

GMT Primer for Science Planning

When thinking about science that one might do with the GMT it would be helpful to have a clear understanding of what the telescope is likely to be able to deliver. In this brief write-up we list the key properties of the telescope, its AO system, and candidate first light instruments. Where possible we also include estimates of sensitivities and scaling laws from telescopes of different aperture.

Overview of Telescope: The GMT primary mirror is composed of seven segments, each 8.4m in diameter. The equivalent filled circular aperture is 22m in terms of collecting area and 24.5m in terms of diffraction. The secondary mirror is also segmented and the secondary segments map one-to-one to the primary mirror segments. The baseline plan is for the secondary mirrors to be adaptive, but there may be other modes for AO early in the life of the telescope. The telescope is built on an Alt-Az drive and will point to elevations of 25 degrees and will be able to track non-sidereal targets.

AO Systems: The GMT will support a number of modes of adaptive optics providing a range of correction, field size and sky coverage. The primary AO mode will be Na D laser guide star tomography. This will provide moderate Strehl diffraction-limited images with high sky coverage. Ground-layer correction with the adaptive secondary should provide an improved seeing-like PSF over a field of $\sim 6\text{-}9'$ in diameter. The exact degree of improvement and nature of the PSF are poorly understood at this time and may vary considerably with atmospheric conditions. Extreme AO is expected to produce contrasts of up to, and perhaps in excess of, $10^8:1$ at a radial distance of $\sim 3\lambda/D$ and lower contrasts into closer working distances.

The diffraction-limit of the telescope at $1\mu\text{m}$ is 10mas. The AO system is expected to deliver images with a resolution of $\sim 12\text{-}15\text{mas}$ at $1\mu\text{m}$ and a similar image size in the H-band.

Candidate first-Generation Instruments: The GMT science working group and Project Scientists have identified a list of candidate first generation instruments. The project construction budget is unlikely to support all of these instruments as part of the first generation build. Nonetheless it would be helpful to frame science discussions in terms of these instruments, or other practical concepts.

The current instrument candidates are:

High-resolution optical echelle: The requirements and concept for the optical echelle call for a one-arcsecond slit resolution product of 40,000. Thus one could achieve resolving powers of 40-100K with reasonable slit widths. The QSPEC concept uses four separate wavelength optimized arms covering relatively small portions of the spectrum between the UV (3200A) to the near-IR (1micron). This should provide very high throughput via optimized coatings and detectors.

Visible Multi-Slit Spectrograph: The concept for a GMT multi-slit spectrograph in the optical uses spatial and wavelength multiplexing to provide a large field of view and high spectral resolution. The four spatial channels will cover a field of $9' \times 18'$, a full $18' \times 18'$ field could be covered with lower throughput. The resolving power of the spectrographs is around $R \sim 3500$ for a $1''$ slit in the red and $R \sim 1500$ in the blue. Multi-slit masks could support one hundred or more slits.

Near-IR Multi-Slit Spectrograph: The near-IR MOS design for GMT, NIRMOS, samples the J, H and K windows over a $5' \times 7'$ field of view with resolution sufficient to allow one to work between the OH sky lines. The spectrograph will use multi-slit masks and it should be possible to use on the order of 100 slits.

Near-IR Echelle: A concept for a high resolution 1-5micron spectrograph has been developed for the GMT. The instrument will provide $R \sim 75,000$ spectra in the J, H and K windows. A separate instrument channel will address the 3-5micron windows using a slit matched to the diffraction-limit of the telescope and produce $R \sim 120-150K$. Both sides of the spectrograph are single-object instruments and cannot be used simultaneously.

Mid-IR Imaging Spectrometer: A two-channel 3-25 micron imaging spectrometer has been designed with the intent of imaging young massive planets via their thermal IR signature. The instrument has two channels, one operating in the 3-5 micron windows, the other in the 8-25 micron windows. The instrument should have coronagraphic and nulling interferometer modes.

Near-IR AO fed IFU: An integral field spectrograph will span a $\sim 3''$ diameter field of view with pixel scales ranging from 50mas to ~ 10 mas. The coarse sampling will be tuned to high redshift galaxies, the fine scale will Nyquist sample the PSF at 2.2 microns and will be used to study black holes and crowded stellar populations. The resolution, $R \sim 5000$, will be targeted at both working between the OH lines and measuring the velocity fields of distant galaxies. This instrument will sample the J, H and K windows.

Near-IR AO Imager: The J, H, Ks AO imager is a $1' \times 1'$ fov camera that Nyquist samples the diffraction-limited LTAO PSF at 1 micron. It is intended as a generic high-contrast imaging system that can be used for exoplanets, stellar populations studies and structural studies of distant galaxies. This capability may be duplicated in part by an imaging mode in the IFU instrument.

