The Gemini Instrument Program

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ABSTRACT

Building instruments suitable for the new 8-10 m class of telescopes has been a major challenge, as specifications tighten, costs, scientific demands, and expectations grow, all while schedules remain demanding. This report provides a top level description of the status of various elements in the Gemini instrument program, and touches on some of the common problems the various teams building Gemini instruments are having. Despite these challenges, Gemini anticipates harvesting great scientific rewards from the combination of its Observatory facilities and exciting complement of scientific instruments.

Keywords: Instrumentation, optical, infrared, detectors, cryogenic

1. INSTRUMENT PROGRAM OVERVIEW

The Gemini instrument program is a large and diverse effort which is centrally managed by the Gemini Observatory. It is being executed by instrument teams in 15 time zones scattered around the world, all of which are members of the 7 nation Gemini Partnership. It encompasses and in many cases *defines* the state-of-the-art in various technologies and engineering used in modern astronomical instrumentation. Grappling with the ever increasing demands for superior performance in ground based instruments, in an environment of finite budgets and demanding schedules, naturally leads to complex trades of costs, scientific capability, and risks in various forms. Like the instrument programs associated with the other large 8-10 m ground based observatories, Gemini's instrument teams have found it to be extremely challenging to extrapolate from the experience base developed in the 4 m telescope era, to building instruments with budgets and masses that are up to an order of magnitude larger than anything they have encountered before. This has often led to significant cost overruns and schedule slips within the Gemini instrument program. Operationally this has led to an increased reliance, early in Gemini's science operations phase, on visitor instruments. Nonetheless, Gemini's instruments are truly at the dawn of a new era in astronomical instrumentation, and together with the Gemini telescopes, the instruments described below will provide a remarkable gateway to scientific discovery in the very near future.

2. PHASE 1 INSTRUMENTS

This report builds on the Gemini instrument descriptions found in Simons *et al.*[1], which includes a description of the telescopes' Cassegrain environment and key features of the Gemini telescopes and support facilities. Instruments are described in the approximate order in which they are expected to enter science operations.

2.1. Near-infrared Imager (NIRI)

NIRI is in the final stages of its integration and test phase, having completed several cold cycles at the place of its fabrication, the University of Hawaii. Key features of its final opto-mechanical design are depicted in Figure 1. NIRI is basically composed of two optical assemblies mounted on opposite sides of a central thick aluminum plate, which is suspended from the vacuum jacket with 3 large A-frame titanium trusses. This plate provides mechanically rigid coupling between the wavefront sensor and science detector. Since the wavefront sensor is used to provide slow flexure compensation of the instrument with respect to the telescope, it is crucial that it remain tied rigidly to the science channel to meet Gemini's standard 0.1 pixel per ~1 hour integration specification.

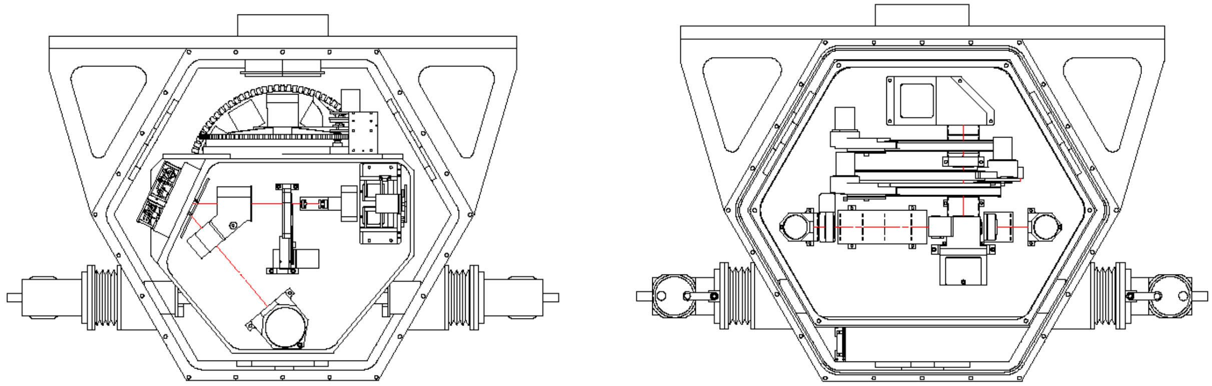

Figure 1 - Two perspectives of the inner cold structure and mechanisms in NIRI are shown. On the left the built in near-infrared wavefront sensor is shown, which occupies roughly half of the instrument. On the right, fold mirrors, filter and pupil wheels, lenses defining 3 cameras and the science detector focus stage are all present. A pair of 130W cryo-coolers are seen protruding from the vacuum jacket.

Referring to Figure 1, which shows the wavefront sensor half of the instrument, light enters through the window on the top and is diverted into the science channel half of the instrument by a large turret containing 3 different mirrors, one for each plate scale of the instrument. Light then passes through a wheel containing various field stops or slits, before entering the science channel, where it is reflected off a pair of mirrors, passed through a pair of filter wheels and a pupil wheel, and is then directed into either an *f*/32 (0.02 arcsec/pix), *f*/14 (0.05 arcsec/pix), or *f*/6 camera (0.12 arcsec/pix), before reaching a 1024^2 ALADDIN 1-5 µm detector. The near-infrared wavefront sensor patrols an area of sky defined on the outside by the window diameter (3.5 arcmin), and on the inside by the size of the turret-mounted pick off mirror, with the finest plate scales offering the greatest patrol field size. Figure 2 shows the fully integrated instrument. A steel space frame structure is used to connect a pair of thermally insulated enclosures for instrument electronics, as well as an interface plate that connects the entire assembly to one of the faces of the instrument support structure (ISS) cube on the telescope. Combined with ballast weights, used to adjust the center of gravity of the assembly, the entire instrument weighs 2000 kg and is handled in either a side or up-looking fashion through facility air carts on the observatory floor.

Tests completed to date indicate that about 2 days are needed to pump NIRI down to levels where its pair of large 130W cold heads can be used. Once activated, NIRI's ~300 kg cold mass reaches its base temperature of 65 K in about 6 days. A network of resistors mounted around the cold structure, which are operated in conjunction with the detector temperature control system, permit warm-up periods of ~2 days. NIRI is nominally expected to be first tested at Gemini-North during the second semester of 2000, at which time it will be commissioned as Gemini's first facility instrument.

