Atmospheric Sodium Column Density Monitoring

N. Ageorges[1], N. Hubin[2], M. Redfern[1]

[1] National University of Ireland, Galway
Physics Department, Galway, Ireland
[2] European Southern Observatory
Karl Schwarzschildstraße 2, D-85748 Garching, Germany

Abstract. In Laser Guide Star Adaptive Optics (AO), a laser is used to excite the mesospheric (90km altitude) sodium (Na) layer and thereby creates an artificial star that can be used as reference for the AO wavefront sensor. The intensity of the created star depends strongly on the amount of Na present in the atmosphere. Experiences to measure the column density and details of excitation of scattering properties of sodium atoms in the corresponding atmospheric layer are thus very important to refine the design parameters of laser and assess the power requirement.

This article reviews the current knowledge on the mesospheric sodium derived from both astronomical and atmospherical studies. It then presents possible methods to study the sodium layer characteristics relevant for adaptive optics laser guide star systems.

1 Introduction

Most recent laser guide star systems for astronomical adaptive optics make use of mesospheric scattering of a sodium laser (at MMT, e.g. Lloyd-Hart et al. 1998, at Lick Observatory, e.g. Olivier et al. 1996, or Calar Alto, e.g. Davies et al. 1998), whereby an artificial reference star is created at the altitude of the mesospheric sodium layer (around 95km in average). The optimisation of adaptive optics systems using Na guide stars requires a detailed knowledge of the temporal and spatial characteristics of the atmospheric Na layer on both long term scales, i.e. seasonal variations requiring statistical studies, and short term scale variations, i.e. requiring daily and hourly monitoring. Indeed the intensity of the laser guide star is proportional to the column density of mesospheric sodium, (although it also depends on the efficiency of the laser to stimulate sodium atoms since the laser frequency has to excite Na atoms in a narrow band - few tens of m$\mathring{A}$), therefore important information about the laser power requirement for the laser guide star (LGS) adaptive optics (AO) can be derived from study of the atmospheric sodium column density.

Section 2 and 3 will present the existing knowledge on the atmospheric sodium layer. It will be shown that the column density of Na and its averaged height varies with time. The seasonal variations of the column density and altitude of the mesospheric Na, have impacts respectively on the necessary LGS power and its focus, and can be studied in a statistical way (section 4). The daily and hourly variations of the column density bring information on the variation of the averaged sodium column density and height and are therefore important for scheduling of LGS-AO observations; monitoring (section 5) is necessary to study them if statistics can be established. The conclusion (section 6) will summarise the characteristics of the atmospheric Na relevant and important for LGS-AO observations and propose means to study them.

2 Indirect knowledge about the atmospheric Na: astronomical observations

Most of the information in this section comes from high resolution spectroscopic studies of the Na D lines in the interstellar medium (see e.g. Welsh et al. 1990, Welsh et al. 1994). It suggests a methodology whereby the mesospheric neutral sodium column density can be determined from normal astronomical observations.

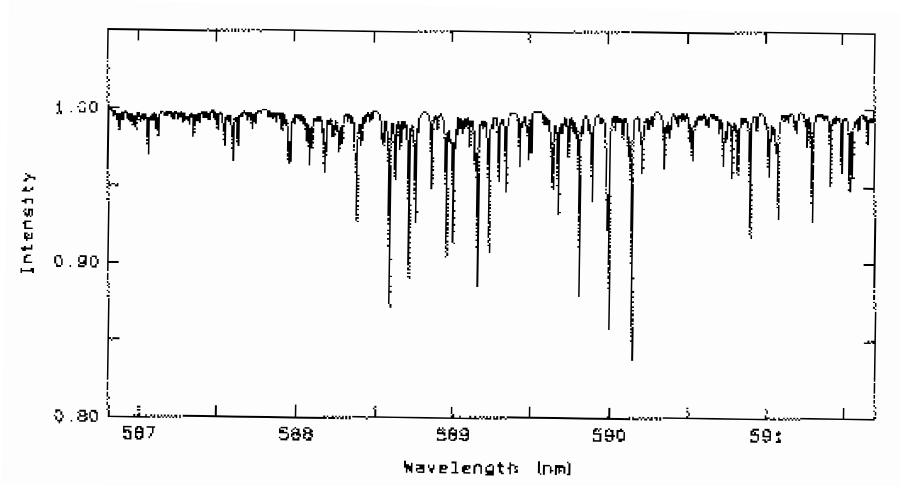

Fig. 1. Synthetic telluric spectrum in the interval $5870\AA$ to $5917\AA$; from Lundström et al. (1991).

There has been, over the last decade, an increasing number of studies of the local interstellar medium (LISM), defined here as d<200pc, using both optical and UV absorption lines (see reviews by Paresce 1984 - and by Cox & Reynolds 1987). Using very high resolution ($< 2\ \mathrm{kms}^{-1}$) ground-based observations of K I, Ca II and Na I, the detailed distribution of each ion's absorption and velocity in the neutral interstellar gas within 200pc of the Sun has been measured. Because of this sort of work a large database of information exists concerning the absorption characteristics and galactic distribution of neutral interstellar sodium (Na I) gas. Specifically, this data has been gained over the past 25 years through observations of the Na I D line doublet at 5890$\AA$ seen in the absorption spectra of galactic early-type stars (e.g. Hobbs 1978) which have no intrinsic sodium features, either in emission or absorption. These observations have formed the basis of current ideas on the general properties of neutral gas in the interstellar medium which have been summarized in the review article by Cowie & Songaila (1986).

The interesting result for the problem considered here, is the fact that the dense neutral interstellar NaI gas is generally absent from the very local interstellar medium. Indeed no sodium absorption was detected toward any of the stars, observed by Welsh et al. (1990), with distances less than 42pc. This means that it is possible, in principle, to measure the mesospheric sodium column density from observations of sodium absorption in early-type stars closer than ~50pc for which there is little or no interstellar contribution (interstellar equivalent width are typically less than 10mA).

