The Gemini 8-M Telescopes Project

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ABSTRACT

Construction of the Gemini Telescopes is underway. The first mirror blank has been completed, concrete piers on both Mauna Kea and Cerro Pachon have been poured, fabrication of the telescope structures has started and the erection of the first enclosures have begun. In this paper, we give a progress report on the Gemini 8-M Telescopes Project. In addition, we highlight some of the unique scientific characteristics of the Gemini Telescopes including our approach to image quality performance, the use infrared wavefront sensors, the development of silver coatings and our "adaptable observing" system. The scientific performance of these telescopes will be heavily dependent on atmospheric conditions, Gemini will be allocating at least 50% of its observing time to "Queue Scheduled Observing". The implications of adopting this novel observing mode on the design of the control system and on the telescope operations model will be briefly discussed.

1. INTRODUCTION

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 (Kurz et al, 1996)[1]. 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.

2. PROGRESS

The first primary mirror blank has been fused, slumped and ground at Corning Inc. in Canton, New York, has become the first 8-m blank to cross the Atlantic and now is at REOSC in France for polishing (see Figure 1). The second Gemini blank has also now been successfully fused (Figure 2), and as with the first blank, exceeding the CTE (coefficient of thermal expansion) and uniformity requirements. Throughout the 8.1m diameter, 22 ton blank of ULE, at no point does the CTE exceed 50 parts per billion per ^{o}C.

Figure 1 The first Gemini blank being loaded into a grain freighter for its successful trip across the Atlantic on its way to REOSC in France.

Figure 2. The second Gemini blank after fusing at Corning Inc. in Canton, New York.

Both on Mauna Kea, Hawaii and on Cerro Pachon, Chile, the concrete foundations and pier have been laid and the enclosure steel work is being erected. The site construction status as of June 1996 is shown in Figures 3 & 4.

Figure 3: The Gemini North site on Mauna Kea, Hawaii

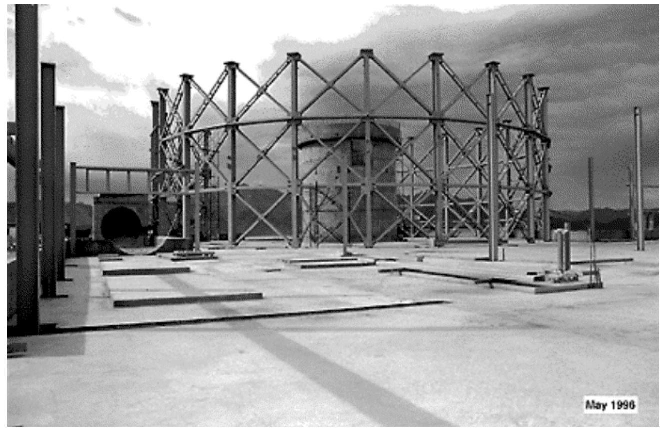

Figure 4: The Gemini South site on Cerro Pachon Chile

The first large components of the telescope structure are being fabricated at the NFM Factory in LaCreusot, France, with the assembly tests expected to start in early 1997. For secondary mirrors we have selected light weight, structured SiC substrates from Morton, Inc. with the mirrors being polished by Carl Zeiss of Germany. The secondary mirrors are attached by three points to a rapid tip/tilt, fast focus and chopping mechanism produced by Lockheed Martin. This mechanism will correct wind shake and atmospheric effects as well as provide the necessary articulation of the secondary for thermal infrared chopping at 10 Hz with amplitude on the sky of 15 arcseconds. To ensure the emissivity contribution of the entire telescope top-end is kept to a minimum, thin (10mm) composite vanes support the secondary mirror assembly from the top end ring.

The overall control of the Gemini Telescopes and its instruments is provided by real time software system using the EPICS (EPICS Architecture, 1993)[2] real time environment. A detailed description of the control system architecture and design approach is given elsewhere at this symposium (Wampler et al, 1996, McGonegal, 1996, Wallace, 1996)[3,4,5]. The first elements of the control system have been delivered to Gemini.

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.

