

Photometric Analysis of the Orion Nebula Cluster

Thomas Cannon

Observed: November 4th, 2014

Analysis Completed: November 26, 2014

1. Abstract

Photometric analysis is a method applied to nearly all celestial objects. It is executed by examining the electromagnetic flux of a given object, and using the results to determine characteristics about the object. One such characteristic of an object, such as in the case of a star, is the spectral type, which can be determined by comparing the flux through two different filters of different effective wavelength midpoints. With the aid of the IDL Programming Language and data collected from an 8-inch reflecting telescope and a CCD camera, one can determine several characteristics of star clusters. Specifically, when the cluster such as the Orion Nebula Cluster has a well studied star for use as a reference, one can create a Hertzsprung-Russell Diagram of the cluster, as well as determine the cluster's approximate age.

2. Introduction

Photometric analysis of a star—more specifically, using photometry to determine the spectral type and age of a star—is no simple task. After extracting the total flux from only values determined to only be caused by the star, one must find the apparent magnitude by comparison with a known star, convert to absolute magnitude while accounting for any interstellar reddening, and determine a proper color value of the star. While it may elongate the process to add multiple stars, there are convenient simplifications that occur when those multiple stars are a part of the same cluster.

Photometry is an area of astronomy in which measurements of electromagnetic flux are recorded in different effective wavelengths. These recordings are of celestial objects, and are used in many cases to investigate and classify the objects. In the case of stars, when photometry is used to classify a star into its spectral type, one can also draw conclusions on other characteristics about the star, such as its age and size. When the characteristics of one star in a cluster are applied to a cluster of stars in which the star might happen to reside, some characteristics such as age can also be extrapolated to the rest of the stars in

the cluster. These findings can also aid in creation of a Hertzsprung-Russell Diagram of the stellar cluster, which further deepens our understanding of the stars.

Photometry without high resolution spectral data is done by comparison. Flux data from the star in question is compared to a star of known magnitude and flux values in the respective filters. However, the data must first be in the proper condition. All irregularities in the CCD detector must be accounted for, as well as any irregularities that may have been caught by the detector. These can be accounted for by such techniques as dark-subtraction, flatfielding, and median combining. An image for the dark-subtraction technique is created by taking images under absolutely dark conditions. This can be achieved by a small CCD camera by techniques such as putting the lens cap over the camera, covering the camera, and insuring that the room has no lights turned on. This uncovers flaws in the camera's pixels such as hot pixels, which show up as active even in completely dark conditions. These values are then subtracted from the images to be used scientifically to produce a cleaner image. The same can be said when taking images of a uniformly lit wall. This uncovers any pixels whose sensitivity might not be as up to par with others. The values are then corrected for and a cleaner image is again produced. Now, irregularities between each image must then be accounted for. This is done by median-combining. This occurs when the values of each in each image are medianed against their counterpart pixels in every other image. This removes any irregularities that may have been captured by each image, such as a stray cosmic ray.

3. Equipment

For observation and data recording, I used an 8-inch Celestron reflecting telescope, a Macbook pro, the program Nebulosity and a Meade DSI Pro II CCD Camera with included B, V, and R filters. The B, V, and R filters have an effective wavelength midpoint of 445, 551, and 658 nanometers respectively. For the data analysis I used the IDL Programming Language on a Windows PC along with SAOImage DS9.

