of planetary satellites (*e.g.* SO_2 from volcanic activity on Io).

Asteroids and Comets. The LSA can study the size and albedo of asteroids, and probe their sub-surface temperatures. LSA continuum observations of comets will explore dust sizes not accessible to optical or radio observations. Spectroscopic observations will determine the molecular composition of the nuclear ices sublimating into the coma, and search for new molecular species. Comparisons with molecular cloud cores will provide clues to the origin of comets.

Extrasolar Planets. The LSA may play an important role in the search for extrasolar planets through accurate astrometry, possibly even direct detection. The detection of planetary atmospheres would of course be of fundamental importance.

Finally, the LSA as one element of a VLBI array will revolutionise millimetre VLBI, which is presently seriously sensitivity limited, giving images with a resolution of 50 micro-arcseconds.

3. The LSA Project

Europe has a strong involvement in millimetre astronomy: the 5 × 15 m IRAM array on Plateau de Bure, the 30-m IRAM antenna, the 20-m at Onsala, the 15-m SEST, the 15-m JCMT, the 10-m HHT, and others. Over 60 institutes around Europe use these facilities, and many institutes have developed technical expertise and leadership in this area together with European industry, so it is natural that a European collaboration should be looking to the future.

The idea of a European southern millimetre array was discussed at a meeting at ESO in May 1991, and the current concept of the very large collecting area of the LSA was proposed later that year. In May 1994 the STC reconfirmed its support for millimetre astronomy at ESO, and initiatives were taken which led to the establishment in 1995 of an LSA Project collaboration between ESO, the Institut de Radio Astronomie Millimétrique (IRAM), the Onsala Space Observatory, and the Netherlands Foundation for Research in Astronomy (NFRA). This consortium of observatories agreed to pool resources for a two-year study, which included site surveys in Chile and critical technical studies. A workshop on "Science with Large Millimetre Arrays" was held at ESO in December 1995, and the proceedings were published the following year in the ESO Astrophysics Symposia Series. A report published in April 1997 ("LSA: Large Southern Array – Combined Report") summarised the first two years of the study, and concluded the first phase of the LSA project.

An important step was taken in June 1997. A similar project is under study in the US (the "Millimetre Array", MMA), and an agreement was made with the US National Radio Astronomy Observatory to explore the possibility of merging the two projects into one. Until then the emphasis in Europe had been on a very large (10,000 m^2) collecting area provided by 16-m antennas operating at purely millimetre wavelengths, while in the US the concept was a smaller (2,000 m^2) array of 8-m antennas with good submillimetre performance. However, as there is also considerable interest in Europe in submillimetre observations, and in the US in a larger collecting area, a compromise seemed feasible.

Three joint working groups were set up to explore the possibility of a collaborative project: a technical working group to study the feasibility of large submillimetre-quality antennas, a science working group to review the science objectives and array concept, and a management working group to explore the possible organisational structure, both between ESO and NRAO and with Chile. It was concluded that a homogeneous array of 64 × 12 m antennas, providing submillimetre performance with a total collecting area of 7,000 m^2, could be built within the target budget of \$400 m. The array would be located at the high (5000 m) Chajnantor site, an hour from the array control centre at San Pedro de Atacama. The project would be a 50–50 collaboration between ESO and NRAO on behalf of their respective communities. In Europe, ESO would draw on its own resources for project management, and involve specialised institutes for their technical expertise. The observatory would probably be run by a Chilean Foundation, incorporated in Chile and controlled by an ESO-NRAO Board.

This concept is presently being elaborated, both in Europe and the US. Eight joint working groups have been established, involving over 80 persons from the European side alone, and design work is underway. The original European consortium has been enlarged to include representatives from all ESO member states, and a Feasibility Study is being carried out. It is intended that a formal proposal be submitted to ESO Council for approval by the end of 1999.

Meanwhile, in Japan there is another millimetre array project, the "Large Millimetre and Submillimetre Array" (LMSA), and it has recently been decided that the LMSA will also be located in the Chajnantor area, less than 10 km from the LSA/MMA. As a result, the two most likely scenarios are (1) a "handshake" arrangement in which the LMSA and LSA/MMA remain independent but sometimes work together in a single large configuration, or (2) a complete merger of all three projects into a "World Array". This should be decided sometime this year. Still other countries are also interested in participating, and would likely do so under the umbrella of one or another of the major partners.

4. Conclusion

It now seems virtually certain that there will be a large millimetre and submillimetre array located in northern Chile. In view of the outstanding scientific potential of this new telescope and the strong synergy with the VLT, the participation of Europe, both scientifically and technically, is highly desirable. Whether it does participate should be known by the end of next year. The telescope will most likely be built in the period 2003–2008, and become incrementally operational over that period.

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The LSA would not be ESO's first venture into millimetre astronomy. ESO has been involved in this field for well over a decade, through its participation in the Swedish-ESO Submillimetre Telescope (SEST). The following papers summarise some of the recent scientific developments and results from the SEST.

SEST UPGRADES AND REPORTS FROM SEST OBSERVERS

SEST Upgrades

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The Swedish-ESO Submillimetre Telescope (SEST) has been in operation successfully for close to 10 years, the first scheduled observations having taken place in April 1988. It has served not only the Swedish-ESO community, but 10% of the Swedish observing time has been used by Finnish astronomers and, recently, Australia has signed an agreement with Sweden, also for 10% of Swedish observing time. The SEST receivers have been upgraded on a regular basis during the past decade, but the original control system is still in place. However, during the past couple of years an in-house project to replace this control system as well as the old computers has been in progress, while continuing normal observations. The project is being carried out by the SEST engineers with assistance from the staff at Onsala Space Observatory and will be completed during 1998. This article will describe the present instrumentation, the new control system and give a brief overview of the plans for the SEST during the coming years.

1. Current Status

The SEST instrumentation presently consists of state-of-the-art SIS receivers covering the 3, 2, 1.3, and 0.8 mm atmospheric windows, and a single-channel bolometer covering the 1.3 mm window. Receiver temperatures are typically on the order of 100–150 K (Single Side Band, SSB), except for the 0.8 mm receiver, which has a receiver temperature of about 300–400 K (SSB). Three Acousto Optical Spectrometers (AOS), two wide band (1 GHz) and one narrow band (86 MHz), each with about 2000 channels, can be used in different combinations with the 3 and 2 mm receivers or the 3 and 1.3 mm receivers simultaneously. During 1997 the three AOS were upgraded with new CCD and electronics by the group from the University of Cologne who designed and built them. This upgrade was needed to ensure ongoing maintenance support, improve the performance of the AOS and prepare them for the new control system.

The telescope, its receivers, spectrometers and other instrumentation are presently controlled by HP1000 computers via HP/IB interfaces and CAMAC controllers. The current control system is very slow due to the old computers and there are other operational limitations; e.g. because there is insufficient computer memory, only two spectrometers can be used simultaneously.

More detailed information about the SEST and its performance can be accessed through the SEST homepage, which is constantly being updated:

http://www.ls.eso.org/lasilla/Telescopes/SEST/SEST.html

2. The Control System Upgrade

The system upgrade essentially consists of replacing the HP1000 computers with a fast HP/B132L workstation and the CAMAC controllers, for telescope and subreflector control, with VME systems. The spectrometers will be controlled by a PC running Linux. The new user interface, *Pegasus,* is a graphical user interface (gui) developed at CFHT (Canadian-French-Hawaiian Telescope). It is used to control the 20-m telescope at Onsala Space Observatory in Sweden, thus a large part of the software developed there has been transferred and adapted to the SEST. The new system will be considerably faster and it will be possible, for example, to use all three spectrometers simultaneously in different combinations with the receivers.

The *Pegasus gui* is very easy to operate and allows the observer to send *all* commands by opening control windows and using the mouse to click on control buttons. An example of what such a setup may look like is given in the figure. On the top of the screen the menu bar gives access to different windows, which can be selected by the observer. Thus, by simply clicking on different buttons in the menu, the observer can, for example, open source catalogues, track a source, choose the receiver/spectrometer setup, search the *Lovas* line catalogue, tune the receivers and then start mapping routines. Thus, the new system is very user-friendly and extremely easy to use and observers will be able to quickly adapt to the gui. The data obtained will be written in FITS format and various data reduction programmes, e.g. CLASS and DRP, will be available on-line.

In November/December 1997, we used a long maintenance period to do initial testing of the new telescope con-

trol system (TCS), the spectrometer control, and the *Pegasus gui.* At the end of this period it was possible through *Pegasus* to track and map a source using all three spectrometers simultaneously. The upgrade project will be finished during the second half of 1998, after which the new system will be in use.

3. The Future

During 1999, SEST will be equipped with a nutating subreflector, designed and built at IRAM (Institut de Radio Astronomie Millimétrique). This will be slightly smaller than the present subreflector and be insensitive to ground radiation spilling over the primary mirror. It means, however, that the telescope focal-ratio will be changed, necessitating a redesign of some of the receiver optics. The new subreflector will make it possible to use one of the new-generation bolometer arrays which, for reasons concerning the uniform illumination of all pixels, can only satisfactorily be operated with such a subreflector. Therefore, in 1999, we will install a 37-channel bolometer array receiver working at a wavelength of 1.3 mm. This will be built by Ernst Kreysa at the Max-Planck-Institut für Radioastronomie in Bonn, with support from the Astronomical Institute of the Ruhr-Universität Bochum and Onsala Space Observatory. Mapping will become much faster due to the large number of channels. The efficiency for mapping extended sources as well as for observations of point-like sources will also increase, because the sky noise added by the atmosphere is correlated between the channels and can thus be eliminated. This implies that it will be possible to work at the detector noise level even in marginal atmospheric conditions.

We also expect that the on-the-fly mapping mode will be available at the end of these upgrades. This is a fast mapping mode during which data is taken continuously while the telescope is scanning across a source, and thus the total mapping time will be decreased by at least a factor of three.

During 1999, SEST will also take delivery of a digital autocorrelation spectrometer (ACS) which will be built at the Australia Telescope National Facility as part of the new Swedish-Australian collaboration. It will have selectable bandwidths decreasing from 1 GHz to 64 MHz by factors of 2 and 2048 frequency channels. This will provide a flexible alternative to the AOS, but it will also be possible to use the AOS and ACS at the same time with different bandwidths.

Further into the future it is foreseen that an SIS heterodyne array receiver, working in the 1.3-mm window with up to 16 elements, will be installed at SEST. This also means that 16 spectrometers will have to be used in combination with the receiver, and thus the present spectrometers will have to be replaced, possibly through the Swedish-Australian collaboration.

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Molecular Lines in Absorption at High Redshift

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Abstract

Molecular absorption lines at high redshift (0.2 to 1) were discovered a few years ago, and they revealed a very precious tool for many purposes. They allow the detection of many molecules, and in particular those not observable from the ground at $z = 0$. such as water and molecular oxygen. The excitation temperature of molecules are often close to that of the cosmic background radiation, and can serve to measure it as a function of redshift. The absorption comes frequently from a gravitational lens in front of a quasar, so that they help to determine time-delays and the Hubble constant. The high spectral resolution of radio observations allows to put constraints on the variation of the fine-structure constant over a large fraction of the Hubble time. With the next-generation millimetre interferometers, many such systems would be observable, which will allow the exploration of young galaxies in the Universe.

1. Background

Absorption lines are a sensitive probe for studying the interstellar medium. Especially in distant objects, where emission lines become diluted with distance squared, whereas the detectability of absorption lines only depends on the observed flux of the background source. This is well known from optical spectroscopy, where the combination of sensitive detectors and large telescopes allows observation of very tenuous gas towards distant background QSO. In principle, absorption of molecular rotational lines can be used to probe the densest and coldest part of the ISM in distant galaxies, much in the same way as optical lines probe the warm and diffuse gas. Since new stars are formed in molecular clouds, a study of this ISM component traces the star-formation conditions and its history in galaxies. There are, however, several difficulties associated with the detection of such lines and it was not before 1993 that the first distant molecular absorption line system was detected. Since then a total of four such systems at redshifts between z = 0.2–0.9 have been observed.

2. Discovery of Molecular Absorption-line Systems

The 15-m Swedish-ESO Submillimetre Telescope (SEST) on La Silla has

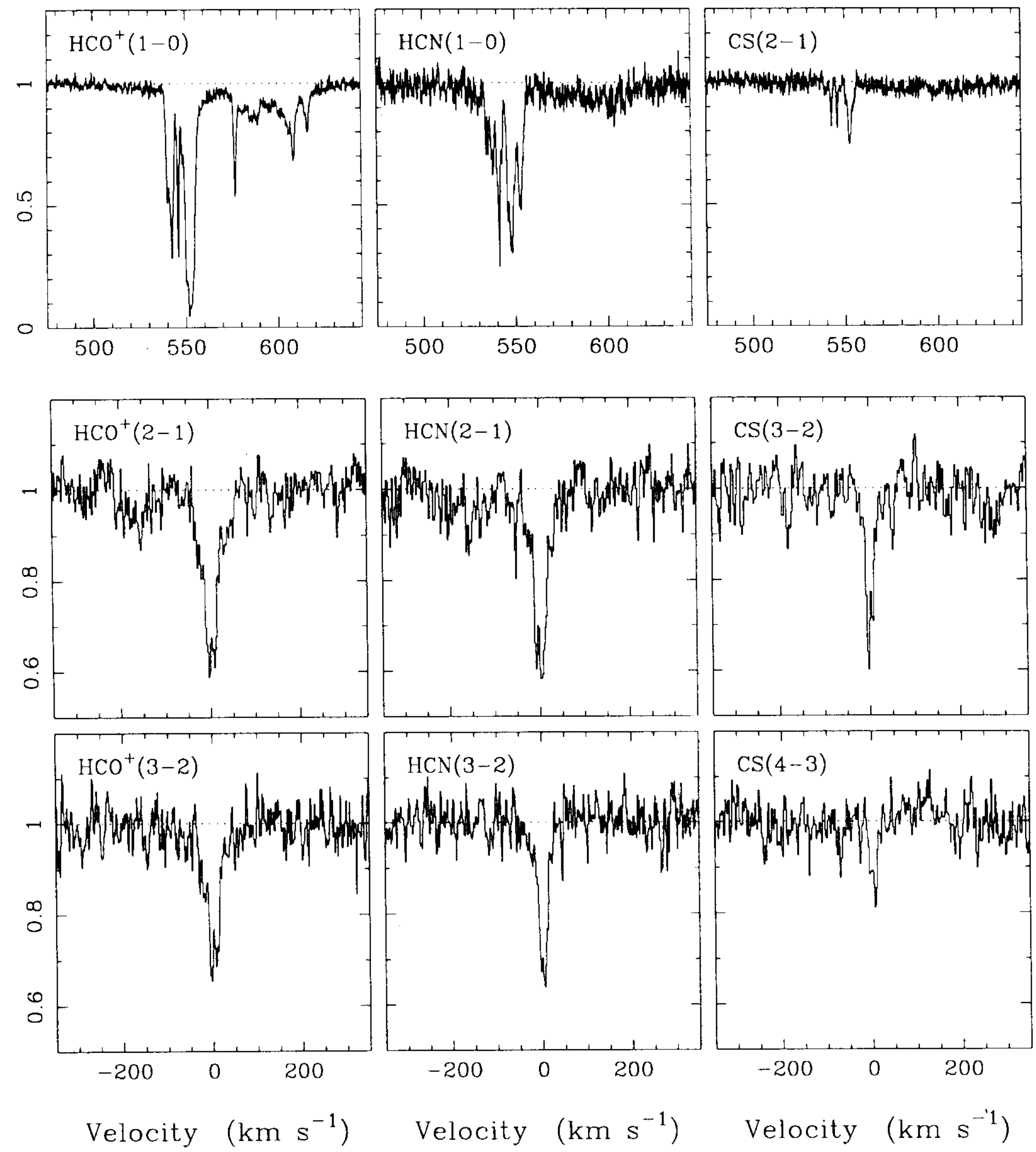

Figure 1: HCO^+, HCN and CS absorption lines towards the nearby Cen A (D ≈ 4 Mpc) and PKS1830-211 (D ≈ 4 Gpc). For PKS 1830-211 two different rotational transitions are shown for each molecule. This illustrates that the detectability of molecular absorption lines does not depend on distance but on the column density and strength of the background continuum source.

played a crucial role in the study of molecular absorption-line systems. The first such systems was detected with the SEST at Christmas time 1993 (Wiklind & Combes, 1994). The most distant molecular absorption line system (z = 0.9) was also detected with the SEST (Wiklind & Combes, 1996a). In the former case (PKS1413+135), the redshift of the absorbing gas was known from both optical spectra and 21 cm HI absorption, occurring at z = 0.247 (Carilli et al., 1992). The molecular absorption line, the CO(1-0) transition, turned out to be so narrow that it could easily have been mistaken for a bad channel in the spectrometer. Observations of additional molecules and using higher spectral resolution showed, however, that the absorption was indeed real. In the latter case (PKS 1830-211), nothing was known about the redshift. The background radio source was suspected to be a gravitational lens (Subrahmanyan et al., 1990), but with no optical counterpart. As such it was a good candidate for molecular absorption. Millimetre wave receivers are characterised by a narrow bandwidth but a high spectral resolution (typically ≤ 1 GHz and 0.1 MHz, respectively). Nevertheless, in the case of PKS 1830-211 we scanned the 3-mm band in frequency until we encountered an absorption line (cf. *The Messenger* 84, p. 23). After some guessing at its identity, we found several additional absorption lines and could determine the redshift of the absorber to be z = 0.88582. To date we have detected four molecular absorption-line systems (see Table 1). Some systems include several velocity components.

These molecular absorption objects are the continuation at high column densities (10^{21}–10^{24} cm^{-2}) of the whole spectrum of absorption systems, from the Lyα forest (10^{12}–10^{19} cm^{-2}) to the damped Lyα and HI 21 cm absorptions (10^{19}–10^{21} cm^{-2}). It is currently thought that the Lyα forest originates from gaseous filaments in the extra-galactic medium, that the damped and HI absorptions involve mainly the outer parts of spiral galaxies. The molecular absorptions concern the central parts of galaxies.

Among the four detected systems, there are two cases of confirmed gravitational lenses, with multiple images (the two other cases are likely to be internal absorption). This is not surprising, since detection of molecular absorption requires that the line of sight to the background QSO must pass close to the centre of an intervening galaxy. The surface density is then larger than the critical one for multiple images. In the present two cases (B0218+357 and PKS 1830-211), the separation between the two images is small enough that only a galaxy bulge is required for the lensing.

Detectability of Molecular Absorption Lines

In addition to the four detected molecular absorption-line systems we have undertaken a systematic survey of about a hundred candidates, selected from flat-spectrum continuum sources. The continuum needs to be at least 0.2

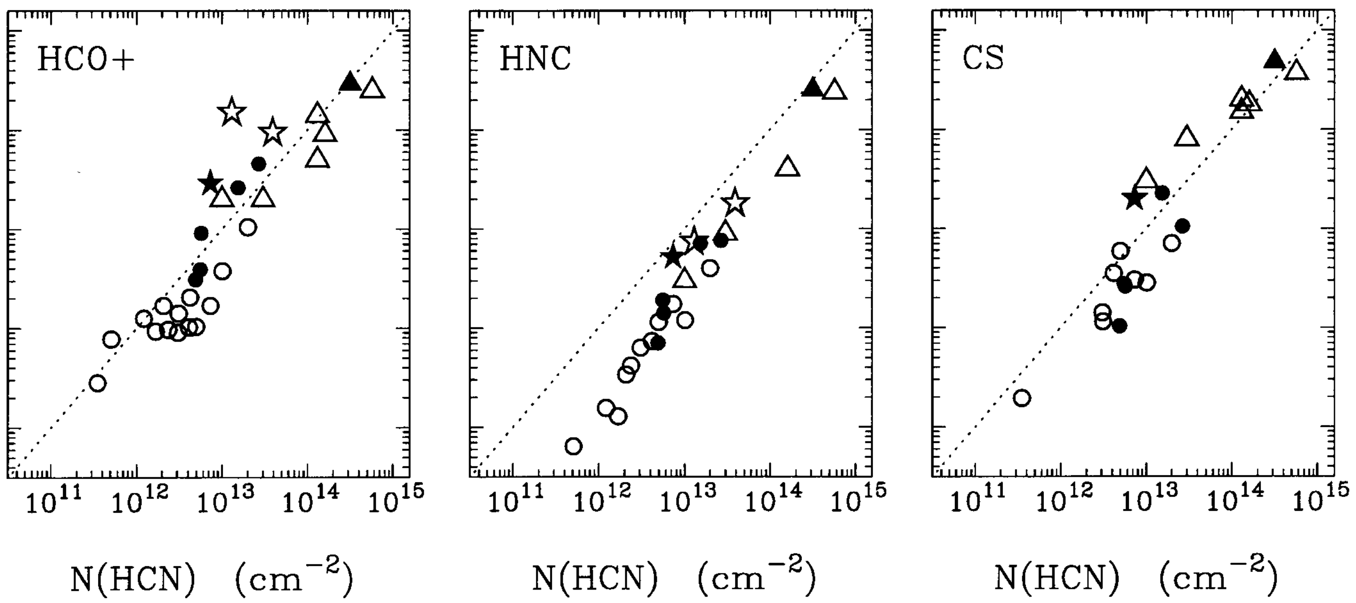

Figure 2: Comparison of column densities for various molecules and absorption systems. Open circles are Galactic diffuse clouds (Lucas & Liszt, 1996), open triangles somewhat denser Galactic clouds seen towards the galactic centre (Greaves & Nyman, 1996), filled circles represent absorption in Cen A (Wiklind & Combes, 1997a). The distant absorption systems are represented by open stars (B1504+377), filled stars (PKS1413+135), filled triangle (PKS1830-211). B0218+357 is too saturated to allow reliable column density estimates. The dotted line represents a one-to-one correspondence and is not a fit to the data.

Jy to allow detection of intervening molecular gas[1]. The redshift of the absorbing candidate is known, either from previously detected HI absorption; 21 cm or damped Lyα, which is the case for PKS1413+135 and B0218+357 (Wiklind & Combes, 1994, 1995) or from optical line emission of a galaxy on the line of sight to a radio source; B1504+377 (Wiklind & Combes, 1996b). When the continuum source is strong enough, at least 1 Jy, and no redshift is known, it is possible to search for absorption lines by scanning in frequency in a manner similar to what was done for PKS 1830-211. This last method is the most promising with the new-generation millimetre instruments, that will gain an order of magnitude in sensitivity. Indeed, the best candidates are the most obscured ones, where no redshift is available.

[1]This limit is set by the sensitivity of today's millimetre wave telescopes to point like continuum sources and scales as the total collecting surface area.

The utility of molecular absorption lines comes from the high sensitivity. First of all, the observed property is the velocity integrated opacity, which is directly proportional to the square of the permanent electric dipole moment. This means that a molecule like HCO^+, which is $\sim 10^{-4}$ less abundant than CO, but has a dipole moment $\sim 10^2$ times larger than that of CO, can be as easily observed. Secondly, the small extent of the background continuum source means that there is no distance dependence, the sensitivity only depending on the observed background flux. Molecular absorption lines are as easy to detect at $z \approx 0$ as at $z = 1$, except that at small distances emission can make absorption-line measurements more difficult. To illustrate this we show in Figure 1 HCO^+, HCN and CS absorption from Cen A at a distance of ~ 4 Mpc (Wiklind & Combes, 1997a) and from PKS 1830-211 at a distance of ~ 4000 Mpc (Wiklind & Combes, 1996a). Both sets of spectra have been obtained with the SEST.

3. Results on Molecular Abundances

About 15 different molecules have been detected in absorption at high redshifts, in a total of 30 different transitions. This allows a detailed chemical study and comparison with local clouds. In Figure 2 we show such a comparison between our high redshift absorption line systems and Galactic absorption (Cen A is also included). The dispersion in column densities reflects the dispersion in molecular cloud properties. The high redshift systems do not appear to be different from local ones, suggesting that the conditions for star formation are the same up to $z \sim 1$ as at the present.

