Characterization of Asteroid 93 Minerva Searching for Variation of the Light Curve to Determine Physical Attributes

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Abstract

In 1967 Pine Mountain Observatory (PMO) made its first observations of astronomical objects that included everything from nearby planets and asteroids to distant nebulae and galaxies. In 2018, PMO continues to make research-grade observations of various kinds of celestial targets. In this poster we present the results of broad-band optical photometry of the asteroid 93 Minerva obtained using the 0.36 m Robbins telescope on September 5, 2018 (UTC). On this night the target asteroid was continuously observed for roughly 2.5 hours to measure variations in its light curve. The shape and magnitude of the changes in the light curve can be used to determine physical characteristics of 93 Minerva including rotation period and three-dimensional shape. Photometry of 93 Minerva, as well as calibration stars, was performed using the Aperture Photometry Tool (v.2.7.5). Although there were non-optimal observing conditions, our obtained light curve closely matches previously published 93 Minerva data. The data are a successful proof-of-concept of our ability to perform accurate photometry of moderately faint objects at PMO. With this successful test, we will soon start an asteroid monitoring program at PMO. In conjunction with our colleagues at Kobe University in Japan, we will collect multiple-epoch, short-cadence photometry on several asteroids to construct light curves and map their three-dimensional features.

Figure 1

Figure 2

Figure 3

I. Pine Mountain Observatory (PMO)

Pine Mountain Observatory, located in Central Oregon, is the observing station of the University of Oregon. The site was discovered by Professor E.G. Ebbighausen in 1965. The initial telescope saw first light in 1967 and made its first research observations in summer of 1968. PMO has four domes (figure 1). The 0.36 m (14 in) Meade Schmidt-Cassegrain telescope was installed in 2015 and dubbed the "Robbins" after Kenneth C. Robins whose contributions made the project possible (figure 2 and 3). The telescope may be operated remotely from the University of Oregon campus in Eugene [4].

II. Asteroids

Asteroids are small astronomical objects orbiting the sun thought to be left-overs from the planet formation process. There are millions of asteroids in the Asteroid Belt, which exists between the orbits of Mars and Jupiter. Many asteroids are thought to be remnants of planetesimals that collided and shattered. Although the majority of asteroids are located in the main belt, there are also near-earth objects (NEO's) whose orbits bring them close to the Earth. There are over 19,000 NEO's but only a fraction of these are currently near Earth. As we move further out in the Solar System, we find the trans-Neptunian objects and then the Kuiper Belt objects. The Kuiper Belt is located from Neptune (30 AU) to about 50 AU (figure 4) [2].

93 Minerva is a carbonaceous, C-type, asteroid discovered on August 24, 1867 by C. J. Watson. 93 Minerva is in the main asteroid belt located between the orbits of Mars and Jupiter (figure 5 and 6) [9, 10]. 93 Minerva has an eccentric orbit with orbital period 4.58 years and perihelion of 2.37 A.U.[9]. Minerva is 77.1 km in radius and nearly spherical in shape. Computer modeling of the 93 Minerva is shown in figure 7 [3].

