CCD Photometry

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ABSTRACT

We measured brightness of the star Pegasus 28, using a 512 by 512 CCD, a R-band filter, and the Leuschner Telescope[1]. We then analyzed the image and used a reference star to calculate the apparent magnitude in the R region.

1. Introduction

In order to do good photometry on Pegasus 28, we first had to determine a number of things about the CCD and telescope we were using. The saturation of the CCD was found. An image of a galaxy was taken in order to become accustomed to manipulating the telescope. Flat fields were taken to correct for different quantum efficiences in the pixels of the CCD, diffraction in the thin layer of silicon on the CCD, and vignetting. The night sky brightness at the Leutschner telescope was found. Data was taken of two stars, Pegasus 25 and Pegasus 28. Four images of each star, jogging to star over four positions, in an attempt to factor out errors from the CCD. We then ran a program that sums the photons counts inside of a radius around the star, and subtracts the sky level in the immediate vicinity of the star. The apparent magnitude of Pegasus 28 was then calculated.

2. Saturating the CCD

It is important to find the saturation level for a CCD, because if an image is taken with areas that have been saturated, then we are losing data about the objects that are saturated. This is fine if the saturated objects are not the point of interest. However, in this lab, we looked at bright stars, and wanted to make sure that we could get an accurate DN for these bright objects.

To create a diffuse light source, we shut the dome, and turned the dome lights on. We found that it was too dark inside the dome to saturate the CCD in any reasonable amount of time without the lights on. We took a series of images with exposure times from 0.1sec, to 25.5 sec. Between 1 and 25.5 secs, we increased the time of the exposure by 1.5 seconds each exposure. The image was mostly saturated by approximatly 24 seconds, and completely saturated by 25.5 seconds. The median pixel level increased linearly until the CCD was saturated. See Figure 1.

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[1] webpage: http://128.32.197.194/index.html

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The saturation level was 16,383 DN, with 85 of those counts being dark counts and bias.

In order to determine if the dark counts associated with these integration times increased linearly, another series of images was taken. The median value of these images was plotted as a funtion of time. See Plot 'Dark Counts vs. Integration Times' in Figure 1. We found that there are so few dark counts in a 25 second exposure, that the shape of this plot does not significantly affect the saturation images. It looks like a step function because the counts are so low, and we plotted the median, which takes an integer value. We suspect that if we took images with longer and longer times, the median of the dark counts would begin to approximate a step function that looks like a line of constant positive slope.

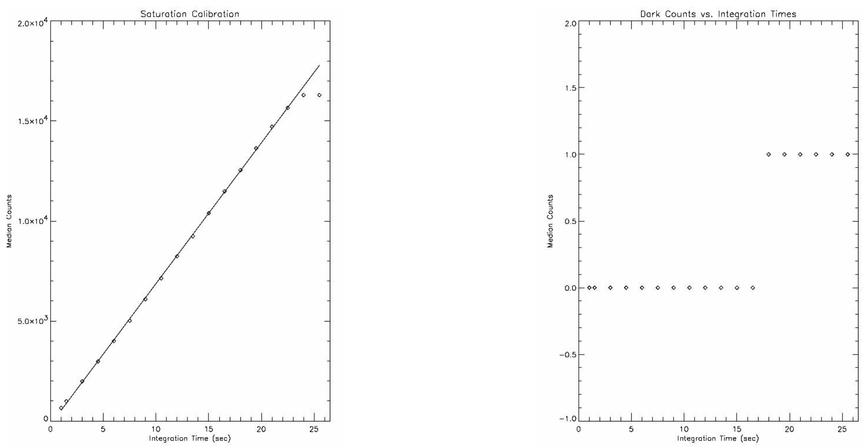

Fig. 1.— The plot on the left is the median counts for our saturation images plotted as a function of the exposure time. The plot on the left is the median counts in our dark images of increasing integration times plotted as a funtion of the exposure time.

