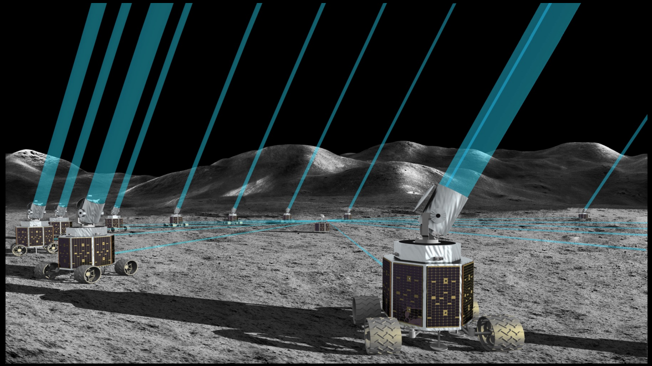
Artemis-enabled Stellar Imager (AeSI): Observing the Universe in High Definition

2024 NIAC Symposium - 2024 10 September

NASA Innovative Advanced Concepts



(Britt Griswold/GSFC)

ARTEMIS-ENABLED STELLAR IMAGER

AeSI

A NASA Innovative Advanced Concept Study

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NIAC Fellow 2024

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NASA Goddard Space Flight Center

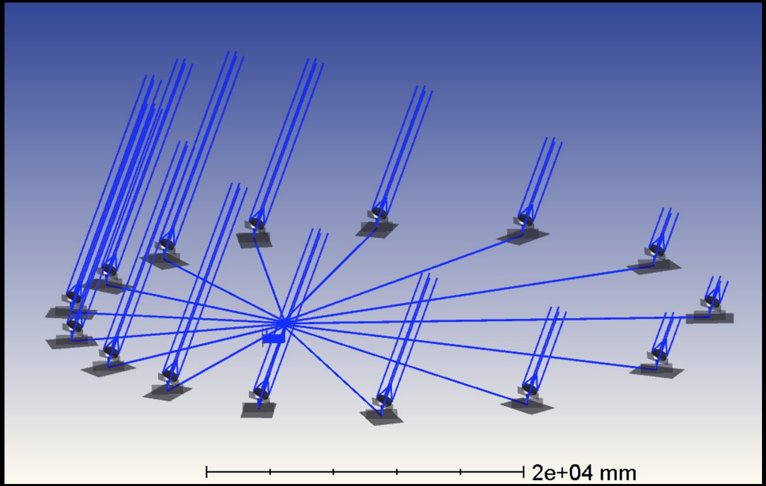
Introduction

Objectives of our Study

Assess whether we can build and operate, in collaboration with the human Artemis Program, a large, sparse aperture observatory (interferometer) on the lunar surface

Determine whether it is competitive with a previously-developed free-flyer, *Stellar Imager (SI)*

Enable the study of our Universe at Ultra High Definition at ultraviolet and optical wavelengths with ~200x the angular resolution of the Hubble Space Telescope!



Impacts of our Study

Boldly expands the realm of the possible – many studies of free-flying space interferometers exist, but there are only limited studies of lunar designs (only radio).

Begins the technical journey toward resolving surface features and weather patterns on the nearest exoplanets and enabling an entire fleet of space interferometers observing from the x-ray to the far-infrared.

AeSI Team

Mission concept under development by NASA/GSFC in collaboration with experts from Industry, Universities, and Astronomical Institutes

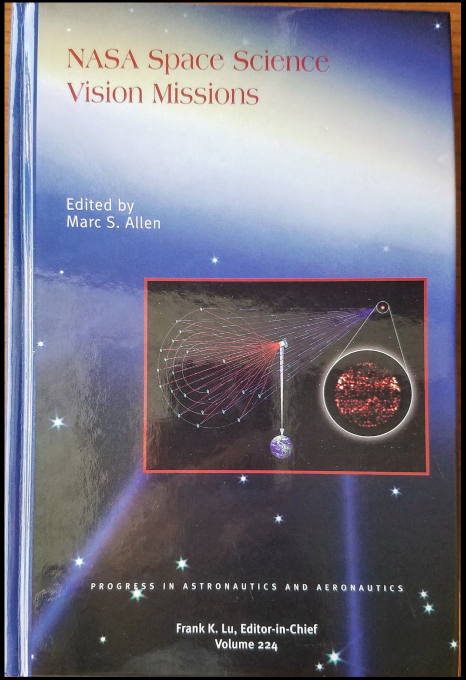
Ken Carpenter	NIAC Fellow, Mission Implementation Lead, IDC Coordinator
Tabetha Boyajian	Ground Interferometry Expert
Michelle Creech-Eakman	Ground Interferometry Expert
Margarita Karovska	Science Definition Co-Lead
David Leisawitz	Space Interferometry Expert
Jon Morse	Senior Advisor, Lunar Science & Infrastructure
Dave Mozurkewich	Lead System Engineer, Time Evolution of Observatory
Sarah Peacock	Science Definition, Study Co-Mgr, Outreach Co-Lead
Noah Petro	Artemis Expert
Gioia Rau	Science Definition Co-Lead, Study Co-Mgr., Outreach Co-Lead
Paul Scowen	Science Definition

