The Magellan Telescope Adaptive Secondary AO System

Laird M. Close[*a], Victor Gasho[a], Derek Kopon[a], Phil M. Hinz[a], William F. Hoffmann[a], Alan Uomoto[b], and Tyson Hare[b]

[a]CAAO, Steward Observatory, University of Arizona, Tucson AZ USA 85721;

[b]OCIW, 813 Santa Barbara St. Pasadena, CA USA 91101

ABSTRACT

The Magellan Clay telescope is a 6.5m Gregorian telescope located in southern Chile at Las Campanas Observatory. The Gregorian design allows for an adaptive secondary mirror that can be tested off-sky in a straight-forward manner. We have fabricated a 85 cm diameter aspheric adaptive secondary with our subcontractors and partners. This secondary has 585 actuators with <1 msec response times. The chopping adaptive secondary will allow low emissivity AO science. We will achieve very high Strehls (~98%) in the Mid-IR AO (8-26 microns) with the BLINC/MIRAC4 Mid-IR science camera. This will allow the first "super-resolution" and nulling Mid-IR studies of dusty southern objects. We will employ a high order (585 mode) pyramid wavefront sensor similar to that used in the Large Binocular Telescope AO systems. The relatively high actuator count will allow modest Strehls to be obtained in the visible (~0.8μm). Our visible light AO (Vis AO) science camera is fed by an advanced ADC and beamsplitter piggy-backed on the WFS optical table. The system science and performance requirements, and an overview the design, interface and schedule for the Magellan AO system are presented here.

1. INTRODUCTION: SCIENCE WITH AN ADAPTIVE SECONDARY AT MAGELLAN

The biggest sensitivity gains to be had from Adaptive Optics (AO) may be in the thermal (~3-25 μm) IR (Mid-IR AO), where it is possible to routinely achieve "perfect" >98% Strehl images (past 8μm). In particular, one can discern, uniquely well, the details of pre-planetary disks (Liu et al. 2005, 2006), debris disks (Liu et al 2004), dust shells and outflows (Biller et al. 2005; 2006), circumstellar disks around tight (<0.1") young binaries (Skemer et al. 2007) and from 3-5μm: cool extrasolar planets (Heinze et al. 2006; Hinz et al. 2006). In general, it is now possible to discern which of the stars in a tight young binary have circumstellar disks; moreover, through 10 μm silicate imaging determine if the disk orientations are similar (Skemer et al. 2007). The silicate 8-14 μm dust spectra of tight young binaries informs us how dust evolves and grows, which is the first step of planet growth. In addition, many solar system bodies such as comets, asteroids, KBOs, gas giants and their moons all have a need of Mid-IR imaging to constrain albedos and morphologies. Moreover, Magellan Mid-IR AO has >6x the resolution of Spitzer and so this is a needed

Figure 1. The world's first adaptive secondary: a 65cm 336 actuator ASM at the MMT.

[*] lclose@as.arizona.edu; phone +1 520 626 5992

Adaptive Optics Systems, edited by Norbert Hubin, Claire E. Max, Peter L. Wizinowich,
Proc. of SPIE Vol. 7015, 70150Y, (2008)
0277-786X/08/$18 · doi: 10.1117/12.789527

capability for high resolution follow-up of bright (>1 mJy) Sptizer galactic and extragalactic sources. For example, the Spitzer Glimpse survey (of the Galaxy's mid-plane, where AO guide stars are common) alone has discovered ~10^5 new sources of this flux density, all of which could benefit from Mid-IR AO imaging with 6x higher angular resolutions.

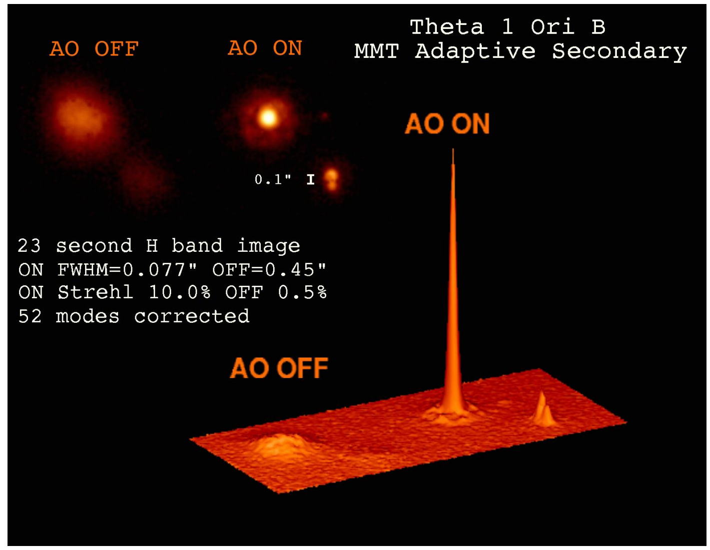


Figure 2. Adaptive correction with the MMT adaptive secondary at H band in a 30 second exposure (Close et al. 2003a). These MMT AO H band (77 mas – AO ON) images of the Theta 1 Ori B complex have positions good to 0.002" (Close et al. 2003a).

The most recent (3ird) US observational "System" meeting noted that diffraction limited 2-20micron imaging on large telescopes was badly needed to match HST's optical/NIR resolutions (recommendation 3, Origins Science talk #2).

1.1 How can you build a low emmissivity Mid-IR AO system for Magellan?

The technique of thermal IR astronomy demand different observing methods, and optical configurations compared to "classical" AO. A classical AO system can easily squander the gains to be had in Mid-IR AO through the use of warm, dusty, relay and deformable optics (Lloyd-Hart 2000). However, if the secondary mirror of the telescope is itself the deformable optic in the AO system then there is no extra emissivity introduced. Therefore, it is possible to have an optimal Mid-IR AO system by use an Adaptive Secondary Mirror (ASM). That is the deformable optic is the telescope's secondary mirror itself. We have proven that this is possible with the world's only adaptive secondary over the last 5 years at the 6.5m MMT telescope (for details on how the MMT works see Wildi et al. 2003; Close et al. 2003a,b; Kenworthy et al. 2004; Liu et al. 2005; Hinz et al. 2006 – see figs 1-4).

