# Fiber-Fed Optical MOS for Giant Telescopes

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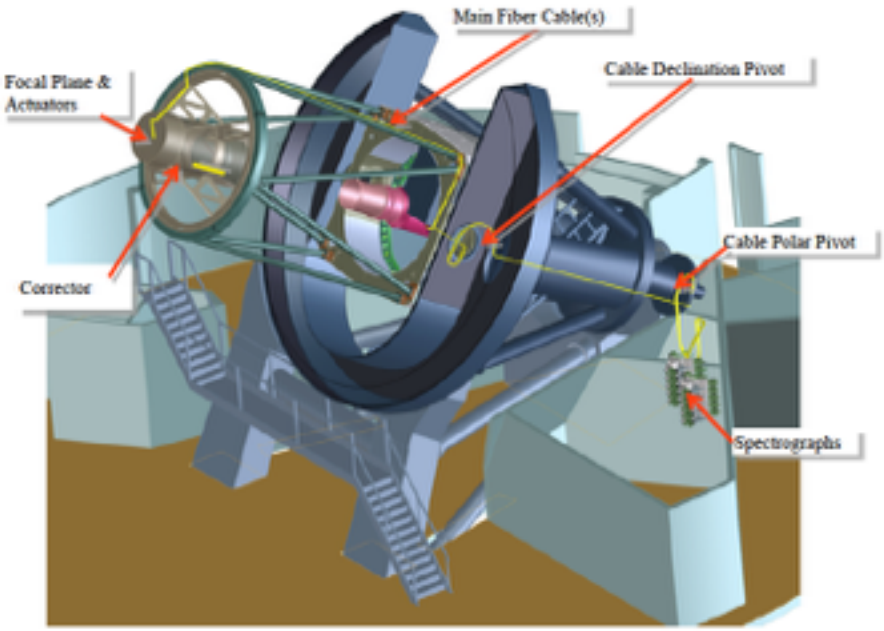
# Fiber-Spectroscopy Over the Next Few Years

- In the past 15 years, fiber-spectroscopy has really come of age: SDSS, 2dF, etc…
- Many fiber MOS projects are coming online over the next few years on 4m-class telescopes:
  - DESI
  - WEAVE
  - 4MOST
- Starting to move to 8-10m-class: Subaru-PFS, VLT-MOONS, Keck-FOBOS

# Dark Energy Spectroscopic Instrument

- Led by Lawrence Berkeley Lab
- Prime-focus ultra wide-field spectrograph on KPNO Mayall 4m telescope
- First light late 2018/2019
- 5000 robotic fiber positioners over 8 sq deg FOV
- Optical fibers feed 10 spectrograph units, each with 3 channels resolving R~2000-5000
- Optimized for z~1 ELG redshift survey over 10,000 deg^2 to measure BAO signal as cosmological standard ruler



# Advantages of Fiber-Fed Spectroscopy

- Decouples spectrograph size from size of the focal plane… spectrographs remain bench-sized
- Easily scaleable for large multiplex or # of spaxels, e.g. DESI, HETDEX
- Stability: Focal plane array rotates, but spectrographs can be bench-mounted with fixed gravity vector + thermal control
- Cross-facility adaptability (see Keck-FOBOS example, later…)
- Switch between large-multiplex vs IFU modes (SDSS BOSS and MaNGA)

