The Giant Magellan Telescope: Science & Status

- Introduction – Project and Science Case
- Design Overview
- First Generation Instruments
- Early Science:
  - Near: Planets & Stars
  - Mid: Stars & Galaxies
  - Far: Galaxies & Cosmology
- Status
The GMT Partnership

- GMTO Corporation — formed in 2006
- An international collaboration of academic and research institutions (not governments).
- New partners welcome!

The GMT Partnership partners include:
- Sao Paulo, FAPESP
- Harvard
- Arizona State U.
- Texas A&M
- Australian National Univ.
- South Korea, KASI
- Carnegie Inst.
- U. of Arizona
- U. of Texas, Austin
- Texas A&M
- Las Campanas, Chile
- Australian National Univ.
- Australian Astronomy Limited
- U. of Chicago
- Las Campanas, Chile
- Carnegie Inst.

Site: Las Campanas Observatory (circa 2005)

- El. ~2,500 m
- Excellent atmospheric stability (0.3-25 µm)
- Low water vapor
- Site owned by Carnegie Institution with a long term lease to the Partnership
Operation in Chile:

Standing in Chile:
- Recognized by the Foreign Ministry
- Agreement with University of Chile

Science Case: a brief lesson from history

- The Black Hole at the center of our Galaxy → Coordinated evolution of black holes and galaxies
Science Case: a brief lesson from history

• The existence of Dark Energy:
  → accelerating expansion of the universe

• Gamma Ray Bursts (most energetic explosions seen) linked to Supernovae:
  → Tests of general relativity (binary star interactions)
  → Back-lighting for studying the chemistry of faint galaxies.
  → “Heavy” chemical element factories (nucleosynthesis)
Science Case: a brief lesson from history

- First direct images (and spectral) of exoplanets

GMT Mission: 50 years of forefront science

GMT Science Book: science goals for the next decade

Top-Level Science Areas:
- Planets & Stars
- Stars & Galaxies
- Galaxies & Cosmology
GMT Mission: 50 years of forefront science

GMT Science Book: science goals for the next decade

Top-Level Science Areas:
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What kinds of objects will we study …
what data will we need?
what instruments?
operational strategies do we want?

New capabilities = new discoveries

• Increased sensitivity: more photons!
  • Collecting power: mirror area (increases as $D^2$)
  • Keeping the light: fewer mirrors (higher throughput, less scattered light, more efficient instruments)

Person
Height: 6 feet
Diameter: 33 feet

Keck I and II
= 5

Giant Magellan Telescope
Diameter: 80 feet
New capabilities = new discoveries

- **Increased sensitivity:** more photons!
  - Collecting power: mirror area (increases as $D^2$)
  - Keeping the light: fewer mirrors (higher throughput, less scattered light, more efficient instruments)

- **Increased angular resolution:** sharper images
  - Diffraction limit (best images): gets better with $D$
  - *Full time AO & Ground layer AO* (30-50% better): enabled by telescope configuration and ASMs

New capabilities: diffraction limited angular resolution

**Natural guide star AO (NGAO):**

- Atmospheric seeing limit: $\theta_j \approx 0.5$ arcsec
- Hubble Space Telescope $\theta_j \approx 0.2$ arcsec
- Webb Space Telescope $\theta_j \approx 0.07$ arcsec
- GMT with NGAO $\theta_j \approx 0.02$ arcsec
New capabilities: diffraction limited angular resolution

Laser guide stars AO (LTAO):
> 80% sky coverage

Galactic Center at 2.2 µm

θ_2 ≈ 0.05 arcsec

VLT Laser AO
New capabilities: diffraction limited angular resolution

- Galactic Center at 2.2 µm
- Laser guide stars AO (LTAO):
  \[ \theta_J \approx 0.05 \text{ arcsec} \]
- GMT Laser AO (simulation)

New capabilities: better angular resolution & wide fields!

