Current and future facility instruments at the Gemini Observatory

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ABSTRACT

At the present time, several new Gemini instruments are being delivered and commissioned. The Near-Infrared Coronagraph has been extensively tested and commissioned on the Gemini-South telescope, and will soon begin a large survey to discover extrasolar planets. The FLAMINGOS-2 near-IR multi-object spectrograph is nearing completion at the University of Florida, and is expected to be delivered to Gemini-South by the end of 2008. Gemini's Multi-Conjugate Adaptive Optics bench has been successfully integrated and tested in the lab, and now awaits integration with the laser system and the Gemini-South AO Imager on the telescope. We also describe our efforts to repair thermal damage to the Gemini Near-IR Spectrograph that occurred last year. Since the last update, progress has been made on several of Gemini's next generation of ambitious "Aspen" instruments. The Gemini Planet Imager is now in the final design phase, and construction is scheduled to begin shortly. Two competitive conceptual design studies for the Wide-Field Fiber Multi-Object Spectrometer have now started. The Mauna Kea ground layer monitoring campaign has collected data for well over a year in support of the planning process for a future Ground Layer Adaptive Optics system.

Keywords: Instrumentation, optical, infrared, detectors, cryogenic

1. CURRENT INSTRUMENTS

The Gemini Observatory has entered a mature and productive era with a number of first- and second-generation instruments on both telescopes being operated in a flexible queue-based observing system[1] that takes best advantage of observing conditions as they occur. The telescopes are designed to allow rapid and flexible switching between instruments, which allows astronomers to obtain data in conditions best suited to the observations. Gemini has pioneered the ability to respond quickly (within minutes) to targets of opportunity, such as gamma ray bursts, or to dynamically define targets and observations for temporal monitoring, such as supernovae or weather monitoring of Titan.[2] Both Gemini telescopes now have sophisticated multi-layer protected silver coatings on their mirrors, giving the Gemini telescopes very low emissivity. Recently Gemini has commissioned a sodium laser guide star system for Adaptive Optics (AO) observations on Gemini-North. Most of the instruments in regular use on the Gemini telescopes are described in previous versions of this SPIE report.[3,4,5,6,7,8]

On the Gemini-North telescope on Mauna Kea, Hawaii, Gemini operates the GMOS optical multi-object imaging spectrograph,[9,10] the MICHELLE mid-IR imager and eschelle spectrograph,[11] the NIRI near-IR imager,[12,13] and the NIFS near-IR integral field spectrograph.[14] NIRI and NIFS are used with the Altair AO system. Altair is now producing excellent results using a sodium laser guide star (LGS), although there is still work to be done to make the system more robust and efficient. Since the last report, NIFS has been fully commissioned on Gemini-North with both natural and laser guide star AO. The TEXES mid-IR high-resolution spectrograph was used as a visiting instrument at Gemini in 2006 and 2007.[15] GNIRS, a near-IR cross-dispersed spectrograph,[16,17] suffered thermal damage when a temperature controller failed last year, and will be repaired and returned to service on Gemini-North in 2009.

At Gemini-South on Cerro Pachón in Chile, Gemini provides access to the southern version of GMOS and the T-ReCS mid-IR thermal imager and spectrograph[18]. NOAO and SOAR have loaned Gemini the Phoenix near-IR high-resolution spectrograph[19] for the past couple of years, and we anticipate using Phoenix on Gemini-South into 2009. The Near-IR coronagraph NICI[20] is currently being commissioned on Gemini-South, and is scheduled to begin regular science operations later in 2008.

Ground-based and Airborne Instrumentation for Astronomy II, edited by Ian S. McLean, Mark M. Casali,
Proc. of SPIE Vol. 7014, 701405, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.789842

1.1 The Near-Infrared Coronagraphic Imager

Gemini's latest addition to its instrument suite at Gemini-South is the Near-Infrared Coronagraphic Imager (NICI).[20,21] NICI is the first Gemini instrument designed specifically to search for and analyze the properties of planets orbiting other stars, and one of the first in the world optimized to image the light from planets directly. With an on-board 85-element AO system, dual imaging cameras with narrow-band methane filters, and an optimized coronagraph, NICI is designed to take advantage of Gemini's excellent image quality to find planets around young stars. Each camera has its own detector and set of methane filters, maximizing sensitivity to giant planets with methane in their atmospheres. NICI was built in Hilo, Hawaii by Mauna Kea Infrared LLC (MKIR) under the leadership of Doug Toomey. NICI is unique among Gemini instruments in that it was funded by a NASA grant as part of NASA's mission to explore extrasolar planets. This independent funding made it possible to design a specialized AO instrument that might not have otherwise been built because of tight funding within the Gemini partnership.

NICI passed acceptance tests in Hilo in October 2006, and was shipped to Cerro Pachón in January 2007. The Gemini and MKIR instrument team assembled NICI and tested it in the lab at Gemini South. NICI was installed on the telescope and saw first light on the night of February 20, 2007. The first observations successfully demonstrated good coronagraphic performance and showed that the AO system was behaving as expected. The AO performance was limited at that time by vibrations in the Gemini secondary mirror control system and by the thickness and resonances of the original deformable mirror (DM).

Figure 1. A technician works on NICI in the instrument lab at Gemini-South.

During the following months, Gemini engineers worked to improve the stability of the secondary mirror control system, and a new DM from the University of Hawaii was delivered. The new DM has a lower minimum radius of curvature, providing significantly greater stroke. It also has higher resonant frequencies, meaning it can be used at higher gain under worse seeing conditions than the original DM. The new DM performed very well in lab tests, and was tested on the sky in July 2007. The results of that run were very encouraging. Strehl ratios of ~50% at 2.2 μm were measured, in line with the expected performance for NICI.

The initial NICI commissioning tests revealed a number of issues that are being resolved before regular science operations with NICI begin. First, the electronics enclosures built by Gemini were inadequate to keep all the NICI electronics cool enough for regular operations on the telescope. The heat exchangers in the enclosures were rebuilt and the ventilation improved. Second, software development by MKIR and Gemini staff continued throughout 2007 to make NICI work as an integrated part of the Gemini queue. Finally, we are improving the reliability of the dual array controllers to produce reliable, low-noise performance on the telescope. Some timing and interference issues between the two detector controllers introduce occasional hangs, lost pixels, and increased noise. These appeared to be minor during early testing, but turned out to be limiting factors when NICI was tested at the limits required to detect faint planets. These issues are being addressed, and we expect NICI planet finding observations to begin in mid-2008.