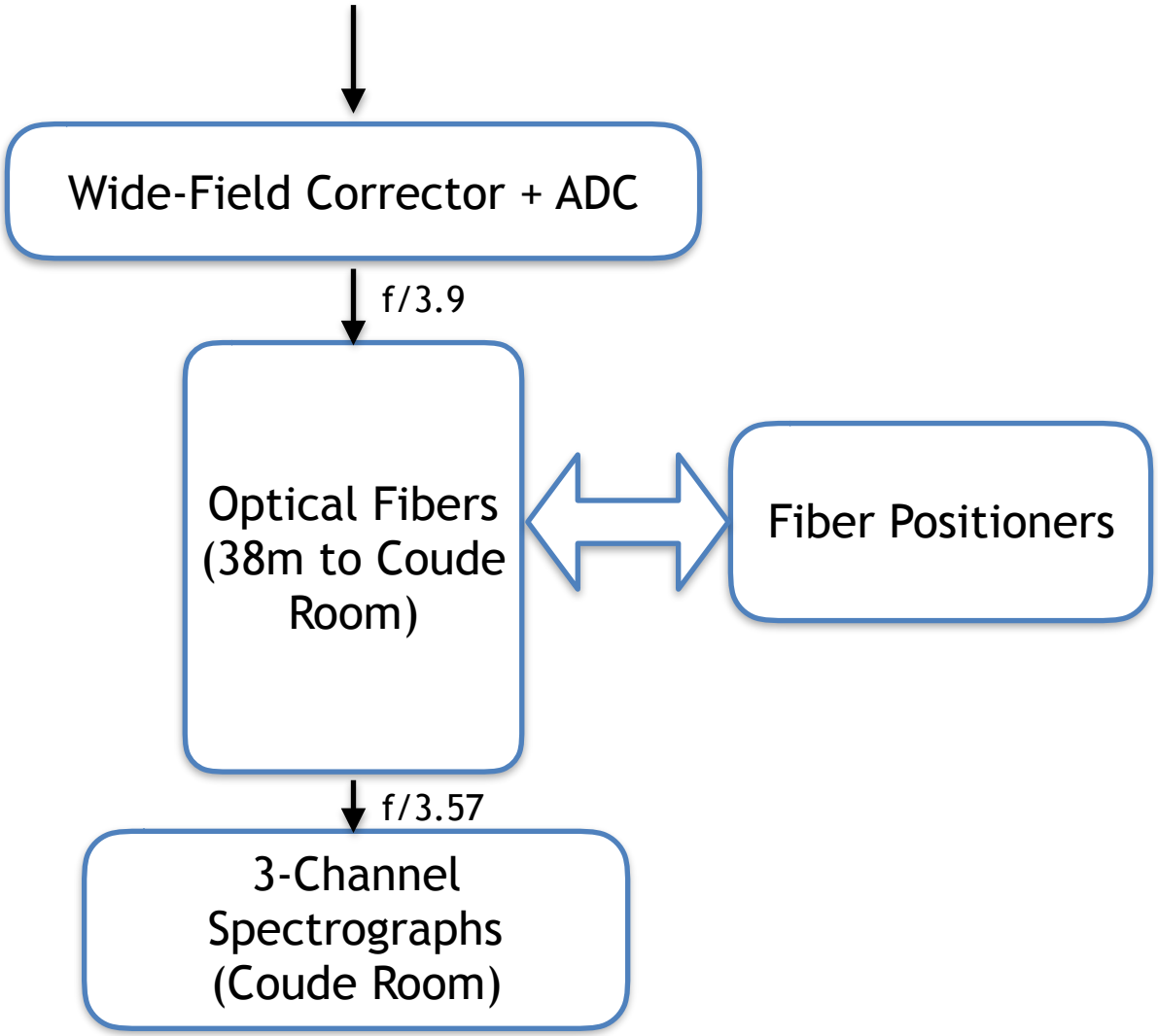
# Keck Fiber-Optic Broadband Optical Spectrograph (FOBOS)

New concept for fiber-MOS for Keck using DESI design heritage. Currently undergoing preliminary design; *Science Definition Workshop June 6th in LBL sponsored by UCO*