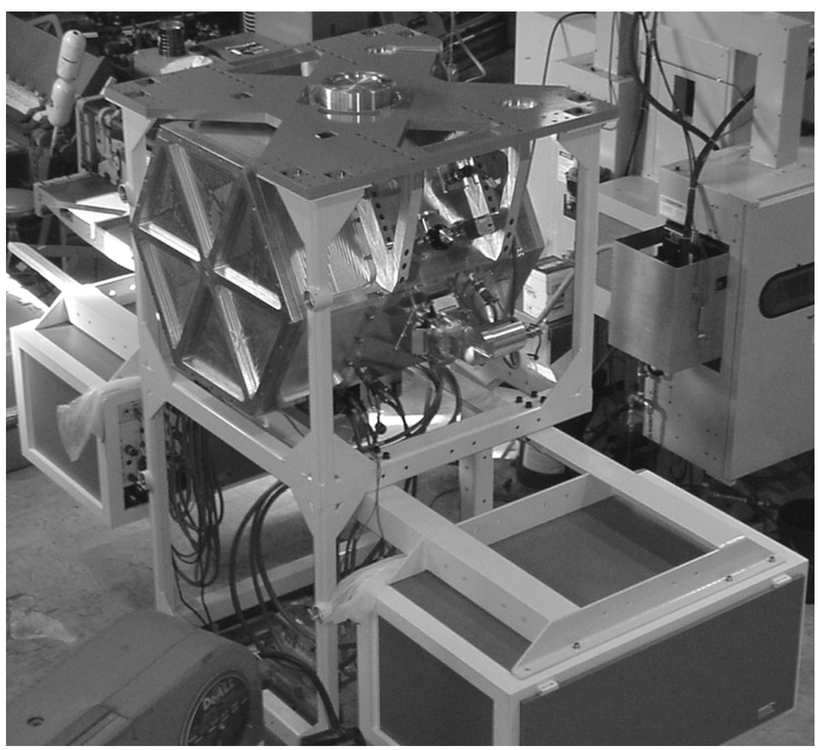

Figure 2 - The fully assembled NIRI is shown. NIRI's vacuum jacket is seen suspended in an up-looking position in the space frame which ties it to a pair of thermally insulated enclosures for its electronics.

2.2. Multi-Object Spectrographs (GMOS)

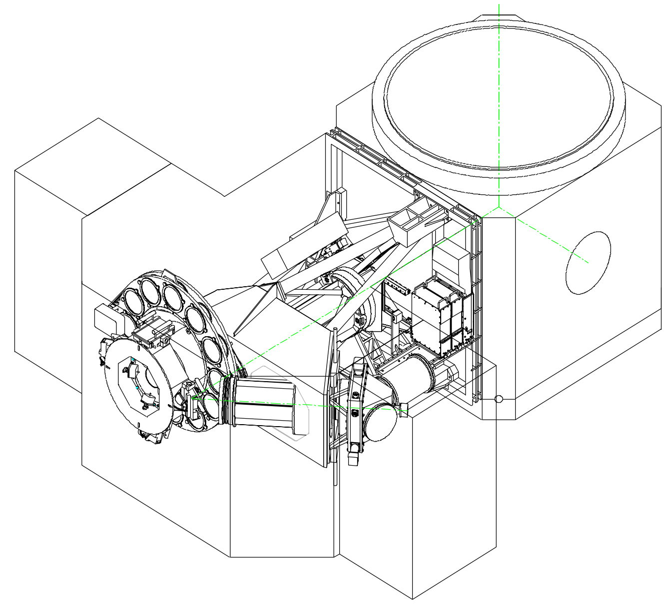

Figure 3 - GMOS is shown attached to a side port of the telescope's instrument support structure. The outline of the instrument is seen surrounding the GMOS opto-mechanical assembly.

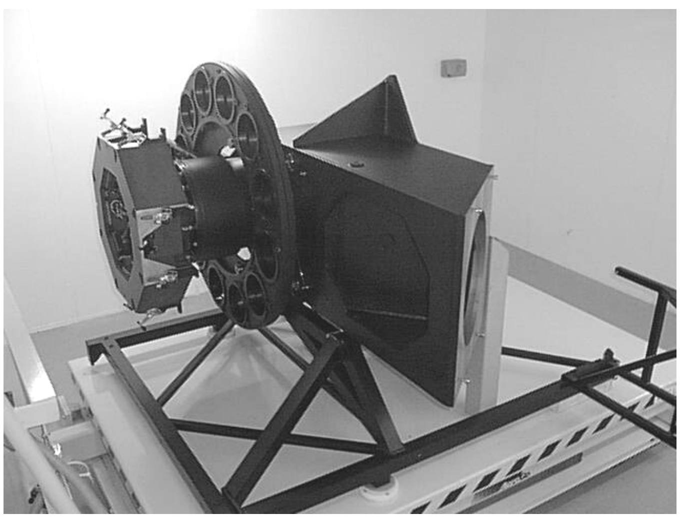

Figure 4 - Much of the post focal plane assembly in GMOS is shown, in a perspective that is similar to that portrayed in Figure 3. The ~1 m diameter filter wheels are prominent, as well as the pneumatically driven grating drive mechanism seen at the far left of the assembly.

In its initial complement of instruments, Gemini is relying on a pair of essentially identical instruments to meet all its demands for optical imaging and low to medium resolution spectroscopy. These important instruments are currently being fabricated in Victoria, Canada at the Herzberg Institute of Astrophysics (HIA) and the United Kingdom at the Astronomy Technology Centre (ATC) in Edinburgh, Scotland. They are scheduled for first scientific use on the telescopes in 2000 (Gemini-North) and 2001 (Gemini-South). Figure 3 shows the ISS with GMOS mounted on a side port and the space envelope for the instrument and its electronics boxes outlined. GMOS offers spectral resolutions of up to ~10,000 and an unvignetted field of ~5.5 · 5.5 arcmin. Its transmissive optical train is effective from ~0.36 - 1.10 µm, and has exceptionally high throughput due to the use of a combination of MgF and SolGel coatings used in its optics. Prominent in Figure 3 are the pair of ~1 m diameter filter wheels which are mounted concentric with the rear grating drum assembly. Figure 4 shows the actual correspond parts, in a frame supported by an air pallet in the GMOS lab at the ATC. The opto-mechanical assembly is suspended from the ISS through a set of nested trusses. A wavefront sensor located in the pre-focal plane assembly will patrol the entrance field for stars that can provide a reference tip/tilt guide signal for the telescope's active secondary, and slow guiding corrections for the telescope's mount. Unlike NIRI, which relies on rigid coupling between its wavefront sensor and science detector, GMOS will achieve its flexure compensation between the slit and detector through a look-up table and an X-Y stage holding the detector package. The instrument bound for Mauna Kea will use a mosaic of three 2048 · 4608 pixel CCDs which have red optimized coatings. The Cerro Pachon twin instrument will be identical in all respects except is will use blue optimized CCDs. The science detector systems used in GMOS are integrated and tested at the CCD laboratory at NOAO, Tucson.

