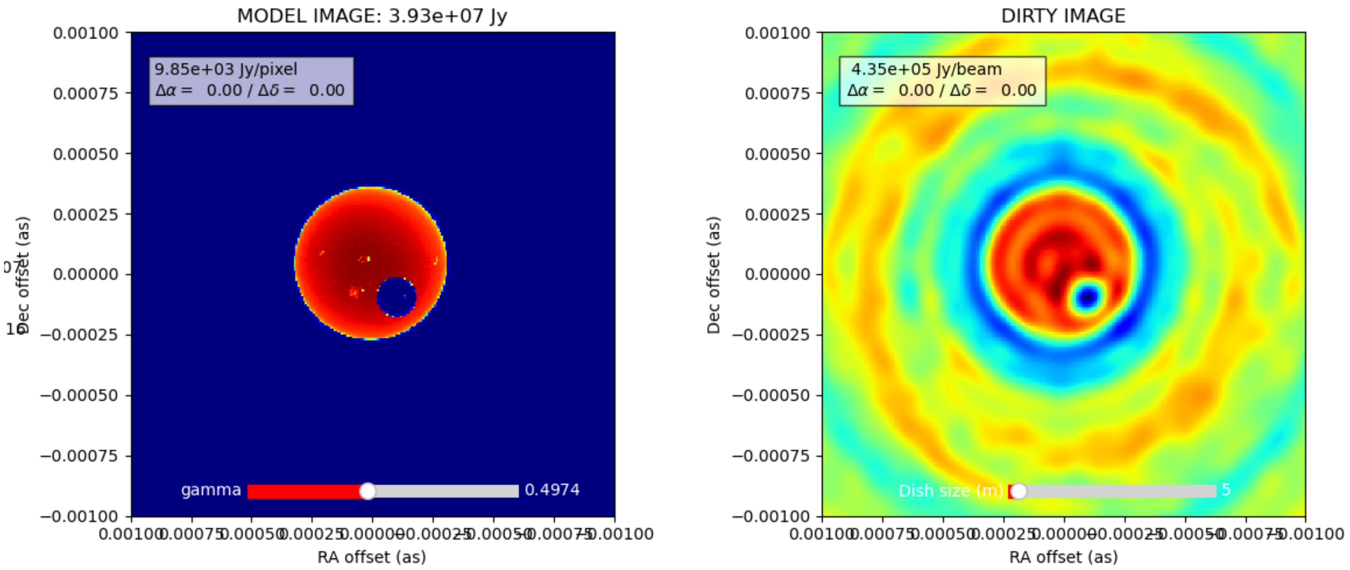


Interferometry on the Fringe: Cutting Edge Developments at Lowell

Dr. Gerard van Belle

Lowell Observatory

Welcome to Acronym Word Salad

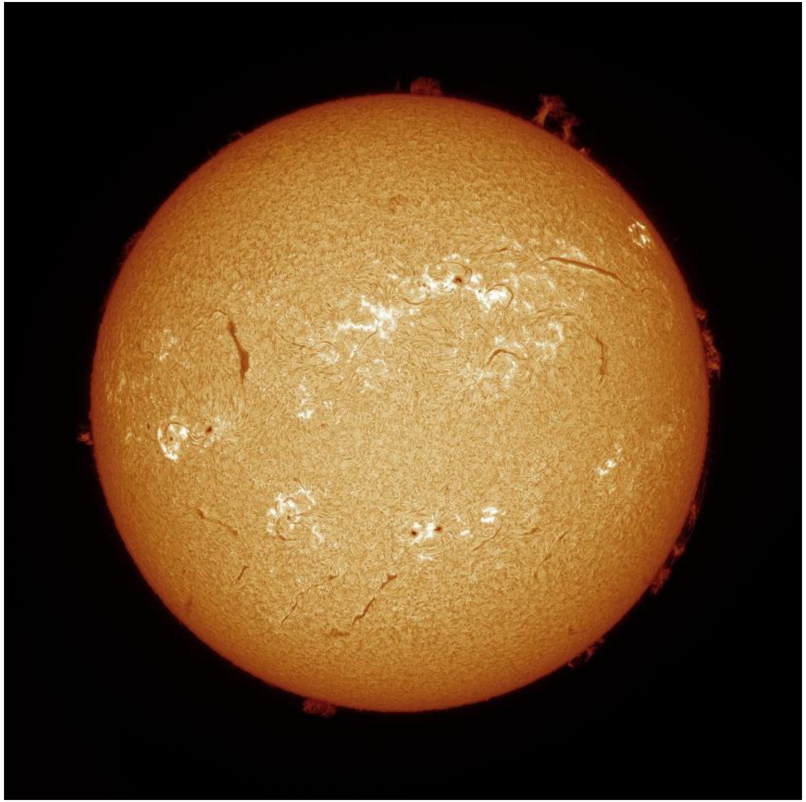
- BFT
- MoonLITE
- AeSI
- KISS

Missing *Affordable* Low-Hanging Fruit

- Bright, small objects
- Imaging with dense {u,v} coverage
- Aggregate **30 years** of ‘lessons learned’ in design, construction, operations, and data reduction

Primary Target:

Main Sequence STARS



BFT – Big Fringe Telescope: Overview

- Compelling, **focused** science case
  - Exoplanet host surface imaging
  - Solar analog surface imaging
  - Exoplanet transit movies
  - Component-resolved binary stars
- Additional general science cases
- **Affordable** architecture
  - COTS parts, 30-years-newer technology, eliminate vacuum & other expensive infrastructure, true parts commonality
  - Construction & O&M costs baked into design from start
  - ***Single, robotic observational mode***
    - *Requirement for <3% annual operations costs*

Focused ‘Marquee’ Science Program

- EXPRES EPRV 100 Earths
  - Brewer+ 2020, table 1
  - 65 objects
  - 0.40-0.60mas: 31/65
  - 0.35-0.55mas: 31/65
  - V<7.6 and K<5.6 for both

- Exoplanet transit movies
  - TFOP: 29 targets with TESS G<7.5, Rplanet > 5 RE, DE>-10, median ~0.40mas

