The Gemini 8m Telescopes

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ABSTRACT

The paper briefly reviews the scientific rational and scientific systems approach used by the Gemini 8M Telescopes Project in the design, construction and operations of the Gemini telescopes. We report on the progress of the telescopes on both Mauna Kea, Hawaii and Cerro Pachon Chile, give an updated schedule and describe some of the science operations concepts and planning that is going into the Gemini Observatory. In addition, at the end of this paper we give a full bibliography of Gemini papers presented at the numerous sessions of the 1998 SPIE meeting in Kona.

Keywords: Gemini telescopes, large telescopes, instrumentation, operations planning

1. SCIENTIFIC APPROACH

The scientific mission of the Gemini 8M Telescopes is predicated on a set of illustrative science programs. As stated in the original 1992 *Gemini Science Requirements Document*, **"the main themes of the science programs are concerned with observing and understanding the origins and evolution of stars and planetary systems, of galaxies, and of the universe itself. The telescopes will be used to observe objects ranging in ranging in distance from within our own Solar System to within 10% of the observable horizon of the universe.[1]."**

To undertake these programs, the fundamental performance criteria of the Gemini telescopes and its instrumentation can be encapsulated in the formula:

$$\frac{S}{N} \;\alpha\; \frac{\text{Telescope Diameter}}{\text{Delivered Image Width}} \cdot \frac{\eta^{1/2}}{\varepsilon^{1/2}} \qquad \textbf{1.}$$

Where S/N is the background limited signal-to-noise ratio reached in a given integration time, η is the total system through-put (including atmospheric transmission and detector quantum efficiency), and ε is the effective system emissivity (sky plus telescope plus instrument). As has been described in previous papers[2,3], to fully exploit our 8m mirrors and the superb imaging and background conditions of our sites on Mauna Kea and Cerro Pachon, we have taken an end-to-end systems approach in the performance of the Gemini Observatory. The design and operation of the telescopes, its instruments, the observing modes and data reduction tools have been treated from the outset of the Project as components of a single scientific system. This approach has allowed us optimized each part of Gemini, such as the enclosure, telescope structure, mirror support system, control system, the individual instrument characteristics, weather dependent queue execution algorithms and data handling system, to maximize equation (1) under any given set of atmospheric conditions. A bibliography of relevant Gemini papers in these Proceedings describing and illustrating our "scientific systems" approach is given in Table 2.

In this paper we give a report on the progress of the Gemini telescopes, give an updated schedule and outline some of the planning that is going into the Gemini Observatory.

2. PROGRESS REPORT – MARCH 1998

Figure 1. The Enclosures. (l) Completed Northern Enclosure; (r) Installation of arch girders on Southern Enclosure.

Both enclosures are now under construction at both Mauna Kea and Cerro Pachon (Figure 1). On Mauna Kea, the enclosure, shutters and large wind gates (the interior which can be been seen in Figure 2) are operating well and as can be seen the assembly of our first telescope is well underway.

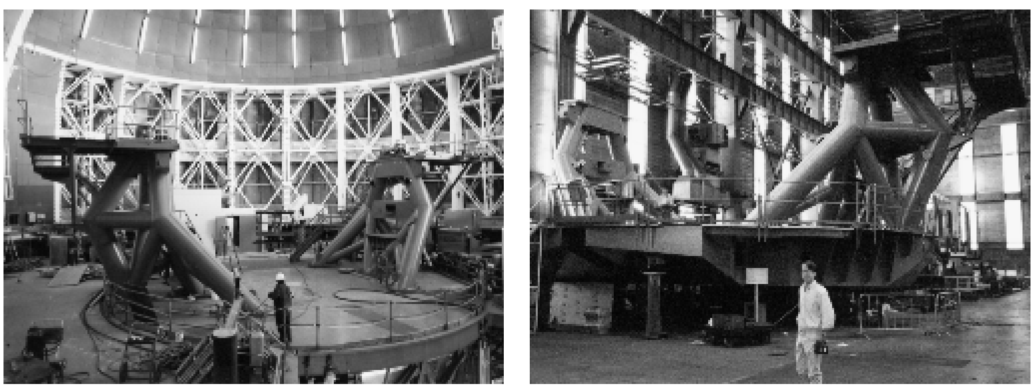

Figure 2. The Telescopes. (l) Installation of the Northern telescope; (r) Construction of Southern telescope

In parallel to the activity on Mauna Kea in Le Creusot, France, NFM have started the pre-assembly of the Gemini South telescope, (Figures 2 & 3). We expect the Gemini South

