GMOS : The GEMINI Multiple Object Spectrographs

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ABSTRACT

The two GEMINI Multiple Object Spectrographs (GMOS) are being designed and built for use with the GEMINI telescopes on Mauna Kea and Cerro Pachon starting in 1999 and 2000 respectively. They have four operating modes : imaging, long slit spectroscopy, aperture plate multiple object spectroscopy and area (or integral field) spectroscopy. The spectrograph uses refracting optics for both the collimator and camera and uses grating dispersion. The image quality delivered to the spectrograph is anticipated to be excellent and the design is driven by the need to retain this acuity over a large wavelength range and the full 5.5 arcminute field of view. The spectrograph optics are required to perform from 0.36 to 1.8 microns although it is likely that the northern and southern versions of GMOS will use coatings optimised for the red and blue respectively. A stringent flexure specification is imposed by the scientific requirement to measure velocities to high precision (1-2 km/s). Here we present an overview of the design concentrating on the optical and mechanical aspects.

1. INTRODUCTION

The GEMINI Multiobject Spectrographs (GMOS) will be versatile optical/near-IR spectrographs which will fully exploit the large aperture and excellent image quality of both GEMINI 8-m telescopes. GMOS is the only instrument funded from the capital budget of the GEMINI project that will be duplicated to be available at both sites. It is required to provide a comprehensive range of capabilities. It is also the only GEMINI instrument being built by an international team: a collaboration between the Dominion Astrophysical Observatory (DAO), the University of Durham and the Royal Observatories. The design and procurement of the optics, together with the pre-slit facilities (including provision for wave-front sensing), are the responsibility of DAO. The integral field capability, the manufacture and analysis of the post-slit structure, and the detailed design of some of the major sub-assemblies (such as the grating turret) are being done in Durham. The overall post-slit mechanical design, layout and packaging, and much of the software, are the responsibility of ROE, where the instrument will be finally integrated.

Elsewhere in this volume there are contributions describing the integral field spectroscopy (Allington-Smith et al), the flexure-compensating detector mount (Hastings) and the maskmaker (Szeto).

2. SCIENTIFIC CASE

In order to establish the top level requirements and goals for the facility low-to-intermediate dispersion spectrograph for GEMINI, the GEMINI Science Committee and GMOS team have explored a wide range of scientific applications. Here we discuss a restricted set of these with the aim of illustrating how the science currently envisaged for GMOS drives the design.

1. Local Group dwarf galaxies have been identified as locations where the gravitational potential is dominated by dark matter[1]. This conclusion is based on high precision velocity measurements of samples of giant stars in the Ursa Minor dwarf galaxy that imply a velocity dispersion of 7.5 ± 1 km/s. These measurements used a resolution of $\sim 12,000$ to achieve a precision of $\pm 2 - 3$ km/s on individual, measurements. With GMOS it will be possible to observe fainter objects in multiaperture exposures, these lower luminosity stars are likely to be more representative of the underlying stellar population and less prone to systematic atmospheric effects which could increase the measured dispersion. In addition, using the area multiplexing gain, we can observe stars in fields over a range of radii to map the velocity dispersion as a function of radius for comparison with more sophisticated dynamical models. The aperture and image quality gain of Gemini imply that this analysis could be extended to the dwarf galaxies that are satellites of M31. These applications demand high spectral resolution with high throughput and mechanical stability.
2. Galaxy redshift surveys now rely on tracing the strong absorption features in the ultra-violet and blue (OII 3727 Å in emission, the CaII H & K absorption features, the 4000 Å break) to the red limit of current spectrographs. For the Canada-France Redshift Survey[2] this limit was 8500Å corresponding to a redshift cutoff of $z \sim 1.3$. In order to probe to higher redshifts we need GMOS to perform at least to the red limit of CCD response and preferably include an upgrade path for spectroscopy in the J & H bands. Furthermore at the faint levels we are considering ($I > 24$) the requirement to maximise the number of spectra obtained per field and minimise the integration times emphasises the need for high throughput and a large detector allowing short slits arranged in multiple tiers to be used that will increase the multiplex gain. The central concentration of galaxy images requires the high image quality delivered to the spectrograph to be retained.
3. The TIGER spectrograph[3] has demonstrated the power of two-dimensional (integral field) spectroscopy for mapping the kinematics and stellar populations of nearby galaxies[4]. The application of these techniques on GEMINI to study intermediate-redshift objects, such as AGNs and the members of galaxy clusters, offers the potential to determine the detailed physical conditions in the ionised gas, the distribution of star formation activity and the internal kinematics out to significant lookback times. Tully-Fisher distance determinations, should be possible to moderate redshifts. Such an integral field unit should have a scale that results in a reasonable field-of-view as well as being matched to the image scale of the HST WFPC-2. It should serve as an effective image slicer allowing efficient spectroscopy at resolutions of up to 5000 to be performed in conditions of poorer image quality. The inherent conflict between covering a large field of view and using the appropriate sampling in the best atmospheric conditions argues in favour of an initial implementation with a relatively coarse scale and an upgrade path to a system with finer sampling that might even to used with the GEMINI adaptive optics system for $\lambda > 0.8\mu$m.

