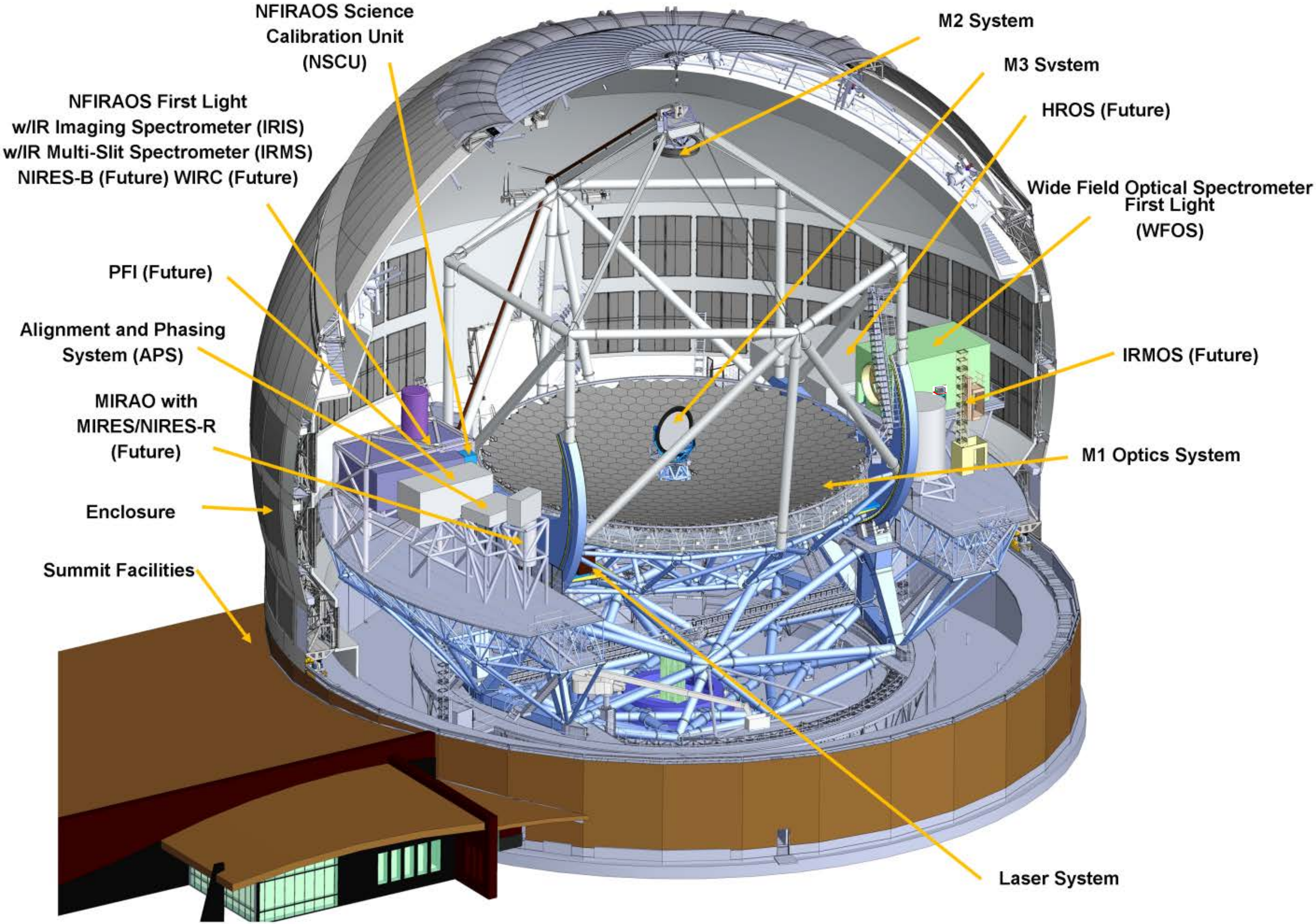
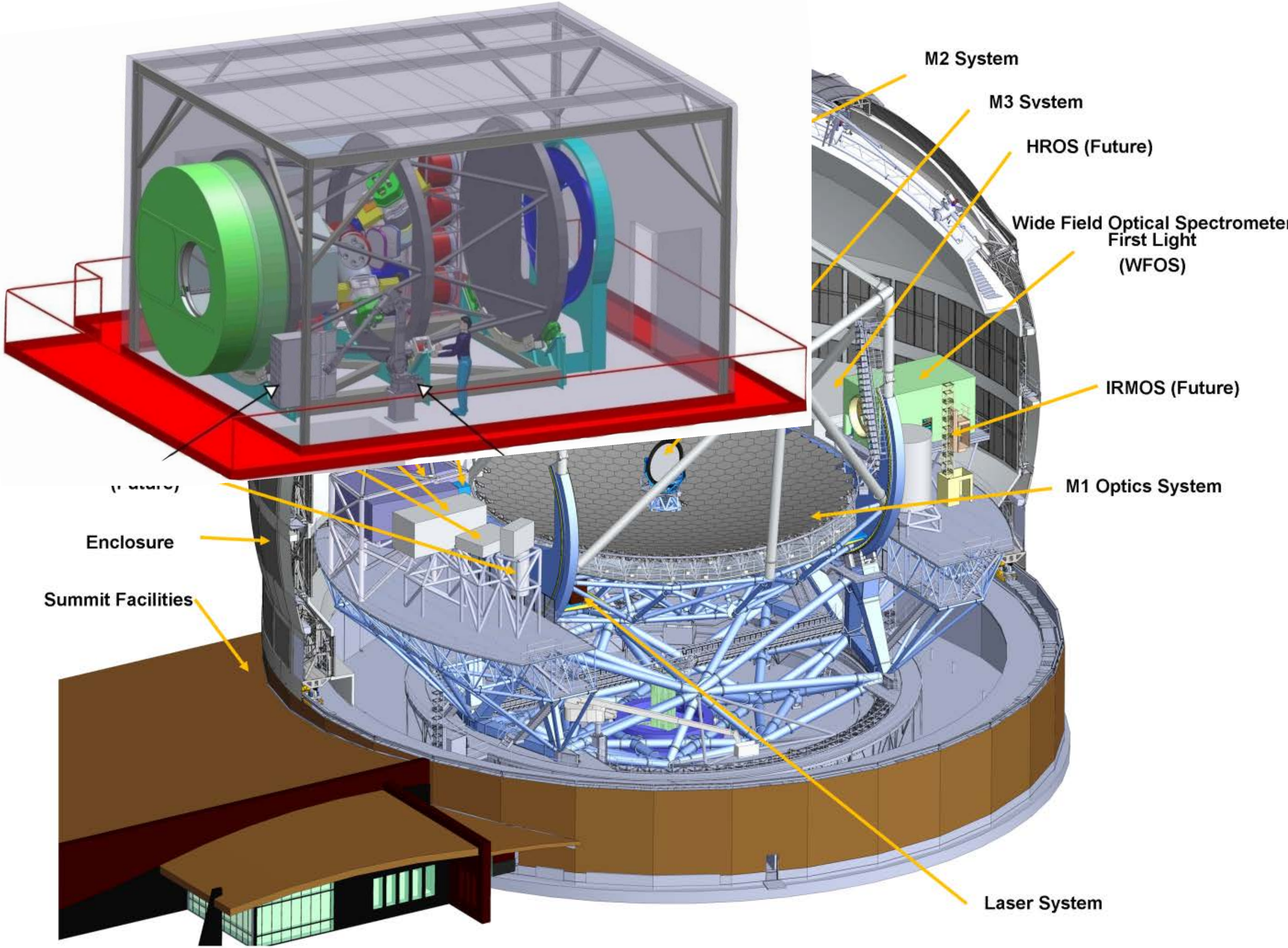
Wide-Field Optical Spectrograph (WFOS) Status and Thoughts for Future Instruments

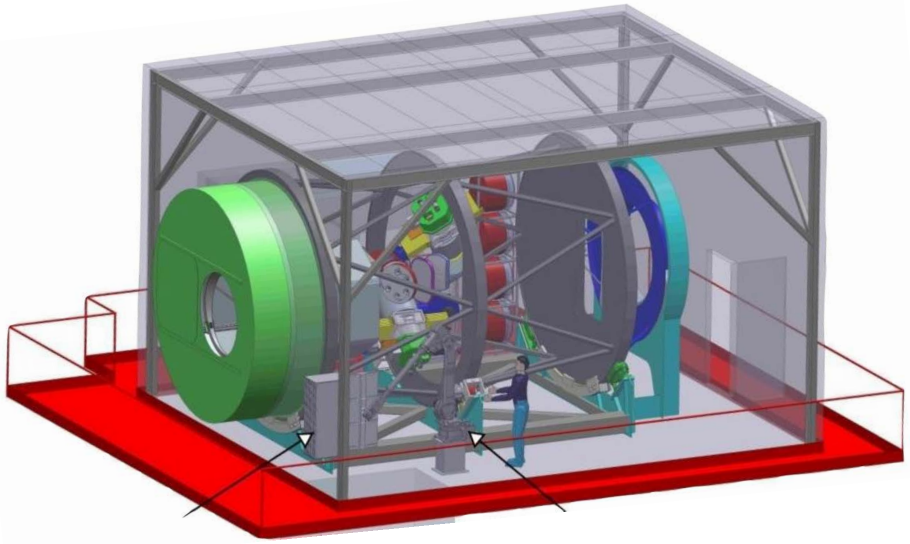
Kevin Bundy

TMT Forum
Mysore, November 2017


NFIRAOS Science
Calibration Unit
(NSCU)
M2 System
M3 Svstem
HROS (Future)
NFIRAOS First Light
w/IR Imaging Spectrometer (IRIS)
w/IR Multi-Slit Spectrometer (IRMS)
NIRES-B (Future) WIRC (Future)
Wide Field Optical Spectrometer
First Light
(WFOS)
PFI (Future)
Alignment and Phasing
System (APS)
IRMOS (Future)
MIRAO with
MIRES/NIRES-R
(Future)
M1 Optics System
Enclosure
Summit Facilities
Laser System

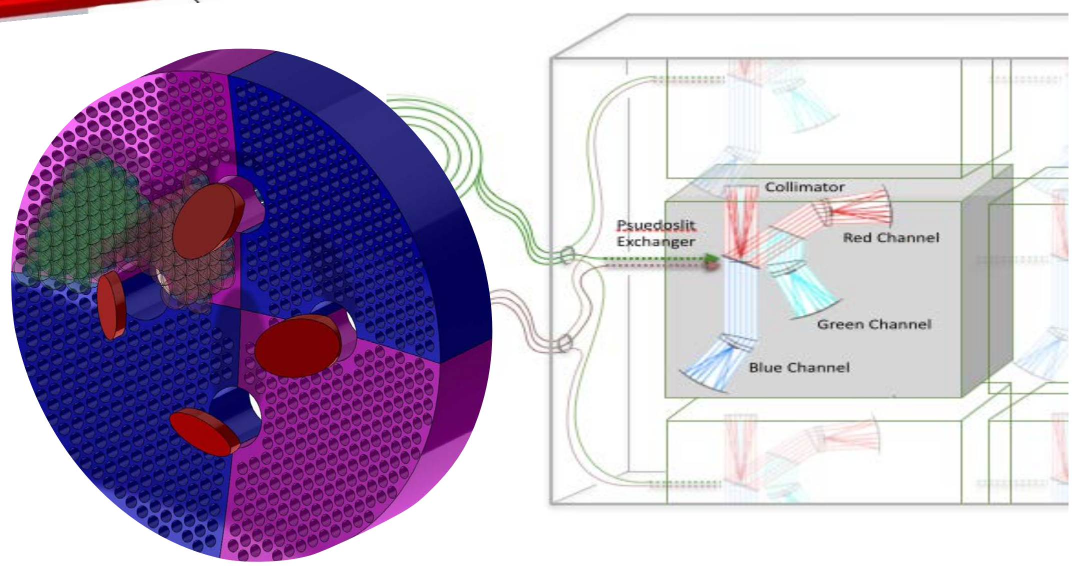


M2 System
M3 System
HROS (Future)
Wide Field Optical Spectrometer
First Light
(WFOS)
IRMOS (Future)
M1 Optics System
Enclosure
Summit Facilities
Laser System

