Photometry Homework
Observational Techniques for Astronomy (AST 6725)

Alyssa Bulatek

November 9, 2020

For various sections of this assignment, I collaborated with Rachel Losacco, Michael Estrada, Sheila Sagear, Francisco Mendez, and Christina Moraitis.

1 Data Handling

1.1 Data Inspection

I first performed a cursory inspection of each of the FITS files. About a year ago, I downloaded an application that allows me to preview FITS files by pressing the space bar while I have the file selected in Finder (I am using a Mac). It is very convenient for quick glances at files. Here is a link to the GitHub page for the application: https://github.com/onekiloparsec/QLFits

My cursory inspection revealed that the dark frames and flat frames looked okay. Some of the h Persei images looked fine. However, some of the h Persei images showed significant evidence of the telescope (or the CCD) moving while the integration was being taken (star shapes appeared elongated in a certain direction).

I will only be using the files with `h_persei_seq`, `h_persei_darks`, and `h_persei_flats` filename prefixes, as the other images are either test images or have the prefix `mars` (which are not mentioned in the observing log, so I will disregard those images). Some dark frames were mislabeled with `h_persei_seq` prefixes. I manually changed those filenames to begin with `h_persei_darks` instead. I also manually ignored two science images in the observing sequence (ending in `49` and `50`) that showed obvious evidence of the telescope moving during the integration.

The Jupyter Notebook I used for this assignment is attached with this writeup. The comments in that Notebook make up most of the text in this writeup.

1.2 Data Processing

Our first goal was to create a final science image in the V band. To accomplish this, we needed to flat-field-correct and dark-subtract the individual science frames before median-combining the individual science frames. First, I created a final dark frame at each exposure time for which we have science images and flat frames. For the science images, there are only 5 second exposures in the V band, and the same is true for the flat frames in the V band.

Next, I created a final flat frame for each filter we used. For this exercise, we are only considering the V filter. All V filter flat frames taken have 5 second exposure times. I median-combined each of the flat frames in the V band and then subtracted my final dark frame at the correct exposure time to get my final flat frame in the V band. I also normalized that final flat frame by dividing each value in the array by the median value of the array.

Then, I performed dark-subtraction and flat-field-correction on our science frames in the V band. Since we are only working with a single exposure time, this process is simplified. First, I dark-subtracted each individual science frame using the final dark frame with the correct exposure time. Then, I flat-field corrected each individual science frame using the final flat frame for the correct filter.

Penultimately, we can align our individual science frames. I did this by measuring the centroid of the same star in each science frame using `photutils.centroids.centroid_sources()`. I then used `np.roll()` to shift each frame by the appropriate amount of pixels so that each other frame is aligned with the first. Finally, I median-combined the science frames to get our final science image.

2 PSF Characteristics

In order to measure the FWHM characteristics of our detector, we have to find the stars in our image. I did this while referencing the documentation for the package `photutils` (taken from https://photutils.readthedocs.io/en/stable/detection.html. Their method starts by finding the mean, median, and standard deviation of the image only for pixels less than three standard deviations away from the image (which involves an initial calculation of those statistics). Then, I only used peaks whose values were between 5,700 and 50,000 ADU ("bright").

I tried to write a 2D-Gaussian fitting algorithm, but it didn't work, so I ended up using a workaround suggested by Francisco and Michael. I fit a 1D Gaussian to the row each peak was in at a point along the row near to the peak (within 20 pixels on each side of the peak). I averaged together the sigma values I got from each peak fit (2.988, 2.951, and 2.738 average to $\sim$2.892). Then, I converted that averaged sigma value into a FWHM. The FWHM value that I got was **6.8103 pixels**.

