An Update on the Wide Field, Multi-Object, Moderate-Resolution, Spectrograph for the Giant Magellan Telescope

D. L. DePoy[a], R. Allen[a], T. Li[a], J. L. Marshall[a], C. Papovich[a], T. Prochaska[a], and S. Shectman[b]

[a]Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843-4242; [b]Observatories of the Carnegie Institution for Science, 813 Santa Barbara Street, Pasadena, CA 91101

ABSTRACT

We review a conceptual design for a moderate resolution optical spectrograph for the Giant Magellan Telescope (GMT). The spectrograph is designed to make use of the large field-of-view of the GMT and be suitable for observations of very faint objects across a wide range of wavelengths. We also review the status of the instrument and on-going trade studies designed to update the instrument science objectives and technical requirements.

Keywords: Extremely Large Telescopes, spectrographs

1. INTRODUCTION

Wide field, multi-object spectroscopy is a key capability for the Giant Magellan Telescope (GMT). Indeed, the original GMT Science Requirements document[1] states: "A spectrometer operating in the visible spectrum (0.32 µm to 1µm) with the capability to observe multiple targets simultaneously is critical to our goals in the areas of star formation, stellar populations and most extragalactic science." 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 scientific information content of such measurements remains high and this capability is unlikely to become obsolete over the expected lifetime of the GMT.

We present an update on the status of the design of the Wide Field, Multi-Object, Moderate-Resolution Spectrograph (called GMACS) for the GMT in this paper. Ultimately, the goal is to build and use an instrument capable of observing the faintest possible targets, those that are substantially fainter than the sky. High throughput, simultaneous wide wavelength coverage, accurate and precise sky subtraction, moderate resolution, and wide field (for an extremely large telescope) are the crucial design drivers for the instrument. These objectives guide our design decisions and are practical choices for the instrument. We believe that meeting these objectives will result in an instrument that will produce a vast range of science at the GMT and satisfy most community needs for optical spectroscopic observations of faint objects.

The science drivers and concept design for the instrument originated more than 10 years ago. Since then the telescope and specific scientific motivation for the instrument have evolved. In particular, the plan for the construction and commissioning of the GMT has changed as various pragmatic constraints have been realized. In response, we are re-examining the science case for the instrument and refreshing the requirements that the instrument must meet to satisfy the expected user community.

2. DESCRIPTION OF ORIGINAL INSTRUMENT CONCEPT

The GMACS conceptual design[2,3,4] provides complete, simultaneous spectral coverage over the wavelength range from ~0.38 to 1.0µm, for hundreds of objects in a 9 ×18 arcmin field of view. The instrument concept splits the GMT focal plane into four "arms", each of which is fed to a "two-channel" spectrograph (that is, each arm sees a 4.5 arcminute × 9 arcminute off-axis field and feeds a double spectrograph). The default resolution with a 0.7 arcsec slit is ~1400 in the blue (at ~520nm) and ~2200 in the red (at 740nm) in the low-resolution mode; the resolution with the same slit in the high-resolution mode is ~2600 in the blue (at ~520nm) and ~4000 in the red (at 740nm). The GMACS concept is

Ground-based and Airborne Instrumentation for Astronomy V, edited by Suzanne K. Ramsay, Ian S. McLean, Hideki Takami, Proc. of SPIE Vol. 9147, 914720 · © 2014 SPIE · CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2056801

designed around a multi-slit approach to provide the best possible sky subtraction and instrumental throughput. The optical design makes extensive use of refractive elements and has a baseline beam diameter of ~300 mm. Typical optical element sizes are ~400 mm. To create the maximum possible field, the optical design assumes the presence of a telecentric corrector and multiple collimators and spectrographs that would be deployed across the telescope focal plane in a "fly's-eye" approach.

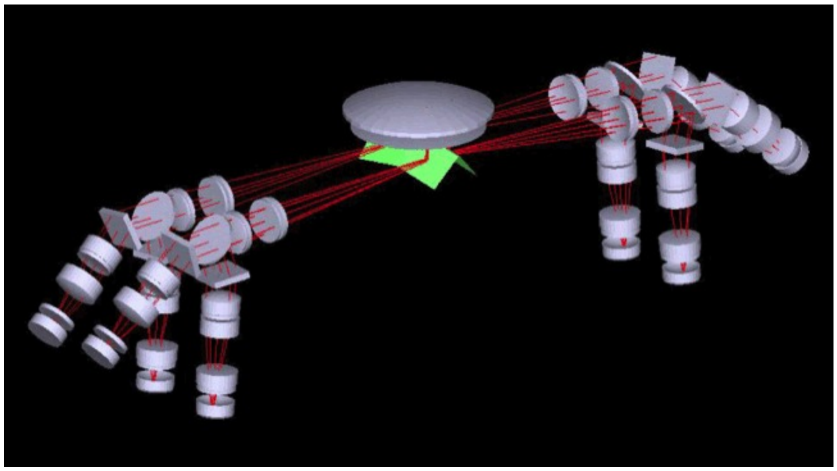

Figure 1: General optical layout of the GMACS design. The large lens in the middle is the last element of the GMT wide field corrector. The green "tent" looking reflections are the four mirrors that direct the quadrants into the individual spectrograph arms. Each arm consists of a two-channel spectrograph.

