Determining Physical Characteristics of the Asteroid 572 Rebekka through Analysis of its Lightcurve

Monsrud R.[1], Imamura J.[1], Fisher S.[1], Tosi S.[1], Wages G.[1], Montague C.[1], Luerken K.[1], Holeman S.[3], Robinson J.[1], Tamai N.[2], Karukome I.[2], Itoh M.[2]

[1] Department of Physics, University of Oregon, Eugene, U.S.
[2] School of Human Development and Environment, Kobe University, Kobe, Japan
[3] Department of Physics, Portland State University, Portland, U.S.

Abstract

Here we present observations of the asteroid 572 Rebekka that were obtained in August 2020 at Pine Mountain Observatory (PMO). The target was observed with the 0.35m Robbins telescope at PMO, using a Sloan g' filter, for a total of 8.5 hours over three nights. The observations produced 605 images of the target which were then analyzed to produce a "lightcurve" of the asteroid. Through photometric analysis of the lightcurve, we have produced a 3-dimensional model of the asteroid which is presented here. Using the programs MPO Canopus (MPO) and Aperture Photometry Tool (APT), photometric estimates of the asteroid's brightness over time are plotted in order to extract the rotation period as well as the shape of the target. To calibrate this data, we compare the asteroid to multiple stars of constant brightness within the same image. This process, known as "relative photometry", allows us to remove atmospheric effects due to air quality, light pollution, and changing air mass. An estimate for the change in magnitude due to air mass, commonly known as the extinction coefficient, is also made. These findings give confidence in PMO's ability to provide research-grade data and serves as an exercise in analyzing and reducing large sets of data. As a collaboration with Kobe University in Japan, this is a continuing project that looks to familiarize students with data analysis, calibration, and astronomical concepts.

I. Pine Mountain Observatory

Figure 1

Pine Mountain Observatory (PMO) is a research-grade facility that is owned and operated by the University of Oregon. Located in central Oregon roughly 25 miles east of Bend, PMO first came into operation in 1967 under the direction of Dr. E.G. Ebbinghausen. Since then, a total of 4 telescopes have been installed at the facility, including the most recent one in 2015. This telescope, known as the "Robbins" (Figure 1/2), has been designed to be operated remotely from the UO campus in Eugene. As a forward look, a group of faculty and students are currently building the 5th telescope for PMO, a dedicated solar telescope that will provide live images of the Sun to the UO campus, as well as the public.

Figure 2

II. Asteroids

Asteroids orbit the sun, and are rocky remnants left over from early solar system formation (around 4.6 billion years ago). There are millions of asteroids in the Asteroid Belt, which exist between the orbits of Mars and Jupiter (Figure 3). Although most asteroids are in the main belt, there are also near-earth objects and Kuiper Belt objects whose orbits fall outside this region.

Asteroid taxonomy works to classify asteroids into several groups that relate their physical composition. Tholen taxonomy is the most common system, which makes classification depending on an asteroid's spectral properties. Asteroids can be categorized into a single type or up to three types at once. The Tholen system classified 572 Rebekka as an XCD-Type asteroid due to its low albedo measurements and high carbon composition, which correlate to the X-type, C-type, and D-type classifications.

572 Rebekka is an XCD-type asteroid that was discovered on September 19th, 1905 by Paul Gotz in Heidelberg, Germany. It is in the asteroid belt between the orbits of Mars and Jupiter. 572 Rebekka has an orbital period of 3.72 yr, perihelion of 2.02 AU, diameter of 29.63 km, and is oblong and triangular. A 3d model of 572 Rebekka is shown in Figures 10 and 11.

Figure 3

III. Theory

An asteroid is classified as a rock-based object with a diameter of >1 meter. However, many asteroids are "rubble piles" consisting of many smaller rocks held together by gravity. Rubble piles are less dense due to cavities between individual pieces, and they deform as they travel. Solid asteroids maintain their shape as they tumble, but rubble piles deform. As an observer, this can be seen through changes in relative brightness.

