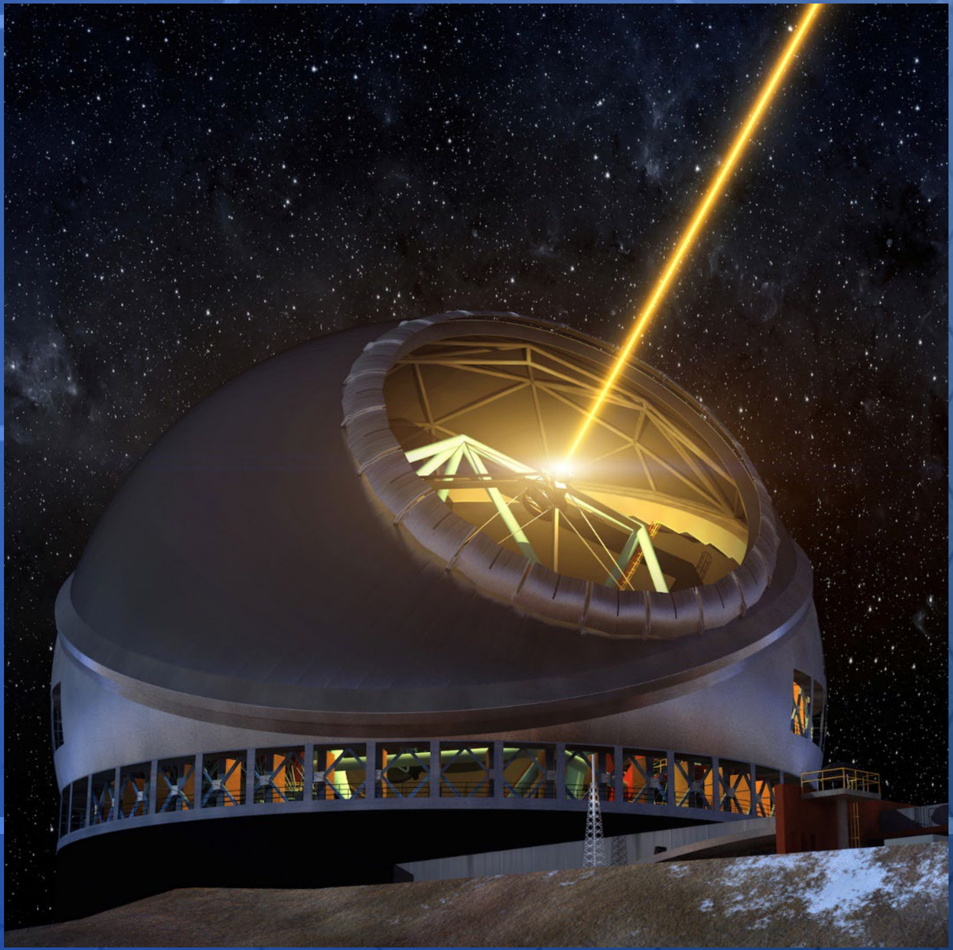
The Infrared Imaging Spectrograph (IRIS) for TMT Instrument Overview



James Larkin,
David Andersen,
Jenny Atwood,
Jennifer Dunn,
Renate Kupke,
John Miles,
Roger Smith,
Ryuji Suzuki,
Kanaka Warad,
Robert Weber,
Shelley Wright

25 April 2023

IRIS Technical Team

David Andersen (TMT) Instrument Group Lead
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
- Kanaka Warad (TMT), PM
- Shelley Wright (UCSD), PS
- Ryuji Suzuki (NAOJ) PE
- Jenny Atwood (NRC-H), CSRO Lead
- Jennifer Dunn (NRC-H), Software Lead
- Renate Kupke (UCSC), UCSC Lead, Optical Design Lead
- Bob Weber (CIT), Lead Mechanical Engineer
- David Andersen (NRC-H), CSRO Systems Engineer
- Kai Zhang (NIAOT), Slicer Lead Optical Designer and NIAOT Lead
- Optical Designers: Dan Reiley (Caltech), 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), 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

41 active members, 14 institutions, 6 countries

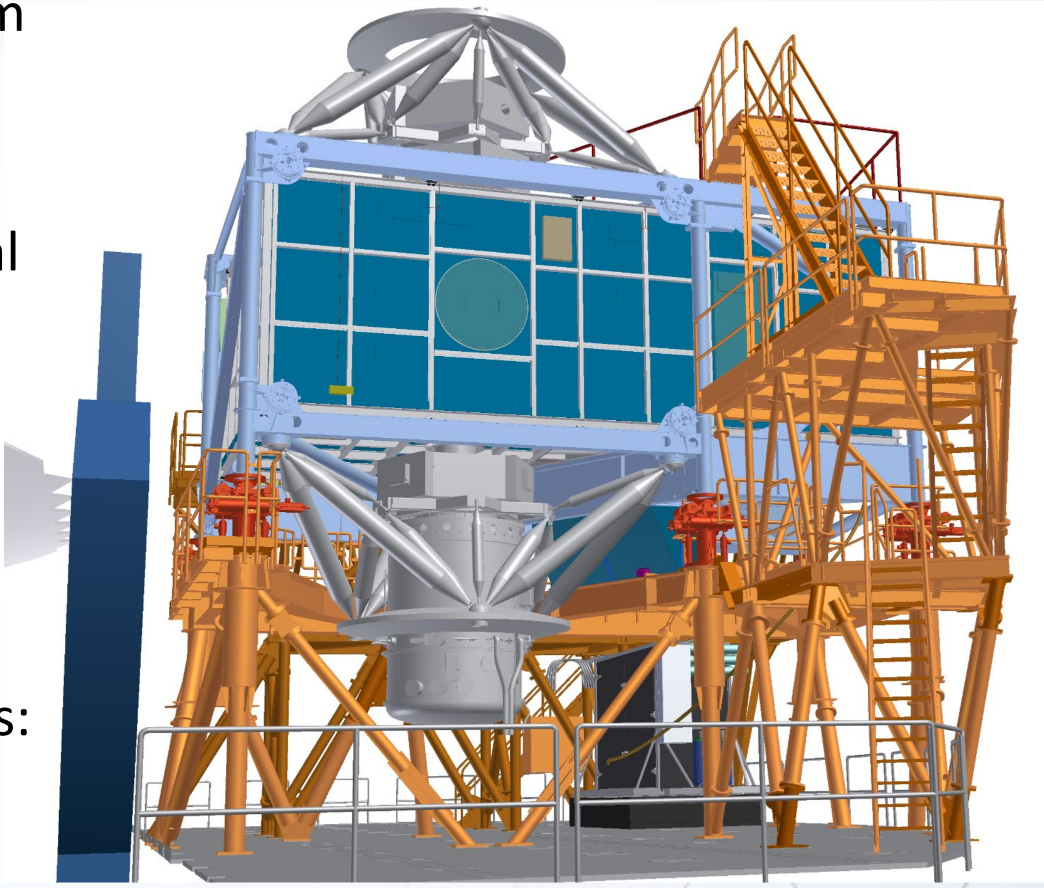
- David Andersen, NRC-Herzberg
- Lee Armus, IPAC/Caltech
- Aaron Barth, UC Irvine
- Shashi Pandey, India Nainital
- Jeffrey Cooke, Swinburne
- Pat Coté, NRC-Herzberg
- Tim Davidge, NRC-Herzberg
- Katherine de Kleer, Caltech
- Tuan Do, UCLA
- Christoph Dumas, TMT
- Andrea Ghez, UCLA
- Satoshi Hamano, NAOJ
- Lei Hao, Shanghai
- Yutaka Hayano, NAOJ
- Matthew Hosek, Berkeley
- James Larkin, UCLA
- Michael Liu, U Hawaii
- Jessica Lu, Berkeley
- Shude Mao, NAOC
- Christian Marois, HIA
- Anne Medling, Caltech
- Anna Nierenberg, UC Irvine
- Nils-Erik Rundquist, UCSD
- Matthias Schoeck, TMT
- Luc Simard, NRC-Herzberg
- Warren Skidmore, TMT
- Annapurni Subramaniam, Indian IofA
- Smitha Subramaniam, India IofA
- Arun Surya, UCSD
- Ryuji Suzuki, NAOJ
- Jonathan Tan, U. Florida
- Hiroshi Terada, NAOJ
- Tsuyoshi Terai, NAOJ
- Tommaso Treu, UCLA
- Chao-Wei Tsai, NAOC-Beijing
- Paolo Turri, Berkeley
- Takahiro Uchiyama, JAXA
- Andrey Vayner, Johns Hopkins
- Gregory Walth, Carnegie
- Mike Wong, Berkeley
- Shelley Wright (PS), UCSD

Thirty Meter Telescope

NFIRAOS – Adaptive Optics System

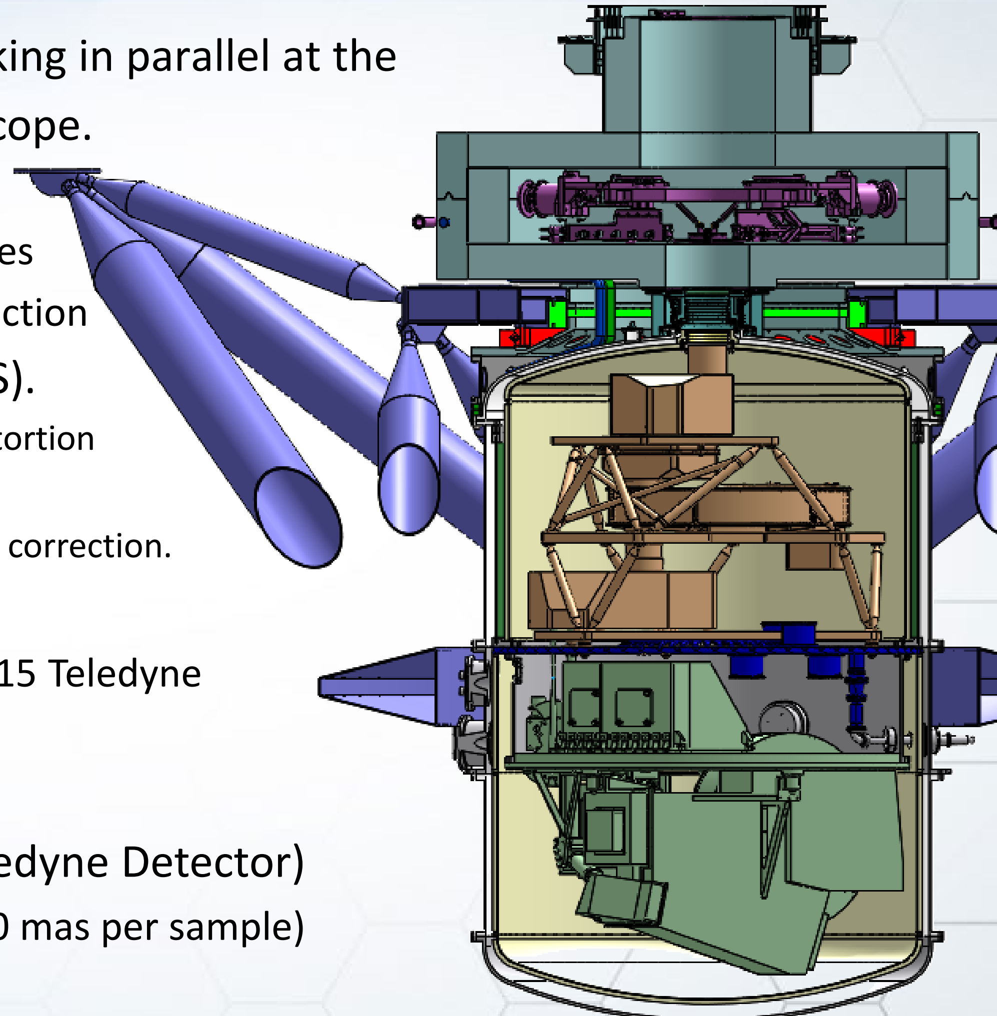
IRIS Infrared Imaging Spectrograph

- Multiconjugate Laser AO system
- Outputs 2 arcminute corrected field to three output ports
- 6 Laser WFSs with 60x60 spatial sampling at 800Hz sampling
- Two deformable mirrors
- Cooled to -30 C for thermal background
- Client instruments have their own infrared wavefront sensors:
    - 1 Tip/Tilt/Focus and 2 Tip/Tilt.



IRIS Capabilities

- First Light Imager and Spectrograph working in parallel at the diffraction limit of the Thirty Meter Telescope.
  - Wavelength Range 0.81-2.4 microns
  - RMS Wavefront Error < 40 nm in fine scales
  - High Order Atmospheric Dispersion Correction
- On-Instrument wavefront sensors (OIWFS).
  - Three sensors to measure tip/tilt, focus and distortion across field.
  - Near infrared sensors to gain from NFIRAOS AO correction.
- “Wide-Field” Imager (60+ filters)
  - 34 arcsec field of view (2x2 grid of H4RG-15 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 16,433 individual, simultaneous spectra.
  - Spectral Resolutions of 4000, 8000 and 10,000 (14 gratings)



