# The Large Fiber Array Spectroscopic Telescope: Is a scalable ELT the future of Intensity Interferometry?

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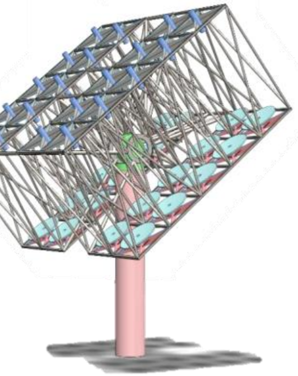
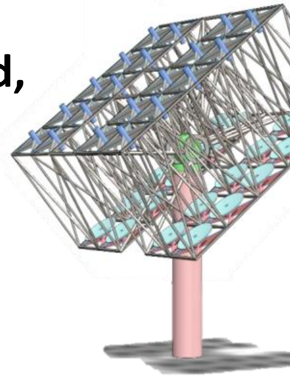
***Chad Bender (LFAST Co-PI)***

***Steward Observatory***

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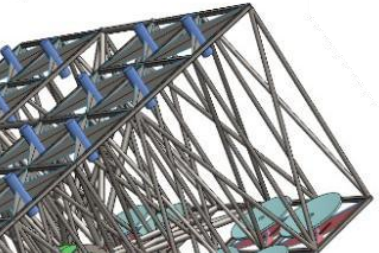
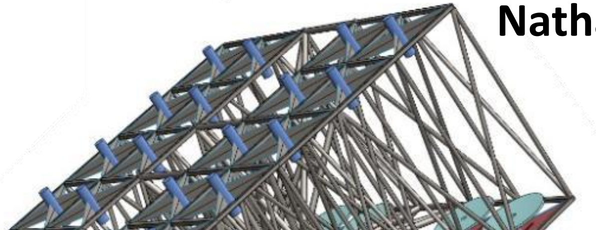
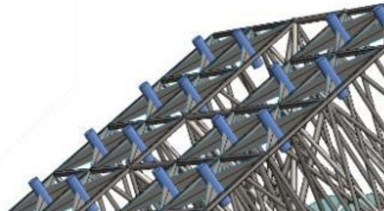
*Science Team:* Xiaohui Fan, Emily Gilbert, Buell Januzzi, Elisabeth Krause, Megan Weiner Mansfield, Sukrit Ranjan, David Sand, Nathan Smith, Ann Zabludoff



*LFAST is supported by Schmidt Sciences LLC.*





# Ground based astronomy has a "big" problem:

1. Astronomy benefits from large ground based telescopes

   → *Hence: GMT (24-m), TMT (30-m), ELT (39-m)*

2. Each will cost several billion dollars: replicating, or building larger is too costly

   → *Can we get equiv. apertures, unphased, for much lower cost?*

   → *Can we scale up to even larger apertures at linear (or better) cost scaling?*

3. Primary mirror fab is slow
   - Each 8.4m mirror takes 4 years to fab
   - Segmented have multiple configs

   → *Can we build this collecting area faster?*

**LFAST aims to provide collecting area of the E-ELT, but for ~10-20x lower cost and at "*fast*"er speed**

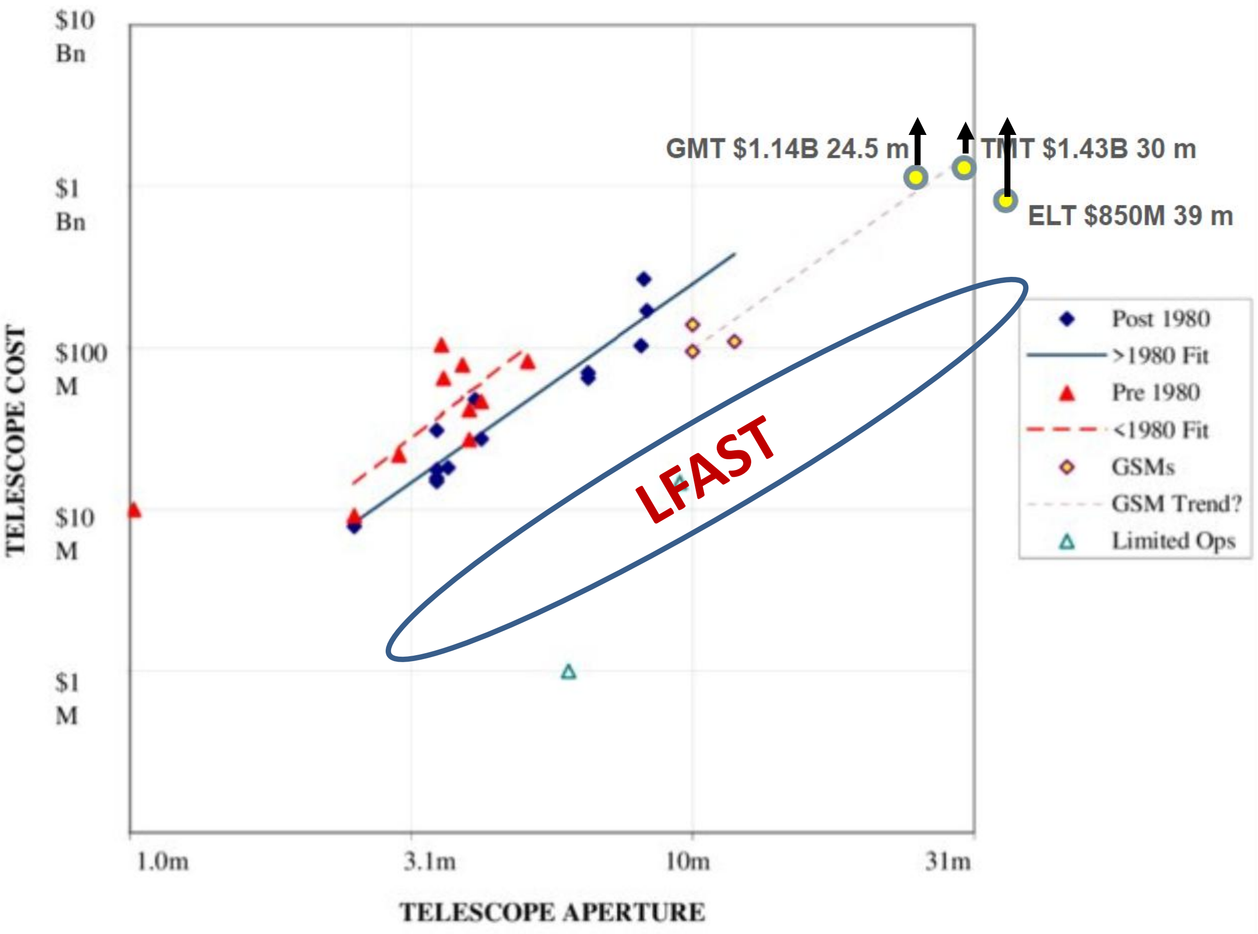



*Figure modified from Van Belle et al. 2004, Berkson 2023*

THE ASTROPHYSICAL JOURNAL, **218**:776–782, 1977 December 15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**An old idea!**

# A VERY LARGE OPTICAL TELESCOPE ARRAY LINKED WITH FUSED SILICA FIBERS

J. R. P. ANGEL, M. T. ADAMS, T. A. BOROSON, AND R. L. MOORE
Steward Observatory, University of Arizona
*Received 1977 April 15; accepted 1977 June 10*

## ABSTRACT

The practical limit in area for single telescope mirrors is around 20 m$^2$. In order to make much larger telescopes, necessary for the study of very faint objects, light must be collected by more than one mirror. A relatively inexpensive telescope with a collecting area of several hundred square meters can be constructed with fibers to bring together light from many mirrors, each of area ~5 m$^2$. This approach is made possible by the recent development for communications of fused silica fibers which show high transmission in the spectral range 0.3–2 $\mu$m over lengths of ~20 m, and which do not badly degrade focal ratio over the same distance. Several single fibers at the prime focus of each mirror would each pick up light from an area of a few square arc seconds, matched to the typical seeing disk. This approach is ideally suited for spectroscopy because the fiber ends would be brought directly to a line at the spectrograph slit. We suggest that flexure errors in the mirror support structure be compensated for by moving the fibers at the prime focus, and that the star field at each prime focus as seen by a sensitive imaging detector be used to determine the correction. No lasers or secondary optics are then needed to coalign the mirrors, and the telescope is made useful for deep imaging by summing all the detector outputs.

*Subject heading:* instruments

# We all know how that ended up…

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3 GMT 8.4m segments, stacked to save space!

