Binary System Candidates for Detection of BYORP

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Abstract

The theoretically predicted binary YORP (BYORP) effect can be confirmed with observations of mutual events between components in small near-Earth binary asteroids. We have identified seven promising candidates for which photometric observations with 1-2m class telescopes during 2010-2015, combined with data from previous apparitions, can lead to detecting a drift in mean anomaly caused by BYORP. We investigated conditions for the BYORP detection in them and found that a good-quality photometry with errors 0.01-0.02 mag is needed to get a low uncertainty of measurements of mean anomaly of 2-3 deg. Another condition needed for successful BYORP detection is to get a good, unique estimate of orbit pole; this requires that at least one apparition of observed BYORP detection candidate has to be covered thoroughly with observations of mutual events spanning at least a few lunations, a couple months or more.

The BYORP effect

The binary YORP (BYORP) effect of solar radiation pressure on the orbit of a satellite around a primary orbiting the Sun was predicted by Ćuk and Burns (2005). McMahon and Scheeres (2010a,b) reviewed and expanded the theory. They showed that, as long as the secondary's rotation remains synchronous, the BYORP effect causes the orbit to expand or contract.

They applied the theory to the binary near-Earth asteroid (NEA) 1999 KW4, for which a detailed model is available, and showed that the BYORP effect can be detected in the system by tracking mean anomaly which grows quadratically in time with an expanding orbit. They derived a scaling of the KW4 results for application to other binary systems for which a detailed shape is not available.

We applied their scaling to our recent data on binary systems (updated from Pravec and Harris 2007) and predicted a magnitude of change of the satellite's orbit in them. We studied conditions of detectability of the predicted secular quadratic drift in mean anomaly compared to a Keplerian system by observations of mutual events between binary system components and identified seven NEA binary systems in which the effect should be detectable with photometric observations with telescopes with sizes about 2 m and smaller by 2015.

BYORP Scaling

The mean anomaly of a slowly changing orbit expanded to the 2nd degree in time is

$$M = n(t-t_0) + \Delta M_d (t-t_0)^2,$$

$$\Delta M_d = \frac{1}{2}\dot{n},$$

where *n* is the mean motion, t_0 is the time when $M_0 = 0$ and *t* is the current time. We adapted the scaling by McMahon and Scheeres (2010) as follows:

$$\Delta M_d = \frac{K}{\sqrt[3]{q(1+q)}D_1^2 \rho^{\frac{4}{3}} P_{\rm orb}^{\frac{2}{3}} a_{\rm hel}^2 \sqrt{1-e_{\rm hel}^2}},$$

$$K = -24\pi \left(\frac{3\pi}{G}\right)^{\frac{4}{3}} \dot{a}_{\rm KW4} \frac{a_{\rm KW4}^3 a_{\rm hel,KW4}^2 \sqrt{1-e_{\rm hel,KW4}^2}}{(1+q_{\rm KW4}^{-1}) D_{2,\rm KW4}^2 P_{\rm orb,KW4}^3},$$

where *q* is the mass ratio between binary components, D_i is the diameter of the *i*-th body, *ρ* is the bulk density, P_{orb} is the orbit period, a_{hel} and q_{hel} are the semi-major axis and eccentricity of the binary's heliocentric orbit, and *G* is the gravitational constant. The current semi-major axis expansion rate of 1999 KW4, $\dot{a}_{\rm KW4}$ was derived by McMahon and Scheeres (2010). This adapted scaling uses quantities that were most straightforwardly estimated or derived from photometric observations of small binaries.

Detectability conditions for the BYORP effect

We investigated conditions of detectability of the predicted secular quadratic drift in mean anomaly compared to a Keplerian system by observations of mutual events between binary system components. We used photometric observations of binary systems that we and our collaborators acquired during the past 10+ years and studied how a precision of measurements of the mean anomaly from modeling of mutual events between components of the binary system depends on quality and distribution of the observations.

Fits of a binary model by Scheirich and Pravec (2009) to data of mutual events in the observed binaries gave a mean error of the mean anomaly measurements of 2-3 degrees with good-quality photometric observations (errors 0.01-0.02 mag). The error of mean anomaly estimation increased by a factor of two to three for observations with photometric errors 0.04-0.05 mag.

