Photometry Procedure and Results

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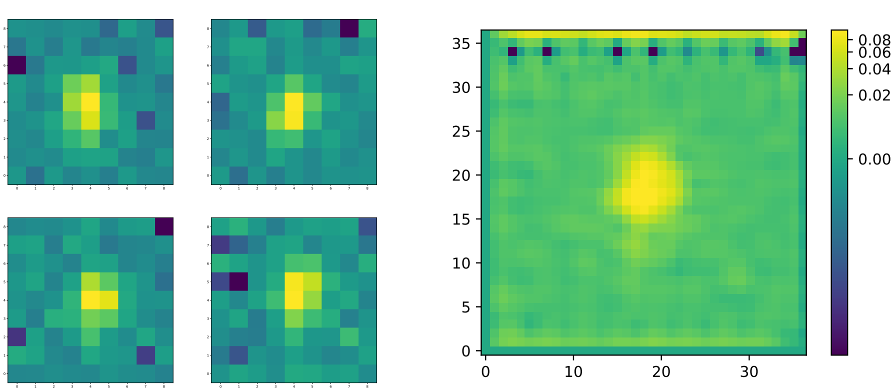
Constructing a PSF

The first thing I had to do to perform the PSF photometry was to create an ePSF. I mainly followed the procedure outlined in the astropy tutorial[1]. First, I summed image frames 40, 56, 71, 88, and 103 so that Vega would be spaced out and that the PSF builder function can use all of them to construct a PSF. I then made a table of stars using the function "find_peaks" which records the positions of peaks that lie outside of a set threshold from the background. Scattering those positions over the image allowed me to make sure that there were no other objects included in the table.

The star cutouts from which we build the ePSF must have the background subtracted. Here I used the function "sigmaclipped_stats" to retrieve the sigma-clipped median value and used that as the background level with sigma set to 2. I then used the function "extract_stars" to extract cutout images centered on stars defined in the input table. From there, I used the function "epsf_builder" to create a PSF to use later. Figure 1 shows the 4 star cutouts of Vega and the created ePSF.



(a) (b)

Figure 1: (a)The star cutouts from the summed image. (b) The created ePSF with oversampling = 4.

Tracking Vega with Stamps

In order to use astropy star tracking functions, I needed to create stamps around Vega in each frame. This decreased the chance of the functions identifying objects and noise other than Vega. Vega oscillates along the y-axis and travels up the x-axis of the image. So I made the y length fixed by subtracting 20 pixels from its minimum y value and adding 20 pixels to its max y value. For the x-direction, I made the length 30 pixels centered around the first x value recorded. Then for each frame, I add 1 pixel to the max and min x value of the stamp (called window) so it would follow the star as it moves up the x-axis. Figure 2 displays a sample of the stamps created. This procedure was repeated with the wavelength data extension.

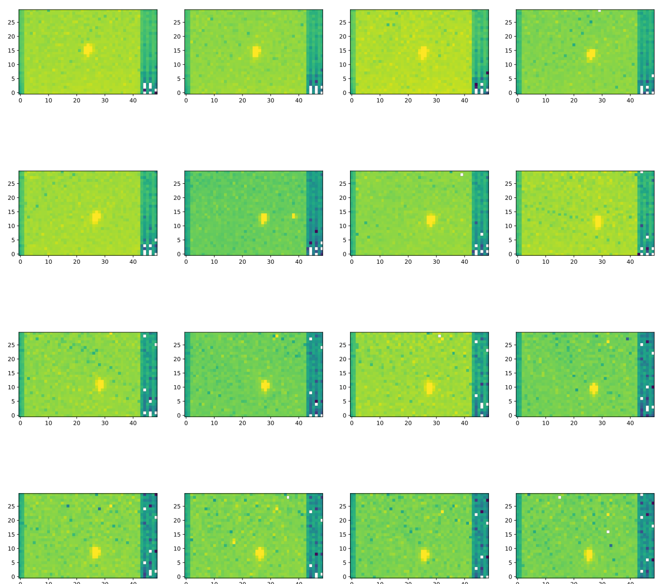


Figure 2: A sample of the stamps created. The astropy function "DAOStarFinder" was used to find Vega's centroid within each stamp.

Performing PSF Photometry

For each stamp, I used the astropy function "DAOStarFinder" to detect Vega and find its centroid. Unfortunately, there were some misidentifications that I had to manually go through and delete. After that, I created boxes of length 3 pixels around the x and y coordinates of the centroids. I repeated the procedure for the wavelength extension. Within those boxes I performed the PSF weighted average using Equations 1 and 2.

