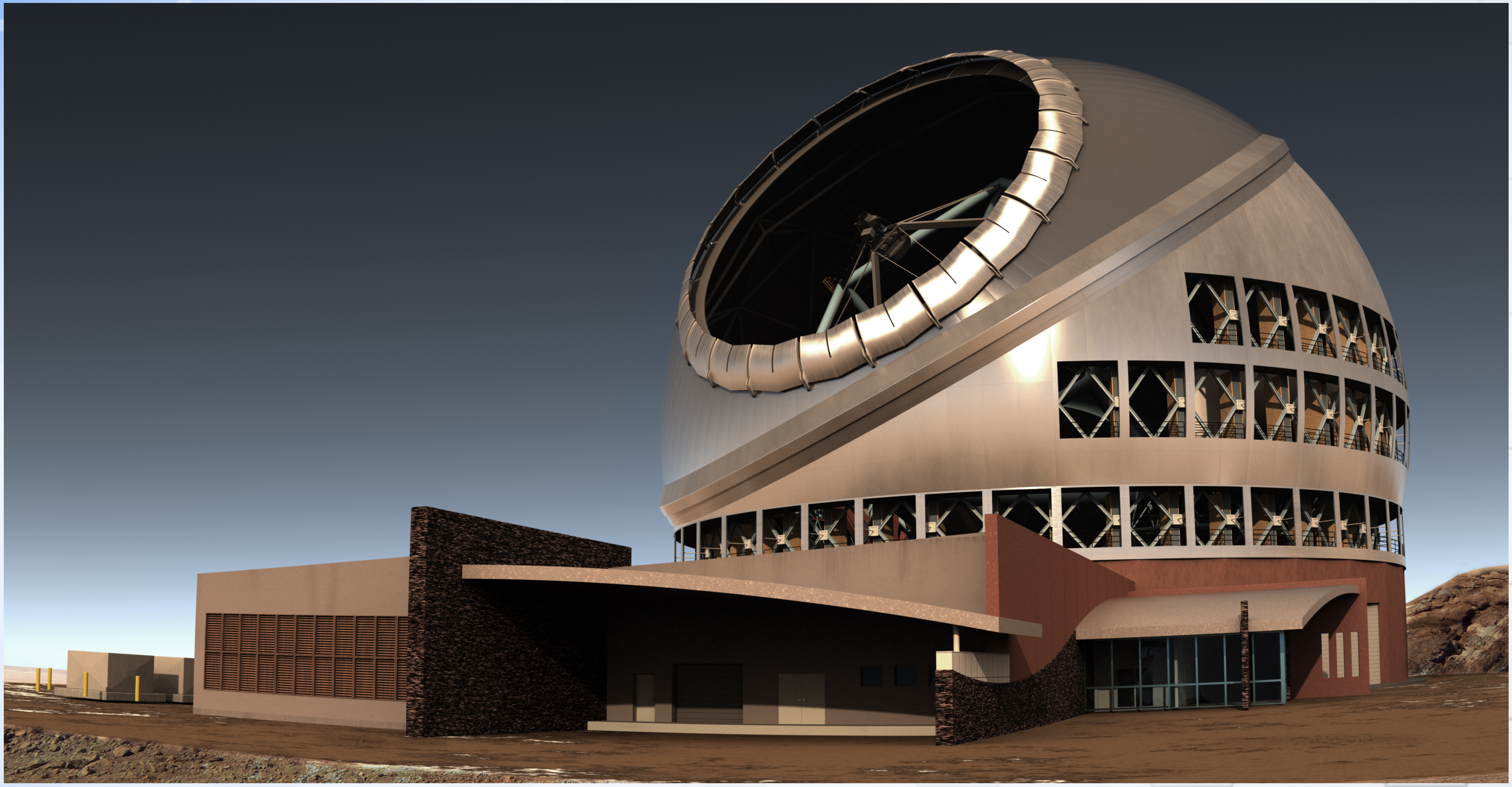
Thirty Meter Telescope First Light Instrumentation Update

Renate Kupke, UCO

Dispersing Elements 2017, Milan

10 October, 2017

The Thirty Meter Telescope International Observatory (TIO)

