

Use of Reflected Light with Asteroid Light Curves

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Abstract— A study of asteroids was done to determine if they have light curves and into theoretical implications of these curves. The primary objective was to determine if the shape of an asteroid (135 Hertha and 51 Nemausa) could be found using an inversion of these curves. Data analysis concluded that asteroids do in fact have light curves which can be replicated with relative consistency. Applications of this conclusion are also discussed.

Index Terms—Differential Photometry, Asteroid shape, Light Curves

I. INTRODUCTION

THE use of Light Curves and Differential Photometry has been used for many years in the field of Astronomy. Light Curves are useful to show the periodic changes in brightness of an object over time. Often this is used to observe exoplanets transiting a star or study the rotation rate of something like a white dwarf star. Both of these are studying direct changes in the brightness a star; but can the same principles be applied to study an object which only *reflects* light? And if so, what can be done with these curves? Both of these questions are addressed in this paper.

II. THEORY

A. Light Curves

The theory behind light curves is relatively straightforward. The apparent change in brightness (flux) of a star is measured across time. This reveals either information about the source causing the light fluctuation (as with exoplanets) or highlights periodic rhythms (as with white dwarfs). In theory, it should be possible to get these curves on something irregularly shaped that is rotating.

To understand light curves and their applications, one must understand how light reflects off of and is observed from a surface.

B. Diffuse Reflection

The nuances and complications between direct and reflected

light curves are analogous to each other. This leads to the idea of Diffuse Reflection. Exoplanet transits account for diffuse reflection in the form of Limb Darkening. This adjusts for the fact that a celestial object does not display uniform brightness to an observer.

This idea can be thought about as observing a changing surface area. Take a square in a 3 dimensional space. The entire square is emitting uniform light; therefore the observed surface area and the brightness are directly related. The observable surface area that is seen looking at the square is its' maximum: where the most light rays can travel directly to an observer, the brightest point. This is illustrated in Figure 1a. If the square is fixed on one axis and moved back (as seen in Figure 1b) the apparent surface area actually changes and becomes

$$SA = l^2 \cos(\theta) \quad (\text{Eq. 1})$$

where SA is the apparent surface area, l is the magnitude of the fixed axis, and θ is the angle of rotation about the plane. Therefore, as θ rotates between 0° - 90° , the square appears dimmer.

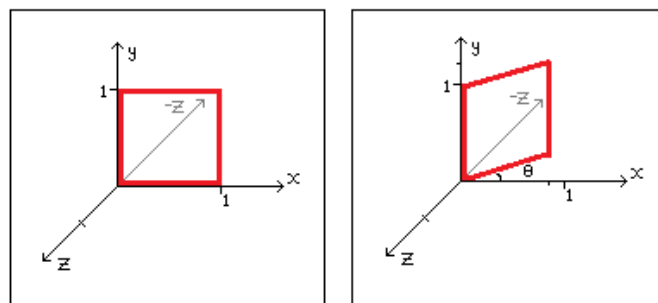


Figure 1 a and b. Different orientations of a square to represent changes in apparent surface area

Diffuse reflection scatters light rays as explained before, except with asteroids it is used to find the shape. Reflection off of a body provides insight as to what kind of surface is needed to create that flux. This flux is then used in a light curve inversion to extract a possible 3D model.

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C. Lambert's Cosine Law

Understanding light reflection is not only understanding the path of light rays, but the effect of orientation on intensity. This is shown in Lambert's Cosine Law (Eq. 2) and depicted in Figure 2 [1].

$$I_{\theta} = I_n \cos(\theta). \quad (\text{Eq. 2})$$

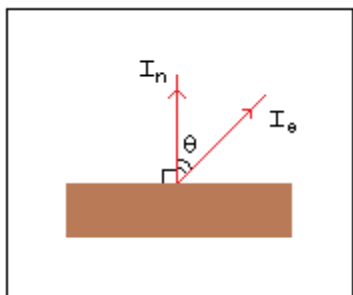


Figure 2. Lambert's Cosine Law. [1]

Here, I_n is the intensity of a light ray normal to a plane and I_{θ} is the intensity θ degrees from the normal.

This shows that as light bends further from the normal, intensity decreases (i.e. a large θ makes light dimmer).