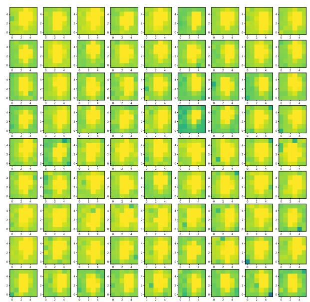
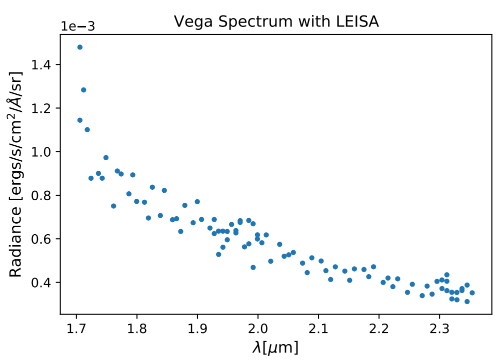


Figure 3: The boxes in which I took the PSF weighted average of the flux.

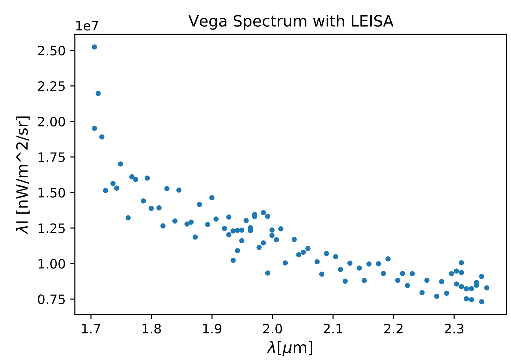
$$\langle F \rangle = \int \frac{F(x,y)P(x,y)dxdy}{P(x,y)dxdy} \tag{1}$$

$$\langle \lambda \rangle = \int \frac{\lambda(x,y)P(x,y)dxdy}{P(x,y)dxdy} \tag{2}$$

With $P(x,y)$ being the ePSF I created. The LEISA flux data has units of ergs/s/cm^2/Å/str, which was converted into units of nW/m^2/sr. I did this by using the conversion factors in Equations 3 and 4. Equation 5 shows the general formula after combining the steps outlined in Equations 3 and 4. Figure 4 shows the plot of this converted flux versus wavelength in microns. Notice that the flux values are on the scale of around 10^7.



(a)



(b)

Figure 4: (a)The measured spectrum of Vega with its original units (before conversion). (b) The measured spectrum of Vega with converted units.

$$1\,\text{ergs/cm}^2/\text{s/sr/Å} = 10^{-3}\,\text{W/m}^2/\text{sr/Å} \tag{3}$$

$$1\,\mathrm{W/m^2/sr/\AA} = 10^9\,\mathrm{nW/m^2/sr/\AA} \tag{4}$$

$$\lambda I_{final} = I_{initial} \times \lambda[\,\mathrm{\AA}] \times 10^6\,\mathrm{nW/m^2/sr/\AA} \tag{5}$$

Kurucz Vega Model

The flux data in the Kurucz Vega model[2] had units of $\mathrm{ergs/cm^2/s/\AA}$. I needed to convert this into units of $\mathrm{nW/m^2/sr}$. I used a similar approach that I used for the LEISA conversion except I had to divide each value by the solid angle of the beam to get the sr^{-1}. The solid angle of the beam was calculated by taking the integral of the 2-D Gaussian with the full width at half maximum as the width parameter rather than σ. The resulting equation is shown in Equation 6.

$$\Omega = 1.13 \times (FWHM \times 60.83 \times 10^{-6})^2[sr/beam] \tag{6}$$

Where FWHM is the full width at half maximum of the star Vega in LEISA's image. To find the FWHM, I first fit a Gaussian to Vega in each stamp and took the average FWHM of the stamps. One of the fitted Gaussians is shown in Figure 5 and the FWHM of each stamp is shown in Figure 6. To convert the FWHM from pixels to radians, I multiplied it by the single pixel field of view 60.83×10^{-6}rad as shown in the equation above.

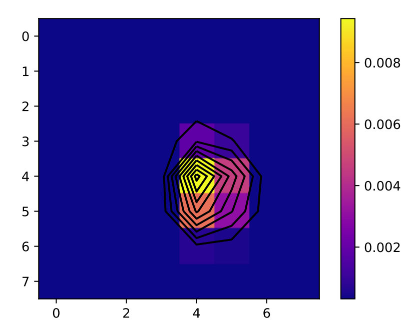


Figure 5: The fitted Gaussian for one of the stamps represented with contour lines. From this, the FWHM and other parameters were extracted.

