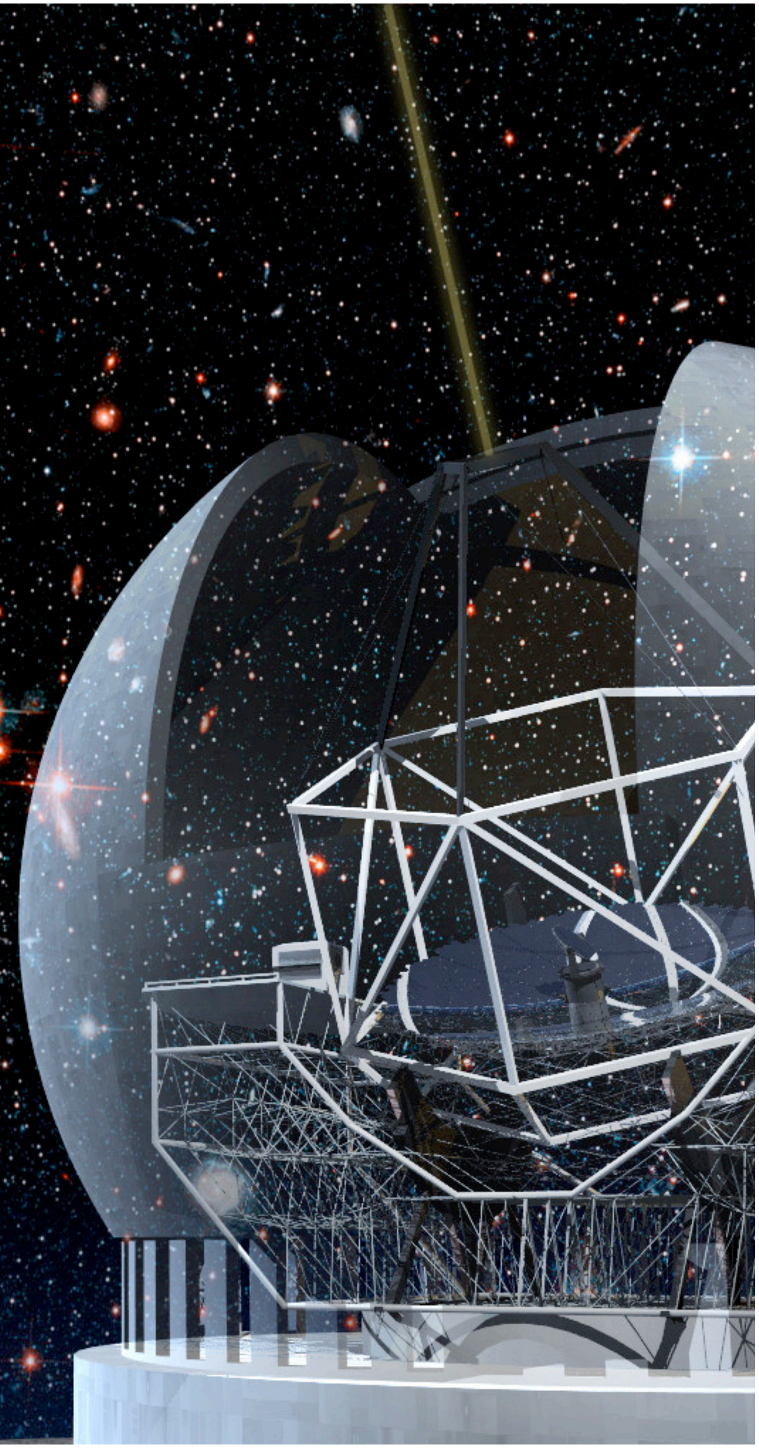
Making the most of the Great Observatories: OIR

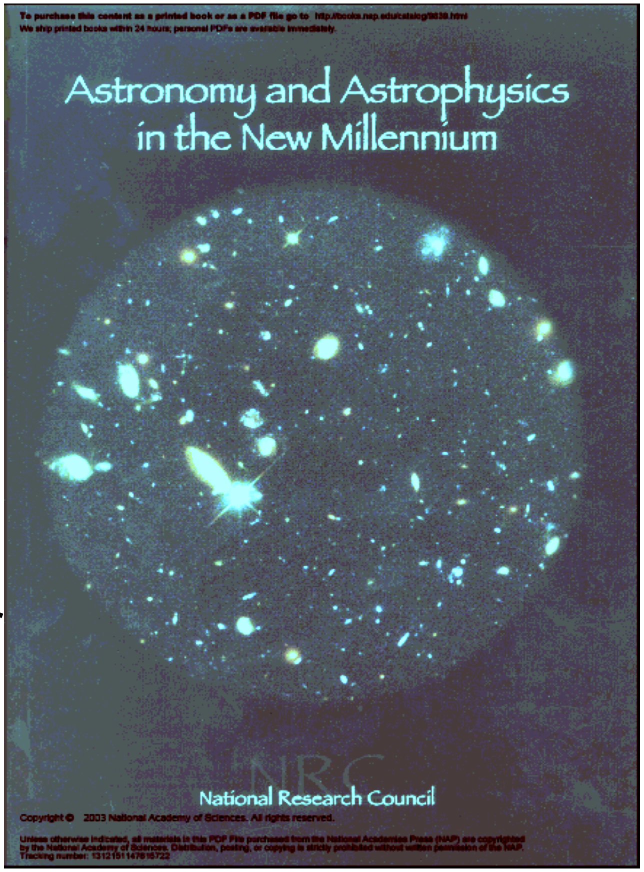
Jeremy Mould

National Optical Astronomy Observatory



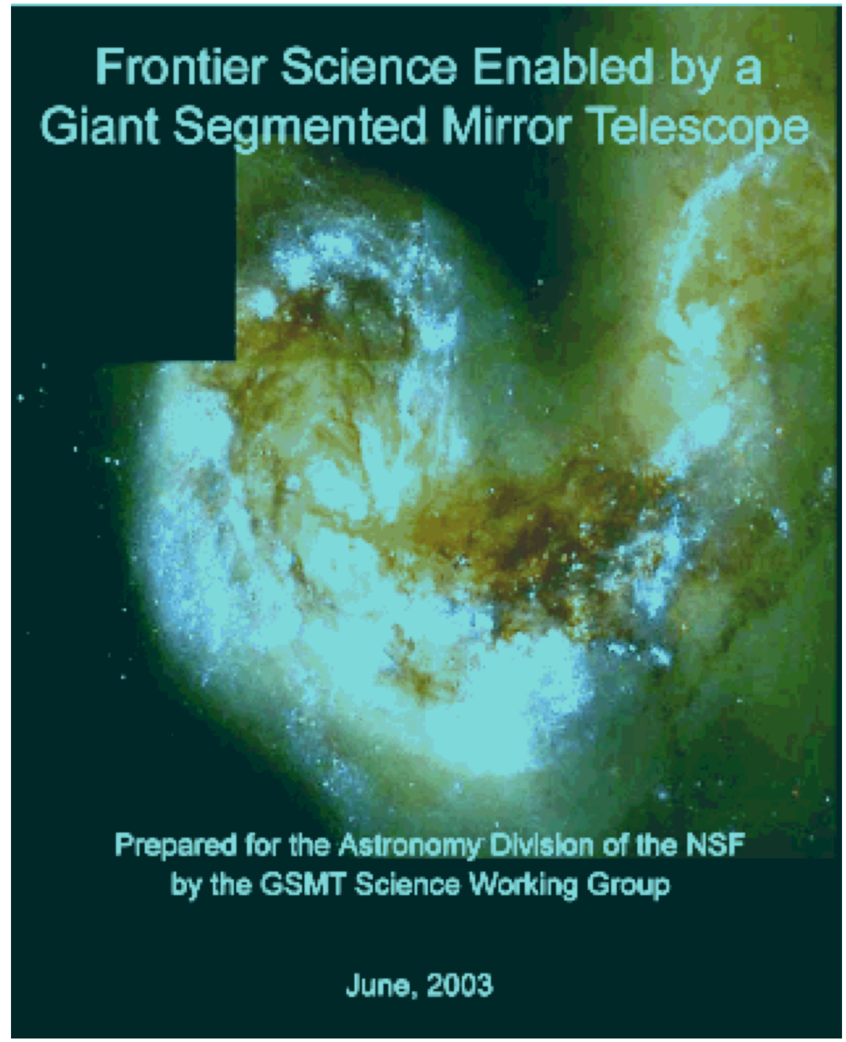
2001 National Research Council Decadal Survey of Astronomy

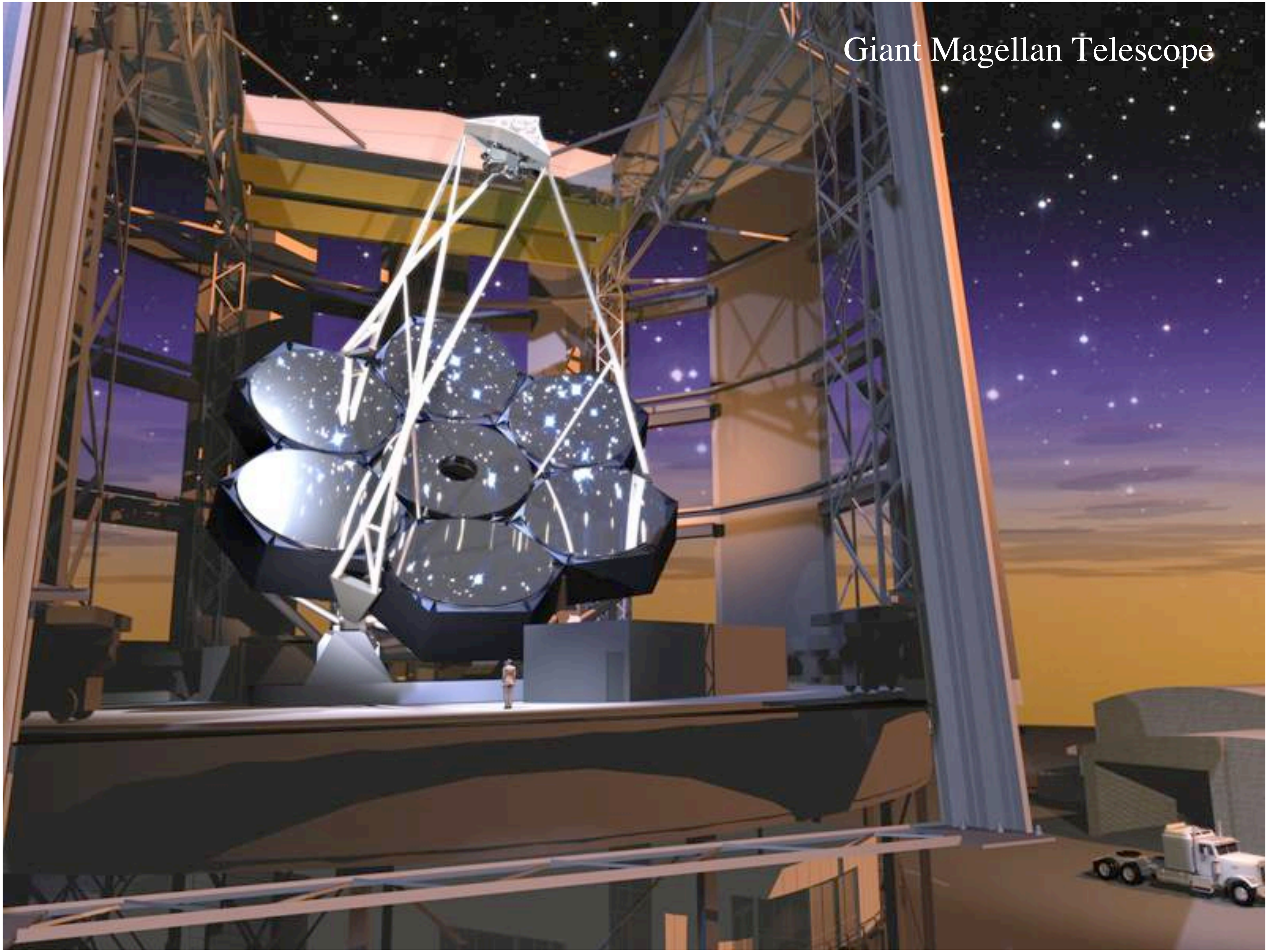
"The **Giant Segmented Mirror Telescope (GSMT),** the committee's top ground-based recommendation, is a 30-m-class ground-based telescope that will be a powerful complement to NGST in tracing the evolution of galaxies and the formation of stars and planets….GSMT will use adaptive optics to achieve diffraction limited imaging in the atmospheric windows between 1 and 25 μm and unprecedented light-gathering power between 0.3 and 1 μm. The committee recommends that the technology development for GSMT begin immediately and that construction start within the decade. Half the total cost should come from private and/or international partners. Open access to GSMT by the U.S. astronomical community should be directly proportional to the investment by the NSF."

