The SHERA Concept

An Astrometry Mission to Detect Earth Analogs Orbiting the Nearest Sun-like Stars

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A Future Space Mission with Very High Precision Astrometry, IAP, Paris, Sept 11-13, 2024

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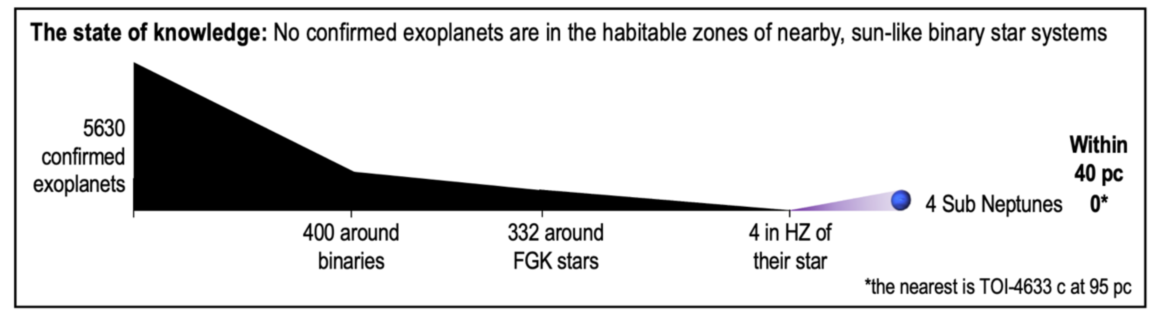
MISSION

SHERA: Searching for Habitable Exoplanets with Relative Astrometry

Landscape of Binaries and Planets:

- A healthy fraction of all nearby Sun-like stars are in binaries/multiples
- Of the 5600 planets less than 10% are found in multiple systems, and **0 of those lie the habitable zones of nearby systems**
- We are lacking in knowledge about the stellar systems that make up a significant portion of potentially habitable zones



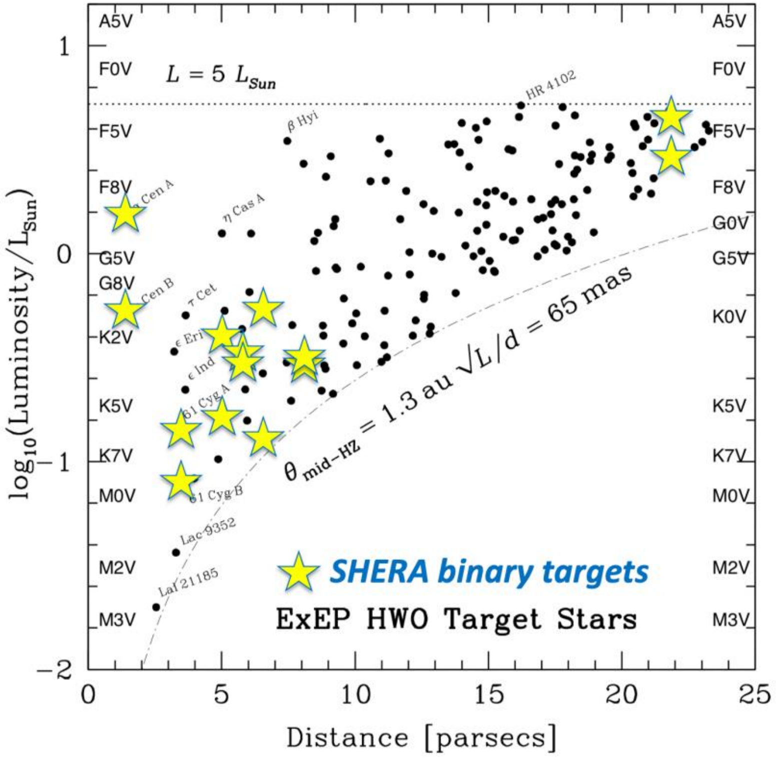
Astrometric Approach:

