An Orbital Analysis of NN Serpentis

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In this paper I investigate properties of the eclipsing post-common envelope binary star system NN Serpentis, through Python based analysis of images captured at the Las Cumbres Observatory in Goleta, California. Through working with this image data I extract information about the periodic flux changes as a result of the orbital nature of the binary system. By fitting the changing flux of the star system over time to a sine form, I conclude that the binary star system has an orbital period of $0.14 \pm .01$ days, as well as a mean flux of 4721.35 counts, and a flux amplitude of 1839.56 counts. Using other literature, combined with the flux-luminosity relation, I discover a flux ratio value of 180 ± 40 Watts per square meter per count. This implies a mean flux of $8.5 \pm 1.9 \times 10^5$ Watts per square meter, and a flux amplitude of $3.3 \pm 0.7 \times 10^5$ Watts per square meter. I also examine the relevance of my own findings to those of similar scientific research, and discuss the astronomical pertinence of the study of binary star systems as a whole.

I. INTRODUCTION

In a binary star system, much can be learned from the continued observation of the system and analysis of the resulting data. These systems are one of the simplest, and easiest to observe of all celestial orbits, and as such are a great tool for understanding many different workings of the universe. NN Serpentis is one such binary star system consisting of a smaller red dwarf and a larger white dwarf orbiting one another. [1] Many studies have been performed on this specific system, and with far reaching results. The system lies in the same plane as Earth, and this causes study of the orbital parameters to be much simpler than a binary star which does not lie in the same plane. Studies show that around fifty percent of stars have a companion, so study of such a simplistic case like NN Serpentis is a great stride toward understanding more complex binary stars, and a gateway for understanding much of the universe. [2] In this paper I present an image based inspection on the orbital parameters of NN Serpentis based on images taken at the Las Cumbres Observatory, along with the conclusions of other relevant scientific literature.

II. MATERIALS AND METHODS

The process of analyzing data for the NN Serpentis system began from images collected at the Las Cumbres observatory in Goleta, California, on the nights of May 5th and 7th in 2014.(See Fig. 1) One of the first implementations made was to ignore the data from the first night's observations. Of the twenty eight images collected on that night, most all were not up to the quality necessary for proper analysis of the NN Serpentis system, so they were ignored in favor of the over three hundred better frames captured on May 7th. These frames had much less incident light and noise, and were much more reliable for analysis.

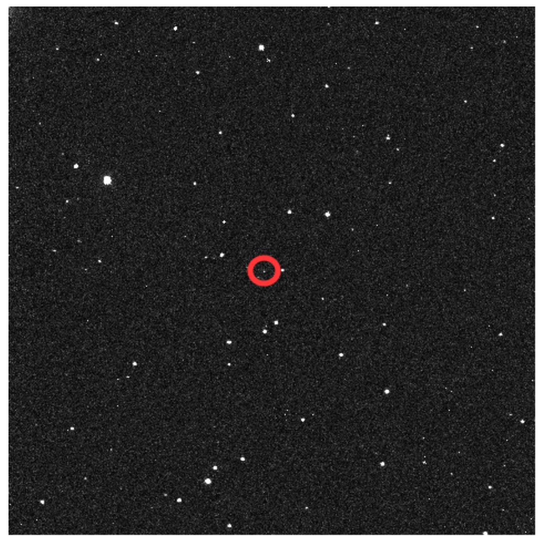

FIG. 1. This is an image of the section of sky for which source data was analyzed. The bright spot inside of the red circle is NN Serpentis.

Gathering these images, I used a python code to run a program called Source Extractor on the images. This program analyzes FITS images to detect and extract sources and produce catalog files of data on the various sources in an image. This lends readily to extracting data on celestial objects from images of the night sky. After gathering catalogs of data for each of the images I had analyzed with Source Extractor, I used another program, called Match Images, to synchronize the large amount of catalog files with one another. Match Images works by taking the cataloged data of two images and analyzing the various point sources in each image with respect to the other sources in the same image, and those in the other image, and matching specific point sources between the two images, thus allowing the same star to be analyzed for each image. Using one of the images as a base frame to match all of the others to, I was able to analyze data for the matched stars in hundreds of different frames, thus accruing a wealth of data to work with.

I was most concerned with the isophotal flux of the various celestial bodies in the images, as the analysis of the changing flux of NN Serpentis would allow me to extract information about the orbital system. In order to account for potential discrepancies between the many images I was working with, I first had to calibrate the potential change in flux between images which was related to the images themselves. To do this, I analyzed the Match Images output files to find seven stars which were detected and had usable data in each of the 303 frames I was working with. Taking the changing flux values of each of these stars over all frames, and then making an array of each of the frames flux ratio with the base frame gave me seven arrays, each of which contained 303 ratios for how flux changed in the stars versus the base frame. Averaging these seven arrays gave me one array of flux adjustment coefficients which I could then use to eliminate potential error in the flux as a result of the different conditions each of each image. These conditional interferences include things such as light flashes in the area of the observatory, or planes flying through the image.