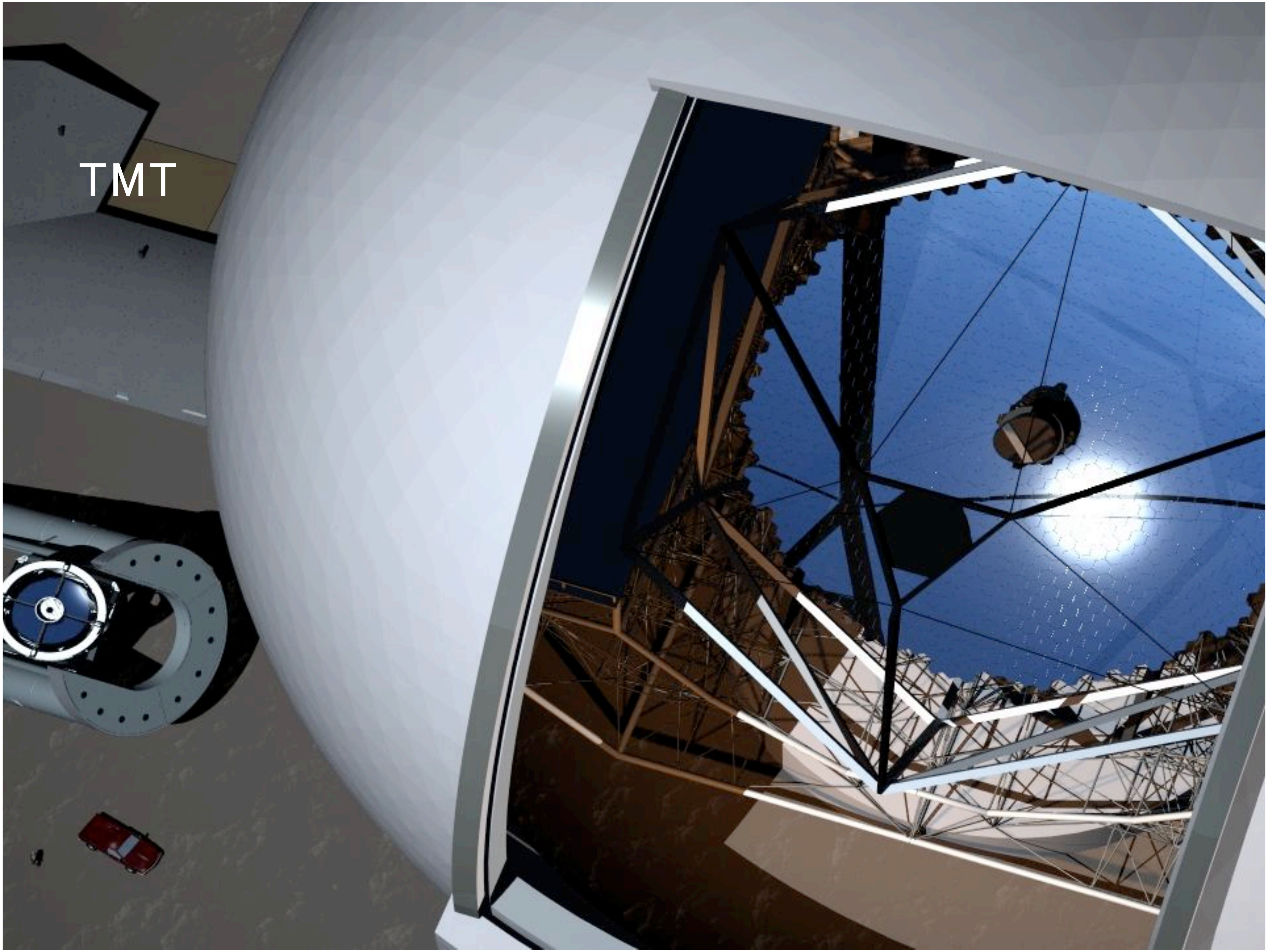


There is no DRM yet, as such

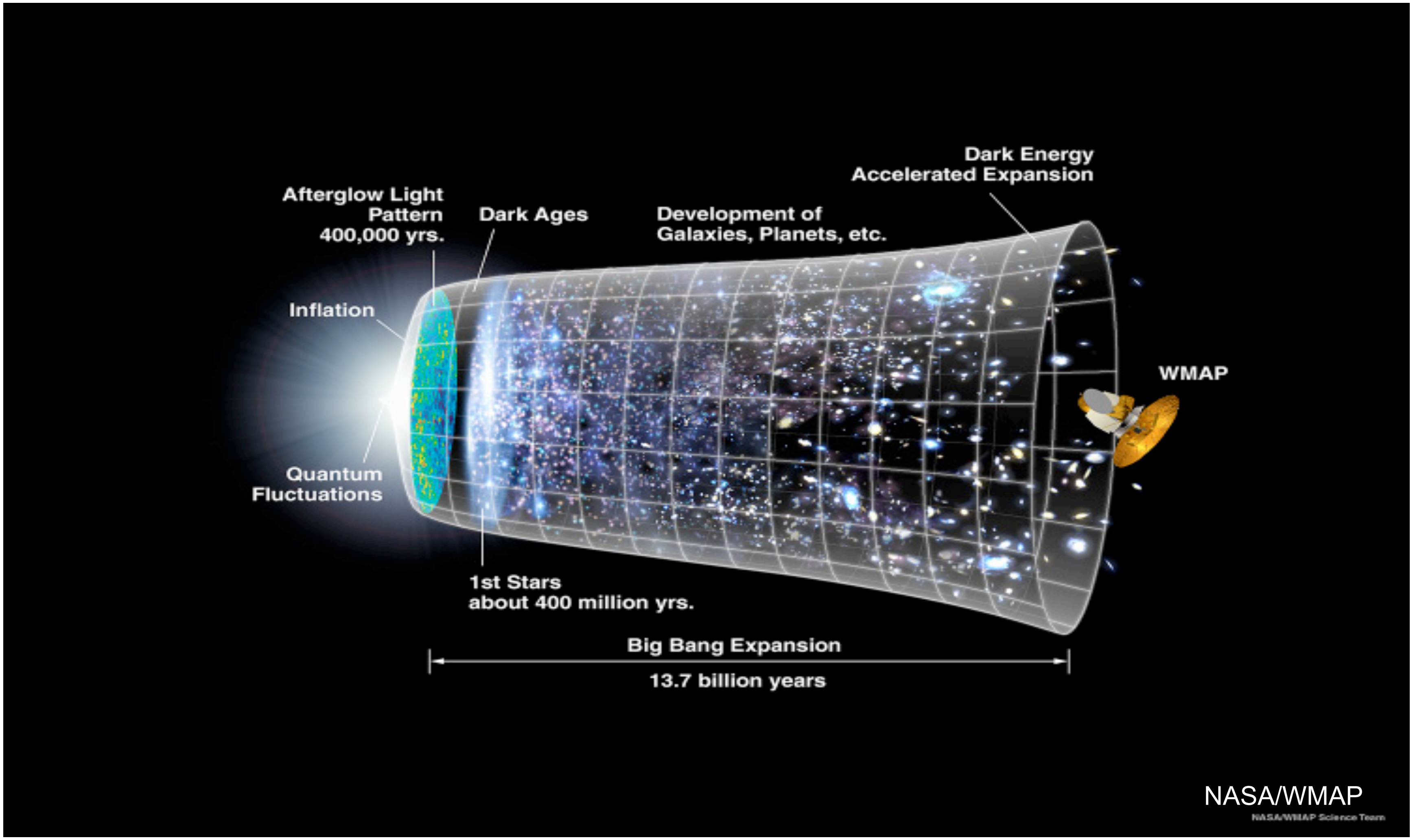
- Decadal survey priority led to NSF sponsored studies of the science case by the GSMT SWG: organized by AURA
- Similar studies have been carried out in Canada and Europe
- Studies all confirm the potential of a 30-m class telescope to address fundamental astrophysical problems




Giant Magellan Telescope


TMT

TMT Discovery Space - 13.3 Gyr



Fundamental Questions in 2015

- What is the nature of dark matter and dark energy?
- What were the first luminous objects in the Universe and when did they appear?
- When and how did the the intergalactic medium become ionized?
- When and how did the most massive compact objects form?
- How did the galaxies form and how do they evolve?
- When and where were the heavy elements produced?
- How do stars and planetary systems form?
- What are the physical properties of exoplanets?
- Does life exist elsewhere in the Universe?

