GEMINI
8-M Telescopes
Project

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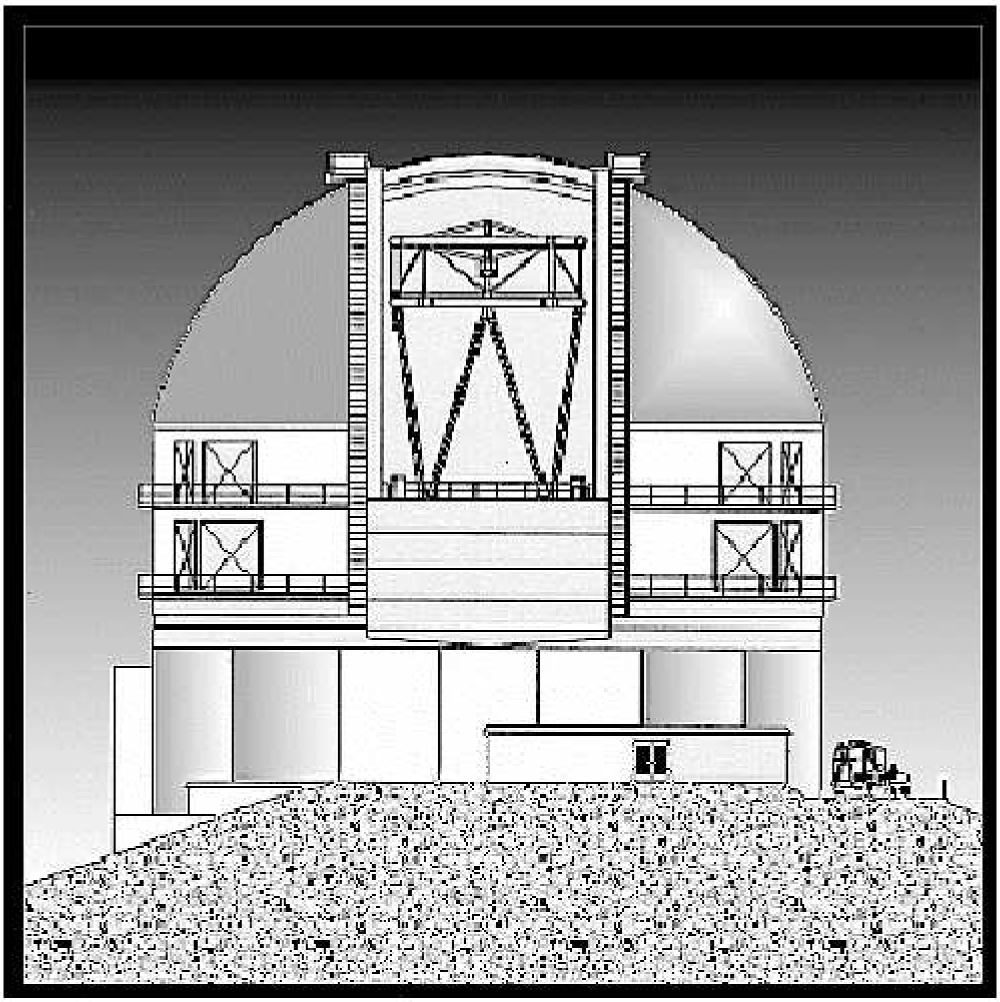
The Gemini 8-M Telescopes Project
- an update



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ABSTRACT

The Gemini Telescopes Project is an international partnership of the U.S., U.K., Canada, Chile, Argentina, and Brazil to build two telescopes, one in the northern hemisphere and one in the south. The telescopes will achieve an unprecedented combination of light-gathering power and image quality over the infrared, optical and ultraviolet spectral regions observable from the ground. The facilities are intended to exploit the best natural observing conditions at the sites to carry out a broad range of astronomical research programs undertaken by the National communities of the partner countries. First light on Gemini-North is scheduled for 1998 and for Gemini-south in the year 2000, with handover to operations in 2000 and 2001 respectively.

1. INTRODUCTION

The main scientific theme of the Gemini partnership is observing and understanding the origins and evolution of stars and planetary systems, of galaxies and of the universe itself. To aggressively pursue this theme, four key scientific capabilities have been adopted for the Gemini Telescopes (Gemini Science Requirements, 1994);

1) **Two 8-m diameter telescopes**. One telescope will be located on Mauna Kea, Hawaii, and the other on Cerro Pachon in Chile. All astronomical objects will be accessible to the Gemini telescopes, regardless of their location on the celestial sphere. Both telescopes have been designed to be identical to support scientific programs spanning both hemispheres and to reduce costs.