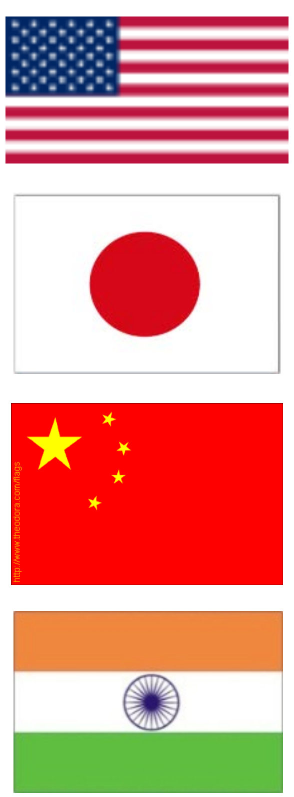


Slicer-WFOS

WFOS
Wide-Field Optical Spectrograph



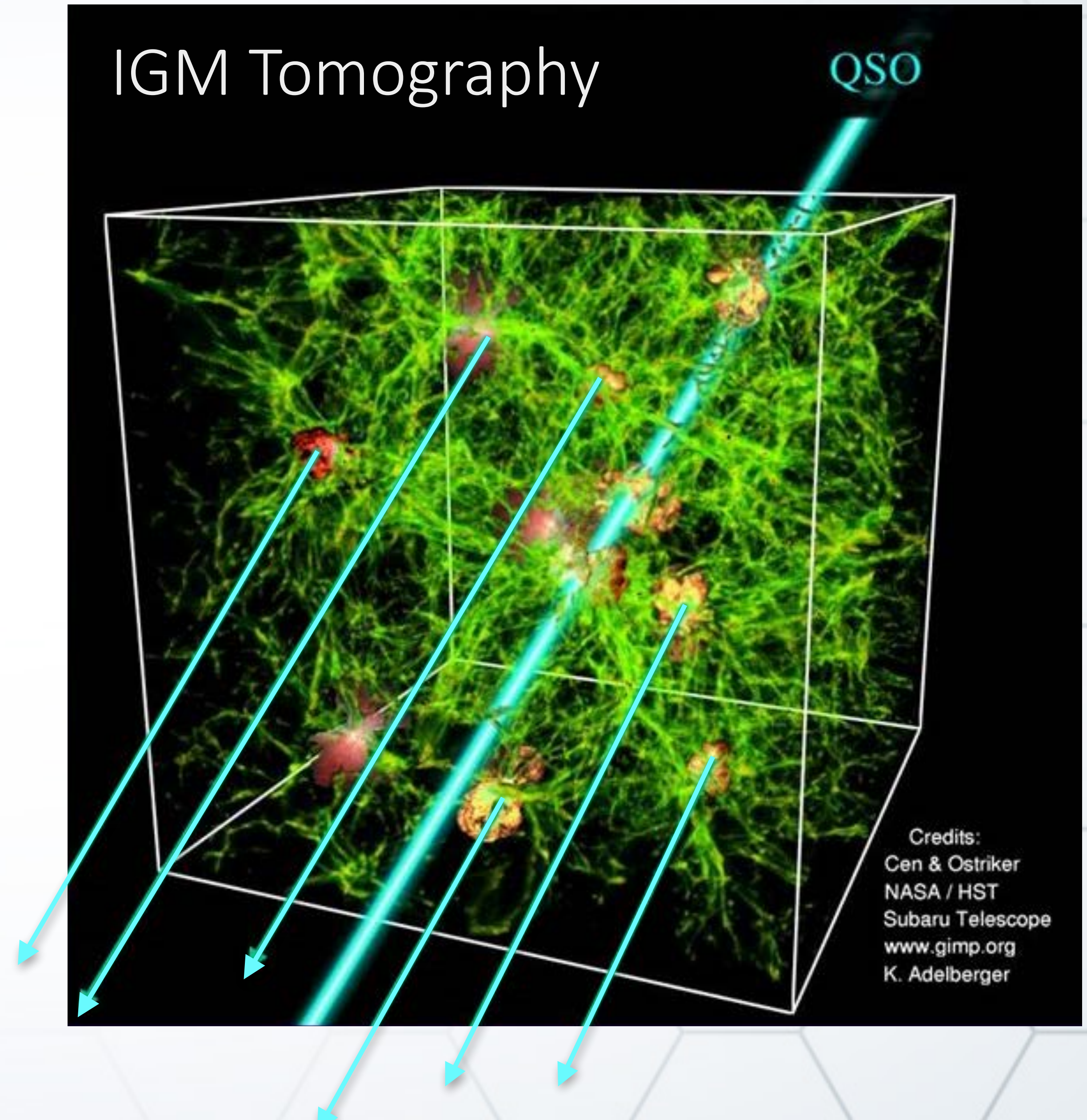
Fiber-WFOS



- UCO led since 2008 when it was called MOBIE
- 2016 - 2017: OMDR Opto-Mechanical Design Requirements ph
    - Bundy (PI) and Savage (PM) join UCO in Fall 2016
    - OMDR Review in May 2017: OMDR design is too risky
- Aug 2017 - Mar 2018: Conceptual Design Phase 1
    - March 2018 down-select: Slicer-WFOS vs. Fiber-WFOS
- Partners include: NAOJ (Japan), IIA (India), NIAOT (China), Calte

Top-level WFOS Capabilities

- Primarily multi-object survey instrument
- Also single-object rapid discovery/ identification mode (e.g., transient science from LSST)
- R~5000 spectroscopy from 310 - 1000 nm
- R~1500 mode beneficial if multiplex and S/N improve
- GLAO ready



Studying proto-galaxies and the gas around them

WFOS Core Science

See OMDR Science Report in Collection 14796

- How are proto-galaxies (z=2-5) shaped by their gaseous environment and how do they affect that environment?

  High-z galaxies and Tomography

- What is the origin and astrophysics of stellar populations in nearby galaxies?

  Stars

- What are the key mechanisms that initiate the final stages of galaxy evolution?

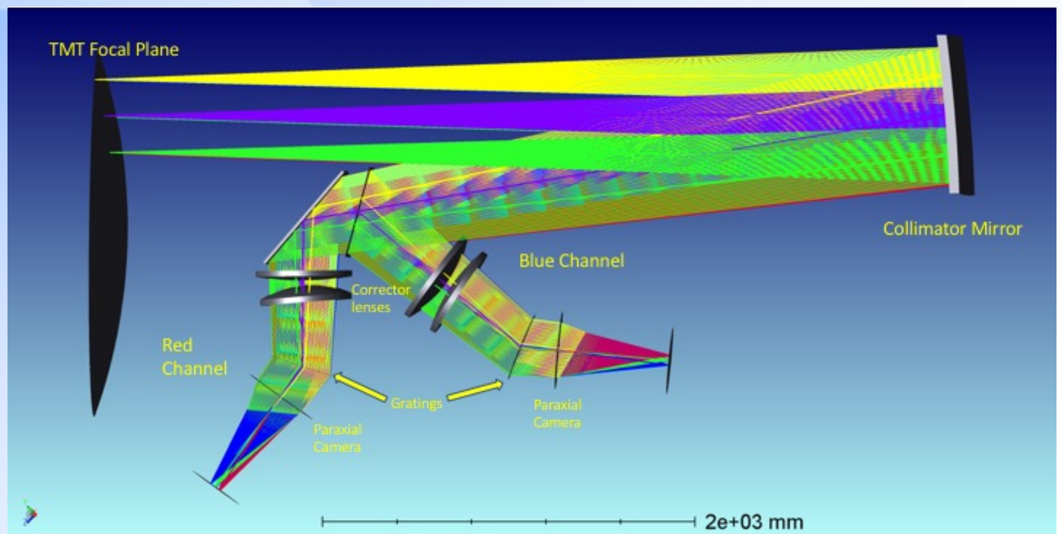
  z~1 galaxies and GLAO

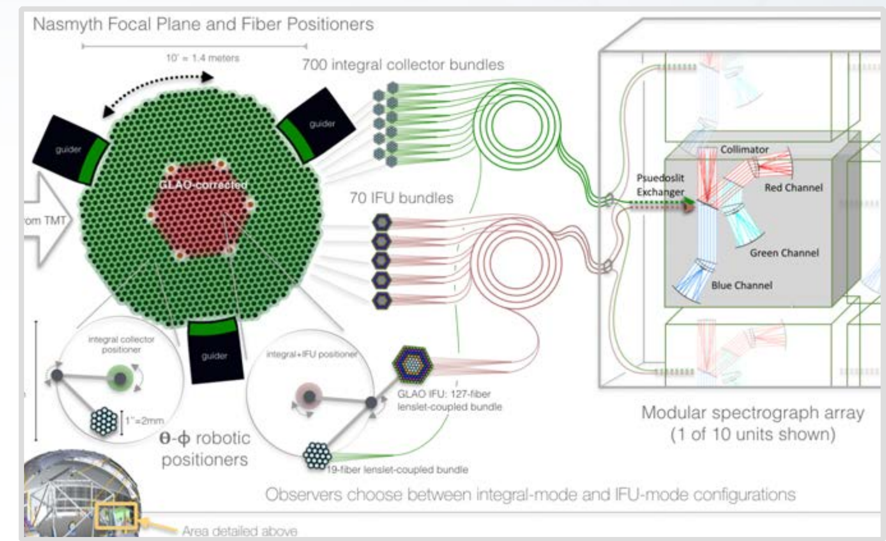
- What is the nature of transient sources?

