



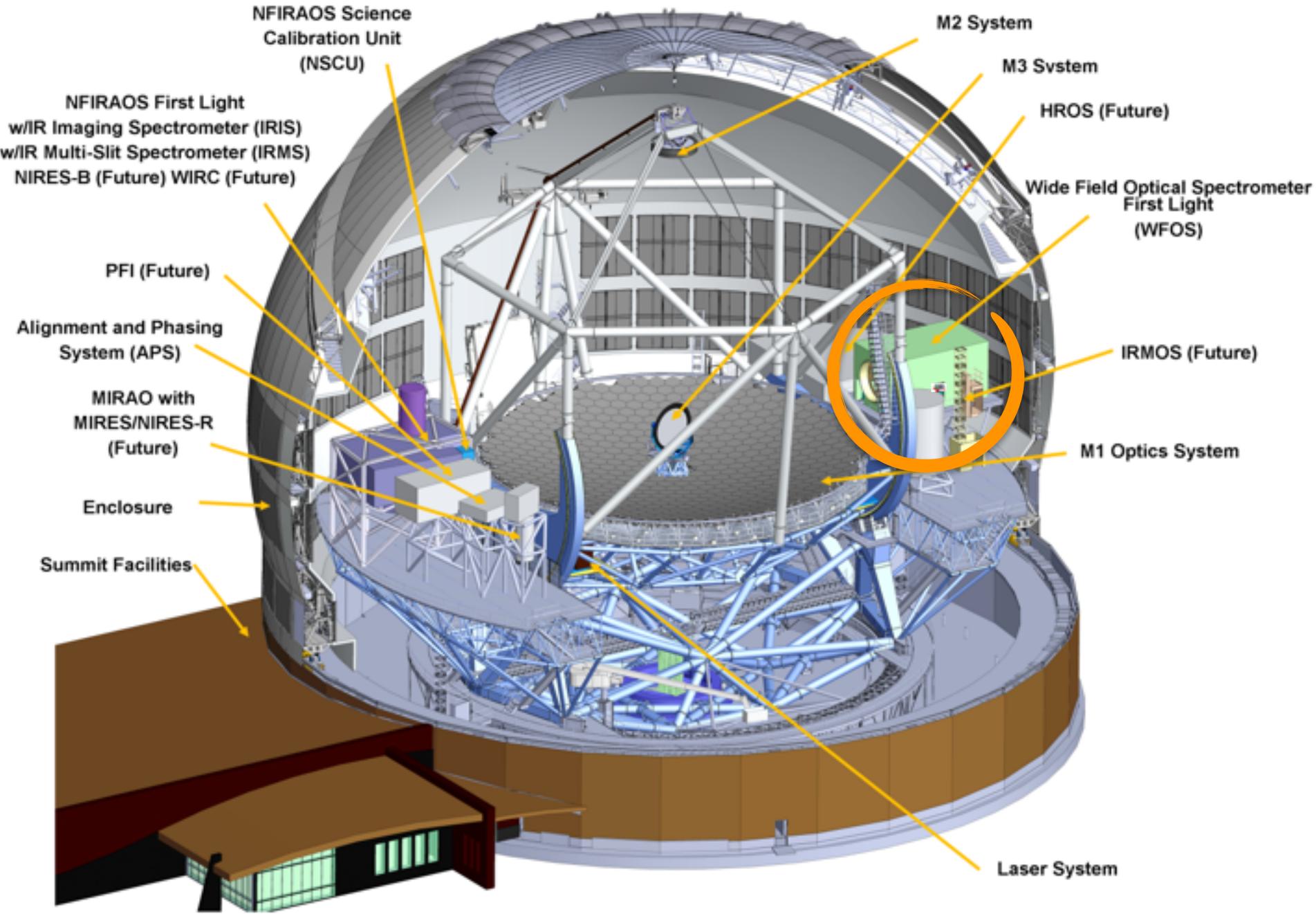
Dark Energy Science with TMT's Wide Field Optical Spectrograph

Kevin Bundy

Shedding Light on the
Dark Universe with ELTs
UCLA
April 2018

TMT Confidential

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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

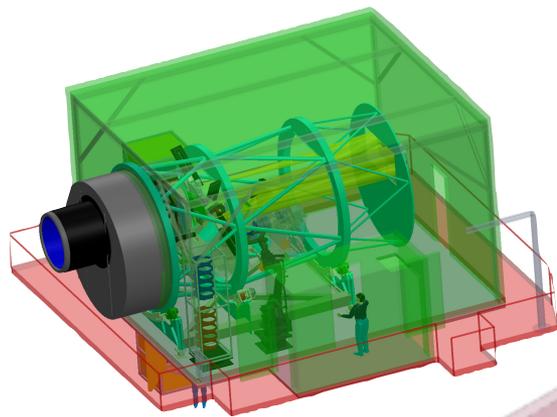
HROS (Future)

Wide Field Optical Spectrometer
First Light
(WFOS)

