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BINARY ASTEROIDS IN MEAN-MOTION RESONANCES

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SUMMARY: The purpose of this study is to investigate the relation between binary asteroids and mean motion resonances (MMRs). For more than 700 asteroids from two catalogues, the *Johnston Archive* (Johnston 2024) and the *Gaia DR3 VizieR* list of binary candidates from Liberato et al. (2024), we applied a resonance identification algorithm, treating all planetary perturbations. Our results showed that the presence of binary asteroids in MMRs largely depends on their dynamical class. The highest percentage, more than 30%, is found in the Trans-Neptunian region where most of these objects have exhibited resonant librations longer than 10 Myr. For the main-belt asteroid pairs, this percentage is about 10-12%. Contrary to expectations, the more unstable region populated with NEOs, showed a higher percentage of resonant pairs (above 17%), but with temporal resonant captures. These results could indicate that the mean motion resonances, particularly the stronger ones, could play a role in the evolution and formation of binary systems. Finally, we highlight that in the present paper, 82 resonant binary asteroids are newly identified.

Key words. Minor planets, asteroids: general – Planets and satellites: dynamical evolution and stability – Methods: data analysis – Methods: numerical

1. INTRODUCTION

The concept of a binary asteroid was first introduced in 1901 by the French astronomer Charles André (André 1901, Radau 1901). According to a NASA/ADS search, the first mention of a binary system appeared in Cook (1971), where the author proposed that the unusual light curve of the Trojan asteroid (624) Hector indicated the presence of a satellite, rather than an elongated, cigar-shaped body[1] (Dunlap and Gehrels 1969). Over the following years, additional asteroids with similar photometric characteristics were identified (see, e.g. Binzel and van Flandern 1979, Binzel 1985, Tedesco 1979). However, the existence of binary asteroids remained speculative (Binzel 1978, van Flandern et al. 1979, Weidenschilling et al. 1989) until 1993, when the Galileo spacecraft directly imaged the (243) Ida-Dactyl asteroid pair (Mason 1994, Belton et al. 1996).

The classical method for the identification of binary and multiple systems[2] is by tracking signatures in their light curves, and it applies to all dynamical classes (although not to widely separated pairs). Faint and distant main belt and trans-Neptunian binaries require more advanced observational methods and are also found by direct imaging or stellar occultations. Near-Earth binaries are often identified on radar images, whereas a small number of systems have been imaged directly from spacecraft. Additional detection methods rely on spectral analysis, astrometric observation residuals, similarities in heliocentric orbits, or analysis of rotational properties (Noll et al. 2023, Margot et al. 2015, de la Fuente Marcos and de la Fuente Marcos 2019).

[1]Further studies showed that both assumptions were correct.

[2]In the following text, for simplicity, we will use only the term *binaries*.

Binary systems exhibit significant diversity, to the extent that nearly every pair could be studied separately. However, certain characteristics, particularly those related to formation, are often shared within the same dynamical classes. Binary Trans-Neptunian Objects (TNOs) are likely to have a primordial origin. Numerous studies (Weidenschilling 2002, Goldreich et al. 2002, Nesvorný et al. 2010, Fraser et al. 2017, Robinson et al. 2020, Nesvorný et al. 2021) investigated models in which the gravitational collapse of pebble clouds transferred the angular momentum to the formation of binary planetesimals. Being less exposed to major planetary perturbations which does not exclude mutual gravitational interactions (Brunini 2020, López and Brunini 2021, Lawler and Pike 2024), these systems could have survived to the present day, accounting for the high fraction of observed binary TNOs (Noll et al. 2008, Lawler and Pike 2024).

In regions closer to the Sun, different scenarios unfold. Main-belt binaries are more likely to be formed in post-collision processes, either by reaccumulation of ejected material or mutual gravitational capture of their larger fragments (Michel et al. 2001, Durda et al. 2004, Durda 1996, Doressoundiram et al. 1997, Giblin et al. 1998). Small Near-Earth asteroids (NEAs) affected by the YORP (Yarkovsky-O'Keefe-Radzievskii-Paddack) thermal force (Rubincam 2000, Vokrouhlický and Čapek 2002, Bottke et al. 2006) are largely studied in the context of binary formation (see, e.g. Ćuk 2007, Pravec and Harris 2007, Scheeres 2007, Walsh and Richardson 2008, Walsh et al. 2008, Jacobson and Scheeres 2011, Wimarsson et al. 2024). Under the action of YORP, the primary asteroid spins up to a rate high enough to shed mass, which then coalesces into a secondary body, forming a binary system[3]. Reported formation times vary widely, from 10^5 years to only a few hours (Wimarsson et al. 2024). Asteroid pairs can form even 'instantaneously', in scenarios where a larger piece falls off from a rubble-pile asteroid due to rotational fission (Scheeres 2009, Jacobson and Scheeres 2011).

Alternative formation mechanisms include tidal forces or migrations from the main asteroid belt (Walsh and Richardson 2006, 2008), but it is unlikely that primordial pairs exist in the dynamically unstable NEA region. However, double craters on terrestrial planets and the Moon (Melosh and Stansberry 1991, Cook et al. 2003, Miljković et al. 2013, Vavilov et al. 2022) indicate their larger presence in the past.

