CCD and photon-counting photometric observations of asteroids carried out at Padova and Catania observatories

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Abstract

We present the results of observational campaigns of asteroids performed at Asiago Station of Padova Astronomical Observatory and at M.G. Fracastoro Station of Catania Astrophysical Observatory, as part of the large research programme on Solar System minor bodies undertaken since 1979 at the Physics and Astronomy Department of Catania University. Photometric observations of six Main-Belt asteroids (27 Euterpe, 173 Ino, 182 Elsa, 539 Pamina, 849 Ara, and 984 Gretia), one Hungary (1727 Mette), and two Near-Earth Objects (3199 Nefertiti and 2004 UE) are reported. The first determination of the synodic rotational period of 2004 UE was obtained. For 182 Elsa and 1727 Mette the derived synodic period of $80.23 \pm 0.08$ h and $2.981 \pm 0.001$ h, respectively, represents a significant improvement on the previously published values. For 182 Elsa the first determination of the $H-G$ magnitude relation is also presented.

Key words:
Asteroids, photometric observations, lightcurves, synodic rotational period, H-G relation

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1 Introduction

Photometric observations of asteroids, through the lightcurves collection, allow us to determine their rotational parameters (synodic rotational period, spin axis orientation, sense of rotation, etc.) and physical properties (shape, colour indexes, surface dishomogeneity, taxonomic class, etc.). The knowledge of the rotational characteristics is important to understand the collisional evolution of single minor planets, of families and of the whole asteroidal population. It is also essential to check the action of the so-called Yarkovsky-O’Keefe-Radzievski-Poddak (YORP) effect on smaller asteroids. It seems to become clear that the spin characteristics of super-fast and slow rotators are the result of the torque from solar radiation and re-radiation (Harris, 2006) with the collisional processes determining the excitation of the tumbling motion on slow rotators.

The results reported in this paper are part of the large photometric observational programme of asteroids undertaken since 1979 at the Physics and Astronomy Department of Catania University (Blanco & Catalano, 1979; Di Martino, 1984; Di Martino et al., 1994; Blanco & Riccioli, 1998; Riccioli et al., 2001). The aim of this long-term programme is to increase the number of asteroids with well-known rotational parameters and consequently improve the database necessary for the investigation of the minor planet evolutionary history. Special attention has been devoted to the asteroids with observational constraints and to those with few known lightcurves, in order to obtain the minimum number needed to apply pole coordinates and shape computational methods (Blanco & Riccioli, 1998). Since the study of Near-Earth Objects (NEOs) is important to improve the knowledge of inner Solar System mechanics and physics (resonance mechanisms, smaller bodies dynamics, connection with meteorites, etc.), we have recently expanded our programme to include these objects.

In this paper we present new photometric observations of six Main-Belt asteroids, 27 Euterpe, 173 Ino, 182 Elsa, 539 Pamina, 849 Ara, and 984 Gretia, one Hungaria object, 1727 Mette, and two NEOs, 3199 Nefertiti and 2004 UE.

The values of the synodic rotational period, lightcurve amplitudes, and $B-V$ colour index of almost all the observed asteroids are presented. For 182 Elsa and 1727 Mette the rotational periods we derived represent a significant improvement on the previously published values. For 182 Elsa also the $H-G$ magnitude relation (Bowell et al., 1989) was obtained. The first observed lightcurve of the small NEO 2004 UE might indicate an elongated shape and possible smooth surface.

The outline of the paper is as follows: we describe our observations and data
reduction in Section 2; the results and comments on each single object are reported in Section 3.

2 Photometric observations and data reduction

The photometric observations reported in this paper were carried out at two different observatories using different telescopes and instruments.

