The GEMINI Multiobject Spectrographs

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ABSTRACT

As the only two optical instruments appearing in its first fleet of instrumentation, the GEMINI MultiObject Spectrograph (GMOS) are indeed being developed as workhorse instruments. One GMOS will be located at each of the GEMINI telescopes to perform: a) exquisite direct imaging, b) 5.5 arcminute longslit spectroscopy, c) up to 600 object multislit spectroscopy, and d) about 2000 element integral field spectroscopy. The GMOSs are the only GEMINI instrumentation duplicated at both telescopes.

The UK and Canadian GMOS team successfully completed their critical design review in February 1997. They are now well into the fabrication phase, and will soon approach integration of the first instrument. The first GMOS is scheduled to be delivered to Mauna Kea in the fall of '99 and the second to Cerro Pachon one year later.

In this paper, we will look at how a few of the more interesting details of the final GMOS design help meet its demanding scientific requirements. These include its transmissive optical design and mask handling mechanisms. We will also discuss our plans for the mask handling process in GEMINI's queue scheduled environment, from the taking of direct images through to the use of masks on the telescope. Finally, we present the status of fabrication and integration work to date.

1. INTRODUCTION

The GEMINI Multiobject Spectrographs will be versatile optical spectrographs which will fully exploit the large aperture and excellent image quality at each of the GEMINI 8-m telescopes. The GMOSs are the only instruments funded from the capital budget of the GEMINI project that will be duplicated to be available at both sites, and are being designed to deliver a comprehensive range of capabilities.

The design for GMOS evolved from that presented at the Preliminary Design Review[1] through to the final detailed design presented at its successful Critical Design Review held in February, 1997. Since that time we have been finalising

fabrication drawings and building components in preparation for the integration phase of the project later this year. Meanwhile, subsystem performance continues to be modelled and measured, and the results used to refine the overall models of system performance.

2. REQUIREMENTS

In order to establish top-level requirements and goals for this low-to-intermediate dispersion spectrograph, a wide range of scientific applications were examined and can be found summarised in the literature[1]. The instrument scientific characteristics thus established are shown in Table 1.

Table 1 GMOS Scientific Characteristics

Wavelength range	0.4-1.1 μm (with goal of 0.36 - 1.8 μm)
Unvignetted field	5.5' diameter
Image scale	0.08" per 15 μm pixel
Image quality	should not degrade the on-axis images delivered at zenith by the telescope, including the atmosphere and telescope optics, by more than 10%
Camera field of view	suitable for 4K x 6K (15 μm pixel) CCD
Minimum slit width	0.20" (2.5 pixels)
Spectral resolution	dispersions from 8Å/mm to 250Å/mm (R=10000 to R=500)
Velocity resolution	2 km/s at R=5,000
Optical throughput	80% (no filter, not including detector)
Main modes	- multiaperture spectroscopy with masks - longslit spectroscopy - integral field (2-D) spectroscopy - direct imaging

These scientific requirements flow down into a number of engineering requirements. Among those requirements, the two which stand out in their challenging nature are those for image quality and stability.

3. IMPLEMENTATION

3.1 Main Optics

.1 Main Optics

Although the basic layout for the main spectrograph optics shown in Figure 1 has not changed since the preliminary design review, the detail of the optical elements have continued to evolve to ensure meeting the image quality and throughput requirements. The design has been finalised, all glasses procured and optical fabrication completed for about half the optical elements.

The difficult image quality specification has demanded great attention to detail in the design and mounting of the optics. The first row in Table 2 shows the image quality requirement for the spectrograph optics. The second row gives the modelled static performance, degraded by 10% for fabrication tolerance and an additional fixed factor to account for the realistic λ/8 grating flatness. The difference between the previous two is allocated to dynamic performance in the third row. It can be seen that the expected performance will meet the requirement, but evidently careful attention will be needed to ensure the delivered optics match the model. To control this process, we are following a sequence in which the collimator elements are completely fabricated and tested, and then the camera is fabricated to a reoptimized design based on the as-built collimator. The optics are mounted in the cells using an elastomeric mount chosen to be stiff enough to meet the dynamic performance requirement while conforming to the thermal properties of the glasses to control thermal stresses caused by the optical mount at temperature extremes. Further, the thermal gradients and stresses in the glass during normal operation have been modelled and found to be only a very small component of the dynamic performance error.