In addition the spectrograph should be stable so that except for the most demanding applications a single calibration can be used for an entire night (if appropriate). High stability and accurate calibration is also required to successfully subtract the highly modulated sky spectrum redward of 7000 Å. All the GEMINI instruments are required to have a high level of reliability, rapid acquisition and low overheads.

Taking into account the scientific requirements such as those described above, and the generic requirements for efficient use, the GEMINI Science Committee has set the following top level goals for the GMOS :

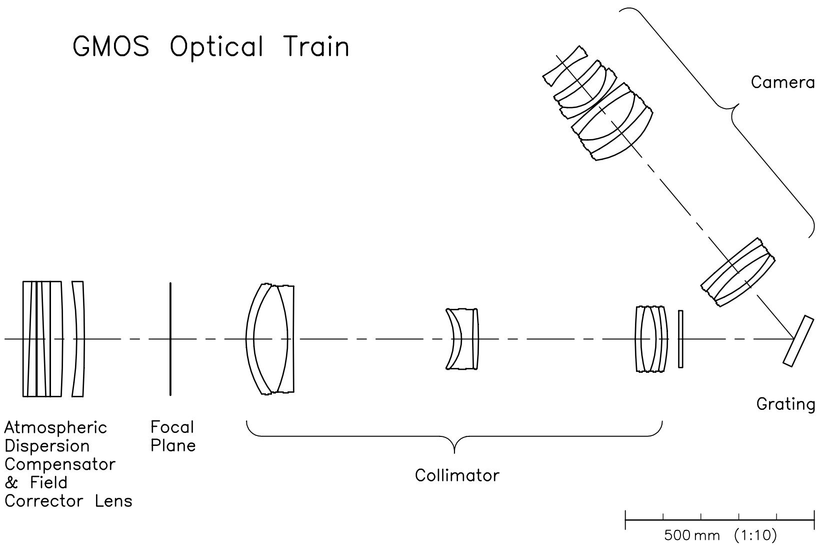

Figure 1: The GMOS Optical Train : showing the atmospheric dispersion corrector with field corrector lens, three element collimator and three element camera, the last element serves as the dewar window.

Field of view	5.5 $\times$ 5.5 arcmin^2
Spectral resolution	$\lambda/\Delta\lambda \leq 10,000$ (0.25 arcsec slit)
Wavelength range	0.36–1.1μmm (design capability to 1.8μm)
Image scale	0.08 arcsec/pixel
Detector	3$\times$(4096$\times$2048) CCD mosaic with 15μm pixels
Fore-optics	Atmospheric Dispersion Corrector integrated with field corrector
Main modes	- Multiaperture spectroscopy via masks - Longslit spectroscopy via masks - Integral field (2-D) spectroscopy : 0.2" elements - Direct imaging

Two such spectrographs are to be provided for a fixed (and low!) cost. A high resolution IFU with 0.1" elements and an extension to 1.6μm have been identified as high priority upgrades.

3. THE DESIGN

3.1. Main optics

In order to translate the top level specifications into technical specifications for the spectrograph the project team have developed extensive internal specifications. Primary amongst these is the image quality specification.

Each observing mode has an image quality specification associated with it. Broadly the spectrograph is required to deliver images that have a 50% (85%) encircled energy diameter of 0.09" (0.21") at 1μm. At redder and bluer wavelengths the specification is relaxed (by up to $\sim$ 10%) to take account of diffraction and the poorer delivered image quality respectively.

One of the remarkable features of the instrument is the fine image scale. This is needed to exploit the excellent images that the telescopes will deliver to the focal plane. At Mauna Kea the median and 10th percentile seeing is 0.4 and 0.25 arcsec (FWHM) respectively. The telescopes will maintain this free-atmosphere performance and provide tip-tilt image stabilisation via an articulated secondary mirror.

