Automatic calibration of photometric observations of asteroids with the PanSTARRS catalogue

Patrycja Poźniak (patrycja.pozniak@protonmail.com)
[1]Astronomical Observatory Institute, Faculty of Physics, Adam Mickiewicz University, Poznań, Poland

Introduction

Asteroid brightness variation, expressed in magnitudes, can be written as:

$$V_{\rm obs}(r, \Delta, \alpha, t) = H + 5\log(r \cdot \Delta) - F(\alpha) + V(t) \tag{1}$$

where: H is asteroid magnitude at zero phase angle, r is distance between the asteroid Earth and Δ is the distance between the asteroid and the Sun. $V(t)$ is called a lightcurve, is in most cases bi-modal, and is caused by rotation of the elongated body about its axis. Asteroid lightcurves are traditionally approximated by Fourier series (see Fig. 1 where data have been fit with a Fourier series of the 6th order). The factor depending on r and Δ can be easily removed, if the asteroid orbit is known. The rest two factors: H and $F(\alpha)$ can be written as:

$$V(\alpha) = H - F(\alpha) \tag{2}$$

This equation describes the dependence of the rotation-averaged magnitude on the solar phase angle and is called mag-phase function. In Fig. 2 an example of three such functions is shown, fit to the data obtained for the asteroid (172) Baucis.

Observations

This work is based on observations done from two locations: the University of British Columbia Southern Observatory, La Serena, Chile (code UBC) and the Borowiec station of Adam Mickiewicz University in Poland (code BOR). The former hosts a 0.35-m robotic telescope, equipped with B,V,R,I Johnson-Cousins filters (FoV = 35' x 35'). The latter hosts a 0.4-m reflector observing in the C "clear" filter (FoV = 12'x 8'). The observing details are included in the table below:

Date (UTC)	α ($^\circ$)	Exp [s]	Fltr	Tel	R [mag]
2013-03-01	4.02	150	C	BOR	8.531
2013-03-03	3.22	150	C	BOR	8.442
2013-03-04	2.85	150	C	BOR	8.355
2013-03-05	2.75	60	R	UBC	8.283
2013-03-05	3.22	150	C	BOR	8.303
2013-03-09	1.82	120	R	UBC	8.271
2013-03-10	1.82	120	R	UBC	8.281
2013-03-12	2.20	60	R	UBC	8.249
2013-03-13	2.48	60	V	UBC	8.428
2013-03-14	2.87	60	R	UBC	8.305
2013-03-16	3.91	100	C	BOR	8.468
2013-03-19	4.84	60	V	UBC	8.573
2013-03-21	5.71	60	V	UBC	8.538
2013-03-21	5.76	60	R	UBC	8.506
2013-03-22	6.20	60	R	UBC	8.504
2013-03-23	6.59	60	R	UBC	8.549

The table contains six columns which represent: UTC date, the asteroid phase angle, exposure time, filter used for observations, location of the telescope, and maximum apparent magnitude at a distance of 1 au from Earth and the Sun, calibrated to R band, respectively.

Reduction

To create the composite curve and mag-phase curve of (172) Baucis, the observations had to be first calibrated to R band. This was achieved by using Photometry Pipeline (PP) software package [1], [5] and $g_{\rm P1}$, $r_{\rm P1}$, $i_{\rm P1}$ stellar magnitudes from PanSTARRS catalogue. PP successively performs data preparation, astrometric calibration, aperture photometry, photometric calibration and target identification and extraction. An example run on 80 UBC frames took approximately 15 minutes. During the run, PP identified 1419 stars out of which 484 were chosen as solar analogs. Asteroids spectra closely resemble that of the Sun. For this reason the differences between the filters used in observations and the standard R band, which they have been calibrated to, could be minimised by selecting solar analogues as calibration stars. Solar colours in the PanSTARRS bands were calculated with data from [7] and transformations from [2], [6]. The results were: $g_{\rm P1} - r_{\rm P1} = 0.364$ and $r_{\rm P1} - i_{\rm P1} = 0.132$. PP used only standard stars which colour indices differed from the given values by no more than 0.2 mag. In this procedure, it was assumed that the difference between the asteroid magnitude and control star magnitude taken from the observation data is the same as the difference between these magnitudes in the desired R band.

