SOAR Telescope
Echelle Spectrograph

Conceptual Design
Vers. 1 – Oct 2002

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1 - Overview

The STELES (SOAR Telescope Echelle Spectrograph) as currently planned is a Nasmyth fed, two channels, grism cross-dispersed echelle spectrograph for the SOAR Telescope. Both channels will operate in quasi Littrow mode and in white pupil configuration. Using two independent tunable slits, the object and nearby sky spectrum will be recorded from 300-890nm in one exposure with a resolving power of R=50,000. The bench spectrograph will be permanently mounted on the telescope, for stability and easy access (below the Nasmyth platform), and fed by a fore-optics installed in one of the SOAR ISB ports.

B.V. Castilho presented a draft proposal for the STELES spectrograph at the SOAR SAC meeting held at the CTIO in October/2001, and the SAC recommended the preparation of a conceptual design study of the instrument.

The instrument large wavelength coverage with a single configuration, high stability and high resolution, will be a powerful tool, allowing SOAR community to conduct many high impact scientific programs on objects as faint as V=16-17 with high efficiency, and very small impact on SOAR operations.

STELES as currently planned will be built by a team from Brazilian Institutes, Universities and external consultants, under the coordination of Bruno Vaz Castilho from Laboratório Nacional de Astrofísica / MCT. The current list of Institutions and Collaborators can be found in the Personnel Section.

The instrument cost, estimated to be about one million US dollars, will be funded mainly by Brazilian Funding Agencies and is planned to be offered to the SOAR community 2.5 to 3 years after the final design review.

The purpose of this document is to present a preliminary version of the conceptual design of the instrument and its main characteristics and capabilities. A preliminary management plan that defines the main work packages, a preliminary cost estimate, and the current responsibilities within the project are presented as well.

We wish to thank all the team members that contributed to to produce this document and design concept, and especially to Bernard Delabre (ESO), Robert Tull (Texas Univ.), Luca Pasquini (ESO), as well as Clemens Gneiding (LNA), Steve Heathcote (SOAR) and F. Santoro (LNA/CTIO) for the fruitful discussions.
High-resolution spectroscopy provides a source of large amounts of astrophysical information. A combination of large spectral coverage and high spectral resolution is a powerful tool. A spectrograph with a resolving power of 50,000 and wavelength coverage from 3000 to 8900 Å represents such a combination for a variety of studies. The design of STELES, being at the Nasmyth focus of the SOAR telescope, will allow the instrument to be slit-fed, and thus it can be optimized for near-UV work. This would be a powerful addition to Southern Hemisphere astronomy. There is no other 4-m telescope in the Southern Hemisphere with high spectral resolution optimized for the near-UV. The high-resolution spectrometer for Gemini South is planned to be fiber-fed (fiber losses in the UV restrict their use to wavelengths bluer than about 3500 Å).

The STELES design takes advantage of the excellent image quality of the SOAR telescope, and will provide high efficiency, such that stars as faint as V=16-17 would be observable at R=50,000. Estimates show that the spectrum of a star with V=14, having a S/N=100 per 3 km/s bin, can be obtainable in a one hour exposure (or S/N=10 at V=17). High-resolution spectroscopy at the magnitude limits described above could be applied to such projects as studies of large numbers of metal-poor stars in the Galaxy, or even to stars in nearby galaxies.

In addition, as it will be coupled to the telescope mounting and fed by the Nasmyth focus, STELES is expected to be very stable. Such a configuration can be used for asteroseismological studies or precise determinations of radial velocities, possibly aiding the search for extra-solar planets. In the following, we list some examples of research projects that would benefit from the facilities offered by the STELES coupled to the SOAR telescope.

*Abundance analyses in the near-UV*: Key projects requiring good efficiency in the near-UV include spectroscopy of the strong electronic OH lines near 3100 Å. These particular OH lines are detectable to very low metallicity and are useful in attempts to derive oxygen abundances in the oldest stars in the Galaxy: such O abundances probe the very earliest chemical evolution in the Milky Way. In addition to OH, the element beryllium is only detectable in the near-UV, via Be II lines near 3130 Å. Beryllium is produced only through cosmic-ray spallation reactions and is a key probe in understanding cosmic-ray nucleosynthesis over the chemical evolutionary history of the Galaxy.
Chemical Evolution of the Galaxy: The chemical evolution of the Galaxy follows the changes in elemental abundances from their initial values into the present compositions of the disk, bulge and halo. Some examples of specific topics related to this subject are the gradients of metallicity and radial and temporal variations of the star formation rate. Concerning the major components of the Galaxy, the study of the bulge is essential to understand the mechanisms of formation of our Galaxy: the bulge may have been formed in the beginning of our Galaxy, although part of the bulge may have formed significantly later. The study of the oldest halo stars provides crucial lithium abundances which result from primordial Big Bang nucleosynthesis. Young stars in the Galactic disk trace the present distribution of chemical abundances and can be used to determine abundance gradients: these gradients provide constraints to Galactic models of star formation and chemical evolution.

*r-Process Enriched Stars:* It has been suggested that one likely explanation for the highly r-process enhanced stars that have been identified recently is that they are members of a binary system with a massive companion that exploded as a type II supernova, which would now be a collapsed object such as a black hole. Radial velocity monitoring of the many examples of these stars we hope to find in the near future will be of extreme importance. The same applies to the metal-deficient stars that are moderately enhanced in their r-process elements.