The principle Gemini optical configuration is a 8-m diameter f/1.8 meniscus primary mirror with a 1.2-m diameter central hole made of Corning ULE™ glass, with a 1.02-m diameter, articulated, SiC secondary mirror with a 0.168-m diameter central hole, providing an F/16 Cassegrain focal plane 4 meters behind the primary mirror. The telescopes have been designed with interchangeable top ends with capacity to accomodate a future f/6 wide field, 45 arcminute, Cassegrain focus.

2) **Superb image quality**. Both Gemini sites have excellent natural seeing. The intent is that the telescopes, including enclosure and tracking effects, will not degrade the best wavefront tilt corrected atmospheric seeing image size by more than 15%. The smallest image sizes will be achieved at near IR wavelengths, where the 2.2µm image quality requirement is for 50% of the encircled energy to fall within a diameter of 0.1 arcseconds, including diffraction.

3) **Versatile Optical/IR capabilities**. The broad scientific goals of the Gemini partnership require the Gemini telescopes to have high throughput from 0.3µm to at least 30µm. Remotely deployable baffles allows the switching between an optimized thermal IR configuration to configurations which support near IR, optical and UV observations. The Cassegrain focal station allows the simultaneous mounting of at least two instruments. In addition, a fibre and (potentially) a direct optical feed to an off-telescope high stability laboratory within the telescope pier will also be available.

4) **Efficient/adaptable Observing.** In order to exploit the best observing conditions for high priority scientific programs, the Gemini facilities will be able to change rapidly between scientific instruments, and support a wide range of observing modes, including both "classical" and queue scheduled observing.

The approaches taken by the Gemini project to achieve these requirments are briefly summarized in the following sections. Further information on the design and performance can be found in the associated references.

2. IMAGE QUALITY

Superb image quality is the key scientific requirement of the Gemini telescopes. To deliver natural 0.1 - 0.2 arcsecond near infrared images to the focal plane required that careful attention be paid to every aspect of the facility design. This necessitated a detailed and unique analysis of the entire Gemini system (Mountain et al 1994a) including: water tunnel (Raybould, et al, 1994a) and super-computer (De Young and Charles, 1995) modeling of the wind flow in and around the Gemini enclosure, thermal modeling of the telescope structure and enclosure components, extensive optical and dynamic finite element analysis of the optical system, telescope and enclosure -- which included its foundations and the soil or rock properties of Mauna Kea and Cerro Pachon.

The Enclosure

The enclosure, seen in Figure 1, has large variable ventilation gates so the enclosure chamber can be flushed effectively by the wind or by an active ventilation system during observing. The control building is separated from the unheated enclosure and electronic boxes within the dome are actively cooled to minimize heat input to the chamber. The telescope elevation axis is 20m above ground level, above the turbulent boundary layer (Raybould, et al,1994a).

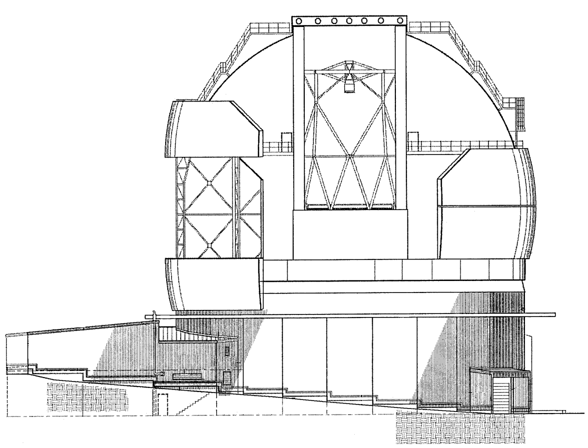

Fig. 1 (left) The Gemini enclosure showing the ventilation gates open on one side and location of the control building.