Observations of weak interstellar D_1, D_2 and K lines are made very difficult by the presence of overlapping, much stronger lines of stellar origin and, in the case of the D lines, of telluric origin (Fig. 1). Detection of these weak absorption features has required high-resolution ($\lambda/\delta\lambda > 50\ 000$) spectroscopic instrumentation coupled to telescopes with aperture of sufficient size to obtain the required high signal-to-noise ratios (SNR) (see Sect. 5.1).

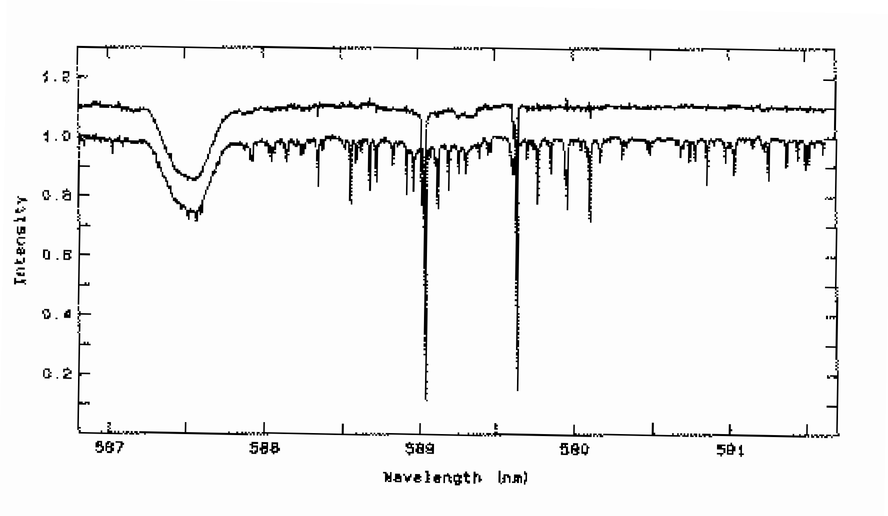

Fig. 2. This image is a comparison of the observed spectrum of HD 31237 before (lower curve) and after (upper curve) elimination of the telluric lines. From Lundström et al. (1991).

Numerous atmospheric water vapour lines occur in the region of the spectrum around 6000$\AA$, and two lines in particular (5889.637 and 5890.09$\AA$) are very close to the rest wavelength of the sodium D_2 line. The problems associated with telluric line contamination of sodium absorption spectra have well been documented by Hobbs (1978). Contaminating effects can be minimised by dividing the stellar spectra by a pure atmospheric absorption spectrum obtained from an unreddened early-type star with no interstellar sodium (e.g. α And, *eta* UMa, α Leo), taken at similar altitude. To ease the calibration problem, Lundström et al. (1991) have developed a program that creates a synthetic telluric spectrum for the wavelength domain around the sodium D_1 and D_2 lines (Fig. 2). Due to the recent interest of astronomers in using the telluric absorption spectrum to measure the equivalent width of these two terrestrial lines, the code has been modified; every telluric contribution is removed from the spectra except these two ones that are fitted and whose equivalent width is found as a by-product of the data calibration.

High resolution spectroscopy of hot, unreddened, young stars closer than 50pc thus offers the possibility to make statistical studies of the atmospheric sodium column density.

3 Atmospheric Sodium Properties Relevant to LGS-AO

3.1 introduction

Study of the atmospheric sodium is considered here under two different aspects:

- the statistical study of the general properties of current and prospective observing sites;
- the direct monitoring of short term variations in the mesospheric sodium, on sites housing large telescope projects. The latter becomes important for queue scheduling of LGS-AO observation programs of large observatories as the ESO VLT.

This section is however divided in long- and short- term variations of sodium; which, as will be shown, does not correspond exactly to this classification.

3.2 Long-term variations

Since the discovery of the presence of alkaline metals in atomic form at the altitude of the mesopause (Slipher 1929, Bricard et al. 1949), the origin and behaviour of this layer of atoms has been the subject of numerous experimental and theoretical researches; studies of the alkali metals, atmospheric sounding, studies of a meteoritic metallic layer at 100km, radar and LIDAR studies of gravity waves, and, since the late 70's, studies of the sporadic sodium layers and measurements to explain the seasonal and meridional variations in the sodium layer height, thickness and density. Because of its relatively high concentration in meteors and its large resonant backscatter cross section, Na is the easiest metallic species and the easiest of the meteoric layer atoms to observe by resonance fluorescence LIDAR techniques (Bowman et al., 1969).

All previous studies have found that the atmospheric sodium column density has diurnal (e.g McNutt & Mack 1963), nocturnal, seasonal (Fig. 3), and latitude dependent variations. Indeed LIDAR measurements of the sodium number

