NGST Straylight

Causes of straylight for a telescope

• Instrumental sources reaching the detectors either directly, or via scattering.
• Celestial sources outside FOV scattered or directly seen by the detectors.

Approach to minimizing straylight for NGST

• Completely shielding the observatory from the sun, earth, and moon.
• Using baffles and stops to prevent direct illumination of detectors by off-axis sources.
• Cooling the observatory (passively or actively) to minimize thermal self-emission.

Considerations particular to NGST

• No telescope tube and large, difficult-to-clean optics promote scattering.
• Sunshield back presents large, comparatively warm surface to the open OTA.
General Scattering from Surfaces

Bidirectional Reflectance Distribution Function (BRDF)

- $P_c = P_s BRDF(\varphi_i, \varphi_o) \Omega$
  - $P_c$ is the power scattered onto the collector
  - $P_s$ is the power from a source
  - $\Omega$ is the solid angle subtended by the collector as seen from the source.
  - $\varphi_i$ and $\varphi_o$ are the incident and output (scattered) angles respectively.

- BRDF can be conceptualized as the fraction of power scattered per steradian as a function of $\varphi_i$-$\varphi_o$ (the angle off-specular or scatter angle.)
Scattering from Contaminated Optics

Mie scatter theory or experiment (Spyak and Wolfe\textsuperscript{1}) gives BRDF function for mirrors with varying distributions of dust particle sizes and coverage.

- Shape of BRDF varies with particle size distribution. We have assumed a particle size distribution following Military Standard 1246C\textsuperscript{2}, an industry standard to which respectable clean rooms adhere. This is an important potential source of error since contamination of NGST’s large mirror segments any time after leaving the clean room environment may produce unknown particle size distributions which will affect the BRDF. On-orbit cleaning?

- The BRDF simply scales linearly with the amount of dust (areal coverage fraction). Various fractions have been used as input, but 1\% has been assumed for the results here unless otherwise noted. (HST’s primary mirror is believed to be between 1 and 2\%)
Scattering from Contaminated Optics (cont’d)

figures for 1% dust coverage

BRDF function (sr⁻¹)

Particle size distribution

scatter angle

microns

λ=1μm
λ=20μm
**Thermal Emission**

**Temperature distribution of sunshield back drives instrumental backgrounds**

- Heats the OTA mirrors.
- Produces photons that can be scattered to focal plane.
- 6 layer sunshield design is dynamic and a recent GSFC iteration\(^3\) has been used as a basis for this study.

[Diagram showing temperature distribution with values in Kelvin (end-of-life)]
Results

Direct instrumental background

- Calculations show sunshield heats primary mirror to ~35K at which temperature its emission is well below natural zodiacal background up to ~24 µm.
- Secondary mirror ~18K and trivial contributor.
- Proper baffles & stops ensure that no other sources are seen directly by the detectors. (e.g. shield shining through P.M.)
Results (cont’d)

Scattered instrumental background

- A MathCad algorithm was used to calculate geometry and power transfer via scattering from each warm sunshield source node to each of the 8 primary mirror petals, and to the secondary.
- Dust-contaminated optics will scatter some amount of each source node’s power to detectors.
Results (cont’d)

Scattered instrumental background (cont’d)

• Scatter paths were summed and totals were calculated over wide wavelength range.

• Sunshield and zodiacal background “cross-over” at 12μm

• Sunshield emission found to be dominant background source.
Results (cont’d)

Scattered instrumental background (cont’d)

- Analyses were performed varying sunshield temperatures and contamination levels. Control of mirror dust & shield temperatures critical to background.
Results (cont’d)

Background from off-axis celestial sources

• Direct illumination of detectors are prevented by:
  – a baffle around the secondary mirror.
  – central baffle surrounding the return beam.
  – a stop at the first (intermediate) focus.

• Properly designed, these can prevent direct rays from off-axis sources entering the instruments.
Results (cont’d)

Scattered celestial source background

- MathCad scattering model similar to that used for the sunshield background was used to determine power scattered from celestial sources.
- Astronomical sources were split into zodiacal light, and everything else (galactic/extragalactic).
  - Zodi-subtracted Mission Average (ZSMA) skymaps from COBE’s DIRBE experiment provided reliable input over a range of wavelengths for the latter.
  - Zodiacal light model by Wright\textsuperscript{4} was adapted by us for the former.
- For a given telescope pointing and time of year, the power transfer via scattering by the secondary and primary mirror petals to the detectors was calculated. The contribution from each skymap pixel visible to the mirror surfaces was summed for the total result.
Results (cont’d)

Scattered celestial source background (cont’d)

DIRBE maps\(^5\)

Full sky map

Zodiacal light removed
Results (cont’d)

Scattered celestial source background (cont’d)

Scattered galactic light (for mid-galactic pointings)
Zodiacal background in field (@ eclipt. pole)
Scattered zodi (for mid-ecliptic pointings)
Detector noise
Results (con’t)

NGST Backgrounds
20% bandpass

- Max & min natural in-field zodi
- Min & max natural in-field zodi
- Min & max galactic light
- Detector noise
- BOL & EOL sunshield
- Primary mirror between 30K & 40K
- Min & max zodi
Utility

- Results in NGST Monograph #2, *Straylight Analysis of the Yardstick Mission*.
- Is being implemented into the NGST ETC as part of the DRM simulator for better assessments of exposure and overall science mission durations.
  - Multiple node (“finite element”) OTA and sunshield model with higher fidelity geometry provides better background estimates than earlier single node calculations.
  - Provides a flexible framework in which one can assess dynamic designs more readily than with large commercial straylight programs, though such products better model details (baffles, diffraction, minor components, etc.)
  - DIRBE maps give more accurate source inputs than previously used starcounts from Allen.
  - Realistic BRDFs as a function of wavelength, dust coverage, scatter angle, and surface microroughness enhance fidelity.
References

3. K. Parrish, personal communications, 1999
5. M. Hauser & COBE DIRBE science team, STScI Press Release 98-01