VWFWFS: VERY WIDE FIELD WAVEFRONT SENSOR

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

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Abstract:

Adaptive optics is an advanced technique developed for large telescopes using custom designs and state of the art components. It turns out to be challenging for smaller telescopes (0.5~2m) due to the small isoplanatic angle, small subperatures and high correction speeds needed at visible wavelengths, requiring bright stars for guiding and thus severely limiting the sky coverage. Traditional AO on 1m-class telescopes may be ideal for planetary objects but remains limited for general purpose observing.

To enable large sky coverage we recognize that we cannot correct the turbulence in a direction where there is no source to illuminate the wavefront perturbation. The next best thing we can do is to 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 in a new type of wavefront sensor, which uses all the available light in the field. The corrective element can either be a deformable lens or a small adaptive secondary mirror, which are now becoming available. In GLAO mode, the resulting images will in general not be diffraction limited but will show a substantial improvement in FWHM. However, improving the resolution over wide fields can yield spectacular results in astrophotography.

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. Implementing readily accessible adaptive optics in astronomy clubs would also likely have a significant impact on citizen science.

Context:

Adaptive optics is a technique which has been developed for large telescopes using state of the art components (custom optics, deformable mirrors, high performance computers). A number of challenges have hindered our ability to apply this technology to smaller telescopes and for general use, especially for amateur telescopes and astrophotography. One of the challenges is that the atmospheric phase disturbances increase with decreasing wavelength, and most amateur astronomers are more interested in visible wavelengths (e.g. most nebulas 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, traditional AO (SCAO: single conjugate adaptive optics) imposes severe limitations for sky coverage:

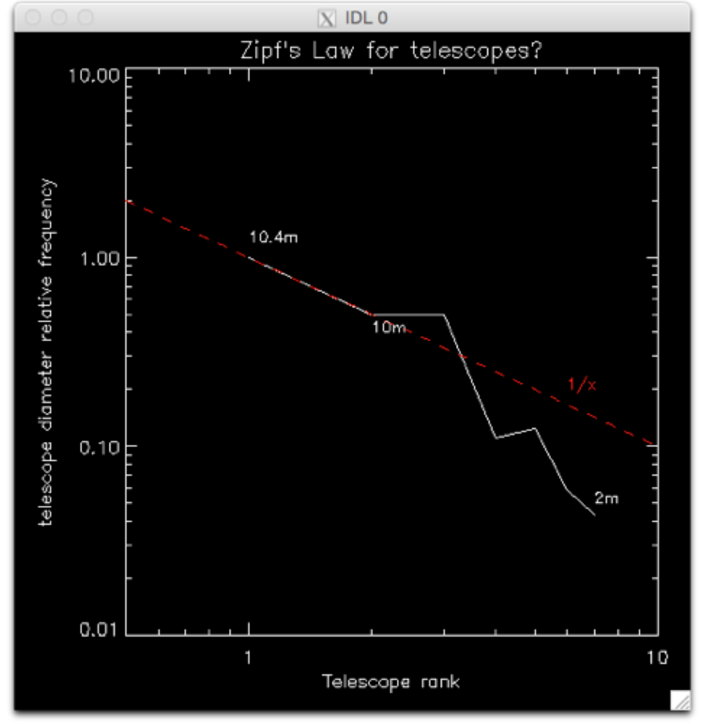
- Due to the small physical size of the subapertures on the primary mirror and the high frame rate, the limiting magnitude is bound to be small (around 5~8, depending on the telescope diameter and the order of the system).
- Because the isoplanatic field is very small in the optical domain, the quality 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.