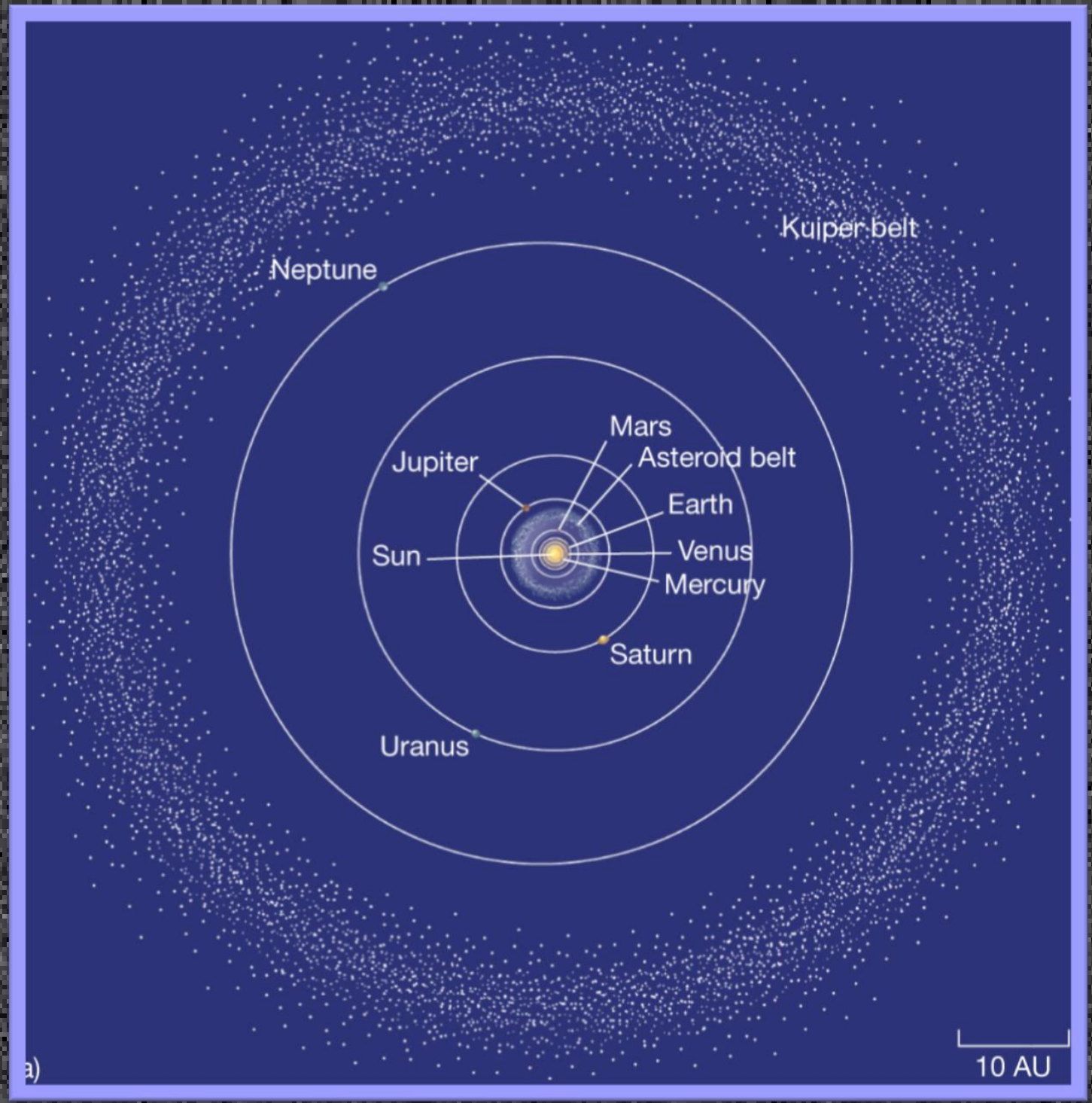

Figure 4

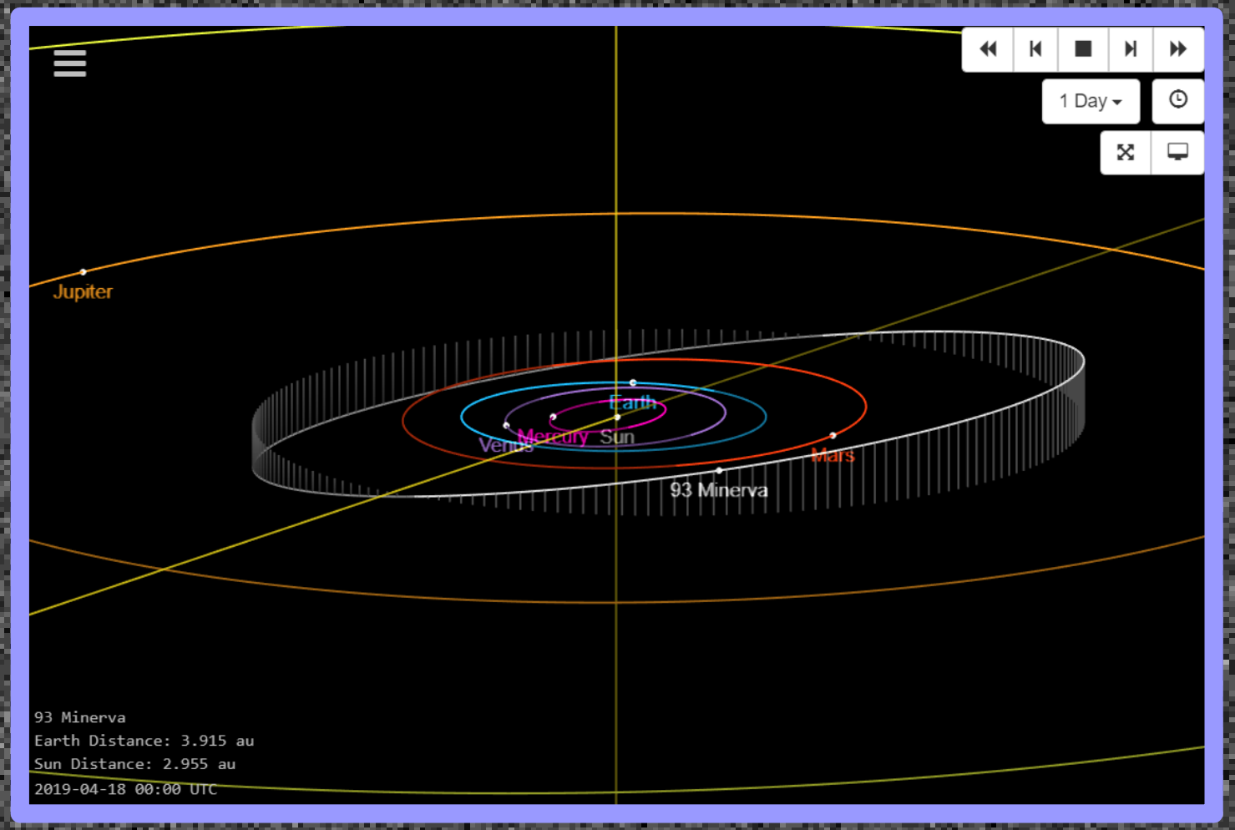

Figure 5

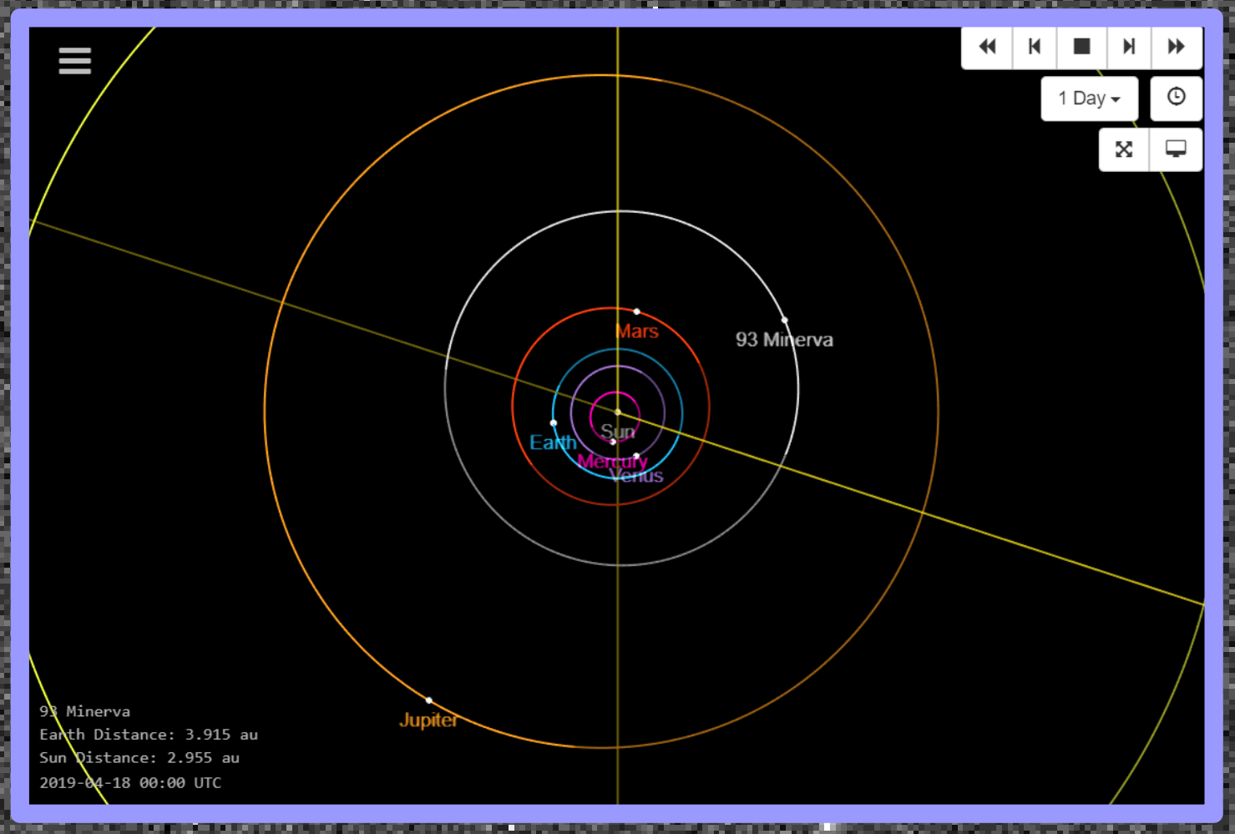

Figure 6

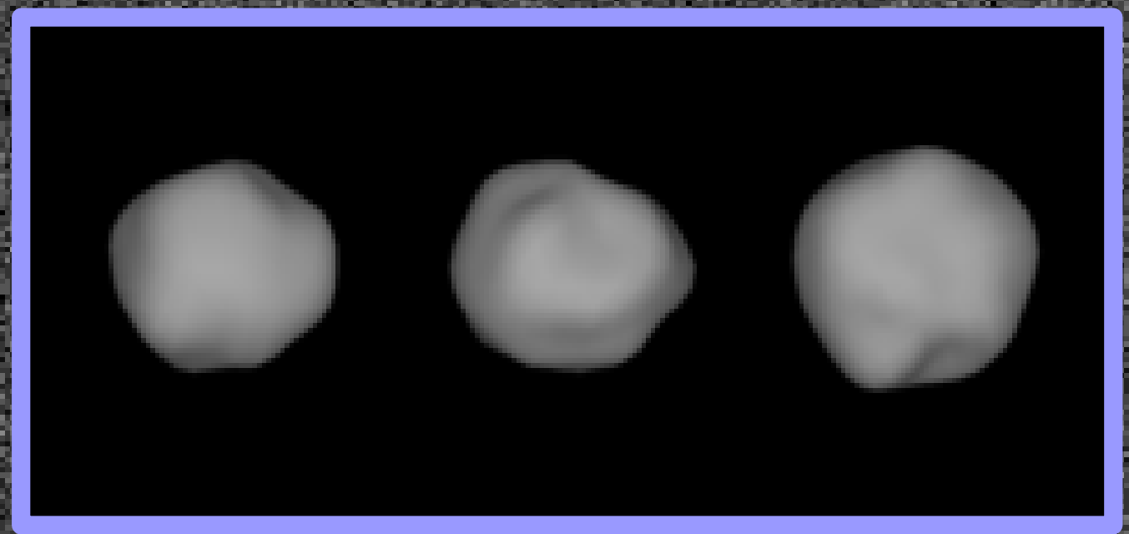

Figure 7

III. Aperture Photometry Tool

The Aperture Photometry Tool[1] 2.7.5 (APT) is a software package used by professional and amateur astronomers to analyze optical imaging data [1]. In this project we used APT to perform relative photometry (that is, to measure the apparent brightness of 93 Minerva compared to standard star) on approximately 250 Flexible Image Transport System (FITS) images. FITS