Chaotic Properties of Minor Bodies in Retrograde Orbits

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Small bodies with orbital inclinations above 90 degrees are not compatible with any scenario of evolution in the Solar System. Many clues indicate, however, that they are connected with comets. Currently, more than 100 objects on retrograde orbits are classified as asteroids. In order to determine precisely the dynamic properties of retrograde asteroids, their orbital evolution must be studied, taking into account potential non-gravitational effects. Using various parameters that quantitatively estimate the presence of chaos, it has been possible to determine how long these objects remain inside the system and what factors determine the long-term stability of their orbits.

1 Introduction

The general objective of our project is to study the dynamics of small bodies in retrograde orbits classified as 'retrograde asteroids'. These objects are a kind of 'interlopers' because they are not yet assigned to any family – although they are gradually reclassified as comets. The more accurate physical properties and more precise perturbation models will certainly contribute to new conclusions about the dynamics of these objects. It is now possible to estimate how much influence non-gravitational effects can have on the evolution and stability of orbits.

2 Methods

The available observational material was selected to model non-gravitational effects only for the best determined retrograde orbits. We selected 31 numbered and multi-opposition asteroids. This allowed to partially eliminate a sort of 'observational bias' by omitting single-oppositional objects and orbits obtained from a small number of observations. Next, we tested the influence of the Yarkovsky effect (long-term thermal acceleration) on the stability of orbits of the 31 retrograde asteroids. We have taken into account extreme obliquity values ($\gamma = 0°$, $\gamma = 180°$) to maximize possible perturbations. We also investigated the effect of cometary accelerations on the stability of the 333P retrograde comet, selected because of the good quality of the observational data.

3 Data and results

First, we analyzed the scenarios with the Yarkovsky effect on the asteroids. Previously (Kankiewicz & Włodarczyk, 2017, 2018) we selected and studied dynamically a group of 25 asteroids. A new, updated list of retrograde asteroids with sufficiently well determined orbits is shown in Table 1. Since we estimated the presence of chaoticity in the sense of Lyapunov, the Lyapunov Times (LT) obtained as a result of simulations with different variants of Yarkovsky's forces are also shown in Tab. 1.

Tab. 1: List of 31 numbered and multi-opposition retrograde asteroids with i, a, e, H (source: JPL Small Body Database, `https://ssd.jpl.nasa.gov/sbdb.cgi`). Three last columns show Lyapunov Times (LT) obtained by gravitational model and relative changes in LT due to Yarkovsky effect (for $\gamma = 0°$ and $\gamma = 180°$), where $\Delta LT_0/LT = (LT_{\gamma=0°} - LT_{\mathrm{GRAV}})/LT_{\mathrm{GRAV}}$ and $\Delta LT_{180}/LT = (LT_{\gamma=180°} - LT_{\mathrm{GRAV}})/LT_{\mathrm{GRAV}}$.

N	Name	i [deg]	a [au]	e	H [mag]	LT_{GRAV}[y]	$\Delta LT_0/LT$ $\gamma = 0°$	$\Delta LT_{180}/LT$ $\gamma = 180°$
1	20461 Dioretsa	160.4	23.9	0.90	13.8	5.77E4	0.69	-0.34
2	65407 (2002 RP120)	119.0	53.9	0.95	12.3	1E5	0.01	-0.19
3	330759 (2008 SO218)	170.3	8.1	0.56	12.8	1.76E5	-0.25	-0.03
4	336756 (2010 NV1)	140.7	290.1	0.97	10.4	4.24E5	-0.54	-0.69
5	342842 (2008 YB3)	105.1	11.6	0.44	9.3	≥1.64E6	-0.75	246.56
6	343158 (2009 HC82)	154.4	2.5	0.81	16.2	1.71E5	3969.76	1.60
7	434620 (2005 VD)	172.9	6.7	0.25	14.3	≥2.55E5	-0.55	-0.66
8	459870 (2014 AT28)	165.6	10.9	0.40	12	1.27E5	0.01	-0.36
9	(1999 LE31)	151.8	8.1	0.47	12.38	1.04E5	-0.27	-0.38
10	(2000 HE46)	158.5	23.6	0.9	14.64	1.17E5	-0.09	-0.42
11	(2004 NN8)	165.5	98.4	0.98	15.25	5.41E4	-0.14	0.96
12	(2005 SB223)	91.3	29.4	0.91	14.17	≥5.65E5	-0.55	-0.69
13	(2006 BZ8)	165.3	9.6	0.80	14.24	1.28E5	0.52	0.19
14	(2008 KV42)	103.4	41.7	0.49	8.63	1.14E5	-0.24	-0.44
15	(2009 QY6)	137.7	12.5	0.83	14.74	1.49E5	0.38	-0.43
16	(2009 YS6)	147.8	20.1	0.92	14.27	1.67E5	0.54	-0.58
17	(2010 CG55)	146.2	31.9	0.91	14.19	2.11E5	1.08	-0.49
18	(2010 GW64)	105.2	63.1	0.94	14.84	5.38E4	15.26	-0.32
19	(2010 OR1)	143.9	26.9	0.92	16.14	≥2.77E5	0.82	-0.03
20	(2011 MM4)	100.5	21.1	0.47	9.3	1.33E5	-0.19	-0.01
21	(2012 HD2)	146.9	62.4	0.96	15.3	≥3.37E5	-0.53	-0.36
22	(2013 BL76)	98.6	1036	0.99	10.8	1.39E5	-0.46	9135.69
23	(2013 LD16)	154.8	80	0.97	16.1	2.04E5	0.20	0.23
24	468861 (2013 LU28)	125.4	175.5	0.95	8	1.04E5	0.58	0.87
25	(2013 NS11)	130.3	12.7	0.79	13.6	1.18E5	0.74	1.32
26	471325 (2011 KT19)	110.1	35.6	0.33	7.2	≥3.22E8	-1.00	-1.00
27	514107 (2015 BZ509)	163.0	5.1	0.38	16	4E5	1246.50	1051.50
28	518151 (2016 FH13)	93.6	24.5	0.61	10.1	2.59E5	-0.41	-0.34
29	523797 (2016 NM56)	144.0	72.7	0.86	11.4	≥2.71E8	-1.00	-1.00
30	523800 (2017 KZ31)	161.7	53.4	0.8	10.2	6.28E4	0.05	-0.48
31	(2005 NP82)	130.5	5.9	0.48	13.81	1.15E5	12172.91	0.69