GMOS masks will be cut from a multi-ply carbon fiber material using a YAG laser and precision X-Y cutting stage at Gemini's Northern Operations Center. Before spectra are recorded, images of target fields will first be recorded through each GMOS running in its imaging mode. Targets will then be selected by astronomers responsible for GMOS science programs. Once identified, slit locations within fields will be electronically transmitted to the Gemini operations center, where they will be translated into files that can drive the mask cutting machine. Finished masks will then be sent to either Gemini-North or South, loaded into GMOS, and used to record spectra. Each instrument can hold enough masks to support several science programs and any mask can be

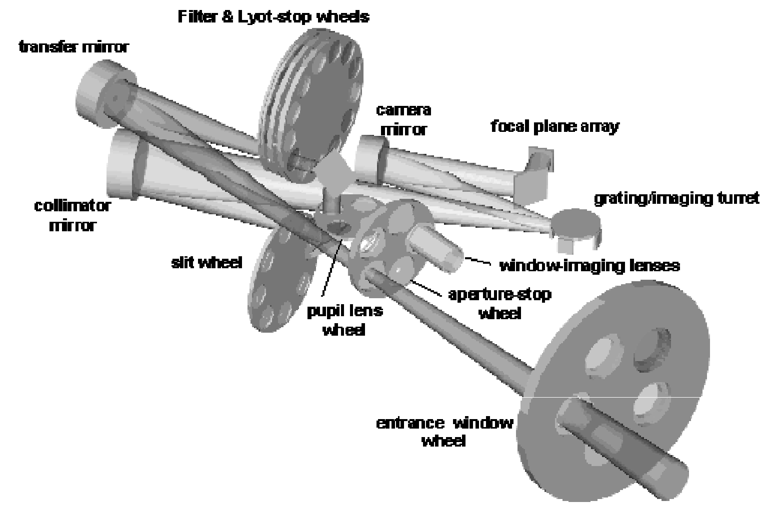

Figure 5 - The filter wheels, aperture wheel, windows, grating turret, various reflective optics, and detector which together compromise the T-ReCS optical assembly are shown.

remotely deployed within the instrument. The entire process will be managed by rigorously tracking the locations of masks, through UPC labels and scanners both at the laser cutting machine and in each GMOS.

Though GMOS is primarily a multi-object slit spectrometer, a 1000 fiber integral field unit (IFU) will be delivered with the first GMOS to provide spectro-imaging across a ~5 arcsec field. Sky reference spectra will be provided through an adjacent 500 fiber IFU. The IFU combination can also be used to support a nodding mode between IFU bundles to further improve sky subtraction, which will be important for the faint high-z targets that will likely be observed with this mode. The IFU assembly fits within the same exchange mechanism used for masks and is therefore also remotely deployable. Long term, it is expected that various IFUs, with custom design features, will be used with GMOS, just as different gratings and filters are commonly exchanged within optical spectrometers today.

2.3. Mid-infrared Imager (T-ReCS)

The next instrument planned for delivery in Gemini's suite will be its facility mid-infrared imager, T-ReCS, built by the University of Florida. This instrument will be the first on Gemini-South, with deployment currently expected in mid 2001. Though originally planned to be only an imager, T-ReCS will be built with a modest spectroscopy capability, yielding resolutions of ~100 at 10 and 20 µm, and R~1000 within narrow regions of the 10 µm atmospheric window. With facility tip/tilt compensation T-ReCS is expected to provide diffraction limited images essentially all the time and, in this manner, will be unique among all of Gemini's facility instruments. T-ReCS will use a Raytheon 240·320 Si:As IBC detector which, combined with its 0.09 arcsec/pixel plate scale, will yield a 22 · 31 arcsec field of view. Running T-ReCS on a queue scheduled telescope like Gemini-South will permit 20 µm science programs to be run with *much* higher efficiency than is typically achieved, since these programs are extremely sensitive to atmospheric water vapor and can be executed quickly when otherwise rare conditions exist.

Figure 5 depicts the optical design of the instrument. Mechanically, the instrument is actually similar to NIRI in the sense it has a central thick plate which acts as an optical bench upon which everything is mounted. For clarity, Figure 5 does not show this aspect of the design. Light first passes through one of several remotely deployable windows, then through an aperture stop, a series of filter and pupil stop wheels, then forms a reimaged focal plane at a slit wheel, is collimated by an off-axis parabolic mirror, bounces off a grating drum which has a simple fold mirror on it to support imaging, then strikes another off-axis parabola which acts as a camera, and finally the

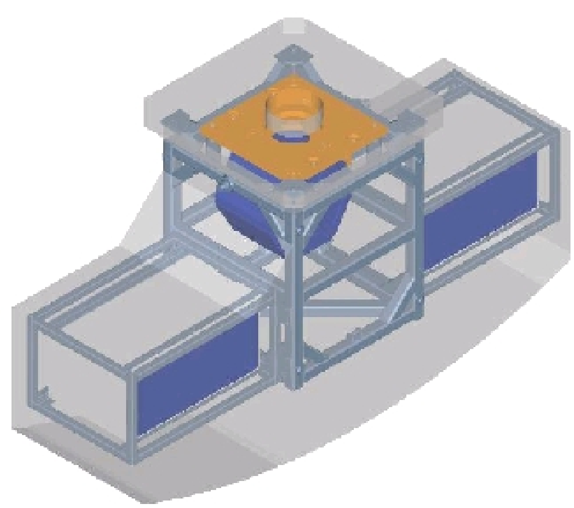

Figure 6 - The T-ReCS space frame, outrigger electronics enclosures (similar to NIRI's configuration), and instrument package are all seen. Unlike most other Gemini instruments, the opto-mechanical assembly actually occupies a fairly small poriton of the available space.

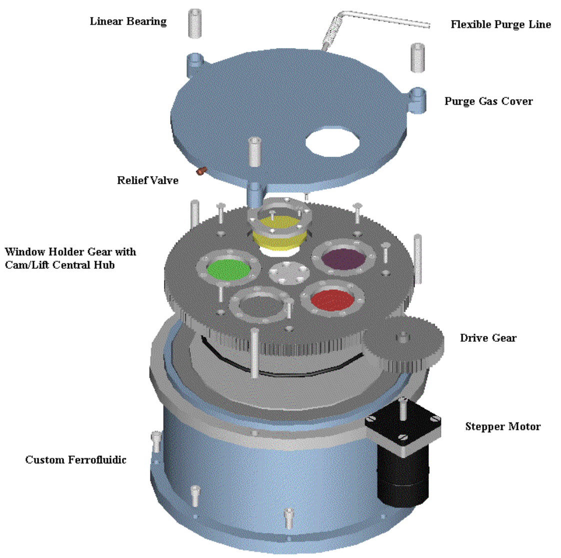

Figure 7 - One of the most unique aspects of the T-ReCS design is the remote controlled window exchange mechanism, which is mounted on a large ferrofluidic feed-through in the vacuum jacket.

Figure 8 - Large rough-cut fused silica intended for use in HROS is shown.

science detector. Excluding the filters and detector, this reflective design should have >75% optical throughput.

