Accretion Explorer Interferometer (AEI)

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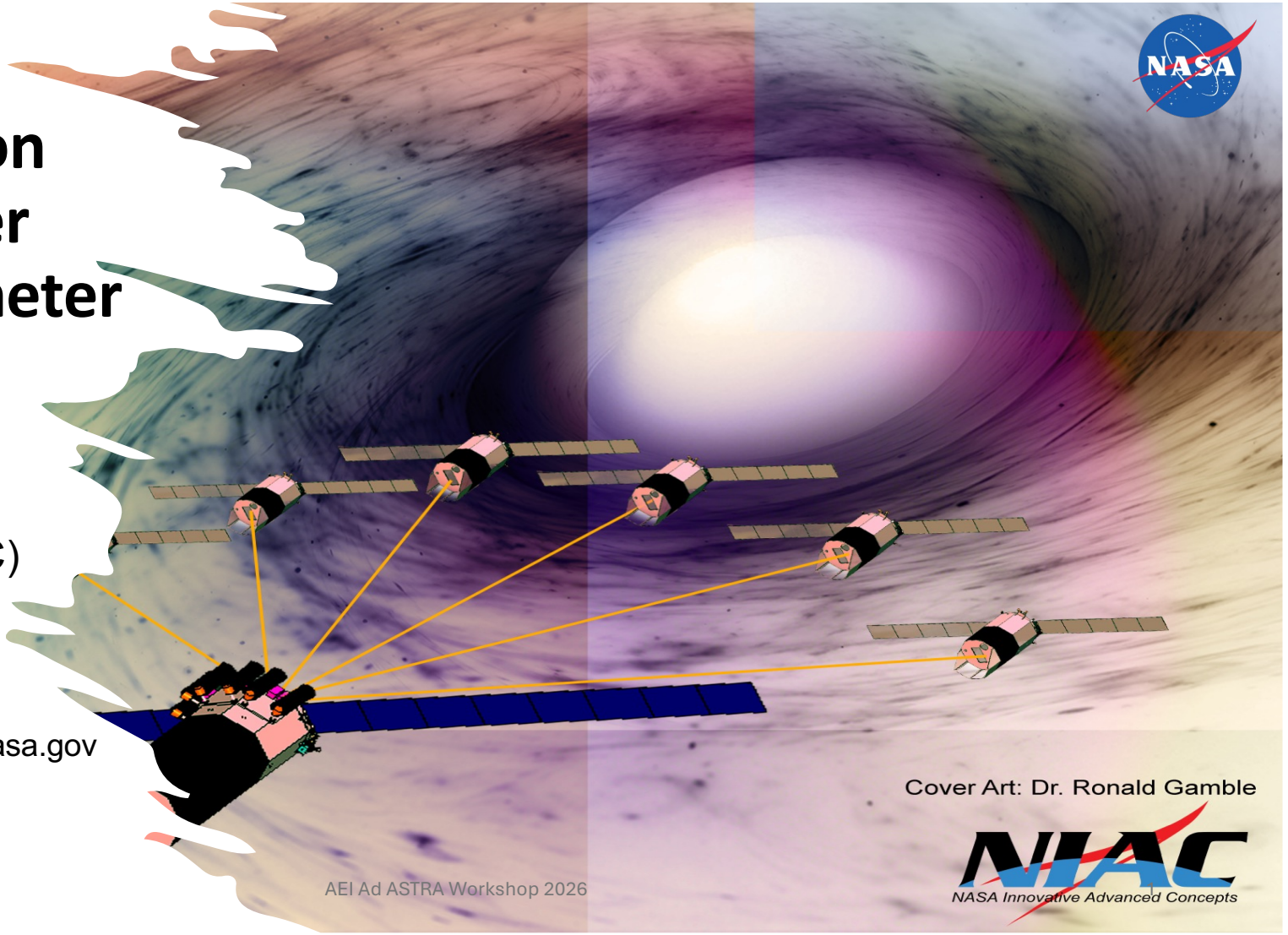
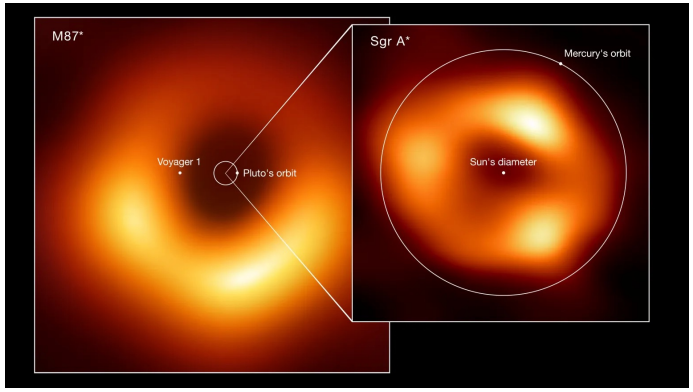