  Transients

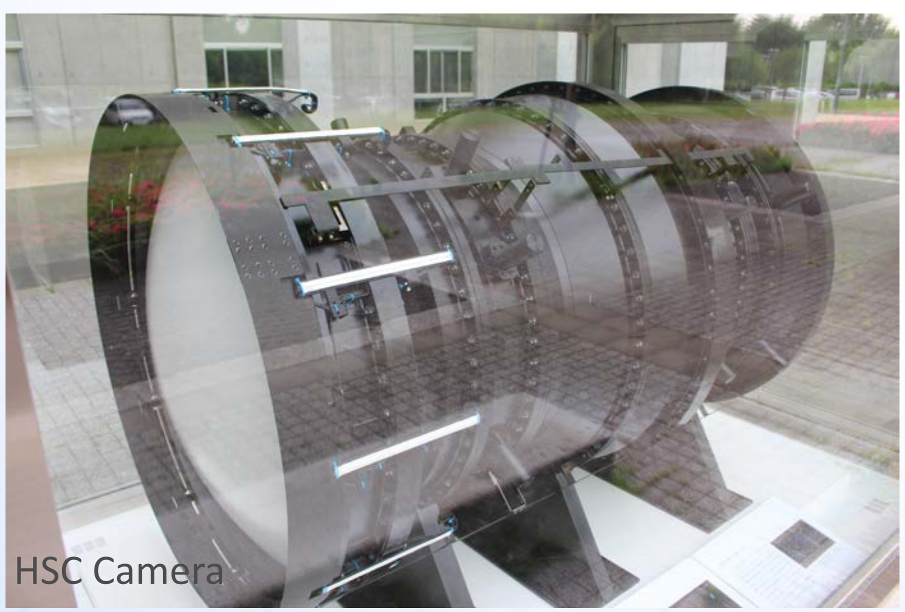
WFOS at a Crossroads…

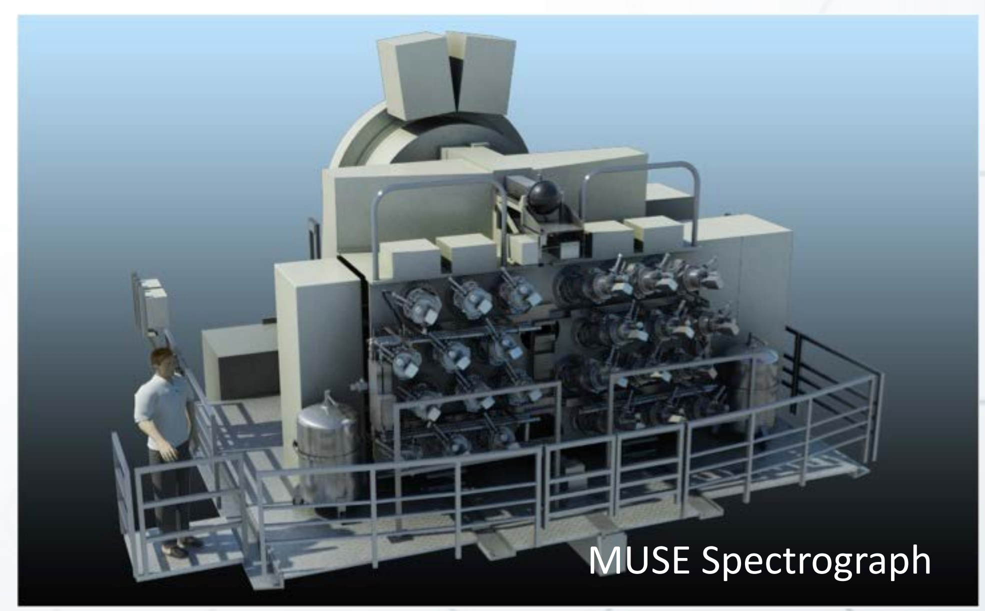
Slicer-WFOS or… Fiber-WFOS





Monolithic or… Modular?





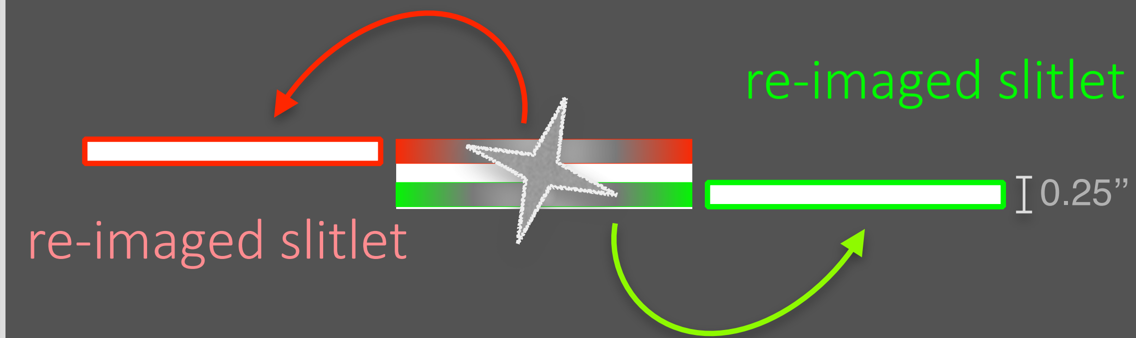
Slicer-WFOS

Slicer design by NAOJ

Slicer-WFOS Specs

- 2-channels with single VPH grating
- Regular slit mask delivers R~1500
- R~5000 achieved with focal plane slicers
- 0.75” slit can be sliced into three and stacked side-by-side
- **~100 low-res slits / ~25 med-red modules**

One of 25 slicer modules for R~5000

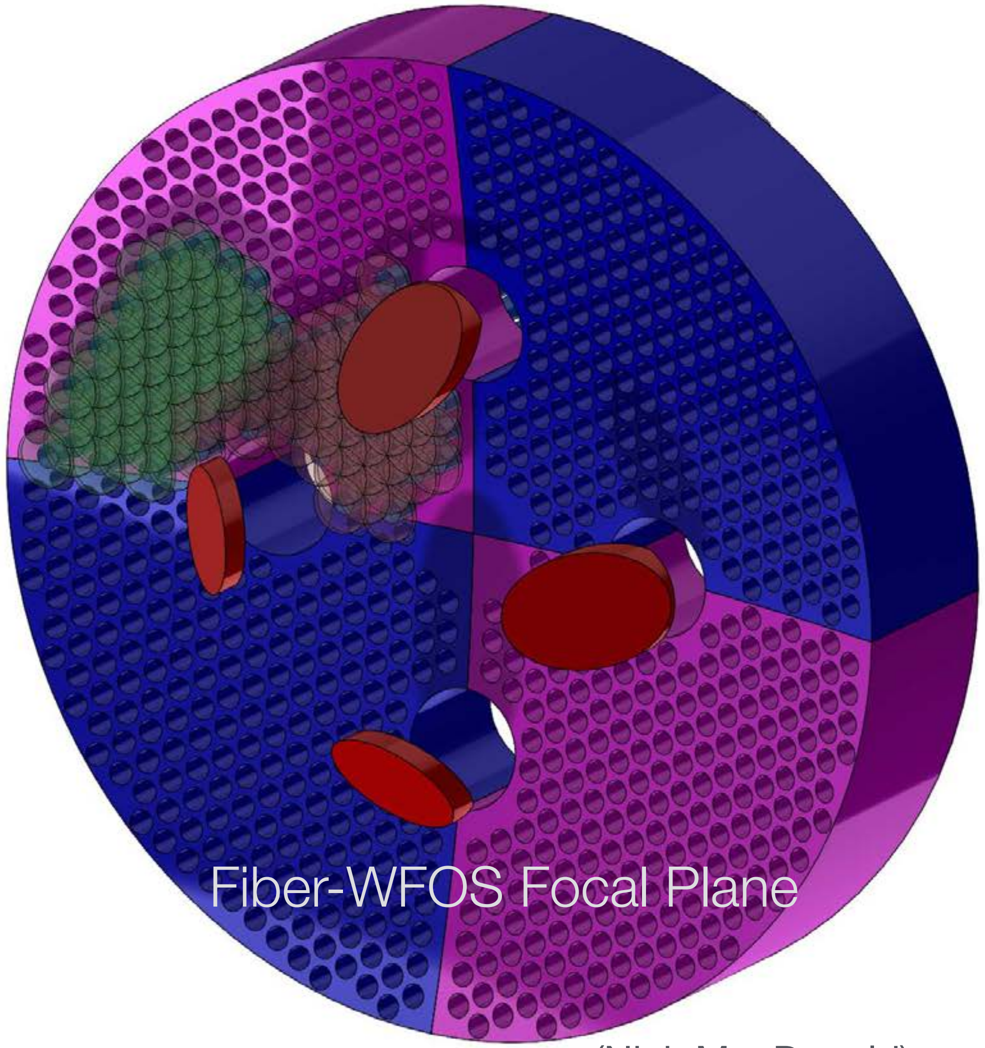


Spectrograph sees 3 slitlets, each 0.25” wide.
Later combine the slits for no aperture loss.

Fiber-WFOS

Fiber-WFOS Specs

- **700 collecting** units,10 arcmin diameter field
- Each collector delivers R~5000
- Initial focus on sky-nodding or beam-switching
- 22” positioner pitch with overlap well matched to science cases
- Fibers feed a mounted array of ~10 spectrographs
- **~70 Deployed IFUs** in GLAO mode



(Nick MacDonald)

Slicer vs. Fiber

How we do we choose?

Develop a quantitative score for both Slicer-WFOS and Fiber-WFOS that compares capabilities to science

We would like to hear from you!

Also detail risks and costs associated with those capabilities

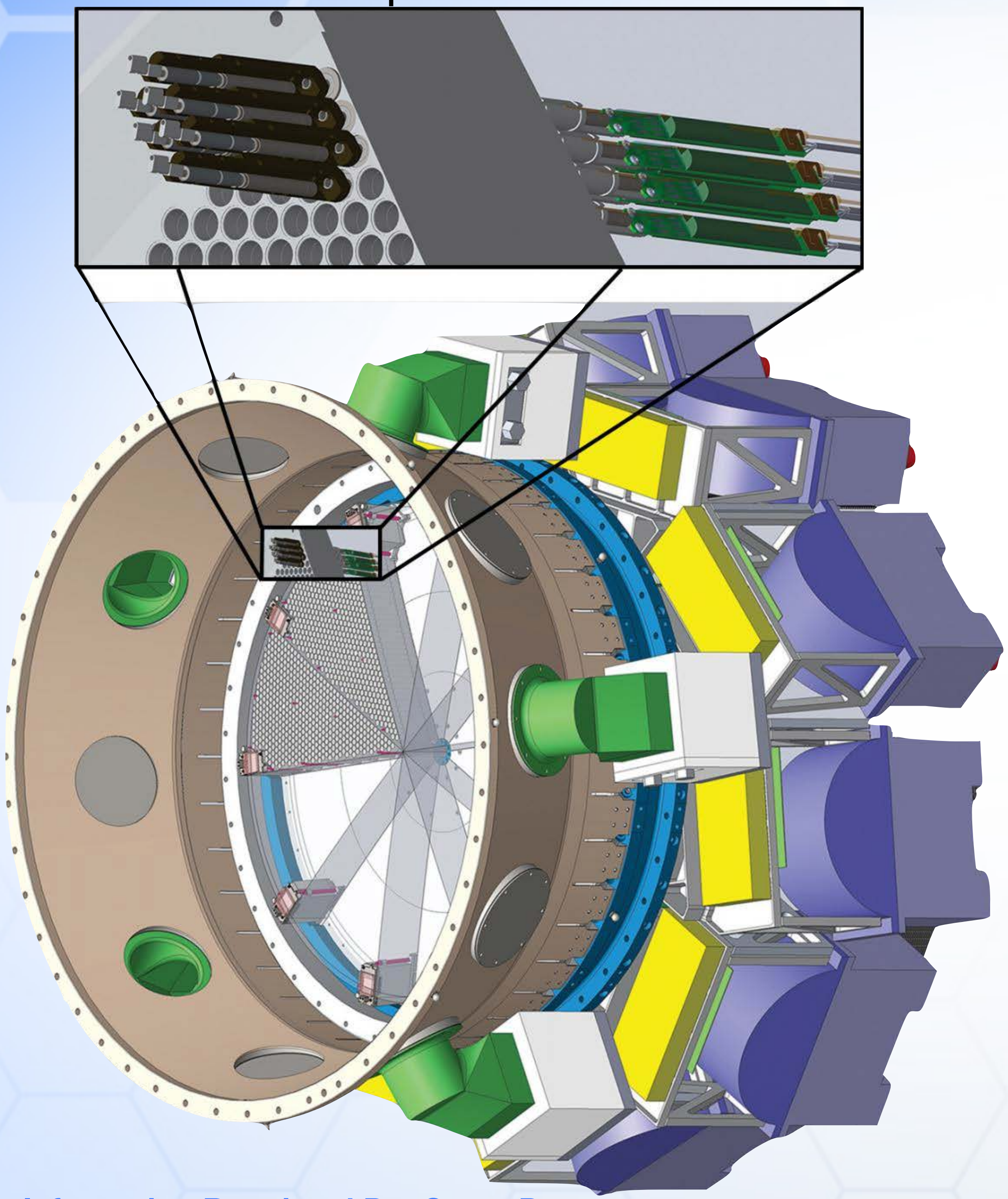
Down-select and external review: March 2018

Thinking About Future Instruments

- Maximize photons from TMT
- Power of GLAO
- Deliver science capacity
- Team Building