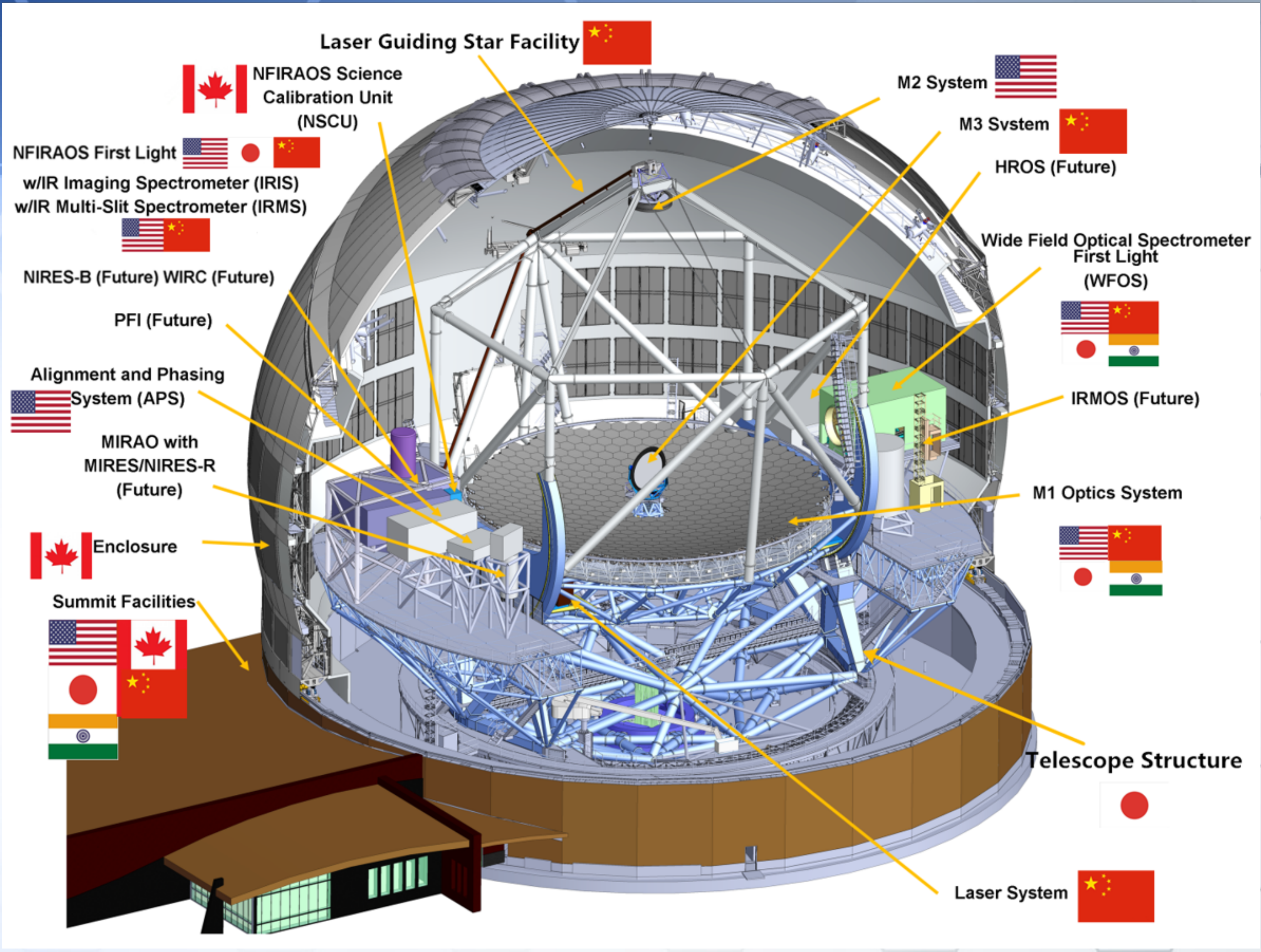


TMT Status

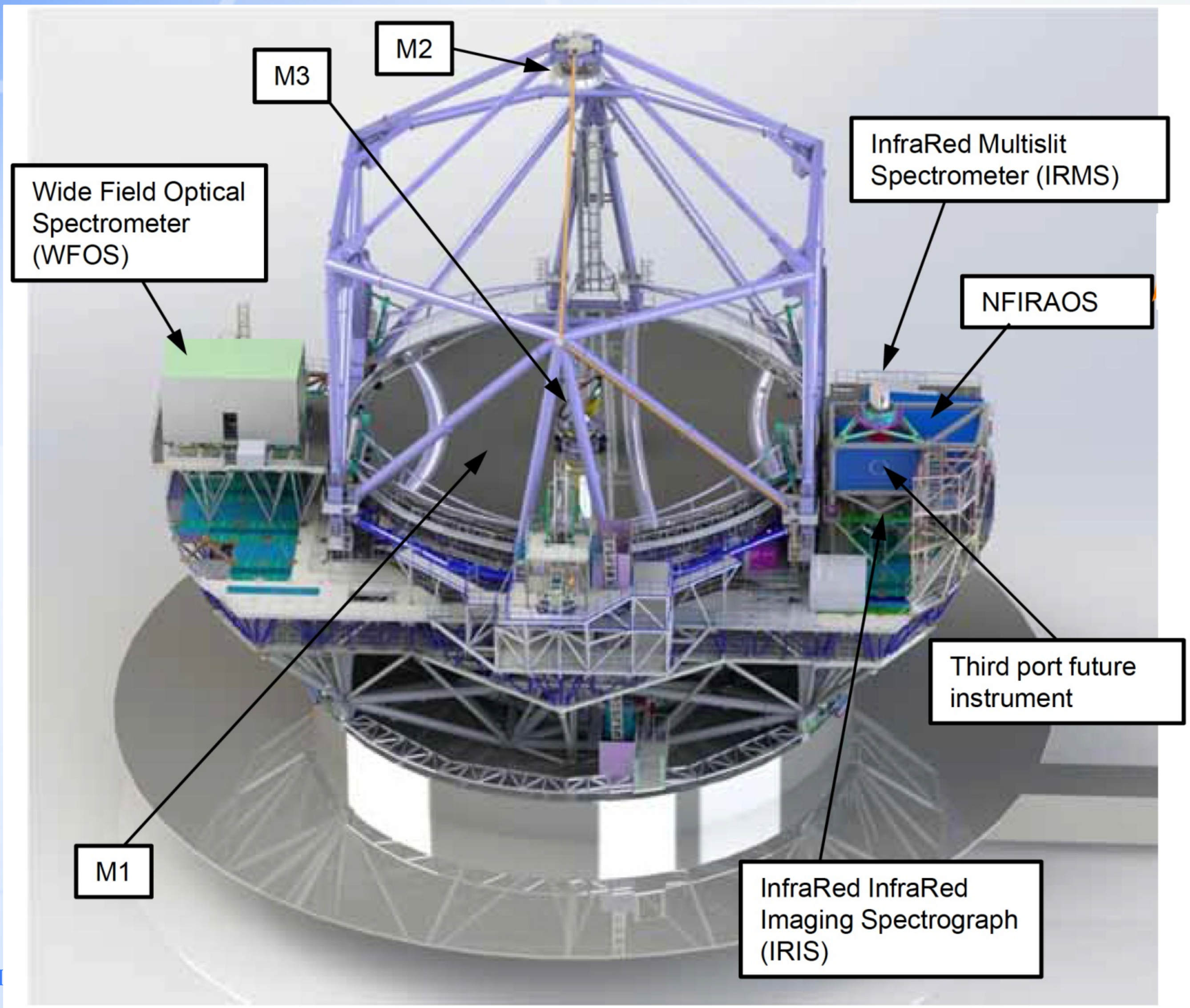
- Site
  - Sept. 29, 2017: Hawaii CDUP issued a new permit to TMT for MK! Lawsuits may follow.
  - Continue pursuing MK as the preferred site, and prepare ORM as the alternative site: site construction to start in 2018
- Requirements and interface definition are mature
- Project planning and control are in place, being exercised, ready for full construction
- Subsystem design and development continue in all partner countries.

Site will be decided in 2018 (MK or ORM)

TMT International Observatory (TIO): a Pacific Rim Partnership


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

Thirty Meter Telescope



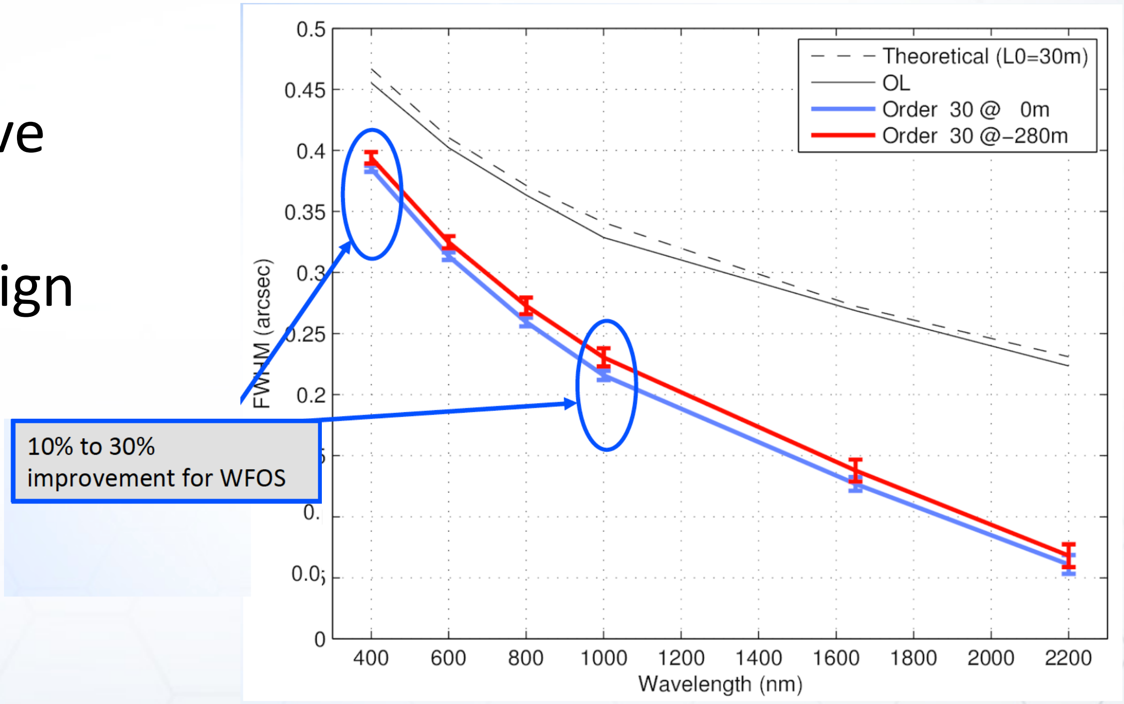
- Ritchey-Chrétien optical design
- 492 segments
- 30-m f/1 primary
- 3.1-m convex secondary
- 2.5 m x 3.5 m flat tertiary
- f/15 final focal ratio
- 20′ Field of view is 2.62m in diameter
- Science instruments mounted on Nasmyth platforms (fixed gravity vector)

Adaptive Optics: NFIRAOS (Narrow Field InfraRed Adaptive Optics System)

High throughput	Minimize surface count
Low thermal emission	-30C operating temperature
Diffraction limited performance in J, H, K bands	Order 60x60 wavefront sensing and correction
30”corrected science field	Atmospheric tomography + **MCAO**
High Sky coverage	Laser guide star (LGS) wavefront sensing
	NGS tip/tilt/focus sensing in the near IR
	MCAO to “sharpen” NGS images
High precision astrometry and photometry on 30” fields	Distortion-free optical design form
	MCAO for uniform, stable PSF
	AO telemetry for PSF reconstruction
Available at TMT first light with low risk and acceptable cost	Utilize existing and near term components and system concepts whenever possible

TMT Adaptive Optics, Schedule

- Laser Guide Star Facility (China) PDR in June, 2018
- NFIRAOS (NRC-Herzberg) final design review (FDR) in June, 2018.
- GLAO with adaptive secondary mirror, feasibility and design study beginning September, 2017.



TMT Instrumentation 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)	1500-5000	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

TMT
Thirty Meter Telescope

First Light Instrumentation 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)	1500-5000	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)	[illegible] diameter field	[illegible]	[illegible]	MCAO
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

Instrumentation Suite - Future

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)	1500-5000	0.31-1.1	Seeing-Limited (SL)
InfraRed Multislit Spectrometer (IRMS)	2′ field w/ 46 [illegible]	R = 4660 @ 0.16″ slit	0.95-2.45	MCAO with NFIRAOS
Multi-IF U imaging spectrometer (IRMOS)	[illegible]	[illegible]	[illegible]	MCAO [illegible]
Mid-IR AO-fed Echelle Spectrometer (MIRES)	3″ [illegible] 10″ imaging	[illegible]	[illegible] 4.5-28(goal)	[illegible]
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

TMT Science Forum "Beyond First Light", Nov 7-9, 2017 in Mysore, India + Call for White Papers, March, 2018 will define TMT's next generation of instruments.

IRIS Capabilities

- First Light Imager and Spectrograph working in parallel at the diffraction limit of the Thirty Meter Telescope.
  - NGSAO and LGS MCAO with NFIRAOS
  - 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 sensors to measure tip/tilt, focus and distortion across field.
  - Near infrared sensors to gain from NFIRAOS AO correction.
- "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

PASSED PDR in September, 2017!

Slide credit: Larkin

IRIS Technical Team

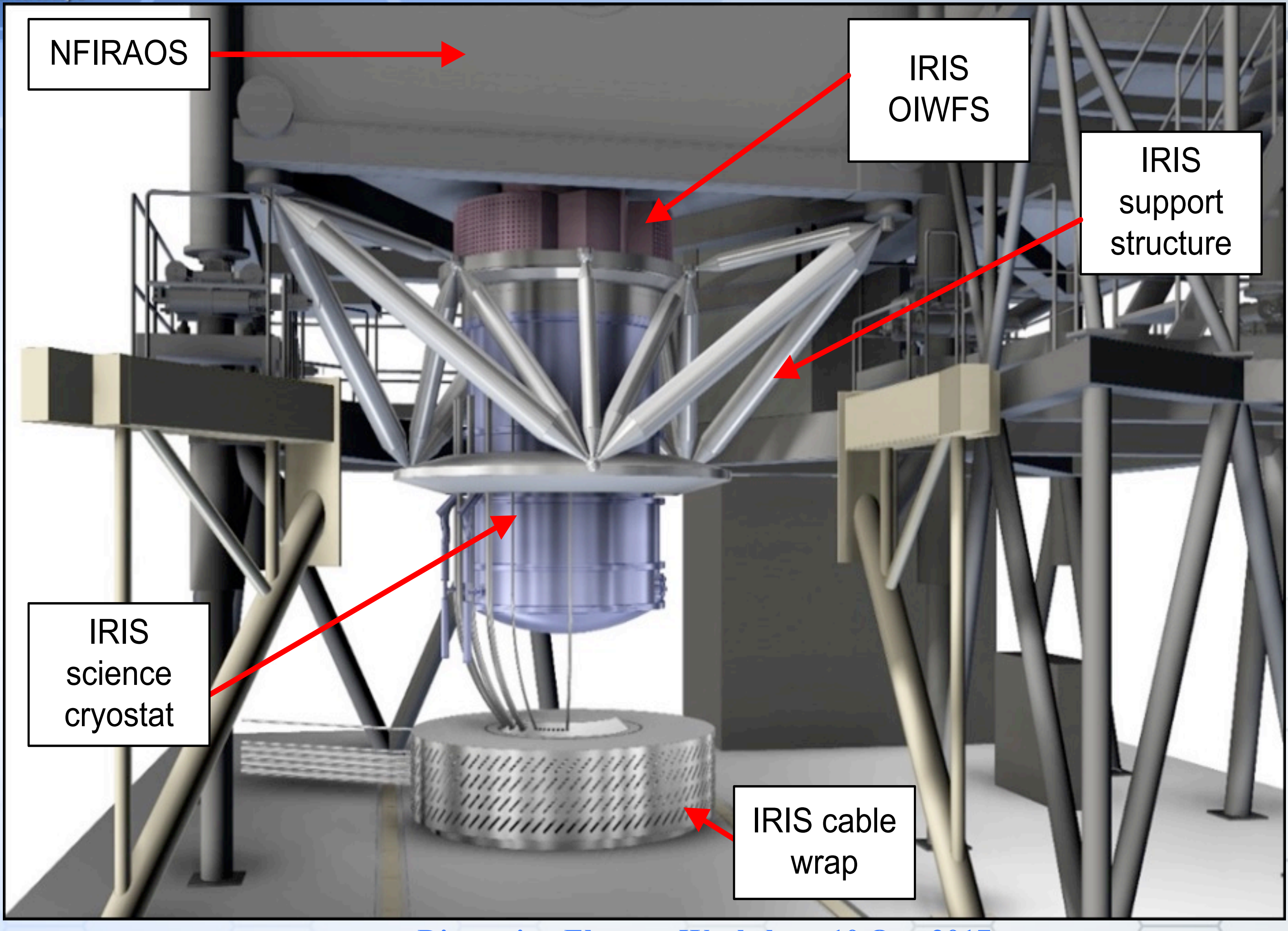
Eric Chisholm (TMT) Instrument Technical Manager
Gelys Trancho (TMT) Senior Systems Engineer
John Rogers (TMT) Senior Systems Engineer
John Miles (TMT) Instrumentation dept. Systems Engineer