**Loading glass for GMT Mirror 7 in October 2023**

*If you're in Tucson, contact me for a tour!*

# What science can large array telescopes do?

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*(phased telescopes are great, but much science doesn't need their angular resolution!)*

- On-demand spectroscopy at R=10,000 – 100,000+
  - High-signal to noise cases
    - Terrestrial (and other) exoplanet atmospheres
    - Disk integrated stellar astrophysics at high spectral resolution and SNR?
  - High cadence follow-up of transients (from ZTF, LSST/Rubin, etc.)
    - Mass loss in stellar evolutionary end states (SNe shocks with circumstellar material)
    - GRB afterglow rapid follow-up
  - Photon starved studies of IGM using quasar spectra absorption lines
    - Chemical and thermal history of the IGM
    - Evolution of fundamental physical constants
    - Studies of large scale structure
    - Constraints on cosmic re-ionization

*(Note: I am not a galactic or extragalactic astronomer, but the science team has several experts. If interested in these topics beyond my knowledge, reach out to **Dennis Zaritsky**)*

***Dedicated spectroscopic facilities at 10-m class, ELT class, and larger***

# What science can large, array telescopes do?

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## *What about for intensity interferometry?*

- On-demand, large apertures with “decent” image quality
  - Resolved stellar disks (stellar activity) to support RV science
    - Can this get tagged as HWO precursor / supporting science?
  - Binary stars, astrometry, star and exoplanet orbits & masses
  - Resolved AGN science
    - Norman Murray: “ Need another 3 magnitudes of sensitivity from current facilities” – LFAST can give you this!
  - Resolved supernovae science
    - Bright tail of objects from LSST/Rubin will be accessible

***Dedicated intensity interferometry facilities at 10-m class, ELT class, and larger??? (or use the bright time??)***

# LFAST is a scalable array of O/IR telescopes

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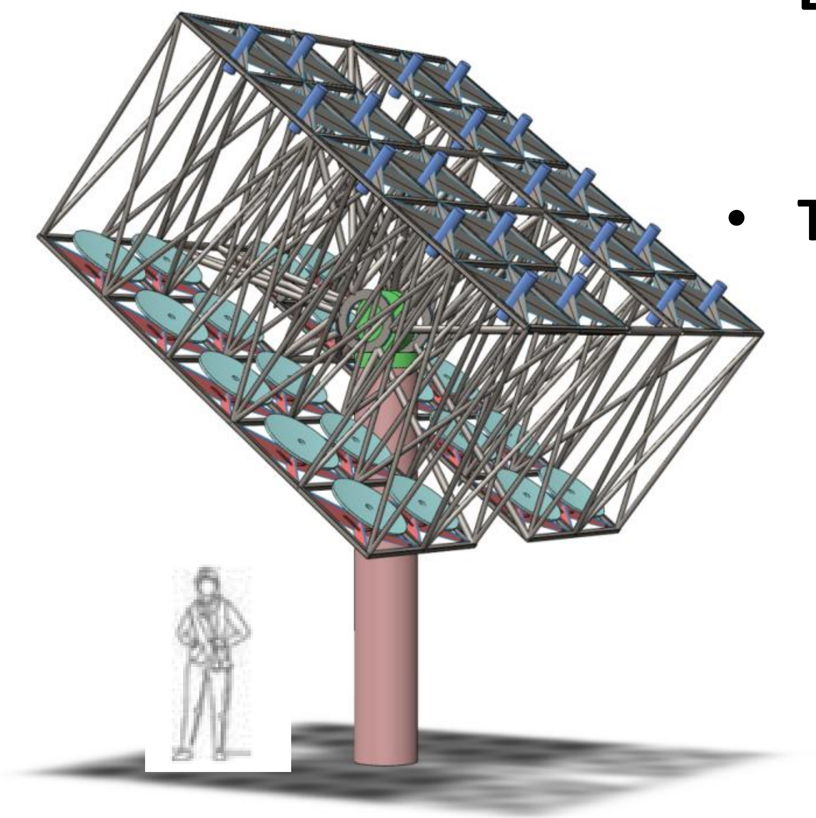
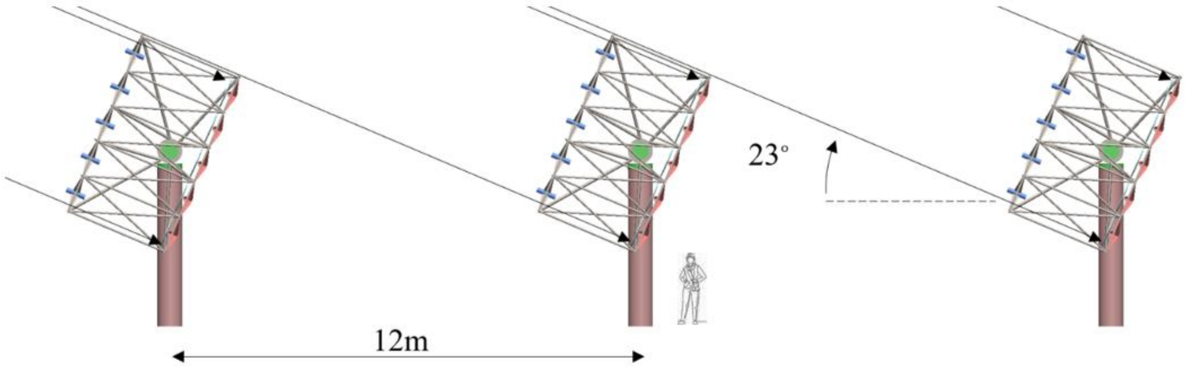
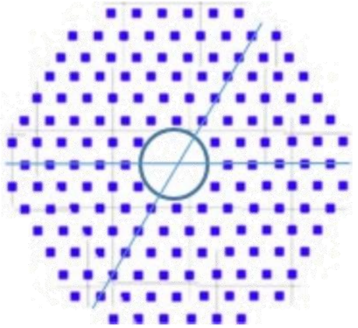
- **Unphased array lowers cost and complexity,**
  → **but still enable cutting edge science**

- **Leverage mass replication of a highly engineered system**
  → ***prototype and build fast, take risks, try to be more like industry***

- **Twenty 76 cm, f/3.3 telescopes, on an Alt-Az mount,**
  **(equivalent to a monolithic 3.5 m telescope)**
  - ***10 units = 10 m equivalent (Keck)***
  - ***132 units = 1200 $m^2$ (ELT equivalent)***





# Where will we put this?

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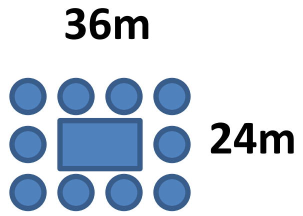
- We're currently looking across the world for potential sites

- 10-m class – 10 structure system is the first site needed
  - Located in the Southwest USA. Drivable from Tucson
  - Approximately 36mx24m site (but not fully developed)
  - 1" seeing to minimize loss at fiber input (bigger fibers → bigger spectrographs)
  - Large number of clear or spectroscopic nights
  - Minimal or consistent wind – no domes!
  - Infrastructure already in place (roads, power, water, data)
  - Interest by site owner of hosting a 10-m class facility