Maximizing Photons: High Multiplex

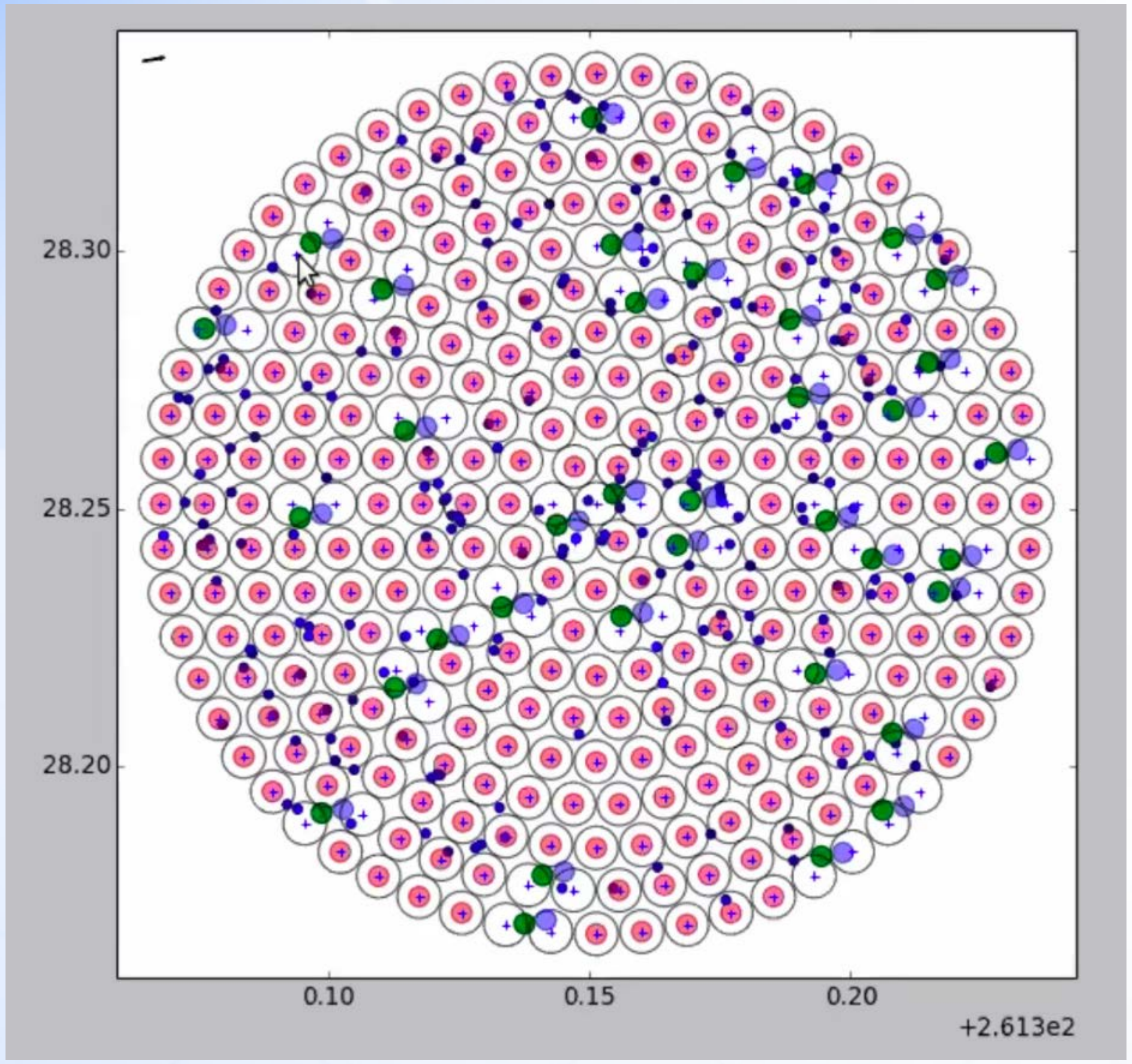
DESI positioners



- Survey speed = Multiplex x Sensitivity
- We can **optimize sensitivity** while delivering high multiplex
- Reformatting the focal plane enhances observing flexibility (e.g., dynamic re-allocation, differing exposure times, etc.)

Maximizing Photons: High Multiplex

Robotic target positioning



Fiber-WFOS target allocation simulations

Maximize efficiency with multilayered programs

Large survey programs

1. IGM z=2-5 tomography: 10 arcmin^{-2}
2. MW halo stars: 0.2 arcmin^{-2}
3. LSST Photo-z training: 6 arcmin^{-2}

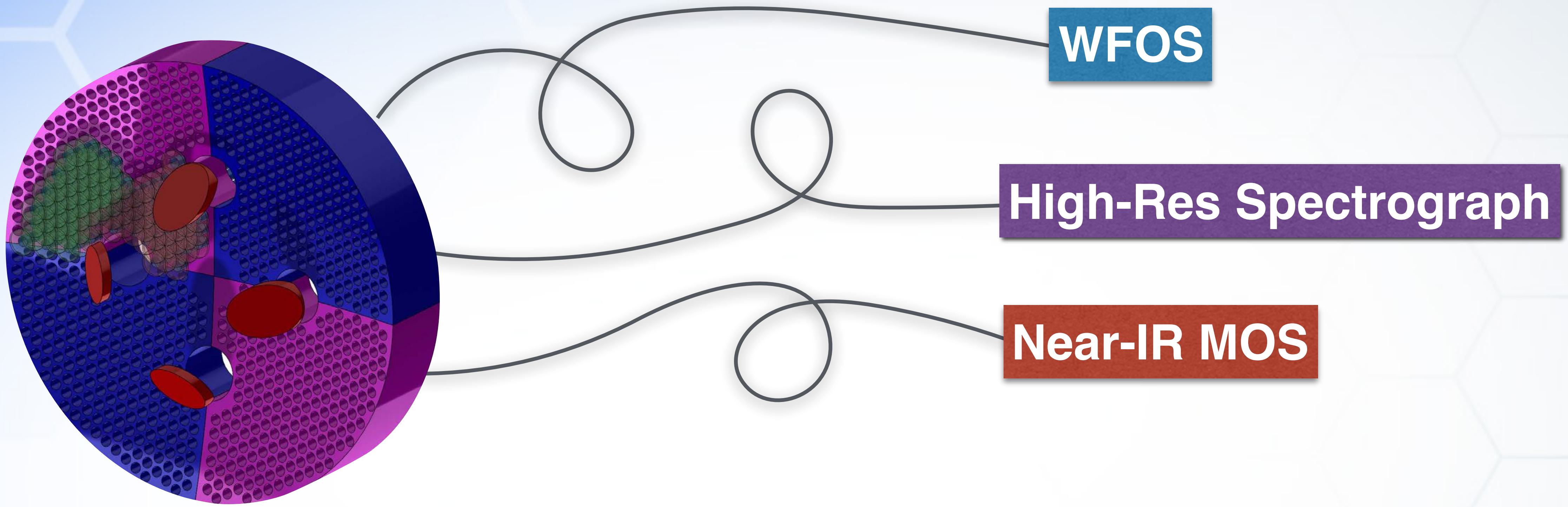
GLAO programs

1. IFUs on z~1 galaxies: 10 arcmin^{-2}
2. z=5 galaxy properties: 5 arcmin^{-2}

Target of opportunity programs

1. Target of opportunity: 1 per pointing
2. EUCLID redshift targets: 20 arcmin^{-2}
3. LSST Photo-z training: 6 arcmin^{-2}

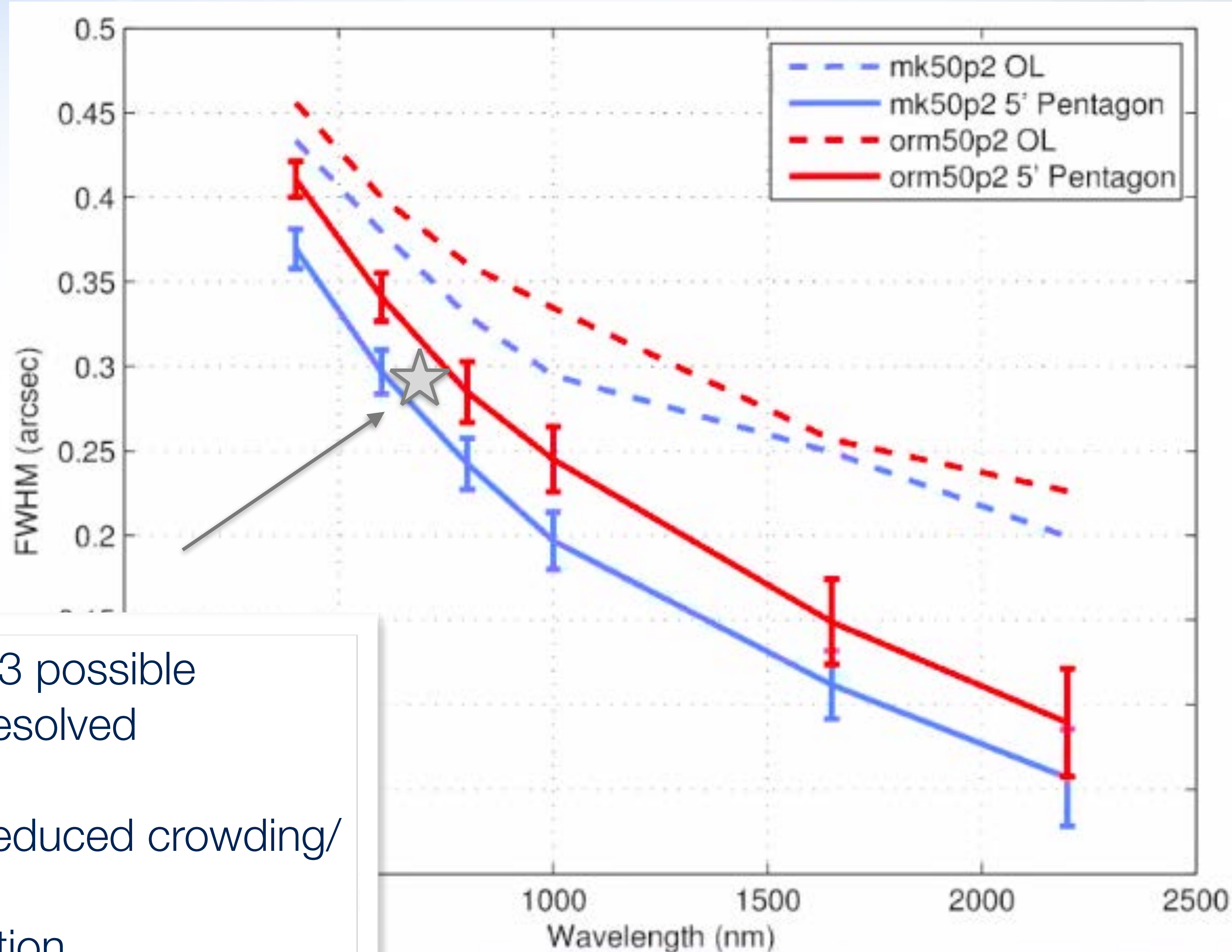
Maximizing Photons: Multiple Instruments



- With Fiber-WFOS, does the robotic positioning system become a facility capability for future instruments?
- Could some be run in parallel? (SDSS-IV observes with optical and near-IR spectrographs simultaneously)

Gains with GLAO

- GLAO simulations for a realistic TMT adaptive secondary
- FWHM 0.3-0.4”
- FOV: 4-6’



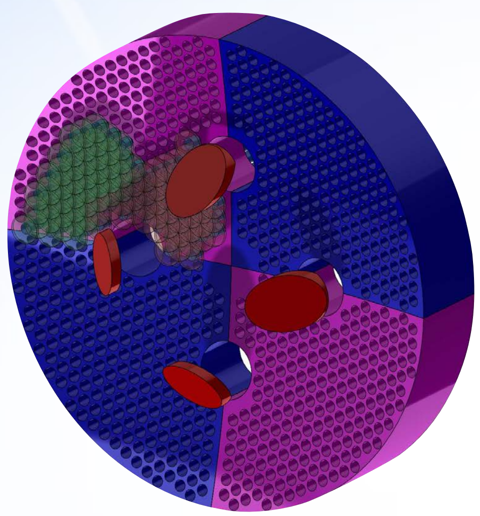
- Sensitivity gains of 2-3 possible
- **New science** from resolved spectroscopy
- **New science** from reduced crowding/ confusion
- Cheaper instrumentation

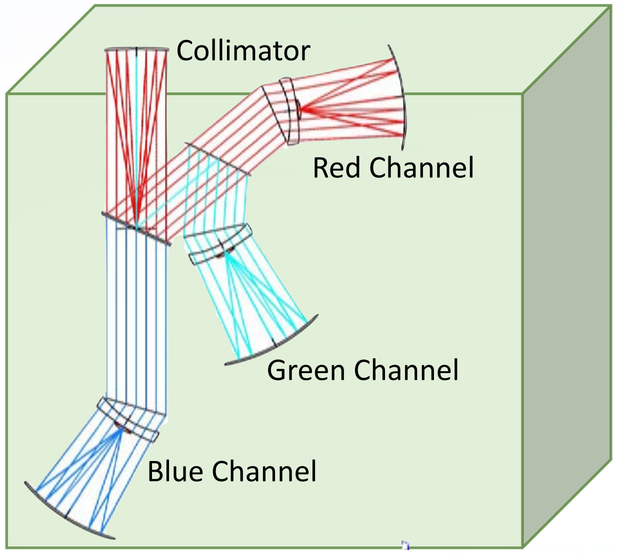
T.INS.

