Adaptive Structures and Scientific Missions

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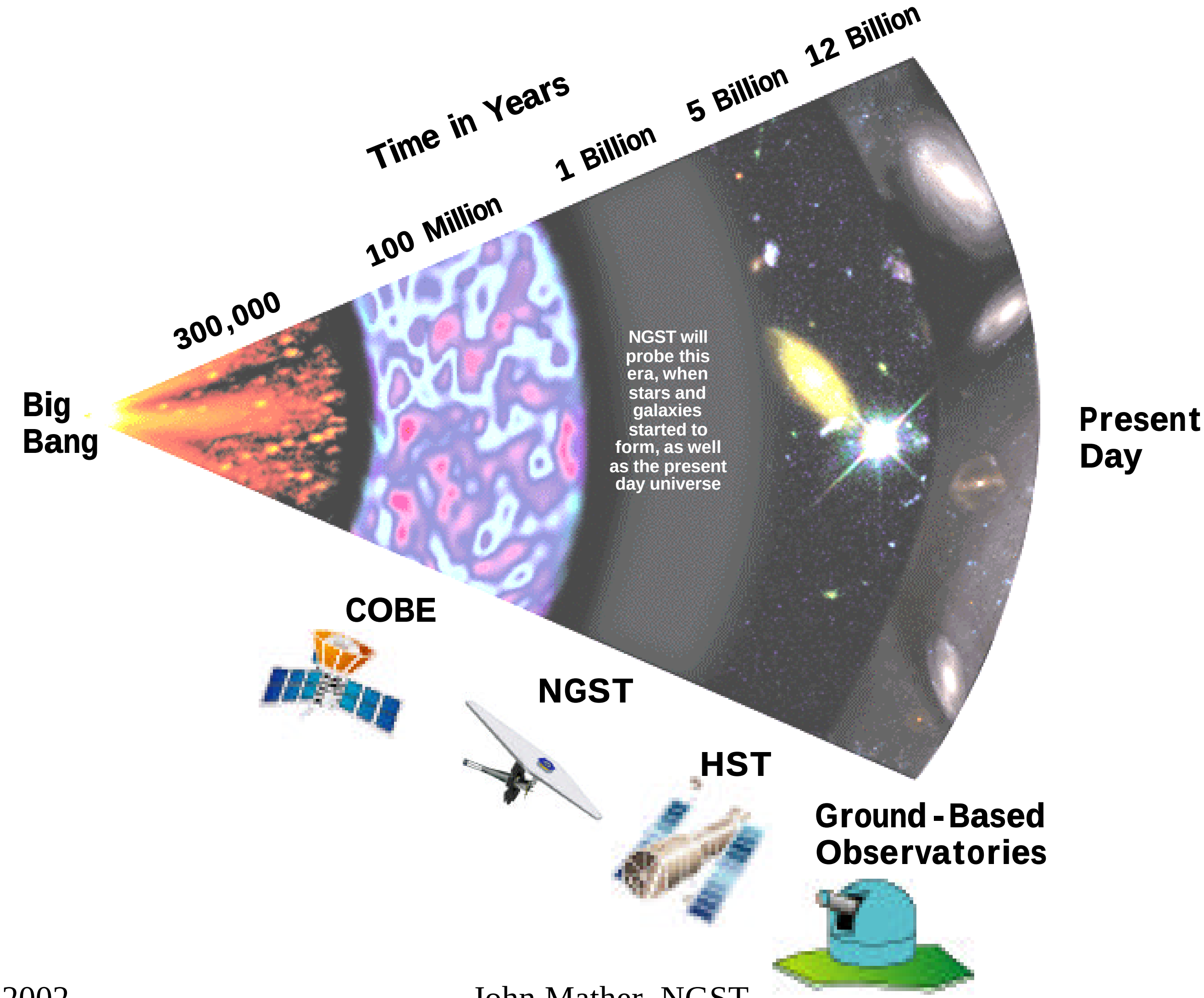
The Challenge

- Extreme image quality demands
- Enormous structures 10^6 - 10^{10} ? across
- Extreme environments (dark, cold, huge thermal gradient, difficult to repair)
- Instability of structures
- Imperfections of optics

