Gemini Observatory's Facility Instrument Program

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ABSTRACT

This is the fourth in a series of SPIE papers that chronicle the accomplishments, challenges, and evolution of Gemini's instrumentation program. For the first time we are pleased to report not just about progress made on instruments being fabricated, but results with completed instruments, now steadily producing world-class scientific results at the Gemini Observatory. With the steady arrival of new facility class instruments, we anticipate phasing out our reliance on visitor instruments, which have enabled our early scientific capabilities at both Gemini-N and Gemini-S. Currently two facility class instruments are operational and six more are due in roughly a year, hence commissioning all of these instruments in Hawaii and Chile will doubtless be an enormous task for the staff at Gemini in the near future.

Keywords: Instrumentation, optical, infrared, detectors, cryogenic

1. OVERVIEW

As a biennial report on Gemini's instrument program, readers are encouraged to peruse past publications (e.g., Simons *et al.*[1], Simons *et al.*[2], Gillett *et al.*[3], and Simons *et al.*[4]) as backup material to the information contained herein, as well as to note the steady growth and maturity of an instrument program that has developed from the early "construction era" of the Gemini 8 m Telescopes Project to the current "operations era" of the Gemini Observatory. Since the first AO corrected images taken with Hokupa'a on Gemini-N were acquired in 1998, visitor instruments from the University of Hawaii, University of Florida, NOAO, and the University of Cambridge were used exclusively at both Gemini-N and Gemini-S, due to the late arrival of the first "wave" of facility instruments. While the early lack of scientific opportunity was mitigated to some extent with the visitor instruments used on Gemini, the much more encompassing control systems provided by facility class instruments will no doubt lead to significant capability enhancements, including greater "open shutter" efficiency, reduced complications in handling complex observing sequences, greater PI observing program input through our Observing Tool, the use of pipeline processing for data quality assurance, etc. Delivery delays have been due to a range of reasons which are worthy of their own publication about "Lessons Learned" within 8-10 m class instrument programs world-wide, but in general were due to lack of experience in extrapolating from the ~4 m class instrumentation built during the 1970's and 1980's to the current generation of 8-10 m instruments which are typically an order of magnitude larger, more expensive, and more complex than anything undertaken by ground-based instrumentation groups before. This enormous leap in instrumentation demands is leading to a rather fundamental overhaul of practices and procedures used by Gemini's instrument groups, where formal project management is required of all new teams, cost, schedule, and risk are tracked regularly, initial budgets are more realistically defined based on past experience, contingency is applied where necessary, etc. Though these changes were rather painful to implement initially and it is too early to determine empirically if these broad programmatic changes have led to better production performance, Gemini's instrument teams are certainly on a new track that should lead to high quality instruments that meet the scientific demands of our international community.

2. OPERATIONAL INSTRUMENTS

Instruments have been split into two categories in this report, namely those that have been delivered, accepted, and are now operational, and those that are still in various stages of development. The latter are presented in roughly the order in which they are expected to be delivered to either Gemini-N or Gemini-S.

2.1. Near-infrared Imager (NIRI)

Figure 1 – NIRI is seen on the up-looking port at Gemini-N. The vacuum jacket is in the center of the photograph, with a pair of thermally insulated electronics enclosures mounted as outriggers below the vacuum jacket. The entire 2000 kg package is contained within a welded steel space frame that places all major subassemblies at the correct location to meet the center of gravity requirements placed on all instruments, which is ultimately driven by dynamic load tolerances of the various telescope drive systems.

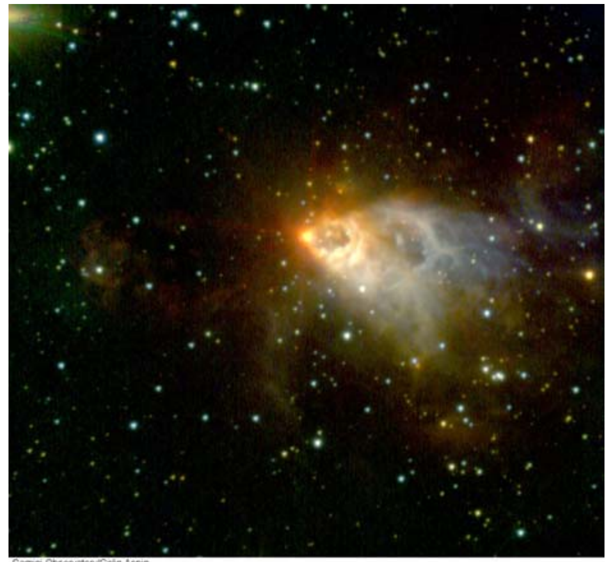

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Figure 2 – AFGL 2591 is shown, as recorded by NIRI's wide field camera atop Mauna Kea. This multicolor composite image reveals the expulsion of gas and dust from the young star, in the field center, which is poised in the midst of a dense molecular cloud that would otherwise make such images impossible at optical wavelengths.

NIRI[5], which was built by the University of Hawaii, is currently operational on Gemini-N and available for community use in a variety of modes, including imaging in any of 3 plate scale (0.12, 0.05, and 0.02 arcsec/pix), as well as low resolution 1-5 µm spectroscopy. These 3 plate scales and their corresponding field of view, given the 1024^2 ALADDIN detector used by NIRI, provide good sampling of either (1) the entire IR optimized 3 arcmin field of the telescope, (2) tip/tilt corrected PSFs during good seeing, or (3) AO corrected PSFs. In fact, by using its finest plate scale, NIRI will be used to commission ALTAIR (Gemini's facility AO system) in 2002. NIRI remains one of the few instruments in operation with a near-infrared on-instrument wave front sensor (OIWFS), which has been demonstrated to work at ~100 Hz on guide stars as faint as J~15 mag. It is typically only used in the middle and finest plate scales, since use of the wide field mode obscures most of the field left for the OIWFS to patrol for guide stars. Alternatively the facility peripheral wave front sensors (PWFSs), in the telescope's acquisition and guidance unit, can be used to provide fast tip/tilt compensation for NIRI. The downside to this approach however is that these wave front sensors are not rigidly tied mechanically to the NIRI science channel, meaning the reimaged field drifts with respect to the PWFSs and stars will trail over long integration periods without further compensation. A new tracking mode, which is to first order similar to non-sidereal telescope tracking, is under development now which will passively compensate for differential flexure between the PWFSs and NIRI to better support NIRI's wide field mode.