Breann Sitarski	Optical Engineer
Gerard van Belle	Interferometry Expert, Mission Design Lead
Jon Brashear	Grad. Student, Science/AI
Derek Buzasi	Astereoseismology
Jim Clark	Mechanical Engineer
Erik Wilkinson	System Engineer
Julianne Foster	System Engineer
Buddy Taylor	Mechanical Engineer
Walter Smith	Mechanical Engineer
Qian Gong	Optical Engineer
Bruce Dean	Optical Engineer/WS&C, AI/ML
Len Seals	Scattered Light/Optical Engineer
David Kim	Power Systems Engineer

Why put Interferometers in Space or on the Moon?

Required for studying the Universe in high-definition over a broad range of colors and times.

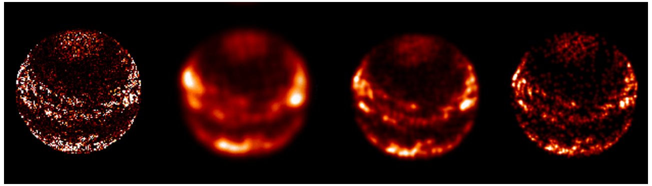
- Broader wavelength coverage
- Higher angular resolution
- Observe continuously over long time periods
- More stable environment
- No atmosphere, no turbulence, beams coherent over larger scales



What Can We See with a Space-Based Interferometer?

Solar-type star at 4 pc in CIV line

Model SIsim images

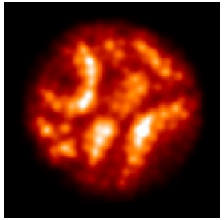


Baseline: 125m 250m 500 m

Evolved giant star at 2 Kpc in Mg H&K line

Model

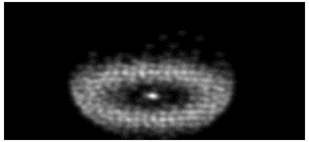
SIsim image (2mas dia)



Baseline: 500 m

SI imaging of planet forming environments: magnetosphere-disk interaction region

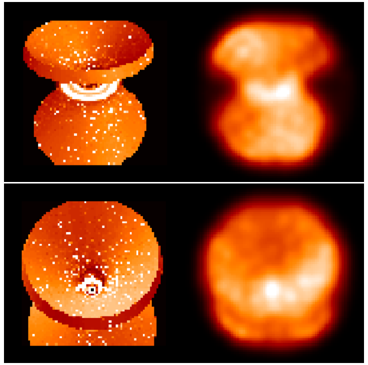
0.1 mas



SI simulation in
Ly α–fluoresced H2 lines

Baseline: 500 m

SI imaging of nearby AGN will differentiate between possible BELR geometries & inclinations



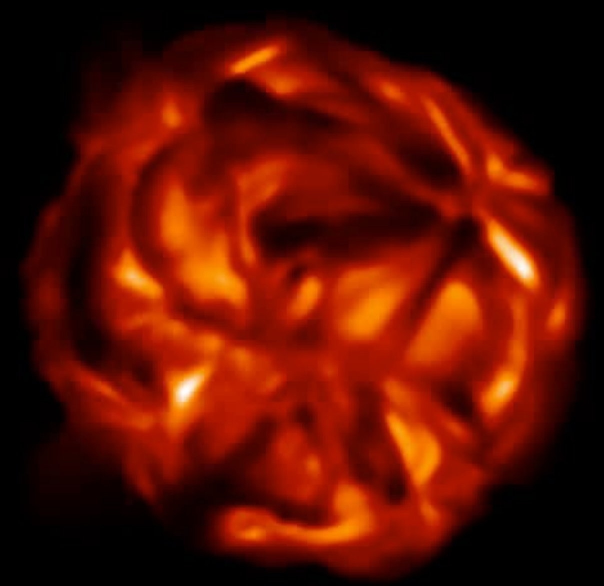
0.1 mas

model

SI simulations in CIV line
(500 m baseline)