TMT Key Science Areas

- Cosmology and fundamental physics
- The early universe and first light
- Intergalactic medium beyond z = 7

- Galaxy formation and evolution
- Black holes and active galactic nuclei

- Stellar populations and star-formation histories in the local Universe
- Evolution of star clusters and the IMF

- Physics of star and planet formation
- Characterization of extrasolar planets

The Early Universe and First Light - the first luminous objects

Synergy

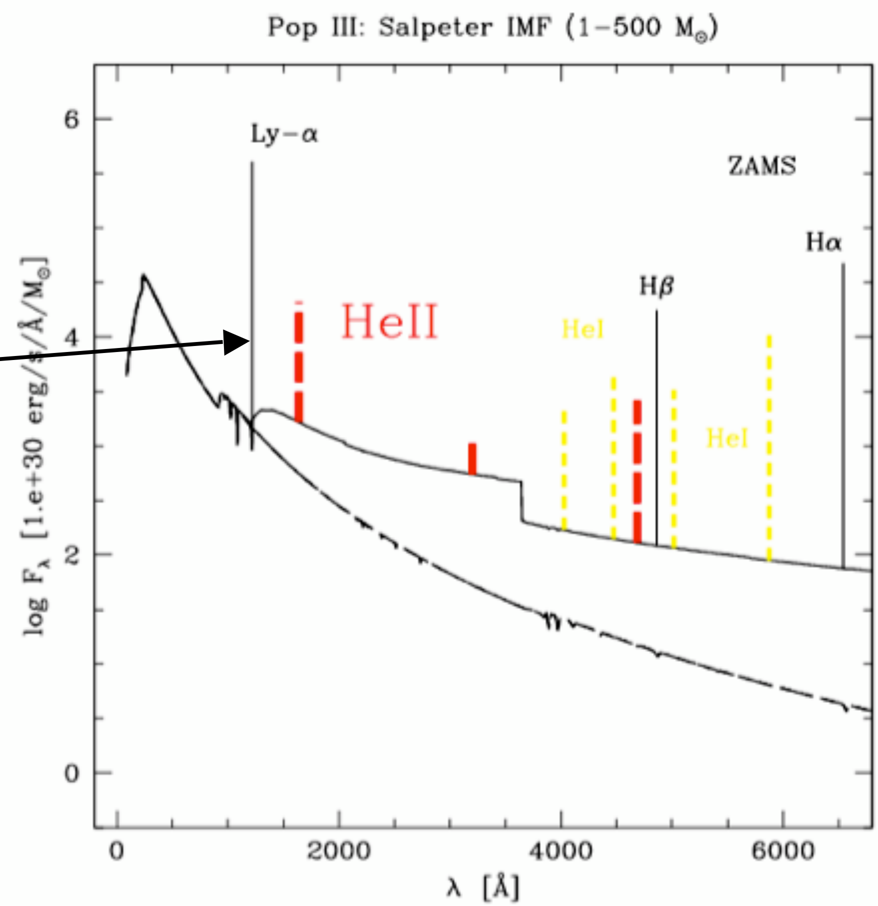
JWST will image it

GSMT will analyze it (spectra)

Targets:

- JWST tbd
- Spitzer EROs
  - Lensing: Egami et al
  - HUDF,NUDF,GOODS
    - Thompson et al astro-ph 0605060
    - Mobasher et al ApJ 635, 832

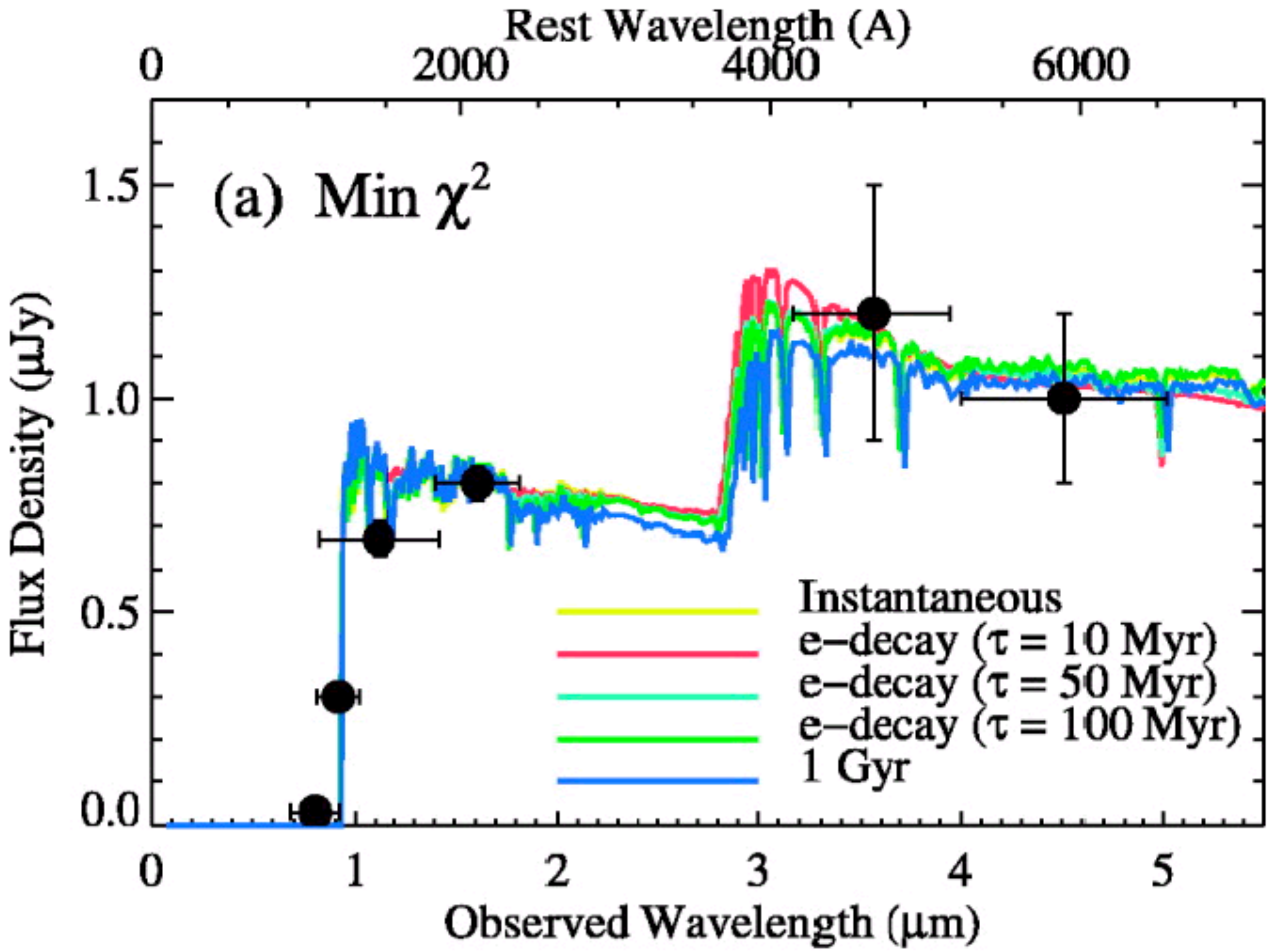
Detection of He II emission would confirm the primordial nature of these objects



Schaerer 2002

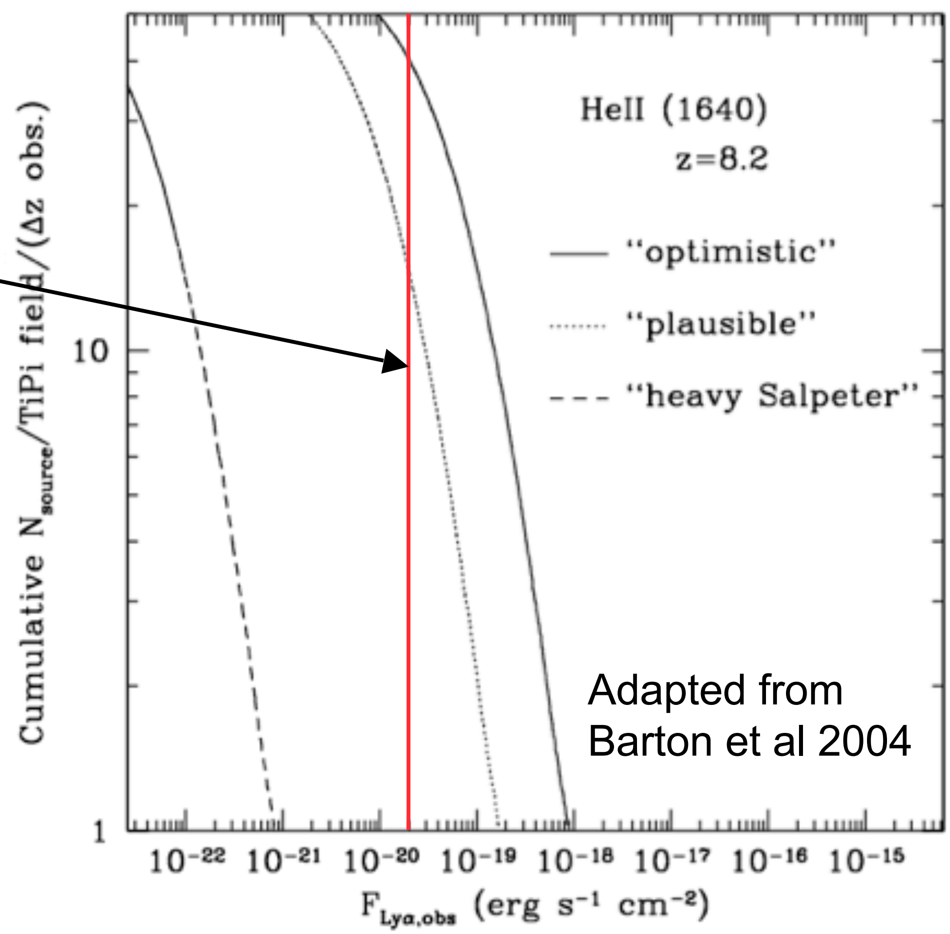
Egami et al ApJL 618, L5

z = 6.7



The Early Universe and First Light - Detecting first light

- *TMT may well be the first telescope to detect first light in the Universe:*
  - TMT will reach ~ $2x10^{-20}$ erg s^{-1} cm^{-2} for 25 mas sources in 4 hrs using adaptive optics.
  - This is more than an order of magnitude fainter than JWST.



Predicted number of He II detections per TMT field (TMT IRMOS-CIT team).

Stellar Populations

HST/ACS will survey galaxy, giant branch

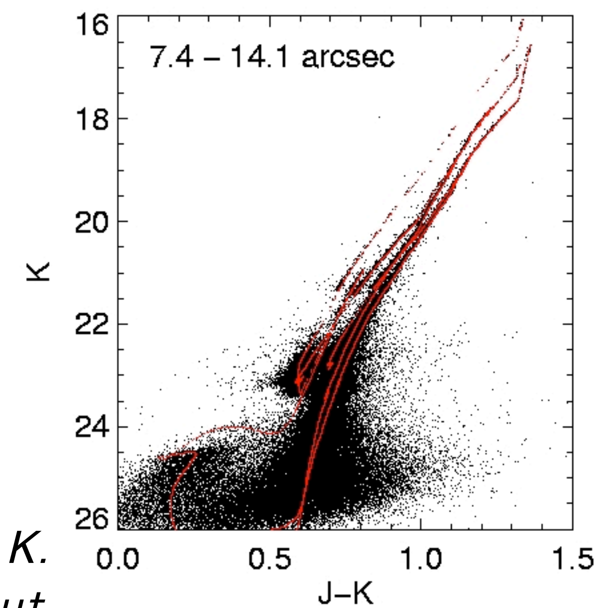
GSMT will do SFH from main sequence

Targets:

- ACS Nearby Galaxy Survey
  - Dalcanton et al Treasury program
  - extend it to Centaurus group
    - other extensions ?
    - full coverage galaxy type
    - WFC3

Population: 10% 1 Gyr ([Fe/H]=0), 45% 5 Gyr ([Fe/H]=0), 45% 10 Gyr ([Fe/H]=-0.3)

