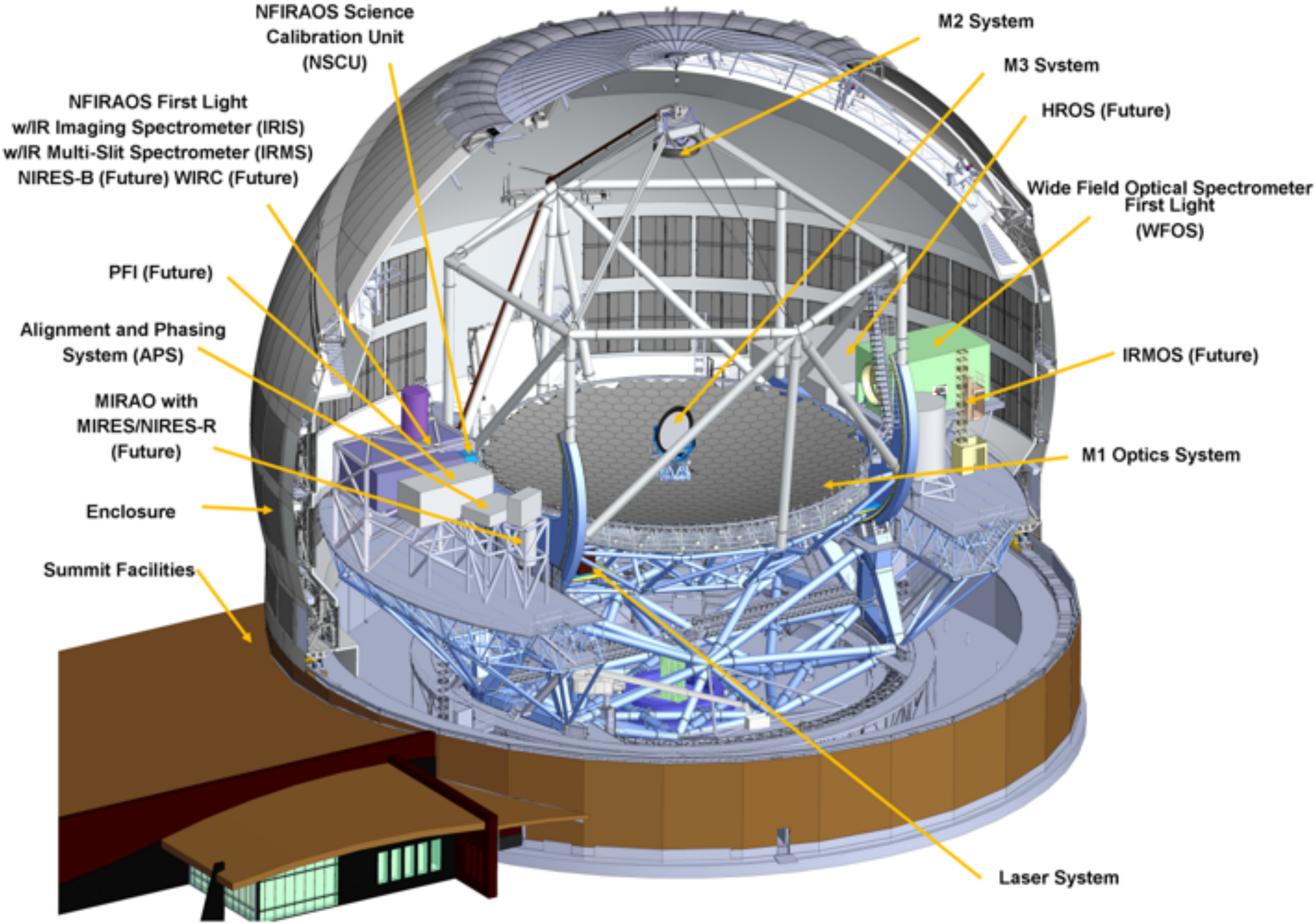
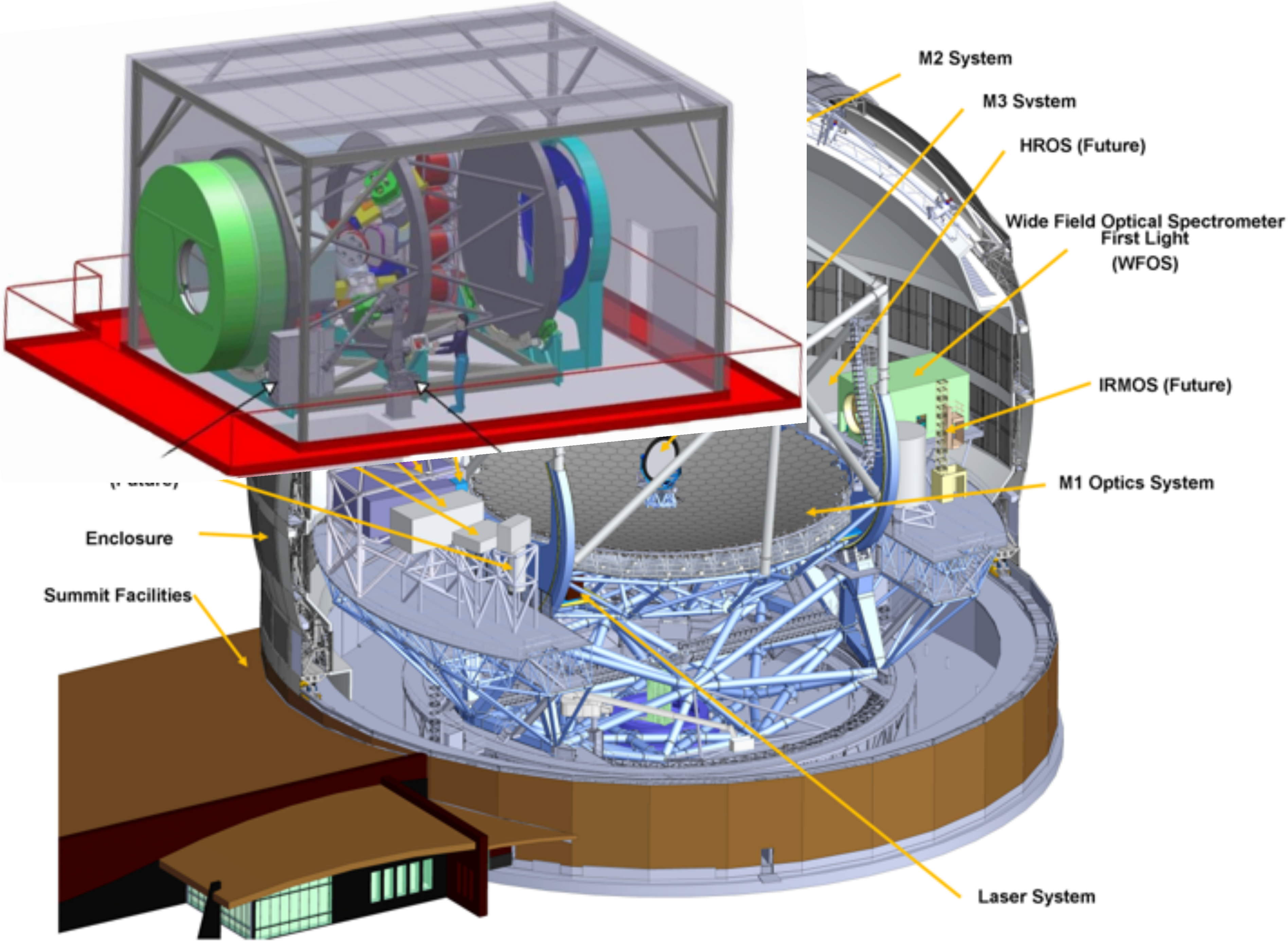
Wide-Field Optical Spectrograph (WFOS) Down-select Status Update

Kevin Bundy

CATAC remote meeting
December 2017



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


M2 System
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(WFOS)
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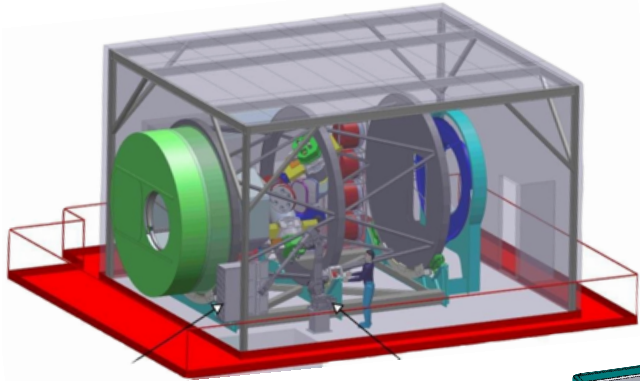
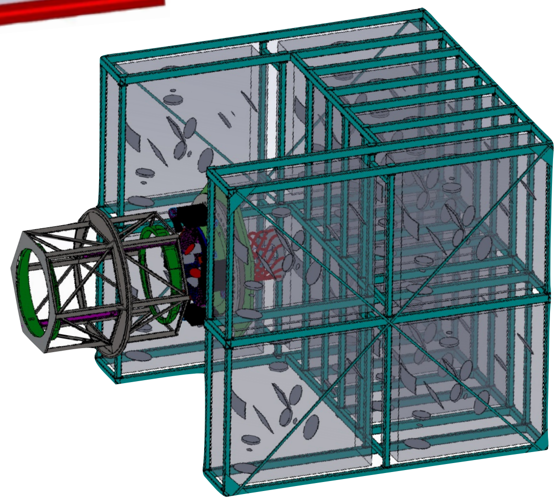
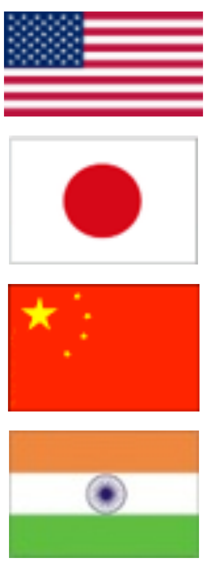


Slicer-WFOS

WFOS
Wide-Field Optical Spectrograph



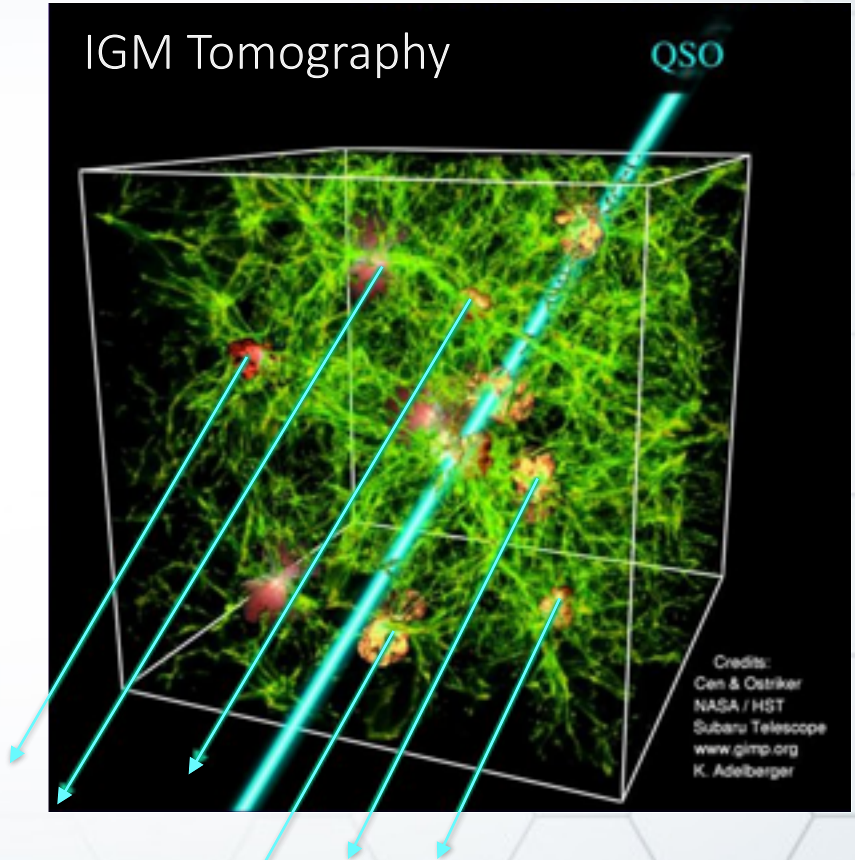
Fiber-WFOS



- UCO led since 2008 when it was called MOBIE
- 2016 - 2017: OMDR Opto-Mechanical Design Requirements phase
  - 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), Caltech

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?

