The Use of Bright, Cool Variable Stars along with Hot Stars to Assess Relative Spectral Response (RSR) Model Accuracy

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Abstract

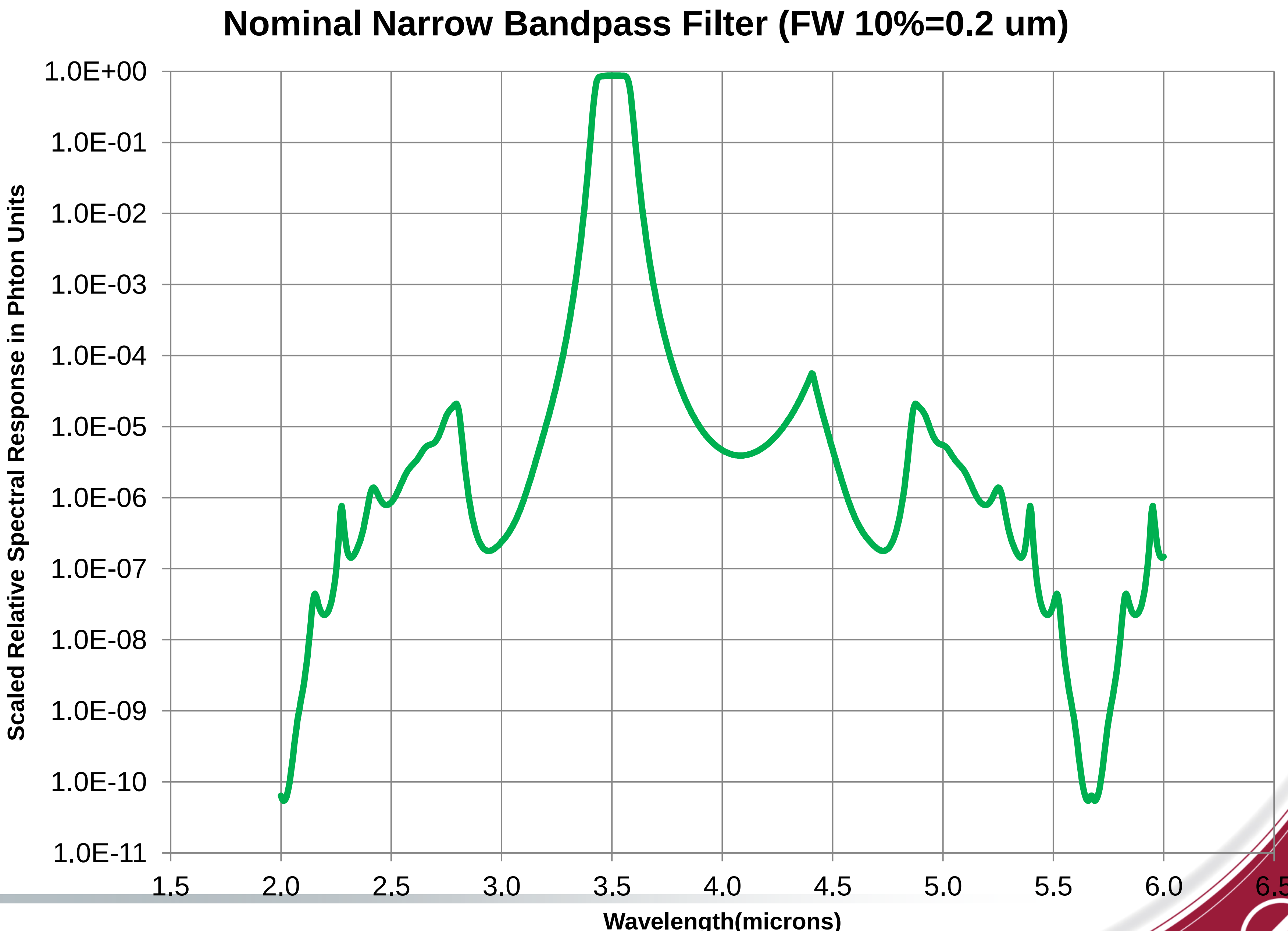
In light of the increased application of absolutely calibrated data obtained in the infrared (IR) from space to a variety of very demanding scientific and applied fields, with global climate monitoring and modeling just two very obvious examples of such fields, it is increasingly important that the relative spectral response (RSR) of each sensor be measured in an end-to-end fashion. The RSR is a critical part of understanding where the photons came from in a scene, and in the interpretation of the data. Notwithstanding the criticality of such a measurement, sometimes programmatics (schedule drivers and cost constraints) drive a program to launch a sensor with only a model based on theory, or component characterization, or a combination, in place. Even sensors which have been measured end-to-end prior to launch may undergo changes during subsequent storage or handling on the ground, during the vibration of launch, or in the on-orbit environment. On-orbit changes may be induced by contamination events, high energy particle effects (including South Atlantic Anomaly effects) in coatings or detector arrays or even electronics, or interactions with the environment (such as chemical interactions with atomic oxygen, for example). While a scannable monochromatic source is not available on-orbit, one can at least check the validity of the RSR by observing a collection of well-calibrated stars with a range of temperatures. This paper will enumerate the range of sources that can be used for such an assessment that are currently being studied as part of The Aerospace Corporation's absolute calibration of stellar spectral energy distributions (SEDs) work, and how these SEDs can be used for the assessment of RSR models. While one may not be able to "fix" an RSR, there are potential work-arounds for some types of problems, and that effort will be discussed.

