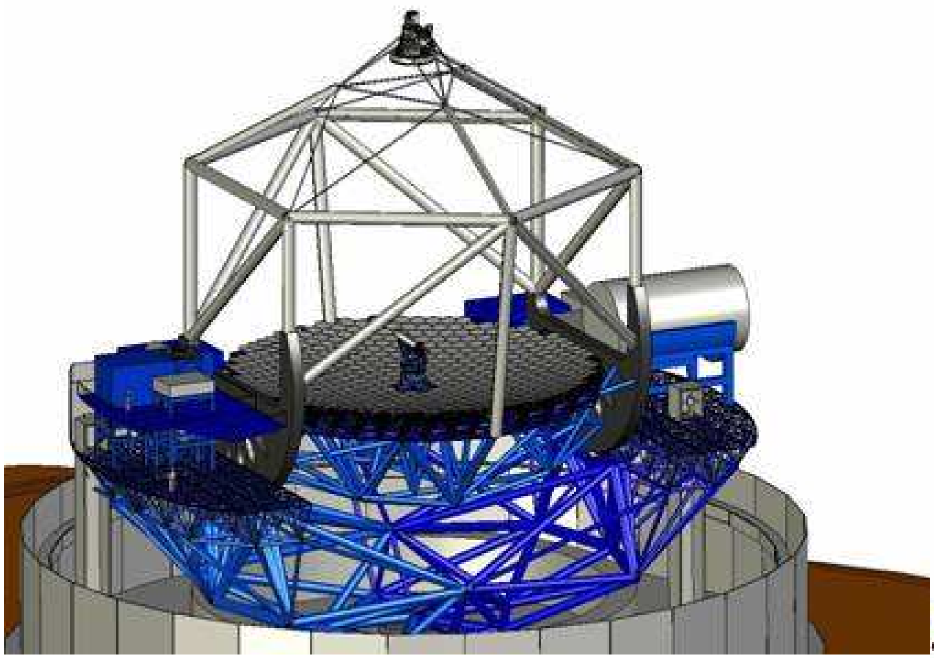
TMT

THIRTY METER TELESCOPE

The TMT: A Giant with an Appetite

T. J. Davidge, HIA

August 25, 2011



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Acknowledgments

Thanks to the following people for contributing material and slides for this presentation:

- David Crampton
- Pat Cote
- Christian Veillet
- Glen Herriot
- David Andersen
- Gary Sanders

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Outline

1. TMT 101
2. First Generation Instrumentation and Selected Science Examples
3. Feeding the TMT

TMT
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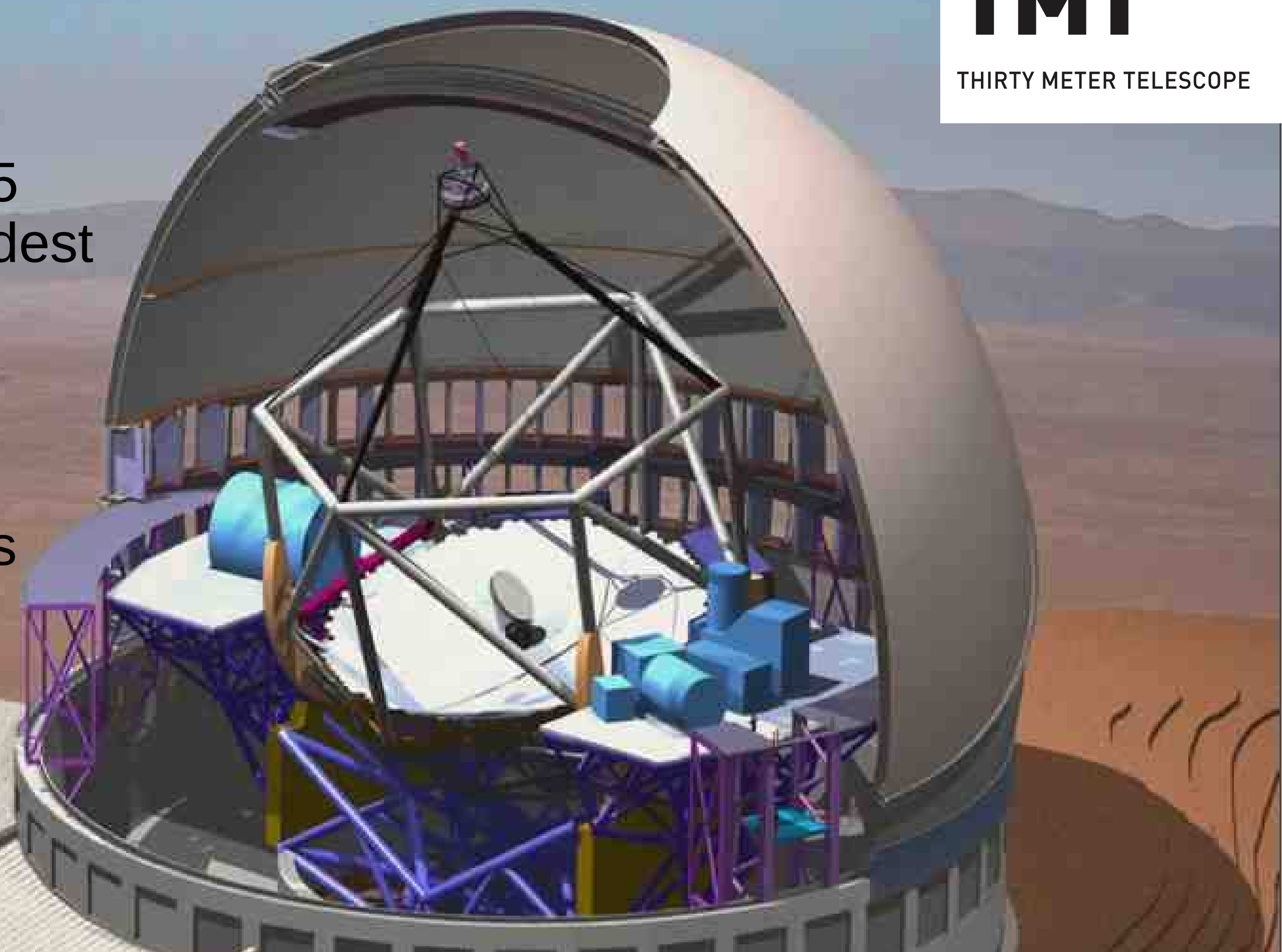
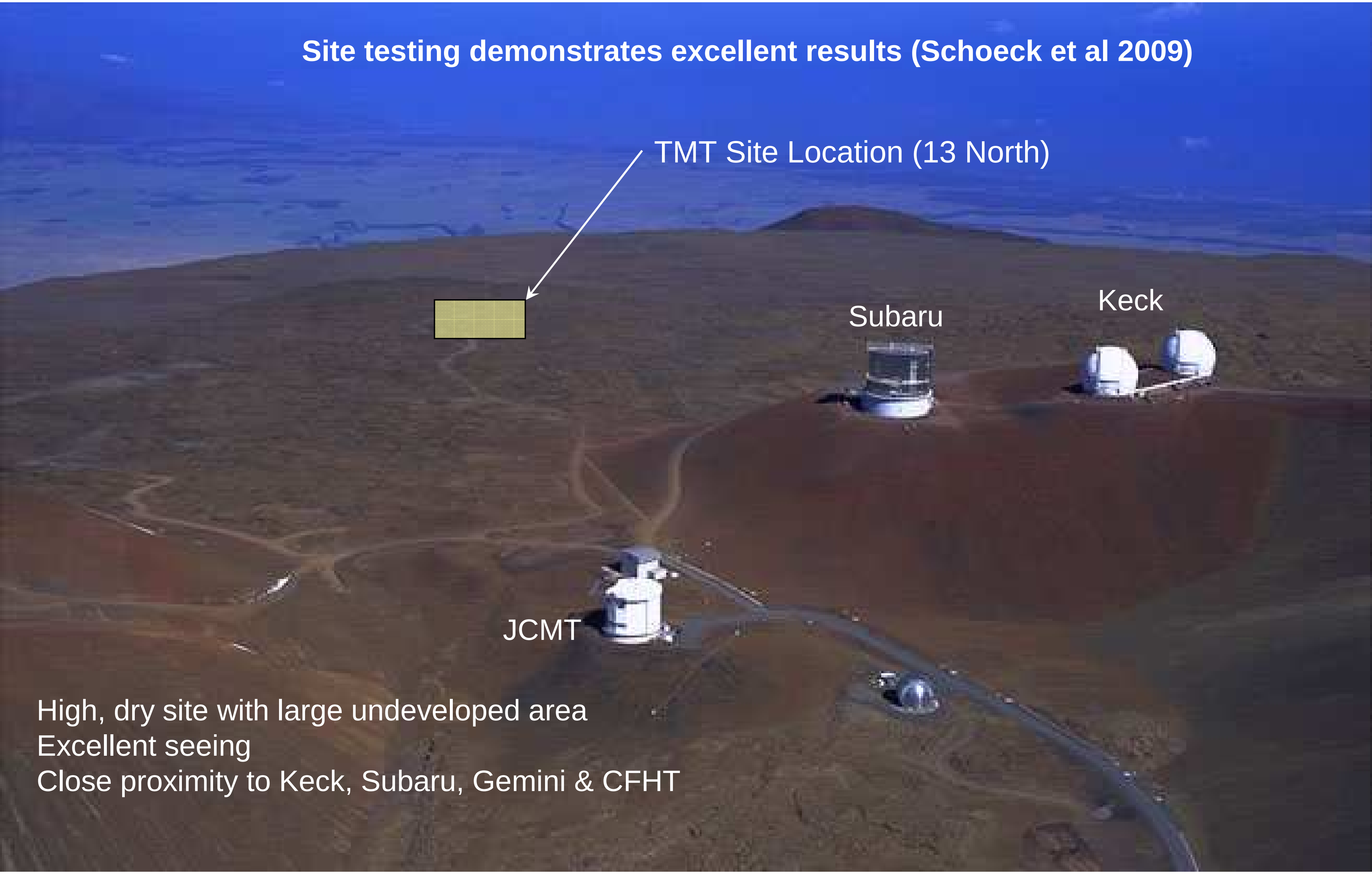
- 30m filled aperture, highly segmented, RC telescope
- f/1 primary
- Unvignetted field of view 15 arcmin; 20 arcmin with modest vignetting.
- Instruments mounted on Nasmyth platform
- Wavelength 0.31 – 28 µm
- Seeing-limited + AO modes



The TMT is a collaboration of:

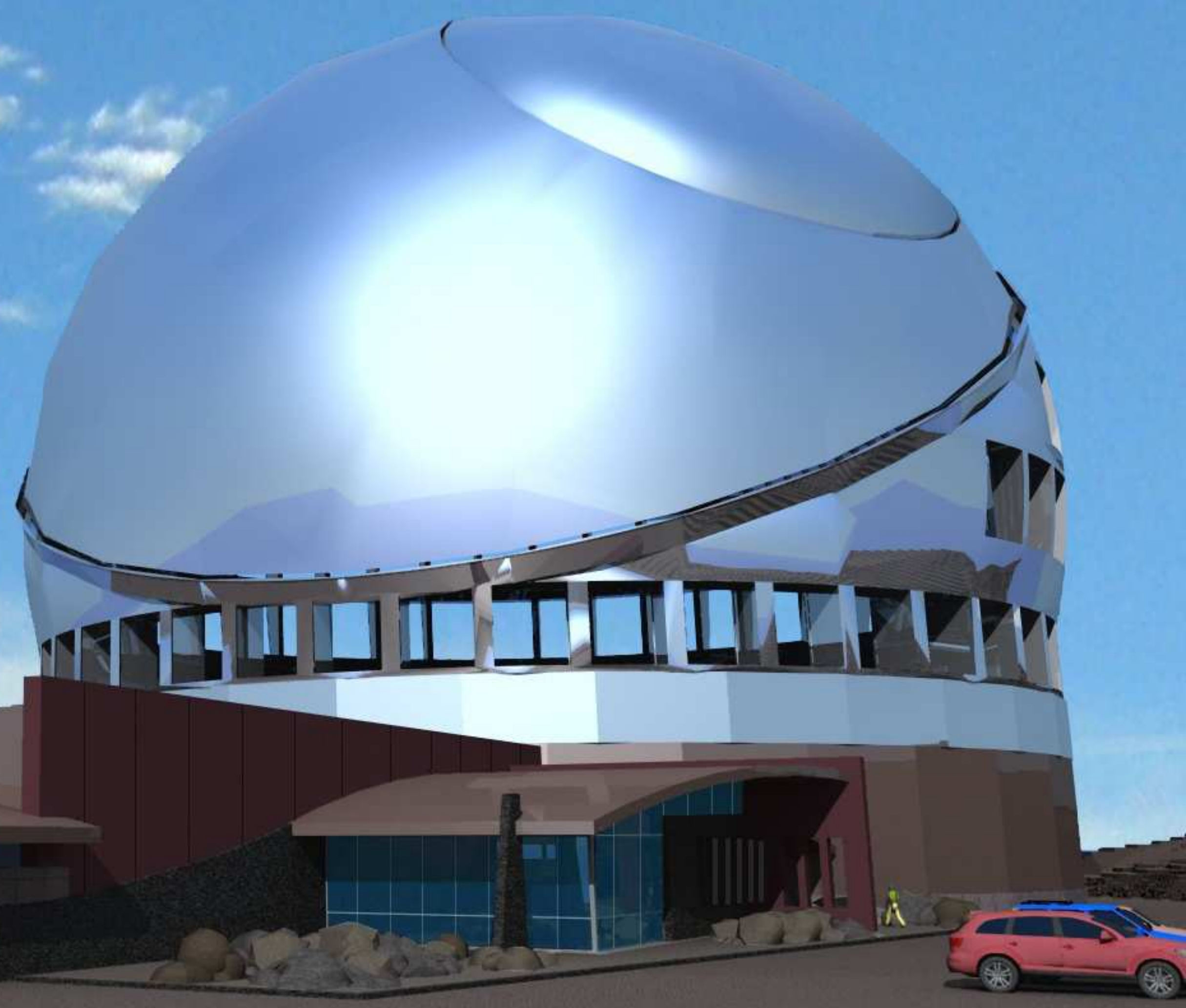
- –The Association of Canadian Universities for Research in Astronomy (**ACURA**)
- –The **University of California**
- –The **California Institute of Technology**
- – **National Astronomical Observatory of Japan** (participant)
- – **National Astronomical Observatories of the Chinese Academy of Sciences** (observer)
- – **Department of Science and Technology of India** (observer)