Cover Art: Dr. Ronald Gamble

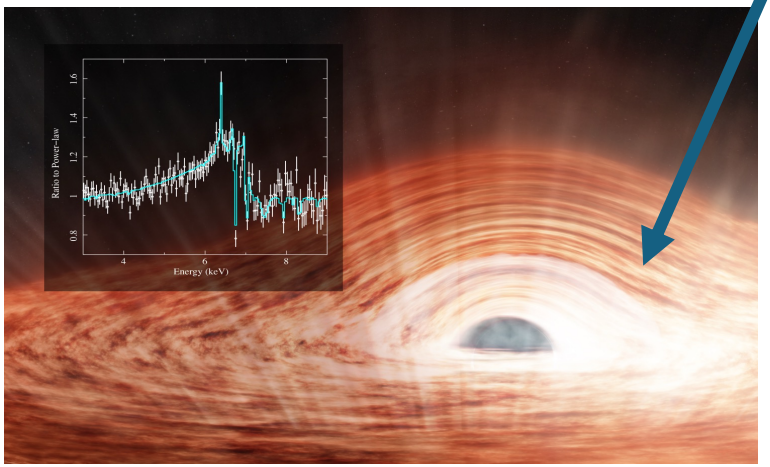
NIAC
NASA Innovative Advanced Concepts

Capability needed for Supermassive black hole accretion, jets, stellar flares…

Imaging resolution at X-ray energies of a micro-arcsecond or better



Radio: nearby SMBH in M87 (left) and Sagittarius A*
www.eso.org/public/news/eso2406/

