Lab 1 - Fitting A Stellar Spectral Energy Distribution (SED)

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Hua

In this lab, we looked at photometric data for five stars: ‘Aua (Betelgeuse), Ka ‘ōnohi ali‘i (Procyon B), Haiku lima (Alioth), Hōkū kau ‘ōpae (Rigel), and Ka maile hope (Alpha Cen A). Using data from SIMBAD, AllWISE, and Provencal et al. (1996), we successfully produced a Spectral Energy Distribution (SED) for each star. These SED plots are created simply from intensity values or magnitudes of a given star at various wavelengths. These values are obtainable through the use of a standard telescope with filters or a spectrograph. In addition to consisting of easily obtainable values (relative), SED plots can offer a huge swath of information about the target star, such as temperature, luminosity, radius, metallicity, and more. This makes it an invaluable tool for astronomers and a reliable first step to understanding a star of interest. It is stellar characteristics like those produced from SED plots that allow us to understand the life cycle of stars, investigate life outside of our solar system, and learn more about our own sun.

Ha‘alele

In order to produce an SED plot for each star, it was important to have photometric data spanning a large wavelength range. In particular, we wanted to cover the U, B, V, R, I, J, H, and K bands, which span the visible spectrum. In addition to these bands, we also wanted to include data in the infrared, so we utilized AllWISE data in their W1, W2, W3, and W4 filters. This gave us a wavelength range of about 0.36 to 22 microns. All of this data was retrieved using Astropy's Astroquery package to navigate through the SIMBAD and AllWISE data pipelines. The one exception to this was the star Ka ʻōnohi aliʻi, which required us to pull photometric data from Provencal et al. (1996). This data only spanned a wavelength range of about 0.14 to 0.78 microns, but as you will see, we were still able to obtain some reasonable approximations of its physical characteristics. Figure 1 and Figure 2 represent the SED plots for all five galaxies and an individual plot of the SED for Ka ʻōnohi aliʻi, respectively. Ka ʻōnohi aliʻi is included in a plot of its own due to the drastic difference in wavelength range.

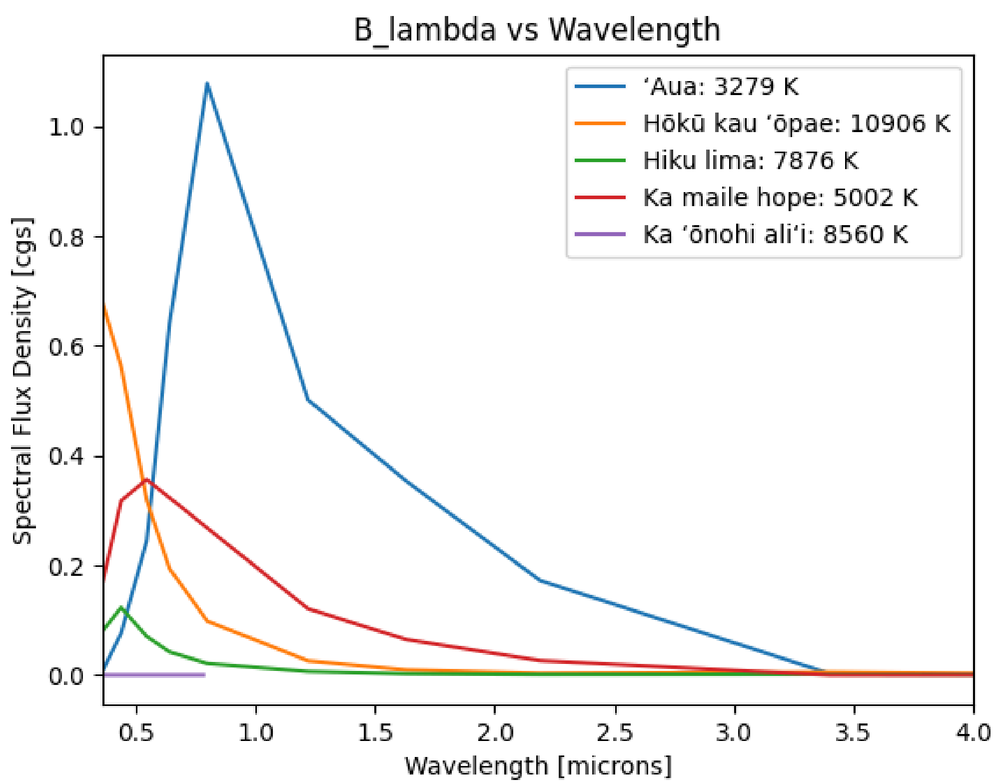

Figure 1: Spectral flux density (cgs) plotted over wavelength (microns) for all five stars with their temperatures labeled.

