Gemini Instrumentation Program Overview

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ABSTRACT

Exploiting instrument platforms like the current generation of 8-10 m class telescopes represents a new era in instrument design, construction, handling, and use. Gemini's instruments are no exception to this revolution. For example, since at least 50% of Gemini's observing time will be queue scheduled, Cassegrain-mounted instruments will effectively remain on-line, ready to be called into service for typically months at a time with minimal delay to match observing programs with changing conditions. Furthermore, effective instrument emissivities of <1% will be needed to take advantage of the very low emissivity of the telescopes. Here we report on the technical status of the Phase I instruments, describe attention being given to the total system performance of the telescopes and instruments, and list some of the considerations going into the Phase II instrument program.

Keywords: instrumentation, optics, cryogenic, infrared, spectroscopy, imaging, wavefront sensing

2. CASSEGRAIN INSTRUMENT ENVIRONMENT

Listed in Table 1 are the Phase I instruments that will be deployed on Gemini North and South over the next ~5 years. They represent core or "workhorse" instruments that will support a broad range of science initiatives across a factor of ~100 in wavelength through optical and infrared imaging and spectroscopy. This table also lists instruments that are under consideration as shared-use instruments at each site. Note that commissioning of Gemini-South will be done with COB, NOAO's Cryogenic Optical Bench, which supports 1-5 μm imaging and other basic telescope diagnostic tasks. Simons *et al.*[1] list additional information about the Gemini telescopes and instruments.

All instruments will be stationed at the Cassegrain focus of the telescope on a mount called the instrument support structure (ISS; see Figures 1 and 2). This structure houses the facility acquisition and guidance (A&G) system in its interior and rotates on a large bearing mounted on the back of the primary mirror cell to compensate for field rotation. Overall the ISS measures 1.6 m on a side, is a welded steel structure, and can support a total payload of 7600 kg. Two opposing faces of the ISS will support a facility calibration unit and adaptive optics unit, each with a mass limit of 800 kg. The remaining 3 ports will be used to mount instruments weighing 2000 kg each. Maintaining proper servo control over the rotation of this structure during integrations demands fairly tight limits on the mass and moment distribution around the ISS, hence counterweights will be used to trim the ballast of the system. A central mirror in the ISS directs light from either the telescope, calibration unit, or facility adaptive optics unit into any of the instruments. Such a design permits rapid deployment of any instrument or facility mounted on the ISS, consistent with Gemini's plans to operate at least 50% of the time from a queued schedule of programs to match science proposals with observing conditions. The up-looking port gives instruments a direct view of the telescope's entrance pupil is therefore infrared optimized (the central fold mirror is retracted to pass the telescope beam into this port). Space has been reserved near the bottom of the ISS in front of the up-looking port for future installation of a

Class	Mauna Kea	Cerro Pachon
Facility	Near-Infrared Imager Near-Infrared Spectrograph Multi-Object Spectrograph	Multi-Object Spectrograph High Resolution Optical Spectrograph Mid-Infrared Imager (shared N/S)
Shared	Michelle (shared with UKIRT)	Phoenix (shared with CTIO)

Table 1 - A list of the initial instruments available at both Gemini sites is shown, which includes both the facility and currently planned shared instruments for each site. Note that the facility mid-infrared imager will be shared between Gemini North and South.

polarimetry module. The field of view passed by the ISS into any of the instruments is 7 arcmin in diameter. A pair of peripheral field wavefront sensors mounted in the A&G unit are used for a variety of functions including maintaining telescope collimation, primary mirror figure, and in some applications tip/tilt sensing for instruments. The central 3 arcmin telescope field is unvignetted and is used by the so-called on-instrument wavefront sensors to patrol for guide stars where minimizing isoplanicity is important. These on-instrument sensors also serve to eliminate differential flexure between science detectors and the A&G system. As seen in Figure 1, all instrument electronics are mounted in enclosed racks that have glycol feeds and air-to-liquid heat exchangers to route heat generated in the Cassegrain environment out of the dome and into a central exhaust system.

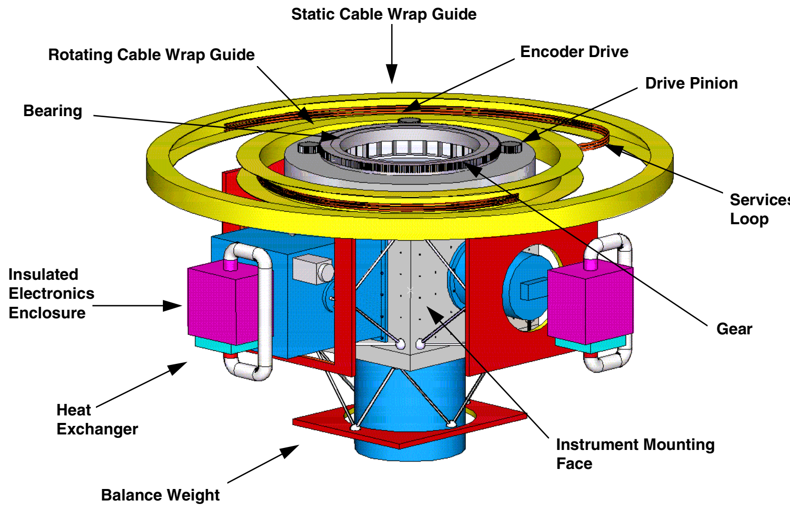

Figure 1 - The Gemini Cassegrain environment is shown. It provides mounting space for nominally three 2000 kg science instruments and two 800 kg auxiliary facilities. The mass and moment of each instrument will be carefully tuned to assure that this rotating structure accurately corrects for apparent field rotation induced by the alt-az mounted telescope. Each instrument will use insulated enclosures for mounting electronics with air-to-liquid heat exchangers to keep the heat injected into the dome to a minimum.

3. PHASE I INSTRUMENT DESCRIPTIONS

3.1 Near-infrared imager

The near-infrared imager (NIRI) is currently under development at the University of Hawaii and is based upon an ALADDIN[2] 1024x1024 array to sense radiation from 1-5.5 μm. Key performance drivers include high optical throughput and low effective emissivity in order to take advantage of the coatings and overall design of the telescope. This instrument will have a unique role in that it will serve as the commissioning instrument for Gemini-North and will be used to test telescope image quality, emissivity, adaptive optics systems, etc. Three plate scales are supported, including a relatively wide field 0.12 arcsec/pix mode (123 arcsec field) to sample the central 3 arcmin central science field, a 0.05 arcsec/pix mode (50 arcsec field) for proper sampling of Gemini's tip/tilt corrected PSF, and a 0.02 arcsec/pix mode (20 arcsec field) for use with adaptive optics. Three wheels are incorporated into the science channel which will house a combination of filters, grisms, a Wollaston prism for polarimetry, and pupil masks. A separate pupil imaging mode is also supported by rotating another wheel in the narrow field camera containing a pair of ZnSe lenses.

