Challenges and Opportunities of Interferometry in Space

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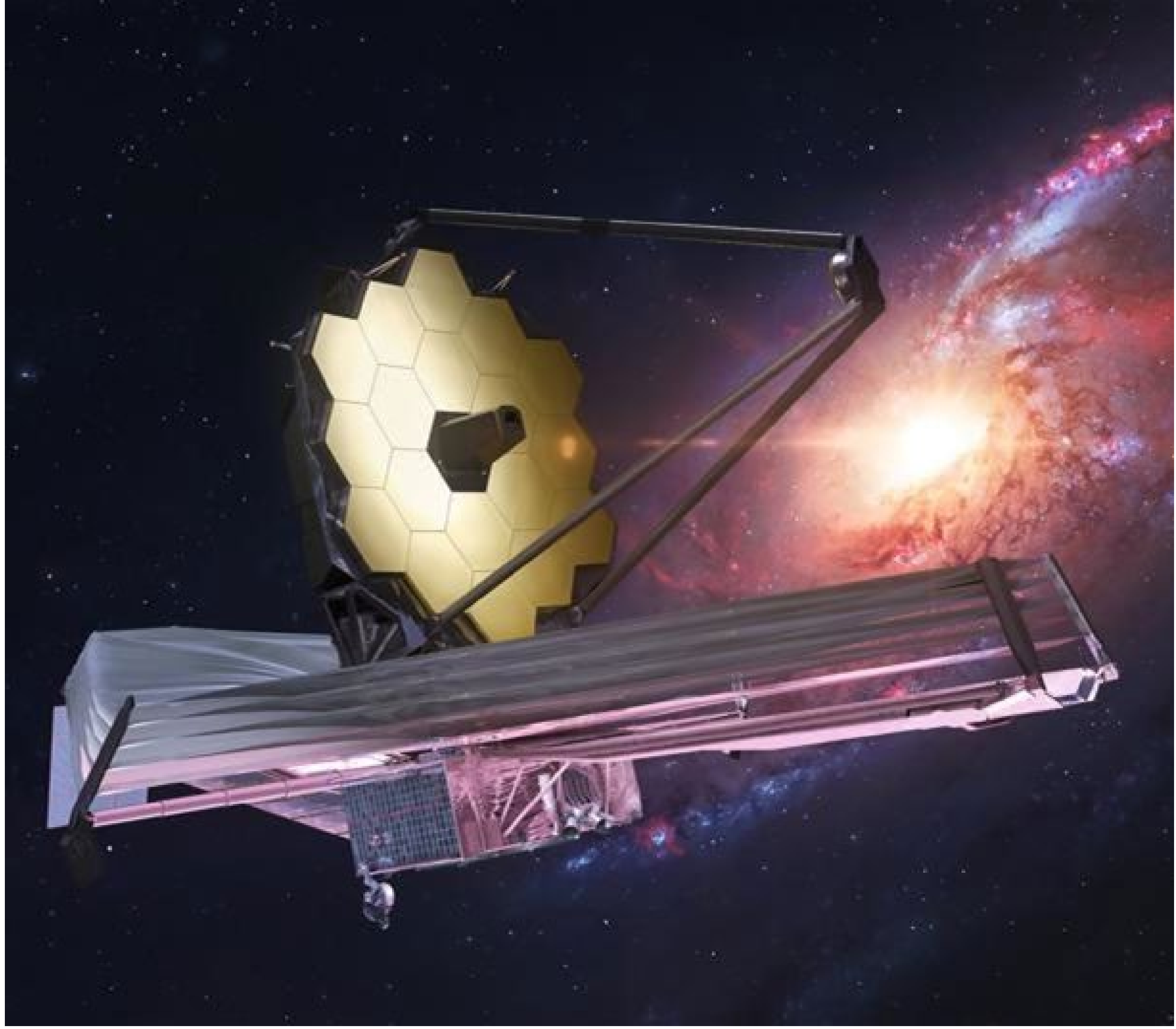
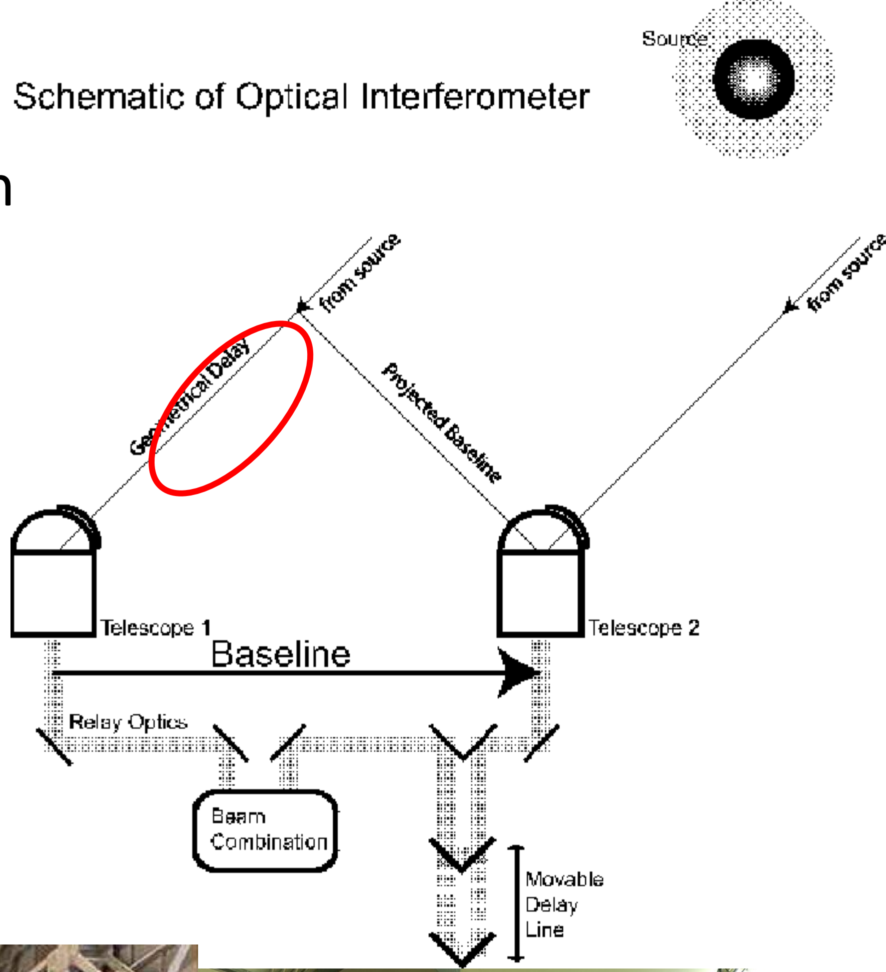
The Good---Lack of atmosphere

