Orbital Dynamics of Resonant Asteroids in the Hungarias Group - The case of 5/7 M

Gabriel Nunes de Araújo[1] Adrián Rodríguez Colucci[1] Anderson Oliveira Ribeiro[2]

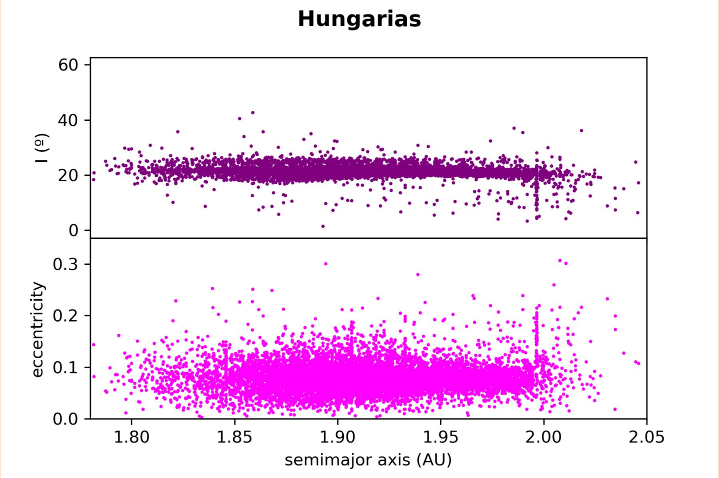
gabriel19@astro.ufrj.br

[1] Observatório do Valongo, Universidade Federal do Rio de Janeiro, RJ - Brasil

[2] Centro Universitário Geraldo Di Biase, UGB, Brasil.

Introduction

The Hungaria group of asteroids, named after (434) Hungaria, orbits the Sun in the inner region of the Solar System (**$1.78 < a < 2.06$ AU**), between the orbit of Mars and the main belt. They occupy a region dynamically protected from most of Jupiter's mean motion (**MMRs**) and secular resonances [1]. The proximity with Mars allows the planet's gravitational effects to dynamically disturb the group, despite having a fairly low mass.

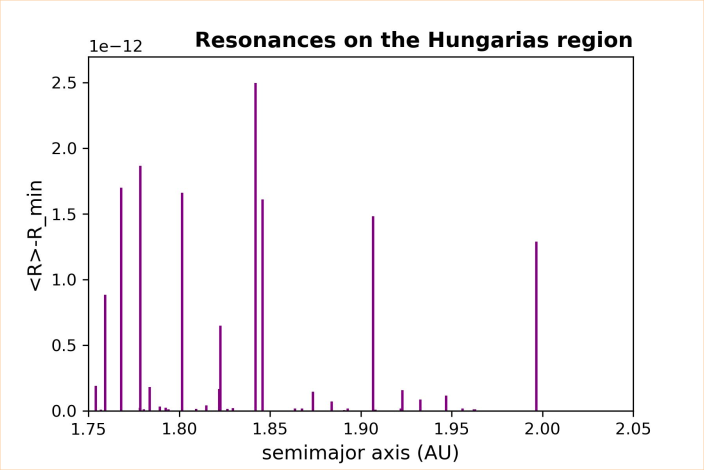


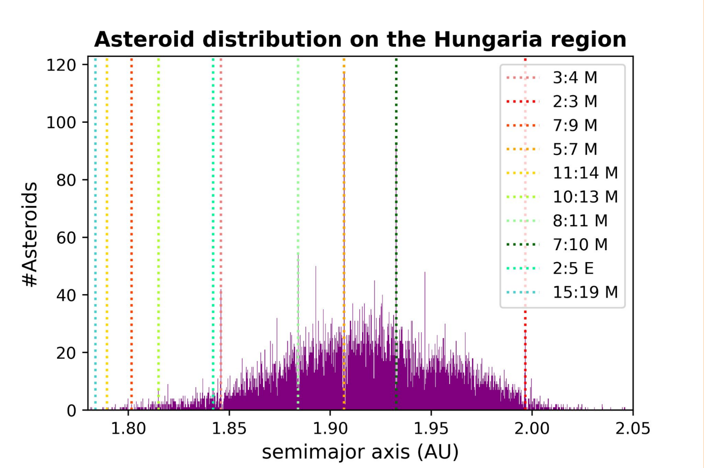
The Hungarias are clustered in low to moderate eccentricities (**$e < 0.18$**) and highly inclined orbits (**16-30º**). Their eccentricity act as a mars-crossing orbit limit, while the inclination protects the group from close encounters with Mars [2][3].

