13 SCIENTIFIC INSTRUMENTS

13.1 Introduction

Effective use of the telescope will require a suite of instruments that make use of the full range of observing conditions and enable a broad range of science. The GMT project will support the construction of a first generation of instruments as part of the initial capital investment in the facility. The GMT science working group and project scientists have identified a set of candidate first generation instruments that address our science goals. Designs have been developed for a number of instruments in response to the requirements listed in Chapter 4. Although some degree of compromise is inevitable, the instruments as designed meet a broad cross-section of the GMT science goals. It is unlikely that all of these instruments will be built as part of the first generation instrument complement. A down select will occur after each of the concepts has been developed to the point of maturity.

13.1.1 Instrument concepts and the GMT science goals

The requirements needed to meet our science goals span a broad range of the parameter space defined by wavelength coverage, field of view, spatial and spectral resolution. Many science programs call for large statistical investigations of faint targets and thus need highly multiplexed instruments with wide fields of view. Other science goals require the highest angular resolution and dynamic range possible and thus push adaptive optics instruments to their theoretical limits.

The suite of candidate first generation instruments contains two survey instruments, two high resolution spectrographs and two adaptive optics imaging spectrographs. The wide field optical spectrograph (GMACS) will address studies of galaxy evolution, tomography of the IGM, and probes of dark energy and dark matter. NIRMOS, the near-IR counterpart to GMACS, will push galaxy evolution studies to higher redshifts and will allow observation of rest-frame visible spectral diagnostics of the evolution of the chemical and stellar content of galaxies and AGN. Together these two instruments will provide an unprecedented capability for faint object studies over cosmologically representative volumes.

The two high-resolution spectrographs are tools aimed primarily at questions of fundamental stellar astrophysics. The high-resolution optical spectrograph will enable studies of nucleosynthesis over a range of stellar types and environments, while the near-IR Echelle (GMTNIRS) will provide a powerful probe of young stars and the dynamics and chemistry of stars embedded in dense clouds. These instruments will also enable studies of the evolution of the IGM through high-resolution spectroscopy of AGNs and GRBs to the highest redshifts.

Lastly, the two diffraction-limited imagers will open a window on the universe at high spatial resolution. The mid-IR imaging spectrograph (MIISE) will allow us to image young planets in the 5 and 10μm windows with high dynamic range. The near-IR AO imager (HRCAM) will explore the properties of bright exoplanets via their reflected light. These instruments, and HRCAM in particular, are powerful multiuse tools with wide application. HRCAM will be used to study the internal structure and dynamics of galaxies and AGN, the probe dense star clusters in the galaxy, the local group and beyond, and will measure the masses of black holes at the extreme ends of the mass distribution.

The instrumentation for ExAO will be implemented in two phases. The initial 1-2.5μm AO camera will incorporate a mode for simultaneous differential imaging, the exoplanet imaging strategy proven at the VLT. At GMT this method has the potential to reach contrast levels of 10^7. It is envisaged that a second instrument will be built to realize the telescope's full potential for detection at a contrast of 10^8 at 56 mas, as considered in Chapter 9, and will be completely dedicated to the ExAO task. This instrument will be designed later and will address a very small field and make use of the highest sensitivity IR detectors available at the time of commissioning.

The list of candidate first generation instruments and their basic requirements are laid out in Chapter 4 (see Table 4-3). We briefly summarize the properties of the proposed instrument concepts as they now stand in Table 13.1 and review their overall properties in sections 13.1.1 through 13.1.6.

Table 13-1. Instrument concepts

Instrument	λ(μm)	Resolution	FOV	Notes
GMTNIRS	1-5	50-120K	2″	Si Emersion R2 & R4 Echelle
MIISE	3-28	5-2000	2′ x 2′	Two Channels; nulling
HRCAM	1-2.5	5-2000	1′ x 1′	Coronographic mode
NIRMOS	0.9-2.5	1500-3500	5′ x 5′	7′ x 5′ imaging field of view
GMACS	0.4-1.0	3500-5000	9′ x 18′	Four double spectrographs

13.1.2 GMTNIRS

The key science goals for the near-IR high-resolution spectrometer are centered on problems in stellar astrophysics and star formation. The instrument will be optimized for observations of stellar photospheres in the 1-5 micron range. The instrument is deployed in two modules, one addressing the 1-2.5μm region, the other addressing the 3-5μm atmospheric windows. The two-channel approach allows optimization of cameras, detectors and entrance apertures. The small size of the individual modules will allow them be deployed on the upper instrument platform.