The Telescope and Optics

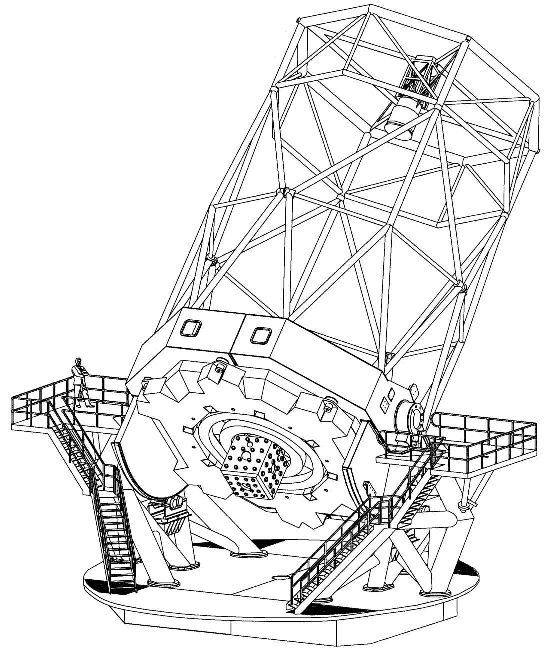

Fig. 2 (above) The Gemini telescope with the Instrument Support structure (ISS) mounted at the Cassegrain focal station.

The stringent image quality requirements have led to a Cassegrain only telescope (Mountain et al, 1994, Raybould, et al, 1994b), shown in Figure 2. With no Nasmyth foci, the entire telescope structure can be designed to minimize telescope contributions to the final image quality. The structure in front of the primary mirror is optimized to support the secondary mirror assembly, minimizing the thermal mass in front of the primary mirror and cross-section for wind loading. The primary mirror is mounted close to the front surface of the center section for efficient flushing of the mirror surface to reduce primary mirror seeing.

The primary mirror assembly is illustrated in Figure 3. The image quality requirements have led to a new approach to the support and alignment of the meniscus primary mirrors (Stepp and Huang, 1994). Eighty percent of the mirror weight is supported by a uniform air pressure. The remaining twenty percent of the weight is taken by 120 axial supports which provide both passive and active control of the mirror figure and position. Lateral support is provided by 72 passive hydraulic supports arranged around the circumference of the mirror.

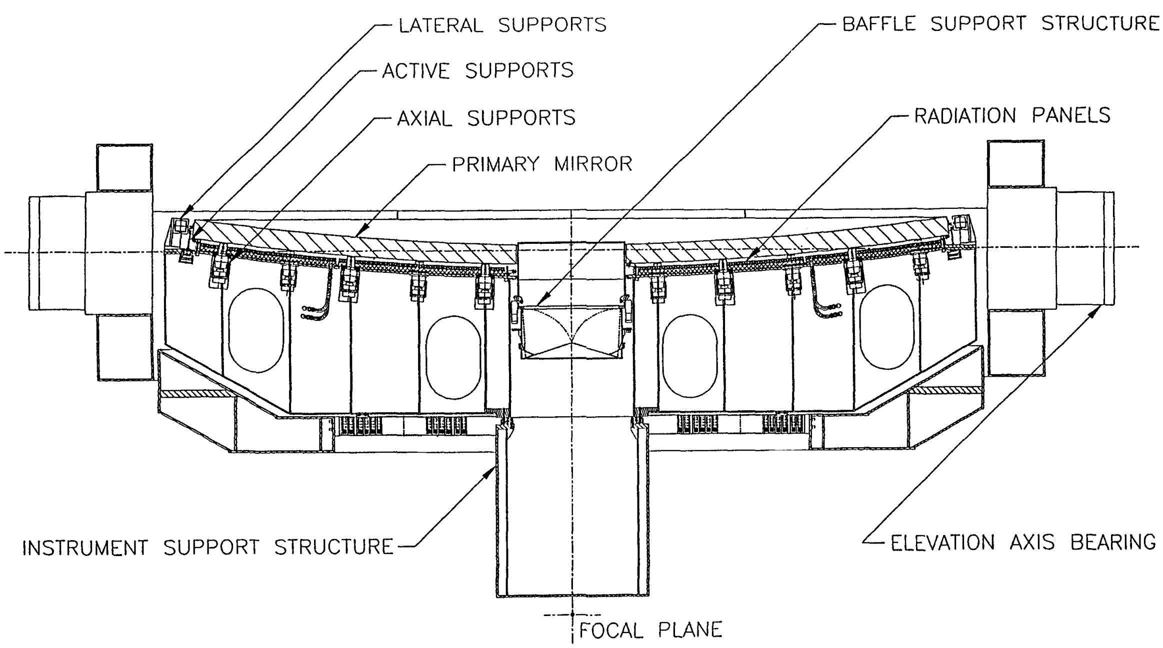

Fig. 3 An overview of the primary mirror assembly indicating major components.