AeSI will see motions of and *within* objects on timescales that would have astonished previous generations

- nearby stars will move across the sky as we watch
- physical processes will be directly visible
  - mass transfer in binaries
  - pulsation-driven surface brightness variations and convective cell structures in giants & supergiants
  - jets in young solar systems

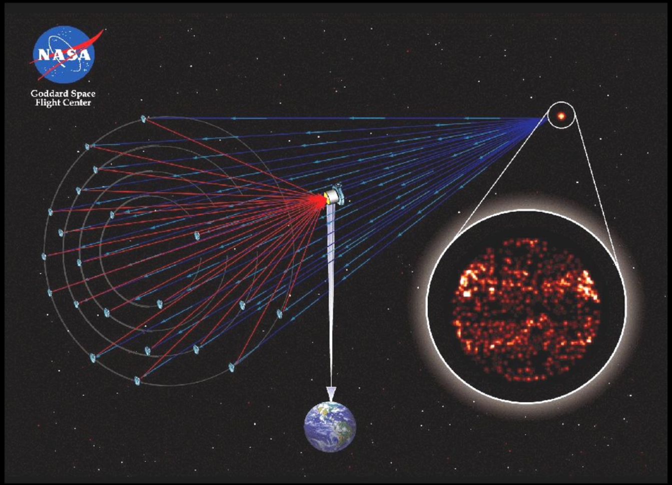


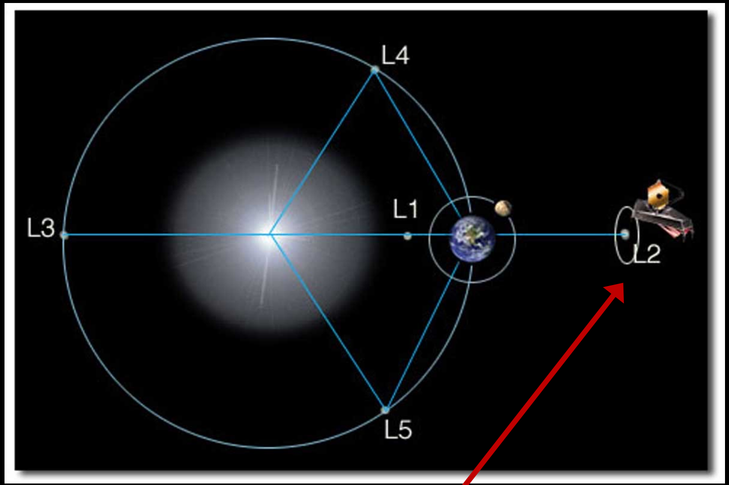
Pierre Bely et al.[1] (1996):

“unless there is a pre-existing infrastructure on the lunar surface, it is easier and better to build a large space interferometer as a free-flyer.”

[1] "Kilometric baseline space interferometry," Proc. SPIE 2807, Space Telescopes and Instruments IV, (12 October 1996)

Original SI Concept: 2005 Vision Mission (VM) Study





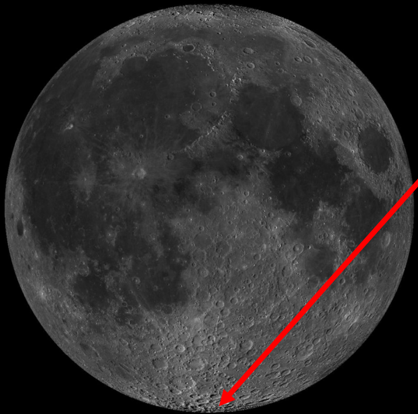
- A 0.5 km diameter UV-optical Interferometer near Sun-earth L2
- 30 primary mirrors, controlled by 1 hub; ***200x the angular resolution of HST***
- Significant Technology Challenges:
  - •Precision formation-flying of ~ 30 spacecraft & Precision metrology over multi-km baselines
  - •Autonomous Control of entire system & How do we test on ground before launch?