TMT Site – Mauna Kea 13 North



Calotte-Type Enclosure

- Excellent overall performance
- Structurally efficient
- Small (66m diameter)
- Energy efficient
- Minimizes visual impact



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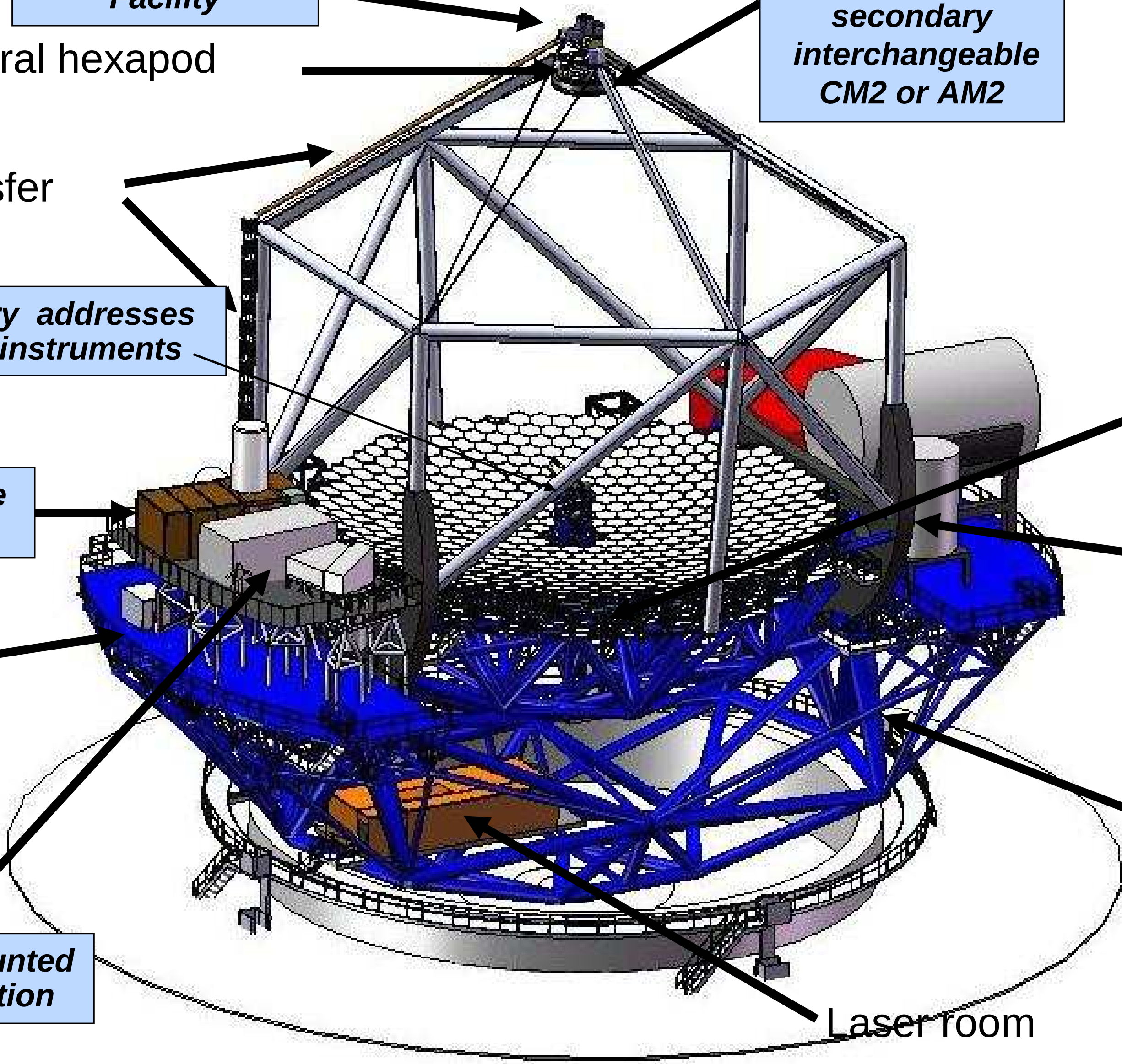
Telescope Layout



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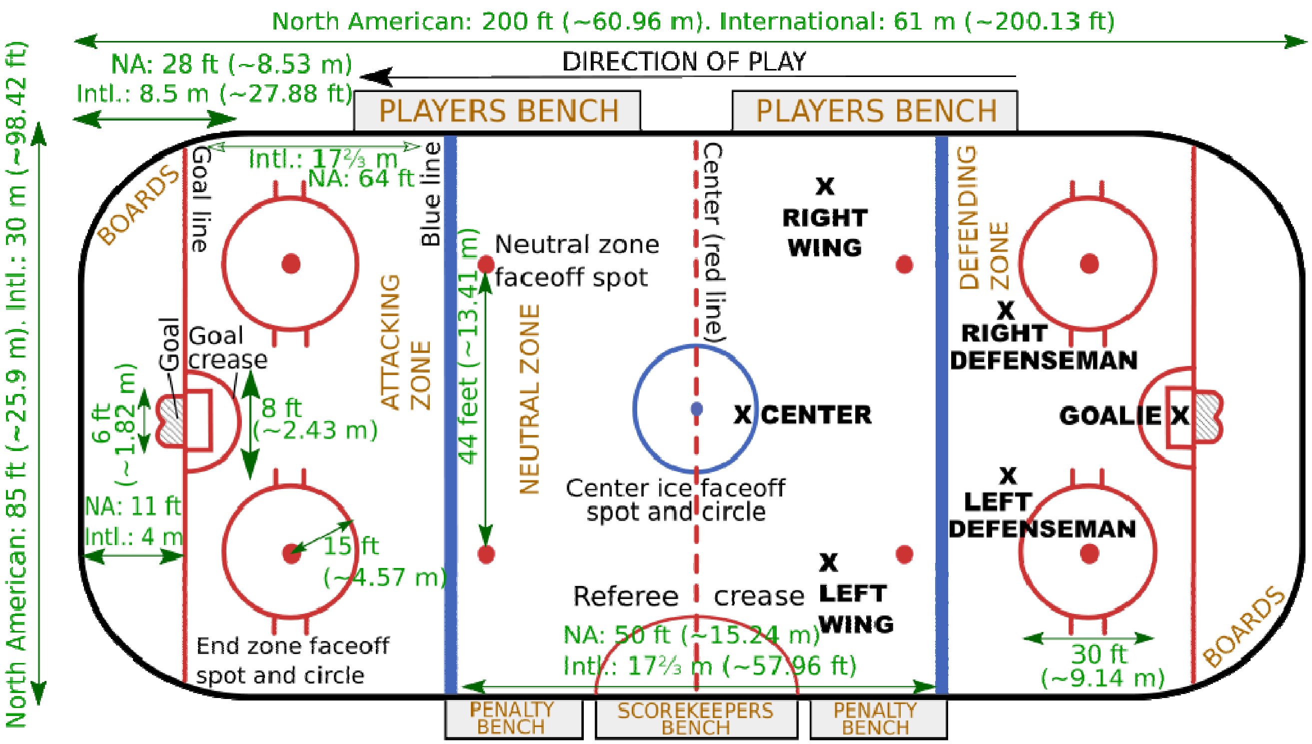
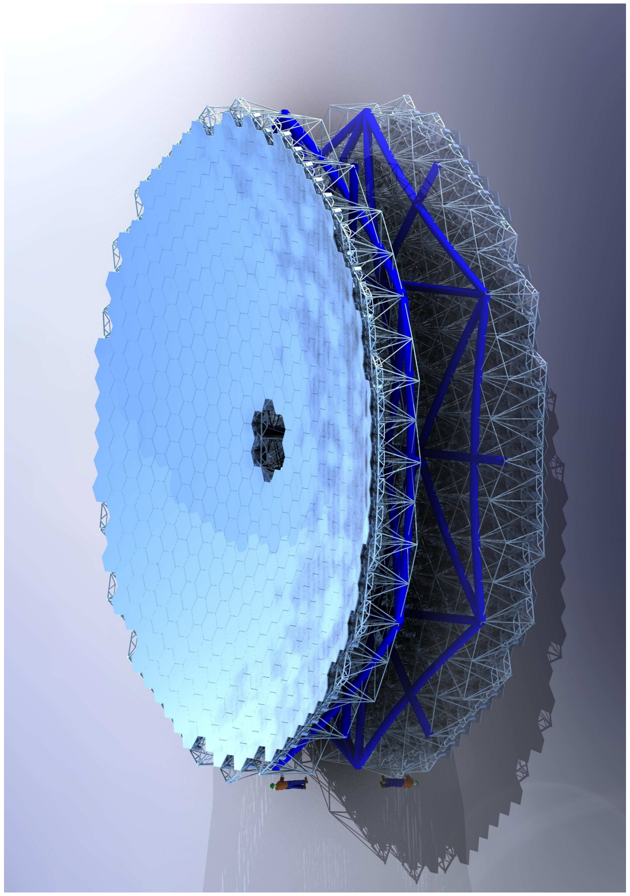
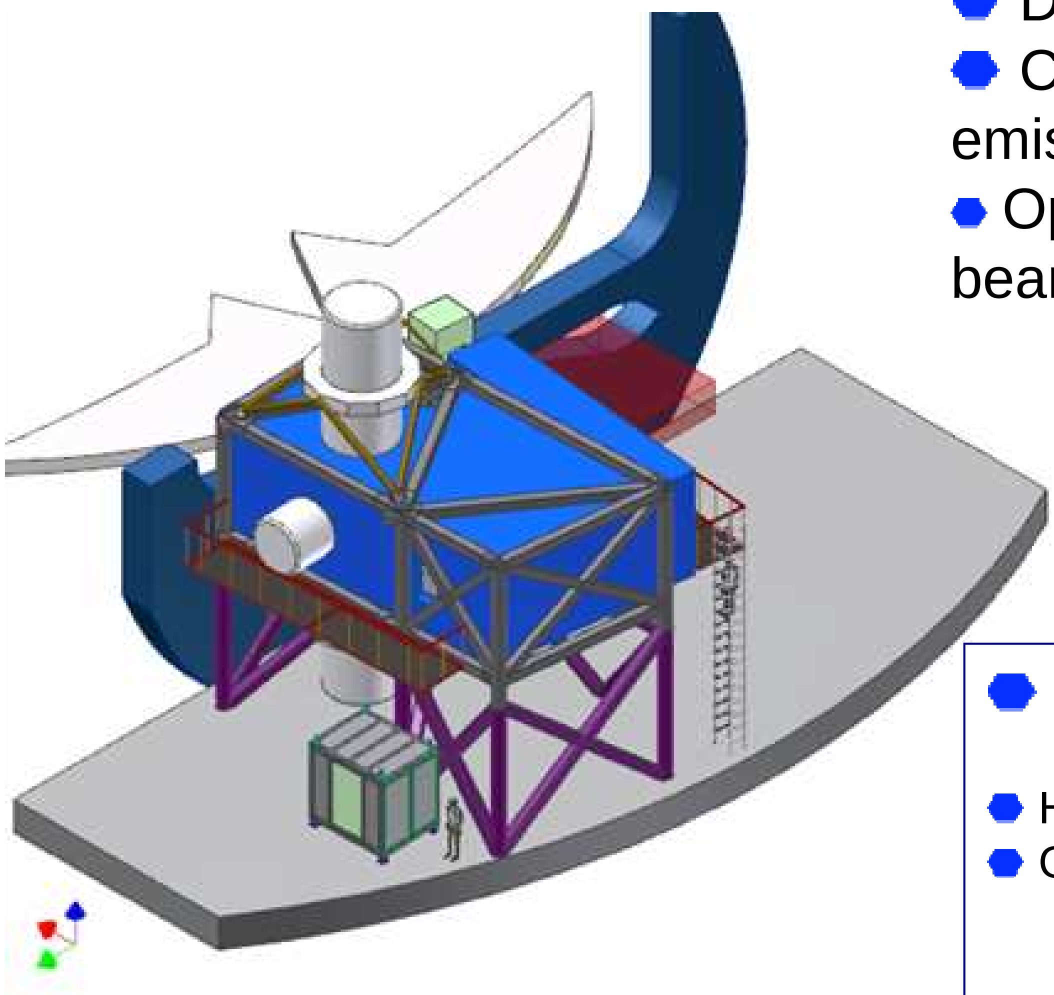
The TMT Primary Mirror in Perspective





