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From CORALIE to HARPS

The Way Towards 1 m s^{-1} Precision Doppler Measurements

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1. Search for Extrasolar Planets by Precise Doppler Measurements

Precise Doppler measurements of stars is a very efficient way to search for extrasolar planets orbiting nearby stars similar to the Sun. The gravitational interactions between a planet and its host star produces a change of the radial velocity of the star that can be detected by Doppler measurements with precision of few m s^{-1}. Thanks to the effort of observations done by precise Doppler surveys conducted world-wide, 67 companions with mass less than 15 M_J have been discovered. Today ongoing surveys regularly monitor the radial velocity of a total sample of 3000 G, K and M stars (Queloz 2001).

The detection of a planet by the measurement of the orbit of its host star brings information on the mass of the planet, the orbital eccentricity and the orbital period. Actually the mass is only known within the uncertainty of the projection factor represented by the sin *i* of the orbit. However, the sin *i* statistics is so sharp that one has 87% probability to be within a factor of 2 (sin *i* between 1 and 0.5).

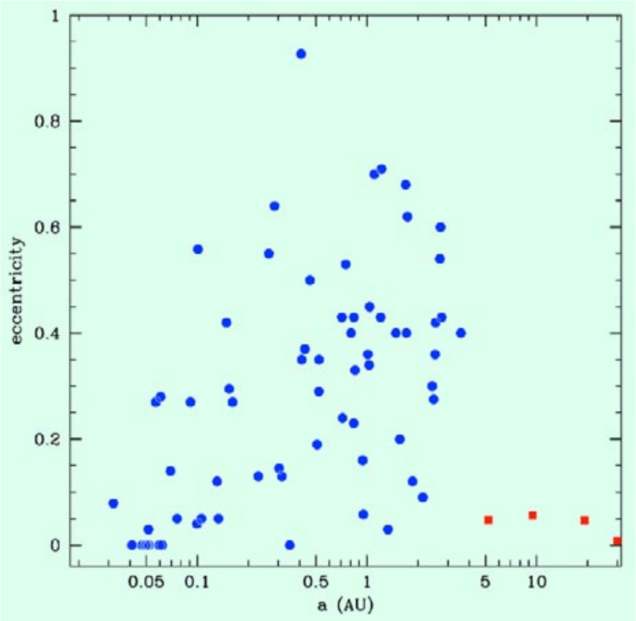


Figure 1: Semi-major axis and eccentricity distribution of the extra-solar planets (blue dots) discovered as of July 2001. In red squares are shown the giant planets of the Solar System.

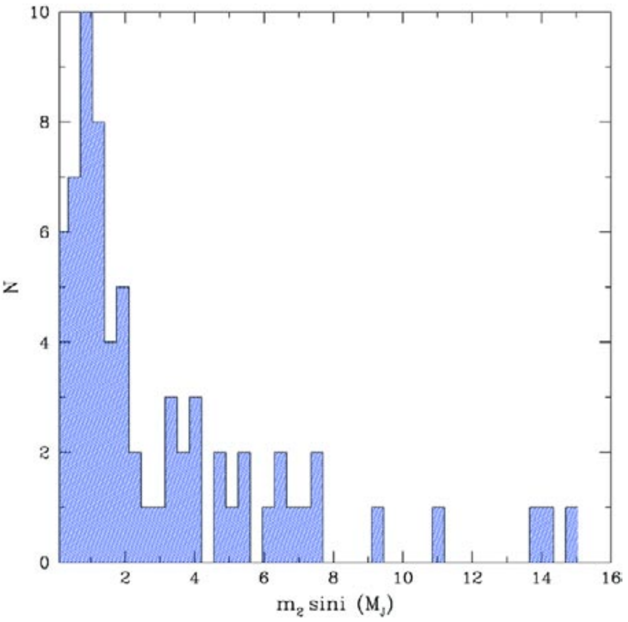


Figure 2: Extra-solar planet mass distribution. Below 1 M_J the mass distribution is biased by the detection threshold that makes planets on far-off orbits harder to detect.

The first planet discovered orbiting the star 51 Peg (Mayor & Queloz 1995) is a giant planet on a very close orbit (4.2 days). Other similar systems have been later detected. The direct observation of a transit of one of these short orbit planets (Charbonneau et al. 2000, Mazeh et al. 2000) brought the final confirmation of their existence. These planetary systems, called "hot Jupiters", do not fit in the paradigm of the planet formation based on the observation of our Solar System (Boss 1995; Lissauer 1995). Extra mechanisms such that planet migration or multi-planet gravitational interactions have been suggested to explain their formation (see references in the review by Marcy et al. 2000).

The orbital characteristics of the extrasolar planets detected so far contrast with the orbital characteristics of giant planets in our solar system (see Fig. 1). The orbits of giant planets in our Solar System are almost circular, a natural consequence of their formation in the protoplanetary disk. The extrasolar planets show a wide range of eccentricity surprisingly similar to the eccentricity distribution of binary systems with stellar companions (Mayor & Udry 2000). This is not understood in the frame of a global planetary formation theory. However the interpretation of data should be made carefully and specifically the comparison with our solar system. Actually ongoing planet surveys have not been able yet to detect a Jupiter analogue (1 M_J object at or above 5 AU). The orbit of Jupiter produces on the Sun a complete radial velocity variation of 13 m s^{-1} amplitude in 11 years. Intensive high-precision Doppler surveys while reaching enough precision (about 3 m s^{-1}) do not yet have enough time coverage. Extra years of measurements are needed to tackle Jupiter mass planets with orbital periods longer than 10 years. Moreover, it is important to recall that Doppler survey are sensitive to a detection systematic that ties together the mass of the planet with the semi-major axis of its orbit, making easier the detection of a planet on a short orbit than of a planet like Jupiter.

Doppler surveys are providing the first results on planet mass distribution. While we can still debate on the maximum mass of planets (See Jorissen et al. 2001) we know for sure that the planet mass function is dramatically rising towards low masses (Fig. 2). If we restrict the analysis to planets with masses larger than 1 M_J and with orbits having semi-major axes less than 3 AU we find a rise $dn/dm \sim m^{-1}$. Below 1 M_J the detection threshold limits the detection to systems on shorter orbits, therefore the observed mass function artificially decreases. With the reasonable assumption that the planet mass function should continue to rise at least in the giant planet mass domain, we can expect that any improvements in the detection threshold should convert into a significant increase of the planet detection rate.

The studies of the content of the atmosphere of stars having a planet show spectroscopic features that distinguish them from field stars with no planet detection. Statistically the stars with planets are metal richer compared to stars with no planet detection (Santos et al. 2001). A recent study on the Li^6 content of the atmosphere of the star HD 82943, hosting a planet, suggests that extra Lithium has been brought to the atmosphere of that star, possibly fed by a planet (Israelian et al. 2001). These observations rise the issue of a possible trace of the planet formation visible in the atmosphere of the star.

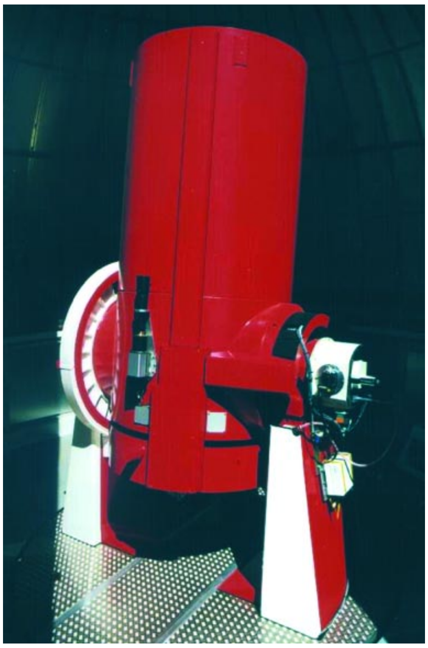


Figure 3: 1.2-m Swiss Leonard Euler telescope at La Silla. The CORALIE front-end adapter is visible at the Nasmyth focus on the top of the right fork of the telescope.

2. The CORALIE Spectrograph

CORALIE is the fibre-fed echelle spectrograph installed in April 1998 at the Swiss 1.2-m Leonard Euler telescope at the ESO La Silla Observatory (Fig. 3). It has been built as a joint project with the Observatoire de Haute-Provence which owns the first specimen, named ELODIE (Baranne et al. 1997; Queloz et al. 2000). The CORALIE spectrograph is fed by two fibres each including a double scrambler device to improve the stability of the input illumination of the spectrograph. The spectrograph itself is located in an isolated and stable environment with an accurate temperature regulation. The fibres are connected to the Euler telescope Nasmyth focus by a front-end adapter. The calibration lamps and the entrance fibre viewer device are part of the front-end adapter.

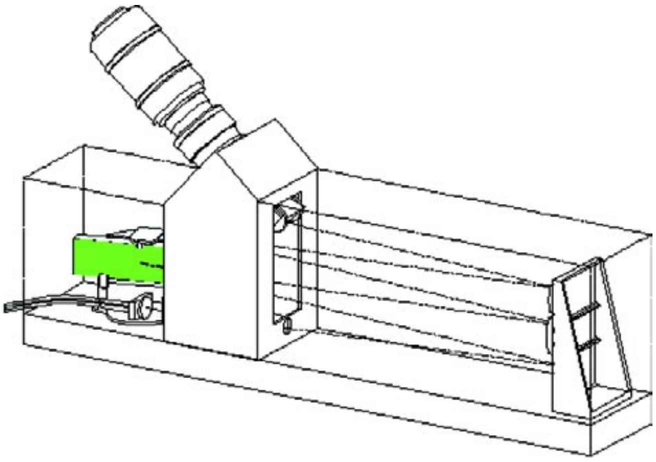


Figure 4: Perspective drawing of CORALIE. The fibre entrance is on the left. The grating is coloured in green.

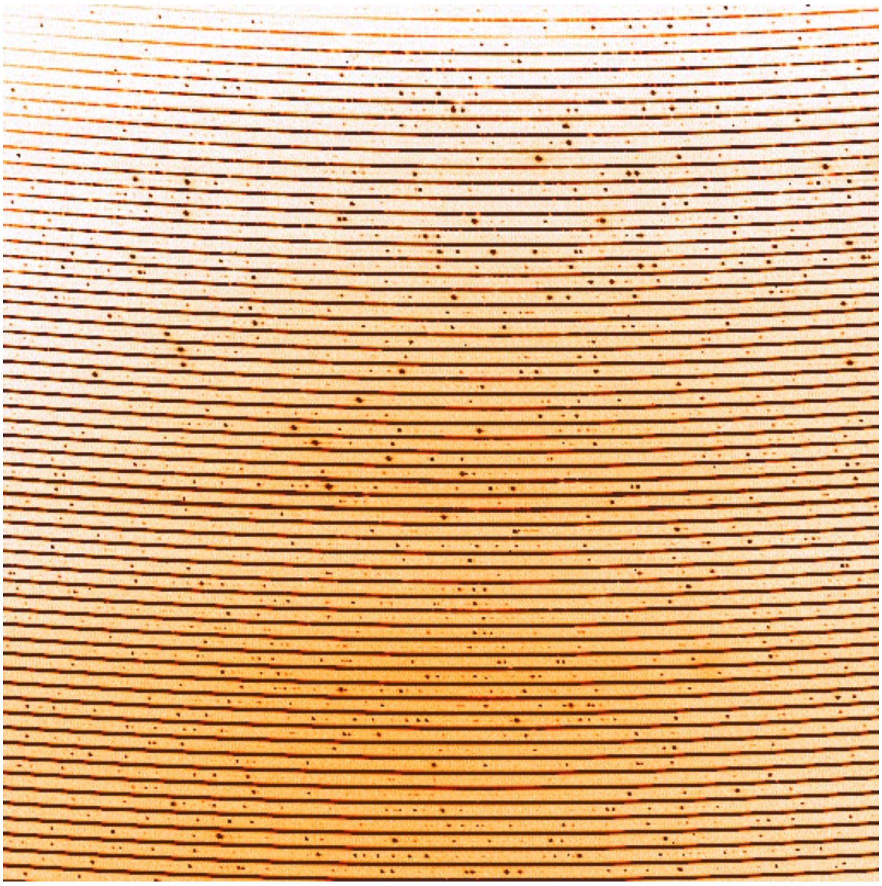


Figure 5: CCD frame of a CORALIE stellar exposure with its simultaneous thorium reference. The emission lines (black dots) of the thorium spectrum are clearly visible between the orders of the stellar spectrum

The optical design of CORALIE is the same as that of ELODIE. The echelle grating is used with tan $\phi = 4$ blaze angle and the cross-disperser is made of a prism and a grism in order to obtain equal spacing between orders through the whole useful wavelength range. The optical system is made of numerous surfaces but allows a compact image with a maximal resolution of 100,000. (See Fig. 4 and Table 2.)

CORALIE has been designed to achieve precise radial velocity measurements and to deliver the measurements shortly after the end of the exposure. The telescope and the spectrograph are operated by a single observer in a semiautomatic mode. The sequence of observations can be prepared before the beginning of the night and run automatically during the night.

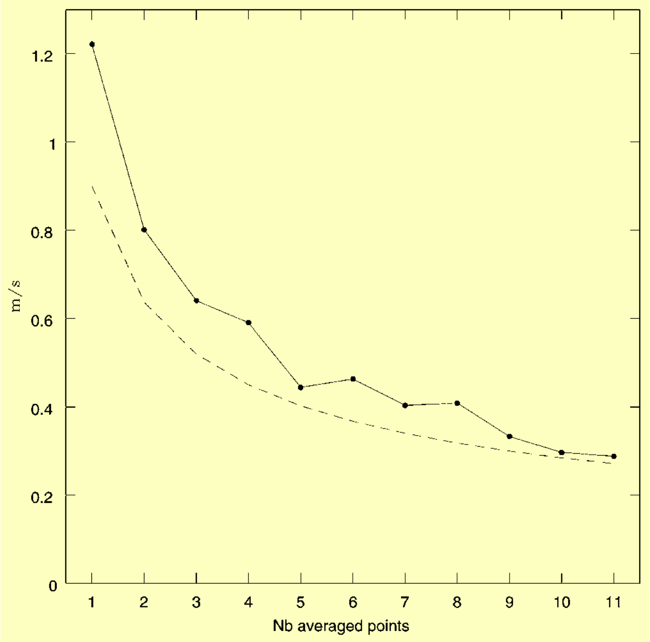
The measurements of stellar radial velocities at a few meter per second precision rely on two key elements. First, one needs enough photons and spectral information to compute the radial velocity with a high precision. Second, one needs a stable reference to measure and to correct the systematic errors of the instrument. The 3000 Å wavelength range ensures a rich spectral information for the computation of the radial velocity balancing the modest size of the telescope. For example, for a K0 dwarf with $v \sin i = 2$ km s^{-1} we reach in 10 minutes a 3 m s^{-1} precision on the radial velocity measurement for a 7.5 magnitude star. The stable reference is provided by the intrinsic very high stability of the instrument itself and regular wavelength calibrations with the thorium spectrum. Moreover, the simultaneous use of the thorium during science exposures corrects from any short-term drifts of the instrument. The technique is known as the simultaneous thorium referencing technique (Queloz et al. 1999). On Figure 5 a CORALIE CCD frame with a simultaneous thorium reference is displayed.

CORALIE has an automatic reduction software that provides fully calibrated spectra and a measurement of the radial velocity by cross-correlation. The general description of this software can be found in (Baranne et al. 1996). Since the CORALIE commissioning, significant modifications in reduction algorithms have been made, leading to an improvement of the long-term precision from 7 m s^{-1} to 2 m s^{-1} (rms).

The long-term reference is provided by the thorium spectrum. The procedure setting the global wavelength solution has been modified in 2001. The wavelength solution fit includes a weighting scheme that takes into account positioning uncertainties of the photo centre of each pixel (about 50 m s^{-1}). The fit of the global wavelength solution is done with 1200 thorium spectral lines. The fit on the solution has 80 m s^{-1} rms residual, corresponding to 2 m s^{-1} error on the zero point of the calibration.

The short-term tracking of the instrument by simultaneous thorium shows no instrument error apart the photon noise (Fig. 6). The measured dispersion of a sequence of radial velocity measurements on the Sun is 1.2 m s^{-1}. Part of it comes from the solar oscillation signal, the rest from the photon noise on the measurement of the instantaneous drift of the instrument. When we average the measurements, the sun oscillation signal averages as well. The convergence of the observed dispersion with the expected dispersion due to the photon noise demonstrates that no extra instrumental noise is seen down to 30 cm s^{-1}. This result

Figure 6: Observed radial velocity dispersion on a 4-hour observation sequence of the Sun. We display the dispersion for different numbers of averaged measurements in order to average the Sun oscillation signal as well. The hatched curve indicates the expected uncertainties on the radial velocity from the photon-noise error on the measurement of the simultaneous tracking. With an average of 10 radial-velocity measurements we average out the solar oscillation signal.



Planet name	$m_2 \sin i$ M_J	a [AU]	O–C m s^{-1}	Discovery
Gl86b	3.4	0.11	9	1998
HD192263b	0.68	0.15	11	1999
HD130322b	0.95	0.32	15	1999
HD83443c	0.15	0.17	6	2000
HD168746b	0.23	0.07	9	2000
HD108147b	0.31	0.10	11	2000
HD83443b	0.34	0.04	6	2000
HD75289b	0.40	0.04	8	2000
HD6434b	0.44	0.15	14	2000
HD121504b	0.81	0.32	9	2000
HD52265b	0.98	0.50	11	2000
HD19994b	1.7	1.23	10	2000
HD169830b	2.8	0.82	10	2000
HD1237b	3.2	0.49	11	2000
HD92788b	3.4	0.97	12	2000
HD162020b	13	0.07	13	2000
HD202206b	13.6	0.76	11	2000
HD168443c	13.7	2.67	6	2000
HD82943c	0.80	0.73	7	2001
HD82943b	1.48	1.16	7	2001
HD213240b	3.3	1.6	12	2001
HD28185b	5.3	1.01	10	2001
HD141937b	8.8	1.49	11	2001

Table 1: List of Extra-solar planets discovered by CORALIE. In the O–C column are the residuals to the planet model fit. Residuals higher than 10 m s^{-1} usually origin from stellar intrinsic activity at the surface of some young star or they suggest another companion yet undetected. References can be found on `http://obswww.unige.ch/~udry/planet/planet.html`

makes possible asteroseismology programmes to detect Solar-type oscillations by radial velocity measurements on dwarf stars.

The long-term precision of radial velocity measurements is tied to the quality and the reliability of the daily zero points. Actually no systematics have been observed apart the 2 m s^{-1} error on the wavelength calibration. The bright star 82 Eri is one of the star used since the installation of CORALIE as a proxy for the long-term precision tracking. We measure a 3.6 m s^{-1} dispersion over a 2.5-year duration with no indications of long-term systematics (Fig. 7). Moreover, the yearly average has a dispersion less than 1 m s^{-1}. It demonstrates that in few years, with a longer time-base, the detection of Jupiter-mass objects on far-off orbits similar to our giant planets Jupiter or even Saturn is to be expected.

3. The CORALIE Planet Search Programme

In mid-1998, right after the successful commissioning of CORALIE, started the CORALIE planet search programme. The survey sample is made of 1650 dwarf stars, brighter than 10th V-mag located in the southern hemisphere, selected according to their distance from the Sun. Actually, different distance criteria have been used for G and K dwarfs in order to compensate for the magnitude difference between spectral types (see in Udry et al. 2000). In the sample 80% of the stars are brighter than 9th V-mag. Active stars and fast rotators are not excluded from the sample but once they are identified they are observed with a lower priority. The exposure time of each observation is set to reach a photon-noise error of about 5 m s^{-1} per radial-velocity measurement. It corresponds to a signal-to-noise ratio per pixel between 30 and 100, depending on the spectral type.

After three years of activity the planet search programme totals 14,000 precise radial velocity measurements. CORALIE has discovered 23 extrasolar planets (Table 1) and contributed to the precise measurement of orbital characteristics of 5 other planets. Amongst the many discoveries made by CORALIE, a very interesting multiple system is displayed in Figure 8. This multiple system is made of two Saturn-mass objects trapped in a 1:10 resonance.

4. Catching the Sound of Stars with CORALIE

Acoustic waves or solar oscillations are observed on the Sun. They are thought to be excited by turbulent convection near the surface. Observations of solar oscillations place important constraints on the internal structure of the Sun and provides a strong test of evolutionary theory as well. The radial velocity effect from the 5-min solar oscillations has a radial velocity amplitude of 23 cm s^{-1}. Many attempts have been made, to detect similar oscillations on other stars. With CORALIE we have been able to detect for the first time an unambiguous oscillation signal of 31 cm s^{-1} amplitude on the star α Centauri A, a nearby solar twin. This corresponds to a wave with an amplitude of 40 metres at the surface of that star.

The star α Centauri A was observed with CORALIE during 13 nights in May 2001. In total, 1850 spectra were collected with typical signal-to-noise ratios in the range 300–420 at 550 nm. The radial-velocity measurement sequence shows a dispersion of 1.53 m s^{-1}. The power spectrum shown in Figure 9 exhibits a series of peaks between 1.8 and 2.9 mHz modulated by a broad envelope. This is the typical signature of solar-like oscillations (Bouchy & Carrier 2001).

In the low frequency range of the power spectrum (ν, < 0.6 mHz), the power of the signal scales inversely to the square of the frequency as expected for a white noise contribution. The mean white noise level in the power spectrum, computed in the range 0.6–1.5 mHz, is 4.3 cm s^{-1} corresponding to a velocity precision of 1.0 m s^{-1} per measurement.

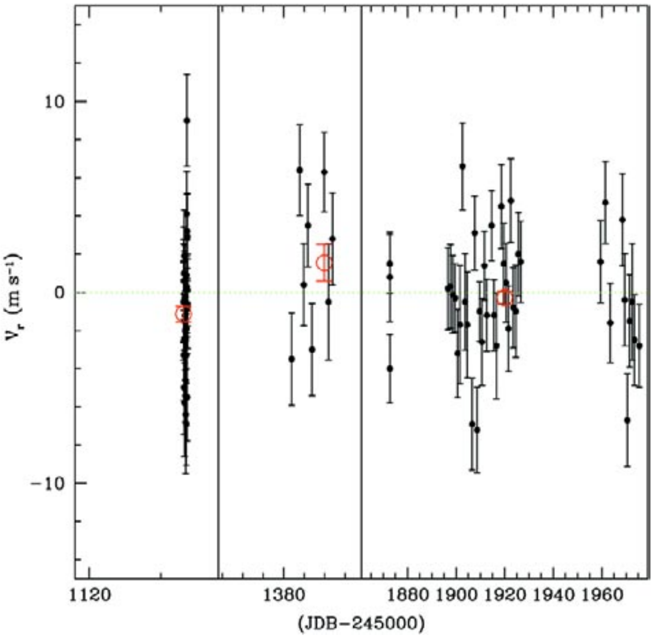


Figure 7: Radial velocity measurements of the bright G8 star 82 Eri. The dispersion of the data is 3.6 m s^{-1}. In red we indicate the yearly average. The dispersion of the yearly average is less than 1 m s^{-1}, suggesting no instrumental systematics down to this level.

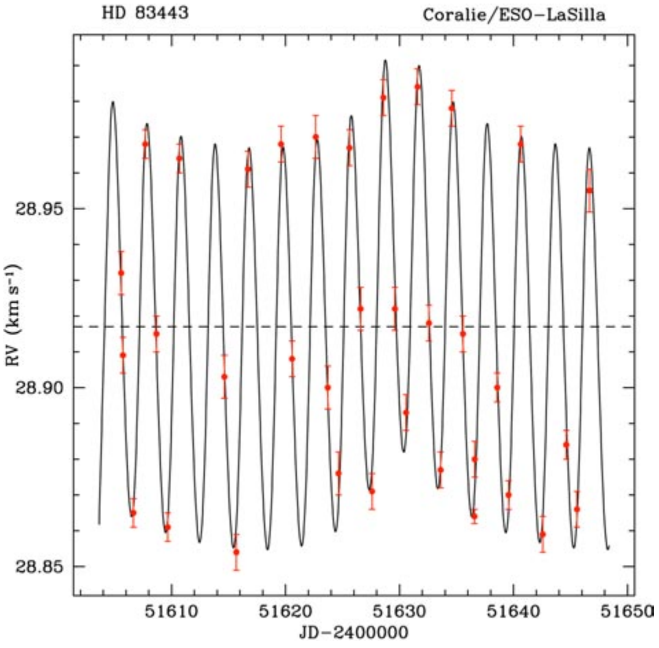


Figure 8: Radial-velocity measurements of the star HD 83443. The curve is the best fit to the data with a two-planet model. The period of the shortest orbit is 2.9853 d and the long one is 29.85 d. Both planets have about the same mass as Saturn. Interestingly, the system may be trapped in a 1:10 resonance.

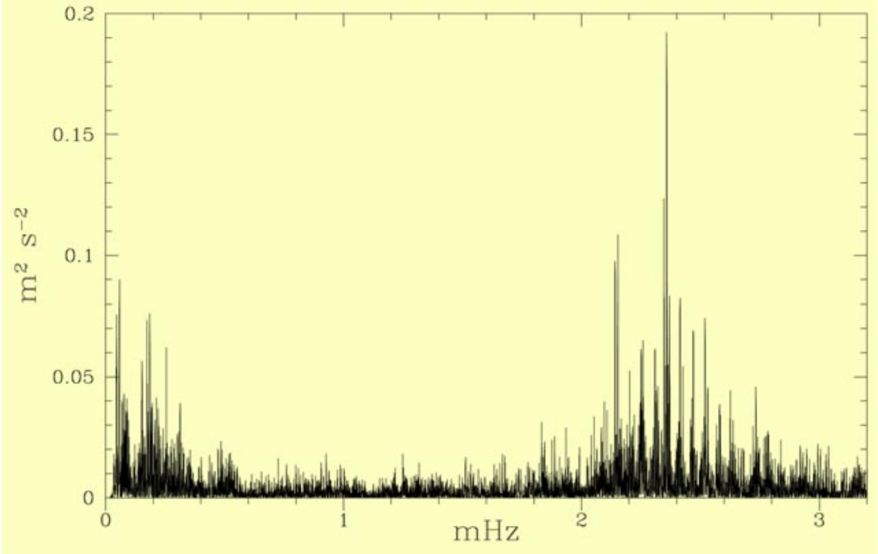


Figure 9: Power spectrum of 13 nights of radial-velocity measurements on the star α Cen A. The series of peaks between 1.8 and 2.9 mHz is the signature of solar-like oscillations.

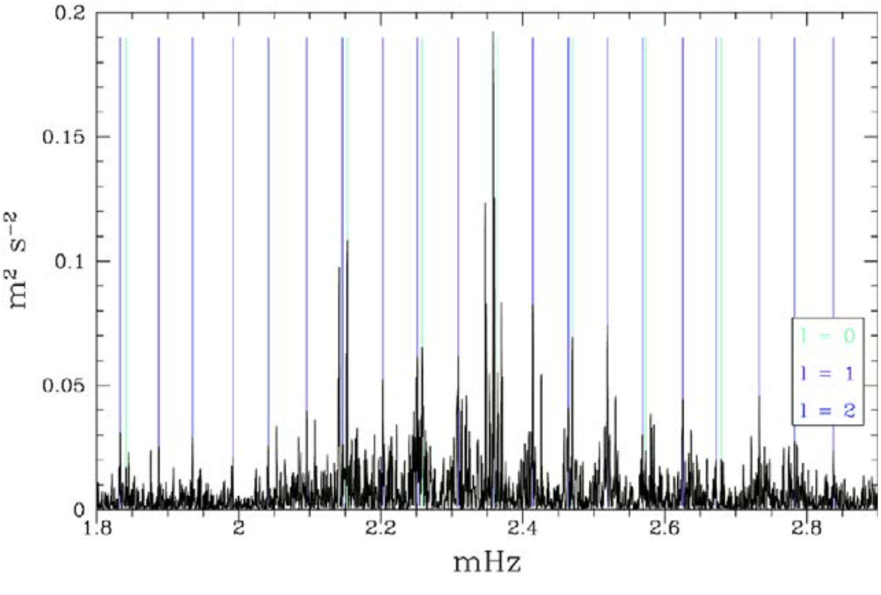


Figure 10: Identified p-mode oscillations in the power spectrum of radial-velocity measurements of α Cen A. l corresponds to the number of knots of the various pulsation orders (n-number), where l = 0 is the radial pulsation. Typical identified pulsation mode n-numbers range from 15 to 25.

The strongest modes are identified in Figure 10. From the measurement of the large splitting ($\Delta\nu = \nu_{n,l} - \nu_{n-1,l}$) and the small splitting ($\delta\nu_0 = \nu_{n,0} - \nu_{n-1,2}$) we constrain the mass and the age of the star. Preliminary results (Carrier et al. 2001) suggest that α Cen A is slightly more evolved than the Sun, with a mass in the range 1.10–1.16 $M_{\odot}$.

5. HARPS: the 1 m s^{-1} Precision Instrument

HARPS is a fibre-fed, cross-dispersed echelle spectrograph design to measure radial velocities of stars with a precision better than 1 m s^{-1}. It will be installed on the 3.6-m ESO telescope at La Silla, Chile. HARPS is the result of an Announcement of Opportunity made by ESO in 1998 for the design, the construction, and procurement of a High-Accuracy Radial velocity Planetary Searcher (HARPS) instrument.

In response to ESO's announcement the Observatoire de Genève has formed a Consortium that has been reinforced considerably by the active participation of the ESO La Silla Observatory and the ESO Garching Cryogenic Group and Optical Detector Team. At present, all design reviews have been passed and the project is in its manufacturing phase. The instrument commissioning is scheduled for the end of 2002. Besides the guarantee time for the Consortium, a large amount of HARPS time will be available to the astronomical community for a broad variety of observational programmes in different domains including for example the search for extrasolar planets and asteroseismology.

The strategical choices of the HARPS project are based on the experience gathered with the ELODIE and the CORALIE instruments. Moreover, to cope with the short track development of the project we have tried to avoid as much as possible any development risk that could jeopardise the project. In general, we preferred to adopt conservative solutions every time the consequences of a proposed new solution on the final result were not known precisely. HARPS design is based on three fundamental technical choices. First, we decided to adopt a fibre-fed illumination with two fibres for simultaneous thorium referencing. Apart the fact that this technique has already proven its efficiency with ELODIE and CORALIE, it is about 4–6 times

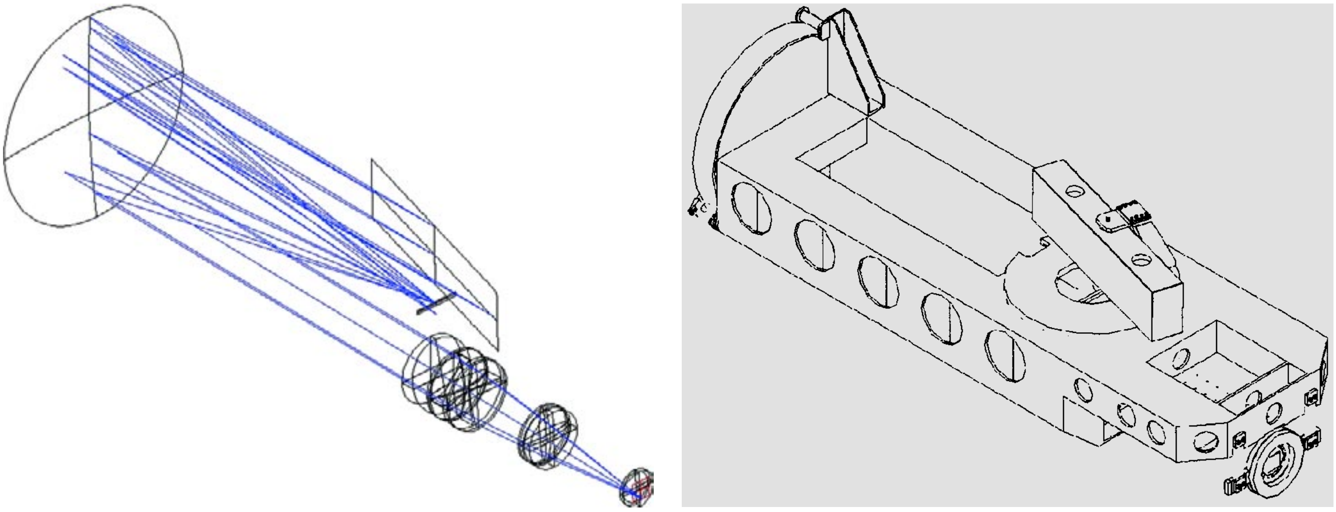


Figure 11: Ray tracing of the HARPS optical design. The optical design is very similar to that of UVES. The main difference is the use of a grism for the cross disperser instead of a reflection grating. This solution is more stable and allows a compact mechanical mount.

more efficient in terms of photon need than using an alternative technique like the iodine cell for example (Bouchy et al. 2001). A fundamental aspect to reach 1 m s^{-1} accuracy on a large sample of stars. Second, we decided to build an instrument using the largest monolithic echelle grating available (837 × 208 mm grating developed for UVES) in order to achieve a very high spectral resolution. For stars with unresolved absorption lines, the precision of the measurement of the radial velocity scales with the 1.5 power of the spectral resolution (Hatzes & Cochran 1992). A good compromise between slit losses and best resolution was finally found to be R = 90,000. More complex solutions for increasing the efficiency and the spectral resolution, like for example using adaptive optics or an image slicer, have been considered but were found not suitable for HARPS. Finally, while the simultaneous thorium referencing technique monitors the instrumental drifts in order to remove them, we made additional efforts to increase the intrinsic opto-mechanical stability of the spectrograph. In order to eliminate the atmospheric pressure variation, which could produce wavelength drifts (100 m s^{-1}/mbar) and to exclude any convective cell circulation in the spectrograph, the entire spectrograph is operated in vacuum. Moreover, the vacuum vessel protects the spectrograph from rapid temperature variations. The vacuum vessel itself is installed inside a temperature-controlled environment which ensures a long-term stability better than 0.1 K. To improve the stability of the spectrograph input illumination as well, each fibre includes a double scrambler. More details on HARPS design can be found in Pepe et al. 2000.

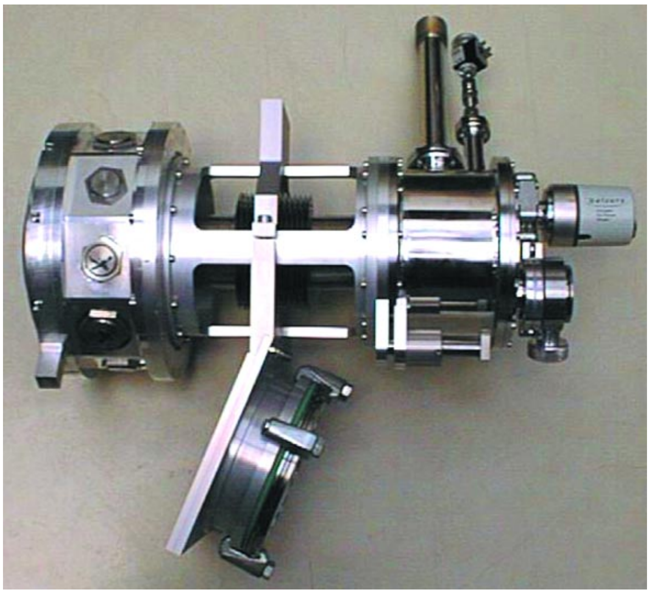


Figure 12: The HARPS dewar consisting of the detector head, the cryostat, and the interface below. The rigid central part replaces the vacuum vessel and allows to simulate the working condition of the dewar.