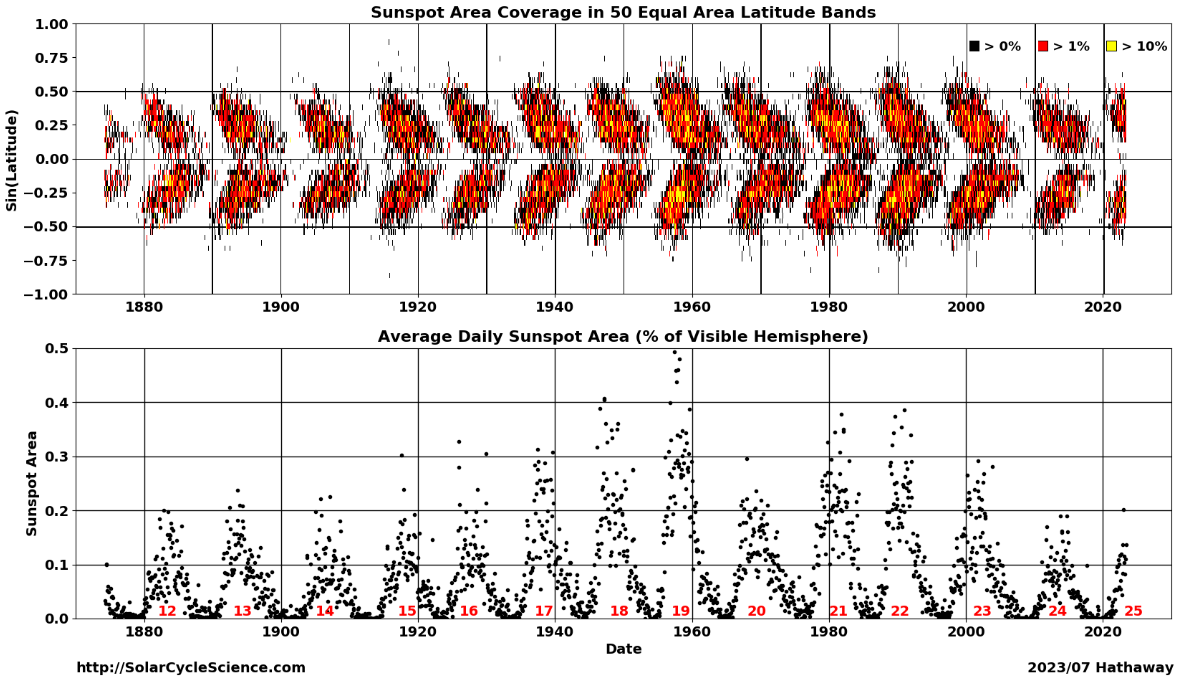
- Solar analogs
  - S-cubed: 69 targets from Radick+ 2018
  - 0.40-0.60mas: 35/69
  - V<6.7 and K<5.0 for all

- Resolved binaries
  - Pourbaix SB9 has 77 targets with DE>-10 and:
  - P<1000d, a~5-360mas, 0.30-0.70mas

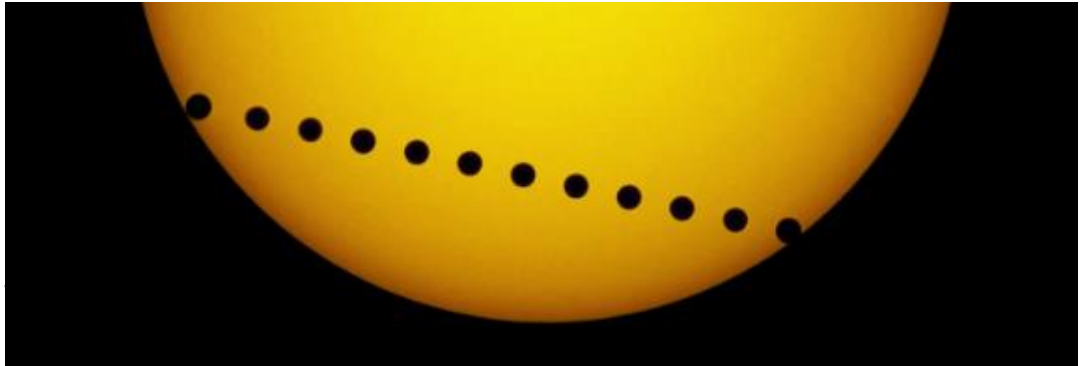
Overall Requirements

- **Resolution**
  - Target 'sweet spot' of 0.40 – 0.60 mas, 20μas pixels
  - Snapshot imaging

- **Sensitivity**
  - Visible (Johnson V, R): < 7.6 (requirement) < 8.0 (goal)
  - Near-infrared (Johnson H, K): < 5.6 (requirement) < 6.0 (goal)



‘Butterfly’ diagrams



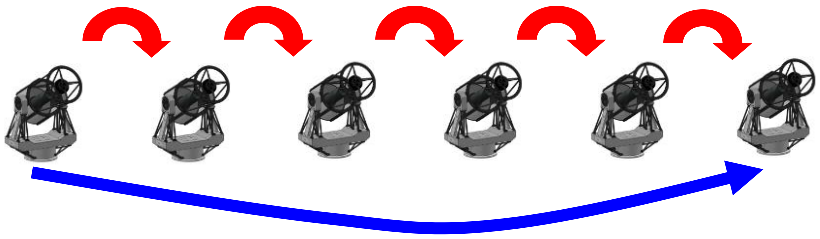
Exoplanet transits

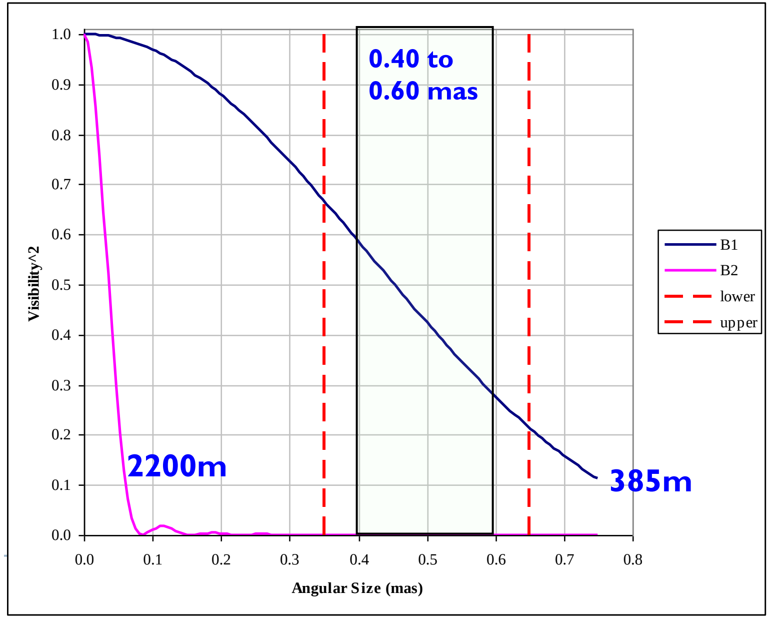
Required Resolution

- Number of pixels across star?
  - Relative size of spots to disk
  - Spot migration tracking
  - **30 x 30 pixels is target**
  - Imaging resolution = 1.22 λ/B
    - 'Airy criterion'
  - Modeling resolution = 0.25 λ/B
    - 'Michelson criterion'
- Overall facility scale
  - 'Pixel' scale: dictates longest baseline
  - Fringe tracking: dictates short baseline spacing
  - Longest baseline has to be made up of short baselines
  - **0.40-0.60 mas stars with 20uas pixels → 2.2km**