images are a data file format commonly used in astronomy. To photometrically calibrate our 93 Minerva data, we also observed known standard star TYC12-1091-1 [7] on the same night. Our standard star TYC12-1091-1 had SLOAN g magnitude (m_g) 11.698. TYC 14-784-1, our local comparison star, was located in the same image frame as 93 Minerva [8]. Analysis of TYC12-1091-1 allowed us to calculate the photometric zeropoint for our imaging system. This important data point allows an absolute calibration of our 93 Minerva data so it can be compared to other data on the same object. For the SLOAN g filter, the measured zeropoint has a magnitude ZP(g) = 23.1 mag. Interestingly, this is the first zeropoint measured for the Robbins telescope and it shows that this small-aperture system is very sensitive with high performance in the optical. This sensitivity also shows the quality of the PMO site.

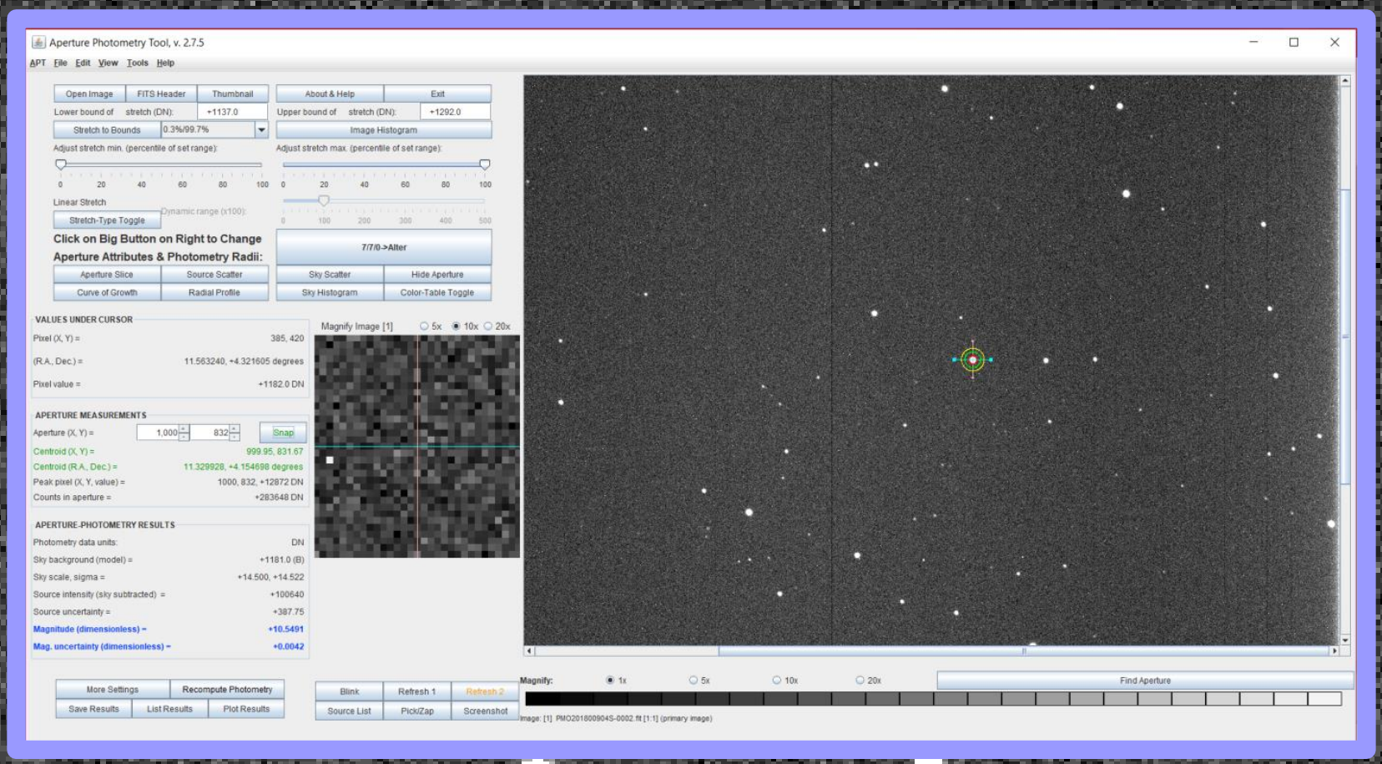

Figure 8

Once 93 Minerva was identified on the frames, we performed aperture photometry using APT. In figure 8 we show an example of how our analysis works. At each point in the image, the signal is a combination of the source and the background,