10-unit LFAST + instrument building

# Unit telescope design:

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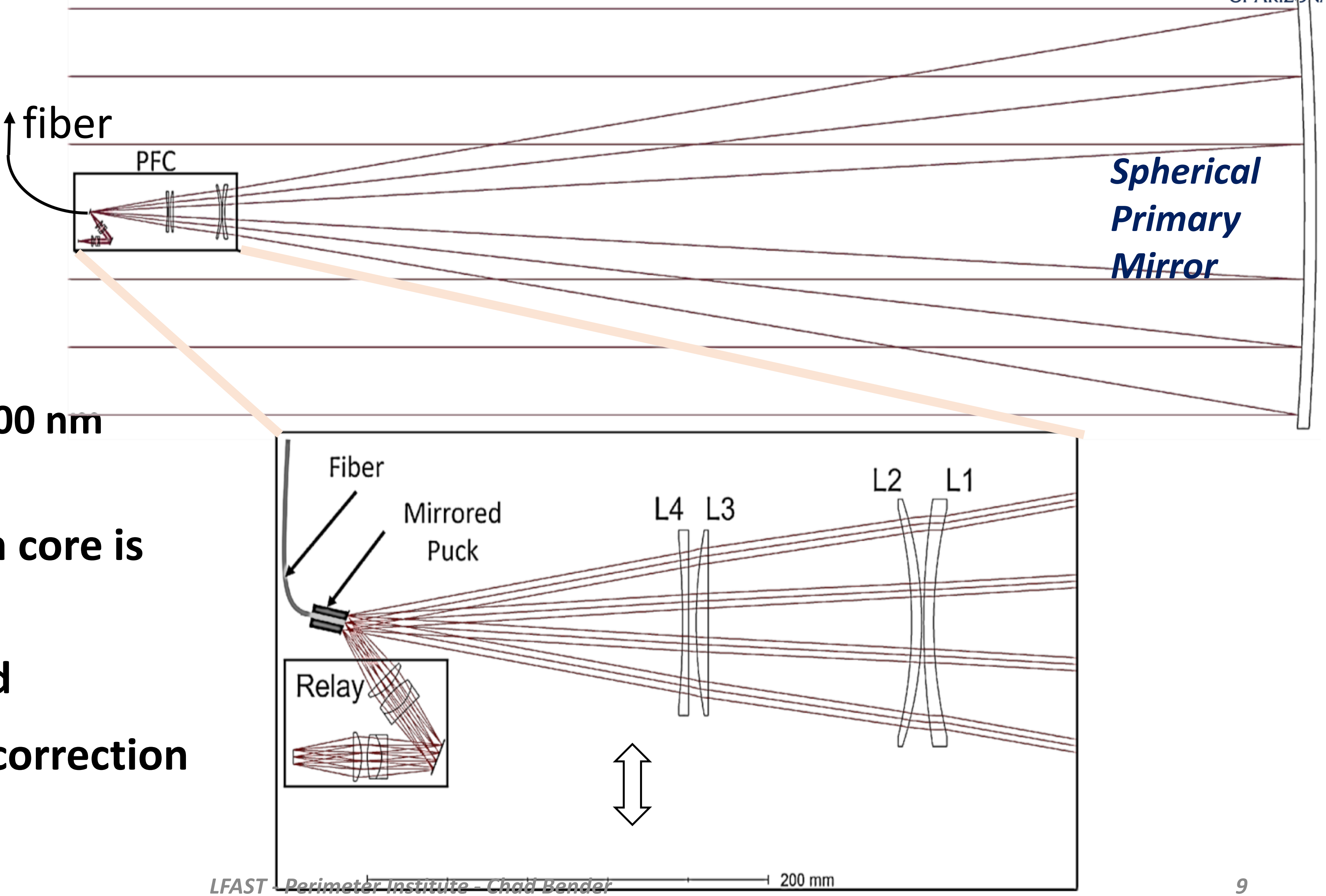
- **76 cm f/3.3 spherical primary – *no axis!***
- **Spherical surfaces mean faster fab.**
- **PFC supports 400nm – 1800 nm**
- **Fused silica fiber, 18 µm core is 1.4” on the sky**
- **8-arcminute guide field**
- **L4 gives ADC and jitter correction**



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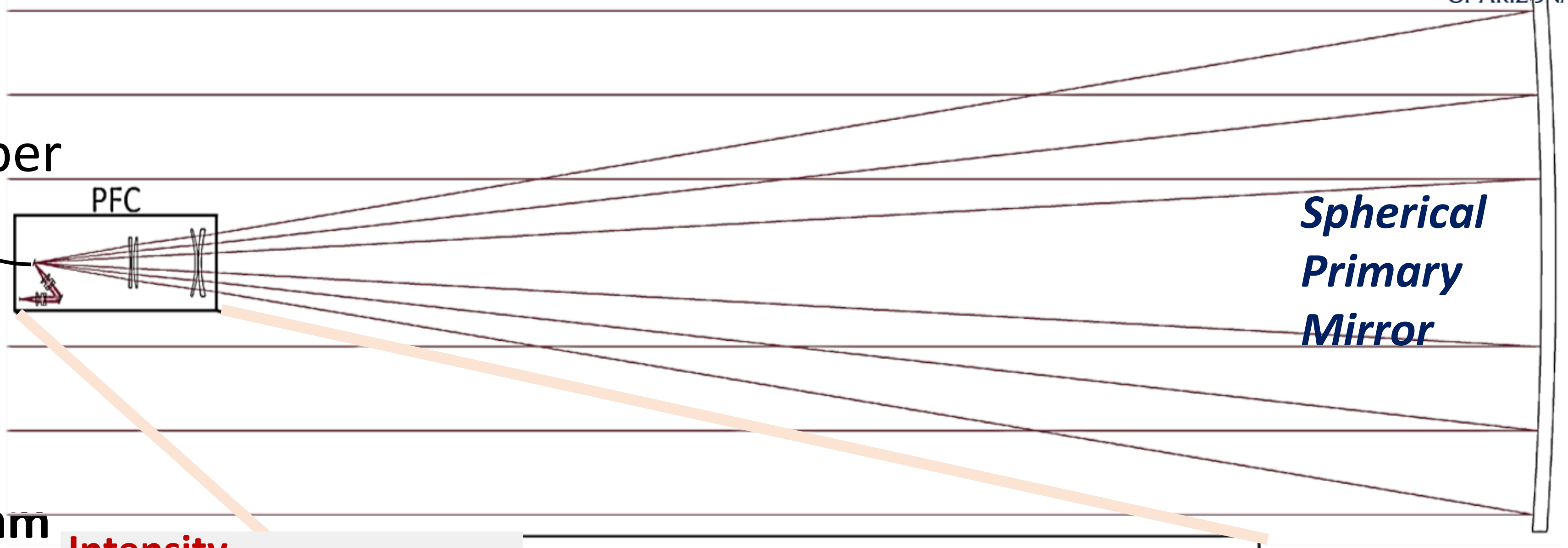


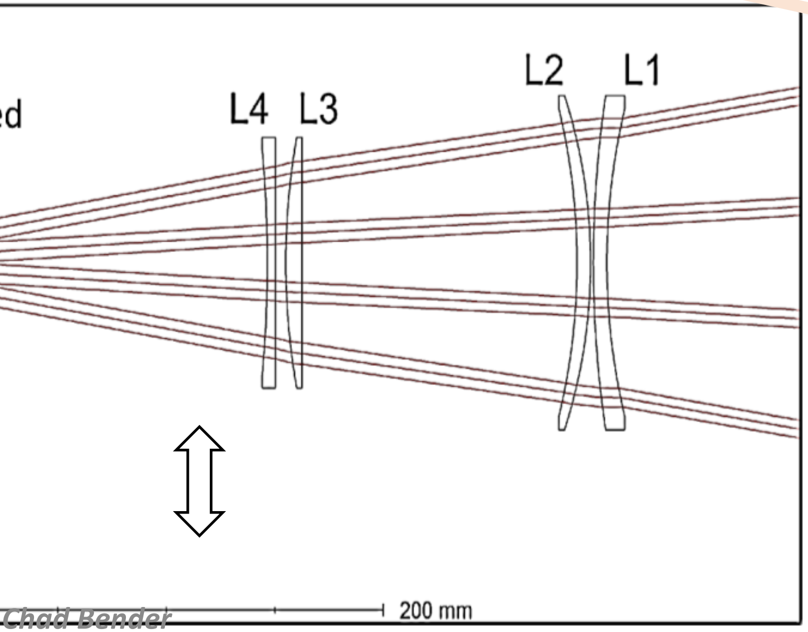


Intensity Interferometry Mod?