The Approach

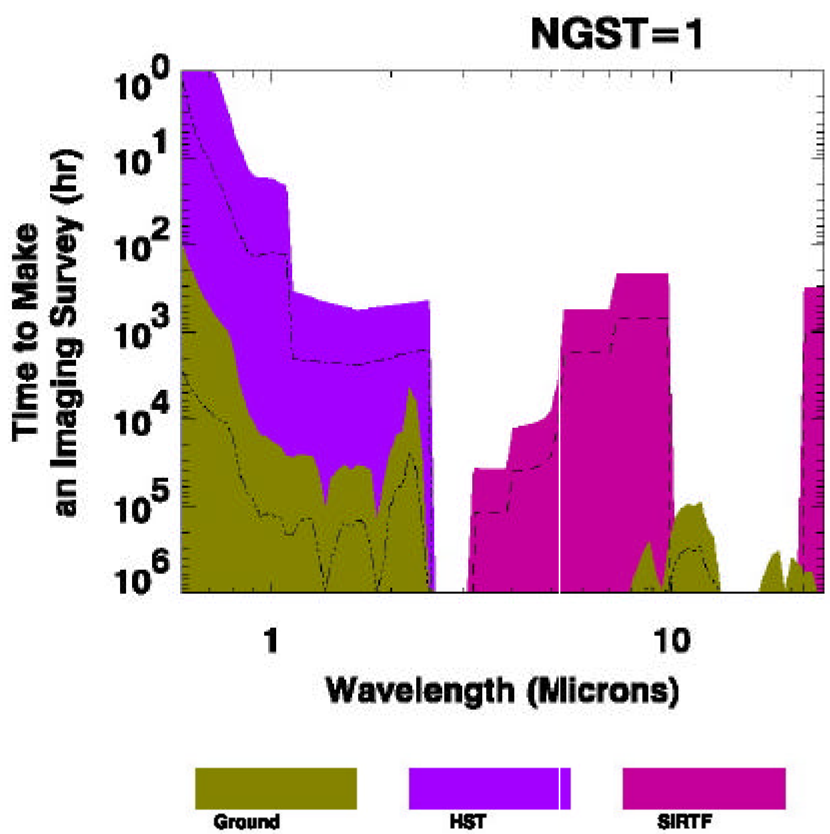
- Rigidize and point the instrument on short time scales with feedback loops from vibration sensors, laser metrology, gyros, coarse stars sensors, fine star sensors, etc.
- Sense image quality from a guide star or other reference
- Correct for long term errors (mirror shapes, mechanical instability, changes of thermal environment) by feedback from scientific sensors (may be the only ones with enough sensitivity to know if there's a problem)

NGST Sees the First Stars and Galaxies



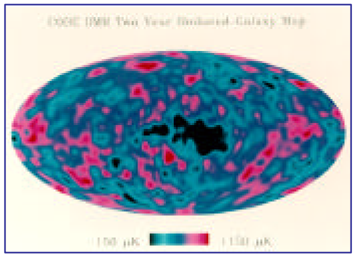
NGST's Place in Space Astronomy

- **Plot of detector integration time on the sky for NGST relative to the other existing observatories as a function of wavelength**
  - NGST is at least an order of magnitude higher performance in every relevant wavelength band
  - Large aperture and sensitive detectors lead the telescope to photon counting in the infrared



Top NGST Goal - Find the First Light after the Big Bang

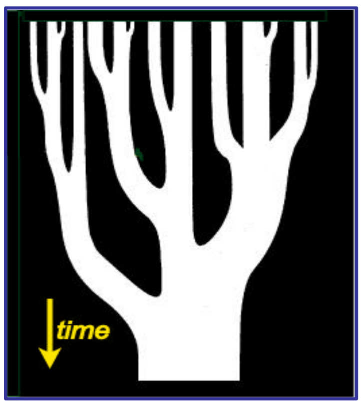
???????
as seen
by COBE



?

Galaxy
assembly

?



Galaxies,
stars,
planets,
life

- How and from what were galaxies assembled?
- What is the history of star birth, heavy element production, and the enrichment of the intergalactic material?
- How were giant black holes created and what is their role in the universe?
- When could planets first form?

NGST Deep Imaging: 0.5–10 ? m

ASWG: Simon Lilly

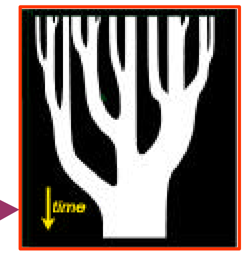
4'x4' deep survey field

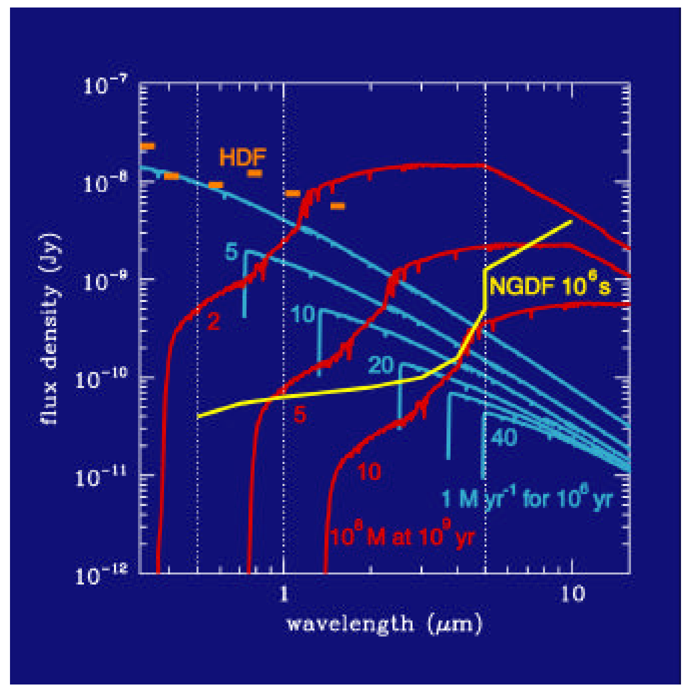
5000 galaxies to AB ~ 28,
10^5 galaxies to AB ~ 34
photometry, morphology & z's

