Observational data and orbits of the asteroids discovered at the VATT Observatory in 2010-2012

Ireneusz Wlodarczyk[1], Kazimieras Černis[2], Richard P. Boyle[3]
[1] Chorzow Astronomical Observatory, IAU 553, 41-500 Chorzow, Poland
[2] Institute of Theoretical Physics and Astronomy, Vilnius University, Saulėtekio al. 3, Vilnius LT-10222, Lithuania
[3] Vatican Observatory Research Group, Steward Observatory, Tucson, Arizona 85721
astrobit@ka.onet.pl
(Submitted on 06.10.2021; Accepted on 02.12.2021)

Abstract.
This paper is devoted to discovering asteroids at the Vatican Observatory in 2010-2012 together with the orbital analysis of two dynamically interesting Distant objects discovered at the VATT, namely 2012 DS85 and 420356 Praamzius (2012 BX85). We used the OrbFit software v.5.0.5 and v.5.0.6 to compute orbits and analyze their orbital evolutions. Also, we computed their Lyapunov times. We showed that the asteroids, 2012 DS85 and 420356 Praamzius (2012 BX85), enter the different mean motion resonances (MMRs) zone, including the MMR 1:1 with Uranus and Neptune, and stay here for several ky. Also, we showed that both studied asteroids might become temporary Trojans of both Uranus and Neptune.
Key words: astrometry – minor planets, asteroids: Near-Earth objects, orbit determination

1. Introduction

New objects were discovered with VATT at the Mt. Graham International Observatory (IAU code 290, longitude 109.89201 W, latitude 32.70133 N, altitude 3178 m). In 2010-2012, during a sky survey of the ecliptic regions, 106 new asteroids were designated by the Minor Planet Center (MPC). Two of them have been numbered, and one of them has been named. Among them, 40 are one-opposition objects with low-accuracy orbits. Soon, we expect to get numbers and credits for another 65 asteroids.

During 2010-2012, about 2000 CCD images (covering field of about 5x5 deg^2 in the sky sphere) were obtained with a limiting magnitude of 22.5 mag (on stacked images, we got about 23 mag objects). We have measured the positions of all asteroids appearing in the CCD frames. 8058 astrometric positions of 1343 objects, including a few NEOs, we published in the Minor Planet Circulars (MPC) and Electronic Minor Planet Circulars (MPE).

We present our sixth paper in the series of works devoted to the asteroids discovered at the VATT Observatory. Until then, we studied asteroids discovered at the VATT Observatory in the following papers: Wlodarczyk et al. [2011, 2014, 2017b], Cernis et al. [2012, 2016].

In this paper, we summarize all the work related to the discoveries of asteroids at the VATT Observatory (Wlodarczyk [2017a]) with a special attention to two dynamically interesting asteroids: 2012 DS85 and 420356 Praamzius (2012 BX85).

2. Astrometric observations of minor planet at the VATT Observatory

Observations were done with the Vatican Advanced Technology Telescope (VATT), including the 1.83 m Alice P. Lennon telescope. Our goal was to search for new asteroids and follow up known main-belt asteroids, Centaurs and trans-Neptunian objects (TNO). The telescope is located at the Mt. Graham International Observatory. It started operation in 2000 December to 2001 May acquiring CCD images at the primary focus (f/1). Since 2010, imaging has been performed at the Gregorian focus using a 4k background-illuminated CCD camera with liquid nitrogen cooling.

Using a 62x62 mm (2000 x 2000 binned pixels) CCD camera, the field of view is 12.7x12.7 $arcmin^2$ with a scale of 0.38 arcsec per pixel. The first object observed was an asteroid of the Centaur group, 2009 HW77, discovered by K. Cernis and I. Eglitis in 2009 April. This asteroid was observed in 2010-2012. I. Wlodarczyk in Wlodarczyk et al. [2011] calculated a new orbit of 2009 HW77.

The first "new " asteroid discovered by Vatican Observatory Research Group was found in 2010, 2010 VC199, by K. Cernis and R. P. Boyle. During the years 2010-2012, the two mentioned observers discovered about 106 new asteroids. Most asteroids were discovered in the morning sky about 30-60 days before their opposition time at elongations 120-150 deg. The sky survey has been done close to the ecliptic (mostly not more than 5 deg from the ecliptic line), taking six CCD images on the same field, with exposures of 6 minutes, without spans between exposures. The 1.83 m reflector with a focal length of 16.5 meters gives good accuracy of astrometric measure, about 0.1". For the measurements, the Astrometrica software (Raab [2019]) was applied. The catalogs of USNO-B1.0 and UCAC-4 were mostly used for the selection of reference stars.

R. P. Boyle did all observations. Part of the observations was done together with V. Laugalys. K. Cernis did all object detections and astrometric measurements. The methods of processing of CCD images and the search of asteroids on VATT exposures are described in our earlier papers: Cernis et al. [2012, 2016].

The limiting magnitude for stars on the VATT is about R= 22.3-22.5 mag on unfiltered CCD images with an exposure time of 360 s and a 1-2" seeing.

In 2010-2012, during the sky survey in the ecliptic regions and the follow-up astrometry of asteroids, 106 new asteroids were discovered. During the investigation of our CCD frames, about 920 unknown asteroids of magnitudes fainter than 21.5 were discovered, but other observatories did not confirm them due to their faintness.

3. Discoveries of asteroids at the VATT in 2010-2012

Table 1 presents a list of asteroids discovered at the VATT Observatory from 2010 through 2012. Four interesting objects were discovered during the search for new asteroids: 2012 BX 85 (TNO), 2012 DS85, and 2012 VU 85 (Distant objects) and one NEO group object 2012 XH16. 32 discoveries could be regarded as independent discoveries, 11 objects have very short observations arc and could be regarded as lost objects. Almost all of the asteroids listed in Table 1 have absolute magnitudes in the range H= 18-19 mag. Only three asteroids (2012 BX85, 2012 VU85 and 2012 DS85) have much lower H, being large objects (70-350 km). In our sample of asteroids presented in Table 1, the brightest is the asteroid Praamzius with H= 5.75 mag, which corresponds to the diameter of 302-425 km. The faintest asteroid is 2012 XH16 with H= 22.29 mag and a diameter in the range 100-230 m.

