Ground and On-Orbit Characterization and Calibration of the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS)

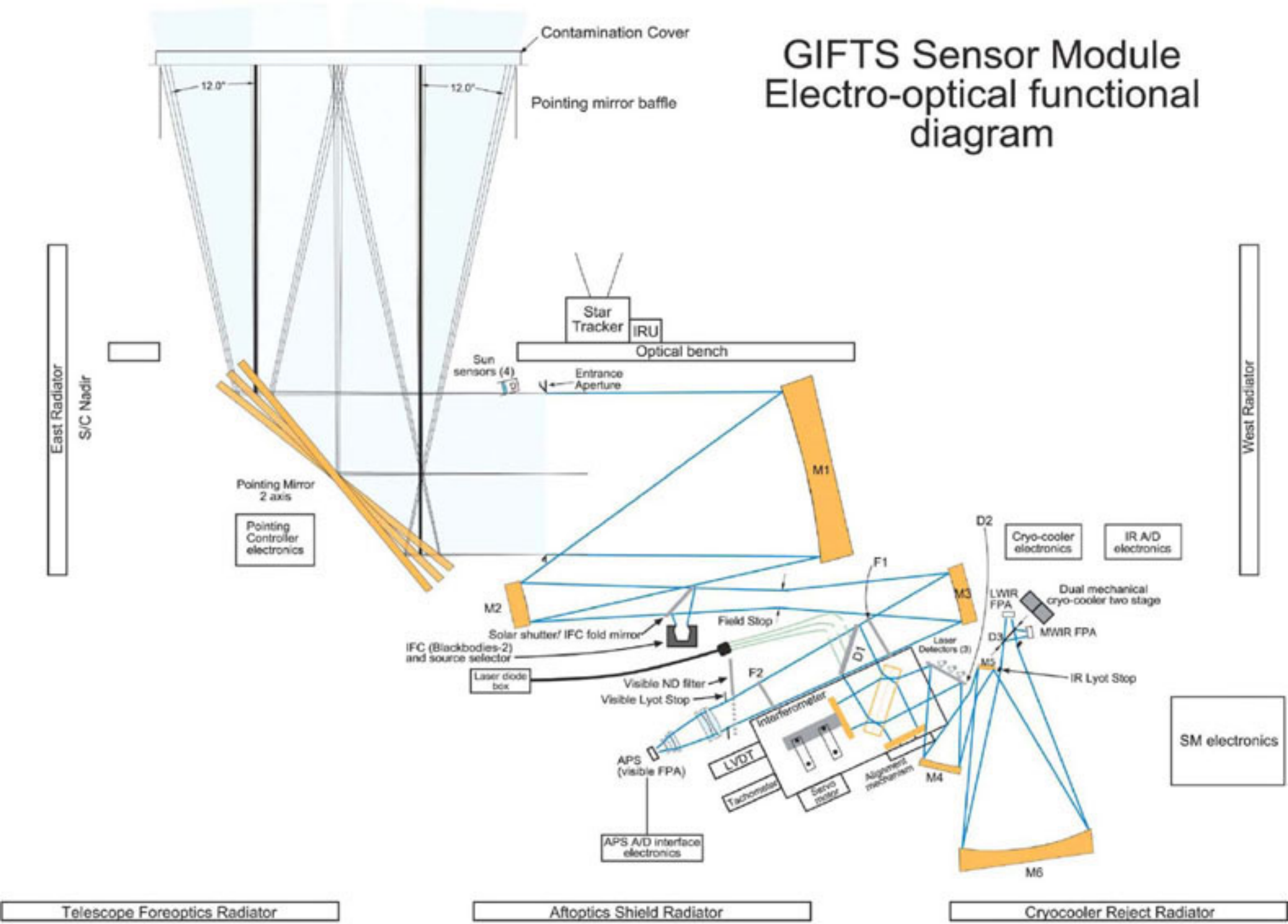
John D. Elwell[1], Deron K. Scott[1]
Henry E. Revercomb[2], Fred A. Best[2],
Robert O. Knuteson[2]

[1]Space Dynamics Laboratory / Utah State University
[2]University of Wisconsin-Madison, Space Science and Engineering Center

