TELESCOPES AND INSTRUMENTATION

GLAS: A Laser Beacon for the WHT

René Rutten (Director, ING)

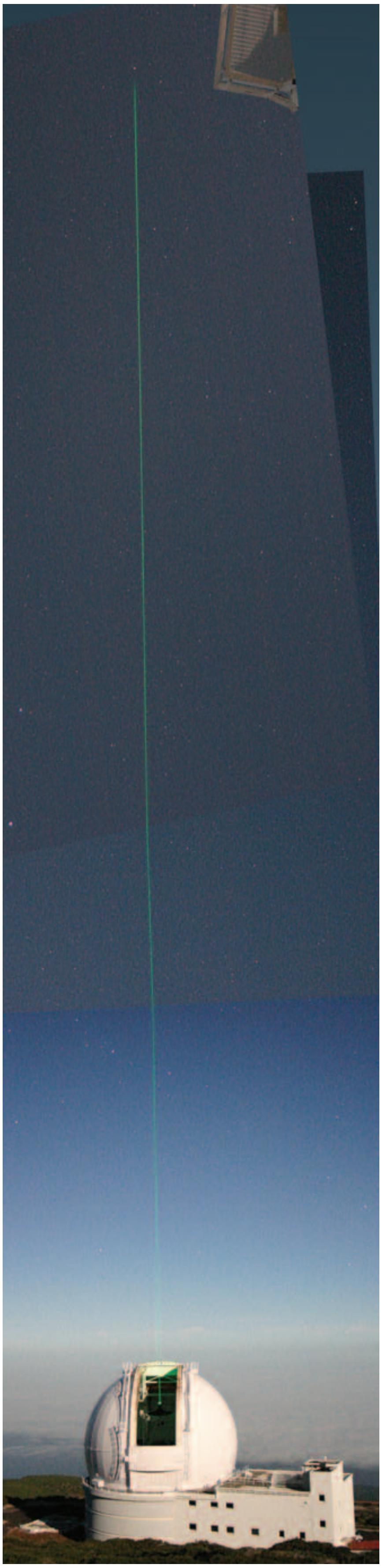

Figure 1. The Durham laser experiment in action at the WHT in April 2004.

In January 2004 the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) announced its full support for the proposed development of a laser beacon for the NAOMI Adaptive Optics (AO) system on the 4.2-m William Herschel Telescope (WHT). Such a laser guide star system will amplify the fraction of sky available to AO observations at visible and infrared wavelengths from about one percent to nearly 100%. In terms of astronomical research, this translates into radical progress as it opens up high spatial resolution observations from the ground to nearly all types of science targets. In combination with the existing and planned instrumentation, the WHT will offer a highly competitive facility to the astronomical community, exploiting a window of opportunity before similar capability will exist on 8-m class telescopes.

AO techniques allow ground-based observers to obtain spatial resolutions better than a tenth of an arcsecond by correcting the image blurring introduced by the Earth's atmosphere. Hence the resulting image sharpness not only carries the advantage of distinguishing finer structure and avoiding source confusion in dense fields, but it also allows observations to go significantly fainter, as the sky background component reduces with the square of the angular resolution. For these reasons, AO instrumentation is being planned for nearly all large telescopes, and it is at the heart of the future generation of extremely large telescopes.

At the WHT, AO recently came to fruition with the commissioning of the common-user AO system, NAOMI, and an aggressive instrument development programme. A main practical limitation for AO is the availability of bright guide stars to measure the wavefront distortions, which has caused AO in general to produce fewer science results than one might have expected from its potential. By using an artificial laser guide star this limitation is largely taken away, thus opening up AO to virtually all areas of observational astronomy and to virtually all positions in the sky. In particular, it opens up the possibility of observing faint and extended sources, and will enable observations of large samples, unbiased by the fortuitous presence of nearby bright stars. With a laser guide star facility, a 4-m class telescope situated on a good observing site like La Palma is highly competitive for AO exploitation next to the larger telescopes. Examples of science areas that may profit from the laser facility are the search for brown dwarfs and disks around solar type stars in obscured star formation regions, super-massive black holes, dynamics of nearby galaxy cores, circumnuclear starbursts & AGN, gravitational lenses, and physical properties of moderately high redshift galaxies.

Since January this year work started on designing the various components of the laser beacon system. Although maybe not a project of a very large scale, the complexity is quite significant and offers various challenges for engineers and astronomers alike. The project will be a joint endeavour with, besides ING, participation from the University of Durham, the ASTRON institute in the Netherlands, the University of Leiden, and the Instituto de Astrofísica de Canarias. Below we will set out the main components and challenges of the laser system and summarise the performance prospects.