Table 1 lists the instruments that will make up the initial complement at each, most of which will go through preliminary design review this year.

Table 1: 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

All the instruments will be mounted at the Cassegrain focus on three faces of our cubic instrument support structure, full details of the Gemini Instrumentation Program are given elsewhere (Simons, 1996)[6].

3. SCIENTIFIC CAPABILITIES

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, we have focused on several key scientific capabilities of the Gemini telescopes to achieve our top level science requirements of a 0.1 arcseconds image quality at 2.2 microns (50% encirled energy diamter) and an infrared emissivity goal of 2% with a requirement of 4% (Gemini Science Requirements, 1994).

3.1 Image Quality & Wind Buffeting

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 has meant paying careful attention to every aspect of the design of the Gemini facilities. A detailed analysis of the entire Gemini system was undertaken (Mountain et al, 1994a)[8] including water tunnel water tests (Raybould et al, 1994a)[9], super-computer modeling of the wind flow in and around the Gemini enclosure (DeYoung et al, 1995, DeYoung, 1996)[10 11], thermal models of the telescope structure and enclosure components (Raybould et al, 1994b)[12], extensive optical analysis and dynamic finite element analysis of the telescope/enclosure system, including the telescope foundations and the soil or rock properties of Mauna Kea and Cerro Pachon. Recent results from hydrodynamic calculations are shown in Figures 5 & 6.

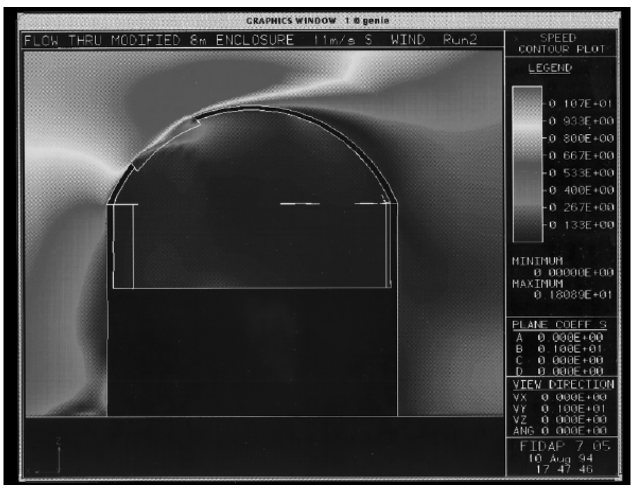

Figure 5: The hydrodynamic calculations of wind flow in and around the Gemini enclosure. In this figure the telescope is looking directly into a 11 m/s wind.

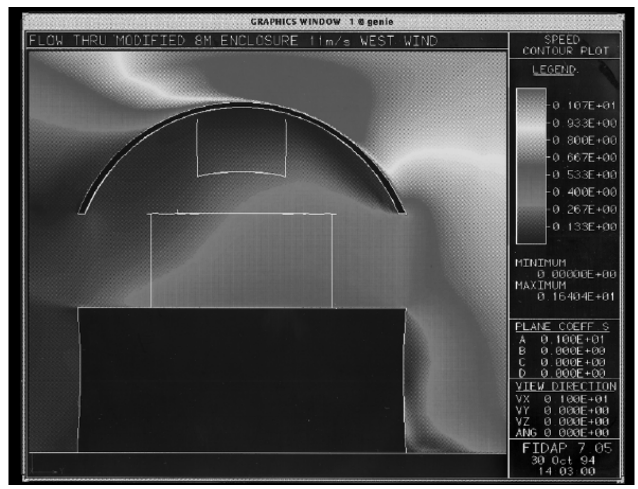

Figure 6: The same calculations as the previous figure but with a 11 m/s wind blowing directly into the ventilation gates, across the telescope

The enclosure 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 recent calculations show that even with a 11m/s wind blowing directly into the slit (Figure 5), the primary mirror and telescope top end are well shielded from wind buffeting. Figure 6 shows the same wind velocity blowing directly into the wind gates, across the telescopes and primary mirror. Again the wind pressure is sufficiently attenuated at the primary mirror and telescope top end to ensure we meet our stringent error budget even under 70th percentile wind conditions.