Figure 1 shows NIRI on the up-looking infrared optimized port at Gemini-N. A variety of auxiliary cables, helium flex-lines, optical fibers, etc. are evident in Figure 1, all of which connect to one of four sets of patch panels on the underside of the Cassegrain rotator. NIRI was the first instrument to rely exclusively on the facility helium distribution system for cooling, which has proven to be fairly reliable since being commissioned shortly before NIRI's arrival at Mauna Kea. This system entails nearly a half mile of oxygen grade fixed and flexible lines, with up to 8 compressors working in parallel to provide the gas throughput and pressure needed to concurrently drive up to 3 facility instruments mounted on the telescope and 1 in the summit instrument lab. It uses a dedicated chiller to pull heat from the helium compressors, and the entire system is ultimately planned to be capable of operating off local (generator) power at each observatory, in the event of loss of commercial power, which in Chile is a significant problem. Given the thermal cycle times of some of these huge instruments (measured in days, given their cold masses), this considerable closed-cycle cooling infrastructure is required to assure that all instruments remain at the correct temperature on a reliable basis, even if bad weather leads to a power loss and prevents access to the observatory for extended periods of time.

As an example of the exquisite image quality NIRI is capable of recording, Figure 2 shows an image of a star formation region (AFGL 2591) recorded by NIRI during its commissioning phase. This is a color composite made at

J, H, and K with a measured image quality of ~0.35 arcsec. The *f*/6 camera or wide field mode was used to acquire this image, which represents a ~2 minute integration in each of the 3 bands used. Acceptance testing of NIRI demonstrated an intrinsic strehl of ~75% in NIRI's rather complex optical train, with a measured system optical throughput of ~50%. Additional measured performance data is available in Table 1.

Filter	λ_c (μm)	Point Sources (mag)	Extended Sources (mag/arcsec^2)
J	1.25	23.6	23.5
H	1.64	22.7	22.5
H2 1-0 S(1)	2.122	21.1	20.9
K	2.20	22.3	22.0
L'	3.77	17.5	17.2
M'	4.68	14.8	14.5

Table 1 – Measured point and extended source sensitivities for a 5σ - 1 hr integration with NIRI are listed.

Though received at Gemini's Hilo Base Facility in May 2000, NIRI experienced a number of start-up problems when actually tested on the telescope, most notably a problem with intermittent flexure within the cryo-structure. This lead to nearly 18 months of delay in the actual acceptance of the instrument after it arrived on Mauna Kea. The problem was manifest as a sudden jump in the reimaged focal plane when NIRI was tipped in certain orientations. Exhaustive troubleshooting eventually led to a steering mirror, near the common pupil for its three cameras, moving within its drive assembly. That steering mirror was replaced by a completely new mechanism using commercial bearings instead of the original bushing design, leading to vastly improved stability under all gravity loads. Again, though NIRI has had a troubled start at Gemini, we remain optimistic that it will fulfill its science mission on Gemini in the years ahead.

2.2. Multi-Object Spectrographs (GMOS)

In May 2001, or about a year after NIRI arrived, the Gemini Multi-Object Spectrograph (GMOS[7,8]) arrived in the Hilo Base Facility, from Scotland. This was the first of a pair of identical instruments that have been under development in Canada at the Herzberg Institute of Astrophysics (HIA), the United Kingdom at the Astronomy Technology Centre (ATC) and the University of Durham, and in the United States at the National Optical Astronomy Observatory (NOAO) labs. With principal components built in 3 countries, namely the mask exchange mechanism, optics, and forward optical support structure in Canada, the grating and filter wheel mechanisms and main optical structure in the UK, and the detector focal plane integrated with a controller in the US, GMOS represented unique management challenges within Gemini's instrument program. The outstanding performance of GMOS-N on Gemini, essentially "out of the box", is a testament to the careful craftsmanship and attention to interfaces and design details by the large team responsible for this instrument. GMOS-N and GMOS-S represent the core optical imaging and spectroscopy instruments available to the Gemini community, hence their on-sky performance enables the bulk of the ~0.4-1.0 μm science at Gemini. Though they don't offer the field of view that some other competing multi-object spectrographs support, they have a broad range of modes and promise to deliver high spectral resolution over their ~5.5x5.5 arcmin fields, which make them unique and scientifically powerful facilities. Beyond the imaging mode, they provide long slit and multislit spectroscopy, integral field spectroscopy, polarimetry, and nod & shuffle readout modes for excellent rejection of background sky lines.

Figure 3 – GMOS is shown on the up-looking port at Gemini-N. Like NIRI, prominent in the physical layout of the instrument are the 2 outrigger thermally insulated electronic cabinets that serve to remove heat from the instrument, through facility glycol lines, which is routed to the outside by a large chiller. The instrument's shiny outer panels serve to buffer the inner GMOS opto-mechanical structure from temperature variations outside.

Filter	λ_c (nm)	Point Sources (mag)	Extended Sources (mag/arcsec^2)
g'	475	27.1	27.0
r'	630	26.7	26.6
i'	780	26.1	25.9
z'	950	24.8	24.6

Table 2 – Measured point and extended source sensitivities for a 5σ - 1 hr integration with GMOS-N are listed.

Unlike most other Gemini instruments, which rely on rigidly tying science detectors to the OIWFS, GMOS was designed to provide internal compensation for differential flexure between its mosaic of three Marconi 42-90 (2048x4608) CCDs and its slit environment. This is achieved by mounting the CCD mosaic on an XYZ stage

Figure 4 – The GMOS IFU is shown with its top protective case removed. A pair of pick-off mirrors are seen on one end, with the 1500 fibers arching within the assembly, suspended by foam lining to provide a protective low stress environment.