NICI is the most specialized of Gemini's instruments thus far, and meeting its science goals will require a large survey of nearby stars conducted over several years. In 2005, Gemini awarded ~50 nights of observing time to a team led by Michael Liu (U. Hawaii), Laird Close (U. Arizona), and Mark Chun (U. Hawaii) to conduct the NICI planet search survey. The NICI planet survey will search for massive planets (like Jupiter) around young, nearby stars. With a census of young planets, the NICI campaign team will address important questions about the distribution of masses and separations of planets in the outer regions of other planetary systems, the affect of the mass of the parent star on the chances of planets forming, and the properties and compositions of young giant planets. Most planets discovered around other stars have been detected indirectly via their gravitational influence on their parent stars (the radial velocity technique). NICI is designed to find a very different class of planets because it will preferentially find giant planets orbiting farther out, in regions of their planetary systems comparable to those occupied by the giant planets in our own solar system. Unlike the radial velocity instruments, NICI will be able to detect the infrared light from the planets directly, revealing much about their masses, compositions, and temperatures.

Planets are much fainter than their parent stars. Diffraction from the bright star forms long-lived speckles that can be confused with a planet. To help distinguish real planets from the speckles, the NICI campaign team will use specialized filters and the spectral differential imaging strategy. The atmospheres of giant planets contain methane, which has strong near-IR spectral signatures. The filters in NICI have been specially designed to maximize the contrast between objects with methane in their atmospheres (planets and brown dwarfs) and those that don't (stars). The campaign team is also exploring the angular differential imaging technique which involves holding the cassegrain rotator fixed during observations.[21] With the rotator stationary, background stars and planets will rotate in the field of view, while the speckle pattern remains unchanged. Companion planets can be difficult to distinguish from background stars, so the NICI campaign will require follow-up observations taken months later. During the time between observations, the nearby star and its planets will have moved relative to the background stars, making it possible to distinguish real planets from background objects. These strategies will maximize the campaign team's chances of finding real planets.

The NICI team continued with commissioning runs at Gemini South in early 2008. NICI was mounted on the side port of the instrument support structure, its nominal position for general operations, and run completely under high-level software control. After calibrating the transformations required to control the AO system steering mirror, formerly long and laborious target acquisitions became a simple, semi-automatic process requiring only a few minutes. Operating with the Gemini observatory control software simplified long or complex sequences of observations. In 0.6 arcsecond natural seeing, the delivered Strehl ratio was 0.35 to 0.40 at 1.6 μm over a 2-hour period. Figure 2 shows images of the star HD 129642 and a nearby background star.

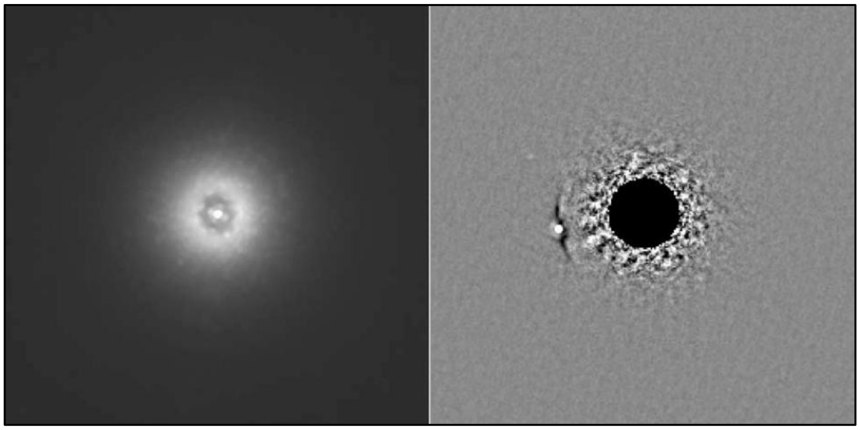

Figure 2. NICI images of HD129642 in the 1.6 μm methane 4% filter. The image at left is a coaddition of 76 images; the star is visible through the semi-transparent 0.3 arcsec coronagraph mask. The image at right was processed to remove the central star, revealing a faint background star (at the 8 o'clock position).

In the next few months we plan to improve NICI's performance in two basic ways. The first is to refine the alignment and tuning of the AO system to deliver higher Strehl ratios. The second is to reduce read noise and improve the reliability of the array electronics. MKIR, together with collaborators at the University of Hawaii and Gemini, is working on array controller improvements to be implemented and tested before the beginning of campaign observations in semester 2008B.

1.2 The Gemini Near-IR Spectrograph

At the end of April 2007, the Gemini Near-Infrared Spectrograph (GNIRS)[16,17] suffered a temperature controller failure that caused it to overheat. Although some significant parts were damaged, most of the GNIRS instrument was undamaged. Gemini has started the process of restoring GNIRS to full functionality in Hilo, where it will be repaired and returned to service on Gemini North.

GNIRS was warmed up in April for routine cold head service. The fast warm-up system and vacuum pumps were used following normal operating procedures that had been successfully followed a dozen times before. The fast warm-up system has a completely independent hardware controller that normally shuts off power to the heater resistors when the temperature set point is reached. For an unknown reason, the controller failed and GNIRS was continuously heated until it reached temperatures of nearly 200° C. Gemini staff members do not normally monitor the temperatures remotely; doing so might have prevented much of the damage. When Gemini personnel returned to the mountain, they shut the heaters off and allowed GNIRS to cool passively with the pumps running for several days.

After the instrument had cooled, the dewar was opened and the main components inspected by a team of Gemini engineers and scientists. With the support of the experts at the National Optical Astronomy Observatory (NOAO) who built GNIRS, Jay Elias (GNIRS PI, NOAO) helped assess the damage and develop the recovery plan. The multi-instrument queue allowed Gemini to quickly adapt to the loss of GNIRS, and no observing time was lost (although the lost opportunity to use GNIRS clearly affected many highly ranked programs). NOAO and the Southern Astrophysical Research (SOAR) consortium agreed to leave the high-resolution infrared spectrometer "Phoenix" at Gemini for the rest of 2007 and 2008. A special call was issued, inviting proposals for additional bright-time programs using GMOS, T-ReCS and Phoenix. These steps help insure that the scientific potential of the telescope was met following the GNIRS accident.

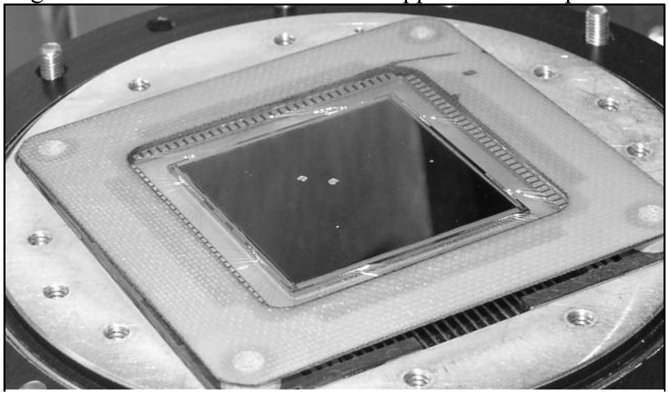

Figure 3. Thermal damage to the Aladdin 3 In:Sb detector.

