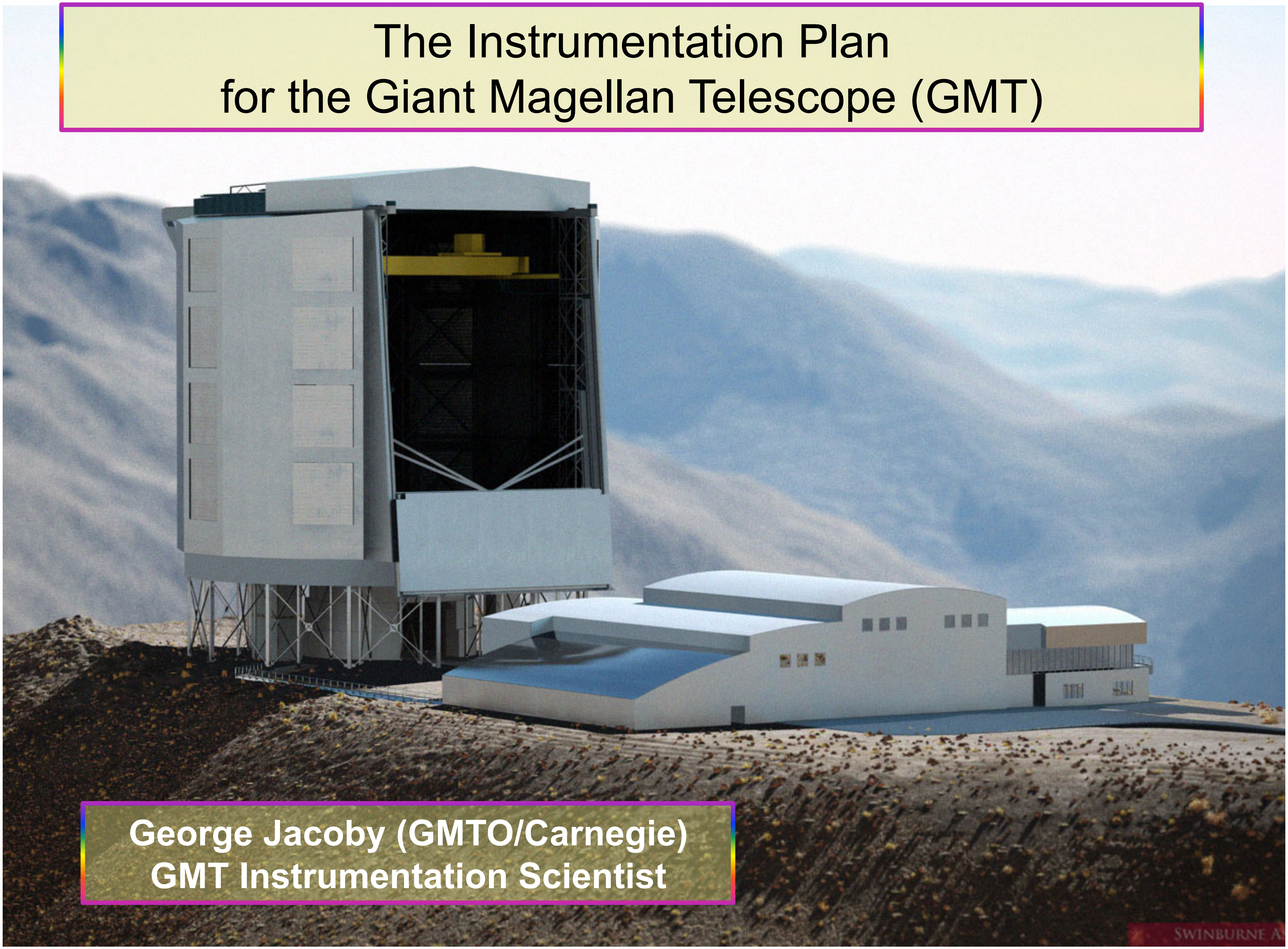
The Instrumentation Plan for the Giant Magellan Telescope (GMT)



George Jacoby (GMTO/Carnegie)
GMT Instrumentation Scientist

Outline

- Project Overview
- Project Status
- Instrument candidates
- The selection: a challenging and dynamic process
- Early science plans

The GMT Concept

Giant-Segmented Mirror Telescope

7 – 8.4-m primary segments
(25.4-m diam; 21.9-m area)