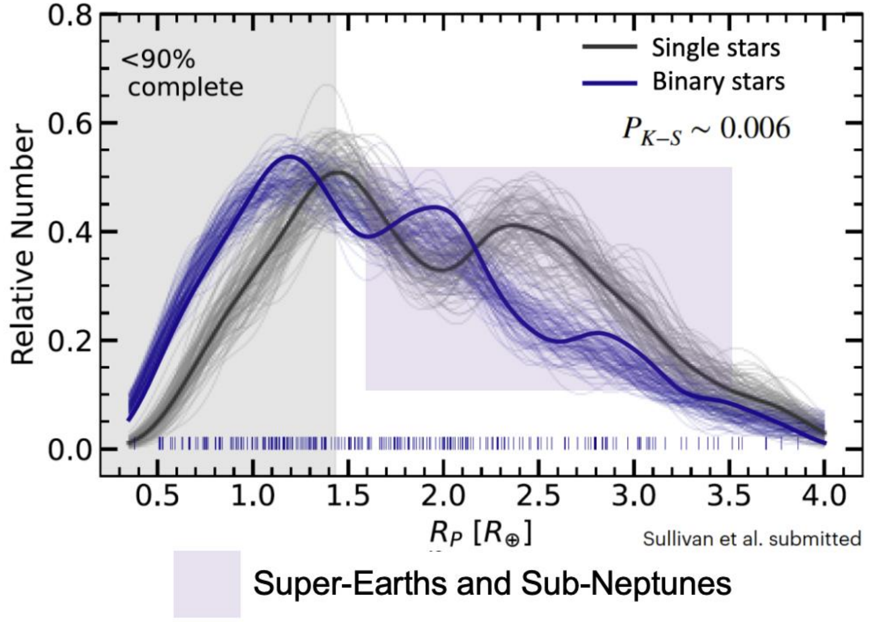
- Use binarity for precise relative astrometry between pairs
- Use a payload is a diffractive ~22 cm M1 in a two-mirror telescope, deployed to a low Earth orbit (LEO)
- Conduct repeated observations ≥10 visual binaries over a 3-year mission to monitor separations to uas levels

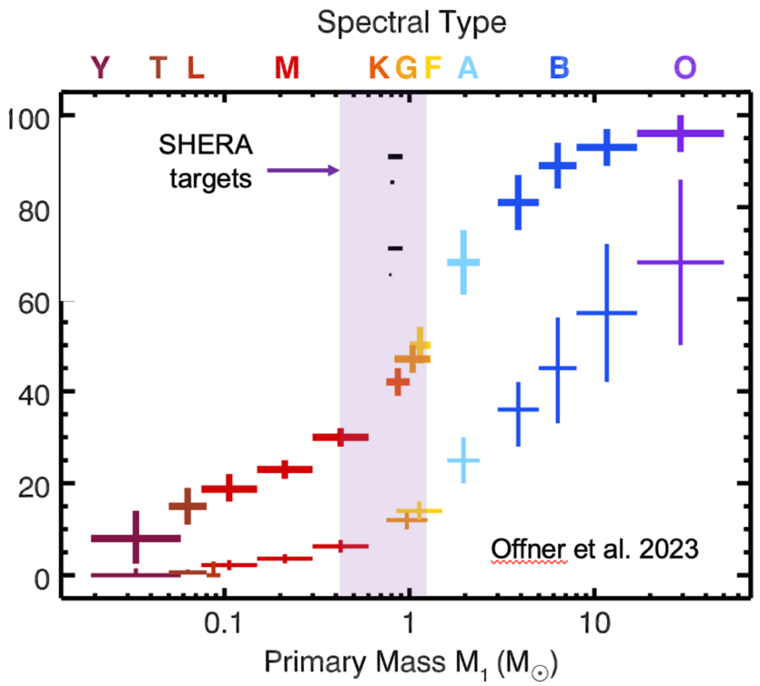
Astrometric Technology:

- Develop diffractive optic PSF shaping approach and advance systems TRL on < 2 yr timescale
- Maintain aggressive development timeline to be considered for upcoming Astrophysics SMEX cycle