Results

PerFit script was used to compute the composite lightcurve with a synodic period of 27.4096 h taken from [4] and best-fitting Fourier series of the 6th order (Fig. 1). Composite lightcurve helped to correct partial lightcurves (which did not cover all rotation phases) to the same level of maximum brightness. The magnitudes of maxima of brightness from different nights were then plotted against the phase angle producing a phase curve. PCFit script was then used to fit three mag-phase functions: (H, G),(H_1, G_1, G_2) and (H, G_{12}) – see Fig. 2. The obtained phase function parameters characterise the scattering properties of the asteroid surface.

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References

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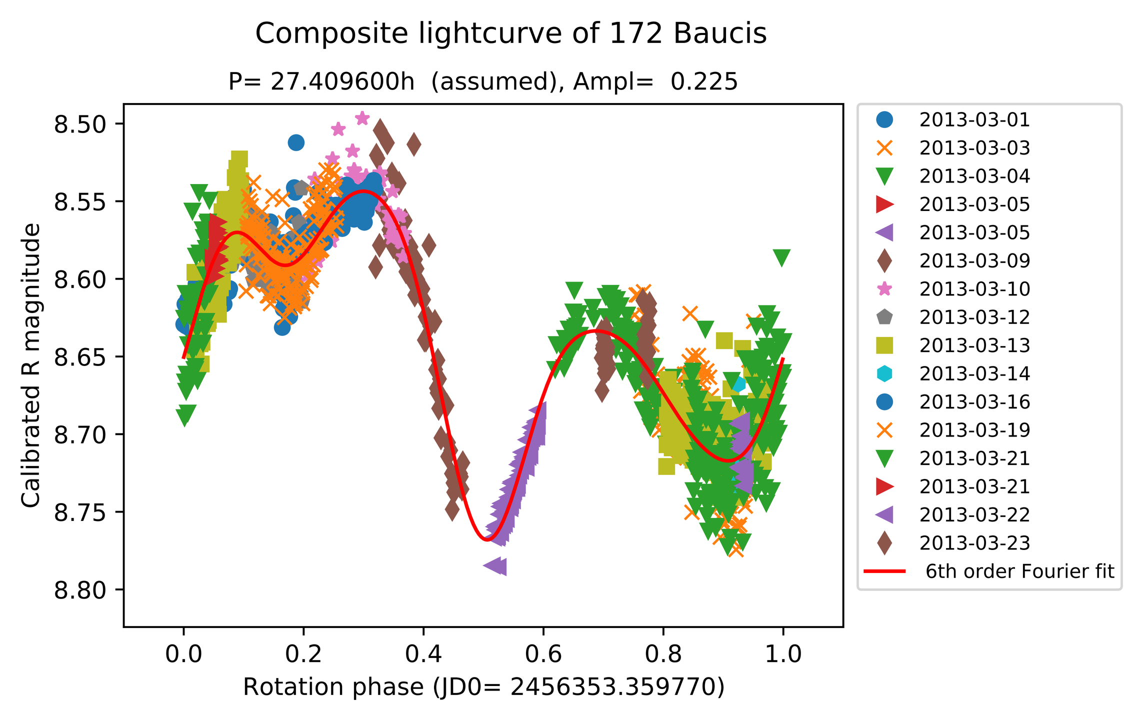
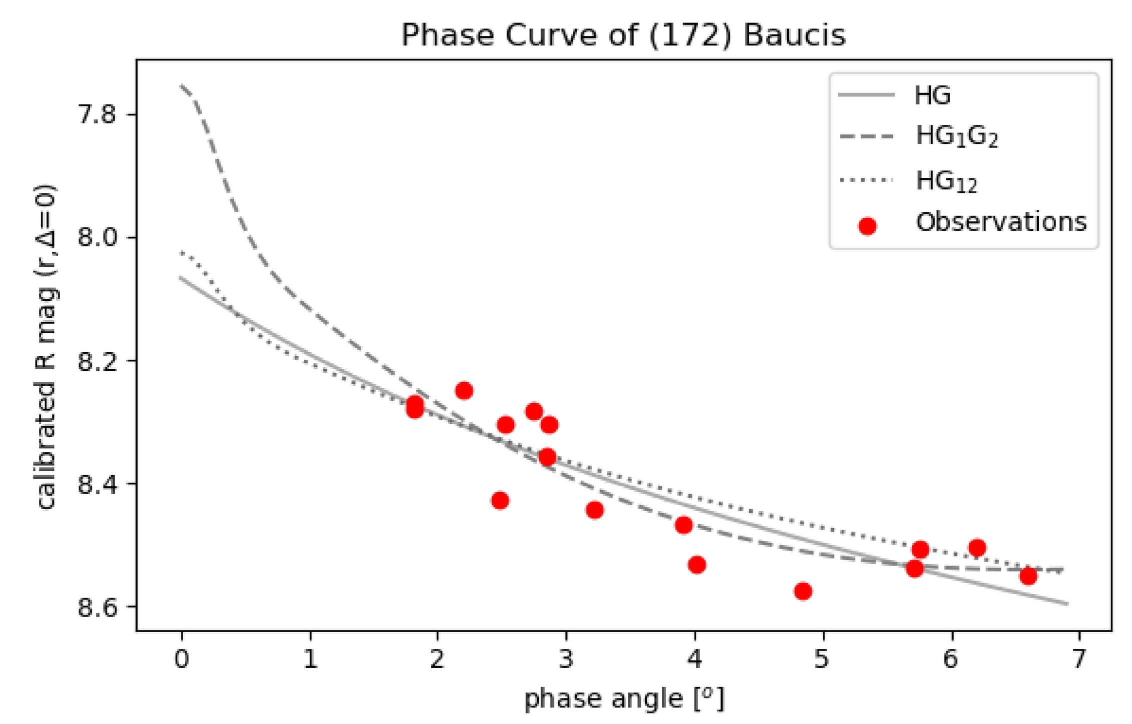
Composite curve [Fig. 1]