CCD imaging photometry was obtained during three observing runs at the Asiago Station of Padova Astronomical Observatory (hereafter PD station), by using the 67/92-cm Schmidt telescope. Unfiltered CCD photometry was performed with the SCAM-1 camera in January and February 2003 with mostly clear and stable weather conditions (mean seeing $\approx 2.0''$). The SCAM-1 camera hosts a front illuminated $2048 \times 2048$ LORAL CCD with a 15 $\mu$m pixel-size. Taking into account the telescope plate scale (95.9 $''$/mm), the resulting projected sky area was about $49' \times 49'$ with an angular resolution of about $1.44''$/pixel. Further CCD photometric observations were carried out using the same telescope equipped with the ITANET camera (Blanco et al., 2004; Gandolfi et al., 2006), hosting a front illuminated $2048 \times 2048$ Kodak-KAF 4200 CCD, with 9 $\mu$m pixel-size. The observations were performed through V and R Johnson filters in April 2003 and November 2004, under photometric weather conditions with seeing varying between 1.5 and 2.0 $''$. Taking into account the telescope plate scale and the detector pixel-size, the resulting field of view turned out to be $29' \times 29'$ with an angular resolution of 0.89 $''$/pixel. The exposure time during both campaigns varied from 2 to 5 minutes, depending on the asteroid magnitude.

CCD image pre-reduction, including bias, dark, and flat-field correction, was made with standard IRAF[1] routines. Nightly twilight flat-fields were used to correct images for optical vignetting, dust shadow, and pixel-to-pixel sensitivity variation. In order to maximize the asteroid signal-to-noise ratio (especially in cases of elongated images of fast moving asteroids), elliptical aperture photometry was performed using the SExtractor software (Bertin & Arnouts, 1996). A set of comparison stars, each having magnitudes similar to that of the observed asteroid, was selected along the object nightly path. From this set of stars, the non-variable star with the highest signal-to-noise ratio was chosen as the nightly comparison star. Due to a filter wheel technical problem no fields of standard star were observed during both runs. Therefore only differential photometry was obtained from CCD imaging data.

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA), inc., under cooperative agreement with the National Science Foundation.
Photoelectric photometry was carried out in November 1993, December 1996, and July, September, October and November 2004 at the 91-cm Cassegrain telescope of M.G. Fracastoro Station of INAF-Catania Astrophysical Observatory (hereafter CT station). The observations were performed with the Johnson $B$ and $V$ standard filters. A 1.5-mm diameter diaphragm, limiting the telescope field to about 22", and a cooled photon-counting single-head photometer equipped with an EMI 9893QA/350 photomultiplier were used. Nearby solar type comparison stars were selected along the asteroid path to neglect the second-order chromatic effects of atmospheric extinction. The $B$ and $V$ linear extinction coefficients were derived each night through the comparison stars. In order to determine the transformation coefficients to the Johnson standard system, several standard stars, selected from Mermilliod et al. (1997), Blanco et al. (1968), and Landolt (1992), were also observed during each night. The observing strategy and data reduction were the same as those already adopted during previous observational campaigns of asteroids (Di Martino et al., 1994).

Both for CCD and photoelectric data, the final error of the single measurements is on average between $\sim 0.01$ and 0.02 mag. On the basis of the asteroid aspect data, the time corresponding to each data point was corrected for light-travel time and, when determined, the standard $V$ magnitudes were also reduced to the unit geocentric and heliocentric distances ($V(1,\alpha)$). The value of the synodic rotational period, the composite lightcurve, the mean reduced magnitude $\bar{V}(1,\alpha)$, and the nightly magnitude shifts were obtained by applying the Fourier analysis, as described in Harris et al. (1989).

The nightly aspect data for each asteroid observed at PD and CT station are listed in Table 1. The first column reports the mean Universal Time (UT) of the nightly observational interval, rounded to a hundredth of a day. The other columns give the heliocentric ecliptic longitude and latitude, asteroid-Sun ($r$) and asteroid-Earth ($\Delta$) distances, and solar phase angle ($\alpha$) at the mean-time of each observing night. For the asteroids observed at CT station, the value of the mean reduced magnitude $\bar{V}(1,\alpha)$ are also reported. The filters used and observatory’s site are listed in the last two columns.
Table 1: Aspect data of the asteroids. The heliocentric ecliptic longitude (\(\lambda\)) and latitude (\(\beta\)), asteroid-sun (\(r\)) and asteroid-Earth (\(\Delta\)) distances, and solar phase angle (\(\alpha\)) are referred to the nightly mean UT listed in the first column. When derived, the mean reduced magnitude (\(\bar{V}(1,\alpha)\)) is also reported. The filters used and observatory’s site are listed in the last two columns.

