

**USING PHOTOMETRIC ANALYSIS TO DETERMINE CHARACTERISTICS OF THE V-2491 NOVA**

PHYSICS SENIOR SEMINAR SPRING 2008

KANNATASSEN APPAVOO

MAY 1, 2008

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### 1. INTRODUCTION:

A nova is a phenomenon whereby a star is thought to “suddenly” appear in a region where none was to be found initially [1]. This is due to the fact that the dim star, i.e. the one considered to be non-existent at first place undergoes a nuclear reaction whereby its optical brightness increases drastically and is consequently visible. Novae are thus considered to be in the cataclysmic variable class of stars owing to their irregular increase in brightness by a large factor and a drop back down to a quiescent state.

Novae are classified into two main categories, namely:

1. Classical – stars that undergo one outburst (8-15 magnitudes) with great rapidity, to later slowly decrease to pre-outburst amplitude.
2. Dwarf – where outbursts are frequent (10-1000 day) and have moderate amplitude (2-6 magnitudes) [3].

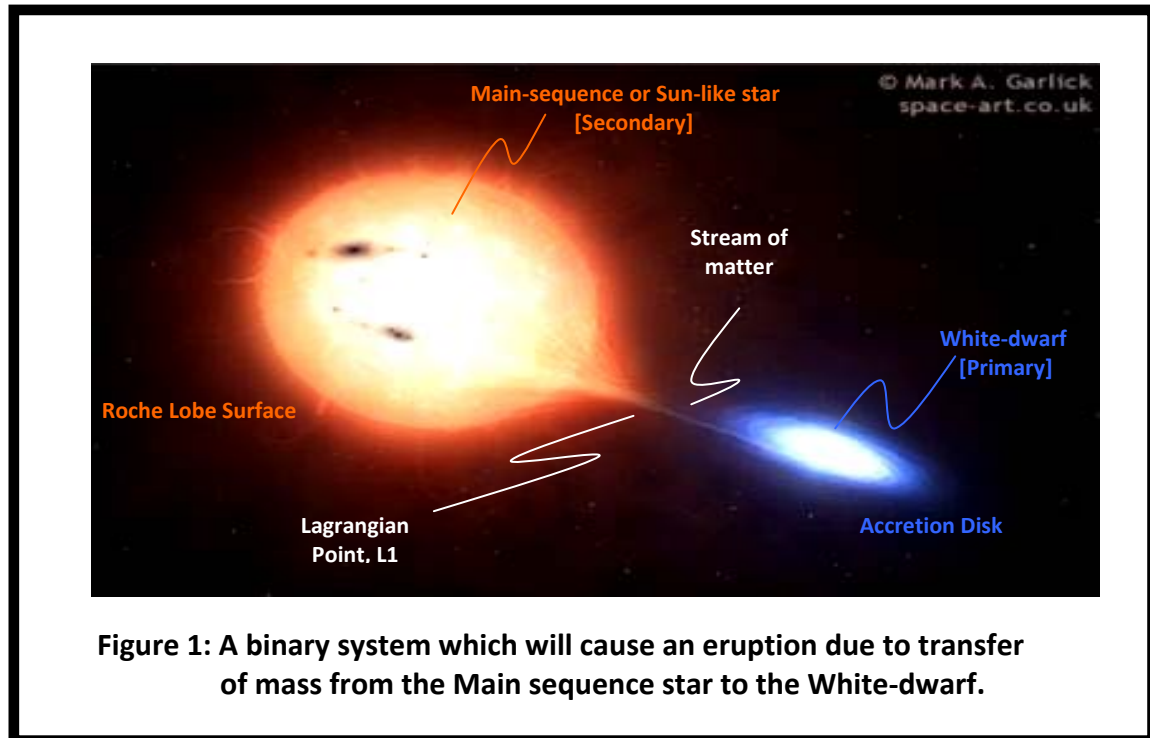
In this paper, we will therefore focus our attention at looking at the visual light curves of V-2491 (photometric analysis) to further categorize this newly seen classical nova based on its behavior according to the duration of rise to maximum and the fall to minimum light.

