LGS Light pollution investigation in Calar-Alto

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Abstract. Preliminary results of Rayleigh scattering measurements obtained at Calar-Alto observatory, in August 1998, with a 4W CW laser are presented here. This laser is used to produce a sodium-layer laser guide star for the MPE adaptive optics system (ALFA). The measurements have been done from the neighbouring 2.2m telescope with a low noise CCD camera. The first experiments and results, obtained on the Na plume and on the Rayleigh cone, are described here, as well as the theoretical light pollution estimates due to Rayleigh scattering.

1 Introduction

Adaptive Optics (AO) techniques are used for an increasing number of research programs in ground based astronomy. All modern observatories are using or are planning to use AO with Laser Guide Star (LGS) to increase sky coverage in a close future.

The LGS system generates a stray light source. Rayleigh scattering in the lower atmosphere (0 to 20 km) makes the laser beam detectable by naked eye from a distance of some hundreds of meters, depending on the laser power. If the line of sight of another telescope in the same observatory gets near the path of the laser beam during the observation, the exposure could be badly perturbed. When a *collision*, crossing of the line of sight with the laser beam, is going to occur, one has to shut-off the laser or to interrupt the observation. Wizinowich et al. (1998) estimate that a collision is succeptible to occur on 20 to 50% of the observing nights in a typical observatory like Mauna Kea. Moreover, multiple scattering can also perturb long time exposures for telescopes up to a large angular distance from the laser beam.

In order to optimise the use of observation time, it is important to evaluate exactly at which point the observation has to be interrupted: the optimal point is when the (multiple) scattered laser light level becomes equal to the sky background for the second telescope. In this perspective, not only the single and multiple Rayleigh scattering by atmospheric molecules but also Mie scattering by aerosols has to be taken into account. Modeling of these phenomena needs an experimental calibration in realistic circumstances.

Therefore in the framework of the network, 'Laser Guide Star (LGS) for 8m class telescopes', a program of Training and Mobility of Researcher from the European Commission, ESO, MPE and NUI, Galway are collaborating on studying the light pollution due to the MPE ALFA laser. This is part of a full study of the LGS operational issues.

The light pollution of the observatory is due to Rayleigh and Mie scattering of the laser beam in the low atmosphere. With the increase of LGS Adaptive Optics (AO) systems, there is a need for a laser management policy which decides when to stop the LGS use as the line of sight of one telescope gets near the laser beam. Precise measurements of single and multiple light scattering in the surroundings of the beam at various altitudes are therefore needed.

Section 2 explains the experimental set-up. Results are presented in section 3 and compared to theoretical expectations in section 4.

2 Experimental Setup

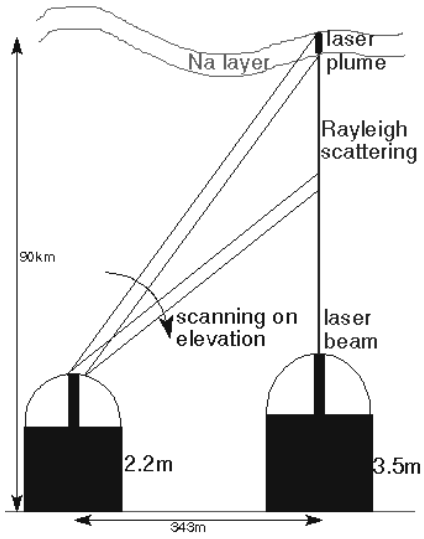

Fig. 1. Experimental set-up at Calar Alto observatory

The present experiments were carried out at the Calar-Alto observatory. The ALFA laser was launched from the 3.5m telescope pointed permanently at zenith and focussed on the sodium (Na) layer (Fig. 1). The observations were done from the 2.2m telescope situated 343 m away on a nearly pure North-South axis.

A 2048×2048 pixels SITE#1d CCD was installed at the Cassegrain focus of the 2.2m telescope. The camera, with a field of view (FOV) of $9.9' \times 9.9'$, was used for direct imaging purpose of the beam. A narrow band interference Na filter (λ_0 = 589.6nm from Elliott Scientific), with 10nm bandwidth and 50% peak transmission was used. The telescope, focussed on the laser plume, was pointed 'manually' along the laser beam at various elevations, i.e. altitudes, from 100km down to few hundred meters.

The observations took place the 16th and 17th of August 1998 in the last 3 hours of the night, with important moonlight (the last quarter had raised for 3 hours) and with a non-homogeneous coverage of cirrus clouds.

3 Results

Results of direct imaging of the laser at different elevations as seen from the 2.2 m telescope are presented here.