- 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
- Renate Kupke (UCO), Lenslet IFS Lead Optical Designer
- Optical Designers: Jenny Atwood (NRC-H), 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…

10 institutions, 4 countries

Slide credit: Larkin

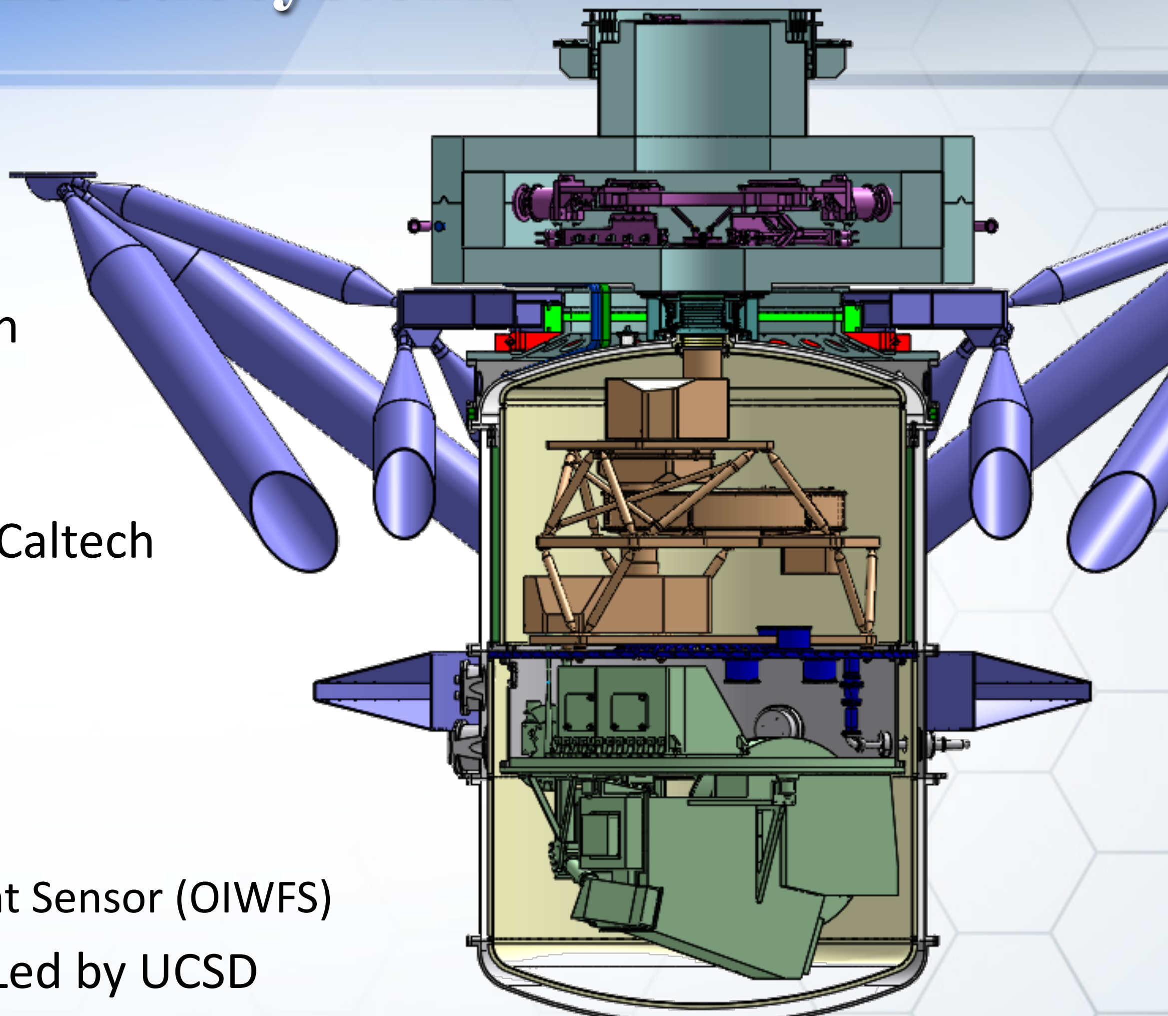
IRIS has up-looking port



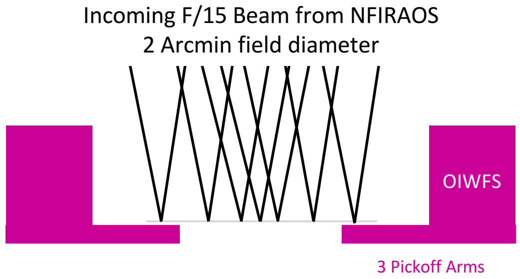
Slide credit: La

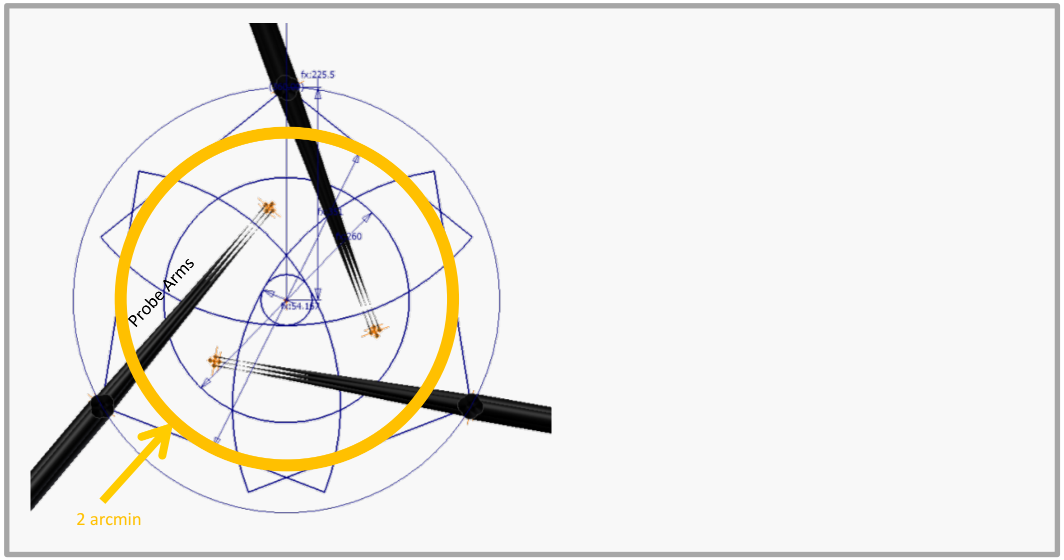
IRIS Subsystems

- OIWFS – Led by NRC-H
- Imager – Led by NAOJ
- Integral Field Spectrograph
  - Slicer – Led by Caltech
  - Lenslet – Led by UCO
- Science Cryostat – Led by Caltech
- CSRO – Led by NRC-H
  - Cable Wrap/cart
  - Support Structure
  - Rotator
  - On Instrument Wavefront Sensor (OIWFS)
- Data Reduction System – Led by UCSD
- Electronics Rack – Led by UCLA
- Instrument Control Interface (ICI) – Led by NRC-H