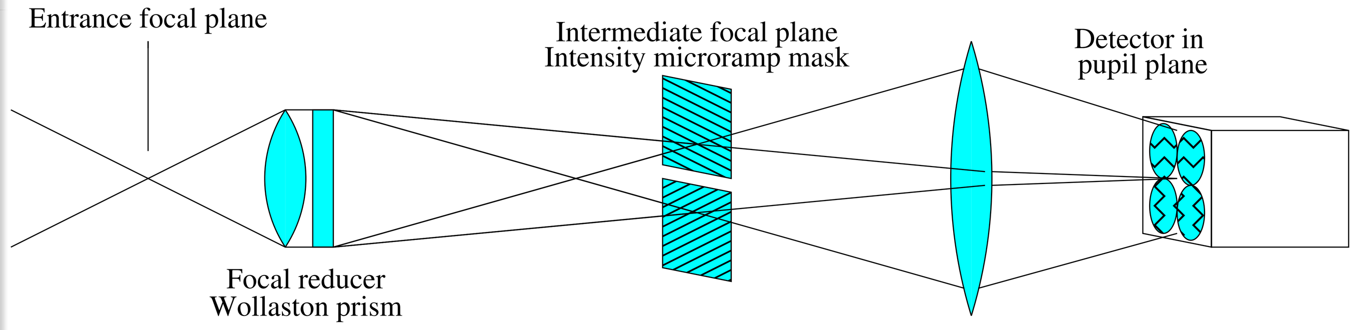
NGS SCAO is ideal for planetary objects but remains limited for general purpose observing. To enable large sky coverage we first recognize that we cannot correct the entire volume of turbulence above the telescope or in a direction where there is no source to illuminate the wavefront perturbation we 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. This will depend on the vertical turbulence profile and will be site-specific, but unless there are shears in the high atmosphere (e.g. jet stream), most sites have strong boundary layers.

Motivation to develop AO on 1-2 m class telescopes

The concept we propose opens whole new fields of applications on smaller telescopes. This potentially makes adaptive optics accessible to whole new communities, especially considering that there are many more telescopes in the 1-2m class than in the 8-10 m class (Zipf's law indicates that the rank is inversely proportional to the frequency, and this applies to telescopes! See Figure 1):

- 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.

