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

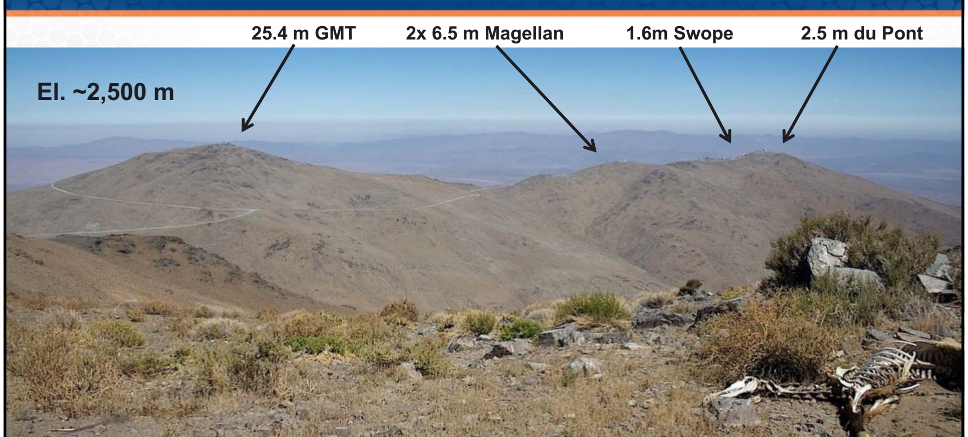
The GMT Partnership

GMT

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

Site: Las Campanas Observatory (circa 2005)

GMT

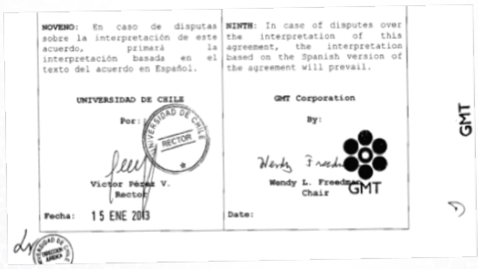


- Excellent atmospheric stability (0.3-25 μm)
- Low water vapor
- Site owned by Carnegie Institution with a long term lease to the Partnership

Operation in Chile:

Standing in Chile:

- Recognized by the Foreign Ministry
- Agreement with University of Chile



NOVENO: En caso de disputas sobre la interpretación de este acuerdo, primará la interpretación basada en el texto del acuerdo en Español.

NINTH: In case of disputes over the interpretation of this agreement, the interpretation based on the Spanish version of the agreement will prevail.

UNIVERSIDAD DE CHILE

Por:

Victor Pérez V.
Rector

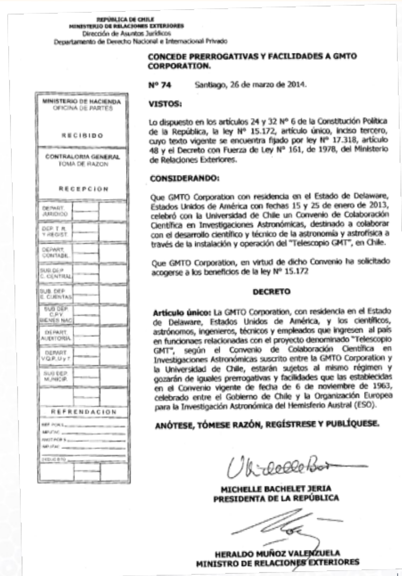
Fecha: 15 ENE 2013

GMT Corporation

By:

Wendy L. Freedman
Chair

Date:



REPÚBLICA DE CHILE
MINISTERIO DE RELACIONES EXTERIORES
Dirección de Asuntos Jurídicos
Departamento de Derecho Nacional e Internacional Privado

CONCEDE PRERROGATIVAS Y FACILIDADES A GMTO CORPORATION.

Nº 74 Santiago, 26 de marzo de 2014.

MINISTERIO DE HACIENDA
OFICINA DE PARTES
RECIBIDO

CONTRALORIA GENERAL
TOMA DE RAZON
RECEPCION

REFRENDACION

VISTOS:

Lo dispuesto en los artículos 24 y 32 Nº 6 de la Constitución Política de la República, la ley Nº 15.172, artículo único, inciso tercero, cuyo texto vigente se encuentra fijado por ley Nº 17.318, artículo 48 y el Decreto con Fuerza de Ley Nº 161, de 1978, del Ministerio de Relaciones Exteriores.

CONSIDERANDO:

Que GMTO Corporation con residencia en el Estado de Delaware, Estados Unidos de América con fechas 15 y 25 de enero de 2013, celebró con la Universidad de Chile un Convenio de Colaboración Científica en Investigaciones Astronómicas, destinado a colaborar con el desarrollo científico y técnico de la astronomía y astrofísica a través de la instalación y operación del "Telescopio GMT", en Chile.

Que GMTO Corporation, en virtud de dicho Convenio ha solicitado acogerse a los beneficios de la ley Nº 15.172

DECRETO

Articulo único: La GMTO Corporation, con residencia en el Estado de Delaware, Estados Unidos de América, y los científicos, astrónomos, ingenieros, técnicos y empleados que ingresen al país en funcionaes relacionadas con el proyecto denominado "Telescopio GMT", según el Convenio de Colaboración Científica en Investigaciones Astronómicas suscrito entre la GMTO Corporation y la Universidad de Chile, estarán sujetos al mismo régimen y gozarán de iguales prerrogativas y facilidades que las establecidas en el Convenio vigente de fecha de 6 de noviembre de 1963, celebrado entre el Gobierno de Chile y la Organización Europea para la Investigación Astronómica del Hemisferio Austral (ESO).

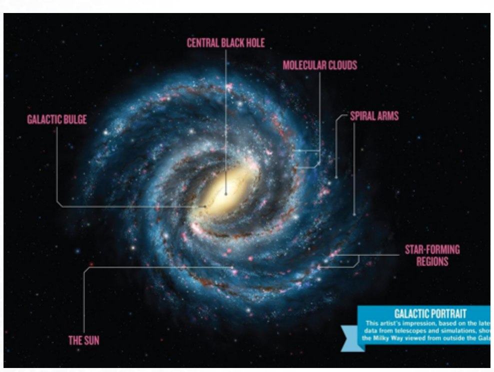
ANÓTESE, TÓMESE RAZÓN, REGÍSTRESE Y PUBLÍQUESE.

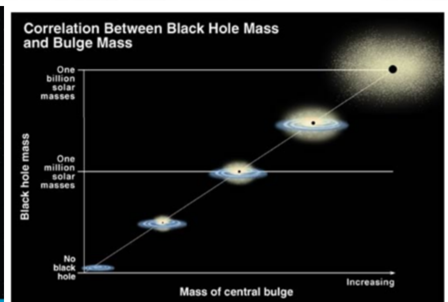
MICHELLE BACHELET JERIA
PRESIDENTA DE LA REPÚBLICA

HERALDO MUÑOZ VALENZUELA
MINISTRO DE RELACIONES EXTERIORES

Science Case: a brief lesson from history

- The Black Hole at the center of our Galaxy
  → Coordinated evolution of black holes and galaxies





Graphical representation of the black hole mass - galaxy bulge mass correlation [Credit: K. Cordes & S. Brown (STScI)]

Science Case: a brief lesson from history

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

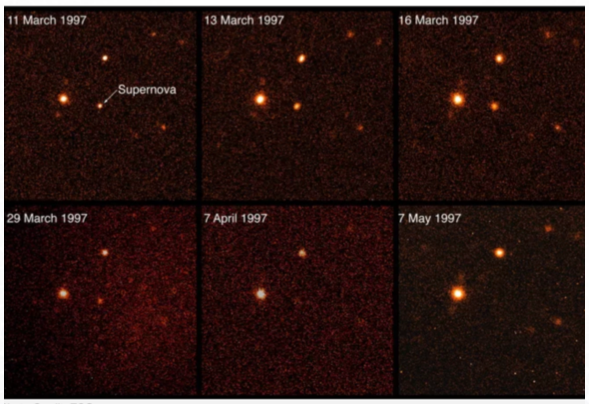
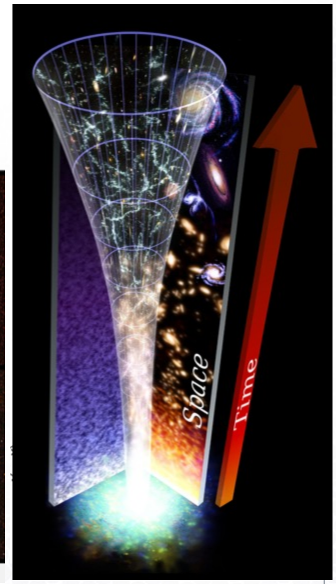


Photo Credit: ESO



Science Case: a brief lesson from history

- 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)

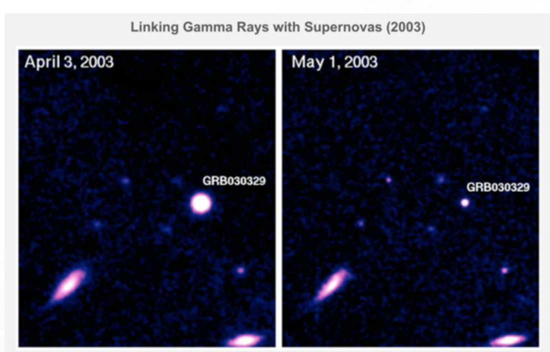


Photo Credit: ESO

Science Case: a brief lesson from history

- First direct images (and spectra!) of exoplanets

First Picture of Exoplanet System (2008)

