GEMINI PROJECT
NEWSLETTER

THE GEMINI 8-METER TELESCOPES PROJECT is managed by the Association of Universities for Research in Astronomy for the National Science Foundation under an international partnership agreement.

September 1993 / Number 6

Gemini Work Packages

One of the strengths of the Gemini project is that it combines the talents and expertise of the astronomy communities of six countries. The Gemini project, of course, benefits from the scientific and financial contributions from the partner countries. The ultimate success of this complex project will also depend on how well we take advantage of the capabilities of the partners for the design, fabrication, and commissioning of the instrumentation, optics, telescope mounts, enclosures, etc.

Over the past year, the Gemini project team has worked with the national project offices in the partner countries to determine how best to carry out the project. We are now close to agreement on how and where the project work will be accomplished. In reaching this agreement, we have taken into account differences in the mandates and interests of the national funding agencies as well as the technical strengths of each of the partners. In those areas where more than one partner wanted to do the same portion of the work and both have demonstrated expertise, negotiations were necessary. While none of the partners will get to do everything they would like to, the overall distribution of work is acceptable to all the partners.

Identifiable pieces of related work have been grouped together into work packages. For example, most of the enclosure above the foundation is a single work package. Some work packages will be open to international bidding. Others will be bid in only a single country, provided suitable bids are actually received from the preferred country. In some cases the Gemini project team will manage commercial contracts in the partner countries directly. In other cases, responsibility for managing a work package has been assigned to one of the national project offices, which may in turn offer portions of that package to international tender.

For all work packages, the Gemini project office retains overall control of the design, schedule, and budget. No country may make contributions in kind. All of the technical specifications, financial arrangements, and management structures must be approved by the international project office in Tucson.

The instrumentation is being handled somewhat differently. To help with defining the science requirements and developing innovative designs, we have established an international working group for each instrument. The working groups will advise the project team through the Gemini Science Committee on the design goals for each instrument. We will also attempt to arrive at a consensus about how to share the instrument development among groups in each country in a way that maximizes the scientific returns from the available funding. We expect to allocate instrumentation work packages approximately in proportion to the financial contributions from the partner countries. We also expect that some international collaborations will be developed for some of the instruments. The plan for Gemini instrumentation will require the approval of the Gemini Board.

— *Sidney Wolff*
Acting Project Director

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***THE TIMES** of London published an editorial concerning the Gemini project in its edition of August 4, 1993. This editorial is quite eloquent in describing the role of astronomy in stimulating public interest in science. The Gemini project will have an impact that extends well beyond the professional communities in the partner countries.*

PER ASTRA AD ARDUA

Astronomy leads us to life's most complex questions

The decision of the Science and Engineering Research Council to back the Gemini telescopes project involves Britain in one of the world's most exhilarating scientific investigations. Over the next seven years, two massively powerful 8m telescopes will be constructed on Mauna Kea in Hawaii and on Cerro Pachon in Chile. They should be scanning the heavens by 2000.

The Gemini telescopes will probe the frontiers of human understanding. Covering the whole sky and the infra-red, optical and ultra-violet regions of the spectrum, they will advance our knowledge of the history of the different chemical elements and of the mysterious "dark matter", which sheds no light but seems to be essential to the structure of the universe. The processes that precede the birth of stars and galaxies will be revealed in greater detail: the chemistry of creation should become a little more intelligible.

So too may its origins. The great early modern astronomers such as Copernicus, Kepler and Galileo tried to explain the basic mechanisms of the universe. But contemporary projects such as Gemini hover on the cusp between physics and metaphysics, allowing man to see light that began its journey to Earth billions of years ago. A beam of light takes just over four years to reach the human eye from Proxima Centauri, the star nearest to the solar system, while our image of the sun is a mere eight minutes old. But the Gemini telescopes will enable us to see galaxies as they were when the universe was only half its present age. Signals seven billion years old will at last be received on this planet. We will edge a little closer to infinity.

Such an achievement is scientifically invaluable. It is also inspiring. Humanity's relationship with the stars has changed dramatically since the Cold War space race. That was driven by the instinct to colonise the solar system, and to stride victoriously through the foothills of the lunar Appennies. But in recent years, as the strange implications of post-Newtonian physics have seeped into popular culture, astronomy has attracted greater interest than space travel.

The profound questions raised in Stephen Hawking's *A Brief History of Time* and other scientific works have nurtured a more contemplative, humbler approach to the mysteries of space. Thirty years ago, the starship was the symbol of future science. Today, it is the telescope. Almost four centuries after Galileo first peered at the moons of Jupiter, mankind is once again looking to the heavens in search of answers rather than conquests. As the poet saw the world in a grain of sand, so the astronomer now searches for its secrets in a pinprick of ancient light.

*(editorial as appeared in **THE TIMES**, August 4, 1993)*

Project Scientist's Outlook

The Gemini Science Committee met in Tucson during a few hot days in July. Two key statements came out of that meeting:

1. The GSC, in consultation with the Project, recommends that the Nasmyth platform be eliminated from the baseline telescope design, with the understanding that:

(a) Full advantage be taken of removing the Nasmyth to improve the ability of the telescope to meet the Cassegrain image quality requirements; to increase the available Cassegrain cluster mass; to permit a full complement of infrared and/or optical instrumentation to be mounted; and that this increased mass be allowed for in the design of the mirror cell as well as in the tracking and pointing systems.

(b) It becomes a Science Requirement that the HROS be able to work at the Cassegrain focus at a resolving power of 120,000, with a stability that shall be no worse than 0.1 resolution elements/hour (exact specifications subject to confirmation or revision by the HROS Instrument Working Group).

(c) Provision is made for a thermally and mechanically stable "high-resolution laboratory" in the telescope pier area.

(d) The project initiate a study of a fibre feed to the HROS when mounted in the pier laboratory.

(e) The project investigate the feasibility of directly relaying a one-arcminute field to the pier laboratory.

With these conditions, the GSC will recommend that the Science Requirement Document be modified accordingly.

2. The Project Scientist is asked to set up a scientific working group in preparation for the November primary mirror PDR. This GSC working group will review the scientific requirements and predicted performance of the system being proposed by the Project Team. This will be a thorough investigation, in consultation with the Project Team, and will lead to a final report to the GSC and Gemini Director prior to the November primary mirror PDR. The charge of this committee is as follows:

(a) Review performance criteria for the PDR consistent with the Science Requirements and, if necessary, propose amendments, in consultation with the GSC, to the Gemini Director.

(b) Review the environment in which the mirror is required to perform.

(c) Review, at the system level, the quantitative performance description of the primary mirror.

(d) Discuss with the Project Team areas of concern and propose or assess possible solutions.

(e) Produce a written assessment for the GSC and Gemini Director, prior to November 1, of the extent to which the primary mirror system meets the requirements outlined above.

The advantages of designing the telescope without Nasmyth foci are discussed later on by Keith Raybould, Manager of the Telescope Structure, Building/Enclosure-Group. So I would like to try and put the Primary mirror PDR in perspective with the rest of the project and outline the types of issues that will have to be addressed in November.

A Gemini Telescope Is Not Just a Primary Mirror

The key science requirement for the Gemini Project is that the telescopes — ***in the absence of an atmosphere*** — should not contribute to the 2.2 micron 50% encircled energy diameter delivered to the focal plane more than 0.1 arcseconds over an hour of integration in up to 70th percentile winds. In what I will call a "classical" optical-infrared telescope the optical alignment is usually maintained passively and look up tables provide pointing and tracking information to a model which drives the telescope (or mount). Errors from wind buffeting or hysteresis in the telescope structure are slowly corrected by monitoring a star using an auto-guider as in ***Figure 1***.

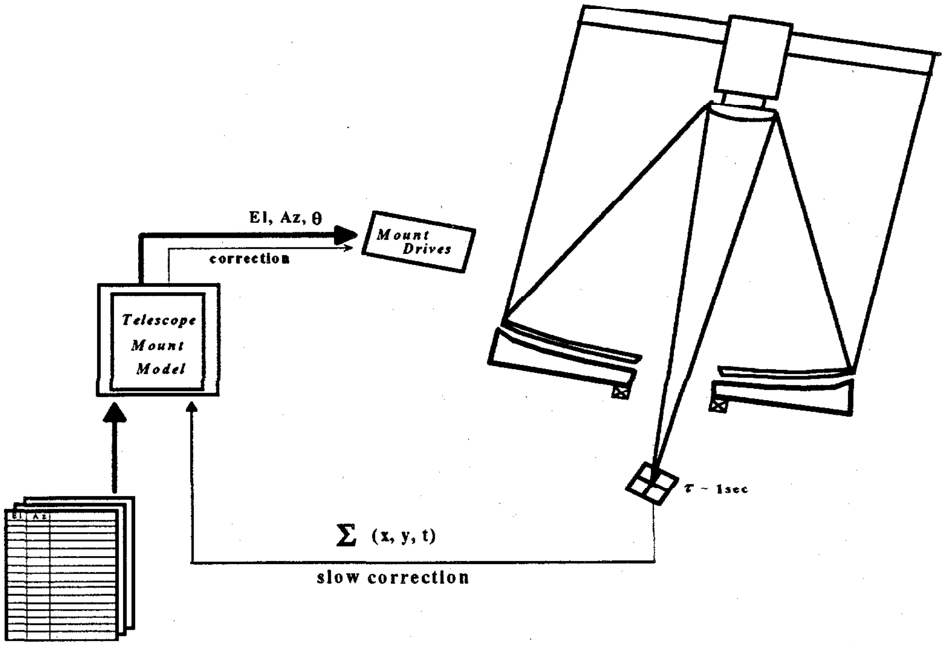

Figure 1. A classical "open loop" telescope control system. Gemini will not be using this approach.