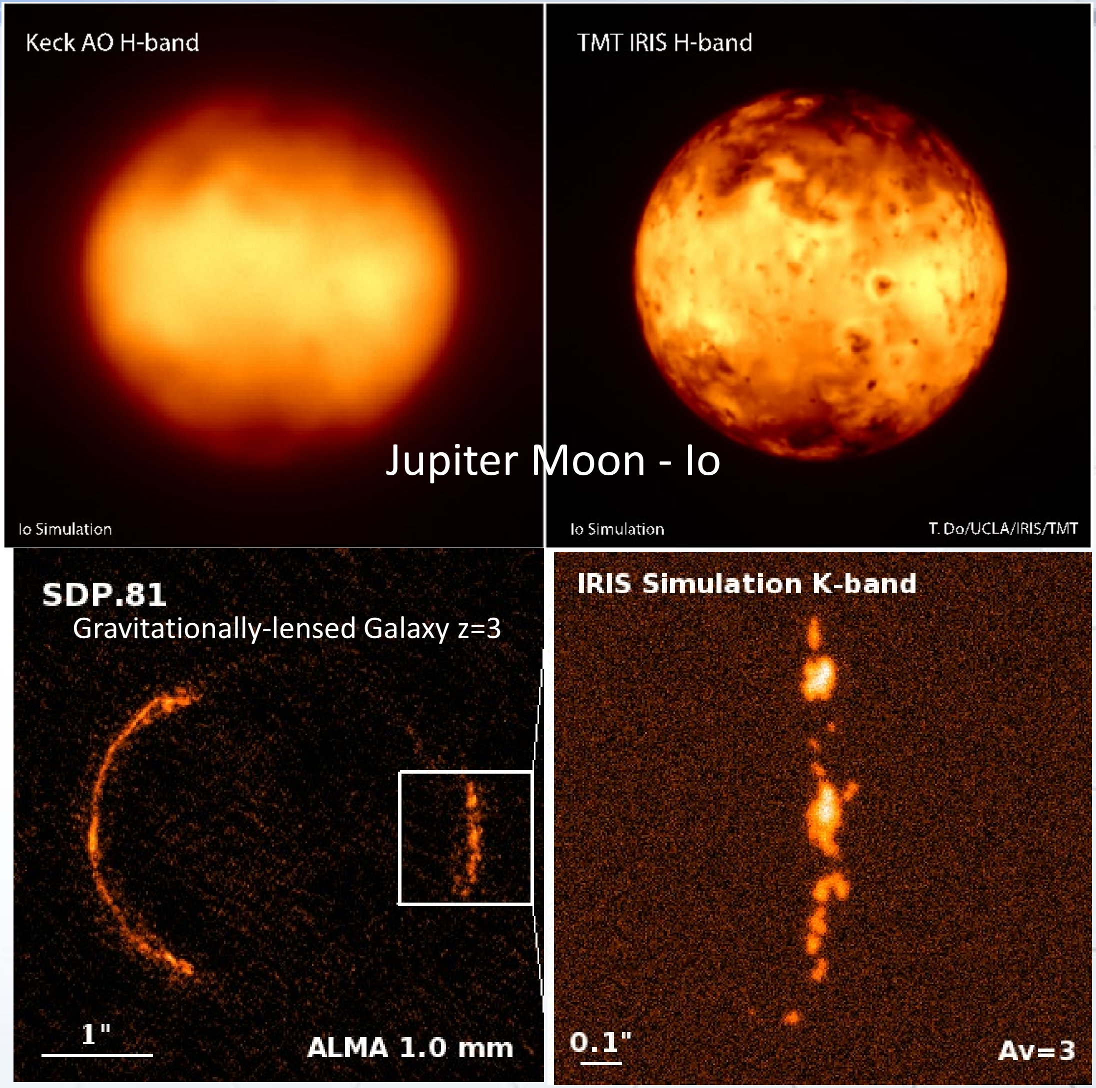
IRIS is versatile and covers a broad range of science goals

224 page Operational Concept Definition Document

TMT
Thirty Meter Telescope

IRIS
Infrared Imaging Spectrograph

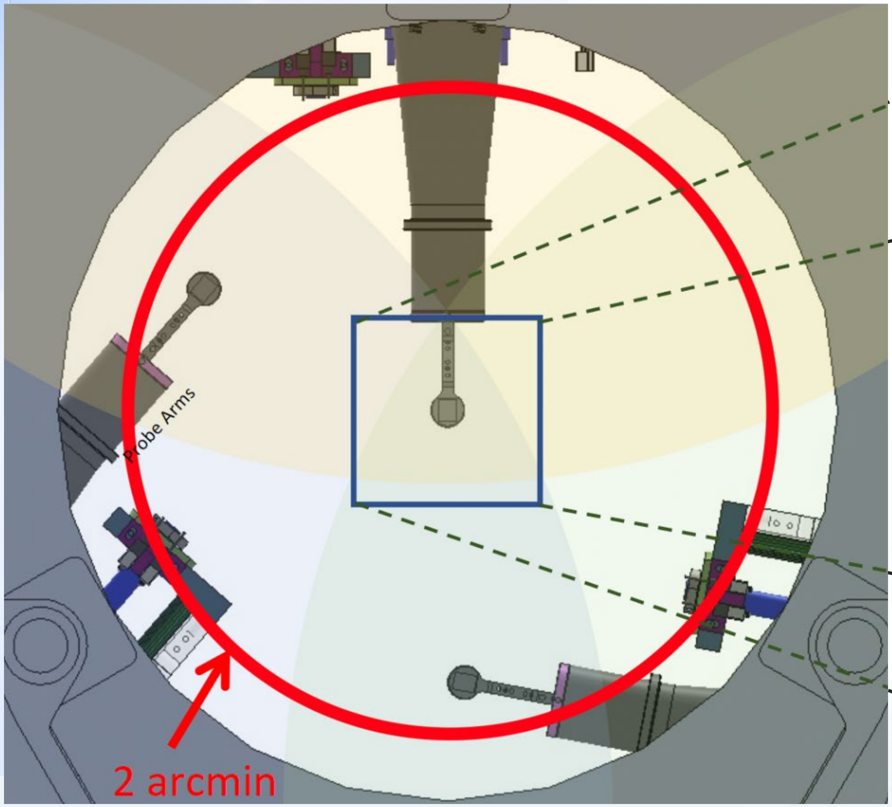
- Solar system
- Extrasolar planets
- Stellar structure & evolution with microlensing
- Star formation
- Galactic Center
- Nearby galaxies & stellar populations
- Supermassive black holes
- High-redshift galaxies
- First light galaxies



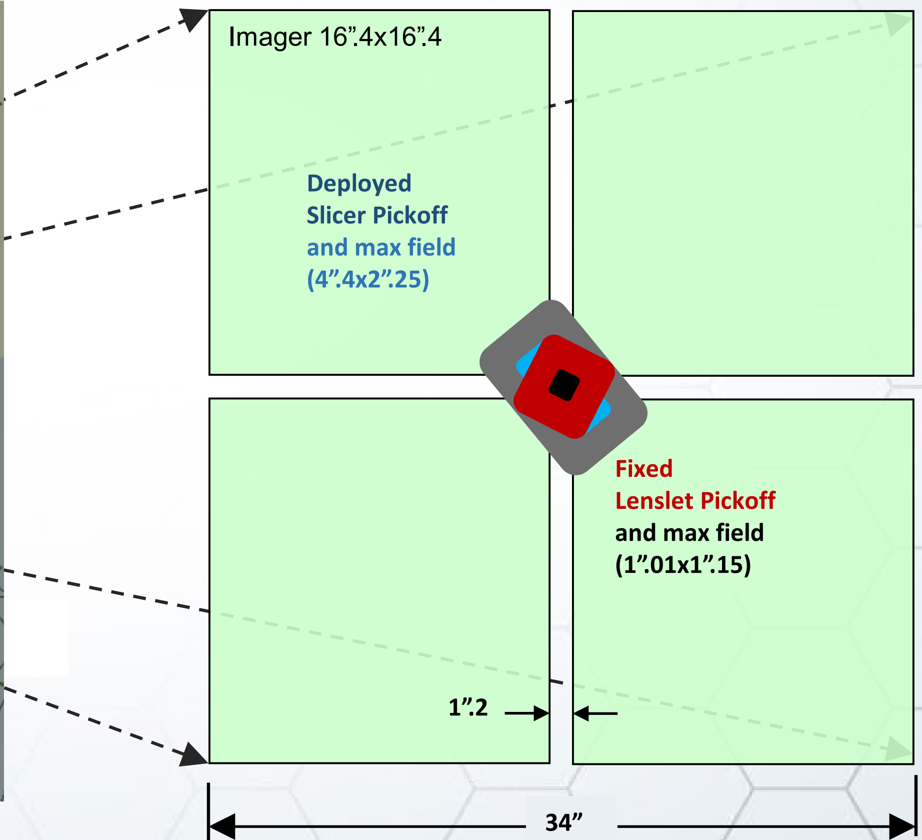
https://arxiv.org/pdf/1608.01696.pdf

IRIS Fields

On-instrument wavefront sensors (OIWFS)



