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FLUTE

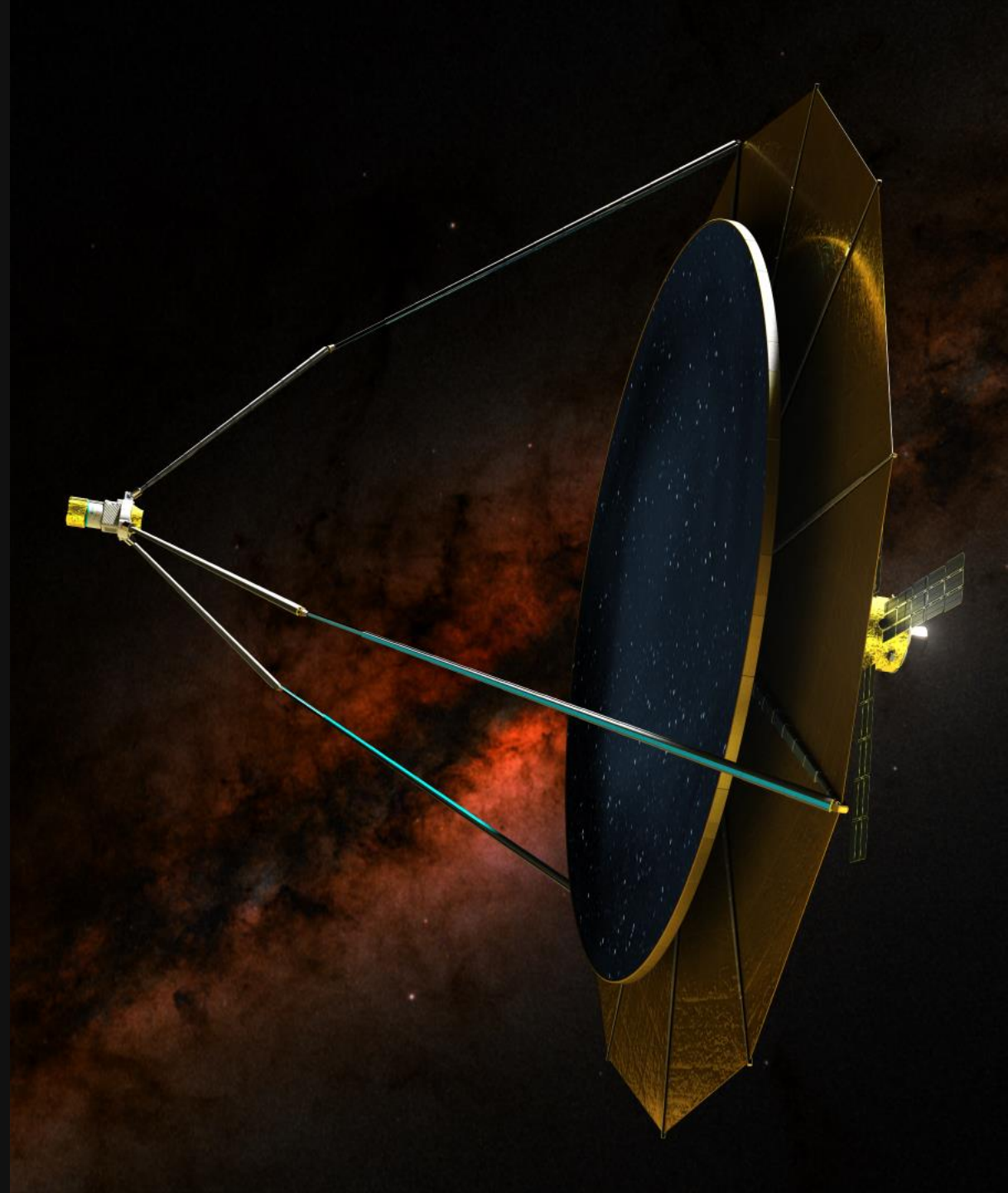
A fluidic path to a monolithic 50-meter space telescope

The Fluidic Telescope (FLUTE) forms large monolithic mirrors from a liquid in microgravity, delivering the angular resolution, light-gathering area, and figure quality of a single filled aperture — created in space rather than folded on Earth.