Molecules Unobservable from the Ground at z = 0

A particular interest comes from transitions that were never detected before. Because of atmospheric absorption in the H_2O and O_2 lines, it is impossible to have a correct estimation of the abun-

Table 1. Properties of molecular absorption line systems

Source	z_a [a]	z_e [b]	N_{CO} cm^{-2}	N_{H_2} cm^{-2}	N_{HI} cm^{-2}	A'_V [c]	N_{HI}/N_{H_2}
Cen A	0.00184	0.0018	1.0×10^{16}	2.0×10^{20}	1×10^{20}	50	0.5
PKS1413+357	0.24671	0.247	2.3×10^{16}	4.6×10^{20}	1.3×10^{21}	2.0	2.8
B31504+377A	0.67335	0.673	6.0×10^{16}	1.2×10^{21}	2.4×10^{21}	5.0	2.0
B31504+377B	0.67150	0.673	2.6×10^{16}	5.2×10^{20}	$< 7 \times 10^{20}$	< 2	<1.4
B0218+357	0.68466	0.94	2.0×10^{19}	4.0×10^{23}	4.0×10^{20}	850	1×10^{-3}
PKS 1830-211A	0.88582	?	2.0×10^{18}	4.0×10^{22}	5.0×10^{20}	100	1×10^{-2}
PKS 1830-211B	0.88489	?	1.0×10^{16} [d]	2.0×10^{20}	1.0×10^{21}	1.8	5.0
PKS 1830-211C	0.19267	?	$< 6 \times 10^{15}$	$< 1 \times 10^{20}$	2.5×10^{20}	<0.2	>2.5

[a]Redshift of absorption line. – [b]Redshift of background source. – [c]Extinction corrected for redshift using a Galactic extinction law. – [d]Estimated from the HCO^+ column density of 1.3×10^{13} cm^{-2}. – [e]21cm HI data taken from Carilli et al., 1992, 1993, 1998.

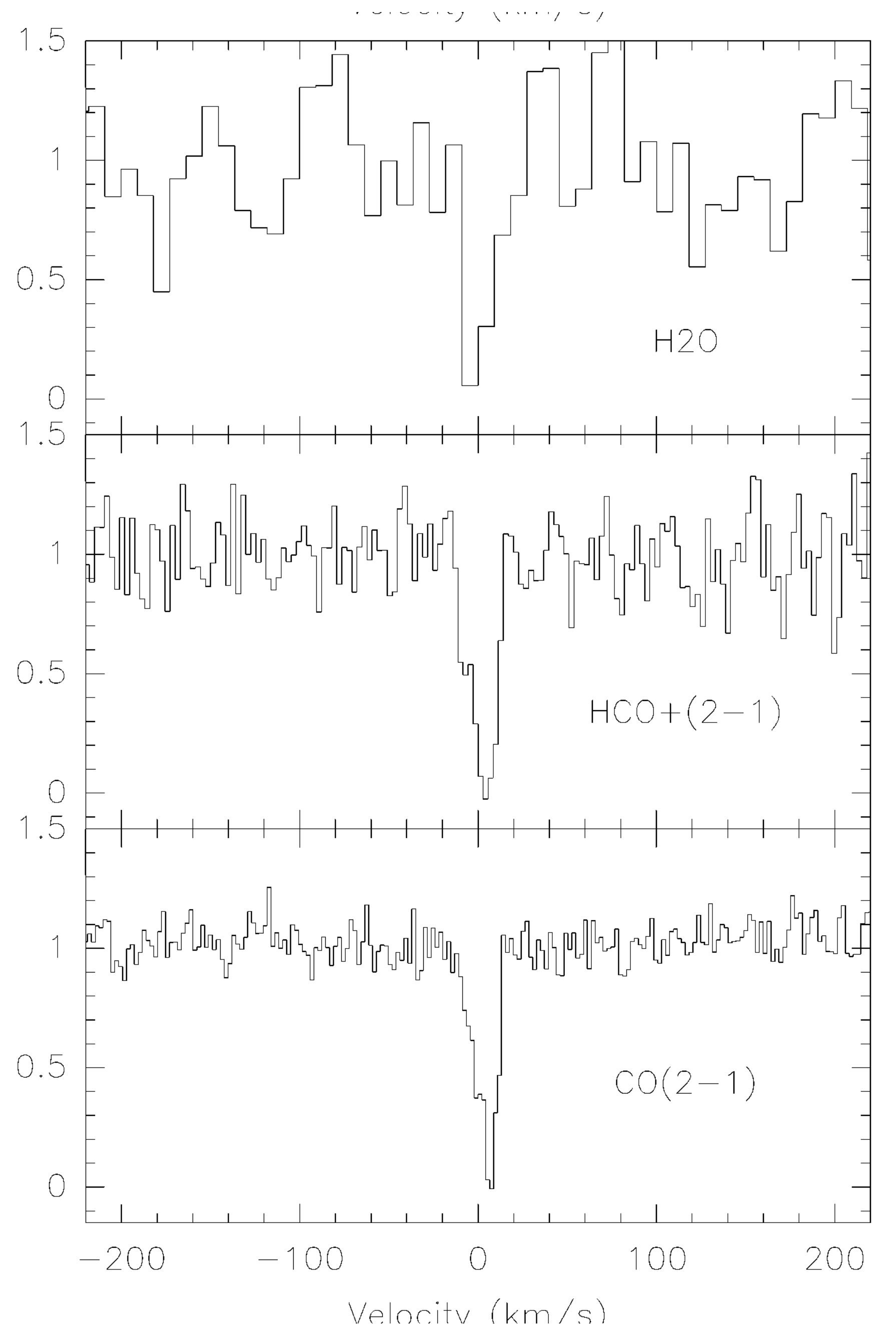

Figure 3: Spectrum of ortho-water in its fundamental line at 557 GHz, redshifted at 331 GHz, in absorption towards B0218+357. The line has the same width as the previously detected HCO^+ (2-1) and CO(2-1) lines. The velocity resolution is 9.1, 2.8 and 2.2 km/s from top to bottom. All spectra have been obtained with the IRAM 30-m telescope, and normalised to the continuum level.

dances of theses two molecules in the local interstellar medium. But these are key elements of interstellar chemistry. The redshift of the distant molecular absorption-line systems shifts the frequency of these lines into atmospheric windows observable from the ground. The highest column density systems (B0218+357 and PKS1830-211) are privileged targets to try to detect these fundamental molecules (e.g. Combes & Wiklind, 1995, 1996).

Water. We have chosen the absorbing cloud in front of B0218+357, where already optically thick lines of CO, ^{13}CO and $C^{18}O$ have been detected (Combes & Wiklind, 1995). The optical depth of the CO(2-1) line was derived to be ~ 1500, and therefore the H_2 column density around 5 10^{23} to 10^{24} cm^{-2}. At $z = 0.68466$, the fundamental ortho transition of water at 557 GHz is redshifted to 331 GHz into an atmospheric window.

According to models, the H_2O/H_2 abundance ratio is expected between 10^{-7} and 10^{-5}, and observations of isotopic lines in molecular clouds of the Milky Way, such as $H_2^{18}O$ and HDO, have confirmed these expectations. It was thought until recently that these abundances concerned only the neighbourhood of star-forming regions, such as the Orion hot core, where water ice is evaporated from grains. However, Cernicharo et al. (1997) detected with the ISO satellite water in absorption at 179 µ in front of SgrB2, and this revealed that cold water was ubiquitous.

Our detection with the IRAM 30-m telescope of ortho-water in its fundamental line at 557 GHz confirms this result. The line is highly optically thick, and has about the same width as the other optically thick lines detected in absorption in this cloud (see Fig. 3). If the excitation temperature was high (as in the Orion hot core), we would have expected to detect also the excited line at 183 GHz (redshifted at 109 GHz). An upper limit on this line gives us an upper limit on T_{ex} of 10–15K, and an estimation of the optical depth of the 557 GHz line of ~ 40,000 (Combes & Wiklind, 1997). This leads to an H_2O/H_2 abundance ratio of 10^{-5}, in the upper range of expected values.

Molecular oxygen. As an element, oxygen is about twice as abundant as carbon (O/H ~ 8.5 10^{-4}), meaning that at most half of the oxygen atoms can be used to make CO. The other half can be found in the form of atomic oxygen (OI), or molecules: O2, OH and H_2O. Since OH and H_2O are much less abundant than CO, in dense molecular clouds, we expect O_2 to be about as abundant as CO. Until recently, the upper limits on the O_2/CO ratio was 0.1, from observations of the isotopic line $O^{18}O$ and the direct O_2 in emission in remote starbursts. The upper limits obtained through absorption lines are more reliable, since they involve only one individual molecular cloud, where O_2 is not photo-dissociated.

We have searched for many O_2 lines with various millimetre telescopes (SEST 15 m, IRAM 30 m, Kitt-Peak 12 m, Green-Bank 43 m and Nobeyama 45 m). All these searches resulted in an upper limit of $O_2/CO < 2\ 10^{-3}$ at 1σ (Combes et al., 1997). This is much below theoretical expectations and suggests that oxygen is frozen on to dust grains, or that steady-state chemistry is never reached. In the latter case, most of the oxygen would remain atomic even in dense molecular clouds.

4. Time-Delay and the Hubble Constant

It is well known that gravitational lenses provide an original method to derive the Hubble constant, in allowing an absolute determination of the distance of a source, for which the redshift is known. Imagine that we observe two images of a quasar through a gravitational lens, and let us call d_1 and d_2 the corresponding lengths of the light paths to these two images. If we measure the time lag between the moment when a burst of light appears on one image and the moment where the same burst appears on the other, we can deduce the

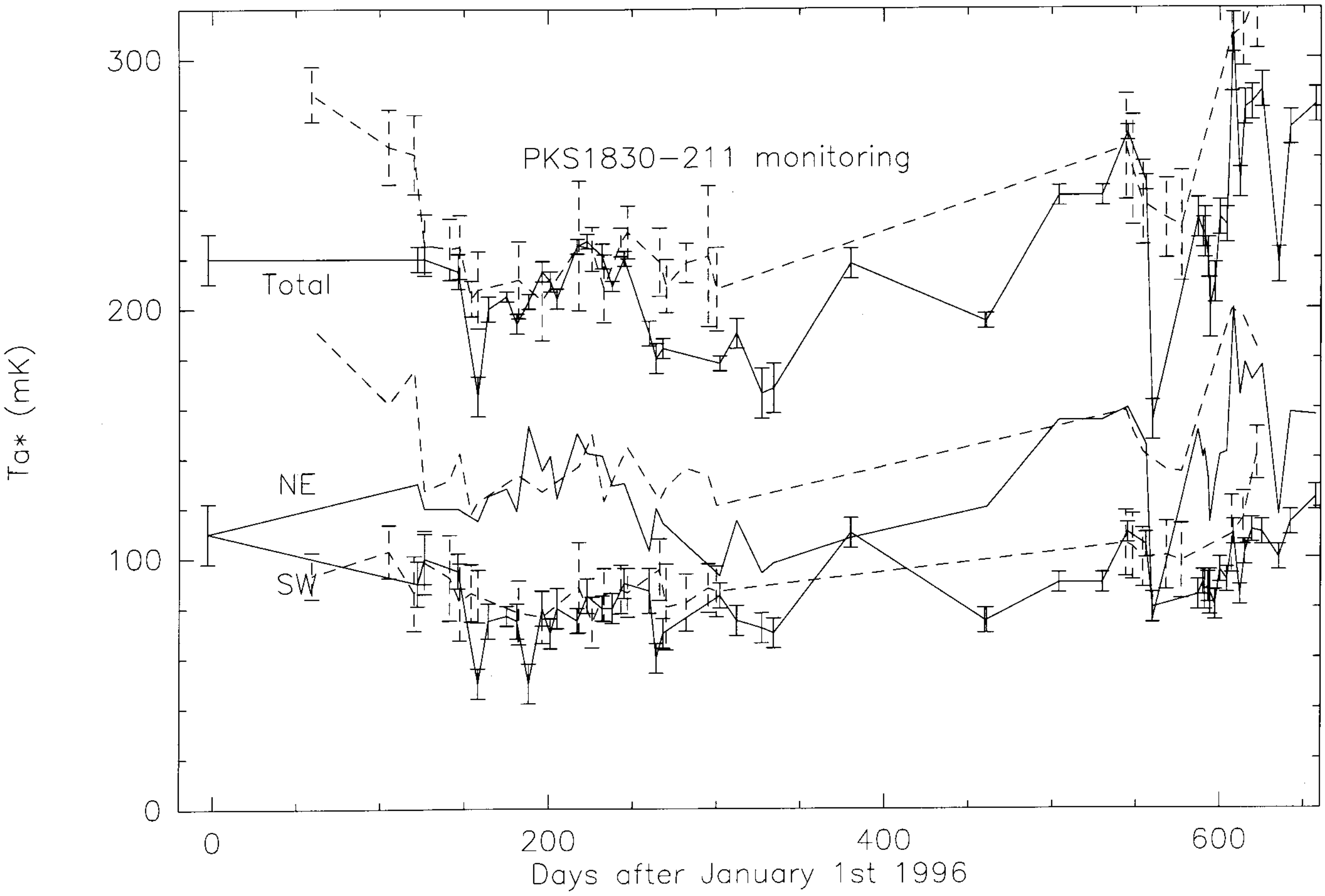

Figure 4: Results of the weekly monitoring of the quasar PKS 1830-211 in the HCO+(2-1) line at z = 0.88582. The full and dashed lines represent observations done at the IRAM 30-m and SEST 15-m telescopes respectively. From bottom to top the curves are the measure of the continuum level successively of image SW, NE and total. An intrinsic level increase appears from 1996 to 1997 in the two images.

difference between the two path-lengths, which is the product of the light velocity by the time-delay. It is also easy to derive the ratio d_1/d_2 from the relative positions of the two images and the lens on the sky. For a point-source lens, this ratio is obtained directly from the ratio of image-lens angular separations on the plane of the sky. Knowing the difference and the ratio between d_1 and d_2 gives the distance to the source and to the lens, together with a geometrical model of the lens. Given the redshift, a relation between the Hubble constant and the deceleration parameter q_0 follows.

In order to derive a time-delay, individual fluxes from the two images must be measured over a certain period of time. In the two systems where molecular absorption occurs in the lensing galaxy (B0218+357 and PKS1830-211), the image separations are 0.3″ and 1″,

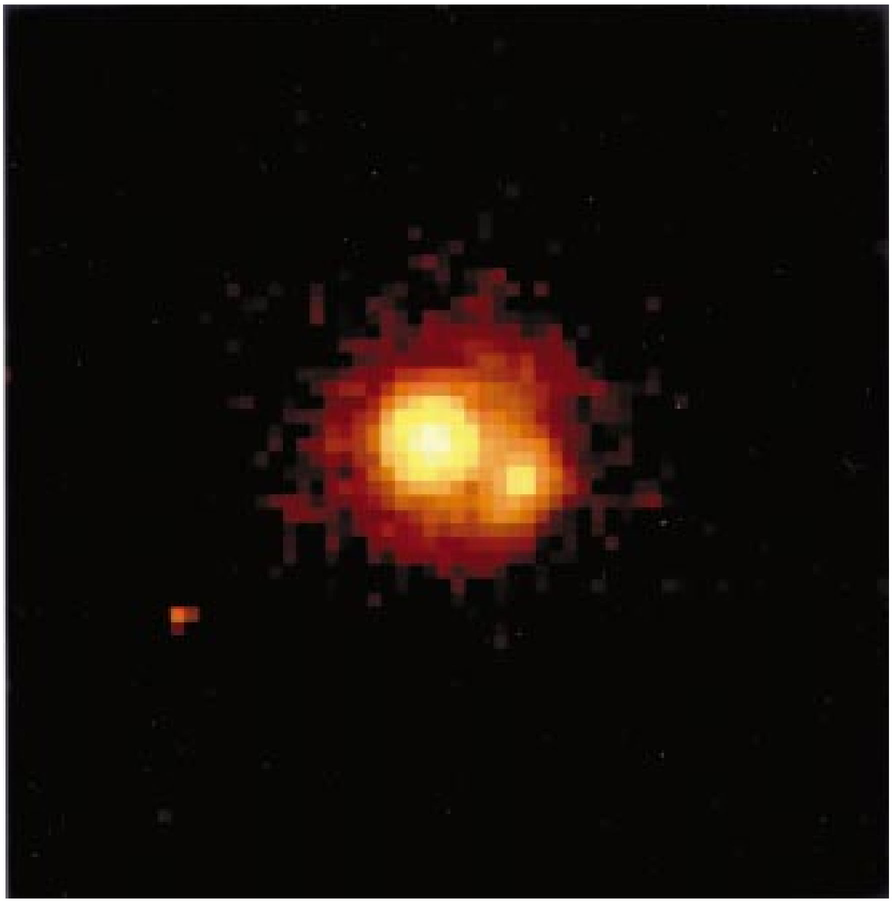

Figure 5: HST F814W image of B0218+357. North is up and east to the left. The pixel scale is 45 mas. The brighter component corresponds to the weak radio core B and the optically weak western component to the brightest radio core A. Comparison of the F555W and F814W bands show no indication of differences in the extinction between the A and B components.

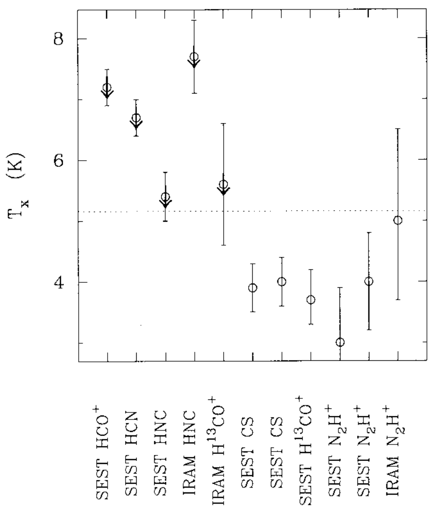

Figure 6: Measure of the excitation temperatures for several molecules shown in abscissa, from two of their rotational transitions. When the lower transition is optically thick, only an upper limit is derived. The horizontal dash line is the cosmic background temperature expected from the big-bang at the redshift of the absorber for PKS1830-211, i.e. z = 0.88582.

respectively. These are too small to be directly resolved with single-dish telescopes. However, fortuitously enough, in both cases the molecular gas obscures only one of the two quasar images. Therefore in the same beam where the two images are observed together, the depth of the saturated absorption line then directly measures the flux from one image, while the total continuum measures the sum of the fluxes of the two images. This has been checked by resolving the two images with the IRAM Plateau de Bure interferometer (Wiklind & Combes, 1998, *ApJ* in press) for PKS1830-211 and with the VLA for B0218+357 (Menten & Reid, 1996). Interferometer observations are, however, cumbersome to obtain and reduce; good-quality monitoring of the fluxes are in these cases best done using single-dish telescopes, since we do not need to resolve the images.

We have carried out a weekly monitoring of PKS1830-211 quasar since the beginning of 1996 with the IRAM 30-m and SEST 15-m telescopes, the results are plotted in Figure 4. The SEST data have been normalised to be compared with the IRAM ones, both are pretty compatible. However, it is difficult to derive precisely the time-delay, since the intrinsic variations of the quasar have not been of high amplitude during 1996-7, and the atmospheric calibrations introduce unwanted noise in the light curves. The expected time-delay is of the order of a few weeks.

The other lens B0218+357 has a very similar configuration, the flux ratio between the two components is around 3–4 at radio wavelengths, while it is 0.15 in the optical. The main image is covered by molecular clouds, but not entirely, 4% of the surface remains uncovered and can be seen in the HST image (cf. Fig 5).

5. Cosmic Background Temperature

Molecular clouds are usually very cold, with a kinetic temperature of the order of 10–20 K. The excitation temperature of the molecules could be even colder, close to the background temperature T_{bg}. This is the case when the absorption occurs in diffuse gas, where the density is not enough to excite the rotational ladder of the molecules. This is the case of the gas absorbed in front of PKS1830-211, where $T_{ex} \sim T_{bg}$ for most of the molecules. The measurement of T_{ex} requires the detection of two nearby transitions. When the lower one is optically thick, only an upper limit can be derived for T_{ex}. Ideally, the two transitions should be optically thin, but then the higher one is very weak, and long integration times are required.

The results obtained with the SEST 15-m and IRAM 30-m are plotted in Figure 6. Surprisingly, the bulk of measurements points towards an excitation temperature lower than the background temperature at z = 0.88582, i.e. T_{bg} = 5.20 K. This could be due to a non-LTE excitation or, possibly, by radiative coupling to a continuum source near the molecular cloud with a colour temperature at millimetre wavelengths lower than T_{bg}.

6. Variation of Fine-Structure Constant

The high spectral resolution of heterodyne techniques, the narrowness of absorption lines and their high redshift make these measurements favourable to try to refine the constraints on the variation of coupling constants with cosmic time, variations that are predicted by for instance the Kaluza-Klein and superstring theories. By comparing the HI 21-cm line (Carilli et al., 1992, 1993) with rotational molecular lines, one can constrain the variations of $\alpha^2 g_p$, α being the fine-structure constant, and g_p the proton gyromagnetic ratio. Also, by intercomparison of rotational lines from different molecules, one can test the invariance of the nucleon mass m_p, since the frequencies are affected by centrifugal stretching.

Recent works on these lines have considerably improved the previous limits (e.g. Potekhin & Varshalovich, 1994). By comparing various optical/UV lines (of H_2, HI, CI, SiIV) in absorption in front of quasars, Cowie & Songaila (1995) constrained the variation of $\alpha^2 g_p m_e/m_p$ to $4 \cdot 10^{-15}$/yr. Varshalovich et al. (1996) from radio lines come to a limit of variation of $\alpha^2 g_p$ of 8 10^{-15}/yr. Drinkwater et al. (1997) by a more careful analysis of the same data conclude to 5 10^{-16}/yr. We have also derived a limit from PKS1413+135 and PKS1830-211 data of $\Delta z/(1 + z) < 10^{-5}$, which yield a corresponding limit of 2 10^{-16}/yr (Wiklind & Combes, 1997b). However, geophysical constraints are in fact superior to all astrophysical ones. Damour et al. (1997) have recently come up with a limit of 5 10^{-17}/yr on α from the natural fission reactors which operated about 2 10^9yr ago at Oklo (Gabon). These results were obtained through analysis of the neutron capture cross section of Samarium, in the Oklo uranium mine.

Notice that we have reached an intrinsic maximum of precision with the astrophysical technique, since the limitation comes from the hypothesis that the various lines compared come from the same material, at exactly the same Doppler velocity along the line-of-sight. This hypothesis is obviously wrong when comparing HI and molecular lines; it is also wrong while intercomparing molecules, or even within lines of the same molecule, since opacity depends on excitation conditions which vary along the line of sight for each transition. The astrophysical techniques do, in contrast to terrestrial methods, test the uniformity of physical constants over large spatial scales.

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Using SEST to Probe the Geometry of the Universe

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Many very interesting results in the field of observational Cosmology have been obtained in the past with the 15-m Swedish ESO Submillimetre Telescope (SEST) at La Silla (see the ESO/STC-148 Report on *Submillimetre Astronomy at ESO).*

The technical upgrades and improvements foreseen for SEST will undoubtedly boost projects in this field which, after a very successful start a few years ago, suffered a loss of competition with respect to other available sub-mm/mm facilities (i.e. IRAM, JCMT).

In view of the future development in the field of sub-mm/mm astronomy at ESO (see the leading article of this issue), the SEST antenna at La Silla will represent the most suited instrument to prepare projects and test instruments for the LSA/MMA arrays. A lot of work can be envisaged: for instance, deep surveys of small sky regions, aimed at looking for the long-sought dusty primeval galaxies, can be started with SEST.

An example of what has been done and hopefully *will* be pursued in the next future in the field of observational Cosmology is reported in this article.

1. The S-Z Effect and the Measure of H_0 and q_0

As already preliminarily described in *The Messenger* (No. 78, December 1994), a group of people (in alphabetic order: H. Böhringer, R. Booth, G. Dall'Oglio, R. Lemke, L. Martinis, L.-Å. Nyman, A. Otàrola, L. Pizzo, P. Shaver, N. Whyborn and myself) have started to use SEST to measure the Sunyaev-Zeldovich (S-Z) effect towards ROSAT clusters of galaxies.

The S-Z effect is one of the major sources of secondary anisotropies of the Cosmic Microwave Background (CMB), arising from (inverse) Compton scattering of the microwave photons by hot electrons in clusters of galaxies. This effect generates a peculiar signal with a decrement at wavelengths longer than 1.4 mm and an enhancement at shorter ones relative to the CMB planckian value. The original computation by Sunyaev and Zeldovich (1972) of the net transfer of energy from the hot e– to the microwave photons predicts a signal for the relative temperature change:

$$\left(\frac{\Delta T}{T}\right)_{therm} = y\left(x\frac{e^x+1}{e^x-1}-4\right) \qquad (1)$$

where T is the CMB temperature, $x = h\nu/kT$ and $y = \int (kT_e/mc^2)\, n_e \sigma_T d\ell$ is the comptonisation parameter, n_e, T_e being the electron density and temperature.