Wavelength-Baseline Bootstrapping

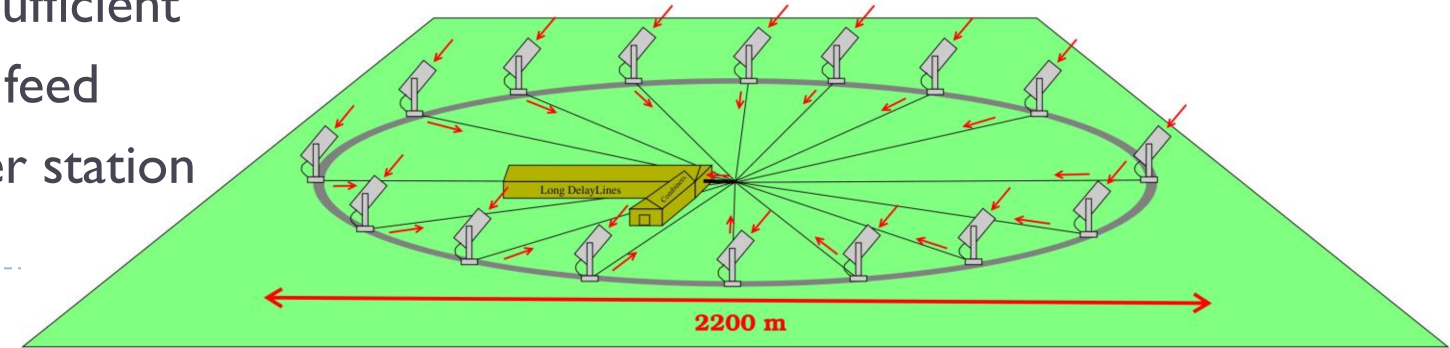
- Track at H-band with short baselines, short atmospheric coherence times
- Image in R-band with medium, long baselines, long synthetic coherence times
- H-band fringe tracking with $V^2 > 0.20$ means for 0.50 mas star, $B_{min} = 385$m





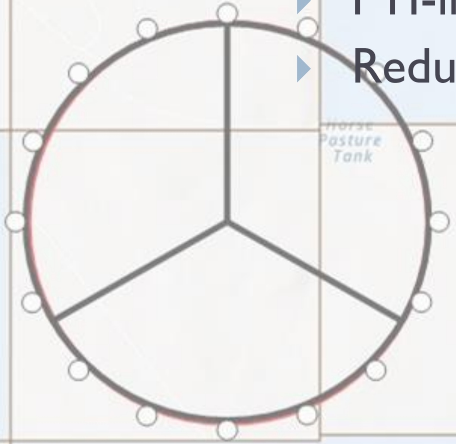
Nominal Layout

- 16 x 0.5 m telescopes
- Small telescopes
  - 'Commodity item'
  - 'Station 0' robotic operations already started at Lowell
  - Enough area for sensitivity requirement
  - Tip-tilt is sufficient
  - Siderostat feed
  - ~$150k per station
- 2,200m ring
  - Sufficient angular resolution for 0.40-0.60 mas targets, ~30x30 20 μas pixels



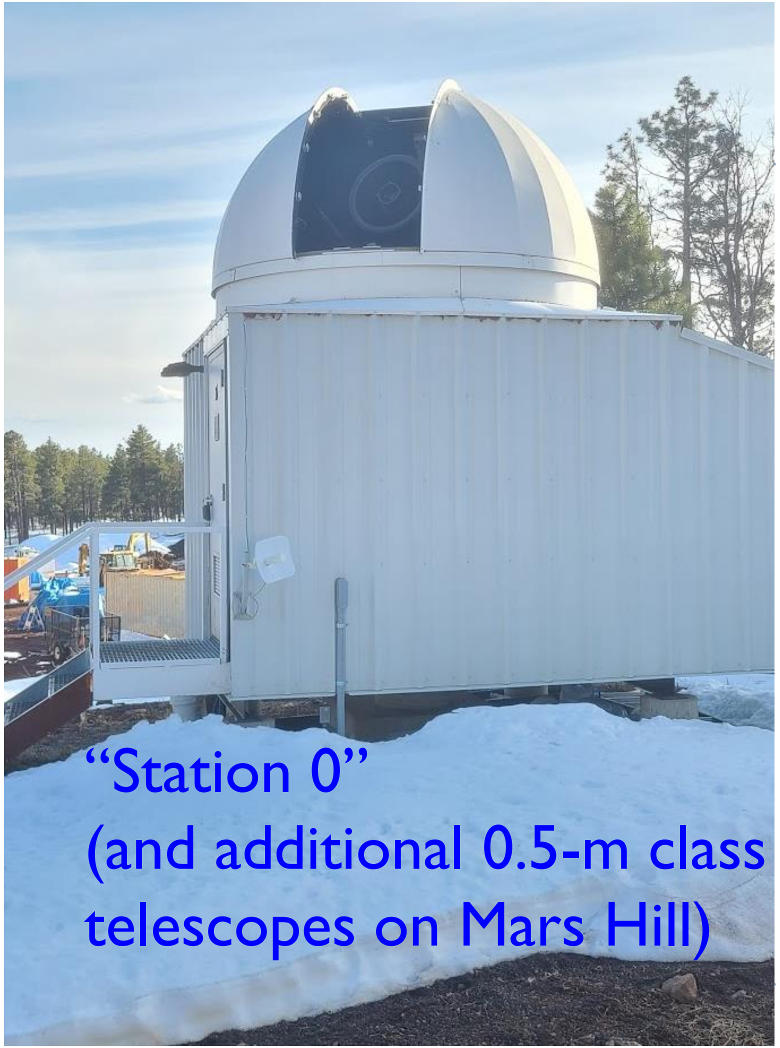
Nominal Infrastructure

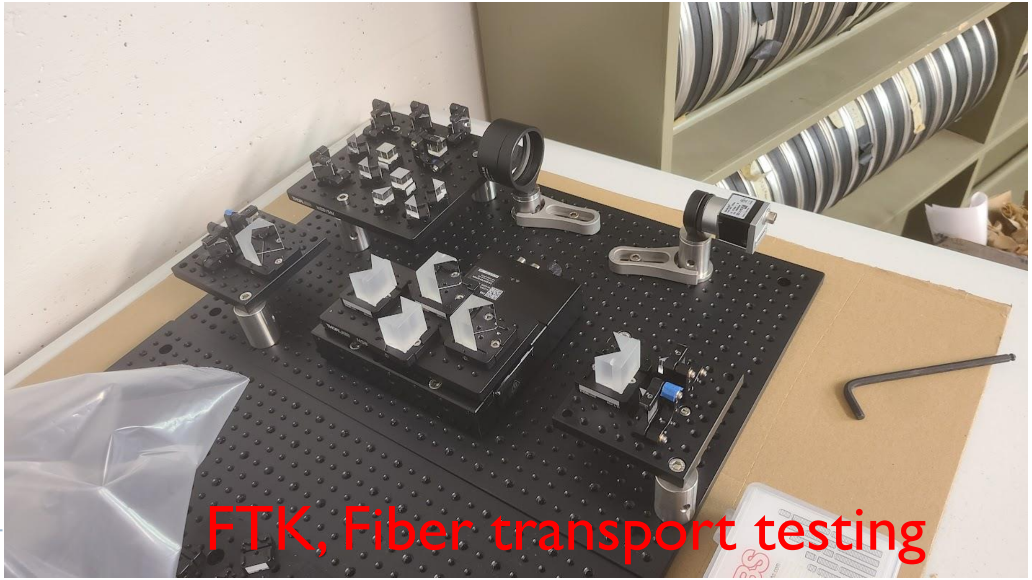
- Lots of high, flat, available land in northern Arizona
- No vacuum systems
  - Eliminate significant cost infrastructure (both construction & O&M)
- Fiber beam transport
  - Testbed in lab at Lowell already
- Next-gen high-speed delay lines
  - Current DLs are 30+ year old technology
  - NSF ATI submitted for development
- Robotic operations
  - PTI-like automation
  - Reduce ops costs