Objectives Trifecta: High Priority Targets, Occurrences, Binary Suppression



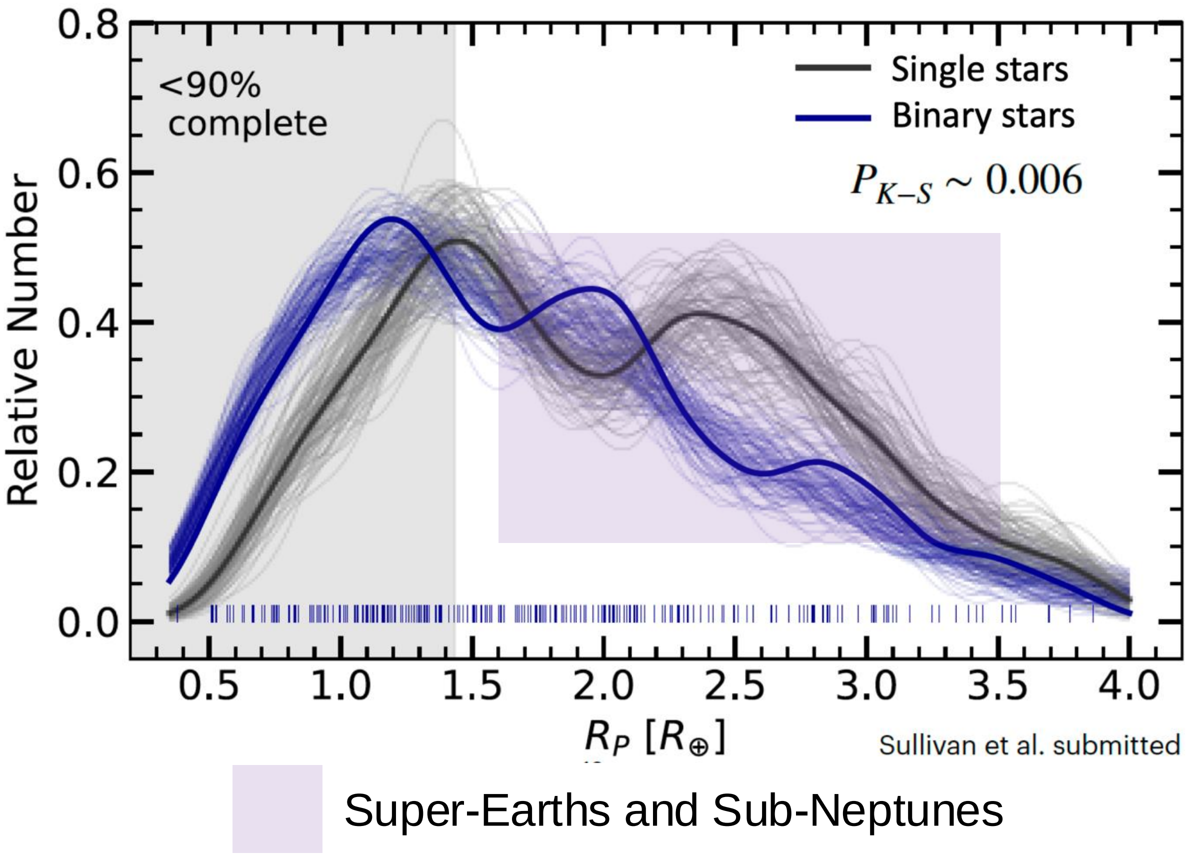




Science Objectives: Suppression

Test the supression of small planets in the habitable zones of binary Sun-like star systems compared to single Sun-like stars;

- Although planet formation largely predicts a reduced number of planets in binary systems at intermediate (10s-100s of au) separations, observations find conflicting results (see e.g. Figure right), and there are no constraints at habitable distances
- Constraining this would be *critical* input to planet formation theory
- Observing a certain number of stars with sensitivity to super-Earths and sub-Neptunes in their HZs, to count if small planets are suppressed in binaries