If the cluster has a peculiar velocity relative to the frame where the CMB is isotropic an additional *kinematic* effect should be measured. The motion of the gas cloud will induce a Doppler change whose relative amplitude, $\left(\frac{\Delta T}{T}\right)_{kin}$, does not depend on the frequency but only on the peculiar velocity, υ_r, and cloud optical depth for Thomson scattering, τ,: $\left(\frac{\Delta T}{T}\right)_{kin} = -\frac{\upsilon_r}{c}\tau$ (where the minus sign refers to a cluster receding from the observer).

There is considerable interest in the detection of this effect also because of its potential in determining the distance and the peculiar and tangential velocities of clusters, and in studying the intracluster medium.

The physics of the effect is well understood, because it relies on properties of ionised gas in hydrostatic equilibrium. Furthermore, the effect does not depend on redshift, because of the luckily combination between the surface brightness dimming, $\propto (1+z)^{-4}$, and the increasing CMB energy density, $\varepsilon_{CMB} \propto (1+z)^4$.

Here it is shown how it is possible to infer the cluster distance without using any secondary calibrators: the method is applicable to any individual source to any cosmological distance and does not depend on the evolutionary properties of the cluster as long as the physical state of the gas is understood. The basis consists of combining the S-Z effect measurements with X-ray data, since the X-ray surface brightness due to thermal bremsstrahlung, Sx, and the S-Z signal, ΔT_{SZ}, scale differently with n_e and a, the cluster core radius:

$$\Delta T_{SZ} \propto \langle n_e T_e \rangle a \qquad (2)$$

$$S_x \propto \frac{V\langle n_e^2 \sqrt{T}_e\rangle}{D_l^2} \qquad (3)$$

where V and D_l is the gas volume and the cluster luminosity distance, respectively. The combination of these measurements provide an estimate of a:

$$a \propto \Delta T_{SZ}^2 S_X^{-1} T_e^{-3/2}\frac{\theta^2}{(1+z)^4} \qquad (4)$$

since a is related to the apparent angular size by the luminosity and angular diameter distance, D_A:

$$\frac{a}{\theta} = D_A = D_l(1+z)^{-2} \qquad (5)$$

Therefore, measuring θ, ΔT_{SZ}^2, T_e, S_X and z gives D_A (D_l) and from it H_0:

$$D_l = \frac{c}{q_0^2 H_0}\{zq_0 + (q_0-1)[-1+\sqrt{1+2zq_0}\,]\} \qquad (6)$$

Many groups in the world (mainly of radio astronomers) have successfully carried out so far observations of the Rayleigh–Jeans (R-J) decrement (see the recent review by Birkinshaw, 1997).

However, an unambiguous signature of the presence of the S-Z effect requires the measurement of both the decrement (negative) and the enhancement (positive), at best simultaneously on the same cluster. Up to now, only two groups (Andreani et al., 1996a, 1998; Holzapfel et al., 1997) have measured also the positive side of the signal at the only wavelength accessible from the ground (i.e. with enough transparency): 1.2 mm.

2. Our Instrument

The Italian group of the III University of Rome have built a photometer with two channels centred at 1.2 and 2 mm to feed the O.A.S.I. (Osservatorio Antartico Submillimetrico Infrarosso) telescope installed at the Italian base in Antarctica (Dall'Oglio et al., 1992). This photometer was adapted to be placed at the focus of the SEST antenna in Chile. The 2-mm band includes the peak brightness of the decrement in the S-Z thermal effect, while the 1.2-mm bandwidth is a compromise between the maximum value of the enhancement in the S-Z and the atmospheric transmission. The field of view in the sky was 44″ at both frequencies. The beam separation in the sky was limited by the antenna chopping system and was set to the maximum chopping amplitude: 135″.

Responsivities, beam shapes and widths were measured with planets and the sensitivity measured at the focus was: 7.5 mK/s at 1.2 mm and 10.7 mK/s at 2 mm. This means that in terms of relative change of the thermodynamic temperatures in one second integration time, we have $\left(\frac{\Delta T}{T}\right)$ = 0.01 and 0.007 at 1.2 and 2 mm respectively.

3. The Choice of the X-Ray Clusters

Candidate sources were selected from the ROSAT southern clusters according to the following prescriptions: (a) high X-ray luminosity and (b) redshift larger than 0.25. This choice matches the two fundamental requirements: a small apparent angular dimension of the cluster core and a large Comptonisation parameter. The cluster angular dimensions should not largely exceed the instrument beam width and they

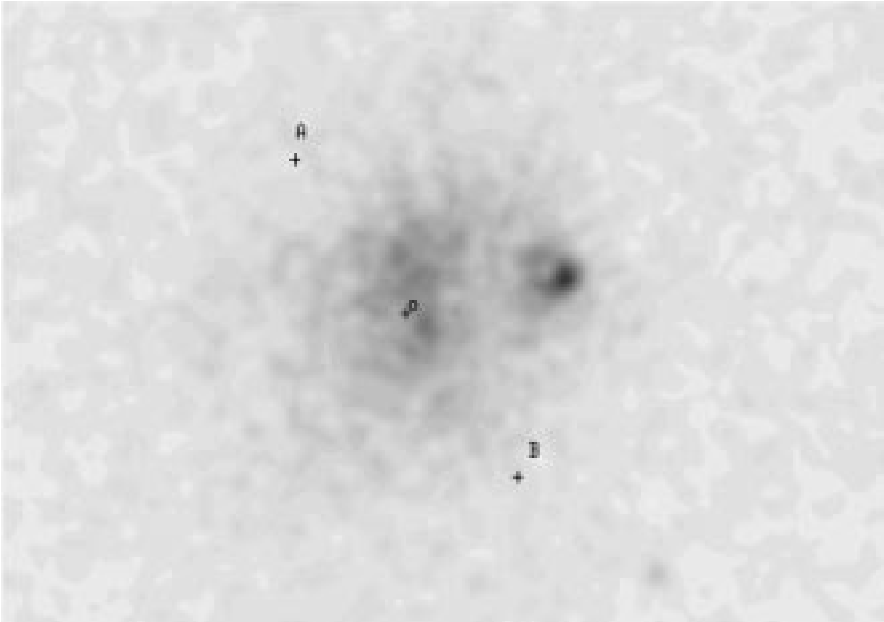

Figure 1: The ROSAT/PSPC X-ray image of RXJ0658-5557. The position of the central beam (o) and the reference beams (A and B) are shown as crosses superposed on the X-ray image. (Courtesy of Hans Böhringer). Field size is 17 arcmin in RA (horizontal axis) and 10 arcmin in declination (vertical axis). The redshift of the cluster is 0.31. The ROSAT count rate in the range 0.1 to 2.4 keV is 0.50±0.04 per second.

must be smaller than the maximum chop throw, otherwise the amplitude of the signal cannot be correctly estimated. A large *y* parameter enhances the amplitude of the effect and therefore its detectability. Figure 1 shows superposed to the X-ray map of RXJ0658-5557 the location of the main beam (at the centre) with the reference beam (position A and B). Beam switching + nodding provides the real-time comparison between the emission from the cluster centre and that from the reference beams A and B.

As it is clear from the figure, the limited chop throw of the focal plane system did not allow us to measure the difference ON-OFF the cluster with the maximum sensitivity. This problem can be successfully tackled only using a wobbling secondary mirror, which is one of the foreseen upgrades of SEST mentioned before.

4. The Observations of the S-Z Enhancement and Decrement

Observations were collected in September 1994 and 1995 towards the X-ray clusters S1077, A2744, S295 and RXJ0658-5557. Description and performance of the instrument were reported in Pizzo et al. (1995) and in *The Messenger* No. 78 (1994), observations in Andreani et al. (1996a, 1996b and 1998).

Detections were found for A2744 at 1 mm and in both channels (at 1.2 and 2 mm) towards RXJ0658-5557. For the first time there was evidence for the S-Z enhancement and both the latter and the decrement were detected on the same source.

Observations of RXJ0658-5557 were carried out in four different nights during September 1–5, 1995. During the observations the sky opacity was very low ($\tau_{1mm} < 0.1$ with an average value of $< \tau_{1mm} > = 0.07$, $\tau_{2mm} < 0.05$ with an average value of $< \tau_{2mm} > = 0.03$) and the sky emission very stable thus producing a very low sky-noise. A total integration time of 12,400 s was spent on RXJ 0658-5557 and the same integration time was spent on a blank sky located 15 min ahead in right ascension with respect to the source position.

The effect we are looking for is very weak. We had therefore to check carefully all the systematics which could affect the measurements. Spill-over from the ground, difference in temperature from one side to the other of the main mirror and other effects could certainly plague the observations. Since it is hard to identify and quantify each effect, we measured them according to the following observing strategy: the source was integrated over time chunks of 600 s, this time interval plus the needed overheads gives a total tracking time on the source of 15 minutes. The same time was spent on a blank sky located with equatorial co-ordinates 15 minutes larger in right ascension. This means that the antenna tracked twice the same sky position in horizontal co-ordinates: once ON the source and the second time on the reference blank sky position. This enabled us to compare the two different measurements and eliminate the spurious signals.

Data were then extracted for the ON and OFF positions and the final estimate of the antenna temperature produced by the S-Z signal is given by $\Delta T_{SZ} = \Delta T_{ON} - \Delta T_{OFF}$. From a maximum likelihood analysis of the data ΔT_{SZ} we could infer an estimate of the antenna temperature at the two wavelengths: $\Delta T_{1mm} = +0.3 \pm 0.06$ mK, $\Delta T_{2mm} = -0.46 \pm 0.13$ mK.

5. mm and X-Ray Data: Modelling the Hubble Constant

The angular diameter distance to a cluster can be observationally determined by combining measurements of the thermal S-Z effect and X-ray measurements of thermal emission from intracluster (IC) gas as shown in equations 2–6 above. While the physical basis is very simple and straightforward, the procedure to estimate the Hubble constant is still affected by large uncertainties. On the one hand, the radio, mm and submm are plagued by the presence of discrete sources and/or diffuse dust in clusters. On the other hand, we still lack a deep knowledge of the distribution of the hot gas and its temperature in the cluster core. The X-ray image modelling involves several steps, each of them contains a source of unknown systematics. The final result is therefore affected by large uncertainties.

Here we show how we did proceed to estimate the luminosity distance to the cluster RXJ0658-5557 by combining the ROSAT X-ray image, the ASCA spectrum and the SZ mm observations.

5.1 Modelling the X-ray data

Our method consists of computing the expected S-Z map from the X-ray observations. This modelling requires the following steps:

(1) the construction of a X-ray surface brightness model fitting the X-ray image. This procedure allows to infer the physical parameter of the e^- gas, i.e. n_e.

(2) T_e is usually determined from the X-ray spectrum of the hot gas. In our case we made use of the ASCA GIS data. The temperature distribution is assumed to be isothermal and symmetrical.

(3) The distribution of the e^- density and temperature are then used to predict the expected S-Z increment and decrement: a map of the comptonisation parameter, *y*, is then built.

(4) Since the observed S-Z signal is the true one modified by the telescope primary beam and the beam switching, the predicted *y*-parameter is convolved with beam pattern and throw. These latter were measured during the calibration phase of the instrument. The convolved y-parameter is hereafter called *Y*.

5.2 A value for H_0

The numerical values in the modelling of the X-ray data depend on the Hubble parameter, H_0, and in this way by comparing the predicted with measured values an estimate of the absolute distance of the cluster and H_0 can be made.

Hence the predicted versus observed Y-parameter are for the 2-mm channel:

$$(Y)_{X-ray} = -2.73\ 10^{-4}\, h_{50}^{-1/2}$$
$$(Y)_{obs} = -2.53\ 10^{-4} \qquad (7)$$

giving a formal result of the Hubble constant of $H_0 = 58^{+35}_{-22}$ km s^{-1} Mpc^{-1}.

As the reader is aware, the error bars are quite large. They take into account many uncertainties still involved in this kind of measurements: the pointing position of the SEST and ROSAT Telescopes, the X-ray modelling and the uncertainties of the mm observations. These latter consider also the fact that the 1.2-mm channel is very likely affected by secondary cluster emission, maybe due to intracluster dust and/or sources.

The only way to get rid of these systematics is the observation of many clusters. Every source in fact contributes in a different way to the various modelling steps so that it is reasonable to assume that the average value of the Hubble constant is a fair estimate of the real one.

This project would never have become a reality without the work of many people, among them I would like to thank my collaborators (H. Böhringer, R. Booth, G. Dall'Oglio, R. Lemke, L. Martinis, L.-Å. Nyman, A. Otàrola, L. Pizzo, P. Shaver, N. Whyborn), the SEST team and the Infrared group at La Silla and in particular Glenn Persson, Roland Lemke, Angel Otàrola, Peter de Bruin, Cathy Horellou, Peter Sinclair and Nicolas Haddad for their fundamental help and assistance during the observations and during the photometer set-up. This work has been partially supported by the P.N.R.A. (Programma Nazionale di Ricerche in Antartide). P.A. warmly thanks ESO for their hospitality during 1995, when part of this work was carried out.

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Cold Dust in Galaxies

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Abstract

The activity of galaxies reaches from the enhanced star-formation rate to the outburst of quasars. These different aspects of converting cold gas into luminosity can be well described by the ratio of infrared luminosity versus gas mass. The process of star formation is characterised by L_{IR}/M_{gas} values of 5 [$L_\odot/M_\odot$] in normal spirals and 100 in active Mkn galaxies while quasars attain values above 500 due to additional non-thermal processes. Moreover, the coldest dust component in extragalactic objects also seems to be correlated with the stage of activity: T_d increases from 15 K in normal spirals to more than 40 K in quasars. New *ISOPHOT* data between 60 and 200 μm and SEST data at 1300 μm corroborate these results for active galaxies but indicate the presence of very cold dust ≈ 10 K) in normal spirals. The implications on the total gas content of galaxies are discussed. It turns out that high-resolution submm measurements of the dust emission with high spatial and spectral resolution play a key role for our understanding of the interstellar medium in external galaxies. In this context, plans for SIMBA, a new 37-channel bolometer array at 1300 μm for the SEST and the need for the LSA are briefly discussed.

1. Activity in Galaxies

In a previous *Messenger* article (Chini and Krügel, 1996, hereafter Paper I) we have described our long-term project on the global star- formation efficiency in various classes of galaxies. Our approach to this problem was the following: The energy of most galaxies originates from the formation of stars; only a few exotic objects like radio galaxies and quasars contain additional sources of energy which probably originate from the accretion of interstellar matter onto a circumnuclear disk. However, both sources of energy have in common that cold interstellar gas is transformed into luminosity. Therefore, the amount of luminosity obtained per unit gas mass, i.e. the ratio L/M_{gas}, should be an appropriate description for the activity in galaxies.

In order to obtain this ratio, we determined the two fundamental quantities L and M_{gas} for three samples of normal spirals, active galaxies and radio-quiet quasars. The total luminosity was approximated by the IR luminosity between 12 and 1300 μm. This interval is nicely covered by the infrared satellite *IRAS* at the wavebands 12, 25, 60 and 100 μm; beyond that we managed to obtain the 1300-μm continuum flux from the 15-m SEST or the 30-m IRAM telescope. The luminosity L_{IR} derived in this way is typically a factor of 10 higher than the blue luminosity L_B, indicating that it is a good approximation for the total luminosity of these objects.

The gas content M_{gas} of the galaxies was determined from the optically thin emission of dust at 1300 μm observed at the SEST and at IRAM. To convert the observed dust emission into a gas mass we used the fact that in the Milky Way, the amount of gas is about 150 times larger than that of dust. An independent check of the gas mass was derived from CO measurements: the intensity of the lower rotational levels J(1-0) and J(2-1) at wavelengths of 2.6 mm and 1.3 mm, respectively, has been verified empirically to be proportional to the mass of molecular hydrogen. The corresponding observations have also been performed at the SEST and the IRAM 30-m telescope. The major results of these studies as outlined in Paper I can be summarised as follows:

1. In normal spirals the spectral energy distribution from 100 to 1300 μm is dominated by cold dust of $T_d = 15 \pm 5$ K. Their gas mass is $2 \cdot 10^9 \leq M_{gas} \leq 6 \cdot 10^{10}$ $M_\odot$ and their IR luminosity is $6 \cdot 10^9 \leq L_{IR} \leq 3 \cdot 10^{11}$ $L_\odot$ yielding a ratio $L_{IR}/M_{gas} = 5 \pm 2$ in solar units.

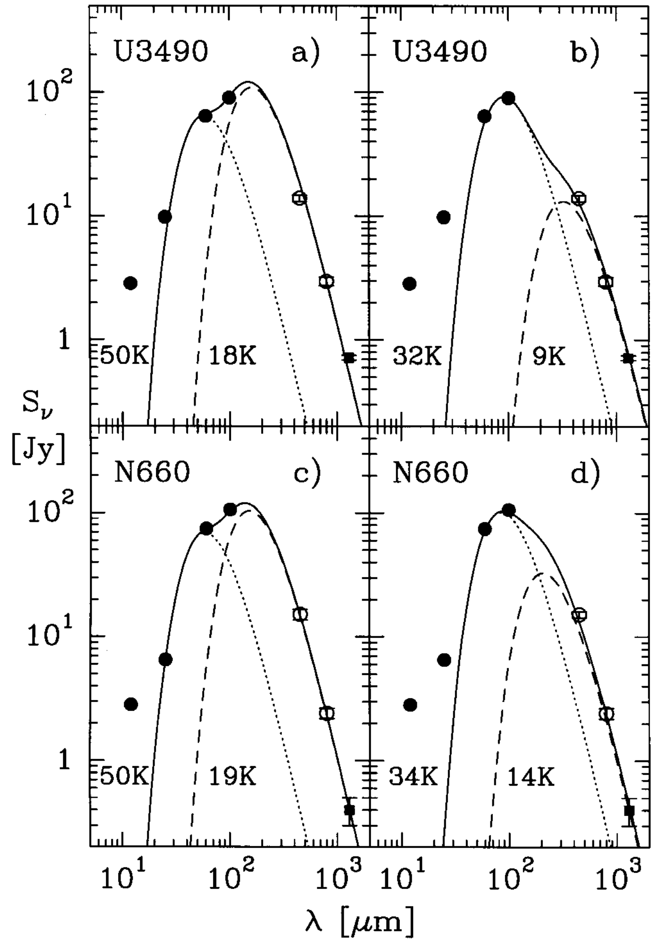

Figure 1: Observed energy distributions of UGC 3490 and NGC 660. Measurements at 450 and 800 μm are from Chini & Krügel (1993) and 1300 μm data come from Chini et al. (1995). Possible decompositions into a cold (dashed) and a warm (dotted) component are shown assuming m *= 2. The temperatures of the individual components are (a) 18 K and 50 K, (b) 9 K and 32 K, (c) 19 K and 50 K, (d) 14 K and 34 K.*

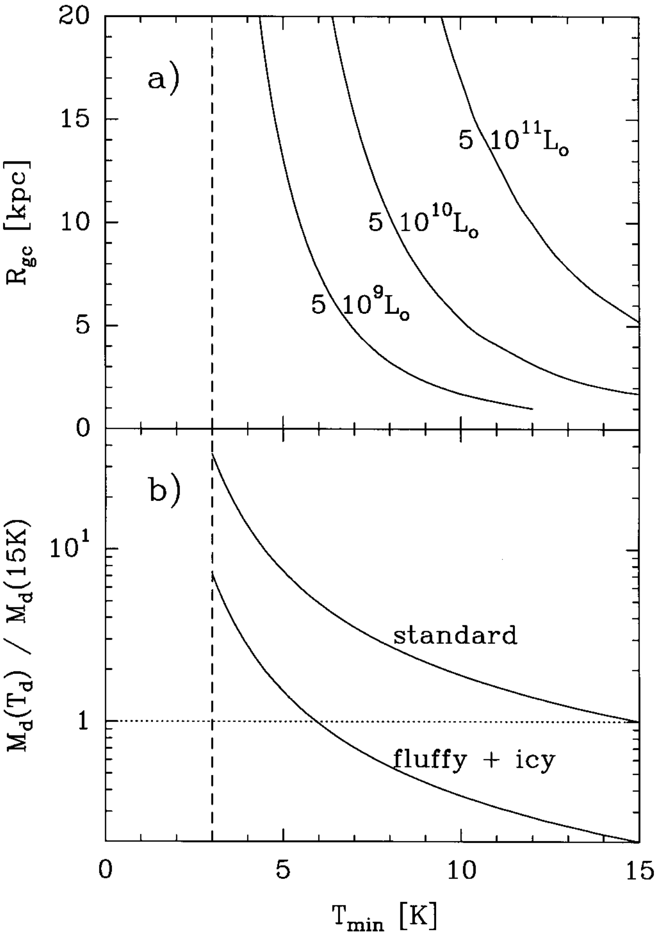

Figure 2: (a) Minimum dust temperature T_{min} as a function of galactocentric radius R_{gc} for $L_{IR} = 5 \cdot 10^9$, $5 \cdot 10^{10}$ and $5 \cdot 10^{11}$ $L_\odot$, respectively. (b) The relative change of dust mass compared to a 15 K component for normal (solid) and fluffy + icy grains (dashed) where κ_{1300} is enhanced by a factor of 5.

2. In active galaxies the spectral energy distribution from 60 to 1300 μm can be described by a coldest dust component of 33 $\pm$ 5 K. We find a range of gas masses of $5 \cdot 10^7 \leq M_{gas} \leq 8 \cdot 10^{10}$ $M_\odot$ and a range of IR luminosities of to $5 \cdot 10^9 \leq L_{IR} \leq 3 \cdot 10^{12}$ $L_\odot$. The ratio $L_{IR}/M_{gas} = 92 \pm 53$, i.e. about a factor of 20 higher than in normal spirals.

3. In radio-quiet quasars, finally, the coldest dust component was found to be about 40K. Their gas content is comparable to that in active galaxies but their ratio $L_{IR}/M_{gas} \approx 550$.

Thus, there is a correlation between the stage of activity and the L_{IR}/M_{gas} ratio as shown in Figure 2 of Paper I. Obviously, the luminosity is no unique indicator for activity because extragalactic objects within the luminosity interval from 10^{11} to 10^{12} occur as normal spirals, active galaxies or quasars. Likewise, objects of a given gas mass produce quite different amounts of luminosity, depending on their activity. Thus only the efficiency of converting mass into luminosity, i.e. the quantity L_{IR}/M_{gas} determines the actual stage of activity. Non-active galaxies are characterised by rather low ratios of the order of 5 whereas active galaxies produce 20 times more luminosity out of the same reservoir of gas. Obviously, the range $5 \leq L_{IR}/M_{gas} \leq 100$ is typical for star formation, whereas larger values, as they occur with quasars, require additional non-thermal processes. In this paper we want to address the importance of the dust temperature and its implication for the activity in galaxies.

2. The Dust Content of Galaxies

The stage of activity as measured by the ratio L_{IR}/M_{gas} seems also to be correlated with the temperature of the coldest dust component in galaxies. According to our previous measurements, dust in normal galaxies attains temperatures as low as 15 K and increases to about 40 K in quasars. As discussed above, the origin of this effect cannot entirely be attributed to the amount of luminosity (because there are normal and active galaxies with identical luminosity), but rather must be dominated by some geometrical effects. Vice versa, the temperature of the coldest dust component determines the total amount of dust and gas and thus scales with the ratio L_{IR}/M_{gas} directly. In this sense, T_d becomes an extremely important quantity which, however, is difficult to determine accurately because of the large gap in the data between 100 and 1300 μm.

