PIGS on Sky – Dream or Reality?

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ABSTRACT

Since several problems of Laser Guide Stars, like conical anisoplanatism, perspective elongation, etc., scales with the telescope diameter, the use of artificial stars will become more difficult with apertures in the range of ELTs. Problems with Laser Guide Stars are reviewed and a way is shown how to overcome most of these difficulties with the concept of Pseudo Infinity Guide Stars (PIGS). A new kind of wavefront sensor is introduced taking advantage of the concept by the means of two optical devices, a reflecting rod and a mask. We explain this novel wavefront sensor, show results of a laboratory experiment, and conclude in further steps to apply the concept with full MCAO capability.

Keywords: Adaptive Optics, Laser Guide Star, wave front sensor,

1. INTRODUCTION

Ground based Extremely Large Telescopes (ELT) (Le Louarn, 2000; Gilmozzi R., 1998) with aperture diameters of up to 100m will deploy their full capabilities only with the help of Adaptive Optics (AO) (Beckers, 1993). Current AO systems are mainly limited due to the low sky coverage with Natural Guide Stars (NGS). A possible way to solve this problem is to generate an artificial guide star in the atmosphere by the means of a laser. However, the use of such Laser Guide Stars (LGS) (Foy and Labeyrie, 1985) has some difficulties:

Perspective elongation: A LGS has a non negligible length. Therefore looking further away from the launch axis the projection of the LGS elongates more and more in radial direction. I.e. for a Sodium LGS fired in the center of a 100m telescope the elongation can become as large as 10" because of the thickness of the mesospheric sodium layer, which is around 10km (Beckers, 1992).

Defocus: The small focal depth of the WFS relative to the length of the LGS leads to a defocus of the sensed image.

Temporal gating: Short laser pulses to overcome the problem of defocus will have strong constraints on the pulse length and format.

Absolute tilt: LGSs provide no information of absolute tilt. Therefore a NGS is still necessary (Pilkington, 1987, Rigaut et all, 1992).

Huge conical anisoplanatism: The LGS builds due to its finite distance a cone of light through the atmosphere instead of a full cylinder, as for NGSs. The opening angle of this cone is proportional to the diameter of the telescope and defines what part of the atmosphere can be sensed and corrected. With larger angles as for ELTs this relation leads to a larger conical anisoplanatism.

Most of these problems are related to the finite distance of the LGS. Therefore one favors a LGS which is created as far away as possible from the telescope. But even Sodium LGSs which originate in the mesospheric sodium layer at about 100km will not solve the problems for ELTs. A possible approach to overcome the problems could be to treat the light of a LGS as if coming from infinity. This leads to the concept of Pseudo Infinity Guide Stars (PIGS).

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2. LAYOUT OF THE PIGS WAVEFRONT SENSOR

Fig. 1 shows a suitable setup for PIGS-WFS. The sensor consists of two independently working sensing devices, a mask with circular slits and a reflective rod. The radial symmetry of the sensing devices favors the use of polar coordinates instead of Cartesian. The rod is placed in the focus of the LGS and senses the azimuthal perturbations, while the mask is located in the focal plane (f1) and measures the radial aberrations. The sensor is a pupil plane sensor and measures the second derivative of the incoming wavefront similar to a curvature wavefront sensor. The lens between the sensing devices creates a telecentric exit pupil as seen from the rod and the last lens in the setup is just for re-imaging the pupil on the CCD detector.

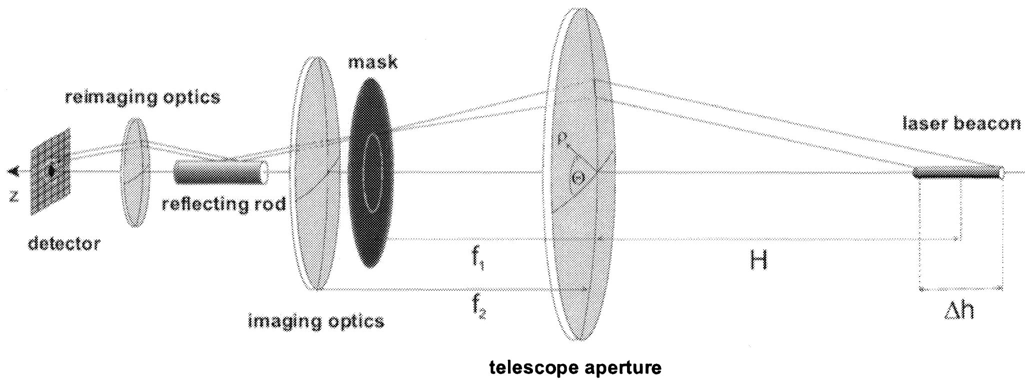

Fig 1: Conceptual design drawing of a PIGS sensor with a reflecting rod and a mask with annular slits as sensing devices. A LGS at the height H with length Δh is illuminating the telescope aperture. Light from a certain angle of the LGS is selected with a mask in the focal plane (f1). A further lens (at f2) creates a telecentric beam for the reflective rod which is placed in the LGS focus. The last lens is re-imaging the pupil on the CCD detector.