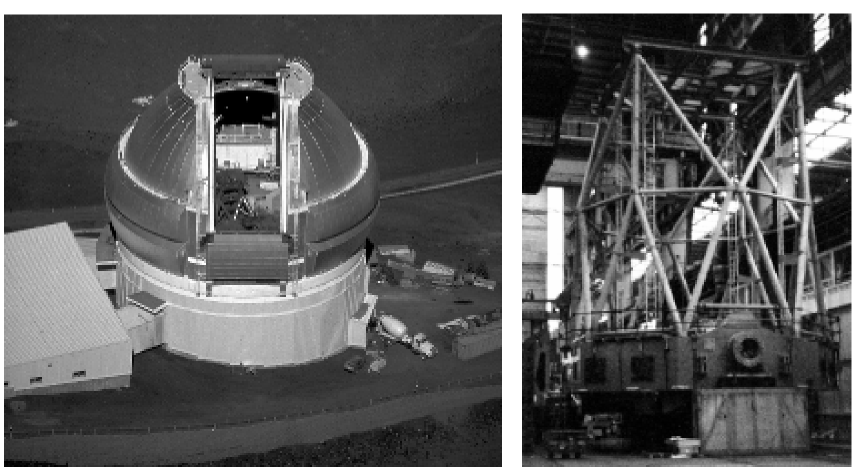

Figure 3. The Telescopes. (l) Installation of the Northern telescope; (r) Construction of Southern telescope

telescope structure to be shipped to Chile in late summer of this year.

In September of last year (1997) our first "super-heavy load", the Gemini North coating chamber was transported to our Mauna Kea site and successfully installed inside the enclosure base. Our second coating chamber arrived in Chile ahead of schedule, and will not actually be installed into the Gemini South enclosure until December this year (1998). The stainless steel coatings chambers are performing well, with the first pump-down tests on Mauna Kea achieving a vacuum of 3×10^{-8} torr. This bodes well for the successful sputtering of high quality Aluminum and high performance Silver coatings in both Gemini coating chambers.

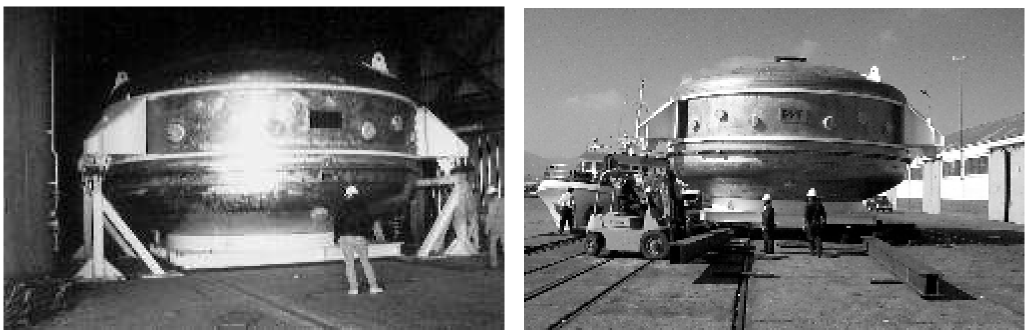

Figure 4. The Coating Plants. (l) Installation at the Northern telescope; (r) Arrival at Gemini South.

3. PRIMARY MIRROR SYSTEMS

The first 8.1m Corning ULE meniscus primary mirror, completed its polishing at REOSC in France and arrived in Hawaii on 18 March 1998 (figure 5). The same figure shows the second Gemini primary mirror on the polishing station at REOSC integrated with the Gemini air-pressure support system used in our cells. The polishing of the second Gemini blank is running slightly ahead of schedule with the mirror figure already within 1 micron rms.

Figure 5. The Primary Mirrors. (l) Northern mirror being un-loaded in Hawaii on March 18, 1998; (r) Southern mirror on the polishing table at REOSC.

The results from the polishing of the first Gemini primary are shown in Figure 5 and are described in detail in Paseri et al[4].

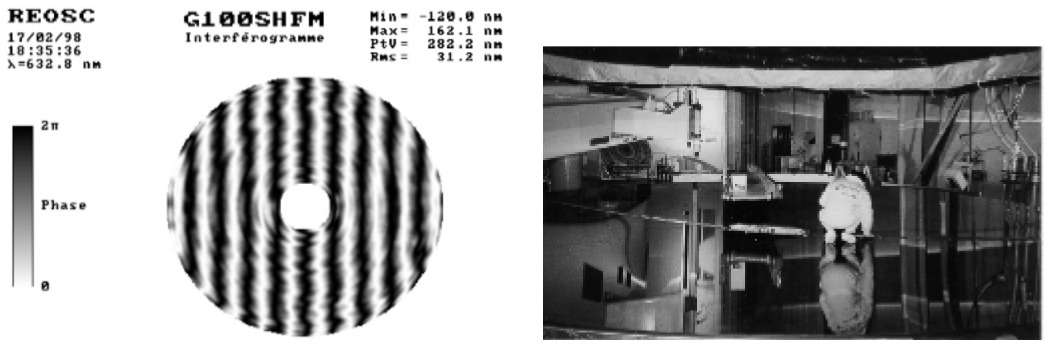

Figure 5. Primary Mirror Polishing. (l) WFS interferogram for Mirror #1; (r) Surface testing of Mirror #1

After correction of the low order bending modes by our active optics system, the mirror figure has a rms surface error of 15nm, with a peak-to-valley error of 141nm. To get a sense of this precision, if this mirror were stretched out over the Atlantic Ocean, the largest wave would be no higher than an foot, or 12 cm.