According to our knowledge, no systematic search of binary asteroids in mean motion resonances (MMRs) has been done so far. Previous works treated only individual cases; for example, Rosaev (2024) investigated resonant perturbation of the pair (5026) Martes and 2005 WW113 caused by the 3E-11 MMR with Earth. Borisov et al. (2024) captured a binary candidate 12499 exactly on the chaotic border of the 4M-7 MMR with Mars. Also, Pravec et al. (2019) found irregular jumps of the pair (10123) Fideöja - 117306, over the 7J-2 MMR, and possible instability of the pair 49791 - 436459 due to the 8M-15 MMR. Pravec et al. (2019) also discussed pairs in secular and spin-orbit resonances, but they are not the subject of this research. Duddy et al. (2012) identified the unknown resonance interacting with the pair 7343-154634 (Pravec and Vokrouhlický 2009), to be the 1M+1J-2 three-body MMR between the asteroid, Jupiter and Mars.

The search for binaries among the resonant Trojan (1J-1) and Hilda (3J-2) populations in the NEOWISE archive was performed by Sonnett et al. (2015). The authors found a surprisingly high binary fraction, of 14%–23% among the Trojan asteroids larger than $\sim$ 12 km and even $30\% - 51\%$ among Hildas larger than $\sim$ 4 km. However, these results are not entirely reliable, as only the binary *candidates*, i.e., asteroids with large light curve amplitudes, were considered.

In the Kuiper belt, Compère et al. (2013) investigated the scarcity of binaries in the Plutino population i.e. in the 2N-3 resonance with Neptune, although newer studies report a high fraction of contact and tight Plutino binaries (Thirouin and Sheppard 2018, Brunini 2023); also Thirouin and Sheppard (2024) found several contact binaries in the 3N-5 and 4N-7 MMRs.

Resonances, particularly the stronger ones, may have played a role in the evolution and possibly the formation of binary systems. Dynamical description of these processes is a challenging task for future work. Here, we aim to make the first step: find all known asteroid pairs captured by mean motion resonances and see whether their presence is larger in MMRs.

2. METHODOLOGY

We use two catalogues of binary asteroids: the Johnston Archive[4] (Johnston 2024), with 477 objects (in October 2024) spanning from the Near Earth to the trans-Neptunian region, and a recently published list from Gaia DR3 dataset (Liberato et al. 2024) containing 357 astrometric binary candidates, mostly from the main belt. All asteroids were integrated with the astronomical package `resonances` (Smirnov 2023) for 100 Kyr, which is the default time of the software. A certain number of trans-Neptunian objects was additionally integrated with Orbit9[5] for 10 Myr. Perturbations from all planets were included in all calculations.

Following the algorithm suggested by Smirnov et al. (2018), we calculated all potential two and three-body mean-motion resonances for each asteroid, using the proximity between the asteroid's and

[3]This scenario refers to rubble pile asteroids.

[4]https://www.johnstonsarchive.net/astro/asteroidmoons.html

[5]http://adams.dm.unipi.it/orbfit/

resonant semi-major axes. For every asteroid-MMR pair, we performed an identification procedure to determine whether the asteroid was trapped in the given resonance. The identification procedure requires two main conditions to be met:

i) The resonant argument σ must librate during the integration. For two-body resonances σ is defined with $\sigma = m_p\lambda_p + m\lambda + n_p\varpi_p + n\varpi$, where λ_p and λ are mean longitudes of the planet and the asteroid; ϖ_p and ϖ are the longitudes of their pericenters, and the integers m_p, m, n_p, and n satisfy the d'Alembert criterion. For three-body resonances, appearing with commensurability between an asteroid and two planets, σ is defined with $\sigma = m_{p_1}\lambda_{p_1} + m_{p_2}\lambda_{p_2} + m\lambda + n_{p_1}\varpi_{p_1} + n_{p_2}\varpi_{p_2} + n\varpi$. The variables are the same as for two-body resonances, with the difference that indices p_1 and p_2 refer to planets 1 and 2 involved in the resonance. We considered only the planar case and the primary subresonance in the multiplet, which implies $n_p = n_{p_1} = n_{p_2} = 0$.

ii) The oscillation frequencies of the resonant argument and semi-major axis should match and the corresponding amplitudes should be sufficiently large to be meaningful (Gallardo 2006).

The identification procedure performed by the `resonances` package is specified in several papers: the resonant axis calculation and classifications of librations for three-body MMRS with Jupiter and Saturn, and two-body MMRs with Jupiter in Smirnov and Shevchenko (2013), the expansion to all possible combinations of planets in Smirnov et al. (2018), and the Python package used in the paper for the identification in Smirnov (2023).