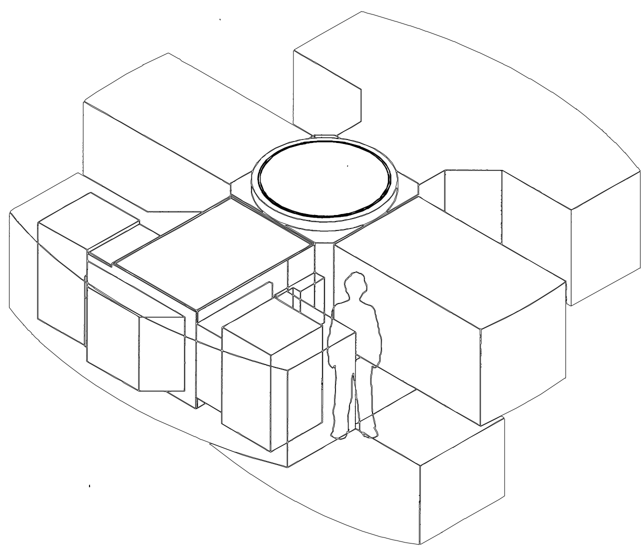

Figure 2 - The ISS with the full space envelopes allocated to each port is shown. GMOS is the instrument depicted in the near port.

Referring to Figure 3, light enters a window passing a ~3.5 arcmin field in the vacuum jacket and first strikes either a pick-off mirror or dichroic mounted in a four position turret. If a mirror is used guide stars are acquired with the on-instrument wavefront sensor in the periphery of the field passed by the window. Otherwise, with a dichroic, guide stars can be acquired anywhere in the field. Since it is impossible without using fairly exotic technologies to provide good reflective and transmissive performance of dichroics across the entire 1-5 µm bandpass, dichroics will probably have reduced spectral coverage. In this way both mirror and dichroic pick-off mechanisms can be supported, offering significantly better sky coverage than say a single large static pick-off mirror used to support all three NIRI plate scales. Light reflected at the pick-off turret is passed through a large wheel containing either field masks, coronagraphic masks, or slit masks to support low resolution grism spectroscopy. Next, light passes through a hole in a central rigid wall defining the cold structure and into the science channel of the instrument. Figure 4 shows the wide field optical layout in an unfolded format. The same field lens and collimator section are used for all three plate scales. All transmissive elements involving relatively common crystalline materials are used (BaF_2, LiF, ZnS, and ZnSe) with all spherical surfaces except for one surface each on the ZnS and ZnSe elements in the wide field camera. These surfaces will probably be diamond turned. Not including the detector, and with the use of high performance silver coatings on the folding mirrors and AR coatings on the lenses, the system should deliver ~75% throughput at K. Changing plate scales is accomplished with a set of flat mirrors on slides that divert light into one of three stationary camera sections. The optical design is oversized to accommodate arrays as large as 2000x2000 pixels with the same 27 µm pitch as the ALADDIN devices for the 0.02 and 0.05 arcsec plate scales in order to support future larger format arrays.

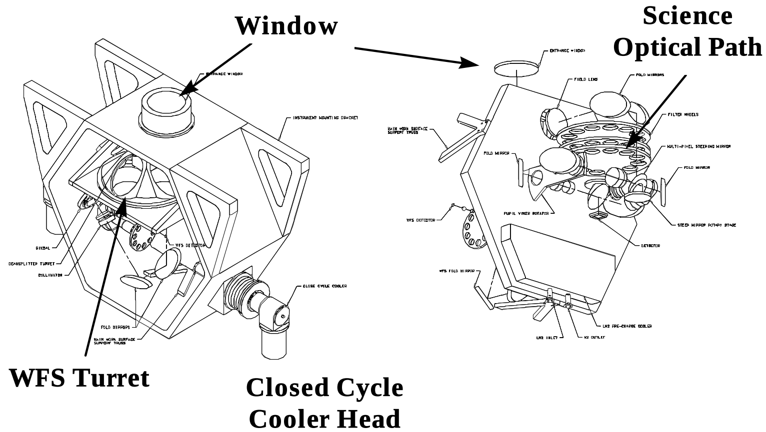

Figure 3 - The opto-mechanical layout for the near-infrared imager is shown. On the left the view is toward the wavefront sensor side of the instrument, enclosed by the vacuum jacket. On the right is the science optical channel.

As can be seen in Figure 3, the outer vacuum jacket for NIRI is a hexagonal structure that is coupled to the inner cold structure using a series of A-frame trusses. The central plate of aluminum which separates the wavefront sensing and science sections of the instrument serves to rigidly couple the built-in wavefront sensor to the science detector, which is crucial to keep flexure under control. A series of modular radiation shields will be used to isolate the science channel while providing easy access to key components, like the array and filter sections. To minimize vacuum jacket feed-throughs and the inherent complexities of these mechanisms, all stepper motors will mounted in the dewar and run cold. Estimates of forces required and motor torques available indicate that most configuration changes (e.g. filters, plate scales, etc.) can be achieved in well under a minute with such cold mechanisms.

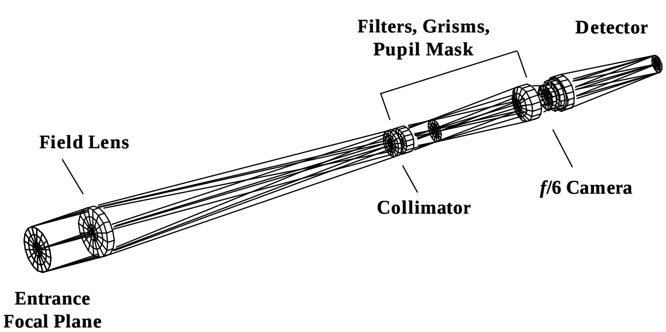

Figure 4 - The all refractive optical design of the near-infrared imager is shown. A set of folding flat mirrors will be used to divert the beam into different camera sections and support a total of three plate scales, all using the same field lens and collimator sections.