Table 2 represents the distribution of asteroids' discoveries and the numbers of astrometric observations of asteroids (both new and known) at the Mt. Graham Observatory. We can see that most intensive observations were done in 2012. The initial orbits of the selected asteroids are presented in Table 3. They are computed with the use of the new software Orbit v.5.0.5 (http://adams.dm.unipi.it/∼orbmaint/orbfit/) which includes the debiasing and weighting scheme described in the paper Star catalog position and proper motion corrections in asteroid astrometry by Farnocchia et al. [2015]. With the OrbFit v.5.0.5 software, we used the error model 'fcct14' described in Chesley et al. [2010] and Farnocchia et al. [2015]. In v5.0.6, we used the error model 'vftc17' according to Veres et al. [2017]. We used the JPL DE431 Solar System model along with an additional 17 massive asteroids as described in del Vigna et al. [2018,2019] and in Farnocchia et al. [2013a,2013b]. The above scheme of computing initial orbital elements of asteroids was used in our previous works: Wlodarczyk et al. [2013a,2013b,2020a,2020b]. Table 3 contains the initial nominal keplerian orbital elements of selected asteroids. The angles: the argument of perihelion ω, the longitude of the ascending node Ω, and inclination i, refer to the Equinox J2000.0. Epoch: 2020-May-31=JD2459000.5 TDB. Due to the short observational arcs and, consequently, the computed orbits' low accuracy, the calculation of the non-gravitational parameters of $A2$ was not performed. Hence, orbital elements are computed only with the pure gravitational model. Everywhere, observations of studied asteroids are updated on 2020 December 10, and:
→ Asteroid 2012 DS85 was first observed at Mt. Graham-VATT on 2012-02-19. According to the International Astronomical Union Minor Planet Center and its MPC Database Search the asteroid is a Distant object type. Discoverer will be defined when the object is numbered. According to the JPL Small-Body Database Browser (https://ssd.jpl.nasa.gov/sbdb.cgi#top) the classification of the asteroid is a Centaur. The orbit of asteroid 2012 DS85 is computed based on 87 total observations over time interval: 2012 02 19.31321 - 2012 12 08.5415? of which all observations were used.

→ The asteroid 2012 XH16 was first observed at the Mt. Graham-VATT on 2012-12-05. The discoverer of this asteroid will be defined when the object is numbered. According to the MPC, the asteroid is an Amor orbit type, Near-Earth Object, and one opposition object seen prior. According to the JPL Small-Body Database Browser (https://ssd.jpl.nasa.gov/sbdb.cgi#top) the classification of 2012 XH16 is an Amor [Near Earth Asteroid]. The orbit of asteroid 2012 XH16 is computed based on 66 total observations over time interval: 2012 12 05.32262 - 2013 04 15.19282 , of which all observations were used.

In Table 3: a denotes semimajor axis, e - eccentricity, i - orbital inclination, Ω - longitude of the ascending node, ω- argument of perihelion and M - mean anomaly.

→ The asteroid (420356) Praamzius = 2012 BX85 was discovered at Mount Graham on 2012-01-23 by K. Cernis and R. P. Boyle. According to the MPC, the asteroid is a distant object orbit type. The asteroid is on the critical list of numbered objects. According to the JPL Small-Body Database Browser (https://ssd.jpl.nasa.gov/sbdb.cgi#top) the classification of the asteroid is a trans-Neptunian Object. The orbit of 420356 Praamzius (2012 BX85) was

Table 1. List of asteroids discovered at the VATT Observatory in years 2010-2012.

No.	Date of discovery	Designation	Number	Status
1	2010 Nov. 11	2010 VC199		* 7 op.
2	2010 Nov. 11	2010 VD199		ID 10 op.
3	2010 Nov. 11	2010 VE199		* 5 op.
4	2011 Sep. 28	2011 SK248		3-day arc
5	2011 Sep. 27	2011 SL248		3-day arc
6	2011 Sep. 27	2011 SM248		4-day arc
7	2011 Nov. 26	2011 WV72	(546013)	ID 7 op.
8	2011 Nov. 27	2011 WR131		4-day arc
9	2011 Nov. 30	2011 WH132		2-day arc
10	2011 Dec. 27	2011 YE70	(463150)	ID 6 op.
11	2011 Dec. 31	2011 YF70		2-day arc
12	2011 Dec. 31	2011 YG70		2-day arc
13	2012 Jan. 2	2012 AL22		None
14	2012 Jan. 23	2012 BE57		2-day arc
15	2012 Jan. 23	2012 BX85	(420356)	*N 12 op.
16	2012 Feb. 19	2012 DU12		* 3 op.
17	2012 Feb. 21	2012 DM13		None
18	2012 Feb. 26	2012 DN43		ID 3 op.
19	2012 Feb. 22	2012 DV54		ID 5 op.
20	2012 Feb. 22	2012 DW54		* 3 op.
21	2012 Feb. 24	2012 DU57		ID 3 op.
22	2012 Feb. 22	2012 DS62		ID 7 op.
23	2012 Feb. 29	2012 DV75		* 6 op.
24	2012 Feb. 29	2012 DW75		2-day arc
25	2012 Feb. 22	2012 DO84		* 8 opps
26	2012 Feb. 22	2012 DP84		4-day arc
27	2012 Feb. 22	2012 DQ84		4-day arc
28	2012 Feb. 22	2012 DR84		* 7 op.
29	2012 Feb. 24	2012 DS84		* 11 op.
30	2012 Feb. 21	2012 DC85		ID 6 op.
31	2012 Feb. 21	2012 DD85		3-day arc
32	2012 Feb. 23	2012 DE85		* 4 op.
33	2012 Feb. 23	2012 DF85		6-day arc
34	2012 Feb. 23	2012 DG85		6-day arc
35	2012 Feb. 23	2012 DH85		6-day arc
36	2012 Feb. 23	2012 DJ85		6-day arc
37	2012 Feb. 24	2012 DK85		None
38	2012 Feb. 24	2012 DL85		2-day arc
39	2012 Feb. 23	2012 DO85		* 8 op.
40	2012 Feb. 23	2012 DP85	(422750)	ID 7 op.
41	2012 Feb. 23	2012 DQ85		* 8 op.
42	2012 Feb. 23	2012 DR85		ID 6 op.
43	2012 Feb. 19	2012 DS85	Centaur	* 2 op.
44	2012 Feb. 24	2012 DH86		ID 6 op.
45	2012 Feb. 19	2012 DX110		* 3 op.
46	2012 Feb. 23	2012 DQ115		* 4 op.
47	2012 Apr. 21	2012 HN16		4-day arc
48	2012 Apr. 23	2012 HY26		* 3 op.
49	2012 Apr. 18	2012 HH58		7-day arc
50	2012 Apr. 18	2012 HY81		* 5 op.
51	2012 Apr. 16	2012 HK91		* 3 op.
52	2012 Oct. 6	2012 TY18	(478542)	ID 4 op.
53	2012 Nov. 8	2012 VP45	(395766)	ID 7 op.
54	2012 Nov. 8	2012 VQ45		ID 10 op.
55	2012 Nov. 12	2012 VX81		None

