MAD Science Demonstration Proposal

Testing the Astrometric and Photometric Accuracy of MCAO Data

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Abstract:

One of the key science requirements for multi-conjugate adaptive optics systems is to enable accurate and repeatable astrometric and photometric measurements to be made across a wide field of view. While simulations suggest this should in principle be possible, there is no on-sky data to test what can actually be done. This is a crucial question, since much of the science planned for the ELT is designed to make use of these capabilities. This proposal is designed to address exactly this issue by observing an asterism several times in order to directly determine the repeatability of the photometry and astrometry across a 1 arcmin field of view. We will compare our derived uncertainties – both as a function of stellar magnitude and position in the field – to those estimated using techniques based on noise statistics in the images.

Scientific Case:

Reliable astrometry and photometry are essential ingredients for a wide range of astrophysical studies. In many situations these quantities must be measured in crowded fields, where the density of stars is a hindrance. As a result, adaptive optics is used to improve the spatial resolution (and sensitivity). Perhaps the two best known examples – among many – where this has been done are the star cluster NGC 3603 (Brandner et al. 2002) and the Galactic Center (e.g. Schoedel et al. 2003). Specifically, in the Galactic Center, the astrometric accuracy of less than a few milliarcsec has made it possible to track a complete orbit of the star S2, and suggests it is feasible to look for precession resulting from the extended mass distribution of the stellar cluster.

However, spatial and temporal variations in the atmospheric turbulence impose strong constraints on what can be achieved using single-conjugate AO. Adaptive optics correction is normally partial, so that a significant fraction (which can vary between observations) of the flux is in a large halo rather than the core. This becomes critical when measuring the variability of sources, since it influences aperture photometry measurements. In addition the PSF degrades across the field. In particular the 'breathing' effect leads, at large off-axis distances, to motion of short-exposure PSFs and elongation of long-exposure PSFs. This has created some doubts about the validity of off-axis astrometry with adaptive optics data. Despite the considerable effort to model and measure the PSF variations (e.g. Britton 2006, Steinbring 2002, Cresci 2005), the sensitivity of the data is still strongly dependent on position in the field, as are the uncertainies in photometry and astrometry. This severely impacts interpretation of the data.

Simulations, and now the first MAD results, indicate that multi-conjugate adaptive optics removes most of the spatial dependencies. As a direct result of this, it easier to derive the PSF (even in crowded fields, Sheehy et al. 2006) and hence account for variations between observations at different epochs. However, there have been not yet been any measurements to determine to what accuracy and repeatability it is possible to perform photometry and astrometry for MCAO data. This is an important issue because it is planned that the ELT should make frequent use of adaptive optics, and have a dedicated MCAO camera. This proposal is therefore designed to directly measure the accuracy and repeatability of these two key issues for MCAO.

We have selected an asterism (from the 'Regular Bright' list) which will give a good AO correction and contain a large number of stars without being excessively crowded. We propose to observe it at 5 different times. The AO performance, which depends critically on atmospheric conditions, will be different for each observation. By comparing the flux and position of each star for each observation, we will be able to derive the true reliability of these parameters.

Based on the number of stars in the central arcmin of this field detected by 2MASS (10), and using the near infrared faint star counts in other fields (Hutchings et al. 2002), we extrapolate that there should be of order 80 stars to K=18 mag, and many more at fainter magnitudes. This is important, since at least to K=18 our flux and position measurements will not be limited by signal-to-noise, which should exceed 30 at this flux level.

Our immediate aims will then be:

1. In the limit of high signal-to-noise, compare the uncertainies in flux and position which are derived from noise statistics in the image, to those directly measured from the 5 separate observations of the field.

2. In the limit of high signal-to-noise, verify that there is little dependence of astrometrical and photometrical repeatability within the field.

3. determine how steeply the uncertainies increase as the signal-to-noise decreases (i.e. for fainter stars).

These results will provide an important benchmark in assessing realistic expectations and limitations for adaptive optics science cases, particularly for the ELT.

We have the resources and – as users of adaptive optics systems – the motivation to process and analyse the data on a short timescale. We have experience in performing photometry and astrometry on AO data in crowded fields (specifically, the Galactic Center). And one of us (RD) was by chance at Paranal during commissioning of MAD, and assisted in reducing some of the data obtained then.

Targets and integration time

Target	**RA**	**DEC**	**Filter**	**Magnitudes**	**Total integration time** (sec)	**Field** (arcmin)
Ast6915	07 56 48.6	-28 57 03	Ks	K=12.5-18	600	1

Guide stars list and positions

Target: Ast6915			
	$\mathbf{RA}''_{rel}$	$\mathbf{DEC}''_{rel}$	**V Mag**
GS1	+44.5	-5.9	11.3
GS2	-28.9	+39.4	10.5
GS3	+18.6	-39.0	10.1

Time Justification:

To achieve the goals of this proposal we need to detect a large number of stars at sufficient signal-to-noise, in order to determine uncertainties in astrometry and photometry due to the adaptive optics rather than limited signal. In the 2MASS PSC there are 10 objects within a $60'' \times 60''$ box in the field centre to K$\sim$15.5 mag. Extrapolating to fainter magnitudes using the relative number counts in other fields (Hutchings et al. 02), we estimate there should be of order 80 sources to K=18 mag. Based on the sensitivity estimates given for MAD, we should reach a SNR of about 30 for such sources in a 10 min integration.

For each observation, we request the single field mode to cover a 1 arcmin field (since this will provide enough stars, and also avoid including the very bright guide stars in the science exposures). Since the field is expected to contain a large number of sources, dithering may not be sufficient for good sky subtraction. We therefore request observations of a blank sky field to the same depth. Thus, including overheads, we estimate this will take 40mins.

In order to test how reliable the astrometry and photometry is from one observation to the next, we request the the field is observed at 5 duifferent times during the 2 SV runs. Thus the entire proposal will require about 2.5 hours.