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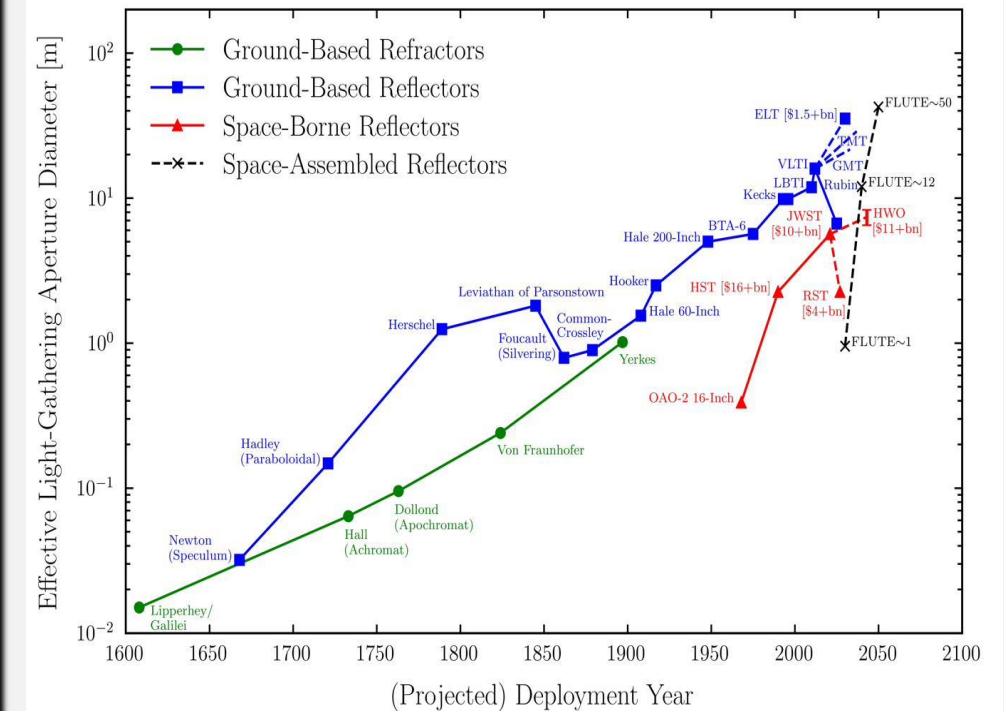
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NASA Innovative Advanced Concepts (NIAC) — Phase II · NASA ARC IRAD



A monolithic mirror that shapes and heals itself

- **Self-forming, self-healing optics** — an optical liquid pinned to a circular frame relaxes under surface tension to a naturally smooth surface with molecular-scale smoothness, obviating the grinding and polishing.
- **Scale-invariant physics** — the capillary length $l_c = \sqrt{\gamma / |\Delta\rho| g} \rightarrow \infty$ as $g \rightarrow 0$, so in microgravity the equilibrium surface is set by surface tension, not gravity; monolithic mirrors of arbitrary diameter form with no self-weight sag.
- **Monolithic, not segmented** — a continuous primary plus one compact aberration corrector eliminates the segment count, co-phasing, edge diffraction, and stability penalties that bound folded apertures such as JWST.
- **Demonstrated heritage** — the first optical component shaped in space aboard the ISS (2022); mirror deployment and fluidic shaping validated in parabolic-flight microgravity (2021, 2022, 2024).
- **Roadmap** — FLUTE-1 (1-m, LEO technology demonstrator, in development) retires deployment, shaping, and metrology risk enroute to FLUTE-50 (50-m observatory at the Sun–Earth L2 point).



Four centuries of roughly exponential aperture growth; the space-borne branch plateaus after JWST. In-space fluidic assembly reopens it (FLUTE-1 / -12 / -50). From Biancalani+2025; Racine+2004.