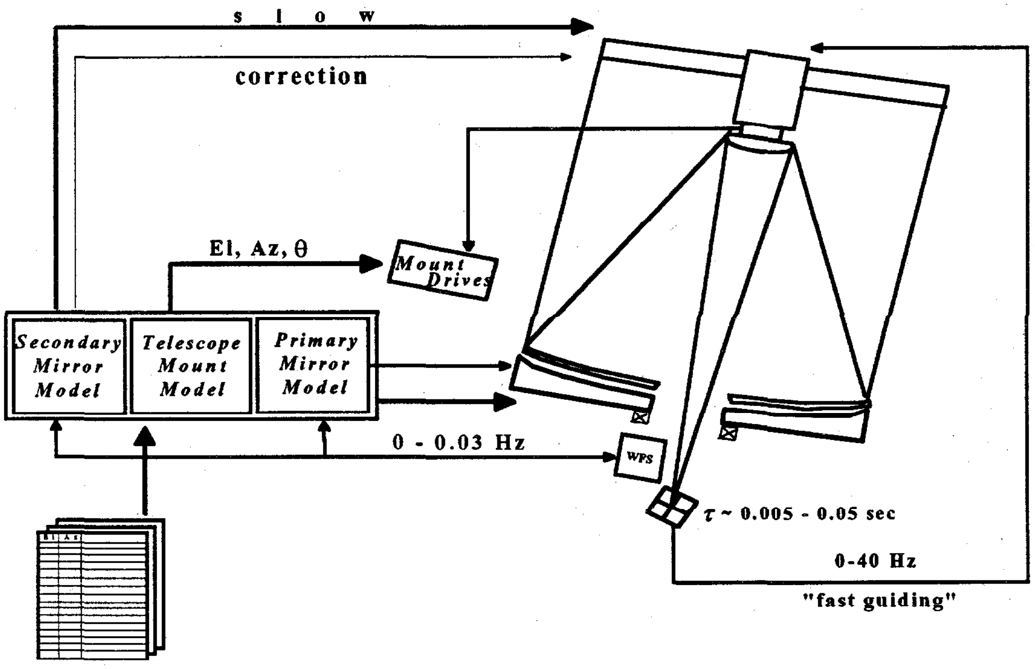

Figure 2. The "Active Telescope" control loops needed for near-diffraction limited operation.

The Gemini telescopes have to be near diffraction limited in the infrared (or contribute no more than ~ 0.2 arcsecond to images in the optical). On windy sites like Mauna Kea and Cerro Pachon the telescopes have to be "active" in order to achieve this. The entire facility must therefore be considered as a system, which includes not just the telescope, but enclosure, acquisition, and guiding philosophies, as well as the operating and observing models of the instruments.

For example, imagine you are on a Gemini Telescope and are trying to do multi-object spectroscopy with 0.3 arcsecond slits across a 2 arcminute field in a 25 mile per hour wind. For a near diffraction limited 8m telescope, in the best seeing conditions on Mauna Kea, roughly 70% of the energy from a point source at 2.2 microns will go down a 0.3 arcsecond slit.

The telescope you will be using will look something like ***Figure 2***. First, the F/16 secondary must be aligned to the optical axis to 33 microns, and the spacing between the primary and secondary has to be held to 2.4 microns. Serrurier trusses cannot be relied on to passively provide this level of alignment, therefore, like many radio and submillimeter telescopes, the secondary mirror must be continually and ***actively*** repositioned as the telescope tracks across the sky. Second, to stabilize the objects on the slits to the required precision (0.02 - 0.03 arcseconds) wind buffeting and atmospheric tip-tilt (at IR wavelengths) will need to be taken out by articulating the secondary mirror. So a guide star must be selected, of appropriate brightness, to be in range of a guide sensor, which in turn must be read out at the optimum frequency to ensure the control system can measure the wind bounce with sufficient accuracy to apply a meaningful tip-tilt correction back to the secondary mirror. Third, the enclosure wind screens must be set so that any telescope buffeting can be corrected by the mount drives, or kept within range of the rapid secondary mirror tip/tilt corrections, so no noticeable coma is introduced into the stabilized images. And finally, the primary mirror in combination with the secondary mirror has to deliver a near perfect wavefront to the focal plane, which at these levels means both mirror surfaces have to be held to a common frame of reference to 50-60nm in the presence of a changing gravity vector, changing temperatures, and wind. A wavefront sensor in the focal plane monitoring a star can ***actively*** control the primary mirror figure to correct for any combined errors from the two mirrors. However, this is possible only if all the thermally induced seeing effects from the telescope structure, enclosure, and mirror surfaces have been reduced to negligible levels, which will depend again on the setting chosen for the enclosure wind screens.

So in setting up for this observation, you, or the telescope operator, will have to find at least two guide stars. The first is for the fast tip-tilt sensor, which will have to be positioned within the isokinetic patch and will probably be within the field of view of your instrument. The second is for the wavefront sensing. The combination of the two is required to monitor the Cassegrain field rotation and plate scale stability. The telescope must maintain the positions of all the objects to 0.03 arcseconds on the 0.3 arcsecond slits for the duration of your integration.

How do we optimize all these facets of the Gemini System and what is the role of the primary mirror system in the realization of this kind of scientific performance on Mauna Kea and Cerro Pachon?

The Gemini Error Budget

The Gemini image quality requirement — which can be expressed more precisely as $0.1 \times \sec^{3/5} Z$ arcseconds where Z is the telescope zenith angle — has to encompass all optical effects, including diffraction, telescope tracking errors and any thermally induced, or ***self-induced seeing***. Self-induced seeing is defined to be seeing caused by temperature differentials within the enclosure or across the telescope structure, mirror cell, or mirror surfaces (mirror seeing). Within the project we track all the competing elements that can degrade our final image quality using an error budget. In this approach, ***all the individual contributions to the error budget have to be quantified***, which is where the majority of the project's analytical capabilities have been directed in the last year. An example of part of our 2.2 micron error budget is shown in ***Figure 3***. This example tracks the contributions to the 50% encircled energy diameter at 2.2 microns, which right at the top has the 0.1 arcsecond science requirement. There are similar error budgets for the 85% encircled energy diameter, 10 micron image quality, and optical and UV image qualities for both the F/16 and F/6 Gemini configurations.

This top level requirement in this example is broken down into three sections — static image quality, dynamic image quality and image smear — all of which are assumed to contribute to the final image quality through a quadratic sum. Taking these in reverse order;

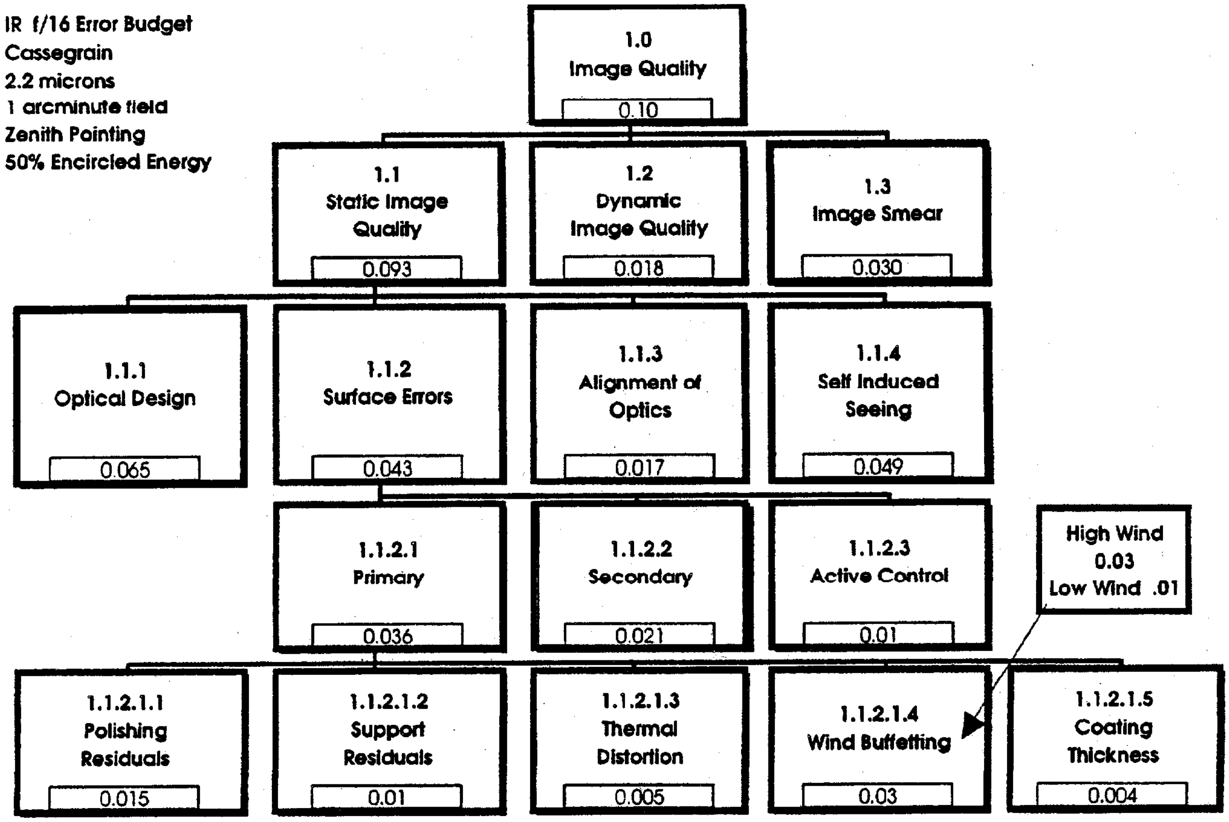

Figure 3. Part of the Gemini F/16 2.2-micron 50% encircled energy error budget. This example traces the error contributions from the primary mirror support system up to the top level science requirement or 0.1 arcseconds.

Image smear — at 0.03 arcseconds, is the time averaged "smear" that can be tolerated in an image in the focal plane during an hour of integration. This is the telescope guiding requirement. Within the error budget this box is broken down into yet another 13 elements which includes servo errors and guide sensor read noise.

Dynamic image quality — all the residual optical errors we may get from trying to correct the telescope wind buffeting have to be contained within 0.018 arcseconds. For example, tipping the secondary to keep the image stationary in the focal plane in a gust of wind or to correct for residual telescope vibrations will introduce coma into the final image.

Static image quality — this element includes all the 'traditional' optical effects such as imperfect design, static alignment errors, field correctors and diffraction — which at 0.065 arcseconds is a significant fraction of the 2.2-micron error budget. Here also is where the project has to account for self induced seeing effects and all the primary mirror support issues, including primary mirror wind buffeting.

The Gemini Primary Mirror

Within this error budget approach it can be seen that the primary mirror system, ignoring mirror seeing for the moment, is constrained to contribute no more than 0.036 arcseconds to the overall 0.1 arcsecond image quality requirement. In the last issue of the Gemini Newsletter I discussed the type of support philosophy we are adopting for our meniscus mirrors as well as the actuator accuracies and the polishing requirements to meet this part of the Gemini error budget. In this issue I will pick two other areas of concern, primary mirror wind buffeting and mirror seeing.