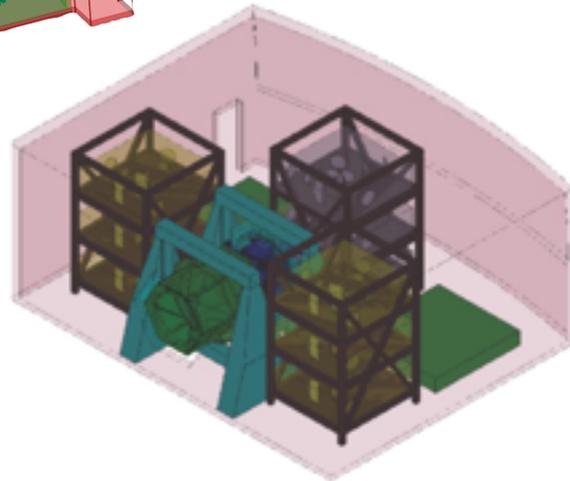
IRMOS (Future)

M1 Optics System

Laser System



Monolithic WFOS



Modular WFOS

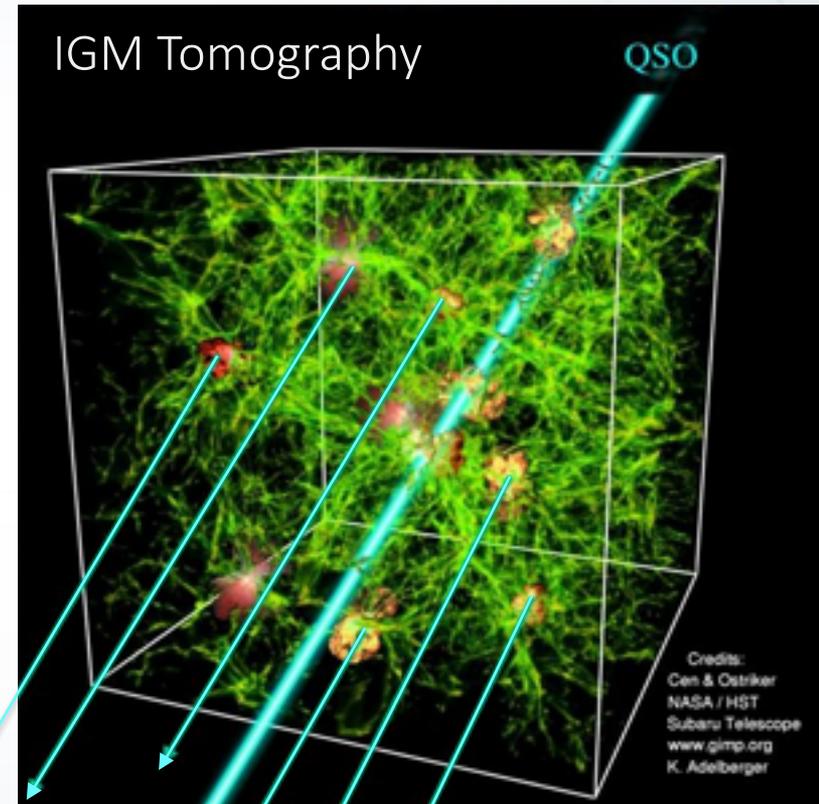
WFOS Wide-Field Optical Spectrograph



- ~\$55M project, UCO-led since 2008 when it was called MOBIE
- Partners include: NAOJ (Japan), IIA (India), NIAOT (China), Caltech
- Aug 2017 - Mar 2018: Conceptual Design Phase 1
- April 2018 down-select: Slitmask-WFOS vs. Fiber-WFOS

Top-level WFOS Capabilities

- Primarily multi-object survey instrument
- Also transient targets-of-opportunity
- R~5000 spectroscopy: 310–1000 nm
- R~1500 (and other) modes beneficial if multiplex or S/N can be traded
- GLAO ready



Studying proto-galaxies and the gas around them

WFOS Core Science

- How are proto-galaxies ($z=2-5$) shaped by their gaseous environment and how do they affect that environment?
- What is the origin and astrophysics of stellar populations in nearby galaxies?
- What are the key mechanisms that initiate the final stages of galaxy evolution?
- What is the nature of transient sources?

High- z galaxies and
Tomography

Stars

$z \sim 1$ galaxies and GLAO

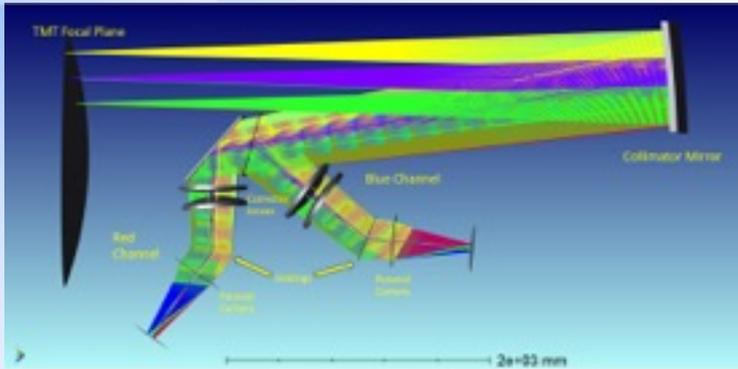
Transients

WFOS at a Crossroads...

