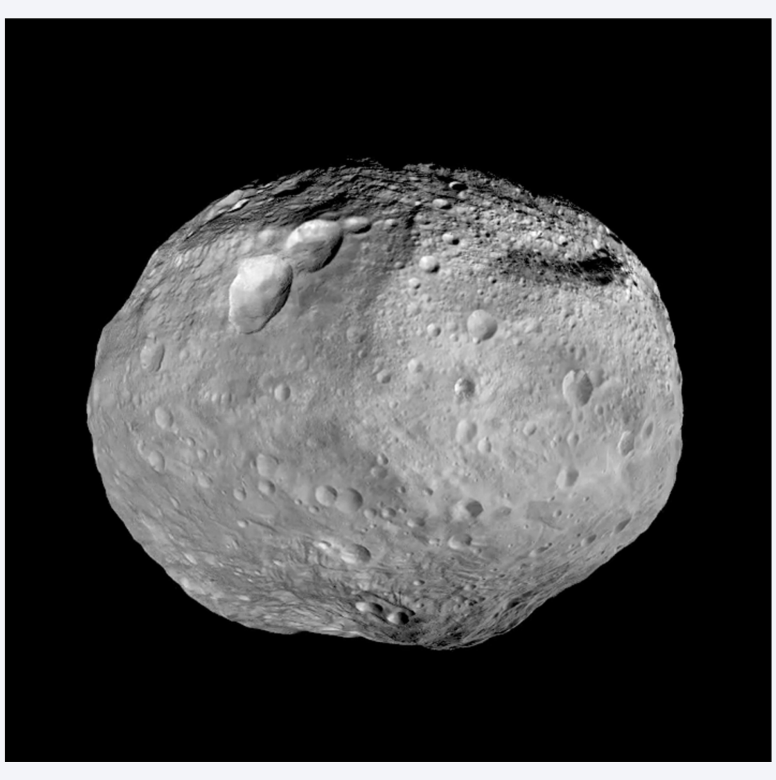
Asteroids in the Solar System

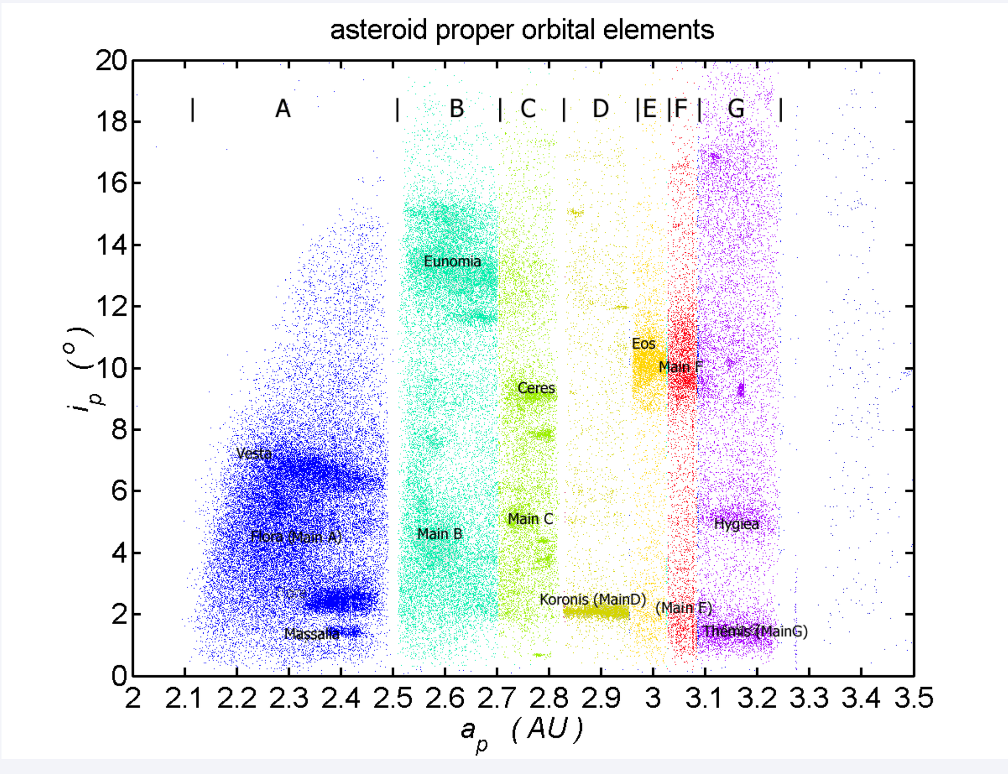
Asteroids is the most numerous and also most interesting group of bodies in **the Solar System**. The first asteroid was discovered in 1801 and more than half a million asteroids are known today.