*Light Element Abundances:* The primordial abundance of light elements and their subsequent Galactic enrichment requires high-quality data to constrain and test their production and evolutionary models. One important problem in this subject is the intrinsic dispersion of Li abundances in dwarf stars of halo globular clusters. Given that globular clusters are among the oldest objects in the Galaxy, their initial Li abundance must be very close to the primordial value. Precise abundance determinations for Li (both 6Li and 7Li) and Be (with only one stable isotope, 9Be) provide essential information relevant to early Galactic cosmic-ray fusion and spallation nucleosynthesis, as well as primordial BBN. Beryllium is an important addition to lithium, however, Be is much more difficult to observe. The spectral regions containing the Be II (3130.41Å and 3131.06Å) and Be I lines (3312Å) are crowded and close to the atmosphere cutoff: a near-UV optimized spectrograph, such as STELES, would be an important addition to light element studies.

*Cluster Analyses:* The determination of accurate abundances in globular cluster stars over a range of magnitudes, covering effective temperatures from 4000 to 6000 K, can address the issue of possible variations in chemical composition existing among stars belonging to the same cluster. This topic is particularly relevant in investigating possible stellar processes, such as
diffusion, dredge-up. STELES will be able to investigate stars down to the main-sequence turn-off (V=17) in several clusters, combining high efficiency with a wide spectral range. Superb image quality, will also allow for spectroscopy in relatively crowded cluster fields.

**Long-Term Velocity Monitoring of Carbon-Enriched Metal-Poor stars:** A large fraction of the stars with [Fe/H] < -2.5 exhibit anomalously strong CH G-bands (and often C2 and CN features) indicative of very high carbon abundance, despite the star's overall low metallicity. It seems quite unlikely that all of the stars involved are participants in close binaries that have undergone mass transfer of carbon-enriched material from their companions. Hence, sorting out which of the stars are radial velocity variables and which are not is an important program. Since the periods of known mass-transfer binaries can reach up to 7-8 years (or more, in some cases), gathering data for their study is a challenge with most telescopes. Correlations between measured abundances of (e.g., s-process) elements and orbital properties would provide invaluable clues for understanding the range of phenomena and the nature of the progenitors in these systems.

**Asteroseismology of Stars:** Certain structural properties of stellar interiors can be probed by the study of the weak non-radial pulsations in solar-like stars, which cause small radial velocity variations. The simultaneous measurement of many spectral lines leads to the detection of small radial velocity variations.

**Search for Extra-Solar Planets:** The detections and follow-up observations of extra-solar planetary systems will bring new constraints to bear on the formation and evolution of stars and planetary systems. This task has been accomplished for Jupiter-like planets revolving around solar-type stars through high-resolution spectroscopy. The current major instrument in the Southern Hemisphere, CORALIE, mounted on the Swiss 1.2m telescope, is limited to only the brighter stars. A potential application of STELES is to the detection of extra-solar planets.

These are only a few ideas for projects for high-resolution spectroscopy, but many more of high scientific caliber are certainly possible (isotopic ratios; carbon abundance in planetary nebulae; heavy metals abundances in low [Fe/H] stars; stellar rotation, line variability studies, emission lines of novae, SN, H II regions, planetary nebulae, AGN; analysis of absorption spectra of high redshift QSO's; kinematics in galactic nuclei and star clusters, etc). In summary, a high-resolution spectroscopic capability for SOAR will be an important addition to its scientific potential.
3 - Instrument Description and Capabilities

3.1 - General Description

- Two channel, grism crossdispersed echelle spectrograph
- White pupil configuration
- Bench mounted
- Nasmyth focus, slit fed
- Resolving power - 50,000 (3 - 2.5 pixel resolution) with a 0.8” slit. Higher resolution can be achieved with narrow slits.
- Wavelength range - 3000 - 8900Å (blue arm 3000-5700Å, red arm 5300-8900Å)
- CCDs - two 2x4k chips are foreseen, both with 15µm pixels, one blue optimized and the other red optimized.
- Fixed configuration: the bench-mounted sub-assemblies of the spectrograph contain few remotely controlled moving components. This ensures reproducibility and stability of the instrument and a less expensive operation and maintenance.
- On-line data reduction software will be available for fast analysis of the acquired data.

Table 3.1 - STELES main parameters

<table>
<thead>
<tr>
<th></th>
<th>STELES</th>
<th>Blue</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength range in one exposure</td>
<td>3000-8900Å</td>
<td>3000-5700Å</td>
<td>5300-8900Å</td>
</tr>
<tr>
<td>Resolving Power</td>
<td>50k</td>
<td>max. (80 k)</td>
<td>max. (67 k)</td>
</tr>
<tr>
<td>Slit Entrance Aperture (arcsec)</td>
<td>0.8”</td>
<td>min. (~0.5”) - 2pix</td>
<td>min. (~0.6”) - 2pix</td>
</tr>
<tr>
<td>Fore Optics Input/Output</td>
<td>F / 16 - F / 7.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrograph Beam Size</td>
<td>100 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-axis Collimators</td>
<td></td>
<td>F / 7.5</td>
<td>F / 7.5</td>
</tr>
<tr>
<td>Echelles</td>
<td>R4</td>
<td>41.67 gr/mm</td>
<td>31.6 gr/mm</td>
</tr>
<tr>
<td>Crossdisperser Grism</td>
<td>600 gr/mm</td>
<td>300 gr/mm</td>
<td></td>
</tr>
<tr>
<td>Dioptric Cameras</td>
<td></td>
<td>F / 3.0</td>
<td>F / 2.5</td>
</tr>
</tbody>
</table>
3.2 - Spectral Format

The spectral format depends on grism apex angle and tilt, which are not yet optimized. We present in this document the calculations provided by R. Tull for the preliminary design. The differences in the final design specifications should appear mainly in the orders uniformity and the spectral ranges are expected to be accurate to about 2% (cf. Appendix A).

