First-Generation Instrument Candidates for the Giant Magellan Telescope

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GMT Instrumentation Scientist

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Take Advantage of GMT’s Strengths

- Large aperture – 21.4-m effective area
  - A bias toward spectroscopy – 5 instruments
  - Optical and IR Echelles
- Large aperture – 24.5-m diameter
  - Motivation for Adaptive Optics – 4 instruments
    - NGS, LTAO, GLAO
- Wide-Field – 20 arcmin diameter
  - Survey spectroscopy – 2 (+1) instruments
  - Optical and IR MOS, with optional Fiber feed
- Southern site – Las Campanas Obs
  - Magellanic Clouds
  - Milky Way Bulge
  - LSST and ALMA synergies
Instrument Selection Factors

• Scientific vision of the partner scientists
  – 2006 Science Case, currently being revised
• Instrument budget – about 10% of overall facility
• Operational balance
  – Bright vs Dark time
  – AO vs natural seeing: sky coverage for natural & laser guide stars
  – Daytime impact – slit masks, instrument changes, calibrations
• Complementarity with other ELTs (or not!)
• Commissioning sequencing
  – AO unlikely to be fully functional at first - natural seeing options
  – Can’t commission many instruments at once, while telescope coming on-line, too
Instrument Locations

Top of Rotator: Instrument Platform
~3 “Small” instruments (AO-fed plus G-CLEF pick-off)

Below IP: Gregorian Instrument Rotator
~4 “Large” instruments (e.g., NIRMOS)
NIRMOS: Near-IR Multi-Object Spectrograph  
Dan Fabricant (CfA)

- YJHK spectroscopy
  - Covers 0.9 – 2.4 μm
  - 7 gratings (R ~ 2700-5000)
- multi-object (~80 x 5”; ~12 slit masks)
- Wide field (6.5 x 6.5 arcmin)
- Natural seeing: median < 0.5”
- GLAO-fed (FWHM ~ 0.25”)
- IR imager: 14 filter slots

- Accepts MANIFEST fiber feed (IFUs, image slicer)
NIRMOS Size: 4.7 x 2.7 x 2.3 m
Weight < 20,000 lbs

VW Bus 1971
2400 lbs

Space Shuttle
Main Engine
7000 lbs
NIRMOS Extragalactic Science Areas

• **First Light**
  - z>7 galaxies
  - Epoch of reionization
  - GRBs

• **Galaxy Evolution z~2-3**
  - Physical Properties: Metallicity, Star formation
  - Massive Ellipticals
  - Galaxy Clusters and Environment
  - Supernovae and Dark Energy

• **Near-field Cosmology**
  - LMC and SMC

See Brown & Fabricant (Tuesday @ 9:10)
G-CLEF: GMT-CfA Large Earth Finder
Andrew Saintgyorgyi (CfA)

- Natural seeing optical Echelle (0.35 – 1.0 μm)
- R ~ 20,000 - 120,000 (depends on fiber input size)
  - Accurate abundances (e.g., extreme metal-poor stars)
  - High precision velocities (< 50 cm/s) – planet characterization
- Good throughput
  - ~40% from 400 – 800 nm
  - >25% from 350 – 900 nm
- Accepts MANIFEST fiber feed
  - wide-field MOS
- Full spectrum coverage
  - Blue and red cameras
G-CLEF Optical Feed

- Optically coupled from tertiary for good blue throughput
- Fibers for last few meters

- On Azimuth disk (“Coudé Room”) for gravity invariance
- In vacuum for pressure stability
- Temperature controlled at 0.01K
G-CLEF EG Science Areas

- galaxy evolution
  - subgiants
  - supergiants
  - stars in Andromeda
- hierarchical formation of galaxies
  - ISM abundances
  - DLA abundances
  - high-z
  - GRB host galaxy abundances
  - stars in dwarf galaxies
  - metal-poor stars in the halo
  - stars in diff. MW populations
  - planet signature in solar twins
  - stars in the solar neighborhood
GMTNIRS: GMT Near-IR Spectrograph
Dan Jaffe (UT Austin)