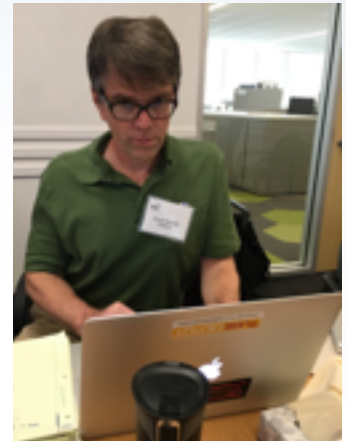
z~1 galaxies and GLAO

- What is the nature of transient sources?

Transients

OMDR Review Outcome

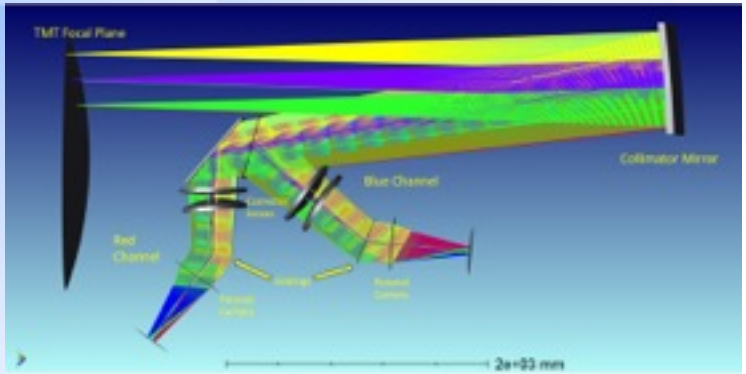


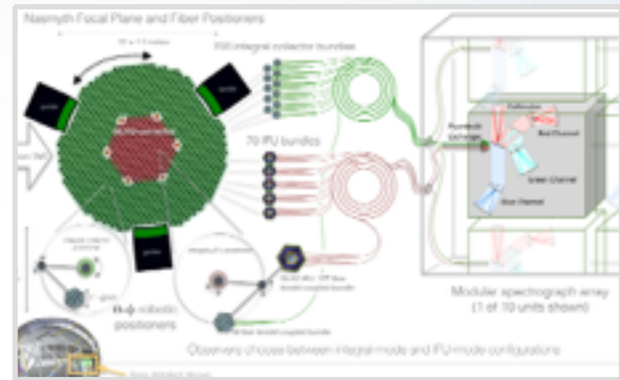




- 2-day OMDR review plus 1-day team meeting: May 2-4, 2017 in Pasadena
- Comprehensive snapshot of the OMDR Baseline design
- Result: while it may be feasible, the OMDR Baseline had too many risks and headaches for somewhat marginal performance.
- Motivates study of alternative concepts: Fiber-WFOS and Slicer-WFOS

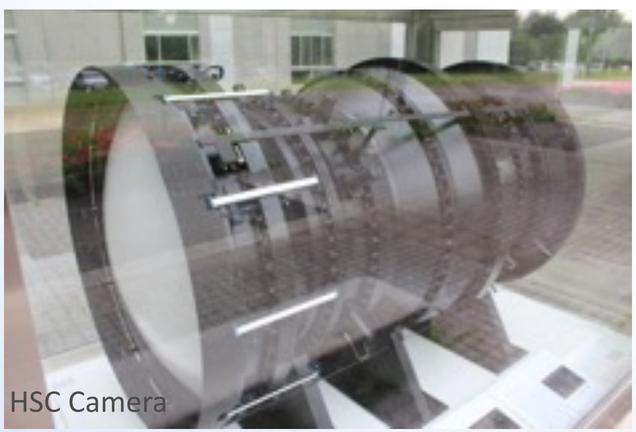
WFOS at a Crossroads…

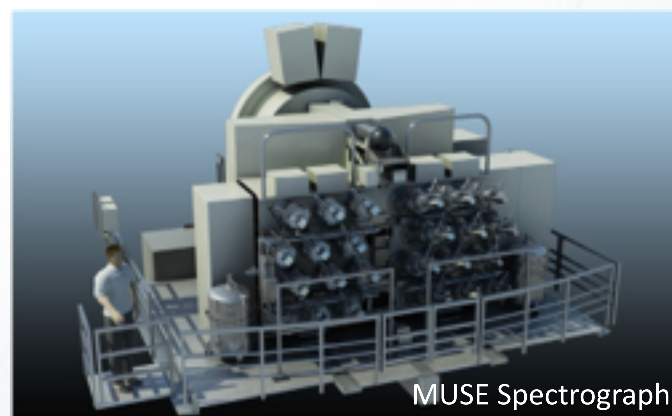
Slicer-WFOS or… Fiber-WFOS





Monolithic or… Modular?


HSC Camera


MUSE Spectrograph

The WFOS team is working hard on a down-selection by Mar 2018

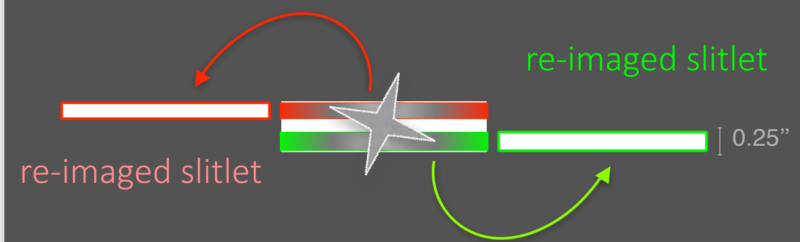
Slicer-WFOS

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

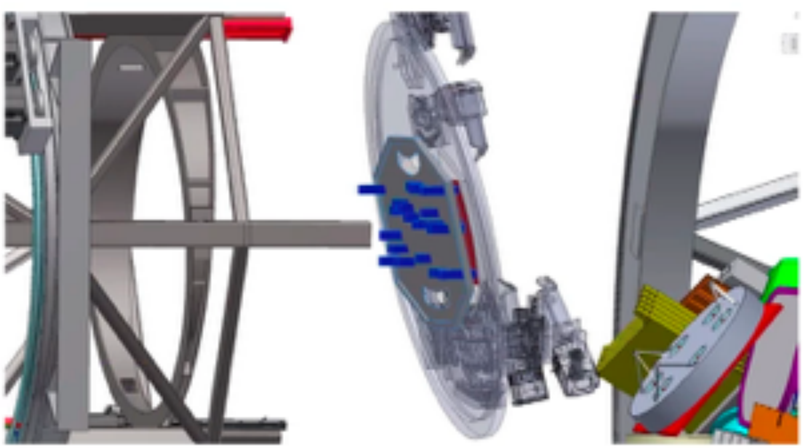


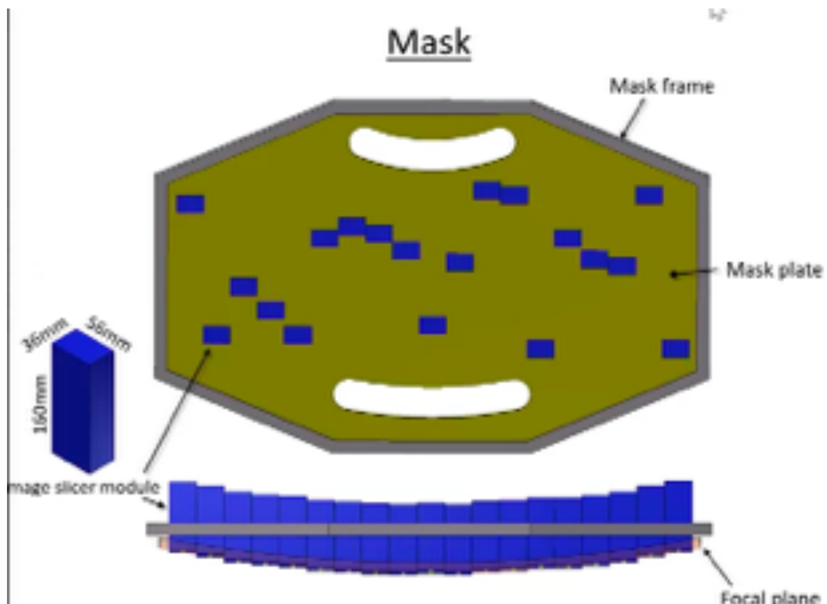
Spectrograph sees 3 slitlets, each 0.25” wide.
Later combine the slits for no aperture loss.

Slicer-WFOS

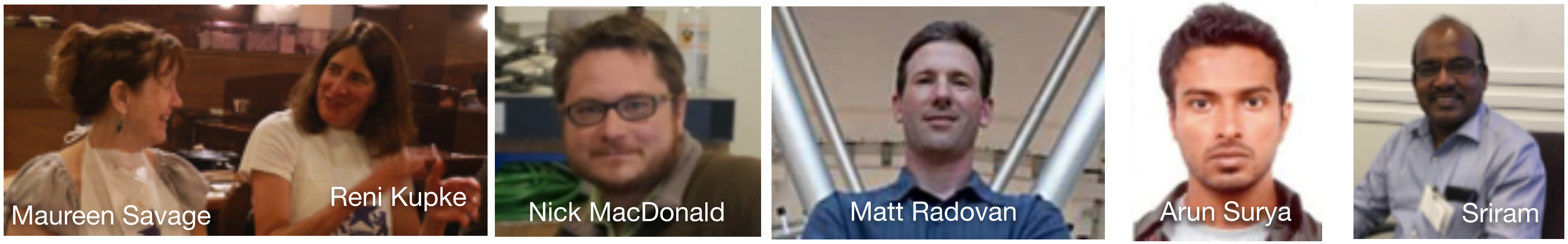
Slicer design by NAOJ

Major challenge is mounting in the focal plane and mask exchange.