3. Galaxy

A 60 second image of the galaxy NGC7814 was taken for our bright galaxy. It was a good night to take images, and this one turned out particularly well. See Image 2. The galaxy is seen edge on.

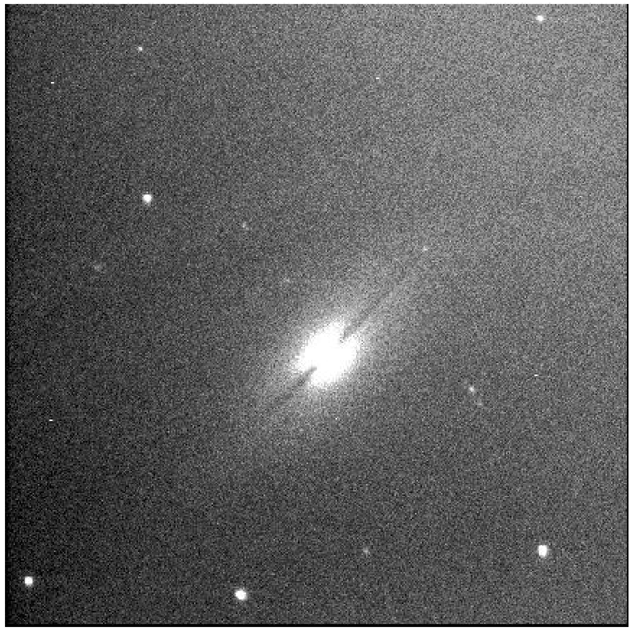

Fig. 2.— NGC7814

4. Night Sky Brightness

To determine the brightness of the night sky at the Leutschner telescope, the telescope was pointed at a dark patch of sky with Ra = 23:19:026 and Dec = 16:28:37. There are several factors involved in sky brightness, including the passage of the moon and light pollution from human habitation in the area. When finding sky brightness, it is necessary to avoid bright objects, which would skew the data. At the Ra and Dec above, where this data was taken, only a few faint stars were visible. Ten exposures were taken, with time differences of ten seconds. See Figure 3. A line was fit, and the projected time for saturation is 13.002 hours.

5. Flat Field

To take good images, it is necessary to know your CCD. There are several problems that occur when taking data with a CCD. Every pixel in a CCD has a slightly different quantum efficiency due to physical properties of the pixel. Every CCD has a slight diffraction pattern across it, which is the result of photons diffrating in the layer of silicon in the CCD. Also, vignetting may be seen if some component of the telescope is blocking part of the light. There are also photons that fall between potential wells, and just end up being absorbed intothe silicon itself.

To compensate for most of these effects, a series of exposures were taken against a uniformly illuminated area (the twilight sky). The effects mentioned abovewere quite apparent in these exposures. Five exposures were taken with times of .1, .2, .4, .6, and 1 second, and five complimentary