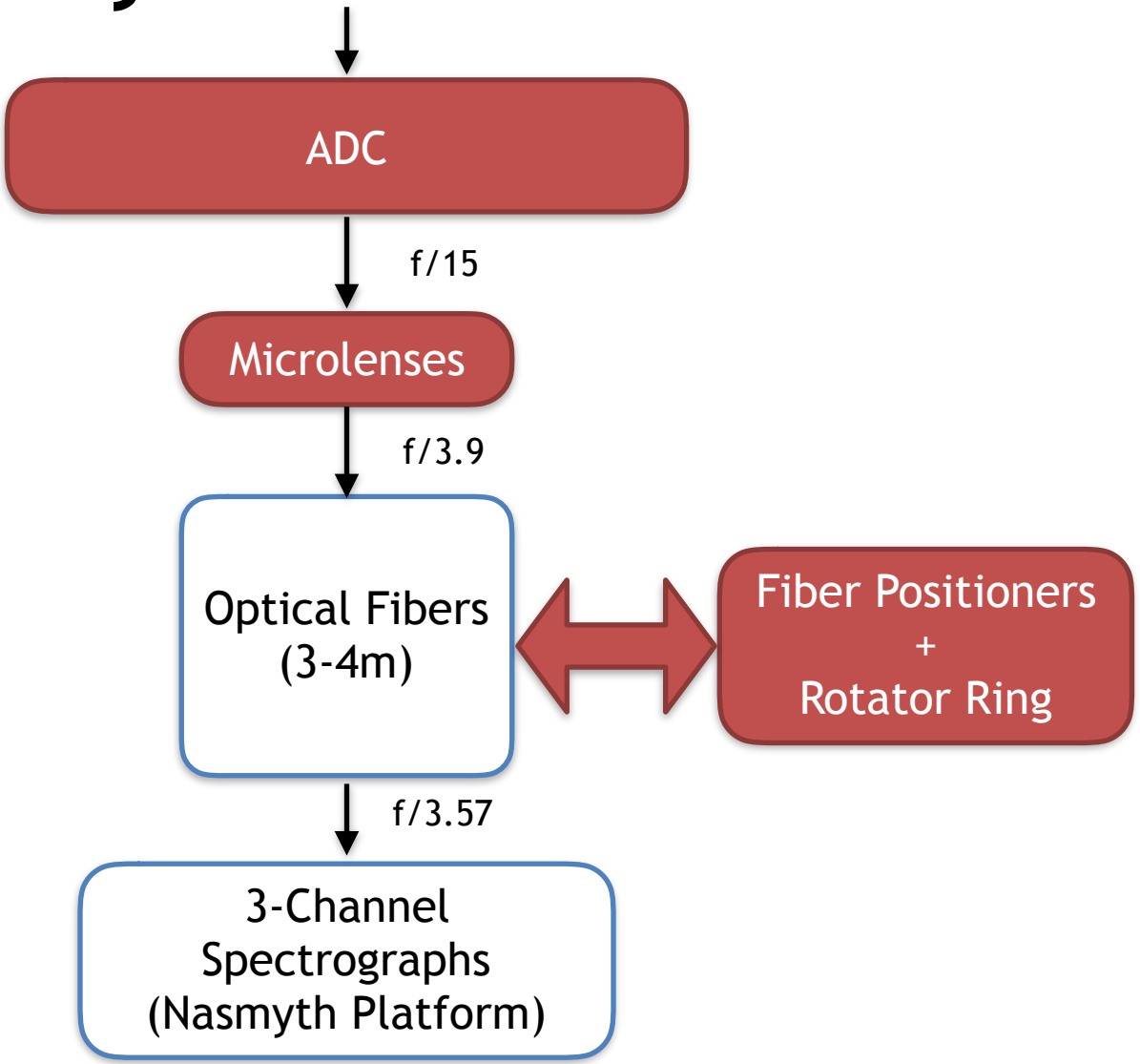
- Atmospheric Dispersion Corrector for simultaneous NUV-NIR coverage
- 500 robotic fiber positioners sampling 20' diameter FOV Nasmyth focus - 7x1 mini-IFU bundles per positioner
- Four DESI-based spectrographs mounted on Nasmyth deck

