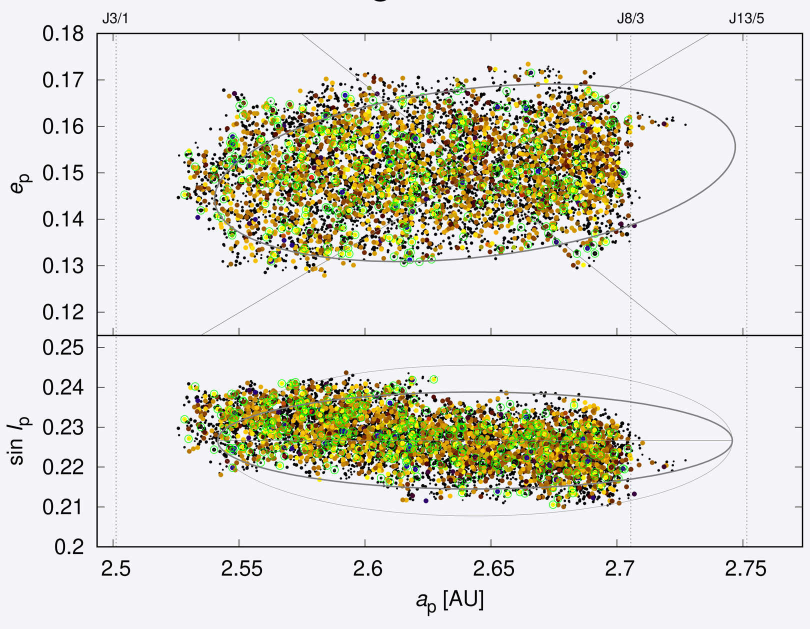
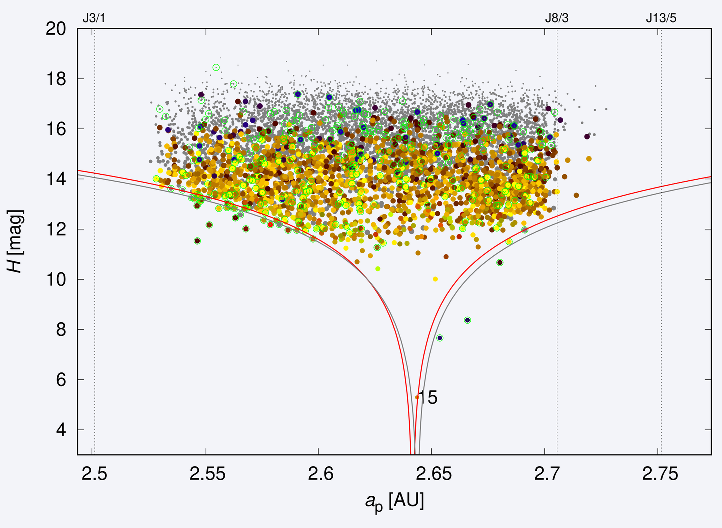
Identification of members of the Eunomia family

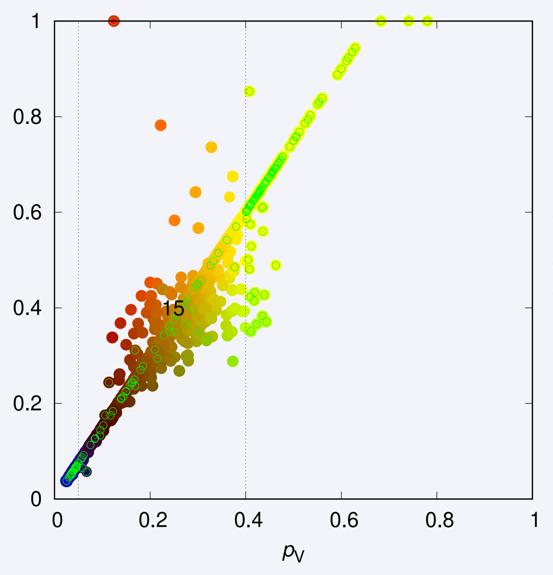
For determining the *Eunomia* family, we used the clustering algorithm. Then, we removed **interlopers** using the relationship between **semi-major axis drift** Δa_{p} and **absolute magnitude** H, and using two spectroscopic methods — the relationship of **albedoes** p_{V} a p_{IR} and the relationship of **color indexes** a^* a $i-z$. Before the removal, the member count was 6503; after using all the mentioned methods it was 6184.



