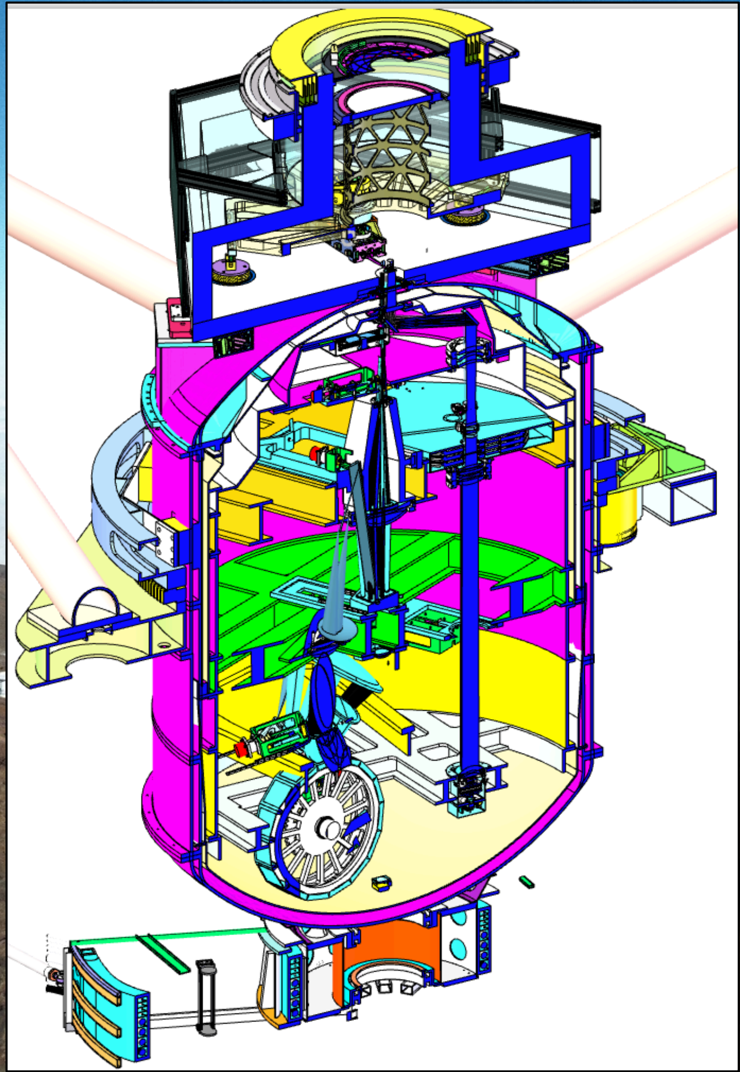
The Infrared Imaging Spectrograph (IRIS) for TMT: Instrument Overview



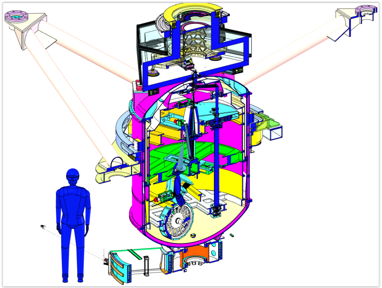
Anna Moore

California Institute of Technology

On behalf of the IRIS team

THIRTY METER TELESCOPE

IRIS Overview



- First light instrument for the Thirty Meter Telescope (TMT)
- Diffraction limited integral field spectrograph and imager to work with TMT AO system (NFIRAOS)
  - Wavelength Range 0.84-2.4 microns
  - Wavefront Error < 30 nm for fine scales
  - High Order Atmospheric Dispersion Correction
- On-Instrument deployable wavefront sensors (OIWFS).
  - Three sensors (one including focus) to measure tip/tilt, focus and distortion across field.
  - Work in near infrared to gain from NFIRAOS AO correction
- Spectrograph
  - Spectral Resolution > 3500 (8000, 10,000 complete the set)
  - IFS with Four Plate Scales (0.004, 0.009, 0.025, 0.050 arcsec per sample)
- Imager
  - 16.4 arcsec field of view (expansion to 33 arcsec underway)
  - 0.004 arcsec plate scale
  - Parallel observations with IFS
- NSCU calibration system internal to NFIRAOS led by Moon and Simard.
- All of IRIS rotates about vertical axis

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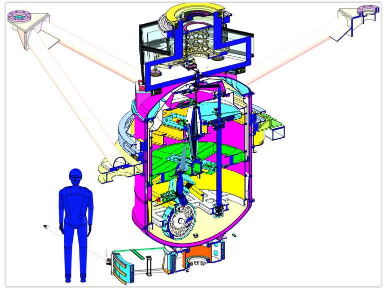
IRIS Overview



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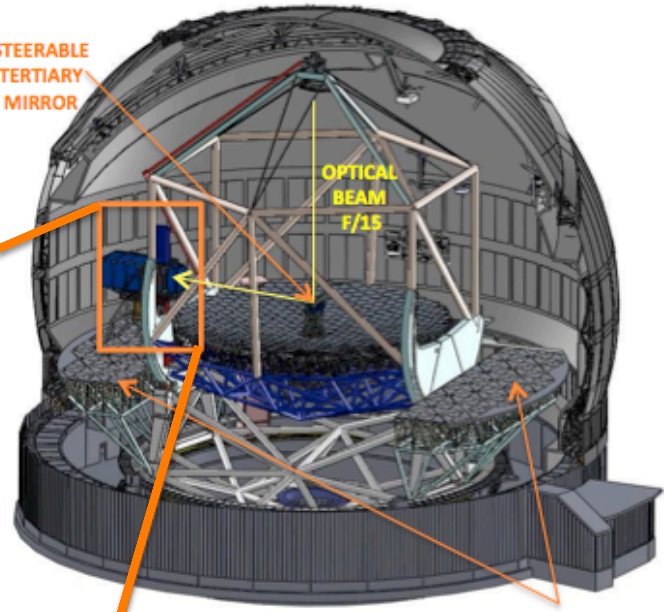
IRIS on TMT



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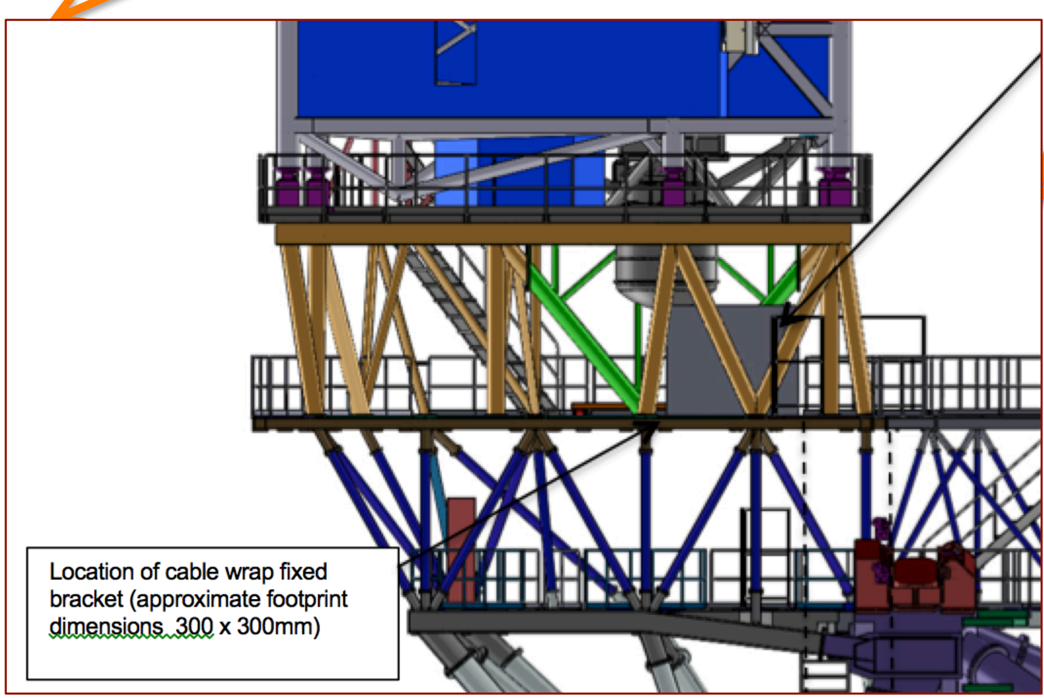

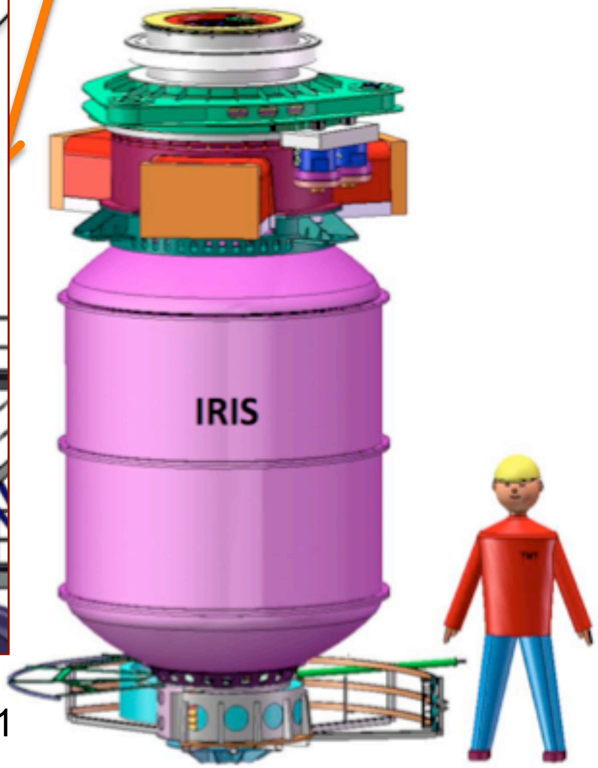

(c)

IRIS Technical Team

- James Larkin (UCLA), PI, Lenslet IFS
- Anna Moore (CIT), Co-PI, PM, Slicer IFS
- Jennifer Dunn (HIA), Co-I, OIWFS, IRIS – NFIRAOS interface, carts
- Drew Phillips (UCSC), Co-I, ADC
- Ryuji Suzuki (NAOJ), Co-I, Imager
- Kai Zhang (NIAOT), Co-I, Image slicer IFS
- Engineers at COO, HIA, NAOJ, UCLA, UCSC
  - SE – James Wincentsen (COO)
  - ME - Alex Delacroix, Bob Weber (COO), Vlad Reshetov (HIA), John Canfield, George Brims, Eric Wang, Ji Man Sohn (UCLA), Yoshiyuki Obuchi, Bungo Ikenoue, Sakae Saito, Fumihiro Uraguchi (NAOJ),
  - OE - John Pazder, Jenny Atwood (HIA)
  - S/W –Bob Wooff (HIA), Jason Weiss, Chris Johnson (UCLA), Reed Riddle(COO)
  - Detectors – Roger Smith (COO)
  - EE – Kris Caputa (HIA)

- Shaojie Chen, Elliot Meyer, University of Toronto, Grating trade study

- @TMT, NFIRAOS: Luc Simard, Brent Ellerbroak, Lianqi Wang, Corinne Boyer, Pete Byrnes, Glen Herriot, Matthias Schoek and the IRIS astrometry team and many many more…

TMT
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IRIS Science Team Members

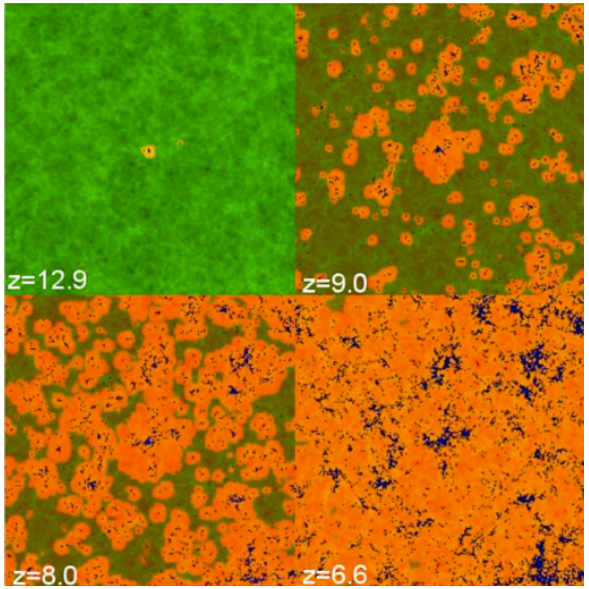
16 Institutions (USA, Canada, Japan, China, India, Australia)

