VERY LARGE TELESCOPE

Laser Guide Star
Monitoring Facility

Feasibility Study
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1. THE LGS MONITORING (LGSM) FACILITY

1.1. TOP LEVEL REQUIREMENTS

The following relevant requirements are extracted from: Laser Guide Star Facility Top Level Requirements Doc. No.: VLT-SPE-ESO-11800-2237 Issue: 3.0, Date: 23.02.2001:

TLR10. *The Artificial Source shall provide a photon return flux > 10^6 photons/sec/m^2 (goal $1.5x10^6$ photons/sec/m^2) at the Nasmyth focus of UT4, pointing at Zenith.*

TLR11. *The LGSF will emit a laser beam quality better than 1.3 × diffraction limited performance.*

TLR26. *Mesospheric Sodium Profile: the sodium profile has to be measured to appropriately focus the LGS. A LIDAR mode shall be implemented on LGSF, which allows to retrieve the relative Na abundance and profile, with a vertical resolution of 0.15 Km, in less than 30 second.*

TLR27. *A side LGS-monitoring telescope will be placed on the VLT site, operated remotely as a sub-system of LGSF, to provide on-line measurements of the following while AO is in closed loop, at a rate <30 second:*

- *Monitor the sodium profile for LGSF, while AO is online, using the elongated LGS spot, with the same resolution and time scales as the LIDAR mode.*
- *Monitor the integrated LGS return flux, to infer transparency and sodium density fluctuations, with a resolution of 1% in the visual magnitude ranges 7-12, in a 30 second time scale*
- *Monitor the LGS spot size, using the transverse LGS spot*
- *Evaluate up-going beam scattering, its intensity and spatial distribution, and the presence of cirrus clouds, with a resolution better than 1 km.*

1.2. FUNCTIONAL SPECIFICATIONS

The LGS monitoring facility is a totally automated system, compatible with the VLT standards. It fulfills the following functions:

- Monitor the mean LGS height variations as a function of time, relative to its initial position.
- Monitor the mean LGS spot size at the mean LGS position.
- Monitor the mean integrated LGS brightness and the LGSM instrumental constant (with reference to standard stars) so as to extract the mean sodium layer density variations assuming nominal launch characteristics for the laser (output power stability better than 15% on a one hour time scale).
- Monitor possible variations of the atmospheric transparency (aerosols, cirrus clouds) with a minimum 5% transmission relative accuracy.

2. SODIUM LAYER DENSITY: INITIAL ASSUMPTIONS

2.1. BACKGROUND

The sodium layer considered here is situated in the mesosphere at 91.5±10 km and has a mean column density of $3x10^{9} cm^{-2}$, value that is strongly latitude dependent.

However this layer 'suffers' from seasonal, daily and short-term variations. The seasonal variations are 'sinusoidal' and affect the sodium column density, the average centroid position of the layer and its thickness (see e.g. Papen et al. 1996). The sodium chemistry is known to be a sensitive function of temperature and the seasonal temperature variations appear to be largely responsible for the seasonal variations in the Na abundance which is maximum in winter (i.e. July-August in Chile). Papen et al. (1996) quote a mean sodium column density (at 40 degrees latitude North) of $4.3x10^{9} cm^{-2}$ (with variations from 1 to $8x10^{9} cm^{-2}$) and a mean layer altitude of 91.7 ± 2 km. Measurements of sodium column density presently available for La Silla (Ageorges 2001, in preparation) show variations from 1 to $4.5x10^{9} cm^{-2}$. Variations of the centroid position of the layer have a direct impact on the focus for laser guide star. Ageorges et al. (2000) quote variations of the centroid altitude position of the layer of up to 400m in 1 to 2 minutes (at 37 degrees North).

For Laser Guide Star Adaptive Optics, the short-term variations of the atmospheric sodium are the most worrisome. These variations can be classified in two types: the daily and 'hourly' ones.

Gravity waves are believed to be responsible for the daily modification of the Na layer, even though it is not yet clear how. Moreover Qian et al. (1998) conclude that these waves play an important role in the formation of sporadic Na layers (Na_s). These are very thin (0.5 to 2 km thick) Na layers superposed to the mean mesospheric sodium layers. They are characterized by a rapid increase in sodium density over a narrow altitude range. They can last few seconds but in average few minutes up to few hours. The 'hourly' variations of the mesospheric sodium layer, mentioned above, are clearly dominated by these sporadic layers.

Sporadics have been detected more frequently at high and low latitude than mid-latitude sites. It has long been recognized that many Na_s are associated with sporadic E layers. It has therefore been suggested that the apparition of these layers might be related to magnetic latitude more than to geographic latitude (Kwon et al. 1998). With the exception of Kwon et al. 1988, none of the other authors mentioning sporadics did see any 'time' correlation for their occurrence; neither does it appear to have significant seasonal difference in occurrence frequency. However many groups have measured enhancement of the sodium concentration during meteor showers (see e.g. Michaille et al. 2001). This can be understood since meteorite ablation is considered as the main source of mesospheric sodium.

Sporadics Na layers will be the most affecting effect for LGS AO; see Clemesha et al. 1995 for a review of this still puzzling effect. Moreover, a sidereal motion is required for the LGS to follow the science object, which produces an horizontal displacement of the probed area in the sodium layer, and thus a possible increase of high frequency density variations which have to be studied.