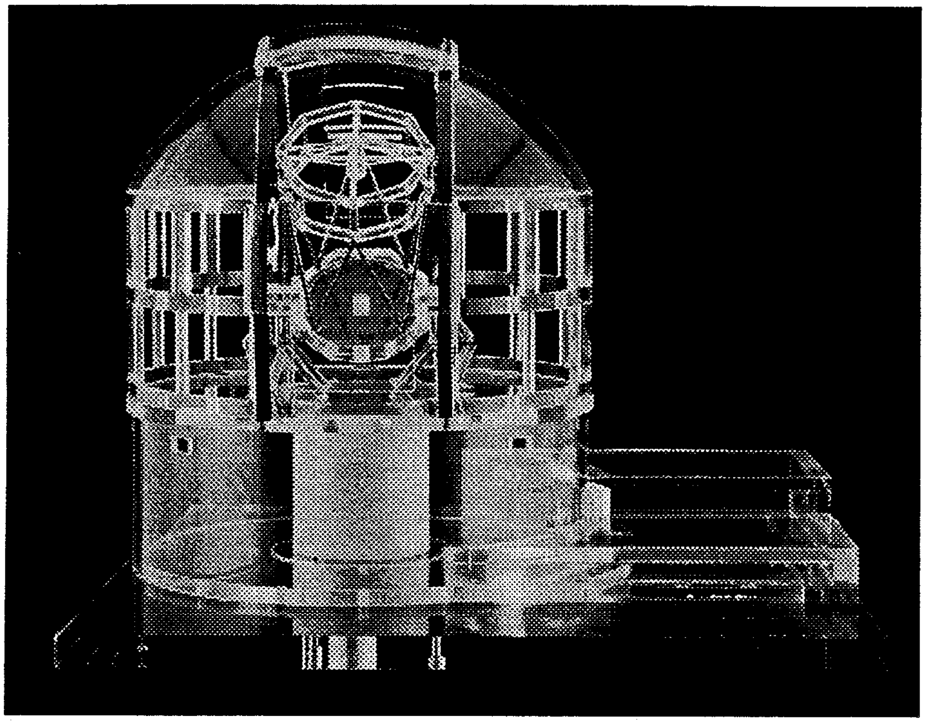

Figure 4. A photograph of the water tunnel model of the Gemini enclosure and telescope. The water tunnel tests are being used to determine wind attenuation across the telescope structure (for wind buffeting) and enclosure and primary mirror flushing efficencies (for enclosure and mirror seeing) as a function of shutter geometry and telescope orientation.

1. Wind Buffeting — By looking along the bottom row of Figure 3 it is apparent that wind buffeting of the primary mirror is one of the largest components in this part of the error budget. A lot of work is going on to try to understand the wind buffeting spectrum and the effects of the enclosure on this spectrum using a mixture of analytical and experimental (i.e., water tunnel) techniques (see ***Figure 4***). These pressure variations can then be applied to finite element models of the system and then the resulting mirror surface can be ray-traced to assess the resulting image quality. The quantitative effect of wind buffeting of the Gemini primary mirrors on their support systems, and the associated uncertainties, is one of the key issues that will have to be addressed by the PDR Science Working Group and the Project. For example:

What are the expected rms pressure variations on the mirror that the support system has to resist; what are the timescales of these variations?

How do these effects transfer to image quality degradation in the focal plane?

How are these effects modified by the Gemini enclosure concept?

What are the requirements on the active control system? For example, what are the spatial and temporal scales that will require correction using a wavefront sensor?

What are the limitations to this type of correction due to atmospheric effects and stellar magnitude limits?

The effect on the primary mirror is not the only reason we are putting so much work into understanding wind buffeting and how to correct it. Equally important to the final image quality in the focal plane, as discussed above, is the combined effect of the dynamic image quality (0.018 arcseconds) and the image smear (0.03 arcseconds). ***Irrespective of the primary mirror***, for the 50% encircled energy diameter at 2.2 microns, the effects of telescope wind bounce are expected to be of comparable magnitude to primary mirror wind buffeting errors.

$$(\text{primary mirror wind buffeting errors})^2 \sim (\text{dynamic image quality errors})^2 + (\text{image smear errors})^2$$

2. Primary Mirror Seeing — Self induced seeing effects account for nearly 25% of the total 2.2 micron error budget (assuming quadrature addition) accounting for 0.049 arcseconds. As many observers have experienced, after optical effects, the intrinsic atmospheric seeing at any telescope can be degraded by:

- The enclosure or dome internal temperature,
- The telescope structure temperature,
- The secondary mirror temperature,
- The primary mirror temperature; and
- Heat sources in instruments, actuators, etc.

Significant temperature differences between any of these surfaces and the ambient air temperature can set up convective eddies in the light path. None of these effects can be considered in isolation; the whole telescope and enclosure is again a single (thermal) system. After all, in front of the primary mirror is the support structure for the secondary, which even after considerable optimization, contains 14 tons of steel and has substantial thermal capacity, as does the enclosure and the air within the enclosure. Fortunately, steel also has high thermal conduction, which means it can quickly be brought into thermal equilibrium with the surrounding air by drawing this air through the structure. Likewise, the entire enclosure volume must be flushed using the wind or active ventilation, which in the Gemini design also means the primary mirror will be efficiently flushed with ambient air.

Like wind buffeting control, the overall thermal control strategy is again a multifaceted approach:

(1) Pre-cool the primary to below nighttime ambient.

(2) Use passive and active ventilation to stabilize the internal enclosure temperature.

(3) Maintain the temperature of the mirror cell and telescope structure close to the ambient temperature — fortunately steel has 15-20 times the thermal diffusivity of glass.

(4) Control the passive and active enclosure ventilation to flush the primary mirror surface.

(5) Investigate active thermal control of the primary mirror surface.

(6) Utilize the significant radiative cooling of the secondary (~ 250 Watts) and the superb thermal diffusivity of silicon carbide (six times that of steel) to control the secondary mirror surface temperature close to ambient.

This description is, however, not very quantitative and much detailed modeling has been undertaken (and is currently underway, see Figure 4) to estimate the relative contributions of these various effects to the final infrared and optical image qualities. The types of questions that the project and the PDR Science working group will have to address in detail are:

What are the typical nightly ambient conditions seen by the telescope structure, enclosure and primary mirror surface on Mauna Kea and Cerro Pachon, and what strategies are available to bring all these elements to near thermal equilibrium with the ambient air?

Racine (Ref. 1) and Iye (Ref. 2), ***Figure 5****, suggest that "mirror seeing" at optical wavelengths may not be sensitive to mirror surface temperatures that are slightly less than ambient. What is the quantitative relationship between the temperature difference between mirror surface temperature and ambient air to the infrared "mirror seeing"?*

Flushing the primary mirror can significantly reduce mirror seeing. What flow rates does the primary mirror experience when we are flushing the enclosure with wind to reduce 'dome seeing'?

In low winds the wind buffeting elements of the Gemini error budget will be negligible (15% of the time on Mauna Kea winds are below 2m/s). In high winds the self-induced seeing effects will probably be small. With this range of conditions, are the proposed thermal control strategies compatible with the rest of the Gemini error budget in achieving the required 2.2 micron image quality?

— ***Matt Mountain***
Project Scientist

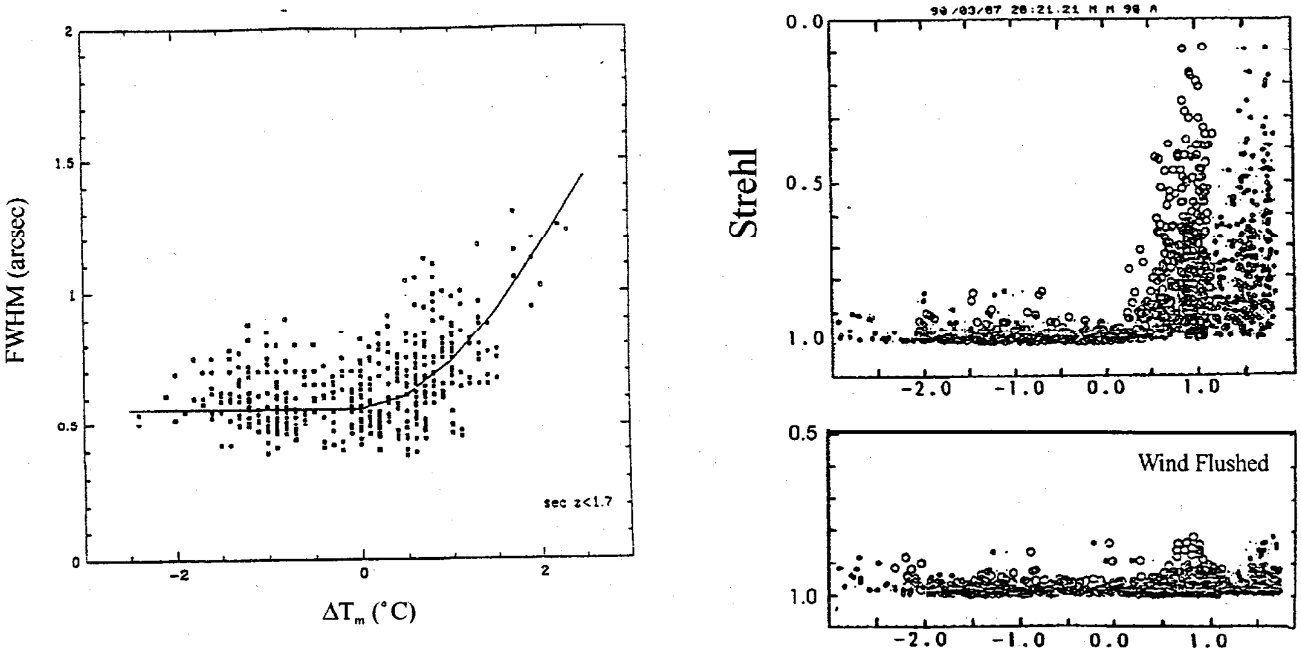

Figure 5. Mirror seeing data taken from Racine (Ref. 1) and Iye (Ref. 2). Racine plots FWHM (arcseconds) as a function of mirror temperature difference from ambient taken from CFHT measurements. Iye uses Strehl Ratio (plotted 1.0 - 0.0) as a function of mirror temperature difference from ambient found during laboratory experiments using a 62 cm mirror and a Shack-Hartmann sensor. Both data sets suggest weak dependence on visible seeing when the mirrors are cooler than ambient air.

