TMT
Thirty Meter Telescope

The Thirty Meter Telescope

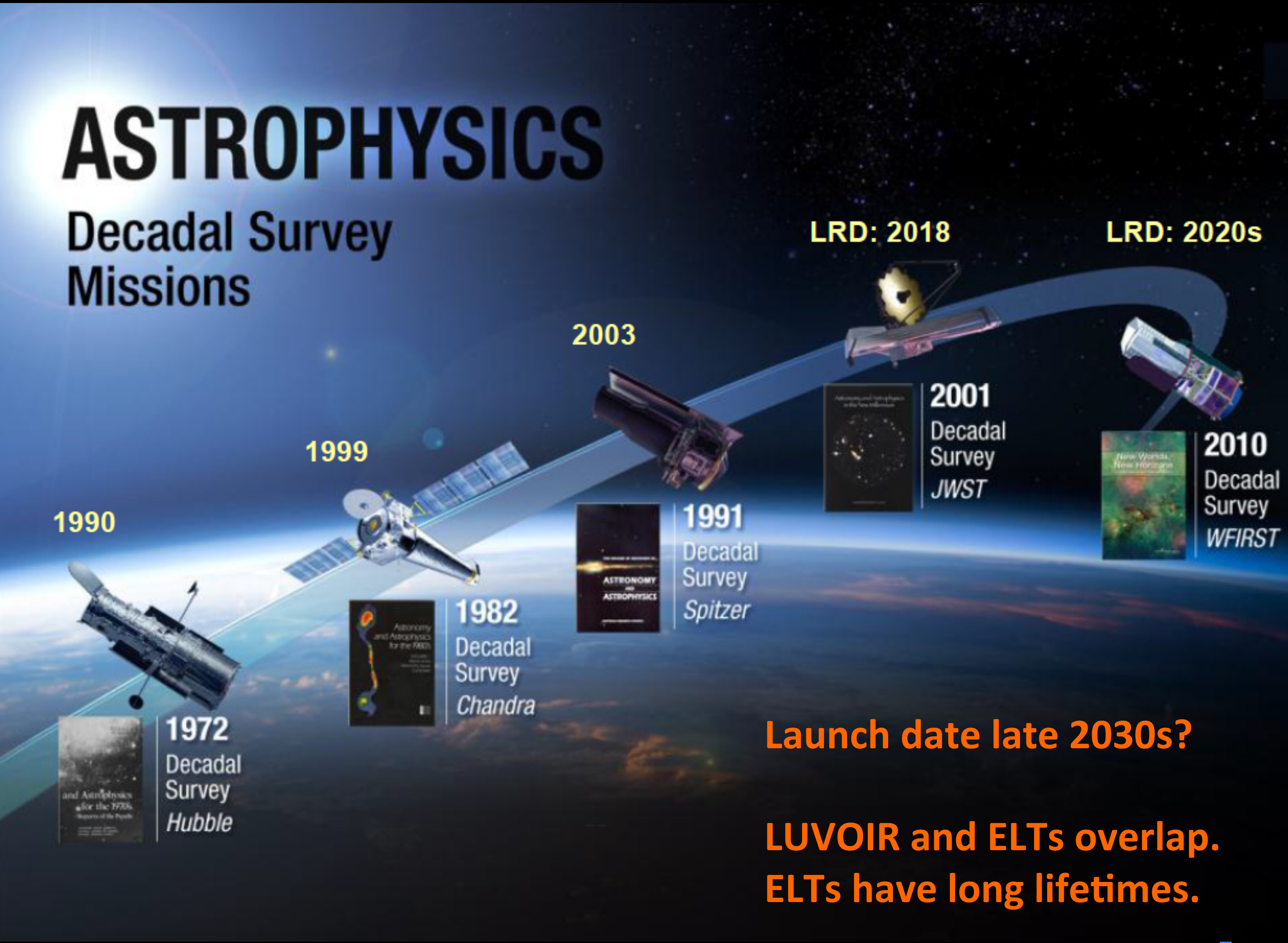
Observing Capabilities and Timeline

Warren Skidmore, TMT System Scientist, Pasadena

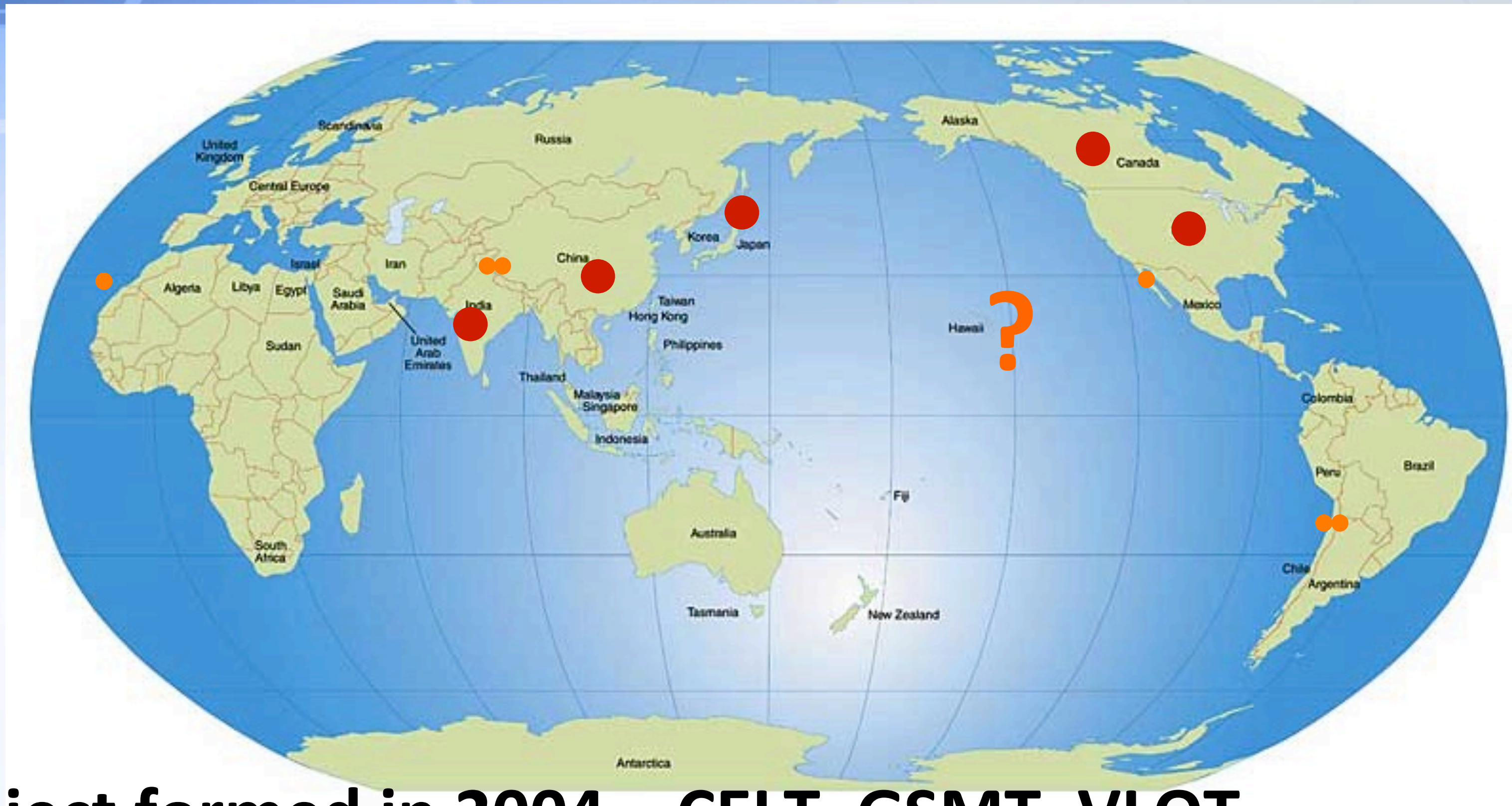
August 18, 2016

LUVOIR STDT Face-to-Face

GSFC


ASTROPHYSICS
Decadal Survey Missions
1990
1972 Decadal Survey Hubble
1999
1982 Decadal Survey Chandra
2003
1991 Decadal Survey Spitzer
LRD: 2018
2001 Decadal Survey JWST
LRD: 2020s
2010 Decadal Survey WFIRST
Launch date late 2030s?
LUVOIR and ELTs overlap.
ELTs have long lifetimes.

TMT Partnership and timescale



Project formed in 2004 – CELT, GSMT, VLOT

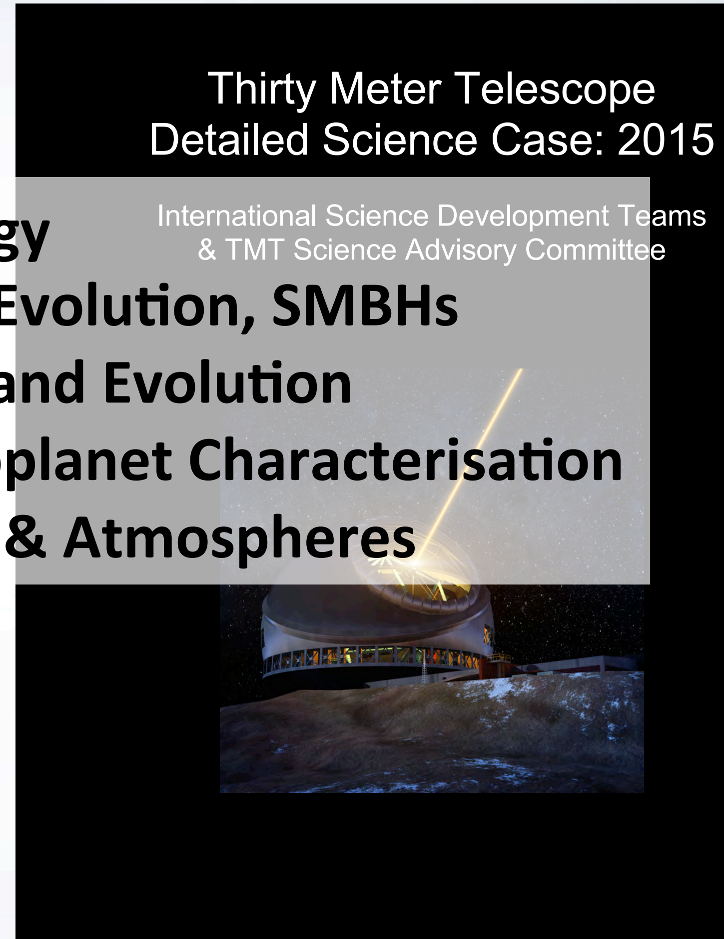
Q2 2014 – Construction Phase

Q2 2018 – Heavy Construction

Q4 2026 – Science Operations

Construction activities continue. All major and critical systems are construction ready (FDP or PDP). Aggressive effort to finalise site.

