# COLLABORATIVE ASTEROID PHOTOMETRY AND LIGHTCURVE ANALYSIS AT OBSERVATORIES OAEGG, OAC, EABA, AND OAS

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Synodic rotation periods and amplitudes are reported for: 1874 Kacivelia, 15.951 ± 0.001 h, 0.21 ± 0.02 mag; 2055 Dvorak, 4.4052 ± 0.0003 h, 0.17 ± 0.04 mag; 2185 Guangdong, 21.089 ± 0.002 h, 0.19 ± 0.02 mag; and 8059 Deliyannis, 6.0041 ± 0.0003 h, 0.39 ± 0.04 mag. The absolute magnitude (*H*) and/or slope parameter (*G*) for some of these asteroids are also reported.

This paper presents the collaborative work among a group of amateur astronomers and undergraduate students gathered in two Argentinian associations: Grupo de Astrometría y Fotometría (GAF) and Asociación de Observatorios Argentinos de Cuerpos Menores (AOACM). The observatories and equipment used were:

- Estación Astrofísica de Bosque Alegre (EABA, MPC 821): 1.54-m Newtonian (NT) and Apogee Alta U9 CCD.
- Observatorio Astronómico Córdoba (OAC, MPC 822): 0.35-m Schmidt-Cassegrain (SCT) and SBIG ST7 CCD.
- Observatorio Astronómico El Gato Gris (OAEGG, MPC I19): 0.35-m Schmidt-Cassegrain (SCT) and SBIG ST10 CCD.
- Observatorio Astronómico Salvador (OAS, MPC I20): 0.2-m Schmidt-Newtonian (SNT) and Starlight ST7-XME CCD.

All images were unfiltered, dark, bias and flat-field corrected, and then measured using Astrometrica software (Raab, 2013). We used *Periodos* software (Mazzone, 2012a) for the period analysis. We find that this software presents some novelties in the mathematical processing of the data. These are discussed in the appendix along with some details regarding our methods.

All targets were selected from the "Potential Lightcurve Targets" web site list on the Collaborative Asteroid Lightcurve Link site (CALL; Warner *et al*., 2011) as a favorable target for observation and with no previously reported period in the Lightcurve Database (LCDB, Warner *et al.*, 2009).

The lightcurve figures contain the following information: 1) the estimated period and amplitude, 2) a 95% confidence interval regarding the period estimate, 3) RMS of the fitting, 4) estimated amplitude and amplitude error, 5) the Julian time corresponding to 0 rotation phase, and 6) the number of data points. In the reference boxes the columns represent, respectively, the marker, observatory MPC code, session date, session off-set, and number of data points. See the appendix for a description of the off-sets and reduced magnitudes.

8059 Deliyannis. We collected 548 data points in five different sessions. The derived period and amplitude were 6.0041 ± 0.0003 h and 0.39 ± 0.04 mag. There is a lack of data between phase angles 0.63 and 0.7. We estimate the absolute magnitude *H* to be 11.92 mag. Previously reported values were 11.8 mag (MPO 233564) and 12.0 (MPC 30957).

1874 Kacivelia. We observed this asteroid between phase angles 17° to 2°. We obtained a period of 15.951 ± 0.001 h and amplitude of 0.21 ± 0.02 mag. The MPCORB file gives *H* = 11.2 (MPO 250216). We estimate a value of *H* = 11.4. Given the wide range of phase angles covering our observations, we considered it appropriate to find the slope parameter, *G* (see the appendix section for details). The MPCORB gives a default value of *G* = 0.15. We found *G* = 0.24 produces a better fit to our data.

2055 Dvorak. Analysis of our data found a period of 4.4052 ± 0.0003 h and amplitude and 0.17 ± 0.04 mag with a large dispersion among the offsets. The calculated absolute magnitude is 12.81. MPO 259350 reports *H* = 12.6 and MPC 17264, *H* = 13.5.