# Optical Subsystems:

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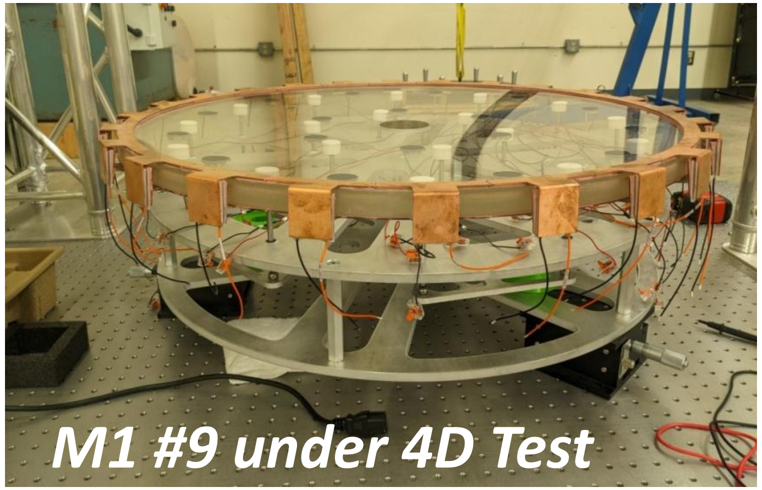
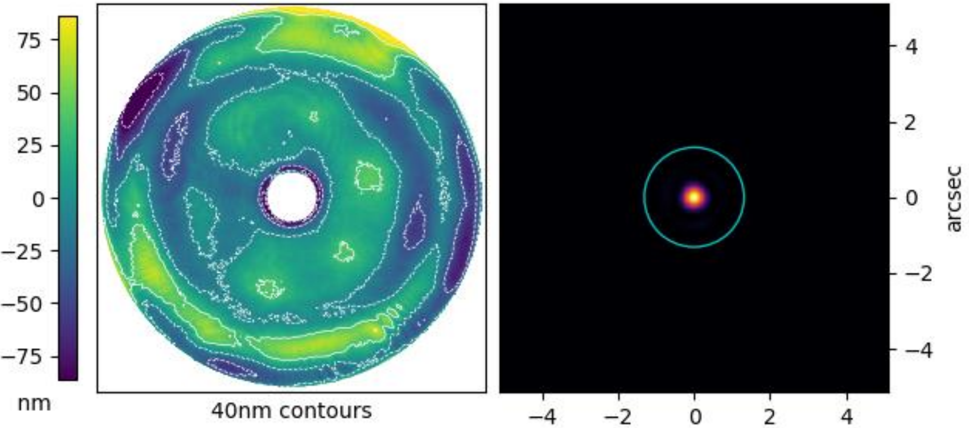
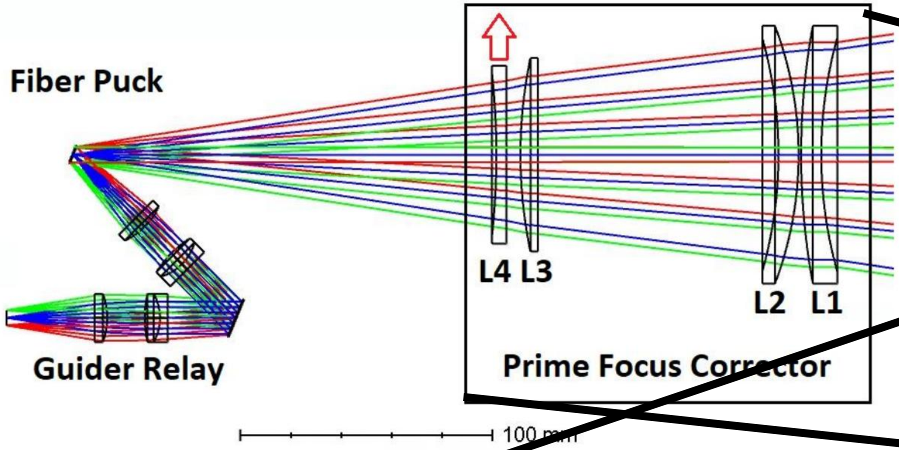
## *Primary Mirrors:*