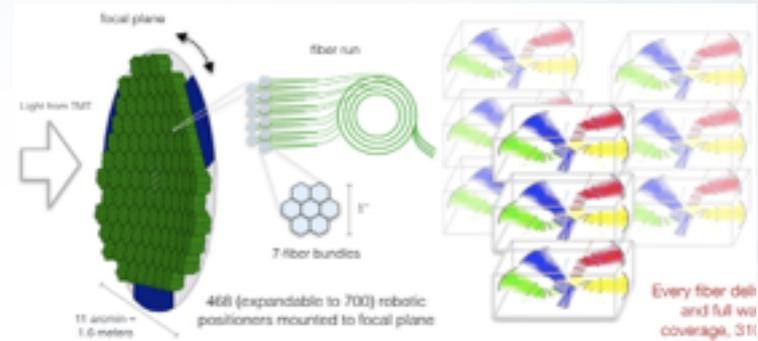
Slitmask-WFOS

or...

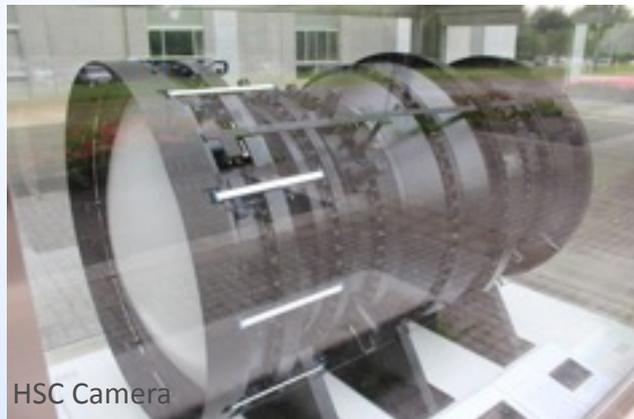
Fiber-WFOS



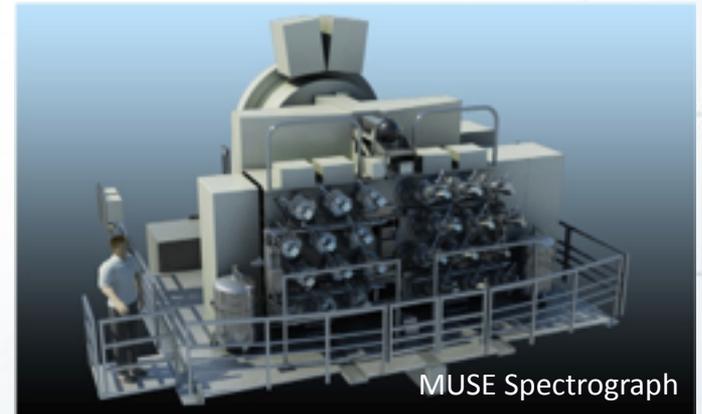
Monolithic



Modular

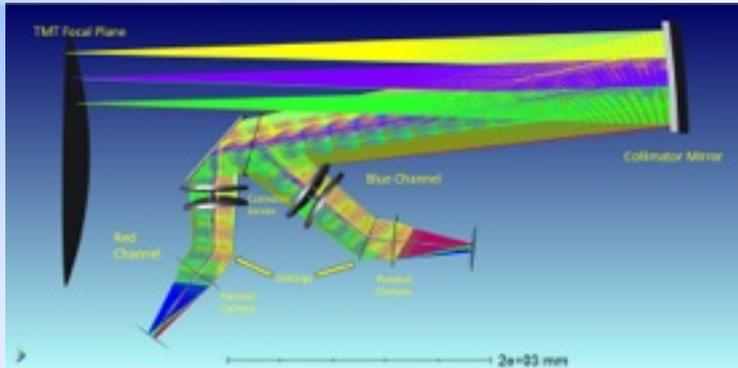


vs.



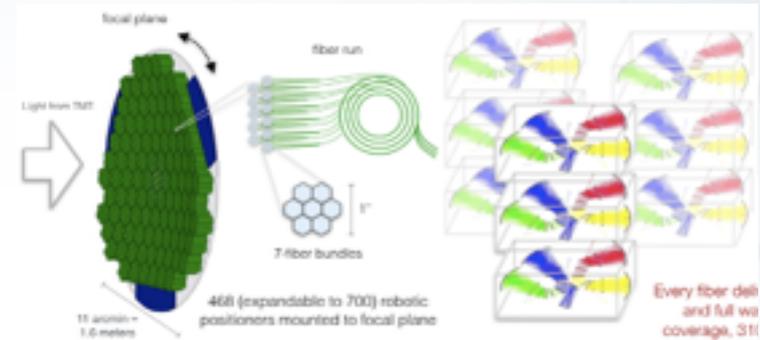
WFOS at a Crossroads...

Slitmask-WFOS



or...