Figure 6. (l) Northern mirror cell with dummy mirror; (r) Installing actuators on Southern mirror cell

The first M1 cell assembly, with its support systems, has now been completed by the Gemini/Royal Greenwich Observatory team in France at NFM. The system, being tested with a steel dummy mirror, is shown in Figure 6. The same figure shows the parallel activity under way on the southern mirror cell where the positions of the 120 hydraulic actuators being surveyed. The clean external appearance of the mirror cells gives little indication of the cells function as a hydraulic wiffle-tree, active optics system and safety restraint system (an earthquake protection system) for our 8.1m mirrors. A rather more faithful view of the mirror cell is shown in Figure 7. showing the details of the safety restraint system. Shown in the same figure is sample of the support system tests showing a test tilting the dummy mirror. The resultant force map shows how the hydraulic wiffle-tree equalizes the forces in each zone, the support system behaving as simple three-point support when in this 3 zone mode. This system is now on its way to Hawaii, to arrive in the second half of June.

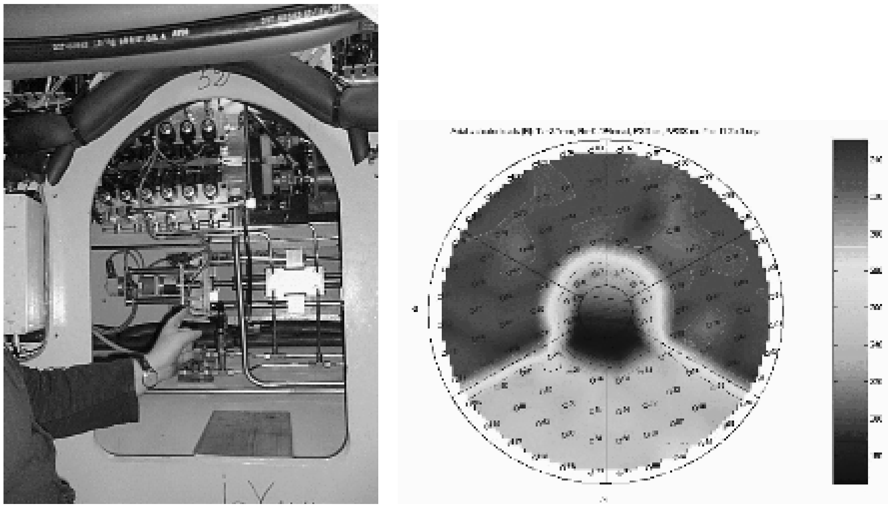

Figure 7. The Mirror Support System. (l) Safety Restraint System inside Cell 1; (r) Force Map of M1 Supports,3 sector mode, mirror tilted.

4. SECONDARY MIRROR SYSTEMS

The secondary mirror system on Gemini plays a crucial role in several areas:

- In compensating wind and atmospheric tip/tilt and focus errors
- Enabling high sensitivity 10 and 20 micron observations through high precision chopping.
- Providing active correction of the telescope alignment during observations
- Providing re-configurable baffles to optimally support optical, near-infrared and thermal-infrared observations.

The first key element of the secondary mirror support system, a tip/tilt & chopping mechanism produced by Lockheed/Martin (figure 8.) is now being integrated in Tucson with the positioning and baffle system, produced by Gemini, and the secondary control system from Royal Observatory Edinburgh. A novel feature of the Lockheed system is an active vibration cancellation system designed to reduce chopping reaction torque's from feeding back into the telescope top-end and structure[5].

Obtaining the high performance secondary mirrors required for this system has proved problematical -- the 1 meter diameter Silicon Carbide (SiC) blanks required have not been produced. Zeiss, the primary contractor for the secondary mirrors, is now producing two 85% light-weighted Zerodur mirrors (figure 8) for use during commissioning and scientific operations. The comparative characteristics of the Zerodur and SiC secondary mirrors are shown in Table 1.

Table 1: The comparative characteristics of the Zerodur and SiC secondary mirrors.

Mechanical Properties		Zerodur	SiC
Mass		54 kg	41.2 kg
Moment of Inertia	Mirror only	3.4 kgm^2	2.5 kgm^2
	Including supports	4.2 kgm^2	3.1 kgm^2
Resonant Frequency	Including supports	135Hz	160 Hz