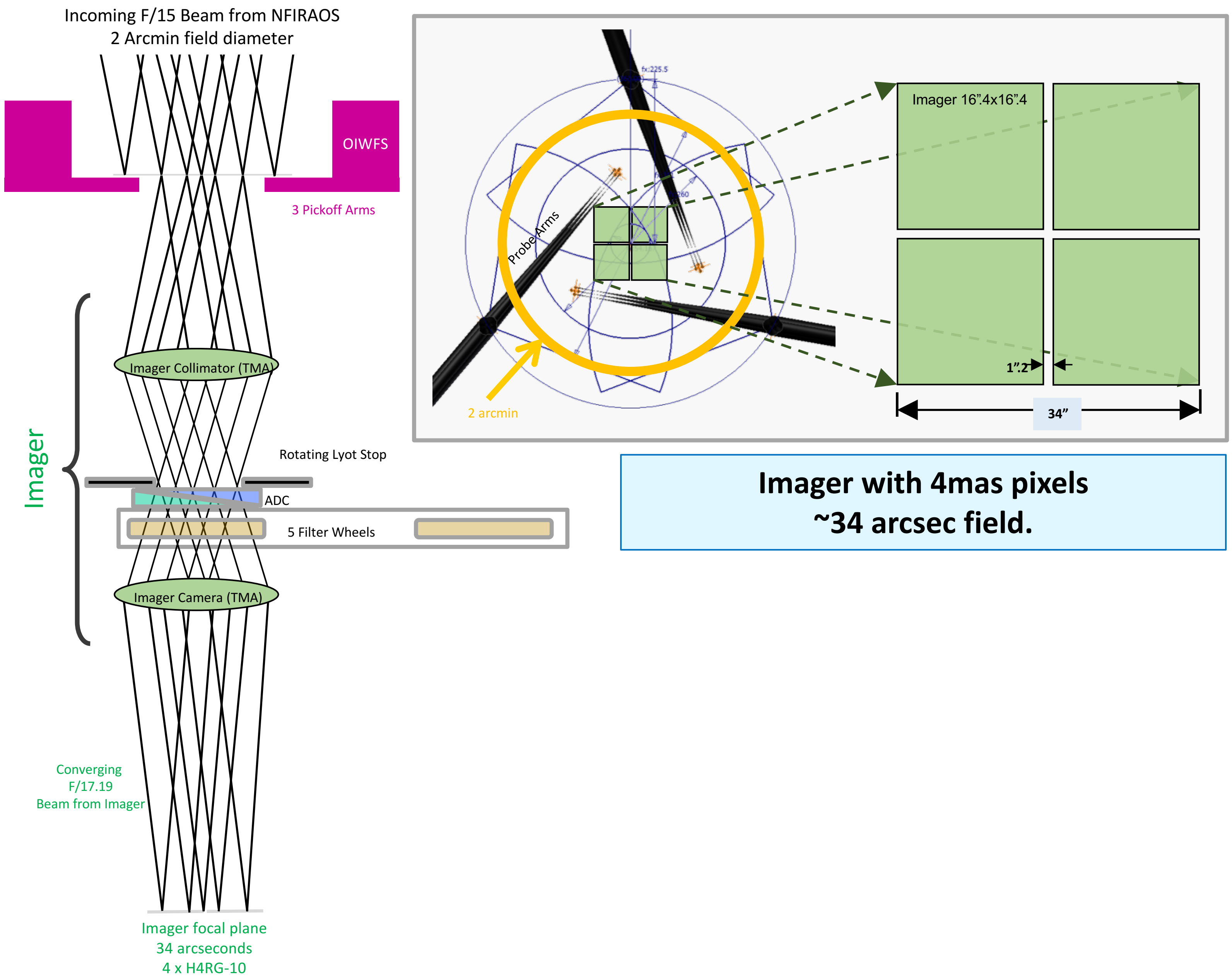
Slide credit: Larki





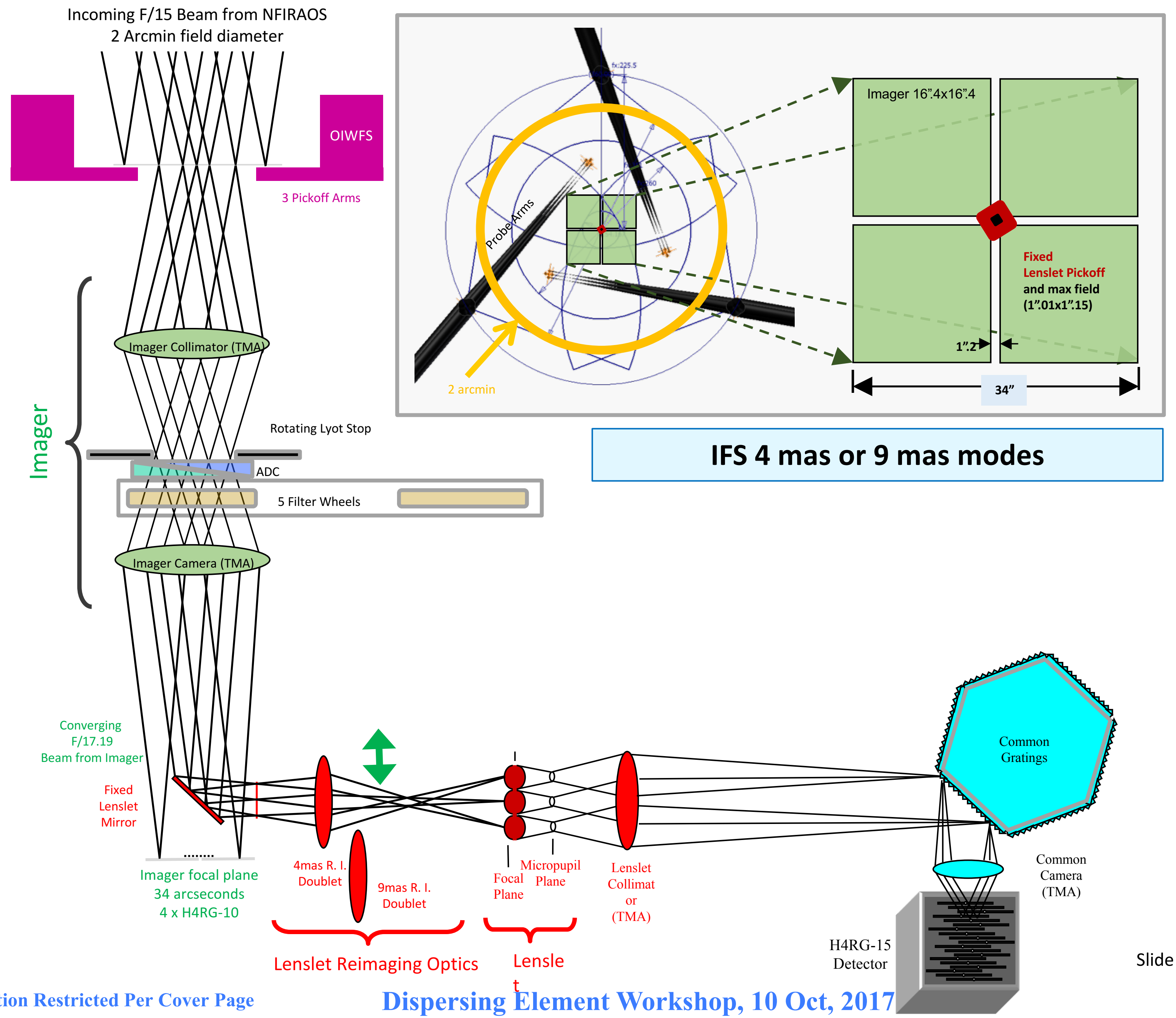
Three OIWFS Arms patrol 2 arcminute NFIRAOS output field.

Slide credit: Larkin

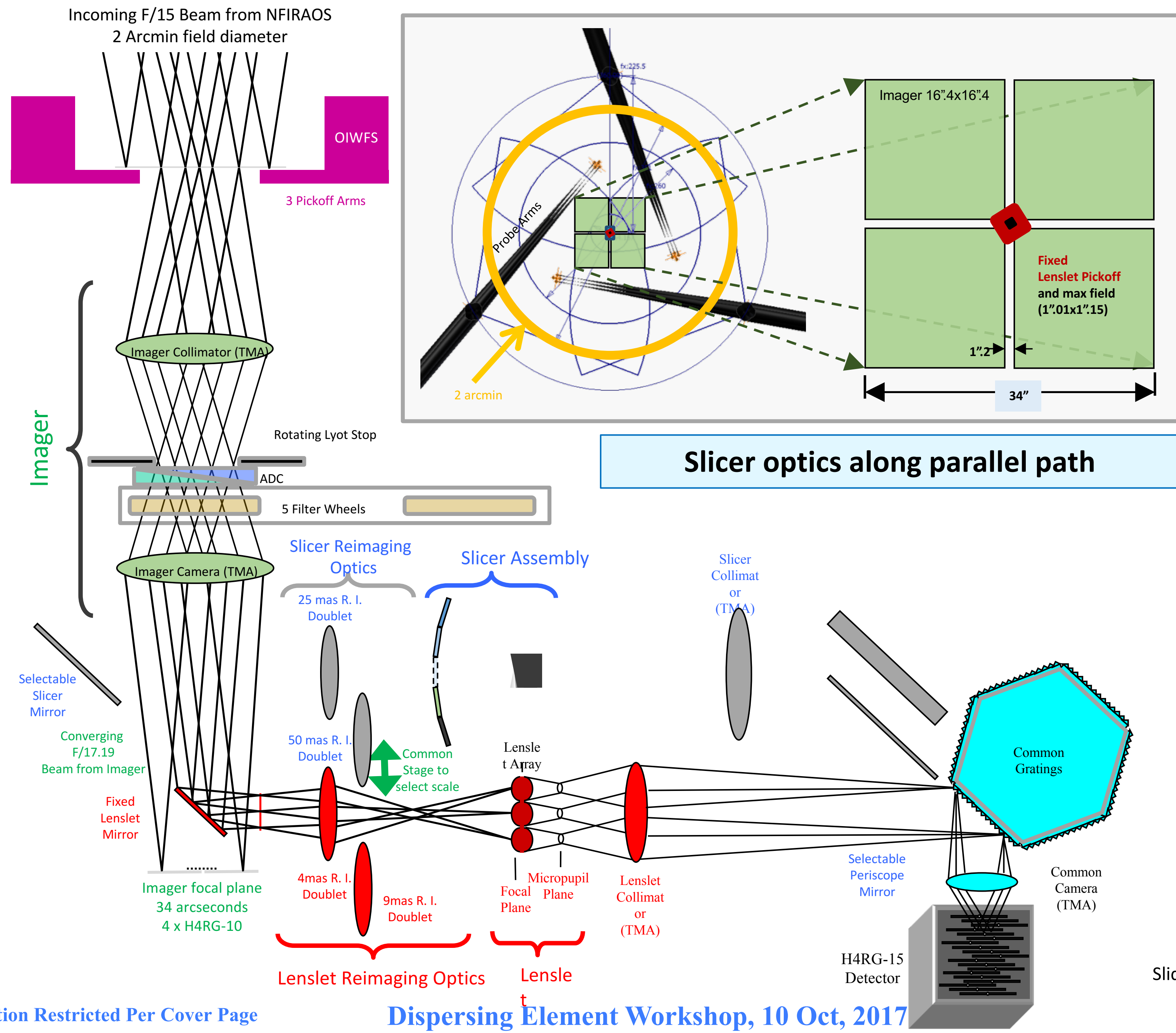


Imager with 4mas pixels
~34 arcsec field.