Another condition for a successful detection of the BYORP effect is that a unique model for the binary's orbit has to be established. To uniquely join binary data from 3 or more apparitions which are needed to detect the drift in the mean anomaly and that are separated by long intervals when the binary is photometrically unobservable, data spanning a sufficiently long time (typically at least a couple months long) are needed to arch over the gaps of unobservability between the apparitions.

BYORP Detection Candidates

We identified seven binaries where the BYORP effect is predicted to be detectable with observations with telescopes of sizes about 2 m and smaller in their apparitions with V < 21 during 2010-2015. By that time we can get data on event epochs in 4-6 apparitions (including their previous observed apparitions) spanning an interval of about 10 years or longer, allowing detection of the BYORP effect with $\Delta M_d > 0.1$ deg/yr^2 in them with a needed redundancy (degree of freedom of 1 to 3). Their basic parameters are summarized in following table. It gives the asteroid's designation, the estimated primary diameter D_1, the size ratio between components of the system D_2/D_1,(the mass ratio *q* is approximately equal to $(D_2/D_1)^3$), the heliocentric orbit's semi-major axis and eccentricity a_{hel} and e_{hel}, and the computed ΔM_d using the above scaling. The estimated orbital period P_{orb} is given in Table 2. The bulk density was assumed to be 2 g/cm^3 for each of the seven binaries.

Table 1: Binary systems – candidates for detection of BYORP by 2015

Asteroid	designation	D_1 (km)	D_2/D_1	a_{hel} (AU)	e_{hel}	ΔM_d (deg/yr^2)
(7088)	Ishtar	1.2	0.42	1.981	0.391	– 0.24
(65803)	Didymos	0.75	0.22	1.644	0.384	– 2.51
(66063)	1998 RO_1	0.8	0.48	0.991	0.720	– 3.14
(88710)	2001 SL_9	0.8	0.28	1.061	0.270	– 3.27
(137170)	1999 HF_1	3.5	0.23	0.819	0.462	– 0.42
(175706)	1996 FG_3	1.5	0.31	1.054	0.350	– 0.89
(185851)	2000 DP_{107}	0.8	0.41	1.365	0.377	– 0.72

Models of BYORP detection candidates

Following table gives a summary of estimated orbit parameters for five of the seven binaries that were modeled from our available photometric observations. Uncertainties of the parameters critical for BYORP detection are given. Here we give L_0 (argument of mean length for given epoch) instead of M_0 because of its independence on secondary's pericenter. Since the uncertainty of L_0 is dominated by uncertainty of the pole of the secondary's orbit in some cases, an uncertainty of $L_0(fix)$ is also given for pole constrained to an area with radius of 3 deg around the best-fit solution.

Table 2: 3-σ uncertainties of key orbit parameters of modeled BYORP detection candidates

Asteroid	Apparition		Orbital Period (h)	Orbital Pole (deg)		L_0 (deg)	L_0 (fix.) (deg)
				λ_P	β_P		
Ishtar	Jan-Feb 2006	I.	20.60 ± 0.05	32^{+180}_{-180}	$+76^{+14}_{-94}$	± 70	± 3
		II.	20.63 ± 0.03	134^{+80}_{-102}	-70^{+88}_{-14}	± 22	± 2
Didymos	Nov-Dec 2003	I.	11.906 ± 0.007	157^{+4}_{-7}	$+19^{+45}_{-15}$	± 11	± 3
		II.	11.920 ± 0.005	329^{+11}_{-194}	-70^{+25}_{-15}	± 3	± 2
1998 RO_1	Sep 2003	I.	14.54 ± 0.02	277^{+180}_{-180}	$+37^{+53}_{-2}$	± 13	± 3
	Sep 2004	I.	14.54 ± 0.03	274^{+17}_{-73}	$+48^{+28}_{-6}$	± 7	± 6
1996 FG_3	Dec-Jan 98/99	I.	16.14 ± 0.01	242^{+96}_{-96}	-84^{+14}_{-5}	± 10	± 7
2000 DP_{107}	Sep-Oct 2000	I.	42.09 ± 0.10	291^{+18}_{-26}	$+80^{+7}_{-40}$	± 12	± 3
	Sep-Oct 2008	I.	42.06 ± 0.04	304^{+180}_{-180}	$+87^{+3}_{-31}$	± 9	± 6

Fig. 1: Orbit pole area of (7088) Ishtar in the J2000 ecliptic coordinates. The dashed area represents the 3-sigma uncertainty range of a model from our photometric observations of 2006.

