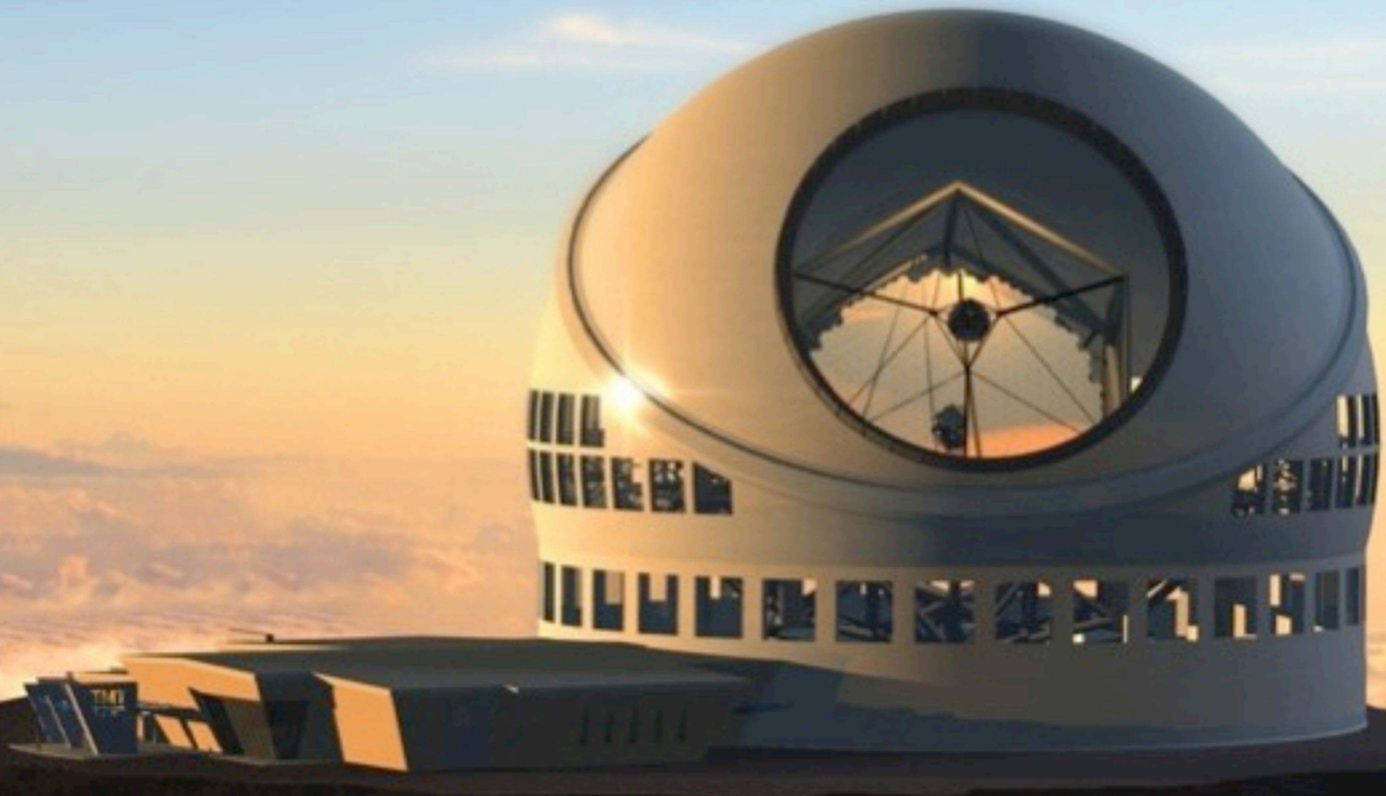
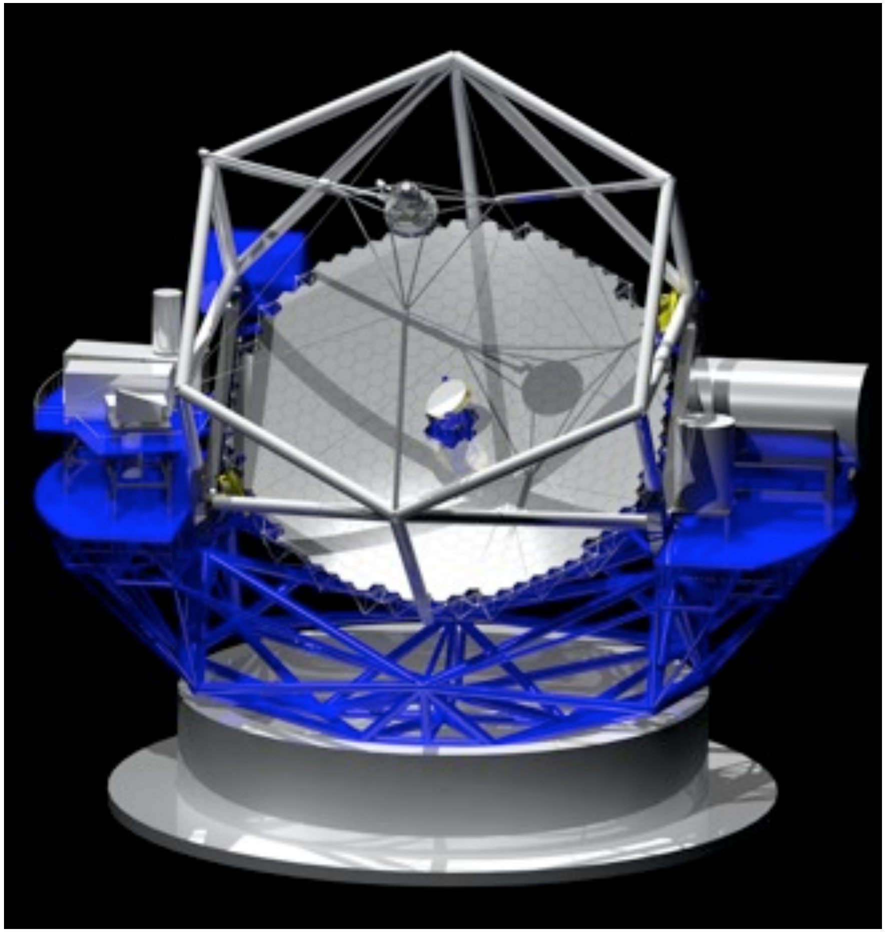
The NFIRAOS MCAO System on the Thirty Meter Telescope



Paul Hickson, UBC
MAD2009 2009-06-10

TMT in a nutshell

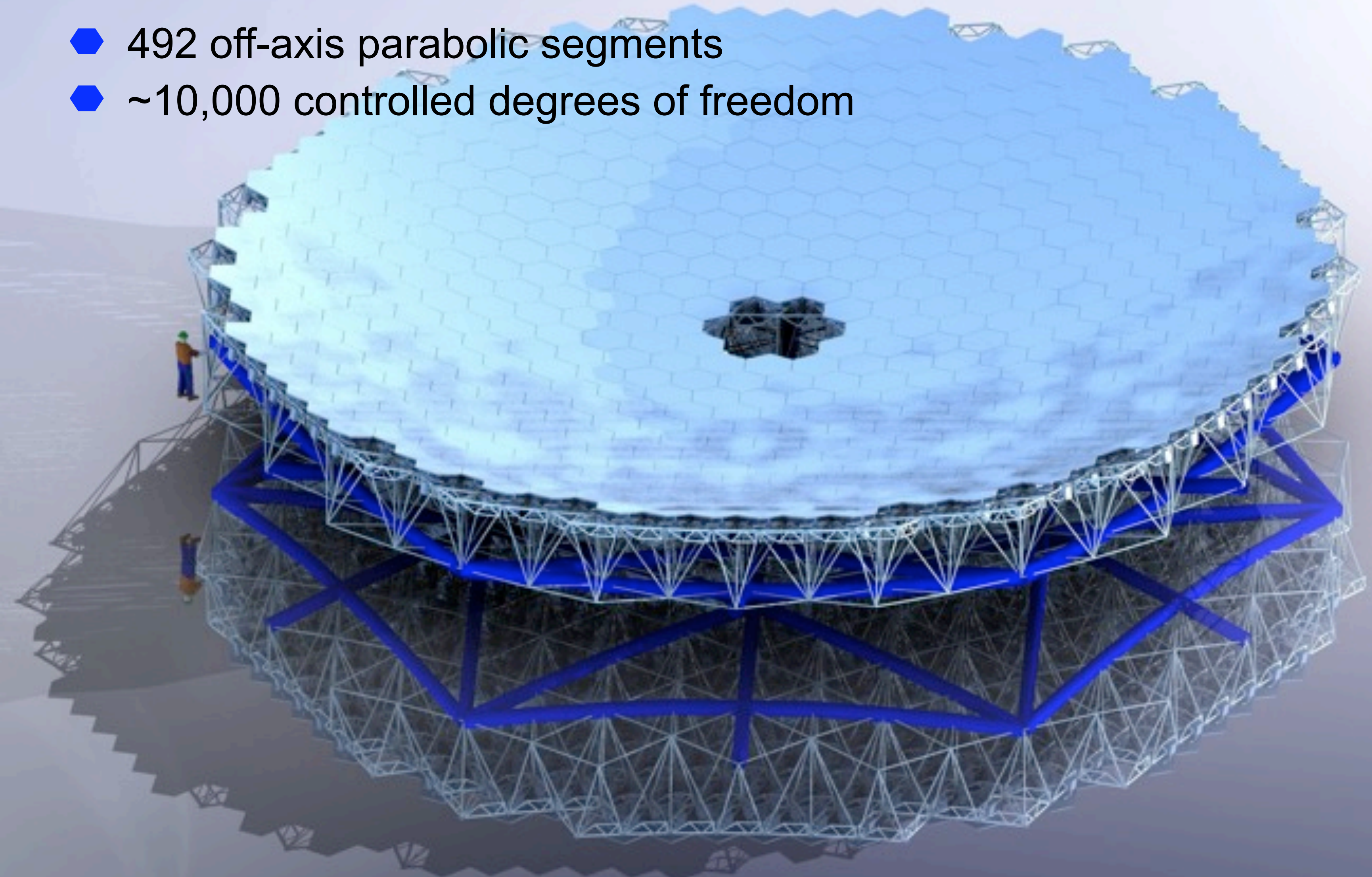
- 30m f/1 primary, RC optics, 20’ field of view
- Filled circular aperture → high contrast PSF
- Integrated AO systems, including laser guide star facility
  - MCAO (NFIRAOS), MOAO, GLAO, MIRAO, EXAO
  - 7 mas resolution at 1 um
- 0.31 - 28 um wavelength range
- Rapid instrument switching (<10 min) using articulating tertiary mirror
- Rapid target acquisition (< 5 min)