Figure 1 Basic Layout for the Main Spectrograph Optics

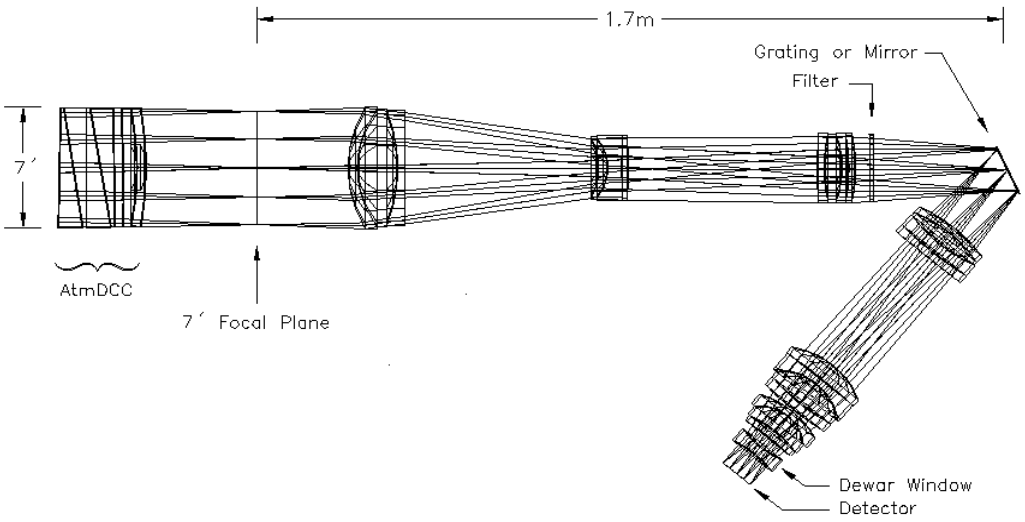
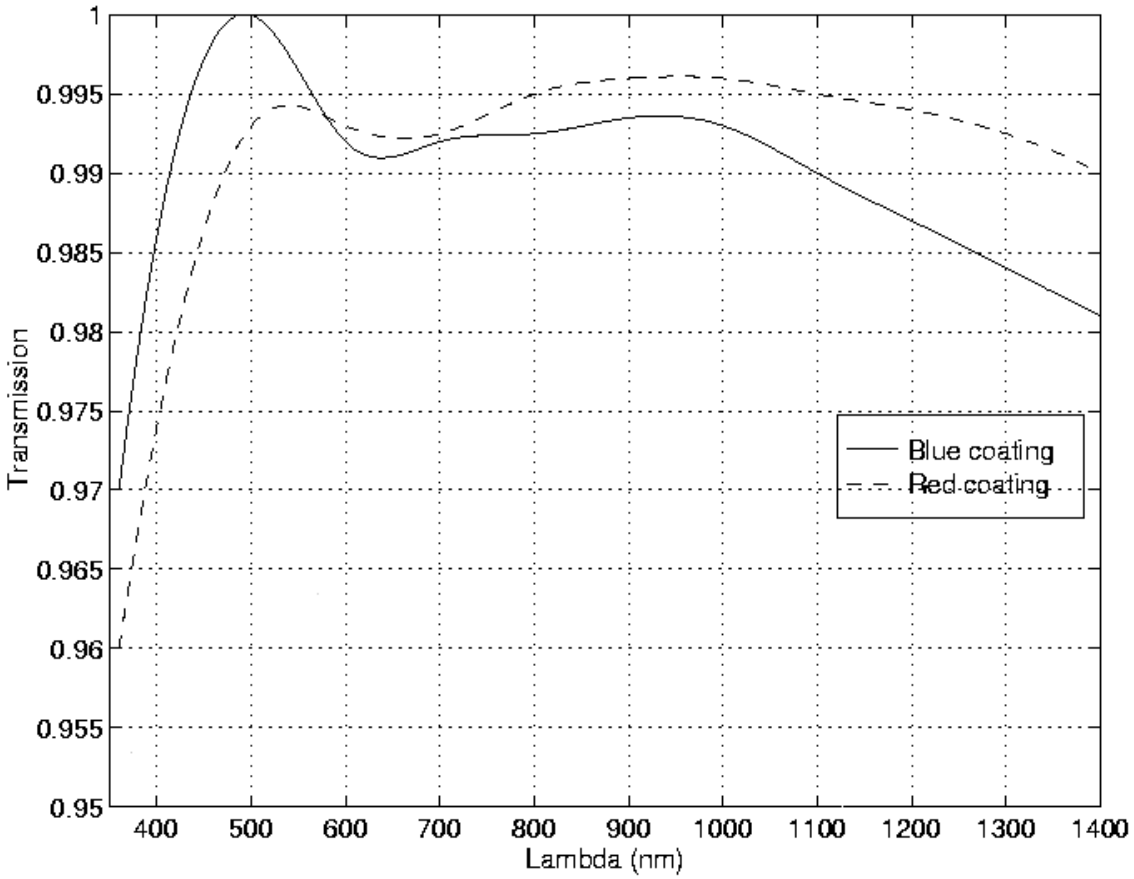