4. Data

The data used for this project was of the Orion Nebula Cluster in the constellation of Orion. The Orion Nebula Cluster sits in and around the Orion Nebula, which created complications in data analysis. It was taken by the previously mentioned Celestron telescope on top of a five-story parking garage in the heart of downtown Charleston, SC. This data was collected on November 4th, 2014 from 00:15 to 01:45. The atmospheric conditions at the

time were approximately 50 degrees Celsius, a humidity of 66%, and clear skies. It should be noted that, as can be seen the data images, the optics of the telescope were misaligned. This caused an optical coma to form in the data. However, since the goal of the project was to conduct meaningful photometry, the assumption that the photons of the given star—however displaced they may be—are still recorded within the images taken. A successful method to extract the displaced data was developed and will be discussed shortly. The gain of the device was set to 47%, and the exposure time set to 0.3 seconds per image. The gain was turned down to allow for a greater discrepancy between the data collected from the nebula and the stars in and around the nebula. The parking garage was not the most still of platforms to be taking precise images off of, so the exposure time was set as low as possible to ensure scientifically meaningful data was captured, while minimizing the risk of an image being distorted beyond use by the shaking telescope. Ten images were taken in each filter (B, V, R, and no-filter) for five different dithering positions. However, one dithering position was dithered too far away from the cluster, giving no meaningful data, and was hence removed from the data analysis.

5. Data Processing

After recording the data, an image that had been processed with a dark, flatfield, was then median-combined was constructed. These new images, still at the four different dithering positions, were then oriented to the same location, and median-combined once more. From here, the photometric analysis begins, starting with obtaining flux values through different filters from desired stars, comparing them to values of a known star, and determining the spectral type.

5.1. Construction of a flatfield and dark images and calibration

As described above, flatfield and dark images were constructed in order to clarify the data recorded. The flatfield was created by taking images of a uniformly-lit, white-painted wall. The number of images taken and the settings of the camera were the same as those when taking the images of the Orion Nebula Cluster. There were therefore, ten flatfield images set at a gain of 47% and an exposure time of 0.3 seconds. These ten images were then median combined to create a flatfield image.

The dark image was constructed in the same manner, but under different conditions. Instead of taking image of a wall, we needed to create the darkest environment possible.

We therefore applied the lens cap and then covered the entire camera to prevent light from getting in.

5.2. Photometry and Calculations

After each image was calibrated and median-combined, it was time to orient them to the same location from their dithered positions. They were then median combined once more to create the best image possible given the data at hand. There are now four images that are to be used in data analysis. Each image represent a different filter—these filters being B, V, R, and clear bandpasses. However, the two filters we are concerned with are going to be the B and V filters.

The IDL program starts off by importing approximate x and y values, which were manually found in the images through the use of DS9. the program then cuts a smaller box around each star. This is to allow the routine GAUSS2DFIT() to work optimally. GAUSS2DFIT() Gauss fits over the stars' values and has the ability to return the max x and y values of the fit. This gives an exact x and y location of the center of the star. From here, the location is used to create a radius array through the command MKRAD(). This command allows us to specify a radius from the center of the star. Here, two radii were specified; one inner radius, whose purpose is to encircle the star light, and one outer radius, whose purpose is to provide a proper background between the outer radius and the inner radius. The background was determined by finding the median of all of the pixel values between the inner and outer radius. This value was then subtracted from all of the values inside the star's inner radius. This leaves behind only the star's light, and this light is what is used in the photometry. This inner/outer radius technique was developed because the stars were in front of and inside a nebula. This made the background for each star completely unique. Therefore a technique which defines the background around each star by using the space between the inner and outer radius was used. What is left now are values for each desired star in both the B and V wavelengths.

Now a star with known apparent magnitude in the image was used as a reference to find the apparent magnitudes of the surrounding stars using the following equation, where m_2 represents the magnitude of the known star, F_2 represents the recorded flux of the know star, and F_1 represents the flux of the star for which we want to know its magnitude.

$$m_1 - m_2 = -2.5 \cdot \log\left(\frac{F_1}{F_2}\right)$$

This process was done on every star in both the B and V filters.