D. YORP Effect

One important contribution towards some asteroid's rotation comes from the sun. Smaller asteroids (~30-40 km in diameter) maintain rotation due to a phenomenon known as the YORP Effect. The sun emits radiation, which is absorbed by the illuminated side of a traveling body. Eventually, the asteroid emits the absorbed radiation providing a thrust the affected side. As this is an unmatched force, it causes rotation. [2]. While this effect does not come into play in the data used here, as Nemausa and Hertha have diameters of around 150 km and 80 km respectively, it could be relevant in any future collections [3].

E. 3D Rendering

If enough information is available, a 3D rendering of an asteroid could be made. Here it would be important to have light curves of the entire period at several different phase angles. This would mean that there is a curve for the entire asteroid from several different viewpoints.

F. The Telescope

Another important aspect of the data is understanding the telescope. The device used was a 24" Ritchie- Chretien telescope collecting data through a Charge Coupled Device (CCD) chip. CCD chips work by collecting photons over a period of long term exposure to find light sources generally too dim to be seen.

III. METHOD

To test if asteroids have light curves, measurements of 51 Nemausa and 135 Hertha were taken at the Paul and Jane Meyer Observatory in Clifton Texas across three nights. Data runs were taken for 4 to 6 hours at a time. Light curves were

compiled using AstroImageJ software. The raw data from Hertha was then put into MATLAB to get a cohesive period across time and run Fourier analyses on the curves.

A. Choosing an Asteroid

The Asteroid 51 Nemausa was initially chosen due to its optimal right ascension (RA) and declination (Dec). The telescope could view anything over 20 degrees above the horizon. Nemausa was up all night, maximizing viewing potential. By the time initial data runs from Nemausa had been analyzed, it was no longer in an optimal position for viewing and 135 Hertha was chosen due to similar reasons stated before.

B. Calibrations

The following calibration images were taken: 30 Biases, 30 flats at 10 second exposures, 30 flats at 30 second exposures for Nemausa observations, 30 flats at 20 second exposures for the first night of Hertha observations, and 30 darks at 10 second exposures. While theoretically all the pixels are identical and that that is what is being read, in practice there are slight variations from pixel to pixel. These three types of calibration pictures help to eliminate noise. Biases measure the amount of electronic noise inherent in the CCD chip. These do not have an exposure time as it is only measuring electronic noise. Darks measure the thermal noise from running the chip for any amount of time. Flats then measure varying sensitivity of the different pixels.

C. Data Collection

The asteroid was found using star fields from The Space Telescope Science Institute [4]. An image of the star field with the asteroid is shown in Figure 3.

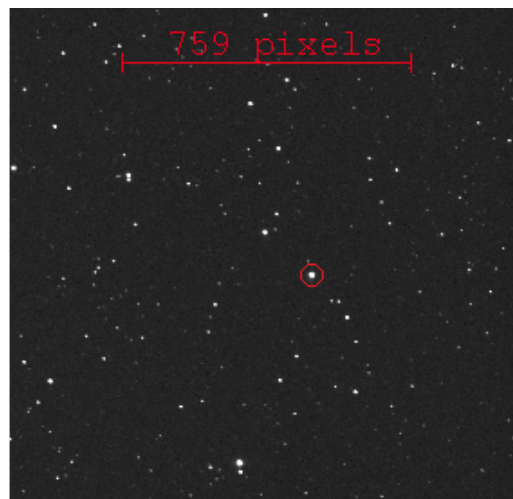


Figure 3. Star Field where asteroid was found. 135 Hertha circled.

Exposure time was determined by trial and error to determine the optimal signal to noise ratio.

On 20150625 30 second exposures were taken with a BG40 filter from around 2200 to 0400 CT.

On 20150713 20 second exposures were taken with a BG40 filter from around 2300 to 0430 CT.

On 20150715 10 second exposures were taken with a BG40 filter from around 2300 to 0400 CT.

Information such as Apparent magnitude, Right Ascension (RA), and Declination (Dec) were retrieved from *Horizons Web Interface* [5].

Tables 1 and 2 show pertinent information on the asteroids on the night of observation.

Table 1. 51 Nemausa observation night information.

51 Nemausa	
Date	20150623
R	18:32:53
T	0:20:59
S	6:09:04
Time	22:00
RA (J2000)	17h 0.427m
Dec (J2000)	-5° 32.288'
App. Mag	9.89
DFO (AU)	1.37
DFS (AU)	2.34

Table 2. 135 Hertha observation night information.