The initial inspection of GNIRS showed that some components with low melting points were damaged. The plastic Delrin^{TM} parts, which are mostly used as lens spacers or filter baffles, had melted. The load-bearing G10 fiberglass components were weakened to the point that some had cracked and began separating. The most significant loss was the In:Sb Aladdin 3 science detector (Fig. 3). The dewar window was coated with plastic and resin (Fig. 4). The dewar shell and optical bench, most mechanisms, wiring, motors and electronics were undamaged.

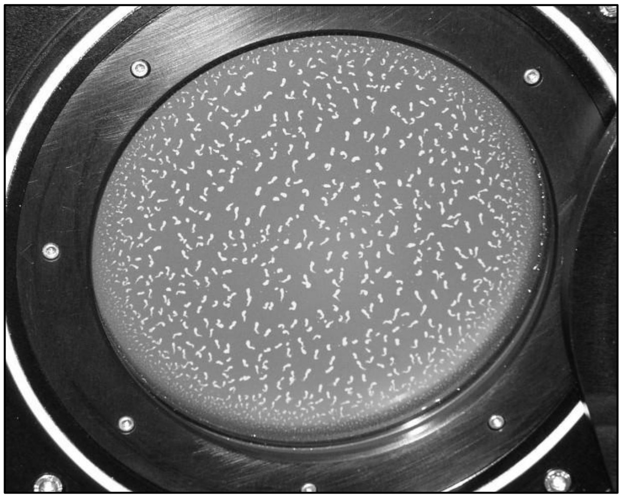

Figure 4. Plastic and resin contamination on the GNIRS window.

In August 2007, GNIRS was prepared for shipment from Cerro Pachón to Hilo, where it is being refurbished. By early September 2007, GNIRS was packed and then flown to Hawaii. In preparation for the arrival of GNIRS, Hilo staff prepared and cleaned the instrument lab, and relocated a clean room and some work benches into the Hilo instrument lab. By late September, Gemini staff members were beginning the second phase of damage assessment and repair at the HBF.

We are now working to fix or replace the damaged parts. The damaged G10 fiberglass supports have been replaced. The resin in the original supports broke down, producing a yellowish deposit that coated parts of the vacuum jacket (the coldest part of the instrument during the overheating event). The fiberglass replacement struts were installed before GNIRS was shipped to Hilo for further repairs. The vacuum jacket and radiation shields have now been thoroughly scrubbed, pressure-washed, and cleaned.

The Aladdin 3 In:Sb science detector was destroyed when its indium layer melted (Fig. 3). We have ordered a replacement Aladdin 3 array from Raytheon Vision Systems and expect delivery in mid-2008. The array will be tested and characterized at NOAO prior to installation in GNIRS. In the meantime, a multiplexer and engineering-grade array are available for testing the electronic and optical systems before installing the new science-grade detector. The GNIRS team considered replacing the science detector with a newer array, such as a Teledyne HAWAII-2RG. We concluded that a different detector would require significantly more time and money to retrofit into GNIRS and produce only minor performance improvements because the GNIRS optical design was optimized for the Aladdin 3 architecture.

The HAWAII-1 Hg:Cd:Te detector in the on-instrument wavefront sensor (OIWFS) must also be replaced. The University of Hawai'i (UH) Institute for Astronomy is providing a new array and repairing the OIWFS. UH built the three nearly-identical OIWFS wavefront sensors for NIRI, GNIRS, and NIFS. The HAWAII-1 array does not need to be science-grade, since only a small subset of pixels in one quadrant are used to track image motion. UH will test existing engineering-grade arrays they have on hand and choose an appropriate one to repair the GNIRS OIWFS. In addition to replacing the array mount and detector, UH will test and refurbish the mechanisms and optimize the optics for use with Altair. The GNIRS OIWFS repair will allow us to test new guiding systems that may allow future improvements to the Altair LGS sky coverage by providing tip-tilt natural guide stars over a wider field of view than is currently accessible with the Altair optical wavefront sensor.

Figure 5. Disassembling and cleaning the GNIRS optical bench.

All of the GNIRS optical elements have been removed and examined (Fig. 5). The entrance window and filters were replaced with spares. A subset of the lenses and mirrors were sent to NOAO for further expert assessment. Several of the optics, even those that were protected from direct contamination, were damaged. Some of the lenses had edge chips. The damage is outside the clear aperture, but the chips will have to be stoned out, and some of the lenses may need to be repolished and recoated. Contamination on some lenses is especially sticky, even with fairly aggressive cleaning with solvents. The lenses have been returned to the original vendors for further assessment and repair, if necessary. The mirrors suffered worse damage than the lenses. One of the fused silica flat mirrors shattered, and the gold coatings on the diamond-turned collimator mirrors were damaged (Fig. 6). The replicated epoxy mirrors and diffraction gratings were damaged, and new gratings will have to be produced. Some mirror samples were sent to Optical Data Associates in Tucson, Arizona, for further testing. Their report showed that the contamination on the mirrors did not have significant absorption features in the near-IR, meaning that any optics with intact coatings may be usable. The flat mirrors will be replaced, and the diamond turned mirrors refigured and recoated. After the optics are cleaned, repolished, recoated, or rebuilt, they will be installed and aligned. We are also repolishing the cross-dispersing prisms to improve image quality, especially when GNIRS is used with the Altair AO system.

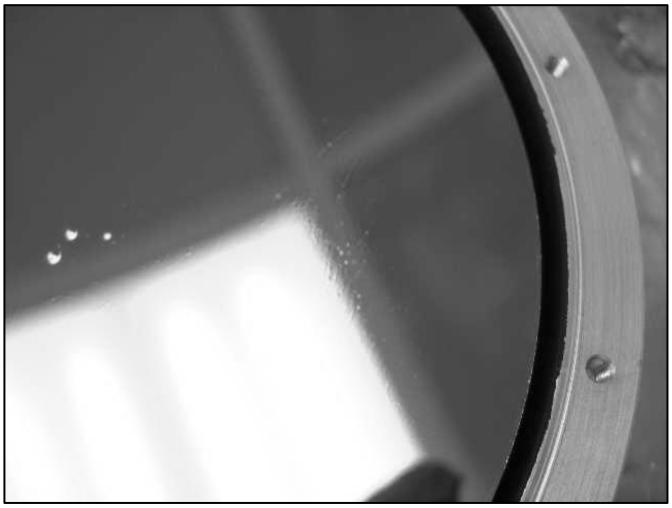

Figure 6. Coating damage is visible as pits and wrinkles on a protected gold-coated diamond-turned mirror.

