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Photometry of Near Earth Asteroids at McDonald Observatory

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Abstract. The McDonald Observatory Near Earth Object (NEO) group has been involved in confirmation and follow-up efforts since 1995. Expanding this program from astrometry to astrophysics, we are attempting to derive refined absolute magnitudes and rotational periods for Near Earth Asteroids including potentially hazardous objects. We have obtained lightcurves for 2002 EZ11, 2001 CC21, 2003 UV11, 65803 (1996 GT), and 2003 SS84. We were able to determine rotational periods for 2002 EZ11 and 2001 CC21 and identified a short period brightness variation superimposed on a longer trend for the other minor planets. The rotational periods were determined using Singular Spectrum Analysis, which has proven to perform quite well on short, noisy time series. 2003 SS84 and 65803 (1996 GT) were also observed at Arecibo and Goldstone providing a comparison for our results. This research is funded by NASA's NEO Observation Program Grants NAG5-10183 and NAG5-1330.

1. Introduction

Asteroid rotation rate statistics are essential in understanding the dynamical and physical evolution of a planetary system. To correctly deduce the frequency and severity of possible collisions with Earth, we need to know their physical properties. We have rotational periods for about 300 Near Earth Asteroids (NEAs), while the number of known NEAs is now about 3600. The rotation rate distribution of NEAs is non-Maxwellian, and it is not consistent with collisional processes (Harris 2002). The lightcurves also provide information on the size and shape of the asteroids, which in combination with the rotation rates can constrain the bulk density. The variation in brightness is mostly due to rotation for single asteroids, but it can be complex if the asteroid is tumbling. For binaries, it is a combination of rotation and orbital geometry.

2. Observational Aspects

We use differential CCD photometry in the R band with the Prime Focus Camera on the 30 inch telescope at McDonald Observatory. Our limiting magnitude is near $M_{\rm V} = 22$, using a 15 min exposure. Exposure times are limited by the lack of telescope tracking in declination, or by trailing stellar images in right ascension for fast moving objects. We restrict our exposures to less than 300 seconds in order to collect sufficient numbers of points for our time series analysis. We also assume that the sky is uniform enough over our field of view to carry out relative photometry, or, in other words, that conditions are stable during the exposure.

3. Time Series Analysis

We use Singular Spectrum Analysis (SSA, Ghil et al. 2002), which was originally developed to deal with short and noisy time series in geophysics. SSA decomposes the time series using the eigenvalues and eigenvectors of a matrix, with elements that are lagged autocorrelations. The largest eigenvalues correspond to the largest oscillatory components in the time series, the smaller ones to noise. A single dominant oscillation is usually represented by a pair of eigenvalues of similar magnitudes (Fig. 1a).

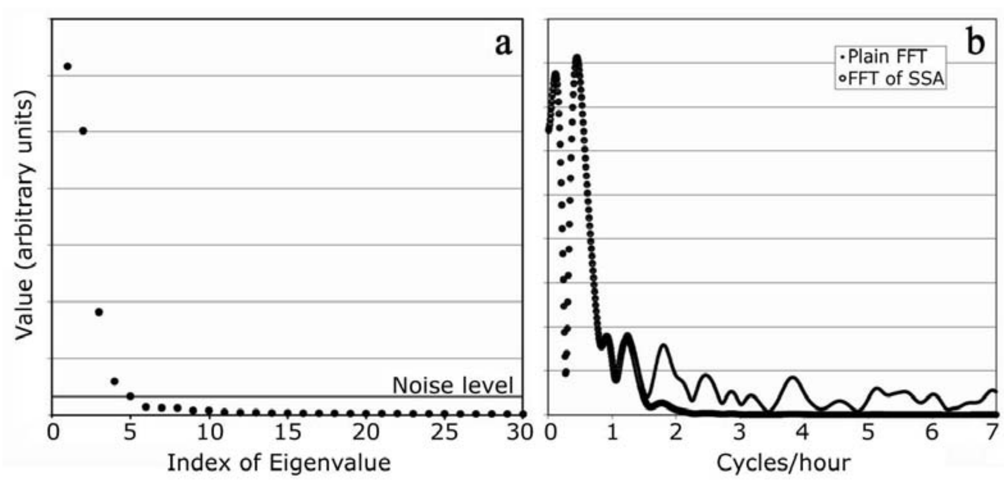

Figure 1. SSA determined eigenvalues for (65803) 1996 GT (a) and a comparison of the Fourier spectrum of the original and the filtered data (b).

The eigenvectors associated with the eigenvalues provide moving average filters. Filtering with the eigenvectors of the largest eigenvalues reconstructs the strongest signals above the noise (Fig. 1b). The filters are data-adaptive, not necessarily sinusoidal, and can accommodate modulations in the amplitudes of the oscillations.

4. Results

In 2003, we observed 2002 EZ11 during bright time, through the R filter, spanning 6.5 hours. We found a 0.10 ± 0.02 magnitude peak-to-peak variation in instrumental (relative) magnitudes (Ries et al. 2003). The large field of view of the prime focus corrector (PFC) insured that we had enough comparison stars for a well-determined relative photometric measurement, although the object moved more than 2 degrees on the sky during the night.