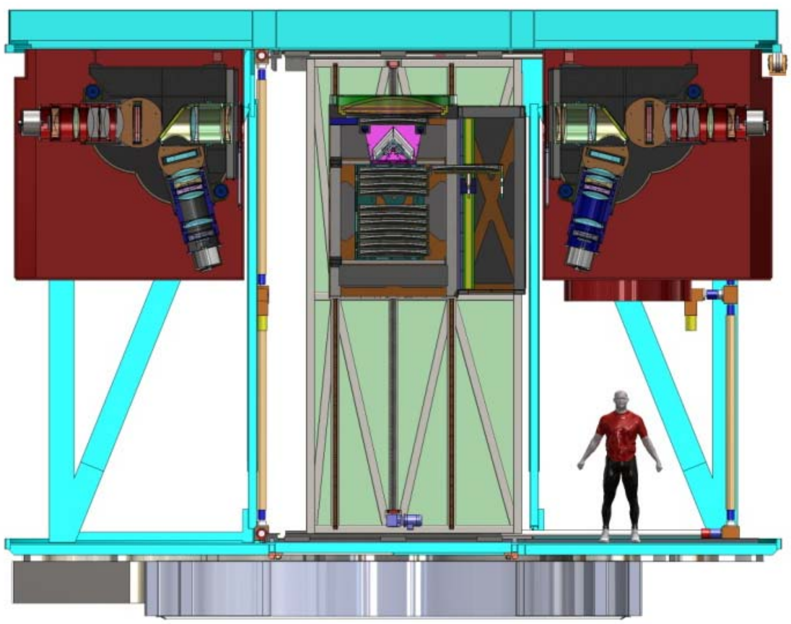

Figure 2: Section view of the GIR with GMACS installed. A person is given for scale.

We plan to review this concept and modify elements of the design as required after the development of a renewed science case and technical requirements.

3. UPDATED SCIENCE CASE

The GMT community participated in a workshop on March 18-19, 2014 at Texas A&M University, in College Station, TX to discuss the scientific requirements for GMACS, the wide-field spectrograph for the GMT. The workshop included 51 participants, representing all the GMT partners, and representatives from non-partners. The participants included expertise in a wide range of astrophysical research. The workshop summary is captured in Table 1. This provides a summary of the technical requirements and goals from the different key science programs. The table lists the requirements and goals, where the goals are in addition, to the requirements.

Clearly, science cases exist for a large range of technical capabilities, and this range enables different science opportunities, all of which are of interest to some segment of the astronomical community. Some consensus exists: the majority of the science case require red spectroscopic coverage with moderate resolution, more than half require blue coverage or set it as a goal, while about half the science cases have the goal of including coverage into the J-band. While not stated explicitly, simultaneous coverage over a large range of wavelength would maximize the efficiency of almost all science cases. Trade-offs will be required in the instrument design. The goal of the science requirements and their technical requirements for the wide-field spectrograph on the GMT will be to maximize the ability of the instrument to enable the most science for the GMT partners and larger astronomical community.

Table 1. Science drivers identified at the GMACS Workshop.

	wavelength range		**Resolution (R)**		**FOV (arcmin)**		
Science Case	**req.**	**goal**	**req.**	**goal**	**req.**	**goal**	**Other constraints**
Time-Domain Science	from blue (370nm) to red (1000nm)	J-band	low [3000 (for IGM studies)]	5000 for IGM studies	N/A	N/A	high relative precision/repeatability/efficiency of operations. Large simultaneous wavelength coverage.
Exoplanet Atmospheres	red 550-950nm	blue 350-550nm	2000		~5		minimum "deadtime" between exposures
Brown Dwarf Meterology	blueward of JWST coverage		2000		~5		
Ages of Stars/Star Clusters	red: coverage of Li 670 nm	blue: coverage of Ca HK 390-400nm; red	>3000: 2Å at 6708Å	7000 at Li 6708	~4	~7	
Accretion Rates in YSOs	blue: from Balmer jump 365nm red: to H-α	J-band: Coverage of He I at 1083nm	2000 at Hβ	4000 at Hβ	5	10 (even 30)	simultaneous wavelength coverage required to study temporal evolution of line profiles
Dwarf Galaxy dynamics	blue (370-520nm: CaHK, G Fe, MgI); red (CaT, 850nm)		2500 at 430nm; 5000 at 860nm		~4	20	3 km/s vel. precision. high vel. stability through night.
Abundances in dwarf galaxies, stars, star clusters	red (650-900nm)	blue 350-550nm	1200 at 500 nm	6000 in the red			simultaneous wavelength coverage desirable for efficiency
Redshift surveys	blue red	J	blue: 1000; red/J: 2000	blue: 2000; red/J: 3000	large		simultaneous wavelength coverage desirable; high multiplexing requirement: source density ~50-60/arcmin^2
Galaxy Assembly	same as ii.d.i		3000				
IGM/CGM	blue and red: 350-1000 nm	J-band	low, 1000 in the blue; 2000 in the red	blue: 2000 red: 5000; J: 3000	large		
Ly-alpha emission at z>6.5	red (650-900nm)	J-band	3000 at 900 nm	5000 in red/J	large		source density of $z > 7$ galaxies is 0.5/arcmin^2. $4<z<6$ galaxies have ~25/arcmin^2.
First Galaxies, z >> 7	J-band		3000 at 900 nm				all rest-frame UV lines shifted into J-band for $z>7$.