### 2. CLASSICAL NOVAE:

Classical novae, as any other novae are basically the transfer of matter from one component of a binary system to the other one. As depicted in Figure 1, they consist of two stars; a white dwarf (primary) and a Sun-like star (secondary). When the stars come close to each other

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(process which is not well understood yet), they distort each other until the larger one (less dense and in this case the Main-sequence star) will reach a critical surface called the Roche Lobe



whereby material will be lost outward to the White-dwarf through the inner Lagrangian point, L1. Since the White-dwarf is compact and thus denser, inflowing material does not reach the surface immediately and but instead spirals into an accretion disk [2]. The fresh, accumulating material (mainly hydrogen and helium) is compressed and heated by the intense gravity of the White-dwarf. Eventually, we reach a critical point at which thermonuclear fusion begins and the surface of the White-dwarf explodes, expelling the newly laid layer outward into space with tremendous velocity. This enormous amount of energy liberated produces an extremely bright outburst of light from the white-dwarf's surface. The rise to peak brightness can be very rapid or gradual which is related to the speed class of the nova; after the peak, the brightness declines steadily. The time taken for a nova to decay by 2 or 3 magnitudes from maximum optical

brightness is used to classify a nova via its speed class. A fast nova will typically take less than 25 days to decay by 2 magnitudes and a slow nova will take over 80 days. Thus, we also attempt to further classify our V-2491 nova into this sub-category.

### **3. TECHNIQUES USED:**

In order to classify this newly discovered nova (April 2008), we will use light curve photometric analysis. In simplistic terms, lightcurve photometry is measuring the variations in brightness of an object over time so as to analyze the obtained data. In so doing, one can find many characteristics of an object by studying that singular point of light. Depending upon the number of light curves obtained (itself relying upon the duration of the project), one may attempt to find the period, the amplitude, the existence of binary system (owing to unusual dips in the light curve) and even the shape and spin axis. For the purpose of this research though, our main goal would be to characterize the nova V-2491, that is as a fast or a slow nova.

#### **3.1. TELESCOPE AND CCD CAMERA:**

To record these changes in light intensity, the 0.6-m f/18 Ritchie-Chretien research telescope from Moore Observatory (University of Louisville) would be used. Equipped with the telescope is an Apogee U9000 3056x3056 12.5 micron pixel CCD camera which would be used to obtain the frames (pictures of the sky containing our nova of interest V-2491) that will need to be analyzed later. Moreover, for completeness of the project, the American Association of Variable Stars Observers' website would be used to gather the additional missing raw data [3].

### **4. THE EXPERIMENT:**

The main purpose of the experiment as described above is to characterize the newly found nova V-2491 in the Cygnus constellation as show in figure 2. In order to do so, frames of that particular nova need to be taken over several nights and then analyze as a collective. This section thus deals with not only obtaining these raw CCD images, but also applying the right

correction scheme so that they can be useful. Moreover, in one night, various frames would be taken using different filters. The filters – ultraviolet, blue, visible and near infrared – are used so that specific spectral line features which fall within the pass band can be used to further characterize V-2491 without the need of spectroscopy. In so doing, the physics of the nova explosion might be better understood.