When an asteroid is irregularly shaped and rotates with a relatively short period (~6 hours), it's perceived brightness can fluctuate in a sinusoidal pattern. When the asteroid presents more surface area, it reflects more light from the sun. Similarly, when viewed at angles with less surface area, there is a lower relative brightness. This "lightcurve" (Figure 4) allows observers to infer many characteristics about an asteroid's shape.
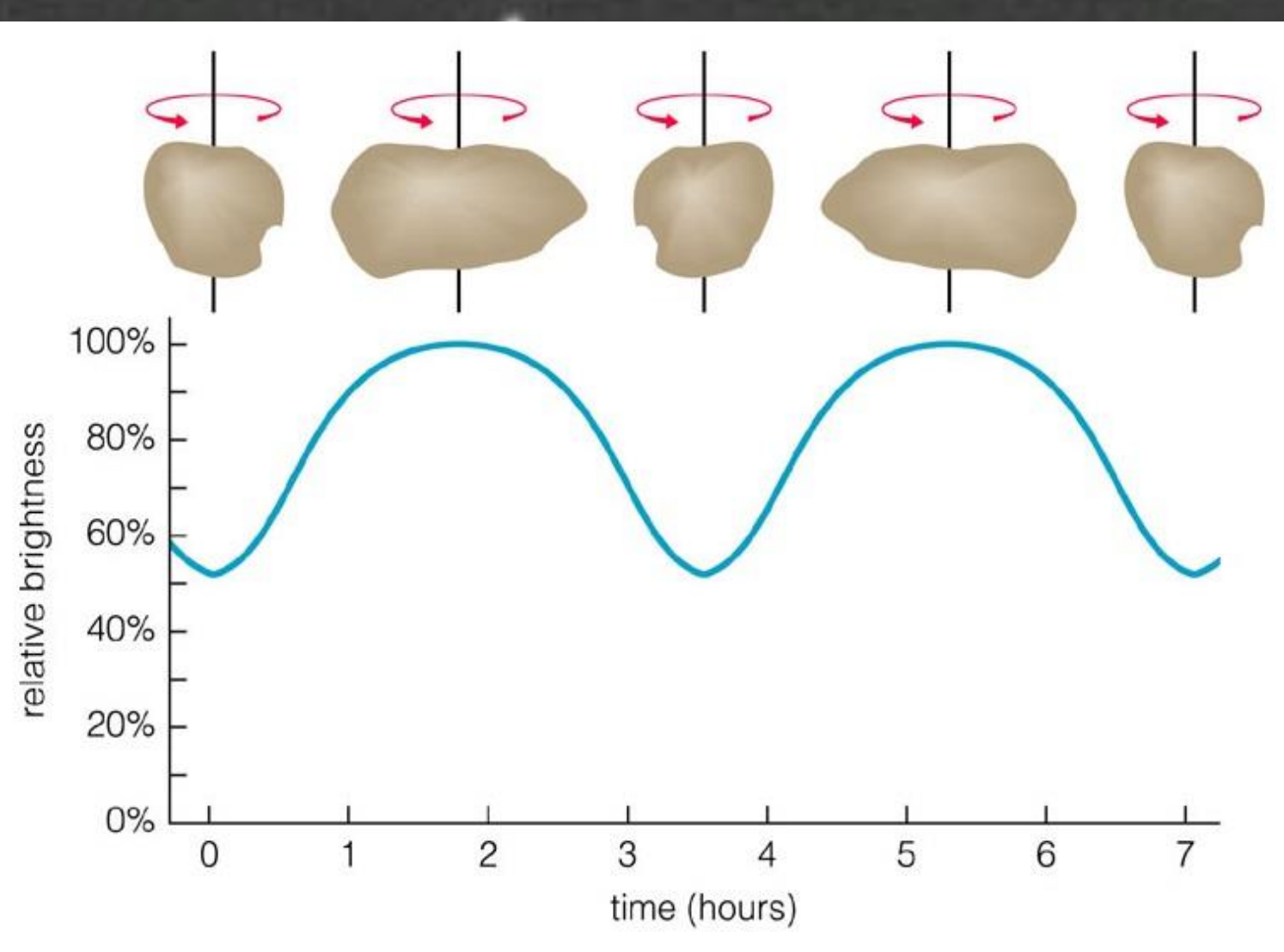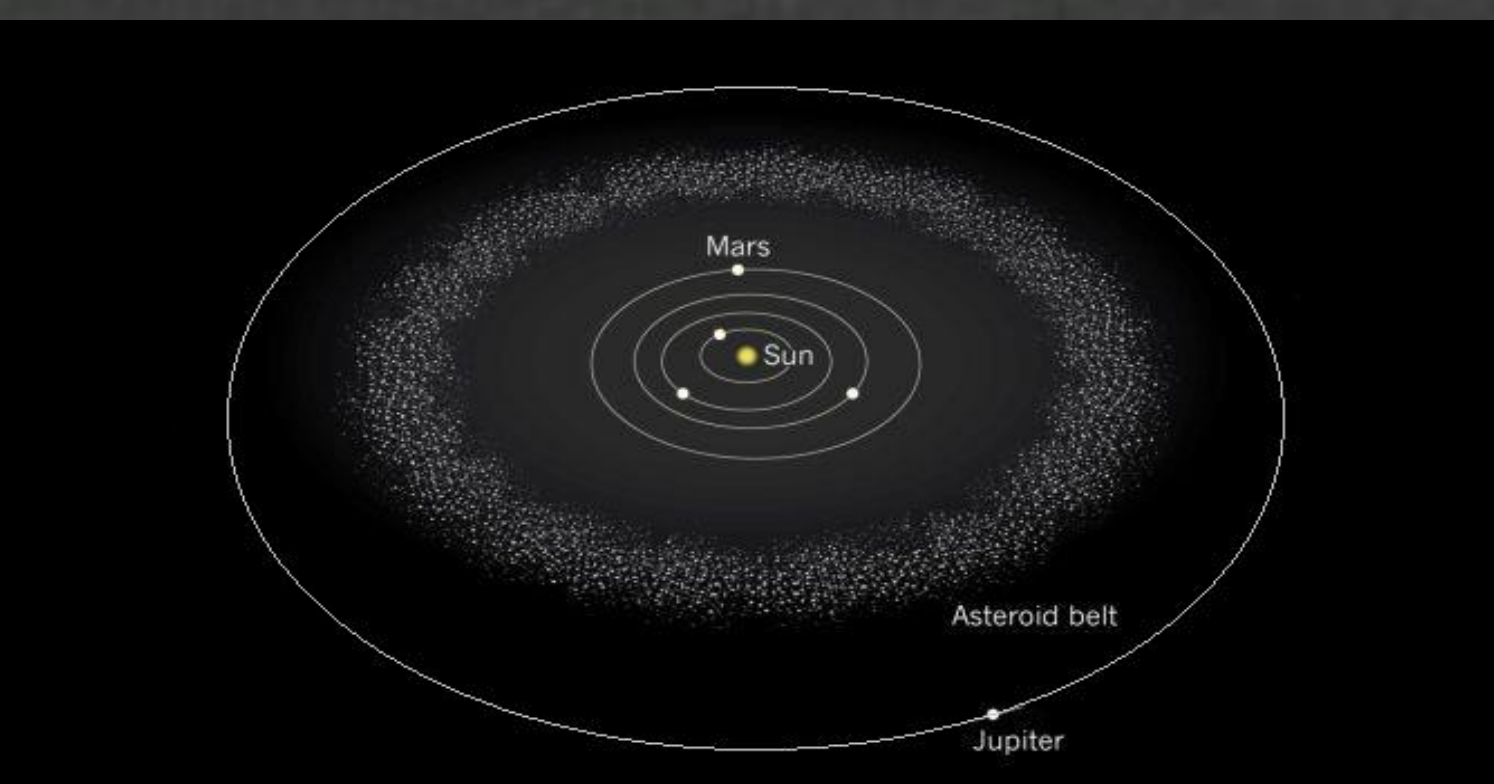