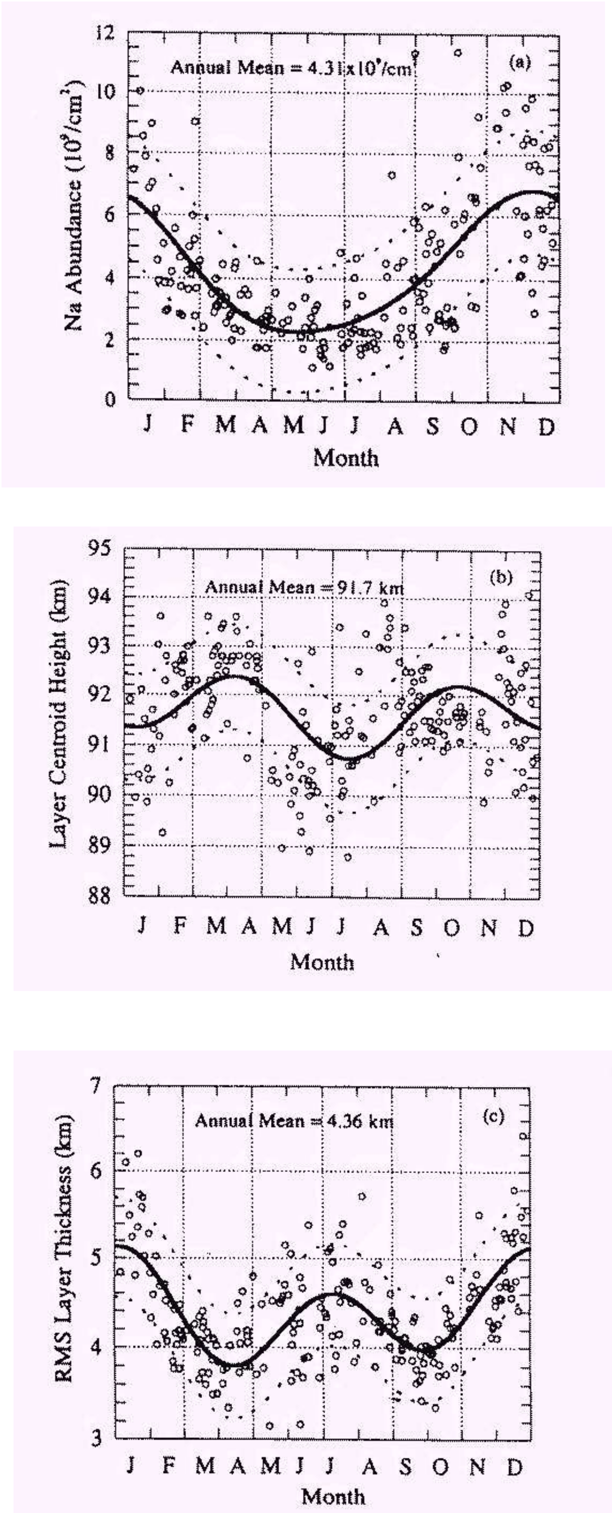

Fig. 3. Seasonal variation of the mesopsheric Na layer at 40°N. The curves represent the abundance, the centroid height and the rms width of the layer versus date. The thick curves are least squares fits to the data including annual plus semi-annual variations; the dashed curves are $\pm 1\sigma$; from Papen et al. 1996.

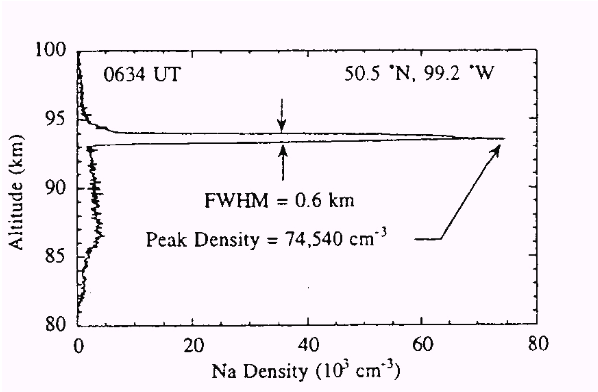

Fig. 4. Sodium density profile obtained with airborne Na LIDAR. The vertical resolution is 48m and the 7sec integration period corresponds to a horizontal resolution of around 1km; from Gu et al. (1995).

densities, performed since 1969 (see e.g. Gibson & Sandford 1971, Simonich et al. 1979 for some of the first ones at different latitude) have confirmed the previous photometric measurements (e.g. Donahue & Blamont 1961, Hunten et al. 1964, Rees et al. 1975), which have shown that the sodium total abundance presents seasonal variations dependent on the latitude (e.g. Jegou 1985).

Recent observations in conjunction with LGS-AO experiments have been aimed at measuring the sodium column density simultaneously with the LGS visible magnitude, which has a direct bearing on the expected efficiency of the LGS adaptive optics correction. For instance, Ge et al. (1997) found an equivalent $m_V = 10.3$ star for the LGS, using a 1W projected circularly polarised sodium laser beam for an atmospheric sodium column density of $3.7 \times 10^9 cm^{-2}$.

3.3 Short-term variations

It has also been found, from the observations mentioned in 3.2, that the averaged altitude of the mesospheric sodium variates as well (Papen et al. 1996). Some of these variations can be extremely quick due to the presence of sporadic layers (see e.g O'Sullivan et al., this proceedings). These sporadic sodium layers or sudden sodium layers are very thin Na layers superposed on the mean mesospheric Na layers have been observed at several LIDAR sites. Their characteristics are that the full-widths at half-maximum are typically from 1 to 2 km, the ratio of maximum peak density of the sporadic layer to the density of the normal layer at the altitude of the peak sporadic layer density is typically from 3 to 5 and their values can be rarely as much as the order of 10. The events can last from a few tens of minutes to several hours. Fig. 4 illustrates the observation of one sporadic event. In the late 70's, Clemesha et al. (1978) and Clemesha et al. (1980) were the first to report such observations at Sao Paulo, Brazil (23°S, 46°W). Kwon et al. (1988) found that most of the sporadics appearing above

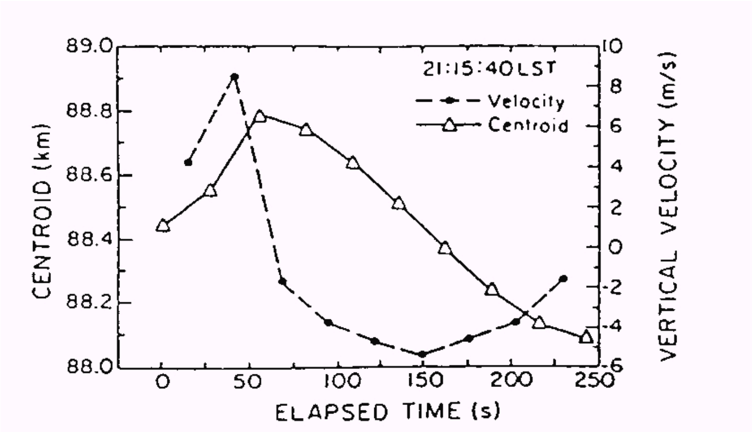

Fig. 5. Temporal variation of the centroid height and vertical velocity of the sporadic Na layer observed at 21:16 LST on March 4, 1988 over Urbana, IL. From Beatty et al. 1988

