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-$\Re$ 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.

[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.

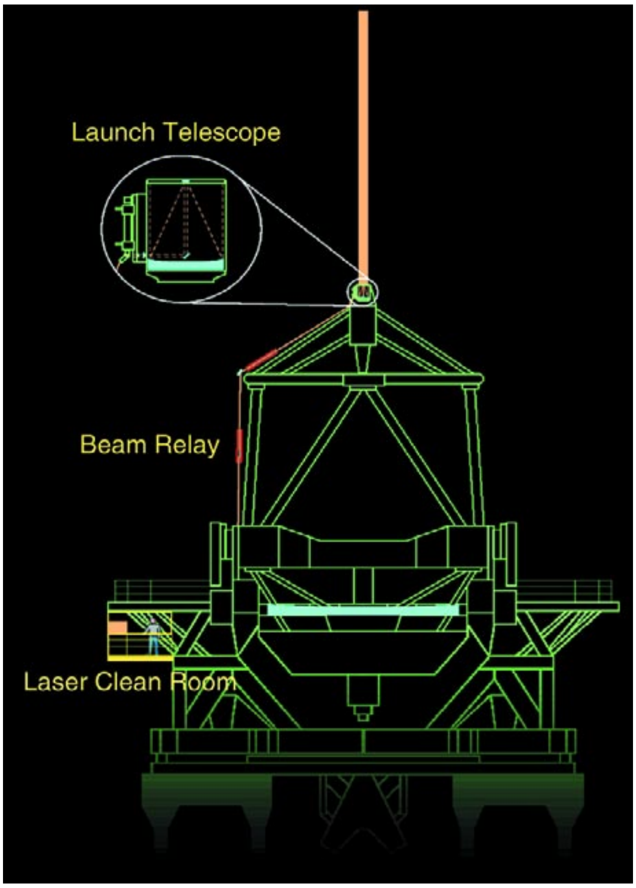

Figure 1: LGSF overview installed on VLT-UT4 (Yepun). Note that the Laser Clean Room is part of the telescope.

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

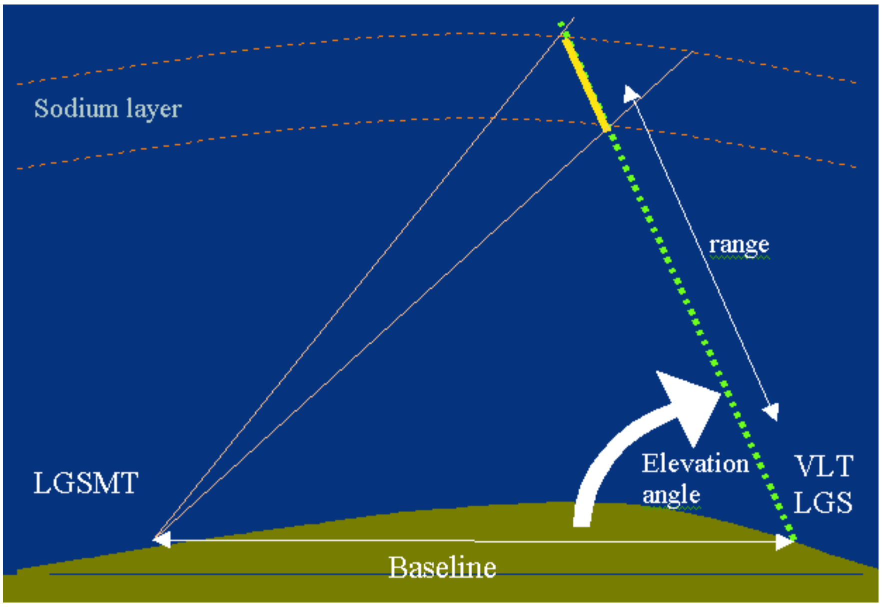

Figure 2: The LGS Monitoring Telescope concept. Imaging the laser plume in the mesosphere, looking from a distance of several km baseline, the sodium density profile, its centroid and the one-axis LGS FWHM may be retrieved.

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.

