The Gemini MCAO bench: system overview and lab integration

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ABSTRACT

We present Canopus, the AO bench for Gemini's Multi Conjugate Adaptive Optics System (GEMS), a unique facility for the Gemini South telescope located at Cerro Pachon in Chile. The MCAO system uses five laser beacons in conjunction with different natural guide stars configurations. A deployable fold mirror located in the telescope Acquisition and Guiding Unit (A&G) sends the telescope beam to the entrance of the bench. The beam is split within Canopus into three main components: two sensing paths and the output corrected science beam. Light from the laser constellation (589nm) is directed to five Shack-Hartman wave front sensors (E2V-39 CCDs read at 800Hz). Visible light from natural guide stars is sent to three independent sensors arrays (SCPM AQ4C Avalanche Photodiodes modules in quad cell arrangement) via optical fibers mounted on independent stages and a slow focus sensor (E2V-57 back-illuminated CCD). The infrared corrected beam exits Canopus and goes to instrumentation for science. The Real Time Controller (RTC) analyses wavefront signals and correct distortions using a fast tip-tilt mirror and three deformable mirrors conjugated at different altitudes. The RTC also adjusts positioning of the laser beacon (Beam Transfer Optics fast steering array), and handles miscellaneous offloads (M1 figure, M2 tip/tilt, LGS zoom and magnification corrections, NGS probes adjustments etc.). Background optimizations run on a separate dedicated server to feed new parameters into the RTC.

Keywords: Multi-Conjugate Adaptive Optics.

1. INTRODUCTION

Gemini selected different companies to deliver the components forming Canopus. The support structure, the bench and its optics, the opto-mechanical software control, the three deformable mirrors and their electronics, the NGS and LGS wavefront sensors and the real-time controller were contracted to different bidders. All those components have been delivered to Chile and we started integration of the system. Some of the less critical assemblies were known not to perform within specification but Gemini decided to have them delivered to start integration in the lab and avoid further slip in the schedule. Several issues have been identified and work started to address them in-house. The system is undergoing integration in a clean room in La Serena. By July 2007, all the major components had been delivered and assembled. A major milestone was accomplished in August 2007 when we successfully closed all the critical MCAO loops (3x DMS, 5x LGSWFS, 3x NGSWFS) in lab conditions using calibration light sources and electronics disturbances [1].

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2. BENCH OVERVIEW

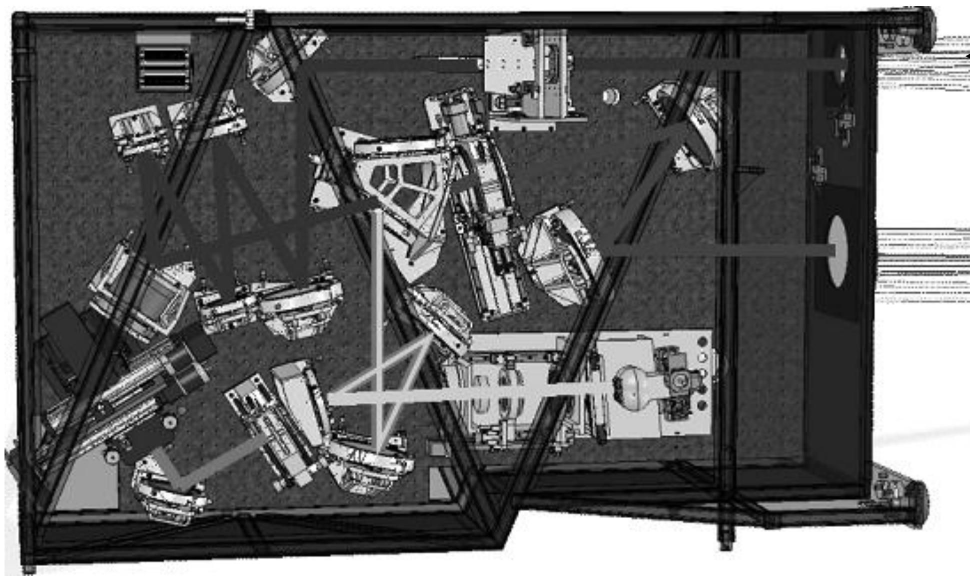

Figure 1. Schematic representation of the three main light paths in Canopus: the input beam from the telescope (blue), the natural guide stars path (red), the laser guide stars path (orange), the corrected output beam for science (light blue).