2.1 The decomposition of spectral energy distributions

To overcome the problem of insufficient spectral coverage and to improve the temperature estimates we have started to fill the gap between 100 and 1300 μm by submm continuum measurements from the JCMT at 450 and 800 μm (Chini *et al.* 1995). Figure 1 shows as an example the spectral energy distribution (SED) of two galaxies, UGC 3490 and NGC 660, where we have included some of the missing spectral points. In order to derive the temperature T_d of the coldest dust component we applied fits of the form $\lambda^{-2} B_\lambda(T_d)$ where B_λ denotes the Planck function and the factor λ^{-2} accounts for the emissivity of the dust grains. Interestingly, despite the additional submm data, the SEDs still cannot be interpreted in a unique way: The emission from UGC 3490 within the range 60 to 1300 μm may be described by two components of 9 K and 32 K (case *a*) but also by a superposition of two temperatures at 18 K and 50 K (case *b*). For NGC 660 the differences are not that extreme but possible solutions still vary between combinations of 19 K and 50 K (case *c*) or 14 K and 34 K (case *d*). This means that even additional submm data at 450 and 800 μm are not sufficient to clarify the problem of spectral decomposition. On the contrary, the new data rise the important question whether a very cold dust component exists in galaxies.

2.2 Is there very cold dust in galaxies?

In Paper I we derived an average temperature for the coldest dust component of 15 ± 5 K in normal spirals and 33 ± 3 K in active Mkn galaxies. It is clear that a whole range of warmer dust is required to explain the entire emission at wavelengths shorter than 60 μm; the amount of material at higher temperatures, however, is negligible in the context of the total mass of interstellar matter in galaxies. On the other hand, observational uncertainties and ambiguities in decomposing the SEDs, leave sufficient freedom for the existence of still colder dust in substantial quantities. The importance of the temperature of the coldest dust component in galaxies is twofold:

1. The optically thin emission of dust at submm wavelengths S_λ is directly proportional to the amount of dust M_d and depends on the temperature T_d:

$$M_d = \frac{S_\lambda}{B_\lambda(T_d)} \frac{D^2}{\kappa_\lambda}, \quad (1)$$

where B_λ denotes the Planck function, κ_λ the mass absorption coefficient and D the distance. Using the Rayleigh-Jeans approximation $B_\lambda(T_d) = 2hc^2/\lambda^2 \cdot k\, T_d$ the dust mass becomes inversely proportional to the dust temperature (T_d)

$$M_d = \frac{S_\lambda}{T_d} \frac{\lambda^2}{2hc^2 k} \frac{D^2}{\kappa_\lambda}. \quad (2)$$

If the 1300 μm flux observed at SEST originates from very cold dust, the total amount of interstellar matter increases and thus our numerical results concerning the activity tracer L_{IR}/M_{gas} have to be revised.

2. Because the emitted energy is proportional T^6_d, a slight decrease in dust temperature causes a large change in the energy balance of a galaxy. It may imply that (i) the average stellar luminosity per unit volume is lower or (ii) the dust is farther away from the stars or (iii) the dust is better shielded from stellar photons.

In order to estimate the minimum possible temperature T_{min} of dust, we neglect both, the possible interstellar matter outside the optical radius of a galaxy and the existence of very small transiently heated particles, which are most of the time at very low temperatures, but do not contribute significantly to the total dust mass.

Very cold dust can only be found deep in the interior of clouds; it must be protected from stellar light and shielded by an optical depth well above 10 mag. Nevertheless, at least for wavelengths beyond 25 μm, clouds are heated by the FIR emission of the galaxy itself. There the optical depth is probably more than a factor of 50 smaller than in the visual. The heating by FIR radiation is not very efficient because of reduced cross sections for absorption, but it is much more important than the heating by the microwave background. To further minimise the heating, we assume that the source of FIR radiation resides in the galactic nucleus. A spatially spread-out energy source, like stars in the disk or heating by radiation of shorter wavelengths, would only increase T_{min}.

The results for T_{min} are shown in Figure 2a, which is reproduced from Chini & Krügel (1996). The calculations are based on two heating components of equal luminosity with a $\lambda^{-2}B_\lambda(T_d)$ spectral shape and temperatures of 15 K and 50 K. Obviously, in a galaxy with an FIR luminosity of $5 \cdot 10^{10}$ $L_\odot$ and an optical size of 15 kpc, like e.g. the Milky Way, the dust in the disk cannot become colder than ~ 6 K; two additional curves in Figure 2 show how T_{min} depends on the luminosity of the galaxy.

To estimate how much dust mass can escape detection, we make the extreme assumption that the observed 1300 μm flux originates entirely from very cold dust without any contribution from a 15 K component. From the solid curve in Figure 2b, which holds for normal dust in the diffuse interstellar medium, we can infer by how much we would underrate the mass of dust at a certain temperature assuming that T_d were 15 K; for example, dust of 6 K would yield a factor of 5. The optical properties of very cold dust, however, are inevitably modified by the deposit of ice mantles and, most likely, coagulation into fluffy agglomerates. This modification leads to an increase in the absorption coefficient κ by a factor of 5 to 10. Consequently, the mass of very cold dust may even be slightly smaller or comparable to the dust at 15 K (see Figure 2b dashed curve); dust of 6 K, e.g., would leave the mass unchanged. As the two effects, lower temperature and enhanced grain emissivity, neutralise each other we conclude that 1300 μm continuum observations yield fair results for the total dust mass.

2.3 Latest answers from ISO

Recently we have combined new *ISOPHOT* data between 60 and 200 μm with 1300 μm observations for six galaxies (Krügel et al., 1998). Eight ISOPHOT wavebands have been selected to cover the peak of the dust emission and thus to derive a very accurate determination of the dust temperature T_d. Three of the objects come from our sample of active Mkn galaxies (see Fig. 3, reproduced from Krügel et al., 1998). Their SEDs can be fitted uniquely by a single dust component of 31 K which is in perfect agreement with our previous estimates.

For the three normal spirals the picture changes considerably: As shown in Figure 4 (adapted from Krügel et al., 1998), least square fits to the data from 60 to 1300 μm require a combination of two dust components – one of about 29 K which dominates the *ISOPHOT* observations and another one of about 10 K which is necessary to explain the 1300 μm emission observed at SEST. Depending on the mass absorption coefficient κ this very cold component may imply an increase of the mass of interstellar matter by a factor of three. As a consequence, the ratio L_{IR}/M_{gas} could be reduced by the

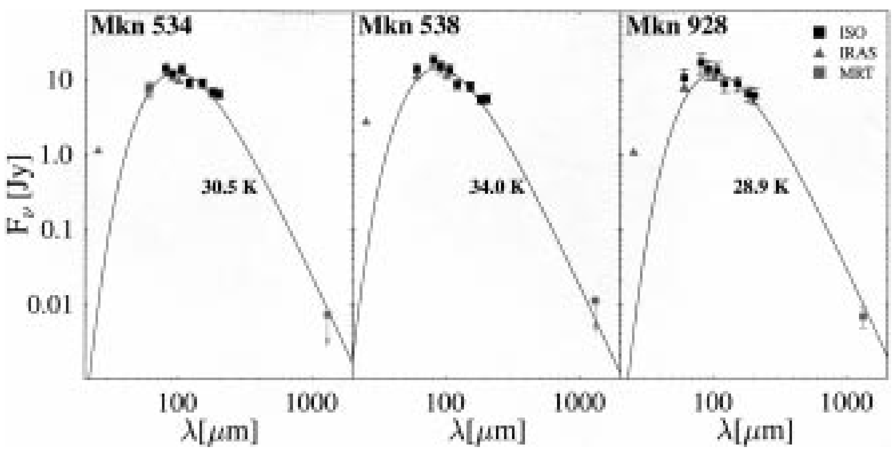

Figure 3: Dust emission spectra of three active galaxies from the Markarian catalogue. The solid lines are one-component fits between 60 and 1300 μm of the form $\lambda^{-2}B_\lambda(T_d)$; *the resulting fit temperatures are indicated.*

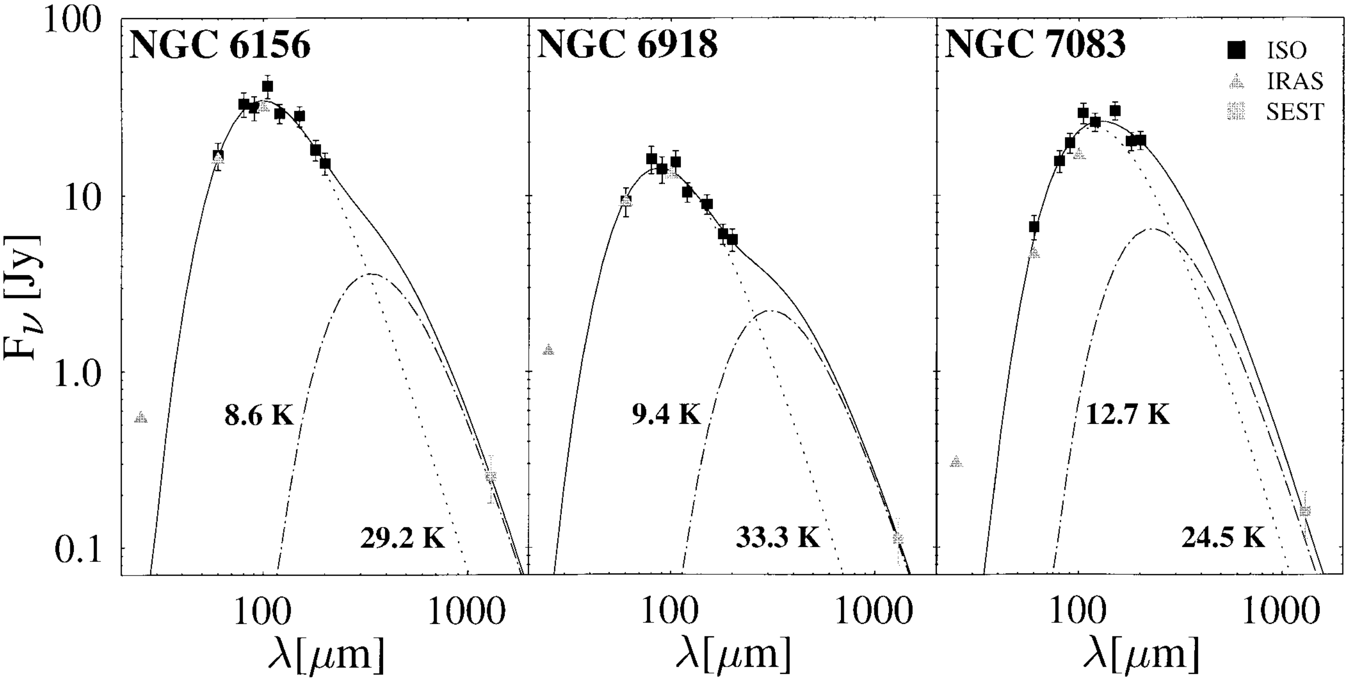

Figure 4: Dust emission spectra of three inactive spiral galaxies. The dotted and dashed-dotted lines are two-component least square fits between 60 and 1300 μm of the form $\lambda^{-2}B_{\lambda}(T_d)$; the solid curves give their sum. The resulting fit temperatures are indicated.

same amount. Certainly, the number of galaxies is still Insufficient to draw general conclusions, but evidence grows that large amounts of cold dust may be present in normal spiral galaxies.

3. Future Developments

Despite the interesting results obtained so far there is obviously heavy demand for an improvement in the decomposition of the SEDs by data of better spectral and spatial resolution and for a complete coverage of extended objects at several submm wavelengths. In order to meet some of these requirements, there are two instrumental developments in the southern hemisphere that will hopefully enrich the observational possibilities in the future:

SIMBA. Measurements of the total dust emission from extended sources like galactic molecular clouds or external galaxies require time consuming mapping procedures: The present 1300 μm continuum detector at SEST consists of a single bolometer element that provides a field of view of only 24 arcseconds. Due to the generally faint extended millimetre emission, continuous mapping is restricted to the brightest objects. Fainter sources have to be observed with ON-OFF procedures that take at least 5 hours to perform e.g. a crude 5-point raster map. As a result, the spatial distribution of dust is so far unknown and/or incomplete for most galaxies and has to be extrapolated. Therefore, the “Astronomisches Institut der Ruhr-Universität Bochum” and the “Max-Planck-Institut für Radioastronomie” in Bonn have agreed upon designing a new ^{3}He-cooled 37-channel bolometer array as a facility device for SEST (SIMBA = SEST IMaging Bolometer Array) with support from Onsala Space Observatory. The new system will operate at a wavelength of 1300 μm and at a spatial resolution of 24 arcsec. With a total field of view of about 300 arcsec in diameter, SIMBA will allow to cover large regions like southern molecular clouds and galaxies and in particular the Magellanic Clouds with unprecedented sensitivity and efficiency. Apart from a factor of 37 in integration time such a multi-channel system has a number of further advantages compared to the existing single channel device: Performing e.g. 37 individual maps of an area implies huge overheads due to repeated pointing and calibration actions between the single coverages whereas a 37-channel map can be run with one pointing and calibration only. Another gain comes when coadding the 37 channels: Individual coverages from a single-channel observation suffer from unavoidable positional uncertainties and thus smear out faint extended structures in the final superimposed image. In contrast, the final map from the new array detector will always produce “sharp” images because the offset between the 37 individual channels is mechanically fixed and well known. Even point-source measurements will benefit from the new device tremendously when using the outer channels of the array to monitor sky fluctuations. Depending on the weather conditions, improvements of factors 2–3 in sky-noise suppression have been achieved with a similar system at the IRAM 30-m telescope. SIMBA will be manufactured throughout 1998 and it is planned to install the system in April 1999 after the new wobbling secondary for SEST has been implemented.

LSA. Apart from measuring the total flux of an object, one is also interested in the detailed spatial distribution of the emission. There is strong evidence, that e.g. most of the interstellar gas in active galaxies is concentrated within an inner region of a few kpc – possibly in form of disks, rings or bars. Likewise, the configuration of interstellar matter in the host galaxies of quasars is entirely unknown, due to insufficient spatial resolution. In order to disentangle fine structures in the mass distribution, spatial resolution of the order of one arcsec or better is required. This can only be managed by future submm interferometers such as the LSA. Located at an appropriate high altitude site, this instrument will eventually be able to fill up the spectral gap between 200 and 1300 μm as set by current air- and spaceborne missions and ground-based observations from SEST and IRAM. Only the simultaneous increase of spatial and spectral resolution will improve our understanding of the origin of global star formation, starbursts and quasars.

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Carbon Monoxyde in the Magellanic Clouds

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1. The Results Achieved with SEST and Future Perspectives

Thanks to the good angular resolution of the SEST, much progress has been done on the properties of molecular gas in the Magellanic Clouds, and this is outlined in the following sections. A substantial fraction of the Clouds has been mapped in the CO lines at a linear resolution of about 10 pc, sufficient to resolve the ordinary molecular clouds inside large gas complexes. Multi-line observations have allowed to explain why these clouds look different in CO than Galactic clouds: this is due to a combination of lower heavy-element and dust abundances and of a higher far-UV flux (and probably MeV-energy cosmic ray flux) in the Magellanic Clouds. However, many observations of faint lines were done with poor signal/noise ratios and should be redone with the new receivers. We still do not know accurately how much molecular gas (essentially H_2) there is in the Clouds. In their inner regions, molecular gas is undoubtedly less abundant than atomic (H I) gas, but this might not be true in the outer regions. More work is required to obtain better estimates of the amount of H_2. This will be done by far-UV observations of H_2 absorption lines in front of a number of Magellanic Cloud stars with the FUSE satellite to be launched late this year. Information on the H_2 content of the molecular clouds themselves should come indirectly from observations of the dust emission at 200 µm presently in progress with ISO, and mainly from observations of this emission at millimetre and submillimetre wavelengths to be performed with the bolometers of the SEST. On the longer term, the LSA/MMA should provide very high-resolution maps of molecular clouds in the CO and other molecular lines as well as in the dust continuum emission: this will open entirely new windows on the physics of the interstellar clouds and of star formation in conditions very different from what can be found in our Galaxy.

2. The Main Goals of CO Observations in the Magellanic Clouds

The Magellanic Clouds are less evolved than our Galaxy. Less interstellar matter has been processed into stars, and they still contain a considerably larger fraction of gas (about 10% of the total mass for the LMC and perhaps one half for the SMC, considering only the atomic gas). Also, the abundances of heavy elements in stars as well as in the interstellar matter are quite smaller (about 1/2.5 and 1/10 of the Solar abundances for the LMC and the SMC respectively). Still, both Clouds presently form stars at a higher rate than our Galaxy, about 10 times per unit area on average that in the Solar neighbourhood. They contain a considerable number of luminous, hot young stars, in particular in giant active regions like 30 Dor in the LMC or N 66 in the SMC, for which there is no equivalent in the Milky Way. These stars emit a large flux of far-UV photons which heats and partly ionises the interstellar gas. All this leads us to expect that the interstellar matter in the Magellanic Clouds should exhibit rather unusual properties. Understanding these properties will help us to understand what happens to interstellar gas in even more extreme situations like those in starburst galaxies or in galaxies at very high redshifts.

In spite of this, relatively little has been done until recently on the study of the interstellar gas in the Magellanic Clouds. This was mainly due to the lack of suitable instruments in the Southern Hemisphere. For example, no sensitive interferometer able to observe the 21-cm line of atomic hydrogen was available before the Australia Telescope Compact Array, and all the previous H I work was done with the 64-m Parkes telescope at the relatively poor angular resolution of 14 arc minutes, corresponding to 200 pc at the distance of the LMC. This situation is rapidly improving: a 21-cm line map of the SMC has just been published with a resolution of 28 pc (Staveley-Smith et al., 1997, *MNRAS* 289, 225), and a similar work is in progress for the LMC. The situation for the molecular gas is comparable: after a single detection of CO in 1975 and a limited CO survey using the ESO 3.6-m telescope equipped with a millimetre receiver (Israel et al., 1986, *ApJ* 303, 186), the 1-m "mini-telescope" of Columbia-Harvard located at Cerro Tololo was used to produce low-resolution (9 arc minutes or about 150 pc) maps of the LMC, then of the SMC in the ^{12}CO(1-0) line at 2.6 mm wavelength (Cohen et al. 1988, *ApJ* 331, L95; Rubio et al., 1991, *ApJ* 368, 173). It is only with the availability of the 15-m diameter Swedish-ESO Submillimetre Telescope (SEST) at La Silla that relatively high-resolution CO line mapping has become possible.

The main goal of the CO observations of the Magellanic Clouds is clearly

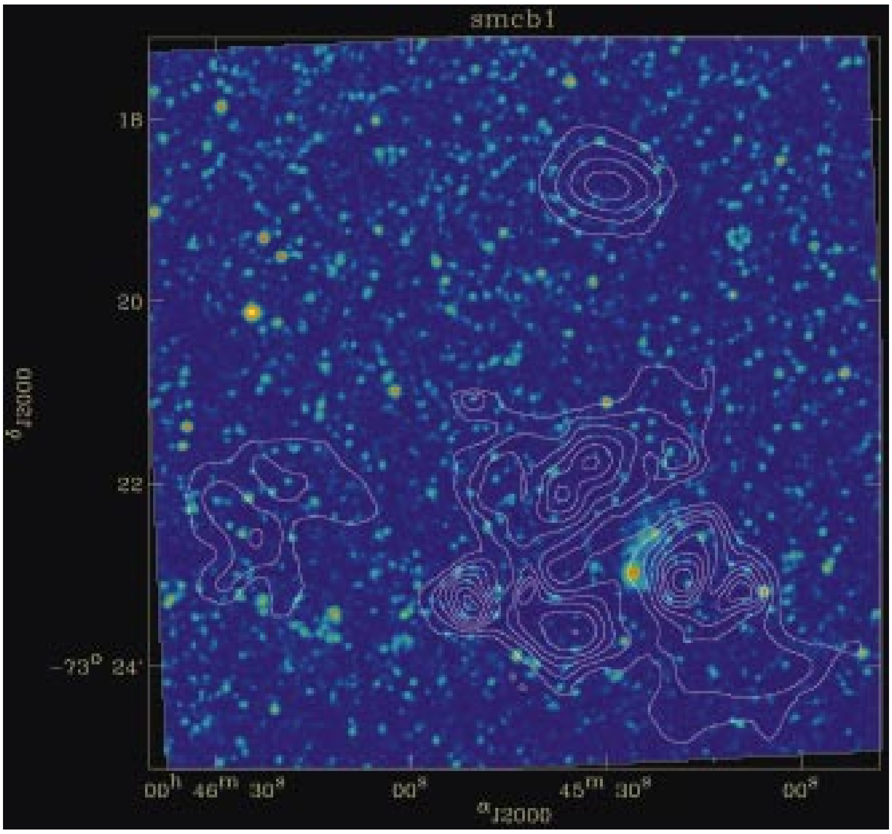

Figure 1: A molecular complex in a region to the south-west of the SMC (SMC-B1), as seen with the SEST in the ^{12}CO(1-0) line, overlaid on the Digital Sky Survey image. There are a few faint H II regions in this area, one of which is visible at the middle of the molecular complex at the bottom right. The cloud to the top is not associated with an H II region, but contains an embedded new-born star.

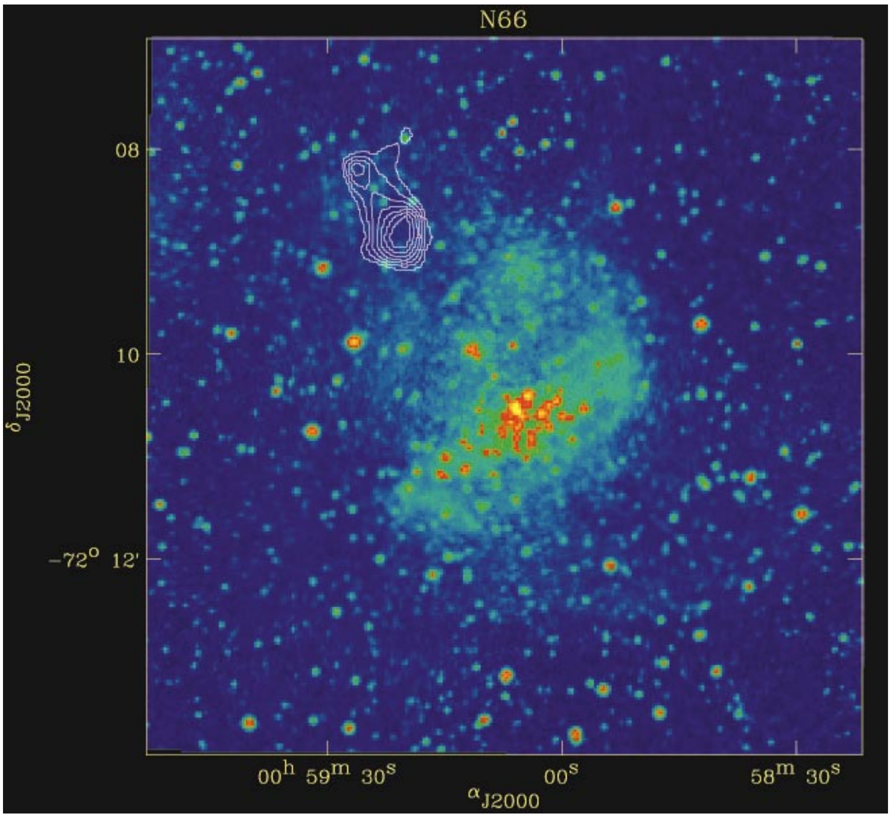

Figure 2: The only surviving molecular cloud in the region of N 66 in the SMC. The contours correspond to the emission in the ^{12}CO(2-1) line, overlaid on the Digital Sky Survey image where the H II region can be seen as a diffuse emission, with the ionising star cluster at the centre.

to look for the molecular component of the interstellar matter. Stars are formed in dense, molecular clouds and the active star formation in the Magellanic Clouds suggests that this molecular component should be present, and perhaps abundant. Of course, molecular hydrogen is the main constituent of molecular clouds but direct observation of its emission is almost impossible unless it is highly excited by some process: one has to rely on other, rarer molecules to trace the molecular gas. CO is the easiest to observe and perhaps also the most interesting of these molecules, but there are others like OH, CS, HCO^+, HCN, HNC, etc. which have also been observed in the Magellanic Clouds, mostly with the SEST. I will not discuss the latter molecules, and will concentrate on CO. I will first describe the present status of the CO observations, and then show how they have been used to derive some physical properties of the molecular clouds. I will also attempt to answer the difficult question of the amount of molecular hydrogen in the Magellanic Clouds as derived from CO line observations.