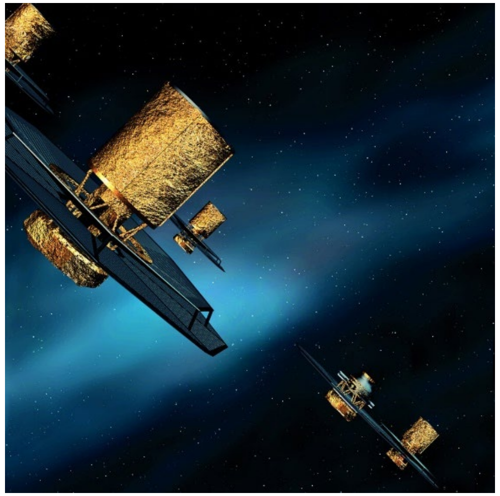
- Wavefront quality and stability at sub-nm level determined by optics quality and local sources of vibration.
  - >90% Strehl at all wavelengths
  - JWST stable ~ $\lambda/100$ over 2 days
- Stable closure phases for image reconstruction
- Stable, lossless beam transmission across large distances
- Passive cooling to <45 K for thermal IR

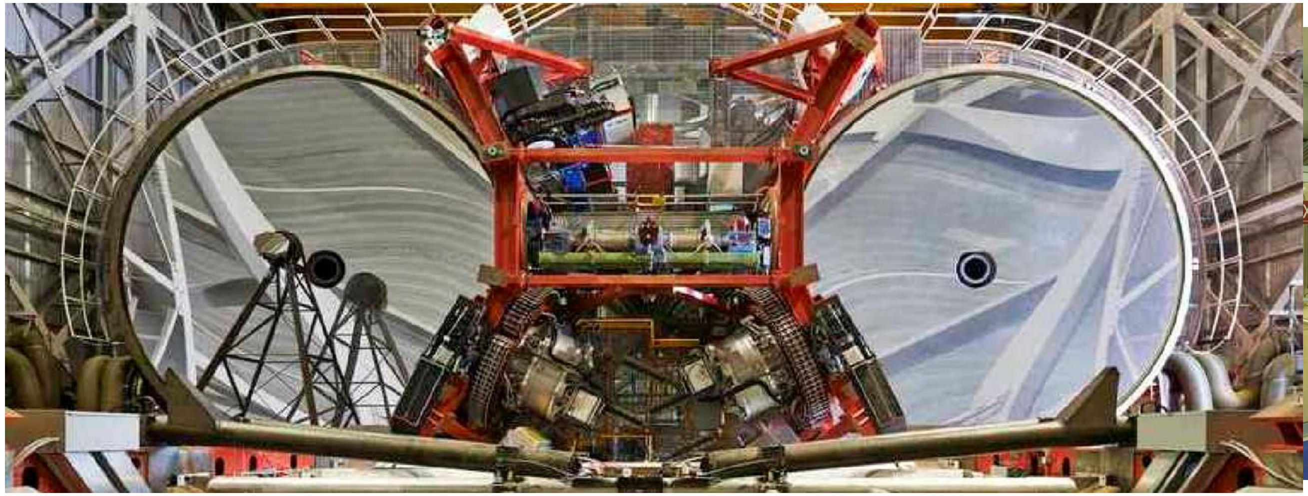


The Good ---Aim the Interferometer



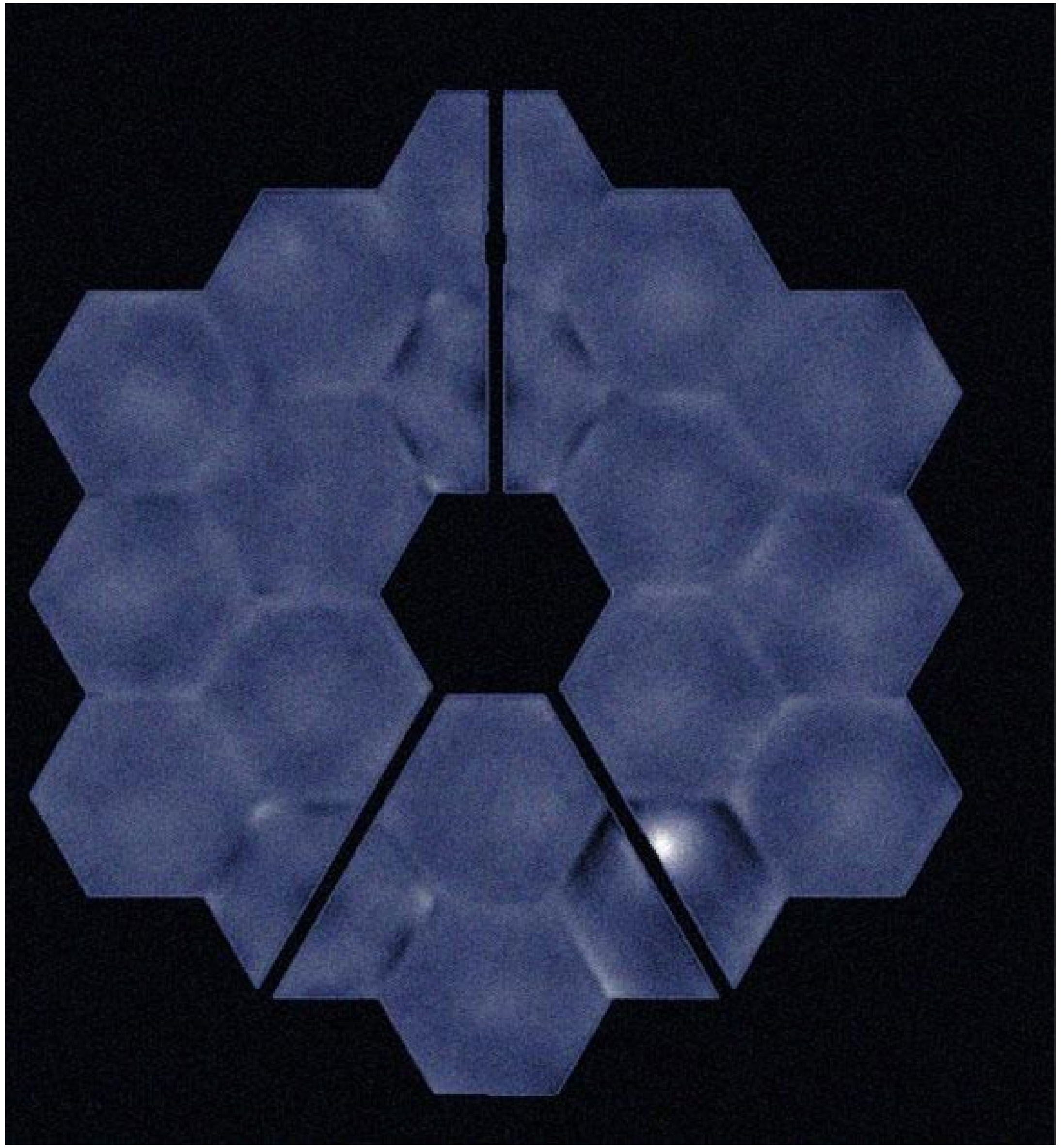
- Geometrical delay from separately pointed telescopes is with Baseline*Cos(theta) ~ tens of meters for ~100 m baseline
  - Keck-Interferometer, CHARA, NPOI,VLTI use multi-tiered delay lines
- Aiming the interferometer, not the telescopes reduces delay line problem from 10s of meters to centimeters
  - LBTI's co-mounted 8-m telescopes with 14 m baseline but represents ground-based limit
- Separated spacecraft on 50-100 m separation require minimal delay length
- Telescopes on separate spacecraft offer highly flexible configuration





