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MAKING ADAPTIVE OPTICS AVAILABLE TO ALL: A CONCEPT FOR 1M-CLASS TELESCOPES.

O. Lai¹, S. Kuiper², N. Doelman^{2,3}, M. Chun⁴, D. Schmidt⁵, F. Martinache¹, M. Carbillet¹, M. N'Diaye¹ and J.-P. Rivet¹

Abstract. Adaptive optics is challenging for smaller telescopes (0.5~2m) due to the small isoplanatic angle, small subapertures and high correction speeds needed at visible wavelengths, requiring bright stars for guiding and thus severely limiting the sky coverage. To enable large sky coverage we can correct the turbulence which is common to the entire field we are trying to capture, which is achieved by the technique of GLAO (Ground Layer Adaptive Optics). The turbulence is measured by averaging wavefront measurements in multiple directions. The corrective element can either be a deformable lens or a small adaptive secondary mirror. The motivation to develop such a compact and robust AO system for small telescopes is two-fold: On the one hand, schools and universities often have access to small telescopes as part of their education programs. Also researchers in countries with fewer resources could also benefit from well engineered and reliable adaptive optics on smaller telescopes for research and education purposes. On the other hand, amateur astronomers and enthusiasts might want improved image quality for visual observation and astrophotography.

Keywords: adaptive optics, wide field imaging, GLAO

1 Introduction

Adaptive optics is a technique which is now mature for large telescopes but a number of challenges have hindered our ability to apply this technology for general use, especially for amateur telescopes and astrophotography. Atmospheric phase disturbances increase with decreasing wavelength, and most amateur astronomers are more interested in visible wavelengths (e.g. most nebulae have their strongest emission lines in that part of the spectrum, commercially available large format CCD or CMOS cameras are sensitive at those wavelengths) but adaptive optics in the visible is challenging. In particular for 1-2 m class telescopes, SCAO (single conjugate adaptive optics with only one reference source) imposes severe limitations for sky coverage:

Due to the small physical size of the subapertures on the primary mirror and the high frame rate, the limiting magnitude is bound to be small (around 5~8, depending on the telescope diameter and the order of the system).

Because the isoplanatic field is very small in the optical domain, the quality of the correction will rapidly decrease further away from the guide star.

Therefore the parts of the sky where adequate correction is possible is limited to tens of arcseconds around some thousands of bright stars or planets. To enable large sky coverage we first recognize that we cannot correct the entire volume of turbulence above the telescope or in a direction where there is no source to illuminate the wavefront perturbation we are trying to correct. The next best thing we can do is to correct the turbulence which is common to the entire field we are trying to capture. This is achieved by the technique of GLAO (Ground Layer Adaptive Optics), whereby a deformable mirror, conjugated to the telescope pupil is used to correct only the ground layer turbulence. This is obtained by averaging wavefront measurements in multiple directions. The corrected wavefront will be limited by the residuals of the free atmosphere turbulence, so resulting images will in general not be diffraction limited but will show a substantial improvement in FWHM.

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2 Motivation to develop AO on 1-2 m class telescopes

The concept we propose opens whole new fields of applications on smaller telescopes and potentially makes adaptive optics accessible to whole new communities: On the one hand, schools and universities often have access to small telescopes as part of their education programs. Furthermore researchers in countries with fewer resources would also benefit from well engineered and robust adaptive optics on smaller telescopes, by improving their performance and exposure to advanced optics. On the other hand, amateur astronomers and enthusiasts would be enthusiastic for improved image quality for visual observation and astrophotography. Implementing readily accessible adaptive optics in astronomy clubs would also likely have a significant impact on citizen science.

2.1 VFWFS: Very Wide Field WaveFront Sensor concept

Every single source in the field contributes to measurement at pupil. Wide fields are required to gather more light and homogenise the flux (as the optical averaging is done on the wavefront sensor and is flux weighted).

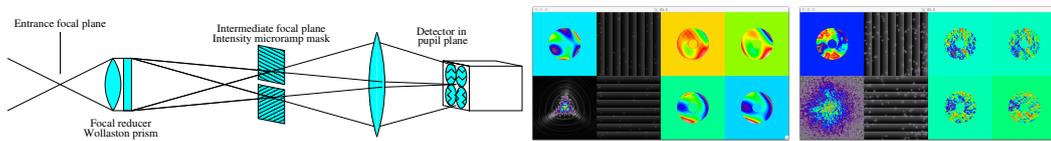


Fig. 1. Left: schematic concept of the VFWFS, with a mask in the focal plane, introducing an optical differentiation operation, and measurement in the pupil plane. **Middle & Right:** example of reconstructed wavefront derivatives for low order aberrations and a turbulent wavefront respectively.

2.2 Expected performance

End to end Monte Carlo simulations using realistic star field (Besancon Model) with more than 400 sources show a gain of ~ 2 in FWHM and Strehl.

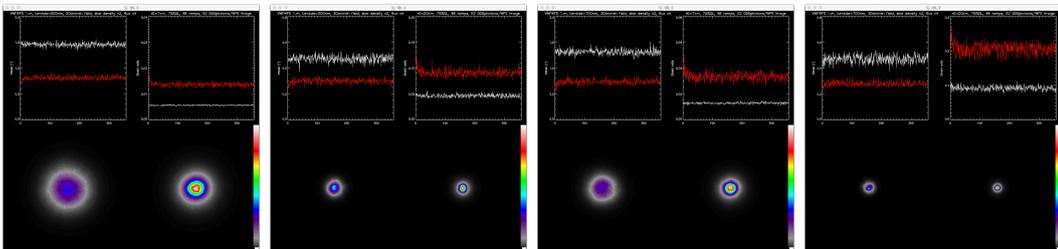


Fig. 2. Strehl and FWHM, White, no correction; red, correction; from left to right: $\lambda = 500\text{nm}$, $r_0 = 7\text{cm}$ and $r_0 = 20\text{cm}$; $\lambda = 700\text{nm}$, $r_0 = 7\text{cm}$, $r_0 = 20\text{cm}$. In all cases the wavefront sensor has 11×11 subapertures, collecting 2×10^5 photons per integration (at 500Hz) over a $30'$ field of view. Lower row shows corrected and uncorrected PSFs on same scale.

3 Conclusions and future work

Adaptive secondary mirrors are becoming available for smaller telescopes using a new actuator technology developed by TNO. A lab demonstrator is currently being planned and telescope tests are being considered for the C2PU 1m telescope and the UH-2.2m imaka AO system. Simulations show that good sky coverage is possible with a $30'$ field on a 1m telescope, but large fields require large optics and the optimal field size depends on the telescope size and the application. For a 1m class telescope aimed at astrophotography, 100% sky coverage may not be necessary, since many interesting fields and nebulae can be found near the galactic plane with high star densities. Commercially available large format detectors for amateur telescopes (e.g. ZWO ASI6200MM, based on Sony IMX455 CMOS with 9576×6388 pixels of $3.76\mu\text{m}$ retails for \$4000) cover fields of 10×10 arcminutes with 0.1 pixels; thus for such a system, a 10 arcminute field of view for the wavefront sensor may be more than adequate and only needs a small number of pixels (40×40) read out at 500Hz.