Thermal damage to the integral field unit (IFU) was significant (Fig. 7). Because of the way the IFU is constructed and the extent of the damage, it is not feasible to repair it. The IFU would most likely have to be rebuilt from scratch, and that would significantly exceed our repair budget. Although the GNIRS IFU is a complete loss, we have not lost the majority of its capabilities. Gemini has recently commissioned the Near-infrared Integral Field Spectrograph (NIFS), an IFU instrument with similar capabilities.[14] NIFS has excellent spatial sampling and is designed to be used with the Altair Adaptive Optics system. The field of view is almost identical to the defunct GNIRS IFU, but with better spatial sampling. NIFS has spectral resolution of ~5000, similar to the resolution delivered by the GNIRS IFU. The one area where NIFS falls short in comparison to GNIRS is in the 2.5 to 5 μm regime. NIFS uses a HAWAII-2RG detector that cuts off at 2.5 μm, while GNIRS is sensitive to 5 μm. The longer-wavelength mode of the GNIRS IFU was not commonly used, however, so we expect that this loss of capability will have limited impact on the science delivered by GNIRS.

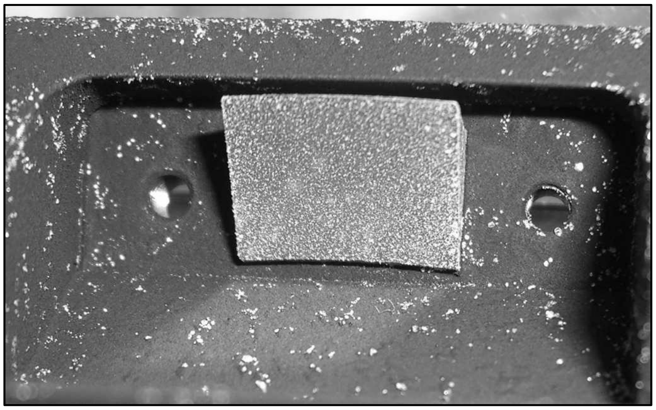

Figure 7. One of the mirrors in the IFU that was heavily damaged.

We have made significant progress on a number of other tasks required to get GNIRS back in working order. The motors have all apparently survived, but some of the cables needed to be fixed. The solder on some connectors melted. A great deal of cleaning was needed to remove the yellow resin residue from the inside of the dewar and to remove the melted plastic from many parts. New Delrin™ replacement parts have now been received. Once all the pieces are cleaned and the optics reinstalled, we will align the optics, test the vacuum and cooling systems, and eventually test the entire system with an engineering or science grade detector.

It is worth emphasizing that GNIRS is not lost. The majority of its parts are fine. The work to fix GNIRS is significant and take ~18 months to restore GNIRS to full science operations from the time of the accident. However, the result will be an instrument even better than the original. GNIRS is one of our most important and sought-after facility instruments, and we are optimistic about getting it back on-line and working as soon as practical. We expect that GNIRS will be ready for re-commissioning on the Gemini North telescope starting in semester 2009A. GNIRS will reclaim its role as a world-class 1 to 5 μm spectrograph on Mauna Kea, where the low background and excellent image quality on Gemini will make it even more sensitive than before.

2. INSTRUMENTS UNDER CONSTRUCTION

2.1 Florida Multi-object Imaging Near IR Grism Observational Spectrometer (FLAMINGOS-2)

FLAMINGOS-2 will provide near-infrared wide-field imaging and multi-object spectroscopy on Gemini South after its scheduled delivery in late 2008.[22] With a 6.2-arcminute imaging field diameter and spectroscopic multiplexing capability of up to 80 or more simultaneous spectra over a broad range in wavelength, FLAMINGOS-2 will be a powerful scientific asset for the Gemini community. It will also work with the MCAO system to provide multi-object spectroscopy at high angular resolution (with 90-milliarcsecond pixels). Currently, FLAMINGOS-2 is fully integrated and undergoing testing and performance verification in the University of Florida lab in Gainesville, prior to acceptance testing (Fig. 8).

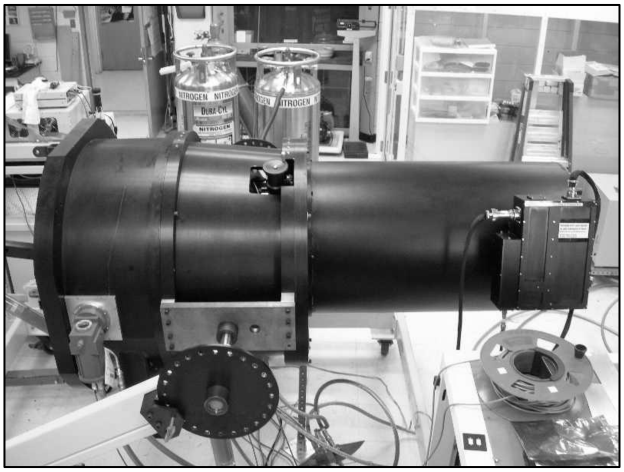

Figure 8. The fully-integrated FLAMINGOS-2 Instrument undergoing final testing at the University of Florida. The MOS fore-dewar, containing the OIWFS and the large MOS mask wheel is on the left.

Since the last report, the Florida team has conducted a number of cold tests, in which the mechanisms and cryogenic systems were tested and a number of problems fixed. All the cryogenic motors were replaced with more robust ones, and all the mechanisms balanced so that they are now working reliably. A number of vacuum problems in the MOS fore-dewar were identified and fixed. Initially poor cooling performance was traced to a number of issues, including inefficient cold head drivers, defective cold heads, faulty temperature sensors, and parasitic thermal loads.

These problems have been fixed, and to add robustness, the Florida team added a second cold head to the MOS fore-dewar.

All the optics have now been received and installed, including the high-resolution grism and some additional filters. The OIWFS, which was built by the Herzburg Institute of Astrophysics (HIA), has now been tested and installed in the FLAMINGOS-2 fore-dewar. Additional baffling was added to reduce stray light. The detector has been installed and the final alignment is now under way. Detector electronics have been tuned to produce the best performance. The software efforts are now nearly complete in spite of the loss of key personnel both at Gemini and UF. The Florida team plans to complete the integration and testing by mid-2008, and ship the instrument to Gemini-South shortly thereafter.

A key highlight of the lab tests so far is that we expect FLAMINGOS-2 to provide exceptional sensitivity for both imaging and spectroscopic observations. The throughput requirements for FLAMINGOS-2 are 50% in imaging mode and 30% in spectroscopic mode (excluding the detector and telescope). Measurements for all optical components as delivered by the optics vendors give actual throughputs of more than 60% in J-band imaging, and greater than 75% in H- and K-band imaging, providing sensitivity gains of ~0.1 magnitude to more than 0.2 magnitude over the initial requirements for FLAMINGOS-2. Likewise, the spectroscopic throughputs are greater than 45% in J+H (R~1300) spectroscopy (Fig. 9), greater than 55% in H+K (R~1300) spectroscopy, and >40% in high-resolution J, H, or K (R~3300) spectroscopy. The excellent throughput alone provides large (~20% to 40%) signal-to-noise gains—or, factors of ~1.3 to ~1.8 reductions in observing time—over the baseline requirements initially envisioned for FLAMINGOS-2.