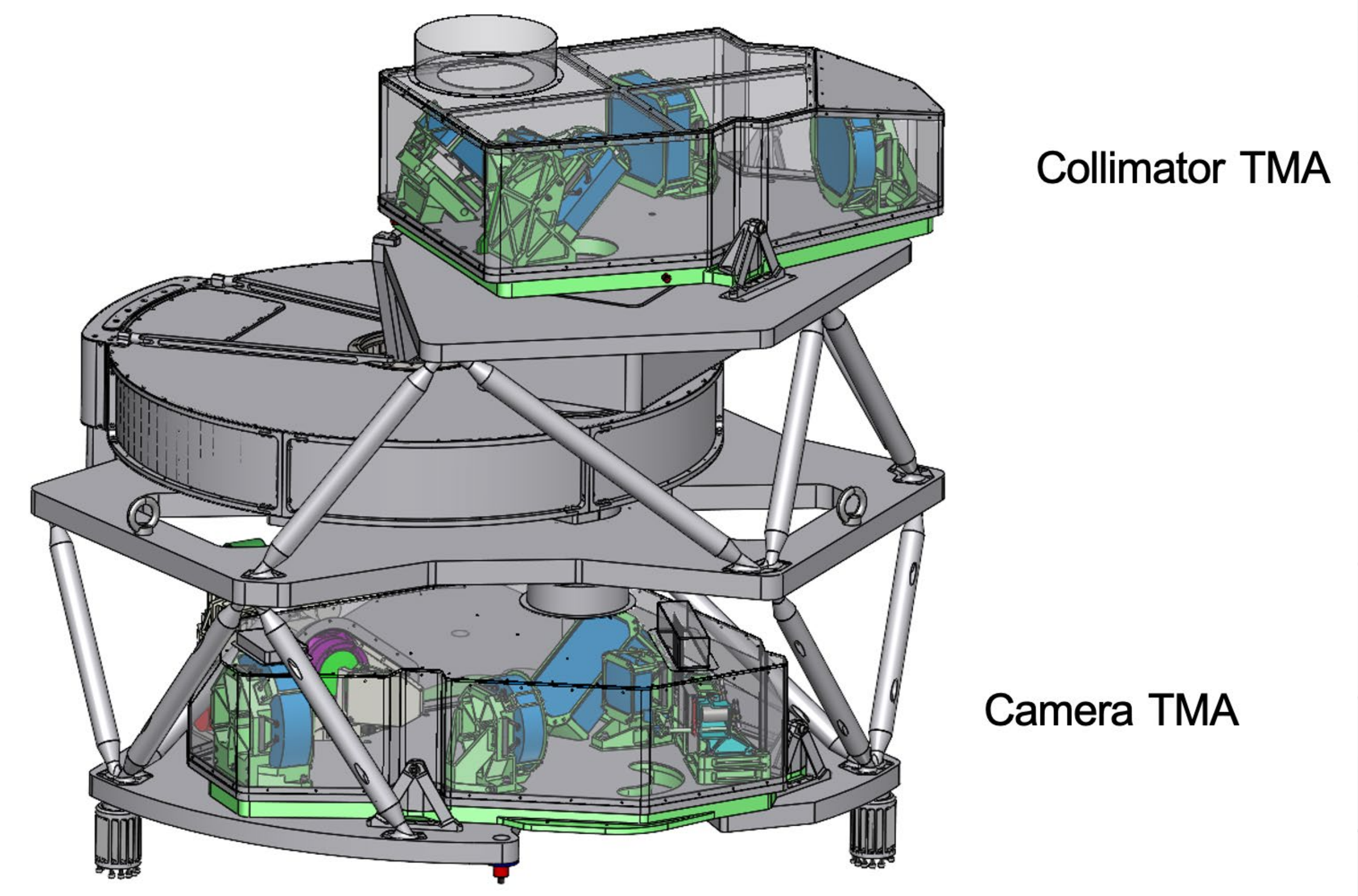
Imager and spectrograph FoV



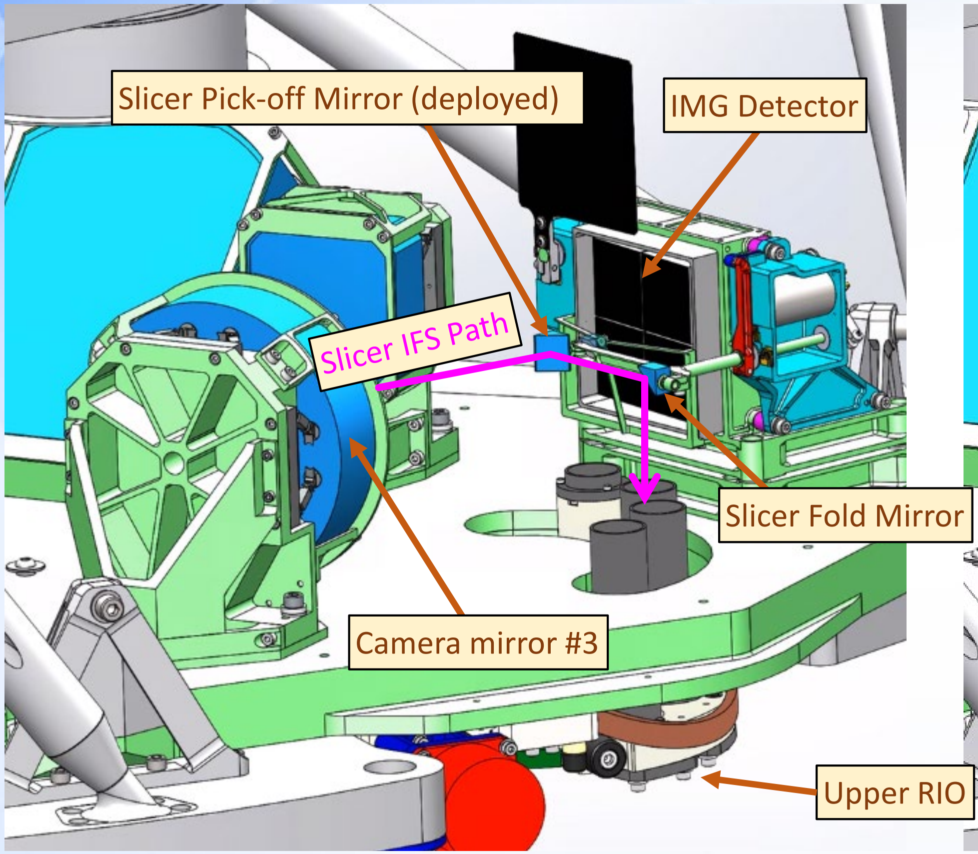
Sequential Design

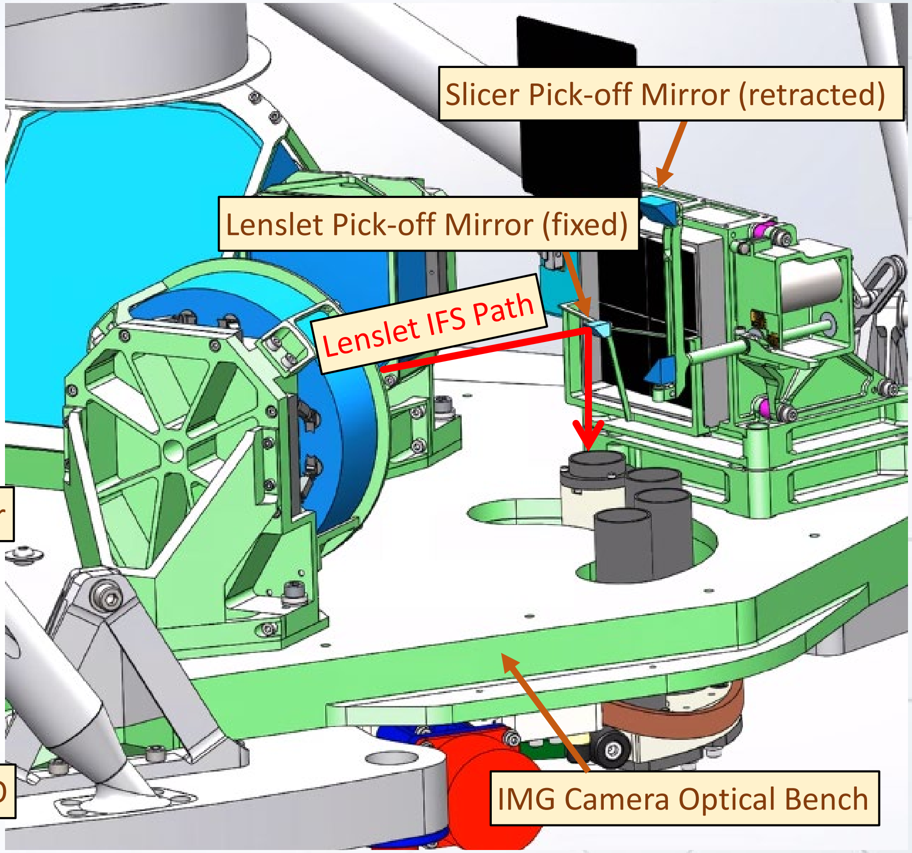
- Imager serves as reimaging optics of spectrograph.
- Both can sit at the center of AO correction.
- AO can correct non-common path optical aberations in both simultaneously.
- Major cost reduction with common ADC, filters, pupil stops.
- Allows dewar to be easily separated into imager and spectrograph for integration in Japan and California.

IRIS Imager – Double TMA
Ryuji Suzuki, Yutaka Hayano (NAOJ)



Spectrograph Splitters



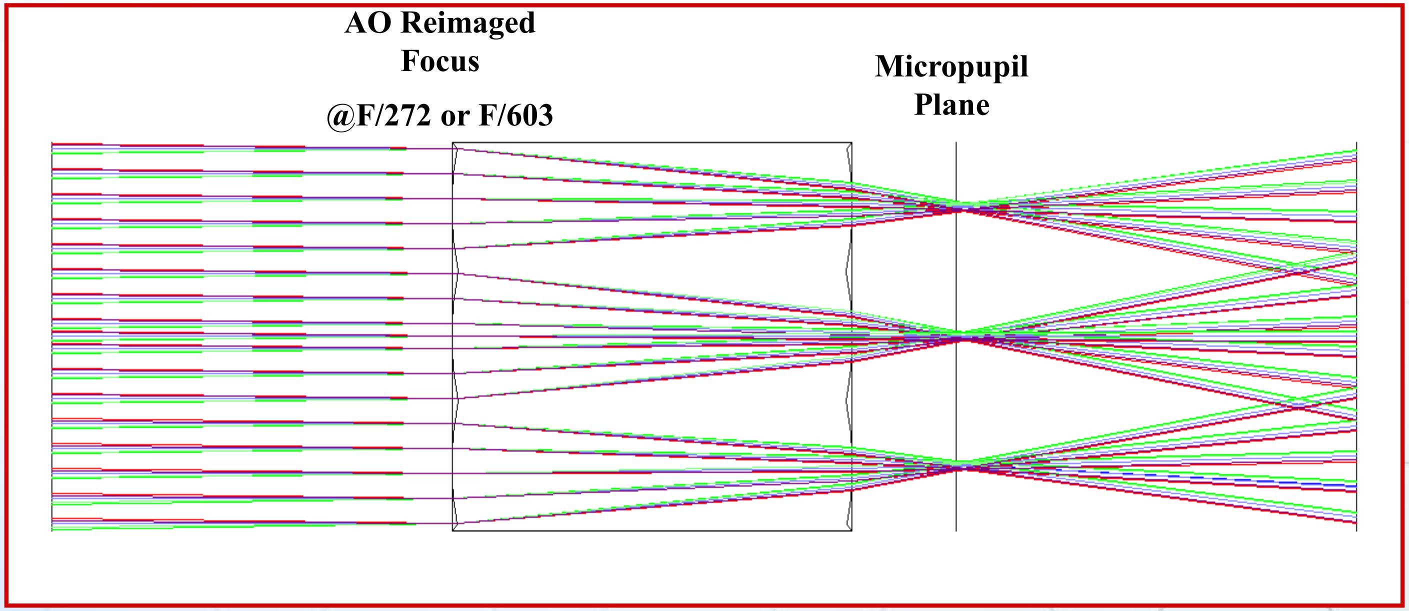


Lenslets vs. Slicer

- Lenslet arrays (e.g. OSIRIS, GPI) are excellent for finest plate scales
  - Easy to expand spatially to >100x100 to sample most of the PSF even at 4 mas scale.
  - Intrinsically low wavefront error since lenslets sample image plane.
    - OSIRIS has undetectable image degradation at ~25 nm rms WFE
    - GPI selected lenslets and existing camera has <25 nm of WFE.
- Slicer IFUs (e.g. SINFONI, NIFS) are excellent for coarser plate scales
  - Easy to expand wavelength coverage once sufficiently large field is achieved in coarse scales.
  - Generally easier data reduction and calibration.

LENSLET ARRAY

- 128 x 128 elements each with 500 spectral elements
  - 0.45”x0.51” @ 0.004” scale
  - 1.01”x1.15” @ 0.009” scale
- Or 16 x 128 elements each with almost 4000 spectral elements
- Spot sizes set primarily by diffraction
- 98% Fill factor

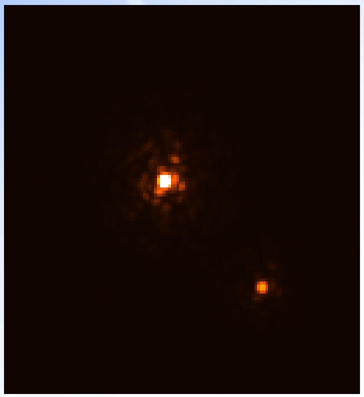


TMT Thirty Meter Telescope

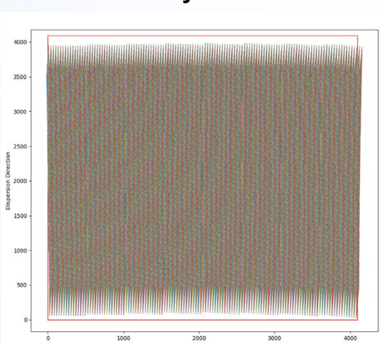
IRIS Lenslet Simulation
16,433 individual spectra

IRIS Infrared Imaging Spectrograph

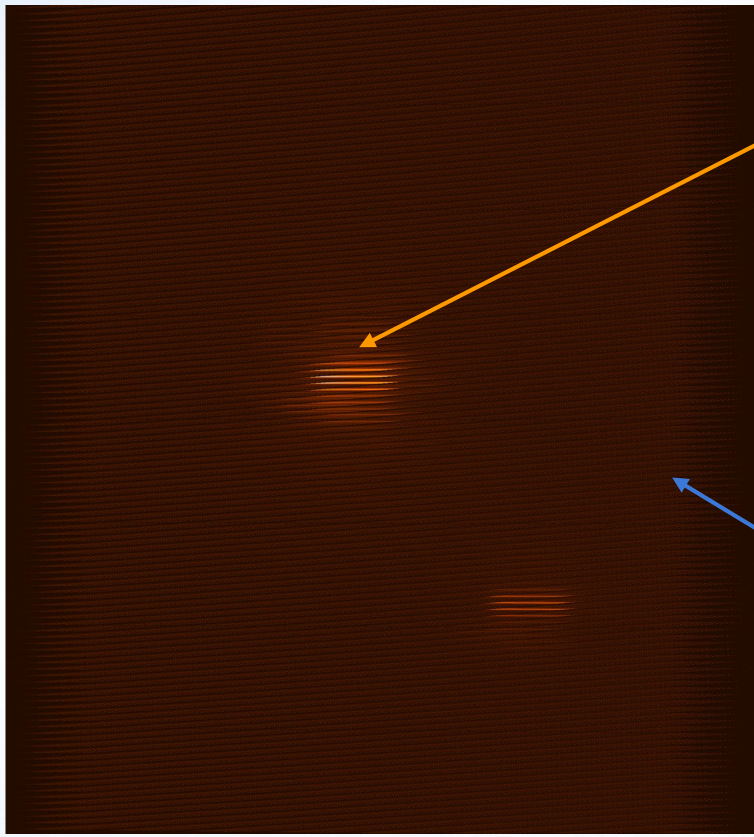
Field

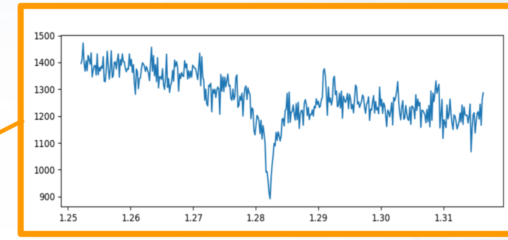


Layout

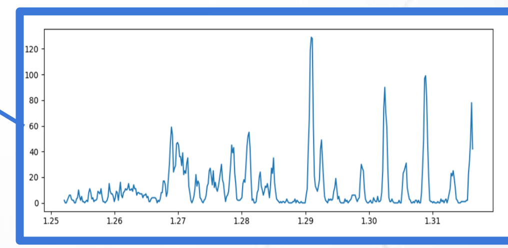


Raw Lenslet Spectra





Stellar Spectra



Sky Spectra

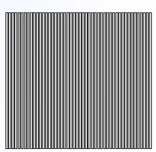
Slicer Spectrograph

TMT Thirty Meter Telescope

IRIS Infrared Imaging Spectrograph

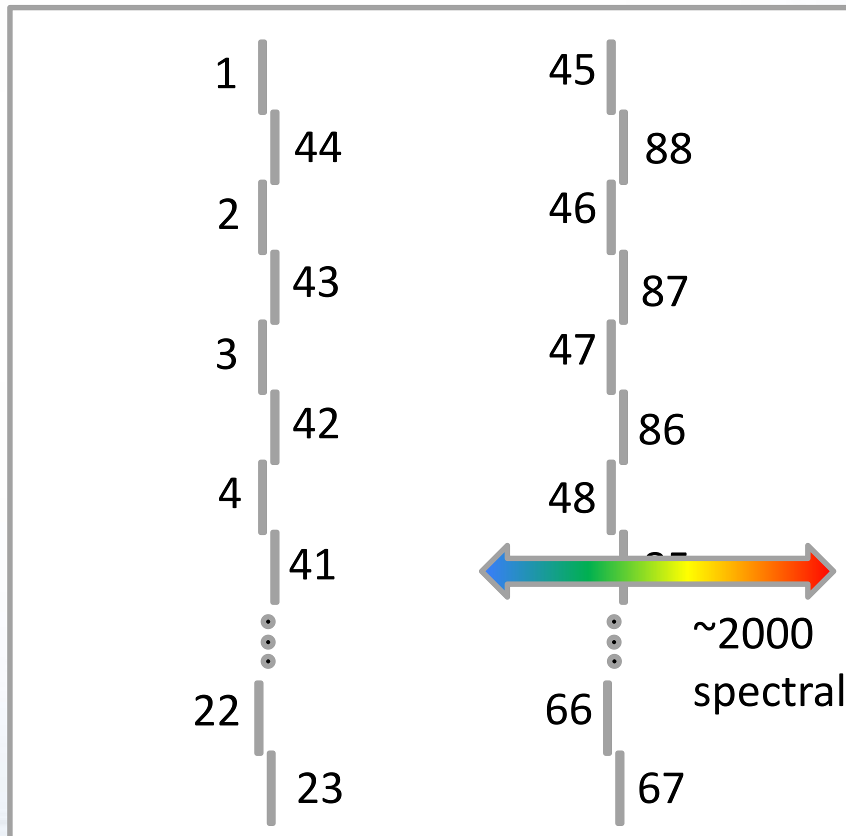
- 88 slicer mirrors reformat field of view into pseudoslit for spectrograph.
- Slices are 25 or 50 mas wide for 2.2” or 4.4” widths.
- Lengths are 1.125” or 2.25” long.

Slicer Stack



1,2,3,…88

Result of Slicer mirror set



At pseudoslit Spectrograph input

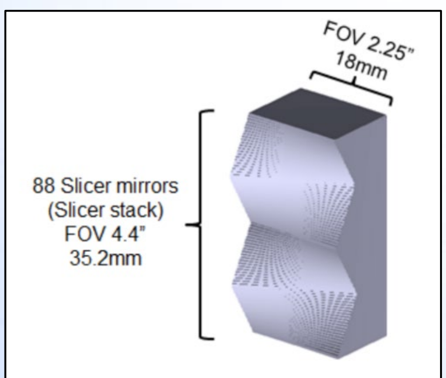
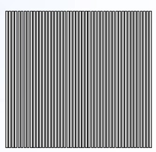


Figure 62 - A model of the IRIS 88-mirror, slicer stack (SS)

Slicer Spectrograph

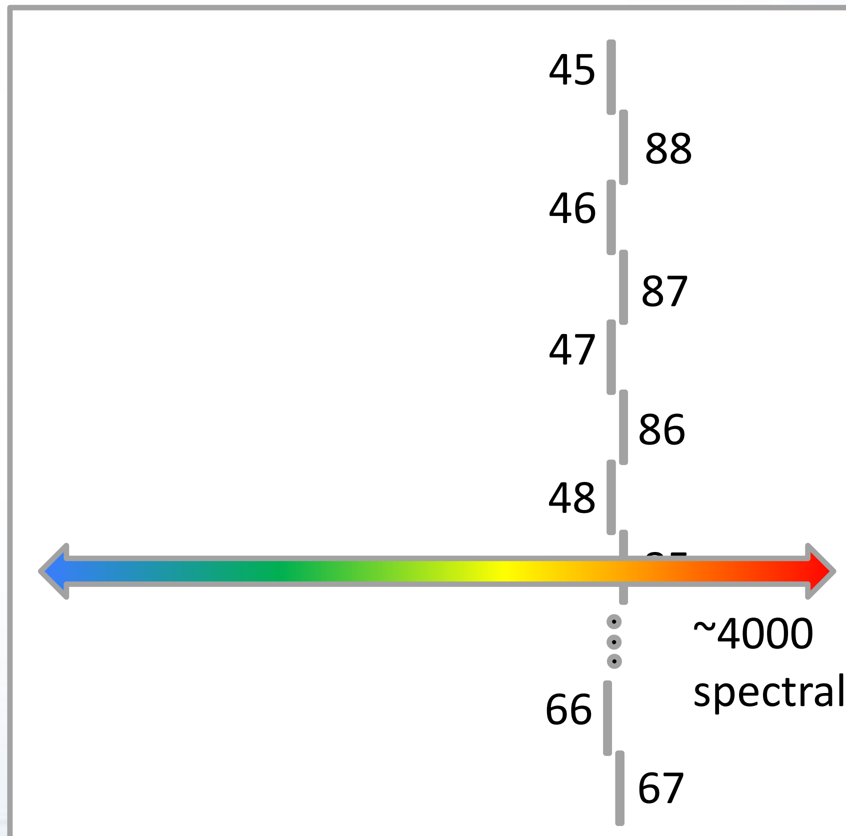
- 88 slicer mirrors reformat field of view into pseudoslit for spectrograph.
- Slices are 25 or 50 mas wide for 2.2” or 4.4” widths.
- Lengths are 1.125” or 2.25” long.