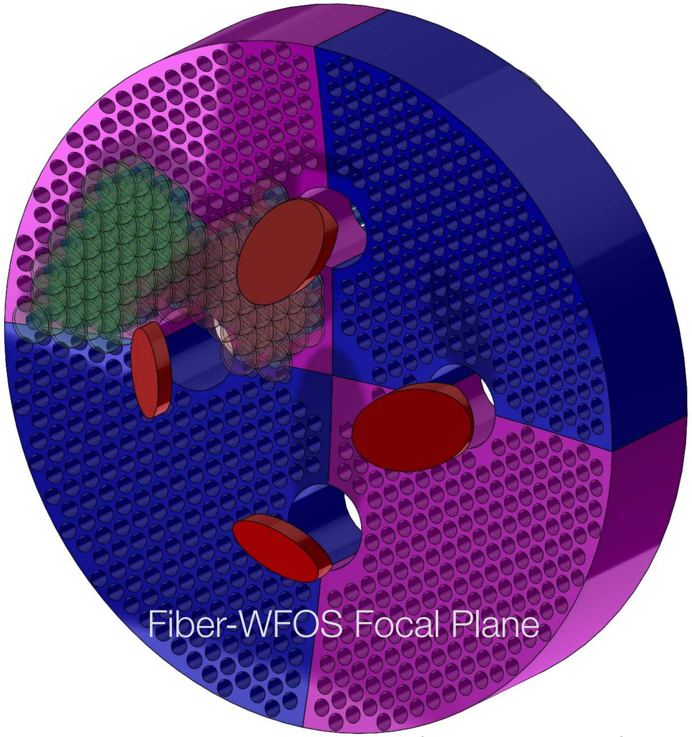


Fiber-WFOS



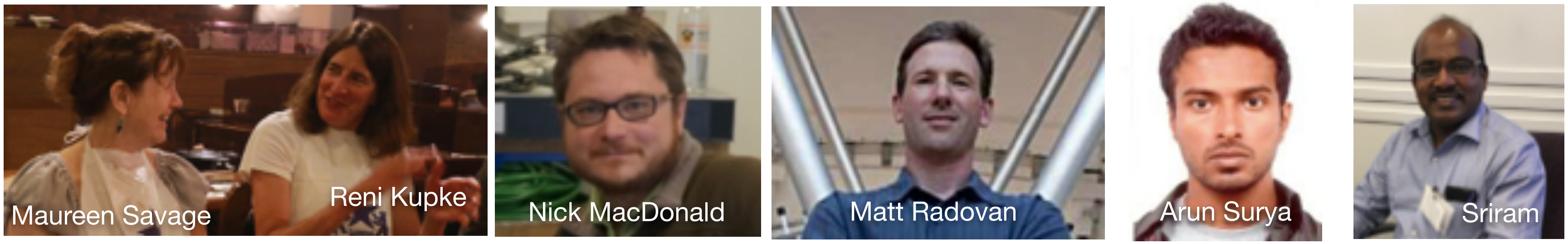
Fiber-WFOS Specs

- **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 7 spectrographs
- **~40 Deployed IFUs** in GLAO mode



(Nick MacDonald)

Fiber-WFOS



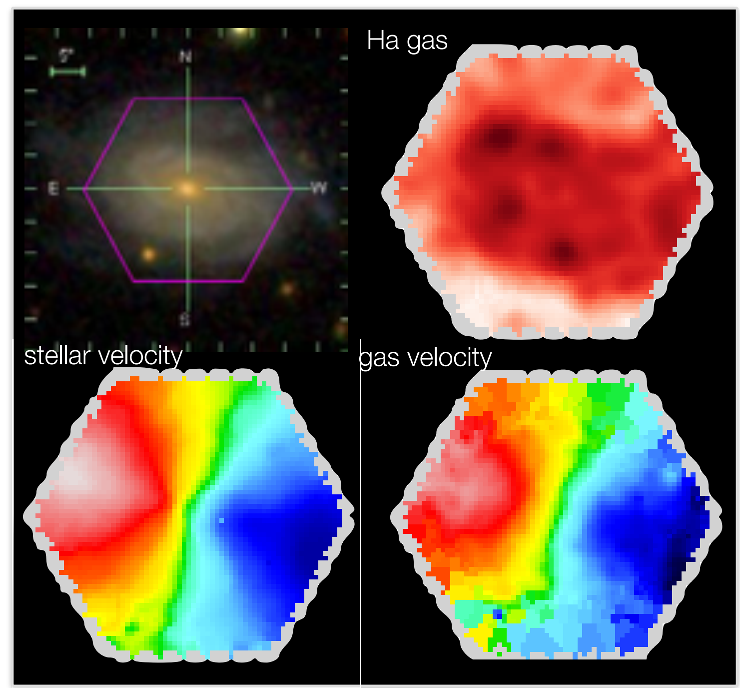
GLAO IFU Mode

40 IFUs sampled at 0.15” resolution

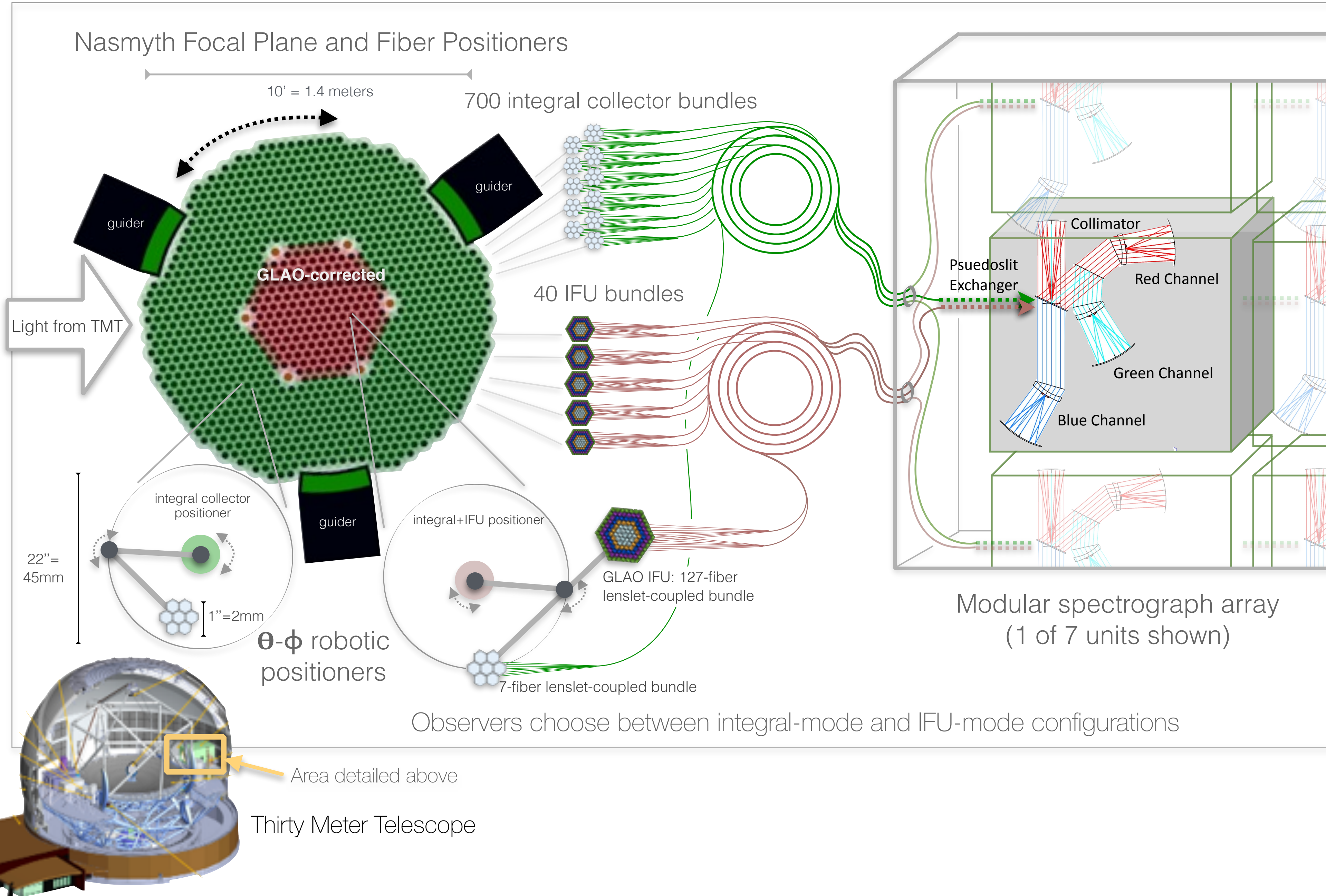
Comprehensive view of z~1 galaxies
complements detailed IRIS followup

How does gas accretion grow disks?
How do bulges and ellipticals form?
What quenches star formation?
How do different mass components assemble?

(Resolved stellar components only possible with 30m aperture)



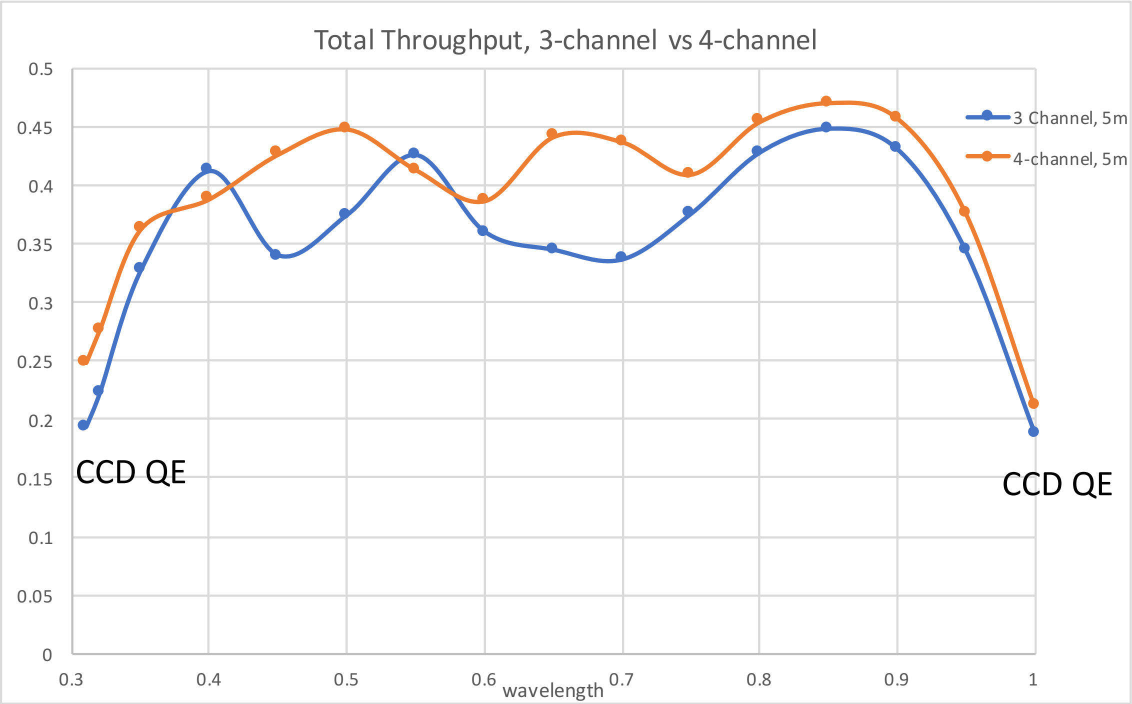
Fiber-WFOS Schematic Layout



Fiber–WFOS Throughput

Throughput – 3 channel vs 4-channel

Note: 3-channel data provided by Wasatch, 4-channel calculated with Gsolver.