Equation 7 shows the general formula used to convert the flux into the appropriate units.

$$\lambda I_{final} = \frac{I_{initial} \times \lambda[\,\mathrm{\AA}] \times 10^6}{\Omega}\,\mathrm{nW/m^2/sr} \tag{7}$$

Figure 7 shows the plot of the converted model flux versus wavelength in microns. This flux is on the scale of 10^8, which is about an order of magnitude

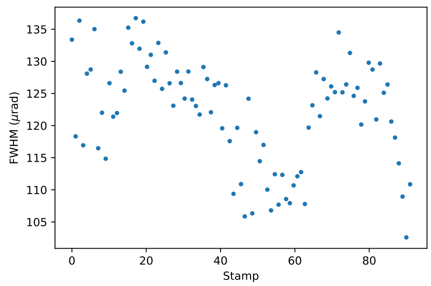
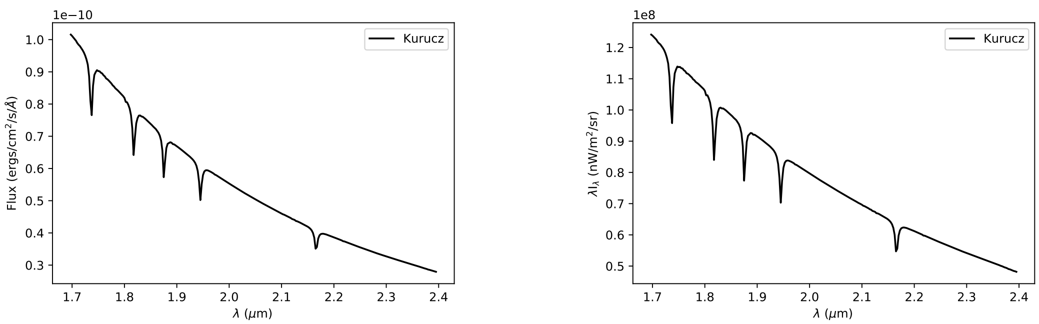


Figure 6: The values of the FWHM for each stamp in pixels. The average of these values was taken for my calculations.

greater than the flux I calculated with LEISA. This comparison is better seen in Figure 8.



(a) (b)

Figure 7: (a)The model flux versus wavelength with its original units (before conversion). (b) The model of Vega's spectrum.The flux values are about an order of magnitude greater than the LEISA flux.

Scaling the LEISA Data to Kurucz

We could not successfully get the LEISA data to match with the Kurucz model. So, I plotted the LEISA data vs. the Kurucz data and fit a line to the data. From this line, I found the slope to be about 0.16 and the vertical offset to be about 219000. This line is shown in Figure 9.

After multiplying the kurucz flux by the slope and adding the offset to the LEISA data, the two sets of data matched up quite well as expected. Figure 10 shows the two data sets plotted on the same graph.

From these scaled values, I took the difference between each pair of data

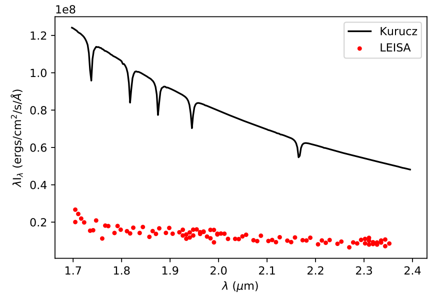


Figure 8: Comparison of the converted LEISA and Kurucz data. They differ by about an order of magnitude.

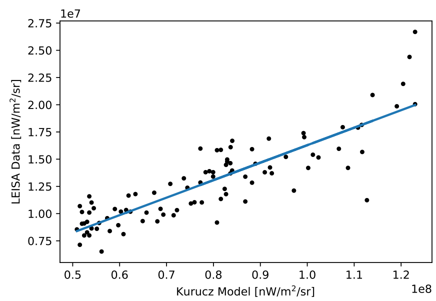


Figure 9: The converted LEISA data vs. the converted Kurucz model. The fitted line yielded a slope of about 0.16 and an offset of about 219000.

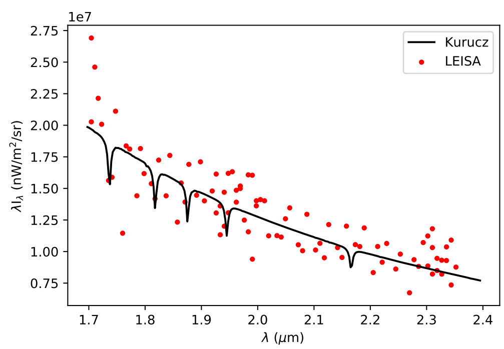


Figure 10: The LEISA data and Kurucz model scaled together. Taking the RMS of each pair of points yields a result of about 2×10^6 nW/m^2/sr.

points and computed the root mean square of the data. I found the RMS to be about 2×10^6 nW/m^2/sr. This value represents LEISA's sensitivity to diffuse brightness, which essentially precludes the possibility of reaching EBL signals.

References

[1] https://photutils.readthedocs.io/en/stable/epsf.html#build-epsf

[2] https://www.stsci.edu/hst/instrumentation/reference-data-for-calibration-and-tools/astronomical-catalogs/kurucz-1993-models