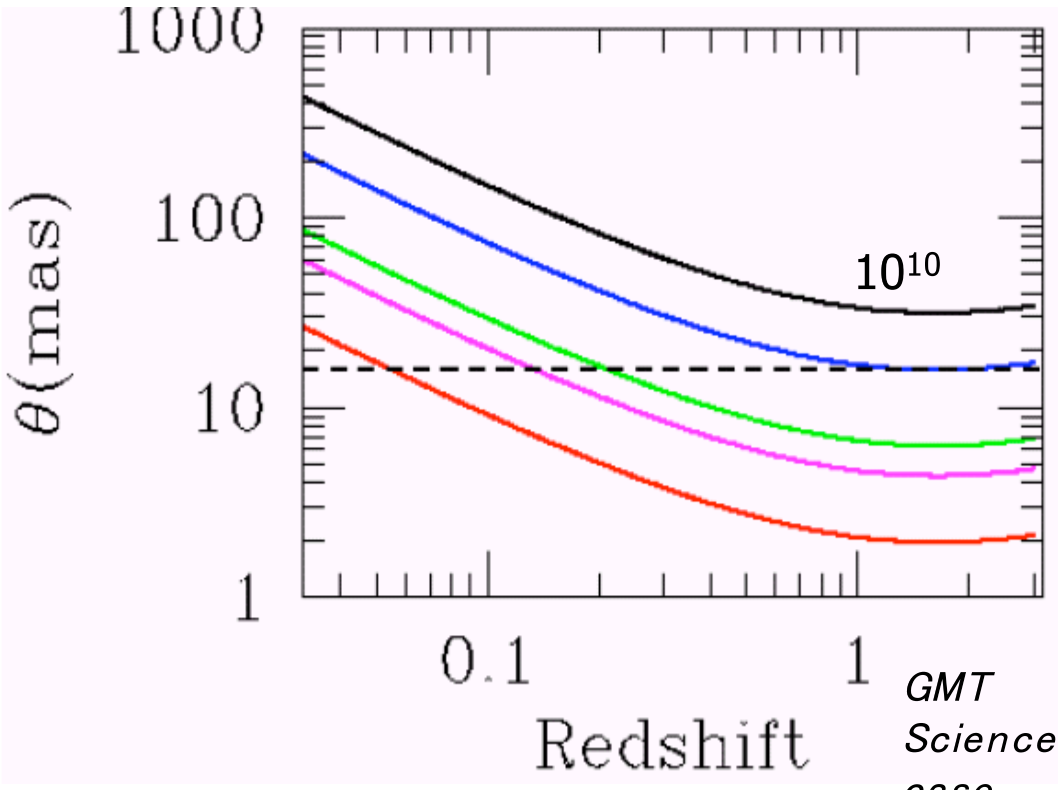
GSMT with MCAO M32



Simulations from K. Olsen and F. Rigaut

Supermassive Black Holes

GSMT resolves the sphere of influence for M. > 5 x 10^9



GMT Science case

Targets:

- host galaxies
  - all redshifts
  - all orientations
- useful to define a sample

- Nuclear phenomena are multiwavelength

Dark Energy

Recent DETF report

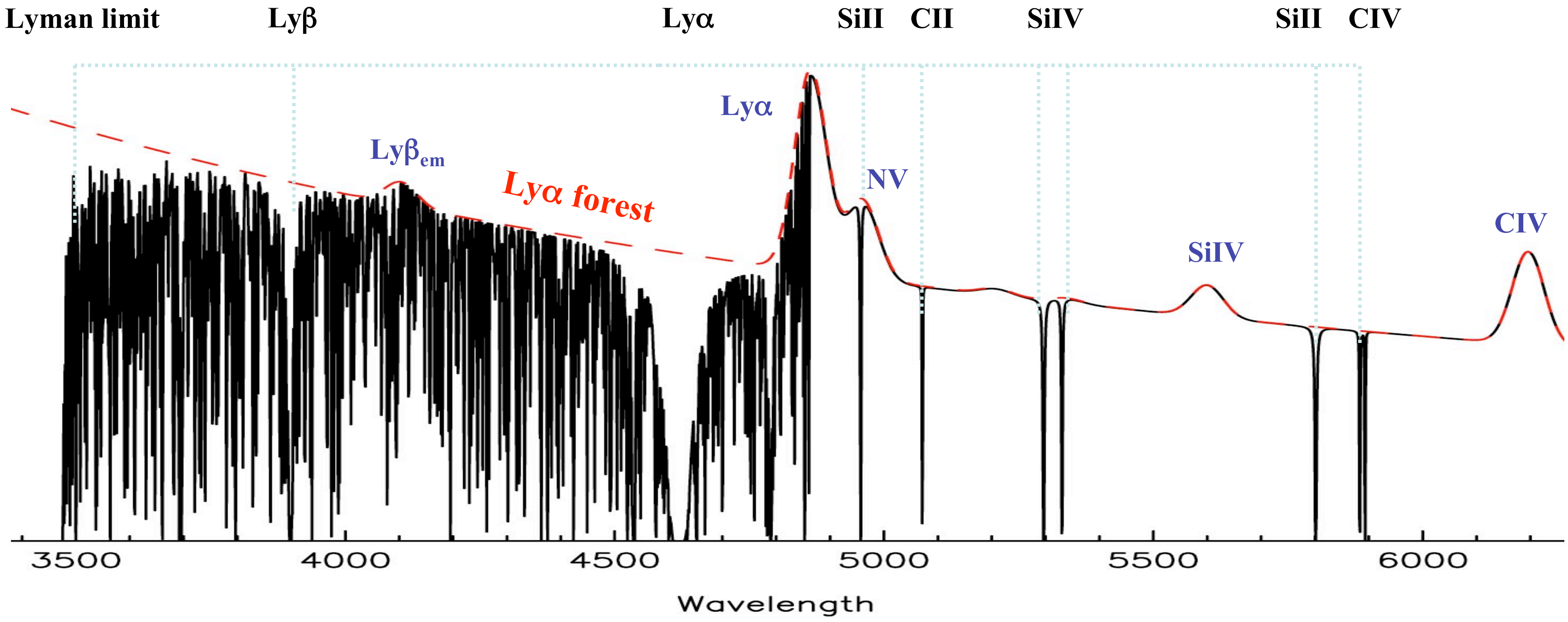
- Weak lensing
- Galaxy clusters
- Supernovae
- Baryon oscillations

Role of the Great Observatories

- Understand Supernova
    - diversity
    - evolution
  - Extend HST legacy to z > 2
    - JWST, SNAP, GSMT
- X-ray data on SZ clusters

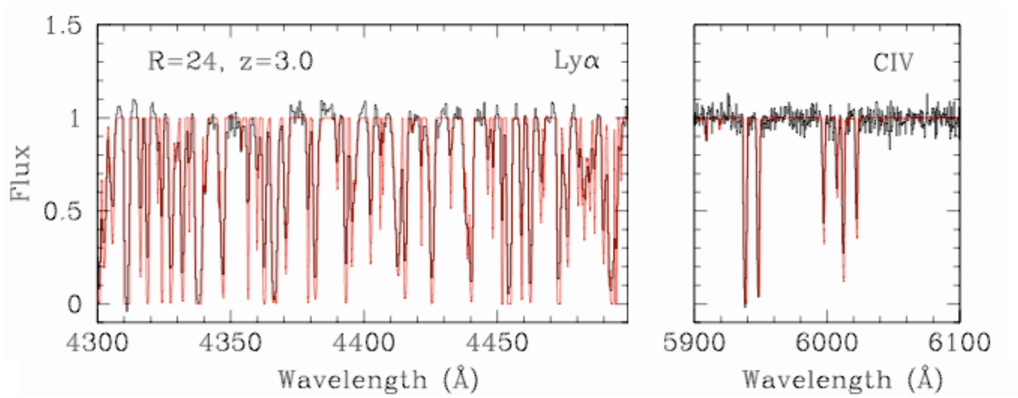
The Intergalactic Medium - Probing beyond *z* ~ 7

- *TMT will use adaptive optics and infrared spectroscopy to probe the evolution of the IGM beyond z ~ 7*:
  - CIV, OI, CII lines are not affected by the Lyman-α forest.
  - Gamma ray bursts could provide high redshift beacons.

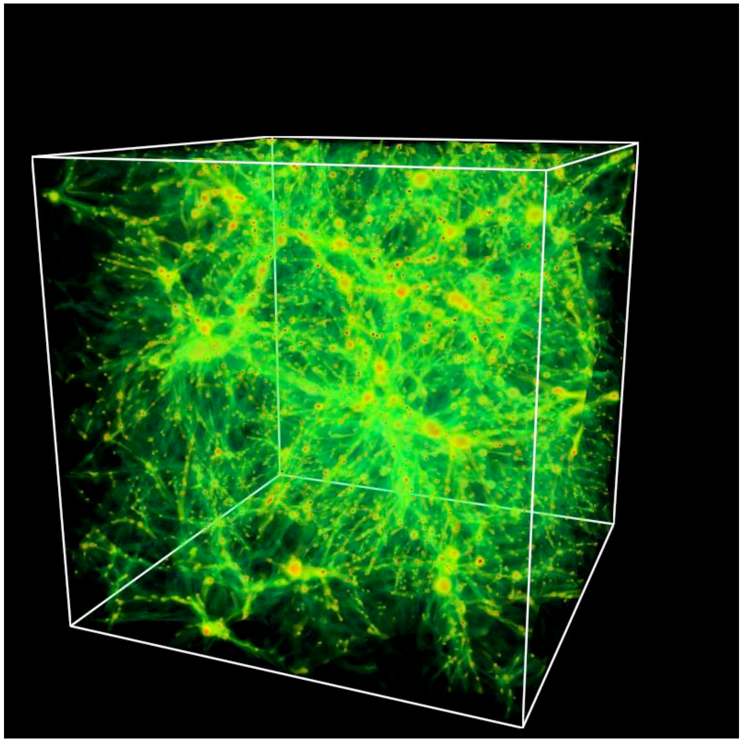


The Intergalactic Medium
- Tomography of the baryonic structure

- TMT will use multi-object spectroscopy of background galaxies to map the structure of IGM during the peak epoch of galaxy formation (z ~ 2 - 3.5).



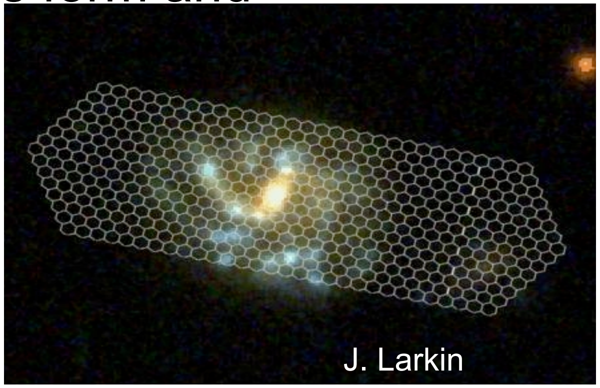
Simulated TMT observation with *R* = 24 source galaxy (WFOS-HIA team).



Simulation of dark matter structure at *z* = 3. (R. Cen, Princeton Univ.)