In the table below we list the basic properties of the candidate instruments and in Figure 1 and 2 we give the results of ETC estimates of the sensitivity of basic modes of GMACS and NIRMOS. Lastly, in table 2 we list the scaling for sensitivity and speed for the various instruments. Seeing-limited instruments scale like D for sensitivity and D^2 for speed except in the case of source-limited observations.

Table 1. Basic Properties of Candidate 1st Generation Instruments

Instrument	λ range (microns)	Resolution	FOV	P.I.
Optical Multi-Object Spectrometer	0.35-1.0	250-4000	18' x 18'	Shectman
Near-IR Multi-Object Spectrometer	1.0-2.5	Up to ~4000	7' x 7'	Fabricant
Optical High Resolution Spectrometer	0.3-1.05	45K 1" slit	3" + fibre mode	MacQueen
Near-IR Echelle	1.0 - 5.0	50-120K	Single Object	Jaffe
Mid-IR Imaging Spectrometer	3.0-25.0	1500	30"	Hinz
Near-IR AO Imager	0.9-5.0	5-5000	30"	Close
NIR AO-fed IFU	0.9-2.5	3000-5000	1.5"	McGregor

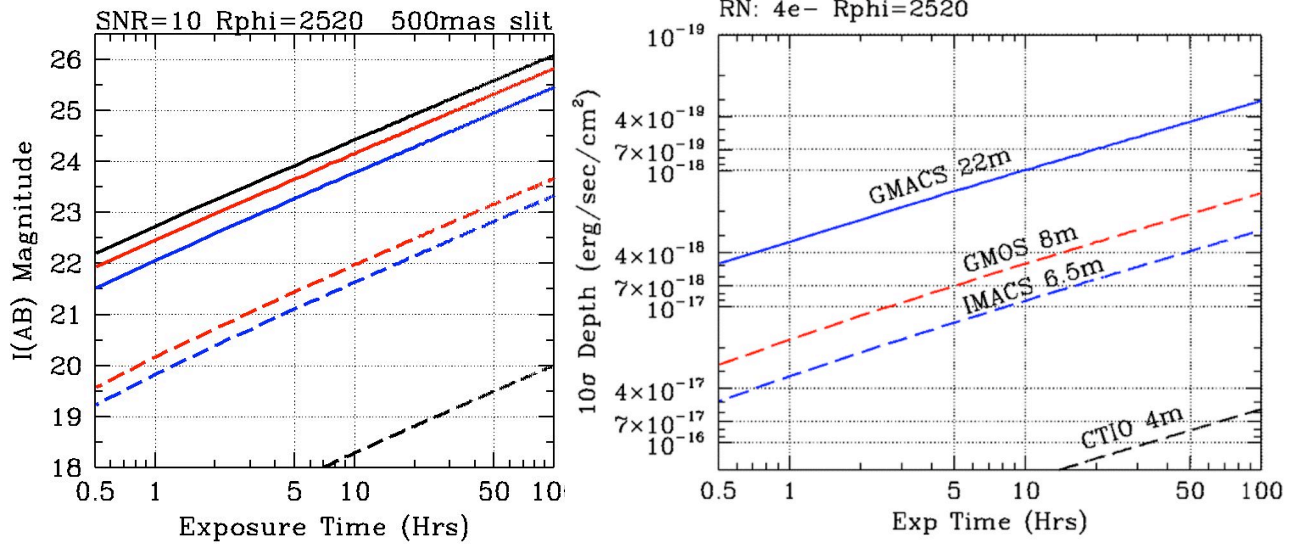


Figure 1. (left) 10σ limiting sensitivities per pixel for continuum observations with GMACS. These estimates are for a 0.5" slit in median seeing using a resolving power of $R = 5040$. (right) 10σ emission-line sensitivities for the same observing parameters. In both panels the x-axis is the exposure time in hours with log spacing. $R\phi$ is the product of the slit width and resolution, or equivalently, the 1" slit resolving power.