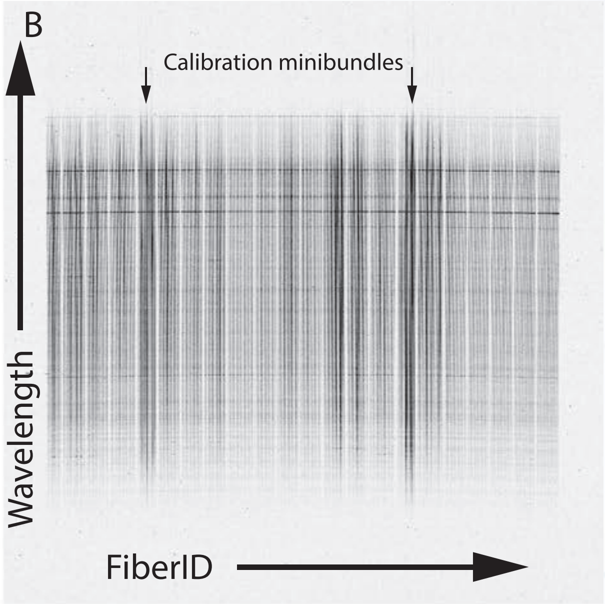
Delivering Science

Philosophy: Deliver the “science” not just the instrument

-Matt Radovan

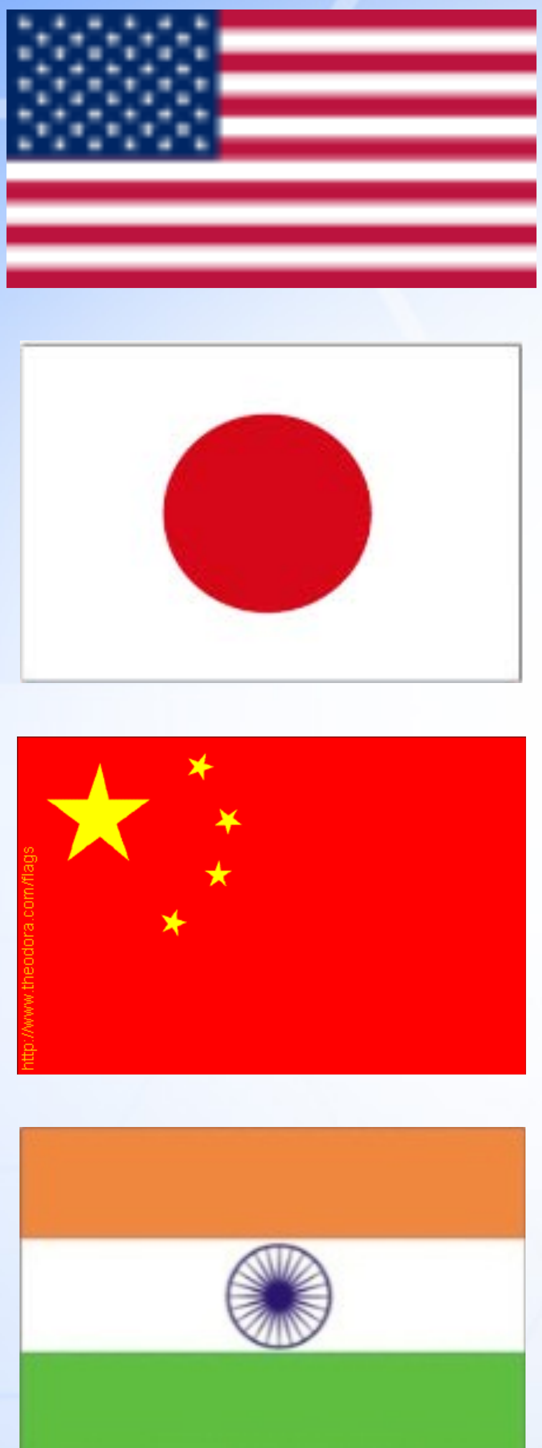






- Data simulation, reduction development as part of instrument design
- Enables quality control and testing during assembly
- Plan now for calibration procedures and strategies
- After deployment: Ongoing instrument characterization and improvement

Team Building and Challenges



Cultural Differences

- Language and writing
- Expectations (on requirements, management, docs…)
- Relationships between scientists, engineers, industry
- Identifying enthusiastic partner institutions

Communication

- **Travel**
- Telecons & email
- Collaboration tools: wiki (Confluence), Slack, repositories
- Version control and agreed terminology

Conclusions

Thinking About Future Instruments

- Maximize photons from TMT
- Power of GLAO
- Deliver science capacity
- Team Building

Lessons from IRIS (a TMT 1st light instrument)

Eric Chisholm

TMT science forum

November 7th 2017

IRIS Technical Team

Eric Chisholm (TMT) Instrument Technical Manager
Gelys Trancho (TMT) Senior Systems Engineer
John Rogers (TMT) Senior Systems Engineer
John Miles (TMT) Instrumentation dept. Systems Engineer

10 institutions, 4 countries

- James Larkin (UCLA), PI
- Eric Chisholm(TMT), PM, Co-PI
- Shelley Wright (UCSD), PS
- John Miles (TMT), Instrumentation dept. Systems Engineer
- Jennifer Dunn (NRC-H), CSRO Lead, Software Lead
- David Andersen (NRC-H), CSRO Systems Engineer
- Yutaka Hayano (NAOJ), Imager Project Manager
- Ryuji Suzuki (NAOJ), Imager Lead Designer
- Andrew Phillips (UCSC), ADC and UCSC Lead
- Bob Weber (CIT), Lead Mechanical Engineer
- Kai Zhang (NIAOT), Slicer Lead Optical Designer and NIAOT Lead
- Optical Designers: Jenny Atwood (NRC-H), Renate Kupke, Drew Phillips (UCSC), Toshihiro Tsuzuki, Mizuho Uchiyama (NAOJ), Shaojie Chen, Elliot Meyer (UofT), Victor Isbrucker (Isbrucker Cons. Inc.)
- Mechanical Designers: Alex Delacroix, Keith Matthews, Reston Nash, Ray Zarzaca, Eric Schmidt (CIT), Dean Chalmers, Brian Hoff, Ward Jensen, Vlad Reshetov, Ramunas Wierzbicki (NRC-H), John Canfield, Evan Kress, Eric Wang (UCLA), Yoshiyuki Obuchi, Bungo Ikenoue, Sakae Saito, Fumihiro Uraguchi (NAOJ)
- Software Designers: Chris Johnson, Ji Man Sohn (UCLA), Takashi Nakamoto (NAOJ) , Ed Chapin (NRC-H), Reed Riddle(COO), Gregory Walth (UCSD)
- Electrical Designers: Roger Smith (Detector Lead, CIT), Tim Greffe (CIT) Kenneth Magnone (UCLA), Adam Trapp (UCLA), Tim Hardy (NRC-H)
- TMT, NFIRAOS: Lianqi Wang, Corinne Boyer, Matthias Schöek (TMT), Pete Byrnes, Glen Herriot (NRC-H) and the IRIS astrometry team and many many more…

IRIS Science Team
(14 institutions, 6 countries)

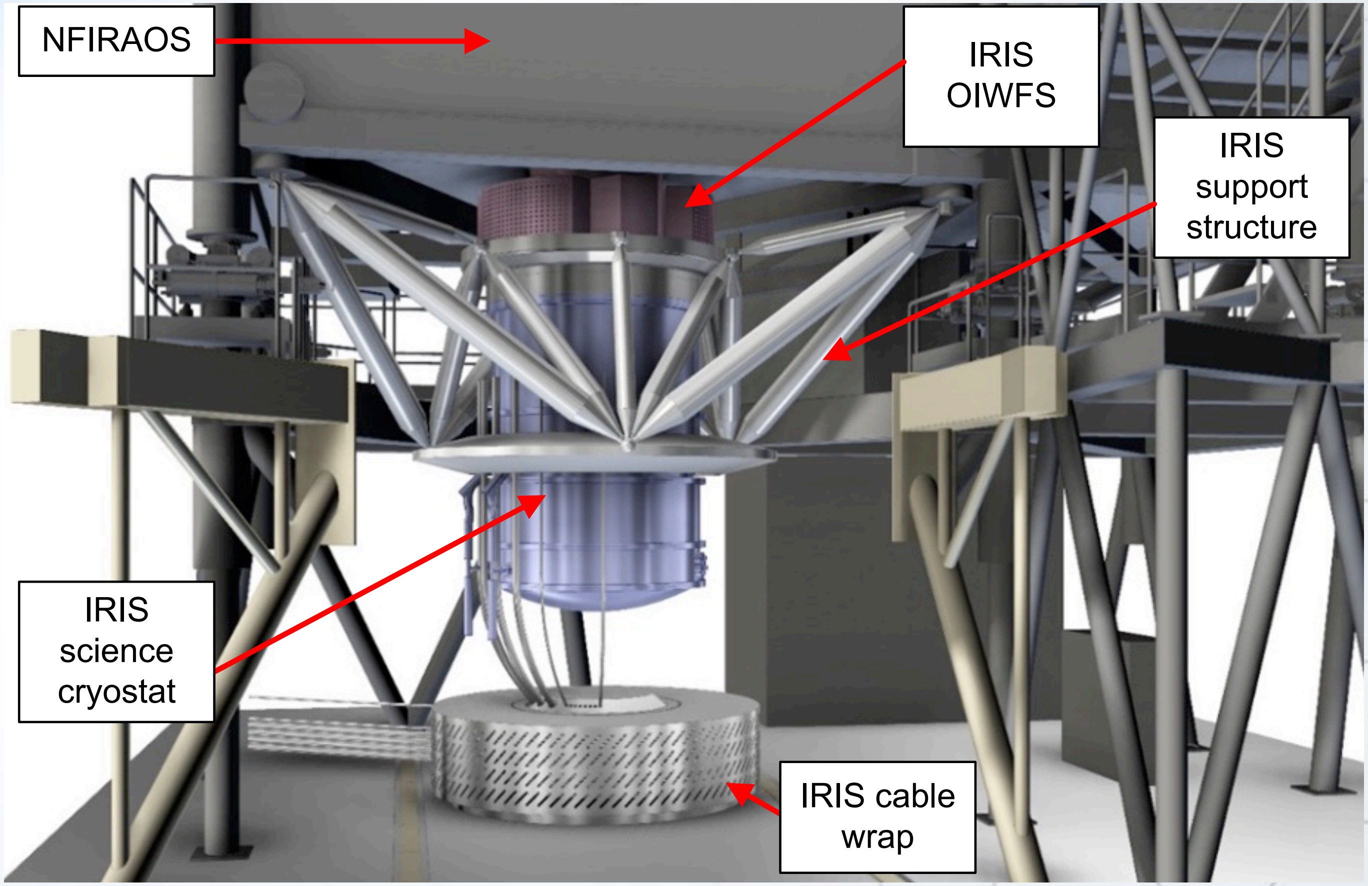
- Maté Adamkovics, Berkeley (Solar System)
- Lee Armus, IPAC (Nearby galaxies, High-z, AGN)
- Aaron Barth, UCI (AGN, SMBH)
- Jeffrey Cooke, Swinburne (First light, High-z)
- Pat Coté, HIA (Nearby galaxies)
- Tim Davidge, HIA (Nearby galaxies)
- Tuan Do, UCLA (Galactic Center, Performance, Astrometry)
- Andrea Ghez, UCLA (Galactic Center, Astrometry)
- Lei Hao, Shanghai (High-z)
- Nobunari Kashikawa, NAOJ (TBD)
- Masahiro Konishi, NAOJ (TBD)
- Michael Liu, U Hawaii (Star formation, Exoplanets)
- Jessica Lu, Berkeley (Star formation, Galactic Center, Astrometry)
- Bruce Macintosh, Standford (Exoplanets)
- Shude Mao, NAOC (Mircolensing, First light)
- Christian Marois, HIA (Exoplanets)
- Shashi Pandey, ARIES (TBD)
- Annapurni Subramaniam, Indian IofA (Stellar)
- Smitha Subramaniam, Indian IofA, (Stellar)
- Jonathan Tan, Florida (Star formation)
- Tsuyoshi Terai, NAOJ (Solar System)
- Tommaso Treu, UCLA (High-z, Grav. Lensing)
- **Gregory Walth, UCSD, TMT IRIS Postdoc (Grav. Lensing, High-z)**
- Mike Wong, Berkeley (Solar System)
- **Shelley Wright, UCSD, PS**