Table 2 GMOS Image Quality Requirements and Predicted Performance

	50% Encircled Energy (arcsecond)			85% Encircled Energy (arcsecond)		
Wavelength (μm)	0.37	0.55	1.00	0.37	0.55	1.00
On-axis Image Quality Spec	0.103	0.092	0.079	0.180	0.180	0.176
Modelled Static Performance	0.080	0.041	0.047	0.105	0.066	0.093
Dynamic Performance Allocation	0.065	0.083	0.063	0.146	0.168	0.149

The requirement of a throughput of 80% over this range while using 19 transmissive optical elements has proven to be a challenging one. After much investigation and development work, the final choice of coatings for the elements is SolGel over a single layer of magnesium fluoride. That combination gave excellent experimental results on BK7 glass. The two cases of a coating optimised for best performance at the red end of our spectral coverage goals, and another optimised for the best blue performance, are shown in Figure 2.

Figure 2 Coating Transmission, one surface of MgF and SolGel



Using these coating results we are able to examine the expected performance of GMOS on the GEMINI telescopes. The throughput of the selected blue coating with all spectrograph glass transmission results in a modelled GMOS throughput as shown in the top solid line of Figure 3. The product of GMOS throughput with the combined reflectivity of the three protected silver telescope mirrors on Mauna Kea (dashed line) and aluminium mirrors on Cerro Pachon (dot-dashed line) are also indicated on the figure. Finally, the combined throughput was multiplied by the estimated CCD quantum efficiency[6] for a CCD chosen for low fringing on Mauna Kea, and one with good blue response to our wavelength limit for Cerro Pachon, to give the lower two curves on that figure. We see that GMOS on the GEMINI telescopes is estimated to deliver over some waveband more than 50% conversion efficiency from photons into the telescope aperture to detected photoelectrons.

3.2 Aperture Masks and Cassettes

The choice of material for slit masks is very important to the scientific performance of GMOS. It was necessary to find a material which a) is capable of supporting up to 600 slits in the 206 by 206 mm slit mask area, b) could accept slits which were narrow enough (120 microns) to match the optical characteristics of the instrument and uniform enough (<1%) to limit errors in background estimation along the slit, c) has a low enough coefficient of thermal expansion that slit masks could be cut and used in a thermal environment which covered the whole operational range, d) is rigid enough and thin enough that it does not degrade the performance with defocus or depth-of-field problems in any gravity orientation, and e) is cheap when compared with other operational costs, 'cuz we'll probably use a lot of the little suckers. The study examining

this has been reported elsewhere[4] and resulted in the selection of carbon fibre sheet supported within an aluminium frame and cut by a laser cutting machine.

