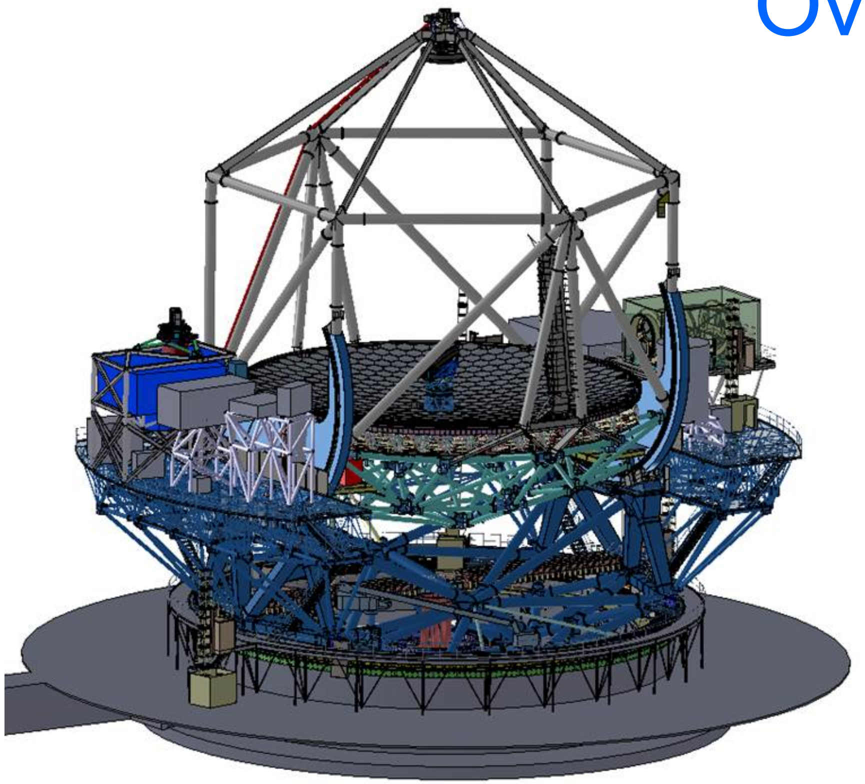


Overview of TMT Instruments and Science Flow-down

Luc Simard
Science Instruments Group Leader

TMT Science Forum
Tucson, Arizona, 17-19 July 2014

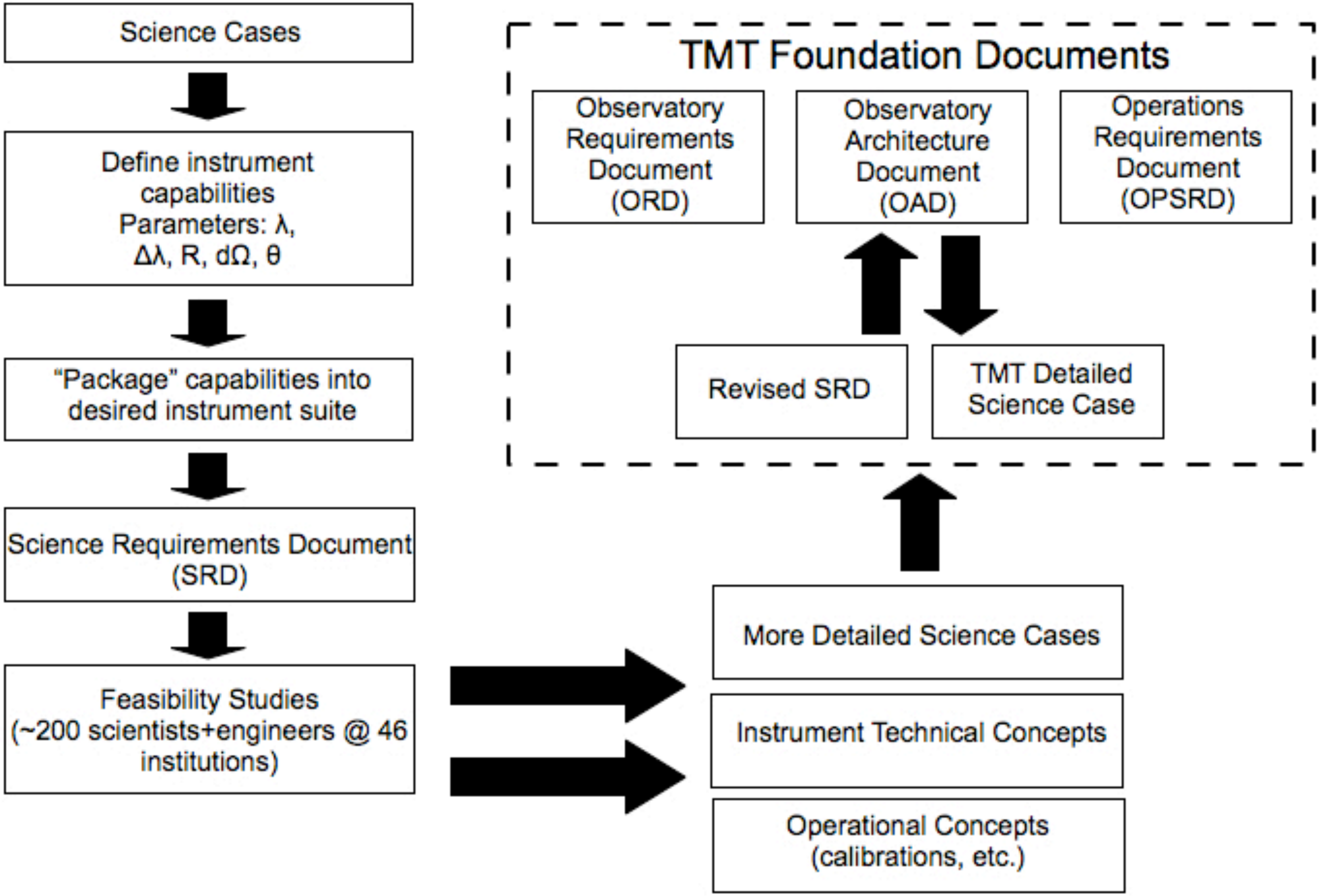
TMT.INS.PRE.14.048.REL01

TMT
THIRTY METER TELESCOPE

Science Flowdown

- Motivation:
  - Are all scientific requirements captured in the technical ones?
  - Will the current technical requirements and architecture for TMT indeed allow it to fully realize its scientific potential?
  - Invaluable in estimating the impact of various design decisions on science returns
- Caveats:
  - TMT is being designed as an observatory and not an experiment. Its scientific mission will evolve over its expected lifetime of fifty years
  - All science cases should be taken as exemplars. It is impossible to predict what questions will dominate astronomy ten years from now. However, these exemplars must push the TMT design into as broad a discovery space as possible.

TMT Science Flowdown



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Summary of TMT Science Objectives and Capabilities

Theme	Science Objectives	Observations	Requirements	Capabilities
Cosmology and Fundamental Physics (Dark energy, dark matter, physics of extreme objects, fundamental constants; DSC Section 3)	Mapping distribution of dark matter on large and small scales (CFP-[1,2,3,4], GAN-[3,4], GCT-1) General Relativity in new mass regime◆ (GAN-[4,D], SSE-4) Very precise expansion rate of Universe (CFP-2) Mapping variations in constants over cosmological timescales Physics of extreme objects ◆ (SSE-[2,3,D])	Proper motions in dwarf galaxies Wide-field optical spectroscopy of R = 24.5 galaxies Microarcsecond astrometry Transient events lasting > 30 days High spectral resolution observations of quasars and GRBs	λ = 0.31-0.62μm, 2-2.4μm R = 1000 - 50000 Very efficient acquisition 0.05 mas astrometry stable over 10 years Field of view > 10′	SL/WFOS SL/HROS MCAO/IRIS/WIRC MCAO/ NIRES
The Early Universe (First objects, IGM at z > 7; DSC Section 4)	Detection of metal-free star formation in First Light objects◆ (GAN-2, GCT-4) Mapping topology of re-ionization (GCT-4) Structure and neutral fraction of IGM at z > 7 (CFP-1, GCT-4)	Multiplexed, spatially-resolved spectroscopy of faint objects High spectral resolution, near-IR spectroscopy	λ = 0.8 – 2.5 μm R = 3000 – 30000 F = 3 x 10-20 ergs $s^{-1}cm^{-2}Å^{-1}$ Exposure times > $15e^3s$	MCAO/ IRMS/IRIS MOAO/ IRMOS MCAO/ NIRES
Galaxy formation and the IGM (DSC Section 5)	Baryons at epoch of peak galaxy formation◆ (CFP-1, GAN-1, GCT-[1,2]) 2D Velocity, SFR, extinction & metallicity maps of galaxies at z = 5-6◆ (CFP-3, GAN-1, GCT-[1,2]) IGM properties on physical scales < 300 kpc◆ (GAN-1, GCT-2)	Optical/near-IR multiplexed diagnostic spectroscopy of distant galaxies & AGNs Optical/near-IR multiplexed identification spectroscopy of extremely faint high redshift objects (to R~27) Spatially-resolved spectroscopy	λ = 0.31 – 2.5 μm R = 3000-5000, 50000 Very efficient acquisition Multiplexing factor > 100	SL/WFOS SL/HROS MCAO/IRIS/IRMS MOAO/ IRMOS
Extragalactic supermassive black holes (DSC Section 6)	Demographics of black holes over new ranges in mass and redshift◆ (GAN-4, GCT-3) Dynamical measurements out to z = 0.4◆ (GAN-4,GCT-[1,3]) Scaling relations out to z = 2.5 and masses at z>6◆ (GAN-4, GCT-[1,3])	Spatially-resolved spectroscopy of galaxy cores	λ = 0.8 – 2.5 μm R = 3000-5000 Precise positioning	MCAO/IRIS MOAO/ IRMOS
Galactic Neighborhood (DSC Section 7)	Abundance of oldest stars in Milky Way (CFP-4, GAN-[2,3], SSE-2) Chemical evolution in Local Group galaxies◆ (GAN-2) Diffusion and mass loss in stars (GAN-1, SSE-1) Resolved stellar populations out to Virgo cluster◆ (GAN-[2,3])	High spectral resolution optical and near-IR spectroscopy High-precision photometry in crowded fields	λ = 0.33-0.9, 1.4-2.4 μm R = 4000, 40000-90000 Photometry precision of 0.03 mag at Strehl = 0.6	SL/HROS MCAO/ NIRES MCAO/IRIS/WIRC SL/WFOS
Planetary Systems and Star Formation (physics of star formation,proto-planetary disks, exoplanets; DSC Section 8, Section 9)	Origin of mass in stars (GAN-[1,2], PSF-1) Architecture of planetary systems (PSF-[2,3,D]) Deposition of pre-biotic molecules onto protoplanetary surfaces (PSF-2) First direct detection of reflected-light Jovians (PSF-2) Characterization of exo-atmospheres (e.g., oxygen) (PSF-[3,4,D])	High-precision, crowded field photometry Diffraction-limited, high spectral resolution mid-IR spectroscopy Very high Strehl AO-assisted imaging: precise wavefront control High spectral resolution optical and near-IR spectroscopy	λ = 1 – 25 μm R = 4000, 30000-100000 Low telescope emissivity Dry site (PWV < 5 mm) Fixed gravity vector and thermal control Very efficient acquisition Contrast ratio of 10^8–10^9	MCAO/IRIS MIRAO/ MIRES MCAO/ NIRES SL/HROS ExAO/PFI
Our Solar System (outer parts, surface physics and atmospheres; (DSC Section 10)	Composition of Kuiper Belt Objects and comets (PSF-2) Monitoring weather, (cryo-) vulcanism and tectonic activity◆	Spatially resolved spectroscopy of objects in solar system Transient events (hours to years)	λ = 1-10 μm R = 1000 – 100000 Non-sidereal tracking Fast response time	MCAO/IRIS/WIRC MCAO/ NIRES MIRAO/ MIRES

Fundamental Physics and Cosmology

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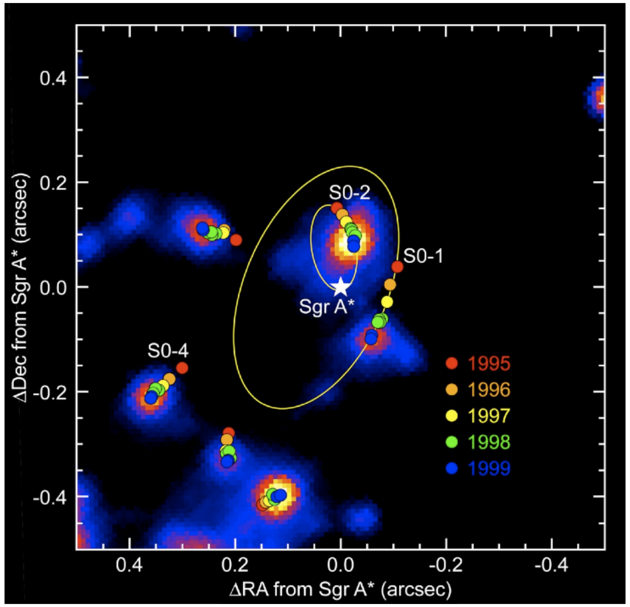
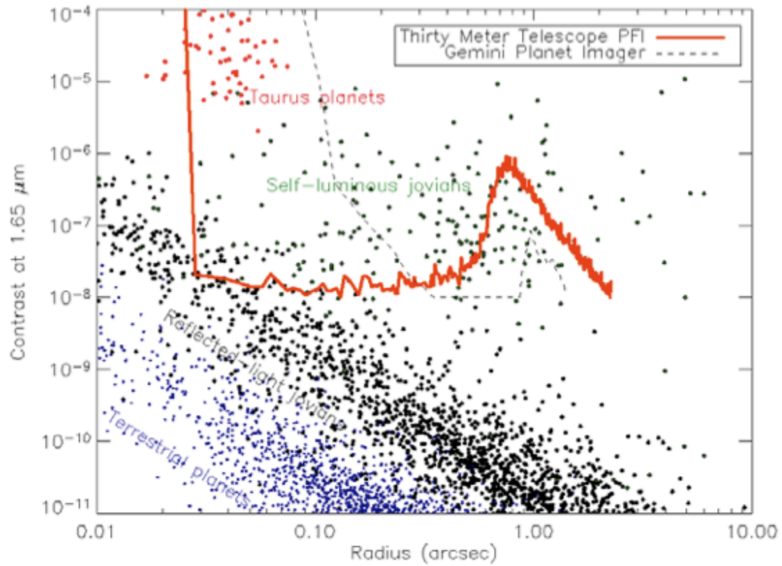
- Science objectives:
  - Dark matter on large and small scales
  - Kerr spacetime in unexplored mass regime
  - Dark energy density versus cosmic time
  - Variations of fundamental constants over cosmological timescales
- Observations:
  - Wide-field spectroscopy (SL/WFOS)
  - Transient events lasting > 30 days
  - High-res observations of quasars/AGNs
  - Proper motions in dwarf galaxies and microarcsec astrometry (MCAO/IRIS/WIRC)



- λ = 0.31-0.62μm, 2-2.4μm
- R = 1000 - 50,000
- Very efficient acquisition
- 0.05 mas astrometry stable over 10 years
- SL Field of view = 20′
- AO field of view = 15″ (w/ stable PSF)

Formation of Stars and Planets

- **Science objectives:**
  - Origin of stellar masses
  - Architecture of planetary systems
  - Pre-biotic molecules in disks
  - First direction of reflected-light Jovians
  - Exoplanetary atmospheres (oxygen)
- **Observations:**
  - High precision, crowded field photometry (MCAO/IRIS/WIRC)
  - Very high Strehl ratio imaging (ExAO/PFI)
  - Diffraction-limited, high-resolution, mid-IR (MIRAO/MIRES)
  - High-res optical and IR spectroscopy



- λ = 1-25 μm
- R = 4000,30000-100,000
- Low telescope emissivity and PWV < 5 mm
- Fixed gravity vector
- Strehl ratio > 0.9 and contrast ratio of $10^{8\text{-}9}$

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From Science to Requirements: WFOS Observing Programs