3. The CO ESO-SEST Key Programme

Most of the CO observations in the Magellanic Clouds have been done in the framework of the CO ESO-SEST Key Programme, by a consortium of astronomers from the Observatories of Leiden, Onsala, Paris, ESO-La Silla, of SRON in Groningen, of the Universities of Chile, of the Rensselaer Polytechnic Institute in Troy (NY, USA), and a few others. A large amount of telescope time at the SEST has been devoted to this programme, shared equally between ESO and Sweden. The programme was entirely done using the first-generation of receivers. This is somewhat unfortunate: it would have been completed much more rapidly with the new, excellent receivers. The first observations consisted in a survey of the ^{12}CO(1-0) line at 2.6 mm in the direction of the main far-infrared peaks mapped with IRAS in the Clouds. Most of them were detected, but the emission was found to be weaker than in comparable Galactic regions by an average factor of 3 in the LMC and 10 in the SMC. The corresponding line of the ^{13}CO isotopic molecule was also observed in the brightest CO sources: the ^{12}CO(1-0)/^{13}CO(1-0) line intensity ratio was found to be 2–3 times larger than in our Galaxy. These results have been published by Israel et al. (1993: Paper I).

The next step was to map molecular cloud complexes. Their approximate location was already known through the 1-m mini-telescope observations cited above. The selected regions were systematically explored with increasingly finer position grids, in order first to detect the CO-emitting regions, then to map them with the full 43″ (about 10 pc) resolution of the SEST. In the SMC we concentrated on several fields in the active star-forming region at the south-west of the main body (Fig. 1), but some CO clouds in other active and quiet places were also included. In particular, a large area around N 66, the main H II region in the SMC, was surveyed but only a single molecular cloud was found to have survived the harsh conditions there (Fig. 2). Many regions have also been observed in the ^{12}CO(2-l) line at 1.3 mm and some in the lines of ^{12}CO(3-2) at 0.85 mm, and in lines of ^{13}CO. Most of these results have been published by Rubio et al. (1993a: Paper II; 1996: Paper V).

A large body of similar observations has also been obtained in the LMC. They concern mainly the region of 30 Dor (Fig. 3), large areas south of it, and the star-formation complex around N 11 at the north-west of the Cloud. Like in N 66, little CO has survived in the region of 30 Dor. Near-IR observations have shown that limited star formation is taking place in the remaining clouds. Only a part of the LMC observations has been published as yet, by Kutner et al. (1997: Paper VI) and by Johansson et al. (1998: Paper VII). A study of the region of N 4 made independently of the Consortium has been published by Heydari-Malayeri & Lecavelier des Etangs (1994, *A&A* 291, 960). We will now discuss the interpretation of these results.

4. The Formation of the CO Lines and the Properties of the Molecular Clouds

Like in our Galaxy, the ^{12}CO lines are almost always optically thick in the Magellanic Clouds, as it can be seen immediately from the low ^{12}CO(1-0)/^{13}CO(1-0) line intensity ratios: they are considerably lower than the expected abundance ratio of the respective molecules which should be close to the ^{12}C/^{13}C isotopic ratio (about 70 in our Galaxy and probably more in the Magellanic Clouds). Due to the optical thickness of the ^{12}CO line the observed emission in this line comes only from the surface of the molecular clouds while the optically thin lines of the rarer isotopic molecules ^{13}CO or C^{18}O come from deeper regions and can tell us something about the inside of the clouds. The ^{12}CO(2-1)/^{12}CO(1-0) line intensity ratios of 1.0 or slightly more that are measured in the SMC and LMC clouds imply that the emitting regions are relatively dense and warm, with a kinetic temperature of at least 10 K: the ratios would be smaller otherwise due to a lower population of the J = 2 level of the CO molecule compared to that of the two lower levels (J = 1 and 0). These relatively high temperatures (compared to those in our Galaxy) are confirmed by the high $^{13}C)(2-1)/^{13}CO(1-0)$ line intensity ratios, which indicate that the inner regions of the clouds are also warm. More accurate values can be derived from multi-line modelling (see Johansson et al., 1997: Paper VII). Then we expect to measure a brightness at the centre of the $^{12}CO(1-0)$ or of the $^{12}CO(2-1)$ line roughly equal to that of a blackbody at 10 K, or more. The observed brightnesses are considerably smaller. This can be explained if the emitting regions cover only a part of the beam of the radio telescope: in other words, the molecular clouds are clumpy and only the clumps emit. Then the average brightness measured by the radio telescope is equal to that of a blackbody at 10 K (or somewhat higher) multiplied by the surface filling factor of the clumps. We find that this filling factor is of the order of 0.1 in the SMC, and probably somewhat closer to unity in the LMC. This contrasts very much with what we normally see in our Galaxy where the brightness of the clouds in the CO lines is not very different from what is expected from independent determinations of their temperature, the filling factor of the emitting regions being then close to unity. This apparent difference in the structure of the clouds explains the paradoxical observation that the molecular clouds in the SMC and LMC emit less in CO than the Galactic ones while being warmer. Details on the preceding reasoning can be found in Rubio et al., 1993b (Paper III).

In order to proceed further, we have compared the observations to the results of models. Molecular clouds are generally immersed in a far-UV radiation field which photodissociates CO and other molecules like H_2 at the surface of the cloud. The UV radiation field also heats up the gas in the outer regions of the cloud. The combined effect of this heating, of photodissociation and of the ^{12}CO line optical depth is such that the $^{12}CO(1-0)$ line (as well as the $^{12}CO(2-1)$ one) is efficiently emitted only in a thin layer. Appropriate self-consistent models of photodissociation regions including chemistry, thermal balance and radiative transfer (in particular in the photodissociating far-UV lines of CO and H_2) have been built by Lequeux et al. (Paper IV). They assumed conditions which are considered to be typical of the SMC: a far-UV radiation field 10 times higher than in our Galaxy in the Solar neighbourhood, and a flux of low-energy cosmic rays also 10 times higher: these MeV particles are probably accelerated in supernova remnants and interstellar bubbles and contribute to the heating of the interstellar matter, especially inside the clouds. Also, the abundances of heavy elements were taken to be 10 times smaller than in our Galaxy, as well as the abundance of dust which however absorbs relatively more in the far-UV than Galactic dust. As expected, these models predict the brightness of the SMC photodissociation regions in the ^{12}CO lines to be significantly higher than in our Galaxy. However, if we consider a cloud with a range of densities it is clear that CO (and H_2) are destroyed preferentially in lower-density regions where the UV radiation penetrates more

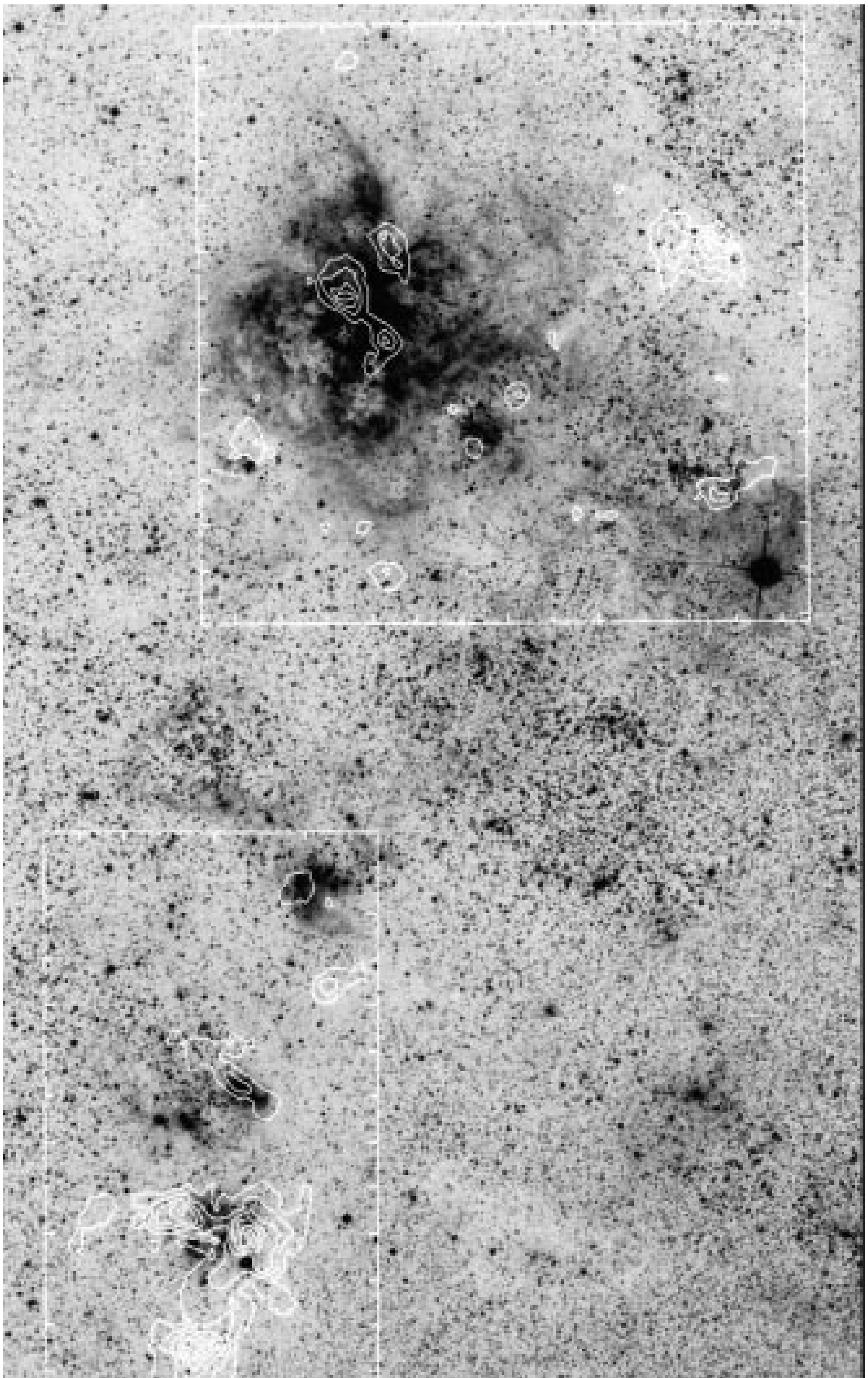

*Figure 3: Molecular clouds in two fields of the LMC fully surveyed in the $^{12}CO(1-0)$ line (rectangles). The CO emission corresponds to the contours, overlaid on a SERC blue Schmidt plate. North is at the top, east to the left. Tickmarks at 2′ spacings are shown. The northern field contains the 30 Doradus region, and the southern field the H II regions N 158C, N 160 and N 159, from north to south. Only a few molecular clouds have survived near 30 Dor. Note the isolated cloud south of N 159. It has different properties from the two clouds directly associated with the H II region: it is colder, and shows no emission in the 158 μm line of [C II] contrary to the two other clouds (Israel et al., 1996, ApJ **465**, 738). From Johansson et al., A&A in press.*

easily. Formation of both molecules is also slower at low densities. Thus CO (and to a lesser extent H_2 which is more resistant to photodissociation) survives only in relatively high-density regions (the clumps) while the lower density ones (the interclump medium) are fully photodissociated. In our Galaxy, the average UV flux is lower, CO is more abundant due to the higher abundance of carbon, and dust which absorbs the far-UV radiation is also more abundant. In consequence, CO can survive in relatively low-density regions, so that most of the volume of the cloud emits and its apparent surface brightness in the ^{12}CO lines is much more uniform. This explains physically the difference between Galactic and SMC clouds. In fact it is now well known that interstellar matter in our Galaxy, including molecular clouds, has a very non-uniform, hierarchical and perhaps fractal structure; there is no reason why the Magellanic Clouds should behave differently in this respect. Of course our clump-interclump model is not an accurate representation of reality, but it allows to understand qualitatively what happens.

5. The Mass of Molecular Gas in the Magellanic Clouds

Now that we understand better the physics of molecular clouds in the Magellanic Clouds, we can try to estimate from the intensity of the $^{12}CO(1\text{-}0)$ line how much molecular gas (essentially H_2) there is in the Magellanic Clouds. In other words, the problem is to determine the quantity $X = N(H_2)/I(CO)$ which relates the column density of molecular hydrogen $N(H_2)$ to the brightness in the $^{12}CO(1\text{-}0)$ line I(CO). This is a noteworthy difficult problem even in our Galaxy, due to the impossibility to estimate directly the amount of H_2. The best recent determinations for our Galaxy converge to values of X in the range 1–2 10^{20} mol. cm^{-2} (K km $s^{-1})^{-1}$. They are based on gamma-ray results from COS-B or EGRET (Strong & Mattox, 1996, *A&A* 308, L21) or on studies of the millimetre continuum emission of dust in spiral galaxies similar to ours (Dumke et al., 1997, *A&A* 325, 124). None of these two methods can be applied to the Magellanic Clouds for the time being. However, a possible way to estimate X there is to assume that the molecular clouds are in virial equilibrium, allowing to derive their total mass. *If this mass is assumed to be made mainly of H_2* (with some correction for helium), it is easy to derive a mean column density of H_2 in the beam of the radio telescope with which the CO observations are made, and to calculate X. This was first attempted on the large complexes detected with the 1-m mini-radio telescope, with the result that X is considerably larger than in our Galaxy (respectively by a factor 6 and 20 for the LMC and the SMC). However this result is questionable because it is not at all certain that these big complexes, 200 pc or so in size, are in virial equilibrium; moreover, atomic hydrogen, which contributes to the virial mass, cannot be neglected at this scale with respect to H_2 due to the very efficient photodissociation of H_2. At the smallest scales that are accessible to the SEST (10 pc), Rubio et al. (1993b, Paper III) find $X \simeq 9\ 10^{20}$ mol. cm^{-2} (K km $s^{-1})^{-1}$ for the SMC, 4–8 times higher than in our Galaxy, while X may be 2 times higher in the LMC than in our Galaxy. The assumption of virial equilibrium is perhaps more reasonable for such small clouds than for large gas complexes in which forces other than self-gravity might dominate. Still, there is the problem that even in 10 pc clouds the gas is only partly molecular due to photodissociation of molecules, in particular CO, in the low-density parts: although as I have said earlier H_2 is more robust than CO against photodissociation due to more efficient self-shielding in the photodissociating far-UV lines, it might well be dissociated too. It is difficult to estimate how much H I exists in the clouds but in any case the above values of X should be considered as upper limits. If we take them at face value, there is a maximum of $10^7\ M_\odot$ of H_2 in the SMC (2% of the total gas content), and of 5 $10^7\ M_\odot$ in the LMC, implying a molecular/atomic gas mass ratio of at most 10%.

Recently, Israel (1997, *A&A* 328, 471) proposed another method to estimate X, which gives different results. It rests on the comparison of H I, CO and far-infrared maps. The basic assumption is that dust, which emits in the far-IR, is well mixed with the gas; in regions far from molecular complexes, the far-IR/21-cm line intensity ratio is proportional to the dust/gas ratio. In the molecular complexes, the far-IR/21-cm ratio is considerably larger. This is due to the far-IR emission of the dust associated with molecular gas, and also to a higher dust temperature since these regions are also in general regions of active star formation, thus of high radiation field which heats the dust. If one corrects for the effect of the higher dust temperature, then one can obtain the amount of molecular gas independently of CO observations. One can then calculate X. Israel uses the observed 60 μm/100 μm intensity ratio from IRAS to estimate the temperature of the dust and its far-IR emission. Unfortunately, this method depends implicitly on assumptions about the nature of the dust (which is known to have different properties than Galactic dust), and the far-IR brightness is extremely sensitive to the dust temperature. The values of the column densities of H_2 and of X derived in this way are extremely high, of the order of $X = 13\ 10^{20}$ mol. cm^{-2} (K km $s^{-1})^{-1}$ for the LMC and 120 10^{20} mol. cm-2 (K km s-l$)^{-1}$ for the SMC, at scales of about 200 pc. Using the millimetre emission of the dust, which is only linearly sensitive to temperature, instead of its far-IR emission, would give considerably safer results. This is the method used by Guélin and associates (Dumke et al., 1997, *A&A* 325, 124 and references herein) for a number of edge-on spiral galaxies, but millimetre data are still lacking in the Magellanic Clouds.

H_2 might also exist in regions far from the large star-formation complexes, even in the absence of CO emission. In the inner regions of the Clouds however the existence of a lot of H_2 is unlikely simply because extinction is generally small and there is far-UV radiation everywhere, as can be seen directly on UV images of the Clouds. Amongst 5 stars observed in the far-UV in each of the Magellanic Clouds, only the one with the largest amount of interstellar extinction (A_V=0.75) shows H_2 absorption on its line of sight (Walborn et al., 1995, *ApJ* 454, L27). Stars with such a high extinction are rare in the Clouds except in the region of 30 Dor. Large amounts of cold H_2 might however exist in regions shielded from far-UV radiation, for example in the outermost regions of the Clouds. Lequeux (1994, *A&A* 287, 368) proposed that there might be a lot of H_2 in the external regions of SMC for which counts of background galaxies apparently show regions of extinction with no correspondence in atomic hydrogen. This should be confirmed, however. Knut Olsen and Paul Hodge are currently working on the problem using deeper galaxy counts and colours from HST images, which are less subject to spatial fluctuations due to clusters of galaxies or to the large-scale structure of the Universe (see Olsen & Hodge, 1996, *BAAS* 188, 61.13).

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Cool Gas in Southern Galaxies

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During the last ten years, the 'Swedish-ESO Submillimetre Telescope' has filled an important astronomical gap. The SEST is by far the largest mm- and submm-wave telescope covering the southern hemisphere and the clear skies of La Silla almost guarantee good weather conditions at 2.6 mm $\lesssim \lambda \lesssim$ 3.8 mm. Since 1995, improvements in receiver sensitivity (Schottky receivers were replaced by SIS frontends) and flexibility (two heterodyne receivers can now be used simultaneously) have dramatically altered observing conditions. Complementing its larger cousins of the northern hemisphere (most notably the 30-m IRAM and the 45-m Nobeyama telescopes), the SEST is the only (sub)mm telescope that allows detailed investigations of prominent molecular 'goldmines' like the Magellanic Clouds or CenA. We thus focus on the LMC and the SMC and on two prototypical southern starburst galaxies, NGC 253 and NGC 4945.

The Magellanic Clouds provide an extremely interesting environment to study astrophysical processes. With respect to the molecular interstellar medium, there are three outstanding properties which motivate ongoing research: (1) Metallicities are smaller than in the Milky Way, (2) UV radiation fields are stronger than in the solar neighbourhood, and (3) a large number of targets is found at a well-known (relatively small) distance. The first two properties have far-reaching consequences for the astrophysical and astrochemical state of the interstellar medium: dust depletion and lack of extinction in cloud envelopes result in reduced shielding against UV radiation and decrease the sizes of molecular clouds relative to the more extended neutral atomic gas. Most of the 'intercloud' gas is not molecular but atomic, with HI, not H_2 as the main constituent (e.g. Lequeux et al. 1994). Another aspect of low metallicity is the depletion of molecular abundances relative to H_2 by one order of magnitude (in the LMC) up to two orders of magnitude (in the SMC) (Chin et al., 1998). Since not all elements are depleted by the same amount ([C/H] = –1.3, [O/H] = –0.6 in HII regions and young stars of the SMC) and because the molecular gas is exposed to high UV fields, relative line intensities in the LMC and SMC differ notably from those observed in galactic clouds:

- HCO^+ J=1-0 emission is stronger than HCN J=1-0 emission, reflecting the high ionisation flux that favours HCO^+ while HCN mainly arises from spatially confined and presumably cool cloud cores.
- Relative to ^{13}CO J = 1-0, the line emission in the C^{18}O J = 1-0 transition is unusually weak. This may be caused by isotope selective photoionisation or by fractionation in a medium with high C^+ abundance. An underabundance of ^{18}O is a third possibility.
- Towards the prominent SMC star-forming region LIRS 36, CN has remained undetected even though a rare CS isotopomer, C^{34}S, is seen. In warm galactic clouds, the main CS species tends to emit weaker lines than CN. The non-detection of CN in LIRS 36 is explained in terms of high cloud densities (n (H_2) $\gtrsim 10^5$ cm^{-3}; much of the lower density gas must be atomic) and a (relatively) high fractional abundance of O_2 that is destroying CN but not CS.

To illustrate some of the the observational results, Figure 1 displays CO J = 1-0 and 2-1 emission from the star-forming region N 113 in the LMC. Figure 2 shows HCO^+, HCN, CS, and H_2CO maps. Beamwidths are 25″ $\lesssim \theta_b \lesssim$ 55″.

Isotope ratios (e.g. Chin et al., 1996; Heikkilä et al., 1998) are also related to abundances, but address stellar nucleosynthesis and 'chemical' evolution. In the LMC, extragalactic deuterium was detected for the first time with certainty. DCO^+ was observed towards the star-forming regions N113, N159, and N44BC, DCN towards N113 and N159 (see Fig. 3 for most of the spectra). HCO^+/DCO^+ and HCN/DCN abundance ratios are 20–70. The data can be used to estimate either the D/H ratio or the electron density of the gas. Because deuterium fractionation depends on small differences in zero-point energies, the process is sensitive to the kinetic temperature. Modeling deuterium chemistry with conditions appropriate for clouds in the LMC, we obtain for T_{kin} $\sim$ 20K a D/H ratio of 1.5×10^{-5} which agrees with the galactic value. The temperatures of the LMC clouds are, however, not that well constrained. The clouds could be slightly warmer (Le-

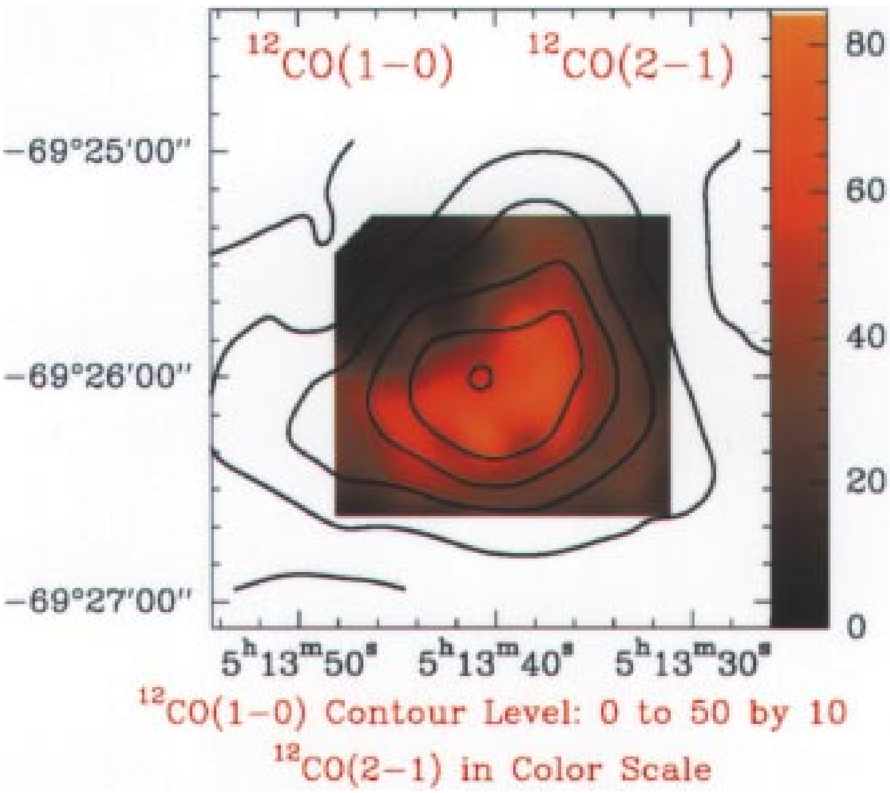

Figure 1: SEST maps of ^{12}CO J=1-0 (contours) and 2-1 line (inserted image) emission from the star-forming region N 113 in the LMC. Angular resolutions are 45″ and 25″, respectively.

