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Casey Seyb – November 12, 2019

Optics Error Budget Review

Flow Down of Science Requirements
to
Instrument Optics Performance Requirements

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TES EOS Program Requirements

- TES shall determine, through a combination of measurement and modeling, the global distribution of tropospheric ozone and the factors controlling its distribution.

- TES shall to the extent possible given cloud interference and other fundamental physical limitations, generate vertical concentration profiles of ozone, carbon monoxide, methane, water vapor, nitric oxide, nitrogen dioxide and nitric acid from the surface to the lower stratosphere

- TES shall provide these measurements on a latitude grid of 5° or better on a continuous basis for 4 out of every 8 days

Required Products

All profiles are measured from the surface to 30 km

- Atmospheric Temperature Profiles
- Surface Temperature
- Land Surface Emissivity
- Ozone VMR Profile
- Water Vapor Profile
- Carbon Monoxide VMR Profile
- Methane VMR Profile
- Nitric Oxide VMR Profile
- Nitrogen Dioxide VMR Profile
- Nitric Acid VMR Profile

- There is an extensive list of second products that are a natural outcome of the TES measurement approach

TES Measurement Approach

TES is an infrared, high resolution, imaging Fourier transform spectrometer for measurement and profiling of essentially all infrared-active molecules present in the Earth's lower atmosphere. In short, TES acquires spectra in limb and nadir viewing geometries of the naturally occurring infrared emission emitted by the atmosphere.

Key Instrument Parameters

Spectrometer Type:	Connes interferometer
Maximum Optical Path Difference:	32 cm (long scans), 8 cm (short scans)
Scan Time:	16 s, long scans; 4 s, short scans
Spectral Coverage:	650 - 3050 cm^{-1} (3.3 - 14.4 μm) in 4 spectral channels
Spectral Resolution:	0.025 cm^{-1} (Long scans for limb views) 0.1 cm^{-1} (Short scans for nadir views)
Atmospheric Viewing Modes:	Limb and Nadir
Limb Vertical Coverage:	0 - 30 km with 16 pixel staring arrays
Pixel Size at Limb:	2.3 km vertical x 23 km horizontal (0.75 X 7.5 mr)
Pixel Size at Surface for Nadir Views:	0.5 km along track x 5 km cross track

Key Measurement Requirements Driving Optics

Signal-to-noise

- **Nadir observations are the driver**

Profile Name	Array	Value @ 6 km	Required Precision	Required SNR	Required NESR ($W/cm^2/sr/cm^{-1}$)
Carbon Monoxide	1A	100 ppb	5 ppb	100	5.1E-9
Ozone	1B	60 ppb	3 ppb	600	1.5E-8
Water Vapor	2A	600 ppm	6 ppm	200	3.2E-8
Atmos. Temp.	2B	249 K	0.5 K	200	6.9E-8

- **Instrument elements controlling signal-to-noise**
  - Optics transmission, Modulation index, Detector/signal chain performance, ICS velocity stability, PCS jitter, interferogram sampling, and optics temperature

The optics allocation is 0.7 for the modulation index and 0.2 for end-to-end transmittance

Key Measurement Requirements Driving Optics

Line-of-sight pointing

- **The line-of-sight inertial pointing requirements are:**

Line-of-Sight Inertial Pointing	Pitch*	Roll*	Yaw*
Accuracy (±1 pixel, approx)	±0.75 mrad 3σ (2.6 arcmin)	±7.5 mrad 3σ (26 arcmin)	±7.5 mrad 3σ (26 arcmin)
Stability over 49.2 sec, goal of 250 sec	0.75 mrad p-p (2.6 arcmin)	0.75 mrad p-p (2.6 arcmin)	0.75 mrad p-p (2.6 arcmin)
Jitter over scan interval, 4 or 16 sec (10% of pixel, approx)	75.0 microrad p-p (15 arcsec)	1.1 mrad p-p (3.8 arcmin)	0.75 mrad p-p (2.6 arcmin)

Driven by the need to target observations and to reliably observe from the surface to near 30 km

Instrument elements controlling line-of-sight pointing

- Pointing and control system, optics alignment, Focal Plane optics/detector alignment

The optical system allocation is +/- 0.4 mr

Key Measurement Requirements Driving Optics

Co-boresight alignment (Field-of-view conjunction)

- **Co-boresight alignment requirements between the four focal planes is:**

  The location of the 1A, 1B and 2A detector arrays shall be optically conjugate to the 2B-detector array to within +/-0.25 of the width of a single pixel. Knowledge is needed to +/- 0.1 of a pixel.

