

The lightcurve of (150) Nuwa

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Photometric observations of the minor planet (150) Nuwa in 2004 December show that its brightness was varying by 0.26 ± 0.03 magnitudes, with a period of 8.1364 ± 0.0008 hours. Its apparent brightness also varied with phase angle, over the range 14.2 to 18.3° , at a rate of 0.0386 ± 0.0024 magnitudes per degree.

Introduction

In recent years, tens of thousands of minor planets have been discovered, their positions measured and their orbits determined. Much less is known about their physical characteristics. The diameter of a minor planet can be estimated by measuring its brightness in optical and infrared; but its shape is harder to determine.

If a non-spherical body rotates, the area of surface we see will be constantly changing (unless the pole happens to be pointing straight towards us). This means that the amount of reflected light will change too, giving a characteristic double-humped lightcurve. Most medium-sized minor planets have a rotational period between 2.5 and 25 hours,¹ and their lightcurves mostly have amplitudes around 0.1 to 0.2 magnitude; few exceed 0.4 mag.²

The actual magnitude of an object can only be determined accurately by using precious observing time for calibrating reference stars. However, differential photometry is adequate to construct a lightcurve. In this case, the variable (the minor planet) is measured along with a comparison star in the same field, which is assumed to be of constant brightness, and the difference between the two is recorded. A second, check star is also measured, as a precaution against the comparison

star proving to be a previously unrecognised variable. (Newer software allows multiple comparison stars to be used, for higher precision, but this was not available at the time.)

Target selection

For minor planets, there is the added complication that they move: they may cross the small field of view of a CCD in a few hours. If a new comparison star has to be used every night, then different nights' data cannot easily be combined without specialised software. However, any minor planet has occasional stationary points, when its motion in right ascension reverses itself. If the motion in declination is not too great at that time, then the minor planet may stay within the same CCD field for several nights. For main-belt minor planets, the stationary points occur at about 120° elongation from the Sun, so it is possible to list all minor planets currently near that elongation, and then to select those which are performing sufficiently tight loops.

The Minor Planet Center (MPC) maintains a list of published lightcurve parameters of minor planets;³ these are coded by reliability, from 1 (poor) to 4 (good). Those with code 2 offer the non-professional astronomer a chance of doing useful science: their published periods are based on less than full coverage, and may be wrong by 30 percent or so. One such is (150) Nuwa.

(150) Nuwa was discovered in 1875 by J. C. Watson at Ann Arbor; it is named for a character in Chinese mythology.⁴ It lies towards the outer edge of the main asteroid belt, 3 AU from the Sun, in a low-inclination, moderate-eccentricity orbit; its diameter is estimated as 157 km.⁵ In late 2004 December, (150) Nuwa was around magnitude 12.5, and moving in a narrow loop which kept it in the same 17-arcminute field for over 10 days (Figure 1).

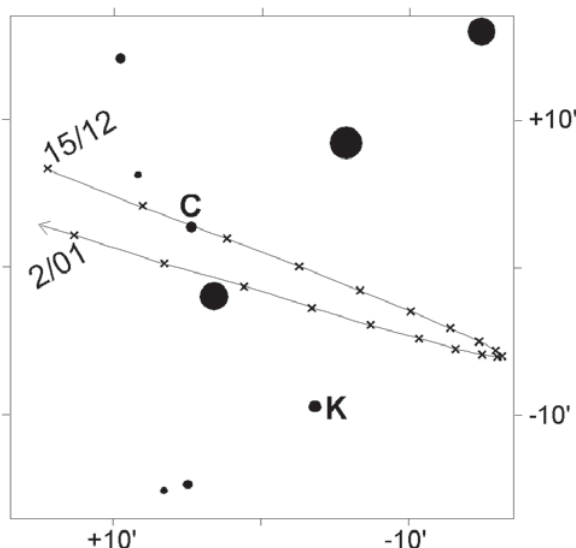


Figure 1. (150) Nuwa at 18h UT from 2004 December 15 to 2005 January 2. The field is 17 arcminutes square, centred on RA 02h36m11s, Dec +13°40'41" (2000.0). Star C (GSC 645:989) was the comparison star for photometry, and star K (GSC 645:557) the check star.