Canopus will be mounted on a side looking port of the telescope Instrument Support Structure (ISS). A fold mirror directs the light collected by the telescope to the upper entrance shutter. The beam is folded by a flat mirror and collimated by an off-axis parabola onto three deformable mirrors conjugated at different elevation (9Km, 4,5Km and 0Km respectively) and a tip/tilt mirror (TTM). A science beam splitter (stage allowing one of two selectable optics configuration) transmits the infra-red light (shown in light-blue on Figure 1.) onto an atmospheric dispersion corrector (Science ADC, a deployable unit). The corrected beam is folded by another flat mirror and refocused at f/32 by an off axis parabola to exit through the bottom shutter. A science fold mirror located inside the telescope acquisition and guiding unit allows to redirect the corrected beam to the instruments mounted on the ISS.

The red and orange paths on Figure 1. represent the light from the natural guide stars and laser constellation reflected by the science beam splitter. The 589nm wavelength from the five laser beacons is reflected by the LGS beam splitter and sent to the Laser Guide Star Wavefront Sensor (orange path on Figure 1.). The LGSWFS consists of five CCDs aligned with the five beams of the LGS constellation. The LGSWFS assembly has motorized components to actively control zoom and magnification corrections.

The visible light from the three natural guide stars (red path on Figure 1.) passes through an atmospheric dispersion corrector (NGSADC) onto the Natural Guide Star Wavefront Sensing Unit. The NGSWFS consists of three independent probes, motorized to allow tracking on their respective guide star on the sky. Each probe is fitted with 4 fiber optics feeds attached to quad cell Avalanche Photo-Diodes sensors. NGS Probe #3 splits the incoming light and sends ~25% of its signal to a slow focus sensor.

Different calibration sources allow characterization and calibration of the system. The calibration unit is retractable and motorized to allow different configurations controllable by software.

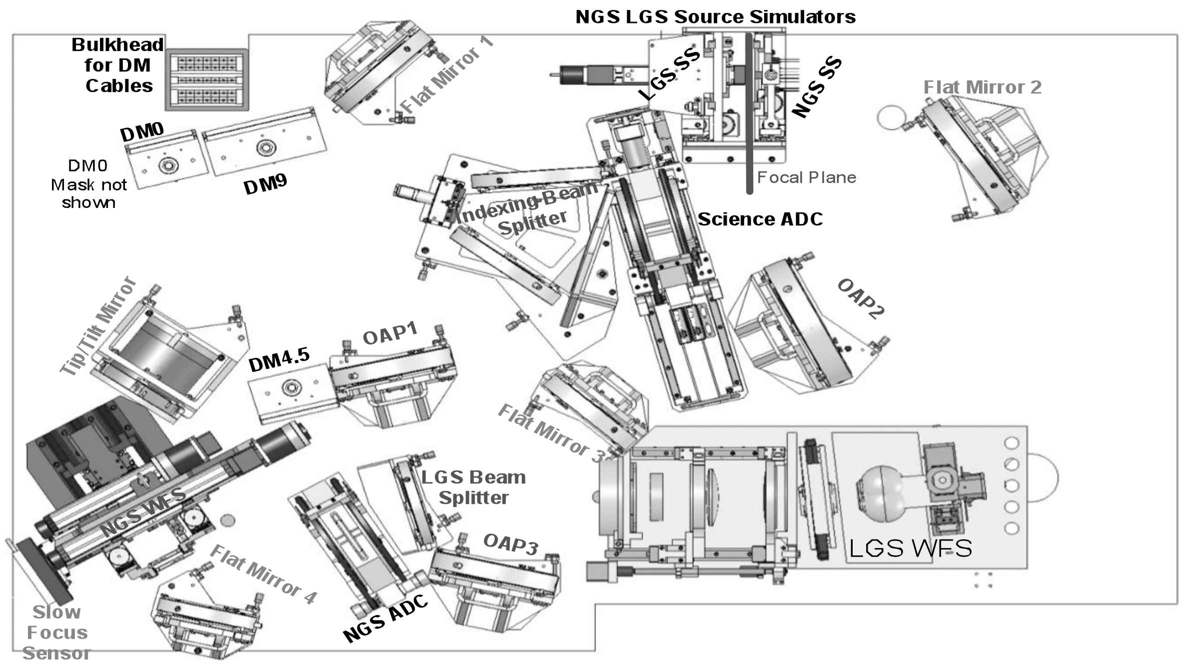

Figure 2. Principal components mounted on the Canopus bench.

3. SUPPORT STRUCTURE

Canopus support structure is built around two separate frames: the first structure holds the bench breadboard and all the optical components; the second structure holds the electronics chassis, cooling and thermal insulation of electronics, heat exchanger, pipe work for glycol etc. The two structures use independent mounting points on the telescope ISS to limit vibrations passed onto the optical bench. The space envelope and mass budget of Canopus comply with Gemini's requirements.