135 Hertha		
Date	20150713	20150715
R	20:29:15	20:19:30
T	1:23:20	1:13:31
S	6:17:25	6:07:32
Time	22:00	
RA (J2000)	19h 21.775m	19h 19.814m
Dec (J2000)	-25° 58.138'	-25° 59.495'
App. Mag	9.64	9.63
DFO (AU)	0.967	0.966
DFS (AU)	1.982	1.98

Tables 1 and 2 show observation information at 22:00 Central Time because this was when most of the observations began.

IV. RESULTS

Figure 4 shows the light curve of 51 Nemausa.

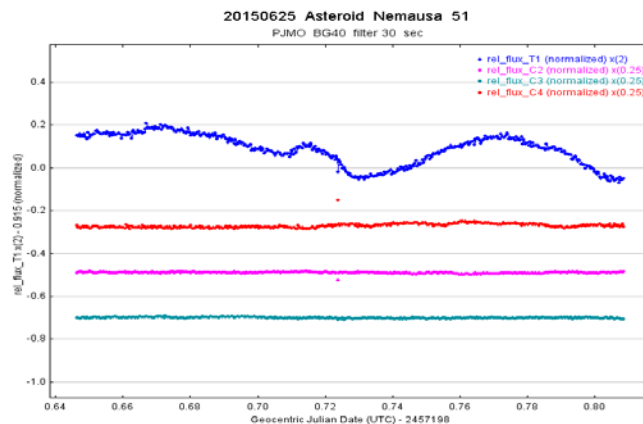


Figure 4. The top curved line is the light curve of Nemausa while the three curved lines beneath are comparator stars.

Since Nemausa’s light curve gave encouraging results, a new asteroid (135 Hertha) was then chosen to study more in depth.

Figures 5 and 6 show light curves that were taken from 135 Hertha on two different nights.

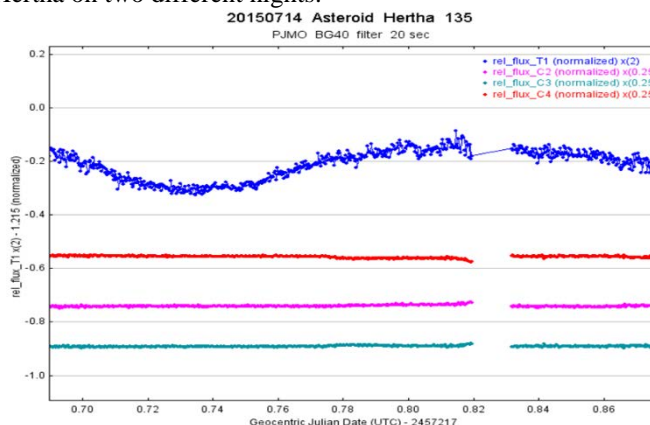


Figure 5. Light curve from Hertha. The top curve is the asteroid and the bottom three are comparator stars. The data gap is deleted data from telescope issues.

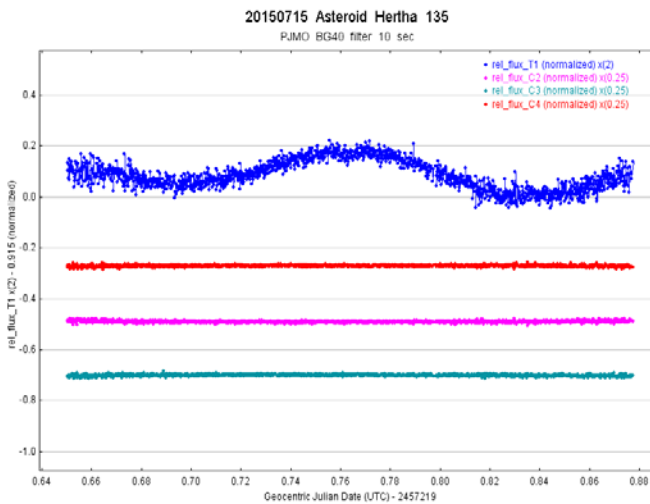


Figure 6. Light curve from 20150715. The top curve is the asteroid and the bottom three are comparator stars.

Figure 7 shows the two curves with their phase angles modified to form a continuous curve between the two.