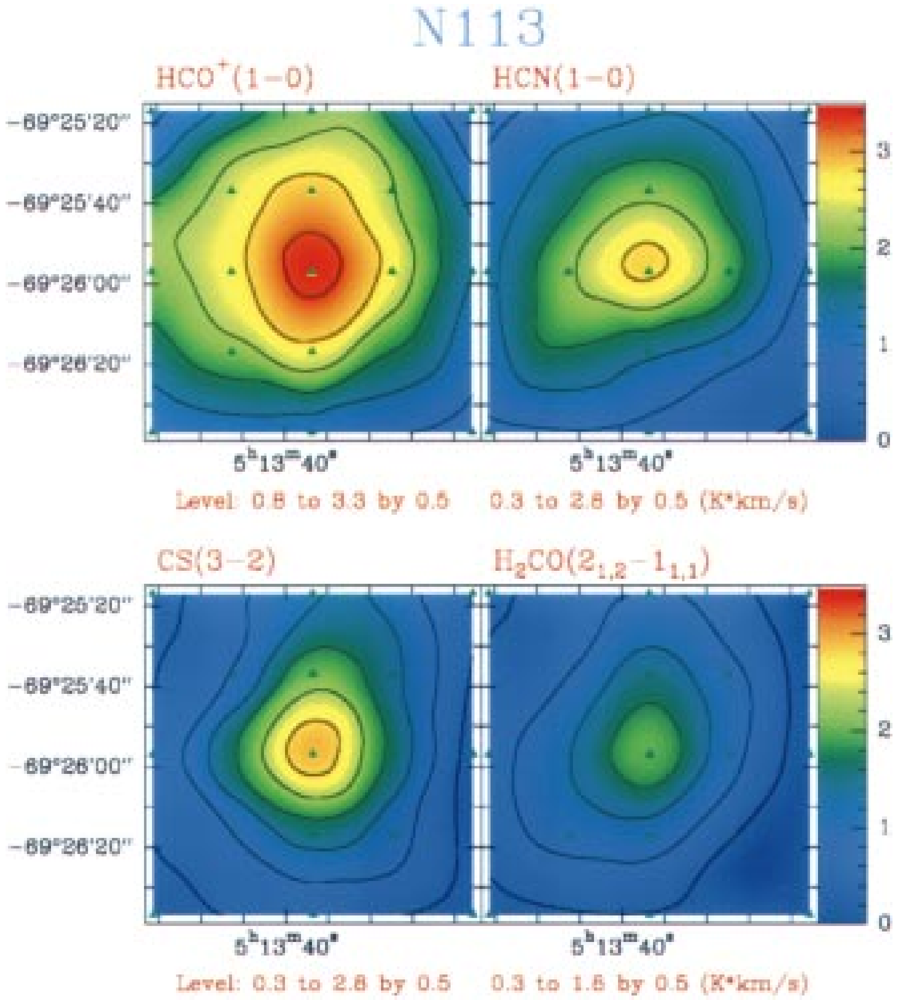

Figure 2: HCO^+, HCN, CS, and H_2CO emission from N113. Angular resolutions are 55″ for HCO^+ and HCN and 35″ for CS and H_2CO.

queux et al., 1994) which leads to higher D/H ratios. At a cloud temperature of 30 K, we would need a D/H ratio of about 10 times the galactic value. This would be consistent with the LMC gas being less processed through stars than that of the Galaxy. Irrespective of these considerations, evidence from the LMC is consistent with an open universe as long as the cosmological constant is small.

First attempts to measure CNO isotope ratios were also successful. The interstellar $^{12}C/^{13}C$ isotope ratio of ~ 50 is similar to that in the inner galactic disk. The $^{18}O/^{17}O$ isotope ratio, however, differs drastically from the galactic value. It is a factor of two below that measured in the galactic plane and a factor of three below that of the solar system. An interpretation in terms of ^{18}O depletion is possible, but as long as the $^{16}O/^{18}O$ ratio is not well known, we prefer not to draw conclusions.

Located at a distance of $\sim$ 2.5 Mpc and showing an IRAS PSC flux of $S_{100\mu m} \sim 1000$ Jy, the edge-on barred spiral **NGC 253** is the brightest member of the Sculptor group showing evidence for starburst activity from radio to X-ray wavelengths. Recent measurements with the SEST (CO J=1-0), the IRAM 30-m telescope (CO J= 2-1), BIMA (CS J= 2-1), and the VLA ($H_2CO1_{10} - 1_{11}$) have revealed an extremely complex integrated structural picture of the nuclear region. A progressive change in position angle appears when going from larger to smaller scale sizes approaching the nuclear region. Apparently, the inner region is warped, reflecting perturbations of the

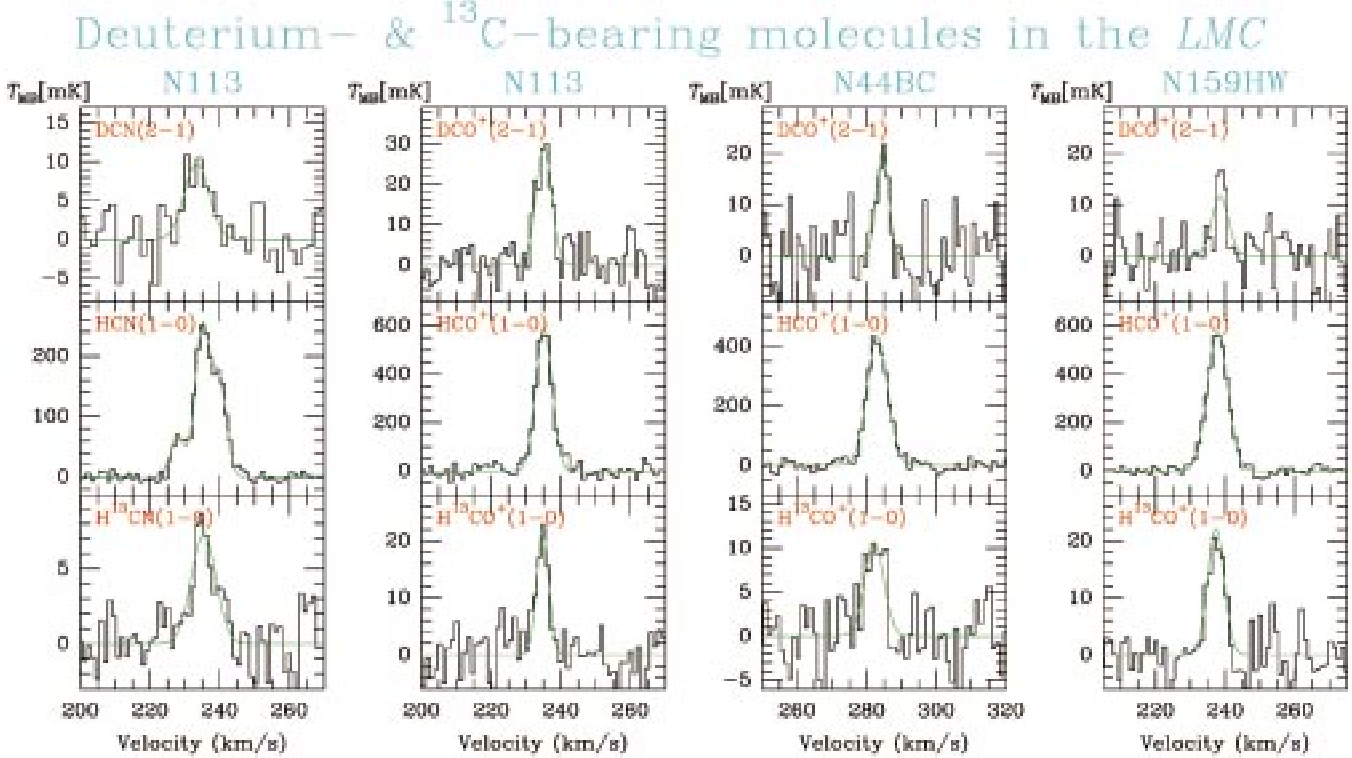

Figure 3: Spectral lines of HCO^+ or HCN and their ^{13}C and deuterium bearing isotopomers towards prominent star-forming regions of the LMC. Beamwidths are 35″ for the deuterated and 55″ for the other species.

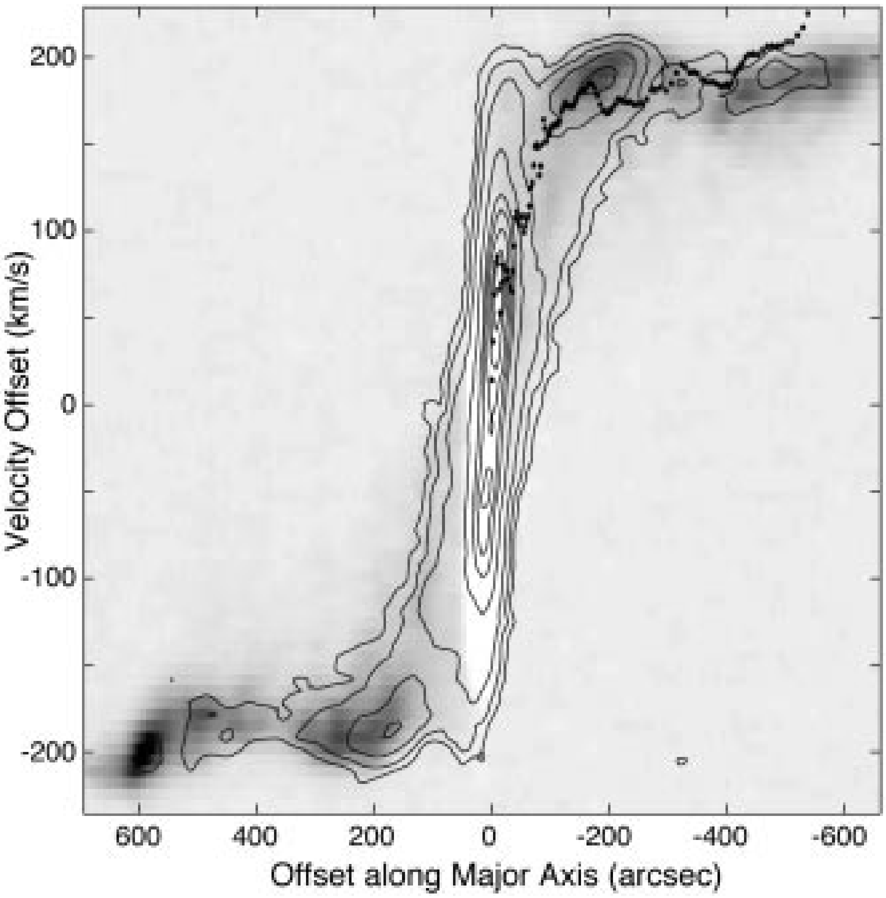

Figure 4: CO J=1-0 (contours), HI (grey scale), and optical (dots) rotation curve of NGC 253. Axes show offsets from α_{2000} = 00° 47ᵐ 33ˢ.4, υ_{LSR} = 235 km s^{-1} (from Houghton et al., 1997).

nuclear region. The following dynamic features can be identified (e.g. Mauersberger et al., 1996b; Baan et al., 1997; Houghton et al., 1997):

• Relatively weak CO emission is associated with the optically visible outer disk at P.A. ~ 50° and is observed out to 11′ (8 kpc) from the nucleus. In the very outer regions the emission is displaced from the major axis and is associated with HI spiral arm features. The intensity ridge shows 'flat' rotation (see Fig. 4).

• An inner CO disk, ridge, bar or spiral with position angle P.A. ~ 64° (Fig. 5) bends back into the outer disk at 120″ (1.5 kpc) on each side of the nucleus. The feature is also seen in the near-infrared and radio continuum.

• The inner 35″ (400 pc) of the galaxy are associated with a rapidly rotating cloud complex enveloping the nucleus. The rotation curve is consistent with solid body rotation (Fig. 4); the velocity gradient is of the order of 0.4 kms^{-1} pc^{-1}, the dynamical mass is 3×10^9 M$_{\odot}$.

• Even further inside, seen against the triple radio continuum source in the inner 10″, a 'compact' molecular disk with a particularly high velocity gradient (~ 1 km s^{-1} pc^{-1}) is measured at P.A. ~ 36–39° (Fig. 5). This innermost disk structure is observed in OH and H_2CO absorption against the nuclear source; it is not seen in molecular emission lines but there is a chain of weak compact continuum sources with similar position angle. The water vapour emission in NGC 253 might be associated with this compact structure.

• Nuclear outflows with a recessional velocity component above the plane of the optical disk are observed in the OH emission plumes, the radio and far-infrared continuum, and possibly in the H_2CO data. The plume jets have a P.A. of ~ –15° that is roughly perpendicular to the P.A. ~ 64° ridge (Fig. 5) observed out to ~ 120″ from the nucleus.

Comparing ^{12}CO and C^{18}O with 1.3 mm continuum emission, it becomes apparent that the commonly assumed correlation between integrated ^{12}CO intensity and molecular column density, derived from clouds of the galactic disk near the solar circle, does not hold. For the nuclear clouds of NGC 253, molecular masses have to be reduced by almost a factor of ten. This is accompanied by a similar reduction of the gas mass in the central region of the Milky Way. For the inner 410 pc × 130 pc of NGC 253, $M_{\rm molecular} \sim 5 \times 10^7$ M$_{\odot}$. We conclude that the nuclear gas mass of NGC 253 is not exceptionally large (a few times that contained in a similar volume in the central region of the Milky Way) and that molecular gas masses in more distant ultraluminous IRAS galaxies may be overestimated. It is the infrared luminosity, not the nuclear gas mass, that makes NGC 253 to be an outstanding galaxy.

NGC 4945 is a nearby edge-on (post-) starburst galaxy with intense infrared, radio, and X-ray radiation from the nuclear region. More than a dozen of molecular species have been detected in this source, most of them with the SEST (Henkel et al., 1994). In addition to a luminous H_2O megamaser, the presence of a spatially unresolved molecular ring, seen almost edge-on, has been established by an analysis of ^{12}CO/^{13}CO J = 1-0 intensity ratios (Bergman et al., 1992). The ring is characterised by densities of ~ 10^3 cm^{-3}; ^{12}CO opacities are of the order of 1–5. The central 80″ × 80″ of NGC 4945 have been mapped with the SEST not only in

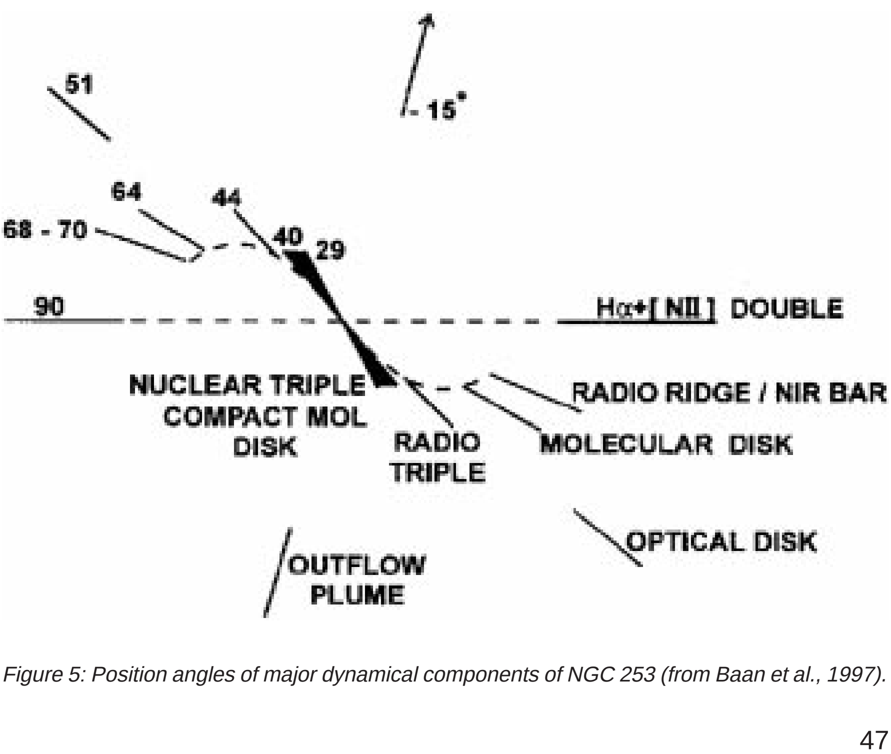

Figure 5: Position angles of major dynamical components of NGC 253 (from Baan et al., 1997).

CO J = 1-0 and 2-1 but also in the CO J = 3-2 transition at 870 μm (Mauersberger et al., 1996a). CO J = 3-2 emission is concentrated towards the kinematical centre with a deconvolved full width to half power size of (11.5±3)″, corresponding to a linear scale of (200±50) pc. This is less than the size of the molecular complex seen in the CO J = 1-0 and 2-1 lines. Position velocity maps reveal three condensations located at the centre and at offsets of ± 5″ along the major axis. As in the central regions of the Milky Way and NGC 253, the standard CO intensity – molecular column density conversion factor appears to be too large and the nuclear gas mass becomes $\sim 10^8 M_\odot$. An embedded active nucleus may contribute to the very high 'star-forming efficiency' of $L_{FIR}/M_{gas} \sim 150 L_\odot/M_\odot$.

All (sub)millimetre data presented here were obtained with characteristic beamwidths of 15″ – 55″. It is not difficult to imagine that the use of a large multi-element interferometer with ∼ 1″ angular resolution would be an enormous qualitative improvement, providing new unprecedented astrochemical tools and leading to detailed views of optically obscured active galactic nuclei.

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La Silla, February 1996. In the fading light of the setting sun, two astronomers are watching the moonrise over the high Andes from the SEST. (Photograph: H.-H. Heyer.)

The ESO Imaging Survey: Status Report and Preliminary Results

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1. Introduction

The ESO Imaging Survey (EIS) presented in earlier issues of *The Messenger* [7, 2], and with up-to-date information on the ongoing observations available on the web (http://www.eso.org/eis), is a concerted effort by ESO and the Member State community to provide targets for the first year of operation of the VLT. It consists of two parts: a relatively wide-angle survey (EIS-WIDE) to cover four pre-selected patches of sky, 6 square degrees each, spread in right ascension to search for distant clusters and quasars and a deep, multicolour survey in four optical (SUSI-2) and two infrared bands (SOFI) covering the HST/Hubble Deep Field South (HDFS) and its flanking fields (EIS-DEEP). From the start, the main challenge has been to carry out a public survey in a limited amount of time requiring observations, software development and data reduction with the goal of distributing the survey data products before the call for proposals for the VLT. To cope with this one-year timetable, a novel type of collaboration between ESO and the community has been established which has allowed EIS to combine the scientific and technical expertise of the community with in-house know-how and infrastructure. In spite of adverse weather conditions in some of the earlier runs, EIS has already proved to be a successful experiment achieving most of its scientific technical goals, thereby laying the ground work for future imaging surveys.

2. Observations

Observations for EIS-WIDE are being carried out with EMMI on the NTT. They started July 1997, and so far 36 out of 42.5 half and full-nights (360 hours) have been used, with data being accumulated in four patches over eight runs. All observing runs have been carried out, in standard visitor mode, by members of the EIS team. In contrast to most earlier work, the EIS mosaic consists of frames with significant overlaps (a quarter of an EMMI frame). The easiest way of visualising the geometry of the EIS mosaic is to picture two independent sets of frames, each forming a contiguous grid (normally referred to as odd and even), superposed and shifted in right ascension and declination by half the length of an EMMI frame. In this way, each position on the sky, except at the edges of the patch, is sampled by at least two independent frames for a total integration time of 300 sec. To ensure continuous coverage, adjacent odd/even frames have a small overlap at the edges (∼ 20 arcsec). Therefore, a small fraction of the surveyed area is covered by more than two frames. Such a mosaic ensures good astrometry, relative pho-

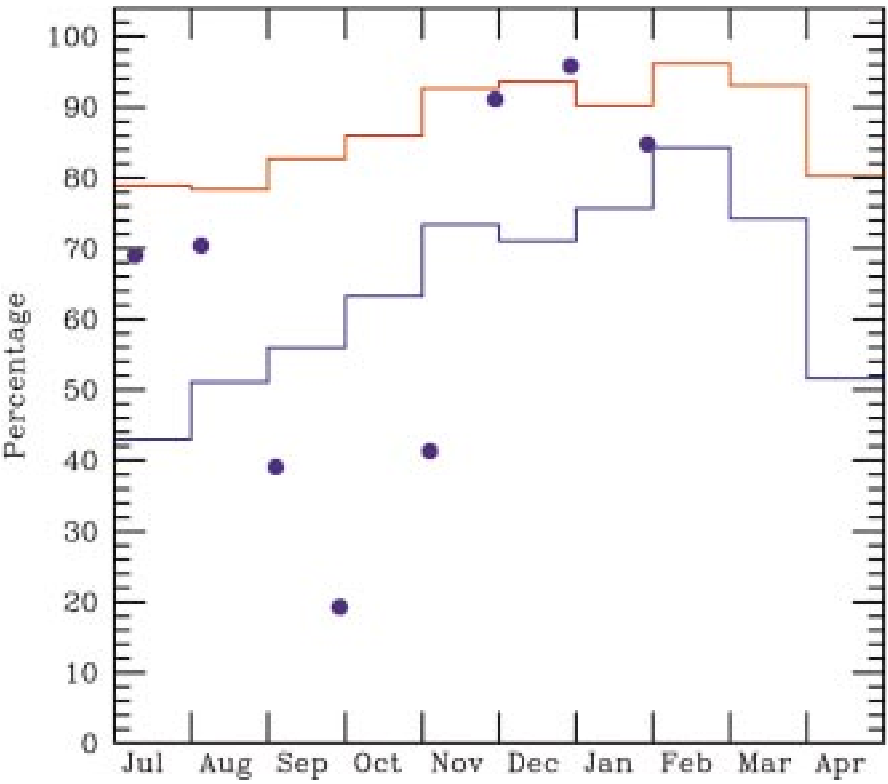

Figure 1: Fraction of allocated time used for observations (filled circles) as a function of EIS run in the period July 1997 to January 1998, compared to the average (over the past five years) number of clear nights (upper line) and photometric nights (lower line) per month at La Silla. Note that runs 1 and 2 were half-nights.

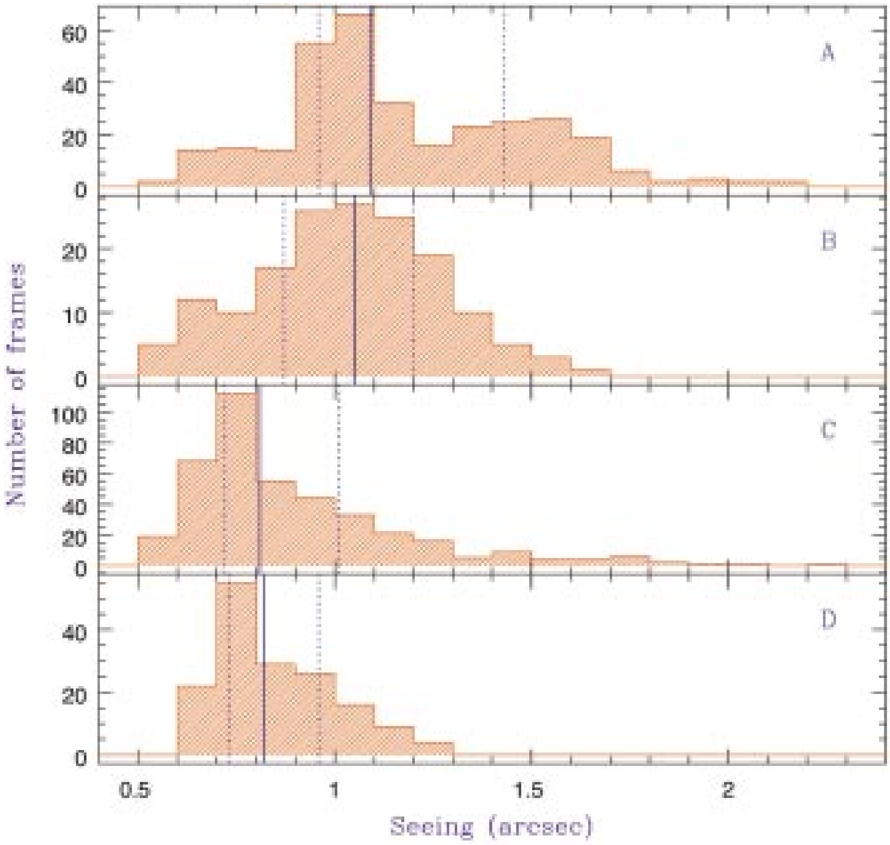

Figure 2: Seeing distribution, as measured from the I-band images in all four EIS patches. The large-seeing tail in the distribution of patch A are frames for which no new observations were possible due to the lack of time.

tometry and the satisfactory removal of cosmic hits and other artefacts.