| Mean UT (yy/mm/dd) | \(\lambda\) (2000) (degree) | \(\beta\) (2000) (degree) | \(r\) (AU) | \(\Delta\) (AU) | Phase Angle (degree) | \(\bar{V}(1,\alpha)\) (mag) | Filters | Obs. |
|-------------------|--------------------------|--------------------------|--------|--------|-----------------|-----------------|--------|-----|
| 27 Euterpe        |                          |                          |        |        |                 |                 |        |     |
| 1993 Nov 13.89    | 21.21                    | -1.52                    | 2.150  | 1.390  | 21.119          | –                | BV    | CT  |
| 1993 Nov 14.88    | 21.53                    | -1.52                    | 2.148  | 1.398  | 21.435          | –                | BV    | CT  |
| 2004 Nov 06.04    | 44.63                    | -1.22                    | 2.038  | 1.048  | 1.349           | 7.062           | BV    | CT  |
| 2004 Nov 07.00    | 44.97                    | -1.21                    | 2.037  | 1.047  | 1.152           | 7.087           | BV    | CT  |
| 2004 Nov 09.06    | 45.72                    | -1.20                    | 2.034  | 1.045  | 1.610           | 7.079           | BV    | CT  |
| 173 Ino           |                          |                          |        |        |                 |                 |        |     |
| 1996 Dec 07.05    | 101.99                   | -10.39                   | 2.575  | 1.773  | 15.398          | 8.820           | BV    | CT  |
| 1996 Dec 08.02    | 102.22                   | -10.35                   | 2.577  | 1.767  | 15.090          | 8.811           | BV    | CT  |
| 1996 Dec 16.07    | 104.15                   | -10.02                   | 2.595  | 1.722  | 12.376          | 8.690           | BV    | CT  |
| 2004 Jul 18.00    | 299.41                   | 6.99                     | 2.513  | 1.513  | 5.319           | 8.435           | BV    | CT  |
| 2004 Jul 19.03    | 299.66                   | 6.93                     | 2.511  | 1.509  | 5.085           | 8.416           | BV    | CT  |
| 2004 Jul 20.04    | 299.92                   | 6.88                     | 2.509  | 1.506  | 4.888           | 8.423           | BV    | CT  |
| 2004 Jul 20.98    | 300.15                   | 6.83                     | 2.506  | 1.503  | 4.740           | 8.398           | BV    | CT  |
| 2004 Jul 22.04    | 300.41                   | 6.77                     | 2.504  | 1.500  | 4.616           | 8.417           | BV    | CT  |
| 182 Elsa          |                          |                          |        |        |                 |                 |        |     |
| 2004 Sep 09.02    | 2.64                     | -1.94                    | 2.106  | 1.172  | 13.829          | 9.875           | BV    | CT  |
| 2004 Sep 10.02    | 2.98                     | -1.94                    | 2.104  | 1.165  | 13.372          | 9.927           | BV    | CT  |
| 2004 Sep 11.04    | 3.33                     | -1.94                    | 2.102  | 1.158  | 12.897          | 9.829           | BV    | CT  |
| 2004 Sep 12.04    | 3.67                     | -1.95                    | 2.100  | 1.152  | 12.425          | 9.772           | BV    | CT  |
| 2004 Sep 13.08    | 4.02                     | -1.95                    | 2.099  | 1.145  | 11.924          | 9.847           | BV    | CT  |
| 2004 Sep 13.98    | 4.33                     | -1.95                    | 2.097  | 1.140  | 11.489          | 9.589           | BV    | CT  |
| 2004 Sep 15.06    | 4.70                     | -1.95                    | 2.095  | 1.134  | 10.953          | 9.835           | BV    | CT  |
| 2004 Sep 16.06    | 5.05                     | -1.96                    | 2.094  | 1.128  | 10.453          | 9.818           | BV    | CT  |
| 2004 Sep 21.02    | 6.76                     | -1.97                    | 2.086  | 1.104  | 7.889           | 9.699           | BV    | CT  |
| 2004 Oct 12.83    | 14.43                    | -2.00                    | 2.053  | 1.064  | 5.331           | 9.622           | BV    | CT  |
| 2004 Oct 17.94    | 16.26                    | -2.00                    | 2.046  | 1.072  | 8.163           | 9.717           | BV    | CT  |
| 539 Pamina        |                          |                          |        |        |                 |                 |        |     |
| 2004 Sep 11.00    | 1.24                     | 6.80                     | 2.162  | 1.213  | 11.907          | –               | BV    | CT  |
| 2004 Sep 12.03    | 1.59                     | 6.80                     | 2.161  | 1.208  | 11.477          | –               | BV    | CT  |
| 849 Ara           |                          |                          |        |        |                 |                 |        |     |
| 2004 Sep 15.90    | 339.39                   | 18.29                    | 2.672  | 1.789  | 12.597          | 8.941           | BV    | CT  |
| 2004 Sep 20.85    | 340.63                   | 18.15                    | 2.679  | 1.819  | 13.488          | 8.945           | BV    | CT  |
| 984 Gretia        |                          |                          |        |        |                 |                 |        |     |
| 2003 Feb 01.80    | 50.45                    | 9.07                     | 2.353  | 2.424  | 23.748          | –               | –     | PD  |
| 2003 Feb 06.80    | 51.92                    | 9.04                     | 2.360  | 2.488  | 23.275          | –               | –     | PD  |
| 2003 Feb 07.81    | 52.22                    | 9.04                     | 2.362  | 2.501  | 23.172          | –               | –     | PD  |
| 2003 Feb 09.79    | 52.80                    | 9.03                     | 2.364  | 2.527  | 22.963          | –               | –     | PD  |
Table 1: Continued.