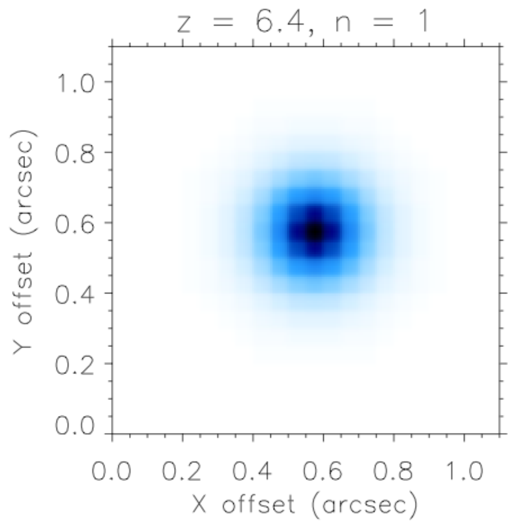
- Maté Adamkovics, Berkeley
- Lee Armus, IPAC
- Aaron Barth, UCI
- Jeffrey Cooke, Swinburne
- Pat Coté, HIA
- Tim Davidge, HIA
- Tuan Do, UCI
- Andrea Ghez, UCLA
- Lei Hao, Shanghai AO
- David Law, Toronto
- Michael Liu, U Hawaii
- Jessica Lu, U Hawaii
- Bruce Macintosh, LLNL
- Shude Mao, NAOC
- Christian Marois, HIA
- Annapurni Subramaniam, India IoA
- Hajime Sugai, Kyoto
- Jonathan Tan, Florida
- Tsuyoshi Terai, NAOJ
- **Shelley Wright (PS), Toronto**
- Tommaso Treu, UCSB

Extremely Broad Science
(Wright et al SPIE 2014 9147-369)

Characterizing the first galaxies in the Universe

- The Lyman α luminosity function at z=7-14
- Resolved spectroscopy of Lyman α

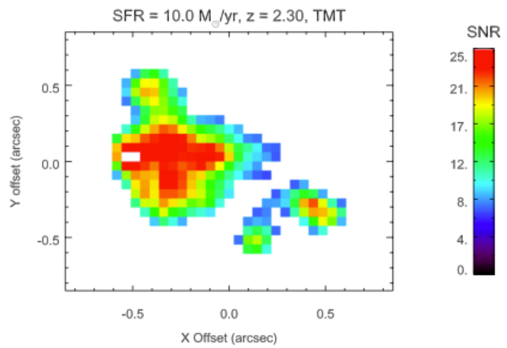




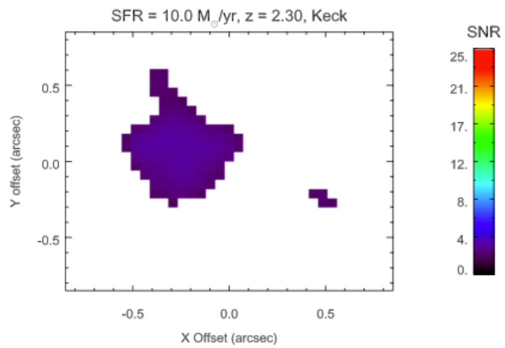
Extremely Broad Science
(Wright et al SPIE 2014 9147-369)

Understanding how galaxies form and evolve in the early universe

- Spatially resolving star forming galaxies and quiescent galaxies (1 < z < 5)
- Wright et al. 2010, SPIE



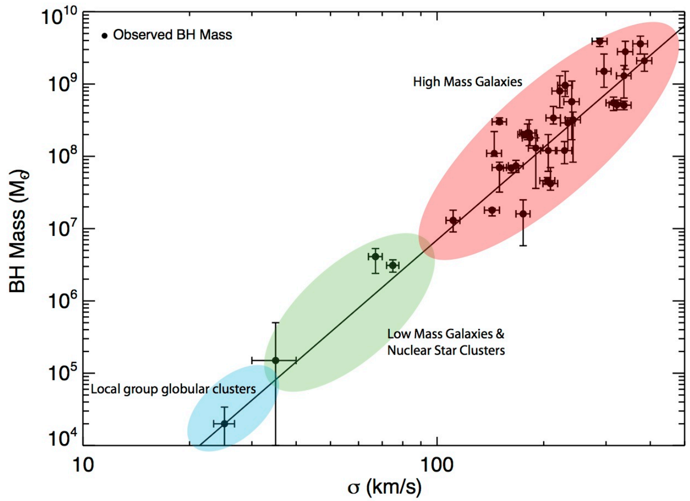
TMT+IRIS

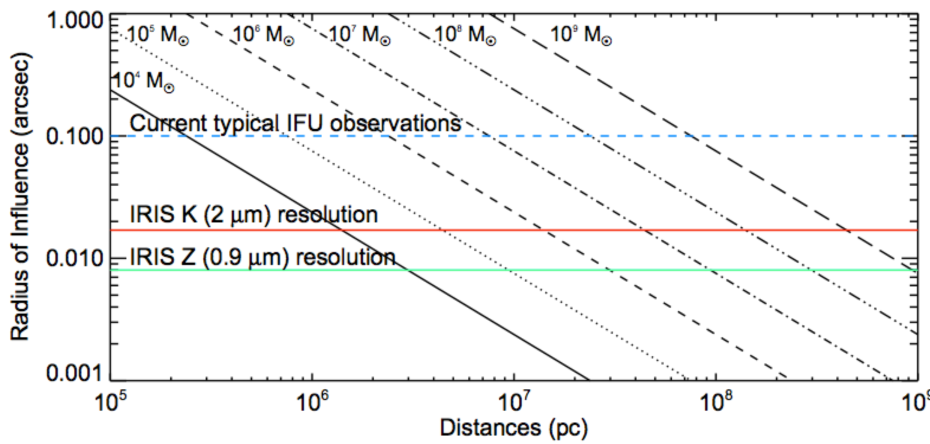


Keck+OSIRIS

Extremely Broad Science
(Wright et al SPIE 2014 9147-369)

The origins of supermassive black holes



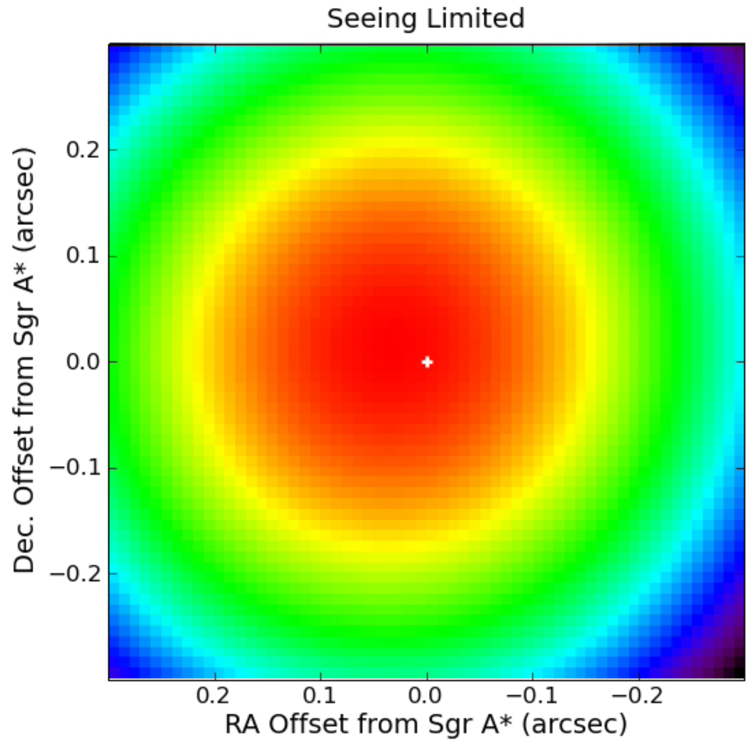


IRIS probing range of SMBH masses at greater distances (**Do et al. 2014, AJ**)

Extremely Broad Science
(Wright et al SPIE 2014 9147-369)

Dynamics and stellar populations in Galactic Center

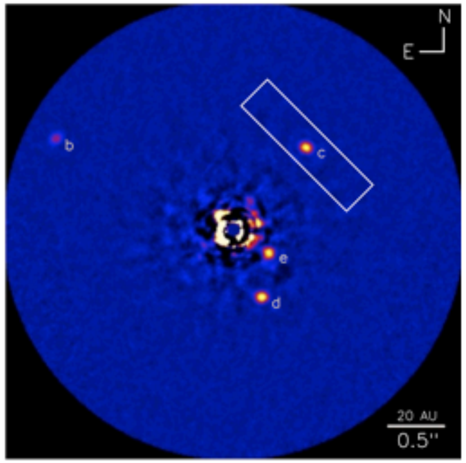
- Testing General Relativity
- Probing dark matter distribution
- Accurate R_o distance to Galactic Center
- Understanding star formation surrounding SMBH



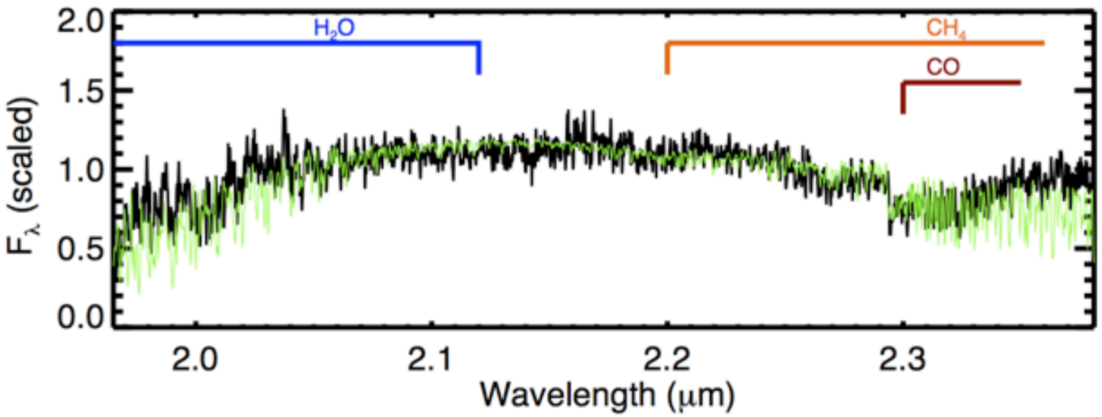
http://www.astro.ucla.edu/~ghezgroup/gc/pictures/Future_GCorbits.shtml

Extremely Broad Science
(Wright et al SPIE 2014 9147-369)

Studying the orbits and atmospheres of extrasolar planets



Keck NIRC2 L' band HR8799 (Marois et al. 2010)

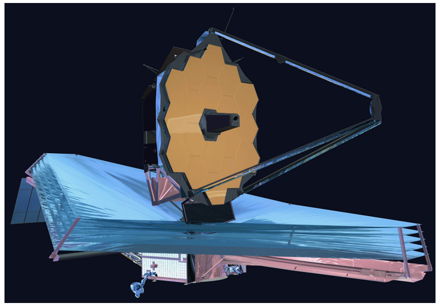


Keck OSIRIS R=4000 HR8799c (Konopacky et al. 2013)