Figure 4

IV. MPO Canopus and Sky Subtraction

MPO Canopus (V10.8) is a program widely used in the professional and amateur astronomy community that provides high-accuracy astrometry and photometry calculations. MPO Canopus works to automate photometry, process and measure images, generate lightcurves and analyze periods and times of minimum. MPO Canopus was used to analyze 605 images that contained both 572 Rebekka and the comparison stars in Figure 6 and Table 1. These results were then confirmed using a separate application named Aperture Photometry Tool (V2.8.4), and closely followed the lightcurve derived from MPO Canopus.
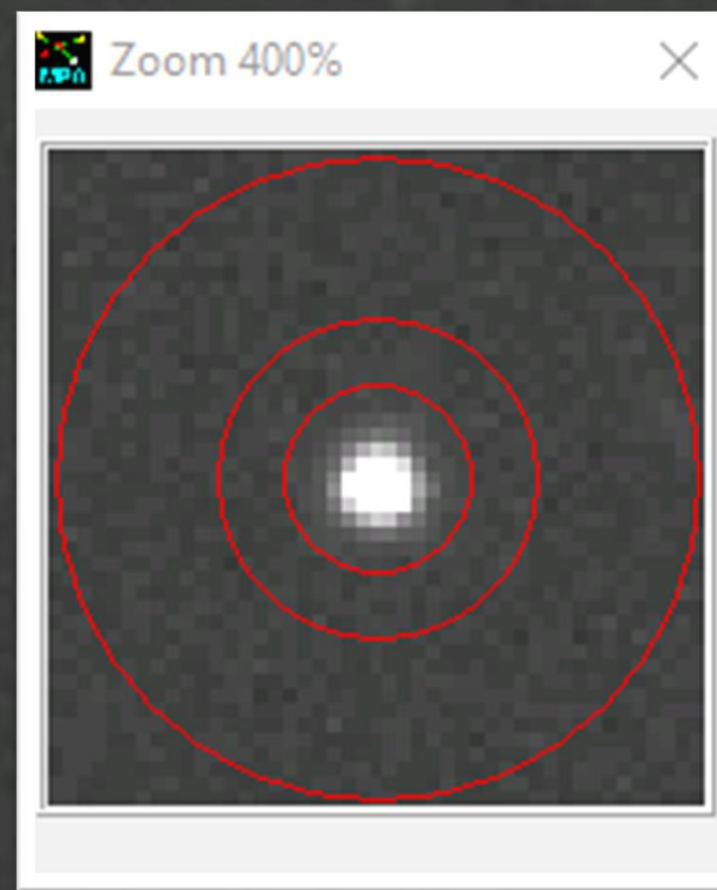