Includes:

- Lenslet array
- Fiber coupling loss
- FRD loss
- Fiber transmission
- Collimator
- Pseudo-slit obscuration
- Dichroics
- Grating efficiency (Wasatch)
- Grating throughput
- Camera Optics
- Camera Obscuration
- CCD QE

WFOS Down-select

Specification	*Slicer-WFOS*	*Fiber-WFOS*
Multiplex (integral sources)	100 at R~1500 25 at R~5000	700 at R~5000
IFU Capability	uncertain	40 IFUs with GLAO resolution
Field of view	25 arcmin	79 arcmin
Cost **(MOBIE budget was $64M in 2017 USD)**	< $60M, details TBD	< $50-52M
Risks	**- Multiple slicer modules required** **- Telecentricity sensitivity** **- Tedious plugging operations** Now defining backstop design…	**Sky subtraction** (remaining skepticism to be addressed…)

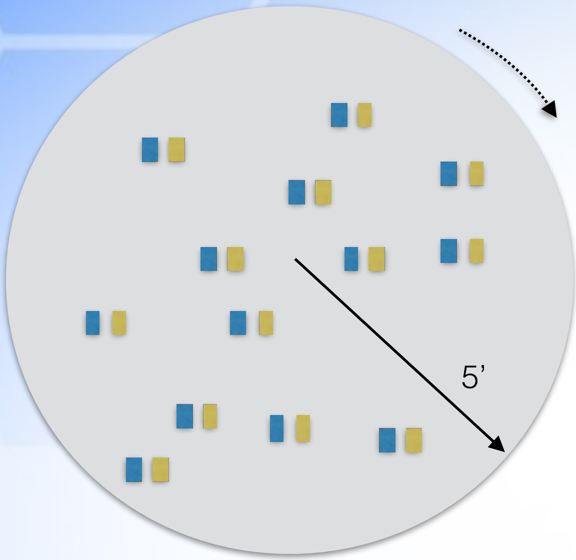
END

Unless you want to talk about sky subtraction…?

Sky Subtraction: Key Points

- WFOS must work 7-8 mag below the sky, requiring 0.1% (per R~5000 pixel) level sky subtraction
- Systematics are a major risk for **any** WFOS design
- Fibers have only recently been used in this regime. We're right to be skeptical
- Slicers and slit masks are also of concern
- Ironically, Fiber-WFOS may be the better choice for systematics. (because spectrographs are mounted and temperature controlled and fiber "scramblers" can stabilize the beam)

Sky subtraction Options



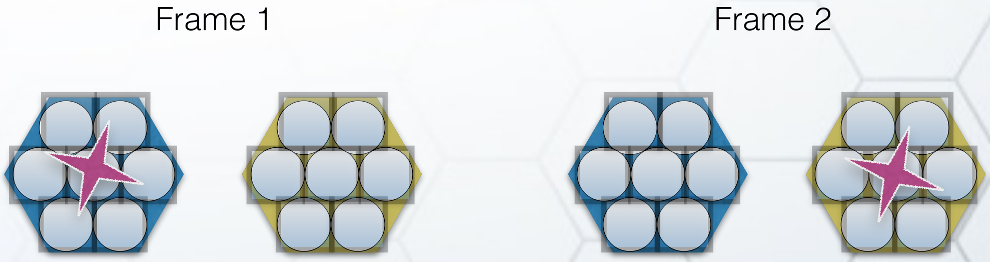
Target - Sky pairs

1. Non-local sky subtraction
   - Simultaneous time sampling, model spatial/instrument sampling
   - Demonstrated to about 1% precision
   - Penalty of 10% multiplex
   - Likely good for much WFOS science - 700 collectors

2. Sky-nodding
   - Near-simultaneous spatial/instrument sampling, model time sampling
   - Also known as “beam switching”
   - Simple and effective
   - Penalty of 50% of observing time (or multiplex)

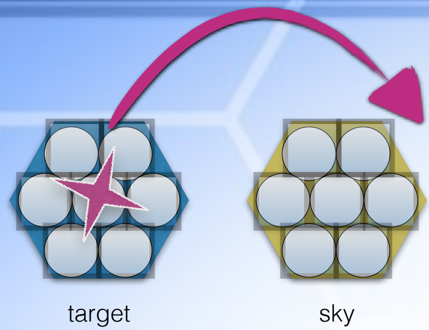
3. Sky nod+shuffle
   - Mitigate readnoise penalty
   - Suffer an additional 50% multiplex loss - 350 collectors

Note: Current Fiber-WFOS ensures all modes (#1, #2, #3) are possible



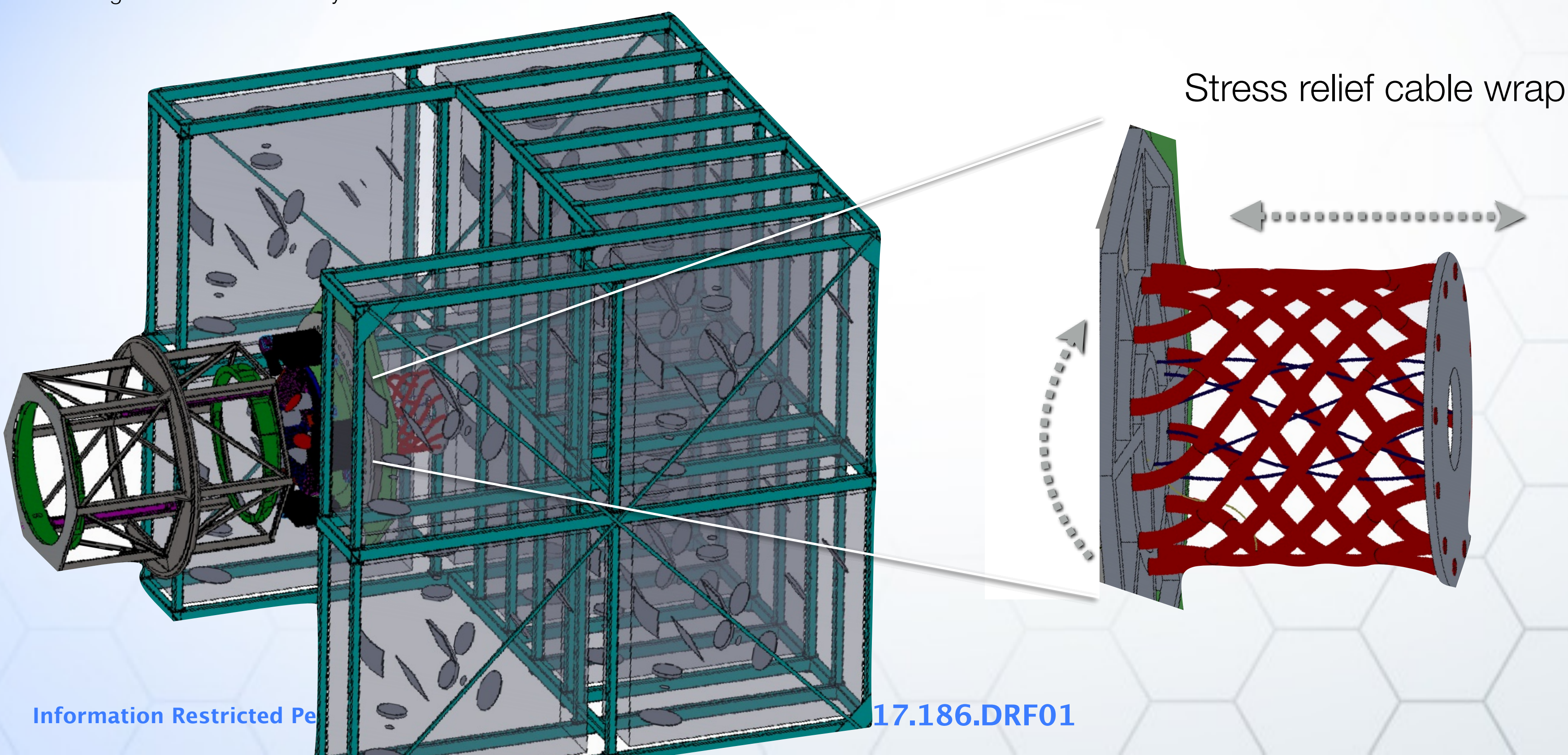
“Cross-Beam Switching”

Sky subtraction Challenge

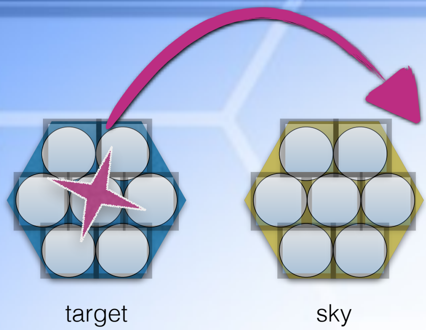


1 minute frame rate ~ 0.5-1.5 deg of rotation

Must ensure stable instrument response between frames



Sky subtraction Challenge

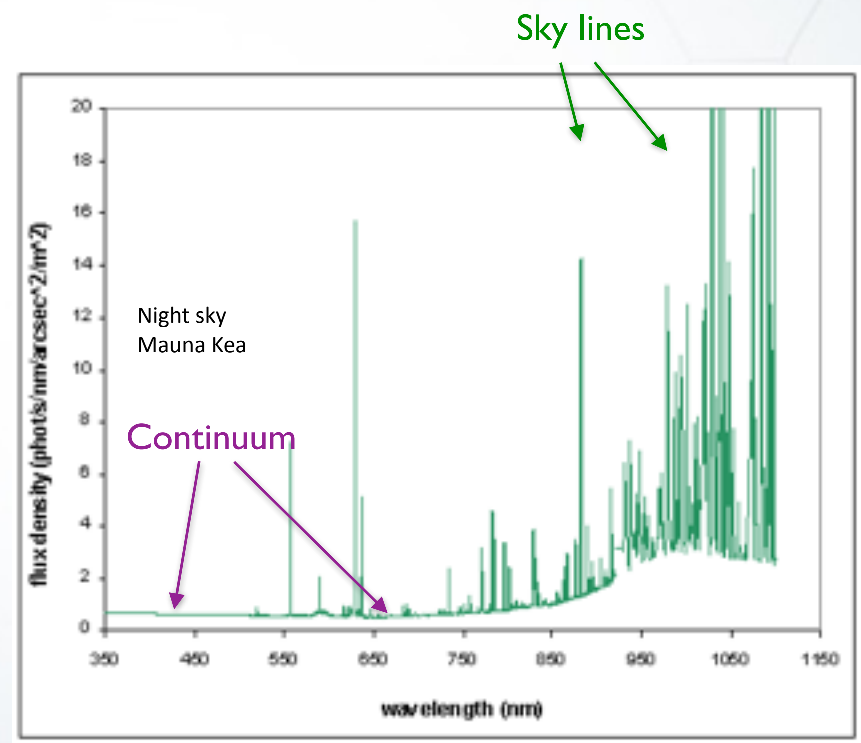


1 minute frame rate ~ 0.5-1.5 deg of rotation

Must ensure stable instrument response between frames

Types of systematics:

- Continuum response: Wavelength-dependent throughput variations
- Sky lines: Variations in line-spread function (LSF)