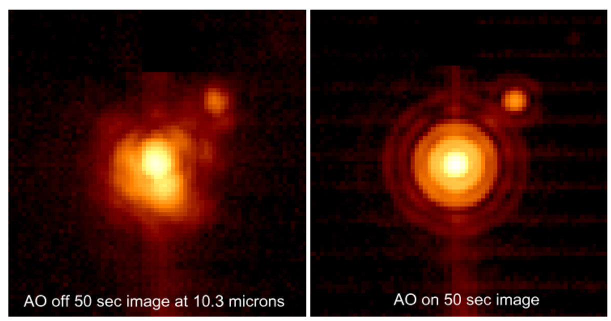


Figure 3. The great improvement in PSF quality with the MMT deformable secondary at 10 μm (Strehls improve from ~50% to 98+/-2% with AO). Log stretch.

At Magellan we will complete the first low emissivity AO system in the southern hemisphere. The south is very important for access to the most interesting galactic objects which are predominately located in the southern hemisphere; like the Galactic center itself, the nearest young stars in clusters like Sco Cen, TW Hya, Chamaeleon, p Oph, Upper Cen Lup, Lupus, Upper Sco, n Cha, Musca, Coalstack, Corona Australis, etc. As well as evolved stars like Eta Car, and those near the galactic center etc. To minimize risk and cost we have built a high performance 585 element "clone" of the Large Binocular Telescope's (LBT) adaptive secondary system customized for the 6.5m Magellan telescope. A brief technical description of the proposed ASM is presented in section 2.0.

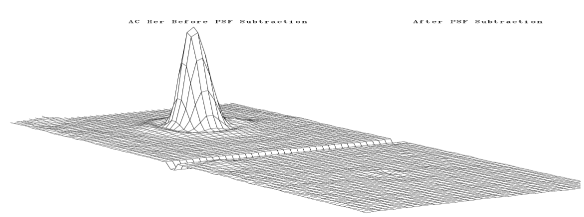


Figure 4. The Mid-IR AO image of AC Her (right) at Strehl 98% and S/N=3000. To the right we simply subtract a scaled image of the PSF star alpha Her. The residuals are less than 0.5% which is at the photon noise limit (Close et al. 2003b).

On good nights (~0.5" seeing, which are frequent at

Magellan) we should be able to make diffraction-limited (~20 mas) optical AO images with the system as designed (this is because 585 elements on a 6.5m pupil is twice as high density as the Keck AO system, for example). Hence, in addition to Mid-IR AO we will bring visible AO (Vis AO) to the southern sky, with Strehls of ~10% and resolutions of ~25 mas at I band on nights of 0.5" seeing.

TOP LEVEL SCIENCE REQUIREMENTS FOR MAGELLAN AO		Req#
MID IR AO MODE (3-25 µm)		
High Strehl & Super resolution (on-axis)	≥96% Strehls @ λ≥8 µm; R≤13	M1
Diffraction-limited Resolutions 8-20 µm	0.25" – 0.6"	M2
Wavelengths bands of interest	8-25 µm	M3
5σ detection of N=0.1 Jy point source	<60 sec	M4
Mid-IR spectra	Silicate features	M5
Circumstellar science	98% suppression of central star	M6
VISIBLE AO MODE (0.5-1.0 µm)		
Moderate Strehl (on-axis)	≥10% Strehl @ λ≥0.85 µm; R≤10	V1
Diffraction-limited Resolutions 0.5-1.0 µm	0.015 – 0.029"	V2
Wavelengths bands of interest	0.5 – 1.0 µm	V3
circumstellar science	<0.1"	V4
Faint & Bright star/binary science	23<V≤5 mag point sources	V5

DESIGN FOR COMPLIENT MAGELLAN AO SYSTEM		Meets Req#
Low emissivity AO system	chopping 585 actuator ASM	M1-M6
Scalable AO WFS with high order corr.	Pyramid, 49-585 elements, 90x90" patrol field	V1-V2
MID IR AO MODE (3-25 µm)	256x265 array	
f/16 MIRAC4 platescales	50 – 100 mas/pix	M1-M2
f/16 MIRAC4 FOV	12.9 – 25.8" square	M1-M2
Filters	N,Q, 5 filter 10% silicate set	M3
Grism	R~80-120 over 7-14 µm at 0.1"/pix	M5
Nulling Interferometer (BLINC)	<2% nulls	M6
VISIBLE AO MODE (0.5-1.0 µm)	1024x1024 EEV CCD47	
VisAO CCD platescales	8.5 – 28.5 mas/pix	V1-V2
VisAO CCD FOV	8.5 – 28.5" square	V1-V2
filters	V,R,I,z,y, Hα, Hα_cont	V3
Coronagraph	0.1" – 1.0" spots	V4-V5
High Speed Mode	3 Hz Full Frame Transfer CCD	V5