2.2. SUMMARY OF IMPORTANT QUANTITIES

- Column density:
  Mean : $3x10^{9} cm^{-2}$
  Range: $1\text{-}5x10^{9} cm^{-2}$
  Maximum (in case of sporadics): $12x10^{9} cm^{-2}$
  Effect of sporadic: multiply the mean value by 2 to 4 in average

- Centroid position of layer:
  Mean altitude: 91.5 km
  Variations: ±2 km

- Modeling the sodium profile:
  Density range: $0.1\text{-}12x10^{4} cm^{-3}$
  Shape: well approximated by a gaussian (possibly superimposed multiple gaussians in case of strong sporadics)
  Temporal stability: ~ 1 minute

3. SYSTEM STUDY

3.1. PRINCIPLE

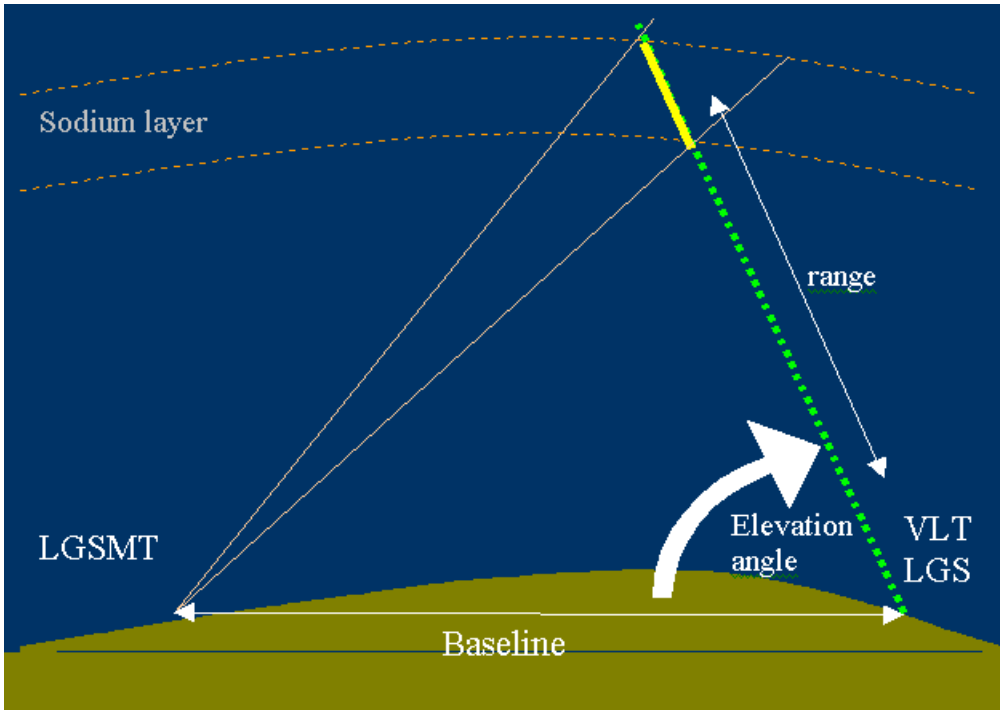


Figure 1: principle of the Laser Guide Star Monitoring System

The operational concept of the LGSM can be easily understood referring to Fig. 1 where the side looking principle of this device is described. A small telescope called LGSMT, located a few kilometers away from the LGS launching telescope, can take short exposures of the sky field where the sodium LGS is generated exciting the mesospheric Sodium layer. From the LGSM site the sodium star is recorded as a bright luminescent plume superimposed on a stellar field.
After an exposure of about 30 sec, an automated software extracts the plume brightness profile from the recorded image. Using telescope encoders absolute positions, VLT pointing coordinates and stellar field analysis, the apparent brightness profile is then converted into relative sodium distribution abundance along the VLT LGS line of sight.
A sodium vertical profile is obtained with LGSF in LIDAR mode after each new pointing of the LGS. The LGSM relative measurements are converted into absolute ranges using this initial information. The centroid position of the LGS is transmitted to the adaptive optics (AO) system to compensate for the defocus parameter. Subsequent analysis of the plume transversal PSF yields the position of the most populated areas of the sodium layer at which to conjugate the focus of the LGS launch telescope.

3.2. SIMULATIONS

In order to better estimate the performances of the LGSM a simulation software has been created both in Excel and IDL to optimize all the free parameters of the instruments. These parameters are described in the following list:

DEFINITION OF TERMS
Aperture: LGSM telescope entrance pupil diameter, in m
Focal Length: LGSM telescope focal length, in m
Pixel size: detector pixel pitch, in arcsec
Global Quantum Efficency (QE): conversion factor from photons to recorded ADU
Field of view: sky field in arcmin on the detector area.
RON: detector read out noise in e/pixel
Gain: camera controller conversion factor from electrons to ADU
Exposure: detector exposure time in seconds

S/N: signal to noise level per pixel along the laser plume (constant flat profile)
Baseline: distance on the ground between LGS launch telescope and LGSMT
Range resolution: projected pixel length along the LGSF laser path at the altitude of the Na layer, in m