Requirements Methodology

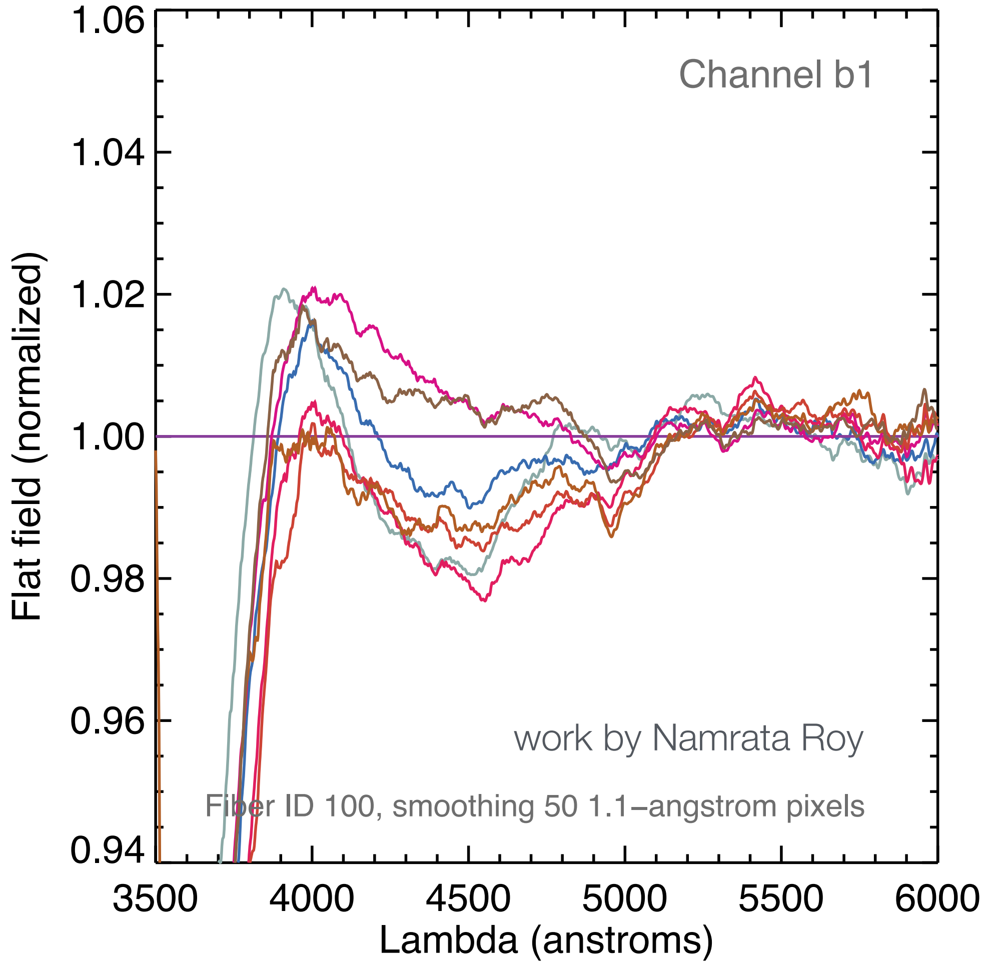
Wavelength-dependent continuum response

Req: Systematic errors shall not degrade the S/N by more than 5%

(for 8-hr on-source integrations)

1. Compute sky flux incident on fiber bundle
2. Account for 4-channel spectrograph throughput and resolution
3. Add read noise according to fiber spectrum trace
4. Optimally extract each fiber's 1D spatial profile
5. Consider a long integration composed of sky-object pairs
6. Assume that fiber continuum response varies independently of sky-nodding sequence (i.e., continuum systematics beat down over time)
7. Determine continuum response stability requirement between exposures