3.2 Image Quality & Thermally Induced Seeing

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 (Racine et al, 1991)[13]. The design of the Gemini telescope and enclosure has been substantially driven by the requirement to minimize both “telescope seeing” and “mirror 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 nighttime 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 minimize supercooling effects during nighttime observations.

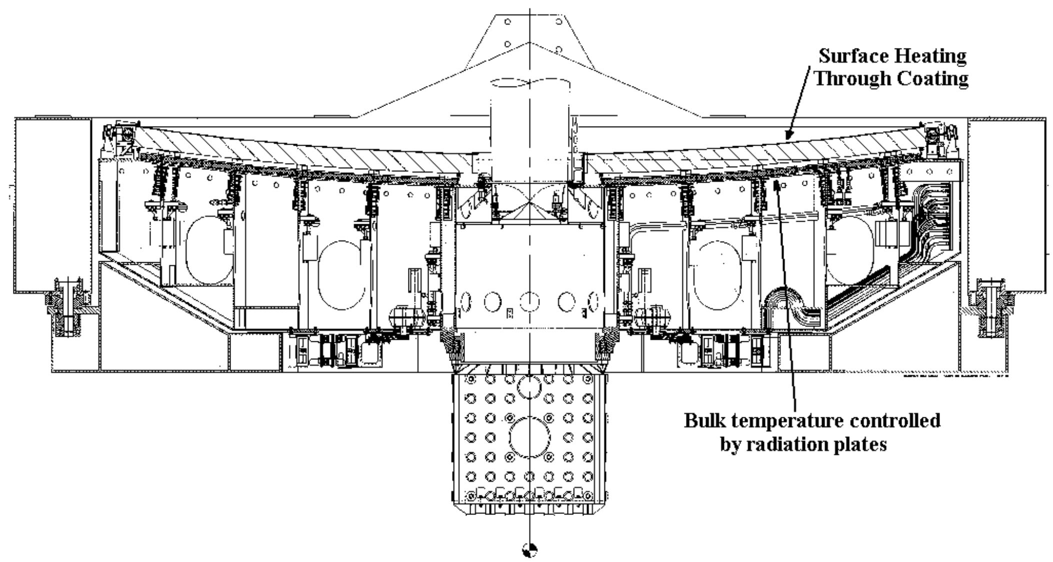

Figure 7. The primary mirror cell thermal control system

The primary mirror temperature is controlled by two interlinked systems. The primary mirror cell (Huang, 1996)[14] (Figure 7) 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. This system also provides slow control of the bulk mirror temperature during the night. Once a thermal gradient is established perpendicular to the mirror surface, the mirror surface temperature tracks the nighttime temperature variations using an electrical current conducted through the reflective coating on the primary mirror, controlling the surface temperature by ohmic heating (Hansen, 1996, Greenhalgh et al, 1994)[15 16]. The current flow is adjusted to follow variations in the ambient temperature. Any residual mirror curvature from the thermal gradients in the ULE subtrate are easily removed by the active optics control system (Cho, 1996)[17]. Figure 8, from Hansen et al 1996, shows the effects on the thermal boundary layer across a 1m prototype mirror of varying the current through the reflective layer. As can be seen when the surface temperature matches that of the ambient air, the thermal boundary layer effectively disappears. Simulations and prototype testing of this system show that the 1 deg C temperature change in the primary mirror surface can be achieved in about 15 minutes.