The light weight, structured SiC secondary mirror is attached to its assembly at three points (Hansen and Roberts, 1994) shown in Figure 4. This assembly, supported by thin (10mm) vanes from the top end ring, incorporates a positioning unit for precise positioning of the secondary mirror perpendicular to the optical axis, and a rapid tip/tilt, fast focus mechanism to correct both wind shake and atmospheric effects.

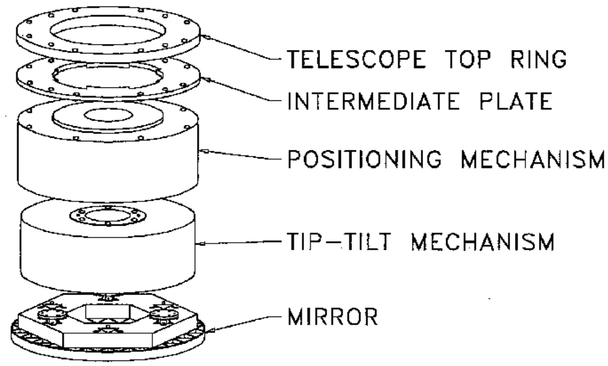

Fig. 4 An exploded view of the secondary mirror assembly.

Thermal control

The intrinsic image quality of a telescope is easily degraded by turbulent mixing of air at different temperatures generated from temperature differentials between the ambient air and components of the telescope and enclosure (see e.g. Racine, etal, 1991). The design of the Gemini telescope and enclosure has been substantially driven by the requirement to minimize these "mirror seeing" and "telescope seeing" effects.

During the day, the enclosure skin is actively ventilated to reduce the solar heat load on the internal enclosure volume. This allows daytime air-conditioning of the enclosure volume so the internal enclosure structure and telescope structure can be preconditioned to near the expected nightime ambient air temperature at the start of observing. In addition, the external surfaces of the dome and upward looking telescope surfaces are painted with a low emissivity paint to mimimize thermal turbulence from supercooling effects during nighttime observations.

The primary mirror temperature is controlled by two interlinked systems. The primary mirror assembly incorporates a radiation plate between the primary mirror and mirror cell for daytime preconditioning of the bulk mirror temperature at or below that expected at the start of observing. In addtion this system can provide slow control of the bulk mirror temperature during the night. To ensure the mirror surface temperature tracks the nighttime temperature variations with higher fidelity an electrical current is conducted through the reflective coating on the primary mirror, controlling the surface temperature by ohmic heating (Greenhalgh, Stepp, Hansen, 1994). The current flow is adjusted to follow variations in the ambient temperature. Simulations and prototype testing show that the a 1 deg C temperature change in the primary mirror surface can be achieved in about 15 min.

Active figure and alignment control

During the course of an observation, the alignment of the secondary mirror must be maintained to within 2 - 20 microns and the primary mirror surface controlled to within 30 nm rms. A pair of peripheral wavefront sensors (PWFS's), consisting of 8x8 Shack-Hartmann wavefront sensors analyse the incoming wavefront, using reference stars in the peripheral field of view surrounding the science field. The control system then uses these measurements to continuously correct the primary mirror figure and the alignment of the primary and secondary relative to the science focal plane on time scales of a few minutes during an observation. The PWFS's can patrol a 14 arcmin Cassegrain guide field, providing wave front sensing corrections over virtually 100% of the sky..

Tip/tilt and fast focus correction

Rapid image motion or jitter due to atmospheric wavefront tilt and windshake of the telescope and enclosure together with focus changes due to atmosphere and telescope effects, are sensed by low-order wavefront sensors integrated into each instrument. The OIWFS's observe reference stars within the isoplanatic patch around the science FOV by means of pickoff mirrors or dichroic beam splitters. The tip/tilt and focus errors sensed by these On-Instrument wavefront sensors (OIWFS) are corrected by means of small tilts and piston motions of the articulated secondary mirror. The Gemini IR instruments are being designed with infrared sensitive OIWFS's (1-2.5 μm) in order to exploit Gemini's imaging performance in dark cloud regions (Simons, 1995). In addtion, by using IR wavefront sensors we can potentially expect better image motion correction even at the galactic poles,and enable daytime observing.