Table 2: Spectrograph characteristics.

	HARPS	CORALIE
Optical design	fibre-fed, cross-dispersed echelle spectrograph	
# of fibres	2 (object and reference)	
Accepted field on sky	1 arcsec	2 arcsec
Collimated beam diameter	208 mm	100 mm
Covered spectral range	380 nm to 690 nm	
Spectral format	68 echelle orders	
	61.44 × 62.74 mm	26 × 26 mm
Spectral resolution	90,000	50,000
CCD chip	mosaic, 2 × EEV 2k4	EEV 2k2
	pixel size = 15 μm	pixel size = 15 μm
Sampling/Spectral element (FWHM)	4 pixels	3.3 pixels
Image quality	< 1.5 pixels	< 1.5 pixels
Minimum inter-order spacing	30 pixels	10 pixels
Spectrograph peak efficiency at 550 nm	28 %	7%
Total peak efficiency at 550 nm	4.5%	1.5%

The optical design, proposed by B. Delabre and adapted by D. Kohler, is very similar to that of UVES. A ray tracing of the optical design is shown in Figure 11. Two fibres, an object and a reference fibre feed the spectrograph with the light from the telescope. The fibres are re-imaged by the spectrograph optics onto a mosaic of two 2 × 4 k CCDs (EEV, 15 μm), where two echelle spectra of 68 orders are formed. The spectral domain ranges from 380 nm to 690 nm with no order lost for the object fibre. A summary of the spectrograph's parameters is given in Table 2.

Realisation of the spectrograph's opto-mechanics is under the responsibility of the Observatoire de

Figure 13: The Cassegrain Fibre Adapter body during manufacturing at La Silla, ESO.

Haute-Provence and made in collaboration with the Physikalisches Institut of the Bern University. The spectrograph optics is mounted on a 2.5-metre optical bench made of plated steel. The orientation of the optical plane is vertical, the echelle grating being mounted on the top side, and the grism and the camera on the bottom side of the bench (Figure 11).

HARPS uses a standard VLT detector head and the ESO controller FIERA. ESO's Optical Detector Team will provide the Consortium with the Detector Unit including detector-head electronics, the LCU, and the Continuous-Flow Cryostat adapted by the ESO Cryogenic group to the HARPS-specific vacuum vessel solution (See Fig. 12).

The vacuum vessel containing the spectrograph will be installed inside the air-conditioned coudé room. It is manufactured under the responsibility of the Geneva Observatory. It consists of a polished stainless steel vessel of 1 m diameter and about 3 m long, evacuated at about $p = 10^{-2}$ mbar.

The HARPS Cassegrain Fibre Adapter is the interface to the telescope. It is entirely made by the La Silla Observatory. It incorporates several instrumental functions and an Atmospheric Dispersion Corrector (ADC). It is presently in an advanced realisation phase (see Fig.13).

HARPS should be an unrivalled facility for conducting planet search programmes and asteroseismology measurements. The improvement made on HARPS compared to CORALIE will reduce the instrumental errors well below the 1 m s^{-1} threshold. The expected performances of HARPS are shown in Figure14. For a G8 dwarf star a radial-velocity measurement at 1 m s^{-1} accuracy is reached in 1 minute exposure for a star of magnitude 7.5. More details on the photon-noise errors of radial-velocity measurements for different stellar spectral types and different $v \sin i$ can be found in Bouchy et al. (2001).

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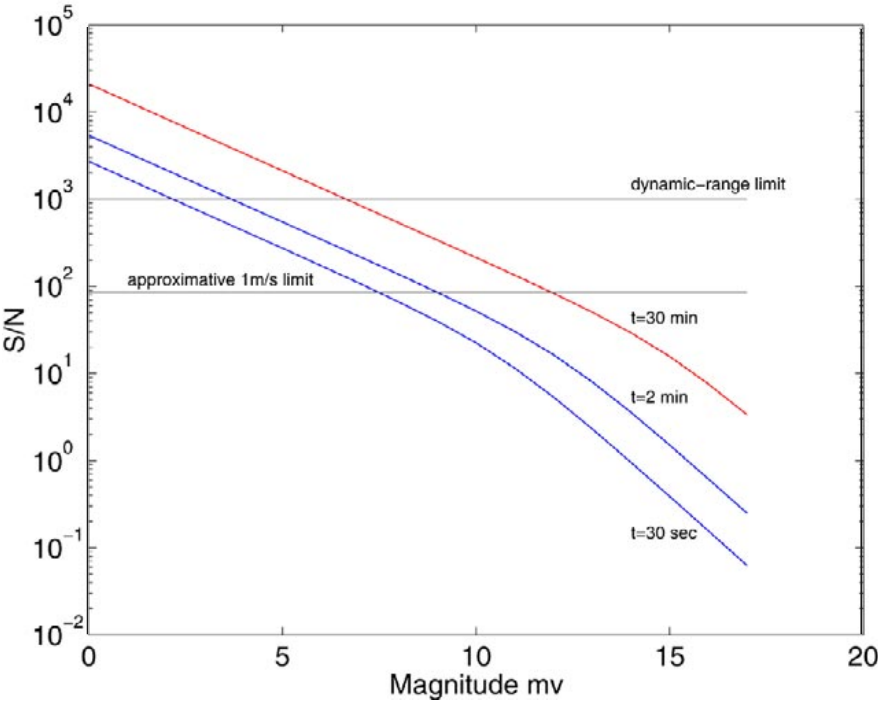

Figure 14: Signal-to-noise ratio per spectral bin at λ = 550 nm. The dynamic range of the CCD and the estimated 1 m s^{-1} limit for a G8 star are shown.

Workshop on Scientific Drivers for Future VLT/VLTI Instrumentation – Summary and First Orientations

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1. Introduction

At the instigation of the ESO Scientific and Technical Committee (STC), a Workshop was held on 11–15 June 2001 at ESO-Garching on Scientific Drivers for future VLT/VLTI Instrumentation. As stated in its announcement, the goals were (1) to obtain input from the ESO community on the VLT scientific results and the competitiveness of the current VLT/VLTI instrumentation, and (2) to identify the scientific drivers and the required characteristics of future instruments. During eight intense half-day sessions, fifty oral contributions and sixteen posters were presented, covering most of the astronomical scene from γ-ray bursts to extra-solar planets. All ESO member states, the United Kingdom and the Australian astronomical communities, were represented. Roughly half of the presentations were science-oriented, but also outlining relevant instrumental needs. The other half was more instrument-oriented, but also stressing corresponding scientific drivers.

Below is a tentative by the authors to summarise the major science drivers and draw possible lines of future VLT/VLTI instrumental developments, in light of the presentations and the 1-hour final general discussion. Instrument proposals that were presented at the meeting have been classified below in three different categories: (a) full-fledged 2nd-generation instruments that would replace present ones; (b) upgrades of 1st-generation instruments and (c) niche capabilities, potentially qualifying for the VLT visitor focus (see http://www.hq.eso.org /instruments/visitor_focus). This summary should be seen as a first attempt, open to even very substantial modifications in the next phases of project selection.

2. The Major Science Drivers

Most of the emphasis was put on:
– detecting the 1st fireworks; rapid follow-up of γ-ray bursts and Supernovae
– high-z evolution of galaxies and of the Inter-Galactic Medium
– 1st galaxy building blocks and galaxy mass assembly
– peering deeper into nearby galactic nuclei
– huge stellar spectroscopic surveys of Local Group galaxies
– stellar formation environment and detection of extra-solar planets
– a closer view of stars (direct and Doppler-Zeeman imaging; stellar oscillations)

3. Towards 1st-Generation Upgrades

The 1st Generation VLT/VLTI instrument complement was widely recognised as a powerful tool, especially if a strong upgrade programme is pursued. In particular, the present VLTI programme, both in infrastructure capability and initial instrumentation (MIDI, AMBER and PRIMA), was seen as representing the dawn of an era, with a number of major upgrades highly desirable, beginning by its imaging capability and the associated infrastructure (more auxiliary telescopes and delay lines) and instrumentation.

The FORS 1 and 2 upgrades are currently underway to cover efficiently the whole optical range from 0.32 to 1 µm. The alternative of developing a single 2nd Generation dichroic-fed spectro-imager, that would require a single Unit Telescope instead of two, was presented at the Workshop and should be carefully compared. Possible extensions of the multiplex capability of the 25′ diameter field FLAMES multi-fiber facility were proposed: MAXIMUS is a survey-oriented instrument with a much higher number of individual fibres and possibly an IR extension, and FALCON a deployable Integral Field Units (IFUs) based system, with sub-seeing corrections from small adaptive optics buttons. UVES may possibly get a spectropolarimetric mode, at the cost of substantial additional complexity however, and/or a medium spectral resolution mode through e.g. binning or implementation of photon-counting detectors. Finally, the so-called 2k × 2k SINFONI upgrade, already recognised as highly desirable, was presented. These potential upgrades are summarised in Table 1.

4. Towards 2nd-Generation Instruments

The case for new 2nd-generation VLT instrumentation was much emphasised for sub-seeing (adaptive optics assisted) imagery and spectroscopy, which require a vigorous long-term research and development programme. One goal would be to cover large field (a few arcmin.) imaging and spectroscopy (MCAO facility), provided the validity of the Multi-Conjugate Adaptive Optics (a.k.a. MCAO) concept is firmly established. Three possible MCAO-based instruments were presented viz. a Gemini-type imaging/multi-slit spectrometer or an integral field system, based either on a single large unit [MIFS] or deployable smaller units [CROMOS]. Another area would be zero field high Strehl imagery for the study of stellar formation and detection of extra-solar planets (Planet Imager). For the more conventional seeing-limit-

Table 1: Potential First Generation Upgrades.

NAME	DEFINITION	SCIENCE DRIVERS
VLTI	Priorities: (1)imaging; (2) shorter λ; (3) “wide-field” capability (> Airy disk); (4) larger baseline? Major R/D required (infrastructure and instruments)	A closer view to extra-solar planets, stellar environments and galactic nuclei
FORS1-2	FORS2-Red and FORS1-UV Tunable Filter mode? Integral Field mode? Or more efficient 2nd-Gen. dichroïc system?	Z ~ 1-1.5 and very high-z objects Detection of Lyα “galaxies” γ-ray Bursts and Supernovae
FLAMES	IR; higher multiplex [MAXIMUS] AO-corrected multiple IFUs [FALCON]	Large Surveys; z~1 galaxy dynamics Galaxies 1st building blocks
UVES	High-$\Re$ spectro-polarimetry X-dispersed medium-$\Re$ capability	A deeper look at stars Very faint stars and quasars
SINFONI	$(2k)^2$ 1-2.5 µm IR detector instead of $(1k)^2$ Higher $\Re \sim 10^4$ grating	Improved stability Stellar formation regions

Table 2: Possible 2nd-Generation Instruments.

NAME	DEFINITION	SCIENCE DRIVERS
KMOS	Cryogenic near-IR multi-object spectrometer Imaging/Multi-slit? Deployable IFUs? single IFU? Large field up to ~ 7′x 7′; cryo-robots?	Universe up to z ~ 3–5 Mass assembly of galaxies
MCAO facility	2’ x 2’ field; near-IR domain Imager/multi-slit? Deployable IFUs? single IFU? Requires proof of MCAO concept(s)	Galaxies building blocks Galactic nuclei
Planet Imager	Near-IR Imager High-order AO and advanced coronograph	Stellar environments Extra-solar planets
Stellar Surveyor	~ 5′ x 5′ medium-$\mathfrak{R}$ Integral Field System FTS or large IFU approach?	Nearby galaxies stellar census

(MC)AO: (Multi-Conjugate) Adaptive Optics; IFU: Integral Field Unit; FTS: Fourier Transform Spectrometer

ed instrumentation, emphasis was put on a K-band cryogenic survey-type system (dubbed here KMOS), for distant galaxy studies. Three different concepts were illustrated, viz. a wide-field spectro-imager [IRMOS], a single very large integral field system [MEIFU] or deployable integral field units [CROMOS]. KMOS eventual IR wide-field imaging capability should be evaluated in relation to the forthcoming VISTA ones. The case for very large stellar spectroscopic surveys of the Local Group (Stellar Surveyor) was also argued for.

Table 2 below show a 1st classification attempt of the themes discussed during the Workshop, listing possible new instruments. The numerous question marks in the Table reflect lively debates on competing approaches, e.g. multi-slit masks versus wide-field integral field systems. In virtually every case, prior development of enabling technologies appears as a prerequisite. In the coming year(s), these concepts will go through a two-steps filtering process: (1) choices and priorities with specific recommendations from the STC and (2) feasibility studies and programmatic analyses conducted with the help of our community.

5. Visitor Instruments

A number of scientific niches were also identified at the Workshop and could eventually be deployed at a VLT Visitor Focus, in particular:

– Fast spectro-photometry [ULTRACAM} to identify cosmic accelerator mechanisms

– AO-assisted spectrometry [AVES] for the study of stellar abundance and dynamics

– Stellar Oscillation measures [STOMACH] to derive stellar internal structure

– Ultra-high resolution heterodyne spectroscopy [THIS] to study the cold interstellar medium

– The case for (very) high-resolution spectroscopy and spectro-polarimetry was also strongly argued for. It may possibly be filled by a combination of an UVES upgrade and a dedicated Visitor instrument. A much more ambitious alternative would be a 0.37 to 2.5 μm dual-echelle 2nd-generation instrument.

6. And Now, What?

The next step in this filtering process will happen in the fall. Based on the Workshop input and STC advice at its regular October meeting, we will come back to the ESO community to launch feasibility studies of the highest priority projects. In many cases, this will in particular require the development of enabling technologies. A word of caution may be appropriate here. Our most important instrumental goal, with major involvement from member states institutes, is presently to complete and put into operation the remaining eleven[1] instruments in the 1st-generation instrument complement of the Paranal Observatory (VLT, VLTI and VST). This implies that the development of 2nd-generation instruments could only proceed gradually. Also, not every upgrade listed above could, nor even should, be made: there is a limit to complexity of a given instrument operation, in particular in terms of number and sophistication of observing modes, beyond which its overall scientific throughput would actually decline.

We deeply thank all Workshop participants for their invaluable help in that sometimes tortuous, but important, process to ensure the competitiveness of a significant fraction of European astronomical capabilities in the coming decade. Much more will be asked down the line! Please, stay tuned for exciting times ahead.

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[1] VIMOS, NAOS/CONICA, FLAMES, VISIR, MIDI, AMBER, OMEGACAM, NIRMOS, SINFONI, CRIRES, PRIMA.

ESO VLT Laser Guide Star Facility

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Abstract

We report in this paper on the design and progress of the ESO Laser Guide Star Facility. The project will create a user facility embedded in UT4, to produce in the Earth’s Mesosphere Laser Guide Stars, which extend the sky coverage of Adaptive Optics systems on the VLT UT4 telescope. Embedded into the project are provisions for multiple LGS to cope with second-generation MCAO instruments.

1. Introduction

The ESO Laser Guide Star Facility (LGSF) will be available for general observing in October 2003. The LGSF will be installed on UT4 (Yepun) at Paranal Observatory (Fig. 1). It will produce a single LGS, to serve two of the 7 adaptive optics systems (AO) of the VLT, NAOS and SINFONI. The relevance and justification of a LGS-AO system has been analysed elsewhere[6]. The Lick Observatory LGS-AO system has recently demonstrated K-band PSF Strehl Ratios up to 0.6, leaving no doubt on the effectiveness of LGS-AO.

NAOS is based on a Shack-Hartmann AO system, coupled with the spectrophotometric camera CONICA. SINFONI has the ESO Multiple Application Curvature AO (MACAO)[1], coupled with the Max-Planck-Institut für Extraterrestrische Physik (MPE) integral field spectrograph, SPIFFI. MACAO is the ESO-produced 60 element curvature system, cloned in 6 different AO systems for VLT[2].

The LGSF is designed, assembled and installed by ESO in collaboration with the MPE and Max-Planck Institut für Astronomie (MPIA). MPE/MPIA are responsible for the laser system, PARSEC (*Paranal Artificial Reference Source for Extended Coverage*), and for the LIDAR operation mode of the LGSF. ESO is responsible for the laser room, the laser beam relay, the laser beam launch telescope with servos, and all the diagnostic and safety measures. The LGSF becomes part of, and it is governed by, the UT4 Telescope Control System. LGSF has to adopt the VLT standards and to be retrofitted on the existing UT4 telescope.

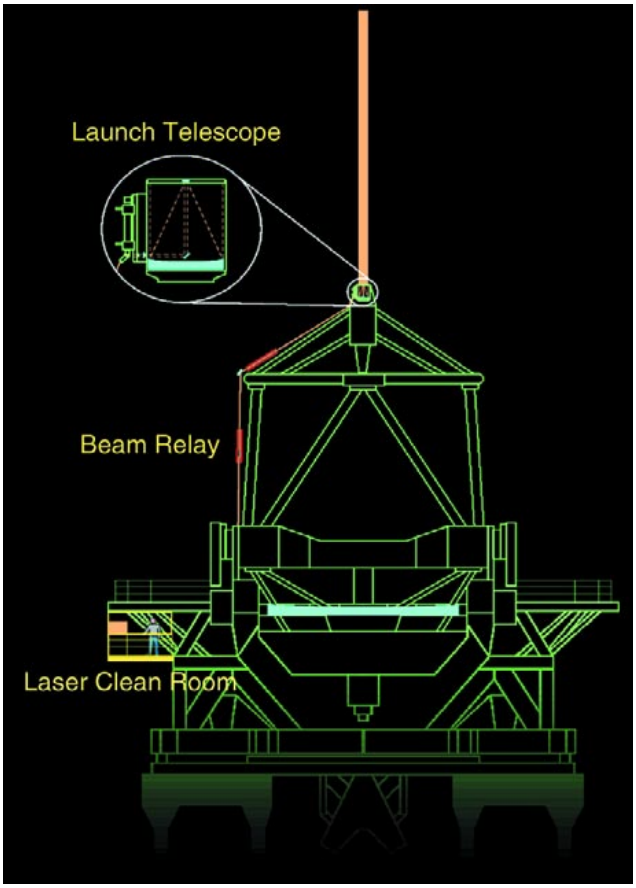


Figure 1: LGSF overview installed on VLT-UT4 (Yepun). Note that the Laser Clean Room is part of the telescope.

The LGSF has to be upgradable to produce and control 5 Laser Guide Stars for MCAO, in 2006. The current LGSF design already embeds provisions for this upgrade.

In the design of the LGSF we take advantage of the field experience obtained with the MPE/MPIA ALFA system, in Calar Alto. All design areas benefit from the ALFA experience, and the LGSF becomes truly a *second-generation* Laser Guide Star Facility.

The project kicked off in September 2000, and reached the Preliminary Design Review milestone on 2 April 2001. At this time we are progressing toward the Final Design Review. We report on the current design solutions and trade-offs.

2. The LGSF Top Level Requirements

The most important LGS top level requirements are agreed between the ESO AO and LGSF teams:

- LGS projection on-axis of UT4 (monostatic projection)
- Continuous-wave sodium laser source
- LGS return flux ≥ 1.0 × 10^6 ph/s/m^2 at Nasmyth focus, implying on-air laser power ≥ 6.0 W CW
- LGS spot size ≤ 1.1″ FWHM, launched beam Ø 0.35 m ($1/e^2$), ≤ 1.3 × diffraction-limited
- LGS residual position jitter ≤ 50 mas rms.
- Operable at UT zenith distances ≤ 60°
- Measure the sodium layer density profile and centroid location in LIDAR mode of operation, when adaptive optics is not working
- Measure the relative sodium density profile, and centroid location, from an additional 30-cm telescope, while adaptive optics is in operation
- Provisions for upgrade to 5 LGS, for VLT Multi-Conjugate Adaptive Optics with LGS
- Safety measures to comply with Class IV lasers, with FAA regulations in Chile, and with Paranal Observatory regulations
- Minimal impact of the LGSF retrofit on UT4 and on Paranal Observatory.

3. Design Overview

The LGSF has five major subsystems:

- PARSEC is hosted in a thermostatic *Laser Clean Room* (LCR). The clean room is mounted under UT4 Nasmyth A platform, therefore the laser and the room rotate with the telescope. The room thermal impact in the telescope dome environment has been carefully made negligible.
- The *PARSEC laser* itself is a CW laser in Master Oscillator Power Amplifier (MOPA) configuration. The 589 nm dye laser uses solid-state pump lasers at 532 nm. This gives optimal conversion efficiency and minimises the power and cooling needs.
- The beam relay system transfers the laser beam from LCR to the Launch Telescope. This allows to skip the other

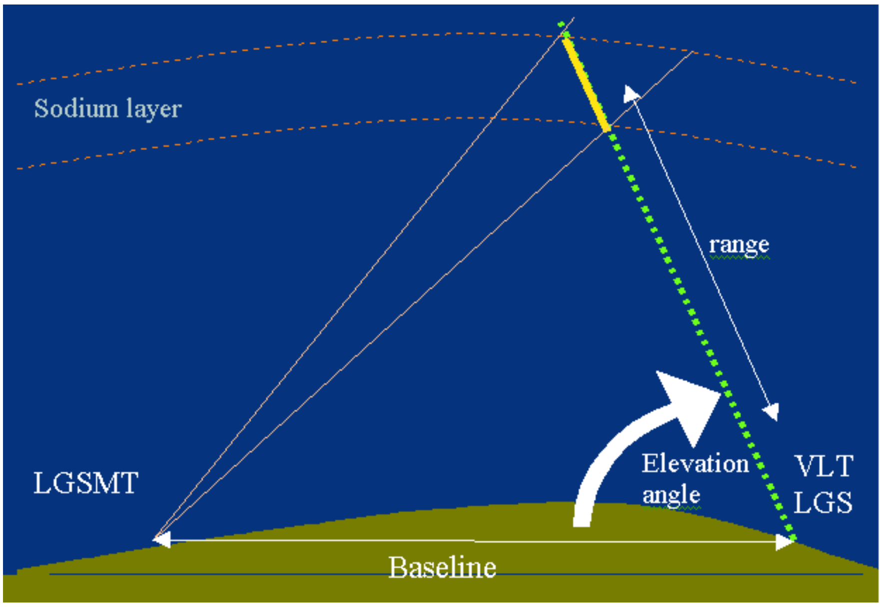


Figure 2: The LGS Monitoring Telescope concept. Imaging the laser plume in the mesosphere, looking from a distance of several km baseline, the sodium density profile, its centroid and the one-axis LGS FWHM may be retrieved.

possible solution with mirror relays, which imply motion-controlled tracking mirrors, turbulence effects, more complexity and costs. Moreover, the single-mode fibre ensures diffraction-limited beam quality at the Launch Telescope Input.

- The 500 mm diameter *Launch Telescope* is located behind the UT4 secondary mirror. The Launch Telescope assembly has embedded a number of diagnostic and safety features.
- The *LGS Monitor*, a remotely-controlled 30-cm telescope located ~ 4 kilometres from the site, to measure the sodium layer density, the LGS FWHM, and the presence of cirrus clouds on line, at a rate of ~ 30 sec (Fig. 2).

The elements of innovation in this second generation design, compared to ALFA are:

- higher power laser system with innovative design (> 10W CW 589 nm dye laser, stable and servo-controlled)
- Commercially available Solid State Pump Lasers – Laser Clean Room on board of the telescope
- Single-mode fibre beam transfer from Laser to Launch Telescope
- Monostatic beam projection (i.e. from UT4 pupil centre).

We have, moreover:

– Full system integration in the UT4 telescope and in the VLT standards

– Large set of built-in diagnostics, LIDAR and LGS Monitor modes.

The major design drivers come from:

– The use of Class IV laser systems. They require a dust-free local environment and high-class optical materials, components and coatings. Areas of attention are super-polished optics, low light-scattering surfaces, coating damage thresholds, thermal effects on the optics and servo-control of laser resonators. Safety measures during laser alignment and operation, training of the personnel and appropriate interlocks, all of it compliant with the international ANSI regulations.

– The retrofit of an operating telescope forces the LGSF design volume, the Software and Hardware standards. The infrastructure and the scheduling constraints are areas of attention. The LGSF has to have a negligible impact on the general UT4 performance.

– The distributed subsystems with non-standard functions for telescopes and instruments: it has special implications for the LGSF control electronics, the interlocks and the safety system.

– The use of front-line technologies requires a careful assessment of the risks, a certain amount of R&D embedded into the project, and the formulation of back-up solutions in case of unanticipated problems.

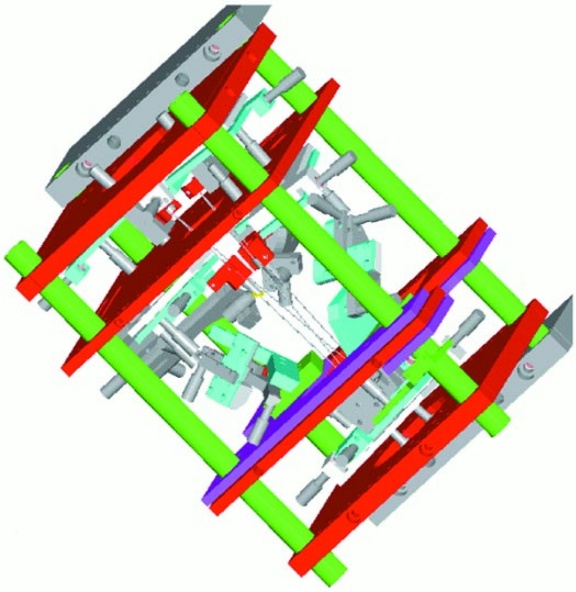


Figure 3: Design of the MPE PARSEC laser power amplifier resonator.

4. The Laser Clean Room

The laser clean room hosts the PARSEC laser, its dye solution pumps, all the LGSF electronics, safety tools and devices. It occupies a volume of 6.4 × 2.8 × 2.2 m^3, remaining confined below the UT4 Nasmyth platform (Figure. 4). It is mounted on a dedicated earthquake-resistant support structure. The support structure has also special attachment foreseen for the LCR three electronic racks and the laser optical bench, to provide resistance to hard earthquakes. LCR is a Class 10,000 clean room, thermally controlled to 17.5 ± 2.5ºC. The outer surface of the room walls, ceiling and floor does not deviate from the telescope dome environment by more then ± 1.5ºC in the operating range 0–15ºC.

The air-circulation can be selected closed cycled or with fresh-air from the dome (e.g. during daytime). The air circulation system will not produce noise levels higher than 60 dB inside the LCR. An automatic fire-extinguisher system is implemented, based on fire sensors, smoke sensors and sound-alerting retardant dispenser nozzles. The interlocks to activate/deactivate the fire-extinguishing system allows a delay for people inside the room to escape out.

A study of the LCR 6 metric tons weight, inertia and wind-load impacts has shown negligible effects on the telescope natural frequencies and tracking. The finite-element analysis has also shown negligible impact on the azimuth torque.

Finally the safety measures implemented in the LCR are:

- automated anti-fire system, sensing liquid spills, smoke, alcohol, flames, with manual overrun possible
- protection of the laser technician during maintenance – special tools
- interlocks on all the class IV laser covers

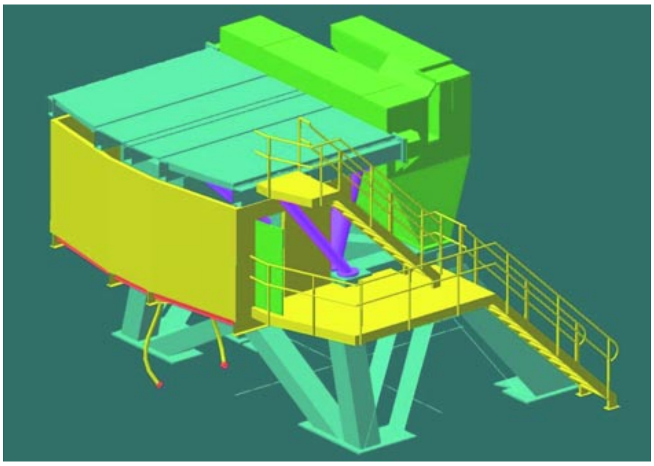


Figure 4: Laser Clean Room attached below the Nasmyth A platform of UT4. The access is from an enlargement of the side steps mezzanine.

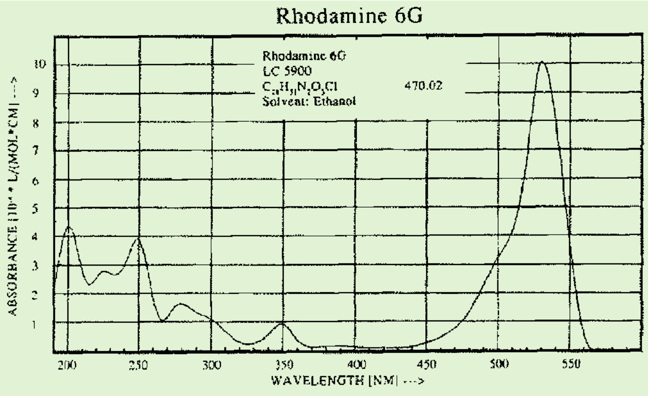


Figure 5: Rhodamine 6G Absorbance spectrum. Note the difference in absorbance when using pumps at 514 nm or at 532 nm.

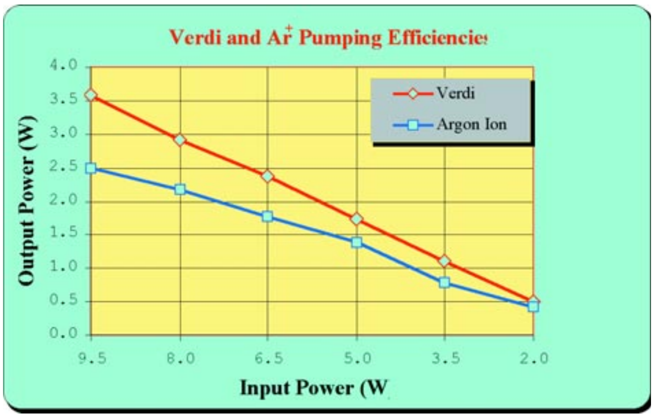


Figure 6: Calar Alto experiment with the ALFA laser. Output powers at 589 nm from the ring-dye laser, for different laser pump powers. The Verdi laser (532 nm) and the Innova Ar+ lasers from Coherent Inc. were used up to 9.5 W of pump power. The Verdi pumping gives up to 44% more output, at equivalent pumping powers.

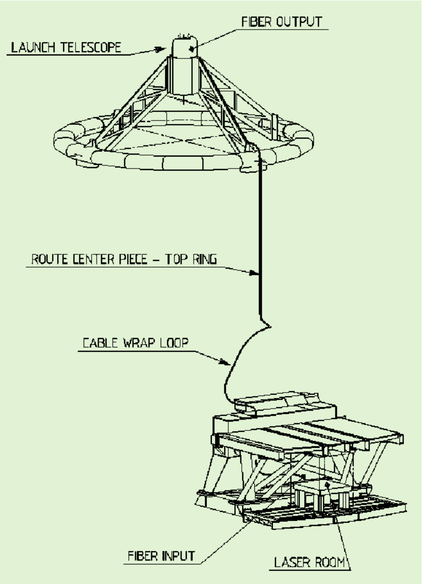


Figure 7: 25 m fibre relay routing on UT4.

- dye spill prevention interlocks
- strict procedures to raise or lower power from standby to full power
- LCR surveillance cameras
- LCR coded access, access monitoring from control room
- laser room automatic fresh-air ventilation during maintenance
- Dye preparation, storage and disposal strict procedures.

5. PARSEC

PARSEC is presented by MPE in more detail in another forthcoming paper. PARSEC is a single mode TEM$_{00}$ CW laser working at 589.15 nm, with a linewidth < 10 MHz, a minimum power output of 10W, and a goal of 15W. Unlike ALFA, which was a modified Coherent 899-21 dye laser pumped with an Ar$^+$ laser, PARSEC uses a MOPA design. A low power dye master oscillator of ~1W CW is frequency stabilised at 589.15 nm. The laser beam is then injected in a length-stabilised power amplifier resonator where two free-flow dye jets are pumped with 4 x10W CW 532 nm solid state lasers. The power amplifier resonator (Fig. 3) has a compact 3D folded-ring optical design, mounted on an Invar mechanical structure. This design allows higher powers than usually achieved with dye CW lasers of good beam quality ($M^2 < 1.3$), and is one of the LGSF elements of novelty. The PARSEC laser fits on an optical table of 1.8 m × 2 m in the LCR. The optical table is in enclosed in a volume of class 100 clean air, with laminar airflow, temperature-stabilized at 20.0 ± 0.2 ºC.

From the ALFA laser experience, the use of ultra-fast, free dye jets has proven an effective choice to increase dye lasers' power. Extreme care has to be taken to the quenching of vibrations, bubbles and turbulence in the dye jet flow. A novel dye nozzle design and high-pressure pumps (~30 bar) are used in PARSEC.

The use of Rhodamine 6G (Rh6G) in ethylene glycol as dye, together with 532nm pump lasers of extremely good beam quality ($M^2 \sim 1.05$), has demonstrated good conversion efficiency in the preliminary experiments done in Calar Alto in 1999[4]. Instead of the ALFA Ar$^+$ laser therefore, ESO has proposed the use of Coherent Verdi pumps for PARSEC. Three main advantages have been proven:

- The pump laser electrical power consumption is reduced by a factor ~ 37, (for e.g. the ALFA equivalent output power of 4.5 W CW, from 46 kW to 1.25 kW), allowing the laser system to be installed in the VLT telescope area.
- The Verdi pump wavelength of 532 nm is perfectly matched to the absorption peak of Rh6G, as opposed to the main Ar$^+$ wavelength at 514 nm (Fig. 5). The dye laser output power should, therefore, increase by > 40% with respect to ALFA.
- The length of the pump laser is reduced by a factor ~ 5, allowing a smaller optical bench in the LCR to be used.