The process which leads from an imaging observation through to the final multiobject spectral observation is bounded by many constraints:

- The requirements on image quality, field size and velocity accuracy are such that highest spectral resolution observations may become limited by differential refraction in one or two hours. There may be a number of nearly-identical masks made for one target field for use at different zenith distances.

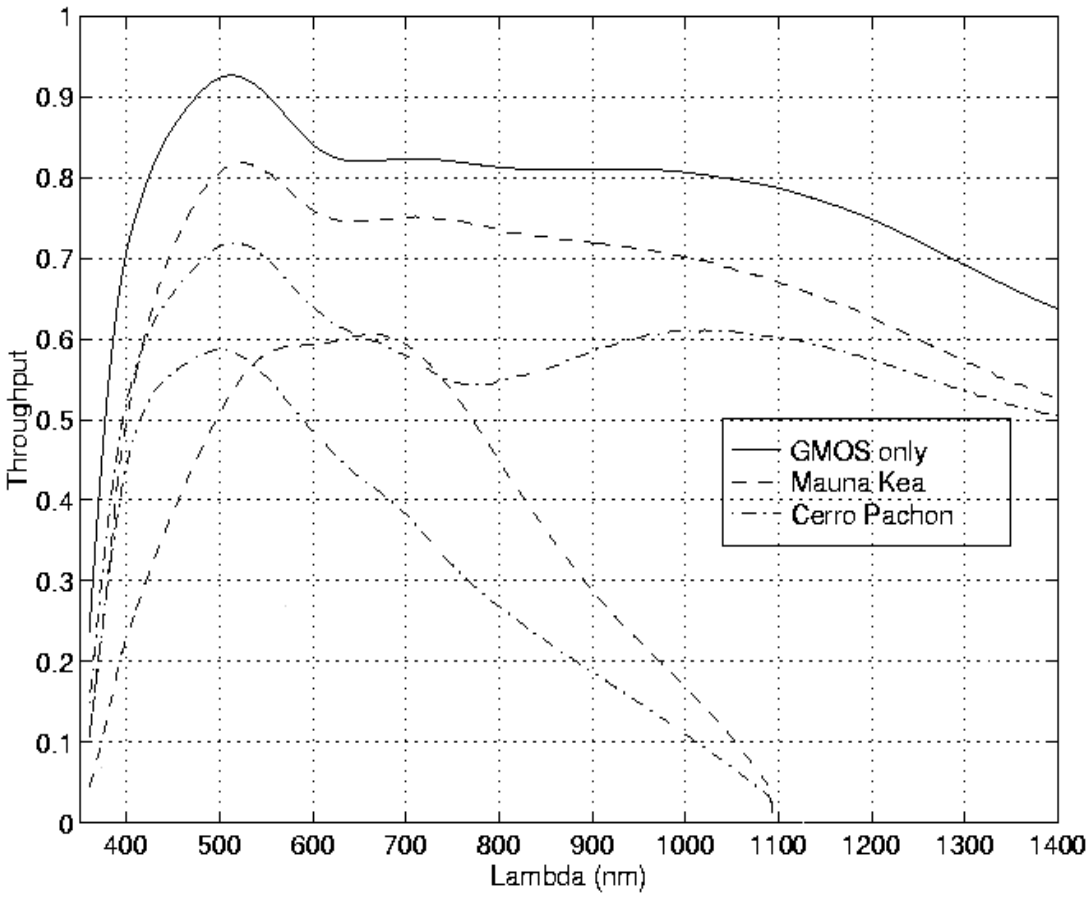
- Optical distortion from the ADC rotation, telescope focus and spectrograph focus changes during typical observations will limit highest spectral resolution observations.

- The dominant observing mode for which GMOS is being designed is queue-scheduled observations.

- There will be only one mask making facility located in Hilo which must serve both GMOSs.

- GMOS must provide archiveable data, hence the data products must be unambiguously traceable to the conditions of the observation.