Moderate resolution spectroscopy (R=4000) on directly imaged exoplanets

IRIS compared to JWST

NIRCam

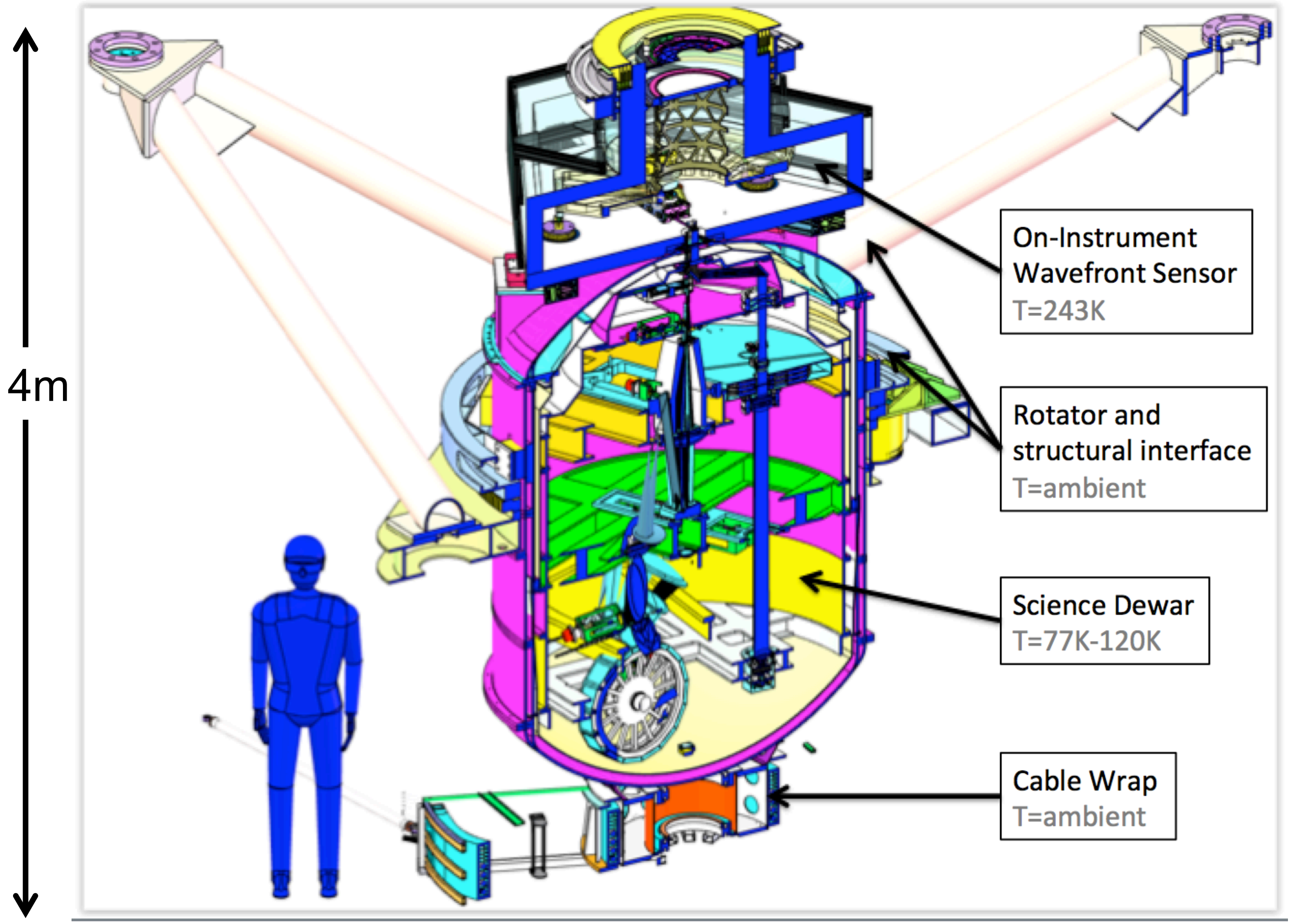


- 0.6 – 5 um imager
- 0.032" and 0.065"/pixel
- 2.2' x 2.2'
- Will conduct deep NB surveys
- TMT+IRIS imager will have comparable sensitivities at Y, Z, J
- NIRCam will gain at longer wavelengths

NIRSpec

- 0.7 – 5 um imager
- Fixed slit spectrograph
- Multiobject spectrograph
- Integral field spectrograph
- R = 100, 1000, 2700
- IFS: 3"x3" with 0.1" sampling
- TMT+IRIS will have unprecedented angular resolution (0.004") with higher spectral resolution

Instrument layout



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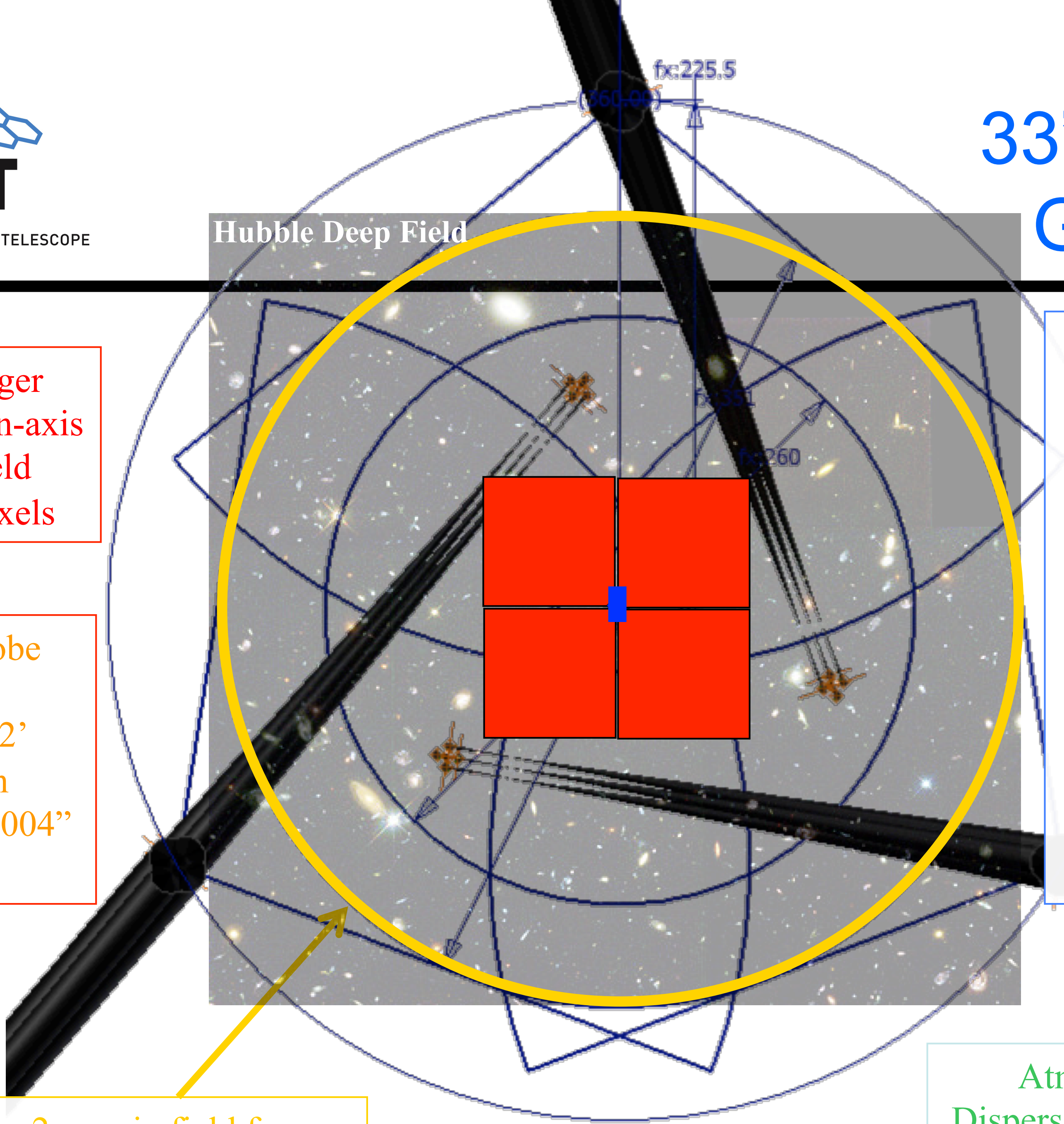
33”x33” Field Geometry

Four imager fields are on-axis
16.4” field
0.004” pixels

Three Probe Arms
Patrol a 2’ Region
4” Fields 0.004” pixels



Spectrographs concentric On-axis

2 Coarse Scales (Slicer)
45x90x~2000 elements
1.125”x2.25”@0.025”
2.25”x4.5”@0.050”

2 Fine Scales (Lenslet)
112x128x500 elements
0.45”x0.64”@0.004”
1.0”x1.15”@0.009”

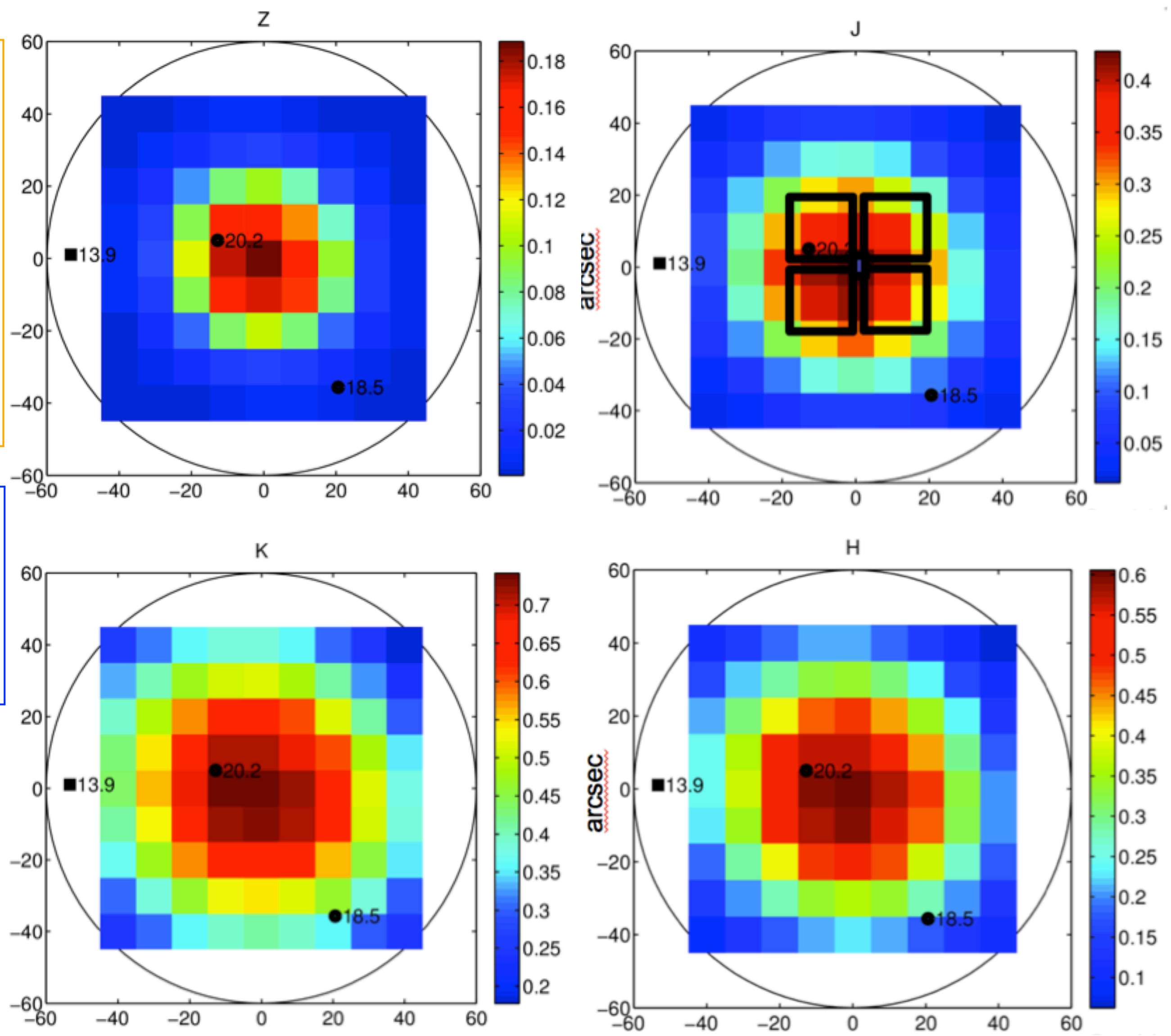
2 arcmin field from NFIRAOS

Atmospheric Dispersion Correctors in all channels

Strehl performance across 2 arcmin FoV

- **Strehl ratio** (SR)
- SR=ratio of peak diffracted intensities of aberrated versus perfect wavefront
- SR value varies between 0-1