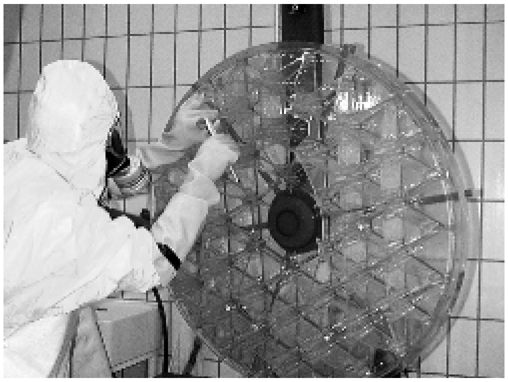 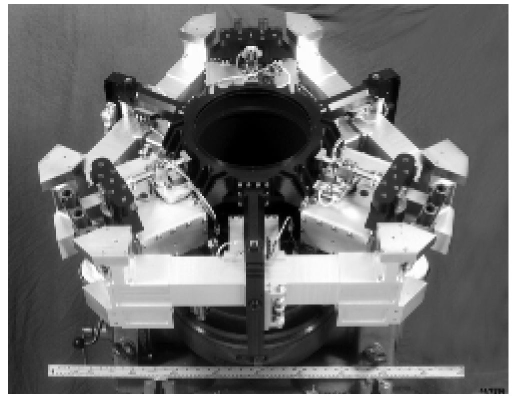

Figure 8. (l) Zerodur Secondary Mirror at Zeiss; (r) Lockheed-Martin Secondary Tilt System

The Zerodur mirrors will be used with our tip/tilt & chopping mechanism. A detailed analysis of Zerodur mirror performance used with the Lockheed/Martin system anticipate four effects which may most noticeably degrade the Gemini's image quality performance at 10 microns:

- A four-fold increase in the gravitational deformation which if uncorrected by the primary active mirror support system could degrade the 50% encircled energy at 2.2 microns by 0.025" at 45 degree Zenith angle. However it is anticipated this deformation will be well within the dynamic range of both the peripheral wavefront sensors and active optics actuators reducing this error in the worst case to 0.01".
- Reduced tip/tilt correction bandwidth due to the lowered resonant frequency of the mirror which in 70^{th} percentile wind conditions may increase the residual errors from wind shake from 0.021" rms to 0.023"rms at 2.2 microns.
- Increased moment of inertia will result in a smaller angular acceleration of the secondary mirror for a given force applied during chopping, reducing the frequency for a 15 arcsecond chop from 9.6 Hz to 8.6 Hz, which may impact the sensitivity of 10 micron observations, under conditions of high sky noise.
- Increased mirror distortion during chopping dwell time could increase the 10 micron image blur from 0.02" to 0.08". This is significant when compared to a 50% encircled energy diameter of ~ 0.3" and so chopping will have to be restricted to lower frequencies and smaller throws.

Other effects such as thermal distortions, edge effects, bevels widths, polishability and coatability are anticipated to be no worse than for SiC. The project is currently evaluating our longer-term requirements and schedule for high performance blanks.

5. FACILITY INSTRUMENTATION

All instruments mount at the Cassegrain focus on the instrument support structure, a cube that contains the acquisition and guidance systems and can support up to three major instruments, a facility adaptive optics unit and calibration unit. The first Instrument

Support Structure (figure 9) has been completed by AMOS in Belgium and has been sent to Zeiss at Jena for integration with the Acquisition and Guiding system. Zeiss is well into the final integration and test activities. The wavefront sensors and acquisition cameras from RGO and Herzberg Institute of Astrophysics, Canada, will be first integrated with the Zeiss work in May-June.

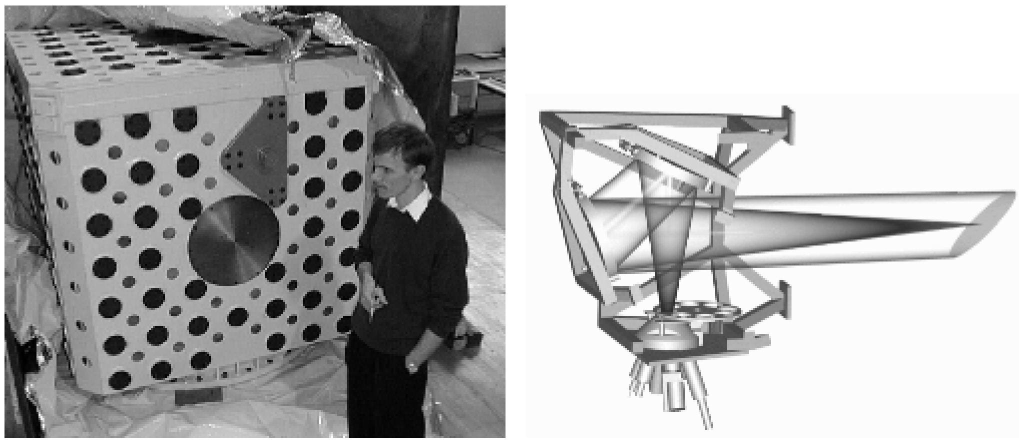

Figure 9. Instrument Support System. (l) Instrument Support Structure (ISS); (r) Gemini Calibration Unit.

A key element of our queue scheduling strategy will be our ability to switch between instruments during the night. Consequently, an integral part of the instrument support system is the facility calibration unit being designed at Royal Observatory Edinburgh. This unit is designed to produce stable flat fields and calibration arcs for all Gemini's optical and near-IR instruments at any telescope orientation -- a schematic is shown in figure 8.