Slicer Stack



1,2,3,…88

Result of
Slicer mirror set



At pseudoslit
Spectrograph
input

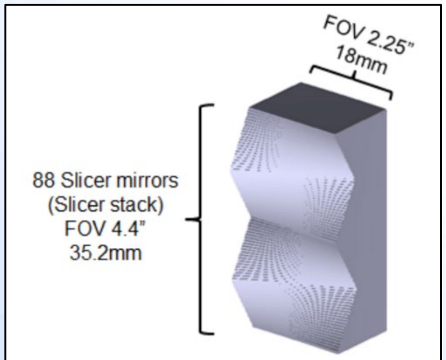
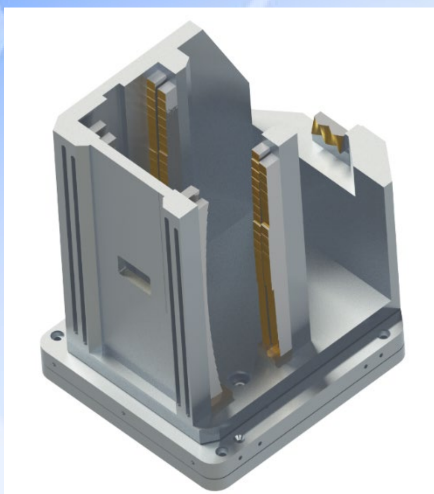
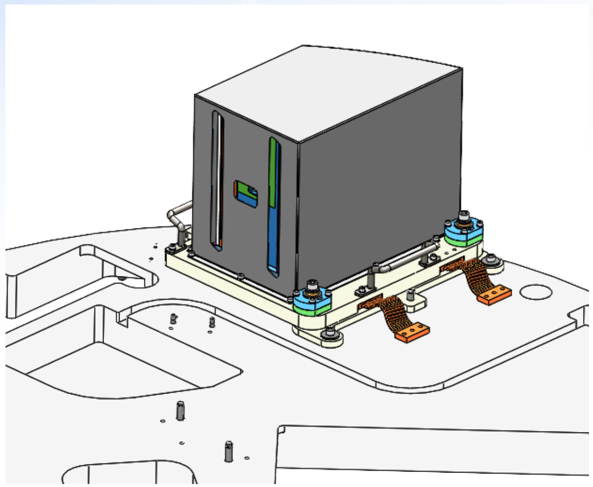
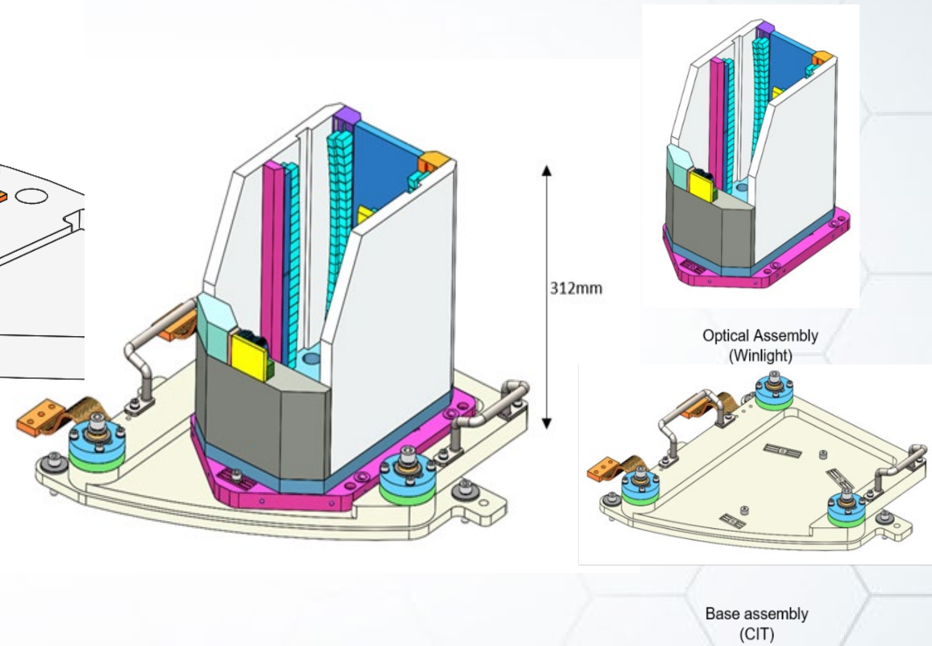


Figure 62 - A model of the IRIS 88-mirror, slicer stack (SS)

Slicer IFU

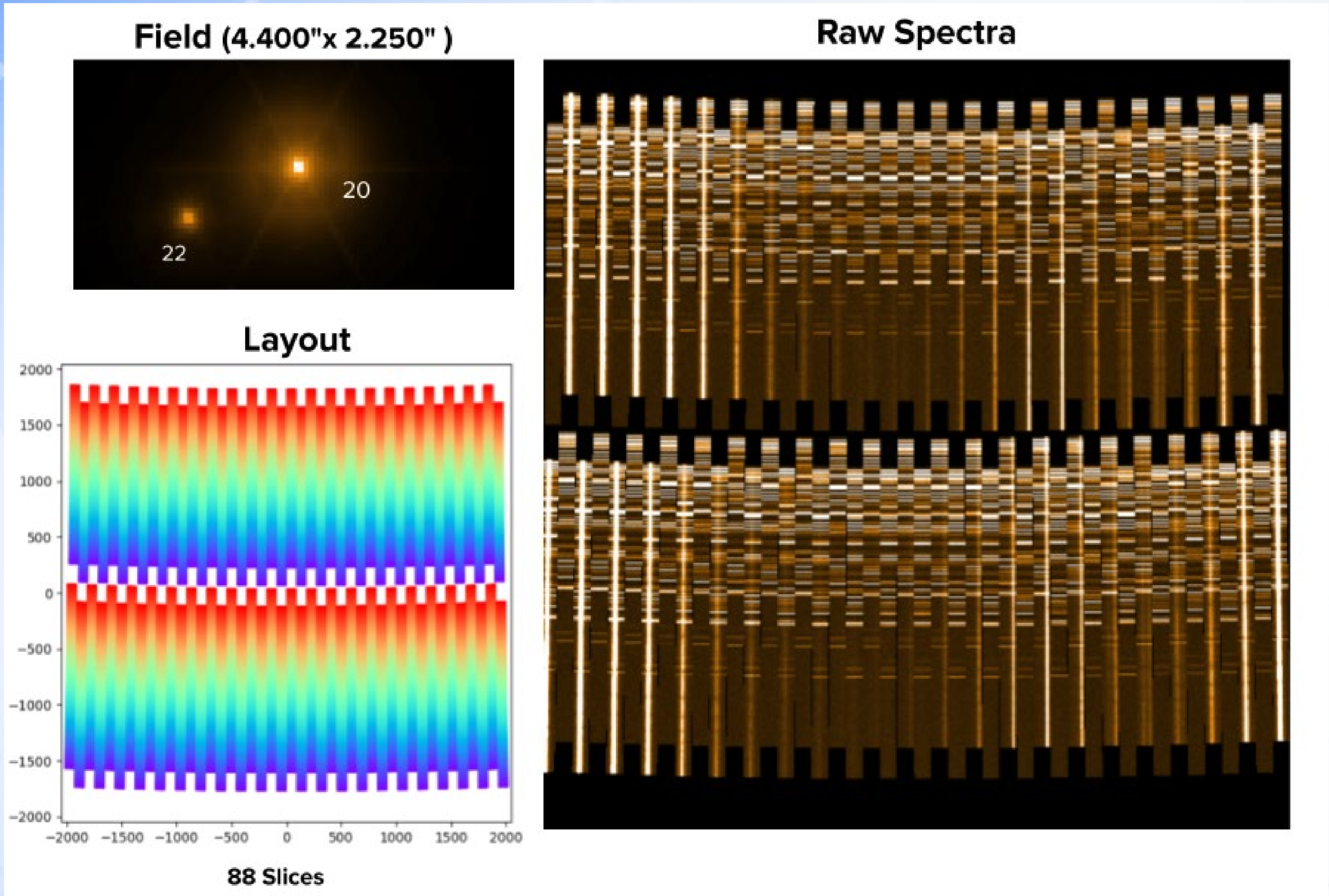






- Final Slicer IFU was designed by Winlight System
  - They will fabricate and align.

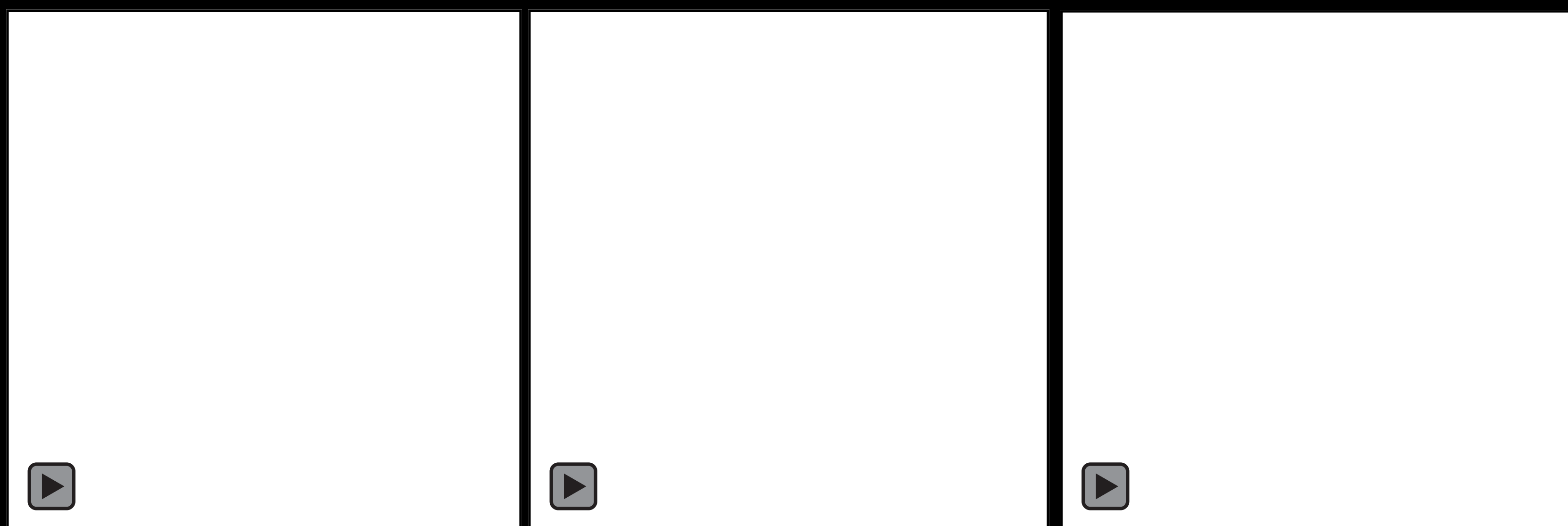
Slicer Raw Spectra



Zemax Model
Slit Trace for all modes
Filters + Grating + Scale
Instrument PSFs

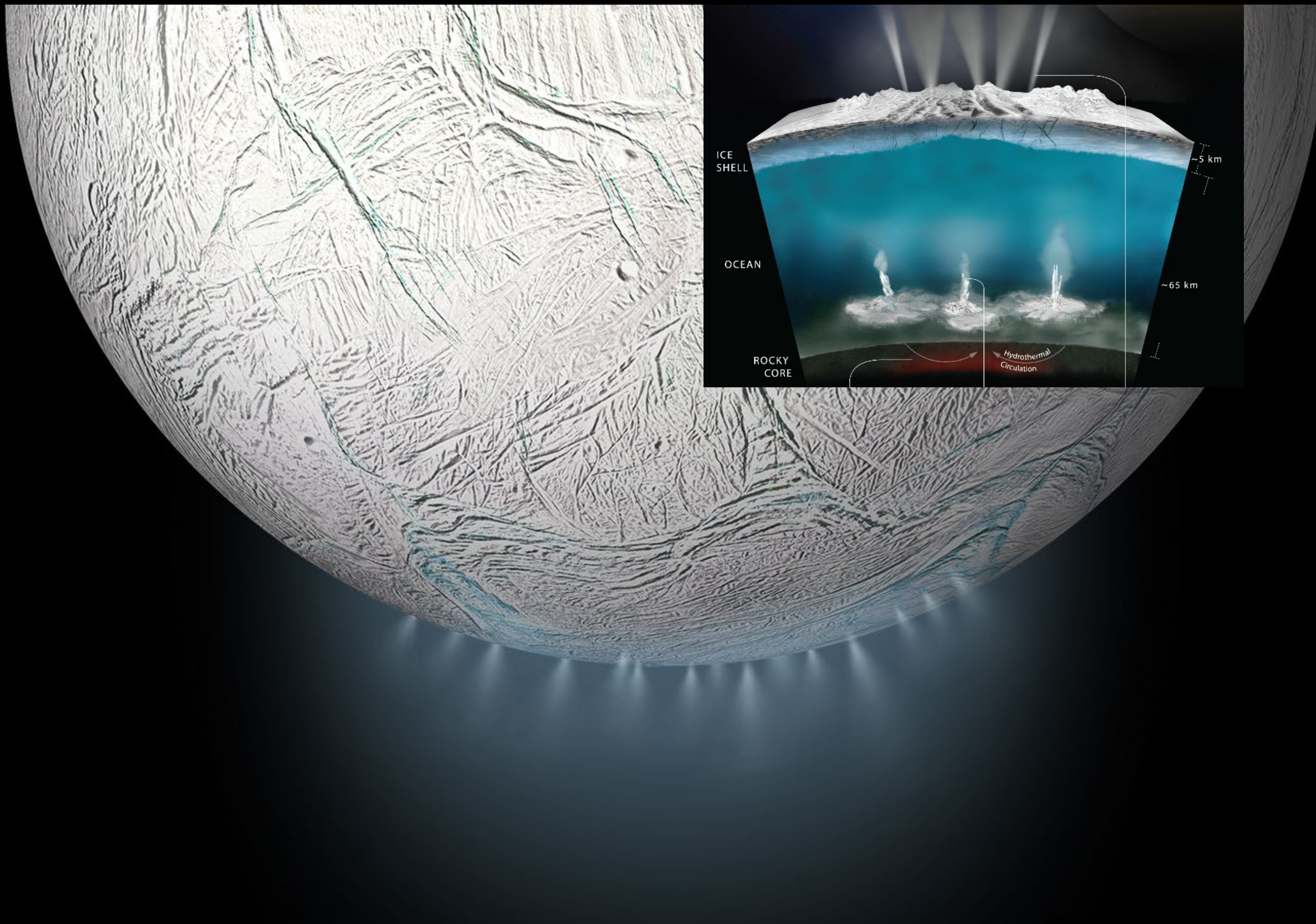
Monitoring Io's volcanism with IRIS

- IRIS simulation
  - Imaging of Io using IRIS 0.004" scale in 2 seconds!