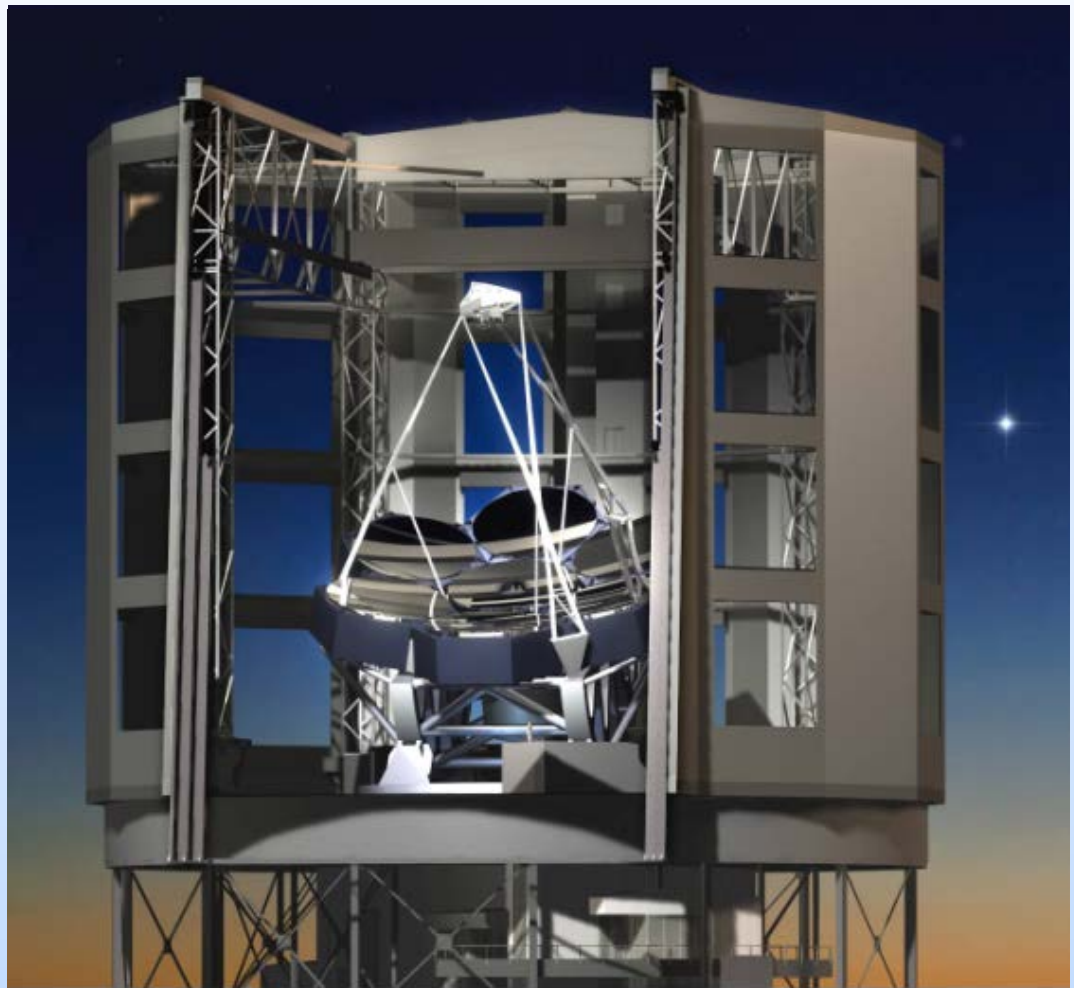
7 – 1.1-m secondary segments

20 arcmin field of view

f/0.7 primary focal ratio

f/8.2 final focal ratio

Plate scale ~ 1.0”/mm

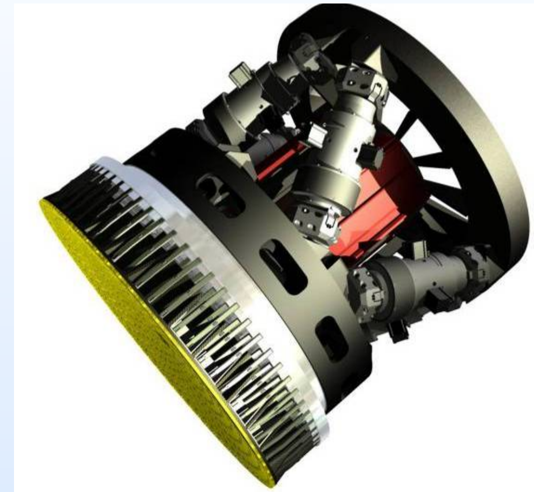


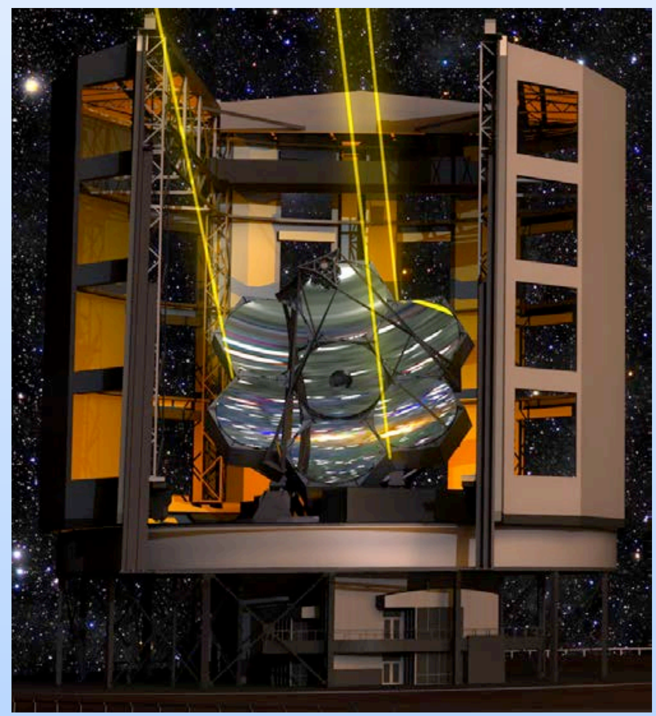
GMT is the smallest of ELTs (Area=E-ELT/e),
But has fewest reflections, and widest-field

Integrated Adaptive Optics System

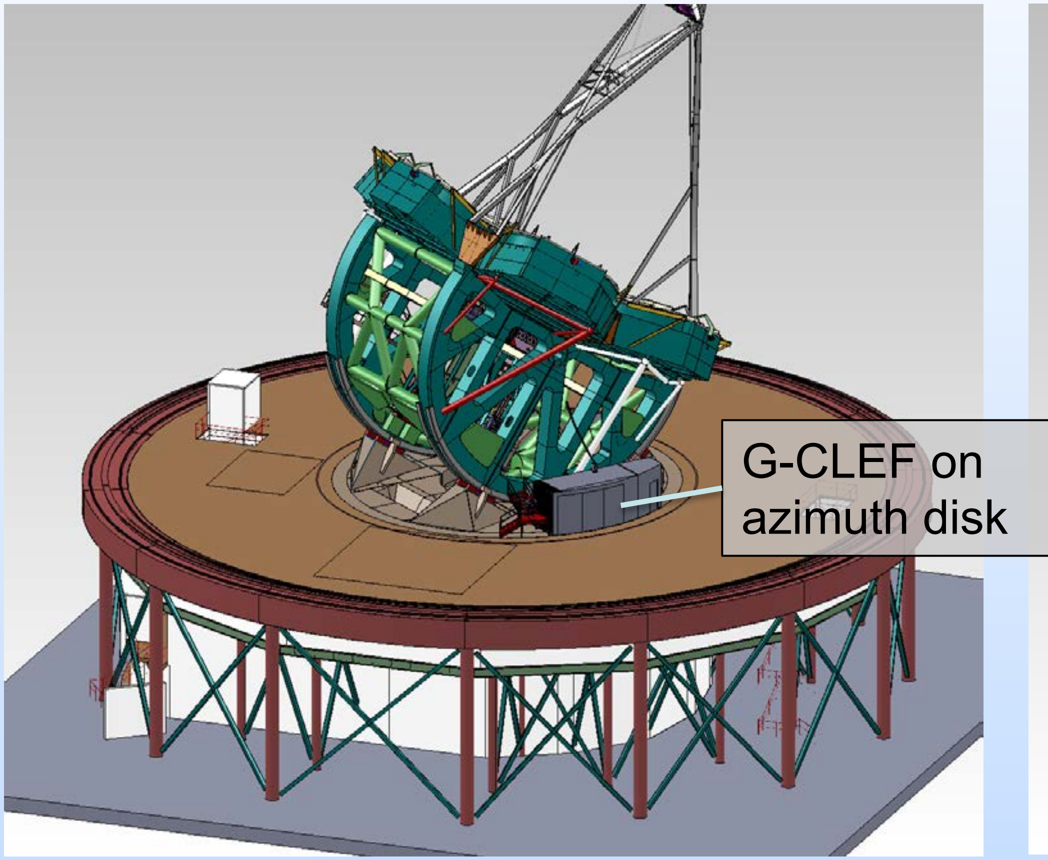
- Adaptive Secondary Mirrors (ASM)
  - 7 x 1.1-m segments, 4704 actuators
- ASM heritage: MMT, LBT, Magellan, (VLT)
- NGSAO/LTAO wavefront sensor package replicated for each AO instrument
- On-instrument IR sensor(s) for tip-tilt, truth
- GLAO using NGS (always available)
- 6 x 20 W sodium lasers for LTAO

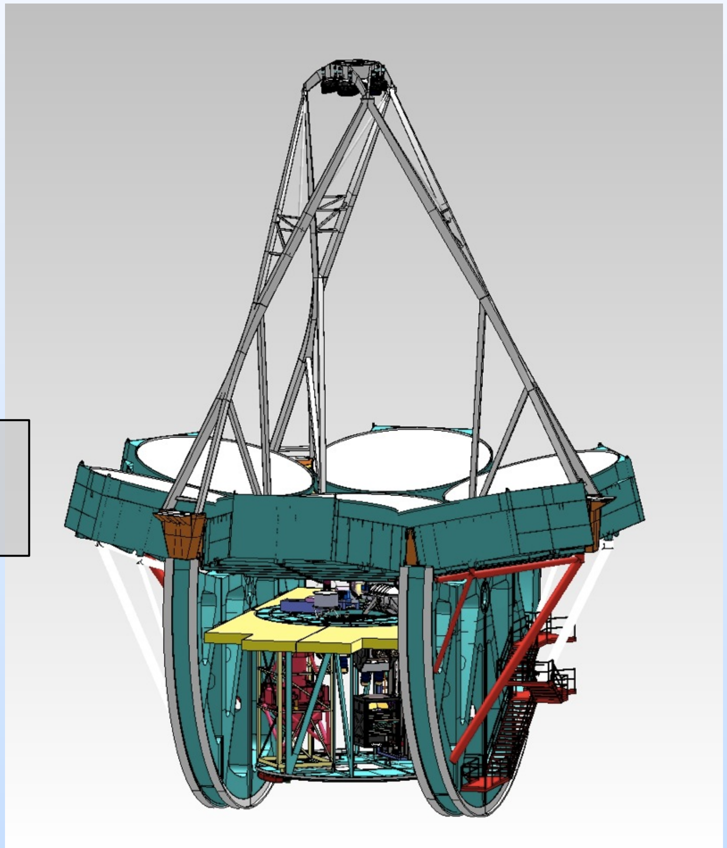
- Available to all instruments (with WFS)