	White dwarfs	Resolved populations	Dark matter mapping	IGM Tomography I	IGM Tomography II	High-z escape fraction
Slits/mask	200	380	100–750	40	70	50
Masks/barrel/night	2	2.5,7	6	2	10	2
Slit width [arcsec]	0.6	0.8	0.6	0.75	0.75	0.75
Number of nights required	3	28	15	40	100	20
Typical integration time/exposure [s]	1800	1200	1200	1800	1800	1800
Typical integration time/mask [ks]	15	9,3	3.6	22	3.6	200
Resolution (blue arm/red arm)	2000	5000	2000/5000	5000	1000	1000
Number of dichroics needed	1	1	1	2	1	1
Good wavelength for dichroic split [Å]	5800	6000	6000	4300/5000	5600	5500
Minimum wavelength (blue arm/red arm) [Å]	3400	4600/7900	3700/8300	3400/4300	3200/5600	5700
... when second dichroic is used:	–		–	4400/5000	–	5700
Maximum wavelength (blue arm/red arm) [Å]	5800	5200/9000	5400/8800	4300/5400	5600/10300	8775
... when second dichroic is used:	–		–	5000/6400	–	5700
Seeing FWHM required [arcsec]	0.7	0.8	0.8	0.8	0.8	0.75
Needs pre-imaging?	✔	✔	✔			
Calibrate with sky lines?					✔	✔
Need very precise flux calilbration?		✔	✔			
Needs very precise sky subtraction?		✔	✔	✔	✔	✔
Benefits from Nod & Shuffle?		✔	✔	✔	✔	✔
Best done in a queue?	✔		✔	✔	✔	✔
Uses blue and red arms at same time?	✔	✔	✔	✔	✔	
Big benefits from GLAO?	✔	✔	✔	✔	✔	✔
Big benefits from SLGLAO?	✔	✔	✔			
Care about LGS beacon positions?	✔		✔			
Benefits from quick switch of dichroics?				✔	✔	✔
Efficiency a strong function of dichroic split?				✔	✔	✔
Hurt by non-contiguous coverage?	✔	✔	✔			
Synergistic with JWST?		✔		✔	✔	✔
Synergistic with ALMA?				✔	✔	

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WFOS ORD Top-Level Requirements

Requirement #	Description	Requirement
[REQ-1-ORD-3950]	Wavelength Range	0.31 – 1.0µm
[REQ-1-ORD-3955]	Image quality: Imaging	≤ 0.2 arcsec FWHM over any 0.1µm wavelength interval (including contributions from the telescope and the ADC at z=60°)
[REQ-1-ORD-3960]	Image quality: Spectroscopy	≤ 0.2 arcsec FWHM at every wavelength
[REQ-1-ORD-3965]	Field of View	40.5 arcmin^2. The field need not be contiguous.
[REQ-1-ORD-3970]	Total Slit Length	≥ 500 arcseconds
[REQ-1-ORD-3975]	Spatial Sampling	< 0.15 arc-sec per pixel, goal < 0.1 arc-sec
[REQ-1-ORD-3980]	Spectral Resolution	R = 500-5000 for a 0.75 arc-sec slit, 150-7500 (goal)
[REQ-1-ORD-3985]	Throughput	≥ 30% from 0.31 – 1.0µm, or at least as good as that of the best existing spectrometers
[REQ-1-ORD-3990]	Sensitivity	Spectra should be photon noise limited for all exposure times >60 sec. Background subtraction systematics must be negligible compared to photon noise for total exposure times as long as 100 Ksec. Nod and shuffle capability in the detectors may be desirable
[REQ-1-ORD-3995]	Wavelength Stability	Flexure at a level of less than 0.15 arc-sec at the detector is required.

Science Flowdown Matrix Parameters

Domain	Parameter Name	
Configuration	Observing Mode	
Spectral Parameters	Wavelength range	
	Spectral Resolution	
	Flux/radial velocity	Relative / absolute
		Precision
		Stability timescale
Spatial Parameters	Image quality	Resolution
		Strehl ratio / contrast ratio
	Geometry	Total areal coverage
		Field of view per observation
		Field overlap
	Astrometry	Relative / absolute
		Precision
		Stability timescale
Multiplexing	Sample size	
	Number of observations	
Tracking	Rate	
Synoptic Signature	Baseline	
	Cadence	
	Duration	

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Science Flowdown Matrix - A small subsection

Science Program	Spatial Parameters: Image Quality — Resolution (mas)	Image Quality — Strehl (S) / Contrast (C) ratio	Image Quality — SRD/ORD Requirement(s)	Geometry — Total Areal Coverage (sq. arcmin)	Geometry — Field of view / observation (sq. arcmin)	Geometry — Field overlap (0-1)	Geometry — SRD/ORD Requirement(s)	Astrometry — Relative/ absolute	Astrometry — Precision (mas)	Astrometry — Stability timescale (years)
Multiplexed spectroscopy of distant galaxies: rest-frame optical DSC 5.4	200		SRD-0070, 0075, 0100, 0105, 0110, 0115, 0120, 0145, [0405-0420], [0455-0470], [0565-0580], 1115	> 350	3.5	0.00	SRD-[0220-0230], 0250, 0260, 0265, 0805, 0815, 1105, 1120, 1140, 1305, 1315, 1320, 1330			
Spatial dissection of forming galaxies DSC 5.5	8	S = 0.5 [7]	SRD-0045, 0070, 0075, 0100, 0105, 0110, 0115, 0120, 0145, [0405-0420], [0455-0470], [0565-0580], [0820-0830], 0915, 1015, 1025, 1030, 1035, 1310	275 [10]	25 [10]	0.00 [10]	SRD-[0220-0230], 0250, 0260, 0265, 0270, 0280, 0805, 0850, 0885, 0890, 0905, 0910, 0920, 1005, 1010, 1030, 1035, 1305, 1315, 1320, 1330	Relative [10]	100 [10]	
IGM: Core samples during galaxy formation epoch DSC 5.6	800 [17]		SRD-0070, 0110, 0120, 0145, [0455-0470], [0565-0580], 1220, 1225, 1230, 1275, 1715, 1720	4 x 4032	40.3 [17]	0.01	SRD-0050, 0220, 0225, 1205, 1230, 1705, 1710, 1720			
Epoch of galaxy formation in 3D DSC 5.7	800 [17]		SRD-0070, 0110, 0120, 0145, [0455-0470], [0565-0580], 1220, 1225, 1230, 1275	4 x 4032	40.3 [17]	0.01	SRD-0050, 0220, 0225, 0250, 0255, 0265, 1205, 1230			
SMBHs in nearby galactic nuclei DSC 6.1	10 [7]	S = 0.5 [7]	SRD-0045,0070, 0075, 0100, 0105, 0110, 0115, 0120, 0145, [0405-0420], [0455-0470], [0565-0580], [0820-0830], 1015, 1025, 1030, 1035	< 10.2 [7]	< 0.03 [8]	0.00	SRD-[0220-0230], 0250, 0260, 0265, 0805, 0885, 0890, 1005, 1010, 1030, 1035	Relative [22]	2 [22]	
			SRD-0045, 0070							

Science Flowdown Matrix - A small subsection

Science Program	Spatial Parameters: Image Quality: Resolution (mas)	Strehl (S) / Contrast (C) ratio	SRD/ORD Requirement(s)	Geometry: Total Areal Coverage (sq. arcmin)	Field of view / observation (sq. arcmin)	Field overlap (0-1)	SRD/ORD Requirement(s)	Astrometry: Relative/ absolute	Precision (mas)	Stability timescale (years)
Multiplexed spectroscopy of distant galaxies: rest-frame optical DSC 5.4	200		SRD-0070, 0075, 0100, 0105, 0110, 0115, 0120, 0145, [0405-0420], [0455-0470], [0565-0580], 1115	> 350	3.5	0.00	SRD-[0220-0230], 0250, 0260, 0265, 0805, 0815, 1105, 1120, 1140, 1305, 1315, 1320, 1330			
Spatial dissection of forming … DSC 5.5			SRD-0045, 0070, 0075, 0100, …				SRD-[0220-0230], 0250, …	Relative [30]	100 [30]	
IGM: Core samples during galaxy … DSC 5.6	800 [17]		… [0565-0580], 1220, 1225, 1230, 1275, 1715, 1720	4 x 4032	40.3 [17]	0.01	… 1205, 1230, 1705, 1710, 1720			
Epoch of galaxy formation in 3D DSC 5.7	800 [17]		SRD-0070, 0110, 0120, 0145, [0455-0470], [0565-0580], 1220, 1225, 1230, 1275	4 x 4032	40.3 [17]	0.01	SRD-0050, 0220, 0225, 0250, 0255, 0265, 1205, 1230			
SMBHs in nearby galactic nuclei DSC 6.1	10 [7]	S = 0.5 [7]	SRD-0045,0070, 0075, 0100, 0105, 0110, 0115, 0120, 0145, [0405-0420], [0455-0470], [0565-0580], [0820-0830], 1015, 1025, 1030, 1035	< 10.2 [7]	< 0.03 [4]	0.00	SRD-[0220-0230], 0250, 0260, 0265, 0805, 0885, 0890, 1005, 1010, 1030, 1035	Relative [22]	2 [22]	

The TMT Science Flowdown is not static – It is updated to reflect changes to existing science programs and to include new ones

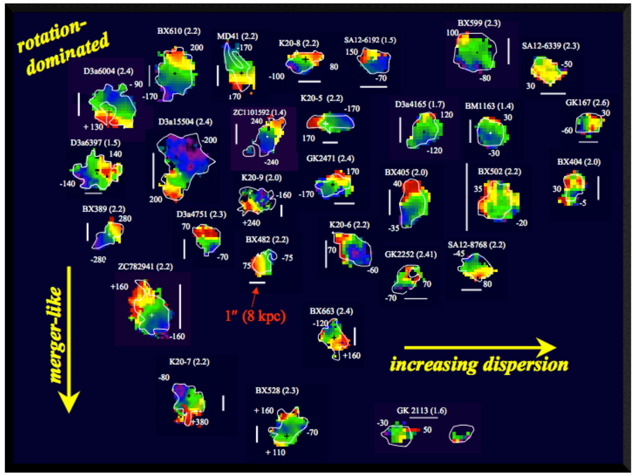
Other Top-Level Observatory Requirements

- Instrument Systems:
  - Target acquisition sequences
  - Access and servicing
- Observatory Systems:
  - Nasmyth structures
  - Mass budget
  - Surface area and height
  - M1 airflow
  - Cooling systems
    - Vibrations must be minimized
    - Four thermal environments: T=10C, -30C, 77K and < 50-60K
  - Cranes

Observatory is being designed as an "end-to-end" system to maximize performance

Multiplexing versus Discovery

- Requirements:
  - Wavelength range, field of view/ slit length, spectral resolution
- Impact:
  - Multiplexing:
    - IGM tomography
    - Topology of reionization
    - Rest-frame UV and optical properties of distant galaxies
  - Discovery:
    - Identification and diagnostic spectroscopy of transient phenomena (e.g., supernovae/GRBs/tidal flares)
    - Metal-free star formation in First Luminous Objects
    - Pre-biotic molecules



Galaxy velocity fields from SINS survey

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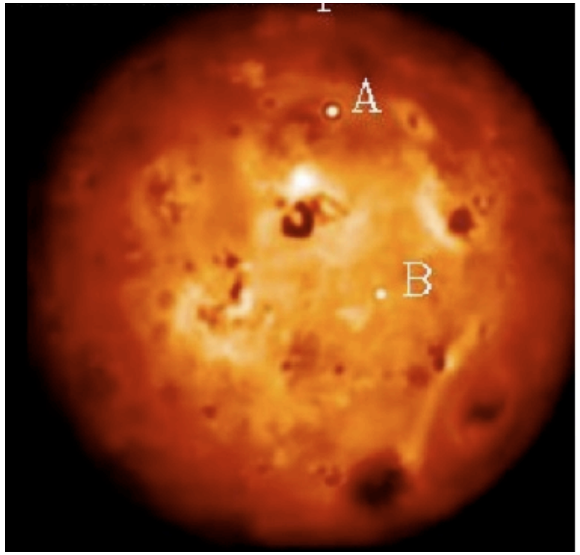
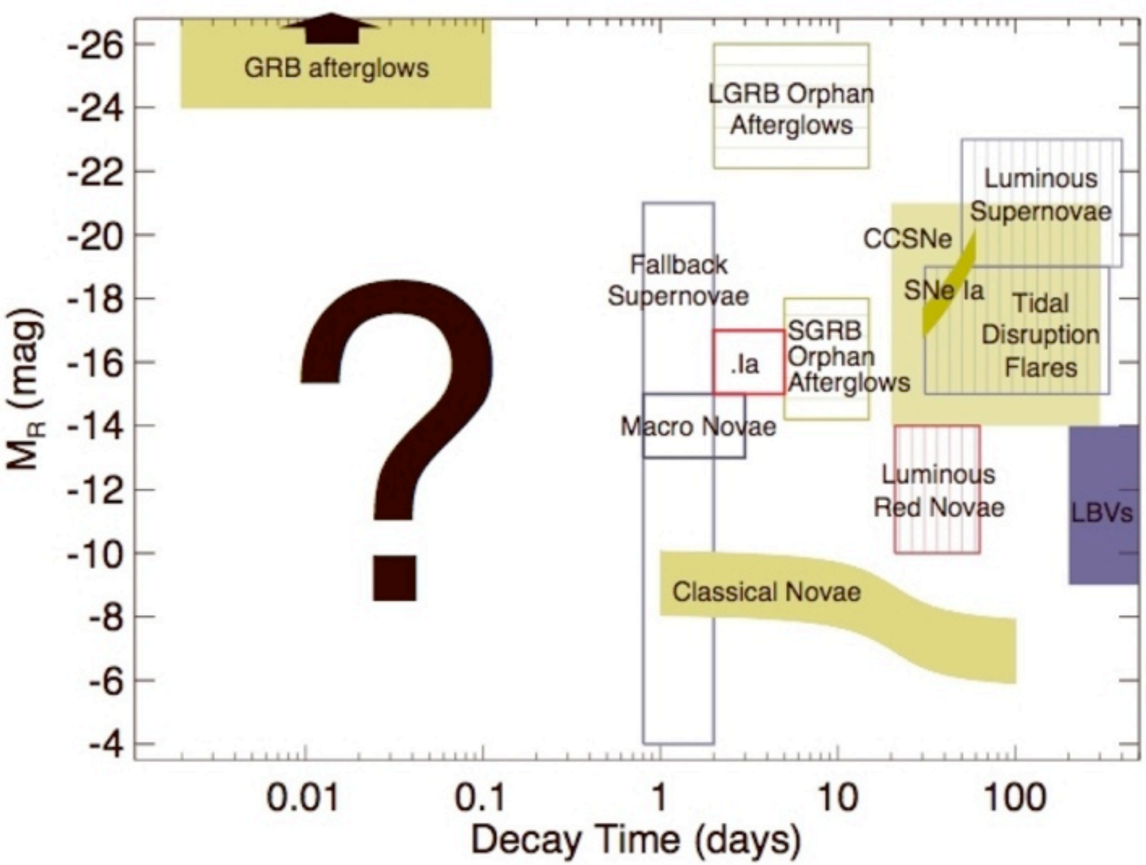
Observing Efficiency

- Requirements:
  - Acquisition, calibration, downtime, fast response and operating weather conditions
- Impact:
  - Large programs (# observations > 500)
    - IGM tomography
    - Jovian exoplanets
    - Doppler detection of planetary systems
  - Time-critical programs
    - Supernovae/GRBs/...
    - Weather and volcanic activity in the outer solar system
    - Exoplanetary transits



Io with TMT/MCAO

TMT as an Agile Telescope: Catching The “Unknown Unknowns”



TMT target acquisition time requirement is 5 minutes
(i.e., 0.0034 day)

