NOAO Observing Proposal *Longterm proposal* **Panel:** *For office use.*
Date: March 31, 2001 **Category:** EGAL - Other

Mesospheric sodium layer monitoring for laser guide star adaptive optics systems in Chile (II)

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
Observations with facility adaptive optics is limited to certain areas on the sky due to the requirement of a stellar source to measure the wavefront distortions. A solution to this sky coverage problem is to use resonant backscattering of a laser beam by mesospheric sodium atoms as an artificial wavefront reference. In this technique, knowledge of the sodium abundance is crucial to determine the laser power required to produce guide stars of sufficient brightness and to efficiently correct for atmospheric distortions with adaptive optics.

Long-terms status was requested for semesters 2001A, 2001B and 2002A to monitor the mesospheric sodium layer abundance and altitude above Cerro Tololo for the benefit of the Gemini and SOAR laser guide star adaptive optics programs. The first Chilean sodium monitoring experiment with a laser took place successfully in February 2001 and the second run will take place in May. We obtained good quality data which shows surprisingly few sporadic events. This AO-friendly behavior will hopefully be confirmed by following runs. Determination of hourly and nightly abundance and altitude variations is on-going.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-0.9m	CFIM + T2K	7	bright	Sep - Sep	Sep - Sep
2	CT-0.9m	CFIM + T2K	7	bright	Nov - Dec	Nov - Dec
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

Runs in Sept. and Nov./Dec. would ensure optimum determination of the sinusoid-like yearly variations of the sodium layer (Max. abundance expected in the Nov.-Dec. time frame). Full moon for run #2 is Nov. 30, hence the Nov/Dec period indicated for run #2 optimal months. Including Sept. 2 and 5 in run #1 would enable simultaneous observations with ESO La Silla.

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

We propose to continue an on-going laser experiment [1, 2] whose purpose is to monitor the abundance and altitude of mesospheric sodium above Cerro Tololo for the benefit of the Gemini and SOAR laser guide star adaptive optics (LGS AO) programs. The experiment goal is to characterize yearly, nightly and hourly mesospheric sodium variations at the latitude of the future LGS AO facilities. The first sodium monitoring run out of a series of 5 runs planned every 3 months took place in February 2001 and yielded useful and promising data on the sodium behavior above Cerro Tololo. A second run is planned in May. Continuation of the experiment will enable to complete the data set over a year. The following key sodium parameters will be measured:

1. Mesospheric sodium column density. More than any other, this parameter is crucial to the sodium LGS technique as the required laser power per beacon is almost directly proportional to it. For instance, a conservative sodium column density of 2×10^9 atom/cm^2 [3] yields a power requirement of 9-15W for Gemini LGS AO observations at 0°and 45°zenith angle respectively. For the planned Gemini South Multi-Conjugate Adaptive Optics (MCAO) system which will use 5 laser beacons, this translates into a maximum power requirement of 75 W if 45°observations were to be made under conservative column densities. Measurement of the minimum sodium column density over a year will set an upper limit for laser power requirements, and seasonal and nightly statistics of sodium density fluctuations equivalent to LGS magnitude fluctuations will give insight on conventional LGS AO and MCAO queue scheduling feasibility and efficiency.

2. Temporal behavior of the sodium layer mean altitude. The rate of mean sodium altitude variations is of prime importance for optimum removal of the focus mode in AO-corrected science images. Focus adjustments in the laser guide star path of adaptive optics systems must distinguish atmosphere-induced focus terms from slow drifts of the guide star altitude. The faster the mean sodium altitude varies, the more difficult it is to distinguish those two effects and adequately correct for them. Measurements of the sodium altitude drift rate will help predict via simulation possible LGS AO and MCAO performance degradation.