6.   SCIENCE INSTRUMENTS

All Gemini's science instruments are built by partner institutions and universities. Detailed descriptions of many of the instruments can be found in these proceedings (see Table 2). Figure 10 gives some indication of the increased scale and complexity of 8m class instruments. For example, the figure on the left shows the cryostat of the Gemini near-infrared imager (NIRI) in construction – the completed instrument weighs just less than two tonnes. The right-hand figure shows the CCD head for our multi-object

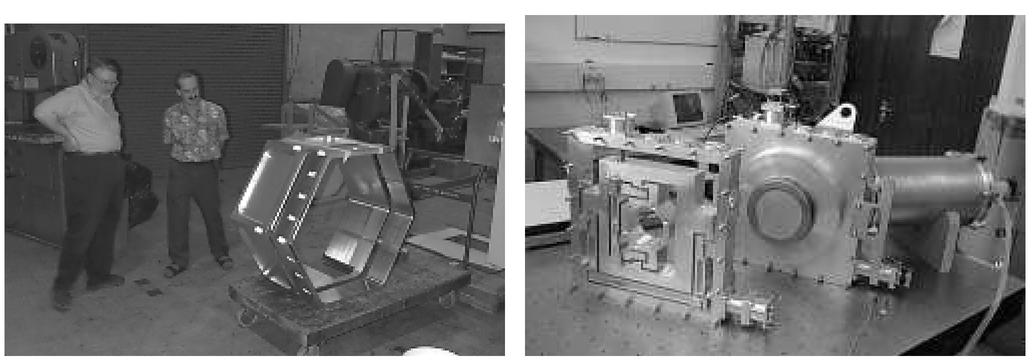

Figure 10. Instrumentation. (l) Part of NIRI's cryostat; (r) The GMOS "active" CCD head

spectrographs (GMOS). In GMOS, flexure is compensated through the active positioning of the CCD head as the telescope tracks across the sky.

7. INFRASTRUCTURE INVESTMENT

Like many large telescopes programs, Gemini has made several investments in infrastructure to support the Gemini Observatory integration, commissioning and operations. The current state of Gemini's "Northern Operations Center" is shown in Figure 11. The Hilo operation will be part of a campus with the Joint Astronomy Center, on the University of Hawaii's, Hilo Science Park.

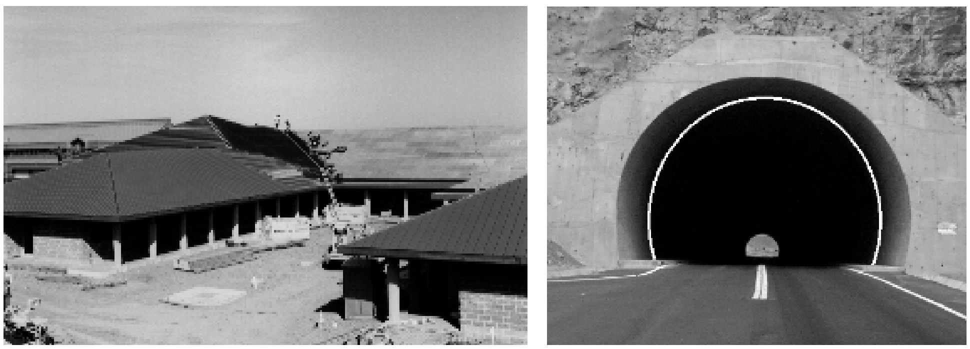

Figure 11. Infrastructure Support. (l) Gemini Observatory Northern Operations Center, Hilo HI; (r) Widened Puclaro Dam tunnel, Chile, indicating the originally intended 8m diameter tunnel.

The picture of the tunnel in figure 11 shows a more unexpected investment. When the Chilean government decided to flood and dam the Elki Valley, the access road to Cerro Pachon was to be taken through an 8m diameter tunnel (outlined in white) – Gemini paid for the tunnel to be built as the now 10 meter diameter tunnel.