Tightly sequenced observations will be key

Source: Figure 8.6, LSST Science Book

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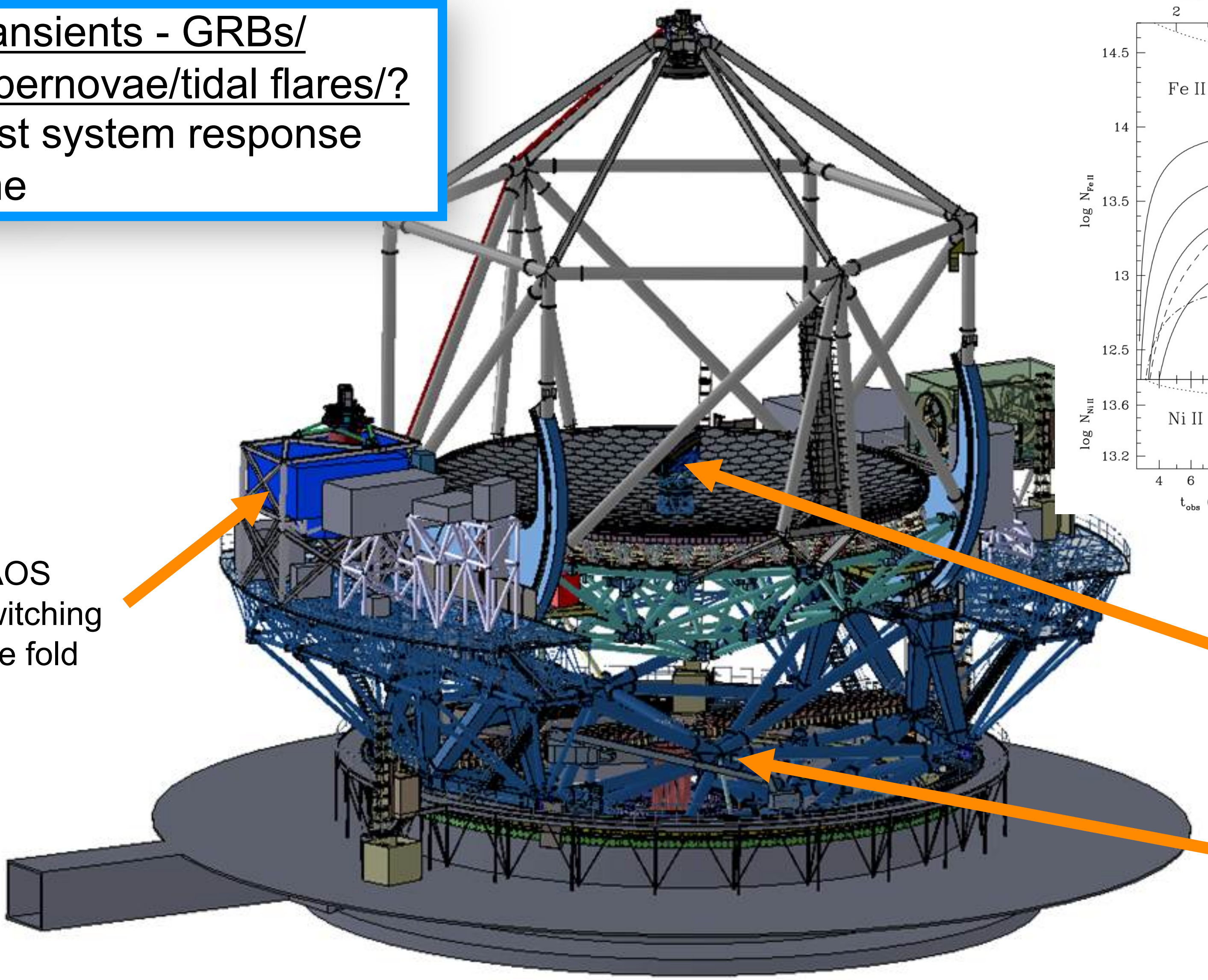
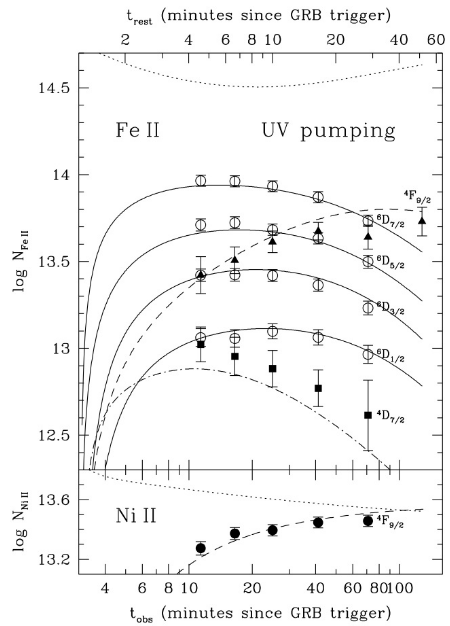
From Science to Subsystems

<u>Transients - GRBs/ supernovae/tidal flares/?</u>
Fast system response time





NFIRAOS fast switching science fold mirror

Articulated M3 for fast instrument switching

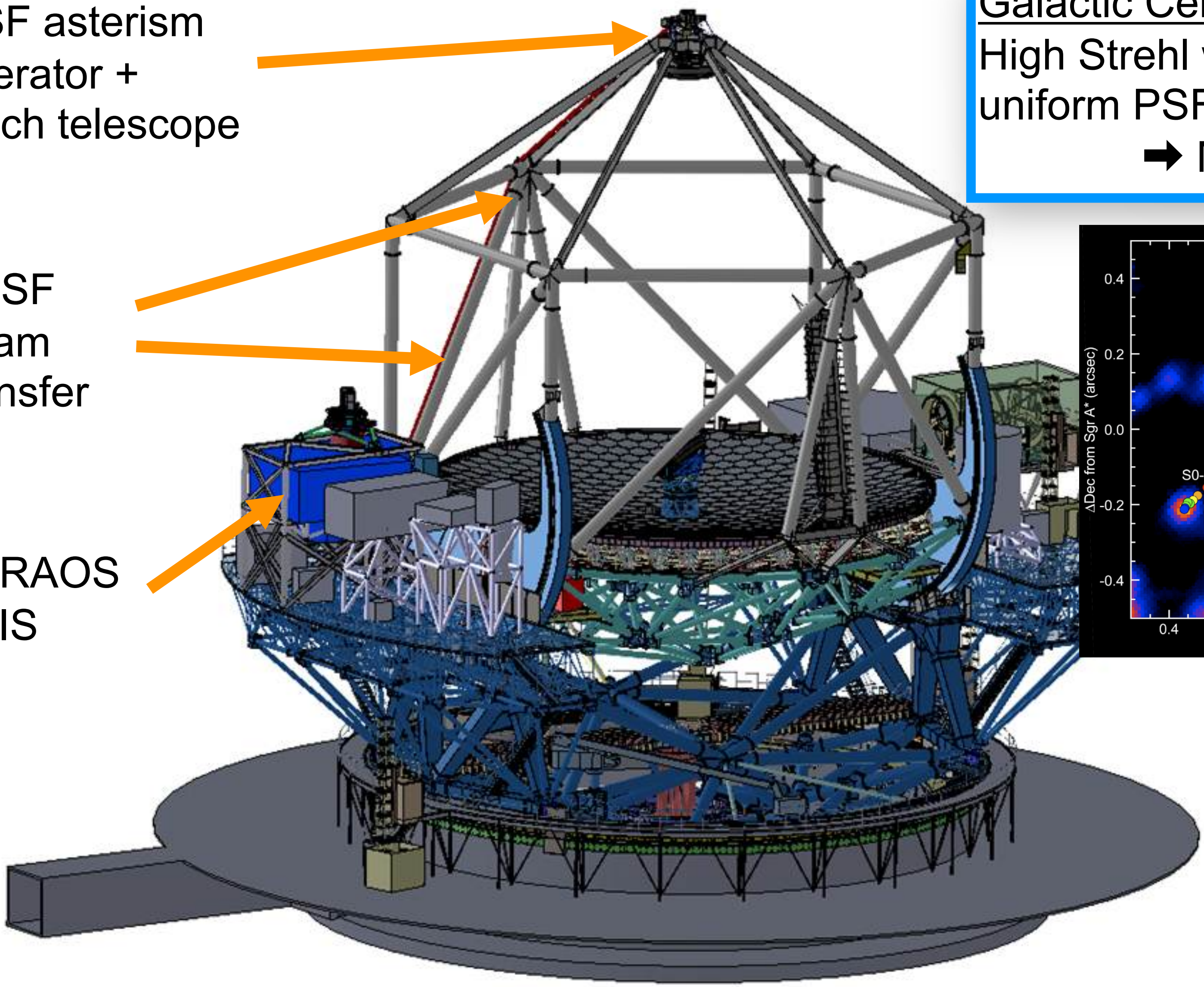
Fast slewing and acquisition

From Science to Subsystems

LGSF asterism generator + launch telescope

LGSF beam transfer

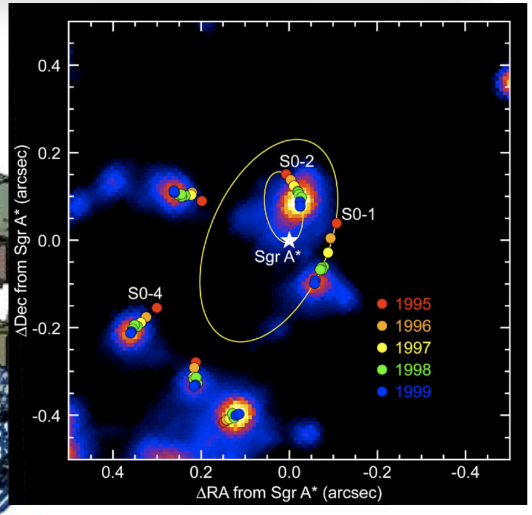
NFIRAOS +IRIS



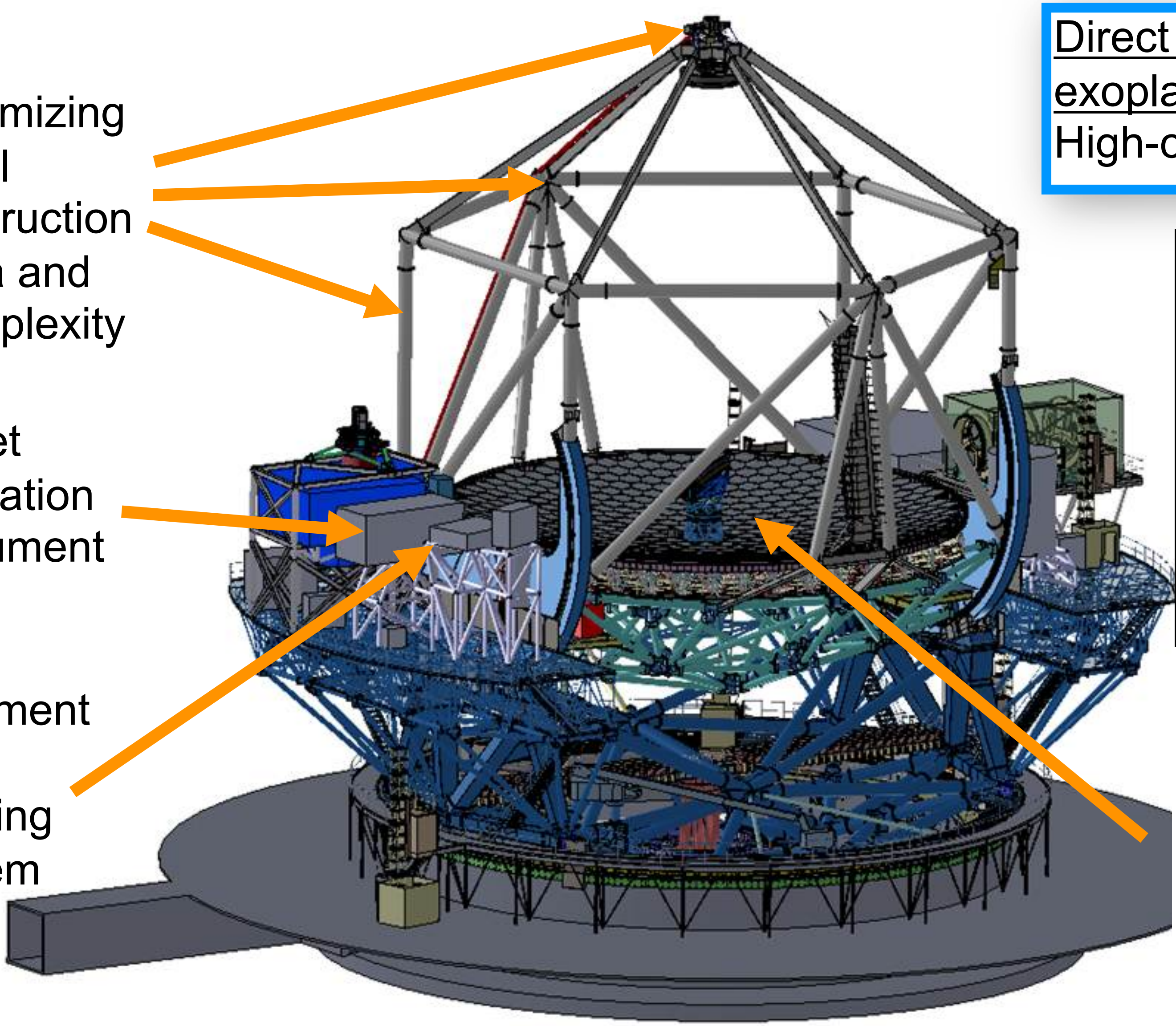
Galactic Center

High Strehl w/ stable, uniform PSF over 15”

➡ MCAO



From Science to Subsystems

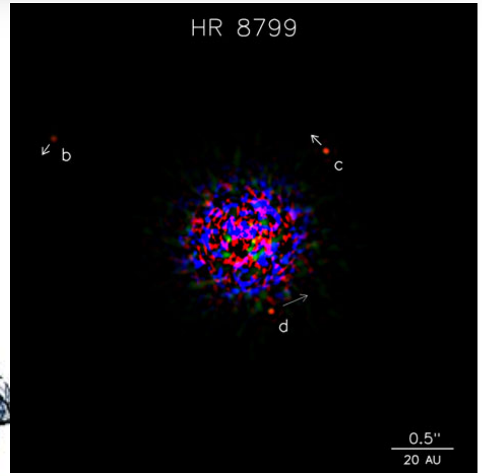


Minimizing pupil obstruction area and complexity

Planet Formation Instrument

Alignment and Phasing System

Direct imaging of exoplanets
High-contrast imaging



Filled aperture + segment surface errors, coating, and cleaning

TMT Planned Instrument Suite

Instrument	Field of view / slit length	Spectral resolution	λ (μm)	Comments
InfraRed Imager and Spectrometer (IRIS)	< 4.″4 x 2″.25 (IFU) 16″.4 x 16″.4″ (imaging)	4000-8000 5-100 (imaging)	0.8 – 2.4	MCAO with NFIRAOS
Wide-field Optical spectrometer (WFOS)	40.3′ squared (FoV) 576″ (Total slit length)	1000-8000	0.31-1.1	Seeing-Limited (SL)
InfraRed Multislit Spectrometer (IRMS)	2′ field w/ 46 deployable slits	*R* = 4660 @ 0.16″ slit	0.95-2.45	MCAO with NFIRAOS
Multi-IFU imaging spectrometer (IRMOS)	3″ IFUs over >5′ diameter field	2000-10000	0.8-2.5	MOAO
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 1-5 (goal)	10^8 contrast 10^9 goal
Near-IR AO-fed Echelle Spectrometer (NIRES)	2″ slit length	20000-100000	1-5	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

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TMT Planned Instrument Suite

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Planet Formation Instrument (PFI)	1″ outer working angle, 0.05″ inner working angle	R≤100	1-2.5 1-5 (goal)	10^8 contrast 10^9 goal
Near-IR AO-fed Echelle Spectrometer (NIRES)	2″ slit length	20000-100000	1-5	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

Visible, Seeing-Limited

THIRTY METER TELESCOPE

TMT Planned Instrument Suite

Instrument	Field of view / slit length	Spectral resolution	λ (μm)	Comments
InfraRed Imager and Spectrometer (IRIS)	< 4.″4 x 2″.25 (IFU) 16″.4 x 16″.4″ (imaging)	4000-8000 5-100 (imaging)	0.8 – 2.4	MCAO with NFIRAOS
Wide-field Optical spectrometer (WFOS)	40.3′ squared (FoV) 576″ (Total slit length)	1000-8000	0.31-1.1	Seeing-Limited (SL)
InfraRed Multislit Spectrometer (IRMS)	2′ field w/ 46 deployable slits	*R* = 4660 @ 0.16″ slit	0.95-2.45	MCAO with NFIRAOS
Multi-IFU imaging spectrometer (IRMOS)	3″ IFUs over >5′ diameter field	2000-10000	0.8-2.5	MOAO
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″ out[illegible] angle, 0.05″ inner working angle		1-5 (goal)	10^8 contrast 10^9 goal
Near-IR AO-fed Echelle Spectrometer (NIRES)	2″ slit length	20000-100000	1-5	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