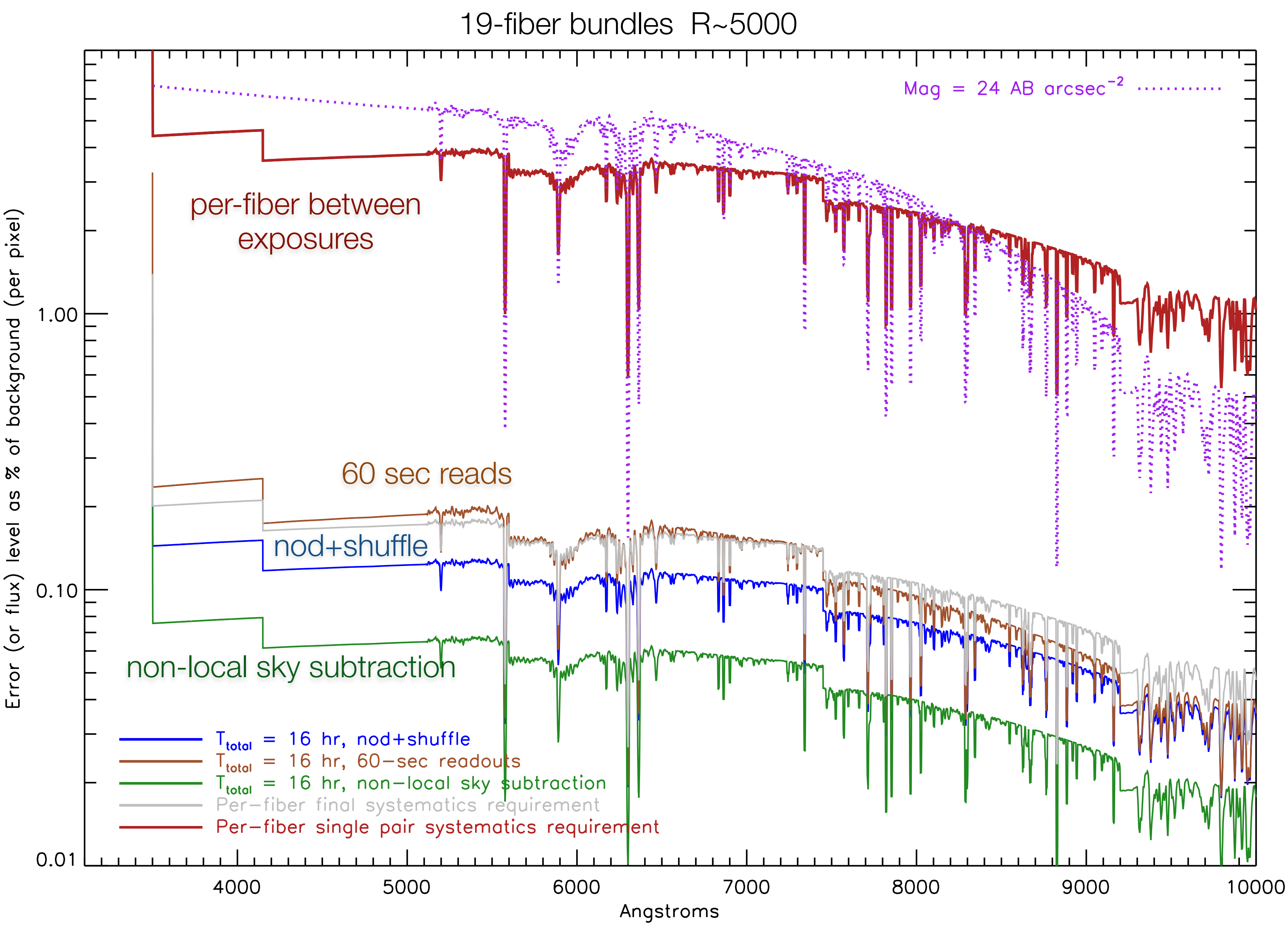
Continuum fiber variation is random



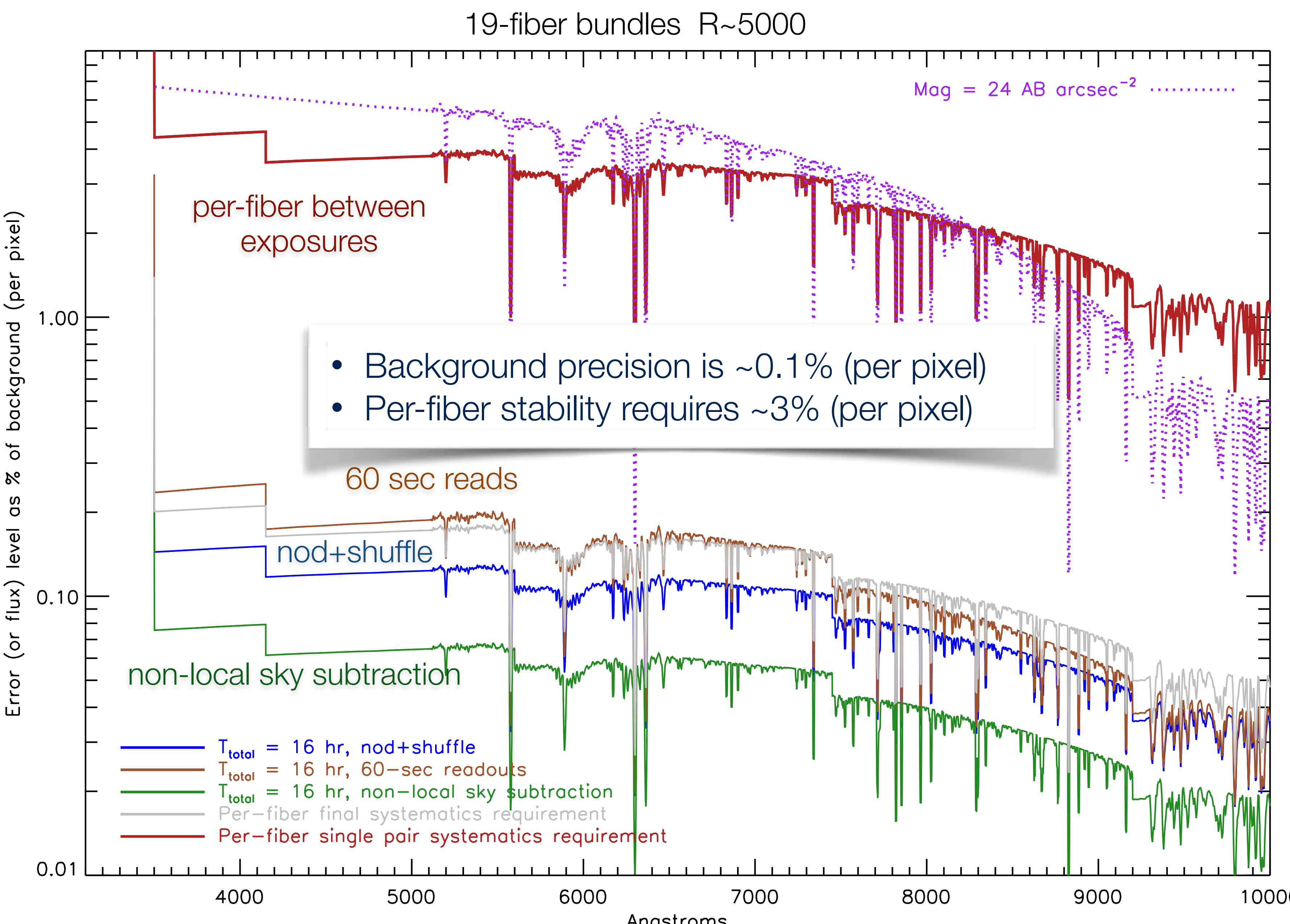
MaNGA flat-field data

The same fiber is stressed differently for each curve

Noise levels expressed as a percentage of background



Noise levels expressed as a percentage of background

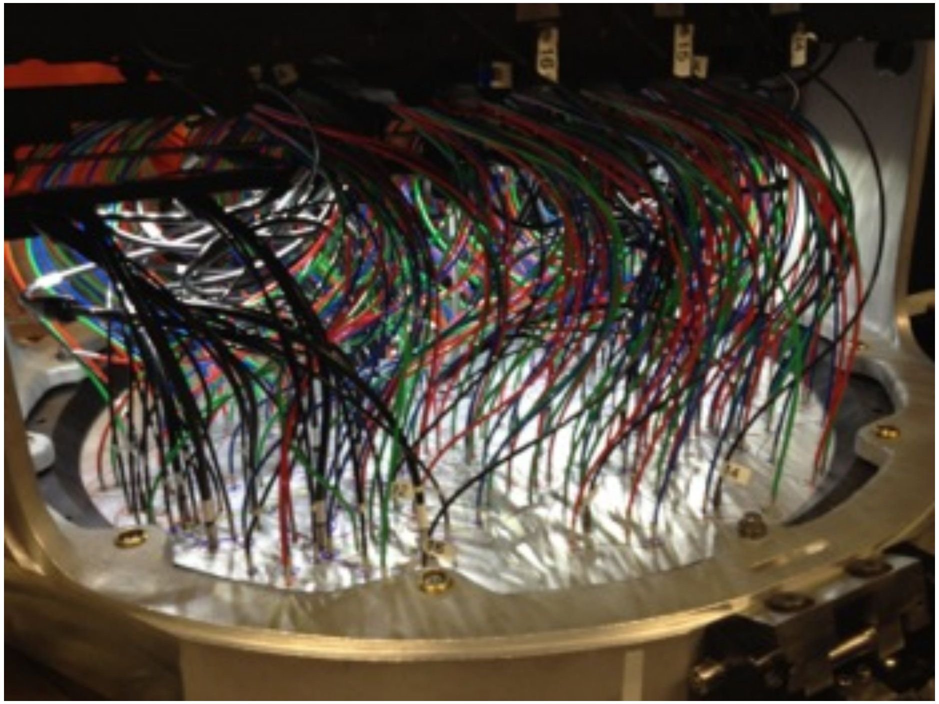


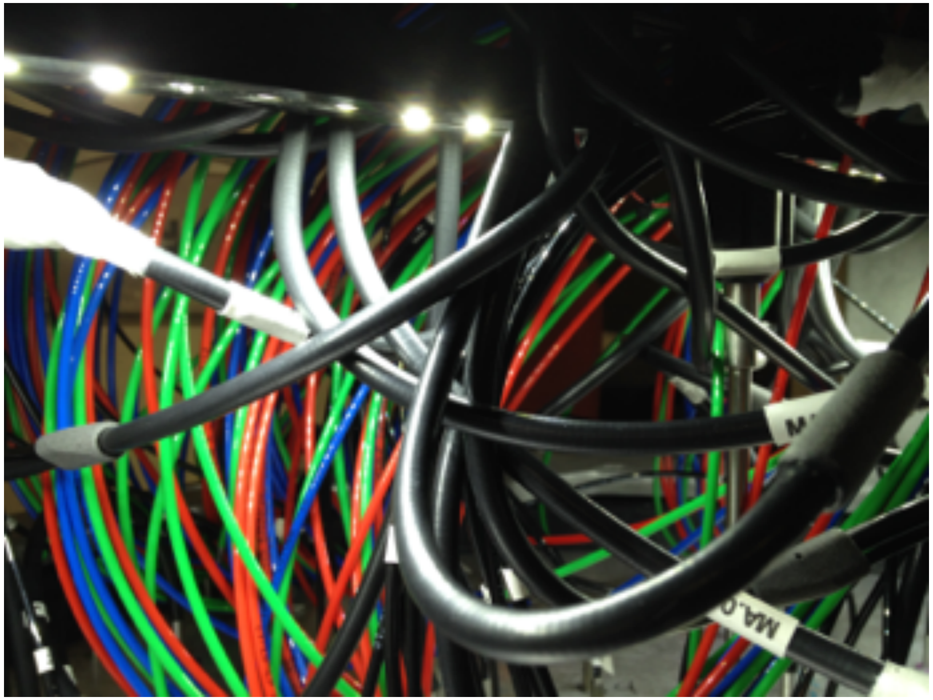
- Background precision is ~0.1% (per pixel)
- Per-fiber stability requires ~3% (per pixel)

Can we meet fiber continuum requirements?

<u>MaNGA calibration tests</u>

- MaNGA fiber bundles are bent in fairly dramatic ways between different pluggings
- WFOS cable relief system does *much* better
- Stress variations over 1 deg WFOS rotation are comparatively tiny





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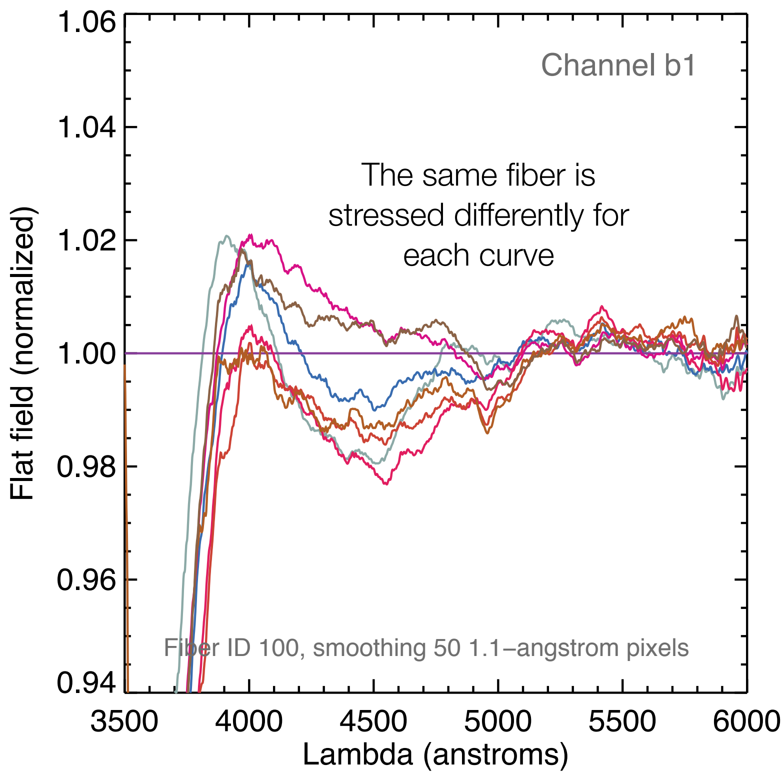
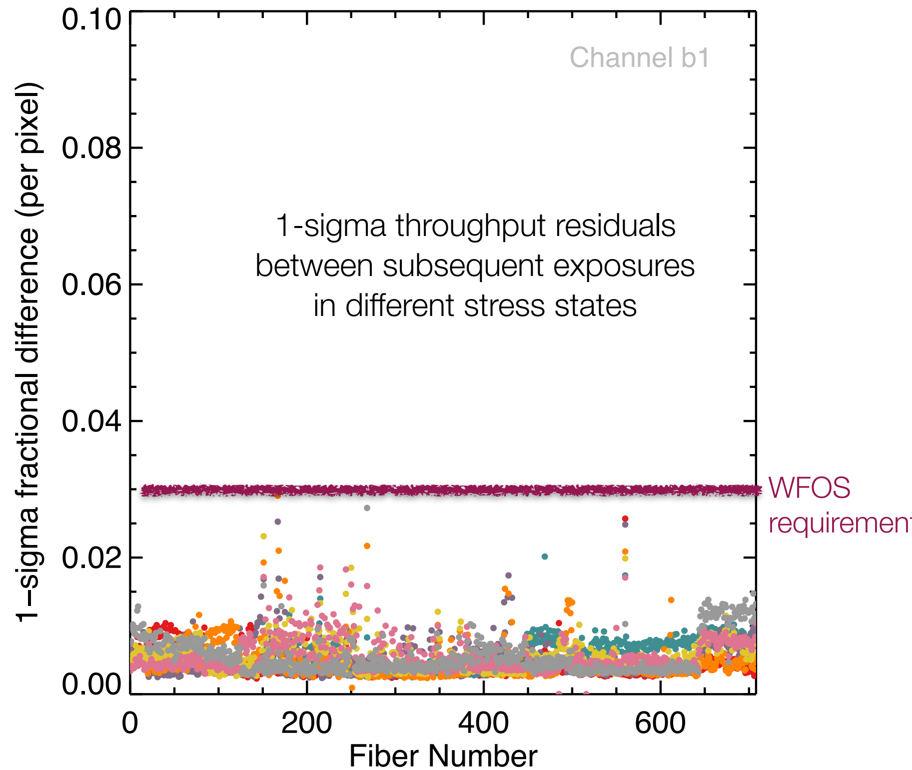
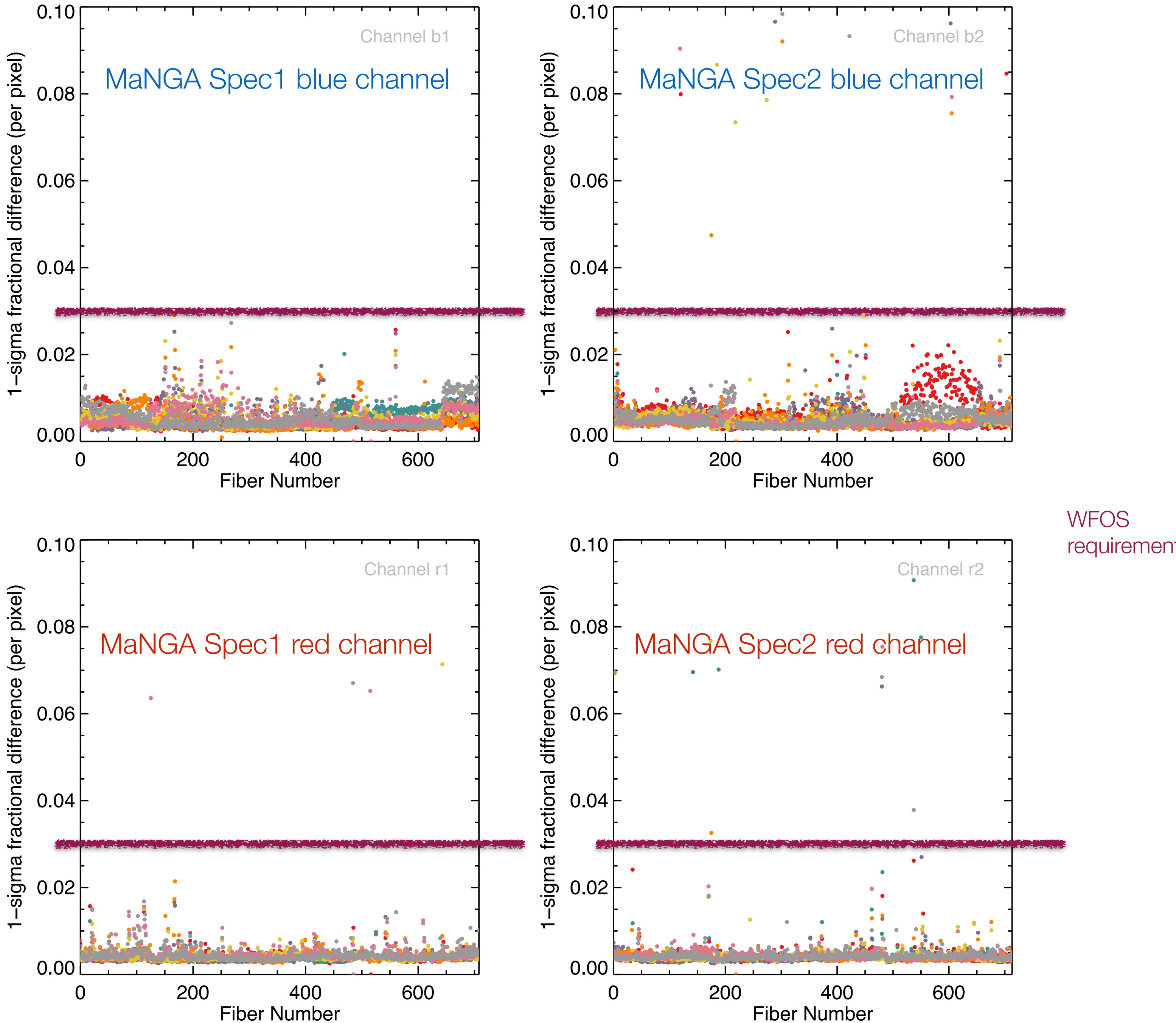