Counts = Source + Background

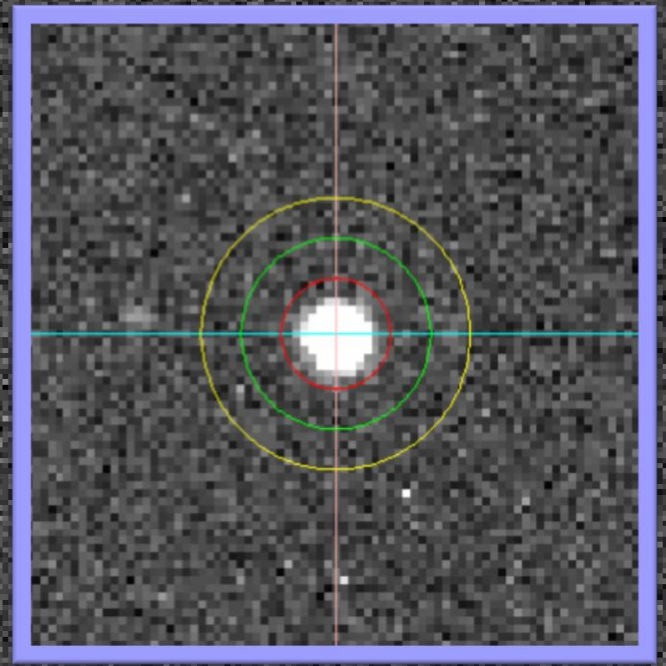

Figure 9

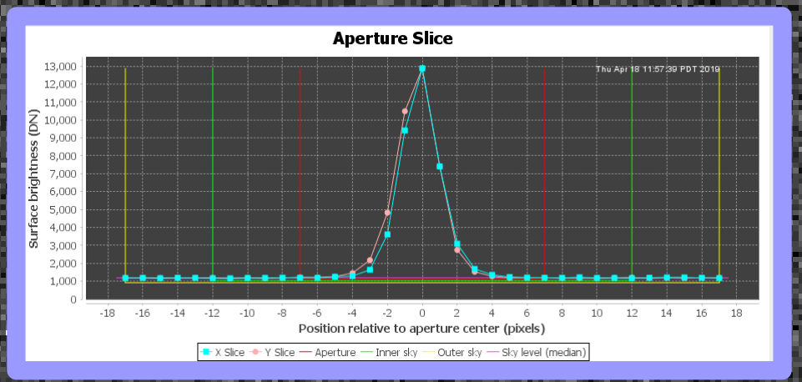

Figure 10

We correct for background in the following manner. APT places three apertures on the sky. The smallest aperture encloses the source. The two outer apertures are chosen to be large enough so that the area between them does not include any contribution from the source, only contribution from the sky background. We show our selected apertures in the Figure 9 and 10. The aperture overlay for the source is the inner red circle and the sky-annulus overlays are the inner green circle and outer yellow circle. We found that the Source aperture overlay needed to be set at 7 pixels. The inner and outer sky-annulus overlays were set to 12 pixels and 17 pixels, respectively. We used APT Model B for the background subtraction. Model B takes the median of the sky computed between the inner and outer sky-annulus. The median value is then subtracted from the signal at each point within the outer aperture. In this manner, we measured the apparent magnitude of 93 Minerva in the 249 images.

Targets	m_g	R.A.	DEC.
Minerva	10.36	Starting: 00:45:18 Ending: 00:45:13	Starting: +4.154° Ending: +4.152°
TYC 14-784-1	10.17	00:45:03	+4.335°
BD+03 101 [6]	9.78	00:44:59	+4.059°
Star 1	11.26	00:45:32	+4.131°
Star 2	11.84	00:45:09	+4.154°
TYC12-1091-1	11.67	00:56:07	+1.074°