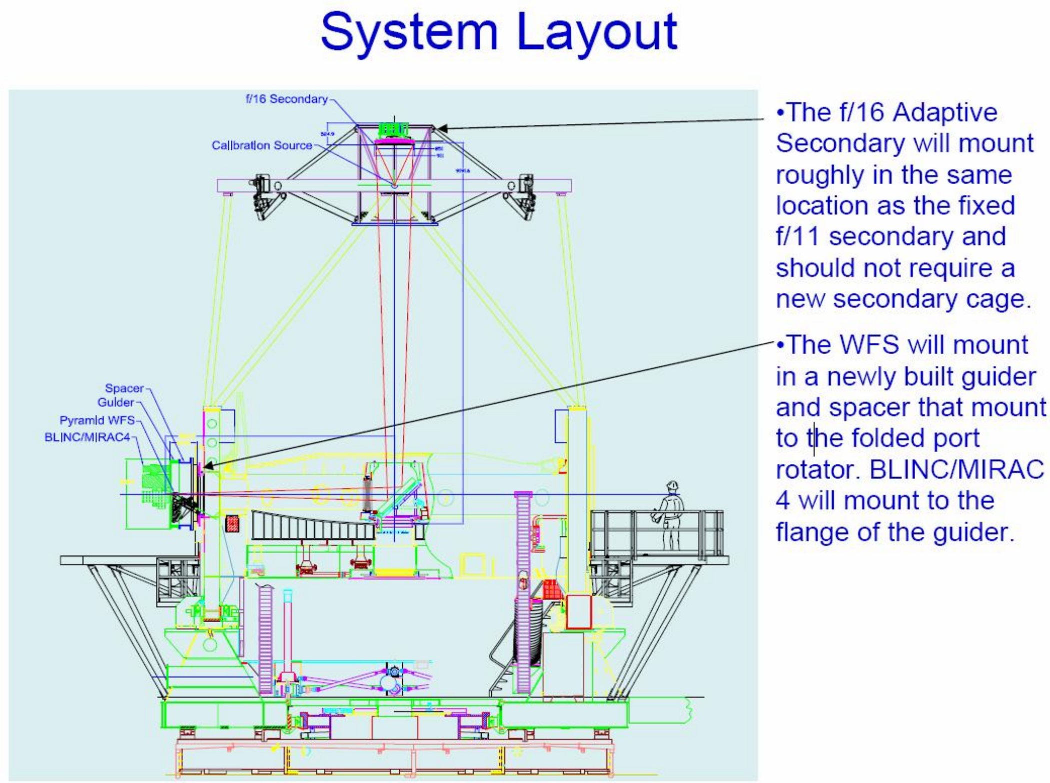


Figure 5: Magellan adaptive secondary mounted on the Magellan telescope as an Gregorian secondary. Note that an LBT secondary of size 0.851m will produce an f/16 beam that focuses just 9 inches past the nominal Nasmyth focal ports for all current Magellan instruments. To the left we show the normal (west) Nasmyth focus where all "first-light" AO instruments (BLINC/MIRAC4, and the Vis AO CCD), and the WFS will be mounted.

2. THE MAGELLAN AO SYSTEM OVERVIEW

To address the unique gains of Mid-IR AO in southern skies the Magellan AO system received a TSIP 2007 award, which in addition to our previous support from the NSF MRI program enables the construction phase of this ambitious project to be finished in 2011.

While the operating principles of the MMT deformable secondary are straightforward, the electromechanical system for many fast and high precision actuators is inevitably highly complex. The design balance for the present mirror was obtained by development with Arcetri Observatory over years of a number of prototypes of progressively increasing sophistication. The process is continuing through new the manufacture of two 91 cm deformable secondaries for the two 8.4 m telescopes of the LBT (the first of these LBT units has passed its electromech acceptance testes; see these proceedings for more on the LBT AO systems; Riccardi et al. 2008: paper 7015-37).

The Magellan secondary AO system embodies all of the MMT and LBT experiences so far, and add the advanced features and robustness desired for Magellan while strictly adopting core LBT standard hardware and software for the ASM (Riccardi et al. these proceedings) and WFS (Esposito et al. these proceedings, paper 7015-229). An LBT standard design will ensure that lab testing and telescope commissioning will occur with maximum robustness and efficiency. Moreover, maintenance and upgrading the system will be become much simpler if all ASM systems on Magellan and both LBTs are almost identical.

The Magellan ASM design is being undertaken, as previously with the MMT and LBT, in collaboration with Piero Salinari and Armando Riccardi at Arcetri Observatory. The Magellan shell (fig 6,7) is identical to the LBT shell except that it is 85.1 cm in dia instead of 91.1 cm used at the LBT. This is significantly larger than the 65cm MMT shell. At this size it will be critically sized for the Magellan pupil.

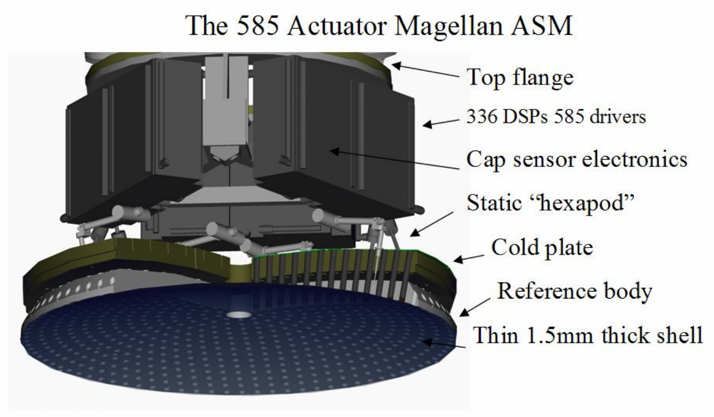


Figure 6: At the top is the flange that connects the ASM superstructure to the Magellan secondary cage. Below this is the electronic boxes that contain the ASM reconstructor and control DSP boards and driver electronics (custom made by Microgate). Below the crates is the "hexapod" attachments to the Al "cold plate" (shown here as green; see also figure 7). This cold plate both holds and liquid cools the voice coil actuators. The next layer down is the ULE reference body with 585 precision holes drilled thru it for the 585 actuators (gray near-vertical cylinders). The reference body (with its capacitive sensors) defines the static shape of the 1.5mm thin aspheric shell. The shell is deformed by 585 magnets that are glued on the back of the shell and driven by the 585 voice coils. The position of each magnet is controlled 100 kHz position sensor loop. Adapted from Riccardi et al.

As of August 2007 the above parts for the Magellan Adaptive secondary are fabricated by Microgate and ADS of Italy. Parts electro-mechanically tested (see fig 10) around the capacitive sensors with our shell mounted on a complete electronics system by LBTO & Arcetri.

Our system will use the more advanced "LBT" electronics to allow improved servo control (electronic damping with position control at 100kHz) for faster response time, (<1 ms compared to the MMT's ~2ms). This will allow a larger gap, to accommodate the larger stroke needed for Magellan and for improved chop angle (~4" P-P) for the thermal infrared. It will also use higher precision encoders for the capacitive sensors to give sub-nm resolution for very high accuracy control of low and intermediate order aberrations needed for Vis AO.