Observations

The observations were carried out at Swilken Brae Observatory in St Andrews, Fife, using an unfiltered Apogee KX260 camera fitted to a 305mm Meade LX200 telescope with a focal reducer. Each pixel on the CCD corresponds to just under 2

arcseconds, giving a total field about 17 arcminutes square.

During the period 2004 December 15 to 2005 January 2, observations were possible on ten nights, for varying periods of time. A total of 483 frames was used in the final analysis; these were mainly 180-second exposures, giving over 24 hours exposure in total. Even with 180-second exposures, the targets were only about 25% saturated; but since the telescope was unguided, longer exposures would have meant an unacceptable number of frames being discarded due to tracking errors.

All these frames were dark-corrected and flat-fielded, and then analysed using *AIP4WIN*.⁶ The comparison star, GSC 645:989, was taken as having a magnitude of 12.56 (the value in the *Guide Star Catalog*); the check star, GSC 645:557, is listed in the same catalogue as magnitude 12.31. GSC magnitudes are known to be unreliable, but only an approximate value is needed here.

Figure 2 shows one night's results. The scatter in the check-star brightness gives an indication of the amount of noise in the data; the standard deviation here is 0.015 magnitudes.

Analysis

The period of (150) Nuwa is given in the MPC list as 8.140 hr.³ The longest sequence of observations was considerably shorter than this, so it was necessary to combine several nights' data to see a complete lightcurve. Unfortunately, they cannot be combined directly, since the apparent brightness of the minor planet is constantly changing, due to the changing Earth-Sun-planet geometry.

The absolute magnitude of a minor planet as defined as the apparent magnitude it would have, if it were at 1 AU from the Sun and 1 AU from the Earth, and fully illuminated. Given its actual distance from the Sun (r) and from the Earth (Δ), we can make a simple inverse-square correction for them by subtracting $5 \log(r\Delta)$. However, the phase-angle effect is not so simple, since most minor planets brighten more at opposition than would be predicted from purely geometrical considerations; this is apparently due to the roughness of the planet's surface. The correction can be taken as $Y \times (\text{phase angle})$, for some unknown constant Y peculiar to each minor planet. During these observations, the phase angle of (150) Nuwa changed from 14.2 to 18.3°, so this correction was significant.

All the magnitudes were corrected for r and Δ , leaving the period P and the phase-angle coefficient Y as unknowns. The original plan was to determine the period, and then to find what value

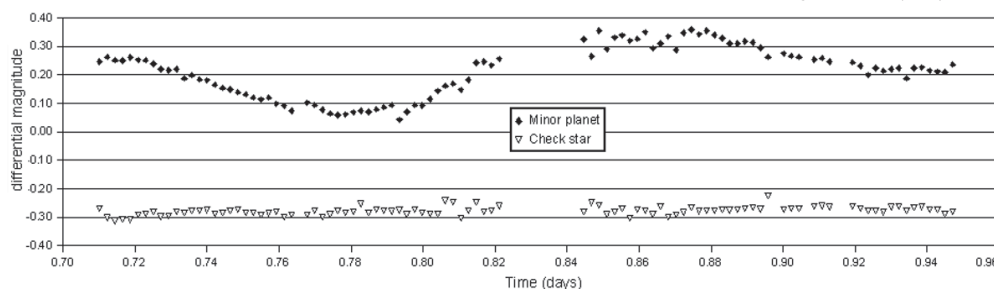


Figure 2. Photometry of (150) Nuwa on 2005 January 2.

of the phase-angle coefficient gave the best fit. However, given the amount of scatter in the data, it proved possible to find several different combinations of P and Y which looked equally good. A different method was therefore used, to quantify the 'goodness of fit'.

A trial period P was chosen, and this was then divided into 30 bins of 16 or 17 points each. All the data points which fell into each bin were combined, and their standard deviation was calculated. The value of the phase-angle coefficient Y was then adjusted until the average standard deviation, over the 30 bins, was as small as possible. The whole process was then repeated with a different trial period P .

Since each bin spanned only 1/30 of the period, the variation due to the actual change in brightness was very small; for an 'ideal' set of noise-free data, the average standard deviation was only 0.009 mag, significantly less than the intrinsic scatter in the data.