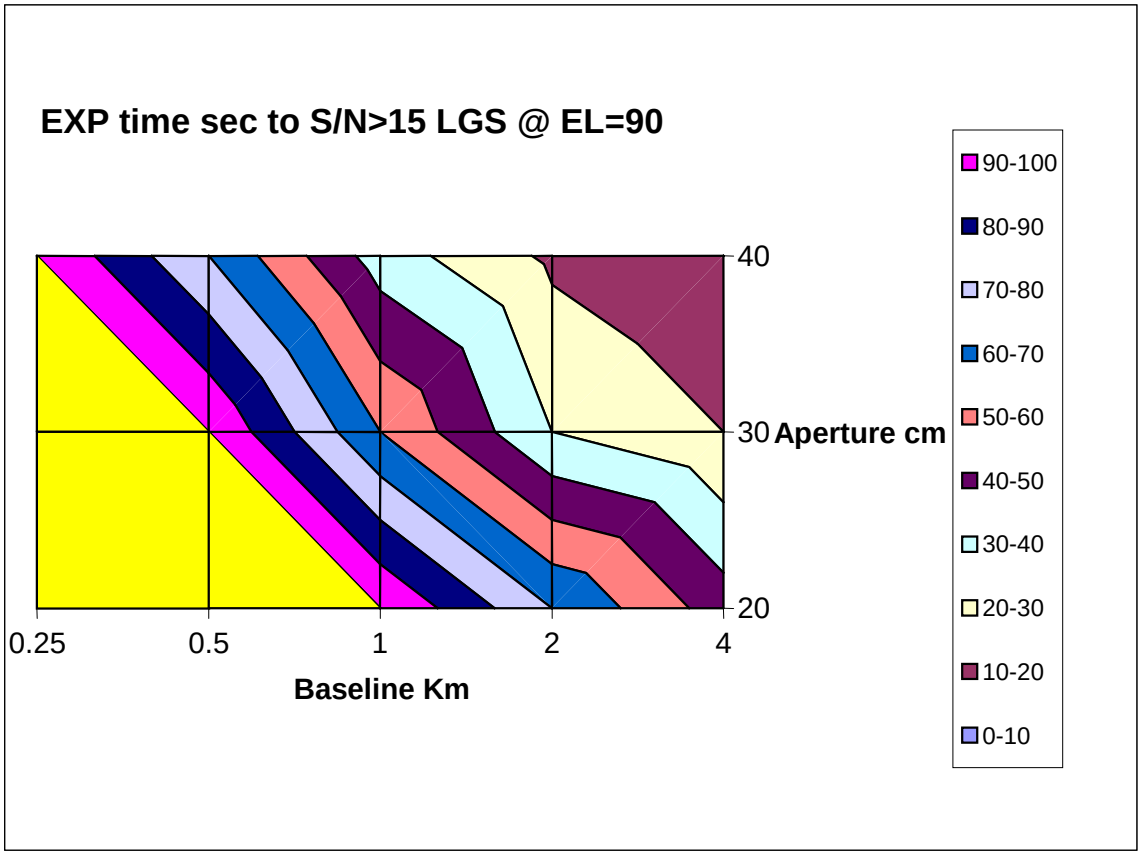


Figure 2: Exposure time required to reach S/N=15 for an LGS at zenith. The detector camera parameters were the followings: total Q.E.: 0.55, RON: 5 electrons, pixel size:15 micron, CCD pixels: 1024 x 1024, Gain=0.33

For a given optical configuration, the range resolution depends on the elevation angle of the laser beam: the system must fulfill the top level resolution requirement with an LGS produced from zenith down to the lowest elevation of 30 degrees. The best range resolution is achieved with the LGS pointing around the zenith. At low elevation angles the perspective projection reduces the dimension of the laser plume on the focal plane of the LGSMT making it faster to record or increasing its S/N for a fixed exposure time with respect to zenith pointing. The following charts Fig.2 and 3 reports the result from simulations where the free parameters were the baseline and the telescope aperture while the focal length was arranged to yield the desired range resolution of 150 m. The exposure time was varied to reach a S/N of 15 enough to reduce the centroiding error due to photon noise to less than $1/5^{th}$ of a pixel (Table 4).

The desired data refresh time of about 30 seconds can be achieved with a limited aperture telescope (<40cm) only if the baseline is larger than 2 km (**Figure 2**), especially when pointing where the LGS will be mainly used, ie. nearby the zenith.

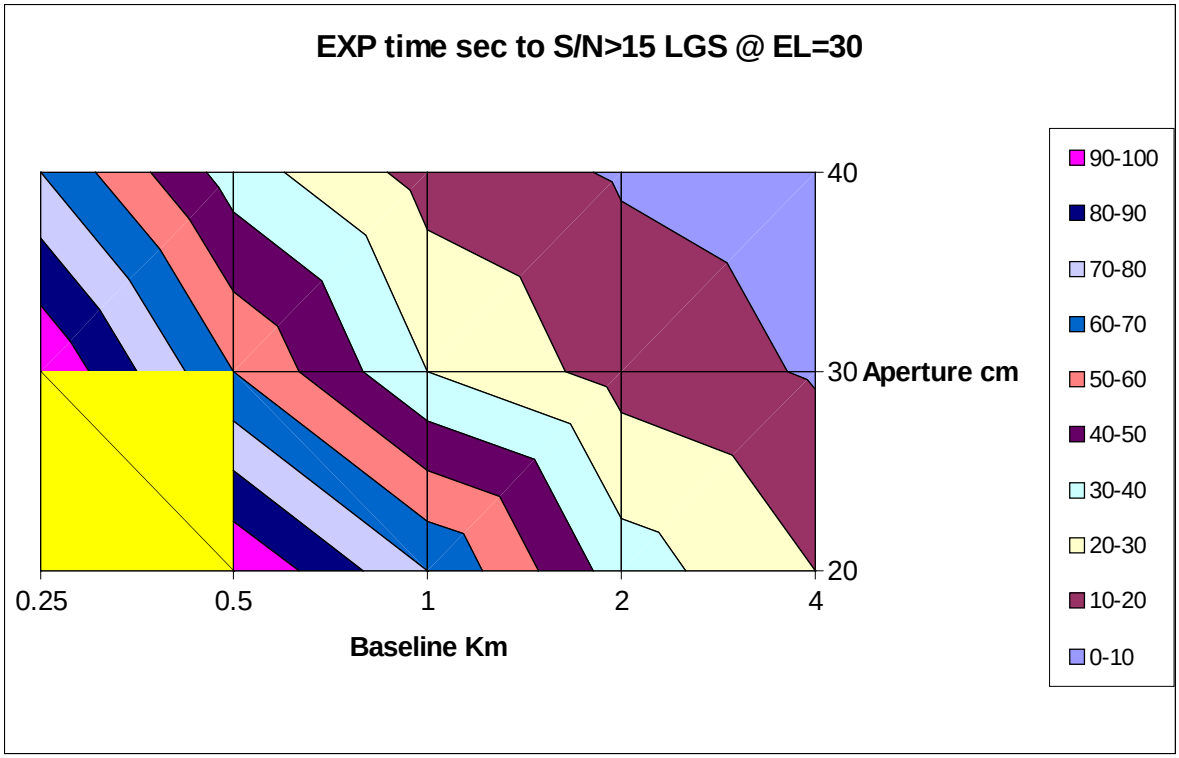


Figure 3: Exposure time required to reach S/N=15 for an LGS at 60 degree zenith angle. The detector camera parameters were the followings: total Q.E.: 0.55, RON: 5 electrons, pixel size:15 micron, CCD pixels: 1024 x 1024, gain=0.33

The results at the minimum elevation of 30 degrees are shown in Figure 3: the S/N value of 15 is obviously reached faster when pointing at LGS with a lower elevation.
Exposure times of about 20 –30 sec. are enough to detect a lot of field stars and other astronomical objects with a good S/N for precise astrometric reduction of the imaged fields (see Table 1). Using on line astrometric catalogs, it will be possible to recognize the stellar field in few seconds and, by means of spherical trigonometry, extract the ranging coordinates of the laser plume along the laser beam, using the Alt-Az pointing coordinates of the LGS launch telescope.