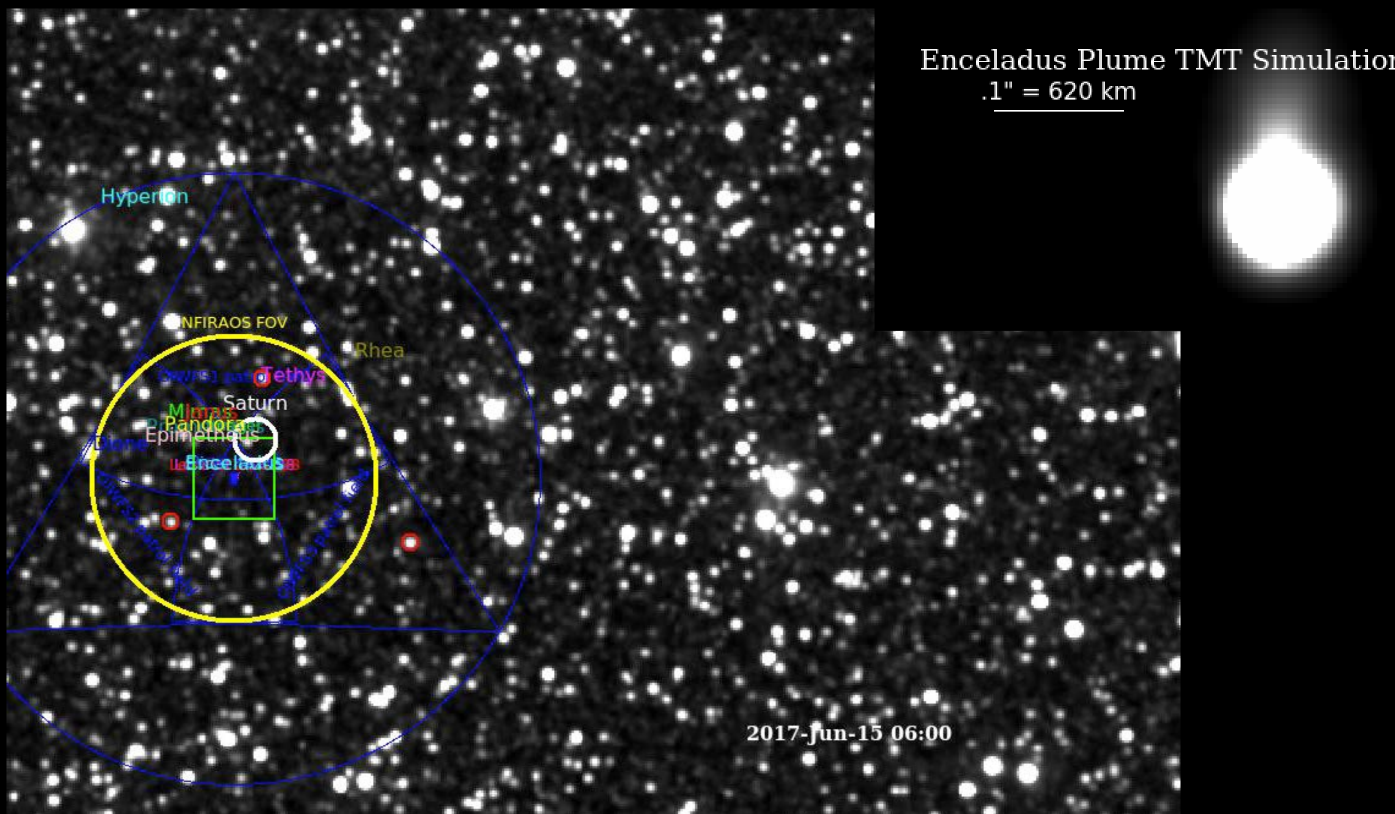
Rundquist et al., in prep

Monitoring Enceladus cryo-volcanism



IRIS and Adaptive Optics tracking solar system targets

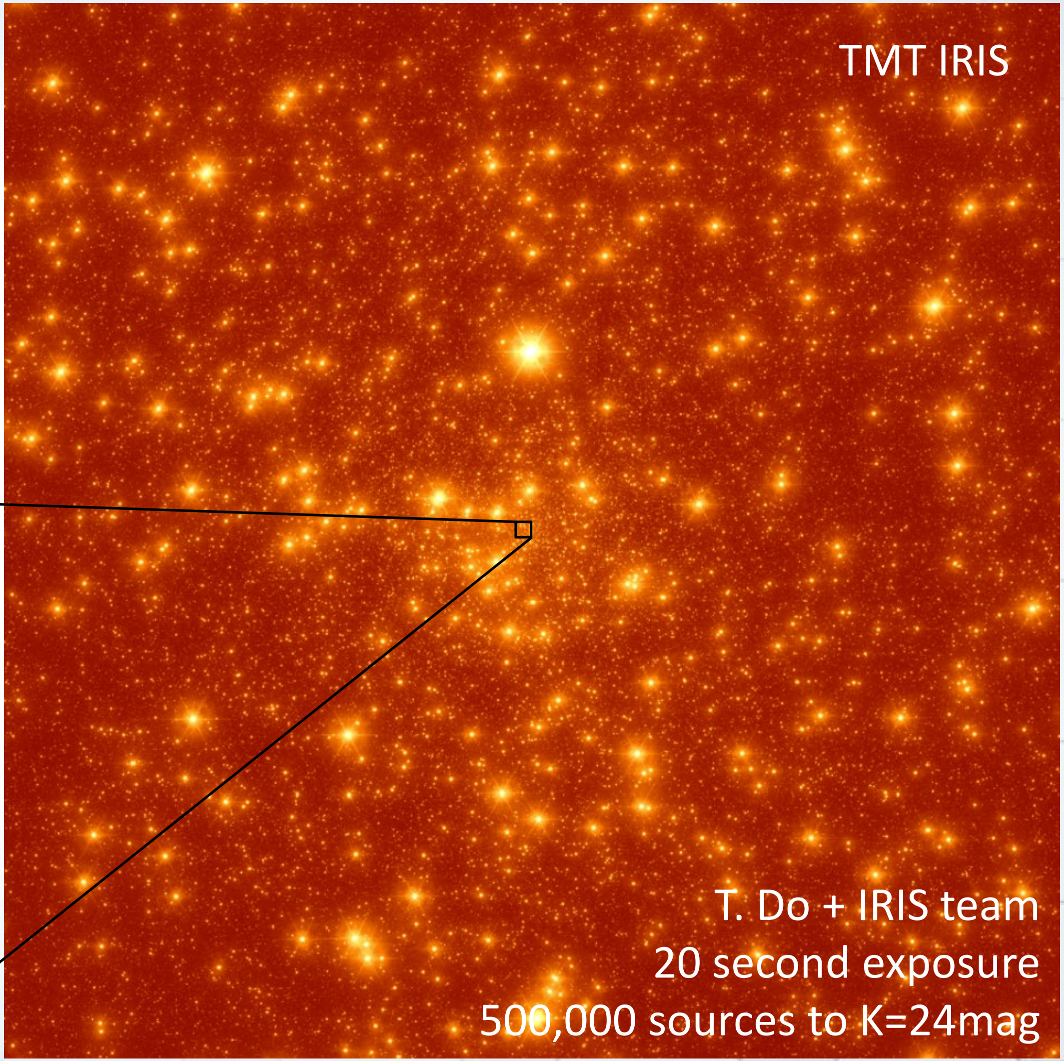
- Observing moons of Saturn (e.g. Enceladus)



Larger Imaging Field Significantly Improves Astrometric Accuracy

IRIS can observe 8 maser sources (VLA astrometry) simultaneously with central stars orbiting GC black hole. Dramatic improvement to astrometric accuracy in this field.

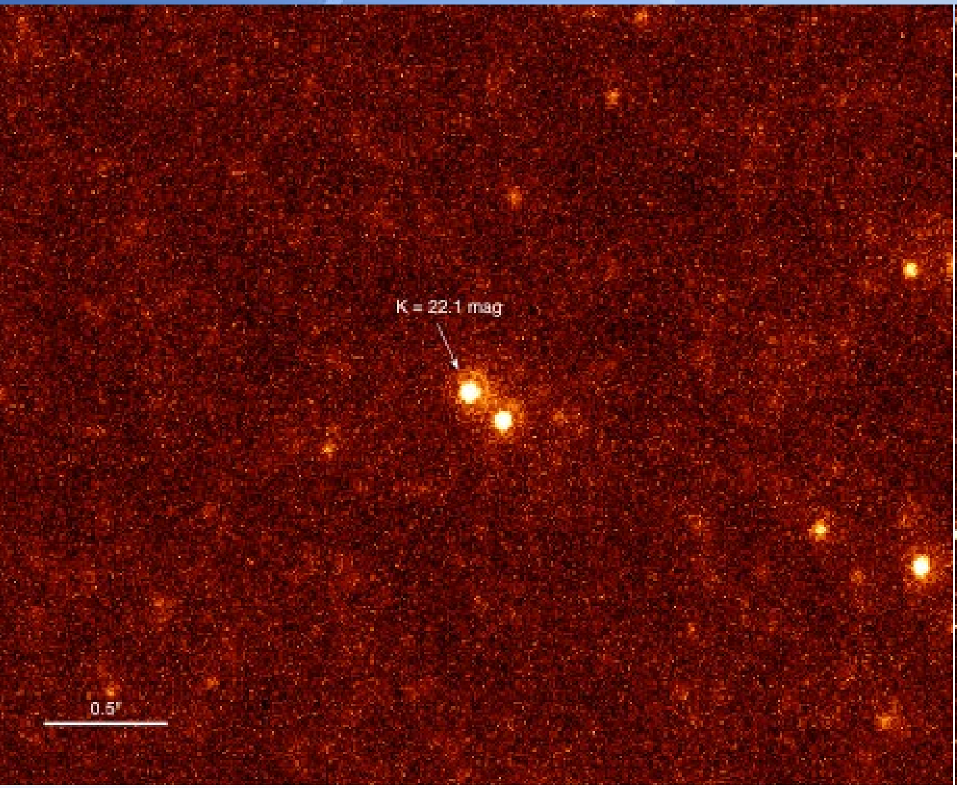
Black hole here

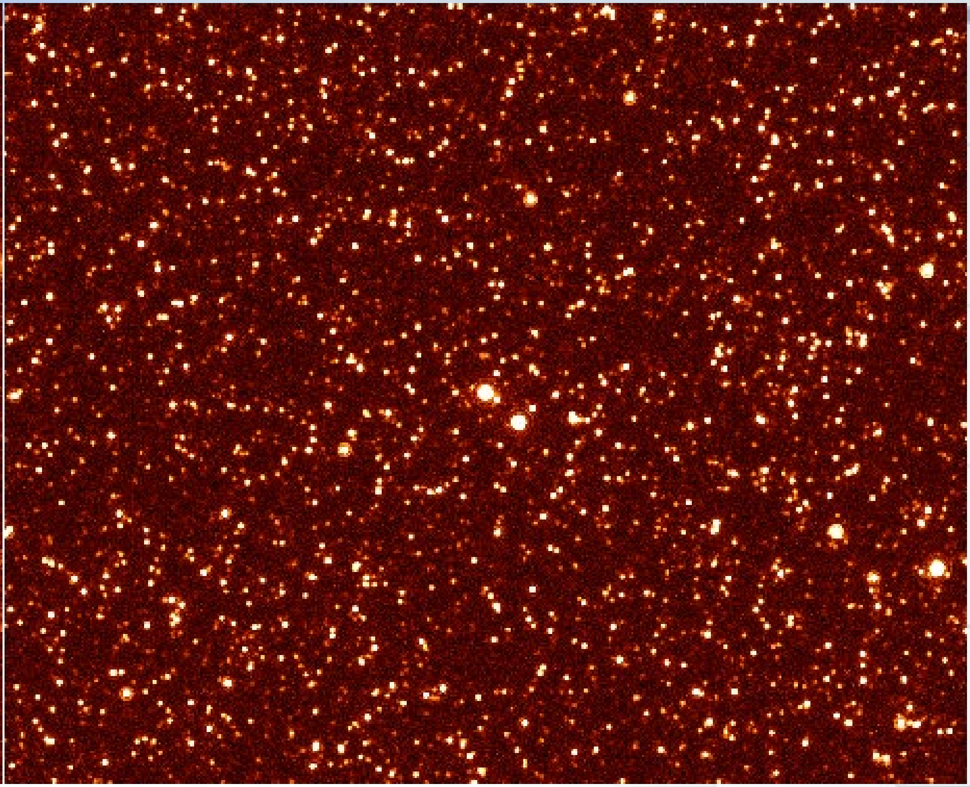


Observing individual stars in nearby galaxies

Nearby Virgo Cluster – 53 million light years away

Individual Stars in Virgo Cluster Galaxies





Keck Adaptive Optics

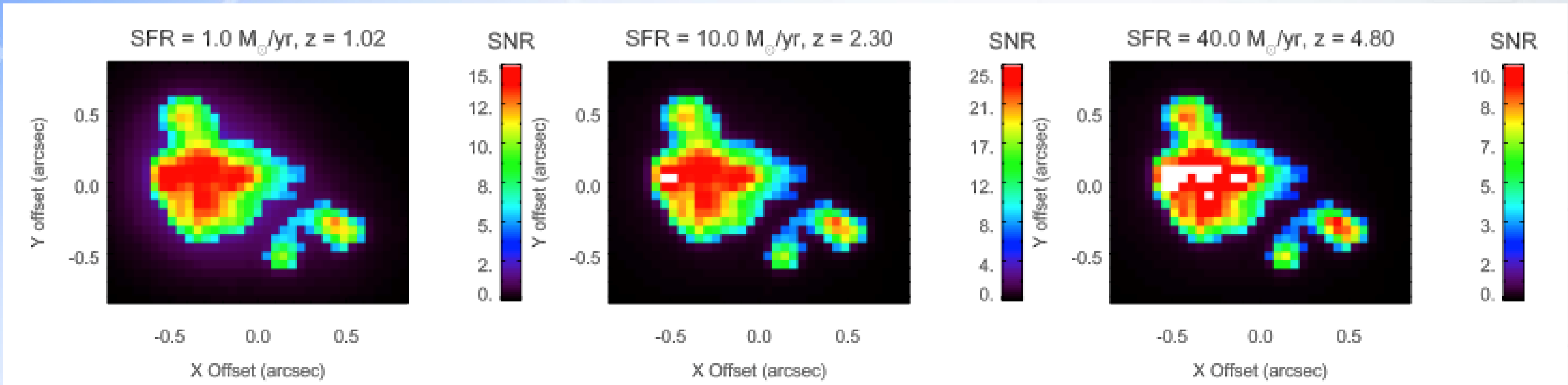
Thirty Meter Telescope

Only very bright AGB stars are detectable.