8. PROJECT SCHEDULE

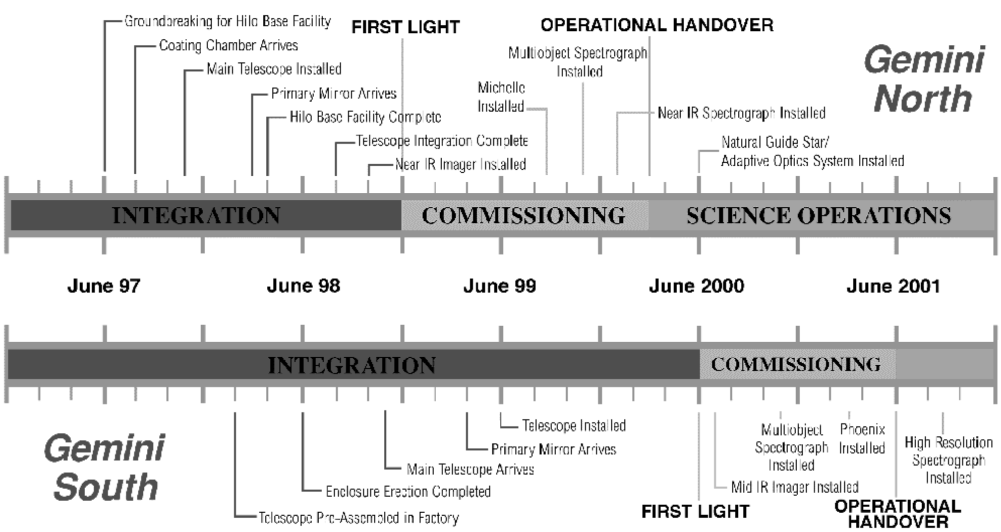

Figure 12. The current Project schedule

9. OPERATIONS PLANNING FOR THE GEMINI OBSERVATORY

In an effort to find a scientifically and cost effective way to operate these sophisticated telescopes in two hemispheres, the Gemini telescopes will be operated on a "single observatory, two telescopes" model. The Gemini Observatory will have coordinated scheduling, a single international time allocation process, and a single user "interface" and use a unified engineering and support team. From operational hand-over, observers will be able to use the telescopes from "operations rooms" in Hilo and La Serena (see Figure 13), which will eventually support the scientific use of either telescope from either Hilo or La Serena.

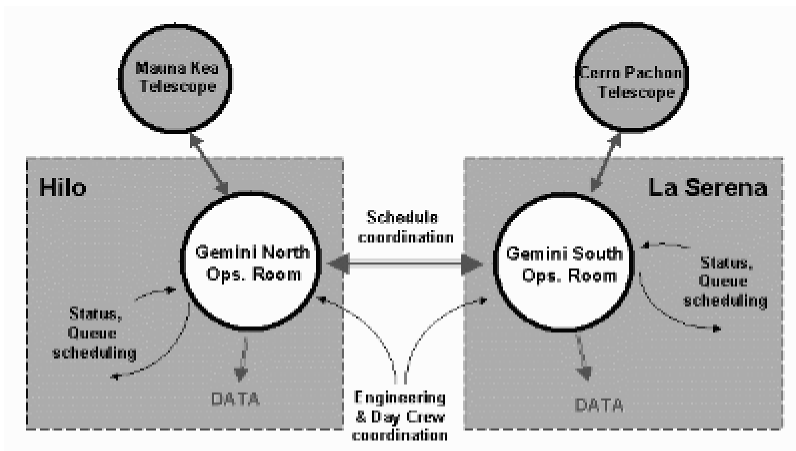

Figure 13. The Gemini Operations Model.

A "*Gemini Science Operations Plan*[6.]" describes the scientific functioning of the Gemini Observatory. To more effectively use the Gemini Telescopes, the development of this plan necessitated a thorough understanding of the following:

- required scientific "data flow"
- the roles of the PI astronomer and the Gemini scientific staff to support both queue and classical observing
- the requirements for software tools to allow our international community of astronomers to more effectively use the Gemini telescopes.

One of the first "products" from this plan was the Gemini Observing Tool (figure 14) which will be used by all observers to pre-plan and execute observations using the Gemini telescope.

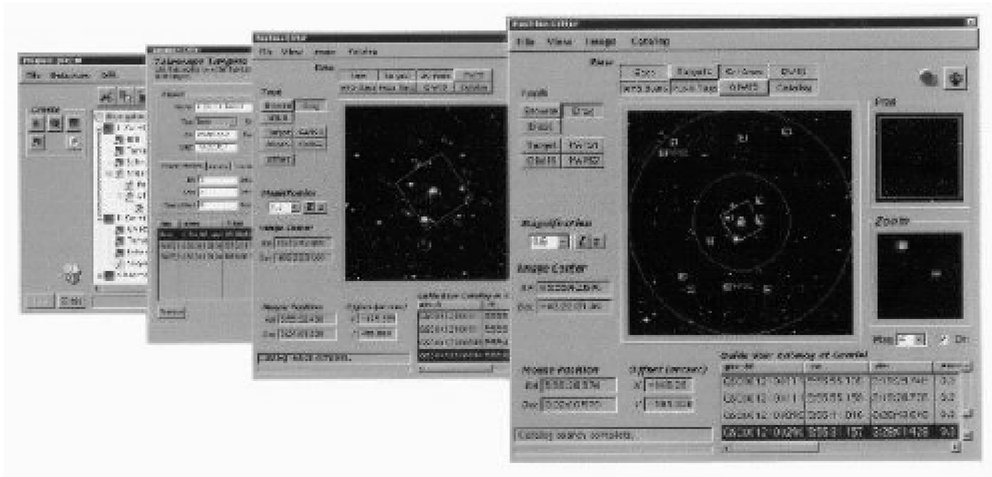

Figure 14. Observing Preparation with the Preplanned Observing Tool.