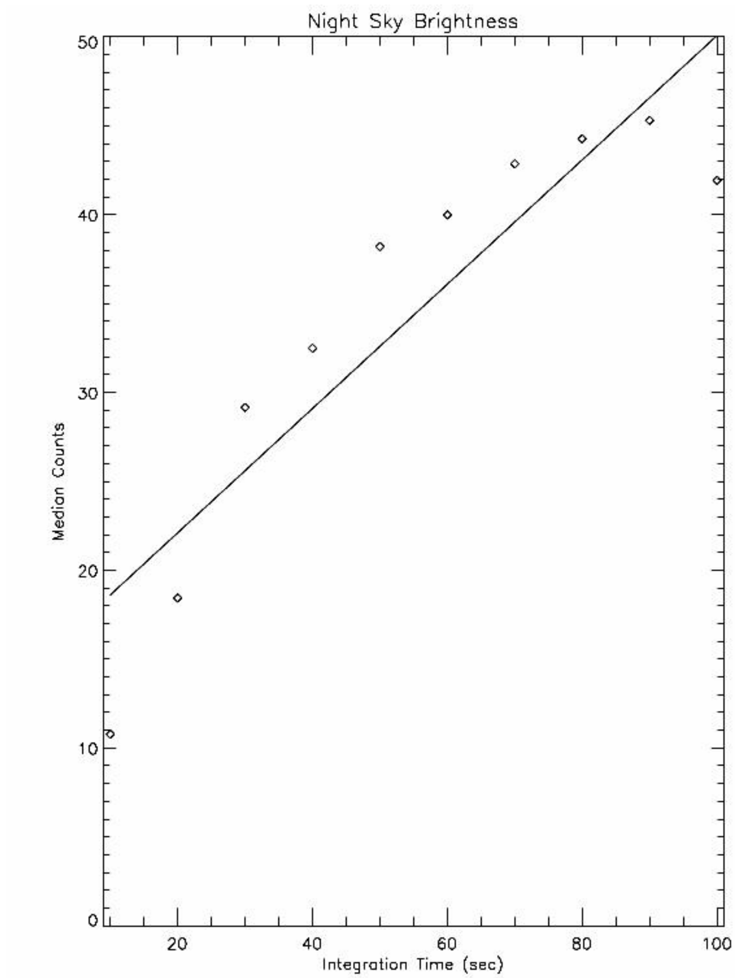

Fig. 3.— NGC7814

darks were taken. These flat field exposures were dark subtracted, and then divided by their own median so that the images could be compared. The corrected images were then analyzed pixel by pixel to find the median value pixel among the five images for each pixel. This eliminated error from cosmic rays. The composite image is shown in Figure 4. The error was analyzed step by step. It was found for the raw image $\sigma_{Ne} = sqrt(gain * DN)$, where $gain = 10$ and for the dark. These errors were added in quadrature, making five arrays of errors. The error for the final composite image was also analyzed pixel by pixel, and the error for the pixel which was chosen to be in the composite image created an array of errors. The median of this array was taken to be the final error, or .00377, or .37 percent.

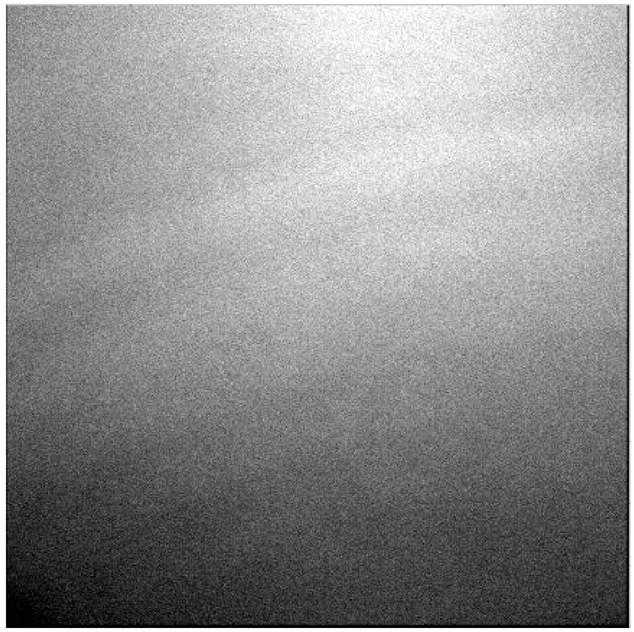

Fig. 4.— Our flat field

6. Photometry

In selecting the star to do photometry analysis on, the effect of cloud cover and relative paths through the atmosphere were taken into consideration. Pegasus 25 and Pegasus 28 were chosen because they were in close proximity to each other, and so there would be less error due to relative paths through the atmosphere, and due to different thicknesses of clouds indifferent areas of the sky. Data for Pegasus 25 and 28 from SIMBAD on the web [3] is seen in Table 1. Data for stars of relatively close spectral type to the ones that we observed were found in Allen's [4] and are seen in Table 2. This data will be used for determining the apparent R-band magnitude of the standard star, which was chosen to be Pegasus 25.

