Laboratory Demonstration of Real Time Frame Selection with Magellan AO

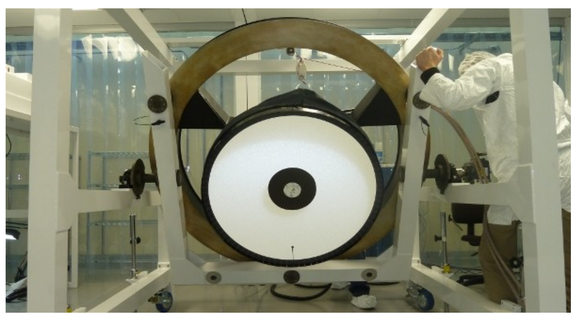
Jared R. Males[1,2], Laird M. Close[2], Derek Kopon[2], Fernando Quiros-Pacheco[3], Armando Riccardi[3], Marco Xompero[3], Alfio Puglisi[3], Victor Gasho[2], Katie M. Morzinski[2], Kate Follete[2], Jason Lewis[2]

[1] Contact: jrmales@email.arizona.edu [2]University of Arizona, Steward Observatory, Tucson, Arizona [3]Istituto Nazionale di Astrofisica, Osservatorio Astrofisico di Arcetri, Firenze, Italy

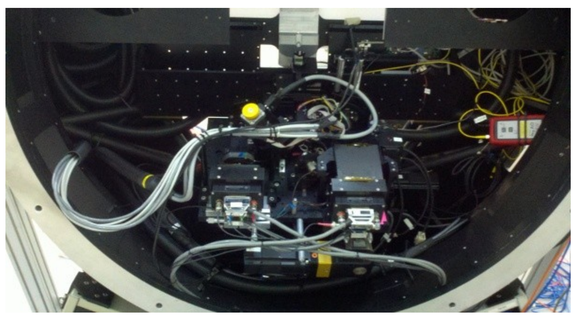
The Magellan AO system combines a pyramid wavefront sensor (WFS) and high-order adaptive secondary mirror (ASM), and will see first light on the Magellan Clay telescope in November 2012. With a 23 cm projected actuator pitch, this powerful system will enable good correction in the optical (0.5 to 1 μm). Realistic laboratory testing has yielded Strehl ratios greater than 40% in i' (0.765 μm) on bright simulated stars. On fainter stars our visible AO camera, VisAO, will work in the partially corrected regime with only short moments of good correction. We have developed a form of lucky imaging, called real time frame selection (RTFS), which uses a fast shutter to block moments of bad correction, and quickly opens the shutter when the correction is good, enabling long integrations on a conventional CCD while maximizing Strehl ratio (SR) and resolution. The decision to open or shut is currently based on reconstructed WFS telemetry. Here we report on our implementation and testing of this technique in the Arcetri test tower in Florence, Italy, where we showed that long exposure i' SR could be improved from 16% to 26% when the selection threshold was set to the best 10% of instantaneous SR.

Follow MagAO at: http://visao.as.arizona.edu

Unpacked: Magellan AO is integrated at LCO, waiting to go on-sky



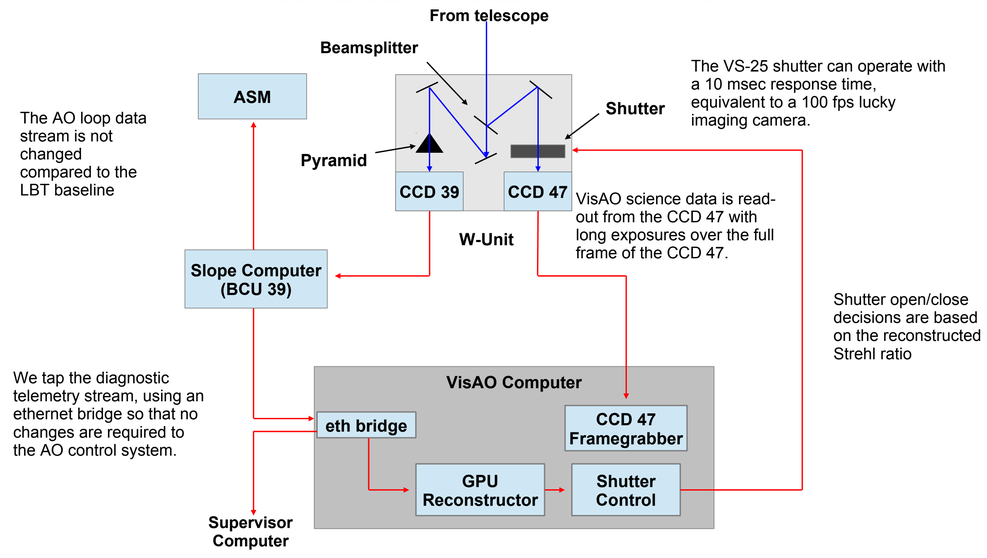
Our 585 element adaptive secondary mirror (ASM) in the cleanroom at LCO.



