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Rotation period and lightcurve analysis of Main Belt Objects: a challenge for small telescopes

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Abstract. Abstract In this work I present the results of the asteroid lightcurve test program in my backyard observatory, in Gagliano del Capo (Le). A 210 mm Dall-Kirkam f/11.5 telescope was fitted with a Sbig ST7 CCD Camera. The observational goal was to determine rotation periods for unknown asteroids and to contribute to long term synoptic projects, e.g. pole determinations. Each asteroid observed was chosen because it entered in opposition in the October - December 2004 period, and it was selected for ESO-VLTI Science Demonstration Time. In spite of the modest aperture of the telescope and the low performance of the CCD camera, it was possible to obtain good results.

1. Introduction

In the last ten years, the number of asteroids discovered has increased considerably above all thanks to the many surveys dedicated to them. At the end of December 2003, about 220000 objects were inserted in the MPCORB database. Nevertheless, knowing more about this population, from the point of view of their rotational evolution, is still a challenge. As a matter of fact, on the same period, the number of minor planets in the Minor Planet Lightcurve Parameters database added up to 1391 objects. If the situation is analysed in detail, it becomes evident that there are really only a little more then one hundred objects of which we know the most important physical characteristics. In accordance with the scheme suggested by Harris & Young (1983), a reliability code is assigned to the lightcurve which gives some information about the precision of the found rotation period. Code 1: the period is based on a fragmentary lightcurve, and may be completely wrong; Code 2: the period is based on less than full coverage, so that the period may be wrong by approximately 30%. It is also used to indicate cases where an ambiguity exists (for example, the true period may be 3/2, 2/3 or some other harmonic of the reported value). Hence the result may be wrong by an integer ratio. Code 3 indicates a definite result with no ambiguity (full lightcurve coverage). Code 4 denotes that, in addition to full coverage, a pole position is reported. The sample of the 1391 considered objects is divided as shown in Tab. 1.

It is plain that it is necessary to enlarge the present set of data regarding the asteroid population's rotational parameters in order to obtain an unbiased, statistically significant sample of their principal physical parameter. Photometric observation and lightcurve analysis are powerful tools in this respect. As a matter of fact, (see "A Guide to Minor Planet Photometry") they:

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Table 1.

CODE	MINOR PLANET
1	188
2	542
3	558
4	103
Total	1391

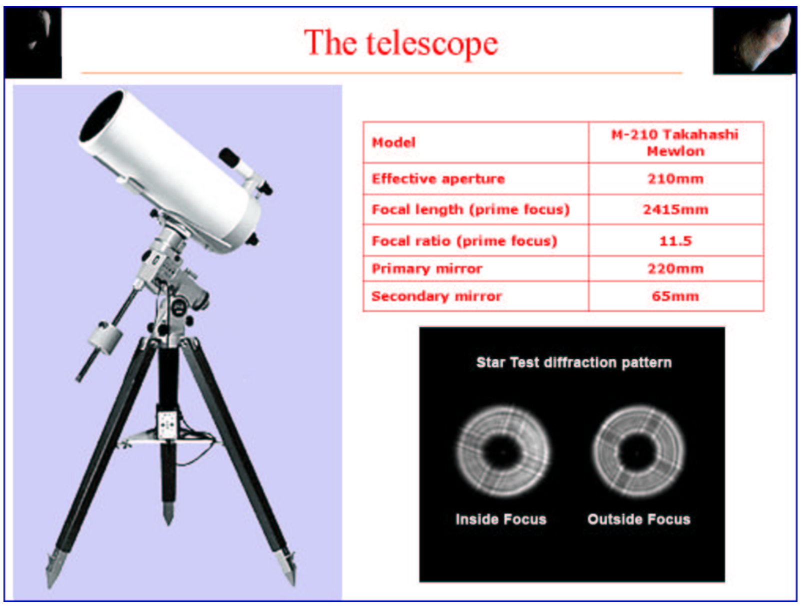


Fig. 1. The telescope used in this work.

1. help to determine the correlation between rotation period and size, spectral class, location in the asteroid belt, etc.

2. can find out, if any asteroids with a period of < 2.25h above 100m exist. There are several asteroids smaller than 100m with periods < 2.25h, some as short as a few minutes. These asteroids are almost certainly not "rubble piles" but of solid composition.