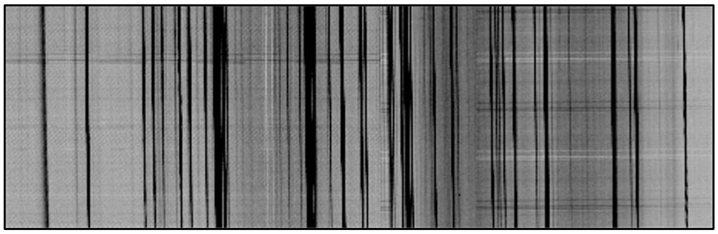

Figure 9. JH spectrogram of a laboratory Krypton arc lamp. The spectrogram used a 4-pixel test slit covering ~1/3 of the field length, and spans the wavelength range of approximately 1.0 to 1.8 μm. The slight tilt of the spectral lines is due to the (correctable) initial coarse alignment of the grism dispersion axis with the slit mechanism.

Other factors also contribute to the exceptional sensitivity we expect for FLAMINGOS-2. The UF team has demonstrated full system read noise with the HAWAII-2 detector of ~10 electrons RMS, indicating very little added noise to the intrinsic read noise of the detector array itself. In addition, they have achieved low instrumental background and dark current, as well as excellent image quality across the entire field of view (we expect less than 10% degradation in image quality even under seeing conditions better than 0.5-arcsecond FWHM). Another recent highlight is that FLAMINGOS-2 completed flexure testing, fully meeting all requirements for this important performance hurdle, ensuring that the excellent image quality will be maintained in the Gemini Cassegrain environment. Work is continuing at the University of Florida at an intense pace to get FLAMINGOS-2 ready for acceptance testing and onto the telescope. The primary effort remaining is final performance verification of the on-instrument wavefront sensor, the focal plane mask mechanism, the (now-fully-loaded) cryogenic grism wheel, and the high-level instrument sequencer control software. The UF team plans to be ready for on-site acceptance testing by August of this year, with shipment to Gemini South and installation on the telescope following shortly thereafter.

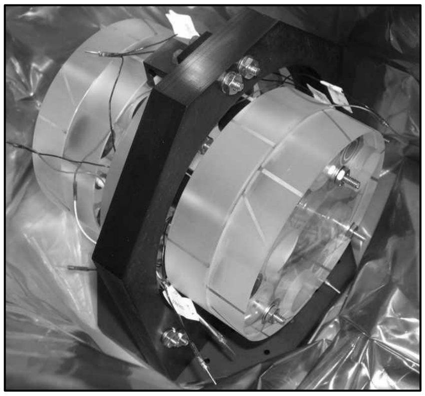

Figure 10. F2T2 dual Fabry-Perot tunable narrow band filter ready for testing at the University of Toronto.

One of the key science questions FLAMINGOS-2 will address is how the first luminous objects formed, and how they ionized the neutral hydrogen in the universe less than a billion years after the Big Bang. At redshifts greater than z=6 the Lyman-alpha emission from hydrogen is shifted into the near-infrared J and H bands (1.1 and 1.6 μm, respectively). To find these objects, special narrow-band filters are being procured for FLAMINGOS-2. In one experiment, very narrow filters will take advantage of the dark gaps between bright atmospheric OH emission lines. In another experiment, a team led by Roberto Abraham at the University of Toronto is building a special tunable filter[23] composed of two Fabry Perot etalons in series (Fig. 10). The etalons have been built and are now being tested in Canada. They will be installed in the FLAMINGOS-2 fore-dewar for dedicated observing campaigns with the MCAO system.

2.2 Multi-Conjugate Adaptive Optics system and the Gemini-South AO Imager

The Gemini Multi-Conjugate Adaptive Optics (MCAO) system is coming together at Gemini South.[24] MCAO will use five laser guide stars and three natural guide stars to correct for limited sky coverage, restricted field of view and the cone effect that affect the performance of single laser beacon AO systems.

The MCAO system passed several important milestones during 2007. First and foremost, we received the remaining subsystems of the AO module, CANOPUS, in July 2007. The natural guide star wavefront sensor (NGS WFS, from EOS Technologies), the laser guide star (LGS) WFS (from the Optical Sciences Company (tOSC)) and the real-time computer (also from tOSC) went through a three-week integration process in July and August which culminated in the first successful laboratory closed-loop tests of the entire system with three operating deformable mirrors acting on correction signals from five laser guide star wavefront sensors and three natural guide star tip-tilt sensors.

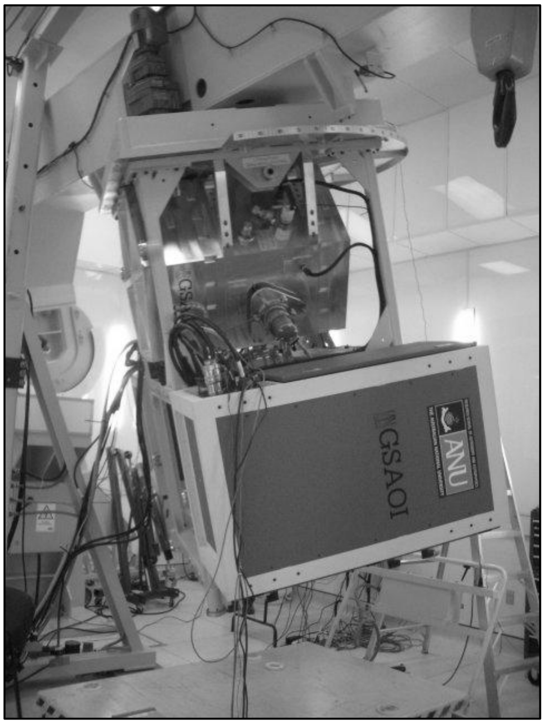

Figure 11. GSAOI being tested on the Gemini-South flexure rig.

In November 2007, Lockheed Martin Coherent Technologies (LMCT) succeeded in producing the required 50 watts of 589 nm laser light with the beam quality and stability specified for the MCAO laser guide star system. This was a major technical hurdle for the project and helps ensure that MCAO will perform to expectations. Recently, LMCT completed the fabrication of the laser bench enclosure. The next milestones in the laser development project include: full characterization of the laser performance on a test bench, final bench vibration and strength testing, complete integration of the optical components on the bench, environmental testing, and factory acceptance. We currently expect the laser to be delivered to Chile this year.

The laser service enclosure and the supporting structure are being designed and built by Gemini staff members. The enclosure is being built at Cerro Pachón and is about 60% complete. The design of the support structure (comprising 10 tons of mass added to the telescope mount) is complete and was reviewed by a structural engineering firm. Fabrication of the truss elements has started.