Detailed Science Case 2015 by TMT International Science Development Teams



Cosmology

Early Universe, Galactic Evolution, SMBHs

Stellar Abundances and Evolution

Star and planet formation, Exoplanet Characterisation

Solar System Surfaces & Atmospheres

Reference: Skidmore et al. 2015, Research In Astronomy and Astrophysics (RAA), Volume 15, Issue 12, Article id. 1945
http://www.tmt.org/sites/default/files/documents/application/pdf/tmt-dsc-2015-release-2015apr29-s2.pdf

TMT resolution at 1μm is 7 mas

7 mas = 200m at 5Mkm, 25 km at 5 AU (Jupiter)

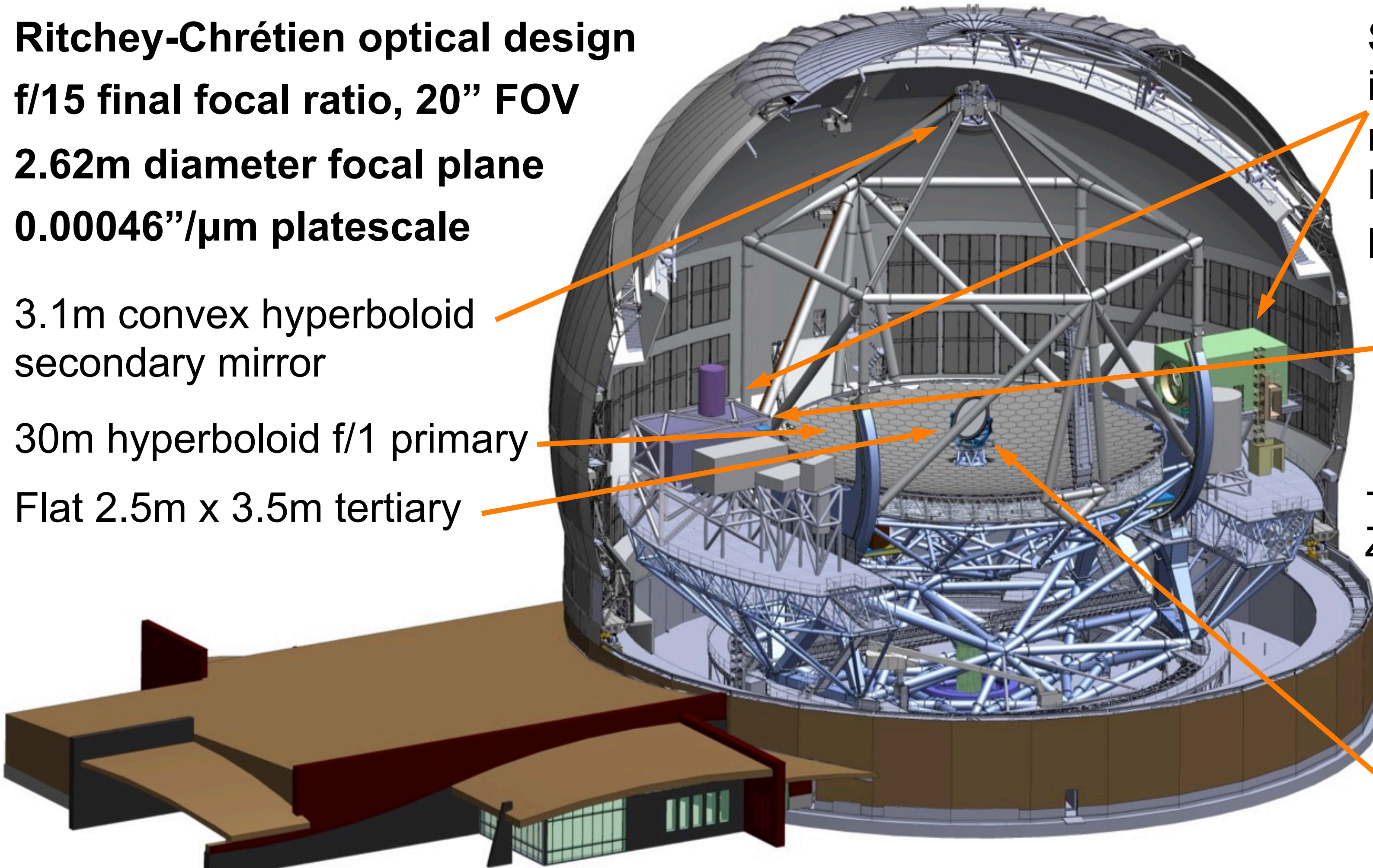
0.035 AU at 5 pc (nearby stars) , 0.034 pc at 1 Mpc, 300 pc at z~2.5

Ritchey-Chrétien optical design

f/15 final focal ratio, 20" FOV

2.62m diameter focal plane

0.00046"/μm platescale

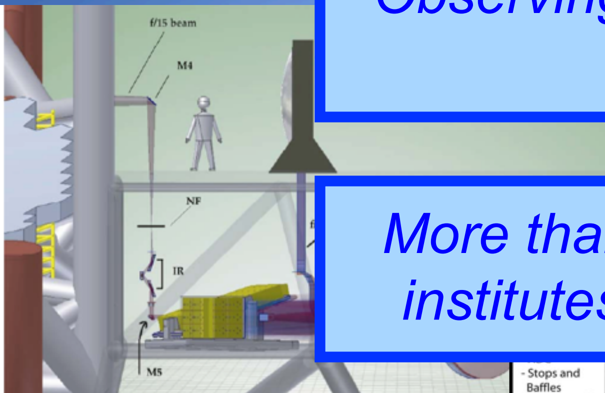


Cross partner large programs
Small programs

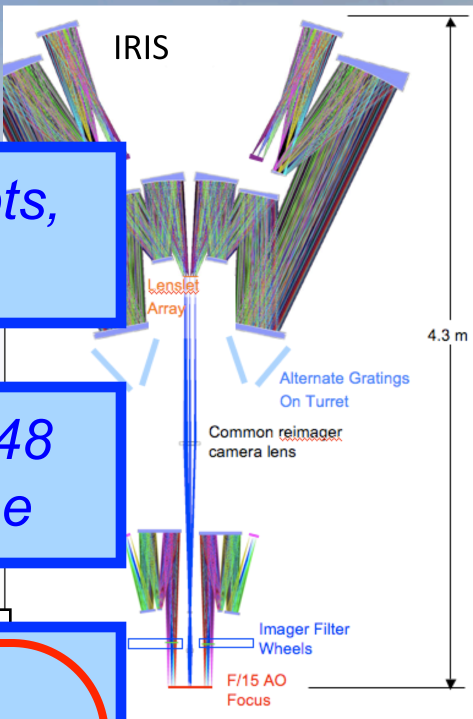
Flexible scheduling

Remote PI led and queue scheduled observations, eavesdropping if needed

A Powerful Development Model – 2005/6 Studies



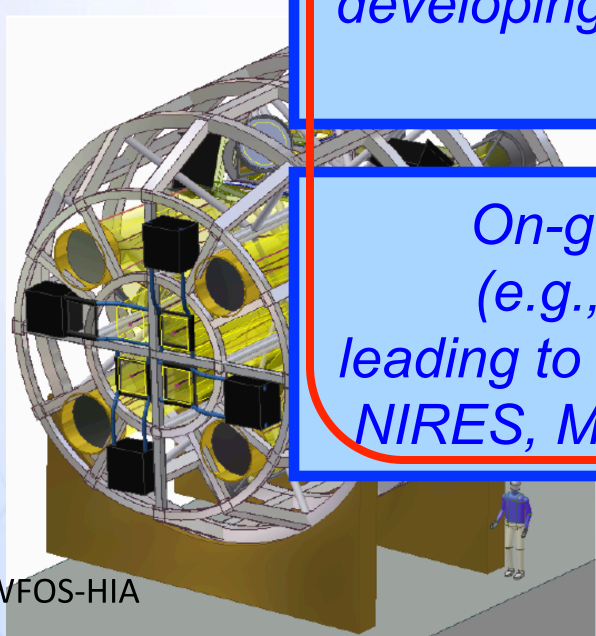
Observing programs, requirements, concepts, performance, etc.



More than 200 scientists and engineers at 48 institutes across North America and Europe

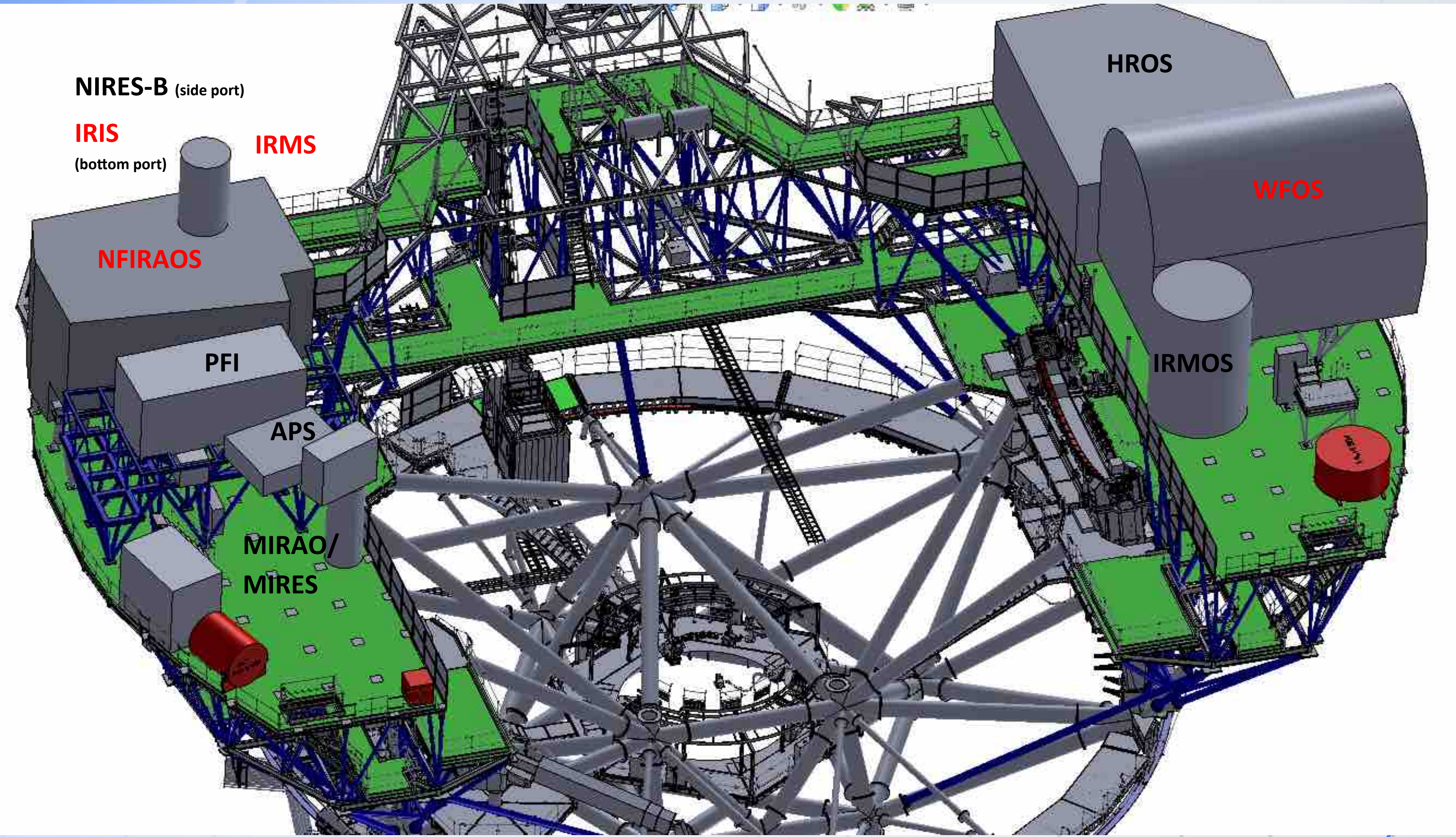
International partners have also been developing science cases and conducting their own instrument studies

On-going "community explorations" (e.g., workshops, testbeds, studies) leading to new concepts (MICHI, SEIT, HROS, NIRES, MODRES) and instruments (RAVEN)



IRMOS-UF

Nasmyth Configuration: Full Instrumentation Suite



TMT Planned Instrument Suite

TMT
Thirty Meter Telescope

Instrument	Field of view / slit length	Spectral resolution	λ (μm)	Comments
InfraRed Imager and Spectrometer (IRIS)	< 4."4 … 16".4 … (imagi…		…2.4	MCAO with NFIRAOS 50μ arcsec astrometry
Wide-field Optical spectrometer (WFOS)	40.3′ s… 576″ (…			Seeing-Limited (SL)
InfraRed Multislit Spectrometer (IRMS)	2′ field… deploy…		…5-2.45	MCAO with NFIRAOS
Multi-IFU imaging spectrometer (IRMOS)	3″ IFU… diame…		0.8-2.5	MOAO
Mid-IR AO-fed Echelle Spectrometer (MIRES)	3″ slit… 10″ im…		8-18 4.5-28(goal)	MIRAO
Planet Formation Instrument (PFI)	1″ oute… angle, … working angle		1-2.5 1-5 (goal)	10^8 contrast 10^9 goal
Near-IR AO-fed Echelle Spectrometer (NIRES)	2″ slit…		1-5	MCAO with NFIRAOS
High-Resolution Optical Spectrometer (HROS)	5″ slit length	50000	0.31-1.0 …3(goal)	SL
"Wide"-field AO imager (WIRC)	30″ im…		0.8-5.0 0.6-5.0 (goal)	MCAO with NFIRAOS

