A Method for Correcting for Telescope Spectral Transmission in the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS)

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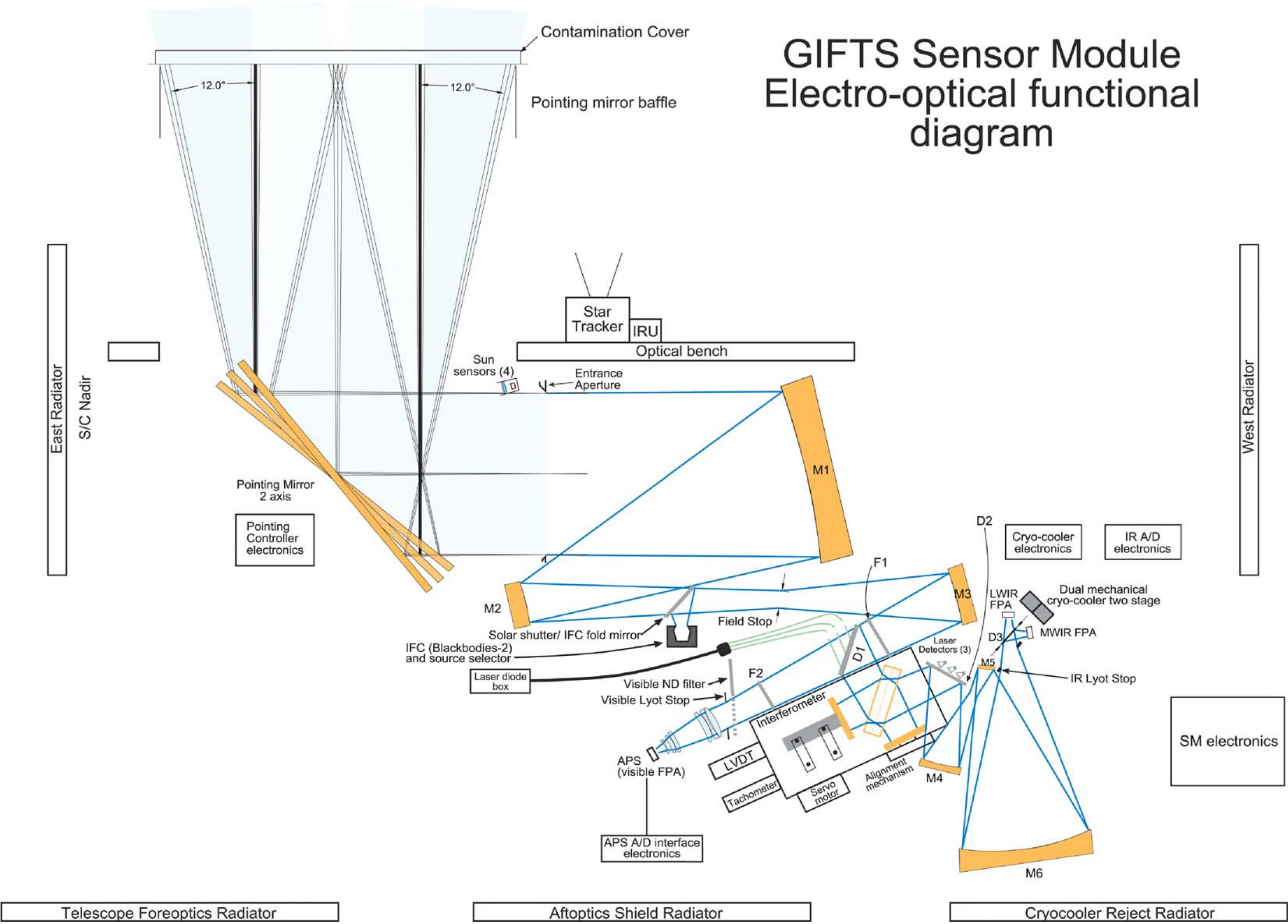
GIFTS

- GIFTS mission is to provide water vapor, wind, temperature, and trace gas profiles from geosynchronous orbit
  - Requires highly accurate radiometric and spectral calibration
- Radiometric calibration will be performed during ground calibration and updated in-flight using two on-board cavity blackbody in-flight calibrators (IFCs) and cold space
- Presentation describes how we will correct for two terms in the responsivity calibration