Figure 6 shows the instrument in an up-looking mode, mounted within a steel space frame, like NIRI's. Two thermally insulated enclosures will be used to house all of the array controller and mechanism control electronics. The vacuum jacket is the small hexagonal structure in the center of the space frame. Unlike most other facility instruments T-ReCS will not use an on-instrument wavefront sensor, instead relying on the peripheral sensors built into the facility Acquisition and Guidance (A&G) Unit to provide fast tip/tilt compensation signals to the telescope's secondary mirror. Accordingly, T-ReCS is designed to be small, relatively light weight, and intrinsically very stiff, to prevent significant differential flexure between the instrument and peripheral wavefront sensors. Figure 7 shows an interesting feature of the instrument - a remote window exchange mechanism based upon a large ferrofluidic feed-through in the front of the vacuum jacket. A total of 5 windows will be mounted in this mechanism, which will have a sealed cover under positive dry-air pressure to keep dust and moisture away from the hygroscopic windows used for the instrument. The windows mounted within this assembly will be made of KRS-5, KBr, or ZnSe, and will be optimized for 10 or 20 μm performance with custom AR coatings. Given the extremely low emissivity expected of the Gemini telescopes, such measures are necessary to insure that T-ReCS always has a clean, low emissivity window available so the T-ReCS/telescope system provides maximum sensitivity on a reliable basis.

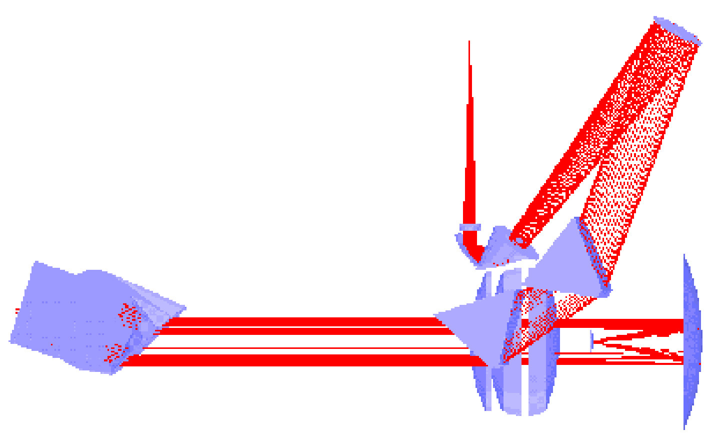

Figure 9 - The HROS optical design is shown, including the actuated collimator at upper right, immersed echelle grating at left, and the camera mirror on the lower right.

2.4. High Resolution Optical Spectrograph (HROS)

The only UV optimized instrument in Gemini's instrumentation program is HROS, which is being built by University College London. HROS is currently scheduled to be deployed in 2002 on Cerro Pachon. This instrument is also the highest resolution spectrograph (R~50,000) of any being built for Gemini, thereby providing an important element in the overall scientific capabilities of the Observatory. It is designed to function from 0.3-1.0 μm and, as seen in Figure 8, relies on large pieces of fused silica throughout much of its optical train. In fact, given the sizes of the optical elements in HROS, combined with the demanding specifications of a high resolution spectrometer (flexure <0.05 of a resolution element over a 1 hour integration), HROS is arguably one of the most complex opto-mechanical systems in the entire instrument program. When combined with aluminum telescope coatings on Gemini-South, and state of the art UV optimized detectors, HROS is expected to be one of the world's most sensitive spectrometers at UV wavelengths.

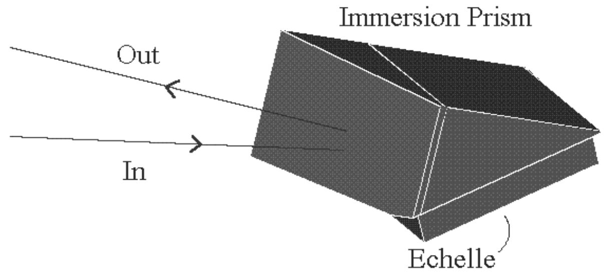

Figure 10 - The immersed echelle used in HROS is seen in greater detail. The grating is optically coupled to a large fused silica prism through a thin oil layer.

Figure 9 illustrates the optical path of light when it enters the instrument. Specifically, light passes through the slit assembly which includes an adjustable slit, shutter, and filter wheel, then strikes a combination folding prism/lens assembly which serves to direct the beam back toward the ISS, where it strikes the collimator mirror. This mirror is on actuators and is an important part of the flexure compensation system. From there light passes through a pair of massive fused silica grisms, then bounces off an immersed echelle grating, through a set of large camera lenses, then a camera mirror, before falling on the detector mosaic, which is mounted on-axis with the final camera mirror. Of all the elements in the instrument, probably the most challenging from an opto-mechanical perspective is the immersed echelle, which is illustrated in Figure 10. In essence this is a standard echelle grating with a large multifaceted fused silica prism floated on top of the echelle by a thin layer of oil, which has been carefully selected to provide optimal transmission properties across the prism/grating interface. Like the collimator, actuators are located along the edge of the immersed echelle assembly to form part of the flexure compensation system. The entire package is expected to flex as it changes attitude on the back of the telescope. HROS's approach to maintaining adequate slit-to-detector alignment under all gravity vectors is to use an infrared laser, shining "backwards" through the optical train, where it will be detected by a small commercial infrared array mounted at the slit. A servo loop will preserve the correct system alignment, again using degrees of freedom built into the collimator and echelle mounts. Like T-ReCS, HROS has no built in wavefront sensor. The combination of relatively large slit sizes and minimal differential flexure expected between the facility peripheral sensors and slit assembly should permit slow guiding corrections with only the peripheral sensors.

HROS will use a pair of 2048 · 4608 pixel CCDs in a compact dewar to form a square shaped detector plane. The use of closed cycle coolers is under investigation as a means of efficiently cooling this package, which will be thermally connected through a fairly long cold strap since the package profile has to be minimized to reduce vignetting of the on-axis reflective camera mirror. Thanks to its cross-dispersed design, and large detector area, HROS will be able to record the majority of its echellogram in a single integration, again keeping with the spirit of making the instrument as efficient overall as possible.

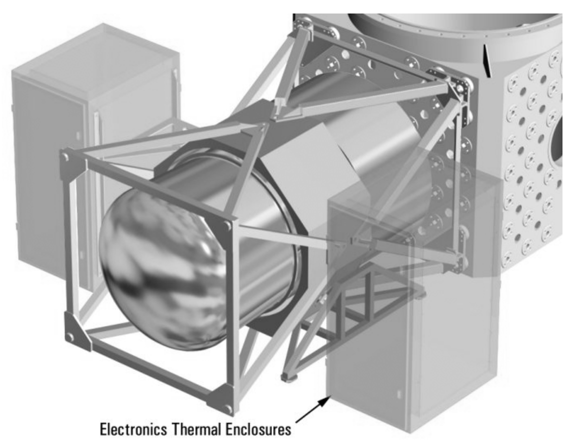

Figure 11 - The GNIRS assembly, including vacuum jacket (center), truss structure, and pair of thermally enclosed cabinets is shown attached to a side ISS port.