After completing the integration, the software automatically detects the resonant and potentially resonant asteroids and generates corresponding images for each asteroid (see Fig. 1). The images are composed of six panels showing the time evolution of resonant angle σ (row 1), its filtered value σ_f (row 2) where all short periodic oscillations with periods less than 500 years are removed, semi-major axis a [AU] (row 3), and eccentricity (row 6). The software also presents two periodograms that illustrate the distribution of all periodic variations in a and σ (rows 4 and 5), where the red and green dashed horizontal lines represent the weak and strong thresholds for periods to be significant. For a more detailed explanation of periodograms and filtering procedures, see Smirnov and Dovgalev (2018) and the documentation of the `resonances`[6] software. The images produced by the software were used by the authors for visual inspection for additional confirmation that the asteroids are in MMRs. Positive cases are classified into two categories:

a) *Libration*: the asteroid librates in the resonance throughout the *entire* integration period.

b) *Transition*: the asteroid is temporarily captured in the resonance and librates in *episodes*.

Libration of the asteroid 119067 in the 4N-7 MMR with Neptune is illustrated in the left panel of Fig. 1. The top two rows show that both σ and σ_f librate during all 100 Kyr, while the semi-major axis oscillates around $a \sim 43.7$ [AU] with approximately the same frequency (row 3). Periodograms for a and σ (rows 4 and 5) give an additional confirmation of resonant status, since they have only one dominant peak at about 16 Kyr. Row 6 gives the asteroid's eccentricity time change, with approximately the same period. Pure librations are marked by the software with 2, as noted at the top of the panel.

An illustration of the *transition* status of the asteroid 20037 in the 8M-11 MMR is given in the right panel of Fig. 1. The first three rows σ, σ_f and a indicate that the asteroid entered and left the resonance several times. Librations in σ are observed between [14,24] Kyr, [28,42] Kyr, [48,60] Kyr and [63,98] Kyr, during which a oscillates with larger amplitudes. The distribution of oscillation periods in rows 4 and 5 shows a higher concentration for $t < 5$ Kyr, with three matching peaks at $t \sim [2, 2.5, 3]$ Kyr. Eccentricity displays a periodic change, but also a slight increasing trend. The software marked the transient resonant status with 1, which is displayed at the top of the panel.

This study is mainly intended to detect asteroids that are already affected by the resonance, meaning that 100,000 years (the default time of the software) can cover the necessary interval for identifying resonant behaviours. For the TNO population, we have repeated the integration of purely resonant objects for 10 Myr, using Orbit9 and the same parameters as used by the `resonances` package.

3. RESULTS AND DISCUSSION

Table 1 provides a summary of the results, presenting the binary asteroids from both the Johnston Archive (hereafter JA) and the Gaia catalogue, categorised by their dynamical classes. It shows the presence of resonant objects within each group, as well as within the overall JA and Gaia binary sets. Detailed lists of resonant binaries, their associated resonances, resonant locations and assigned statuses are given in Table 2 for JA, and Table 3 for the Gaia set.

Trojan binaries are in the 1J-1 MMR by definition. All 8 Jupiter Trojans from JA (Table 2) and 6 from Gaia (Table 3) have pure librations (L). Besides them, the largest fraction of binaries in MMRs (30.5%) is found among TNOs. This result aligns with earlier studies, which suggest that the primordial origin of TNO binaries may be preserved in resonances, shielding these systems from dynamical disruption throughout the Solar System's history. The