Figure 11

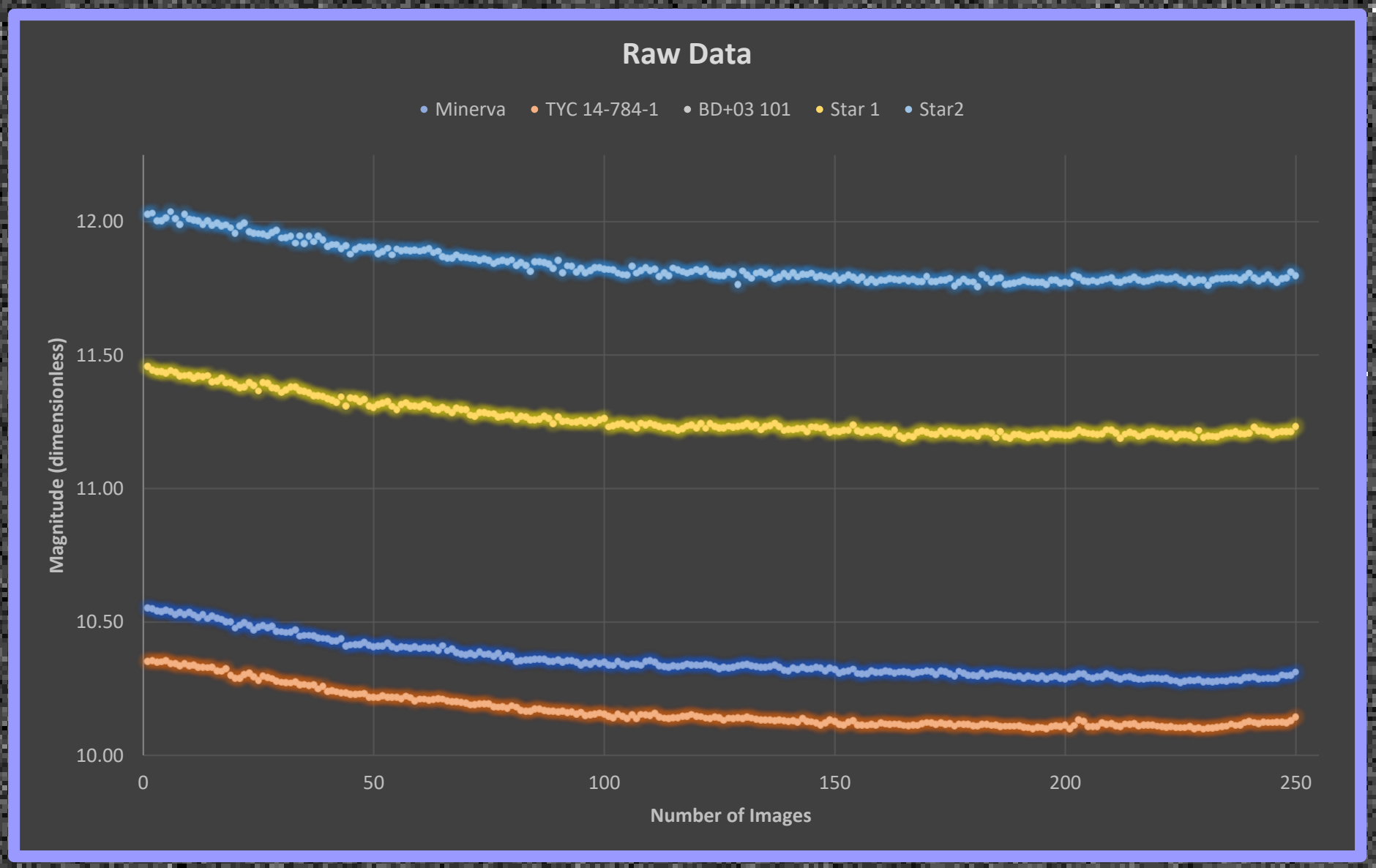

Figure 12

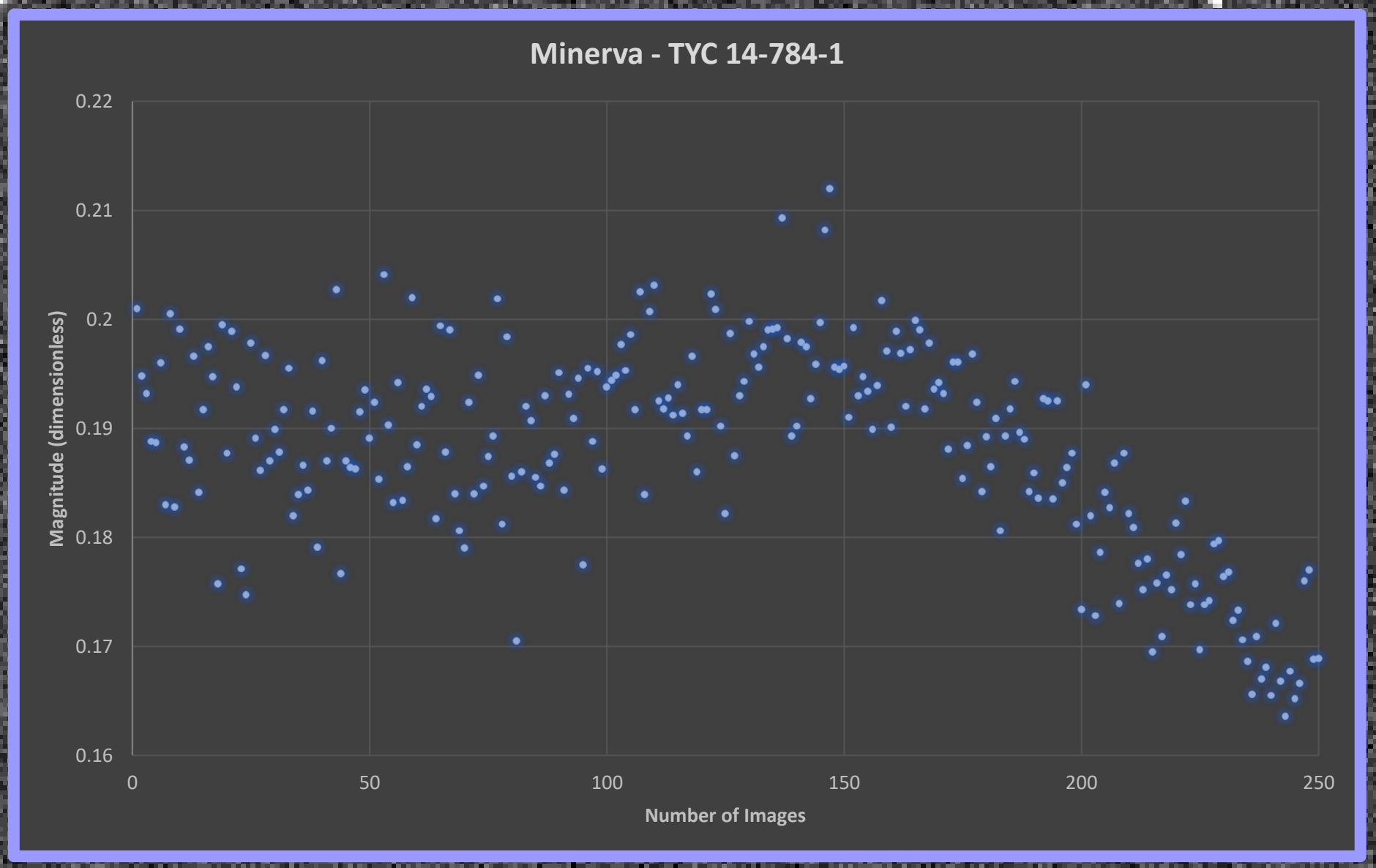

Figure 13

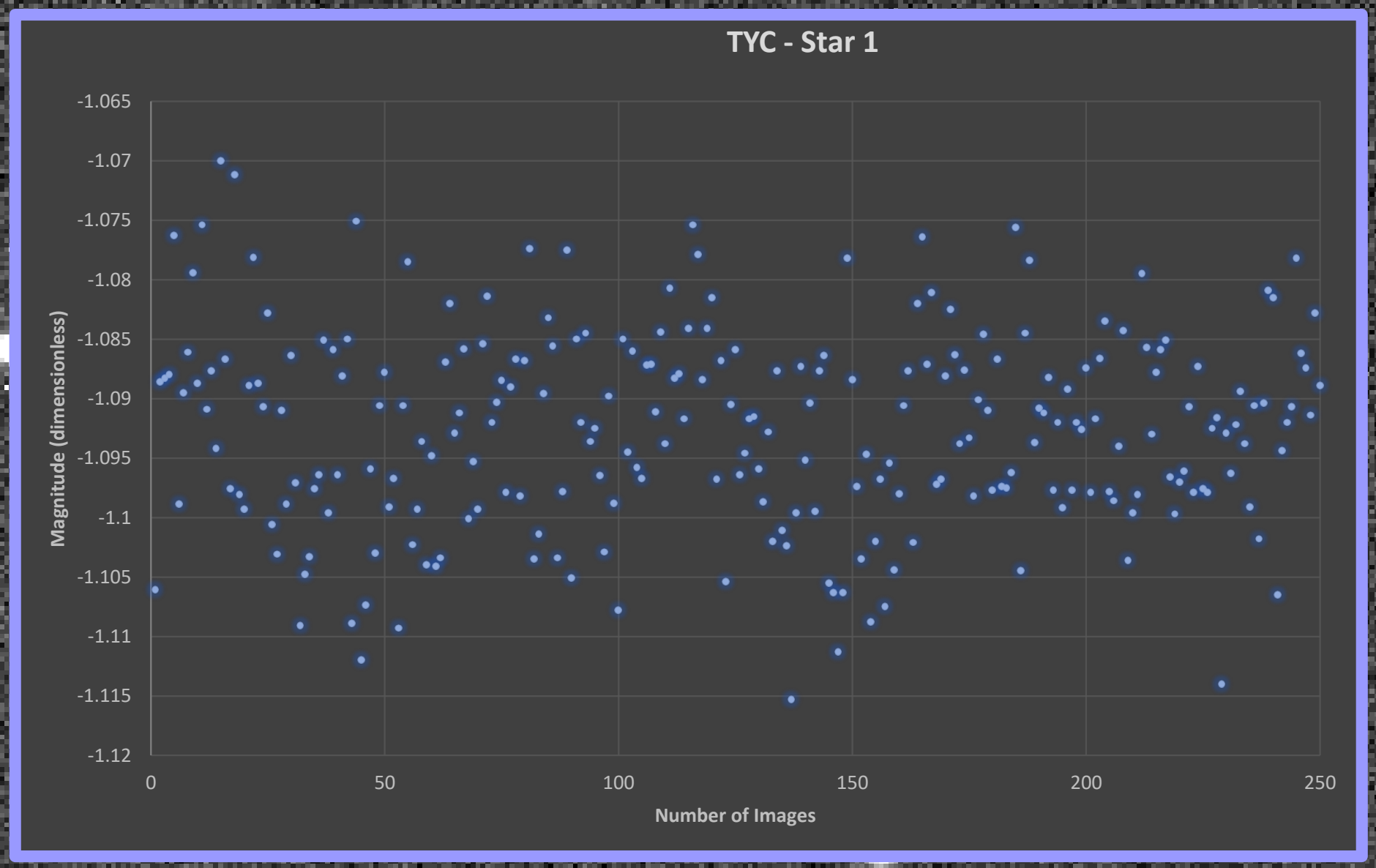

Figure 14

IV. Data Analysis and Results

We observed 93 Minerva on September 5, 2018 from 09:32:42 to 06:33:05 UTC. Here UTC stands for Coordinated Universal Time. The night we observed 93 Minerva, there was smoke from local forest fires which affected our data. We can see that all the observed stars in the field were affected by the smoke due to the fact that even our standard star showed similar downward slope (see figure 12). We correct for the non-optimal observing conditions by subtracting TYC 14-784-1 from 93 Minerva (figure 13). When TYC 14-784-1 was subtracted from comparison Star 1, the residuals were flat with scatter of about 0.01 magnitudes (figure 14). This suggests our uncertainty was on the order of 0.01 magnitudes. We see that 93 Minerva was initially constant in brightness, falling by 0.035 magnitudes in the final 45 minutes. This closely resembles the published light curve of 93 Minerva in figure 15[5]. From the calculations and uncertainty, we have concluded it is very likely we obtained a portion of Minerva's light curve.