IRIS

IRIS
Infrared Imaging Spectrograph

A FEW FAST FACTS:

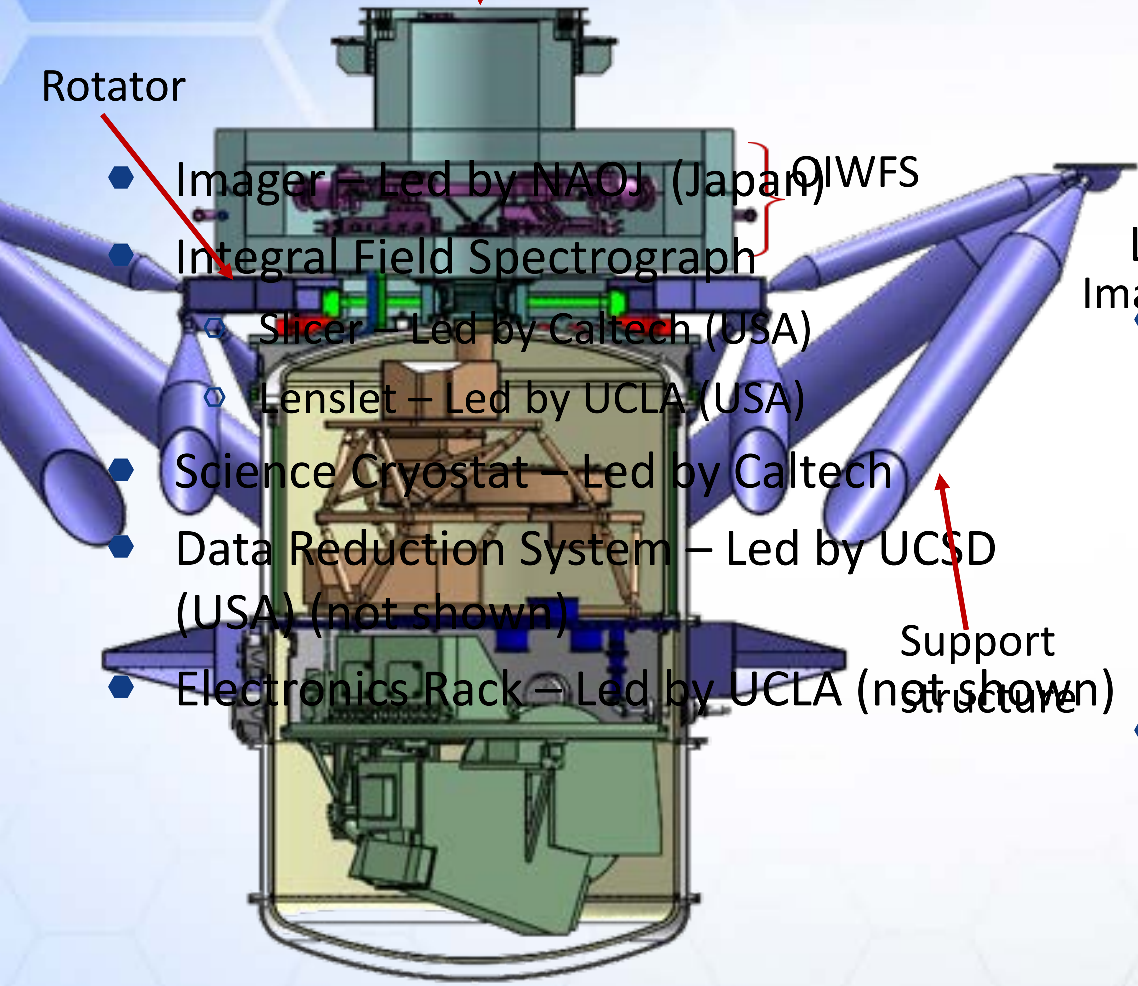
- 6.8 suspended tonnes
- Vacuum / cryogenic
- Slightly smaller in size then a compact car
- AO assisted instrument paired with NFIRAOS
- Parallel (and sequential) imaging and spectrographic modes
- Three on-instrument wavefront sensors
- Fixed gravity orientation
- We are currently entering Final Design!

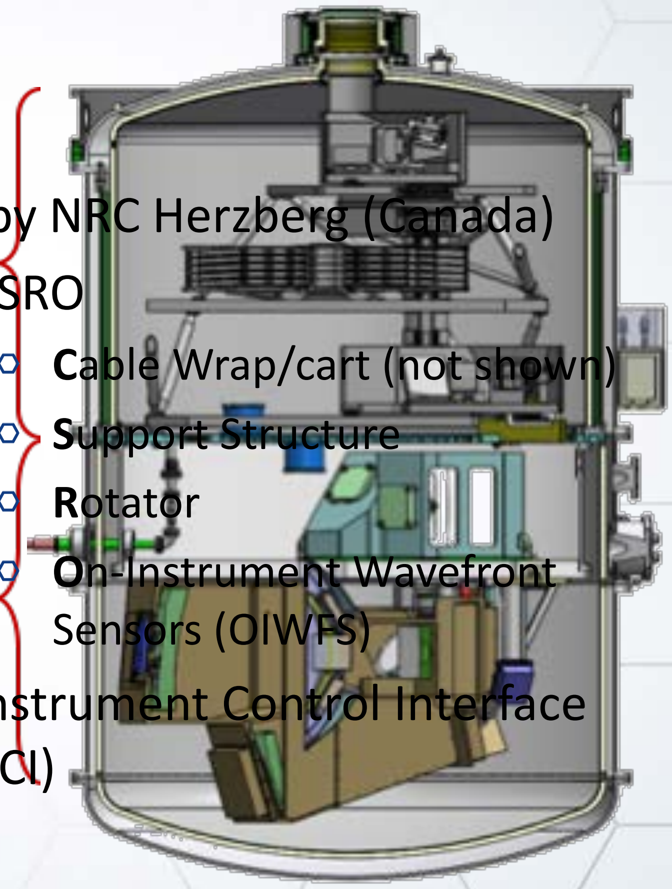


IRIS Capabilities

- First Light Imager and Spectrograph working in parallel at the diffraction limit of the Thirty Meter Telescope.
  - Wavelength Range 0.84-2.4 microns
  - RMS Wavefront Error < 40 nm in fine scales
  - High Order Atmospheric Dispersion Correction
- On-Instrument wavefront sensors (OIWFS).
  - Three NIR sensors to measure tip/tilt, focus and distortion across field.
- "Wide-Field" Imager
  - 34 arcsec field of view (2x2 grid of H4RG-10 Teledyne Detectors)
  - 4 mas plate scale (Nyquist @ 1.15 μm)
- Integral Field Spectrograph (H4RG-15 Teledyne Detector)
  - IFS with Four Plate Scales (4, 9, 25 and 50 mas per sample)
    - Up to 14,378 individual, simultaneous spectra.
  - Spectral Resolutions of 4000, 8000 and few exotic modes

A "look inside"



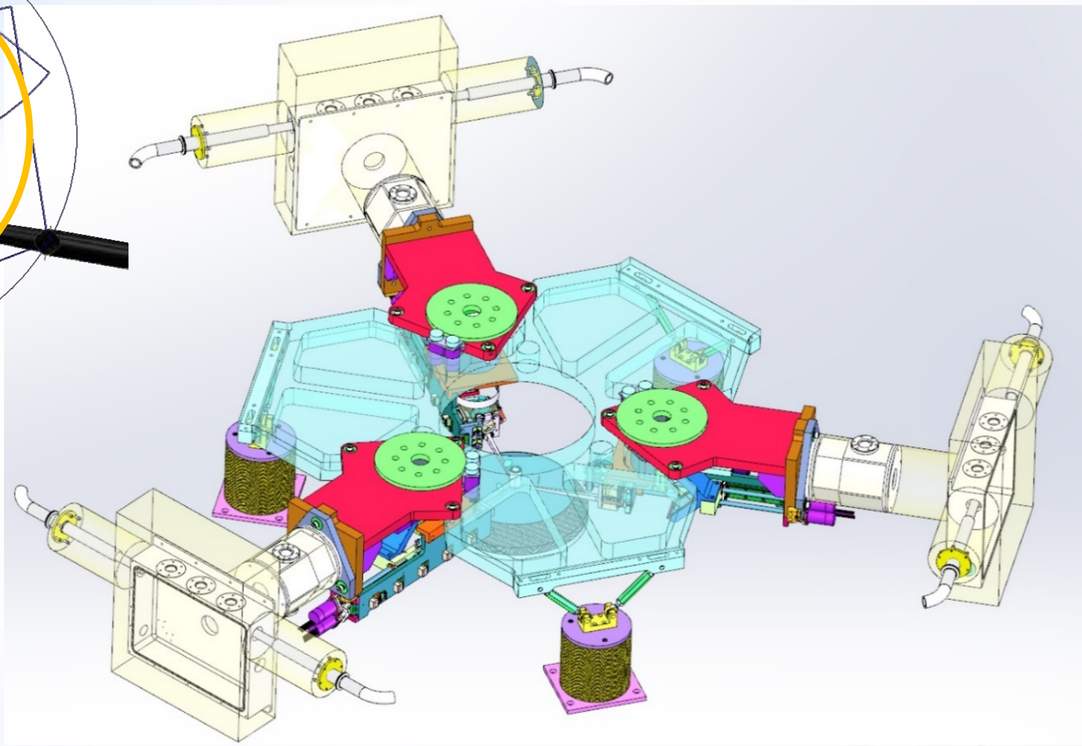


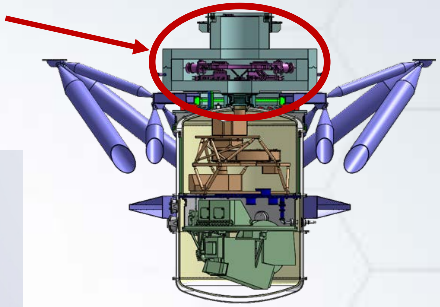
- Imager – Led by NAOJ (Japan)
- Integral Field Spectrograph
  - Slicer – Led by Caltech (USA)
  - Lenslet – Led by UCLA (USA)
- Science Cryostat – Led by Caltech
- Data Reduction System – Led by UCSD (USA) (not shown)
- Electronics Rack – Led by UCLA (not shown)