Near-IR, AO-assisted

TMT Planned Instrument Suite

THIRTY METER TELESCOPE

Instrument	Field of view / slit length	Spectral resolution	λ (μm)	Comments
InfraRed Imager and Spectrometer (IRIS)	< 4.″4 x 2″.25 (IFU) 16″.4 x 16″.4″ (imaging)	4000-8000 5-100 (imaging)	0.8 – 2.4	MCAO with NFIRAOS
Wide-field Optical spectrometer (WFOS)	40.3′ squared (FoV) 576″ (Total slit length)	1000-8000	0.31-1.1	Seeing-Limited (SL)
InfraRed Multislit Spectrometer (IRMS)	2′ field w/ 46 deployable slits	R = 4660 @ 0.16″ slit	0.95-2.45	MCAO with NFIRAOS
Multi-IFU imaging spectrometer (IRMOS)	3″ IFU diame			MOAO
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 1-5 (goal)	10^8 contrast 10^9 goal
Near-IR AO-fed Echelle Spectrometer (NIRES)	2″ slit length	20000-100000	1-5	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

High-Contrast AO

TMT

THIRTY METER TELESCOPE

TMT Planned Instrument Suite

Instrument	Field of view / slit length	Spectral resolution	λ (μm)	Comments
InfraRed Imager and Spectrometer (IRIS)	< 4.″4 x 2″.25 (IFU) 16″.4 x 16″.4″ (imaging)	4000-8000 5-100 (imaging)	0.8 – 2.4	MCAO with NFIRAOS
Wide-field Optical spectrometer (WFOS)	40.3′ squared (FoV) 576″ (Total slit length)	1000-8000	0.31-1.1	Seeing-Limited (SL)
InfraRed Multislit Spectrometer (IRMS)	2′ field w/ 46 deploy[illegible]	R = 4660 @ 0.16″ slit	0.95-2.45	MCAO with NFIRAOS
Multi-IFU imaging spectrometer (IRMOS)	3″ IFU[illegible] diameter field	[illegible]	[illegible]	MOAO
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 1-5 (goal)	10^8 contrast 10^9 goal
Near-IR AO-fed Echelle Spectrometer (NIRES)	2″ slit length	20000-100000	1-5	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

Mid-IR, AO-assisted

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TMT First-Light Instrument Suite

Instrument	Field of view / slit length	Spectral resolution	λ (μm)	Comments
InfraRed Imager and Spectrometer (IRIS)	< 4.″4 x 2”.25 (IFU) 16”.4 x 16”.4” (imaging)	4000-8000 5-100 (imaging)	0.8 – 2.4	MCAO with NFIRAOS
Wide-field Optical spectrometer (WFOS)	40.3′ squared (FoV) 576” (Total slit length)	1000-8000	0.31-1.1	Seeing-Limited (SL)
InfraRed Multislit Spectrometer (IRMS)	2′ field w/ 46 deployable slits	*R* = 4660 @ 0.16″ slit	0.95-2.45	MCAO with NFIRAOS
Multi-IFU imaging spectrometer (IRMOS)	3″ IFUs over >5′ diameter field	2000-10000	0.8-2.5	MOAO
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 1-5 (goal)	10^8 contrast 10^9 goal
Near-IR AO-fed Echelle Spectrometer (NIRES)	2″ slit length	20000-100000	1-5	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

Selection of First-Light Instruments

- Our first-light instruments were selected at the December 2006 SAC meeting in Vancouver
- This downselect was very successful because
  - It was primarily science-driven, but it also paid attention to technical readiness, cost and schedule
  - Extensive information from the instrument feasibility studies
  - SAC did a lot of "groundwork" ahead of the December meeting
- Balance between fundamental observing modes: seeing-limited vs AO, visible versus infrared, and imagers vs spectrometers
- Workhorse capabilities and synergy

Selection of First-Light Instruments

- Our first-light instruments were selected at the December 2006 SAC meeting in Vancouver

- This downselect was very successful because

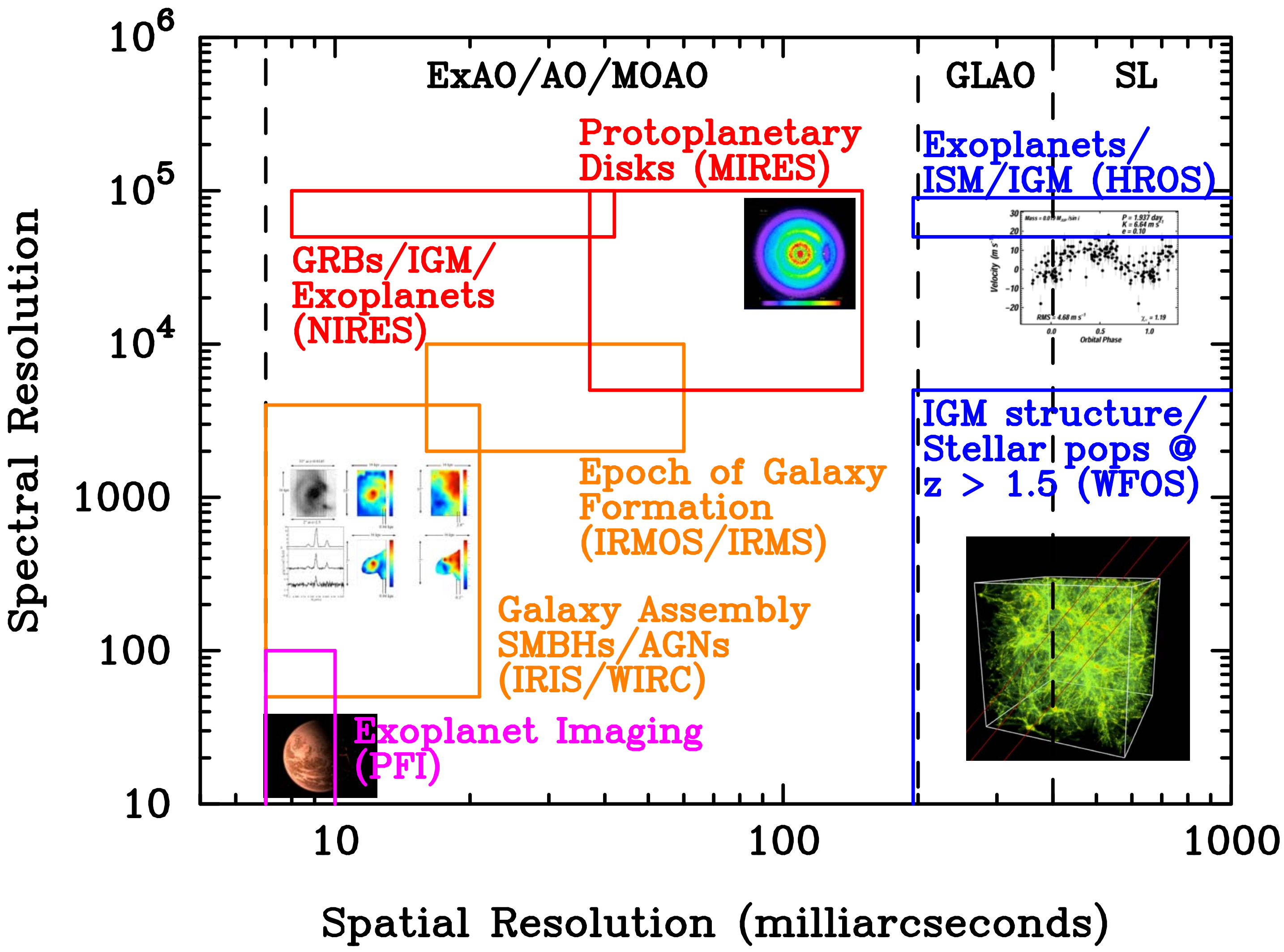
nical

Selection reaffirmed by TMT SAC following partner-wide instrument workshop in 2011

- Balance between fundamental observing modes: seeing-limited vs AO, visible versus infrared, and imagers vs spectrometers

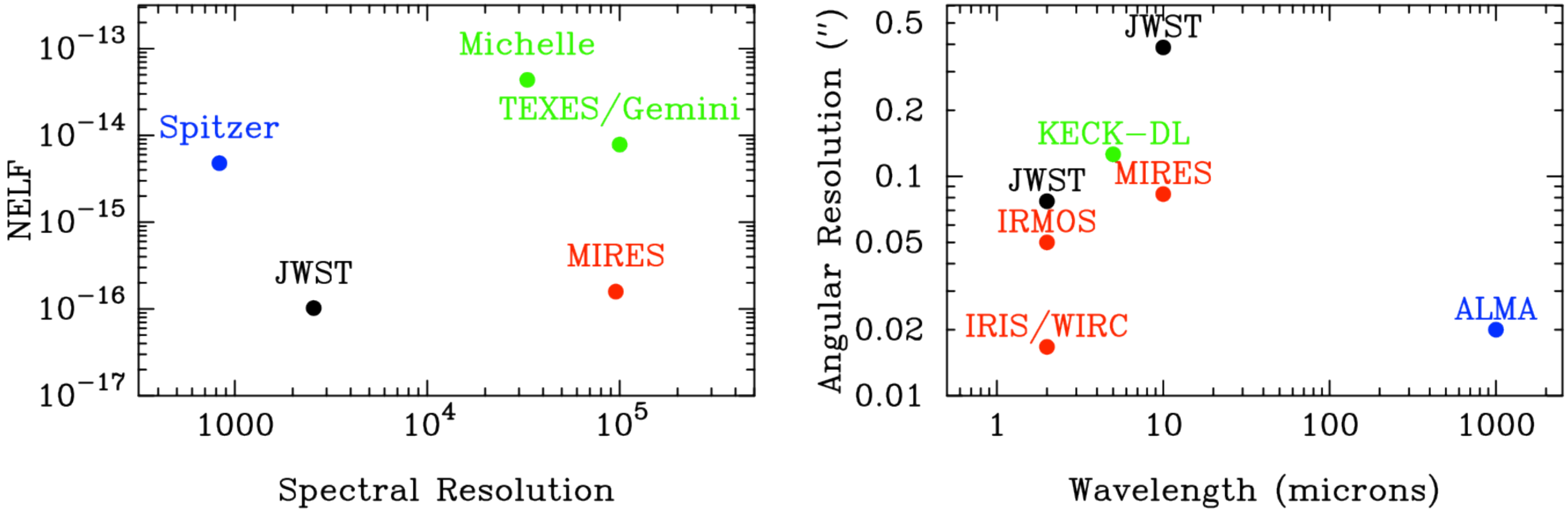
- Workhorse capabilities and synergy

Strong Overlap Between Science and Instrumentation



Synergy with Space/IR and ALMA

(TMT capabilities are shown in red)

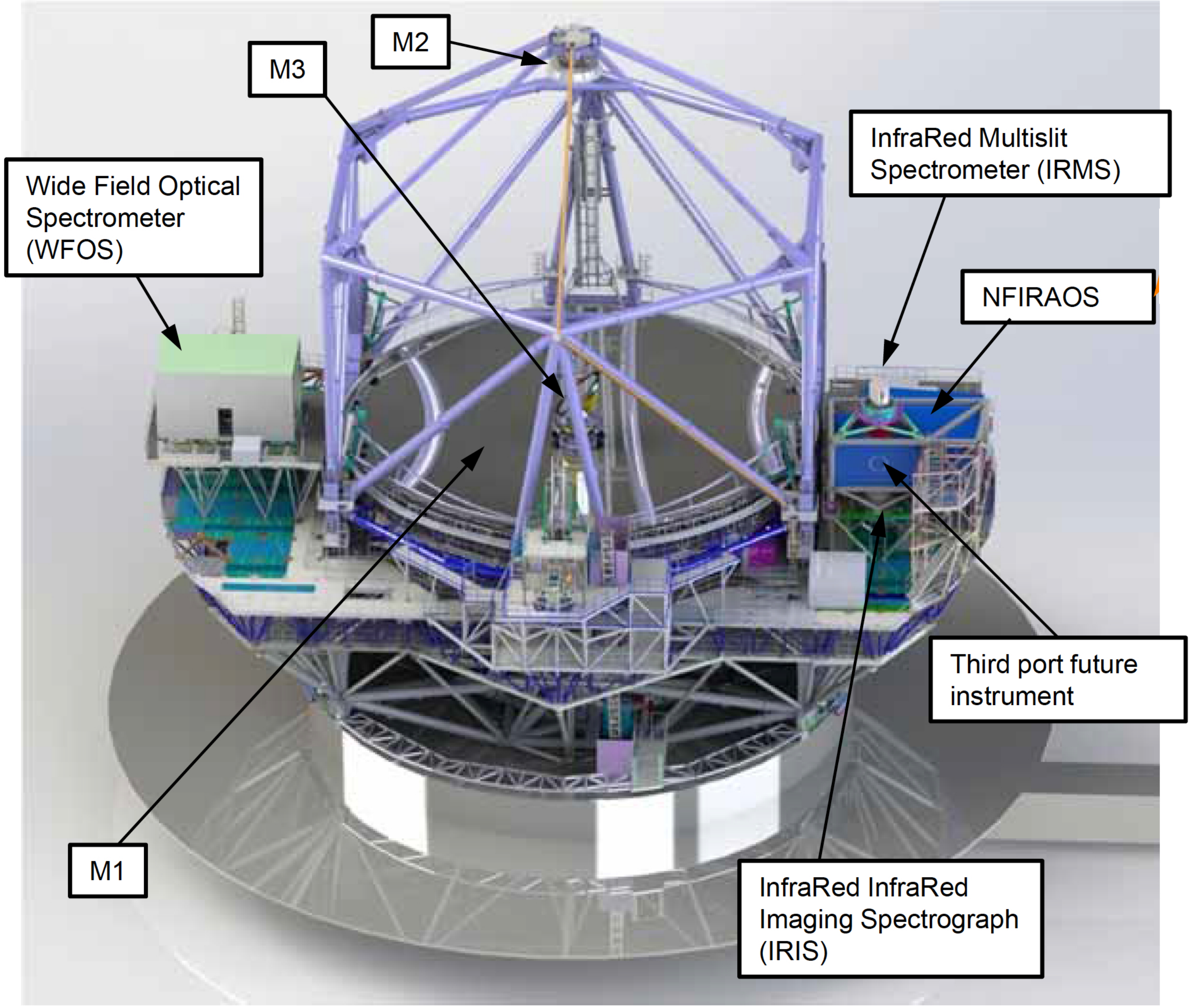


TMT/MIRES will have comparable spectral line sensitivity (NELF) to infrared space missions with a much higher spectral resolution

The angular resolution of TMT instruments nicely complements that of JWST and ALMA

TMT is a "near IR ALMA"!