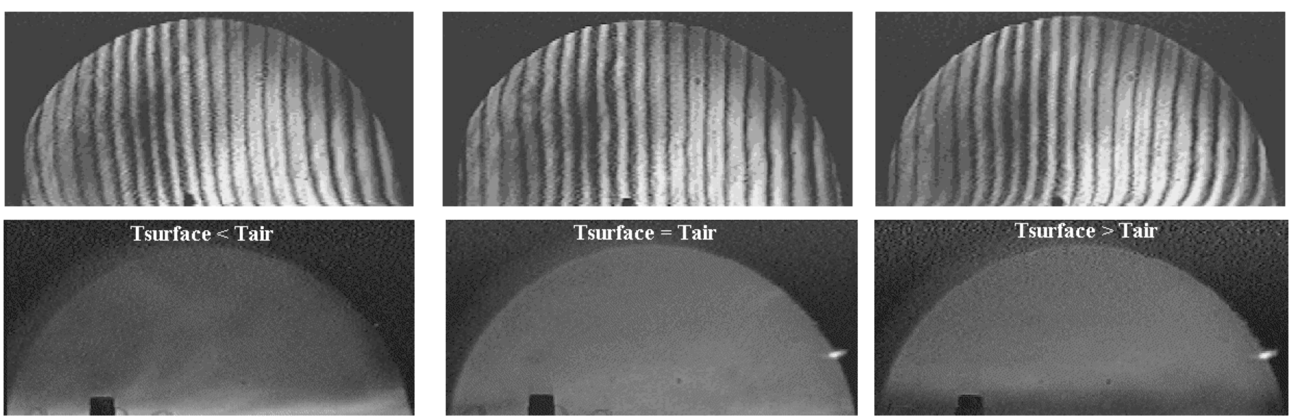

Figure 8. Shows the effects on the thermal boundary layer across a 1m prototype mirror of varying the current through the reflective layer (Hansen, 1996)[15]. When the surface temperature matches that of the ambient air, the thermal boundary layer effectively disappears.

3.3 Image Quality & Tip/tilt and fast focus correction in the Infrared

Rapid image motion from atmospheric wavefront tilt or jitter due to wind shake 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, see figure 9.

The on-instrument wavefront sensors (OIWFS) observe reference stars within the isoplanatic patch around the science field of view using pickoff mirrors or dichroic beam splitters. In addition, this allows any differential flexure between the instrument and telescope axis to be continually corrected, the measured tip/tilt and focus errors are corrected by the articulated secondary mirror. The Gemini IR instruments are using cooled dichroic pickoff mirrors and are being designed with infrared sensitive OIWFS's (1-2.5 mm) in order to exploit Gemini's imaging performance in dark cloud regions (Simons, 1995a)[18], see Figure 10. In addition, using IR wavefront sensors we can potentially expect better image motion correction even at the galactic poles, and enable daytime observing.

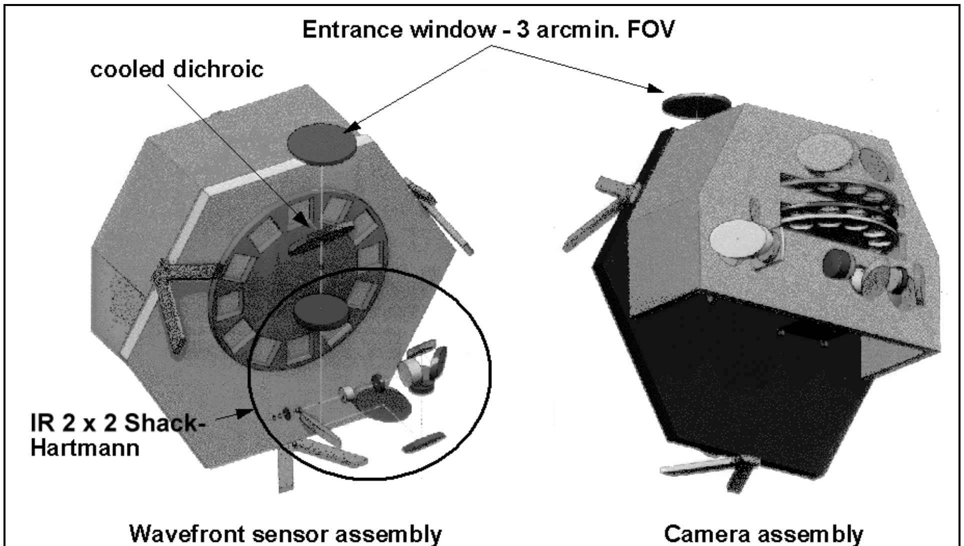

Figure 9. A schematic of the Gemini near IR camera (NIRI), showing the 2x2 Shack-Hartmann wavefront sensor integrated into the instrument.