V magnitude	Number of stars
6	0.1
8	0.7
10	3.3
12	12
14	33
16	112
18	256
20	560

Table 1: The forecasted star density, for a 20 x 20 arcmin area, at high galactic latitude (less crowded areas) from Bahcall and Soneira (1983).

4. PROPOSED CONFIGURATION

4.1. SITE LAYOUT

The distance of the LGSM to the LGSF launch site determines the size of the primary optics of the LGSMT, a major hardware cost component in the project: as shown on, the longer the separation, the smaller the telescope. On the other hand, the cost of underground communication lines increases with the distance up to a point where radio waves become preferable. The tradeoff shall be made at a later stage of the project. According to Figure 4 and taking into account existing infrastructure in the VLT science preserve, the summit of **La Montura** (intersection of lines 60 and 79 on Figure 4, 3.6 km from LGSF) is the preferred site.

A second choice would be the vicinity of the so-called **NTT peak**, now the site of the **VISTA** telescope (intersection of lines 59 and 77, 1.4 km from LGSF), requiring less infrastructure developments, but at the cost a larger collecting area. The site of **La Montura** is known to be about 20% less windy than **Paranal/NTT peaks** with 93% of the time less than 10m/s (VLT Report 62) but shows 10 to 20% worse seeing conditions. A tower and a small control room were built there in 1989 in the course of the VLT site survey.

The range resolution achieved by the LGSM located at **La Montura,** 3.6 km to the NE of the LGSF along the Na plume centered at 92 km above ground level, with the operating parameters of section 4.2 is given in Table 2 for various LGS elevations.

LGS Zenith Angle	Range resolution (m/px) 82km/92km/102km
0	11.3/14.2/17.4
10	12.0/15.0/18.4
20	13.9/17.5/21.4
30	18.0/22.5/27.6
40	26.1/32.7/40.0
50	44.1/55.3/67.7
60	93.2/116.8/143.1

Table 2: Performance of the LGSM at La Montura, 3.6 km from the LGSF

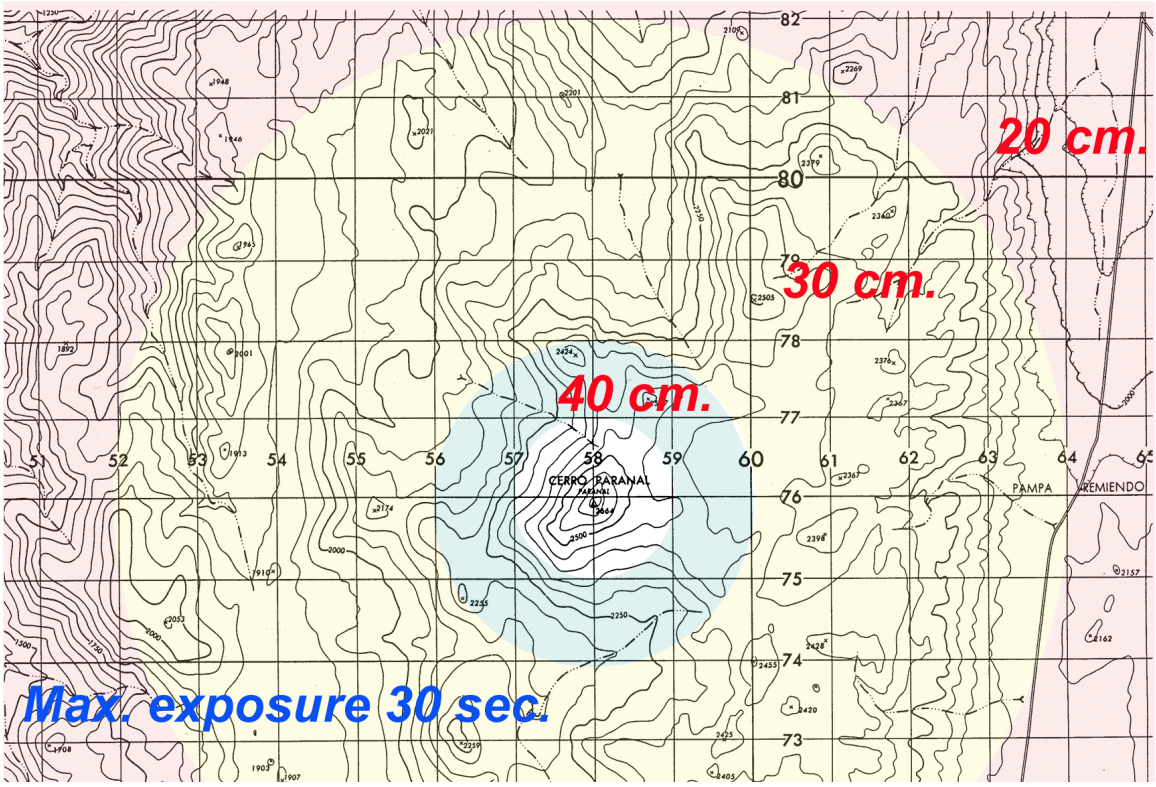


Figure 4: Telescope aperture required to achieve S/N=15 with a 30s exposure time on a zenith LGS as a function of the distance to the LGS launch site.

4.2. OPERATING PARAMETERS

An IDL based end to end model has been developed to take into account non analytical effects, such as the differential motion of the laser plume versus the stellar field when observed off axis. The model is run with a "La Montura" configuration corresponding to a LGSM offset versus UT of 2km East, 3km North, and -0.2km in altitude, thus a baseline of 3.6km. The selected hardware configuration for the LGSM is the following:

Telescope 30 cm aperture, focal length 250 cm
Plate scale 1.238 arcsec/pixel
Exposure 30 sec
Detector characteristics: QE=0.8, RON=5e, Gain=0.33
Focus: at the LGS altitude
Field rotation compensation

Because of the parallax introduced when LGS and LGSM are not collocated, one should expect that the stellar background moves differently from the LGS as viewed from the LGSM. Two examples of real fields simulated when viewed from the proposed site are shown on Figures 5 and 6 for the same technical configuration, when the LGSM is tracking the LGS centroid. They illustrate the large variations in the relative motion of the background depending on the position of the LGS in the sky. It is believed however that astrometry is still possible in all cases because the blurring of the background is perfectly predictable.