Narrow-Field IR AO System (NFIRAOS)



- Dual conjugate AO system
- Cooled to -30C to prevent elevating emissivity
- Optically efficient: 7 reflections + one beam splitter + window

- Completely integrated system
  - Fast (<5 min) switch between targets
- High sky coverage, even at galactic poles
- Good performance over 2' field
  - VLT/MAD and Gemini/Gems results demonstrate MCAO potential

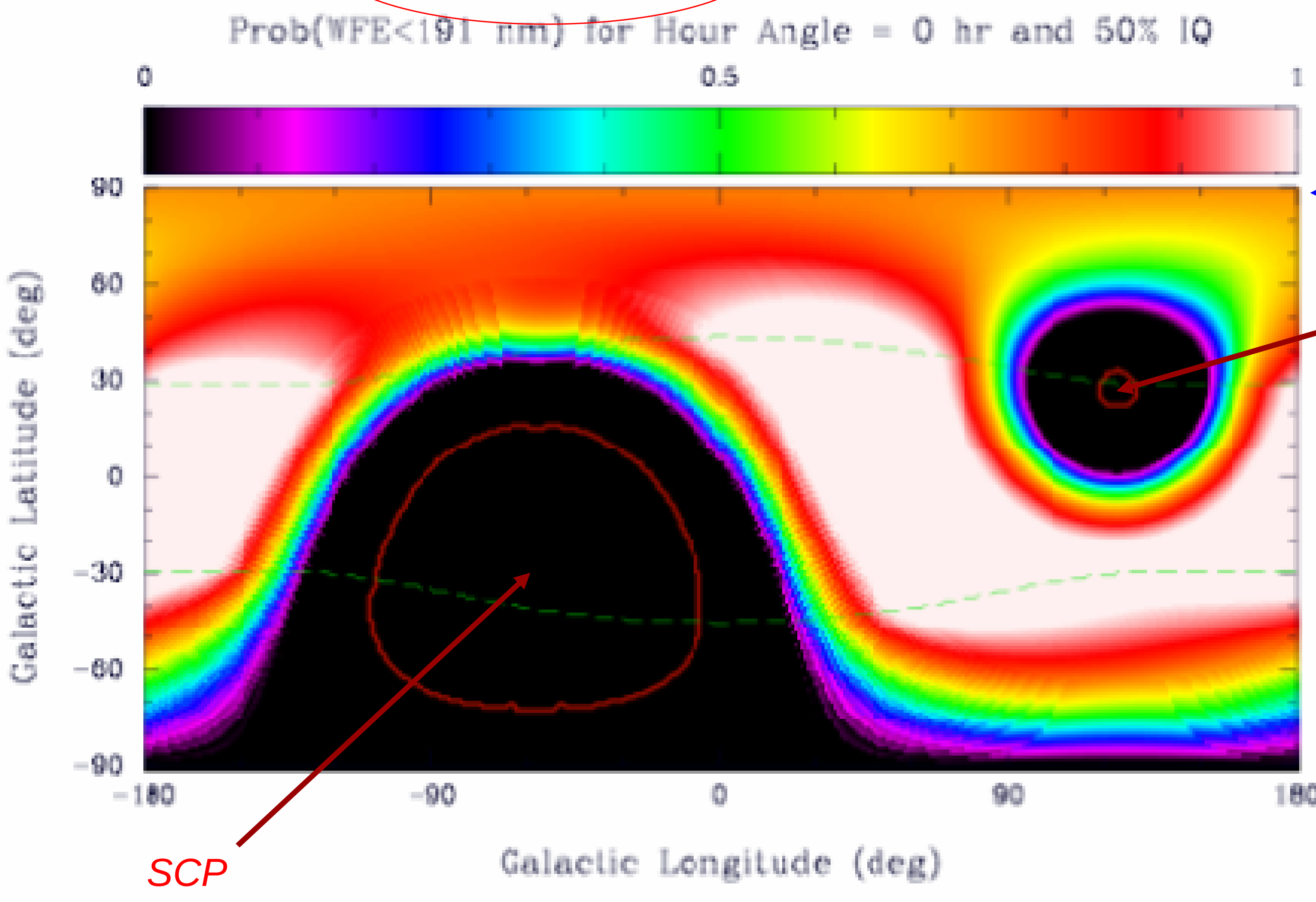
NFIRAOS Top-Level Requirements

- **Throughput** 80%, 0.8 to 2.5 μm
- **Background** Thermal emission < 15 % of sky and telescope
- **Wavefront Error** 187 nm RMS on-axis, and 191 nm on a 10” FoV *(Strehls ~ 0.8 in K, and 0.6 in H)*
- **Sky coverage** 50 % at the Galactic pole
- **Differential photometry** 2% for a 2 minute exposure on a 30” FoV at $\lambda = 1$ μm
- **Differential Astrometry** 50 μas for a 100 s exposure on a 30” FoV in the H band
- **Available** from **standby** <10 minutes
- **Acquire** a new field < 5 minutes
- **Downtime** < 1 per cent unscheduled

Sky Coverage: Prob(191 nm WFE) vs. Galactic Latitude & Longitude

S = 0.77 (K), 0.57 (H)

- Probability 191 nm WF error, 17” Field, hour angle = 0



Galactic pole

NCP

>7500 stars per square degree

65 deg. Zenith observing limit

SCP

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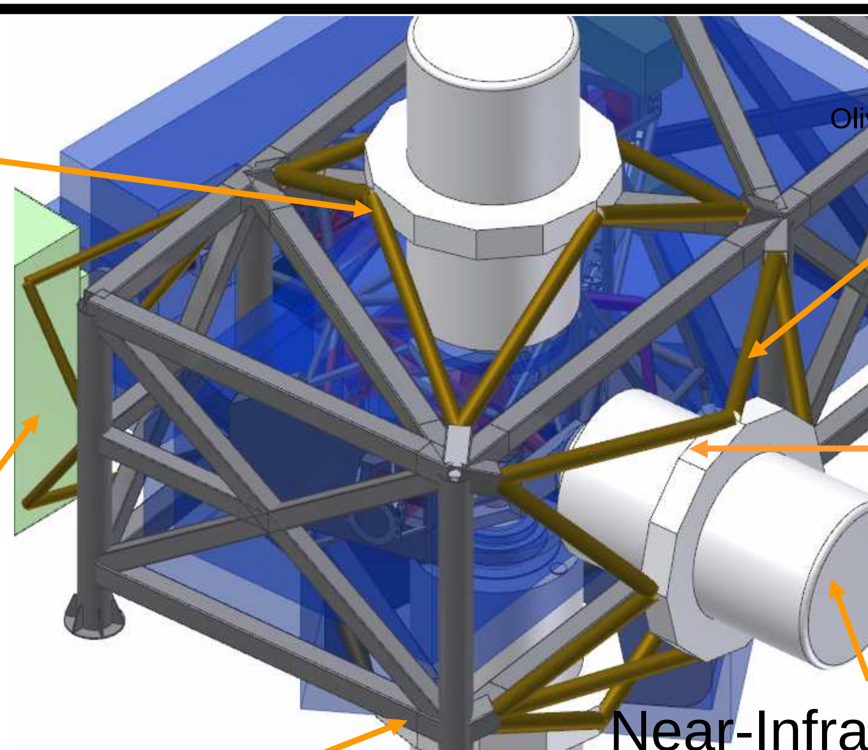
NFIRAOS Client Instruments



Olive Trusses supplied by Instruments

Instrument rotator

NSCU: Science Calibration Unit

InfraRed Multi-Slit Spectrometer (IRMS, early light)

- Rest-frame optical properties of high-redshift galaxies
- Metal-free star formation in the Early Universe

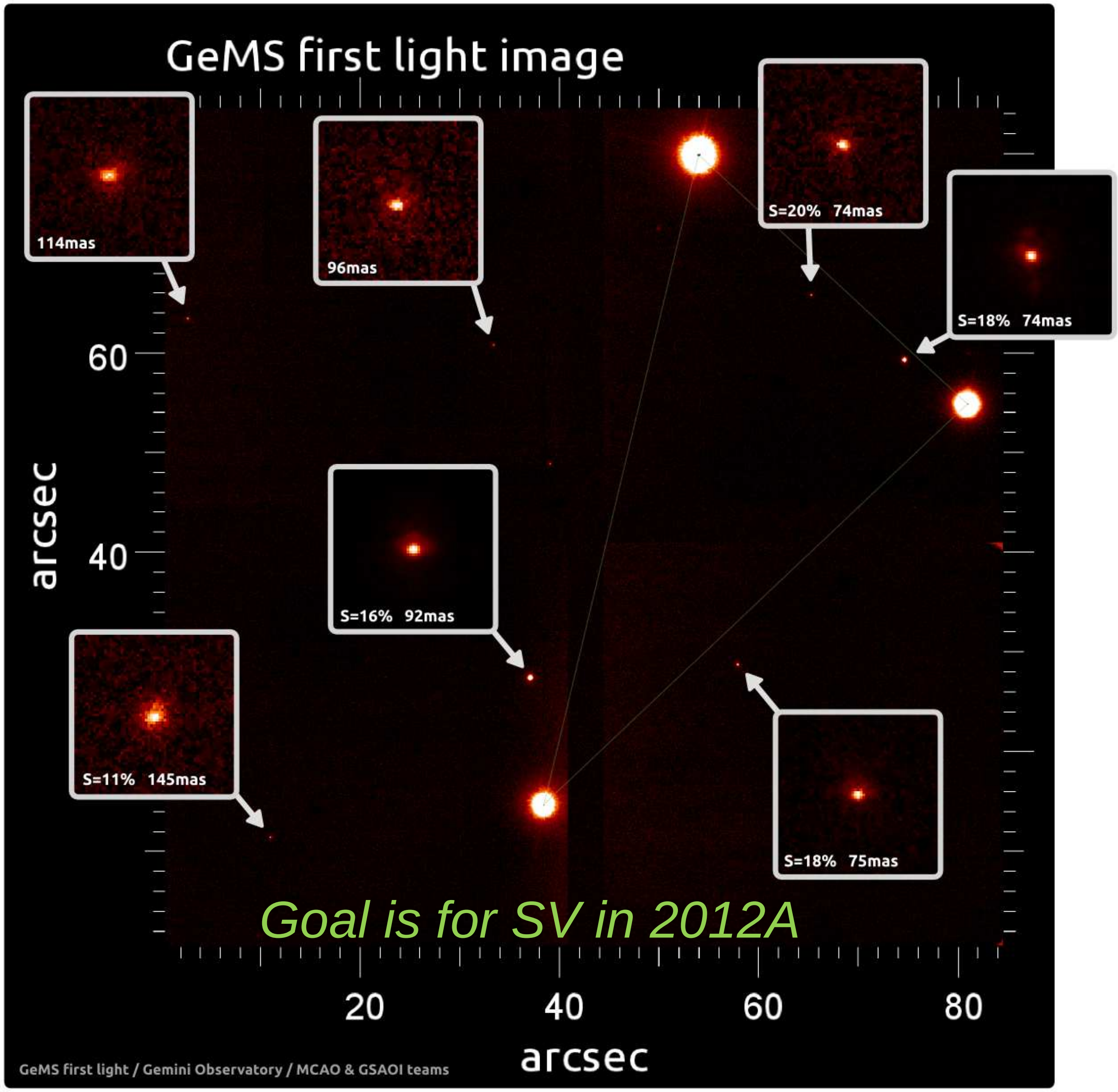
InfraRed Imaging Spectrometer (IRIS, early light) Lenslet/slicer IFU + imager

- Tests of General Relativity
- Supermassive black holes
- First Light Objects

Near-InfraRed Echelle Spectrometer (NIRES, 1st Decade)