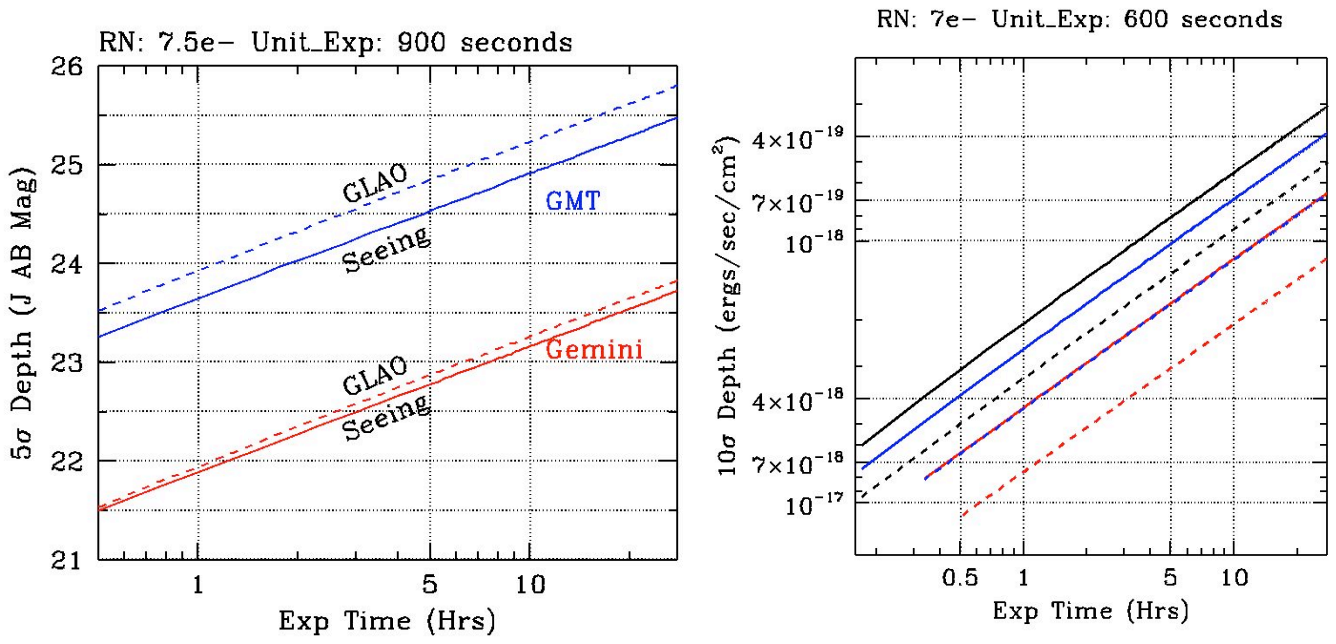


Figure 2. (left) 10σ limiting sensitivities per pixel for continuum observations with NIRMOS in the J-band. These estimates are for a $0.5''$ slit in $0.45''$ seeing using a resolving power of $R = 3200$. The detector read noise was taken to be $7.5e^-$ with a gain of 2 and unit-exposure times of 600 seconds. The inter-line sky was assumed to correspond to “grey” conditions. (right) 10σ emission-line sensitivities for the same observing parameters. In both panels the x-axis is the exposure time in hours with log spacing.

<i>Instrument</i>	<i>Sensitivity</i>	<i>Speed</i>	<i>Notes</i>
Optical Echelle	D	D^2	Sky-limited
Optical MOS	D	D^2	Seeing-limited
Near-IR MOS	D^1	$\sim D^3$	GLAO PSF
Near-IR AO-fed IFU*	D^{1-2}	D^{3-4}	Diff. limited
Near-IR Echelle	D^2	D^4	Source-limited
Mid-IR Imager	D^2	D^4	Sky-limited
PRV Echelle	D	D^2	Source-limited
Near-IR AO Imager	D^2	D^4	Sky-limited