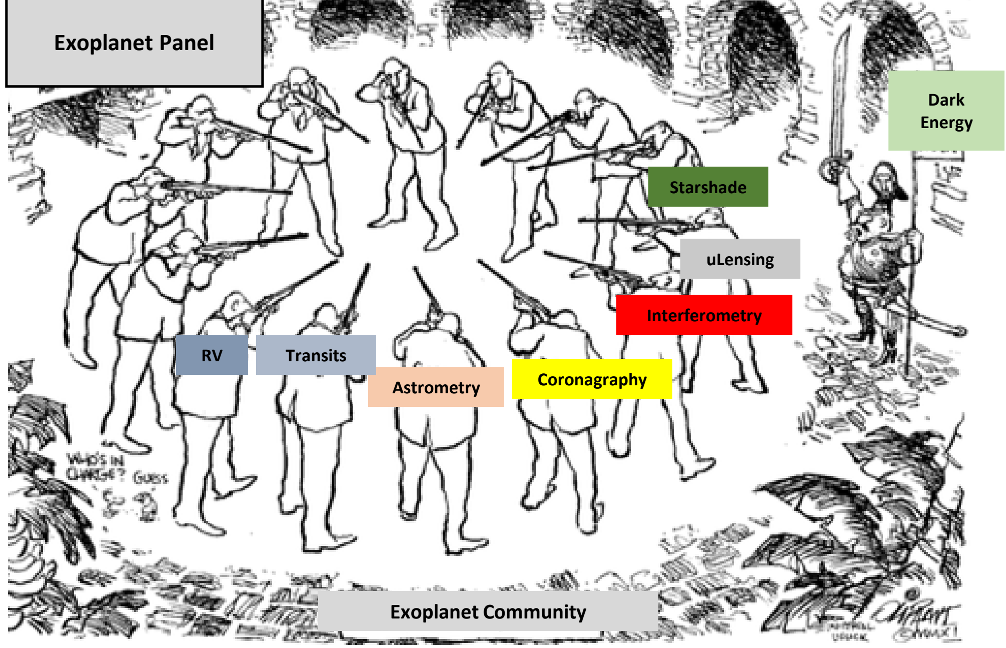
The Bad

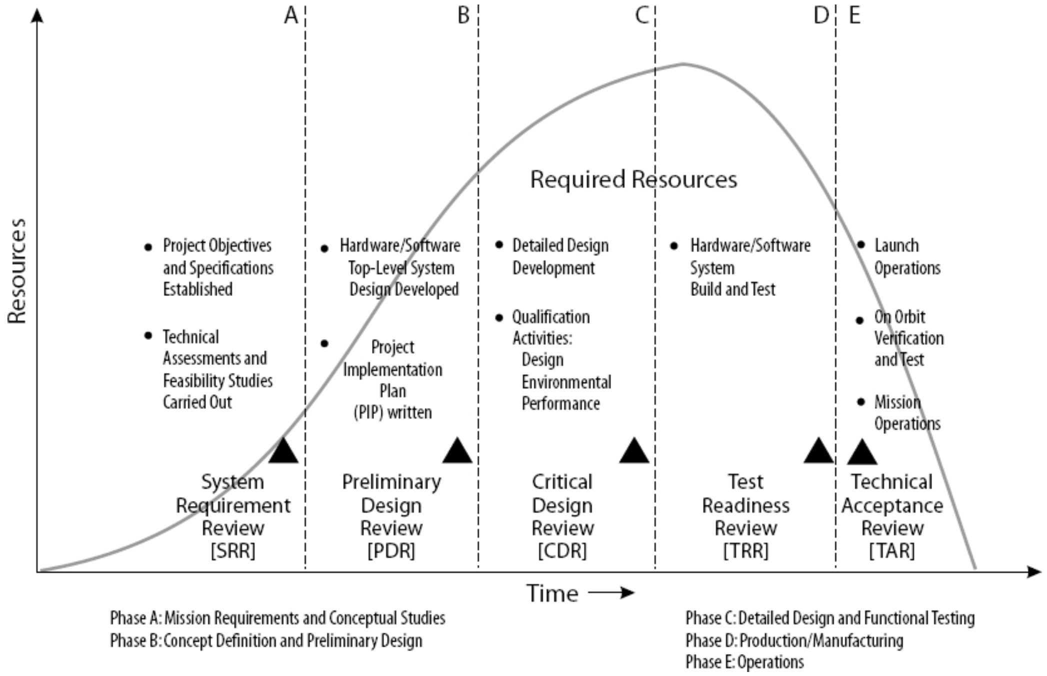
- Mircometeroid hits can affect telescope performance
- For baselines longer than 10 m or so, each telescope (plus a central receiving combining spacecraft) needs a dedicated spacecraft with its own precision 3-axis control, maneuvering fuel, power, communication, thermal control
- Beam transport between separated spacecraft requires protection from scattered and diffracted light and thermal radiation, view of thrusters, etc
- Repair, refueling, etc in most attractive orbits (L2) is (impossible| far in the future| expensive)



The Ugly

- Ambitious space missions are expensive and take many years to develop the require broad support among multiple stakeholders:
    - Discipline experts
    - Broad astronomical community
    - Funding Agencies
    - Public
- Long development period (25+ years) requires dedicated, multi-generational participants with clear paths for achievement, advancement, and succession

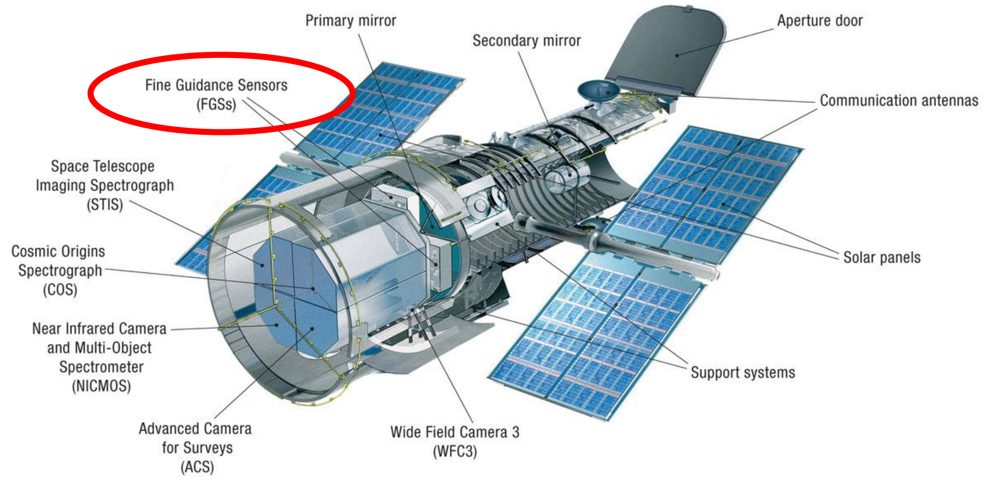




Nguyen, N. M. (2000). Effective space project management. Paper presented at Project Management Institute Annual Seminars & Symposium, Houston, TX. Newtown Square, PA: Project Management Institute.