The mirror will be figured as a concave ellipsoid (to be used as a Gregorian secondary at Magellan) so it can be easily tested in the test tower with artificial aberrated starlight (fig 5,9). It will have a deployable artificial source, so it can be tested subsequently on-telescope as a Gregorian mirror at the Magellan II (Clay) telescope. The larger size allows the use of larger, more efficient magnets in the actuators than in the MMT. The power per actuator and per unit area to correct turbulence is reduced despite the larger scale.

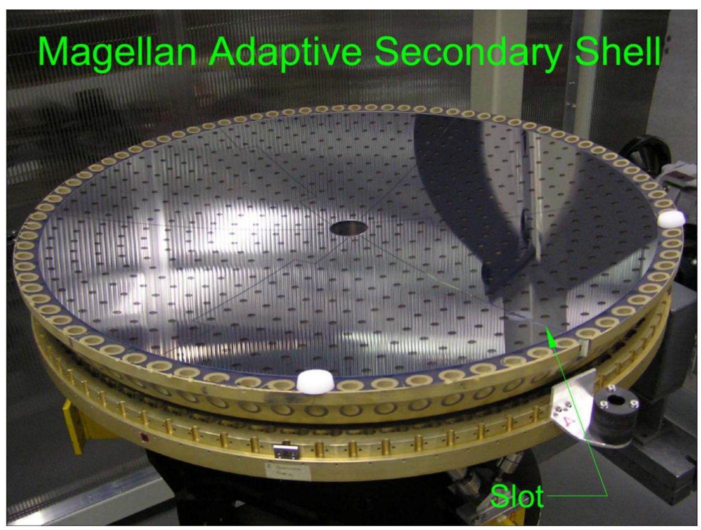


Figure 7. The fully figured and polished 1.5mm thick aspheric Magellan Adaptive Secondary Shell mated to its reference body in Italy (ADS's lab in Milan). Our Shell is only Al coated on the back face at this time. The regularly spaced dots are areas that have been masked during coating and are where the 585 magnets are glued. The six radial lines are masked areas that serve to electrically isolate distinct actuator sectors from one another for the control electronics. There is a 6cm long 3mm wide "slot" in the glass. This slot is located along one of these radial lines as shown in the picture and will be aligned behind one of Magellan's spiders, and is not expected to degrade the AO image quality. The size of the Magellan shell is 85.1 cm dia. Photo credit Guido Brusa LBTO.

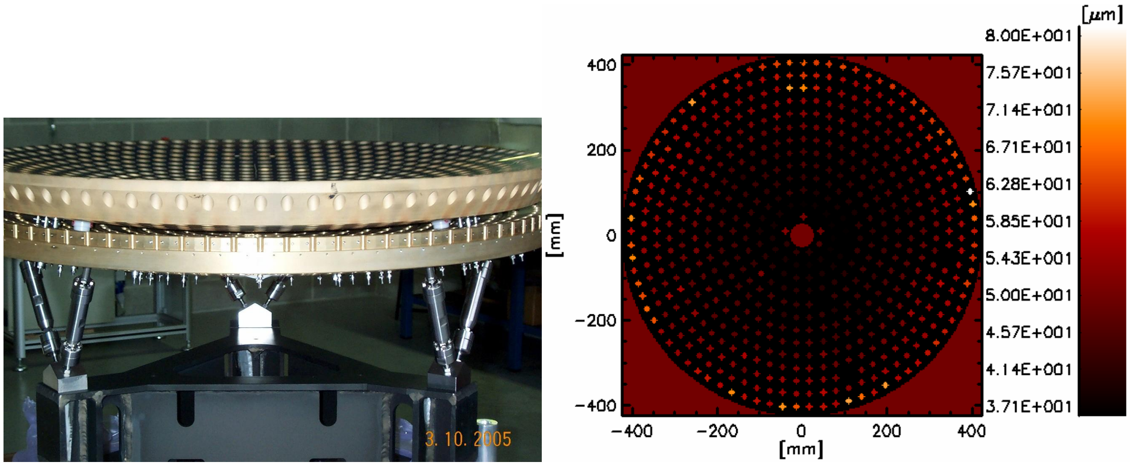


Figure 8: Left: a cross section of the Magellan reference body (top), cold plate (middle) and the support "hexapod" arms to the ASM superstructure. The top of this superstructure connects to a flange that attaches to the existing Magellan secondary cage. Photo credit ADS. Right: Real closed-loop capacitive sensor positional data on the Magellan shell when fully assembled in a complete ASM system (July 2007). Other than a smooth 6.3 µm rms focus term (which will be easily removed by secondary collimation at the scope) the rest position of the shell (no optical WFS feedback) is very close to flat as expected. The next step will be to optically flatten the shell in the test tower with a 4D interferometer and Pyramid WFS. The ~20µm stroke of the mirror is more than enough to obtain an excellent optical "flat" without using a significant amount of system stroke.