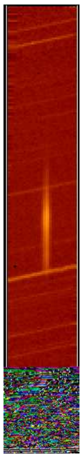

Fig. 2. Images of the laser plume in the mesospheric sodium layer. The oblique tracks are from stars crossing the field of view. The top ellipsoid is the laser Na plume, the faint vertical column at the bottom of the two right most images is the top of the Rayleigh cone.

Fig. 3. Longitudinal profiles of the 2 laser plumes shown in the right of figure 2. These profiles are zoomed on the plume itself and integrated along the lateral dimension. The x-axis is the altitude in km. The y-axis gives the integrated number of photons received on the CCD camera.

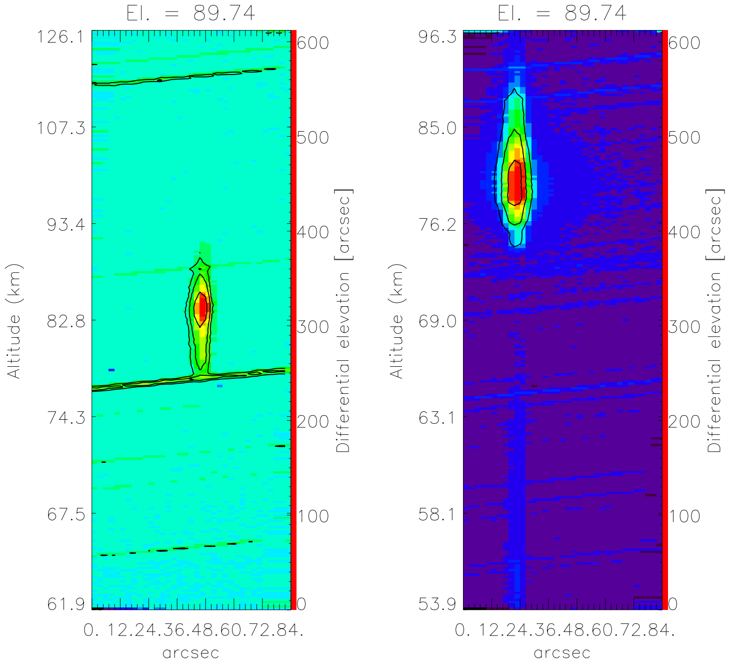

Fig. 4. Images of the laser plume in the mesospheric sodium layer. The vertical axis is the altitude in km at left and the differential elevation (relative to the bottom of the image) at right, while the width of the image is calibrated in arcsecond.

3.1 The laser plume

Images of the laser plume in the mesospheric sodium layer were obtained at a typical 20 minutes interval. Each integration time was of 5 minutes.

The laser plume seen from the side at a distance of 343m from the launch position of the laser appears to have a full width half max of 46″ (which corresponds to a layer thickness of about 5 km $FWHM$. Some of the plume images can be seen in Fig. 2. The oblique lines are star trails (since no tracking was on). The images were originally taken with the full resolution but, to enhance the signal to noise ratio in the data presented here, they have been binned by 8 pixels along the laser, i.e. along the vertical axis. At the bottom of the two right most images, one can already see the Rayleigh cone. In the original two right most non-binned images, and even on the binned ones, noticeable variations in the flux distribution of the plume can be seen (figure 3). Their standard deviation is of the order of 10% rms. This proves that the density profile of the Na layer can vary on middle time scales (20 minutes) as was also shown by other authors using different methods of investigation (O'Sullivan et al. (1998)). However, this has very few effects on the position of the laser guide star barycenter for wavefront sensing. Shorter time scale variations could not been seen in our experiment due to the 5 min exposure time.