Fiber-WFOS



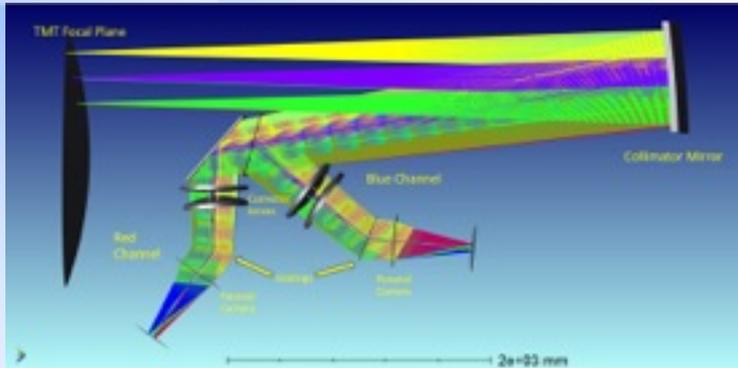
- User-specific spectral modes
- $R=15,000$ is feasible
- 10% greater throughput
- Direct imaging mode

- Factor ~ 10 greater survey speed
- Full instantaneous λ coverage
- Access 2D spatial information
- Dynamic target allocation

MUSE Spectrograph

WFOS at a Crossroads...

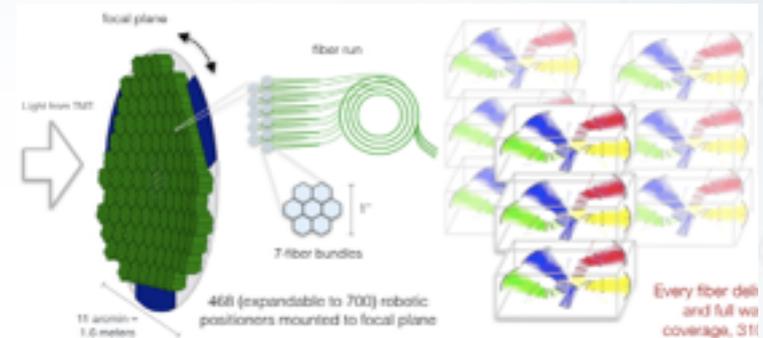
Slitmask-WFOS



- User-specific spectral modes
- $R=15,000$ is feasible
- 10% greater throughput
- Direct imaging mode

or...

Fiber-WFOS

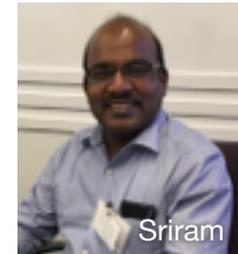


- Factor ~10 greater survey speed
- Full instantaneous λ coverage
- Access 2D spatial information
- Dynamic target allocation

MUSE Spectrograph

Fiber-WFOS: Schematic layout

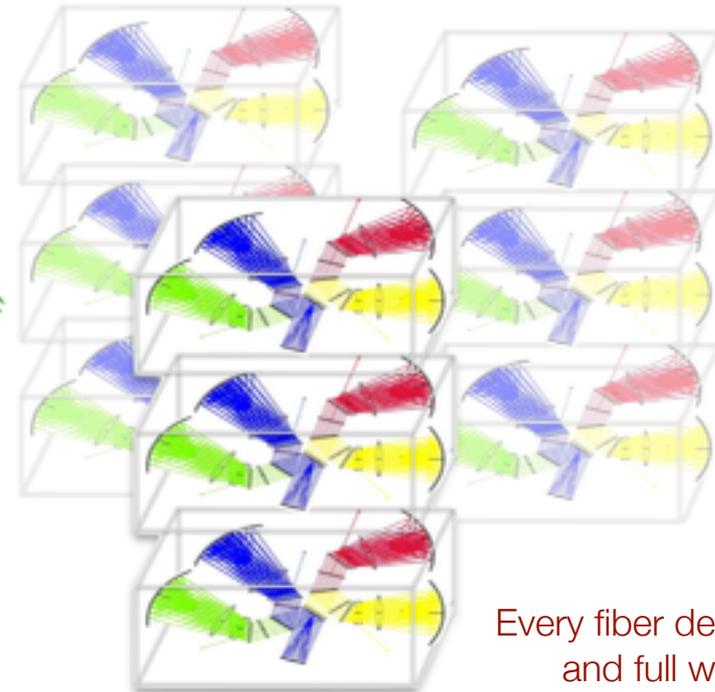
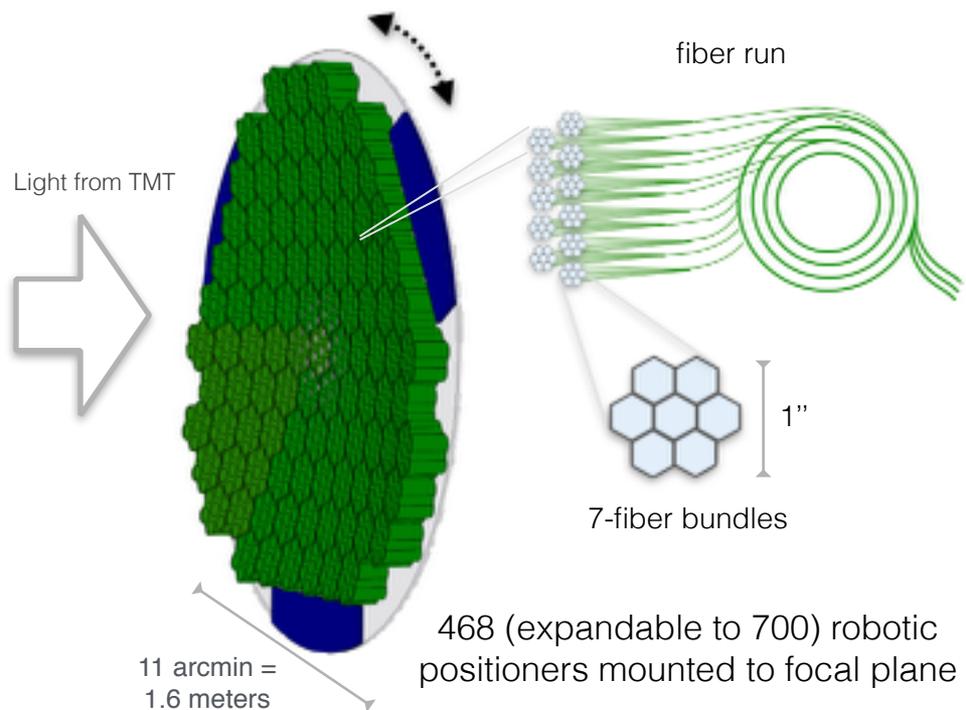
Design led by UCO