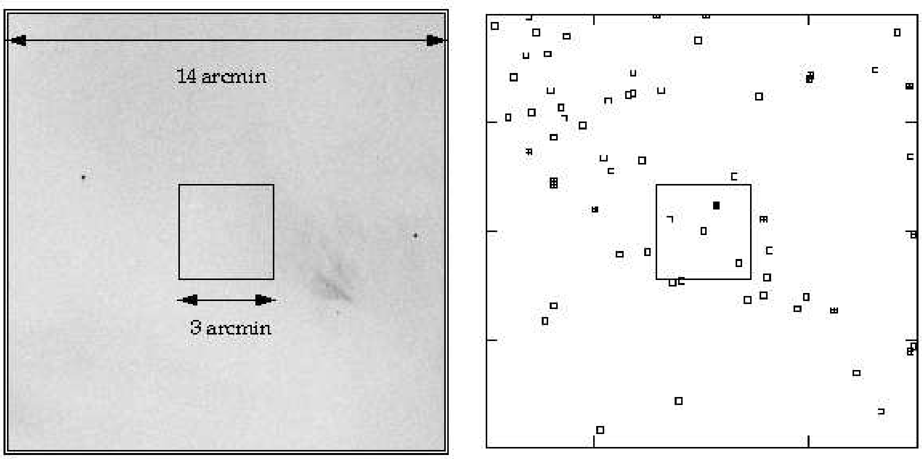

Figure 10. An example of the effectiveness of IR wavefront sensing in the star-forming region Ophiucus. The left hand figure shows a typical guide field in the visible, while on the right the same field is shown at 2.2 microns.

3.4 Image Quality & Predicted Performance

The inclusion of the features described above, integrated into a complete system model, gives the predicted image quality performance shown in Figures 11 and 12. The degradation in image quality as the guide star moves off-axis is due solely to the atmospheric tip/tilt and focus decorrelation. At 2.2 microns, the Gemini telescopes will be essentially "atmospheric limited" even in the best 10^{th} percentile conditions (Oschmann et al, 1996)[19].

4. 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 compromising performance means that we will need the option of being able to use at least two different coatings on our primary and secondary mirrors. The intent is to schedule "Aluminum" and "Silver" semesters for both Gemini Telescopes so we can optimally support UV/Optical and Optical/Infrared observations.

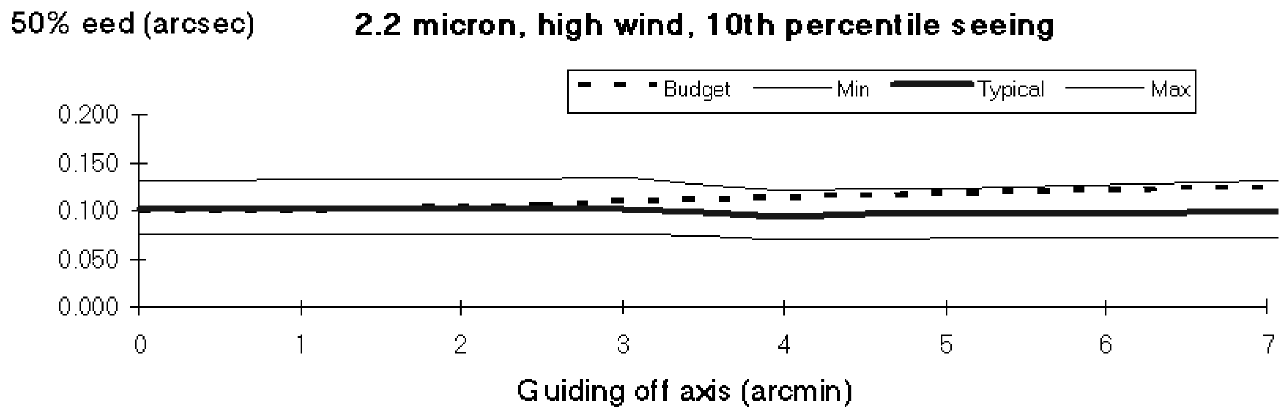

Figure 11. The predicted telescope performance at 2.2 microns as a function of guide star separation from the science object.