- **Ground layer AO**: 30-50% improvement over natural seeing
  \[ \theta_R \approx 0.25 \text{ arcsec (75th percentile)} \]
- Seeing limited: \( \theta = 0.65'' \)
- Ground-layer corrected: \( \theta = 0.25'' \)

10 arcminute fields of view
The role of ELTs: spectroscopic follow-up

- **High resolution** spectroscopy of faint sources: chemistry & dynamics
- **Multi-object spectroscopy using a wide field of view:** statistical samples

- **LSST**
- **LIGO**
- **WFIRST**
- **SKA**
- **JWST**
- **ALMA**

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GMT design

- Optical to Infrared (0.3 – 25µm)
- 25.4 m diameter primary mirror
- Double segmented:
  - M1: seven 8.4m segments
  - M2: seven 1.1m seg.
- Telescope mass: 1,400 tons

GMT design strengths

- Aplanatic Gregorian optical configuration
- Fast primary (f/0.7) & final f/ratio (f/8.2)
  - Compact structure: cheaper, more stable
  - Wide FOV: 10 arcmin (20 arcmin w/ corrector)
  - Small plate scale: 1.0 mm/arcsec
    - facilitates wide field instrumentation
  - Real primary focus for alignment & calibration
GMT design strengths

- Adaptive secondary mirrors for full time AO
  - M1 & M2 segments are conjugate 1:1
  - 2 reflections: high efficiency, low background
  - GLAO enabled by M2 location

- Standard M2 system (FSM) for backup
**GMT design strengths**

- Upper truss support:
  - Outer segments unobscured (clean pupil)
  - Facilitates high contrast AO

- No Naysmith platforms.
GMT design strengths

GMT tour:
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First instrument: Commissioning Camera, Imager

**Commissioning Camera**  
Pl: J. Crane (Carnegie)

First light: alignment & image quality, 6x6 arcmin field of view  
Early Science: Narrow- and Wide-band imaging; 10 filter slots  
Simple, low cost, fast development cycle

• Stellar populations in nearby clusters and galaxies  
• Nearby and distant emission line object studies (e.g., Narrow-Band)
### Natural Seeing / GLAO Optical Spectrographs

#### G-CLEF
**PI: Andrew Szentgyorgyi, CfA/SAO**
- Stabilized, fiber-fed, dual channel echelle
  - $R = \lambda/\Delta\lambda = 19,000 – 35,000 – 108,000$
  - Velocity accuracy: < 50 cm/s per observation
- Abundances: Planetary atmospheres, stars, transients, QSOs, absorption line systems
- Dynamics: planets, clusters, dwarf galaxies
- Precision Radial Velocities: exoplanets (<10 cm/s)

#### GMACS
**PI: Darren DePoy, Texas A&M**
- Multi-object, slit-fed, red/blue channels
  - $R = \lambda/\Delta\lambda = 1,000 – 6,000$
  - 7.5’ diameter FoV spectroscopy / imager
- Abundances: stellar pops, galaxies, ISM, IGM, exoplanet atmospheres
- Dynamics: galaxies & clusters, Lyα systems, stellar systems

### AO-Fed, near- and mid-IR Spectrographs

#### GMTIFS
**PI: Rob Sharp, Australia National Univ.**
- Slit & IFU spectrograph & imager (0.3” - 20x20”)
  - $\lambda = yJHK$
  - $R = \lambda/\Delta\lambda = 5,000 or 10,000$
  - Pixel scales: 6, 12, 25, or 50 mas
- Galaxy chemical enrichment history
- First galaxy structure and assembly
- IGM at high redshift
- Black hole masses

#### GMTNIRS
**PI: Dan Jaffe, UTexas, Austin**
- High resolution, high throughput IR echelle
  - $\lambda = JHKL$ (simultaneously!)
  - $R = \lambda/\Delta\lambda = 50,000$ (JHK) – 100,000(LM)
  - Efficiency: x10,000 gain over current best
- Composition of stars & nebulae
- Galaxy chemical evolution history
- Exoplanet structure and atmospheres
- Star and planet formation
AO-Fed, near- and mid-IR Spectrographs