AGB plus upper stars on the RGB allow for age and chemical composition directly.

Simulated image from region of 22 mag/sq arcsec

IRIS will resolve high-z individual star forming regions



Hα at z=1.02 in J-band

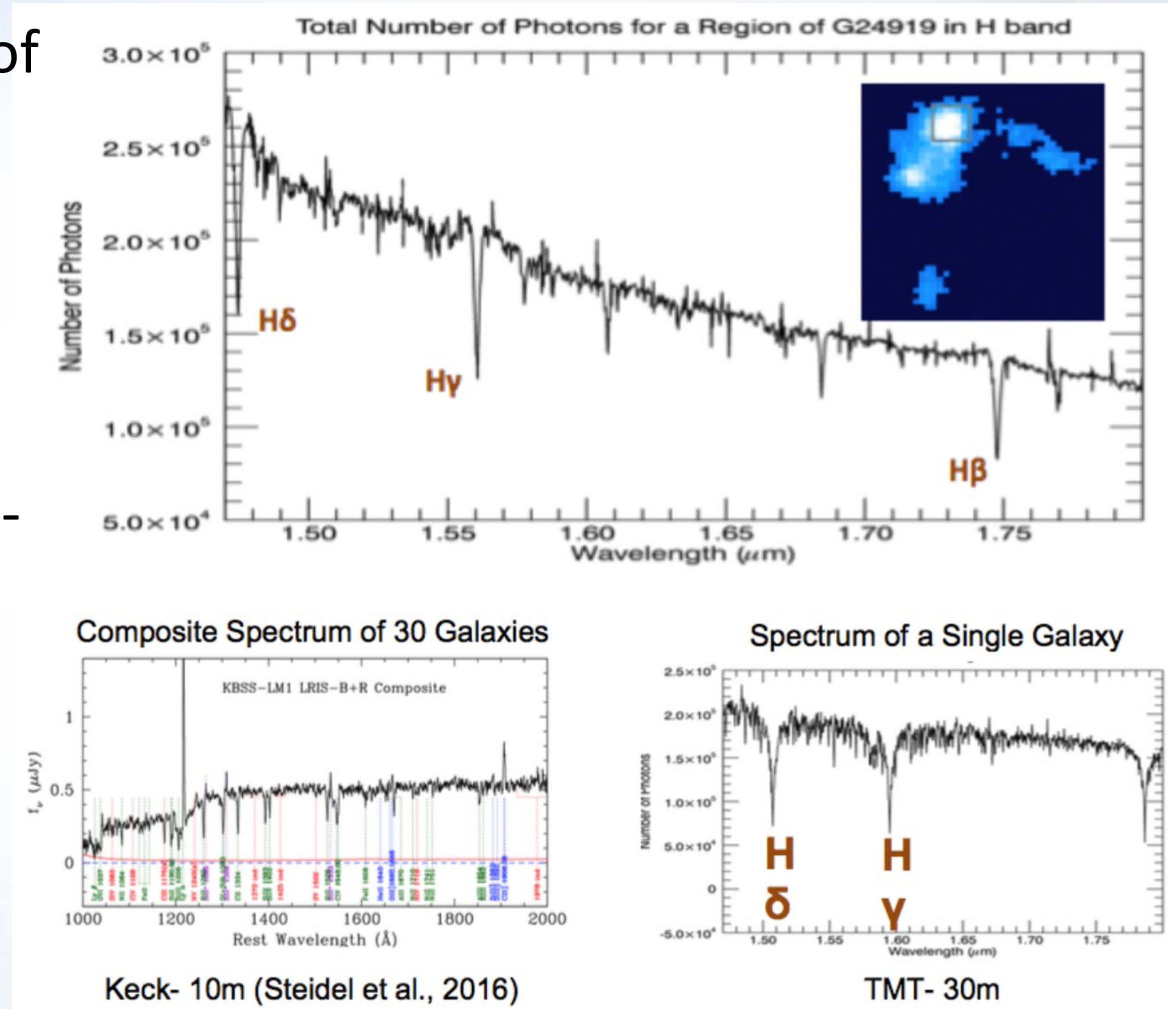
Hα at z=2.30 in K-band

[OII]3727 at z=4.8 in K-band

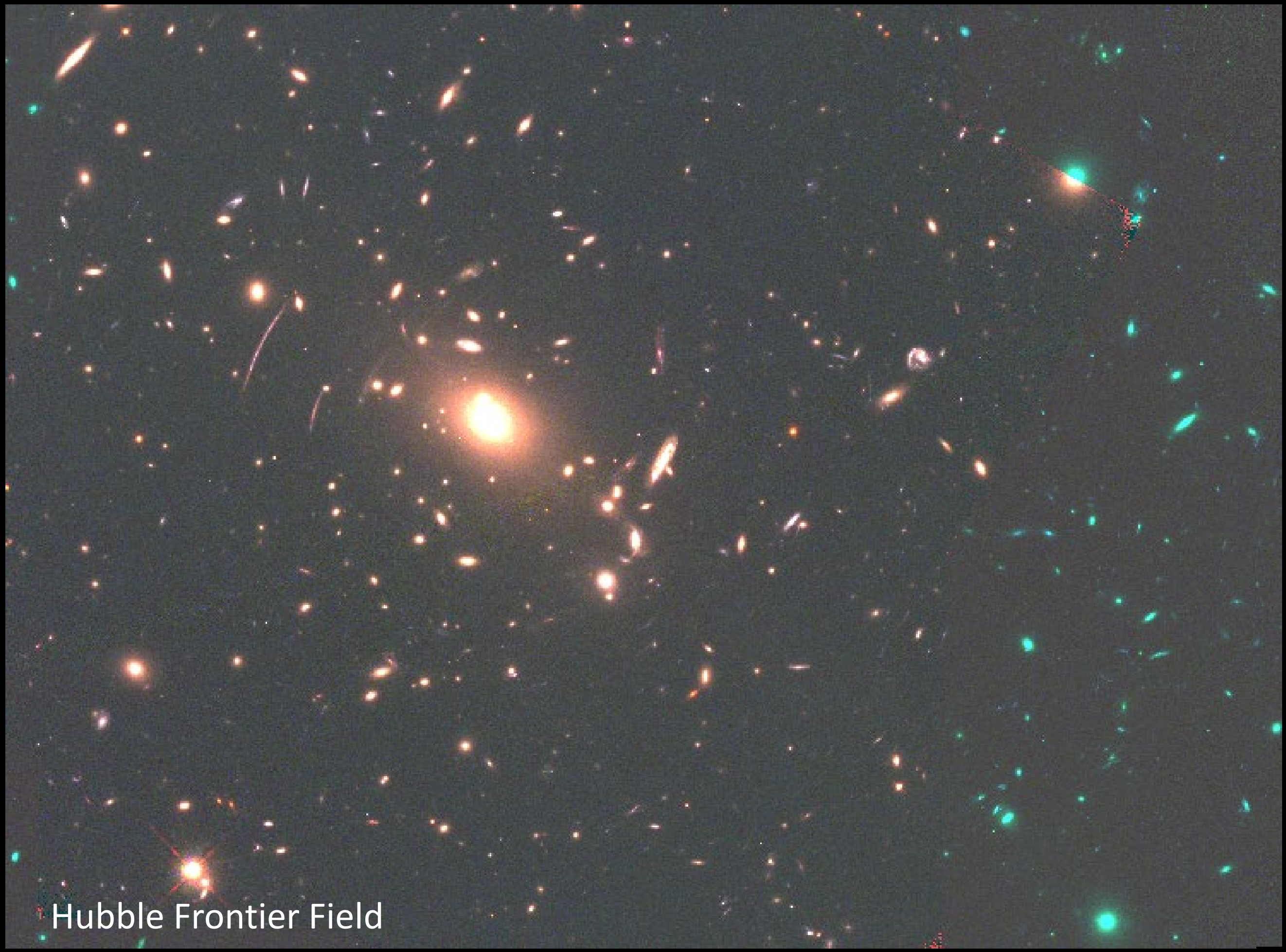
- IRIS is 2nd generation and learns from past IFUs like OSIRIS and SINFONI. Coarse scales are optimized for low surface brightness work.
- Simulation is coarsest 0.050” scale with slicer.

Studying quiescent galaxies in distant universe

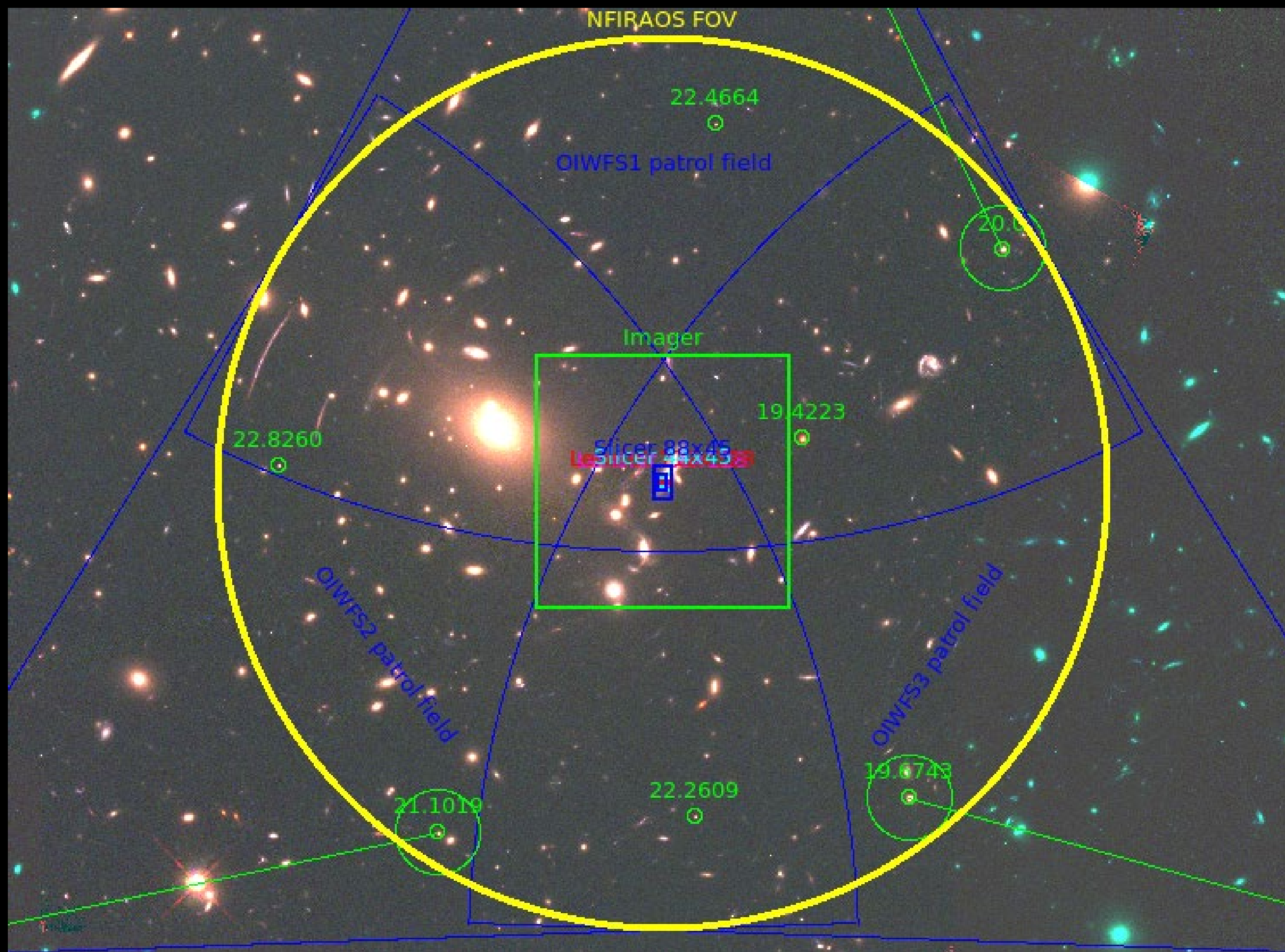
- Resolved spectroscopy of a 900 Myr stellar population in a z=2.6 galaxy. The thumbnail is 2"x2" region of a simulated galaxy using the IFS 50mas scale at H-band.
- Compared to stacked Keck spectrum from MOSFIRE of 30 z~2 galaxies.



