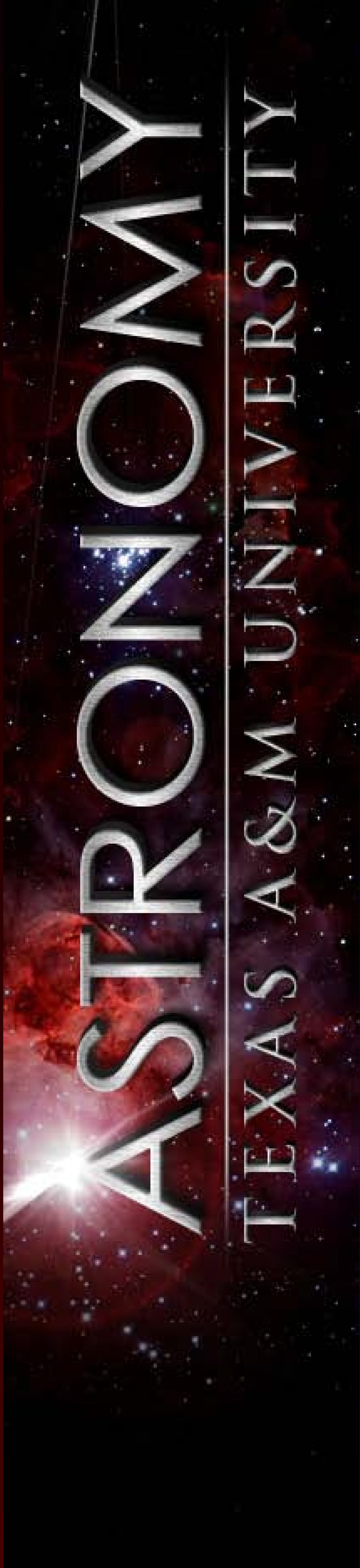
The GMACS Spectrograph for the GMT

J. L. Marshall[1], D. L. DePoy[1], S. A. Shectman[2], C. Papovich[1], S. A. Smee[3], R. H. Barkhouser[3], T. M. Prochaska[1], R. P. Hammond[3]

[1]Texas A & M University, [2]GMT Observatory, [3]JHU/IDG.



Abstract

We describe a conceptual design for a wide field, multi-object, moderate-resolution optical spectrograph (known as GMACS) for the Giant Magellan Telescope (GMT). The crucial design drivers for the instrument are high throughput, simultaneous wide wavelength coverage over the entire optical window, and accurate and precise sky subtraction. The range of science projects enabled by the instrument is huge: from mineralogical studies of distant asteroids and KBOs to stellar population studies of high redshift galaxies.

Science with GMACS

The ability to obtain moderate resolution spectra of astronomical targets at optical wavelengths has been a fundamental scientific capability for more than a century. The GMACS spectrograph on GMT will be able to observe targets that can be only imaged with broadband filters today; the scope of future science opportunity with this instrument and telescope is vast. We expect that GMACS will form one of the most basic scientific capabilities of the GMT.

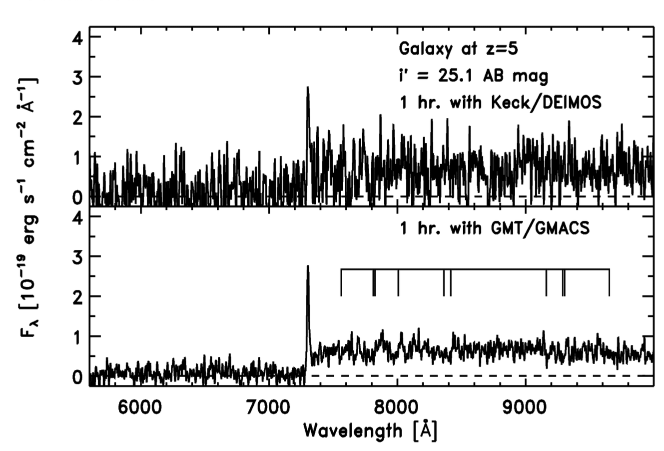
The GMACS Conceptual Design Report outlines several specific science cases (see http://instrumentation.tamu.edu/gmacs.html) for which GMACS will be particularly powerful. However, it is worthwhile pointing out explicitly that these specific cases are merely representative of the science that GMACS can and will produce.