The blue channel spectrum format fits a 2x4k CCD (30.7 mm wide, 61.4 mm high), with 75 orders. The red channel spectrum format fits a 2x2k CCD (30.7 mm x 30.7 mm) (but considering that we currently don't have all the optics optimized done, we are still working with the possibility of using 2 2x4k CCDs) with about 47 orders. The orders separations also depends on grism apex angle and tilt, but the values are expected to be in the range of 9 arcsec to 20 arcsec in the blue channel, and 8 arcsec to 19 arcsec in the red channel, allowing good sky subtraction for a 1 arcsec seeing spot. The spectral formats are presented in Tables A1 and A2 (Appendix A).

3.3 - Overall Efficiency

The efficiencies of the components of the instrument as well as the overall efficiency were not calculated yet. Efficiencies will be computed as soon as optics and coatings are optimized and the CCDs efficiency is known. However we can have a rough estimate of the overall efficiency of the instrument based on ESO-UVES spectrograph. Both instruments have similar optical design concepts, but these figures have to be taken only as rough indicators of possible STELES performance.

![Figure 3.1 - UVES + Telescope efficiency can be used as an indicator for STELES efficiency goal.](image-url)
4 - Optical Layout

The STELES optics conceptual design was done by Bernard Delabre (ESO), using some concepts developed for FEROS and UVES spectrographs. The present design has some modifications as a result of the discussions taken with the project team and the suggestions of the project consultant Robert Tull (Texas Univ.) (see A.1).

As described in Sec. 3, the spectrograph is a two channels, bench mounted, grism crossdispersed, R4 echelle. For both channel the configuration is a quasi Littrow white pupil spectrograph. The optics was calculated for a resolving power of 50,000 (3 - 2.5 pixel resolution) with a 0.8" slit and a wavelength range of 3000 - 8900Å (blue arm: 3000-5700Å, red arm: 5300-8900Å).

The scientific requirement of reaching 3000Å with acceptable efficiency led to the choice of a two channel design, so each channel optics, coatings and CCDs can be optimized. Two 2k x 4k CCDs can accommodate all the wavelength range (3000-8900Å) with R=50,000 with a good spectral sampling (3 pixels); and reach slightly higher resolution with narrower slits. The white pupil layout and refractive cameras, as well as the choice of grisms as crossdispersers are intended to improve the instrument efficiency.

Since we intend to observe objects close to the limiting magnitudes, the sky contribution is not negligible and sky subtraction capability is required. The order separation was specified in a way that good sky subtraction (seeing x 10) could be done for a median seeing of 0.8". Moreover being installed in a multi-instrument telescope optimized for high spatial resolution we can foresee that a significant fraction of the observations with STELES will be done in gray or bright time.

Another constrain driven by the UV choice is that the instrument have to be fed through the Nasmyth focus without the use of a optical fiber. Considering that STELES is proposed to be permanently installed on the telescope fork, the instrument would not compete with other Nasmyth instruments and still have stability to be used for radial velocity studies.
4.1 - Fore-optics

The fore-optics system takes the light from the ISB port to the spectrograph arms through a distance of about 3.2m. The native SOAR F/16 focal ratio is changed to F/ 7.5 and a field derotator is included in the optical train, besides there is enough clear space in the collimated beam to insert further optical components as filters, ADC etc. Below we describe briefly the main components. In Figure 4.2 a schematic view of the fore-optics and its components is shown.

4.1.1 - Pick-off Prism

First reflection prism (~2.0’ field), breaks the light direction 90° allowing light to focal reducer and spectrograph. As is the case for all the fore-optics components it must have very broad band coating to be efficient in the entire wavelength band required.

4.1.2 - Transfer Lens

The transfer lens consists of a doublet system of Silica / CaF$_2$. The system transfers the beam across the long distance down to the focal reducer, derotator and eventually the spectrograph slit.

4.1.3 - Field Derotator and Focal Reducer

This system is an Abbe-Koenig derotator prism of fused silica. It is feeded by the F/16 beam from the transfer lens, and after the 3 internal reflections the light passes through a cemented Silica/CaF$_2$ system that collimates the beam. After the dichroic mirror (that splits the beam at 5500Å) two doublets re-image the Nasmyth focal plane on the slits at F/7.5. This allows a very compact spectrograph, with a collimator focal length of 750mm.

![Derrotator Prism and collimator lens](image-url)
Figure 4.2 - STELES fore-optics schematic view.
4.1.4 - Dichroics

Two dichroic filters are planned for STELES, providing the split of the incoming light at an angle of incidence of 45° and random polarization. One of the dichroics reflects in average 95% or more in the spectral range 3000-5300Å, and transmits more than 90% in 5700-8900Å. Its pass band is centered at 5500Å, with a bandwidth at 50% transmission of approximately 500Å. It has been designed for a fused silica substrate, with a preliminary cost estimate of ~US$2500.00, quoted by Barr Associates. The spectral characteristics of this dichroic are shown in the figure below. A second dichroic is to be designed with a different band pass set according to science requirements, possibly 500Å towards the blue region.

Figure 4.3 - Dichroic efficiency curves calculated for STELES by Barr Associates. Blue reflected and Red transmitted.

4.2 - Spectrograph

The choice of the R4 echelles allow smaller beam size and camera focal lengths, for the same resolution and throughput efficiency. Using a beam size of 100mm and collimators with F/7.5 a very compact design was achieved, allowing to the mount the instrument in the telescope fork bellow the Nasmyth platform and reducing significantly the material and fabrication costs of the optics. Bellow we describe the spectrograph components. In Figure 4.4 we show the diagram of both STELES arms. The five rays shown at the camera focal plane represent the central
wavelengths in five spectral orders spanning the spectral range for each channel (see Tables in A.1): Blue $m= 85, 97, 112, 131, 155$; Red $m= 71, 79, 88, 100, 115$.