In order to measure the plate scale of the RHO telescope, I compared our image of h Persei to an SDSS image of the cluster (which can be found here). I was able to match two nearby stars in our image to the SDSS image. These stars are circled in Figure 1. I recorded the right ascension and declination of those two sources using their Gaia DR2 coordinates and then measured the angular separation between those two locations (40.605 arcseconds). To measure the pixel separation of the two stars, I found their centroids with `photutils.centroid_sources()` and used the distance formula to calculate the pixel distance between the two stars (69.340 pixels). Dividing the two values, we get a pixel scale of **0.5856 arcsec/pixel**, which gives us a FWHM value of **3.988 arcsec**.

3 Aperture Photometry

3.1 Procedure

I chose "bright," "medium," and "faint" stars based on the counts of their peaks which were found using the same method as I described for initial star finding above. I chose the count boundaries arbitrarily to get the correct number of stars in each "brightness" bin. I used six stars in to-

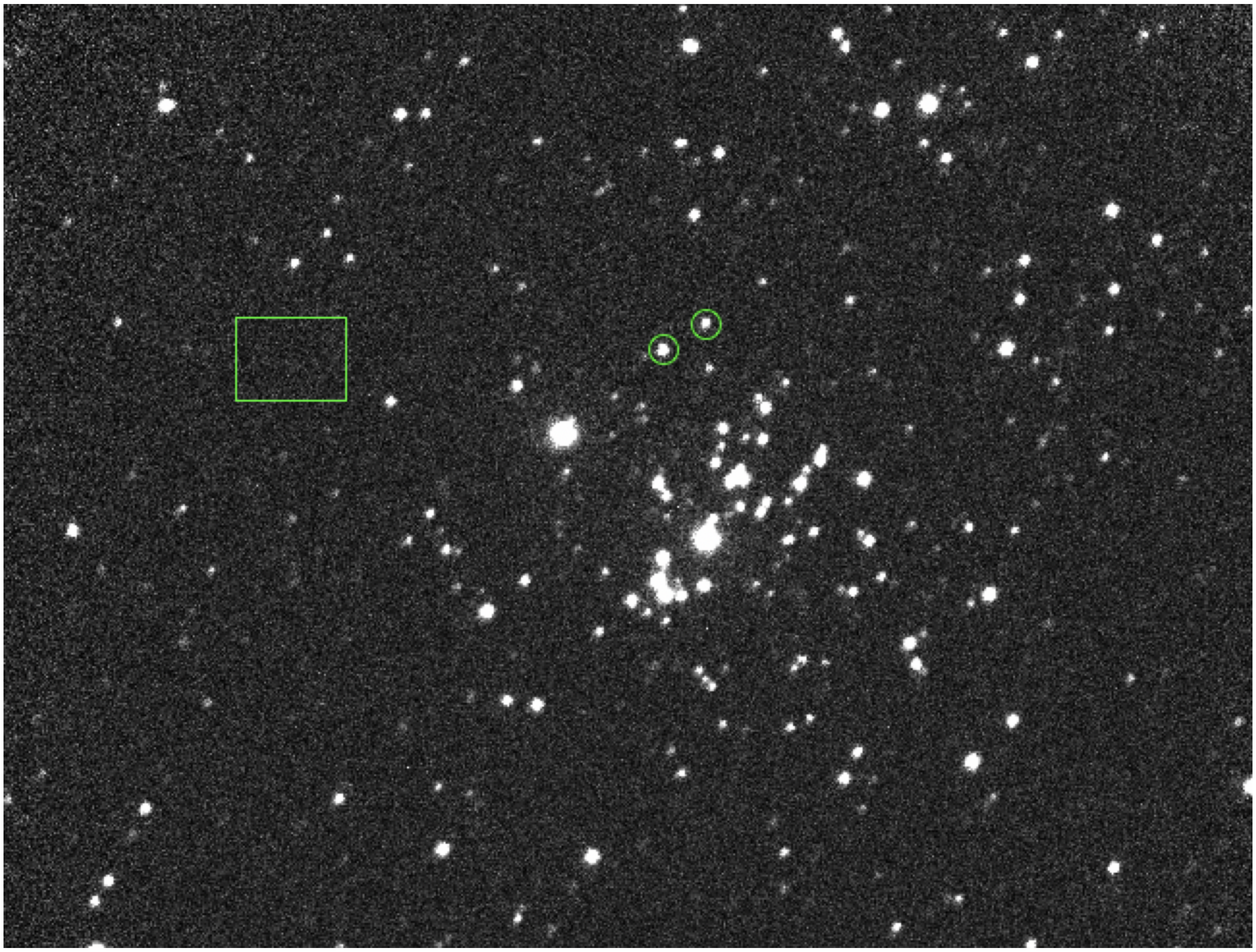

Figure 1: A screenshot of our final science image from RHO with the two stars I used for our plate scale estimate circled. The rectangle in the upper left area of the image was going to be used as a region for sky background estimation, but it can be ignored in this image.

tal, two of each brightness level. Bright stars had between 10,000 and 50,000 peak counts, medium stars had between 4,400 and 4,500 peak counts, and faint stars had between 1,750 and 2,000 counts.

After going through the photometry process for one star, I wrote a function, which I creatively called `photometry()`, that performed the required aperture photometry step by step as it was described in the assignment prompt. Here, I'll start by describing the function, and then I'll cover the specifics of choosing different star aperture and sky annulus sizes. The photometry procedure begins by creating a star aperture and sky annulus with `photutils.CircularAperture` and `photutils.CircularAnnulus` respectively. It then uses `photutils.aperture_photometry` to sum up the signal in each of the star and sky apertures. The raw flux of the target star, $F_{targ,\ raw}$, is calculated in this step. It then calculates the area of the star aperture (or the number of pixels in it), N_{targ}.