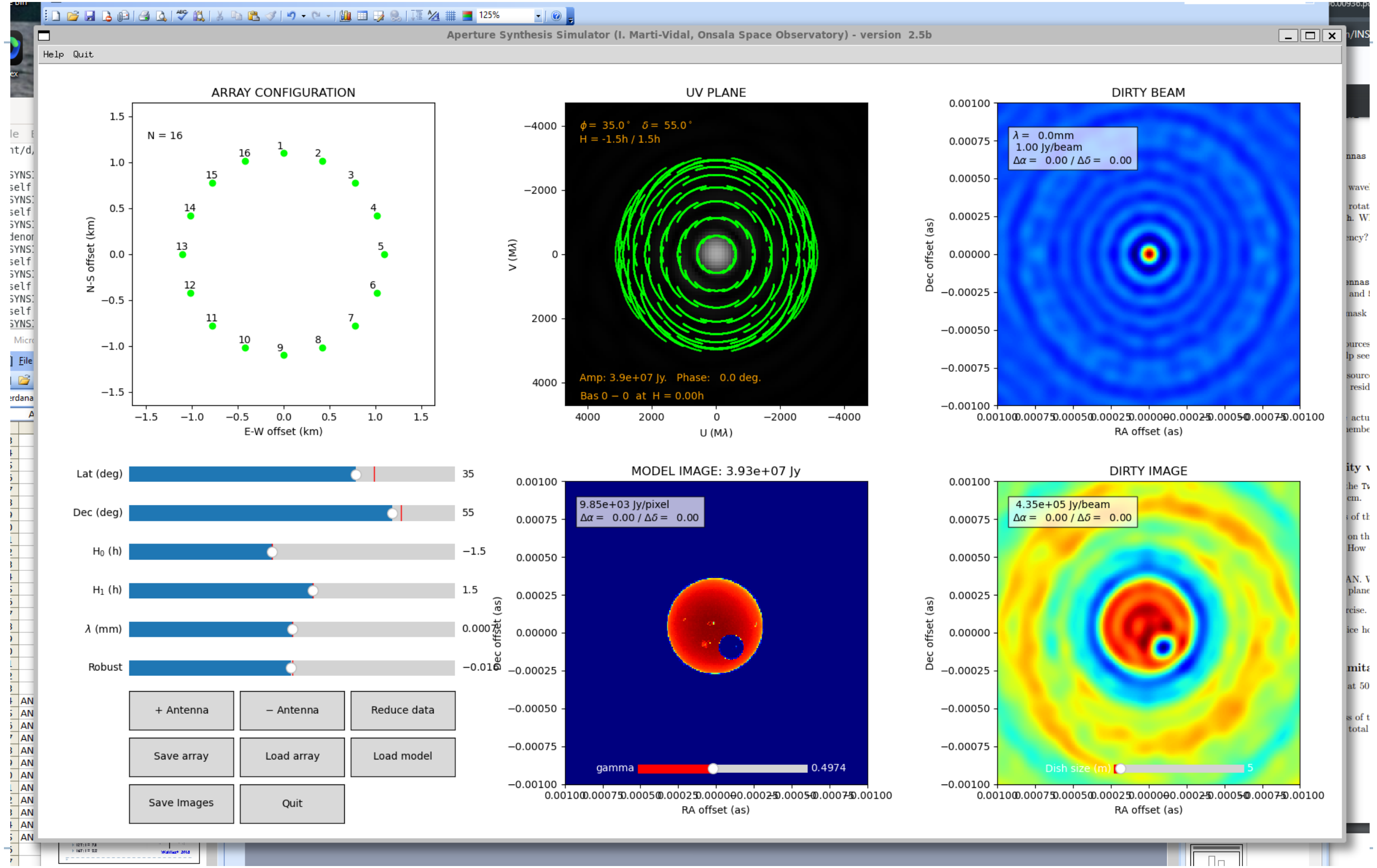
Scalable Development

- Lab → single baseline → full deployment





Snapshot from simulated planet transit movie



MoonLITE

What is MoonLITE?

- LITE = Lunar InTerferometry Explorer

- A **submitted** NASA Astrophysics Pioneers proposal
- A two-element, 100 meter Michelson interferometer
- CLPS-delivered to lunar surface
- Capable of V=17 **isolated objects**, for objects 0.1-1.6mas in size, measure 0.1-5.0% sizes

Lester (2006)

“The only thing the moon

has to offer astronomy is

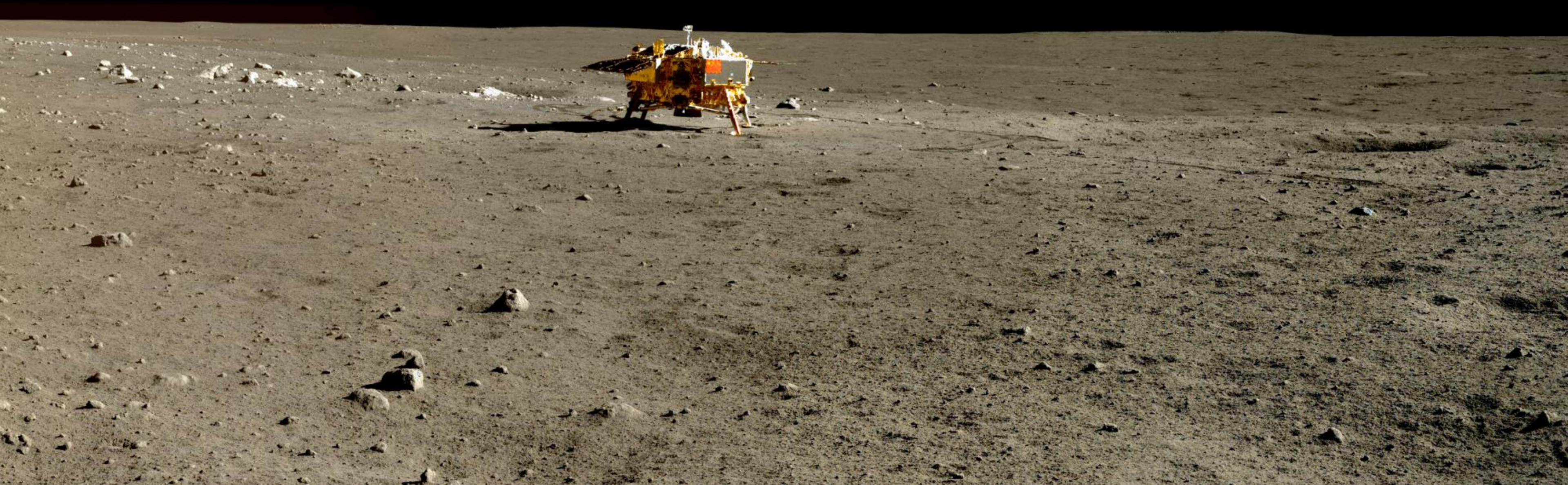
dust

and **gravity**”