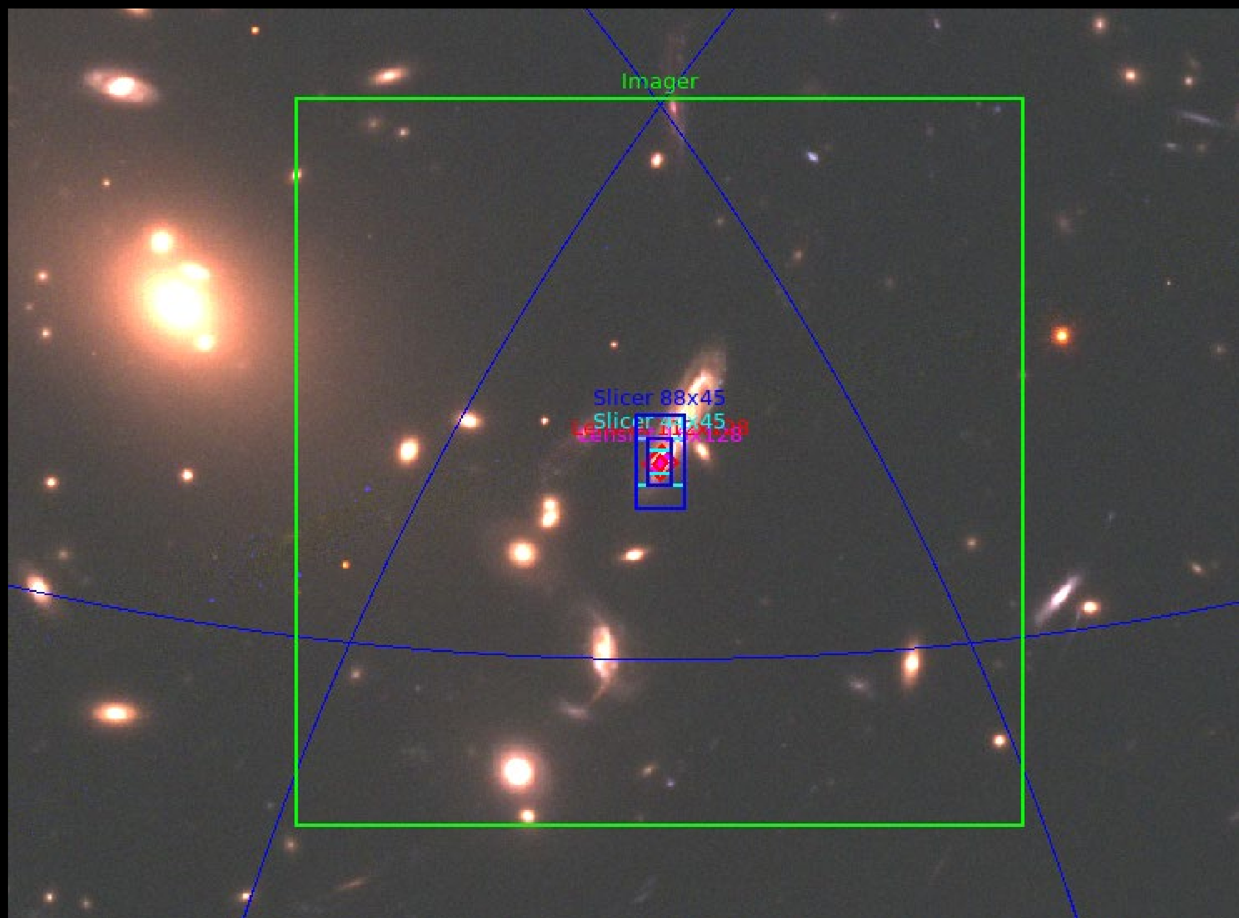
Observational planning on gravitationally-lensed galaxies



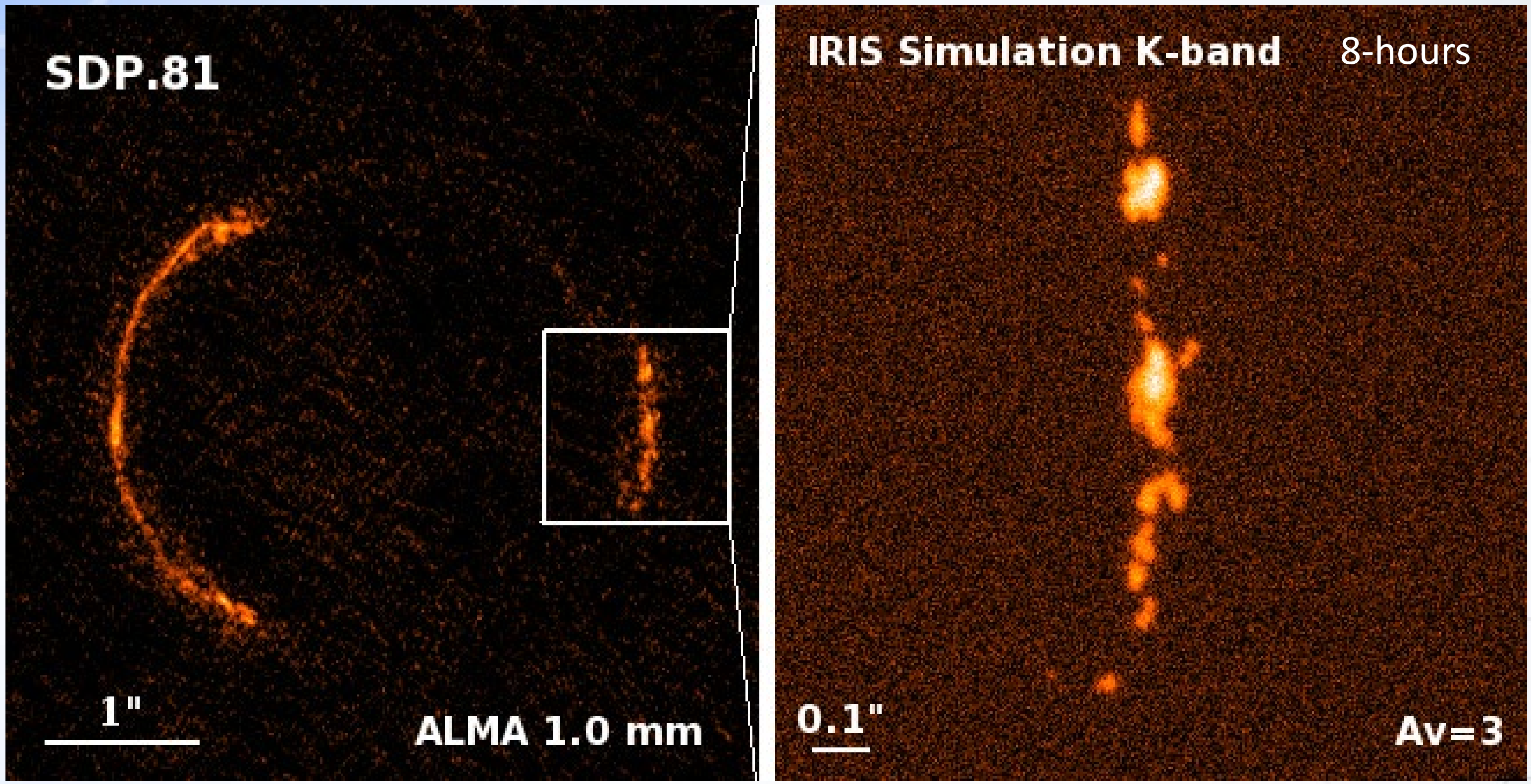
NFIRAOS and OIWFS field of view



IRIS imager and IFS field of view



Studying Gravitationally lensed galaxies

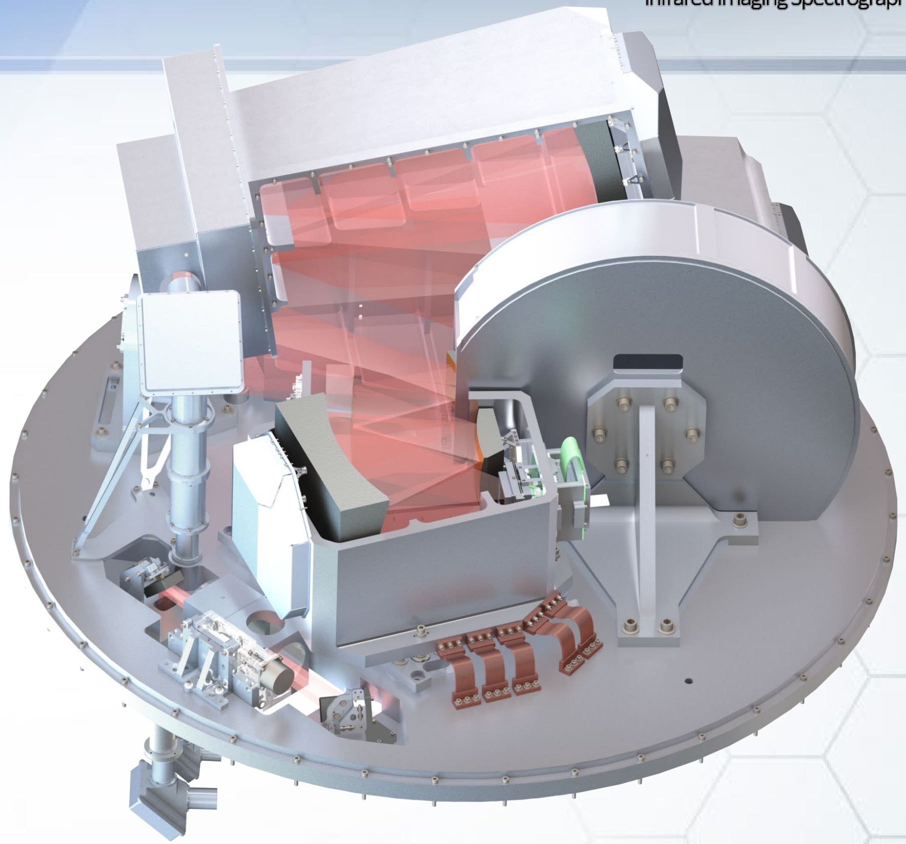


With combination of gravitational lensing and IRIS resolution, we get 10 pc source plane sampling of this z=3.04 galaxy. Image is extrapolation of stellar light including A_V of 3.

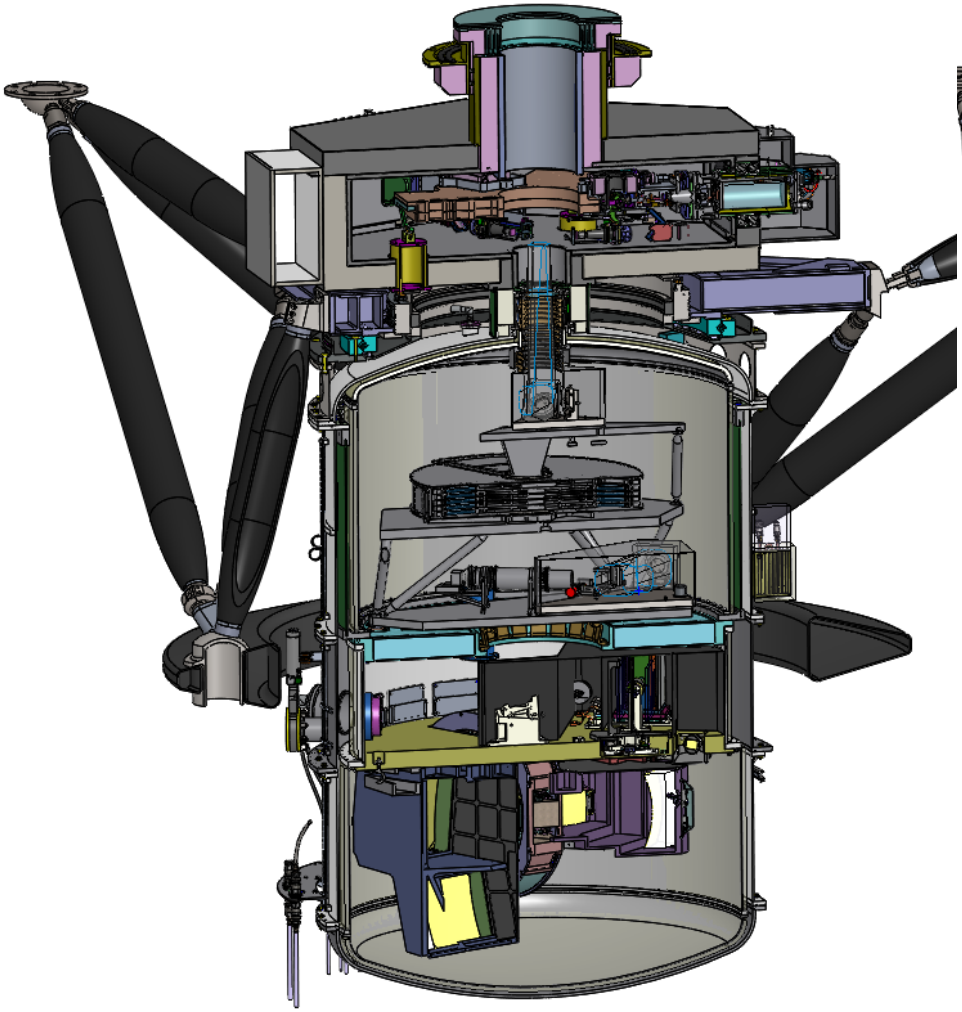
Wright et al. 2016

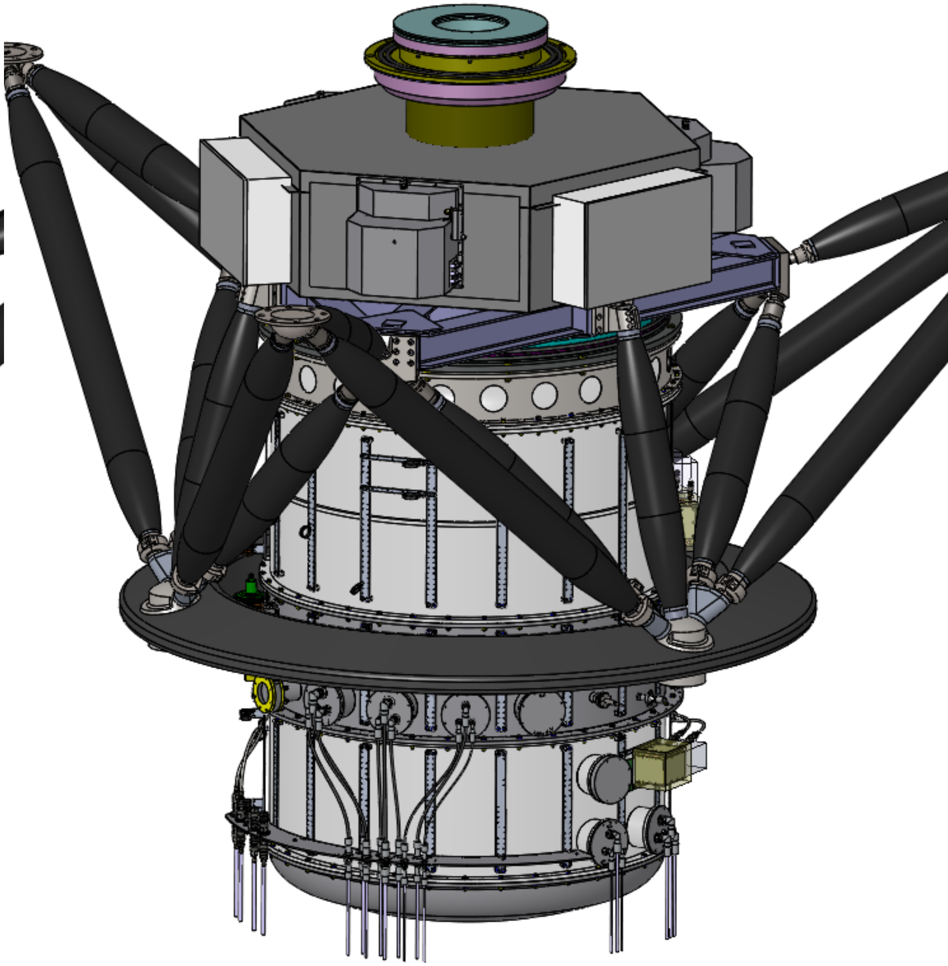
Final Design Phase - 3

- IRIS needs to be ready well before TMT first light in order to integrate with NFIRAOS.
- Officially in final design phase (Started Oct, 2017).
- Four formal final design reviews (Level C):
  - Science Cryostat 28, 29 May 2021
  - Data Reduction Software 5 May 2021
  - Support Structure, Rotator, On-Instrument WFS 19 May 2021
  - Imager and IFS – 21, 22 June 2021