Cooling will be achieved with a pair of 135 W closed cycle cryocooler heads mounted in a momentum compensated configuration that is similar that used successfully in NOAO instruments. Warming the instrument will be achieved with built-in resistive heaters and a computer controlled network of sensors to assure that the proper level of heat is delivered to warm the metal, optics, and array in a safe fashion. Current estimates of thermal mass, radiative loads, etc. indicate NIRI can be cycled between room temperature, its operating cold temperature, and back to room temperature in about three days. Array control will be achieved through the use of a modified Wildfire controller, currently under development at NOAO, where Gemini's near-infrared spectrograph is being designed and the ALADDIN array program is managed. The use of a common controller for both NIRI and the near-infrared spectrograph will simplify long term operational support of these instruments and is being coordinated through careful attention to the electronic interfaces by the central Project office.

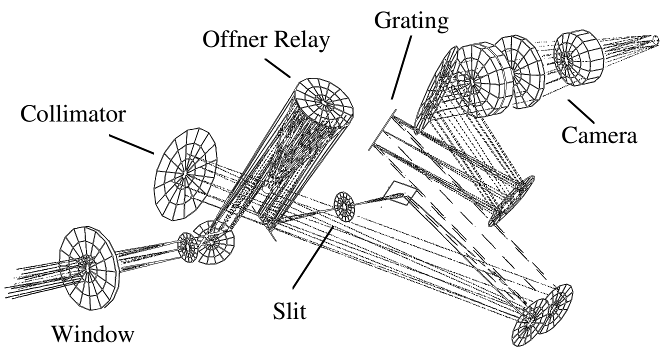

Figure 5 - The near-infrared spectrograph optical design for the short camera is shown. A front-end Offner relay is used to isolate background flux entering the system from the main slit/grating area. A total of 4 cameras are planned, including red and blue optimized cameras for the fine (0.05 arcsec/pix) and course (0.15 arcsec/pix) plate scales.

3.2 Near-infrared spectrograph

As seen in Table 1, also scheduled for delivery on Mauna Kea as part of the Phase I program is a near-infrared spectrograph (GNIRS). Detailed design trades are still being made with GNIRS but the capabilities of the instrument and basic design are now fairly well established. First, like the NIRI, GNIRS will use a 1x1 K ALADDIN array for sensing radiation from 1-5.5 μm. Figure 5 illustrates the optical layout for one of the four camera modes planned. In order to minimize the contribution of background flux at the science detector, an Offner relay is used on the front end of the optical train. A small amount of power has been added to the window to provide a high quality image at the secondary of the Offner, where a cold stop will be located. The 1-to-1 reimaged focal plane of the Offner is passed through a filter and into the slit environment before being folded by a small mirror and passed into on off-axis paraboloid which collimates the beam. Slit lengths range from 50" with the long cameras to 100" with the short cameras. Another fold mirror is used to direct the light toward a grating mounted in a turret. Currently there are three gratings planned, providing resolutions of 2000, 6000, and 18000 with the long cameras and 667, 2000, and 6000 with the short cameras. The resolutions of 6000 and greater are intended to allow resolving OH emission lines for improved sky subtraction during post-processing of GNIRS data. A cross dispersing element is used to separate the J, H, and K bandpasses for simultaneous sampling at the detector. Alternatively, a mirror can be rotated into position at the cross-disperser post to support long slit spectroscopy. A final fold is used to pass the light into one of four cameras, two optimized for 1-2.5 μm bandpass with 0.05 and 0.15 arcsec/pix plate scales and two optimized for a 2.8-5.5 μm bandpass with the same plate scales. The intent of this design is to provide a fine plate scale for use on nights of good seeing (with adaptive optics) and a course plate scale for median seeing nights, making GNIRS functional and efficient across the bulk of seeing conditions on Mauna Kea. All four cameras are parfocal hence no refocus at the science detector between camera changes is needed. Unlike the wavefront sensing pick-off used in the NIRI, GNIRS will have a fixed pierced mirror with a super-slit at the forward focus of the instrument. Light reflected off this mirror will pass into a built-in near-infrared wavefront sensor with a ~3 arcmin patrol field. This mode does not support guiding on-source, but a careful assessment of the science vs. technical trades of various pick-off schemes led to the conclusion that such a pierced mirror arrangement would provide good performance with minimal cost in terms of scientific performance. A MgF_2 Wollaston prism is included in the baseline design and will be used to provide dual-channel polarimetry.

Target acquisition is performed by imaging through the forward mounted super-slit, rotating the rear narrow slit out of the optical path, and inserting a pair of mirrors in the subsequent optical path. In this way precise slit placement on complex fields can be supported independently of the facility acquisition camera built into the A&G system. Like NIRI, GNIRS will use cryocooler heads to maintain the nearly 800 kg of cold mass at operating temperature and a modified Wildfire controller for science array support.

An important upgrade under consideration is an integral field module that would be installed in the slit environment and effectively split the entrance focal plane into a large number of pieces that would be dispersed and reconstructed into a data cube containing spectral and spatial data. Another possible upgrade supports use of a 1x2 K mosaic of arrays, stretching the long-axis of this mosaic across the dispersion direction of the spectrograph.

3.3 Mid-infrared imager

A mid-infrared imager (MIRI) rounds-out the Phase I instruments intended to work longward of 1 µm. This instrument is still very early in its procurement and is expected to enter a conceptual design phase during the second half of 1996. Currently MIRI is planned to be transportable between Gemini-North and South. MIRI is intended to be a simple, single purpose high throughput imager capable of critically sampling Gemini's diffraction limited PSF across the ~8-25 µm range using a Si:As IBC detector. At these wavelengths Gemini is expected to deliver near diffraction limited images most of the time, hence MIRI may be a "fall back" instrument when seeing conditions deteriorate for other instruments working at shorter wavelengths. Again, this is an area in which a queue scheduled telescope combined with a unique instrument can be efficiently combined. The format of the detector will be $\sim 256^2$, pending progress in the development of these sensors. The next generation of mid-infrared arrays is currently under development at Rockwell and SBRC. These devices have ~70000 pixels (or nearly 4x more than previous generation devices) that are 50 µm across, nearly 100% fill factor, at least ~350 Hz frame rates, roughly 2×10^6 e^- full well, and are based upon Si:As IBC architectures. These detectors obviously represent significant advances over current technology and if ongoing development efforts are successful would be quite interesting for use in the Gemini mid-infrared imager. Like NIRI and GNIRS, MIRI must be designed to exploit the low emissivity platform the telescopes offer, hence one of the key design challenges will be to keep the effective instrument emissivity contribution to <1% in the low emissivity atmospheric windows. The combination of MIRI's high throughput and location on telescopes with low emissivity at dry sites running from queued schedules opens the exciting possibility of high-performance 20 µm imaging, which requires very low water vapor and is difficult to execute using classical observing techniques (see Figure 6).