Table 1 continued.

No.	Date of discovery	Designation	Number	Status
56	2012 Nov. 12	2012 VY81		3-day arc
57	2012 Nov. 12	2012 VZ81		None
58	2012 Nov. 14	2012 VU85	(463368)	* 5 op.
59	2012 Nov. 13	2012 VR87		3 op.
60	2012 Nov. 13	2012 VS87		2-day arc
61	2012 Nov. 14	2012 VT87		3 op.
62	2012 Nov. 14	2012 VU87		None
63	2012 Nov. 14	2012 VV87		None
64	2012 Nov. 14	2012 VW87		ID 9 op.
65	2012 Nov. 14	2012 VX87		ID 9 op.
66	2012 Nov. 14	2012 VY87		* 5 op.
67	2012 Nov. 13	2012 VF94		* 6 op.
68	2012 Nov. 13	2012 VG94		2-day arc
69	2012 Nov. 13	2012 VH94		2-day arc
70	2012 Nov. 13	2012 VJ94		2-day arc
71	2012 Nov. 13	2012 VK94		2-day arc
72	2012 Nov. 15	2012 VO96		ID 5 op.
73	2012 Nov. 12	2012 VC98		ID 6 op.
74	2012 Nov. 8	2012 VF104		ID 5 op.
75	2012 Nov. 13	2012 VX108		3-day arc
76	2012 Nov. 13	2012 VZ114		* 4 op.
77	2012 Nov. 14	2012 VA115		* 5 op.
78	2012 Nov. 12	2012 VM131		* 4 op.
79	2012 Nov. 24	2012 WZ41		ID 7 op.
80	2012 Nov. 13	2012 WB42		* 2 op.
81	2012 Nov. 22	2012 WY23		None
82	2012 Nov. 22	2012 WD27		None
83	2012 Nov. 20	2012 WH32		4-day arc
84	2012 Nov. 23	2012 WJ32		ID 2 op.
85	2012 Nov. 23	2012 WK32		None
86	2012 Nov. 23	2012 WL32		* 7 op.
87	2012 Nov. 24	2012 WM32	(478908)	ID 7 op.
88	2012 Nov. 25	2012 WG33	(531789)	ID 7 op.
89	2012 Nov. 25	2012 WH33		ID 4 op.
90	2012 Nov. 23	2012 WM36		None
91	2012 Nov. 25	2012 WR41		* 3 op.
92	2012 Dec. 5	2012 XH16	NEO	131-day arc
93	2012 Dec. 4	2012 XK46	(528971)	ID 6 op.
94	2012 Dec. 5	2012 XA49		3-day arc
95	2012 Dec. 5	2012 XE49	(476156)	ID 7 op.
96	2012 Dec. 5	2012 XF49		ID 6 op.
97	2012 Dec. 5	2012 XC69		ID 5 op.
98	2012 Dec. 5	2012 XD69	ID 9 op.	
99	2012 Dec. 5	2012 XE69	5-day arc	
100	2012 Dec. 5	2012 XX102		2-day arc
101	2012 Dec. 5	2012 XY102		ID 10 op.
102	2012 Dec. 7	2012 XR104		None
103	2012 Dec. 5	2012 XA142		ID 8 op.
104	2012 Dec. 7	2012 XJ145		ID 5 op.
105	2012 Dec. 13	2012 XN152		4-day arc
106	2012 Dec. 17	2012 YG2	ID 8 op.	

Notes:
asteroid 420356 (2012 BX85) is trans-Neptunian Object, named as Praamzius
asteroid 463368 (2012 VU85) is Centaur
asteroids 2012 HH58 and 2012 VR87 are Mars-crossers
* - Credited for discoveries from Vatican Observatory
ID - An independent discovery
None - The lost asteroids

Table 2. Distribution of discoveries of asteroids and the numbers of astrometric observations of asteroids (both new and known) at the Mt. Graham Observatory in 2010-2012.