2.1 THE RADIAL SENSING DEVICE

Collimated light beams from infinity with a certain angle to the optical axes are focussed in one point in the focal plane of the telescope, e.g. the light of stars. A LGS is extended in the focal plane of the telescope because of its finite distance. A mask in the focal plane with an annular slit will select light from the LGS coming from a certain direction radial symmetric to the optical axis (see Fig.2). Hence the light origin at the LGS seems to be from infinity (pseudo infinity guide star). By using several concentric annular slits different angles are selected and more light of the LGS is used (angular gating). Although the mask is blocking a certain amount of photons, at least more light is reaching the detector compared with conventional temporal gating for a Shack-Hartman sensor. In fact up to 10 times more photons can be utilized with angular gating than with temporal gating. Any wavefront distortion in radial direction changes the amount of light falling into a slit as can be seen in Fig. 3. Perturbations in azimuthal direction will not change the amount of light passing the slit. The mask with annular slits is only sensitive to radial wavefront distortions.

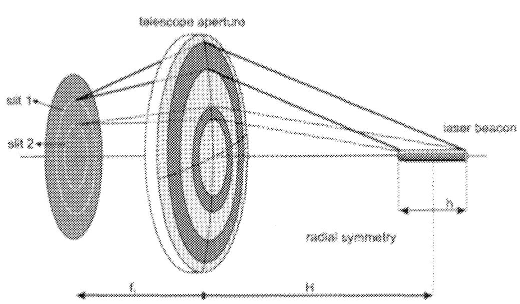

Fig 2: A mask with circular slits is able to select light with a certain angle radial symmetric to the optical axis.

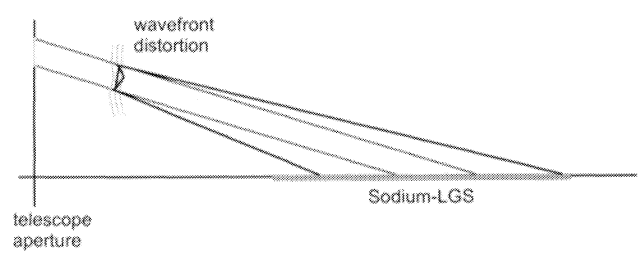

Fig 3: Depending on the wave front distortion (here approximated with roof like shape) more or less light of the LGS is refracted into the sub-aperture. The sensitivity of the WFS depends strongly on the ratio H/D^2.

2.2 THE AZIMUTHAL SENSING DEVICE

In order to sense the incident wavefront in azimuthal directions, we use a reflecting rod. The concept of such a z-invariant WFS was already presented in Ragazzoni et al. (2001). The principle of the WFS is shown in Fig. 4. The rod placed in the LGS focus reflects a ray without aberration into the same direction while a distorted ray will change its direction with a certain angle. The rod amplifies azimuthal perturbations and changes therefore the intensities in sub-apertures in the re-imaged pupil. The minimal dimension of a sub-aperture is defined by the rod diameter. We also want to mention, that the rod transforms due to the reflection any spot of a finite size into an arc, which implies some contraints for the realisation of such a sensor. The length of the arc is depending on the curvature of the rod and depends on the chosen rod radius. As for the mask perspective elongation does not matter with the rod. Any slice of the rod can be conjugated to an altitude and only the length of the rod has to be chosen such that it covers the full range of the LGS to be used.

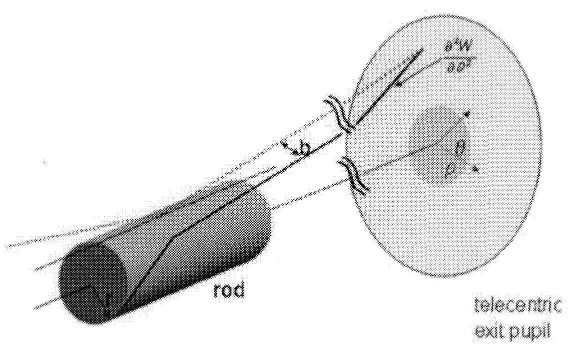

Fig 4: The rod simply reflects a ray without aberration while a ray with aberration is shifted by an amount b and gets deflected.