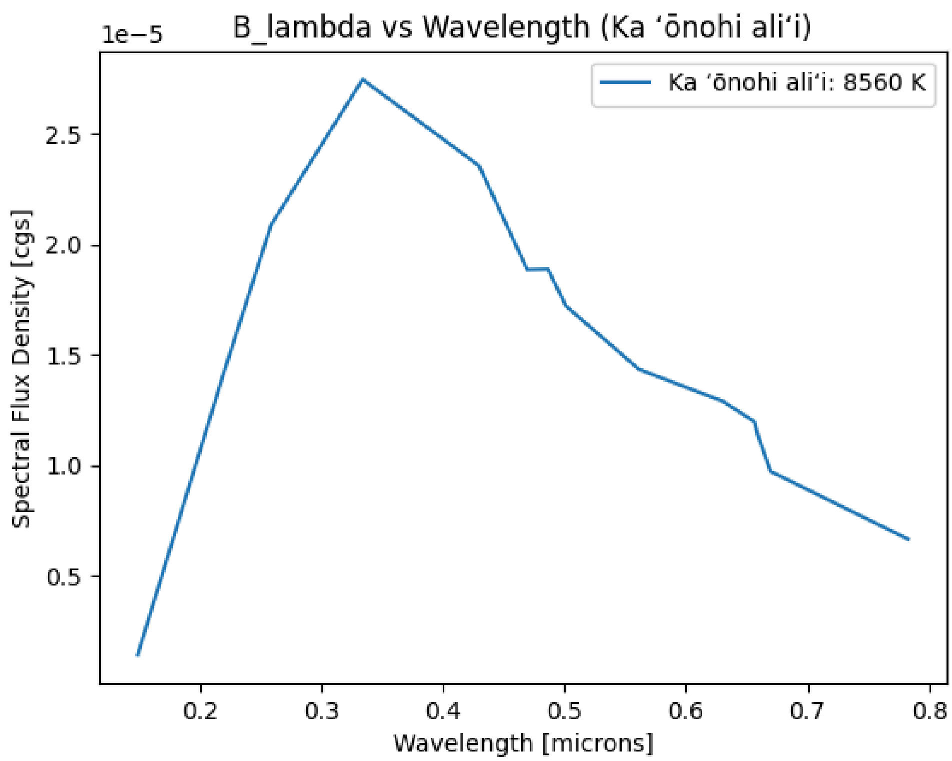

Figure 2: Spectral flux density (cgs) plotted over wavelength (microns) for Ka ʻōnohi aliʻi.

Huakaʻi

With these five SED plots, our goal was to obtain a temperature, luminosity, and radius for each star. The first of these values, temperature, required us to fit the λ form of the Planck black-body function to our SED plots. We used Scipy's curve_fit function to achieve this. Our black-body function takes in the wavelength range, a guess at the temperature, and a scaling factor. We do not know the true temperature of the star, but we gave the curve_fit function an initial guess of 5000 K as we knew the temperatures would likely fall roughly within +- 5000 K of that. We also did not have the scaling factor that adjusts for the star's distance from Earth, so we opted to calculate an initial guess using the effective wavelength of the V band divided by the spectral radiance (unscaled) at that wavelength, given our initial temperature guess. With these two initial guess, we were able to feed the curve_fit function our Planck function, and it would output the closest matching temperature.

Next, we needed to calculate the luminosity of each star in order to get their radii using the Stefan-Boltzmann Law. The luminosity comes from the total flux, which can be easily calculated by integrating under the SED curve using the Simpson rule. The only other thing we needed to calculate the luminosity was the distance from Earth. We calculated this using the parallax values provided by SIMBAD. Finally, with the luminosity, we were able to plug into the Stefan-Boltzmann Law to find a radius for each star.

Hoʻina

Calculated values for total_flux, luminosity, radius, temperature, and the error on the temperature calculation can be found in Table 1.

Name	Total Flux [cgs]	Luminosity [cgs]	Radius [cm]	T [K]	T_err [K]
ʻAua	8.85e-05	2.47e+38	5.47e+13	3279	221
Hōkū kau ʻōpae	1.57e-05	1.32e+38	3.61e+12	10906	906
Hiku lima	3.31e-06	2.54e+35	3.04e+11	7876	1224
Ka maile hope	2.77e-05	6.02e+33	1.16e+11	5002	798
Ka ʻōnohi aliʻi	1.01e-09	2.19e+29	2.39e+08	8560	820

Table 1: Table containing calculated values for total flux, luminosity, radius, temperature, and temperature error. Temperature is defined as the absolute value of the difference between SIMBAD's measured temperature and our temperature.

From Table 1, we can see that the average T_err was 793.8 K. This amount of error is definitely significant, but can be expected when using photometric data due to its lack of precision compared to other methods such as spectroscopy. We can at least see that the calculated temperature (T) values are not arbitrary and do, in fact, follow the trend we would expect across all five stars.

If we compare the Radii from Table 1 to the known radii of each star, we can see that all of the values are either at the same order of magnitude or off by one order of magnitude. This is quite impressive for, ultimately, being a rather simple and generally imprecise method. If we compare these radii to that of our sun (6.957e10 cm), then we see that most of them are at least one order of magnitude larger, with the exception of Ka ʻōnohi aliʻi, which is smaller.

Most of these stars would not be considered typical. The exception to this is Ka maile hope, which resembles our sun as it is also a yellow dwarf on the main sequence. The other stars, however, are either giants/supergiants or dwarf stars nearing the end of their lives. The dwarf stars have stopped sustaining fusion in their core entirely, but the giants and supergiants have begun performing a new type of fusion. Instead of fusing hydrogen in their core, they now fuse heavier elements like helium, carbon, oxygen, and iron. Eventually, they will exhaust all their fusion resources and collapse into a supernova.

Hāʻina

The temperature values calculated using this photometric data and the Planck black-body function lacked a significant amount of precision. This is likely largely due to the fact that we only have one datapoint for each wavelength band. If we were able to capture intensities in between the effective wavelengths of each filter, then we could produce a much smoother curve. A smoother and more accurate curve would give us a much closer fit to the black-body function and therefore narrow down to a more precise temperature value. We could also have used a more precise scaling factor for the Planck function if we used a precise distance from Earth instead of estimating based on wavelength and a temperature guess. Despite the lack of precision with our temperature calculations, the radii calculations were generally quite accurate. Future implementations of the methods laid out here could benefit from more precise integration methods and curve fit functions. Beyond that, the most impactful improvement would be a greater abundance of data at intermediate wavelengths.

Work Cited

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