0.8-2.5μm 4.5" FOV IFU
34" FOV Broad Band Imager

0.31-1.0μm 40"^{2} Imager
200 objects, R up to 16000

0.95-2.5μm 2' Imager
46 objects, R up to 5000

multiple 3" FOV IFUs
0.8-2.5μm, 5' field

8-18μm R~100,000
10" Imager

1-2.5μm R~100 IFU
>10^8 contrast, 1" IWA

1-5μm R~100,000
Facility AO fed

0.31-1.1μm R up to 50,000

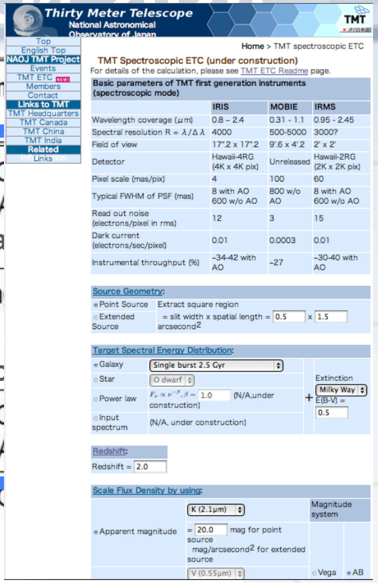
0.8-5μm Imager
30" FOV, R~5 to 100

8

TMT First Light Instrument Suite
Part of Observatory Construction Q4 2026

TMT
Thirty Meter Telescope

Instrument	Field of view / slit length	Spectral resolution	λ (μm)	Comm
InfraRed Imager and Spectrometer (IRIS)	< 4."4 x 2".25 (IFU) 2x2 16.4"x16.4" (imaging)	4000-8000 5-100 (imaging)	0.8 – 2.4	MCA NFIRA 50μ a
Wide-field Optical spectrometer (WFOS)	40.3′ squared (FoV) 576" (Total slit length)	1000-8000	0.31-1.1	Seein (SL) Up to
InfraRed Multislit Spectrometer (IRMS)	2′ field w/ 46 deployable slits	R = 4660 @ 0.16" slit	0.95-2.45	MCA NFIRA
Multi-IFU imaging spectrometer (IRMOS)	3 IFUs over >5′ diameter field	2000-10000	0.8-2.5	MOA
Mid-IR AO-fed Echelle Spectrometer (MIRES)	3″ slit length 10″ imaging	5000-100000	8-18 4.5-28(goal)	MIRAO
Planet Formation Instrument (PFI)	1″ outer working angle, 0.05″ inner working angle	R≤100	1-2.5 [illegible]	10^8 contrast [illegible]
Near-IR AO-fed Echelle Spectrometer (NIRES)	2″ slit length	[illegible]	[illegible]	MCAO with NFIRAOS
High-Resolution Optical Spectrometer (HROS)	5″ slit length	50000	0.31-1.0 0.31-1.3(goal)	SL
"Wide"-field AO imager (WIRC)	30″ imaging field	5-100	0.8-5.0 0.6-5.0(goal)	MCAO with NFIRAOS


Thirty Meter Telescope
National Astronomical Observatory of Japan
TMT

Top
English Top
NAOJ TMT Project
Events
TMT ETC NEW!
Members
Contact
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TMT Headquarters
TMT Canada
TMT China
TMT India
Related Links

Home > TMT spectroscopic ETC

TMT Spectroscopic ETC (under construction)

For details of the calculation, please see TMT ETC Readme page.

Basic parameters of TMT first generation instruments (spectroscopic mode)	IRIS	MOBIE	IRMS
Wavelength coverage (μm)	0.8 – 2.4	0.31 - 1.1	0.95 - 2.45
Spectral resolution R = λ/Δλ	4000	500-5000	3000?
Field of view	17".2 x 17".2	9'.6 x 4'.2	2' x 2'
Detector	Hawaii-4RG (4K x 4K pix)	Unreleased	Hawaii-2RG (2K x 2K pix)
Pixel scale (mas/pix)	4	100	60
Typical FWHM of PSF (mas)	8 with AO 600 w/o AO	800 w/o AO	8 with AO 600 w/o AO
Read out noise (electrons/pixel in rms)	12	3	15
Dark current (electrons/sec/pixel)	0.01	0.0003	0.01
Instrumental throughput (%)	~34-42 with AO	~27	~30-40 with AO

Source Geometry:
Point Source — Extract square region
Extended Source — = slit width x spatial length = 0.5 x 1.5 arcsecond²

Target Spectral Energy Distribution:
Galaxy — Single burst 2.5 Gyr
Star — O dwarf
Power law — $F_\nu \propto \nu^{-\beta}, \beta =$ 1.0 (N/A,under construction)
Input spectrum — (N/A, under construction)
+ Extinction Milky Way E(B-V) = 0.5

Redshift:
Redshift = 2.0

Scale Flux Density by using:
Apparent magnitude — K (2.1μm) = 20.0 mag for point source mag/arcsecond² for extended source — V (0.55μm)
Magnitude system — Vega / AB

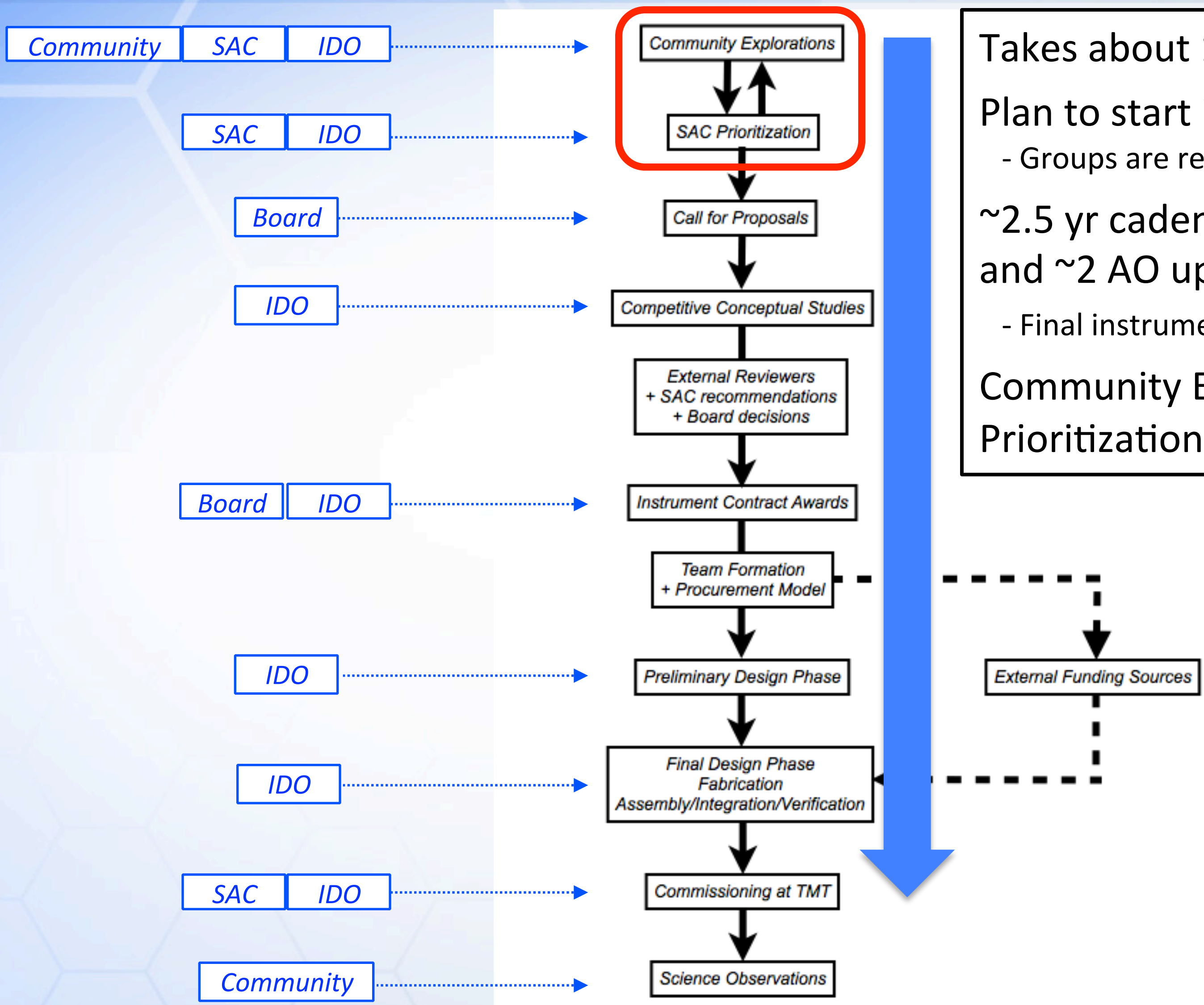
Possible instruments within TMT instrument roadmap. A call for 2nd generation instruments will be released in 2017 (TBC)

An ELT Instrumentation "Equivalence Table"

Cheat sheets for E-ELT, GMT and TMT capabilities

Type of Instrument	GMT	TMT	E-ELT
Near-IR, AO-assisted Imager + IFU	GMTIFS	IRIS	HARMONI
Wide-Field, Optical Multi-Object Spectrometer	GMACS	WFOS	MOSAIC-HMM
Near-IR Multislit Spectrometer	NIRMOS	IRMS	MOSAIC-HMM
Deployable, Multi-IFU Imaging Spectrometer		IRMOS	MOSAIC-HDM
Mid-IR, AO-assisted Echelle Spectrometer		MIRES	METIS
High-Contrast Exoplanet Imager	TIGER	PFI	ELT-PCS
Near-IR, AO-assisted Echelle Spectrometer	GMTNIRS	NIRES	HIRES
High-Resolution Optical Spectrometer	G-CLEF	HROS	HIRES
"Wide"-Field AO-assisted Imager		WIRC/IRIS (Imager)	MICADO

Steps Towards Future Instruments



Takes about 10 years

Plan to start in 2017 (TBD)

- Groups are ready

~2.5 yr cadence for ~6 instruments and ~2 AO upgrades

- Final instrument delivery in early 2040s!

Community Explorations and SAC Prioritization ensure flexibility

TMT International Science Development Teams

- ~215 individuals in 9 teams
  - Early Universe, Galaxy Formation and the IGM
  - Exoplanets
  - Formation of Stars and Planets
  - Fundamental Physics and Cosmology
  - Milky Way and Nearby Galaxies
  - Solar System
  - Stars, Stellar Physics and the ISM
  - Supermassive Black Holes
  - Time Domain Science