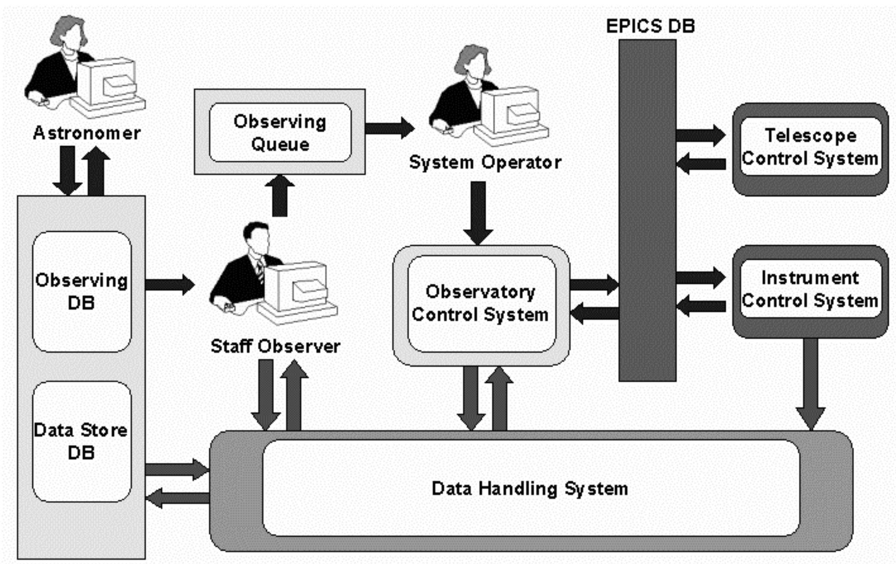

Figure 15. Gemini Data Flow during Operations.

An illustration of how the Science Operations Plan will work, using a detailed "walk through" of a typical observation is given in Puxley et al.[6] Figure 15 shows the complete Gemini Data Flow, with the Astronomer, Staff Observer and System Operator all considered as "elements" in the overall design and implementation of the Gemini observing system. A key element in this system is the Gemini "Data Handling System", which produces quick-look reduced data and archives all the science data, giving both the real time and long term "feed back" to our astronomers on the scientific quality and productivity of the Gemini telescopes.

ACKNOWLEDGEMENTS

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4. Paseri, J. et al. "Gemini 8.2-m Primary Mirrors Polishing". SPIE 1998 (these proceedings)
5. Lorell, K. R. et al. "Test and performance evaluation of the Gemini secondary mirror chopper and position control system". SPIE 1998 (these proceedings)
6. Puxley, P.J. et al. "Gemini Observatory Science Operations Plan". SPIE 1998 (these proceedings)

TABLE 2

LIST OF GEMINI PAPERS IN THESE PROCEEDINGS

3349-08, **Gemini Observatory science operations plan**, P.J. Puxley, F.C. Gillett, C.M. Mountain; Gemini 8-m Telescopes Project

3349-13, **Infrastructure of the Gemini Observatory control system**, K. K. Gillies, S. Walker; Gemini 8-m Telescopes Project

3349-49, **Gemini Phase 1 science proposal entry tool**, D. Kotturi; Gemini 8-m Telescopes Project

3349-50, **Support Capability Requirements of 8-M Telescope Science**, P.J. Puxley, Gemini 8-m Telescopes Project; T. Boroson, NOAO; P. Roche, Oxford Univ (UK); J-R. Roy, Univ. Laval (Canada)

3351-02, **Gemini facility instrumentation**, J. M. Oschmann, D. Montgomery, M. R. Hunten, Gemini 8-m Telescopes Project; S. C. Craig, N. Dillon, Royal Greenwich Observatory (UK); B. Leckie, Dominion Astrophysical Observatory (Canada)

3351-05, **Gemini world coordinates**, P. T. Wallace, Rutherford Appleton Lab. (UK)

3352-02, **Gemini 8m Telescopes Project**, C.M. Mountain. F.C. Gillett, R. Kurz; Gemini 8-m Telescopes Project

3352-21, **Gemini 8.2-m primary mirrors polishing**, J. Paseri, M. Cayrel, E. Dromas, REOSC (France)

3352-23, **Gemini prime focus wavefront sensor**, J. M. Oschmann, S. S. Smith, J. R. Wright, J. Robinson, M. K. Cho, D. M. Walther, C. P. Cavedoni, Gemini 8-m Telescopes Project

3352-35, **Development of silver coating options for the Gemini 8-m telescopes project**, M. R. Jacobson, Optical Data Associates; R. Kneale, K. Raybould, F. C. Gillett, Gemini 8-m Telescopes Project; R. Laird, BOC Coating Technology; R. P. Shimshock, Southwall Technologies; D. C. Booth, Sigma Labs.

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3352-64, **Status of CVD-SiC secondary mirrors (M2) for the Gemini 8-m Telescopes**, E. D. Knohl, A. Schoeppach, Carl Zeiss (FRG); M. A. Pickering, Morton International/CVD, Inc.