- **Evolution of the distribution of cold gas around galaxies from z=2 to z=4**
- **Measuring evolution of Lyα emission fraction in galaxies at z < 7.4.**
- **Census of local group dark matter mass function and the dark matter profiles of dwarf galaxies**
- **Constraining the galactic halo and galactic center through spectroscopy of galaxy halo and hypervelocity stars**
- **The end of the stellar mass function: identifying brown dwarfs and cool subdwarf stars**
- **Measuring the faint end slope of the Lyα luminosity function at z ~ 6**
- **White dwarfs as a probe of stellar evolution**
- **Surface composition of Kuiper Belt Objects**
- **A measurement of the galaxy power spectrum at z > 2.5**

In the CoDR we also describe in detail specific synergies with LSST that will make GMACS+GMT a powerful instrument in the southern hemisphere. Below we outline two specific science cases that GMACS+GMT will be able to complete particularly well:

The evolution of the distribution of cold gas around galaxies from z=2 to z=4

The intervening absorption systems in background galaxy spectra provide our best constraints on the extent of cold gas in the circumgalactic medium around distant galaxies. Rest-frame UV spectra of distant galaxies allow for the detailed study of galaxy-scale outflows of cold gas via strong interstellar absorption lines and Lyman-alpha emission. GMACS observations could provide the first direct detection of these cold-gas components at these redshifts.



Simulation of the expected GMACS data quality of a galaxy at z=5 with i=25.1 AB mag. The top panel shows a simulated spectrum of the galaxy in 1 hr with Keck/DEIMOS where the S/N is ~0.5 per pixel and only Lyman-alpha in emission would be detected (if present). The bottom panel shows the equivalent spectrum with 1 hr on GMACS, where the predicted S/N is ~5 per resolution element. In this spectrum, galaxy ISM absorption lines are already visible.

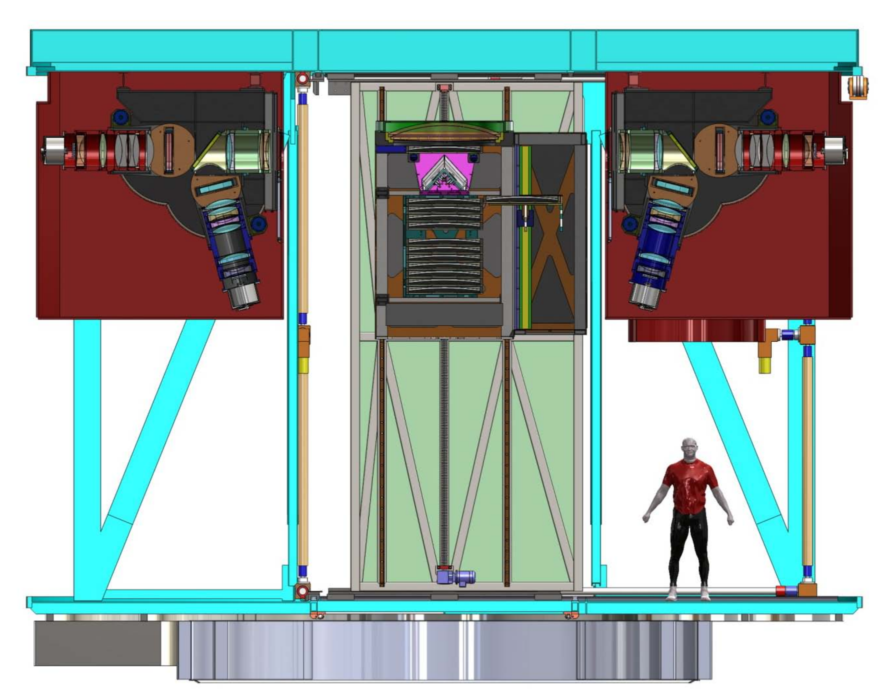
Census of local group dark matter mass function and the dark matter profiles of dwarf galaxies

Assuming that the dark-matter halo of the Milky Way tracks the expected distribution of sub-halos in the current Lambda-CDM paradigm, there could be as many as 1000 satellites within 400 kpc that are brighter than the faintest known dwarf galaxies. Current results (e.g., Simon & Geha 2007, Tollerud et al. 2008) alleviate the primary worries of the so-called missing satellite problem in CDM if various assumptions about the completeness limits from the Milky Way are correct. However, these same models predict that deep, wide-field surveys such as DES and LSST will deliver a complete census of dwarf satellite candidates out to the virial radius of the Milky Way, offering the potential of new limits on the free-streaming scale of dark matter and the low-luminosity threshold of galaxy formation in the faintest galaxies.