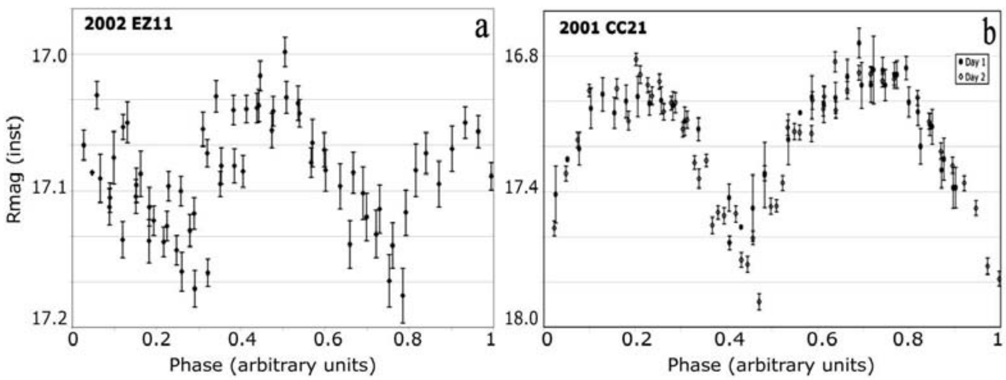

Figure 2. Composite lightcurves created by folding the time series onto one full phase with the periods determined from SSA.

The lightcurve of 2002 EZ11 (Fig. 2a) is simple. We assumed, that the variations are due to rotation, and that the shape of the asteroid can be approximated by a triaxial ellipsoid, giving two brightness peaks during one revolution. The SSA decomposition indicated one dominant period at 1.16 hours. If our assumption is correct, 2002 EZ11 is not an unusually fast rotator. However, the 2.32 hour period combined with the small amplitude and its **H** (absolute magnitude, defined as the magnitude of an asteroid at zero phase angle and at unit heliocentric and geocentric distances), indicates that it is close to the upper limit of spin rates for bodies held together by self gravity only. We observed (98943) 2001 CC21 on two consecutive nights, and had enough data to obtain separate period estimates. For the composite lightcurve (Fig. 2b) we used 5.02 hours, which is between the two separate estimates. (We did correct for brightness change due to changing distance, but not for light travel time difference.) This rotation rate is not unusual, but the amplitude of the lightcurve is 2 or 3 times larger than the average (0.2 mag) for a typical NEA. Table 1 summarizes the asteroids for which we have obtained lightcurves. (**H** is adopted from the Minor Planet Center (MPC) database and M(V) is the estimated visual magnitude at the time of the observations.)

Table 1. NEAs observed at McDonald Observatory

Designation	Date	Phase(deg)	**H**	M_V	ΔM_R	Period(h)
65803	11/27/2003	$8.3 - 7.6$	18.4	13.4	≈ 0.25	2.29*
98943	12/1, 2/2003	$23 - 24$	18.6	17.5	≈ 0.8	5.02
2002 EZ11	2/17/2003	$38 - 35$	18.1	15.6	0.10	2.32
2003 SS84	9/28/2003	24.8	21.8	18.1	≥ 0.3	TBD
2003 UV11	10/28/2003	$20 - 22$	19.4	15.5	≥ 0.3	TBD

Our quick-look photometry program calculates catalog magnitude and instrumental magnitude averages after removing the largest reference star outliers. The differences of the averages are used to correct for changing sky conditions. Although these values have some error due to scatter in the catalog averages, by

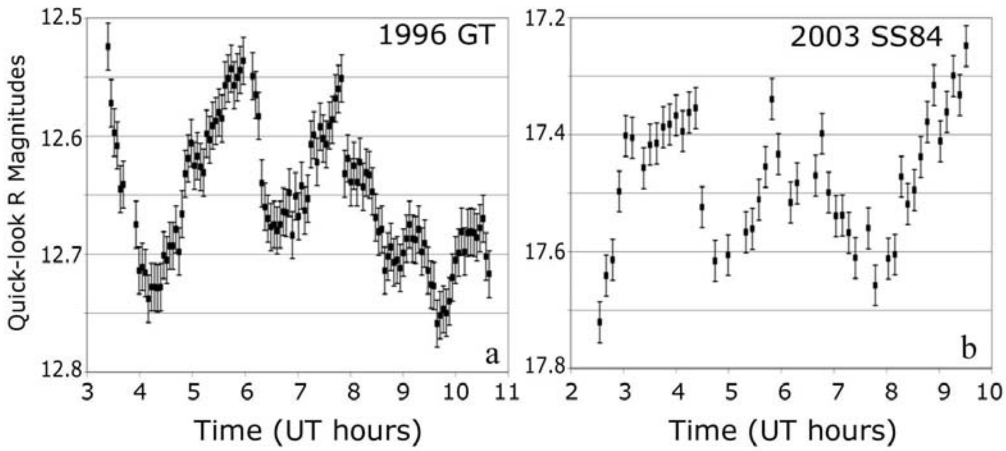

Figure 3. Quick-look lightcurves. 1996 GT, a binary, has a complex lightcurve (a). While the quick-look data is noisy, we were able to recover the 2.29 hr short period variations reported by Pravec et al. (2005).

the end of the night we can determine whether the target merits follow-up and rigorous calibration (Fig. 3).

5. Summary

Due to the nature of NEA orbits, the viewing geometry changes rapidly, so lightcurves from different observing runs cannot be combined without performing a complete analysis of the orbital position and rotational state of the asteroid. However, with lightcurves obtained at different orbital phases, we can determine **H** and can attempt to determine the orientation of the rotation axis, the general size, and the aspect ratio of the asteroid (Kaasalainen & Torppa 2001). We need more observations for a period determination for 2003 UV11, which shows short period variations superimposed on a longer trend. The source 2003 SS84 also requires detailed observations since it is a binary, and its lightcurve is made more complex by the orbital motion of its components.

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