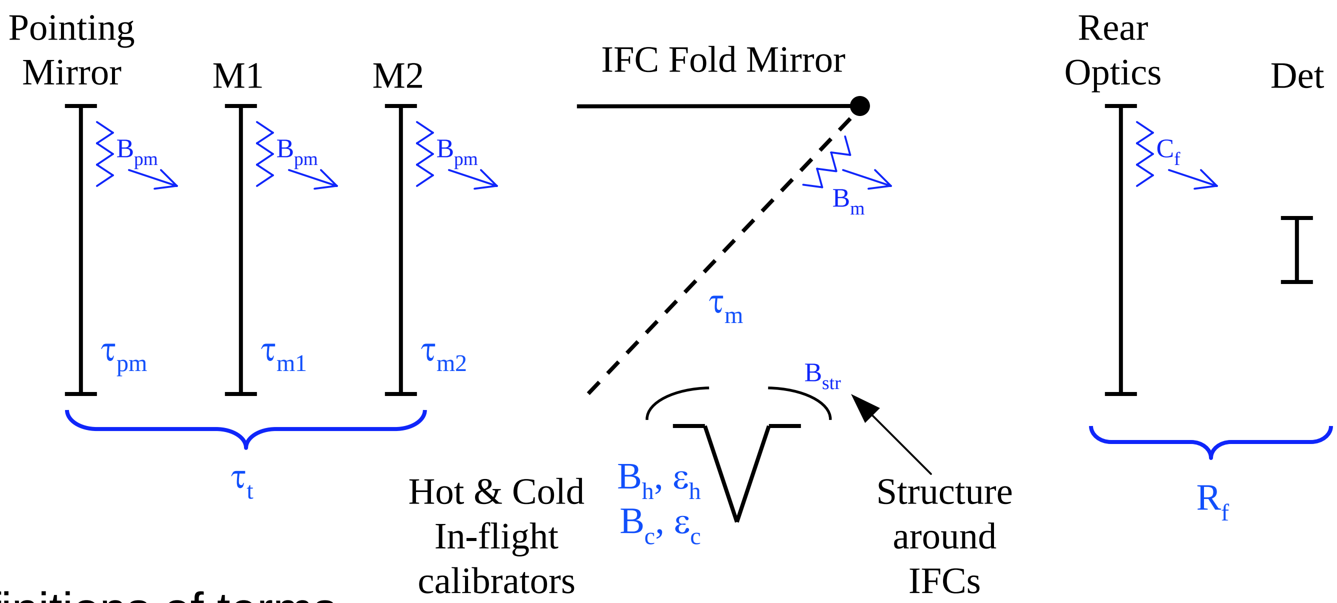
GIFTS Imaging Interferometer Specifications

- Two IR focal planes
  - Short/midwave
    - 4.4 to 6.1 μm
    - 1 K absolute accuracy for scenes >240 K
  - Longwave
    - 8.8 to 14.6 μm
    - 1 K absolute accuracy for scenes >190 K
  - 128 x 128 pixels, 110 μm pitch, 4-km pixel footprints at nadir
  - 7 spectral resolutions from 0.6 cm^{-1} to 38 cm^{-1}
  - 0.2 K reproducibility