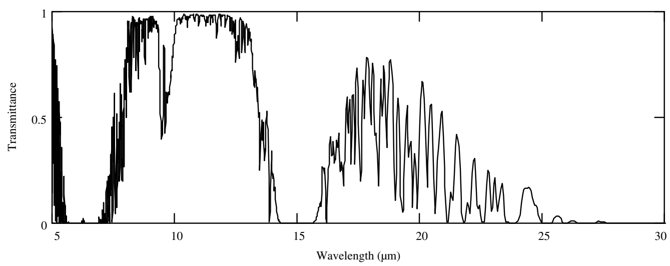

Figure 6 - A model atmospheric transmission curve for Mauna Kea under nominal 1 mm PWV conditions is shown for the wavelength range that is relevant for the mid-infrared imager. At such high altitude sites like Mauna Kea and Cerro Pachon, the atmospheric transparency is remarkably high in the 8-12 µm range. Water vapor will be particularly important in defining system performance at wavelengths exceeding ~15 µm and Gemini's unique queue scheduling system will be able to assure that observations requiring rare ultra-low PWV conditions can be executed.

3.4 Multi-object spectrographs

A pair of visible light multi-object spectrographs (GMOS) are currently being designed in a collaborative effort between Canada and the United Kingdom. These instruments will be identical except for the AR coatings used on the transmissive elements. Nominally the Mauna Kea based instrument will have red-enhanced AR coatings while blue-enhanced coatings will be used for the southern GMOS. Spectral resolutions in the range of 500 to 10000 will be possible using slits from 0.5 to 0.25 arcsec and conventional gratings. A single plate scale of 0.08 arcsec/pix is used, yielding a 5.5 arcmin field of view. The imaging mode of GMOS is primarily intended to support mask production, used as the first step in defining the locations and sizes of slits scattered across the field. Masks will be laser milled at each observatory, probably using a carbon fiber composite material for the masks. Under Gemini's queue operational model, masks will likely be generated a day or two after fields are imaged, then loaded into the GMOS mask cassette for acquisition of spectra on a subsequent night. Also note that these instruments will be the only facility visible light science grade imagers in the Phase I suite.

Figure 7 shows the optical layout of GMOS, which features all transmissive optics except for a single fold defined by either a grating or mirror. An atmospheric dispersion compensator is mounted in front of the entire optical assembly which protrudes slightly into the ISS wall. A single ~1 m diameter filter wheel will house enough filters to support imaging and spectral order sorting (see Figure 8). The optics are all mounted in a nested truss system which assures that elements only undergo parallel shears, not tilts, under all gravity loads. A four position turret is used to

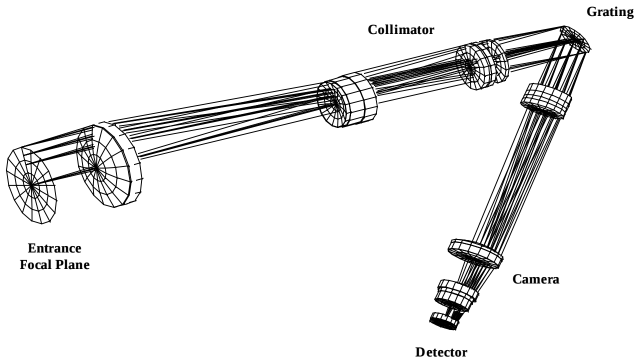

Figure 7 - The optical layout of GMOS is shown, except for the forward mounted ADC. The design is all transmissive except for a single fold, where either a grating is mounted for spectroscopy or a mirror is mounted for direct imaging. A 4x6 K CCD mosaic will be used as the science detector in the final focal plane.

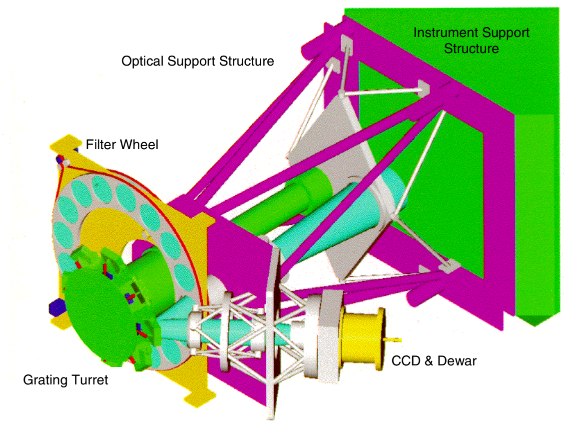

Figure 8 - A 3D solid body representation of major GMOS components mounted on the ISS is shown. Key to the mechanical design is a nested truss system used to support the lenses and a CCD/dewar within the instrument. GMOS does not have an active flexure compensation system and instead will rely on look-up tables of flexure and a motorized detector focal plane to compensate for drift over long exposures.

mount 3 gratings and a flat mirror for imaging. The GMOS detector will consist of three 2048x4096 pixel CCDs butted together to form a 4096x6144 pixel mosaic. The detector mosaic is mounted in a motorized cryogenic X-Y stage which moves under a set of look-up tables to compensate for flexure over the course of long integrations. Due to cost and complexity, there is no means of closed-loop flexure compensation provided but the open-loop approach adopted should reach Gemini's flexure specifications. The optical design, though all transmissive, supports observations from 0.36 to ~1.8 µm so that if a near-infrared detector is used J and H band observations can be attained. Clearly, an instrument capable of multi-object spectroscopy from the near-UV into the near-infrared would have *broad* scientific applications.

Figure 9 shows the forward slit environment of GMOS in detail. A beryllium probe-arm is used to pick-off field stars to support the optical on-instrument wavefront sensor with minimal vignetting of the science field. Slit masks are mounted in frames that are in turn loaded into a cassette which can position any mask in the focal plane through remote control. Also mounted in the cassette will be modular integral field units (up to two IFUs at a time) that can be deployed using the same interchange mechanism. The IFUs serve to split up the entrance focal plane into ~10^3 elements, each 0.2 arcsec across, and through a fiber-optic reformatter send light into GMOS's slit where is it dispersed into individual spectra. This technique offers powerful multiplex advantages over conventional single-slit spectroscopy in complex fields, yielding a data cube with a spectrum at each point in the sampled field. The sky will be sampled with several separate fibers located ~1 arcmin from the center of the IFU's 8 arcsec field of view.