Galaxy Formation and Evolution: Detailed mapping of high-redshift galaxies

- *TMT will probe chemistry and dynamics of high-redshift galaxies and study the assembly of galaxies with 100 pc resolution using adaptive optics.*
- Multiple deployable IFUs will provide statistically significant samples.
- Key questions:
  - How does the age of the stellar population compare to the dynamical age of the galaxy?
  - How do star formation modes relate to the dynamical state?
  - How do massive galaxies of old stellar populations form and evolve?
  - How does the Hubble sequence arise?
  - How do bars, bulges,disks form?
  - How important is feedback?



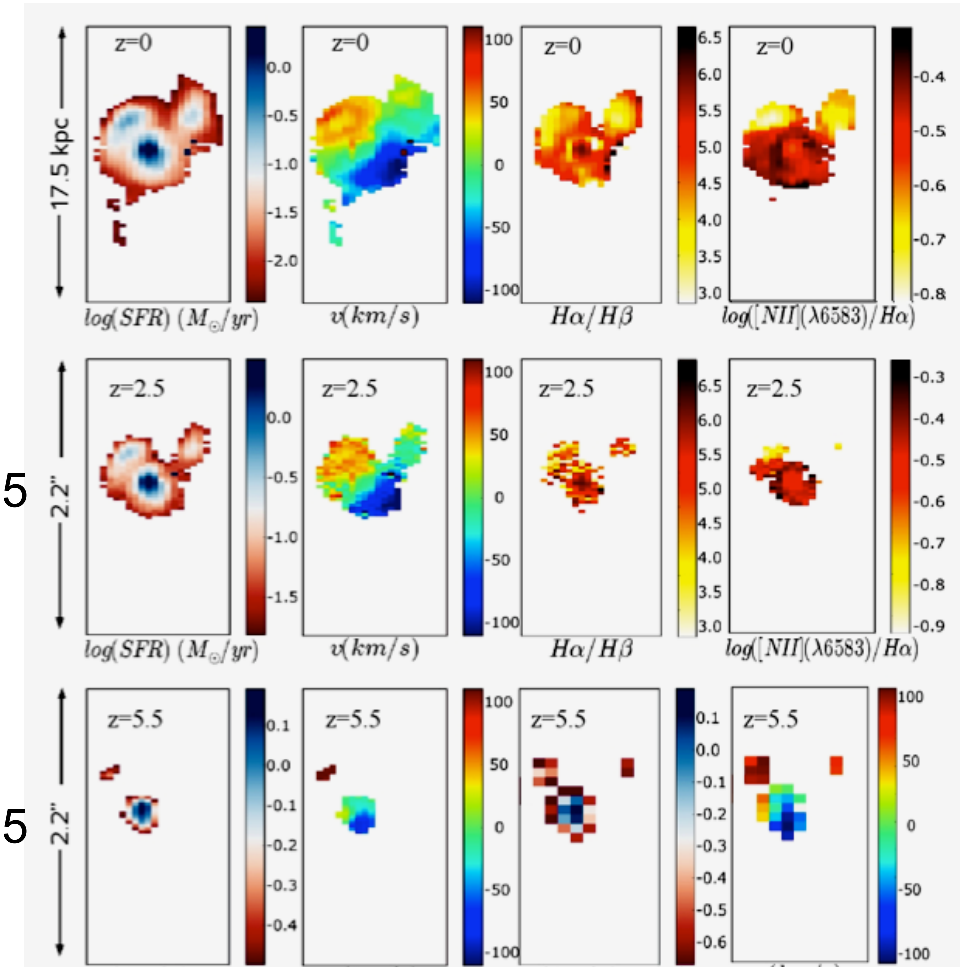
Galaxy Formation and Evolution: Physics of galaxy formation

- *TMT will use adaptive optics to map the physical state of galaxies over the redshift range where the bulk of galaxy assembly occurs:*
  - Star formation rate
  - Metallicity maps
  - Extinction maps
  - Dynamical Masses
  - Gas kinematics

z = 0

z = 2.5

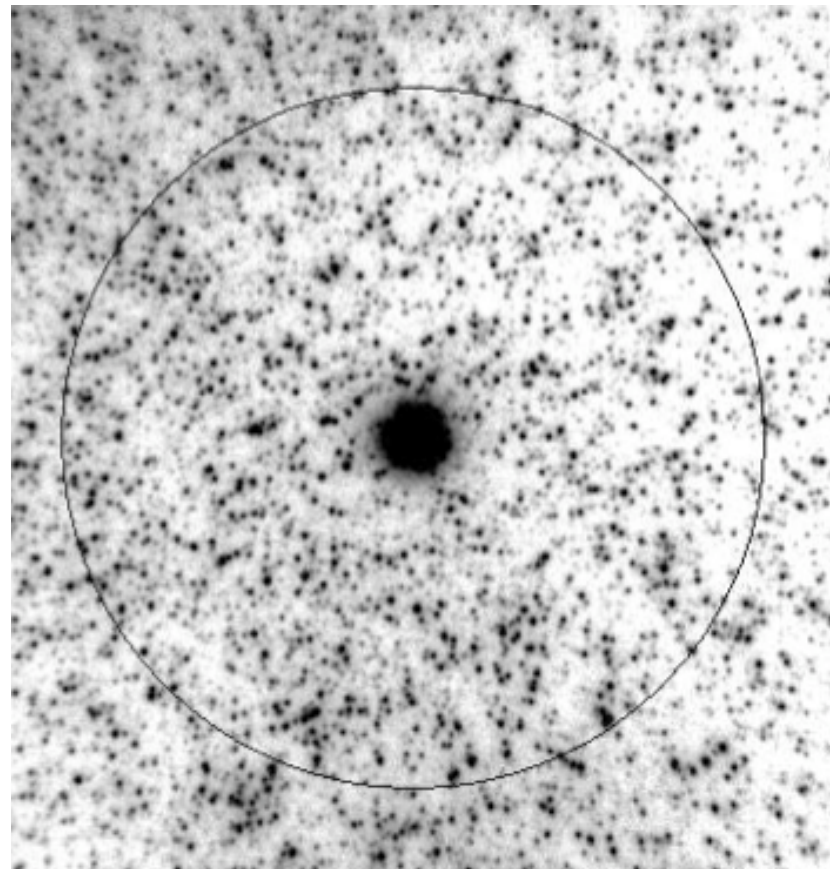
z = 5.5



TMT IRMOS-UFHIA team

Evolution of Star Clusters and the IMF

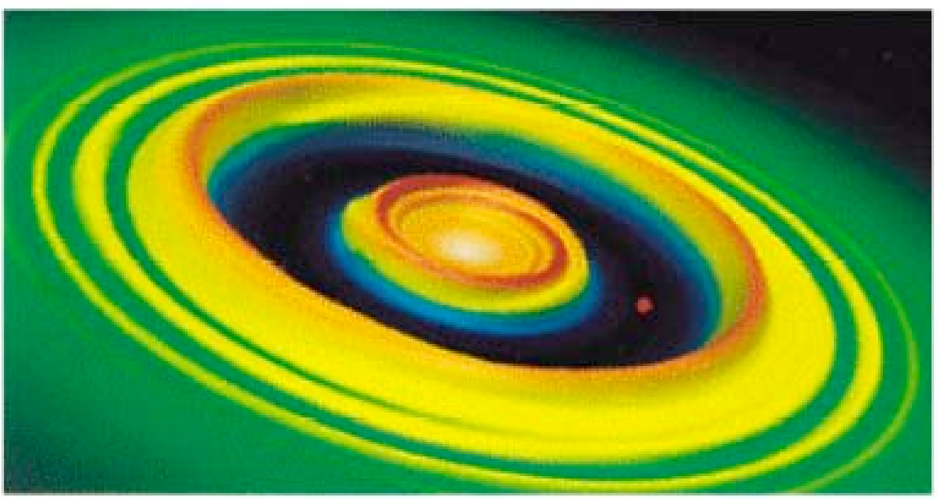
- *TMT will allow us to determine the initial mass function in star clusters from < 1 to 100 $M_\odot$ in a range of stellar environments:*
  - IFU imaging/spectroscopy at the diffraction limit with multiconjugate adaptive optics.



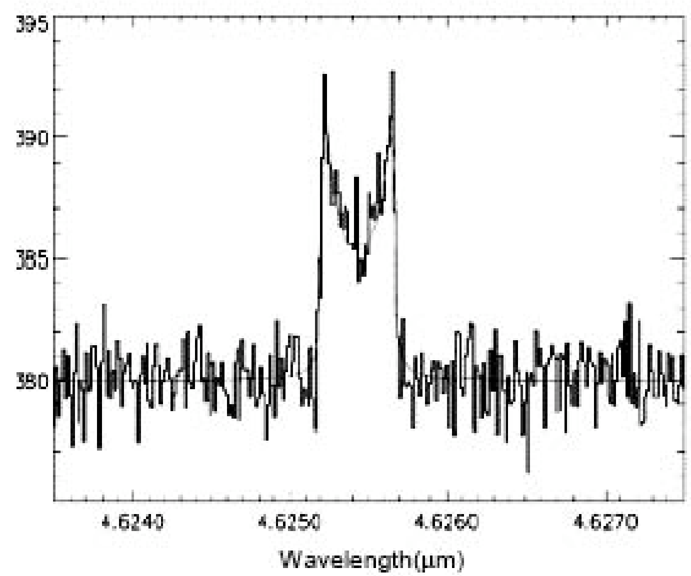
AO image of star field in M31 from Gemini/Altair. TMT's MCAO will provide better psf uniformity, higher Strehl ratios, 4x sharper images and ~ 20x deeper imaging (TMT IRIS team).

Physics of Star and Planet Formation: Protoplanetary disks

- *TMT will resolve the inner regions of protoplanetary disks to study abundances, chemistry, and kinematics*
- *Synergy between spatial resolution and spectroscopic resolution*
  - TMT MIR spectroscopy can detect gaps produced by EGPs
  - Complementary to ALMA: lower excitation regions of outer disk
  - and to JWST (some mid-IR lines are blocked from ground)
  - Spitzer disk studies