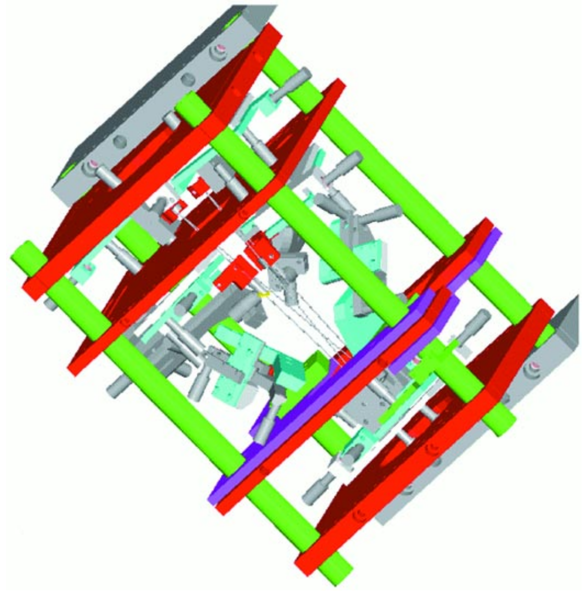

Figure 3: Design of the MPE PARSEC laser power amplifier resonator.

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

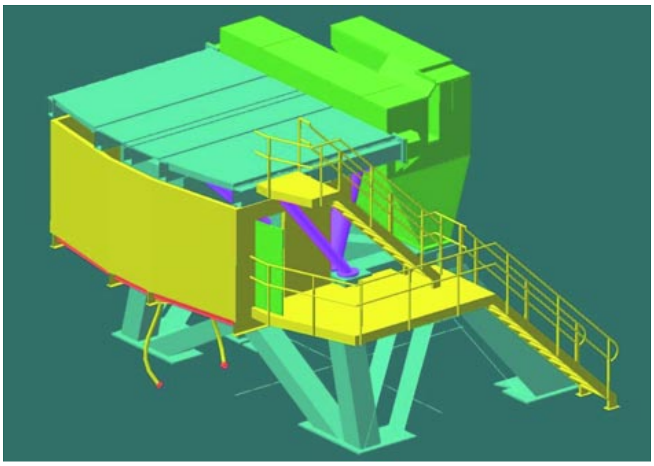

Figure 4: Laser Clean Room attached below the Nasmyth A platform of UT4. The access is from an enlargement of the side steps mezzanine.

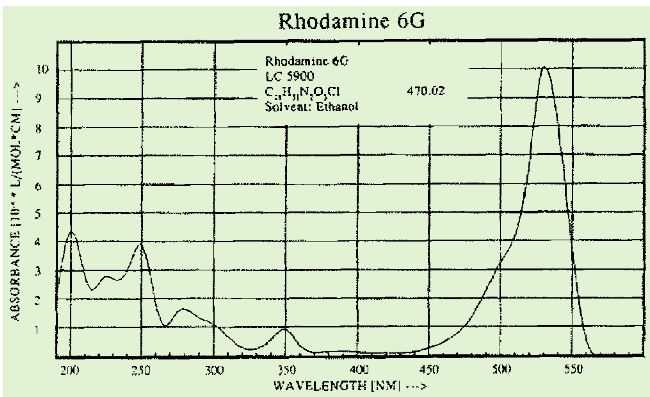

Figure 5: Rhodamine 6G Absorbance spectrum. Note the difference in absorbance when using pumps at 514 nm or at 532 nm.

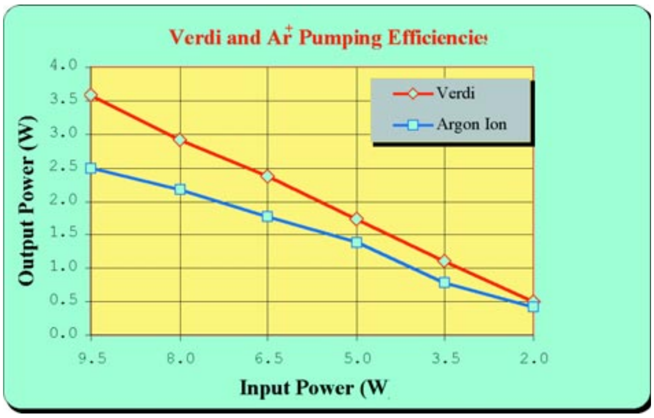

Figure 6: Calar Alto experiment with the ALFA laser. Output powers at 589 nm from the ring-dye laser, for different laser pump powers. The Verdi laser (532 nm) and the Innova Ar+ lasers from Coherent Inc. were used up to 9.5 W of pump power. The Verdi pumping gives up to 44% more output, at equivalent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