References:

1. Racine, *et al.*, "Mirror, Dome and Natural Seeing at CFHT", The Astronomical Society of the Pacific, September 1991.

2. Iye, *et al.*, "Evaluation of Seeing on a 62-CM Mirror", The Astronomical Society of the Pacific, July 1991.

GEMINI GROUP UPDATES

Telescope Structure, Building/Enclosure Group

Telescope Structure

Following extensive discussions, meetings and reviews, a decision has been taken by the Gemini Science Committee to remove the Nasmyth foci from the telescope design. Consequently, approximately 6,000 kg of non-structural steel has been removed from the telescope top-end, and the primary mirror pole moved from a position 0.5m below the altitude axis to a position above the axis. This has several effects, many of them leading to improved image quality:

- The reduced mass above the primary mirror will reduce self-induced seeing that results from heat being released into the telescope beam from structure that is at a different temperature from the ambient air.
- The telescope natural frequencies have been increased due to the mass reduction of the telescope tube.
- By allowing the primary mirror pole to be moved higher, we can now allow more mass to be allocated for the primary mirror cell. This has improved the stiffness properties of the primary mirror cell and its support.
- For reasons similar to those stated above, we can now allow a greater mass at Cassegrain. This has improved the versatility of the Cassegrain cluster.
- The altitude cable wrap design has been improved due to the increased space available.
- We are planning to pass ambient air through the telescope tube structure to drive its temperature towards the ambient air temperature. As we now do not need to provide a clear aperture for the Nasmyth beam, bringing the air through the altitude trunnions will be greatly simplified.

As a result of these changes, Mark Warner is updating the telescope Design Requirements Document, Mike Sheehan is developing a new system level Finite Element Model of the telescope, and Peter Hatton is updating the telescope assembly drawings.

Enclosure, Support Facility and Site Plan Design

A Preliminary Design Review was held in Tucson on May 17 and 18 and represented a major milestone in the enclosure, support facility and site plan schedule. The review was chaired by Tony Abraham (KPNO). Members of the Committee included Fred Gillett (US project scientist), Walter Grundman (DAO), Matt Mountain (Gemini Project Scientist), Donald Pettie (ROE), Steve Shectman (Magellan Project), and Jerry Sovka (CFHT). Andy Woodsworth (DAO), Larry Daggert (NOAO), and Mike Morris (RAL) attended as observers representing the Canadian, US and UK Gemini Project Offices. Committee members unable to attend include Dan Blanco (WIYN), Hans Boesgaard (Keck) and Neil Parker (RGO).

Prior to the PDR, the design was formally presented to the Gemini Science Committee on March 25 in Victoria. This was followed by a meeting between the National Project Scientists (Roger Davies, Fred Gillett, Richard Green, Gordon Walker) and the enclosure group in Tucson, where we were able to discuss the enclosure design in more detail. Based on the meetings, the Project Scientists prepared a report which was presented at the PDR as the formal scientists' review of the enclosure, support facility and site plan.

Other progress:

- Steve Hardash and Gordon Pentland have completed the Design Requirements Document for the Support Facility. The document has been passed to our design Contractors, M3 Engineering, for estimating construction costs prior to producing the Construction Documents for Mauna Kea.
- We have received the schematics from our Contractor, W Oki, for relocating the utilities that currently cross our site on Mauna Kea. The drawings have been passed to Mauna Kea Observatories, IFA, Helco and Hawaiian

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Telephone for comment prior to producing the Construction Documents.

- We have received comments from the Institute for Astronomy Hawaii (IFA) on our Conservation District Use Application (CDUA). We have incorporated their comments and returned the CDUA to IFA for their final review. IFA is planning to submit our CDUA to the Department of Land and Natural Resources (DLNR) in August. This should allow the project to start work on Mauna Kea in June 1994.
- Paul Gillett has written specifications for the Commercial Power and Road Construction for Cerro Pachon. Enrique Figueroa of CTIO is preparing the documents for bidding the design for this Construction.
- Ruth Kneale has completed the site testing of the Prime site on Cerro Pachon. The results, together with the numerical modeling done by Dr. DeYoung of KPNO, confirm that the height we have selected for the telescope altitude axis locates the primary mirror above the turbulent boundary layer.
- Bob Ford has completed the thermal model of the enclosure and has run many cases to predict the performance under different conditions.
- The first round of water tunnel tests has been completed at the University of Washington. The tests have allowed us to determine the most efficient placement of the side wall vents. In addition, flushing rates under different orientations of the shutter to the wind have been measured, and these have been used directly in Bob Ford's thermal model.

— Keith Raybould
Telescope Structure, Building/Enclosure Manager

Optics Group

The Optics Group has grown considerably this year — not by hiring new employees, but by starting to take advantage of the experienced personnel available in our partner countries. We have been busy setting up studies and work packages in the UK and Canada. We expect this to have an immediate effect in leveraging our capabilities for design and analysis, and these work packages play a major role in our preparations for the Preliminary Design Review (PDR) this fall.

Primary Mirror Assembly

We have set up three related work packages in the UK for design of the primary mirror assembly. These are for: (1) mirror support design, (2) thermal control system design, and (3) mirror cell structural design. The first two work packages have already progressed to the point that prototypes have been built and are now being tested. Getting these work packages started up so quickly has taken a lot of effort on both sides of the Atlantic, and I would particularly like to thank Eric Hansen, Eugene Huang and Ken Krohn of the Tucson staff, and Justin Greenhalgh, Jim Lidbury, Brian Mack and Gary Rae of SERC for their hard work and cooperation.

We are currently in the middle of the process of selecting a polisher for the primary mirror. A preproposal conference was held at Corning's Canton, NY plant on June 17 to acquaint the interested bidders with mirror transportation issues. Proposals were due August 6, and we have, in fact, received proposals from a number of well-qualified bidders. Now we have several weeks of proposal evaluation work ahead of us.

The day before the polishing preproposal conference, we had a quarterly review meeting with Corning. They are making good progress with their ULE^{TM} glass fabrication. The quality of the glass they are currently producing is superb — the coefficient of thermal expansion is coming out significantly better than the 0 ± 15 parts per billion we specified, and the number of bubbles and inclusions per boule is orders of magnitude lower than specified.

Eugene Huang has completed a conceptual design study for the mirror cell structure. The goal of this study was to reduce the gravity deformation of the mirror cell caused by changes in telescope orientation. This will be important if we use an over-constrained defining system to stiffen the mirror against wind buffeting. Working with Mike Sheehan of the Telescope/Enclosure Group, Eugene developed an improved connection between the telescope center section and the mirror cell, with the result that the flexure of the cell was reduced by a factor of three, and the effect on the mirror was reduced by a factor of five. Preliminary analysis results indicate this will enable the design to meet the tight primary mirror error budget.

Optics Group staff participated in a joint Gemini/ESO VLT meeting in Garching, Germany, on July 29 and 30. The design challenges faced by the two projects are very similar, and we have found that we can learn a lot from each other. A number of features in the Gemini primary mirror cell design are derived from designs by ESO, and we are gratified to see that the VLT project is now adopting some design approaches developed by Gemini. We are also collaborating with the Subaru project, with equally productive results.

— ***Larry Stepp***
Optics Manager

Controls Group

System Design Review

At the current time, potential reviewers are being contacted to determine their interest and availability. The purpose of the review (scheduled for 9/28/93 through 10/1/93) is to verify and validate the group's proposed standards, guidelines, plans, designs and work package descriptions — to ensure that the delivered systems meet the Science Requirements while being on budget and on schedule. We need to make sure that the work packages are sufficiently decoupled and their interfaces specified in sufficient detail that we can start some of the work packages without having to worry about the impact of future packages.

Workshop on Control Software

The Software and Controls Group held its first workshop (July 19-23) on the software components that have been proposed as suitable tools in the development of control software. These tools include (among others):

- VxWorks
- EPICS
- PV-Wave
- Khoros
- TCL
- ADAM

The purpose of the workshop was to acquaint the work package developers with this software and to acquire a consensus on the suitability of these tools for use with the Gemini project. Jeremy Bailey is providing a report on the workshop to the Controls group.

Electronic Design Specification

ASA Automation, under contract to Gemini, has prepared a draft specification for Gemini electronics that is being circulated for comment among the Gemini working groups. Once initial comments have been incorporated, this document will be made available to any interested parties. The purpose of this document is to provide a common framework for all electronics produced for Gemini.

Electronic Access to Documents

The Gemini Controls Group is working with NOAO to establish more convenient access to Gemini documents through the use of a *Gopher* server. This server provides a convenient menu-driven interface into the Gemini project reports from sites across the Internet and is in addition to the ftp access that has been available. Expect a more complete announcement on how to access this gopher server to appear in the gemini ftp area:

gemini.noao.edu:~ftp/gemini

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after testing is complete.

Khoros and LACE

(S. Wampler)

A Graphical User Interface (GUI) has been developed using Khoros for the LACE program. LACE is a program for the simulation and analysis of adaptive optics systems that was written as part of the STARFIRE project at Philips Laboratories in Albuquerque, New Mexico. The interface allows the user to quickly enter, review, and change the parameters to LACE. A second GUI interface is planned to graphically display intermediate results from LACE. This will provide the user with a quick check facility before invoking the rather lengthy computations involved with a full adaptive optics analysis. The system is broken into separate modules that can be run either as standalone processes under Unix, or from within the Cantata visual programming environment available with Khoros.

Operational Concept Definition

(S Wampler)

The Gemini Operational Concept Definition is approaching draft three. This document provides a conceptual overview of the functioning of the Gemini telescope systems during typical operation, providing a general "feel" for telescope behavior and use. Current efforts are focused on incorporating new material and rewriting to integrate material from numerous sources into a more homogeneous form.

Software Design Description

(S Wampler)

The Software Design Description provides the framework for the Gemini control systems design structure. Based on Ward and Mellor strategies for the design of real-time systems, the SDD provides developers with a reference that illustrates how the various system components interact and the functional role of each component as part of an integrated whole. This design structure is presented using several different 'views', corresponding to the varied requirements found in software development and maintenance.

One presentation found in more conventional SDDs that is omitted from the Gemini SDD is the detailed design view. Rather than impose a strictly defined and detailed design on the groups developing work packages, the software and controls group plans to work with these groups to develop specific design details for each work package. The full system design description for Gemini telescope control can thus be viewed as the master SDD in conjunction with the design work done for each individual work package.