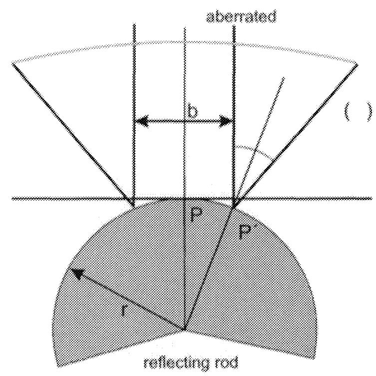

Fig 5: A spot of the size b reflected by the rod will be transformed into an arc. The angle of the arc is a function of the radius r of the rod.

3. LAB EXPERIMENTS AND FIRST RESULTS

An experimental setup of a PIGS sensor was built up in the laboratory and first measurements were done. The lab setup is shown in Fig. 8. Since the sensitivity of the mask scales with H/D^2 it was only feasible to test the rod concept. Scaling down a Sodium LGS and a 100m telescope of a factor 1000 would imply a setup of 100m length with an entrance pupil of 0.1m. Our setup is about 1m long and the entrance pupil has a diameter of 0.1m. Hence we tested the mask qualitatively and did the quantitative measurements only with the rod. In order to simulate the atmospheric perturbations we used simple window glass (Fig. 7). The aberrations of the glass were measured with an interferometer and were showing more low order aberrations than high order, close to a Kolmogorow distribution.

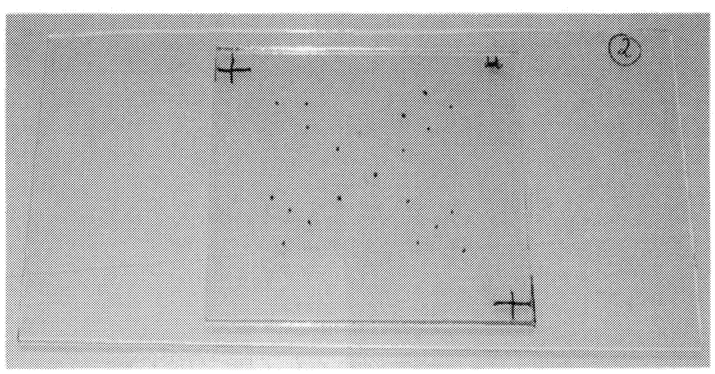

Fig. 7: Phase screens used in the lab experiment. The glass placed upon the Phasescreen includes fiducial marks.