In order to retrieve the signal from the sky annulus, I create a mask that selects the sky annulus pixels from the image and I then retrieve a one-dimensional array of those pixel values from the image. I calculate the median of those pixel values to get $F_{sky/pix}$, the median pixel flux in the sky annulus. The function then calculates the flux of the target, F_{targ}, by subtracting the median sky background from the star aperture using the following equation.

$$F_{targ} = F_{targ,\ raw} - N_{targ} * F_{sky/pix} \tag{1}$$

The function repeats this process for each of the six stars that were found in the previous step.

Once aperture photometry is completed for the stars, the function calculates the instrumental magnitude of the stars from the observation. I first calculate the flux in counts per second, $F_{counts/sec}$, by dividing the target flux values from Equation 1 by the exposure time for this observation (5 seconds). I then calculate the instrumental magnitude for each source using the following equation.

$$m_{inst} = -2.5 * \log_{10}(F_{counts/sec}) \tag{2}$$

We then have our final instrumental magnitudes for each star observed.

3.2 Results

I calculated the instrumental magnitudes for several different aperture configurations as described in the assignment prompt. First, I began with a star aperture radius of 1.3 times the FWHM and a sky annulus between 2 times and 3 times the FWHM centered on the star. Second, I kept the sky annulus the same, but shrunk the star aperture to a radius of 0.5 times the FWHM. Third, I brought the star aperture up to a radius of 2 times the FWHM and kept the sky annulus the same. Last, I brought the star aperture radius back to 1.3 times the FWHM, but changed the sky annnulus to be from 1.5 times to 3 times the FWHM.

The measured target fluxes in counts and counts per second as well as the instrumental magnitudes for each source are summarized in Tables 1 through 4 for each aperture configuration.

In order to compare my measured photometry values for these stars to catalog values, I found it helpful to compare images of the stars. To aid in my explanation, an image of my chosen stars from our RHO image is shown in Figure 2, and the corresponding field from SDSS (visible here) is shown in Figure 3.