Year	Number of discoveries	Number of observations	Number of observed objects	References MPC No.
2010	3	330	55	66190, 66452, 71065, 72444, 73054
2011	9	480	80	74815, 75147, 76338, 76737, 77170
2012	94	7248	1208	77585, 77928, 78331, 78791, 79143, 79475, 79749 80460, 81146, 81620, 82025, 82462, 82870
Total	106	8058	1343	

Table 3. Initial nominal keplerian orbital elements of selected asteroids. The angles ω, Ω, and i refer to Equinox J2000.0. Epoch: 2020-May-31=JD2459000.5 TDB. Orbital elements are computed with different error models.

error model	a (au)	e	i (deg)	Ω (deg)	ω (deg)	M (deg)
			2012 DS85			
fcct14 KEP	18.8615	0.13188	16.797878	129.05579	301.839	82.616
vfcc17 KEP	18.8604	0.13154	16.797746	129.05574	301.935	82.567
fcct14 RMS	0.0096	0.00233	0.000833	0.000285	0.629	0.307
vfcc17 RMS	0.0170	0.00422	0.00146	0.000510	1.151	0.566
			2012 XH16			
fcct14 KEP	1.6315378	0.3607212	3.756445	52.969084	100.572651	168.5751
vfcc17 KEP	1.6315459	0.3607241	3.756473	52.969173	100.572520	168.5658
fcct14 RMS	0.0000464	0.0000163	0.000118	0.000254	0.000370	0.0534
vfcc17 RMS	0.0000409	0.0000144	0.000113	0.000303	0.000366	0.0470
			420356 Praamzius (2012 BX85)			
fcct14 KEP	42.48702	0.0126508	1.102183	314.266814	4.713	180.056
vfcc17 KEP	42.48715	0.0126481	1.101470	314.267366	4.639	180.131
fcct14 RMS	0.00186	0.0000338	0.000139	0.000458	0.113	0.116
vfcc17 RMS	0.00243	0.0000439	0.0000850	0.000613	0.0603	0.0618
			463368 (2012 VU85)			
fcct14 KEP	29.08253	0.3080411	15.097973	252.5935091	265.6186	321.5367
vfcc17 KEP	29.08195	0.3080305	15.098000	252.5934996	265.6203	321.5346
fcct14 RMS	0.00349	0.0000910	0.000218	0.0000675	0.0106	0.0127
vfcc17 RMS	0.00497	0.000134	0.000405	0.0001220	0.0167	0.0181

computed using 223 total observations over time interval: 2002 12 31.272164 - 2020 04 17.334790, of which all observations were used.

→ Asteroid 463368 (2012 VU85) was discovered at Mount Graham on 2012-11-14 by K. Cernis and R. P. Boyle. According to the MPC, the asteroid is a distant object orbit type. According to the JPL Small-Body Database Browser (https://ssd.jpl.nasa.gov/sbdb.cgi#top) classification is a Centaur. The orbit of the asteroid 463368 (2012 VU85) is based on 123 total observations over time interval: 2012 11 14.27951 - 2016 11 13.52716, of which all observations were used.

We searched for family status for each asteroid with synthetic proper elements according to
https://newton.spacedys.com/∼astdys2/propsynth/all_tro.famrec.

As of 2021 July 10 there are 540,950 asteroids with synthetic proper elements. Only ten of all asteroids found on VATT have been calculated and published proper elements. Eight of these ten asteroids do not belong to any family: 463150, 422750, 478542, 395766, 476156, 2012DS84, 2012DR85, 2012VO96. Only two belong to different families: 478908 belongs to the Veritas family and 2012VC98 belong to the Klumpkea family.

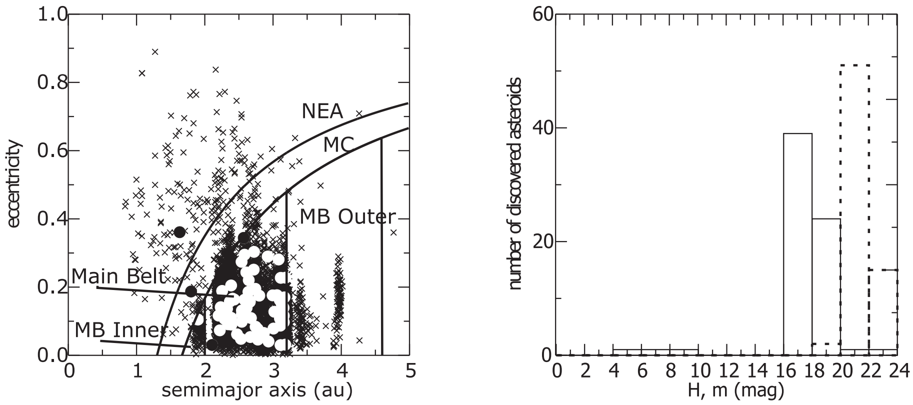

Fig. 1. The discovered of asteroids at the VATT Observatory: left panel - position in the (a, e) plane, right panel - histogram of their discovered absolute magnitude.

Fig.1 presents in the left panel the position of discovered asteroids in the (a, e) plane. 68 of all 106 discovered asteroids at the VATT Observatory presented in Table 1 have a well-computed orbit. Most of them are 63 Main-belt asteroids, one near-Earth asteroid 2012 H16, two Mars-crossers, one Centaur, and one TransNeptunian Object. In the right panel, against the background of the first 10,000 asteroids, a continuous line of histograms of discovered asteroids with their absolute magnitude H (magnitude at one au from the Sun and observer) is marked. The three asteroids have the greatest absolute magnitude H: 5.75 mag, 7.30 mag, and 9.4 mag. The dashed line marks their apparent magnitude, which is between 16.9 and 22.3 mag.