These images had already been adjusted for bias frames and dark frames, and had also been flat-field corrected, so these were not factors I had to worry about in terms of maximizing the equality of the images. A potential source of error here could arise if I accidentally chose any variable flux sources in the seven that I picked to calibrate the frames, which I was careful to avoid by identifying each of the stars on a celestial map.

I then had to create the array of fluxes for NN Serpentis in each frame. I used a celestial map found at http://www.sky-map.org/ to find NN Serpentis, and by inspecting the image found there as well as the image of the base frame, I was able to find which source in the base frame was NN Serpentis, this being object 211. I then made an array of the flux values, and another of the extracted errors for flux, of NN Serpentis in all of the other frames, by using the matched image files and taking the flux and error values for the objects which matched 211 in the base frame. Because only 200 of the frames had a match for object 211 from the base frame, the fluxes for the frames which did not match were given a value of zero. This zeroing did not create a source of error, but simply may have made the orbital fitting tougher as I had less data points to work with, and these zero points were eventually ignored. I then applied the flux calibration array I had created earlier, multiplying it with the array for the various fluxes of NN Serpentis, and thus adjusting these fluxes for the frame to frame discrepancies. I also extracted the modified Julian date of each frame, and matching these to each other, plotted the changing flux of NN Serpentis over time. As a result of the frames for which NN Serpentis did not match, this graph had a hundred or so points which had a zero value for flux, and thus would throw off any sort of curve fitting. (See Fig. 2) I remedied this by creating a python code which eliminated the Julian dates and fluxes for those which had a zero in the flux, from my previous solution to the frames which didn't match, this being how I ignored the zero points without creating a new source of error.

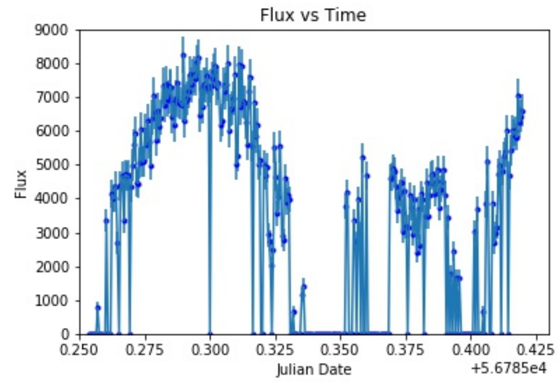

FIG. 2. This is a graph of the adjusted flux vs Julian time for the data, prior to elimination of the zero points. I allowed for connection between the points to serve as a visual aid for how these zero points would skew a curve fitting to be inaccurate. The sinusoidal fit was essential for extracting orbital parameters of the star system, and as such these points had to be excluded.

This left me with a series of data points which I could analyze to find properties of orbital motion from. By fitting this data to a sinusoidal form, I would be able to extract orbital data including period, average flux, and flux amplitude. To achieve this curve fit, I first plotted an estimate sine wave, using the calculated mean of the data as a vertical shift estimate, and the calculated standard deviation as an amplitude estimate. I estimated a period for the curve fit from the peak to peak points of the data, and after graphing with these three parameters, used an estimated phase shift to make my guess more accurate. I then used a scipy.optimize function to minimize the difference between my guess for the sine fit and the data itself, thus giving myself output parameters for the best sinusoidal fit to the graph.

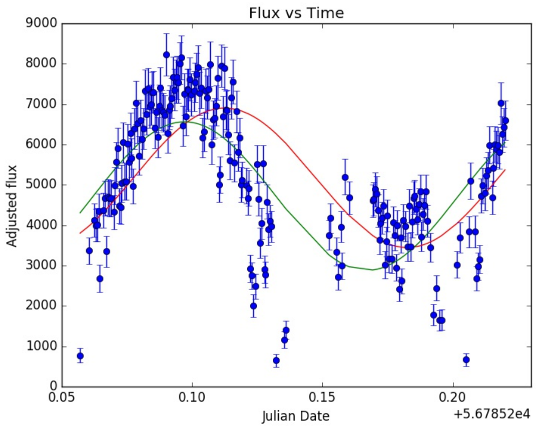

FIG. 3. This is a graph of the adjusted flux vs Julian time for the data which was extracted from frames which successfully matched NN Serpentis with the base frame. The error bars are taken from the source extracted error of the flux of each source.

III. RESULTS

The sine fit I produced gave me an orbital period of $0.14 \pm .01$ days, equivalent to 3 hours 21 minutes and 36 seconds. It also gave a mean flux of 4721.35 counts, and a flux amplitude of 1839.56 counts. This means that the two stars in this binary system orbit one another just over 7 times per earth day. This sine fit is plotted in green in Fig. 3 Finding the masses for these two stars as $M_{WhiteDwarf} = 0.535 \pm 0.012\ M_{sun} = 1.064 \pm .002 \times 10^{31}$ kilograms and $M_{SecondaryRedDwarf} = 0.111 \pm 0.004\ M_{sun} = 2.21 \pm .08 \times 10^{29}$ kilograms [3], we can use Kepler's 3rd law, along with the period calculated from the sine fit, to find the separation between the two stars. This equation is,

$$a\,(t) = (\frac{Gt^2(m_1 + m_2)}{4\pi^2})^{1/3} \tag{1}$$

[4]

where G is the gravitational constant, a is the separation of the two stars, m_1 and m_2 are their two masses, and t is the period of their orbit. For the taken values, this gives an a value of $1.4 \pm .15 \times 10^9$ meters.