3. VERSATILE OPTICAL/IR CAPABILITIES

The Gemini telescopes will provide superb image quality from the UV to IR. To scientifically exploit this broad wavelength range without comprimising performance requires that the telescopes and facilities support a number of different configurations

Optical to IR Baffling

The telescopes are equipped with a fixed chimney baffle mounted from the central hole in the primary mirror, and a three-position remotely deployable secondary baffle mounted on the positioning unit behind the secondary mirror. The optical and UV configuration uses the fully deployed secondary baffle position, about 2 m in diameter, to block direct sky illumination of a 12 arcminute diameter field of view in the telescope focal plane. For the thermal IR configuration this secondary baffle is fully retracted and then set at intermediate positions with deployed diameters of between 1.1 and 1.2 m diameter for near IR observations.

High Reflectivity and Low Emissivity Coatings

The coating plants will need the capability for depositing a variety of mirror coatings. Gemini has undertaken a series of development programs for sputtered Alumimum coatings and for protected Silver (Ag) coatings. The reflectivity of samples produced by these programs is shown in Table I compared to the reflectivity requirements and goals for the optical surfaces (Gemini Science Requirements, 1994).

Table I : Al and Ag Sample Reflectivity

	0.33-	**0.40-**	**0.70-**

	0.40µm	**0.70µm**	**1.1µm**
Bare Al	$\underline{0.87}$	$\underline{0.89}$	$\underline{0.90}$
Bare Ag	0.80	$\boxed{0.97}$	$\boxed{0.98}$
Minimal Protected Ag	0.76	$\underline{0.95}$	$\boxed{0.98}$
Protected Ag	0.86	$\underline{0.92}$	$\underline{0.96}$

$\underline{\textit{Meets Requirements}}$

$\boxed{\textit{Meets Goals}}$

At thermal infrared wavelengths it is not just the reflectivity of the mirrors which is important but also the total telescope emissivity. Both Mauna Kea and Cerro Pachon are very dry sites (with the exception of the Southern Hemisphere site in summer months), with transmission in portions of the atmospheric windows around 2.3, 3.7 and 10µm in excess of 98%. To exploit the correspondingly low atmospheric background emission, the Gemini telescopes IR configuration is designed to have a telescope emissivity less than 4% with a goal of acheiving 2% in the thermal IR beyond 2.27µm. To this end, IR configuration includes thin, 10mm secondary vanes, a pupil stop at the secondary mirror, and small bevels on the secondary mirror. The secondary mirror itself has been designed with a central hole so even in reflection the focal plane "sees" only cold sky in the vicinity of the central primary mirror bore and chimney baffle. Emissivity measurements on bare and protected Silver coatings together with APART analysis of the telescope configuration indicates that with Silver coatings on the primary and secondary mirrors, the Gemini telescope emissivity should approach the goal of 2%. (Dinger, 1993)

Consequently the intent is that Gemini will schedule “Aluminum Semesters” and “Silver Semesters” at both sites, to optimally support UV-Optical programs and Optical-IR programs respectively.

In order to maintain the extremely low telescope emissivity for extended periods of time between mirror recoatings, an effective and frequent (about once per week) in-situ mirror cleaning capability is required. Comparative cleaning tests using CO_2 snow and Excimer lasers have indicated potentially better cleaning performance for a laser cleaning approach (Kimura, Kim, and Balick, 1994). Further cleaning tests on sample Aluminum and bare and protected Silver mirrors are still underway.

Chopping Secondary Mirror

The articulated secondary mirror will be capable of simultaneous tip/tilt compensation and "chopping" at 5 to 10 hz for 10 and 20µm observations. Both capabilities are incorporated into the tip/tilt mechanism supporting the secondary mirror. This mechanism includes an active vibration compensation system to allow the 1m diameter secondary mirror to be “chopped” up to 10Hz without inducing vibrations into the telescope structure, so that the image quality during chopped observations will not be compromised

Cassegrain Instrument Support

The Cassegrain Instrument Support Structure (ISS) (Figure 5) incorporates acquisition and guiding capabilities, the PWFS's, and a science fold mirror for directing the telescope beam to any of the four side-looking insturment ports. The science fold mirror can also be retracted to allow the uplooking instrument port a clean, unimpeded access to the telescope beam for polarimetry, UV and thermal IR instruments. The ISS allows three 2000 kgm science instruments to be mounted simultaneously at the Cassegrain focus. In addition a Calibration Unit and an Adaptive Optics (AO) unit can be mounted on the remaining sidelooking ports. The AO module accesses the sky via a AO feed mirror in the ISS and can then feed, using the science fold mirror, a AO corrected F/16 beam to any instrument mounted on the ISS. The entire Cassegrain assembly rotates to maintain the orientation of scientific instruments with respect to the sky during any observations (Montgomery, Robertson and Wieland, 1994).

