TWO ASTEROID PAIRS CLOSE TO ZERO ORDER THREE BODY RESONANCE: POSSIBLE COMMON ORIGIN. A. E. Rosaev[1] , [1]Regional Scientific and Educational Mathematical Center "Centre of Integrable System"(150000, Sovetskaya Str. 14, Yaroslavl, Russia, hegem@mail.ru)

Introduction: The detection of several asteroid families and pairs with very recent formations (about 1.5 Myr or less) in the past decades has generated a new and exciting development [1]. These discoveries are very important, because various collisional and dynamical processes have had little time to act on these families to alter their properties. As we noted in previous paper [2], some of young pairs orbited close to mean motion resonances and display very complex dynamical behavior.

Here we report about our studying of two such pairs close to zero order three body resonance: (7343) Ockeghem - (154634) 2003 XX38 and (56232) 1999 JM31 - (115978) 2003 WQ56.

Pravec et al. [1] estimated a lower limit of 382 kyr for the age of the pair (7343) Ockeghem and (154634) 2003 XX38. Duddy et al. (2012) [3] found that these two asteroids have very similar spectra to that of S class. They identified that this pair was orbiting in the 2-1J-1M three body resonance. The resonance argument is:

$$\varphi = 2\lambda - \lambda_{Jupiter} - \lambda_{Mars}$$

Here λ, $\lambda_{Jupiter}$, λ_{Mars} are the longitudes of the asteroid, Jupiter and Mars accordingly.

Methods: To study the dynamic evolution of asteroid pairs, the equations of the motion of the systems were numerically integrated over 800 kyr using the N-body integrator Mercury and the Everhart integration method.

To calculate the nominal resonance positions, we used the values of the time averaged planet semi-major axes: 1.52368 AU for Mars, 5.20259 AU for Jupiter and 9.5549 AU for Saturn.

Results: We conducted backward integrations on the orbit of the pair (7343) Ockeghem - (154634) 2003 XX38 with different values of the Yarkovsky effect. We observe that in the case of medium values of the coefficient Yarkovsky drift in semi-major axis $A_2 = 1 \cdot 10^{-14}$, asteroids stay within the neighborhood of resonance in a stable orbit for at least 1 Myr. Conversely, when a larger value is used i.e. $A_2 = 1 \cdot 10^{-13}$, we observe a jump from one side of resonance to the other.

We calculate that the observed centre of the chaotic resonance zone is a=2.19340 AU. The nominal position of this resonance is 2.192728 AU.

We have found a second pair (56232) 1999 JM31 and (115978) 2003 WQ56 close to the same resonance (Fig. 1). Backward integration of their heliocentric orbits suggest that these two asteroids separated about 130 kyr ago (Pravec et al., [1]). Both members of this pair are trapped in the considered resonance. For this pair we observe a jump from one side of resonance to the other already for the nominal orbits (Fig. 1).

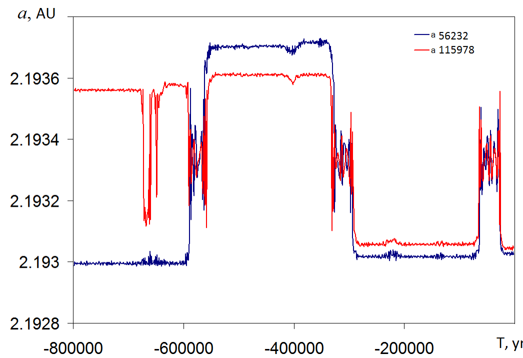

Fig.1. The (56232) 1999 JM31 and (115978) 2003 WQ56 semimajor axis evolution

However, using backward integration with the Yarkovsky effect taken into account, we have found that the position of the centre of resonance for the second pair is different, at about a=2.19333 AU.

The proper elements of both pairs are very similar (Table 1) and therefore the resonance 2-1J-1M has a significant effect on both pairs.