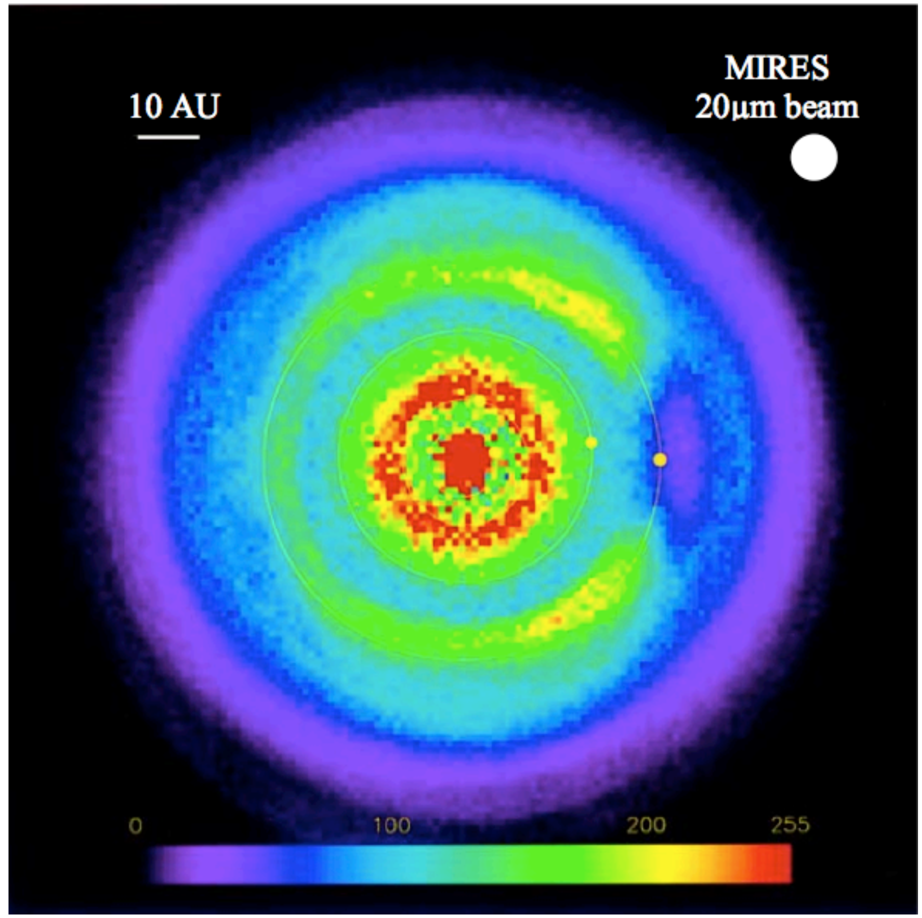


G. Bryden



Physics of Star and Planet Formation: Planet formation

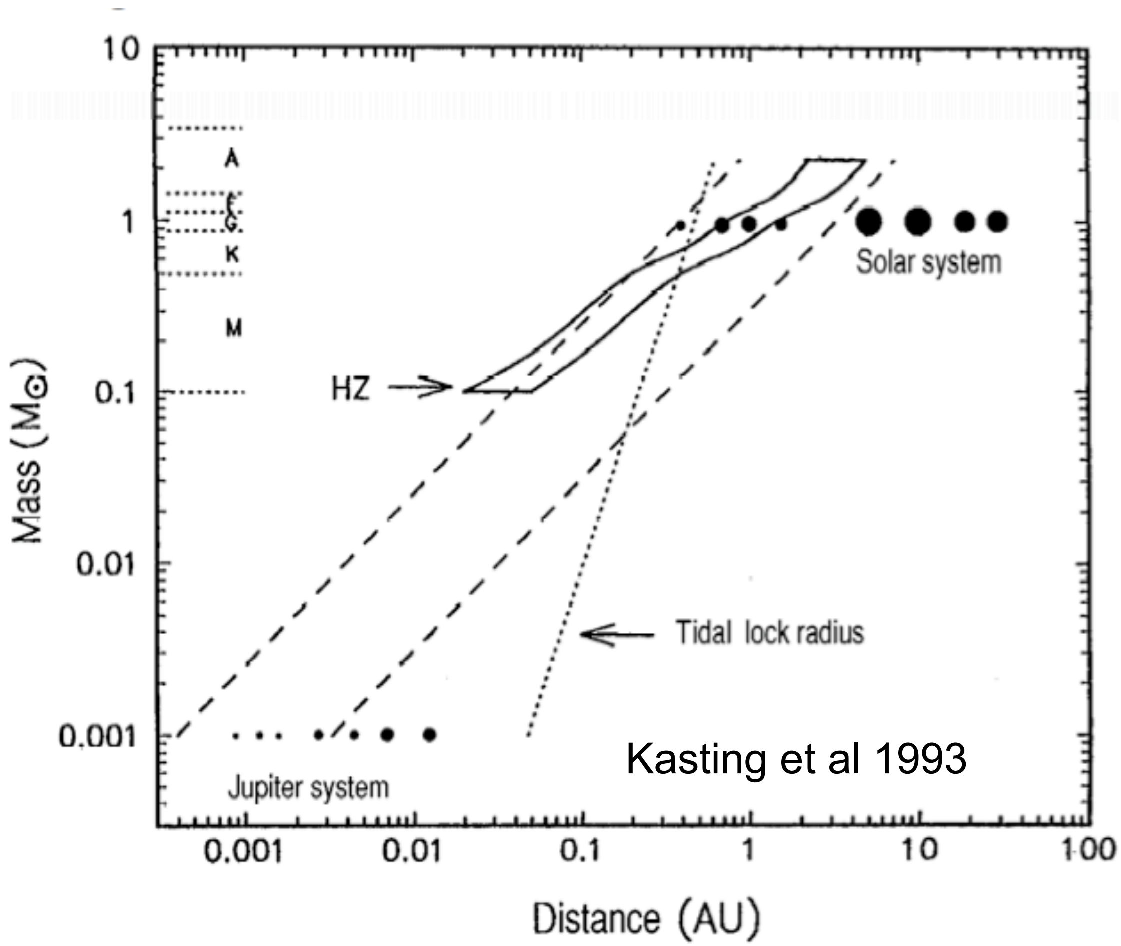
- *TMT will be able to image protoplanetary disks and detect features produced by planets with mid-infrared adaptive optics:*
  - TMT will have 5x the resolution of JWST.



Simulation of Solar System protoplanetary disk (Liou & Zook 1999)

Characterization of Extrasolar Planets: Doppler detection

- *TMT will be able to detect Earth-mass planets in habitable zones around nearby M stars:*
  – M stars are the most common stars in the galaxy. Their habitable zone is 0.01 - 0.3 AU.



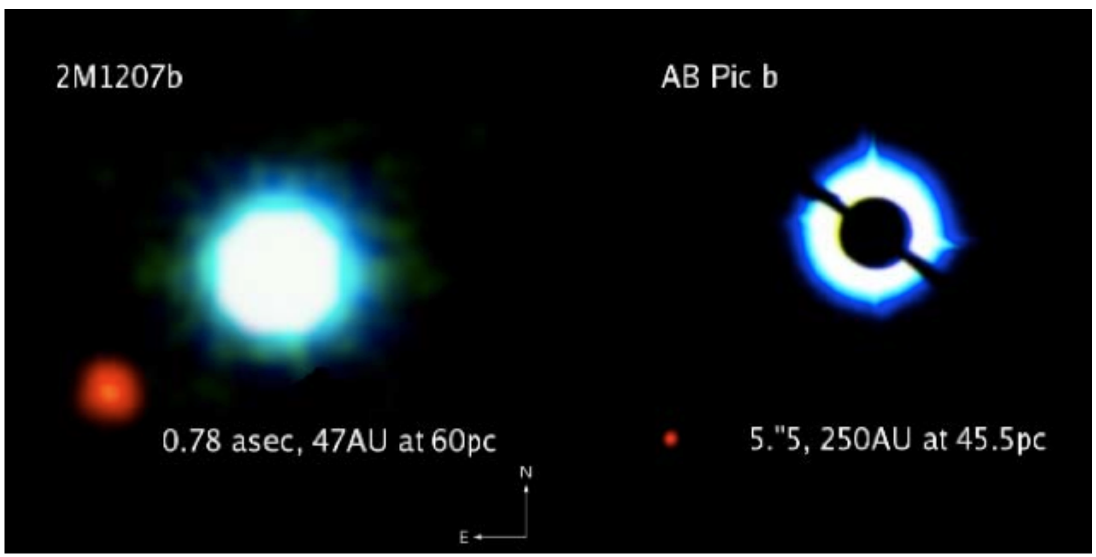
Kasting et al 1993

Characterization of Extrasolar Planets: Direct detection

- *TMT will directly image young planets near low-mass stars using high-order adaptive optics (ExAO)*

4 M_J planet orbiting a brown dwarf

~80 M_J planet orbiting an old K star

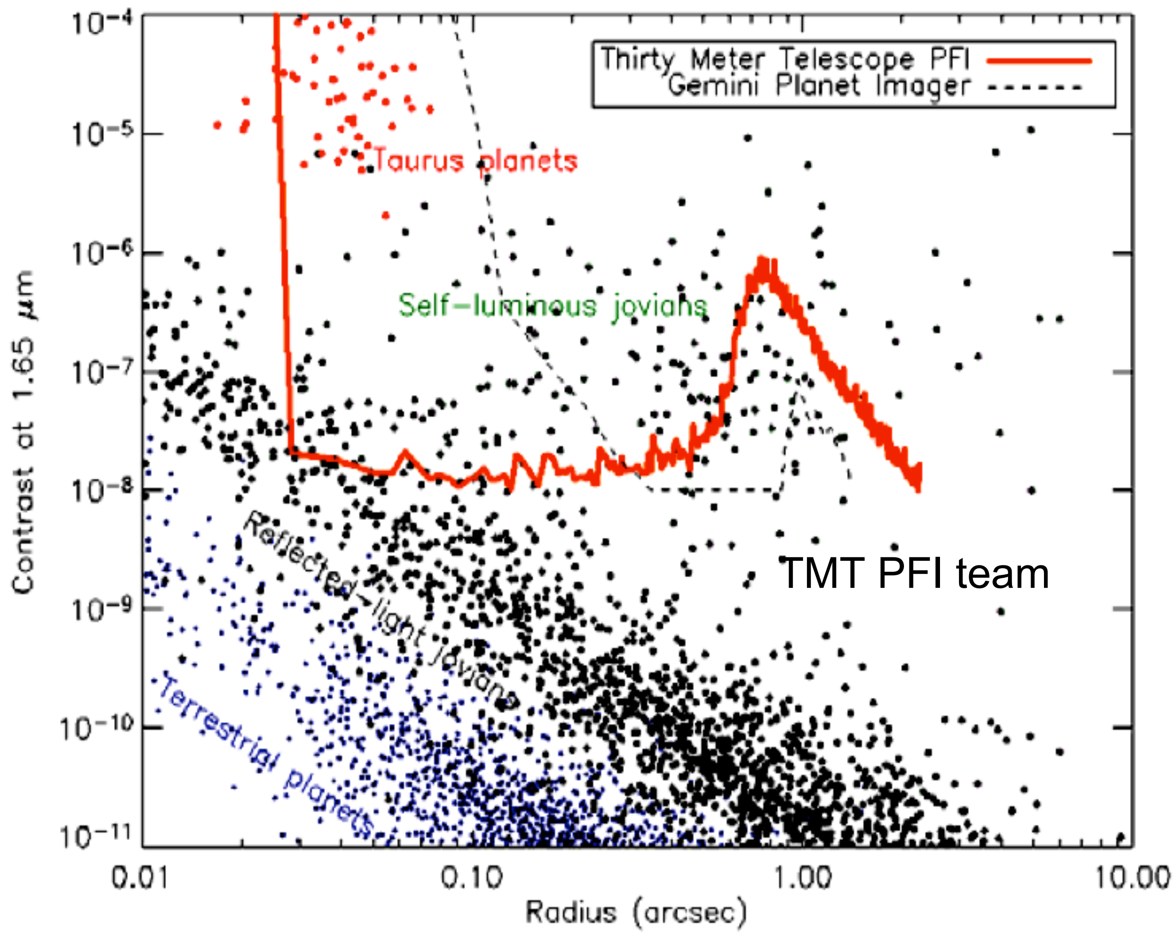


Investigate diversity thru spectroscopy

GSMT's Voyager-like role

Exoplanets

- supporting role of Great Observatories
  - more transit spectroscopy ?
- supporting role of Gemini, LBT etc
  - develop technology
  - enlarge exoplanet sample