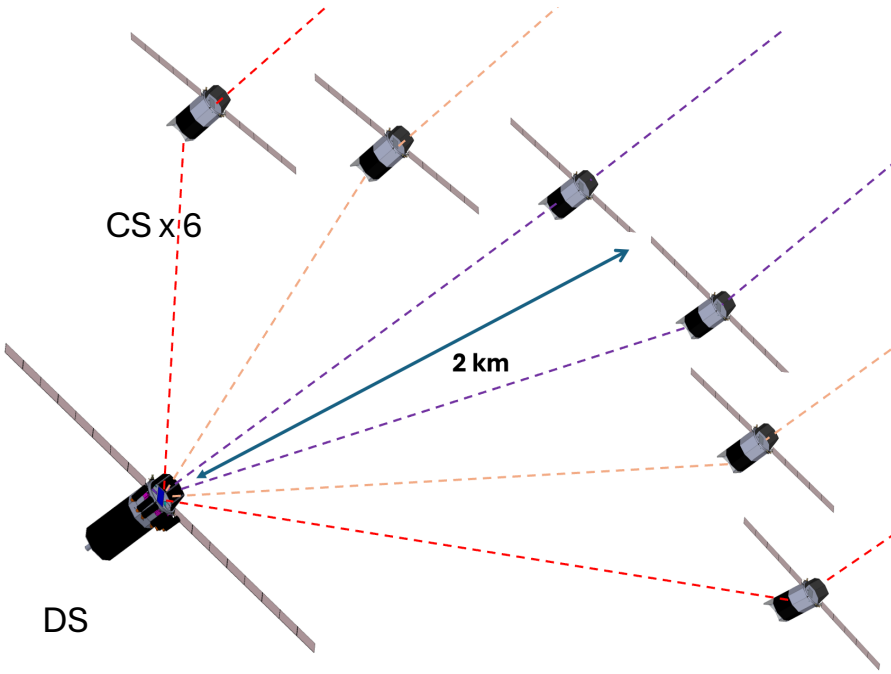


XRISM spectrum of MCG-6-30-15 - SMBH with relativistic effects
(inset, Brenneman et al. 2025, ApJ, 995, 200)

NIAC-funded Phase I study led by Kim Weaver at NASA/GSFC

- Established feasibility of an X-ray array if the pointing precision can be maintained
- Identified several technical tall poles and needed optics development
- Pointed out key trade studies and where industry partners will be crucial

The Accretion Explorer Interferometer (AEI)



one detector satellite (DS) and six collector mirror satellites (CS)

NIAC Phase I report: https://hires.gsfc.nasa.gov/accretion-explorer/resources/AEI_NIAC_PhaseI_Report_Weaver.pdf

X-ray interferometer with μas angular resolution

Formation flying array; ~0.7-2.2 keV, ~5-7.5 keV

100 picometer precision along science boresight

Two X-ray spotting telescopes for target acquisition, have ~0.1" and ~mas angular resolution

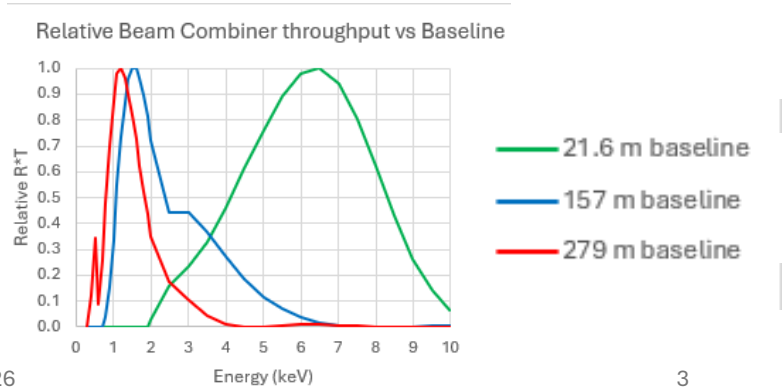
Area (preliminary) ~100 cm^2; exposures of days to weeks

FoVs: span from ~100 x 400 μas to ~0.3"x0.3" to ~10'x10'

Baselines of 21.6 m, 157m, and 279 m

Pointing accuracy: 0.5" (outer two CS pairs); 0.1" (inner CS pair); Knowledge: 0.05 " (outer two); 0.01 " (inner)

CS stability: milli-arcsecond (tip/tilt)