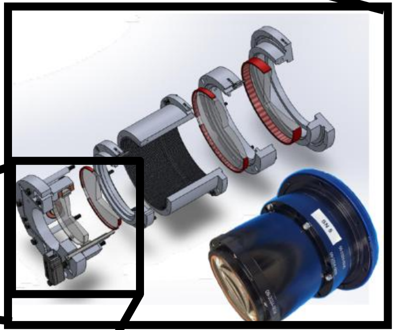


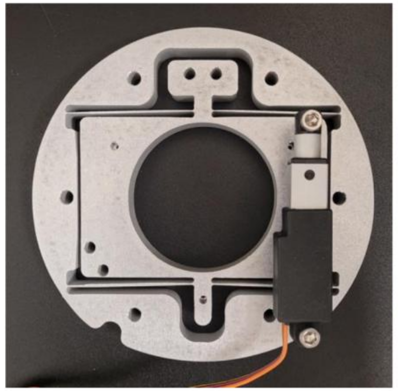

Sph subtracted iteration 6 has 32nm rms wavefront error and 87% efficiency

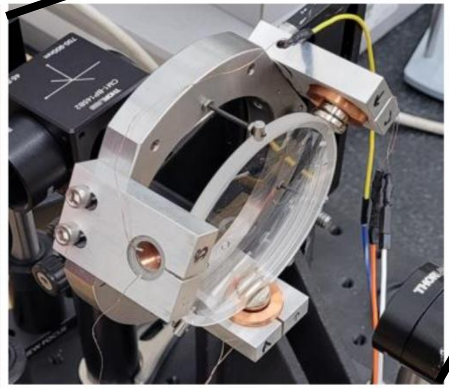



***Mirror with TEC correction approaches diffraction limit***



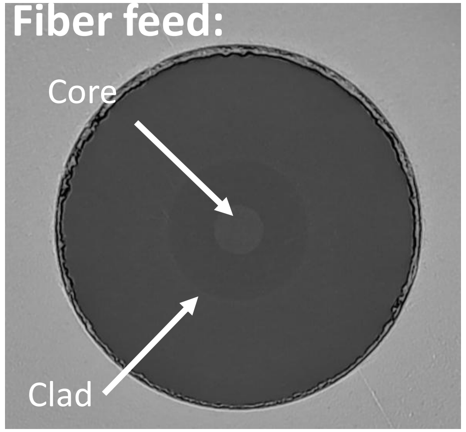



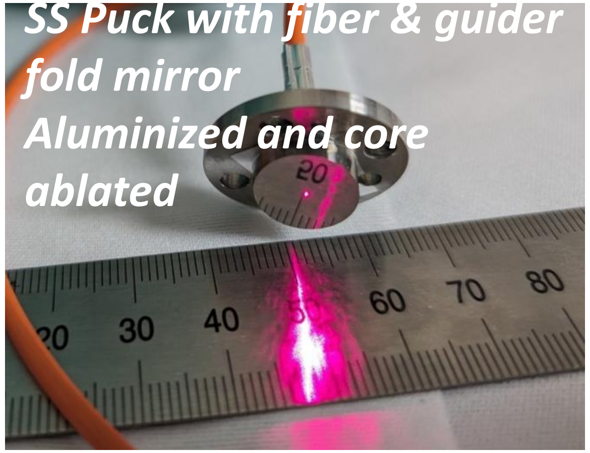




***L4 30 Hz active correction for wind and seeing***

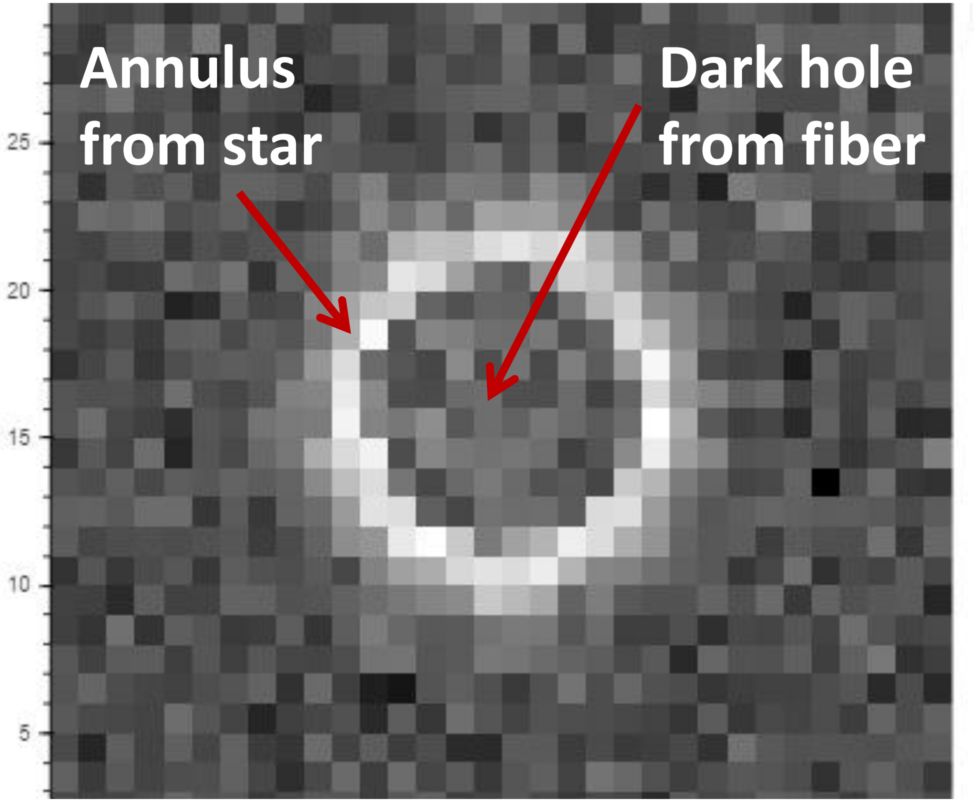
***More details in SPIE last summer***



# Guider Performance

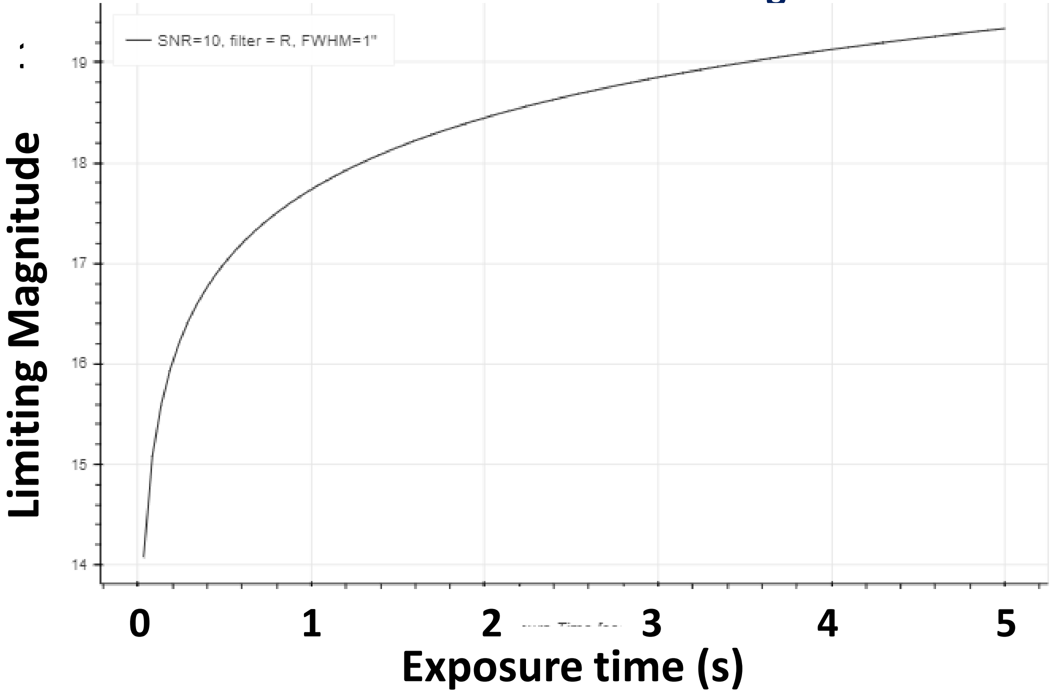
**High speed corrections (30Hz) for on-axis objects become photon starved at $R_{mag}$=11**




**Simulated annulus for:**

- $R_{mag}$=10 in 1” seeing around 1.4” fiber
- IMX226 CMOS with RN=3e$^{-}$

**Slow, off-axis guiding performance predicted SN=10 @ $R_{mag}$=17.5**




**In 8’ guider FOV, chance of at least one guide star:**

- **R<14 is 85%**
- **R<15 is 98%**
- **R<16 is 100%**

# Fiber Feed Design: "De-slicing" the telescope

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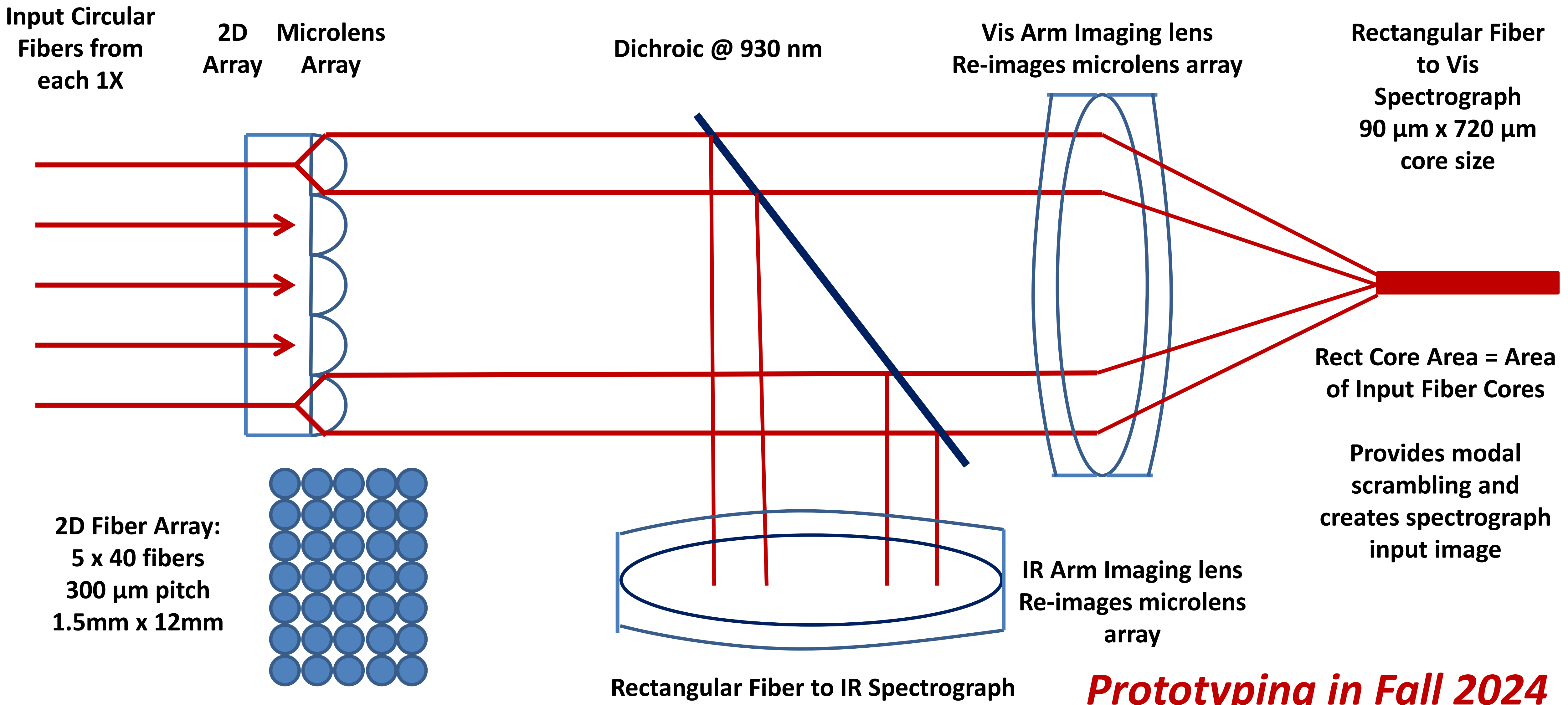


Provides modal scrambling and creates spectrograph input image

***Prototyping in Fall 2024***

# Fiber Feed Design: "De-slicing" the telescope

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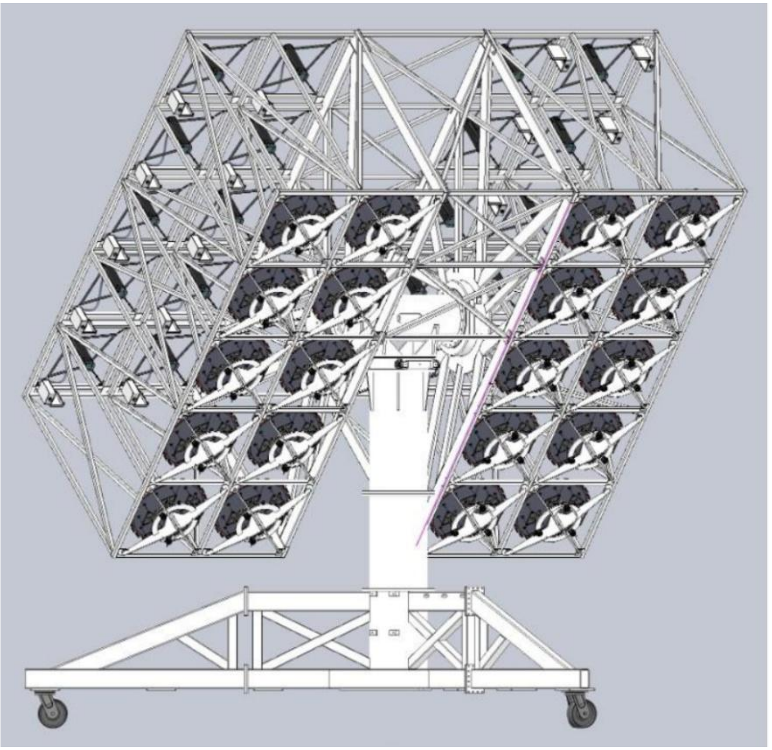
**May not want to do this for intensity interferometry**