Figure 3 GMOS, Telescope and Detector Throughput



Although classical modes of observing are certainly possible and will be exercised during commissioning of telescope and instruments, the fact that GEMINI telescopes are being designed to operate primarily in a queue-scheduled mode make it possible to use this feature to resolve some of the other constraints.

The cycle of a multiobject observation begins by scheduling and taking the direct images of the science field. A large suite of ancillary information is gathered and must accompany that image data through the mask process. This includes the position of the telescope three axes, absolute on-instrument guider position, spectrograph temperature and focus settings, mean ADC position, and observation waveband. Once the field images are taken, the observer would be notified (usually at his/her home institute) that the images are available, and may prepare for the next stage of observation.

The observer will retrieve the images and process them to identify where slits are required for spectroscopic observation. GEMINI will make available a standard set of tools to perform this task, but the observer may use whatever is most appropriate for the science program as long as the end result of this analysis is a file listing the slits in a standard format known as the Object Definition File. The Object Definition File specifies slits for one mask, as described in the detector co-ordinate system. Evidently one target image may result in a few Object Definition Files, each seeking spectra of different objects in the same field. This file, as in each of the subsequent files, propagates the complete header information taken from its parent.

Once the Object Definition File is transmitted by the observer to GEMINI, the operations staff will convert it to a Mask Definition File. This process applies whatever corrections are necessary to go from the detector co-ordinate system to the mask co-ordinate system expected during observations, applying such corrections as the measured field distortion and the change in differential refraction for the zenith distance of the observation. The resulting data are then converted to a file of native instructions for the mask maker. At the mask preparation facility in Hilo, a bar code is attached to the mask, scanned by the mask maker prior to cutting the mask, and finally the mask is fabricated. Once the mask is successfully made, the entire file consisting of bar code label, machine instructions and history of the data flow from the original image are sent to the GEMINI data store. The masks for both telescopes are fabricated in Hilo and shipped to the telescopes where they would be stored in the instrument preparation area until loaded onto the instrument.

The GMOS instrument holds three focal plane cassettes, each of which may contain up to 8 masks or an Integral Field Unit (IFU). In the day prior to a night's observation with GMOS, a spare cassette would typically be loaded in the instrument preparation area with whatever masks may be required for that night, and the cassette taken to the instrument and exchanged with one of the onboard cassettes. Upon being released from its maintenance mode, the instrument control system recognises the presence of a new cassette, checks whether that cassette is an IFU or mask cassette, withdraws each cassette element and reads its bar code to identify and catalogue it. The final step in this mask cycle is to take the calibrations (which may be done in the daytime, prior to or after science observation) and the science observations with the mask. The bar code will be recorded in the headers of any images taken with the mask, and can be used in an archive to unambiguously associate the observation and calibration data as well as the entire process from which the mask was created.

3.3 Integral Field

One of the scientifically exciting observing modes which will be available with GMOS is that of integral field spectroscopy. The Integral Field Unit will provide two-dimensional spectroscopy over a contiguous sampling of the input plane. A second and smaller field located about one arcminute from the primary field is also available in the IFU to allow for background estimation in more extended objects, and for beam switching. This unit is a distinctly separate module within GMOS, and is designed to be treated very much like another slit mask. It is inserted into the instrument on a cassette and loaded into the focal plane by means of the mask loading mechanisms. Indeed, although only one IFU will be delivered with the instrument, GMOS is able to accommodate three IFUs onboard at one time. This feature facilitates the potential for designing and building future IFUs which are tailored for the science they address, for example perhaps with different spatial sampling or different field geometry.

Given the independent nature of the IFUs, they have moved onto a development schedule which is different from the main instrument. The preliminary design which was presented earlier[2] has evolved at a slower pace, and is now approaching the critical design phase. A description of the current concepts for GMOS IFUs will be found elsewhere in this volume.