Mauna Kea are located in the same two hours slot of LST time. The occurrence of sporadic layers of neutral sodium and other metals at heights around 100km, with thickness much less than the atmospheric scale height, is an interesting and puzzling phenomenon, which has been nicely reviewed by Clemesha (1995). The recognition of these layers is crucial for LGS-AO since they cause rapid variations (increase) in the column density but also a displacement of the centroid of the layer (Fig. 5). The appearance of a sporadic layer induces a sudden increase in the sodium column density and a variation in the effective Na layer altitude (the centroid height) because the centroid moves first upwards as the sporadic layer appears and then downwards (Fig. 6). This produces a rapid focus shift for the LGS on a time scale of a few seconds to several minutes. The largest centroid variation observed in Fig. 5 represents an increase of $\approx$ 235m in 30sec. For the VLT such a defocus would mean a wavefront error of $\sigma \sim 37$ nm rms. Knowing that the error budget, for NAOS (the AO system for the VLT telescopes), linked to this problem should not exceed 15 nm rms, one realises the importance of recognising the sporadics. Statistics about their appearance can be established (see e.g. Kwon et al. 1988); it would then be good to possibly avoid observing while they appear (scheduling).

4 Statistical study

The statistical study aims essentially at giving a general idea of the average amount of sodium present in the upper atmosphere in order to establish the laser power necessary for LGS-AO.

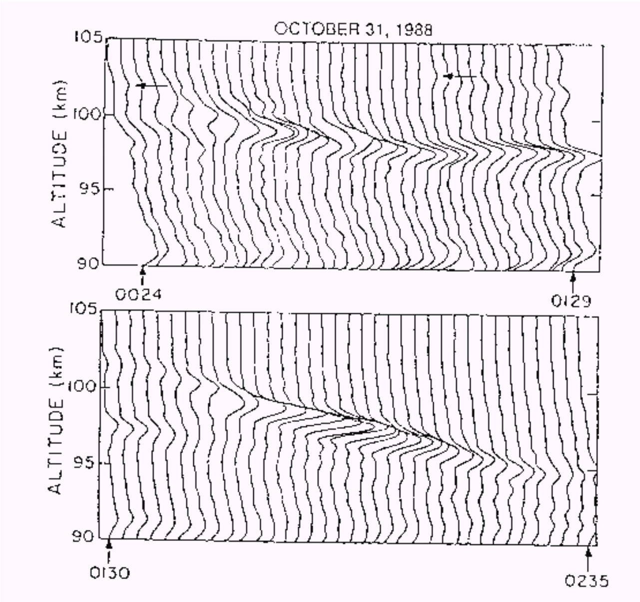

Fig. 6. Sequence of Na density profiles, obtained by LIDAR experiment, illustrating the vertical motion of the sporadic layers observed on October 31, 1988, at Urbana, Illinois; from Senft et al. (1989).

4.1 Archive work

One possibility for a statistical study of column density alone is to use data from astronomical archives. To reduce the work, sites having and/or planning to have LGS-AO have been identified from the list established in Rigaut (1997). In the second part of the work we set out to identify existing archive data for those particular sites that could be used for the statistical study.

For LaPalma and Hawaii, 'free access' archives exist; as well as for most Australian sites (for which, however, no planned LGS-AO project is known). A few American observatories have archive (mostly through NOAO) data but their use is first subject to prior approval. No useful data archive exists for the Chilean observatories (Cerro Tololo, Cerro La Silla and Cerro Las Campanas) and, of course, there is none for Cerro Paranal, which is a new site, even though it is potentially one of the most important sites for which we would wish to monitor the sodium column density.

This study has established that there is little high resolution spectroscopic data at the interesting wavelengths in the available data archives. Moreover, the existing data are sparse and spread over time and places. Hence there is no reasonable possibility to make a meaningful statistical study of the atmospheric sodium density above any particular observatory. In the long term a dedicated archive will have to be created.

4.2 What is currently being done

Among others, there is a very active group in Urbana, Illinois, who has been studying the atmospheric Na for the last 20 years (Rowlett et al. 1978), using LIDAR technology. They studied the site of Urbana (e.g. Gardner et al. 1986), Mauna Kea (e.g. Kwon et al. 1988), Arecibo (e.g. Beatty et al. 1989 and Hecht et al. 1993), and the Arctic (e.g. Gardner et al. 1988). Although their primary interest was the study of atmospheric gravity waves (e.g. Senft & Gardner 1991), they have accumulated precious information about the long term behaviour of atmospheric sodium (see e.g. Papen et al. 1996).

More recently R. Angel's group (Tucson, Arizona) has started a monitoring program of the atmospheric Na directly in connection with their LGS-AO experiments (e.g. Ge et al. 1997). This will be presented more extensively in section 5.2.

A group in Instituto de Astrofisico de Canarias (Fuensalida & Chueca, in preparation) is currently carrying out a sodium monitoring campaign in the Teide and Roque de los Muchachos observatories during the day time (by observing the Sun), and night time (using both the Moon and selected stars). Changes in abundances, even spectroscopic profiles, of mesopheric sodium are detected on short time scales.

Since it became apparent, from studies of the data archives, that no data existed concerning the abundance of sodium above the Chilean observatories, we decided to make high resolution spectroscopic measurements of selected stars at the European Southern Observatory at La Silla specifically for this purpose. The only other measurements existing in South America have been done in Brazil by Clemesha et al. (1992). Whilst no LGS-AO is planned for La Silla it is for Cerro Paranal, which is $\approx$ 700km northward. The Na abundance may, of course, differ somewhat between La Silla and Paranal, however, in the absence of specific measurements at Paranal itself, these are preliminary observations which give a general idea of the amount of sodium present. They are also interesting for comparison with the results from the Brazilian observations.