| Mean UT  | $\lambda$ (2000) | $\beta$ (2000) | r   | $\Delta$ | Phase Angle | $\bar{V}(1, \alpha)$ | Filters | Obs. |
|----------|------------------|----------------|------|---------|-------------|----------------------|---------|------|
| (yy/mm/dd) | (degree) | (degree) | (AU) | (AU)   | (degree) | (mag)     | Used |
| 1727 Mette |                  |                |      |         |             |                       |         |
| 2003 Jan 31.11 | 136.42 | 1.40 | 1.723 | 0.750 | 7.676 | – – | PD |
| 2003 Feb 06.02 | 138.86 | 2.42 | 1.729 | 0.747 | 4.246 | – – | PD |
| 2003 Feb 06.96 | 139.25 | 2.59 | 1.730 | 0.747 | 3.980 | – – | PD |
| 2003 Apr 01.88 | 161.00 | 11.18 | 1.793 | 1.091 | 29.440 | – R | PD |
| 2003 Apr 04.93 | 162.22 | 11.61 | 1.797 | 1.122 | 30.120 | – V | PD |
| 2003 Apr 05.96 | 162.62 | 11.75 | 1.799 | 1.133 | 30.330 | – R | PD |
| 2003 Apr 07.93 | 163.40 | 12.03 | 1.801 | 1.153 | 30.706 | – R | PD |
| 2003 Apr 08.88 | 163.78 | 12.16 | 1.802 | 1.163 | 30.876 | – V | PD |
| 3199 Nefertiti |                  |                |      |         |             |                       |         |
| 2003 Feb 01.11 | 150.47 | 6.18 | 1.647 | 0.792 | 24.738 | – – | PD |
| 2003 Feb 07.13 | 152.66 | 4.78 | 1.669 | 0.765 | 20.176 | – – | PD |
| 2004UE |                  |                |      |         |             |                       |         |
| 2004 Nov 09.08 | 47.86 | -0.08 | 1.010 | 0.025 | 39.128 | – R | PD |

3 Results

With the exception of Figure 5, where the $\bar{V}(1, \alpha)$ vs. phase angle of 182 Elsa is plotted, the composite lightcurves are presented in Figures [1][11]. Different symbols refer to different observing nights. Only for the objects observed at CT station, the magnitude shifts, applied to the single night lightcurve to obtain the composite one [Harris et al., 1989], are reported in brackets near the observing date. The rotational phases were computed according to the synodic rotational period reported in each Figures and Table 2. The period reliability codes [Harris & Young, 1983], lightcurve amplitude, and mean $B-V$ colour index, as well as the Tholen’s taxonomic class [Tholen, 1989] and diameter (Jet Propulsion Laboratory database, JPL [2]; Near Earth Objects Dynamic Site, NeoDys [3]) are also listed in Table 2.

The potential of the data published in the present paper can be fully exploited when combined with other observations from different apparitions to derive pole positions and shape models. For this reason the present data are completely available upon request.