Component	Weight (kg)
Electronics	248
Electronics Enclosures	226
Bench Support Structure	256
Optical Bench	180
Opto-Mechanical components	310
Total	1220

Table 1. Canopus mass budget

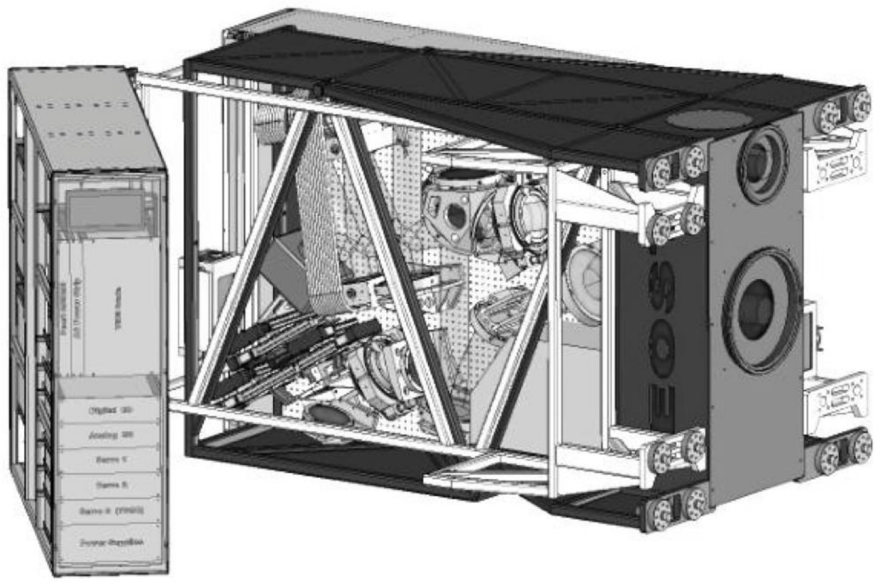

Figure 3. Canopus support structure, +X panel shown opened providing access to the optical bench.

The structure holding the electronics consists of two panels mounted on hinges to provide convenient access for maintenance when the system is mounted on the telescope. The +X side (facing on Figure 3.) opens up to the optical bench. The front side +X panel holds a VME controller for real-time control of the opto-mechanical components, the power amplifier electronics for motors, the Slow Focus Sensor (SFS) computer, network, serial and KVM equipment. All the electronics are remotely controllable over the network using remote AC power control outlets. The backside of the +X panel contains the Real Time Controller (RTC) and extension chassis, the electronics for Tip/Tilt mirror and NGSWFS Avalanche Photo Diodes.

The -X side panel (back of Figure 3.) holds the electronics and high voltage power supplies for the three deformable mirrors, the SDSU CCD power supply and controller for the five laser guide star wavefront sensors, the lamps, leds and electronics for the calibration sources. This side of the structure is also mounted on hinges although access is more limited due to the DMs and CCD cabling routed to the optical bench. All the electronics can again be remotely AC powered.

4. OPTO-MECHANICS AND CONTROLS

Control of the motorized stages and status information from a variety of sensors mounted on the bench is implemented using the Experimental Physics and Industrial Control System [5]. EPICS is a standard framework adopted at Gemini. It provides low-level drivers to control hardware (motor controllers, digital and analog input/output etc.), a network transparent layer (Channel Access) to distribute command and status information, a variety of graphical user interfaces builder to generate high level applications. EPICS systems are commonly referred to as IOC (input/output controller). EPICS records constitute basic building block units and encapsulate low-level controls (either hardware: device and I/O channels, or purely logical constructs that implement command/status). EPIC also provides a Sequencer Notation Language to create event state logics to coordinate lower level controls. The collection of records defined in an IOC constitutes the EPICS system database.

EPICS controls the following components in Canopus:

- Entrance and Exit shutters
  - two positions devices, opened or closed to protected against dust and/or light contamination
- Natural Guide Star source simulator
  - Controls the insertion/extraction of the stage and sources intensity. The sources are arranged in two separate arrays (Inner/Outer) to allow different NGS configuration.
- Laser Guide Star source simulator
  - Controls insertion/extraction of the stage and sources intensity. The source consists of 5 LEDs emitting 591 nm closely matching the LGS constellation beacons. An additional assembly allows to control Z-axis motion to change focus (Na layer distance varying from 85 to 200km)
- Power and Temperature status information for the three deformable mirrors
- DM0 mask
- Selection of the science beam splitter
- Science ADC
  - Controls the insertion/extraction of this deployable stage, tracking telescope elevation when inserted.
- NGS ADC
  - Similarly, tracks the telescope (this stage is always inserted)
- NGS Probe 1, 2 and 3
  - Each probe has two independent degrees of freedom to allow centering on their respective guide star. The probes are mechanically arranged on top of another to allow more efficient control during offset/dither (no relative motion of one probe to another)
- LGS zoom and magnification correction
  - Motorized stages accounting for variations of the atmosphere Sodium layer distance.
- Several status channels reporting temperatures, power etc. information
- Interface to the Gemini Interlock System

5. DEFORMABLE MIRRORS

Canopus uses three deformable mirrors conjugated at different altitude. The DMs have been manufactured by CILAS and passed acceptance prior to being shipped to Chile. Upon delivery, the mirrors were re-tested and several parameters re-measured (stroke average, influence functions, differential stroke, position stability and hysteresis using a phase shifting interferometer) using dedicated software. No significant changes or degradations were found.