From MaNGA Flat Fields multiple pluggings

- WFOS stresses are likely to be far less
- Bundle telecentricity errors mostly removed
- Drory flat analysis: telecentricity, FRD, f/# matching, dirt
- This tests far-field illumination variations



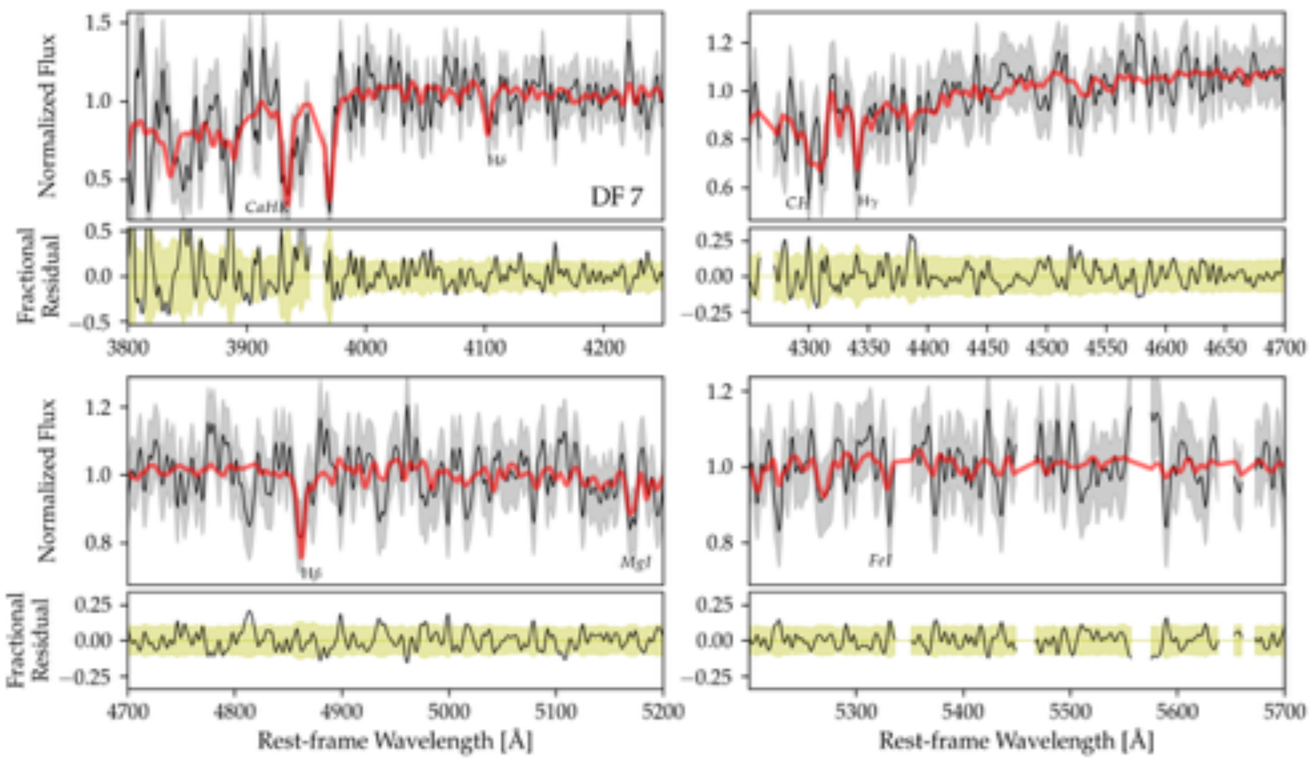
MaNGA Spec1 blue channel
Channel b1
MaNGA Spec2 blue channel
Channel b2
MaNGA Spec1 red channel
Channel r1
MaNGA Spec2 red channel
Channel r2
WFOS requirement
1−sigma fractional difference (per pixel)
Fiber Number

Okay fine, but has it been done before?

Gu et al. 2017

- 27.6 AB arcsec^{-2} with 14-hr MaNGA exposures in 19-fiber bundles.
- This is 0.2% of sky background. Similar level of control needed for faint WFOS targets.

MaNGA spectrum of Coma UDG: 24.4 AB arcsec^{-2} at S/N~9 A^{-1}



Bob raised two concerns:

1. Only seeing the best examples?

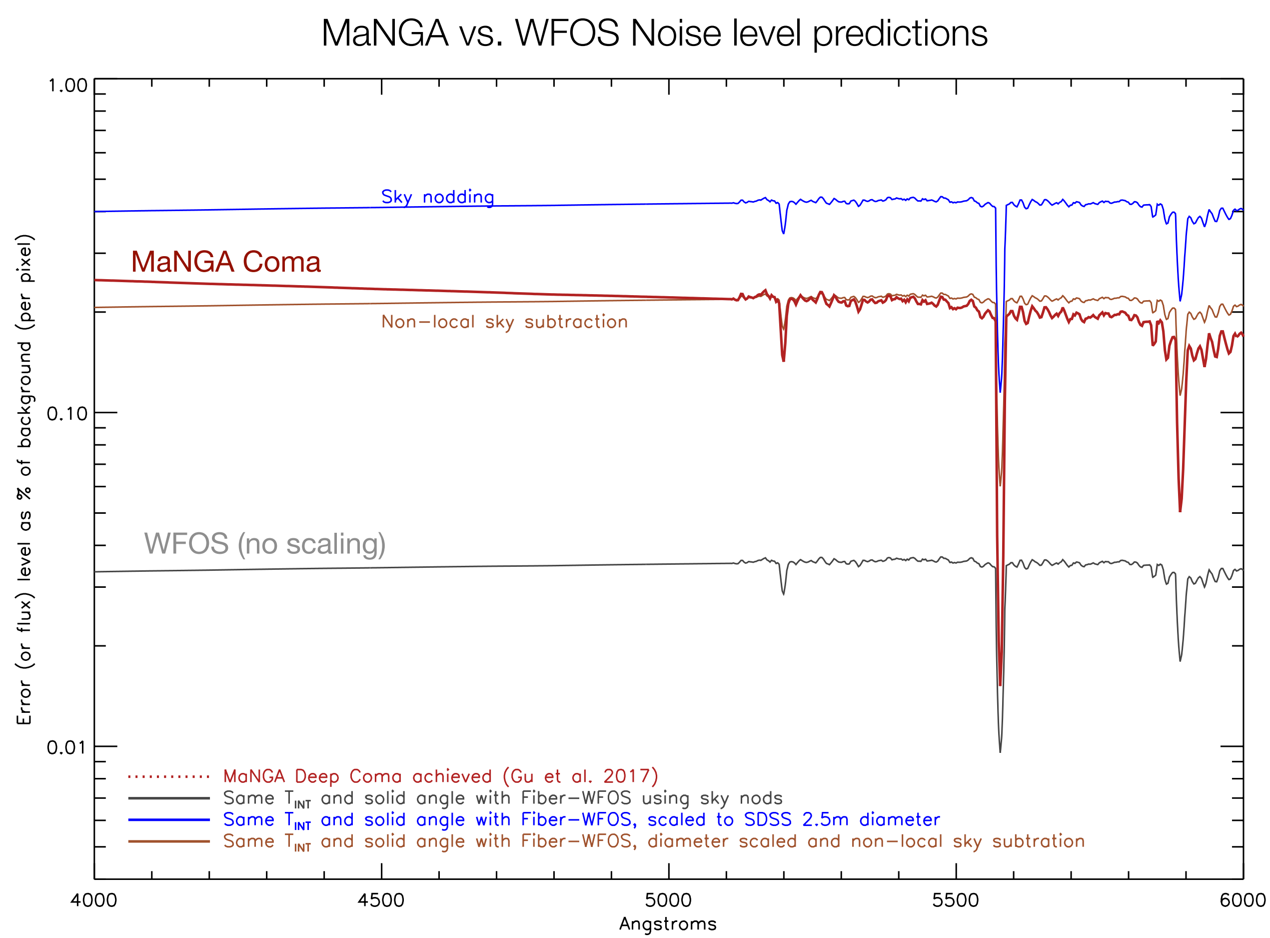
- Actually, all 3 UDGs are presented
- 3 ICL targets *are* being worked on. Fainter surface brightness. Paper II.
- SDSS & MaNGA were never designed for these faint limits.

2. What about the red channel?

- Stellar population science is in the blue
- Spectrographs are telescope-mounted and flex dramatically
- Skyline subtraction is therefore an even bigger challenge

Okay fine, but has it been done before?

- Gu et al. 2017 achieved 27.6 AB arcsec^{-2} with 14-hr MaNGA exposures in 19-fiber bundles.
- This is 0.2% of sky background. Similar level of control needed for faint WFOS targets.
- The plot compares WFOS noise predictions for the same total integration time (with and without scaling for telescope aperture).
- Assume here that WFOS fibers subtend same solid angle as MaNGA.
- After diameter scaling and using non-local sky subtraction, we predict the level Gu et al. achieve. Their control of systematics was excellent.