The sources, selected from Welsh et al. (1994), are unreddened early-type stars closer than 50pc. This allows to observe pure atmospheric absorption spectra in the vicinity of the NaD doublet free from interstellar absorption and stellar features in absorption or emission. The stars are of type A & B and have been selected to have $m_V < 10$, for high incoming flux.

We know that we would like a signal to noise of 1000 (see section 5.1); and that it is defined as follow:

$$SNR = \frac{DQE \times \delta\lambda \times N_{obj} \times t}{\sqrt{(DQE \times \delta\lambda \times N_{obj} \times t) + (DQE \times \delta\lambda \times N_{sky} \times t) + DN^2}} \tag{1}$$

where DQE is the dectector quantum efficiency (0.65 for EMMI), δt the width of a spectral resolution element (in $\AA$), N_{obj} the number of photons per second per $\AA$ per spatial resolution element incident on the detector from the object, N_{sky} same as N_{obj} but for radiation incident from the sky, t the integration time (in sec.) and DN the detector noise per resolution element. Since we are considering only bright stars ($m_V < 6$), the sky contribution is negligible and will thus not be considered in this calculation.

The detector of interest is the CCD#36, which has a read_out_noise of 5 electrons and a dark of 1.7 electrons/pixel/hour; so that $DN = N \times 5 + (1.7/3600) \times t$, with the integration time and N the total number of exposures. This term is however negligible since the observations are dominated by the photon noise. It is thus reasonable to approximate the signal to noise ratio by:

$$SNR \approx \sqrt{(DQE \times \delta\lambda \times N_{obj} \times t)} \tag{2}$$

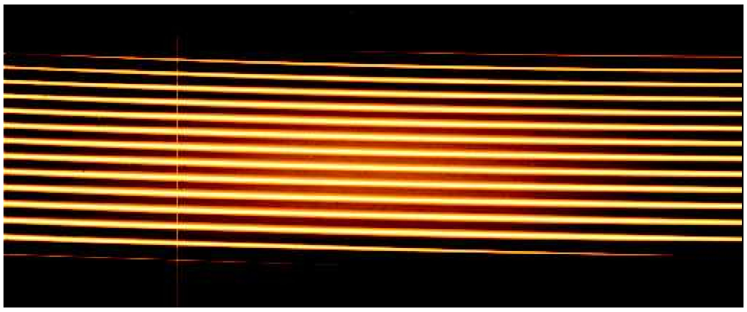

Fig. 7. Spectrum of β Lib. It is a sum of 36 row spectra for a corresponding integration time of 2325sec.

For EMMI at the NTT and the echelle grating that we used, Dekker et al. (1994) quotes the arrival of 1 photon/$\AA$/sec at 5500$\AA$ for a $m_V = 16.6$ star, at an airmass of 1. Knowing the pixel scale of $0.27''$, the pixel size of 40m$\AA$, for the selected echelle grating, the linearity of 50000 ADUs of the detector, and the gain of 2.2 electrons/ADU, it has been found that one can integrate up to 273 sec. with a m_V=4.7 star without saturating the detector. To reach the wished signal to noise ratio, we will then have to make, e.g. 23 exposures of 4 minutes; which represents 2 hours on the source when taking the overheads into account.

Fig. 7 represents a spectrum obtained with EMMI at the NTT. The individual spectrum of β Lib have been coadded to create this image, on which no processing has been done. The data reduction is currently in progress.

What can already be concluded from this is that due to the dynamic range of the CCD and the minimum exposure time needed on source to reach the requested SNR, the time resolution on the atmospheric sodium is at best of 2 hours.

4.3 Conclusion

Statistical studies should have two main purpose for LGS-AO systems:

- determine the minimum amount of atmospheric Na one can expect for a given observing site; this should help deriving the minimum laser power requested;
- make a statistics of the appearance of sporadics and thus determine possible observing windows where the percentage of sporadics expected is low; this has direct consequences on scheduling.

5 Monitoring

As explained previously, the mesospheric sodium has long term (seasonal) but also short term (daily or hourly) variations. The last ones can't be studied statistically, since they are random. The importance of the detection and recognition of sporadic layers, for example, has been stressed before. One thus understands the necessity to monitor the sodium to study these short time scale variations. In the following, the different requirements for such a monitoring will be presented first. Then on-going monitoring experiments will be mentioned as well as future possibilities.

5.1 Instrumental requirements

The first constraint is directly linked to the sodium itself. The D1 and D2 line are respectively at $5895.94\mathring{A}$ and $5889.773\mathring{A}$. The last one having an hyperfine structure with a separation of $19\mathrm{m}\mathring{A}$. The major problem for spectroscopic observations comes from the atmospheric water lines in absorption. They are much stronger than the D lines and are very close to them, i.e. at 5889.637 and $5890.09\mathring{A}$. This implies that any instrument of interest must have a minimum resolving power of 50000 to resolve the D1 line from the closest water line. For the D2 line, the minimum resolving power requested increases to 130000. With a resolution of one million, one is then able to resolve the hyperfine structure of the D2 line. The other point to consider is the equivalent width of $1\mathrm{m}\mathring{A}$ of the atmospheric Na D1 line. This means that a signal to noise of 1000 is necessary to detect it with a 15% accuracy.

From a pure observational point of view, it has already been mentioned in section 2 that sources have to be closer than 50pc from us in order to avoid any contamination of the measurements by interstellar sodium. In order to also avoid any problem with stellar contribution, it is advisable to select unreddened early-type stars since their spectrum is flat. Then, one directly obtains a pure atmospheric spectrum. These stars are thus of A & B spectral type. Possible targets fulfilling these criteria can be found e.g. in Welsh et al. (1994). To reduce the integration time, it is also preferable to select them as bright as possible, to have as much incoming flux as possible. Ideally one would like to have short integration times to detect the sporadics and quick variations.