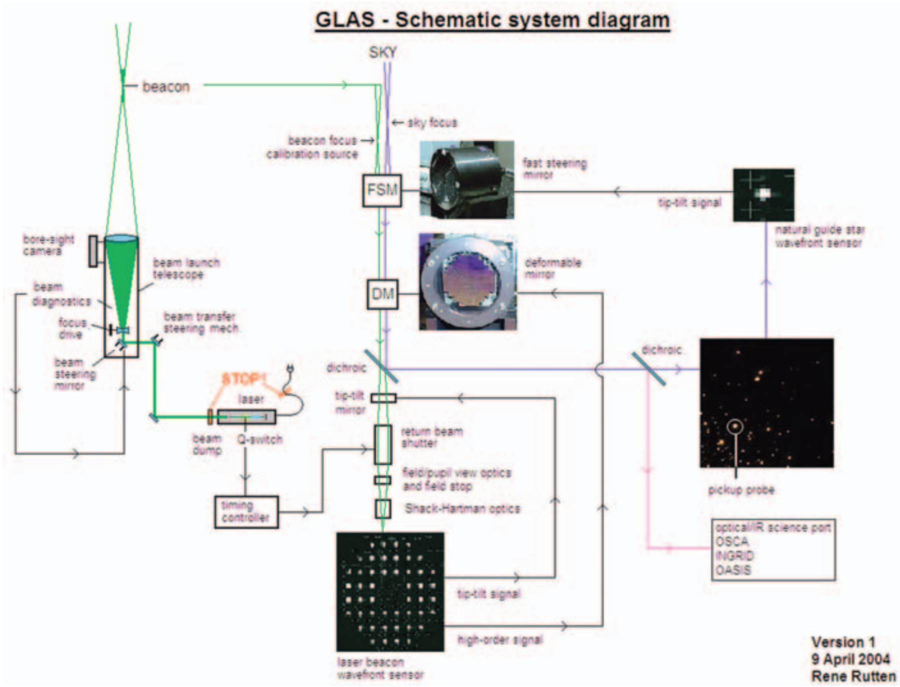

Figure 2. System diagram for the GLAS and NAOMI system.

Laser Guide Stars Basics

The idea is simple: a laser beam is used to generate a point source as high as possible in the sky, projected towards the same area as where the telescope is pointing. That laser beacon illuminates the atmospheric turbulence above the telescope and is used for sensing the corrugation of the wavefront caused by that turbulence. The higher the laser beacon is projected the better it is, as in that way it best approximates a source from infinity.

There are basically two ways to produce a laser beacon: either exploiting a layer of relatively high sodium density in the atmosphere at some 90 km, or 'just' using back scatter in the atmosphere. The sodium laser option is technologically very demanding for reason of laser technology and for the implications it has on the design of the AO system. The Rayleigh laser, however, is somewhat easier as it can use existing off-the-shelf laser technology which is also much less expensive and easier to maintain. The Rayleigh has however the disadvantage that the beacon will at best be at an altitude of some 20 km. The lower elevation implies that atmospheric turbulence very high in the atmosphere will not (properly) be sensed. Turbulence close to observatory will be well measured, and therefore it is often referred to as ground-layer AO. This feature has given the name to the laser project for the WHT: GLAS, for Ground layer Laser Adaptive optics System (or better in Dutch, Grondlaag Laser Adaptieve optiek Systeem).

Evidence built up over the years indicate that ground-level turbulence often dominates, a nice example of which is shown in the paper in this Newsletter by García et al. Over the next several months more solid experimental data will be gathered about the turbulence characteristics.

System Overview

First of all, the Rayleigh laser system is designed to work in conjunction with existing AO equipment (NAOMI) and its ancillary instrumentation and infrastructure like the INGRID IR camera and the OASIS integral-field spectrograph. A powerful 25 to 30W pulsed laser will be focussed to some 20 km altitude from a launch telescope mounted behind the secondary mirror. The pulse will produce a short (tens of meters) column of light that travels through the atmosphere. The Rayleigh back scattered light from this pulse will find its way back to the telescope. About 10% of all the light is scattered into the atmosphere, but of course in all directions and along the full depth of the atmosphere. Only a very small fraction of the laser light returns to the telescope and can be used to sense the turbulence, hence the need for a powerful laser in order to produce a beacon that is bright enough to serve for AO.

Only photons returning from a certain set altitude range are useful to us. Hence unwanted photons have to be blocked from entering the detector. This will be done using a combination of a geometric filter that will obstruct most of the unwanted light, and a very fast electro-optical Pockels cell shutter. The timing of this Pockels cell shutter opening will be slaved to the laser pulse signal, and open exactly when the Rayleigh scattered light from an altitude of 20 km returns to the telescope. The very short period during which the shutter remains open sets the length in the atmosphere over which the laser beacon will extend.

Having passed the shutter, the Rayleigh back-scattered light will be detected by a wavefront sensor system that measures the instantaneous wavefront shape from the laser guide star. The results from this measurement, some 300 times per second, will provide the demanded shape that the deformable mirror of the AO system will have to take in order to correct for the wavefront corrugation.

So far the situation is very similar to a 'standard' natural guide star AO system, except that laser light is used rather than light from a star. However, as the laser light travels through the atmosphere twice along more or less the same path, the measured wavefront does not contain information on the overall image shift (tip-tilt) caused by the atmosphere. Hence to measure the tip-tilt component still a natural guide star is required, but such star can be quite faint and may be relatively far away from the science object.