* Some components of distant galaxies will be resolved and won't gain by D^4

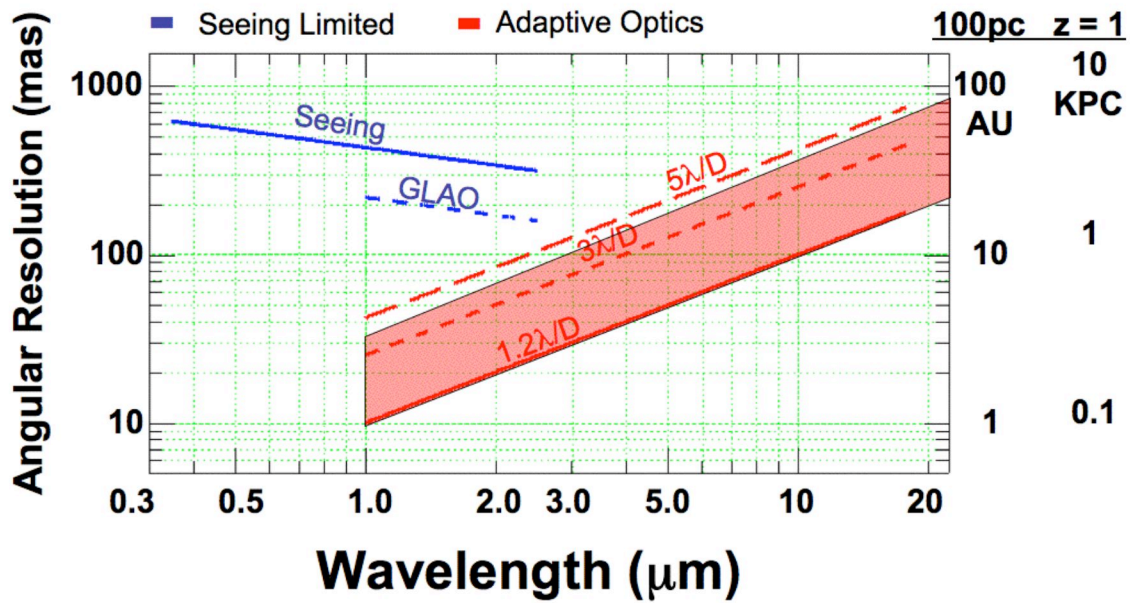


Figure 3. Angular resolution discovery space for the GMT. The red lines show the resolving power ($1.2\lambda/D$) and typical inner working radii for high contrast AO modes as a function of wavelength. The angular scale, in milli-arcseconds, is shown on the left, linear scales at 100pc and at $z = 1$ are shown on the right. The shaded red area is the new discovery space compared to existing 8m telescopes. The diffraction limit at $1\mu\text{m}$ projects to 1AU at 100 pc and 100pc at $z = 1$.

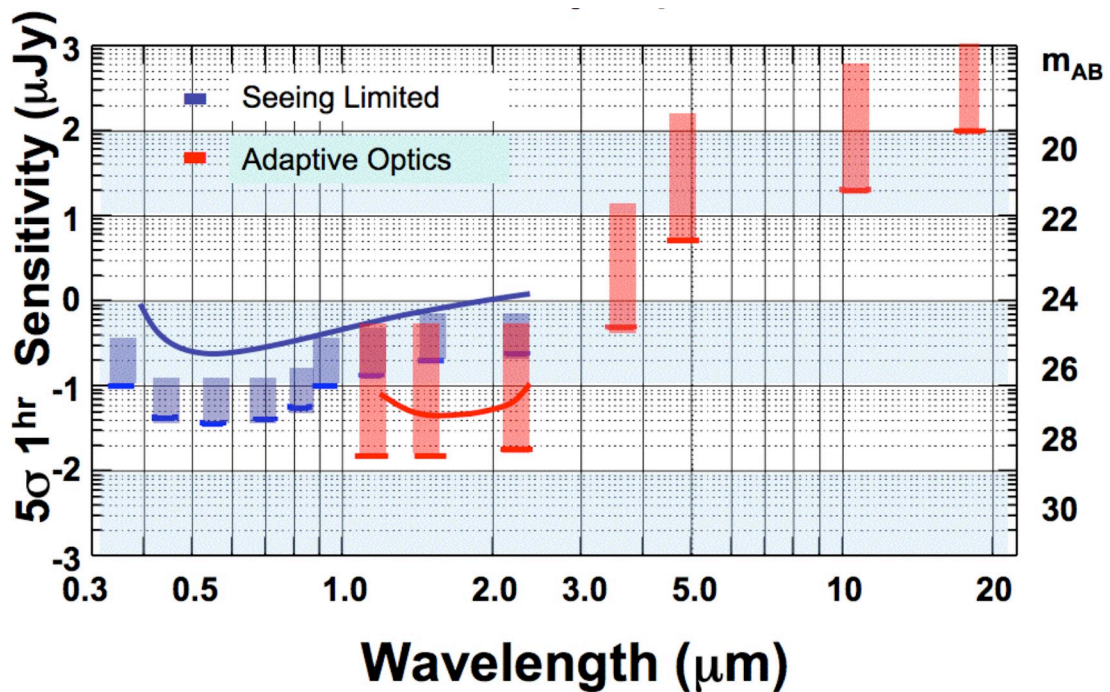


Figure 4. The depth discovery space for GMT. The 5σ 1-hour integration imaging sensitivities for various pass bands are shown by the horizontal bars. The scale on the left is in micro-Janskys, the scale on the right is AB magnitudes. The curves show the limits for intermediate resolution spectroscopy. The shaded vertical bars show the gains over current 8m telescopes. The top of the shaded bars are the 8m sensitivity, the bottom is the GMT sensitivity. The gains in the near-IR where AO is powerful and the sky is relatively dark are most dramatic.