EIS was one of the first programmes to use the upgraded NTT and as expected had to overcome some problems both on and off the telescope. These included: some limitations of the current version of the Phase-2 Proposal Preparation software (P2PP) for large programmes; unexpected overheads from the new data flow system (DFS) and VLT control system (VCS); failures of the EMMI controller (CAMAC); problems with the pointing model and difficulties in retrieving data from the ESO Archive. The pointing model was particularly relevant to EIS because of the mosaic pattern adopted. Thanks to the dedication of people in the NTT team, the User Support Group, the Archive Group and the EIS team, these issues have been largely overcome. As expected, EIS has proved to be a useful test case for supporting the smooth transition between the first releases of software engineering products and routine science operations at the NTT.

These problems and the need for calibration of the new filters have led to some time losses. However, the impact that these time losses have had on the overall performance of the survey has been relatively minor as compared to the losses due to bad weather. This is illustrated in Figure 1, which shows for each EIS run the percentage of time used for observations. The figure does not tell the whole story as dismal full-night runs such as runs 4 and 5 had a considerably larger impact on the sky coverage than earlier half-night runs. Furthermore, the quality of nights has also varied considerably within a run and from run to run. These difficulties were brought to the attention of the EIS Working Group (WG) which recommended several adjustments in the scope of the observations, such as giving priority to the I-band observations and limiting the scope of the B-band coverage of patch B. However, the changes will not severely affect the primary science goals of the survey as originally proposed, with the exception of the search for high-redshift ($z \gtrsim 3$) QSOs.

So far a total of about 2000 science frames, roughly equivalent to 20 square degrees, have been taken. In Table 1, we list the position of the centres (J 2000) of the various patches and the current sky coverage, in square degrees, for the different passbands. In order to maintain some degree of uniformity of contiguous regions, most regions observed under poor conditions have been re-observed. In Figure 2, we show the seeing distribution for all the I-band frames that have been accepted for co-addition up to run 7. Even though these re-observations have limited the sky coverage, some 3 square degrees have been re-observed, they have been worthwhile since currently the median seeing in the different patches is in the range 0.8–1.1 arcsec. We should emphasise that since EIS is being carried out over a fixed amount of time, a trade-off between area and data quality is unavoidable.

3. EIS Pipeline

By far the most demanding task of the EIS team has been the development of a fully automated pipeline to handle the large data volume generated by EIS. A major aim of the EIS software is to handle the generic problem posed by building up a mosaic of overlapping images, with varying characteristics, and extraction of information from the resulting inhomogeneous co-added frames. The long-term goal has been to develop a "portable" system, which may eventually be installed in other European institutes.

Due to time constraints, it was decided early on that the development of the pipeline should take advantage, as much as possible, of pre-existing software elements such as: (1) standard IRAF tools for the initial processing of each input image; (2) the Leiden Observatory Data Analysis Center (LDAC) software, developed for DENIS[3], to perform photometric and astrometric calibrations; (3) the SExtractor object detection and classification code[1]; (4) the "drizzle" image co-addition software[4, 5], originally developed for HST, to create coadded output images from the many, overlapping, input frames.

However, handling mosaic data taken on different nights under varying conditions has required significant changes in the pre-existing software and the need for new concepts and intermediate products to provide the necessary information for the source extraction and data quality control of the co-added superimage, from which the final object catalogues are created. In order to illustrate the power of the tool being developed, a brief description of the architecture of

Table 1. Current Sky Coverage

Patch	α	δ	B	V	I
A	22:42:54	–39:57:32	—	1.2	3.2
B	00:49:25	–29:35:34	1.5	1.5	1.6
C	05:38:24	–23:51:00	—	—	5.6
D	09:51:36	–21:00:00	—	—	2.8
	—	—	1.5	2.7	13.2

the pipeline is necessary. For each input frame a weight map, which contains information about the noise properties of each pixel in the frame, and a flag map, which contains information about the pixels that should be masked, such as bad pixels and likely cosmic hits, are produced. After background subtraction and astrometric and relative photometry calibration, each input frame is mapped to a flux-preserving conical equal area projection grid, chosen to minimise distortion in area and shape of objects across the relatively large EIS patch. The flux of each pixel of the input frame is redistributed in the superimage and co-added according to weights of the input frames contributing to the same region of the co-added image.

In the process of co-addition, combined weight and context maps are created. The combined weight map provides the information necessary for the object detection algorithm to adapt the threshold of source extraction to the noise properties of the context being analysed. SExtractor has been modified to incorporate this adaptive thresholding. The context map characterises the origin of each pixel of the superimage and provides information which relates each detected object to the set of input frames that have contributed to its final flux. A context should be viewed as a virtual frame with its depth and seeing being almost uniform and determined by the combination of a unique set of input frames. For a survey such as EIS, being carried out in visitor mode with varying seeing conditions, the context information is essential as it may not be possible to easily characterise the PSF in the final co-added image, which can compromise the reliability of the galaxy/star classification algorithm. More importantly, the contexts represent regions of uniform noise, seeing and depth. Therefore, using the information available for each context, one may *a posteriori* define “uniform” regions with well-defined limiting magnitudes from which object and derived catalogues (e.g. the candidate cluster catalogue) may be extracted.

The pipeline works equally well for stacking dithered images and, in this case, the context map can be used to easily carve out the deepest part of the co-added image. Images from EMMI, SUSI and DENIS have been used for tests providing excellent results.

Another area, common to all large programmes, that has demanded considerable attention is the bookkeeping and monitoring of the progress of the observations, the data reduction and data quality. This has required interfacing the pipeline to a database, with calls installed in the various modules of the pipeline, which allows the status of a particular frame or a set of frames (corresponding to ten EMMI exposures that make up an EIS observational block) to be tracked throughout its lifetime in the pipeline and archive. In addition, logs of the observations and the reductions, reports (monitoring the progress of the observations, down time, survey efficiency, etc.) and diagnostics produced by the different modules of the pipeline (monitoring the pointing, seeing, astrometry and relative photometry) are created and posted on the web automatically for easy access by all team members.

In order to allow full control of the data flow, from the preparation of the observations to the final archiving of the data, it is essential to have a suitable data-acquisition system which can be interfaced to the data reduction pipeline, such as the DFS/VCS implemented on the NTT. Even though some additional features are still required, most of the basic tools are already in place. There are areas where improvements can be made such as the mass production of observational blocks (OBs), essential for large programmes with well-defined observing protocol, and the automatic generation of the observed schedule, which would allow the automatic updating of the status of the OBs resident in the re-

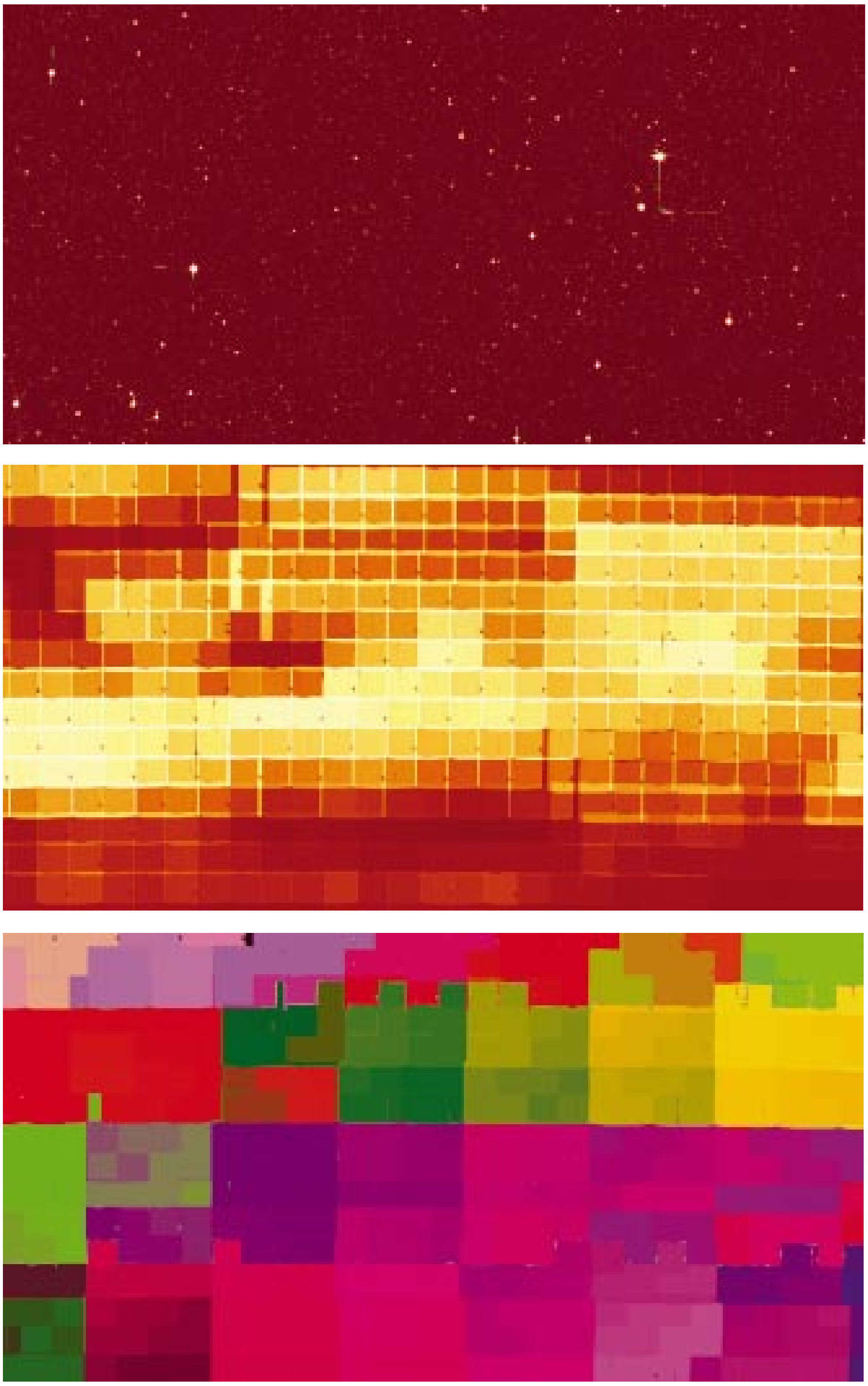

Figure 3: Co-added I-band image of patch A (top panel) showing a region approximately 2° × 1° and the corresponding weight (middle panel) and context maps (bottom panel). In the weight map, dark colours represent regions of higher noise.

Figure 4: Colour composite obtained from a selected region 13′ × 7.5′ of the co-added B, V and I images of patch B. Note the presence of ghost images around bright stars present in the B and V filters. In the region a nearby cluster (z ∼ 0.1) is seen as well as a concentration of red galaxies at the lower-left of the figure.

pository. The DFS has been a remarkable undertaking that will have an enormous impact on the efficiency with which large programmes will be conducted at the VLT. Similar systems, even if simpler versions, should be considered for other telescopes dedicated to survey work.

Even though considerable work lies ahead and several tests of the performance and fine-tuning of different modules of the pipeline remain to be carried out, it has been possible to streamline the pipeline to only a few scripts that control the entire process of data reduction. Under normal conditions, the data reduction requires four commands to go from raw frames residing in the Archive to co-added frames to object catalogues back into the Archive. The typical data flow rate is of 0.032 MB/sec on a 250 MHz UltraSparc2, which means that the reduction of a 6-square-degree patch requires about 70 hours. We should point out that at this stage no attempt has yet been made to multiplex operations, and the flow rate given above should be considered as a very conservative lower limit.

The pipeline is being developed in close collaboration with the ESO Archive group. The ESO Archive is the entry point of the raw data into the EIS pipeline and the distribution point of the final products to the community. Furthermore, we are using the EIS data to prototype general-purpose tools which will be required by the Science Archive Research Environment. This collaboration has been mutually beneficial yielding: (1) a general server to support EIS catalogues (fits binary tables) and the display of conical equal area co-added image sections; (2) the installation of a server to display the superimage, stored in 4k × 4k sections; (3) the implementation of additional features in SKYCAT; (4) The implementation of the EIS database; (5) the development of algorithms to cross-correlate the EIS catalogues with other available databases.

4. Preliminary Results

In order to illustrate the final products of the pipeline, Figure 3 shows a low-resolution (3 arcsec/pixel) representation of the I-band co-added image of patch A. This low-resolution image is created automatically by the pipeline and serves as a preliminary check of the co-addition. Also shown are the associated weight and context maps. In patch A, there are over 3500 contexts for 300 input frames, spanning a wide range of scales. About 520 are "big" contexts where there are two overlapping images. The average size of these is roughly 3.7′ × 3.7′. While most patches have been observed primarily in I-band, 1.5 square degrees of patch B have been covered in B, V and I, and, as an illustration, Figure 4 shows a true-colour composite image of a small area with multi-colour information.

The final catalogue of objects extracted from the co-added image uses the weight map to adapt the threshold of the source extraction algorithm and for each detected object identifies the context in which it has been found. The characterisation of each context is critical to control of the completeness and uniformity of the object catalogues derived from the co-added image. This is currently the main area of software development.

One of the major concerns has been whether the observations would be deep enough to search for distant clusters of galaxies. To address this and other questions posed by the WG and OPC, the EIS team has also developed basic tools for the scientific evaluation of the data, which allow for the comparison of star and galaxy counts with those of other authors and for the search of clusters using the matched-filter algorithm. A preliminary comparison of EIS galaxy counts with those obtained by the Palomar Distant Cluster Survey (PDCS)[6] shows that the EIS galaxy counts extend beyond those of the PDCS. Preliminary tests with EIS I-band data also indicate that about 15–20 candidate clusters per square degree can been found in the estimated redshift range $0.2 < z < 1.2$, which will yield over 300 candidate clusters after the completion of EIS-WIDE. Tests have also shown that "complete" cluster samples will be able to be produced by an adequate selection of "uniform" areas within the survey region using the context information. The astrometry of the EIS catalogues has an internal accuracy of about 0.03 arcsec, more than adequate for multi-slit spectroscopy at the VLT. The relative photometric accuracy is estimated to be of the order of 0.05 mag. However, the absolute calibration of patch A is still uncertain as it relies to a large extent on data not yet available from other telescopes.

5. Data Release: Catalogues and Images

EIS will produce a wide range of data products including the following catalogues:

1. Single-frame catalogues
2. Object catalogues extracted from the co-added images
3. Colour catalogues
4. Derived catalogues (e.g. candidate clusters).

The object catalogues will include positions, magnitude, major and minor-axis, position angle, stellarity index, SExtractor flags, and in the case of the catalogues extracted from the co-added image, the context and the characteristics of the context such as noise, a measure of the seeing, the 1σ limiting isophote and the limiting magnitude for point sources in that context.

The following pixel maps will also be available in the ESO Archive:

1. Astrometrically and photometrically calibrated frames
2. Co-added images, weight and context maps at both full resolution and in compressed form
3. Cut-outs of selected regions.

Currently, the EIS team and the ESO Archive group are studying the ways and means of making the EIS data accessible to the community. The target date of July 31, 1998 has been proposed to the OPC for the full release of the data from calibrated frames to co-added images to object catalogues and derived catalogues. The date is a compromise that takes into account the workload of the EIS team and the call for proposals for the VLT, expected to be issued on August 1, 1998. Given the large amount of data involved, a questionnaire is available on the EIS home page to survey the type of data products the astronomical community is most likely to request in the final release. The results of this survey will help evaluate the demand and the definition of a general policy that optimises the distribution of the data to the largest possible number of astronomers in the community.

However, recognising the value that a preview of the data would have, even if in a preliminary form, it has been decided that some products will be distributed earlier. A tentative schedule for the release of these products is available on the EIS home page (http://www.eso.org/eis), with the first release expected to be in March, soon after the publication of the present issue of *The Messenger*. In this first release we expect to make available reduced single frames with astrometric and photometric calibration, and corresponding catalogues. In addition, the compressed co-added image, weight and context maps of patch A and the corresponding preliminary catalogue will be available on-line. This release will also be accompanied by a complete description of the observations, data reduction and the contents of the catalogues as well as other information characterising the quality of the data and catalogues, prepared by the EIS team. A catalogue of cluster candidates will also be produced for distribution together with image cut-outs to serve as finding charts.

The hope is that this preliminary release will trigger valuable feedback from the community and will already provide useful data for the preparation of VLT projects. These preliminary releases will also serve as a test case for the final delivery, allowing the EIS team and the Archive group evaluate the amount and type of requests, the performance of the on-line server and the requirements posed by the distribution of large amounts of data in the form of pixel maps. Since several applications may not require the data at full resolution, the EIS team is currently analysing the performance of various compression algorithms, and their impact on the astrometry and photometry. This information is available on the EIS home page and, whenever possible, this option should be considered as it would greatly facilitate the distribution of large volumes of data.

Finally, it is important to emphasise the enormous workload of the EIS team. It includes observations, software development, tests of the pipeline, data reduction of survey frames as well as from other telescopes for the photometric calibration of the survey. Moreover, the team is also involved in the preparation for EIS-DEEP and the upgrade of the software to handle data from the wide-field imager at the 2.2-m telescope. Therefore, the team will not be able to provide support to the users until the final release of the data. For the time being, technical inquiries should be addressed to the ESO Archive Group (awicenec@eso.org with copies to eisweb@eso.org). Time allowing, answers to the most frequently asked questions will be made available on the EIS home page.

6. EIS Software and By-Products

Besides the astronomical data, the EIS team is committed to make publicly available to the ESO community all the software that has been developed for EIS. Our ultimate goal is to make, as much as possible, the EIS pipeline portable to other institutes. By July 1998, a detailed description of the various algorithms used in the different modules of the EIS pipeline should become available. Full documentation and in-depth discussion is also envisioned by the end of 1998, if the necessary resources are available. For that purpose, an effort is being made to keep the complete history of EIS on the web for future reference documentation, summaries of meetings, results of tests, error reports, software upgrades, and relevant communication between team members. Although time consuming, this activity has been considered an integral part of the development phase in view of the long-term prospects of the EIS pipeline and the expected turnover of the members of the EIS team.

In addition to these more tangible products, EIS has also provided other important by-products including valuable information on the performance of the NTT and the DFS/VCS. It has been used to prototype several developments in the ESO Science Archive Research Environment (SARE) and has created some useful new interfaces between ESO and the community, such as the EIS WG and the EIS team.

This shows the usefulness of public surveys not only for finding astronomical targets for the VLT but also from the operational point of view. It has also shown the agility of ESO in responding to a challenge, attracting talent spread throughout the ESO community and coordinating an effort such as EIS at short notice. Without all of these elements it would have been impossible to keep to the ambitious timetable of EIS.

7. The EIS Team and the Involvement of the ESO Community

The community has played an active role in the survey by participating in the EIS Working Group, which met three times during 1997 to decide on the modifications of the survey strategy as they became necessary. The ESO Member State community is also broadly represented in the EIS team, which is composed primarily of visitors and represent over 80% of the 4.5 FTEs allocated to the project in 1997.

Equally important has been the contribution given by the Geneva Observatory, which has monitored the extinction measurements during the EIS observations, and the Leiden Observatory, which has provided time for observations of standard stars and several pointings of the fields being observed, as well as DENIS data to be used for external calibration. H. Boehnhardt and collaborators also supplied observations taken at the 2.2-m telescope. All of these efforts have been extremely helpful in order to recover from the time losses caused by El Niño, providing essential data for the calibration of the photometric zero-point of the different patches.

EIS has also captured the interest of the astronomical community with the EIS home page being accessed about

3500 times during the month of January 1998 and averaging 4000 hits per month in 1997.

8. Conclusions

Even though the weather was not very co-operative at the beginning of the survey, it is fair to say that EIS is achieving most of its originally planned goals. A detailed account of the ongoing work has been presented to the EIS WG and to the OPC. As a result, the OPC has given the go ahead for the continuation of EIS-WIDE and has allocated time for EIS-DEEP. It should be mentioned that since SOFI will only be available in June, the EIS WG has recommended that the goals of the original DEEP-I and II[7] be combined to cover the HDFS region and its flanking fields, with the observations scheduled to start in July 1998.

Observations for EIS-WIDE with EMMI will be completed in March 1998, to be followed by U-band observations with SUSI-2 in the fall of 1998 over about 1.5 square degrees of patch B. already covered in B, V and I. At the same time the preparations have started for the EIS-DEEP observations. Trial reductions with single frames, taken with EMMI and SUSI, have shown that the EIS pipeline can adequately handle dithered optical images. Attention will now turn to interfacing EIS with the SOFI data reduction pipeline.

The EIS pipeline is already a reality, taking raw data and producing co-added images, object catalogues and derived catalogues, largely unsupervised. Most of the remaining work is to implement and verify the production of final object catalogues with the required "context" information for data-quality control, essential in the preparation of complete samples for statistical studies. The pipeline has been developed with one eye on short-term needs and the other on the long-term, which should facilitate its upgrade to handle the data from the wide-field camera at the ESO/MPIA 2.2-m telescope.

Preliminary results clearly indicate that the EIS data meet the requirements for the primary science goals of the project which, in conjunction with the various by-products outlined above, make this pilot programme a success. One of the important remaining challenges is to make the data reach the community in a timely and easy-to-use manner. Hopefully, by doing so, EIS will pave the way for gradually more ambitious public surveys.

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Après EIS

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1999 will be the first year of the VLT scientific operations, yet this will not be the only novelty brought by the new year. In 1999 the flow of scientific data from the old La Silla Observatory will be several times higher than in 1998. Indeed, with the full dedication of the ESO/MPIA 2.2-m telescope to wide-field imaging, the ESO community will have for the first time an efficient survey instrument: the 8k $\times$ 8k camera covering a 0.54° $\times$ 0.54° field of view. In the meantime, the construction is about to start of a new 2.5-m telescope to be placed on Paranal by 2001, which will have a four times bigger field of view (and data flow rate). This sudden expansion of ESO wide-field imaging and survey capabilities requires a major effort by both ESO and its community, in order to take full advantage of these new facilities that are primarily designed to support and foster the science to be done with the VLT.

1. Providing Targets for the VLT

With the advent of the VLT, European astronomy has – perhaps for the first time in this century – a real chance to successfully compete in ground-based, optical-IR astronomy. In the early years of next century there will be twelve 8-m-class telescopes in operation. Competition will be fierce, and leading or lagging behind others in critical areas of astronomical research will not just depend on the performance of the big telescopes and their instrumentation, but also on the ability to *timely* feed them with the appropriate targets. For this very reason, imaging surveys as a continuous, long-term need for the full scientific exploitation of the VLT are now widely endorsed within the ESO community.

For such surveys, 2–4-m-class telescopes are much more cost-effective than the VLT in finding objects of special interest for the deep imaging and spectroscopic study at the VLT itself. For this to be true, such targets have to be relatively rare, and the imager must have a substantially larger field of view compared to VLT imagers. Instead, if the potential targets are very numerous per field of view of the VLT imagers (e.g. FORS, VIMOS, NIRMOS), then the VLT itself may offer a competitive, or even more appropriate alternative. Classes of such "rare" objects that are scientifically attractive targets for the VLT are listed in Table 1.

While these potential targets will certainly not exhaust the capabilities of the VLT, it seems fair to say that all together they are likely to take a major share of the VLT observing time. This is exemplified in Table 2, instrument by instrument, following the order of instrument implementation at the VLT. The list is probably largely incomplete, yet it should give an idea of the variety of VLT programmes that will depend on independent wide-field imaging. No attempt is made here to describe the scientific goals of the specific possible programmes, but to a large extent they are self-evident. Yet, a couple of examples may help illustrate the case.

(1) Clusters of galaxies are very interesting objects *per se,* and allow a number of astrophysical investigations such as the study of the member galaxies, of their mass distribution by mapping the gravitational shear and magnification, etc. However, as recently illustrated in a spectacular way, clusters can be used as *gravitational telescopes* to magnify background galaxies at extremely high redshifts ($z \gtrsim 5$) that otherwise would be beyond reach even to an 8-m-class telescope. However, with the scanty statistics presently available one may expect that only a tiny fraction of all clusters will contain a bright red arc produced by a magnified $z \gtrsim 5$ galaxy. Quite probably, thousands of clusters will have to be inspected before collecting a statistically significant sample of extremely high redshift galaxies for the VLT spectroscopic study. Redundant samples of moderate redshift clusters are essential even for the detailed study of their member galaxies, because especially interesting spectral features (e.g. the Mg/MgH blend near 5000 Å used to derive the Mg_2 index and the central velocity dispersion in ellipticals) will not be contaminated by atmospheric lines only for clusters within relatively narrow redshift intervals.