5.2 Existing experiments - Ongoing work

The group of R. Angel (Tucson, Az) has been doing atmospheric Na measurements for the last couple of years in relation with their LGS-AO experiments at the MMT (Lloyd-Hart et al. 1998 & Lloyd-Hart et al. 1995). Their main interest is to calibrate the laser power with simultaneous measurements of Na LGS flux and Na layer abundance.

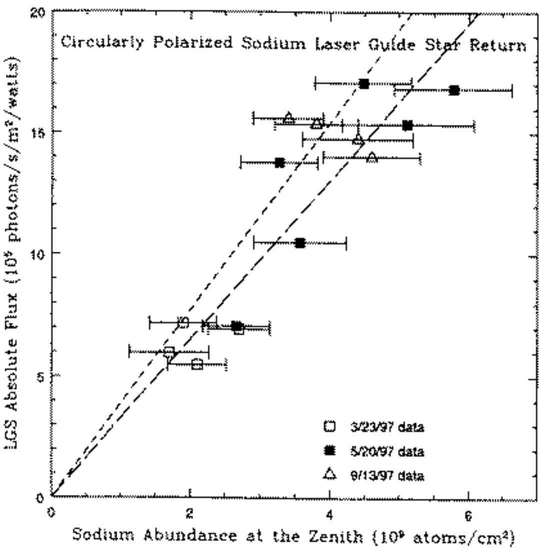

Fig. 8. Absolute flux of Na laser return of circularly polarized beam versus Na layer abundance at zenith; from Ge et al. (1998)

They made several successful simultaneous measurements in the March and May runs, 1997. The guide star was created by a monochromatic 3 W cw laser, tuned to the peak of the sodium D_2 hyperfine structure and launched from the MMT. The sodium layer abundance was measured at the CFA 60 inch telescope with the Advanced Fiber Optic Echelle (AFOE) spectrograph by looking at telluric sodium D_1 absorption in the spectra of bright stars. The telescope is only about 1km away from the MMT on the same mountain. Therefore, similar sodium layer patches were monitored during the simultaneous return experiments.

They found that linearly and circularly polarized laser returns are proportional to the simultaneous sodium column density (Fig. 8). Moreover, circularly polarized laser provides $\sim 30\%$ increase in fluorescent return over linearly polarized laser (Ge et al. 1997). A laser guide star with $m_R = 10.1$ mag. or absolute flux of 9.2×10^5 photons s^{-1} mm^{-2}, could be formed from a 1 watt projected circularly polarized sodium laser beam. Together with the distributed column density measurements (e.g. seasonal and diurnal variations), they can now project laser power requirements for any specified guide star brightness. They used the results as key for the choice of laser type and power for the laser guide star AO systems.

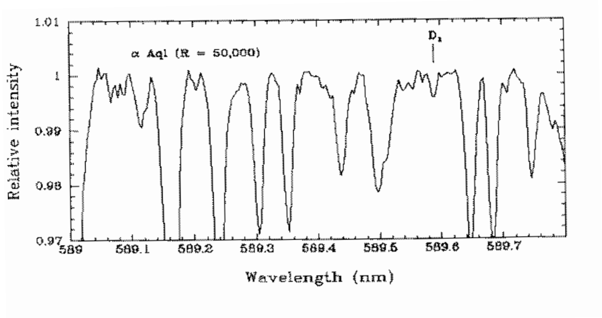

Fig. 9. Typical telluric sodium D_1 absorption spectra obtained at the CFA 60 inch telescope with the AFOE spectrograph; from Ge et al. (1998).

In addition to simultaneous measurements, they also monitored from Tucson the mesosphere sodium column density variation throughout the year, through sodium absorption line measurements in stellar and solar spectra (Ge et al. 1997). Fig. 9 illustrates a typical observed spectrum. Note that observations of bright stars led them to short exposure time, as it did for our ESO measurements. They claim to use an absorption method more direct and probably more accurate than the LIDAR methods normally used. The seasonal variation amplitude were found to be smaller than that at higher latitudes. The annual mean sodium column density, $3.6\mathrm{x}10^9\mathrm{cm}^{-2}$, tends to be lower than at higher latitudes. Diurnal sodium column density could vary by a factor of two which could happen within 1 hour time scale.

Other groups related to existing or planned LGS-AO systems recognise the importance of studies as described above. Most of them are thus thinking of monitoring the mesospheric sodium but using existing spectrographs at a nearby telescope.

5.3 Future possibilities

In order to monitor the atmospheric sodium as efficiently as possible, one would like to have short exposure time. One way is by increasing the throughput of the experiment. For spectroscopic measurements, one could think of fiber coupling the telescope and the spectrograph, as was done for the Heidelberg Extended Range Optical Spectrograph (HEROS, Fig. 10).

Presently the best solution for short measurements of the Na column density is via LIDAR technology. These can be quite portable and with a 20 Hz 100mJ

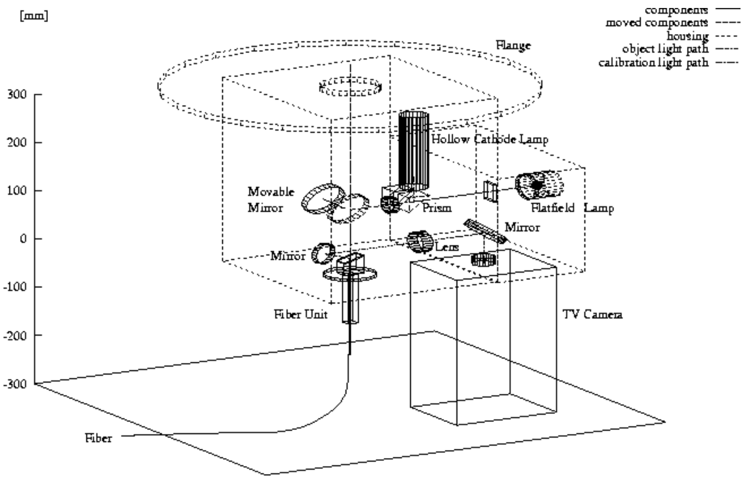

Fig. 10. Schematic layout of the telescope unit for HEROS.

pulse at 590nm, one can record the sodium layer in about 10 seconds, in clear nights, with a 2.7m collector (Wuerker & Wong 1997). A 1m collector, would mean 10 times longer integration time, which is still largely over what is reachable presently with high resolution spectroscopic studies. An other advantage of LIDAR techniques is the determination of the profile of the sodium layer. The main drawback is the cost of at least few $10000 for the laser.