3. Sodium layer thickness and appearance of sporadics. The sodium thickness will determine the laser guide star spot elongation as viewed from a subaperture located near the edge of the telescope pupil (this is 1 arcsec for an 8m telescope and comparable to the guide star spot size). The larger the telescope, the more elongated the spot, the more sensitive the adaptive optics system is to the noise and therefore the more laser power is required to achieve a given Strehl ratio. The appearance of sporadic layers [4, 5] has the ability to degrade performance as well, by shifting the spot intensity centroids. Therefore the measurement of appearance rate, thickness and intensity of sporadic layers is also important for accurate prediction of LGS AO and MCAO performance.

The latitude-dependence of parameters 1, 2 and 3 observed in the northern hemisphere [1-5] has yet to be confirmed in the southern hemisphere, as well as a possible North/South symmetry for the mesospheric sodium abundance behavior over a year. Data gathered with the proposed observations will also contribute to test and refine the models for atmospheric gravity waves and the identification of a possible sodium reservoir in the upper atmosphere.

Observations must be carried over a full year to characterize seasonal variations. Data obtained in February tends to show slowly varying nice and smooth sodium profiles with very few sporadics that are well-suited for LGS AO observations. Following runs will hopefully confirm these trends.

References

[1] Michaille et al., 2000, Mon. Not. R. Astr. Soc. (in press)

[2] Ge et al. 1998, in Adaptive optical system technologies, Proc. SPIE 3353, 242

[3] Papen et al. 1996, in Adaptive Optics, Vol. 13, OSA Technical Digest Series, 96

[4] Clemesha et al., 1992, J. of Geophys. Research 97, 5981

[5] Ageorges et al., 1999, in Astronomy with adaptive optics, Proc. ESO 56, 3

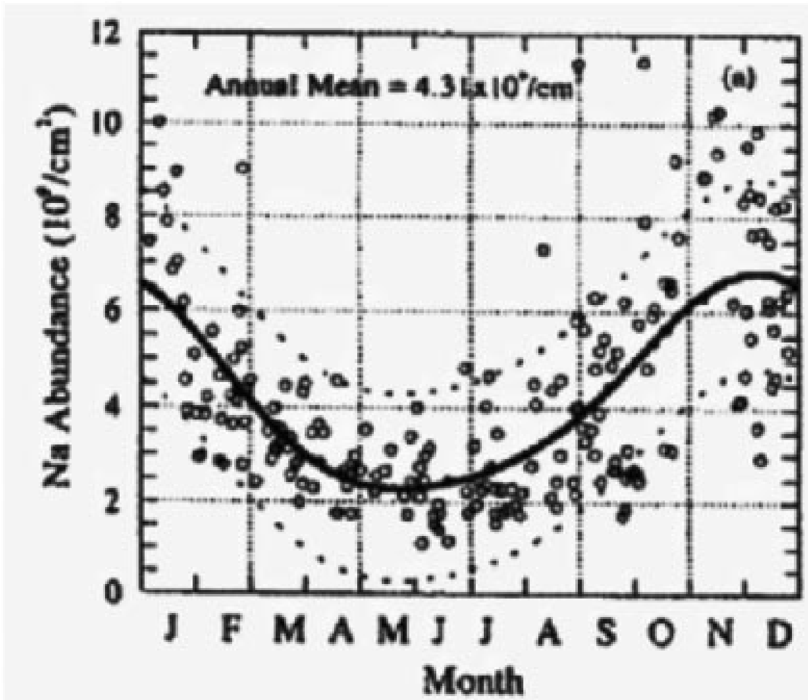

Figure 1: Seasonal variation of the mesospheric sodium column density at Urbana, Illinois (40°N). The solid curve is a least squares fit to the data, the dashed curves indicate $\pm\sigma$. From Papen et al. [3].