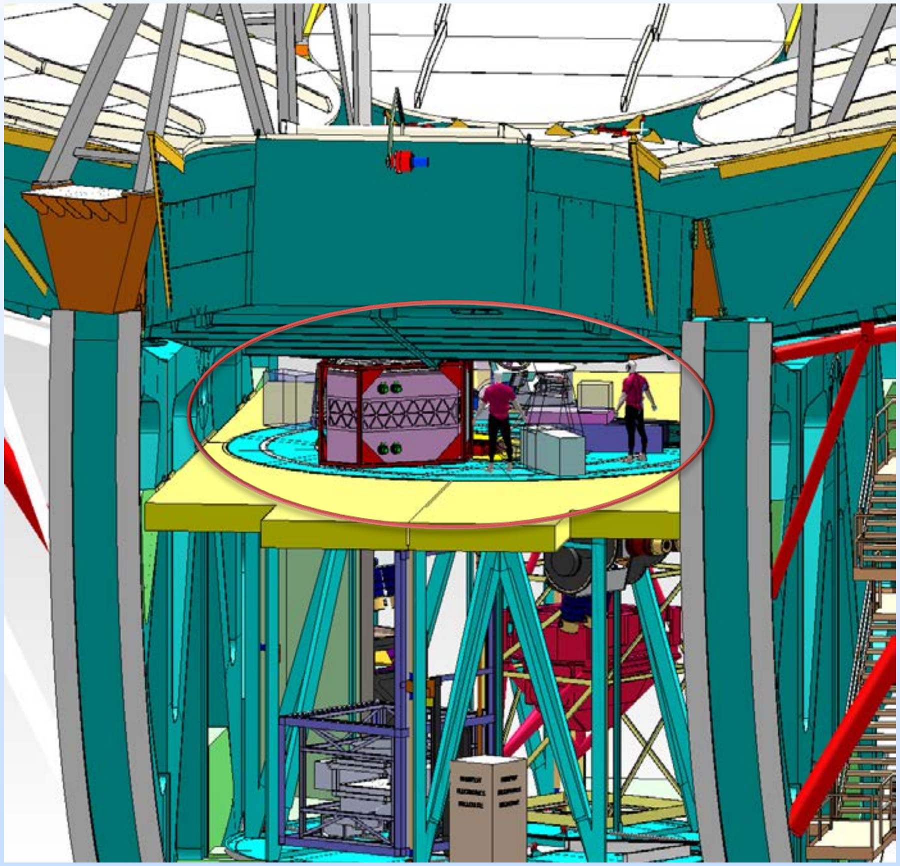
Instrument Locations: Gravity invariant station

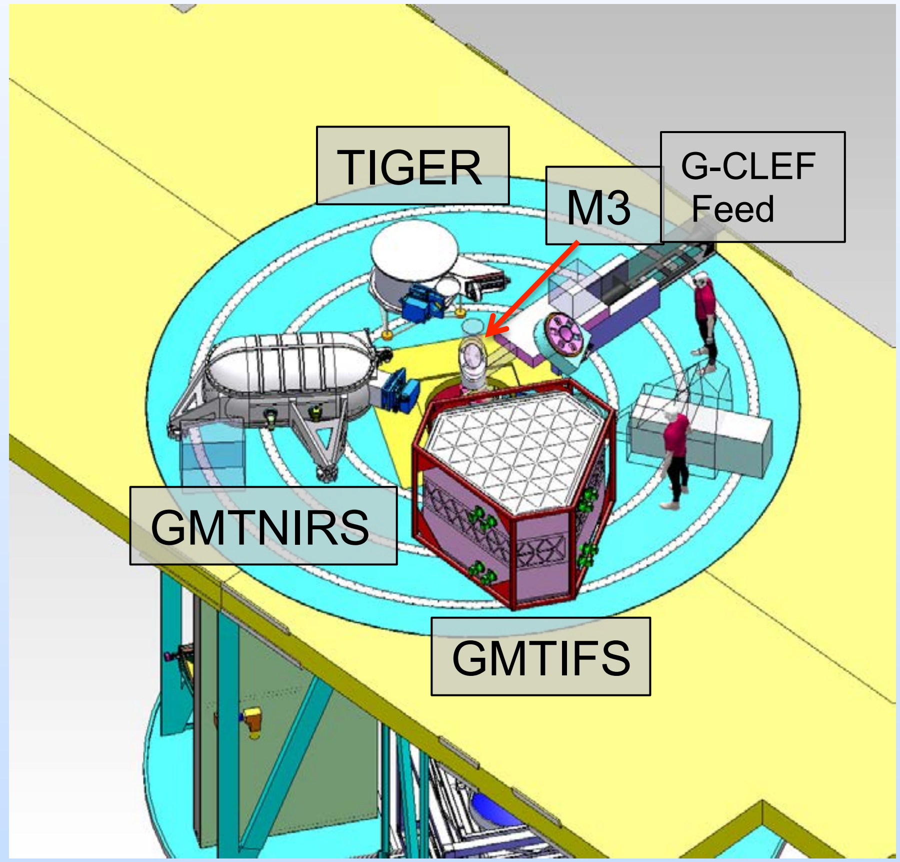




GIS max weight: 20,000 kg

Instrument Location: Folded Ports (3 AO)

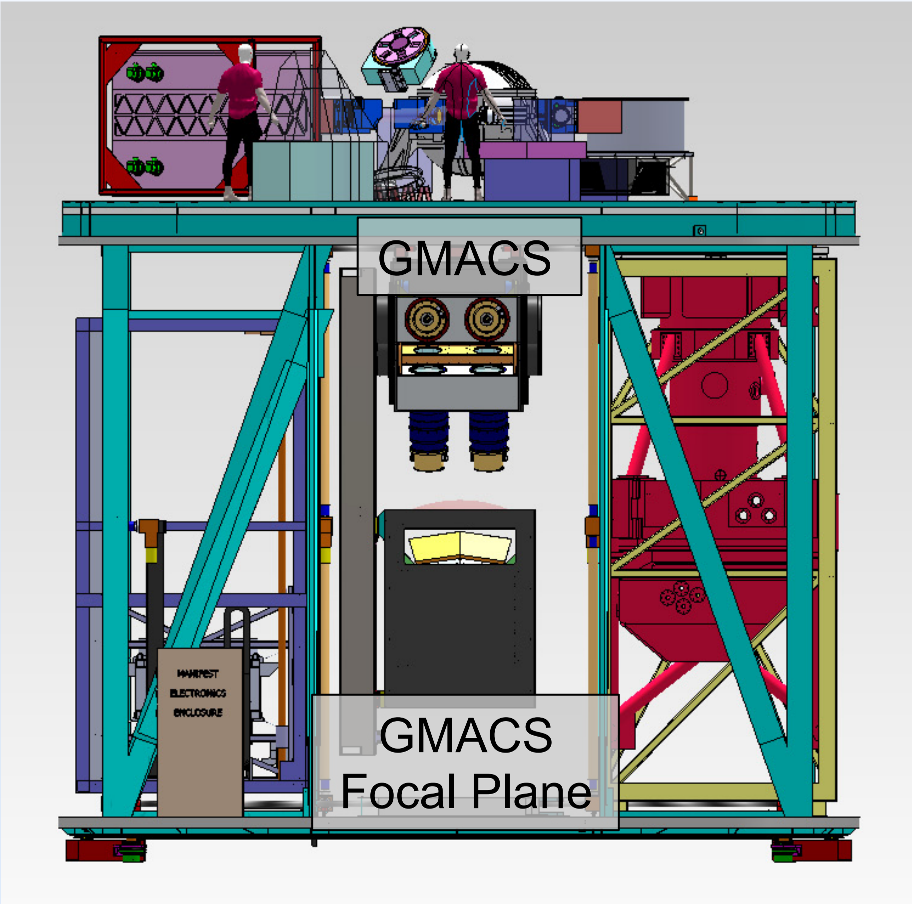


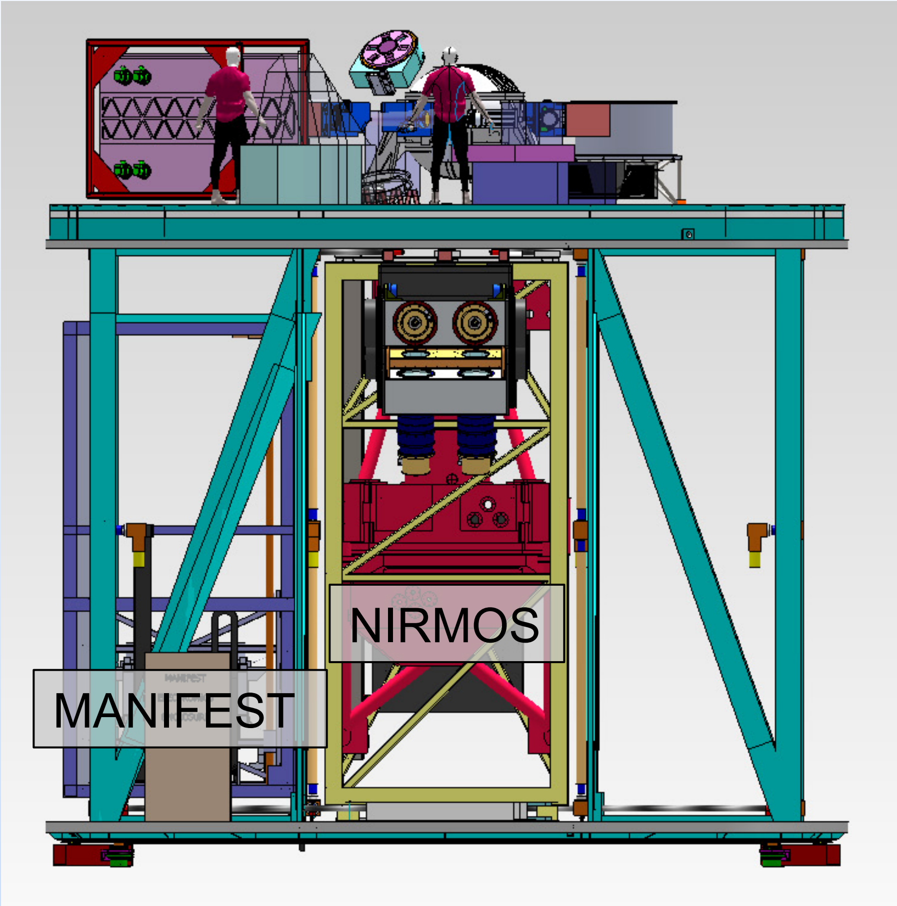


FP max weight: 6,500 kg

FP max size: 3.5 x 5.5 x 1.9-m

Gregorian Instrument Rotator (4 natural seeing)