2.5. Near-infrared Spectrograph (GNIRS)

The final instrument planned for deployment as part of the Phase 1 set is GNIRS, which should enter science operations by late 2002 or early 2003. It is being designed and built at NOAO in Tucson, Arizona. GNIRS has recently undergone a major redesign due to problems with excess mass and flexure discovered with the previous

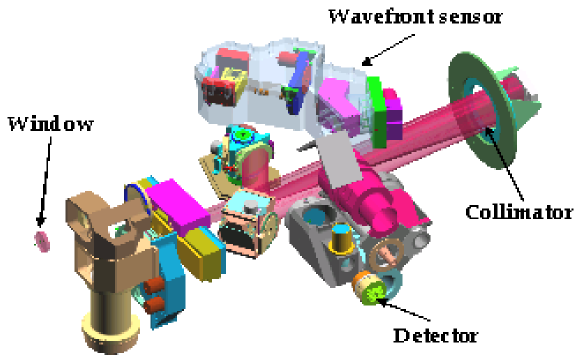

Figure 12 - The various modules that define the GNIRS opto-mechanical assembly are shown, including the Offner pre-slit optics at far left, rear-mounted collimator, wavefront sensor package, and detector system. A pair of cryo-coolers are planned to be used, in conjunction with an LN_2 precharge system to accelerate GNIRS cooldowns.

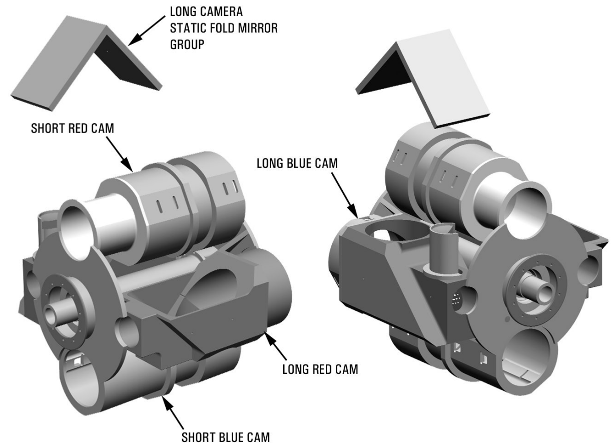

Figure 13 - The GNIRS 4-camera turret assembly is shown.

design. A new management and engineering team has been formed to redesign the instrument and is responsible for the innovative design depicted in Figures 11 through 13, below.

Referring to Figure 11, GNIRS is mechanically coupled to a central rigid bulkhead structure, to which ties its optical bench, cryo-coolers, and support frame. Like NIRI and T-ReCS, the array controller electronics and mechanism control electronics are housed in a pair of thermally insulated enclosures. A non-structural vacuum jacket will enclose the cold structure. Figure 12 shows the preliminary layout of the primary components in GNIRS, including the window, Offner relay fore-optics, slit/decker/IFU assembly, cross dispersion prism and Wollaston prism turret, camera lens turret (Figure 13), grating turret, collimator, and on-instrument near-infrared wavefront sensor. The wavefront sensor package is actually being built at the University of Hawaii, given that it is essentially identical to that used in NIRI. Also like NIRI, GNIRS will use an ALADDIN 1024^2 detector. A combination of 3 gratings and 2 pairs of cameras (1-2.5 µm and 3-5 µm optimized) provide spectral resolutions of approximately 700, 2000, 6000, and 18,000. The cameras yield either 0.05 (50 arcsec long slit) or 0.15 arcsec (100 arcsec long slit) sampling, providing either adaptive optic or tip/tilt optimized spatial sampling. Given its ability to provide 1-5 µm slit or integral field spectroscopy, cross dispersion, spectro-polarimetry, and plate scales tuned to match various seeing conditions, GNIRS is intended to act as a "work horse" multi-mode instrument capable of supporting a variety of science programs.

One of the more interesting aspects of GNIRS is the pair of integral field units being designed at the University of Durham and scheduled to be delivered as part of the final instrument configuration. The IFUs will be mounted in the GNIRS slit/decker assembly, which yield either 0.04 or 0.12 arcsec sampling and reformat the entrance focal plane into many pieces that are passed into the GNIRS post-slit environment, dispersed, and recorded as closely packed spectra on the detector. When reconstructed through post-processing, a data cube containing both spatial and spectral information is produced. The IFUs will be made of diamond machined thin slices of metal, stacked and aligned to preserve proper pupil transfer into the GNIRS post-slit system. They are arguably the most complex and technically challenging aspects of the GNIRS optics, but promise to provide a powerful capability, particularly when used with the facility adaptive optics systems planned for Gemini.

3. CALIBRATION, POLARIZATION, AND ADAPTIVE OPTICS FACILITIES

Beyond the aforementioned Phase 1 instruments, the Gemini instrument program is funding several common-use facilities to augment the functionality of the entire instrument set. These facilities include a polarization modulator, which supports imaging and spectro-polarimetry from UV to near-infrared wavelengths, a calibration unit, which provides flat fielding and spectral calibration for all instruments except T-ReCS, and an adaptive optics system, which can feed the entrance port to any instrument mounted on Gemini-North. These facility instruments are described in more detail below, again in the order in which they are expected to be completed

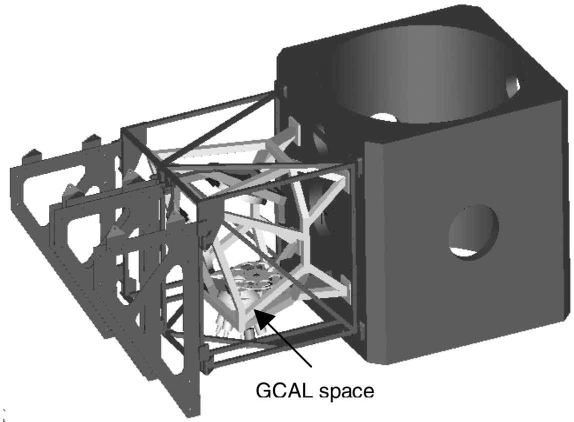

Figure 14 - The ISS and support structure for A&G electronics is shown with the GCAL space frame in between.