Slide credit: Larkin

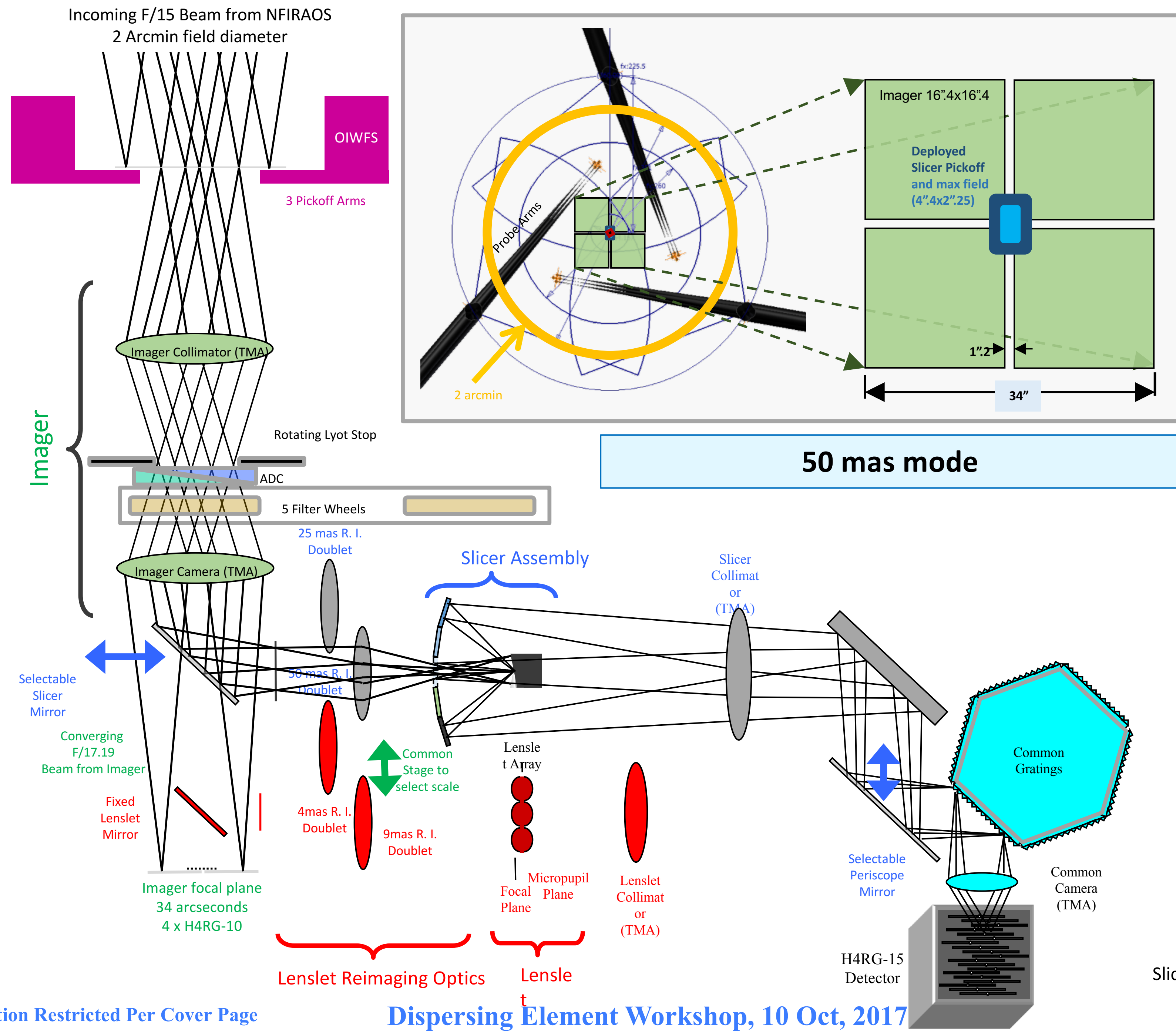


Slide credit: Larkin



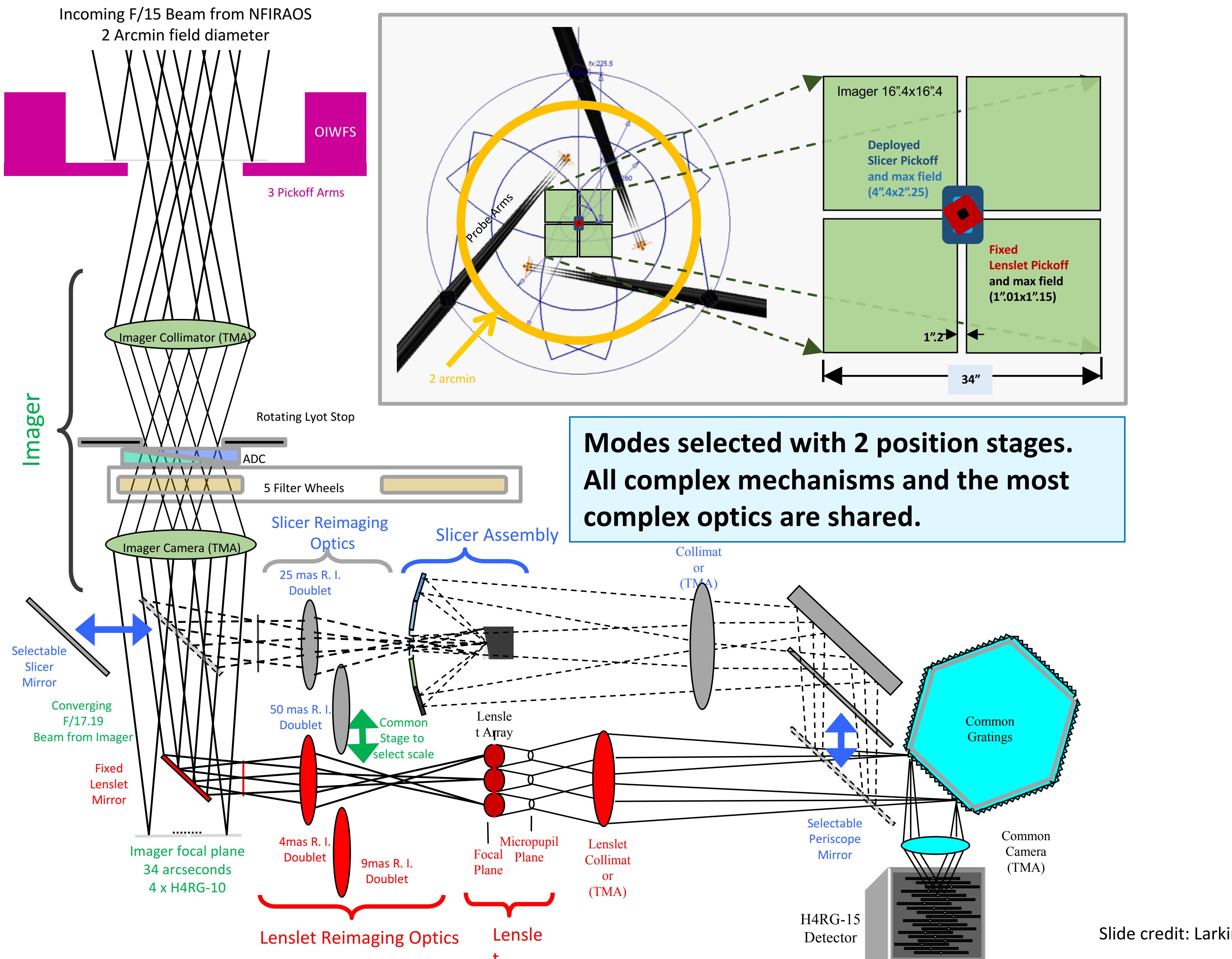
Slicer optics along parallel path

Slide credit: Larkin



50 mas mode

Slide credit: Larkin



Modes selected with 2 position stages. All complex mechanisms and the most complex optics are shared.

Slide credit: Larkin

IRIS Schedule

- Final Design phase: 2017 – 2020
  - Protyping IFS TMAs mounting and alignment
- IRIS has modular design
  - OIWFS built in Canada
  - Imager built in Japan
  - Slicer IFS built by CIT
  - Lenslet IFS built by UCLA
- Full integration phase is long – will be coupled with NFIRAOS at NRC Herzberg facility
- First-light 2027

WFOS Capabilities

- First-light, wide-field multi-object spectrograph.
- Moderate spectral resolution, R=5000
- Optical wavelengths 0.31 – 1.1 µm.
  - Simultaneous, full-resolution spectra over full bandpass
- Seeing-limited.
- Transient follow-up

WFOS Technical Team

University of California Observatories, Santa Cruz: Principal Investigator: **Kevin Bundy**, Project Manager: **Maureen Savage**, Matt Radovan, Renate Kupke, Drew Phillips, Nick MacDonald, Jerry Cabak, Zheng Cai, Kyle Westfall

National Astronomical Observatory, Japan: Satoshi Miyazaki, Shinobu Ozaki, Toshihiro Tsuzuki, Noboru Ebizuka, Yoshiyuki Obuchi

Indian Institute of Astrophysics: Sivarani Thirupathi, Sri Padmanaban Nadar (Sriram), Arun Surya, Devika Divakar