focal plane

fiber run

Light from TMT

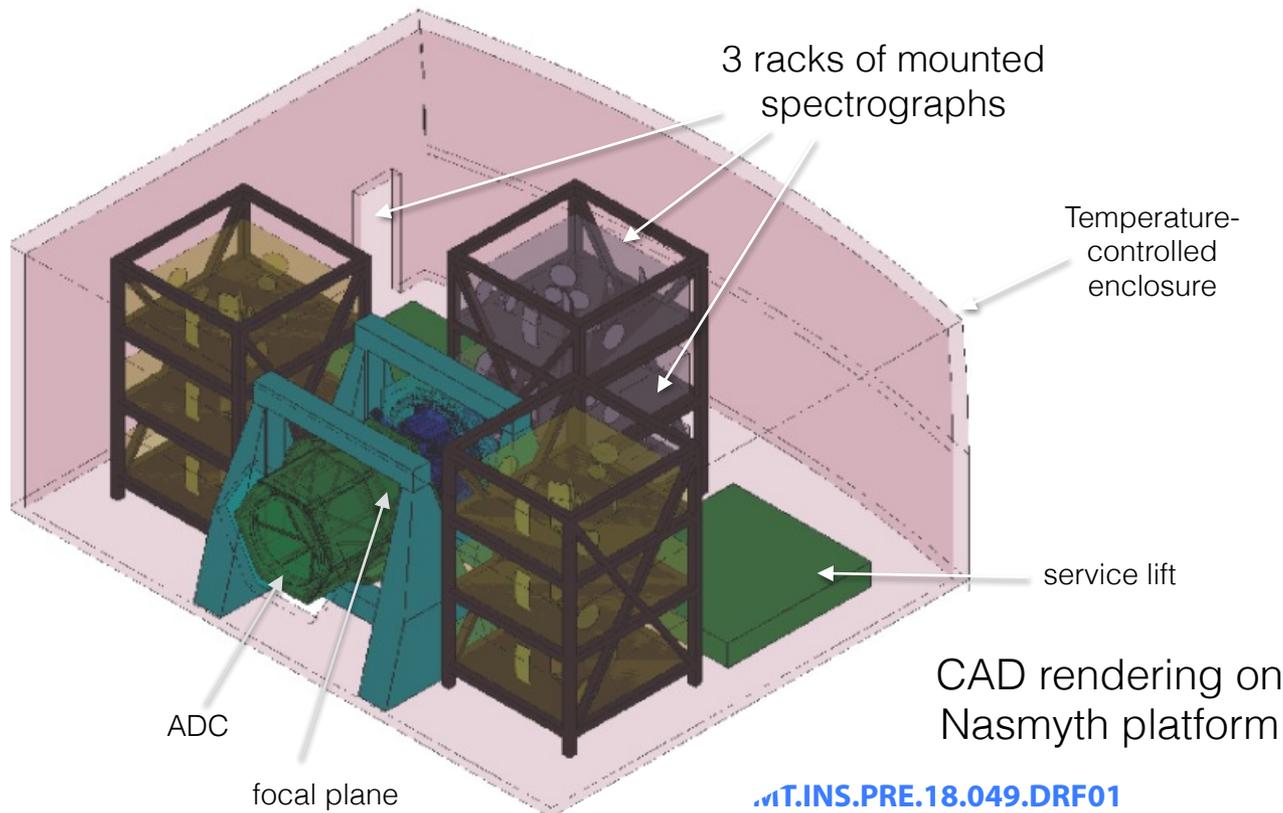


Array of 6 (9) spectrographs, each with 4 wavelength channels

Every fiber delivers R~5000 and full wavelength coverage, 310-1000 nm.