[6] Available at: https://smirik.github.io/resonances/libration/

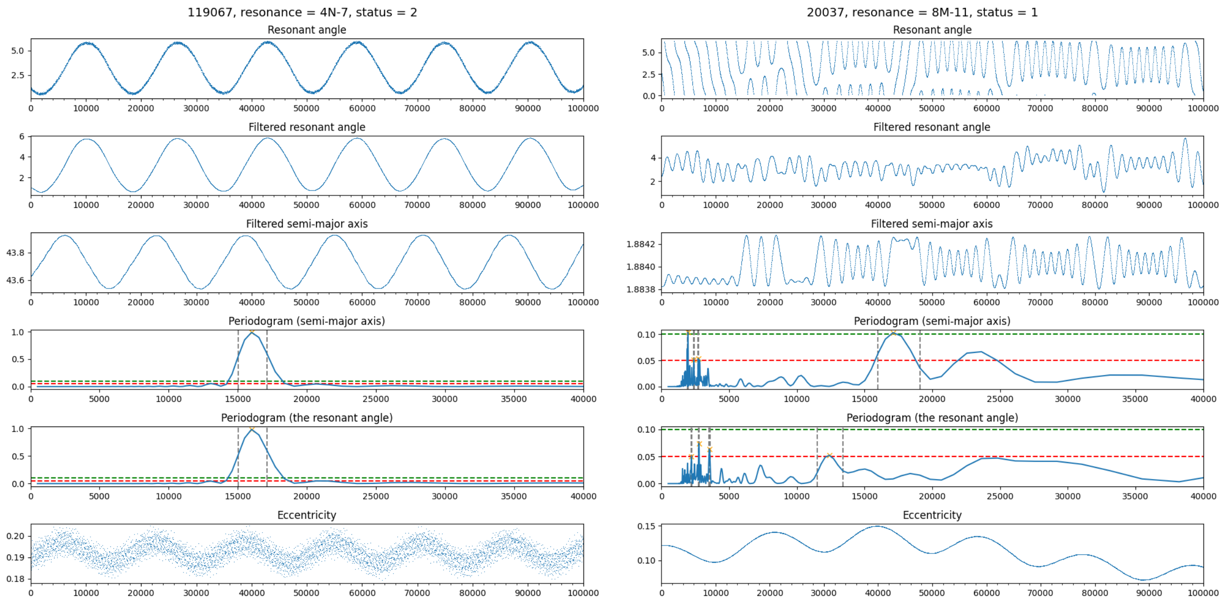

Fig. 1: **The left plot** illustrates the case of pure *libration* of the asteroid 119067 in the 4N-7 MMR with Neptune. The first two rows show that the resonant angle σ and its filtered value σ_f librate during the whole interval of 100 Kyr, while a oscillates with the same frequency (row 3). The two periodograms (rows 4 and 5) indicate that the dominant period for both σ and a aligns at approximately 16,000 years. The last row displays the change in eccentricity with approximately the same period. **The right panel** shows the so-called *transition* status for the asteroid 20037 in the 8M-11 MMR with Mars. The asteroid is trapped in the resonance in several episodes between $t = \{[14, 24], [28, 42], [48, 60], [63, 98]\}$ Kyr when σ and σ_f (rows 1 and 2) librate, and a oscillates with somewhat larger amplitudes (row 3). The two periodograms (rows 4 and 5) show a dense period distribution for times less than 5000 years, with the most dominant peaks at 2 kyr, 2.5 Kyr, and 3 Kyr. The eccentricity of the asteroid (row 6) illustrates a periodic change, but also a slight average increase in the first 50 Kyr.

distribution of the binary TNOs in the a-e plane between 35 and 56 AU is shown in Fig. 2 (for comparison, see Fig. 1 in Lawler and Pike 2024). Resonant binaries (red triangles) appear to be prevalent in the densest parts of the TNO region, particularly between 44 and 45 AU. The 2N-3 MMR, for which Forgács-Dajka et al. (2023) found to hold a significant amount of TNOs, also dominates in a number of binary resonant objects (in Table 2, 8 TNOs are in the 2N-3 MMR, all have pure librations). Let us note that this resonance also captures a significant number of contact binaries (Thirouin and Sheppard 2018, Brunini 2023), which are not contained in JA.

Almost all TNOs (except one - 65489 Ceto) listed in Table 2 convincingly reside in their resonances exhibiting pure librations during 100 Kyr, suggesting a long-term stay. We repeated the calculation of these asteroids for 10 Myr using Orbit9, and found that 19 out of 25 TNOs remained in pure libration in the long runs. The six TNOs in Table 2 designated with 'LT' (column 6) are those objects that have shown pure librations for 100Kyr, but passed into transient statuses (T) on the repeated 10 Myr integrations. Each of these 6 asteroids has actually left and re-entered the resonance multiple times over a period of 10 million years. A more detailed analysis of this phenomenon and an assessment of stability are beyond the scope of this paper and may be examined in a future study.

The main belt pairs in JA and in the Gaia set are resonant objects in 10.8% and 12.3% cases, respectively, and most of them in transition statuses. Even three asteroids in JA (88710, 1803 Zwicky and 78085, see Table 2) and three in the Gaia set (43341, 6364 Casarini and 68304, see Table 3) resided in more than one resonance during 100 Kyr. Transitions from one resonance to another most likely arise from resonance overlap in this region densely populated with MMRs. In Tables 2 and 3, we provide the locations of resonances (their centers), but not their widths, which are essential for identifying resonant chains that enable such transitions. More studies, which are beyond the scope of this paper, are required to explore these possibilities.

Out of 34 Mars-crossers in JA, 6 (17.6%) were found in resonances, 1 Mars-Trojan, 5261 Eureka, and 1 resident of the 2J-1 MMR, the asteroid 8373 Stephengould, exhibit pure librations, while the remaining 4 asteroids display a transient nature. The percentage of 17.6% is above the main-belt average, but the small sample may render this conclusion uncertain.

Table 1: This table summarises the results on the resonant binaries search from the Johnston Archive (JA) and the Gaia DR3 dataset, obtained with the `resonances` package over the 100Kyr integrations. Dynamical types and the number of objects in them are in column 2 and column 3, respectively. The number of resonant objects in each class is given in column 4, while column 5 gives the number of objects in libration (L) and transient (T) regimes. Column 6 gives the percentage of resonant objects in each of these groups.