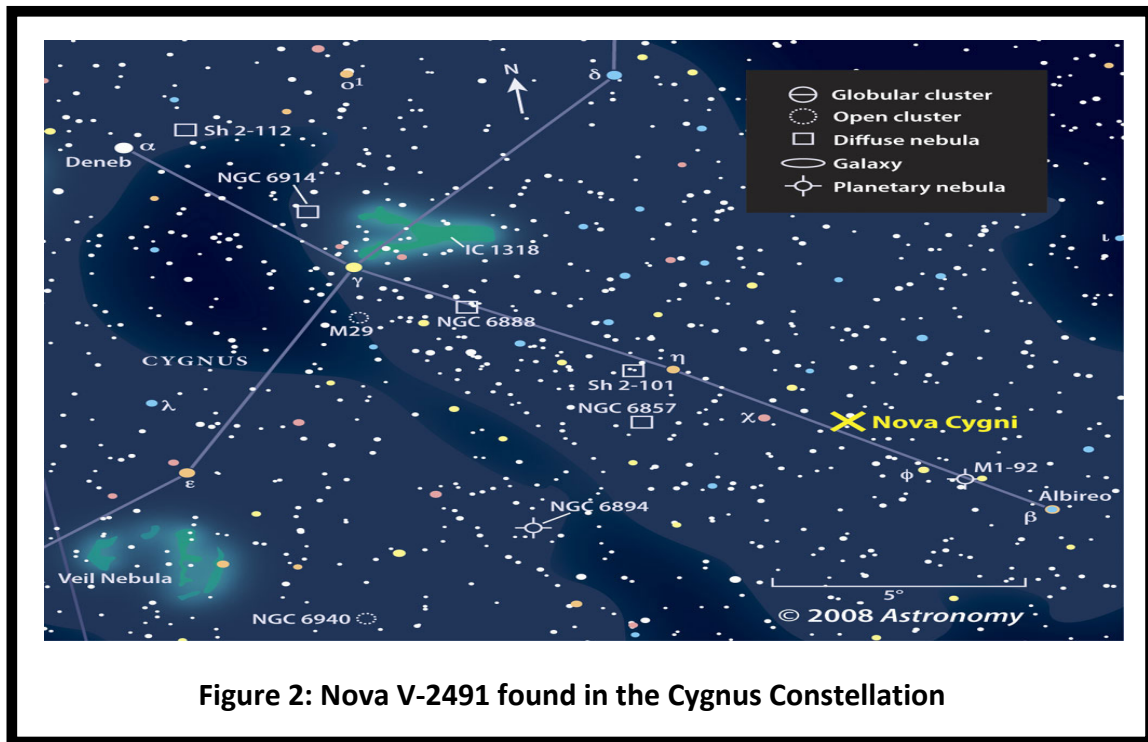


Figure 2: Nova V-2491 found in the Cygnus Constellation

explosion might be better understood.

#### 4.1 PROCESSING THE RAW CCD IMAGES:

Reducing, or processing the CCD data consists of taking the array of values stored on the pixels of an image, manipulating it in such a way that we produce an image in which the numerical value in each pixel is directly proportional to the number of photons falling on the detector at that location.

Hence, the first reduction performed on our raw CCD image is a method called dark subtraction.

This is done to remove the additive source of signal which is due to the thermal electrons, that is

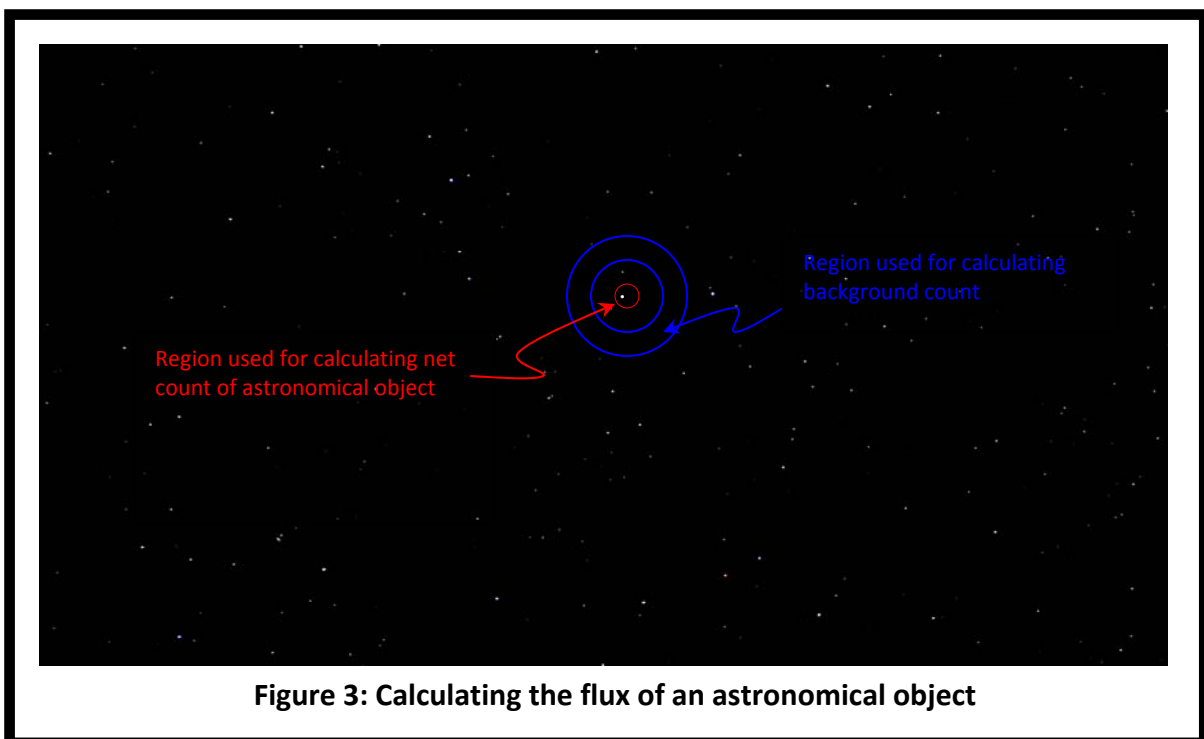
the motion of the electrons that arises from the thermal energy of the CCD camera. Hence, to obtain an accurate value of the photo-electrons, we subtract the thermal electrons from the measured pixel value. This is done by taking long exposures with the shutter speed closed and thus, later subtracting this known noise from the data at each square pixel. In our case, this was performed, by the electronics at the Moore Observatory itself.