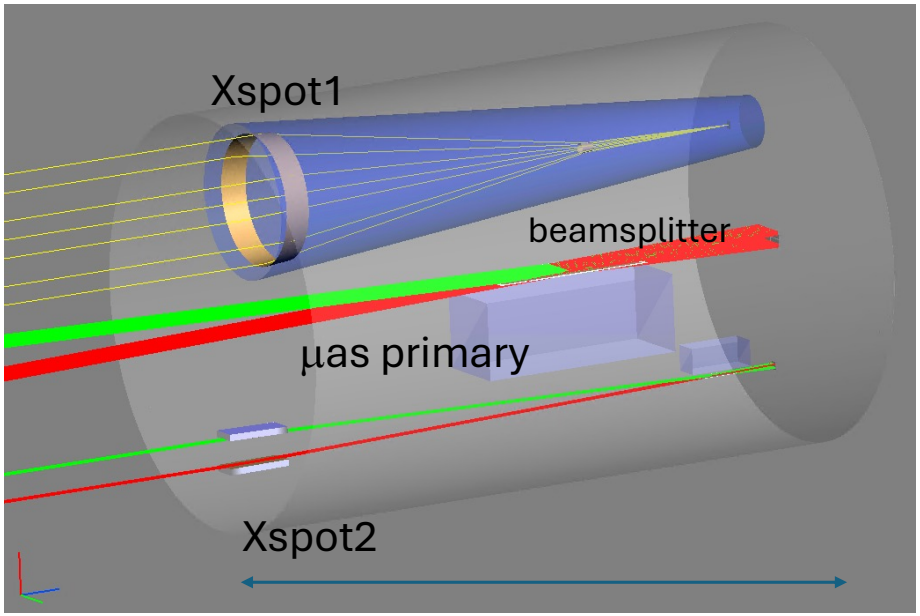
Daunting, Then and Now

- All X-ray interferometer concepts advanced since the late 1990s have remained conceptual, consistently blocked by low-TRL X-ray optics and extreme wavefront-control requirements.
- NIAC Phase 1 study highlighted the large number of parallel technological developments that are required for an X-ray interferometer, even now that all technologies are more within reach.
- Other programs are developing formation flying, pointing precision, attitude control, and navigation but these are not yet ready for AEI's requirements.
- **The X-ray specific aspects of AEI must be advanced.**
- Phase I suggested a truss-mothership concept that does offer some advantages worth exploring, assuming the technical challenges of building a large truss structure can be met.
- LISA Pathfinder (referenced by Weaver et al. 2026 NIAC report), while demonstrated, does not address X-ray-specific optics, stray-light suppression, or imaging-reconstruction challenges
- **Ambitious goal => collecting beams that preserve phase and combining them to create a true interferometer.** Need full assessment of the collecting area, signal-to-noise, and detection sensitivity to collect enough X-ray photons to make meaningful measurements.

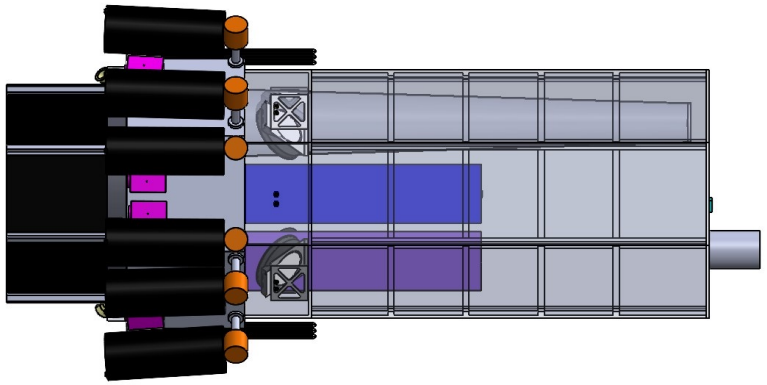
Critical / key enabling technology for AEI - 1

Spotting telescopes for target centering.

- Xspot1 requires resolution of <0.5"
- Xspot2 requires milliarcsecond resolution