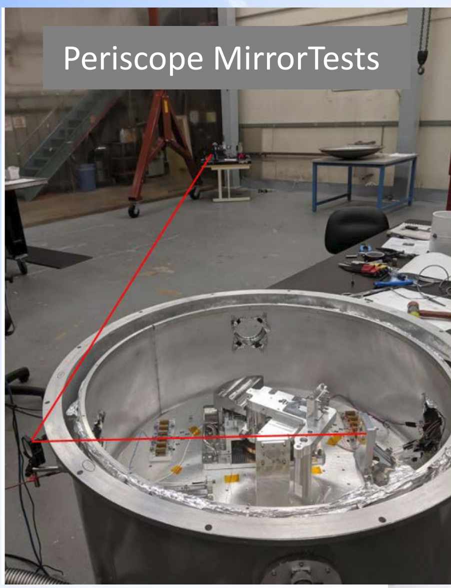


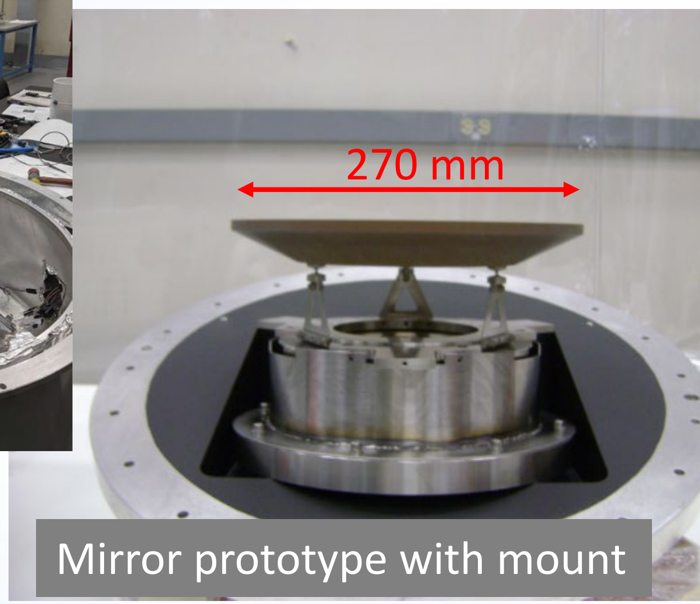
Very mature Mechanical Design
Bob Weber (Lead ME, Caltech)

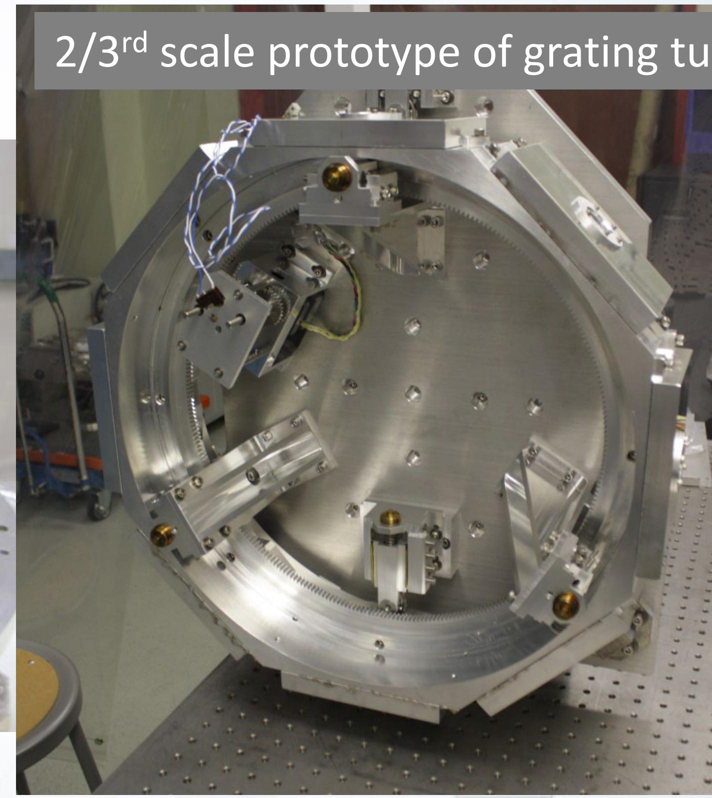




We've already completed large amounts of prototyping and lifetime testing.

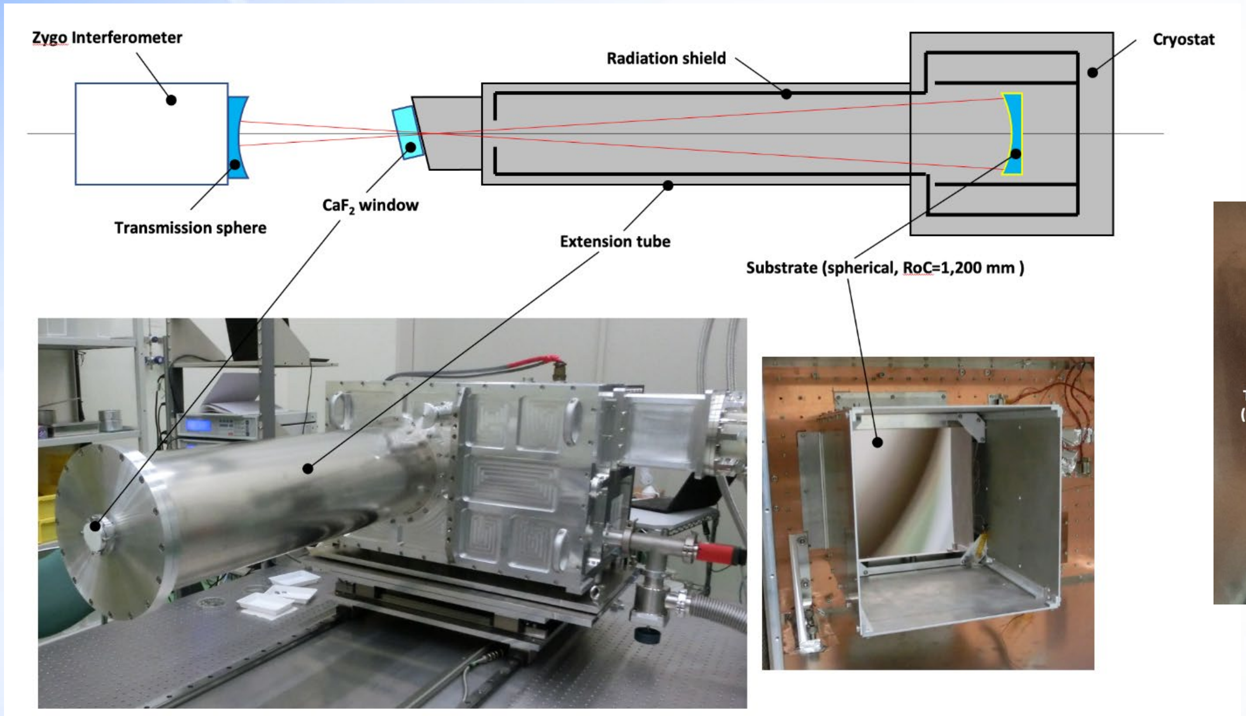


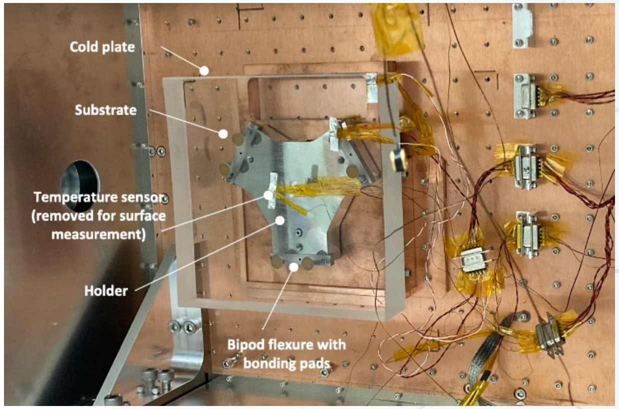




32

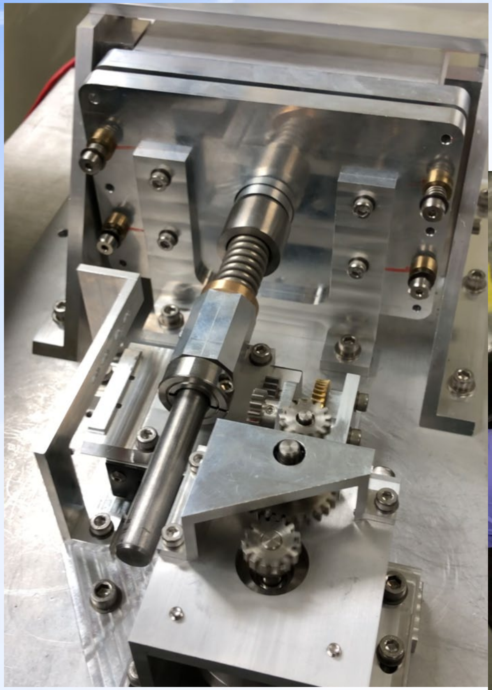
Mirror deformation measurement and modeling - NAOJ at cryogenic temperature



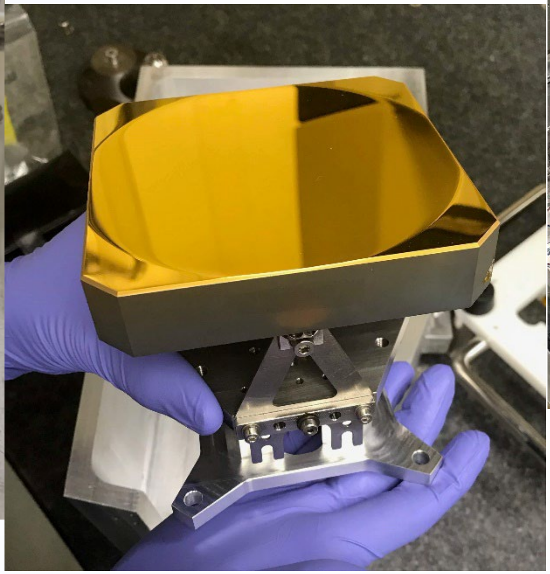


33

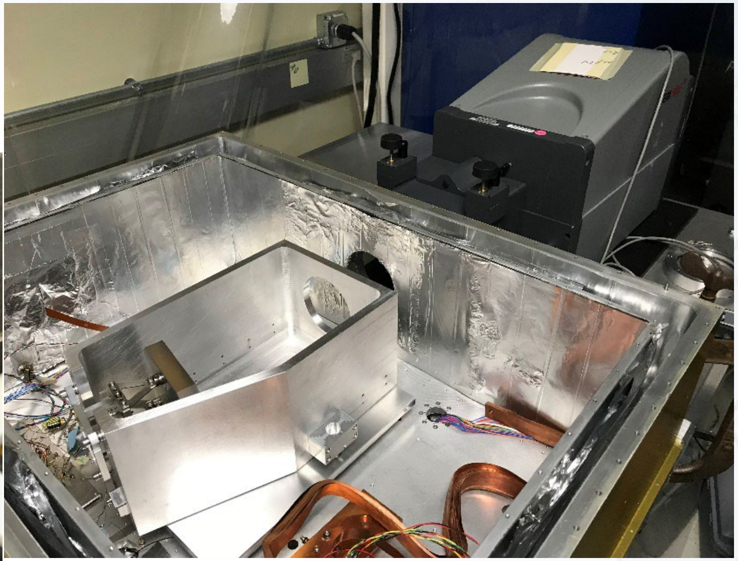
Large amounts of prototyping and lifetime testing.



Grating Piston Stage



Prototype TMA Mirror from AOS



Cryogenic Aseembly Station

34

NRC Integration Facility

Summary

- IRIS will be a revolutionary diffraction limited instrument for TMT.
- Sequential, hybrid design yields high performance and efficiency.
- Dedicated and very active science team. Advanced simulator and data reduction pipeline.
  - https://oirlab.ucsd.edu/IRIS_sims.html
- We are at end of final design phase.
- For more read our past papers (SPIE), the OCDD and thousands of pages of documents!

Acknowledgments

The TMT Project gratefully acknowledges the support of the TMT collaborating institutions. They are the California Institute of Technology, the University of California, the National Astronomical Observatory of Japan, the National Astronomical Observatories of China and their consortium partners, the Department of Science and Technology of India and their supported institutes, and the National Research Council of Canada. This work was supported as well by the Gordon and Betty Moore Foundation, the Canada Foundation for Innovation, the Ontario Ministry of Research and Innovation, the Natural Sciences and Engineering Research Council of Canada, the British Columbia Knowledge Development Fund, the Association of Canadian Universities for Research in Astronomy (ACURA), the Association of Universities for Research in Astronomy (AURA), the U.S. National Science Foundation, the National Institutes of Natural Sciences of Japan, and the Department of Atomic Energy of India.