***Prototyping in Fall 2024***

# 20-X Prototype Structure:

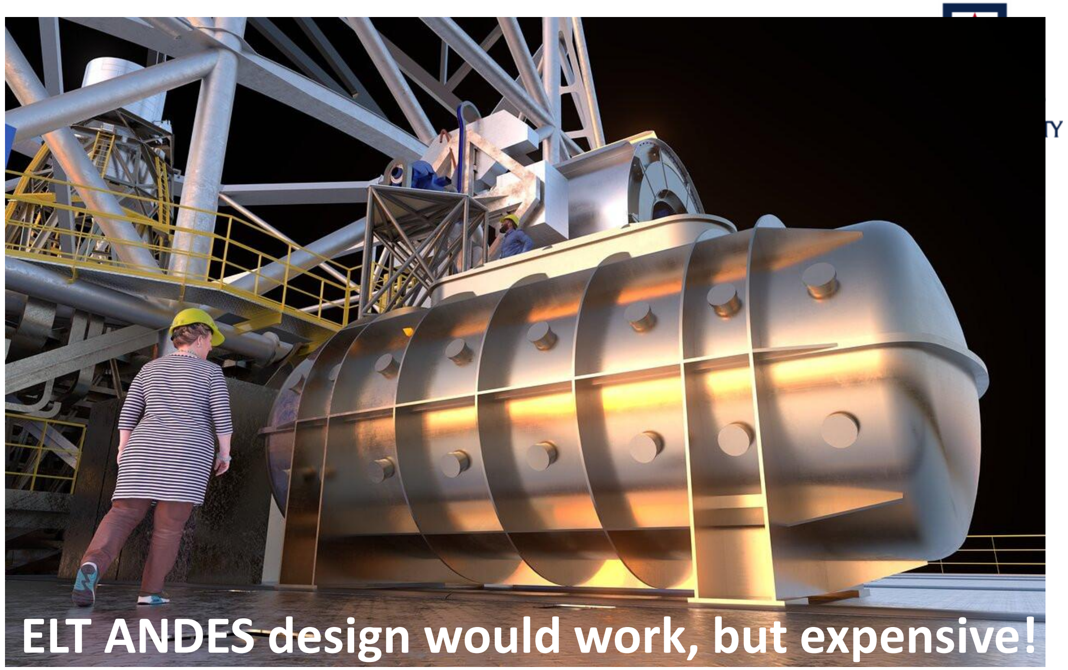


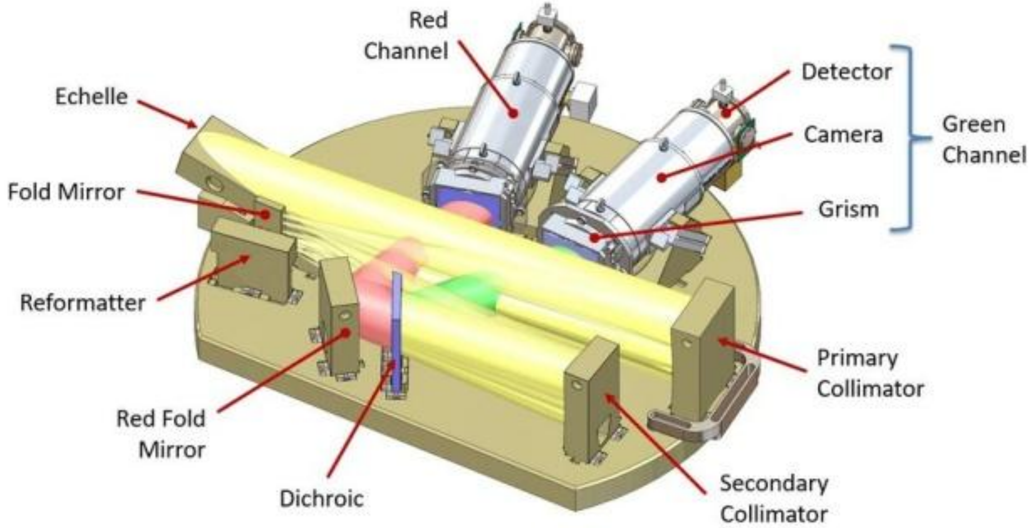
*Prototype structure designed around portable  pier to enable indoor & outdoor integration and testing*

*Frame assembly completed in August*

# Standard LFAST implementation feeds spectrometers

- PFC optics support 400nm – 1800nm
- étendue equivalent to traditional telescope, so we need a huge spectrograph!
- Biosignatures desire a high resolution (R~100 – 150K in VIS, R~80K in NIR), but extragalactic only needs R~10K
- But, what instruments do we want for intensity interferometry? If you suggest (or build) it, we can easily fiber connect it to the telescope or mount at prime focus.


ELT ANDES design would work, but expensive!



KPF design proven for 10-m class – multiplex??

# Spectrometer Concept: 10m class, Two Arms

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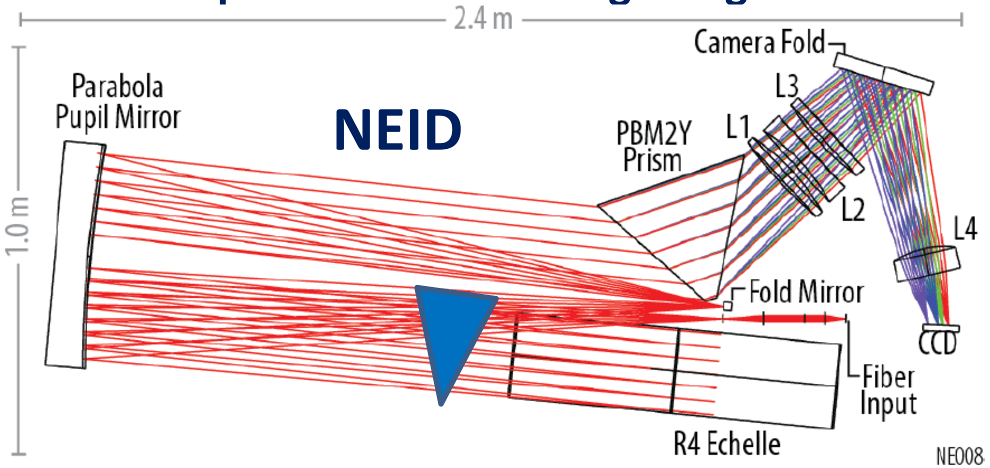
## *Visible*

- 380 – 870 nm (Ca HK – Ca IR Triplet)
- R=150,000
- 10k x 10k 9 micron pitch CCD
- 2.5 pixel / res sampling (minimum)

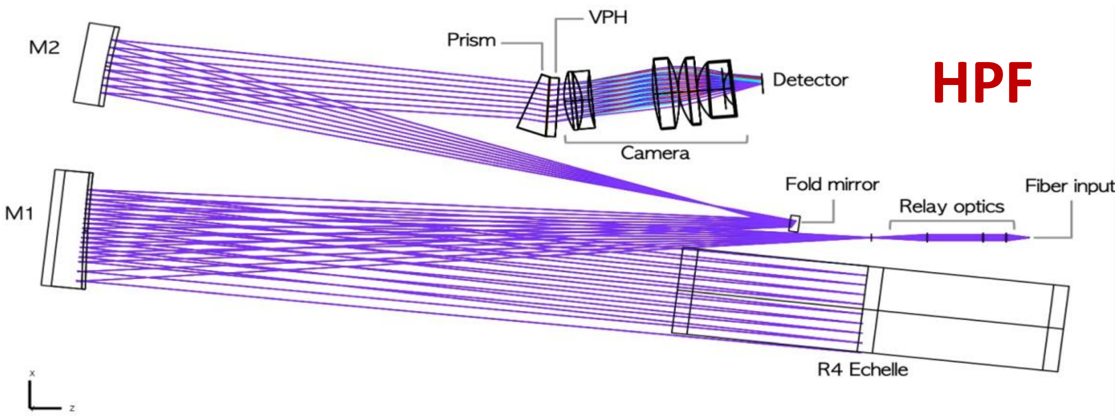
**This is a modified NEID white pupil design. Cross-dispersion needed for the larger étendue accomplished by adding a second prism in collimated space in front of the grating.**




## *Near-IR*

- 1.15 – 1.8 micron (bluer if possible)
- R=80,000
- Hawaii-4RG 4k x 4k 15 µm pitch FPA
- 2.5 pixel / res sampling (minimum)

