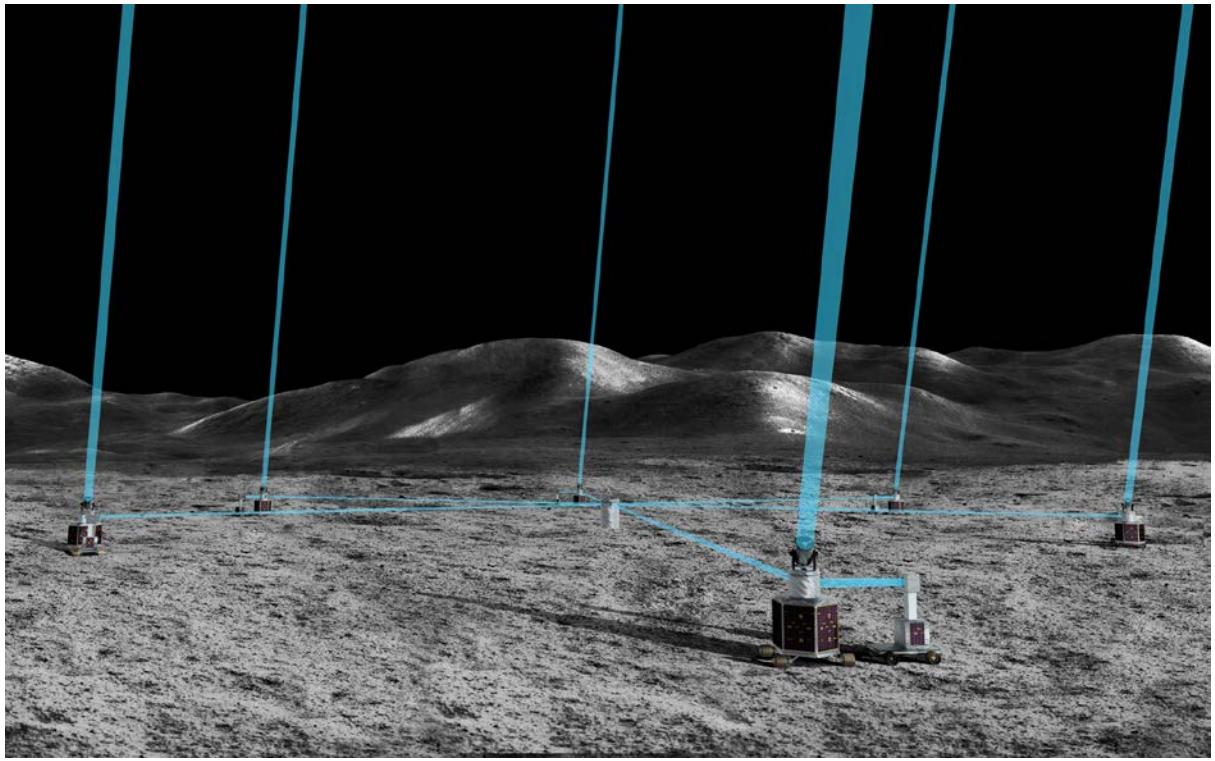
ULTRAVIOLET ASTRONOMY IN THE XXI CENTURY

JcUVa

A High-Resolution Imaging Interferometer at the Lunar South Pole: *Stellar Imager – Lunar Pole (SI-LP)*



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Context/Background for *SI-LP*

1st NUVA Conference (2007):
"Vision Mission" (VM) Concept for a free-flying, large baseline, UV/optical space interferometer called *Stellar Imager (SI)*

5th NUVA Workshop (2020):
A new concept, derived from *SI* but intended for construction on the lunar surface

What has changed in the last 13+ years? Why the lunar option?