TMT International Science Development Teams

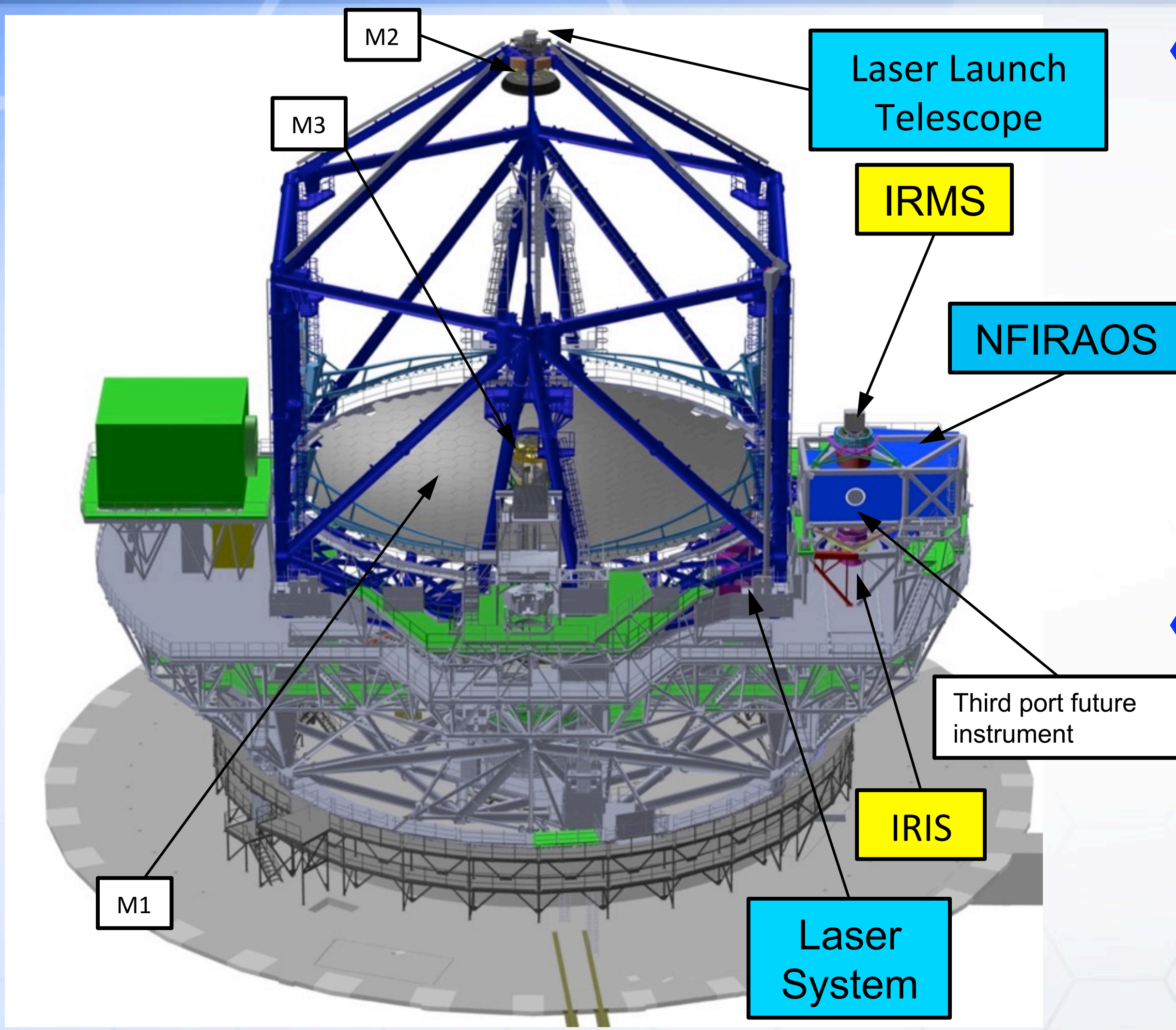
- All volunteers (no financial assistance)
  - Annual renewal of membership/calls for new members
- Coordinated by TMT SAC members Tommaso Treu and Mark Dickinson
  - Varying levels of self-organisation up to organising topical conferences
- Activities
  - All input for 2015 Detailed Science Case from ISDTs
  - Proposals for Cross-Partner Key Programs
    - Several dozen proposals for ~15 years of telescope time!
  - Updated science requirements flowdown
  - WFIRST/TMT synergies

Summary

- TMT will be a general purpose observatory with all major forms of instrumentation
- Q4 2026 Science operations
  - 1st light instruments under development
    - Work horse capabilities, broad use cases
    - Near IR AO fed IFU, imager and MOS
    - Optical wide field MOS
- ~2.5 yr cadence for new instruments and AO
  - Concepts are actively being developed
  - Decision and development process is defined
    - Flexible on the timescale for LUVOIR overlap
- TMT International Science Development Teams
  - Can provide science input if needed
- CHEATSHEETS – TMT, E-ELT and GMT

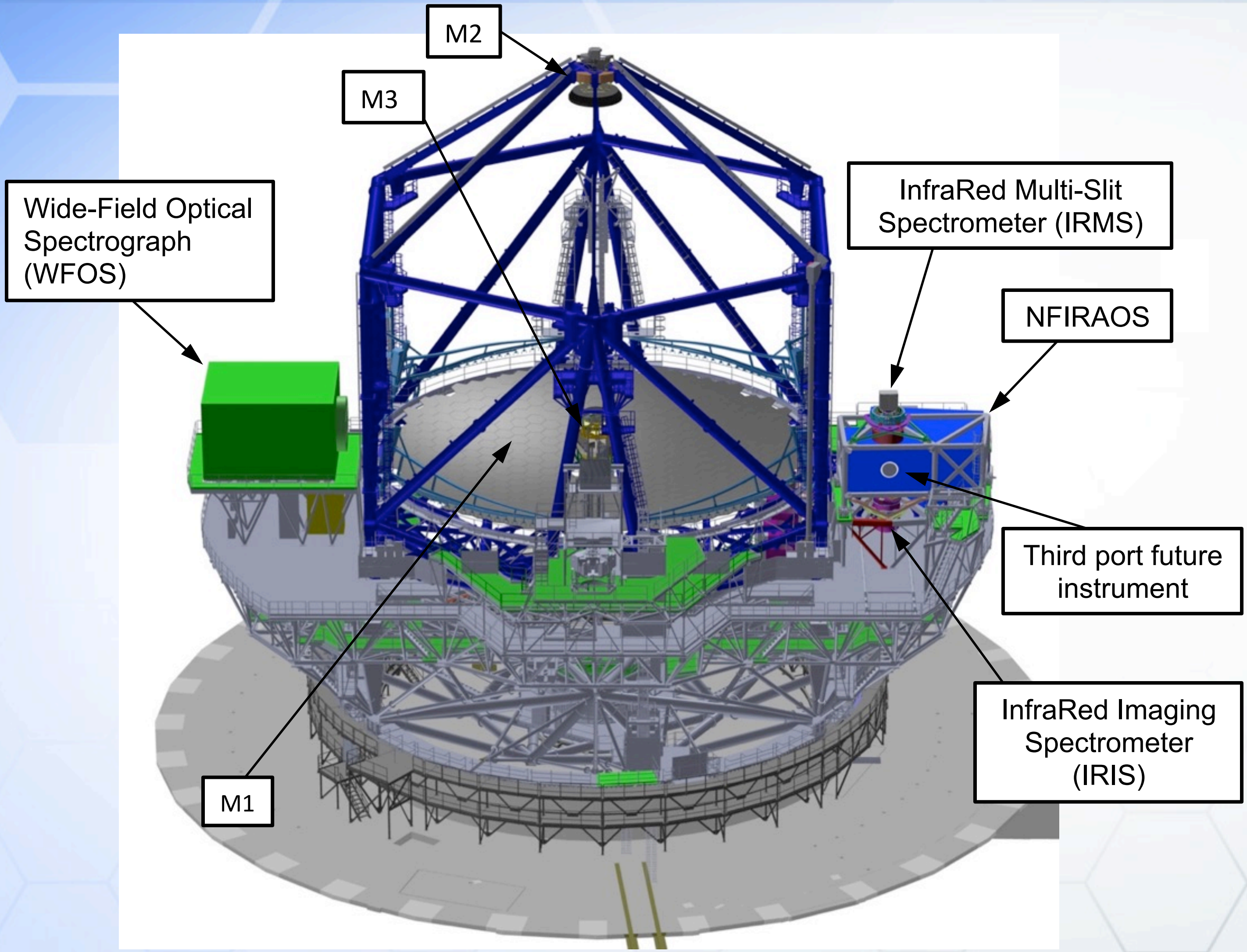
Backup slides

TMT First Light AO System



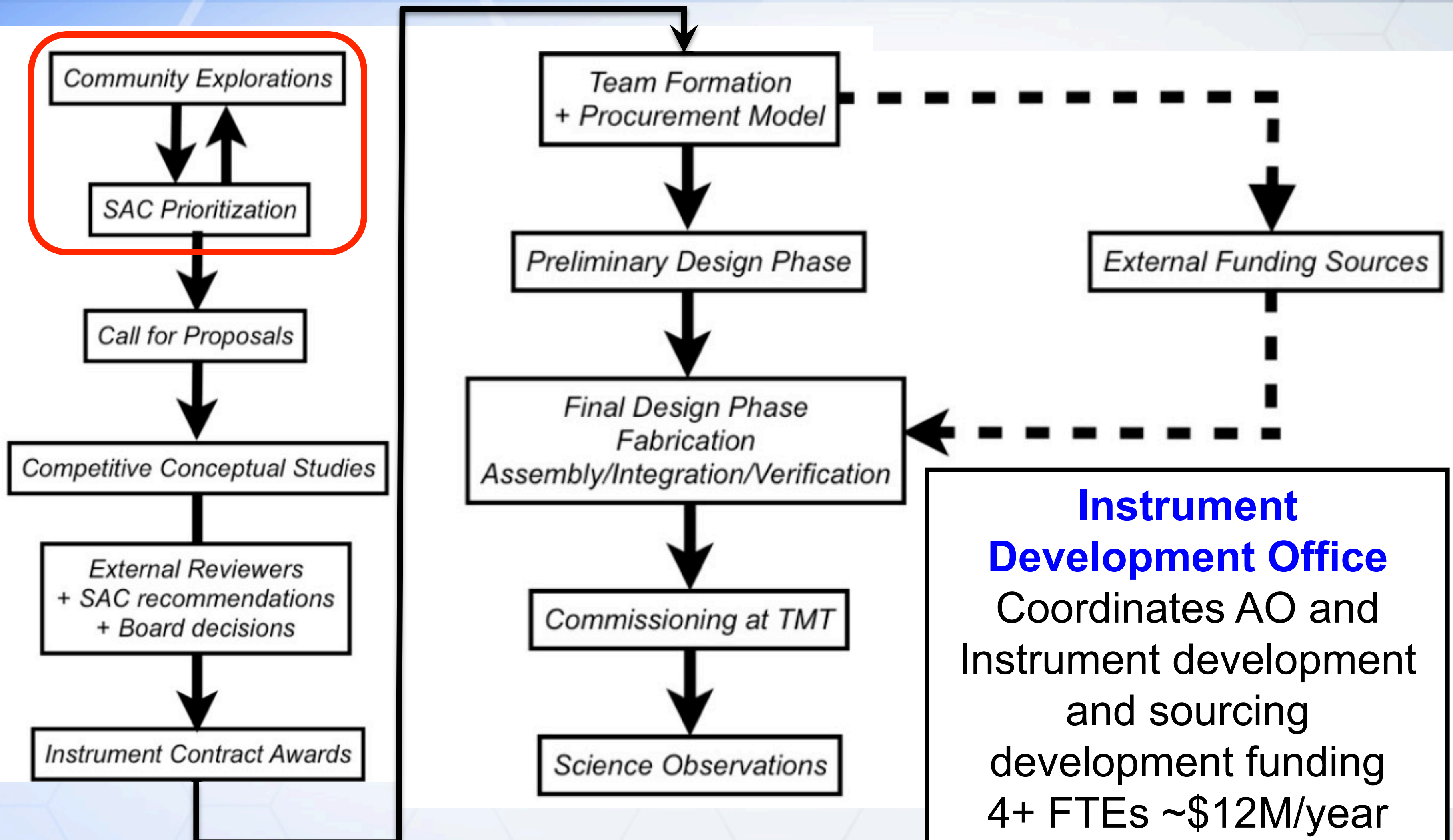
- Narrow Field IR AO System (NFIRAOS)
  - LGS, multi-conjugate AO
  - 6 laser guidestar WFSs
  - Two Piezostack DMs
  - Tip/tilt stage
  - Order 60x60 correction
  - 800Hz update rate
  - Fast (< 5 min) switch between targets with same instrument
- Tip/tilt/focus Infrared NGS WFSs in client instruments IRIS, IRMS
  - Science detector "On Detector Guide Windows"

TMT First-Light Science Instruments on the Telescope



- Ritchey-Chrétien optical design
- 30-m f/1 primary
- 3.1-m convex secondary
- 2.5 m x 3.5 m flat tertiary
- f/15 final focal ratio
- 20′ Field of view is 2.62m in diameter
- Science instruments mounted on Nasmyth platforms (fixed gravity vector)