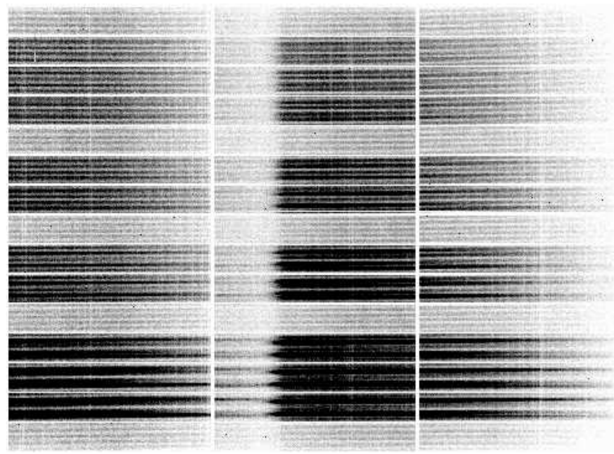

Figure 5 – A raw GMOS IFU spectrum is shown for a 10 minute integration on M32. The bright vertical lines which split the field in thirds are the CCD mosaic gaps. Sky lines from the 500 fiber outrigger are the relatively light (low signal) horizontal bars which divide the field into fifths.

which automatically moves the detector package as a function of instrument orientation. Demonstrated performance of the combination of the OIWFS and detector compensator, both of which are ultimately tied to the slit as a fiducial, leads to ~2 km/s spectral resolution across the GMOS field if its atmospheric dispersion compensator (ADC; not currently commissioned) is used. This remarkable level of stability, combined with the ability to simultaneously record spectra on ~200 targets, will enable a broad range of science programs. The OIWFS, which is a 2x2 Shack-Hartmann system, provides tip/tilt, as well as focus and astigmatism control in the telescope active optics. Given the significant vignetting pattern of the PWFSs in the fairly large GMOS field the PWFSs are generally retracted and the relatively slender profile of the OIWFS is used to control the main mirror deformation modes of the telescope in real time. This capability is crucial, since unlike NIRI the use of the PWFSs incurs a significant field of view penalty, hence cannot be used routinely as an alternate means of closing the telescope's active optics loop. Masks for GMOS are now regularly cut with a laser milling machine in the Hilo Base Facility, after science fields are imaged and mask definition files are generated, which act as input to the milling machine's control algorithm. These files are generated using custom code that is distributed to PI's after acquisition fields are imaged using fairly short integrations. The carbon fiber mask material used has proven to be inexpensive and fairly easy to cut, while producing high quality slits that are insensitive to the temperature excursions between Hilo and the summit of Mauna Kea.

GMOS offers in its baseline functions a state of the art integral field unit (IFU), which is deployed remotely using the same mask exchange mechanism that is used to hold multi-slit masks. This remarkable unit has a pair of entrance fields, measuring 5x7 arcsec (composed of 1000 fibers) or 3x5 arcsec (composed of 500 fibers). They are separated by a fixed 1 arcmin separation on the sky, with spectra interlaced in the reformatted field to produce sky and target spectra concurrently. Figure 4 shows the IFU in its cartridge assembly, weighing ~10 kg with a pair of fiber streams evident within the structure. The measured optical throughput of the IFU is ~60%. The spectrum generated by this configuration is shown in Figure 5, which depicts how sky and object spectra are interlaced across the detector. Given the demonstrated success of the first IFU, delivered around the time of GMOS-N, a second identical IFU is now under construction at the University of Durham for scheduled used with GMOS-S, thereby providing integral field capability for both GMOS instruments. The GMOS IFU is actually the first of a series of such instruments, as a

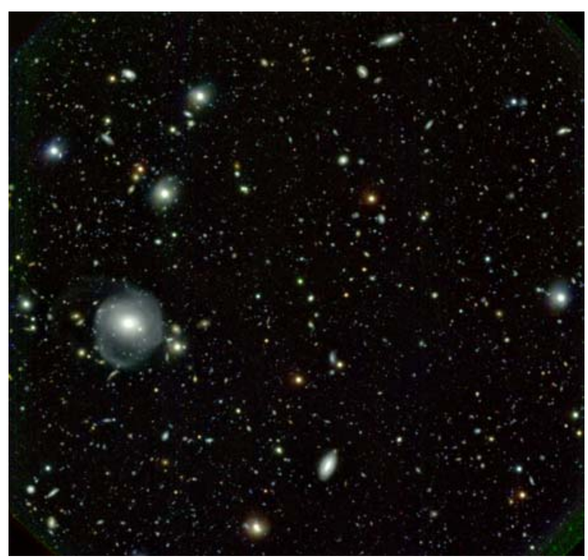

Figure 6 – A deep multicolor image recorded with GMOS is shown. While ~2-2.5 mag less deep than the HDF field, this frame was recorded in only ~5% of the time.

total of 4 optical and near-infrared IFUs will be available in facility instruments at Gemini-N and Gemini-S by the end of 2003. This commitment to IFU technology reflects a key technical and scientific strategic direction for Gemini, in which IFUs will be used to dissect high resolution images, on the expectation that forefront science will occur on relatively small fields in the age of 8-10 m telescopes.

Figure 6 further demonstrates the remarkable sensitivity of GMOS. It is a 5 hour integration in each of 3 filters of a QSO field (z=4.1). The 5σ sensitivity limit of this field is ~27 mag. Compared to the well known Hubble Deep Field (HDF), these photometric limits are ~2-2.5 mag less deep than the HDF, but were recorded in only ~5% of the time and has ~0.5" resolution, heralding the age of ultra-deep imaging on 8-10 m telescopes that is certainly competitive with anything achieved to date from space.

2.3. Gemini Calibration Unit (GCAL)

In addition to NIRI and GMOS-N acceptance, since the previous SPIE report facility calibration units[8] are now installed at both Gemini telescopes, which provide flat fielding as well as spectral calibrations for all instruments out to ~3 µm. These units were built at the UK/ATC in Edinburgh. While these may seem like rather mundane instruments, having a common calibration system that can be operated from the same control environment through preprogrammed scripts with the facility instruments is a powerful calibration technique that saves valuable observing time compared to more conventional methods (e.g., dome flats). Figure 7 shows the unique hemisphere integrating chamber in GCAL. One of several potential light sources (e.g., quartz halogen, black body, or arc lamps) is used to inject light into the hemisphere. The calibration flux first strikes a small mirror, which diverts the light to a switchable diffusion screen which can be set to either optical or infrared modes. Light is scattered off this screen, within the chamber, providing a remarkably uniform illumination pattern on the screen which is reimaged by a pair of large projection mirrors into the telescope's science fold mirror, which ultimately directs the beam into any Cassegrain mounted instrument. In practice this diffuser has actually proven to be brighter than anticipated, necessitating the use of weaker sources (bulbs) and/or tuning power to the continuum sources to match science instrument sensitivities.

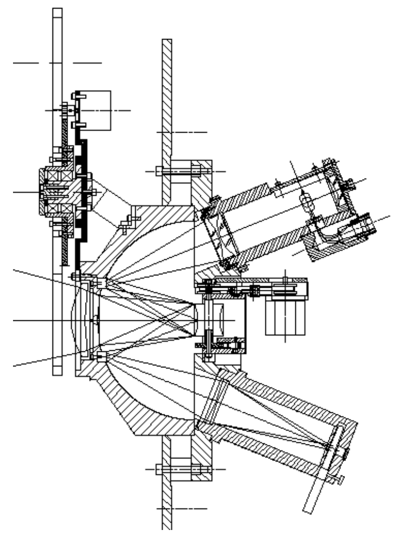

Figure 7 – A cross section of the novel GCAL integrating hemisphere is shown, which injects a beam of light generated by one of several sources into the main projection mirrors.