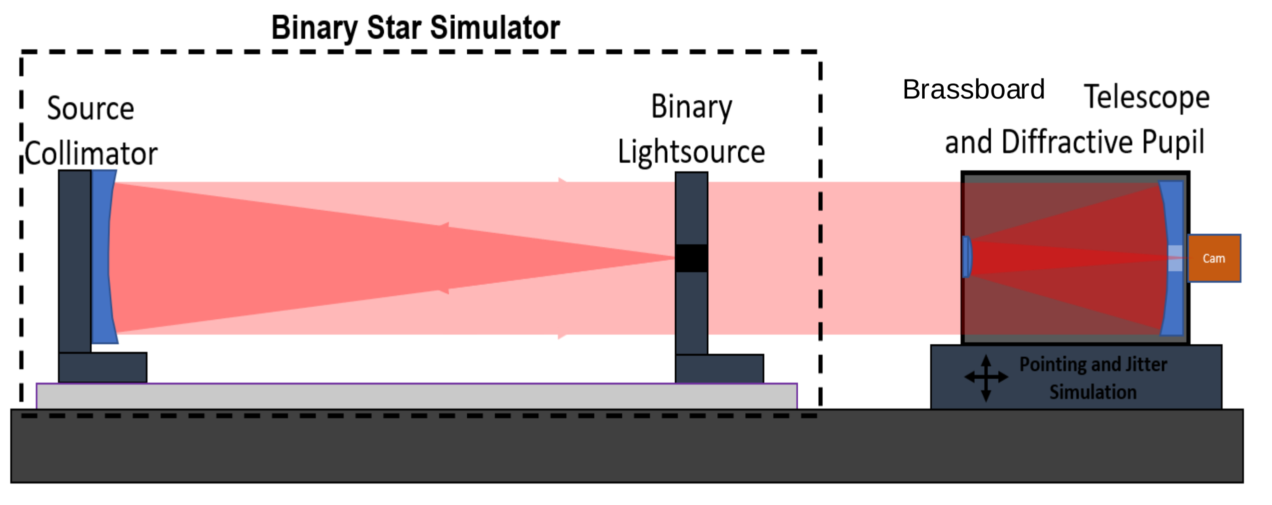
JNEXT/SHERA Technology program

- Goals: Develop SHERA components/methods to requisite TRLs

- Technology testbed with a 10 cm diameter two-mirror telescope with a diffractive M1
  - M1, M2, Filter, Sensor
  - Thermal control system
  - Data modeling and astrometry analysis

- Vacuum environment with a PIC binary star simulator to demonstrate separation measurements at the uas level

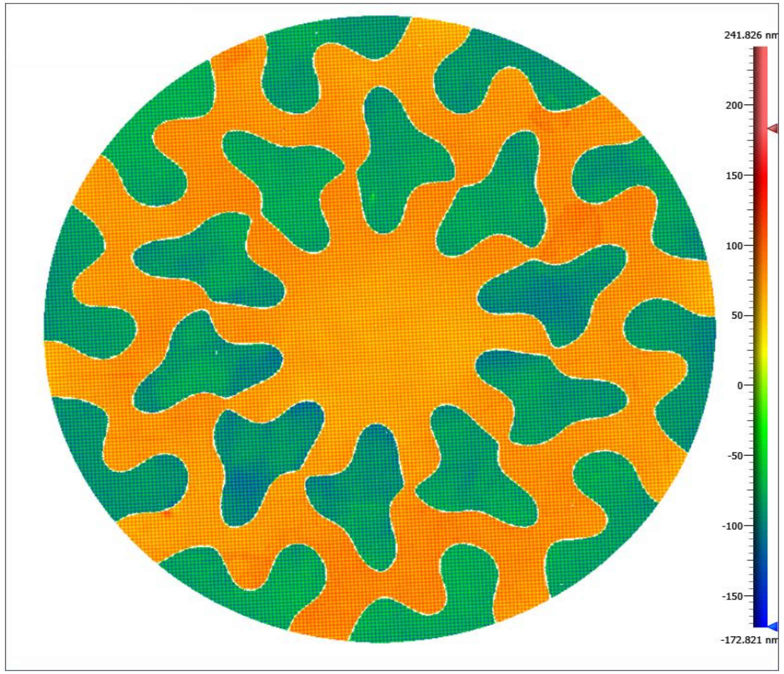
Component:	Functionality:	Performance Requirement:
Diffractive Pupil	Create a specific diffractive pattern at the telescope focal plane that will allow for astrometric measurement extraction.	This image of the pattern created by this DP should match the designed pattern to within a surface error tolerance. Must be done an a Cassegrain-style mirror
Sensor	Capture the diffracted image of the binary stars	Knowledge of pixel location must be known to < 0.3% of pixel pitch. Standard linearity and flat field requirements are necessary
Astrometric Vector Extraction	Process images from the TOLIMAN telescope and extract astrometric vectors	Extract the astrometric vectors at the 1μas level