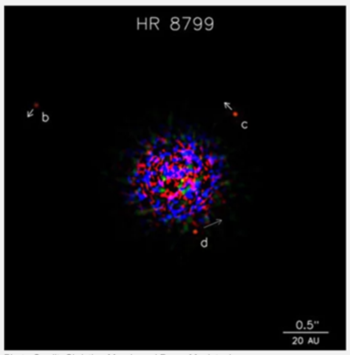


Photo Credit: Christian Marois and Bruce Macintosh

First Direct Spectrum of an Exoplanet (2010)

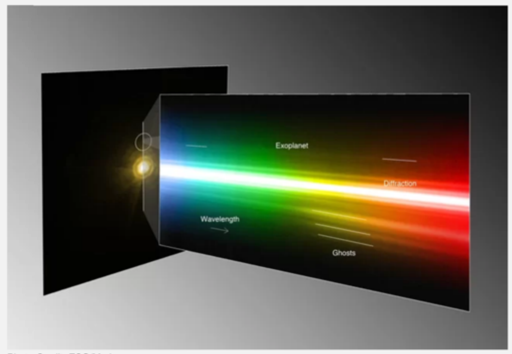


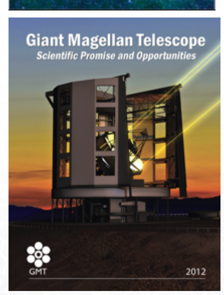
Photo Credit: ESO/M. Janson

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

GMT Science Book: science goals for the next decade

Top-Level Science Areas:

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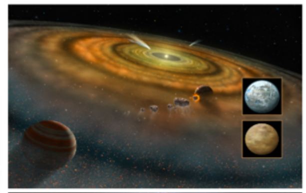
What kinds of objects will we study …

what data will we need?

what instruments?

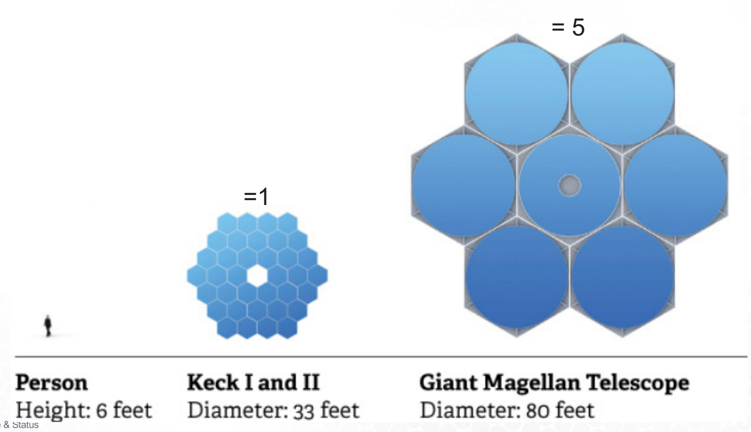
operational strategies do we want?



New capabilities = new discoveries

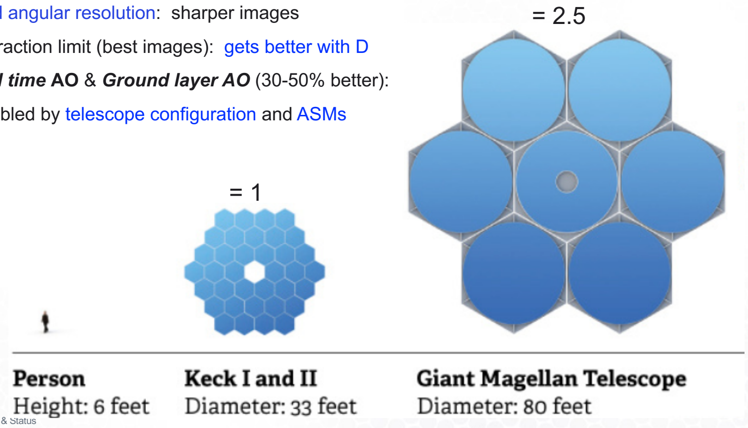
GMT

- 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)



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

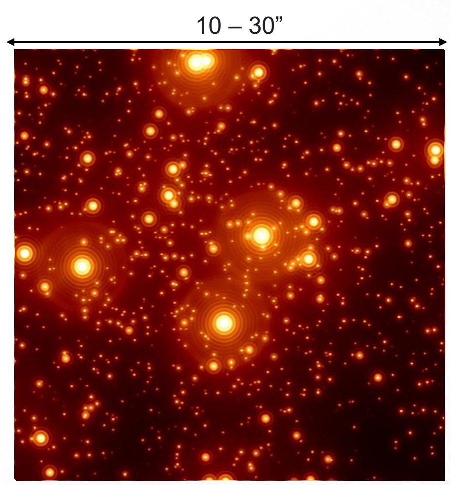
Natural guide star AO (NGAO):

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

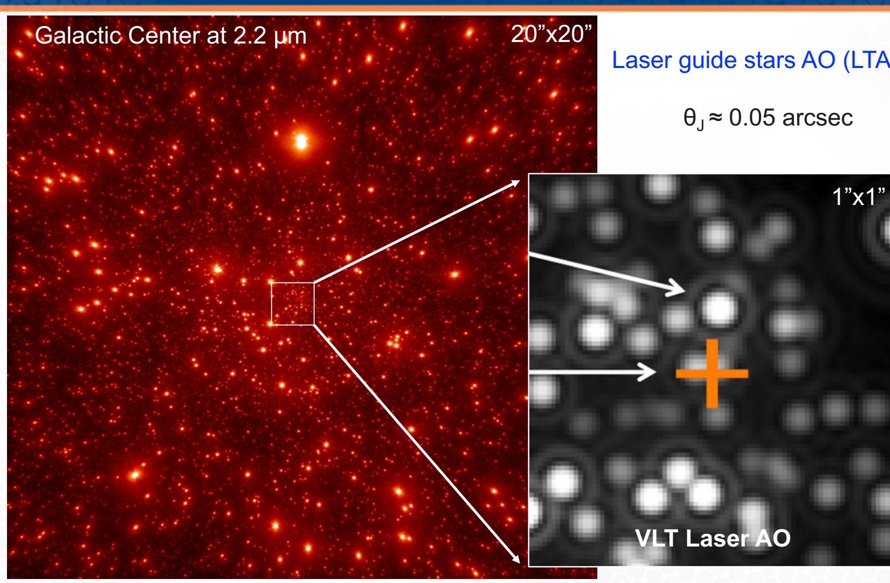
GMT

Laser guide stars AO (LTAO):

> 80% sky coverage

New capabilities: diffraction limited angular resolution

GMT

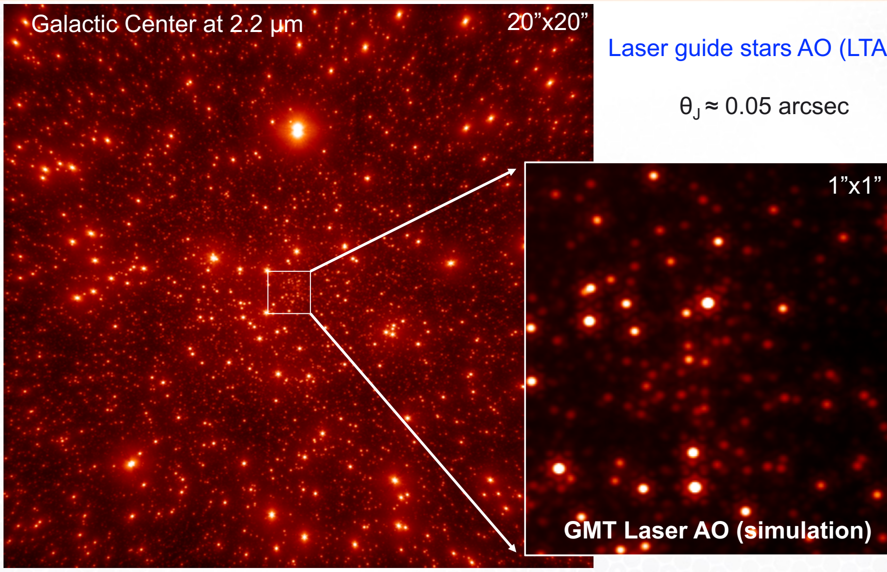


Laser guide stars AO (LTAO):

$\theta_J \approx 0.05$ arcsec

New capabilities: diffraction limited angular resolution

GMT



Laser guide stars AO (LTAO):

$\theta_J \approx 0.05$ arcsec

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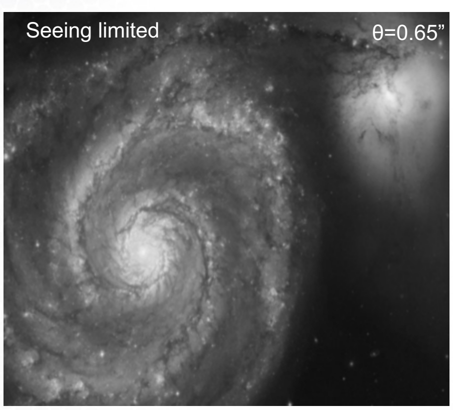
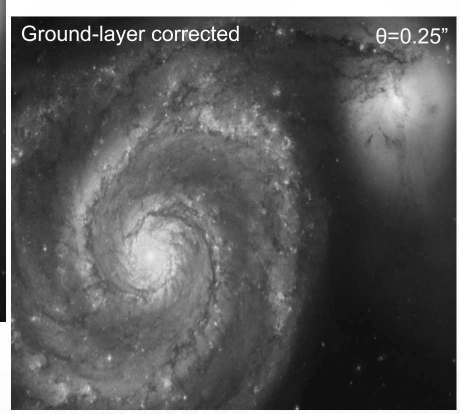
New capabilities: better angular resolution & wide fields!