- Typical guide star asterism
- 50% sky coverage
- Zenith



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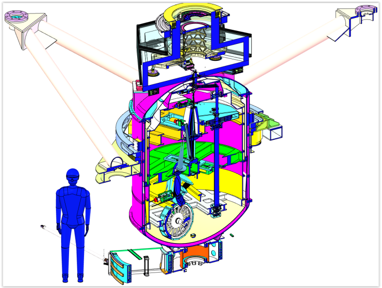
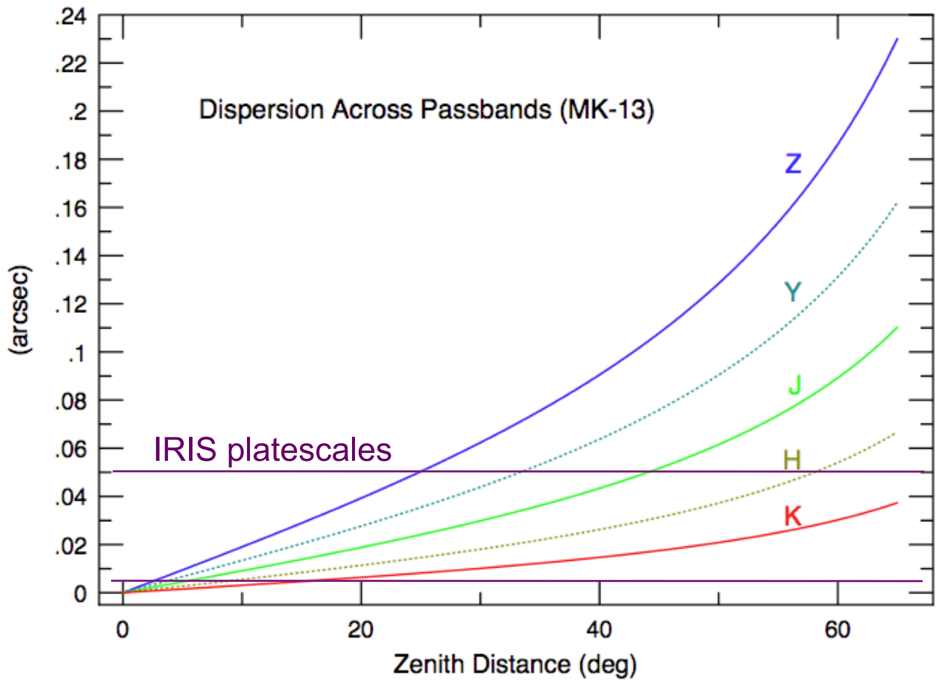
IRIS Performance Requirements



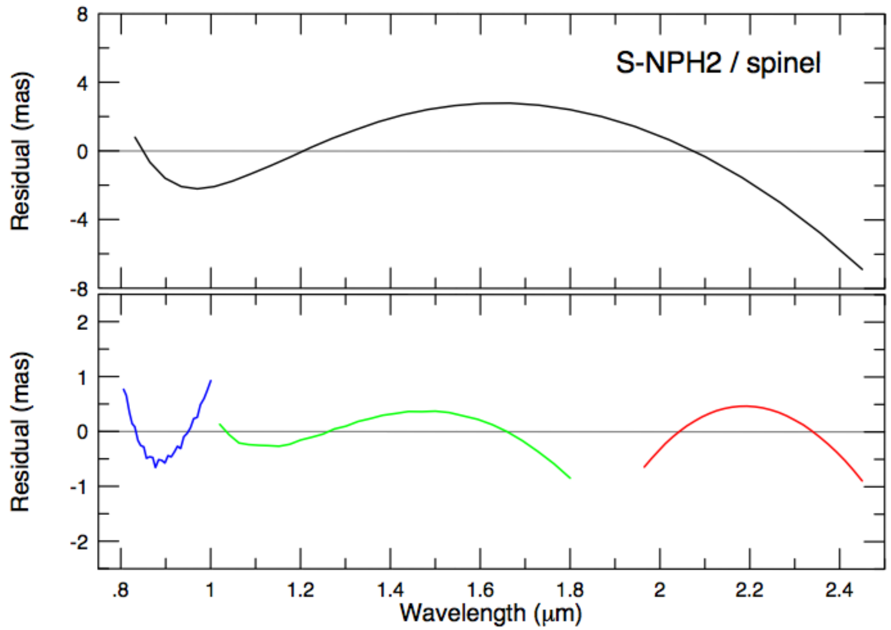
Performance category	***Value***	***Comment***
Expected Strehl ratio for greater than 50% of sky	J band: 0.41 H band: 0.60 K band: 0.75	For on-axis object. Relative Strehl ratio variations of 1.5-2.5% across entire IRIS field on account of multi-conjugate correction.
Airy ring size	J band: 21 mas H band: 28 mas K band: 37 mas	Diameter (FWHM)
Ensquared energy	J band: 0.35 - 0.57 H band: 0.50 - 0.66 K band: 0.62 - 0.72	Over 16.4 x 16.4 $arcsec^2$ imager field. *Energy in box with diameter of PSF FWHM* Uncertainty originates from different conversions between WFE and EE.
Astrometric accuracy	Relative precision: 10 μas Relative accuracy: 30 μas Absolute accuracy: 2-4 mas	Relies on multiple visits to a particular field and a variety of reference fields.
Limiting magnitude (Imager)	J band: 27.8 H band: 27.3 K band: 26.9	Point source sensitivity. Five hour integration, S/N=100, 2λ/D aperture. AB magnitude.
Limiting magnitude (Spectrograph)	J band: 25.8 H band: 26.0 K band: 25.2	Point source sensitivity for 4 mas pixel scale. Other scales are significantly more sensitive. Five hour integration, S/N=10, 2λ/D aperture. AB magnitude.

Atmospheric Dispersion Corrector

- Within a 20% band, dispersion can reach 0.2"
  - This rotates during an exposure making ADC essential for most observations.
- Knowledge must be <0.001"
- Drew Phillips (UCSC) investigated over 240 glass combinations for all of our ADC needs
- Current trade study to investigate a 2 arcmin "global" ADC within NFIRAOS

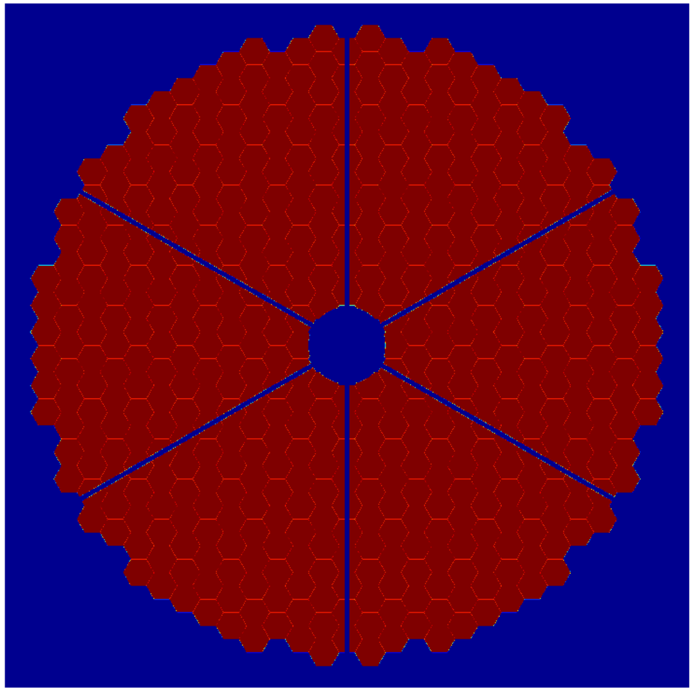


Example Correction @ 45



Pupil Tracking

- Thermal Background must be effectively blocked.
  - Will require high quality internal pupil
  - Tracked Cold Masks



  - Planning common pupil for all spectrograph scales

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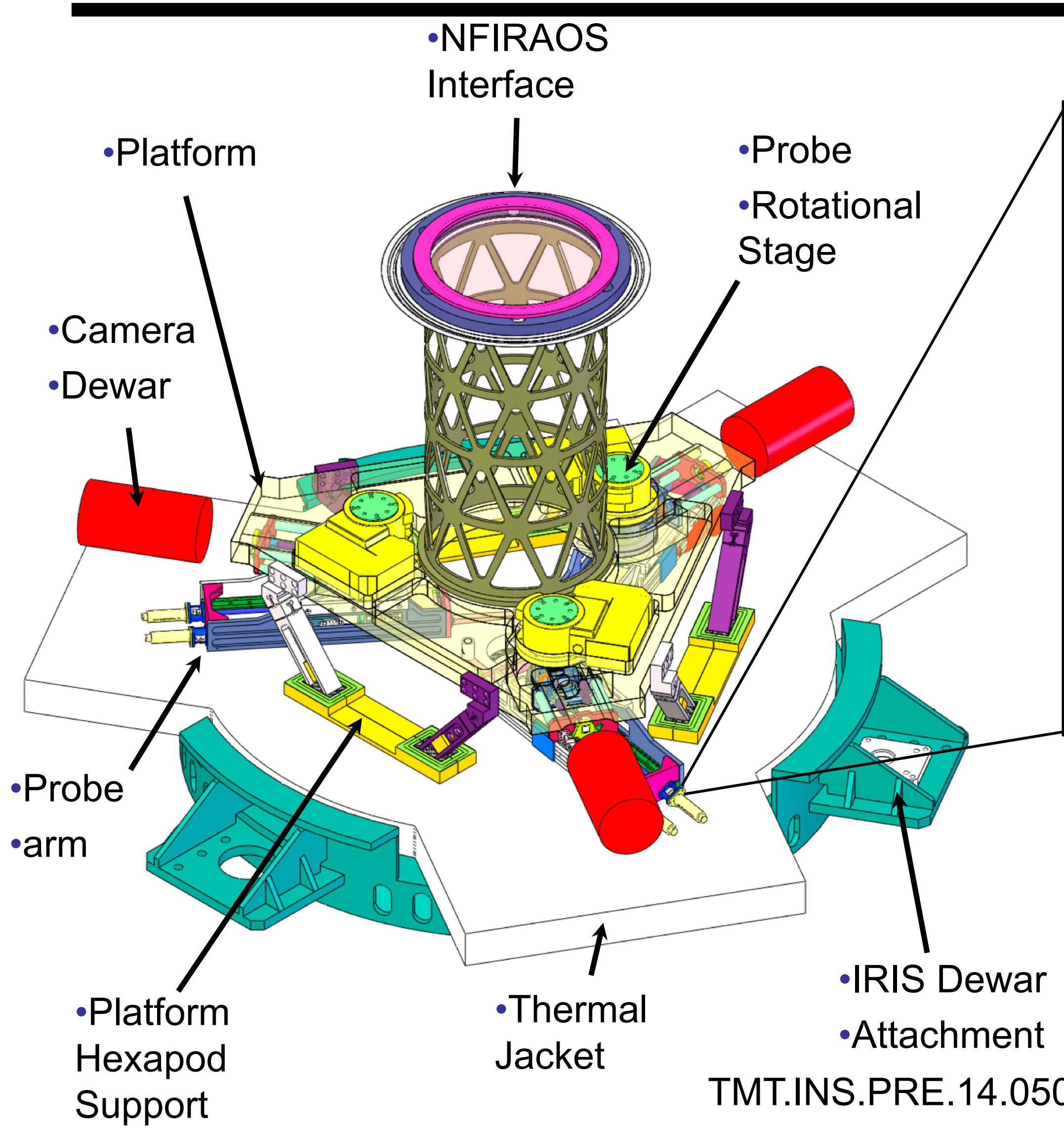
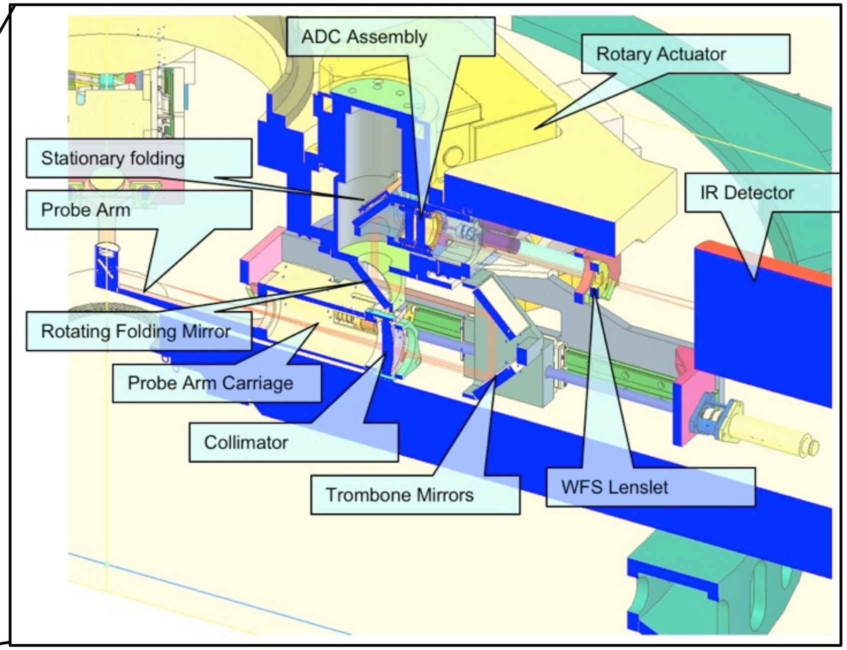
Astrometry