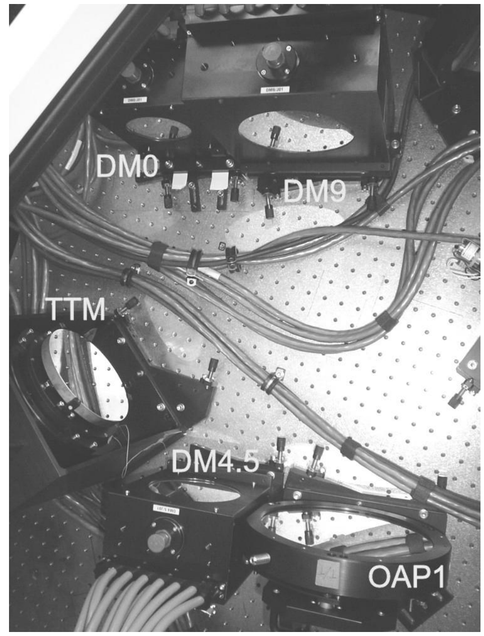

Figure 4. DM9 on interferometer test rig (left) Deformable mirrors mounted on the bench. (right)

	Clear aperture diameter	Number of actuators	Actuator spacing	Maximum stroke average	Mechanical coupling average	Differential stroke average	Mirror surface roughness
DM0	80 mm	293	5 mm	8.20 um @ 800 V PV	23 %	2.41 um @ 800 V PV	0.728 nm
DM4.5	106 mm	416	5 mm	7.71 um @ 800 V PV	24 %	2.39 um @ 800 V PV	0.849 nm
DM9	132 mm	208	10 mm	4.71 um @ 400 V PV	22.2%	2.68um @ 800 V PV	0.834 nm

Table 2. DMs characteristics and measurements from factory acceptance test

6. DM ELECTRONICS

The DM Electronics, under contract with Cambridge Innovation (CI), was specified to have protections for: Max. Slew Rate, HV polarity unbalance and over temperature protections. Besides this the maximum voltages was restricted to +/-370 [V] for better DMs protection. The restricted by hardware slew rate is 27 [V/ms].

	+ HV [mA]	- HV [mA]
DM0	440	440
DM4.5	540	544
DM9	270	273

Table 3. Measured consumption for DMs in flat command condition.

	DM 0 293 Actuators	DM4.5 416 Actuators	DM9 208 Actuators	Max. Power Consumption
CONSUMPTION	9.5 [A]	8.0 [A]	9.0 [A]	2.92 [KW]

Table 4. Maximum power consumption measured while exercising all actuators at maximum stroke.

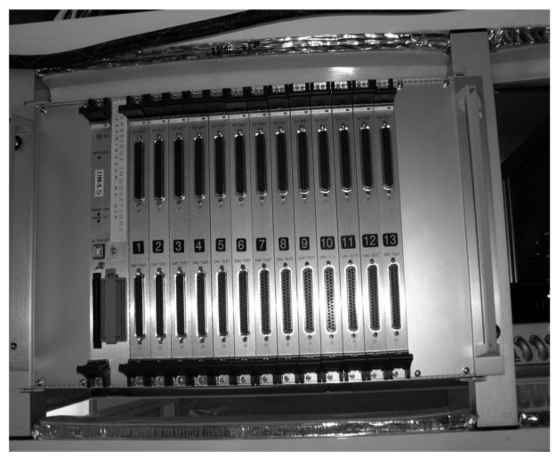

Figure 5. DMs Electronics. HV Power Supplies and Programmable Power Sequencers (left). DM 4.5 HV Driver Boards Rack (right).

7. DIAGNOSTIC WAVEFRONT SENSOR

A Diagnostic Wavefront Sensor unit was built to allow characterizing performance of the bench during integration in the lab. The rig is mounted on top of Canopus to collect the corrected science beam using two fold mirrors temporarily mounted on the bench.

The DWFS was designed and built selecting some of the bench components. Electronics designed for the gimbals motors was embedded into the bench servo chassis. The unit is motorized along X,Y axis, a translations stage allows to select the active camera, a gimbal stage controls pointing while off axis (the beam is not telecentric). Components reuse (electronics, power supply, software) provided a convenient platform to debug issues.