Learn more about Stellar Imager here: https://hires.gsfc.nasa.gov/si/

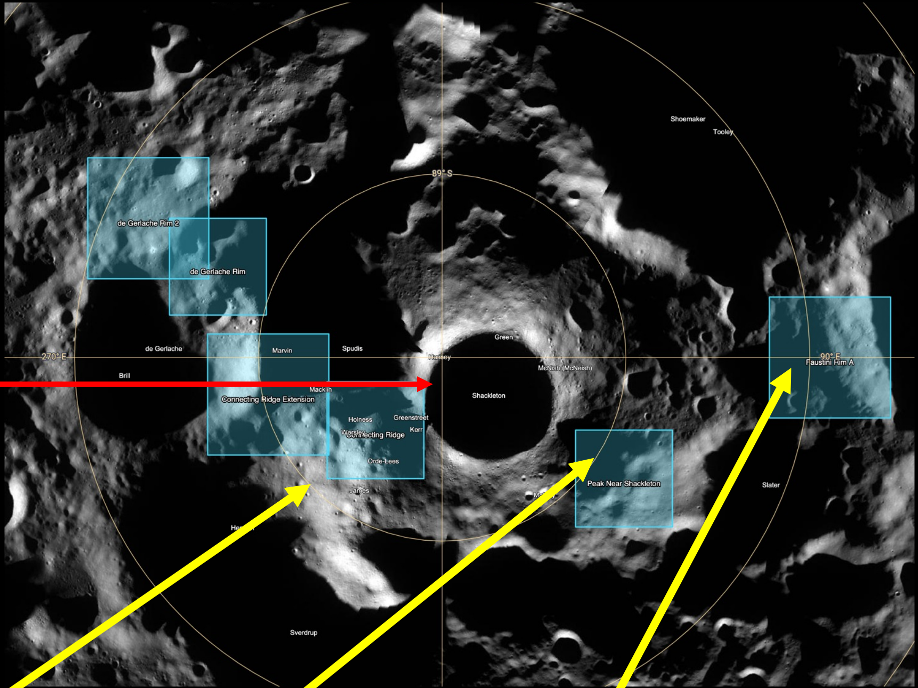
With the Artemis Project on track to put humans and their infrastructure on the Moon within the next decade.
It is time to fully consider the lunar option!

New Opportunity for Space Interferometry: Cooperation with Artemis Human Spaceflight Program

- Our NASA Innovative Advanced Concepts (NIAC) program is studying the feasibility of constructing and operating the ***Artemis-enabled Stellar Imager (AeSI)*** supported by the Artemis Program (humans & robots)



Shackleton Crater
South Pole

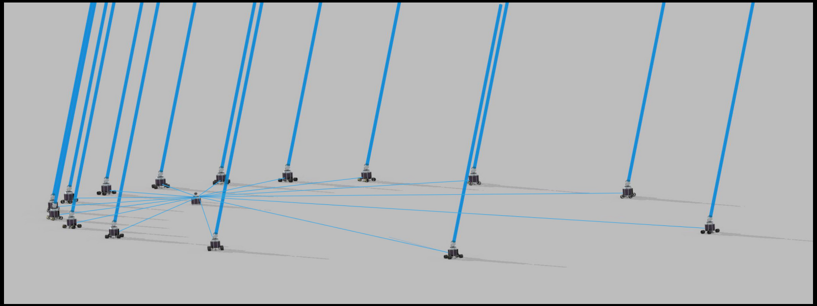


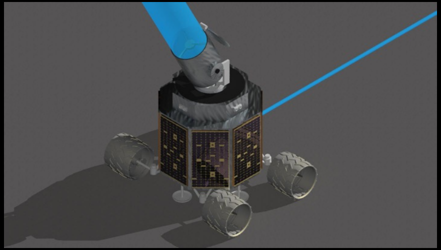
Candidate AeSI Sites near: Connecting Ridge, Peak Near Shackleton, and Faustini Rim A

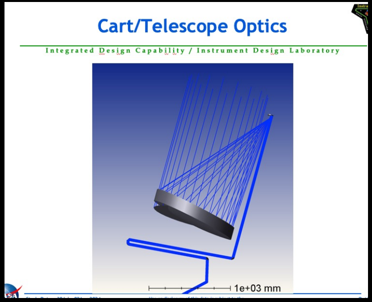
Baseline Design: GSFC Integrated Design Center (IDC)

Stage 1: 15 rovers, elliptical array to avoid long delay-lines. 1 km major-axis

Stage 2: 30 rovers, enhanced hub





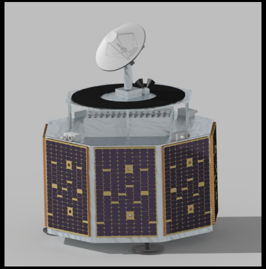


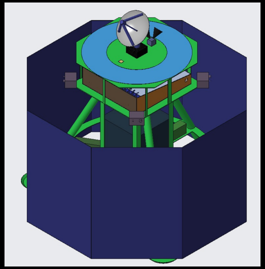
Mirror Station: artist's concept (B. Griswold) and internal optics (IDC/D. Mozurkewich)