The existing wavefront sensor system will be dedicated to tip-tilt measurements on a star. The requirement for having such star near the science object still poses a limitation on the effective sky coverage. To maximise our chances of finding a suitable star even more, the existing wavefront sensor will be upgraded with a Low-Light-Level CCD that has virtually zero read noise and would give us an extra magnitude in faintest detectable star. As can be seen in the adjacent figure (courtesy Remko Stuik, Leiden) the *conservatively estimated* sky coverage will be extremely good, even at the galactic pole.

The laser light scattered into the atmosphere of course has to be blocked from entering the science instruments, both at the WHT as at other telescopes at the observatory. Within NAOMI a dichroic mirror will block the laser light from going into the science beam. But the situation with other telescopes is more complicated and requires a coordination of laser operation and the pointing of all telescopes that might be affected in order to avoid that some telescope will inadvertedly cross the laser beam. Much experience with this problem has been obtained at Mauna Kea observatory where such a laser traffic control system has been put into operation. A similar system will be put into operation at La Palma. The system will collect pointing information and inform all telescopes whether or not there is a risk of crossing the laser beam. If necessary the laser beam will automatically be intercepted.

Performance Expectations

In preparation for this project, various performance predictions were carried out by Richard Wilson at Durham University. As the main scientific niche for AO at the WHT rests with the visible light OASIS integral-field spectrograph the focus is on achieving moderate but significant improvements of image quality down to 0.6 nm. It is unrealistic with current technology to aim for high Strehl ratios at these wavelengths. But as the calculations below show, image FWHM will improve very significantly at short wavelengths and performance in the near IR is even better.

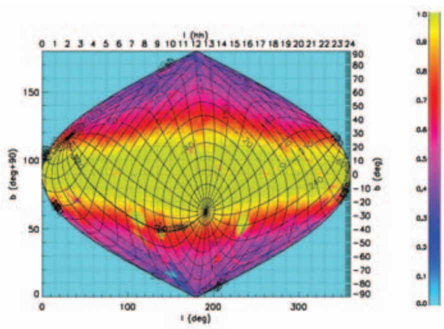

Figure 3. Representation of the sky coverage for finding a star brighter than R=18 within a search diameter of 1.5 arcminutes (courtesy Dr Remko Stuik, Leiden University).

The model calculations were designed to deliver realistic figures for the expected improvement of image quality as a function of seeing, wavelength, natural guide star brightness, and distance of the natural guide star to the science object. A typical profile of atmospheric turbulence strength with height was assumed. The following table shows a few of the model results. The model calculations indicate very attractive improvements in image quality when NAOMI will be used with a laser beacon. But of course above all, the laser enhancement will provide such performance for nearly any point in the sky, thus opening up the exploitation of AO to surveys of large number of targets.

	R-band FWHM (")	H-band FWHM (")
Faint tip-tilt star on-axis		
Typical seeing (0.74")	0.28	0.14
Good seeing (0.54")	0.17	0.12
Faint tip-tilt star at 60 arcsec		
Typical seeing (0.74")	0.32	0.17
Good seeing (0.54")	0.21	0.15

Scientific Invitation

The GLAS project will open up a new exciting area of astronomical exploitation for the William Herschel Telescope. There is much work ahead, and much to learn on how to optimally use the future new facility. Moreover, an added attraction of the laser system is that it can serve as a testbed for concepts of future laser systems at much larger telescopes.

Progress on this project will be reported in future articles in this Newsletter. If you are excited about the prospects as we are, and interested in working with us to define detailed scientific plans, don't hesitate to contact us. ¤

René Rutten (rgmr@ing.iac.es)

Cute-SCIDAR: An Automatically Controlled SCIDAR Instrument for the Jacobus Kapteyn Telescope

J. J. Fuensalida[1], B. García-Lorenzo[1], J. M. Delgado[1], C. Hoegemann[1], M. Verde[1], M. Reyes[1] and J. Vernin[2]

1: Instituto de Astrofísica de Canarias; 2: Laboratoire Universitaire d'Astrophysique de Nice

In February 2004 the Cute-SCIDAR instrument was installed at the 1m Jacobus Kapteyn telescope (JKT) for a systematic monitoring of the atmospheric turbulence at the Observatorio del Roque de los Muchachos (ORM). The proper knowledge of the atmospheric turbulence structure is crucial for optimising the efficiency of adaptive optics systems. SCIDAR has proved to be the most contrasted and efficient technique from ground level to obtain the optical vertical structure of the atmospheric turbulence. The classical (Vernin & Roddier, 1973; Rocca, Roddier & Vernin, 1974) and generalised SCIDAR (see e.g. Klueckers et al., 1998; Ávila, Vernin & Masciadri, 1997; Fuchs, Tallon & Vernin, 1994) techniques analyse the scintillation patterns produced at the telescope