(slightly paraphrased)

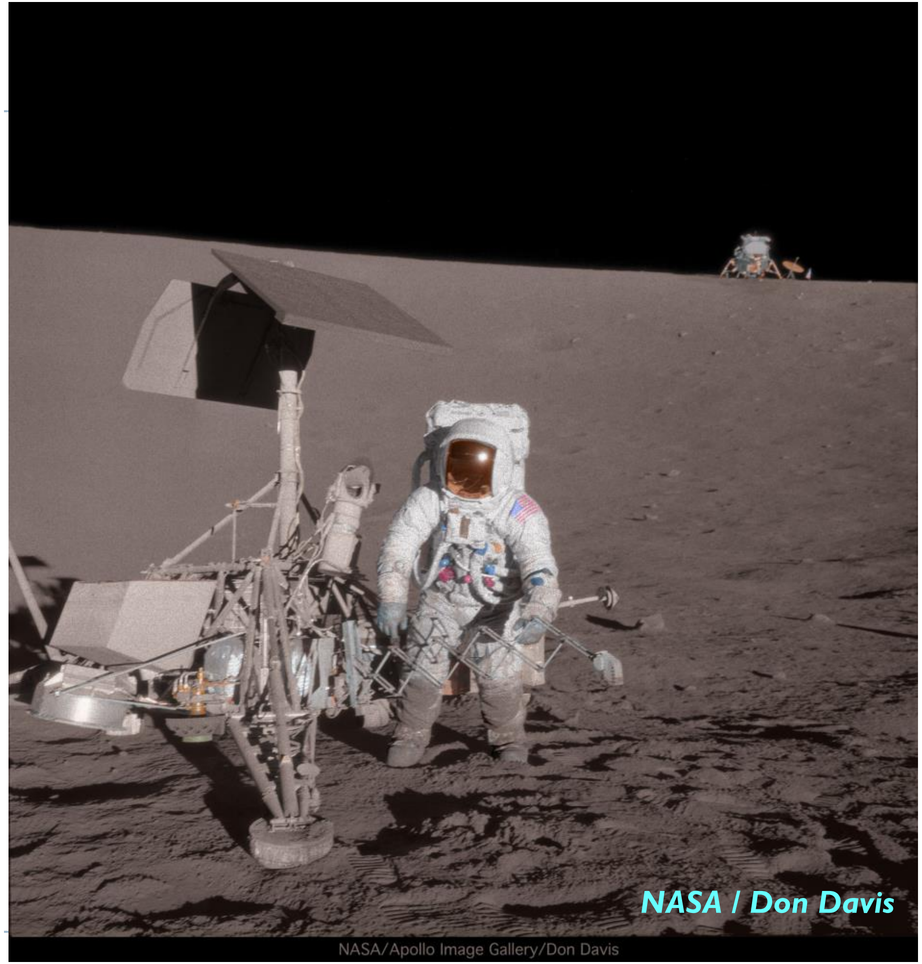
Dust: LUT on board Chang'e-3 Lander

- UV telescope with **years** of operations (2015 - 2018+)
- **Dust not a problem**



Gravity

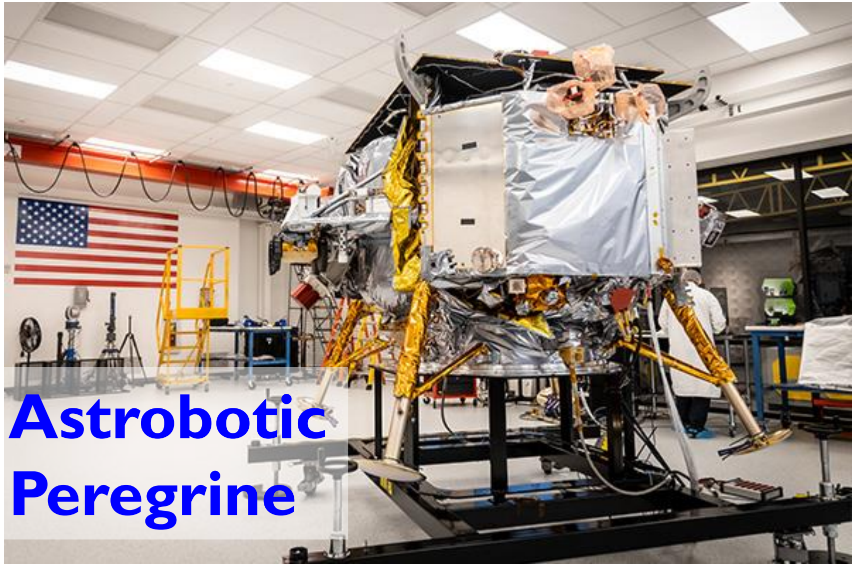
- It's not a bug, it's a **feature**
  - Eg. Surveyor 3, Apollo 12: 180m baseline, stable relative position for the past 50 years
  - Nearly perfect for large optical interferometers
  - Formation flying is unsolved, expensive
- Greatly simplifies pointing
  - Stable reaction mass
  - 'Solved' for orbital platforms, but expensive and buggy – Eg. HST reaction wheels, Kepler, IUE, etc.