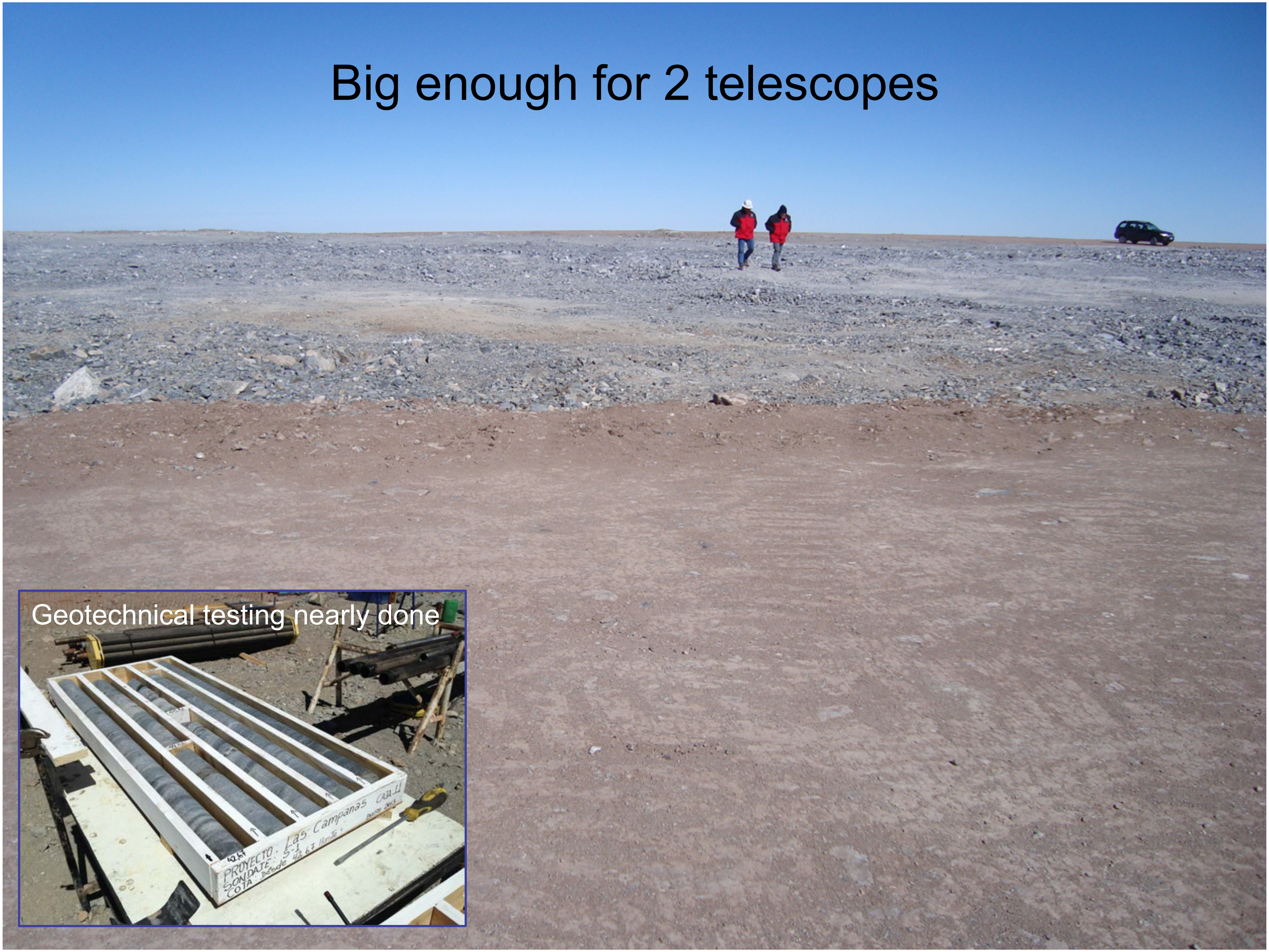




GIR max weight: 11,500 kg

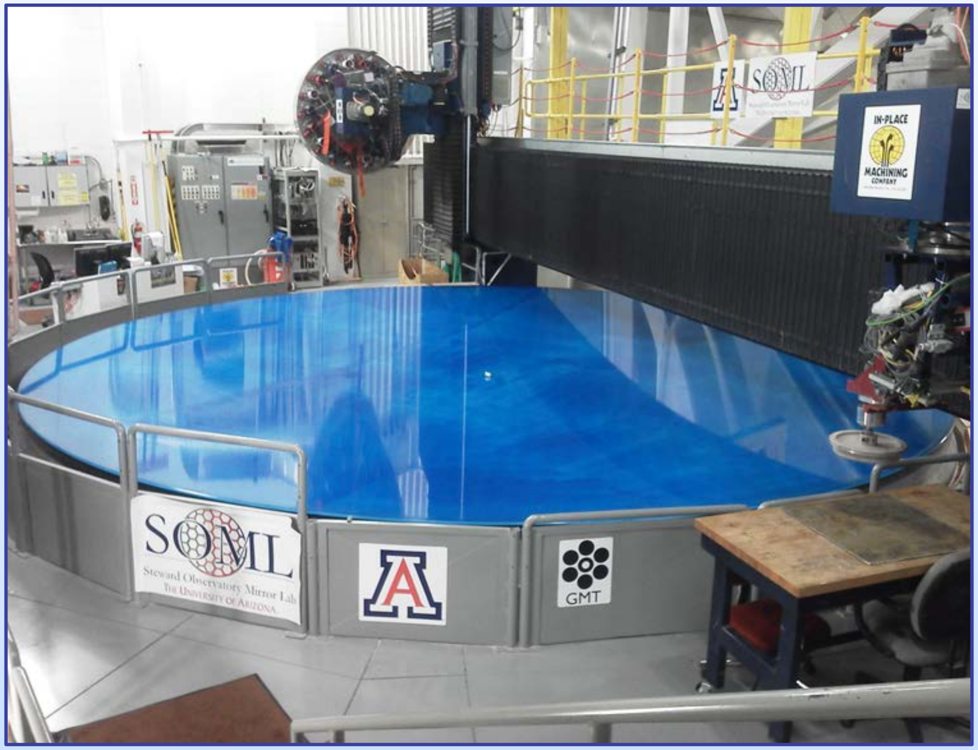
GIR max size: 2.8 x 2.8 x 5.5-m

Site has been cleared on Las Campanas

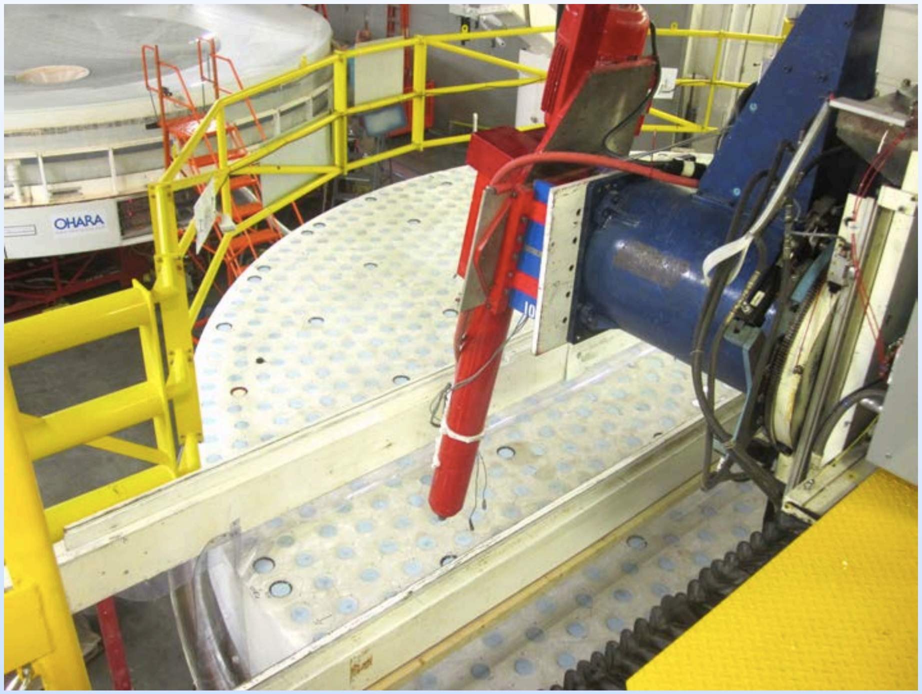

Big enough for 2 telescopes
Geotechnical testing nearly done
PROYECTO: Las Campanas
SONDAJE: S-1
COTA