- IGM at $z > 7$
- Exoplanet atmospheres
- Composition of comets

GEMS First Light Image



Goal is for SV in 2012A

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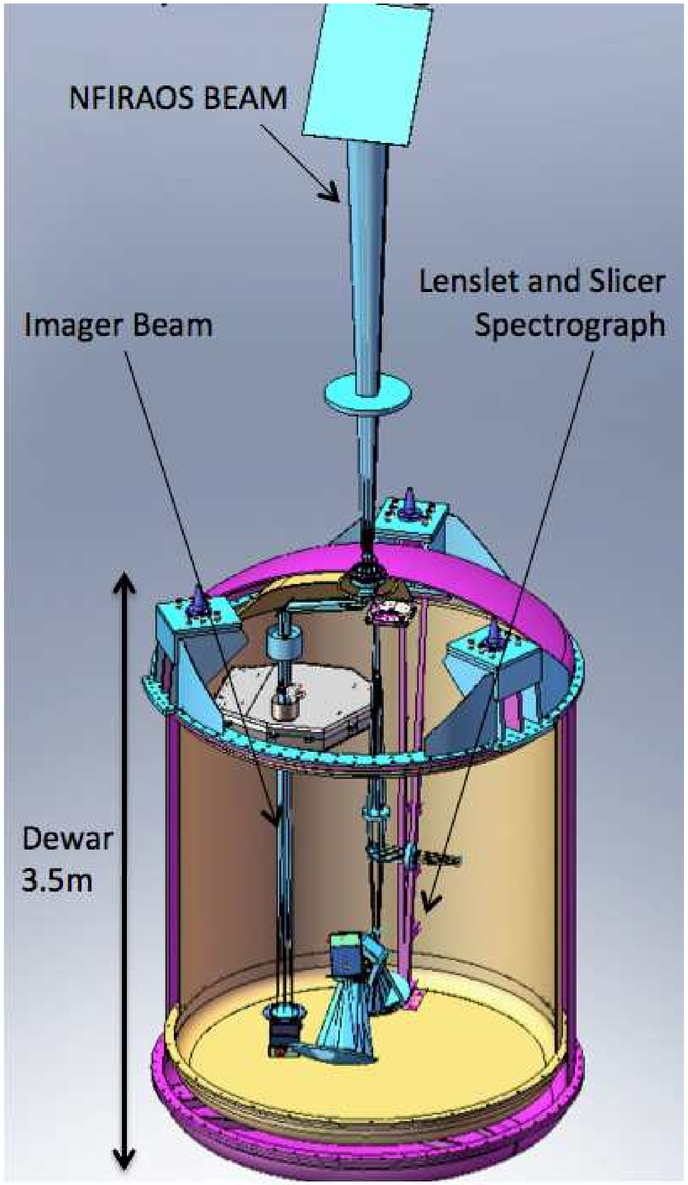
TMT First Decade Instruments

Early Light Instruments

Instrument	λ (μm)	Field of view/ Slit length	Spectral resolution	Science Cases
InfraRed Imager and Spectrometer (IRIS)	0.8 – 2.5 0.6 – 5 (goal)	<3″ IFU >15″ imaging	> 3500 5-100 (imaging)	• Assembly of galaxies at high z • Black holes/AGNs/Galactic Center • Resolved stellar populations in crowded fields
Wide-field Optical spectrometer and imager (WFOS)	0.31 – 1.0	>40 arcmin^2 >100 arcmin^2 (goal) Slit length>500″	1000-5000@0.75″ slit >7500 @0.75″ (goal)	• IGM structure and composition at 2 < z < 6 • Stellar populations, chemistry and energetics of z > 1.5 galaxies
InfraRed Multislit Spectrometer (IRMS)	0.95 – 2.45	2 arcmin field, up to 120″ total slit length with 46 deployable slits	R=4660 @ 0.16 arcsec slit	• Early Light • Epoch of peak galaxy building • JWST follow-ups
Deployable, multi-IFU, near-IR spectrometer (IRMOS)	0.8 – 2.5	3″ IFUs over >5′ diameter field	2000-10000	• Early Light • Epoch of peak galaxy building • JWST follow-ups
Mid-IR AO-fed Echelle spectrometer (MIRES)	8 – 18 4.5 – 28 (goal)	3″ slit length 10″ imaging	5000-100000	• Origin of stellar masses • Accretion and outflows around protostars • Evolution of gas in protoplanetary disks
Planet Formation Instrument (PFI)	1 – 2.5 1 – 5 (goal)	1″ outer working angle, 0″.05 inner working angle	R≤100	• 10^8 contrast ratio (10^9 goal) • Direct detection and spectroscopic characterization of exoplanets
Near-IR AO-fed echelle spectrometer (NIRES)	1 - 5	2″ slit length	20000-100000	• IGM at z > 7, gamma-ray bursts • Local Group abundances • Abundances, chemistry and kinematics of stars and planet-forming disks • Doppler detection of terrestrial planets around low-mass stars
High-Resolution Optical Spectrometer (HROS)	0.31 – 1.1	5″ slit length	50000	• Doppler searches for exoplanets • Stellar abundance studies in Local Group • ISM abundance/kinematics • IGM characteristics to z~6
"Wide"-field AO imager (WIRC)	0.8 – 5.0	30″ imaging field	5-100	• Precision astrometry (e.g., Galactic Center) • Resolved stellar populations out to 10 Mpc

IRIS: Diffraction Limited Imager and Integral Field Spectrograph

- Imager 17”x17”, 4 mas pixels
  - Precision photometry
  - 30 µarcsec relative astrometry
- Lenslet IFS
  - 128 x 128 lenses
  - Bandpass: 5%/exposure
  - Finest scales (4, 9 mas)
- Slicer IFS
  - 45 slices, field up to 2”x4”
  - 25, 50 mas scales
  - Best sensitivity
- IFSs share common spectrograph and detector



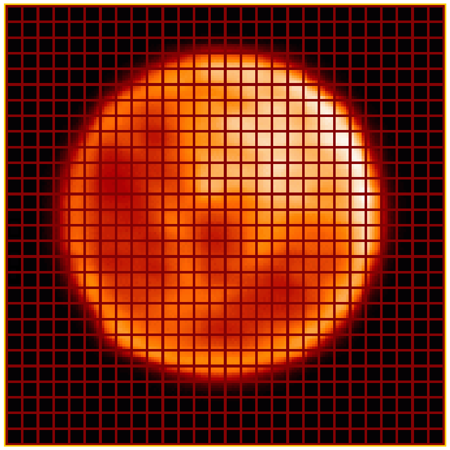
The Sharp Science Vision of IRIS

- Should be the most sensitive astronomical IR spectrograph ever built
- Unprecedented ability to investigate objects on small scales.

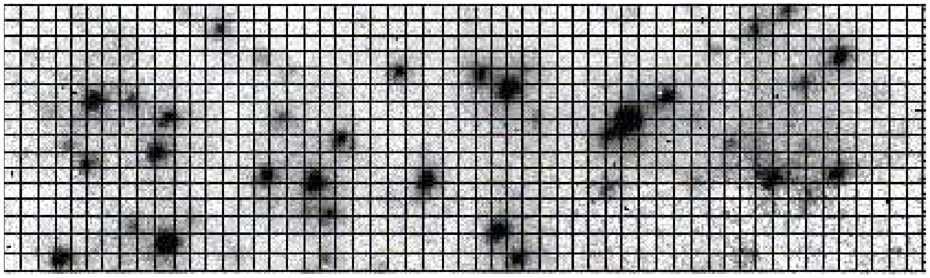
0.01" @	5 AU	= 36 km	(Jovian's and moons)
	5 pc	= 0.05 AU	(Nearby stars – companions)
	100 pc	= 1 AU	(Nearest star forming regions)
	1 kpc	= 10 AU	(Typical Galactic Objects)
	8.5 kpc	= 85 AU	(Galactic Center or Bulge)
	1 Mpc	= 0.05 pc	(Nearest galaxies)
	20 Mpc	= 1 pc	(Virgo Cluster)
	z=0.5	= 0.07 kpc	(galaxies at solar formation epoch)
	z=1.0	= 0.09 kpc	(disk evolution, drop in SFR)
	z=2.5	= 0.09 kpc	(QSO epoch, Hα in K band)
	z=5.0	= 0.07 kpc	(protogalaxies, QSOs, reionization)

λ/D in H

Equivalent to seeing-limited resolution in the LG

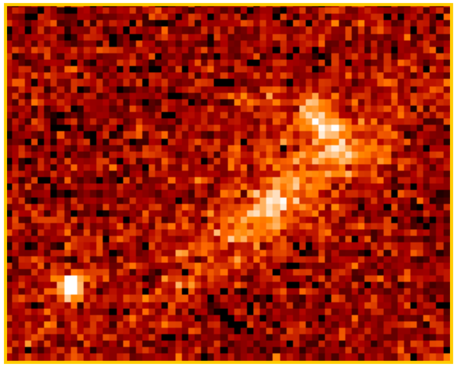


Titan with an overlayed 0.05'' grid (~300 km) (Macintosh et al.)



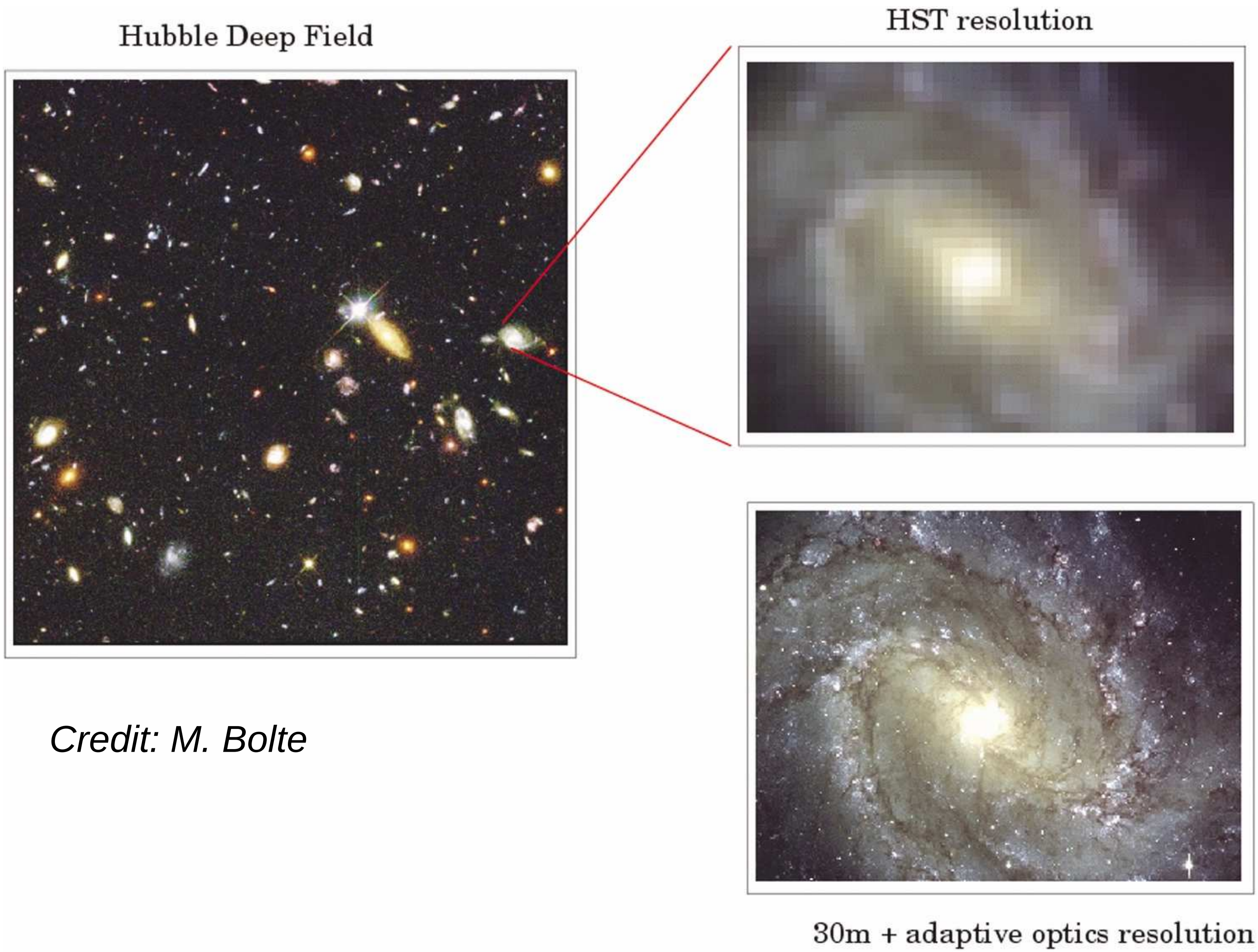
M31 Bulge with 0.1" grid (Graham et al.)

Keck AO images



High redshift galaxy. Pixels are 0.04" scale (0.35 kpc).Barczys et al.)