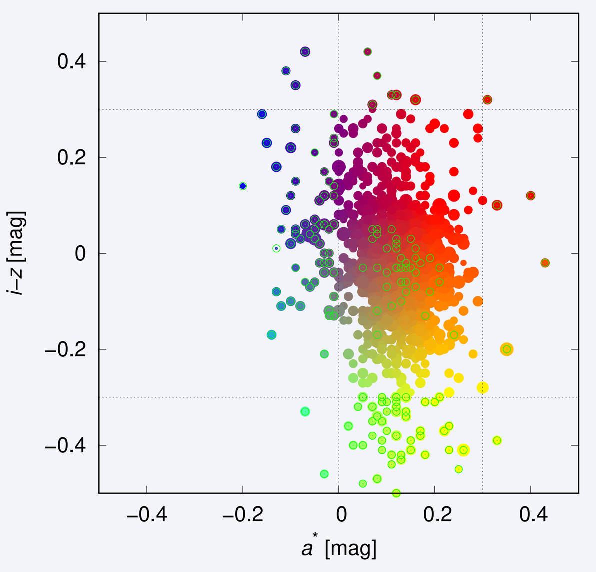
(a) Observed *Eunomia* family identified by HCM with $v_{\mathrm{cutoff}} = 44\,\mathrm{m/s}$ in space of **proper semi-major axis** a_{p} and **proper eccentricity** e_{p} (top) and in space of **proper semi-major axis** a_{p} and **proper inclination** sin I_{p} (bottom). The color code is adapted from the **albedoes** p_{V} and p_{IR} from the WISE catalogue[3].



(b) **Proper semi-major axis** a_{p} versus **absolute magnitude** H. We can see a typical „V“-shape, which is caused by an initial **velocity field** and the **Yarkovsky effect**, which is even magnified by the **YORP effect**, which leads to an increased concentration of small asteroids at the edges of the family.



(c) **Albedoes** p_{V} (in the visible spectrum) and p_{IR} (in infrared) from the WISE catalogue. The colors don't resemble real color. For identification of **interlopers**, the following values were chosen $0{,}05 \leq p_{\mathrm{V}} \leq 0{,}4$.



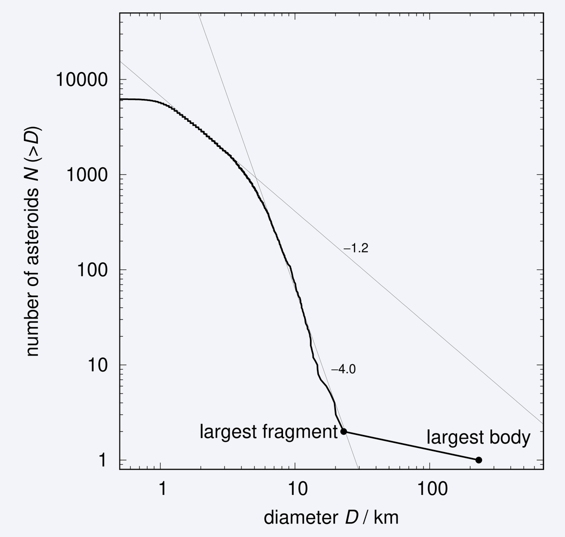
(d) **Color indexes** a^* and $i-z$ from the Sloan catalogue[4]. The colors don't resemble real color. For identification of **interlopers**, the following values were chosen $0 \leq a^* \leq 0{,}3$ a $-0{,}3 \leq i-z \leq 0{,}3$.