Many of the parameters of an eclipsing star system require spectroscopic information which I did not have, however much of this can be found in other scientific literature about NN Serpentis. These parameters include a white dwarf temperature $= 55000 \pm 8000$ K $= 9.52 \pm 1.38\ T_{sun}$ which is an O type star and a red dwarf temperature $= 2900 \pm 150$ K $= .50 \pm .03\ T_{sun}$ which is an M type star, as well as the age of the system, which is found to be in the range of $10^6 - 10^7$ years.[5] Taking the luminosity to temperature relation,

$$L = 4\pi\sigma R^2 T^4 \tag{2}$$

where L is luminosity, R is the radius of an approximately spherical celestial body, σ is the Stefan-Boltzmann constant, and T is the temperature of that body, analyses of the binary system can be made. [2] Taking radius values from other scientific literature, the white dwarf's radius was found to be $0.0211 \pm 0.0002\ R_{sun}$ and that of the red dwarf to be $0.149 \pm 0.002\ R_{sun}$. [3] Using radius and temperature values in relation to their values in our own sun allows us to modify the luminosity equation by dropping constants and giving our answer in terms of the suns luminosity. Combining these radius values with temperature values and the modified luminosity equation gives the white dwarf luminosity equal to $9.2 \pm 1.4 \times 10^{18}\ L_{sun}$ and the red dwarf luminosity equal to $1.6 \pm 0.1 \times 10^{12}\ L_{sun}$. Thus the max luminosity is approximately equal to that of the white dwarf based off the much larger order of magnitude, and the sinusoidal motion in the Flux vs Time graph Fig. 3 is mostly due to the larger red dwarf blocking the flux of the smaller, yet brighter and heavier white dwarf from reaching the setup at Las Cumbres Observatory. This can be expressed, as in DB Woods' "An Analytic Model of Eclipsing Binary Star Systems" as

$$L_{tot}(t) = L_A + L_B - L_E(t) \tag{3}$$

[6] where $L_{tot}(t)$ is the total observed luminosity as a function of time, L_A is the luminosity of the first star, in this case the white dwarf, L_B is the luminosity of the second star, in this case the red dwarf, and $L_E(t)$ is the luminosity lost by the two stars eclipsing each other with respect to time. This eclipse luminosity function is dependent on the parameters of the two stars, specifically temperature and size, and is different for any binary star system which is not and identical copy of another. The distance to the system from Earth from the Monthly Notices of the Royal Astronomical Society paper, "Precise mass and radius values for the white dwarf and low mass M dwarf in the pre-cataclysmic binary NN Serpentis," was found to be 1670 ± 140 light years $= 1.6 \pm 0.1 \times 10^{19}$ meters. [3] Using the flux luminosity relation,

$$F = \frac{L}{4\pi D^2} \tag{4}$$

[2] where F is the flux of an object, L is the total luminosity of that object, and D is the distance to

the object from the observing point, gives a max flux value of $1.1 \pm 0.2 \times 10^6$ Watts per square meter when taking the max luminosity as that of the white dwarf, which is accurate due to its much greater magnitude than the luminosity of the red dwarf. Combining this with the count values I found for mean flux and flux amplitude, 4271.35 and 1839.56 counts respectively, gives a max flux count of 6110.91 counts. This implies a ratio of 180 ± 40 Watts per square meter per count, which leads to my count values representing a mean flux of $8.5 \pm 1.9 \times 10^5$ Watts per square meter, and a flux amplitude of $3.3 \pm 0.7 \times 10^5$ Watts per square meter.

IV. DISCUSSION

The orbital period I calculated from my orbital image study, $0.14 \pm .01$ days, is arguably the most central characteristic of a binary star system. However, using other techniques like spectroscopy which can be found in relevant scientific literature, it can be seen that this is just the tip of the iceberg in terms of the usefulness of investigation of binary stars. Analysis of binary star systems such as NN Serpentis proves to be a very key realm of astronomical study, as the analysis of orbital parameters is the most accurate way to deduce the mass of distant stars. [3]

Fluctuations in the orbital motion of binary stars can also be used to infer the presence of planetary systems orbiting the binaries which may be too dim to detect on earth. NN Serpentis specifically has been found to have to planets orbiting in its system, the closest being 2.28 ± 0.38 times the mass of Jupiter, with an orbital period of 2830 ± 130 days. The further planet has a mass of 6.91 ± 0.54 times that of Jupiter, and an orbital period of 5660 ± 165 days.[7] Study of these systems can be used to analyze other celestial bodies, whether it be application to other period dependent objects like neutron stars, or simply using the effects of binary systems to study objects close enough in proximity to feel their effects. The effects of such a seemingly minute study can be applied to countless other necessities, and this reason is why binary star analysis continues to be a broad study in the field of astrophysics.

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