Depth: AB ~ 34 in 10^6 s

Redshifts: Lyman ? to z = 40 (?)
4000 Å to z = 10

NGST will detect 1 M yr^{-1} for 10^6 yrs to z ? 20 and 10^8 M at 1 Gyr to z ? 10 (conservatively assuming ? = 0.2)





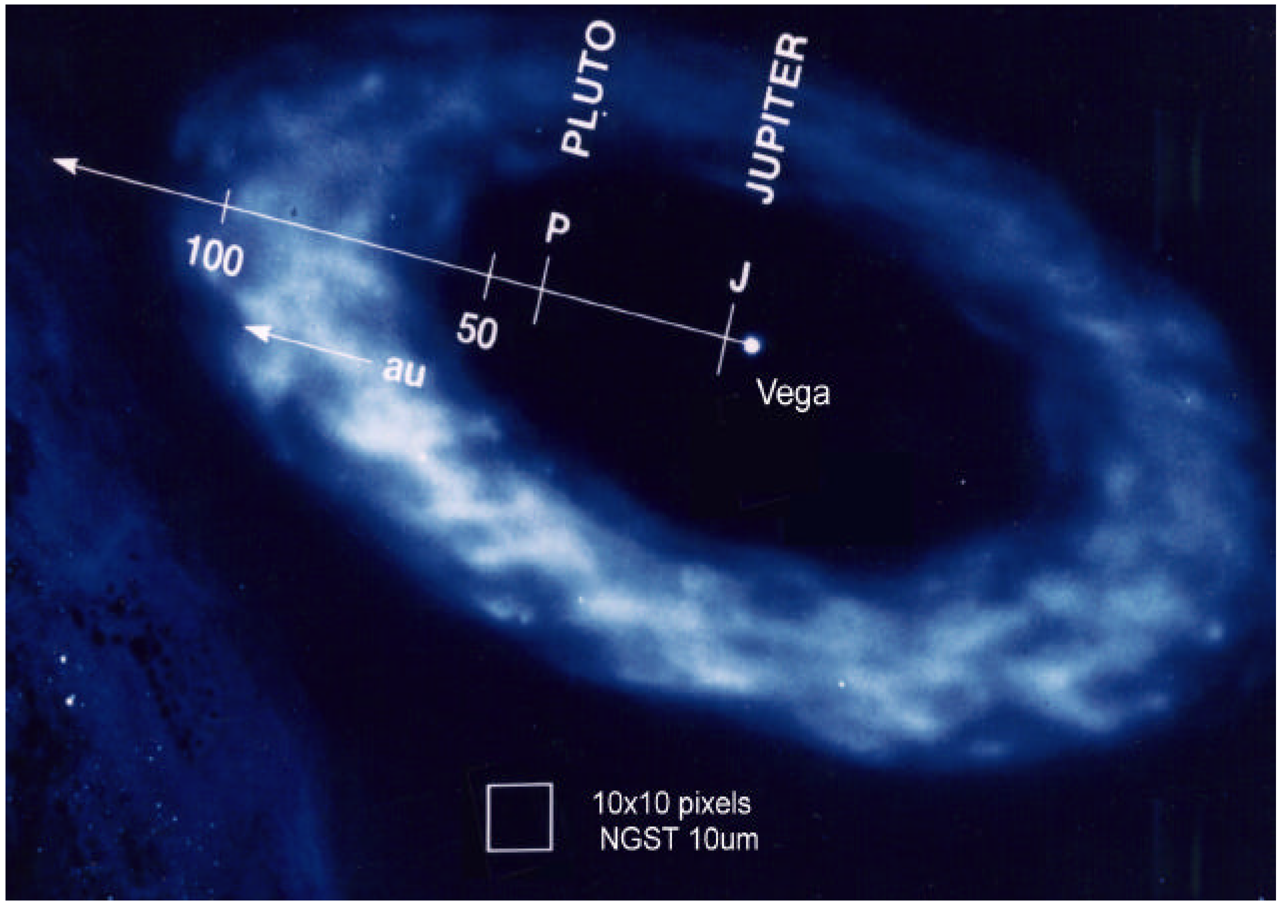
Evolution of Planetary Systems

ASWG: Marcia Rieke

Vega Disk Detection

?	Flux*	Contrast
??m)	(?Jy)	Star/Disk
11?m	2.4	$1.5x10^7$
22?m	400	$2x10^4$
33?m	1300	$3x10^3$

Reflected & emitted light detected with a simple coronograph.