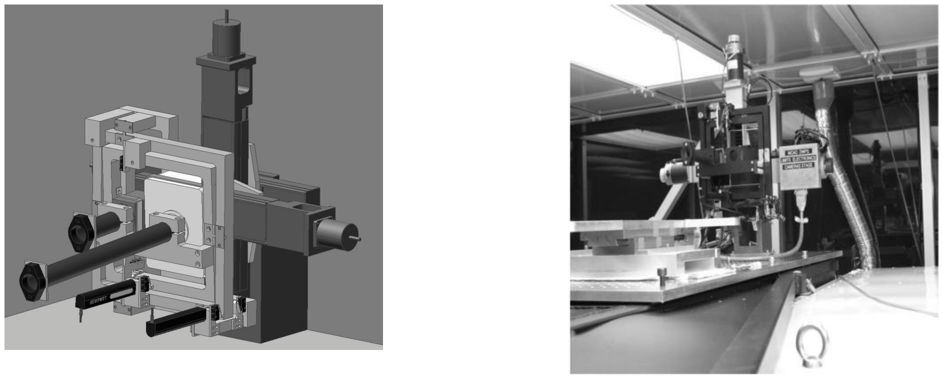

Figure 6. DWFS design study (left) Final assembly installed on Canopus (right). The turbulator hot air exhaust tube and fan – attached to the clean room's roof – can be seen in the background.

Two sensors are mounted on the DWFS: an imaging camera (SBIG ST402) and a commercial wavefront sensor (Mini-Wavescope from AOA). All the components of the DWFS have been interfaced by software to allow remote execution of diagnostic and calibration routines from high-level tools developed in-house (Figure 11).

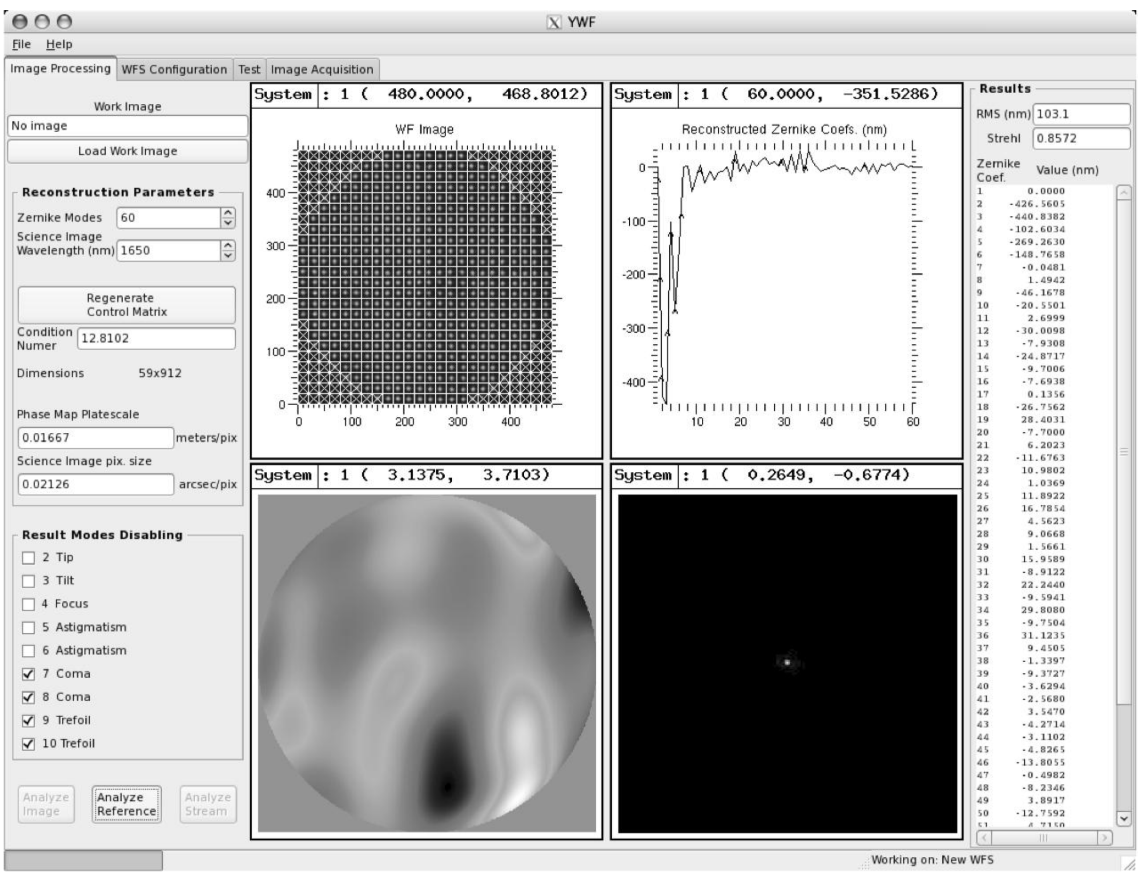

Figure 7. DWFS diagnostics and reductions interface.

