

USING THE PARALLAX METHOD TO DETERMINE THE DISTANCE TO AN ASTEROID

Max Adolphson, Sarah Cantu, Kent Montgomery,
Thomas Renshaw
Texas A&M University-Commerce
PO Box 3011, 2600 W Neal Street
Commerce, TX 75428
maxadolpshon@yahoo.com

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By simultaneously imaging an asteroid from two separate telescopes on Earth, it is possible to use the parallax method to determine its distance. This study outlines the steps necessary and results obtained from using the method on asteroid 166 Rhodope.

The purpose of this project was to measure the distance to an asteroid using its parallax angle as determined by taking synchronized images of it from two different locations on earth.

Telescope time was obtained at the two SARA (Southeastern Association for Research in Astronomy) telescopes, one at Kitt Peak National Observatory in Arizona the other at Cerro Tololo Inter-American Observatory in Chile on the night of 2014 January 2 UT.

Asteroid 166 Rhodope was chosen for this study because it was fairly bright at 9th magnitude, its location in the sky was optimal for both telescopes, and its proximity to earth allowed a large enough parallax angle for an accurate measurement (Figure 1).

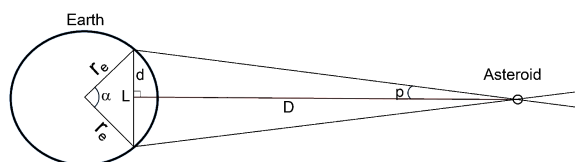


Figure 1. Finding the distance to an asteroid using parallax.

Asteroid 166 Rhodope was discovered in 1876 by C.H.F. Peters (JPL). It is an S-type main belt asteroid with an orbital inclination of 12°. The eccentricity of its orbit is 0.21 with a semi-major axis of 2.68 AU. At the time of the observations Rhodope was at a solar distance of 2.199 AU and an earth distance of 1.460 AU (Figures 2 and 3). These distances were determined using the *MPO Canopus* software program and Rhodope's known orbital elements. (JPL and Warner, 2011)

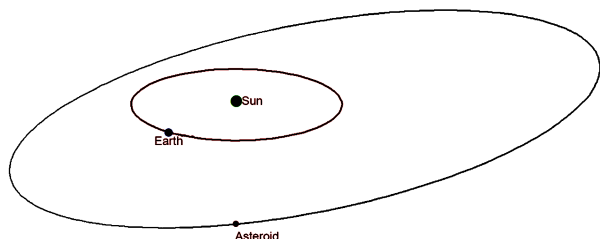


Figure 2. Side view of 166 Rhodope's Orbit

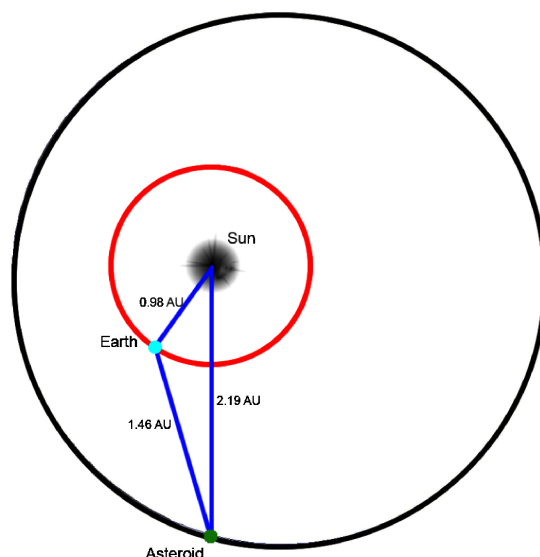


Figure 3. Top view of 166 Rhodope's orbit.

The Parallax Method

The method used to determine the distance to the asteroid using its parallax angle is outlined here. It required determining the parallax angle by operating two telescopes separated by as large a distance as possible. By using images taken simultaneously from both telescopes of the same asteroid and the known physical distance between the telescopes, the distance to the asteroid can then be determined.

The chord length equation was used to find the distance between the two telescopes, see Eq. 1. The known radius of the Earth is r_e and angle α was found by using the difference between the longitude and latitude of the two telescopes (see Figure 1).

$$L = 2r_e \cdot \sin\left(\frac{\alpha}{2}\right) \quad (1)$$

From Eq. 1, L was then used to find d . The value d is necessary in order to complete the triangle of which D , the distance to the asteroid, is one side.

$$d = \frac{L}{2} \quad (2)$$

The angle p was found using the difference in positions of the asteroid on simultaneous images from the two telescopes. Then using trigonometric functions, the distance (D) is found by using equation 3.

$$D = \frac{d}{\tan(p)} \quad (3)$$

Data and Analysis

On 2014 January 2 UT, the Southeastern Association for Research in Astronomy (SARA) telescopes were used for observations of 166 Rhodope. The SARA northern telescope (SARA-N) is located at Kitt Peak National Observatory at a longitude of 111° 35' 59.4" W and latitude of 31° 57' 36.0" N. The SARA southern telescope (SARA-S) located at Cerro Tololo International Observatory is at a longitude of 70° 47' 57.0" W and a latitude of 30° 10' 19.6" S. The SARA-N has a 0.9-m objective mirror and the SARA-S has a 0.6-m objective mirror.