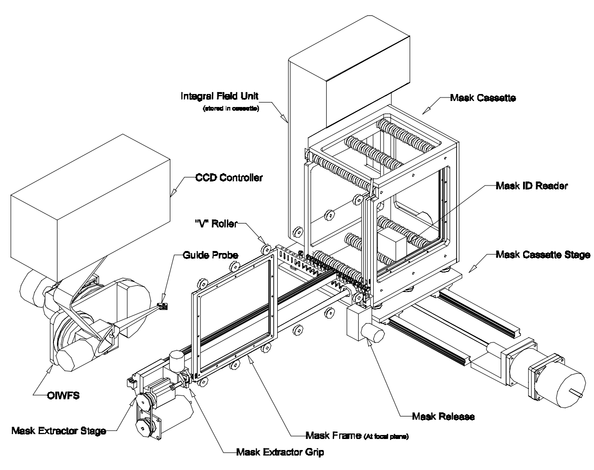

Figure 9 - The mechanical layout of the slit area of GMOS is shown. At left is the on-instrument wavefront sensing assembly. On the right is a mask cassette and a single IFU. Any mask or IFU loaded into this cassette can be remotely inserted in the focal plane.

3.5 High resolution optical spectrograph

The Gemini astronomical community identified UV high resolution spectroscopy as one of its key science goals. The High Resolution Optical Spectrograph, or HROS, is designed to meet this need. Specific science goals for this instrument include ISM studies, stellar populations in the Milky Way, primordial abundances in distant galaxies, stellar pulsations, etc. A principal design driver for HROS is therefore high throughput across a fairly broad (0.3 - 1.0 µm) wavelength range. The approach

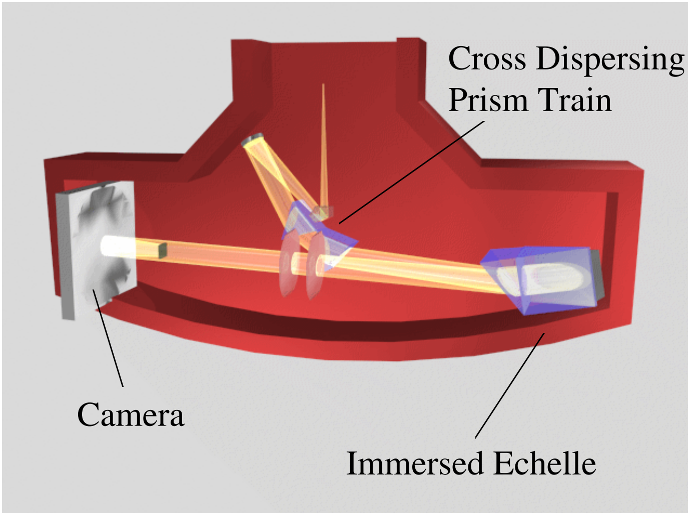

Figure 10 - A solid body representation of the HROS optical layout is shown. The outer space envelope allocated to instruments surrounds the optics.

taken is to utilize Gemini's high performance telescope coatings and mount HROS at the Cassegrain focus in order to achieve sensitivities that are competitive with spectrographs on other telescopes, including 10 m class instruments. HROS will use only fused silica or reflective optics in order to work down to 0.3 µm. Note that either Gemini telescope can be configured with either silver or aluminum coatings, offering considerable front-end throughput gains over conventional telescope coatings across a very broad (0.3 to 30+ µm) range.

University College London is leading the effort in designing and fabricating HROS, which is scheduled to be the last of the Phase I instruments and will be delivered late in the commissioning phase of the Cerro Pachon telescope. At the time of this report HROS is approaching its conceptual design phase, hence details of the instrument's performance may change as technical and science trades are made. The current plan is for HROS to use a pair of 2048x4096 buttable CCDs in its detector focal plane, to cover a large spectral region in a single integration (e.g., 0.35 - 0.7 µm). The instrument will have two baseline spectral resolutions, including R ~ 50000 and R ~ 120000-150000, with a throughput of at least 10%. These resolutions assume 3 pixel slit sampling. Slit lengths will be variable up to 1 arcmin. Stability will be important in the use of this instrument and the requirement is for HROS to have <0.05 of a resolution element drift over a 1 hr integration. For higher stability modes, e.g. planet searches and asteroseismology, the option of mounting HROS in the observatory pier lab with a fiber feed from GMOS is under consideration.

Figure 10 depicts a conceptual layout for HROS at one of the Cassegrain instrument ports. Light passes through a folding prism and is then collimated before passing through a pair of cross dispersing prisms. From there light enters the heart of the spectrograph, an immersed echelle grating which combines a pair of fused silica prisms and a grating through an optical couplant to function as a single optical element, offering the level of high throughput and resolving power needed to support HROS's science requirements. Finally the light is passed into a camera and imaged onto the aforementioned mosaic of CCDs. Maintaining the alignment of this structure, particularly within the immersed echelle, under all gravity vectors at Cassegrain is clearly one of the most challenging aspects of the HROS design.

4.0 TELESCOPE/INSTRUMENT SYSTEM CONSIDERATIONS

Considerable resources are being invested in the Gemini telescopes' abilities to achieve exquisite image quality, high throughput, and low emissivity, and all instruments will in general take advantage of these telescope attributes. These design drivers are reflected in a number of ways within the observatories including,

- Enclosure - adjustable ventilation, daytime air conditioning, etc.
- Telescope Structure - minimal thermal mass above the primary, low wind buffeting cross section, etc.
- Primary Mirror Temperature - backside substrate cooling, plus surface coating heating
- Coatings - high performance silver and aluminum available at both sites on primary and secondary

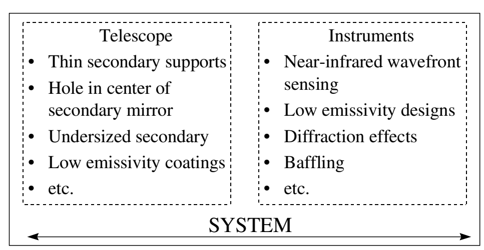

Figure 11 - Across the entire observatory factors implemented to assure good system wide infrared performance are listed.