Distant Galaxies and the TMT



Credit: M. Bolte

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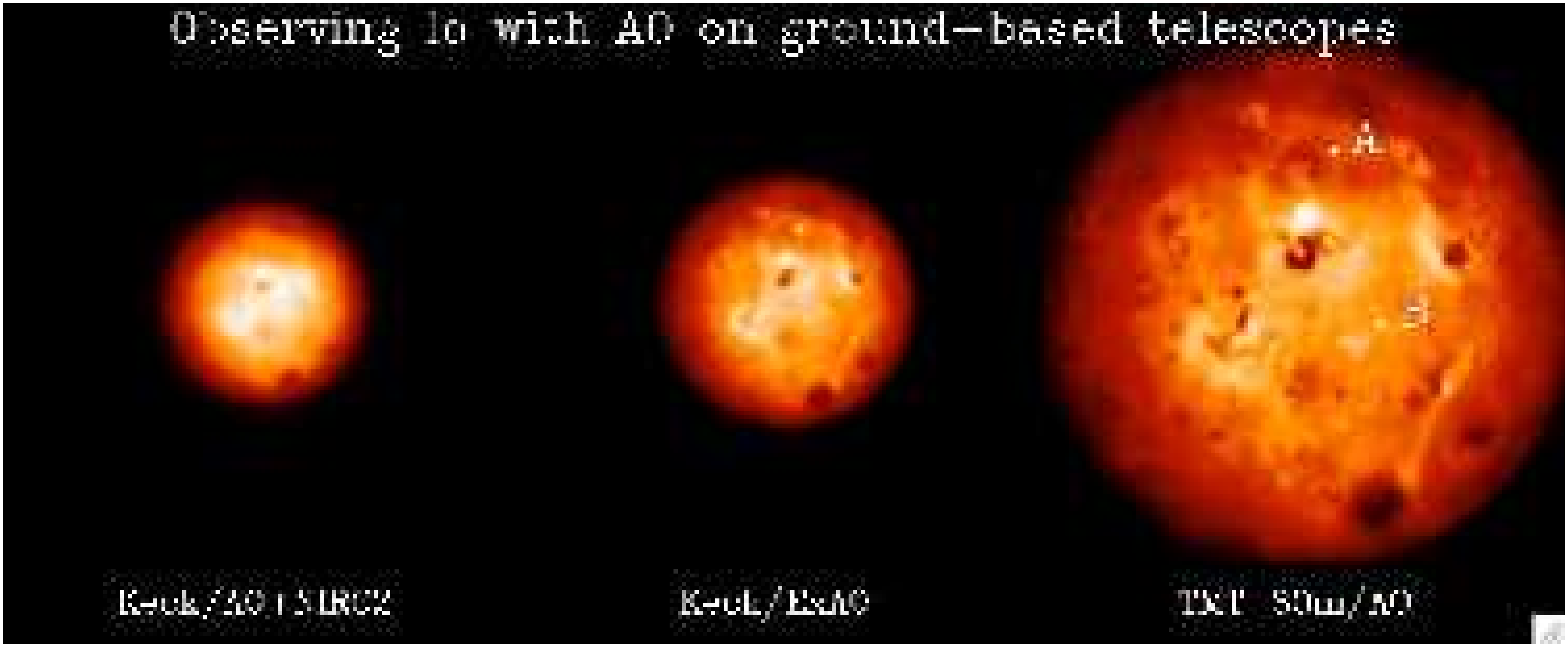
Io with TMT/IRIS

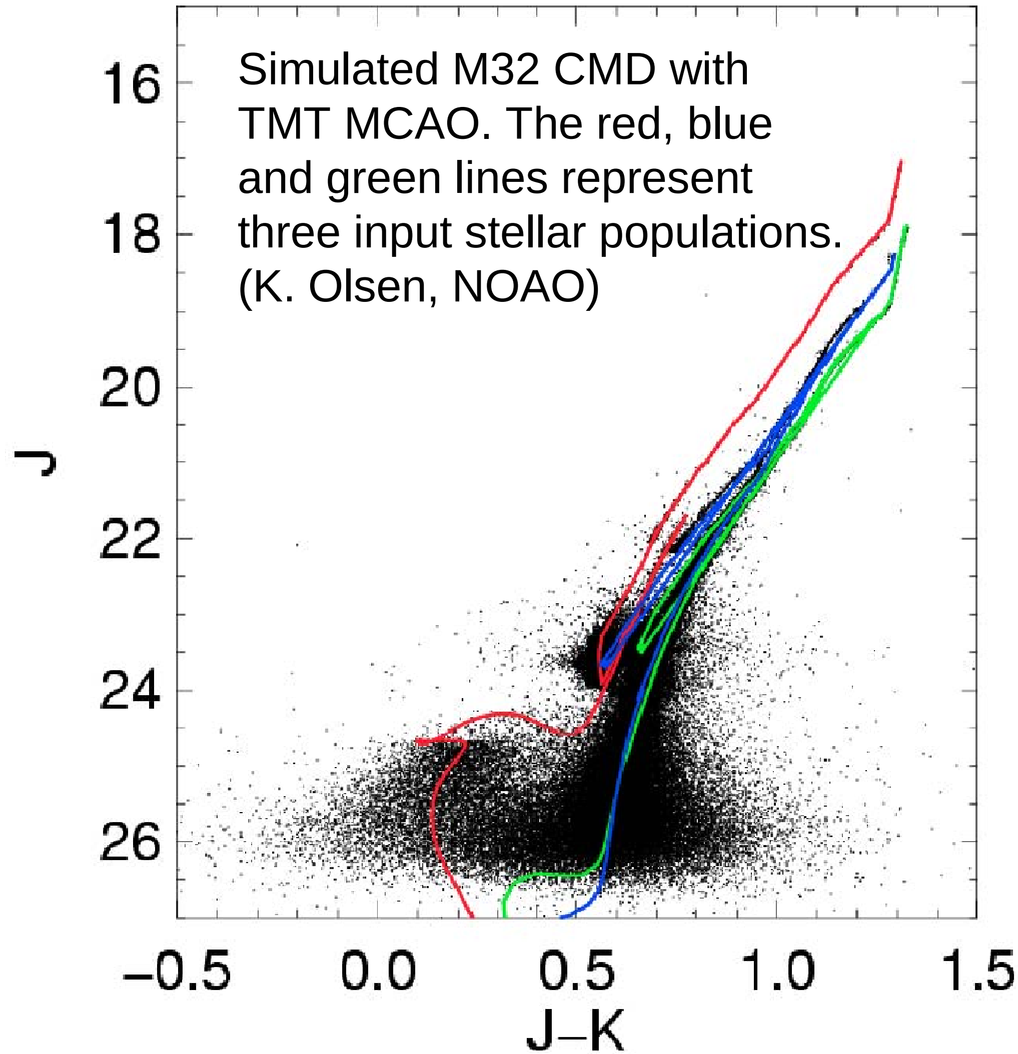


Simulations of Io Jupiter-facing hemisphere in H band. (courtesy of Franck Marchis, UC Berkeley/SETI)

TMT resolution at 1µm is 7 mas = 25 km at 5 AU (Jupiter)
(0.035 AU at 5 pc, nearby stars)

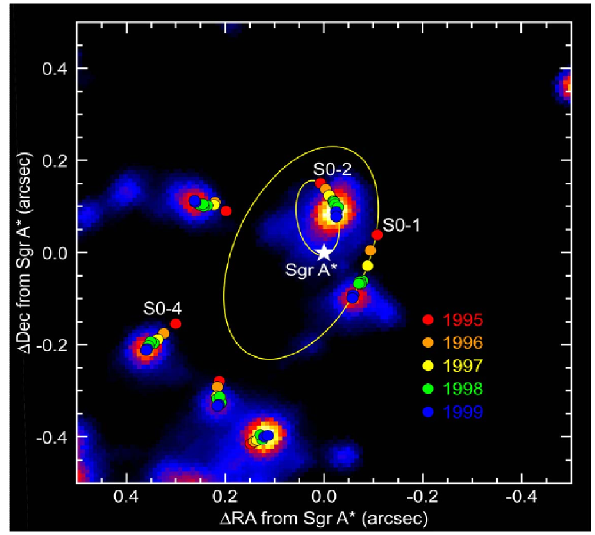
IRIS: Stellar Populations in the Local Universe

- *TMT will determine the star formation history in galaxies out to the Virgo cluster:*
  - Adaptive optics will allow photometry of resolved stellar populations in crowded fields.
  - This will give star-formation history and metallicity in a wide range of environments.
  - Complementary to high-z galaxy studies. The picture of galaxy evolution deduced from nearby galaxies should be consistent with that from distant galaxies.
  - Follow-up IRIS, IRMS, WFOS and HROS spectroscopy will provide element abundances for galaxies within a few Mpc.

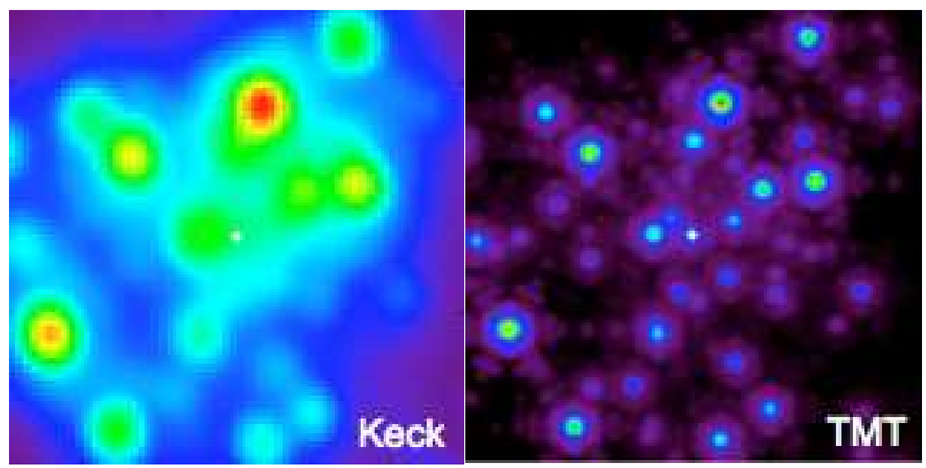


IRIS: The Galactic Centre

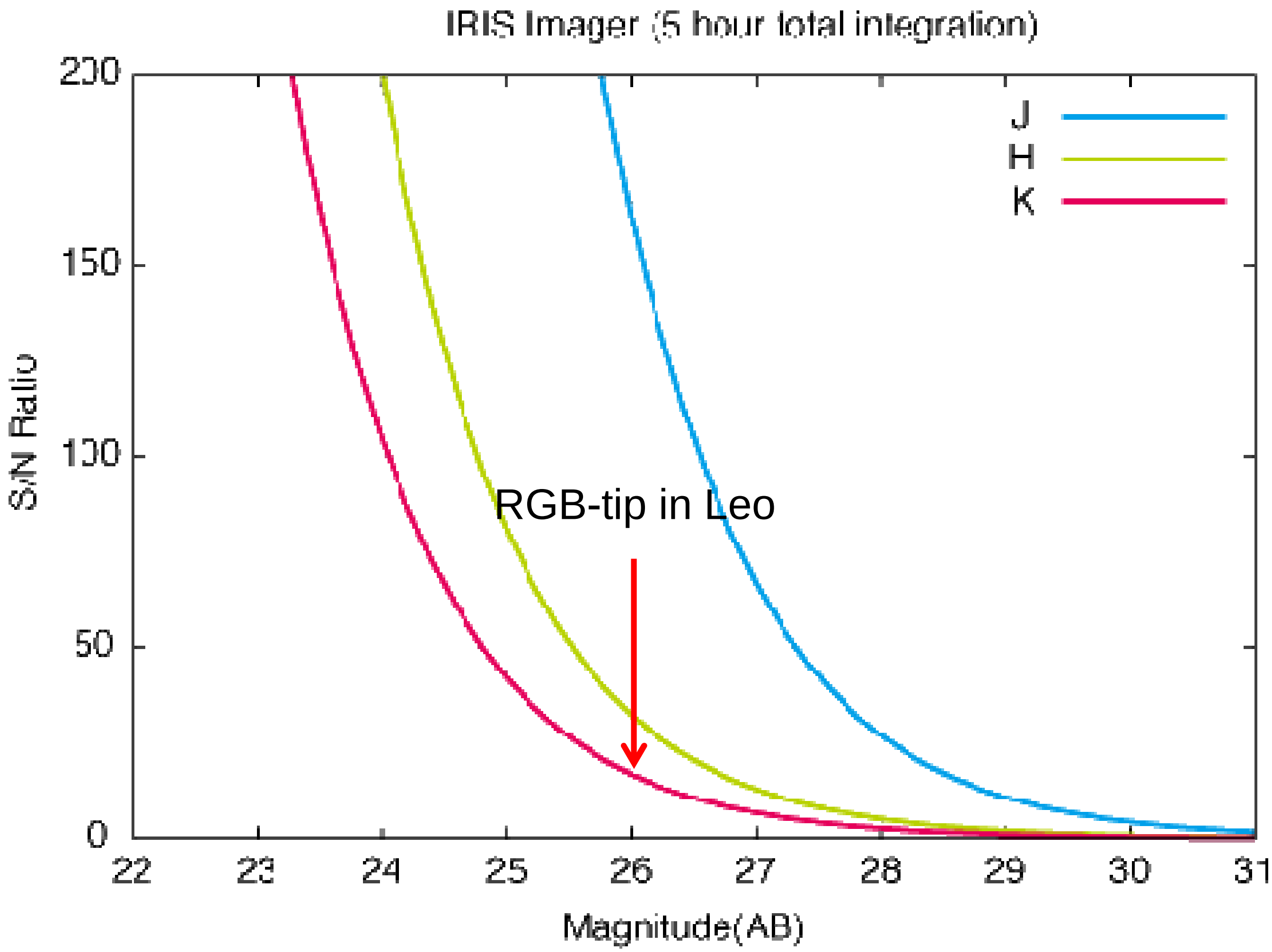
- TMT/IRIS will map stellar orbits in the galactic center with precision ~30 μas to probe the gravitational potential, study the nature of dark matter on small scales, and measure general-relativistic effects.
- The dynamics of stars throughout the entire SgrA complex will provide insights into the origins of the star-forming material.
- TMT will 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.