Sourse	Dynamical type	No. of objects	No. of objects in MMRs	Res. status		Result in [%]
JA	NEA	82	14	L T	1 13	17.1
JA	Mars-cros.	34	6	L T	2 4	17.6
JA	Main belt	268	29	L T	3 26	10.8
JA	Trojans	8	8	L T	8 0	100
JA	TNOs	85	26	L T	25 1	30.5
JA	all	477	83	L T	39 44	17.4
Gaia	NEA	2	0	L T	- -	-
Gaia	Mars-cros.	8	0	L T	- -	-
Gaia	Main belt	341	42	L T	12 30	12.3
Gaia	Trojans	6	6	L T	6 0	100
Gaia	all	357	48	L T	18 30	13.4

In the NEA region, almost all resonant pairs (except 452561 in the 2J-1 MMR) have transient statuses, showing a high mobility through resonances. It could be expected that these dynamical transitions contribute to separation of asteroid pairs, since they are more exposed to planetary perturbations and chaos, in general. Surprisingly, the unstable NEA region showed a higher proportion of resonant pairs (17.1%) compared to those in the main belt (10.8% and 12.3%). This, certainly, is a topic that needs to be investigated. In the Gaia catalogue, none of the 2 NEAs or 8 Mars-crossing binaries are found to be in a resonance.

The total percentage of resonant objects in the Johnston Archive is 17.4%, undoubtedly influenced by the high percentage of resonant TNOs. The mean value for the Gaia set is 13.4%. We recall the result from Smirnov et al. (2018), who used a similar algorithm for resonance identification on all asteroids from the AstDyS database known at that time. They found that 14.1% (65,972 out of 467,303 objects) of asteroids were resonant. However, their results were not categorised by dynamical classes, which complicates the direct comparison with the results presented in Table 1. If we compare the overall rates of 17.4% from JA and 14.1% from Smirnov et al. (2018), since both cover the regions from NEAs to TNOs, we infer that binary asteroids have a greater tendency to reside in MMRs. This could mean that resonances not only protect asteroid pairs but, perhaps, they also *produce* them. Long stays in stable resonances open up the possibility for mutual encounters, gravitational captures and formation of new pairs. This could explain the high fraction of binary asteroids among Trojans (14%–23% larger than 12 km) and Hildas (30% − 51% larger than 4 km) estimated in Sonnett et al. (2015).

Finally, column 3 of Tables 2 and 3 lists the sources in which asteroids are reported to be resonant. In addition to standard references, objects classified as resonant on the Minor Planet Center webpage[7] are marked with "MPC." Most resonant TNOs are identified in the Boulder database[8], while two asteroids are referenced only on wiki-style websites without cited sources[9]. Objects marked with

[7] https://www.minorplanetcenter.net/

[8] https://www.boulder.swri.edu/~buie/kbo/desclass.html

[9] The asteroid 119067 (2001 KP76) is listed as resonant on Wikiwand: https://www.wikiwand.com/fr/articles/S/2008_(119067)_1, and 174567 Varda (2003 MW12) on The Solar System Fandom: https://thesolarsystem.fandom.com/wiki/Varda

Table 2: Binary asteroids from the Johnston Archive identified in various mean motion resonances (listed in column 4). Their dynamical classes, resonant statuses (L for libration or T for transition), and semi-major axis of resonant locations (Gallardo 2006), are provided in columns 7, 6 and 5, respectively. Column 3 cites the previous studies where these asteroids have been classified as resonant. Out of the 26 TNOs, 6 of them, marked with 'LT', entered into transient statuses in the repeated 10 Myr integrations. Newly identified resonant binary asteroids (44 in total) are indicated with a double asterisk (**).