2.4. Gemini Polarization Unit (GPOL)

Finally, a pair of facility polarization units have also been accepted for use at Gemini-N/S. Like GCAL, these units were built in Edinburgh by the UK/ATC. These units incorporate polarization modulators capable of working from ~0.4 – 5 µm, as well as a set of fixed calibration plates. The entire GPOL assembly is installed in the bottom of the Acquisition and Guidance unit, thereby permitting polarimetric observations with any instrument on the up-looking port that is equipped with a corresponding analyzer, which in most cases is a Wollaston prism. Currently NIRI, GMOS, and GNIRS have in their baseline designs Wollaston prisms for use with GPOL and the number of instruments that are GPOL compatible will surely grow over time, making polarimetric observations at Gemini fairly routine. As seen in Figure 8, when injected into the telescope beam, the ~95 mm wave plates in GPOL are actually surrounded by 3 fused silica annular plates which serve to transmit the peripheral telescope beam to the same focal plane delivered by the wave plates. This allows an OIWFS in an instrument to patrol the surrounding field for guide stars. The wave plates are designed to move in discrete steps using Hall sensors for position feedback under

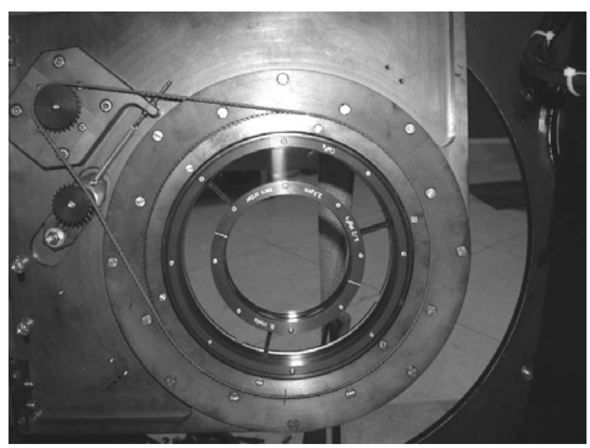

Figure 8 – A picture of one of the waveplates in GPOL, when deployed into the telescope beam, is shown. The waveplate is in the center circular cell and is immediately surrounded by an annulus of fused silica, which the OIWFS in an instrument uses to find guide stars.

computer control from the same high-level software environment that is used to control the instrument and telescope, meaning complex sequences of integrations using different telescope dither patterns in tandem with wave plate rotational angles can be easily scripted to enhance observing efficiency.

3. INSTRUMENTS CURRENTLY UNDER CONSTRUCTION

3.1. Mid-infrared Imager (T-ReCS)

The Thermal Region Camera and Spectrometer (T-ReCS; Figures 9 and 10) remains under development at the University of Florida and is expected to be commissioning during the second half of 2002 on Cerro Pachon. Given the gains of a thermal infrared imager on an infrared optimized telescope like Gemini, the popularity of T-ReCS is expected to be quite high. Use of queue scheduling, in which the instrument will be operated preferentially on rare ultra-dry nights, will also enable 20 µm observations with much greater certainty and scientific gain than comparable instruments have in the past. This capability will be further enhanced by a unique remote window exchange mechanism, which can hold 5 separate windows, four of which can be sealed and protected while a 5^{th} is actually in the beam. This permits the use of a "fresh" and optimized window based upon the current conditions, e.g., tuned for either 10 or 20 µm observations. This is all ultimately driven by the extremely low emissivity specification for the Gemini telescopes, which in turn demands that the instruments have intrinsically low emissivity to remain truly background limited. Beyond providing diffraction limited imaging, T-ReCS has a modest spectroscopy capability at 10 and 20 µm, capitalizing on a relatively simple grating turret that inserts either gratings or a mirror into the optical beam. Other mechanisms provide fairly conventional features including filter wheels, slit wheels, and insertion of optics for inspecting either the window (to directly verify its condition) or the entrance pupil to the telescope, to make sure pupil alignment is accurate and no anomalous heat sources are in the beam.

The demonstrated optical performance of T-ReCS' optics in the lab is superb and they are expected to meet all of the stringent requirements for throughput, image quality, distortion, etc. placed on the instrument. Like several other mid-IR instruments that are just now coming into use, T-ReCS will use a state-of-the-art Raytheon 240×320 Si:As IBC detector. One area of concern in the performance of T-ReCS has been flexure along the optical path between the Raytheon detector and Cassegrain instrument support structure (ISS). Unlike most other Gemini instruments, T-ReCS does not have an OIWFS, instead relying on the PWFSs to provide guiding, even when the signal is being chopped by the telescope's secondary mirror. Lab tests to date have revealed flexure within the central optical bench assembly that could not be reduced to meet the stringent detector/ISS flexure specification for the instrument, even

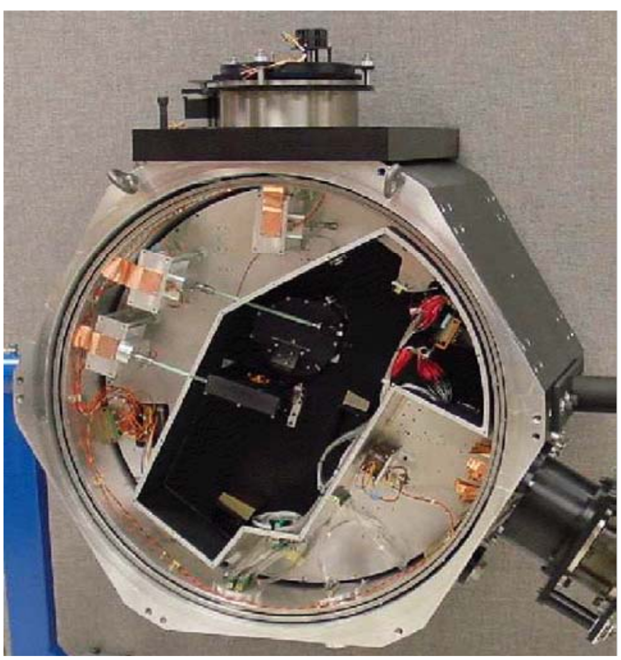

Figure 9 – A view of T-ReCS from the "bottom" is shown. Cryomotors are seen with fiberglass feed-throughs into the central light-tight baffle box, which contains various optical elements.