*Philosophy: Perturbation around the DESI design!*

# DESI System Flowchart



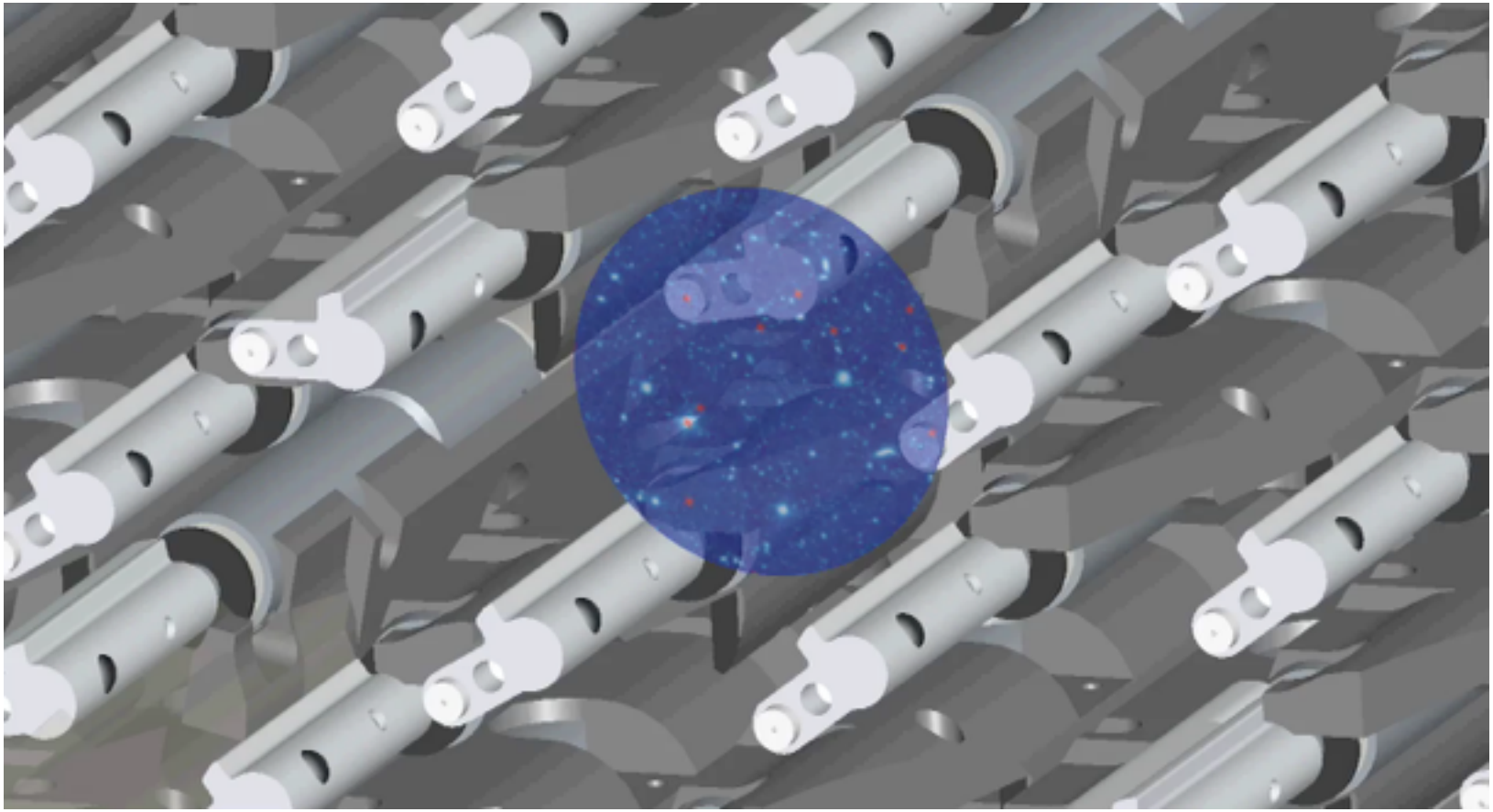
# FOBOS System Flowchart



# Nasmyth Fiber MOS Setup

VLT-MOONS, but Keck-FOBOS has similar setup…

# DESI Fiber Positioners



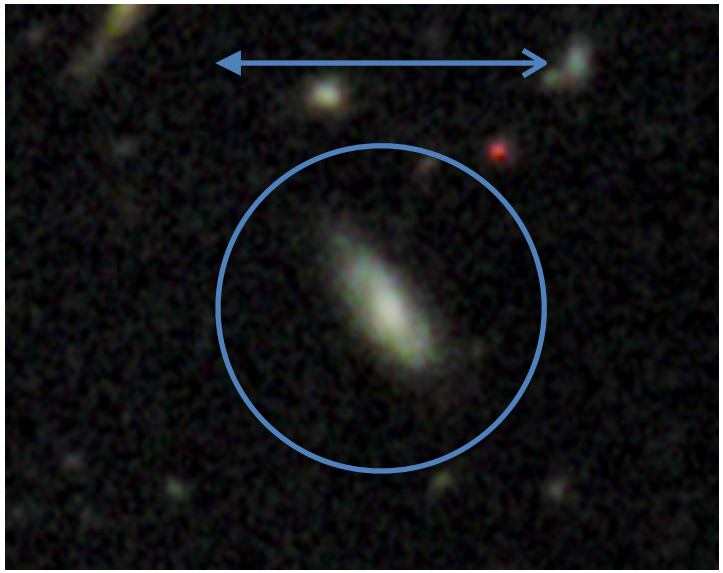
# Coupling Keck focal plane to DESI Fibers

- DESI fibers are ∅=107 micron and ~f/3.9 at injection
- Keck focal plane is at f/15, and need to be converted prior to fiber injection
- Micro lenses to convert f/15 to f/3.9. With ∅=107 micron at fiber injection, this would span ∅=412 micron at Keck focal plane
- With the Keck plate scale of 725 micron/arcsec, this means each fiber will sample 0.57 arcsec

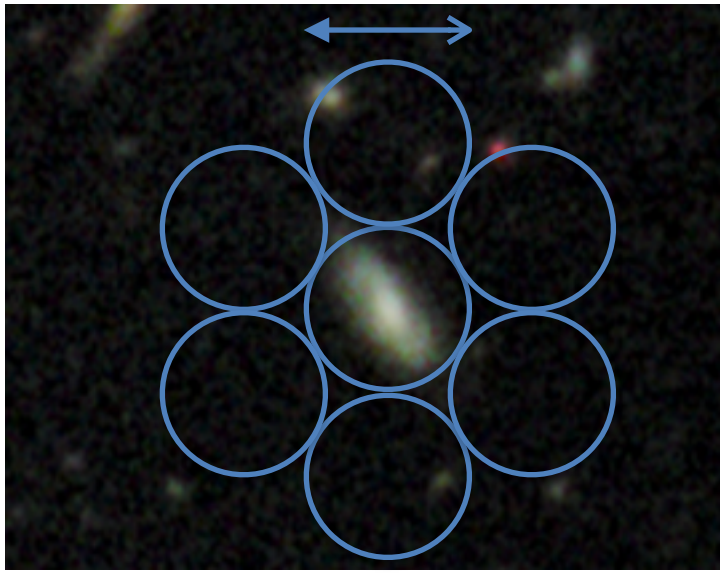
*This is probably unacceptably small for a PI instrument!*