- Astrometry requirements force team to continually assess end to end TMT/NFIRAOS/IRIS design
- Both imager *and* IFS will be enabled by precision astrometry
- Dedicated IRIS Astrometry team (led by Matthias Schoek)
- Tools for making IRIS a powerful astrometry machine
  - OIWFS is an integral part of IRIS (mechanically stiff assembly)
  - OIWFS probe arm has met performance requirement
  - OIWFS have large field (~4” sampled at 4mas) so on chip dithering for all operating modes
  - Precision pinhole masks in NSCU/NFIRAOS
  - IRIS is gravity invariant
  - H4RG (IRIS IR detectors) will be evaluated for PSF response prior to shipment
  - 34”x34” imager detector can be used in window mode to guide if sufficiently bright stars available
  - Imager and IFS share filter hence accurate PSF monitoring while using IFS
  - All critical mechanical stages are 2 position with hard stops (<1μm)
  - GAIA catalogue (200 uas absolute reference for OIWFS stars V=20)

OIWFS (HIA)
(Vlad Reshetov: HIA)



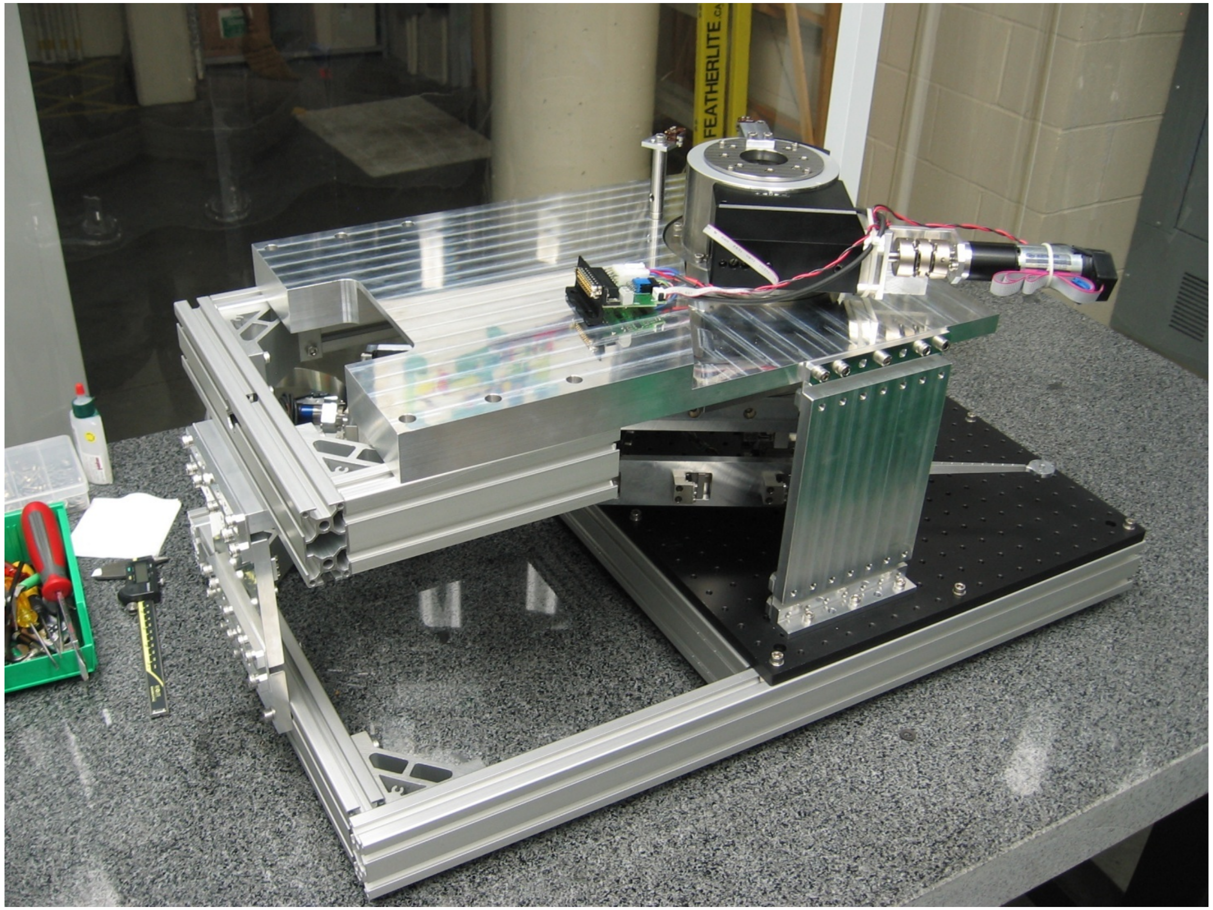
•Probe arm



Mature mechanical design
Prototype probe arm complete
Arms can perform TT or Focus measurements

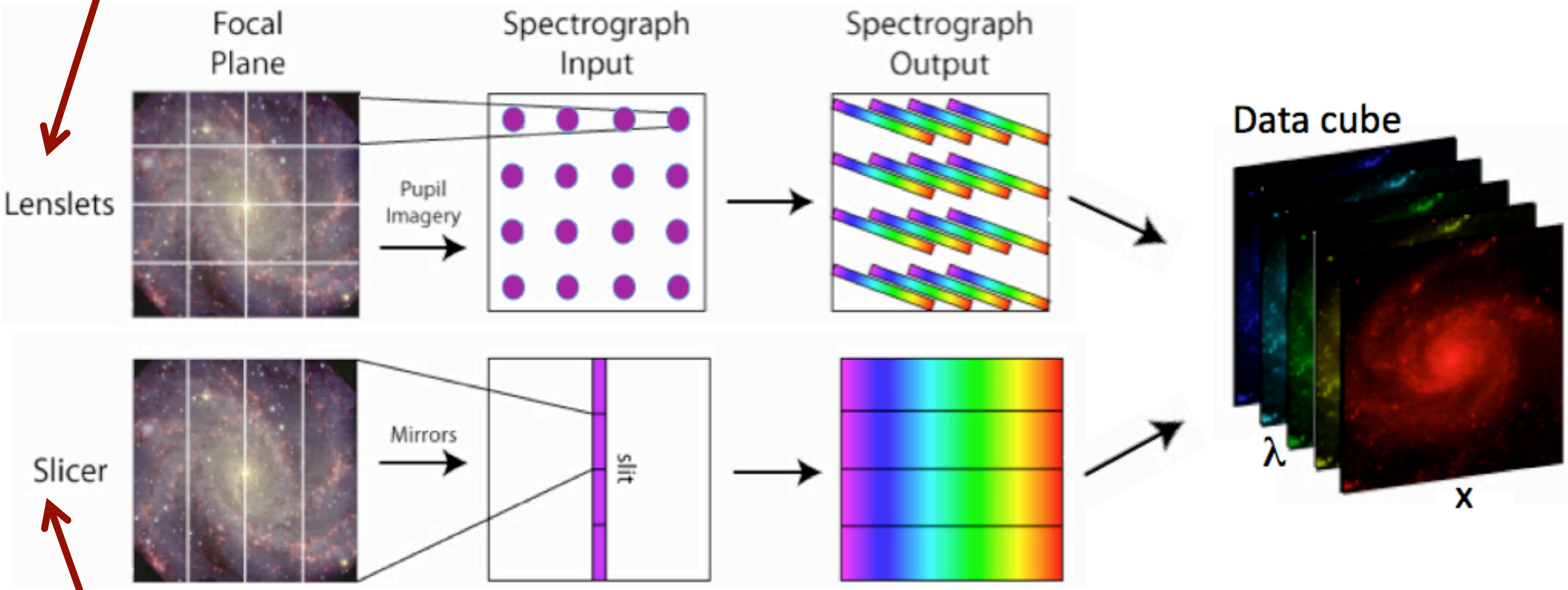
PROBE ARM PROTOTYPE (Vlad Reshekov-HIA)

- Successful tests with coordinate measuring machine.
  - Rotary actuator ±2.6μm (3σ) Linear actuator ±8μm (3σ)
  - Requirement is ±13.2μm (3σ) which is 2 mas rms



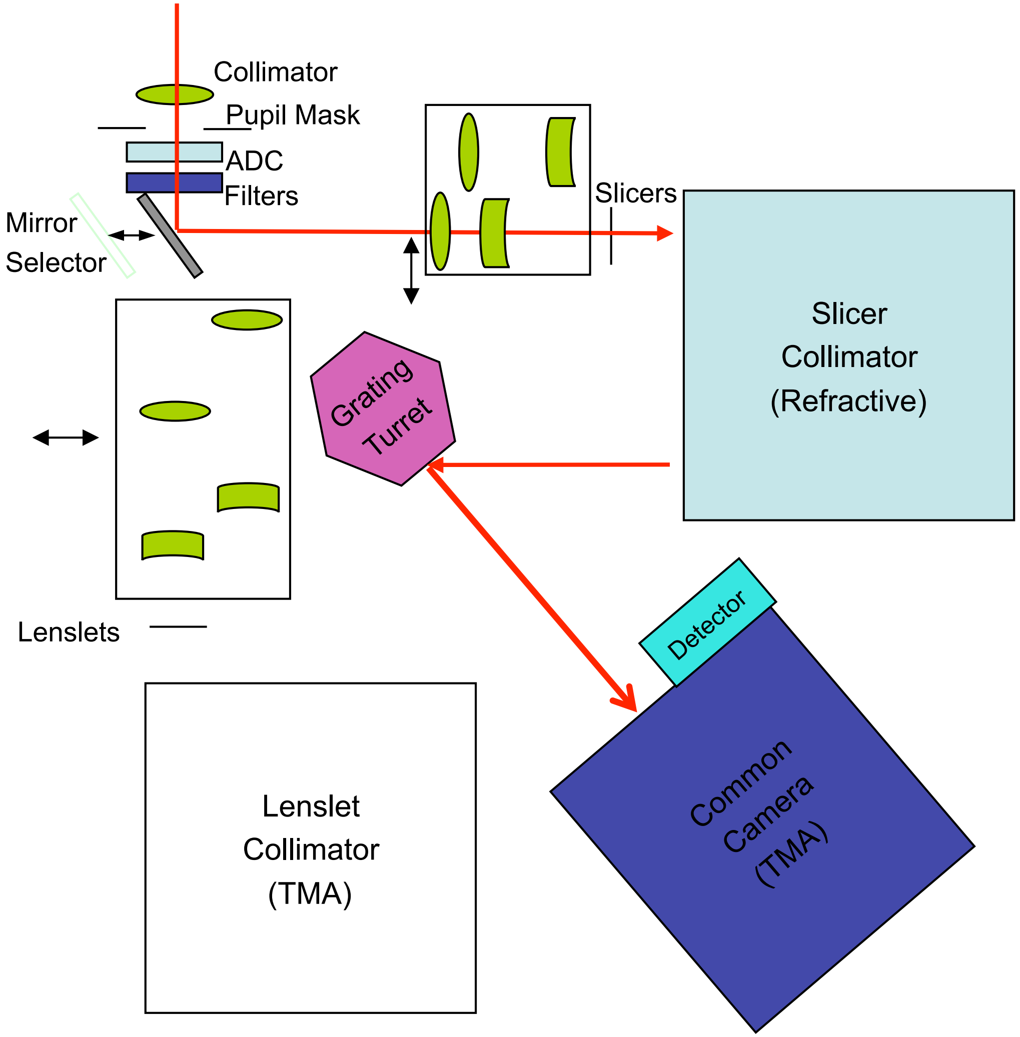
Hybrid IFS

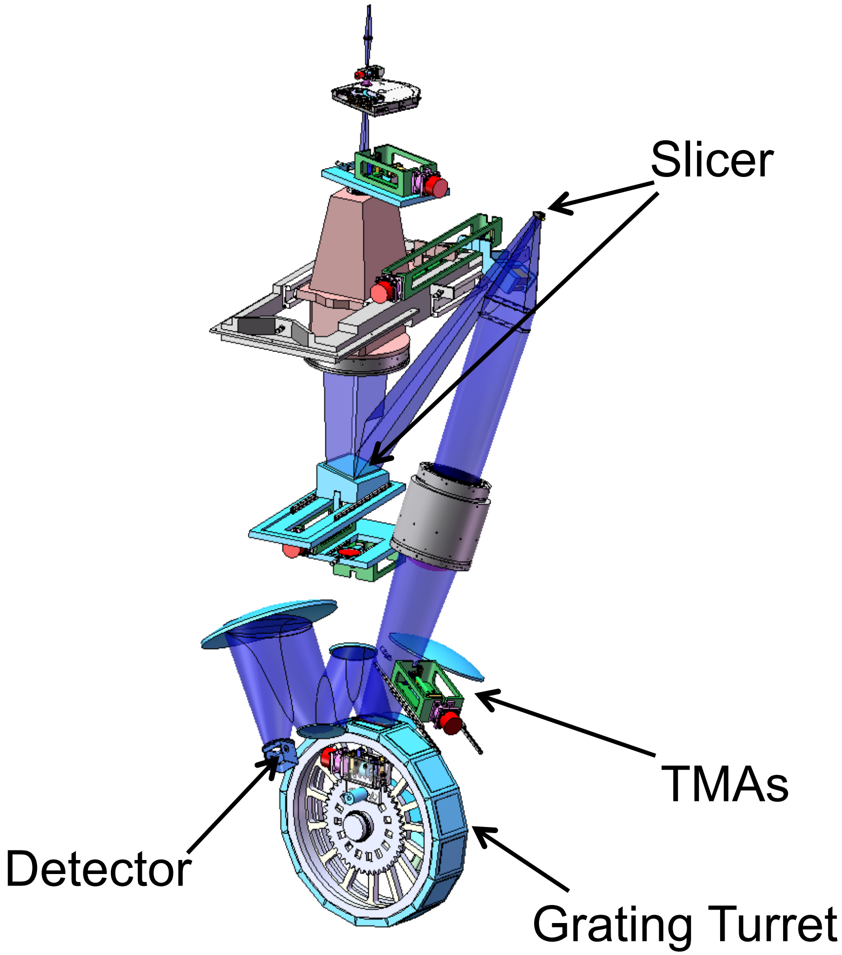
Excellent WFE, good FoV for fine plate scales=4mas, 9mas