Resolution AND flux in a single filled aperture

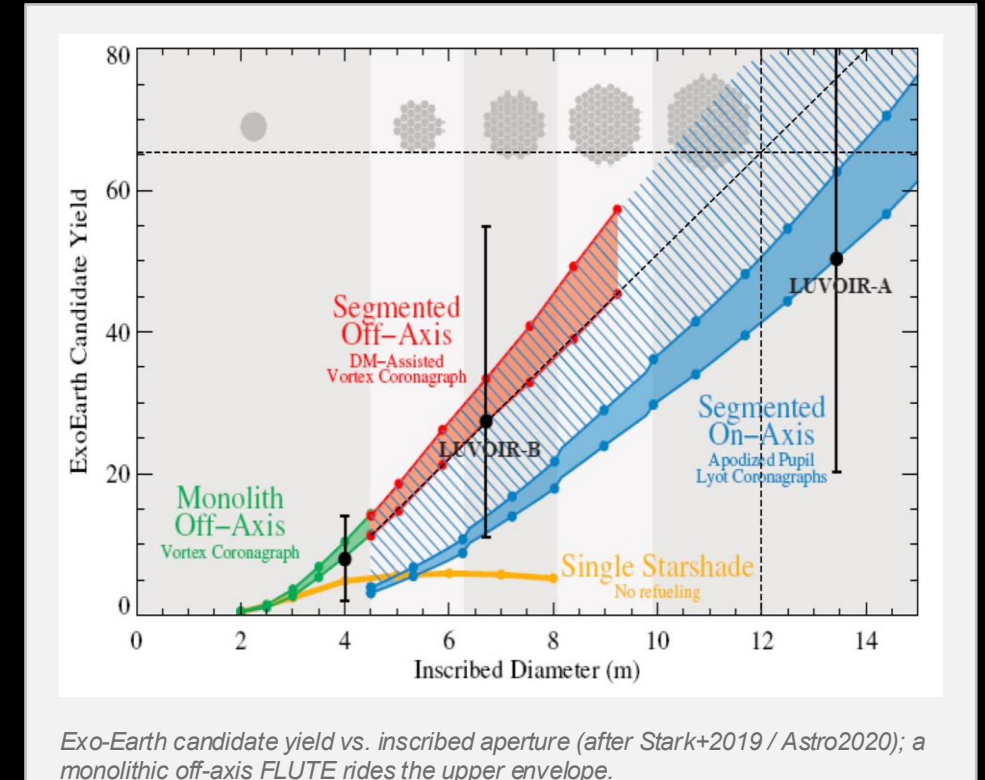
Angular resolution can be reached in many ways; pairing it with the photon-collecting area and complete uv-coverage of a filled aperture is what almost no other architecture provides. This combination, plus a high-quality monolithic figure, are the strengths of FLUTE.

Architecture	Angular resolution	Collecting area	Imaging (uv-coverage)	Net capability
Monolithic filled aperture (FLUTE-50)	$\approx 2.5 \text{ mas @ } 0.5 \text{ }\mu\text{m}$ ($1.22 \lambda/D$)	$\approx 2000 \text{ m}^2$ (full $\pi D^2/4$)	Complete $\rightarrow$ true imaging + faint-target spectroscopy	Resolution + flux
Long-baseline interferometers	Set by baseline B (up to $\sim 200 \text{ m}$)	Only the small sub-apertures	Sparse $\rightarrow$ photon-starved; bright sources only	No flux
Sparse / multi-aperture arrays	Each unit's λ/D — not the array span	Grows with unit count; averages systematics	Improves sensitivity, not single-dish resolution	No resolution

Bottom line: only a filled monolith delivers diffraction-limited resolution at the sensitivity that reflected-light exo-Earths (contrast $\approx 10^{-10}$) and faint-source astrophysics demand. Every projected science case follows from this combination of resolution, area, and figure.

Performance scaling with aperture diameter

- **Yield $\propto$ aperture** — exo-Earth candidate yield rises monotonically and steeply with diameter (Stark+2019). A ~12-m fluidic aperture already exceeds the Astro2020 / HWO yield by ~3 $\times$; a 50-m aperture moves the field from detection toward a statistically complete census.
- **Integration time $\propto D^{-4}$** — for background-limited point sources, exposure time falls as the fourth power of diameter, enabling time-domain science (rotation, weather, seasons) and large samples within a fixed mission lifetime.
- **Survey volume $\propto D^3$** — the accessible stellar and extragalactic volume scales with the cube of diameter, broadening samples and the probability of rare, high-value detections.
- **Resolution $\propto \lambda/D$** — $\theta \approx 2.5$ mas at $0.5 \mu\text{m}$ for $D = 50$ m ($1.22 \lambda/D$) — roughly 3 $\times$ sharper than LUVUOIR-A (15 m) — resolving structure from protoplanetary disks to individual stars in galaxies well beyond the Local Group.