# Mini-IFU Bundles

*1.1” fiber aperture (Subaru- PFS)*



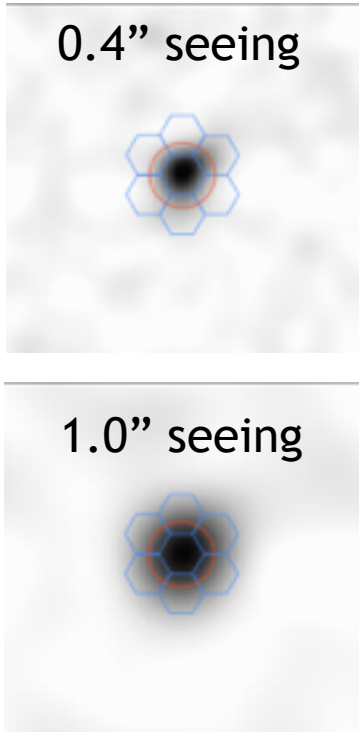
*7 x 0.6” fiber bundles (FOBOS)*

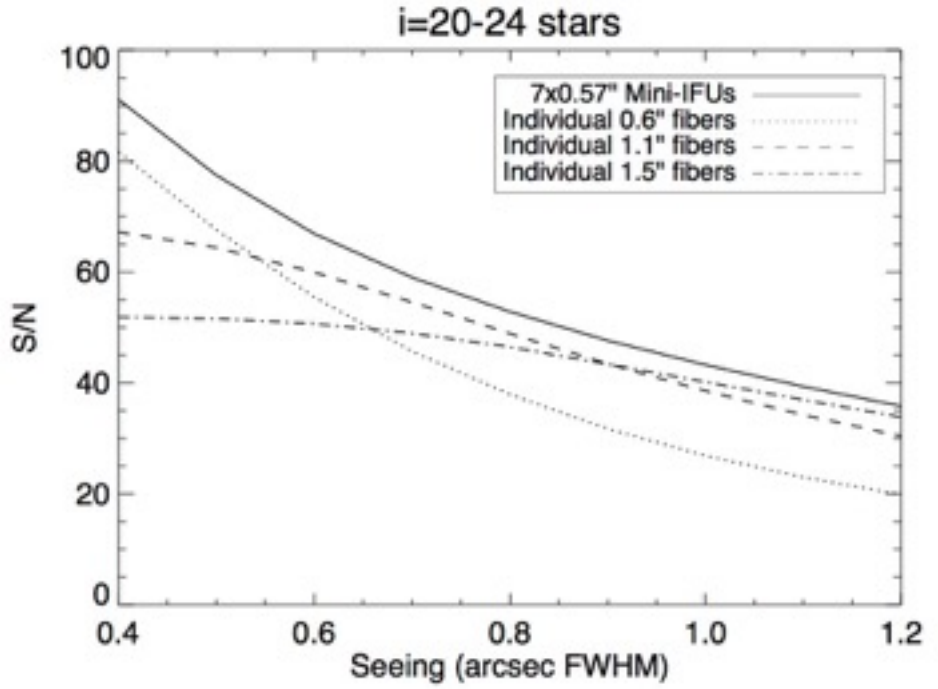


- Fixed fiber apertures give ‘lower-limit’ on seeing, e.g. Subaru-PFS 1.1” cannot exploit 0.5” good seeing (sometimes…) on Mauna Kea
- Mini-IFU bundles give flexibility between good-seeing conditions and bad-seeing (or extended sources).

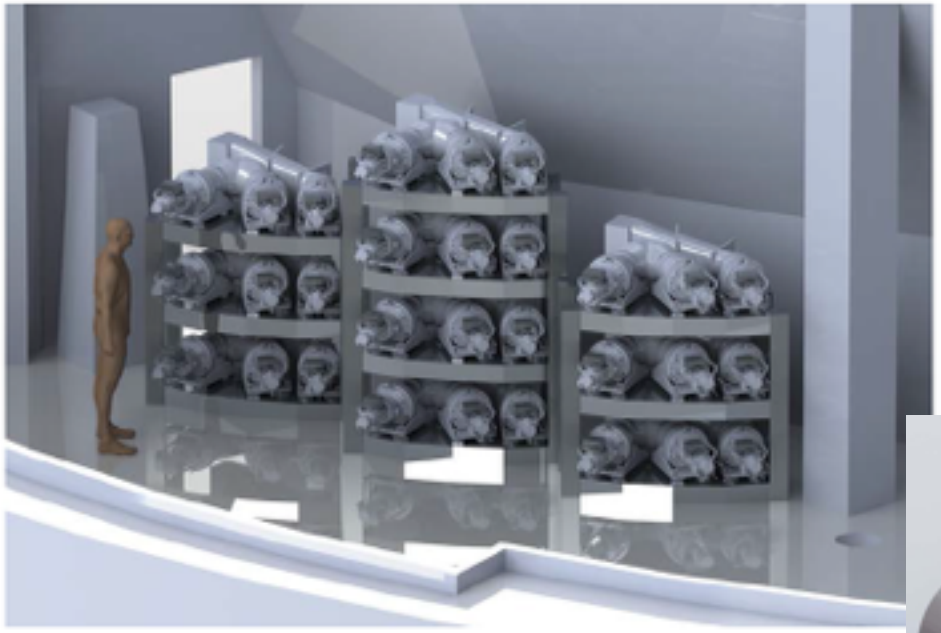
# S/N Advantage from Mini-IFUs

Mini-IFUs reduce overall multiplex, but provides superior S/N over single fibers if optimally combine signal all apertures $(S/N)_{total}^2 = (S/N)_1^2 + (S/N)_2^2 + \ldots$