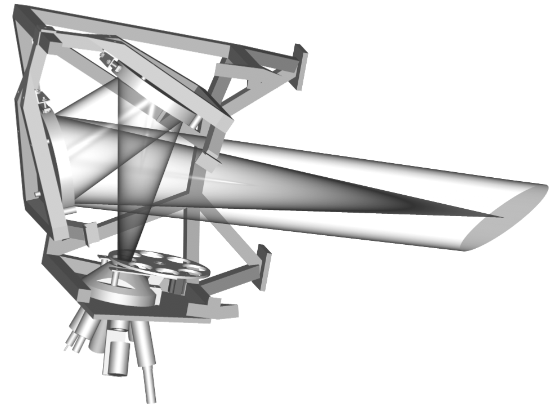

Figure 15 - GCAL uses a series of lamps, seen at the bottom, that are projected into a novel hemispherical reflecting dome, together with a pair of large mirrors that project an extremely uniform beam which simulates the telescope's beam into any of the facility instruments.

3.1. Calibration Unit (GCAL)

The UK's ATC is building a pair of facility calibration units for Gemini, which are nominally scheduled to be installed on Gemini-North and South during 2000. These are designed to replicate the telescope's beam and send an extremely flat field of illumination into instruments mounted on the ISS.

As seen in Figure 14, GCAL mounts on the side of the ISS in a space between the electronics racks used for the A&G system. The central science fold mirror in the A&G directs GCAL's beam into any of the 3 facility instruments mounted on the telescope at a time. It is intended to provide the calibration needs of all but the thermal infrared instruments, which nominally use either the sky or a built-in calibration system. A combination of quartz halogen, grey body, gas lamps, and hollow cathode lamps act as flat fielding and spectral calibration flux sources. These lamps are projected into a clever reflecting hemisphere chamber which illuminates either an optical or infrared optimized diffusing screen (remotely selectable). This system is estimated to yield an output beam that is ~20· greater than would be achieved by a conventional integrating sphere. Light emerges from the hemisphere and passes through a single filter wheel which houses neutral density filters and color balancing filters. From there the beam is reflected off a pair of large diamond turned projection mirrors which yield an *f*/16 beam that passes into the ISS, where it is directed into an instrument of choice. This beam is expected to be uniform in illumination to the ~1% level across the central 3 arcmin of the telescopes' field of view. The entire system is mounted in a lightweight space frame, which is adequate given the large opto-mechanical flexure tolerances that are intrinsic to the design of GCAL. Though this calibration unit is certainly the least complicated of any of the facility instruments, it is expected to have the longest lifetime due to the flexible nature of its design, which can accommodate many different types of flux sources in the

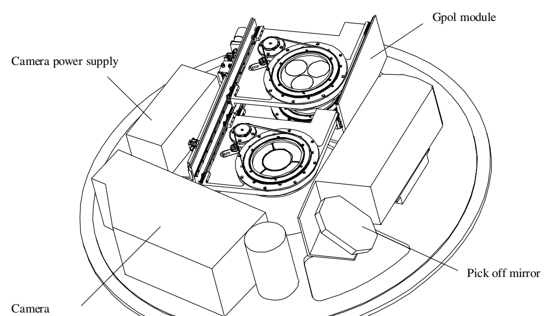

Figure 16 - GPOL, as seen in the base of the A&G, is depicted.

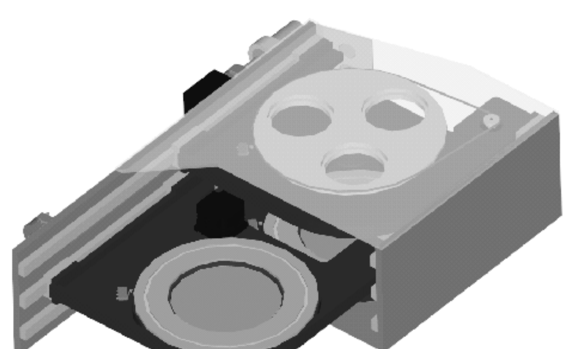

Figure 17 - The facility polarization unit is shown, which is mounted in the base of the A&G and uses linear slides to insert waveplates or polarimetry calibration plates into the telescope beam.

future, and it will play a key role in essentially all data recorded with the Gemini telescopes.

3.2. Polarization Unit (GPOL)

The UK's ATC is also building a pair of polarimetry units that will permit observations through $\lambda/2$ waveplates from ~0.3 to ~4 µm for instruments mounted on the up-looking port of the telescopes. GPOL is being designed as a retrofit in space remaining in the bottom module of the A&G unit, as shown in Figure 16. Each telescope will receive a GPOL unit, though initially only a single set of the rather costly waveplates will be purchased and shared between Gemini-North and South, as science programs demanding polarized observations are block scheduled. Both GPOL's are currently scheduled to be commissioned during the first semester of 2001. Each GPOL consists of a set of 3 deployable trays, each of which has a motor driven turntable to permit rotation of the waveplate to various position angles on the sky. The upper tray has 3 smaller calibration waveplates, held at fixed angles with respect to the instrument and telescope. The lower 2 trays have ~95 mm diameter waveplates that support unvignetted polarimetric observations in the narrow field modes of all instruments having corresponding analyzers. Each waveplate is mounted in an annulus of fused silica so on-instrument wavefront sensors mounted in instruments can patrol the field outside the waveplate for guide stars. The fused silica has an identical optical depth as the waveplate, to yield a common telescope focal plane in the instrument, when deployed.

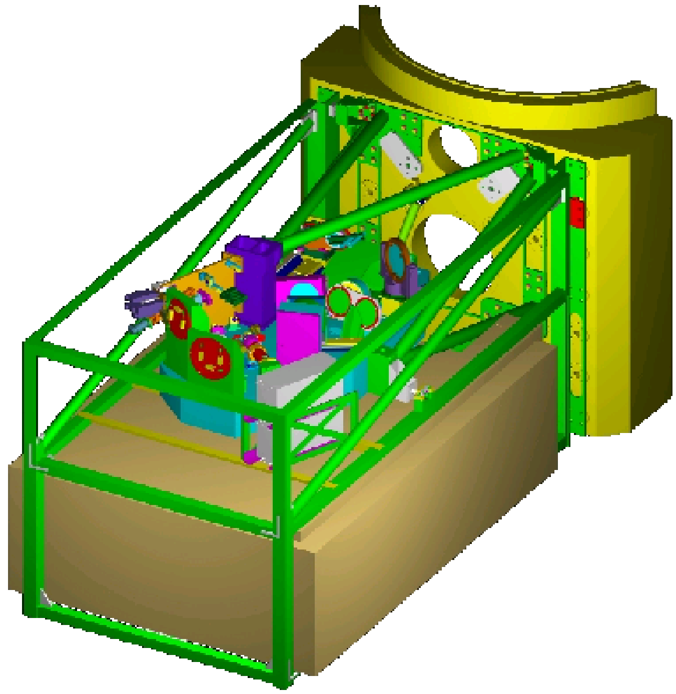

Figure 18 - The facility adaptive optics system ALTAIR is shown above, including the nested truss mechanical system used to tie the optical bench to the ISS and a custom thermally enclosed electronics package below the bench.