GIFTS Sensor Module Electro-optical functional diagram



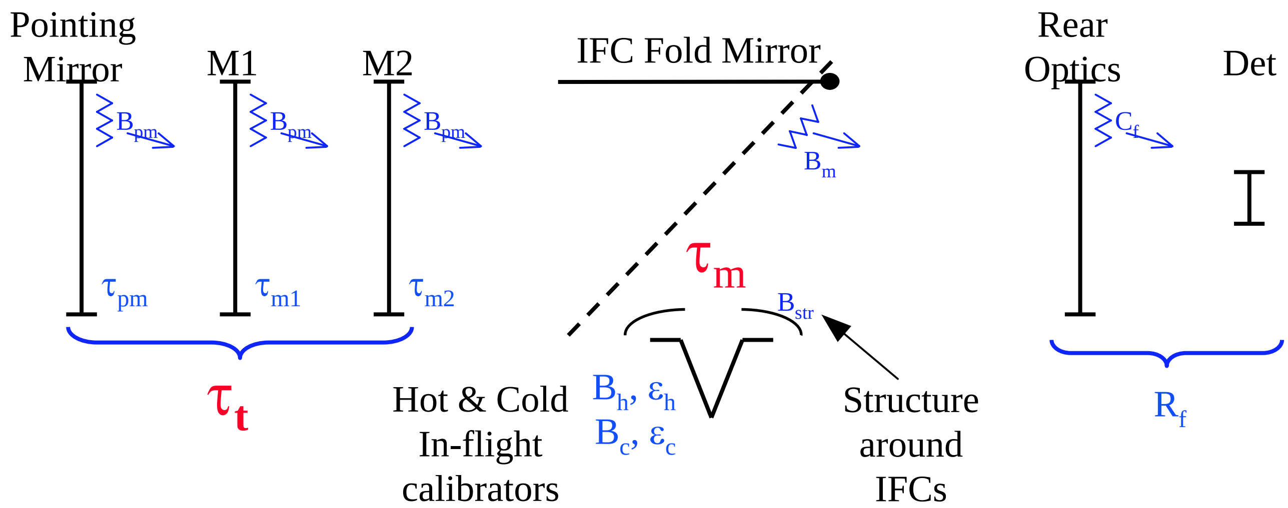
GIFTS Optical Schematic



Definitions of terms

- $\tau_?$ Transmissions (reflectances) of elements
- $\varepsilon_?$ Emissivities of elements
- $B_?$ Planck radiances at element temperatures
- C_f Complex response to emissions of the rear optics
- R_f System responsivity

GIFTS Optical Schematic



Need to correct for:

τ_t – signal transmission of the telescope mirrors

$$\tau_t = \tau_1 \cdot \tau_2 \cdot \tau_3 \qquad \tau_t = (1 - \varepsilon_1) \cdot (1 - \varepsilon_2) \cdot (1 - \varepsilon_3)$$

τ_m – transmission of the blackbody pick-off mirror

Radiometric Calibration

Scene radiance using inflight calibrators[1]:

$$N = \left(\frac{\tau_m}{\tau_t}\right) \cdot \mathrm{Re}\left(\frac{C_e - C_s}{R_f}\right) + B_s \qquad \text{where} \qquad R_f = \frac{C_h - C_c}{B_h \cdot \varepsilon_h - B_c \cdot \varepsilon_c}$$

where: N — Computed scene radiance

B_h, B_c — Planck radiances of hot and cold references

ε_h, ε_c — Emissivities of hot and cold references (assumed equal)

B_s — Planck function of cold space (effectively 0 for GIFTS)

C_h, C_c, C_e, $C_{s,}$ C_f — Measured responses to hot and cold reference, scene, space, and structure (Back end temperatures assumed constant between IFC views)

τ_m — Blackbody viewing mirror transmission (assumed constant temp)

τ_t — Telescope transmission (reflectivity)

[1] Revercomb, et al., “On Orbit Calibration of the Geostationary Imaging Fourier Transform Spectrometer (GIFTS)”, Calcon 200

τ_m and τ_t Measurement

- Fold mirror τ_m and telescope τ_t will change during flight, and such changes must be periodically measured
- The experiments for deriving τ_t and τ_m will be performed quarterly

Assumptions Made in Measuring τ_m and τ_t

- Absorption of gold-coated aluminum telescope mirrors is negligible
- Mirror reflectivities (transmissions) can be computed if mirror emissivities are known

$$\tau = 1 - \varepsilon$$

- Mirror emissivities can be estimated by measuring mirror emissions and the mirror temperatures
- τ_m can be determined in-flight by viewing either IFC at two different fold mirror temperatures