Future Instrumentation Development Plan



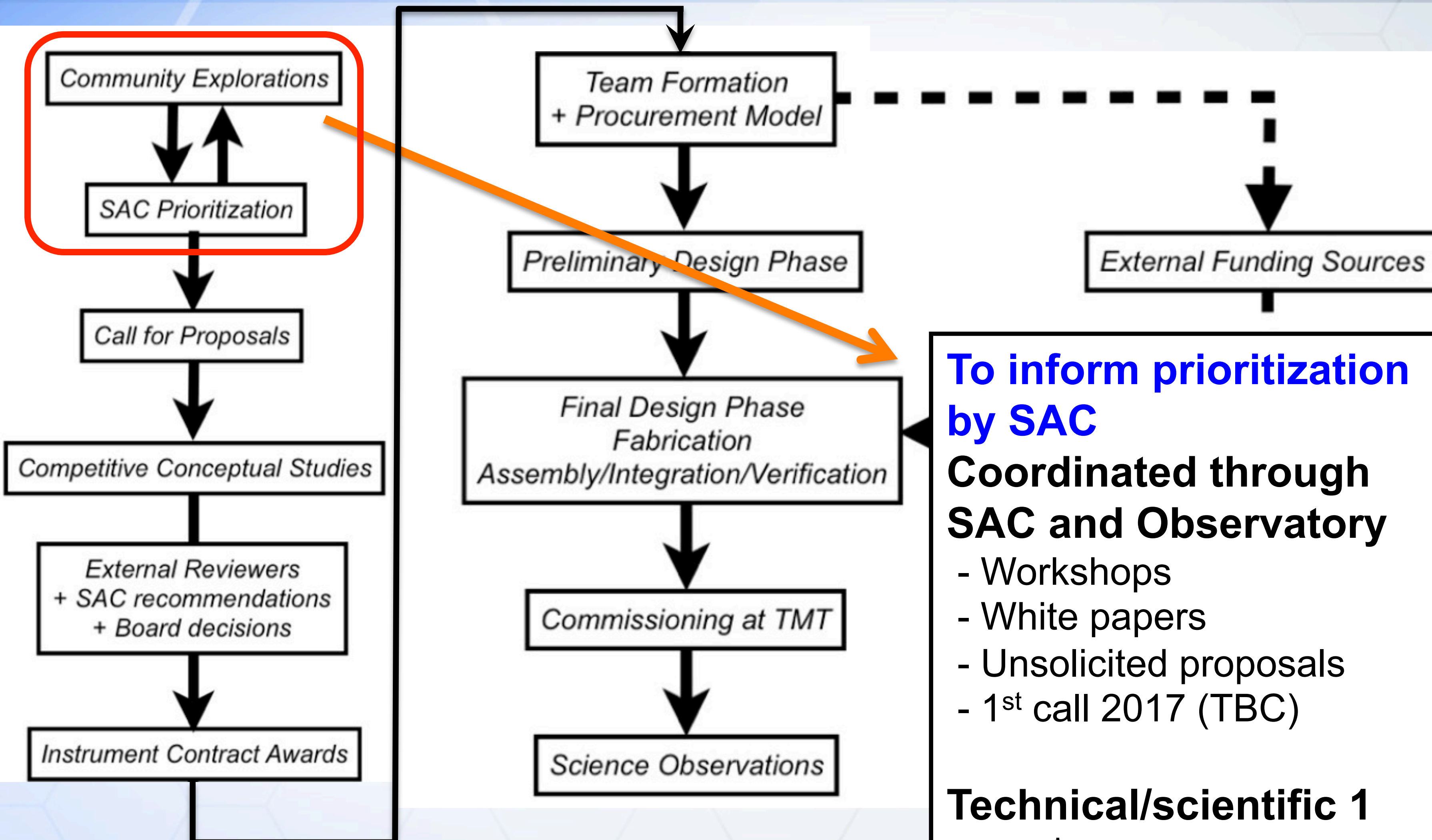
Instrument Development Office

Coordinates AO and Instrument development and sourcing development funding

4+ FTEs ~$12M/year

Forming late 2016

Future Instrumentation Development Plan



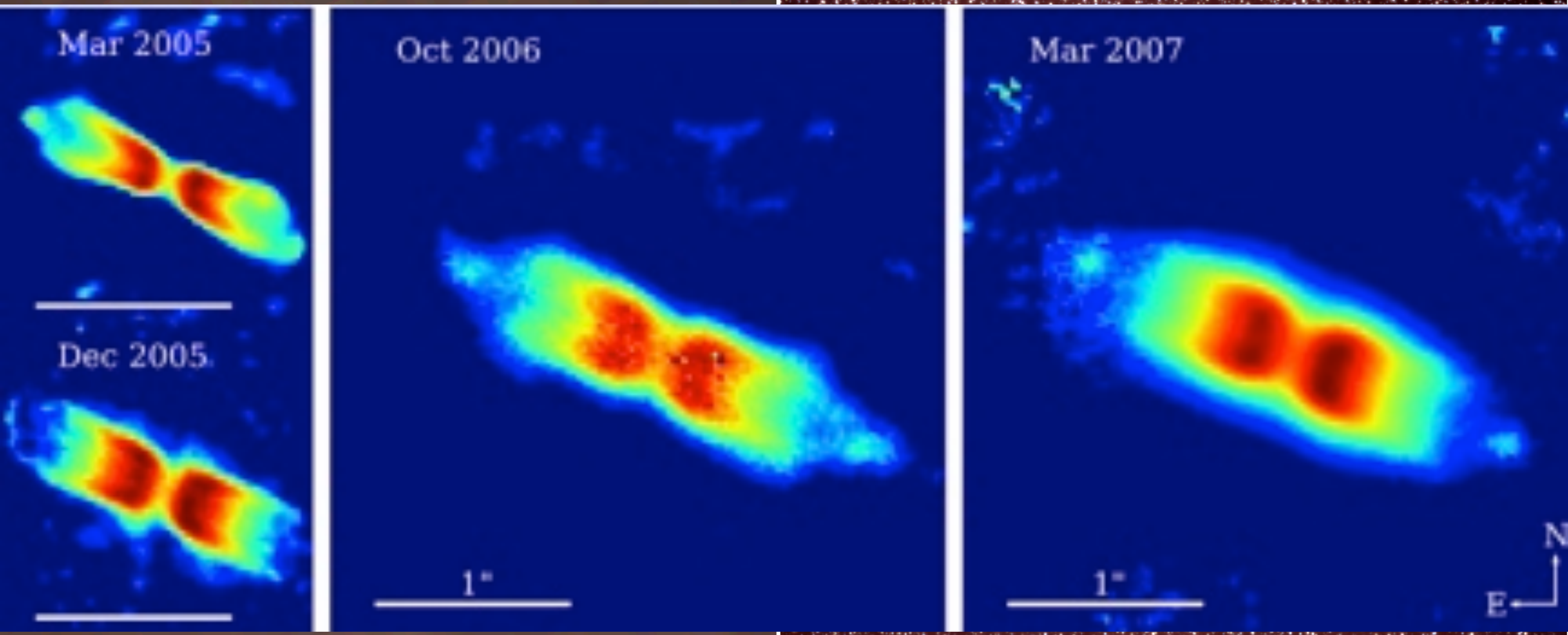
To inform prioritization by SAC

Coordinated through SAC and Observatory

- Workshops
- White papers
- Unsolicited proposals
- 1st call 2017 (TBC)

Technical/scientific 1 year $100K mini-studies

Diffraction limited observations with AO on TMT



TMT resolution at 1μm (λ/d) is 7 mas, 4 mas pixels

7 mas = 200m at 5Mkm, 25 km at 5 AU (Jupiter)

0.035 AU at 5 pc (nearby stars) , 0.034 pc at 1 Mpc, 300 pc at z~2.5

Future Instruments: Feasibility Studies?

- Feasibility studies for future instruments: Why now?
  - **Very** strong interest across partnership
  - Updated and/or new instrument concepts
  - Updated technical information required (e.g., cooling requirements)
  - Updated cost and schedule estimates for development budget planning
  - **Foster new collaborations and involve new groups into our instrumentation effort – important at this critical time for TMT**

- A possible plan:
  - ~3-4 studies with 1.5 year duration
  - Modest cash contributions leveraging larger in-kind contributions
    - MICHI team produced a very impressive feasibility report with NSF ATI funding and Japanese contributions
  - Call for proposals in 2017Q1 (see proposed timeline)

Future Instruments Studies: A Proposed Timeline

Step	Description	Timelines		
		First-light Instruments	2nd Gen Instruments Proposed New Timeline	2nd Gen Instruments Original Timeline
1	Initial science cases and desired capabilities	<= 2004	2016Q1 - 2016Q4	(Missing steps from this timeline -> Future instruments 1 and 2 selected on the basis of 10-year old scientific and technical information)
2	Call for Feasibility Studies (~$150K+~1.5 yr / study)	2005Q1 (10 studies; 8 capabilities)	2017Q1 (TBD studies; TBD capabilities)	
3	Feasibility Study Phase: ° Expanded science cases and operational concepts ° Instrument designs and their technical readiness ° Schedule and Budget Estimates	2005Q2 - 2006Q1	2017Q3 - 2018Q4	
4	Feasibility Study Reviews	2006Q1	2019Q1	
5	Revised science cases and instrument concept ranking	2006Q2 - 2006Q3	2019Q2 - 2019Q3	2016Q2 - 2016Q3
6	Instrument concept selection	2006Q4	2019Q4	2016Q4
7	Call for Conceptual Design Studies (~$1M+ ~1.5 yrs / study)	2007Q3	2019Q4	2016Q4
8	Team selection and formation	2007Q4	2020Q2	2017Q2
9	Statement of Work and work package development	2007Q4	2020Q3 - 2020Q4	2017Q3 - 2017Q4
10	Conceptual Design Studies start	2008Q1 (Two studies: WFOS and IRIS)	2021Q1 (Two studies TBD)	2018Q1 (Two studies TBD)

Science Instrument Status

- IRIS: Preliminary Design Phase started in April 2013 and scheduled for completion in November 2016
- WFOS:
  - Conceptual Design Handover Workshop held in October 2013
  - A 1-year “mini-study” phase with participants from 15 institutes across the TMT partnership was completed in April 2015
  - An “Opto-Mechanical Design and Requirements” (OMDR) phase was initiated in January 2016 and is scheduled for completion in January 2017
- IRMS:
  - A 2013 mini-study showed IRMS to be a viable option for TMT +NFIRAOS
  - Mini-studies are under discussion
- Future instruments: Call for Feasibility Study proposals in early 2017 under discussion