The analyzers mounted in instruments are in general Wollaston prisms. They have varying compositions within the facility instruments, including MgF_2 for NIRI and Calcite for HROS. These provide efficient dispersion for orthogonal polarization states of transmitted flux and, when used in conjunction with a field mask in the instrument, generate a pair of images in the focal plane, the relative intensities of which map into the degree to which the target's light is polarized.

3.3. Adaptive Optics System (ALTAIR)

Gemini-North will have a facility adaptive optics system capable of feeding any instrument on the ISS with an AO corrected beam. This system is being built in Canada by the HIA. ALTAIR will initially be used in a natural guide star mode, but will be delivered laser guide star ready so it can take immediate advantage of a planned sodium laser launch system for the telescope. ALTAIR is optimized for ~0.85 - 2.5 µm use and is predicted to deliver end-to-end system strehls of ~40% at H on bright guide stars, this strehl including wavefront degradations due to the telescope and instrument optics. It preserves the telescope focal plane location, as well as the pupil, so is essentially "transparent" to the instrument when deployed. An unvignetted 2 arcmin field will be used to acquire guide stars, with a low noise 80^2 frame transfer CCD being used as the wavefront sensor detector. ALTAIR is capable of working with the tip/tilt signal of the wavefront sensors located in instruments to correct for atmospheric and telescope jitter. When used in its laser guide star configuration, the combination of ALTAIR's 12x12 Shack-Hartmann facility wavefront sensor and the near-infrared tip/tilt sensor in instruments like NIRI and GNIRS leads to AO corrected observations across much of the sky, *including* dark cloud regions.

Referring to Figure 18, the ALTAIR opto-mechanical assembly is mounted on a stiff bench that is suspended from the ISS through a series of nested trusses, similar to the strategy used for GMOS. Coupled independently to the ISS is a frame that supports a custom thermally insulated electronics cabinet, which contains a variety of electronics including the high voltage drivers needed for the deformable mirror. A single RISC processor is dedicated to reconstructor processing tasks while 3 other high performance processors take care of the rest of the control system, various housekeeping functions, etc.

The most unique aspect of ALTAIR compared to other AO systems is the fact that its deformable mirror is optically conjugated to a turbulence layer ~6.5 km above Mauna Kea, which past tests have indicated forms the dominate turbulence layer in the optical path of the telescope. This approach significantly increases the complexity of the ALTAIR control system, compared to conventional AO systems, which typically conjugate to the exit pupil of the telescope, but promises to provide a corrected field that is nearly twice the size of comparable conventional AO systems. The key to making this system work is the myriad of dome and local seeing reduction strategies used in the observatory.

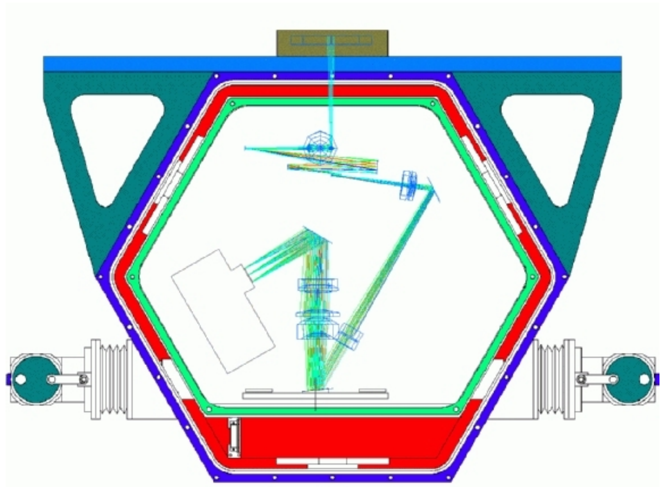

Figure 19 - The science channel in NIFS is shown. Comparing this to Figure 1 immediately reveals the use of common components between NIRI and NIFS, which is part of Gemini's effort to "recycle" elements of instruments in successive generations to accelerate fabrication times and reduce costs.

4. ON-GOING INSTRUMENT PROGRAM

Beyond the previously summarized Phase 1 instrument program there are a variety of instruments in an early conceptual design stage which represent the next generation of instruments for the Gemini observatory. While the Phase 1 instruments typically represent multi-mode general purpose instruments, many of the instruments in the on-going program represent more specialized systems that fill unique scientific niches that Gemini Observatory is poised to offer its Community. These include a coronagraph, which is intended for use on Gemini-South around 2003. This will be Gemini's first dual-channel instrument with a built-in adaptive optics unit that will permit differential imaging of the environments immediately surrounding stars to search for low mass companions, orbiting material, etc. When combined with the exceptionally smooth telescope optics, thin secondary mirror support structure, and a telescope enclosure that minimizes dome seeing, the new coronagraph represents a unique "marriage" of instrumentation and telescope systems that will support searches for faint companions to bright stars at an unprecedented level of sensitivity.

Another example of an instrument that fills a niche within the "work horse" environment of other instruments like NIRI and GNIRS is the near-infrared integral field spectrograph (NIFS), which is in a conceptual design phase at the Australian National University (RSAA). NIFS is essentially a mono-mode instrument, which is intended to be used with ALTAIR to provide integral field spectroscopic observations of galactic nuclei, YSO's, and complex compact fields. Figure 19 shows a cross sectional view of NIFS. Comparing this to Figure 1 reveals a common design theme between NIFS and NIRI. In order to accelerate the NIFS, and reduce its costs, this instrument will use hardware and software from NIRI to the extent practical. For example, the same vacuum jacket, wavefront sensor, and some of the mechanisms and software from NIRI will be duplicated and used in NIFS.

Another instrument which is currently in a competitive design study phase at the University of Florida and AAO is a near-infrared multi-object spectrograph. This instrument will provide 1-2.5 μm direct imaging as well as multi-slit spectroscopy across a ~3-4 arcmin field of view. The 2-pixel spectral resolution will be >4000 across the 1-2.5 μm region using 0.3 - 0.5 arcsec slits, which should be high enough to permit observations between OH emission lines in recorded spectra. A cold slit environment that is capable of rapid thermal cycles will permit the deployment of enough cold slits in the instrument to easily support a full night of spectroscopic observations.

Again, in order to reduce costs and accelerate fabrication times, this instrument will build upon the designs of IRMOS's being fabricated now with similar basic capabilities (FLAMINGOS and IRIS2). Like GMOS, the new IRMOS will have its slits cut with Gemini's facility laser milling machine.