Primary Mirror Segments (8.36-m)

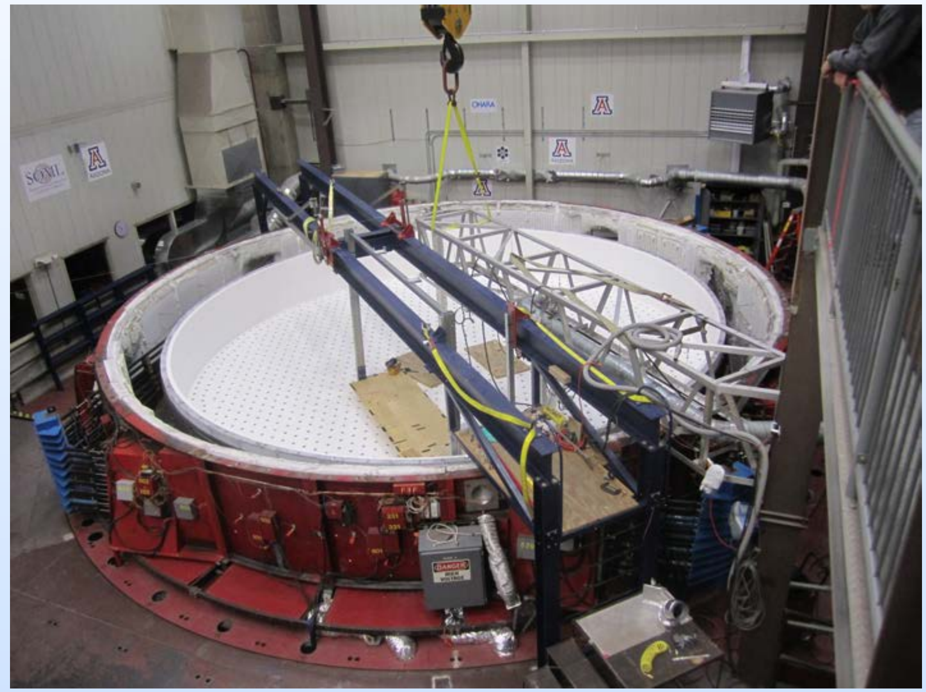
- First segment accepted (off-axis)
  - Accurate to 19 nm RMS
- Seg 2 was cast: Jan 2012
  - Back-side surface generation
- Seg 3 to be cast: Aug 24, 2013
- Seg 4 glass on order (center)
- Commissioning to start ~2019 with 4 segments



GMT2 / GMT3 Segments



GMT2 being prepared for rear surface generation. LSST M1/M3 in background.



Preparing the furnace for firing of GMT3 in August 2013.

Major Milestones – One Year Horizon

- Design Reviews

– Enclosure and facilities:	[Jan 2013]	Passed
– Adaptive Optics:	[May 2013]	
– Telescope systems:	[Aug 2013]	
– Software and controls:	[Sep 2013]	
– System-wide PDR:	[Oct 2013]	

- Construction approval: [Jan 2014]

- Instrument Contracts to start next design phase (workshops)

– Near-IR IFU/Imager	[Apr 2013]	(Mar 12-13, 2013)
– Optical MOS	[Apr 2013]	(Jun 13-14, 2013)
– Echelle	[May 2013]	(Oct 22-23, 2013)

Approx Schedule Plans – Later Years

• Primary segment 4 delivered:	Q1 2019	
• Telescope commissioning start:	Q2 2019	
• First instrument delivered:	Q2 2019	G-CLEF
• Second instrument delivered:	Q4 2019	GMACS
➢ Early science begins:	Q2 2020	
• AO commissioning begins:	Q1 2021	
• Third instrument delivered:	Q1 2021	GMTIFS (AO)
• Primary segment 7 delivered:	Q1 2022	
➢ Construction phase complete:	Q1 2023	

GMT Instruments: Candidates and Selection

(details in SPIE 2012 papers)

Instrumentation Background Thoughts

- Selection pre-determines the science focus 7 years later
  - Example: Planet characterization vs galaxy assembly at z~7
- Science focus affects the perceived impact of the facility
  - With funding sources, among our peers, with the public
- Challenges
  - Science landscape will change after selection
  - Can't have it all; scientists want it all … at first light
  - Budget: limited and changing; instruments expensive
- "Magellan philosophy": keep instruments simple; do a few things well

Selection Activities

- First notions in 2004, leading to GMT System CoDR in 2006

	Instrument	λ(μm)	Resolution	FOV	Notes
★	GMTNIRS	1-5	50-120K	2″	Si Emersion R2 & R4 Echelle
	MIISE	3-28	5-2000	2′ x 2′	Two Channels; nulling
	HRCAM	1-2.5	5-2000	1′ x 1′	Coronographic mode
	NIRMOS	0.9-2.5	1500-3500	5′ x 5′	7′ x 5′ imaging field of view
★	GMACS	0.4-1.0	3500-5000	9′ x 18′	Four double spectrographs

- Conceptual design studies (7 instr): Jun 2010 - Oct 2011
- **Instrument Advisory Panel:** Feb 2012 → 3 instruments (or 5?)
  - Partner scientists recommend first generation instruments
- Implementation plan submitted to Board: Jun 2012
  - Accommodate IAP report within budget and schedule
- Board authorization to release contracts: Mar 2013 ???
  - *Instrument teams on "hold" since CoDR (now ~16 months)*

IAP Selection Factors: "Static"

- Science potential of each & the combined suite of instruments
- Technical merit, readiness to advance
- Cost envelope for instrumentation
- Operational balance (bright vs dark, site conditions)
- Synergies with other facilities

Instrument Advisory Panel
Representing GMT partners
With 2 community members
Feb 2-3, 2012

Other Factors: “Dynamic”

- Global economy and government support
- Total budget and cash flow profile
- Project time line and schedule

- When is it time to decide? Later is better, but can’t be too late!
  - Can respond to changing science landscape
  - Instrument teams (and others) continue to think up great ideas
  - Desire to keep many partners engaged intellectually
  - Technical advances (detectors, AO performance)
  - Design disasters (some widget or design fails to perform)

The GMT Plan Today

Instrument	Function	λ Range, μm	Resolution	Field of View
G-CLEF*	Optical High Resolution Spectrometer / PRV	0.35 – 0.95	20 – 100K	Single Object
GMACS*	Optical Multi-Object Spectrometer	0.36 – 1.0	1500 – 4000, 10,000	40-50 $arcmin^2$
GMTIFS	NIR **AO**-fed IFU / Imager	0.9 – 2.5	4000 – 10,000	10 / 400 $arcsec^2$
GMTNIRS†	JHKLM **AO**-fed High Resolution Spectrometer	1.2 – 5.0	50 – 100K	Single Object
NIRMOS*	Near-IR Multi-Object Spectrometer / imager	0.9 – 2.5	2700 – 5000	42 $arcmin^2$
TIGER	Mid-IR **AO**-fed Imager and Spectrometer	1.5 – 14	300	0.25 $arcmin^2$
MANIFEST*	Facility Robotic Fiber Feed	0.36 – 1.0		300 $arcmin^2$

Optical | 1-2.5 μm | Mid-IR

- Proceed to Next Design Phase
- Develop Grating Technology
- Develop Prototype
- Include in Second Generation Call

★ GMACS, NIRMOS, and G-CLEF can be fed by MANIFEST (20 arcmin FoV, multi-IFUs, image slicers)