[2] http://www.jpl.nasa.gov/
[3] http://newton.dm.unipi.it/cgi-bin/neodys/neoibo
Table 2: Synodic rotational period value, period reliability code (Harris & Young, 1983), lightcurve amplitude, mean $B-V$ colour index, taxonomic class (Tholen, 1989), and diameter (JPL and NeoDys database) of the observed asteroids.

| Asteroid   | $P_{\text{syn}}$ (hours) | Reliability Code $^\dagger$ | Light. Amp. (mag) | $B-V$ (mag) | Taxonomic Class | Diameter (km) |
|------------|---------------------------|------------------------------|-------------------|------------|----------------|---------------|
| 27 Euterpe | 10.377±0.008              | 2                            | 0.14±0.02 $^a$    | 0.84±0.02  | S              | 96            |
| 173 Ino $\dagger$ | 6.113±0.002              | 3                            | 0.13±0.01 $^a$    | 0.71±0.01  | C              | 154           |
| 173 Ino $\ddagger$ | 6.111±0.002              | 3                            | 0.14±0.01 $^a$    | 0.71±0.01  |                |               |
| 182 Elsa   | 80.23±0.08                | 3                            | 0.69±0.02 $^a$    | 0.86±0.01  | S              | 44            |
| 539 Pamina | –                         | 1                            | –                 | 0.71±0.01  | –              | 54            |
| 849 Ara    | 4.117±0.001               | 3                            | 0.26±0.01 $^a$    | 0.70±0.01  | M              | 62            |
| 984 Gretia | 5.780±0.001               | 3                            | 0.66±0.02 $^b$    | –          | –              | 32            |
| 1727 Mette | 2.981±0.001               | 3                            | 0.26±0.01 $^b$    | –          | S              | 7             |
| 1727 Mette $\ast$ | 2.981±0.002              | 3                            | 0.22±0.01 $^a$    | –          |                |               |
| 1727 Mette $\ast\ast$ | 2.981±0.002              | 3                            | 0.20±0.01 $^c$    | –          |                |               |
| 3199 Neferiti | 3.021±0.002               | 3                            | 0.19±0.02 $^b$    | –          | S              | 2             |
| 2004 UE    | 5.6±0.2                   | 2                            | 0.98±0.02 $^c$    | –          | –              | 0.17-0.38     |

$^\dagger$ Meaning of the reliability code: 1) Result based on fragmentary lightcurves. Insufficient data to estimate a period value; 2) the result is based on less than full coverage, so that the period may be wrong by 30% or so; 3) a sure result with no ambiguity and full lightcurve coverage.

$^\ddagger$ December 1996; $^\ast$ January-February 2003; $^\ast\ast$ April 2003.

The first determination of the synodic rotational period of 27 Euterpe was reported by Chang & Chang (1962), who observed this asteroid during three nights in December 1961 and January 1962, obtaining a value of $P_{\text{syn}} = 8.500 \text{ h}$. Their complete lightcurve shows two asymmetrical maxima and minima having different levels, with an amplitude of $\sim 0.15 \text{ mag}$. Further photometric observations of 27 Euterpe were performed by Lagerkvist et al. (1988), who derived the slope parameter $G$ and the absolute magnitude $H$, and by Denchev et al. (1998), who observed this asteroid only for four hours on January 22, 1991 through the $U$ filter, reporting an amplitude of 0.12 mag. During the 2001 apparition, Stephens et al. (2001) estimated a longer synodic rotational period of $10.410 \pm 0.002 \text{ h}$, obtaining an “interesting lightcurve with a single strong peak confirmed by multiple nights of observations and a very weak secondary peak”.

Our first observations of 27 Euterpe, performed in November 1993 at CT station, are too few to give a reliable estimation of the rotational period value.
Figure 1. Composite $V(1, \alpha)$ lightcurve of 27 Euterpe vs. rotational phase. The zero phase corresponds to JD 2453317.0 (corrected for light-travel time). Different symbols refer to different observing nights. The magnitude shifts derived by applying the Fourier analysis method to each night lightcurve in order to obtain the composite curve are reported in brackets after the dates. The rotational phases were computed according to the synodic rotational period reported in the lower right corner of the Figure and in Table 2.