On-orbit Irradiance Responsivity Coefficients

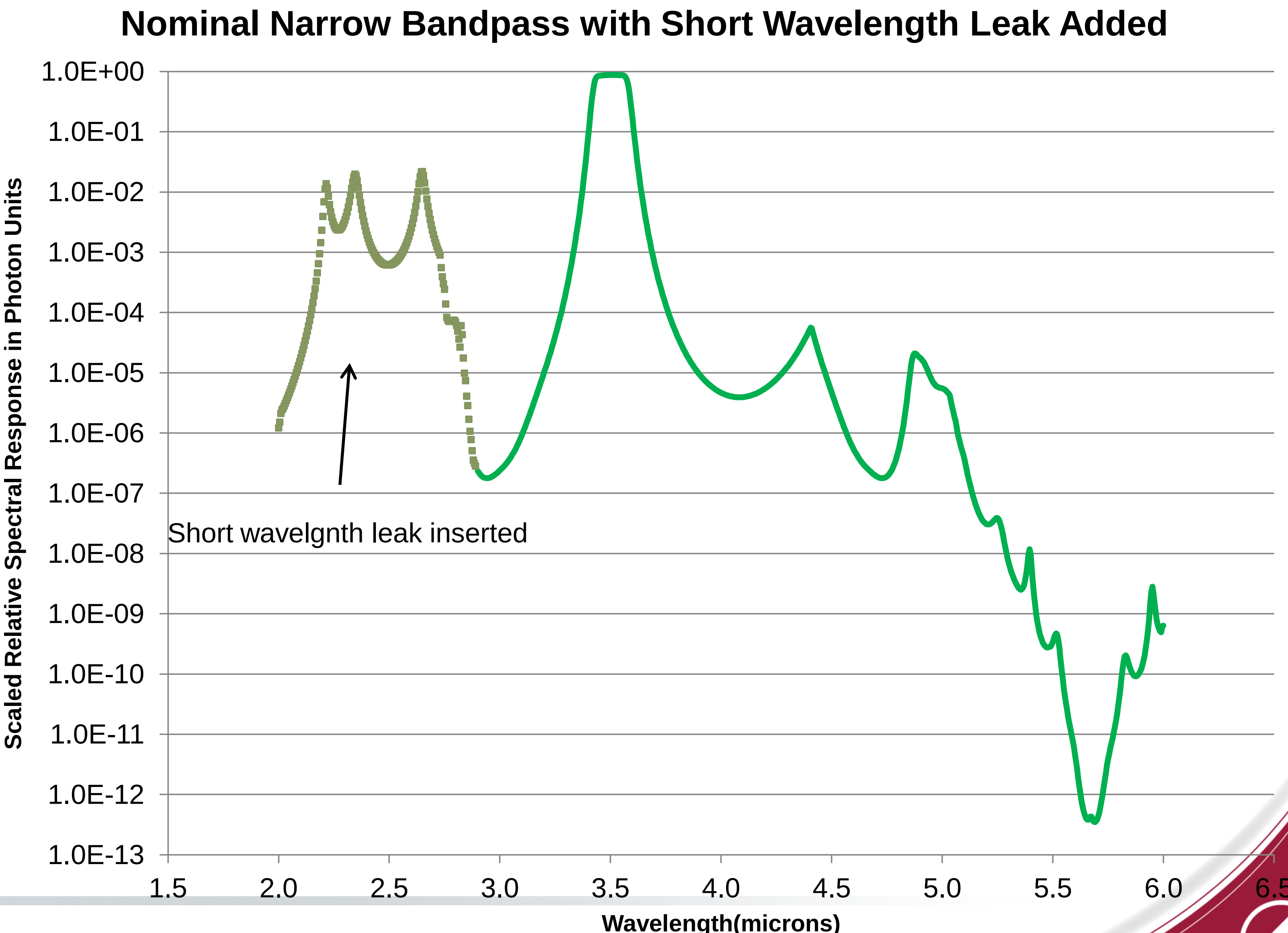
- A fundamental property of a sensor that is meant to characterize the intensity of point targets is the point source (irradiance) responsivity
  - *Can be measured on the ground through a combination of extended source responsivity and point response function solid angle*
  - *Can be measured with a collimated point source*
    - Issues with diffraction and scattered light loss
    - Issue with accurate area of the pinhole used to produce the point source
- Derivation of irradiance responsivity coefficients on-orbit can be performed using stars as sources
  - *Has the advantage of true point source*
  - *Requires very accurate absolutely calibrated spectral energy distributions over spectral region of the sensor's response*
    - Can only assess RSR to accuracy of absolutely calibrated SEDs
- BOTH approaches require an accurate end-to-end relative spectral response (ETE RSR, or just RSR) function for each band of the sensor
  - *Some programs, when they get to the calibration phase, are very pressed for time and resources, & so launch with only a model for the RSR made up of component (or worse, witness sample) characterizations multiplied together*
  - *Some programs attempt ETE RSR calibrations, but encounter problems*