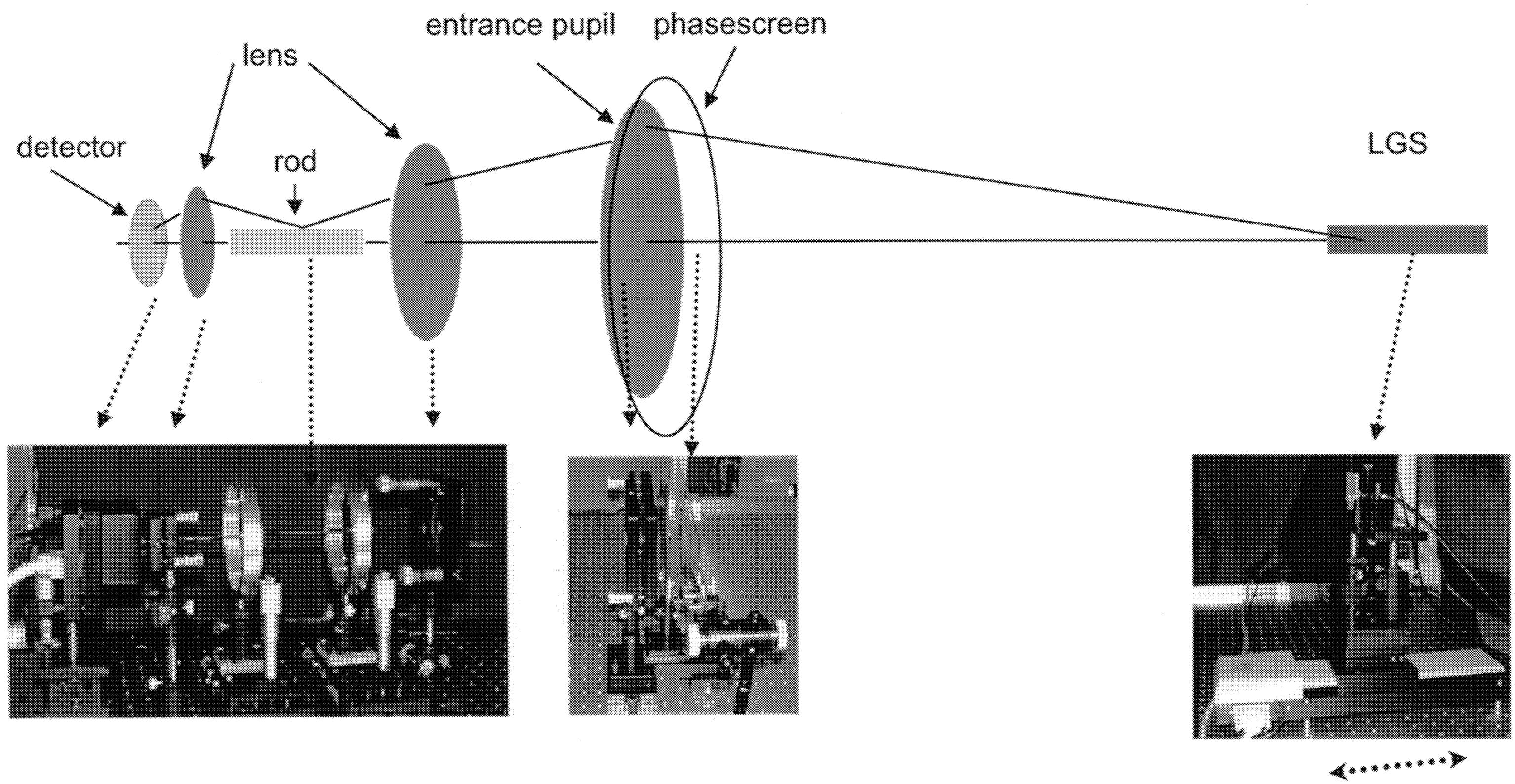

Fig 8: Lab setup of the first PIGS lab experiment. Since it is not feasible to realise in the lab a 1:1000 downscaled (see text) version of the real conditions on sky, we could test the mask sensing device only qualitatively and removed it for the measurements. The LGS was simulated by a light source which was mounted on a motorized linear stage, which was moving during the exposure. As phasescreens we used simple window glass. Interferometric measurements showed, that their power spectrum was close to a Kolmogorov distribution.

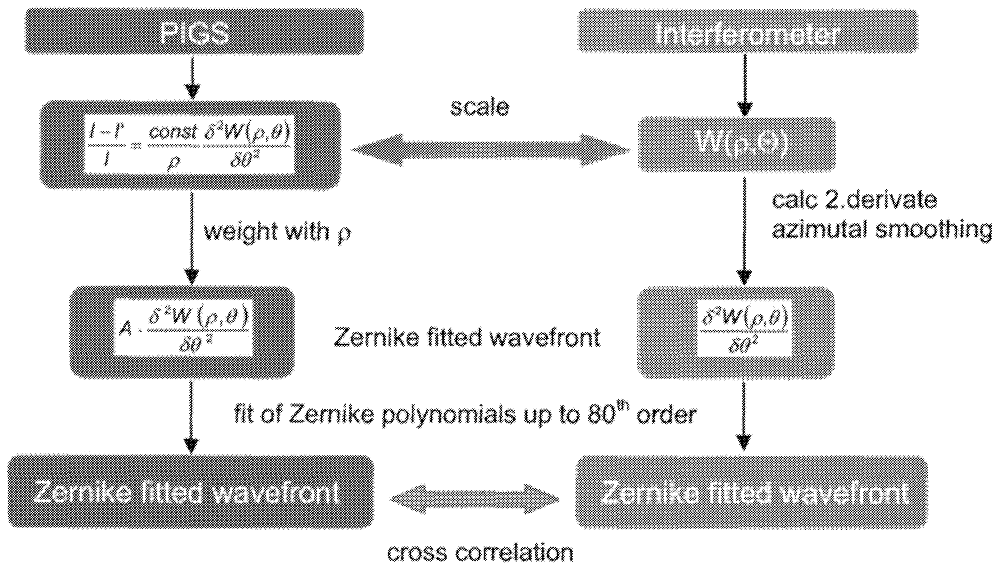

Fig. 9: Data flow of reduction process.