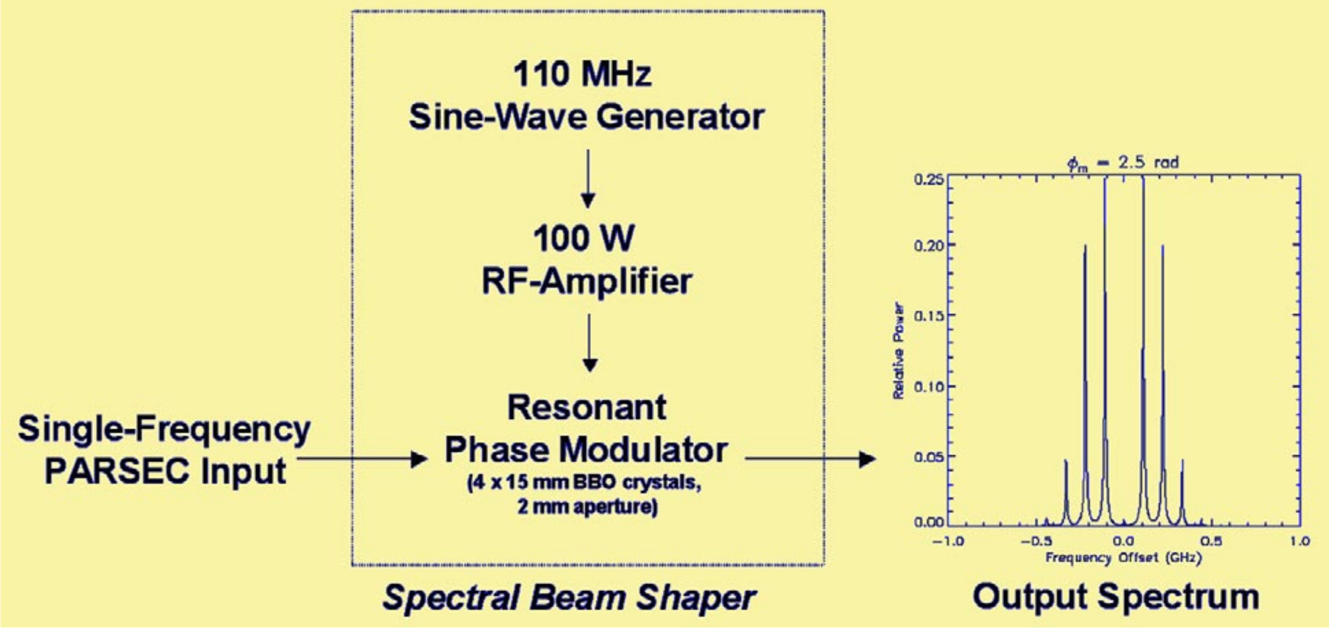


Figure 8: SBS suppressing scheme. A 110 MHz sinusoid is applied to a Resonant Phase Modulator of BBO crystals, which creates from the PARSEC single line, the spectrum shown to the right. This allows to reduce the SBS gain below threshold.

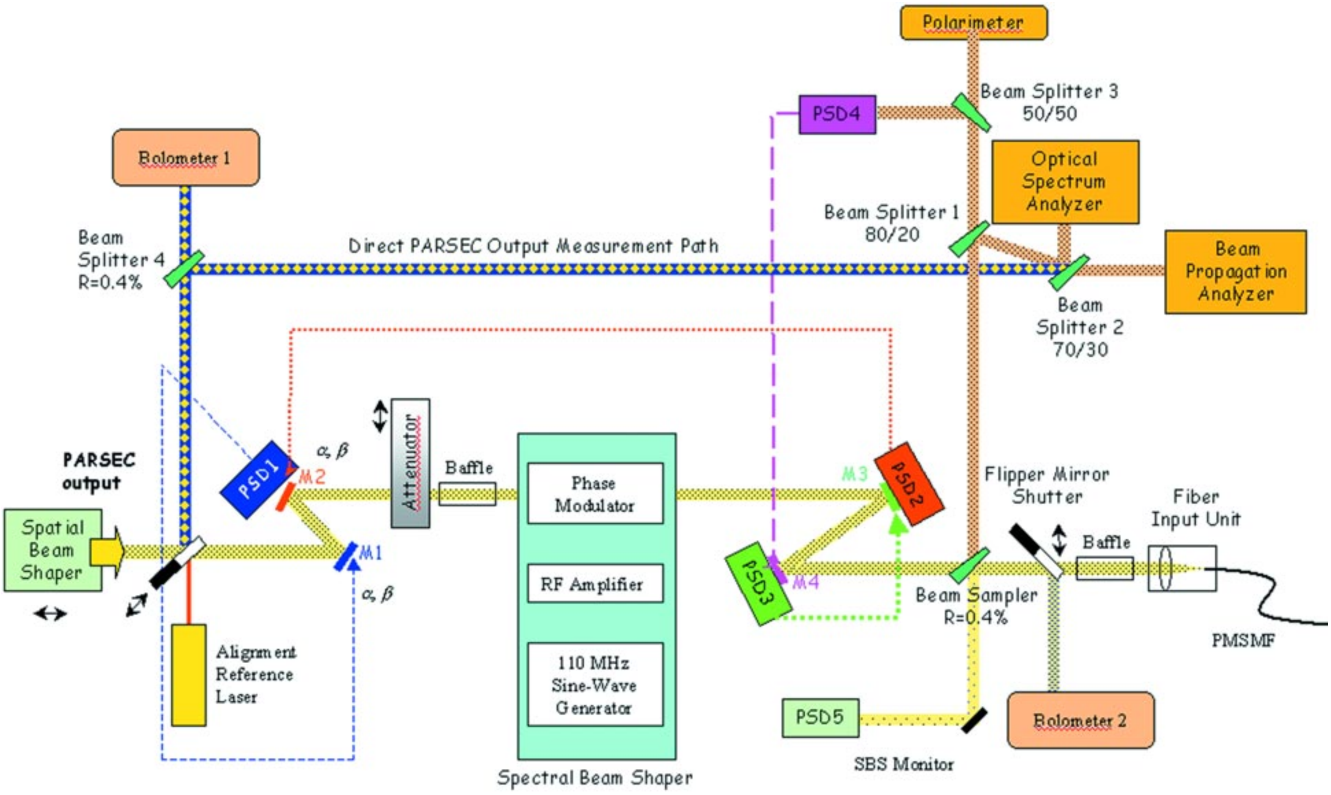


Figure 9: Beam Relay System Input Module. The functionalities are shown in the diagram. Note the PSD-piezo tilt combinations to stabilise the beams in x-y-q-f on the modulator, and independently at fibrer input.

As shown in Figure 6, the results of the 1999 experiments at Calar Alto confirm the theoretically predicted improvement in pump power conversion efficiency.

Recently, a conversion efficiency of 36.8% has been confirmed again experimentally by the MPE PARSEC team. Pending the full power test confirmation, it can be extrapolated that 4 × 10 W pumps at 532 nm will give ~ 16 W CW at 589 nm, with fresh RhG6 dye solutions.

The PARSEC output interface with the fibre Beam Relay Input System is defined at a waist location of 0.66 mm in diameter. The PARSEC output beam will be also jitter stabilised, and monitored in relative power, spectral format and residual rms jitter.

The PARSEC laser operation will not require a laser specialist on duty all the time. It is foreseen to run the laser at reduced power (standby mode) continuously together with its servo-controls. The transient from standby to full power will require from 10 minutes to 1 hour, to be determined yet, and will be done by the telescope operator with a checklist of actions. A specialist laser technician will perform daytime maintenance, at weekly and monthly rates.

PARSEC is now undergoing prototype assembly, with a Final Design Review scheduled in March 2002.

6. Beam Relay System

The beam relay system uses a single-mode Large Effective Area Fibre (LEAF). It runs from the PARSEC optical bench in the LCR to the Launch Telescope, for a length of 25 m. Diagnostic devices measuring beam parameters, spectral format, power and polarisation are embedded both at the input and at the output of the fibre relay. Figure 7 shows the layout of the fibre relay on UT4, from the laser room to the Launch Telescope.

The single mode fibre delivers a diffraction limited beam at the launch telescope focal plane. The requirement is to achieve an overall beam relay throughput ≥ 74%, including losses from fibre injection, bending and input/output diagnostic beam splitters. We have designed a custom LEAF fibre, then produced it in collaboration with Dr. Kirchhof and co-workers at the Institut für Physikalische Hochtechnologie (IPHT) in Jena. This fibre is single mode with a mode field diameter of 13 µm and is currently under test. This fibre will be capable of meeting our specification of 10 W CW beam relay. A second LEAF option we are exploring experimentally is with Photonic Crystal

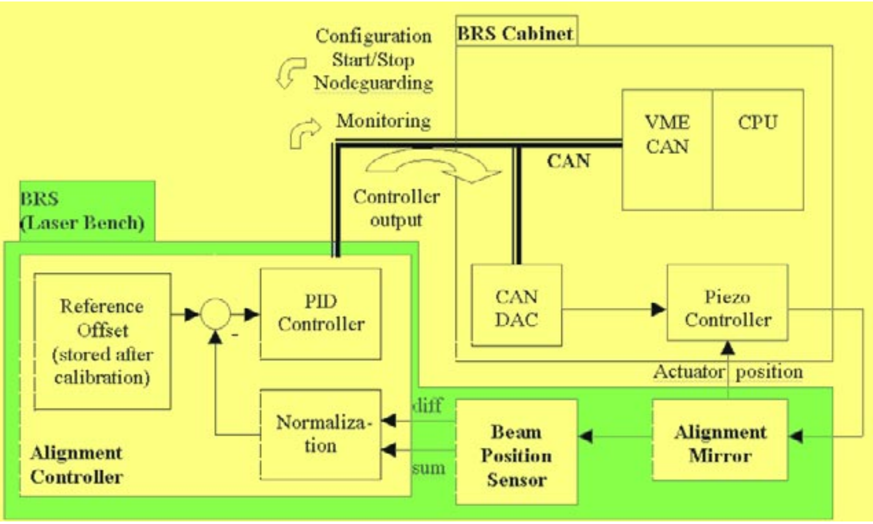


Figure 10: LT LGS jitter control scheme. Besides the AO commands, we have the option to use a faster jitter loop driven by a PSD sensor, in case we are faced with high frequency vibrations in the LT.

Table 1: Launch Telescope System specifications, applied to mounted assembly, mirrors coated, under UT4 operational conditions. It takes into account fabrication and alignment tolerances.

Parameter	Value	Comment
Entrance Pupil Useful Diameter	40 +0./-0.1	*On M2, input laser beam diameter*
Exit Pupil Useful Diameter	500 +0/-1.25	
Beam Waist on M1	360 +0/-1.25	*Gaussian beam* *$1/e^2$ intensity diameter* *at 0.72xRadius of M1*
Central beam obstruction	45.0+0./-0.1	*On M2, on axis beam*
Beam output decentre/tilt tolerance	± 0.1 mm / ± 10 arcsec	*Referenced to M1 vertex coordinates*
Angular magnification	12.5X	*Input beam from Nasmyth port*
Field of View	2 arcmin diameter	*Unvignetted beam waist*
Wavefront quality	Better than 30 nm rms, single pass, image space, over nominal FoV	*Includes all terms except focus (15 nm Zernike), tilt* *30 nm over 360mm central diameter* *50 nm over full 500mm aperture*
Surfaces Roughness rms	SiC 100 <4 nm SiC 100/CVD <1 nm	*Option of CVD SiC100 coating* *Or other composite material*
Input Laser Power	Up to 50W CW	*$<4W/cm^2$ energy density at M2 and M3* *$<0.03W/cm^2$ energy density at M1*
Input Laser Wavelegth	589.15 nm	*Sodium D2 line*

Fibres. They are capable of even larger mode-field diameters and suffer less from bending losses.

The power density inside the waveguide fibre is ~ 7.5 MW/cm^2 for 10 W CW, which onsets non-linear effects like the Stimulated Brillouin Scattering (SBS). To suppress SBS, we optimally broaden the ~ 10 MHz laser line format at 110 MHz spacing within a 0.5 GHz envelope (Fig. 8). The spectral format has been optimised taking into account the SBS suppression and also the photon return from the mesospheric sodium[5]. The spectral shaping and SBS monitoring are performed in a Beam Relay Input 50 × 60 optical table, located in the PARSEC laser volume at LCR. The Beam Relay Input has several diagnostic functions for the PARSEC output beam and for the Fibre input laser beam, as shown in Figure. 9. The laser beam is Z-folded to be servo-stabilised on the electro-optic modulator and at the fibre input.

The fibre output produces an f/12.5 Gaussian beam at the focal plane of the Launch Telescope (LT), were the image scale is 0.03 mm/arcsec. The fibre is on an x-y translation stage to be positioned within ± 30″ field of view, mounted on a Physik-Instrumente Nanopositioner for LGS fast jitter control. For the provision of 5 fibres/LGS a custom developed nanopositioner is being designed together with Physik-Instrumente.

The LGS fast jitter servo-system is custom developed at ESO (Figure 10). The control signal comes from the Adaptive Optics System at refresh rates up to 700 Hz, with an option for higher jitter frequencies controlled/sensed via a Position Sensitive Device (PSD), monitoring the LT output beam. The same controller is used for the PSD-piezo mirror combinations to stabilise the optical axis from vibrations and thermal transients, at four locations in the fibre input module (Fig. 9) and within PARSEC at six more different locations.

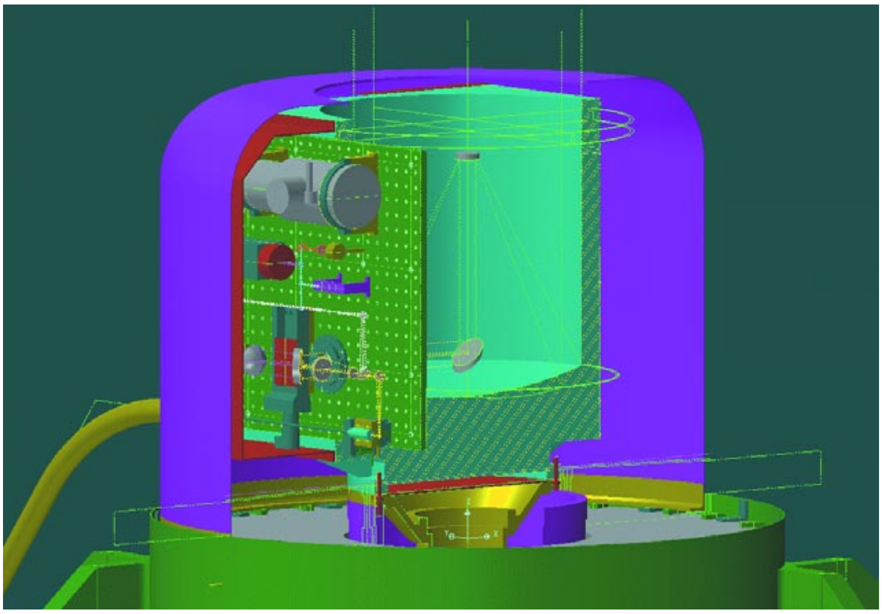


Figure 11: Launch Telescope assembly on top of the M2 hub, with diagnostic table, windshield cover and exit window. All the optics are enclosed in dry N2 atmosphere at normal pressure and temperature, to avoid dust and preserve the high power coatings.

Beam diagnostics at the LT is done on the forward beam, and on LT exit window returned beam. The diagnostics sense the beam spatial properties with a Coherent Modemaster, the beam profile, the relative laser power, the beam jitter and the beam wavefront Zernike decomposition off-line. A motorised beam selector allows to measure the forward (fibre output) laser beam, the beam at the LT exit window, and to multiplex between different laser beams as provision for the 5 LGS upgrade.

7. The Launch Telescope

The diameter of the Launch telescope has been optimised considering the median Paranal atmosphere and minimising light losses of the gaussian beam. The requirements dictated by the allowed volume between the UT4 M2 hub and the telescope dome, impose a very compact LT design. The 1.2-m diameter available space at LT location does not allow a reflective off-axis design. The LT can be at most 650 mm long, including the exit window and cover mechanism.

Several designs have been explored, including a highly aspheric refractor. The chosen design is a compact f/0.9 Cassegrain 12.5 × beam expander, made with confocal parabolas, which delivers a 589 nm PSF Strehl Ratio > 0.96 over a 2 arcmin field of view.

The LT design drivers are:

- compressed volume, 1200 mm in diameter by 650 mm height, requires compact f/0.9 LT design;
- 12.5 × Beam expander design, 40 mm parallel beam input, 500 mm output;
- isolation of laser beam and optics from weather and wind, up to the exit window surface;
- the need for very good optical quality across field points, better than 50 nm rms;
- high power path, provision for 5 × 10W CW (MCAO) operation. Coating damage threshold high on small optics;
- low scattering losses from optical surfaces are required;
- sturdy LT support, high mechanical modes frequencies, > 150 Hz;
- optics and coatings to stay in dust-free environment and dry N^2 atmosphere;
- minimal impact on the UT4 and its thermal environment;
- minimise the electronics required behind M2.

For all these reasons, the LT is the most demanding optical system of the LGSF. The primary mirror useful diameter is 500 mm, with the $1/e^2$ point 360 mm in diameter. The secondary mirror is 40 mm in diameter. This geometry is very compact, and allows the use of light-weight glasses, SiC and/or composite materials to make a very stiff LT. Table 1 shows the LT assembly system specifications, while Figure 11 shows a layout of the LT, with the diagnostic optical table attached.

The remote location of the LT, and the limited space has prompted ESO to introduce as standard the use of the CANOpen bus to communicate with the many electronics devices on board of LT.

Almost all of the electronics required for the LT devices is hosted in the LCR VME cabinets. The LT electronics is cooled via the UT4 liquid coolant system. Interlocks and maintenance devices are embedded in the design.

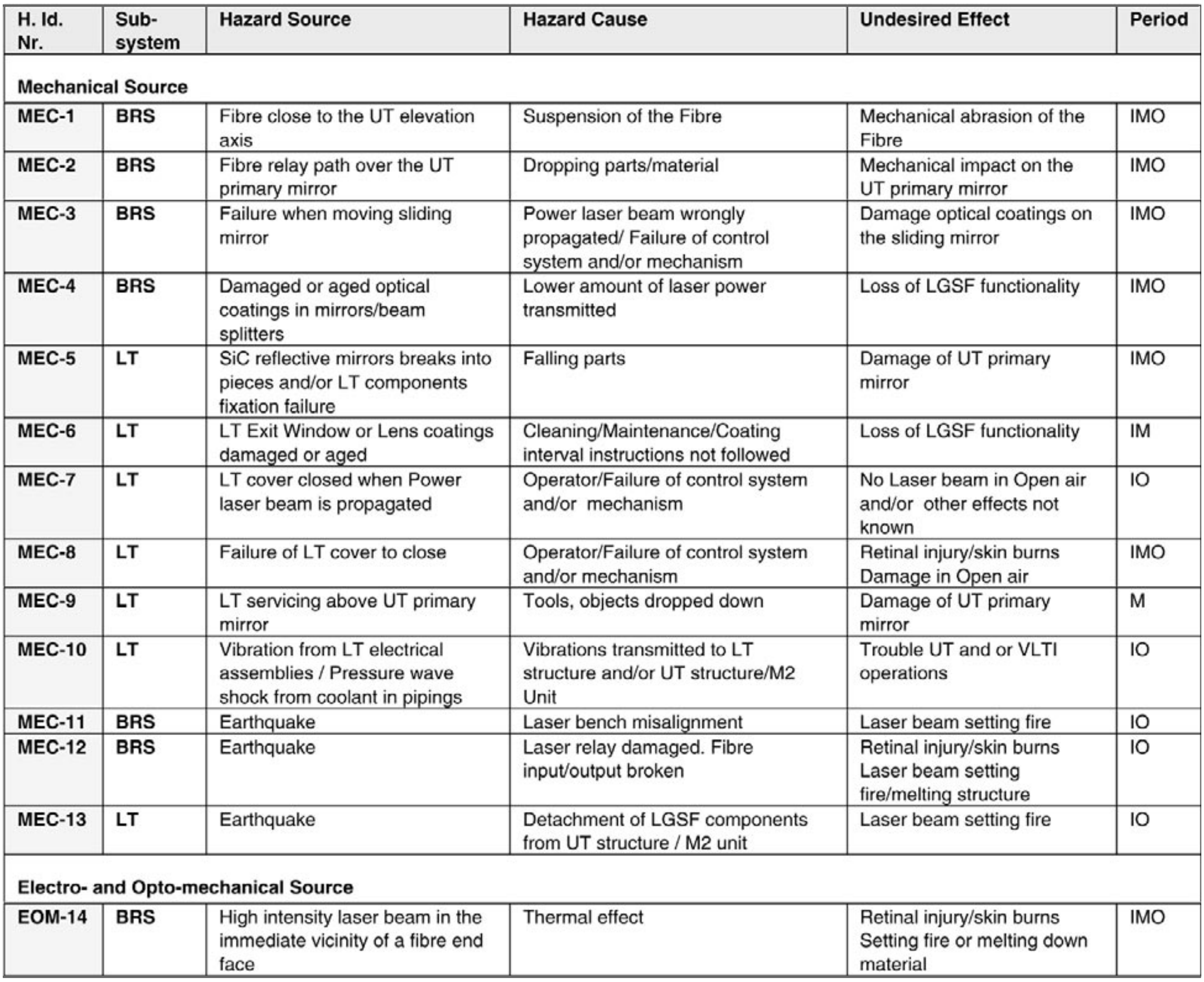
Using F.E.A. with the telescope model, the impact of a < 120 kg Launch Telescope mounted on the M2 hub of UT4 has been assessed. It shows negligible impact in terms of UT4 static flexures, dynamic properties, and extra torque under wind conditions. The reduced electronics and its cooling system prevent heat dissipation, critical for the seeing if present in this area.

To mount the LT behind M2 and have sufficient volume for all the devices, the original deployable baffle system of UT4 has to be removed.

8. The LGSF Safety System

The safety measures of the LCR have been analysed and listed for the Preliminary Design Review. They are being deepened and will be cross-checked with external consultants/experts before the Final Design Review. The necessary Class IV laser interlocks are implemented in PARSEC following the German TÜV guidelines. Moreover, the PARSEC laser has interlocks for dye spills, for dye jet interruptions, for fire hazards. Table 2 shows the Hazard list identified for LGSF. Each item is being analysed and counter measures or interlocks are appropriately designed to prevent damage.

Table 2.



H. Id. Nr.	Sub-system	Hazard Source	Hazard Cause	Undesired Effect	Period
Mechanical Source					
MEC-1	**BRS**	Fibre close to the UT elevation axis	Suspension of the Fibre	Mechanical abrasion of the Fibre	IMO
MEC-2	**BRS**	Fibre relay path over the UT primary mirror	Dropping parts/material	Mechanical impact on the UT primary mirror	IMO
MEC-3	**BRS**	Failure when moving sliding mirror	Power laser beam wrongly propagated/ Failure of control system and/or mechanism	Damage optical coatings on the sliding mirror	IMO
MEC-4	**BRS**	Damaged or aged optical coatings in mirrors/beam splitters	Lower amount of laser power transmitted	Loss of LGSF functionality	IMO
MEC-5	**LT**	SiC reflective mirrors breaks into pieces and/or LT components fixation failure	Falling parts	Damage of UT primary mirror	IMO
MEC-6	**LT**	LT Exit Window or Lens coatings damaged or aged	Cleaning/Maintenance/Coating interval instructions not followed	Loss of LGSF functionality	IM
MEC-7	**LT**	LT cover closed when Power laser beam is propagated	Operator/Failure of control system and/or mechanism	No Laser beam in Open air and/or other effects not known	IO
MEC-8	**LT**	Failure of LT cover to close	Operator/Failure of control system and/or mechanism	Retinal injury/skin burns Damage in Open air	IMO
MEC-9	**LT**	LT servicing above UT primary mirror	Tools, objects dropped down	Damage of UT primary mirror	M
MEC-10	**LT**	Vibration from LT electrical assemblies / Pressure wave shock from coolant in pipings	Vibrations transmitted to LT structure and/or UT structure/M2 Unit	Trouble UT and or VLTI operations	IO
MEC-11	**BRS**	Earthquake	Laser bench misalignment	Laser beam setting fire	IO
MEC-12	**BRS**	Earthquake	Laser relay damaged. Fibre input/output broken	Retinal injury/skin burns Laser beam setting fire/melting structure	IO
MEC-13	**LT**	Earthquake	Detachment of LGSF components from UT structure / M2 unit	Laser beam setting fire	IO
Electro- and Opto-mechanical Source					
EOM-14	**BRS**	High intensity laser beam in the immediate vicinity of a fibre end face	Thermal effect	Retinal injury/skin burns Setting fire or melting down material	IMO

EOM-15	**BRS**	Function failure of optical components of beam relay input system (attenuator, folding mirror, beam relay shaping optics)	Secondary beam radiation generated by materials and substances	Retinal injury/skin burns	IMO
EOM-16	**BRS**	Function failure of Stimulated Brillouin back scatter Suppresser (SBS)	Secondary beam radiation generated by materials and substances	Retinal injury/skin burns	IMO
EOM-17	**BRS**	Function failure of closed-loop system for fibre input alignment	Secondary beam radiation generated by materials and substances	Retinal injury/skin burns	IMO
EOM-18	**BRS**	Fusion of fibre along the wave guide length	Secondary beam radiation generated by materials and substances	Retinal injury/skin burns	IMO
EOM-19	**LT**	Function failure of closed-loop system for fibre output alignment	Secondary beam radiation generated by materials and substances	Damage of LT component/assembly/unit	IMO
EOM-20	**BRS**	Quality degradation of the beam at the fibre input	Loss of performance of the closed-loop system for fibre input alignment	Retinal injury/skin burns. Random laser reflection in the optical bench	IMO
EOM-21	**BRS**	Fibre input beam	Opto-mechanics misalignment	Random laser reflection in the optical bench	IMO
EOM-22	**BRS**	Laser beam	Persons cross beam (cloth or bare skin)	Skin injury Setting fire	IMO
EOM-23	**BRS**	Modulator amplifier noise	Electro-magnetic noise	Electro-magnetic susceptibility of surrounding electronics equipment	IO
EOM-23 bis	**BRS**	Modulator amplifier frequency stability	Quality degradation of the beam	Loss of performance of the beam propagation	IO
EOM-24	**BRS**	Laser beam	Function failure of beam switching unit	Laser beam sent to unpredictable locations	IMO
EOM-25	**BRS**	Laser beam output	Function failure of beam output shutter (Dye laser shutter)	Momentary loss of laser beam propagation control	IO
EOM-26	**BRS**	Laser beam output	Unfulfilled functional requirement of beam output shutter (not completely at limits)	Laser beam sent to unpredictable locations	IO
EOM-27	**BRS**	Laser beam out of control	Flammable material hit by the beam	Setting fire	IO
EOM-28	**LT**	Open air laser beam	Hitting Aircraft/aircrews/passengers	Retinal damage, visual disturbances, Psychological adverse effects	IO
EOM-29	**BRS**	Laser beam /secondary laser beam	Attenuator moving in	Radiation hazards	IMO
EOM-30	**BRS**	Laser beam /secondary laser beam	Malfunction of modulator or calibration mirror	Radiation hazards	IMO
EOM-31	**BRS**	Laser beam	Loss of connection with LT devices		IMO
Electrical/electronic Source					
ELE-32	**BRS**	High voltage	Amplifiers for Piezo actuators-contact with connector's pins	Electric shock	M
ELE-33	**BRS**	Laser beam	Failure in the electro-optic modulator	Laser beam reflected to unpredictable directions	IMO
ELE-34	**BRS**	Modulator amplifier fans	Strong air Flux	Impact Electronic cabinet air cooling	IO
ELE-35	**BRS**	Electrical (High voltage)	Indirect or direct contact	Electrical shock	M
ELE-36	**BRS**	Electrical (High voltage)	Erroneous installation	Setting Fire	IMO
ELE-36 bis	**LT**	Electrical short-circuit between conductors	Loss of function	Setting Fire	IMO
ELE-37	**BRS**	Electrical (High voltage)	Faulty operation of system	Electrical shock	M
ELE-38	**BRS**	Electrical (High voltage)	Faulty operation of laser	Beam hazard	IO
ELE-39	**BRS**	Electrical (High voltage)	Limited Operation Manual	New effects not known	IO
ELE-40	**BRS**	Electrical (High voltage)	Wrong/Limited number of signs	Human injury	IMO
ELE-41	**BRS**	Electrical (High voltage)	Badly selected switches, operating consoles	Not known	IMO
Chemical Source					
CHE-42	**LT**	Liquid coolant	Spills in/from LT	Hitting M1	IMO
CHE-42 bis	**LT**	Condensation water	from LT coolant piping	Impact on LT Electronics	IO

CHE-43	**BRS**	Poisonous Dye solution	Leaks in high pressure system	Poisoning of personnel	IMO
CHE-44	**BRS**	Flammable Dye ingredients	Leaks in high pressure system	Catching and setting fire	IMO
Fibre Mechanical Source					
FIB-45	**BRS**	Laser beam	Fibre breaks	Ignition material at breaking point	IMO
FIB-46	**BRS**	Laser beam	Fibre Cable wrap entangles/breaks fibre	Beam hazard	IMO
FIB-47	**BRS**	Laser beam	Output fibre positioning fails, exceeding off-sets	Creating dangerous reflections in LT	IMO
FIB-48	**BRS**	Laser beam	Output fibre breaks	Beam hazard	IMO
Miscellaneous Source					
MIS-49	**LR**	Unauthorised access to Laser Room	Exposure to direct, indirect or diffuse laser light	Retinal injury or skin burns	IMO
MIS-50	**LR, LT**	System hazards	Operator errors		IMO
MIS-51	**LR, LT**	System hazards	Operator + hardware failure		IMO
MIS-52	**LR, LT**	System hazards	Operator unavailability/absence		MO
MIS-53	**LR, LT**	System hazards	Handling of dangerous products		IM
MIS-54	**LR**	System hazards	Proximity to dangerous system		IMO
MIS-55	**LT**	Environmental condition	Rain, snow, dust in system		IMO
MIS-56	**LT**	Environmental condition	Strong wind causing disintegration of system and damage to humans/material		IMO
MIS-57	**LR, LT**	Environmental condition	Lightning causing power break/fire		IMO
MIS-58	**LR, LT**	Environmental condition	EMC		IMO
MIS-59	**LR**	Environmental condition	Wild life intrusion		IO
MIS-60	**LR, LT**	Environmental condition	Temperature extremes		IMO
MIS-61	**LR, LT**	Environmental condition	Humidity extremes		IMO
MIS-62	**LR, LT**	System intrinsic hazards	One/Two hardware failure		IMO
MIS-63	**LR, LT**	System intrinsic hazards	One hardware + one software failure		IMO
MIS-64	**LR, LT**	System intrinsic hazards	One / Two software failure		IMO
MIS-65	**CR**	Enclosure not aligned with telescope	Laser beam reflected on inside of the UT Enclosure	Retinal injury and skin burns	IMO
MIS-66	**CR**	Lack of alert in case of severe undesired effects (fire, leakage of dye solution)	Delay of intervention	Dangerous situation for human loss of material	IMO
MIS-67	**LT**	Aging of some Polymer material component	Disintegration. Component function failure.	Impact on UT primary mirror	O
MIS-68	**LT**	LT Maintenance hazard	Failure of beam output shutter while Maintenance at LT	Retinal injury and skin burns	M
MIS-69	**LT**	UT Emergency brake	High value of acceleration on LT	Fracture of fixation element	O

It is foreseen to train the ESO personnel (and refresh training at regular intervals) on the general Class IV laser hazards and on the specific hazards of the LGSF on UT4. Only trained personnel will have access to LGSF and its PARSEC laser in the LCR. It is foreseen to have surveillance cameras monitoring the LCR, the PARSEC laser volume, and the Launch Telescope diagnostics' device volume.

8.1 Aircraft detection

We have computed that the 10 W CW laser diluted over 500 mm beam diameter is within the aircraft's pilot safety boundaries according to the newest ANSI standards. Therefore, an automatic aircraft detection system, triggering a laser beam shutter, is not mandatory. Nonetheless, we have implemented a double-camera automatic detection system which cross-correlate visible images over 70º field of view. The cameras are mounted on the top-ring of UT4 (Fig. 12), and have on-board computing power to perform the computations. We are evaluating commercial solutions for the aircraft detection cameras.

When an aircraft is detected, a warning signal is sent to AO.

The aircraft detection system gives 1 second time delay to the AO systems, in order to stop gracefully its operations before the laser beam is shut-off. Then a flipper mirror shutter in the LT is closed, the laser beam is sent to an absolute power meter and to the diagnostic devices of the LT. In this way the laser beam properties continue to be monitored during the time of safety shut-off.

9. Project Status and Conclusions

The retrofit of a Laser Guide Star Facility on an operational, highly demanded telescope is not a trivial task. The past experiences of other LGS

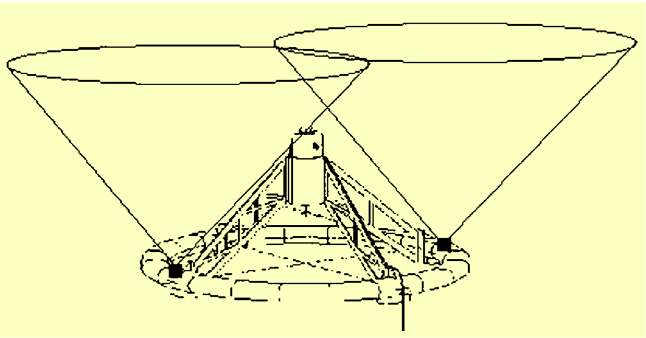


Figure 12: UT4 aircraft detection cameras mounted on the side of the telescope top ring. A field of view of 70 degrees allows to safely trigger commercial aircraft flying up to 400 m above the observatory, and to stop the laser propagation before they come across the laser beam.

projects have taught the lesson that highly redundant safety and diagnostic systems are necessary to have smooth operations. Therefore the LGSF becomes a rather complex and elaborated system, especially to fulfil the requirements of automatic operation with moderate operator assistance.

In order to ensure the timely completion of the project, we have separated the design and installation phases of the Laser Clean Room, which requires heavy infrastructure work, from the remainder of the LGSF systems. The LCR has been placed on fast-track, and will be erected in February 2002, to minimise the impact on the UT4 telescope operations.

The critical items to be procured are the fast Launch Telescope and the PARSEC laser. The R&D activities related to the LGSF project are the PARSEC laser (MPE), the fibre lasers for MCAO and the single mode fibre relay (ESO).

The project status at the time of this writing is:

- LGSF Preliminary Design passed, identified perceived risk areas, identified back-up paths.
- Placed the contract of the Laser Clean Room and its support structure.
- Specialty fibre contract issued, 1st prototype received. Photonic Crystal Fibres received. Fibre relay tests on the way.
- *Launch Telescope:* feasibility assessed for SiC substrates and structure, other composite or lightweight optical materials are being explored. LT is out for enquiry, together with mechanics.
- Breadboard of the Fibre input subsystem assembled and under test.

Operation plan and LGS light-pollution policy for the Paranal observatory drafted, under discussion.

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*ESO technical reports may be requested from the authors or from vltarchive@eso.org

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Service Mode Scheduling: A Primer for Users

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Introduction

The execution of observations in Service Mode is an option at many ESO telescopes, especially at the VLT telescopes. In this operations mode, observations are not scheduled for specific nights, they are scheduled flexibly. Each night observations are selected from a pool of possible observations based on Observing Programme Committee (OPC) priority and the current observing conditions. Ideally, the pool of possible observations contains a range of observations that exactly match the real range of conditions and the real number of available hours, so that all observations are completed in a timely manner. Since this ideal case never occurs, constructing the pool of observations must be done carefully, with the goals of maximising scientific return and operational efficiency.

In this article, basic Service Mode scheduling concepts are presented. The goal is to provide users with the information they need to better estimate and perhaps improve the likelihood that their observations will be completed. A specific VLT focus is maintained for most of this article, but the general principles are true for all ESO facilities executing Service Mode runs.