TMT GMT First Generation Instrument Status

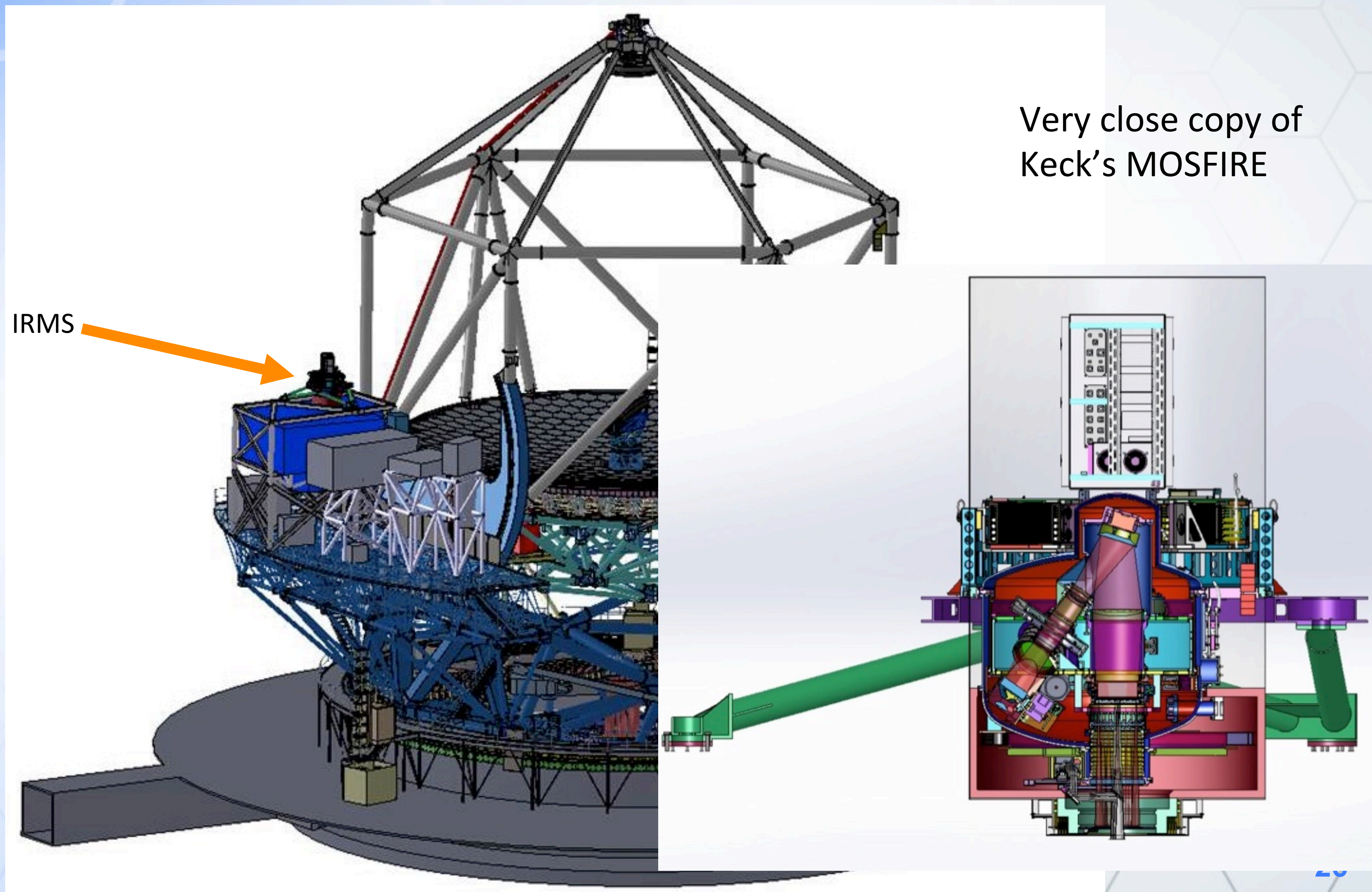
Thirty Meter Telescope

Instrument / Mode	Capabilities	λ Range, µm	Resolution	Field of View
G-CLEF / NS, GLAO, NGSAO	Optical High Resolution Spectrograph / PRV	0.35 – 0.95	19,000 – 108,000	7 x 0.7,1.2” fibers
GMTIFS / LTAO, NGSAO	NIR AO-fed IFS / Imager	0.95 – 2.5	5,000 & 10,000	10 / 400 $arcsec^2$
GMACS / NS, GLAO	Wide-Field Optical Multi-Object Spectrograph	0.35 – 0.95	1,000 – 6,000 (8K with MANIFEST)	7.5’ diameter
ComCam / NS, GLAO	Optical Imager	0.34 – 1.0	0.06 arcsec/pix	6 x 6 arcmin
GMTNIRS / NGSAO, LTAO	JHKLM AO-fed High Resolution Spectrograph	1.1 – 5.3	50,000 / 75,000 (JHK / LM)	1.2” long-slit
MANIFEST / NS, GLAO	Facility Robotic Fiber Feed	0.36 – 1.0		20’ diameter

Current Phase	Next Phase
Final Design	Fabrication
Preliminary Design	Final Design
Conceptual Design	Preliminary Design
Silicon Grating Technology Development	Preliminary Design
Science demonstrator closeout	Concept Design

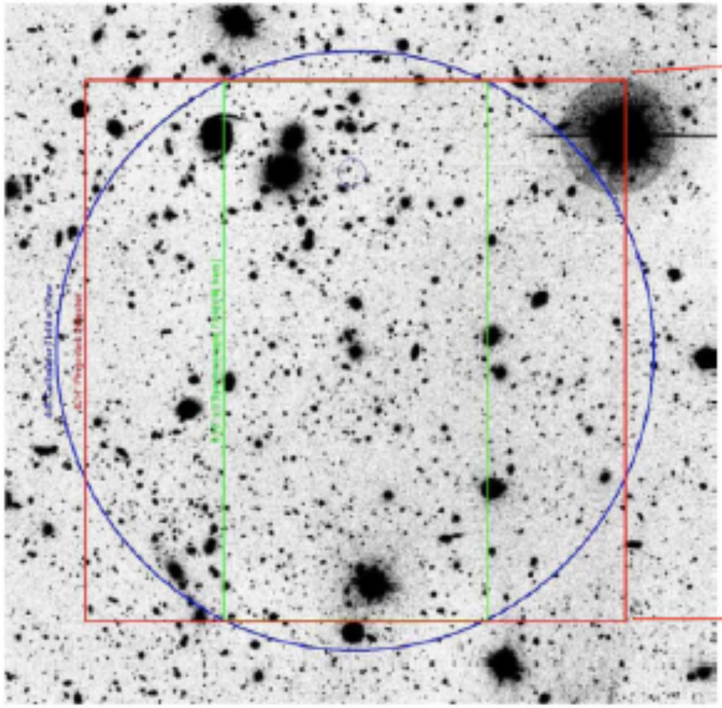
Additional information

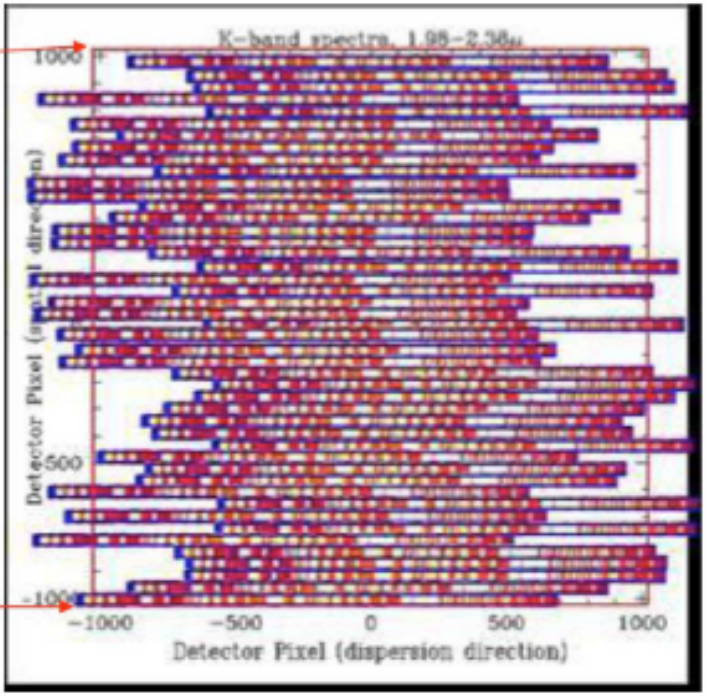
TMT Instrument – InfraRed Multi-object Spectrograph



Very close copy of Keck's MOSFIRE

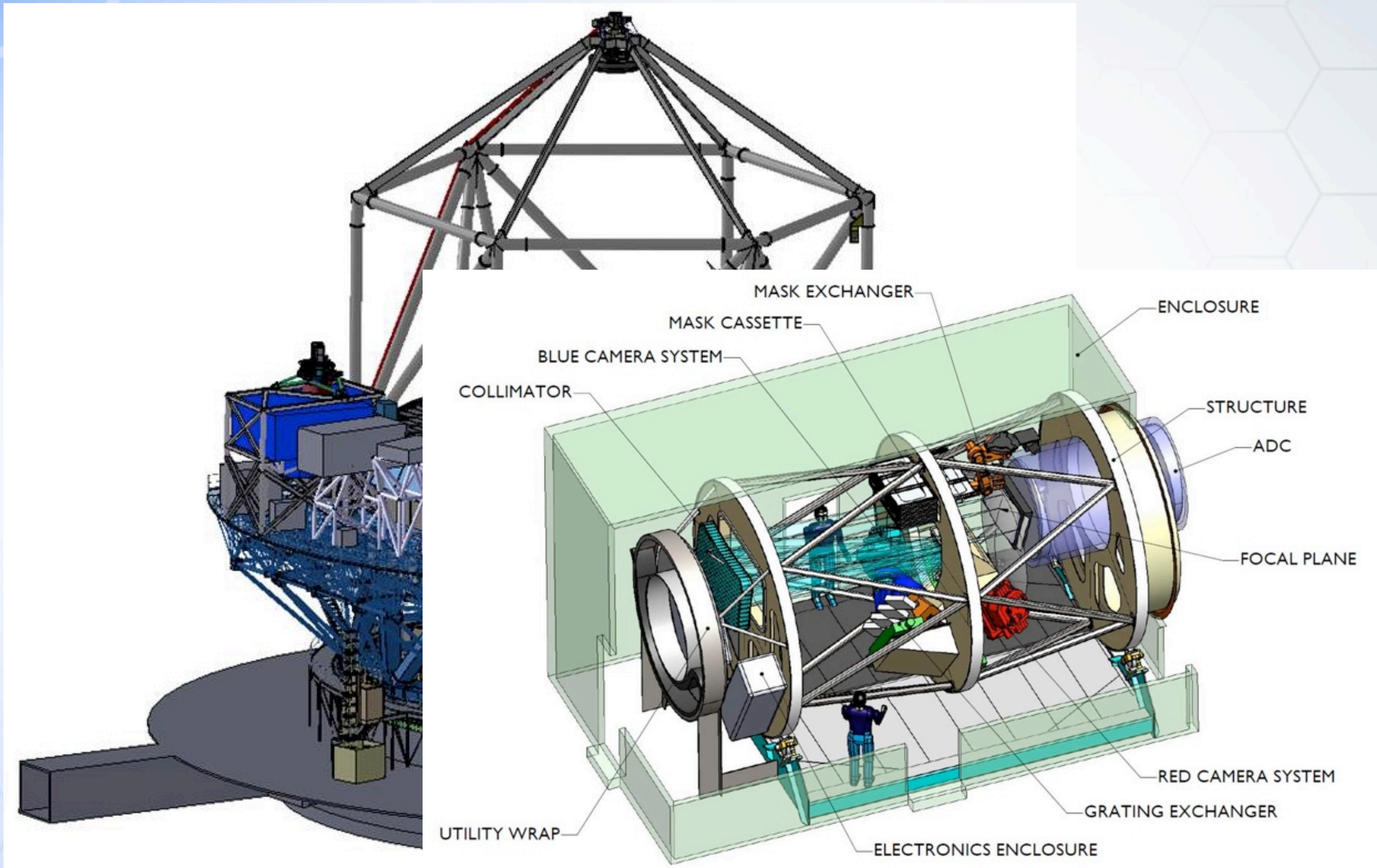
IRMS Spectra





Full Y, J, H, K spectra with R ~ 5000 with 160mas (2 pix) slits in central ~1/3 of field

WFOS first light instrument



IRIS Focal Plane: Imager + 2 IFUs + 3 Guide Stars

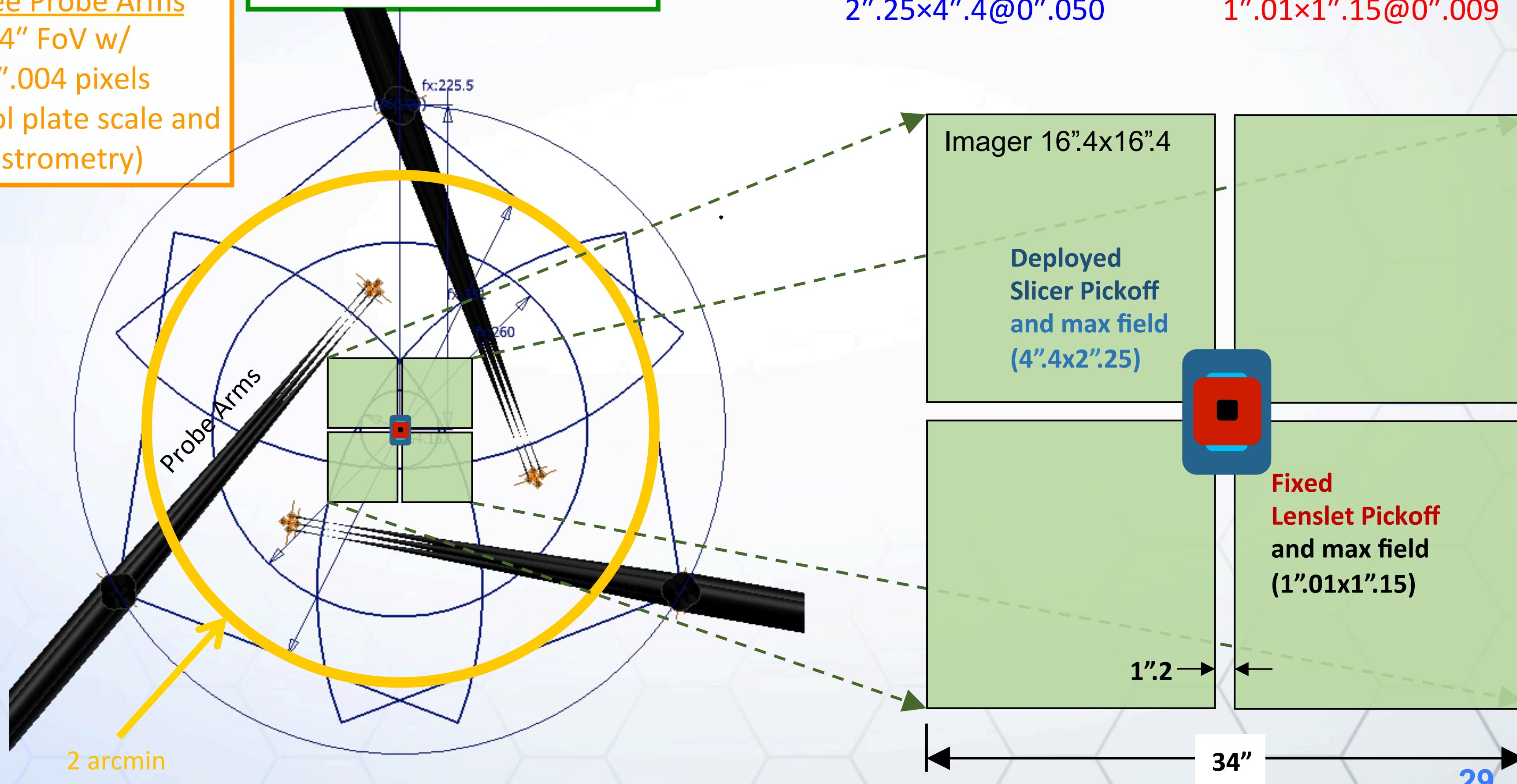
Imager
16".4×16".4 field (on-axis)
w/ 0".004 pixels
(JHK + Narrow-bands)