In **the main asteroid belt** between *Mars* and *Jupiter*, asteroids form **families** — groupings created by a initial **breakup** of the same parent body, caused by a collision with another body. In our work, we focus on a large family called *Eunomia*, located in the middle main belt.

By studying collisional families, we can find out more about the creation of the Solar System and its **dynamical structure** [1], for example we can support the **Late Heavy Bombardment** theory) [2].



(a) Asteroid *(4) Vesta* — second largest and most massive body of the main belt.



(b) Main asteroid belt in the space of **proper orbital elements** — proper semi-major axis a_{p} and proper inclination. sin I_{p}.

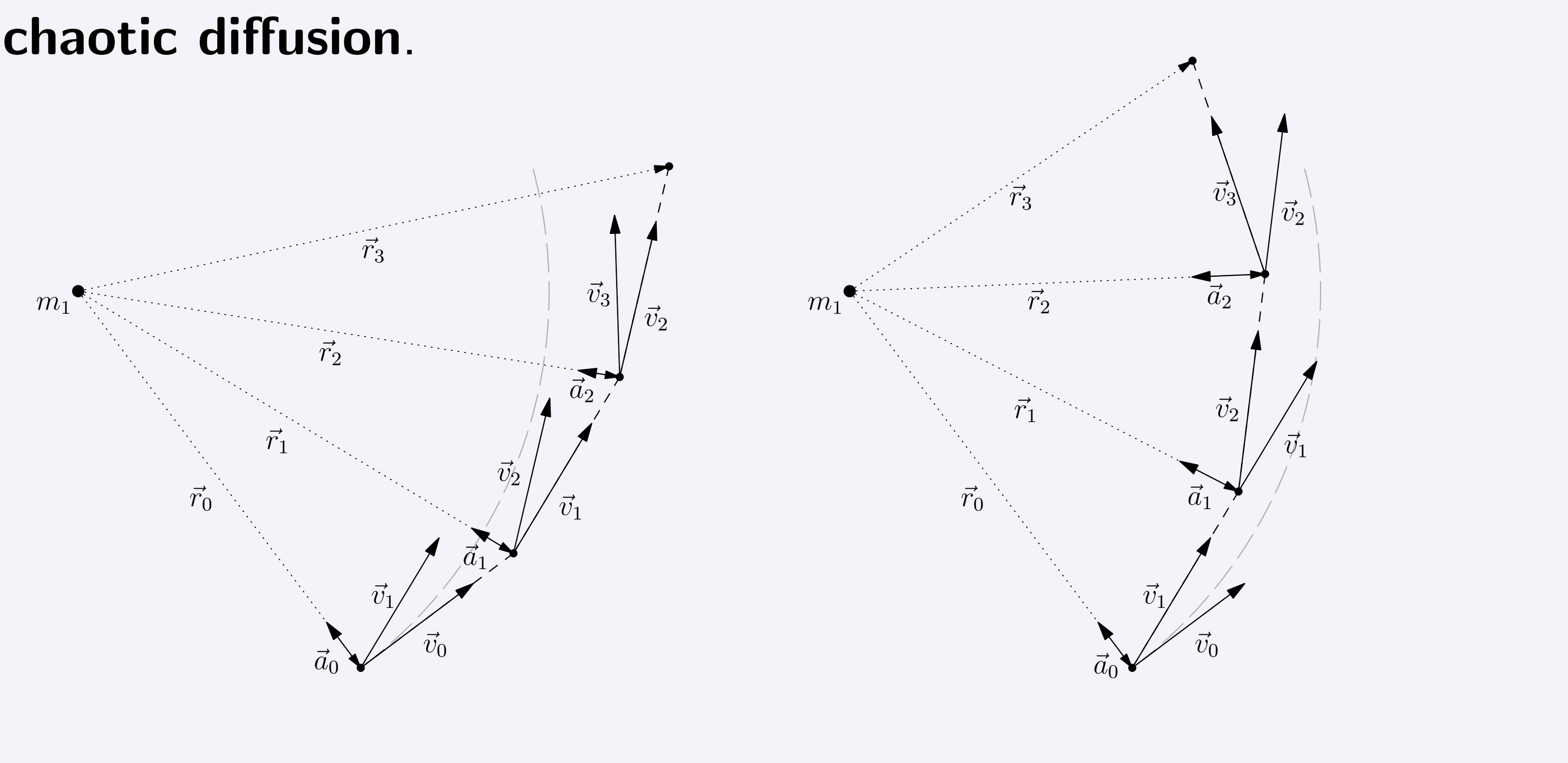
Methods of celestial mechanics

The fundamental problem of celestial mechanics is the **N-body problem** — calculate the position of bodies, that are gravitationally bound together according Newton's law of universal gravitation, at any time.

$$\vec{F}_i = m_i \vec{a}_i = -\sum_{\substack{j=1 \\ j \neq i}}^{N} G \frac{m_i m_j}{|\vec{r}_i - \vec{r}_j|^3} (\vec{r}_i - \vec{r}_j) \,, \qquad \text{pro } i \in \{1, 2, \ldots, N\}$$

For simulation of orbital evolution, we use a **numerical integrator SWIFT**, which counts with

- **Yarkovsky effect**,
- **YORP effect**,
- **random collisions**,
- **chaotic diffusion**.