- The large "Vision Missions" (esp. interferometers) were mostly put on hold pending completion of the James Webb Space Telescope
- Per Pierre Bely et al.'s study[1], it was perceived that **unless there was a pre-existing infrastructure on the lunar surface,** it was easier and better to build a large space interferometer as a free-flyer. So the VM studies all considered free-flyers
- **Now the Artemis Project plans to put humans and their infrastructure on the moon within the next decade and it is time to consider in detail the lunar option**

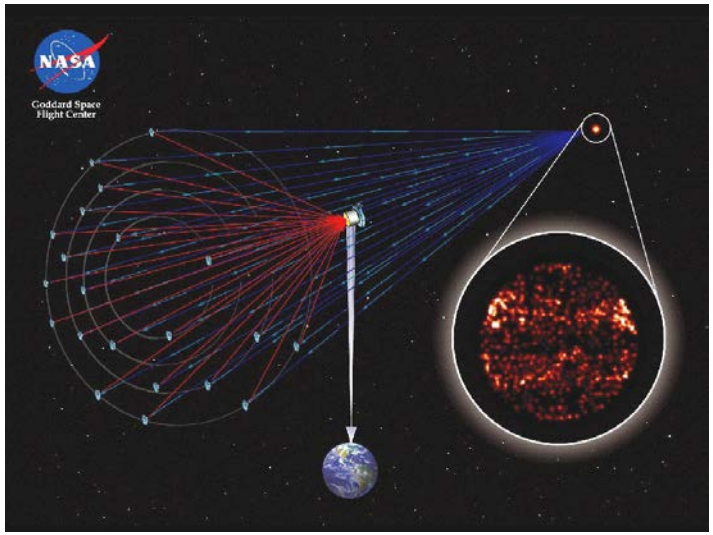
[1] ("Kilometric baseline space interferometry," Proc. SPIE 2807, Space Telescopes and Instruments IV, (12 October 1996); doi: 10.1117/12.255123)

Required Capabilities for *UV/Optical Space Interferometer*

- Wavelength coverage: 1200 – 5000 Å
- access to UV emission lines from Ly-alpha 1216 Å to Mg II 2800 Å for stellar surface imaging
  - Important diagnostics of most abundant elements
  - much higher contrast between magnetic structures and background
  - smaller baselines (UV save 2-4x vs. optical, active regions 5x larger)
  - ~10-Å UV pass bands, e.g. C IV (100,000 K); Mg II h&k (10,000 K)
- broadband, near-UV or optical (3,000-10,000 K) for high temporal resolution spatially-resolved asteroseismology to resolve internal structure
- angular resolution of 50 micro-arcsec at 1200 Å (120 μas @2800 Å)
- ~1000 pixels of resolution over the surface of nearby dwarf stars
- enable energy resolution/spectroscopy of detected structures
- a long-term (~ 10 year) mission to study stellar activity cycles:
  - individual telescopes/hub(s) can be refurbished or replaced

Heritage for *SI-LP: Stellar Imager (SI)*

- UV-Optical Interferometer to provide 0.1 mas spectral imaging of
  - magnetic field structures that govern: formation of stars & planetary systems, habitability of planets, space weather, transport processes on many scales in Universe
- A "Flagship" (Vision) mission in the NASA 2005 SSSC Roadmap and a candidate "Pathways to Life Observatory" in the NASA 2005 EUD Roadmap
- Mission Concept
  - 20-30 "mirrorsats" formation-flying with beam combining hub
  - Launch to Sun-earth L_2
  - baselines ~ 100 - 1000 m
  - Mission duration: ~10 years



Prime Science Goals

image surface/sub-surface features of distant stars; measure their spatial/temporal variations to understand the underlying dynamo process(es)

improve long-term forecasting of solar and stellar magnetic activity

understand the impact of stellar magnetic activity on planetary climates and life

understand transport processes controlled by magnetic fields throughout the Universe