**This is the Habitable Zone Planet Finder white pupil design, but with a bigger detector, shifted into the H-band,**



# Prototype unit telescope

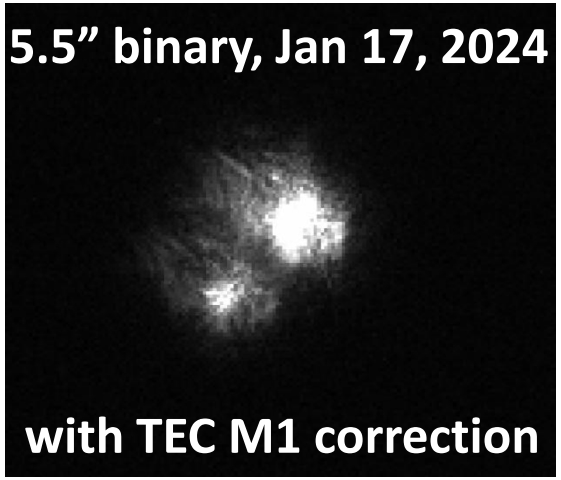
- Single 1X prototype
- Full scale mount, half scale drive
- First light May 2023
- Weekly on sky during Fall 2023, Winter 2024

*Engineers Kevin Gilliam & Erich Bugueno setting up for night-time testing*

# LFAST 1X on-sky


Images at
Prime Focus:

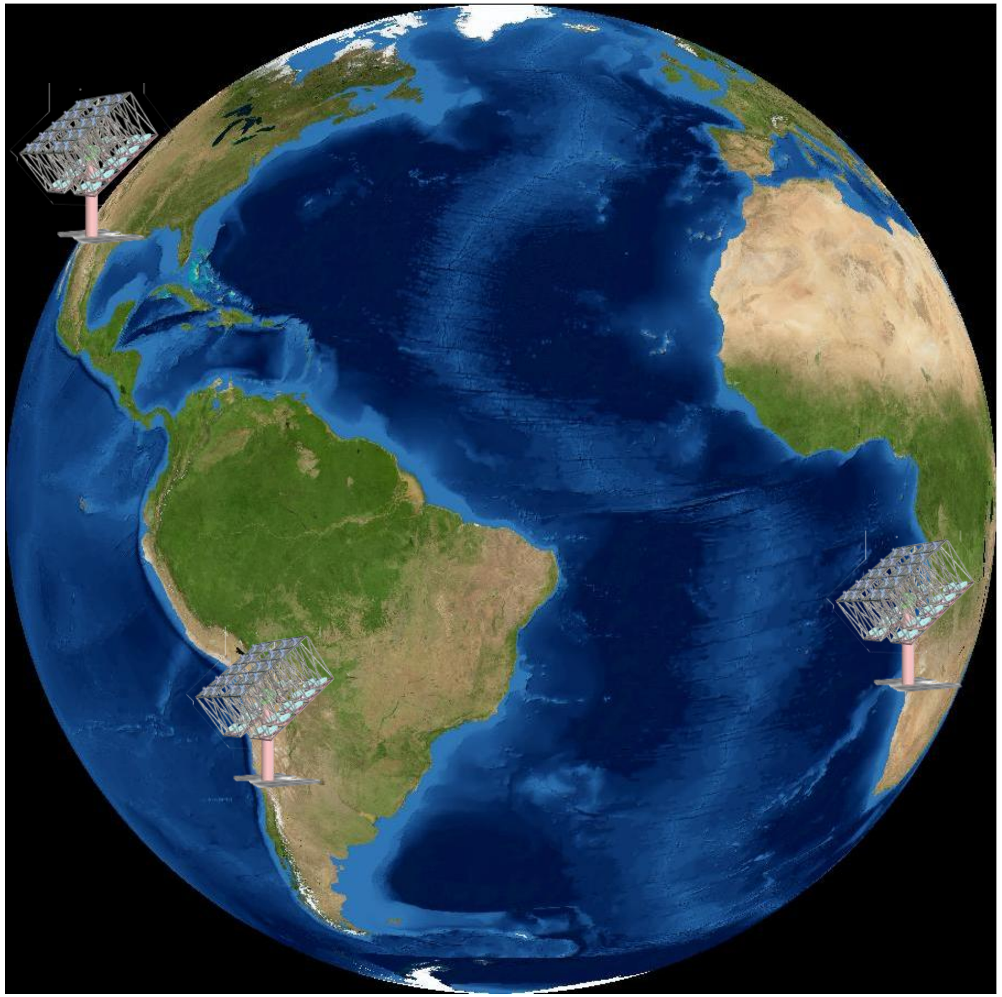


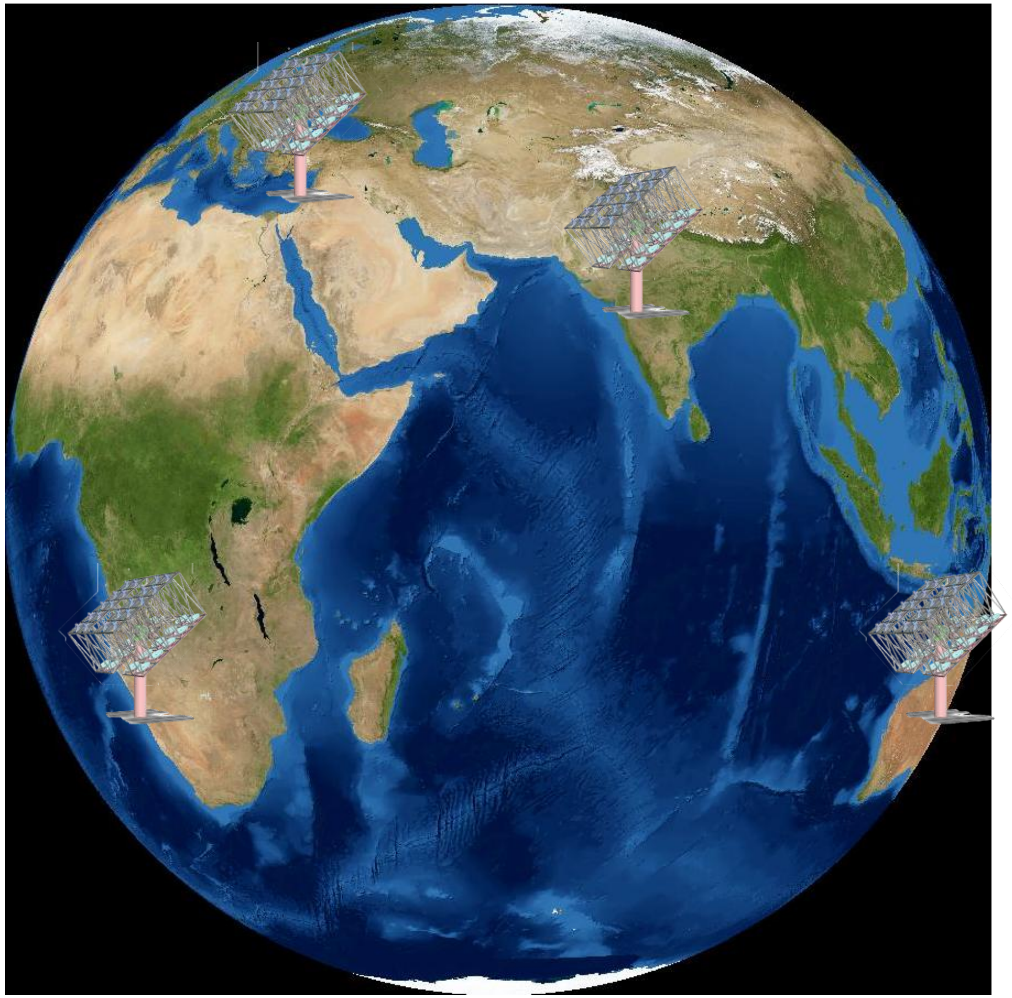



# LFAST can provide EHT baselines and near continuous coverage with longitude

**LFAST 1000 m$^2$ arrays produced on an assembly line could span the globe for < $ than one current ELT**

**(Caveat: Locations shown are conceptual only and do not indicate any agreement with site holders)**





(Images from https://www.fourmilab.ch/earthview/vplanet.html)