TMT
THIRTY METER TELESCOPE

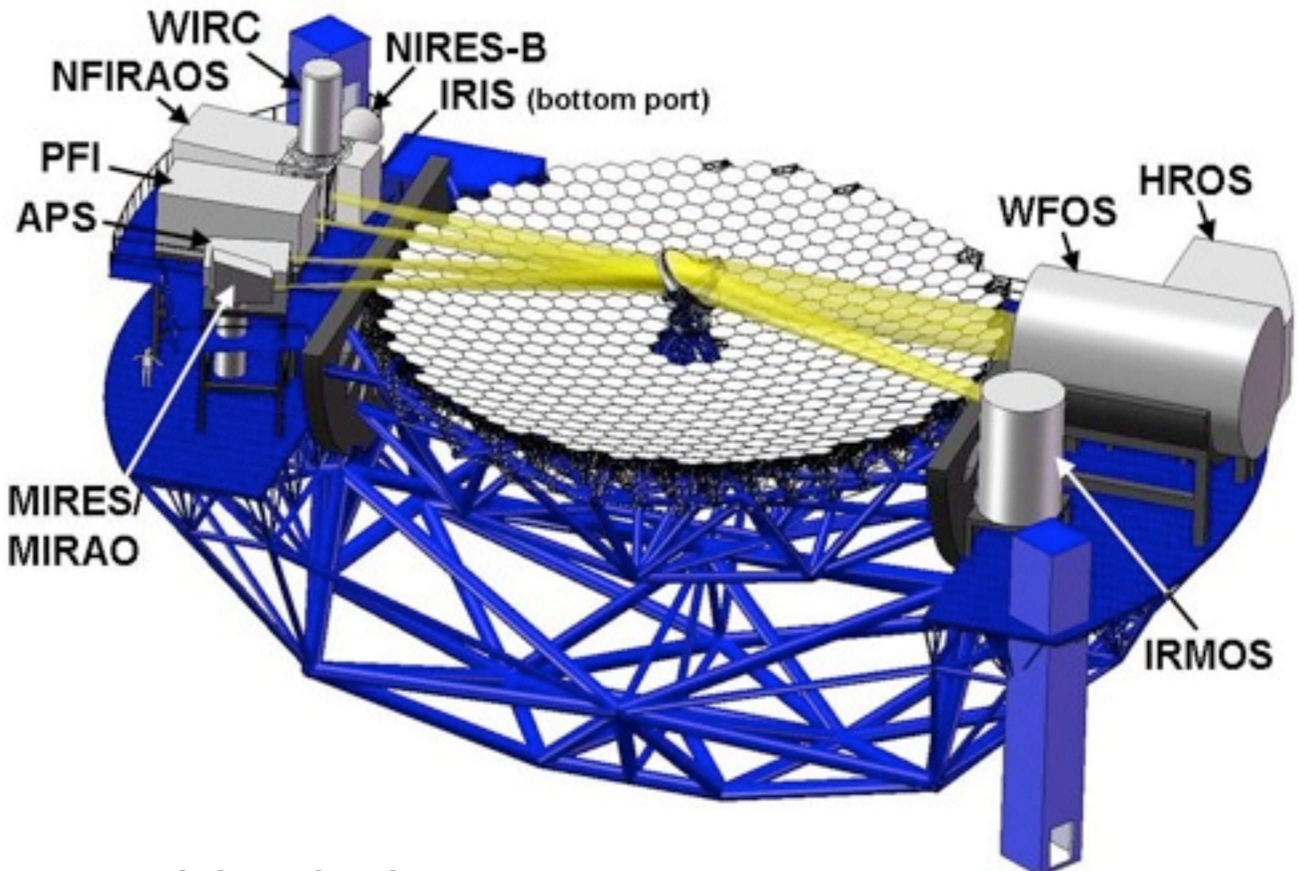
TMT primary mirror

- 492 off-axis parabolic segments
- ~10,000 controlled degrees of freedom

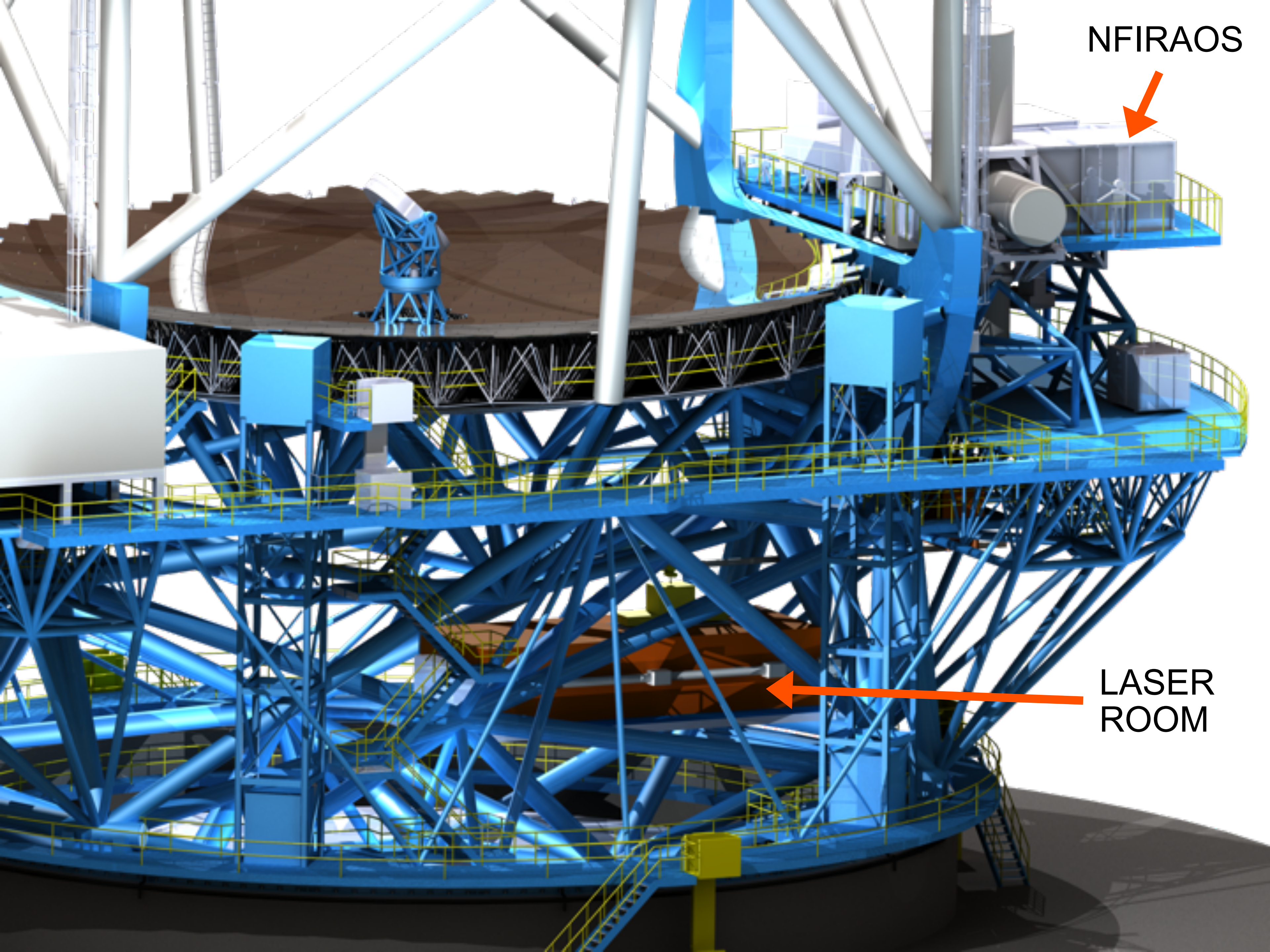


Science instruments

- Initial complement:
  - IRIS
  - IRMS
  - WFOS
- First decade:
  - NIRES
  - MIRES
  - PFI
  - HROS
  - WIRC
  - IRMOS

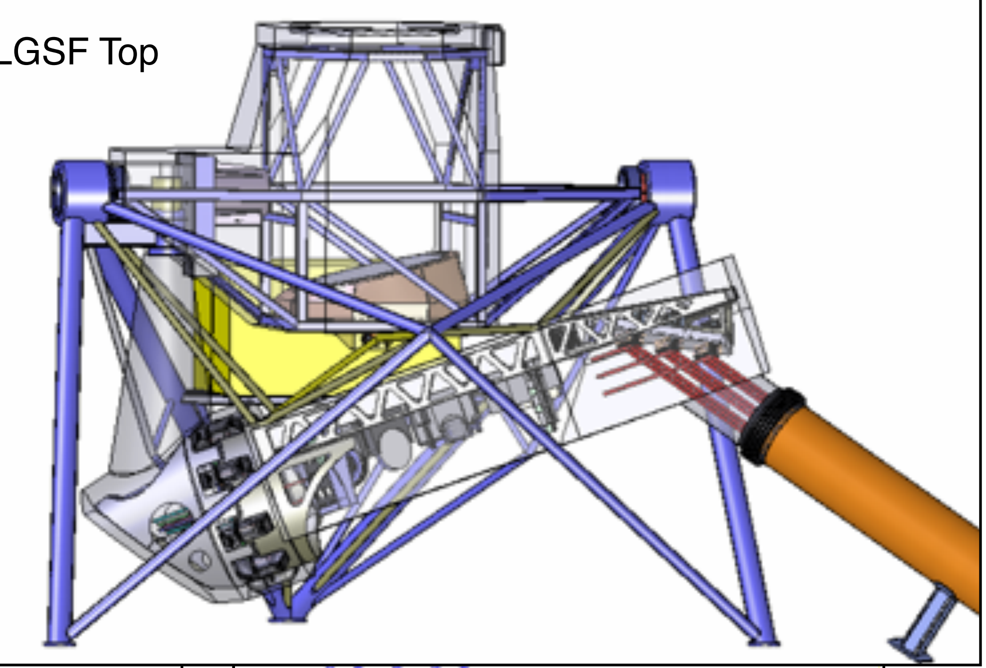


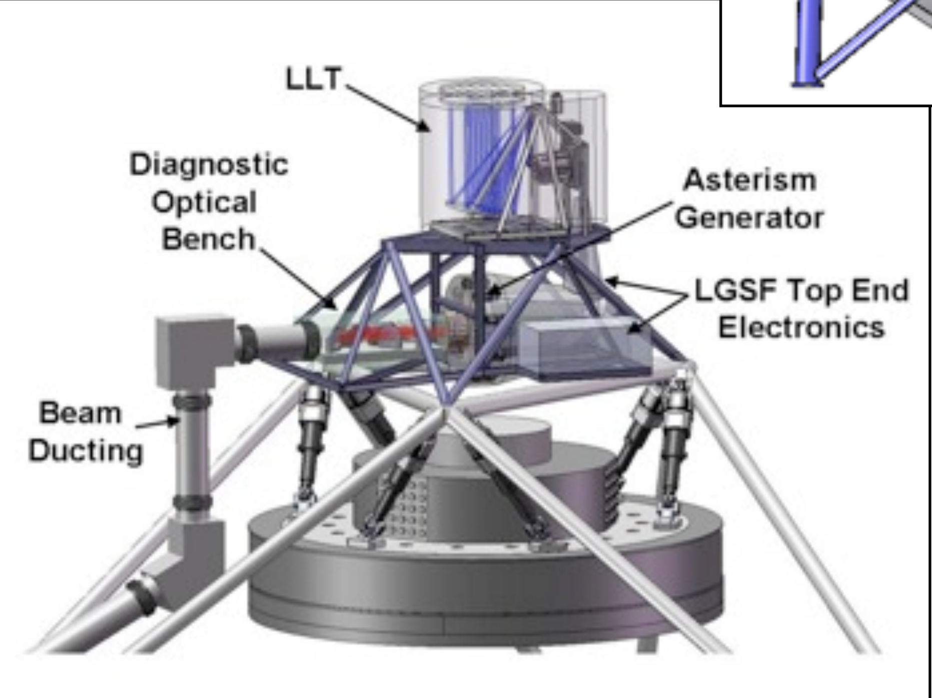
Uses NFIRAOS MCAO system

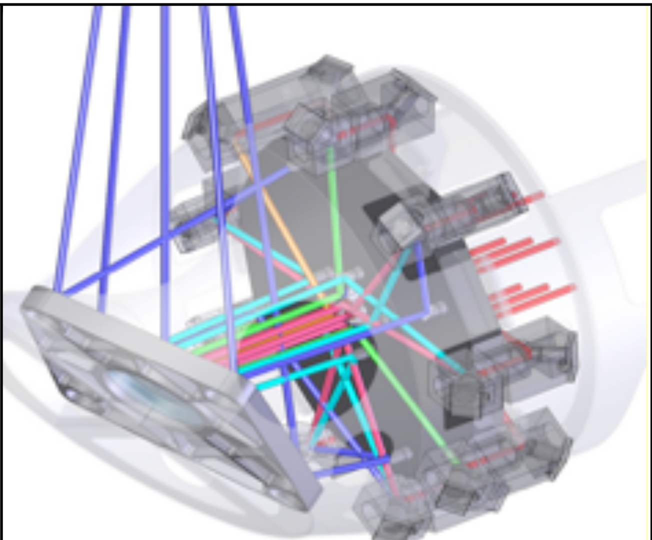

NFIRAOS
LASER
ROOM

TMT LGS facility

- Employs three 50W CW 589 nm lasers
- Projects asterism of 6 LGS
- Variable geometry
- Uplink tip-tilt control