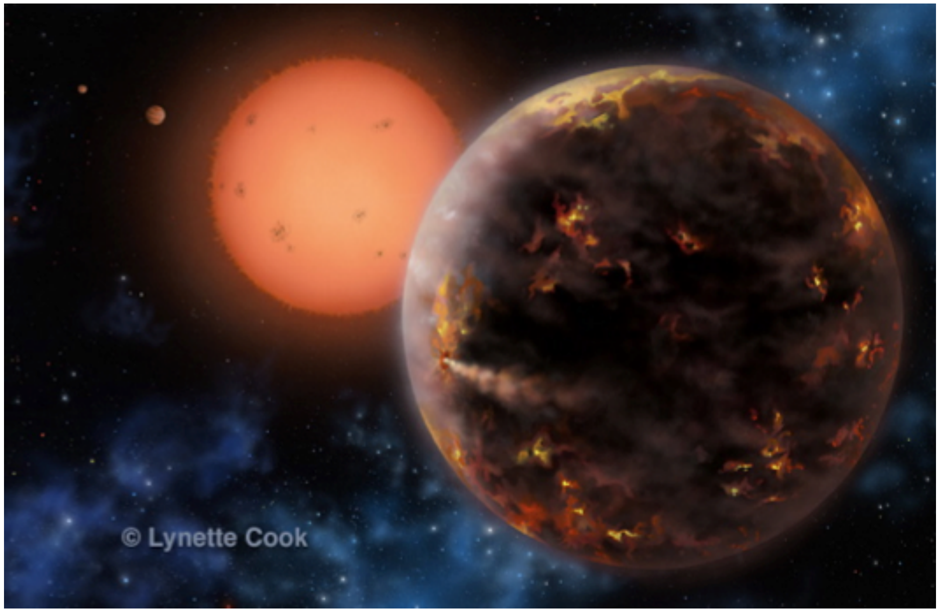


Extreme adaptive optics

Characterizing Extrasolar Planets: Properties of exoplanets

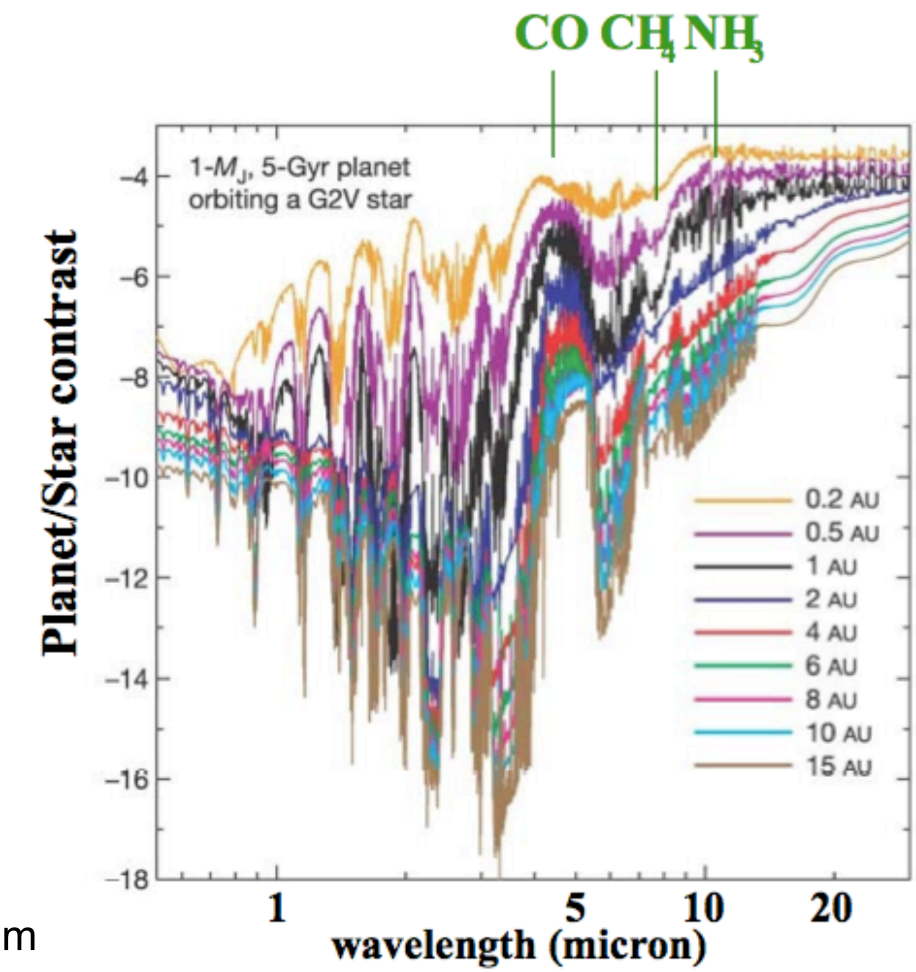
- *TMT will provide*:
  - Doppler follow-up of transit detections.
  - Absorption spectroscopy of atmospheres of transiting planets.
  - Reflected light spectroscopy of “hot jupiters”.
  - Direct spectroscopy of massive planets.

GJ 876d: 7.5 $M_{\oplus}$



Characterization of Extrasolar Planets; Atmospheres of massive planets

- *TMT will be able to measure the spectra of massive planets in the mid-infrared:*
  - Contrast is lower in the mid-infrared.
  - Strong molecular lines characterize the atmospheric composition.
  - Spectral deconvolution can reveal the planetary spectrum



TMT MIRES team

Summary for 30-m Class ELTs: Survey and Coordinated Observations

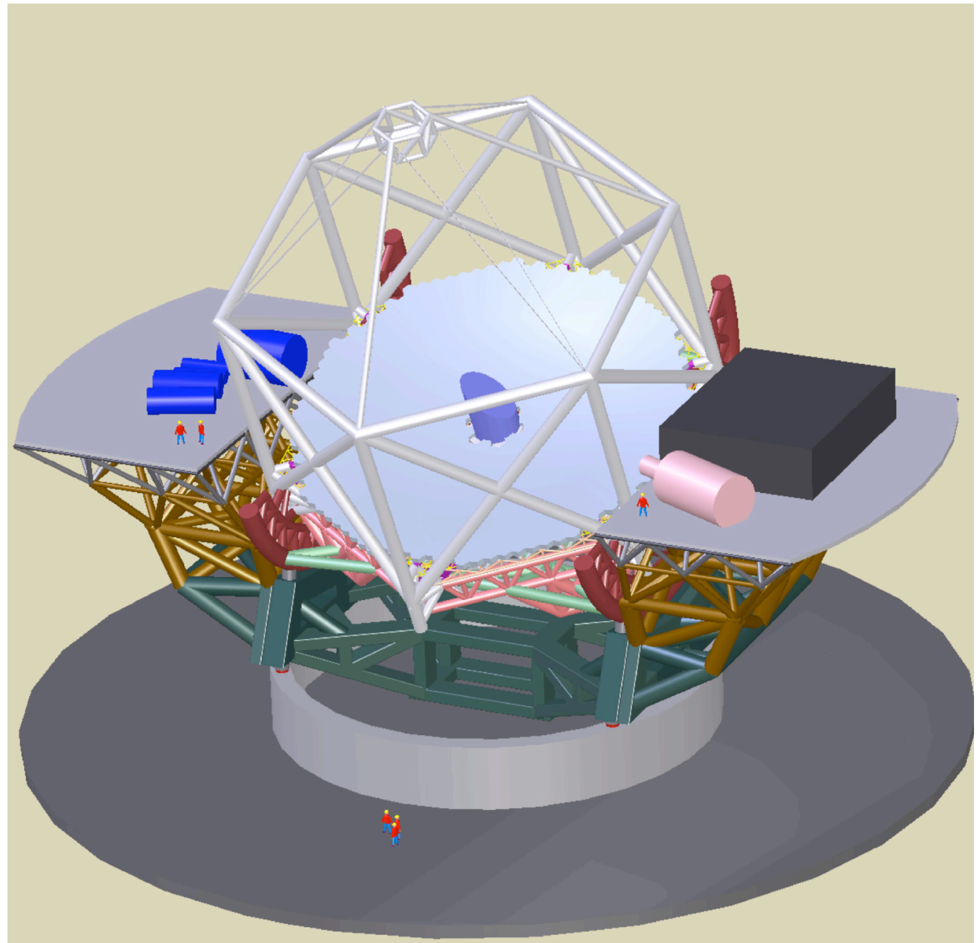
Subject area	GSMT role	Survey/Coordinated Observations
3D map of gas & galaxies (z >2)	WF spectroscopy of 5 x 5 degree (SDSS) volume	LBGs to R = 24, galaxies to R = 26 with LSST or Dark Energy Camera
Star and galaxy formation during the epoch of reionization	Survey and spectroscopy	JWST imaging; ALMA surveys; Spitzer reconnaissance
Stellar populations in nearby galaxies	Crowded field photometry	HST ACS/WFC3/JWST imaging
Planet formation environments	HiRes infrared spectroscopy	ALMA +SMA survey of accretion disk properties (masses; sizes)
Characterization of extrasolar planets	High contrast imaging and spectroscopy	Existing Doppler surveys Ongoing occultation surveys