Tracking Error Budget

(M. Burns)

We now have a tracking error budget where the wind shake and atmospheric tilt components are based on a bottom-up analysis. The error budget for non-linear effects remains a top-down analysis and is the topic of current work.

Baseline Telescope Simulation

(M. Burns)

The baseline simulation of the entire dynamical model of the telescope has been created in Matlab, debugged, and tested. This model is based on finite element analysis of the telescope structures as well as realistic models of the telescope drives, encoders, and bearings. It now runs well, although slowly: a 10 second simulation-time run takes around 12 minutes of real time. It is expected that the newly acquired Matlab upgrade will provide a factor of 2-10 improvement in performance once the sparse matrix operations are incorporated into the model.

Kaman Aerospace continues to support development of the model with their knowledge of non-linear effects of servo motors and bearings.

EPICS

(P. McGehee)

The use of the EPICS (Experimental Physics and Control System) based encoder lab testbed continued throughout this quarter. Several demonstrations of the system were given to Gemini and to NOAO/KPNO staff, and a full presentation is planned for the Gemini Controls Workshop.

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Work Package Descriptions

(P. McGehee)

Definitions of the following work packages were completed during this quarter:

- Enclosure
- Telescope Mount
- Primary Mirror Support
- Primary Mirror Thermal Control
- Instrument Control Infrastructure
- Secondary Mirror Control

In each case, the definition consists of an overview document, a description of the expected functionality of the system, Ward/Mellor essential model diagrams (generated using TSEE/EMB), and relationship diagrams for both hardware and software components. As these documents are finished they will become available via ftp and gopher.

Software Programming Standards

(P McGehee)

The Gemini Controls Group has developed a Software Programming Standards document for use by all Gemini development sites. This standard attempts to establish coding standards which minimize problems with interfacing, maintainability, and enforcing the Gemini Software Management, Configuration Control, and Quality Assurance Plans. Some of the issues covered by the Programming Standards include language selection, coding practices, source code format, naming conventions, directory structures, and makefile standards. Examples of recommended practices include the use of the ANSI C language and the IMAKE system for makefiles.

Software Configuration Plan

(P McGehee and S Wampler)

Given the large amount of software expected to be needed in Gemini telescope control and operation, it is important that some means of maintaining and managing software be developed. The Software Configuration Control Plan document describes the Software and Controls Group's strategy for managing this mass of software. The plan represents a balance between the needs for tight management of software configurations and the need for development groups to operate autonomously.

The current version of the SCCP is available via ftp and gopher.

— ***Rick McGonegal***
Controls Manager

GEMINI GROUP UPDATES

Instrumentation Group

Adaptive Optics Modeling

A sampling of preliminary results from an analysis done for Gemini by Brent Ellerbroek at Starfire Optical Range is presented here. The modeling done to date has been very valuable in assessing the performance of various adaptive optics systems with natural and laser guide stars.

His analysis shows the performance of tip/tilt systems as well as of natural and laser guide star systems for two different models. These models were:

— A 4 X 4 subaperture grid pattern (2 m subaperture), 25 zonal actuators
— A 6 X 6 subaperture grid pattern (1.33 m subaperture), 49 zonal actuators

The first model is roughly equivalent to a 7th order correction. The second is equivalent to a 9th order system.

The initial system model uses a Hartmann-Shack wavefront sensor and a continuous facesheet deformable mirror with a linear spline influence function conjugate to the primary mirror. The reconstructor is a minimal variance reconstructor with closed loop constraints. In the modeling, control bandwidths were selected to optimize the on-axis Strehl ratio. The performance was modeled at 2.2 and 0.7 microns. Of greatest interest was the encircled energy within 0.1 and 0.25 arcseconds, as a function of guide star offset angle.

For these calculations, we adopted an $r_0 = 22.5$, for the average seeing case, and an $r_0 = 40.9$ cm, for the good seeing case (r_0 being measured at 0.5 microns). These values are identical to the numbers used by the Gemini Adaptive Optics Working Group in formulating their recommendations. The calculations show the effect of separations between natural guide star and object (for the natural guide star case) or the effect of the separation of the tip/tilt guide star and object out to 90 " (in the laser guide star case). In the laser guide star case, it is assumed that the laser guide star is coincident with the science object.

A sample of the results for the natural guide star case are shown in ***Figures 6-8***.

—David J. Robertson and Stephen M. Pompea
Gemini Instrumentation Group

Infrared Spectroscopy Working Group Meeting at UCLA

The 3rd meeting of the Infrared Spectroscopy Working Group was held at UCLA on July 21, 1993. Present were: T. Davidge, J. Elias, T. Geballe, P. Harvey, P. Roche (Chair), M. Mountain, and S. Pompea. Also B. Jones and A. Tokunaga were present for the first half.

Actions from the 2nd meeting of the IRSWG included:

- The mid-infrared science case for multi-object science was presented to the GSC.
- The US project office circulated a letter to the US community soliciting letters of interest from groups that would like to participate in building IR instruments.
- A note on the views of the IRSWG concerning guaranteed time in return for instruments was circulated and discussed widely, and it seems that there is more support than appeared at the last meeting.
- The implementation of the MgF_2 polarizing prism in IRIS at the AAT was described.
- Collection of data on the emissivity and transmission of lens and window materials is continuing.
- Collection of instrument specifications and predicted performance for the VLT, Keck and Subaru telescopes is continuing. The VLT IR instruments are summarized in a preprint from the Orlando SPIE meeting, and the other telescope instruments were described at UCLA.

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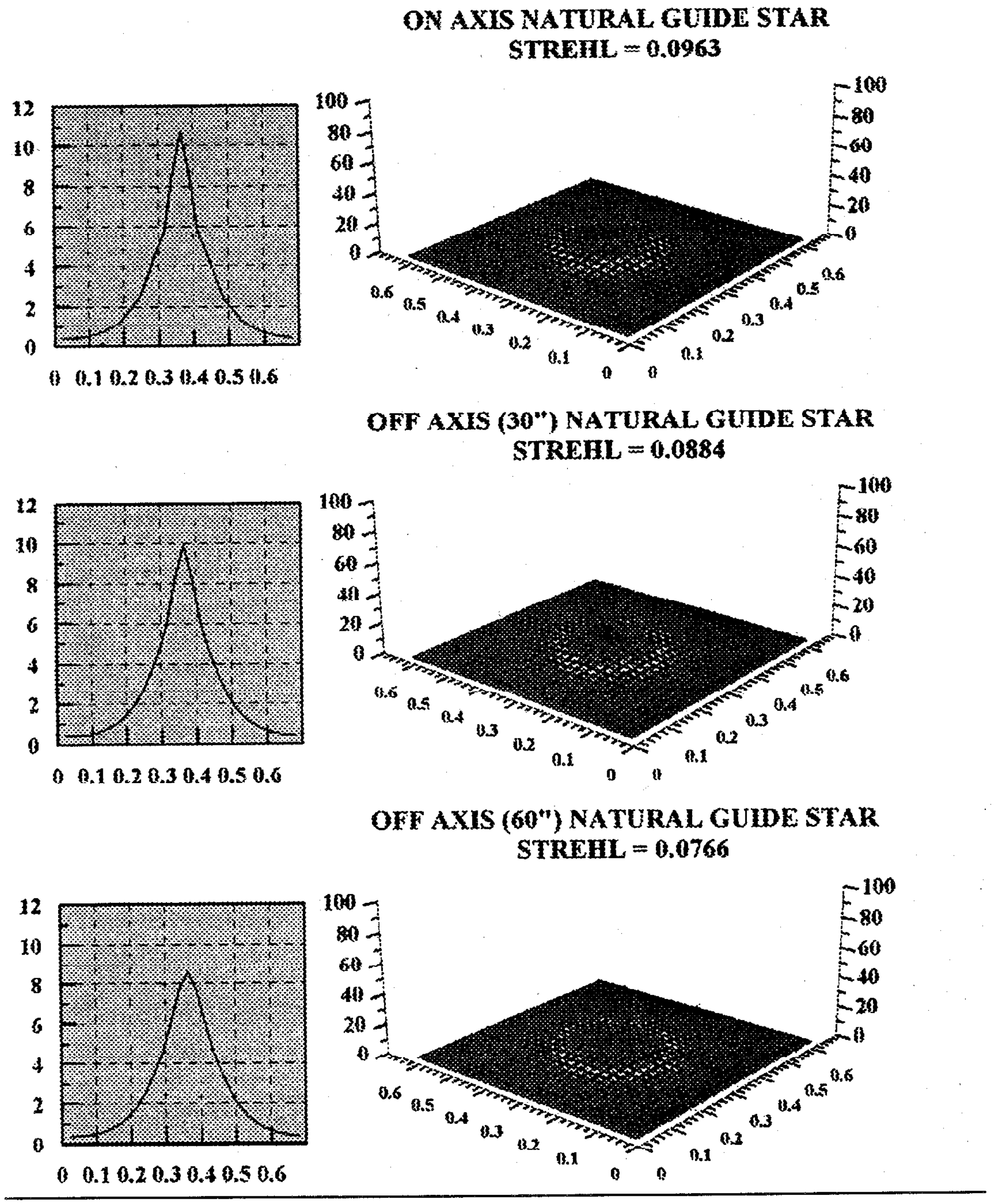
2.2 µm TIP/TILT **r_o = 22.5 cm @ 0.5 µm**


ON AXIS NATURAL GUIDE STAR
STREHL = 0.0963

OFF AXIS (30") NATURAL GUIDE STAR
STREHL = 0.0884

OFF AXIS (60") NATURAL GUIDE STAR
STREHL = 0.0766

Figure 6. Adaptive optics performance modeled by B. Ellerbroek of Starfire Optical Range.