Figure 5

Once 572 Rebekka was identified in-frame, we performed relative photometry using MPO Canopus. In Figure 5, an example of the process is shown. In each frame, three apertures are placed around the source. The smallest aperture encloses the source, while the larger two apertures enclose the sky background. MPO Canopus takes the mean sky background count and subtracts it from the source to remove any background noise from the image.
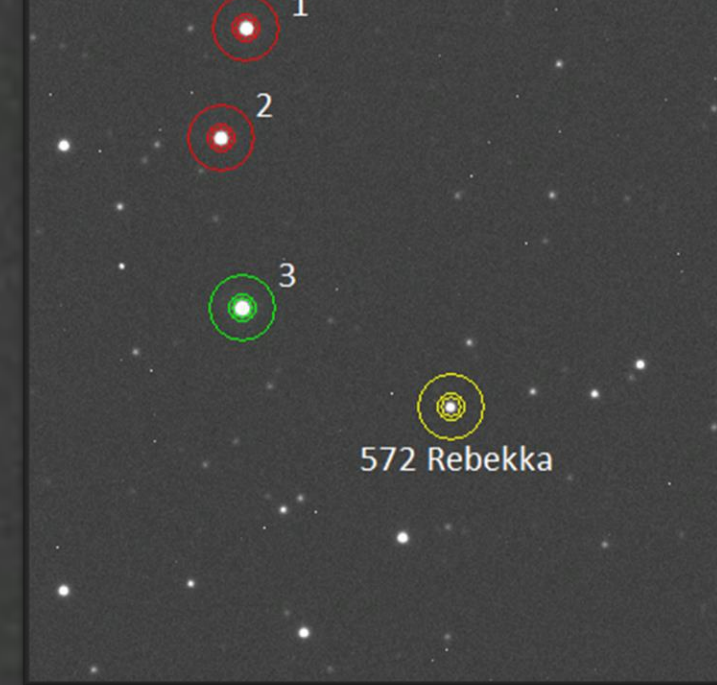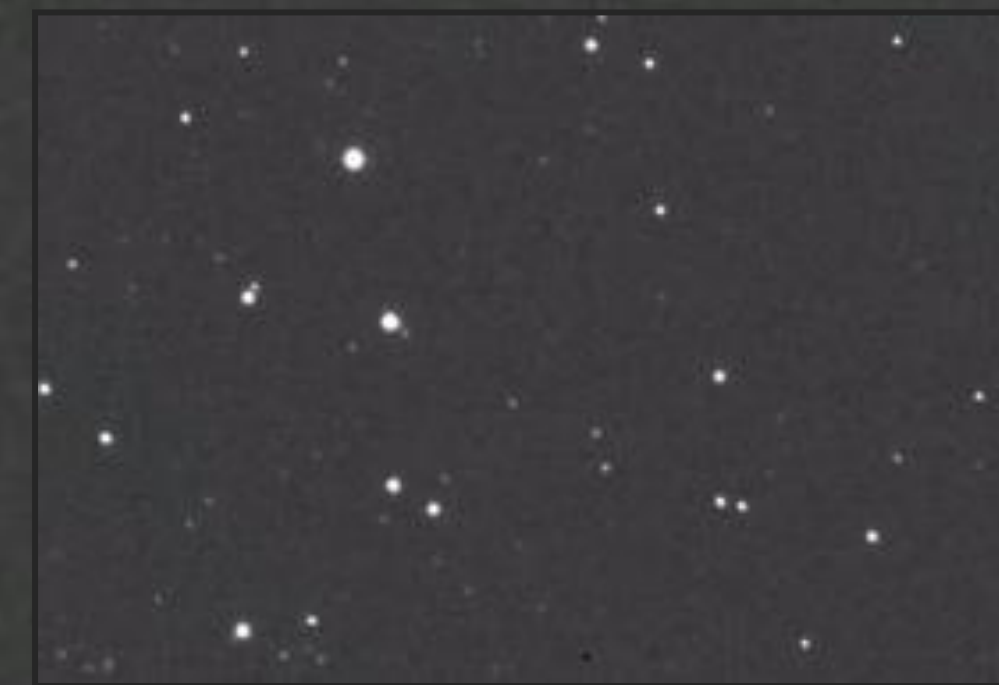

Figure 6

Figure 7

To remove the effects of changing airmass (a measure of atmosphere thickness as the asteroid approaches the horizon), air quality, and light pollution, we compared 572 Rebekka to stars of known brightness that were identified in the frame (Table 1). Subtracting the atmospheric effects (Figure 8) from the source value of 572 Rebekka, we can correct for non-optimal observing conditions. Though there are limitations to this technique, as shown in Figure 7. An occultation with a star prevented accurate photometry for a section of data on August 14th, 2020.