3. are able to find "slow rotators". These are asteroids with periods of days and even months. A new theory has been proposed that may explain the reason some asteroids have such long rotation periods, but more data on more objects is needed.

4. are used for long term studies of a given asteroid which can determine the phase coefficients, i.e., the absolute magnitude and slope parameters that define the asteroid's brightness, especially near opposition when the "opposition effect" causes the asteroid to brighten faster than at larger phase angles.

5. are able to obtain lightcurves over several months at a given apparition and to repeat this process during several apparitions for the determination of the rotation axis orientation and even the asteroid shape.

6. enable shape determinations during an occultation, when the asteroid passes in front of a star.

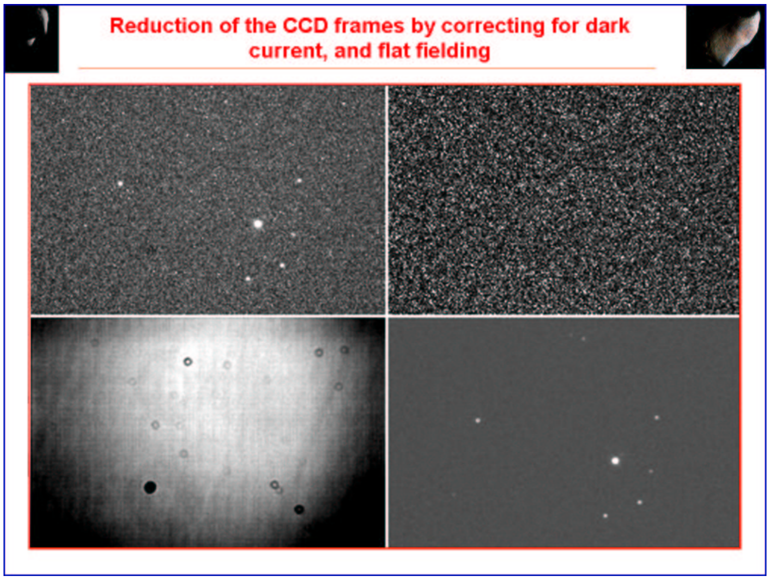


Fig. 2. CCD calibration frames.

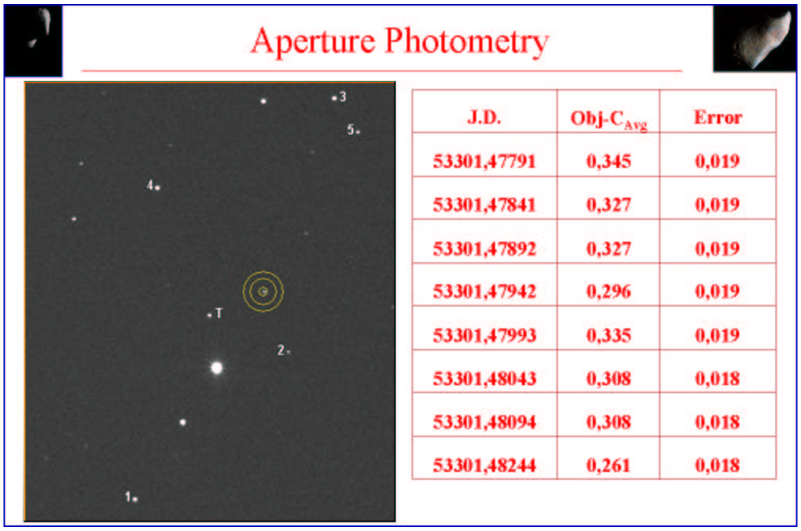
7. can be taken at the same time as radar observations to better determine the size, shape, and nature of the asteroids. Such efforts have helped to discover or confirm several binary asteroids.

8. remove the observational bias towards brighter main belt asteroids. The more complete the sampling of asteroid lightcurves, the better astronomers can develop theories concerning the origin and dynamics of the minor planet system.

The aim of this work is to demonstrate that it is possible to provide an important contribution even with a telescope of the 20 cm aperture category and a dated CCD sensor. Many asteroids have a lengthened shape, like a potato. During its rotation, the asteroid surface reflects light which varies continuously, passing through maximum and minimum phases. These variations are easily identifiable in the lightcurve. Generally, two maximums and two minimums are present, but there are more exotic asteroids with three extremes per cycle. In the case of a bimodal curve, in good approximation, the time elapsed between two adjacent maximums and minimums is equal to half a period. Analysing the database mentioned above, it becomes evident that a great number of asteroids have rotation periods that are about ten hours shorter. This makes it possible to obtain a good part or the whole of the curve in a single observation, at least during the winter. Besides, in proximity to the opposition the asteroids become reasonably bright (V mag < 15) with a lightcurve width up to 0.6-0.7 magnitude. As a matter of principle, it is therefore possible to exploit the high quantum efficiency of CCD detectors and obtain a good light curve also with a modest aperture telescope.