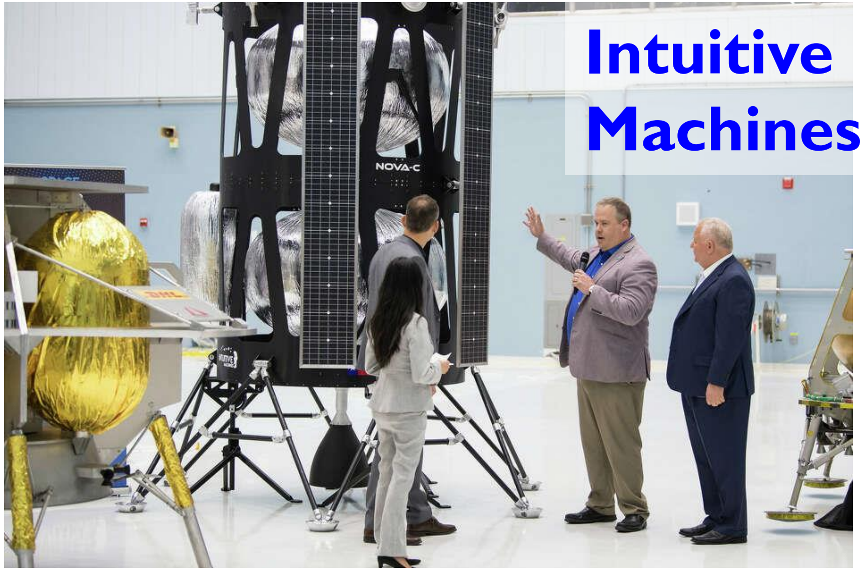


Other Features

- No atmosphere
  - No atmospheric coherence time limit
  - A 2" aperture has greater sensitivity than an 8m VLTI aperture after first second of integration; 300+ sec possible
  - Free vacuum → clean beam propagation, no vacuum machinery
- Stable surface
  - Apollo seismometer data indicates <20nm vibrational background on week+ timescales

NASA Commercial Lunar Payload Services (CLPS) Landers





- Hosted payloads to the lunar surface, with rover
- **Allowable under NASA Astrophysics Pioneers**

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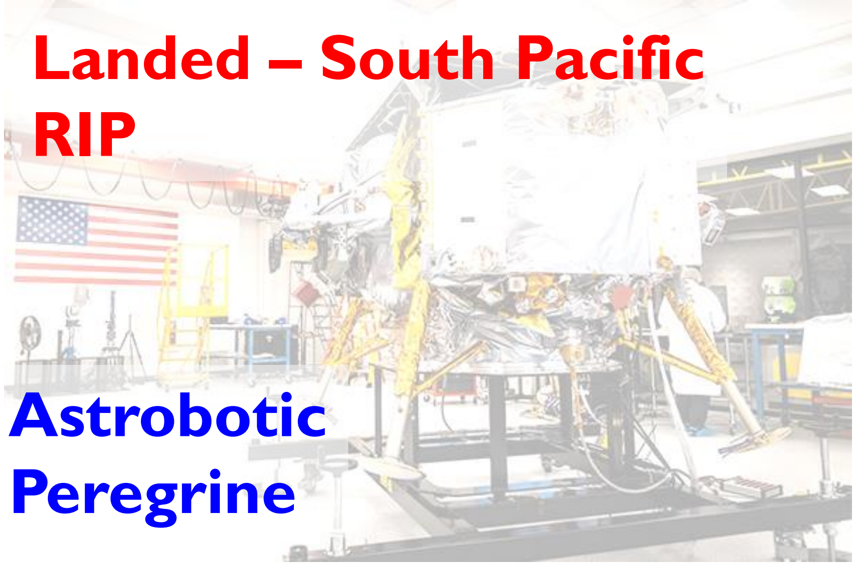

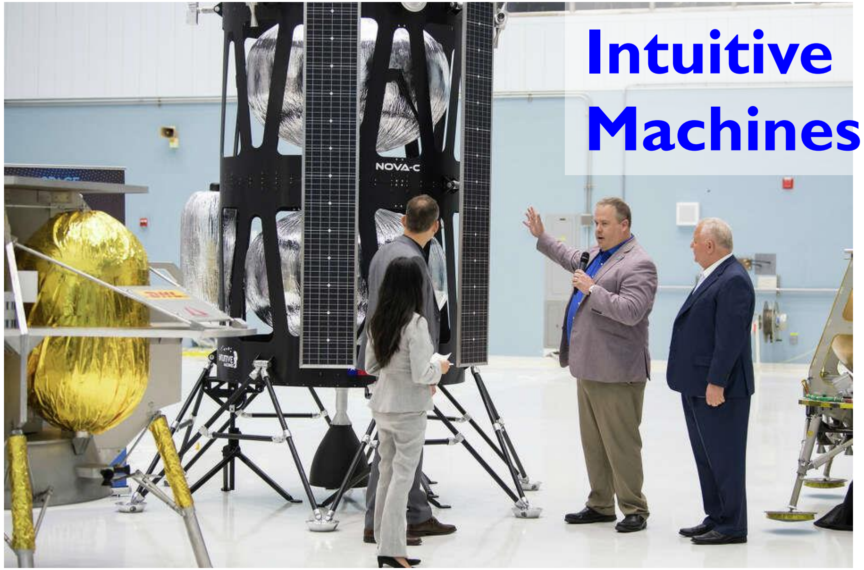

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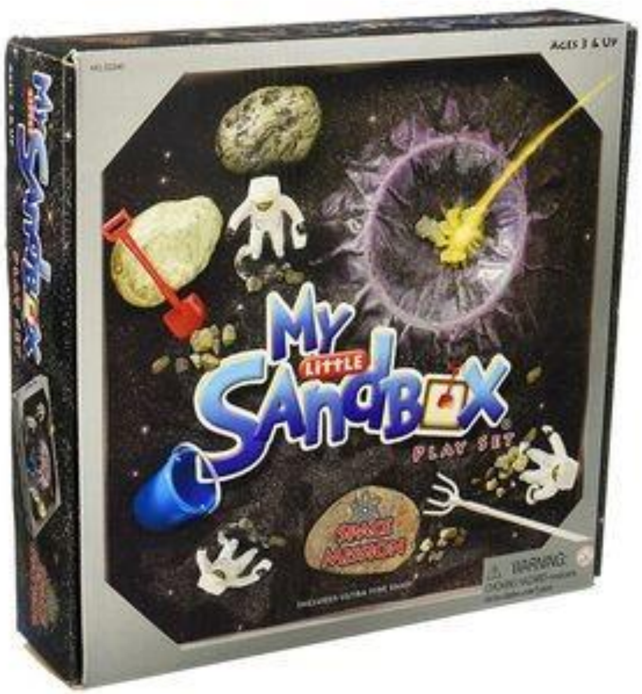
NASA Commercial Lunar Payload Services (CLPS) Landers