- AO fed IR Echelle (1-5 μm; simultaneous JHKLM)
- Single slit of 0.085 x 1.2 arcsec
- R ~ 50,000 (JHK) – 100,000 (LM)
- Single configuration spectrograph
- Good throughput
  - Silicon immersion gratings allow size reduction and cross dispersion (with VPH gratings)
  - “Large” slit width (relative to diffraction limit) collects more light
  - Can produce R>50,000 spectra with decent S/N for all 2MASS sources
Inside GMTNIRS
GMTNIRS Sensitivity

GMTNIRS Sensitivity (JHK: R=50,000, LM: R=100,000)

Signal-to-Noise in 6 x 600 sec

Target Vega Magnitude

Texas A&M: March 14-16, 2011
GMTIFS: GMT Integral Field Spectrograph  
Peter McGregor (ANU)

- JHK Integral Field Spectrograph – image slicer system
- Medium resolution: R \( \sim \) 5,000 (R \( \sim \)10,000 being considered)
- Multiple scales and fields of view

<table>
<thead>
<tr>
<th>Spaxel size (mas)</th>
<th>6</th>
<th>12</th>
<th>25</th>
<th>50</th>
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<tbody>
<tr>
<td>Field of view (arcsec)</td>
<td>0.54×0.27</td>
<td>1.08×0.54</td>
<td>2.25×1.13</td>
<td>4.5×2.25</td>
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- Data cube (“a rectangular prism”)
  - 45 (slits) x 88 (slitwise) x 4096 (spectral)
- Near-IR AO imager:
  - 5 mas/pixel
  - 20.4×20.4 arcsec FOV
  - Dual filter wheel (~16 filters)
Inside GMTIFS

- Three levels of optics
- Example Imager Slicer
- From MIRI (JWST)
GMTIFS Science Areas: Assembly and Structure

Resolving galaxies

HST/ACS UDF
Elmegreen et al. 2009

See Rob Sharp (Tuesday @ 10:25)
GMTIFS sim of UDF6462
Galaxies at Epoch of Star Formation

UDF6462, $z=1.571$
Bournaud et al. 2008
HST/ACS UDF imaging

VLT-SINFONI 5 hr
Bournaud et al. 2008
$R \sim 3000$
Scale $\sim 0.5''$

GMT-GMTIFS 9(+3 sky) hr
Full artificial observation and pipeline reduction
$R \sim 5000$
Scale $\sim 0.05''$
sufficient S:N for 0.025''

Rob Sharp, ANU
rgs@mso.anu.edu.au
GMACS: GMT Areal Camera and Spectrograph
Darren DePoy (Texas A&M)

• 8 arcmin × 16 arcmin field
  • Four “arms” – each having 4 arcmin × 8 arcmin fields
  • Blue and red “channels” for each “arm”
    • Total of 8 “channels”
    • Provides good coverage and sensitivity over 370 – 1000 nm
• Multi-slit masks – ~200 slits per mask
• Moderate resolution
  • ~1400 in blue
  • ~2700 in red
• Uses GMT facility wide-field corrector + ADC
• Fiber feed from MANIFEST – full 20 arcmin coverage
GMACS: Inside GMT

Collimators

Corrector Lens, Focal Plane & Tent Mirrors

Optical Bench

Lift Mechanism

Red Cameras

Blue Cameras
GMACS: Science Areas

• Galaxy Assembly
  • tomographic measurements of the IGM
  • determination of the stellar mass evolution of galaxies over a wide range of redshift.

• Dark Energy
  • baryonic oscillations at $z > 4$
  • spectroscopic monitoring of faint distant supernovae to reduce systematic errors in the SNe Hubble diagram.