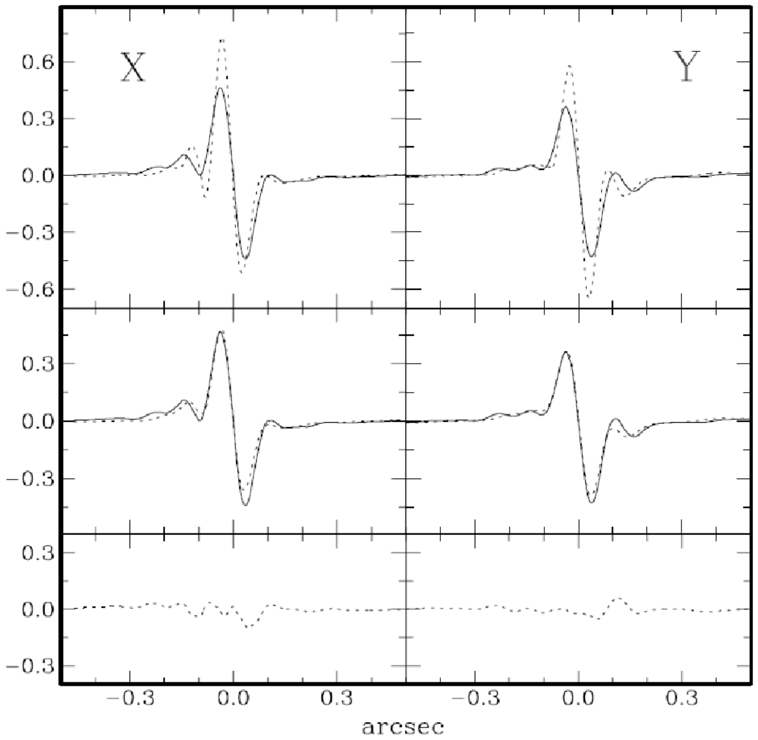
HST's The Fine Guidance Sensor (FGS)

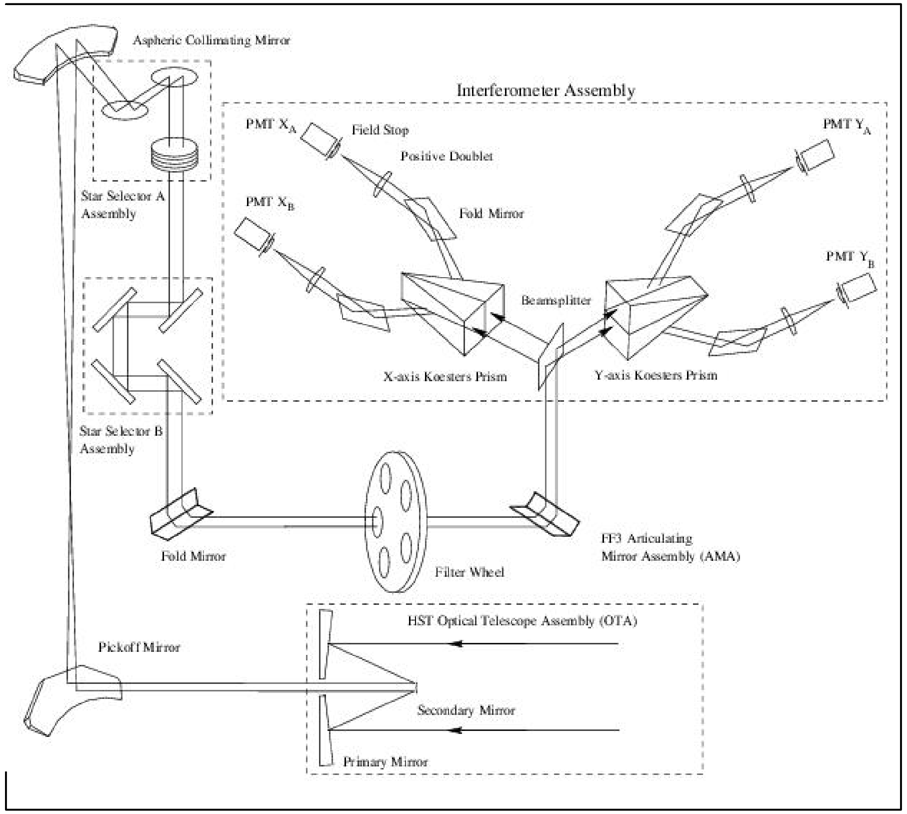
- A white-light shearing interferometer measures the tilt of the collimated wavefront rather than the path difference of two beams gathered by separate apertures.



https://hst-docs.stsci.edu/fgsihb/chapter-2-fgs-instrument-design/2-1-the-optical-train