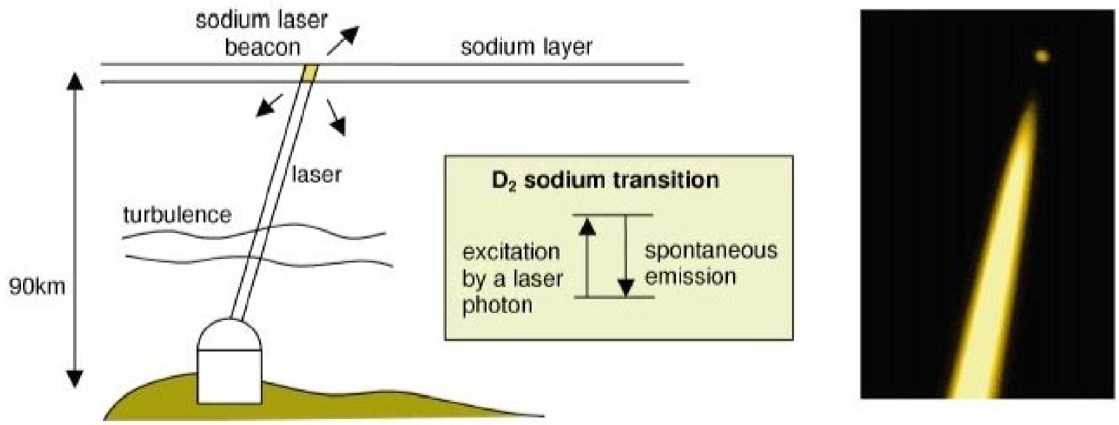

Figure 2: Left: A laser, tuned to the sodium D2 line, can be used to excite sodium atoms and create a laser guide star for adaptive optics observations. Sodium monitoring with a laser uses the same experimental set-up. Right: Image of the laser beacon taken with a small telescope 3m away from the launch site during a sodium monitoring campaign for the planned William Herschel Telescope LGS AO system at the Observatorio del Roche de los Muchachos, La Palma Island, Spain (2000). The small spot at the top is the sodium laser beacon.

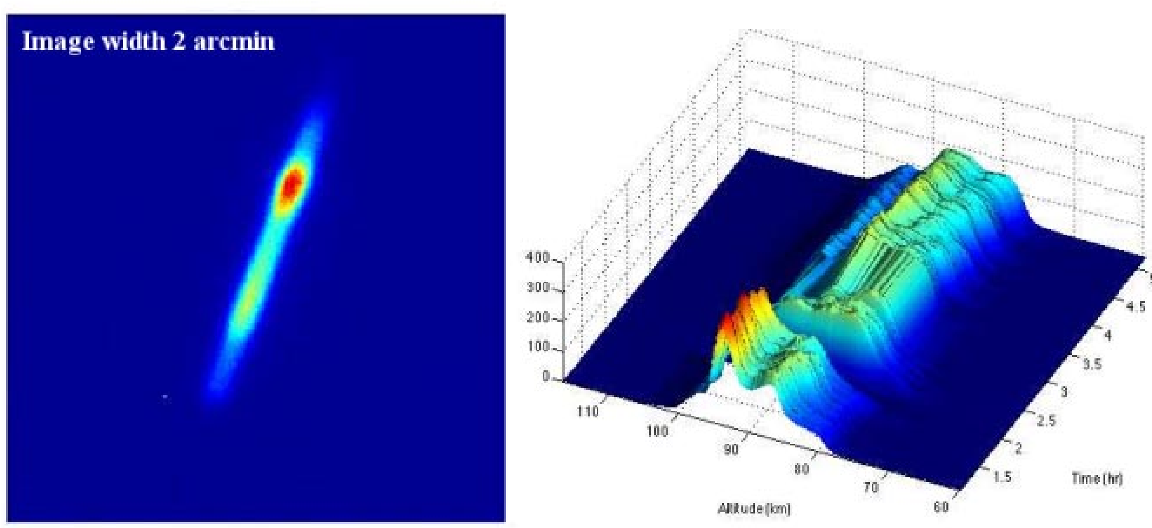

Figure 3: Left: A pseudo-color image of the resonant backscatter from the sodium layer as viewed from the 0.9m telescope, 140m away from the launch site. This 30 second exposure was taken on Feb. 12, 2001 at 2:32am. Right: Relative sodium column density profile measured on the night of Feb. 11-12, 2001 (first night of the first run), vs. time around midnight and altitude. This profile exhibits a clear sporadic layer at about 95km around midnight.