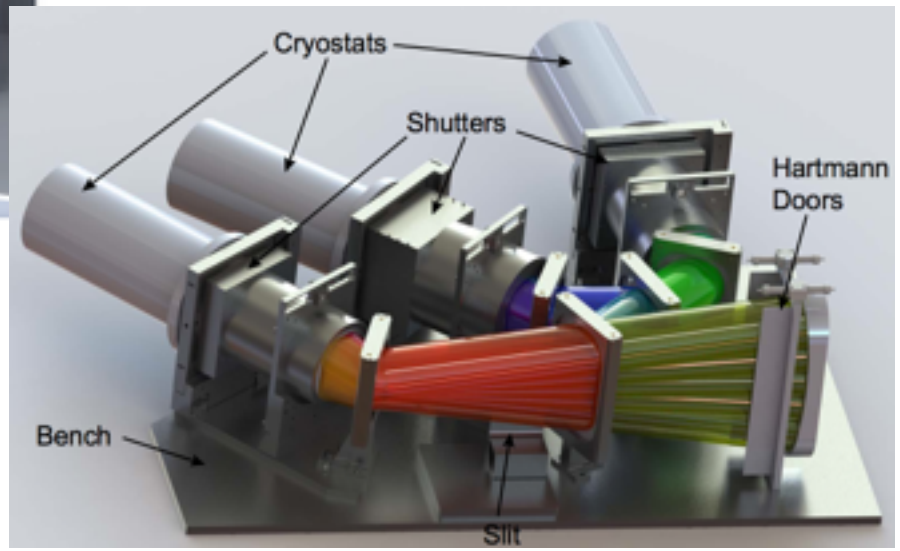
# DESI Spectrographs



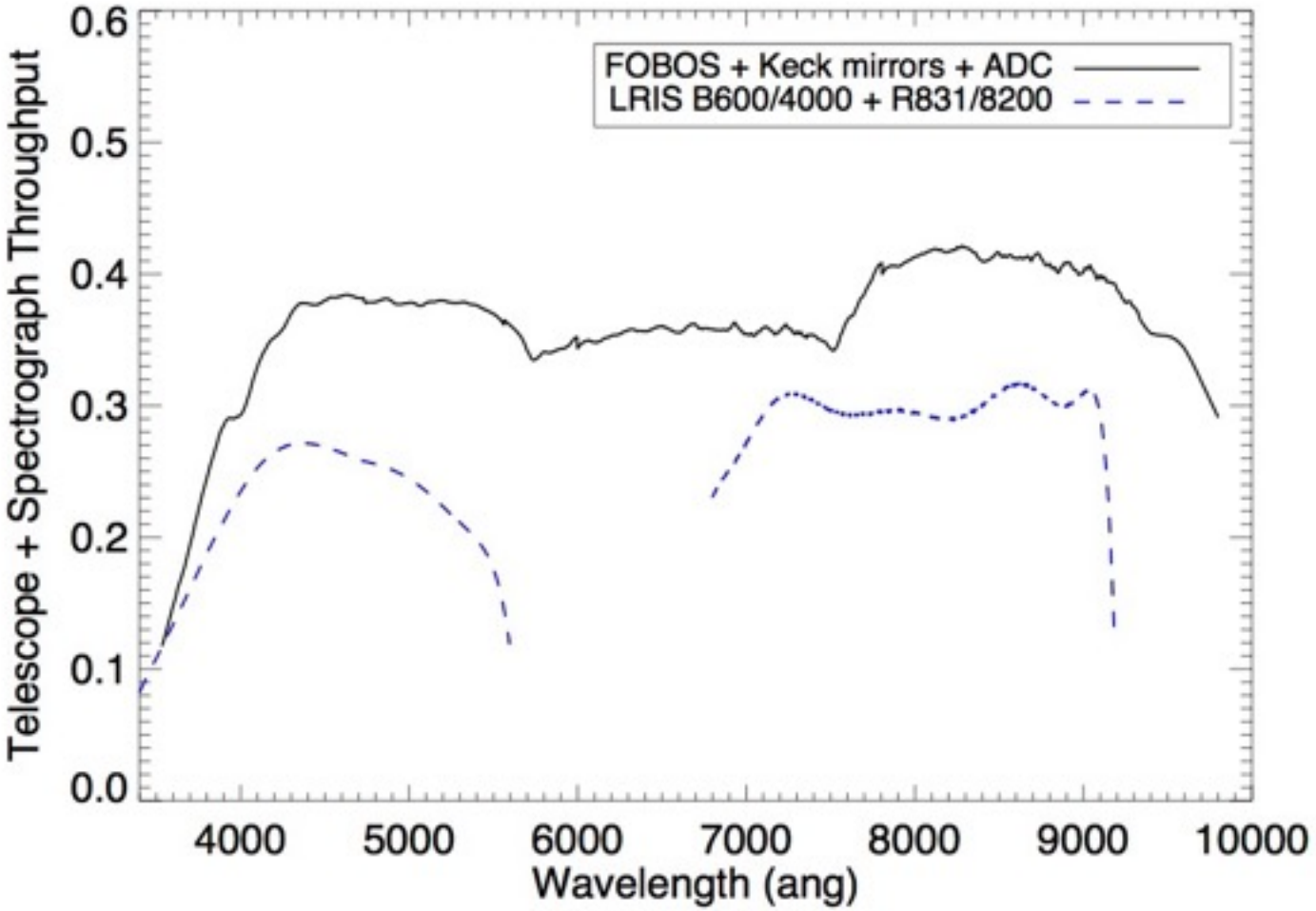
Continuous coverage from blue-NIR:

- Blue: 350-550nm, R~2500
- Red: 550-750nm, R~4500
- NIR: 750-980nm, R~4800

(*Additional NIR arm can be added*)



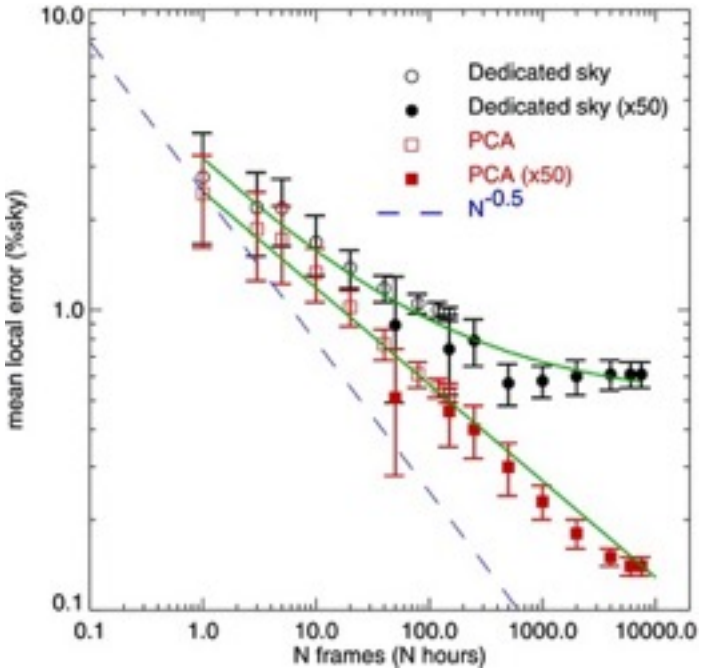
# High-Throughput Design!



# Sky Subtraction

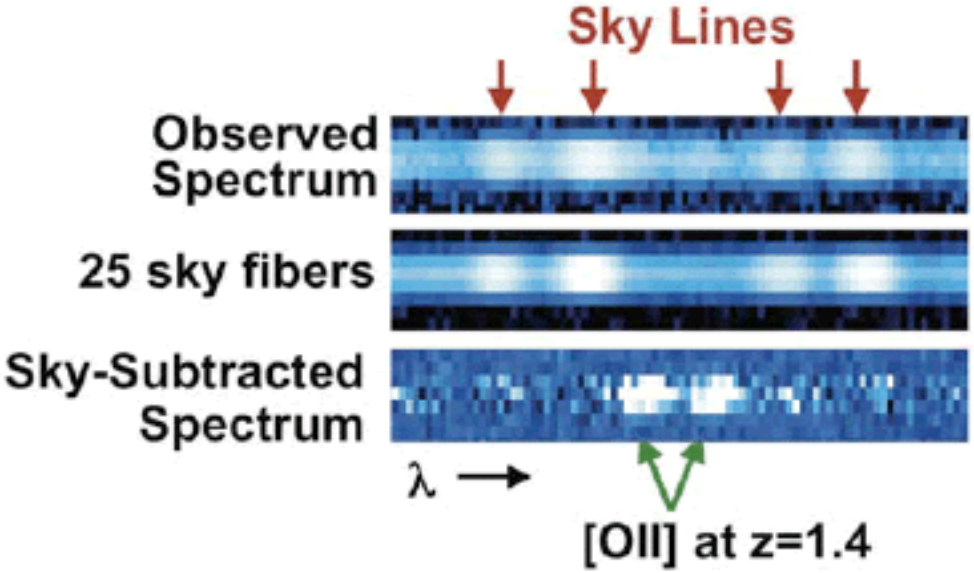
- Faint-object fiber spectroscopy is limited by sky subtraction using traditional methods, i.e. subtracting each spectrum with the same median sky spectrum
- Sharp & Parkinson 2010: Studied sky-subtraction on 4m AAT/ AAOmega
- Used PCA method to targets the sky in individual spectra
- This method yields S/N∝t^0.32 (c.f. S/N ∝t^0.5 from Poisson limit) with no obvious systematic floor