No. and name	Prov. name	Reference	MMR	a_{MMR}	status	class
3122 Florence	(1981 ET3)	**	5J-1	1.778	T	NEA
35107	(1991 VH)	**	4E+2J-5	1.128	T	NEA
5646	(1990 TR)	**	3M-5	2.141	T	NEA
7888	(1993 UC)	**	3J-1	2.500	T	NEA
7889	(1994 LX)	**	12E-17	1.261	T	NEA
85804	(1998 WQ5)	**	5M-6	1.720	T	NEA
88710	(2001 SL9)	**	5V-9	1.070	T	NEA
88710	(2001 SL9)	**	9V-16	1.061	T	NEA
152931	(2000 EA107)	**	7E-6J-6	0.948	T	NEA
163693 Atira	(2003 CP20)	**	4V-15	1.745	T	NEA
164121	(2003 YT1)	**	5M-3S-3	1.112	T	NEA
452561	(2005 AB)	**	2J-1	3.276	L	NEA
458732	(2011 MD5)	**	3J-1	2.500	T	NEA
613286	(2005 YQ96)	**	3E-2	1.310	T	NEA
620082	(2014 QL433)	**	4J-1	2.064	T	NEA
5261 Eureka	(1990 MB)	MPC	1M-1	1.523	L	mars crossers
8373 Stephengould	(1992 AB)	Roig et al. (2002)	2J-1	3.276	L	mars crossers
20037 Duke	(1992 UW4)	**	8M-11	1.232	T	mars crossers
34706	(2001 OP83)	**	7J-2	2.256	T	mars crossers
218144	(2002 RL66)	**	5J-4S-1	2.303	T	mars crossers
12008 Kandrup	(1996 TY9)	**	3J+3S-1	1.996	T	mars crossers
617 Patroclus	(A906 UL)	MPC	1J-1	5.201	L	trojan
624 Hektor	(A907 CF)	MPC	1J-1	5.201	L	trojan
3548 Eurybates	(1973 SO)	MPC	1J-1	5.201	L	trojan
15094 Polymele	(1999 WB2)	MPC	1J-1	5.201	L	trojan
16974 Iphthime	(1998 WR21)	MPC	1J-1	5.201	L	trojan
17365 Thymbraeus	(1978 VF11)	MPC	1J-1	5.201	L	trojan
29314 Eurydamas	(1994 CR18)	MPC	1J-1	5.201	L	trojan
100624	(1997 TR28)	MPC	1J-1	5.201	L	trojan
22 Kalliope	(A852 WA)	Nesvorný and Morbidelli (1998)	4J-4S-1	2.906	T	main belt
93 Minerva	(A867 QA)	**	3E+13	2.657	T	main belt
216 Kleopatra	(A880 GB)	**	2M-5J-3	2.795	T	main belt
1803 Zwicky	(1967 CA)	**	4E+15	2.413	T	main belt
1803 Zwicky	(1967 CA)	**	5E-18	2.348	T	main belt
1803 Zwicky	(1967 CA)	**	9M-17	2.328	T	main belt
2171 Kiev	(1973 QD1)	Nesvorný and Morbidelli (1998)	7J-2	2.256	T	main belt
2623 Zech	(A919 SA)	**	5M-9	2.254	T	main belt
26420	(1999 XL103)	**	9M-16	1.038	T	main belt
3187 Dalian	(1977 TO3)	**	10M-19	2.337	T	main belt
3390 Demanet	(1984 ES1)	**	6M-11	1.017	T	main belt
3657 Ermolova	(1978 ST6)	**	6M-11	1.017	T	main belt
3865 Lindbloom	(1988 AY4)	**	4J-2S-1	2.396	L	main belt
4901 O Briain	(1988 VJ)	**	13J+4	2.370	T	main belt
4296 van Woerkom	(1935 SA2)	**	15J+4	2.154	T	main belt
4492 Debussy	(1988 SH)	**	4E-19	2.825	T	main belt
4951 Iwamoto	(1990 BM)	Nesvorný and Morbidelli (1998)	7J-2	2.256	T	main belt
5319 Petrovskaya	(1985 RK6)	Nesvorný and Morbidelli (1998)	7J-2	2.256	T	main belt
5536 Honeycutt	(1955 QN)	**	15J+4	2.154	T	main belt
5872 Sugano	(1989 SL)	**	15J+4	2.154	T	main belt
6615 Plutarchos	(9512 P-L)	**	1V-1E-2	2.170	T	main belt
12218 Fleischer	(1982 RK)	**	4M-7	2.212	T	main belt
15107 Toepperwein	(2000 CR49)	**	7M+12	1.063	T	main belt
15430	(1998 UR31)	**	7J+2	2.256	T	main belt
16525 Shumarinaiko	(1991 CU2)	**	4J-2S-1	2.396	L	main belt
18503	(1996 PY4)	**	13J+4	2.370	T	main belt
21149 Kenmitchell	(1993 HY5)	**	7M-10	1.932	T	main belt
57027	(2000 UB59)	Szabó et al. (2020)	3J-2 (Hilda)	3.969	L	main belt
57202	(2001 QJ53)	**	4M-2J-7	2.337	T	main belt
78085	(2002 LV23)	**	5J-4S-1	2.303	T	main belt
78085	(2002 LV23)	**	2E-7	2.305	T	main belt
118303	(1998 UG)	**	3M-5J-4	2.264	T	main belt
26308	(1998 SM165)	Boulder	1N-2	47.811	L	TNO
38628 Huya	(2000 EB173)	Boulder	2N-3	39.467	L	TNO
47171 Lempo	(1999 TC36)	Boulder	2N-3	39.467	L	TNO
65489 Ceto	(2003 FX128)	**	1N-6	99.452	T	TNO
60621	(2000 FE8)	Boulder	2N-5	55.480	L	TNO
66652 Borasisi	(1999 RZ253)	**	4N-7	43.739	LT	TNO
82075	(2000 YW134)	Boulder	3N-8	57.919	L	TNO
90482 Orcus	(2004 DW)	Boulder	2N-3	39.467	L	TNO
119067	(2001 KP76)	Wikiwand	4N-7	43.739	L	TNO
119979	(2002 WC19)	Boulder	1N-2	47.811	L	TNO

Table 2: continued from the previous page.