Next these values needed to be converted to apparent magnitude. Using a value of 412 parsecs (Reid et. al. 2009) the absolute magnitude was calculated with the following equation for all of the values in both the B and V filters using the following equation with d representing 412 parsecs, and m_{app} representing the apparent magnitudes found earlier.

$$M_{abs} = m_{app} - 5 \cdot \log\left(\frac{d}{10}\right)$$

From this point, it is simply a matter of subtracting the absolute magnitudes of the stars in the V filter from their counterpart absolute magnitudes in the B filter. This gives the color of the star. These colors represent a value which can be looked up to give its corresponding spectral type (Carroll, B Ostlie, D. 2006). Also, a plot of these values on the x axis, with the V values on the y axis gives an H-R diagram.

5.3. Error Analysis

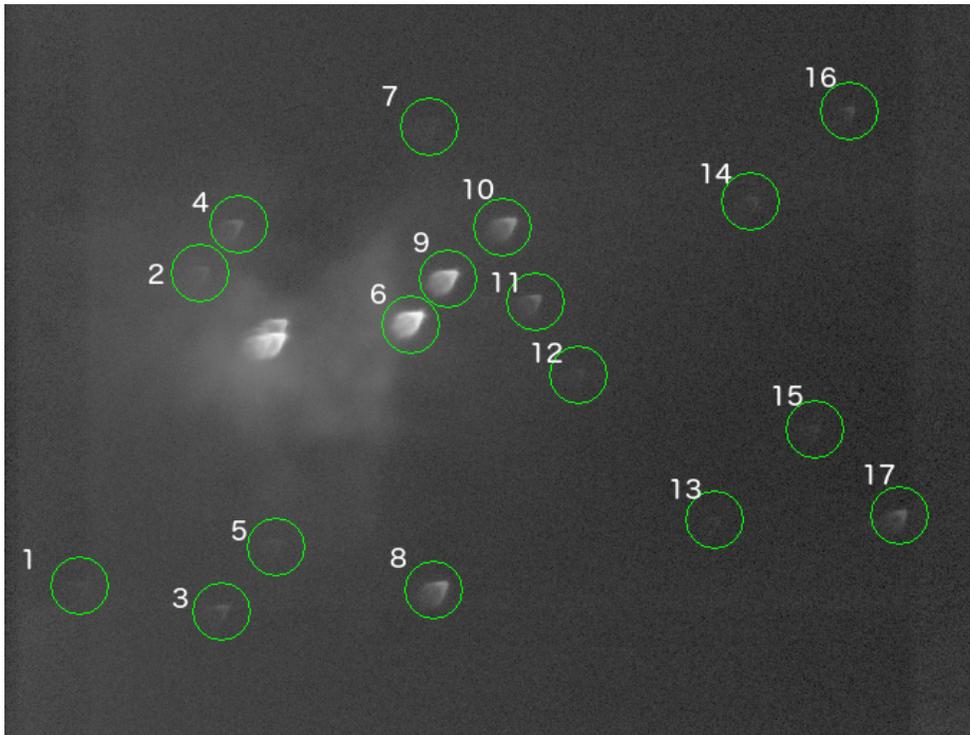
Error propagation began in the standard deviation of the background for each star in each filter. This deviation was propagated through each calculation and determined to be reasonable. However, there are other sources of error. One of which is built in to the inner/outer radius method. This method worked wonderfully for nearly all of the stars with the exception of two (stars 1 and 5). In these cases, the background around the annulus was so non-uniform, that it threw the median off drastically. Here, when the median was subtracted from the starlight, we obtained negative values. Both of these occurrences happened in the V band, which was the dimmer of the two and therefore more understandable that the median would be erroneous. Knowing that a negative flux value was an impossibility for the stars, these values were removed from the analysis.

6. Results and Discussion

The age of the cluster is dependent on it star that is farthest up the main sequence. the cluster can only be at most the age of the star whose spectral type has the shortest lifetime. In our case, that star is most likely star number 16, an O-type star. The lifetime of an O-type star is anywhere from or less than 1 to 10 million years (ATNF). Comparing this to published values of other stars in the cluster, it seems reasonable to conclude that the Orion Nebula is an active star forming region (Poveda, A., et al. 2005). It is therefore difficult to pin down an age for the cluster as it is still producing stars.