GMT

Ground layer AO: 30-50% improvement over natural seeing



$\theta_R \approx 0.25$ arcsec (75th percentile)



10 arcminute fields of view

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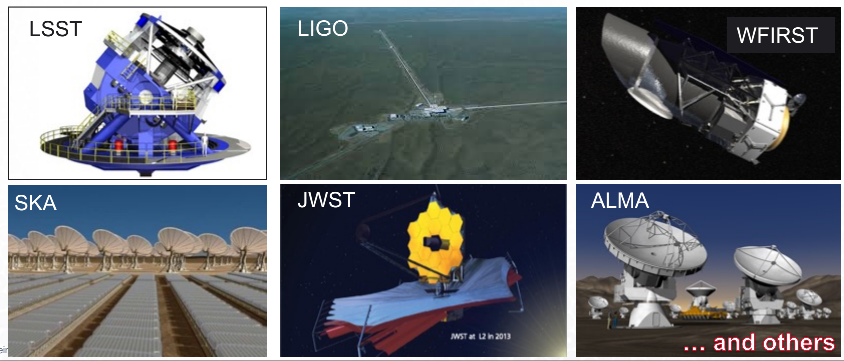
The role of ELTs: spectroscopic follow-up

GMT

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



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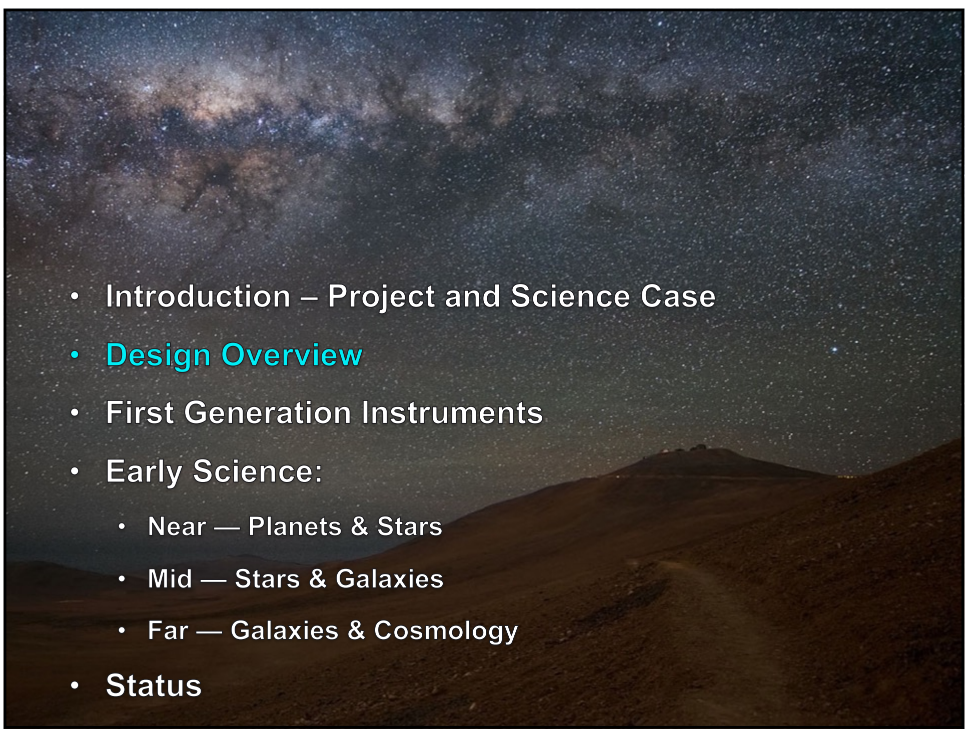
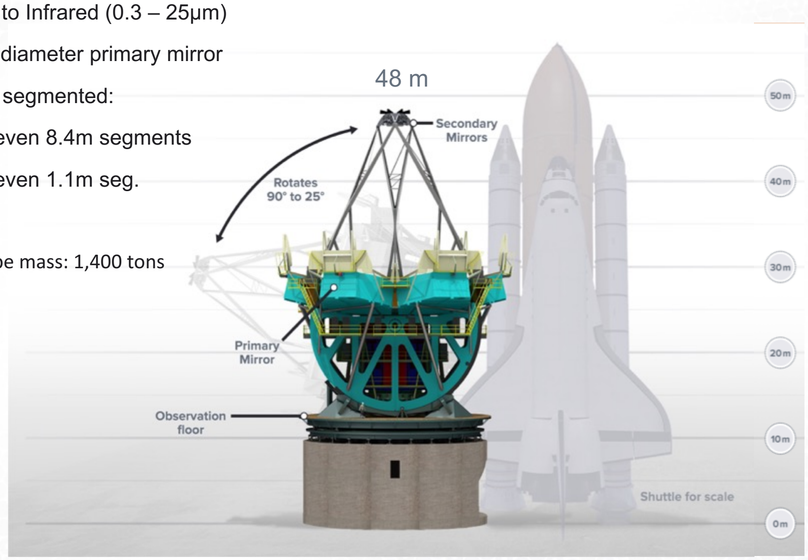


GMT design

GMT

- 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

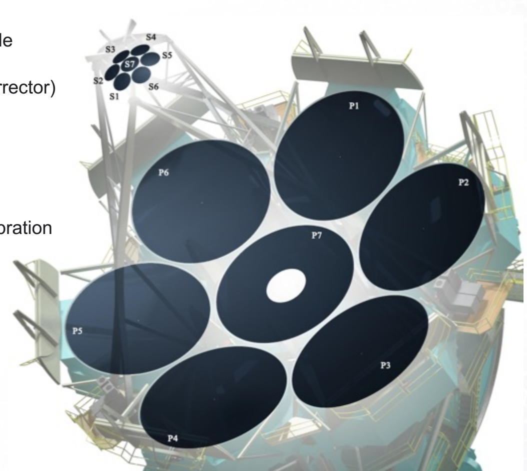


GMT design strengths

GMT

- 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

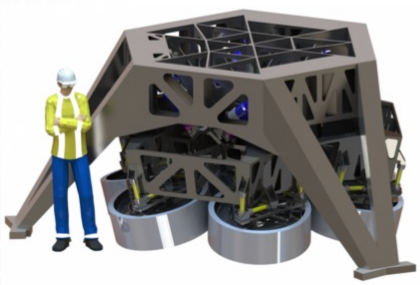
    facilitates wide field instrumentation
  - → Real primary focus for alignment & calibration

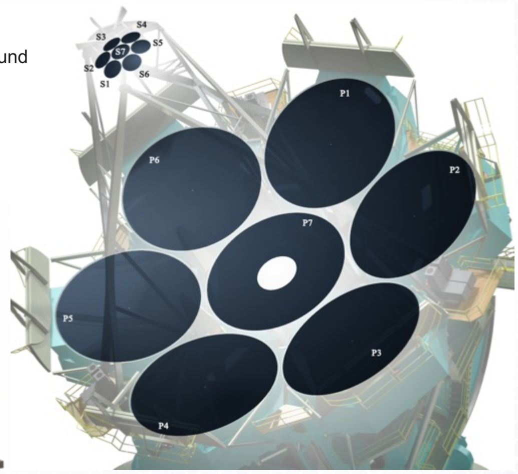


GMT design strengths

GMT

- 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





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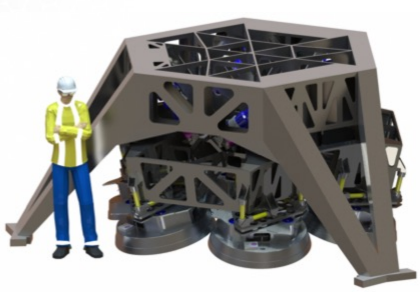
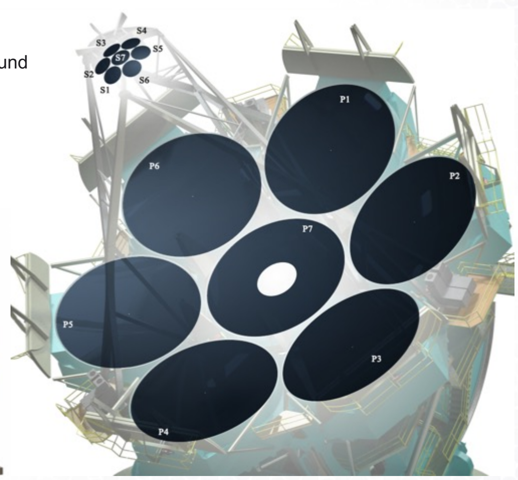
GMT design strengths