Absent a good calibration on the ground, or if a program simply wants to validate the RSR on-orbit, What can be done?

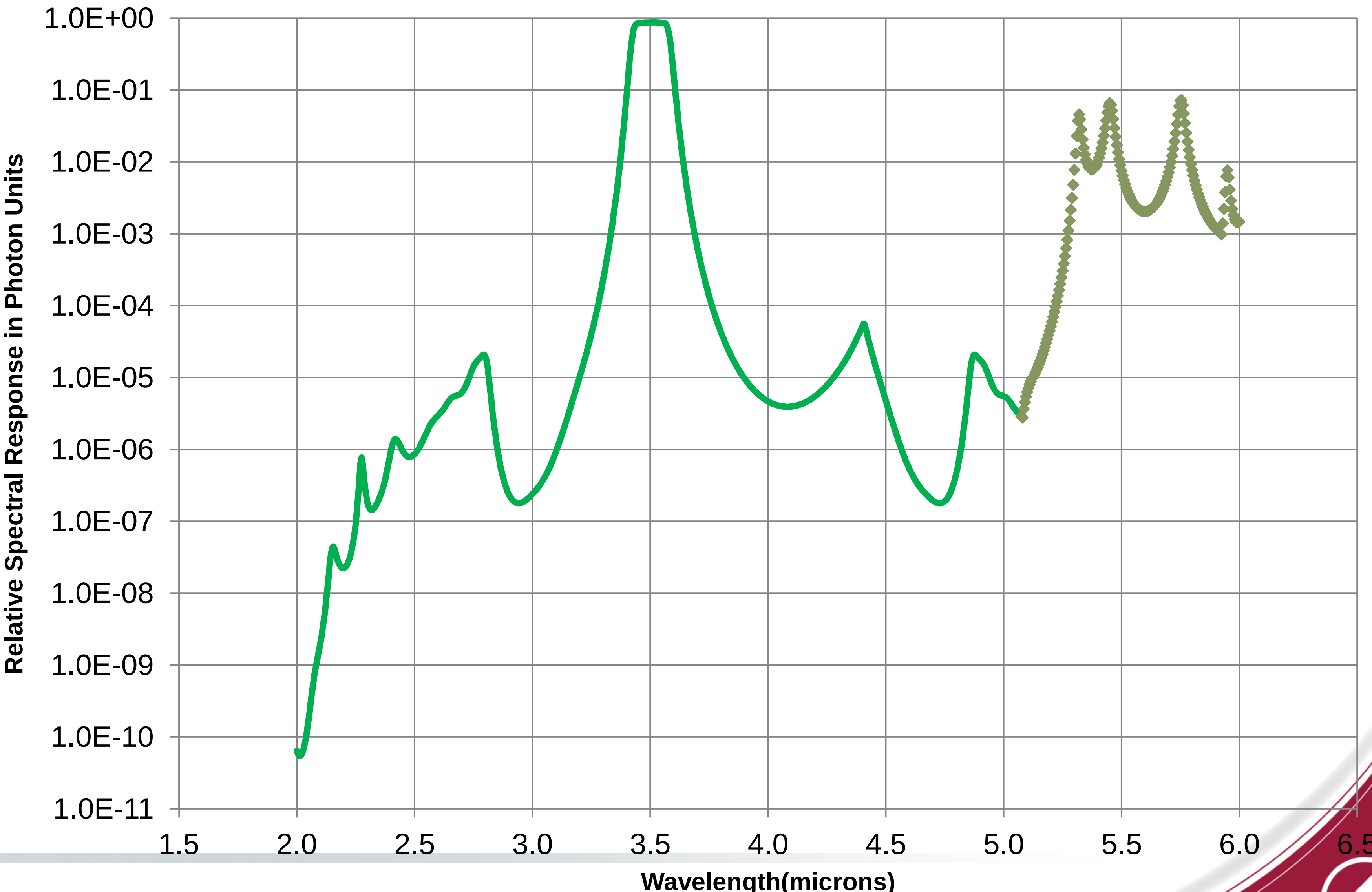
- Stellar energy distributions exhibit a dramatic difference in slope, depending upon the type of star
  - *Early type stars exhibit ~10,000 – 40,000K distributions approximating blackbody shapes*
    - A Lyrae (Vega) is ~9700K
  - *Late type stars are typically ~3000K or lower, and if they have a dust shell, the temperature can be <600K*
    - CRL 618 can be represented by a sum of 237K and 515K blackbodies
- To evaluate our ability to diagnose significant out of band (OOB) spectral leaks, we have created relative spectral responses for a narrow bandpass filter near 3.5 um, based on a design provided by Pete Fuqua
  - *We have then taken the theoretical OOB leak and modified it and added it to the filter transmission function, first on the short wavelength side, and then on the long wavelength side of the nominal bandpass*
  - *We used a fairly extensive 2-6 um spectral range, often representative of an InSb system with Si or Ge components, even though some systems now use HgCdTe detectors that have cut-offs that are tailored to the application*