3.4 Flexure Control

In addition to the image quality, a second requirement which has proven to be equally challenging to satisfy is that for image stability. The basic requirement is that one can measure the velocity of objects with a precision of 2 km/s at R=5,000 and with a 0.5 arcsecond slit. This requirement flows down to the need to control image motion during a one hour observation to less than 3.125 μm at the detector.

The design strategies which address this requirement are twofold. The first thrust is to develop a design for the main structural components of this 2 tonne instrument in which flexure is repeatable and predictable. This is done through the use of Serrurier trusses, simple cantilevers, and careful design and control of mating surfaces: the use of deep penetration welds where ever possible, robustly-bolted attachments, etc. The mechanical design has been extensively modelled and we have confidence we can predict accurately how it will flex.

The second thrust is the use of an open loop flexure compensation system. The GMOS control system will monitor variables such as temperature and gravity vector, and will use this information to predict image motion seen at the CCD as well as spectrograph focus corrections. The dewar has been designed with the ability to move the CCD along three axes over a range and resolution sufficient to correct for the modelled flexure and focus change. By controlling the detector position, therefore, we can cancel the repeatable component of any flexure. Since the control system is open loop, that is, we do not measure the image motion in real time and close a control loop on that error, the limit to our flexure performance will be a result of the non-repeatable component as well as any model and measurement errors. The GMOS flexure error budget embodies these strategies: it assigns and combines the non-repeatable component of flexure errors in the various GMOS subsystems. This allows us to use a more cost-effective mechanical design while continuing to meet the requirements.

The GMOS mechanical design and flexure control system can be found described in paralysing detail elsewhere in this volume.

4. STATUS

The project is proceeding largely on schedule, with mechanical fabrication work underway at each of the three institutes. Optical fabrication of most elements is also complete, although there continues to be some difficulty in getting the large calcium fluoride pieces needed for the collimator. The electrical system is being assembled and debugged, control computers are running and now beginning coding.

Once the Canadian assemblies (consisting of everything in advance of and including the focal plane, as well as the optical barrels) and the United Kingdom assemblies (all the main structure and mechanisms of the spectrograph, as well as instrument enclosure) are completed and verified, they will be brought together at Royal Observatory Edinburgh for final integration and testing through latter 1998 and the first half of 1999. Detectors, data processing software, control software templates and the mask maker are being provided to the GMOS team by the GEMINI Project Office.

We eagerly anticipate use of the first GMOS at Mauna Kea in the fall of 1999, and the second at Cerro Pachon in mid 2000.

5. ACKNOWLEDGEMENT

We particularly wish to acknowledge the staff of the GEMINI 8-m Telescopes Project for their continuing interest and commitment to this project. Their input is a vital part of making these spectrographs a success. The GEMINI 8-m Telescopes Project is managed by the Association of Universities for Research in Astronomy, for the National Sciences Foundation and the Gemini Board, under an international partnership agreement.

6. REFERENCES

1. R. L. Davies et al, "GMOS: The GEMINI Multiple Object Spectrographs", *SPIE 2871*, pp 1099 - 1106, 1996.
2. Jeremy Allington-Smith, Robert Content, Roger Haynes, Ian Lewis, "Integral field spectroscopy with the GEMINI Multiobject Spectrographs", *SPIE 2871*, pp 1284 - 1294, 1996.
3. Peter R. Hastings, "Focus and translation mechanism for the Gemini Multi-Object Spectrograph (GMOS)", *SPIE 2871*, pp 1216 - 1221, 1996.
4. Kei Szeto, James Stilburn, Tim Bond, Scott Roberts, Jerry Sebesta, Les Saddlemyer, "Fabrication of Narrow-Slit Masks for the Gemini Multi-Object Spectrograph", *SPIE 2871*, pp 1262 - 1271, 1996.
5. Roberts, S., Fletcher, M., Leckie, B., Saddlemyer, L., Szeto, K., Sebesta, J., "Opto-Mechanical Design of the Gemini Multi-Object Spectrograph On-Instrument Wavefront Sensor", *SPIE Conference 3132, July 31 - August 1*, San Diego 1997.
6. Todd Boroson, private communication.