† GMTNIRS now includes Y-Z coverage @ R ~8000

Development Toward Science Goals

Science Topic/Stage	Early (1)	Enhanced (2AB)	Full (3)	1st Decade	Techniques
Primary mirrors	4 segments	7 segments	7 segments	7 segments	separated beams, stacked, phased
Instruments	G-CLEF/MACS	GMTIFS	MANIFEST/NIRS	TIGER, NIR Spec	near-UV through mid-IR imaging and spectroscopy
Science Book Chapter/Modes	Seeing	8m AO	24m AO Wide field	ExAO, GLAO	NGSAO, LTAO, GLAO, ExAO
Formation of Stars and Planetary Systems					
2.1 From Stars to Planets	Little or no	Some	Some	Excellent	AO imaging of disks
2.2 Young Stars	Little or no	Some	Strong	Excellent	Spectroscopy, Chemical analysis
2.3 The IMF and Planets	Little or no	Some	Strong	Excellent	Imaging, Astrometry
2.4 Disk Evolution	Little or no	Little or no	Some	Excellent	Spectroscopy, AO Imaging
2.5 System Architecture	Some	Strong	Excellent	Excellent	Spectroastrometry
2.6 Solar System Studies	Some	Some	Strong	Excellent	Imaging, low-dispersion spectroscopy
Properties of Exoplanetary Systems					
3.1 Formation Models	Some	Some	Strong	Excellent	Doppler, transit, and imaging demographic studies
3.2 Atmospheres	Strong	Excellent	Excellent	Excellent	Transit Spectroscopy
3.3 Imaging Exoplanets	Little or no	Some	Some	Excellent	Reflected light and thermal imaging
3.4 Habitable Worlds	Strong	Excellent	Excellent	Excellent	Precision Radial Velocities
Stellar Populations and Chemical Evolution					
4.1 Population Studies	Strong	Excellent	Excellent	Excellent	High-resolution spectroscopy, Survey follow-up
4.2 Stellar Archeology	Strong	Excellent	Excellent	Excellent	High-resolution spectroscopy
4.3 Abundances in Dwarfs	Some	Excellent	Excellent	Excellent	High-resolution spectroscopy, photometery
4.4 Milky Way Halo	Some	Excellent	Excellent	Excellent	High-resolution spectroscopy
4.5 Globular Clusters	Strong	Strong	Excellent	Excellent	Integrated light spectra, AO Imaging & Photometry
Assembly of Galaxies					
5.2 Local Dwarf Galaxies	Strong	Strong	Excellent	Excellent	High-resolution spectroscopy, photometry
5.3.1 Mass Assembly	Strong	Strong	Strong	Excellent	visible/near-IR spectroscopy, photometry, AO
5.3.2 Dynamical Masses	Little or no	Strong	Excellent	Excellent	spectroscopy, IFU
5.3.3 Gas Kinematics	Little or no	Strong	Excellent	Excellent	IFU spectroscopy
5.3.4 Mass-Metalicity Relation	Some	Some	Some	Excellent	Rest-frame visible spectroscopy
5.3.5 Feed-Back and the IGM	Strong	Excellent	Excellent	Excellent	Rest-frame UV spectroscopy
5.4 Massive Black Holes	Little or no	Some	Excellent	Excellent	IFU Spectrocopy
Dark Matter, Dark Energy, & Fundamental Physics					
6.1 Cosmological Parameters	Some	Strong	Strong	Strong	Survey follow-up, spectroscopy, High A-Omega
6.2 LSST Follow-up	Strong	Strong	Excellent	Excellent	Multi-object spectroscopy, Near-IR imaging
6.3 Clusters & Dark Matter	Strong	Strong	Excellent	Excellent	Spectroscopy
6.4 Dark Matter in Dwarfs	Some	Strong	Excellent	Excellent	Radial velocity surveys
First Light and Reioinzation					
7.2 First Stars & Galaxies	Some	Some	Strong	Excellent	Near-IR spectroscopy
7.3 Early Galaxies	Strong	Strong	Strong	Excellent	AO imaging, visible and near-IR spectroscopy
7.4 Population III Stars	Little or no	Strong	Strong	Excellent	Near-IR spectroscopy
7.5 Probing Reionization	Some	Strong	Strong	Excellent	Red and near-IR spectroscopy
7.6 HI Topology	Some	Strong	Strong	Strong	Lyman alpha imaging
7.7 IGM Spectroscopy	Some	Strong	Strong	Strong	Intermediate and high-resolution spectroscopy
Transient Phenomena					
8.2 Long-Duration GRBs	Some	Strong	Strong	Strong	High-resolution spectroscopy, photometry
8.3 Supernovae	Some	Strong	Strong	Strong	low-resolution spectroscopy, spectropolarimetry
8.4 Other Transients	Strong	Excellent	Excellent	Excellent	rapid response spectroscopy

Little or no Match

Some Match

Strong Match

Excellent Match

Science Topic/Stage		Early (1)	Enhanced (2AB)	Full (3)	1^{st} Decade	Techniques
	Primary mirrors	4 segments	7 segments	7 segments	7 segments	separated beams, stacked, phased
	Instruments	G-CLEF/MACS	GMTIFS	MANIFEST/NIRS	TIGER, NIR Spec	near-UV through mid-IR imaging and spectroscopy
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Formation of Stars and Planetary Systems						
2.1	From Stars to Planets					AO imaging of disks
2.2	Young Stars					Spectroscopy, Chemical analysis
2.3	The IMF and Planets					Imaging, Astrometry
2.4	Disk Evolution					Spectroscopy, AO Imaging
2.5	System Architecture					Spectroastrometry
2.6	Solar System Studies					Imaging, low-dispersion spectroscopy
Properties of Exoplanetary Systems						
3.1	Formation Models					Doppler, transit, and imaging demographic studies
3.2	Atmospheres					Transit Spectroscopy
3.3	Imaging Exoplanets					Reflected light and thermal imaging
3.4	Habitable Worlds					Precision Radial Velocities
Stellar Populations and Chemical Evolution						
4.1	Population Studies					High-resolution spectroscopy, Survey follow-up
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4.3	Abundances in Dwarfs					High-resolution spectroscopy, photometery
4.4	Milky Way Halo					High-resolution spectroscopy
4.5	Globular Clusters					Integrated light spectra, AO Imaging & Photometry
Assembly of Galaxies						
5.2	Local Dwarf Galaxies					High-resolution spectroscopy, photometry
5.3.1	Mass Assembly					visible/near-IR spectroscopy, photometry, AO
5.3.2	Dynamical Masses					spectroscopy, IFU
5.3.3	Gas Kinematics					IFU spectroscopy
5.3.4	Mass-Metalicity Relation					Rest-frame visible spectroscopy
5.3.5	Feed-Back and the IGM					Rest-frame UV spectroscopy
5.4	Massive Black Holes					IFU Spectrocopy
Dark Matter, Dark Energy, & Fundamental Physics						
6.1	Cosmological Parameters					Survey follow-up, spectroscopy, High A-Omega
6.2	LSST Follow-up					Multi-object spectroscopy, Near-IR imaging
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6.4	Dark Matter in Dwarfs					Radial velocity surveys
First Light and Reioinzation						
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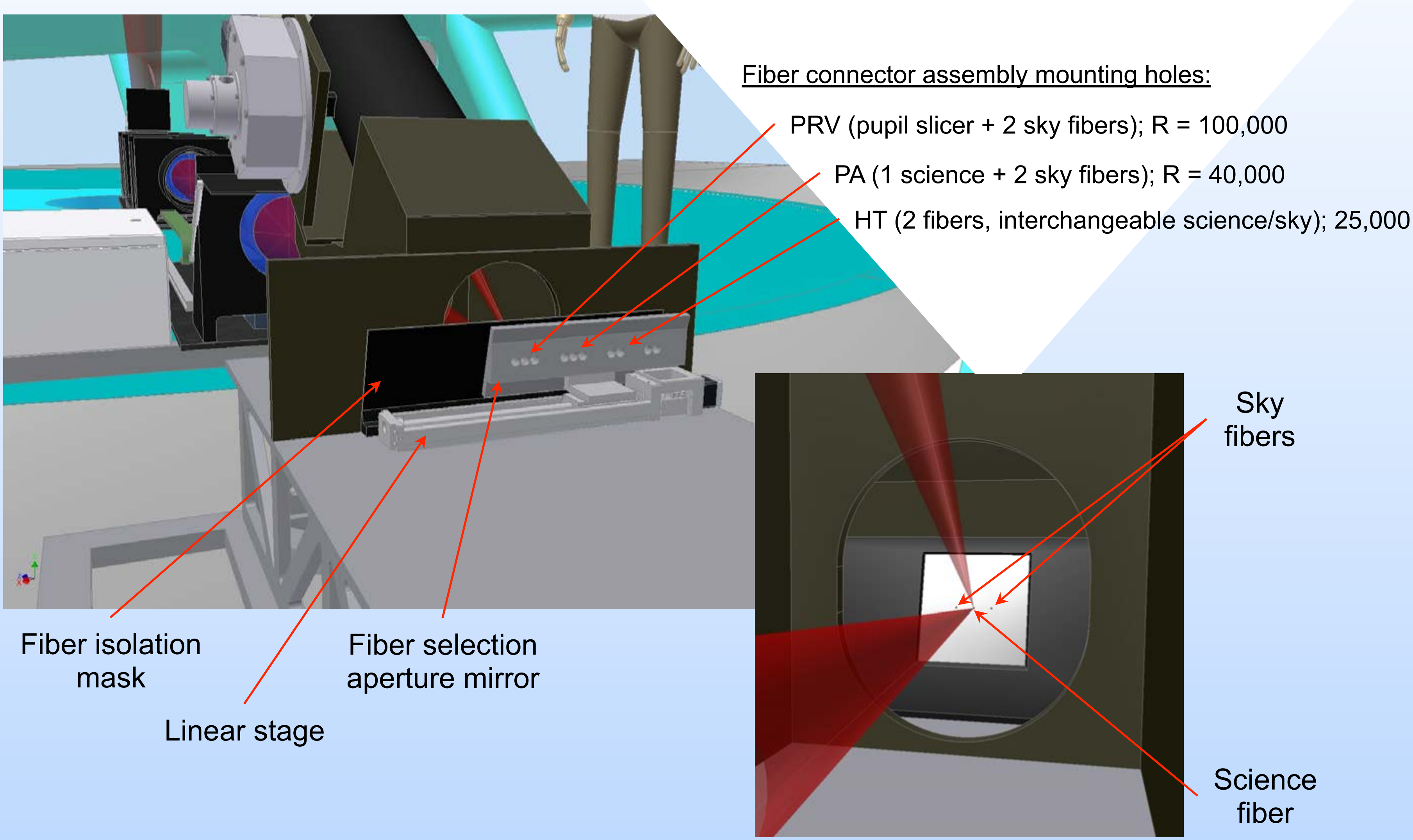
7.3	Early Galaxies					AO imaging, visible and near-IR spectroscopy
7.4	Population III Stars					Near-IR spectroscopy
7.5	Probing Reionization					Red and near-IR spectroscopy
7.6	HI Topology					Lyman alpha imaging
7.7	IGM Spectroscopy					Intermediate and high-resolution spectroscopy
Transient Phenomena						
8.2	Long-Duration GRBs					High-resolution spectroscopy, photometry
8.3	Supernovae					low-resolution spectroscopy, spectropolarimetry
8.4	Other Transients					rapid response spectroscopy