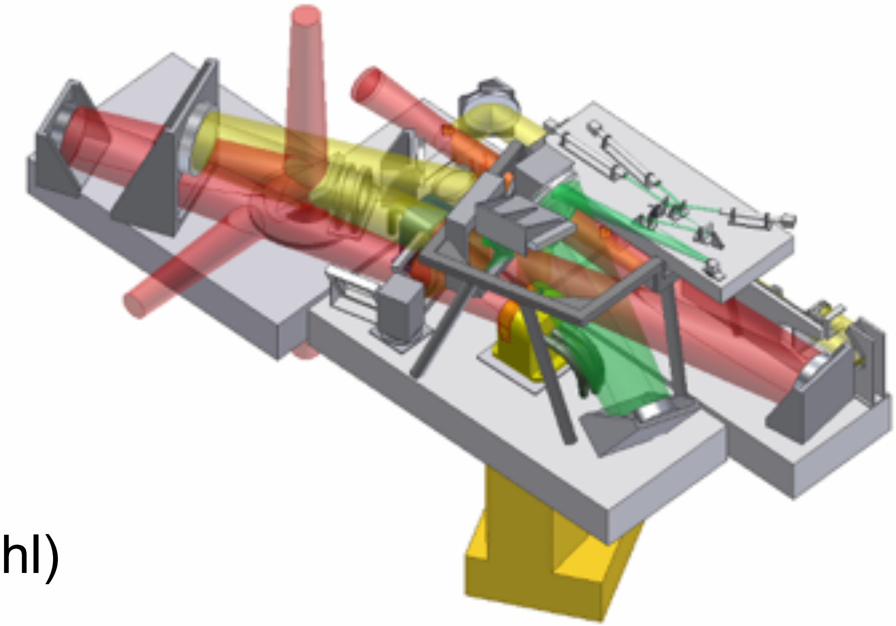

LGSF Top

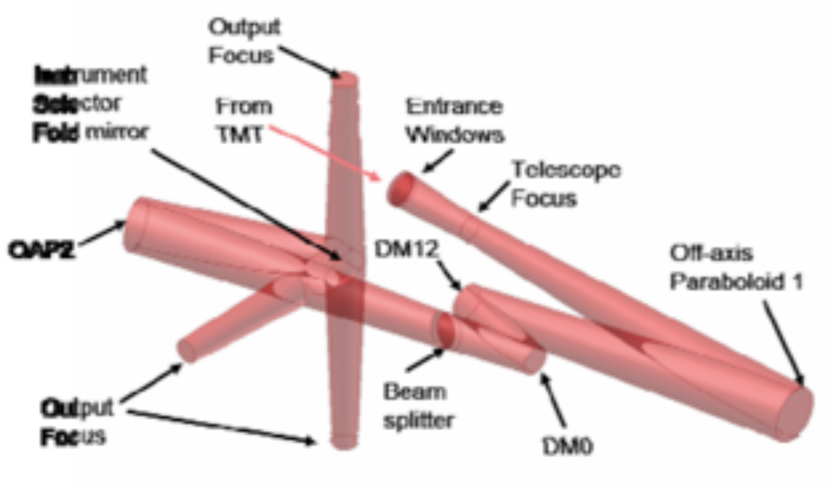


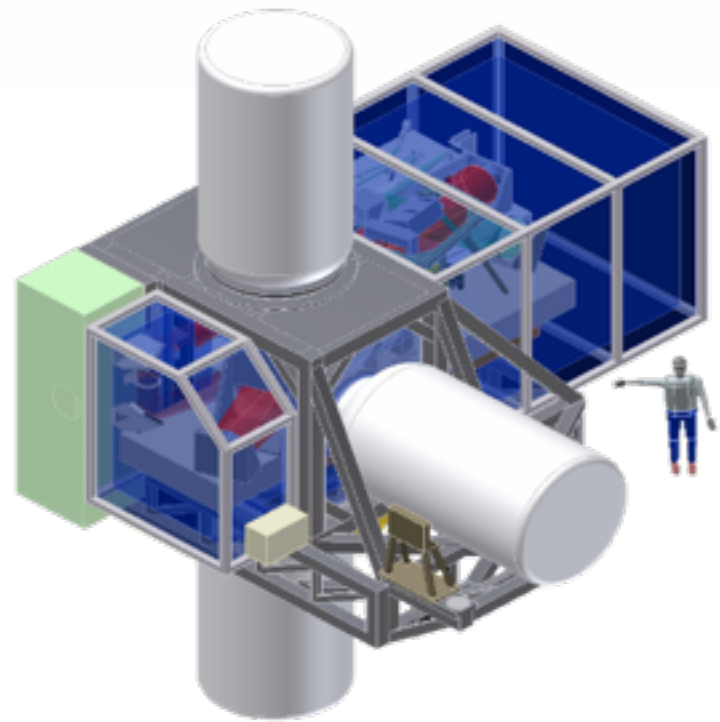

Asterism generator

NFIRAOS

- MCAO system with 2 DMs
  - 61x61 + TTS at 0 km
  - 75x75 at 12 km
- 0.8 - 2.5 um λ range
- 191 nm WFE over 10” field
- 2.3 arcmin field (30” with high Strehl)
- 85% throughput, cooled to -30C
- 50% sky coverage at galactic pole
- 6 LGS plus 3 IR natural guide stars

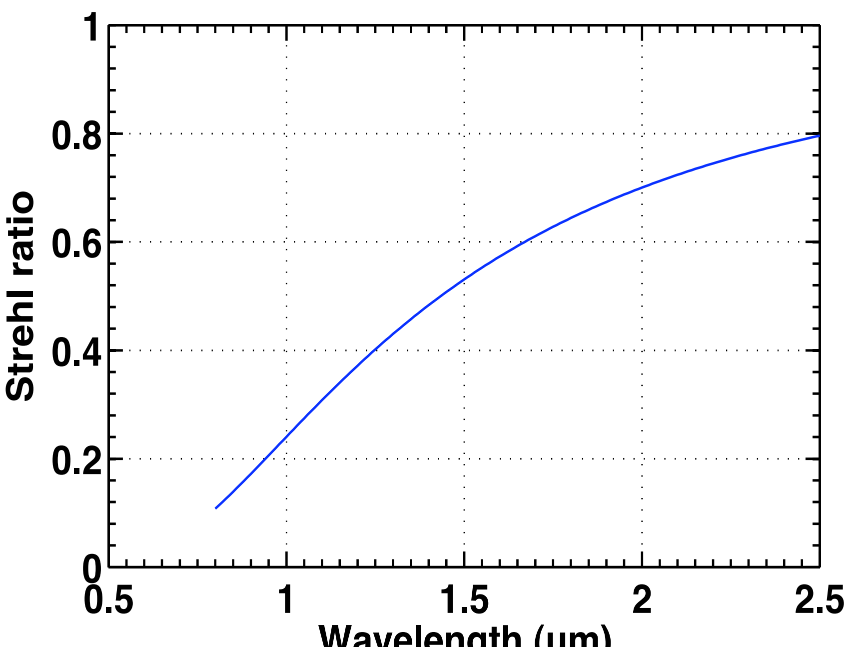


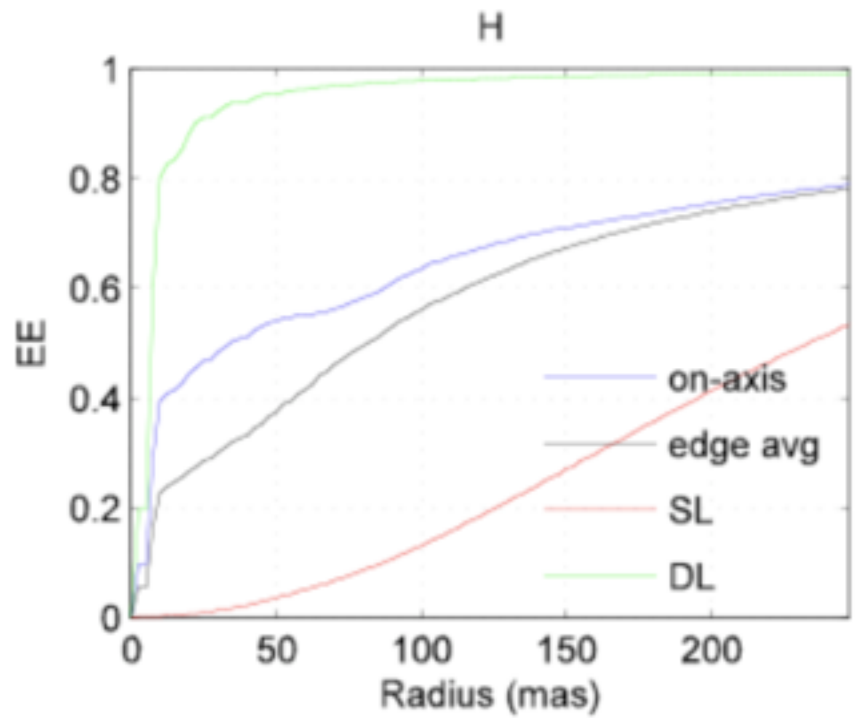




NFIRAOS performance

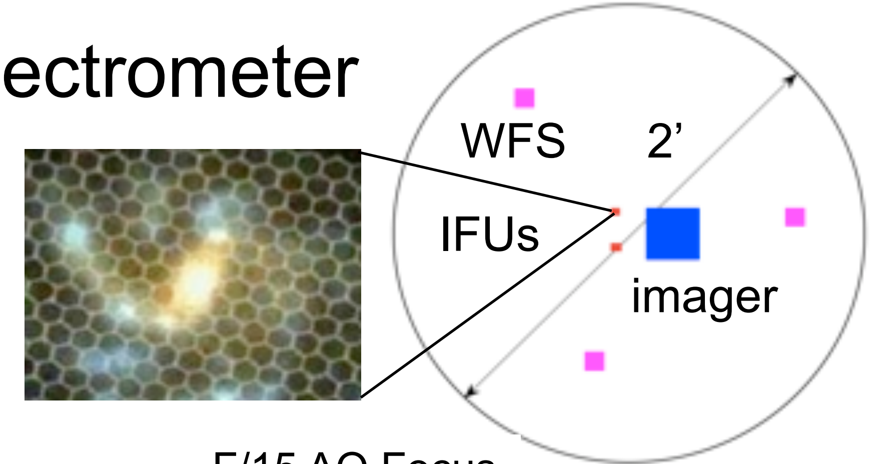
- Lower wavefront error than current AO systems (191 nm vs ~ 300 for Keck)
- Near-constant Strehl ratio over 30” field
- 80% EE within 160 mas over 30” in K band
- 50% encircled energy within 160 mas dia. over 2.3’ field (H band)



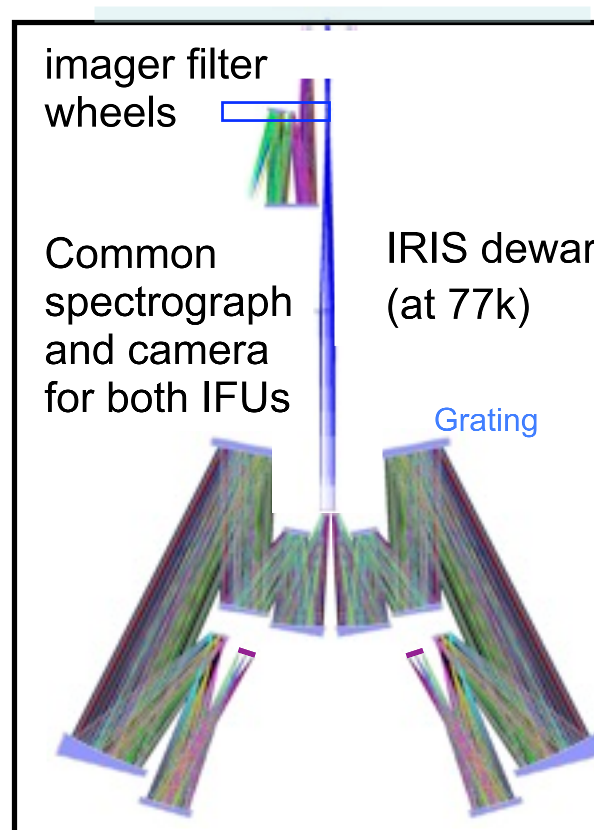


IRIS - Infrared imaging spectrometer

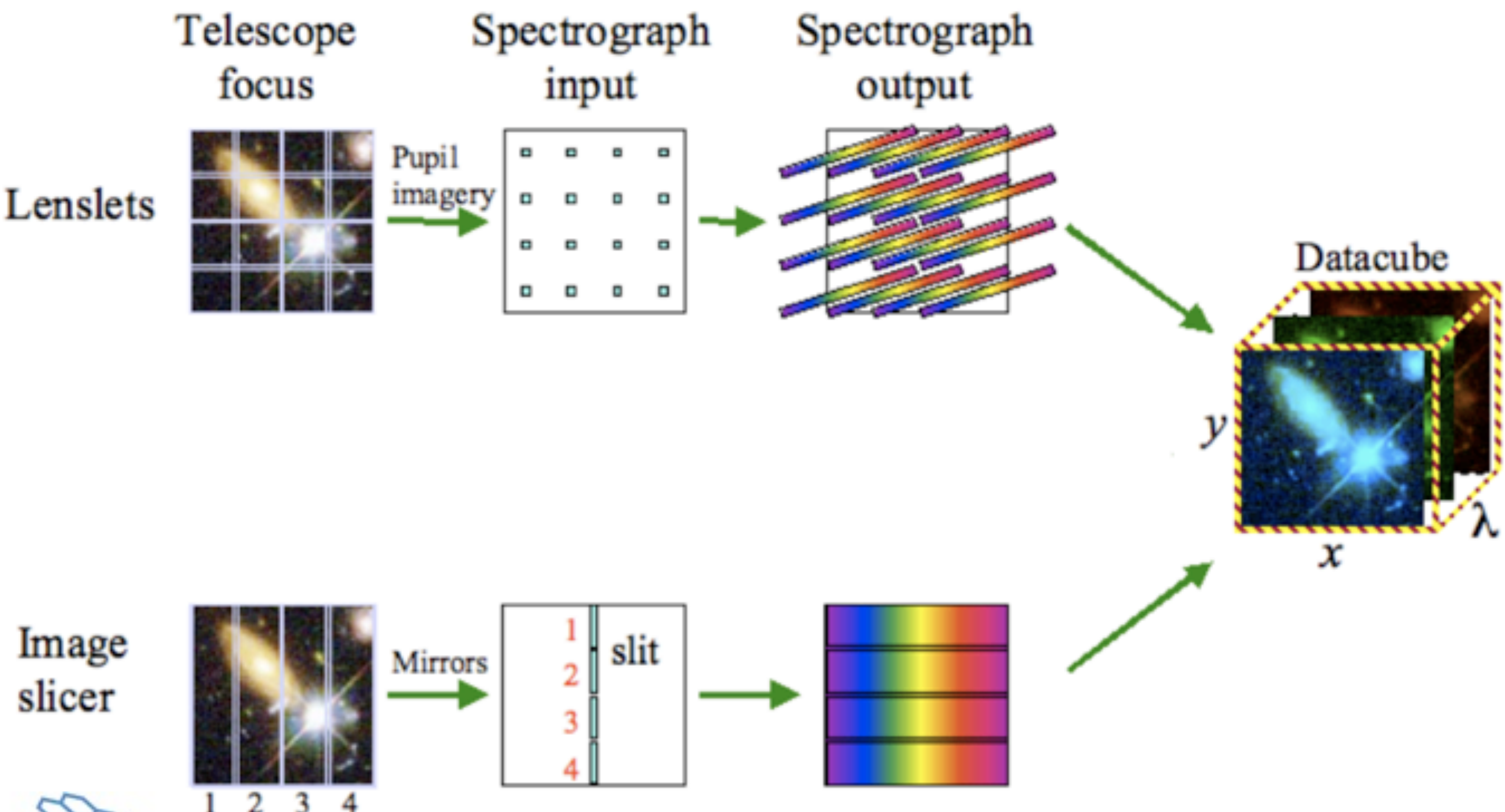
- 0.8 - 2.5 um wavelength range
- 15” x 15” imager with 4 mas pixels
- Distortion correctable to 50 uas
- Spectrometer overs entire J, H or K band at *R* ~ 4000
- Lenslet IFS
  - 128x128 spatial pixels
  - 4 mas scale: 0.5” x 0.5”
  - 10 mas scales: 1.3” x 1.3”
  - Best wavefront error
- Image slicer
  - 90 slices; 2:1 aspect ratio
  - 25 mas scale: 1.1” x 2.2”
  - 50 mas scales: 2.2” x 4.4”
  - Best sensitivity