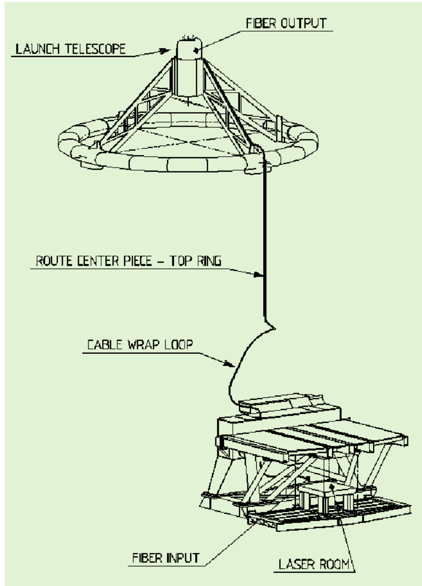

Figure 7: 25 m fibre relay routing on UT4.

• 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~ 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.

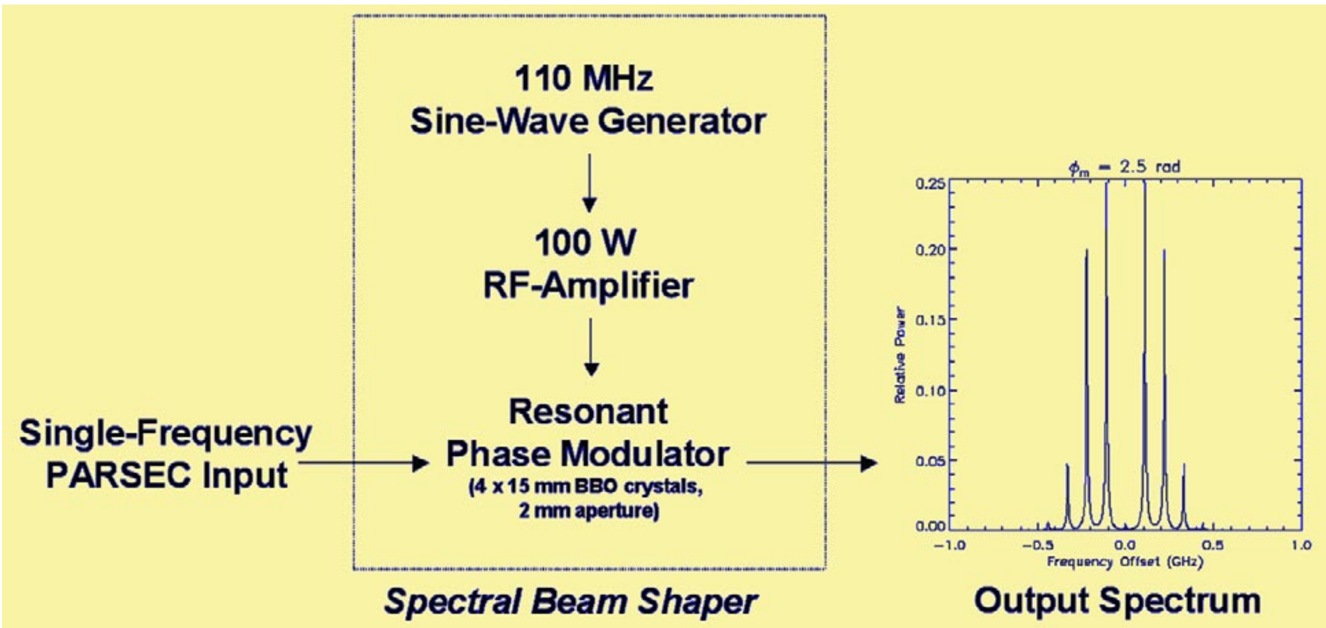

Figure 8: SBS suppressing scheme. A 110 MHz sinusoid is applied to a Resonant Phase Modulator of BBO crystals, which creates from the PARSEC single line, the spectrum shown to the right. This allows to reduce the SBS gain below threshold.