Diffractive Pupil Fabrication

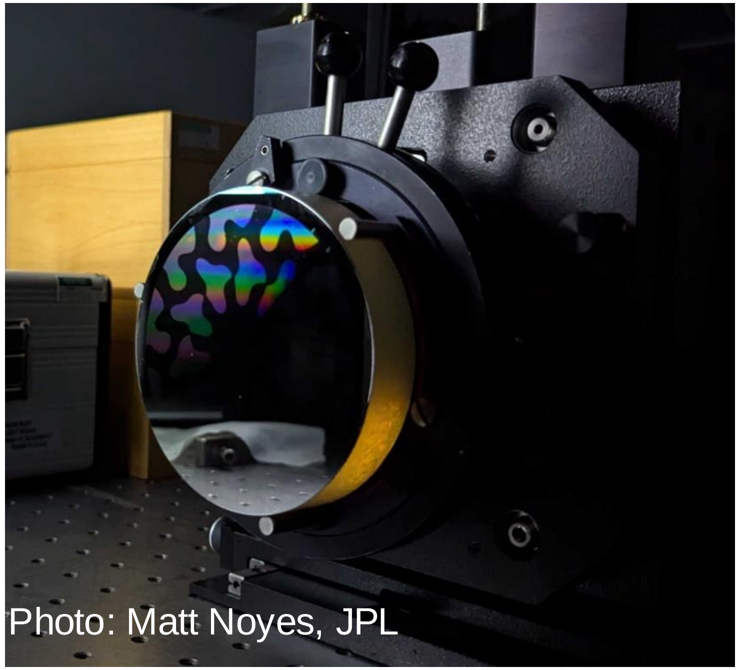
At JPL's microdevices laboratory we have completed the e-beam fabrication of a 10 cm Toliman-style binary diffractive pupil on flat Zerodur (D. Wilson, M. Noyes)

- And measured it to show that final WFE meets Strehl requirements
- Proceeding to fabrication on a 10 cm curved surface with a thru-hole
- Designing a SHERA diffractive optic, suitable for a wide range of targets