A well-defined minimum average standard deviation of 0.020 mag was found, for periods ranging from 0.339005 to 0.339025 day. This suggests that the true period is 0.339015 ± 0.000010 day, or 8.13636 ± 0.00024 hr. However, these figures are unrealistically precise, and this analysis does not allow for possible systematic errors between one night and another (the comparison star, for example, may in fact be slightly variable). Any such systematic errors should also show up in the observations of the check star. The measured magnitude of the check star proved to be consistent, from night to night, to within 0.01 mag.

Around phase 0.8, the lightcurve is changing most rapidly, at 0.28 mag/hr; here an uncertainty of 0.01 mag corresponds to an uncertainty of 0.0357 hr. At this point the lightcurve is determined by observations from 2004 December 17 and 2005 January 2, which are separated by 47 com-

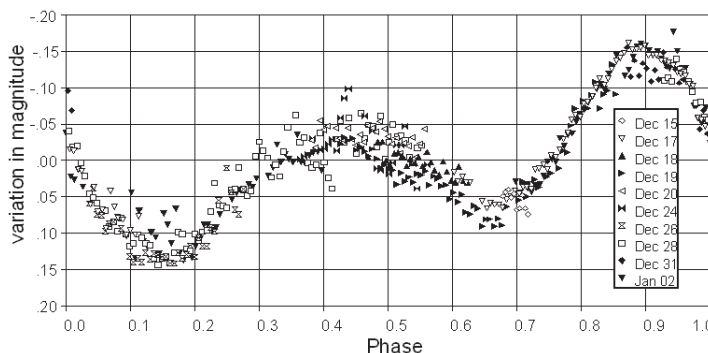


Figure 3. All the observations of (150) Nuwa combined, assuming a period of 8.13636 hr and a phase-angle correction of 0.03859 mag/degree. Phase= 0.0 at 2004 December 15 04:00 UT.

plete cycles; so the average uncertainty in each cycle is 0.00076 hr – three times the formal error. Therefore the most probable rotation period is 8.1364 ± 0.0008 hours.

The corresponding best value for the phase-angle coefficient was found to be 0.03859 mag/deg, with a formal uncertainty of 0.0006 mag/deg. However, since each night's observations was only accurate to 0.01 mag, and the observations spanned 4.1° of phase angle, the estimated uncertainty is 0.0024 mag/deg.

Figure 3 shows all the data, combined using these values.

Comparison with earlier observations

In 1996, Blanco *et al.*⁷ determined the period of (150) Nuwa as 8.140 ± 0.005 hr. This research confirms and refines that period. Figure 3 also compares favourably with a lightcurve from 2005 January published on the Geneva Observatory website.⁸

However, the MPC list of lightcurve parameters³ lists the variation in brightness of (150) Nuwa as only 0.09 mag, whereas Figure 3 indicates a variation of at least 0.25 mag. In 1998, Blanco & Riccioli⁹ gathered published observations and plotted the magnitude variation against heliocentric longitude, in order to determine the position of the rotation pole; their plot for (150) Nuwa (p.390), based on only a handful of points, shows the amplitude ranging from approximately zero (at longitude 90 and 260°) to 0.1 mag (at longitude 170 and 350°). The present observations, which were carried out with the minor planet around longitude

125° , clearly show that this object exhibits more significant rotational changes in brightness, depending on its ecliptic position, than previously reported.

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References

- 1 Pravec P. *et al.*, 'Asteroid Rotations', in Bottke, W., *et al.* (eds.), *Asteroids III*, University of Arizona, 2002, p.115
- 2 Cunningham C. C., *Introduction to Asteroids*, Willmann-Bell, 1988, p.64
- 3 <http://cfa-www.harvard.edu/iau/lists/LightcurveDat.html>
- 4 Schmadel Lutz D., *Dictionary of Minor Planet Names*, Springer-Verlag, 1992, pp.39–40
- 5 Cunningham, *op.cit.*, p.148
- 6 Berry R. & Burnell J., *The Handbook of Astronomical Image Processing*, Willmann-Bell, 2000
- 7 Blanco C. *et al.*, *Planet. Space Sci.*, **44**, 93–106 (1996)
- 8 <http://obswww.unige.ch/~behrend/r000150a.png>
- 9 Blanco C. & Riccioli D., *A&A Suppl. Ser.*, **131**, 385–394 (1998)

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