Figure 5: VLT pointing close to zenith: alfa 00 00 00 VLT, delta -24 00 00, hour Angle 00 00 00. LGSM at La Montura, exposure 30 s, seeing 1.2 arcsec, sky background 19.5, field size: 750x750 pixels.

Figure 6: VLT pointing to the pole, alfa 00 00 00, delta -90 00 00, hour angle 00 00 00. LGSM at La Montura, exposure 30 s, seeing 1.2 arcsec, sky background 19.5, field size: 750x750 pixels.

4.3. PHOTOMETRIC OPTIMIZATION

With a laser plume recorded with the LGS at 45 degrees elevation viewed from a distance of 3.6 km from the launch site, a Johnson V filter of 90% peak transmission and 100 nm FWHM, the zenith LGS flux at the ground is 0.5 10^6 photons/sec/m^2 with an FWHM of 10 km at 92 km above ground level. With a 0.7 arcsec seeing and a 21st Mag V sky background, the pixel level at the peak of a V=17 star is 150 ADU and 700 ADU at the maximum of the LGS plume. The saturation (60000ADU) is reached for stars brighter than 9th magnitude, according to Table 1 each image should have at least one saturated pixel in the least populated area of the sky. With a plume covering at most 1000x3 pixels, the probability that one of them is saturated is then 3/1000. In the most crowded areas, this number rises to e.g.: 1/100 in the galactic equator

LGS Zenith Angle	S/N per pixel, Johnson V filter	S/N per pixel, D2 Filter
0	11	10
10	11	10
20	12	10
30	12	10
40	13	11
50	15	12
60	17	14

Table 3: Signal to noise achieved at the centroid of the Na plume with the proposed configuration and the operating conditions of Figure 5. The signal to noise on a star of 15th Mag is 50.

It is possible to achieve 1/10th pixels astrometric accuracy with a minimum number of 3 useful objects in the field with a signal to noise per object greater than 20 (see Table 4). According to Table 1, there are more than three stars in the imaged field fainter than magnitude 10 in the least populated area.
In the operating conditions of Figure 5, a S/N of 500 is reached on a 10th magnitude object. The image is assumed to be photon noise limited, which implies that the CCD dark current level and readout noise remain lower than the square root of the electron sky level (in dark nights: 64 e- for a 30s exposure with the proposed configuration).

Adding a D2 filter is suggested to reduce star light contamination in crowded fields: a 10 nm FWHM interference filter of 50% peak transmission is equivalent to a loss of about 3.2 magnitudes with respect to the standard V filter. The S/N achieved with such a filter on the 10th magnitude object is then 127, fully within the astrometry requirements. The saturation magnitude range is then 5.8-6.3 and the S/N ratio achieved on the laser plume is given on Table 3. The sky background is then reduced to only 4 e- in a 30s exposure and the dominant noise source is the camera. The simulation shows that the probability that one pixel of the plume is saturated becomes 3/10000 in the least crowded area of the sky and 15/10000 in the galactic equator.

Pixel S/N	Barycentric Centroiding error (px)
10	0.25
20	0.10
30	0.07
50	0.04
100	0.02

Table 4: Centroiding error due to image noise (photon, flat field, and readout noise) of a single pixel source.

4.4. TECHNICAL SPECIFICATIONS

The described LGSMT solution can be build mainly around industrial components to reduce the costs and the delivery time. The 30 cm. F# 8.3 optic must yield a distortion free focal plane covering a field

of 20 arcmin. Both the Maksutov or the Ritchey-Cretien designs can satisfy this requirement and are available from optical companies as off the shelf configurations. The constraint about the F# is not mandatory and a 10% tolerance can be well accepted. A stiff mount implemented with sub arcsecond resolution encoders is mandatory for excellent pointing and tracking performances needed for a fast and reliable automated astrometric reduction of the exposed field. The control system can be easily interfaced to the VLT LGS LAN by using a ESO LCU module with its software providing the bus connection to the boards required for the telescope motion, the camera controller and the dome opening. The standard ESO VLT software libraries will be implemented in the LCU for routine astrometric computations, the telescope pointing model and the online reduction and distribution of data. The dome itself can be selected between standard production housings for remote controlled small telescope preferring a removable roof solution to avoid the control of the enclosure rotation. A list of technical specification is reported:

- Optical design: Ritchey Cretien or Maksutov telescope, with closed tube to minimize maintenance.
  Free distortion field: > 20 arcmin
  Aperture: > 30 cm. (F# ~ 8.3)
  Bandpass Filter: Johnson V (100 nm FWHM) & D2 (10nm FWHM, peak transmission > 50%)
- Mount type : alt-az with field de-rotation
  Controls: brushless motors and sub-arcsecond on axes encoders
  Slew speed: > 5 Deg./sec.
  Tracking jitter: better than 0.2 arcsec for 1 minute in open loop
  Mechanical stability: resonance frequency > 15Hz
- Camera : CCD with 1Kx1K pixel, V band enhanced (Q.E. > 85%)
  r.o.n. < 5e-, dark current < 0.3 e^-/pix/sec, read out time: < 10 sec
  frame transfer time < 10ms or interline transfer.
  cooling: maintenance free system (Peltier or cryo-cooler)

