Yarkovsky effect in the motion of asteroids in retrograde orbits

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Since the last few years, many small bodies in retrograde orbits was discovered, classified as asteroids. Main aim of our work is the analysis of their dynamical past and future. For 56 asteroids in retrograde orbits ($i > 90$) we studied the orbital evolution and calculated median dynamical lifetimes. Due to important role of the Yarkovsky effect in the motion of small bodies, we decided to apply the model with the Yarkovsky forces. Because the physical properties of these objects are still not well determined, we collected thermal parameters from literature or calculated from available formulas. Results obtained with these parameters allowed us to estimate the influence of the Yarkovsky effect on the stability of retrograde orbits.

1 Introduction

We present the result of long-term numerical integration (+/- 100 My) of 56 known asteroids on retrograde orbits. Main aim was the estimation of Yarkovsky drift in the motion of these asteroids. Usually, such kind of calculations refer to main-belt asteroids or NEA, because of well-determined physical data needed to Yarkovsky force calculation. In this case, we tried to estimate the influence of this effect to distant, retrograde orbits.

2 Data and methods

We determined nominal orbits of 56 retrograde objects, (available: 2014-06, but all initial elements reduced to epoch JD 2456600.5). The list of objects includes mainly TNO and Centaurs: (20461)Dioretsa, (65407), (330759), (336756), (342842), (343158) (NEA, Apollo), 1999 LE31, 2000 DG8, 2000 HE46, 2004 NN8, 2005 NP82, 2005 SB223, 2005 TJ50, 2005 VD, 2005 VX3, 2006 BZ8, 2006 EX52, 2006 LM1, 2006 RG1, 2006 RJ2, 2007 VA85 (NEA, Amor), 2007 VW266 (Main-belt), 2008 KV42, 2009 DD47, 2009 QY6, 2009 YS6, 2010 BK118, 2010 CG55, 2010 EB46, 2010 EQ169 (Main-belt), 2010 GW64, 2010 GW147, 2010 LG61, 2010 OR1, 2010 OM101, 2010 PO58, 2011 MM4, 2011 OR17, 2011 SP25, 2011 WS41, 2012 HD2, 2012 TL139, 2012 YO6, 2012 YE8, 2013 BN27, 2013 BL76, 2013 HS150, 2013 LA2, 2013 LD16, 2013 LU28, 2013 NS11, 2013 UQ4, 2014 AT28, 2014 CW14, 2014 JJ57 (Main-belt), 2014 LJ9.

We used Orbfit software (Milani et al., 1997), (Milani et al., 2005) for the determination of orbits and to generate 100 clones along the line of variation (LOV)

Table 1: Thermal properties assumed in Yarkovsky model (if observational data not available)

Class.	r[m]	bulk density $[kgm^{-3}]$	surface density $[kgm^{-3}]$	thermal conduct. $[W/K/m]$	thermal capacity $[W/kg/K]$	albedo p_v	IR emiss.	rotation period [h]	spin
Centaurs/ TNO	$f(H, p_v)$	1125	1125	0.006	760	0.08	0.9	8.4	random
MBA	$f(H, p_v)$	3000	1500	0.001	680	0.10	0.95	6.0	random
NEA	$f(H, p_v)$	1200	1200	0.08	500	0.14	0.9	$f(R)$	random

for each nominal orbit. In the next stage, we used two dynamical models: Simplified, gravitational model – marked as 'Grav. model' and model with thermal forces – marked as 'Yark. model'.The main tool used for the numerical integration was the swift_rmvsy package (Brož et al., 2011). Details of Yarkovsky effect computations used in swift_rmvsy package were described by Vokrouhlicky (1998) and Vokrouhlický & Farinella (1999).

To reproduce Yarkovsky forces in the numerical integration, the complete set of physical properties is necessary for each asteroid (Vokrouhlicky, 1998). This set includes the following parameters: radius, albedo, bulk/surface density, thermal conductivity, thermal capacity, IR emissivity, rotation period and spin. Most of objects in retrograde orbits are classified as Centaurs/TNOs. For such objects, it is difficult to find reliable estimations of physical properties. Due to these reasons, we found typical values presented in literature and used it as a kind of approximation.

Our main assumptions, concerning physical data were based on the approximation of unavailable thermal parameters. Diameter was calculated from the equation (Fowler & Chillemi, 1992):

$$D[km] = \frac{1329}{\sqrt{(p_v)}} 10^{-\frac{H}{5}}. \quad (1)$$

Mean values of albedo, bulk/surface density, thermal conductivity, thermal capacity, thermal emissivity we adopted from literature (Bauer et al., 2013), (Nugent et al., 2012), (Carruba et al., 2014), (Mueller, 2007), (Guilbert-Lepoutre, 2011), (Brož, 2006), (Sheppard et al., 2008). Assumed typical rotation periods (if not determined yet): 8.4 h as mean for TNO and Centaurs (Sheppard et al., 2008) and 6.0 h for MBA, (by Sheppard and Jewitt, 2002). For 2 available retrograde NEAs: $P[h] = 5(2R/1000)$ (Brož, 2006). We used random spin values for all asteroids (unavailable for all objects). Results concerning the Yarkovsky model include averaged (not max.) drift values.

3 Results and conclusions

We studied the evolution of retrograde orbits (max. time span: $\pm 10^8$ y) and calculated dynamical lifetimes of asteroids (Fig. 1).

The dynamical model with Yarkovsky forces for distant, retrograde orbits still has many limitations. From this reason, the estimation of Yarkovsky drift is only an approximation. It should be improved after obtaining more complete data from observational campaigns (esp. physical parameters).

Due to short dynamical lifetimes, most of test particles (clones) used in the integration were ejected. The probabilities of these 'ejections' are very high. The integration time scale of 100 My appears to be much longer than the expected lifetime of retrograde orbits.

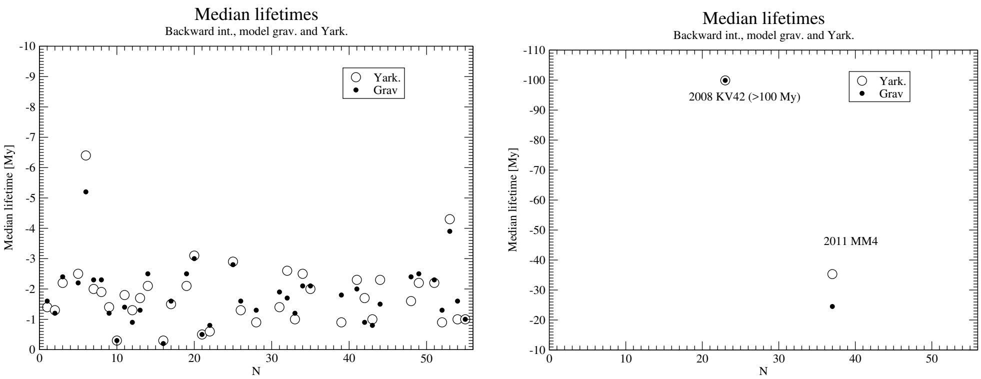

Fig. 1: Median dynamical lifetimes of asteroids in retrograde orbits (past)

Results of the backward and forward integration show that in most cases, retrograde orbits are unstable. The influence of Yarkovsky effect can potentially play important role, especially in 10^6 y time scales. We extended the integration time to max. 1 Gy only for two objects: 2008 KV42 (TNO) and 2011 MM4 (Centaur). For these asteroids, we obtained median lifetimes longer than 10 My.

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