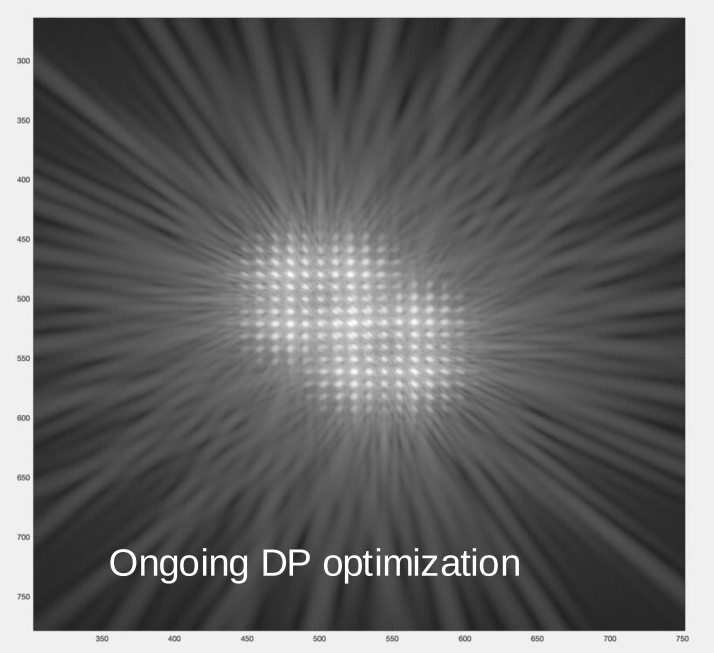


Toliman-style binary DP grating pattern

Photo: Matt Noyes, JPL



DP grating flat in interferometer testing



2D Comb PSF, with a multi-level E-beam diffractive optic

Tuthill et al. 2024, Proc. SPIE, https://doi.org/10.1117/12.3019256
Bendek et al. 2023, Proc. SPIE, https://doi.org/10.1117/12.2677828
Desdoigts et al. 2023, Proc. SPIE, https://doi.org/10.1117/1.JATIS.9.2.028007
Langford et a. 2024, Proc. SPIE, https://doi.org/10.1117/12.3019202

Detector Calibration using Focal Plane Metrology

- Measure the position of CMOS pixels (6.5 um) to ~1E-3 pixel or better relative to a perfect grid;
- Measure the uncertainty in the flat field to similar levels
- Uses laser fringe metrology techniques (Shao et al. 2023, **DOI** 10.1088/1538-3873/ace3f4)

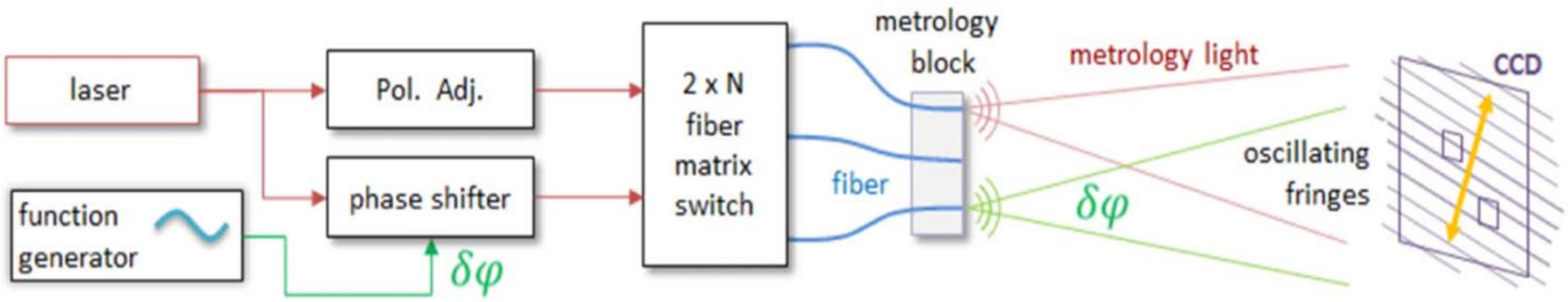
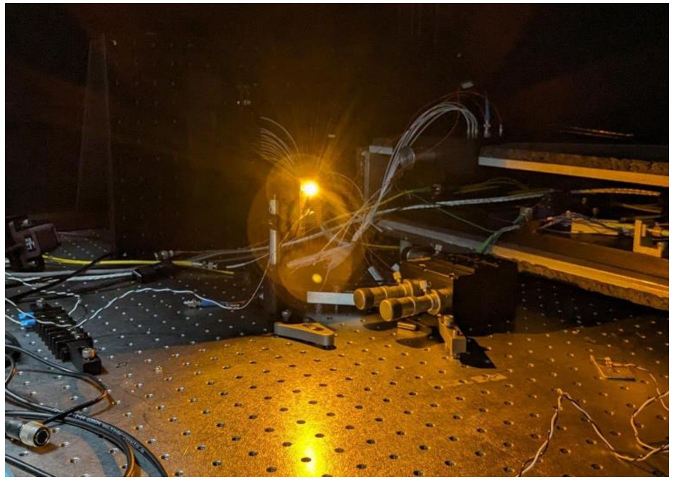


Figure from Shao et al., PASP,135:074502, 2023

Camera (left), sensor edge (right)