NGST resolution at 24?m = 5 AU at Vega, > 10 pixels across the inner hole

**per Airy disk*

Beyond NGST

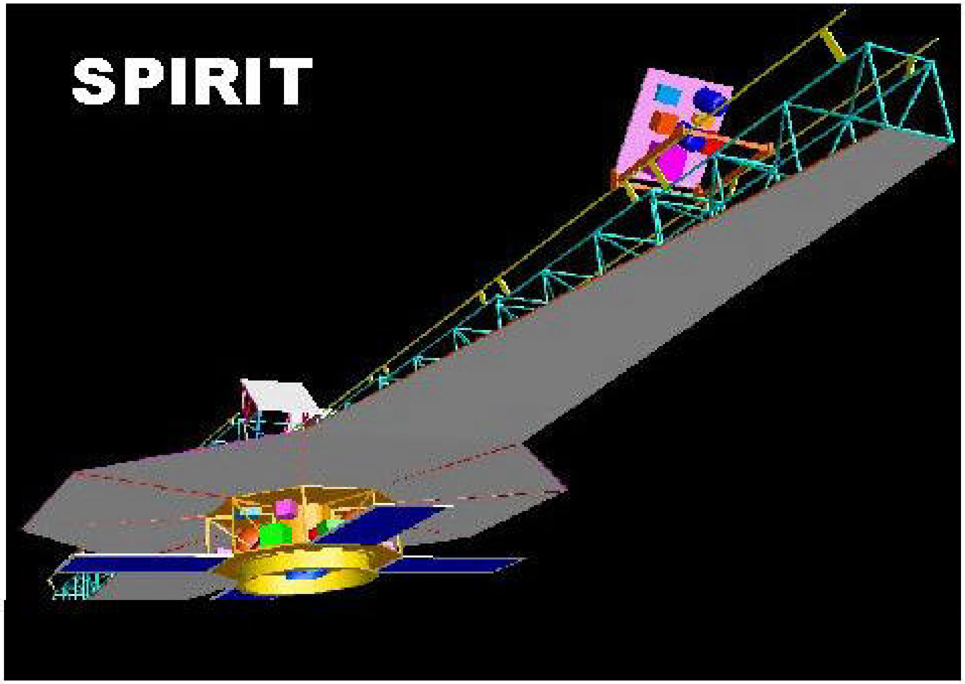
- SAFIR (Single Aperture Far IR) and SUVO (Space UV Optical) telescopes
- SPIRIT and SPECS (Far IR interferometers)
- TPF (Terrestrial Planet Finder) interferometer or coronagraph
- Stellar Imager (visible interferometer)
- MAXIM (X-ray interferometer)
- LISA (Laser Interferometer Space Array) gravity wave antenna

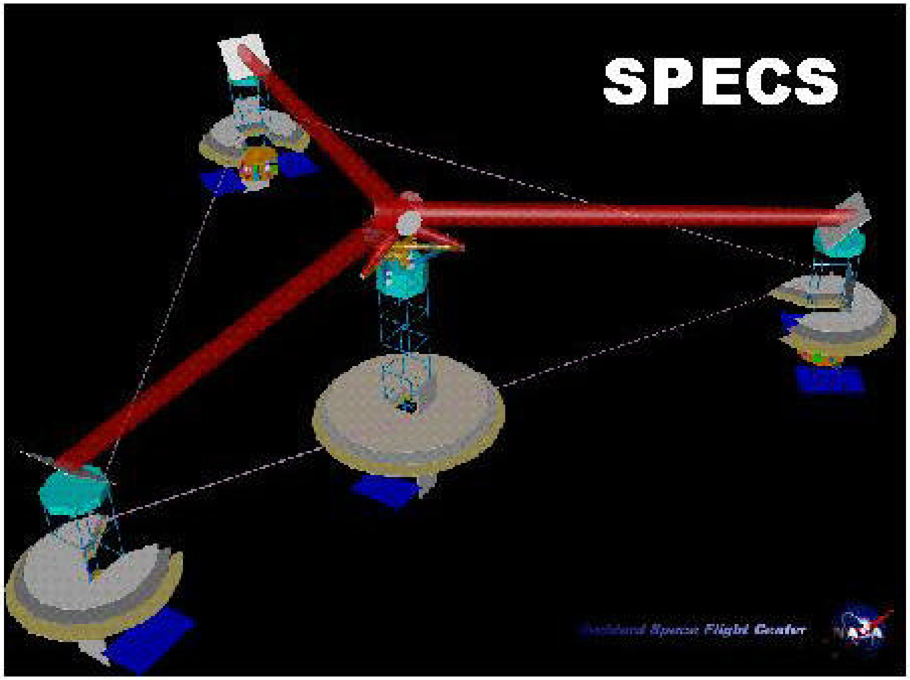
SAFIR: Far IR Successor to NGST

- Like NGST but larger and colder (~ 5 K) and 10x less accurate
- Challenge: stability and adjustment when cold