GMT

- 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





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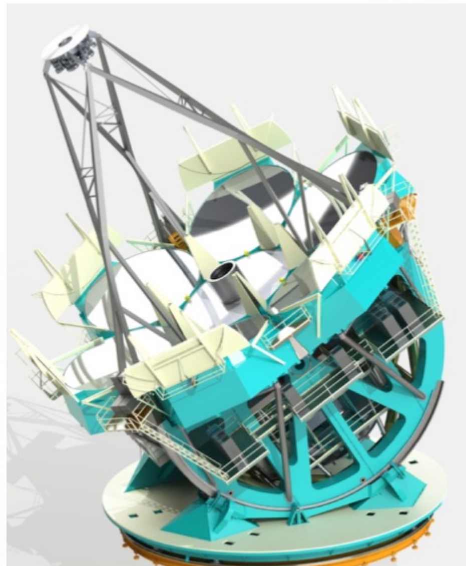
GMT design strengths

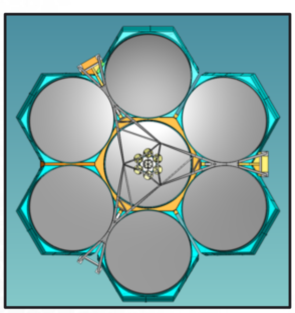
- Upper truss support:
  - Outer segments unobscured (clean pupil)
  - Facilitates high contrast AO

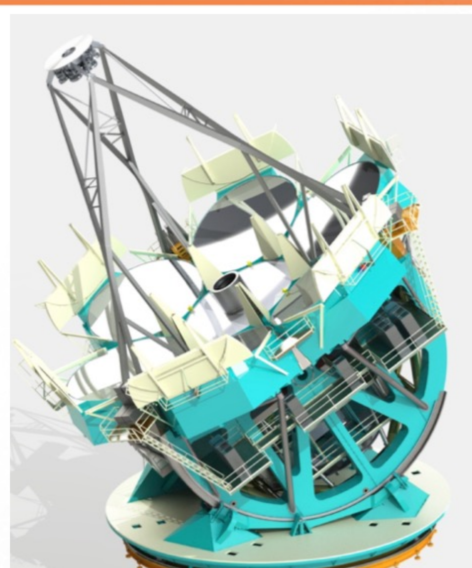


GMT design strengths

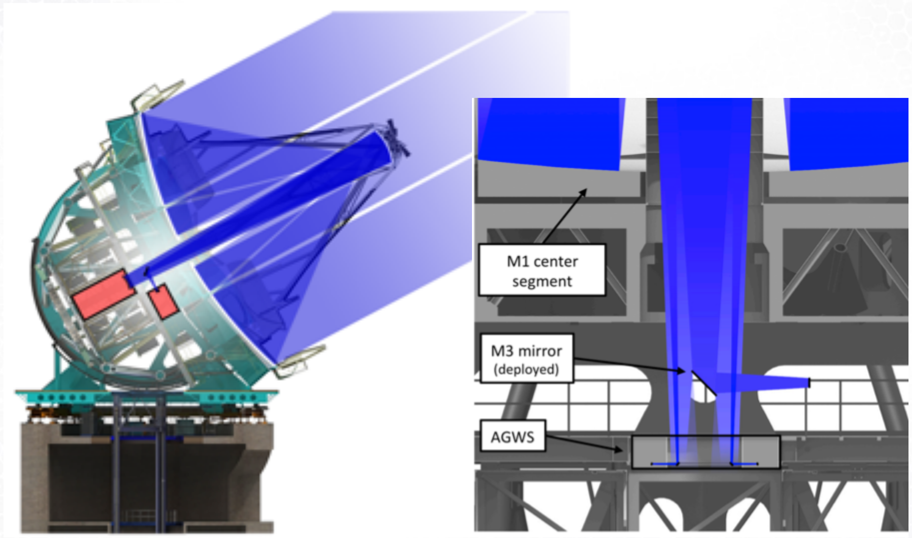
- Upper truss support:
  - Outer segments unobscured (clean pupil)
  - Facilitates high contrast AO

- No Naysmith platforms.





GMT design strengths



GMT tour:

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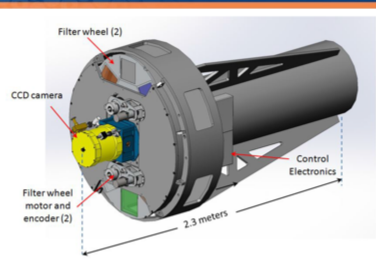
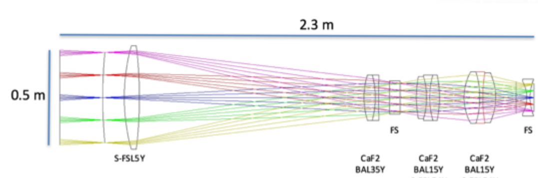
First instrument: Commissioning Camera, Imager

GMT





Commissioning Camera
PI: 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)

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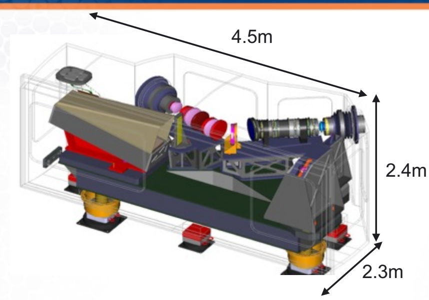
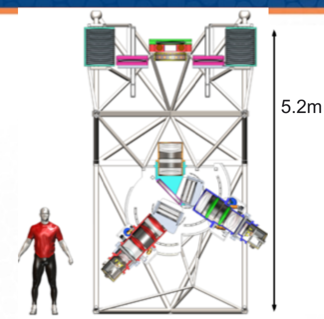
Natural Seeing / GLAO Optical Spectrographs





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

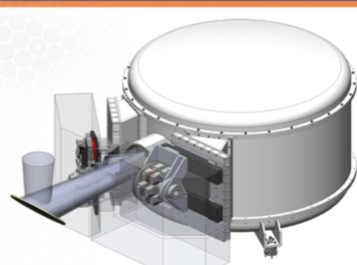
- **Abundances:** Planetary atmospheres, stars, transients, QSOs, absorption line systems
- **Dynamics:** planets, clusters, dwarf galaxies
- **Precision Radial Velocities:** exoplanets (<10 cm/s)

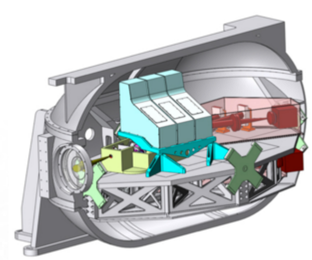
GMACS
PI: Darren DePoy, Texas A&M

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")
- λ = 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**

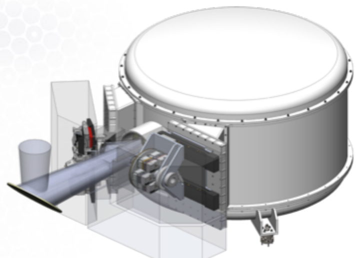
GMTNIRS
PI: Dan Jaffe, UTexas, Austin

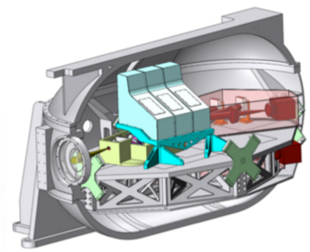
High resolution, high throughput IR echelle
- λ = JHKLM (simultaneously!)
- R = $\lambda/\Delta\lambda$ = 50,000 (JHK) – 100,000(LM)
- Efficiency: x10,000 gain over current best

- **Composition of stars & nebulae**
- **Galaxy chemical evolution history**
- **Exoplanet structure and atmospheres**
- **Star and planet formation**

AO-Fed, near- and mid-IR Spectrographs

GMT





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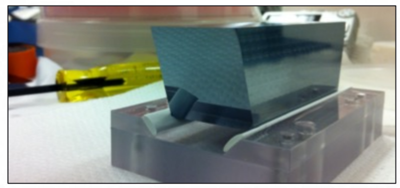

Silicon immersion gratings + Bigger telescope + 1 exposure vs 200

= 5,000-20,000 times more efficient

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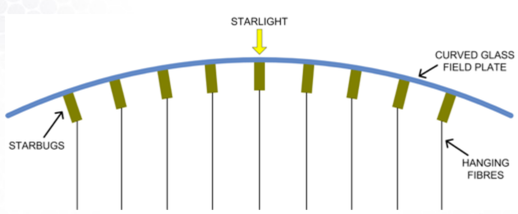
Facility Fiber Feed to Spectrographs