Simulation of orbital evolution

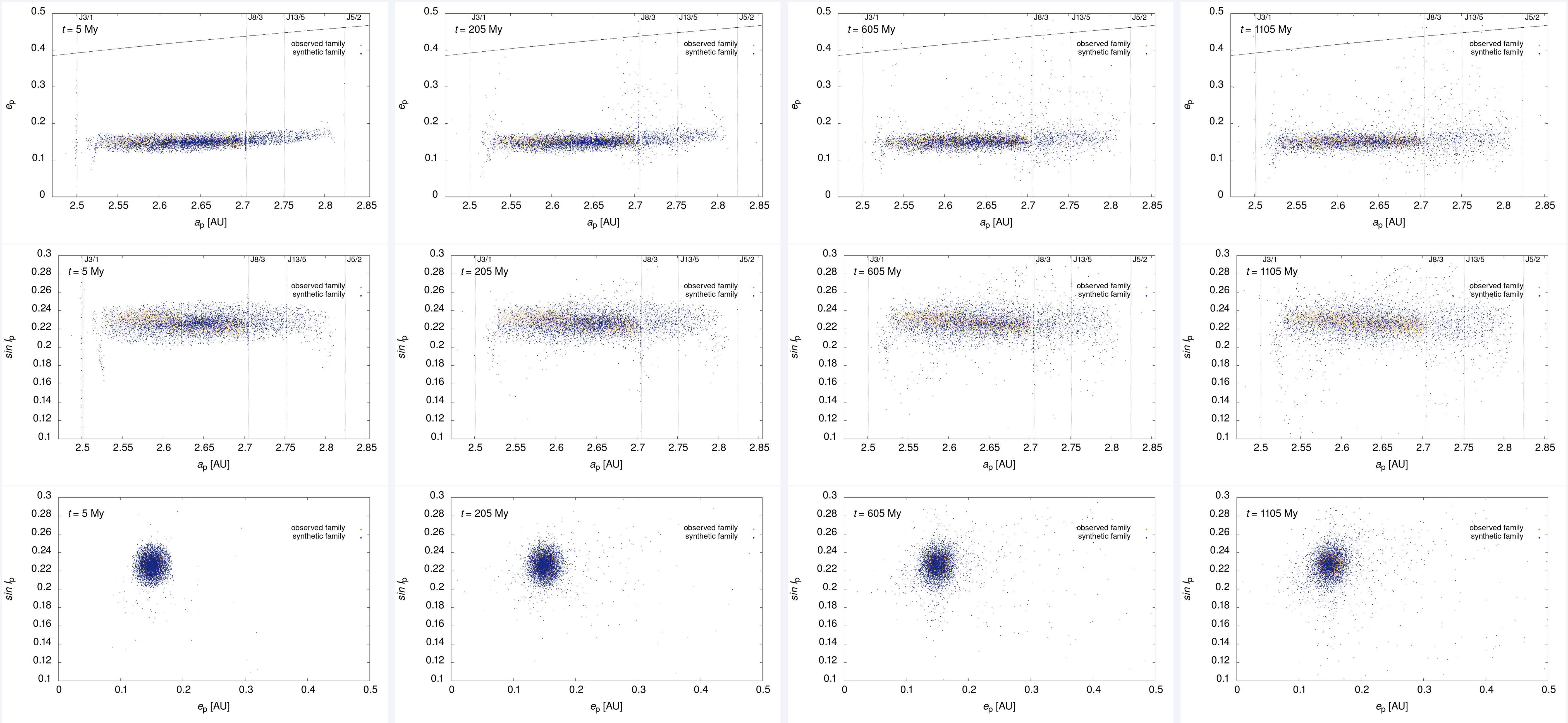
When creating the **synthetic** population of asteroids, we assigned the following properties to the particles

- **diameters** (from observed data — we took the **size-frequency distribution** into account),
- **albedoes** (from observed data),
- **rotational axis orientations** (randomly; influence on the **Yarkovsky effect**),
- **initial velocities** (simulating an **isotropic breakup** at the location on the orbit with values $f = 90^\circ$ and $\omega + f = 50^\circ$).

We simulated a population of **6210 particles** for 1,3 **billion years**. The computation was run on a **server of the Astronomical Institute of Charles University**; it took around **50000 CPU hours** and and the total amount of **binary data** was $3\,\mathrm{GB}$.