**GMTIFS**
PI: Rob Sharp, Australia National Univ.
Slit & IFU spectrograph & imager (0.3” - 20x20”)
- \( j = yJHK \)
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Silicon immersion gratings + Bigger telescope + 1 exposure vs 200 = 5,000-20,000 times more efficient

Facility Fiber Feed to Spectrographs

**MANIFEST**
Jon Lawrence (AAO) / Matthew Colless (ANU)
Robotic fiber-feeds: 2-3 min configuration time
Single fibers, IFUs, Image slicers
Extendable to thousands of fibers
Feeds multiple instruments (G-CLEF, GMACS, future IR MOS)

- Extends/Adds multi-object capability over 20’ FoV
- Enables very high AΩ survey science (stellar abundances, galaxy surveys)
- Allows simultaneous observing with multiple instrument (“parallels”)
Addition 1st generation: SuperFIRE

SuperFIRE (prelim. studies)
PI: Rob Simcoe, MIT

IR echelle spectrograph
\[ \lambda = \text{JHK} \]
\[ R = \frac{\lambda}{\Delta \lambda} \approx 6,000 \]
8" slit length
Heritage: FIRE on Magellan

NIRMOS (developed to CoDR, 2011)
PI: Dan Fabricant, CfA/Harvard

Multi-Object Wide-field near-IR Spec.
\[ \lambda = \text{yJHK} \]
\[ R = \frac{\lambda}{\Delta \lambda} \approx 3,000 \]
Slit-fed (or by MANIFEST– J only)
6.5'x6.5' Field of view

First light (z>7), galaxy evolution z~2, Galactic Center, near field cosm., planets

Deferred 1st generation: TIGER

TIGER
Phil Hinz (Univ Arizona)

Dual channel imager and spectrograph
\[ \lambda = 1.5-5 \mu \text{m}; 7-14 \mu \text{m} \]
\[ R \approx 300; \text{ Spatial } \approx 7 \text{ mas} / \text{ pixel} \]
Field of view: 30 arcseconds
Contrast to $10^{-6}$ in L band @ 3 \( \lambda / D \)
Addition 1st generation: before the ASMs

G-MagAO-X (Co-Is: Laird Close, Jared Males, UA)

- Technology being developed at Magellan (NSF funded)
- Visible and near-IR Exoplanet Imaging
  - Internal deformable mirrors
  - State of the art coronagraphy

Exoplanet imaging in first year!

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Early Science Goals:

- GMT, 8m, 4m spectroscopic limits (20hrs) at ~0.8µm
  - 5σ detection limits for imaging surveys

GMT will be able to take spectra of nearly any object in the LSST deep catalog

Science nearby: Exoplanets

- How do planetary systems form?
- How common are systems like ours?
- Are there other Earths?
- Can we detect life?

Methods:
- Measuring Masses
- Direct Imaging
- Detecting atmospheres
Measuring masses of Earth-sized planets

Proxima Centauri b:
- parent star: red dwarf
- 1.3 M$_E$ planet
- "habitable" zone (liquid water)
- 0.05 AU, 11.5 day orbit

Current precision limits ~1m/s

Low Mass Planets Cause Slow Stellar Wobble

Sun's Wobble Speed Due to
- Jupiter: 22 m/s
- Earth: 4.2 m/s
- EPOX Precision

Speed of Desert Animals & EPOX Precision
- Kangaroo: 9 m/s
- Dune Runner: 2 m/s
- Desert Tortoise: 0.2 m/s

Radial Velocity (cm s$^{-1}$)
Detecting life — atmospheres

Turnbull et al. 2006

Direct imaging:

Proxima Centauri b: 0.38 arcsec angular separation

- 8m telescope: 1.2 λ/D ... Hard!
- GMT: 3.8 λ/D ... Easy!
- Contrast needed: 5,000,000:1

Current capabilities:

Beta Pic: 10 M_{jup}

VLT/AO at 3.5μm
Angular Differential Imaging and apodizing coronagraphy
Direct imaging:

Proxima Centauri b: 0.38 arcsec angular separation
- 8m telescope: 1.2 \( \lambda / D \) ... Hard!
- GMT: 3.8 \( \lambda / D \) ... Easy!
- Contrast needed: 5,000,000:1

GMT simulation:
1 hr total integration
ADI, apodizing coronagraph

Planets detectable at 0.5-10 \( M_{\text{Jup}} \)

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Chemical Enrichment & Dwarf Galaxies

RGB stars around M31 from P AndAS.
Rebecca Bernstein – GMT Science & Status

Chemical Enrichment & Dwarf Galaxies

Current Limit
GMT Limit

VLT+SINFONI, with AO
(Genzel et al.)

Only massive galaxies are within detection limits of 8m telescopes

Galaxy assembly, evolution, & chemistry

Targets: M* galaxies at z~2, peak galaxy formation
Method: Velocity channel maps (IFU spectroscopy)

VLT+SINFONI, w/o AO
(Förster-Schreiber et al.)

5L.
Galaxy assembly, evolution, & chemistry

Galaxy assembly, evolution, & chemistry

Simulation: Gemini 8m IFU Spectrograph

Simulation: GMT simulation
Quasars & the intervening absorption line systems:

Light travel time from this distance is ~3 Billion years:

(Artist's impression, Credit: ESO)

QSO at z~3
Quasars w/in reach at z=2:

8 Quasars (m_r < 18)

Credit: G. D. Becker, Ryan Cooke

Single exposure, multi-object spectroscopy

8 QSOs (m_r < 21)

Credit: G. D. Becker, Ryan Cooke
GRBs are easily detected at their peak … but fade very rapidly.

Bloom et al. (2009) 1 day!

Galaxy formation and the IGM:

GRB’s as cosmic probes:

GRB050904    z=3.6
MIKE/Magellan

Chen et al. (2005)
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Distant: Formation and Evolution of Galaxies

- When did the first galaxies form?
- When and how did re-ionization begin?
- How do galaxies assemble and evolve throughout cosmic time?
- How do black holes and galaxies co-evolve?

Most distant galaxy identified with HST
Distant: Formation and Evolution of Galaxies

Methods:

- Surveys provide candidate targets — WFIRST satellite!
- Follow-up spectra: distances, chemistry, dynamics (mass, dynamics, content)

Most distant galaxy identified with HST

GMT/SuperFIRE
4 hours

Keck/NIRSpec
4 hours

Credit: S. Finkelstein (UT), R. Simcoe (MIT)
Selecting vendors to complete final design

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Primary Mirror Production

1. Front Surface Polishing
2. Rear Surface Polishing
3. Ready for Front Surface Generating
4. Mold Under Construction
5. Glass on Hand
6. Glass on Order
7. Front Surface Polishing

COMPLETE

GMT 2

Giant Magellan Telescope Mirror Segment #2 Casting

University of Arizona Steward Observatory Mirror Laboratory

March 2011 - May 2012
2012: Site Cleared and Leveled, Road Graded

Site: Las Campanas Observatory (circa 2025)

4m du Pont  2x 6.5 m Magellan
Construction progress: support sites

Support site 1: Warehouse, M1 Factory & M2 Metrology

Support site 2: Residences, Dining & Recreation Facilities

Summit Offices & Metrology Station

Main Access Road

Warehouse / M1 Factory / M2 Metrology

Summit Utility Building

Enclosure

Summit Support Building
Timeline to early science and operations:

**Final Procurements**
- Telescope: Full performance
- Instrument: Widest field of view (20 arcmin)

**Intermediate Procurements**
- Telescope: 7 M1+M2 segments, Adaptive M2s
- Start AO
- Instrument: AO-fed IR spectrographs

**Early Procurements**
- Essential infrastructure
- Enclosure, Telescope Mount
- Summit Support Building
- Telescope: 4 M1+M2 segments
- Instruments: Imaging, non-AO spec

- Commissioning Start
- Close out
The Vision