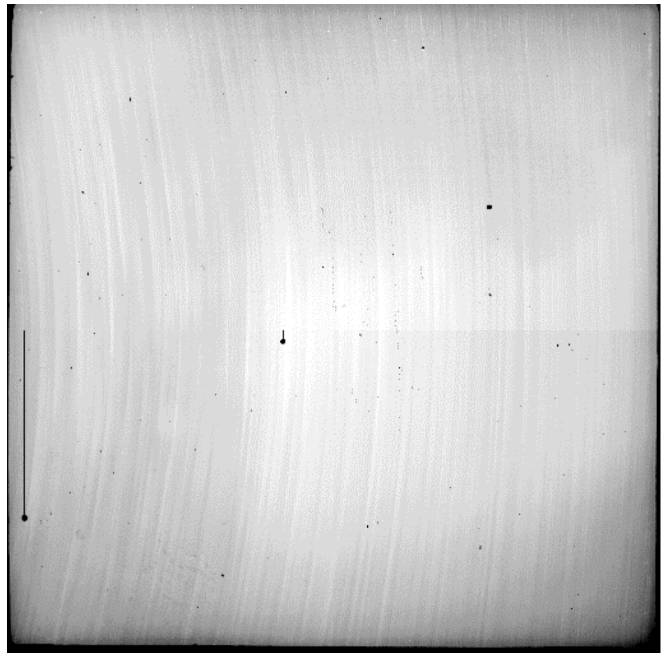

Figure 20 - The 1024^2 InSb ALADDIN science detector intended for use in NIRI is shown using flat field illumination.

Beyond developing a new IRMOS, Gemini's instrument program is funding technology studies at AAO and within the UK (ATC and University of Durham) that will feed into the development of an advanced cryogenic near-infrared spectrometer which will be designed to exploit the output of a facility adaptive optics system on Cerro Pachon. The design studies include tests of the cryogenic performance of various types of fibers, mechanical deployment schemes of bundles of cold fibers within an instrument, micro-lens array alignment and mounting schemes when used with fibers in a cryogenic instrument, and various deployable integral field unit opto-mechanical schemes. Studies of the cryogenic application of volume phase holographic gratings are also included in this work, the intent being to significantly increase spectral resolution and throughput with these advanced dispersion elements.

Finally, Gemini has an on-going detector development program, which supports the use of state-of-the-art detectors in all of its facility instruments. Perhaps the most successful element of the entire instrument program has in fact been the 1024^2 InSb detector procurement, which yielded a total of 12 detectors, 10 of which have 4 operable quadrants and many of these are science grade devices. Figure 20 shows the detector that is destined to be used with NIRI. These detectors will act as the cornerstone in many of Gemini's facility infrared instruments, including NIRI, GNIRS, and the coronagraph. In the optical, Gemini is pursuing advanced UV optimized CCDs, generated with molecular beam epitaxy, for use as upgrades to the baseline detectors in HROS. When combined with the highly UV optimized design of that instrument and high quality aluminum coatings anticipated with Gemini's sputtering coating plant, HROS should be one of the most UV sensitive ground based astronomical instruments in the world.

5. CHALLENGES - PAST AND FUTURE

The previous description of Gemini's instrument program illustrates how a complex balance between science considerations, budgets, numerous engineering disciplines, and international management structures must be achieved to satisfy the end "customer", the Gemini astronomical Community. This is obviously a non-trivial task, and a number of valuable lessons have been learned along the road to building all of these instruments, which are mentioned below. As the instrument program continues to mature and develop, these lessons are being incorporated into the principles defining Gemini Partnership interactions and in many cases provide a "guiding light" to keep the overall program on course.

Certainly one of the most important lessons learned by many teams over the past few years is the value of project management in the design and fabrication of 8 m class instruments. The need for project management goes far beyond the use of formal progress charts and work breakdown structures. It implies management that is actively engaged with the instrument team, discussing trades in design options, costs, and performance considerations, keeping staff informed of decisions and involved in making them, etc. Most instrument teams have developed a technical and management skill base from building relatively modest size instruments for 2-4 m class telescopes.

Extrapolating the management model they have successfully used on smaller instruments to Gemini facility class instruments has generally been unsuccessful. In fact, this has led to significant cost and schedule overruns by most instrument groups. It is therefore reassuring to note that all of the newer instrument teams in the program have taken on board the need for better project management and have allocated manpower to support this function within their organizations.

Another significant problem has been resource conflicts within instrument groups that are trying to juggle too many commitments. Often the same institution is responsible for several elements of Gemini's overall instrument program. This naturally leads to competition for resources need for machining, drafting, FEA modeling, etc. and slips in fabrication schedules. Maintaining a credible balance between Gemini's demand for manpower to support its instrumentation program and the manpower actually available in instrument labs is an on-going challenge, but one that is being met better as improved resource estimates are developed from the growing experience of Gemini's teams.

To some extent a "not invented here" syndrome has impacted past instruments as well, as teams have viewed the construction of instruments to be something of a cerebral experience and not focused adequately on the benefit from cost, schedule, and science perspectives of adopting proven technologies and designs to solve common engineering problems. NIFS is a wonderful example of how Gemini is moving beyond this perception within its teams, as this instrument borrows heavily from an instrument that is nearly complete by cloning the vacuum jacket, wavefront sensor system, central support plate and much of the NIRI control software to generate an integral field spectrograph.

Software has been a continuing challenge for Gemini's instrument teams as well. The typical experience of software engineers has been to invest a large amount of time, early in the instrument's development, learning the subtleties of EPICS and the software environment to which their software must interface. This tends to build delays into the software development compared to the rest of the instrument. Considerable resources are required to train software engineers in EPICS on a recurring basis, as new teams build instruments for Gemini. To mitigate this problem in the future Gemini is examining approaches to simplify the implementation of EPICS within instruments. For example, several teams are now using EPICS as only a "thin layer" for communications to preserve the functionality and design of existing interfaces to the observatory control system, but use more conventional code under EPICS to simplify architectures, accelerate code generation, and where possible use pre-existing code (e.g. with array controllers) to reduce cost and risk.

Beyond the aforementioned problems, other measures are being taken now to streamline contract negotiations, review the costs of instruments on a regular basis to ensure that they do not spiral out of control, clearly define a customer/vendor relationship between Gemini and its instrument teams, and develop long term incentives to make it attractive to build instruments for Gemini in an otherwise very competitive world of ground and space based instrumentation builders. All of this is intended to respond to the problems encountered in the past few years in the instrument program, and has been inspired through a constructive dialog between instrument teams and Gemini to define a mutually beneficial set of operating conditions.

While the challenges of developing and maintaining a robust instrument program for the Gemini Observatory have been large, they have certainly not been overwhelming, as is proven by the previous descriptions of the remarkable technical achievements made by Gemini's instrumentation teams. Combined with the fantastic platforms the Gemini telescopes offer, these instruments will probe observing "parameter space" in terms of wavelength coverage (0.3 - 30 μm), spatial scales (~5 arcmin to ~30 mas), sensitivity (e.g., a few percent total system emissivity at thermal wavelengths), and spectral resolution (broadband to R ~ 50,000) in a manner consistent with the far reaching scientific ambitions and expectations of Gemini's astronomical Community. We eagerly await their arrival and look forward to the scientific discoveries these instruments will bring.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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