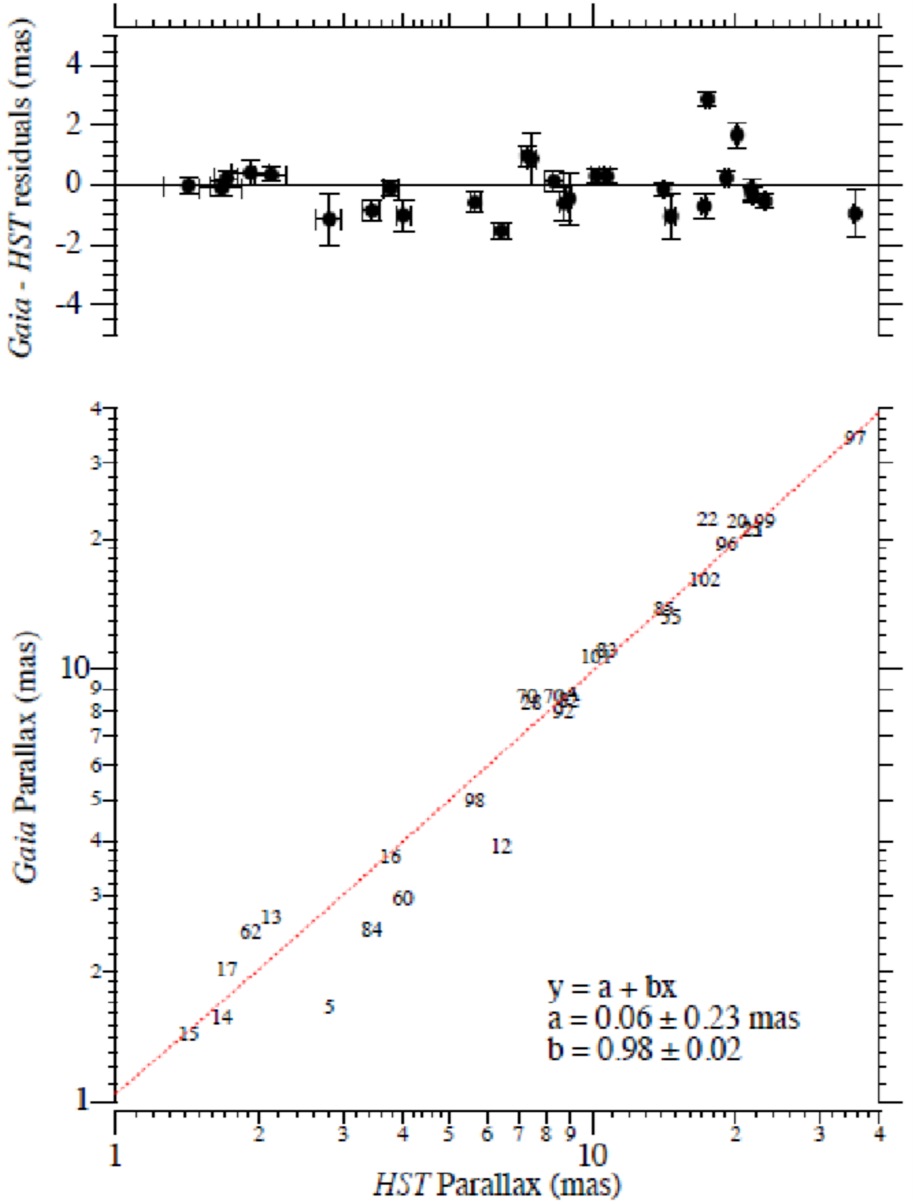
- FGS simultaneously tracks fringes in two orthogonal directions, providing centroids at ~1 mas (0.02 λ/D) to meet HST pointing budget of 7 mas





(Modest) Science with FGS

- Absolute Parallaxes of over 100 Cepheids and R Lyrae stars with 0.2 mas precision in pre-Hipparcos/Gaia era for distance scale determination
- Stellar Diameters of Mira variables R Leo (70 mas; Lattanzi et al 1997)
- Masses and orbits of known exoplanets
  - Masses of known exoplanets in the 2-100 MJup range with NO Vsin(i) ambiguity
  - Multiplanet planet coplanarity (Ups And)
  - Turning HD 136118’s planet into a Brown Dwarf: Msini=11.9 M_{Jup} M_{true}=42 M_{Jup}