The optical design uses refractive optics. The layout of the design is shown in Figure 1. Despite the recent withdrawal of many high-performance glasses from the market, the design provides very good throughput and image quality. The use of very broad-band anti-reflection coatings such as Sol-Gel is being studied. Our intention is to choose coatings to optimise throughput in different wavelength ranges for the north (red) and south (UV-blue).

Retaining good performance in the UV-blue spectral region has been a significant design driver for the optics. This is a long standing problem for refracting spectrographs and great improvements to the optical design have been made to achieve this goal. The current design now meets the image quality specification over the whole field of view down to 3800Å for a high resolution spectroscopic application (where image quality remains important). At shorter wavelengths slits need to be positioned towards the "red" end of the focal plane in order to retain the imaging performance. At 3600Å slits can be placed in $\sim$ 30% of the the field of view and still meet the image quality specification. This situation is illustrated in Figure 2.

The optical system includes an integrated atmospheric dispersion compensator and corrector which partially flattens the field to improve image quality in both imaging and spectroscopy modes.

3.2. Aperture masks

Remotely deployable masks will be used for both multiple aperture and single aperture spectroscopy. Because of the great accuracy required in the location of the slits, it is likely that all masks will be designed with the aid of direct images taken with GMOS. Because the telescope will be at least 50% queue-scheduled, it will be possible for these images to be taken some time ahead of the spectroscopy to give the investigators enough time to design the masks and transmit the manufacturing instructions to the observatory where the masks will be made by means of a dedicated facility. Figure 3 shows a detail of the cassette which holds both masks and integral field units. The cassette can hold either 3 IFUs or 24 masks (or combinations of the two), we estimate that changes from one mode of observing to another using this system will be made in less than 1 minute.

Slits as narrow as 0.25 arcsec will be possible so as exploit the best seeing conditions or to achieve the highest spectral resolution. The combination of large field and excellent image quality implies a very large multiplex gain. To estimate the maximum number of objects observable we might consider slits of length 20 pixels (just 1.6") arranged in three banks (and with a bandpass filter to precisely delimit the ends of each spectrum), this would produce 600 slits. Realistically such a configuration would require a field well populated with point source objects and could only be observed in the very best conditions. Nevertheless GMOS will have the potential of producing hundreds of spectra in a single exposure.

Accurate target acquisition is also critical to the instrumental throughput. The simplest and most reliable method will be to image the sky through masks which include small holes through which reference stars can be viewed. The mask-sky displacement is then used to offset the telescope to ensure accurate registration.