Another possibility, presently under study at NUI, Galway, is the use of the photon counting camera (see O'Sullivan et al., this proceeding) not only to make profile of the LGS plume in the mesopsheric Na layer but also to determine its column density at given altitude layers. Presently one obtains profile of the relative density. After calibrating the absolute sensitivity of the detection system (telescope and camera) with spectrophotometric standards stars and calibrating the laser, i.e. knowing exactly the power delivered, one could then determine the absolute amount of sodium present in the atmosphere.

Patriarchi (this proceedings) is offering a new solution to the monitoring problem. His system is based on a magneto-optical filter already widely used in solar observations (Cacciani et al. 1994). This filter is compact, stable in wavelengths and profile shape. It displays a very narrow spectral transmission band (down to 70m$\AA$) and also has a high peak transmission (up to 40%). It is proposed here to make short time integrations to monitor the mesospheric sodium layer column density with small aperture ($\approx$ 50cm) telescopes.

To summarise, presently, the Na monitoring experiments performed in conjunction with LGS-AO observations have been aimed at determining simultaneously the LGS intensity and the atmospheric Na column density in order to derive information on the LGS efficiency. This is possible because monitoring the laser power and estimating the amount of Na present in the atmosphere at the moment of the observations (monitoring), enable to predict the return from the laser (magnitude of the LGS). A by-product of this study is the monitoring of the LGS-AO itself, in terms of quality of correction under known observing conditions in comparison to a theoretically perfect system.

What is currectly missing is a monitor of the centroid of the atmospheric Na height. It has been shown here that, in the event of a sporadic layer, this can have dramatic effects on the focus of the LGS-AO experiment. A monitor is essential to detect these short time scale (up to a few minutes) and large altitudes variations. The observing conditions during these periods of Na sporadics are unsuitable for accurate AO correction; the data should therefore be discarded.

6 Conclusion

Table 1 summarises the actual knowledge on the study of Na layer for LGS-AO systems. The first column compiles the main Na characteristics influencing the LGS experiments; the corresponding LGS parameters are in column 2. The last column indicates ways of studying these characteristics in order to predict the efficiency of the LGS-AO system used.

Atmospheric Na layer characteristics	LGS parameters	Means of observation
Column density		
Seasonal variation	LGS power	statistical study
		spectroscopy
Daily variation	Scheduling of observations	monitoring
		on-site statistics
Hourly variations	Scheduling	monitoring
		LIDAR
Altitude variation		
Long term variations		statistical studies
	LGS focus	LIDAR
Short term variations		Monitoring

Table 1. Table summarising the impact of some characteristics of the atmospheric Na layer on LGS-AO systems and the means to study them.

From the statistical studies, one would like to know the minimum Na column density in order to derive the laser power required to produce a LGS of specified magnitude. The interest of monitoring the sodium on a daily basis, therefore, is to give an indication of the expected LGS-AO correction. A comparison with the actual correction is also a way of checking on the system performances.

Due to their adverse effect on the stability of the mesospheric sodium centroid height, it is desirable to establish the statistics of the sporadics'appearance. If, as

Kwon et al. (1988), one finds a LST slot where a huge majority of these sporadics appear for the observing site, LGS-AO observations can then be programmed outside this window. It is also very important to determine the time scale of these altitude variations. Indeed, if changes in focus, due to sporadics, happen on time-scale bigger than $\approx$ 10 min., one could then correct for it by recording the defocus on the wavefront sensor and averaging over few minutes to determine the correction needed. If however, as it seems from LIDAR observations, changes occur on seconds to few minutes time scale, one then needs a separate monitor to identify these periods. The previously mentioned way of correcting the defocus is not possible anymore since on short time scale one does not know how much of the defocus is due to the atmosphere and how much is linked to the motion of the sodium layer itself. Of course, what can be called the boundary between 'mid-' and 'short-' term variations depends on the defocus rms accepted by the AO systems used (15nm rms for the VLT).

Different possibilities to solve the monitoring problem will be presented in Ageorges (1998, in preparation).

7 Acknowledgments

NUIG and ESO are part of the EU TMR Network 'Laser Guide Star for 8m-class Telescopes' (contract no. FMRX-CT96-0094). NA is grateful to the EU for financial support. The ESO NTT team is also thanked for its support during the recent observations.

References

Beatty T.J., Collins R.L., Hostetler C.A., Sechrist C.F.Jr., (1989): Simultaneaous radar and LIDAR observations of sporadic E and Na layers at Arecibo Geophysical Research Letter **16**, 1019

Bowman M.R., Gibson A.J., Sandford M.C.W., (1969): Atmospheric sodium measured by a tuned laser radar. Nature **221**, 456–457

Bricard J., Kastler A., Robley R., (1949): C.R. Acam. Sci. Paris **228**, 1601–1603

Cacciani A. et al., (1994): Theoretical and experimental study of the magneto-optical filter. Jet Propulsion Laboratory internal report D11900, Pasadena

Clemesha B.R., (1995): Sporadic neutral metal layers inthe mesosphere and lower thermosphere. J. of Atmospheric and Terrestrial Physics **57**, 725–736

Clemesha B.R., Simonich D.M., Takahashi H., Batista P.P., Sahai Y. (1992): The annual variation of the height of the atmospheric sodium layer at 23°S: Possible evidence for convective transport. J. of Geophysical Research **97**, 5981–5985