We have also made significant progress on the beam transfer optics system. All of the active optics mechanical assemblies are built and the electronics subsystems are complete. End-to-end computer control tests have begun in the Cerro Pachón instrumentation lab prior to integration on the telescope. We have also sent the first natural starlight through the laser launch telescope to characterize the image quality of the up-link propagation. One last pending subsystem, the laser bench stabilization system, is being designed to cancel the jitter of the beam injected into the beam transfer optics. CANOPUS, the adaptive optics bench, has seen slower progress due to involvement of staff in telescope operation and maintenance. There are ongoing efforts to fix or improve some mechanical systems (in particular, the thermal management), electronics systems (the servo motors for the moving elements), and the optical systems (for final acceptance of the laser guide star wavefront sensors). Several summer students who worked with us for two months made significant contributions to the development of the software for the diagnostic WFS, the slow focus sensor, the motor drivers, and the avalanche photodiode tip-tilt sensor protection system. The all-sky camera is currently working reliably on Cerro Pachón and will be deployed at Gemini North to support laser operations there while a second system is built and deployed on Cerro Pachón for MCAO.

We currently plan to have the MCAO system assembled and ready to begin commissioning on the telescope early in 2009. Science commissioning with the Gemini South AO imager (GSAOI) should be completed by the end of 2009. Since the last report,[8] GSAOI has been accepted and delivered to Cerro Pachón (Fig. 11) and awaits further commissioning with the MCAO system. Some GSAOI software testing is needed to fully implement the guide window functionality of the four HAWAII-2RG detectors in its focal plane.

3. THE ASPEN INSTRUMENTS

3.1 The Gemini Planet Imager

The first major component of the Aspen instrumentation program to be built is the Gemini Planet Imager (GPI)[25]. The GPI team, led by Bruce Macintosh at the Lawrence Livermore National Laboratory (LLNL), has just completed the design phase (Fig. 12). The critical design review (CDR) for GPI was held in May 2008. Gemini has been working with the project manager Dave Palmer (LLNL) and the systems engineer Les Saddlemyer (HIA) to better define how GPI will work within the Gemini environment. The GPI team, including the University of California at Los Angeles (integral field spectrograph), the Jet Propulsion Laboratory (JPL, calibration interferometer), the American Museum of Natural History (AMNH, coronagraph), HIA (mechanical structure and software), University of California at Santa Cruz (deformable mirror, assembly and testing), and Université de Montréal (data processing software) are working together to ensure that this precision optical instrument performs to specification for many years, even in the dusty, vibrating, and changing environment on the telescope.

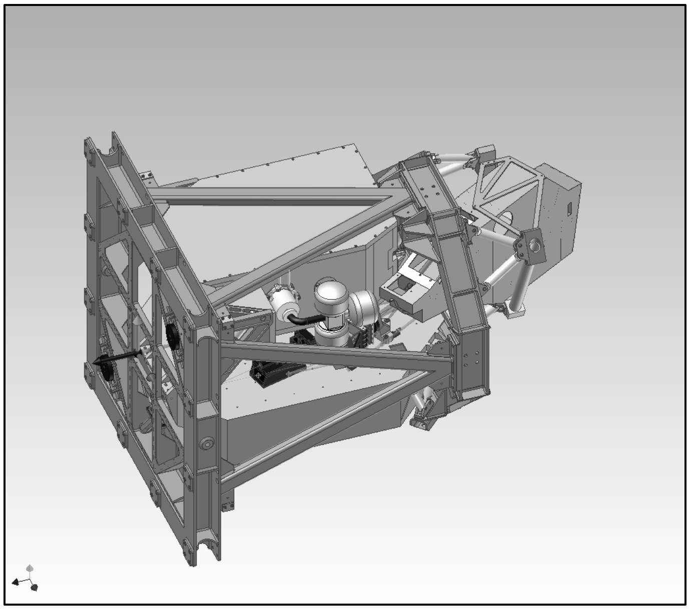

Figure 12. The arrangement of the various GPI subsystems in their mechanical frame. The integral field spectrograph is on the top, the AO bench below, and the calibration interferometer extends to the right.

The GPI team has made considerable progress since the preliminary design review a year ago. The systems engineering team has worked closely with Gemini staff engineers to better define the instrument performance in the Gemini environment, including in particular the vibrations on the telescope, the effects of dust contamination over time, and the influence of tip-tilt errors due to wind shake. The GPI team now has sophisticated models to predict end-to-end system performance and delivered contrast ratios (Fig. 13). The team has also been exploring some of the key technologies

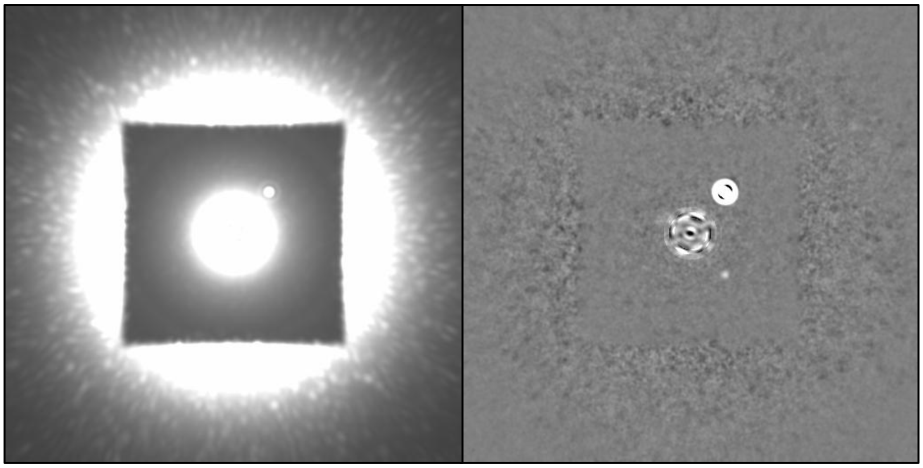

Figure 13. Simulated 2-hour raw image of a 100 Myr old star at a distances of 10 pc (left). The right frame shows a differential image (using a three-wavelength speckle suppression technique). The two simulated planets (at 1 o'clock and 5 o'clock) are 5 and 1 Jupiter-mass companions located 4 AU from the star ($\Delta H=12$ and 17.4 mag, respectively).

needed for GPI. A prototype 4096-element microelectromechanical (MEMS) deformable mirror (DM) built by Boston Micromachines is now being tested in Santa Cruz (Fig. 14). The AMNH team has tested several different technologies for creating the proper gradients in the pupil apodizers. High energy beam sensitive (HEBS) glass tests are currently under way with apodizers being written at JPL, while the micro-dot prototype has been received and is being tested at AMNH (Fig. 15). A design for an atmospheric dispersion corrector has also been chosen, and the science team has helped optimize the wavelength coverage and spectral resolution of the integral field spectrograph. At the present time, we expect that the instrument performance will reach the 10^7 contrast ratio GPI was designed to achieve.