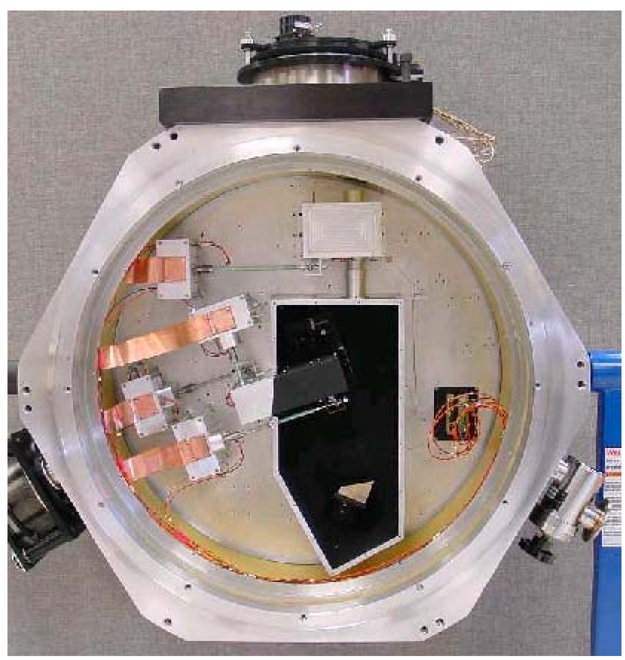

Figure 10 – Same as Figure 9 but the view from the "top" of the instrument is shown. At the top of the vacuum jacket is seen the novel window rotating mechanism which puts 1 of 5 windows into the beam.

with substantial additional bracing that was retrofitted onto the bench. After considerable effort the flexure (which amounted to a few pixels peak-to-peak) was reduced to the point that it can be fairly easily removed through passive compensation with telescope tracking. In a similar vein as the GMOS compensator, the telescope tracking will be adjusted slightly as a function of instrument orientation to keep the science field fixed on the detector. Since the flexure is smooth and mostly along the slit, its expected impact on spectroscopy will also be negligible. Nonetheless, experience has repeatedly shown that the whole area of flexure in the large Cassegrain mounted instruments on 8-10 m telescopes is fairly daunting. In general, given the 2000 kg mass limit and space envelope limits set by the telescope, instruments have taken either of two approaches to dealing with flexure, namely a "brute force" approach to build the opto-mechanical structure as stiff as possible or to build a compensator of some sort into the design from the outset. Though the number of instruments completed remains small, the trend thus far is that the "brute force" approach does not work nearly as well as a built-in compensator.

3.2. Bench High Resolution Optical Spectrograph (bHROS)

Gemini's bench mounted high resolution spectroscopy facility is currently in an integration phase at University College London. The baseline instrument is capable of R~120,000 optical spectroscopy and will be housed in the Cerro Pachon pier lab, which is on the ground floor of the observatory. Being inside the pier the instrument will be surrounded by thick concrete walls, which offer excellent thermal stability and of course vibration isolation from the dome and external observatory structure. Figure 11 shows a layout of the instrument, not including the fiber feed system. Light exiting the fiber bundle first enters a slit including a high performance image slicer. It then passes through a filter wheel, before the expanding beam strikes an OAP which acts as a collimator, which in turn diverts light through a large pair of fused silica prisms which serve to cross disperse the light. From there it strikes an echelle grating that is actuated so that the resulting echellogram can be scanned across a fixed detector package downstream of the grating. A relatively simple camera is used to focus the dispersed light onto this detector package, which contains a pair of Marconi 2048x4608 CCDs oriented side-by-side. Future potential upgrades to the baseline system include an R=300,000 camera, an R~34,000 camera, and a detector package that includes a much larger mosaic of CCDs to capture a larger portion of the echellogram.

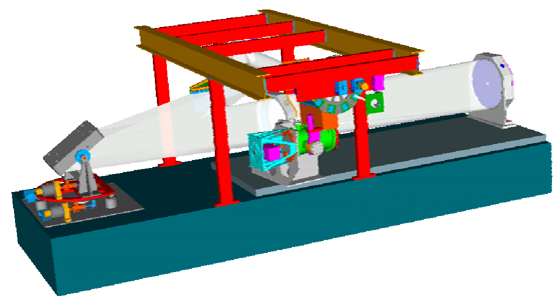

Figure 11 – A CAD rendering of the completed bench spectrograph is shown. This is Gemini's only fiber fed instrument, which is capable of high stability spectroscopy at fairly high resolution across optical wavelengths.

Referring to Figure 12, one of the more unusual aspects of this instrument is that it will be something of a hybrid between GMOS-S and a conventional bench spectrograph. It also represents Gemini's only fiber fed instrument. In order to avoid occupying an entire ISS port for a simple fiber feed unit, a fiber feed module that fits into the existing GMOS mask exchange mechanism will be used. Furthermore a custom fiber routing system will be used that safely navigates the fiber around the ISS and associated instruments, prevents the fiber from catching on any instruments as the Cassegrain rotator moves, prevents the fiber from being bent below its minimum bend radius, and takes up slack as the telescope is tipped in elevation. The pick-off cartridge is fully removable from GMOS, so that it can be safely stowed just under the floor of the azimuth platform. When loaded with this module, GMOS can still be configured to hold up to 13 slit masks and an IFU, any of which can be remotely installed to rapidly switch between instruments. Acquisition for bHROS will be achieved by running GMOS in its standard imaging mode to acquire target fields in the clear area surrounding the fiber pick-off. From there a single telescope offset will

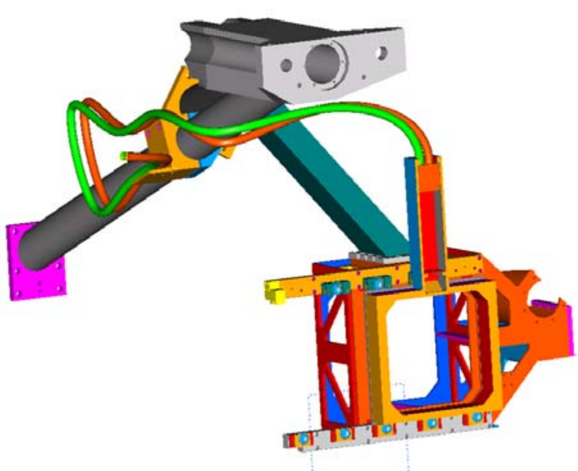

Figure 12 – The GMOS module that contains the fiber entrance feed for bHROS is shown. This module inserts within the GMOS mask exchange mechanism like an IFU, meaning GMOS can be configured to rapidly support straight through imaging, MOS spectroscopy, bHROS spectroscopy, or integral field spectroscopy, through remote control.

serve to locate the science target on the fiber entrance. Two modes are available, one offering an ~0.7 arcsec input that will be interlaced with a sky fiber, or a ~1 arcsec fiber that can be used during periods of poor seeing, albeit at the cost of not having simultaneous sky sampling.