Both telescopes used Apogee Alta E6-1105 CCD cameras cooled with liquid nitrogen to a temperature of -110°C . Images were binned 2x2 pixels which produced effective pixels of 12x12 microns. Images from SARA-S were shot through a luminance 5 filter and the images from SARA-N were taken through an IR-blocking filter. Five images from each telescope were taken. Typical images from both telescopes are shown in Figures 4 and 5.

After reducing the images using calibrated flat fields and biases, it was found that astrometry measurements were unaffected by the reduction process. Thus raw images were actually used to determine the asteroid position in order to measure the right ascension (RA) and declination (Dec). Each image was opened in the software program *MPO Canopus* and the fields matched to the catalog of stars from the MPOSC3 Catalog, which is a combination of data from the Carlsberg Meridian Catalog 14 (CMC-14) and the Sloan Digital Sky Survey (SDSS). The values measured can be found in Table 1. Since there were no significant differences in the right ascension, the difference in declination of each pair of synchronized images was found in arcseconds and averaged. This number was then converted from arcseconds to degrees and divided by two in order to find the parallax angle, p .

Using a known value of the radius of the earth, 6378.1370 km, (NASA) and Eq. 1, the distance between the telescopes was determined.

$$L = 2(6378388m)\sin\left(\frac{62.13211111^{\circ}}{2}\right)$$
$$L = 6582827m$$

Equation 2 was then used to find d , the half-distance of the chord length, L .

$$d = \frac{6582827.4}{2}$$
$$d = 3291415m$$

Equation 3 applies d and the angle p to find the distance between Earth and the asteroid, D .

$$D = \frac{3291415}{\tan 8.5 \times 10^{-4}}$$
$$D = 2.21854934 \times 10^{11}m$$

The final distance measured (D) was then converted into 1.48 AU. using 1 AU = 149,597,871,000 m (Astronomical Unit). The known distance from orbital elements was 1.460 AU as given by *MPO Canopus* (Warner, 2011). The difference in methods gives results similar to within <2%.

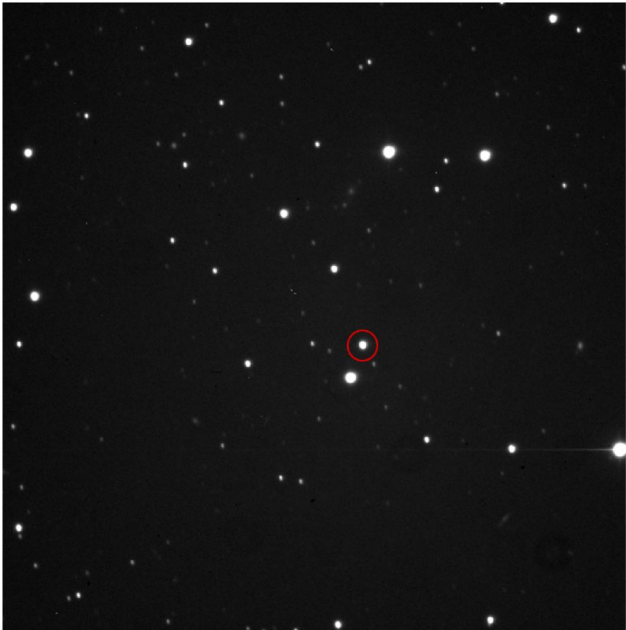


Figure 4. Image taken by SARA North telescope with asteroid position shown.

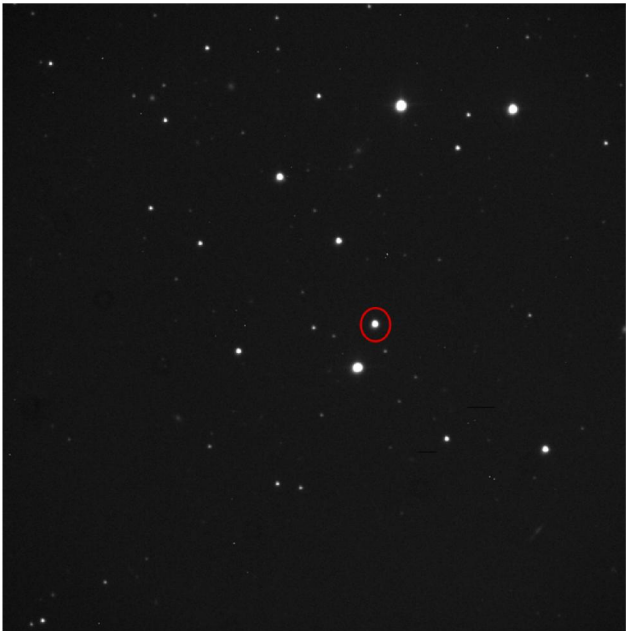


Figure 5. Image taken by SARA South telescope with asteroid position shown.