4.5. OPERATION

The LGSM is unattended and linked via LAN to the VLT backbone from which its main functions can be controlled (LGSM is in **MANUAL** mode) and its operational mode can be checked (LGSM in automated operation). The LGSM has permanent access to the VLT-ASM (Astronomical Site Monitor) meteorological data and to the VLT-UT alt-az coordinates. The LGSM is normally in **IDLE** mode (ready to operate, dome closed, checks the meteorological conditions and computes solar elevation every one minute, no hardware activity). At the reception of a <***WAKE-UP***> message from the LGSF containing target coordinates, the LGSM attempts to switch to **SLEW** mode (opens the enclosure and slews the telescope to the prescribed coordinates) if meteorology and solar elevation permit. Once the target coordinate is reached, the telescope is switched to tracking mode, the LGSM moves to **FIELD** mode, in which bright stars in the field are identified and the detector plate scale and sky coordinates are permanently updated. At the reception of a <***LIDAR***> message from the LGSF, containing the sodium layer initial abundance and profile, the LGSM switches to **MONITOR** mode, first scanning the field until the LGS appears, then in a 30 second infinite loop cycle, extracts the various LGS parameters, sends a <***LGSM DATA LOG***> back to LGSF, checks meteorology and applies tracking offsets. The loop is broken in the following circumstances:

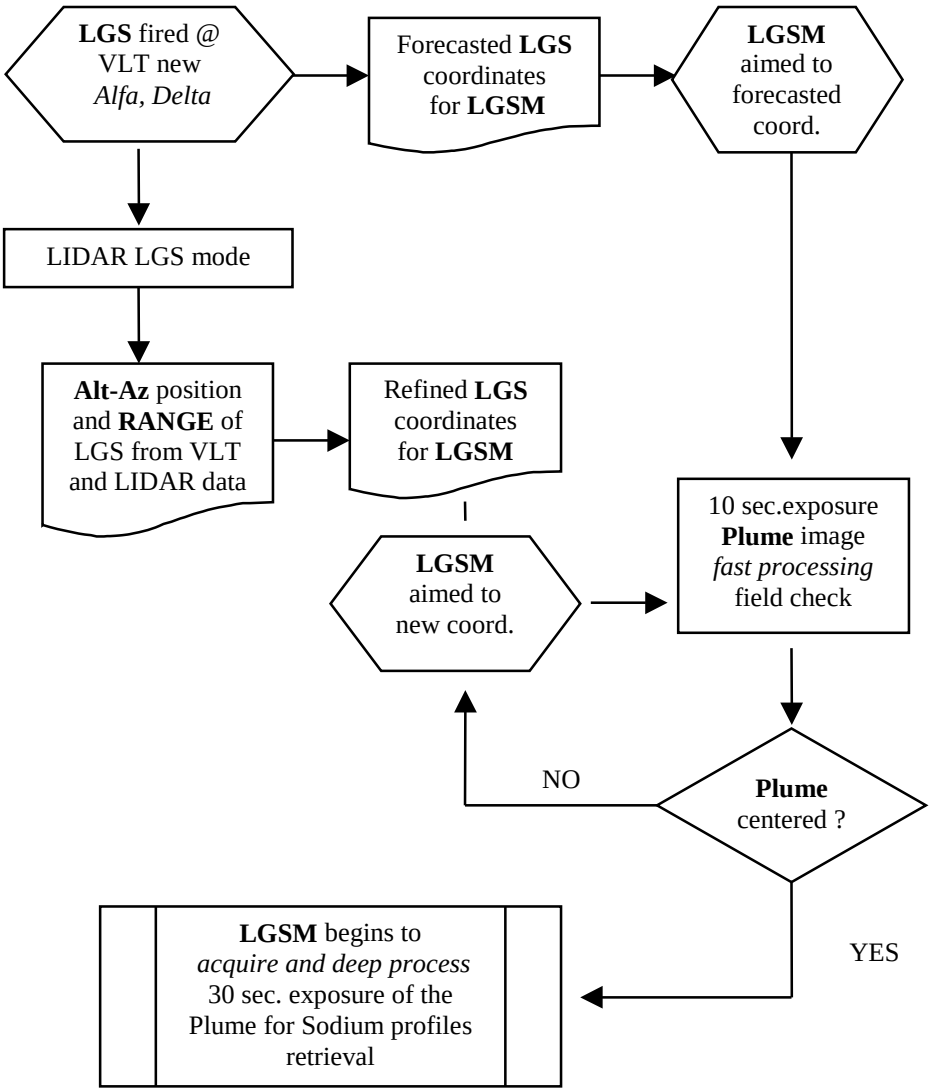
- When meteorological conditions exceed limit values, the system is then sent back to **IDLE** and tries to fulfill the current <***WAKE-UP***> call.
- At the reception of a new <***WAKE-UP***> message containing new target coordinates, the system is sent back to **SLEW** mode.
- At the reception of a <***SHUTDOWN***> message from the LGSF, indicating the end of operation, the current <***WAKE-UP***> call is then cancelled and the system is sent to **IDLE** mode.
- When the solar elevation exceeds its limit value, the system is then sent back to **IDLE** and the current <***WAKE-UP***> call is then cancelled.