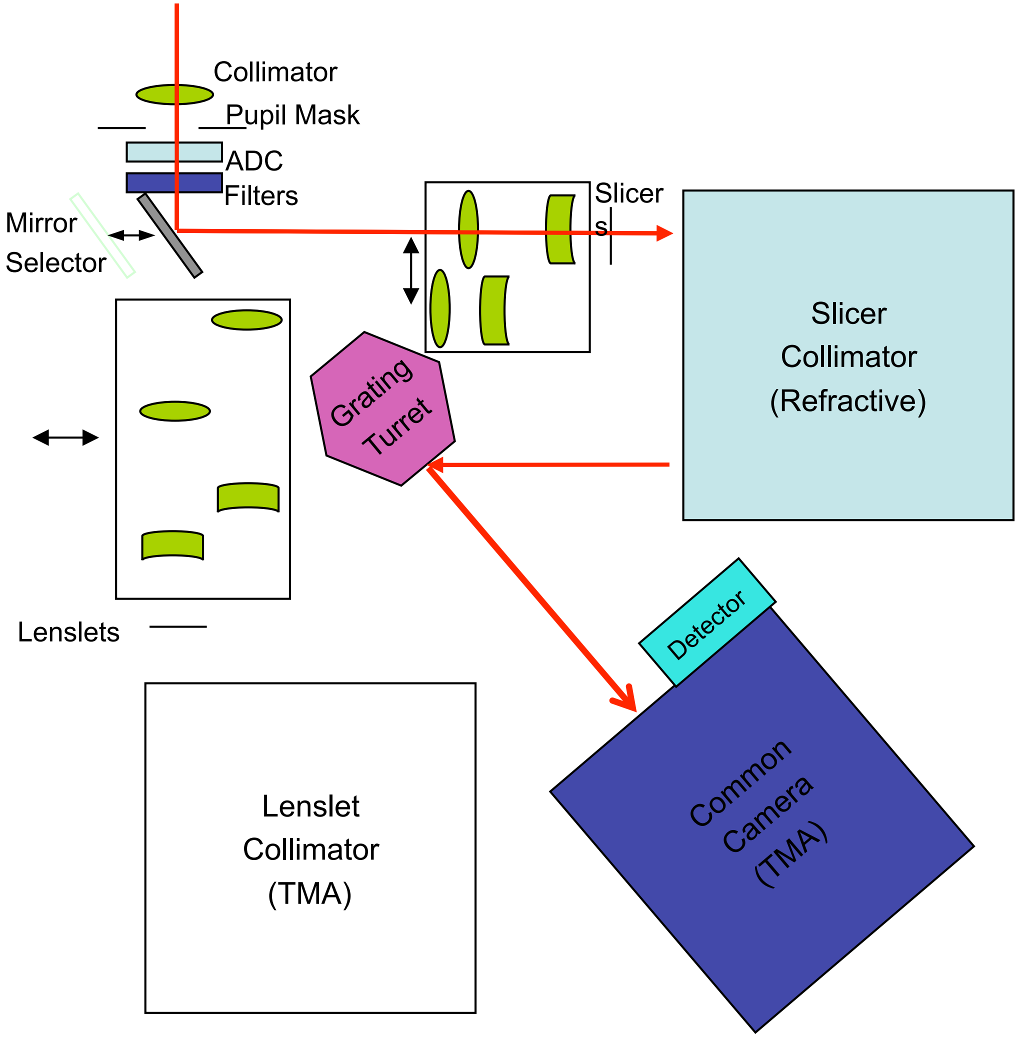
Excellent bandpass, largest FoV=25mas, 50mas

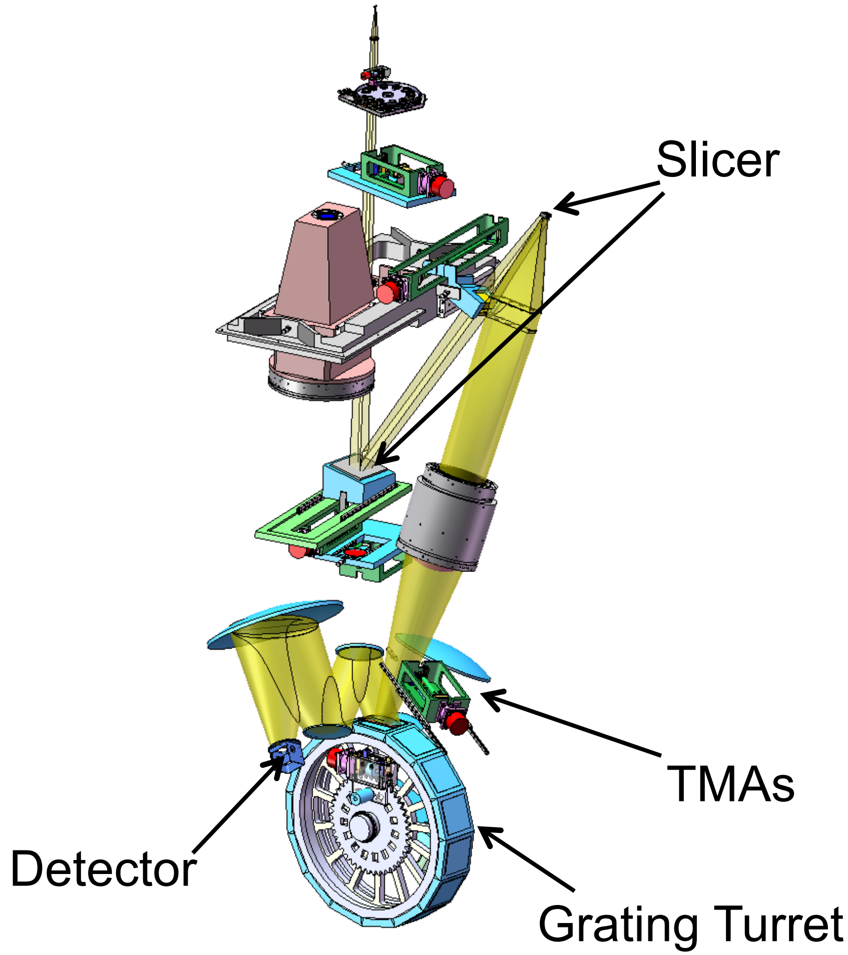
Folded Geometry (50 mas scale)



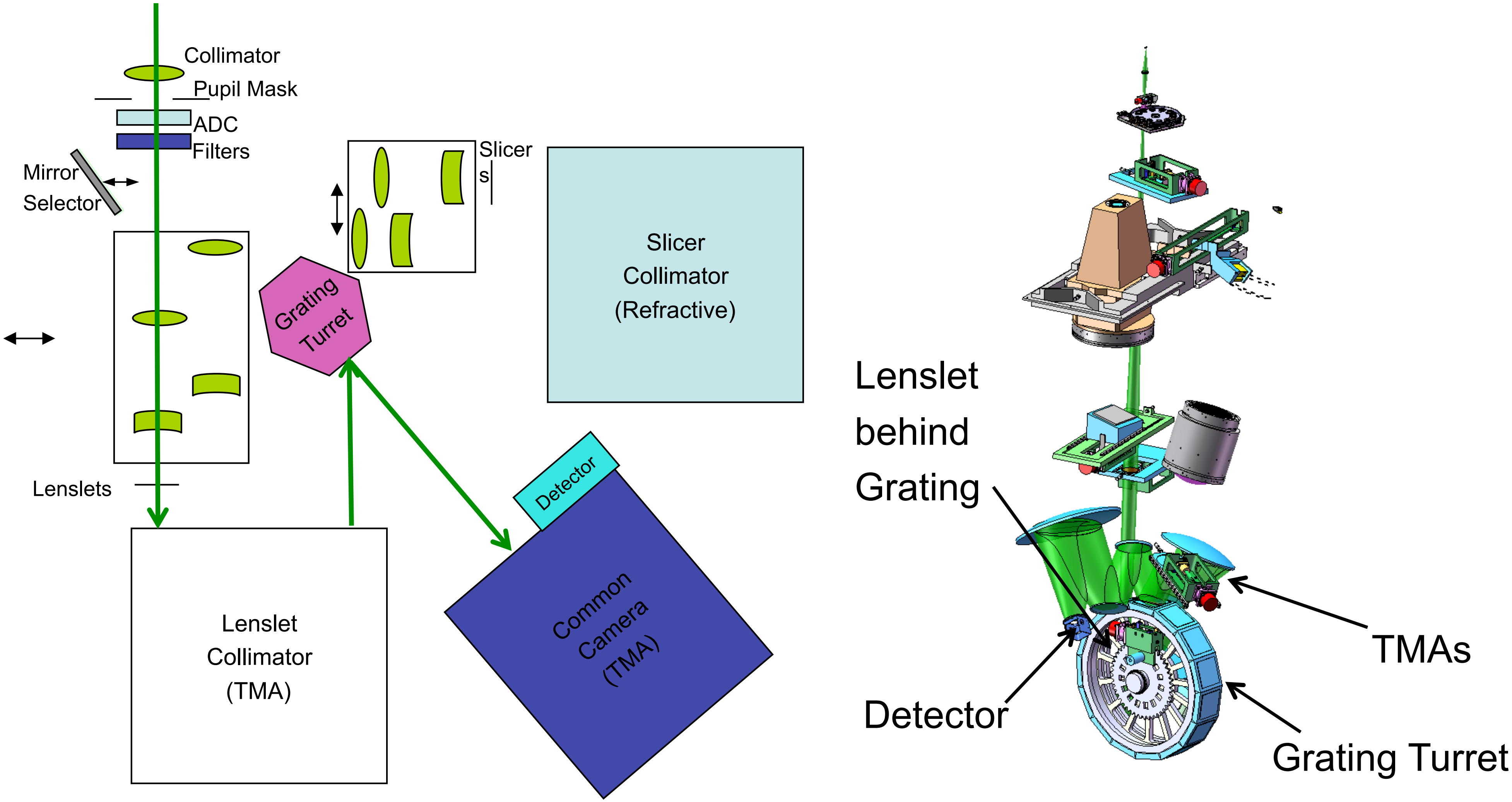


Folded Geometry (25 mas scale)