Far IR Interferometry

- Half the luminosity of the Universe in far IR
- Cryogenic Imaging interferometer, < 1 μm measurement, 1 cm control over spans of 1 km to achieve 0.05 arcsec resolution
- Formation flying to sweep out a 1 km aperture in 1 day using small mirrors, with tethers to keep down fuel consumption

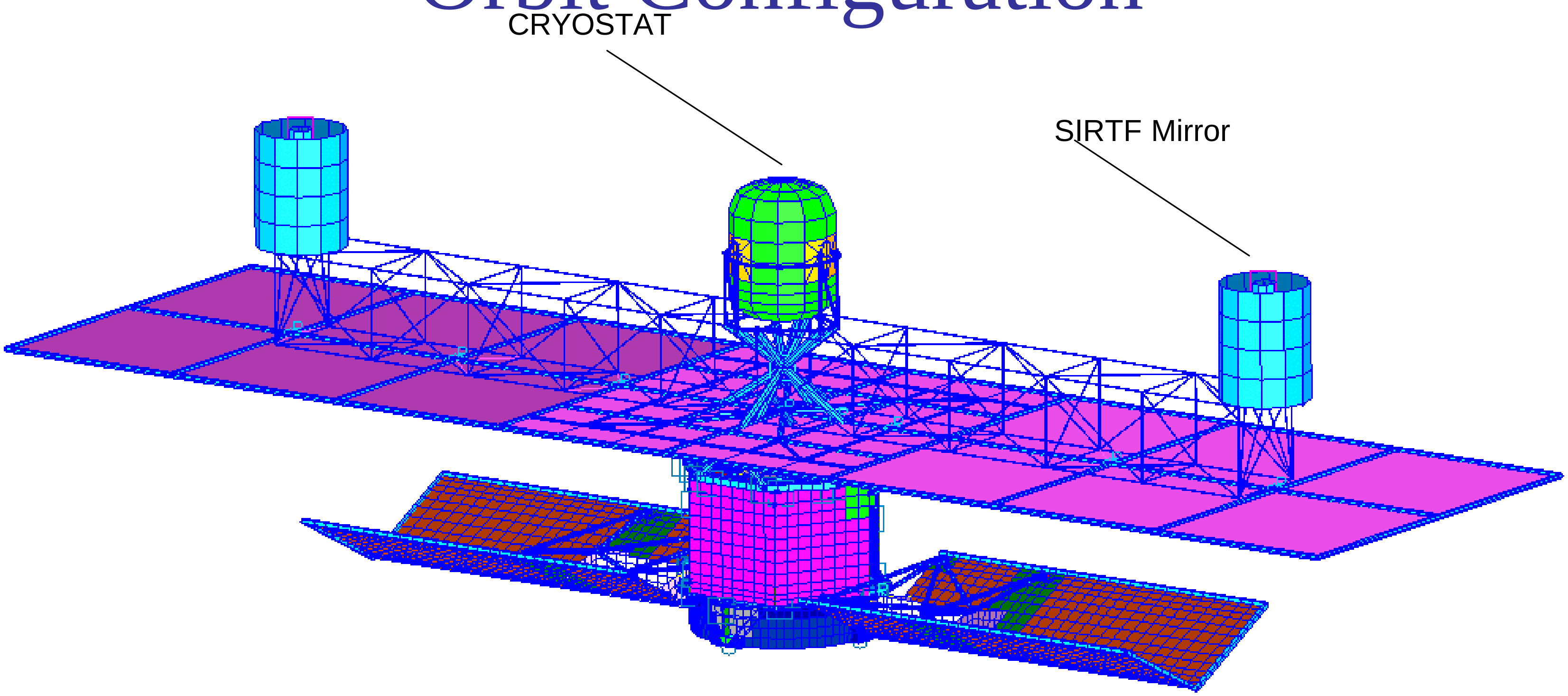




Planet Finding Requirements

- Suppress starlight by $10^7 - 10^{10}$ to see planet
- Coronagraph needs ?$/10^4$ optical surfaces at UV
- Infrared interferometer needs ?$/10^5$ short term position control to null starlight (intensity is quadratic)
- Catch a lot of stellar photons to tell when we're out of adjustment
- Be stable long enough to compensate to desired tolerance

