Characterizing Dust Grains in Circumstellar Debris Disks Spatially Resolved by Herschel Space Observatory

Justin Beaurone (Jet Propulsion Laboratory, Moorpark College) • Dr. Farisa Morales (Jet Propulsion Laboratory, California Institute of Technology, Moorpark College)

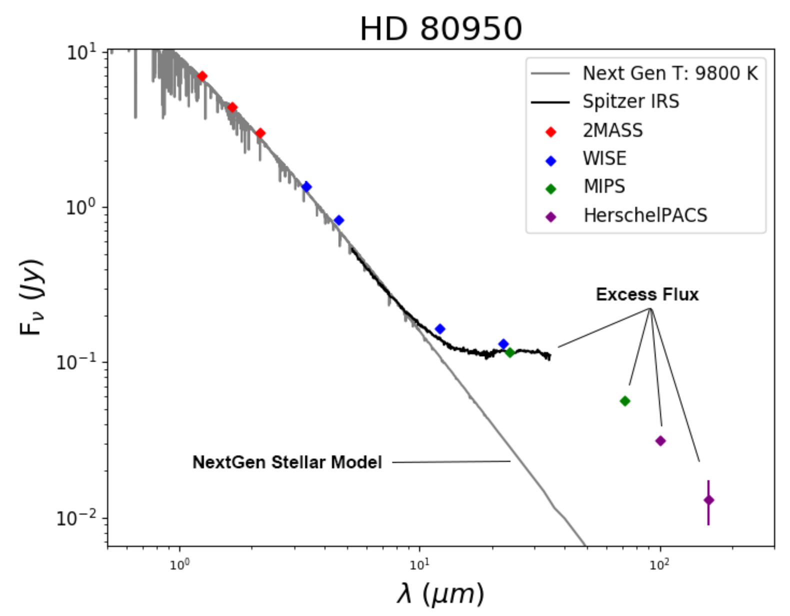
What is Excess Flux?

Synthetic stellar models predict a flux distribution very similar to a black body curve. Observations made by Spitzer's Infrared Spectrograph reveal excess flux not accounted for by a stellar model alone. The excess flux is best explained by the presence of dust grains around the star, forming a debris disk, usually composed of two debris belts: one inner, rocky debris belt, and one outer, icy debris belt. The Solar System is an example of this, as it has an inner Asteroid belt and an outer icy Kuiper belt.

The goal of this research project is to reconstruct the observed flux, including the excess flux, using two primary stellar models:

1. Two simplistic black body debris belts
2. Two debris belts with realistic grain characteristics

All of the computations are done using Python.



Plot of Flux vs Wavelength for star HD 80950. The gray line shows the flux as predicted by the NextGen stellar model, yet Spitzer IRS and Herschel PACS both observed flux far above the stellar model.

Simplistic Black Body Belts

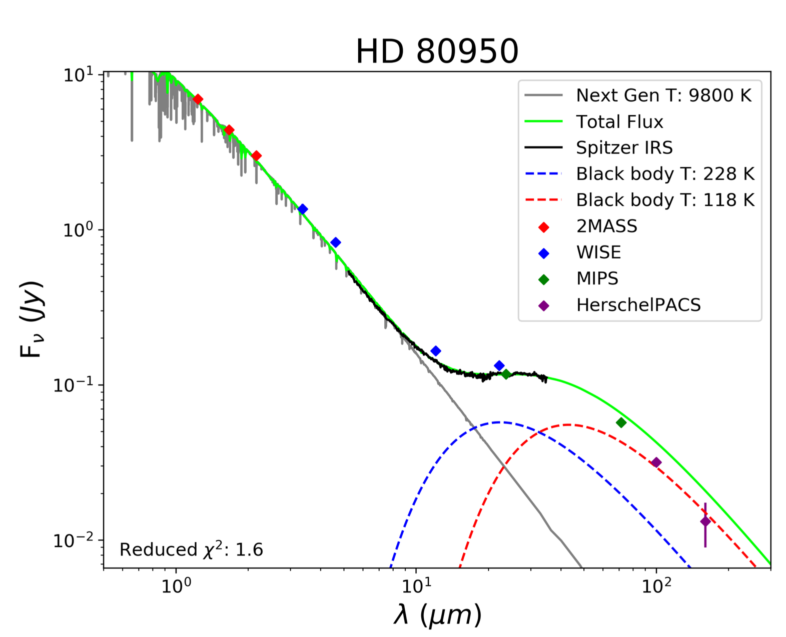
For simplistic black body debris belts, assume that all of the grains are perfect black body objects that emit 100% of all absorbed radiation. The Planck Function models the radiation from a perfect black body object:

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

To reconstruct the observed flux, add the flux from two black body belts, each with a unique characteristic temperature, to a synthetic stellar model by NextGen.

$$F_{total} = N_1 B_\lambda(T_1) + N_2 B_\lambda(T_2) + N_\star NextGen$$

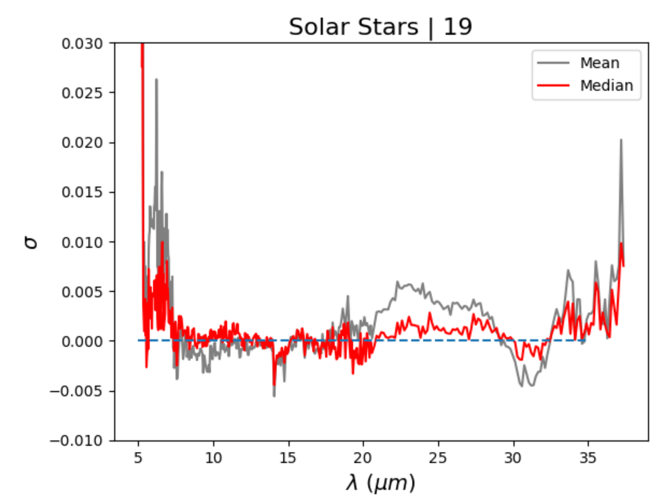
Each black body and the stellar model has a normalization factor. This equation is used in an optimization routine that finds the best temperatures and normalization factors.



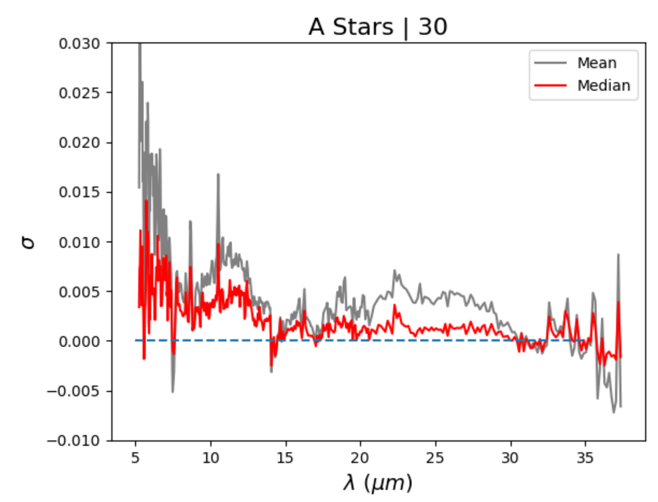
Plot of Flux vs Wavelength for star HD 80950 with the results of fitting the two belt simplistic black body model to the data. The blue curve shows the warm belt, with a characteristic temperature of 228 Kelvin. The red curve shows the cold belt, with a characteristic temperature of 118 Kelvin. The green line shows the sum of the black body belts and the stellar model. Notice how the total flux does not pass perfectly through the longer wavelength (<70 microns) observations.

Variance Stacking

This project looks closely at 49 stars that have been spatially resolved by *Herschel Space Observatory* and have *Spitzer-IRS* observations. To look for general trends in the data, the variance of the black body fits from the *Spitzer-IRS* spectra is calculated and then averaged. The results suggest the presence of Astronomical Silicate grains, which have flux distributions with features at 10 microns and 20 microns.



Solar type stars are within the range of spectral types: F4, F5, ..., F9, G0, G1, ..., G9, K0, K1, ..., K9



A type stars are within the range of spectral types: B0, B1, ..., B9, F0, F1, F2, F3

Adopting Realistic Grain Characteristics

For fits with realistic grain properties, each grain can no longer be considered a perfect black body. Instead, each has its own emissivity profile across a range of wavelengths, and the emissivity depends on the optical properties of the grain. Prior to running the realistic grains fitting routine, the following must be calculated:

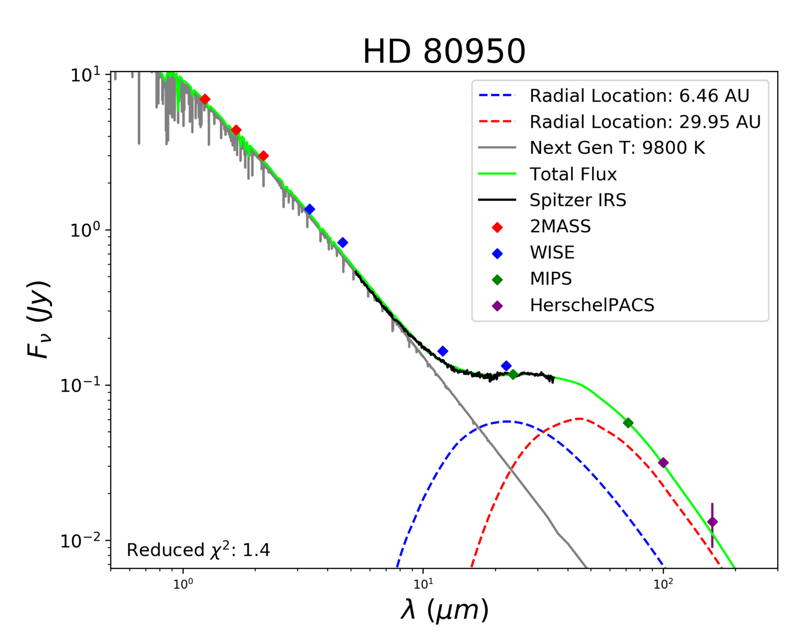
- The optical constants of the grains, using Effective Medium Theory
- The emissivity profile of the grains, using Mie Scattering Theory
- The temperatures of the grains, using conservation of energy principles

The amount of radiation emitted by the grain still depends on the Planck function, except now it is multiplied by some fractional emissivity at each wavelength. Therefore, a debris belt cannot be considered as an infinitesimally thin ring with uniform temperature. Now the temperature of each grain at each radial location is considered.

$$F_\lambda(r_0) = \frac{1}{4d^2} \int_{0.6r_0}^{1.4r_0} \int_{a_{min}}^{a_{max}} a^2 \cdot \epsilon_\lambda(a) \cdot B_\lambda\big(T(a,r)\big) \cdot Ca_r(r) a^q \, da \cdot 2\pi r dr$$

To reconstruct the observed flux, add the flux from two realistic grain belts to a synthetic stellar model by NextGen. Previously, each belt had a characteristic temperature, but now they have a characteristic radial location in relation to the star. Again, each component of the model has a normalization factor.

$$F_{total} = N_1 F_\lambda(r_1) + N_2 F_\lambda(r_2) + N_\star NextGen$$



Plot of Flux vs Wavelength for star HD 80950 with the results of fitting the two belt realistic grains model to the data. The blue curve shows the warm belt, with a characteristic radial location of 6.46 Astronomical Units (1 AU is the mean distance of Earth to the sun). The red curve shows the cold belt, with a characteristic radial location of 29.95 AU. The green line shows the sum of the two debris belts and the stellar model. Notice how the model does pass through the longer wavelength (>70 microns) observations.

Conclusion

The realistic grain characteristics model is a more robust model than a simplistic black body model for three reasons outlined in this poster:

1. The black body fits, while being great approximations to the characteristic temperatures of the debris belts, do not pass sufficiently well through all of the observed data points.
2. The variance plots suggest the presence of Astronomical Silicate grains because of the 10 microns and 20 microns features.
3. The realistic grain fits improve the model by passing through all of the observed data points.

Literature Cited

All logos were retrieved from their respective institutions. The plots shown here were all made during the course of this research project using original Python code.

Data for the flux observations were made by the following ground-based and space-based telescopes:

- *Herschel* Photoconductor Array Camera and Spectrometer (PACS)
- *Spitzer Space Telescope* Infrared Spectrograph (Spitzer-IRS)
- *Spitzer* Multiband Imaging Photometer (MIPS)
- Wide-field Infrared Survey Explorer (WISE)
- Two Micron All Sky Survey (2MASS)

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Future & Ongoing Research Interests

Ongoing work includes:

- Continuing the data stacking using the variance of the realistic grain fits instead of the black body fits
- Calculating flux ratios for the belts vs the stellar model

Future work includes:

- Writing Monte Carlo Markov Chain and/or Neural Network fitting routines
- Implementing more robust realistic grain fitting routines:
  - Optimizing the size distribution of grains in the belts
  - Fitting with co-located belts of different grain sizes