No. and name	Prov. name	Reference	MMR	a_{MMR}	status	class
136108 Haumea	(2003 EL61)	Pinilla-Alonso et al. (2009)	7N-12	43.142	LT	TNO
139775	(2001 QG298)	Boulder	2N-3	39.467	L	TNO
174567 Varda	(2003 MW12)	Wiki	8N-15	45.798	LT	TNO
208996	(2003 AZ84)	Boulder	2N-3	39.467	L	TNO
225088 Gonggong	(2007 OR10)	Boulder	3N-10	67.209	LT	TNO
341520 Mors-Somnus	(2007 TY430)	Boulder	2N-3	39.467	L	TNO
385446 Manwe	(2003 QW111)	Boulder	4N-7	43.739	L	TNO
469420	(2001 XP254)	Boulder	3N-5	42.339	L	TNO
469505	(2003 FE128)	Boulder	1N-2	47.811	L	TNO
506121	(2016 BP81)	**	4N-7	43.739	LT	TNO
523624	(2008 CT190)	Boulder	3N-7	52.986	LT	TNO
523764	(2014 WC510)	Boulder	2N-3	39.467	L	TNO
525816	(2005 SF278)	Boulder	4N-7	43.739	L	TNO
554099	(2012 KU50)	JA	5N-8	41.202	L	TNO
612088	(1999 CM158)	Boulder	2N-3	39.467	L	TNO
612176	(2000 QL251)	Boulder	1N-2	47.811	L	TNO

Table 3: The same as Table 2 for the Gaia binary candidates from Liberato et al. (2024). The 38 objects marked with ** are not found in the previous literature as resonant asteroids.

Name	Prov. name	Reference	MMR	a_{MMR}	Status	class
53 Kalypso	(A858 GA)	Nesvorný and Morbidelli (1998)	6J-1S-2	2.618	T	Main Belt
217 Eudora	(A880 QA)	**	2M+5S-6	2.872	T	Main Belt
605 Juvisia	(A906QJ)	**	7M-20	3.067	T	Main Belt
625 Xenia	(A907 CG)	**	1V-7	2.646	T	Main Belt
674 Rachele	(A908 UK)	**	1E-5	2.924	T	Main Belt
923 Herluga	(A919 SK)	Nesvorný and Morbidelli (1998)	2J+2S-1	2.616	T	Main Belt
1438 Wendeline	(1937 TC)	**	5J-2S-2	3.173	L	Main Belt
1963 Bezovec	(1975 CB)	**	9M-19	2.507	T	Main Belt
3561 Devine	(1983 HO)	Brož and Vokrouhlický (2008)	3J-2 (Hilda)	3.969	L	Main Belt
4031 Mueller	(1985 CL)	**	7E-19	1.945	T	Main Belt
5044 Shestaka	(1977 QH4)	**	4E-13	2.194	T	Main Belt
5747 Williamina	(1991 CO3)	**	4J-2S-1	2.396	L	Main Belt
6364 Casarini	(1981 ET)	**	2E-5M+3	2.748	T	Main Belt
6364 Casarini	(1981 ET)	**	2M+1S-5	2.867	T	Main Belt
6612 Hachioji	(1994 EM1)	**	1V-1S-6	2.422	L	Main Belt
7071	(1995 BH4)	**	5J-2S-2	3.173	L	Main Belt
8284 Cranach	(1991 TT13)	**	1V+9	3.129	T	Main Belt
8632 Egleston	(1981 FR)	**	4J-1S-1	2.214	T	Main Belt
9661 Hohmann	(1996 FU13)	Brož and Vokrouhlický (2008)	3J-2 (Hilda)	3.969	L	Main Belt
11218	(1999 JD20)	**	9J-4	3.029	T	Main Belt
12914	(1998 SJ141)	**	3M-7	2.680	T	Main Belt
13840 Wayneanderson	(1999 XW31)	**	1M-2	2.418	T	Main Belt
14717	(2000 CJ82)	**	5J-2S-2	3.173	T	Main Belt
15063	(1999 AQ3)	**	2J+1S-1	2.900	T	Main Belt
15373	(1996 WV1)	Brož and Vokrouhlický (2008)	3J-2 (Hilda)	3.969	L	Main Belt
18840 Yoshioba	(1999 PT4)	**	5E-18	2.348	T	Main Belt
22150	(2000 WM49)	**	4J-2S-1	2.396	L	Main Belt
31359	(1998 UA28)	**	7M+12	2.182	T	Main Belt
43326	(2000 KH73)	**	7M+12	2.182	T	Main Belt
43341	(2000 RK62)	**	3E+13	2.657	T	Main Belt
43341	(2000 RK62)	**	8M-17	2.518	T	Main Belt
47211	(1999 TX290)	**	3E-10	2.231	T	Main Belt
53245	(1999 CH152)	**	12J-5	2.901	T	Main Belt
55125	(2001 QD173)	**	2V-4E+3	2.522	T	Main Belt
61574	(2000 QE79)	**	1M-2	2.418	T	Main Belt
68304	(2001 FO97)	**	1V-9	3.129	T	Main Belt
68304	(2001 FO97)	**	16S-3	3.129	T	Main Belt
72039	(2000 XG49)	**	6E-19	2.156	T	Main Belt
87719	(2000 SL45)	**	3V-20	2.562	T	Main Belt
88538	(2001 QG187)	**	2E+9	2.725	T	Main Belt
115321	(2003 SK219)	**	8J-3	2.704	L	Main Belt
115664	(2003 UL142)	**	1E-3J-4	3.060	L	Main Belt
121297	(1999 RU195)	**	13J+6	3.106	L	Main Belt
160293	(2003 DK24)	**	2J+2S-1	2.616	T	Main Belt
207591	(2006 QH56)	**	3J-2 (Hilda)	3.969	L	Main Belt
1867 Deiphobus	(1971 EA)	McNeill et al. (2021)	1J-1	5.201	L	Jupiter Trojan
3596 Meriones	(1985 VO)	McNeill et al. (2021)	1J-1	5.201	L	Jupiter Trojan
31344 Agathon	(1998 OM12)	MPC	1J-1	5.201	L	Jupiter Trojan
35277	(1996 RV27)	MPC	1J-1	5.201	L	Jupiter Trojan
55563	(2002 AW34)	MPC	1J-1	5.201	L	Jupiter Trojan
60322	(1999 XB257)	MPC	1J-1	5.201	L	Jupiter Trojan