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. List all telescopes on which you have applied for or been granted time for observations related to this project. For each, indicate the nature of the observations, and describe the importance of the observations proposed here in the context of the entire program. (limit text to one page)*

The present long-term program is a collaboration between Gemini, Imperial College (London), CTIO and ESO. The sodium monitoring experiment consists in launching a laser to the sky to excite mesospheric sodium atoms and imaging the laser star with one or two distant telescopes. Fluorescing sodium atoms are distributed along the laser beam and appear as a streak on the CCD camera of a distant telescope. The further the telescope, the more elongated the streak. The streak must not be stretched too thin so that sufficient signal to noise ratio (SNR) is preserved. Distance of the telescope to the launch location, CCD pixel size, typical laser star widths obtained on the sky and typical seeing dictate the choice of the telescope which is best suited to obtain good spatial resolution on the sky. The telescope diameter then sets the lower limit to exposure times achievable with reasonable SNR.

The intensity profile along the laser star elongated image gives direct information on the sodium abundance distribution versus altitude. Sodium atoms are excited with a low-power continuous-wave laser whose interaction with the atoms is well-known. Provided that all due telescope calibrations are performed and that the atmosphere optical transparency is measured during the night, the CCD data contains all information necessary to retrieve the sodium column density, sodium layer width and relative altitude. Observation of the laser star with an auxiliary telescope is desirable to derive higher accuracy on the sodium layer absolute altitude. Synchronization of exposures between the two observing telescopes enables the use of a passing star trail beginning or end location on the CCD cameras to derive the absolute altitude by triangulation.

5 runs, 3 months apart, have been planned over a year. The program was granted 10 nights of simultaneous observations at the CTIO 0.9m and Schmidt telescopes in February 2001. Operation of the laser did not cause any serious difficulties and we obtained good quality data over the full 10 nights of the run. A second 10-night run is planned in May with the 0.9m and Schmidt telescopes as well. Weather permitting, we expect this second run to be as successful as the first. We propose to complete the sodium data set over a year during three more runs in Sep. and Nov./Dec. 2001 and Feb. 2002. Among other things, conducting the sodium monitoring campaign over a year will yield the minimum value of sodium abundance necessary to derive the laser power requirement for LGS AO applications.

Monitoring of the sodium layer with a laser is a powerful technique that provides knowledge of the sodium variability on the shortest time scales (a few seconds typically). Another technique, which relies on high-resolution spectroscopy (R=50-250k) of the sodium D1 line and proved difficult in the past due to the presence of strong water-vapor lines nearby, requires long exposures and prevent observation of short-lived sporadics. On February 11 2001 (first night of the sodium monitoring first run at CTIO), we successfully monitored the sodium content above Cerro Tololo with our laser set-up while at the same time at the La Silla and Paranal Observatories, colleagues at ESO were collecting spectroscopic data at the sodium D1 line wavelength. This couple of hours of data overlap will enable us to cross-calibrate the laser monitoring technique with the spectroscopic technique. It will also give insight on the variations of sodium abundance with latitude in the Southern hemisphere. Note that ESO La Silla will conduct additional spectroscopic observations on Sept. 2 and Sept. 5 2001 so that we have the fortunate opportunity to perform simultaneous observations again during the proposed September 2001 run. Simultaneous sodium data taking by both observatories constitutes a great asset to the overall program.

Long-term Details *If you are requesting long term status, list the observing runs (telescope, instrument, number of nights) requested in subsequent semesters to complete the project. Note that long term status is not available for Gemini runs at this time.*

We had already requested long-term status in the 2001A proposal. In 2001A we have obtained two 10-nights runs on the CTIO 0.9m and Schmidt telescopes (Feb 11-20 and May 2-11). In this proposal for 2001B, we request two similar 7-night runs at the 0.9m (or 1.3m if available) and Schmidt telescopes during bright time in September and November/December 2001. We intend to request telescope time on the 0.9m (or 1.3m) and Schmidt telescopes for one final 7-night run during bright time in February 2002.