To prepare for CDR, the science team (led by James Graham at UC Berkeley) has developed several proposed planet-finding surveys for GPI. These "design reference missions" help the team make complex design decisions as they arise. The GPI team anticipates finding 200 or more planets by looking at approximately 2500 nearby young stars in an observing campaign of ~380 nights. Such an extensive survey, possibly including both Gemini North and South telescopes, would be conducted over a period of several years and could survey a complete sample of young and adolescent stars in the solar neighborhood. A GPI campaign science team will be selected in 2009 through an open competition within the Gemini partnership. We look forward to finding planets at Gemini-South with GPI starting in 2011.

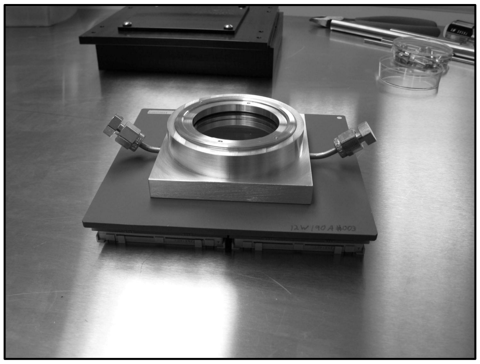
Figure 14. Prototype 4096-actuator MEMS DM in its environmental housing

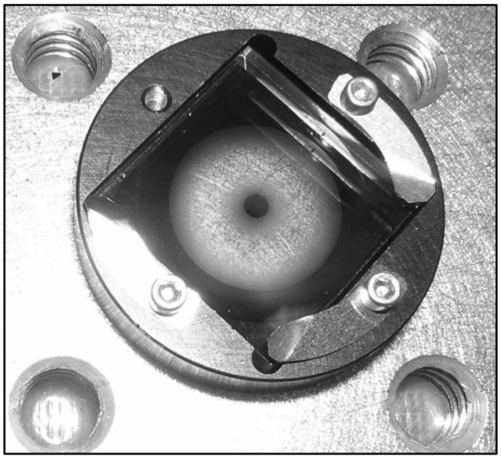
Figure 15. Prototype microdot apodizer being tested at AMNH.

3.2 Wide-Field Fiber Multi-Object Spectrometer

The scientifically highest-ranked instrument to emerge from the Aspen process[7,8] was WFMOS. WFMOS would permit about 4,500 spectra to be taken simultaneously across a ~1.5-degree field of view. This multiplex gain makes WFMOS a truly transformational instrument, one that will answer key questions in the areas of galactic evolution and the nature of dark energy. It will revolutionize our understanding of the history of the Milky Way Galaxy and the evolution of the universe by measuring the properties and motions of millions of stars and galaxies.

Gemini is planning this ambitious instrument in collaboration with our Japanese colleagues at the Subaru Telescope (operated by the National Astronomical Observatory of Japan). WFMOS is being designed for use at the Subaru Telescope, where it will share a common wide-field optical corrector with the Subaru optical imager HyperSuprime Camera.[26,27] During the WFMOS Feasibility Study in 2004-2005, Gemini and Subaru agreed to explore the possibility of collaborating on WFMOS. Subaru would be a much better platform than Gemini for such a massive, wide-field prime focus instrument (Fig. 16). If built, the Japanese community will be partners in the construction and scientific mission of WFMOS. Subaru and Gemini will share

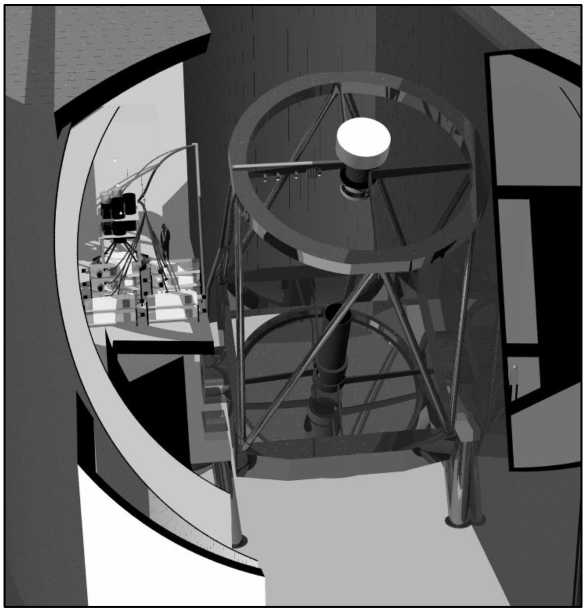
Figure 16. WFMOS concept for Subaru as suggested by the original AAO Feasibility Study. Fibers carry light from the prime focus unit to a bank of spectrographs located off the telescope.

construction costs and observing time on all three telescopes (the two Gemini telescopes and Subaru). Some infrastructure development would be shared with HyperSuprime Cam, leading to further cost savings. Japanese astronomers would have access to unique Gemini instrumentation and the southern hemisphere, while Gemini astronomers would be able to use WFMOS on Subaru to address fundamental questions of interest to everyone. It is truly a win-win situation, as the Gemini and Subaru telescopes will be used for the observations for which they were designed and optimized. Neither observatory would likely be able to build such an ambitious and expensive instrument alone.

In October 2005, Gemini decided to fund two competitive Conceptual Design Studies for WFMOS. Two years ago, just before the June 2006 Orlando SPIE meeting, uncertainty in the availability of funding for WFMOS resulted in a pause in the conceptual design studies, which were just getting started at the time. The Gemini Board decided to suspend the studies until adequate funding could be found. A few months later, in September 2006, the funding for the design studies was committed, and Gemini began the challenging process of re-engaging the design study teams. Now, two years later, we have finally succeeded in re-starting two competitive conceptual design studies. One team is led by Sam Barden of the Anglo-Australian Observatory (AAO). Richard Ellis (Oxford and Caltech) heads a second team headquartered at JPL. Both teams include international members from across the Gemini partnership and Japan. Competition is an essential element of the conceptual design studies because it encourages creative thinking about the technical aspects of such a revolutionary instrument, and it maintains pressure on the teams to be as realistic as possible with their cost estimates and performance requirements. The conceptual design studies are scheduled to be completed in March 2009.

HyperSuprime Cam has been partially funded and is now being designed, and the Japanese astronomical community is solidly in support of the HyperSuprime Cam science missions. Given the synergies with WFMOS, we are confident that support of WFMOS by the Japanese astronomical community will continue to grow as the project becomes better defined and the terms of a partnership negotiated. Gemini is actively engaged in negotiations with the Japanese, and is exploring possible organizational models for coordinating WFMOS construction across a number of institutions around the world. An instrument as expensive and complex as WFMOS will demand new ways of working together within the Gemini partnership, with the Japanese, and with institutions around the world.