4. Orbital evolution of the asteroids 2012 DS85 and 420356 Praamzius (2012 BX85)

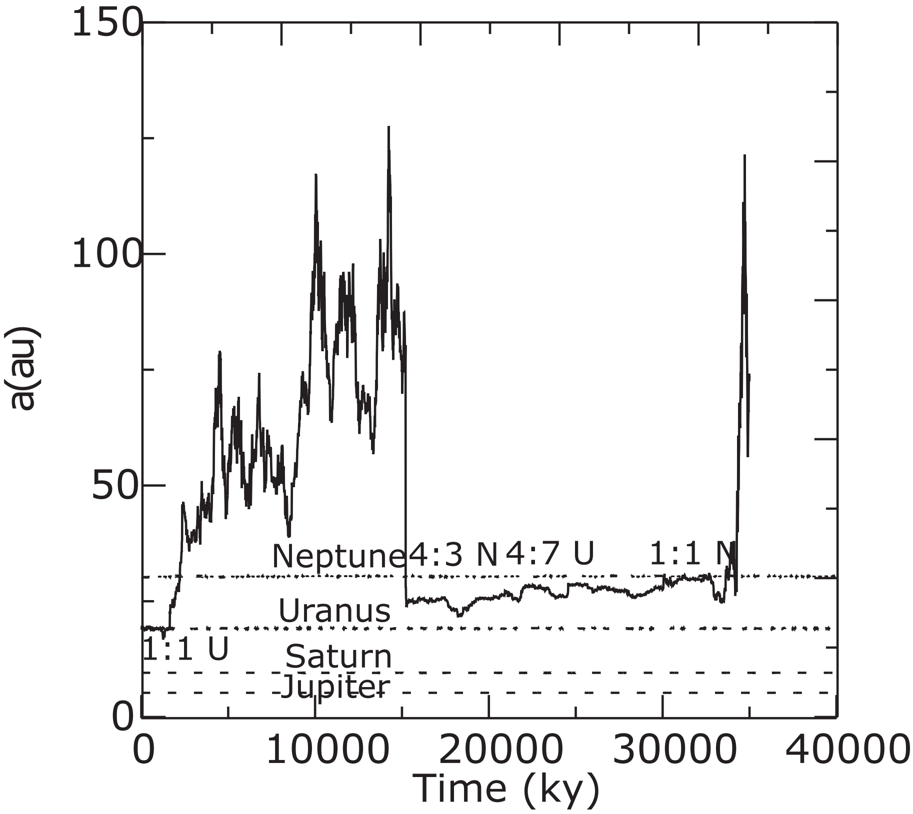

Fig. 2. Forward evolution of the semimajor axis of the asteroid 2012 DS85. Horizontal lines denote computed semimajor axes of the four giant planets. Also, the positions of the mean motion resonances with Uranus and Neptune are marked.

Fig. 2 presents 50 My forward evolution of the semimajor axis of the asteroid 2012 DS85. The horizontal lines denote computed semimajor axes of Jupiter, Saturn, Uranus, and Neptune. Also, the mean motion resonances (MMR) with Uranus (4:7) and Neptune (4:3 and 1:1) are marked. For better readability, they are marked in the next 40 My. Interestingly, the asteroid 2012 DS85 enters the MMR 1:1 with Neptune and stays here for about 2.5 My. According to the Minor Planet Center, https://minorplanetcenter.net/iau/lists/t_neptunetrojans.html, as of 2019 May 23, there are 23 Neptune Trojans. So the asteroid 2012 DS85 can enrich the space of Trojans of Neptune in the future.

In this 40 My period, every 5000 years, which equals 8000 events, we calculated the MMR of giant planets dominant for each outputted interval. The results are in Table 4.

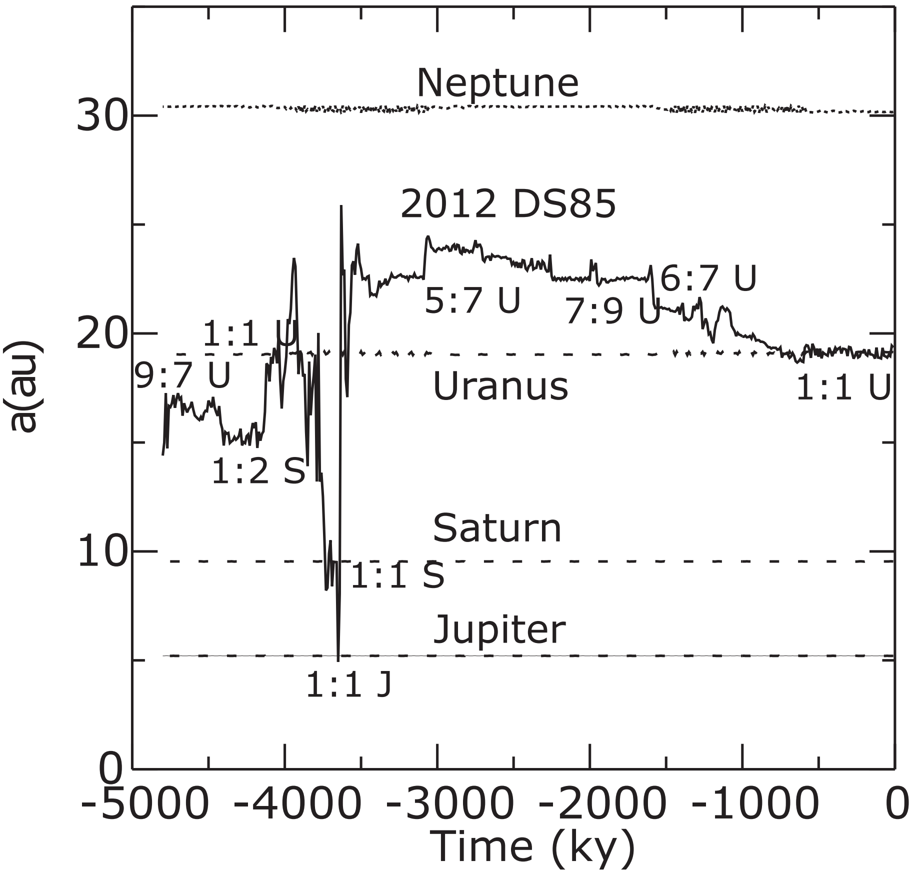

Fig. 3. The same as in Fig. 2 but for backward evolution. The positions of the mean motion resonances with Uranus are marked.

Fig. 3 presents 5 My backward evolution of the semimajor axis of the asteroid 2012 DS85. Similar to Fig.2, horizontal lines denote computed semimajor axes of Jupiter, Saturn, Uranus, and Neptune. The mean motion resonances with Uranus (9:7, 1:1, 5:7, 7:9, and 6:7) are marked. Interestingly, the asteroid 2012 DS85 enters the Trojans of Uranus and stays in two time-spans here for about 0.5 My. According to the Minor Planet Center, https://minorplanetcenter.net/iau/lists/t_neptunetrojans.html, as of 2019 May 23, there is only one Uranus Trojan. So the asteroid 2012 DS85 will enrich the shortlist of Uranus trojans in the future. In this 5 My backward period, every 5000 years, which equals 1000 events, we calculated the MMR of giant planets dominant for each outputted interval. The results are presented in Table 5.