But, predictions don't yet account for optimal extraction

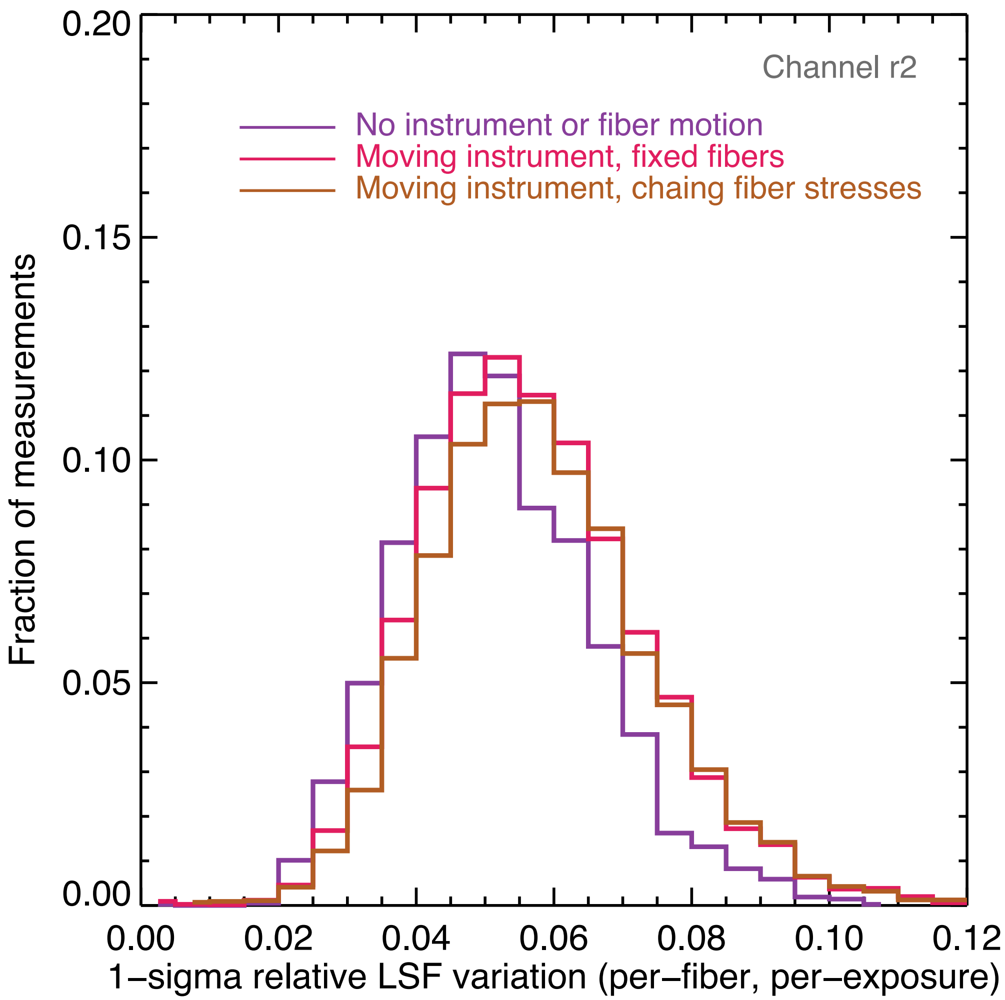
Line-Spread Function (LSF) Stability

Req: LSF FWHM shall vary less than 1% between fiber exposures

How well does SDSS / MaNGA do? Harder to address:

1. MaNGA's telescope-mounted spectrographs flex like crazy. Must isolate the fiber contribution from spec. flexure.
2. Line width measurements are noisy.
3. Arc lamp light fills the MaNGA fiber face. WFOS bundle optics, however, re-image the pupil onto the fibers and under-fill them.
4. But, we can model how the (distorted) fiber-output PSF drives the LSF.

MaNGA Fiber LSF Stability

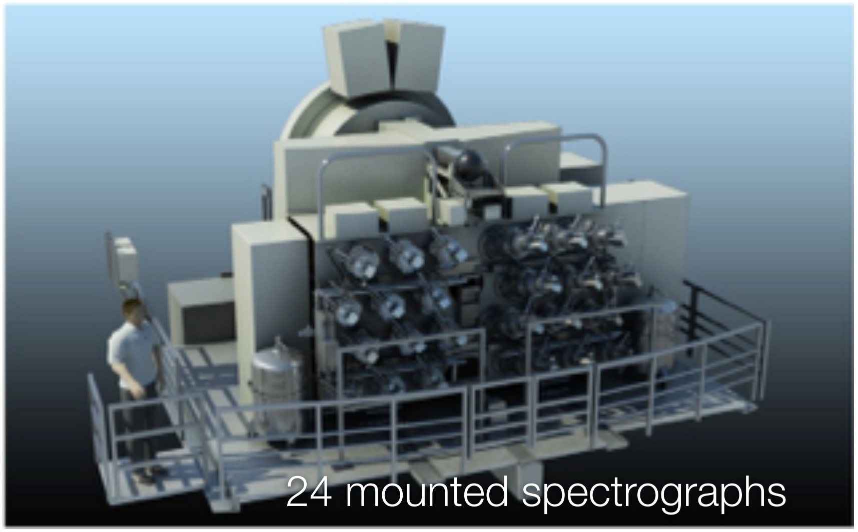


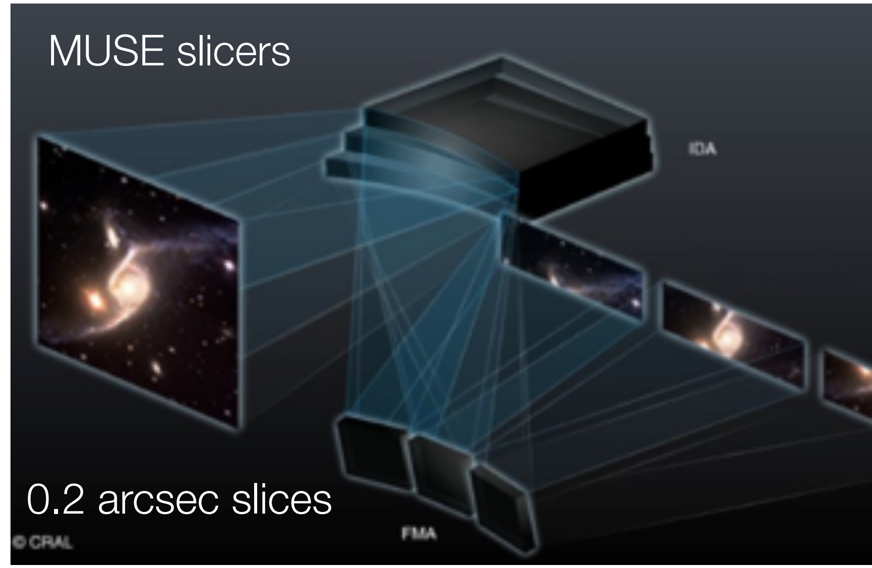
- Use a number of clean arc lines
- For each fiber compute the line-width difference compared to the median of the 5 nearest fibers on either side
- Compute how this offset varies across exposures
- 'Relative LSF variation' is the 1-sigma scatter in this variation
- Measurement error dominates

Compare magenta vs. brown: fiber stresses induce no additional LSF variation, at least within ~0.5%

Slicer-WFOS: Stability risk

Insight from VLT-MUSE





- 1x1 arcmin IFU, 470-930 nm, R ~ 2000 - 4000
- 24 coarse slicers direct light to 24 spectrographs
- Each spectrograph slices its beam again into 4x10 slitlets
- K-mirror for rotation, no instrument motion, no temp control

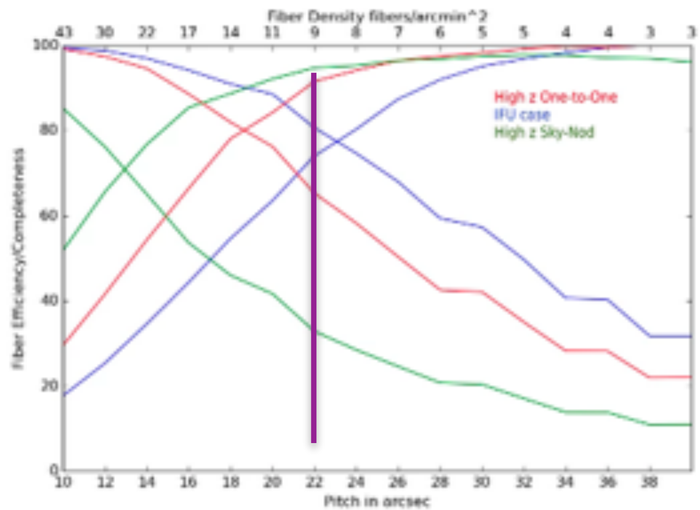
Following slides are *preliminary*, courtesy of Sebastiano Catalupo

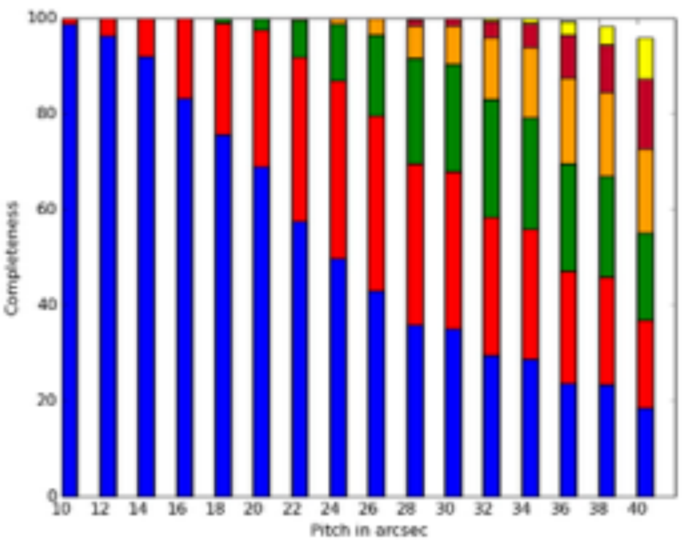
Conclusions

- WFOS must work 7-8 mag below the sky, requiring 0.1% (per R~5000 pixel) level sky subtraction
- Systematics are a major risk for **any** WFOS design
- Fibers have only recently been used in this regime. We're right to be skeptical
- Slicers and slit masks are also of concern
- Ironically, Fiber-WFOS may be the better choice for systematics. (because spectrographs are mounted and temperature controlled and fiber "scramblers" can stabilize the beam)

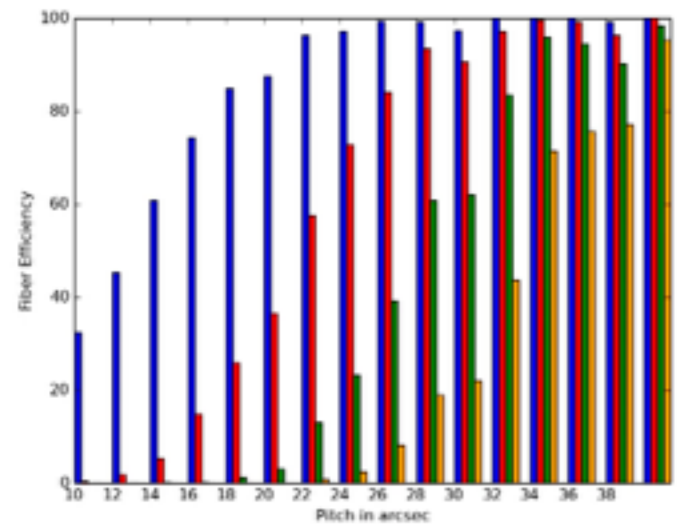
END #2

Fiber–WFOS Targeting





High-z
10 arcmin^{-2}



GLAO at TMT

GLAO a new priority for TMT?

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

(Lianqi Wang, reported 27-Apr-2017)