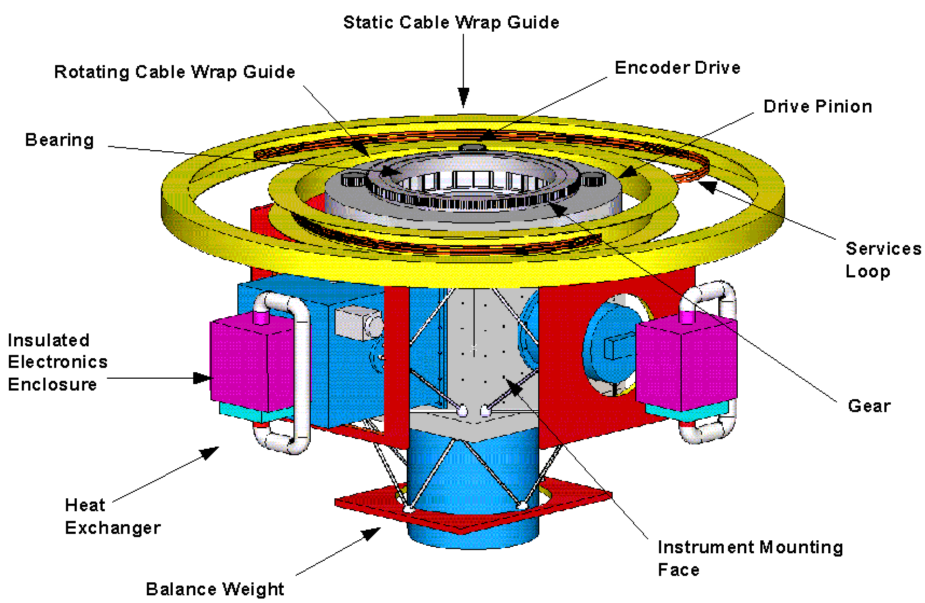

Fig. 5 The Instrument Support Structure(ISS) layout. Instruments can be mounted on the side-looking faces and on the up-looking face of the ISS.

4. EFFICIENT/ADAPTABLE OBSERVING

With the stringent image quality and emissivity requirements of the Gemini telescopes, the sensitivity of most observations will be limited solely by the physics of the atmosphere. Consequently, the "dynamic range" of delivered image quality and and infrared background will be far greater than we have experience with conventional groundbased telescopes. Observing time will also be at a premium on the Gemini telescopes, especially that time which exploits the unique characteristics of the telescopes and sites. Therefore the observatory operating philosophy will be key to maximizing the scientific productivity of the Gemini telescopes (Mountain et al, 1994b). These facilities will therefore support a range of observing modes; "classical" observing with the astronomer present at the telescope, modes with the astronomer either participating remotely, or more innovative modes (for ground based telescopes) such as queue scheduled observing where observatory staff carry out observations for the astronomer matching the observing conditions to the most appropriate observations. At least 50% of the observing time will be allocated to queue scheduled observations to allow the entire Gemini partnership to scientifically exploit the best conditions. To maximize scientific productivity under changing sky conditions, the observer can readily adapt the facility by changing between mounted instruments during the night by reconfiguration of the control system and secondary baffle and redirecting the science beam to alternative instruments with the science fold mirror. Consequently, as part of the Gemini observing system, efficient observation preparation tools, scheduling and rescheduling tools, environmental monitoring and data quality assessment capabilities will be provided. In addition, the necessary high bandwidth communication links to support remote observing will be available. Gemini will keep a permanent record of observations and ancillary data in perpetuity, sufficient for the future re-creation of the observations and adequate for useful archiving.

Time Allocation

The time allocation process relies on National Project Offices within the partner countries to interface with their communities. Proposals will be solicited semi-annually from the partner communities by the Gemini National Project offices. Within each of the partner countries an appropriate National TAC will rank the proposals into priority-ordered lists for "classical" and queue observations and forward them to Gemini, who will merge the national lists into a preliminary schedule of "classical" time and queue listings, taking into account observation requirements, national shares, instrument availability and engineering support requirements. A single International TAC, made up of representatives from the NTAC's, will review the preliminary schedules and make recommendations for the final schedules. The ITAC will also review the results of past observing periods to ensure fairness and effectiveness of the allocation and observation execution processes.