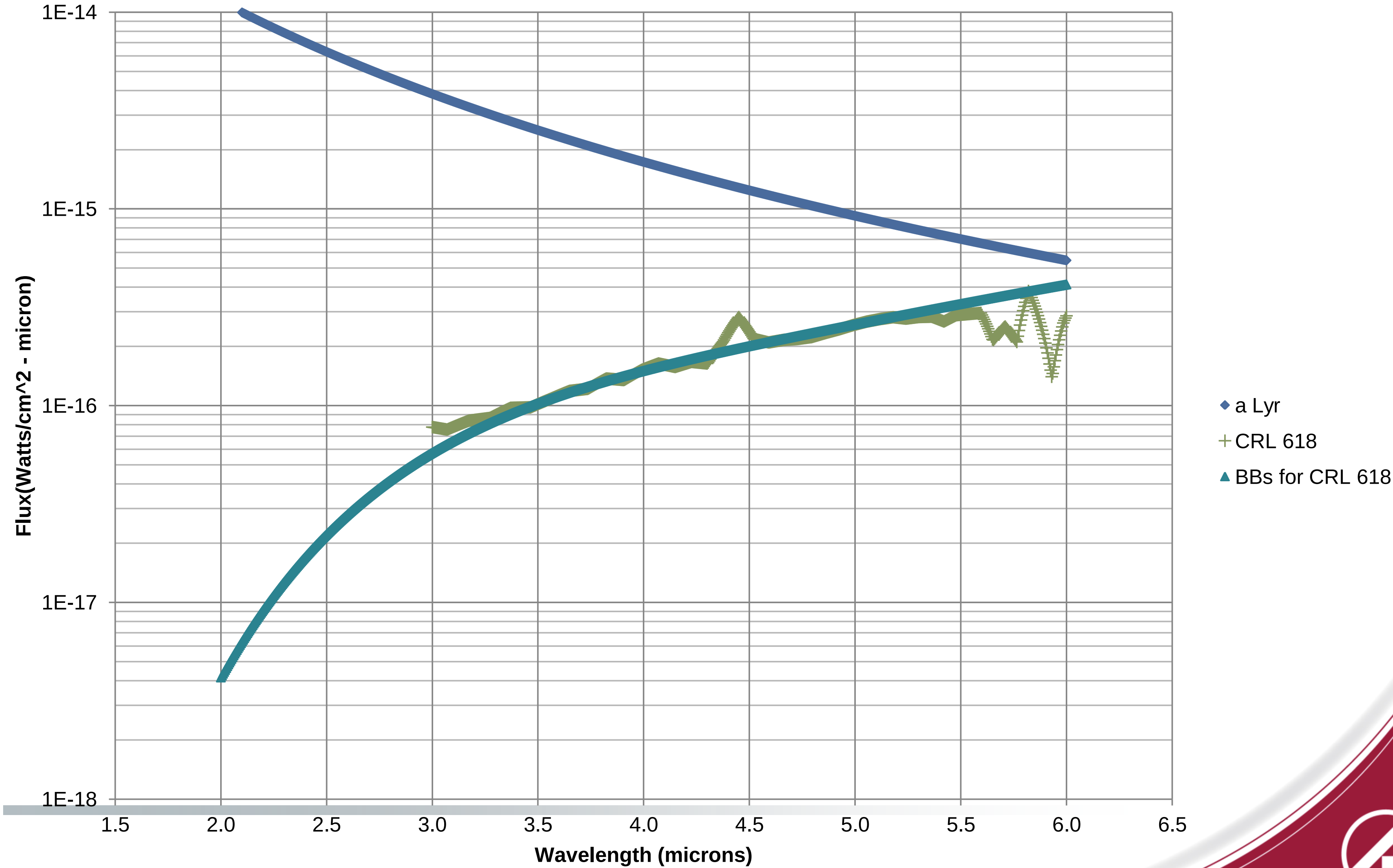
Nominal Narrow Bandpass Filter (FW 10%=0.2 um)
Scaled Relative Spectral Response in Phton Units
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10
1.0E-11
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
Wavelength(microns)