V. Extinction and Calibration

Targets	m.	R.A.	DEC.
572 Rebekka	13.741	Starting: 20:25:46.37 Ending: 20:18:04.34	Starting: -02:16:47.3 Ending: -04:00:04.9
TYC 5167-177-1	11.83	20 25 53.781	-02 15 54.05
TYC 5167-256-1	11.84	20 25 54.457	-02 14 20.59
TYC 5170-865-1	11.45	20 17 34.255	-03 54 10.02
TYC 5170-701-1	12.06	20 17 37.033	-03 59 38.51

Table 1

An estimate for the extinction value was also made. Extinction is the change in magnitude due to airmass, which comes into affect when an asteroid nears the horizon on any observing night. From analysis of the 605 images obtained, the atmospheric extinction coefficient is estimated at 0.24 ± 0.05 (κ). The data is described by the linear relation mg= mg0 + κX, and κ is retrieved from a linear fit of Figure 9. This estimate lacks accuracy due to the data from August 2020 not being absolutely photometric.

VI. Results

Pictured in Figure 10 and 11 are 3d-models of 572 Rebekka, that were made from an extension of the program MPO Canopus, named LCInvert. LCInvert uses Fourier analysis to relate the period, magnitude shift, and lightcurve shape to estimate the physical form of asteroids. This process, known as lightcurve folding, produces a model that closely follows published data of 572 Rebekka
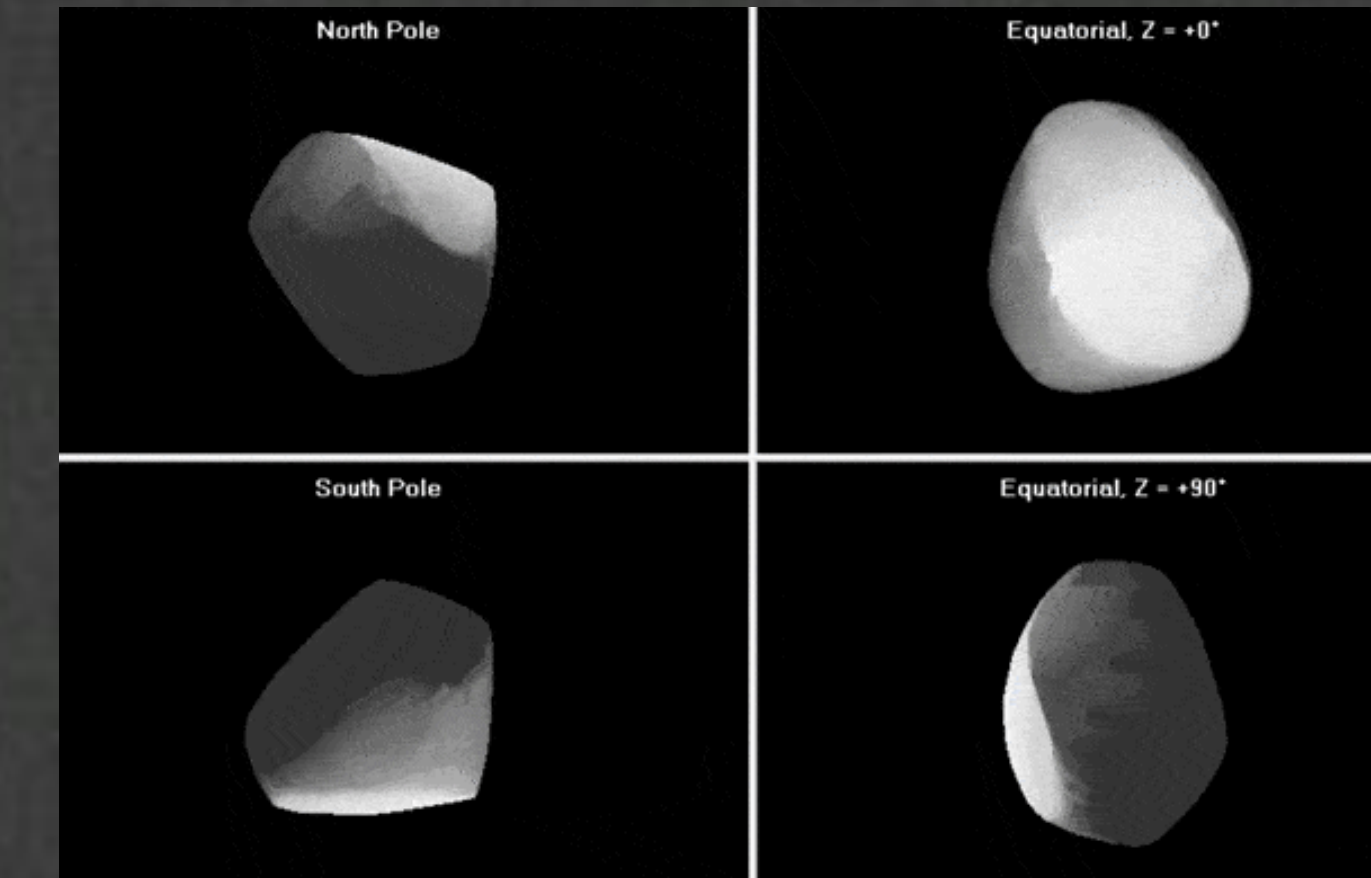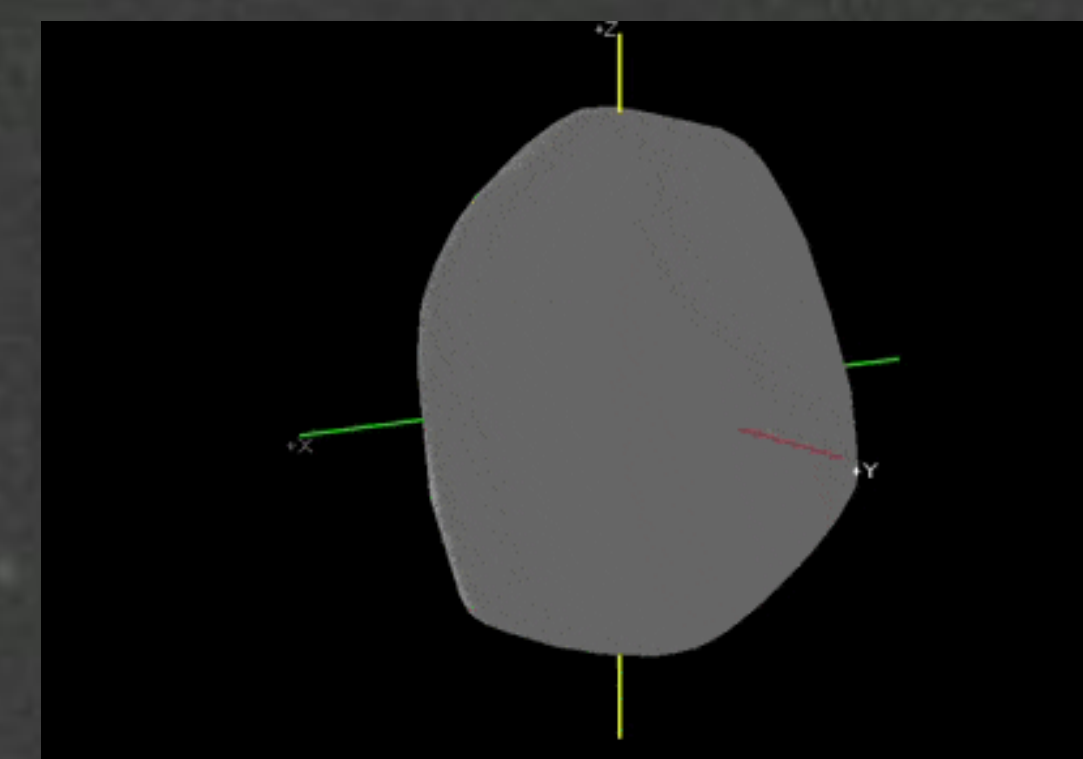