8. TURBULATOR

The turbulator was designed in-house. It recreates high order atmospheric turbulences in laboratory conditions by mixing hot and cold air. Combined with the RTC capabilities to generate low order `electronics` turbulences, the system allows characterizing the bench performance under realistic conditions [3] prior to its integration on the telescope. This unit is installed in front of DM0, we are considering a second unit for DM9 to further enhance our testing setup.

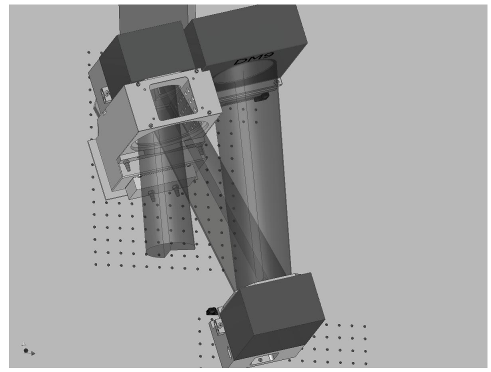

Figure 8. 3D model of the turbulator mounted in front of DM0

9. NATURAL GUIDE STAR WAVEFRONT SENSORS

Canopus is equipped with three Natural Guide Star Wavefront Sensors. The design uses a nested arrangement to minimize relative movement between probes. Each probe is illuminated by a f/44 beam split by a reflective pyramid and injected into a set of 4 optical fibers (Polymicro FIP320885415) feeding Avalanche Photodiodes quad cell (Perkin Elmer's model SPCM-AQ4C) for tip/tilt determination. Probe #3 sends 25% of its signal to a slow focus sensor (SFS) Alta-U47 camera. Each sensor is mounted on a motorized stage to allow patrolling the field. Probe #3 that holds the SFS covers 100% of the field, while the others cover ~60% (Figure 9.) High-level software tools help setting up optimal configuration of the NGS probes geometry.

The probe holders were redesigned and retrofitted to relieve stress from the fibers (Figure 10.). An interlock system was designed to prevents accidentally turning on the APD when ambient light is detected.

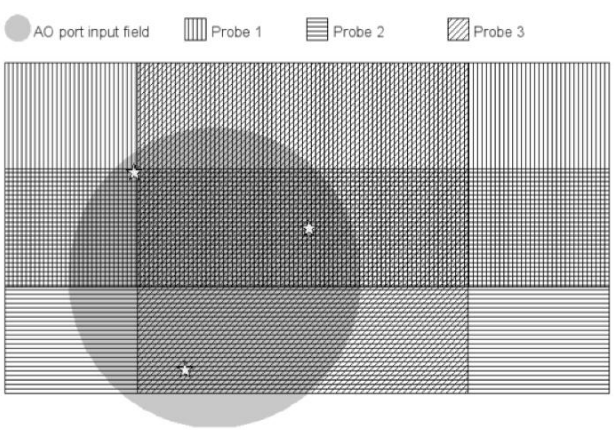

Figure 10. NGS tested in the lab

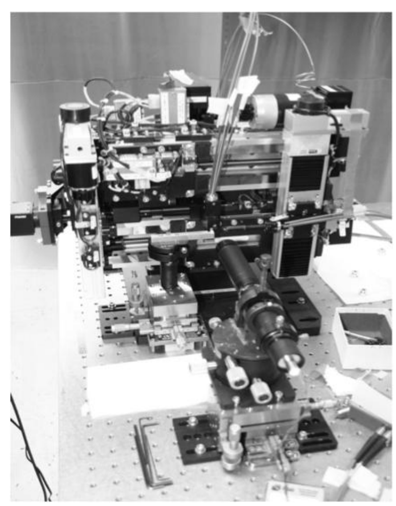

Figure 9. NGS probes patrol fields

10. LASER GUIDE STAR WAVEFRONT SENSOR

The Laser Guide Star Wavefront Sensor consists of five E2V39 CCDs imaging 16x16 Shack-Hartmann Wave Front Sensors, a total of 5x 204 = 1020 active subapertures. A San Diego State University (SDSU) Leach III unit controls the five cameras. The LGSWFS can operate at a rate up to 800Hz. The opto-mechanical assembly uses stepper motors to control zoom and magnification correction to account varying sodium layer distance. Refer to [6] for more details about the LGSWFS.

