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 will probe this era, when stars and galaxies started to form, as well as the present day universe.

Big Bang

Time in Years

300,000

100 Million

1 Billion

5 Billion

12 Billion

COBE

NGST

HST

Ground-Based Observatories

Present Day
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

- 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

Depth: $AB \sim 34$ in $10^6$ s
Redshifts: Lyman $\alpha$ to $z = 40$ (?)

$4000$ Å to $z = 10$

NGST will detect $1 M_\odot$ yr$^{-1}$ for $10^6$ yrs to $z$ = 20 and $10^8 M_\odot$ at 1 Gyr to $z$ = 10 (conservatively assuming $\Omega = 0.2$)

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

4'x4' deep survey field

ASWG: Simon Lilly
### Vega Disk Detection

<table>
<thead>
<tr>
<th>Wavelet (μm)</th>
<th>Flux (Reflected &amp; Emitted)</th>
<th>Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>2.4</td>
<td>1.5x10^7</td>
</tr>
<tr>
<td>22</td>
<td>400</td>
<td>2x10^4</td>
</tr>
<tr>
<td>33</td>
<td>1300</td>
<td>3x10^3</td>
</tr>
</tbody>
</table>

Reflected & emitted light detected with a simple coronograph.

**NGST resolution at 24 μm = 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
• 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 $\chi/20$, made possible by grazing incidence optics - forgiveness of sins in proportion to $\sin(\chi)$
- Use bright guide stars and laser interferometer sensors to get $\mu$arcsec resolution and feedback control relative to sky coordinates and other spacecraft
Gravity wave detection

- $\sim 10^5$ laser interferometry across $5 \times 10^6$ km (LISA) from 0.1 mHz to 0.1 Hz to see death spirals of black hole and neutron star pairs
- Acceleration noise $< 3 \times 10^{-15}$ m sec$^{-2}$ Hz$^{-1/2}$
- $\mu$N 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