We can therefore date the cluster in this range. As can be seen below, the stars' colors

and magnitudes create a reasonable H-R diagram. Now only that, but many of the stars can be see entering the turn-off point. This is where the stars begin to take the trip from their main-sequence stage into their giant stage. It is evident in the graphs by the vertical spike off of the normal diagonal line of the main-sequence. Also worthy of mention is the possibility of white and red dwarfs stars. As can be seen in star 15, the color value of the star is incredibly high compared to others around it. This could suggest that the star emits very little blue light compared to red light, and could therefore be a red dwarf. Also star 16, by the same logic, is incredibly blue. It could possibly be an incredibly rare star of a spectral type more extreme than an O5, or it could be a white dwarf. Both are likely given the age of the cluster and the fact that it is still producing massive stars. Without more detailed spectral data, the determination of the true spectral type of such stars is beyond the scope of this project and left only up to speculation.



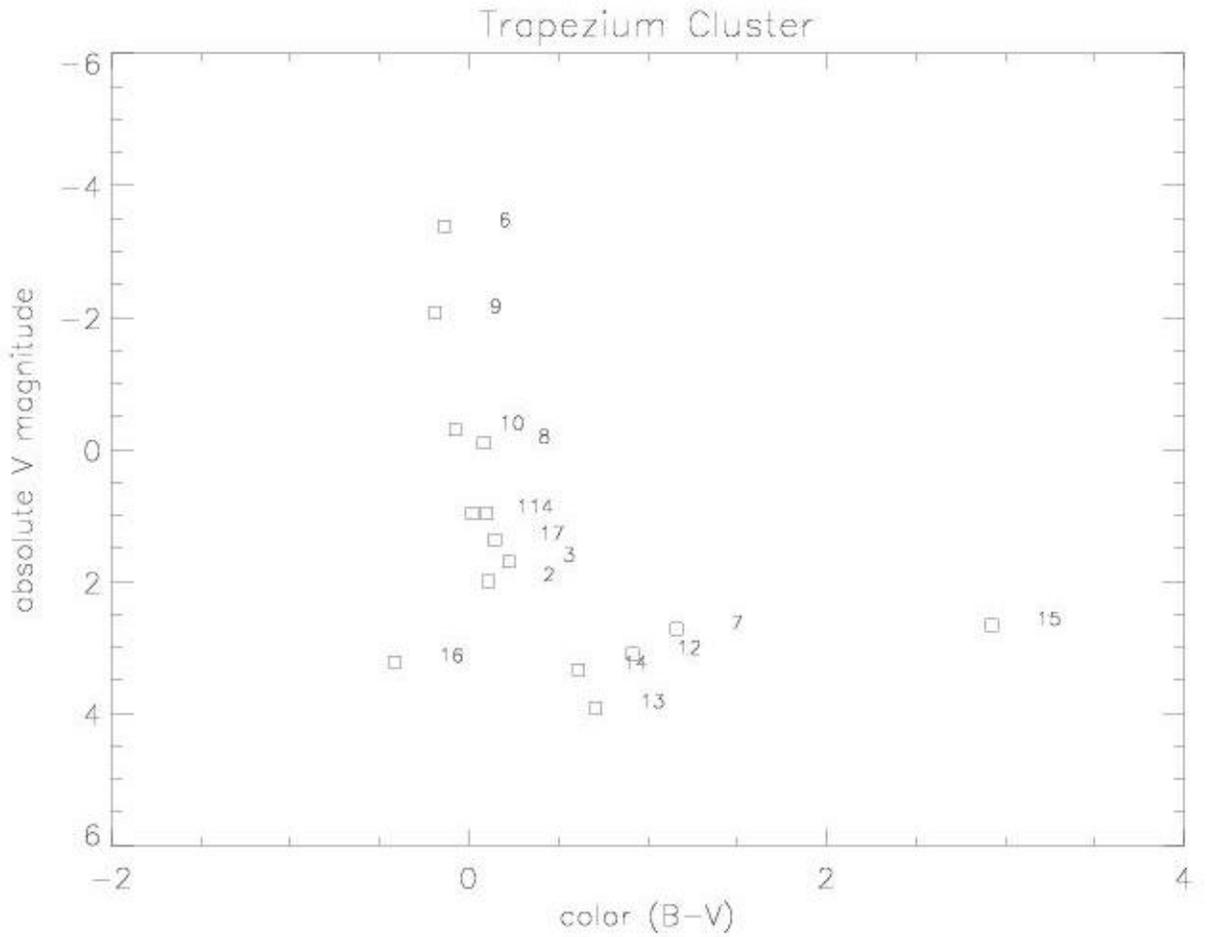
The Stars Chosen for Analysis with the Orion Nebula Clearly Visible