Purpose of Calibration & Characterization

- Verify that GIFTS meets its fundamental radiometric absolute accuracy specification of <1 K (3σ) brightness temperature for remote sensing and climate applications
- Provide a complete instrument characterization
  - Measure instrument responses independently in each domain (radiometric, spectral, spatial, etc.)
  - Characterize intra-domain responses
  - Quantify inter- and intra-domain characteristics as a function of time
- Estimate uncertainties
- Provide numerical results for downstream data processing (instrument products (IPs))

GIFTS Sensor Module Electro-optical functional diagram



GIFTS Specifications

- Two IR focal planes
  - Short/midwave - 4.4 to 6.1 μm
  - Longwave - 8.8 to 14.6 μm
  - 128 x 128 pixels, 4-km pixel footprints at nadir
  - 7 spectral resolutions from 0.6 cm^{-1} to 38 cm^{-1}
- Visible focal plane
  - 0.5 to 0.8 μm
  - 512 x 512 pixels, 1-km pixel footprints at nadir
- All three focal planes are co-aligned
- Pointing mirror provides 12 x 12 degree field for coverage of earth as well as viewing cold space

Calibration and Characterization

- Ground calibration and characterization will be performed at SDL using the MIC2 calibrator and a separate high-accuracy extended source, coupled with the GIFTS test chamber
- On-orbit calibration will be done throughout mission life
  - Two in-flight calibrators (IFCs) will provide radiometric calibration
  - Celestial sources will allow goniometric calibration
  - Atmospheric lines will allow spectral calibration update
- All critical and time-dependent instrument products will be updated on-orbit to maintain accuracies throughout the life of GIFTS

Ground Calibration Challenges

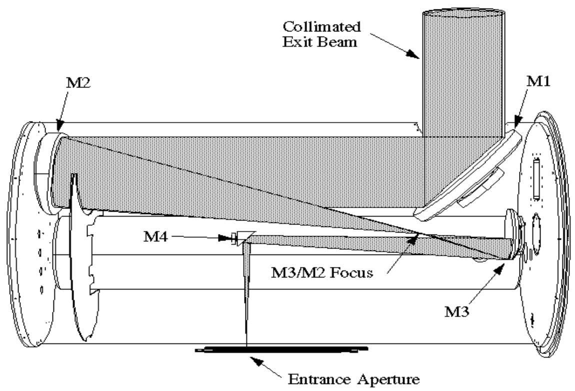
- Data Volume
  - One high resolution scan (11 seconds) creates 200 megabytes of data and 32,768 complex interferograms
  - A typical data collection event of 100 high-resolution scans collected in 18 minutes would fill 41 CD-ROMs or 6 DVD-ROMs
- Data Validation
  - The large data volumes require automated verification that the data collected is correct before moving to the next test setup
- Data Reduction
  - Where possible, a subset of pixels will be analyzed and the results generalized to all pixels, e.g. PRFs, distortion map, polarization responses
    - However, some instrument products will need to be calculated on a per-pixel basis

Ground Calibration Configuration

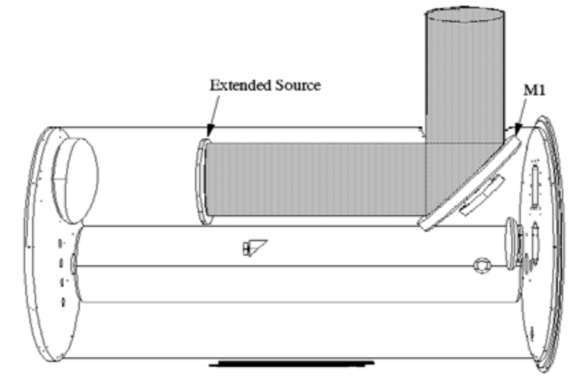
- GIFTS will be installed in a test chamber that will simulate on-orbit operating conditions
  - Sources can be changed without the need to cryo-cycle GIFTS
- The SDL multifunction infrared calibrator (MIC2) calibrator will be used for spectral and spatial calibrations
- The SDL high accuracy extended source will be used for absolute radiometric calibrations
  - Source temperature: 77 to 350 K, emissivity: 0.999
  - Absolute radiance uncertainty
    - Short/midwave: 0.45% from 190 – 300 K
    - Longwave: 0.22% from 190 – 300 K