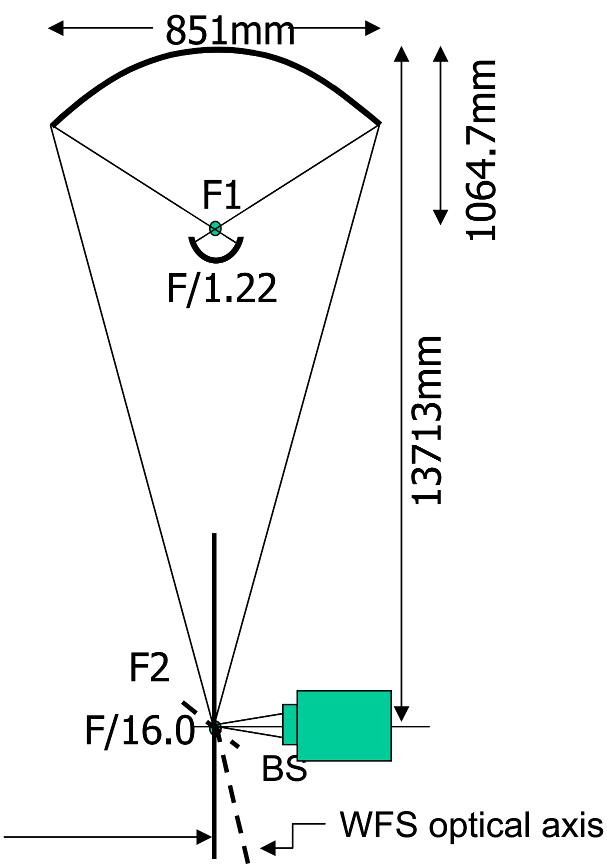


Figure 9: The concave nature of the Magellan Gregorian secondary and identical optical prescription to the LBT's secondaries allow it to be tested in the LBT test tower. The principal of the test is to double pass illuminate the secondary with an artificial "star" at the f/15 focus (focus F2) and retroreflect the reflected beam with a f/1.22 reflector suspended under the secondary. Then this upwards beam illuminates the secondary exactly as the real Magellan primary would illuminate an Gregorian secondary. The resulting downwards propagating f/16 beam is then folded into a 4D interferometer just past F2. Hence the exact wavefront coming off the secondary's f/16 beam can be measured and therefore the sensors can be set to "flatten" the secondary. Adapted from Riccardi et al. In this same test setup a beam splitter (BS) allows the pyramid WFS to sample the wavefront off the secondary. In this manner it is possible to take interaction matrixes and fully close the AO loop in the Lab (with an optional turbulence simulator for acceptance tests). We will also suspend a similar reflector when the Magellan secondary is mounted at the LBT and Magellan telescopes to allow daytime calibrations.

An important goal for this secondary is a robust software control system for the highest reliability and least maintenance. We have much experience through on-telescope use of the first MMT secondary, fixing practical problems and developing safe operating procedures. All of these will be incorporated into the new control system. Software and hardware elements will be included to keep mirror position and actuator forces within safe margins. This control system will form a solid basis for future ELT deformable secondaries for GMT. In fig 10 (right) we show the successful electro-mechanical tests of the Magellan shell with the full ASM.

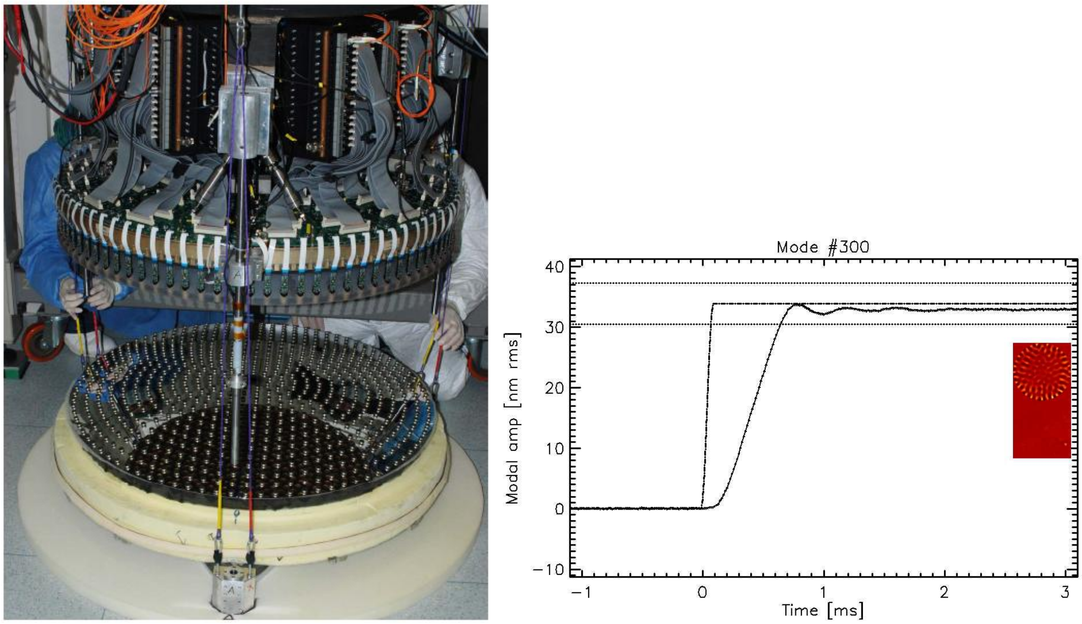


Figure 10: Real time closed positional loop data on the Magellan Shell with ASM electronics. Right an image of the test set-up left: the results of dynamical tests of system mode 300. The shell and positional feed back system have the desired dynamical response. Test results from Arcetri Obs. Microgate, ADS & LTBO.

Figure 11a. The new MIRAC4/BLINC camera for the Nasmyth focus of the Magellan II (Clay) telescope. The blue vacuum vessel is BLINC, containing the cryogenic interferometer, and the gold box encloses the mechanically (pulse tube) cooled MIRAC4 Mid-IR AO camera.

3. New Science Enabled with the Magellan ASM

Several new science fields will be opened up in the south with our new ASM. Mid-IR AO (low emissivity 8-25 μm imaging and 8-14 μm spectra) will be immediately available in the southern hemisphere for the first time. We will use the mid-IR AO camera MIRAC4 for the first facility mid-IR AO camera in the south. As well we will use the BLINC nulling interferometer for unique nulling of host stars (to reveal new debris disks) in the south. In addition the very high number of actuators (585) on a 6.5m telescope will enable some modest correction in the visible 0.5-1.0μm (Vis AO).

3.1 Thermal Mid-IR AO Science Enabled in the Southern Hemisphere

Science with adaptive optics in the thermal infrared will be possible with the Magellan adaptive secondary with a concurrently developed Thermal-IR camera, the Mid-Infrared Array Camera (MIRAC4) and associated nulling interferometer, the Bracewell Infrared Nulling Cryostat (BLINC; See fig 11a).