2. The telescope and the CCD camera

In this test, a 210mm f/11.5 Dall-Kirkham telescope supplied with highlevel optics corrected to $\lambda/20$ RMS was used (see Fig.1), coupled with a Sbig ST7 CCD camera with an old Kodak KAF400 ABG sensor. The CCD detectors are characterised by a linear response to a good part of the dynamic range, and this makes them devices especially suitable for photometric measurements. The old sensors equipped with antiblooming (ABG), however rapidly lose this fundamental characteristic. In the case analysed, a series of tests done on purpose, demonstrated a non-linear trend



J.D.	Obj-C_{Avg}	Error
53301,47791	0,345	0,019
53301,47841	0,327	0,019
53301,47892	0,327	0,019
53301,47942	0,296	0,019
53301,47993	0,335	0,019
53301,48043	0,308	0,018
53301,48094	0,308	0,018
53301,48244	0,261	0,018

Fig. 3. Aperture photometry example. T is the target, numbered stars are reference stars.

of the sensor above 9000-9500 ADU. For the magnitude 13 objects, the maximum integration time was about 40 seconds, with a signal to noise ratio near 100; translated to magnitudes, these measurements are of about 0.01 m precision. The ST7 Camera also has a high Dark Current value (0,2 e^{-}/sec at 0°C) producing a signal which, combined with the sky background signal, makes it difficult to single out and even more so, to measure weak stars. The quantum efficiency in the R band is about 35-40%, a rather low value if compared with the new sensors which reach 50-60%. With a 2415 mm focal length, the sensor's field of view is about 10x7', whereas the sampling is approximately 0.72 sec/pixel. Generally, night time seeing does not permit the employment of the full resolution and therefore we resort to binning (2x2 or 3x3).

3. The observations

The asteroids chosen for this test were in opposition in the October-December 2004 period. The adverse meteorological conditions, nevertheless, allowed for only a few observation sessions, which concentrated on two objects: (1459) Magnya and (378) Holmia. Both the asteroids had been chosen as targets for ESO-VLTI Science Demonstration Time observations.

(1459) Magnya was situated at about 1,4 astronomical units from Earth and of magnitude 13 in the V band, whereas (378) Holmia was at about 1,6 astronomical units from Earth and of magnitude 13,7 (October 2004).

The Main Belt Objects move approximately 0.25deg/day; during 8 hours they change their position by about 4' and this almost always makes it possible to use the same stars as a reference for all the observation session. Moreover, by chosing, as for as possible the best sky fields where the asteroids appeared, accompanied by many reference stars of similar magnitudes, and by performing the observation when the asteroids were sufficiently above the horizon in order to decrease the variation of the air-mass, the image taking procedures become easier and the effect of color-dependent variation in atmospheric extinction is minimised. The photometric integration time of 40 seconds was used for every asteroid. CCD technology also allows for the taking of a great number of images to compensate for a low S/N ratio and poor seeing conditions. The photometric observations were taken using no filters and no data transformation to B or V was attempted. In order to achieve the best photometric precision possible, it was necessary to process the image very carefully. Even the best CCDs are a matrix of pixels, each with its own sensitivity, sometimes with defects such as dead clusters and their own dark current. Moreover, light reaching different parts of the CCD array is generally not uniform because of telescope vignetting and shadowing by dust on mirrors and CCD windows. Therefore, it is necessary to process the images with calibration frames. A masterdark frame, obtained from the average of a adeguate number of same length darks and at the same temperatue of the science frame was used, as well as a masterflat frame obtained from the median combination of a suitable number of dome flats.