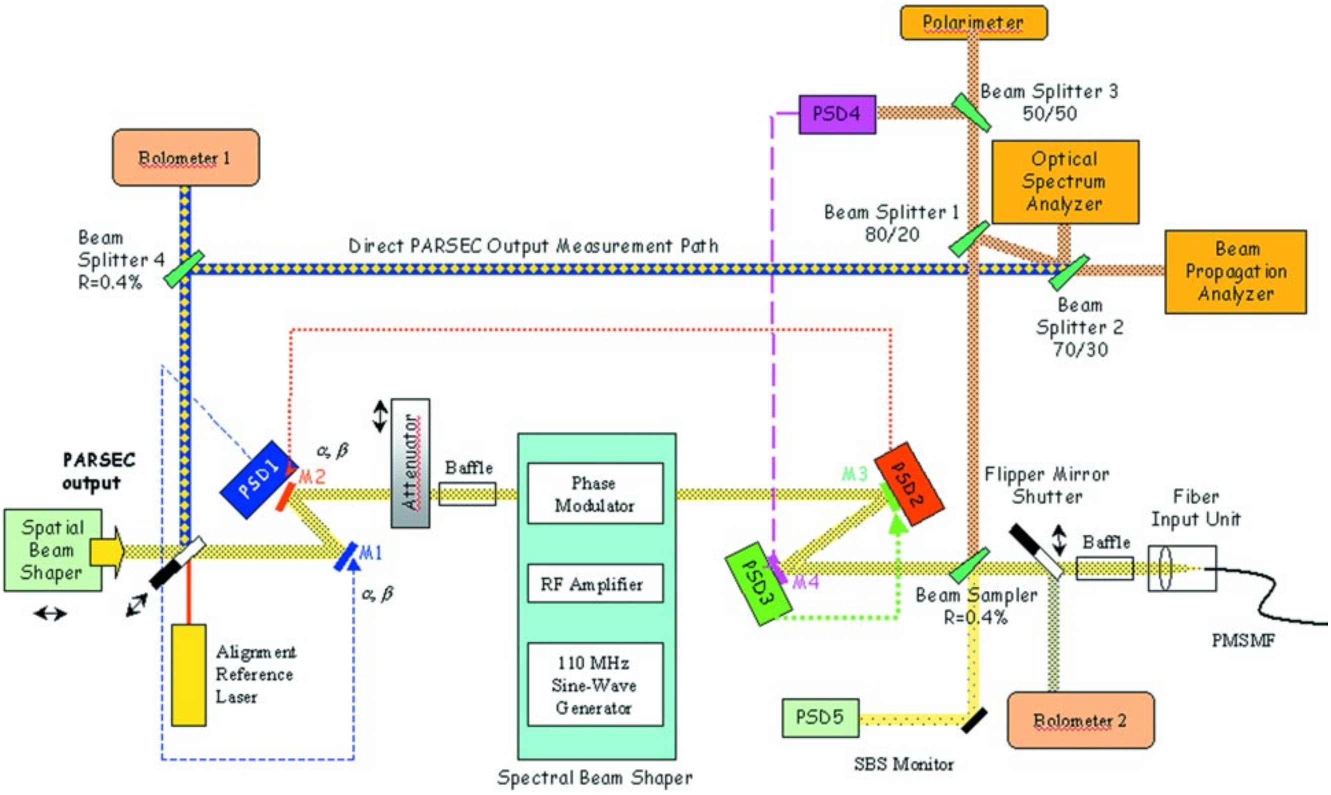

Figure 9: Beam Relay System Input Module. The functionalities are shown in the diagram. Note the PSD-piezo tilt combinations to stabilise the beams in x-y-q-f on the modulator, and independently at fibrer input.