[1]Correa-Otto, J.A, Cañada-Assandri, M., Dynamic portrait of the region occupied by the Hungaria Asteroids: The influence of Mars, MNRAS, 479, 2018.

[2]Migliorini, F. et al., Origin of multikilometer Earth and Mars-Crossing asteroids: A quantitative simulation, Science, 281, 1998.

[3]Michel, P. et al., The population of Mars-Crossers: Classification and dynamical evolution, Icarus, 145, 2000.





Results

For better comprehension of the dynamical structure of the Hungarias, there were identified the resonances present in the region of semimajor axis occupied by the group. A map was constructed by numerical methods using the SuperAtlasV2 [4] calculating all MMRs until the 20th order (**q <= 20**) with **k,kp < 20**.

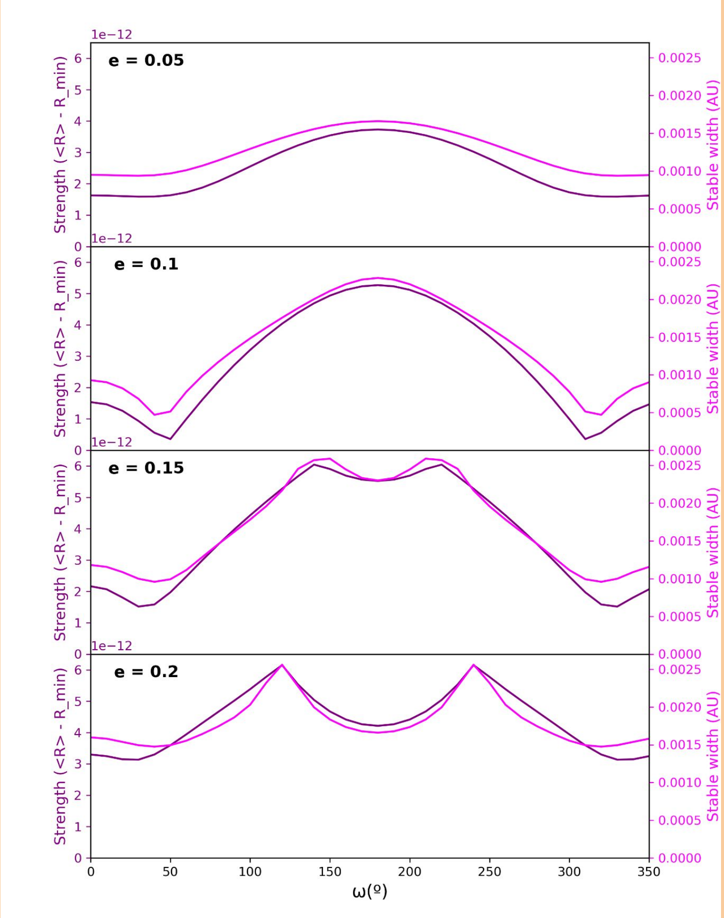
Utilizing the data of proper elements from the **AstDyS** [5] database, the distribution of asteroids in the region was compared to the position of occurence of the 10 strongest MMRs in the semimajor axis space.

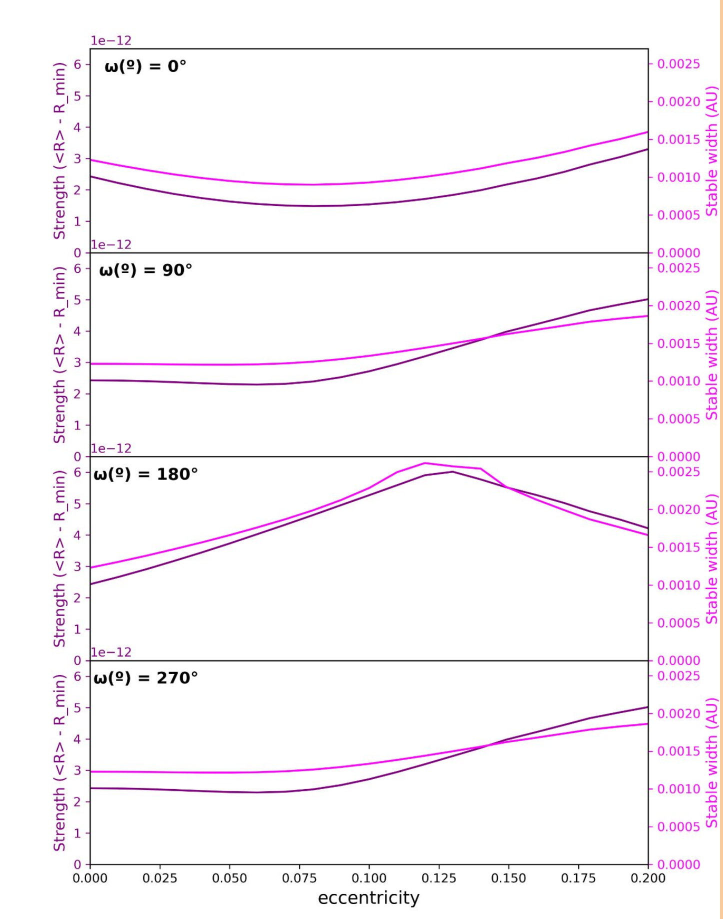
[4]Gallardo, T. Evaluating the signatures of the mean motion resonances in the solar system
[5]https://newton.spacedys.com/astdys/index.php?pc=5