4.6. MAINTENANCE TASKS

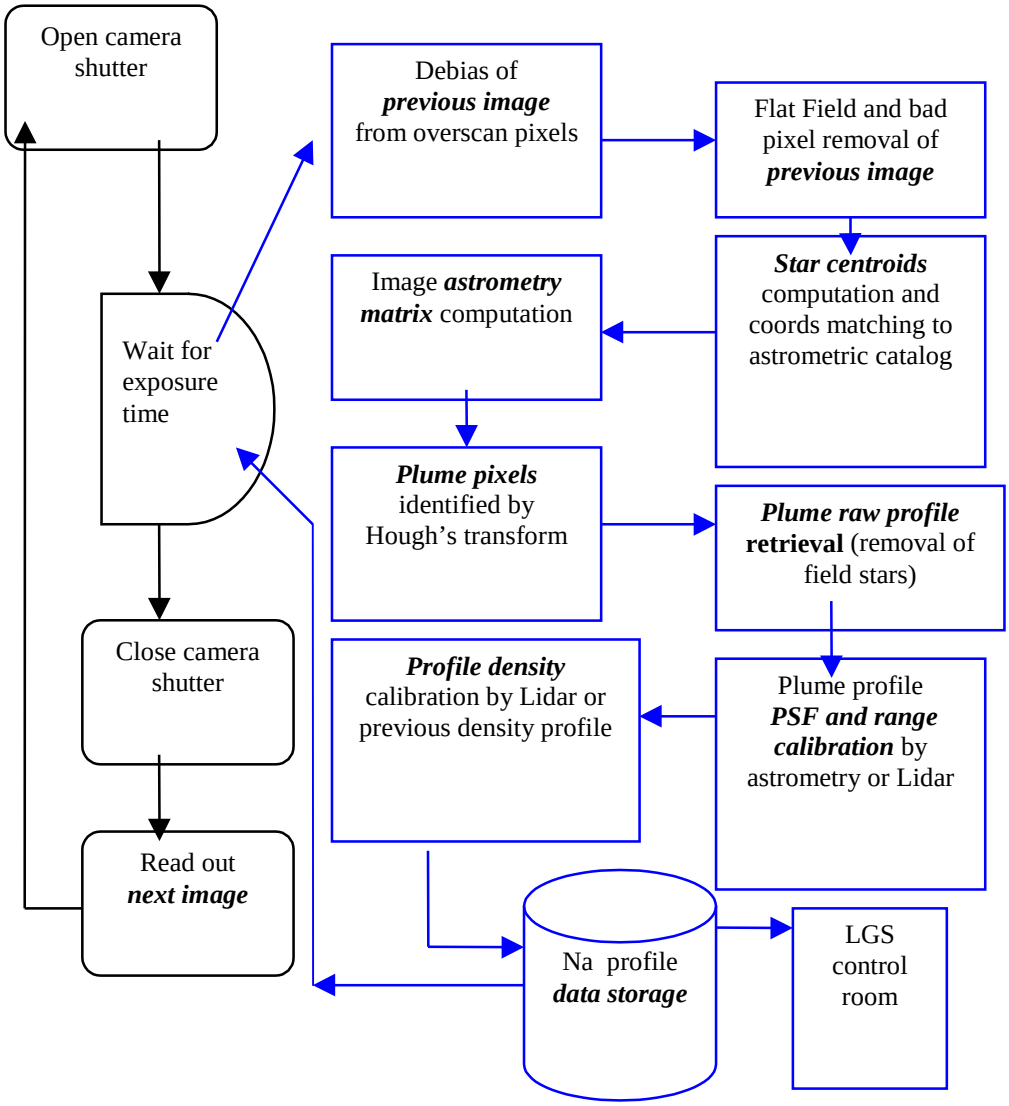
The LGSM is provided with an automated control of the photometric quality, it shall request extraordinary maintenance when required (eg. flat fielding).
Regular maintenance tasks are taken over by LGSF operation: cleaning the optics (monthly), chiller maintenance.

4.7. DATA PROCESSING

4.7.1. Functional bloc diagram



4.7.2. Pipeline Description



The flow chart above shows the main tasks involved in the pipelined data reduction for the Sodium density profile retrieval. The exposure time of 30 sec. during each image acquisition will be used for the data processing of the previously acquired image. This means that each image is processed while the next image is exposed and read-out. To really exploit all the advantages of a pipelined data reduction, it is mandatory to strictly schedule the image processing software so that all the needed tasks are completed before the shutter is closed and the next image acquired. A brief description of the main tasks is following.

- **Debias and flat-fielding**

This is a standard astronomical image pre-processing task needed to remove noise due to the different pixel sensitivity of the CCD sensor. The calibration image (flat field) used is stored in the instrument database and has been acquired and computed during the previous service/calibration run.

- **Star centroids**

During this task the image is scanned to identify structures with a gaussian like shape above a flux threshold. Then on the identified stellar source the luminosity centroid is computed to refine its coordinates down to sub-pixel resolution in view of the cross-correlating it with an astrometric position

catalog extracted from the GSC, composed of the brightest sources inside the imaged area. Once the correlation has been performed, each source is attached to a couple of alfa-delta coordinates.

- ## Astrometry

All the sources with attached alfa-delta coordinates are processed to compute an astrometric conversion matrix. With this output it is possible to attach to each pixel or fraction of it in the image, a couple of alfa-delta coordinates. Such a mapping is needed for the range determination task.

- ## Plume pixel extraction

In this phase the pixels belonging to the laser plume are be identified by using the Hough's transform. This peculiar algorithm extracts only the linear shapes returning the offset and angle of every line present in the analyzed field. The back transformation after the filtering in the Hough's space returns an image without stars with only the plume ready to be de-rotated by the plume angle. After this step the profile is ready to be extracted along the x and y-axes. The effect of the relative drift of the plume with respect to the reference stars (**Figure 5**) has to be studied in more details

- ## Plume raw profile retrieval

The plume is isolated from the background field stars by subtracting a synthetic image. Such an image is calculated applying to the previous exposure a shift corresponding to the expected sidereal motion.

- ## Profile range calibration

Due to the perspective aberration of the plume the range coordinates along it do not follow a linear scale. The following trigonometric algorithm sets the range of each pixel of the plume. In the triangle AÛC we know the length AU, the angles CÂU and CÛA and we compute the lengths AC and CU (CAU = 90-CÂE-UÂO, CÛA = 90-FÛC-OÛA). Finally DU = CU / sin (DÛC)