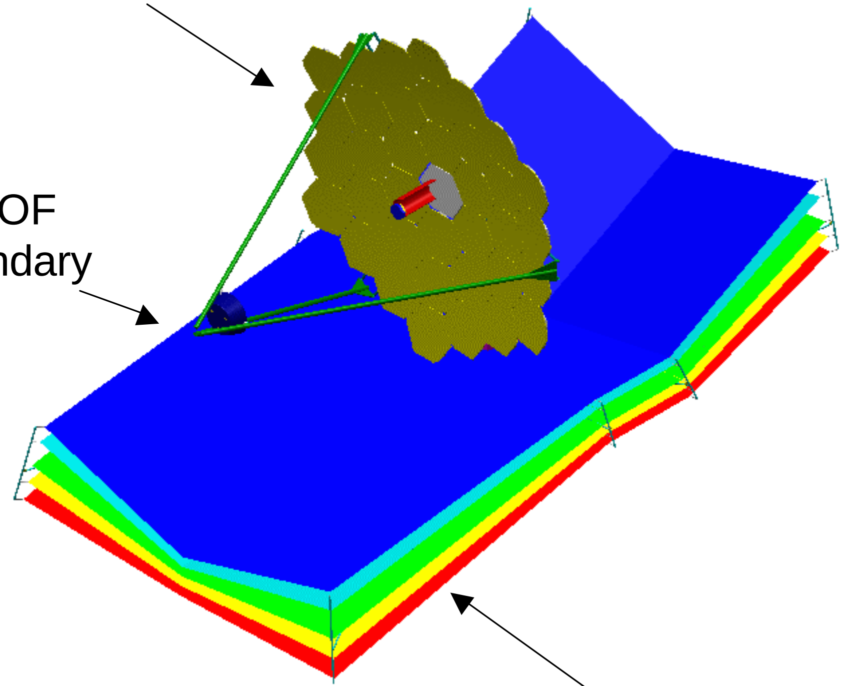
TPF Interferometer - 9 m baseline on-Orbit Configuration



Lockheed Martin team concept for a Terrestrial Planet Finder, 12/01 San Diego review meeting, for nulling interferometer, small version before much larger instrument

TPF IR Coronagraph Design Concept - TRW team

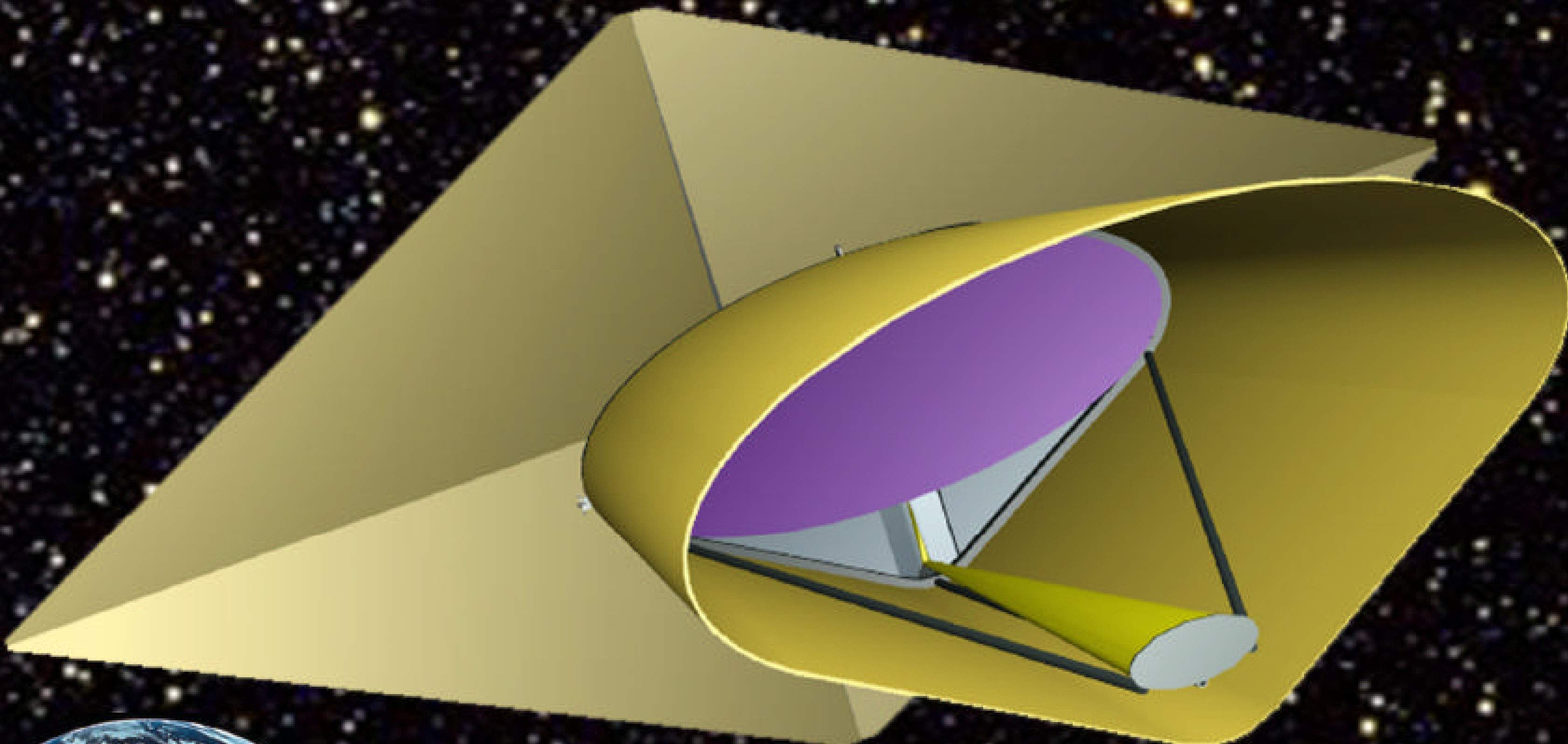
- 28-meter filled aperture telescope
  - Three-mirror anastigmat
  - 36 segments, 4-meter flat-flat
  - Composite replica optics
  - Gold mirror coatings
- Multi-layer sunshade
  - Passive cooling to ~30K
- IR Coronagraph for planetary detection/characterization
  - 107 contrast at 100 mas
- IR camera and spectrograph for general imaging/spectroscopy
  - 2 x 2 arcmin FOV
- Launched with EELV heavy to L2
  - On-orbit assembly option