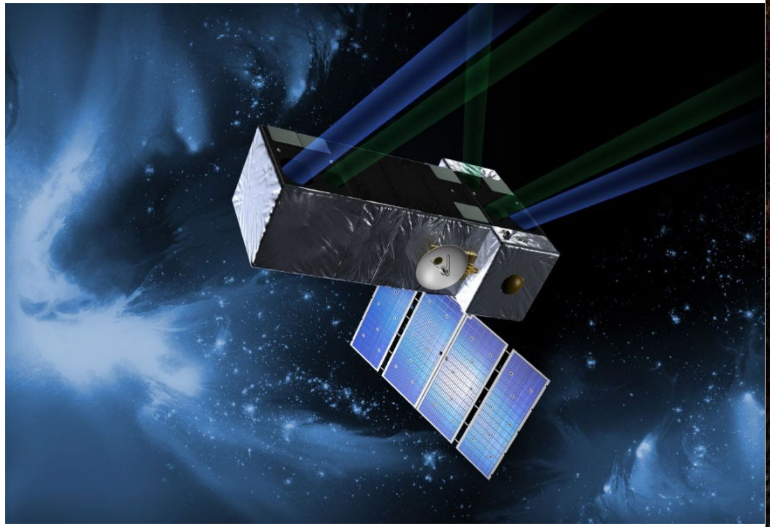


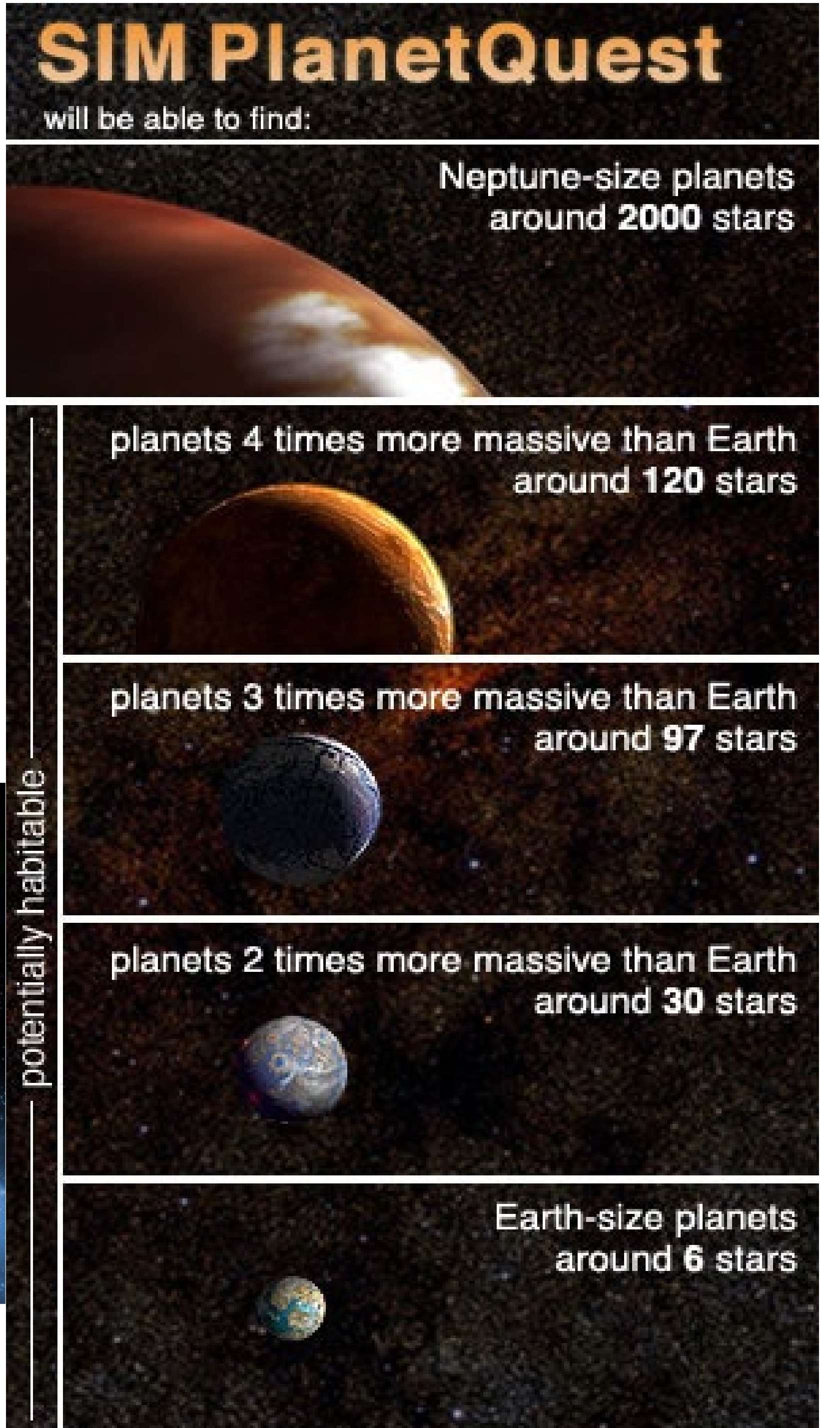
Benedict et al 2017 PASP, 129, 12001
https://arxiv.org/abs/1610.05176

The Space Interferometer Mission

- Astrometric precision of <0.1 microarcsecond to measure reflex astrometric motion of an Earth orbiting a G star at 10 pc (0.3 uas)
- SIM Optical Configuration
  - 3 stellar interferometers connected by a laser optical truss (<100 picometer accuracy)
    - 2 Guide interferometers hold the spacecraft attitude stable at the uas level,
    - 1 Science interferometer measures the position of targets within its 15 deg field of regard (1 target, one axis)