Though a bench spectrograph has been in Gemini's instrument development plans for several years, the adaptation of the original HROS into a fiber-fed bench instrument represents a fairly radical departure in the evolution of Gemini's high resolution spectroscopy facilities. This change was made primarily due to (1) concerns about the technical development of HROS, which was arguably the most complex instrument under development at Gemini in terms of opto-mechanical requirements, and (2) unacceptable delays in completing the baseline instrument, which failed to meet the needs of the high resolution spectroscopy community within the Gemini consortium. The decision to fast-track the bench spectrograph by adapting existing HROS optical elements was a compromise between a multitude of competing technical, programmatic, scientific, and strategic factors. While the resulting instrument will enable many of the high resolution spectroscopy goals of the Gemini science community, due to fiber losses, it will not provide a competitive UV capability. This may be addressed in the next round of instrument development at Gemini, with a completely new instrument.

3.3. Near Infrared Integral Field Spectrograph (NIFS)

The last instrument currently planned in the Gemini instrument program for deployment on Mauna Kea is NIFS, which is now in an integration and test phase at the laboratories of the Australia National University at Mt. Stromlo observatory. This instrument represents the single most aggressive attempt to date within Gemini's program to build a fully optimized integral field spectrograph. While GMOS-N, GMOS-S, and GNIRS will all include IFU modes, NIFS, when used with the facility AO system (ALTAIR), *only* supports J, H, or K-band IFU spectroscopy over a small AO corrected field. Like NICI, it is a relatively specialized instrument, that will be susceptible to a limited target set initially, until the planned laser guide star (LGS) mode of ALTAIR is commissioned. Even without an LGS AO system feeding NIFS, the baseline natural guide star mode of ALTAIR feeding NIFS is still expected to provide years worth of targets for astronomers to use this unique facility to perform integral field spectroscopy of complex compact targets including YSOs, AGNs, etc.

Figure 13 shows the science channel in NIFS at the ANU lab. Like NIRI, the OIWFS and science channel are on opposite sides of a thick central 6061 Al plate that is tied to the vacuum jacket using titanium trusses. In this way, though the bulk cold structure will flex with respect to the telescope focal plane, the OIWFS is rigidly tied to the science detector and since the telescope guide loop is closed around the OIWFS, this flexure has no detrimental effect on data recorded. Figure 14 shows what is arguably the most developmental aspect of NIFS, a portion of the

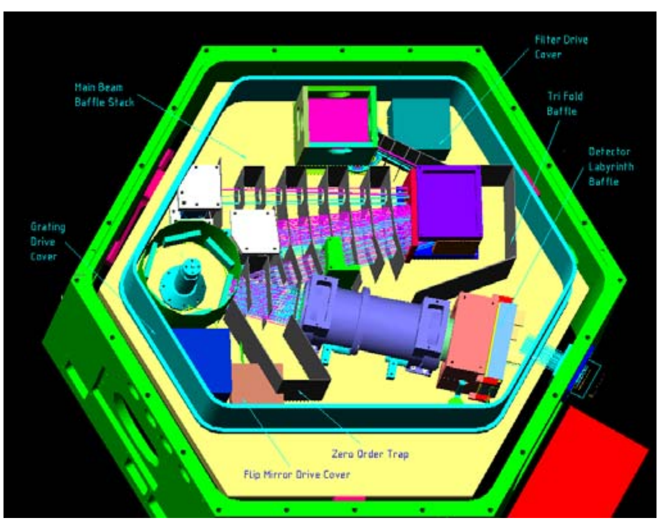

Figure 13 – The NIFS science channel is shown. The IFU feeds a turret (left side of assembly) containing a selection of gratings that are tuned to provide J, H, or K-band sampling at R~5000 in a single integration using a HAWAII-2 HgCdTe detector. This detector is housed in the structure to the lower right, within the cold light shield that contains all of the optics and mechanisms.

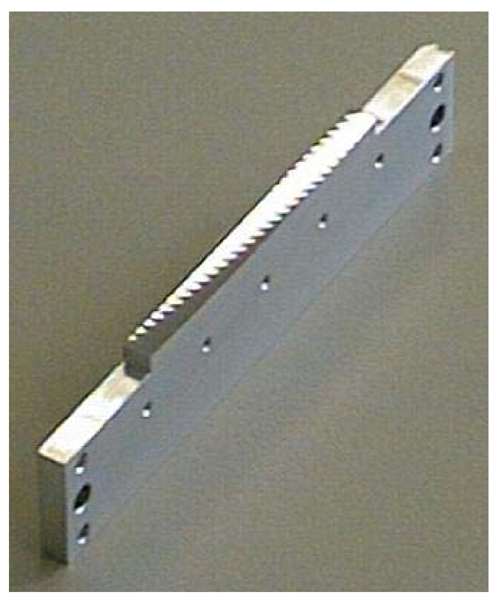

Figure 14 – One of the IFU mirror arrays is shown. Facets were diamond machined from a single piece of metal.

diamond machined IFU mirror array. This monolithic array was milled from a single piece of Al, meaning alignment between the facets is predetermined, consistent with the overall "bolt and go" approach being used ever more frequently to build modern instrumentation. In order to accelerate its development, the NIRI vacuum jacket, cold plate, OIWFS, and control software were adopted as baseline design elements very early in the development of the instrument. NIFS in fact had a rather unusual CDR as a result of this approach – the vacuum jacket, space frame, ISS interface plate, central cold plate, etc. were *already built by the time of the NIFS CDR*. Precious effort was focused on the novel IFU elements, grating system, detector thermal control system, etc., all of which are key new elements in developing a photon-starved instrument like NIFS. This technique of "recycling" designs from existing instruments to expedite the development of new instruments is intended to be a growing theme within Gemini's instrument program.