I used the Gaia DR2 photometry values from Aladin, which give all of Gaia's passbands. I am comparing our measurements to the G passband (`phot_g_mean_mag`), which covers both of the other Gaia passbands. We must choose one star in the field to be a standard star. I will choose star 1, as measured in the first aperture configuration ($m_{inst} = -12.86$) to compare to. The difference in magnitude between the Gaia catalog measurement for this star and my measurement is $8.102315 - (-12.86) = \mathbf{20.96}$. If this is true, then if we calculate the required offset for each of our other stars given by

$$m_{obs} = m_{inst} + 20.96 \tag{3}$$

we should see little deviation from the observed values. The Gaia photometry values appear in a column of each of Table 1 through 4. The observed values I calculate using Equation 3 above appear in the following columns. The percent difference between the Gaia magnitude and our observed magnitude appears in the final columns of each table. In general, using this offset, my observed magnitudes tend to be closest to the Gaia magnitudes for the larger star aperture (2 times FWHM) setup and the larger but reaching-closer-in sky annulus, and my observed magnitudes are less close to the Gaia magnitudes than the smaller star aperture (0.5 times FWHM).

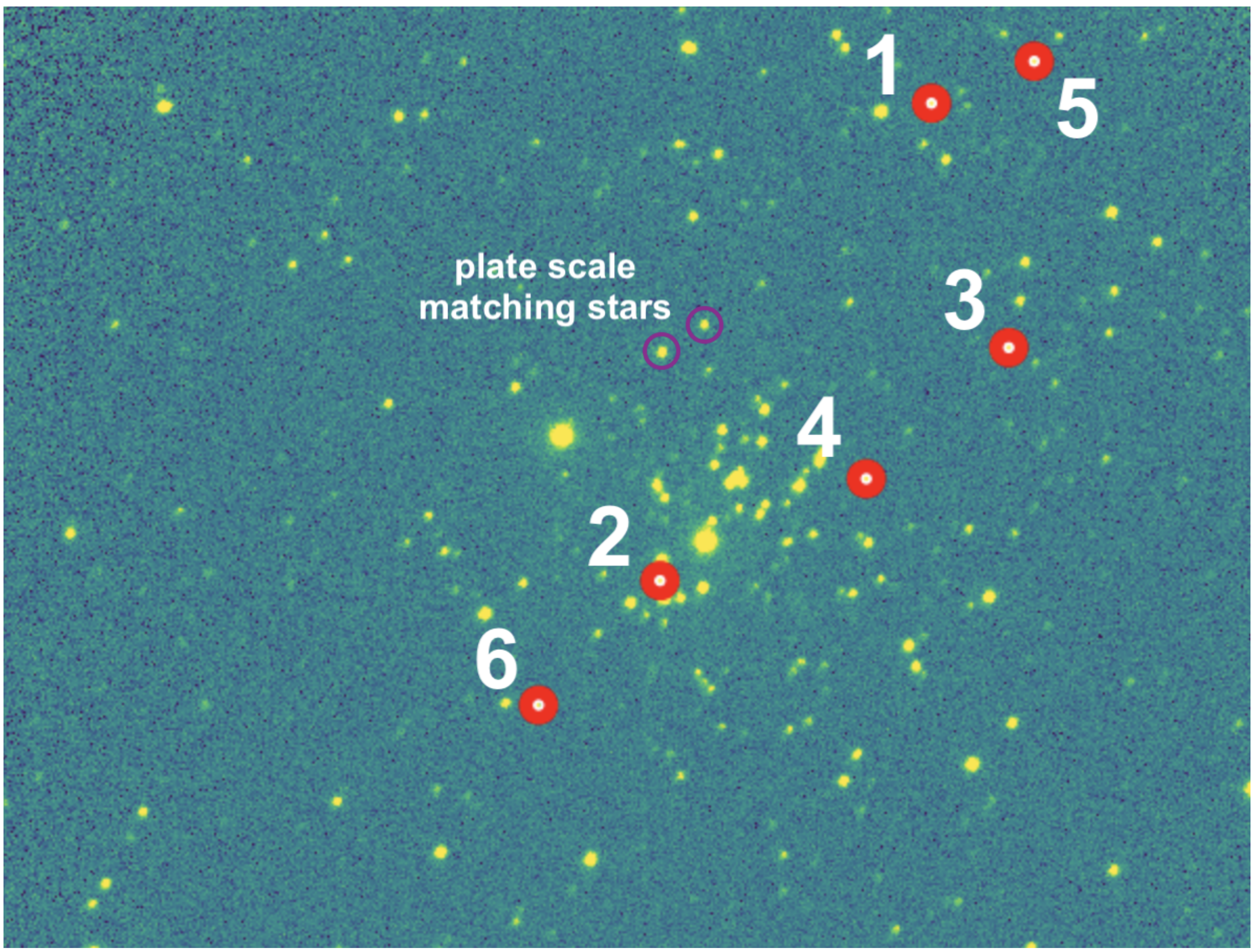

Figure 2: A RHO image of our target field with the sources I measured circled and numbered. The two stars I used for measuring the plate scale are also circled, but not numbered.