Led by NRC Herzberg (Canada)

- CSRO
  - **C**able Wrap/cart (not shown)
  - **S**upport Structure
  - **R**otator
  - **O**n-Instrument Wavefront Sensors (OIWFS)
- Instrument Control Interface (ICI)

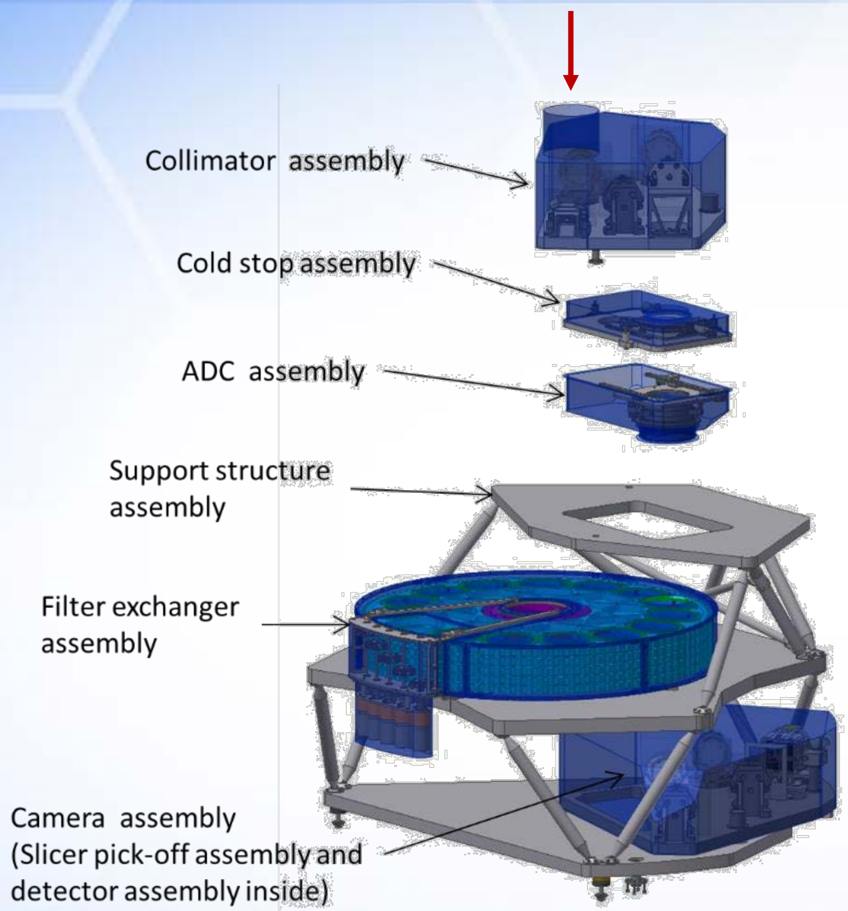
On-instrument wavefront sensors (NRC & Caltech)

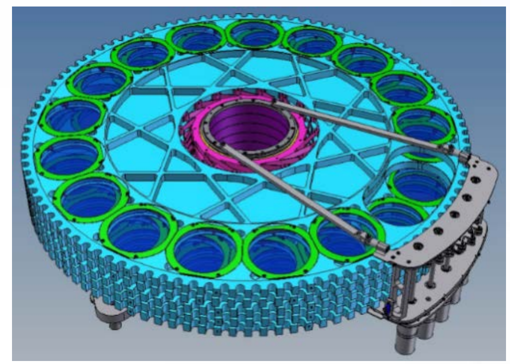


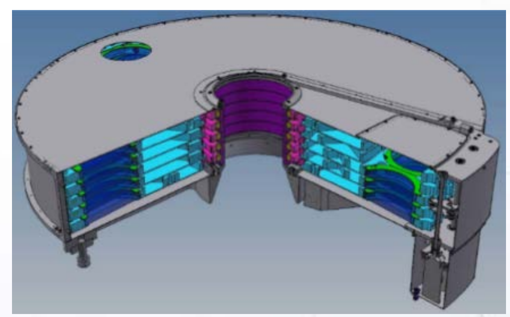


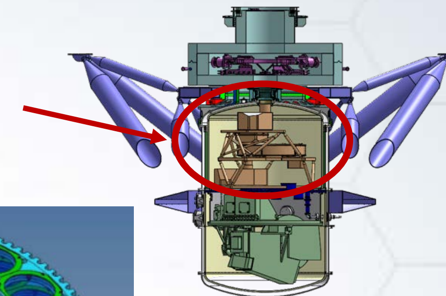
(L) Three deployable probe arms patrol the outer area of the 2 arcmin field delivered by NFIRAOS. (Middle) Detailed view of the three probe arm assemblies as well as the OIWFS support platform and thermal base plate. The IRIS OIWFS are under design by our colleagues at NRC and Caltech (contact dave.andersen@nrc.ca or Jennifer.dunn@nrc.ca for additional details)

Imager (NAOJ)



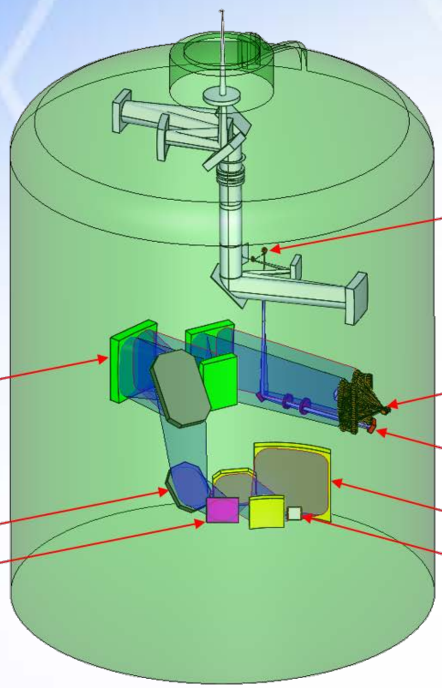


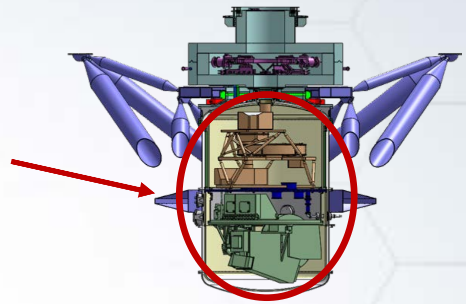


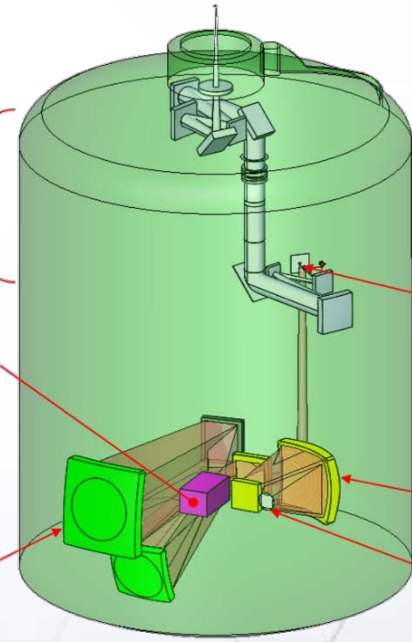


(L) Full model of the Imager subsystem. (Mid top/bottom) Expanded view of the IRIS filter wheel.
The IRIS imager is under design by our colleagues at NAOJ (contact ryuji.suzuki@naoj.org or yutaka.hayano@naoj.org for additional details)