Measuring τ_m Experimentally

- Collect data viewing an in-flight calibrator at two different flip-in mirror temperatures
- By taking the difference of measured emissions at two different fold mirror temperatures, τ_m can be computed as:

$$\tau_m = \left[\mathrm{Re}\left[\frac{(B_h - B_c)}{(C_h - C_c)} \cdot \frac{(C_{m1} - C_{m2})}{(B_{m1} - B_{m2})} \right] + 1 \right]^{-1}$$

- B_{m1}, B_{m2}, C_{m1}, C_{m2} are the Planck radiances and the measured responses to the cold blackbody with the fold mirror at two different temperatures

τ_m Uncertainties

- Principle uncertainties in measuring τ_m

Error Source	Error	2000 cm^{-1} τ_m Uncertainty	900 cm^{-1} τ_m Uncertainty
T_{m1}	1K	0.016	0.046
T_{m2}	1K	0.182	0.107
T_h	0.1 K	0.013	0.010
T_c	0.1 K	0.005	0.007
ε_h	0.002	0.008	0.014
ε_c	0.002	0.002	0.008
RSS		0.184%	0.118%

Measuring τ_t Experimentally

- Collect a minimum of three measurements with each optical element at different temperatures
- The following steps will be performed to collect data
  - Turn off telescope cooling loop and collect data for 24 hours
  - Collect emission data by viewing cold space
  - After each emissions data collection, close the fold mirror and collect tail-end optics emissions data by looking at the cold blackbody

Deriving τ_t

- Cold space response:

$$C_s = \left(B_s \cdot \tau_t + L_t\right) \cdot R_f + C_f$$

B_s Planck radiance of space (4 K), assumed to be 0

τ_t Telescope transmission

L_t Total emission from telescope

R_f System responsivity

C_f Complex emission from optics behind the telescope

With B_s=0, the unknowns are the telescope emission, Lt, and the complex emissions from the rear optics, Cf

Deriving τ_t

- C_f can be measured for each telescope emission measurement by looking at the cold IFC

$$C_f = C_c - \left[\left[\left(B_c \cdot \varepsilon_c\right) + B_{str} \cdot \left(1 - \varepsilon_c\right)\right] \cdot \tau_m + B_m \cdot \left(1 - \tau_m\right)\right] \cdot R_f$$

- L_t, total telescope emission, is the sum:

$$L_t = B_{pm} \cdot \varepsilon_{pm} \cdot \left(1 - \varepsilon_{m1}\right) \cdot \left(1 - \varepsilon_{m2}\right) + B_{m1} \cdot \varepsilon_{m1} \cdot \left(1 - \varepsilon_{m2}\right) + B_{m2} \cdot \varepsilon_{m2}$$

- This can be linearized with the substitutions:

$$\alpha_1 = \varepsilon_{pm} \cdot \left(1 - \varepsilon_{m1}\right) \cdot \left(1 - \varepsilon_{m2}\right) \qquad \alpha_2 = \varepsilon_{m1} \cdot \left(1 - \varepsilon_{m2}\right) \qquad \alpha_3 = \varepsilon_{m2}$$

Deriving τ_t

A set of simultaneous linear equations can be set up to solve for L_t

$$\frac{C_s - C_f}{R_f} = B_{pm} \cdot \alpha_1 + B_{m1} \cdot \alpha_2 + B_{m2} \cdot \alpha_3$$

- The values on the left side are known
- The B values are computed from element temperatures
- With more than three samples, these equations are then solved using a least-squared error approach for α_1, α_2, and α_3
- The resulting mirror emissivities can be computed as:

$$\varepsilon_{pm} = \frac{\alpha_1}{\left(1 - \varepsilon_{m2}\right) \cdot \left(1 - \varepsilon_{m3}\right)} \qquad \varepsilon_{m1} = \frac{\alpha_2}{\left(1 - \varepsilon_{m2}\right)} \qquad \varepsilon_{m2} = \alpha_3$$