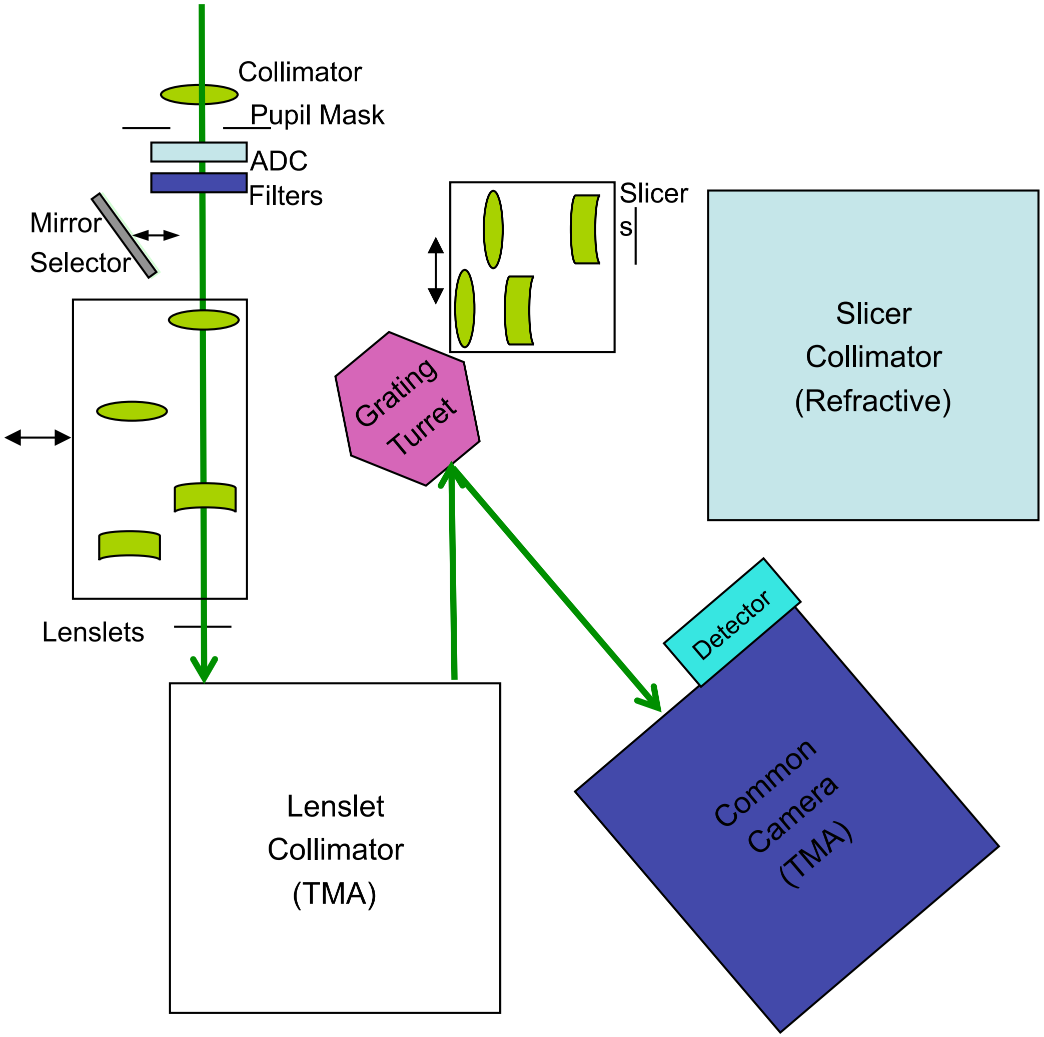


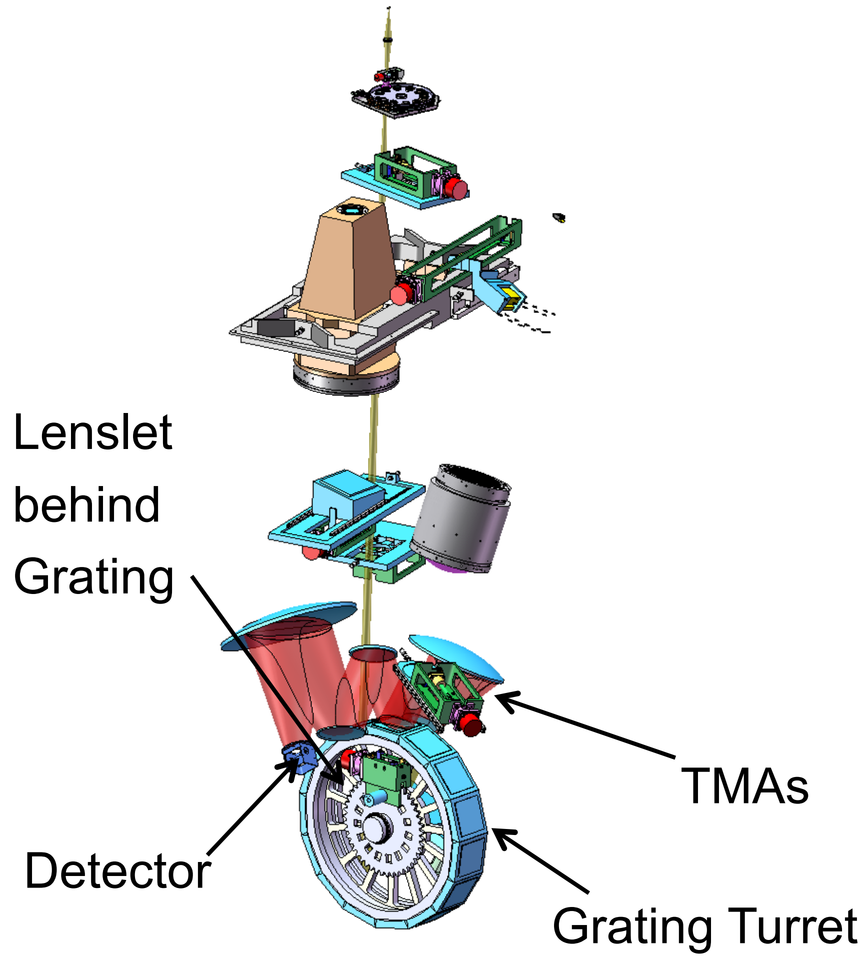


Folded Geometry (9 mas scale)

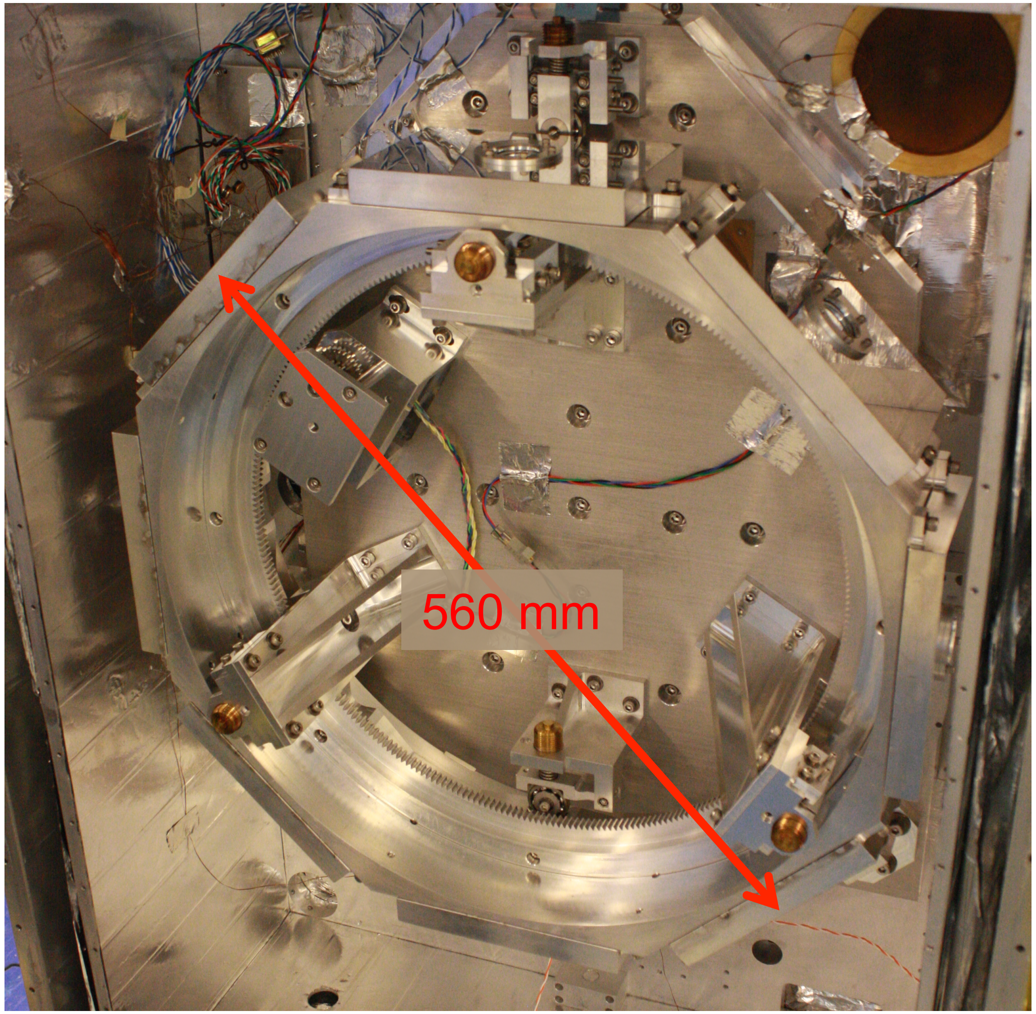


Folded Geometry (4 mas scale)





Cryogenic Grating Turret Prototype (2/3rds full size) (John Canfield: UCLA)



- 8 Full size “Gratings”
  - Each 100x150 mm
  - 25mm precision mirror mounted in each
- From any position to any position in less than 30 seconds.
- Repeatability very good in crucial axis (<20mradians)

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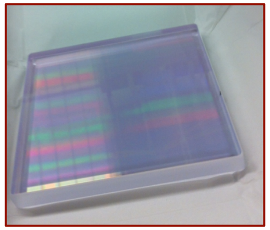
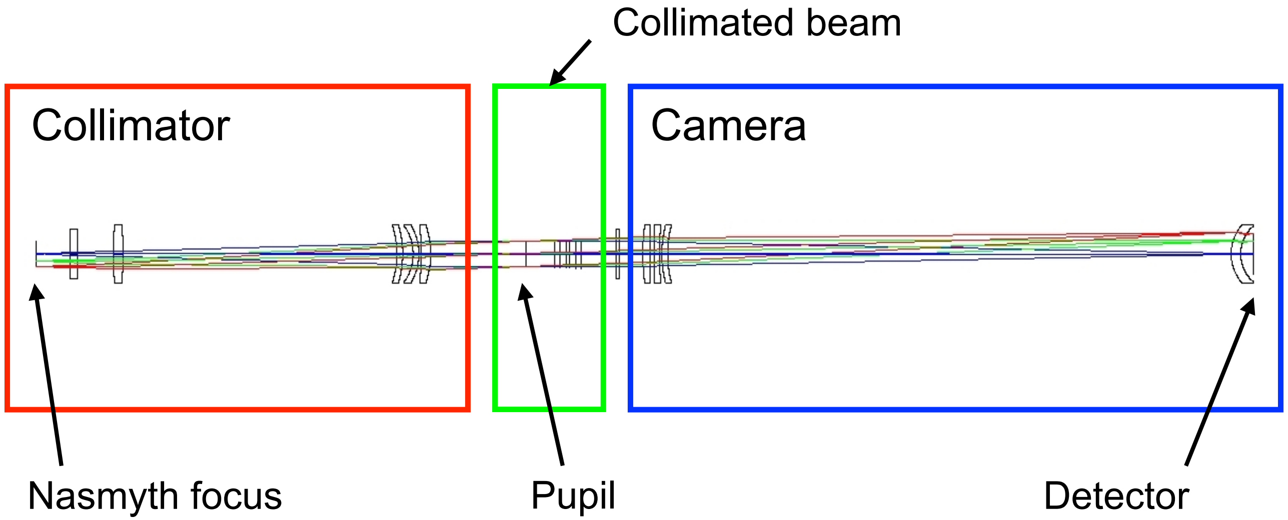
VPH versus Ruled Gratings