G-CLEF: GMT-CfA, Carnegie, Catolica, Chicago Large Earth Finder Andrew Szentgyorgyi (CfA)

- Natural seeing dual-beam optical R4 Echelle (0.35 – 1.0 μm)
- Full spectrum coverage
- R ~ 20,000 - 100,000 (depends on fiber mode)
  - Accurate abundances
  - Precision velocities (goal ~10 cm/s)
- Good spectrograph throughput
  - ~40% from 400 – 800 nm
  - ~12% all inclusive (tel, feed)
  - ~20% with AO
- Accepts MANIFEST facility fiber feed
  - 20’ FoV
  - MOS -- 40 objects (limited λ-coverage)
- **Workshop Oct 22-23 (tentative)**

Fiber Selection



GMACS: GMT Areal Camera and Spectrograph
Darren DePoy (Texas A&M)

- Classic optical dual-beam MOS
- ~5 x 9 arcmin field
- Excellent sensitivity over 370 – 950 nm
- ~12 Multi-slit masks – ~80 slits per mask
- R ~1000-2000 (blue); 2500-5000 (red)
- Accepts fiber feed from MANIFEST
  - full 20 arcmin coverage
  - R ~ 10,000 with image slicer
  - Deployable IFUs

- **Currently in re-design for on-axis operation**

- **Workshop June 13-14 (tentative)**

Early Science

- Survey spectroscopy
  - Lyα galaxy distributions & luminosity functions to z ~ 6 (source of re-ionization)
  - Local Group dark matter distributions (kinematics in galaxy halos and dwarfs)
  - Stellar populations and streams (kinematics and abundances)
  - Galaxy assembly (gas inflow and outflow over time)

- Follow-up LSST / DECam targets

GMTIFS: GMT Integral Field Spectrograph
Peter McGregor (ANU)

- ZJHK Integral Field Spectrograph – image slicer system
- Medium resolution: R ~ 5,000 and 10,000
- Multiple scales and fields of view
- Data cube (rectangular prism): 45 (slits) x 88 (slitwise) x 4096 (spectral)

Spaxel size (mas)	6	12	25	50
Field of view (arcsec)	0.54×0.27	1.08×0.54	2.25×1.13	4.5×2.25

- Near-IR AO imager (0.9 – 2.5 μm)
  - 5 mas/pixel, 20.4”× 20.4” FoV
  - Dual filter wheel (~16 filters)

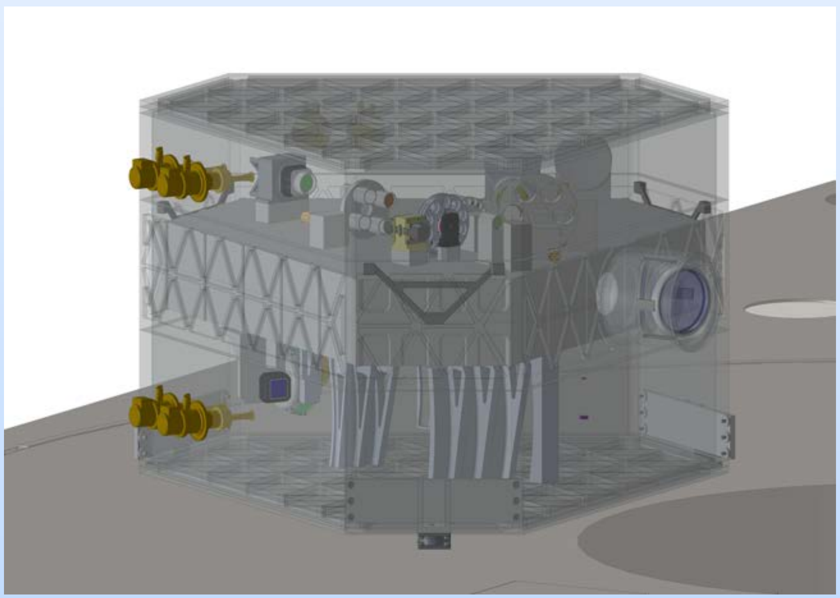
- **Workshop March 12-13, 2013**

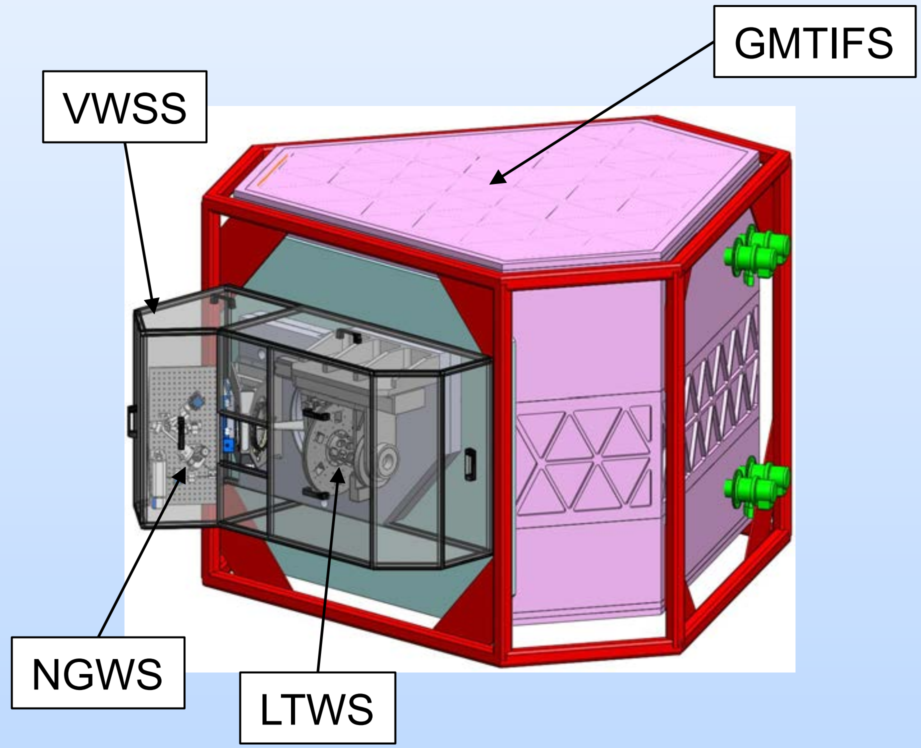
Early Science

- Galaxy assembly vs time with Lyα and Hα emission kinematics
- Black hole and galaxy formation (galaxy nuclei from stellar and gas kinematics)
- Star formation and chemical histories of nearby systems (resolved pops)