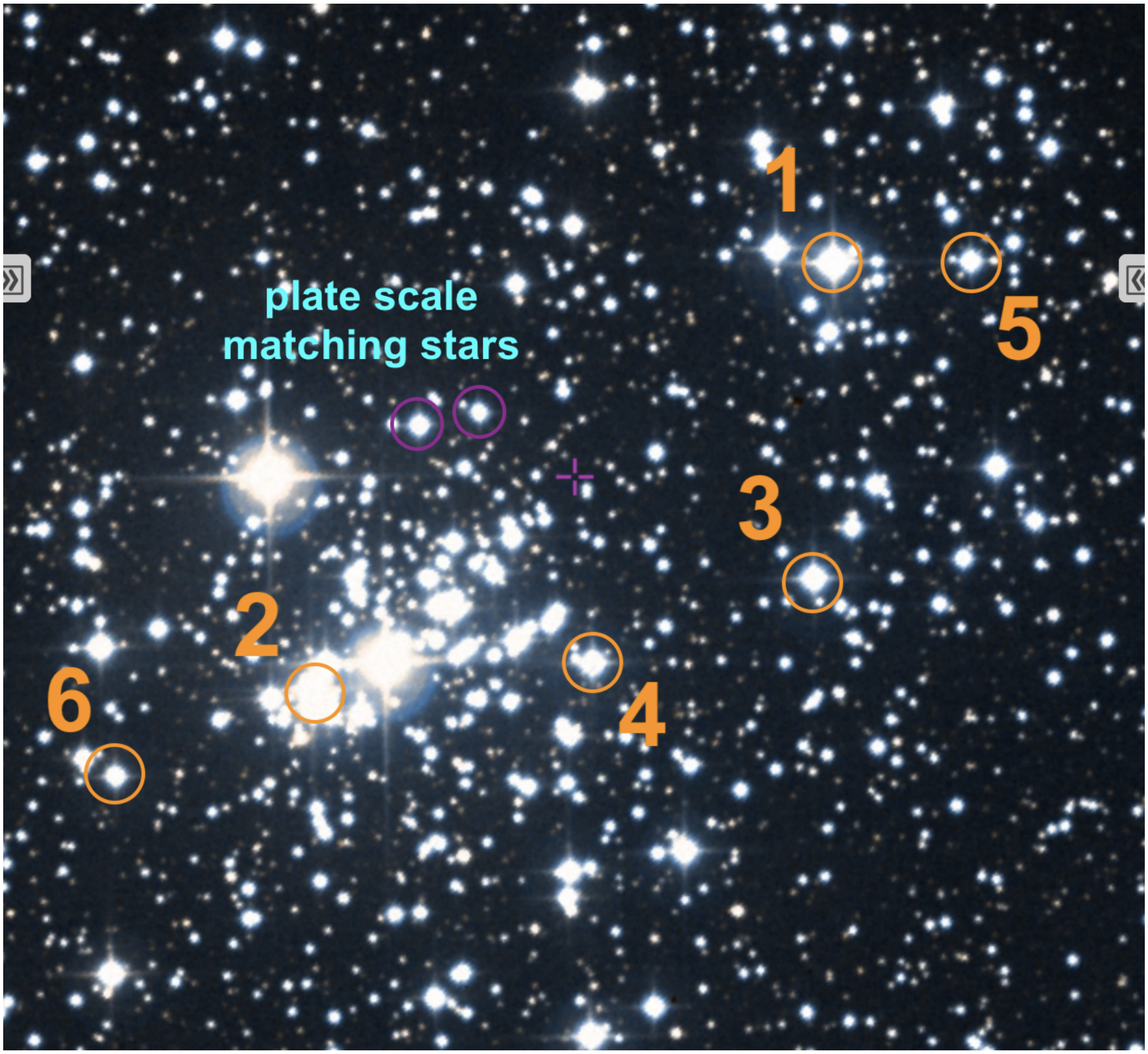

Figure 3: An SDSS image of our target field with the sources I measured circled and numbered. The two stars I used for measuring the plate scale are also circled, but not numbered.

Source	x	y	$F_{targ,\ raw}$	$F_{counts/sec}$	m_{inst}	m_{Gaia}	m_{obs}	% diff
1	433	134	694574	138914	−12.86	8.102	8.100	0.025%
2	795	771	490045	98009	−12.48	8.355	8.48	1.5%
3	330	460	222548	44509	−11.62	9.325	9.34	1.6%
4	520	635	219643	43928	−11.61	9.269	9.35	0.87%
5	296	78	108869	21773	−10.84	10.167	10.12	0.46%
6	957	937	90788	18157	−10.65	10.200	10.31	1.1%

Table 1: Aperture photometry of the six stars I selected for the first aperture configuration: a star aperture at 1.3 times the FWHM and a sky annulus from 2 times to 3 times the FWHM.

Source	x	y	$F_{targ,\ raw}$	$F_{counts/sec}$	m_{inst}	m_{Gaia}	m_{obs}	% diff
1	433	134	298271	59654	−11.94	8.102	9.02	11%
2	795	771	221930	44386	−11.62	8.355	9.34	12%
3	330	460	98304	19660	−10.73	9.325	10.23	9.7%
4	520	635	97139	19427	−10.72	9.269	10.24	10%
5	296	78	49617	9923	−9.99	10.167	10.97	7.9%
6	957	937	38510	7702	−9.72	10.200	11.24	10%