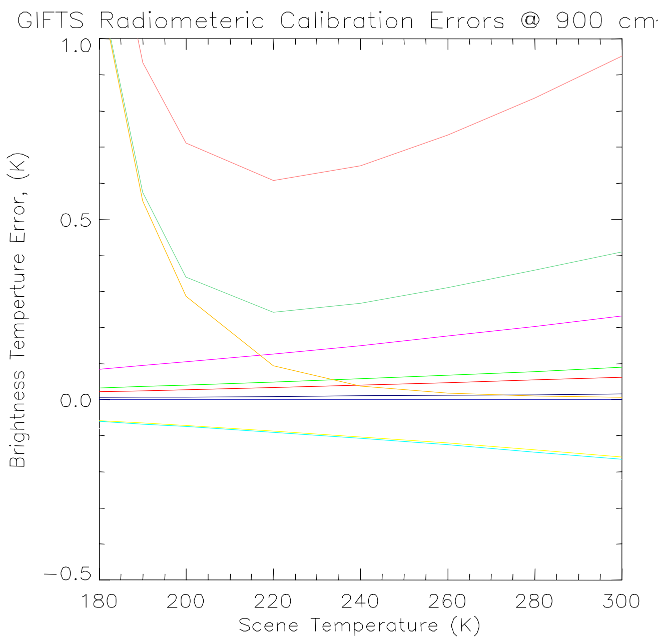
τ_t Uncertainties

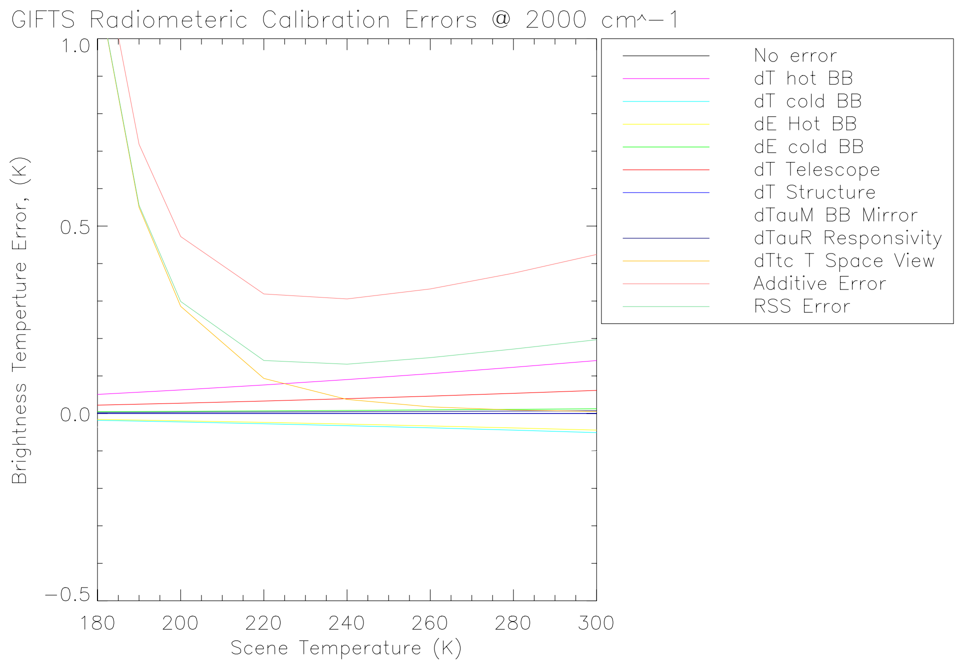
- Principle uncertainties in measuring τ_t

Error Source	Error	2000 cm^{-1} τ_t Uncertainty	900 cm^{-1} τ_t Uncertainty
T_{pm}	1K	0.067	0.030
Tm1	1K	0.064	0.030
Tm2	1K	0.067	0.031
T_h	0.1 K	0.021	0.016
T_c	0.1 K	0.007	0.011
ε_h	0.002	0.006	0.011
ε_c	0.002	0.002	0.006
RSS		0.117	0.057

Overall Radiance Calibration

- The combined uncertainty of the radiance calibration and derivation of τ_t and τ_m has been modeled





- Responsivity must be computed seperately for each pixel, therefore multiple scans must be collected to do any averaging
- τ_m and τ_t are applicable to all pixels
  - A single scan of interferometer data will provide about 16000 samples over which τ_m and τ_t can be averaged
- Still to be addressed
  - Residual nonlinearity
  - Changes in responsivity over 24-hour telescope thermal cycle