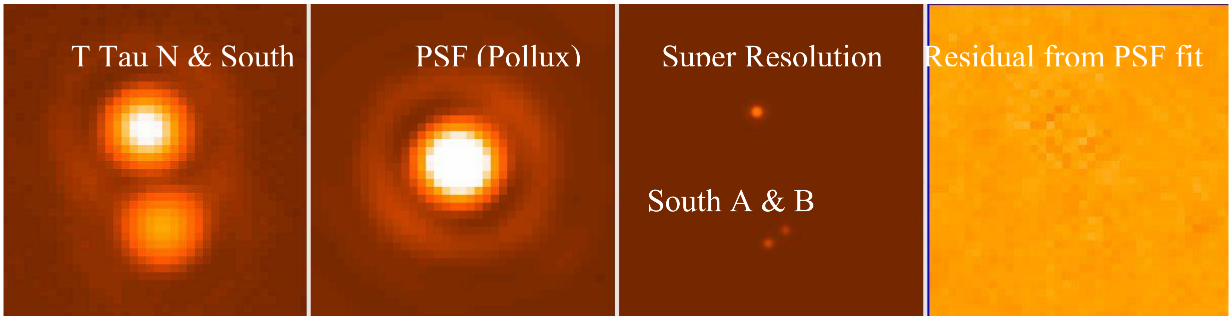


Figure 12: Images of the prototype young triple T Tauri. These images were made at first light of the Magellan Facility instrument MIRAC4 (at the MMT with our existing ASM). Here we see how ~100% Strehl Mid-IR AO can be used to probe structures at $\leq 0.3\lambda/D$. Here we are able to use super-resolution to resolve T Tau into a triple system for the first time in the Mid-IR. In particular, we have split T Tau South A from South B which are only 0.11" apart. Moreover, we find that South A has deep Silicate absorption proving the existence of an edge-on disk. While South B has no such absorption, implying that South A and South B do not have aligned disks (Skemer et al. 2008). This result was only possible with the use of Mid-IR AO. Many more exciting discoveries will be possible with Magellan and this MIRAC4 camera combined with observing the young southern clusters.

3.2 A Visible AO system for Magellan

Our dense actuator grid has an effective actuator spacing of 23 cm when the pyramid sensor is "30x30" and fully sampled (i.e. when the WFS CCD is used in unbinned mode; this is higher resolution sampling than any other large telescope AO system in operation today for science). So that implies that we are well sampling the turbulence at a lambda where r_o=46 cm. At the excellent Magellan site where often r_o=20 cm at 0.55 μm it is clear that at λ~ 0.9 μm there will be AO correction on bright stars. Hence moderate Strehls will be possible in the I and z bands on good nights on bright stars. The resulting angular resolutions of such CCD images will be a spectacular 20-30 mas (although the corrected FOV will limited by the isoplanatic angle to less than 8.5" typically). To maximize this Vis AO science without impacting our Mid-IR AO mode we have designed an AO science CCD with an ADC ready at first light to capitalize on these amazing resolutions (2x better then the

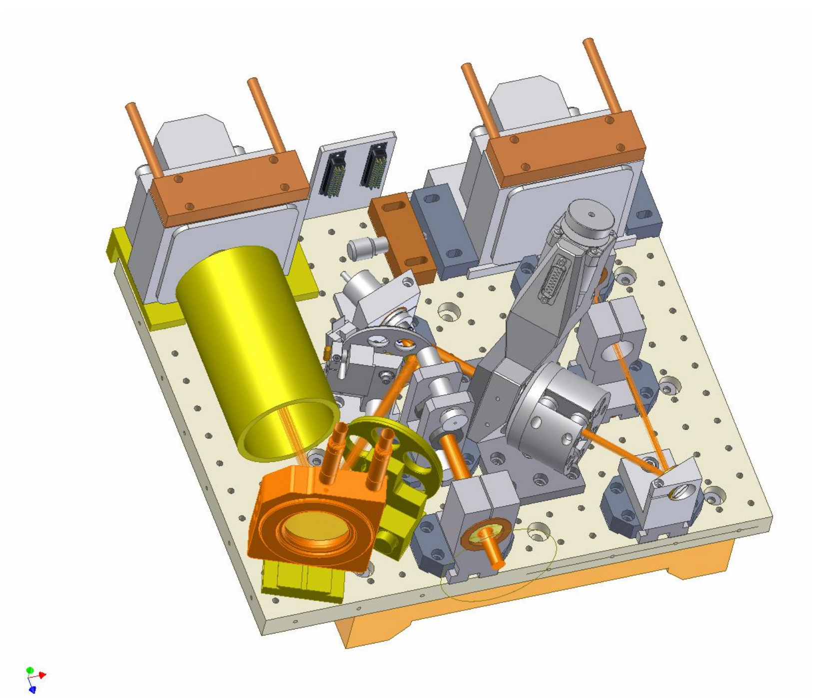


Figure 11b: The Vis AO camera (gold half) of the WFS optical table (which itself patrols ±90" for guide stars) for more detail on the Vis AO camera see Kopon et al. 2008 these proceedings.