The short wavelength channel will be optimized for the natural seeing PSF. It will use a 300mm Si immersion grating producing an R3 immersion Echelle with an 83mm collimated beam. The slit-limited resolving power is 10^5 for a 0.15" slit and 2.5×10^4 for a 0.6" slit. The long-wavelength channel will have a scale and slit size matched to the diffraction-limited PSF at 3.5μm. A single 2048 x 2048 array will allow coverage of the entire L band with adequate spacing between the orders.

13.1.3 MIISE

This instrument will operate in the 3-28μm atmospheric windows. Its primary function is to produce high-resolution high-dynamic range images using LTAO. The main science drivers for this instrument are studies of young planets and star formation in obscured regions, although there are also applications in wide range of fields. This instrument will be deployed on the upper instrument platform and will be integrated with the facility AO and wavefront sensing system.

The instrument concept is an outgrowth of a similar instrument under construction for the LBT. The instrument is split into two cameras, one operating in the 3-5μm windows, and the other working in the 8-25μm bands. Each channel will have scales matched to critically sample the diffraction-limited PSF at the short end of its wavelength range. The short wavelength channel can be used in coronographic and spectroscopic modes via an intermediate focal plane. The long wavelength channel provides for nulling interferometry.

13.1.4 HRCAM

This instrument will be the workhorse camera for diffraction-limited imaging in the near-IR. It will have a mode optimized for high-dynamic range ExAO imaging, yet it will also produce diffraction-limited images with Strehl from ~0.2 – 0.7 over fields of 30″ x 30″ or more. It will use the GMT adaptive secondary and LTAO system to deliver an AO corrected beam. The instrument will feed a 4k x 4k focal plane array with a pixel scale matched to Nyquist sample the PSF at 1μm. This instrument will also be deployed on the upper instrument platform and will be integrated into the facility adaptive optics wave-front sensing system.

13.1.5 NIRMOS

The near-IR multi-object imaging spectrometer will be a survey class instrument aimed at photometric and spectroscopy studies of faint galaxies and other high surface density targets. It will be optimized to make use of a GLAO corrected PSF, although it will also perform well with seeing-limited images. The design is based on a refractive camera-collimator combination using CaF_2 and BaF_2 elements. The instrument will image a 7′ x 5′ field and take spectra over a 5′ x 5′ field. Multiplexing is accomplished via removable slit masks. A set of VPH gratings will provide resolving powers of ~ 3000 in each of the J, H, and K bands; coarse surface relief gratings will allow coverage of two bands simultaneously with R~1500. Rotating pupil masks will be used to remove sky and thermal emission from the gaps between the primary mirror segments. The camera-collimator combination feeds a 6K x 10K focal plane mosaic, possibly built from Rockwell Scientific Hawaii 2RG HgCdTe arrays. This instrument will be deployed at the straight Gregorian focus.

13.1.6 GMACS

The wide-field optical spectrograph is based on a multi-armed system comprised of four separate multi-slit spectrographs. Each spectrograph is a double spectrograph with red and blue channels addressed by dichroic beam-splitters. The field of view of each spectrograph is 4’ x 9’, giving a total field of roughly 8’ x 18’ and a total field area of 140 square arc-minutes. VPH transmission gratings will deliver resolving powers of 3000 and greater for slits ~0.7” in width. The blue and red arms will use optimized coatings, grisms, and detectors. Two-by-eight mosaics of 3-side-buttable CCDs are envisions for each channel. Multiplexing factors of ~ 400 should be achievable. This instrument will be located at the straight Gregorian focus and will use the wide-field corrector and atmospheric dispersion compensator. The instrument is likely to be optimized for spectroscopy and may not provide a suitable imaging capability. It is possible that not all arms of the spectrograph would be commissioned as part of the first generation instrument suite; additional spatial or wavelength channels could be added as funds and schedule allow.

13.1.7 Second Generation Instruments

The concepts discussed below address the need for a first generation of instruments that address a broad range of science goals and aid in the development of the telescope architecture. At the project progresses we will continue to explore new concepts that make use of developing technologies. Areas of particular interest include OH suppression Bragg fibers, energy resolving detectors, and fast photon counting IR arrays. The second generation GMT instruments are likely to be more specialized and targeted a high priority science questions that come to the fore as we approach first light.

The AO instruments described below present our concepts for diffraction-limited instruments using mature technology. These instruments will not meet our most ambitious goals, such as achieving contrast levels of 10^8 on 50 mas angular scales. The AO system described in Chapter 9 is very powerful and will form the foundation of our approach to high-resolution and high-dynamic range imaging. We recognize that considerable challenges remain in developing instruments that realize the full capability of the GMT AO system and we expect to devote a great deal of energy to this process in the design development phase of the project.