Furthermore, the image is then reduced by a technique called flat-fielding. Since the sensitivity to light of the many pixels in any CCD will vary with position (due to manufacturing process), this will create an additional source of error when taking measurement. In order to circumvent this problem of variation of pixel-to-pixel sensitivity, the CCD camera is exposed to a uniformly illuminated light source, such as the twilight sky. This would have the effect of providing us with a flat-field frame whereby this profile would help us to average all the pixel values and thus provide us with a method to uniform the sensitivity.

Thus,

$$\text{Calibrated Image} = (\text{raw data} - \text{dark current}) / \text{flat field}$$

Finally, in order to find the flux of nova V-2491, that its apparent brightness or the number of



photons from the object received per second on Earth, we need to deduct the background light noise of the sky from the total counts obtained for that object [an example is illustrated in Figure 3]. This is performed by a process known as the aperture photometry.

Therefore,

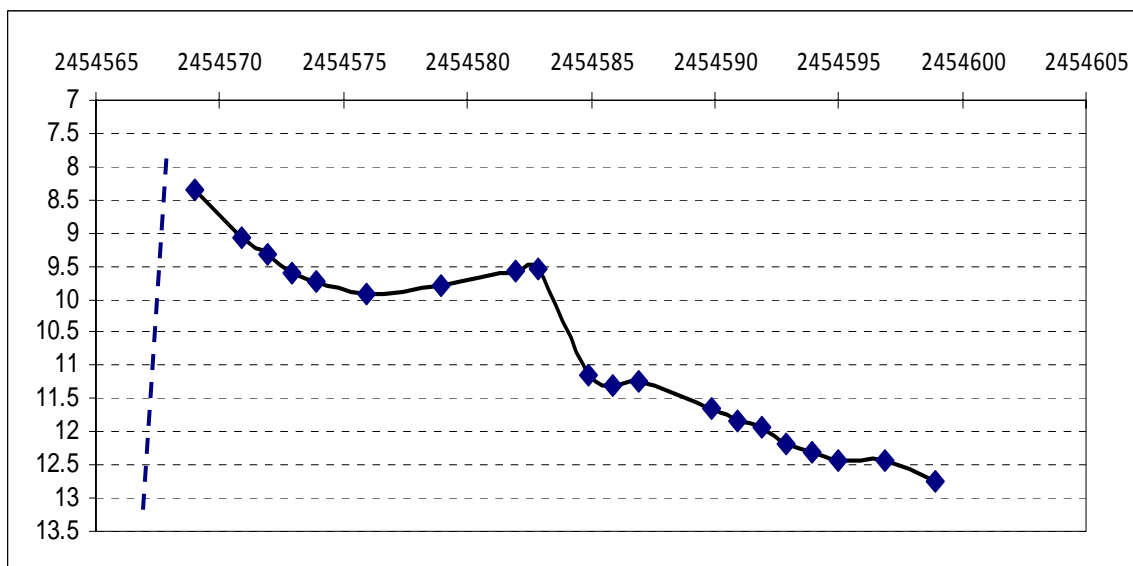
$$\text{Flux} = \text{counts in the nova of the calibrated image} - \text{average counts in background sky}$$