2185 Guangdong. This was a difficult target due to its relatively long rotation period. Unfortunately, the second half of the lightcurve has substantially fewer data than the first half. We derived a period of 21.089 ± 0.002 h and amplitude 0.19 ± 0.02 mag. We computed an absolute magnitude of *H* = 11.57. The MPCORB file gives *H* = 11.3 using *G* = 0.15. We found that *G* = 0.33 produces a smaller root-square norm for off-sets.

## Appendix: Data Analysis Strategy

In this section, we describe the method used for the data analysis, which has some differences with the usual methodology in similar work. We have successfully used these techniques before (Ambrosioni *et al.*, 2011; Oey *et al.*, 2012).

We programed a set of MATLAB® functions that implemented the calculations described below using functions from *Periodos* and *orbit_calc* (Mazzone, 2012a; Mazzone, 2012b).

Suppose that $m_i^j$, for $j = 1,\dots,N$ and $i = 1,\dots,M_j$, are the measured magnitudes for the asteroid corresponding to times $t_i^j$. Here $N$ is the number of different sessions and $M_j$, $j = 1,\dots,N$, is the number of data points in the session $j$. By session we mean the data collected by a unique observatory on a single night.

First we perform some corrections on the data. More specifically, times $t_i^j$ were light-time corrected and magnitudes were corrected to unity distance and normalized to the zero phase angle by applying standard formulas (Dymock, 2007). This reduction requires some orbital calculations, which are made by an adaptive collocation method that solves the n-body problem. Sun, planets and Moon were modeled as point masses.

Second we fit the model function

$$f(t_i^j) = \alpha^j + a_0 + \sum_{k=1}^{n} a_k \cos(\frac{2k\pi t_i^j}{T}) + b_k \sin(\frac{2k\pi t_i^j}{T})$$

to the observed data. More precisely, we look for parameters $\alpha^j, a_k, b_k$, and $T$ that minimize

$$\sum_{j=1}^{N}\sum_{i=1}^{M_j} | m_i^j - f(t_i^j) |^2$$

The fitted value of $T$ and $a_0$ can be interpreted as being the synodic rotation period of the asteroid and the absolute magnitude *H*, respectively. The parameters $\alpha^j$ depend on the sessions and represent the offsets among sessions. Usually one wants them to be zero. In order to obtain a well-posed problem, we need to introduce an extra condition. We adopted the restriction that the offsets $\alpha^j$ have a zero mean, i.e. $\sum \alpha^j = 0$. We think that this is a plausible assumption, if we consider offsets random normally distributed variables. However this affirmation is false in general. For example, an inaccurate determination of the slope parameter *G* induces a pattern in the offsets. We think that the value of *G* such that the offsets squares sum $(\alpha^1)^2 + \ldots + (\alpha^N)^2$ are minimized gives a good estimate for the *G* parameter. In this way we obtained the value of *G* reported for 1874 Kacivelia and 2185 Guangdong.

We note that our methods incorporate a Fourier algorithm (Harris *et al.,* 1989) and simultaneously adjust the offsets. This is a non-linear curve fitting problem and we use the native lsqcurvefit MATLAB® function for solving it.

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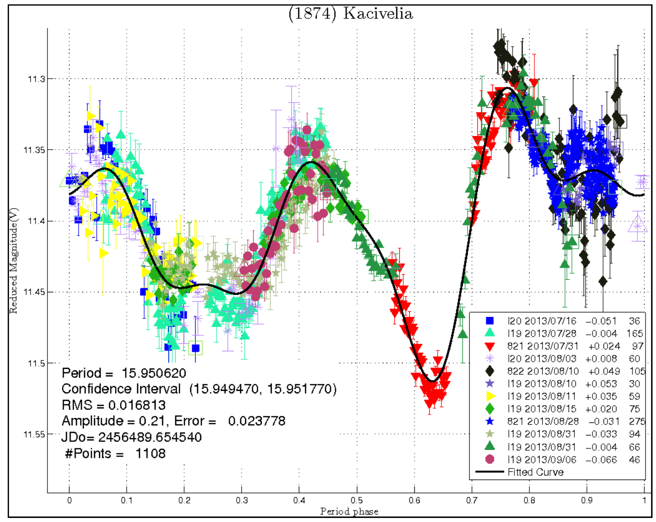