Figure 10

Figure 11

Through analysis and phase matching of each session of observation, a lightcurve can be constructed (Figure 12) that reflects the sinusoidal behavior due to 572 Rebekka's shape. From the lightcurve, it was found that 572 Rebekka has a rotation period of 5.591 h +- 0.011h with an amplitude of 0.23 magnitudes. Conditions on the nights of 8/26 have noticeably larger errors due to forest fires around Pine Mountain.

To quantify the error bars for each frame, MPO Canopus uses listed catalog magnitudes of each comparison star, and compares it to the measured instrumental value from the telescope. This value is then averaged across each star selected and used as an error for the measured asteroid.
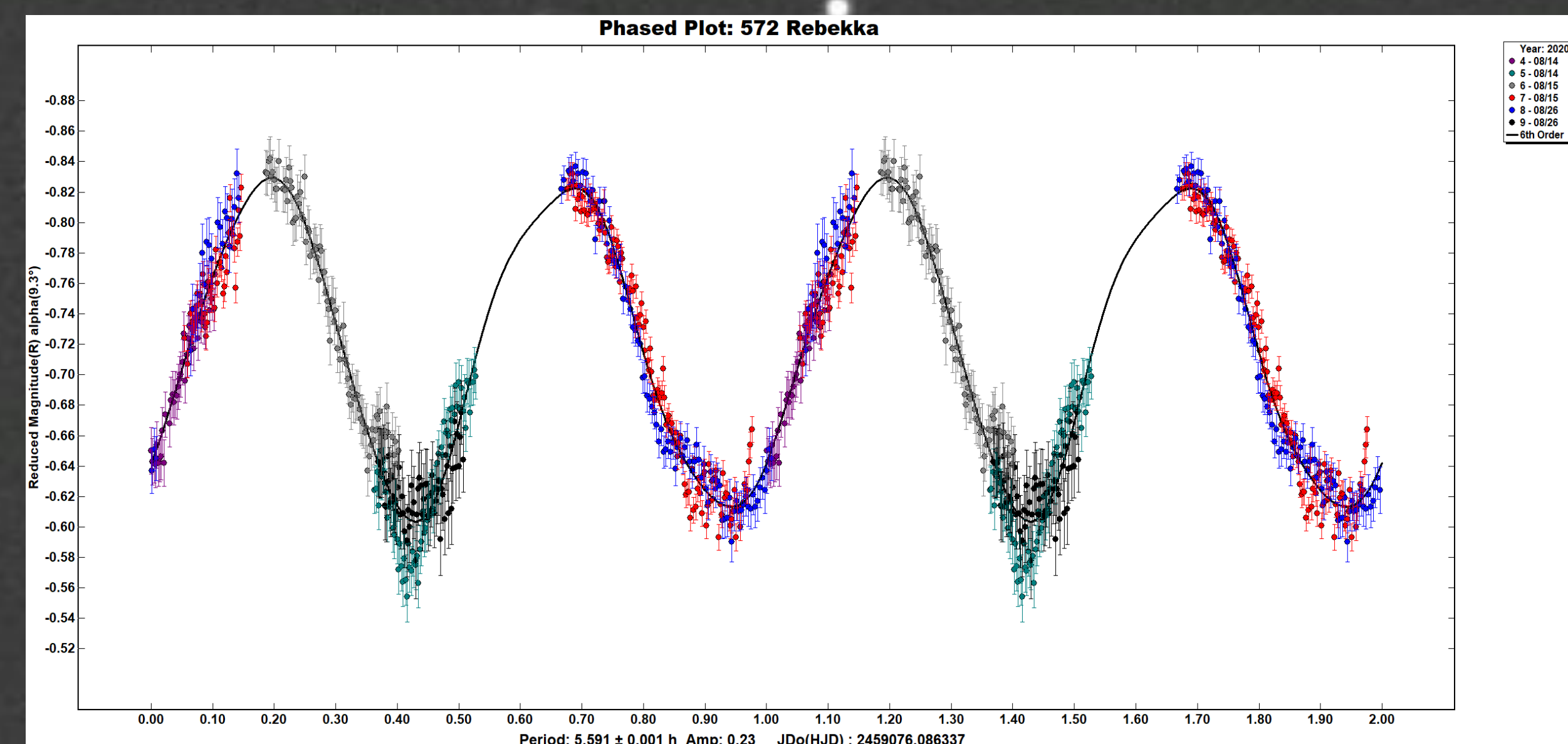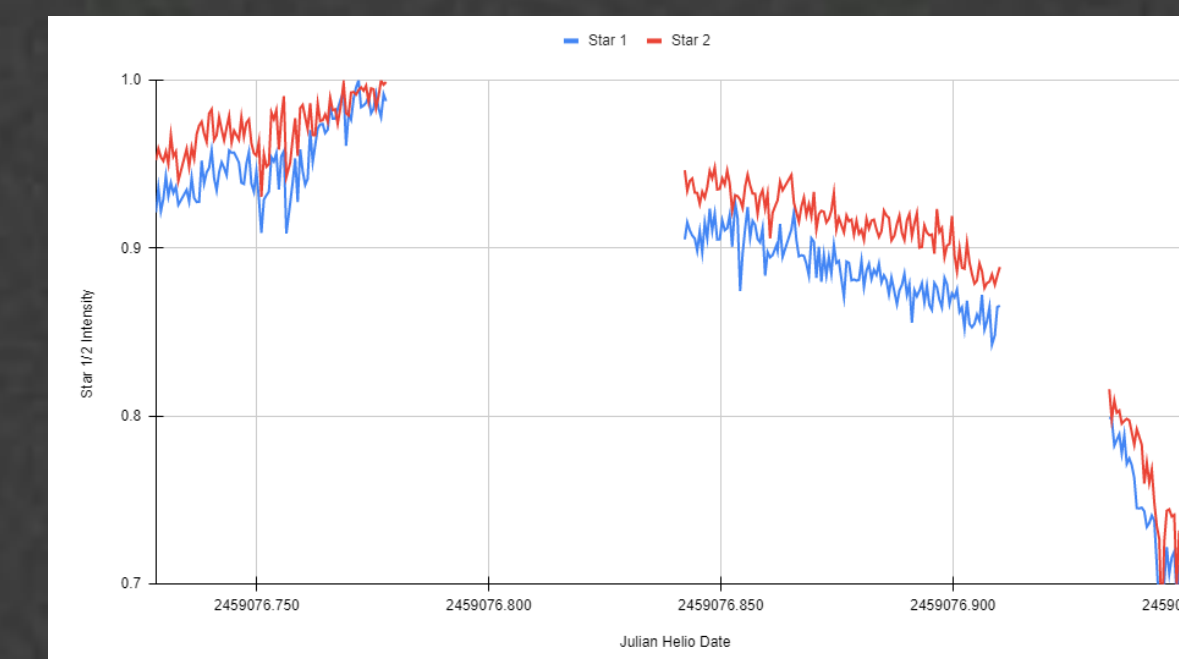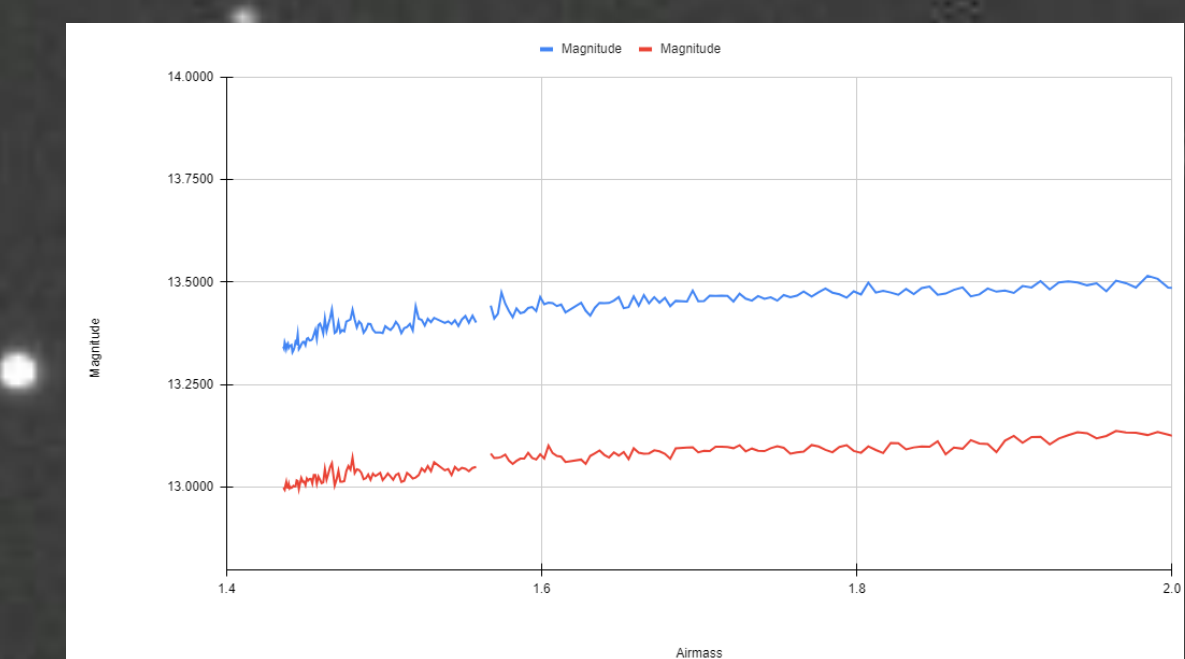