- Cleaning Program - extensive mirror cleaning capabilities built into facilities (laser and CO_2 snow under consideration)
- Facility Wavefront Sensing & Active Correction - adaptive optics, on-instrument, and peripheral field sensors
- Queue Scheduled Observations - at least 50% of observations will be queued to match conditions with proposals

All of these considerations reflect the Project's efforts to build telescopes that are fundamentally limited by the physics of the atmosphere and the sites. This in turn drives the instrument designs if they are to exploit the unique observing platform Gemini offers. There are numerous examples of how an integrated approach is being used tie in instruments with the telescope, data handling, and acquisition systems. For example, to maintain good infrared performance with the observatory *system*, telescope and instrument design considerations are listed in Figure 11. A specific example of this philosophy in systems design is described below with the near-infrared wavefront sensors.

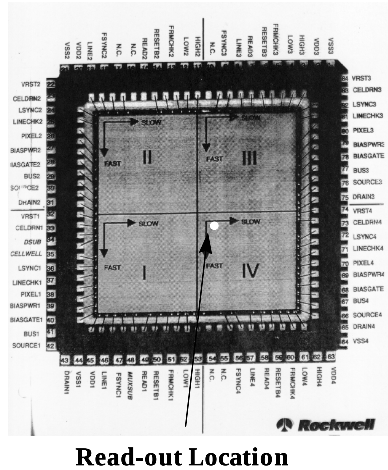

Figure 12 - The quadrant layout and location of the fast read-out region (indicated by the small white spot) for a Hawaii 1K array are shown.

4.1 Near-infrared wavefront sensors

The gains possible with near-infrared sensing vs. optical sensing include increased guide star flux, a tighter PSF to centroid on, and all sky coverage, *including dark clouds*. The detector used in the near-infrared wavefront sensors will be engineering grade Hawaii 1K arrays. Though much larger in format than is needed for Gemini's sensors, these devices were chosen because they are the only commercially available non-thermal arrays available now that meets the Gemini performance specifications for speed, read noise, quantum efficiency, etc. Tests have been made at the University of Hawaii of Hawaii array running in a fast read-out mode in order to determine various performance characteristics. A read noise of ~6 e^- was demonstrated with read rates in the ~50-100 fps range using 4 sample reads in a 6x6 pixel subarray. The fastest read rate supported by this detector is ~ 2-3 µs per pixel. Given the locations of the read-out amps in the Hawaii array, and the tendency for bump-bonds to fail preferentially along the edge of these devices, the optimal location for the read-out is just to the lower right of array center, in Q4, next to an amplifier (see Figure 12). Surprisingly no significant change in QE was found at different operating temperatures up to ~100 °K, hence any temperature in the ~65-100 °K range should be adequate for maintaining array performance. External amplifiers will not be needed to support a wavefront sensing mode, as the built-in amplifiers will provide adequate line driving capacity and corner glow will certainly not be an issue with the read-out region located near the array's center.

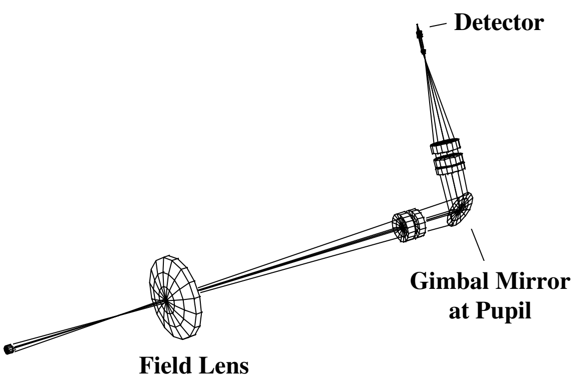

Figure 13 - The feed optic concept envisioned for NIRI and GNIRS is shown.

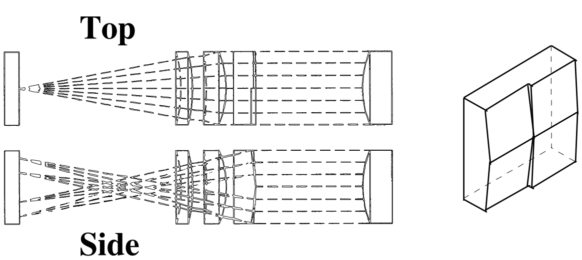

Figure 14 - The Shack-Hartmann element used in the near-infrared wavefront sensors is a four facet prism which, when placed in a collimated beam and used with the final lenses in the assembly, yields four spots in a column at the detector.

Both NIRI and GNIRS will use essentially identical feed optics along their wavefront sensing paths, though the details of the pick-off mechanisms will be different (these pick-off mechanisms were described earlier). Figure 13 shows the planned system. A large forward mounted field lens is followed by a set of reimaging optics and a 2-axis gimbal mirror conjugated to the telescope entrance pupil. Scanning the gimbal mirror directs flux from stars in the central 3 arcmin guide field into the Shack-Hartmann prism and detector. Figure 14 shows the prismatic Shack-Hartmann stage at the end of the optical path. This design yields four spots in a column at the detector, permitting

Mauna Kea		Cerro Pachon	
Instrument	Possible Upgrade	Instrument	Possible Upgrade
Near-infrared Imager	2x2k array	**GMOS**	High-res OIWFS High-res. IFU
Near-infrared Spectro.	IFU Cross Disperser	**HROS**	High Stability Lab
		Near-infrared Imager	
GMOS	Near-IR Mode High-res. OIWFS High-res. IFU	Near-infrared Spectro.	IFU Cross Disperser
8-30 µm Spect. (MICHELLE)		**8-30 µm Imager (N/S)**	
NGS AO System	Laser Upgrade	*LGS AO System*	
Near-infrared Coronagraph (N/S)		*CCD Dev (N/S)*	
		Phoenix	

Table 2 - The Phase I and possible Phase II instruments and upgrades are listed. Phase I baseline instruments budgeted within the construction fund are in bold while possible shared instruments with either UKIRT in Hawaii or CTIO in Chile are underlined. Possible Phase II instruments are shown italicized.

more rapid read-out than is possible with a more conventional 2x2 arrangement of spots.