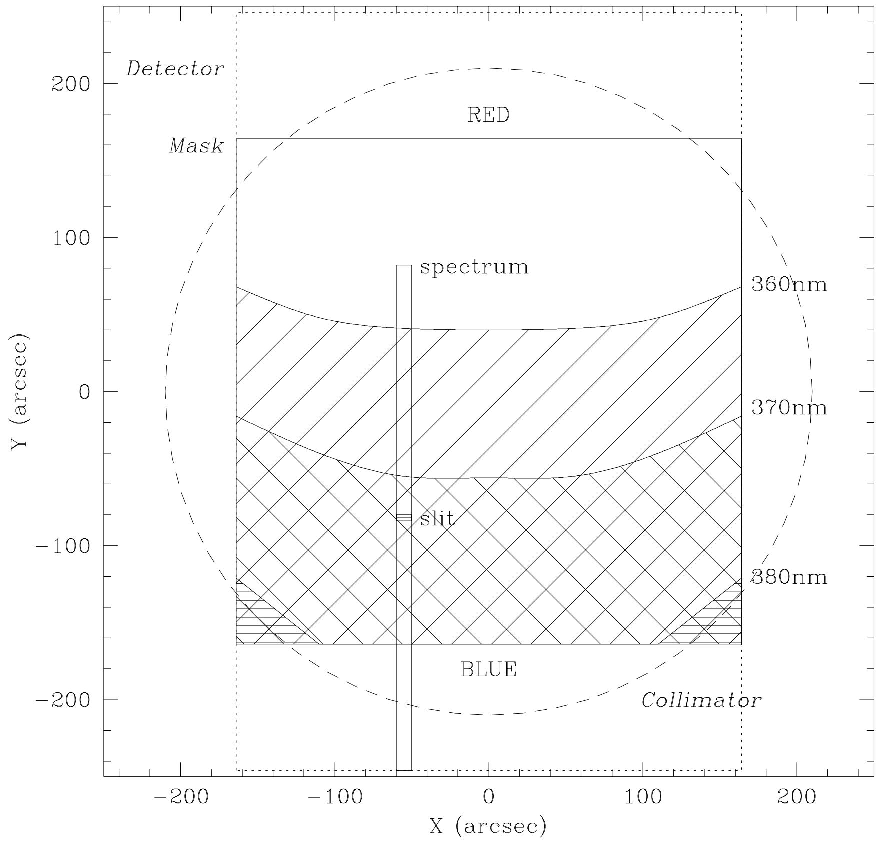

Figure 2: The figure shows the focal plane of GMOS with the shaded regions indicating the field-of-view over which the image quality specification is met at 3600Å (no hatching), 3700Å (single hatching) and 3800Å (cross hatching). In a very small portion of the field-of-view (horizontally hatched) the specification is violated at 3800Å. The spectrograph is configured such that 3600Å falls at the lower edge of the detector, the slit position corresponds to 4160Å and the red end of the spectrum is at 4650Å. The exact spectral coverage (that meets the image quality specification) obtained for any given slit position will depend on the dispersion used.

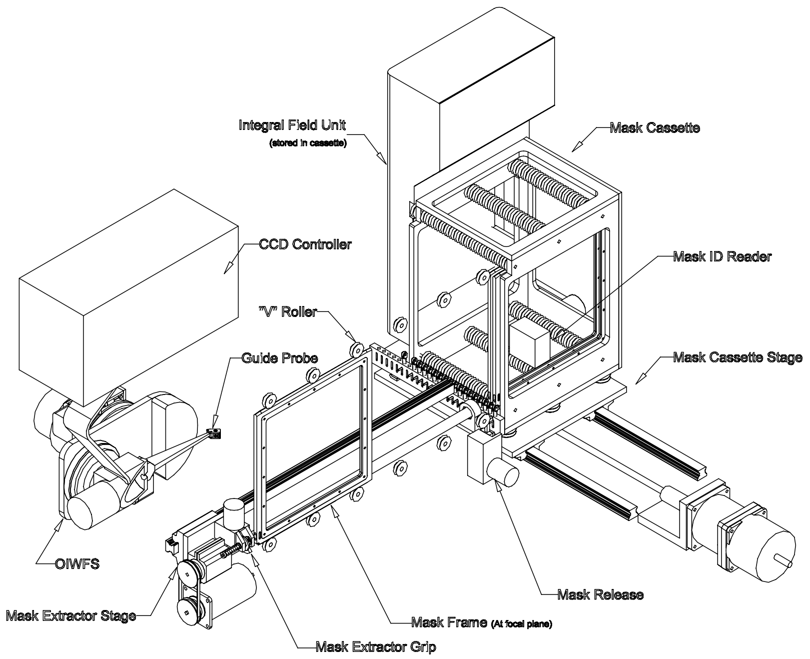

Figure 3: The layout of the focal plane showing (i) the guide probe for the on-instrument wavefront sensor, (ii) the cassette that holds both masks and integral field units and (iii) the stage used to position masks in the focal plane.

3.3. Integral field unit

Perhaps the most revolutionary aspect of GMOS is the integral field unit (IFU) which will provide two-dimensional spectroscopy over a contiguous field of $\sim$50 arcsec^2 with 0.2 arcsec sampling. A small *background* field will be available at fixed separation (1-2 arcmin) from the main *object* field for accurate background subtraction in cases where the object completely fills the IFU object field. This aspect is described in greater detail by Allington-Smith et al. elsewhere in this volume.

By using a combination of microlens arrays and fibre bundles, the IFU aims to achieve the multiple goals of contiguous area coverage, large wavelength range and high transmission. The spectrographs will convert to the integral field mode simply by deploying the IFU in the focal plane in the same way as a mask. In this way, it will be possible to employ different IFUs with different field geometries or spatial sampling. The IFU field is converted into two longslits, offset so that each produces a spectrum 3072 pixels long.

3.4. Dispersion

The spectrographs will provide a large range of dispersion options via a 4-position grating turret which will include a plane mirror for imaging. The gratings will be removable and it will be possible to mount them in the turret with the grating normal pointing either towards the camera or towards the collimator.