GMT



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")**

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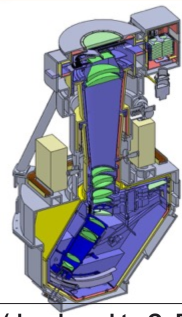
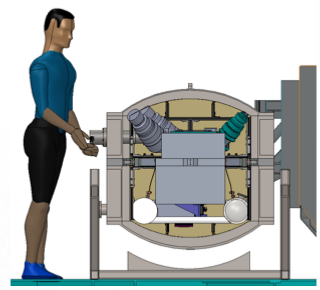
Addition 1st generation: SuperFIRE

GMT



5m



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

Multi-Object Wide-field near-IR Spec.
λ = yJHK
R = $\lambda/\Delta\lambda$ ~ 3,000
Slit-fed (or by MANIFEST– J only)
6.5'x6.5' Field of view

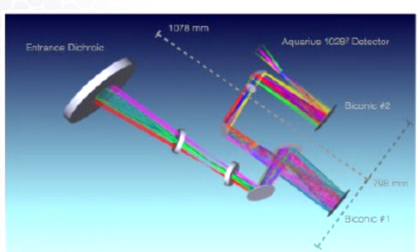
Super FIRE (prelim. studies)
PI: Rob Simcoe, MIT

IR echelle spectrograph
λ = JHK (simultaneous)
R = $\lambda/\Delta\lambda$ ~ 6,000
8" slit length
Heritage: FIRE on Magellan

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

Deferred 1st generation: TIGER

GMT



TIGER
Phil Hinz (Univ Arizona)

Dual channel imager and spectrograph
λ = 1.5-5 μm; 7-14 μm
R ~ 300; Spatial ~ 7 mas / pixel
Field of view: 30 arcseconds
Contrast to 10^{-6} in L band @ 3 λ/D

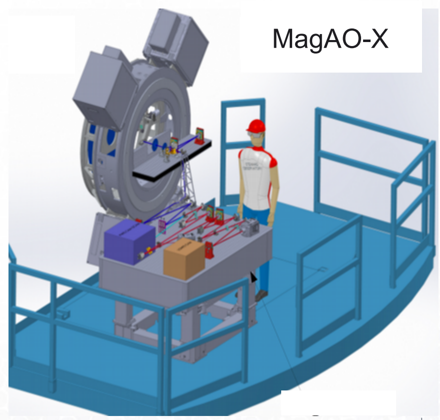
Addition 1st generation: ***before*** the ASMs

GMT

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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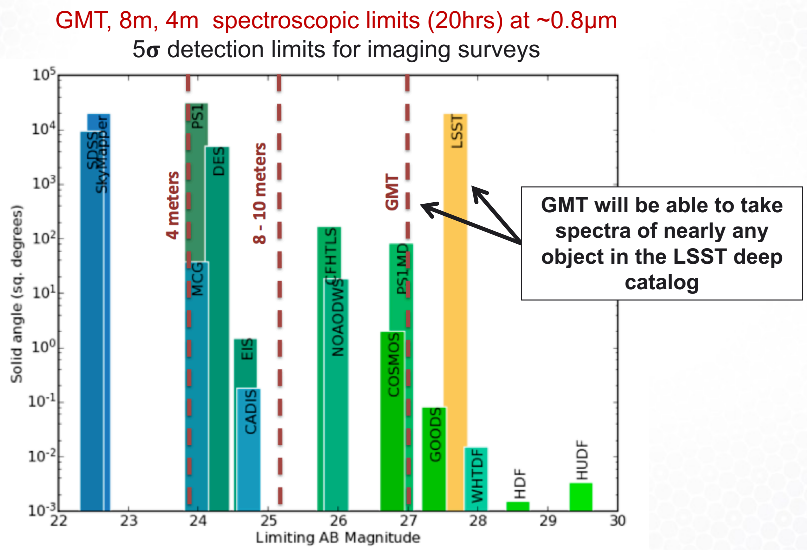
Early Science Goals:

GMT



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Science nearby: Exoplanets

GMT

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

Methods:

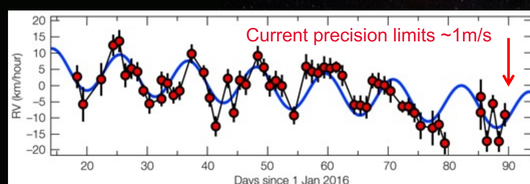
- Measuring Masses
- Direct Imaging
- Detecting atmospheres

Measuring masses of Earth-sized planets

GMT

Proxima Centauri b:

- parent star: red dwarf
- 1.3 M_E planet
- “habitable” zone (liquid water)
- 0.05 AU, 11.5 day orbit



Measuring masses of Earth-sized planets

GMT

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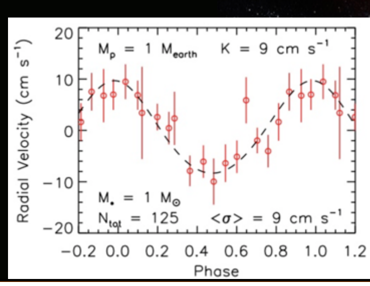
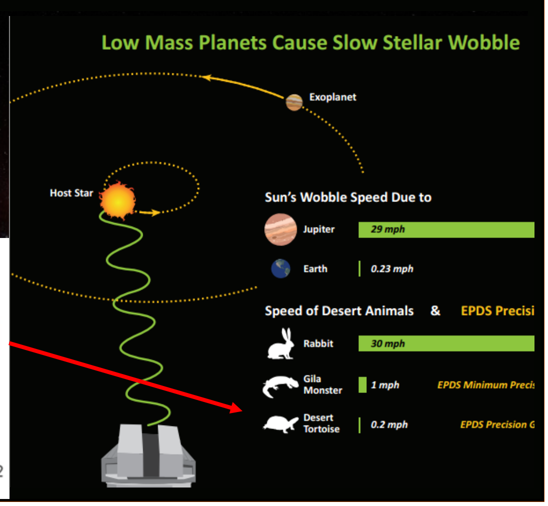
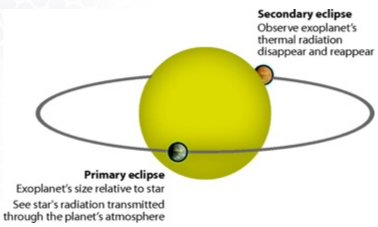
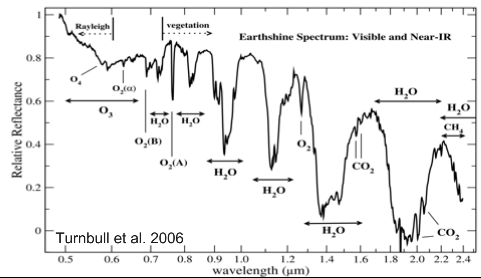
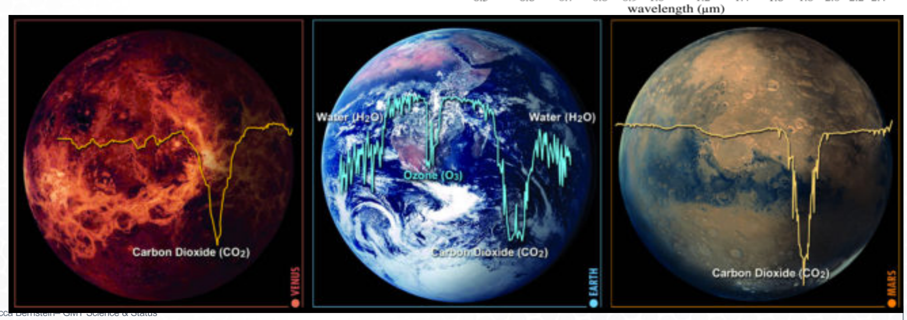




Detecting life — atmospheres







Direct imaging:

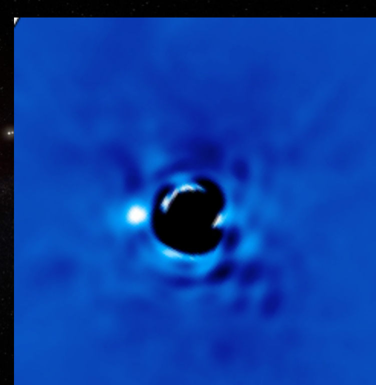
Proxima Centauri b: 0.38 arcsec angular separation

- 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:

GMT

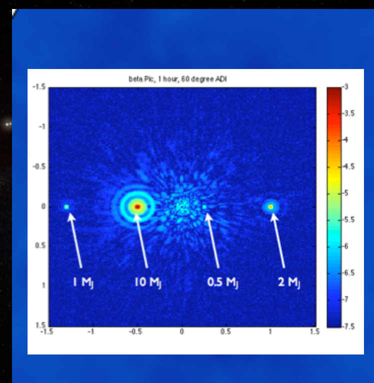
Proxima Centauri b: 0.38 arcsec angular separation

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

GMT simulation:

1 hr total integration
ADI, apodizing coronagraph

Planets detectable at 0.5-10 M_{Jup}



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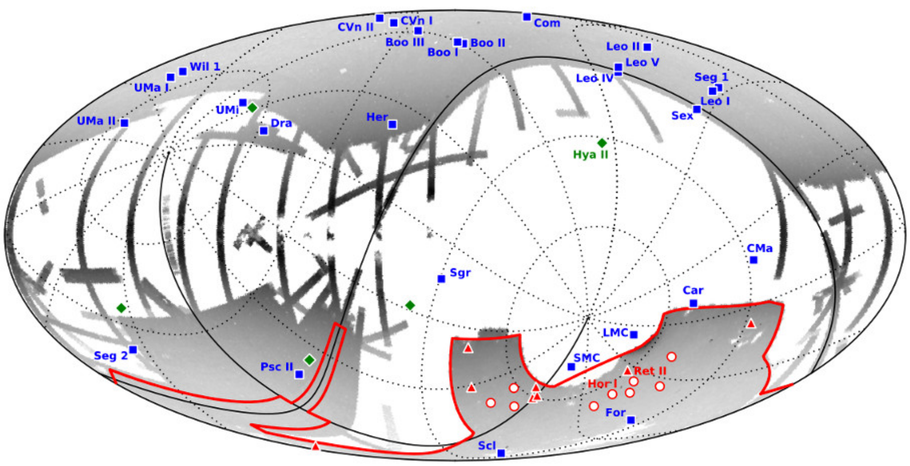
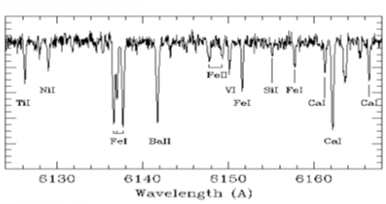
Chemical Enrichment & Dwarf Galaxies

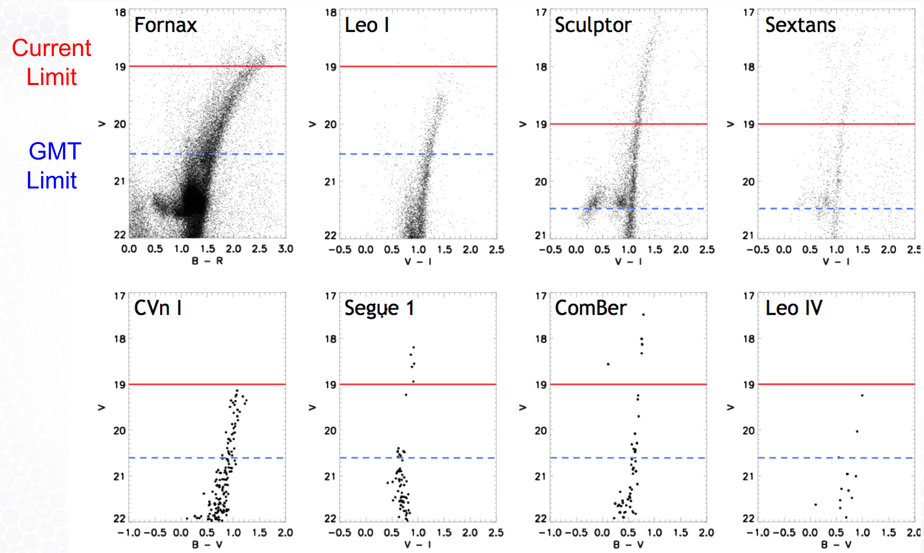


Chemical Enrichment & Dwarf Galaxies



Chemical Enrichment & Dwarf Galaxies

GMT



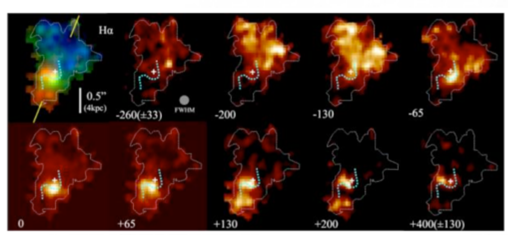
Galaxy assembly, evolution, & chemistry

GMT

Targets: M* galaxies at z~2, peak galaxy formation

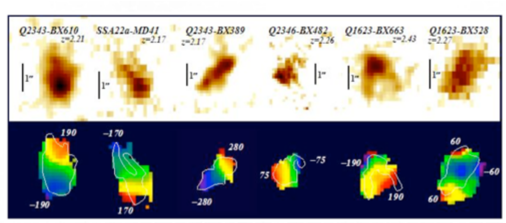
Method: Velocity channel maps (IFU spectroscopy)

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



5L*

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

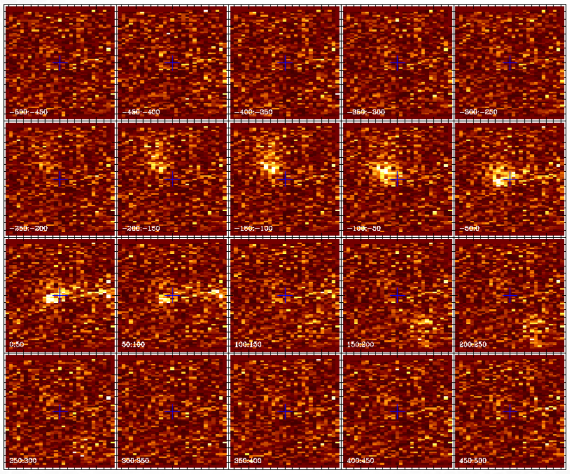


Only massive galaxies are within detection limits of 8m telescopes

Galaxy assembly, evolution, & chemistry

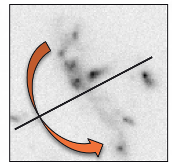
GMT

Milky Way size galaxy, 10 hr integration

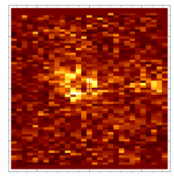


Simulation: Gemini 8m IFU Spectrograph

HUDF - i



NIFS - Sum

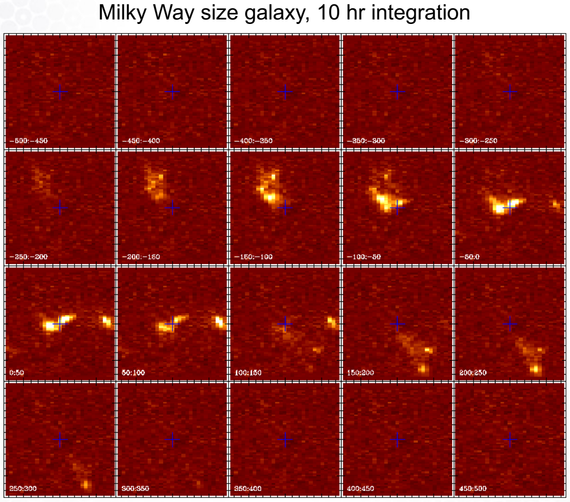


Clump cluster

Galaxy assembly, evolution, & chemistry

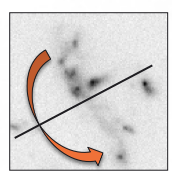
GMT

Milky Way size galaxy, 10 hr integration

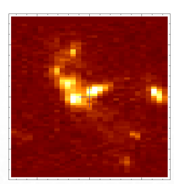


Simulation: GMT simulation

HUDF - i

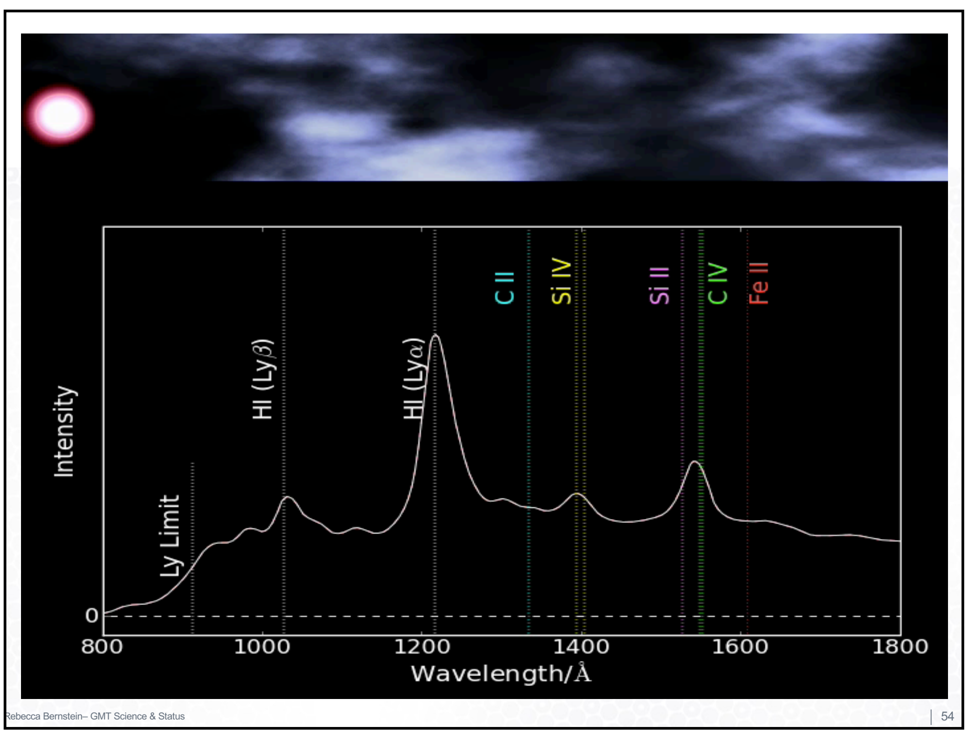


GMT - Sum



Clump cluster


Quasars & the intervening absorption line systems:
GMT
Light travel time from this distance is ~3 Billion years:
QSO at z~3
(Artist's impression, Credit: ESO)
53