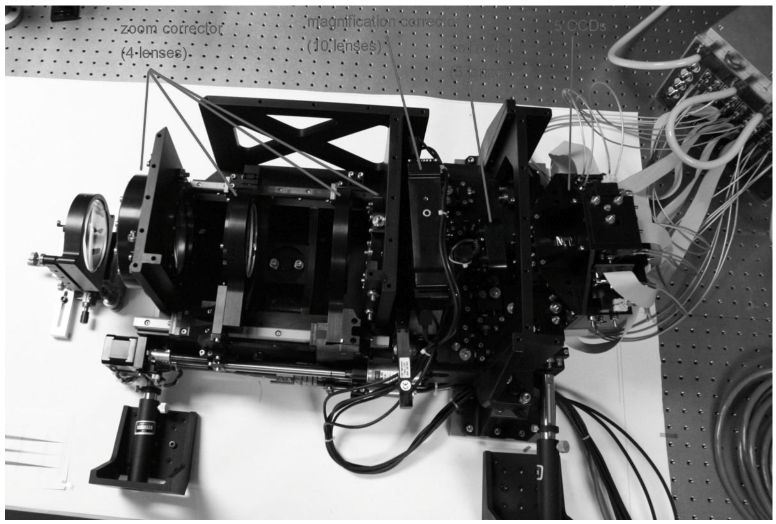

Figure 11. Laser Guide Star Wavefront Sensor Assembly

11. REAL-TIME CONTROLLER

The Real Time Controller (RTC) is the heart of the MCAO control system. It is responsible for measuring and correcting wavefront errors. The signal from the five laser guide star wavefront sensors and three natural guide star wavefront sensors is collected and analyzed to control the three deformable mirrors and the tip/tilt mirror.

We will give a short overview and some characteristics of the system. Thorough details on this critical and complex system are covered in a separate paper [5].

The RTC is built using components off the shelf. A Pentium CPU hosts the graphical user interface and runs miscellaneous background tasks. The host implements the TCP/IP layer to the observatory command and status interface. Hard real time computations and control of the hardware (5x LGSWFS, 3x DMs, 3x quad APDs and TTM) are handled by an array of 12 TigerSHARCs DSPs (two TS201S cards hosting 6x 550MHz DSPs each) mounted on a PCI extension chassis. Repartition of tasks on different DSPs allows a high degree of parallelisms. Communication between the different processes in the RTC is accomplished using shared memory. Different ring buffers store real time information. That content of the buffer can be saved on disk to be accessible to background optimization processes and diagnostics utilities [1].

Stringent operations of the RTC have been implemented in assembly to meet the high throughput and low latency requirements of MCAO. The delivered system surpassed our expectations as we measured ~50us. overall latency (a factor 2 improvement over our requirement).

The RTC interfaces to the Gemini time bus system to retrieve accurate timestamps, and the Gemini reflective memory bus to blend-in external wavefront sensors signal (On Detector Guide Windows for GSAOI, On-Instrument Wavefront Sensor for Flamingos2). The reflective memory is also used for offloading to the telescope secondary mirror and steer the laser on the sky with the Beam Transfer Optics Fast Steering Array (BTO/FSA).

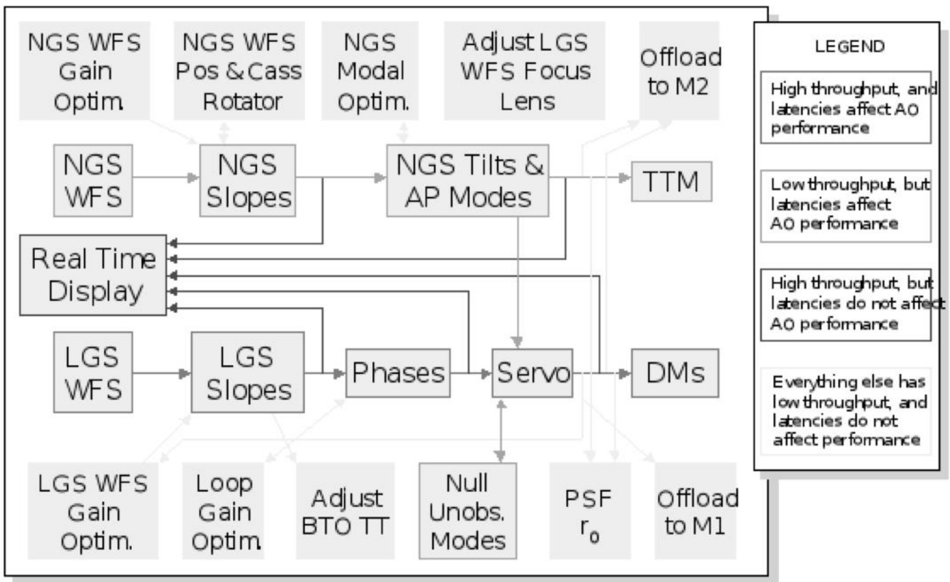

Figure 12. Real Time Controller processing functions (*)

LGS Sub-Apertures	5x 204 = 1020
Phase gradients	2x 1020 = 2040
Reconstructed phases	240 (DM0) + 324(DM4.5) + 120 (DM9) = 684 (active actuators)
Extrapolations	53 (DM0) + 92 (DM4.5) + 88 (DM9) = 223 (passive actuators)
Nominal rate of operation	800Hz
TTM latency	6 us
Total latency	50 us

Table 5. RTC characteristic numbers

(*) "Final design for the Gemini South MCAO Real Time Controller" - S. Browne et al

The RTC graphical user interface provides control and a rich variety of diagnostic and display of the underlying system: raw pixel from LGS and NGS WFS, histograms, slope displays, DMs phases and commands, statistics etc. Sub-windows are cursor sensitive, a textual window reports value information for the elements pointed at.