A. Ghez, UCLA



D^4 In Action on the TMT

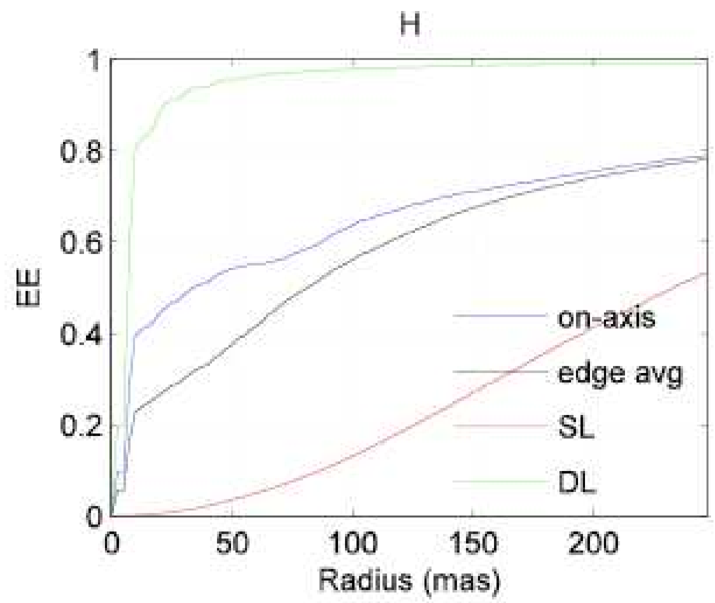


From www.tokoku-archives.org

IR Multi-Slit Spectrometer (IRMS)

•=> IRMS: **clone** of Keck MOSFIRE, first step towards IRMOS

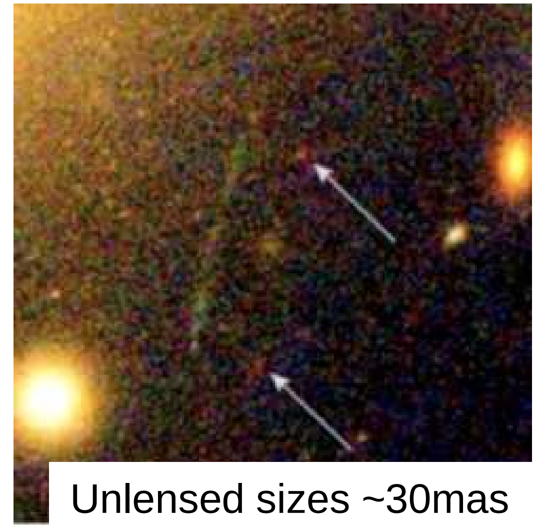
- Multi-slit NIR imaging spectrograph
- 46 slits
  - Slit widths of160+ mas, and lengths of 2.5”
- **Deployed behind NFIRAOS**
  - Images the entire 2’ field
- Spectral resolution up to 5000
- Full Y, J, H, K spectra (one at a time)



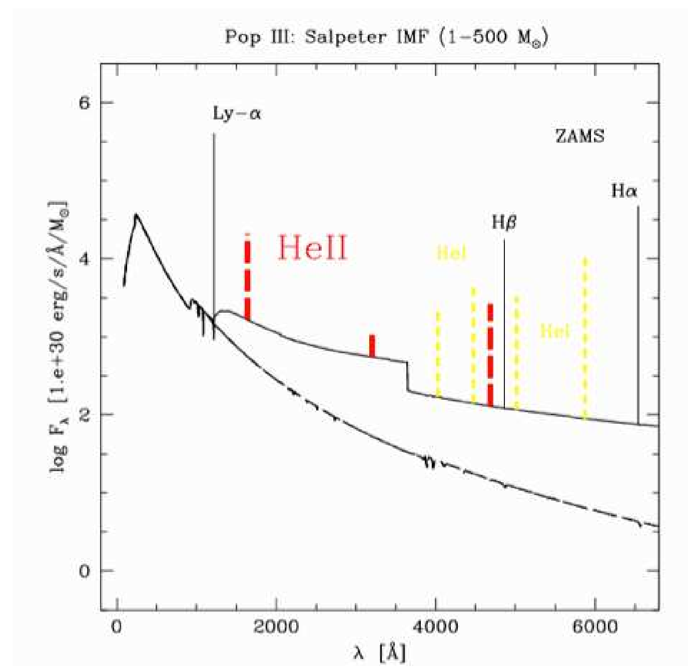
Whole 120” field

A Key IRMS Project: Exploring the Early Universe

- Early Sources and cosmic reionization
  - Synergy with JWST and 21cm surveys: Expect JWST to detect brightest sources in each ionized bubble. TMT, with AO, should go 1 mag fainter (or more if objects are physically small)
- TMT IRIS, IRMS and NIRES will study detailed properties of first galaxies and influence on IGM
  - Pop III stars (intense HeII 1640)
  - Tracing SF (Ly Alpha) in ionized bubbles
  - Escape fraction from Ly alpha profiles
  - IGM at z > 7 using quasars or GRBs



Unlensed sizes ~30mas



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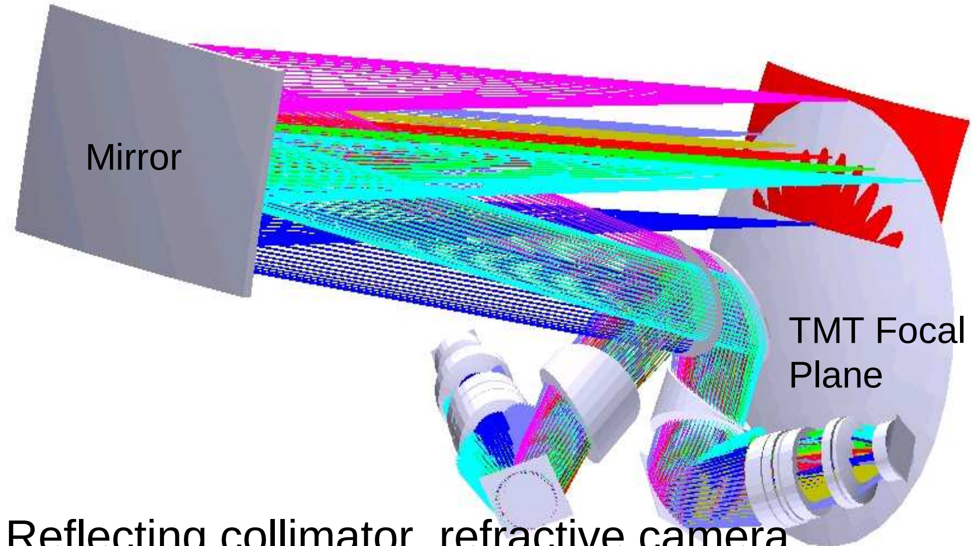
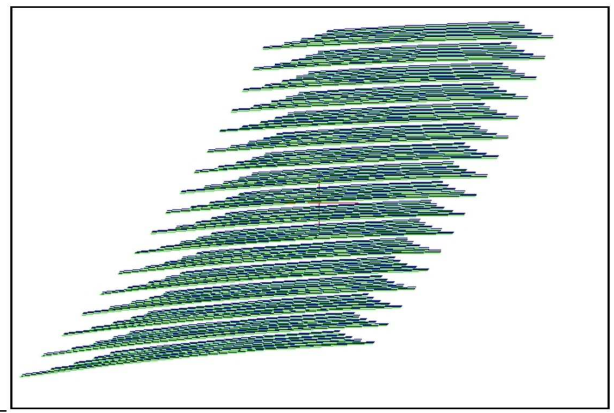
Wide Field Optical Spectrograph
Seeing-limited, 0.3-1μm

- Only seeing-limited, optical capability for ~ first 5 years
  - A workhorse instrument, designed for discovery, characterization, and survey science
  - Anticipate heavy usage, given experience with equivalent instruments on 8-10 meter telescopes.
  - Will be sole `Poor IQ' capability for first few years.
- Echellette design
  - Full wavelength coverage
    - Blue and Red channels
  - R ~1000 - 8000
  - 9' x 4' field



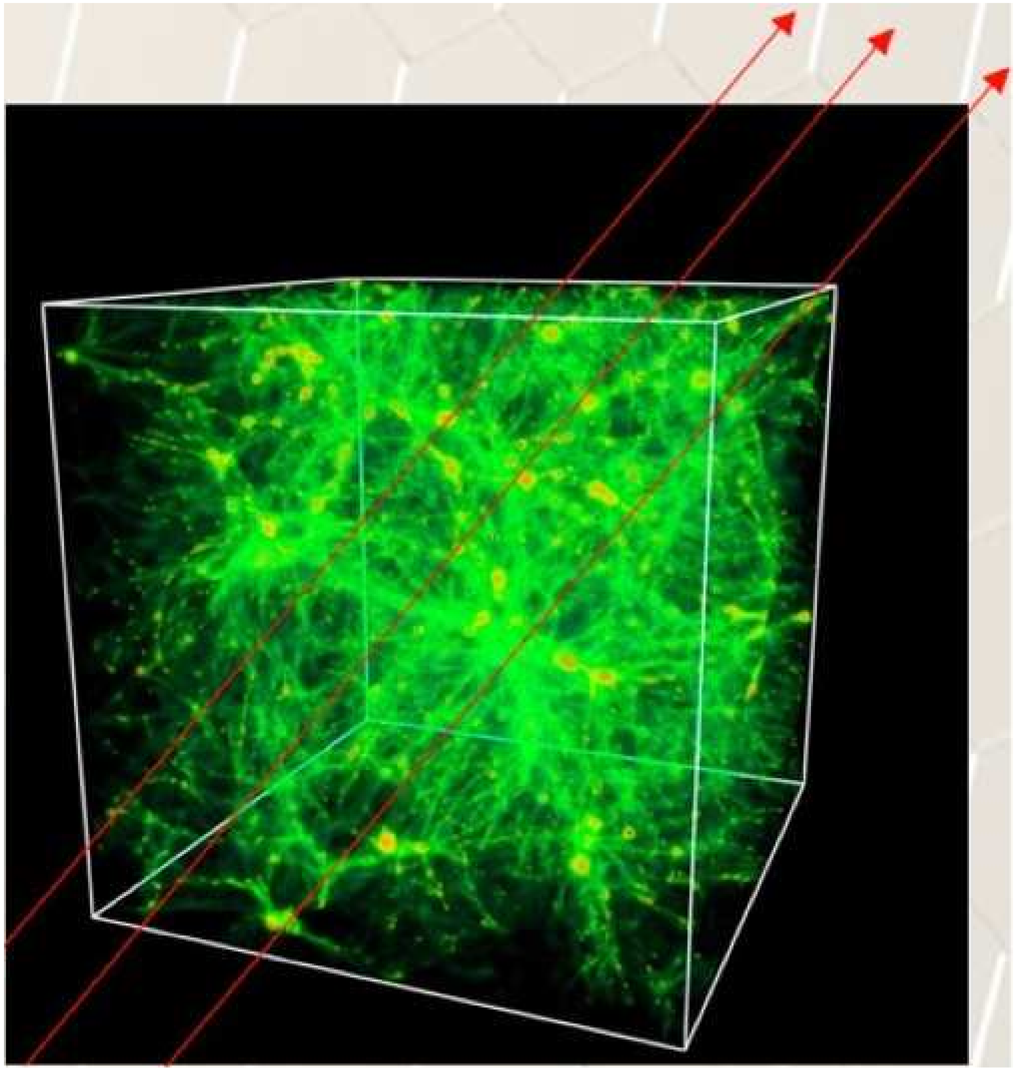
Reflecting collimator, refractive camera
Prism cross dispersion



Spectral footprint in higher dispersion mode - 3'' slits spaced 25'' apart, five orders

WFOS-MOBIE can trade multiplexing for expanded wavelength coverage in its higher dispersion mode

WFOS: IGM Tomography



(R. Cen, Princeton U.)

The SFH of the Universe suggests that the gas reservoirs of galaxies are replenished throughout their lifetimes, probably from the inflow of material along filaments.

Given that TMT+WFOS will perform spectroscopy down to R_{AB} = 24.5 mag with a spectral resolution of 5000 and S/N≥30, background UV-bright galaxies will then become usable beacons, and the surface density of sightlines on the sky for intergalactic medium tomography will be ~200x higher than currently observable with 8-10m class telescopes.

This means that one will be able to probe *individual* galaxy haloes through multiple sightlines

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? → "Wide"-field AO imager (WIRC)	0.8 – 5.0	30″ imaging field	5-100	• Precision astrometry (e.g., Galactic Center) • Resolved stellar populations out to 10 Mpc

The PRO: One Strategy for Feeding The TMT

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Why a PRO?