4. Data analysis

A differential aperture photometry was performed on each image to determine the differential magnitude of the asteroid with the check star. Differential photometry means that one measures the difference between a comparison (or average of several comparisons) and the target. The result is sometimes called the ”Delta Magnitude”. With a modest CCD field of view, the process becomes very simple and very effective as the comparisons are often within the field with the target at all times. This means that all of the stars and targets have very similar air masses and so extinction effects all but cancel out, providing the stars and the target are similar in color. I used at least two comparison stars. The second star, the ”check star”, is used just in case the primary comparison is variable. When possible, I used more stars, using the average value of the sum of the individual magnitudes as the single comparison value. This helps smooth out minor errors when measuring each star. Another advantage of differential photometry is that it does not require reducing the values to a standard magnitude system. The disadvantage is that the magnitude difference will not be the same, as when using a standard system. In spite of the filterless configuration, errors in the zero point and extinction will have little or no effect on the derived period. The times reported have been corrected for light-travel time.

Fourier analyses of the data were performed using the method described by Harris et al. (1989), to obtain the composite lightcurves and the rotation periods. This method consists of a Fourier analysis of the data to derive the composite lightcurves. All the data are fit by a Fourier series, which can be chosen to be of any degree. The solution provides a value for the rotation period, the magnitude offset for each individual lightcurve, and Fourier coefficients, defining the shape of the composite lightcurve to any degree specified. The method also provides formal error estimates for all quantities computed.

All the images were processed using the software program AIP4win and Canopus.

The lightcurve obtained for (1459) Magnya is the classical bimodal curve with two maximums and two minimums of slightly different height and depth, and an amplitude of 0.58±0.02 mag. The derived value of the synodic rotational period is 4.679±0.001 hrs in agreement with the one published by Almeida et al. (2004).

In the case of (378) Holmia, a data binning was executed to compensate for the low signal to noise ratio and the modest width. Neverthless, it wasn’t possible to obtain the whole lightcurve. This object was also tested with a CCD SXV-H9 camera equipped with a modern ICX285 sensor, with an average quantum efficiency of 55% in the R band and a highly reduced dark current (less then 0.02 e^{-}/sec at 10°C). With only 15 seconds integration time, a signal to noise ratio equal to 100 for a magnitude 14 object is obtained, meanwhile, the old ST7 CCD stopped at S/N ratio of about 60 with an integration time of 40 seconds.

5. Conclusions

Figure 4 shows the (1459) Magnya’s complete lightcurve. Results confirm that even with modest instruments, the rotation periods of many asteroids could be determined if the necessary precautions are taken. Annoting Alan

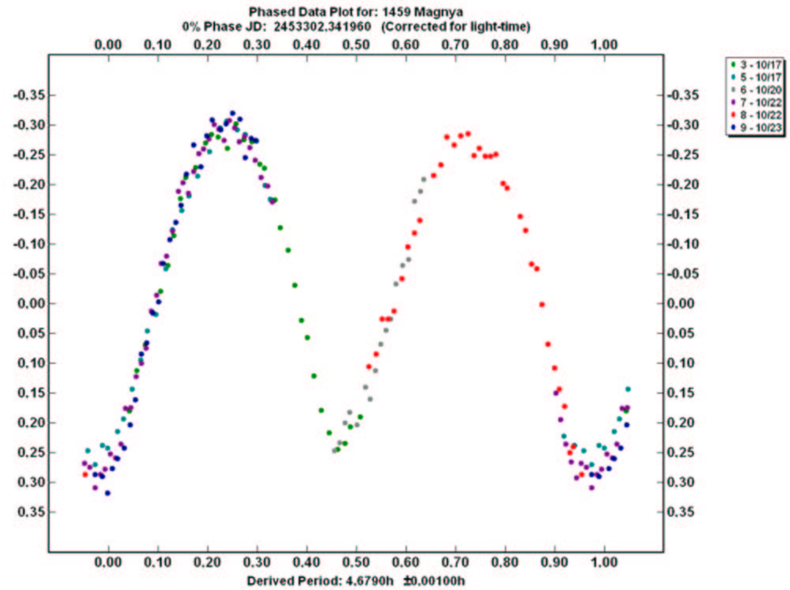


Fig. 4. (1459) Magnya lightcurve.

W. Harris (2004): *"In the last year or two a new paradigm has emerged, where it appears that the evolution of spins of asteroids smaller than a few tens of kilometers in diameter are dominated by radiation pressure, the so-called YORP effect It's a rich new field for theorists, but requires observational data to vindicate (or refute) the theories . . .*

. . . It's an exciting time for asteroid studies generally, and lightcurve studies in particular, so I look forward to future contributions from the many small observatories now engaged in this work"

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