5 m



Detector satellite with three X-ray telescopes and CCD focal planes

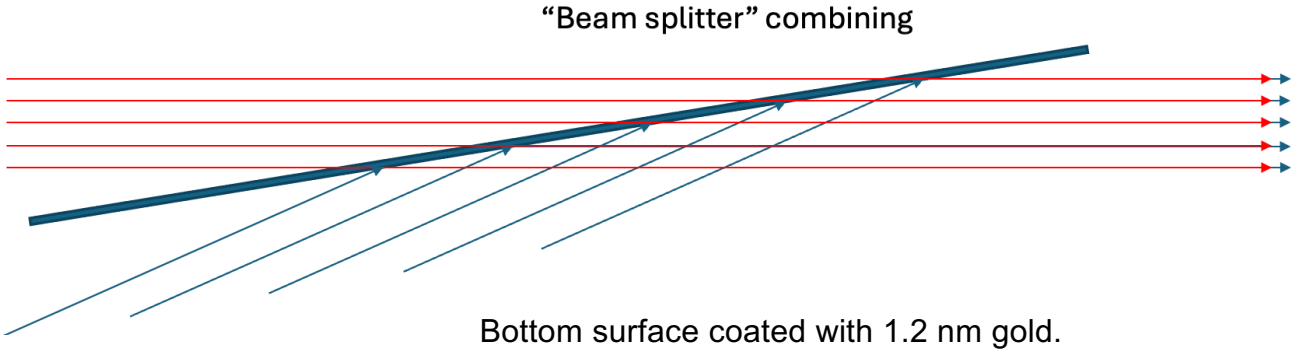
Low TRL X-ray optics; trade space for spotting telescopes

These can be ANY workable solution that provides the needed collecting area

Partnership opportunity

Critical / key enabling technology for AEI - 2

X-ray beamsplitter - Eliminates long distance between combiner mirror and detector. Fringe separation can be adjusted with a single tilt, tailored to the sizes of objects being observed. For <4 keV, requires <0.1 μm thick substrates with well controlled layer of reflecting material and need to maintain good figure.

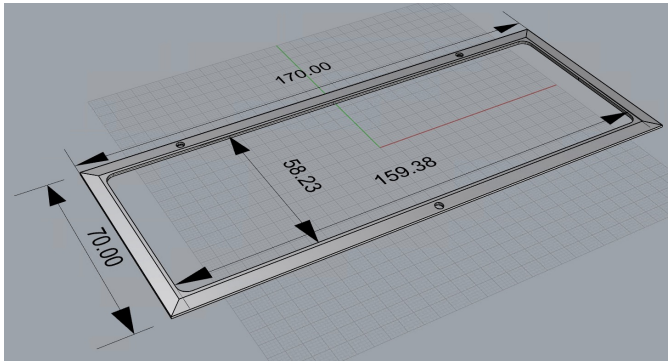


If the "mirror" is thin enough, 50% of the red ray power will transmit and 50% of the incident blue power will reflect, allowing the two beams to interfere immediately

The EUV lithography field has pursued very thin, optically transparent components (Gallagher et al. 2015 https://doi.org/10.1117/12.2199076 , Nam et al. 2022 https://doi.org/10.1039/D2NA00488G). For higher energies (e.g., Fe K lines at 6.4-7.0 keV), substrates can be 1 μm or thicker. Sub-micron polyimide (Kapton) is commercially available.

High-level technology development plan

1) Beamsplitter testbed



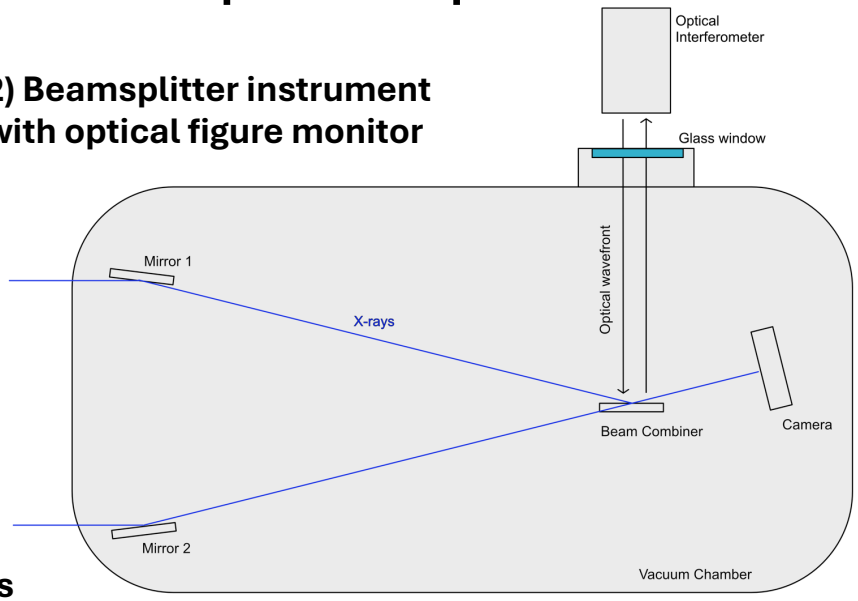
Manufactured pellicle frame design – (needed customized frames).