A PRO will co-ordinate resources of TMT partners in an efficient way

- Allow facility optimization (important for surveys)
- Allow partners to gain access to capabilities that they may not have at their own facilities
- Spread out development costs (Why develop the same instrument on two different telescopes?)
- Reduce operating costs

- There are partners with ties between multiple large facilities on MK:
  - Canada: CFHT and Gemini
  - US and US universities (excluding UH): Gemini and Keck
  - UH: Every facility
- There is a precedent for sharing resources on MK:
  - MKSS
  - Shared personnel (e.g. for night time safety checks)
  - Times swaps involving Gemini, Keck, and Subaru
  - Shared environmental monitors (MKAM + ASIVA)

The ngCFHT: A Component of the PRO

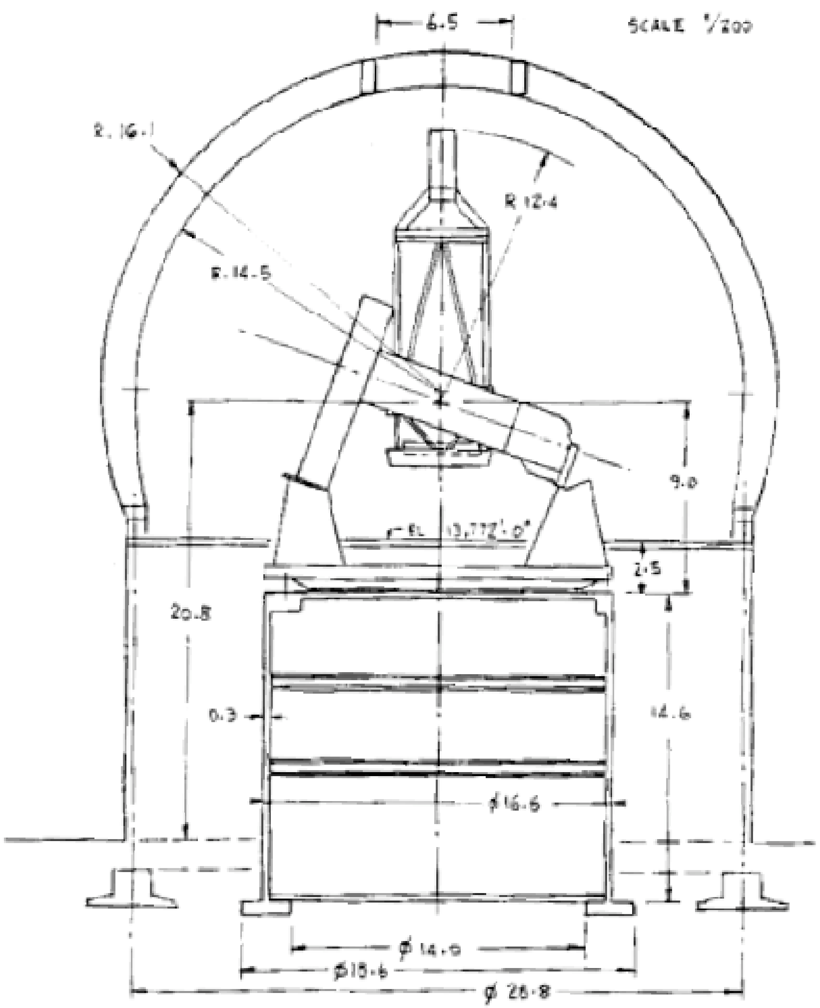
- The 2010 LRP identified an upgraded CFHT as a high priority; the science case is `unassailable'.
  - The existing facility is 4 decades old: CFHT 3.6m weighs 266 tonnes; Keck is 270 tonnes
  - The goal is to develop a 10 metre class facility.
- Will deliver a 1.5 degree^2 spectroscopic survey field
  - Order a few times 10^3 fibres
  - Spectroscopic resolution $10^3 – 10^4$
- Follow-up synergy with SDSS, MegaCam, HyperSuprimCam, LSST EUCLID, etc
- A concept study is underway, and will be completed by late 2012.
- Interest has been expressed by a number of countries, including China and India

Mauna Kea and CFHT redevelopment

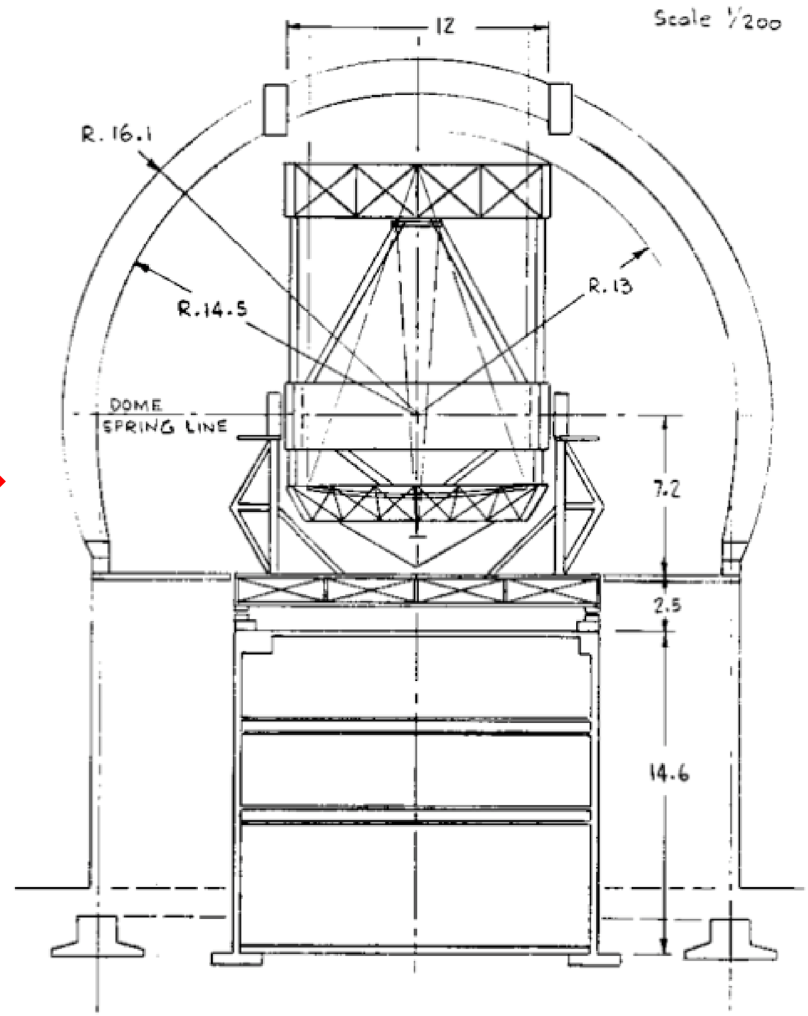
- **Mauna Kea Master Plan**
  - Allowed to redevelop the CFHT site
    - Must keep within the same 3-D footprint
    - Must not harm the ground beyond what has already been done
  - the ngCFHT will stay within the same envelope
  - Minimize work done at the summit (e.g., keep the building and pier if possible)

- **Redevelopment of CFHT is not a new idea**
  - e.g. SAC Working Group on the Future of CFHT (1996)
  - Resulted in “CFH 12 - 16m Telescope Study”, Grundmann (1997)

CFHT redevelopment



CFHT 3.6m Telescope Facility
Figure 1.



10m Telescope on CFHT Pier
Figure 20.

The ngCFHT: A Summary

Primary Mirror	**10m (segmented)**			
Field of View	**1.4 degree FOV (circular); Omega=1.5 sq. degree**			
Vignetting	**<15%**			
Wavelength Range	**370 - 970nm**			
IQ	**FWHM < 0.55 arcsecs (free atm. ~0.40 +/- 0.05)**			
Total system throughput*	**0.15-0.21 (low res) / 0.12-0.18 (hi-res)**			
Spectral Resolution*	**1500 420-650**	**3500 630-970**	**5000 480-550/815-885**	**20000 480-680**
Fibre diameter *	**1.15 arcsecs (core)**			
No. fibres	**3200 (low + hi-res) / 800 (hi-res with complete wavelength coverage)]**			
Positioner patrol region	**100 arcsec diameter (with some overlaps)**			
Configuration time*	**~40 seconds**			
glim [Texp=1hr]	**23.1 (R=5000, S/N=5 per A) / 19.7 (R=20000, S/N=20 per A)**			

* From Ellis et al.(2009)

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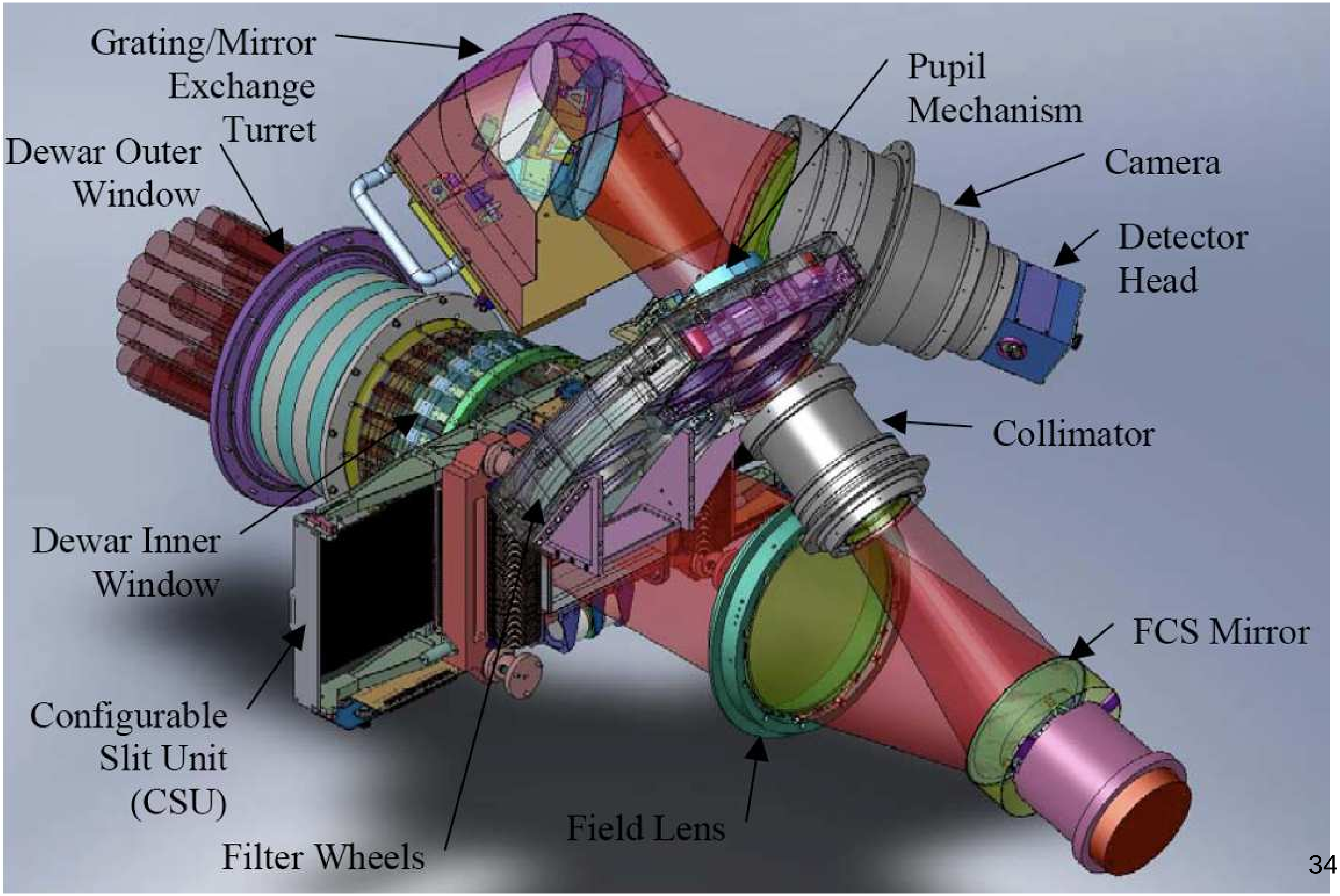
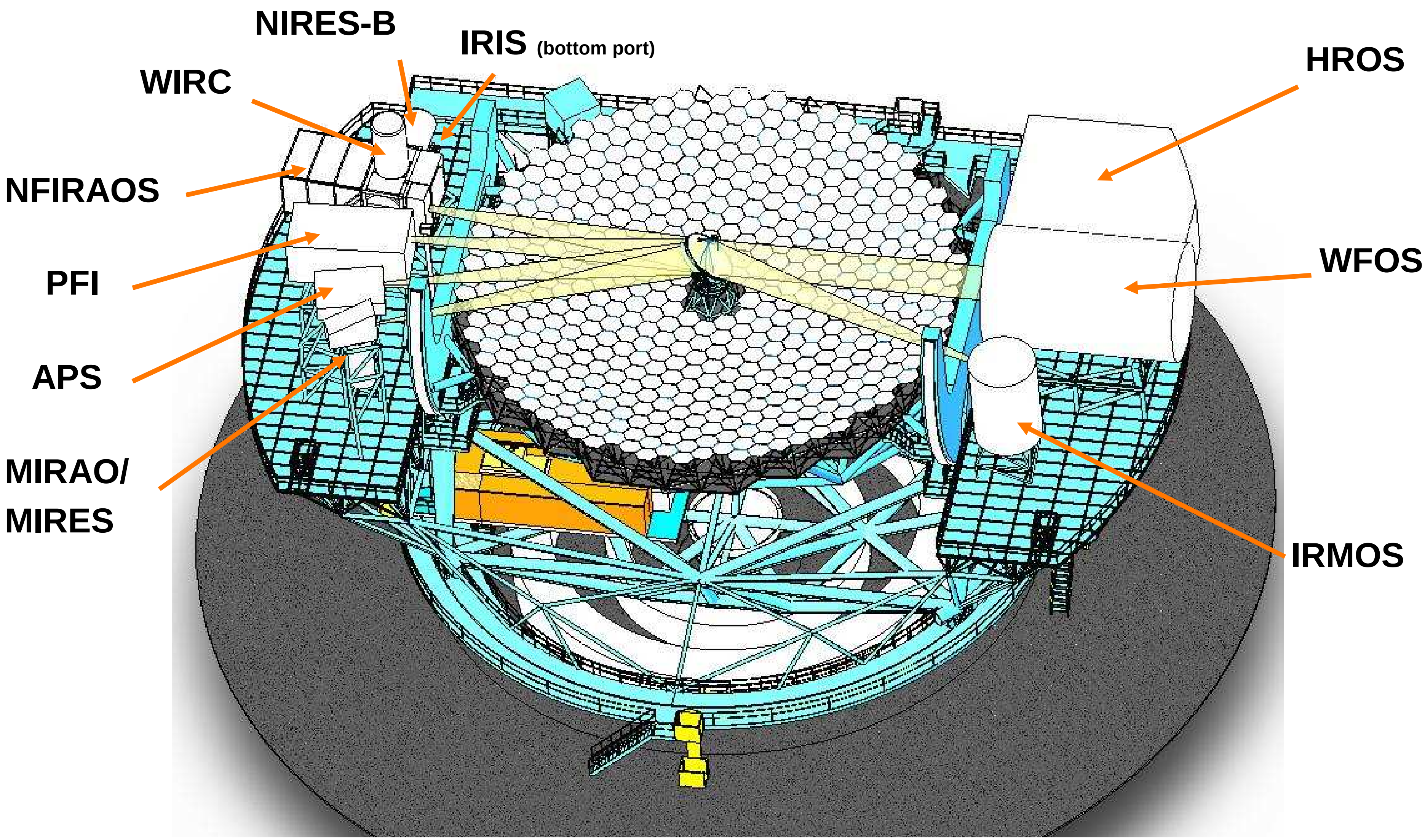
Acknowledgments

The TMT Project gratefully acknowledges the support of the TMT partner institutions. They are the Association of Canadian Universities for Research in Astronomy (ACURA), the California Institute of Technology and the University of California. This work was supported as well by the Gordon and Betty Moore Foundation, the Canada Foundation for Innovation, the Ontario Ministry of Research and Innovation, the National Research Council of Canada, the Natural Sciences and Engineering Research Council of Canada, the British Columbia Knowledge Development Fund, the Association of Universities for Research in Astronomy (AURA) and the U.S. National Science Foundation.