  - Descoped multiple science telescopes for fuller UV coverage
- Narrow angle measurements over a ~1 deg radius field of regard.
- λ =0.45~0.95 um in 80 spectral channels (wavelength synthesis imaging of simple objects)
- Initial recommendation of AIM mission in 1990 Decadal Report
- Endorsed in 2000 Decadal report
- After 500M in technology and mission funding, killed in 2010 NAS report in a footnote:

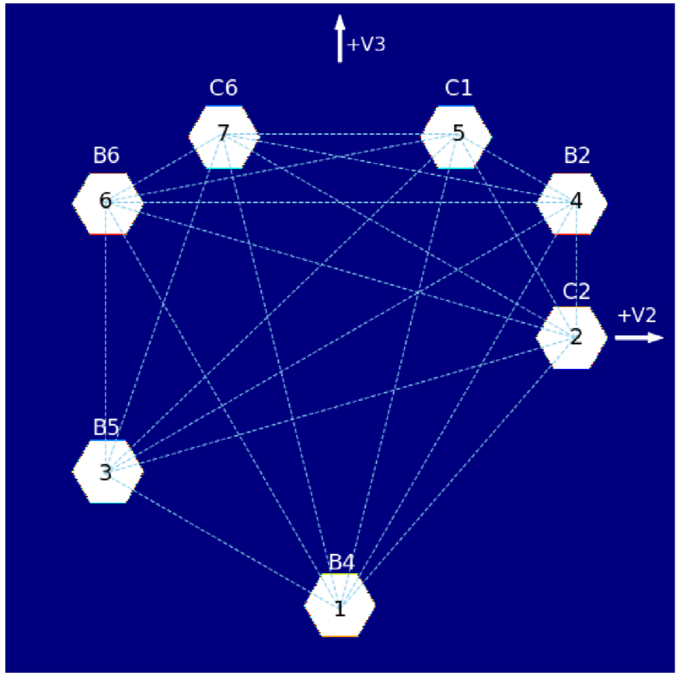
" SIM (now SIMLite) [is] not included in the recommended program for the decade, following the committee's consideration of the strengths of competing compelling scientific opportunities and the highly constrained budget scenarios described in this report."