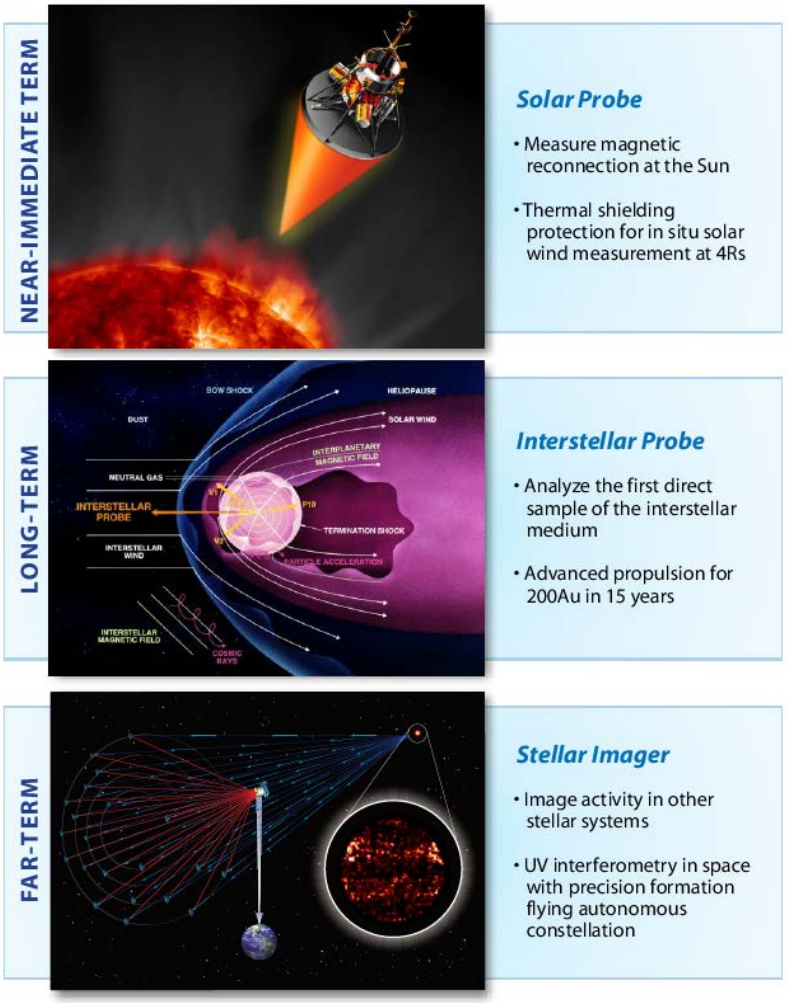
perform high angular resolution studies of Active Galactic Nuclei, Quasars, Supernovae, Interacting Binary Stars, Forming Stars/Disks