Table 1. Star Photometry Data

Star	App. B Mag	App. V Mag	Abs. B Mag	Abs. V Mag	B-V	Error	Spec. Type
1	14.75	–	6.29605	–	–	–	–
2	10.66	10.45	2.20541	1.99699	0.108412	4.53E-03	A4
3	10.47	10.15	2.02328	1.70232	0.22096	2.16E-03	A7
4	9.62	9.42	1.16731	0.96931	0.0979961	1.56E-03	A3
5	16.47	–	8.02385	–	–	–	–
6	5.03	5.07	-3.42117	-3.38144	-0.139732	6.49E-04	B6
7	12.43	11.18	3.98378	2.72461	1.15917	1.14E-02	K5
8	8.54	8.35	0.0842409	-0.0972519	0.0814928	9.13E-04	K0
9	6.29	6.38	-2.16098	-2.07098	-0.19	6.54E-04	B4
10	8.17	8.15	-0.27838	-0.300347	-0.0780331	7.39E-04	B9
11	9.53	9.42	1.08331	0.967219	0.0160955	1.35E-03	A1
12	12.57	11.55	4.11596	3.1021	0.913854	7.79E-03	K2
13	13.17	12.37	4.72526	3.91658	0.708687	4.99E-02	A3
14	12.5	11.79	4.04905	3.33686	0.612195	2.11E-02	G1
15	14.12	11.12	5.68846	2.66477	2.92369	4.96E-02	>M8
16	11.36	11.67	2.90648	3.22264	-0.416158	9.86E-03	<O5
17	10.07	9.82	1.61714	1.37193	0.145213	1.92E-03	A5

Table 2. Published SIMBAD Star Photometry Data (Used as Reference and Comparison)

Star	Star Name	App. B Mag	App. V Mag	Spec. Type
9	θ_2 Orionis B	6.29	6.38	B2 - B5
10	θ_2 Orionis C	7.9	8.24	B4



A Distribution Resembling an H-R Diagram from Graphing B-V vs Absolute V

7. Acknowledgments

I would like to acknowledge Kellen Lawson's help in construction properly working for-loops in writing the code for the project. I would also like to acknowledge Annie Steele for her assistance in the plotting functions of the code.

8. Works Cited

Reid, M. J. et al. (2009). "Trigonometric Parallaxes of Massive Star Forming Regions: VI. Galactic Structure, Fundamental Parameters and Non-Circular Motions". *Astrophysical Journal* 700: 137. arXiv:0902.3913. Bibcode:2009ApJ...700..137R. doi:10.1088/0004-637X/700/1/137

Carroll, B Ostlie, D. (2006). *An Introduction to Modern Astrophysics*. 2nd ed. Pearson.

Australian Telescope National Facility <http://www.atnf.csiro.au/outreach/education/senior/astrophysics/>

Poveda, Arcadio; et al. (2005). "Low-Mass Runaway Stars from the Orion Trapezium Cluster". *Astrophysical Journal* 627 (1): L61L64. arXiv:astro-ph/0506002