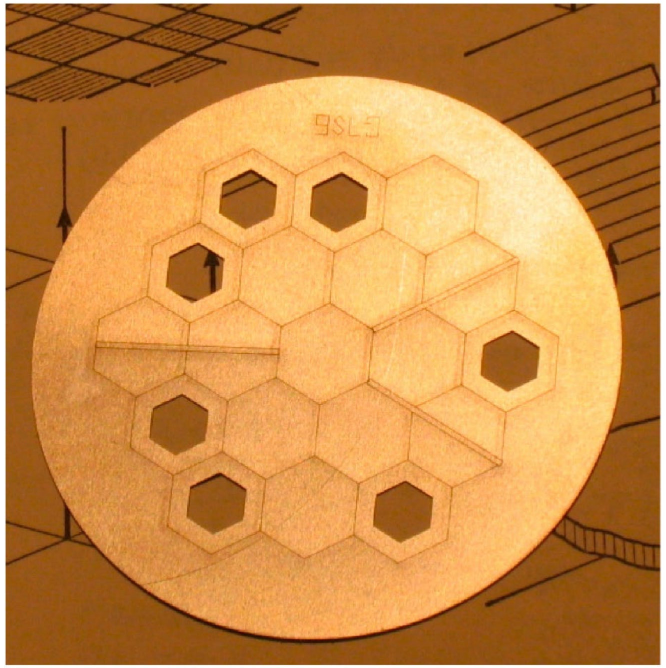


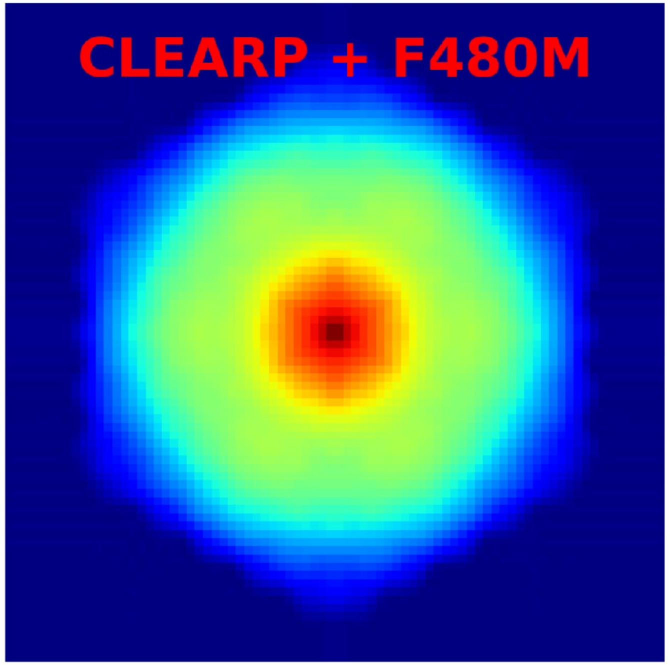


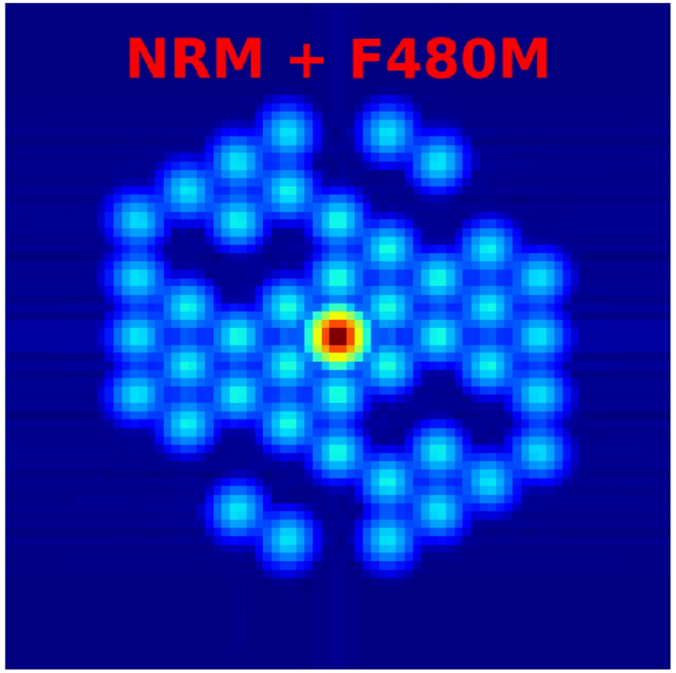
Interferometry with JWST

- Non-Redundant or Aperture Masking Interferometry (NRM/AMI) creates 7 ~1 m sub-apertures across 6.5 full aperture (Sivaramakrishnan, A., Tuthill, P., Lloyd, J.~P., et al.\ 2022, arXiv:2210.17434)
  - 7*6/2=12 independent baselines from 1.3 to 5.3 m
  - Stable image reconstruction using closure phases
  - Inner Working Angle λ/2D vs. 4λ/D
  - Outer Working Angle λ/d~0.8” vs >10”
  - Contrast ratio of 8 mag vs. 15 mag
  - Uses only 20% of full area
  - Suffers photon noise from unattenuated starlight
- Kernel Phase Interferometry identifies sub-aperture pairs across full JWST aperture (Martinache, F., Ceau, A., Laugier, R., et al. 2020, A&A, 636, A72)
  - Use accurate map of highly stable aperture OPD
  - Higher SNR than AMI on faint objects at somewhat lower contrast and IWA
  - Uses full area of JWST but higher saturation level
  - Suffers photon noise from unattenuated starlight









Interferometry with JWST

- Initial AMI performance indicates promise in selected areas of modest contrast, simple structures needing highest angular resolution
- Comparison between AMI/KPI ongoing

Item	NIRISS AMI	NIRCam Lyot	MIRI FQPM
IWA	λ/2D 70” (3.8 um)	4λ/D 480” (3.8 um)	2λ/D 700” (11 um)
OWA	0.8”	>10”	>10”
Contrast	7-8 mag	10-15 mag	10-15 mag