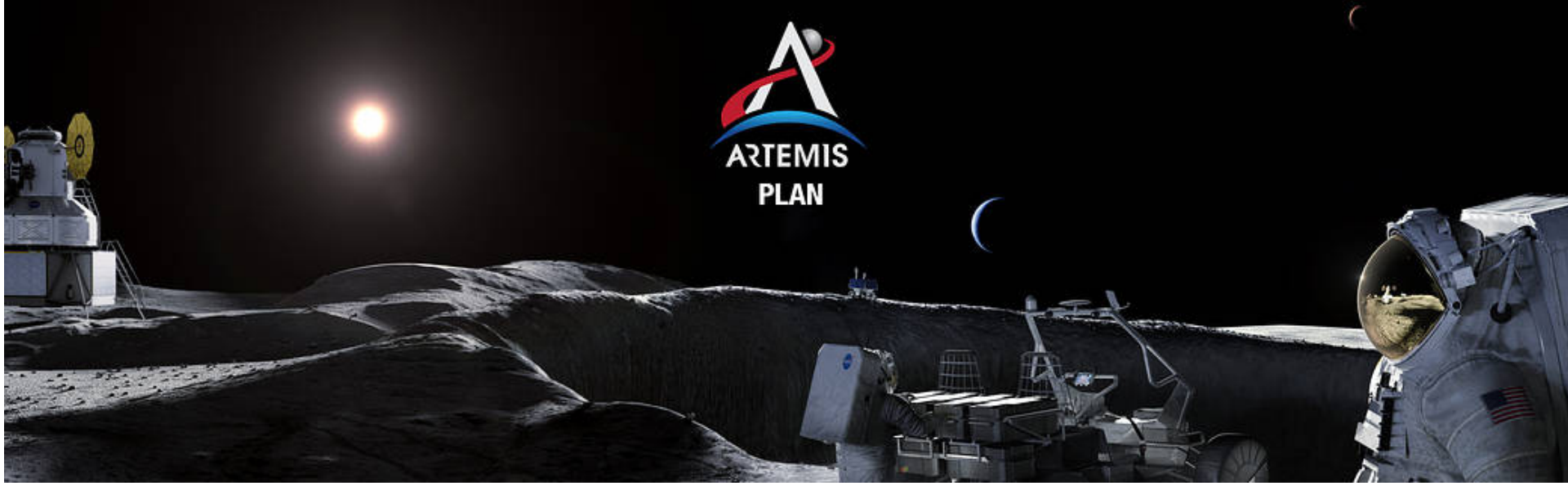
http://hires.gsfc.nasa.gov/si/

SI Status

- In NASA Heliospheric Division Roadmaps 2000-2005
- SI selected in 2003 for concept development as NASA “Vision Mission”
- Partnerships established w/ LMATC, SAO, BATC, NGST, JPL, CU to develop concept
- Testbeds:
  - GSFC Fizeau Interferometry Testbed (FIT) refined nm-level closed-loop optical control of array
  - Synthetic Imaging Formation-Flying Testbed (SIFFT) refined cm-level formation-flying of an array of s/c (GSFC/MIT/MSFC)
- GSFC Integrated Design Centers produced system design & tech. dev. roadmaps
- In 2005 NASA Strategic Roadmaps, SI was
  - A “Flagship” (Landmark Discovery) mission in the SSSC (Heliospheric) Roadmap
  - A candidate “Pathways to Life Observatory” in the EUD (Exploration of the Universe) Roadmap
- Interest in space interferometers cooled in the 2010’s