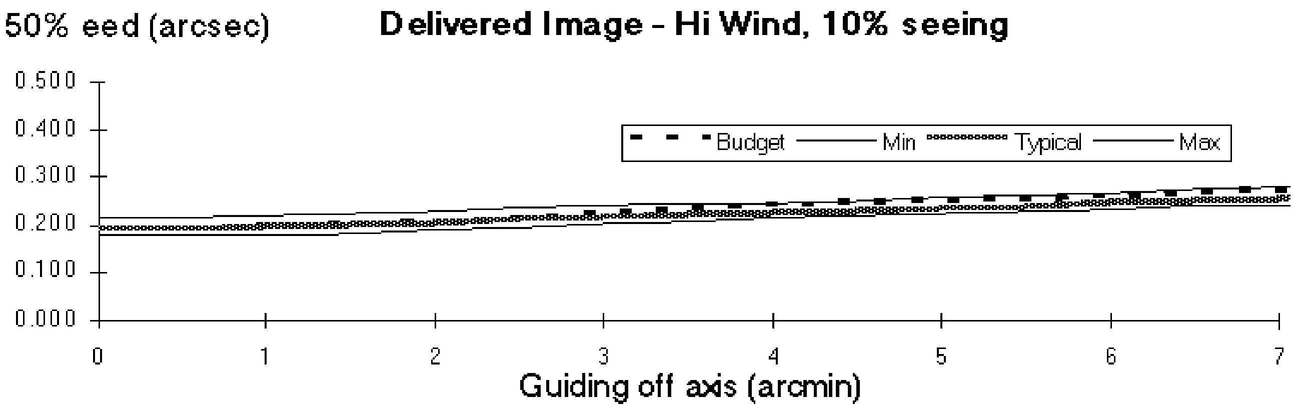

Figure 12. The predicted delivered image quality at 2.2 microns as a function of guide star off axis angle in the best 10th percentile conditions on Mauna Kea.

4.1 High Reflectivity and Low Emissivity Coatings

The coating plants have been designed with the capability for depositing a variety of mirror coatings. Gemini has undertaken a series of development programs for sputtered Aluminum coatings and for protected Silver (Ag) coatings. The reflectivity of samples produced by these programs is shown in Table II compared to the reflectivity requirements and goals for the optical surfaces (Gemini Science Requirements, 1994)[7].

Table II : Al and Ag Sample Reflectivity

	0.33-0.40µ	**0.40-0.70µ**	**0.70-1.1µ**
Bare Al	0.87	0.89	0.90
Bare Ag	0.80	0.97	0.98
Minimal Protected Ag	0.76	0.95	0.98
Protected Ag	0.86	0.92	0.96
Meets Requirements			
Meets Goals			

4.2 Silver Development Program

The development of good, durable silver coatings has been a key development activity for the Gemini Project. Figure 13 shows the relative through-put of an all aluminum telescope (3 reflections) compared to that of an all silver telescope (3 reflections) for a variety of silver coatings. The third mirror is included to account for our science fold mirror, which is used to direct the telescope beam to instruments mounted on the side faces of our Instrument Support Structure. At wavelengths beyond 4000 Angstroms, silver gives a substantial throughput boost over a conventional aluminum coated telescope.