Clemesha B.R., Kirchhoff V.W.J.H., Simonich D.M., Takahashi H., Batista B.P., (1980): Space LIDAR and nightglow observations of an atmospheric sodium enhancement. Journ. of Geophys. research **85**, 3480–3484

Clemesha B.R., Kirchhoff V.W.J.H., Simonich D.M., Takahashi H., (1978): Evidence of an extraterrestrial source for the mesospheric sodium layer. Geophys. Res. Let. **5**, 873–876

Cox D.P., Reynolds R.J. (1987): The local interstellar medium ARAA **25**, 303

Cowie L.L., Songaila A. (1986): High resolution optical and ultraviolet absorption studies of interstellar gas ARAA **24**, 499

Davies R.I. et al., (1998): *Adaptive optical system technologies* (Proc. SPIE **3353**), in press

Dekker H., D'Odorico S., Fontana A. (1994): Test of an R4 Echelle Mosaic The Messenger **76**, 16-20

Donahue T.M., Blamont J.E, (1961): Sodium in the upper atmosphere. Ann. geophys. **17**, 116–133

Gardner C.S., Senft D.C., Kwon K.H., (1988): LIDAR observations of substantial sodium depletion in the summertime Arctic mesosphere Nature **332**, 142

Gardner C.S., Voelz D.G., Sechrist C.F. Jr., Segal A.C., (1986): LIDAR studies of the nighttime sodium layer over Urbana, Illinois. I - Seasonal and nocturnal variations J. of Geophys. Research **91**, 13659

Ge J. et al., (1997): Mesosphere Sodium column density and laser guide star brightness. ESO workshop on *Laser technology and laser guide star for adaptive optics astronomy* (Proceedings # 55, edited by N. Hubin), 10–15

Ge J. et al., (1998): Simultaneous measurements of sodium column density and laser guide star brightness. *Adaptive optical system technologies* (Proc. SPIE **3353**), in press

Gibson A.J., Sandford M.C.W., (1971): The seasonal variation of the nighttime sodium layer. J. Atmosp. and Terres. Phys. **33**, 1675–1684

Gu Y.Y., Qian J., Papen G.C., Swenson G.R., Espy P.J., (1995): Concurrent observations of auroral activity and a large sporadic sodium layer event during the ANLC-93 Geophysical research Lett. **22**, 2805-2808

Hecht J.H., Kane T.J., Walterscheid R.L., Gardner C.S., Tepley C.A., (1993): Simultaneous nightglow and Na LIDAR observations at Arecibo during the AIDA-89 campaign J. of Atmospheric and Terrestrial Physics **55**, 409

Hobbs L.M., (1978): Optical interstellar lines toward 18 stars of low reddening. III. Ap.J. **222**, 491-507

Hunten D.M., Vallance Jones A., Ellyett C.D., McLauchlan E.C., (1964): Sodium twilight at Christchurch, New-Zealand. J. Atmosph. and Terrestrial Physics **26**, 67–76

Jegou J.P., (1985): Etude experimentale et théorique des métaux alcalins dasnla haute atmosphère de 70 à 110km. PhD Thesis, Univ. Paris VI

Kwon K.H., Senft D.C., Gardner C.S., (1988): LIDAR observations of sporadic sodium layers at Mauna Kea Observatory, Hawaii. J. of Geophysical Research **93**, 14199–14208

Lloyd-Hart et al., (1998): First astronomical images sharpened with adaptive optics using a sodium laser guide star Ap.J. **493**, 950

Lloyd-Hart et al., (1995): Adaptive optics experiments using sodium laser guide star. Ap.J. **439**, 455-473

Lundström I., Ardeberg A., Maurice E., Lindgren H., (1991): A synthetic telluric spectrum in the wavelength region surrounding the D_1 and D_2 lines of sodium A. & A. Supp. **91**, 199-208

McNutt D.P., Mack J.E., (1963): Telluric absorption, residual intensities, and shifts in the Fraunhofer D lines Journ. of Geophysical Research **68**, 3419–3429

Olivier et al., (1996): First significant image improvement from the Lick Observatory laser guide star adaptive optics system American astronomical society meeting **189**, #42.08

Papen G.C., Gardner C.S., Yu G., (1996): in Adaptive Optics **13**, OSA Technical Digest Series (optical Society of America, Washington DC), 96

Paresce F., (1984): On the distribution of interstellar matter around the Sun AJ **89**, 1022

Rees M.H., Romick G.J., Belon A.E., (1975): The intensity of the sodium D_lines in the auroral zone. Ann. Geophys. **31**, 311–320

Rigaut F., (1997): ESO workshop on *Laser technology and laser guide star for adaptive optics astronomy* (Proceedings # 55, edited by N. Hubin), 1–5

Rowlett J.R., Gardner C.S., Richter E.S., Sechrist C.F. Jr., (1978): LIDAR observations of wave-like structure in the atmospheric sodium layer Geophys. Research Let. **5**, 683

Senft D.C., Gardner C.S., (1991): Seasonal variability of gravity wave activity and spectra in the mesopause region at Urbana J. of Geophysical Research **96**, 17229–17264

Senft D.C., Collins R.L., Gardner C.S., (1989): Mid-latitude LIDAR observations of large sporadic sodium layers Geophysical Research Lett. **16**, 715–718

Simonich D.M., Clemesha B.R., Kirchhoff V.W.J.H., (1979): Mesospheric sodium layer et 23°S: nocturnal and seasonal variation. Journal of Geophys. Res. **84**, 1543–1550

Slipher V.M., (1929): PASP **41**, 262

Welsh et al., (1994): The local distribution of Na I interstellar gas Ap.J. **437**, 638-657

Welsh et al., (1990): High-resolution sodium absorption-line observations of the local interstellar medium Ap.J. **358**, 473-484

Wuerker R.F., Wong A.Y., (1997): ESO workshop on *Laser technology and laser guide star for adaptive optics astronomy* (Proceedings # 55, edited by N. Hubin), 201–203