5.0 PHASE II INSTRUMENTATION PLANS

The Project is beginning to formulate plans for Gemini's Phase II instrumentation program. In general the emphasis on Phase I instruments has been to develop the so-called "work horse" instruments that are expected to be used across a broad range of observations. Due to funding constraints within the Phase I program, not all desirable options could be included in each instrument and the Project has worked closely with the Phase I instrument builders to assure that clear upgrade paths exist to support retrofits of upgrades. The Phase II instrument program will therefore consist of a combination of new instruments and upgrades to Phase I instruments. This blend of new Phase II instruments and upgrades to Phase I instruments is a cost effective approach to delivering maximum capability in the overall instrument program while working within a cost-constrained budget. Though there is duplication between some of the Gemini N/S "work horse" instruments, in general the Phase II instruments will be directed at either gaps in the capabilities of the Phase I instruments or targeted at unique capabilities that the Gemini telescopes offer for instrumentation. Table 2 lists the Phase I instrument package, planned shared instruments, possible upgrades to Phase I instruments and some possible Phase II (new) instruments. It should be noted that the upgrades and suggested Phase II instruments are only *illustrative* of what might be included in a Phase II program.

The instrumentation program outlined in Table 1 is fundamentally driven by science applications that exploit what the Gemini telescopes will do best. Ideally new Phase II instruments should take advantage of unique telescope design features to provide new capabilities that other telescope/instrument combinations may not be able to achieve as well. One such example, listed in Table 1, is a near-infrared coronagraph. For such an instrument it is crucial that sources of scattered light be cut to a minimum in order to maximize contrast ratios. Certainly one of the most important elements in the optical path that effects scattering is the primary mirror. Gemini has already set rigorous specifications for the smoothness of its primary mirrors and the elimination of harmonic scattering. Between the primary mirror polishing specification and the ability to actively control its surface figure, it should be possible to achieve significantly lower scattered light contamination in a Gemini-mounted coronagraph than is currently achieved with coronagraphs on most 3-4 m class telescopes. The small obscuration ratio and thin vanes used to support the secondary mirror will also lead to reduced diffraction effects. Of course telescope throughput boosts the performance of all instrumentation, and a coronagraph is no exception. The high reflectivity coatings used in the

Gemini telescope, together with the planned mirror cleaning schedule, will certainly boost the performance of a coronagraph in terms of throughput and scattering. All of these design features make the Gemini telescopes fairly natural platforms for a high performance coronagraph.

6.0 SCIENCE MOTIVATIONS FOR INSTRUMENTATION PROGRAM

Gemini instrument functionality is sculpted from the scientific research goals of the Gemini Community. Historically astronomy has relied heavily on wide field instrumentation working at relatively low spatial resolutions to achieve scientific gains. The recent implementation of multi-object spectrographs at several observatories is the latest manifestation of this approach. Like so much of astronomical research, this trend has been driven in part by advances in technology, specifically in optical fibers, micropositioning technology, and precision laser milling. While the scientific returns of such research have been great, increasingly telescopes are placing a greater emphasis on high spatial resolution studies over small scales. The refurbished HST has already demonstrated the power of high resolution imaging and the generation of 8 m class telescopes currently under construction will carry this even further through infrared observations with adaptive optics.

As discussed above, a high performance AO coronagraphic imager fits well into the design optimization of the Gemini telescopes. Some of the likely science applications for this mode include searches for:

- dust disks around stars and proto-stars
- very low mass stars and brown dwarfs around M stars
- underlying luminous material surrounding Seyferts and QSOs
- extra-solar planets

These are non-thermal applications because (1) the tightest AO PSFs will be obtained in the 1.0 - 2.5 µm regime hence maximizing coronagraphic performance, (2) warm external field masks can be used, and (3) the AO system will not be very effective at thermal wavelengths anyway due to its intrinsic emissivity. Probably the easiest target in this list will be dust disks, reflecting light in the near infrared, surrounding stars or proto-stars. At this "low" performance end, what will be needed is a rejection in dynamic range of ~6-7 mag to image at H (1.65 mm) moderately bright dust disks ~5 - 30 arcseconds away from primaries. The peak in the phase space probability for brown dwarfs orbiting nearby M stars is ~0.5 to a few arcseconds and a contrast ratio of ~10 mag will be required to detect objects down to the base of the brown dwarf mass regime (~0.01 $M_{\&}$) in the near infrared. Arguments that attempt to identify brown dwarfs based upon broad band photometric properties or even spectroscopy are all fairly model dependent. Candidates that reside in close orbital proximity to M stars though can have their mass measured through straightforward techniques on time scales of a few years, and if such a target is found to have a mass £0.06 $M_{\&}$, there would be no doubt that it is a brown dwarf given the certainty of the physics that goes into calculating the minimum mass of an object capable of sustaining core fusion. Accordingly, a survey of M stars could be very effectively handled with a Gemini coronagraph out to many tens of parsecs (a few thousand stars to select from) to take a census of the number of brown dwarfs orbiting nearby stars. This in turn would provide valuable information on the mass-luminosity relation for low mass stars, objects which are known to dominate the stellar populations of galaxies yet remain one of the least understood types of stars in astronomy due to their intrinsic faintness and extreme red color. Finally, perhaps the most

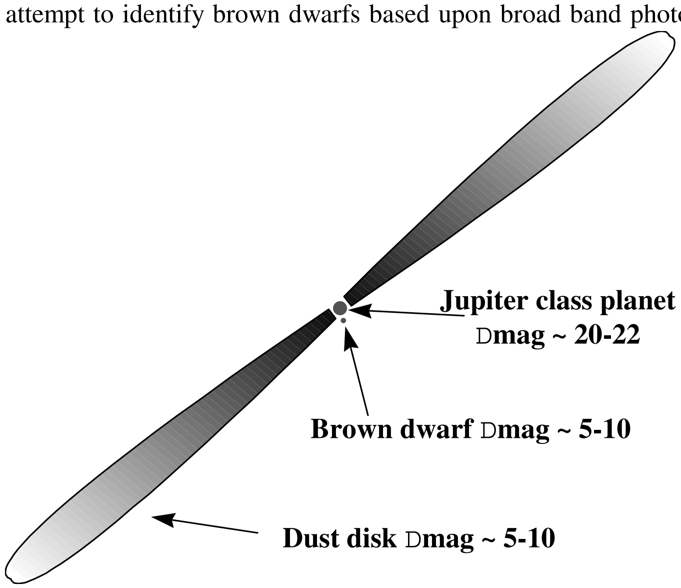

Figure 15 - Science applications for a well designed coronagraph on Gemini range from searches for dust disks and brown dwarfs to potentially extra-solar planets.

demanding application for a coronagraph is the detection of extra-solar planets. Using the formulae in Nakajima[3] one can estimate that in order to detect a Jupiter class planet orbiting a star ~2 pc away at a separation of ~1.5 arcsec, a contrast ratio of ~21 mag will be required. This may well be beyond the grasp of anything but a fully optimized coronagraphic telescope, either on the ground or in space. Nonetheless the importance of performing a census of Jovian class planets in the solar neighborhood has deep implications on planet formation theory and the possibility of using high performance ground based telescopes like Gemini for this purpose should receive serious attention.