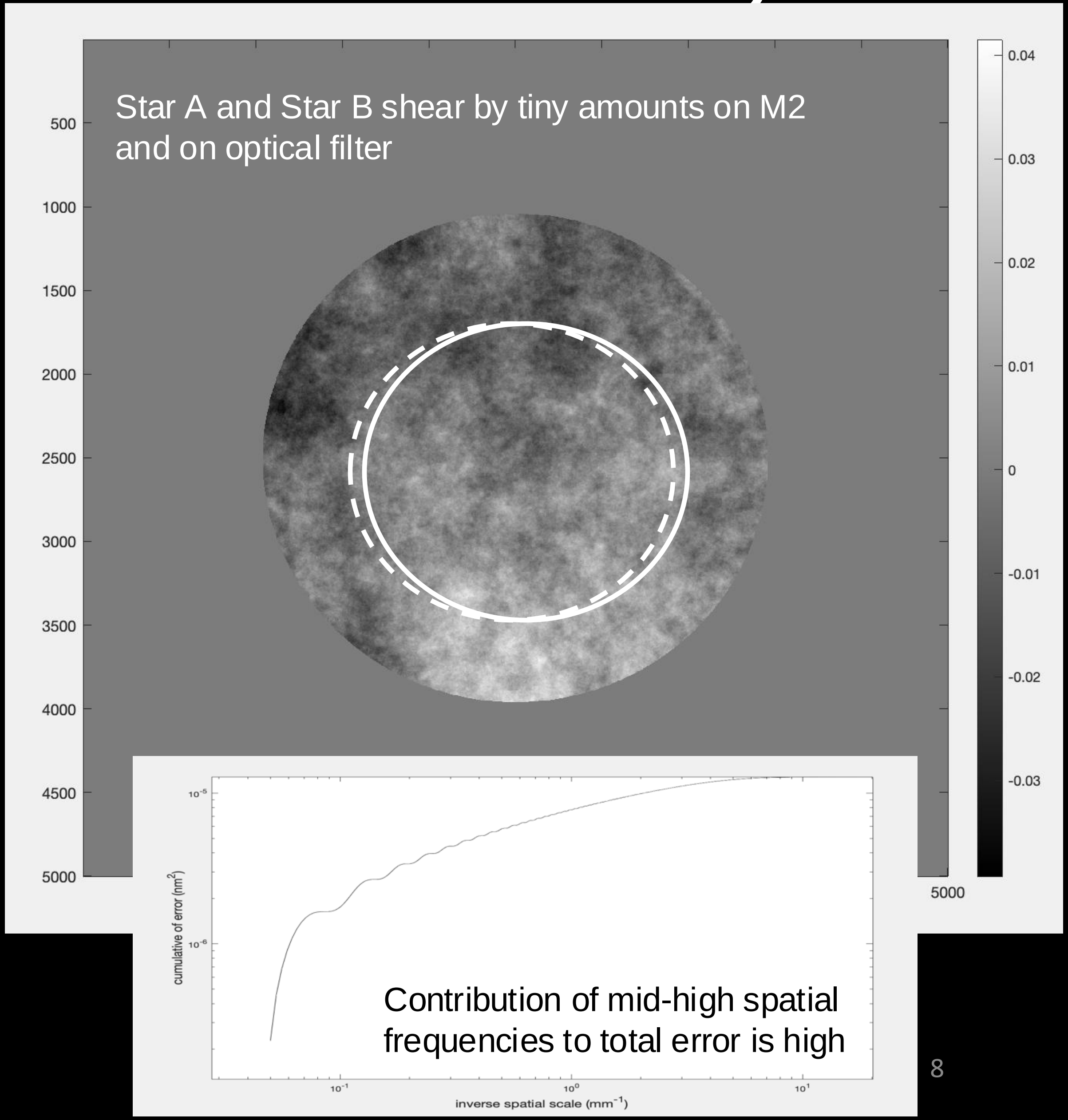


Current calibration lightsource

Photo: Insoeb Hahn

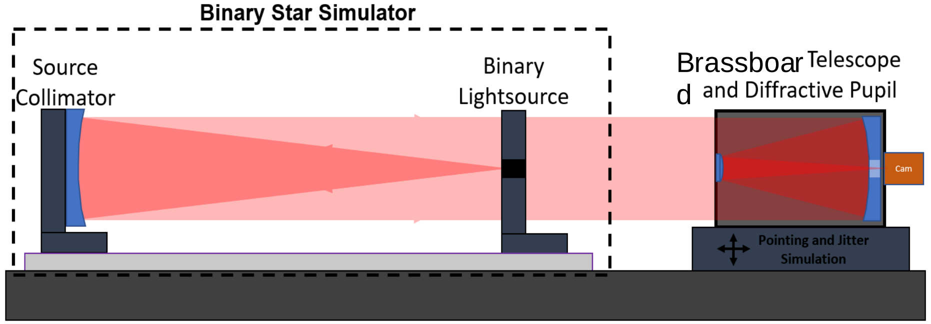
Wavefront Error, Optical Beamwalk, Filter coatings etc.

- In SHERA the optical footprints separate on M2 and filter by ~5-50 microns
- These are nevertheless subject to microarcsecond error arising from evolving WFE, beam-walk due S/C pointing, etc
- Filter location and coating performance is also critical



SHERA/JNEXT Performance budgeting and testing

1. Achieve <10 uas in 1 hr of testbed measurement
2. Evaluate long term averaging properties of 1 hr measurements



One-hour Measurement Error 10 uas

- Photons, etc.
  - A magnitude
  - B magnitude
- Spacecraft
  - Pointing
  - S/C Velocity
- Detector
  - Flat-field knowledge
  - Pixel geometry knowledge
- Optics
  - In flight distortion
  - Beamwalk
- Data Analysis
  - Diffractive Pupil
- Astrophysical
  - AB Jitter
  - AB Color