The W-Unit contains the pyramid wavefront sensor (WFS) and the VisAO science and acquisition camera.

Following nearly a year of testing and a successful pre-ship review in Arcetri, Italy, the Magellan AO system has been shipped to Las Campanas Observatory (LCO), Chile. The system has been fully re-integrated and tested at LCO and is ready to go on-sky in November, 2012.

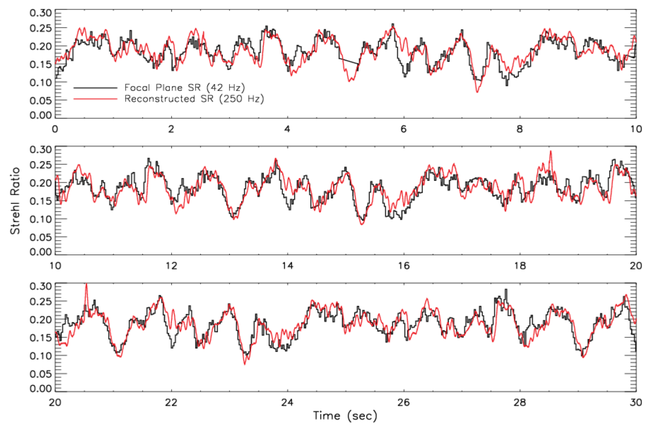
Real Time Frame Selection



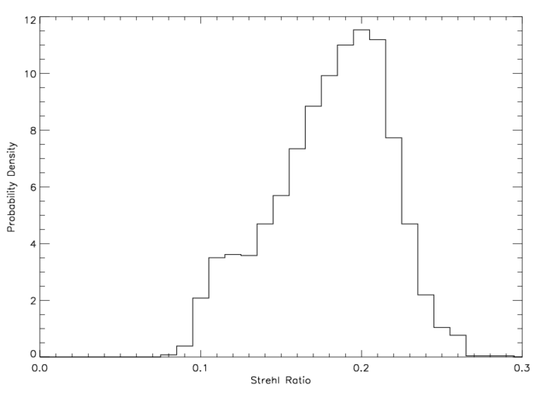
The slope-vector is reconstructed on a GPU, which results in a 34% improvement in speed. MagAO uses modal control, so calculating Strehl ratio (SR) simply requires summing the reconstructed mode amplitudes in quadrature. The modes are normalized with unit variance.

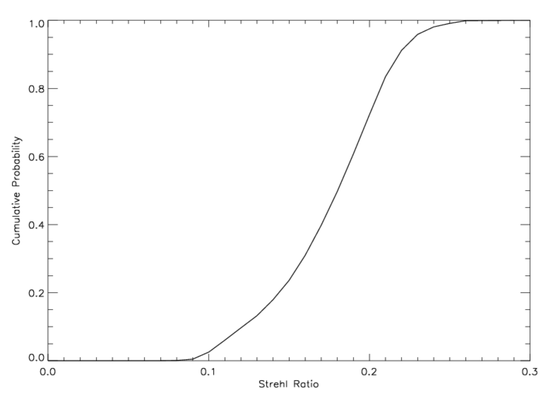
A digital low-pass filter is applied to prevent over-driving the shutter with high-frequency changes in SR.