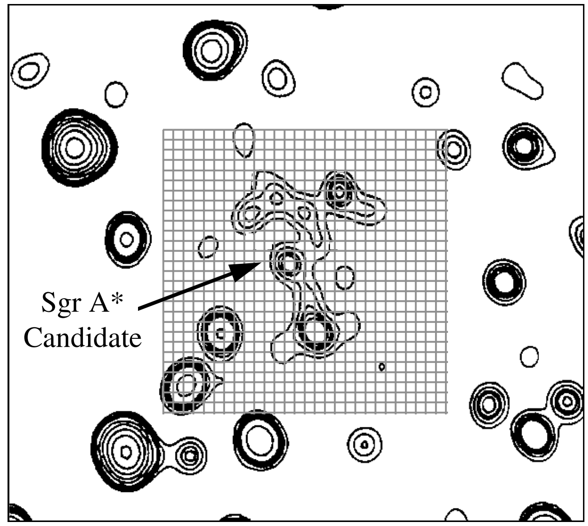

Figure 16 - The best published image of an infrared counterpart to Sgr A* is shown, adapted from Eckart *et al.* (1995). This image has ~0.15" resolution. Overlaid is a grid corresponding to 0.05" pixels in an IFU having a ~1.2 arcsec field of view.

The Galactic center is a second example of a specific field in which Gemini could offer large scientific gains. Much of the research emphasis on the Galactic center in recent years has been on achieving ever higher spatial resolution to disentangle the complex physical mechanisms at work in the Galactic center. A number of experiments have demonstrated that the enclosed mass within the central few arcseconds in the IRS 16 region is well in excess of 10^6 $M_{\odot}$ (Sellgren *et al.*[4]). To date inadequate spatial and spectral resolution from ground based observations have made it impossible to pinpoint where this mass is located, e.g., is it in the form of a large number of degenerate stars or is it contained in a black hole? Accordingly Gemini will be a valuable tool for further dissecting this complex region. Though it is probable that NICMOS on HST will be used for further investigation of Sgr A*, the comparative spectroscopic capabilities of NICMOS vs. an IFU-equipped GNIRS on Gemini-South should leave Gemini with a clear advantage. A specific experiment that could be run would be to make an IFU observation of the ~1 arcsecond region centered on Sgr A*. The position of the possible Sgr A* infrared counterpart Eckart *et al.*[5] found is now tied in to the radio source at the ~0.1 arcsec level, hence with an infrared on-board wavefront sensor it should be possible to execute a precision offset from the bright nearby supergiant IRS 7 onto Sgr A* with adequate accuracy. Integral field spectroscopy of the target found by Eckart *et al.* at the CO (2.3 µm) absorption transition would in principle permit velocity measurements for each of the knots of emission seen in the immediate vicinity of Sgr A* (see Figure 16), which could in turn pinpoint the enclosed mass at a *much* finer scale than has been possible to date, assuming these sources are in the immediate vicinity of the long suspected blackhole in this region. This could in turn lead to the critical discrimination between the unseen mass in the Galactic center being point-like (hence contained in a black hole) or distributed.

The previously mentioned optimized coronagraph and near-infrared IFU are but a couple of examples of how instrumentation technology and the Gemini telescopes can be married to yield a powerful new capability. The pace of technical developments in fields that can support astronomy is staggering and instrument builders will be challenged to incorporate the latest in optics and electronics to assure Gemini users of effective research tools in an increasingly competitive era of large telescopes. For example, if the recent spectacular images of the "pillars" in M16 with HST emerged after much of the Phase II instrument program outlined in Table 2 were built, Gemini users would have at their disposal a wealth of instruments to effectively dissect these peculiar star formation regions and extract the underlying physics of the pillars (see Figure 17). Specifically, it would be possible to follow-up on the HST imaging with 10 µm imaging of the pillars to identify embedded proto-stars. From there, high resolution near-infrared imaging might be used with a Gemini-South based adaptive optics system to reveal the type of bipolar outflows that are so often associated with forming stars. The integral field unit in the near-infrared spectrograph may then be used to explore the dynamics of the gas outflows surrounding the proto-star. The near-infrared coronagraph could then be used explore the phase space in the immediate environment of proto-star, perhaps leading to the detection of a faint substellar companion. Finally, 0.1" slits could be used with the combination of the adaptive optics system and near-infrared spectrograph to isolate flux from the primary and its faint nearby companion, leading to the spectrum of forming substellar object - no small feat in current ground based astronomy. Clearly such a sequence of observations relies on a fortuitous set of targets, but the Phase II instrument capabilities illustrated by such a hypothetical series of observations, and the ability to probe complex regions at a variety of wavelengths and spatial scales, will hopefully emerge as we define and design the next generation of instruments for Gemini.

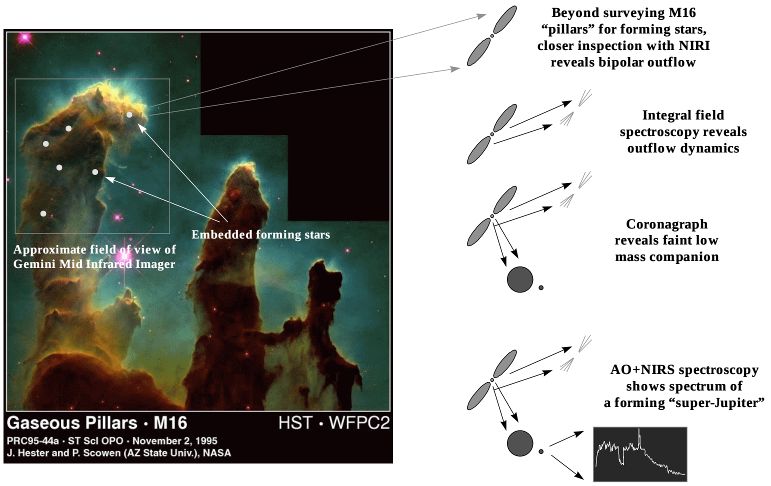

Figure 17 - This hypothetical series of observations demonstrates how the full Phase I and II instrument complement can be used to effectively dissect complex embedded sources.

7. ACKNOWLDEGMENTS

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