### 5. RESULTS AND OBSERVATIONS:

As shown in the previous section, the flux is obtained through reduction followed by photometry. Consequently, all the raw CCD data obtained are processed in a similar fashion using astronomical software Mira Pro 7 and the magnitude of the nova is calculated for each night using the formula:

$$m = -2.5 \log (\text{counts} / \text{CFZM}) , \text{ where CFZM is the count for the zero magnitude}$$

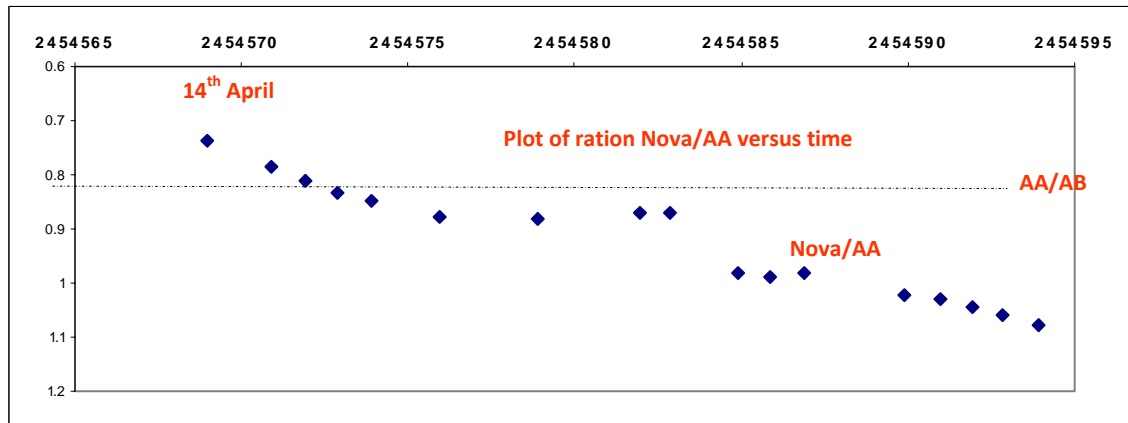
Thus, a graph of the relative brightness versus the date is plotted where the Julian date 2454570 is the 14<sup>th</sup> of April 2008. Also, we note that a lower magnitude would imply that the nova is brighter.



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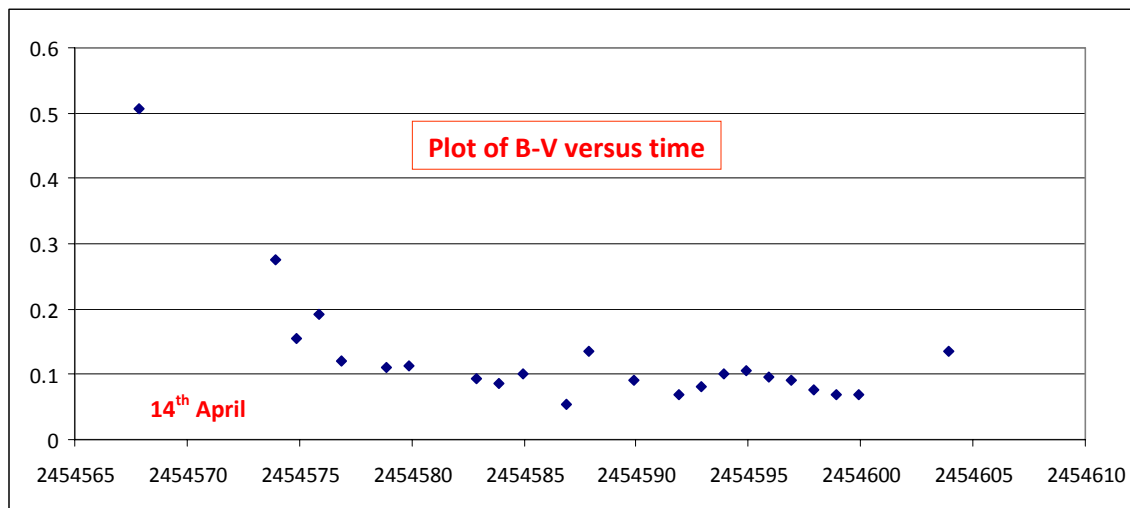
From the graph above, we first note that the data starts at 2454568, which is two days after the explosion that created a drastic increase in the brightness of the nova. The increase in optical brightness is due to the fact that the in-falling matter from the companion star cause the white dwarf to approach a mass of 1.4 times that of the Sun (a mass called the Chandrasekhar limit after the scientist who discovered it) whereby the pressure at the center will exceed the threshold for the carbon and oxygen nuclei to start to fuse uncontrollably [2]. This phenomenon results in a thermonuclear detonation of the star which explains the sudden increase in optical brightness (depicted on the graph as the dotted line). The photosphere moving outward in radius is considered to reach its maximum extent near its peak visual brightness. Moreover, we see that there is a decrease in the brightness of the nova as we progress in time. This can best be explained by the fact that as the photosphere increases in size, it's rate of cooling increases. Thus, more energy is dissipated and therefore the less bright the nova appears. Furthermore, we can see that between 2454575 and 2454583, we have an increase in brightness. This might be explained by the fact that the hot winds coming from the nova after the eruption has a greater speed than the surrounding one. Thus, when they interact, the collision created would cause a release of energy in the form of light and hence, this may account for the increase in optical brightness of the star.