GMT+GMACS will provide highly efficient follow-up of dwarf galaxies discovered in forthcoming imaging surveys. GMACS has the appropriate field-of-view (some dwarfs will have diameters up to 30 arcminutes), spectral resolution (R~5000), and sensitivity (1500 stars per night at R=21.2, 35 min with velocity uncertainties 3 km/s) to do this science. Surveys with GMT+GMACS can target up to 15 dwarf candidates from wide-field surveys per night, with the potential to more than double the number of known dwarfs in as little as a few nights.

Instrument Overview

Wide field, multi-object spectroscopy will be a key capability for the Giant Magellan Telescope (GMT). The GMACS instrument on GMT will enable new science that has not been possible to this point. Here we present the GMACS conceptual design, which meets the technical requirements set by the science cases we have outlined for the instrument.

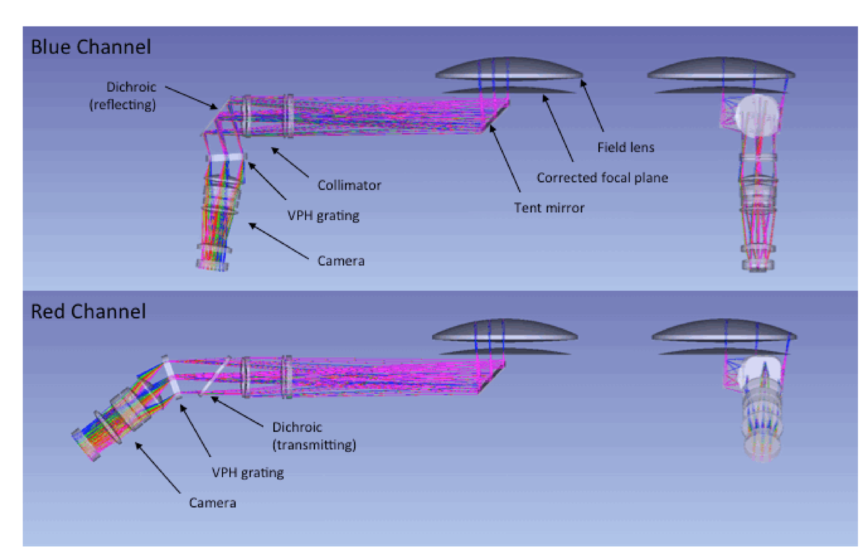


The technical objectives drawn from the GMACS science case include:

- **Sensitivity: High throughput: >50% at peak and no worse than 30% at any wavelength**
- **Sensitivity: Detectors with low readout noise (<5% addition to background noise)**
- **Excellent image quality: <0.2 arcsec rms over the entire detector plane**
- **Accurate and precise sky subtraction: use direct slits**
- **Multi-object capability: focal plane masks**
- **Wide field: large focal plane masks**
- **Broad wavelength coverage: at least 400-950nm (goal is 350-1100nm)**
- **Moderate resolution: R~1000-5000**
- **Seeing limited operation: 0.7 arcsec slit (could make use of GLAO in the far red)**
- **Spectral accuracy over long exposures of <0.1 resolution element; flexure compensation**

The GMACS conceptual design presented here meets or exceeds all of these requirements.

Optical design

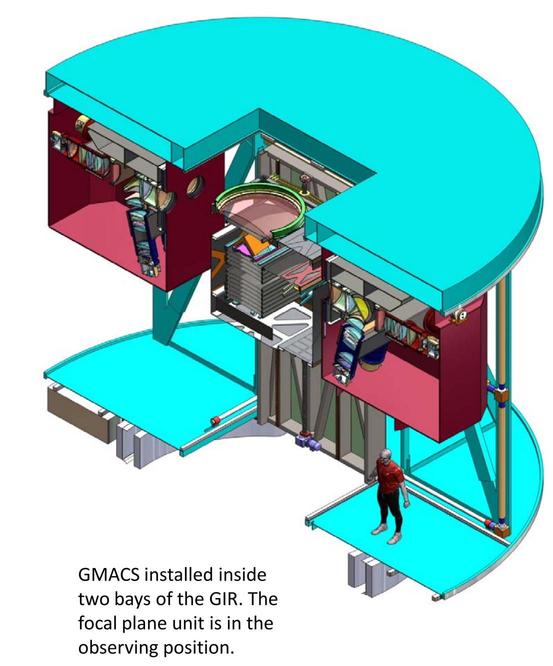


Optical ray tracing diagram of one arm only, showing the blue and red channels in two orthogonal orientations. For scale, note that the large initial lens is the final element of the GMT wide field corrector, which is ~1.5m in diameter.