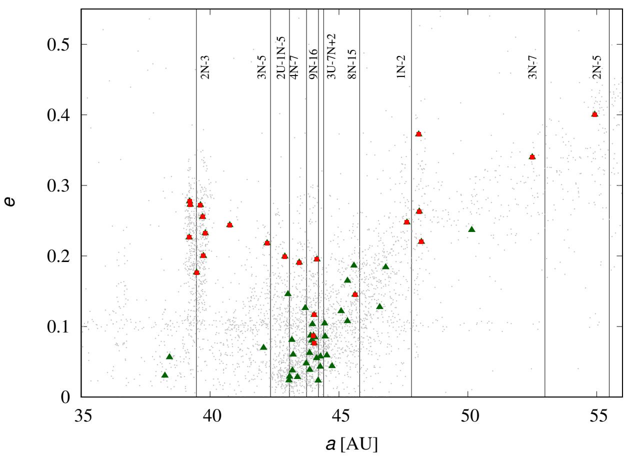

Fig. 2: Binary resonant (red triangles), binary non-resonant (green triangles), and non-binary numbered (grey dots) asteroids in the TNO region. The vertical dashed lines mark the positions of semi-major axes for the most dominant MMRs in the region. The largest concentration of resonant binaries is found in the most populated TNO region between 44 and 45 AU, and in the most populated 2N-3 MMR in the region.

double asterisk (**) are those we could not find in the literature, indicating they are the newly discovered resonant binaries. A total of 82 such cases were found.

4. CONCLUSIONS

The results of this study showed that the percentage of binary asteroids in mean motion resonances largely depends on their dynamical classes.

The highest fraction of approximately 30% resonant asteroids is observed among the TNO binaries, meaning that MMRs offer a protective environment for these systems to survive perturbations. The lower fraction of resonant binaries in the main asteroid belt suggests that the post-collision processes, often responsible for binary formation in this region, do not favour long-term resonance captures. This conclusion is supported by the observed clustering of main-belt binaries near weaker MMRs and by their transient nature. NEA binaries show a high resonance fraction, with most cases involving transient captures. These findings are somewhat unexpected, given the dynamically unstable nature of the NEA region, where frequent planetary encounters and perturbations disrupt these pairs and can lead to the breakup of asteroid systems.

Binary systems have a slightly higher representation in resonances (17.4%) compared to the overall asteroid population (14.1% from Smirnov and Dovgalev 2018). Moreover, stable resonances could facilitate binary formation through low-velocity encounters or angular momentum exchange. This suggests that, in addition to the primordial nature of the binary TNOs, significantly younger systems could be expected among TNOs and in various dynamical classes of small bodies, and may also explain the large percentage of binaries observed among Trojans and Hilda populations.

Future research should aim to extend integration timescales, incorporate additional binary catalogues, and explore the influence of individual components within these systems. Binary asteroids in resonances remain a topic for further investigation.

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ДВОЈНИ АСТЕРОИДИ У ОРБИТАЛНИМ РЕЗОНАНЦАМА

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Оригинални научни рад

Циљ овог рада је испитивање везе између двојних астероида и орбиталних резонанци (или резонанци у средњем кретању, РСК). За више од 700 објеката из два каталога, Џонстонове архиве (Johnston 2024) и *Gaia DR3 VizieR* листе бинарних кандидата из Liberato et al. (2024), применили смо алгоритам за идентификацију орбиталних резонанци, укључујући пертурбације свих планета. Резултати су показали да присуство бинарних астероида у РСК у великој мери зависи од њихове динамичке класе. Највећи проценат двојних астероида у резонанцама је пронађен у транс-нептунском региону (преко 30%). Већина ових објеката је показала дугорочне боравке у резонанцама од преко 10 милиона година. За парове астероида главног појаса, овај проценат је 10-12.3%. Супротно очекивањима, показало се да нестабилнији регион у близини Земље има већи проценат резонантних парова (изнад 17%), али са краткотрајним боравцима у резонанцама. Ови резултати указују на могућност да резонанце у средњем кретању, посебно оне јаче, могу имати удела у еволуцији или формирању двојних система. Такође, истичемо да су у овом раду идентификована 82 нова двојна астероида у резонанцама.