In the Beginning: Proposals, Programmes, and Runs

In general, users submit observing proposals twice a year for Observing Programme Committee (OPC) review. Each proposal describes a scientifically unified **observing programme** which is composed of one or more **observing runs**. A run provides the high-level technical specifications for a set of observations: operations mode (Visitor or Service), targets, telescope, instrument, total execution time, and required observing conditions (e.g., seeing, lunar phase, and transparency).

Pre-OPC:
Determining the Available Time

Before each OPC meeting, ESO determines the total **available time**, i.e. how much time will be available for scientific observations. For example, for a normal Period, each VLT telescope will have about 140 nights available for scientific observations. The other 42 nights are used for the ESO Calibration Plan, the Director’s Discretionary Time programme, and regular technical maintenance of the instruments and telescopes (e.g. pointing maps, multi-day technical interventions). Some Periods or telescopes have less available time, either due to major technical activity (e.g. instrument commissioning periods) or because the time has been preallocated to Large Programmes. As a guideline, the OPC will allocate up to 30% of available time to Large Programmes. For any given Period, the time allocated to Large Programmes in previous Periods must be deducted before new time can be allocated.

Over-Subscription and Relative Visitor/Service Mode Demand

Once the available time is determined, the ratio between total requested time and available time (**global over-subscription**) can be calculated. The Paranal global over-subscription ratio is shown in Figure 1 (left axis = Mode Over-subscription) for both Visitor and Service Mode as a function of Period. Over-subscription has been falling steadily over time. Figure 1 also shows the requested time ratio between Service and Visitor Mode (**mode demand**). The demand for Service Mode has been climbing. Note that the allocated mode demand can be larger than the requested mode demand because the OPC may select more Service Mode runs than Visitor Mode runs. But in the end, the scheduled mode ratio is enforced by ESO to be close to 1, i.e. an equal split between Service and Visitor. The issue of Service/Visitor Mode balance is discussed in more detail below.

Users should note, however, that **local over-subscription** (over-subscription as a function of RA) can be much larger, and is typically highest in the RA ranges 0–4 and 10–14. In these ranges, the over-subscription ratio regularly exceeds 5 and has approached 10, especially during dark-time. Demand in these RA ranges is highest not only because they provide access to the prime extragalactic co-ordinate space, but also because they straddle Period boundaries.

The OPC: Scientific Prioritisation and Time Allocation

The main task of the OPC is to produce a scientifically prioritised list of runs and to allocate a total execution time (i.e. integration time plus operations overheads) to each run. Although all the runs within a given programme are usually given the same grade, the OPC does have the option of assigning each run a different grade, or even rejecting individual runs within a single programme. (The OPC is subject of an article in *The Messenger* No. 101, p. 37.) The details of the OPC process are not discussed here; suffice it to say that a lot of time and effort goes into this generally thankless task!

While making these decisions, the OPC does not typically consider technical feasibility (unless a proposed run contains an obvious error) or requested observation mode (Visitor or Service). An OPC grade is based primarily on scientific merit. The OPC also does not generally consider the final distributions in RA or observing conditions. In principle, it is possible for the OPC to allocate all available time to runs requiring excellent seeing and photometric conditions within a narrow RA range. Of course, in practice this extreme case does not occur, but a post-OPC technical and scheduling review is necessary before the final schedule can be constructed.

Post-OPC: Technical Review and Preliminary Long-Term Schedule

Once the OPC review is completed, it is the responsibility of ESO to produce the **Long-Term Schedule (LTS)**, i.e. the list of runs scheduled for a given Period. The goal is to schedule (and execute) all runs above the so-called OPC cut-off line, i.e. the line defined by the available time at each telescope and/or instrument.

This process starts with a technical feasibility review. Each telescope team is given the opportunity to provide technical feedback on runs above the OPC cut-off line.

The technical review evaluates whether or not the technical goals (e.g. signal-to-noise, observation execution concept) of each run are achievable. Technically infeasible runs are rejected, no matter what their scientific priority was. This may seem wasteful – why ask the OPC to review a technically infeasible run? Consider the over-subscription rate: a pre-OPC technical review would take 3–4 times as much effort as a post-OPC review. Furthermore, the number of runs rejected for technical reasons is very small, e.g. approximately 2% per Period at the VLT.

The technical review also evaluates whether or not a run is suitable for Service Mode. Runs which requested Service Mode can be switched to Visitor Mode if the telescope team judges that successful completion of the observations cannot be guaranteed in Service Mode. This decision is usually taken when a run requires a complex, unusual observing strategy and/or a less common or non-standard observing mode. More rarely, runs that requested Service Mode are switched to Visitor Mode, typically to reduce the number of Service Mode runs per Period to a level that ESO can support within available operational resources.

In parallel to this technical review period, the preliminary LTS is constructed. Pre-allocated, continuing Large Programme and newly approved Visitor Mode runs above the OPC cut-off line are assigned specific nights. The remaining available time is assigned to Service Mode. The split between Visitor and Service Mode varies by telescope and Period. For the NTT and 3.6-m, approximately 10% of the available nights are assigned to Service Mode. Approximately 50% of the available time is assigned to Service Mode at the VLT telescopes. Starting with Period 68, at a large fraction of the available time will be assigned to Service Mode at the 2.2-m/WFI, and eventually this may climb to close to 100%.

After the technical review is completed, the preliminary LTS is adjusted to reflect the outcome. Runs are moved from Visitor Mode to Service Mode, or visa versa, as necessary. Technically infeasible runs are removed from the LTS. This revised LTS, particularly the revised list of Service Mode nights, is one of the inputs to the Service Mode LTS construction process.

Building the Service Mode LTS

In the classic Visitor Mode style of operations, users are assigned specific nights. Sometimes these nights are not scheduled exactly when the user wanted. During the actual nights, the observing conditions may not be exactly what was desired. In combination, these two things force the user to adapt their observing programme (and often their science goals) to the actual situation.

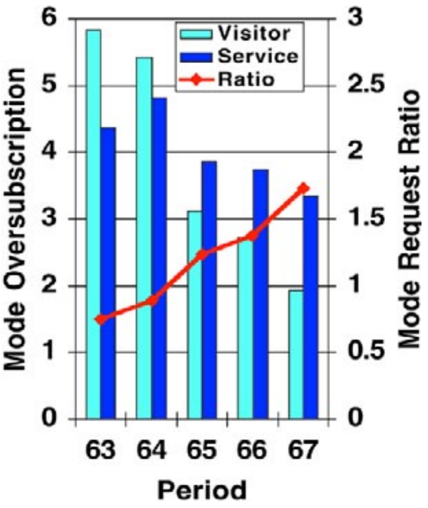


Figure 1: Paranal Global Over-subscription and Mode Demand. *The bars show the oversubscription (left axis, total requested time over available time) across all available instruments. For Periods 63 and 64, only ISAAC and FORS1 were operational. For latter Periods, the instruments were FORS1, FORS2, ISAAC, and UVES. Requested and available time per instrument as made available to the OPC are used. Actual telescope used is ignored. The red line illustrates the mode demand (right-axis, time request ratio between Service and Visitor Mode).*

One of the goals of Service Mode is to execute the observations exactly as described in the approved observing proposal. At the end of the OPC meeting, however, there is no guarantee that this is possible, even for the highest ranked runs. It is necessary therefore to determine if a Service Mode run is executable or not within the context of the actual OPC ranked list of runs and the nights allocated to Service Mode in the LTS.

Basic Principles

Due to statistical fluctuations in observing conditions and down-time, it is highly unlikely that all runs above the OPC cut-off line can be completed. For example, it is known that 15% of available time will be lost to downtime randomly over a long enough time baseline. Initially, any LTS assumes ideal conditions (clear skies, good seeing) but reality is never so kind. Thus, ESO has adopted the following high-level principles:

(1) In general, the scientific objectives of an observing run are not achieved unless all observations are completed.

(2) Therefore, a run should not be scheduled unless it has a high probability of completion.

(3) It is better that a smaller number of runs are totally completed than that all runs are incomplete.

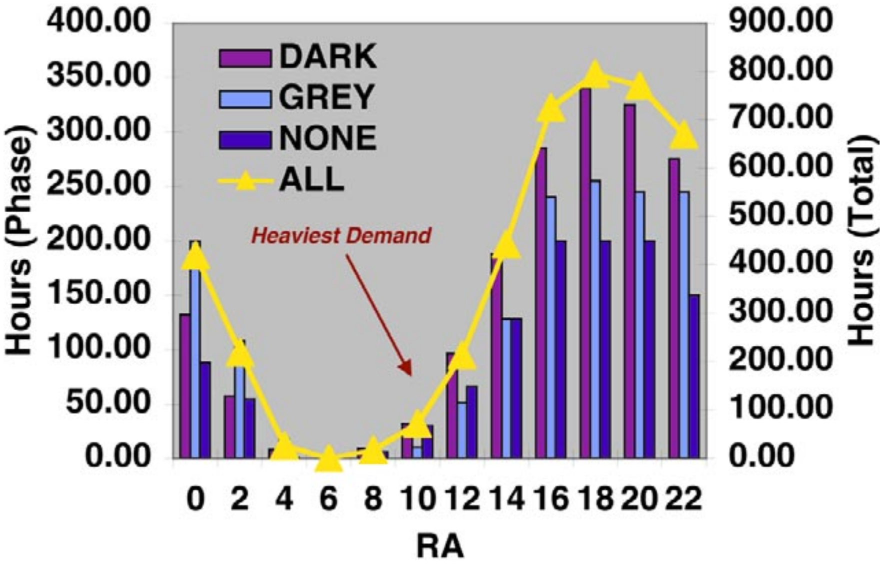


Figure 2: RA/MOON Accessibility Example. *The computed number of hours per RA bin and lunar phase bin are shown for Period 67 and Kueyen (UT2). The shape of this function is driven by the specific nights assigned to Service Mode and the finite length of the Period. Without Period boundaries, each RA bin would be roughly equally accessible over time.*

(4) Observing conditions permitting, runs with higher scientific priority as defined by the OPC should be completed preferentially to lower-priority runs.

These principles are conservative and have been discussed in many forums. Those discussions will not be repeated here.

An important technical principle is that the Service Mode LTS process should manage RA space, not nights. A range of RA is available on any given night. Conversely, any given RA is observable on many nights. For Service Mode, it is more appropriate to manage co-ordinate space than calendar space. This facilitates one of the key advantages of Service Mode: the time-averaged observing conditions for any given target will be better than the conditions on any random night. However, it is also true that this will only be true if a large enough fraction of time is made available to Service Mode operations.

Describing Schedule Parameter Space

The Service Mode LTS review process is driven primarily by principle 2 above. Many parameters determine whether an observing run is likely to be completed or not. *Since some of these parameters are under control of the user, it is possible for the user to fine-tune them at the time of proposal submission to maximise the likelihood that their observations will be completed.*

The most important parameters are requested target distribution and lunar illumination. Within a given sequence of nights, any given point on the sky is observable for a finite number of hours under specific lunar conditions. This **accessibility function** (number of hours available per RA and Dec at a given lunar illumination) is determinate, i.e. it is fixed by the specific sequence of Service Mode nights. An example is shown in Figure 2. Each Service Mode run can be de-composed into specific targets at specific positions with specific total times and lunar conditions. If too many runs want to observe in the same region of the sky under similar lunar conditions (e.g. HDF-S and dark-time), the number of possible hours can be exceeded. This is one example of **local over-subscription**.

To simplify the construction of accessibility function, some assumptions are made. First, RA is binned into 2-hour intervals. Second, for each RA bin, the mean visibility (hours per night above 1.5 air masses) is assumed to be the maximum visibility for that RA that night minus one (1) hour. Objects at different declinations will have different visibilities, but simulations show that this assumption is reasonable. Finally, the lunar illumination distribution is parameterised as dark (moon below horizon or FLI $<$ 0.3), grey (moon above horizon and 0.3 $\leq$ FLI $<$ 0.6), or bright (moon above horizon and FLI $>$ 0.6).

The next most important factors are the fractional seeing and transparency distributions. Unlike the accessibility function, these distributions are statistical and only valid over long enough time baselines. Each site has a known statistical free-air R-band seeing distribution. For scheduling purposes, it is assumed that in the mean, the R-band delivered image quality distribution in the focal plane follows the R-band free-air distribution, at least for the VLT telescopes. This distribution shifts as a function of wavelength – how this affects scheduling is discussed below. This distribution has been calculated from historical DIMM data in 0.2 arcsec bins averaged over 30 minutes. Analogous to seeing, the statistical site transparency distribution is also available. Here, a conservative assumption is made. The reported photometric fraction (e.g. 78% for Paranal) is split into photometric (PHO) and clear (CLR) bins. It is likely that much of the CLR time is truly PHO, based on available trends in FORS zeropoints. All other usable time is called thin cirrus (THN), i.e. non-photometric. Of course, some time is completely lost to bad weather (e.g. clouds, high humidity), as discussed further below.

The fractional seeing and transparency distributions can be combined into a single **cumulative seeing and transparency distribution**. The Paranal distribution used for Period 67 scheduling is shown in Figure 3. *Users should consider this figure carefully.* Many users regard a seeing of 0.8 and a CLR transparency to be conservative. In fact, this combination of conditions arises only 42% of the time on Paranal. Moreover, while it is exciting to consider that the VLT can deliver 0.4 arcsec images under CLR conditions, Figure 3 shows this happens less than 5% of the time in the R-band. It will happen more frequently at near-IR wavelengths but not by many factors. Finally, users should also keep in mind that these percentages are valid over long-time baselines. On a night-to-night basis, seeing and transparency can vary on short-time scales. Such short-term variability is obvious from the astroclimatology information linked from the Paranal Observatory Web home page.

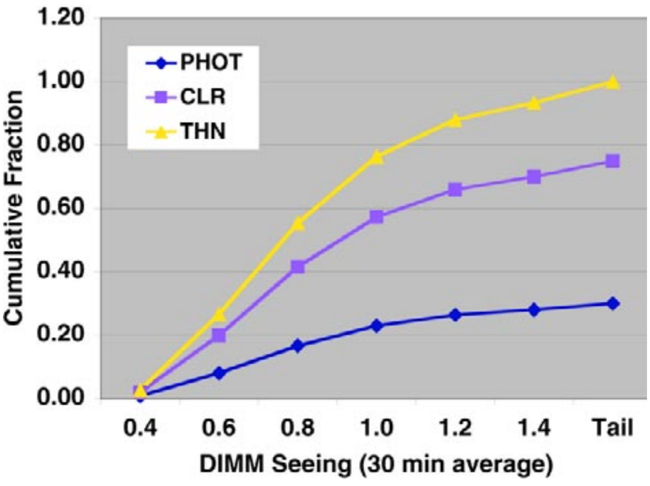


Figure 3: Adopted Paranal SEE/TRANS Cumulative Function. *See text for description.*

The combination of the accessibility function and the cumulative seeing/transparency distribution produces a four-dimensional matrix called the **RA/MOON/SEE/TRANS (RMST) accessibility matrix**. Each element of this matrix is an estimate of cumulative time available in a given RA bin for a specified lunar illumination bin, seeing value, and transparency value. Since this is a cumulative distribution, these are estimates of the number of hours that the seeing and transparency will have these values or better.

The final important factor is downtime, i.e. time schedule for science operations but lost to technical run weather problems. As technical downtime is laudably low (2–5%), total downtime is driven by weather and is a function of month. For Paranal, the total down-time since the start of science operations has been 10–15% per Period. Of course, downtime is statistical.

The Review Algorithm

The review algorithm is best presented in pseudo-code.

```
INPUT
  prioritised list of runs
  precise list of Service Mode nights
    for these Service Mode nights, computed:
      total Available Time
      RMST matrix

FOR each newRun

  CREATE newSchedule
  NewSchedule  = currentSchedule
  + newRun
  newRMST = currentRMST +
  newRunRMST

TEST newSchedule
  NewScheduleTotalTime  ≤
  availableTotalTime?
  newRMST ≤ accessibleRMST?

IF both TRUE:
  ACCEPT newRun
  currentSchedule = newSchedule
  currentRMST = newRMST
ELSE
  REJECT newRun
```

Input runs are prioritised in the following order: Guaranteed Time Observations (GTO), Large Programmes (LP), selected Chilean runs (RCH), and Normal runs. High priority Chilean runs are selected in accordance with the principles established in the Chile/ESO operations agreement. There are two additional special cases. Target-of-Opportunity runs are de facto high priority unless the OPC recommends otherwise, in recognition of their time-critical nature. Runs that require a rigid time sequence of observations are also de facto high priority – such observations have to be done on a fixed schedule or it is not possible to achieve the science objective.

If a run has multiple targets, the RMST test must be done for each target or group of targets. If the test is violated for one target, the entire run is rejected.

Although lunar illumination is strictly not cumulative, runs with high priority that can be executed in bright-time are allowed to consume grey and dark-time if necessary.

Likewise, high priority grey-time runs can consume dark-time. This concept is illustrated by the UT1/Antu situation over the last few periods: the OPC has allocated significantly more time to ISAAC runs than to FORS1 runs and consistently given ISAAC runs higher priority. To schedule and execute these runs, ISAAC runs have been allowed to consume dark-time.

So far, downtime has not been explicitly accounted for in this review process. In general, technical downtime has been negligible, except for some early problems with ISAAC. Fractional weather down-time is somewhat dependent on time of year, but this is difficult to model, even in a statistical sense. It has been ignored for now.

Each rejected run is reviewed. Based on this review, a run can be:

Accepted without priority change: run was only marginally in violation of RMST boundary conditions;

Accepted at reduced priority: run significantly violated one run more RMST boundary conditions, but the amount of available time has not been exceeded;

Rejected*:* run significantly violated one or more local boundary conditions and/or total available time has been exhausted.

Because the Service Mode review assumes a specific, preliminary Visitor Mode LTS, it is possible that low priority Visitor Mode runs consume enough time within a specific RA range that a higher priority Service Mode run cannot be scheduled. In this special case, the lower priority Visitor Mode runs may be removed (rejected) from the preliminary Visitor Mode LTS to allow the higher priority Service Mode run to be scheduled, and the Service Mode review is repeated. This is an iterative (and manual) process.

This rejected run review can be illustrated by two real-world examples. The runs used in both examples were highly ranked by the OPC. Table 1 shows the first example. Here, a highly ranked run requested more excellent seeing time than was statistically available. It was automatically rejected. However, this was an ISAAC run specifying observations in the K-band where the delivered image quality distribution is known to be shifted to better seeing. This run was accepted at reduced priority (Rank B), and ultimately more than 70% of the run was completed. Table 2 shows a more complicated example. This run did not request very strenuous conditions. However, the single target was located in a part of RA space demanded by other higher priority runs. This run was rejected. In fact, it has proven difficult to finish the scheduled runs in this RA range due to weather downtime – the rejected run, if accepted at lower priority, would never have been started.

Above the OPC Line: Rank A and B

Once the Service Mode review is completed, each accepted Service

	RA Bin = 2 hrs, Moon = NONE, Trans = CLR						
	Seeing						
	0.4	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**Any**
Accessible Hours	3.8	38.4	80.6	109.4	126.7	134.4	144.0
Scheduled Hours (All Runs)	0.0	0.0	0.0	6.0	0.0	0.0	5.0
Requested (Run X)	7.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 1: First Run Review Example. *This run had one target in the RA = 2 hours bin. No lunar restrictions were specified but clear conditions were desired. The requested seeing was 0.4 arcsec. Three vectors are shown. Top: the cumulative accessible hours for this RA, lunar, and transparency bin as a function of seeing. Middle: the scheduled hours for higher priority runs. This row is not cumulative. Bottom: the user requested hours. As described in the text, although the user request is statistically infeasible, the proposed observations were in the K-band, where the delivered image quality is known to be on average better. Furthermore, this run could be executed under any lunar condition. This run was accepted with lower priority.*

	RA Bin = 10 hrs, Moon = DARK, Trans = CLR						
	Seeing						
	0.4	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**Any**
Accessible Hours	0.6	6.4	13.4	18.2	21.1	22.4	24.0
Scheduled Hours (All Runs)	0.0	0.0	13.2	4.5	0.0	0.0	0.0
Requested (Run X)	0.0	0.0	0.0	14.0	0.0	0.0	0.0

Table 2: Second Run Review Example. *This run had one target in the RA = 10 hours bin. Dark-time under clear conditions and 1.0 arcsec seeing were requested. Three vectors are shown. Top: the cumulative accessible hours for this RA, lunar, and transparency bin as a function of seeing. Middle: the scheduled hours for higher priority runs. This row is not cumulative. Bottom: the user request. The accessible hours are 18.2. The cumulative scheduled hours are 13.2 + 4.5 = 17.7. Thus, the sum of the Run X requested hours plus the cumulative scheduled hours exceeded the accessible hours. Scheduling this run was made more difficult by the request for dark-time and the knowledge that this RA is often negatively affected by weather downtime. This run was rejected.*

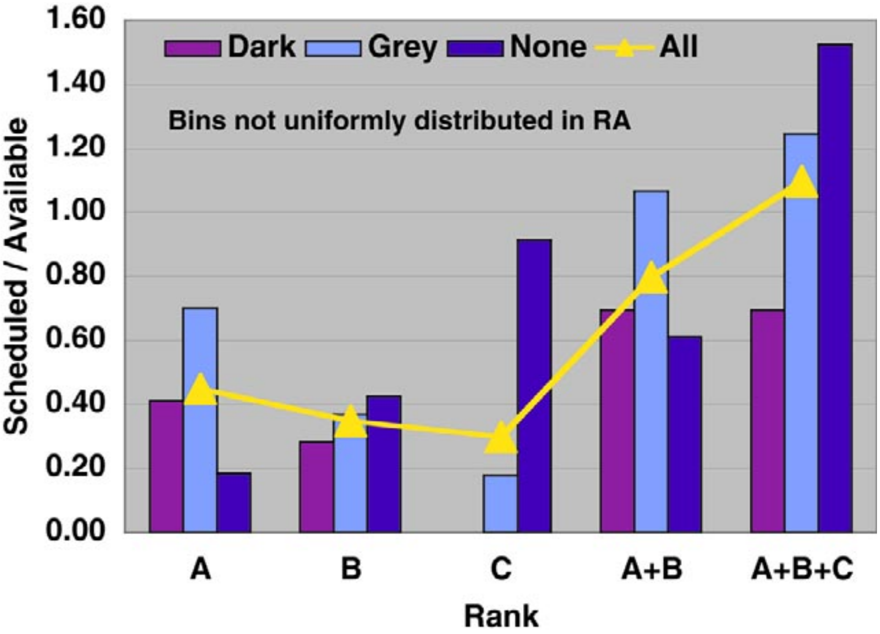


Figure 4: Scheduled vs. Available Time by Rank. *For Period 67 at Kueyen/UT2, the ratio of scheduled vs. available time is given as a function of rank and lunar phase bin. As discussed in the text, scheduled time is split roughly equally between Rank A and B, but the sum of Rank A and B is less than the available time, except for grey-time. This implies that runs that requested grey time received a high enough OPC grade to be scheduled in dark-time. As expected, the filler queue (Rank C) is heavily weighted to runs with no lunar restriction.*

Mode run above the OPC cut-off line can be assigned a priority rank. Such runs are assigned either Rank A ("high priority") or Rank B ("medium priority"). Rank is assigned primarily based on OPC priority. The available Service Mode time is split roughly evenly between Rank A and B. This is illustrated by an example in Figure 4. In principle, this means that statistical fluctuations in down-time or observing conditions will not have a significant impact on Rank A runs. The exception is when a Rank A run has a specific target or time-constraint which is unachievable due to a prolonged period of downtime.

ESO commits to completing Rank A runs whenever possible, even if it takes multiple Periods. ESO does not commit to complete Rank B runs – these have lower scientific priority. If a Rank B run is incomplete at the end of a Period, it is terminated. This strategy ensures that the highest priority runs from each OPC meeting are eventually completed, while preventing too large a fraction of the LTS from being filled with runs carried forward from previous Periods.

The Filler Queue: Rank C

In an ideal world (from the scheduling perspective!), the runs allocated time by the OPC would request targets and observing conditions that span RA and expected observing condition space uniformly. Furthermore, delivered observing conditions would follow their statistical trends and there would be no down-time. In this situation, Rank A and B run completion rate would approach 100%. Reality is not so kind. In particular, the list of Rank A and B runs tends not to include enough runs for the inevitable periods of seeing worse than 1.0 arcsec and/or non-photometric transparency (see Fig. 3). Without LTS modification, unnecessary telescope idle time becomes inevitable.

To deal with this situation, the so-called filler queue (Rank C) is created. Candidate runs for this queue are selected from below the OPC cut-off line but with an OPC grade better than 3. Only runs requesting seeing worse than 1 arcsec and non-photometric conditions (CLR or THN) are selected. Preference is given to runs with no lunar restriction. Runs which have strict timing constraints (i.e. target-of-opportunity projects, time series observations) are not considered. The ideal filler run contains a sample of targets that span RA space but does not require that all targets are observed to produce a sound scientific result. Candidate runs are reviewed by the telescope team for technical suitability. They are also reviewed by the OPC chairman to obtain formal OPC approval. Runs which pass these reviews are inserted into the LTS with Rank C ("low priority"). One realisation of this process is illustrated in Figure 4.

Closing the Loop: Phase 2, Run Execution, and Run Completion

Phase 2

Users awarded Service Mode time are required to submit a Phase 2 package, which includes a description of their observations in the form of Observation Blocks. The scheduling constraints included in these OBs are checked against the observing requirements requested in the original observing proposal, i.e. what was used to build the LTS. Users are not allowed to specify better conditions at Phase 2 than they requested at Phase 1. By enforcing the original requests, it is assured that the executed schedule is in close agreement with the constructed schedule.

However, users are not prevented from requesting more lenient conditions. Some users take advantage of this to relax their Phase 2 scheduling constraints to increase the likelihood that their OBs will be executed. From the ESO (and OPC) perspective, this is an acceptable strategy, as long as this relaxation is not extreme. For example, relaxing the seeing constraint by 0.1 arcsec is not extreme, but relaxing it by 0.5 would be! Such a change would call into question the original justification for the observing run. In truly extreme situations, the OPC would be asked to review the situation.

Some relaxation is actively encouraged. In particular, users who requested photometric (PHO) conditions at Phase 1 are encouraged to submit enough OBs to obtain a proper photometric calibration but to request clear (CLR) conditions for most of their OBs.

Users are also not prevented from redistributing their allocated time between a sub-set of targets. This is necessary in cases where, for example, the OPC only approved a sub-set of targets, time required for operational overheads was underestimated in the original observing proposal, or higher signal-to-noise is desired for a smaller set of targets. From a scheduling perspective, such changes can be problematic. In the worse case, the Phase 1 run had many targets over a range of RA, but the Phase 2 proposal is to use all the allocated time on a single target, creating an unexpected case of over-subscription. During the Phase 2 review, users are contacted when their time re-distribution creates a potential over-subscription situation.

Run Execution

Finally, Phase 2 packages are delivered to the telescope teams for execution. The whole operational process of run/OB management and execution could be the subject of another lengthy *Messenger* article. Only a few key points are mentioned here.

Naturally, OBs are selected for execution primarily by OPC priority, as parameterised by Rank. The next most important criteria is lunar illumination followed by seeing, transparency, and air mass. It is sometimes necessary to override other considerations to execute time-critical OBs (e.g. ToO, time series). OB scheduling is always more complicated in situations where the instrument configuration must be changed manually before the start of the night (e.g. to insert a special filter or a MOS mask). To maintain operational efficiency, it is sometimes necessary to continue executing OBs requiring these manually inserted elements, even if the (improved) conditions would allow the execution of different OBs.

Finally, recall that ESO is trying to complete entire runs, under the principle that the entire run is needed to achieve the desired scientific goal. When selecting OBs for execution, emphasis is placed on completing runs before starting runs. This becomes more important as the Period progresses.

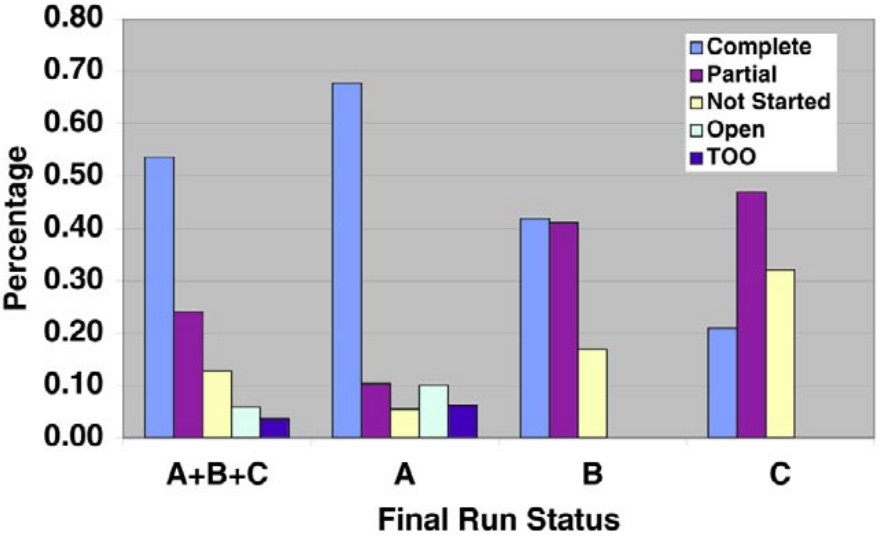


Figure 5: Period 63–66 Run Completion Summary. *Run completion status percentages are given for Period 63–66 VLT Service Mode runs.* ***Completed:*** *all user observations executed with specifications;* ***Partial:*** *run started, not completed;* ***Not Started:*** *run not started;* ***Open:*** *on-going Large Programmes, incomplete Rank A runs;* ***TOO:*** *Target of Opportunity Runs.*

Run Completion Statistics

The fundamental goal of Service Mode is to complete the highest ranked runs first under their requested observing conditions. Is this goal being achieved? Figure 5 illustrates that the answer is “yes”.

In Figure 5, the Service Mode completion status for Periods 63–66 are presented. Run Status is explained in the figure caption.

All **Rank A** Open runs will eventually be completed, driving the Rank A Completed fraction to above 80%. It will never be 100% for several reasons. First, Rank A Target of Opportunity runs depend on random events – if the events do not occur, the runs cannot be completed. Second, some Rank A runs turn out to be impossible to complete due to post facto impossible combinations of target, date, instrument configuration, and/or observing conditions. Consider a real situation. Titan observations were requested with 0.4 arcsec seeing on specific dates in February 2001 – since the seeing was never that good on the specified days, the observation was impossible. Finally, there can always be unforeseen technical difficulties. After consultation with the users, such runs are abandoned. Incomplete Rank A runs eventually end in the Partial or Not Started categories.

The **Rank B** situation is more complicated. Although runs in this queue are not guaranteed to be completed, it is perhaps disappointing that the Rank B Completed fraction is only approximately 40%. However within the Partial category there are many runs which are more than 50% completed. Those runs probably produced a scientifically useful data-set as well, but of course that must be evaluated by the users, not by ESO. On the other hand, most runs in the Partial category which are less than 25% complete probably do not produce a scientifically useful data-set and might as well be considered Not Started. This is a hidden scientific inefficiency – it would be far better to produce fewer runs with scientifically useful data-sets than many runs with marginal data-sets. By putting emphasis on run completion, not just OB completion, ESO is trying to avoid the latter outcome.

Rank B completion rate is ultimately limited by the combined technical and weather downtime fraction. To date, Paranal is suffering 10–15% downtime (mostly due to weather) per Period. By design, Rank B runs absorb the impact of this downtime. Since such downtime occurs semi-randomly (some months are statistically worse than others), more than 10–15% of the Rank B runs may be affected.

As expected, the **Rank C** filler runs have the lowest completion rate and the highest Not Started rate. However, the relatively high Partial fraction (40–50%) is consistent with the filler queue concepts discussed above.

Summary: Lessons for Users

When writing observing proposals or preparing Phase 2 packages, users should consider the following key points.

The most critical consideration is a strong observing proposal which results in a high OPC grade. No matter what else is needed or wanted, a high grade increases probability of execution success. Suggestions from the OPC for writing a successful proposal can be found on the ESO Web site.

The local over-subscription is highest in the RA ranges 0–4 and 10–14 hours. If possible, select targets at other RA ranges. It is also recommended to propose specific targets, not a range of targets to be reduced at Phase 2. Finally, targets at widely separated RA (e.g. 2 and 11) should be split into separate runs.

The VLT is capable of delivering truly excellent image quality in the focal plane. Nevertheless, such excellent seeing occurs relatively infrequently (see Fig. 3). Keep in mind that runs with lower priority (Rank B or C) which require better than median seeing are unlikely to be completed and may not even be started. To achieve success with rare conditions, a high OPC grade is necessary.

Consider Figure 3 and the filler queue description carefully. It is much easier to schedule and execute runs which require less stringent conditions (upper right corner). Furthermore, these runs are candidates for the filler queue (Rank C), so they have an increased chance of being scheduled (although not necessarily executed).

Also remember that seeing and transparency varies on short-time scales. This makes it difficult-to-impossible to obtain *continuous* conditions (especially seeing) over many hours within a single night. This is the main reason that ESO requires individual OB execution times to be less than one (1) hour and discourages the submission of tightly linked sequences of OBs.

At telescopes where the fraction of time devoted to Service Mode is low (3.6-m, NTT), it is unrealistic for users to expect excellent observing conditions (e.g. better than median seeing) during Service Mode nights. Service Mode proposals for these telescopes should plan accordingly.

Users are reminded to read the Phase 2 instructions and the specific User’s Manuals carefully when preparing their Phase 2 packages. These documents provide more hints and suggestions about maximising the success of your run.

Acknowledgements

The ESO scheduling process is a delicate balance of scientific and technical considerations, as well as human-relations management. The ESO community has benefited immensely in this area from the dedication and careful work of Jacques Breysacher over the last 25 years.

Scheduling concepts related specifically to Service Mode have been discussed within ESO for many years. Roberto Gilmozzi, Gautier Mathys, Palle Møller and, of course, Jacques Breysacher have made significant contributions to the refinement of these discussions into the current operational concepts.

Interesting and probing discussions with the ESO Observing Programme and User's Committees are gratefully acknowledged.

The actual operational execution of these concepts would not be possible without the hard work and dedication of the members of the Visiting Astronomer Section (VISAS), the User Support Group (USG), and Paranal Science Operations (PSO).

Systems and tools that support these activities have been provided by the User Support System (USS) team.

Jacques Breysacher, Fernando Comerón, Peter Jakobsen, Gautier Mathys, Francesca Primas, and Martino Romaniello provided thoughtful and thorough feedback on earlier drafts.

Peter Quinn provided the original version of Figure 1.

Hunting the Southern Skies with SIMBA

(Taken from ESO Press Release 20/01 – 30 August 2001)

A new instrument, SIMBA ("SEST IMaging Bolometer Array"), was installed at the Swedish-ESO Submillimetre Telescope (SEST) at the ESO La Silla Observatory in July 2001. In order to achieve the best possible sensitivity, SIMBA is cooled to only 0.3 deg above the absolute zero on the temperature scale.