• First Light and Reionization – Direct observations of the first galaxies.
GMACS: Detailed Stellar Populations

- VLT spectra of planetary nebulae yield single-star abundances to ~4 Mpc
- GMT offers a 2-3X gain in distance, to the nearest true elliptical galaxies
- Measure He, N, O, Ne, S, compositions for hundreds of stars in E/S0/S galaxies
  - Metallicity distribution functions for stars in old, intermediate, and young stellar populations: uniformity of chemical enrichment; radial gradients; halo compositions
  - Kinematic properties of the stellar sub-populations (bulge, disk, halo, IGM) for different galaxy and cluster types
GMACS: Detailed Stellar Populations

- VLT FORS on NGC 5128
  - 7.6 hours, R ~ 1000
  - Useful data for ~10 PNe
  - Radii of 5 – 17 kpc

- GMACS –8 hours, R ~ 3000, Fornax Cluster reachable

- Kinematics are much easier, to 100 Mpc and beyond (10-20 km/s)
  - dark matter distribution in galaxies and clusters
TIGER: Thermal Infrared imager for the GMT, providing Extreme contrast and Resolution

- Mid-IR imager: 2 channels
  - 2.9 – 5.1 μm (Short wavelength channel)
  - 8 – 14 μm (Long wavelength channel)
- High contrast: $10^{-6}$ at $2 \lambda/D$
- AO-fed
- Low resolution spectroscopy: $R \sim 300$
- Field of view: 30 arcsec (both channels)
- Pixel scale: 0.01 / 0.03 arcsec (SWC / LWC)
- Throughput: ~30% / 20%
Inside TIGER

- Two levels
  - 8-14 μm upper
  - 2.9 – 5.1 μm lower
TIGER: EG Science Themes

- Galaxy assembly
  - Star clusters forming in ULIRGS at high $z$
  - AGN structures

- Primarily a Galactic instrument
  - Planet characterization
  - Stellar disks
  - Trace water / ice throughout disks
- ~1000 moving Starbugs covering the GMT’s full 20’ diameter field
- Single-fibre/image-slicer/IFU feeds for NIRMOS/GMACS/G-CLEF
- Provides higher multiplex and/or higher spectral resolution
MANIFEST + GMACS

- IGM tomography
- 452 image-slicing probes (17 fibres, ~1” diameter) over 20’ FOV
- Image-slicing provides R ~4500 (Blue); R ~ 9000 (Red)
- ~30 nights for both tomography (10 nights) & galaxy survey (20 nights) over 1 deg²

Number density of Lyα lines (left) and 2-pt correlation function (right)
MANIFEST + NIRMOS

- **Galaxy mass assembly at 1.5 < z < 2.5**
- 14 mini-IFU probes (91 fibres, 2.5” diameter) over 7’ GLAO FOV measuring distribution of properties within forming galaxies
- 118 image-slicing probes (7 fibres, 0.9” diam) over 20’ FOV surveying ~1 deg² over ~30 nights to complement MANIFEST+GMACS survey
- Target surface density 0.1 arcmin⁻² (I<24.5) or ~400 over 7’ FOV

GDDS z~1.5 cluster
[white circle is 30” diameter]

GDDS ‘red nuggets’ (compact passive galaxies) at z~1.5
[ scale bar in images is 1”]
**MANIFEST + G-CLEF**

- **Chemical history of the Local Group**
- 43 single-fibre probes each 0.7” diameter
- $R=30,000$ (binned) for a single order
- ~80 nights to measure S/N~30 spectra for abundances of ~1000 stars in ~10 LG galaxies

McConnachie et al., 2009, Nature, 461, 66
Spatial density distribution of PAndAS stars consistent with RGB stars in M31.
Many Opportunities for Extragalactic Science with First-Generation GMT Instruments

- Many Opportunities for Extragalactic Science with First-Generation GMT Instruments
  - Dark Matter Distributions
  - Dark Energy
  - Galaxy Assembly
  - Black Hole Growth
  - AGN Structure
  - Star Formation History
  - Chemical Evolution

- Second Generation:
  - process is not defined yet
  - $8-10M / year of “operations” allocated for instrumentation
Synergies

ALMA

LSST