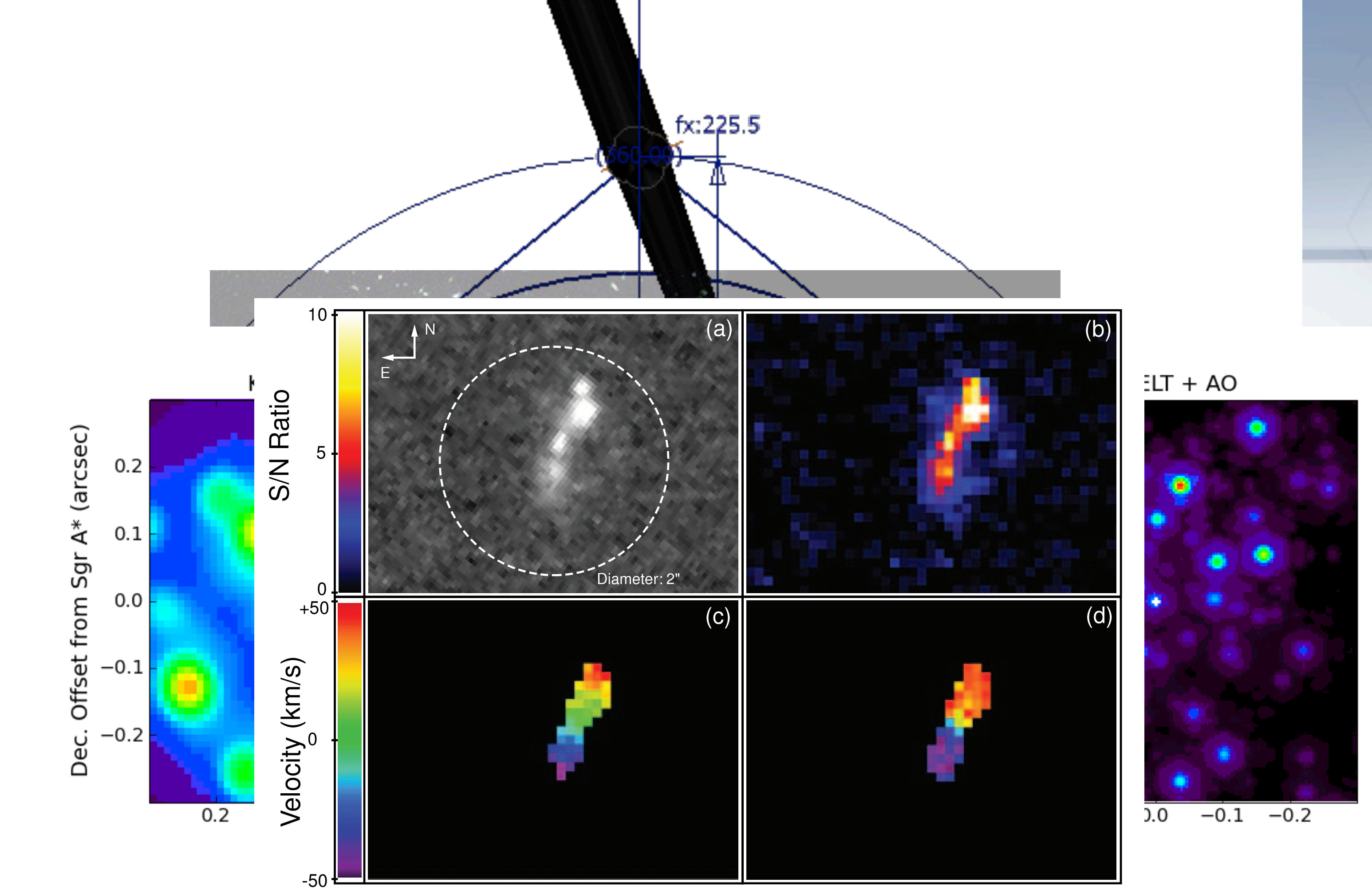
Lenslet and Slicer IFUs
0.84 -2.4μm, R = 4000-8000

2 Coarse Scales (Slicer)
1".13×2".20@0".025
2".25×4".4@0".050

2 Fine Scales (Lenslet)
0".45×0".51@0".004
1".01×1".15@0".009

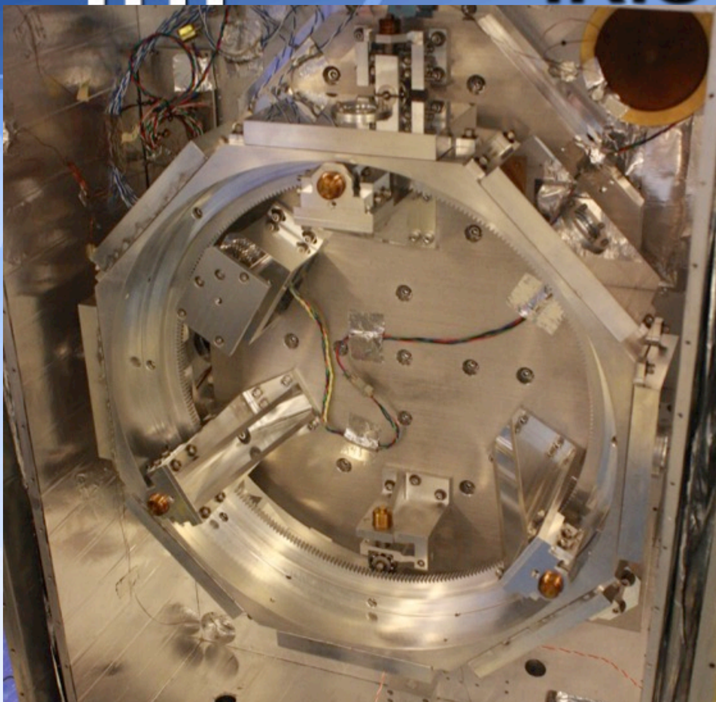
Three Probe Arms
4" FoV w/
0".004 pixels
(control plate scale and astrometry)