Figure 4.4 - Zemax layout of both STELES arms. Obs. - The cameras shown in the figure are the preliminary 375mm (blue) and 300mm (red). The drawings for the new 300 and 250mm are not presently available.
4.2.1 - Collimators

STELES collimators are two off-axis paraboloids in symmetrical mountings for each channel. They are segments of the same paraboloid with a focal length of 750 mm, i.e., effective focal ratio of F/7.5.

"Both M2 collimator mirrors are greater than the M1 ones (M1 diameter = 330mm, M2 = 400mm), to accommodate the larger offset of the beam due the reversed grism angle $\gamma$. The two off-axis paraboloidal mirrors M1 and M2 could be cut from the same large mirror, however, since both red and blue channels have identical collimator systems, it would work better to cut both M1s from a single paraboloid and both M2s from a larger one."

4.2.2 - Echelle Gratings

A resolving power of R~50,000 may be achieved with a slit of width $\phi=0.86$ (blue arm) - 0.95 (red arm) arc sec and a beam aperture of 100 mm with a R4 echelle grating (blaze angle = 76$^\circ$). A R4 echelle grating with 41.49 grooves/mm and dimensions of 112×408 mm was chosen for the blue channel. The dispersion over the 71 orders varies from 1.25 to 2.28 Å/mm. The red channel operates with a R4 echelle, 31.6 grooves/mm, and a useful area of 112×410 mm. The spectral format comprises 45 orders, with dispersions of 2.66 to 4.31 Å/mm. In both the blue and the red channel, the gratings are used in quasi Littrow mode: the beam is reflected with an angle of 1.25$^\circ$ in the direction perpendicular to the dispersion. The gratings suggested for STELES are from the Thermo RGL (Richardson Grating Lab.) 2002 diffraction grating catalogue.

4.2.3 - Crossdispersers

The crossdispersers separate the spectral orders of the echelle operating in very high orders of dispersion. The crossdispersers chosen for STELES are grisms, which combines the properties of a transmission gratings with that of prisms. With this configuration, the required order separation is mostly provided by the grating so that the prism may be smaller than if a prism was used alone. A Silica grism with 600 grooves/mm and an apex angle of 23.3$^\circ$ was chosen for the blue channel, providing an order separation of 9.0"-21.9". For the red channel BK7 a grism, with 300 grooves/mm and an apex angle= 24.1$^\circ$ was chosen, providing an order separation of 8.2"-19.4".
4.2.4 - Cameras

Obs.: The cameras shown here are the ones calculated in the preliminary design. The new ones have focal ratios F/3.0 (blue arm) and F/2.5 (red arm) are still being optimized by Delabre. However they will not differ in the main characteristics.

Both STELES cameras are dioptics systems. With an estimated transmission of about 85%, they have no vignetting or central obstruction and the focal plane is located far enough from the last surface so that a standard dewar window can be used, i.e., a standard SOAR dewar designed by CTIO can be used. The cameras will be mounted on tilt tables that allow the front part of the cameras to be moved relatively to the dewar window to provide focussing. The field curvature created by the collimator is corrected by the cylindrical surface on the last lens. The red camera uses Silica, F2, SF1 and S-FPL51 glasses, while the blue one due the UV requirement are made of Silica and CaF₂.

In Figure 4.5 and 4.6 the optical layout of the cameras are shown. In Figures 4.7 to 4.12 we show 3D renderings of the spectrograph optical layout.

![Fig. 4.5 - Blue camera optical layout.](image1)

![Fig. 4.6 - Red camera optical layout.](image2)
Fig. 4.7 - Cameras 3D rendering showing the used glasses.
Fig. 4.8 - Spectrograph 3D rendering. Front view

Fig. 4.9 - Spectrograph 3D rendering. Isometric view, top
Fig. 4.10 - Spectrograph 3D rendering. Bottom view.

Fig. 4.11 - Spectrograph 3D rendering. Red arm optical components.
4.2.5 - Coatings

Due to the large number of reflections in the spectrograph, the fore-optics surfaces need to be coated with a high efficient coating in the entire spectral range (3000 to 9000Å). For all reflecting surfaces (2 flat folding and 2 collimators mirrors) we are investigating high-reflectivity coatings in the respective spectral ranges.

The lenses of the fore-optics system will have also to be coated with broad band coatings, while the blue and red arms lenses can be coated with specific ones. We expect to have soon some quantitative information about the development of the SolGel coatings in CTIO and IAG, and possibly consider this coating facilities as providers for the broad spectral range coatings for the STELES optics.
5 - CCD Detector

5.1 - CCD Detector

We foresee the use of two 2k x 4k (15µm pixel) CCD detectors in STELES. Depending on the yield of the SOAR consortium we can use one red and one blue optimized Lincoln Labs detectors. Otherwise STELES project will have to procure and acquire its own detectors. A third, but not likely possibility, is in case of failing or delay of the two first options that we can consider moving the dewars+CCD’s from other SOAR instruments for STELES runs. The dewar change is not the ideal option, but since they will be positioned outside STELES enclosure it can be done without moving the instrument itself.