5. TRADE STUDY

In addition to renewing the science drivers for the instrument, we are also analyzing the cost and complexity of various technical requirements the instrument may need to meet to achieve these new drivers. We summarize the range and scope of these potential requirements in Table 2.

Table 2. Summary of principal trade studies.

Parameter	Range of Values to Explore	Comments
Field of view	30, 50, 75 arcmin sq.	Roughly equivalent to diameters of 8, 10, and 12 arcmin. Original GMACS (and TMT WFOS) have 4.5 x 9.0 arcmin fields (10' diameter)
Wavelength coverage	• Blue limit: 350, 375, 400 nm • Red limit: 930, 980, 1030 nm • Optional near-IR arm: 1.3, 1.5 μm	"Limit" refers to wavelength where throughput drops to 60% (blue) and 25% (red) of peak
Spectral resolution	• Blue: 1250-2500 • Red: 2500-5000 • Higher resolutions: 7500? 10000?	Assumes slit width of 0.7" and that the Rφ product is constant. At the higher resolutions, wavelength coverage may be sacrificed, but full coverage is required at the lower resolutions.
Peak throughput	45%, 55%, or 65%	Spectrograph only, not telescope, *Low priority*
Image quality	80% EE at 0.2, 0.4 arcsec	This parameter may be linked to resolution
Stability	0.1 and 0.3 resolution elements/hour	Affected, for example, by flexure or temperature
Option for corrector/ADC		This parameter may be linked to field of view, image quality, wavelength coverage, and throughput
Channels	Dual channel (blue, red), or single? Triple to include IR?	Also worth considering is an optical-IR dual channel configuration.
Mask storage	8 to 16 per night	Low priority
Cooling system	LN2, Cryocooler, Refrigeration	Low priority
Grating exchange		How many gratings per channel?

The goal of the trade study analysis is to allow coupling between a set of science drivers, technical requirements, and, ultimately, overall cost/schedule of the instrument.

6. CONCLUSIONS

We have a solid conceptual design for a wide-field, multi-object, moderate resolution optical spectrograph for the GMT; the concept fits in the available volume/weight constraints of the telescope instrument platforms and meets all of the initial science objectives. The scientific potential of the instrument is substantial and we believe that the range of specific science cases we have developed demonstrate that GMACS will have impact across most of modern astrophysics. If historical precedent is a guide, then GMACS will be one of the most heavily used and popular instruments on the GMT. The conceptual design of the instrument is soundly establishes a basis for the instrument and demonstrates mitigation of the most serious technical risks. The optical design performs well and all the individual elements can be fabricated. The mechanical design of the instrument fits within the allocated volume and is based on proven heritage. We have an excellent team and adequate facilities to design, fabricate, assemble, and test an instrument of this size and scale.

The science drivers and technical requirements for the instrument are in the process of being reviewed and up-dated. We are currently performing trade studies to determine an optimal mix of science capabilities, technical requirements, and cost of the instrument. We expect to begin re-development of the instrument concept, drawing heavily from previous work, in late-2014.

ACKNOWLEDGEMENTS

This material is based in part upon work supported through the National Science Foundation under Scientific Program No. 10 as issued for support of the Giant Segmented Mirror Telescope for the United States Astronomical Community, in accordance with Proposal No. AST-0443999 submitted by AURA. We also wish to thank Charles R. '62 and Judith P. Munnerlyn and George P. '40 and Cynthia Woods Mitchell and their families for generous contributions to our program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] http://www.gmto.org/Resources/GMT-ID-01404-GMT_Science_Case.pdf
[2] DePoy, D. L., et al. "GMACS: a Wide Field, Multi-Object, Moderate-Resolution, Optical Spectrograph for the Giant Magellan Telescope" Proc. SPIE 8446, 292 (2012).
[3] Barkhouser, R., et al., "Conceptual optical design for GMACS, a wide-field multi-object moderate resolution spectrograph for the Giant Magellan Telescope (GMT)," Proc. SPIE 8446, 293 (2012).
[4] Smee, S, et al., "Optomechanical design concept for GMACS: a wide-field multi-object moderate resolution spectrograph for the Giant Magellan Telescope (GMT)," Proc. SPIE 8446, 294 (2012).