3.4. Gemini Near-infrared Spectrograph (GNIRS)

The future near-infrared spectroscopic "workhorse" in Gemini's fleet of instruments will be GNIRS, which is currently in an early test phase at his home at the NOAO headquarters in Tucson, Arizona. Like most Gemini instruments, it is actually composed of subassemblies that are built throughout the Gemini partnership, including its OIWFS by the University of Hawaii and integral field unit by the University of Durham. GNIRS is undoubtedly the most complex cryogenic instrument being built for Gemini, as it is intended to provide a number of spectroscopic capabilities when used on Cerro Pachon, including single slit spectroscopy from 1-5 μm at 2 plate scales (0.05 and 0.15 arcsec/pix), spectral resolutions ranging from ~700 to 18,000, a cross-dispersed mode that will offer broad spectral sampling in the J, H, or K bands, a spectropolarimetry mode when its Wollaston prism is deployed and GPOL is introduced in the telescope beam, and an integral field unit providing ~0.12 arcsec sampling across a ~3x3 arcsec field of view. This combination of spectroscopic capabilities will ensure continual use of GNIRS on Gemini-S for many years to come, starting in 2003 when it is expected to arrive in Chile and undergo an intensive integration and commissioning phase.

Figure 15 below shows the massive cold structure of GNIRS as it is being lowered into the bulkhead section of its vacuum jacket. The nominal 65 K operating temperature of the cold structure will be achieved by a combination of an LN_2 pre-charge system and four 100W cryo-coolers. The cold structure shown will eventually be enshrouded by a complex set of radiation shields before being loaded into a welded vacuum jacket seen in Figure 16. The inner cold structure is tied to the non-structural vacuum jacket via a bulk head assembly that also ties the instrument, through a set of trusses, to Gemini's instrument support structure. A standard pair of thermal electronics enclosures is used, which house all of the mechanism control electronics, sensors, and array controllers for both the ALADDIN 1024^2 science detector and the HAWAII-1 detector used in GNIRS' near-infrared OIWFS, which was built by the University of Hawaii.

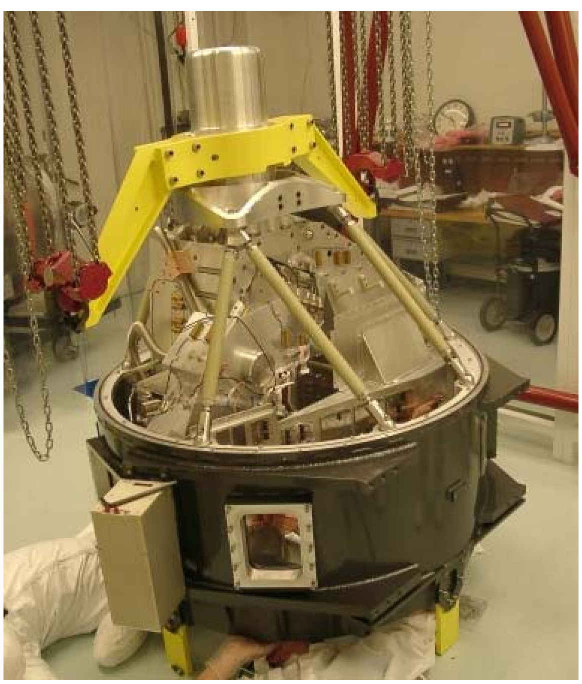

Figure 15 - The GNIRS cold structure held vertically by a crane in the NOAO clean room is shown as it is being lowered into the bulkhead assembly.

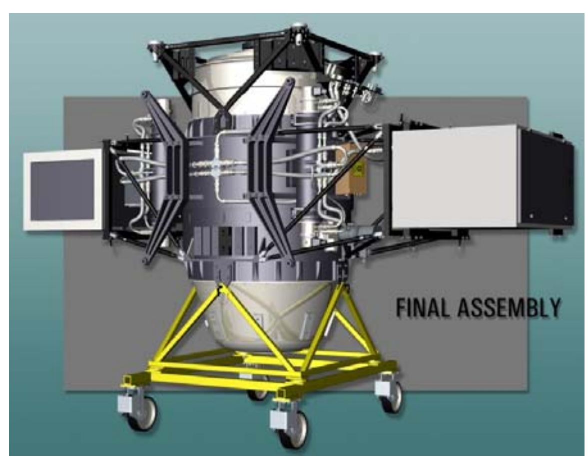

Figure 16 – A CAD rendering of the completed GNIRS in an up-looking mode is shown. The central bulkhead seen in Figure 15 ties together the other vacuum jacket sections, electronics enclosures, and ISS interface plates.

As reported in Simons *et al.*[4], all of this effort is being driven be a new team at NOAO, who took over the project after major management and technical problems emerged with the original GNIRS instrument. The formidable task of repackaging the instrument, leading to one that is stiffer yet lighter than the original design, while preserving essentially all of the science capability of the instrument throughout a major transformation is a testament to the skills and dedication of the new GNIRS team at NOAO.

3.5. Near Infrared Coronagraphic Imager (NICI)

Unlike GNIRS, which is intended to provide a variety of modes in a single package, NICI is a highly specialized instrument designed to attack one of the most difficult types of observations in astronomy, namely the detection of faint companions in extremely high contrast environments. Accordingly, NICI stands to be a platform for discovery in the field of brown dwarfs, super-Jupiter class planets, circumstellar disks, etc. Destined for deployment on Gemini-S in 2005, it is the only Gemini instrument that incorporates its own adaptive optics unit, an 85 element curvature system built at the University of Hawaii, under subcontract to Mauna Kea Infrared, the prime contractor for NICI.

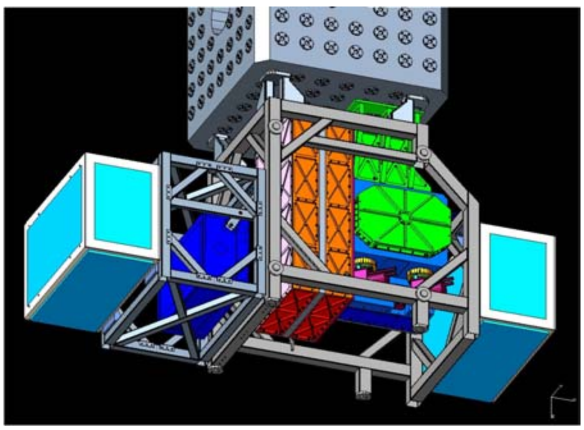

Figure 17 – NICI is shown mounted on the uplooking ISS port. The instrument is split into a warm AO front end that feeds a dual imaging camera. Three thermal enclosures are used to house all of the mechanism control electronics, bimorph drive electronics, a pair of array controllers, and all of the APD power supplies.