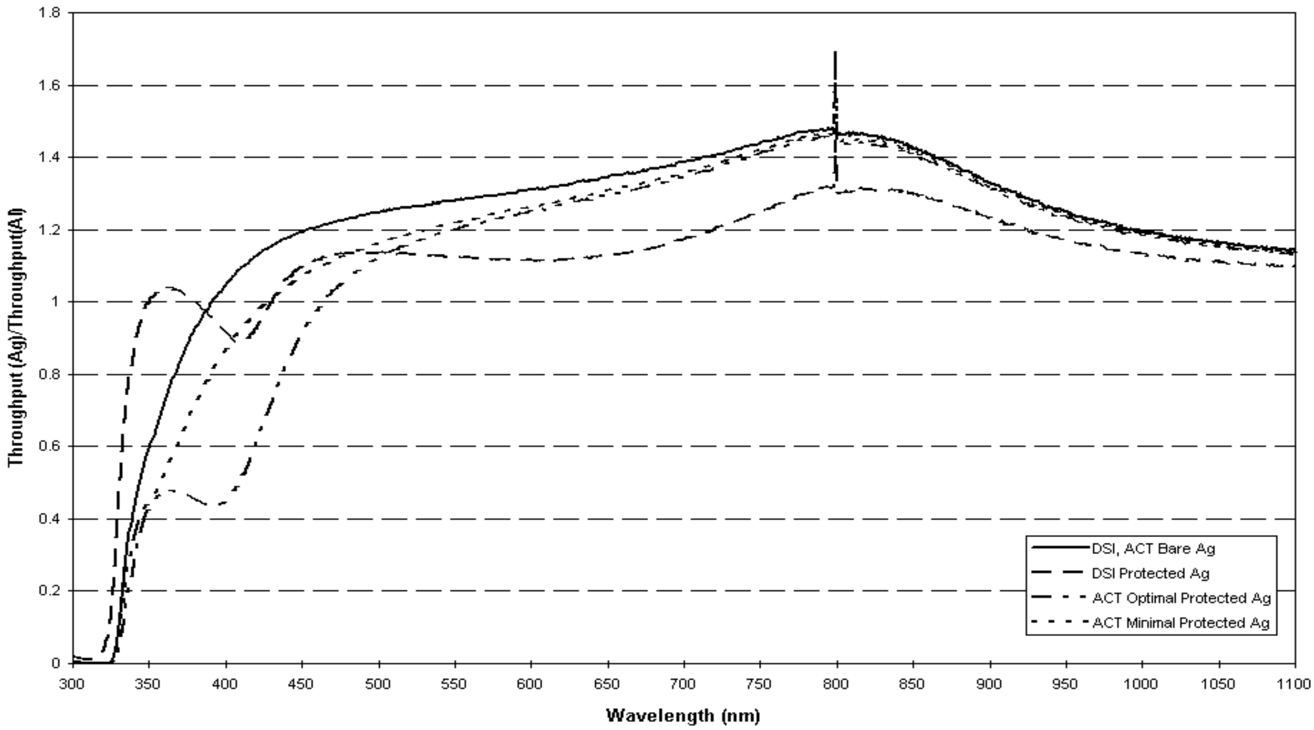

Figure 13. The relative throughput of an all aluminum telescope (3 reflections) compared to that of an all silver telescope (3 reflections) for a variety of silver coatings.

5. ADAPTABLE OBSERVING

5.1 The Gemini Observing Approach

The Gemini operating philosophy will be key to maximizing the scientific productivity of the Gemini telescopes (Mountain et al, 1994b)[20]. We 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 observations to the most appropriate conditions. 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 (Puxley et al, 1996)[21]. To maximize scientific productivity under changing sky conditions, the observer can readily adapt the facility by changing between mounted instruments during the night. This is accomplished 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 through the use of an archive.

5.2 Image Quality Dynamic Range

The sensitivity of most observations on the Gemini Telescopes will be limited solely by the characteristics of the atmosphere. Consequently, the "dynamic range" of delivered image quality and infrared background will be far greater than we have experienced with conventional groundbased telescopes, see Figure 14.