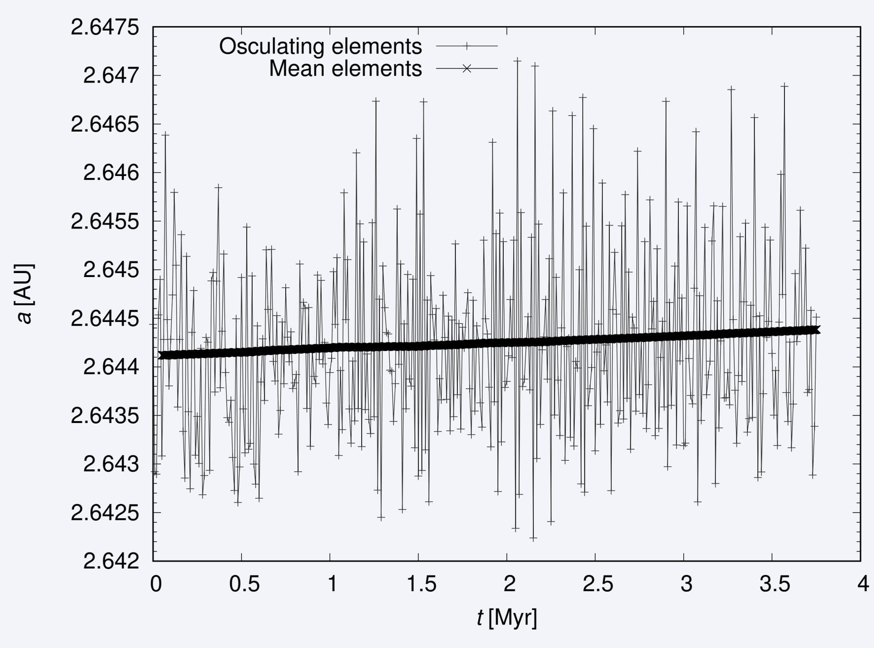


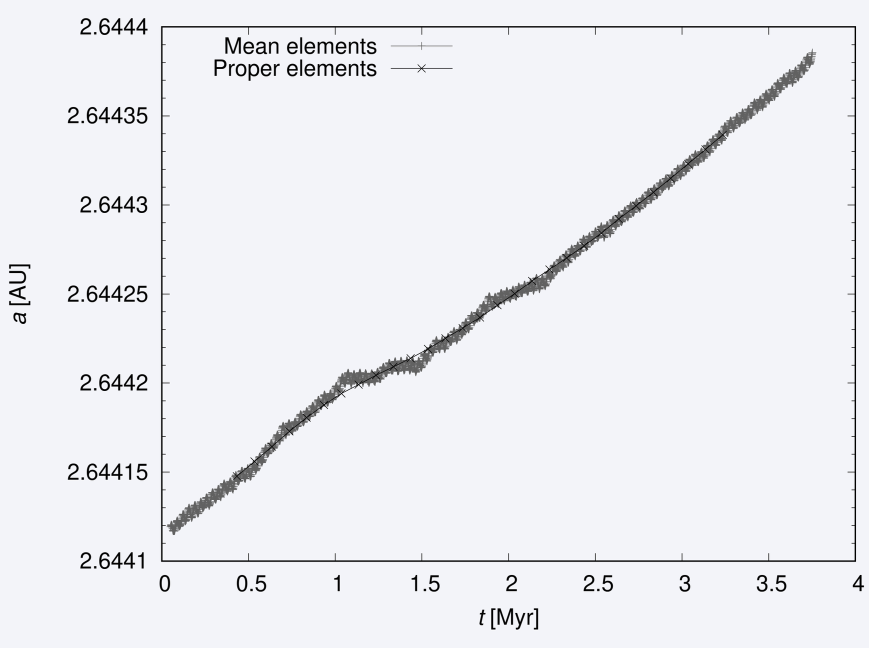
Obrázek: Illustration of a simpler integration method — **Euler's method** — which is in principle similar to ours.

The orbit around the Sun of an asteroid can be described with **orbital elements**:

- **semi-major axis** *a*
- **eccentricity** *e*
- **inclination** *I* (or also sin *I*)

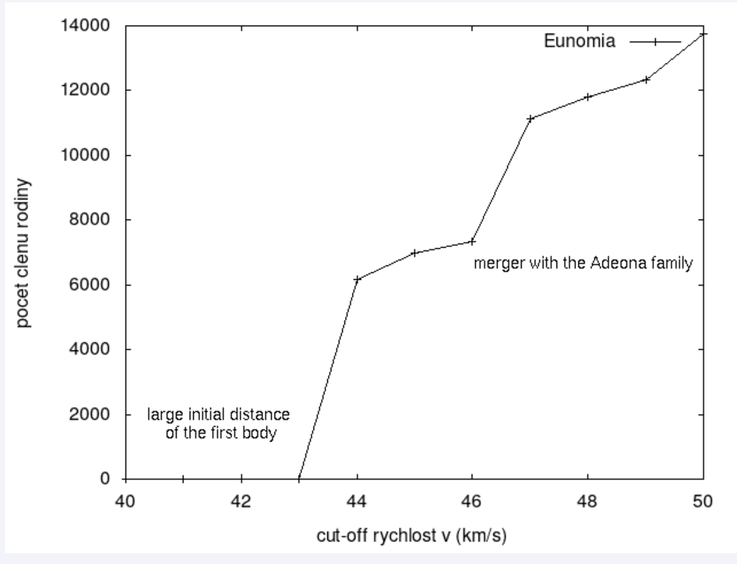
They are subject to change by **perturbations** (e.g. gravitational forces of other planets); we can thus „average“ them over long periods to **mean** and to **proper orbital elements**, where the latter are not subject to any periodical forces.





Obrázek: Comparison of **osculating** (actual) and **mean** semi-major axis (left), and **mean** and **proper** semi-major axis (right) for one particle simulated for 3.76 million years.

For identification of members of a family, we use the **hierarchical clustering method** (HCM): in the phase space (a_{p}, e_{p}, sin I_{p}) we choose a cut-off „distance“ of bodies v_{cutoff} (with units of velocity), according to which, beginning with the parent body *(15) Eunomia*, we then determine the members.



Obrázek: Dependence of the number of the members of the family *Eunomia* on the chosen cut-off velocity v_{cutoff} while using the HCM.

$$v_{\mathrm{cuttoff}} = na_{\mathrm{p}} \sqrt{C_a \left(\frac{\Delta a_{\mathrm{p}}}{a_{\mathrm{p}}} \right)^2 + C_e (\Delta e_{\mathrm{p}})^2 + C_i (\Delta \sin i_{\mathrm{p}})^2}$$