Nominal Narrow Bandpass with Short Wavelength Leak Added
Scaled Relative Spectral Response in Photon Units
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10
1.0E-11
1.0E-12
1.0E-13
Short wavelgnth leak inserted
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
Wavelength(microns)

Nominal Narrow Bandpass Filter with Long Wavelength Leak Added



Standard Reference Star is a Lyrae, CRL 618 is a dust-enshrouded star – Spectral Energy Distributions Proportional to # photons per spectral interval are shown below



Derive effective Irradiance Responsivity Calibration Coefficients from "Observations" of these Two Stars

Alpha Lyr Cal Coefficients	BB sum (CRL 618) Cal Coefficients	Star Cal Coefficient Condition
0.4316	0.4219	Theoretical, only in-band Response (RSR*F(wl))/ In-band Source Flux

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0.4520	0.4233	RSR w/ Short Leak*F(2-6 um)/ In-band Source Flux

If RSR viewing Alpha Lyr is greater than expected, the band pass filter could have a **short- wave** out-of-band leak, as the hot stellar continuum is strongest at shorter wavelengths.

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0.4316	0.4222	Nominal Responsivity ~ RSR*Flux(wl=2-6 um)/ In-band Source Flux
0.4520	0.4233	RSR w/ Short Leak*F(2-6 um)/ In-band Source Flux
0.4387	0.5559	RSR w/ Long Leak*F(2-6 um)/ In-band Source Flux

If RSR viewing CRL618 is greater than expected, the band pass filter could have a **long- wave** out-of-band leak, as the cool spectrum is strongest at longer wavelengths.

Derive effective Irradiance Responsivity Calibration Coefficients from "Observations" of these Two Stars

Alpha Lyr Cal Coefficients	BB sum (CRL 618) Cal Coefficients	Star Cal Coefficient Condition
0.4316	0.4219	Theoretical, only in-band Response (RSR*F(wl))/ In-band Source Flux
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Comparison of Hot Star Cal Coef w/ Short Leak to Nominal Model shows ~5% increase, Comparison of Cool Star Cal Coef w/ Long Leak is ~30%

Future Work

- Use existing sensors which have calibrated RSR curves and which have observed some of the stars with both high and low temperatures to validate our model and analysis method

- Perform similar analyses for other stars for which we have measured high accuracy spectral energy distributions

- Run additional analyses to assess potential value to other programs, based on their filter curves and target temperatures

Conclusions

- We have outlined a method that uses measured, absolutely calibrated spectral energy distributions of hot and cold stars to assess the validity of either measured or modeled relative spectral energy distributions for on-orbit sensors
  - *While this method cannot "fix" a bad RSR, it can show that the modeled or calibration-based RSR is correct within some uncertainty*

Acknowledgements

We gratefully acknowledge Dr. Peter Fuqua's filter modeling that provided the starting point filter functions for this work, and for his positive suggestions that improved the presentation.

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Thank You

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