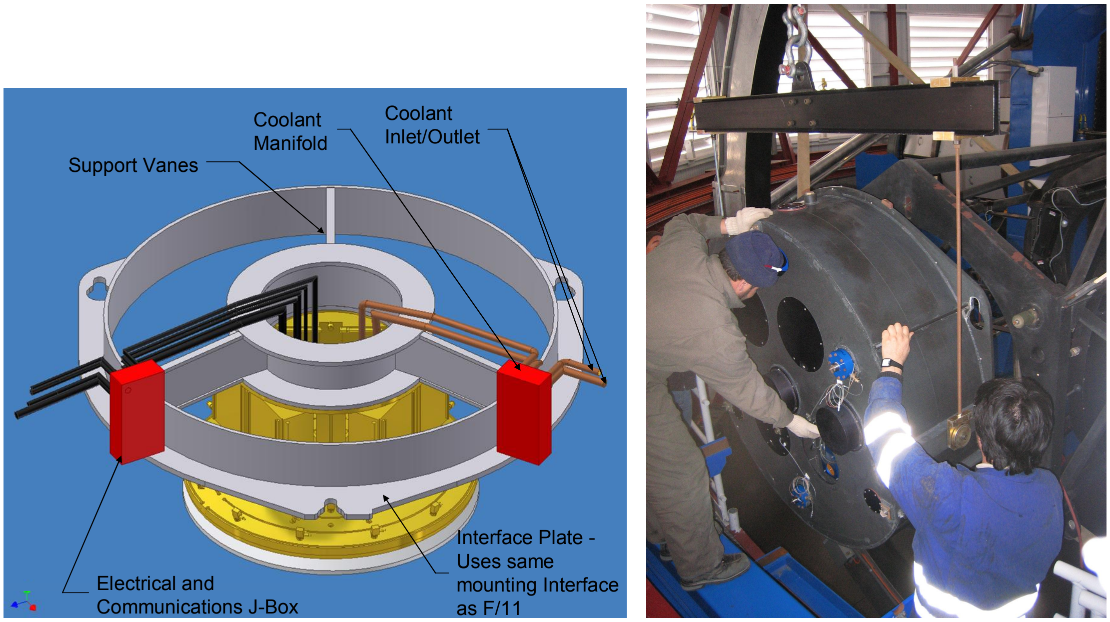


Figure 13: Top end Magellan interface detail. Left shows an early design of the opto-mechanical interface between the f/16 ASM and the "hex" steel secondary "cage" of the Magellan top-end. To the right we see the current 1.3m f/11 secondary being removed from the Clay telescope for re-coating. Our ASM slides inside the dark steel hex interface plate. The Magellan spiders which attach to the cage can drive the secondary in tip-tilt, piston, and X and Y by ±15mm for static collimation of the system.

best HST ACS images). For more on our Vis AO science camera an advanced ADC see fig 11b and the paper by Derek Kopon in these proceedings (Kopon et al. 2008; paper 7015-242).

One might question if adaptive optics in the visible is even possible with 585 modes? The Pyramid optical Strehl estimates of Esposito et al. 2008 for the LBT scaled to our system suggests that in the z, I and R bands Strehls will be significantly greater than 15, 10, and 5% when r_o>20 cm for stars brighter than R=10 mag. While these Strehls are low compared to what will be achieved at 10 µm, there is still a large body of science that can be done at lower Strehl. Indeed most current ~200 actuator 8-10m AO systems do not achieve Strehls much higher than 2% in the I band (0.85 µm). If we estimate no better control than say these current systems, and note that our fitting error is a factor of 2x rad^2 better, then it is clear that our Strehls with bright star (fitting error limited) will trend towards I band Strehls of 16%.

To take full advantage of the periods in a night when the seeing is 0.5" requires the Vis AO camera to "always be ready". Our design is convenient in that the Vis AO camera is integrated into the WFS stage. Hence at "a click of a button" we can select a beamsplitter to steer 10-50% of the WFS visible light into the EEV CCD 47 (with 8.5 mas pixels) to make Vis AO science images. As well we have designed an apochromatic triple ADC to allow wide band (0.5-1.0 µm) Vis AO at up to 2 airmasses (Kopon et al. 2008). This is design is similar to our BESSEL visible AO system that can achieve 99% I band Strehls on a very small refractor (Peters et al. 2008). As far as we know BESSEL holds the record for high Strehl visible images from the ground. To learn more about our optomechanical designs for our "always ready" Vis-AO mode for Magellan see Kopon et al (2008).

4. OVERVIEW OF THE INTERFACES TO MAGELLAN

We have already utilized the existing NSF MRI award to fully fabricate a 0.851-m deformable secondary mirror which will be mounted on the 6.5-m Magellan Clay Telescope (Figure 5) in 2011. A new support interface from the Secondary Cage to the secondary super structure (fig 13; left), will be provided by Magellan to accommodate the new AO secondary mirror assemblies. Clamping mechanisms will allow convenient interchange between the existing f/11 secondary (see fig 13) and the ASM. The Cage will also be upgraded to include mounting provisions (not shown) for a deployable AO calibrator return optic assembly at prime focus (near top of fig 9). Space above the AO secondary is available for the future addition of laser launch optics (not