Fiber-WFOS Structure Maintains Spectrograph Stability

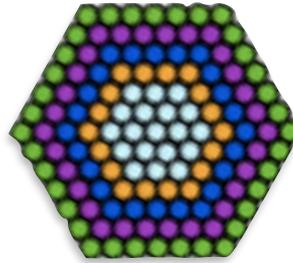
Design led by UCO



- Fiber-WFOS spectrographs experience no flexure
- Short fiber cable run (for good UV throughput)

Fiber-WFOS: High-Multiplex Integral Field Units (IFUs)

Fiber-WFOS IFU Mode

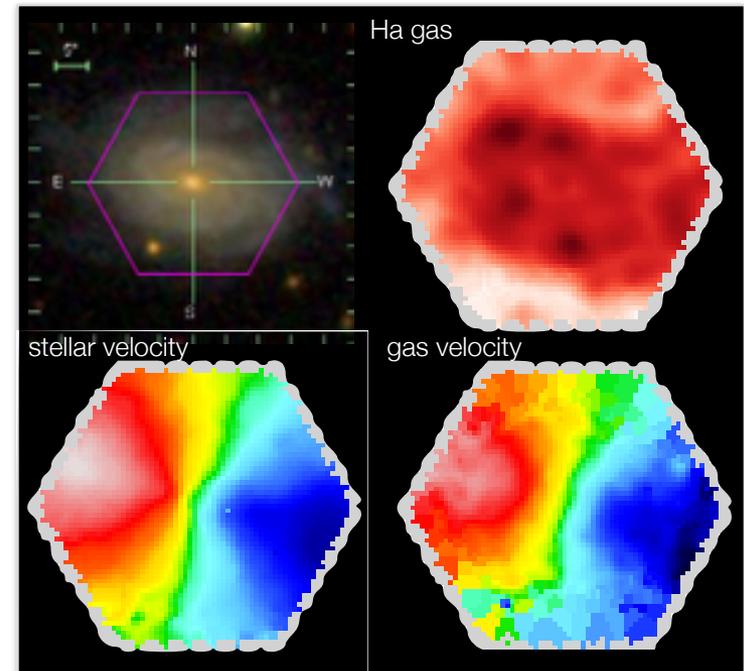


30-40 large IFUs:

- 4" diameter at 0.3" resolution (seeing-lim.)
- 1" diameter at 0.15" resolution (GLAO)

Comprehensive view of $z \sim 1$ galaxies and
their assembly histories

(Resolved stellar components only possible with 30m aperture)



Fiber-WFOS and Dark Energy

- LSST Photo-z training
- Kinematic Weak Lensing

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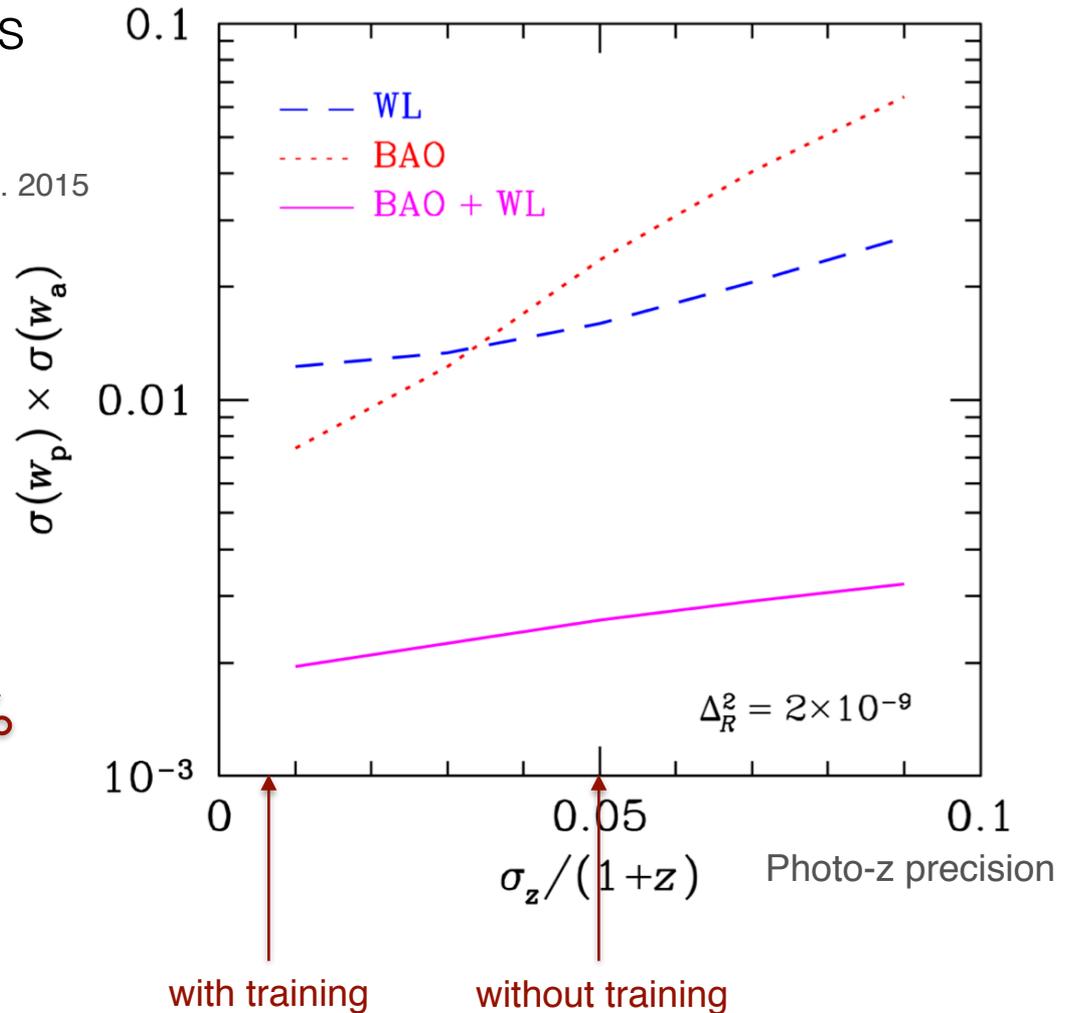
Enhancing Dark Energy Probes