Since the images of the PIGS sensor and the interferometer measurements have different sizes the images have to be scaled to each other. Therefore we used fiducial marks on a screen we put on top of the other. After scaling the images the PIGS data has to be weighted with a radial factor and as the interferometer delivers the direct wavefront the second derivative was calculated. On this data set we fitted Zernike polynomials up to the 80^{th} order and cross correlated them with each other (see Fig. 9). This was done with three different phase screens. Although the results were clearly limited by the low surface quality of the reflecting rod a cross correlation of 85%, 78% and 75% could be obtained. Since the lab setup was only using the azimuthal sensing component the pure radial orders of the Zernike polynomials should be removed. This was not done yet. We expect a higher cross correlation after removing the radial orders.

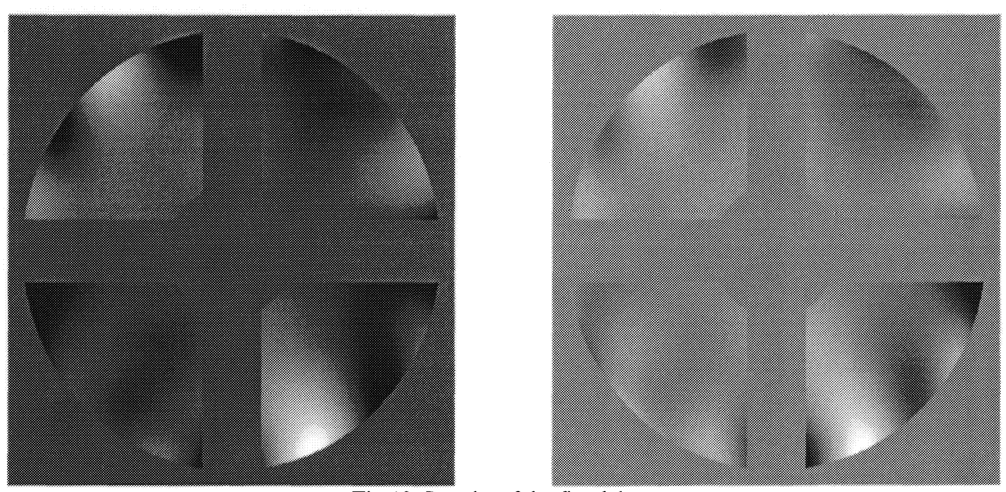

Fig 10: Results of the first lab test.

4. APPLICATION TO MCAO

The problem of conical anisoplanatism can only be overcome in a Multi-conjugated Adaptive Optics (MCAO) (Beckers J., 1988; Ellerbroek, 1994) setup . A possible arrangement with the new sensor we explained before is depicted in Fig. 11. Multiple sodium LGS will be sensed by different mask and rod arrays. The detectors will be placed conjugated to altitude in the layer oriented fashion (shown in Fig. 6) while each LGS is sensed separately in the star oriented.

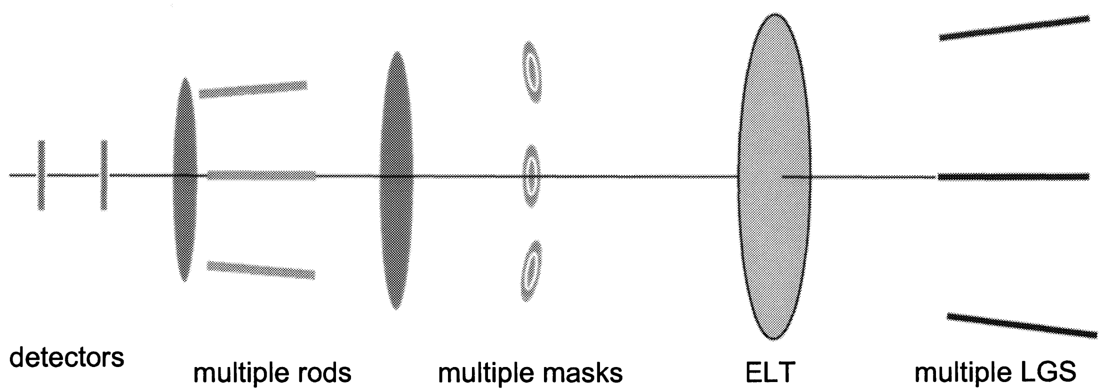

Fig 11: Sketch of a possible MCAO setup with the PIGS wavefront sensor. From right to left.

5. CONCLUSION

We have shown a new kind of wavefront sensor using LGS with the concept of Pseudo Infinity Guide Stars. An experiment with a part of the WFS was set up in the laboratory and first results obtained. The data correlates very well with independent measurements. The PIGS sensor can overcome several problems known with LGSs and conventional sensing methods and can easily be extended to a MCAO system. Since MCAO and LGSs will play a big role to deploy the full capabilities of ELTs the PIGS-WFS is an interesting option.

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