First Light Instrumentation on the Telescope



Science instruments mounted on Nasmyth platforms (fixed gravity vector)

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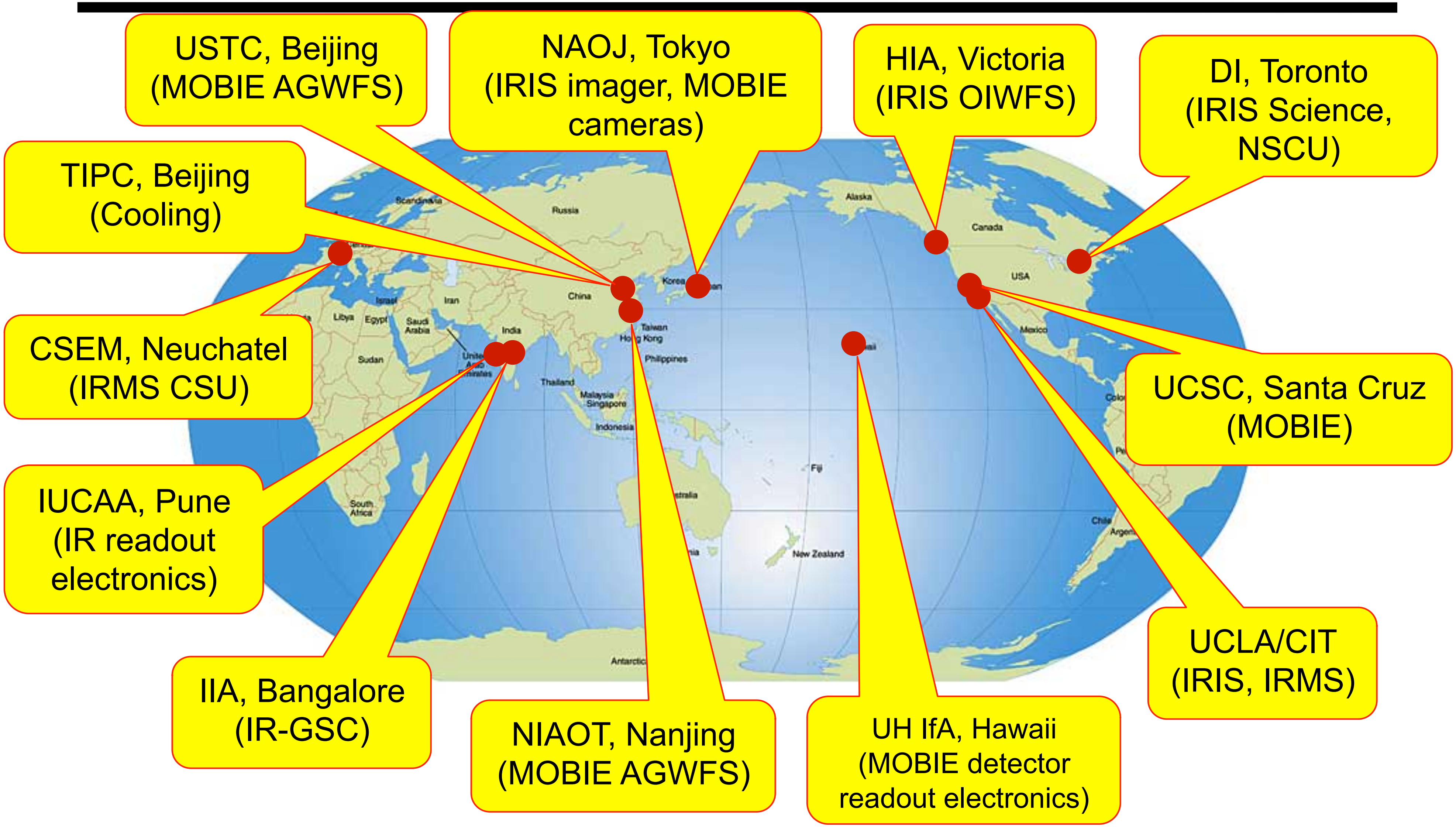
An ELT Instrumentation "Equivalence Table"

Type of Instrument	GMT	TMT	E-ELT
Near-IR, AO-assisted Imager + IFU	GMTIFS	IRIS	HARMONI
Wide-Field, Optical Multi-Object Spectrometer	GMACS	MOBIE	OPTIMOS
Near-IR Multislit Spectrometer	NIRMOS	IRMS	
Deployable, Multi-IFU Imaging Spectrometer		IRMOS	EAGLE
Mid-IR, AO-assisted Echelle Spectrometer		MIRES	METIS
High-Contrast Exoplanet Imager	TIGER	PFI	EPICS
Near-IR, AO-assisted Echelle Spectrometer	GMTNIRS	NIRES	SIMPLE
High-Resolution Optical Spectrometer	G-CLEF	HROS	CODEX
"Wide"-Field AO Imager		WIRC	MICADO

Building Instrument Partnerships

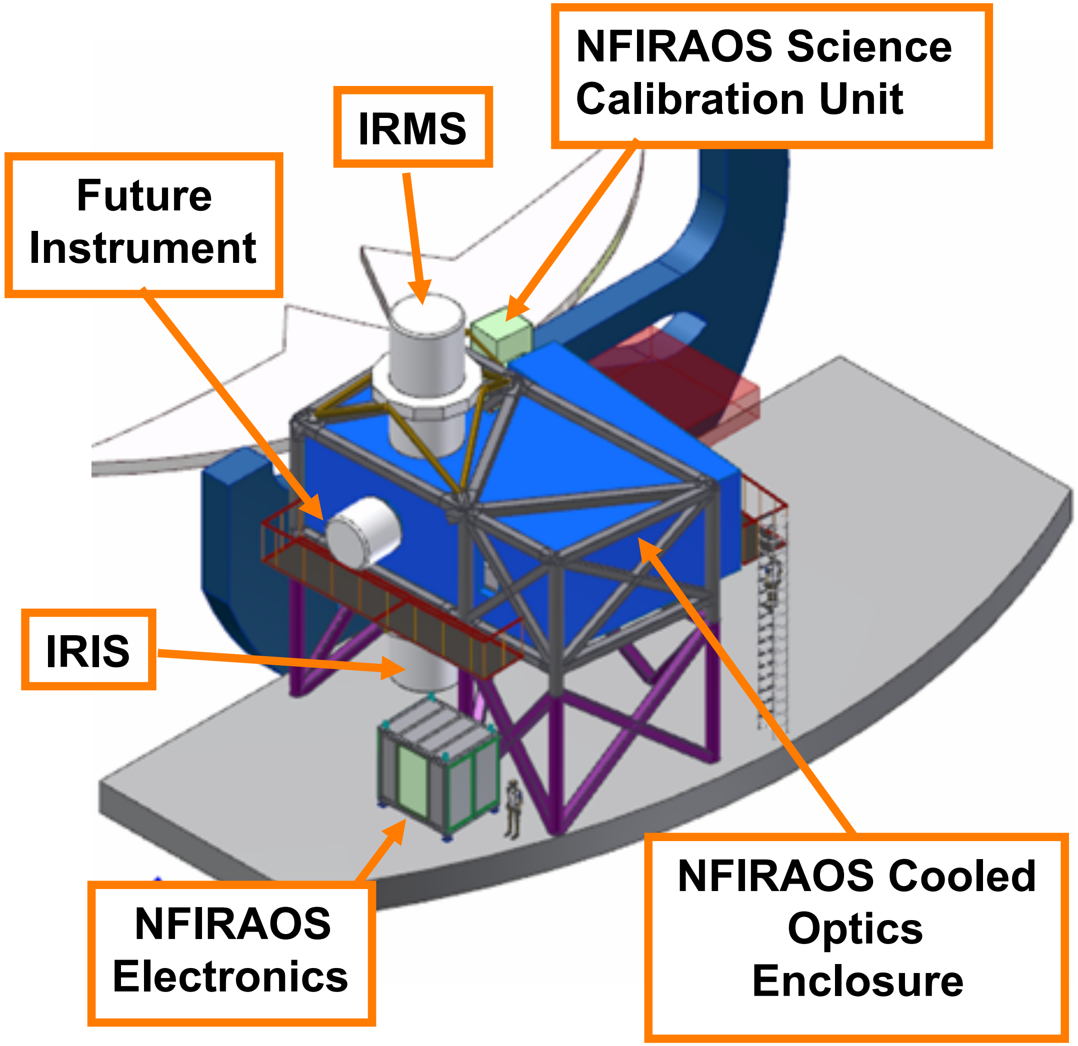
- Each TMT instrument will be built by a multi-institution consortium with industrial partners
- Strong interest from all partners in participating in instrument projects:
  - Primarily driven by science interests of their respective science communities
  - Large geographical distances and different development models
  - Broad range of facilities and capabilities
- Significant efforts are already under way to fully realize the exciting potential found within the TMT partnership
- Goal is to build instrument partnerships that make sense scientifically and technically while satisfying partner aspirations

TMT Global Participants – First Light Science Instruments

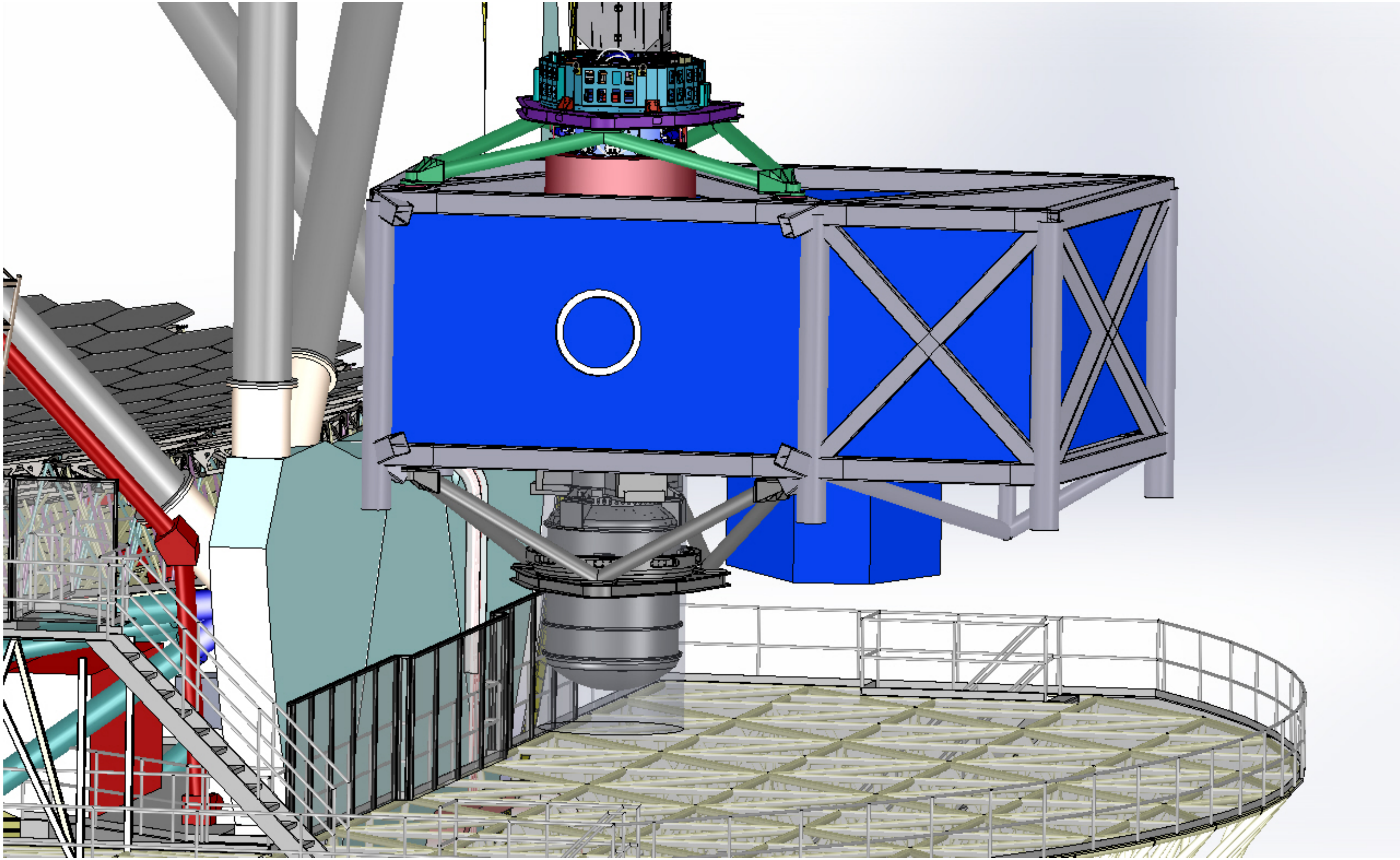


NFIRAOS:
First-Light MCAO System

- Dual Conjugate Laser Guide Star (LGS) AO System
  - Feed 3 IR Instruments
  - 60x60 order system operating at 800Hz
  - 4 OAP relay to eliminate distortion
  - Operation at -30°C to reduce thermal emission
- Completed preliminary design phase in December 2011
  - Very successful review led by panel of external reviewers
- FDR to start April 2014 with industry involvement



IRIS and IRMS mounted on NFIRAOS



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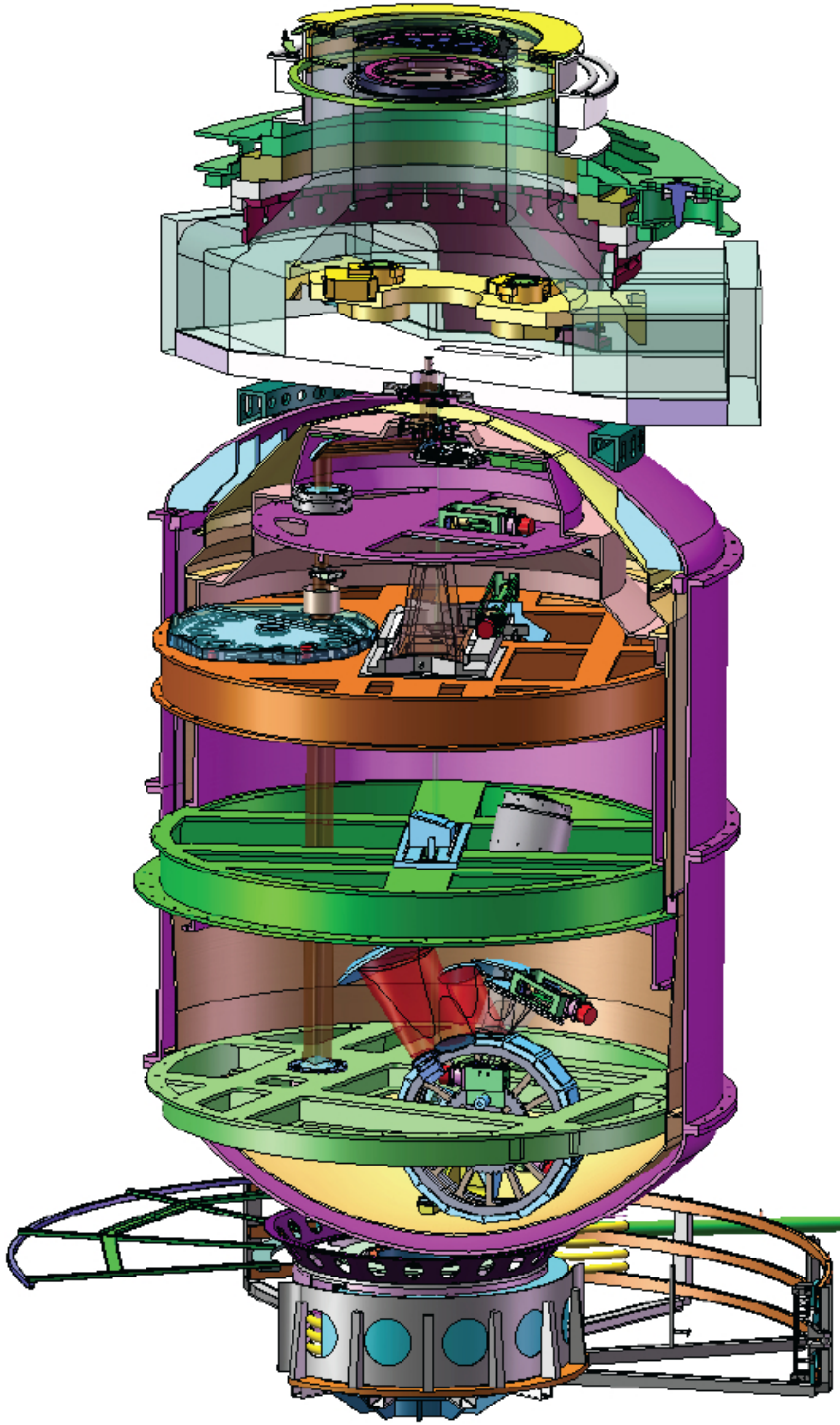
Cut-Away View of IRIS Assembly



Rotator and NFIRAOS interface

Internal chamber cooled to match NFIRAOS chamber.