The derived mean $B - V$ colour index is $0.83 \pm 0.02$ mag. We again, we observed this asteroid from the same site during three nights in November 2004, obtaining a lightcurve covering about 80\% of the rotational phase (Figure 1). The derived value of the synodic rotational period is $10.377 \pm 0.008$ h, slightly shorter than the Stephens et al.’s (2001) one. The amplitude of the lightcurve is $0.14 \pm 0.02$ mag; the mean $B - V$ colour index is $0.85 \pm 0.02$ mag, in agreement with our previous determination. If a maximum were located between the 0.2 - 0.4 phase interval, as it seems to be present both in ours and Stephens et al.’s (2001) lightcurve, 27 Euterpe would have a three maxima and minima lightcurve.

3.2 173 Ino

The first observations of this C-type asteroid are by Lagerkvist (1978) and Schober (1978). The former detected photometric variations but with no indication of both rotational period and lightcurve amplitude; the latter observed 173 Ino during three nights in 1977, obtaining an asymmetric lightcurve with the extrema at different level and an amplitude of 0.04 mag. The best fit of the photometric data was obtained using a synodic rotational period of
Figure 2. Composite V(1, α) lightcurve of 173 Ino vs. rotational phase as derived from the photometric data collected in December 1996. The zero phase corresponds to JD 2450430.0 (corrected for light-travel time). See the caption of Figure 1 for further details.

5.93 ± 0.01 h. Using Schober’s period, Di Martino & Cacciatori (1984) covered about 70% of the rotational phase, deriving an amplitude of about 0.11 mag. A longer period was found by Debehogne et al. (1990) and by Erikson (1990), who reported $P_{\text{syn}} = 6.15 ± 0.02$ h and $P_{\text{syn}} = 6.11 ± 0.06$ h, respectively. Michalowski (1993) and De Angelis (1995), using the lightcurves from the 1977, 1983, and 1988 oppositions, computed the spin axis direction, triaxial shape, and sense of rotation of 173 Ino. The former author also derived the sidereal rotational period $P_{\text{sid}} = 0.256798$ d and a new value of the diameter ($D = 159$ km) of this asteroid. Michalowski et al. (2005) performed additional photometric observation during the 1998, 1999, and 2002 apparitions, improving both the shape model and pole orientations, and deriving a new value of the sidereal rotational period ($P_{\text{sid}} = 0.2548546 ± 0.0000004$ d).

We observed 173 Ino during three nights in December 1996 at CT station (Figure 2), deriving a $B - V$ colour index of $0.71 ± 0.01$ mag, in good agreement with previous determinations (Tedesco, 1989). According to a synodic rotational period of 6.113 ± 0.002 h, we obtained a two maxima and two minima symmetric lightcurve with an amplitude of $\sim 0.13 ± 0.01$ mag.

Further $B$ and $V$ observations were carried out at the same site during five nights in July 2004. We derived a synodic rotational period of 6.111 ± 0.002 h and a $B - V$ colour index of $0.71 ± 0.01$ mag, both in good agreement with our previous determination. The composite V(1, α) lightcurve shows four symmet-
Figure 3. Composite $V(1, \alpha)$ lightcurve of 173 Ino vs. rotational phase as derived from the photometric data collected in July 2004. The zero phase corresponds to JD 2453206.0 (corrected for light-travel time). See the caption of Figure 1 for further details.

Seric extrema at the same respective level and an amplitude of $0.14 \pm 0.01$ mag (Figure 3). The 1996 and 2004 lightcurves show a similar shape and behaviour. Two small jumps seem to appear during the minima phases in the 2004 lightcurve (Figure 3); one of them is clearly visible also in the 1996 lightcurve (Figure 2).

### 3.3 182 Elsa

From previous photoelectric observations of 182 Elsa carried out by Harris et al. (1980, 1992) during the 1978 and 1981 apparitions, only an indication of the rotational period value was given ($\sim 80$ h).

Our observations of this S-type asteroid were performed at CT station during eleven nights, between September and October 2004. We derived a value of the synodic rotational period of $80.23 \pm 0.08$ h. The composite $V$ lightcurve shows a nearly symmetrical sinusoidal trend with an amplitude of $0.69 \pm 0.02$ mag (Figure 4). The two maxima have the same height, while the minima show different levels. The mean value of $B - V$ colour index is $0.86 \pm 0.01$ mag.