F/15 AO Focus

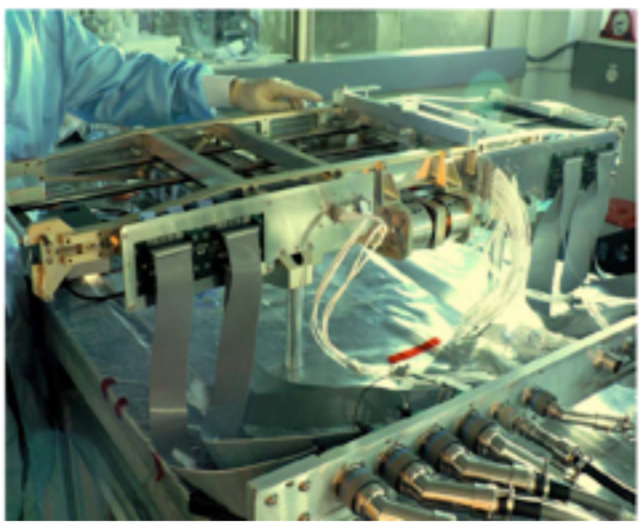


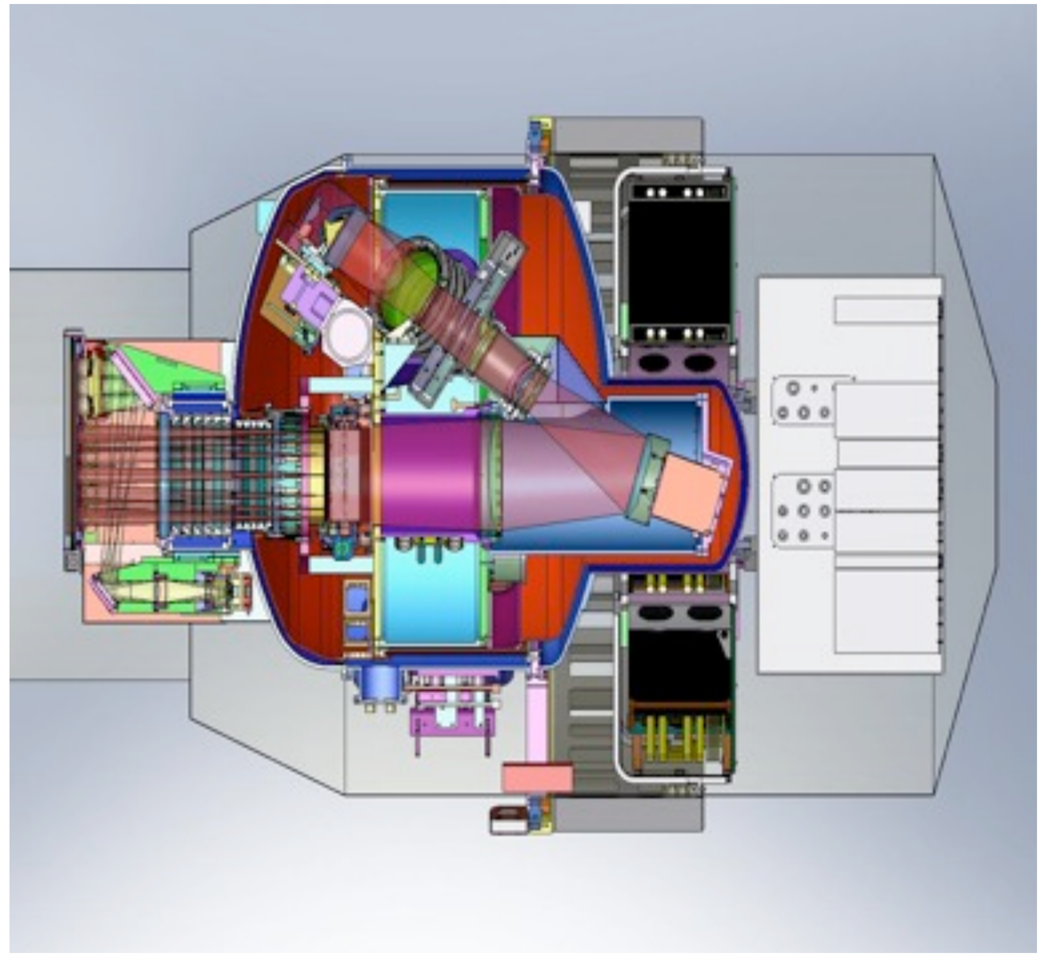
IRIS lenslet + image slicer



IRMS - Infrared multislit spectrometer

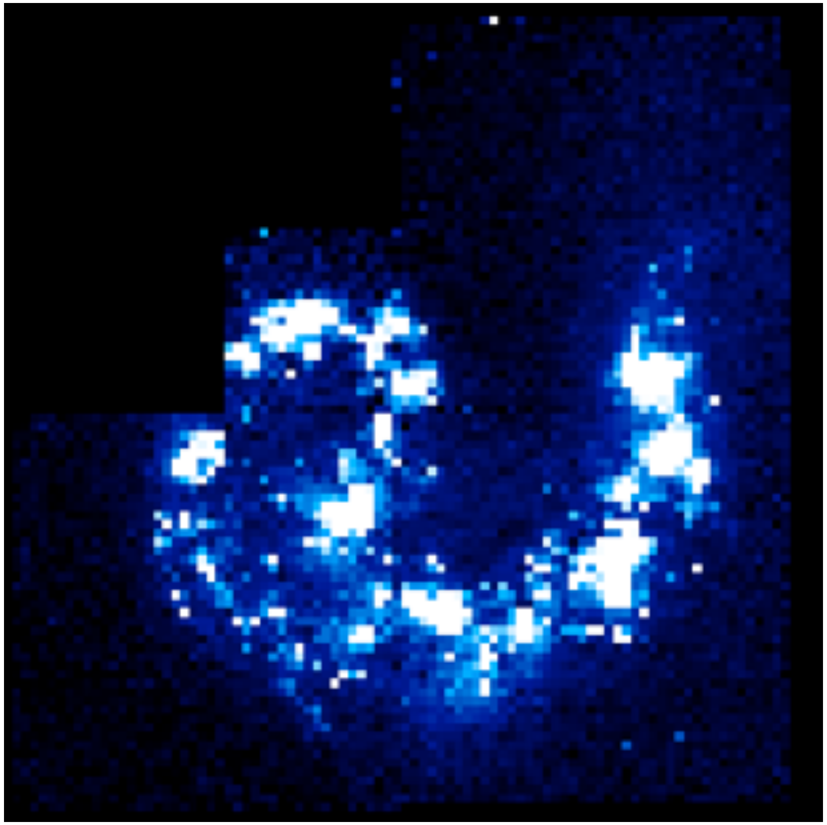
- 0.8 - 2.5 um cryogenic multi-slit spectrometer
- 2.3 arcmin field of view
- 60 mas sampling
- 46 movable slits 2.4” long x 160+ mas wide
- Covers entire Y, J, H or K band at *R* = 4660





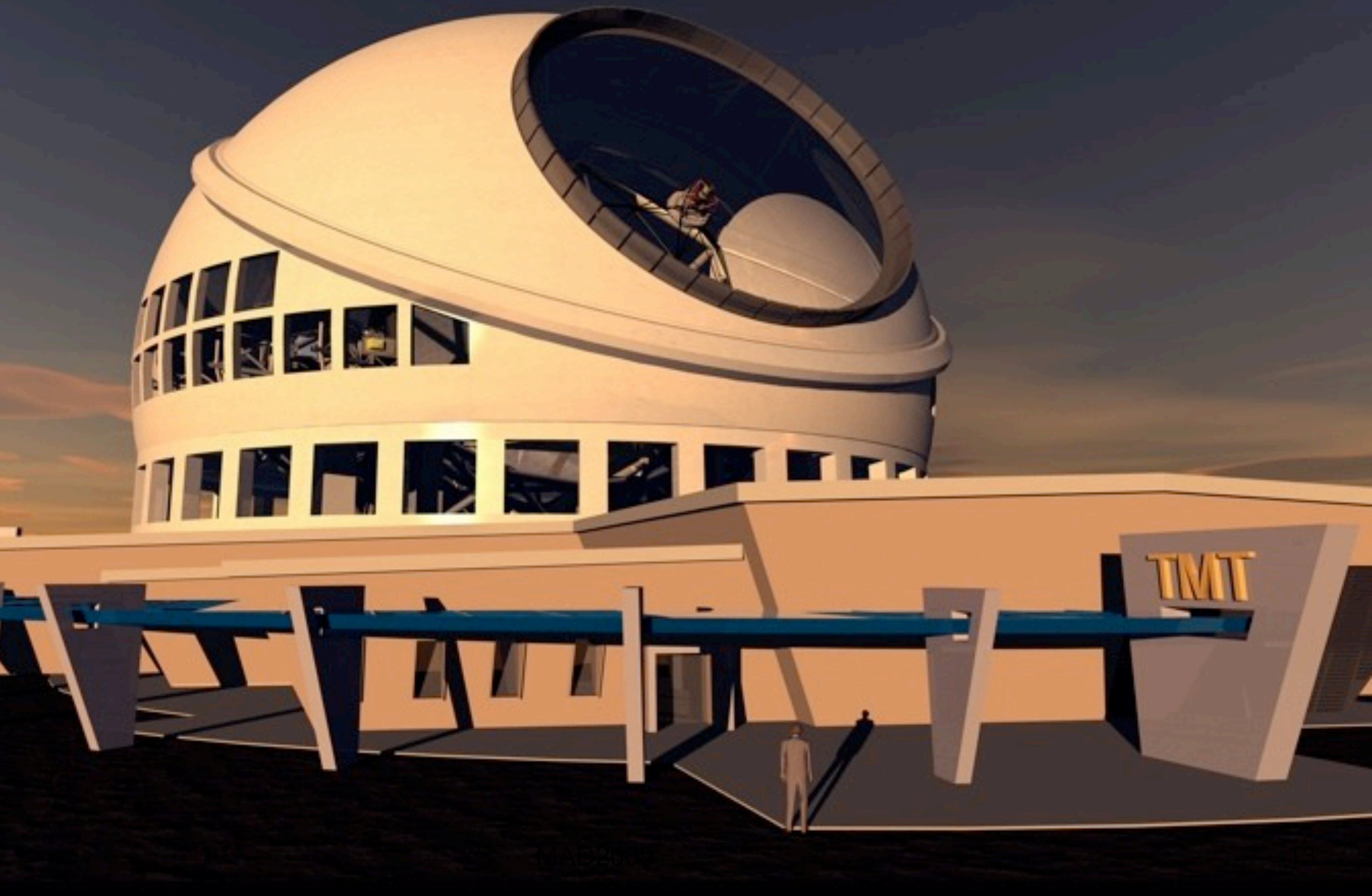
NFIRAOS+IRIS performance

- Time required to reach a given s/n is proportional to $D^{-4}S^{-2}$
- Flux limit for fixed exposure time is proportional to $D^{-2}S^{-1}$
- K = 22.6, H = 24.8 in 1 hr for point sources (s/n = 10)
- Line flux to ~ 2×10^{-20} erg s^{-1} cm^{-2} should be possible
- Resolution to 7 mas (~ 50 pc at z > 1)



Slice of IRIS data cube for simulated observation of “Antennae” at z = 3, at 15 mas sampling (IRIS Science Team)