LSST Dark Energy Requires Photo-z training

Newman et al. 2015

Errors on dark energy equation of state parameters

Photo-z training offers 50% gains on billion dollar experiments



LSST Photo-z Training Requirements

Newman et al. 2015

- 30,000 spectroscopic redshifts
- 75% or 90% redshift success
- magnitude limited to $i = 25.3$ AB
- 15 fields of 0.09 deg^2 (324 arcmin^2) each
- Excellent “piggy-backing” program

Implications for Fiber-WFOS:

- Ideal targeting density is $\sim 6 \text{ arcmin}^{-2}$.
- Fiber-WFOS is field-of-view limited
- For $R=5'$, required multiplex = 700

Fiber-WFOS in 2030: Full-depth LSST training

Enhancing Dark Energy Probes

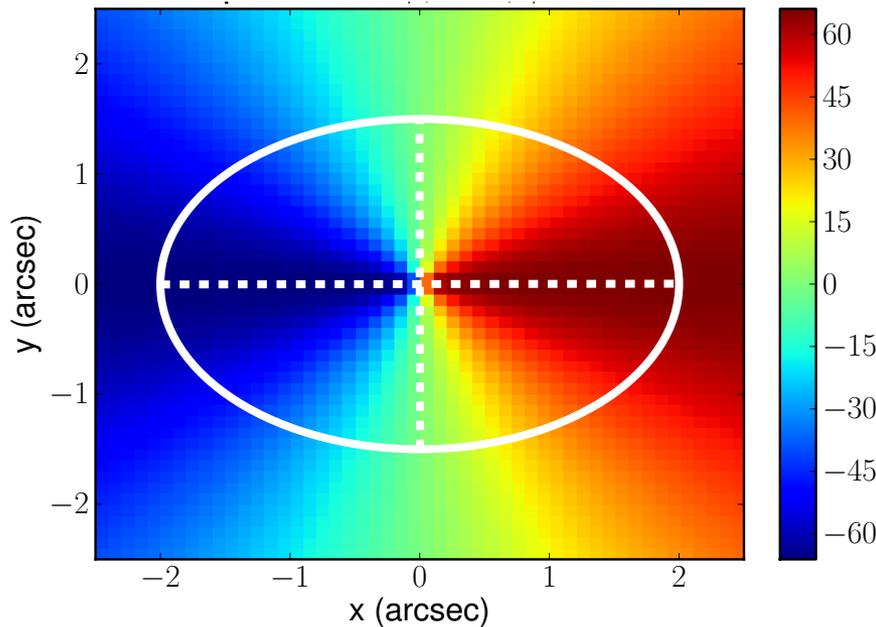
Photo-z training: fiber-WFOS is highly competitive

<i>Instrument</i>	<i>Survey time: LSST depth, 75% complete</i>	<i>Survey time: LSST depth, 90% complete</i>
<i>Keck / DEIMOS</i>	<i>10.2 years</i>	<i>64 years</i>
<i>Subaru / PFS</i>	<i>1.1 years</i> \$36M	<i>6.9 years</i>
<i>GMT MANIFEST (w GMACS)</i>	<i>5-9 months</i>	<i>2.6-4.7 years</i>
<i>fiber-WFOS (R=5')</i>	<i>50 nights</i> \$14M	<i>10 months</i>