T (internal)= -30°C

On-Instrument Wavefront Sensors

Cooled to match NFIRAOS chamber

T= -30°C

Science Dewar

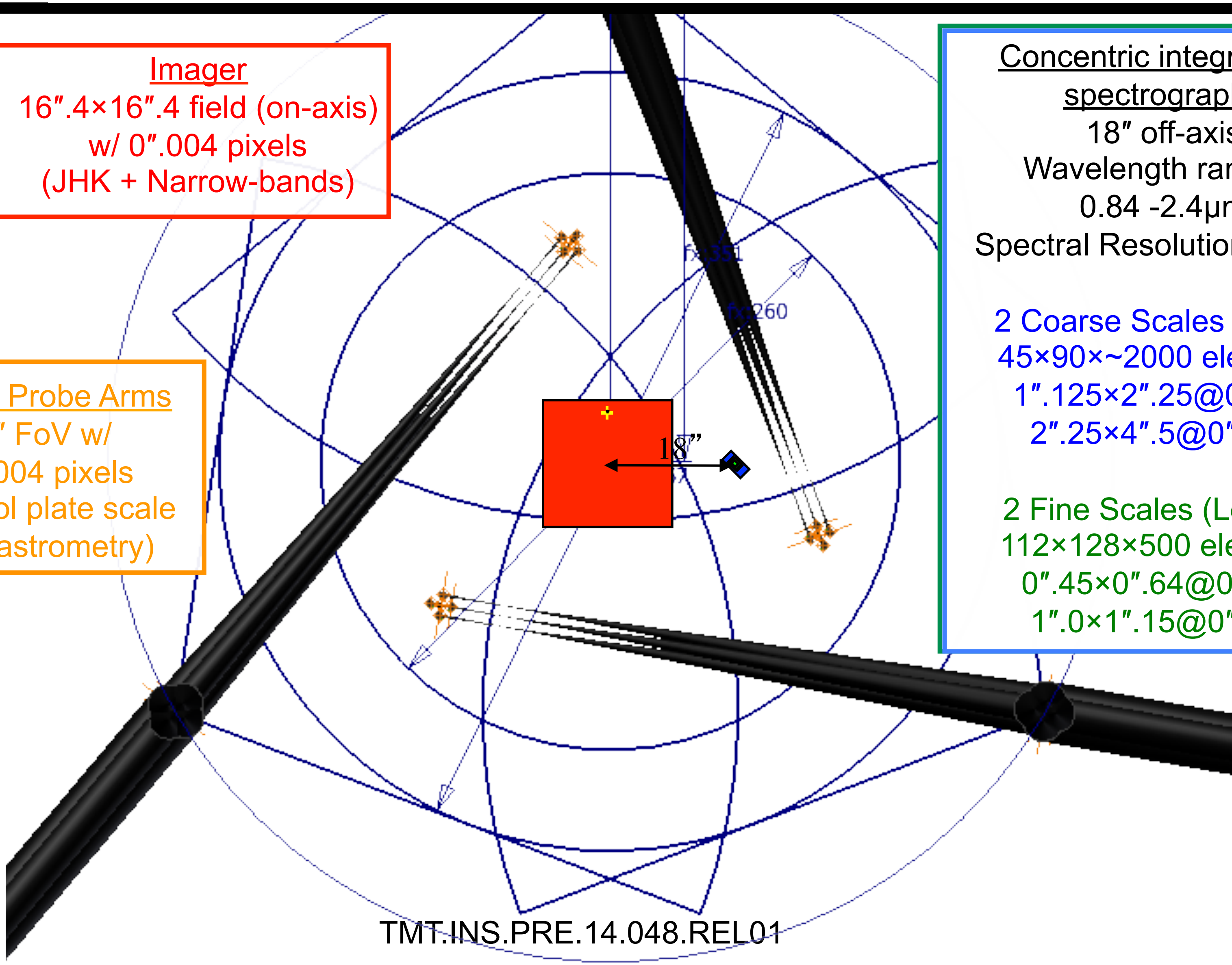
Cryogenic

T= 77K – 120K

Cable Wrap

T= ambient

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



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

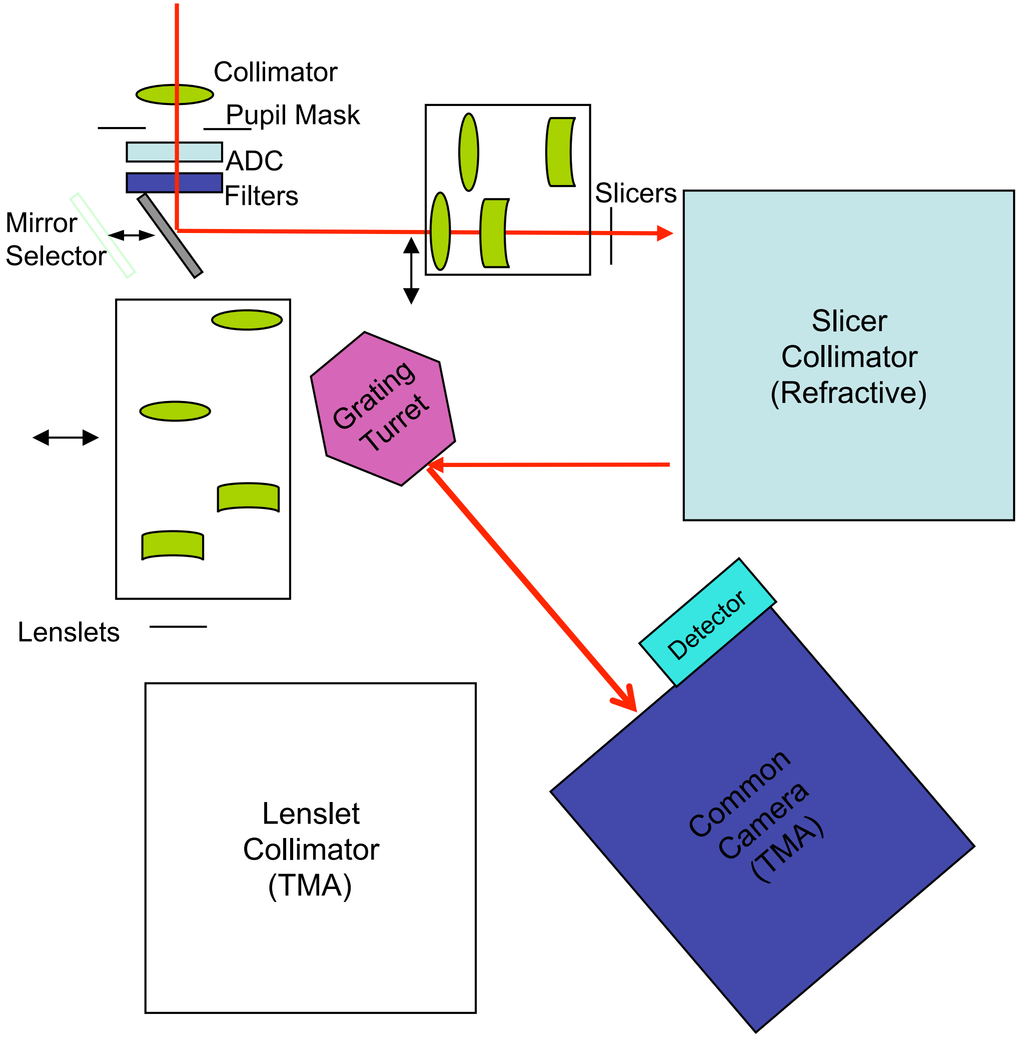
Three Probe Arms
4″ FoV w/
0″.004 pixels
(control plate scale
and astrometry)

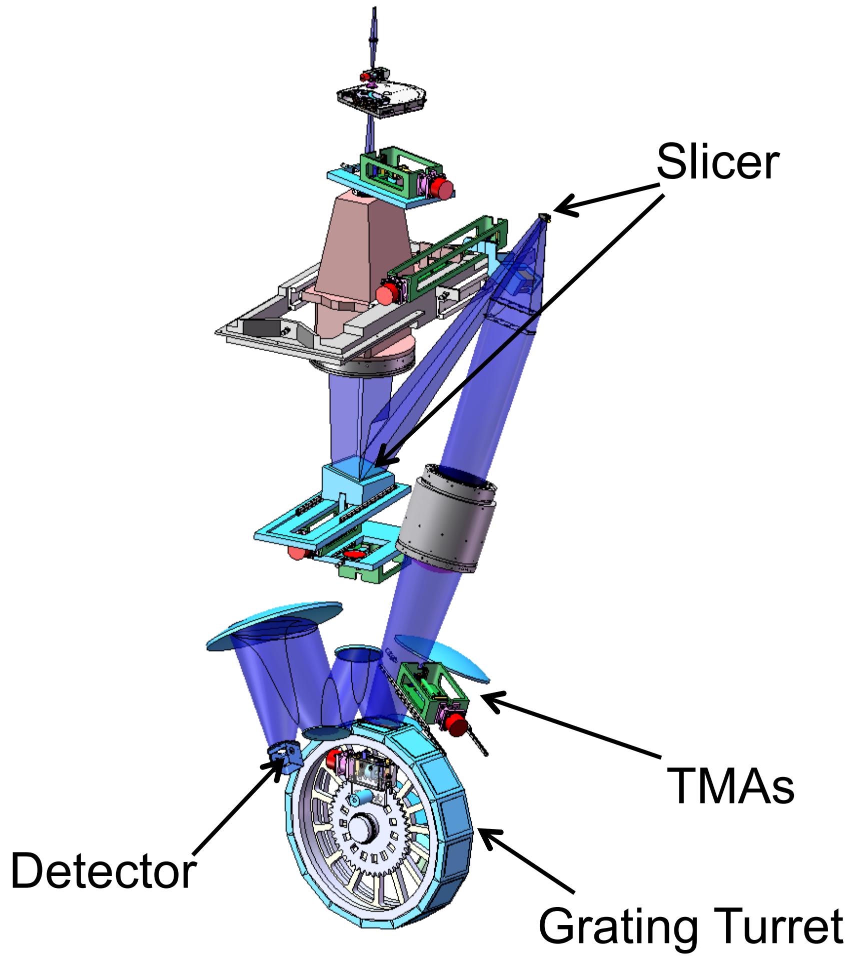
Concentric integral field spectrographs
18″ off-axis
Wavelength range =
0.84 -2.4μm
Spectral Resolution = 4000

2 Coarse Scales (Slicer)
45×90×~2000 elements
1″.125×2″.25@0″.025
2″.25×4″.5@0″.050

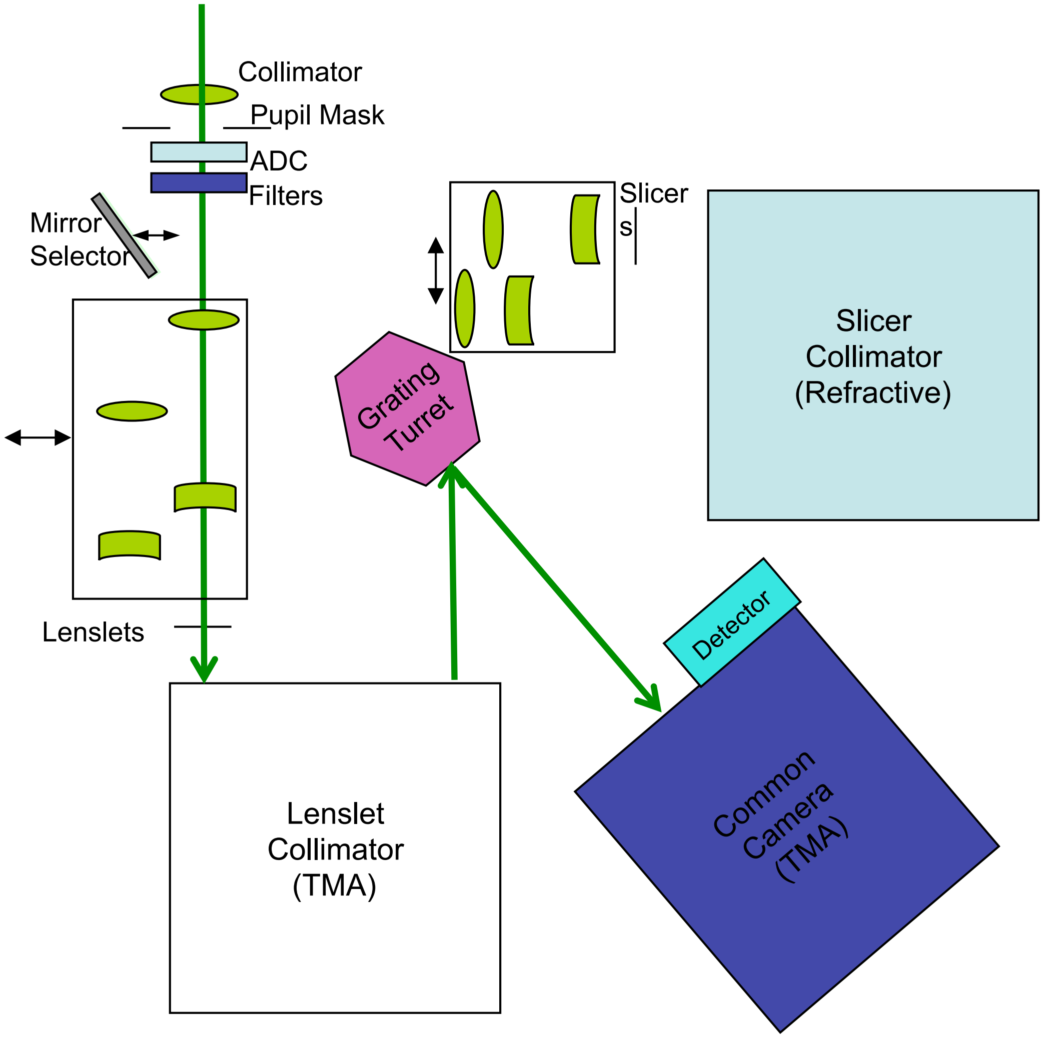
2 Fine Scales (Lenslet)
112×128×500 elements
0″.45×0″.64@0″.004
1″.0×1″.15@0″.009

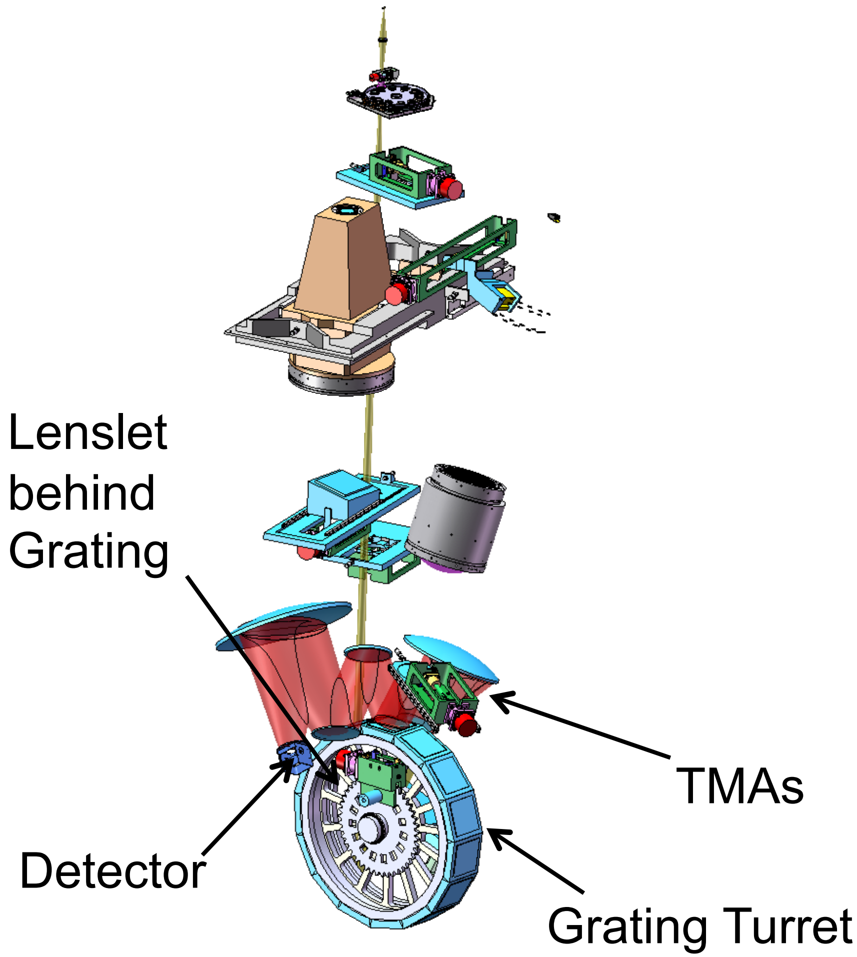
Folded Geometry (50 mas scale)





Folded Geometry (4 mas scale)