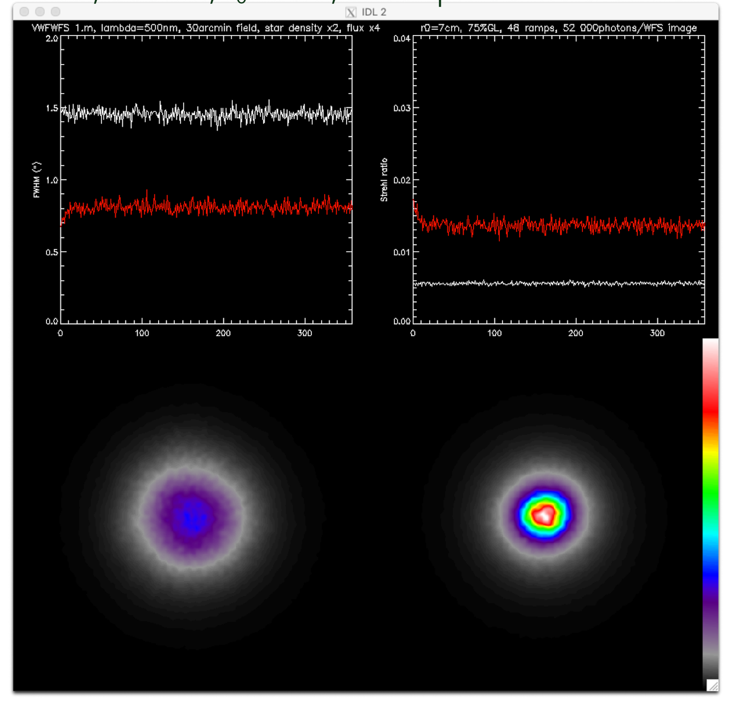




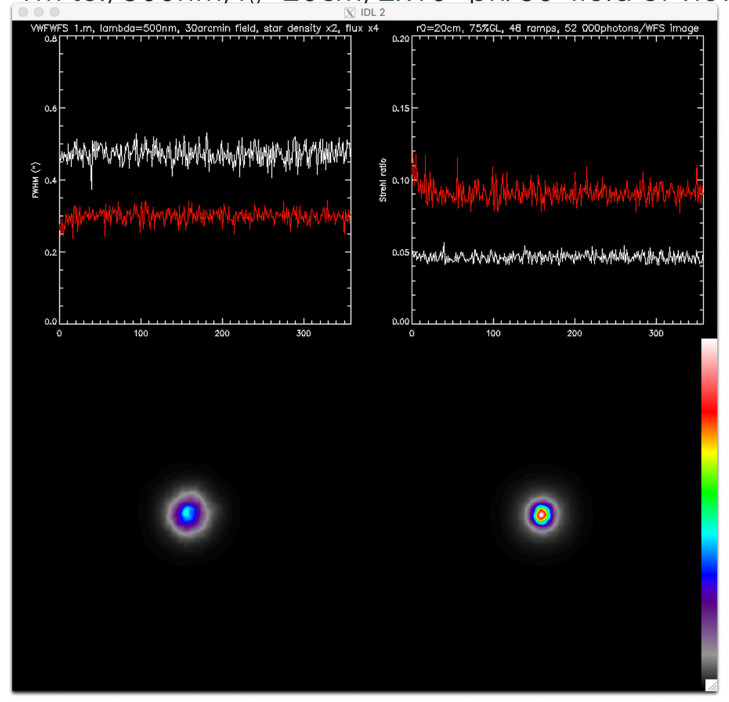
Wavefront Sensor concept: VWFWFS

Using every single source in the field to contribute to pupil images. Wide fields required to gather more light and homogenise flux (optical averaging is done on the wavefront sensor and is flux weighted).

Expected performance: End to end Monte Carlo simulations using realistic star field (Besancon Model) with more than 400 sources show gain of ~2 in FWHM and Strehl. Results below: White, no correction; red, correction with 11x11 DM. PSFs shown on same scale.



1m tel, 500nm, r_0=7cm, 2x10^5 ph/30' field of view



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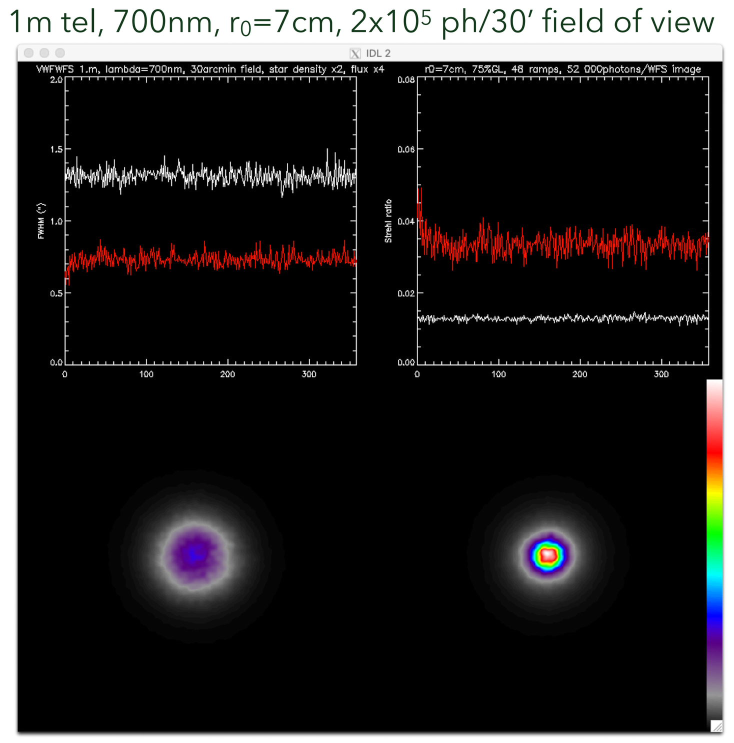
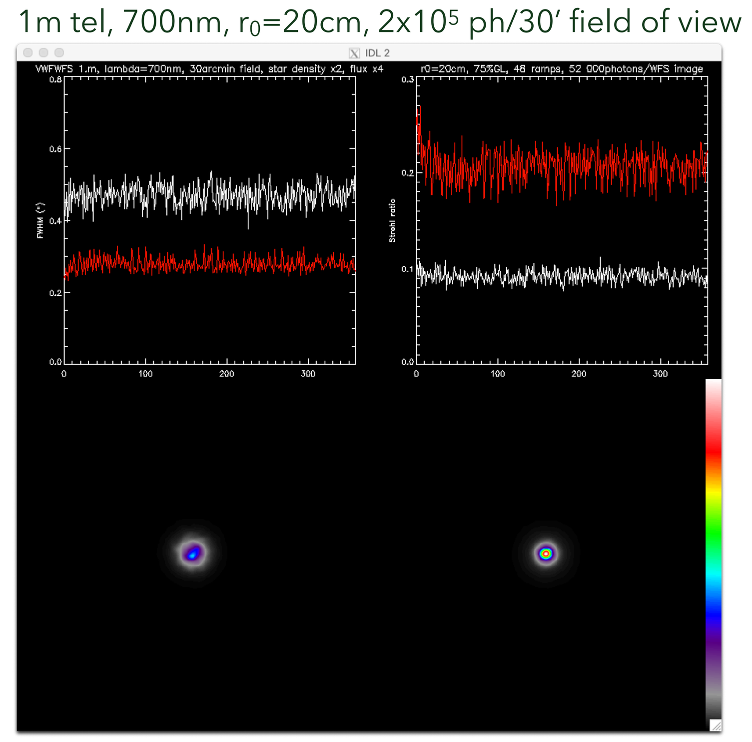
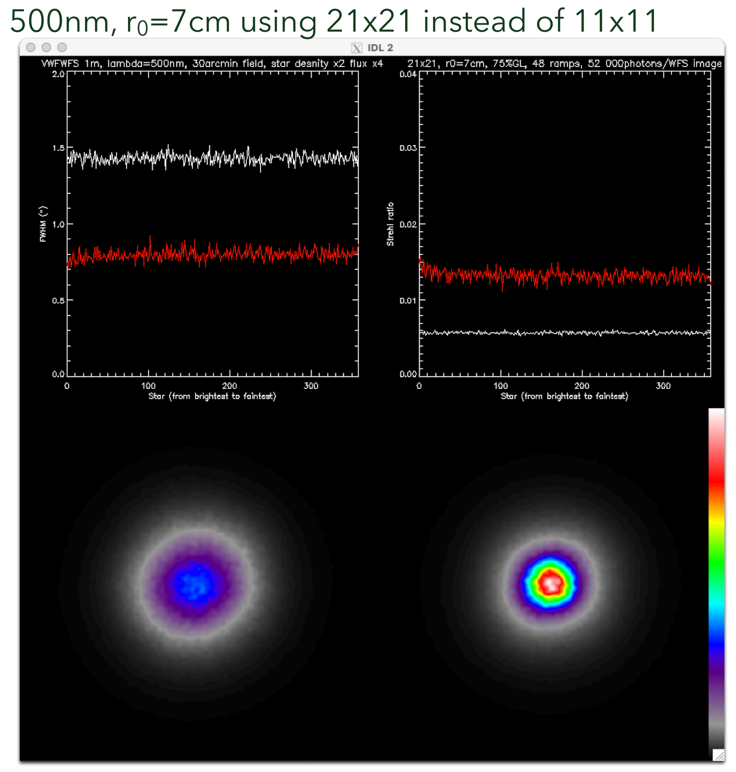