Laboratory Closed Loop Results

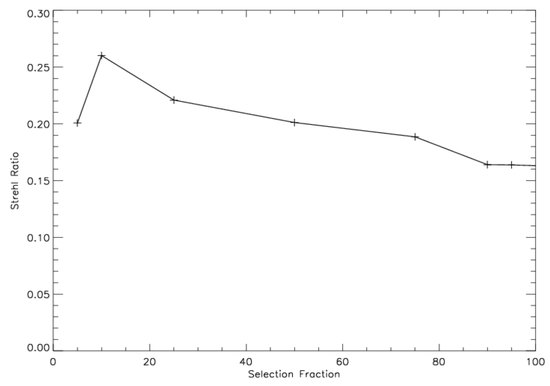


Measured short exposure (42fps) and reconstructed SR. The reconstructed SR is calibrated using the short exposure time series by matching the spread (std. dev.) and mean. The reconstructed SR is also low-pass filtered in real-time to suppress high frequencies which would over-drive the shutter.

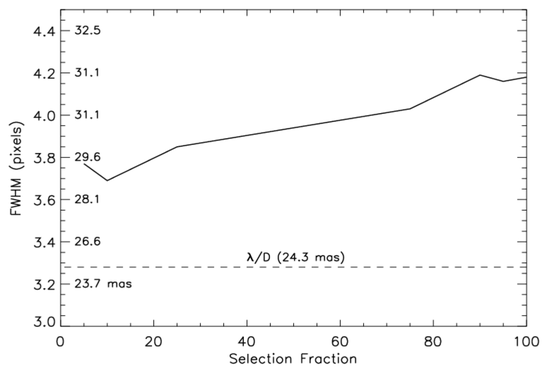




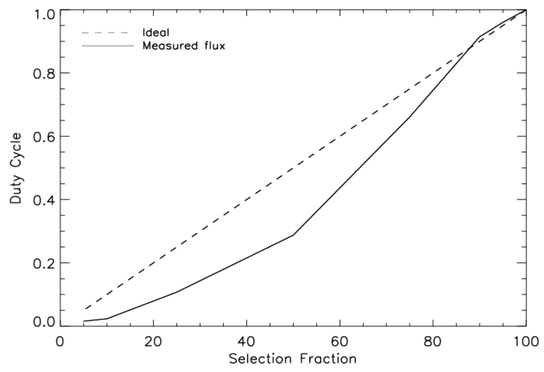
The probability density function and cumulative distribution of the short exposure strehl. For this experiment the loop was intentionally degraded, operating at 500Hz on a 9th mag star with gain set somewhat high to be unstable. This was necessary to generate a time series with enough variablity to test RTFS. Though a laboratory artificiality, simulations and prior work in closed loop AO show that the achieved SR distributions and variability are realistic for fainter stars.



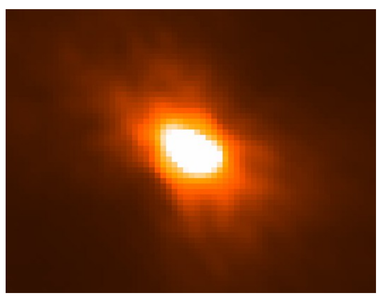
Long exposure SR vs. the selection threshold. A threshold of 50% implies that the system attempts to open the shutter whenever SR was above the median short exposure value. The shutter has a finite actuation time of about 10msec. The drop in achieved SR when only the best 5% was selected is likely due to this actuation delay compared to the narrowness of the corresponding SR peaks in the time series.



FWHM vs the selection threshold.



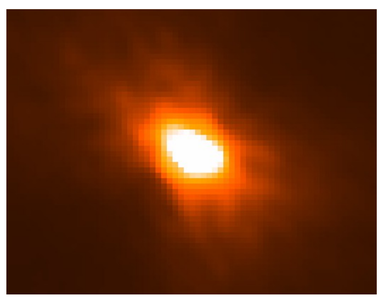
Duty cycle, measured photometrically, compared to the selection fraction. This plot is a good proxy for accuracy: a perfectly accurate system would follow the y=x line. The current implementation, with no prediction algorithms in use, tends to under select, resulting in a lower than expected duty cycle.