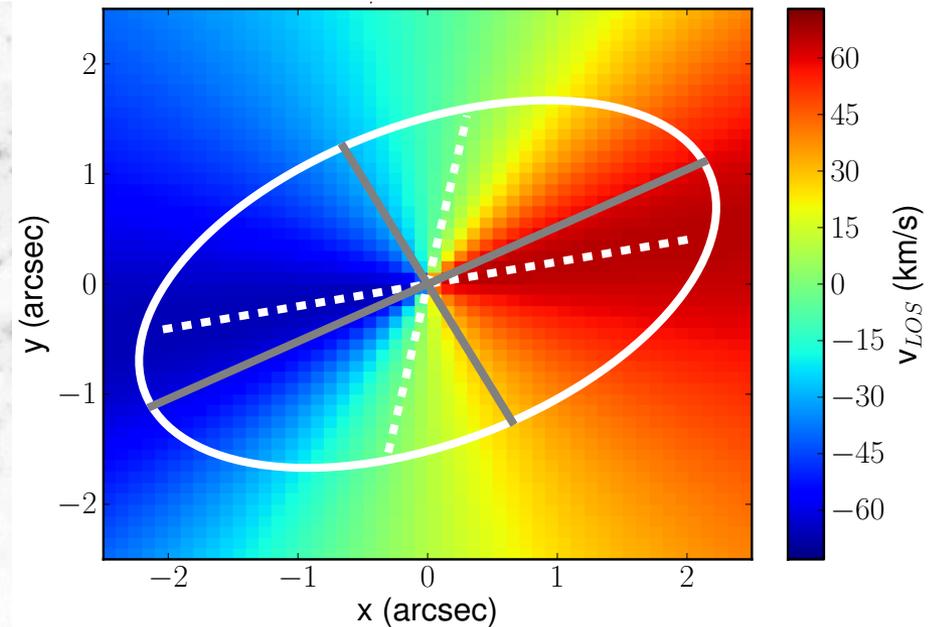
Courtesy of Jeff Newman

Kinematic Weak Lensing

Idealized galaxy velocity field



Weak-lensing shear applied

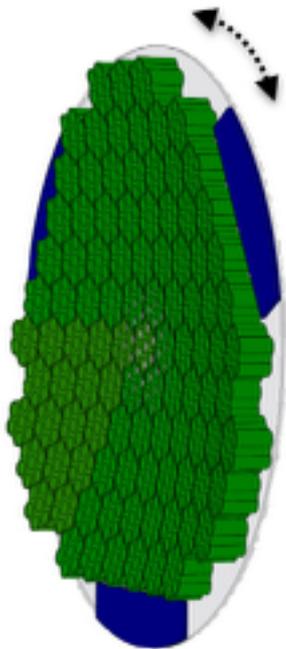


Lensing distorts and misaligns kinematic and photometric axes

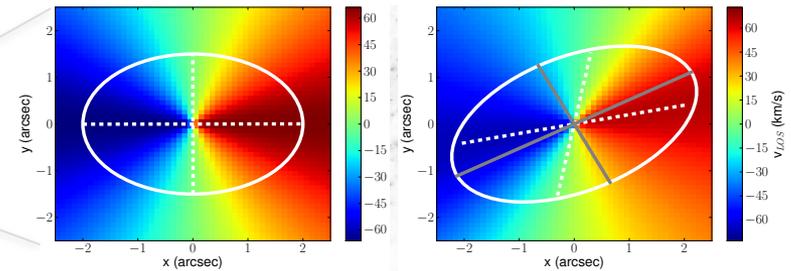
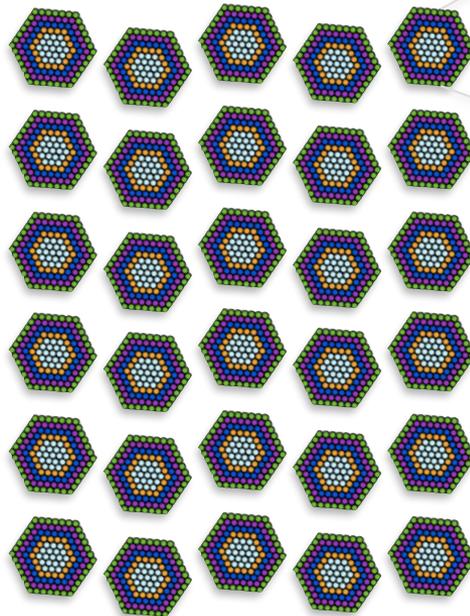
Per-galaxy weak-lensing S/N is ~ 10 times greater than shear

courtesy Eric Huff

Fiber-WFOS in IFU Mode



30-40 IFUs per field



Applications

- Filler program complementary to shear imaging surveys (study needed?)
- Tests shear systematics: photo-z, intrinsic alignment, shear calibration, PSF correction
- Improve mass estimates of individual clusters (cluster cosmology)

Further study needed...!

WFOS Timeline

- 2017-2021: Design Completion
- 2022-2025: Fabrication
- 2025-2026: Integration & Testing
- 2027: Delivery
- 2028: Commissioning
- 2029—: Science programs



Stay tuned to meet the new WFOS soon!

END