Observations are spread over one year from February 2001 to February 2002 in order to characterize the sodium layer seasonal variations. Those particular months have been chosen to match the expected maximum (Nov./Dec.) and minimum (May) of the sodium column density sinusoid-like variations (see figure 1).

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the Principal Investigator during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal.*

2001A

* CTIO 0.9m, 20 nights, Bright time, Feb. 11-20 & May 2-11

* CTIO Schmidt, 18 nights, Bright time, Feb. 11-20 & May 2-11 (May 17-20 were 0.5 nights)

These runs were the 2 first runs out of 5 runs planned over a year for the proposed sodium monitoring program. We obtained good quality data on all 10 nights of the first run. Reduction of this data is on-going and results will be available before the beginning of the second run in May. A preliminary report on the sodium monitoring campaign at Cerro Tololo with reduced data for the February run will be included in the Gemini Multi-Conjugate Adaptive Optics Preliminary Design Review (MCAO PDR) to be held on May 24-25 at Gemini North, Hilo, Hawaii. These results are expected to back up the Gemini South MCAO laser requirements and confirm that they are based on reasonable grounds.

At least one and possibly two or three referee papers will be published after the one-year campaign is complete to present the mesospheric sodium layer abundance, width and altitude variations over a year. In addition to statistics on the sodium abundance, layer width and altitude, the papers will include: (i) the analysis of sporadic events intensity and frequency over Cerro Tololo, (ii) the effects of sodium yearly, nightly and hourly variations on conventional LGS AO and MCAO performance, and (iii) a revised error budget for the Gemini South MCAO laser system.

Why CTIO? *(For CTIO proposals only.) Explain why access to the southern hemisphere is needed to achieve your scientific goals.*

We are mostly interested in obtaining mesospheric sodium data in relation with the Gemini South and SOAR laser guide star adaptive optics programs. The Gemini South and SOAR telescopes are located on Cerro Pachón in Chile. Cerro Tololo is very conveniently located close to the Cerro Pachón site which makes CTIO an ideal location for the sodium monitoring experiment. The mesospheric sodium content above Cerro Pachón is expected to be identical to the one above Cerro Tololo.

Observing Run Details for Run 1: CT-0.9m/CFIM + T2K

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for WIYN-2hr, WIYN-SYN, YALO, and Gemini runs).*

The sodium laser set-up is already in place in the utility building below the 4m telescope. Parts were assembled in February 2001 a few days before the first sodium monitoring run (Feb 11-20) and the laser was successfully run during the full 10 nights of the run. The set-up will be used again during the second sodium monitoring run on May 2-11. We do not expect difficulties during that run either. The set-up includes a 5'x10' optical table, a 7W argon-ion laser pumping a low power Spectra Physics ring dye laser and a 500mm clear aperture launch tower. The dye laser wavelength is tuned to the peak of the sodium D2 line with a feed-back loop using the laser absorption signal in a sodium cell. The laser beam diameter is expanded from 0.5mm to 250mm before it is launched to the sky at a fixed and known position close to zenith. A small fraction of the laser light is absorbed by mesospheric sodium atoms which re-radiate the 589 nm photons in all directions through deexcitation.

Typical launched laser powers are in the 200-300 mW range, and produce a 13-14 magnitude laser guide star. We use about 25 times less power than required to create a laser guide star useful for adaptive optics observations. The power level is low enough so that it is safe for moving observers like aircraft pilots. It is important to note that even if this is an eye-safe experiment according to current ANSI laser safety standard, we did contact the local air traffic control ahead of time before the first run and subsequently received authorization from the Chilean authorities to propagate our laser above Cerro Tololo. Their only request was for us to provide them with the dates and times at which we intend to propagate the laser. This procedure was successfully implemented during the February 2001 run and will be renewed before each sodium monitoring run.