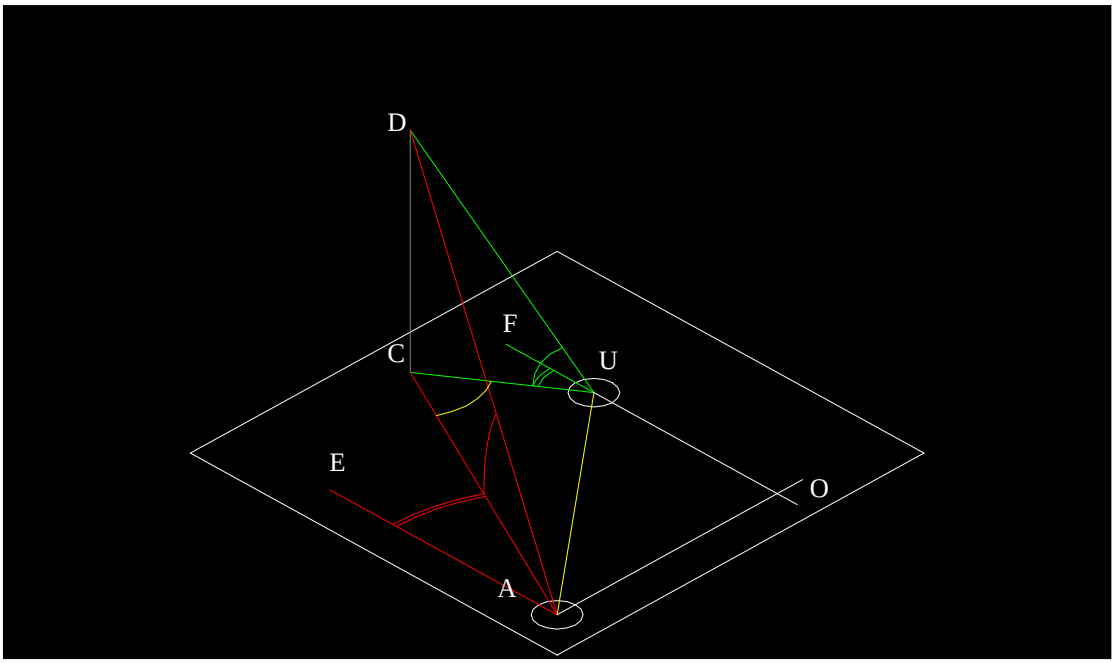


Figure 7: Geometrical definitions for an LGS in D, VLT in U and LGSM in A
<u>Input</u>: a) VLT pointing coordinates: azimuth FÛC & elevation DÛC,
b) LGS centroid coordinates in the LGSM astrometric field: azimuth CÂE & elevation DÂC
<u>Output</u>: range DU of the centroid of the laser plume

- **Plume transverse characteristics measurements**

The transversal sections of the laser plume are used to check the focus of the LGS. Due to the relative under-sampling of the LGSM (1.23 arcsec/pixel), adjacent lines of pixel are re-centered and added to better extract the plume transversal PSF, thus exploiting the natural dithering of the plume itself on the CCD array.

- **LGS range determination**

The centroid of the plume profile is computed as the barycenter of the flux along the LGSF line of sight, thus determining the LGS range.

4.7.3. Data storage

The sodium profiles and centroids are stored in the LGSF database. The photometric and astrometric parameters are stored locally (LGSM database) for self-check purposes and decision making on maintenance actions. One image per hour as well as all the images having generated an error code shall be stored for further inspection.

5. PROPOSED TIME SCHEDULE (AS OF SEPTEMBER 2001)

5.1. PROJECT ORGANISATION

Although not part of the LGSF project, the Laser Guide Star Monitoring facility (LGSM) remains a sub-system of the Laser Guide Star Facility (LGSF). The system engineering part of the LGSM shall be conducted in close collaboration with the LGSF team, therefore participating in the HW/SW design tradeoffs and documents review. The purpose is to ensure a seamless and fast integration into LGSF already in the design phase.

5.2. PLANNING

The LGSM schedule is linked to the LGSF planning, which has a first star commissioning seen in March 2003 (Ref.: Laser Guide Star Facility: Management Plan and Schedule, Doc. No.: vlt-pla-eso-11800 2276, Issue: 2.1, 30.04.2001).

If the LGSM is expected to be in phase with the LGSF, the planning is the following:

- Sep-Dec 2001, detailed specifications of LGSM, selection of components
- Jan-Sep 2002, procurement manufacturing, assembly of components, software design
- Oct-Dec 2002, acceptance and shipment of components, software optimization
- Jan-Feb 2003, on site LGSM integration and tests
- Mar 2003, commissioning and delivery to LGSF

5.3. MILESTONES

1. 30 December 2001, delivery of the LGSM detailed design document
2. 30 June 2002, delivery of new technical CCD system (Doc TEC-TOS-01/0062, 05.06.01)
3. 30 September 2002, delivery of data processing software
4. 30 December 2002, on site delivery of hardware components
5. 15 March 2003, delivery of the LGSM to LGSF

5.4. DELIVERABLE ITEMS

Tbd after detailed specifications are completed

6. PRELIMINARY COST ESTIMATE

6.1. MANPOWER

The following internal resources are required (FTE)

Project Management	**0.2**
Control System (CS)	**1.4**
CS Hardware requirements & design	0.1
CS Hardware assembly	0.1
CS Software specifications & requirements	0.2
CS Software design	0.3
CS Software implementation & tests (Garching)	0.5
CS Integration & commissioning (Paranal)	0.2
Operational Data Reduction Software (DR)	tbd
DR Software specification DR Software design DR software integration and commissioning	

The development of data processing simulation software including the detailed description of the data reduction algorithms is performed at Roma observatory (OAR) following an ESO-OAR agreement to

be finalized. The share of OAR is also foreseen to include the supervision of telescope mechanical design and system integration. OAR will participate to the commissioning of the LGSM.

6.2. BUDGET

Code	Item	2001	2002	2003	Totals
17470	*LGSM Management / System*	28	60	70	158
	Visitors/ travel/meetings	4	10	20	
	Staff travel	4	10	20	
	External consultants/manpower	20	40	30	
17480	*LGSM Facility*		410		410
	Tower		50		
	Enclosure		70		
	Telescope Assembly		100		
	Detector Assembly		100		
	Control Systems		40		
	Site Infrastructure		50		
17490	*Control Software*		40		40
	Workstation OS Software				
	LCU ICS Software				
	Computer hardware		40		
	Sub-Totals:	28	510	70	608

7. ALTERNATIVE SOLUTIONS

The current approach is only applicable to one single LGS. However it is reasonable to consider that the sodium distribution averaged over 30 seconds is uniform within the observed field in the case of multiple laser guide stars.
A direct monitoring of the Sodium layer characteristics by LIDAR is an alternative solution which however also requires a launch telescope similar to the LGSM in addition to the laser itself and the receiver, thus a probably more expensive project.

8. BIBLIOGRAPHY

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