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

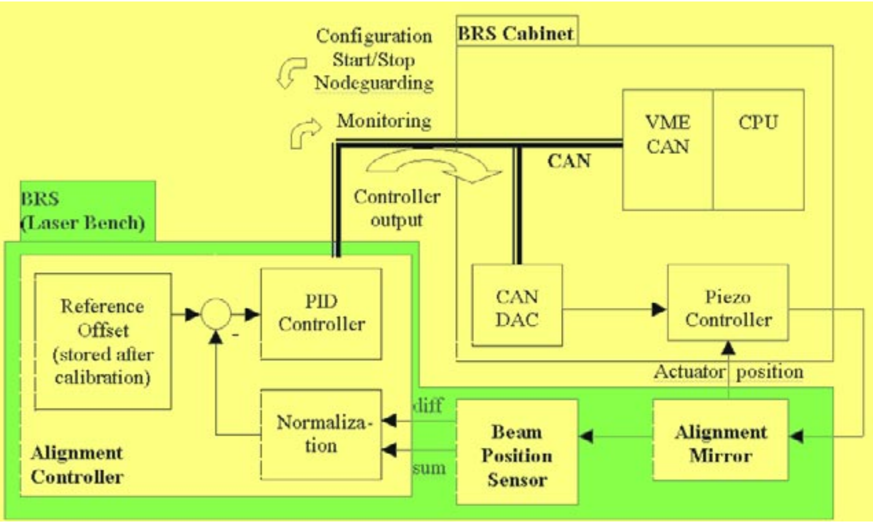

Figure 10: LT LGS jitter control scheme. Besides the AO commands, we have the option to use a faster jitter loop driven by a PSD sensor, in case we are faced with high frequency vibrations in the LT.

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.

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.

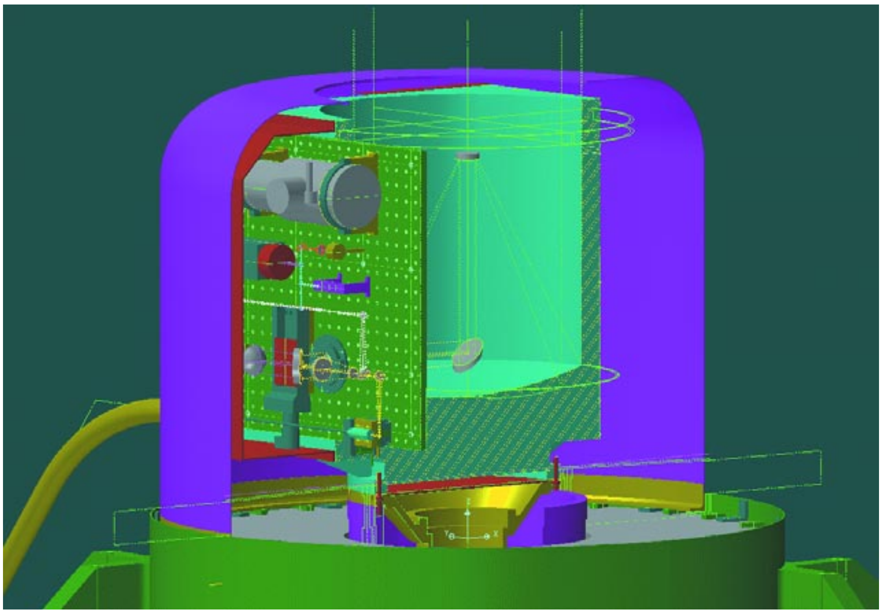

Figure 11: Launch Telescope assembly on top of the M2 hub, with diagnostic table, windshield cover and exit window. All the optics are enclosed in dry N2 atmosphere at normal pressure and temperature, to avoid dust and preserve the high power coatings.

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

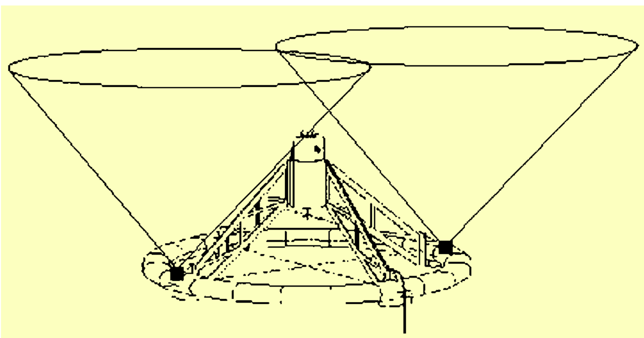

Figure 12: UT4 aircraft detection cameras mounted on the side of the telescope top ring. A field of view of 70 degrees allows to safely trigger commercial aircraft flying up to 400 m above the observatory, and to stop the laser propagation before they come across the laser beam.

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

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 Prorammes. 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