(2) High redshift galaxies ($z \gtrsim 3$) are now easy to find via photometric redshifts. Measuring the mass of such galaxies is of paramount importance for a proper comparison with current theories of structure and galaxy formation. However, most galaxies so far discovered are too faint for the internal kinematics to be properly understood, hence for their mass to be determined. This should be possible only for galaxies at the top end of the luminosity function at higher and higher redshift, when such objects become rarer and rarer, hence larger and larger areas need to be surveyed.

Similar arguments hold for most of the targets listed in Table 1, as interested readers can easily convince themselves. Hence, the VLT need for targets yet more difficult to find is only bound to increase, as it will progressively complete the observation of the more obvious, or more common, or easier-to-find targets. This is especially true as the various VLT UTs will progressively come to completion along with their instrumentation. Moreover, and this is the really critical point, the VLT Observatory will not work in a vacuum, but will have to compete with many other observatories of its class. To ensure the VLT will maintain a leading role, ESO wide field capabilities should be first class, fully competitive with those at other observatories.

TABLE 1: EXAMPLES OF VLT TARGETS FROM SURVEYS.

• High-redshift objects

- High-redshift clusters of Galaxies (HRC)
- High-redshift clusters with bright foreground star (HRCS)
- High-redshift quasars (HRQ)
- Close pairs of high-redshift quasars (HRQP)
- Multiply lensed quasars (MLQ)
- Most luminous high-redshift galaxies, i.e. the top end of the luminosity function at each high redshift (MLG)
- High-redshift galaxies with strong emission lines (ELG)
- High-redshift supernovae (HRSN)
- Extremely red galaxies (ERG)

• Objects in relatively nearby galaxies (ONG)

- Globular clusters
- H II regions
- Planetary Nebulae/ Intergalactic PN
- Emission-line stars
- Novae
- Top end of the IMF

• Galactic stars (STARS)

- Subdwarfs
- White Dwarfs
- Very metal poor stars
- Very metal rich stars
- Other special stars
- Brown dwarf candidates (BDC)
- Highly magnified lensed stars

• Solar-system objects (SSO)

- Remote comets
- Unknown asteroids
- Transneptunian objects

2. ESO Wide Field Imaging Capabilities

2.1 The Wide Field Imager at the 2.2-m Telescope (WFI@2.2)

After starving for so many years for wide-field imaging, the ESO community will soon face the opposite problem, i.e. a limited capability to *digest* the enormous flow of data in the form of wide-field images that is about to start. The new 8k × 8k camera (WFI@2.2) to be placed next October at the 2.2-m telescope will provide a field of view of 0.54° × 0.54° (for more information see http://www.ls.eso.org/lasilla/Telescopes/2p2T/E2p2M/ELVIS/news/ELVISP62.html) When factoring in telescope aperture, field of view, troughput of the optics and QE of the CCDs, the WFI@2.2 will be ~ 6 times more efficient than EMMI for wide angle (survey) work. The WFI@2.2 will have 12 times the field of view of EMMI (that was used for EIS), will deliver images with 16 times larger digital format than EMMI/red, and – perhaps most importantly – the 2.2-m telescope will be the first of its class wordwide to be fully dedicated to wide-field imaging with a large-format camera. For comparison, EIS-WIDE consists of just about 30 nights with EMMI@NTT. All in all, with the advent of the WFI@2.2 the survey potential capability of ESO over the three year period 1999–2001 is equivalent to ~ 200 EIS(!).

To continue this comparison a little further, it is easy to realise that the number of pixels of the WFI@2.2 CCDs is about twice that of all other ESO instruments on La Silla, namely 67 Mpx vs. ~ 35 Mpx. When considering that the WFI@2.2 will be permanently mounted at the 2.2-m, while the other telescopes will on average use either a 1k × 1k or a 2k × 2k device, it follows that the WFI@2.2 data flow alone will be several times larger than the combined flow from all other ESO telescopes on La Silla. During 1999, the WFI@2.2 data flow is estimated at a rate of ~ 8 Gby/night, which compares to ~ 4 Gby/night from the VLT UT1. The global ESO data-flow rate will then increase by a factor larger than five in 1999 compared to 1998.

This surge in data flow clearly requires adequate preparation and investments not only at ESO premises, but especially at concerned institutes in the ESO member states where this flow will eventually

TABLE 2: TARGET NEEDS OF VLT INSTRUMENTS.

UT1

FORS1

HRC:	multicolour photometry of cluster galaxies spectroscopy of cluster galaxies (redshifts, scaling relations) deep high-res. imaging (gravitational shear maps) giant-arc spectroscopy (redshift, star-formation rate)
MLG:	spectroscopy (redshift, internal kinematics, abundances, star-formation rate)
MLQ:	imaging; spectroscopy (variability, absorption systems)
ELG:	spectroscopy (redshift, abundances, kinematics)
ERG:	Spectroscopy (redshift, abundances, kinematics)
HRSN:	spectroscopy (redshift and classification)
ONG:	spectroscopy (kinematics, abundances)
SSO:	spectroscopy

ISAAC

HRC:	multicolor photometry of cluster galaxies spectroscopy of cluster galaxies (redshifts, scaling relations) giant-arc spectroscopy
MLG:	spectroscopy (redshift, internal kinematics, abundances)
ERG:	imaging, spectroscopy (redshift, star formation rate)
HRQ/HRQP:	spectroscopy (absorption systems)
STARS:	spectroscopy (radial velocity, abundances)
BDC:	spectroscopy
SSO:	imaging; spectroscopy

CONICA

HRCS:	High-resolution imaging; spectroscopy (morphology, scaling relations)
MLG:	High-resolution imaging; spectroscopy (morphology, scaling relations)
MLQ:	imaging, spectroscopy (variability, absorption systems)

UT2

UVES

HRQ/HRQP:	high-resolution spectroscopy (intergalactic medium at high z)
STARS:	high-resolution spectroscopy (radial velocity, abundances)

FORS2

Same as FORS1

GIRAFFE (formerly called FUEGOS)

All programmes will need target lists from a wide-field imager

UT3

VIMOS

HRC:	Integral Field spectroscopy
MLQ:	Integral Field spectroscopy

VISIR

MLG:	imaging; spectroscopy (abundances, star-formation rate)
ERG:	imaging; spectroscopy (abundances, star-formation rate)
BDC:	imaging; spectroscopy

UT4

NIRMOS

HRC:	Integral Field spectroscopy
MLQ:	Integral Field spectroscopy

CRIRES (probably none)

UT1

SINFONI

MLG:	3D spectroscopy (internal kinematics)
MLQ:	3D spectroscopy (absorption systems)
ERG:	imaging; spectroscopy (abundances, star-formation rate)

meet its final destination. It is also important to realise that the data flow will keep increasing in the following years, exacerbating the situation if proper measures are not immediately taken. In fact, two more UTs will enter operation in 2000, and the last UT in 2001, along with an even more demanding survey telescope.

2.2. The VLT Survey Telescope (VST) on Paranal

Though already a respectable facility for survey work, the 2.2-m telescope is now just a temporary solution for the ESO needs of wide-field imaging. The offer of a new 2.5-m telescope on Paranal made by the Capodimonte Astronomical Observatory was enthusiastically endorsed by the STC at its meeting of October 28–29, 1997. According to current planning, the telescope will be delivered for operation during 2001.

It is estimated that the 2.5-m telescope on Paranal will have an overall efficiency $\sim$ 12 times higher than that of the WFI@2.2. This figure comes from the combination of better site, higher throughput, and larger field of view and format of the camera (one square degree covered by at least a 16k $\times$ 16k array of CCDs). Therefore, the availability of the new telescope will mark another quantum jump in the ESO capability of conducting imaging survey work, primarily – though not necessarily exclusively – in support of VLT Science. With its very large detector, the data flow from the VST will rival the data flow of the whole VLT/VLTI. Although the VST with its one square degree camera will not be the largest telescope with a very wide-angle imager, it will likely be the first such facility to be fully dedicated to wide field imaging. ESO is now issuing an Announcement of Opportunities for the procurement of this camera.

The sharing of the observing time at the new telescope will naturally follow the same scheme of the 2.2-m: there will be guaranteed time for the MPIA in compensation for an anticipated eventual decomissioning of the 2.2-m telescope, for the CAO for having provided the telescope, and to the institutes that will have provided the instrumentation. Nevertheless, probably substantially more than 50% of the time will still remain available to the rest of the community.

The advantages offered by the VST over the 2.2-m telescope can be appreciated when considering that a factor $\sim$ 10 gain in efficiency means that either a given survey can be completed ten times faster, or that for a given telescope time a ten times larger area can be explored (hence ten times rarer objects can be found), or that a survey can be pushed more than one magnitude deeper, or that more numerous pass-bands or narrower ones can be used. Clearly, such a jump opens a whole unexplored parameter space, offering to the community a variety of opportunities and alternatives all very attractive for the VLT science, though not only for it. For example, the large proportion (~ 77%) and even distribution of photometric nights on Paranal makes the VST uniquely suited for the extensive observation of microlensing events in the Galactic bulge, and the search of extrasolar planets using this technique (cf. *The Messenger*, 90, 15). In essence, a long-sighted scientific planning for the use of the VST should be of great benefit for the ESO community, and the experience gained with the 2.2-m telescope will be critical in this respect.

3. Surveys from Present to Future

3.1. Building a Strategy

From these crude numbers it emerges that – as far as wide-field imaging is concerned – from now on the real bottleneck is not in getting observing nights and images, but in the ability to process them properly, and especially to do so in a timely fashion. The sooner suitable targets are found for the VLT, the sooner ESO astronomers will have an opportunity to anticipate other observatories in fundamental discoveries. It would instead be both a missed opportunity and a waste of resources if images from the WFI@2.2 were to remain unused waiting for the necessary HW/SW tools and human resources to be secured. A demonstrated capacity to deal with a large volume of data should be considered as a double plus by OPC when allocating time at the 2.2-m telescope.

ESO is now setting out a plan to help the community to cope with such an enormous increase in data flow. Of course, ESO cannot provide hardware or manpower to institutes in the member states, but can help in various other ways. To some extent EIS was designed to address these problems, starting just before the beginning of VLT operations a survey that no other institute in the member states was prepared to undertake on such a short notice and tight schedule. The primary aim was to simplify for ESO users the selection of VLT targets, thus allowing them to concentrate on the preparation of an aggressive use of the VLT. But in doing the survey, additional advantages are coming for the community. Indeed, EIS will soon provide the ESO community with:

• Survey data (images and catalogues)

• Survey software tools

• Astronomers trained in survey work.

In fact, besides survey data, all software that has been developed, adapted, and implemented for EIS is publicly available to the ESO community. With the advent of the WFI@2.2 this survey software needs to be significantly expanded and upgraded, with the aim to (1) allow a prompt use of the 2.2-m for survey work, and (2) make the survey software and tools really "portable", i.e. distributing them to the community. These tools will allow a series of image processing to be performed in an automatic fashion, including image coaddition, dithering, mosaicing, astrometric and photometric calibrations, etc. The aim is to allow interested institutes in the member states to undertake major survey work (either public or private), but of course some of these tools will also be useful to process images for more modest projects dealing with a limited number of frames.

It is unlikely that ESO will have the necessary resources for making the survey pipeline fully portable (e.g. fully documented, independent, etc.). Essential to make it portable are the astronomers having been trained themselves in survey work at ESO, first with EIS, then with the WFI@2.2. Much of the EIS Team is indeed composed of astronomers from the community, having spent several months working in Garching, then returning to their home institutes bringing back their experience with survey work and its tools. Institutes interested in developing their own independent capacity in wide-format image processing may consider the opportunity to send people at ESO to work in the EIS Team, then getting them back with accrued experience and bringing along well understood tools with which they have gotten fully acquainted. With this process one builds on the EIS experience, and with relatively modest incremental efforts one aims at enabling the community to take full advantage first of the WFI@2.2, and later of the further expanded capabilities of the VST.

3.2. The 1999 Pilot Survey at the 2.2-m Telescope

The EIS Working Group has recommended to start in Period 62 a Pilot Survey at the 2.2-m telescope, taking of order of one third of the available time. The Pilot Survey is now being designed under the supervision of the Working Group, and will be submitted to the OPC by April 15. If approved, ESO will make an effort to implement the following schedule:

• October-December, 1998: implementation, commissioning, and science verification of the WFI@2.2.

• April-December, 1998: EIS pipeline upgrade to WFI-survey pipeline and its commissioning.

• January 1 – March 31, 1999: WFI@2.2 offered to the community in Period 62.

• January 1 – March 31, 1999: Observations for the Pilot Survey.

• February 1 – July 31, 1999: Processing of the Pilot Survey data.

• July 31, 1999: Release of the survey products.

Thus, 1/3 of the dark time in the second half of Period 62 will correspond to about 15 nights. Given the factor of ~ 6 advantage of the 2.2-m telescope for survey efficiency over the NTT, this is equivalent to ~ 90 NTT nights, or roughly three times EIS-WIDE. The Pilot Survey will then represent a major step forward with respect to EIS, even if using a modest number of nights.

Observations and data processing for the Pilot Survey will be conducted by a dedicated Team which, similar to the EIS Team, will be composed by astronomers from the community and will be supported by ESO and ECF staff and fellows.

EIS and Pilot Survey data will immediately enter the VLT Archive, and will in fact provide an opportunity to scientifically verify the Archive itself. Proprietory VLT data will not be accessible for one year after release to the PIs, hence little users access to the archived VLT data is expected during 1999. Instead, public survey data will immediately be accessible through the Archive, and a major use of them is expected in the preparation of the VLT programmes and proposals. This will offer the opportunity for an early test and optimisation of Archive procedures and data distribution.

3.3. Beyond 1999

What is going to happen after the 1999 Pilot Survey is difficult to predict at this time. Public and private major surveys, first with the WFI@2.2 and then at the VST, will probably coexist with a series of less demanding imaging programmes. The share of telescope time among these various uses of the facilities will be recommended by the OPC on the basis of the scientific merit and the requests from the community.

The Working Group for public surveys (possibly reconstituted through an Announcement of Opportunities process) will continue on its tasks to collect input from the community, scientifically optimise public surveys before their submission to the OPC, and monitor the execution of the surveys and the release of their products.

With the survey pipeline being installed at other institutes in the community, the capability to process large amounts of survey data will disseminate, and the necessity to maintain a survey Team at ESO will progressively diminish. This will be especially true after the VST starts operating, and the survey pipeline will have been upgraded to cope with images from its camera, each likely to be composed by 32 subimages each of 2k × 4k format. All in all, with this long-term programme in imaging surveys new ways of cooperation and interaction between ESO and its community will be explored, with the prime aim of getting the ESO community more and more competitive in the VLT era.

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ESO STUDENTSHIP PROGRAMME

The European Southern Observatory research student programme aims at providing the opportunities and the facilities to enhance the post-graduate programmes of ESO member-state universities by bringing young scientists into close contact with the instruments, activities, and people at one of the world's foremost observatories.

Students in the programme work on an advanced research degree under the formal tutelage of their home university and department, but come to either Garching or Vitacura-Santiago for a stay of up to two years to conduct part of their studies under the supervision of an ESO staff astronomer. Candidates and their national supervisors should agree on a research project together with the potential ESO local supervisor. It is highly recommended that the applicants start their Ph.D. studies at their home institute before continuing their Ph.D. work and developing observational expertise at ESO.

The ESO studentship programme comprises about 14 positions, so that each year a total of up to 7 new studentships are available either at the ESO Headquarters in Garching or in Chile at the Vitacura Quarters. These positions are open to students enrolled in a Ph.D. programme in the ESO member states and exceptionally at a university outside the ESO member states.

The closing date for applications is **June 15, 1998**.

For further information on the programme, the scientific interests of the ESO astronomers, and application forms please contact:

European Southern Observatory
Studentship Programme
Karl-Schwarzschild-Str. 2
D-85748 Garching bei München, Germany
e-mail: ksteiner@eso.org

or look up: http://www.eso.org/gen-fac/adm/pers/vacant/student.html and for a brief outline of the scientific research areas of ESO astronomers: http://www.eso.org/gen-fac/adm/pers/vacant/reslist.html

SECOND ANNOUNCEMENT

ESO/ST-ECF Workshop on NICMOS and the VLT:

A New Era of High-Resolution Near-Infrared Imaging and Spectroscopy

May 26–27, 1998
Hotel Baia di Nora, Pula, Sardinia, Italy

ST-ECF and ESO are organising in collaboration with the NICMOS IDT and STScI a workshop on near infrared imaging from space and ground. The purpose of the workshop is to review what has been achieved with the Near Infrared and Multi Object Spectrograph (NICMOS) on board of HST, what can be achieved in the remaining lifetime of the instrument, and how NICMOS observations can be optimised taking into account the availability of IR imaging and spectroscopy on ESO's Very large Telescope (VLT) in the near future. The meeting will be held in May 1998, about one year after science observations started with NICMOS, and about half a year before the Infrared Spectrometer and Array Camera (ISAAC) starts to operate on the VLT. Currently, it is expected that NICMOS will operate until the end of 1998.

The purpose of the workshop is to exchange both technical and scientific information on NICMOS and the VLT. In order to encourage discussions and interaction among the participants, attendance will be limited to about 60 participants.

- **Registration deadline for the workshop is March 15, 1998.**
- More information and registration forms are available at http://ecf.hq.eso.org/nicmos/meeting

Organising Committee: P. Benvenuti, G. De Marchi, R. Fosbury, W. Freudling (chair), A. Moorwood, N. Pirzkal, R. Thompson, W. Sparks, B. Sjøberg

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List of ESO Scientific Preprints

(December 1997 – February 1998)

1255. F. Comerón, J. Torra. A.E. Gómez: Kinematic Signatures of Violent Formation of Galactic OB Associations from Hipparkos Measurements. *A&A.*
1256. L. Binette: Radiative Acceleration of Coronal Gas in Seyfert Nuclei. *M.N.R.A.S.*
1257. R.A. Méndez and R. Guzmán: Starcounts in the Flanking Fields of the Hubble Deep Field. The Faint End of the Disc Stellar Luminosity Function and its Scale-Height. A&A.
1258. R.A.E. Fosbury et al.: Radio Jet Interactions in the Radio Galaxy PKS 2152-699. *M.N.R.A.S.*
1259. Th. Rivinius et al.: Stellar and Circumstellar Activity of the Be Star μ Cen. I. Line Emission Outbursts. *A&A.*
1260. B. Leibundgut: Type Ia Supernovae and q_0. To appear in *Supernovae and Cosmology*, eds. L. Labhardt, B. Binggeli, R. Buser, Basel, University of Basel.
1261. P.-A. Duc and I.F. Mirabel: Young Tidal Dwarf Galaxies Around the Gas-rich Disturbed Lenticular NGC 5291. *A&A.*
1262. R. Buonanno et al.: On the Relative Ages of Galactic Globular Clusters. A New Observable, a Semi-Empirical Calibration and Problems with the Theoretical Isochrones. *A&A.*

THE 34TH LIÈGE INTERNATIONAL ASTROPHYSICS COLLOQUIUM

The Next-Generation Space Telescope – Science Drivers and Technological Challenges

Liège, Belgium, 15–18 June 1998

Following the recommendation of the "HST and beyond" Report, NASA is investing a considerable effort in the definition of a large aperture (8 meter class) near IR space telescope (known as the Next Generation Space Telescope) to study the Universe at high redshift (5 < z < 30) and in particular the formation and evolution of galaxies at that early epoch. ESA has recently decided to join NASA in these preliminary studies in view of a possible future collaboration in the construction and operation of such an important astronomical facility. ESO is also supporting a European participation in NGST because of the scientific complementarity between VLT and NGST observing programmes.

The main purpose of the Workshop (co-sponsored by ESA, ESO, NASA, STScI and Belgian organisations) is to offer the European and US astronomical communities a forum where they may discuss and better define the prime scientific objectives of the NGST, and its complementarity with other large space and ground facilities as well as reviewing the technological challenges, with particular emphasis on those areas where European industry can offer innovative contributions.

Topics to be covered include:

- reviews of the current NGST concept and capabilities
- status reports from the NASA and ESA NGST studies
- early formation of stars, galaxies, and quasars
- sub-mm observation of high-z galaxies
- structure and dynamics of galaxies at z>2
- distant supernovae
- gravitational lensing
- stellar populations in the nearby universe
- extra-solar planets and young stars
- instrument concepts for NGST
- light-weight mirror technologies
- orbit and mission concepts for NGST

Preliminary list of invited speakers:

R. Angel, S. Beckwith, P. Bely, R. Bonnet, C. Burrows, S. Charlot, L. Cowie, S. Cristiani, R. Davies, A. Dressler, R. Ellis, A. Ferrara, M. Franx, R. Genzel, P. Jakobsen, R. Kennicutt, R. Kirshner, O. LeFevre, S. Lilly, A. Loeb, P. Madau, J. Mather, J.-L. Puget, M. Rees, A. Renzini, P. Schneider, C. Steidel, M. Stiavelli, P. Stockman, E. Weiler and S. White.

Organising committee:

P. Benvenuti (Co-chair), R. Fosbury, D. Fraipont-Caro, R. Hook, P. Jakobsen, P. Madau (Co-chair), B. Sjøberg, J. Surdej, J.-P. Swings (Chairman local organisation).

Further information: http://ecf.hq.eso.org/ngst/ngst.html
E-mail contact: ngstconf@eso.org

PERSONNEL MOVEMENTS

International Staff

(1st January – 31st March 1998)

ARRIVALS

EUROPE

BECKERS, Jean-Louis (B), Project Controller
BOGUN, Stefan H. (D), Astronomical Data Reduction Specialist
DELL'ERBA, Anna (I/ZA), Secretary to the Office of the DG (December 1997)
DONALDSON, Robert (GB), Software Engineer
FOURNIOL, Nathalie (F), Associate ST-ECF
JUNG, Yves (F), Coopérant
KASTELYN, Nathalie (B), Assistant to HoA
KURZ, Richard (USA), Chief Engineer
LEVEQUE, Samuel (F), Associate
MEHRGAN, Hamid (IR), Infrared Detector Engineer
MIGNANI, Roberto (I), Associate ST-ECF
ZAGGIA, Simone (I), Associate EIS

CHILE

CULLUM, Martin (GB), Temporary Transfer to Paranal
DUCHATEAU, Michel (F), Temporary Transfer to Paranal
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SANDROCK, Stefan (D), Transfer to Paranal
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WINNBERG, Anders (S), Associate SEST

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AGEORGES, Nancy (F), Fellow
BELHACHEMI, Khadidja (F), Archive Assisant
DOUBLIER, Vanessa (F), Student
SAVAGLIO, Sandra (I), Fellow
VAN DER STROOM, Margaretha (NL), Contract Officer
WOLFF, Norbert (D), Control Engineer

CHILE

BRILLANT, Stéphane (F), Student
MAUGIS, Michel (F), Electronics Technician
PEREZ, Isabel (E), Student
VAN DE STEENE, Griet (NL), Fellow

Local Staff

(1st January – 31st March 1998)

ARRIVALS

RAHMER BASS, Gustavo (RCH), Optical Detector Engineer
GUZMÁN TANAKA, Juan Carlos (RCH), Applicant Programmer
ARGOMEDO ZAZZALI, Javier (RCH), Applicant Programmer

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 eight countries: Belgium, Denmark, France, Germany, Italy, the Netherlands, Sweden and Switzerland. It operates the La Silla observatory in the Atacama desert, 600 km north of Santiago de Chile, at 2,400 m altitude, where fourteen optical telescopes with diameters up to 3.6 m and a 15-m submillimetre radio telescope (SEST) are now in operation. The 3.5-m New Technology Telescope (NTT) became operational in 1990, and a giant telescope (VLT = Very Large Telescope), consisting of four 8-m telescopes is under construction. It is being erected on Paranal, a 2,600 m high mountain in northern Chile, approximately 130 km south of Antofagasta. Eight hundred scientists make proposals each year for the use of the telescopes at La Silla. The ESO Headquarters are located in Garching, near Munich, Germany. It is the scientific, technical and administrative centre of ESO where technical development programmes are carried out to provide the La Silla observatory with the most advanced instruments. There are also extensive facilities which enable the scientists to analyse their data. In Europe ESO employs about 200 international Staff members, Fellows and Associates; at La Silla about 50 and, in addition, 150 local Staff members.

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 Information Service at the following address:

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