It is a key requirement that the tilt of each grating be maintained precisely even when moved out of the light path so that the spectroscopic setup is not disturbed during target acquisition. The instrument flexure will be

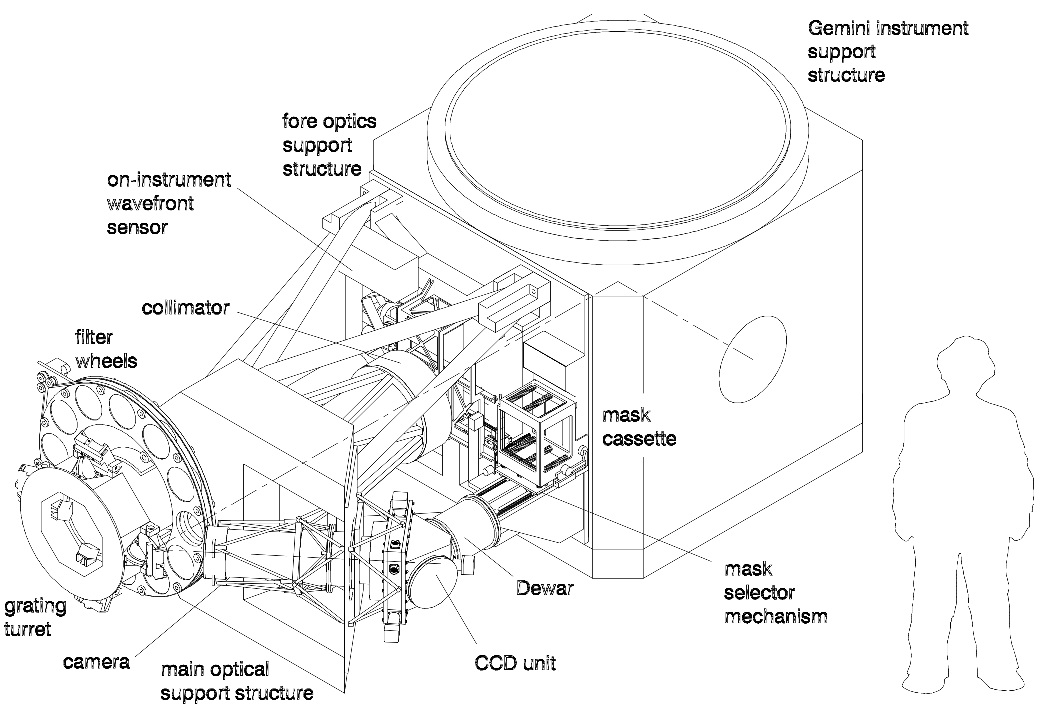

Figure 4: GMOS showing the mounting onto the Instrument Support Structure, and the principal sub-components. The total length of GMOS is around 2m.

controlled to low levels to reduce the need for on-target wavelength calibration. In the limit, it will be possible to measure radial velocities to an accuracy of 1-2 km/s from one line with hourly on-target wavelength calibration. Combining this capability with the large multiplex gain and aperture means that the velocity distribution in dwarf spheroidal galaxies within the local group can be characterised in the equivalent of a single night. This requires resolving powers up to 10,000 which will be provided either with a 0.25 arcsec slit with normal gratings or with a 0.5 arcsec slit via an upgrade to immersed gratings.

3.5. Guiding and wavefront sensing

The telescope tip-tilt system requires signals from a wavefront sensor. This must be tightly integrated with the slit area to eliminate guiding errors due to differential flexure. The sensor is fed via an angled pick-off mirror which can be deployed throughout the field. This will give a patrol field sufficient to provide at least a 90% probability of finding a suitable reference star even at the galactic poles.

3.6. Flexure control

GMOS will normally be mounted at a side-port of the instrument support structure at the Cassegrain focus and fed via a fold mirror. The mass is fixed at 2 tonnes and there are tight tolerances on the centre of gravity which means that the instrument cannot be folded to aid rigidity. In order to eliminate flexure between the slit, grating and detector, the mechanical design (Figure 4), must be innovative. Trusses have been used extensively to eliminate tilts between the optical elements while allowing them to translate exactly in parallel so that decentering aberrations are eliminated. The remaining bulk translation can be removed simply by *translating the detector* orthogonal to the optical axis. The correction signals will either be generated by a look-up table or by closed-loop monitoring of reference light injected at the telescope focal plane.

4. STATUS

GMOS has passed successfully through its Preliminary Design Review. We are in the process of ordering the glasses required for the optical system. The next milestone is the Critical Design Review in early 1997. The delivery of the first instrument is scheduled for 1999.

5. ACKNOWLEDGEMENTS

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