This is driven by the need to use observation from one detector array to retrieve species profiles from observations with the other three detector arrays. The most important example is the need to use temperature, retrieved from the 2B detector array, for the retrieval of all species in the other three arrays.

Instrument elements controlling co-boresight

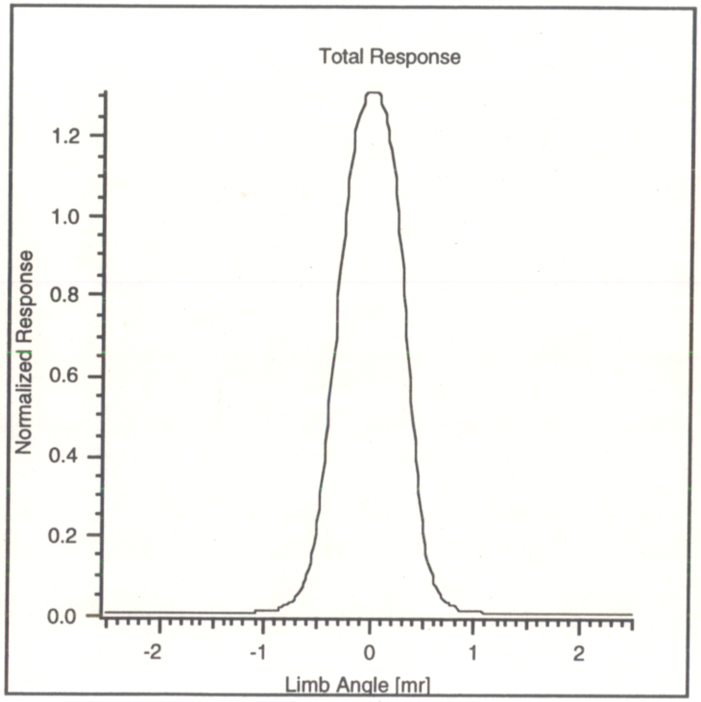
- Optics alignment, focal Plane optics/detector alignment, and optics bench mechanical stability.

The optics system allocation is +/-0.25 of the width of a single pixel (+/- 0.19 mr)

Key Measurement Requirements Driving Optics

Optics Modulation Transfer Function

The science requirement related to MTF is field-of-view response function. Field-of-view response function drives the vertical resolution of the limb measurements.



Instrument elements controlling Field-of-view response:

- Detector pixel response function and optics MTF

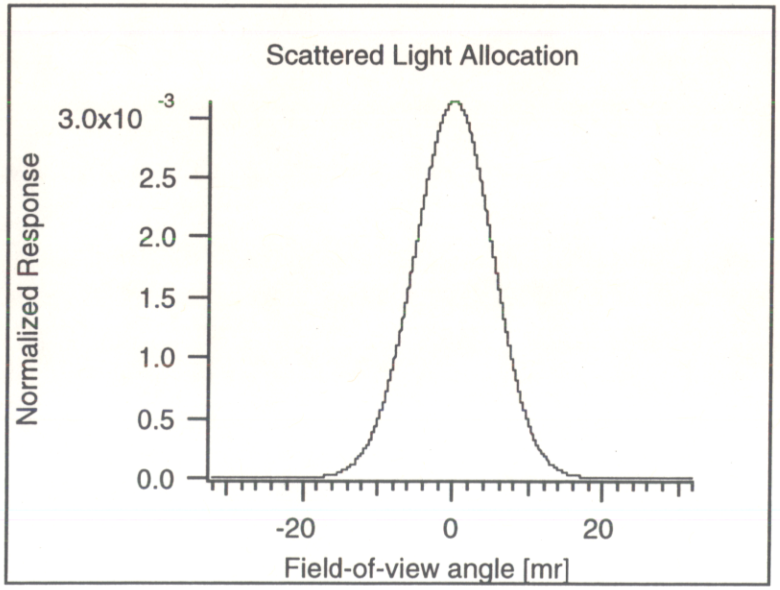
The optics system MTF allocation is 75% of the diffraction limited MTF at 6.7 mm^{-1} and 0.95% at 2 mm^{-1}.

Key Measurement Requirements Driving Optics

Stray Light

The science requirement for stray light is:

- **Unmodeled input into the instrument shall be less than 1 part in 500 of the input of a 290 K black body. The objective is to keep stray light below the spectral noise.**
- **The angular distribution of stray light be below the stray light allocation to the field-of-view response function. This is to minimize lower atmosphere contributions to observations of the upper atmosphere.**



Instrument elements controlling scattered light contribution

- Scattering of earth and instrument emission from M1 and M2.

The optics system requirement is the same as the science requirement