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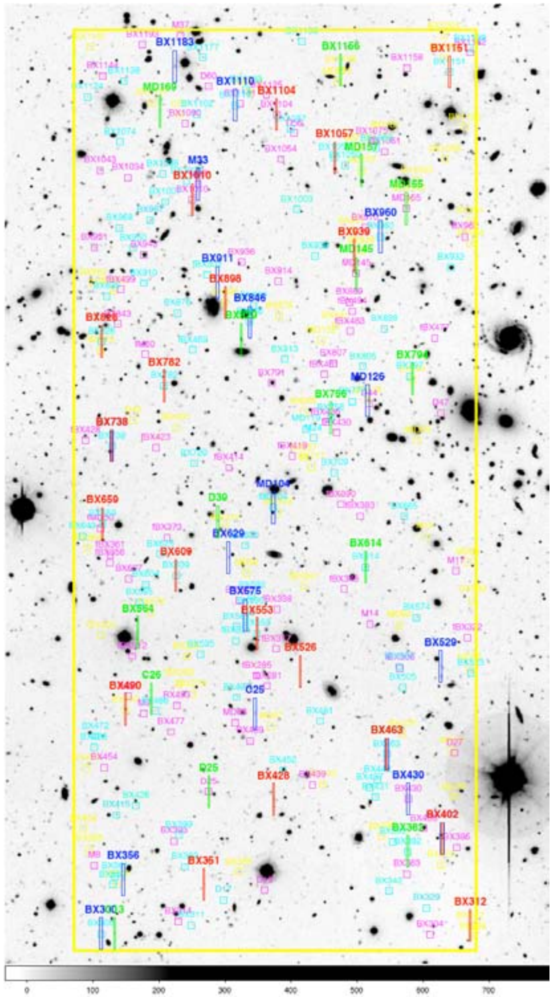
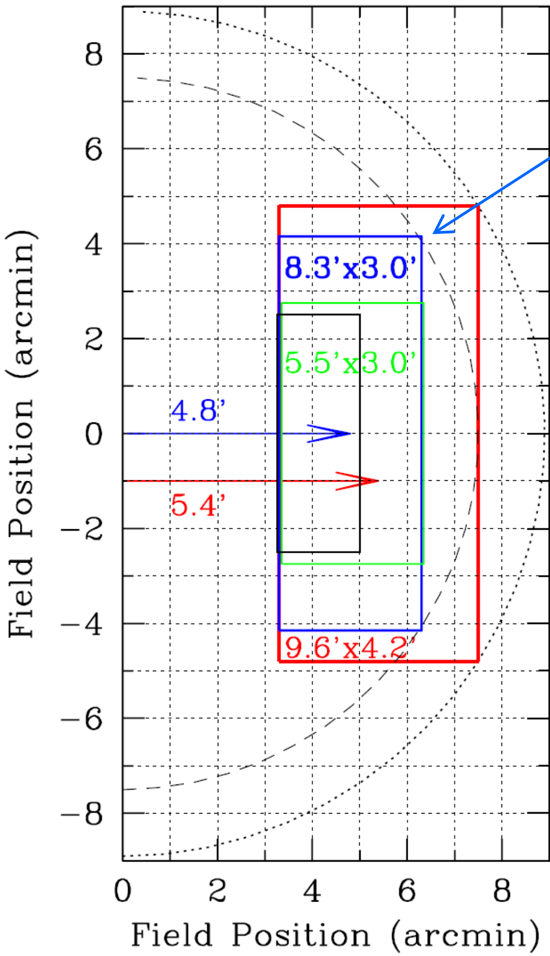
MOBIE Science Field Geometry



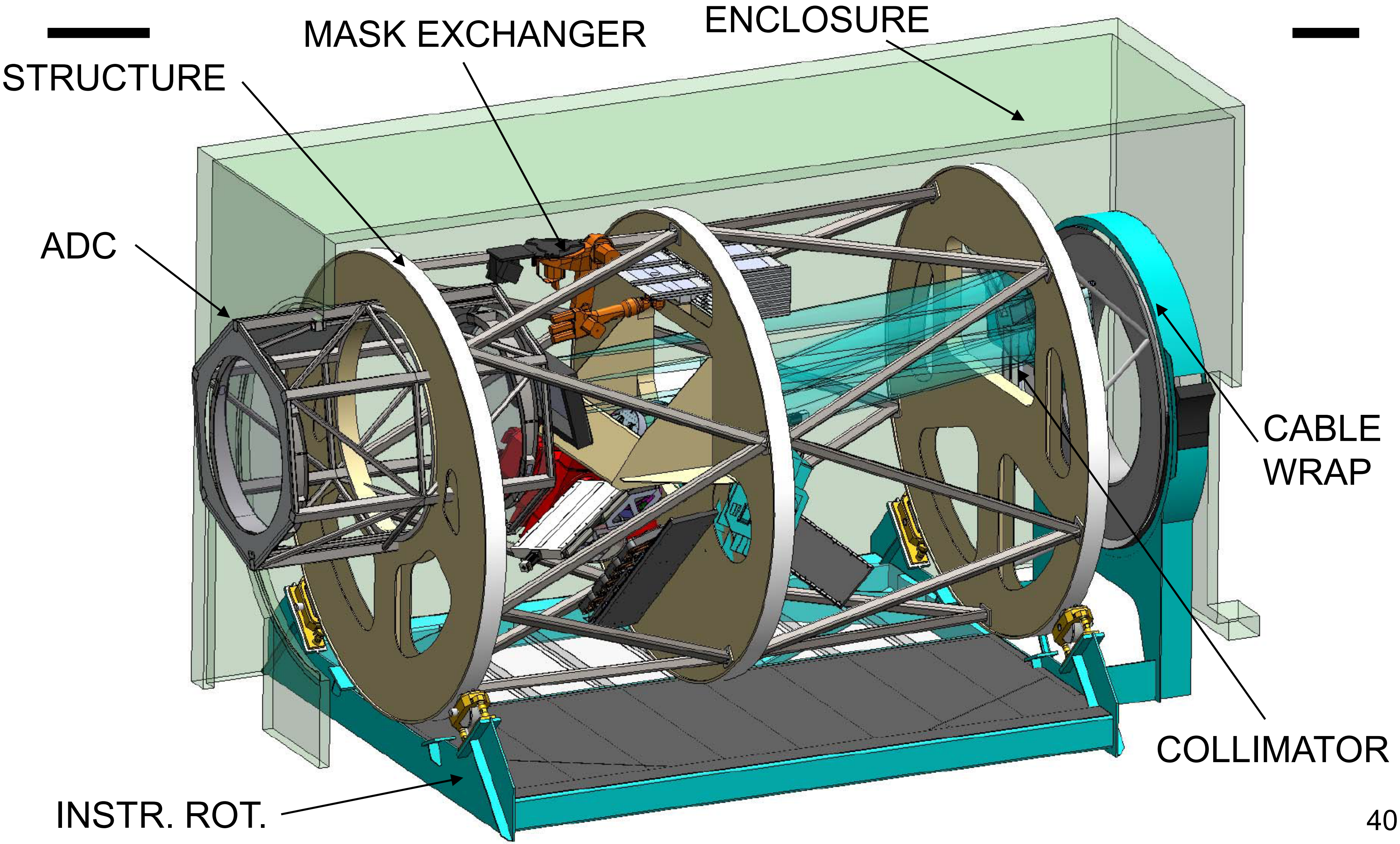
Multi-object mask making simulation



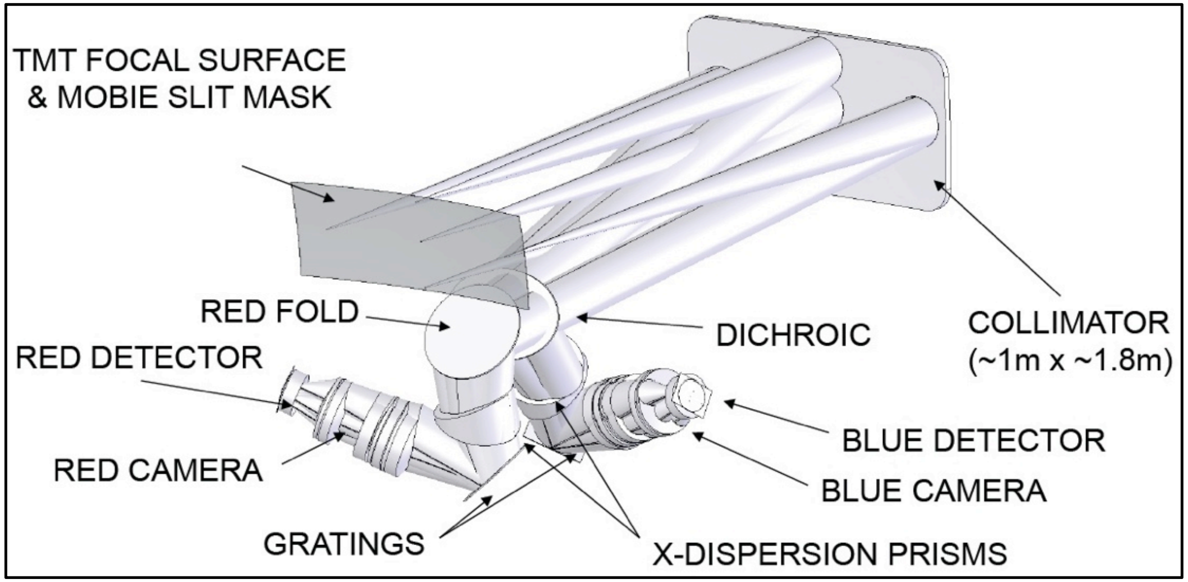
MOBIE-OPT:

- "Best" VE study cost-performance configuration
- Deletes field area with worst image quality & vignetting
- Reduces ADC and collimator optics sizes
- FoV size hardest return to quantify
- Good match to CCD formats

MOBIE Schematic View



MOBIE Echellette Design: Survey and Diagnostic Spectroscopy



Bigelow et al. 2010, SPIE 2010

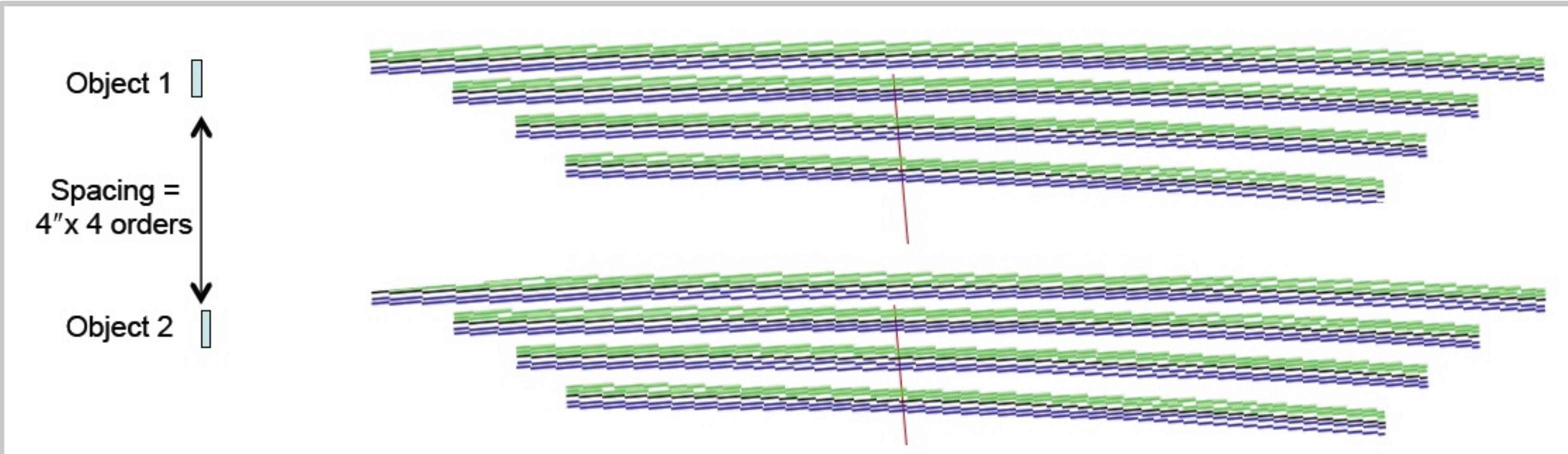
0.31μm - 1.1μm (Blue sensitive)

40.3 arcmin^2 FoV

576″ total slit length
(i.e., up to ~200 objects)

R = 1000 - 8000 (for 0″.75 slit)

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



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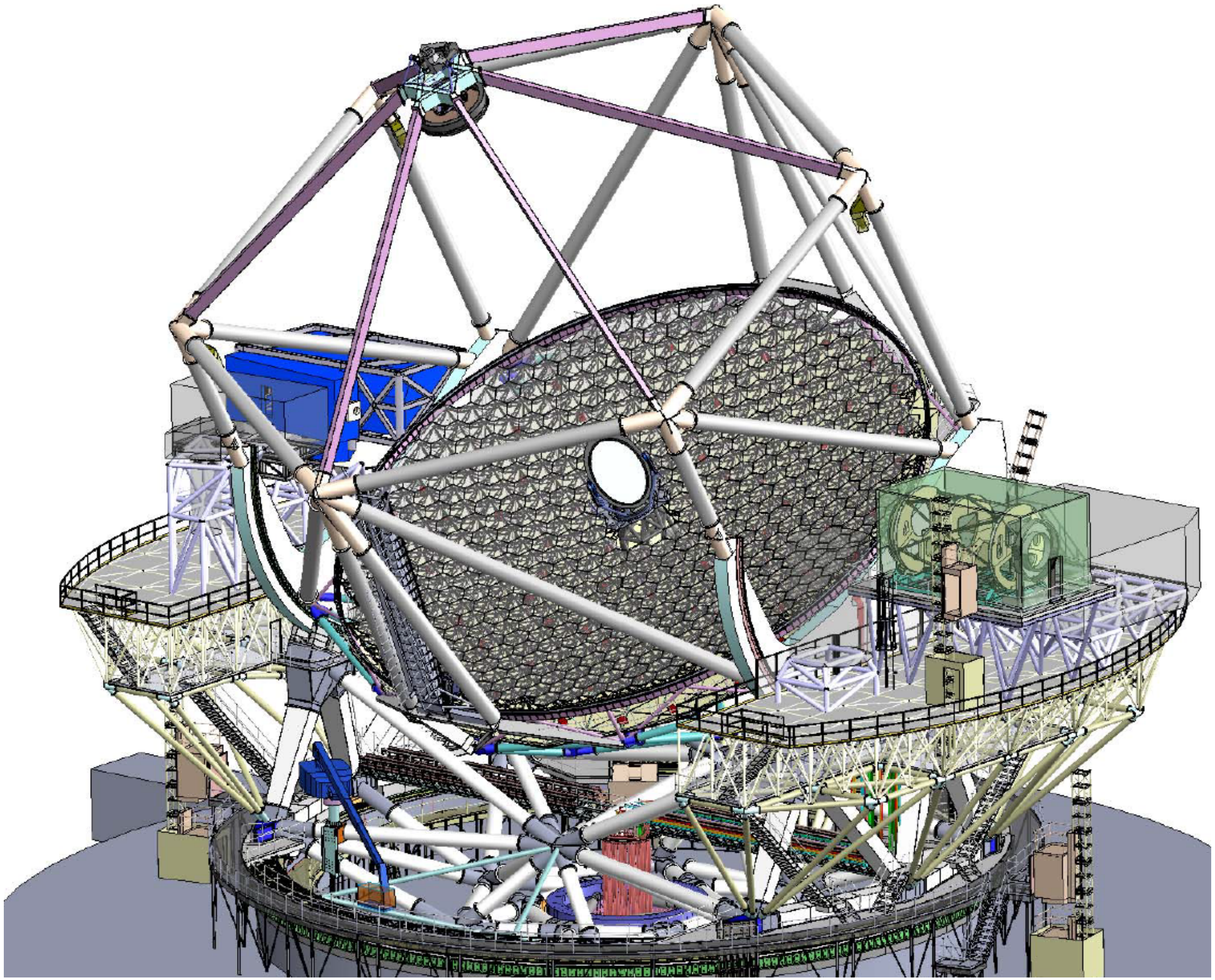
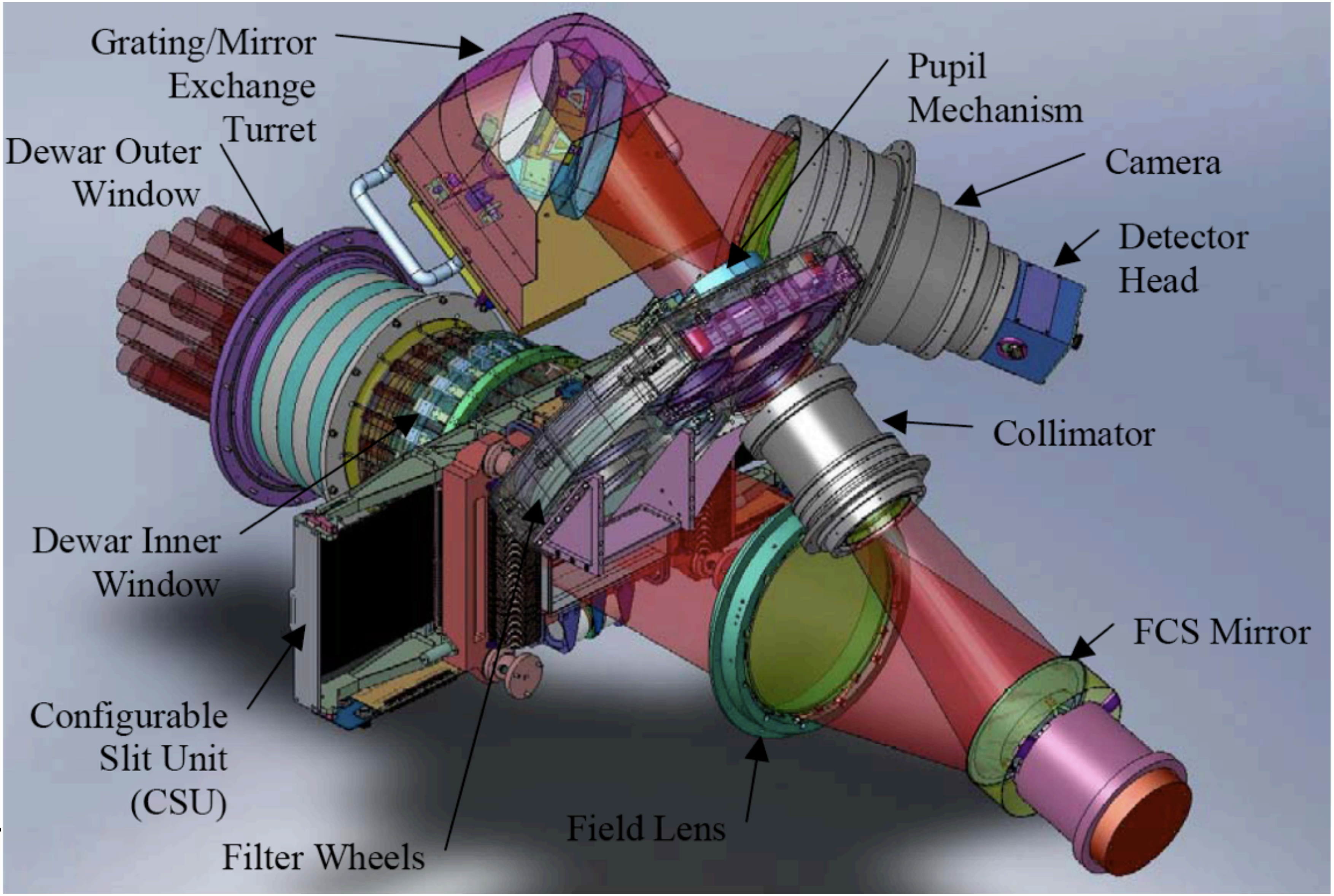
MOBIE on TMT