It was noticed that the semimajor axis near **1.9068AU** corresponding to the position of the MMR 5/7 with Mars (**5/7M**), also has a concentration of more than a hundred objects. A local maxima in the number of asteroids was also noted in the distribution of the osculating semimajor axis, indicating that 5/7M could dynamically influence the structure of the group.

We analyzed how the resonance's strength and width depends on the asteroid's orbital elements. We calculated strength/width values by variating the **argument of pericenter (ω)** with fixed **eccentricity** and vice versa.

The results indicate that the strength and the width of the resonance suffer significative shifts with the variation of both the argument of pericenter and eccentricity.





This dependence could difficult the capture by the MMR since **ω** has a periodic property and the strength would undergo large fluctuations, allowing the escape from the resonance.

In order to study effects of the resonance for longer time periods, we analyzed the libration's center of the 5/7M for different values of **ω** and **eccentricity.**

The libration center was shown to circulate for eccentricity values **< 0.15** and for **e >= 0.15** it oscillates around **180º** when **ω** variates. While **e** varies, the libration center circulates for values **differing from 180º** and for **180º** the libration center is also **180º**.

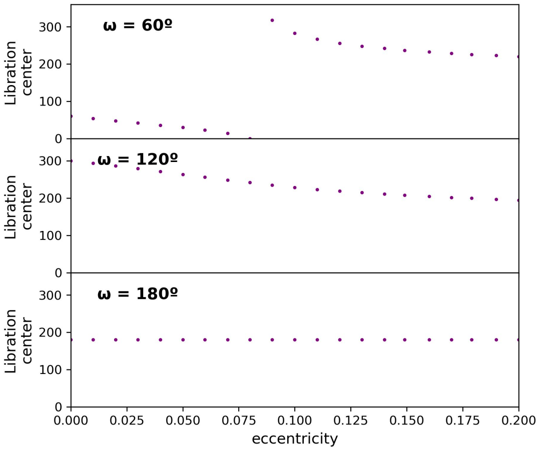
A new round of simulations were constructed covering the whole angular space from **0º to 360º** with a step of 90º, resulting in 4 simulations with initial **σ = 0º, 90º, 180º, 270º**.

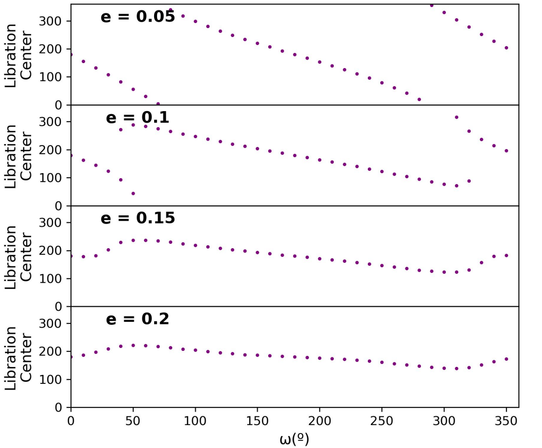
$$\sigma = 7\lambda - 5\lambda_M - 2\varpi$$

To investigate whether the **5/7M** could be a source of temporary stability and/or mars-crossing asteroids we numerically integrated a synthetic asteroid population near the occurrence of the MMR. We use the criteria from JPL/NASA [6] for mars-crossing asteroids:

We've performed the integration with 7 planets from Venus to Neptune in a timespan of **50 Myrs** utilizing the **Mercury** [7] package. The simulation only take into account gravitational effects from planets. The initial grid was composed by **1000 asteroids** with a semi major axis ranging from **1.90AU** to **1.91AU** and eccentricity values **< 0.2**.