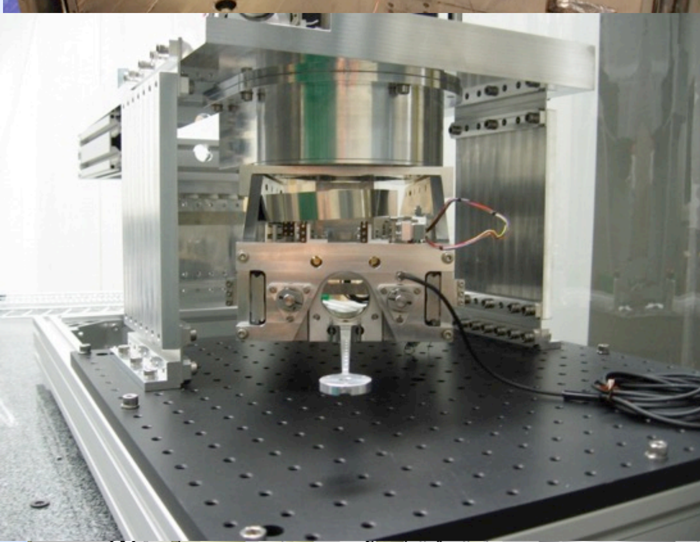


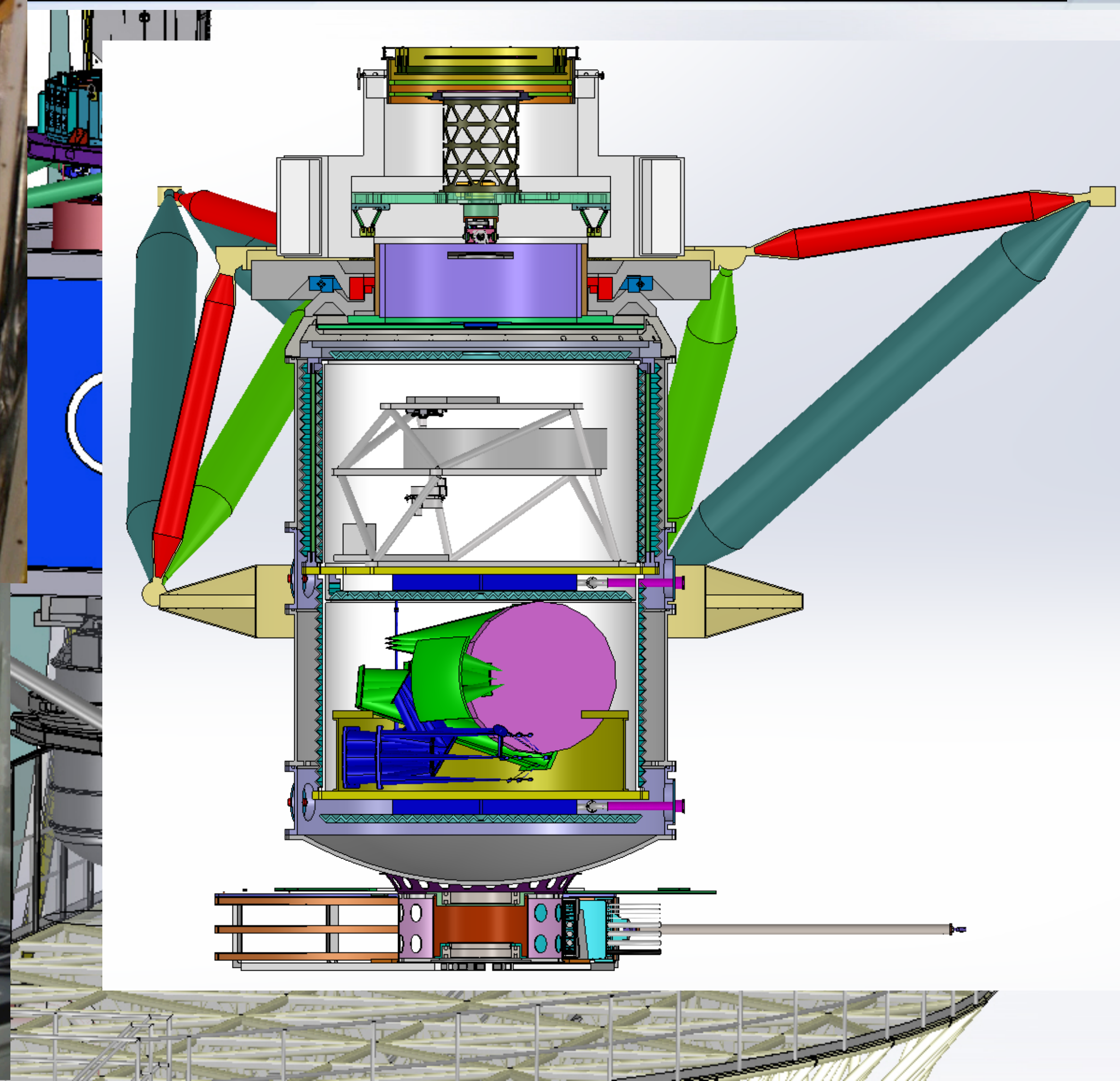


Galaxy/metallicity evolution
High-z dynamics/morphology

IRIS Mounted on NFIRAOS

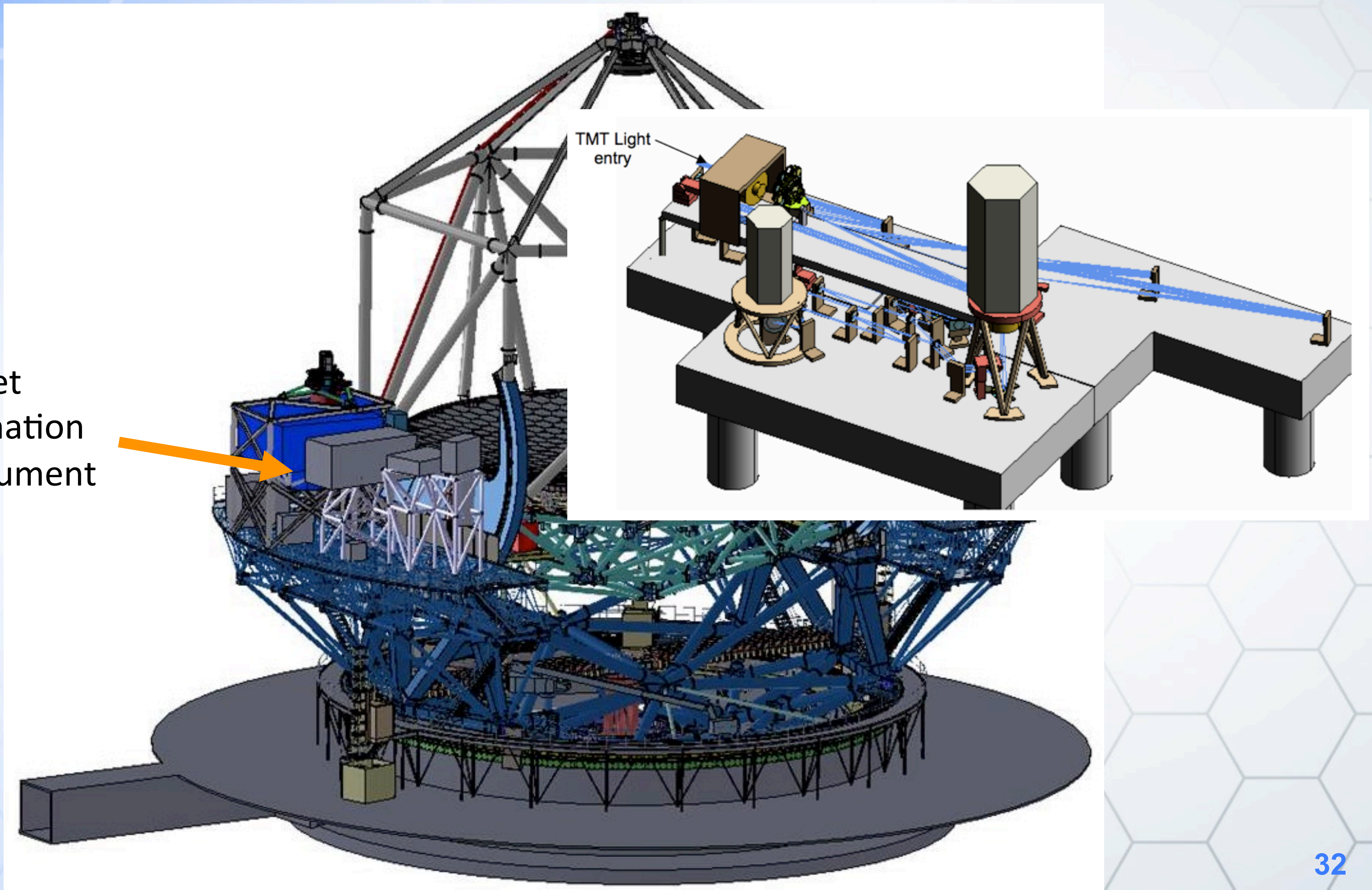




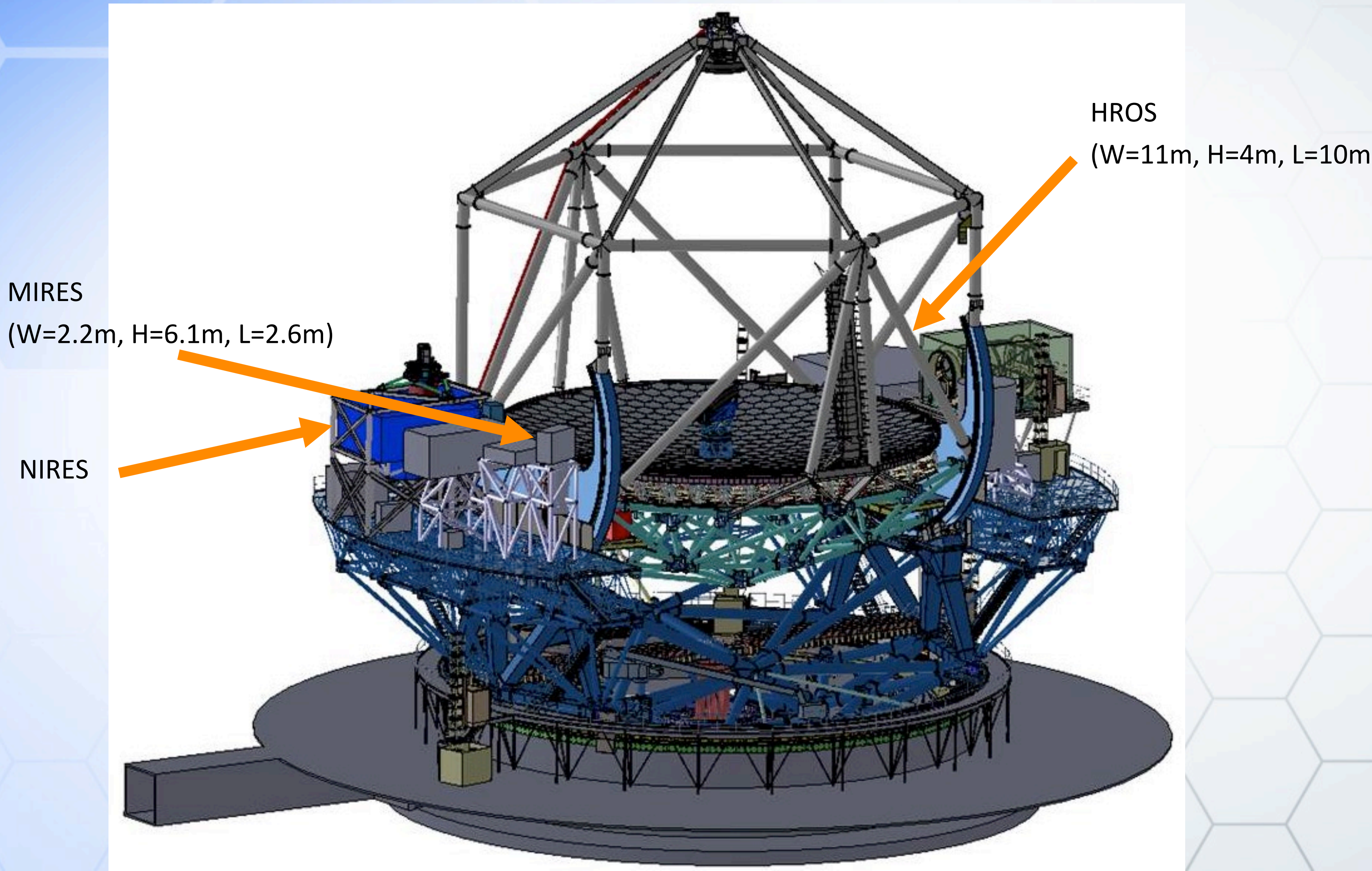


From Science to Subsystems

Planet Formation Instrument

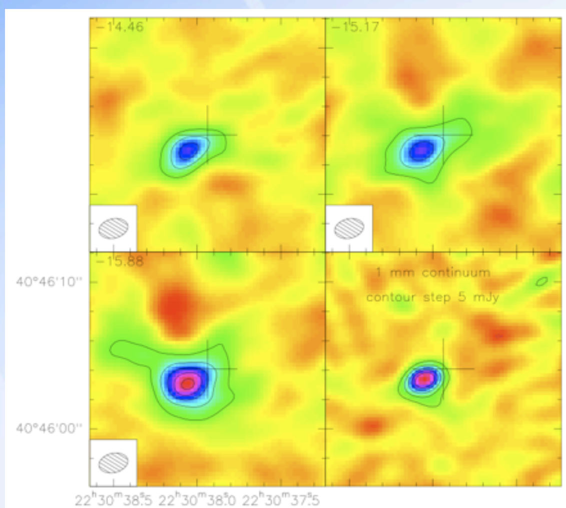


From Science to Subsystems



Mid-IR spectroscopy - Solar System

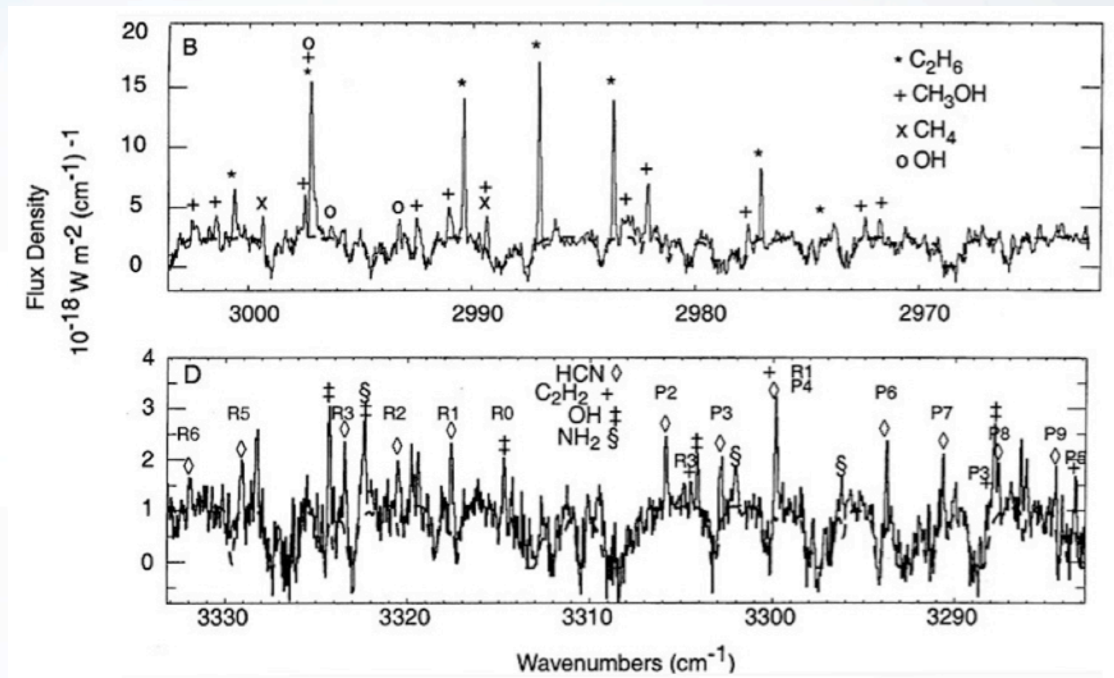
Physics and Chemistry of Cometary Atmospheres – mid-IR requires low PWV and MICHI



CO(2-1) emission and dust continuum from Comet Hale-Bopp at 1'' resolution with with IRAM

Submm+optical = nucleus albedo and size

(Figure 40 - "Science with ALMA" Document)



Detection of parent volatiles in Comet Lee (C/1999 H1) at R=20, 000. TMT/NIRES will allow diffraction-limited observations at R=100,000 over the range 4.5 - 28 μm

Look for "chemical families" as probes of the Oort Cloud

TMT Thirty Meter Telescope

From Science to

10 minute maximum system response time