MIC2 Configurations

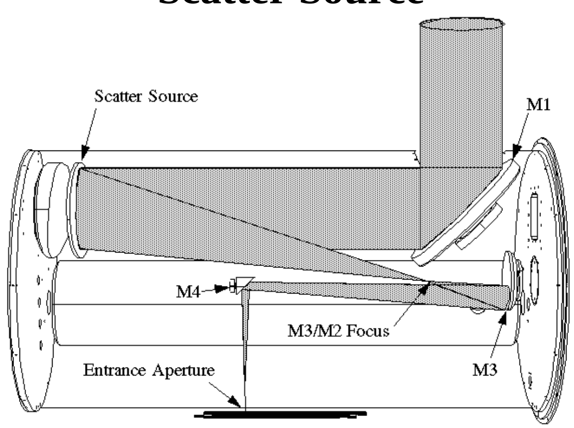
Collimator Source



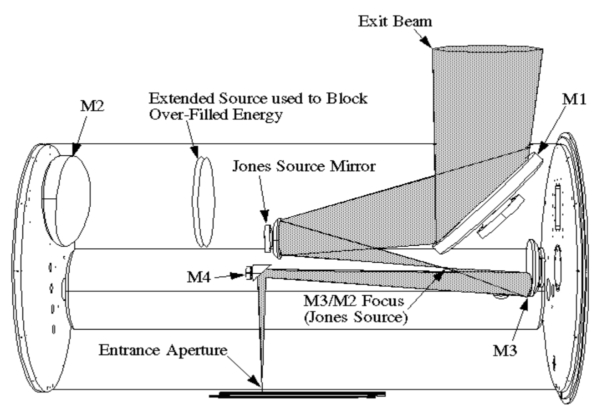
Extended Source



Scatter Source



Jones Source



Daily Benchmark

- Characterizes repeatability of spectral radiance responsivity, offsets, and noise
  - Data will be collected daily throughout calibration under similar conditions
- Configuration:
  - Extended source (MIC2 or high accuracy extended source)
  - In-flight calibrators
  - Cold background (cold shutter in the MIC2 or extended source)
  - Dark offset and electronic offset

Linearity

- Characterizes the nonlinear response of the IR focal planes throughout their dynamic range
  - Determined for all pixels
- Configuration:
  - MIC2 Jones source with an external blackbody and chopper will provide a constant level AC flux
  - MIC2 extended source will provide a background flux from below noise to saturation
  - Interferometer carriage is stopped and the DC and AC components of the combined flux sources are recorded

Polarization Response

- Characterizes spectral responsivity as a function of variable polarization input flux
  – Analyzed for a subset of pixels
  – Will allow modeling of polarization sensitivity to apply a first-order correction of responsivity changes as a function of the pointing mirror angle
- Configuration:
  – MIC2 with an external blackbody and polarizer to collect data with the input flux polarized at steps over 360 degrees
  – Repeated at several locations over the field-of-regard

Spatial Calibration

- Characterizes point response functions, ensquared energy, near field scatter, optical distortion, and co-alignment of the two IR and one visible focal planes
- Configuration:
  – MIC2 collimator and a cold aperture to provide an unresolved point source for the IR focal planes
  – Large aperture (~ 4 IR pixels in diameter) to allow calculation of the centroid of energy to subpixel resolutions
  – Source that simultaneously produces a response in all three focal planes
  – Data collected for a subset of detectors across the focal plane

Spectral Line Shape and Position

- Characterizes instrument line shape, position of the line on a wavenumber scale, and estimate of position error
- Configuration:
  - MIC2 scatter plate to illuminate the focal planes
  - Strong line source from IR lasers and/or an external blackbody and absorption cell
  - Data collected with line(s) within the passband of both IR focal planes

Responsivity & Temperature Effects

- Characterizes spectral radiance responsivity and noise over the dynamic range, spectral radiance responsivity as a function of focal plane temperature, and compares the external extended source to the in-flight calibrators
- Configuration:
  - High-accuracy extended source
  - Extended source shutter
  - Responsivity data collected over the expected range of FPA temperatures