The GMACS optics provide complete, simultaneous spectral coverage over the wavelength range from 0.38 to 1.0 μm for hundreds of objects in an 9×18 arcmin field of view. The resolution with a 0.7 arcsec slit is 1400 in the blue and 2700 in the red. GMACS incorporates a multi-slit mask to provide the best possible sky subtraction and instrumental throughput. To create the maximum possible field, the optical design divides the focal plane into four quadrants and makes use of multiple collimators and cameras with fields of 4.5 × 9 arcmin each, providing a 9 × 18 arcmin overall field of view. The total available slit length is 36 arcmin.

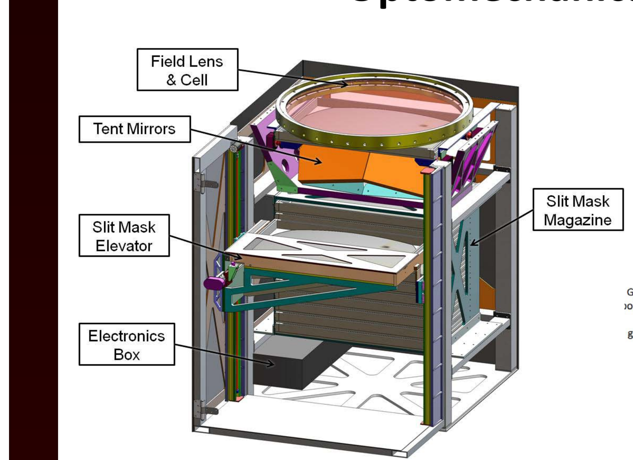
GMACS on GMT

GMACS will be mounted inside the GMT Gregorian Instrument Rotator (GIR). Three distinct assemblies will be mounted inside two bays of the GIR. The top of each bay holds the main optics modules for two of the four GMACS channels. A central focal plane unit is stored in the bottom of one of the bays and is deployed to the focal plane when the instrument is being used. The remaining two bays of the GIR are reserved for other GMT instruments, which can be moved into the GMT focal plane when in use.

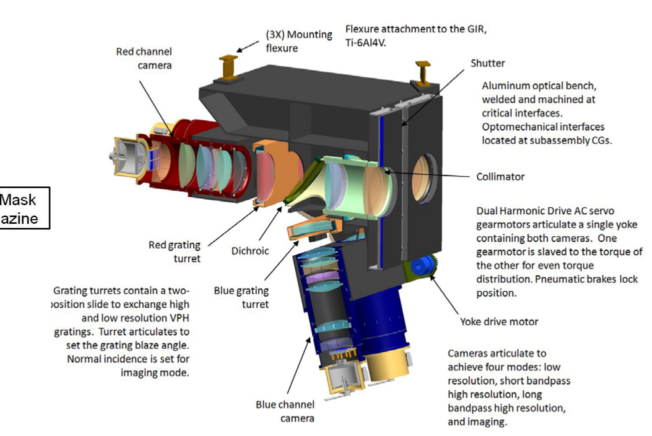


GMACS installed inside two bays of the GIR. The focal plane unit is in the observing position.