Table 2: Aperture photometry of the six stars I selected for the second aperture configuration: a star aperture at 0.5 times the FWHM and a sky annulus from 2 times to 3 times the FWHM.

Source	x	y	$F_{targ,\ raw}$	$F_{counts/sec}$	m_{inst}	m_{Gaia}	m_{obs}	% diff
1	433	134	754698	150939	−12.95	8.102	8.01	0.025%
2	795	771	534240	106848	−12.57	8.355	8.39	0.42%
3	330	460	243774	48754	−11.72	9.325	9.24	0.91%
4	520	635	239871	47974	−11.70	9.269	9.26	0.097%
5	296	78	117688	23537	−10.93	10.167	10.03	1.4%
6	957	937	101035	20207	−10.76	10.200	10.20	0%

Table 3: Aperture photometry of the six stars I selected for the third aperture configuration: a star aperture at 2 times the FWHM and a sky annulus from 2 times to 3 times the FWHM.

Source	**x**	**y**	$F_{targ,\ raw}$	$F_{counts/sec}$	m_{inst}	m_{Gaia}	m_{obs}	**% diff**
1	433	134	692294	138458	-12.85	8.102	8.11	0.099%
2	795	771	487526	97505	-12.47	8.355	8.49	1.6%
3	330	460	221512	44302	-11.62	9.325	9.34	0.16%
4	520	635	218801	43760	-11.60	9.269	9.36	0.98%
5	296	78	108058	21611	-10.84	10.167	10.12	0.46%
6	957	937	90221	18044	-10.64	10.200	10.32	1.2%

Table 4: Aperture photometry of the six stars I selected for the fourth aperture configuration: a star aperture at 1.3 times the FWHM and a sky annulus from 1.5 times to 3 times the FWHM.