Selected Fraction: 100%

Strehl = 16.3%

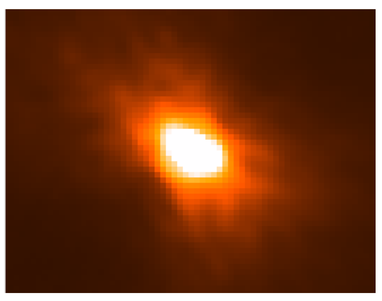
FWHM = 4.18 pix (30.9 mas)



Selected Fraction: 95%

Strehl = 16.4%

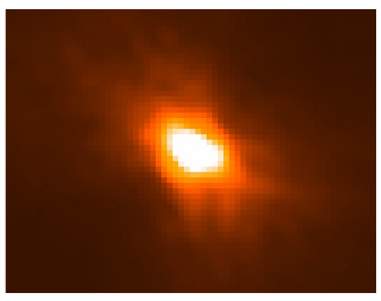
FWHM = 4.16 pix (30.8 mas)



Selected Fraction: 90%

Strehl = 16.4%

FWHM = 4.19 pix (31.0 mas)



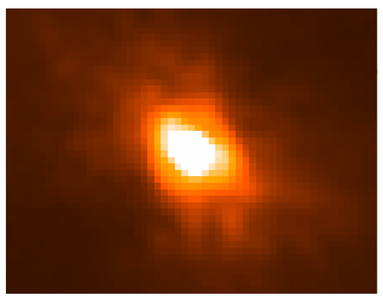
Selected Fraction: 75%

Strehl = 18.9%

FWHM = 4.03 pix (29.8 mas)

These images show the resultant PSF for various selection thresholds, at SDSS I'. RTFS improved Strehl from 16% to 26%, and FWHM improved from 30.9 mas to 27.3 mas.

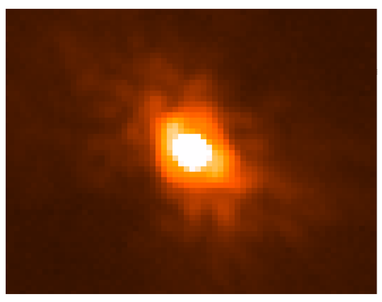
The perfect 24.3 mas Airy pattern is shown below for comparison.



Selected Fraction: 50%

Strehl = 20.1%

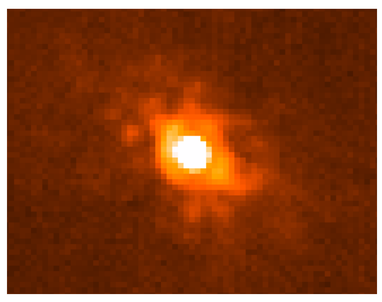
FWHM = 3.94 pix (29.2 mas)



Selected Fraction: 25%

Strehl = 22.1%

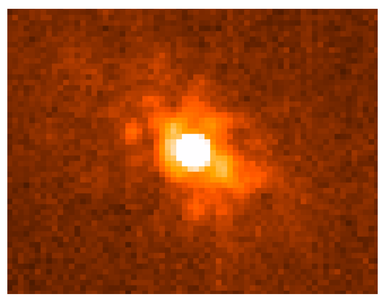
FWHM = 3.85 pix (28.5 mas)



Selected Fraction: 10%

Strehl = 26.0%

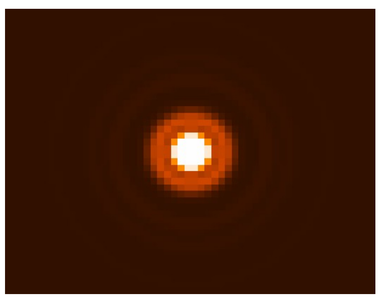
FWHM = 3.69 pix (27.3 mas)



Selected Fraction: 5%

Strehl = 20.1%

FWHM = 3.77 pix (27.9 mas)



Airy Pattern

Strehl = 100%

FWHM = 3.28 pix (24.3 mas)