Fig. 4 represents the laser plume with intensity contour lines. The y-axis is

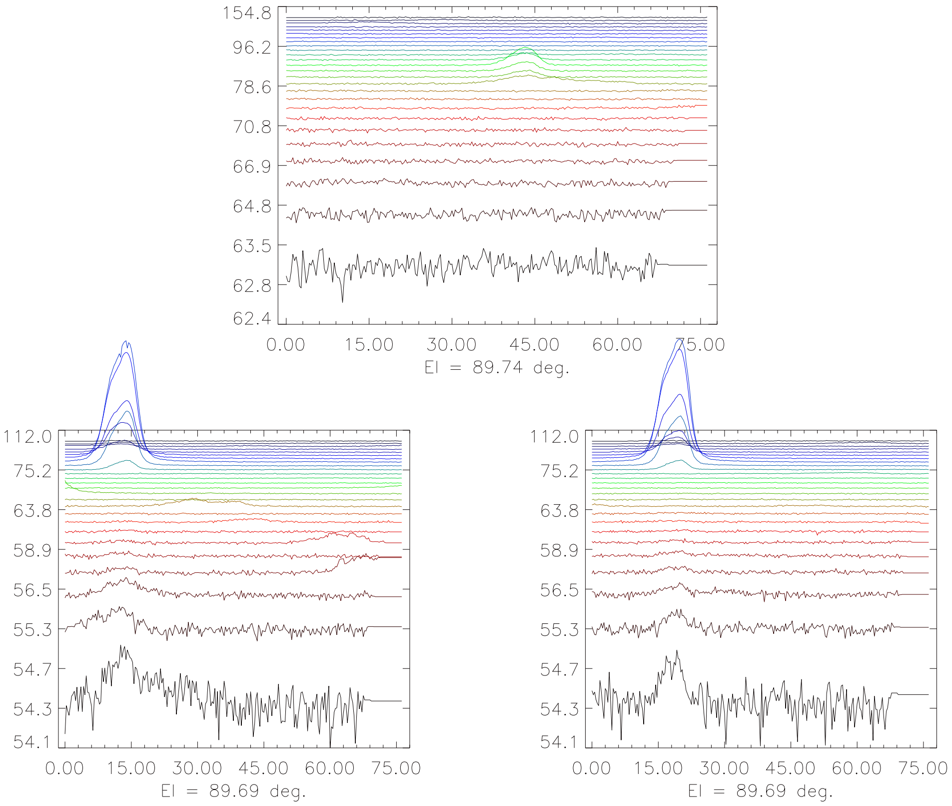

Fig. 5. Profile of the laser plume images presented above. The y-axis is the altitude in km of the facing profile lines and is plotted in a logarithmic scale. The profiles of the image intensity are plotted in arbitrary logarithmic scale. The elevation of the telescope for each observation is indicated below the horizontal axis. In the upper image the laser plume is hardly to recognise. In the other images, traces of the Rayleigh cone are visible at around x=15$''$.

calibrated in terms of altitude in m. The image to the left is unbinned, one pixel corresponds to 0.3$''$. To the right, the image has been binned by 8 in the direction of the laser. The contour lines enhance the fact that the Na density profile is highly variable : the shapes of the contour lines are very different between both images.

The average altitude of the laser plume is $\approx$ 85km. The Rayleigh scattering is observable up to 69km at a mere 80$''$ from the bottom of the laser plume, in our experimental conditions (separation between the telescopes of 343 m). In this image, the Rayleigh scattering intensity reaches 1% of the laser plume maximal intensity, 7$'$ below the plume 'centroid'. This can also be seen in the profiles (Fig. 5), computed from the same images. The small lateral bumps seen on some profile lines are due to the star trails crossing the profile lines.

3.2 Top of the Rayleigh cone

Other images were taken at different altitudes corresponding to exactly $24''$ elevation difference, just beneath the top of the Rayleigh cone. Each image has a different mean elevation but partially overlap with the next image.

The profiles of those images are produced in Fig. 7. One notices that the beam intensity increases when going down and then decreases due to the balancing effect between the perpsective and the atmosphere; when going down, the scatterer density increases while the total scattering volume contributing to the light collected by one camera pixel decreases; this will be developed in section 4.

It is obvious that single scattering is dominant but multiple scattering can be identified in the wings of the profiles, as small enhancements at the bottom of the straight lines of the main beam profile. At $66\ ''$ from the beam center, i.e. just after the limit of single scattering, the light intensity is ≈ 4.8 % of the beam maximal intensity.

The 'bizarre' transverse profile shape is induced by the laser launch telescope. Indeed the 25 cm laser beam is launched slightly off-axis from the 50 cm launch telescope. The central obscuration of this one thus occults a non centered part of the beam and this shape is observed from the side by the 2.2 m telescope (Fig. 6).

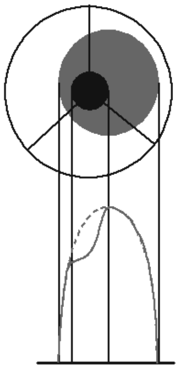

Fig. 6. Schematic geometry of the laser launch telescope and its effect on the laser beam transversal profile as seen from the 2.2 m telescope

3.3 Along the laser beam

This time the images have been taken at $32''$ elevation away from one another, with a 30sec. exposure time. Each image is rebinned 8×8 in both direction, so that each pixel corresponds to $2.4''$. Each image corresponds to a different mean elevation, indicated at the bottom of each figure, and does not overlap with the following observation. The profiles (Fig. 8) are classified in altitude: the highest elevation at the top and the lowest elevation and thus altitude at the bottom of