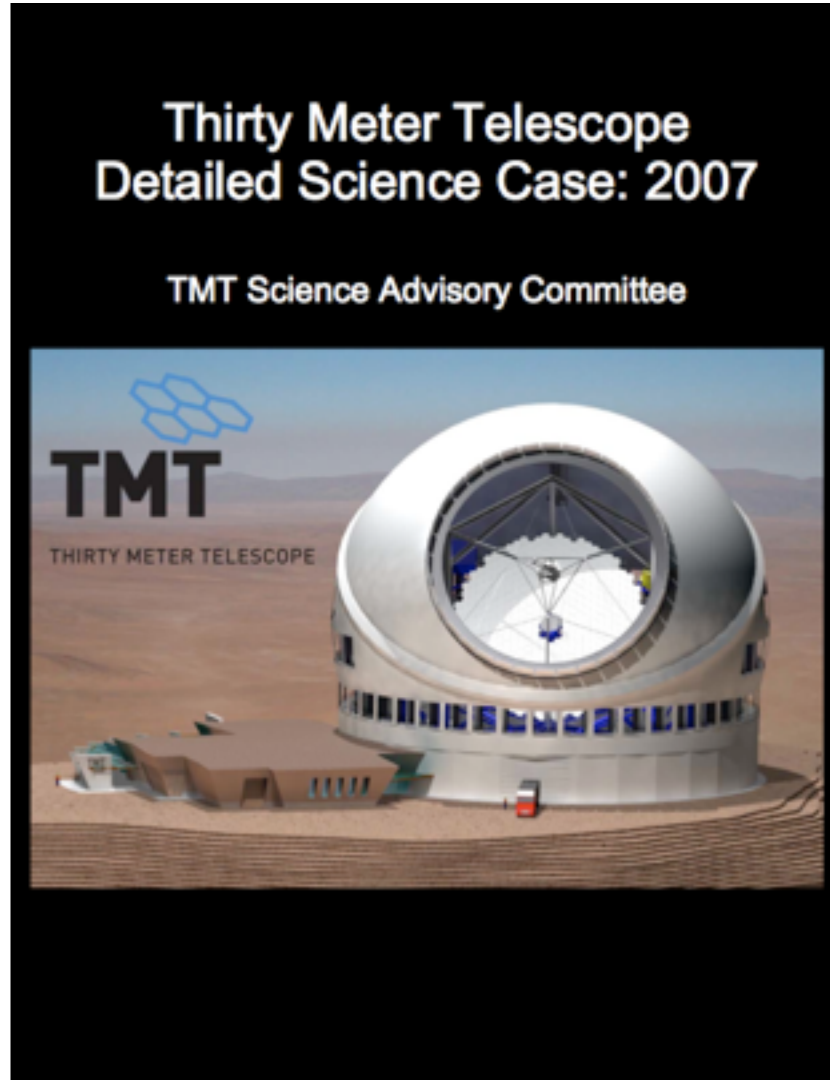
TMT / NFIRAOS key science programs



TMT Detailed Science Case

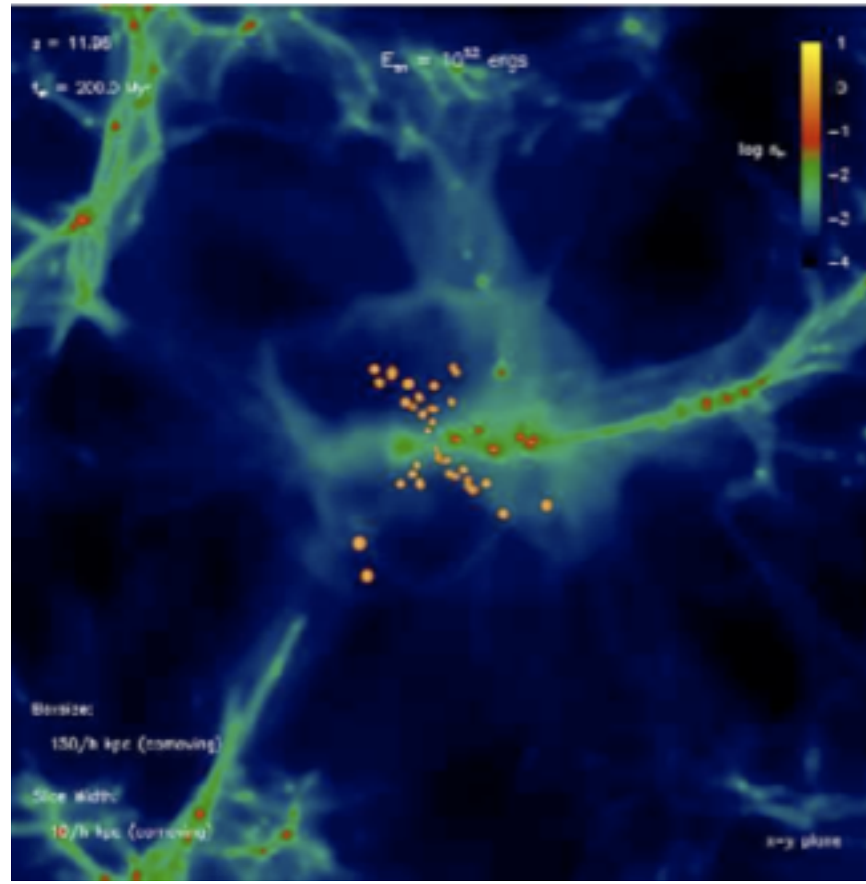
- 100-page summary of TMT science programs
- Posted publicly in Oct 2007
- Available at www.tmt.org (see Foundation Documents)

- Ongoing work by IRIS science team



The first stars and galaxies

- Detect and study the first luminous objects
- Spectroscopic followup of sources found with JWST
- Moderate resolution (R > 4000) integral field spectroscopy
- Targets are supermassive stars, star clusters and protogalaxies
- Look for rest-frame UV emission lines redshifted into the near-infrared (Ly-α, He II, etc)
- Detect supernovae from early stars

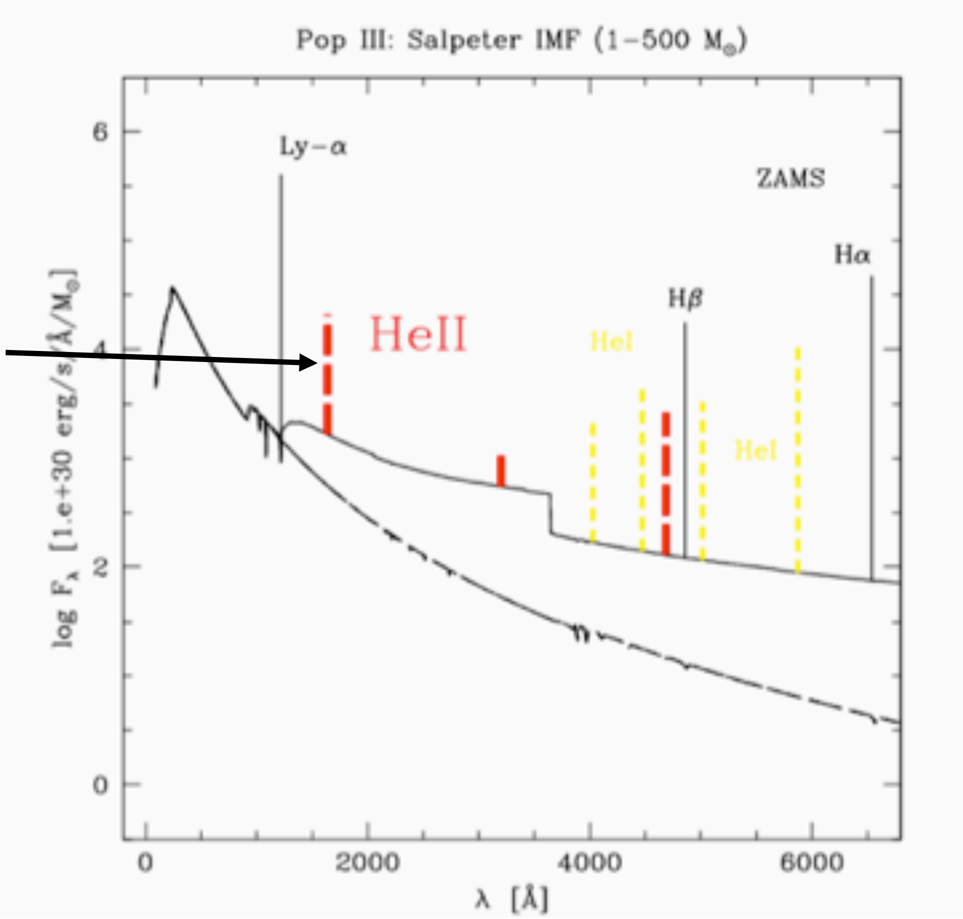


Gas density 200 Myrs after the formation of the first stars. Orange dots show supernovae. (Grief, Johnson and Bromm, 2008)

TMT THIRTY METER TELESCOPE

The first stars and reionization

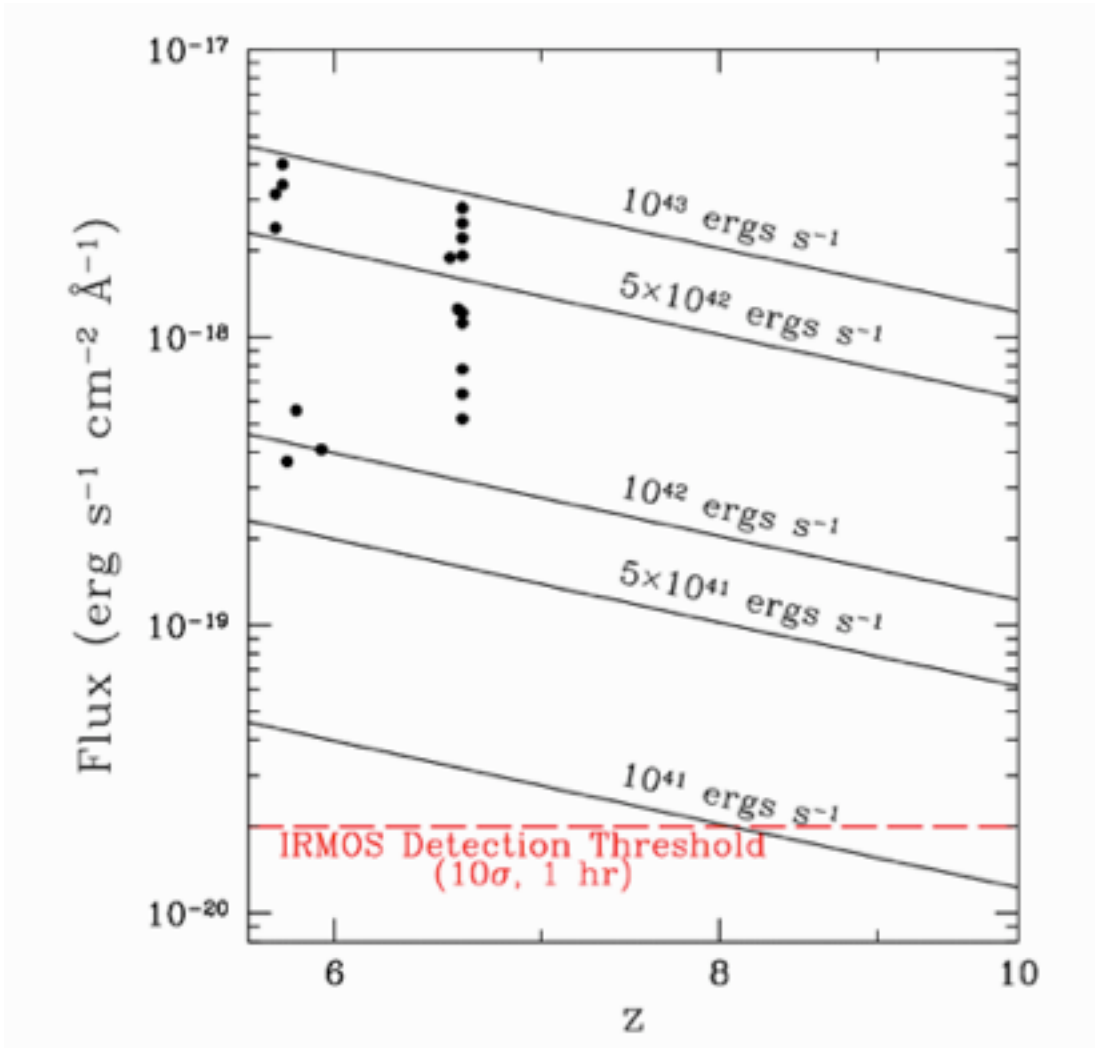
- Study the distribution and spatial extent of sources, and the size and topology of the ionization region via Ly-α line
- Detection of He II λ1640Å emission would confirm existence of primordial (population III) stars
- Observe between the OH lines at R ~ 4000 with IRIS IFU
- IRIS should reach ~ 2×10^{-20} erg s^{-1} cm^{-2} for 25 mas sources in 4 hrs (an order of magnitude fainter than JWST)



Schaerer 2002

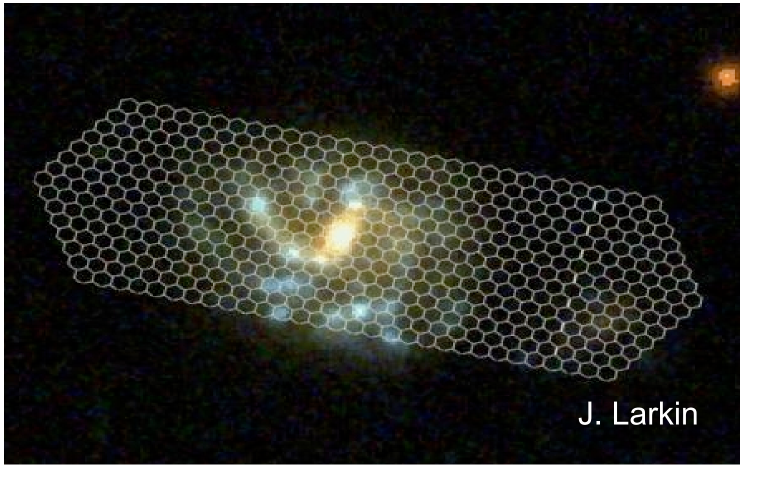
High-redshift galaxies

- Determine the Ly-α luminosity function for z ~ 7 - 20.
  - narrowband imaging with IRIS imager
  - target JWST galaxies
  - target caustics of gravitational lens systems
- There are potentially many sources per TMT field of view, depending on the transparency of the intergalactic medium.