*This is the worst-case scenario!*



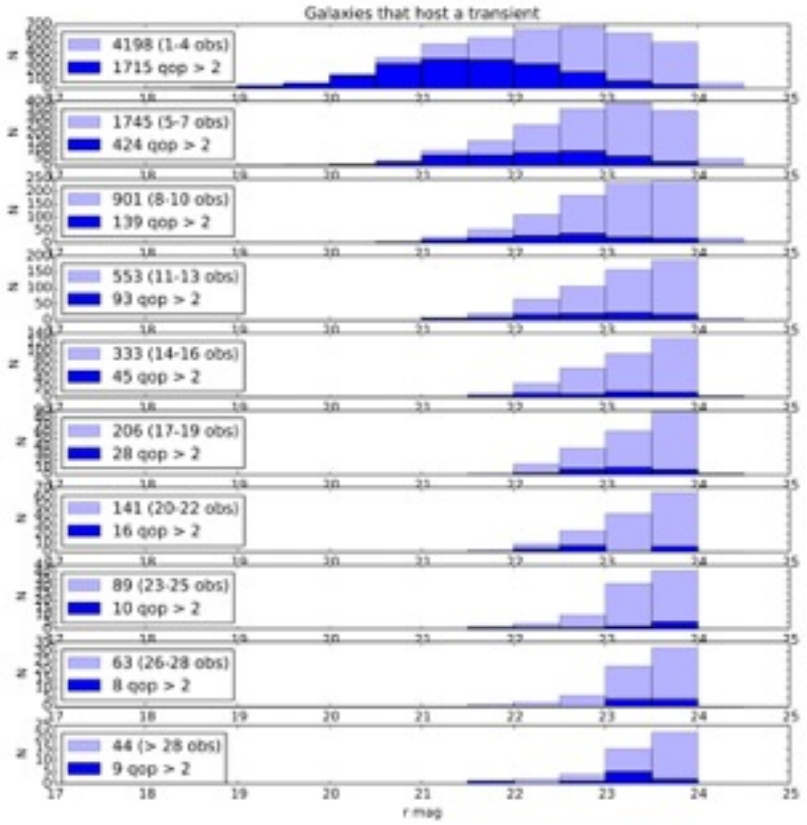
# Spectro-Perfectionism

- The sky spectrum varies negligibly within a typical telescope FOV (except continuum gradients during bright Moon!)
- Most ‘sky subtraction’ errors are in fact due to errors in spectral extraction
- Bolton & Schlegel 2010 ‘Spectro-perfectionism’: Extraction involves model of 2D PSF across the CCD
- Simulated tests shows at least <0.5% sky subtraction



# AAT OzDES Survey

- Ongoing spectroscopic follow-up program for DES Supernovae
- Conducted on AAT/AAOmega
- Total exposure time: **up to 50hrs per source**
- Targeting as faint as r=25
- No sky subtraction floor encountered yet, after ~30hrs on deepest source
- Are willing to share data to characterize performance




*Courtesy of Chris Lidman (AAO)*

# Price Point for FOBOS

- ADC + rotator plate: ~$3M
- Positioners + fibers: ~$2k per target (inc. R&D + mini-IFUs)
- Spectrographs: ~$1.5M per unit sampling 125 targets = $12k per target

Hardware cost = $3.0M + (N/500) * $7M

= **$9M**

***This is an instrument with 3x FOV of DEIMOS, 3.5x multiplexing of DEIMOS, better throughput than LRIS, full UV-NIR spectral coverage***

# Can we do this for TMT?

- TMT has same f/15 speed as Keck!
- In principle, exact same design can be directly adapted
- 0.22” spaxels per aperture, combine into mini-IFUs for natural seeing and can exploit GLAO

# Can we do this for TMT? (II)

- Assume 12 spectrograph units
- MOS mode with 550 multiplexing over 20’ diameter FOV, with 19 x 0.22” mini-IFUs each target
- IFU mode with 20 arcsec x 20 arcsec footprint, 0.22” spaxels

# How much would this cost?

- $7M for focal plane array (positioners + fibers)
- 12 x $1.5M per spectrograph unit

$25M total hardware cost