Scaling laws are robust; absolute yields are illustrative and depend on coronagraph throughput, wavefront stability, and deployment quality.

A general-purpose observatory for large-aperture astrophysics

FLUTE-50 is a near-UV / optical / near-IR facility whose objectives span the breadth of astrophysics enabled by a large filled aperture — unified by the resolution, photon collection, and monolithic figure quality only such an aperture provides.

- **O1 · Habitable worlds & life** — directly image and obtain reflected-light/thermal spectra of rocky planets in the habitable zones of nearby stars; search for atmospheric and surface biosignatures and determine the frequency of habitable conditions.
- **O2 · The cosmic baryon cycle** — map gas flows among the intergalactic medium, circumgalactic medium, and galaxies via UV absorption-line tomography, connecting gas supply to star formation over ~10 Gyr.
- **O3 · Assembly of cosmic structure** — reach the epoch of reionization, the first galaxies, and faint dwarf satellites to test galaxy-formation and dark-matter models at the earliest times.
- **O4 · Birth of stars and planets** — resolve protoplanetary disks and star-forming regions; quantify accretion, disk structure, and chemistry that set initial conditions for planetary systems.
- **O5 · Resolved stellar populations & dynamics** — photometer and astrometer individual stars in galaxies beyond the Local Group to recover star-formation histories and internal motions (dark-matter content).
- **O6 · Solar System remote sensing** — monitor giant-planet atmospheres, ocean-world activity, and small-body populations at spatial resolution previously requiring flyby or orbiter probes.

Key measurements and the aperture properties they require

Science case	Key measurement & method	What the 50-m filled aperture provides
Habitable-zone exo-Earths	Direct reflected-light imaging + low-resolution spectroscopy at $\sim 10^{-10}$ contrast within a few λ/D of the star	Resolution sets the smallest resolvable star–planet separation; collecting area sets exposure time ($\propto D^{-4}$)
Search for life	Detect O_2 / O_3 , H_2O , CH_4 , CO_2 bands across a population of imaged exo-Earths	Sample size grows with aperture, so a non-detection becomes statistically meaningful
Circumgalactic / IGM gas	UV absorption-line tomography ($Ly\alpha$, O VI, Ne VIII) against background QSOs and galaxies	UV throughput + area reach faint sightlines at the density needed to map the cosmic web
Reionization & first galaxies	Deep imaging and spectroscopy of faint high-redshift sources	Photon collection for depth; resolution to deblend crowded, faint fields
Resolved stellar populations	Crowded-field photometry to tens of Mpc; multi-epoch internal proper motions in the Local Group	Diffraction-limited resolution + depth recover star-formation histories and dynamics
Solar System bodies	Time-resolved imaging / spectroscopy of giant planets, ocean-world plumes, comets, KBOs	mas-scale resolution yields flyby-class maps and monitoring cadence from L2