Intensity
Wavelength/Å
0
800
1000
1200
1400
1600
1800
Ly Limit
HI (Lyβ)
HI (Lyα)
C II
Si IV
Si II
C IV
Fe II
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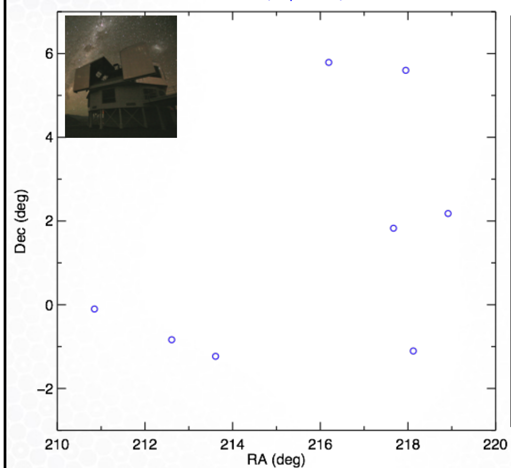
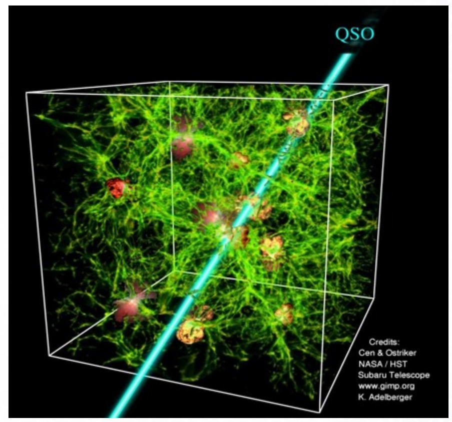
Quasars w/in reach at z=2:

8 Quasars (m_r < 18)





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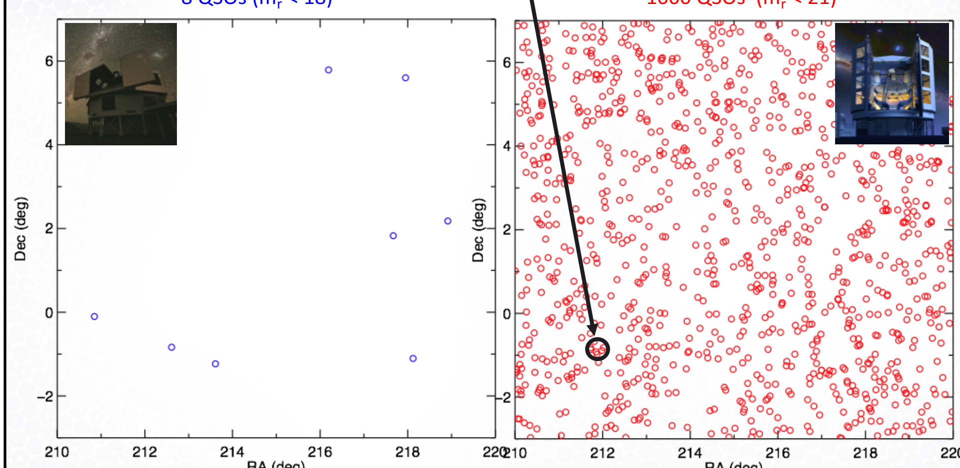
Quasars w/in reach at z=2:

Single exposure, multi-object spectroscopy

8 QSOs (m_r < 18) 1000 QSOs (m_r < 21)



Credit: G. D. Becker, Ryan Cooke

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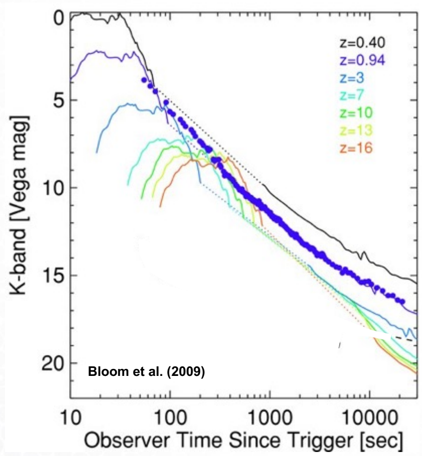
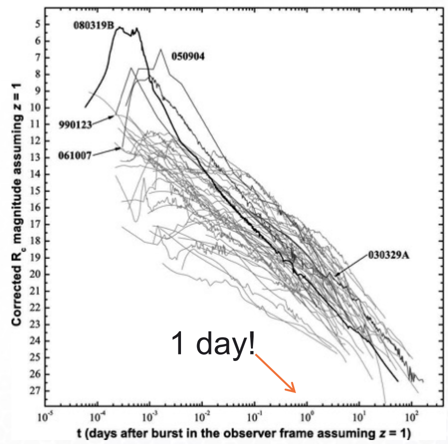
Galaxy formation and the IGM:

GRB's as cosmic probes:

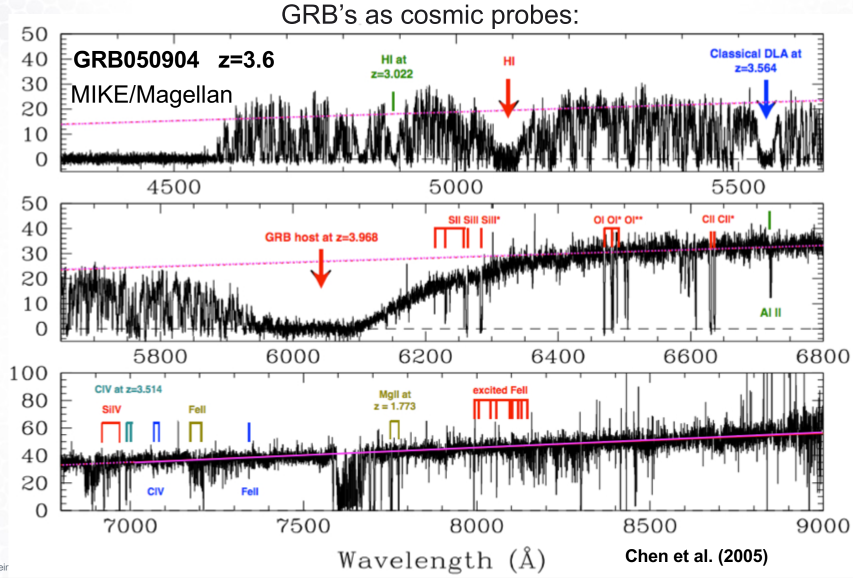
GRBs are easily detected at their peak … but fade *very* rapidly.





Galaxy formation and the IGM:

GRB's as cosmic probes:



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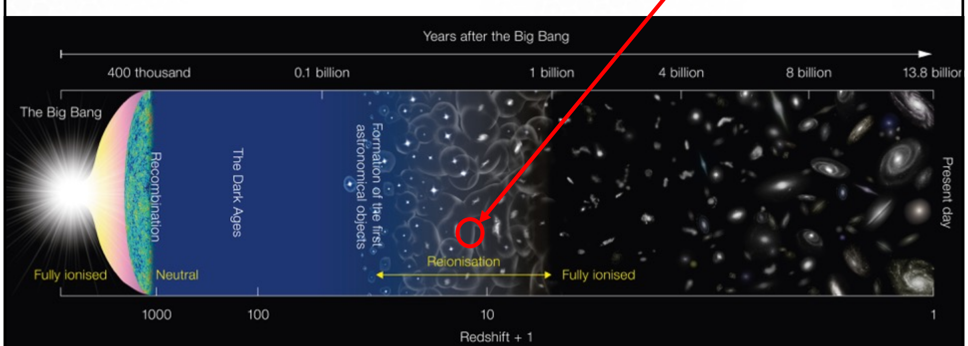
Distant: Formation and Evolution of Galaxies

GMT

- 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

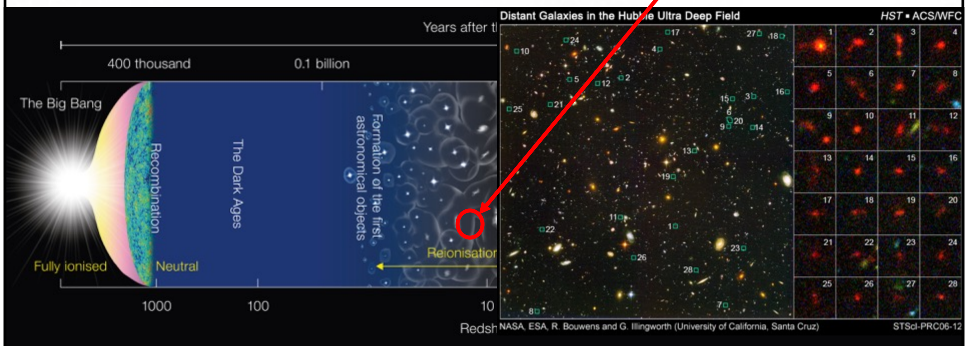


Distant: Formation and Evolution of Galaxies

Methods:

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

Most distant galaxy identified with HST



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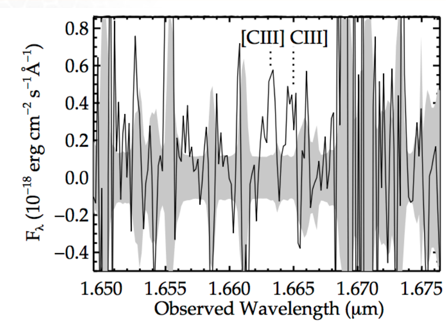
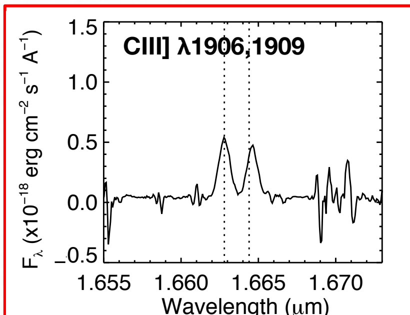
Distant: Formation and Evolution of Galaxies



Keck/NIRSpec

4 hours



GMT/SuperFIRE

4 hours

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Credit: S. Finkelstein (UT), R. Simcoe (MIT)

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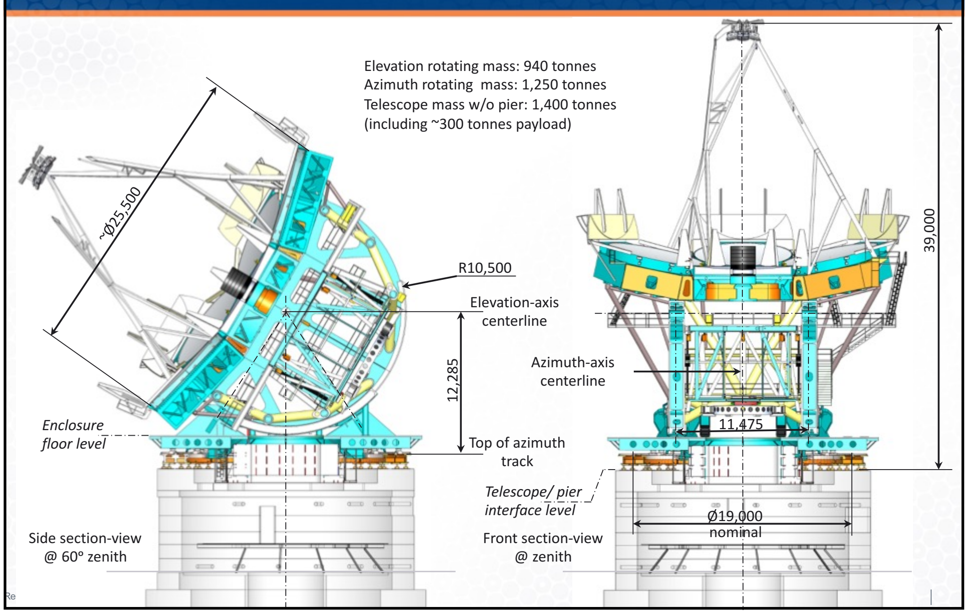
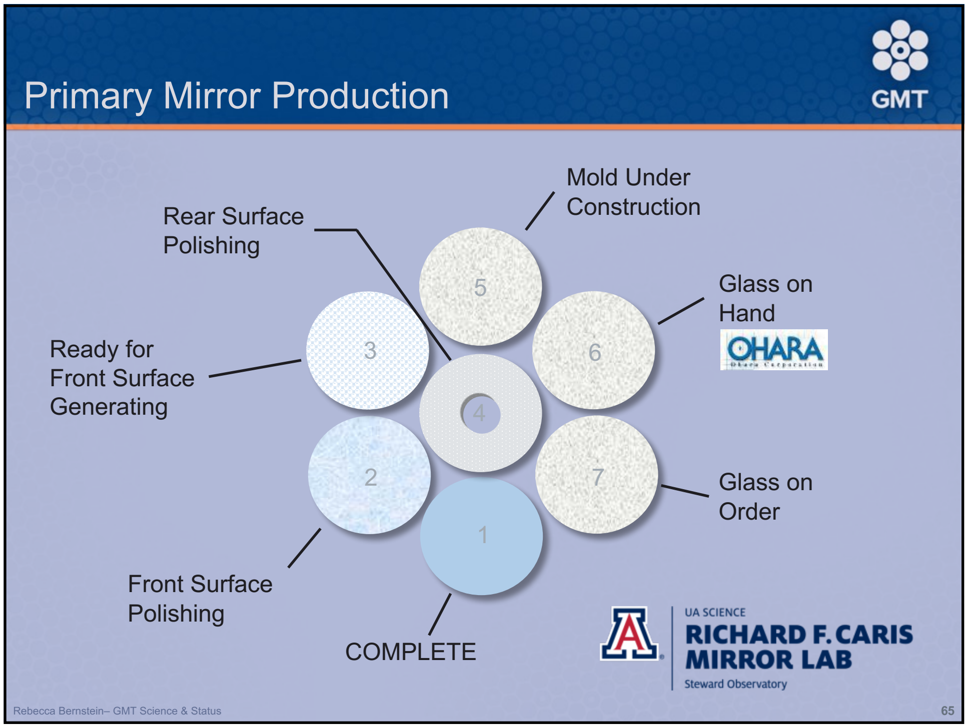
Selecting vendors to complete final design




Primary Mirror Production
GMT
Mold Under Construction
Rear Surface Polishing
Glass on Hand
OHARA
Ready for Front Surface Generating
Glass on Order
Front Surface Polishing
COMPLETE
5
3
6
4
2
7
1
UA SCIENCE
RICHARD F. CARIS MIRROR LAB
Steward Observatory
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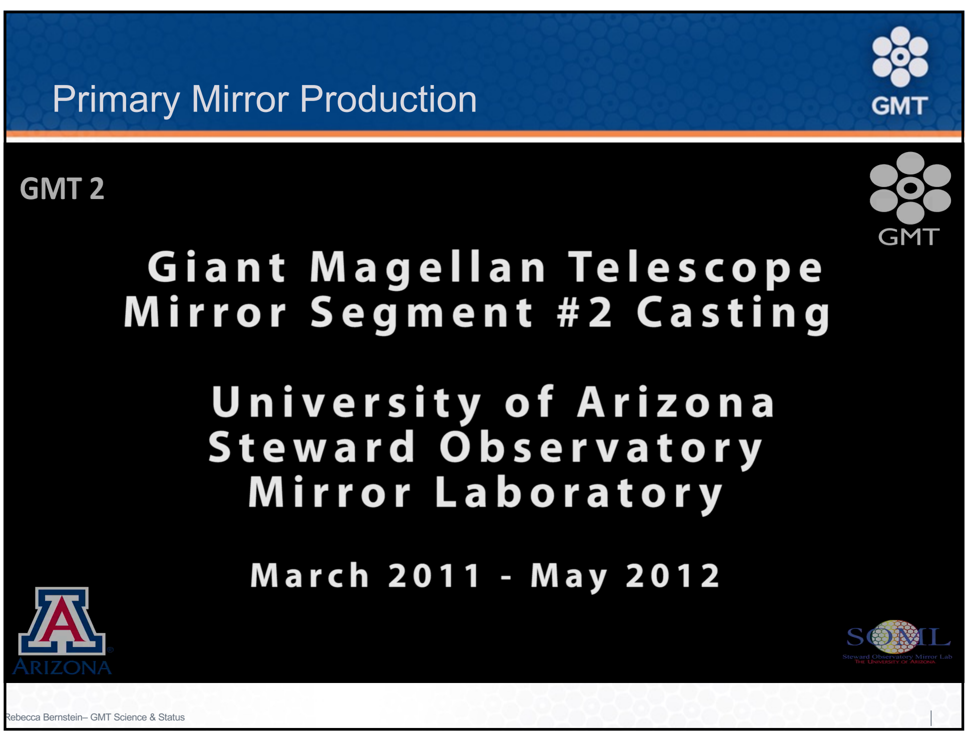
Primary Mirror Production
GMT
GMT 2
GMT
Giant Magellan Telescope
Mirror Segment #2 Casting
University of Arizona
Steward Observatory
Mirror Laboratory
March 2011 - May 2012
ARIZONA
SOML
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2012: Site Cleared and Leveled, Road Graded
67


Site: Las Campanas Observatory (circa 2025)
GMT
4m du Pont
2x 6.5 m Magellan
GMT Site
Masterplan Rendering
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Rendering of GMT at Las Campanas Site
GMT
Warehouse / M1 Factory / M2 Metrology
Summit Support Building
Summit Utility Building
Enclosure


Construction progress: support sites
GMT
Summit Offices & Metrology Station
Main Access Road
Support site 1: Warehouse, M1 Factory & M2 Metrology
Support site 2: Residences, Dining & Recreation Facilities

Construction progress: summit

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

2017 2019 2021 2023 2025 2027

Commissioning Start

Close out

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The Vision

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