The detectors quantum efficiency are very important in the overall instrument efficiency. The two chips concept allows that each chip can be optimized for the intended wavelength range, and will give better results than an individual chip. In Figures 5.1 and 5.2 we show the efficiency curve of one of one red LL CCD (CCID-24, 15-2-4, 2-layer broad-band AR coating \((\text{HfO}_2 + \text{SiO}_2)\) and illustrate the possible blue efficiency with the curve of one Marconi chip.

![Figure 5.1: Efficiency curve for one red LL CCD.](image-url)
5.2 - CCD Mounting, Detector Head and Cryostat

We intend to use the same CTIO dewar as the ones used the SOAR optical imager and IFU spectrograph, as well as the CCDs controllers and take advantage of the previous experiences in mounting, alignment and integration with the ICS.

Figure 5.1 - Efficiency curves for one blue Marconi CCD.

Figure 5.2 - The SOAR dewar detector head and mounting.
6 - Mechanical Layout

6.1 - General Description

The optical design is optimized to be build with no moving optical parts, an important advantage for an unattended instrument. Only additional small auxiliary devices need to be adjusted as function of the observing program. STELES will have 8 moving auxiliary devices, most of them not having critical aspects for alignment, operation or maintenance. The main auxiliary devices are: the main spectrograph shutter, fore-optics light buffer, field derotator motor, dichroics changer, 2 slit motors and 2 detector shutter motors (for more detail on motors see Sec. 8).

A constrain driven by the UV capability choice is that the instrument have to be fed by the Nasmyth focus directly and do not use optical fibers. That means that the instrument should be mounted close to the telescope.

6.2 - Weight and space envelope

SOAR was designed to carry a total payload of 7400kg – 3000kg at each Nasmyth port, 300kg at each of the 3 bent Cassegrain ports, and 500kg for the bench spectrograph. With the present set of instruments it was already approaching those limits once the weight of the ISB/ISC's is included. In discussions with SOAR team they find that it would take a more detailed analysis to determine the exact amount of weight still allowed and the possible impacts on the lifetime of the bearings and motors. Thus their suggestion is that for the purposes of the conceptual design we aim for a total weight of no more than 1000kg.

But as the moment is much more of an issue than the weight. The vertical position which puts the weight as close as possible to the azimuth axis would be preferred. Being fixed on the telescope fork STELES could be permanently installed, not competing in volume with the other Nasmyth instruments and still having enough stability to be used for radial velocity studies.

"As far as the space envelope is concerned, for this position, the corner of the platforms for the Bench spectrograph and Azimuth electronics racks at the base, and the Nasmyth platforms at the top sweep out circles as the telescope moves in azimuth are the further limits." Being a low profile instrument STELES will fit most of its volume into the wedge shaped volume bounded by the vertical side of the Yoke, the horizontal Nasmyth platform above, and the two slanting struts which support that (see Figure 6.3).
Based on similar instruments we believe that STELES will weight around 800kg, including the optical table (see Sec. 6.4.1), and much of the weight is fixed as close as possible to the vertical side of the yoke. In Figure 6.1 to 6.3 we show the proposed positioning of STELES on SOAR telescope.

*Figure 6.1* - The proposed positioning of STELES on SOAR telescope.
Figure 6.1 - The proposed positioning of STELES on SOAR telescope. Front view.
Figure 6.3 - The proposed positioning of STELES on SOAR telescope. Side view.
6.3 - Fore-optics

6.3.1 - Pick-off prism

The STELES pick-off prism mounting system of in the ISB is very similar to the one used with the SIFUS mirror. We are investigating the possibility of sharing the same stage in the case that STELES will use the optical port in front of SIFUS one. Considering the SIFUS mirror specifications we expect to have: 2 positions (In/Out), 180mm travel, repeatability = ±1.3µm, accuracy = ±18µm, resolution = 1.25µm, configuration time < 10 sec.

![Figure 6.4](image)

**Figure 6.4** - Two views of the SIFUS pick-off mirror and guide mechanism, exemplifying a possible mounting for the STELES pick-off prism.

6.3.2 - Transfer Lens

The mounting and alignment of the transfer optics with the spectrograph will be a critical parts on the mechanical design. Since they will be located around 1280mm far from the ISB box, a very stable, but at same time light, mounting should be foreseen. After finite element calculations and simulations together with the ISB mechanism we can be able to analyze the need of an active laser system to keep the system aligned.
6.4 - Spectrograph

The spectrograph will be assembled on a single optical bench, customized to be fixed vertically on the telescope. The enclosure will cover all the optical parts and will leave the CCD dewars rear part in the outside in order to facilitate nitrogen filling operations.

6.4.1 - Optical Table

The optical table for STELES will have 1.6m x 1.8m (2.88m²). Will be positioned on the vertical and may require a reinforced top plate, allowing the use of a thinner bench. If we choose a Dumped Honeycomb Tech Base, with thickness of 57mm, (62kg/m²) we will have a total weight of 180Kg. Even in the case that the structure analysis shows that we need a thicker table (thickness 108mm, 66 Kg/m² = 188Kg (information from Oriel Instruments catalog 2002)) we do not increase too much the table weight. One heavy constrain on table and supports thickness is the very small distance from the center of the light beam to the telescope fork (~ 330mm). Our first estimates of supports thickness shows that this distance can fit the supports and table. Figure 6.3 shows the low profile of the instrument and the space between the center of the light beam to the telescope fork.

6.4.2 - Optical Mounts

Most of the optical mounts for STELES can be adapted from similar spectrographs designs like FEROS and UVES, taken in account the different orientation of the bench. There some more challenges in the STELES mechanical design because of the very compact design, what means that the light beam crossing in the Littrow design leave very small clear space for the supports, but again we can take advantage of similar designs. For example: the small folding mirror that is placed between the echelle grating mounting and the beam coming to the second collimator - the Giraffe spectrograph team had the same problem and solved it gluing the mirror behind a DILVER-P mount (has the same expansion coefficient as the optical glass.