Extension of HST science by GSMT

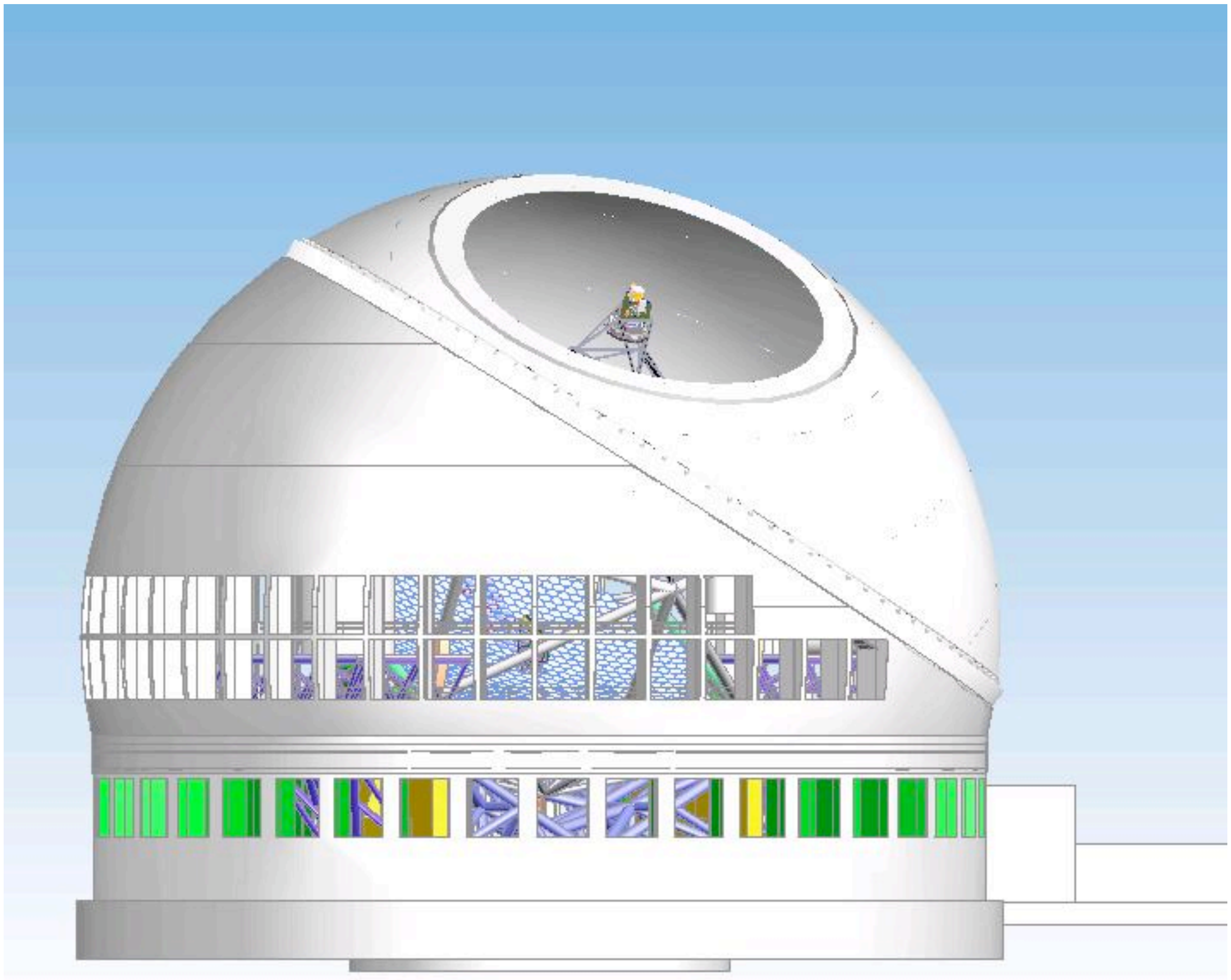
Subject area	GSMT role	Complementarity
Cosmology with SNe	Detect evolution	JWST, SNAP
Proplyds in Orion	Structure and physical state of protoplanetary disks	ALMA, JWST
supermassive black holes	Formation and evolution	Chandra
Starbursts and Lyman break galaxies	Kinematics	Spitzer, JWST
Stellar populations	Star formation History from MS turnoff	HST giant branch [Fe/H]
UV studies of IGM	Reach the reionization epoch	SKA

TMT Reference Design

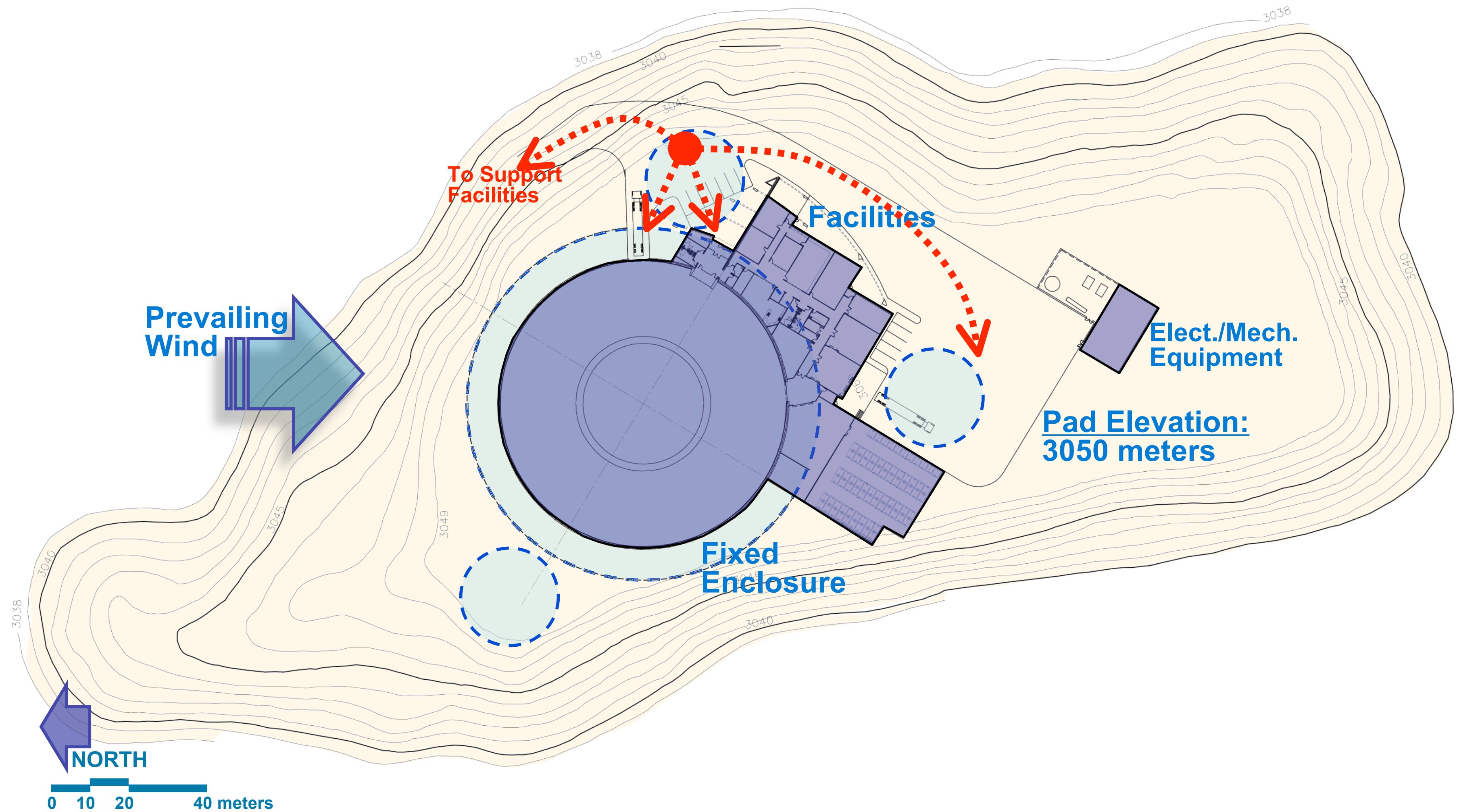
- 30m filled aperture, highly segmented
- Aplanatic Gregorian (AG) two mirror telescope
- f/1 primary
- f/15 final focus
- Field of view 20 arcmin
- Elevation axis in front of the primary
- Wavelength coverage 0.31 – 28 μm
- Operational zenith angle range 1° thru 65°
- Conventional and adaptive secondary mirrors to be interchanged
- No telescope baffles
- AO system requirements and architecture defined
- First generation instrument requirements defined



TMT Calotte Enclosure



Armazones Conceptual Site Plan



Cloud Cover – All-sky Cameras

Installed 19 Oct 2005 on Tolar

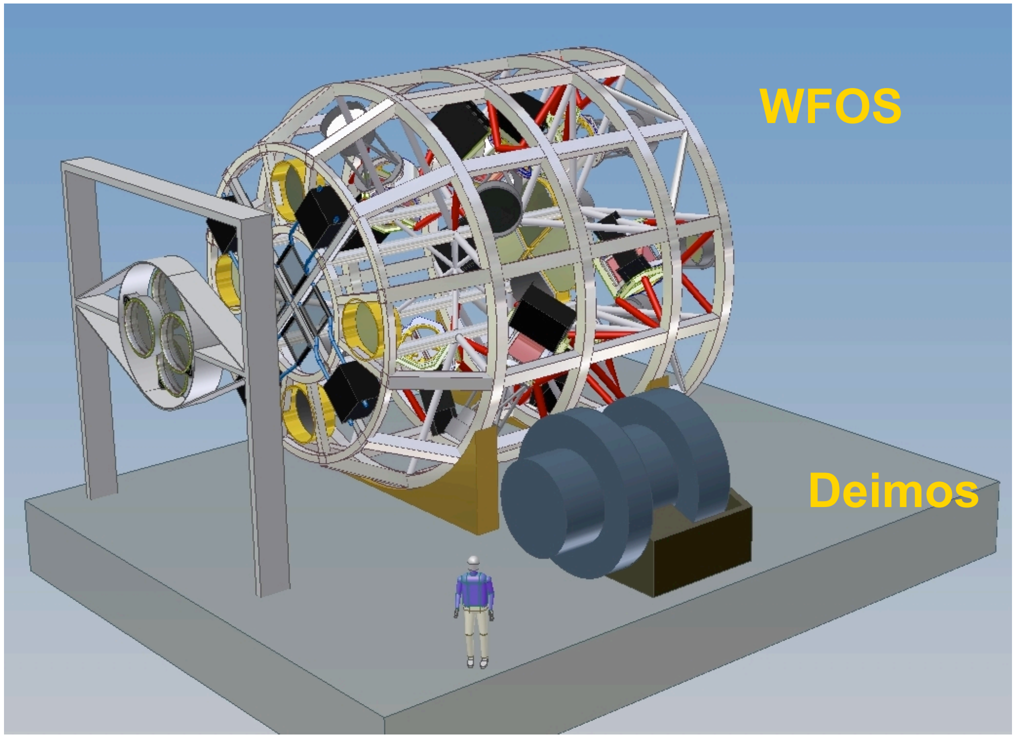

Summit ridge site
Mauna Kea
4210m
13 North Site

TMT Science Instrument Summary

Instrument	Spectral Resolution	Science Case
Near-IR DL Spectrometer & Imager (IRIS)	≤4000	• Assembly of galaxies at large redshift • Black holes/AGN/Galactic Center • Resolved stellar populations in crowded fields • Astrometry
Wide-field Optical Spectrometer (WFOS)	300 - 5000	• IGM structure and composition 2<z<6 • High-quality spectra of z>1.5 galaxies suitable for measuring stellar pops, chemistry, energetics
Multi-IFU, near-DL, near-IR Spectrometer (IRMOS)	2000 - 10000	• Near-IR spectroscopic diagnostics of the faintest objects • JWST followup
Mid-IR Echelle Spectrometer & Imager (MIRES)	5000 - 100000	• Physical structure and kinematics of protostellar envelopes • Physical diagnostics of circumstellar/protoplanetary disks: where and when planets form during the accretion phase
ExAO I (PFI)	50 - 300	• Direct detection and spectroscopic characterization of extra-solar planets
Optical Echelle (HROS)	30000 - 50000	• Stellar abundance studies throughout the Local Group • ISM abundances/kinematics, IGM characterization to z~6 • Extra-solar planets!
MCAO imager (WIRC)	5 - 100	• Galactic center astrometry • Stellar populations to 10Mpc
Near-IR, DL Echelle	5000 - 30000	• Precision radial velocities of M-stars and detection of low-mass planets

Scale and Complexity of Seeing Limited Instruments !

- WFOS
  - 8m diam x 12m high
  - Size of an 8m telescope!
- HROS "classic"
  - 12m x 16m
  - 3m off-axis parabolic collimators
  - 1.3m camera lenses
  - Huge echelle
    - 5x8 mosaic of gratings
    - 1m x 3.5m
- Complexity !



Joint Spitzer-NOAO, HST-NOAO, Chandra-NOAO Programs

• Time on ground-based facilities can be requested in the Great Observatory proposal.

• Adds value to “Making the Most of the Great Observatories” proposals.

• Survey instruments:

- ODI
- DEC
- NEWFIRM

Site Testing Equipment on Mauna Kea