Table 1. Proper orbital elements

Object	*Sin i*	*e*	*a*
(7343) Ockeghem	0.06029	0.13630	2.19254
(154634) 2003 XX38	0.06038	0.13646	2.19253
56232 (1999 JM31)	0.04023	0.14220	2.19332
115978 (2003 WQ56)	0.04072	0.14228	2.19328

In our previous paper [4] we have presented the approximation of orbital elements of some asteroids. Here we have applied this method to the considered pairs. The formal results of our eccentricity approximation for these two pairs using the method stated by Rosaev & Plavalova [4] are:

$$e_{7343} = 0.15 + 0.054\cos(0.0206t + 2.3) - 0.025\cos(0.136t + 3.7)$$
$$e_{56232} = 0.15 + 0.049\cos(0.0213t + 0.2) - 0.024\cos(0.138t + 2.4)$$

The period of the (7343) Ockeghem perihelion precession is about 45.95 kyr. The detected period of short periodic eccentricity perturbation is about 46.06 kyr. The period of the 56232 (1999 JM31) perihelion precession is about 45.49 kyr. The according period of short periodic eccentricity perturbation is about 45.40 kyr.

The long period in eccentricity is about 305.01 kyr for the (7343) Ockeghem - (154634) 2003 XX38 pair and 294.98 kyr for the (56232) 1999 JM31 - (115978) 2003 WQ56 pair.

We have highlighted the remarkable phase difference in eccentricity perturbations of these pairs at present epoch (Fig.2).

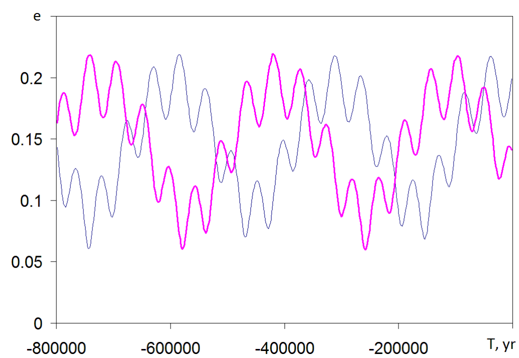

Fig.2. The (7343) Ockeghem and (56232) 1999 JM31 eccentricity evolution (present epoch)

Possible common origin: As we can see in table 1, proper elements of these two pairs are very close: the distance in semimajor axis is less 0.00074 AU. By this reason, it is interesting to consider the hypothesis of their common origin. However, on base of the equations above, we have highlighted the remarkable phase difference in eccentricity perturbations of these pairs. The period between sequence coincidences of the eccentricity phase is about 7.49 Myr and most recent such event was about 5.8 Myr ago (Fig.3). At this time the relative velocity between pairs has minimal value, so this epoch can be most probable origin for this two pairs. The ages of each pairs are much smaller and significantly different. Therefore, we can conclude that these two pair can be only the product of the cascade disruption and cannot have origin in a single event.

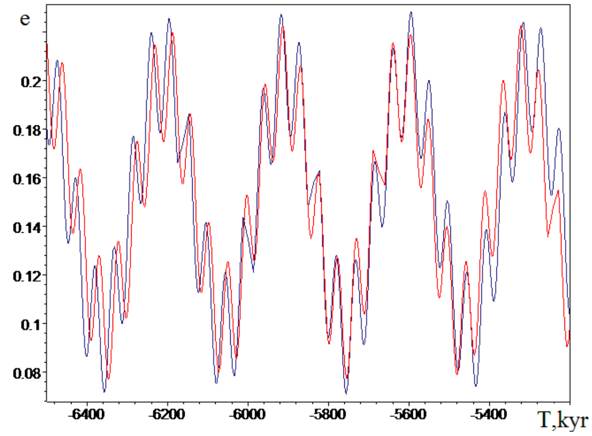

Fig.3. The (7343) Ockeghem and (56232) 1999 JM31 eccentricity evolution (around 5800 kyr ago)

Conclusions: Here we report about our studying of two pairs close to the zero order three body resonance 2-1J-1M: (7343) Ockeghem - (154634) 2003 XX38 and (56232) 1999 JM31 - (115978) 2003 WQ56. We have tested the hypothesis of the common origin of these two pairs and have concluded that they can be only the product of the cascade disruption and cannot have origin in a single event.

References: [1] Pravec P., et al. (2019) Icarus. 333, 429. [2] Rosaev A., et al (2020) *Res. Notes AAS* **4** 239. [3] Duddy et al. (2012) A&A 539, A36.[4] Rosaev A., Plavalova (2021) PSS. 202, 105233