Imager/IFS sequential optical path

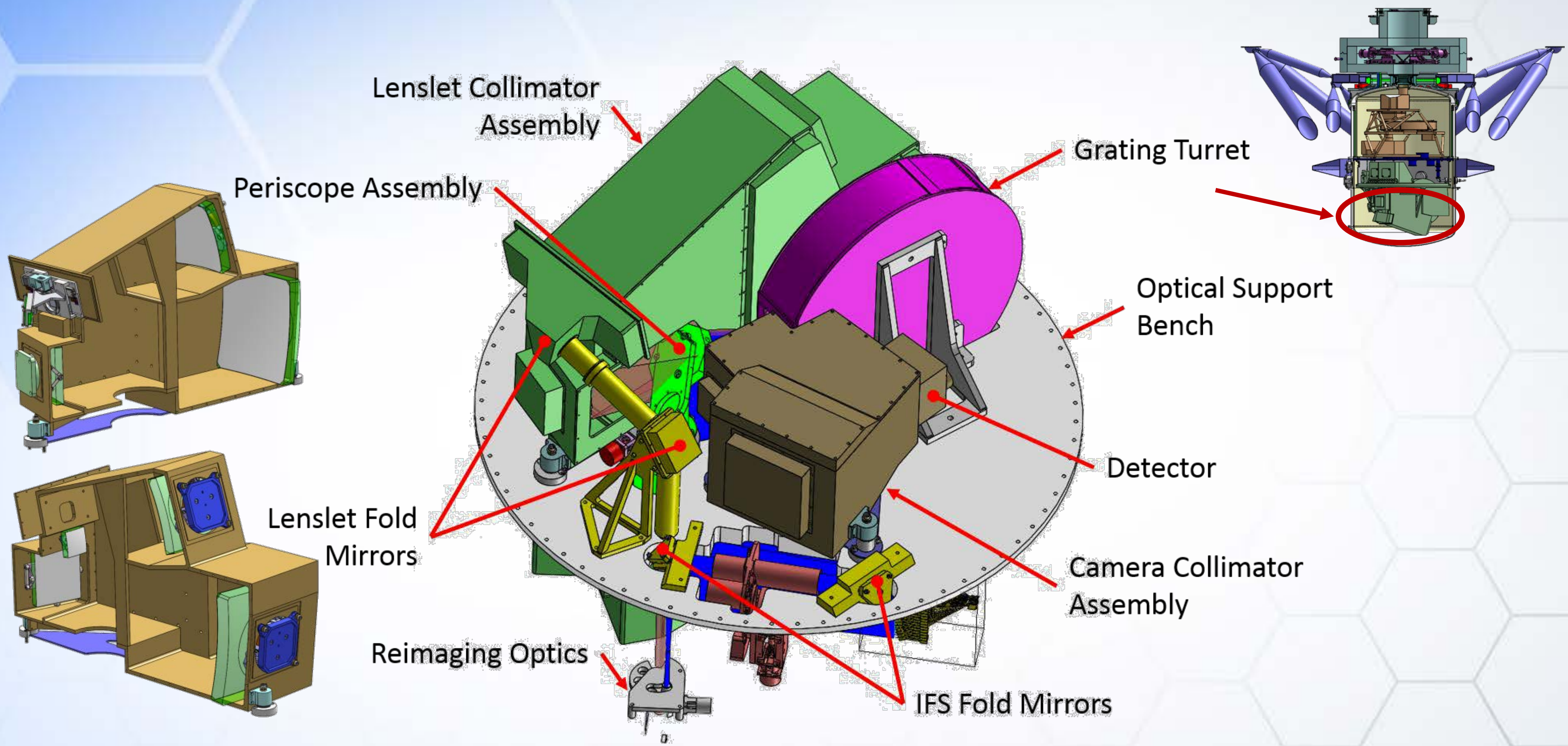




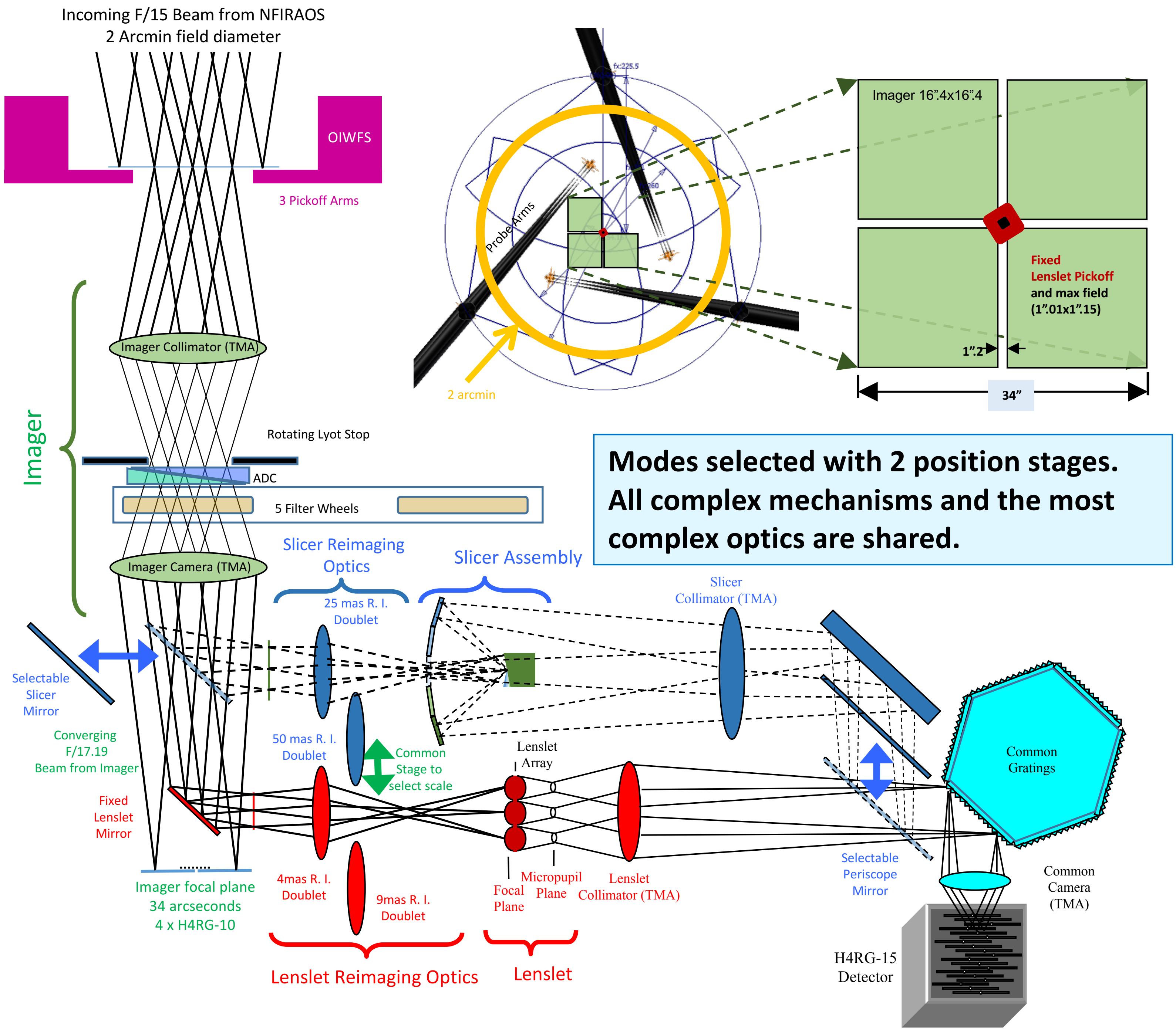


(top) Optical path highlighted for the sequential Imager/Slicer channel IRIS mode. (Lenslet elements have been suppressed in Solidworks). **(right)** Optical path highlighted for the sequential Imager/Lenslet channel IRIS mode. (Slicer elements have been suppressed in Solidworks).

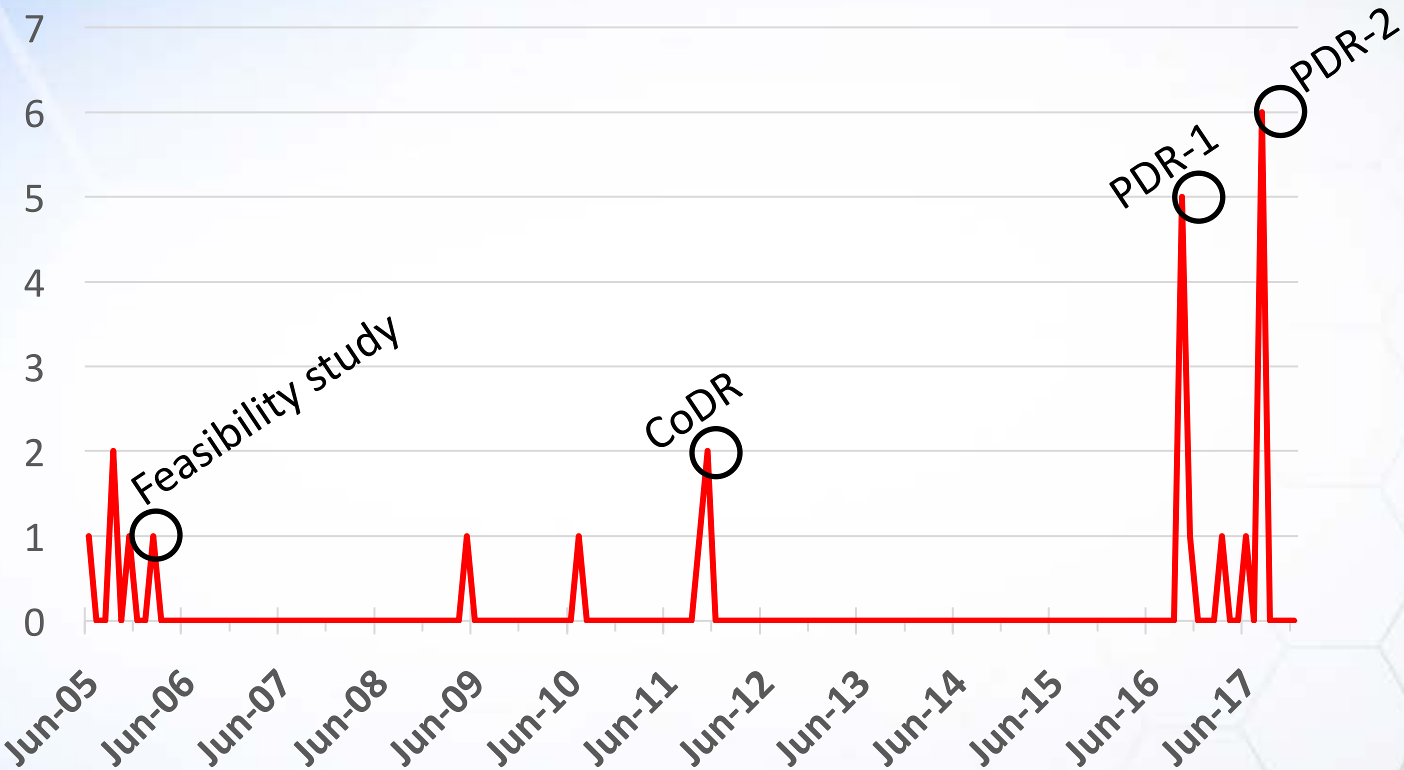
Lenslet IFS (UCLA)



(L top/bottom) View of the TMA collimator showing placement of the Lenslet mask, three collimator mirror and housing design as well as packing fold-mirror. (Mid) Lenslet channel assemblies and common grating turret/TMA camera and H4RG-15 detector assembly. The IRIS Lenslet IFS is under design by our colleagues at UCLA (contact James Larkin larkin@astro.ucla.edu for additional details)


Incoming F/15 Beam from NFIRAOS
2 Arcmin field diameter
OIWFS
3 Pickoff Arms
Probe Arms
2 arcmin
Imager 16".4x16".4
Fixed
Lenslet Pickoff
and max field
(1".01x1".15)
1".2
34"
Modes selected with 2 position stages.
All complex mechanisms and the most complex optics are shared.
Imager
Imager Collimator (TMA)
Rotating Lyot Stop
ADC
5 Filter Wheels
Imager Camera (TMA)
Slicer Reimaging Optics
Slicer Assembly
25 mas R. I. Doublet
Slicer Collimator (TMA)
Selectable Slicer Mirror
50 mas R. I. Doublet
Common Stage to select scale
Converging F/17.19 Beam from Imager
Lenslet Array
Common Gratings
Fixed Lenslet Mirror
4mas R. I. Doublet
9mas R. I. Doublet
Focal Plane
Micropupil Plane
Lenslet Collimator (TMA)
Selectable Periscope Mirror
Common Camera (TMA)
Imager focal plane
34 arcseconds
4 x H4RG-10
H4RG-15 Detector
Lenslet Reimaging Optics
Lenslet

The 1st generation instrument have been underway a long, long time



Release dates vs. review milestones for the IRIS operational concepts

Learn to live with team turnover

- Instrument design timelines are long enough that people should consider their career objectives and set realistic commitments i.e. you may only support an instrument for 1-2 phases.
- IRIS/TMT team evolution between Preliminary Design Review 1 (Nov 2016) & Preliminary Design review 2 (Sep 2017)


Anna Moore (Caltech)


Brent Ellerbroek (TMT)


Jason Weiss (UCLA)


James Wincentsen (Caltech)


Luc Simard (NRC)

"Your instrument is only going to be as good as your requirements"

- Requirements have to be understood by both astronomers and engineers. For this to work, hefty discussions that capture the thought process of the requirement author and what the intent is are required. (make sure you document these).
- If you are going to engage with industry, fuzzy and conflicting requirements will cost money and waste time.
- Requirements will change as the consequences of those requirements become clear.

"Understand what is driving your design (and do you need it?)"

- <u>Don't let wishes drive the design to unreasonable places</u>.
- Added features are always nice BUT will these "break the bank". You may not discover this until you begin interacting with vendors (and iterating to scale things back is also costly – time/money).
- Are your requirements really requirements? Or are they design choices? e.g. requirements on motors/stages.

Big projects need professionals in each role

- You need to have professional:
  - Project managers
  - Systems engineers
  - Quality assurance engineers

- You also need to structure your team so you have people at the right time.
- Likely to have a significant percentage of the team at a fraction of a full time employee – need to provision for occasions when you “crash” the design area with resources.

Figuring out how to communicate effectively

- Time zones /dates / holidays are challenging – you will need to be flexible
- Language barriers and cultural norms need to be respected and understood – check your assumptions and take time to learn from each other.

FACT: TMT partner nations represent ~42% of the global population!

Figuring out how to communicate effectively (part 2)

- Be mindful of the changing landscape of virtual communication tools – do they add value?
- How do you best work on shared information – can it work for all partners? (don't design via e-mail!)

Polycom slack JIRA CISCO WebEx zoom BlueJeans

Developing an instrument in parallel to an Observatory is hard!

- Understand impacts of change – MK or ORM?
- Prepare for potential redesign - Change in Observatory cryogenic system.
- Interfacing systems will develop at unpredictable rates – Data reduction system vs. Data management system; IRIS - NFIRAOS.

Broaden your knowledge of things outside your instrument and understand this will be a continual dialogue

Advantage - We might have more negotiation space.

How will you divide the design? i.e. really working together

- We currently use a more “classical design” approach i.e. each partner gets a piece of the instrument.
- Can we find efficiencies by changing our strategy and exploiting an almost 24-hour work day?
- “Hand-off” engineering. Might involve more upfront work BUT will build strong team relationships, a deeper understanding of the full system and our various approaches to design and should facilitate smoother end integration.

Thanks and good luck to future teams!

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