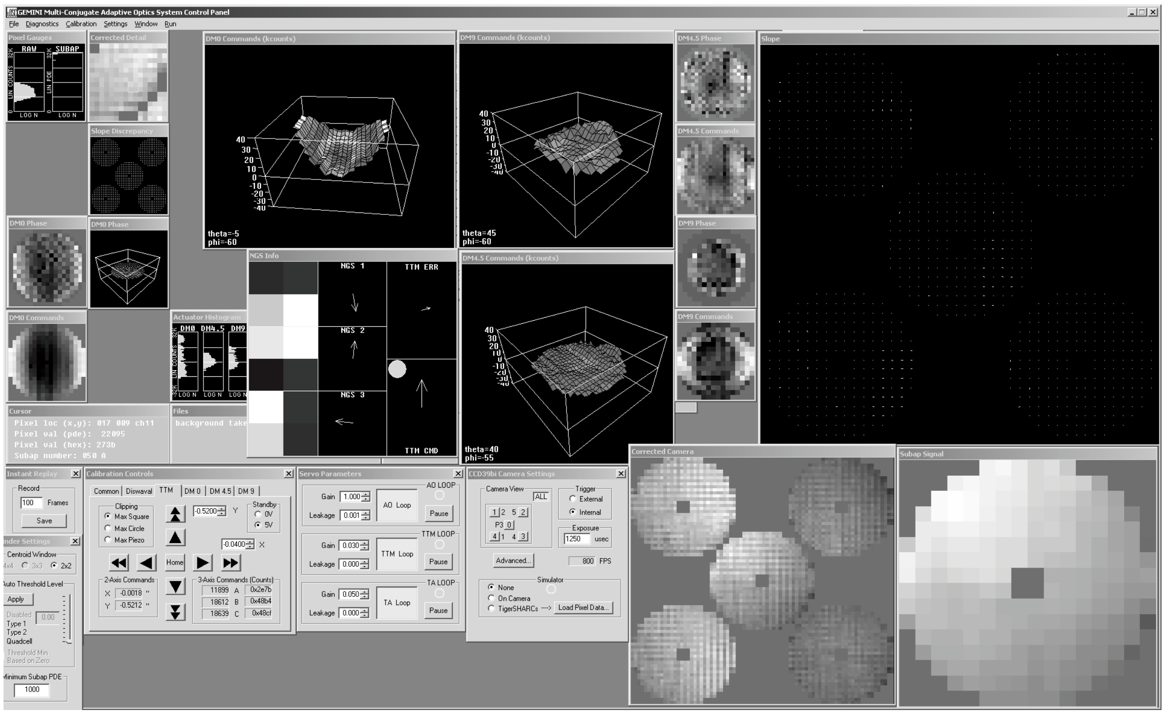

Figure 13. RTC Graphical User Interface

The RTC UI also offers remote viewing capability, exporting information packets over TCP/IP. Gemini implemented an EPICS based x86 system to collect and redistribute that information. Coupled with our EPICS command and status database, we were able to provide a truly distributed backend to the RTC and develop high-level analysis, sequencing and diagnostic applications [1].

12. SUMMARY

The integration of Canopus in the lab allows us to exercise crucial aspects of the bench prior to its integration on the telescope. We have been able to uncover and fix several issues with the motor controller electronics, implemented mechanical enhancements to the NGS probes, resolved some vignetting issues. The integration of the RTC allowed us to demonstrate MCAO functionality under realistic turbulence conditions in the lab.

At the time of this writing, we are completing flexure tests and reviewing results. Upcoming activities will cover end-to-end test of all the opto-mechnical controls, completion of the thermal cooling redesign for the DM electronics and enclosure insulation rework, investigation of Pixel Edge Diffusion effect on the LGSWFS, recoating of DM0, comprehensive vibration analysis.

We are planning to transport Canopus to Cerro Pachon in January 2009 for further tests and verification in the lab, coupling it with the Gemini South Adaptive Optics Imager (GSAOI) – shortly followed by GEMS nighttime commissioning on the telescope [4].

13. ACKNOWLEDGEMENTS

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