In June 2019 we will restart our observing campaign of 93 Minerva with the goal of obtaining > 10 hours of light curve data to ensure we measure one complete rotation of the target. Our 93 Minerva observations will be part of a larger asteroid monitoring program where our goal is to obtain high-quality light curves for roughly 12 asteroids over summer 2019.

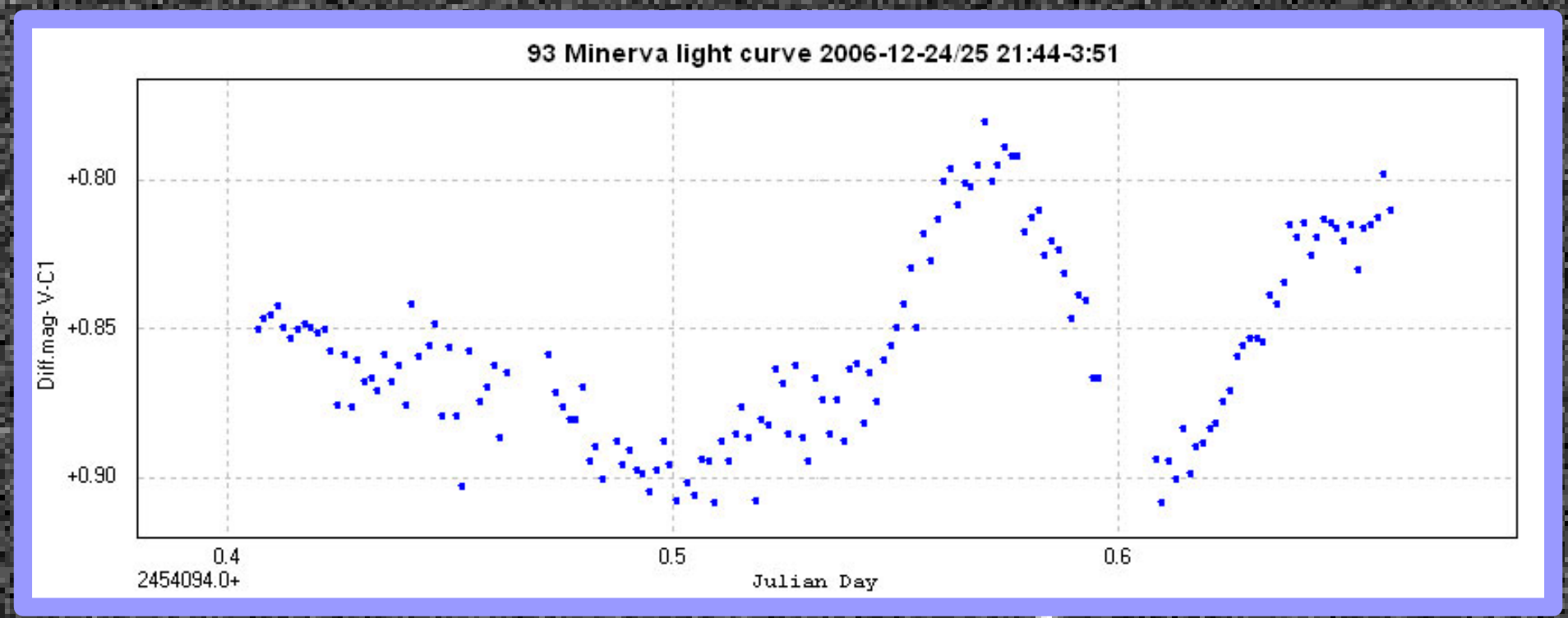

Figure 15

This project was supported in part by funding from the NASA Oregon Space Grant Consortium, the Roundhouse Foundation, and grants from the University of Oregon

[1] Aperture Photometry Tool (Version 2.7.5.). (n.d.). Retrieved from http://www.aperturephotometry.org/aptool

[2]Asteroid Belt vs. Kuiper Belt vs. Oort Cloud. (2014, December 22). Retrieved from http://ryanmarciniak.com/archives/390, 2011 Pearson Education, Inc.

[3]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

[4]Ebbighausen, 1968, PASP, 80, 230E

[5]Haukka, H. (2006, December 26). Retrieved from http://www.taurushill.net/2006/12/26/asteroid-93-minerva-lightcurve-measured-in-taurus-hill-observatory/

[6]SIMBAD query result. (n.d.). Retrieved from http://simbad.u-strasbg.fr/simbad/sim-id?Ident=BD 03 101&submit=submit id

[7]SIMBAD query result. (n.d.). Retrieved from http://simbad.u-strasbg.fr/simbad/sim-id?Ident= TYC12-1091-1&NbIdent=1&Radius=2&Radius.unit=arcmin&submit=submit id

[8]TYC14-784-1. (n.d.). Retrieved from http://simbad.u-strasbg.fr/simbad/sim-id?Ident=TYC14-784-1&submit=submit

[9](n.d.). Retrieved from https://ssd.jpl.nasa.gov/horizons.cgi#results

[10](n.d.). Retrieved from https://ssd.jpl.nasa.gov/sbdb.cgi?sstr=93 Minerva;old#orb