As the second non-gravitational effect, we investigated the possible influence of cometary accelerations. Considering the relatively large number of updated observations of the 333P comet (previously known as NEA retrograde: Kankiewicz & Włodarczyk (2010)), we have determined the orbit and the most probable parameters of cometary accelerations A_1 and A_2 (Tab. 2).

As part of our models, we tested different variants of A_1 and A_2 to investigate the propagation of errors in the determined values and the final effect on stability (Fig. 1). The obtained LT values vary from 100 to almost 1000 years.

Tab. 2: Retrograde NEO 2007 VA85/333P: orbital elements (JD 2458600.5=2019-04-27) and selected physical data.

Name	a [au]	e	i_{2000} [deg]	Ω_{2000} [deg]	ω_{2000} [deg]	M [deg]	no. of obs. used
333P	4.22259	0.735955	131.883	115.582	26.114	127.062	663
1-σ rms	5.63695E-06	2.65910E-07	1.57958E-05	1.84383E-05	1.81079E-05	2.10593E-04	
Cometary non-gravitational acceleration coefficients [au/d^2]:							
A_1=2.095E-10 ± 1.350E-10 (radial)							
A_2=-1.906E-11 ± 1.181E-11 (transverse)							

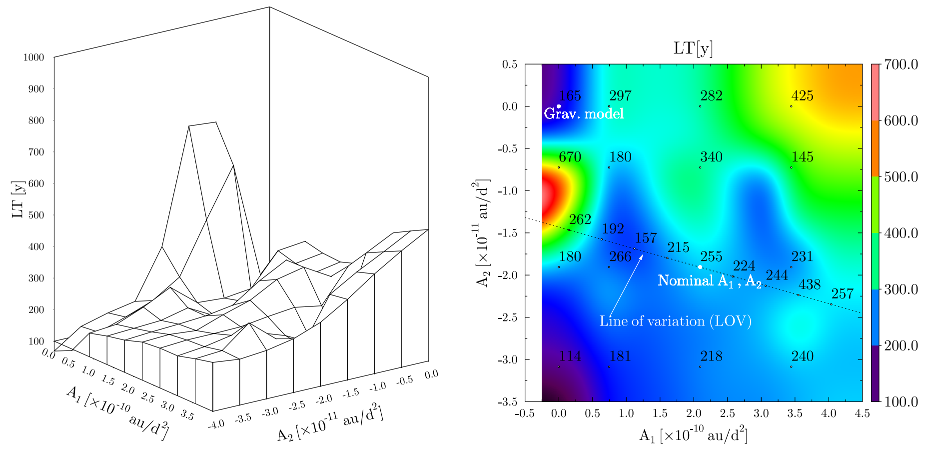

Fig. 1: The stability map of comet 333P: The influence of NGR coefficients A_1, A_2 determined from observations on Lyapunov Time.

4 Summary

Yarkovsky forces potentially affect the stability of the studied objects, but it is not possible to judge clearly whether they destabilize orbits or not. In general, it seems that the model with prograde rotation ($\gamma = 0°$) produces more stable orbits. Moreover, for retrograde rotation there is a clear tendency that in most cases $LT_{\mathrm{GRAV}} > LT_{\gamma=180°}$. Nevertheless, an individual approach to each object is required for a thorough investigation of the cause.

For bodies in the inner Solar System, where orbits are generally less stable, non-gravitational (cometary) forces can significantly change Lyapunov's Times. Even if the retrograde comet exhibits very small activity. The application of enhanced non-gravitational models in retrograde asteroid dynamics is almost always justified. Unfortunately, observational limitations make it still difficult to obtain a set of parameters for these models.

References

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