From lab to space — technology maturation steps

Lab



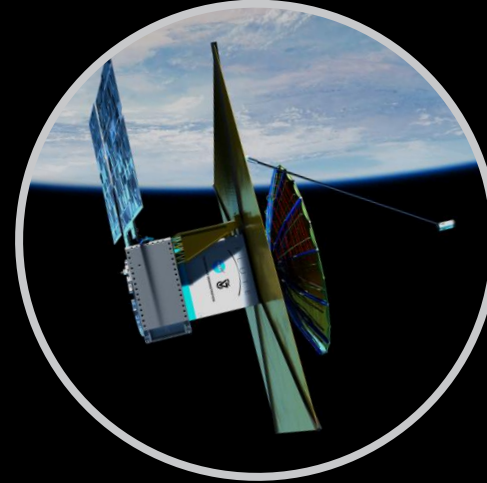
Microgravity
flights



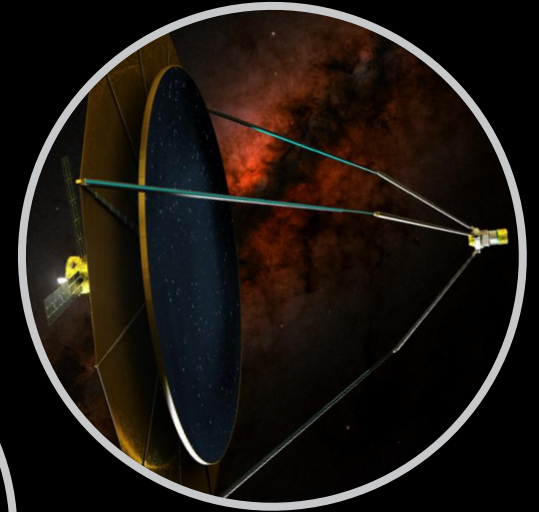
ISS



Smallsat
demo

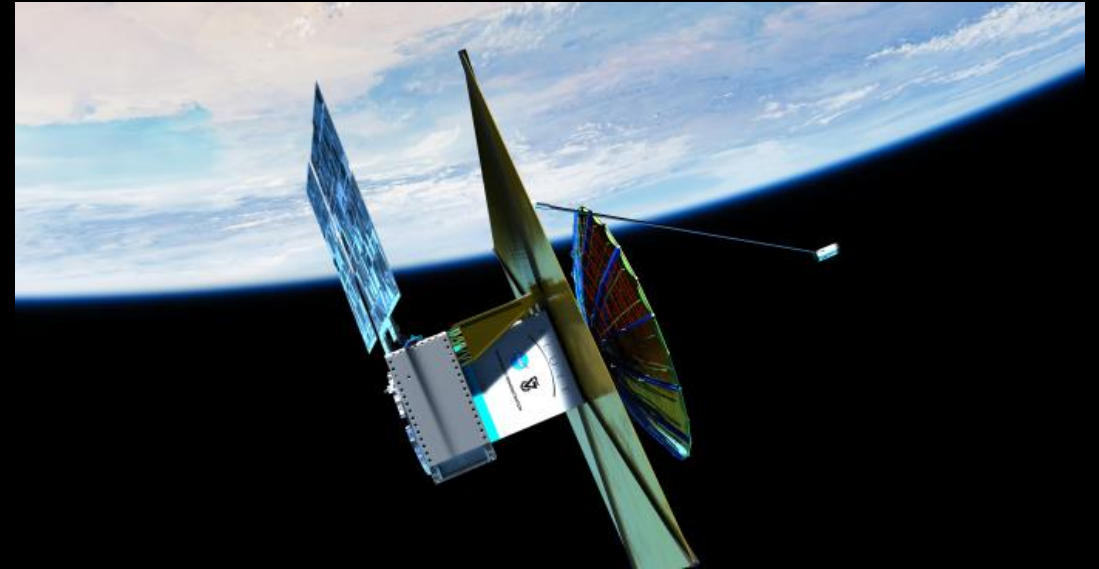


Large space
observatory



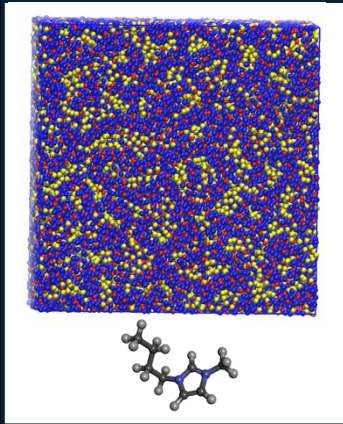
Risks retired by FLUTE-1

- **Mirror surface disturbances mitigation** — disturbances are to be expected from slewing, station-keeping, micrometeorite impacts, changing gravitational field, etc. We have developed a thermocapillary stabilization method that restores the mirror surface to its nominal shape on operationally suitable timescales: seconds to minutes.
- **Shape control** — a relaxed liquid forms a spherical section surface. The same thermocapillary stabilization method used for disturbances mitigation can also be used to transition the mirror surface to an aspherical geometry, such as parabolic or hyperbolic.
- **Wavefront stability** — JWST operates at the nm level and HWO targets pm; FLUTE's achievable stability is the key open question that the 1-m demonstrator is designed to quantify.
- **First-light wavefront sensing** — large initial wavefront error requires wide dynamic range; image-based phase retrieval plus an asymmetric-pupil Fourier wavefront sensor provide capture range in a compact, robust package.
- **Assembly, metrology & thermal** — in-space assembly, edge metrology, and thermal control of the liquid mirror remain to be demonstrated at the full aperture scale.
- **Deployment risk** — the entire concept rests on clean fluidic deployment in microgravity — precisely the capability FLUTE-1 aims to prove before any commitment to scale.