Figure 12

Figure 8

Figure 9

[1] Aperture Photometry Tool (Version 2.7.5.). (n.d.). Retrieved from http://www.aperturephotometry.org/aptool
[2] MPO Canopus (V10.8) and LCInvert (V10.8). (n.d.). Retrieved from http://www.minorplanetobserver.com/MPOSoftware/MPOCanopus.htm
[3] Ringsdorf, N., et al. May 2019, Undergraduate Research Symposium, University of Oregon. https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/24618/ringsdorf_urs_2019.pdf?sequence=1&isAllowed=y
[4] Ďurech, Astronomical Institute of the Charles University:, J., & Sidorin, V. (2014, April 15). A three-dimensional model of 93 Minerva that was computed using light curve inversion techniques. Retrieved from https://commons.wikimedia.org/wiki/File:93Minerva_(Lightcurve_Inversion).png
[5] Ebbighausen, 1968, PASP, 80, 230E
[6] SIMBAD query results for comparison stars (n.d.). Retrieved from http://simbad.u-strasbg.fr/simbad/
[7] JPL Small-Body Database Browser, https://ssd.jpl.nasa.gov/sbdb.cgi#top9
[8] Lightcurve and asteroid rotation period figure (2020, June 17). Retrieved from https://community.dur.ac.uk/physics.astrolab/a_lightcurve.html
[9] Asteroid Belt Formation figure (2017, September 14). Retrieved from https://www.zmescience.com/space/asteroid-belt-formation-423410
[10] Tamai, N., et al. May 2021, Undergraduate research Symposium, University of Oregon.