Galaxy formation and evolution

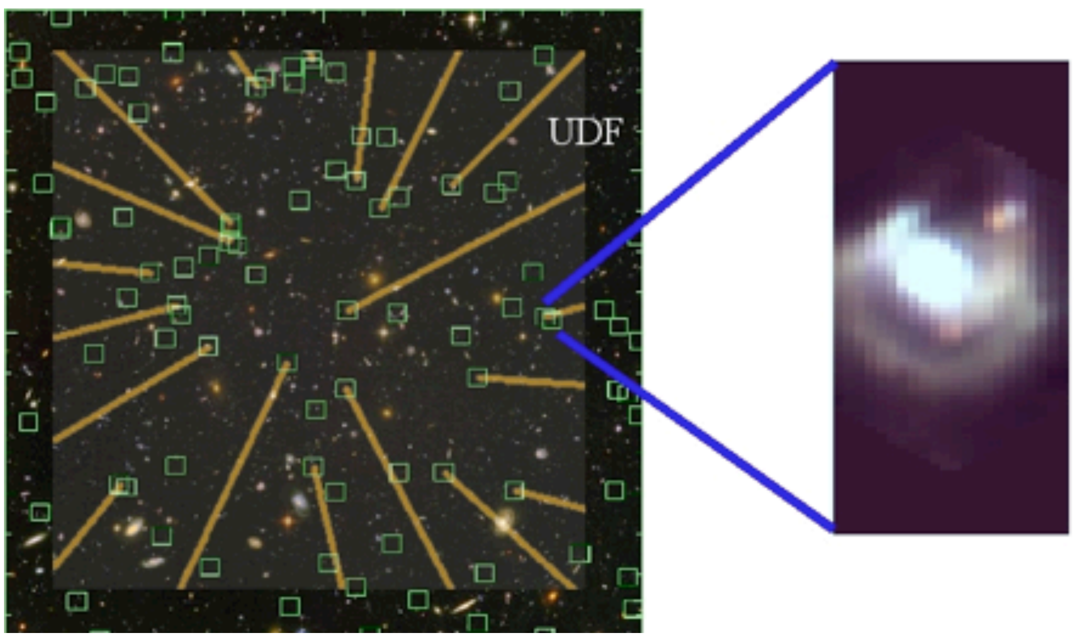
- Probe chemistry and dynamics of high-redshift galaxies and study the assembly of galaxies with 50-100 pc resolution (IRIS, IRMS, IRMOS)
- Outsanding issues:
  - How does the age of the stellar population compare to the dynamical age of the galaxy?
  - How do star formation modes relate to the dynamical 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?

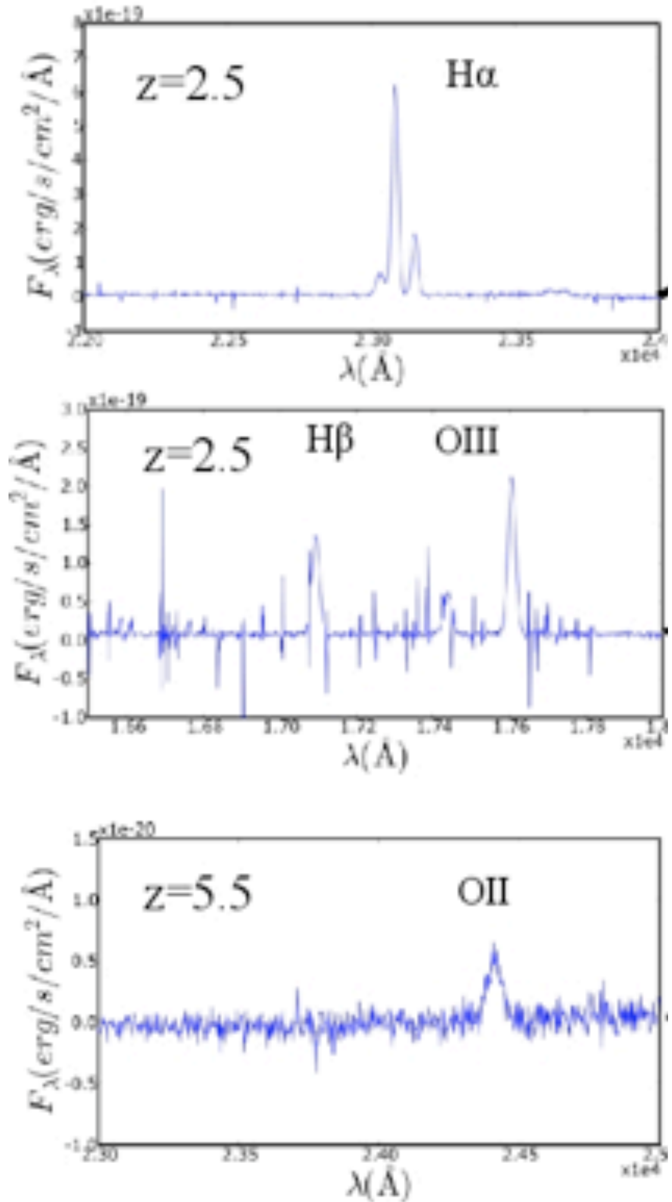


TMT THIRTY METER TELESCOPE

Dissecting galaxies at z ~ 1 - 6

- Spatially-resolved spectroscopy at at 50 - 100 pc scales (IRIS, IRMS, IRMOS)
- Map kinematics, chemistry, star-formation, to z ~ 6





The physics of galaxy formation and evolution

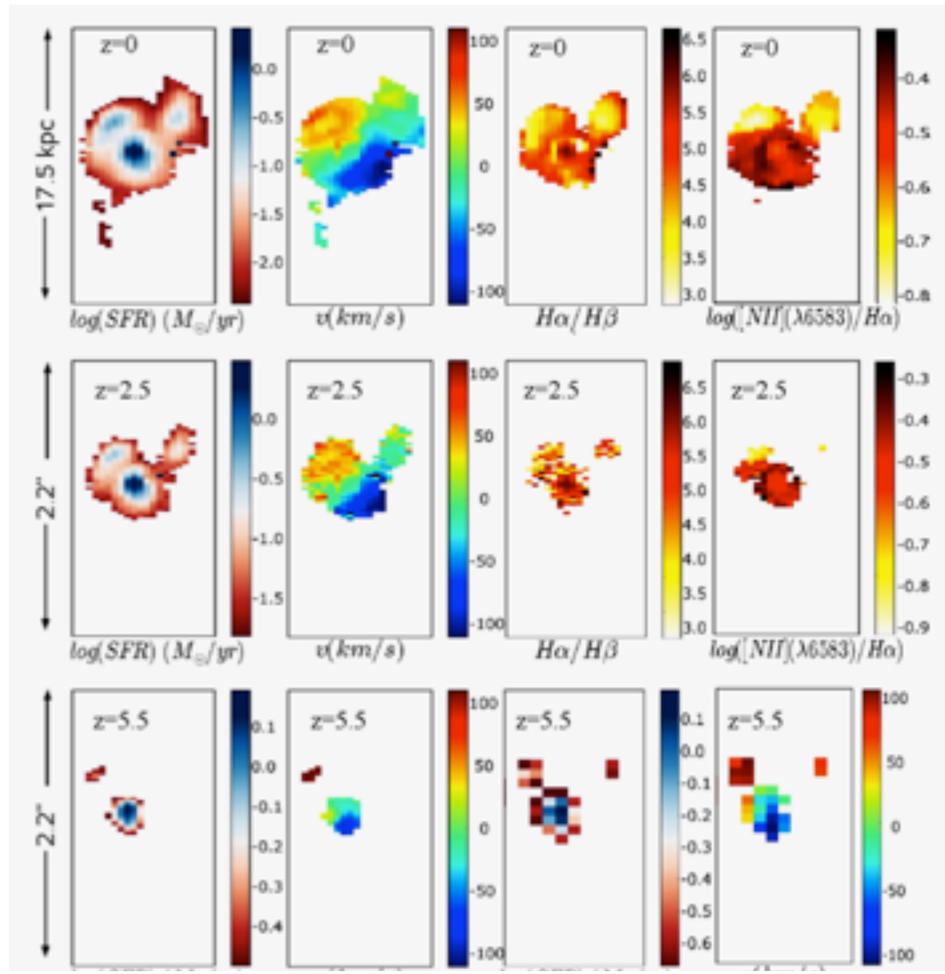
- Mapping the physical state of galaxies over the redshift range where the bulk of galaxy assembly occurs:
  - Star formation rate
  - Metallicity maps
  - Extinction maps
  - Dynamical Masses
  - Gas kinematics
- Synergy with ALMA:
  - Molecular emission