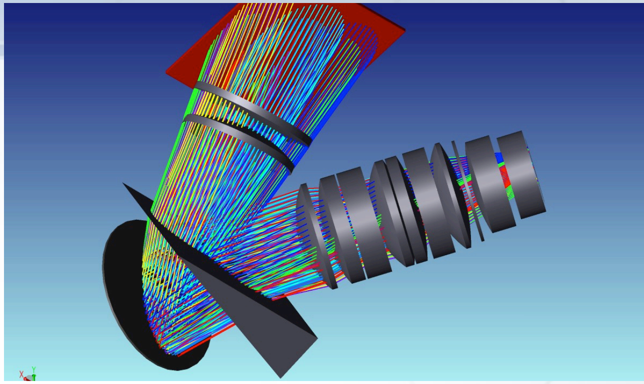
California Institute of Technology: Project Scientist: **Charles Steidel**, Richard Dekany, Jason Fucik, Roger Smith

Nanjing Institute of Astronomical Optics and Technology: Hangxin Ji, Zhongwen Hu

Lawrence Livermore National Laboratory: Brian Baumann

Thirty Meter Telescope: Luc Gilles

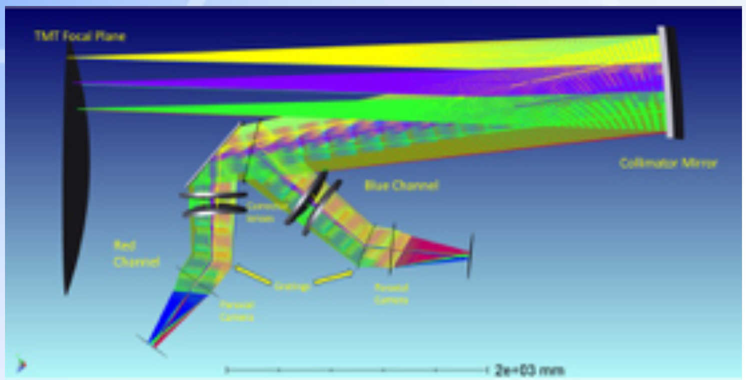
A Brief History of WFOS



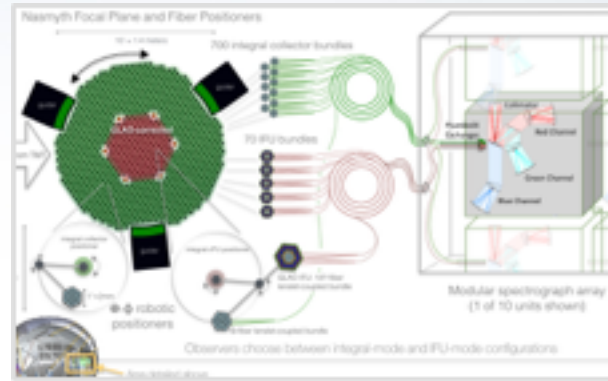
- 2008 – 2013 MOBIE
- 2013 – 2015 MOBIE mini-studies
  - Handover review identifies risks.
  - Mini-studies initiated to build team, address issues.
- 2016 – 2017 WFOS OMDR
  - PI Kevin Bundy and PM Maureen Savage join WFOS
  - OMDR Review May, 2017: baseline design is buildable but has significant risk in components, stray light.
- Aug 2017 – Mar 2018: Conceptual Design Phase 1
  - Trade study for down-select: Fiber-WFOS or Slicer WFOS?

The Future of WFOS

SLICERS?



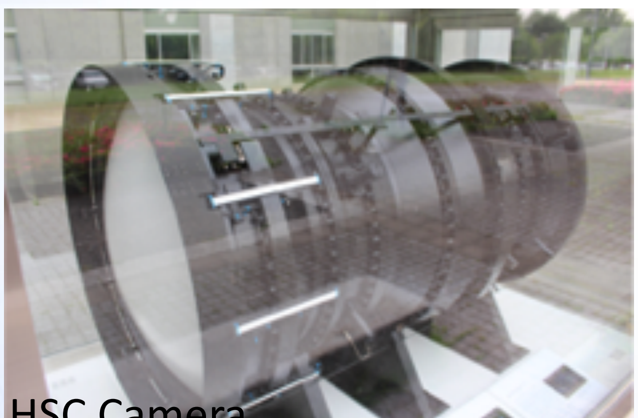
FIBERS?

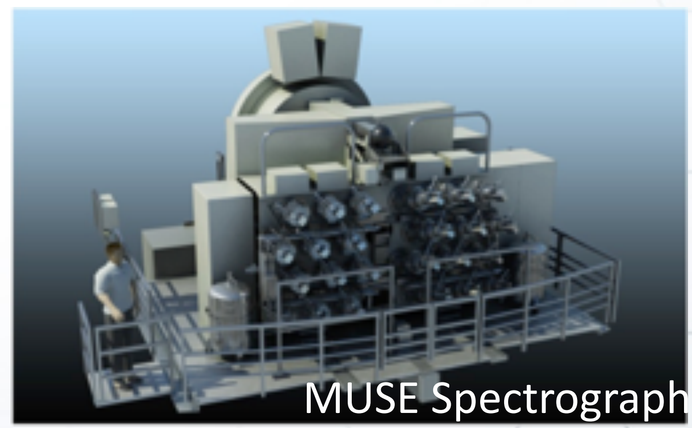


MONOLITHIC?

OR

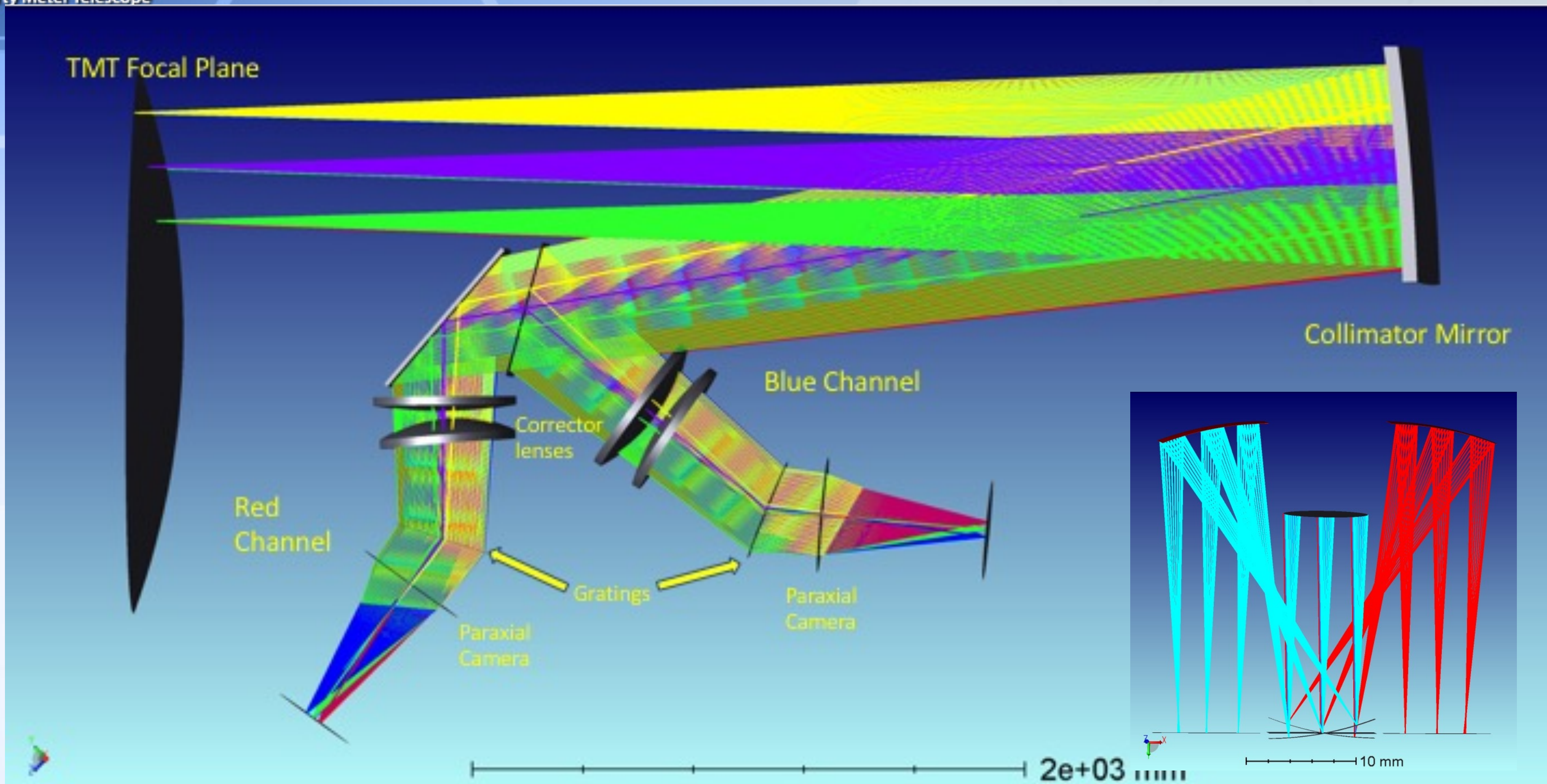
MODULAR?