During our eleven-night photometric run, the solar phase angle of 182 Elsa varied between $\sim 5^\circ$ and $14^\circ$. We used the nightly mean reduced magnitudes $\bar{V}(1, \alpha)$ to obtain a least-squares fit of the $H - G$ magnitude relation, as
Figure 4. Composite $V(1, \alpha)$ lightcurve of 182 Elsa vs. rotational phase as derived according to the synodic rotational period reported in the Figure and in Table 2. The zero phase corresponds to JD 2453271.0 (corrected for light-travel time). Due to the great number of observing nights, the same point-symbol was used for all the nights. For the same reason, neither the observing dates nor the nightly magnitude shifts were reported in the Figure.

described by Bowell et al. (1989). The mean reduced magnitude $\bar{V}(1, \alpha)$ and fitted phase curve, both vs. phase angle, are plotted in Figure 5. The best-fitting value for $H$ and $G$ is $9.26 \pm 0.09$ mag and $0.34 \pm 0.12$, respectively. The latter result is consistent with the S-type taxonomic classification of this asteroid.

3.4 539 Pamina

This asteroid was observed only during one night in August 1981 by Harris et al. (1992), who obtained a mean $B-V$ colour index of $0.70 \pm 0.01$ mag, detecting a magnitude variations but without any indication of a possible rotational period or amplitude. The first complete lightcurve was obtained by Prav (2005) who derived a synodic rotational period of $13.903 \pm 0.001$ h, with an amplitude of $0.10 \pm 0.01$ mag.

Our observations were carried out during two nights in September 2004 at CT station. We found a mean $B-V$ colour index value of $0.71 \pm 0.01$ mag, in good agreement with the one reported by Harris et al. (1992). Due to the poor sampling of our data, we were not able to construct a significant composite lightcurve, even using the period value reported by Prav (2005).
3.5 849 Ara

The only published lightcurve of this M-type asteroid was obtained during six observing nights in May-June 1981 by Harris et al. (1992), who found a synodic rotational period of 4.11643 ± 0.00005 h.

849 Ara was observed at CT station on September 15 and 20, 2004. We derived a synodic rotational period value of 4.117 ± 0.001 h, in very good agreement with the one reported by Harris et al. (1992). The well-covered composite lightcurve (Figure 6) shows four extrema as well as an amplitude of 0.26 ± 0.01 mag. The lightcurve behaviour appears irregular, with a linear trend before and after the highest maximum peak and falling-in and jumps in the remaining lightcurve parts. The mean $B-V$ colour index is 0.70 ± 0.01 mag, in good agreement with the one reported by Tedesco (1989).

3.6 984 Gretia

The first lightcurve of 984 Gretia was obtained from photographic plates by van Houten (1962) who derived a synodic rotational period of 5.76 h. This value was improved to 5.781 h by Di Martino (1984) and Piironen et al. (1994). Additional observations were performed by two of the present authors (Riccioli et al., 2001) who obtained a synodic period of 5.560 ± 0.018 h, i.e. about two hundredth shorter than the one previously published by Di Martino (1984) and Piironen et al. (1994).
Figure 6. Composite $V(1, \alpha)$ lightcurve of 849 Ara vs. rotational phase. The zero phase corresponds to JD 2453266.0 (corrected for light-travel time). See the caption of Figure 1 for further details.

The present data of 984 Gretia were obtained during four nights in the first decade of February 2003 at PD station using the SCAM-1 CCD camera, without filters. Figure 7 reports the relative magnitude lightcurve, phase folded with the $5.780 \pm 0.001 \text{ h}$ synodic rotational period value, in good agreement with the one reported by Piironen et al. (1994) and Di Martino (1984). The lightcurve behaviour is regular with four symmetric extrema at different level and an amplitude of $0.66 \pm 0.02$ mag.

3.7 1727 Mette

The asteroid 1727 Mette is a relatively small object ($D \approx 7 \text{ km}$; Wisniewski & McMillan, 1987), belonging to the Hungaria zone, as defined by Zellner et al. (1985). Previous CCD photometric observations were reported by Wisniewski & McMillan (1987), Prokof'eva et al. (1992), and Sarneczky et al. (1999), who derived unreliable synodic rotational periods of $2.637 \pm 0.004 \text{ h}$ and $3.22 \pm 0.22 \text{ h}$, on the basis of poor-sampled and incomplete lightcurves.