Table 4. Forward orbital mean motion resonances of asteroid 2012 DS85.

with planet	number of events	% of events
Jupiter	36	0.45
Saturn	288	3.6
Uranus	1229	15.4
Neptune	1947	24.3

Table 5. Backward orbital mean motion resonances of asteroid 2012 DS85.

with planet	number of events	% of events
Jupiter	76	7.6
Saturn	80	8.0
Uranus	205	20.5
Neptune	119	11.9

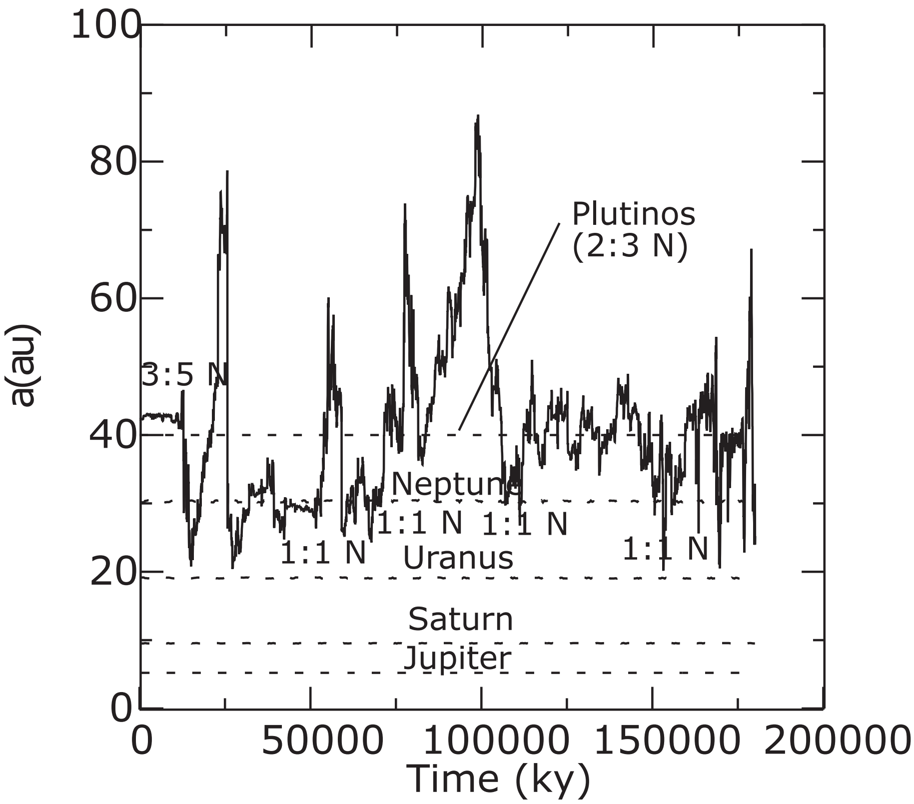

Fig. 4. Forward evolution of the orbital elements of the asteroid 420356 Praamzius (2012 BX85). Horizontal lines denote computed semimajor axes of four giant planets. Also, the positions of the mean motion resonances with Neptune are marked.

Fig. 4 presents 180 My forward evolution of the semimajor axis of the asteroid 420356 Praamzius (2012 BX85). The horizontal lines in the left upper panel denote computed semimajor axes of Jupiter, Saturn, Uranus, and Neptune. Also, the mean motion resonances with Neptune (3:5, 2:3, and 1:1) are marked. Interestingly, the asteroid 420356 Praamzius (2012 BX85) enters many times the zone of the MMR 1:1 with Neptune and stays here for several My. So the asteroid can enrich Trojans of Neptune's area in the future. In Fig. 4, we can see that the asteroid 420356 Praamzius (2012 BX85) can enter the space of Plutoids (or Plutinos, objects in 2:3 mean motion resonance with Neptune) for semimajor axis 39-40 au https://www.minorplanetcenter.net/iau/lists/OuterPlot.html. In this 180 My period, every 200000 years, which equals 900 events, we calculated the MMR of giant planets dominant for each outputted interval. The results are given in Table 6.

Table 6. Forward orbital mean motion resonances of asteroid 420356 Praamzius (2012 BX85).

with planet	number of events	% of events
Jupiter	0	0
Saturn	90	10.0
Uranus	143	15.9
Neptune	217	24.1

In Fig. 5, the orbital evolution of an asteroid (420356) shows the ejection of an asteroid from the Solar System under the influence of various MMRs with Neptune. Asteroid escapes Solar System model (SSM) reaching the value of semimajor axis greater than 250 au. During this time, eccentricity is getting closer to 0.8, while inclination is getting closer to zero.

In this 33 My backward period, every 10000 years, which equals 3300 events, we calculated the MMR with the giant planets dominant for each outputted interval. The results are given in Table 7.

Table 7. Backward orbital mean motion resonances of asteroid 20356 Praamzius (2012 BX85).

with planet	number of events	% of events
Jupiter	27	0.82
Saturn	252	7.6
Uranus	1432	43.4
Neptune	1389	42.1

Fig. 6 presents close approaches of the asteroids 2012 DS85 and 20356 Praamzius (2012 BX85) during forward and backward integration. Close approaches only within 0.1 au are presented. As can be seen from the above figures, due to the large eccentricity and inclination of the orbits of a stud-