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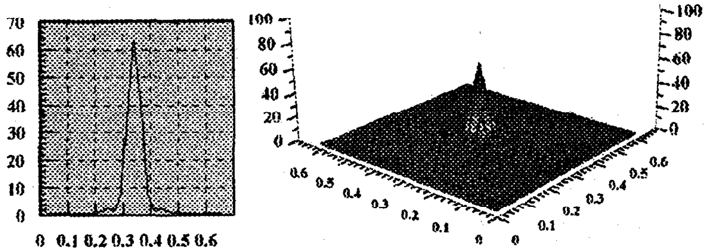
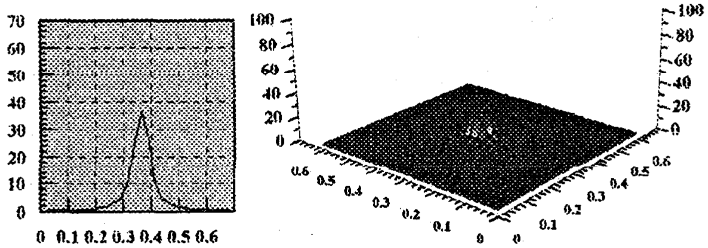
2.2 µm D/d = 4 **r_o = 22.5 cm @ 0.5 µm**

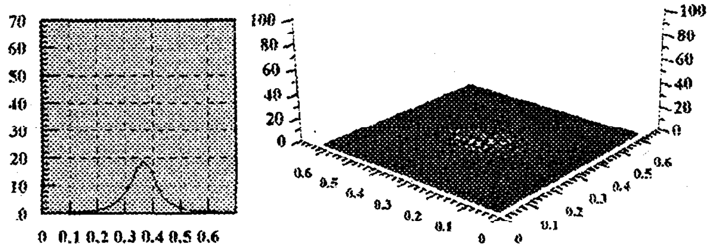
ON AXIS NATURAL GUIDE STAR
STREHL = 0.5700



OFF AXIS (30") NATURAL GUIDE STAR
STREHL = 0.3306



OFF AXIS (60") NATURAL GUIDE STAR
STREHL = 0.1690



OFF AXIS (90") NATURAL GUIDE STAR
STREHL = 0.1090

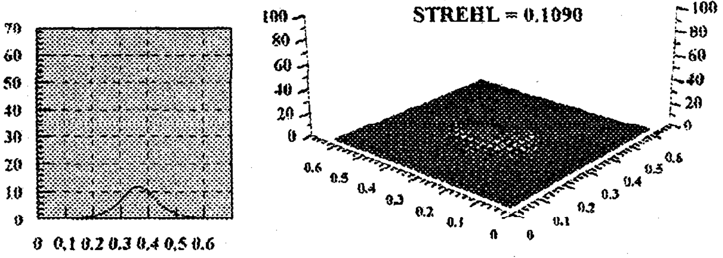
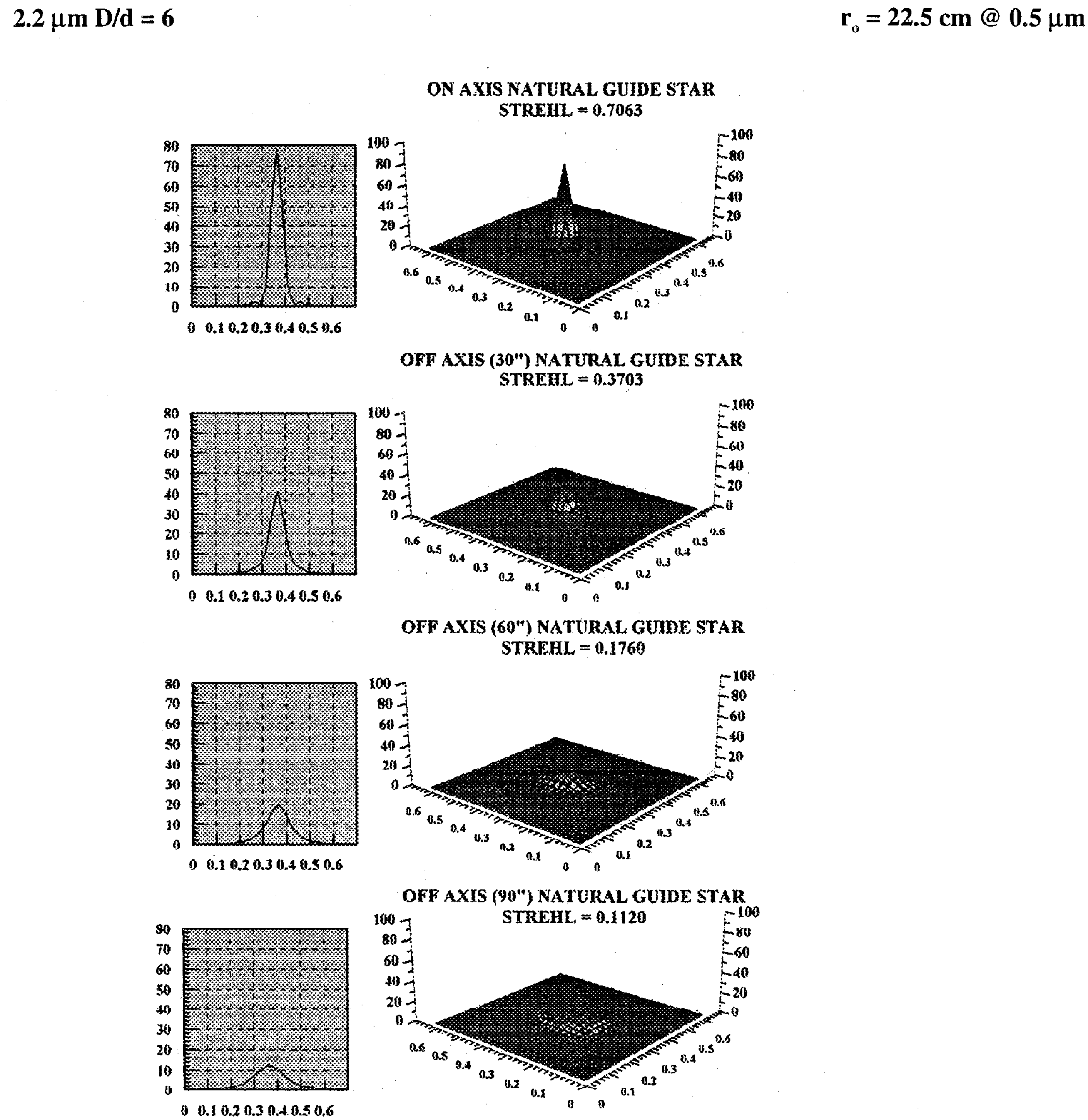


Figure 7. Adaptive optics performance modeled by B. Ellerbroek of Starfire Optical Range.

GEMINI GROUP UPDATES



2.2 µm D/d = 6

r_0 = 22.5 cm @ 0.5 µm

ON AXIS NATURAL GUIDE STAR
STREHL = 0.7063

OFF AXIS (30") NATURAL GUIDE STAR
STREHL = 0.3703

OFF AXIS (60") NATURAL GUIDE STAR
STREHL = 0.1760

OFF AXIS (90") NATURAL GUIDE STAR
STREHL = 0.1120

Figure 8. Adaptive optics performance modeled by B. Ellerbroek of Starfire Optical Range.

GEMINI GROUP UPDATES

The group discussed a number of tasks given by the Gemini Science Committee at their recent meeting. These tasks included the following actions:

- Compare the specifications and performance of Gemini instruments with those of other facilities
- Investigate the implementation of multi-slit capabilities
- Develop an operational concept model for the IR spectrometers
- Provide a final report to Matt Mountain by September 1,1993

P. Harvey, P. Roche and S. Pompea attended the NATO Advanced Study Institute on Adaptive Optics in Corsica and S. Pompea presented a paper on stray light issues in AO systems. The consensus at the meeting was that AO is indeed going to be extremely important for most IR observations and that low power laser systems may also provide useful enhancements. This emphasizes that the Gemini instruments should be designed to allow the optical light to feed a wavefront sensor. A document by Fred Gillett quantifies the sensitivity achieved with an ambient temperature adaptive optics system and the tradeoffs between increased emissivity and decreased image size. The tradeoffs depend on the emissivity and throughput of the AO system and the prevailing weather conditions, but in general the J and H bands almost always benefit from the higher order high-emissivity AO system, while at L and M low order correction gives better sensitivity.

A specification for the 1-5 micron spectrometer was agreed upon and is presented below. It must have state of the art sensitivity and be able to take full advantage of low telescope emissivity and high image quality.

- Wavelength range: 0.9- 5.5 micron
- Array format 1024x1024 pixels
- Resolving power: ~2000, 8000
- Pixel scales: 0.05, 0.15 arcsec (selectable while cold)
- Slit Length: 50 arcsec
- Imaging Capability
- Polarizing Prism

With additional goals of:

- Cross dispersion covering IJHK (and perhaps LM bands separately)
- Resolving Power: 15000
- Slit Length: 150 arcsec
- Multi-Object capability: 20 slitlets

General Instrument Requirements:

- up and side-looking
- output of visible light to wavefront sensor
- minimal liquid cryogens
- pupil imaging
- calibration system
- high reliability
- full documentation and spares

The spectrometer will be an observatory workhorse and must combine high sensitivity with excellent reliability. The instrument builder will need to be able to carry out extensive testing including environmental and flexure tests to ensure that the spectrometer meets the rigorous standards required.

The group agreed that the goal should be a standard IR array controller for the Gemini instruments. If standards are imposed, the instrument builders will require the controller and array early on in the construction of the instrument so that they are fully able to take into account any constraints. Gemini will have to pay for modifications to shared or subsidized instruments if it insists that standards are adhered to.

— Pat Roche and Stephen Pompea

Infrared Imaging Working Group Meeting in Pasadena

Participants (and observers) in the Working group which met on July 23 at IPAC included: C. Beichman* (Chair), T. Davidge, R. Doyon*, B. Jones*, K. Hodapp*, M. Mountain , D. Nadeau , Steve Pompea*, P. Puxley*,

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C. Telesco*, (* denotes committee members). Absent was James Graham who expressed his interest in rejoining the group.

The main item of discussion was the specification of the 1-5 um camera for Mauna Kea. Subsidiary topics included commonality of controllers and the present lack of any 5-30 um capability at first light.

1-5 Micron Imager

The thrust of the 1-5 micron camera discussion was to: 1) focus on the unique scientific attributes of Gemini; and 2) to simplify the requirements on the camera sufficiently that savings could be found to enable procurement of other instruments, such as a long wavelength camera or a second 1-5 micron imager for Pachon.