Mag-phase curve (preliminary) [Fig. 2]



For HG,

$$H = 8.07^{+0.08}_{-0.06}, \tag{3}$$

$$G = 0.15^{+0.21}_{-0.14}, \tag{4}$$

For HG_1G_2,

$$H = 7.76^{+0.30}_{-0.31}, \tag{5}$$

$$G_1 = -0.79^{+1.44}_{-1.14}, \tag{6}$$

$$G_2 = 1.09^{+0.82}_{-1.02}, \tag{7}$$

For HG_{12},

$$H = 8.02^{+0.60}_{-0.09}, \tag{8}$$

$$G_{12} = 0.27^{+2.02}_{-0.50}, \tag{9}$$

Conclusions

The ability to automatically calibrate photometric observations of asteroids opens a whole new world of possibilities as presented above. Using this method, observations done in different filters can be calibrated to a single band and further used for desired purposes. Unlike the traditional "all-sky photometry" the present one does not require observations done during photometric nights. Similar procedure of observing asteroids has been proposed by [3]. They developed a dedicated asteroid data extraction pipeline for their 0.43-m PIRATE telescope, using it for the same task as described in this work. The advantage of the current approach is the use of a standard PP package, which can be easily adjusted to any telescope. Thus, a network of small telescopes (especially those owned by amateur astronomers) can be used for observations. Their different locations make them less dependent on weather conditions. What is more, the lack of standard Johnson-Cousins filters is not an obstacle and a high volume of heterogeneous data can be easily dealt with.