- **Working in the lab with materials and components**
- **Have begun a fringe acquisition and radiometric analysis**

A radiometric analysis converts pixel values into levels of intensity, to determine the science signals on the CCD detectors.

Determine settling times to acquire a target and establish the positional stability for an observation. Questions associated with jitter / time constants / data collection time.

2) Beamsplitter instrument with optical figure monitor

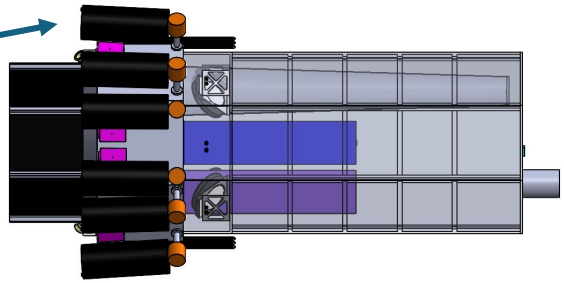


GSFC 100 m beamline vacuum chamber

Demanding design drivers for spacecraft bus

High-precision pointing and stability

- pointing achieved with LISA telescope technology
- need metrology scaling to X-ray picometer tolerances amid photon noise and stray light
- other laser-ranging options may be available



Mitigate against micro vibrations and external forces

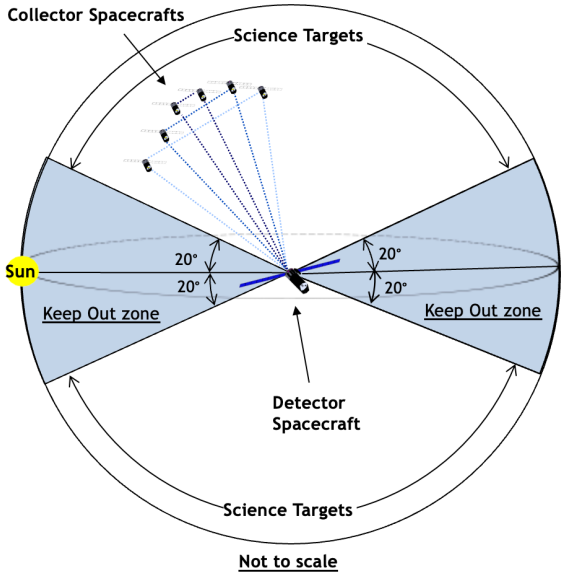
- achievable with current micro thruster technology
- but designs are not optimal for this system
- current navigation estimates require large Δv

Careful optimization of fuel resources

- further explore operations and navigation options
- truss structure could save on propulsion / trade study

Sunshade design

- shield against solar flare events, optimize for array rotation, Sun avoidance angles for CS



AEI implementation strategy

Enabling technology	Status	Need (next step)	Other Drivers	Next step	Outcome (Mid-term)
Combiner beamsplitter optic (for micro-arcsec)	Low TRL lab demo	At least TRL3		Combiner instrument prototype (SAT/APRA)	Test flight for 0.1- 0.5 arcsec interferometer **CubeSat, Balloon**
X-ray optics for 0.1 arcesc and mas (Xspot1, Xspot2)	Low TRL lab demo	At least TRL3	Other X-ray concepts (ASTRA)	SAT/APRA	**Viable Design for Xspot 1 and Xspot 2 Test flights**
Propulsion	TRL 6+ Hall micro thrusters / vs. Electrospray (mN vs. μN)	**Mid-size option or dynamic micro thrusters to optimize resources**	CubeSATs, SSDS* program, **commercial use**	**Properly sized thrusters**	**Test flight for a mas interferometer**
Laser ranging technology	LISA telescopes and lasers	**mid-power option, further development**	Space Geodesy, GRACE-FO*, **space debris tracking**	distributed formation & alignment test	**Properly sized technology Test flight for a mas interferometer**
Navigation	lack of proper tools	develop 6-dof tools for navigation	**Other formation flying arrays or constellations**	apply tools in simulated study	Update the concept of operations