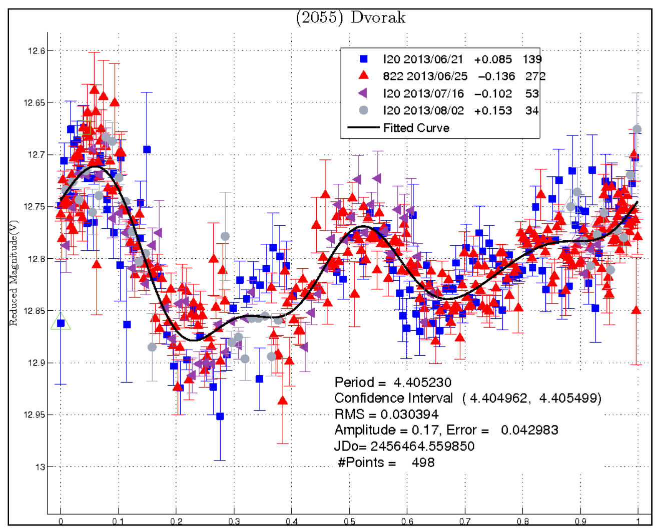


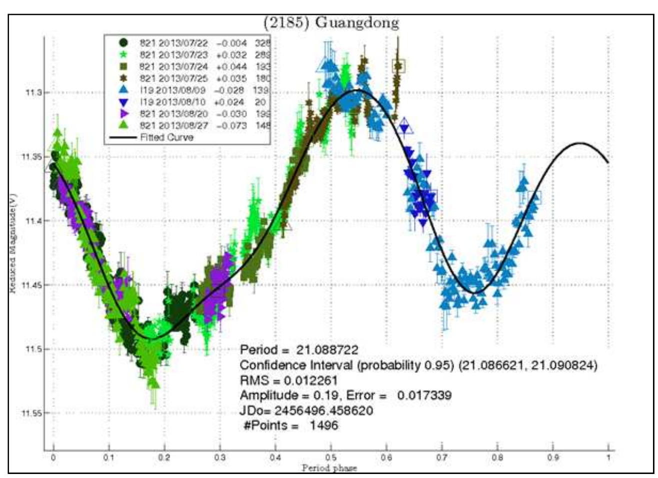

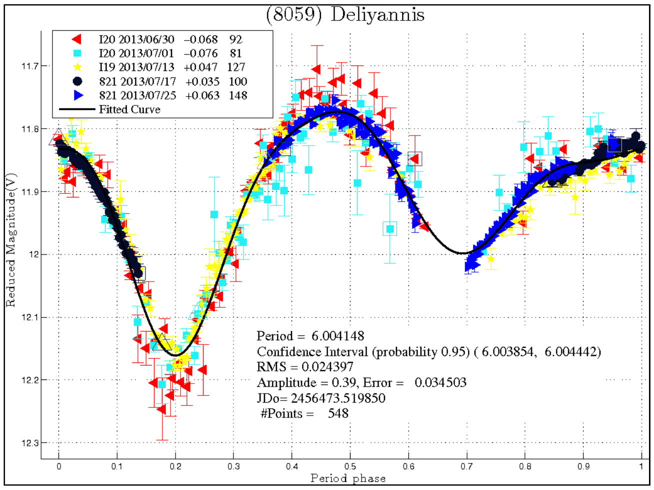


## ROTATIONAL PERIOD AND H-G PARAMETERS FOR ASTEROID 2213 MEEUS

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The main-belt asteroid 2213 Meeus was observed over several nights in 2013 August in order to determine its synodic rotation period, amplitude, absolute magnitude, and phase slope parameter. Lightcurve analysis shows a synodic period $P$ = 2.651 ± 0.001 h with an amplitude $A$ = 0.19 ± 0.03 mag. The H-G curve analysis shows an absolute magnitude $H$ = 13.118 ± 0.083 and a slope parameter $G$ = 0.139 ± 0.122.