Because the sodium layer has a finite thickness in the 5-12km range, the laser star looks elongated when it is imaged from a distance to the launch telescope. The intensity profile over the star angular spread is directly proportional to the sodium abundance over the sodium layer altitude. During the February 2001 run (as we plan to do in May too), we used the 0.9m and Schmidt telescopes to take simultaneous 10-30s exposures of the sodium streak with sodium filters. For the 0.9m telescope, located 140m away from the launch tower, the 0.4 arcsec pixel size yields a maximum altitude resolution of 121m (seeing and laser launch conditions permitting). Binning is used to adjust the macro-pixel size of the image with the laser star width actually obtained on the sky. Together with windowing, binning also enables shorter exposures, hence higher temporal sampling of the sodium layer variations. We observed with the Schmidt telescope as well in spite of its larger pixel size (2.3 arcsec) and closer distance to the launch tower (110m) for two reasons: (i) taking simultaneous exposures with the 0.9m telescope enables to determine the absolute sodium layer altitude with a better accuracy via triangulation, and (ii) keeping the 0.9m telescope always pointed at the fixed laser star makes data-reduction easier. We used the Schmidt telescope to calibrate the atmospheric transmission on bright stars (V-filter) a few times per night. The 0.9m telescope transmission in the visible was calibrated simultaneously with the Schmidt transmission twice, at the beginning and at the end of the run. A 8-inch Meade telescope located some 5 meters away from the launch tower was also used to image the Rayleigh plume and the laser guide star at the tip of the plume. The Meade was used to spot cirrus clouds that might "artificially" lower the measured sodium return and help to select telescope data used for sodium abundance calculation.

This experimental set-up has been extremely successful so far and we plan to proceed similarly during future runs. Note that discussions are currently taking place with Pat Seitzer at the University of Michigan to obtain telescope time on the Schmidt in 2001B. We expect a positive answer. Note also that if the 1.3m telescope were to become available for observations in 2001B, it would actually offer a more favorable configuration for the sodium monitoring experiment than the 0.9m telescope does. Located some 320m away from the launch tower, the 1.3m telescope with its 0.28 arcsec pixel size and binning factors of 3 and above would enable to take images of similar SNR and exposure times than the 0.9m but with comparatively better spatial resolution of the sodium layer profile. We would apply for time on the 1.3m instead of the 0.9m if possible.

In order to obtain meaningful statistical data on the behavior of sodium density (average and sporadics) during the course of a night, we need at least 3-4 clear nights per run with medium to good seeing conditions. Allocation of 7 nights per run will certainly mitigate risks of bad weather, poor seeing and unexpected hardware failures. We request telescope time during full moon because sky background is not an issue for this high-SNR experiment. The use of a sodium filter to image the sodium streak enables observations during bright time.

Instrument Configuration

Filters: visitor sodium filter	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

1. We will not use the telescope tracking mode but keep the telescope pointing fixed in the direction of the steady sodium plume during all night instead.

2. During simultaneous observations with the CTIO 0.9m and Schmidt telescopes, we had synchronized exposures from both telescopes. This was done by means of a trigger cable running between the two telescopes. The purpose of this precise timing was to increase the absolute altitude measurement accuracy via means of triangulation with the two telescopes. We would do the same for runs in 2001B, between the 0.9m and Schmidt or 1.3m and Schmidt depending on which telescope we are granted time on.

3. Before the beginning of the Feb 2001 run, precision surveying to derive the pointing direction of the laser with respect to the 0.9m and Schmidt telescopes made it possible to find the laser star right away in the sky during the first night of observation. If we were to observe from the 1.3m telescope instead of the 0.9m, the same survey should be done ahead of time.

Observing Run Details for Run 2: CT-0.9m/CFIM + T2K

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for WIYN-2hr, WIYN-SYN, YALO, and Gemini runs).*

The experiment set-up and observation plan are identical to run #1.

Instrument Configuration

Filters: visitor sodium filter	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Same comments as for run #1.