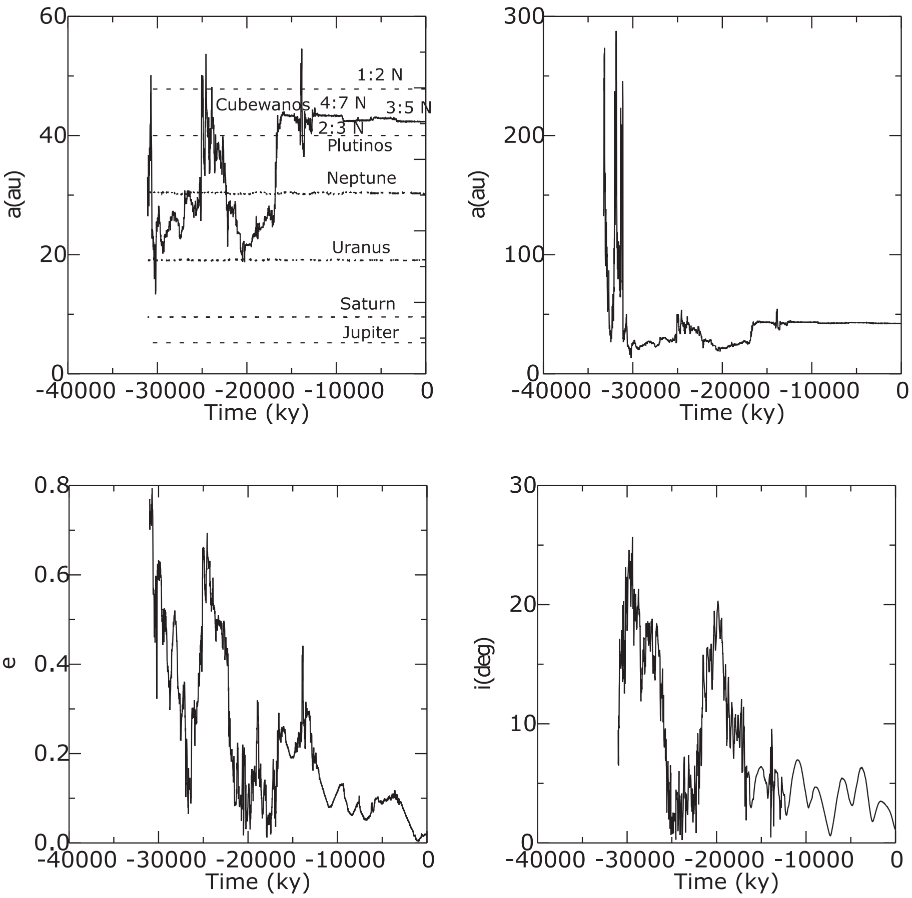

Fig. 5. Backward evolution of the orbital elements of the asteroid (420356). The right upper panel shows semimajor evolution up to about -33 My. Two bottom panels present the evolution of eccentricity and orbital inclination. As can be seen from the panels after numerous MMRs with Neptune, the asteroid escapes the Solar System model (SSM), reaching the value of the semimajor axis greater than 250 au. During this time, eccentricity is getting closer to 0.8, while inclination is getting closer to zero. Asteroid leaves the SSM.

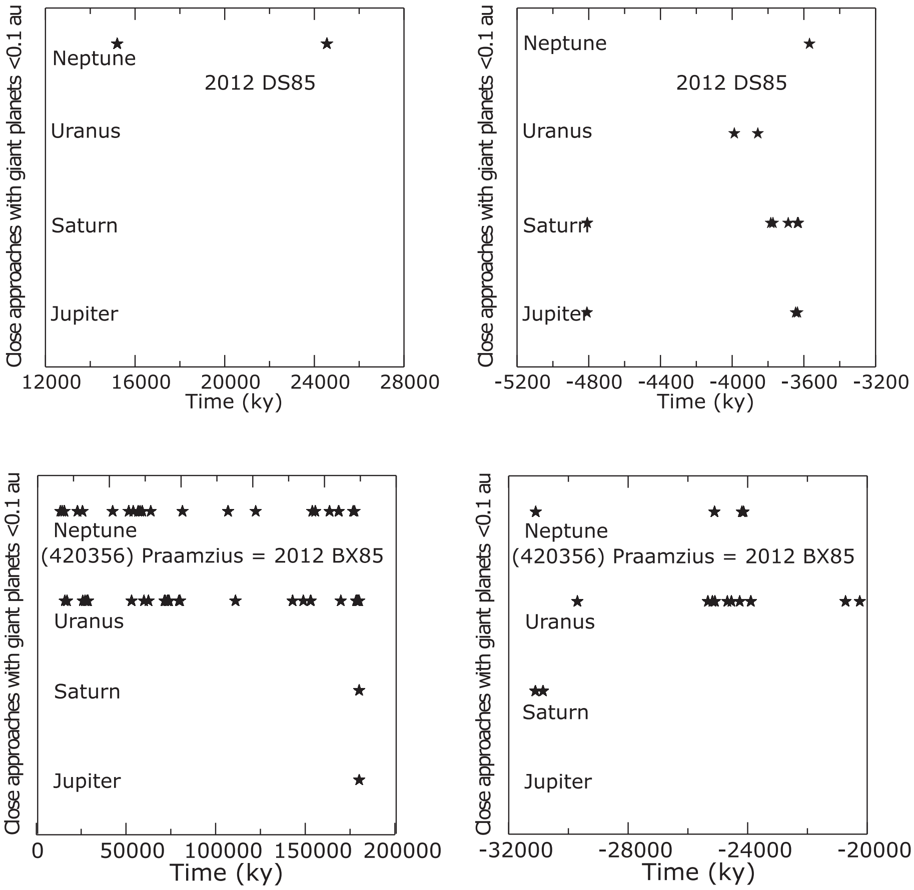

Fig. 6. Close approaches of the both studied asteroids, 2012 DS85 and 20356 Praamzius (2012 BX85), with giant planets within 0.1 au.

ied asteroid, not all close approaches (CAs) coincide with the planet's MMR and vice versa. Not all MMRs match the computed CAs. CAs cause an asteroid ejection from the Solar system or a collision either with planets or the Sun. These CAs are particularly visible in Fig. 5 on Praamzius 20356 (2012 BX85), particularly during forward and backward integrations. It also limits the computing range of our Solar system models.

Fig. 4 and Fig. 5 show the region where usually asteroids are called plutinos and in Fig. 5, cubewanos. Plutinos have MMR 2:3 with Neptune. Most cubewanos are between plutinos and the MMR 1:2 with Neptune. The orbital evolution of the studied asteroid 420356 Praamzius (2012 BX85) passes through the area covered by cubewanos. Hence we see the delivery mechanism for cubewanos and plutinos in the example of 420356 Praamzius (2012 BX85).