commercial industry advancements and **strategic partnerships**

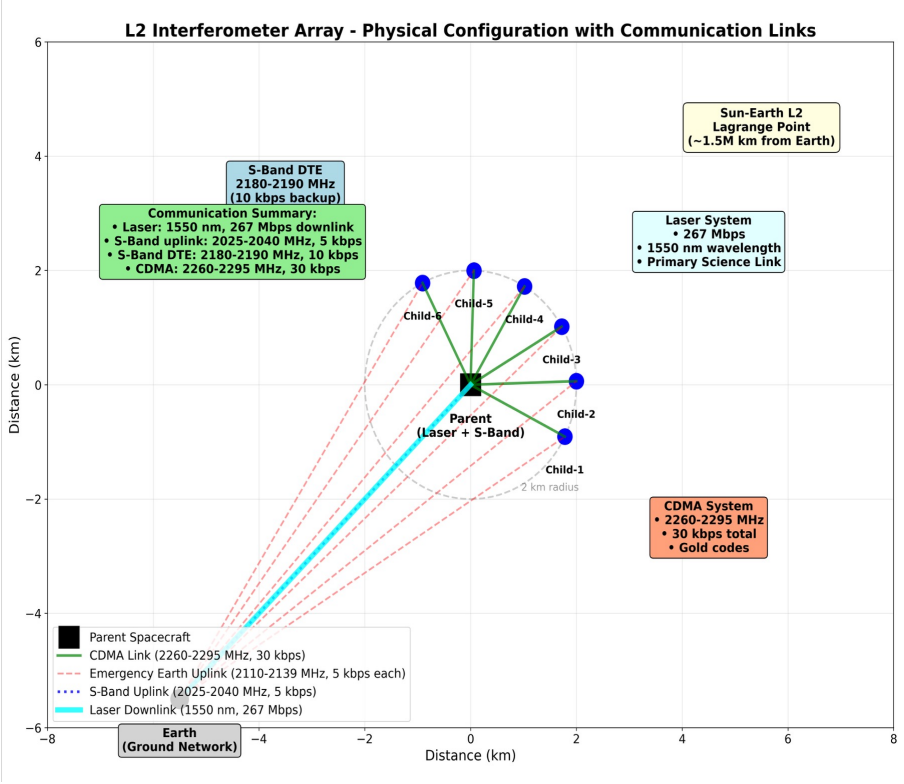
*GRACE-FO is the Gravity Recovery and Climate Experiment Follow-On. SDSS is the NASA Small Spacecraft & Distributed Systems program

Use of Artemis infrastructure

- Optical communications structure
- Ride shares to orbit

Industry and partnerships

- Partner institutions like U. Colorado, MIT, Northwestern U.
- External companies for truss study, beamsplitter manufacturing.
- Small-scale NASA programs, including the Small Spacecraft and Distributed Systems (SSDS) program
- SSDS expands the ability to execute unique missions through rapid development and demonstration of capabilities for small spacecraft applicable to exploration, science and the commercial space sector.
- Intermediary stages or precursors for AEI would be scaled down interferometers with our optic plus collector mirrors to test formation flying components and achieve lower angular resolution (between 0.1" and a mas) as test flights.
- Companies external to NASA that provide launch rideshares include SpaceX, the United Launch Alliance (ULA), and Rocket Lab.



NIAC Phase I communications spectrum study (Weaver et al. 2026, Phase I report)

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ASTRA AEI submission

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