The echelle gratings will probably produce the grater contribution to the total stray light. This effect shall be minimized via baffles in the echelle mounting. Other baffles will be placed strategically to minimize as possible the stray light. In Figures 6.5 to 6.7 we show preliminary concepts for the optical mountings of STELES.
6.4.3 - Camera, shutter and CCD dewar

We intend to use the same CTIO dewar design as for the SOAR optical imager and IFU spectrograph. The choice for this dewar was driven by compatibility with SOAR instruments, and maintenance plan; despite the modifications in the initial (more compact) optical design to accommodate it.

Figure 6.5 - Preliminary concept for the STELES optical mountings. Motors and bafflers not shown.
Figure 6.6 - Preliminary concept for the STELES optical mountings. Zoom on the beam splitting mounting.

Figure 6.6 - Collimator mounting and clamps based on the FEROS mountings.
The camera lens support is one of the most sensitive systems in the spectrograph. We also shall take advantage of the UVES design, which has very similar cameras, and adapt it to STELES specifications. The camera design must include also the shutters, since the distance from the last lens to the dewar windows are very small.

![Figure 6.5 - The SOAR CCD dewar and the mounting.](image)

### 6.4.4 - Enclosure

The enclosure shall cover all the optical parts and mountings, but will leave part of the CCD dewars outside, to facilitate the refilling operation and connections. An easily deployable and dust-tight cover made from 2 mm, black anodized aluminum is foreseen and will be mounted and fixed on the optical table. Two removable doors on front side will give access to the spectrograph mountings for maintenance.

STELES enclosure will have a temperature isolation system and will be maintained at a stable temperature using the cooling flow facility provided by SOAR, to compensate the heating by electronics and motors. The enclosure design should take this in to account.
7 - Telescope Facilities

Bellow we describe the facilities provided by the telescope that will be used by STELES.

7.1 - Calibration Unit

The calibration unit will be mounted on the upper side of the optical ISB and will provide the instruments with emission line spectra for the wavelength calibration and a continuum-light source for flatfielding purposes. "Light from the lamps is first integrated in a reflecting hemisphere (concentrator) that directs the light from a calibration lamp efficiently into a beam of a controlled f-ratio. After 3 reflections light from the selected lamp arrives at the instrument focal plane, covering the 8 arcmin science field with a focused beam of quite uniform intensity at the proper f-ratio. A field lens at the exit of the concentrator locates the virtual pupil at the same distance from the focal plane as the telescope pupil to best simulate the telescope beam. Large-scale spatial variability in the field intensity should not be more than a few percent and may be very much less. Perfect absolute flatness is not necessary for making flat field exposures since, as long as they do not change with time, small non-uniformities are easy to eliminate during data reduction. The SOAR comparison system should be very stable because it has no moving parts other than the M3 flat and is relatively insensitive to misalignment." A Xe or Deuterium source may be desired for higher flux flat fielding in the UV (3000-3600Å).

Figure 7.1 - Calibration Unit design status on Jun 2002.
Designs for projectors are already available with housings for hollow cathode lamps with, for example, a Th-Ar bulb. An ordinary hollow cathode Thorium–Argon lamp seems to be sufficient for wavelength calibration. However the filling gas Argon shows very strong lines in the red beyond 6700Å, so for appropriate illumination in the blue the detector is saturated in these red lines forming strong blooming features. For this reason we may follow FEROS approach and use a combination of a Thorium–Argon hollow-cathode lamp with the spectral region above 6700Å blocked by an edge filter and a Neon lamp to provide additional spectral lines in this red spectral region.

7.2 - Atmospheric Dispersion Corrector

The atmospheric dispersion correction is very important for STELES, considering that it is a slit spectrograph, specially in the blue side. H. Epps is designing the ADC under the coordination of C. Clemens (UNC). The prisms will be made of fused silica and it is being optimized for the 3200-11000Å range. The performance below 3200Å is not well studied, but it "should be fine at zenith distance of 30-40 degrees, but not so good at higher airmasses". For special observations on the 3000-3200Å spectral region it is desirable that the ADC can be deployed and this should be a requirement for the ADC mechanical design.

7.3 - Guiding Probe

The guide probe consists of a pick off mirror that can be positioned to pick the light of a guide star located within the patrol field re-image it on the guide sensor. The guide sensor shall have useful sensitivity over the wavelength range 400nm to 1000nm. Having a small field of view STELES can easily search for a guide star in the 8' probe field without field obstruction. The guiding accuracy required is driven by the slit width of ~ 1.0" to 0.6". See Figure 6.2.1 b.

7.4 - Electrical Power

The spectrograph movable systems will be based on Silvermax Smart motors, in accordance with SOAR specifications (see Sec. 6.1). The total power required for the 8 motors (Sec. 8) is estimated to be 160W, but most of then will be used few times in a run and only the derotator motor (20W) will be working continuously during the exposures. Besides the motors the only other power consuming devices are the 2 CCD controllers (see Sec. 5.5). This means a
very low power requirement for the instrument. Electrical connectors, cabling, and conduit shall be defined in accordance with SOAR specifications and to be consistent with high reliability operation and EMC constraints.

### 7.5 - Cooling Flow

The STELES enclosure will be maintained at a stable temperature using the cooling flow facility provided by SOAR project to compensate the electronics and motors heating. The enclosure design should take this into account.
The control system, besides controlling all the movable parts of the spectrograph is responsible for the integration of the instrument with the user, telescope, calibrations unit and the other telescope facilities. We shall use LabView for the control system and the SOAR library to integrate it to the TCS. LNA is in charge of the SIFUS control system and will have all the required experience to perform this task for STELES.