We observed 1727 Mette using the CCD SCAM-1 camera at PD station. The observations were performed in white-light during three nights in January and February 2003. The composite lightcurve (Figure 8) shows an amplitude of $0.26 \pm 0.01 \text{ mag}$ and an almost symmetric trend with four well-defined extrema at different depth and height. We derived a synodic rotational period of $2.981 \pm 0.001 \text{ h}$, improving the previous determinations.
Figure 7. Unfiltered composite lightcurve of 984 Gretia vs. rotational phase. The zero phase corresponds to JD 2452675.0 (corrected for light-travel time). See the caption of Figure 1 for further details.

Figure 8. Unfiltered composite lightcurve of 1727 Mette vs. rotational phase. The zero phase corresponds to JD 2452675.0 (corrected for light-travel time). See the caption of Figure 1 for further details.
In order to confirm our result, further $V$ and $R$ photometric observations were carried out during five nights in April 2003, at the same observing site using the CCD ITANET camera. We derived a synodic rotational period of $2.981 \pm 0.002 \, h$, in perfect agreement with our previous value. The $V$ and $R$ lightcurve are plotted in Figure 9. They both show a trend similar to that of Figure 8 as well as four well-defined extrema at slightly different levels. The $V$ and $R$ lightcurve amplitudes are $0.22 \pm 0.01$ and $0.20 \pm 0.01$ mag, respectively. Despite the lightcurve amplitude usually increases with increasing phase angle, the latter values are slightly lower than our previous determination. This might be due to a variation of the aspect angle between the two observing runs. In fact the viewing/illumination geometry can also play a role in changing the amplitude of the lightcurve.

3.8 3199 Nefertiti

The first photometric observations of this S-Amor NEA were performed by Harris & Young (1985) who obtained a synodic rotational period of $3.01 \, h$ and an amplitude of $0.12$ mag. During the 1986 apparition Wisniewski (1987) derived a shorter value of $2.816 \, h$. Pravec et al. (1997) using photometric data from the 1982, 1984, 1994, and 1995 apparitions, obtained a synodic rotational period of $3.0207 \pm 0.0002 \, h$, close to the value reported by Harris & Young (1985). Kaasalainen et al. (2004), thanks to a long-term photometric data-set spanning from 1982 to 2003, obtained a rotational period value of $3.020167 \, h$, as well as the pole position and shape model.

We observed 3199 Nefertiti during two nights in January and February 2003 using the SCAM-1 CCD camera at PD station. The composite unfiltered lightcurve, (Figure 10), shows a nearly sinusoidal trend with four well-defined extrema, as well as an amplitude of $0.19 \pm 0.02$ mag. We derived a synodic rotational period of $3.021 \pm 0.002 \, h$, in good agreement with the values obtained by Pravec et al. (1997) and Kaasalainen et al. (2004).

3.9 2004 UE

This small Apollo-type asteroid ($D \sim 0.17$-0.38 km) was discovered by the LINEAR survey in October 2004. We observed this asteroid at PD station using the CCD ITANET camera. $R$ filter photometric observations were collected during its close path to the Earth in November, 2004, when the asteroid reached its maximum apparent $V$ brightness of about 14.2 mag. Unfortunately, we were able to observe 2004 UE only during one night both due to bad weather conditions and the short time-span of the favorable apparition.
Figure 9. Composite $\Delta V$ and $\Delta R$ lightcurve of 1727 Mette vs. rotational phase. The zero phase corresponds to JD 2452736.0 and JD 2452735.0, respectively (corrected for light-travel time). See the caption of Figure 11 for further details.

The $R$ lightcurve is presented in Figure 11. We derived a synodic rotational period value of $5.6 \pm 0.2$ h and a magnitude variation of $0.98 \pm 0.02$ mag. The lightcurve shows a smoothed trend with four nearly symmetrical extrema. The large amplitude value and the regular trend of the lightcurve might indicate an elongated shape without large surface dishomogeneities.
Figure 10. Composite unfiltered lightcurve of 3199 Nefertiti vs. rotational phase. The zero phase corresponds to JD 2452675.0 (corrected for light-travel time). See the caption of Figure 1 for further details.

Figure 11. Composite ΔR lightcurve of 2004 UE vs. rotational phase. The zero phase corresponds to JD 2453319.0 (corrected for light-travel time). See the caption of Figure 1 for further details.
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