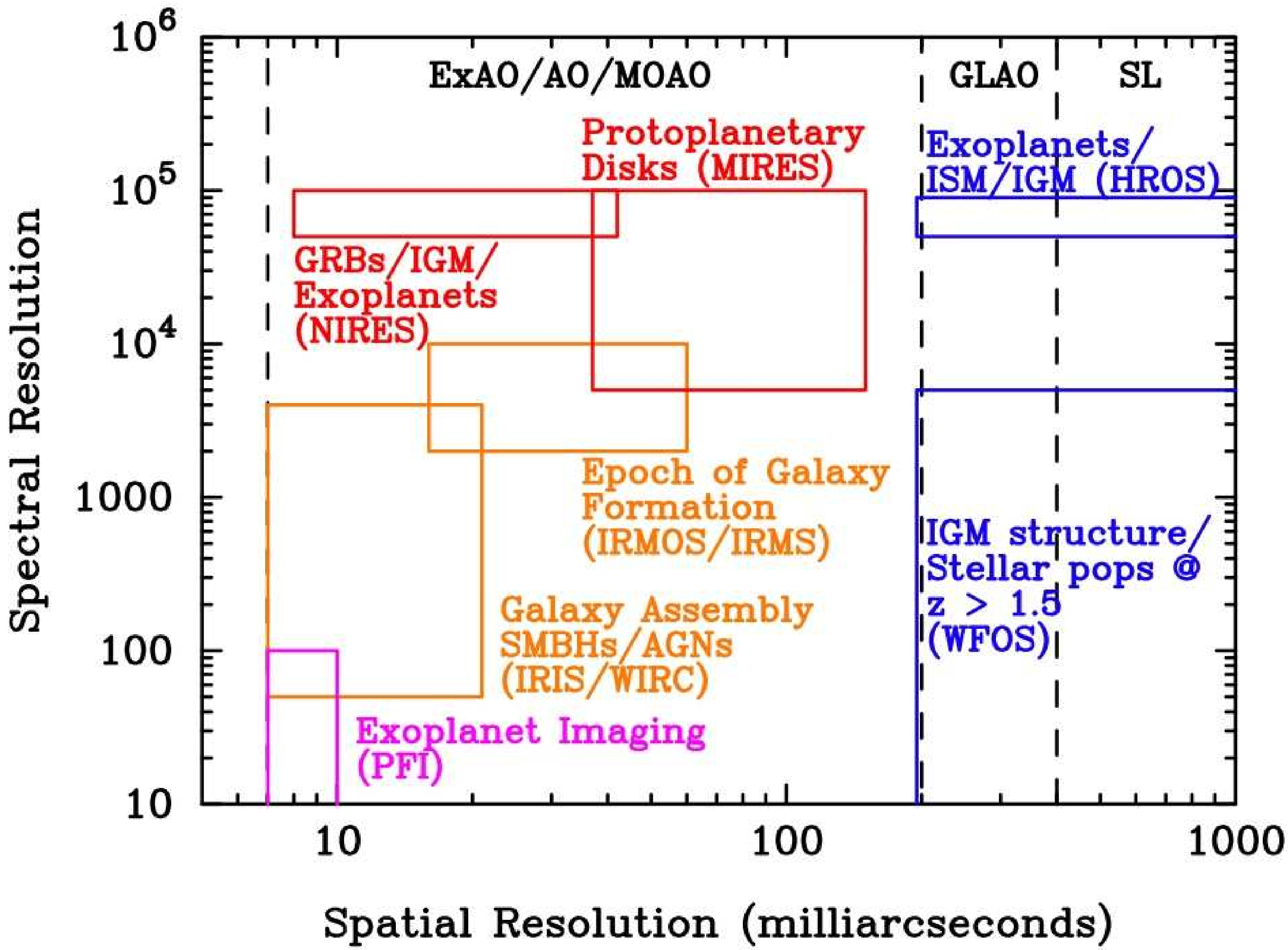
InfraRed Multi-slit Spectrometer (IRMS) (aka Keck/MOSFIRE on TMT)



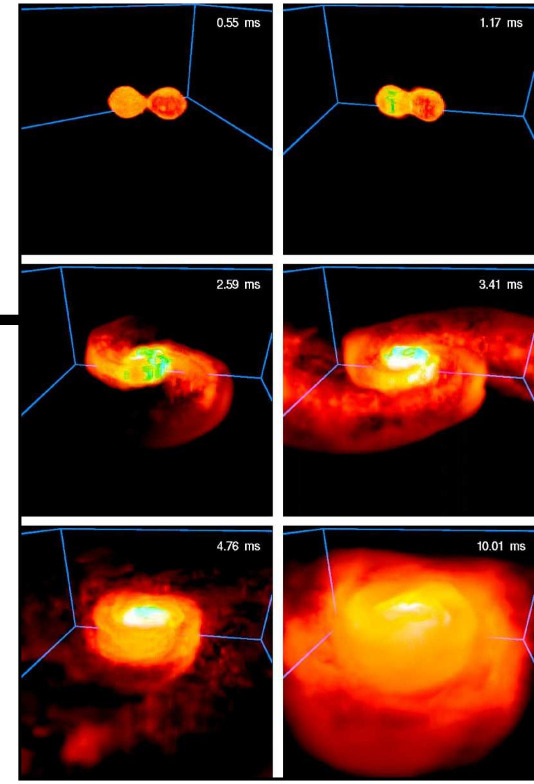
Nasmyth Configuration:
First Decade Instrumentation Suite



TMT Discovery Space at the End of the First Decade



A Flexible Operations Model: Rapid Response Example

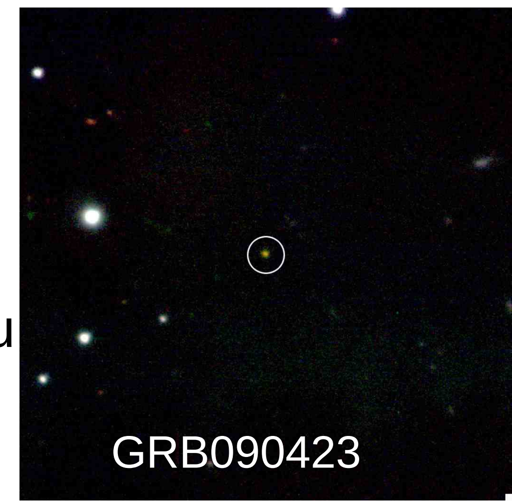


- GRBs are very bright but only for a short time interval
- Expect a significant fraction at very high redshift
- GRBs are point sources - D^4 advantage with AO

=> Potential for high S/N, high resolution spectra

  - Physics of extreme events and objects at high z
  - IGM studies at high z

- Instruments:
  - WFOS measurements of redshift, physical conditions
  - IRIS imaging and IFS with R = 4000
    - Detection and IFU spectroscopy of host galaxies
  - NIRES (AO fed) R = 50,000 spectroscopy over 0.8 - 2.5mu
    - Time sequences of high S/N spectra of high z objects
  - MIRES: R = 100,000 spectroscopy in 5-28micron region
  - HROS: R = 50,000 spectroscopy in 0.3 - 1micron region



Narrow-Field IR AO System (NFIRAOS): TMT's Facility AO system

TMT
THIRTY METER TELESCOPE

- Dual conjugate AO system
- Cooled to -30C to prevent affecting emissivity
- Optically efficient: 7 reflections + one beam splitter + window

- Completely integrated system
  - Fast (<5 min) switch between targets
- High sky coverage, even at galactic poles
- Good performance over 2' field
  - VLT/MAD and Gemini/Gems results demonstrate MCAO potential

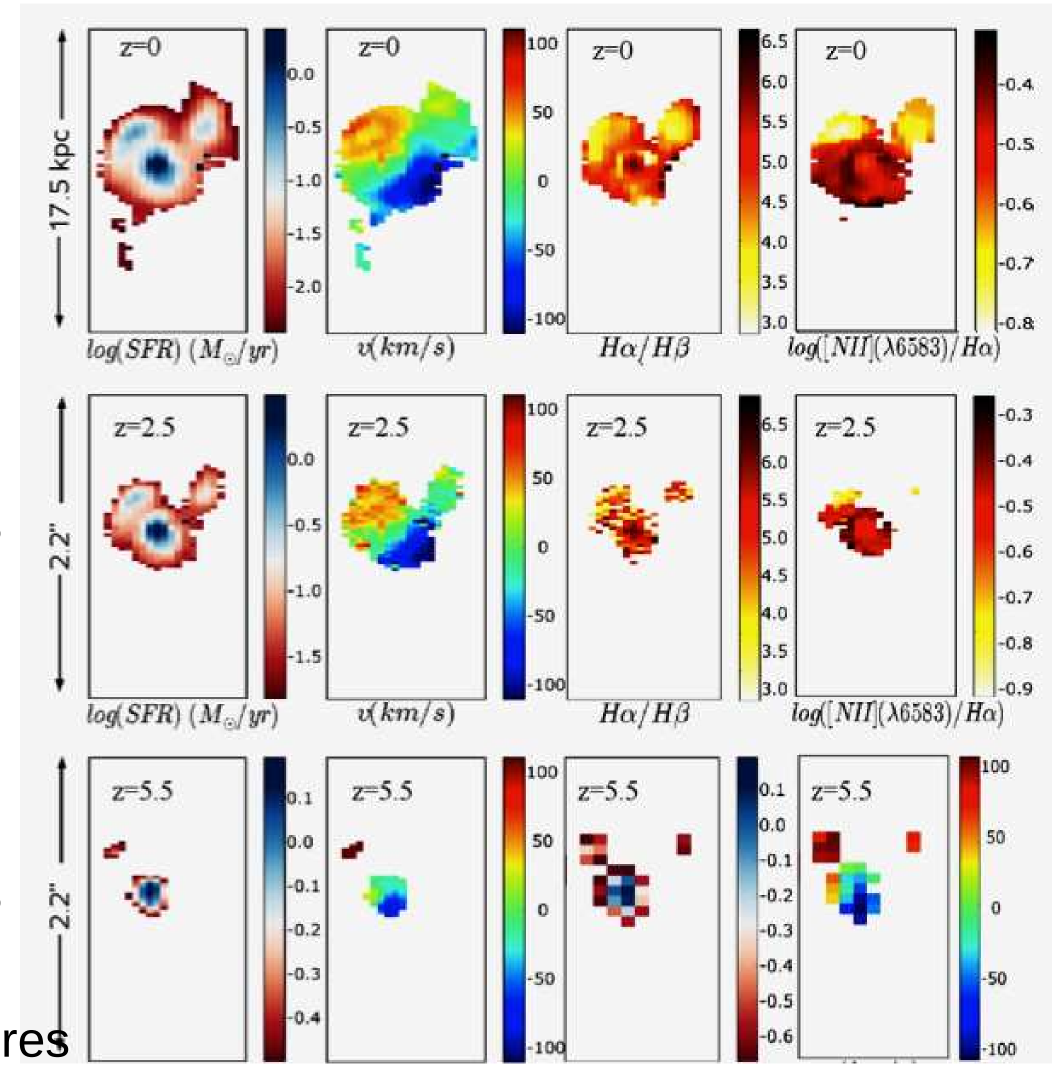
IRIS: Galaxy Formation and Evolution

- *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
- *Synergy with ALMA:*
  - Molecular emission

z = 0

z = 2.5
1h exp

z = 5.5
4h exp
500pc res



TMT IRMOS-UFHIA team