Instrument Design

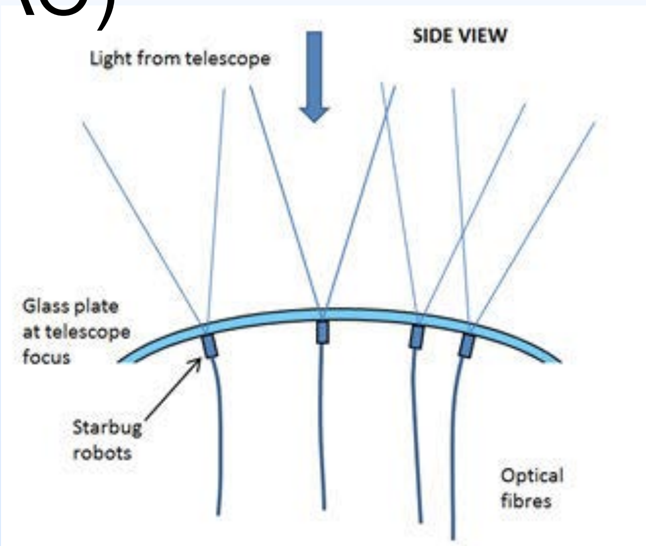
- Three levels
  - Upper: Imager
  - Lower: Integral Field Spectrograph
  - Center: Optical feed and science selector, guide star optics

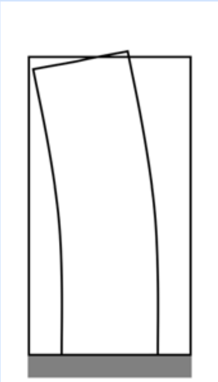


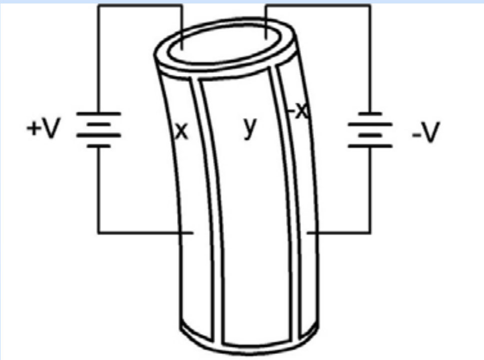


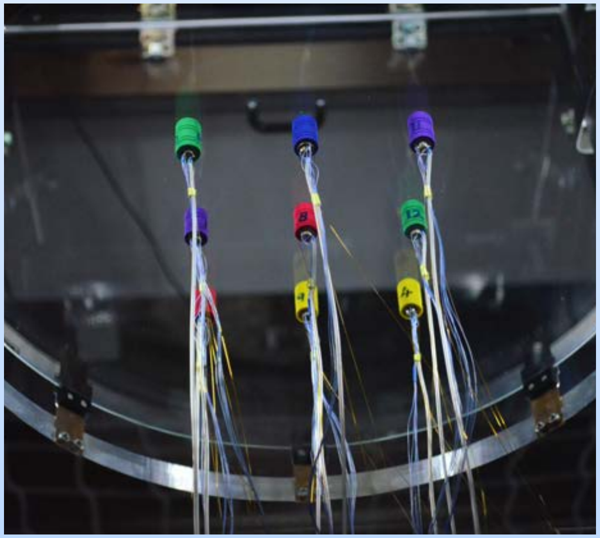
MANIFEST: MANy Instrument FibEr SysTem
Jon Lawrence (AAO)

- ~2000 moving Starbugs
- Covers the GMT's full 20' diameter field
- Single-fiber, image-slicer, and IFU feeds for GMACS and G-CLEF (simultaneously)
- Configuration time < 3 min
- Object spacing ~ 10 arcsec
- Excellent for "AΩ science" (e.g. LSST/DECam follow-on)



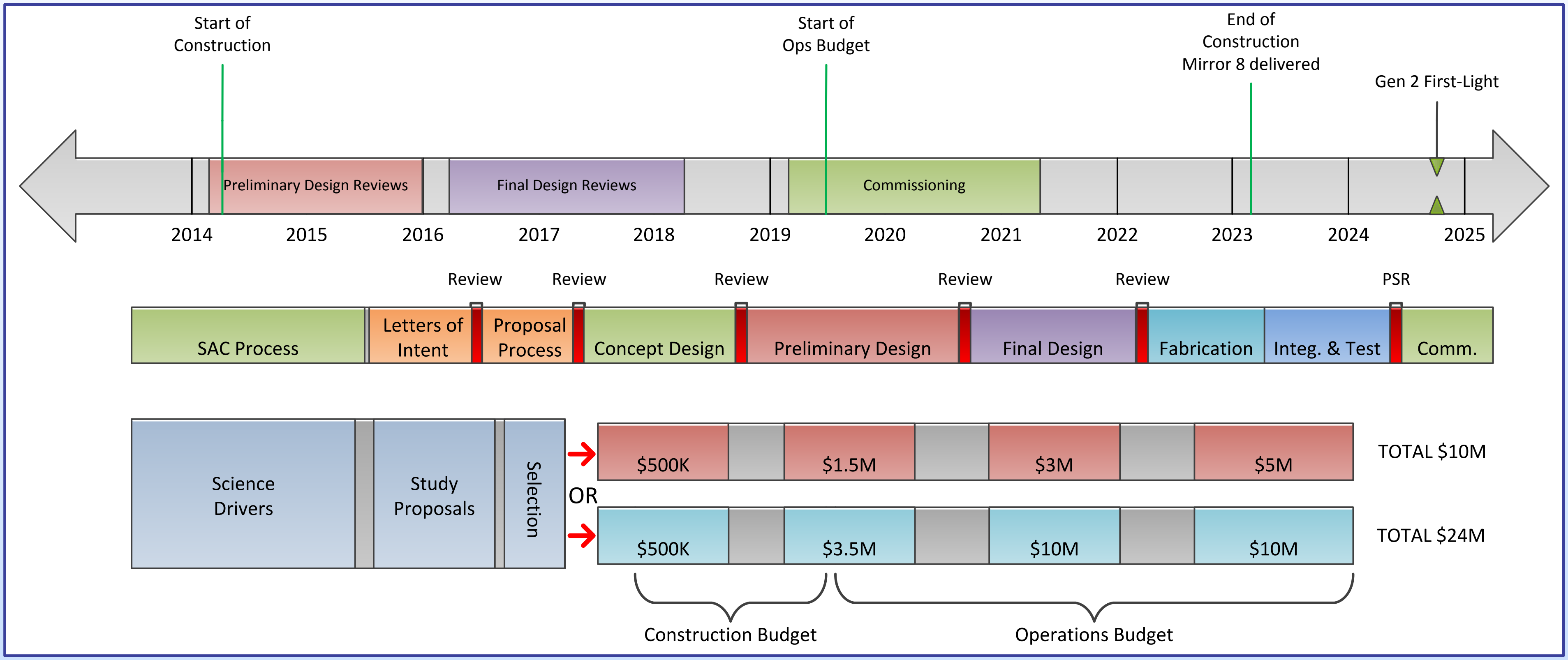






Second-Generation Instrument Roadmap

(notional! still under discussion)



Funded from Operations Budget (2019)
Process can be repeated every few years

Summary

- GMT project is advancing
  - In production mode for 4 primary segments
  - Subsystem reviews being completed or scheduled
  - Instrument design toward PDRs about to start
- First generation instruments have broad application
  - Largely meet demands of GMT partnership & science case
    - Strengths in extragalactic, chemical abundances, planet characterization
    - Meets operational demands for bright/dark, AO/non-AO modes
- E-ELT instrument selections – all good choices!
  - An optical MOS is always a good idea (Gemini)
  - High resolution spectrograph on large telescope has high impact (Keck)
  - A mid-IR instrument on a southern ELT will be unique for years

END