UV Telescope Requirements

- 6 m diffraction limited telescope at 0.2 μm --> surface accuracy of 6 nm, angular resolution of 0.008 arcsec (5-10x < HST and NGST)
- Stability after launch --> adjustment to 6 nm precision and stability between adjustments
- Pointing control to 1/20 beamwidth rms = 0.4 milliarcsec
- Obtain image quality from star images and feed back to adjusters

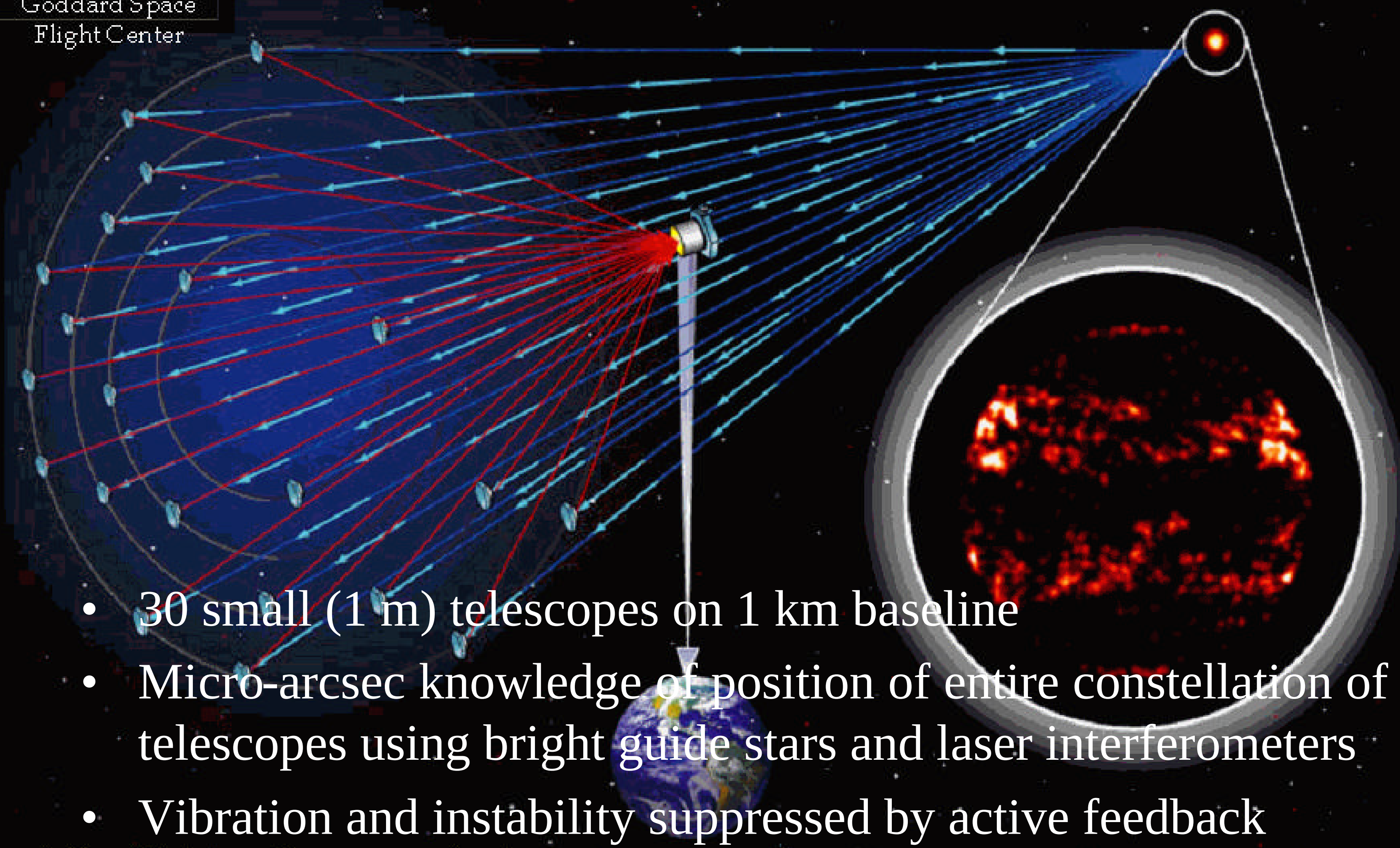
Is this the UV astronomers' dream telescope too?