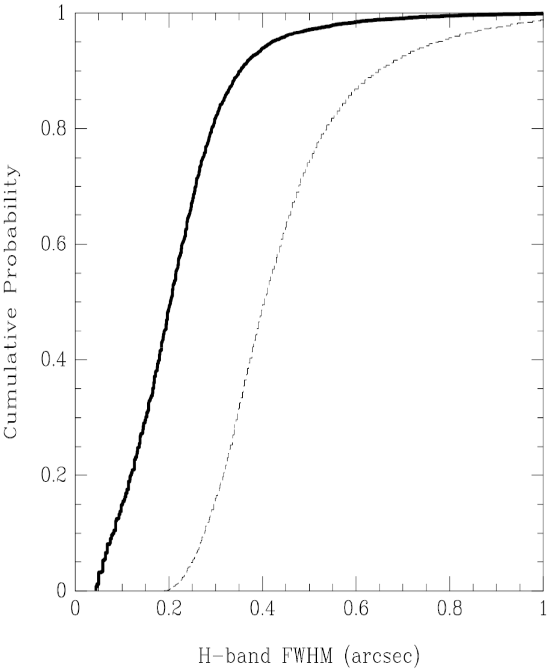

Figure 17. Expected delivered image quality for a GLAO system on Gemini-North at 1.6 μm (solid line) compared to the natural seeing (dashed line). 0.3 arcsec images should be obtained in the near-IR 80% of the time with GLAO (plot courtesy of D. Andersen, L. Jolissaint, M. Chun, R. Wilson, T. Butterley, and R. Avila).

3.3 Ground Layer Adaptive Optics

The Ground Layer Adaptive Optics (GLAO) concept being explored for Gemini-North is a specialized AO system that would use five laser beacons and an adaptive secondary mirror to correct the turbulence very near the ground on Mauna Kea. GLAO will provide a corrected field of view several arcminutes across with 0.2 to 0.3 arcsecond resolution (FWHM) across the field. The effect of improving image quality is to reduce integration times for a wide range of observations using existing and future instruments, making the telescope more efficient and productive. Some science projects that would otherwise require prohibitively long exposures, such as deep imaging of very faint, distant galaxies, will become possible with GLAO. As an additional benefit, the Strehl ratio and system emissivity in the mid-infrared will be significantly improved using the adaptive secondary mirror alone.

We continue to explore the possibility of building a GLAO system for Gemini North. A team led by Mark Chun at the UH Institute for Astronomy is collecting data on the turbulence in the lowest layers of the atmosphere over Mauna Kea.[28] They are operating an atmospheric profiler on a 16-inch Meade telescope mounted on the coude roof of the UH 2.2m on Mauna Kea. The system has been operating for well over a year now, and had collected over 20,000 atmospheric profiles by the end of 2007. We anticipate running the profiler through the end of July 2008. So far, the data indicate that a significant turbulent ground layer exists more than half of the time. The lowest 50 m of the atmosphere contains between 30% and 70% of the integrated turbulence at least 60% of the time. The ratio of integrated turbulence below 50m to the total integrated turbulence is usually ~0.5. Furthermore, there is only rarely significant turbulence between 100 m and 500 m above the summit. Correcting for the lowest layer with a wide-field GLAO system would allow Gemini to deliver 20-percentile image quality 80% of the time in the near-infrared, and possibly even improve seeing in the optical as well (Fig. 17).

To better quantify the gains that could be realized with GLAO, Gemini is working with the international team that conducted the original GLAO feasibility study in 2004 (the University of Durham, the University of Arizona, and HIA) to update the numerical models with the new ground layer measurements collected by the UH team. We expect that the results of this investigation will be used to justify a conceptual design study for GLAO, possibly starting in 2009.

3.4 Precision Radial Velocity Spectrograph

The Precision Radial Velocity Spectrograph (PRVS) was designed to be a high-stability fiber-fed bench spectrograph sensitive from 1 to 1.6 μm.[29] Its principal science mission was to conduct radial velocity searches for planets orbiting low-mass M-dwarf stars, which are very numerous in the solar neighborhood and brightest at near-IR wavelengths. Planets in the habitable zones of M-dwarf stars have short-period orbits, and the low-mass stars will wobble more due to the influence of the planets.

Two competitive PRVS conceptual design studies were completed in October, 2006. Contracts with the winning team (led by the UK Advanced Technology Centre) were negotiated by the end of 2007. In March 2008, after resolving the partnership status of the UK in the Gemini partnership, the Gemini Board of Directors decided not to proceed with PRVS in light of budgetary uncertainties; hence PRVS will not be built for use on Gemini. Gemini regretted cancelling the PRVS project, but the Board felt it was important to focus on the highest priority elements in the Aspen instrumentation program given the financial uncertainties in the Gemini partner countries.

4. A LONG RANGE PLAN FOR GEMINI INSTRUMENTATION

The Aspen (Phase 3) instrumentation program was developed to provide the Gemini Observatory with cutting-edge, specialized instruments with which to pursue the community's ambitious scientific goals in the 2005 to 2010 time frame.[7,8] Now, in 2008, with much of the Aspen instrument activity just beginning, we must begin the process of drafting a strategic plan for the next 5-year post-Aspen period. Obviously, construction of WFMOS and GLAO will extend well into the next 5-year period if they are funded beginning in 2009. The same science goals that motivated the Gemini partners in 2003 in Aspen will continue to be relevant in the coming decade. At the same time, the current Gemini international partnership agreement expires at the end of 2012, so the partnership renegotiation will begin soon. Developing a long-range plan for future instruments at Gemini will be an important part of that renegotiation. Finally, in the coming decade, we will have to balance our desire for specialized cutting-edge instruments designed for specific science cases with our need to replace the current generation of aging general-purpose instruments like GMOS and NIRI, which are now approaching the end of their design lifetimes. Some of the phase 1 and 2 instruments may be upgraded and refurbished, keeping them current and competitive. Some may be retired and replaced with other instruments. Construction of GLAO will demand new instruments to take advantage of its wide field of view. With the construction of WFMOS, time-sharing with Subaru (and possibly other observatories) will increase by an order of magnitude, making it even more important for Gemini to maintain a competitive set of instruments for the benefit of the whole community of Gemini users. All these considerations will be important in crafting a long-range plan for Gemini's future instrumentation during the coming two years.

5. ACKNOWLEDGEMENTS

The authors would like to thank and acknowledge the helpful input of the following individuals to this paper and to the Gemini instrumentation program: Gustavo Arriagada, Etienne Artigau, Marcel Bergmann (Gemini), Mark Chun (UH IfA), Steve Eikenberry (UF), Tom Geballe, Percy Gomez, Markus Hartung, Tom Hayward (Gemini), Bruce Macintosh (LLNL), Rolando Rogers (Gemini), Douglas Toomey (MKIR LLC), and Steven Varlese (Gemini). The Gemini Observatory is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the Science and Technology Facilities Council (United Kingdom), the National Research Council (Canada), CONICYT (Chile), the Australian Research Council (Australia), Ministério da Ciência e Tecnologia (Brazil), and SECYT (Argentina).

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