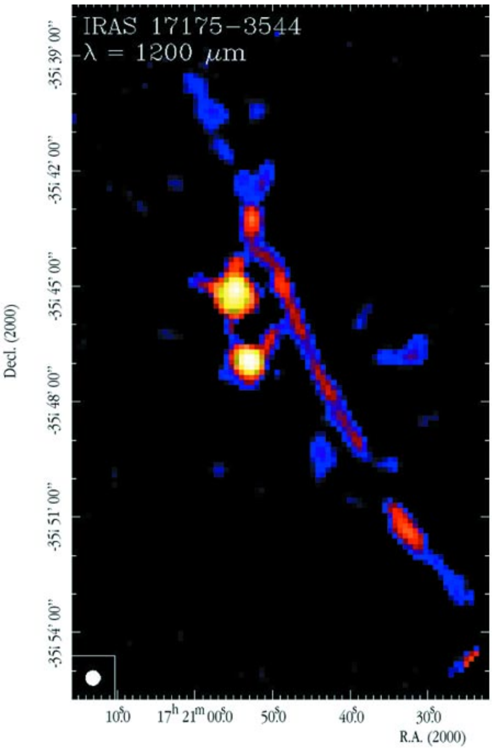
The SIMBA ("Lion" in Swahili) instrument detects radiation at a wavelength of 1.2 mm. It has 37 "horns" and acts like a camera with 37 picture elements (pixels). By changing the pointing direction of the telescope, relatively large sky fields can be imaged.

SIMBA was built and installed at the SEST within an international collaboration between the University of Bochum and the Max Planck Institute for Radio Astronomy in Germany, the Swedish National Facility for Radio Astronomy and ESO.

SIMBA is the first imaging millimetre instrument in the southern hemisphere. Radiation at this wavelength is mostly emitted from cold dust and ionised gas in a variety of objects in the Universe. Among others, SIMBA now opens exciting prospects for in-depth studies of the "hidden" sites of star formation, deep inside dense interstellar nebulae. While such clouds are impenetrable to optical light, they are transparent to millimetre radiation and SIMBA can therefore observe the associated phenomena, in particular the dust around nascent stars.

This sophisticated instrument can also search for disks of cold dust around nearby stars in which planets are being formed or which may be leftovers of this basic process. Equally important, SIMBA may observe extremely distant galaxies in the early universe, recording them while they were still in the formation stage.

Figure 1: This intensity-coded, false-colour SIMBA image is centred on the infrared source IRAS 17175-3544 and covers the well-known high-mass star formation complex NGC 6334, at a distance of 5500 light-years. The southern bright source is an ultra-compact region of ionised hydrogen ("HII region") created by a star or several stars already formed. The northern bright source has not yet developed an HII region and may be a star or a cluster of stars that are presently forming. A remarkable, narrow, linear dust filament extends over the image; it was known to exist before, but the SIMBA image now shows it to a much larger extent and much more clearly.



During the first observations, SIMBA was used to study the gas and dust content of star-forming regions in our own Milky Way Galaxy, as well as in the Magellanic Clouds and more distant galaxies. It was also used to record emission from planetary nebulae, clouds of matter ejected by dying stars. Moreover, attempts were made to detect distant galaxies and quasars radiating at mm-wavelengths and located in two well-studied sky fields, the "Hubble Deep Field South" and the "Chandra Deep Field" .

Various SIMBA images have been obtained during the first tests of the new instrument. The first observations confirm the great promise for unique astronomical studies of the southern sky in the millimetre wavelength region.

These results also pave the way towards the Atacama Large Millimetre Array (ALMA), the giant, joint research project that is now under study in Europe, the USA and Japan.

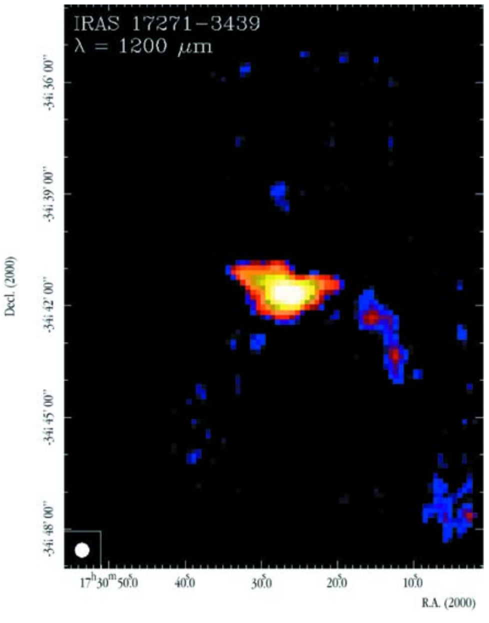


Figure 2: This SIMBA image is centred on IRAS 17271-3439 and includes an extended bright source that is associated with several compact HII regions as well as a cluster of weaker sources.

The EIS Pre-FLAMES Survey: Observations of Selected Stellar Fields

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1. Introduction

The primary goal of the ESO Imaging Survey (EIS) project is to produce data sets matching the foreseen scientific goals and requirements of different VLT instruments (e.g. Renzini and da Costa 1997) and to publicly release them prior to the commissioning and first year of operation of these instruments. With this goal in mind, for the past two years EIS has been carrying out the Deep Public Survey (DPS), an optical/infrared deep survey of high-galactic latitude fields, and the Pre-Flames (PF) Survey, a *B V I* survey of selected stellar fields, to provide suitable samples for VIMOS and FLAMES (Fibre Large Array Multi-Element Spectrograph, Pasquini et al. 2000), respectively.

FLAMES, which will be installed on the A Nasmyth platform of the VLT Kueyen telescope, consists of a fibre positioner, covering a corrected field of view of ≃ 25 arcmin in diameter, a dedicated fibre-fed spectrograph (GIRAFFE) and a fibre link to the UVES spectrograph located on the B Nasmyth platform. An important feature of the FLAMES set-up is that it will allow for simultaneous observations with both GIRAFFE and UVES. More details about FLAMES can be found in Pasquini et al. (2000) (see also the URL “http://www.eso.org/instruments/flames”). In the Medusa mode, GIRAFFE will be fed by 130 fibres 1.2 arcsec in diameter. The relatively small diameter of the fibres together with the lack of an imaging mode in FLAMES, make the preparation of target lists with accurate astrometry ($\lesssim$ 0.2 arcsec) essential in order to minimise off-centre light losses. For instance, under seeing conditions typical of Paranal (~ 0.7 arcsec), as much as ≃ 50% of the flux of an object can be lost by misplacing a fibre by ~ 0.5 arcsec. In addition, to take full advantage of GIRAFFE, multi-colour source catalogues with reliable photometry (e.g. ~ 0.03 mag at V = 20) over the large field-of-view of FLAMES are required for an adequate selection of targets for spectroscopic observations and for their subsequent analysis.

Foreseeing the need for building suitable data sets for FLAMES, ESO’s Working Group for public surveys recommended the EIS project to carry out an imaging survey of selected dense stellar fields, the so-called Pre-Flames (PF) Survey. The survey is being conducted with the wide-field imager (WFI) at the MPG/ESO 2.2-m telescope, with a field of view (34 × 33 arcmin) comparable to that of FLAMES (≃ 25 arcmin in diameter). As in the case of other public surveys carried out by EIS, the ultimate goal has been not only to gather the imaging data, but develop and test procedures to produce science grade products in the form of fully calibrated images and multi-colour stellar catalogues, from which samples for observations with FLAMES can be extracted. The survey was designed to observe a suitable number of fields for commissioning and first year of operation of FLAMES. The selected fields have surface densities > 1000 objects per square degree at the magnitude limit of FLAMES. Such fields will provide enough targets for the 130 fibres available in the Medusa mode. Considering that in a typical night the MEDUSA mode can produce around 1000 stellar spectra in five to ten different fields (Pasquini 2000), this implies that approximately 500 stellar fields per year can be observed with FLAMES. While some teams will be able to gather their own preparatory imaging data, others may have to rely on public data. To meet this potential need, a total of 160 fields were selected for observations. These were assembled from suggestions of potential users as compiled by the FLAMES team. Table 1 gives: in column (1) the type of target; in column (2) the number of fields originally selected; in column (3) the number of observed fields of each type at the time of writing; and in column (4) the completeness by type. As can be seen, the survey is nearly completed, except for Local Group galaxies and the Magellanic Clouds.

In this contribution, we present a progress report of the Pre-Flames survey reviewing the main characteristics of the first set of data recently released. A more comprehensive discussion of the reduction techniques and of the results can be found in Momany et al. (2001). The released catalogues and images can be retrieved at the URL: “http://www.eso.org/eis/”.

2. Survey Strategy

The observations for the PF Survey have been carried out using the WFI camera at the Cassegrain focus of the MPG/ESO 2.2-m telescope at the La Silla observatory. WFI is a focal reducer-type mosaic camera with 4 × 2 CCD chips of 2048 × 4098 pixels. The pixel size is 0.238 arcsec and the full field of view of the camera is 34 × 33 arcmin, with a filling factor of 95.9%. Test runs were conducted during the first semester of 1999, as part of the EIS Pilot Survey. These earlier data helped defining the observing strategy subsequently adopted in the PF survey,

Table 1: Pre-FLAMES targets.

Target (1)	Fields (2)	Observed (3)	Completion (%) (4)
Globular Clusters	32	29	90.6
Open Clusters	33	28	85.2
Milky Way Bulge/Halo	18	18	100.0
Local Group Galaxies	18	4	22.2
Sagittarius	17	17	100.0
Large Magellanic Cloud	34	15	44.1
Small Magellanic Cloud	8	3	37.5
Total	160	103	64.6

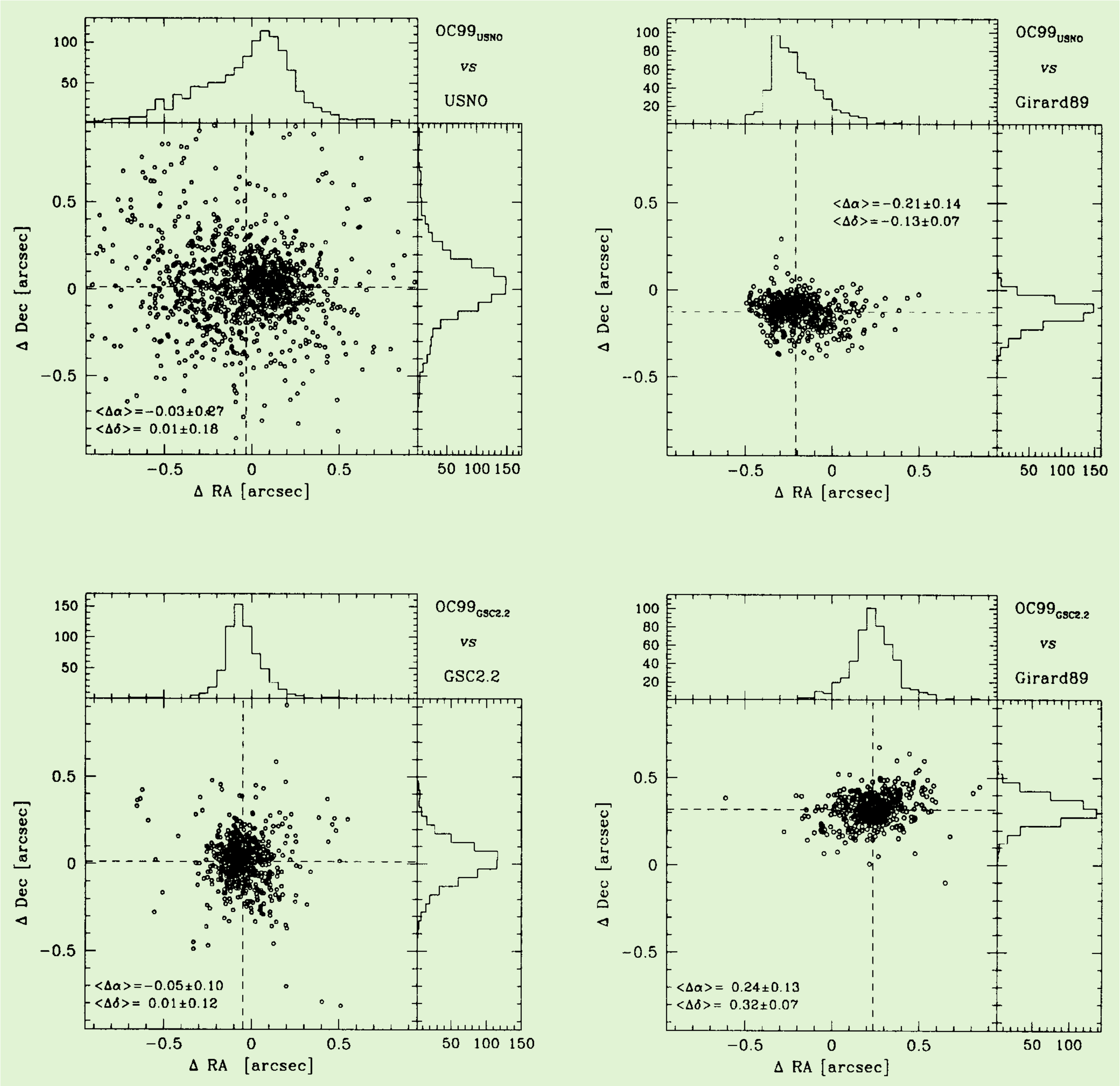

Figure 1: The two-dimensional (RA, Dec) distribution of positional residuals relative to the reference catalogue used (left panels) and the astrometric catalogue of Girard et al. (1989) (right panels) for the USNO 2.0 (top panels) and GSC 2.2 (lower panels). The vertical and horizontal dashed lines mark the mean residuals in RA and Dec after applying a 3a clipping to the data. The mean values with the final 1-σ rms are given in the figure. Also shown are the histograms of the residuals as a function of RA (top) and Dec (right).

which started in October 1999. The PF observations have been conducted in B, V and I to provide colour information for the selection of targets. The exposures were split into a short-exposure of 30 seconds (SHALLOW), to avoid saturating bright objects, and two deep exposures of four minutes each (DEEP). These are dithered by 30 arcsec both in right ascension and declination. The long exposures are sufficiently deep to reach the required signal-to-noise at the spectroscopic limit of FLAMES, while the short exposures allow one to recover saturated bright stars (a gain of ~ 4 mag). This is important because bright stars will be used as guide stars and should be in the same astrometric system as that of the target list.

Table 2: Released Fields.

EIS ID (1)	Name (2)	RA (3)	Dec (4)	Filter (5)	Seeing (6)	Detected Objects (7)
OC 3	Berkeley 20	05 32 58	+00 13 04	*B,V*	1.0	7190
OC14	NGC 2506	08 00 11	−10 47 17	*B,V*	0.9	18,900
OC12	NGC2477	07 52 17	−38 32 48	*B,V*	1.1	38,800
OC99	M 67	08 51 22	+11 49 00	*B,V*	1.1	4290
SMC 5	SMC	00 56 45	−72 19 00	*B,V*	1.3	280,000
SMC 6	SMC	01 03 35	– 72 19 00	*B,V*	1.3	246,000

3. Data Reduction

The WFI images are being processed using the new EIS pipeline described in more detail by Vandame et al. (2001) (see also Arnouts et al. 2001). The astrometric calibration performed by the pipeline makes extensive use of the method developed by Djamdji et al. (1993) based on the multi-resolution decomposition of images using wavelet transforms. As described in Arnouts et al. (2001), this package is used both to obtain a crude first estimate of a suitable reference pixel for the WFI images of each run, and an accurate determination of the astrometric solution for each image. Once an astrometric solution is found for each CCD in the mosaic, the images are corrected for the distortions and stacked. In its first implementation, the image warping was done using a *nearest neighbour* criterion to relocate the flux. More recently, the algorithm has been generalised and it is currently being tested (see below). Another issue not addressed in the first release of the PF data was the strong and variable fringing visible in the I-band images. Since the strategy adopted in the reduction of deep I-band images requires several consecutive frames, it could not be used to reduce the PF data. Therefore, the release of the PF I-band images was postponed (see below).

The source extraction and stellar photometry (PSF fitting technique) are being carried out using the DAOPHOT/ALLSTAR packages (Stetson 1987). Catalogues extracted from the SHALLOW and DEEP images are then combined to produce single-passband catalogues covering a wider range of magnitudes. Finally, these catalogues are associated to produce colour catalogues for each of the observed fields. Comparison with data available in the literature shows that a typical scatter of ≃ 0.07 mag at V ~ 20 is reached in both magnitude and colours. The measured colours are in excellent agreement with those measured by other authors in spite of the large colour term required to transform WFI instrumental magnitudes into the Johnson-Cousins system.

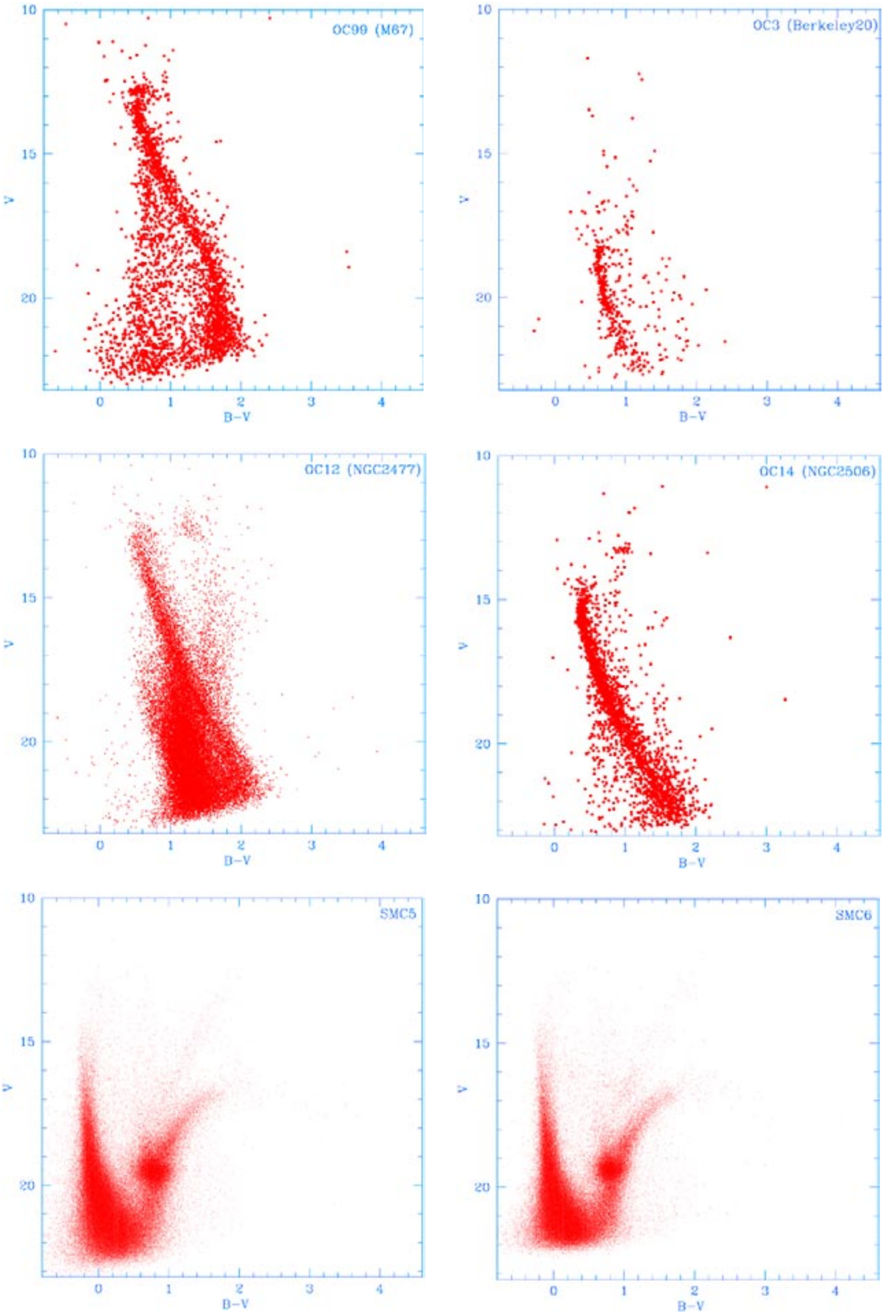

Figure 2: The CMD for the six fields presented in this paper. The CMDs have been obtained from the combination of the catalogues extracted from the SHALLOW and DEEP images, as described in the text. To minimise foreground contamination the CMDs of Berkeley 20 and NGC 2506 correspond to circular regions of 3 and 5 arcmin in radius, respectively, around the nominal centre of the cluster.

4. Astrometry

Considering the importance of an accurate astrometric solution in the preparation of target lists for any fibre system, such as FLAMES, several tests were performed in order to evaluate and fine-tune the new pipeline algorithms. A detailed discussion of the results can be found in Momany et al. (2001). One of the issues addressed was the impact that the choice of the astrometric reference catalogue may have on the final results.

To assess the accuracy of the astrometric calibration, the M 67 field was used to investigate the distribution of the positional residuals relative to the reference catalogue used and to the astrometry obtained by Girard et al. (1989), properly accounting for proper motion. Figure 1 shows these distributions for the catalogues extracted from the images calibrated using the USNO 2.0 (top panels) and the GSC 2.2 (bottom panels) as references, respectively. The left panels show the residuals of the astrometric solution, while the right panels show the comparison with the Girard et al. data.

From this figure it is easy to see that while both reference catalogues yield comparable values of the *rms*, GSC 2.2 is far superior showing no systematic effects and residual distributions in both coordinates which are well represented by a Gaussian. From the comparison with the Girard et al. data, one finds that the astrometric solution has an accuracy of $\lesssim$ 0.15 arcsec, well below the 0.2 arcsec limit imposed by FLAMES and that the internal error of the astrometric calibration is better than ~ 0.1 arcsec. Note that the mean offsets are not relevant for the preparation of target lists for FLAMES since its fibre positioner is allowed to move within a 2 arcsec window (Pasquini, private communication). It is important to emphasise that these results were obtained by re-sampling the image to avoid the discreteness effects imposed by the nearest-neighbour approach adopted in warping the image. As discussed below, this limitation has now been overcome by introducing a suite of kernels in the warping algorithm.

While the recently released GSC 2.2 catalogue yields by far the best results,

Figure 3: Colour composite Image of the B V I *exposures of the SMC 5 field covering a field of view of 34 × 33 arcmin. This image is the combination of the DEEP dithered Images. In this field the following systems are present: NGC 346 (the brightest HII region in the SMC, see Fig. 6), NGC 330 (see Fig. 7), IC 1611, NGC 306, NGC 299, OGLE 109, OGLE 119, OGLE 99.*

at the time of the data reduction it did not cover all the fields of interest. Therefore, the USNO 2.0 reference catalogue was used instead. It is worth pointing out that the astrometric accuracy obtained using the latter is still within the requirements set by the FLAMES team.

5. Survey Products

Table 2 lists the fields for which fully calibrated images and catalogues have been released. These fields were all observed during a single run in the period November 27–29, 2000. The table gives: in column (1) the EIS target identification; in column (2) the name of the primary object being observed; in columns (3) and (4) the J2000 right ascension and declination; in column (5) the filters; in column (6) the mean seeing during the exposures; and in column (7) the number of detected objects in each field.

The images already released include the combined deep *B* and *V* exposures of each field. All images are normalised to 1 second exposure, and are presented in the TAN projection. In the data release, the science images have been combined with their corresponding weight-maps into a single fits file containing two image extensions. In addition to the pixel maps, the following catalogues are also available: (1) three catalogues for each pass-band: the SHALLOW, the DEEP and the combined catalogues, listing instrumental magnitudes, all in ASCII format; (2) a calibrated *B V* colour catalogue available in three different formats: a FLAMES input file, a SKYCAT input file and a normal ASCII file.

In order to illustrate the scientific potentiality of the data, Figure 2 shows the colour-magnitude diagram (CMD) for each of the observed fields. The CMDs include all the detected objects within the area covered by WFI, except for Berkeley 20 and NGC 2506. For these two cases the CMDs were computed using objects within a circular region of 3 and 5 arcmin in radius, respectively, around the nominal cluster centre in order to minimise foreground/background contamination. Figure 2 shows systems with well-defined main-sequences, probable binary sequences, blue straggler populations, red clump stars, potential white dwarf candidates, very red objects and systems with composite stellar populations, including very young stellar associations. The different pointings also provide valuable data for galactic structure studies.

Figure 4: Same as in Figure 3 for the open cluster OC 26 (NGC 6253).

Even though still a small sample, the examples presented here show the large variety of stellar systems being observed by the PF survey in terms of age, metallicity, size, distance and environment. The wide-area and the extended magnitude coverage (~ 13 mag) down to V ~ 23 provide an invaluable data set to extract samples suitable for the scientific drivers of FLAMES which include, among others, studies of: chemical abundances of stars in clusters and selected galactic components (bulge, disk, and halo); stellar kinematics and structure of stellar clusters; chemical composition and dynamics of nearby dwarf spheroidal galaxies; circumstellar activity in young stellar objects; very low mass stars and brown dwarfs in star-forming regions. In addition, the PF survey data can be combined to other publicly available data sets (e.g. 2MASS) which can greatly enhance the scientific value of the survey (see Momany et al. 2001). Moreover, combining the optical and infrared data may also allow for the spectral classification of objects by matching the photometric measurements against template spectra (Hatziminaoglou et al. 2001, submitted). This may help further disentangle different populations and search for particular types of stars.

7. Recent Developments

As mentioned above, at the time of the first release of the PF data there were two problems which had not been adequately addressed: a more general warping algorithm, to overcome the discreteness effects of the nearest-neighbour approach, and the fringing correction of the I-band images. In addition, the performance of the astrometric algorithm for very dense globular clusters had not been tested. These problems have now been addressed and the new algorithms are currently being tested. To illustrate the results of these tests, Figures 3–5 show colour images, covering 34 × 33 arcmin, of fields of different stellar density: a SMC field, an open cluster and one of the closest globular clusters. These images are the combination of the *B V I* DEEP images produced using the new warping algorithm. It is interesting to note the large number of stellar systems seen in the SMC field, among them: NGC 346, NGC 330, IC 1611, NGC 306, NGC 299, OGLE 109, OGLE 119, OGLE 99 (e.g. Bica & Dutra 2000 for an updated census of star clusters in the SMC). Figures 6–7 show cutouts around two of these systems. Note the absence of any detectable colour gradient in the images of the objects over the entire field of view. This result shows that the images in different passbands are accurately registered, attesting to the internal accuracy of the astrometric solution.

Figure 5: Same as in Figure 3 for the globular cluster GC 10 (NGC 6121).

The algorithms developed to deal with the PF survey data are currently being incorporated into the EIS survey system framework. This should allow the efficient reduction of all of the remaining data gathered by this survey. Current estimates of the pipeline throughput indicate that the image reduction part of a PF field takes about 23 minutes, not including overheads, well matched to the observing data rate. Once incorporated into the EIS data flow, it will be possible to reduce the images for the entire survey in ~ 40 hours.

Recently, new data from the PF survey as well as data publicly available in the archive have been used to further test the performance of the algorithms for a broader range of stellar densities, different observing strategies and filter combination. Some of these fields are shown in Figure 8, to illustrate the variety of systems considered so far. The ongoing tests have shown that the algorithms being implemented are robust and fast.

8. Summary

Based on the results presented so far and from the progress of the observations, the following goals of the survey have been met: (1) an astrometric accuracy better than ~ 0.10 arcsec; (2) a photometric accuracy below ~ 0.10 mag at the magnitude limit of FLAMES; (3) a completion level above 80% for the galactic fields; (4) a sufficient number of fields for commissioning, science verification and first year of operation. Equally important is that the new algorithms developed have proven to be robust, general and efficient, properly handling crowded stellar fields.

The PF survey has already covered 103 fields, corresponding to a total area of ~ 30 square degrees, surveying a variety of stellar systems and different directions of the Galaxy. The accumulated *B V I* data represent a valuable homogeneous dataset, with the final colour catalogues spanning almost 13 magnitudes. These data provide a wealth of information which can be used not only for the selection of FLAMES targets but also for a variety of other studies. It is important to emphasise that even though the filters being used are not standard for galactic work, the colour transformations seem to be adequate for most purposes. Finally, it is worth reminding that all the PF data will be publicly available before

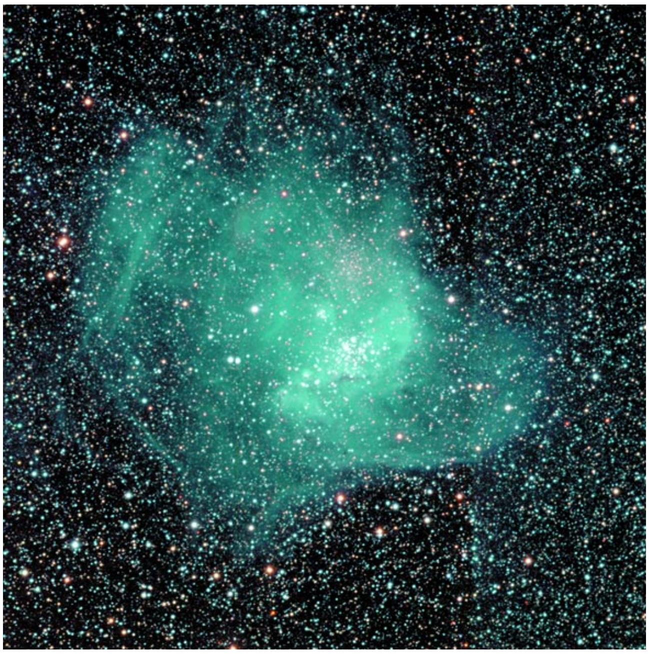

Figure 6: Expanded view of NGC 346, the brightest HII region in SMC, extracted from the colour image shown in Figure 3. The figure shows a 8 × 8 arcmin region.

Figure 7: Expanded view of the globular cluster NGC 330 extracted from the colour image shown in Figure 3. The figure shows a 4 × 4 arcmin region. The seeing is ~ 1.3 arcsec.

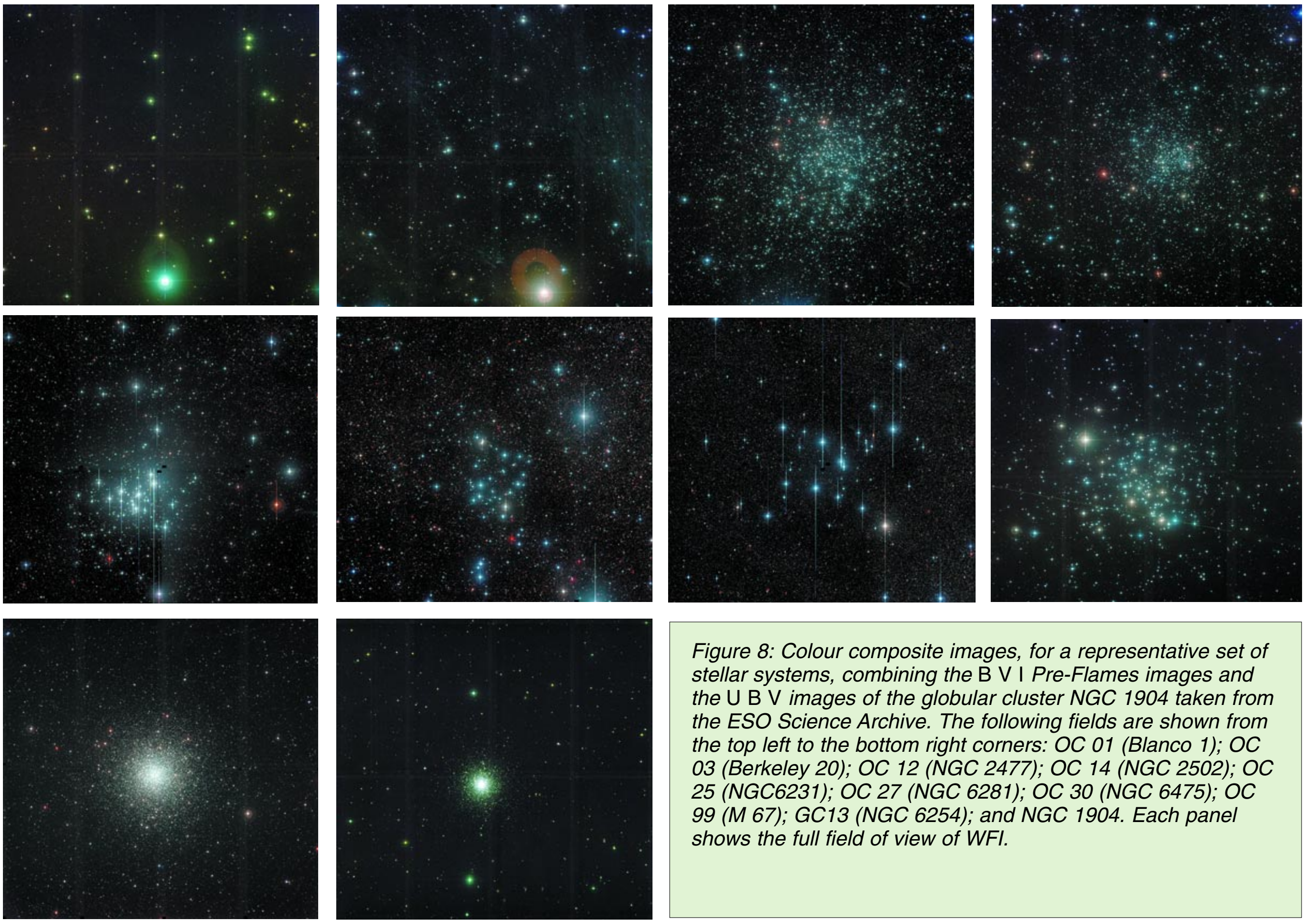

Figure 8: Colour composite images, for a representative set of stellar systems, combining the B V I *Pre-Flames images and the* U B V *images of the globular cluster NGC 1904 taken from the ESO Science Archive. The following fields are shown from the top left to the bottom right corners: OC 01 (Blanco 1); OC 03 (Berkeley 20); OC 12 (NGC 2477); OC 14 (NGC 2502); OC 25 (NGC6231); OC 27 (NGC 6281); OC 30 (NGC 6475); OC 99 (M 67); GC13 (NGC 6254); and NGC 1904. Each panel shows the full field of view of WFI.*

the beginning of operations of the FLAMES facility.

We would like to thank Luca Pasquini and Alvio Renzini for their support and input to the Pre-Flames survey, and to the several people that contributed in the selection of the fields.

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The XMM Large Scale Structure Survey and its Multi-λ Follow-up[1]

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Abstract

We present a unique European project which aims at mapping the matter distribution in the distant universe from hundreds of megaparsecs to galaxy scales. This comprehensive scientific approach constitutes a new step in the synergy between space- and ground-based observatory resources and therefore a building block of the forthcoming Virtual Observatory.