Coronagraphic TPF concept, off-axis elliptical telescope, Ball Aerospace, 12/01, San Diego review meeting

Goddard Space Flight Center

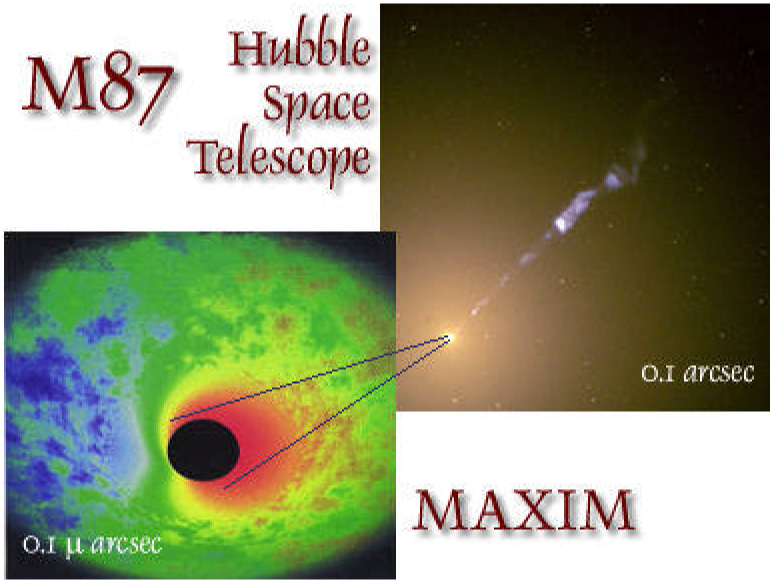
Stellar Imager (SI)



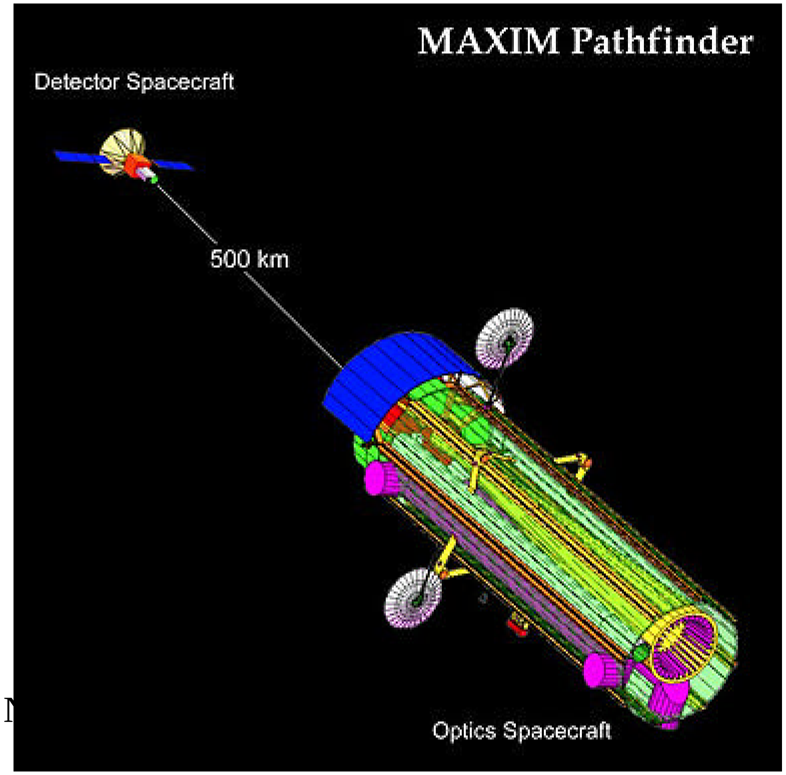
- 30 small (1 m) telescopes on 1 km baseline
- Micro-arcsec knowledge of position of entire constellation of telescopes using bright guide stars and laser interferometers
- Vibration and instability suppressed by active feedback

http://hires.gsfc.nasa.gov/~si

X-ray requirements



- Formation flying X-ray interferometer
- Wavefront knowledge to ? $_x$/20, made possible by grazing incidence optics - forgiveness of sins in proportion to sin(?)
- Use bright guide stars and laser interferometer sensors to get μarcsec resolution and feedback control relative to sky coordinates and other spacecraft



Gravity wave detection

- ?/10^5 laser interferometry across 5 x 10^6 km (LISA) from 0.1 mHz to 0.1 Hz to see death spirals of black hole and neutron star pairs
- Acceleration noise < 3×10^{-15} m sec^{-2} $Hz^{-1/2}$
- μN spacecraft thrusters
- GREAT (Gravitational Echoes Across Time) mission to see gravitational waves from the Big Bang needs < 10^{-17} m sec^{-2} $Hz^{-1/2}$ acceleration noise, 100 W lasers, 8 m telescopes