SSSC (Heliospheric Sciences) Landmark Discovery Missions



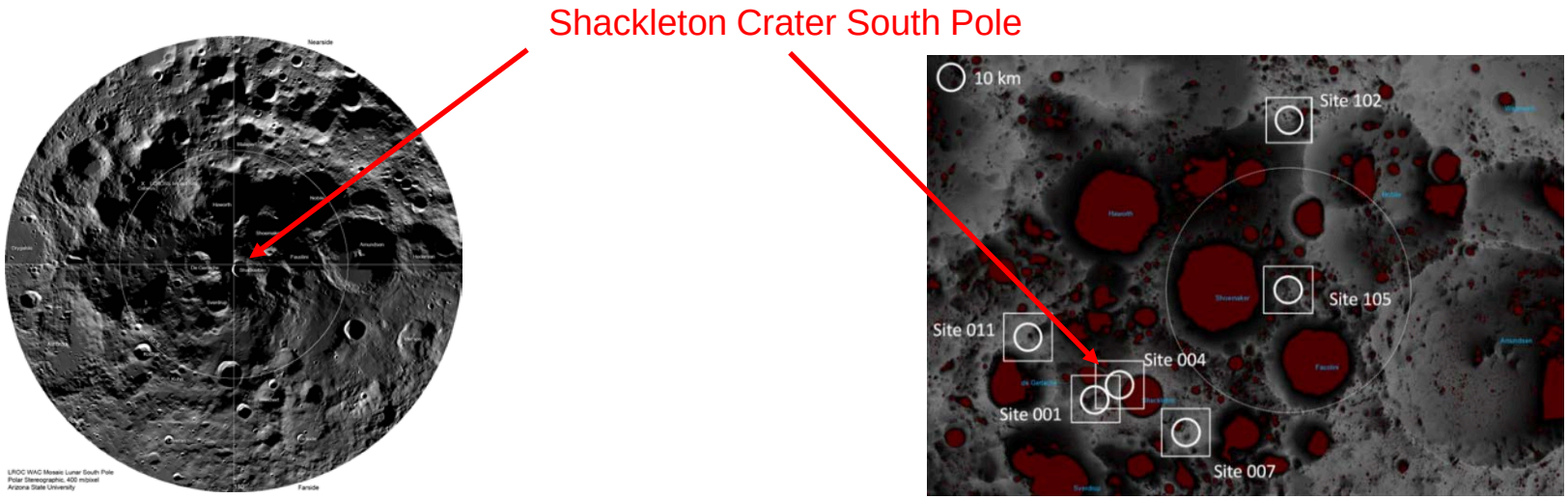


A New Hope:

Cooperation with Human Spaceflight Lunar Program

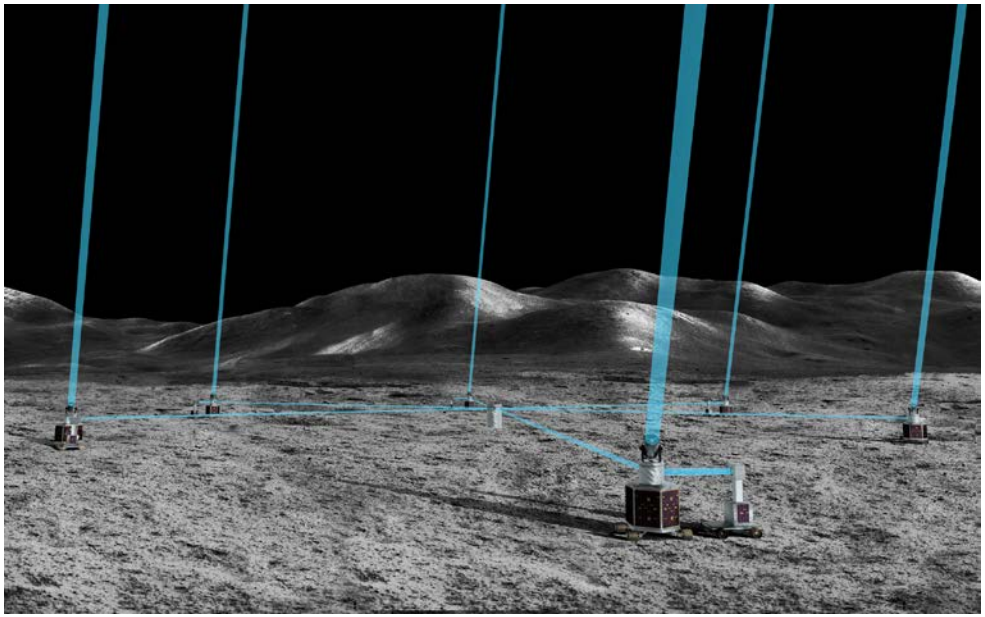
New Opportunity for Space Interferometry

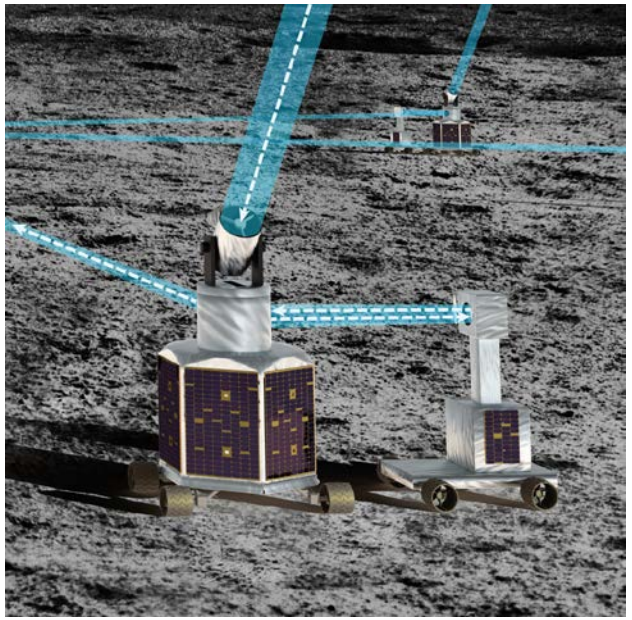
- The environment is changing with the establishment of the Artemis Program and the aggressive push to establish a permanent human presence on the moon, starting with a base near the lunar south pole, perhaps by 2024
- Even now, there is interest in small science experiments that could take advantage of the infrastructure; the scale of those opportunities will grow
- If we are to be ready to take advantage of those opportunities, we must begin concept development **now**
- We have thus proposed to the NASA Innovative Advanced Concepts (NIAC) program to study the possibility of constructing a large-baseline, UV/optical interferometer near a human base to leverage off that infrastructure