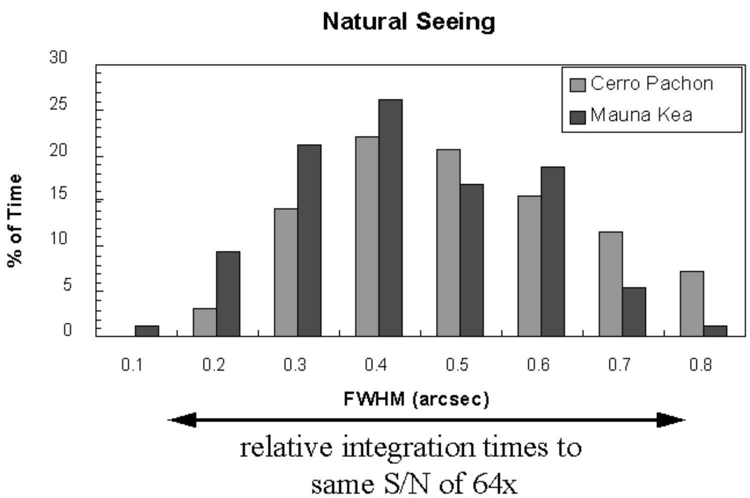

Figure 14 The variation in site seeing at both Mauna Kea and Cerro Pachon.

With the implementation of adaptive optics (Herriot, 1996)[22], the time to complete a given observation could vary by up to a factor of 64 depending on conditions.

5.3 Predicting Observing Conditions

In such an environment where we are so sensitive to atmospheric condition, it becomes natural to ask whether it will become possible to predict the quality of the night at least 12 to 24 hours in advance? Early studies by ourselves and ESO have shown that using IR satellite data to predict water vapor column is a real possibility in the coming years (Simons, 1995b)[23], see figure 15 .

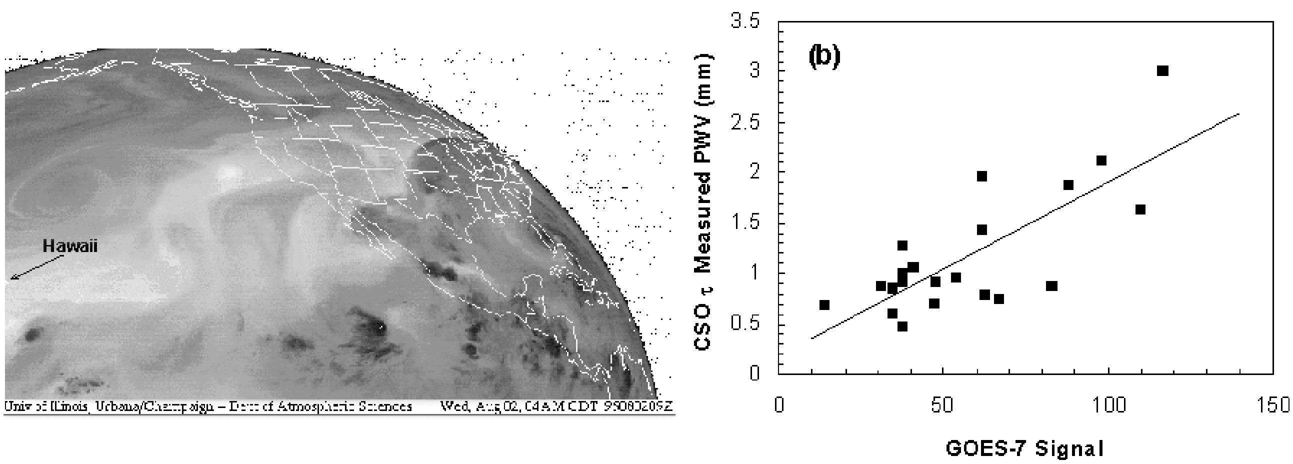

Figure 15. The measured correlation between the GOES -7 satellite image and the Mauna Kea water column as measured at 230 GhHz.

In addition, Sarazin et al are beginning to hint at the possibility of predicting, good, median or bad seeing using statistical techniques.

5.4 Conclusion

Observing time will be at a premium on the Gemini telescopes, especially that time which exploits the unique characteristics of the telescopes and sites. Add to this the great sensitivity to atmospheric conditions any given observation will have, combined with the possibility of future predictive algorithms to allow pre-planning of key programs, a new approach to observing on groundbased telescopes is called for.

6. AKNOWLEDGEMENTS

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