The control system shall include means to control all the movable devices individually, or in combination under computer control. All motorization will follow SOAR suggestion of using Silvermax Smart motors. This high performance servo motors have fully integrated design, built-in motion controller, internal non-volatile program memory, master-slave operation; what means that they can easily be integrated with the LabView ICS and TCS.

STELES project shall provide a modular LabView ICS to control each sub-system and monitor its status and provide a LabView based interface, in which all these modules are integrated in order to control all STELES sub-systems in standalone mode. SOAR shall be responsible for final integration of the ICS with the SOAR TCS.
The data reduction package developed for STELES must be able to automatically receive and reduce the data obtained with the spectrograph. The on-line data reduction should be built to produce reduced data (automatically or semi-automatically) but should also be able to show quick checks and evaluation of the spectra.

It is also important to be based on a public and well known platform. Initially we choose to use IRAF as it fits the requirements above and can be installed in most of the usual operational systems, even in inexpensive Linux PCs. This point means that all users can have access to the code and that it requires little training for the users and the technical support team. A multi-institutional team will develop the data reduction package (as it is being done for SIFUS spectrograph software).

The basic reduction procedure should be the standard for echelle spectra accounting for the particular characteristics of STELES data. The reduction package shall include: flat-field correction, order definition, echelle blaze function definition, stray light extraction, background subtraction, sky subtraction, optimal order extraction, wavelength calibration, order merging, correction for the instrument response function, graphical user interface and data-archive facilities.

An exposure time calculator is also foreseen. It will help the observing time proposals and preparation for the observing runs. Given the observation parameters, the necessary time to achieve a specified S/N will be computed as a function of wavelength.
10 - Maintenance Concept

Since the STELES will work in a fixed configuration with few auxiliary movable parts only few time for the instrument setup is required. Therefore, to maintain the instrument performance during operations a small amount of maintenance work is needed. In the Operations Manual all required routine maintenance operations will be identified. The procedures for this maintenance as well as all special tools and supplies shall be identified in detail. This includes re-alignment and calibration in the case that a component requires removal and replacement.

A list of critical spares including all relevant information regarding, model, vendors, and recommended spare stocking strategy will be provided as well.

11 - Safety Aspects

During the setup of the instrument, the operation, and the maintenance work, a small number of safety aspects have to be considered to avoid hazards to the human personal.

In this sense, the following list refers to items with critical handling:

The optical bench is a heavy and large component and therefore requires a particularly careful handling during the set-up phase. Especially the transport and fixation up to the telescope yoke has to be considered. Further heavy and sensitive optical components: echelle + mounting, collimators + mountings, and camera/CCD unit.

The handling of liquid nitrogen for the dewar refilling must be in accordance with the common operation instructions.

No electrical hazards are expected since all the electrical components of the instrument operate in low currents and voltages. Anyway critical points will be adequately labeled.

All components of the bench-mounted part of the spectrograph will be permanently fixed onto the bench with clamps. Therefore, no moving or dropping heavy mechanical components will be encountered during potential earthquakes. A specialized simulation for earthquakes will be contracted to identify any potential weak points in the mechanical structure and fixation.
12 - Management Plan

This section defines a work breakdown structure for the project and shows a preliminary schedule from the start of the STELES project until commissioning at Cerro Pachon. The project team and management structure is described. Also contained in this section is a preliminary projected spending for labour and materials.

12.1 - Strategy and Responsibilities

The STELES project will be based at the Laboratório Nacional de Astrofísica, Itajubá - MG. The group has been chosen as the principal focus of design and manufacture for STELES and looks forward to successfully completing the detailed design, manufacture and commissioning for the STELES instrument. Items that cannot be manufactured in LNA workshops will be procured from outside suppliers. One scientist is permanently engaged to coordinate the project (B. Castilho, LNA), and many of the team members will be working at the same institution.

12.2 - Schematic Work Structure
12.3 - Project documentation and Meetings

Project documents will be produced in accordance with the requirements. Any additional design documentation may be produced at LNA’s discretion in support of the mandatory documentation. LNA will in due course issue a document control and numbering/naming system for approval with SOAR. All project documentation and drawings will conform to the agreed system. From time to time, as the schedule dictates, this document will be revised and re-issued. The purpose of these revisions will be to keep all staff involved with STELES fully informed as to the current status of the STELES project.

LNA shall provide SOAR with a brief progress report by E-mail at bimonthly intervals. These reports intend to record the project progress, identify any problem areas and to describe how they will be resolved and should establish plans and goals for the future.

LNA shall conduct and support the following formal reviews:

- **Conceptual Design Review (CoDR)**

The scope of the meeting is to review the conceptual design and identify and suggest any modification and possible better solutions for the concept. Drawings and specifications shall be provided to SOAR before the review. Duration: One (1) day. Schedule: 4 months after SOAR approves the instrument proposal.

- **Project Design Review (PDR)**

LNA shall conduct one PDR to review all elements of the STELLES design and define the final modifications required in the instrument project. Drawings and specifications shall be provided to SOAR before the review. Duration: One (2) days total; Schedule: 5 months after CDR.

- **Final Design Review (FDR)**

The scope of this meeting is the final review of all STELES elements, including the modifications and suggestions from the PDR, and aims the starting of the procurement and construction of the instrument. Drawings and specifications shall be provided to SOAR before the review. Duration: One (2) days total; Schedule: 3-4 months after PDR.