Furthermore, in order to make sure that this change of brightness was solely due to the phenomenon itself, we plotted the ratio of two stars having constant brightness (tag as AA and AB) and also plotted the ratio of the nova's brightness to that of one of the other star (magnitude of nova/magnitude of AA in this case). This would provide us a plot of the relative change in brightness of nova V-2491 with respect to AA.

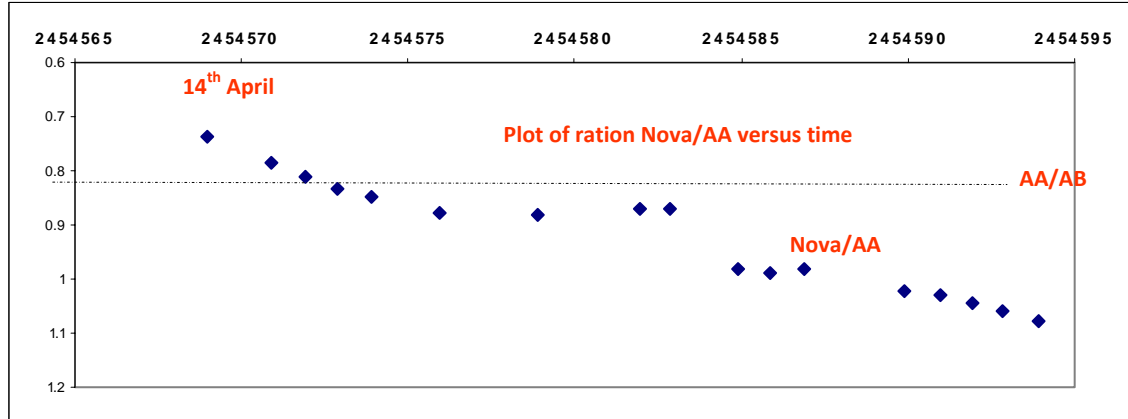


As we can see, the ratio of magnitude of the nova and magnitude of AA has similar features as the other graph, which means that the change in brightness occurred owing to a change in the system.

Furthermore, we also plot a graph of B-V versus time, that is the brightness of the nova in B minus the brightness of the nova in V.



As we can see, the magnitude of B-V is decreasing which means that the magnitude in B is decreasing at a faster rate than that of V. This can be physically equated to the fact that after peaking to a maximum, the photosphere shrinks and gets closer to the white dwarf. In so doing, the spectral lines emissions (due to hydrogen and helium) which are predominantly in the blue regime will dominate and thus account for a decrease in the B-V value.



## 5.2. FINDING ABSOLUTE BRIGHTNESS AND DETERMINING DISTANCE:

From the first graph, we can also determine the absolute brightness of the nova and later use this value to determine its distance from the earth. In order to do so, we first find the derivative of the slope to have an accurate measure of the decrease of brightness in given time frame.

Thus, time taken for decrease of 2 units in optical brightness is 7.01 days.

Using Celia Payne-Gaposhkin empirical formula (1938), that is  $M_{max} = a_n \cdot \log(t_n) + b_n$ , we can find absolute magnitude to be  $M_{max} = -8.6618$ , where the constant for a 2 units decrease in magnitude are  $a_n = 2.41$  and  $b_n = -10.7$  (Warner 263).