SI-LP: Innovations

- **Build**: a 0.5 km baseline UV-Optical interferometer on the Moon
- **Novel technologies**: dust repellers, rovers to move delay-line optics and primary mirror stations on surface, hub to combine beams from stations in variable configurations, technologies needed for long-baseline interferometers in space
- **Eliminates** the need for precision formation flying
- **Science**: supports broad spectrum of science investigations
- **Timing**: can build as soon as infrastructure available on the Moon

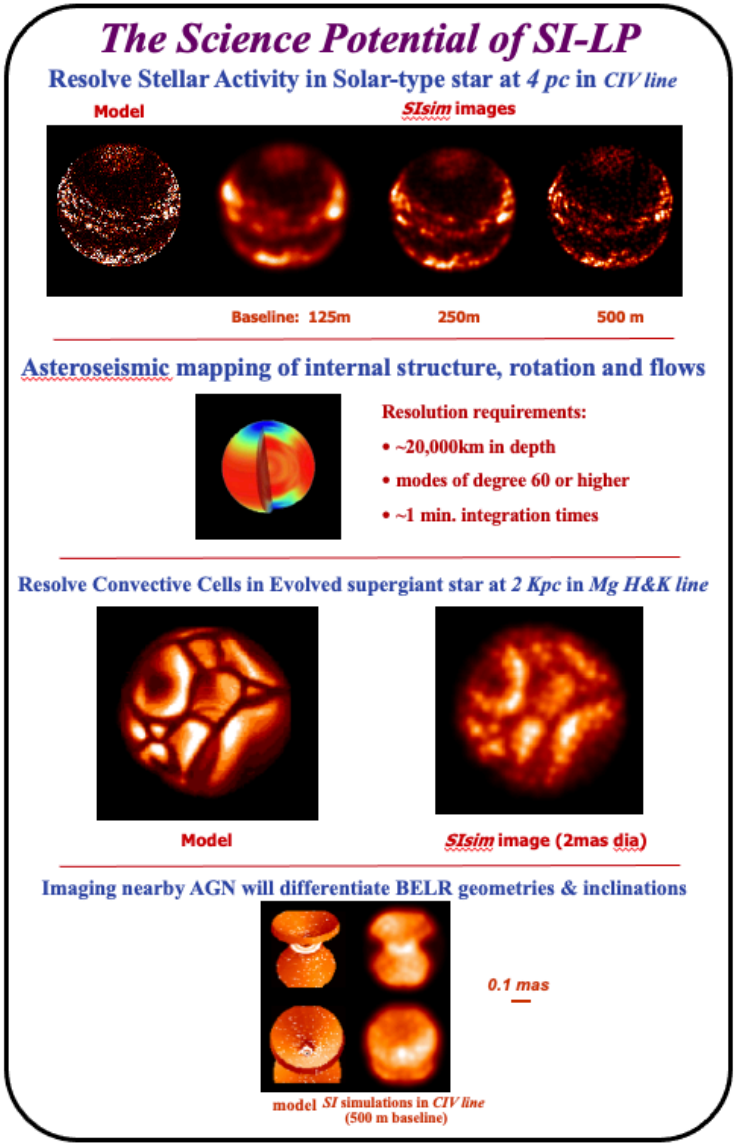




(Britt Griswold/GSFC)