- **Acceptance Test (AT)**
This meeting will be an integral part of the acceptance of the STELLES by SOAR. The scope of this meeting is TBD. LNA shall provide a final Acceptance Test Plan to SOAR prior to the meeting. During this meeting LNA shall demonstrate the ability of the STELLES to meet all requirements stated in the FDR.

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<th>Milestone</th>
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<td>Delivery</td>
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* - Estimated schedule with complete funding occurring at the FDR time.
12.4 - Key Personnel

The following scientists and technicians are nominated for functions within the management structure of the STELLES project

Table 12.2 - Project Team †

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>Bruno V. Castilho</td>
<td>LNA/MCT</td>
</tr>
<tr>
<td>Science</td>
<td>Beatriz Barbuy</td>
<td>IAG/USP</td>
</tr>
<tr>
<td></td>
<td>Kátia Cunha</td>
<td>ON/MCT</td>
</tr>
<tr>
<td></td>
<td>Gabriel P. Franco</td>
<td>IF/UFMG</td>
</tr>
<tr>
<td></td>
<td>Verne V. Smith</td>
<td>U. Texas</td>
</tr>
<tr>
<td></td>
<td>Gustavo P. Mello</td>
<td>OV/UFJ</td>
</tr>
<tr>
<td></td>
<td>Thais Idiart</td>
<td>IAG/USP</td>
</tr>
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<td>Project Team</td>
<td>Bruno V. Castilho</td>
<td>LNA/MCT</td>
</tr>
<tr>
<td></td>
<td>Germano R. Quast</td>
<td>LNA/MCT</td>
</tr>
<tr>
<td></td>
<td>Clement D. Gneiding</td>
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</tr>
<tr>
<td></td>
<td>Simone Daflon</td>
<td>ON/MCT</td>
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<tr>
<td>Optical Designer</td>
<td>Bernard Delabre</td>
<td>ESO</td>
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<tr>
<td>Optical Consultant</td>
<td>Robert G. Tull</td>
<td>U. Texas</td>
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<tr>
<td>Managing</td>
<td>Célio Andrade</td>
<td>LNA/MCT</td>
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<td></td>
<td>Marília J. Sartori</td>
<td>LNA/MCT</td>
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<tr>
<td>Mechanics</td>
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<td>Supervised</td>
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<td></td>
<td>+ Collaboration with</td>
<td>UNIFEI *</td>
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<tr>
<td></td>
<td>Fernando Santoro</td>
<td>LNA/MCT</td>
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<td>Gustavo Monteiro</td>
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<td></td>
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<td>Control Systems</td>
<td>Francisco Rodrigues</td>
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<td>Maximiliano Abans</td>
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<td>Marília J. Sartori</td>
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<tr>
<td></td>
<td>Rodrigo Campos</td>
<td>LNA/MCT</td>
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† - Most of the listed personal are only partially dedicated to this project.
* - The Mech. Dept of UNIFEI can participate in some subsystems projects, yet to be defined.
** - A greater involvement of F. Santoro on this project depends on the SOAR ISB schedule.

During the proposal of this instrument to the SOAR community we received the Scientific Support of several colleagues (other then the ones listed above), which we would like to record here:

LNA    Carlos A. Torres    Mariângela O. Abans    Albert Bruch
IAG/USP Antonio M. Magalhães  Marcos P. Dias  Augusto Daminelli
      Eduardo J. Pacheco  Jane Gregorio-Hetem  Walter Maciel
      Nelson V. Leister  Silvia Rossi
ON/MCT  Ramiro de La Reza  Celso Batalha  Cláudio Bastos
      Thais Mothe  Lécio da Silva
      Nelson V. Leister  Silvia Lorenz
OV     François Cuisiner  Wagner Corradi
UFRN   José Renan de Medeiros
UFMG   Domingos Soares
UFES   Roberto Ortiz
UFES   Paulo Poppe  Vera Martin
MSU    Timothy Beers  Steve Sepf
UNC    Jim Rose  Chris Clemens
ESO    Luca Pasquin
Lick Obs.  Ricardo Schiavon  Christopher Wilmer
12.5 - Cost and Funding

The instrument estimated cost is about one million US dollars. The project should be funded through projects mainly by Brazilian Scientific Funding Agencies. A more detailed cost estimate will be made in the next months, based on procurement of the specified parts and work blocks. This detailed cost worksheet will be used together with the conceptual design in the projects to be submitted to the Brazilian agencies.

Presently the STELES project has a granted budget of R$ 300,000 (~ US$ 80,000), provided by the MEGALIT\(^*\) project, which can fund the instrument through the project phase to the DDR review (costs of the project do not include the personnel salaries, that are being paid by their own institutions).

Below we show a preliminary cost worksheet based on costs for similar echelle spectrographs and some estimates based on actual SIFUS costs.

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<th>Construction</th>
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<td>FDR level Project</td>
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<td>Meetings / Travels</td>
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<td><strong>Total</strong></td>
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<td><strong>Total</strong></td>
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\(^*\) The Megalit Project, coordinated by B. Barbuy (IAG/USP) is an special project, funded by FINEP and CNPq agencies, for the development of Astronomical Instrumentation in Brazil.
13 - Possible Future Upgrades

Some possibilities for future upgrades in STELES:

- Fiber link to the ISB Calibration unit for simultaneous wavelength calibration.
- UV optimized ADC, exchanging the SOAR one for special UV observations.
- Image Slicers or
- Microlens arrays substituting the slits.
- New crossdispersers for long slit, few order, spectroscopy

Appendix A - Optical Design Options, Report by R. Tull

See PDF file - Steles-RTull_report.pdf - distributed with this text.