1. The New Generation of Surveys

Over the last two decades there has been tremendous growth in effort to systematically map the matter distribution in the universe. This has been motivated by questions which are fundamental to cosmology. Firstly, how much matter is there; secondly, what form does it take; and thirdly, how is it distributed? The first two questions directly relate to the mean cosmic density, a parameter that governs the eventual fate of the universe. It has been convincingly argued that up to 90% of the existing matter may be invisible, possibly non baryonic, and only detectable through its gravitational effects. At the same time, there is increasing evidence that a significant fraction of the "normal" matter may be hidden in obscured objects as well as in warm diffuse intergalactic clouds.

The third question relates directly to the origin and evolution of the large-scale distribution of matter, and this issue is still open to considerable debate. Although the universe appears homogeneous and isotropic on the largest scales, local surveys of galaxies have revealed the existence of foam-like structure. Galaxies are confined within sheets and filaments surrounding large "voids" with scales of 100 h^{-1} Mpc. Galaxy clusters are usually located at the intersections of these sheets and filaments. In the current standard theoretical paradigm, structure originated in the very early universe and is observed directly at an early time in the cosmic microwave background radiation (CMB). It was subsequently amplified, first by gravity and then by the effects of galaxy formation to produce the presently observed structure. The present-day "cosmic web" is therefore shaped by the details of several key cosmological processes. It depends upon the process which first originated structure, on the nature and amount of dark matter, on the nature of galaxy formation and on the specific values of cosmological parameters. Because of this, observational studies of large-scale structure (LSS) constrain these processes and parameters, complementing observations of the CMB and of constraints from supernovae (SN) on the cosmic expansion rate. Observations of large-scale structure are therefore a key element in our global understanding of the universe.

The most direct way to study LSS is to map the galaxy distribution over a large area of sky and to considerable depth, the strategy adopted by the Sloan, 2dF and VIRMOS surveys. This gives the best possible mapping of structures traced by galaxies, together with strong constraints on models for structure evolution. Unfortunately, it is extremely data-intensive. Moreover, the results depend on both the global cosmological parameters and the details of galaxy formation. Breaking the degeneracy between these two factors is nontrivial. The study of structure using only clusters of galaxies can offer significant advantages both because it is easier to define a complete sample of objects over a very large volume of space and because the objects themselves are in some respects "simpler" to understand (at least in terms of their formation and evolution). Consequently, with currently available observational resources, larger volumes of the universe can be studied to substantially greater depth, and the interpretation of the results is less dependent on models of how galaxies form. *Such studies can independently check cosmological parameter values determined from the CMB and SN studies, can break the degeneracy between the shape of the power spectrum and the matter density, and can check other fundamental assumptions of the standard paradigm (e.g. that the initial fluctuations were gaussian).* Unfortunately, clusters of galaxies become increasingly difficult to identify optically with increasing distance because their contrast against foreground and background galaxies is strongly reduced. This has greatly hampered investigations of high-redshift optically selected clusters.

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[1] http://vela.astro.ulg.ac.be/themes/spatial/xmm/LSS/index_e.html

On the other hand, X-ray observations are well suited for detecting distant clusters: cluster emission is extended and so easily distinguishable from (point-like) QSOs, and confusion and projection effects are negligible. Following on from the REFLEX cluster survey, based on the ROSAT All-Sky-Survey (Guzzo et al. 1999, Böhringer et al. 2001), and taking advantage of the unrivalled sensitivity of the XMM-*Newton* X-ray observatory, we have designed an XMM wide area survey with the aim of tracing the large-scale structure of the universe out to a redshift of z ~ 1–2 as traced by clusters and QSOs: the XMM-LSS Survey (Fig. 1).

The X-ray survey is coupled with an extensive follow-up programme of radio, optical and IR observations. Our approach makes full use of the current range of European and other observational facilities to observe the survey region over the widest possible range of wavelengths. Especially, *extensive and high-quality optical information – imaging and spectroscopy – is crucial for the success of the programme.* As a result, we will be able to identify clusters with unprecedented efficiency and reliability. In addition, our multi-wavelength observations of the XMM-LSS sources (clusters and AGNs) will form the basis of a uniquely comprehensive study of the evolution of the structure of the universe from hundreds of Mpc down to galaxy scales. For the first time, it will be possible to map and study the distributions of hot gas, luminous galaxies, and obscured or dark material in a coherent way. We will compare the results of our observations with the predictions of various cosmological scenarios using extensive numerical simulations generated as part of our programme.

The wide scope of the project has motivated the set-up of a large consortium in order to carry out both the data reduction/management and the scientific analysis of the survey. The XMM-LSS Consortium comprises the following institutes: Saclay (Principal Investigator), Birmingham, Bristol, Copenhagen, Dublin, ESO/Santiago, Leiden, Liège, Marseille (LAM), Milan (AOB), Milan (IFCTR), Munich (MPA), Munich (MPE), Paris (IAP), Santiago (PUC) as well as two US Scientists, S. Snowden (NASA/GSFC) and G. Bryan (MIT). The XMM-LSS team has also a well-defined collaboration with the SWIRE SIRTF Legacy Programme team (PI, C. Lonsdale).

2. The XMM Large-Scale Structure Survey

2.1 The survey design

The survey consists of adjacent 10 ks XMM pointings, separated by 20′. It will ultimately cover a region of 8 × 8 sq. deg. to a mean sensitivity of about 3 10^{-15} erg/s/cm^2 for point sources in the [0.5–2] keV band (with a deeper central 2 sq. deg. area). This makes the XMM-LSS some 1000 times more sensitive than the REFLEX survey and the only wide area X-ray deep survey for the coming decade. There are no prospects for a comparable survey with the forthcoming X-ray missions currently under study such as XEUS or Constellation-X. The XMM-LSS field is located around RA = 2 h 20 m, Dec = –5 deg. Out of the 300 expected sources per square degree, about 15 will be clusters of galaxies, 200 active nuclei, and the rest, nearby galaxies and stars. A histogram of the predicted cluster redshift distribution is shown on Figure 2.

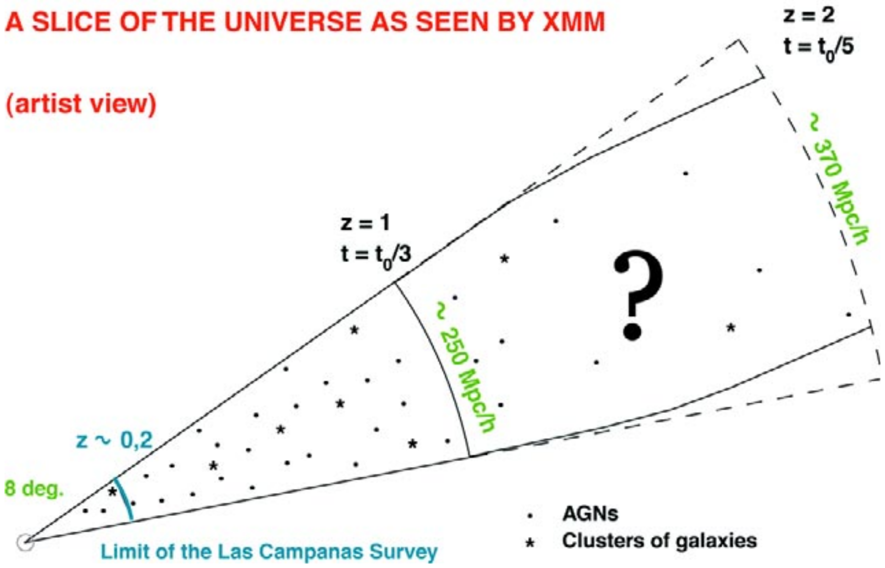

Figure 1: An artist view of the XMM-LSS. Transversaeal distances are in comoving units. QSOs should be discovered out to a redshift of ~ 4. Some 300 sources per square degree are expected, with a density of about 15 clusters per square degree. For the first time, a huge coherent volume of the distant universe will be uniformly sampled.

2.2 Basic follow-up

In order to ensure the necessary identification and redshift measurement of the X-ray sources, we have started an extensive multi-wavelength follow-up programme. Optical and NIR imaging has been initiated at CFHT and CTIO and will be continued with the 2nd generation of wide-field imagers such as MegaCam[2] and WFIR (CFHT) and the NIR camera to be installed at UKIRT. The survey field would be an ideal initial target for VISTA (ESO/UK). Subsequent spectroscopic identifications and redshift measurements will mainly be performed by the VLT/VIRMOS instrument at ESO and other 4–8-m-class telescopes to which the consortium has access. The goal is to obtain redshifts for all detected clusters and for a representative selection of the QSO population. The complete survey region is being mapped using the VLA at 74 MHz and 325 MHz.

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[2] http://www.cfht.hawaii.edu/Instruments/Imaging/Megacam

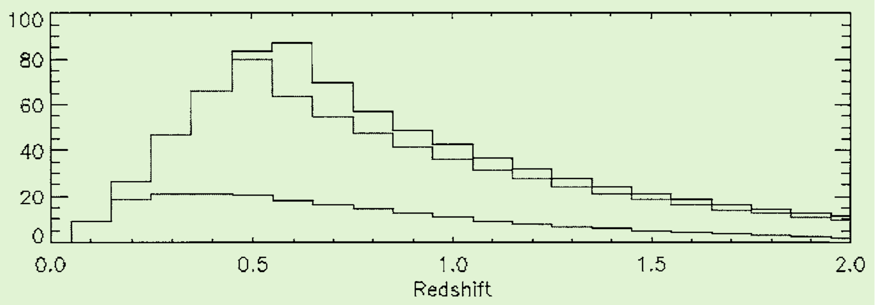

Figure 2: The predicted XMM-LSS cluster redshift distribution, computed using the local cluster luminosity function and properties; redshifted thermal spectra convolved with the XMM response were simulated, source number counts were computed and, finally, these were compared to the survey sensitivity limit. Three detection bands are shown ([2–10], [0.6–8] and [0.4–4] keV, from bottom to top respectively). The [0.4–4] keV band is the most sensitive for clusters, whereas the hardest one is quite inefficient since the majority of the cluster/group population has a temperature of the order of 2–3 keV (rest frame). Up to 800 clusters are expected out to z = 1 and of the order of 100 between 1 < z < 2 (if there is no evolution).

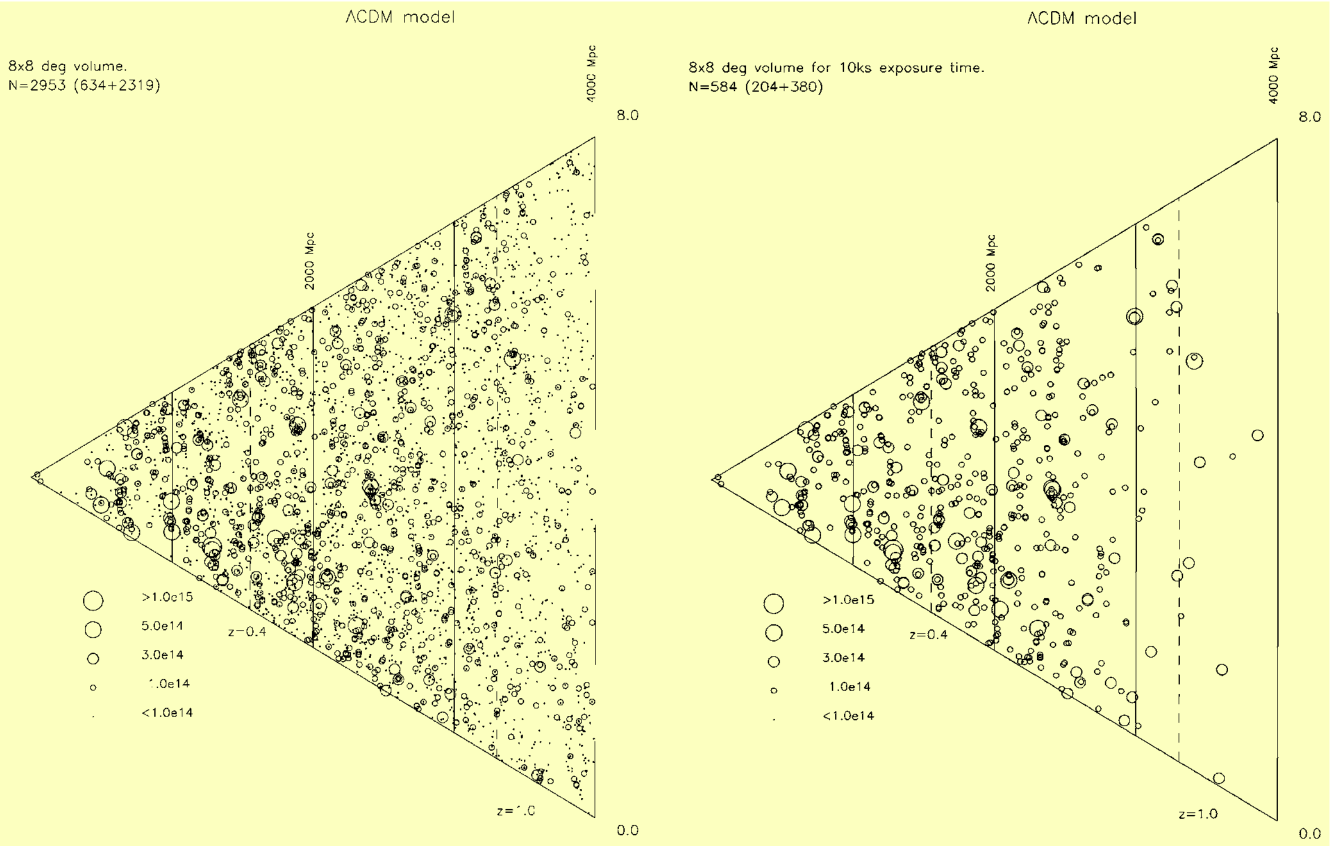

Figure 3: Simulation of the XMM-LSS cone, using the Hubble Volume[3] Lightcone cluster catalogue for a ΛCDM model. Symbol sizes indicate cluster masses. Together with Figure 2, this wedge diagram shows, in a striking manner, how the XMM-LSS will provide the next hierarchical step as compared to traditional galaxy surveys. Points are now galaxy clusters, the size of point indicating the cluster mass which are the carriers of a cosmologically significant parameter: their mass. Predicted numbers of clusters in the 0 < z < 0.5, 0.5 < z < 1 bins are given in brackets. Left: the cluster distribution; cosmic evolution can be appreciated from the decrease of the number density of massive clusters at high redshift. Right convolution by the XMM-LSS selection function: only massive clusters are detectable at high redshift. (Valtchanov et al. 2001, Virgo)

2.3 Data release

A first version – quality certified – of *the multi-λ XMM-LSS catalogue will be released to the international community* no later than one year after the completion of the XMM AO1 observations (2003) and will be subsequently updated on a yearly basis as the X-ray coverage and associated follow-up proceed. The public version of the catalogue will be hosted at Centre de Données de Strasbourg.

3. Expected Science

The survey has been designed to have sufficient depth and angular coverage to enable the determination of the cluster 2-point correlation function in two redshift bins (0 < z < 0.5, 0.5 < z < 1) to an accuracy of better than 15% for the correlation length. In more qualitative terms, we shall obtain a 3D map of the deep potential wells of the universe within an unprecedented volume. Beside these main goals, we can also address several other *key cosmological issues* as well as any question related to *serendipitous science* using our multi-wavelength data set.

– The survey is deep enough to allow a search for massive ($L_{2-10\ \mathrm{keV}} \sim 3\ 10^{44}$ erg/s) clusters out to a redshift of ~ 2 (Fig. 2). The number density of such systems is of key importance since the cosmological constraints provided by the cluster number density evolution are complementary to those of LSS.

– We shall compute, to a high degree of accuracy, the 2-point correlation function of X-ray QSOs out to z ~ 4.

– The study of the combined X-ray/optical/radio evolution of clusters and QSOs, of their galaxy content and of their environment is another obvious by-product of the XMM-LSS. This is particularly important at redshifts above 1, where galaxy and cluster mergers are expected to be more common and star formation is more pronounced than in the local universe. Indeed, preheating and shocks are thought to influence the ICM properties of forming clusters. Moreover, these effects are redshift dependent since cluster sizes, densities and temperatures are expected to vary as a function of redshift, on a purely gravitational basis. Although there is both theoretical and observational evidence for traces of feedback in the low-redshift cluster population (e.g. David et al. 1993, Metzler et al. 1994), its influence needs to be assessed and quantified at earlier times (Menci & Cavaliere 2000). The radio data provide an important source of complementary information for our understanding of merger processes, as well as probing the magnetic fields and high-energy particles in the clusters which affect the state of the ICM.

– Finally, it will be possible to see how the QSO population fits into the LSS network defined by the cluster/group population. This will directly complement the understanding of AGN in terms of unification schemes. Indeed, these schemes alone do not explain the observed strong QSO clustering, or the fact that BL Lac objects (for example), are preferentially found in clusters or groups (Wurtz et al. 1997). The environmental properties of AGNs, as supplied by our survey are key to understanding their formation. In addition, the XMM-LSS data set will also provide decisive statistical information regarding the effect of gravitational lensing on QSO properties.

3.1 Advanced follow-up

Subsequently to the core programme science, a detailed follow-up will be undertaken for objects that appear espe-

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[3] http://www.physics.lsa.umich.edu/hubble-volume

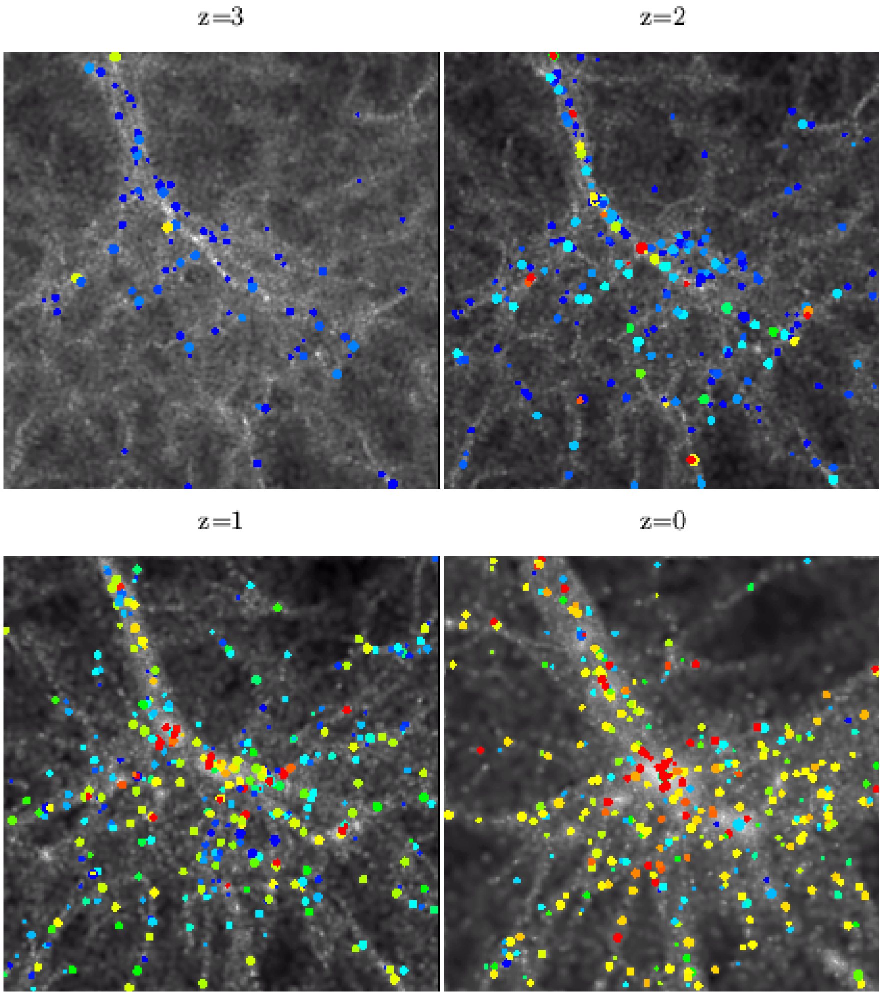

Figure 4: This simulation, performed by the MPA group, nicely illustrates one major goal of the XMM-LSS/SWIRE collaboration: the study of the evolution of structure from large scales (the images here are 40 Mpc across ; the XMM-LSS will encompass scales more than 10 times larger at $z = 1$) down to individual galaxies. The combined data set will provide the an ideal playground resource to study all kinds of environmental aspects. In these images the dark matter distribution is represented in grey-scale while galaxies are represented by the coloured symbols with symbol size corresponding to stellar mass and symbol colour to specific star-formation rate. The hot gas was not followed explicitly in this simulation but other simulations from MPA and elsewhere show it to follow the dark matter closely, being especially bright (in X-rays) at the filament intersections where galaxy clusters form. The evolution of structure and of the galaxy population from redshift 3 to 0 are clearly visible. This particular simulation assumed a critical density universe (τCDM, $\Omega = 1$, $\Gamma = 0.21$, $\sigma_8 = 0.6$). Evolution is much slower in simulations of low-density universes (Kauffman, Colberg, Diaferio, White 1999).

cially relevant to other cosmological studies.

– For example, deep XMM pointings will be used to study complexes of high-z forming clusters (Pierre et al. 2000).

– Also, the expected high density of QSOs in the survey will allow us to derive a detailed 3D picture of the baryon distribution from high-resolution optical spectroscopy of the Lα forest (e.g. Cen & Ostriker 1999).

– The deep and high-quality optical coverage of the entire 64 square degree area by MegaCam will enable an unprecedented weak-lensing analysis[4]. The cosmological implications of the results will be directly compared to the constraints derived from the XMM-LSS cluster sample.

– Sunyaev-Zel'dovich observations (S-Z) are also planned. Clusters in the XMM-LSS field will be targets of the prototype OCRA (One-Centimetre Radiometer Array) instrument from 2002. The full XMM-LSS field will be mapped by the complete OCRA, and will be an early target of the Array for Microwave Background Anisotropy (AMiBA) after 2004. This will enable a statistical analysis of the physics of the ICM as a function of redshift. In the long term, these observations will also provide invaluable information on the low-density structures such as cluster outskirts and

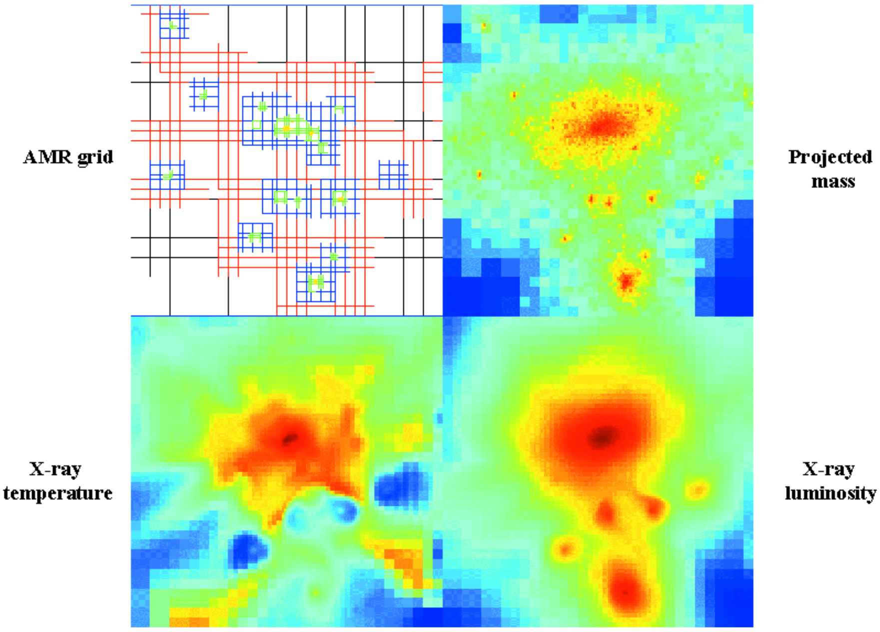

Figure 5: This simulation (12.5 h^{-1} Mpc a side) represents a cluster of galaxies of 7 10^{14} solar masses. It has been performed by RAMSES, an adaptive mesh refinement code recently developed at CEA Saclay and designed to study the formation of large-scale structures in the universe with high spatial resolution. The upper left panel shows the resolution of the simulation grid which automatically follows density contrasts. The upper right panel is the resulting projected mass, which is especially relevant for comparison with weak lensing analyses. The lower panel shows the predicted X-ray properties of the cluster; merging sub-groups have clearly lower temperatures than the central main body. Such simulations are essential to understand the observed global properties of clusters; in particular how physical processes such as cooling or feedback from early star formation, modify the properties of the intracluster medium with respect to what is expected from a pure gravitational evolution. The understanding of these phenomena is necessary to relate the evolution of the observed properties of clusters to cosmology (Teyssier 2001).

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[4] http://terapix.iap.fr/Descart/

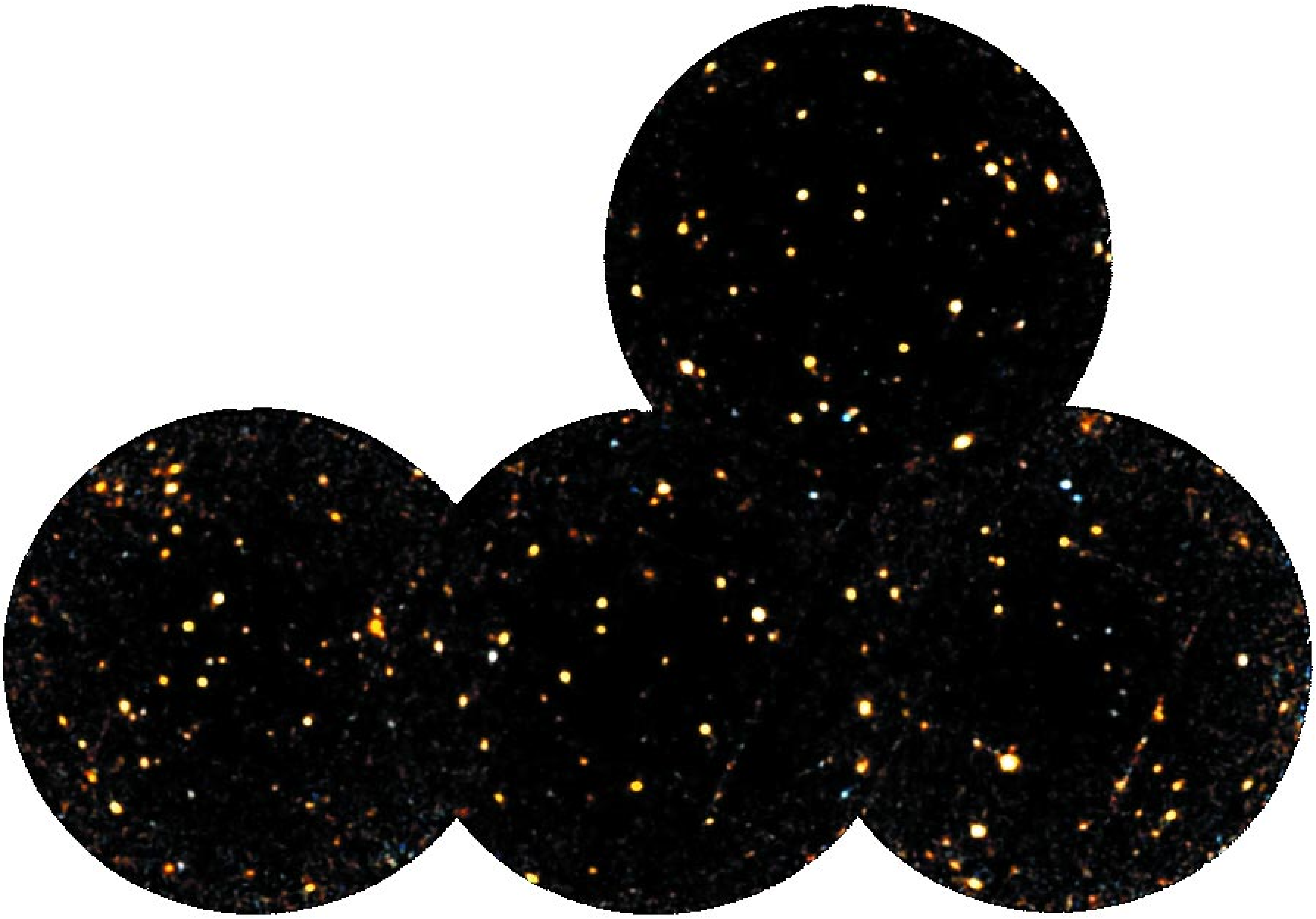

Figure 6: First XMM pointings of the survey obtained during the Guaranteed Time part of the programme owned by the Liège/Milano/Saclay groups. This preliminary mosaic in true X-ray colours is a fraction of the central deeper 2 sq.deg. area; red: soft sources (< 2 keV), blue: hard sources (> 2 keV). The individual images have a diameter of 25 arcmin and the exposure time is 20 ks on each field. The source density is found to be ~ 600 / sq.deg. in the [0.5–2] keV band (Valtchanov et al. 2002, in preparation). [Based on observations obtained with the XMM-Newton observatory, an ESA science mission with instruments and contributions directly funded by ESA Member States and the USA (NASA).]

their connections to the cosmic filaments. These measurements are complementary to the X-ray and weak lensing data regarding the masses of clusters and the structure of the hot gas they contain. The three data sets together should provide an independent and direct check of the extragalactic distance scale.

3.2 Associated SIRTF Legacy Programme

The SIRTF Wide-area InfraRed Extragalactic Survey (SWIRE[5]) will cover 10 sq.deg. of the XMM-LSS in 7 wavebands from 4 to 160 μm. The estimated IR source numbers in this area are around 20000/900/250 and 700/50/500 for starbursts/spiral-irregular/AGN in the $0 < z < 1$ and $1 < z < 2$ redshift intervals, respectively.

The coordinated SWIRE observations will clarify an important aspect of environmental studies: how star formation in cluster galaxies depends on the distance to the cluster centre, on the strength of the gravitational potential, and on the density of the ICM (as inferred from the X-ray data). Galaxy environment and optical spectroscopic properties will be the main parameters in modelling IR activity. Here also, the location of IR AGNs within the cosmic web will help establish their nature. The combined X-ray/FIR observations will also provide invaluable information regarding the existence and properties of highly obscured AGNs. Finally, a comparison of the LSS distribution of matter given by the X-ray (hot matter), IR (obscured matter) and weak lensing (dark matter) analyses will help understand bias mechanisms as a function of environment, scale and cosmic time.

4. Simulations

Our consortium has carried out extensive simulations in order to optimise the scientific outcome of the survey. We illustrate this by three examples focussing on some of the main goals of the XMM-LSS: Figures 3, 4, 5.

5. A Glimpse to of the First Observations

The first XMM observations were performed in July 2001 in excellent conditions. A pre-view is presented on Figure 6.

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[5] http://www.ipac.caltech.edu/SWIRE

Report on the FLAMES Users Workshop (FUW)

J.R. WALSH (ESO), L. PASQUINI (ESO), S. ZAGGIA (ESO and Trieste)

Following the precedent set by the Potential Users of UVES (PUU) workshop held at ESO in 1998, it was decided to hold a similar-style workshop for FLAMES. FLAMES (Fibre Large Array Multi-Element Spectrograph) is the ESO VLT multi-object fibre facility which is under construction and expected to be released to the user community in 2002. FLAMES itself is a ‘facility’ consisting of a Nasmyth corrector for the full 25-arcmin field, the OzPoz fibre positioner, being built under contract by a consortium from the Anglo-Australian Observatory and Mount Stromlo and Siding Spring Observatory, the optical spectrometer Giraffe under construction by a team from Observatoire de Paris-Meudon (OPM) and a fibre link from the OzPoz positioner to UVES. A team from the Geneva and Lausanne observatories is providing the pipeline reduction software for Giraffe and another consortium (ITAL-FLAMES) from the observatories of Bologna, Cagliari, Palermo and Trieste is providing instrument control software and the pipeline for UVES fibre reduction. The complexity of this instrument and the need to introduce users to techniques for its full utilisation demanded an introductory workshop. The FLAMES Users Workshop (FUW) was held at ESO Garching on 9 and 10 July with a total of 60 contributors mostly from the ESO member states and including the UK and Australia. The aim was both to prepare the community for use of this complex facility and hopefully to encourage collaborations between participants as a result of the interaction.

The Workshop consisted of six sessions: an introduction to the instrument and its software; an outline of the observing plans by the instrument consortia for use of their guaranteed time; there were scientific sessions devoted to Galactic programmes, Local Group and extragalactic science; the workshop closed with a round-table discussion. We summarise the contents of the workshop and focus on a few highlights.

Instrument + Software

Luca Pasquini is the instrument scientist for FLAMES and outlined the components of the facility (see the FLAMES Web page for full details http://www.eso.org/instruments/flames/). Since the preliminary acceptance of the instrument modules will not take place before September 1 2001, then FLAMES cannot be offered for visitor or service observing in Period 69. The earliest that it will be offered will be in Period 70 with the call for proposals of March 2002. As well as the instrument capabilities, of most interest to potential observers are the constraints on observation. Owing to the need to obtain calibration data for each set-up, the number of spectrometer set-ups per night will be limited. Another limitation is the available time a given set-up can be retained without the field rotation and atmospheric refraction losses for the single object (1.2 arcsec diameter) fibres (MEDUSA mode) resulting in substantial throughput loss. A fundamental step is the fibre allocation to astronomical objects and the AAO 2dF fibre-allocation software has been adapted for FLAMES (FPOSS); Manuela Zoccali (ESO) described its use (see Fig. 1). This is an interactive tool to allow users to plan their observations. It will also be employed to set up the fibre assignments at the telescope for users in visitor mode.

Simone Zaggia described the progress made on the ESO 2.2-m WFI imaging survey of high priority fields for FLAMES. A number of fields in the Galactic Bulge and Halo, several globular and open clusters, Local Group galaxies including Sagittarius and the Magellanic Clouds have been selected. Service observations have been made and the EIS team have produced catalogues with the astrometric accuracy required to allow MEDUSA fibre assignments (typically ± 0.2 arcsec). These catalogues are publicly available and will provide for the needs of a substantial fraction of the community in their first use of this instrument. Full details can be found on the FLAMES Web page (http://www.eso.org/eis/) and also in the article on the EIS release in this edition of *The Messenger*. A first release of images and catalogues for some of the Pre-FLAMES fields has already been made.

Since many hundreds to thousands of spectra can be taken per night, then traditional interactive analysis will not be realistic and pipeline methods are mandatory. Following the example of the 2dF project, pipeline-reduced spectra will be delivered and André Blecha (Geneva) described the Geneva-Lausanne consortium Data Reduction Software (DRS). Going one step further than removal of the instrument signature, an Ancilliary Data Reduction software package (ADAS) is being written to catalogue spectra, such as providing radial velocities, line indices, etc. This task is being undertaken by a collaboration between the OPM and Geneva-Lausanne groups and Frédéric Royer outlined its scope. Andrea Modigliani (ESO), who is responsible for the UVES pipeline, described the pipeline software for extracting the eight spectra (of which one can be a simultaneous calibration fibre) when the red arm of UVES is fed by fibres from OzPoz.