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3352-98, **Hardware implementation of the primary mirror surface heating system for the Gemini 8-m telescopes**, B. Perona, E. R. Hansen, A. C. Rudeen, Gemini 8-m Telescopes Project; D. Hagelbarger, National Optical Astronomy Observatories

3353-13, **Design aspects of the reconstructor for the Gemini adaptive optics system (GAOS)**, L. K. Saddlemyer, Dominion Astrophysical Observatory

(Canada)3353-24, **Innovations in Gemini adaptive optics system design**, G. Herriot, S. Morris, Dominion Astrophysical Observatory (Canada)

3353-57, **Gemini adaptive optics plan**, M. R. Chun, F. C. Gillett, International Gemini Project Office; G. Herriot, S. Morris, Dominion Astrophysical Observatory (Canada); J. Oschmann, D. A. Simons, International Gemini Project Office

3353-60, **Optical design of adaptive optics for the Gemini 8-m telescope**, E. H. Richardson, Univ. of Victoria (Canada); J. M. Fletcher, C. L. Morbey, Dominion Astrophysical Observatory (Canada); J. Oschmann, Gemini 8-m Telescopes Project

3353-102, **Mechanical design of the Gemini adaptive optics system**, S. Roberts, G. Singh, National Research Council of Canada

3353-114, **Graphical user interface for the LACE adaptive optics performance analysis package**, D. Kotturi, Gemini 8-m Telescopes Project; B. L. Ellerbroek, A. L. Wells, Air Force Research Lab.

3354-04, **Characterization of Gemini near-IR arrays**, W. Harrison, Gemini 8-m Telescopes Project; W. Ball, A. M. Fowler, National Optical Astronomy Observatories

3354-21, **Advanced image slicer for integral field spectroscopy with UKIRT and GEMINI**, R. Content, Univ. of Durham (UK)

3354-36, **Future Gemini instrumentation**, F. C. Gillett, C. M. Mountain, Gemini 8-m Telescopes Project

3354-37, **Gemini mid-infrared imager**, , R. Pina, C.Telesco, University of Florida

3354-38, **Gemini near-infrared imager (NIRI)**, K. Hodapp, J. L. Hora, T. T. Young, E. M. Irwin, H. Yamada, J. Douglass, J. Bell, D. Neill, Univ. of Hawaii/ Manoa

3354-39, **Design of the Gemini near-infrared spectrometer**, J. Elias, D. Vukobratovich, J. R. Andrew, M. K. Cho, R. W. Cuberly, K. Don, A. Gerzoff, C. F. Harmer, D. Harris, J. B. Heynssens, J. Hicks, A. Kovacs, C. Li, M. Liang, I. K. Moon, E. T. Pearson, G. Plum, N. A. Roddier, J. Tvedt, R. J. Wolff, W. Wong, National Optical Astronomy Observatories

3354-110, **Polarimetry for the Gemini telescopes**, J. Hough, D. K. Aitken, A. C. Chrysostomou, Univ. of Hertfordshire (UK)

3354-117, **Design of a grating mechanism for a near-infrared spectrograph**, W. Wong, R. W. Cuberly, J. R. Andrew, National Optical Astronomy Observatories

3354-118, **Design review of flexure-based focus stages for Gemini NIRI and Subaru IRCS**, J. Douglass, T. T. Young, K. Hodapp, L. Robertson, Univ. of Hawaii/ Manoa

3354-120, **Gemini near-infrared imager on-instrument wavefront sensor gimbal tilt stage**, R. Thornton, T. T. Young, K. Hodapp, J. Douglass, H. Yamada, Univ. of Hawaii/Manoa

3354-121, **Gemini near-IR controllers**, N. A. Roddier, N. C. Buchholz, N. A. Gaughan, J. B. Heynssens, K. Merrill, National Optical Astronomy Observatories; W. Harrison, Gemini 8-m Telescopes Project

3354-122, **Cryostat design and fabrication for Gemini NIRI instrument**, T. T. Young, K. Hodapp, D. Neill, E. Irvin, L. Robertson, Univ. of Hawaii/Manoa

3354-126, **Design study of the GNIRS bracket structure**, M. K. Cho, Gemini 8-m Telescopes Project; C. Li, R. Cuberly, W. Wong, I. K. Moon, NOAO

3355-09, **Gemini multi-object spectrographs**, R. G. Murowinski, National Research Council of Canada and Dominion Astrophysical Observatory (Canada)

3355-11, **Acquisition and guiding unit for Gemini 8-m telescopes: a progress report**, W. Heilemann, H. Naumann, Carl Zeiss (FRG)

3355-73, **Gemini multi-object spectrograph: a flexure-critical design**, K. Szeto, R. Bennett, T. Bond, C. G. Dickson, P. Hastings, R. G. Murowinski, S. Roberts, National Research Council of Canada

3355-76, **Structural analysis and active flexure compensation of the high-resolution optical spectrograph for the Gemini South Telescope**, R. Wade, Rutherford Appleton Lab. (UK); B. Fell, Daresbury Lab. (UK)

3355-77, **Engineering solution for the high-resolution optical spectrograph on Gemini South Telescope**, A. Charalambous, P. D'Arrigo, Univ. College London (UK)

3355-120, **Gemini WFS CCD's and controllers**, B. Leckie, T. Hardy, National Research Council Canada