SFR Velocity Hα NII/Hα

z = 0

z = 2.5

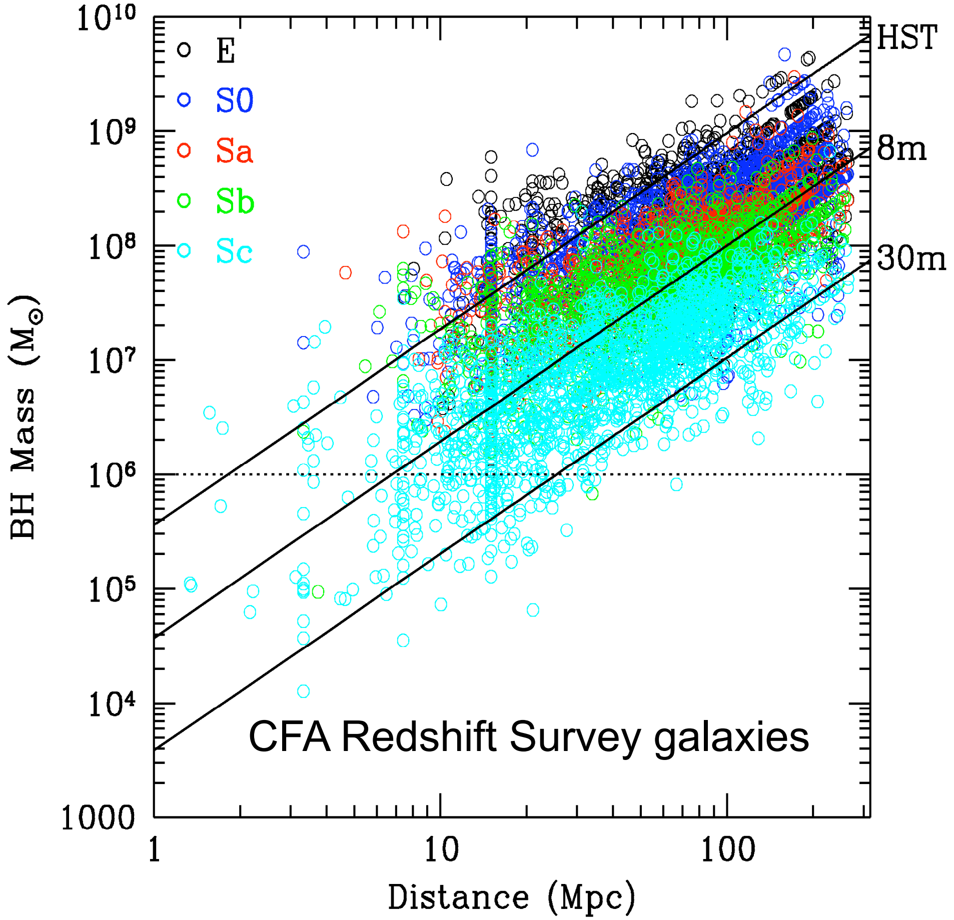
z = 5.5



TMT IRMOS-UFHIA team

Black holes and active galactic nuclei

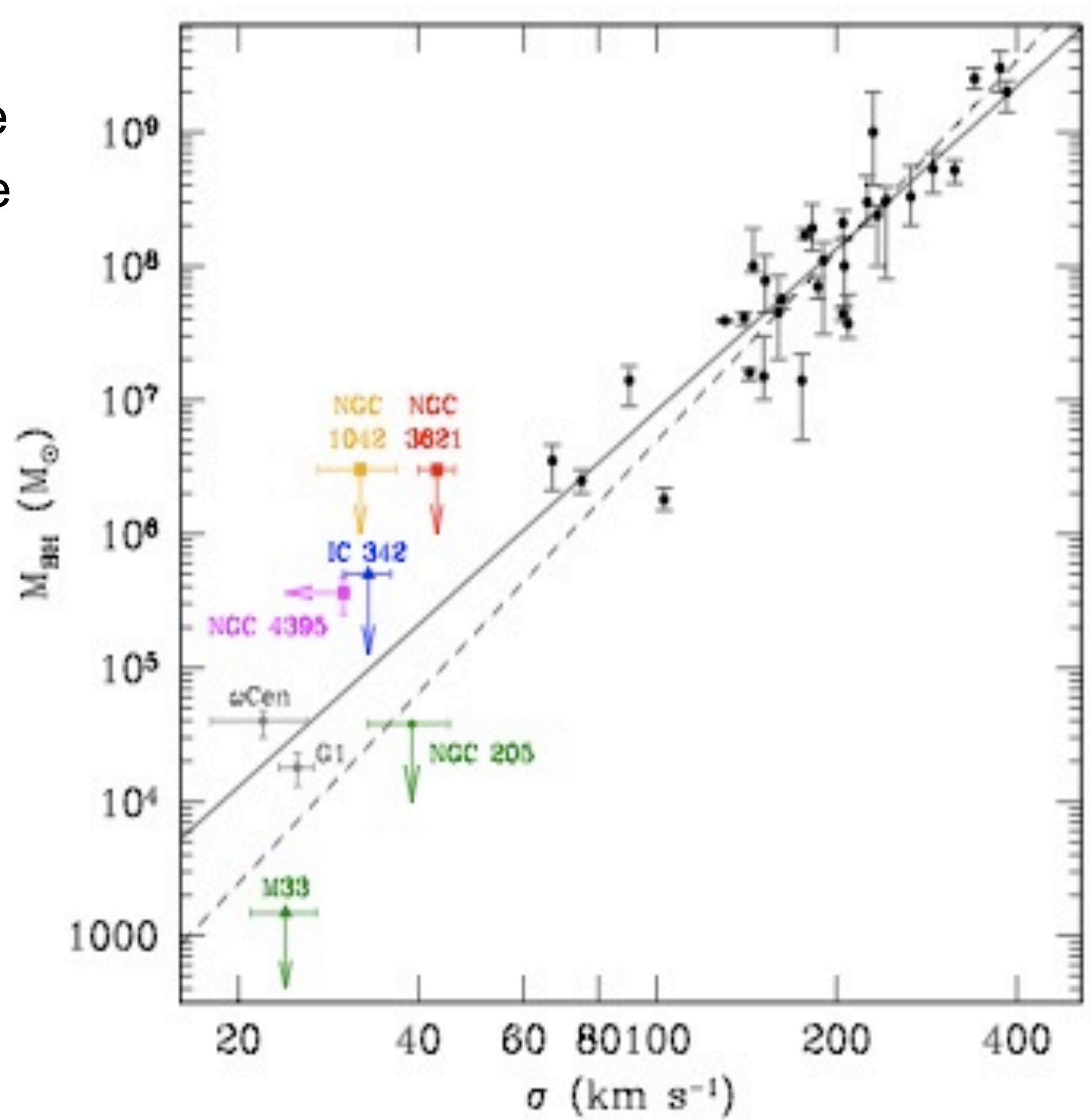
- Determine black hole masses over a wide range of galaxy types, masses and redshifts (IRIS)
- TMT can resolve the region of influence of a $10^9\ M_\odot$ BH at any redshift.
- Outstanding issues:
  - When did the first super-massive BHs form?
  - How do BH properties and growth rate depend on the environment?
  - How do BHs evolve dynamically?
  - How do BHs feed?



Low-mass galactic black holes

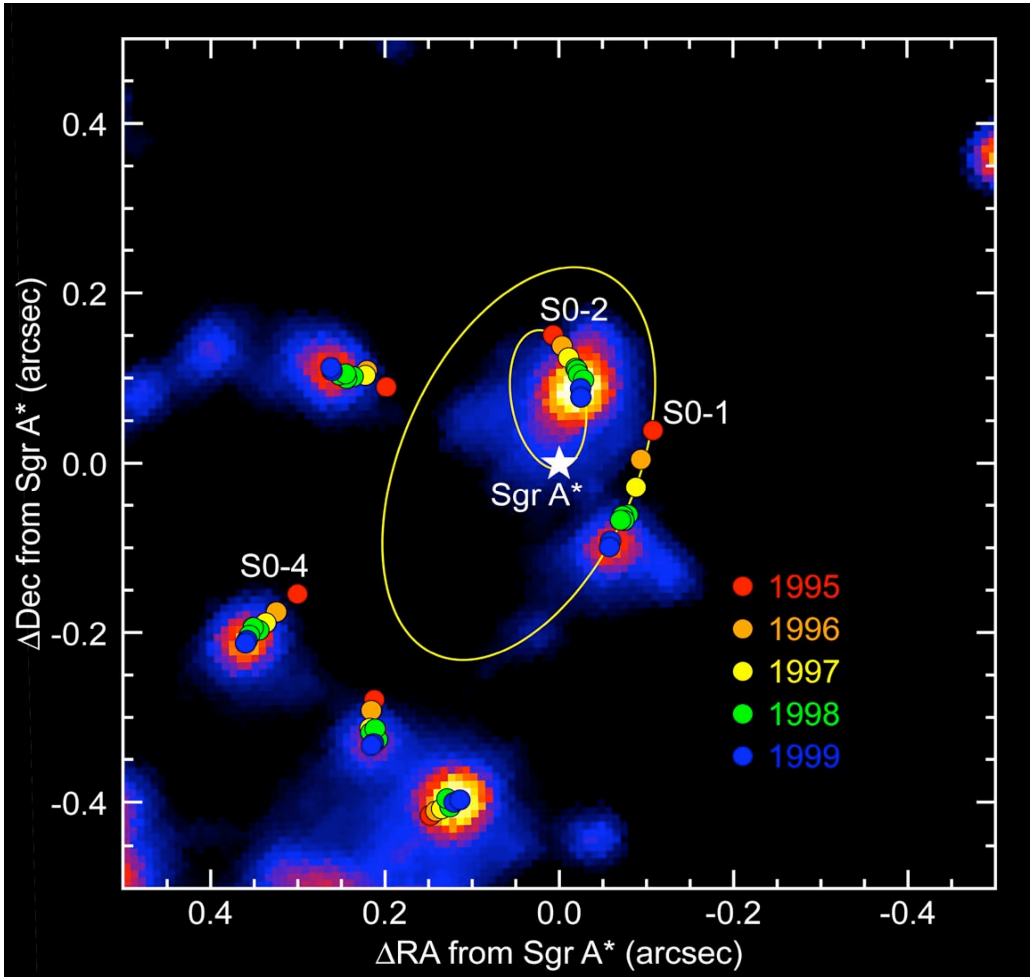
- Extend M-sigma relation to the 10^3 - 10^6 $M_\odot$ range
- Requires R > 4000 at the diffraction limit

Barth et al. 2008



Black holes and active galactic nuclei

- Map stellar orbits in the galactic center with precision ~30 uas to probe the gravitational potential, study the nature of dark matter on small scales, and measure general-relativistic effects (IRIS, WIRC)
- Detect and spatially resolve accretion disks and the spheres of influence of massive black holes to z > 1, and study AGN mass and metallicity at all redshifts (IRIS)



A. Ghez, UCLA

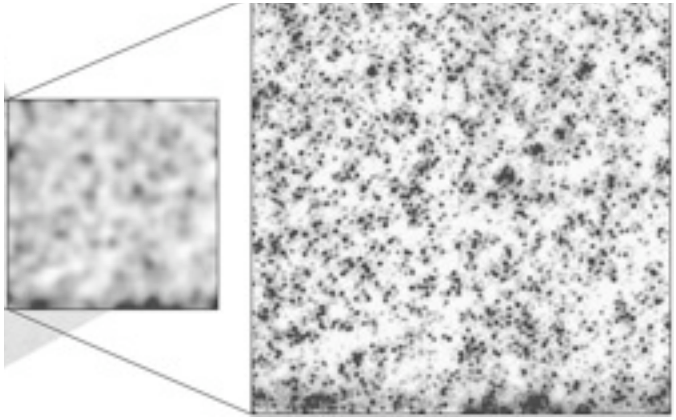
Stellar populations in the local Universe

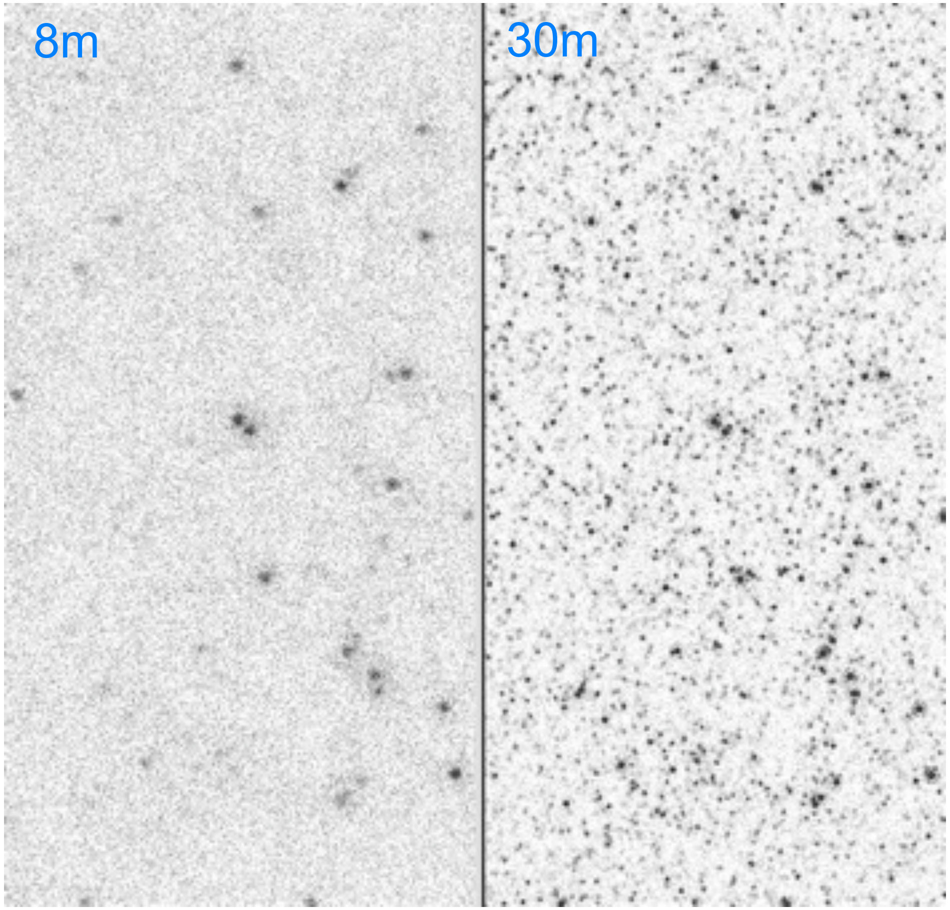
Simulations of a field in a Virgo Spheroid using MCAO.

Left: 3 hr exposure in K with an 8 m telescope.

Right: 3 hr exposure in K with a 30 m telescope.

Larger aperture provides D^4 sensitivity gain and D^2 reduction in confusion.