To find the apparent brightness of these stars experimentally, the images were dark- and flat-corrected, and a program was written that created a circle of certain radius over the star, and summed the counts within the circle. An annulus surrounded that circle, from which the median sky level was determined. This value was subtracted from each pixel in the inner radius. The resultant data is found in Table 3. For the four determined counts for Peg28:

$$\overline{x} = 80434.$$
$$\sigma_(\overline{x}) = 40217.$$

[3] http://simbad.harvard.edu/sim-fid.pl

[4] Allen's Astrophysical Quantities. Editor: Arthur N. Cox, 4th Edition. Published by AIP, 2000

Star	Spectral Type	Ra	Dec	B	V
Pegasus 25	B7Vne	22:07:50.3	+21:42:10.5	5.707	5.78
Pegasus 28	A3III	22:10:30.18	+20:58:40.7	6.533	6.44

Table 1: Data from Simbad

Spectral Type	B-V	V-R
B8	-.11	-0.02
A2	+0.05	+0.08
A5	+0.15	+0.16

Table 2: Data from Allens

Star	Image Number	Exposure Length (s)	Star Counts	Sky Level	Uncertainty
Peg25	1	2	133929	82	1160
Peg25	2	2	137478	82	1170
Peg25	3	2	146977	81	1210
Peg25	4	1	76637	82	875
Peg28	1	2	82302	81	907
Peg28	2	2	81253	81	901
Peg28	3	2	73033	82	854
Peg28	4	1	42574	79	652

Table 3: Observed Star Data

The above sources were used to determine that $B_{Peg25} = 5.837$ and $B_{Peg28} = 6.223$. The data was then analyzed using the equation:

$$m_* - m_{ref} = -2.5log_{10}((N_*/t_*)/(N_{ref}/t_{ref})) \tag{1}$$

With $m_{ref} = R_{Peg25} = 5.837$, $m_* = R_{Peg28}$, $N_* = counts_{Peg28}$, and $N_{ref} = counts_{Peg25}$. Results are found in Table 4.

Image (Peg28)	Determined R	Computed Error
1	6.365	.12
2	6.379	.15
3	6.495	.20
4	6.328	.21

Table 4: Calculated R value for Peg28, using image 1 for Peg25

The experimentally found R magnitudes for Pegasus 28 all appear to be within 0.272 magnitudes of the 'correct' magnitude, 6.223.

7. Comments

I think that our flat field image is a good one, particularly because we took the median of the images, not the mean. This eliminated little blips from cosmic rays or stars as the twilight sky got darker. Also note the diffraction and vignetting.

The plot for the night sky brightness was expected to be linear, but our data turned out to be only slightly linear. The variations in our data are the result of the Earth's movement and the change in the amount of atmosphere that the path of sight travels through as a result. Variations are also caused by the passage of heavenly bodies, like the Moon. Since the time for the night sky to saturate the CCD was found to be abotu 13 hours, we will not have to worry about the night sky saturating the images, especially in this lab, where we are looking at bright objects.

The Photometry data was taken, unfortunately, when it was cloudy out. That especially was responsible for our decision to take data from stars close together. We did not anticipate getting final magnitudes anywhere near what they should be. Because we did not anticipate getting very good data, we did not think it important to find the exact B-V and V-R corrections for the spectral type of our stars. We just found what we could that was closest. It was a surprise that our data ended up being as close to what we think the R value for Pegasus 28 would be, or even so close to each other. It makes me suspicious that there isn't some error that is making the data seem more accurate. However, my classmates are getting similar results, and the experimentally derived magnitudes are not within the error of each other. This could be explained by the presence of clouds.

I would have liked to use the IDL function 'gauss2dfit' to fit my center and radius for my star counting program, but I couldn't figure out how to do it in time. I think a lot of error is introduced when the center and raduis is entered by looking at the image, and approximating it by hand. Nevertheless, I am very proud of the programs that I wrote for this lab.