Figure 17 shows NICI fully integrated as a CAD rendering. NICI is conceptually divided into several distinct components, including a warm adaptive optics front end, a cold dual imaging camera which uses a pair of ALADDIN 1024^2 1-5 μm detectors, three thermal enclosures to house all of the electronics (which are significant given the two array controllers, APD electronics, mechanism controller, etc.) all of which is tied together with a steel space frame. Though the AO system in NICI in some sense serves as a high order OIWFS (in the same vein as that used in NIRI, GNIRS, etc.), it is actually not tied rigidly to the science detectors since the AO system cannot work at cryogenic temperatures (Figure 18). To deal with differential flexure between the AO bench and the science detectors, which are coupled through the vacuum jacket, a set of back-illuminated fibers will be fixed in the reimaged focal plane corners that act as fiducials so that image pairs can be registered through post processing. By detailed differential analysis between the recorded images, it will be possible to detect companions that have a particular spectral signature (e.g., methane absorption) across image pairs. This powerful approach to differential imaging is expected to address systematic errors that past coronagraphs have been susceptible to, since the PSF will be essentially identical across image pairs given the *precise* synchronization of their integrations.

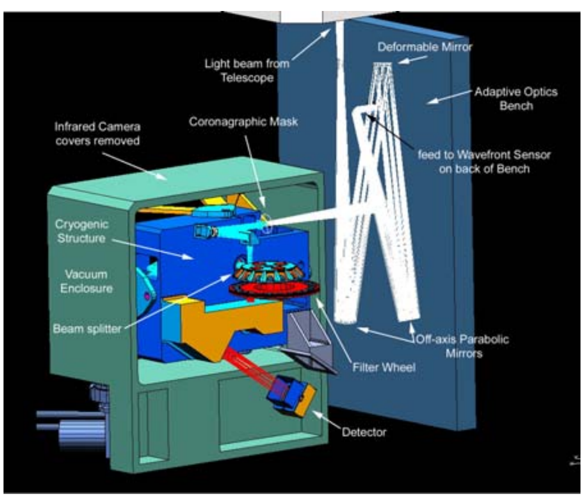

Figure 18 – The two principal components in the NICI opto-mechanical assembly are shown. The AO bench, which houses and 85 element curvature wavefront sensor, is shown only schematically here.

NICI represents the first attempt by a commercial contractor to build an instrument for Gemini, and is ultimately funded by NASA in order to place a high performance coronagraph on a large southern telescope. The Gemini telescopes, which have been optimized for high resolution imaging, have monolithic smooth primary mirrors, unique domes, and thermal control systems are an ideal platform for such an instrument. Accordingly NICI stands to be one of the most unique and powerful instruments for high dynamic range imaging ever built.

4. GEMINI INSTRUMENTATION PROGRAMMATICS

The long term instrument deployment schedule is illustrated in Figure 19, which also includes the northern and southern facility AO systems (ALTAIR and GSAO respectively). A significant imbalance between northern and southern facilities is implied, which will be addressed in the future to help assure that the large amounts of telescope time needed to commission all of these instruments does not overwhelm Gemini-S. This blend of instruments, which provides wavelength sensitivity from ~0.4 – 25 µm, imaging and spectroscopy in a variety of modes (e.g., slit, multi-slit, cross-dispersed, IFU, etc.) with resolving powers up to R~120,000, will provide a powerful baseline capability for the next decade.

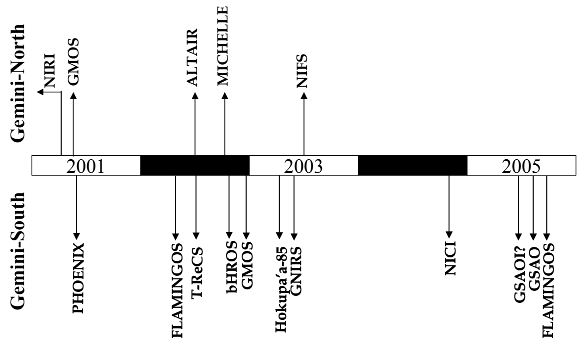

Figure 19 – The current North/South instrument deployment plan is shown. Dates shown indicate expected delivery times, not availability times. Facility instruments delivered beyond 2004 as well as visitor instruments are not discussed in detail in this report.

Since the previous SPIE report on the overall Gemini instrument program, considerable progress has been made toward developing and delivering new facility instruments for Gemini. In Hawaii, with a pair of instruments operational (GMOS-N and NIRI), this means queue based operations are now being conducted. This has numerous beneficial implications since science time between two instruments and telescope engineering time can be dynamically and effectively scheduled. That said, Gemini-S still awaits its first facility instrument, the typical instrument undergoes a 7-figure cost overrun and suffers a multi-year delivery slip. The failures within Gemini's instrument program have arguably impacted Gemini's operations more than any other problem encountered during the early operational phase of the Gemini Observatory. Visitor instruments have therefore been relied upon heavily to provide early scientific capability, in the absence of facility instruments, and to date clearly the bulk of the scientific successes on Gemini are attributable to the visitor instrument program. Those successes have not come without a price though, as Gemini's science staff has been unexpectedly used to "fill the gap" between PI's, the various control systems in use at the observatory, and non-standard visitor instruments. Likewise, visiting instrument teams receive telescope time in exchange for providing instruments and supporting them, which is an issue when relatively few science hours are allocated to the community in the early operational phase at Gemini. This has led to a challenging transitional period for Gemini, as we enter the era of steady state operations and balance the need to commission a range of new facility instruments while phasing out visitor instruments to maximize, long term, the scientific potential of the Gemini Observatory.

In 2003 Gemini will organize a workshop that will effectively chart the course for Gemini instrumentation built during the ~2004-2009 time frame. The outcome of this scientific workshop will no doubt define the next generation of Gemini instruments and be reported upon during the next SPIE meeting on astronomical instrumentation. These recurring Gemini instrumentation science workshops provide a mechanism for the Gemini community to help determine the types of instruments they foresee needing to achieve future science goals, which naturally change as new discoveries are made and other ground and space based observatories emerge. Despite the challenges of the past, one thing is certain as we begin a new chapter in Gemini's instrument program. Given the technical strength and scientific leadership of the teams who build instruments for Gemini, and the unrivaled nature of the twin Gemini telescopes, research conducted at Gemini will be pivotal in astronomy for many years to come.

5. ACKNOWLEDGEMENTS

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