[6]Chamber, J.E., Mercury: A software package for orbital dynamics, Astrophysics Source Code Library, 2012.
[7]https://ssd.jpl.nasa.gov/sbdb_help.cgi?class=MCA





The bins are **~0.0001AU** for the semi major axis and **0.01** for the eccentricity. For the inclination, all the particles started with the mean inclination of the population **(20º)**. The simulation results are shown in the Table 1.

The results showed that during the whole integrated time and only a small number finished it inside 5/7M domain.

An additional set of simulations was constructed similar to the last one, although, the semi major range was narrowed so all the asteroids started within the resonance's domain **(1.906 < a < 1.908 AU)**. The results are shown in Table 2.

[8]Forgács-Dajka, E., et al., A survey on Hungaria asteroids involved in mean motion resonances with Mars, Astronomy & Astrophysics, 2021
[9]Dermott, S. et al., Dynamical evolution of the inner asteroid belt, MNRAS, 2021.

It was noted that, for both integrations, the elimination ratio is very low **(< 5%)**. Nevertheless, the majority of the asteroids **(~ 60%)** evolves to Mars-crossing orbits and a few amount **(< 5%)** acquire NEO-like orbits.

The Yarkovsky effect is known to play a significant role in the Hungaria group [8], but our first integrations only take conservative forces into account. In order to study the influence of dissipative effects, new simulations were performed including semi major axis shifts generated by the Yarkovsky effect acording to Darmett, S. (2021) [9].

Besides asteroids inside 5/7M domain, objects outside were also included near the separatrix on both sides of the resonance.

Table 1

σ[º]	0	90	180	270
Number of survivor asteroids (%)	964 (96.4)	950 (95.0)	956 (95.6)	934 (93.4)
Mars-crossing asteroids (%)	564 (56.4)	669 (66.9)	525 (52.5)	655 (65.5)
Effective MCAs (%)	389 (38.9)	507 (50.7)	400 (40.0)	530 (53.0)
Survivor MCAs (%)	529 (53.9)	622 (62.2)	483 (48.3)	589 (58.9)
Final semi major axis inside 5/7 (%)	135 (13.5)	106 (1.1)	129 (12.9)	89 (8.9)
T_{med} inside 5/7 [Myrs]	18.77	14.14	18.10	12.75
Impact Sun (%)	29 (2.9)	42 (4.2)	30 (3.0)	50 (5.0)
Ejected (%)	2 (0.2)	6 (0.6)	11 (1.1)	6 (0.6)
Collision with planets (%)	5 (0.5)	2 (0.2)	3 (0.3)	10 (1.0)
Amor orbit (%)	45 (4.5)	111 (11.1)	77 (7.7)	133 (13.3)
Aten orbit (%)	9 (0.9)	7 (0.7)	11 (1.1)	12 (1.2)

Statistics of the synthetic asteroid population with semi major axis ranging from 1.90 < a < 1.91 AU with bins ~0.0001AU, eccentricity (e) lesser than 0.2 with bins ~0.01 and Inclination (I) equals to 20º. Only conservative forces were considered during this integrations. Mars-crossing asteroids (MCAs) have perihelion distance (q) > 1.33, aphelion distance (Q) < 1.66 and semi major axis (a) < 3.2AU. T is the average time that the objects stay inside the 5/7M domain. Effective MCAs are asteroids that, in addition to being MCAs, have at least 1 close encounter with Mars[10].

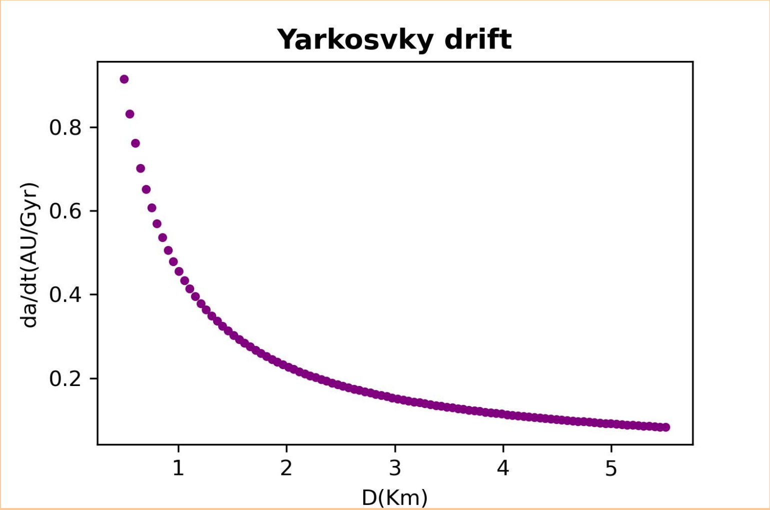
[10]Froeschle, C., et al., Secular Resonances and the dynamics of Mars-Crossing and Near-Earth Asteroids, Icarus, 1995.