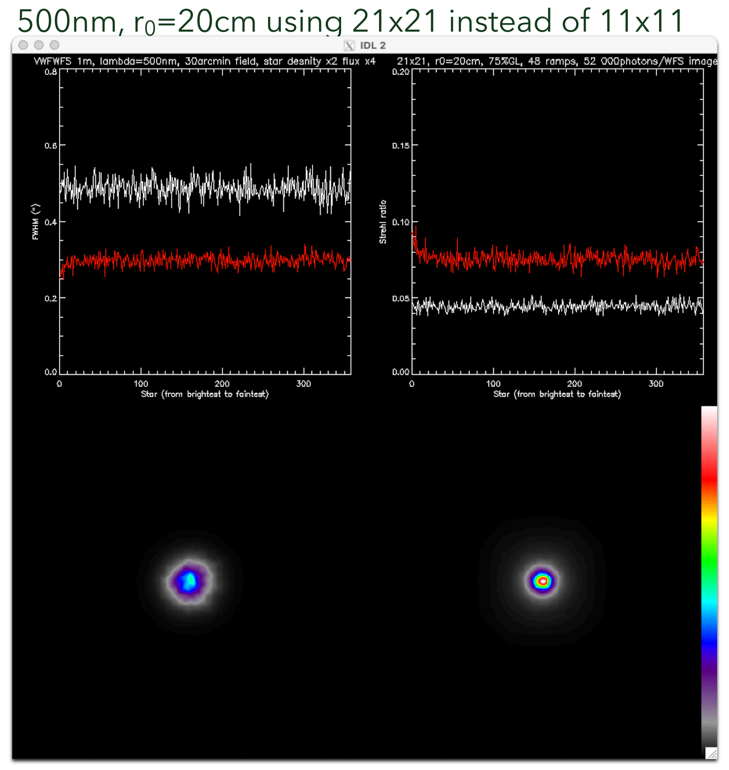
1m tel, 700nm, r_0=7cm, 2x10^5 ph/30' field of view