The most successful wide-field multi-object spectrometer is the AAO 2dF, and Matthew Colless presented a very sobering ‘Lessons Learned’ talk. FLAMES is a simpler system than 2dF which has 400 fibres and a top-end configuration but it will still have to face the realities of working with fibres, such as breakages and recovery from problems with “lost” fibre buttons. Among the frequently made mistakes are too few guide stars or guide stars too faint, too few sky fibres being allowed (a good rule of thumb is (total no. fibres/2)$^{2/3}$), inadequate calibrations and over-optimism about precision of flux calibration.

Consortium Guaranteed Time Projects

The OHP team, led by François Hammer, are concentrating on a few topics on the theme of the stellar component to galaxies. From chemical abundances of individual stars in local dwarf galaxies, to globulars in nearby galaxies to kinematics in high-redshift galaxies, a variety of programmes were sketched with emphasis on using the 15 small Integral Field Units (mini-IFU’s with 20 fibres and a field of 3.1 × 2.1arcsec) for collecting the light of small galaxies. Among the projects of the Geneva-Lausanne group are the presence of B stars in Magellanic Cloud clusters and velocity fields of galaxies acting as lenses to compare the lensing mass with the kinematic mass. Using the large integral field unit (ARGUS 10.4 × 7.8 arcsec field with 300 0.52-arcsec pixels) mapping of the kinematics and spatial variation of abundances in HII galaxies will be undertaken. Carla Cacciari outlined the projects of the ITAL-FLAMES consortium which cover topics from chemistry and dynamics of Galactic glob-

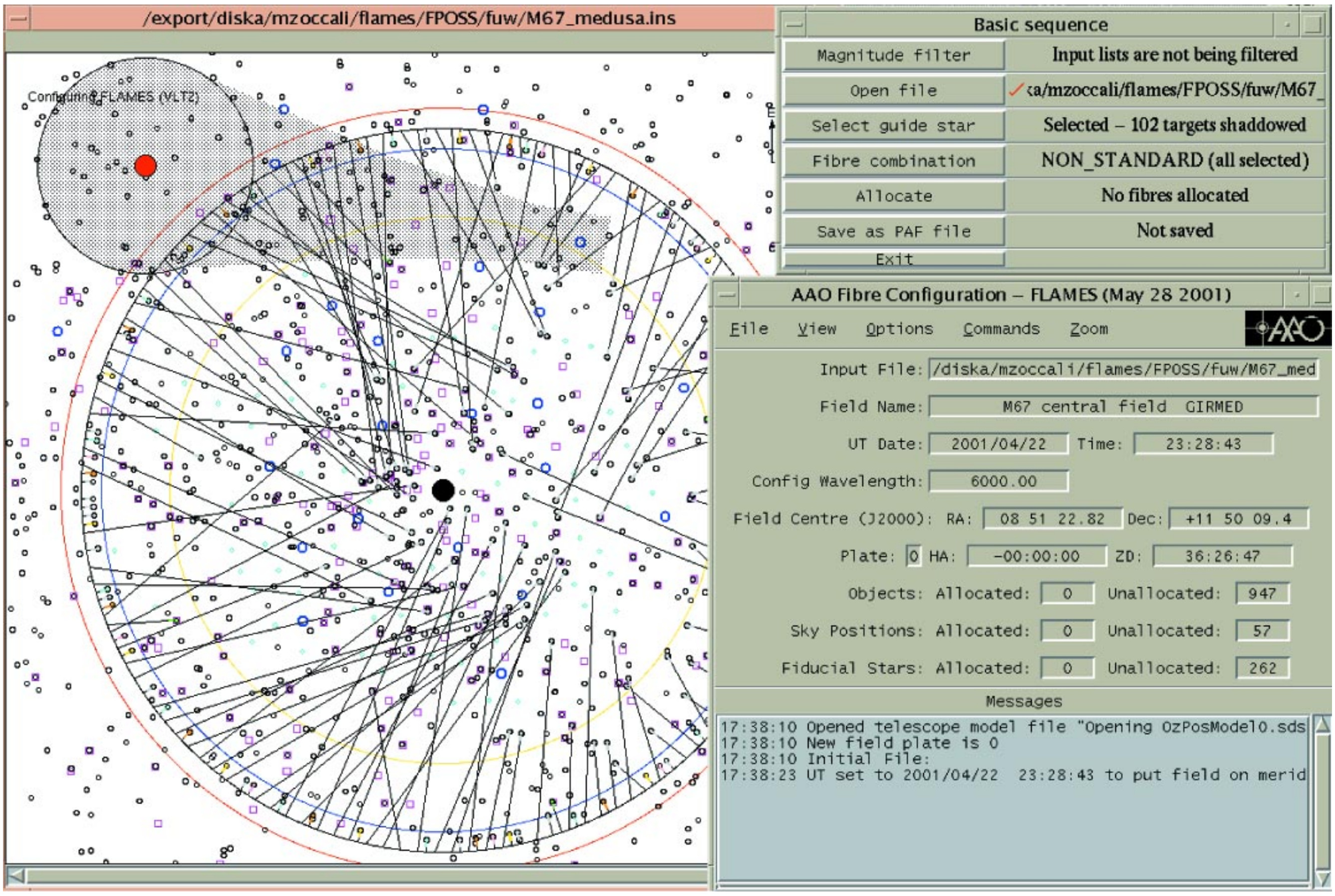

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Figure 1: An example session of the FLAMES FPOSS fibre configuration software is shown. The star positions are taken from an input catalogue for the open cluster M67 and are indicated as small blue lozenges. The black circular area in the middle is the area obscured by ARGUS, and the blue circle traces the 25 arcmin diameter field. The shaded area at the top corresponds to the region obscured by the VLT guide probe. The VLT guide stars in the field are shown by large blue open circles. The catalogue stars assigned by fibres are shown as black open circles at the end of the solid lines, which represent the assigned fibres from the outer annulus. The fibres should be as close as possible to the radial direction (to minimise fibre bending). Squares correspond to positions suitable for sky fibres. The control panels can be seen to the right of the figure.

ular clusters and Local Group dwarf galaxies to the 3D mapping of the diffuse ISM from interstellar absorption lines. Many of these Guaranteed Time projects included collaborators who were at the workshop and the observations will form the foundations of large programmes.

Milky Way Projects

The power of FLAMES in its MEDUSA mode is to extend current spectroscopic studies of a few stars in particular environments to very many stars and to search for rare objects. A good example is the anomalous red giant branch detected in a WFI imaging campaign of Omega Cen (Pancino et al., *ApJ*, 534, L87, 2000) This survey has photometry of 230,000 stars and reveals a very thin anomalous red giant branch. Francesco Ferraro (Bologna) suggested that in a rather short observing time of about 20 hours the kinematics and metallicity of the ~ 700 stars in the giant and anomalous giant branches could be well characterised – a task almost inconceivable with a long-slit spectrometer. The relatively high spectral resolution of Giraffe allows accurate radial velocities of many stars to be collected, and John Danziger (Trieste) described a programme to study the internal kinematics of globular clusters in order to search for evidence for central black holes and the possible presence of dark matter. The nearby cluster NGC 6397, at 2.2 kpc, would be ideal to begin this programme. Ulli Heber (Erlangen) described a programme of spectroscopy of sub-dwarf B star binaries in the field and among globular cluster Horizontal Branch stars. Determining the stellar parameters of substantial numbers of these very hot stars would make a contribution to understanding the UV upturn in elliptical galaxies. By observing in the Galactic Bulge many spectra of these faint targets could be collected by FLAMES using the Giraffe spectrometer.

Obviously the Galactic Bulge, whose declination makes it ideally placed for Paranal, will dominate early use of FLAMES. However, only one talk concentrated on the Bulge, and Michael Rich (UCLA) made the case for large-scale studies to extend the currently available kinematics of ~ 1000 stars to much larger samples to allow full kinematic modelling of the Bulge. In addition to the kinematics, the alpha element to Fe ratio is a fundamental indicator of star-formation history and could be obtained for many K giants with FLAMES. The Magellanic Clouds is another region in which massive spectroscopy will have many benefits. Since pulsation and rotation, which regulate mass loss, in B stars is metallicity dependent, then observing in the SMC would allow the dependence on metallicity to be well determined. Dietrich Baade (ESO) advocated Giraffe observations to cover many B stars. Pierre North (Geneva) described how detached eclipsing binaries (DEB's) can provide light curves which can yield stellar masses to 1% and radii to 2%. By observing in the SMC up to 10 DEB's could be observed simultaneously (currently about 30 are known in the SMC with periods ~ 2 days); this programme would dramatically increase the small sample of about 50 stars (all in the Milky Way) with accurate masses. In addition to their role as distance indicators, stellar models can yield the ratio of enhancement of helium to metals (Delta Y/Delta Z), which is a key ingredient to Big Bang nucleosynthesis.

Local Group Projects

A number of talks concentrated on spectroscopy of Local Group dwarf galaxies. The Sagittarius dwarf, which is already well covered by the WFI pre-FLAMES survey and is well placed for the VLT, will be an obvious first target for FLAMES. Kinematics, mass-to-light ratio, abundance spread, alpha/Fe abundance ratio will yield to Giraffe spectra, and Piercarlo Bonifacio (Trieste) described a large programme to determine pipeline abundances of many elements for many stars using interpolation within grids of synthetic spectra. The UVES-fibre link would be employed to obtain R ~ 50 000 spectra to check the abundances from the lower-resolution (R ~ 10,000) Giraffe spectra. Eline Tolstoy (Groningen) showed that it is feasible to obtain spectra of every Red Giant star in LG dwarfs such as the Fornax dwarf spheroidal. Using UVES spectra of a few stars it was shown how Giraffe spectra at the Ca II triplet could be used to determine metallicities. A group of talks by Andreas Korn (Sternwarte Munich), Danny Lennon (ING, La Palma), Artemio Herrero (IAC), Norbert Przybilla (Sternwarte Munich) showed how O and B star spectra together with model atmosphere analysis can provide high quality abundances for large samples in many Local Group galaxies. The key is to extend the sample size – for example only 14 B stars outside the Galaxy have been spectroscopically well studied. In the SMC for example there are on average 70 B stars per FLAMES field, providing good multiplex advantage. The challenge will be to find techniques to side-step the very labour-intensive atmosphere modelling to allow reliable abundances of large numbers of early-type stars. The cooler stars in the Local Group were not forgotten and Vanessa Hill (ESO) showed how alpha/Fe element ratios from UVES spectra of Magellanic Cloud cluster giants had been used to constrain the star-formation history. Such studies can be extended with Giraffe spectra but using the higher-resolution UVES spectra to confirm the derived abundances.

Extra-Galactic Projects

For spectroscopy of unresolved sources in nearby galaxies (e.g. globular clusters, super-giant stars) the MEDUSA mode is usable but for more distant galaxies ARGUS is required to provide a global spectroscopic view. For high-redshift galaxies, the deployable mini-IFU's can provide full coverage of the sources. The kinematics of the globular cluster systems in galaxies to ~ 50 Mpc was outlined by Andre Blecha (Geneva). The MEDUSA mode can be used to collect spectra of hundreds of globulars in the outer regions whilst the ARGUS IFU is required for the high background and crowded central regions. A programme of Giraffe spectroscopy of emission-line dwarf galaxies was described by Véronique Cayatte (OPM) using ARGUS. Both kinematics and abundances can be derived for tidal dwarf galaxies and merger systems using the lowest resolution mode (R ~ 5000). Given a match of the IFU size to the object then many emitting clumps within larger halos can be studied. The 2dF project has had success by applying charge shuffling on the CCD together with co-ordinated telescope nodding to obtain the sky spectrum at exactly the same pixels on the detector as the object spectrum (called nod+shuffle). Whilst there is some loss due to the time spent on sky, very accurate sky subtraction can be obtained and near-optimal signal-to-noise is achievable. Piero Rosati (ESO) described the possible application of this technique to FLAMES MEDUSA mode.

Although galaxies at high redshift are small enough that spectra can be obtained with the MEDUSA mode, spatial resolution of sub-components, such as in merging systems, requires an IFU. Denis Burgarella (Marseille) described a programme to study spectra of Lyman-α emitting galaxies with FLAMES. There are as many as 100 Lyman-α emitters per unit red-shift in a single FLAMES field, making it an efficient survey device. The line profiles of the Lyman-α and other emission lines can be used to constrain the physics of the emission (infall, outflow). Daniel Thomas (Sternwarte Munich) showed that whilst dwarf galaxies dominate the galaxy statistics by number this is not reflected in observed number counts on account of the difficulties of detection. The limited number of spectra of these targets so far collected can provide ages, metallicities and formation time scale. A programme in nearby galaxy clusters was proposed using the 15 mini-IFU's to build up a large spectroscopic sample.

Panel Discussion

The Workshop closed with a one hour discussion session chaired by Danny Lennon (ING, La Palma). There was discussion about Science Verification, complementary observations, detectors and imaging surveys.

The dates for the commissioning of FLAMES are not yet fixed and there were questions whether observing time might become available in period 69. If so then this will be handled in the call for period 69 in March of 2002. Following successful commissioning of FLAMES, there will be Science Verification of all the modes with the aim to demonstrate the scientific capabilities of the instrument. This is handled by the VLT Programme Scientist (Alvio Renzini). SV data for all VLT instruments is public.

Since any given observing configuration may not allocate all MEDUSA fibres and may not use the link to UVES, the question naturally arose whether there might be set of complementary observations for standards. One suggestion was that sky spectra could be collected to form a library of template sky spectra which could be used when high signal-to-noise sky spectra are required. There is no plan to obtain extensive spectra of standards (radial velocity, spectrophotometric, etc.) during commissioning, other than that required to characterise the instrument, but this could be a possibility for SV. The suggestion was made that there could be calibration programmes which could piggy-back on service observations in order to build up libraries of standards. This was thought to be too complex in terms of scheduling and the OPC would better view proposals which were efficient in terms of using as much as possible of the FLAMES facility (e.g. Giraffe and UVES simultaneously).

Several attendees asked about the possibility of binning of the Giraffe CCD. This would aid in the detection of faint objects by reducing the readout noise penalty. Since allowing binning by one factor would entail a doubling of the number of calibration files, it may be contemplated for visitor mode. Nod and shuffle is not possible with the currently planned EEV CCD since the read-out direction is along the dispersion direction. However, there was a strong feeling that the possibility of applying nod-and-shuffle should be considered for the future in order for the facility to stay competitive. François Hammer (OPM) raised the question about installing a red sensitive CCD to allow competitive observation of high-redshift targets, since the currently selected EEV CCD is blue sensitive. This change-over is not foreseen for the early operation of the instrument but will be reviewed by the FLAMES Instrument Science Team; the current aim is to procure a CCD with high DQE in the blue and the red.

There were several calls for an extension of the Pre-FLAMES WFI imaging survey. The fields in the Magellanic Clouds are far from complete but the large area would be more efficiently covered by VST. It was clear from contributions at the Workshop that a number of groups are already embarked on imaging surveys with the aim of selecting targets for multi-object spectroscopy. The problems of performing astrometry did not appear to be problematic and there was no consensus that an astrometric pipeline be made available for WFI data. Based on experience of other observatories with input files for multi-object spectroscopy, some checking of the validity of the users' co-ordinates was recommended and could save wasted observations. There was discussion about selection of filters for VST when it replaces WFI. Although Sloan bands are broader than Johnson ones they are not much used in globular cluster photometry. A few users asked if Stromgren filters could be provided for VST but generally the Johnson set was preferred. If Sloan filters are used, then good standards must be provided to allow transformation to the standard system.

At the end of the two days of the Workshop, the conclusion was that there are many exciting observing programmes waiting to be done with FLAMES and that the user community is waiting with anticipation for the data avalanche. The Workshop was informal in the sense that no published proceedings are foreseen. However, many speakers contributed printed versions of their presentations and a bound copy is available on request from jwalsh@eso.org.

The Great Observatories Origins Deep Survey (GOODS)

R. FOSBURY and the GOODS Co-Is at ESO/ST-ECF
(J. BERGERON, C. CESARSKY, S. CRISTIANI, R. HOOK, A. RENZINI AND P. ROSATI)

What is GOODS?

In the tradition of the Hubble Deep Fields (HDF-N and HDF-S), the Great Observatories Origins Deep Survey (GOODS) is designed to push the performance of major modern observational facilities to their sensitivity limits. GOODS unites the deepest observations from ground- and space-based facilities at many wavelengths, and was selected in late 2000 as one of six Legacy programs for the Space Infrared Telescope Facility (SIRTF: the fourth of NASA's Great Observatories after Hubble, Chandra and Compton). The Legacy program is meant to "...maximise the scientific utility of SIRTF by yielding an early and long-lasting scientific heritage… producing data that will enter the public domain immediately". Under the leadership of the PI, Mark Dickinson at ST ScI, the programme will map two fields with SIRTF, one Northern one Southern, exceeding a total of 300 square arcmin. GOODS will produce the deepest observations with the SIRTF IRAC instrument at 3.6–8 microns, and at 24 microns with the MIPS instrument pending on-orbit demonstration of instrument performance relative to SIRTF Guaranteed Time observations, which will also survey these same fields at 70 and 160 microns. The depth will be such that ordinary L* galaxies will be detected in their rest-frame near-infrared light out to a redshift of 4 or beyond. Luminous starburst galaxies and AGN – even the obscured 'type 2' objects – will be seen beyond the current record redshift of ~ 6 if any lie in the fields. At the longest wavelength (24 microns), the mid-IR emission from starburst galaxies will be seen to a redshift ~ 2.5 (see Fig. 1).

The two fields selected are already amongst the most intensively studied areas of the deep 'extragalactic' sky: HDF-N (around 12.6 hr RA and +62 deg Dec) and the southern Chandra Deep Field (CDF-S: around 3.5 hr RA and –28 deg Dec). Both areas have already been imaged with the Chandra X-ray satellite with an exposure time of one million seconds, the deepest X-ray observations ever. CDF-S has been extensively observed by ESO telescopes: fairly deep optical and near-infrared imaging (SUSI2, SOFI, WFI) has been secured as part of the EIS project and further observations are planned, while several VLT programmes targeting this field have been executed (FORS deep imaging and multi-object spectroscopy and ISAAC deep imaging and spectroscopy). All these ESO data are already public or will soon be so.

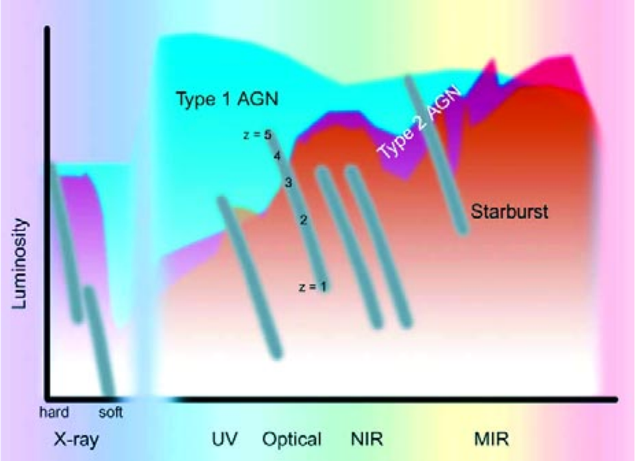


Figure 1: A schematic SED for Type 1 and Type 2 AGN and starburst galaxies showing the expected sensitivity limits as a function of redshift in a selection of GOODS bands.

In support of the SIRTF/GOODS programme, a wide range of other observations are being planned or have already been carried out which will, over the next four years, provide a public data-set covering the entire electromagnetic spectrum from X-ray to radio wavelengths at unprecedented depth. Ground-based telescopes, notably the VLT, Gemini-S and the CTIO 4-m for CDF-S, will be used to produce complementary imaging both at optical and near-infrared wavelengths. The principal role of the large telescopes, however, will be to provide follow-up spectroscopy with their new multi-object spectrographs. Time has already been allocated by ESO to begin a long-term programme using ISAAC for JHKs imaging of CDF-S. This requires some 32 pointings in each of the three filters (see Fig. 2). Some HST data are already available in these fields (most notably the HDF-N WFPC2 and NICMOS observations themselves), and new observations will be proposed for the new Advanced Camera for Surveys, scheduled to become available on HST early in 2002, for deep imaging in several filters to study galaxy morphology at a depth comparable to the HDF but over a much larger area.

To probe even higher energies than Chandra, XMM-Newton is currently being used to map the fields with its large effective collecting area and excellent spectral capabilities. The favourable K-correction and the superior high energy sensitivity of the new X-ray telescopes enables them to see most of the X-ray background as discrete sources. The combination of the spatial resolution of Chandra and the sensitivity and spectral response of XMM-Newton makes an extremely powerful diagnostic tool, even in the presence of heavy obscu-

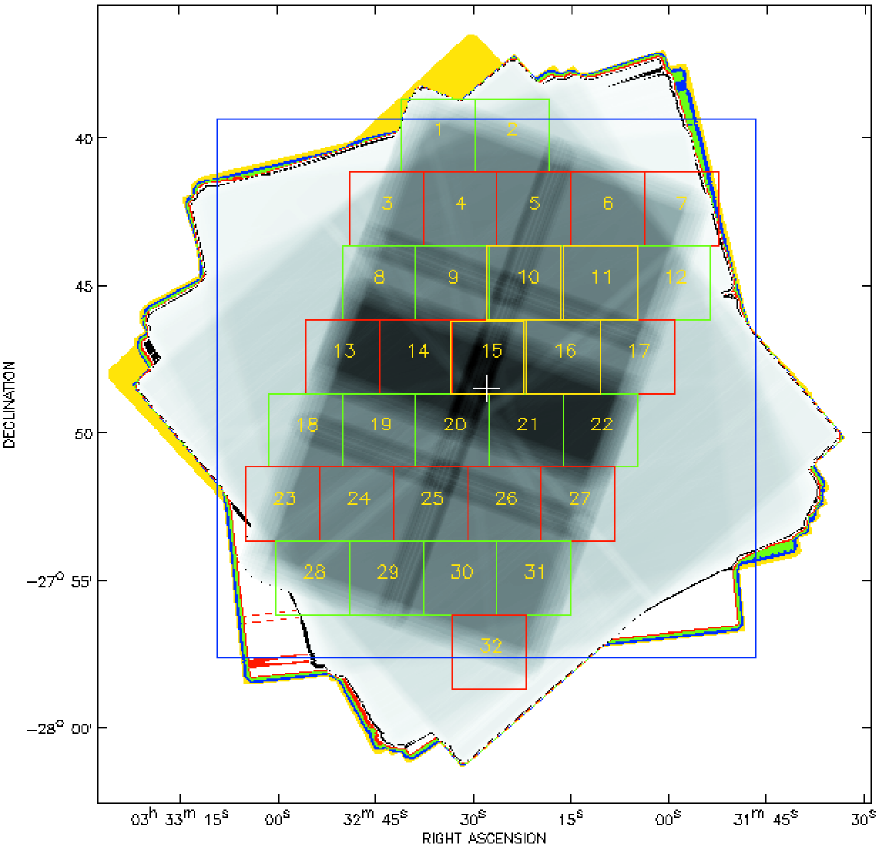


Figure 2: CDF-S showing Chandra and SIRTF (IRAC) exposure maps (greyscale; outer rotated squares and inner rectangular area respectively), the EIS SOFI field (blue) and the proposed ISAAC JHKs pointings (red and green tiles). The four fields marked in yellow have already been observed with ISAAC (PI E. Giallongo) in J (~ 12 kiloseconds) and Ks (~ 30 kiloseconds) in ESO programmes 64.O-0643, 66.A-0572 and 68.A-0544.

ration. At longer wavelengths, the fields will be mapped with bolometer arrays in the mm- and sub-mm bands. Deep radio surveys already exist and it is very likely that these will be pushed to even fainter limits over the next few years. In the future, it is clear that these fields will become prime targets for study with FIRST-Herschel, NGST and ALMA.

What are the Scientific Goals?

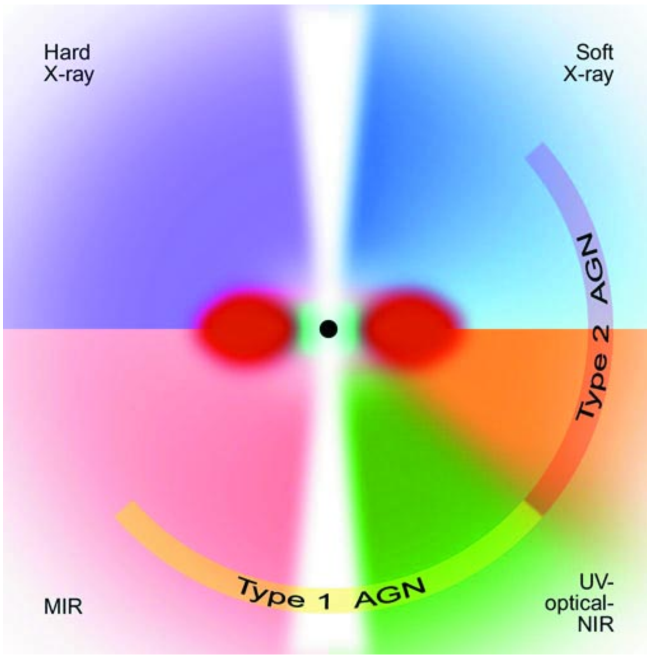


Figure 3: A cartoon illustrating the radiation anisotropies of AGN in different wavebands produced by the obscuring torus and the Doppler-boosted jets.

The essential purpose of GOODS is to provide the most sensitive census of the distant Universe, making it possible to follow the mass assembly history of galaxies and the nature and distribution of their energetic output – from both stars and black holes – over a broad span of cosmic history. With SIRTF in the mid-infrared, the rest-frame near-IR light from evolved stars (which trace the baryonic mass) can be followed to high redshifts. The combination of mid-infrared and hard X-ray observations allows the use of their intrinsically isotropic radiation in these bands to find and identify essentially all of both the type 1 (unobscured) and type 2 AGN which fall in the GOODS fields (see Fig. 3). The GOODS database will be used to:

- Make reliable estimates of the stellar and dynamical mass of bright galaxies all the way to redshift ~ 5
- Measure the star-formation rates in complete samples of galaxies selected at all explored redshifts.
- Obtain detailed morphological information for all such galaxies, hence mapping the emergence of the Hubble sequence.
- Measure the relative role of stars and black-hole-powered AGN in the global energetics of the universe.
- Measure the contribution of individual sources to the extragalactic background radiation at all wavelengths.

Europe's Role

Approximately a quarter of the SIRTF/GOODS Co-Is are from European institutes, the largest participation in any SIRTF Legacy program. Their specific roles include the XMM-Newton observations, a significant involvement with planning, proposing and processing the HST observations and, especially, the planning, processing and prompt public distribution of the ESO observations. In addition to the planning and execution of the observations and the archiving of the data, it is clear that major efforts will go into data processing and scientific exploitation. All data will be in the public domain and it is clear that the scientific return will go to those teams that are organised to react quickly and efficiently to their availability. In order to give young European researchers the opportunity to benefit from this uniquely large and rich dataset, a proposal has been made to the European Commission by 15 institutions in 7 countries to set up a dedicated Research Training Network which, if funded, could support up to 336 person-months of (mostly) postdoctoral appointments of young people over the next four years.

Useful websites

http://www.STScI.edu/science/goods/
http://sirtf.caltech.edu/
http://www.eso.org/goods/
http://www.eso.org/science/eis/eis_proj/deep/pointings.html
http://chandra.harvard.edu/photo/cycle1/cdfs/index.html
http://sci.esa.int/home/xmm-newton/

ESO: Research Facilities in Santiago

D. ALLOIN, ESO/Santiago

With the start of operations on Paranal, a major increase of the ESO staff with duty station in Chile has taken place: as of today, the number of ESO scientists (staff, postdocs, paid associates and PhD students) has doubled with respect to 1998, leading as well to a larger number of visiting scientists and students on short-term training. The research facilities offered by ESO to its staff in Chile had to be adapted to this growth and the scientific life had to be boosted accordingly.

The ESO/Chile research facilities are located in Vitacura, Santiago, close to the United Nations building. The ESO ground lays along the river Mapocho, facing to the North the beautiful Manquehue volcano and to the East the Andes chain covered with snow in winter time. Together with research facilities, the buildings host the ESO administrative support in Chile, related to activities such as the official representation of ESO in Chile, the personnel, financial, purchase, customs, ... procedures which contribute to making the work of ESO observatories in Chile a reality.

In this paper I shall restrict to a presentation of the research facilities, where substantial changes have occurred over the past 3 years and where even more will happen in the future!

1. The People

The scientists working at ESO/Chile share their time between the site of their functional duties (Paranal, La Silla) and the site of their research activities (Vitacura). This is why the ESO/Vitacura offices must provide high-level support for research work, both in terms of scientific life and in terms of hard- and soft-tools (offices, computers, library ...).

As of January 2002, the ESO/Chile astronomical staff will comprise on a permanent basis: about 35 staff, 15 fellows (postdocs), around 5 paid associates (at the level of either staff or fellow) and 10 PhD students/co-operants. In addition, 2 scientists of the EROS2 experiment on La Silla are hosted at ESO/Santiago. And we have of course a number of temporary visitors: astronomers on the ESO/Chile Visiting Scientist programme, or students on short-term training, or visiting astronomers in between two observing runs at ESO observatories. The number of temporary visitors at a given time is highly variable and has reached up recently the figure of 12 (peaks in January/February – the Chilean summer – and May/June – training period for students in European universities).

The Office for Science at ESO/Chile has the tasks, among others, of providing/maintaining the facilities required for research activities and of creating the scientific environment which will allow ESO/Chile staff to produce top-level research results.

In addition to the support received from the administrative staff on various matters, the Office for Science has a supporting team comprising:

– one librarian who takes care of the three ESO/Chile libraries (Santiago/La Silla/Paranal),

– one secretary,

– one system administrator and one assistant dealing with the maintenance of computers and peripherals. Yet, the pressure is very high on computing facilities, especially with the ever-growing demand on networking, laptops, handling of large data volume (i.e. preparation for VST datasets).

The hiring of ESO/Chile fellows and the allocation of ESO/Chile studentship for PhD students are performed through the Fellows and Students Selection Committee (FSSC). This committee is made of 6 staff nominated by the Directors of the ESO observatories (3 for La Silla and 3 for Paranal), in addition to the Head of the Office for Science at ESO/Chile. One fellow will join the FSSC soon. With the start of operations on Paranal (8 fellows perform their duties on Paranal) and the rapid turn-over of fellows (some of them moving to ESO staff positions, others leaving), the work of the FSSC has been intensive and interesting. Similarly, the number of PhD students has more than doubled since 1998, and we encourage students from ESO member states in particular to take the opportunity of preparing their PhD at ESO/Chile under the joint supervision of an astronomer in the university where they register and an ESO/Chile astronomer.

On a temporary basis we also host visitors (ESO/Chile Visiting Scientists programme) and students on short-term training (programmes described below). More and more often, visiting astronomers travelling to Chile for an observing run on Paranal or La Silla stop by at ESO/Vitacura to deliver a colloquium or to work with a collaborator.

2. Temporary Visitors

2.1. Senior Visiting Scientists programme

Similarly to ESO/Garching, ESO/Chile runs a Visiting Scientist programme. The goal of this programme is to stimulate the scientific life, to bring in-house new ideas and to ease collaborative work. It also aims at strengthening links between the astronomical communities in ESO member states and ESO staff and offers the opportunity to exchange more closely with Chilean colleagues from the universities (Antofagasta, Concepción, La Serena, Santiago ...)

There are roughly three categories of visiting scientists:

– renown senior astronomers who can share their expertise with the group here in Santiago, through a series of lectures,

– direct collaborators of ESO/Chile scientists

– co-supervisors of the PhD students

Twice a year, ESO/Chile scientists are invited to suggest names for visiting scientists. Then, the Visiting Scientists Committee (VSC) reviews the applications, selects the visitors and decides on the terms of their visit. The VSC comprises 3 staff members, 2 fellows and the Head of the Office for Science at ESO/Chile.

As a mean, there are two visitors at any time, although the distribution shows peaks around October–January and March–July.

Early February 2001, a survey was made of the opinion of the 33 visiting scientists who had spend some time (two weeks at least) at ESO/Santiago on this programme since 01.11.98. A large proportion (85%) of the visiting scientists replied:

– showing a high degree of satisfaction regarding the practical organisation of their stay in Chile,

– acknowledging their interactions with ESO/Chile astronomers (particularly with fellows and students)

– appreciating the general scientific atmosphere at ESO/Santiago

Advancement/finalisation of a joint research work with ESO/Chile scientists occurred in 70% of the cases, while new collaborations started in 50% of the cases. Another benefit of this programme is to provide the opportunity of interacting with the Chilean astronomical community at large: 50% of ESO visiting scientists met and discussed with Chilean colleagues.

2.2. Students on short-term training

A lively research atmosphere also benefits from the presence of young students. This is why visits of students on short-term training has been encouraged. This type of training is funded mostly on the DGDF and it is therefore the direct responsibility of each staff to select the student and monitor the advancement of the training. The number of students on short-term training has notably increased: in 2001, we have received 13 undergraduate students (12 from Europe and 1 from Chile).

3. The Hard and Soft Tools

3.1. Office space

With the rapid increase of the number of ESO/Chile scientists, available office space has quickly turned short and office sharing has become the rule up to saturation. The critical needs for more office space will be met soon by the reshaping of the old Astro Workshop, located on the ESO grounds to the North-East of the main building, and vacant for many years.

Starting in the middle of 2000, exchanges took place with the architect to design the arrangement of this large volume, without changing its global architecture, and to make the best use of it:

– the use of the underground level has been made possible by removing the earth on two sides of the building, arranging a terrace and a hanging-garden, opening two series of windows as well as an inner communication with the ground-floor,

– the volume on the ground-floor now comprises a mezzanine, for about half its surface, while three light-wells have been opened in the roof to shed light over the stairs and unite the three levels.

Figure 1: The former Astro Workshop reshaped into offices for scientists.

The building (Fig. 1) offers a cafeteria, two meeting rooms and can host up to 40 work-positions. It is at the stage of final installation and we expect to start moving in early October 2001.

3.2. Libraries

The library at ESO/Santiago is a full-scale astronomical research library, offering all the bibliographic facilities needed to prepare scientific publications. A smaller library more oriented towards the needs of actual astronomical observations is located at La Silla and a similar one is under installation at Paranal. All existing bibliographic information in the three ESO libraries in Chile as well as that in Garching can be easily accessed and searched in various ways using the online catalogue. This catalogue contains descriptions of all journals, books, observatory publications and multimedia documentation. Direct links to the main journals are available from within the catalogue. The ESO libraries, hence including ESO/Chile, subscribe to electronic versions of these journals.

From public terminals placed in the libraries, users may thus not only access the catalogue but also download articles, print tables of contents, and make searches. The public terminals offer access to the main astronomical databases.

The web page for the ESO Research Facilities in Santiago (see hereafter) presents the latest information about ESO/Chile libraries.

3.3. Secretarial office

The secretary of the Office for Science is in charge of the practical aspects related to its activities:

– for the FSSC (fellows and students hiring),

– for the Visiting Scientist programme,

– for ESO/Chile staff/fellows/students research travels and research needs,

– for the organisation of ESO colloquia and JAS,

– for the organisation of the Topical Meetings,

– for the organisation by ESO/Chile of International Workshop and for the preparation of the related Proceedings.