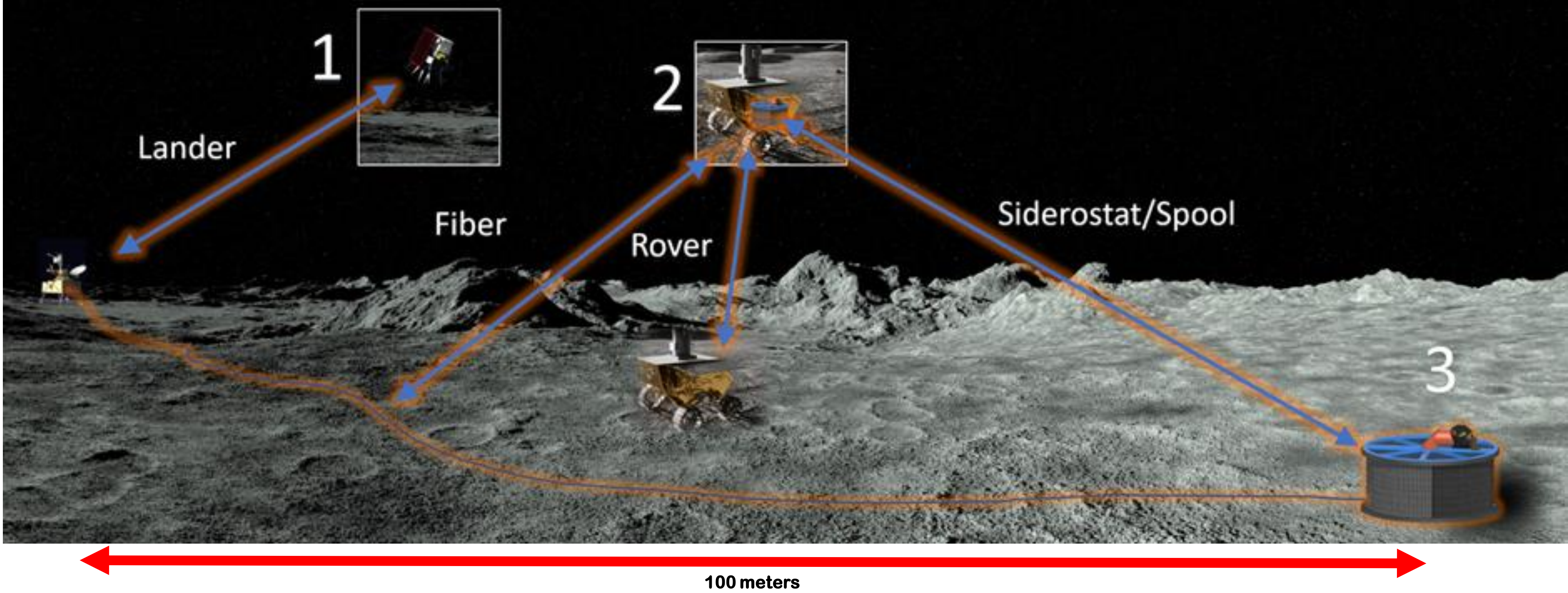
Launched Feb 15

Landed on Feb 22

The Pioneers CLPS Box

- $20M cap
- 50 kg, 200 W, 300kbps
- Daytime operations *only*

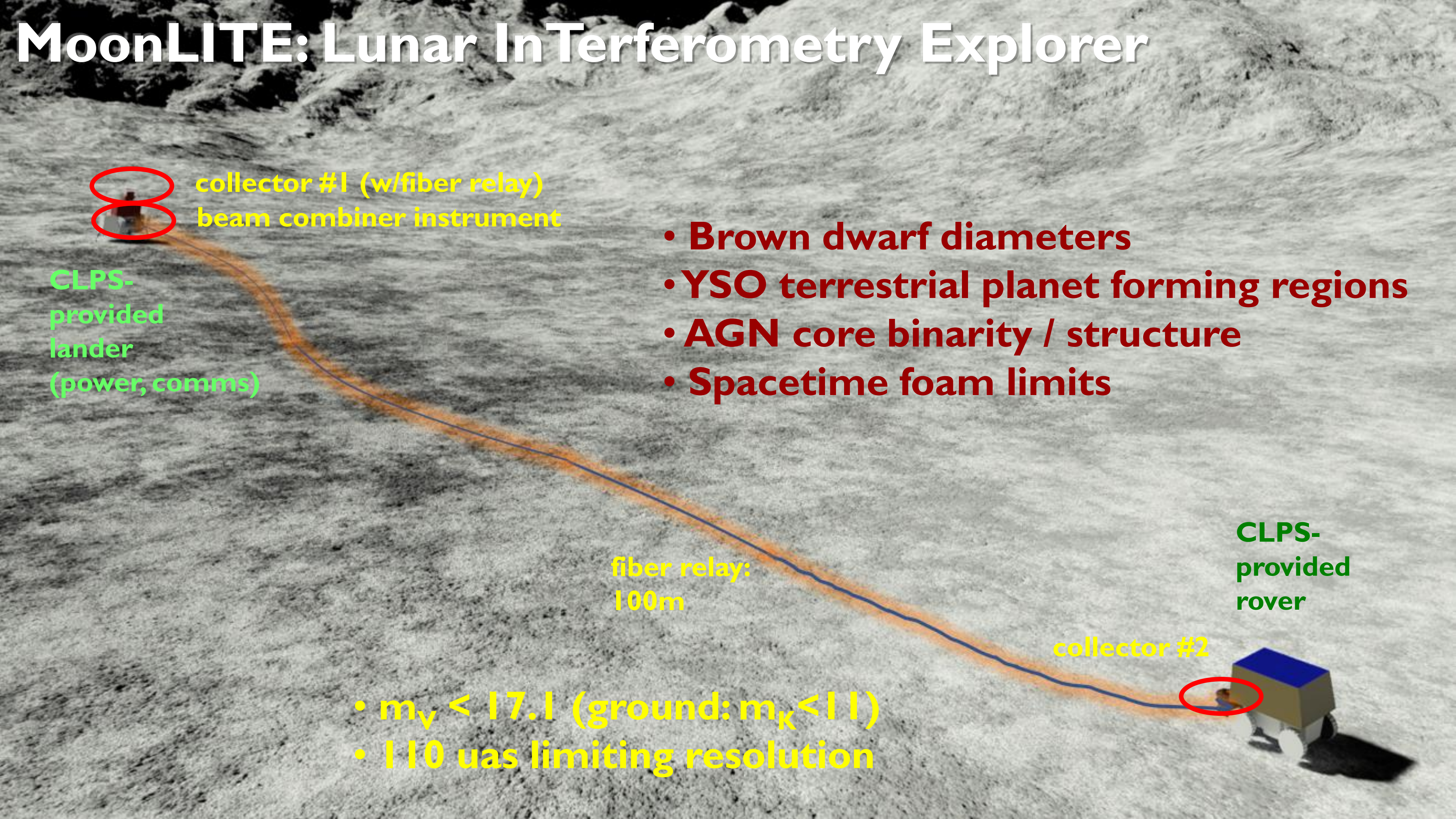




Emphasis on simplicity: one deployment step

Given lunar surface stability, hosting by lander, resources can be focused on the experiment itself