The main-belt asteroid 2213 Meeus was selected from the "Low Phase Angle Opportunities" list for 2013 July-September that appeared in the *Minor Planet Bulletin* (Warner *et al.*, 2013). All the observations were carried out from F. Fuligni Observatory near Rome (Italy) using a 0.35-m *f*/10 Meade Advanced Coma Free telescope and SBIG ST8-XE CCD camera with Bessel R filter. All images were calibrated with dark frames. Differential photometry and period analysis were done using *MPO Canopus* (Warner, 2012).

The derived synodic period was $P$ = 2.651 ± 0.001 h (Fig. 1) with an amplitude of $A$ = 0.19 ± 0.03 mag. The favorable initial phase angle at the beginning of the observations allowed extracting the absolute magnitude of $H$ = 13.118 ± 0.083 and slope parameter of $G$ = 0.139 ± 0.122 by means of the H-G Calculator utility of *MPO Canopus* (Fig. 2). These compare favorably with the values of $H$ = 13.3 and $G$ = 0.15 reported in the MPCORB file at the time (*http://www.minorplanetcenter.org/iau/MPCORB.html*).

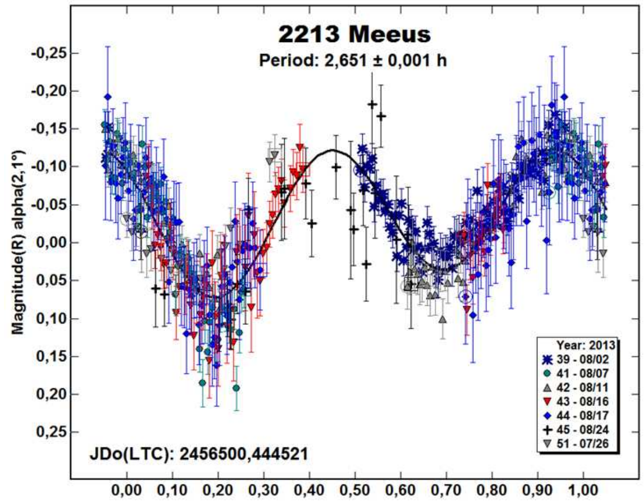


Figure 1. The lightcurve of 2213 Meeus with a period of 2.651 ± 0.001 h and an amplitude of 0.19 ± 0.03 mag.

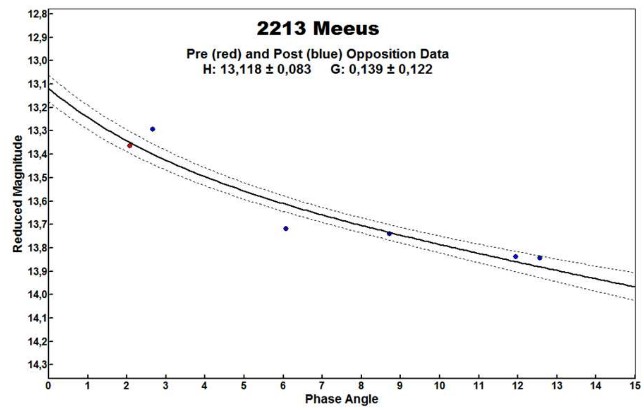


Figure 2. Reduced Magnitude of 2213 Meeus versus phase angle. The absolute magnitude and the slope parameter are, respectively, $H$ = 13.118 ± 0.083 and $G$ = 0.139 ± 0.122.

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