IDC: Engineering Study
- Systems
- Mechanical Design
- Optical Design
- Communications
- Thermal
- Power

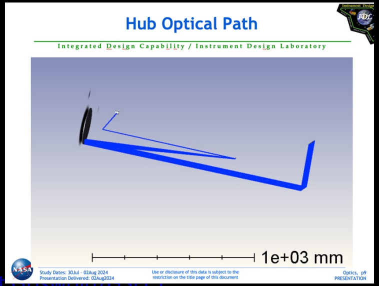
Conclusion: Feasible!!!

IDC provided many good recommendations for further studies and technology development.





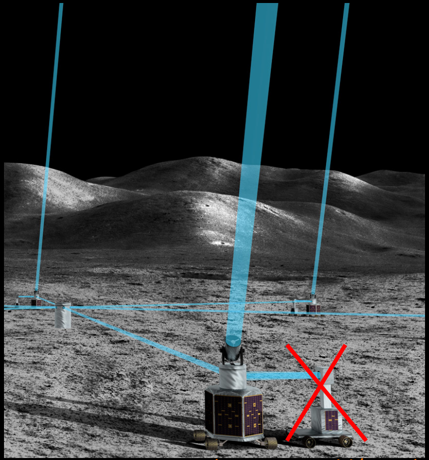
Hub: artist's concept (B. Griswold) and internal details/ optics (IDC & D. Mozurkewich)



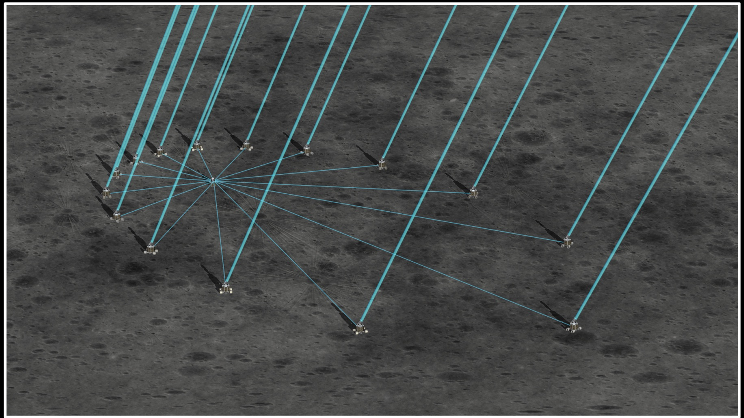
(Britt Griswold/GSFC)

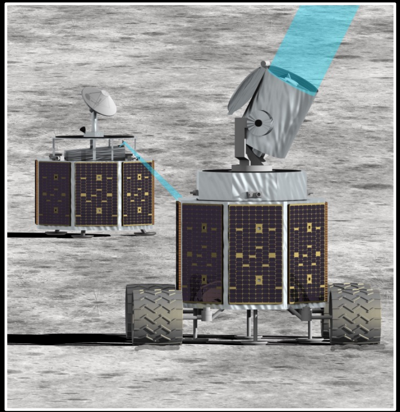
Biggest Improvements to-date

- Eliminated 2nd set of rovers for delay-line optics by using asymmetric primary array configurations to remove large path-length differences (target-to-primary-to-hub) for off-zenith targets; remaining delay line can be fit inside rovers



(Britt Griswold/GSFC)





(Britt Griswold/GSFC)

- Primary mirrors sizes increased to improve sensitivity, array baseline increased to maintain resolution while going deeper into sky for more targets

Challenges and Future Work

- Low UV-Sensitivity due to # of reflections in delay-lines require:
  - Better-reflectivity UV mirror coatings
  - More sensitive detectors, esp. for 1200-1600 A
- Refine dust & scattered light control
- Pursue Remote Power Station Options to enable more continuous operations, even in array night
  - Solar arrays on higher illumination, nearby peaks
  - Nuclear source over nearby hill
  - Supplied by Artemis infrastructure
- Investigate possibility of putting primary mirror carts on rails
- Refine support needed from human/robotic infrastructure
  - Deployment and/or servicing

Artemis-enabled Stellar Imager (AeSI)

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.

https://hires.gsfc.nasa.gov/si/aesi.html

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

Supernovae & Planetary Nebulae
close-in spatial structure

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

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

Exoplanet Host Stars
escaping atmospheres from gas giants; H II fluorescence in hot Jupiter atmospheres; transit light source effect