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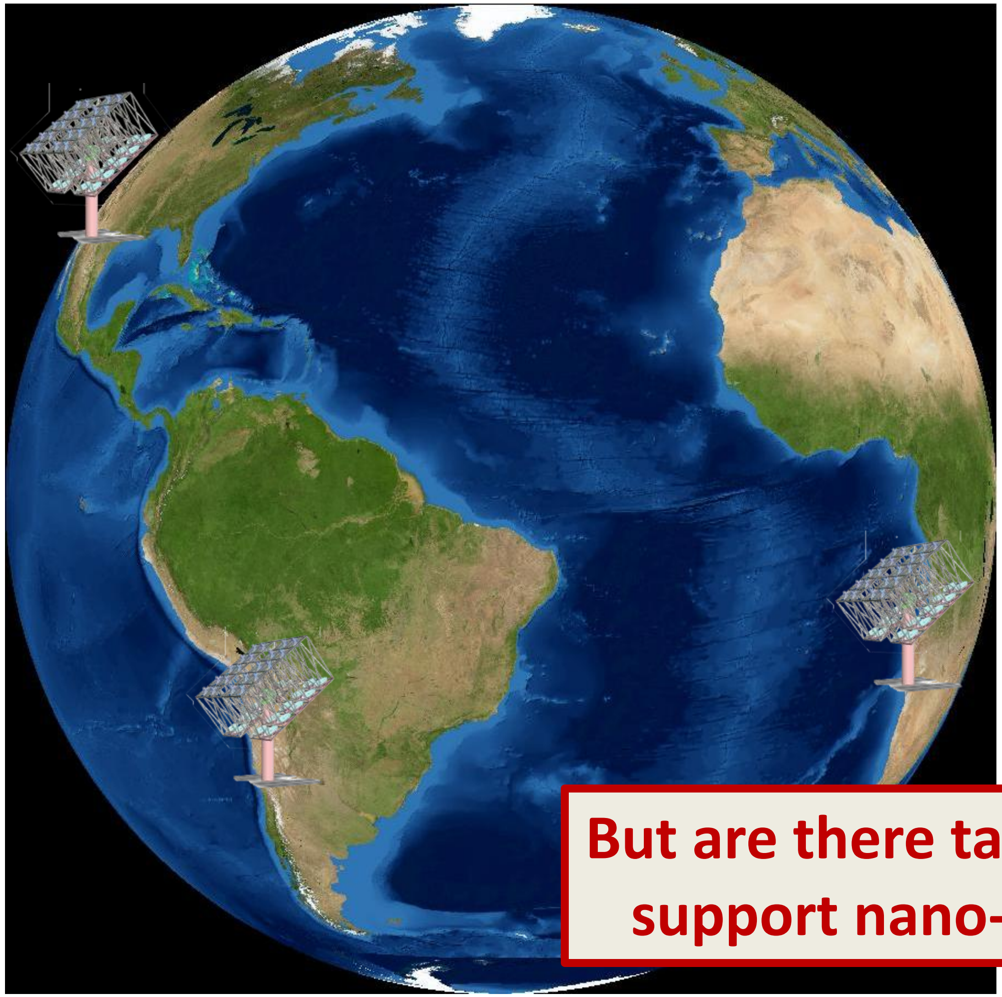
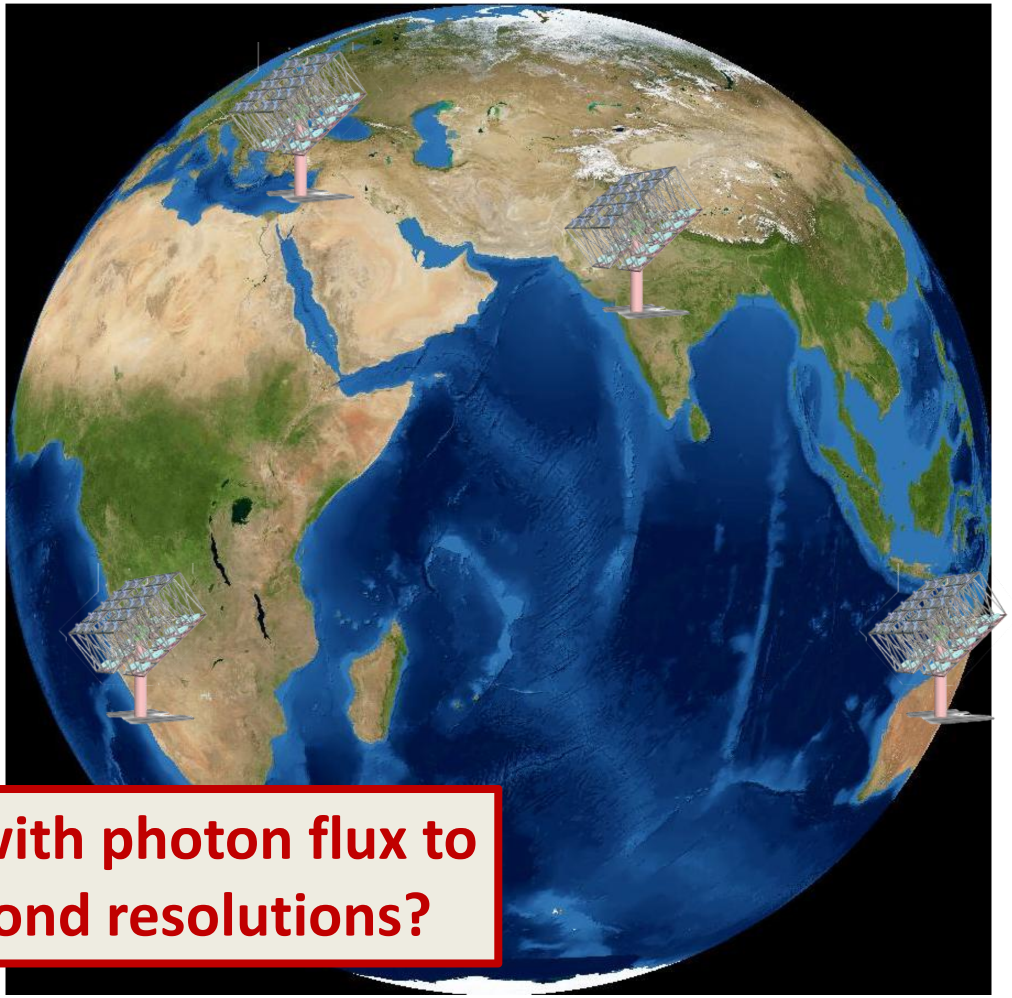


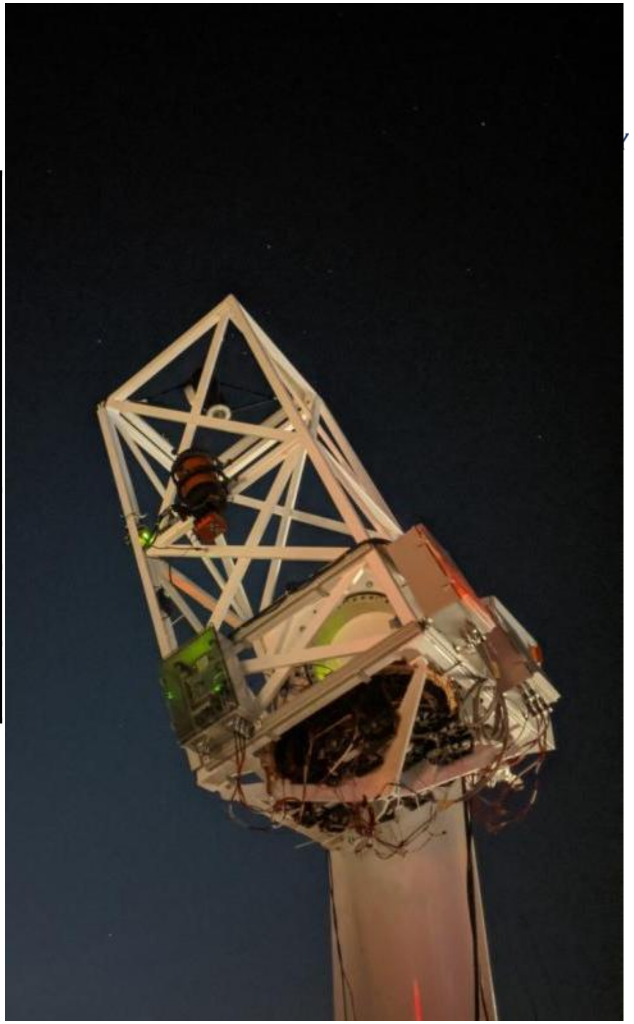


**But are there targets with photon flux to support nano-arcsecond resolutions?**

(Images from https://www.fourmilab.ch/earthview/vplanet.html)

# LFAST: An economical ELT

| Prototype Phase (20X – 3.5m) | | | 200X Phase (10-m) | | | ELT Phase (1200 m$^2$) | |
|---|---|---|---|---|---|---|---|
| 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 |
| | Science Book | | | | | | |
| 1X Build & Test | | 20X Build | On-Sky | Operations? | | | |
| | | | 200X (10 unit - 10m equiv.): Build | | | On Sky Operations | |
| | | | | | | ELT Array Start | |
| | | | | | Plan worldwide network | | |



- ***Science and Programmatic Thoughts:***
  - ***The capabilities/requirements of instruments get defined early! By PDR certainly!***
  - ***Talk to me now (or soon) about intensity interferometry science cases and/or hardware modifications we need to consider.***

***The LFAST prototype is supported by Schmidt Sciences, LLC***

The University of Arizona

Schmidt Sciences