HSC Camera


MUSE Spectrograph

Both concepts are being developed for a down-select in March, 2018

Slicer-WFOS



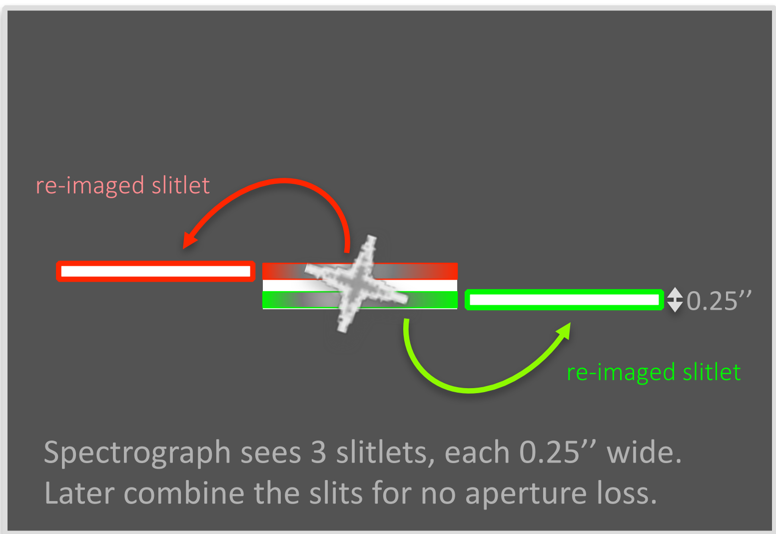
- 2-channels with single VPH grating
- Regular slit mask delivers R~1500
- R~5000 achieved with focal plane slicers
- 0.75" slit can be sliced into three and stacked side-by-side
- Similar trade in resolution vs. multiplex
- Packaging is much easier

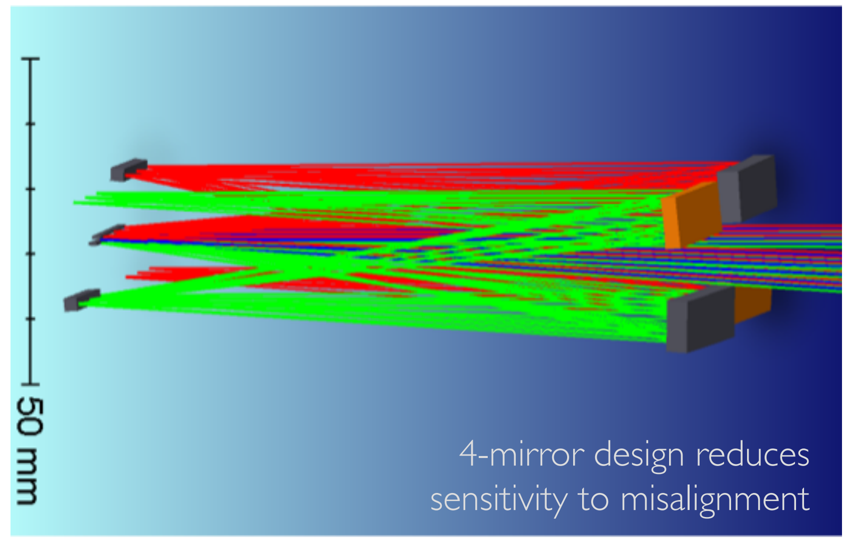
Slide credit: Bundy

Slicer-WFOS

Slicer design by NAOJ

One of 25 slicer modules for R~5000

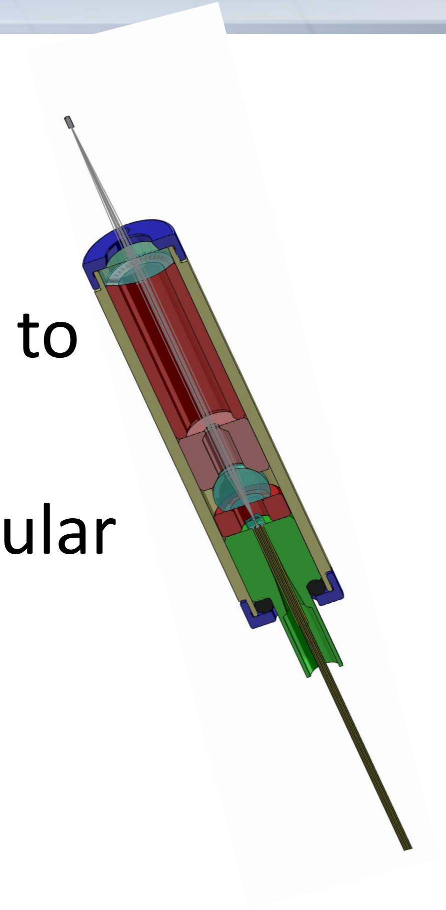


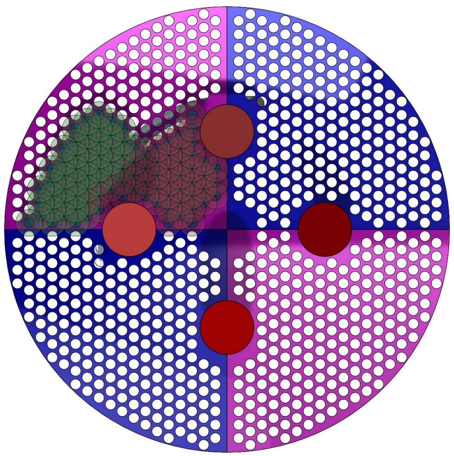


Slide credit: Bundy

Fiber WFOS

- 700 Collecting Units over a 10’ Field.
- Each collector delivers R=5000.
- 22” patrol field per collector well matched to science cases.
- Fibers feed a mounted array of 10-15 modular spectrographs.
- GLAO IFU-mode.