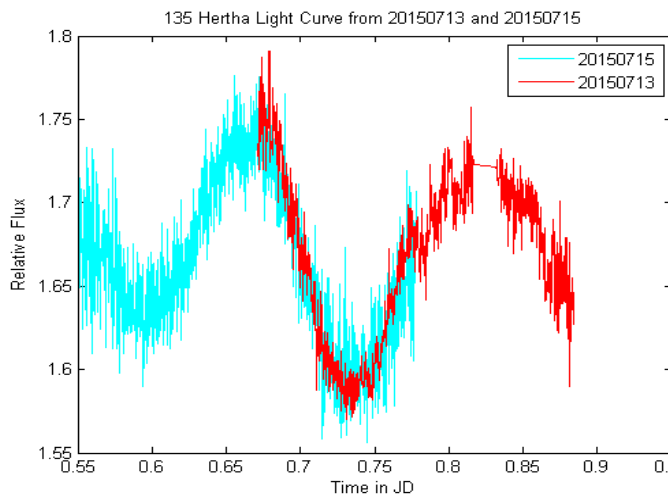


Figure 7. Two of Hertha's light curves plotted where they would be with respect to its period.

V. ANALYSIS

A. Data

Figure 5 shows a discontinuity from around 0.81-0.83 JD. This is from a telescope issue that pointed the telescope at the dome causing data to be thrown out. Figure 6 shows a smooth and continuous light curve, as predicted. Figure 6 has the light curve from Figures 5 and 6 match up almost perfectly when the time is adjusted to coincide with the rotation rate.

B. Future Applications

The light curve of a full rotation of an asteroid could yield the period, and a Fourier Transform could deconstruct the contributing frequencies.

If enough light curves are obtained from an asteroid, an inversion could be performed to create a 3D model. Curves would need to be obtained from several perspectives of the asteroid and they would need to encompass the entire period.

Software was found using a method of light curve inversions to construct a 3D rendering of an asteroid. To use this software, light curves of the full period plus several light curves at a ten and twenty degree phase angles. Due to telescope time restrictions, this amount of data was not available.

VI. CONCLUSION

Experimental results concluded that light curves can be taken using only reflected light as oppose to only changes in apparent brightness. Asteroid 135 Hertha has also been shown to have consistent, measureable light curves. Given enough of these curves from different orientations of any asteroid, it is plausible to obtain a 3 Dimensional model using inversion techniques.

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Christine E. Colson was born in Buffalo, New York on May 28, 1994. She is currently a student at Canisius College in Buffalo, pursuing a B.S. in Physics. She plans to attend graduate school in the field of either astrophysics or astronomy.

She has gained experience as a physics Teaching Assistant in her home university and has worked on projects such as building a 3D printer and construction of a radio telescope in her home town. In her undergraduate years, she assisted in the implementation and presentation of an Affective AI robot at the 2014 AAAI Conference. In addition, she was accepted into CASPER's NSF REU Program at Baylor University in Waco, TX, giving her the opportunity to study and add to the scientific, astronomical, and astrophysical body of knowledge.



Alicia G. Wadsworth was born in Uniontown, Pennsylvania on March 3, 1994. She is currently a student at California University of Pennsylvania, pursuing a B.A. in physics. She plans to attend graduate school for her master's degree in the field of engineering, medical physics, or astrophysics.

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Dwight P. Russell is an associate professor of Physics and a member of CASPER (the Center for Astrophysics, Space Physics, and Engineering Research) at Baylor University. He has been active in research in a variety of areas including acoustics of steel drums as musical instruments, surface science and radiation effects on materials. He is currently active in observational astronomy as the Paul and Jane Meyer Observatory performing measurements of variable white dwarfs, exoplanet transits and asteroid rotation light curves.

Dr. Russell received his Ph.D in Physics from Vanderbilt University in 1986. Before coming to Baylor he worked at the Jet Propulsion Lab and the University of Texas, El Paso.



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Mr. Campbell comes to Baylor with 36 years of military aircraft operations, aircraft systems design and manufacturing experience in the Defense industry. His previous research and design activities related to improving aircraft systems and protecting military aircraft from hostile threats. He is currently turning his attention to the protection of commercial airliners and other non-military aircraft, which are now susceptible to threats in today's uncertain and hostile world.