The discussions in this section also show that many of the clones of the two studied asteroids discovered in the VATT may become Uranus or Neptune Trojans. Their number is smaller in our solar system than in Jupiter's Trojans because the masses of S, U, and N are smaller than J. We have also seen many MMRs with giant planets, which may cause the orbital stabilization of these asteroids.

5. Lyapunov Time

Next, we computed Lyapunov time (LT) for the asteroid 2012 DS85 and 420356 Praamzius (2012 BX85). To compute the Lyapunov time of the studied asteroid, we used the $LOV1$ method similar to that in Wlodarczyk [2019]. We also used the OrbFit software v.5.0.5 similar to that for asteroid 2012 XH16 in Wlodarczyk et al. [2014]. Table 8 presents the computed values of LT.

Table 8. Computed values of LT.

asteroid	LT(years)	
	forward integration	backward integration
2012 DS85	1095	1000
420356 Praamzius (2012 BX85)	333	1740

It turned out that they have a similar short Lyapunov Time. Hence both asteroids are in a similar area of chaos. In comparison, in Whipple [1995], it appeared that 75% of 175 asteroids with perihelia less than 1.6 au have LT<100 years, and 18 asteroids have LT<50 years.

6. Summary

We present 106 discovered asteroids at the VATT observatory. Also, we studied two dynamically interesting Distant objects discovered at the VATT, 2012 DS85 and 420356 Praamzius (2012 BX85). We showed that the asteroids, 2012 DS85 and 420356 Praamzius (2012 BX85), often enter the mean motion resonances (MMRs) zone, including the MMR 1:1 with Uranus and Neptune, and stay here for several ky. Also, we computed that both studied asteroids may become temporary Trojans of both Uranus and Neptune.

Acknowledgments

We would like to thank the anonymous reviewer for many helpful suggestions. Also, Ireneusz Wlodarczyk thanked the Space Research Center of the Polish Academy of Sciences in Warsaw for the chance to work on a computer cluster. Kazimieras Černis acknowledges the Europlanet 2024 RI project funded by the European Union Horizon 2020 Research and Innovation Programme (Grant agreement No. 871149).

References

Černis K., Boyle R. P., Laugalys V., Wlodarczyk I., 2012, *BaltA, 21, 455. doi:10.1515/astro-2017-0403*

Černis K., Boyle R. P., Wlodarczyk I., 2016, *BaltA, 25, 189. doi:10.1515/astro-2017-0121*

Chesley, S. R., Baer, J., Monet, D. G., 2010, *Icarus 210, 158-181*

Del Vigna, A., Faggioli, L., Milani, A., Spoto, F., Farnocchia, D., Carry, B., 2018, *Astronomy and Astrophysics 617, A61*

Del Vigna A., Milani A., Spoto F., Chessa A., Valsecchi G. B., 2019, *Icar, 321, 647-660.*

Farnocchia, D., Chesley, S. R., Chodas, P. W., Micheli, M., Tholen, D. J., Milani, A., Elliott, G. T., Bernardi, F., 2013a, *Icarus 224, 192-200*

Farnocchia, D., Chesley, S. R., Vokrouhlický, D., Milani, A., Spoto, F., Bottke, W. F., 2013b, *Icarus 224, 1-13*

Farnocchia, D., Chesley, S. R., Chamberlin, A. B., Tholen, D. J., 2015, *Icarus 245, 94-111*

Jedicke, R., Granvik, M., Micheli, M., Ryan, E., Spahr, T., Yeomans, D. K., 2015, *Asteroids IV, 795-813*

Knežević, Z., Milani, A., 2000, *Celestial Mechanics and Dynamical Astronomy, 78, 17-46*

Marzari, F., Tricarico, P., Scholl, H., 2003, *Astronomy and Astrophysics, 410, 725-734*

Milani, A., Nobili, A. M., 1988, *Celestial Mechanics, 43, 1-34*

Milani, A., Chesley, S. R., Sansaturio, M. E., Tommei, G.,Valsecchi, G. B., 2005, *Icarus 173, 362-384*

Milani, A., 2006, *Serbian Astronomical Journal, 172, 1-11*

Raab, 2019, *http://www.astrometrica.at/*

Šidlichovský, M., Nesvorný, D., 1996, *Celestial Mechanics and Dynamical Astronomy, 65, 137-148*

Tiscareno, M. S., Malhotra, R., 2003, *The Astronomical Journal, 126, 3122-3131*

Vereš P., Farnocchia D., Chesley S. R., Chamberlin A. B., 2017, *Icar, 296, 139. doi:10.1016/j.icarus.2017.05.021*

Whipple A. L., 1995, *Icar, 115, 347. doi:10.1006/icar.1995.1102*

Wlodarczyk, I.,2007, *Acta Astronomica, 57, 103-121*

Wlodarczyk I., Cernis K., Eglitis I., 2011, *MNRAS, 418, 2330. doi:10.1111/j.1365-2966.2011.19621.x*

Wlodarczyk I., Cernis K., Boyle R. P., Laugalys V., 2014, *MNRAS, 438, 2621. doi:10.1093/mnras/stt2382*

Wlodarczyk, I., 2015, *Acta Astronomica 65, 215-231*

Wlodarczyk, I., 2017, *BlgAJ, 27, 89*

Wlodarczyk, I., Černis, K., Boyle, R. P., 2017, *Acta Astronomica, 67, 81*

Wlodarczyk I., Boyle R., Cernis K., 2017a, *EPSC*

Wlodarczyk I., Černis K., Boyle R. P., 2017b, *AcA, 67, 81. doi:10.32023/0001-5237/67.1.6*

Wlodarczyk I., 2019, *OAst, 28, 180. doi:10.1515/astro-2019-0016*

Wlodarczyk I., Černis K., Eglitis I., 2020a, *OAst, 29, 179. doi:10.1515/astro-2020-0017*

Wlodarczyk I., 2020b, *BlgAJ, 32, 27*