The following list of requirements was arrived at after the morning's discussion:

- 1024x1024 array (almost certainly InSb) with ~25 micron pixels providing wavelength coverage from 0.9 to 5.5 micron.
- Two plate scales (descoped from three in previous IRIWG documents). The plate scales will be optimized for diffraction-limited imaging in the J,H,K and the L,M bands separately. Further, each wavelength region may have two sets of optics to allow for easy insertion of coronagraphs and other field optics. Nominal plate scales are 0.02 arcsec and 0.08 arcsec at J-K, and 0.04 and 0.1 arcsec at L-M. The emphasis was placed on high spatial resolution at the expense of large fields of view. This choice emphasizes Gemini's unique capabilities and decreases the costs of the optics.
- Two filter wheels with 20-30 slots for ~ 2" filters, grisms and polarizers. Including three wheels is desirable but not required.
- A cold focal plane wheel with a variety of field stops, slits, etc.
- Low resolution grism for J-K and possibly for L-M.
- Pupil imaging for commissioning purposes.
- Provision for external (warm) Fabry-Perot, ADC, and rotating quarter wave plate provided by Gemini.
- Operation as up-looking or side-looking instrument.
- Provision of optical radiation from the 2-3 arcmin science field using a cold dichroic for use by the adaptive optics system.
- Full complement of spare electronics.
- Standard stepper motors and electronics where possible. Barbara Jones noted that Keck experience with common stepper motor drivers was quite good and that the project should provide up to ~6 drives and cables to be used for all instruments.
- The IRIWG felt strongly that the project needed to develop a detailed acceptance and test plan to guide the UH activities.

Common Array Controller

There was considerable discussion about the desirability of having a single array controller for all the IR instruments. First, the committee was worried that the requirements resulting from the wide variation in photon rates, read-out rates, numbers of pixels, numbers of output channels, and noise levels might make a single controller technically difficult to achieve for the entire 1-30 um region. Second, people worried about ensuring adequate performance (e.g., whose fault is that 30 e^- of noise pickup) if the controller vendor were different from the instrument builder(s). Despite these concerns, the IRIWG thought that in the specific case of the two 1-5 micron instruments (camera and spectrograph), a common set of electronics made technical and programmatic sense and that the project should consider enforcing such a requirement on the instrument builders.

5-30 Micron Camera

The committee was distressed that no 5-30 micron camera appears in the first light complement of instruments. The report of Pat Roche on the scientific utility of these wavelengths was noted and appreciated. The parameters of a basic capability were defined as follows:

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- A 256x256 (512x512?) array with ~50 micron pixels providing wavelength coverage from 5-34 micron and optimized for performance at 10 microns.
- Two plate scales optimized for λ/2D and for λ/6D sampling at 10 microns, (0.13 arcsec and 0.04 arcsec) for Nyquist and super-resolution sampling.
- Two filter wheels with 20-30 slots for 1-2" filters, grisms and polarizers.
- A cold focal plane wheel with a variety of field stops, slits, etc.
- A low resolution grating mode (R ~300) to observe the 8-14 micron window in a single setting.
- Members of the IRWIG with experience in building instruments of this type felt that $1M would be sufficient to provide such a basic capability.

— Chas Beichman and Stephen Pompea

A Fibre Fed Laboratory for High Resolution Spectroscopy

The Gemini High Resolution Optical Spectrometer (HROS) will be capable of resolutions from 30,000 to well in excess of 100,000. (Gemini WG report, March 1993) In order that the radial velocity precision be maintained at the highest resolutions achieved, it is required that the instrument be stable to changes in virtually all environmental factors. These include flexure, vibration, and temperature changes.

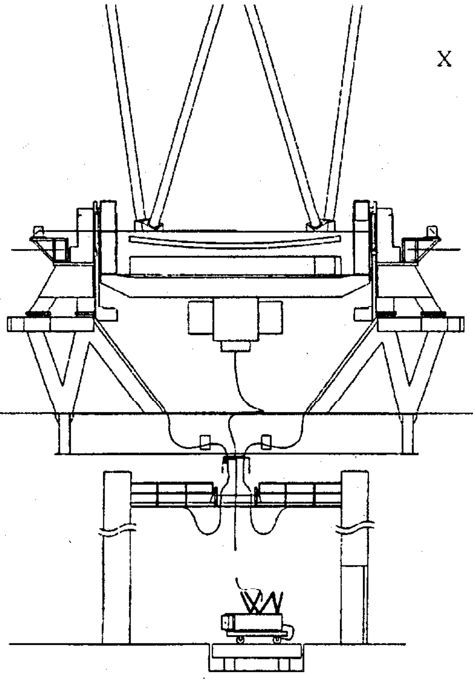
The usual way to provide this stability is to remove the instrument to a laboratory where such effects are not present or can be controlled. In the case of the Gemini Telescopes it is suggested that such a laboratory be built into the pier of the telescopes. The room is also easily accessed from the Instrumentation Laboratory and preparation room. This solution offers several advantages, which are described below.

In this plan, the fibre or fibres will pass from the Cassegrain Instrument Mount directly to the cable twister on the Azimuth Axis of the mount, bypassing the Elevation cable bender. This offers the shortest path (approximately 25 metres) between the telescope and the laboratory. This implies that a facility to store the cable and adapter when not in use must be built into the Azimuth platform floor. The cable will be armoured to avoid damage, and sufficiently flexible so as not to interfere with the elevation motion of the telescope.

In order to maintain constant fibre transmission characteristics it is necessary to avoid variations in bends and stresses. Both of these effects can change the pupil illumination at the output of the fibre and can potentially modulate the measured wavelength at the spectrometer. The proposed path goes directly from the RC focus to the Laboratory with minimum flexure.

Since the pier is a large and massive concrete construction, it will be thermally very stable. A thermal model shows a gradual decline in temperature of less than a degree during a night's observations. No active control is foreseen for this facility, since the very gradual temperature

Path of Fiber from Cassegrain to Fiber Laboratory



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change indicated is easier to calibrate out than a fluctuating temperature around a mean value, which a temperature stabilization system will provide.

A major advantage of using the interior of the pier as a laboratory is that it is isolated vibrationally from the dome and other external disturbances. To enhance further the mechanical stability of the instrument we propose to provide a vibrationally damped platform on the floor of the lab to hold HROS . We propose also to provide at least two additional vibrationally damped optical benches to allow experimental fibre fed setups. Further studies on this concept will be done by the Instrumentation Group.

— ***William G. Weller***
Gemini Instrumentation Group

Progress on the High Resolution Optical Spectrograph

C. Pilachowski (Chair), on behalf of the Instrument Working Group for the HROS: J. Landstreet (UWO), M. Pettini (RGO), D. Walker (UCL), and D. York (U. Chicago).

The Working Group for the High Resolution Optical Spectrograph met in Tucson in early June to continue our discussion of design specifications for the Gemini HROS. The primary issues for discussion were the location for mounting the instrument (Cass vs. Nasmyth) and the spectral resolution for optimization.

The Working Group reached a consensus that the HROS could be successfully mounted at the Cass focus, if appropriate consideration were taken in the design stage of the requirements for stability. A majority of the scientific programs proposed for the HROS can be achieved with a Cassegrain mounting location. A few programs which place stringent requirements for stability (programs for precise radial velocities or accurate line profiles) cannot. These programs will benefit in any case from a fiber-optic feed to the instrument and can be accommodated by conveying the light from the Cass focus through optical fiber to the instrument mounted on a stable platform in a laboratory in the pier.

The Gemini Project Staff have accommodated this requirement by designing such a laboratory into the pier. The length of optical fiber necessary to connect the spectrograph to the telescope is 25 meters.

Strong arguments can be made for two regimes of spectral resolving power - 50K (for abundances and other measurements on faint objects) and 120K (for studying QSO absorption lines, precise radial velocities, interstellar lines, and accurate line profiles). The Instrument Working Group recommends that the HROS be designed to provide these two resolutions, with the former optimized specifically for the highest possible throughput, and the latter for good throughput, but with emphasis on photometric and velocity precision. It is the hope of the working group that a configuration can be found which will provide both resolution regimes without changes in grating, camera, or detector. The instrument should be designed with full spectral coverage and adequate (2.5 pixel) sampling at a resolving power of 120K, and should be used with binning and skipper amplifiers to achieve the lower spectral resolution without a penalty of readout noise. Because of the need for minimum flexure, it may not be possible to design the instrument for interchangeable cameras and gratings to accommodate a wider range of resolution. A slit width of 0.33" for a resolving power of 100K has been adopted for the basic design.

— ***Caty Pilachowski***

Optical-UV Multi-Object Spectroscopy Working Group

The OUVMOS Working Group met in Tucson June 22-23, 1993 to discuss the comments and requests from the Gemini Science Committee and the Project Staff on its earlier work and reports. Members of the working group include: J. Allington-Smith, D. Crampton, J. Huchra, P. Osmer (Chair), R. Schommer, and W. Weller.

The Working Group has concentrated on the f/16 configuration because it will be implemented first on both telescopes.

The Working Group envisions three modes for the Optical/UV, Multiple Object Spectrograph: 1) A high spatial resolution (HR) mode that will take full advantage of the superb image quality that will be delivered by the Gemini telescopes; 2) A wide-field (WF) mode that will cover a 7 arcmin diameter field for multi-object spectroscopy and will have wavelength coverage from the blue to near infrared; and 3) an ultraviolet (WF/UV) mode that will reach

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down to the atmospheric cutoff while giving field coverage of order 6 arcmin at least along the slit axis.

The spatial scales of the different modes should be designed to yield good performance both during the times of best image quality delivered by the telescopes and during median conditions. The HR mode will be used with the adaptive optics capability of Gemini: the other two modes will take advantage of the fast-guiding capability.

The Working Group envisions a range of spectral resolutions being required for the different modes. For observing the faintest objects in the HR mode, spectral resolutions, R, in the range of a few hundred to a few thousand should be available. High system throughput is also essential.

For the wide field mode, there is a strong scientific case for R of at least 10,000. This should be achievable with an entrance slit of 0.5 arcsec and also with high throughput. To obtain both high efficiency and good image quality over the wavelength range 310 - 1100 nm will require the two modes, WF and WF/UV.

Proposed parameters for the different modes are listed in the tables below:

HR mode

Field size:	2 arcmin with AO
Image scale:	0.04 arcsec / pixel
Wavelength range:	500 - 1100 nm with AO 370 - 1100 nm desirable for use without AO
Min/nominal:	0.1/0.25 arcsec slit width
Spectroscopic Res.:	~ 300 - (2000 - 4000) at nominal slit width

WF mode

Field size:	7 arcmin diameter
Image scale:	0.1 arcsec / pixel.
Wavelength range:	370 - 1100 nm
Min/nominal:	0.2/0.5 arcsec slit width
Spectroscopic Res.:	1000 - 10000 at nom. slit width

WF/UV mode

Field size:	≥ 2 x 6 arcmin
Image scale:	0.1 arcsec / pixel
Wavelength range:	310 -- ~500-600 nm
Min/nominal:	0.2/0.5 arcsec slit width
Spectroscopic Res.:	1000 - 10000 at nom. slit width

From the exploration of design concepts carried out to date, the Working Group believes the above requirements can be met satisfactorily. For example, an all transmitting system using grisms can be used for the HR mode with a collimated beam size in the range 50 - 115 mm. Transmitting optics and reflection gratings can be used for the WF mode. The WF/UV mode, however, may require a reflective collimator as well as reflection gratings. The Working Group welcomes suggestions from the community on innovative design approaches. It is aware, for example, that immersed gratings offer a path for achieving spectral resolutions significantly in excess of 10,000.