Telescope Background

- Characterizes telescope radiance model and uncertainties to derive telescope emissivity and transmission
- Configuration:
  - Cold target
  - Internal flight calibrators

Saturation and Crosstalk

- Characterizes saturation recovery and crosstalk effects from saturated to unsaturated pixels
- Configuration:
  - High-accuracy extended source and cold shutter
  - MIC2 collimator with a hot external blackbody

Miscellaneous Tests

- Far-field characterization
- Subpixel characterization
- Sampling mode characterization
- Out-of-band responsivity
- Medium term repeatability

Ground Calibration Data Collection

Calibration Test	Data Volume (Gbytes, compressed)	Collection Time (hours)
Daily Benchmarks	12 (daily)	1 (daily)
Linearity	17	9
Spectral Radiance Responsivity	365	22
SRR as f(FPA Temp)	30	22
Polarization	59	20
Telescope Background	141	36
Spatial Characterizations	66	18
Far Field Scatter	35	9
Spectral Line Shape/Position	71	13
Saturation & Temporal	33	14
Misc. tests	344	53
Totals	approx. 1100 Gbytes	appox. 27 days

GIFTS & Source Prep Time (approx. 16 days)

On-Orbit Calibration Experiments

- Calibration sequence
  - Collects electronic offset, dark offset, cold space, visible stim, and IFC data
  - Provide radiance calibration data and other instrument products
- Telescope tests
  - Updates telescope transmission and flip-in mirror reflectance for changes on-orbit
- Subpixel validation
  - Improves IR LW FPA operability by selectively enabling subpixels

On-Orbit Calibration Experiments

- Star scans over the FOV, FOR
  - Provide pointing calibration information within the field of view and field of regard
- Calibration reproducibility
  - Determine the allowable time between calibration sequences to maintain radiometric accuracies
- Solar loading and transition zone
  - Provide knowledge of how the instrument will perform, radiometrically and spatially, during the solar loading cycle

GIFTS On-Orbit Radiometric Calibration Concept

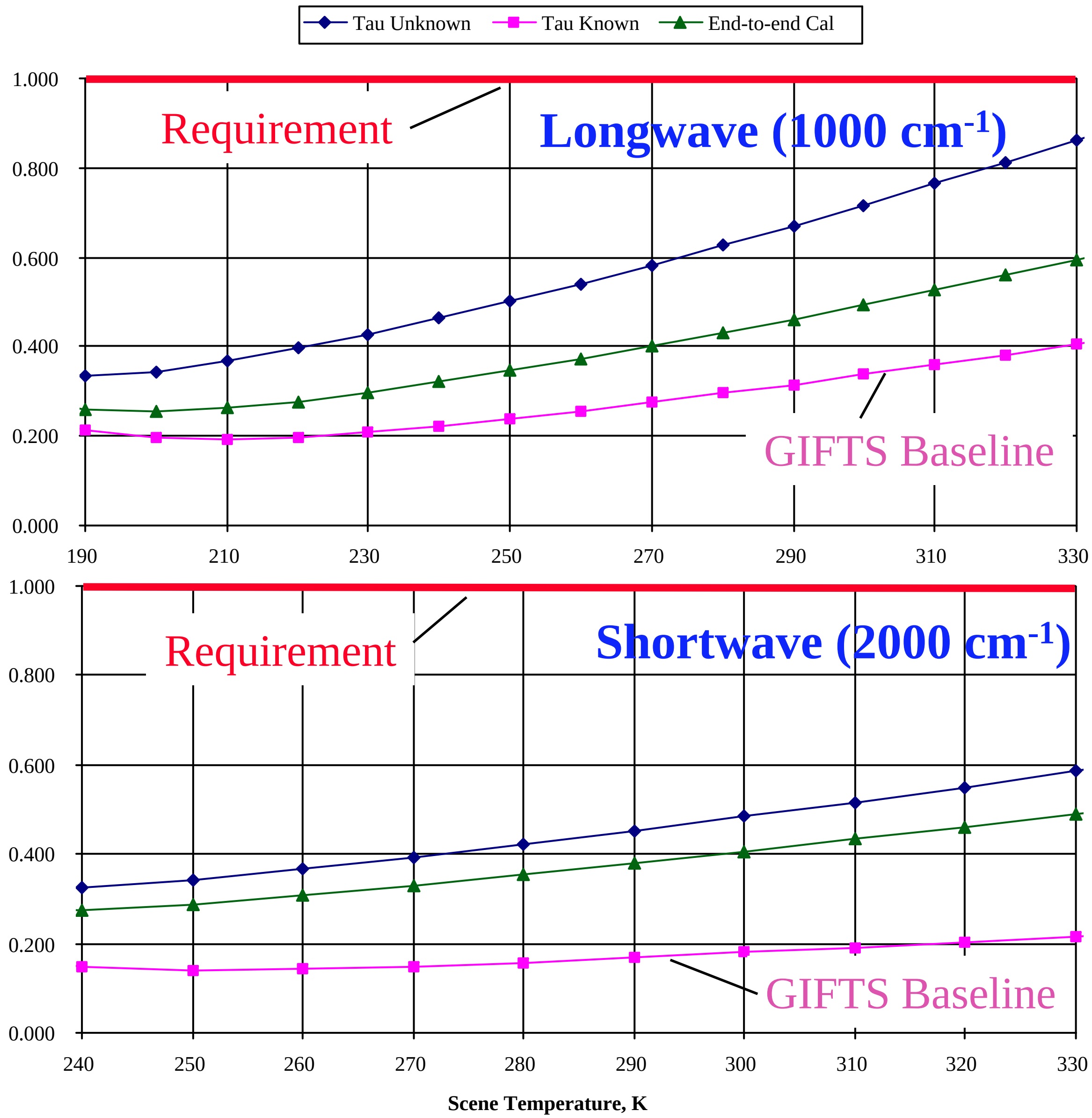
- Two small reference blackbodies located behind telescope, combined with space view
- The combination of the internal blackbodies and the space view allow tracking of any in-flight changes of the fore-optics transmission
- Blackbody design is scaled from the UW ground-based AERI and NAST/S-HIS aircraft instruments. (Best et al., CALCON 2003)
- Advantages compared to large external blackbody:
  - (1) Higher emissivity is practical with small size
  - (2) Protection from solar forcing
  - (3) Mass and volume savings
  - (4) Smaller range of pointing angles