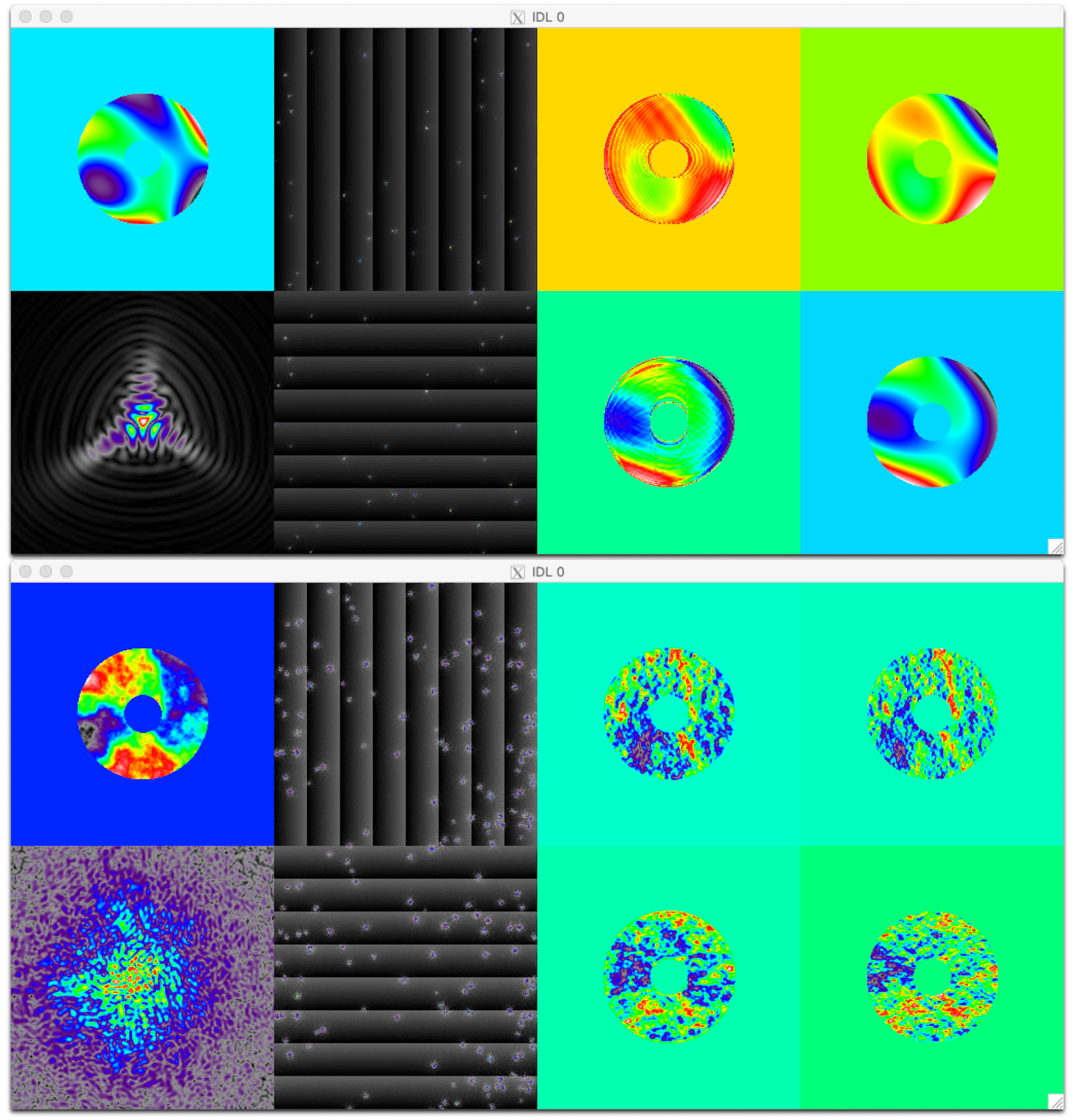
1m tel, 700nm, r_0=20cm, 2x10^5 ph/30' field of view



500nm, r_0=7cm using 21x21 instead of 11x11



500nm, r_0=20cm using 21x21 instead of 11x11



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 9576x6388 pixels of 3.76μm retails for $4000) cover fields of 10x10 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.