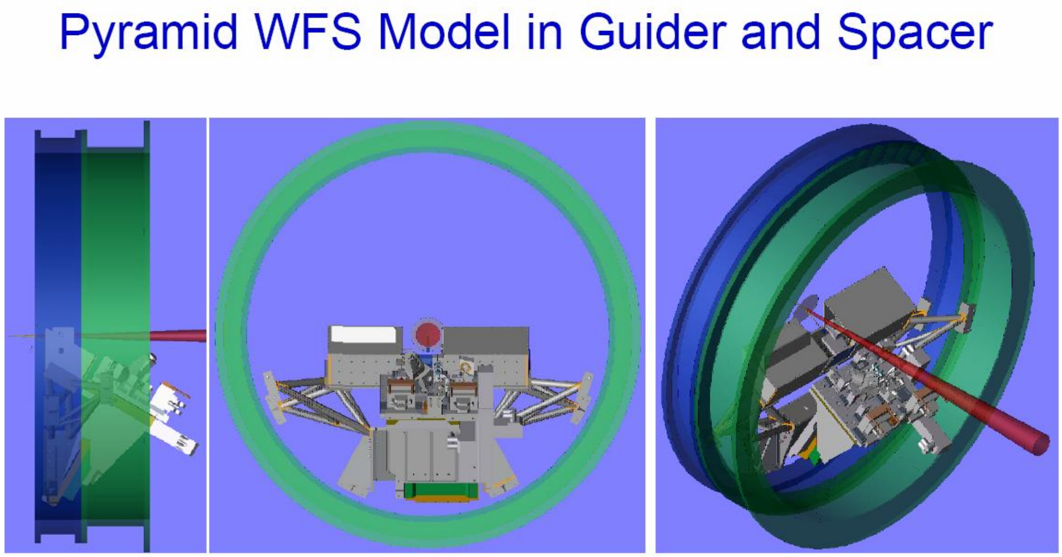
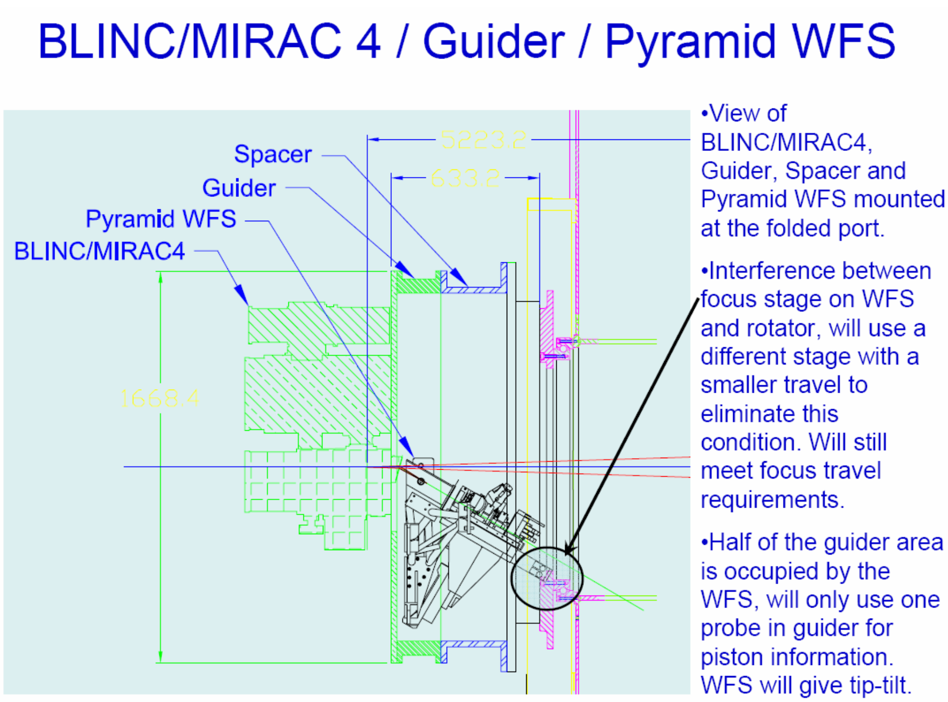


Figure 14: A 3-D model of the Pyramid WFS (Arcetri; Esposito et al. 2008) inside the Magellan Nasmyth rotator. Right image: the red beam is the incoming on-axis f/16 beam which is reflected off the MIRAC4 dichroic/window sending the visible light from the guide star into the WFS.

yet funded), currently this will be used for a counter balance mass to keep the ASM balanced on the crane's load spreader (fig 13; right).

At a diameter of 0.851 m the Magellan secondary just fits the pupil size for an on-axis star. Thus this critically sized secondary mirror forms the entrance stop of the telescope optical system. Some scattering (by diffraction) of the warm slightly oversized reference body will illuminate the edge of the pupil (even thought it will be hidden behind a simple sky-imaging annulus optic). Nevertheless, a slightly (<5%) undersized cold pupil inside the Mid-IR camera will eliminate most of this diffracted thermal light, leading to <1% increase in system emissivity at 13 μm (Hinz, GMT study).



5. MAGELLAN AO MAJOR FUTURE MILESTONES

- March 2009 – final electromech ASM acceptance tests at Microgate
- Oct. 2010 – finish "end-to-end" closed loop tests at Arcetri Obs.
- Dec. 2010 – Ship Magellan ASM and MIRAC4 to Magellan. Day time Tests.
- Feb. 2011 – First Light of Magellan AO (ASM & WFS)
- June 2011 – Magellan AO and MIRAC4 & AO science CCD commissioned
- October 2011 – Start Campaign mode observing with Magellan AO.
- June 2012 – Magellan AO system accepted as facility instrument

Acknowledgments

This project could not be possible without help from our partners and collaborators. The ASM and WFS could not have been possible without the design work of Microgate and ADS in Italy as well as Arcetri Obs. (A. Riccardi and S. Esposito et al) and the LBT observatory. We would also like to thank the NSF MRI and TSIP programs for generous support of this project.

REFERENCES

Biller B.A. Close L.M. et al. 2005, ApJ 620, 450
Biller B.A. et al. 2006, ApJ 647 464
Biller B.A. et al. 2006, IAUC 200 proc
Brusa, G. et al. 1999, Backaskog workshop on Extremely Large Telescopes, ESO Workshop Proceedings 57, 181
Brusa G. et al. 2003 proc SPIE 4839, 691.
Burrows, A., Sudarsky, D., Lunine, J. 2003, ApJ
Close L.M. 2000, IAU 200, 555
Close L.M. et al. 2003a, ApJ 599, 537
Close L.M. et al. 2003b ApJ 598, 35L
Close L.M. et al. 2005a proc "ESO workshop on science with AO"
Close L.M. et al. 2005b NATURE 433, 286
Ellerbroek, B. L. et al. 2003, SPIE
Ellerbroek, B. L. et al. 1994, JOSA A
Esposito S. Et al. 2008 these proceedings
Georges, J. A. et al. 2003, Astronomical Adaptive Optics Systems and Applications, SPIE 5169, in press
Glassman et al. 2002, ApJ 581, 865
Heinze, A. Hinz, P. Et al. 2006 SPIE 6272 121
Hinz, P.M. et al. 2000, SPIE 4006, 349
Hinz, P.M. et al. 2006, ApJ 653 1486
Hoffmann, W. et al. 1998, SPIE 3354, 647
Peters, M.A., et al. 2008, New Astronomy 13, 359
Lenzen R., et al. 2005 proc "ESO workshop on science with AO", 115
Liu, W. Hinz, P. et al. 2004, ApJ, 610, 125L
Liu, W. Hinz, P. et al. 2007 ApJ 658, 1164
Lloyd-Hart 2000, PASP 112, 264
Riccardi A. et al. 2008 these proccedings
Skemer, A, et al. 2008, ApJ 676, 1082
Weigelt G. et al. A&A, 347, L1
Wildi, F. et al. 2004 SPIE 4839 p 155