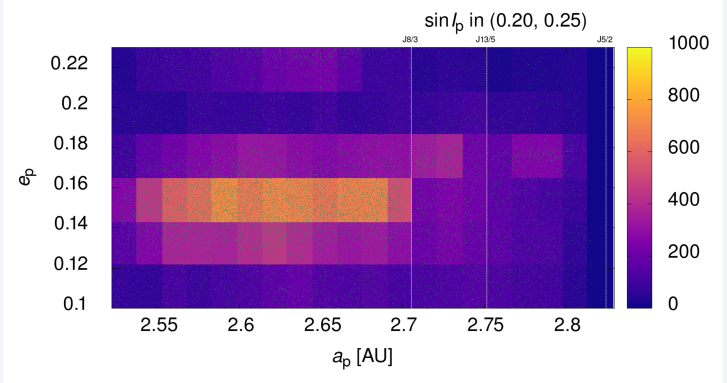


Obrázek: **Size-frequency distribution** of the *Eunomian* asteroids.



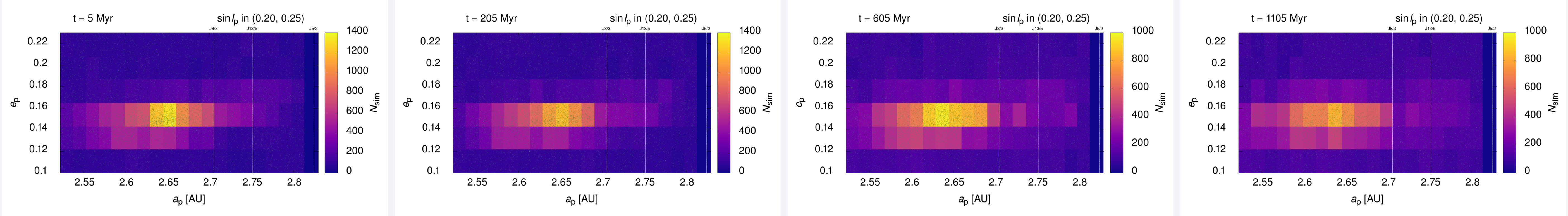
Obrázek: Results of the simulation in space of $(a_{\mathrm{p}}, e_{\mathrm{p}})$, $(a_{\mathrm{p}}, \sin I_{\mathrm{p}})$ and $(e_{\mathrm{p}}, \sin I_{\mathrm{p}})$ at times $t = 5, 205, 605, 1105$ million year. The labels J3/1, J8/3, J13/5 a J5/2 indicate the most significant **resonances** with *Jupiter*. The black line at the top indicates the edge of the region, where the asteroid's orbit crosses *Mars'*. A similar border exists for **Jupiter** as well, but it is located outside these graphs (at $e = 0{,}65$). The purple rectangle labels the region chosen for a sample for the **background** population.

- Due to the specific **proper elements** calculation process from initial velocities, at $t = 5$ million years, we can see a slightly unsymmetrical shape of the simulated family.
- The mechanism, through which the asteroids **leave** the family is the following: due to the **Yarkovsky effect**, the asteroid gets close to a **resonance**, the eccentricity of its orbit **increases** until it starts to **cross the orbit** of *Mars* or *Jupiter*, whereat due to a **close encounter** it gets swung out of its orbit.



Obrázek: Graph $(a_{\mathrm{p}}, e_{\mathrm{p}})$ for the observed *Eunomia* family. The color code indicates the number of particles in the given **box**.

- The asteroids initially located near the J5/2 resonance, were very quickly diffused, thus they are not present at the $t = 5\,\mathrm{My}$ graph.
- **Resonances** J8/3 and J13/5 clearly divide the family into three parts, which have different widths, and thus the asteroids in them get diffused at different rates.
- It is confirmed, that the J8/3 **resonance** is stronger than the J13/5 **resonance** (asteroids near the J8/3 resonance at $t = 205\,\mathrm{My}$ got diffused into a region of width $0{,}05 < e_{\mathrm{p}} < 0{,}5$, while near the J13/5 resonance, they reached only $0{,}1 < e_{\mathrm{p}} < 0{,}23$)
- At the $(a_{\mathrm{p}}, \sin I_{\mathrm{p}})$ graph, we can observe a slight „**tilt**“ of the observer family (the part under $a \approx 2{,}62\,\mathrm{AU}$ has a higher inclination I_{p}), which we can unfortunately not yet spot on the simulated family.
- With time, the concentration of asteroids in space **decreases**, which is caused by **all** the present **resonances**.



Obrázek: $(a_{\mathrm{p}}, e_{\mathrm{p}})$ graph of the simulated *Eunomia* family for $t = 5$, 205, 605, 1105 million years. Notice the change in the color code.