Optomechanical Subassemblies



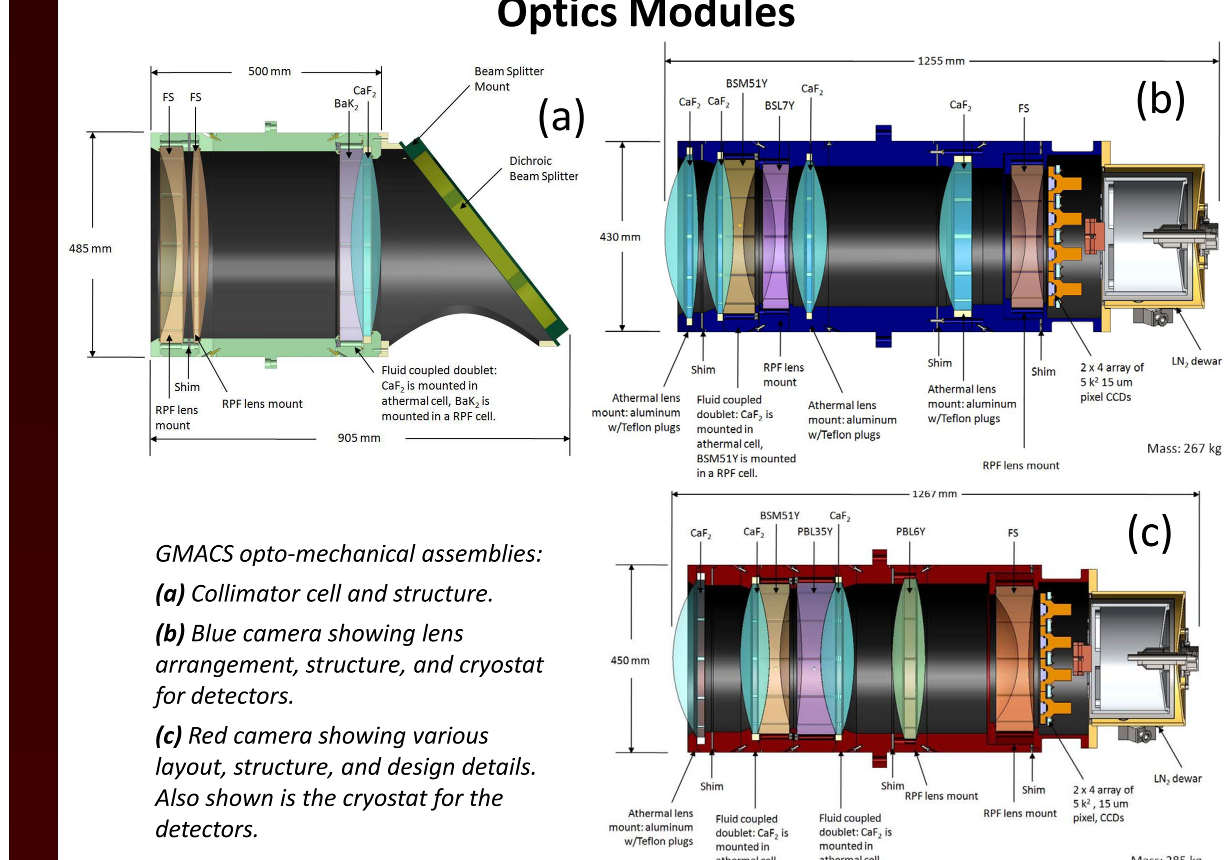
Focal plane unit and labeled sub-assemblies.



Cut-away of optics module with various additional detail.

The conceptual mechanical design of GMACS has two basic sub-systems: a focal plane unit that translates into the active space in the GIR and is lifted to the telescope focal plane via an elevator mechanism and a pair of optics modules that contain the individual arms and channels. The focal plane unit is stored in the lower half of one GIR bay; the optics modules are permanently fixed to the "ceiling" of the GIR and occupy the top half of two bays.

Optics Modules



GMACS opto-mechanical assemblies:

***(a)** Collimator cell and structure.*

***(b)** Blue camera showing lens arrangement, structure, and cryostat for detectors.*

***(c)** Red camera showing various layout, structure, and design details. Also shown is the cryostat for the detectors.*

The GMACS focal plane is divided into four arms, two per optics module. The light is split in each arm into a red and blue channel. Each arm contains a collimator, dichroic, four VPH gratings (low and high resolution for each bandpass), and a red and a blue camera. Each pair of cameras (red and blue on each side) articulate as a pair to achieve different spectroscopic modes.

Texas A&M University Department of Physics and Astronomy is an institutional member of:

Munnerlyn Astronomical Instrumentation Lab, Texas A&M University · GMT · HETDEX: Hobby-Eberly Telescope Dark Energy Experiment — Illuminating the Darkness · LSST: Large Synoptic Survey Telescope · Dark Energy Survey

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