In addition, the secretary provides support in administrative tasks to be coordinated with ESO/Garching, such as the budget preparation for example.

3.4. Computing facilities, communications, software

Computing facilities is another area which has required a lot of attention and effort over the past 3 years, and where a major step forward has been made.

Regarding desk-top facilities, most of the old equipment (x-term stations) which was in place in 1998 has been removed. All work-positions are equipped with Unix Sun machines or Linux PC, the later being now preferred by most users. Moreover, ESO/Chile staff and fellows who share their time between research in Santiago and duties at ESO observatories can use a laptop in order to ease their work across the two sites.

Servers and common equipment have been replaced or upgraded. Common disk-storage capacity has been largely extended by the installation of 3 RAIDs providing today a total of 400 Gb, in addition to the storage capacity available for each desktop computer (about 20 Gb). More peripherals, printers, scanners, DLTs ... have been installed and will also equip the new building.

A powerful Sun machine , with RAID and DLT/DAT was acquired in 1999 to be dedicated to the reduction of large datasets (WFI): its evolution/replacement is under examination, to match future needs for the reduction of VST datasets.

3.5. Communication

Communication and network is the area in which a major effort had to be made because of a really poor situation (very slow access and frequent failures). Great improvements are on the way and the situation should very soon come to normal/excellent, raising ESO/Santiago to the current standards of ESO/Garching in terms of communication performances. In the same spirit, the multi-point video-conferencing system has been improved, allowing better communications among the four sites and savings on travel time/money.

3.6. Software

One of the ESO/Santiago servers hosts a mirror-site of the Scisoft package which is developed and maintained by ESO and ECF in Garching. In this way, regular and automatic updates are performed on the host-server, making available at any time to ESO/Chile astronomers the latest versions of the software tools they need for their research. Floating licenses for Fortran and IDL have been installed locally. Moreover, the ESO/Garching IDL license server can be accessed by ESO/Santiago users, optimising the use of these tools. Discussion and co-ordination with ESO/Garching and ECF have been instrumental in establishing these systematic links.

4. Scientific Activities

The scientific life at ESO/Santiago takes place through a number of activities:

4.1. ESO/Santiago and Santiago-based activities

– ESO colloquia and lunch talks: since mid-1998, there has been a mean of 1.3 colloquium per week. Scheduled colloquia, together with the list of past colloquia, can be found on the ESO/Chile science web page: (http://www.sc.eso.org/santiago/science),

– the monthly Joint Astrophysical Seminar (JAS), organised jointly by the 3 astronomy groups in Santiago (ESO, PUC, UChile). The idea is to give the 3 communities an occasion for meeting. Renown astronomers are selected for the JAS and its location rotates among the 3 institutions, either at ESO/Vitacura or on the PUC/campus in San Joaquim or at Cerro Calan observatory.

– research working groups have been set up (or already existed) at ESO/Chile, about the Solar System, about the physics of galaxies, about stellar physics. They are at the origin of several joint observational projects among ESO/Chile scientists and sometimes, like in Paranal, even linked to an observatory project.

– Vinos-Verbos-Vitacura is an informal meeting which takes place each Friday afternoon and allows a rapid exchange of information among the scientists present in Vitacura.

4.2. Scientific activities directed to the wider astronomical community within Chile

A series of Topical Meetings was started in 1999, with the goal of boosting exchanges between ESO astronomers and the astronomical community at large in Chile. There are astronomy groups in several Chilean universities (Antofagasta, Concepción, La Serena, Santiago), some isolated astronomers (Tarapaca, Valparaíso) and astronomers working in the other international facilities currently hosted by Chile (CTIO/AURA, Gemini, Las Campanas, SOAR). The Topical Meetings are organised at ESO/Vitacura. Some recently held and some planned Topical Meetings are indicated below:

– “New Facilities for Astronomy in Chile”, December 2000

– “Astrophysical Niches for High Resolution Spectroscopy”, October 2001

– “Brown Dwarfs and Planets”, October 2001

– “A Week for Interferometry”, January 2002

In a similar spirit, ESO/Chile promoted the organisation of a meeting of all postdocs in Chile which was held on June 6–8 2001 in the Andes, close to Santiago.

4.3. International scientific meetings

Since 1990, the three international observatories, ESO-CTIO-LCO, organise jointly every two years an international Workshop. In 2000, it was ESO’s turn to take the lead in the organisation: the Workshop “Stars, Gas, Dust in Galaxies: Exploring the Links” was held in La Serena in March 2000 (ASP Conf. Series, vol #221). For the 2002 version, organisation and funding of the Workshop have been opened to new institutions and it is now named IAOC, the Workshop of International Astronomical Observatories in Chile, in order to acknowledge and welcome the installation in Chile of Gemini and, in the future, of ALMA. The organisation of the 2002 Workshop is led by CTIO: it will take place on March 11–15 in La Serena on the topic of “Galactic Star Formation”.

More international meetings are organised in Chile. In some cases ESO is the principal organiser: “Magnetic Fields across the HR Diagram”, Santiago, January 2001 (to appear in the ASP Conf. Series, vol #248). In other cases, ESO only provides some funding support: “Gravitational Lensing”, San Pedro de Atacama, July 2000, organised by PUC-Princeton, or “Extragalactic Star Clusters”, Pucon, March 2001, organised by the University of Concepción.

4.4. Exchanges with the Chilean community

The relationship and the scientific exchanges with the Chilean community have developed very well. Several colleagues from Chilean universities have been invited to spend some months at ESO/Santiago under our Visiting Scientist programme. Many of them also gave colloquia at ESO/Vitacura. More and more opportunities occur to build up scientific links (Topical Meetings, Workshop). In 2001, three ESO/Chile fellows will start spending their third year of fellowship hosted by a Chilean university. An increasing number of common observational projects are submitted to ESO observatories and one can expect that even more collaborative efforts will show up in the future.

4.5. Training internal to ESO

Following a strong demand from ESO administrative staff, a series of popular lectures about astronomy has been organised jointly by the Public Relations and Human Resources Offices, in collaboration with the Office for Science. The various talks that have been delivered so far by ESO/Chile scientists have received great success and the contributions will be CD-recorded.

6. How to Learn More About Research Facilities/Activities at ESO/Santiago?

At the end of 1998, the Office for Science in Santiago opened a web site to display information about the ESO/Chile staff, fellows, students, about the Visiting Scientists programme, about research activities (ESO colloquia, JAS, Topical Meetings, international Workshop, etc.), about computing facilities and libraries ... The Office for Science also made a list of all astronomers working in Chile (available on the web page) and a list of all ESO/Chile postdocs since 1977, together with their current position. The web site can be accessed at: http://www.sc.eso.org/santiago/science, or from the Garching ESO web page under Science Activities/Research facilities in Santiago.

In conclusion, one could state that the conditions are now fulfilled for ESO/Santiago to be a lively place where scientists can achieve outstanding research, develop strong links with ESO/Garching staff, with the astronomical communities in ESO member states, with Chilean colleagues and with astronomers from all over the world. Next time you travel to Chile, you are most welcome to stop by at ESO/Vitacura and share some time with us!

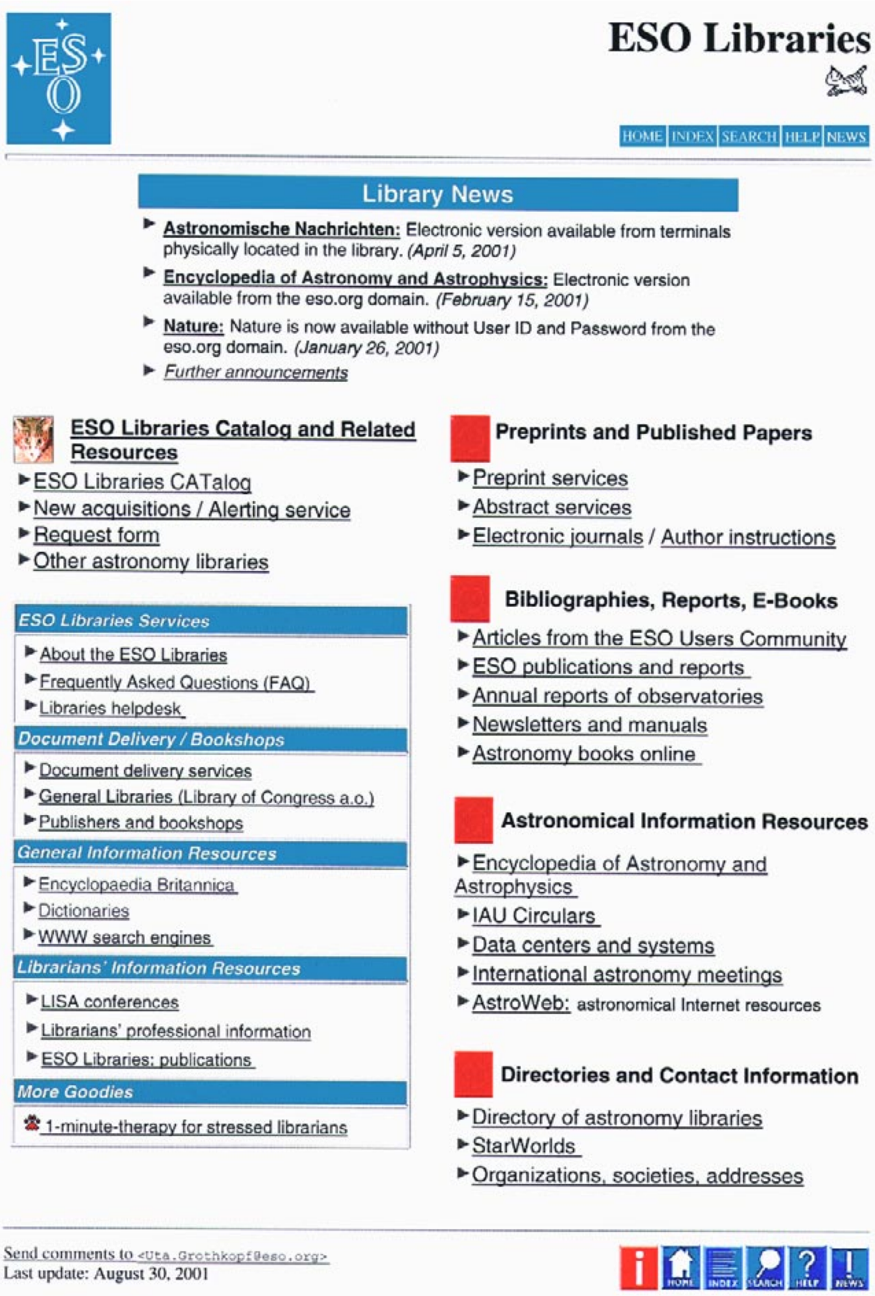
The ESO Libraries: State of the Art 2001

U. GROTHKOPF[1], A. TREUMANN[1], M.E. GÓMEZ[2], ESO

[1]ESO Garching; [2]ESO Santiago

The main task of the ESO libraries is to provide ESO scientists and engineers with access to all information resources they need for their work. In order to do so, physical libraries are maintained in Garching, Santiago, La Silla and (in future) Paranal as well as an electronic library on the world wide web (Fig.1).[1]

In the era of electronic information dissemination, astronomers expect to find all important resources online, ready for use from their desktops. Scholarly communication is changing, and to stay informed about recent findings two services seem to be sufficient: the NASA ADS abstract service for searches of published articles including access to electronic journals, and the LANL astro-ph preprint server. Relatively unnoticed by scientists, librarians contribute to the efficiency of these and other services in a number of ways. The traditional librarian's tasks retrieving, obtaining, making available and archiving publications are evolving as print literature is complemented, if not replaced, by electronic publications. Enhancing electronic library services, monitoring and evaluating new information retrieval technologies, reviewing and negotiating licenses for electronic journals and books, maintaining content-rich web pages and guiding local and distant users to appropriate search tools are some of the more recent services provided by libraries.



Library News

- **Astronomische Nachrichten:** Electronic version available from terminals physically located in the library. *(April 5, 2001)*
- **Encyclopedia of Astronomy and Astrophysics:** Electronic version available from the eso.org domain. *(February 15, 2001)*
- **Nature:** Nature is now available without User ID and Password from the eso.org domain. *(January 26, 2001)*
- *Further announcements*

ESO Libraries Catalog and Related Resources

- ESO Libraries CATalog
- New acquisitions / Alerting service
- Request form
- Other astronomy libraries

ESO Libraries Services

- About the ESO Libraries
- Frequently Asked Questions (FAQ)
- Libraries helpdesk

Document Delivery / Bookshops

- Document delivery services
- General Libraries (Library of Congress a.o.)
- Publishers and bookshops

General Information Resources

- Encyclopaedia Britannica
- Dictionaries
- WWW search engines

Librarians' Information Resources

- LISA conferences
- Librarians' professional information
- ESO Libraries: publications

More Goodies

- 1-minute-therapy for stressed librarians

Preprints and Published Papers

- Preprint services
- Abstract services
- Electronic journals / Author instructions

Bibliographies, Reports, E-Books

- Articles from the ESO Users Community
- ESO publications and reports
- Annual reports of observatories
- Newsletters and manuals
- Astronomy books online

Astronomical Information Resources

- Encyclopedia of Astronomy and Astrophysics
- IAU Circulars
- Data centers and systems
- International astronomy meetings
- AstroWeb: astronomical Internet resources

Directories and Contact Information

- Directory of astronomy libraries
- StarWorlds
- Organizations, societies, addresses

Send comments to <Uta.Grothkopf@eso.org>
Last update: August 30, 2001

Figure 1: The ESO libraries web homepage.

The Library Sites

Compared to former times, the importance of local library holdings is diminishing. We notice a smaller number of scientists coming to the physical sites, and many of these walk-in users are not staff members, but scientific visitors who stay at ESO only a limited time. Often they need public computer facilities as much as the books and journals provided by the library. Despite this trend, most publications are not yet available in electronic format, and ESO puts emphasis on maintaining ample paper-based collections. The library system comprises currently three, in future four sites. The present three libraries provide a total of approximately 15,000 book titles, covering the main subject areas of astronomy and related physical sciences as well as engineering, mathematics and computer sciences. Current journal subscriptions amount to about 150 titles. The majority of books and journals are available in Garching as well as Santiago, only a selection is purchased for La Silla as this library is designed to support astronomers and engineers at the telescopes in their specific needs.

In addition to current publications, three historical collections are available in Garching: the library of Prof. G. Franke which was donated to ESO after his death, a collection of Prof. J.H. Oort, one of ESO's founding fathers, and the ESO Historical Archive, compiled and classified by Prof. A. Blaauw. The latter is physically not located in the library, but descriptions of all items pertaining to the Archive are included in the catalogue. The number of library staff are 1.5 FTE (full time equivalent) in Garching and 1 FTE in Chile. Central services like journal subscriptions, license negotiations, book purchases, cataloguing and co-ordination of activities are taken care of in the main library Garching. Here, also the telescope bibliographies are compiled which are of increasing importance to

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[1] http://www.eso.org/libraries/

Table 1: Media provided at ESO sites.

Media provided	**Garching**	**Santiago**	**La Silla**	**Paranal**
Print journals	large variety	large variety	only most important	selected donations
Print books	large variety	large variety	only most important	few
Electronic publications	yes	yes	yes	yes

observatories (see Bergeron & Grothkopf 1999).[2]

A fourth library will become available on Paranal, located in the Residencia. For this new site, a different collection management policy will be applied (Table 1). As all major astronomy journals can be accessed online, most of them even back to volume 1, current issues will only be provided in electronic format. Only some back volumes of journals (mainly *A&A* and *ApJ*), donated by ESO scientists, will be available on paper. This electronic-only approach is new to astronomers, and whether or not this solution is feasible will have to be evaluated during the coming years.

All sites used to be visited frequently by astronomers who appreciated among other things the display of latest preprints, but the impact of paper preprints is going down. The ESO libraries received a substantially lower number during the past five years, with a parallel dramatic increase in preprints submitted to the LANL server (Fig. 2). As a consequence, we decided to discontinue our preprint database as of June 2001 and keep paper copies for one year without trace in our catalogues. However, only a certain percentage actually appears in both electronic and print format; snapshots taken at NRAO and STScI during recent years show that approx. 50% of the preprints received in their libraries is available only in hard copy.

In 1992, we started to build an electronically accessible library catalogue. The software selection was determined by some essential requirements: we wanted an integrated, modular system based on client/server architecture and running on Unix with an easy-to-use, yet powerful user interface. After comparison of various software packages, the Unicorn Library Management System was selected. The system performed well from the beginning; it has evolved considerably in the course of time, incorporating innovative technologies and features that keep the system up-to-date. The public user interface[3] provides access to all records of the library holdings as well as hyperlinks to electronic publications.

When the automated library catalogue was opened to the public, we issued two print user guides to introduce it. Since then, no further information material on paper was produced as it usually becomes obsolete within a short time. All necessary information is made available on our web pages. This is inexpensive, less time-consuming and available to users whenever needed. A page with frequently asked questions (and answers) gives basic information about services and procedures. Library news are provided on the homepage as well as on a dedicated page. In addition, we send alerts regarding new services and resources by e-mail. Monthly lists of book purchases are distributed electronically to subscribers and are also available on the web.

The classification system used at ESO originates from the time when the organisation was founded and has undergone only minor changes since then. It consists of five broad subject groups – astronomy, physics, engineering, mathematics, and handbooks/dictionaries – each divided into several sub-groups. Initially, the classification system had merit in locating books by subject; now it is mainly used to order books on the shelves. To provide specific keywords for scientific literature searches, IAU Astronomy Thesaurus terms (Shobbrook & Shobbrook 1993) are added to records for astronomy books. ESO employees can borrow all library items except journals and selected reference material. We do not adhere to strict loan periods, but expect users to return borrowed items in case these are requested by somebody else. Traditionally, the ESO libraries are open 24 hours per day, 365 days a year. Therefore, emphasis always has been put on a self-issue circulation system, i.e., users can check out items without assistance from librarians.

The Electronic Library

Maintaining sophisticated electronic libraries has become an essential task of librarians. Many scientists visit our library for the first time on the web; therefore our homepage is like a business card. Here we can introduce our services, invite users to contact us with requests and provide starting points for their information search. As users typically don't spend much time at pages that require a lot of reading to be understood, we try to design our site as clearly and attractive as possible. From discussions with astronomers we learned that many of them appreciate the library web pages and use the provided links. With an ever increasing range of electronically available resources, we face (almost) no limitations to what we can offer our users; the border between local resources and those that reside elsewhere is hardly noticed anymore. The concept of "virtual libraries" will become even more evident in future as information resources become more and more interconnected, offering researchers a single entry point from where all relevant data can be reached.

In order to measure usage of the library pages, the most reliable indication will be feedback from users. It will reveal which resources are appreciated and may also prompt suggestions for additional ones. Another way of evaluation is to look at the access statistics although the numbers may be misleading, for instance because of hits originating from automated crawlers. Not surprisingly, our statistics show that the web catalogue is among the most frequently visited resources, followed by pages with links to electronic journals, abstract services and preprint databases. Two resources are particularly popular among astronomy librarians: the Directory of Astronomy Librarians and Libraries, a compilation of contact persons, addresses and web pages of astronomy libraries around the world[4], and a listing of annual reports of observatories that is maintained in co-operation with the CFHT librarian[5].

Collection Development

The number of print publications purchased at ESO has decreased only slightly during recent years. Several book series, typically for conference proceedings, are obtained automatically upon publication through standing orders; other publications are selected mainly based on staff recommendations, pre-publication information received from book vendors and publishers, and astronomy libraries' new acquisitions lists.

At ESO, no effort is made to create a collection of digital media that are not networked, e.g., CD-ROMs stored offline. Electronic (online) books, however, are among the topics we will investigate in detail in the near future. Like electronic journals, e-books provide en-

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[2] Query form at http://archive.eso.org/wdb/wdb/eso/publications/form

[3] http://www.eso.org/libraries/webcat.html

[4] http://www.eso.org/libraries/astro-addresses.html

[5] http://www.eso.org/libraries/reports.html

hanced searching and indexing capabilities, and they can be accessed (almost) from anywhere and at any time. Access technology is evolving rapidly, but the usage terms and conditions currently cater for large university libraries rather than small specialised libraries; for instance, customers often are obliged to purchase complete collections regardless of their actual requirements and budgets. The main subject areas covered at present are computer technology, business and management; other disciplines certainly will follow shortly.

Since the 1970s, we have seen steep increases in the prices of scientific journals, and the "serials crisis" still is one of the most discussed topics among librarians. By now, three quarters of the ESO libraries' media budget are spent on subscriptions. Whenever feasible, paper and online versions of journals are subscribed in parallel. Electronic versions do not come for free though but confront libraries with additional expenditures which are not compensated by corresponding increases in our budgets.

ESO employees can access electronic journals in a variety of ways. Most frequently, astronomers would carry out searches at ADS from where they can click through to full texts of articles. In addition, the library's e-journals web page[6] provides links to the most important journals. Hyperlinks to journals' homepages are also available from catalogue records. Typically, access to electronic publications is managed by IP address so that they can be used without user ID and password from all computers pertaining to the eso.org domain. While it is fairly easy to evaluate use of print library items, tracing page views and downloads from electronic publications can be difficult. Access statistics have to be analysed, but these reside on the publishers' servers. Some publishers are reluctant to reveal these figures because they fear subscription cancellations of electronic as well as print versions. Librarians often try to ensure access to statistics through special clauses in the license agreements.

Up to now, no print subscription has been cancelled because of electronic availability. The two main reasons to continue paper editions are that (a) several scientists still appreciate the opportunity to browse and read print journals and (b) paper still is the only reliable medium for archiving. The latter reason diminishes in importance though as electronic editions provide features that cannot be reproduced on paper; electronic versions therefore increasingly are regarded as the reference or master copy of journals.

In 1999, several journal subscriptions were discontinued. These titles were of minor interest to ESO scientists and engineers and the money spent on them was needed to cover rising costs of more important publications. An additional argument to cancel subscriptions was the fact that requests for journal articles not owned by the ESO libraries usually can be fulfilled rapidly and at reasonable prices through document delivery services. However, document delivery, in particular from electronic publications, is severely affected by changes in copyright regulations. Many publishers as well as governments consider current copyright laws unsuitable for the digital environment; they fear misuse of electronic publications through uncontrolled dissemination of articles. Existing copyright regulations of many countries therefore are being amended by clauses that restrict traditional user rights, e.g., free use of publications for research and personal information. Librarians are negotiating intensely with publishers in order to achieve more favourable usage conditions.

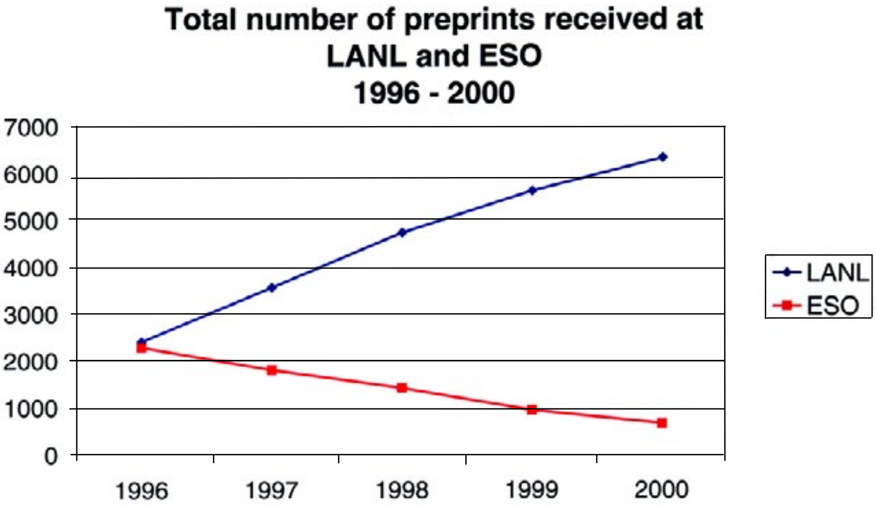

Figure 2: Total number of preprints received at LANL and ESO 1996–2000.

Archiving

With respect to paper-based publications, archiving is one of the central library functions. Even small specialised libraries can provide highly valuable repositories. In order to integrate them in the electronic knowledge base, many historical print documents are now converted into digital format.

In the electronic environment, archiving is undergoing vast changes. Preserving digital publications requires thoughtfulness, vision, long-term commitment and a lot of money for equipment as well as manpower. In order to guarantee future access, physical storage of electronic media is not sufficient; the danger of unexpected or unbridgeable gaps in the availability of hardware and software required to use them is too large. Instead, electronic publications should be encoded in system- and vendor-independent formats like SGML or XML and be transferred in regular intervals to storage devices that comply with current technological standards. The integrity of publications has to be ensured at any time. No data must be lost, and in addition to the content, all relevant accompanying information regarding provenance (a document's origin and chain of custody) and context (links within as well as from and to documents) must be preserved.

At present, archives of electronic journals, if they exist at all, mostly are kept by publishers. Future access to scientific literature depends on their good-will and position in the market; they determine who can use the archives and at which costs. In the interest of the scientific and the general public, better solutions are sought and discussed heatedly among experts. Some models favour large non-profit organisations like national libraries, national archives or the Public Library of Science[7] as archiving institutions. Centralised solutions bear some risks though as they tend to be inflexible and any failure in meeting the challenges of the digital age can have fatal implications. Other solutions like the Open Archives Initiative[8], having its roots in dissemination of content through e-print servers, promote distributed archiving based on interoperability standards. In any case, mature and standardised solutions for preserving, retrieving and accessing electronic publications have to be implemented soon, otherwise data may be lost. Small specialised libraries probably will be mainly responsible for providing access to archived publications rather than for preservation itself, and they will continue to mediate between authors/readers, publishers and archives.

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[6] http://www.eso.org/libraries/ejournals.html
[7] http://www.publiclibraryofscience.org/
[8] http://www.openarchives.org/

Communicating with Library Users and Other Librarians

Communicating with library users is an essential part of our work; only if we know their requirements, we will be able to provide good service. As many astronomers visit the physical libraries less frequently than before, communication increasingly is through electronic means rather than face-to-face (see Grothkopf & Cummins, in press). We consider it essential that users can contact us easily. A variety of access points for electronic submission of enquiries is provided: several e-mail addresses (esolib@eso.org, library@eso.org, libchile@eso.org and accounts under the names of the librarians); links to the main e-mail account on all library web pages; two web pages for requests and suggestions[9, 10]. During introductory library tours, our e-mail addresses are mentioned repeatedly, acknowledging the fact that it will be impossible for new users to memorise everything we tell them – and hoping that they do remember our e-mail address. Thus, they will always know where to send any questions they may have.

There are various types of users. A large number of scientists don't visit the (physical or virtual) sites regularly. They do not bypass the library entirely though; often they use our services without noticing it, for instance by using electronic journals which are paid for and made accessible by the library. These users hardly seek direct communication with us, except for "troubleshooting" when problems arise. Librarians, in turn, often don't dare to interrupt them in their work to talk to them. Other users appreciate and frequently use the information resources provided by the library, and often they take the time to tell us about further services which they consider worthwhile adding. Their suggestions are most helpful in order to identify users' needs. A third group of users appreciate our assistance for all kinds of requests from access instructions to special enquiries. Actually, these requests sometimes are so specialised that we enjoy the challenge.

A way to ensure communication with astronomers on a regular basis would be to set up a library committee, but for various reasons this idea was never pursued at ESO. Likewise, distributing questionnaires among faculty members to get feedback has been avoided in the past as answering them is too time-intensive. Occasionally, we do send short questions on specific topics by e-mail though. Our experience with these informal surveys is very good; usually we receive a large number of replies. During recent years, communication with astronomers beyond the immediate user community at ESO was through the IAU. Becoming a consulting member of the Commission 5 Working Group on Libraries has provided the opportunity to inform scientists about ongoing projects in astronomy libraries, as well as get feedback on library services in general.

Communication among astronomy librarians world-wide is excellent. A reliable network of mailing lists, professional organisations and personal contacts is in place that ensures exchange of information and expertise among colleagues. This is particularly important for small specialised libraries which are not part of university systems or library consortia and therefore lack assistance for reference questions and material requests. Given the high prices of some information retrieval products, it is obvious that special libraries cannot afford all of them either and sometimes require help to answer user enquiries. Networking also allows us to take a co-ordinated position towards publishers and vendors in license negotiations and requests for product enhancements.

Because of its international status, ESO is in an excellent position to foster international co-operation and projects among librarians. Information exchange is mainly by e-mail as well as during occasional personal visits. Through publication of articles in journals and books, postings on mailing lists and presentations at conferences or during visits to other libraries we help to stimulate discussion with colleagues around the world. Participation in national and international professional organisations like the Special Libraries Association[11] and an active role in the LISA conferences (Libraries and Information Services in Astronomy)[12] has always been very rewarding with regard to exchange of ideas and insight into new trends and standards in information technologies.

Conclusion

We are witnessing vast changes in information search and retrieval. End-user searching has become the standard in astronomy, and scientists increasingly expect all resources including publications, astronomical catalogues, databases and software tools to analyse and use data to be interlinked. Resources and services that are not tied into the network are becoming marginal.

As scholarly communication changes, the publication paradigm is evolving too. While the underlying structure of journals certainly will continue to exist for some time, knowledge may no longer be tied to physical containers like books and journals in future. Rather than self-contained articles, scientists probably will request specific information from interconnected resources, assembled on demand in information clusters (Boyce 2001). Libraries will be integrated in this system by providing access to knowledge bases and mediating between researchers and information providers.

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We would like to thank Ellen Bouton, NRAO library, Brenda Corbin, USNO library, Marlene Cummins, University of Toronto Astronomy Library, and Sarah Stevens-Rayburn, STScI library for ongoing discussions and exchange of ideas, as well as Dietrich Baade, ESO, for helpful comments.

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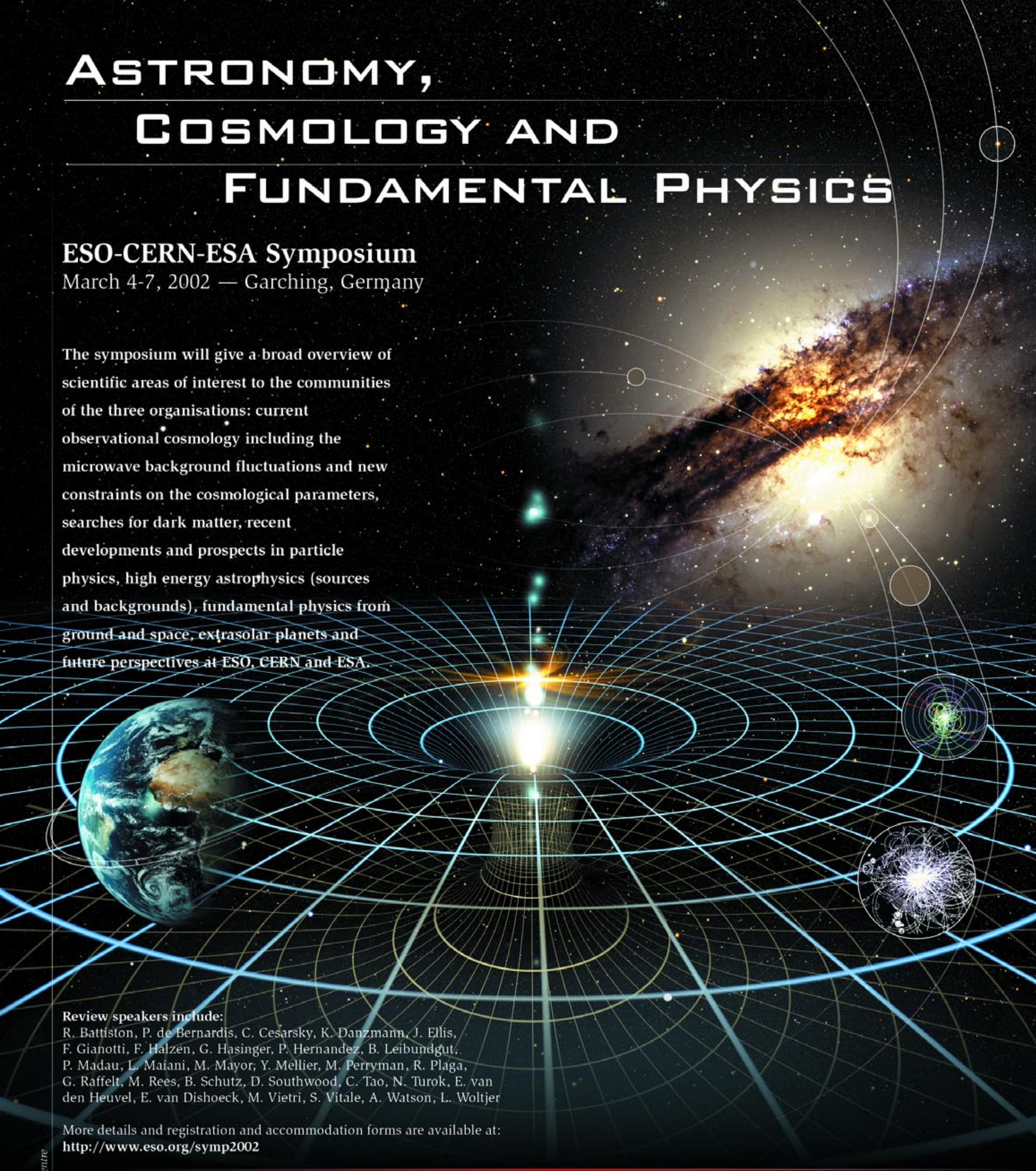
[9] http://www.eso.org/libraries/request.html

[10] http://www.eso.org/libraries/lib-helpdesk.html

[11] http://www.sla.org/

[12] http://www.eso.org/libraries/lisa.html



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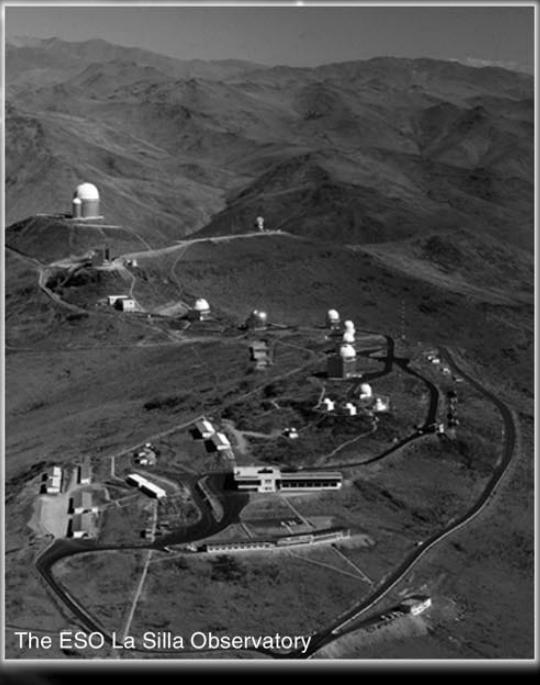

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1434. F. Marchis, R. Prangé and T. Fusco: A Survey of Io's Volcanism by Adaptive Optics Observations in the 3.8 μm Thermal Band (1996–1999). *Journal of Geophysical Research*, Io Special Issue, 2001.
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