Hereafter, we can use the distance modulus formula to find the distance between the nova and planet Earth. Thus, from  $m - M = -5 + 5 \log_{10} d$ , the distance is 16306 parsec.

## 6. CONCLUSIONS:

In the light of the research, we have shown that the newly discovered nova V-2491 is considered to be a fast nova. Moreover, we were able to relate its light curve which spanned a one month period to the physical interactions occurring during that time and use its characteristic curve to find how far away V-2491 is from planet Earth.

## 7. ACKNOWLEDGEMENTS:

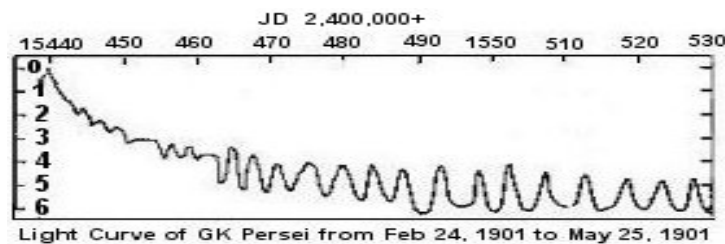
The author of this paper would like to thank Dr. Tracy Hodge for her unconditional help throughout this semester. Also, the author would like to express his gratitude to the personnel at the Moore observatory who readily shared their results and to the Berea College Physics Department.

## 8. APPENDIX:

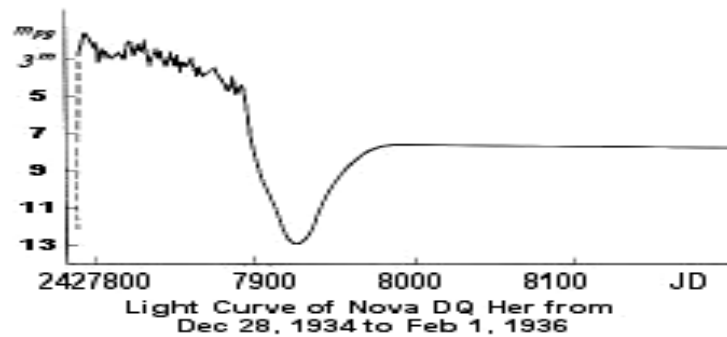
The **Roche lobe** is the region of space around a star in a binary system within which orbiting material is gravitationally bound to that star. If the star expands past its Roche lobe, then the material outside of the lobe will fall into the other star. It is an approximately tear-drop shaped region bounded by a critical gravitational equipotential, with the apex of the tear-drop pointing towards the other star (and the apex is at the Lagrange L1 point of the system).

**Fast novae:** The rise is very steep and it lasts one or, at the most, just a few days; the decline is such that the brightness reaches 3 magnitudes below maximum within 110 days at the latest, and generally much sooner. Nova Persei 1901 is a good example of a fast nova.

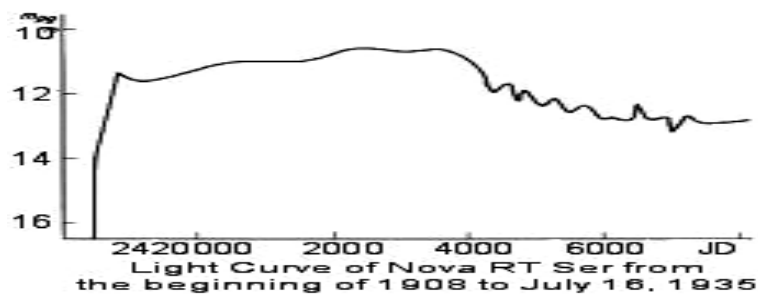
From Burnham's Celestial Handbook Vol. 3, 1978, p.1427:



**Slow novae:** The 3-magnitude decline takes more than 100 days. Some of these novae show a deep, wide minimum about 2-5 months after maximum. This may be due to dust condensation that blocks the visible light. As the ejected material dissipates, the nova recovers to magnitude approximately equal to that expected in an undisturbed decline.



**Very slow novae:** In 1915 the prototype, RT Ser, rose slowly to 10.5 magnitudes, remained at this level for almost 10 years, and then began to fade very slowly, reaching



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