Table 2

σ[º]	0	90	180	270
Number of survivor asteroids (%)	955 (95.5)	965 (96.5)	955 (95.5)	949 (94.9)
Mars-crossing asteroids (%)	611 (61.1)	616 (61.6)	616 (61.6)	620 (62.0)
Effective MCAs (%)	398 (39.8)	372 (37.2)	405 (40.5)	422 (42.2)
Survivor MCAs (%)	568 (56.8)	581 (58.1)	572 (57.2)	573 (57.3)
Final semi major axis inside 5/7 (%)	543 (54.3)	548 (54.8)	512 (51.2)	528 (52.8)
T_{med} inside 5/7 [Myrs]	33.00	32.55	32.63	32.19
Impact Sun (%)	36 (3.6)	27 (2.7)	36 (3.6)	34 (3.4)
Ejected (%)	5 (0.5)	4 (0.4)	5 (0.5)	5 (0.5)
Collision with planets (%)	4 (0.4)	4 (0.4)	4 (0.4)	5 (0.5)
Amor orbit (%)	40 (4.0)	43 (4.3)	45 (4.5)	77 (7.7)
Aten orbit (%)	4 (0.4)	8 (0.8)	6 (0.6)	7 (0.7)

Statistics of the synthetic asteroid population with semi major axis ranging from 1.906 < a < 1.908 AU with bins ~0.0001AU, eccentricity (e) lesser than 0.2 with bins ~0.01 and Inclination (I) equals to 20º. Only conservative forces were considered during this integrations. Mars-crossing asteroids (MCAs) have perihelion distance (q) > 1.33, aphelion distance (Q) < 1.66 and semi major axis (a) < 3.2AU. T is the average time that the objects stay inside the 5/7M domain. Effective MCAs are asteroids that, in addition to being MCAs, have at least 1 close encounter with Mars[10].

We constructed 2 simulations with Yarkovsky's drift values for **2** and **4 km (2.28e-10, 1.14e-10 AU/year)**. The initial orbital elements were chosen in a similar way to the conservative integration **(e<0.2, I = 20º)**. Results are shown on Table 3.



Discussion

The Hungaria group is of high interest because of his complex dynamics and the proximity with the Earth could lead to a collision with an massive asteroid. The full comprehension of their dynamical structure it is important not only for the dynamical point of view, but for life itself.

Our results showed that asteroids in the domain of 5/7M have a low elimination rate for the timespan of 50Myrs. Nevertheless, the majority of objects acquire mars-crossing orbits that in some cases lead to their orbital instabilities. Moreover, we note that a small number of asteroids acquired NEO-like orbits, indicating that the 5/7M could be a temporary source of near Earth asteroids.

The inclusion of dissipative effects increased the number of NEOs and decreased the MCAs pointing that in a more realistic scenario the domain's region of 5/7M could be more stable.

Table 3

D[Km]	2	4
Number of survivor asteroids (%)	3762 (94.1)	3755 (93.9)
Eliminated (%)	238 (5.9)	245 (6.1)
Mars-crossing asteroids(%)	2077 (51.93)	2205 (55.1)
Effective MCAs (%)	1690 (42.3)	1737 (43.4)
Survivor MCAs (%)	1847 (46.2)	1962 (49.1)
Final semi major axis inside 5/7 (%)	322 (8.1)	739 (18.5)
T_{med} inside 5/7 [Myrs]	9.65	14.90
Amor orbit (%)	241 (6.0)	239 (6.0)
Aten orbit (%)	16 (0.4)	13 (0.3)

Statistics for the synthetic asteroid population including the Yarkosvky effect. The objects were allocated in 4 regions with semi major axis (a) equals to [1.905, 1.906], [1.906, 1.907], [1.907, 1.908], [1.908, 1.909], the eccentricity (e) lesser than 0.2 with bins ~0.01 and Inclination (I) equals to 20º. Mars-crossing asteroids (MCAs) have perihelion distance (q) > 1.33, aphelion distance (Q) < 1.66 and semi major axis (a) < 3.2AU. T is the average time that the objects stay inside the 5/7M domain. Effective MCAs are asteroids that, in addition to being MCAs, have at least 1 close encounter with Mars[10].