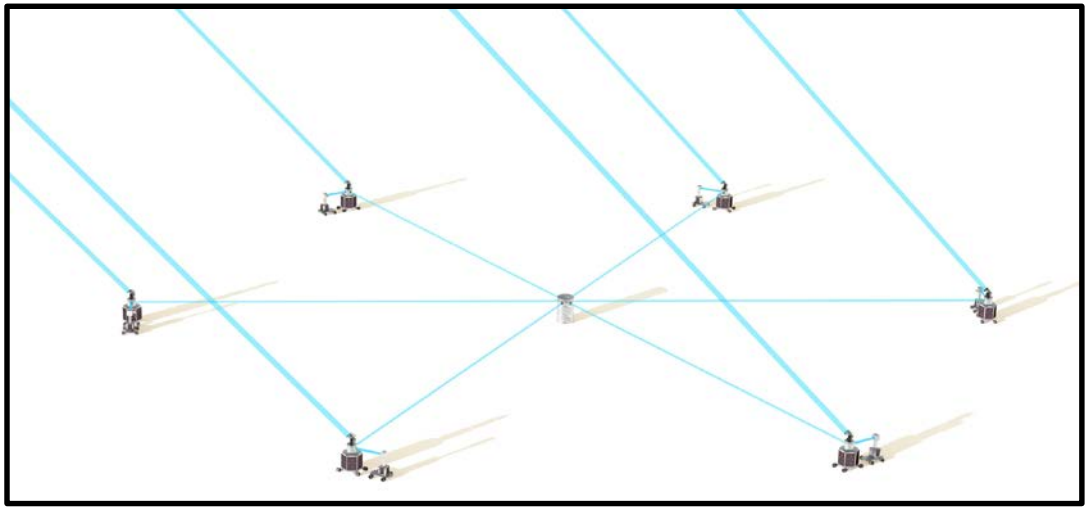
SI-LP: Potential and Benefits

- **100x higher resolution than Hubble,** resolving stellar surfaces and inner regions of black hole environments
- **Perfect timing** to leverage planned Artemis human lunar infrastructure by late 2020's
- **Prospects superb:** ground-based optical interferometry works; forthcoming infrastructure makes a lunar surface architecture both practical and compelling
- **Boldly expands realm of the possible:** many studies of free-flying space interferometers exist, but only limited studies of lunar designs (far-side radio)



SI-LP: Technical Approach

- **Major Tasks: Address problems specific to interferometers on the lunar surface**
  - Dust mitigation
  - How to accommodate delay lines without massive structures
  - Determine support needed from human infrastructure
  - Develop plan for evolving facility over time
- **Goals: Determine**
  - Optimal array configurations
  - Beam combination techniques
  - Architecture



(Britt Griswold/GSFC)

The *Stellar Imager – Lunar Pole (SI-LP)*

is a UV-Optical, space-based interferometer for 0.1 milli-arcsecond spectral imaging of stellar surfaces and interiors and of the Universe in general.

It will resolve for the first time the surfaces and interiors of sun-like stars and the details of many other astrophysical objects & processes, e.g.:

Magnetic Processes in Stars
activity and its impact on planetary climates and on the origin and maintenance of life;
stellar structure and evolution

Stellar interiors
in solar and non-solar type stars

Infant Stars/Disk systems
accretion foot-points, magnetic field structure & star/disk interaction

Hot Stars
hot polar winds, non-radial pulsations, envelopes and shells of Be-stars

Cool, Evolved Giant & Supergiant Stars
spatiotemporal structure of extended atmospheres, pulsation, winds, shocks

Supernovae & Planetary Nebulae
close-in spatial structure

Interacting Binary Systems
resolve mass-exchange, dynamical evolution/accretion, study dynamos

Active Galactic Nuclei
transition zone between Broad and Narrow Line Regions;
origin & orientation of jets;
distances