  - Background objects

Instrument

Relationship between astrometry and Imaging

Year 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 50

Direct imaging from ground (thermal IR)

VLTI/GRAVITY (~30µas)

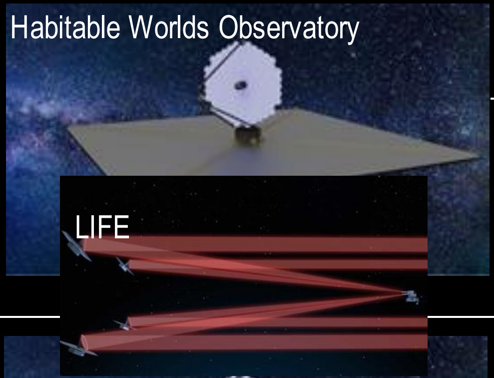
Gemini/GPI2

Era of Extremely Large Telescopes →

Note: HZ Earth-size planets around Sun-like stars are not achievable for existing or near-term missions such TESS, CHEOPS, JWST, Ariel

Direct imaging from space or stratosphere (reflected/thermal light)

PICTURE-D (2025+)

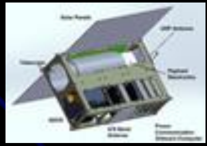


High precision astrometry

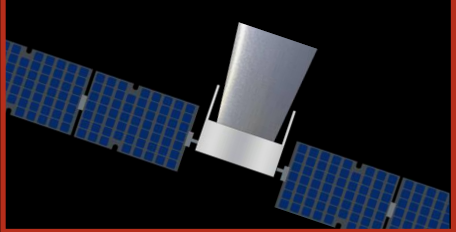
aCen (~50µas)

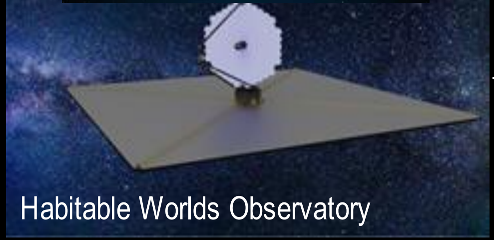
Fontanive+ Gagliuffi 2021 (~10µas)

Toliman, sub-µas, αCen only (~2025+)



SHERA, sub-µas concept, ~2028+)





Super-Earths and larger | Pushing towards small planets in habitable zones of nearby stars | Habitable planets around many FGK stars