— ***Pat Osmer***

The CFHT Adaptive Optics Bonnette

by ***David Crampton***
Dominion Astrophysical Observatory
National Research Council of Canada

What do you do with a 3.6m telescope to remain competitive in the era of HST and 8 - 10m telescopes? The CFH community decided at their users' meeting last year (Arsenault, 1992) that an adaptive optics bonnette (AOB) was part of the answer. (The "bonnette" part of the name signifies that the device will be more than a camera — it will deliver compensated images to full-size instruments such as spectrographs). The spectacular results obtained with the DAO/CFHT high resolution camera, HRCam, convinced the community of the benefits that could be obtained by even modest improvements in the image quality. Although originally conceived as a prototype, HRCam has become the most frequently used visitor instrument at CFHT (McClure, p.42 of Arsenault 1992, discusses the scientific programs). Through fast tip/tilt guiding on natural guide stars as faint as 19.5, HRCam delivers median images of FWHM ~ 0.6", and it is obvious that images better than 0.4" could frequently be obtained if it were not for limitations imposed by the telescope optics and alignment (Racine, p.37 of Arsenault 1992, gives details). It should be emphasized that the quoted figures for the performance of CFHT + HRCam have been established during hundreds of nights of actual scientific data acquisition.

By 1991, it was realized that improvement of the image quality beyond the 0.4" seeing barrier would require active control of the telescope alignment and focus and some way of correcting the residual aberrations of the primary mirror. Therefore, the decision was made to go further and correct for at least low-order atmospheric terms. Two factors played a role in this decision: the achievements of HRCam, and Roddier's elegant demonstration of remarkable gains in image quality with a relatively simple technique that was affordable (Roddier, Northcott and Graves 1991). Considerations of the available (and projected) technologies combined with the scientific requirements established by a "Working Group" and the CFHT Scientific Advisory Committee led to the following specifications for the AOB:

- must provide a median image quality equivalent to a Strehl angle of 0.2";
- must have a usable wavelength range 0.4 to 2.5 microns;
- must be usable over at least 60% of the sky (this effectively defines the guide star limiting magnitude and level of correction);
- must be able to feed full-sized instruments at the f/8 Cassegrain focus; and
- the direct f/8 (uncorrected) 6' field must be accessible (and confocal) as a backup or for wide-field programs.

Phase A of the project began in late 1991 after a preliminary optical layout by E.H. Richardson (Victoria) was selected and after the technical specifications were developed:

- 100% of rays to be within 0.06" over whole 1.5' field;
- Average transmission > 85% (not including beamsplitter);
- Atmospheric dispersion compensator to give residual spectra < 0.4" for Z < 60 deg for 0.4 - 1 microns;
- To incorporate both a tip/tilt and a bimorph deformable mirror;
- To use a curvature wavefront sensor (a la Roddier) capable of controlling the mirrors to correct the first 15 Zernike modes;
- Light from a reference star anywhere within 1.5' of target to be fed to the wavefront sensor by (one of several) beamsplitters;

- Light from the curvature sensor to be relayed to 19 avalanche photodiodes (APDs) by a lenslet array and fibres;
- Control (by the observer) to allow optimization of level (maximum 15) and speed of corrections according to seeing conditions and brightness of reference source;
- Output beam at f/20, which gives 0.04" per 15 micron pixel, 0.07" per 40 micron pixel; and
- Rigid opto-mechanical bench/bonnette to support 300kg, 1800 NM with a maximum flexure 17 microns or 0.05" at the f/20 focus for any 15 degree motion of telescope.

An isometric drawing of the optical components is shown in ***Figure 1***. The AOB mounts directly to the existing Cassegrain bonnette (A&G, rotator). As with any real project, both technical and scientific compromises had to be made. The principal technical issues were whether to gamble that the performance of CCDs would improve sufficiently that they would out-perform APDs and whether to use a piezo-stacked actuator mirror instead of a bimorph — the APDs and the bimorphs won. From the scientific point of view, the main issue was whether to design the AOB to adequately sample the smallest possible central diffraction spike versus the size of the available field (many HRCam projects were limited by field size and availability of a PSF star in the field). A compromise was struck which may be alleviated by changing the CCD pixel size and/or reimaging optics. The modal feature of the control is designed to provide assistance to the observer in choosing the optimal degree of compensation, etc. depending on the scientific requirements for image and field size, location and brightness of the reference star, and prevailing weather conditions. Furthermore, all sub-units are modular so upgrading of any of the critical components should be relatively straightforward.

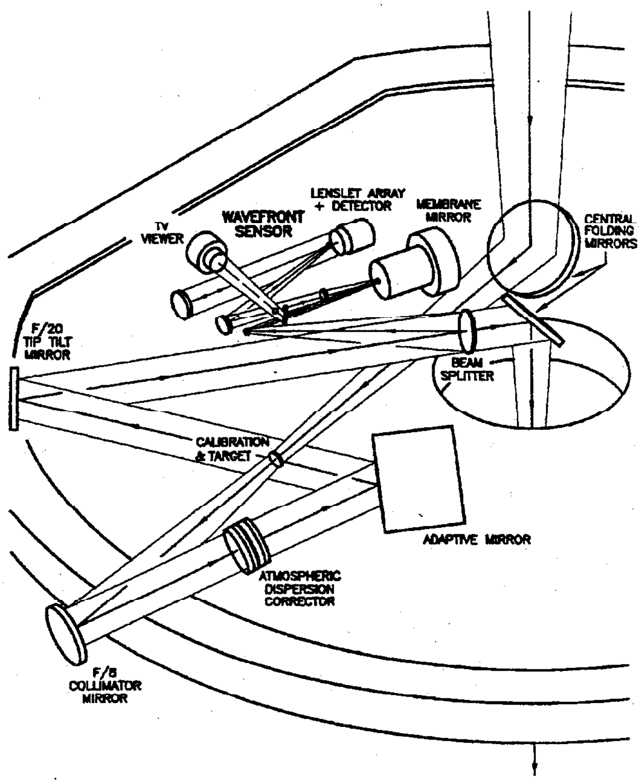

Figure 1. CFHT Adaptive Optics Bonnette (Optical Components)

The project is now in the construction phase, with completion scheduled for late 1994. CFHT is providing the overall management of the project, which involves four institutions: UH Institute for Astronomy (technical advice), DAO (opto-mechanical bench, wavefront sensor), Laserdot, a French commercial company, (bimorph mirror and control) and Observatoire de Paris-Meudon (tip-tilt mirror, integration). Recent results by Roddier's group with a prototype device mounted at the CFHT provide considerable optimism that the goals will be attained and forefront science will be achievable: images with FWHM of 0.08" were obtained at a wavelength of 8500A.

Much has been learned from our experience with HRCam at CFHT, and similarly, it can be anticipated that much will be learned through scientific observations with the CFH AOB that will be beneficial to the development of the next generation instrument for Gemini.

<u>References:</u>

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Roddier, F., Northcott, M. and Graves, J.E. 1991, PASP, 103, 131.

Reports from the National Project Offices

Canadian Project Office Report

We are pleased to announce that we have (finally!) hired a Canadian Project Engineer. Glen Herriot was trained as a systems design engineer and brings us many years of experience in the design and manufacture of scanning electron microscopes and other precision instrumentation. Glen reported to work in early July.

The Canadian Project Office is now fully staffed. All of the following staff members are physically located in the Dominion Astrophysical Observatory in Victoria, with the exception of Gordon Walker at the nearby University of British Columbia. Affiliations are shown in parentheses.

Tim Davidge - Project Astronomer (UBC)

Glen Herriot - Project Engineer (NRC)

Jennifer Holland - Secretary (NRC)

Gordon Walker - Project Scientist (UBC)

Andy Woodsworth - Project Manager (NRC)

A number of other Canadians are making important contributions to the Project by serving on committees, the Board, design review panels, etc.

— ***Andy Woodsworth***
Canadian Project Manager

UK Project Office Report

A new Deputy UK Project Manager has recently been appointed to assist the UK Project Manager in handling the increasing work load of the office.

Phil Williams is an Electronics Engineer with several years of experience in the design and manufacture of astronomy related instrumentation. He returned to the UK in November 1992 after an extended posting to the Joint Astronomy Centre in Hawaii.

Justin Greenhalgh has left the Project Office team to concentrate on the Primary Mirror Cell Thermal Control System and Mirror Cell Structural Design Work Packages. The office is indebted to him for his contribution during the formative years.

The team and their physical locations are now as follows.

Terry Lee - UK Project Manager, Royal Observatory, Edinburgh.

Phil Williams - Deputy UK Project Manager, Royal Observatory, Edinburgh.

Roger Davies - UK Project Scientist, University of Oxford.

Jeremy Allington-Smith - Deputy UK Project Scientist, University of Oxford.

— ***Terry Lee***
UK Project Manager

US Project Office Report

The US Gemini Project Office is in the process of developing as a division of NOAO. The position of US Gemini Project Scientist is now being advertised. In the meantime, Larry Daggert and Fred Gillett, with the assistance of Richard Green, are manning the office. In addition, Jay Gallagher (University of Wisconsin) has joined the Project office staff as Associate US Project Scientist for the rest of this calendar year. His major activity is advocacy of Gemini within the US scientific community.

— ***Fred Gillett***
Acting US Gemini Project Scientist

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8-M Telescopes
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The following technical report has been published by the Gemini Project since the last edition of the Gemini Newsletter (June 1993). Copies of this publication are available on request by contacting the Gemini Project at the above address, Fax number or by E-mail (lfriedmn@noao.edu), attention: Linda Friedman, Documentation Coordinator. Specific report numbers are listed following the author(s) name in parenthesis.

Technical Reports

5/25/93 — Image Smear Error Budget with Required Servo Bandwidth and Sampling Rate, M. Burns (TN-C-G0008)