5. INSTRUMENTATION PROGRAM

To exploit the superb image and low emissivity characteristics of the Gemini telescopes requires a new generation of instruments and detectors. As with the telescopes, new approaches are having to be developed for instrument design, such as extensive use of finite element analysis, active correction of optical flexure, detailed scattering analysis to reduce instrument emissivities and incorporating both optical and IR wavefront sensors into the instruments. All the instruments will be mounted at the Cassegrain focus. on three faces of the ISS. Table 2 lists the instruments that will make up the initial complement at each site (Simons, Robertson and Mountain, 1995).

Table 2: Initial Scientific Instrumentation

Mauna Kea	**Cerro Pachon**
◆ Multi-Object Spectrograph	◆ Multi-Object Spectrograph
◆ Near IR Imager	◆ High Resolution Optical Spectrograph
◆ Near IR Spectrograph	
◆ NGS Adaptive Optics	
←Mid IR Imager→	
◆ Shared Instrumentation with UKIRT	◆ Shared Instrumentation with CTIO
↳ Mid-IR Spectrograph	↳ Near IR Spectrograph
	↳ Near IR High-Resolution Spectrograph
	↳ Commissioning IR Imager

Adaptive Optics

Initially on Mauna Kea we will be implementing a Natural Guide Star (NGS) Adaptive Optics system, designed for use in the 0.9 to 2.5μm range and capable of delivering images with Strehl ratios of 0.5 at 1.6μm in median seeing conditions. The corrected f/16 beam can be fed to any instrument port on the ISS. The plate scale and slit sizes for the infrared instruments are chosen to explicitly exploit this capability. In addition we are exploring the use of integral field units for imaging spectroscopy from 0.9-1 micron for the Mauna Kea GMOS instrument.

The Instruments

The 1-5μm imager will be used for commissioning the Mauna Kea telescope, as well as scientific observations, and will utilize a 1024^2 InSb array, have plate scales of 0.02, 0.05 and 0.11"/pixel for use with and without AO, and very low internal instrument background, consistent with the low telescope emissivity.

The 1-5μm spectrograph for Mauna Kea is also based on use of a 1024^2 InSb array, will provide spectral resolutions of about 2000 and 8000, two plate scales (0.05"/pixel and 0.15"/pixel), cross dispersion capability, and option for an integral field module.

There will be two Multi-Object spectrographs (MOS) operating over the 0.36-1.1μm range, one for Mauna Kea, with coatings optimized for red performance, and one for Cerro Pachon, with coatings optimized for blue performance. Each incorporates three 2kx4k CCD arrays, an image scale of 0.08"/pixel, spectral resolution of up to 10,000 and an integral field module with options for extending wavelength coverage to 1.8μm and additional integral field modules. The MOS's also include an imaging mode, primarily to support definition of the multi-slit masks.

The 8-30μm imager will initially be deployed at Mauna Kea and will be available for use at first light on Cerro Pachon. It will utilize at ~256x256 Si:As IBC array, a pixel scale of < 0.13"/pixel, and an internal instrument background consistent with the low telescope emissivity.

The High Resolution Optical Spectrograph (HROS) will be designed as a Cassegrain instrument on Gemini South and will use active flexure compensation to maintain high stability. The highest priority is for this instrument's throughput, particularly in the UV. The instrument will use two 2kx4k CCD arrays, and have resolutions of 50,000 and 120,000.

The commissioning instrument for the Cerro Pachon telescope will be a 1- 5μm imager borrowed from CTIO.

Shared Instrumentation

Because of the limited budget available for the initial instrumentation, Gemini is exploring sharing instruments with UKIRT (MICHELLE, a mid IR spectrometer/imager) and with CTIO (Phoenix, a 1-5μm high resolution, R=100,000 spectrometer).

Development Program

The broad instrumentation capabilities will permit a rapid scientific exploitation of the Gemini facilities. Futhermore, Gemini will have an ongoing instrument development program as it enters its operations phase that will serve to enhance and upgrade the initial instrumentation and provide next-generation instruments. A key priority for this program will be the provision of a fully capable adaptive optics system on the Cerro Pachon telescope.

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