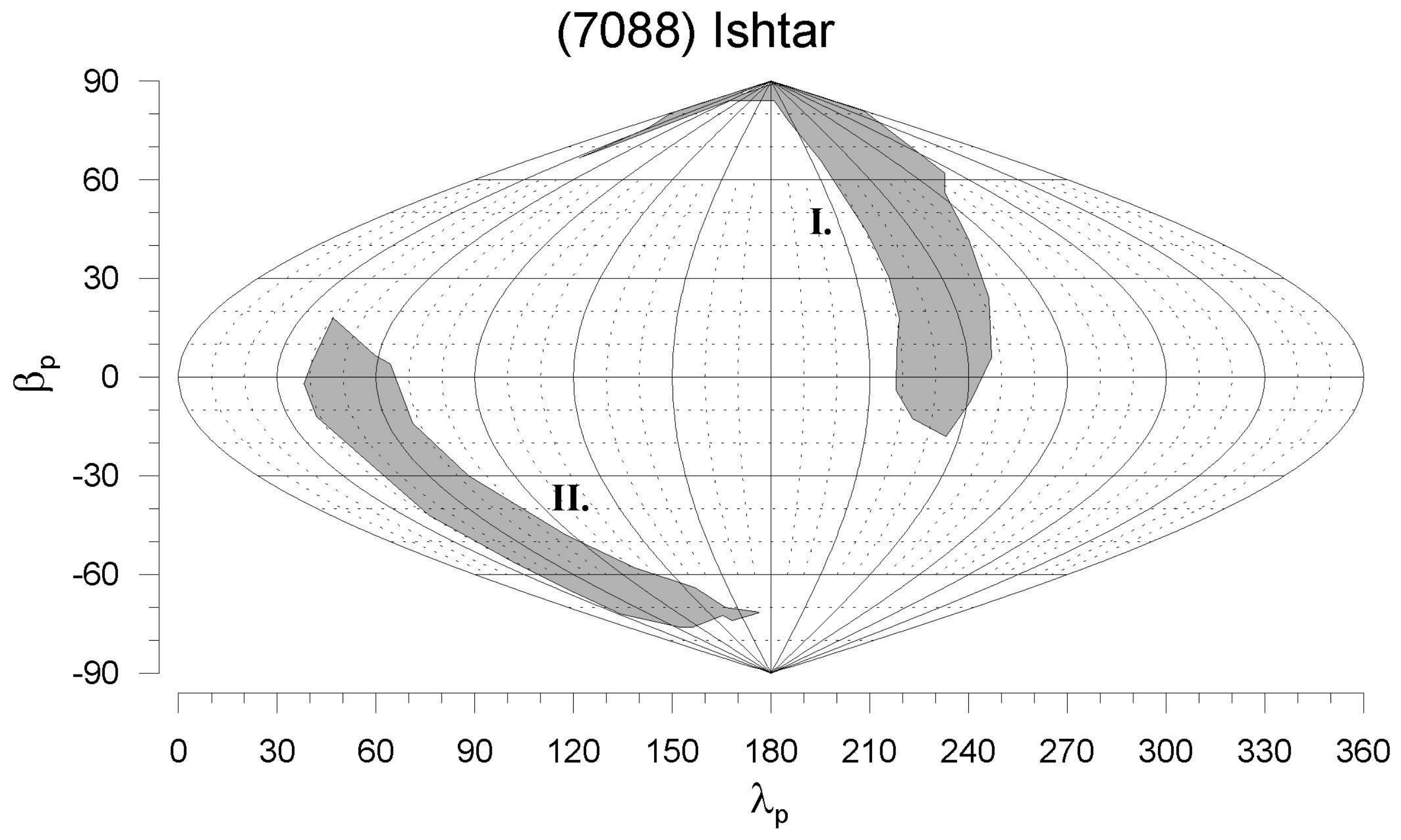
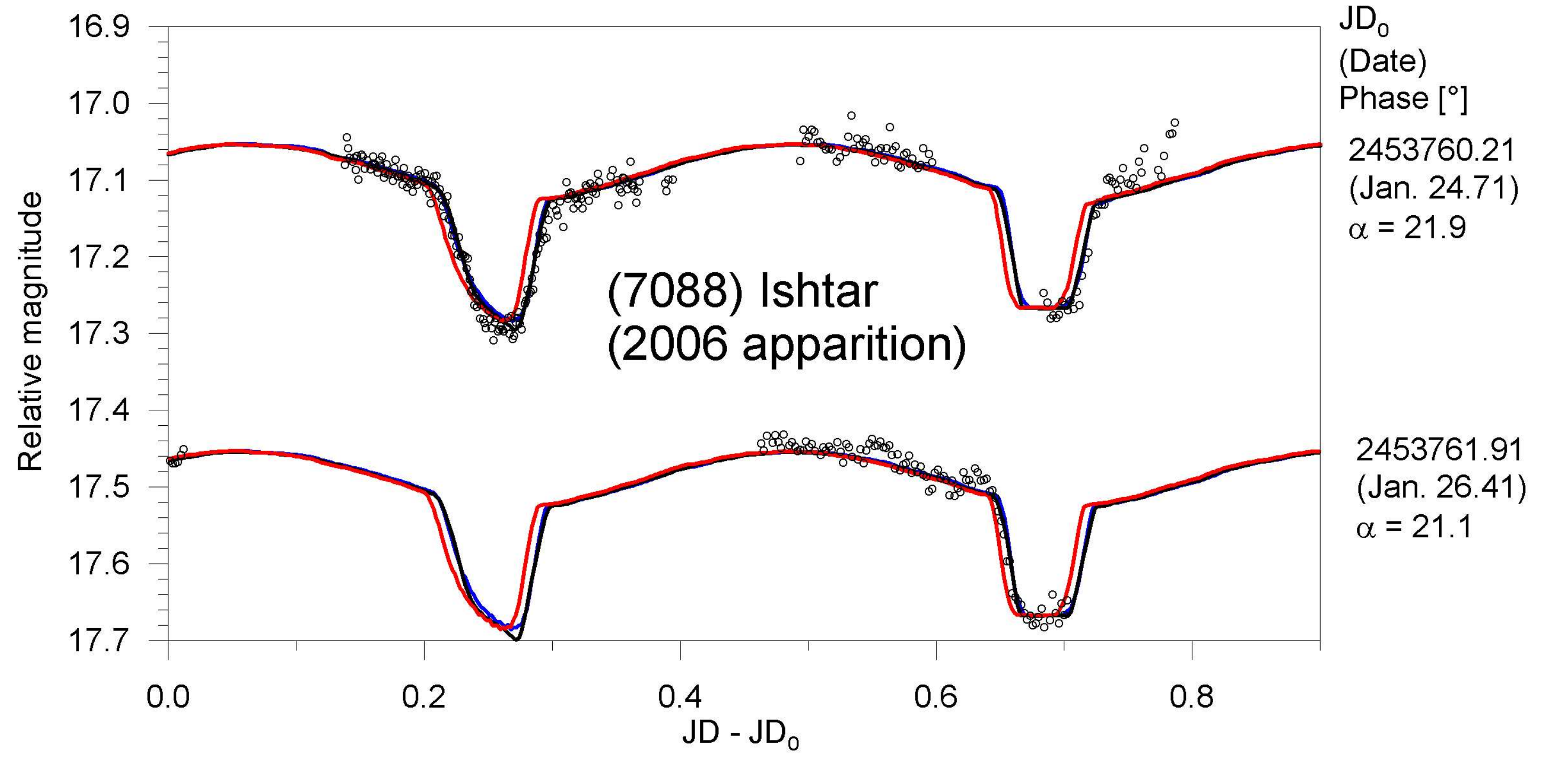


Fig. 2: Two examples of observed lightcurves and model fits for (7088) Ishtar. The blue and black lines are synthetic lightcurves of the best-fit solutions I and II, and the red line is for the best-fit solution I with L_0 shifted by 3 degrees.



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