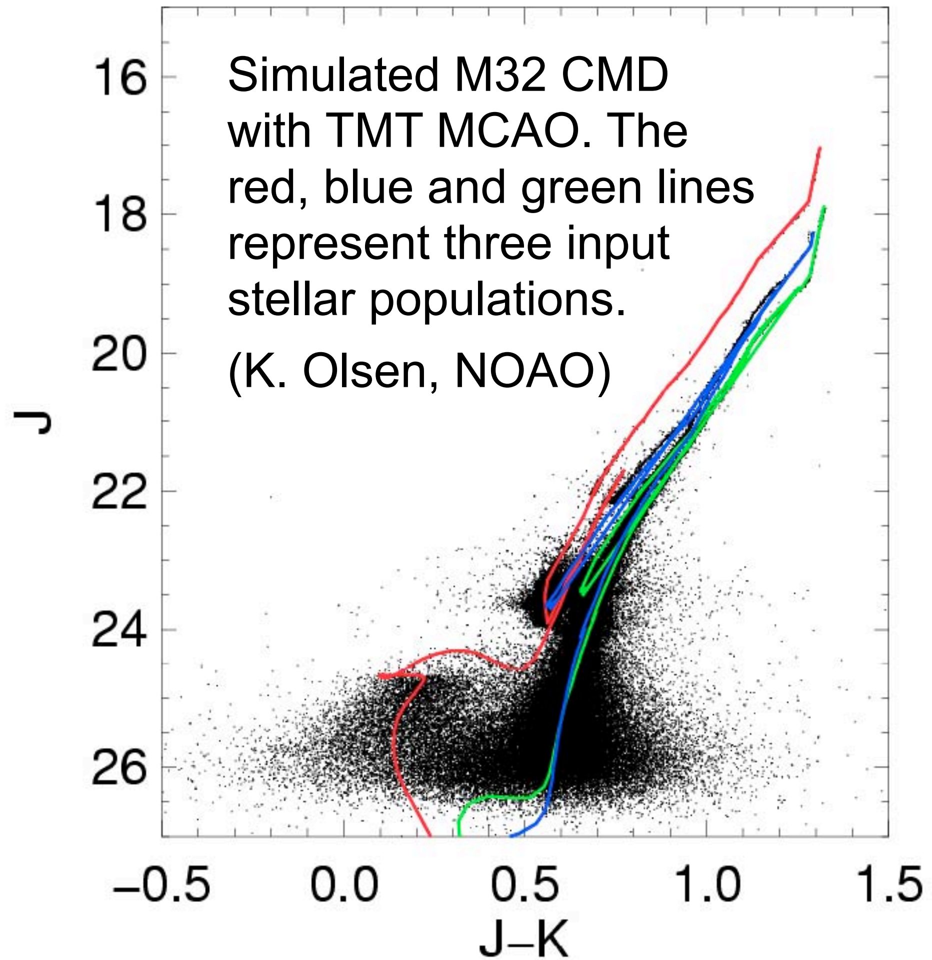




IRIS Science Team

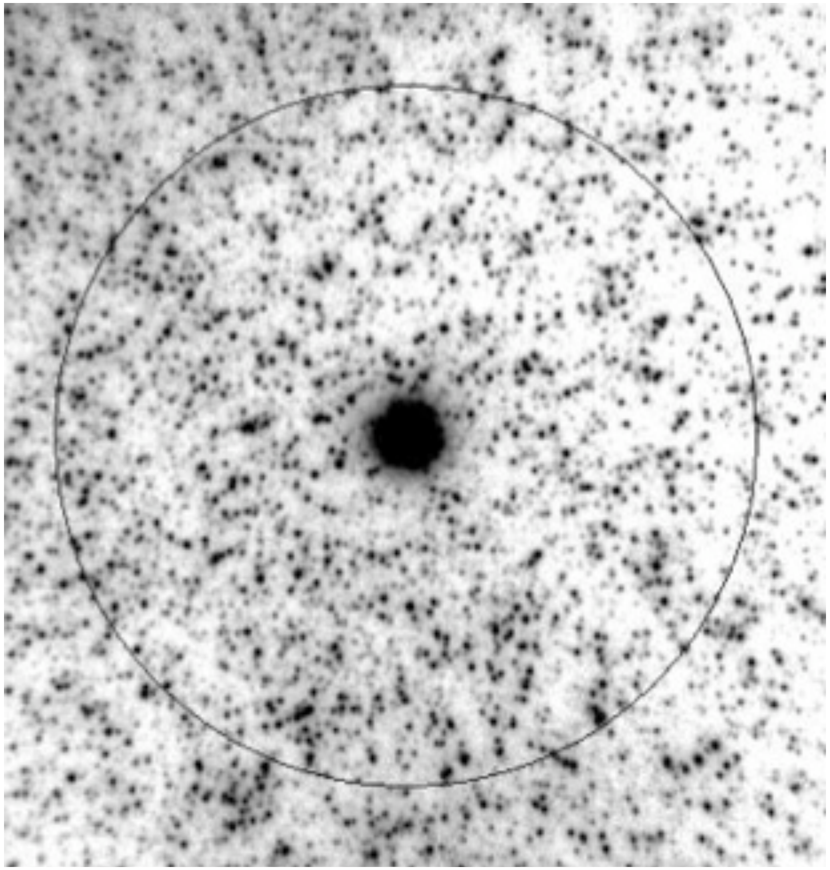
Stellar populations in the local Universe

- Determine the star formation history in galaxies as far as the Virgo cluster (IRIS, WFOS, HROS)
- Study star-formation history and metallicity in a wide range of environments.
- Moderate and high-resolution spectroscopy will provide element abundances.
- Complimentary to high-z galaxy studies.



Evolution of Star Clusters and the IMF

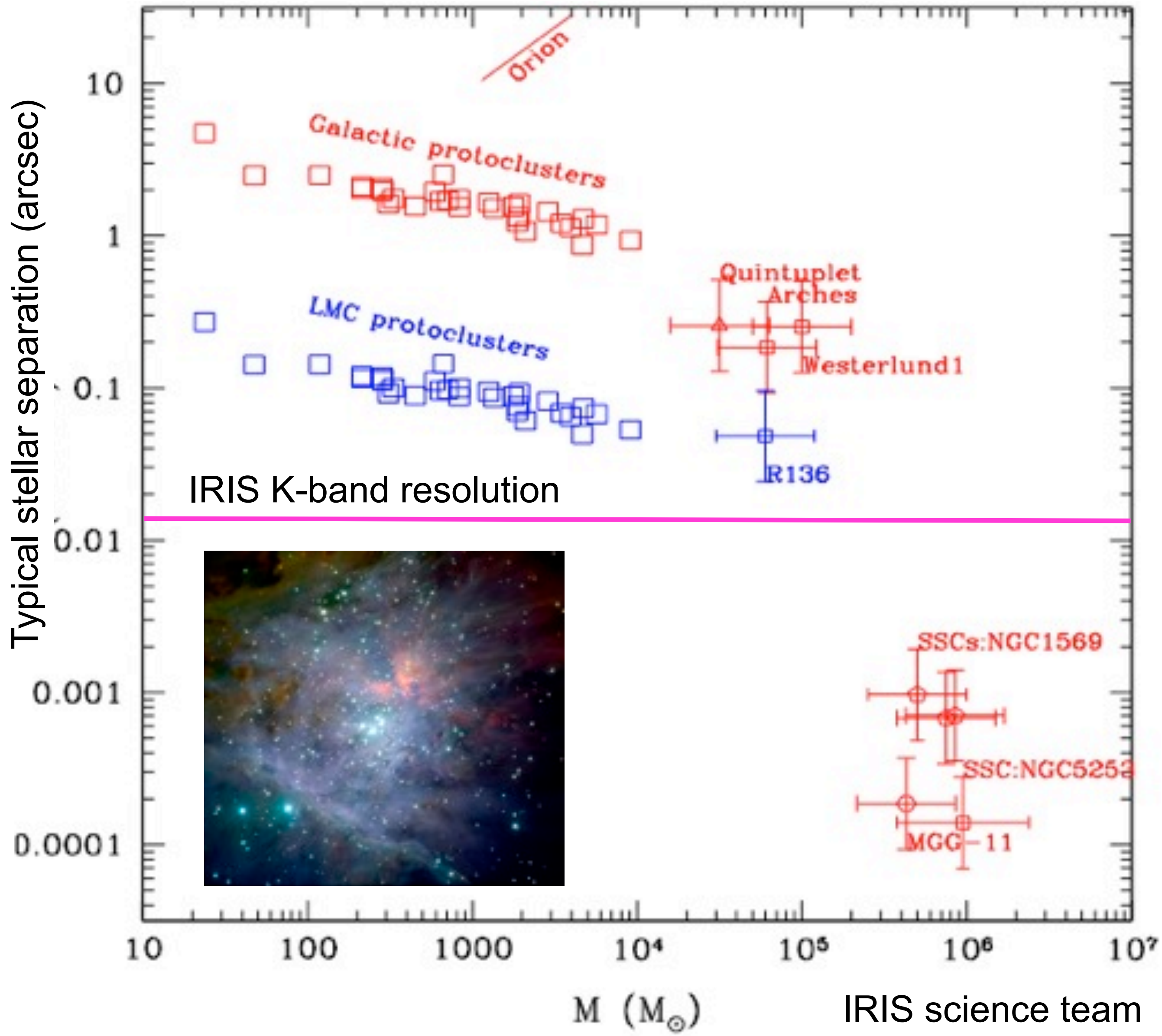
- Determine the initial mass function in star clusters from < 1 to 100 Mpc in a range of stellar environments (IRIS)
- ~50 uas astrometric accuracy → binaries from proper motion



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).

Star formation

- Measure IMF in embedded clusters over an order of magnitude in metallicity and gas density
- Detect stars to HBL as far as 50 kpc



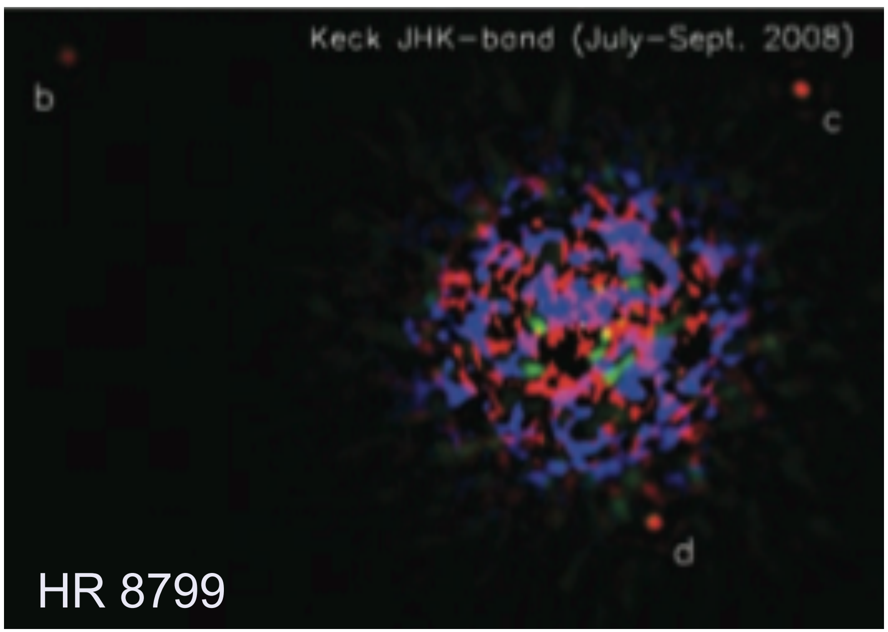
IRIS science team

TMT
THIRTY METER TELESCOPE

Characterization of extrasolar planets

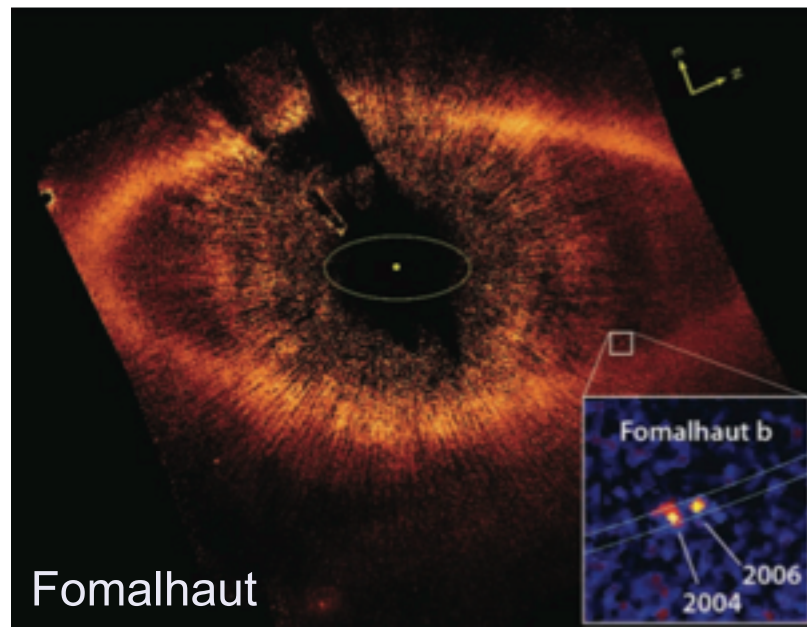
- Direct imaging of young planets near low-mass stars (IRIS, PFI)
- IR spectroscopy of jovian planets to characterize atmospheres
- Doppler detection of Earth-like planets in habitable zone of M stars (HROS, NIRES)

Keck/Gemini AO



Marois et al. 2008

HST



Kalas et al. 2008

Characterizing extrasolar planets

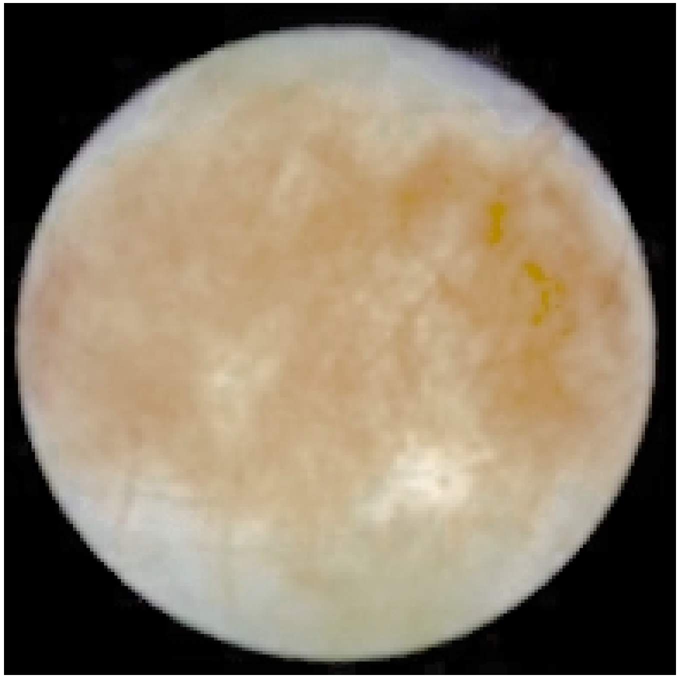
- Doppler follow-up of transit detections (HROS, NIRES)
- Absorption spectroscopy of atmospheres of transiting planets (HROS, NIRES).
- Reflected light spectroscopy of Jovian planets (IRIS, PFI).
- Direct spectroscopy of massive planets (IRIS, PFI).

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

Lynette Cook

TMT Solar System Capabilities

- Spatial resolution (25 km at Jupiter) comparable to space probes (at least in outer solar system)
- Spectral resolution (0.3 - 30 micron) much higher than space probes
- Sensitivity ~ JWST, ALMA
- Good temporal monitoring possible to observe variable phenomena (atmosphere and surface)
- Short time scale to respond to transient and unpredictable events
- IRIS will detect a 1 km TNO at 50 AU in 15 min.
- Precision astrometry (< 50 uas)
- Precision radial velocities (< 1 m/s)



Europa at the resolution of TMT adaptive optics (M. Brown, CIT)

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