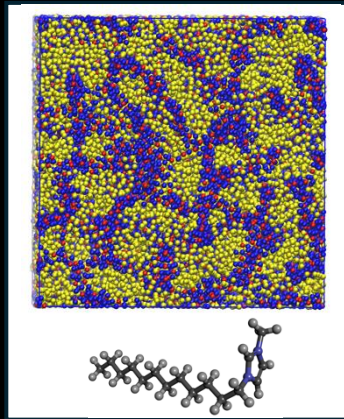


Each risk maps to a FLUTE-1 measurement: the purpose of the 1-m demonstrator is to retire them before scale-up to larger apertures.

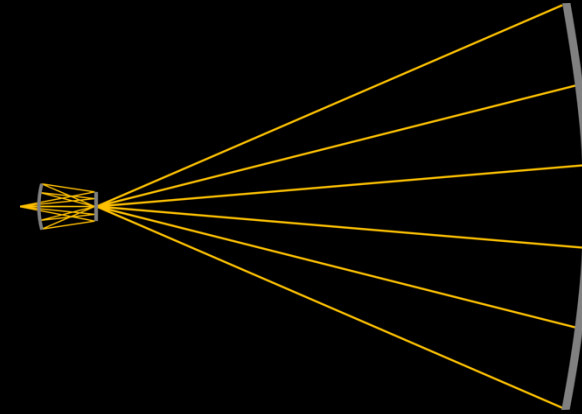
Select other ongoing work



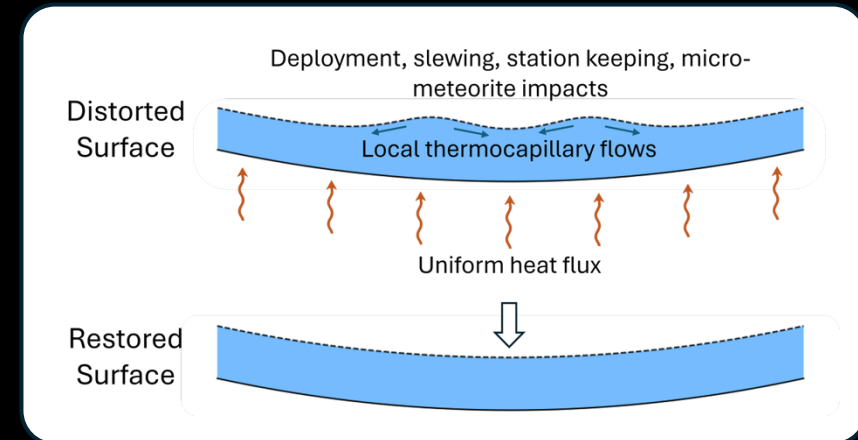
Ionic liquids reflectivity enhancement:
analytical and numerical modeling



Ionic liquids reflectivity enhancement:
laboratory experiments and measurements

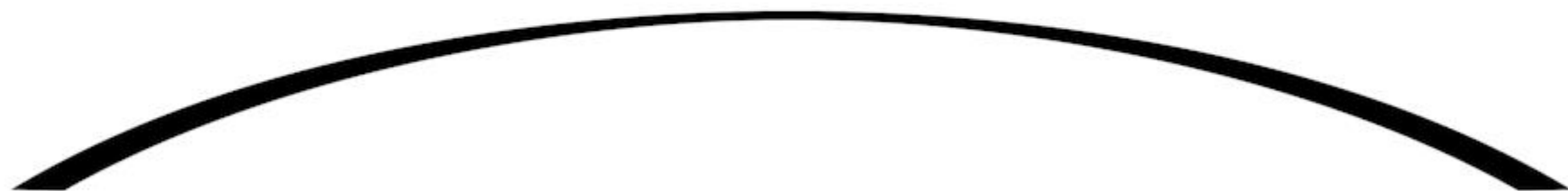


Optical design for FLUTE-1 and FLUTE-50



Thermocapillary stabilization: analytical models,
numerical models, and laboratory experiments

F L U T E



GET INVOLVED

Join the concept team

We welcome interested community members onto the FLUTE mission-concept team. Expertise in coronagraphy, UV/optical instrumentation, fluidics, wavefront sensing & control, and mission systems is especially valued.

TEAM & PARTNERS

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