MoonLITE: Lunar InTerferometry Explorer

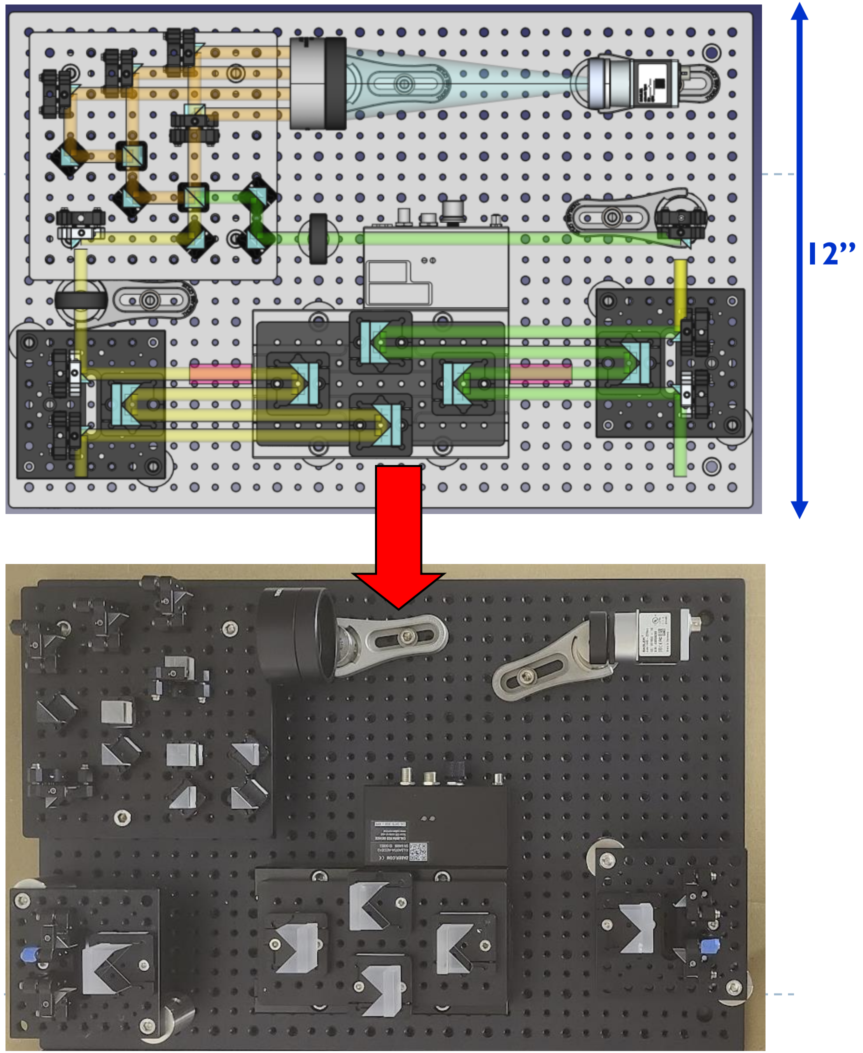


- **Brown dwarf diameters**
- **YSO terrestrial planet forming regions**
- **AGN core binarity / structure**
- **Spacetime foam limits**

- $m_V < 17.1$ (ground: $m_K < 11$)
- 110 uas limiting resolution

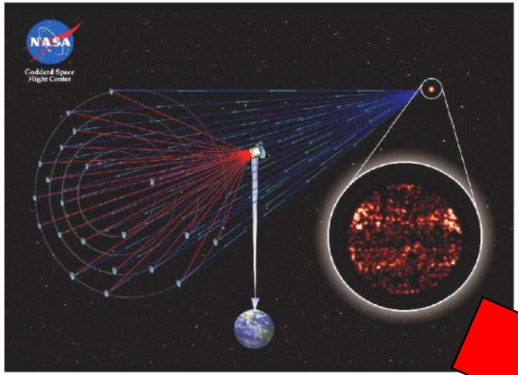
Status

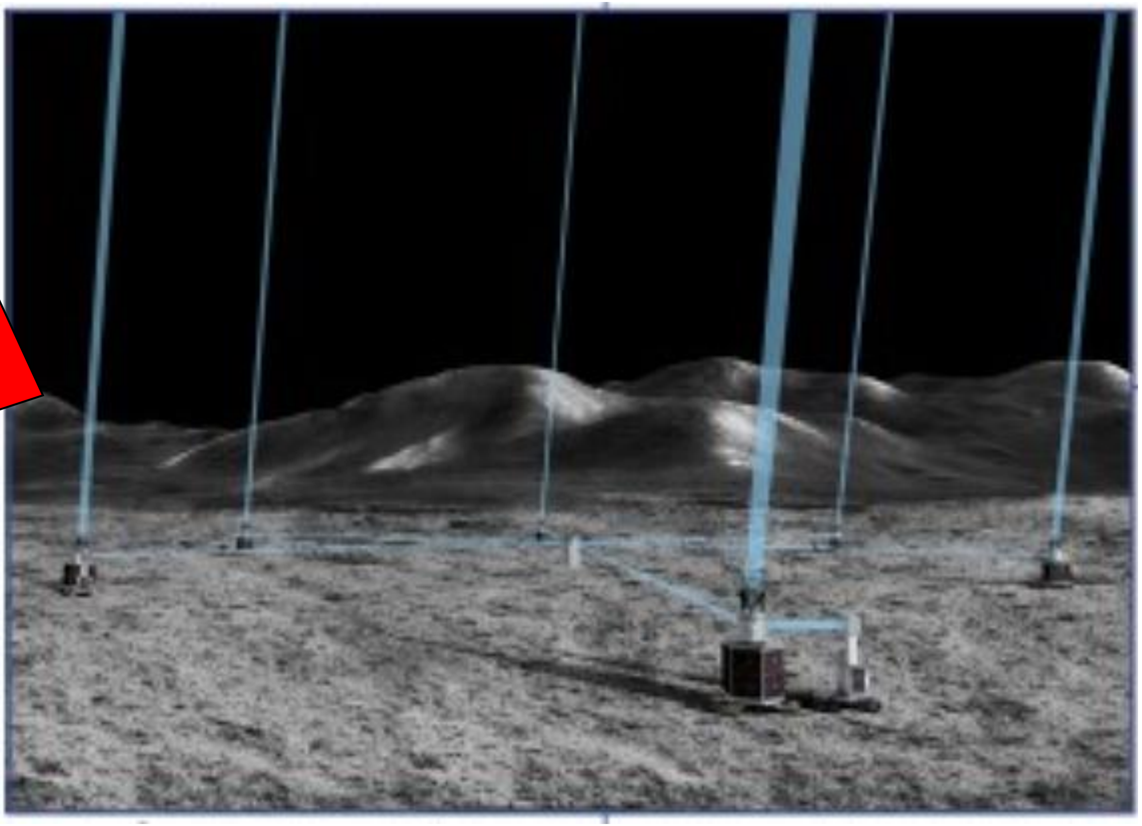
- Proposal declined
  - **Resubmission encouraged**
  - Supporting NASA SAT, NSF ATI proposals also submitted
- Progress with building opEDU with internal funds
- Aim to test opEDU in lab and then *on-sky* with telescopes available at Lowell
  - Tech can apply to BFT as well



AeSI

Artemis-enabled Stellar Imager





- NASA NIAC-funded **study**
- 30 x 1m telescopes
- 500m @ 1200Å

Keck Institute of Space Studies (KISS) Study Program

KISS Study Program:
"Astronomical Optical Interferometry from the Lunar Surface"

2023 Study Programs

- Blazing Paths to Observing Stellar and Exoplanet Particle Environments
- Determining the Interior Structure of Uranus
- The Biology of Biosignature Detection
- Managing Soil Organic Carbon for Climate Change Mitigation