Image Number	R.A. SARA (S)			Dec SARA (S)			R.A. SARA (N)			Dec SARA (N)			Difference arcsec
	h	min	sec	°	'	"	h	min	sec	°	'	"	
1	3 ^h	28 ^m	39.81 ^s	2 [°]	53'	41.2"	3 ^h	28 ^m	40.05 ^s	2 [°]	53'	35.1"	6.1"
2	3 ^h	28 ^m	39.81 ^s	2 [°]	53'	42.2"	3 ^h	28 ^m	40.05 ^s	2 [°]	53'	36.0"	6.2"
3	3 ^h	28 ^m	39.81 ^s	2 [°]	53'	43.0"	3 ^h	28 ^m	40.05 ^s	2 [°]	53'	36.9"	6.1"
4	3 ^h	28 ^m	39.81 ^s	2 [°]	53'	44.1"	3 ^h	28 ^m	40.05 ^s	2 [°]	53'	38.0"	6.1"
5	3 ^h	28 ^m	39.81 ^s	2 [°]	53'	44.6"	3 ^h	28 ^m	40.04 ^s	2 [°]	53'	38.5"	6.1"
													Avg: 6.12"

Table 1. Measured RA and Declination of the asteroid from two locations and the difference due to parallax.

Conclusion

The purpose of the project was to test the feasibility of determining the distance to an asteroid using the parallax method with two telescopes and simultaneously imaging it. As this paper shows, it can be done with fairly high precession.

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FIRST PHOTOMETRIC OBSERVATIONS OF NEAR-EARTH ASTEROIDS AT TIEN-SHAN ASTRONOMICAL OBSERVATORY

Leonid Elenin

Keldysh Institute of Applied Mathematics RAS
 ISON-NM Observatory (MPC H15), ISON
 140007, Lyubertsy, Moscow region, 8th March str., 47-17
lelenin@gmail.com

Anatoly Kusakin

Fesenkov Astrophysical Institute
 Tien-Shan Astronomical Observatory (MPC N42)

Igor Molotov

Keldysh Institute of Applied Mathematics RAS
 ISON

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In this paper, we present results of our first photometric observations of near-Earth asteroids at high-mountain Tien-Shan Astronomical Observatory (TShAO) of Fesenkov Astrophysical Institute (Republic of Kazakhstan). All observations were carried out on the recently modernized 1-meter Zeiss-1000 telescope. For the first target, we chose near-Earth asteroid (387733) 2003 GS, which did not have a known rotation period at the time. Based on the data, we conclude a rotational period of $P = 2.46 \pm 0.02$ h with the amplitude $A = 0.1$ mag.

Tien-Shan Astronomical Observatory was founded in 1957. It is located 30 km south of Almaty, Republic of Kazakhstan, at 2,750 meters above sea level. The observatory is equipped with several

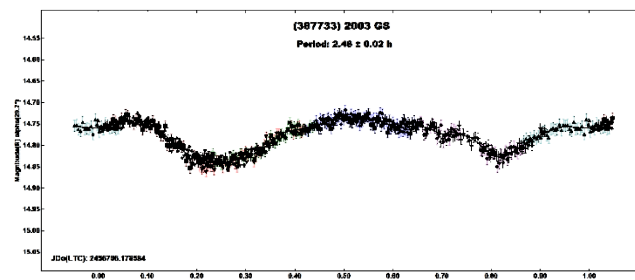
optical telescopes, including two Zeiss-1000 (1-m $f/13$) in the east and west cupolas. These telescopes were upgraded in 2011-2014. During this work, a new telescope control system was installed along with new CCD cameras and a 5-element focal reducer designed by A. Yudin (KIAM, ISON) for the east Zeiss-1000. In this configuration, the telescope has 19x19 arcmin field-of-view. Both telescopes are equipped with Johnson B, V, R filters by *Astrodon Photometrics*. Analysis of images and possible rotation period was carried out using the *MPO Canopus* package (Bdw Publishing).

(387733) 2003 GS. Asteroid (387733) 2003 GS is a near-Earth asteroid (Aten family, $q = 0.6977$ AU, $a = 0.8926$ AU, $e = 0.2184$, $i = 12.032^\circ$), discovered by LONEOS on 2003 Apr. 4 (Marsden, 2003). The asteroid was well-observed during the 2014 apparition, with the rotation period independently defined by several observers: $P = 2.467$ h (Benishek, 2014c; Warner, 2014k) and $P = 2.469$ h (Hicks, 2014e). Observations at TShAO were carried out a week later, 2014 Apr. 18, with a Johnson R filter and 30-sec exposures in orbital tracking mode. Detailed information about the observational runs is shown in Table 1.

t, UT	Δ, AU	r, AU	Θ, deg	$mag.$
2014-04-18T16:17:41	0.093	1.084	29.6	15.2
2014-04-18T21:38:10	0.093	1.083	30.2	15.2

Table 1. Photometric observations of (387733) 2003 GS.

Based on our analysis, we found a rotation period of $P = 2.46 \pm 0.02$ h with a relatively low amplitude $A = 0.1$ mag. This estimate is comparable with the above values.



Acknowledgements

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