GPC-SWARM: THE COSMOSCOPE

Measuring the Geometry of the Universe Directly via Wavefront Curvature interferometry

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1. EXECUTIVE SUMMARY & OBJECTIVE

■ **Primary Objective:** Establish wavefront-curvature interferometry as a new astronomical observable, bypassing standard-candle dependencies to enable direct, model-independent distance-ladder measurements.

■ **Mission Concept:** Deploy a modular, scalable heliocentric satellite swarm (growing from 4 to 20 nodes) that measures the minute geometric curvature of astronomical wavefronts across vast spatial baselines.

■ **Strategic Value:** Combines transformational astrophysics with distributed-spacecraft architectures to unlock a direct rung on the cosmic distance scale.

2. UNDERLYING PHYSICS: WAVEFRONT CURVATURE

Beyond Plane-Wave Approximations: While standard trigonometric parallax measures angular position, GPC-SWARM exploits the subtle physical curvature of incoming astronomical wavefronts.

Van Cittert-Zernicke Extension: By extending the VCZ theorem, the mission isolates a "parallax phase" (`ϕ_parallax`) that accumulates linearly as the receiver array translates through space.

$$\phi_{parallax} \approx (2\pi / \lambda) \cdot (\Delta X \cdot \Delta x / r)$$

λ: Wavelength | **ΔX:** Heliocentric translation baseline (~1 AU)
Δx: Swarm baseline (100–10,000 km) | **r:** Direct geometric distance

3. RESOLVING KEY COSMOLOGICAL MYSTERIES

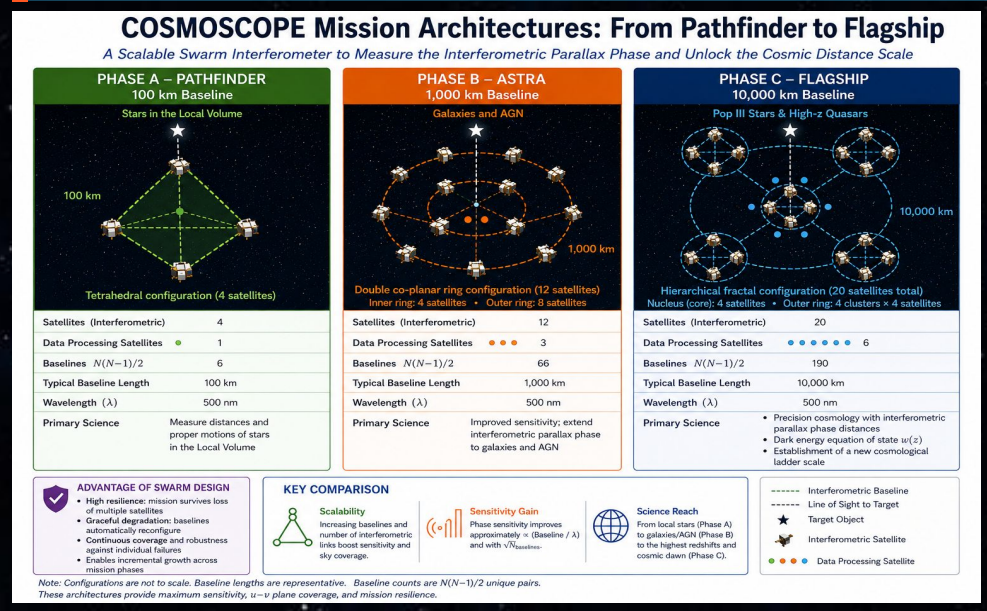
■ **The H_0 Tension:** Delivers absolute, geometric distance measurements to AGNs and pulsars with minimal astrophysical calibration, resolving local vs. CMB Hubble constant discrepancies.

■ **Dark Energy (w_0, w_a):** Provides model-independent measurements of angular-diameter distance D_A(z) and cosmic expansion history H(z) to break degeneracies in dark energy equation-of-state parameters.

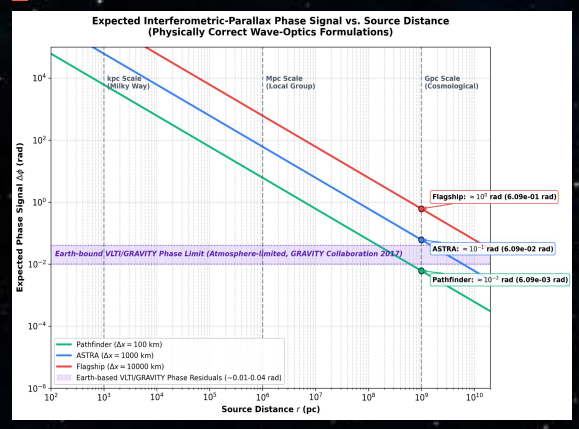
■ **Dark Sector Mapping:** Maps dark matter substructures in the Local Volume through precision timing and micro-lensing phase shifts detected across the swarm.

■ **Multi-Messenger Synergy:** The swarm's precision LRI and drag-free capabilities inherently enable the detection of low-frequency gravitational-wave (GW) signals from supermassive black hole mergers as an emergent scientific capability, providing a multi-messenger distance scale without requiring additional dedicated hardware.

4. MISSION ROADMAP & SWARM ARCHITECTURES



5. EXPECTED PHASE SIGNAL VS. DISTANCE



Multi-Scale Coverage:
The baseline hierarchy seamlessly spans galactic scales (kpc), Local Group objects (Mpc), and deep cosmological redshifts (Gpc).

Sensitivity Milestones:
Flagship configuration achieves ≈ 1 rad phase shift at cosmological scales, far exceeding Earth-bound VLTI/GRAVITY atmospheric limits.

6. TECHNOLOGY HERITAGE & PARTNERS

■ **LISA & LISA Pathfinder:** Drag-free spacecraft control and inertial sensing to shield internal sensors from non-gravitational solar radiation pressure.

■ **GRACE-C & GRACE-FO:** Laser Ranging Interferometry (LRI) heritage for nanometer and picometer-class inter-satellite metrology.

■ **VLTI / GRAVITY & Gaia:** Nanometer-class optical path metrology, fringe tracking, and microarcsecond astrometry.

■ **Strategic Coalition:** Agencies (ESA, ASI, CNS) for hardware, observatories (ESO, NRAO) for target context, and DOE for HPC correlation.

7. SELECTED REFERENCES

[1] Jain, P., & Ralston, J. P. (2008). "Direct determination of astronomical distances and proper motions by interferometric parallax." *Astronomy & Astrophysics*, 484, 887–895.
[2] National Academies (2023). *Pathways to Discovery in Astronomy and Astrophysics for the 2020s* (Astro2020 Decadal Survey).
[3] NASA Astrophysics Division (2026). *Mission Concepts for the Astrophysics Strategic Technology & Research Accelerator (ASTRA) Initiative*.