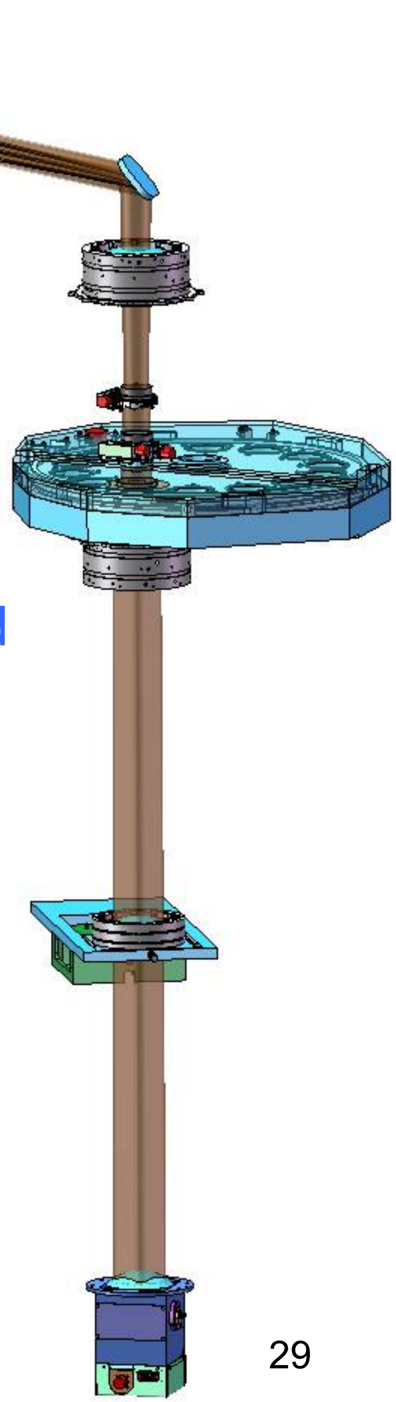


- Shelley Wright, Shaojie Chen and Elliot Meyer (University of Toronto) are leading this work
- Trade study commenced in 2013 to investigate performance of VPH gratings for IRIS
  - CODR design used ruled reflection gratings
- A range of VPH and ruled gratings were obtained from a variety of vendors (including CIOMP) with same specifications (J, H R=4000, J=8000)
  - Low line density identified as a challenge by VPH vendors
  - IRIS IFS (both slicer and lenslet) require large off Bragg angles (a possible issue for VPH gratings)
- Throughput testing now completed
- Chen et al SPIE 2014 9147-334, Meyer et al SPIE 2014 9147-349

IRIS Imager (NAOJ)
(0.004” Scale)

- Refractive Apochromatic Triplets (Five other design families were considered).
- Below 30nm of WFE in almost all positions and bands.
- Supports a Pupil Viewing Mode
- Current trade study to investigate increasing imager field to 34”x17” or even 34”x34” (ApT & TMA)





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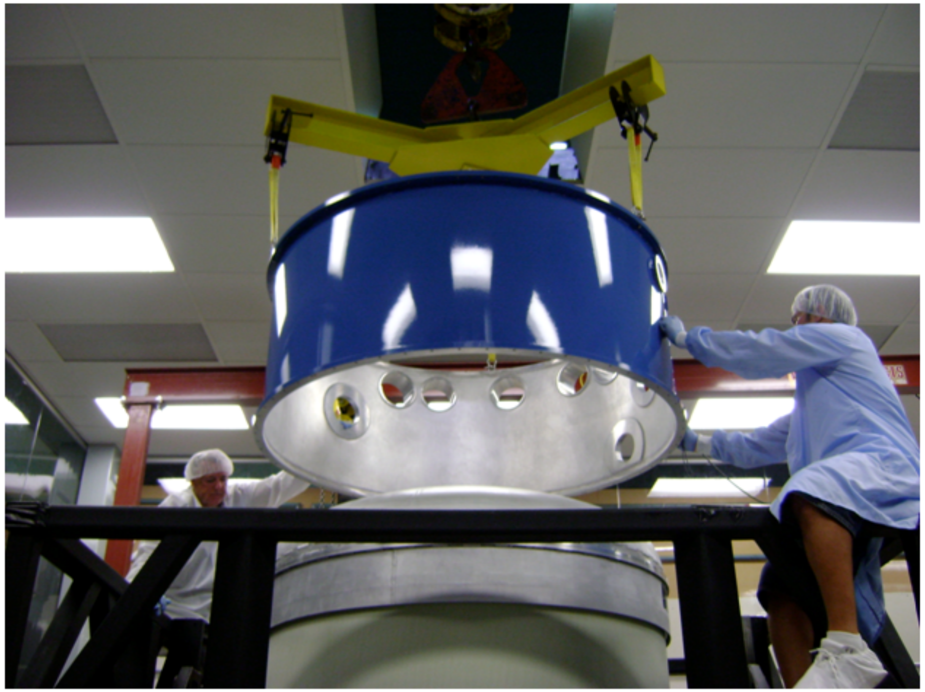
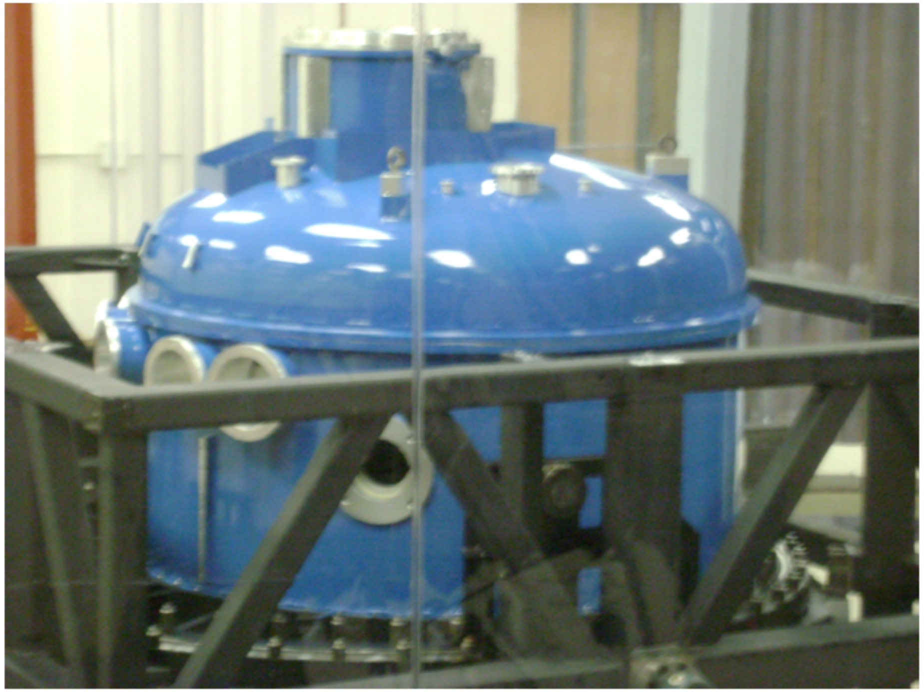
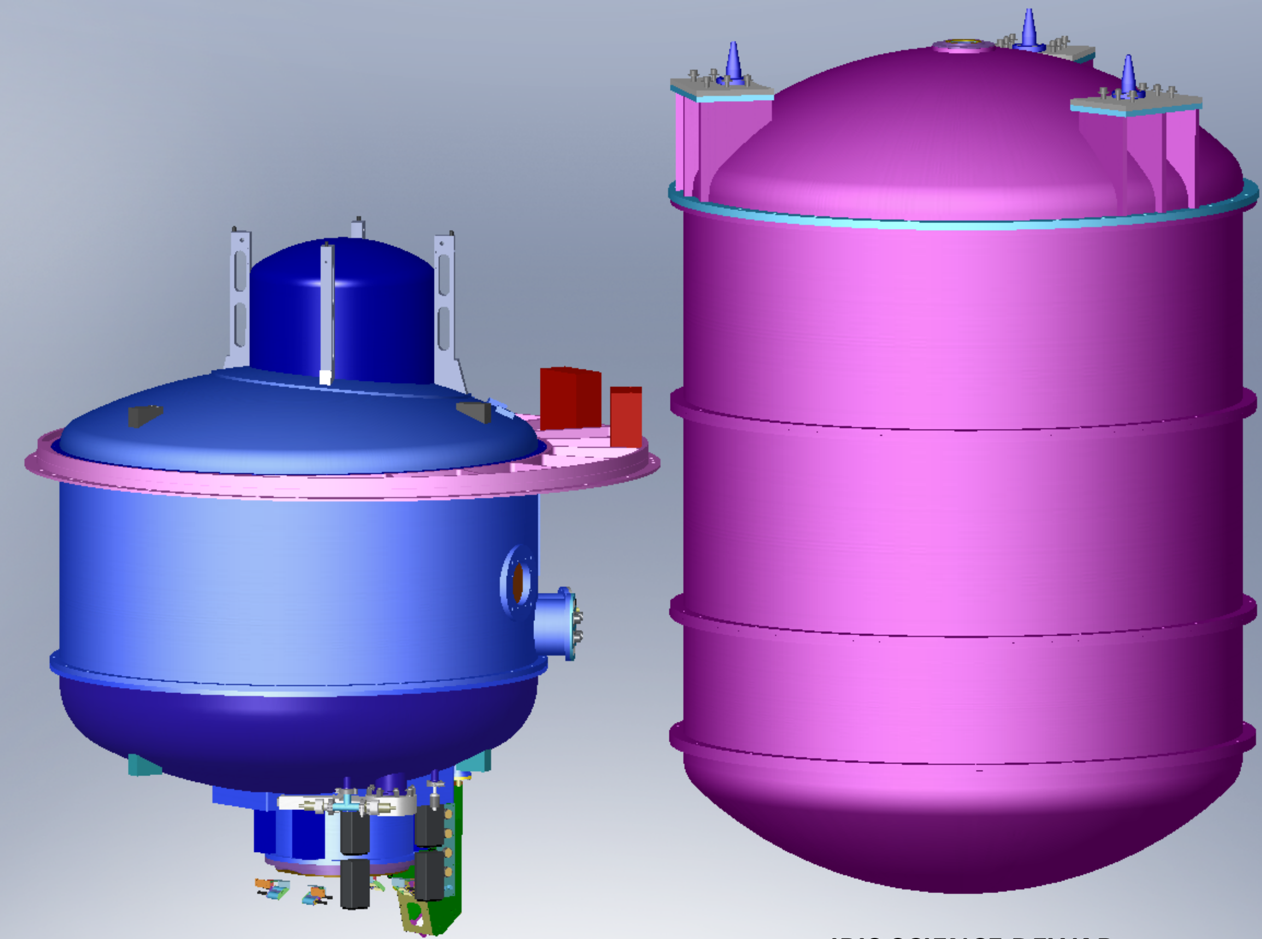
MOSFIRE Dewar Assembly





- An excellent collaboration between UCLA, Caltech, UCSC, Keck Observatory and international industry.
- Dewar has about ½ IRIS volume and many comparable challenges. On sky since 2013.

COMPARISON WITH MOSFIRE (IRMS)
But IRIS has fixed gravity orientation



- **MOSFIRE**
  - Cooled Surface Area: 8.4 m^2
- **IRIS SCIENCE DEWAR**
  - Cooled Surface Area: 16.8 m^2

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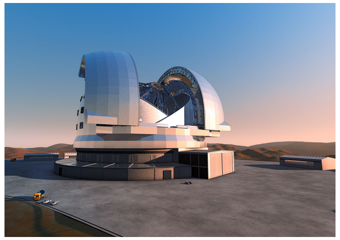
TMT Forum “out of the box” ideas are welcomed too

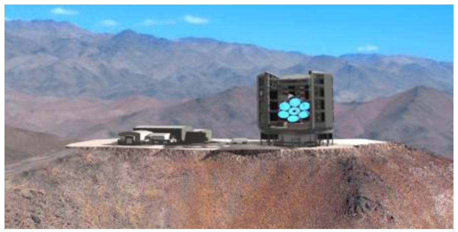
- Imager data
  - IRIS has a parallel imaging mode
  - Power of IFS will likely be under demand
  - BUT every IFS pointing acquires a 34”x34” image, 4mas/pixel with MCAO with exquisite astrometry
  - IRIS will likely receive an appreciable number of nights in first few years of operation = hundreds of images with long exposures
  - What can be done with this dataset?
  - Imager ADC=low resolution spectra (R~100?)
- OIWFS
  - 4” field sampled at 4mas, ADC correction, $JHK_{s,}$ baseline H2RG (1/4 field)
- Fast time domain
  - TMT/IRIS has super collecting power
  - Second/millisecond/microsecond?? (EELT have thought about this)

THIRTY METER TELESCOPE

“Coopetition”

- IRIS/GMTIFS and HARMONI
  - Instrument teams have healthy relationship
  - Often on review panels
  - Technology/approach ideas often discussed eg SPIE
  - While we are competing, each instrument has a uniqueness driven by science community/heritage of proposing team
- Synergies (as opposed to direct competition)
  - At a top level the instruments look very similar hence capabilities identical
  - There are differences under microscope
    - E.g. GMTIFS and IRIS have parallel imaging *but* field splitting done spectrally in GMTIFS and spatially in IRIS





Summary

- IRIS will be a revolutionary diffraction limited instrument
- IRIS is in the Preliminary Design Phase (PDR early 2015)
- Trade studies almost complete
  - Imager FOV and layout
  - ADC location
  - Grating technology
  - OIWFS bandpass
- Challenging components have been prototyped or will be during the LPDP
  - Probe Arms
  - ADC's
  - Grating Turret
  - Cryogenic TMAs
  - Slicer Mirrors
  - OIWFS detectors
- Dedicated and very active science team
- First light December 2023

IRIS is well underway

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