GIFTS Radiometric Calibration Concept

$$N = \left(\frac{\tau_m}{\tau_t}\right)\left(B_H - B_C\right)Re\left(\frac{C_E - C_S}{C_H - C_C}\right) + B_S$$

- Radiance *N* derived from raw spectra of earth (C_E), space (C_S), and the internal hot (C_H) and cold (C_C) blackbodies
- τ_t is the signal transmission of the telescope mirrors and τ_m is the transmission of the blackbody pick-off mirror
- B is the Planck radiance from the hot, cold, and space references

GIFTS Calibration Accuracy



GIFTS On-Orbit Spectral Calibration

- Primary issue to be addressed by the spectral calibration is wavenumber scale “stretch” across the array
- Instrument line shape effects are negligible because of the small angular size of individual pixels
- The wavenumber scale stretch variation over the array is large, but is physically well understood and can easily be removed using known positions of absorption lines
- Pre-flight spectral calibration parameters determined during ground calibration
- Highly stable laser serves as an in-flight calibration reference
- Verify in-flight using known atmospheric absorption lines

<u>See Dave Tobin’s Presentation (CALCON 2003)</u>

Calibration DCE Times and Volumes

Calibration Data Collection Event (DCE)	DCE Frequency	DCE Duration (minutes)	DCE Collection time (minutes)	DCE Data Volume (Gbytes, compressed) (note 1)
Calibration sequence (2)	30 minutes	7	7	2.5
Telescope Tests (3)	quarterly	3089	90	32
Sub-pixel mask	semi-annually	40	40	13
Non-rejected Earth Radiance	semi-annually	27	27	7
Spectral calibration (4)	continuously			
FOV star calibration	quarterly	215	215	20
FOR star calibration	semi-annually	130	130	6
Calibration reproducibility	annually	480	480	80
Vignetting	annually	24	24	2
Solar Loading Effects (5)	annually	1440	650	222
Visible calibration	semi-annually	20	20	7
Totals during checkout (6)	9 DCEs	5472	1683	392
Totals over one year (7)	19 DCEs	15594	2808	578