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



TMT
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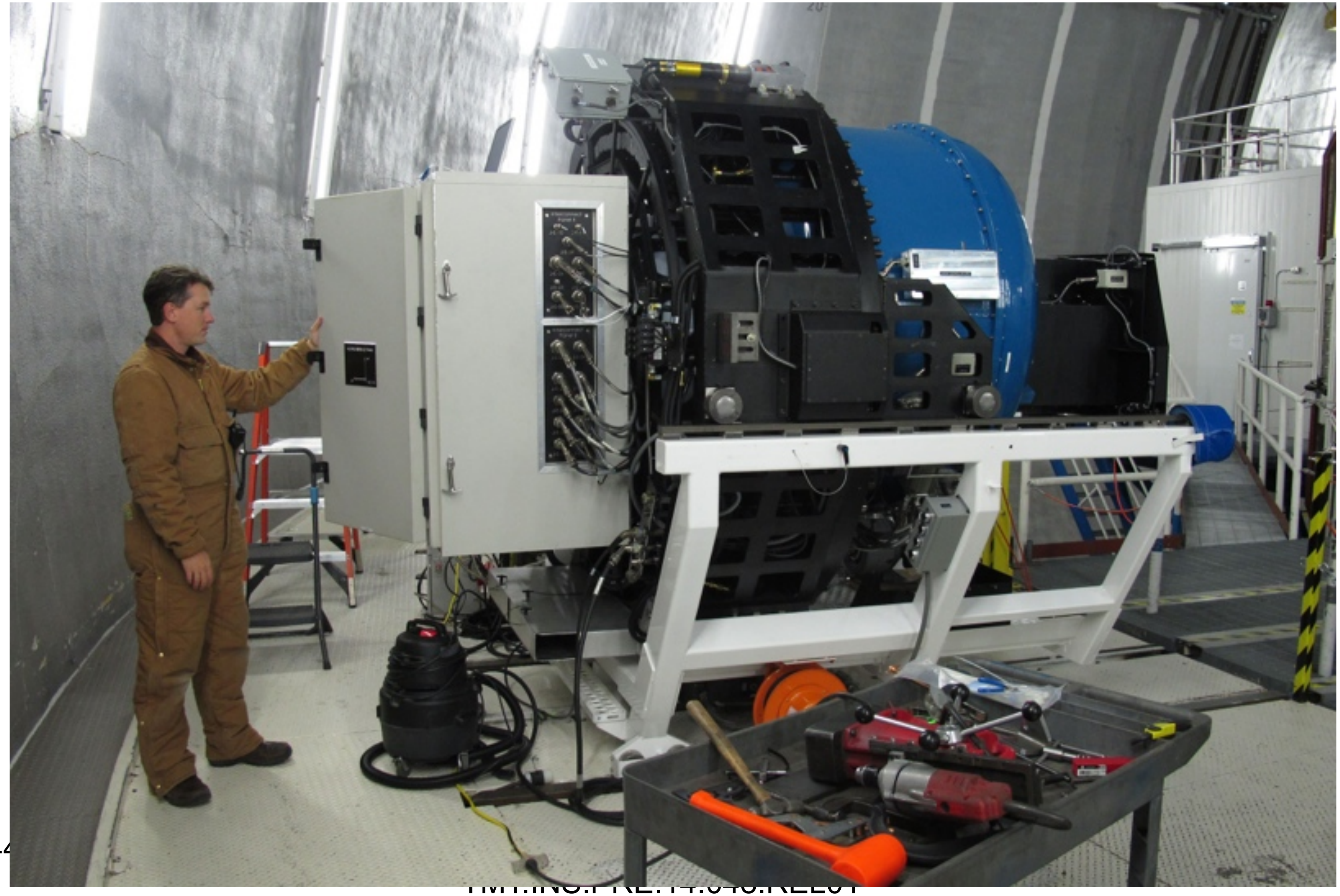
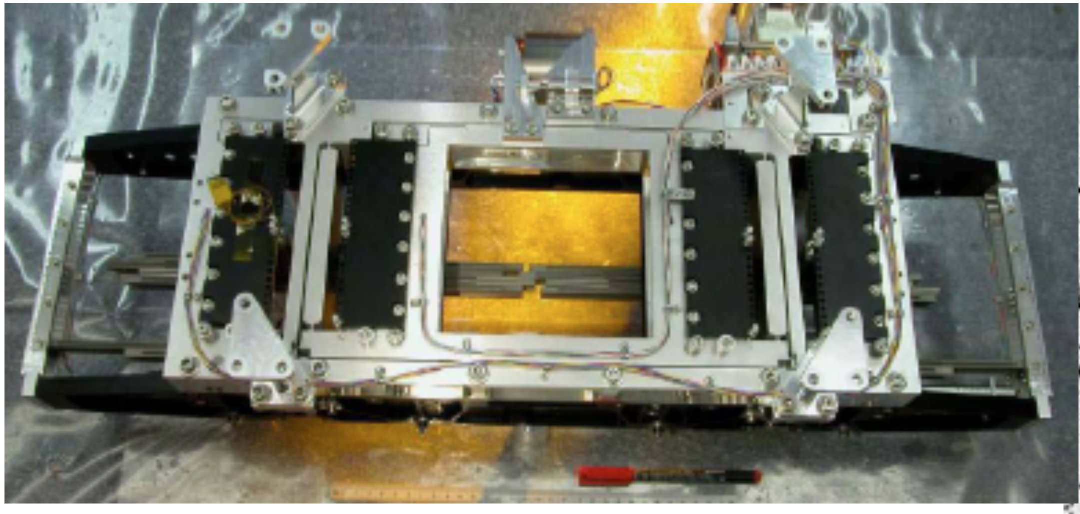
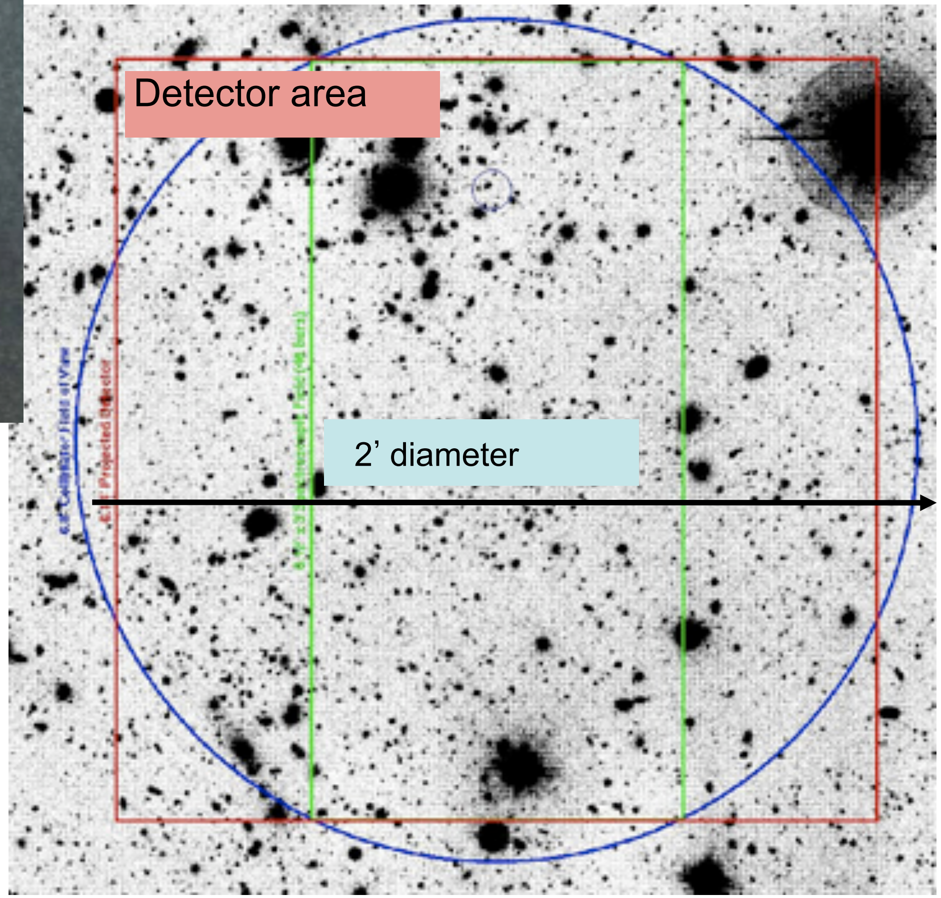
MOSFIRE at Keck



IRMS Slit Unit & Field

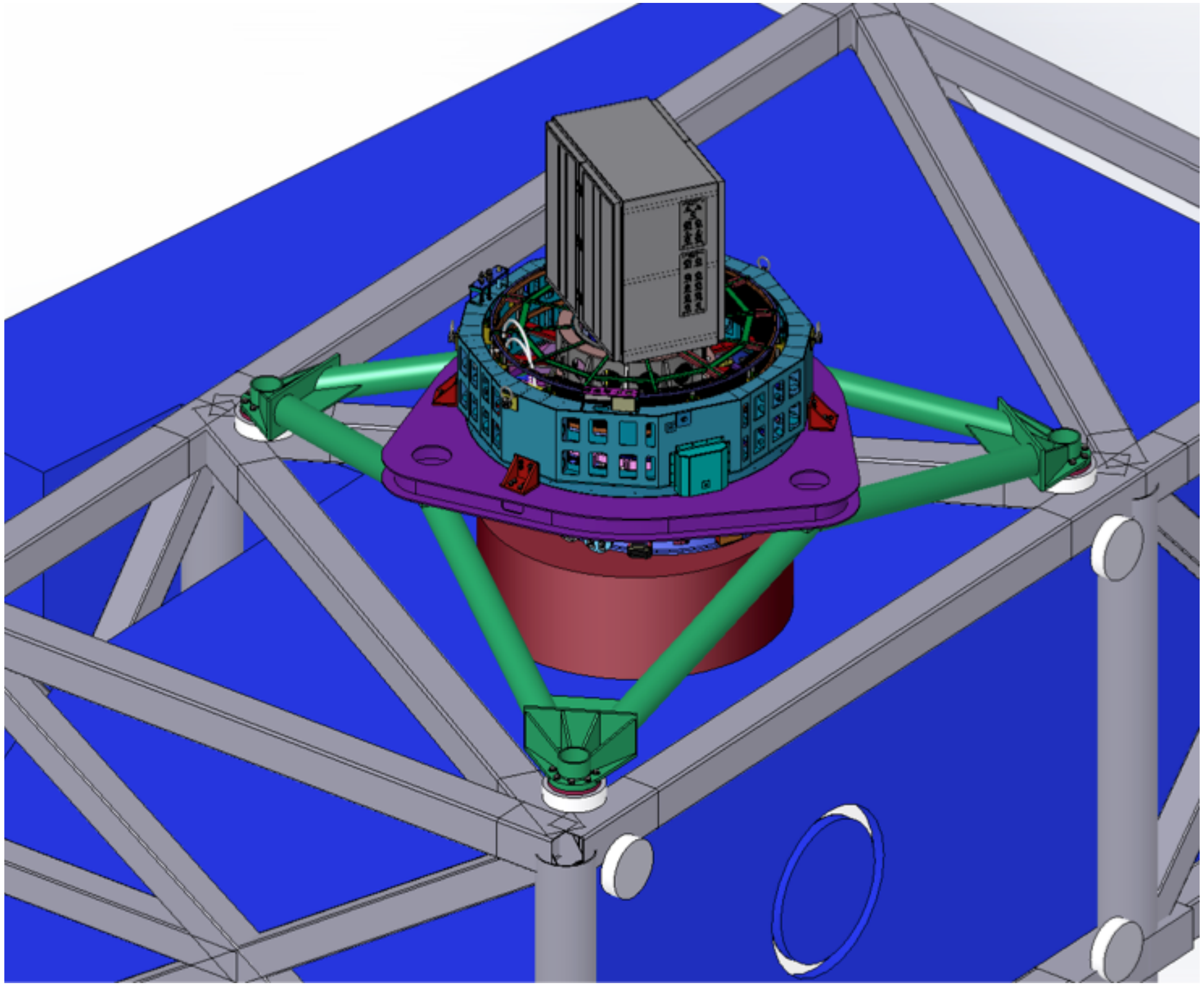




CSEM configurable slit unit

- Slits formed by opposing bars
- Up to 46 slitlets
- Reconfigurable in ~3 minutes

IRMS on NFIRAOS



Instrument mass = 2.5 T

Rotator module mass = 1.1T

Support Structure mass = 2.3T

Total mass = 5.9T

TMT
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Current Instrumentation Status

- NFIRAOS: Final Design Phase started in April 2014
- IRIS: Preliminary Design Phase started in April 2013 and scheduled for completion in December 2014
- MOBIE:
  - Conceptual Design Handover Workshop held in October 2013
  - A short “mini-study” phase with participants from across the TMT partnership now getting underway and scheduled for completion in December 2014
  - “delta” conceptual design phase is scheduled for January-July 2015
- IRMS:
  - An initial study showed IRMS to be a viable option
  - A “mini-study” phase will start in September 2014 followed by a “delta” conceptual design phase in April-October 2015

Summary

- TMT science programs span the full cosmic timeline:
  - From the “Dark Sector” and First Light
  - Including our own Solar System!
- TMT has a powerful suite of planned science instruments and AO systems that will make the Observatory a world-class, next-generation facility
- **There are many opportunities for all TMT partners**
- **We all look forward to TMT’s first light in 2023!**

THIRTY METER TELESCOPE

Acknowledgments

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