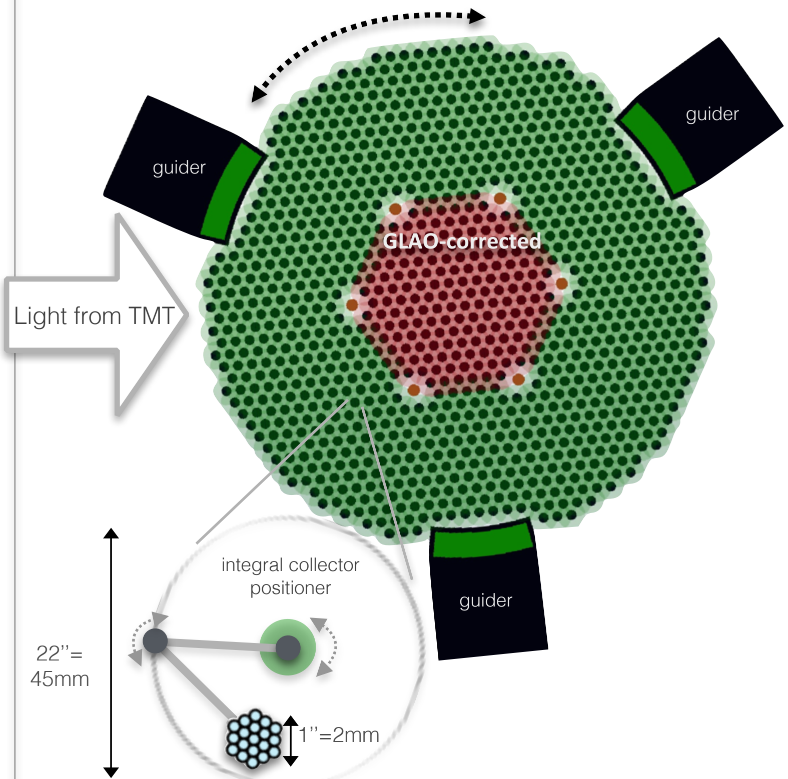


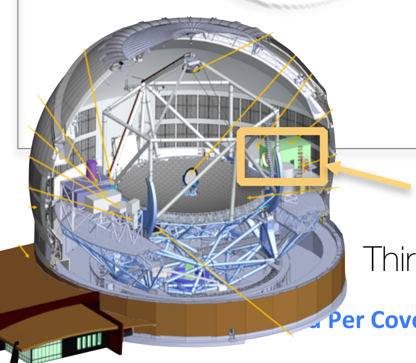


Fiber-WFOS Schematic Layout

Nasmyth Focal Plane and Fiber Positioners

10’ = 1.4 meters

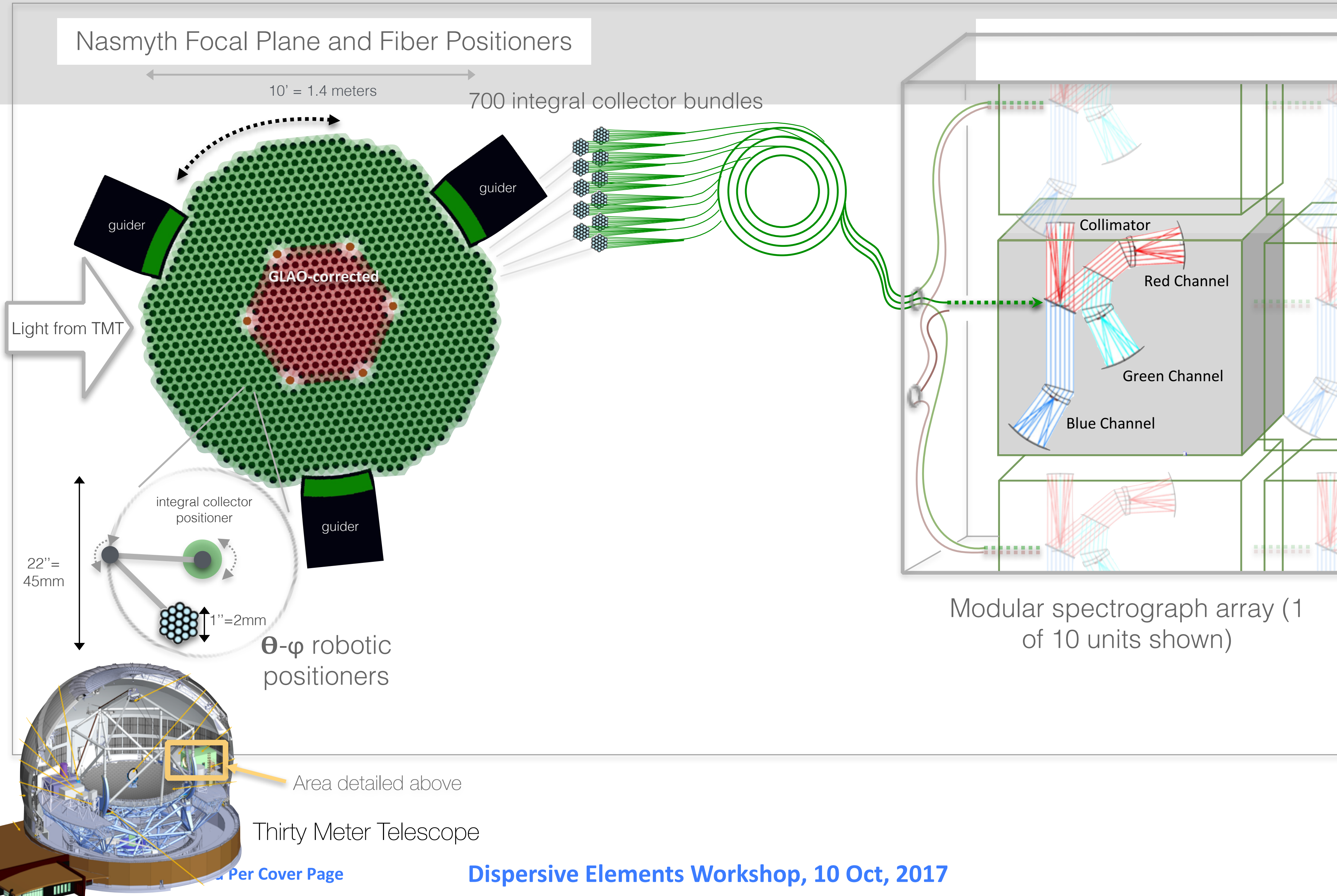




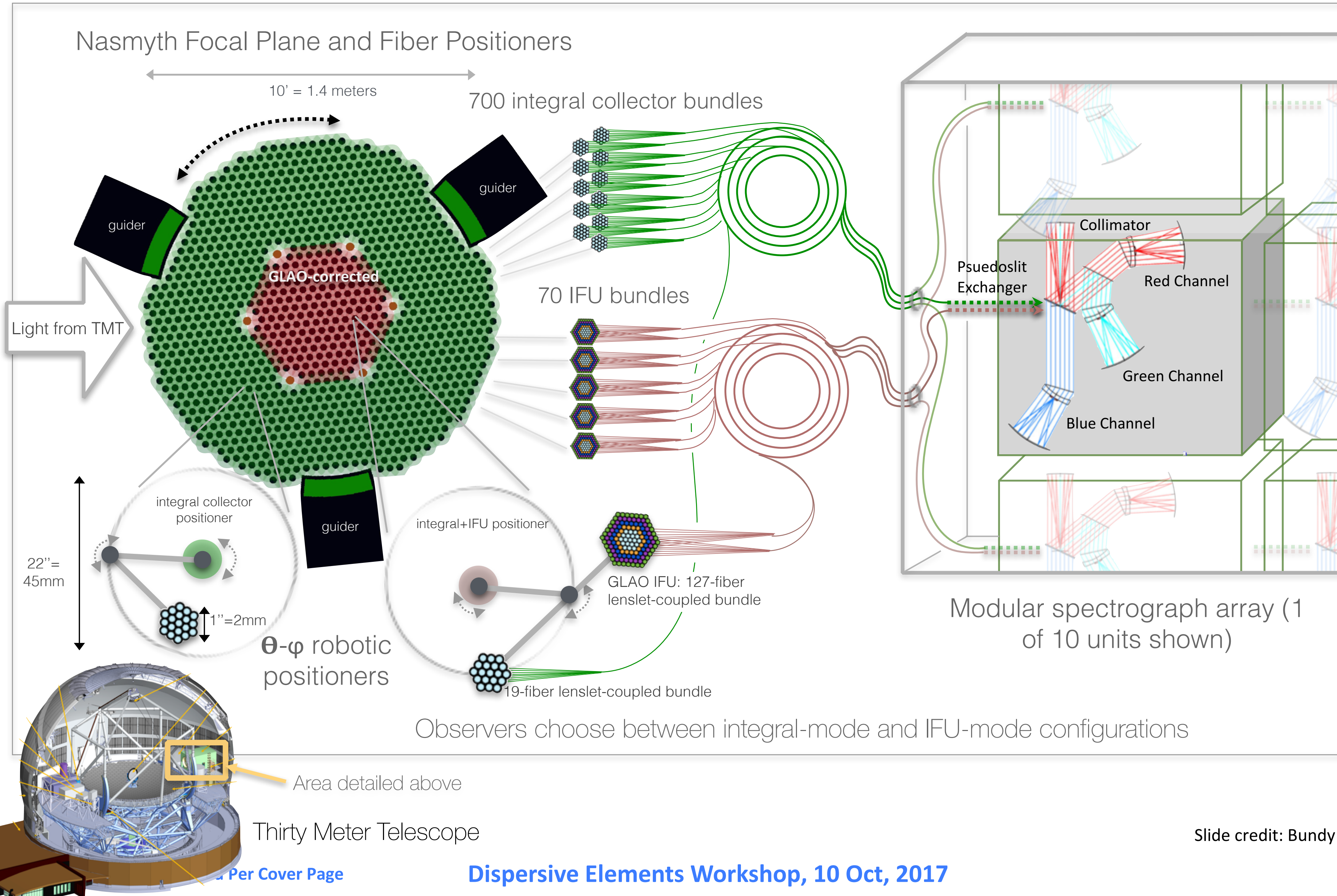
Area detailed above

Thirty Meter Telescope

Fiber-WFOS Schematic Layout



Fiber-WFOS Schematic Layout



Slide credit: Bundy

Per Cover Page

WFOS Downselect, March 2018

Specification	*Slicer-WFOS*	*Fiber-WFOS*
Multiplex (integral sources)	100 at R~1500 25 at R~5000	700 at R~5000
IFU Capability	may not be possible due to focal plane curvature; max would be ~7	70-100 IFUs with GLAO resolution
Field of view	25 $arcmin^2$	79 $arcmin^2$
GLAO Ready?	Yes	Yes
Cost	< $60M	< $60M
Major risks	Slicer module placement system	Cost pressure leads to reduced multiplex

33

Gratings for IRIS

- IRIS requires 20 gratings:
  - NIR bands J, H, K
  - Low Groove Densities
  - 100 mm pupil
- The IRIS team carried out a diffraction grating efficiency early on in the conceptual design phase:
  - Prototype IR VPH and Reflective Gratings were produced to specification by several companies and efficiency tests were performed at UCSD under direction of Shelly Wright

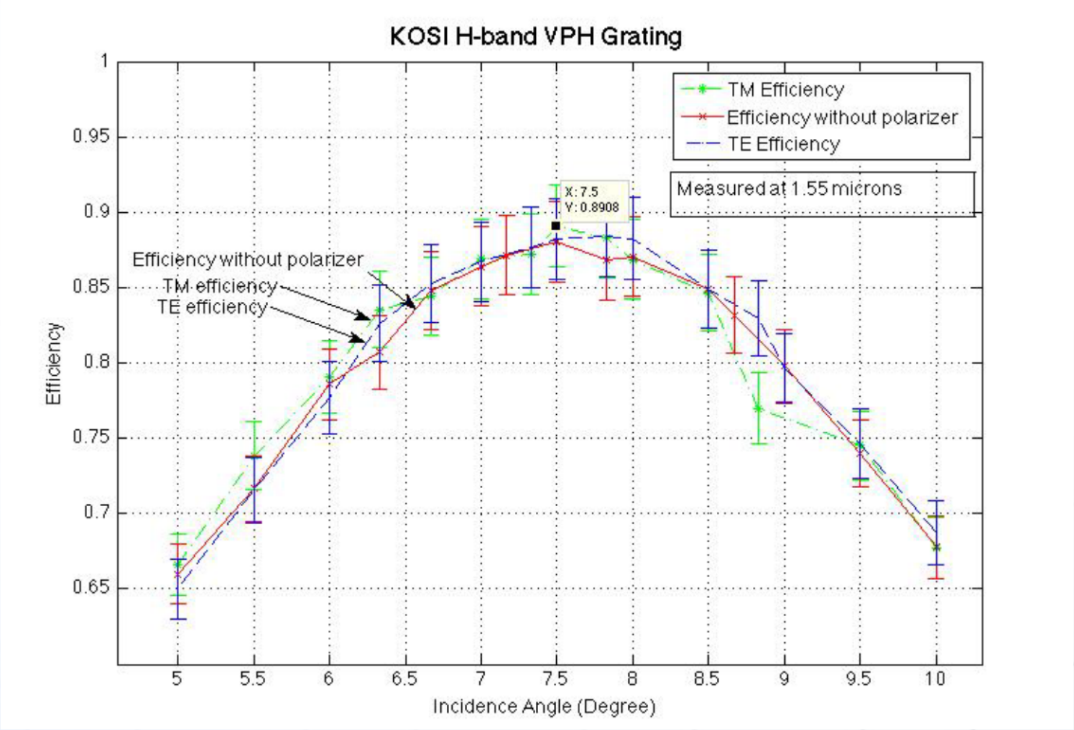
References:

Chen et. al, 2014, "The Infrared Imaging Spectrograph (IRIS) for TMT: Volume Phase Holographic Grating Performance Testing and Discussion", SPIE Proc, vol 9147

Meyer et. al, 2014, "The Infrared Imaging Spectrograph (IRIS) for TMT: Reflective ruled diffraction grating performance testing and discussion", SPIE Proc, vol 9147

Gratings for IRIS

- Results:
  - CIOMP Reflective Gratings (China) had the highest efficiency (85%) across bandpasses and less dependence on field angle.
  - VPH gratings' efficiencies showed a large dependence on incidence angle (23% drop in efficiency for angles equivalent to lenslet FOV).



Gratings for WFOS

- Requirements for WFOS VPHs:
  - Low line density for good efficiency across bandpass.
  - Transmission into the UV (0.31 µm).
    - Current adhesives drop off in transmission below 0.35 µm.
    - Possible to use NOA88 (UV adhesive)? Will need prototyping.
  - Large format (300+ mm pupil diameter).
- For fiber-WFOS modular spectrographs, we may need upwards of 40 gratings (10-15, 4-color-channel spectrographs)!

Gratings for TMT

- Confirmation of everything said yesterday:
  - Large format (> 300 mm)
  - High efficiency (> 80%)
  - Large wavelength range (0.31 – 2.4 µm)

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.