Asteroid Families in the Proper Elements Space

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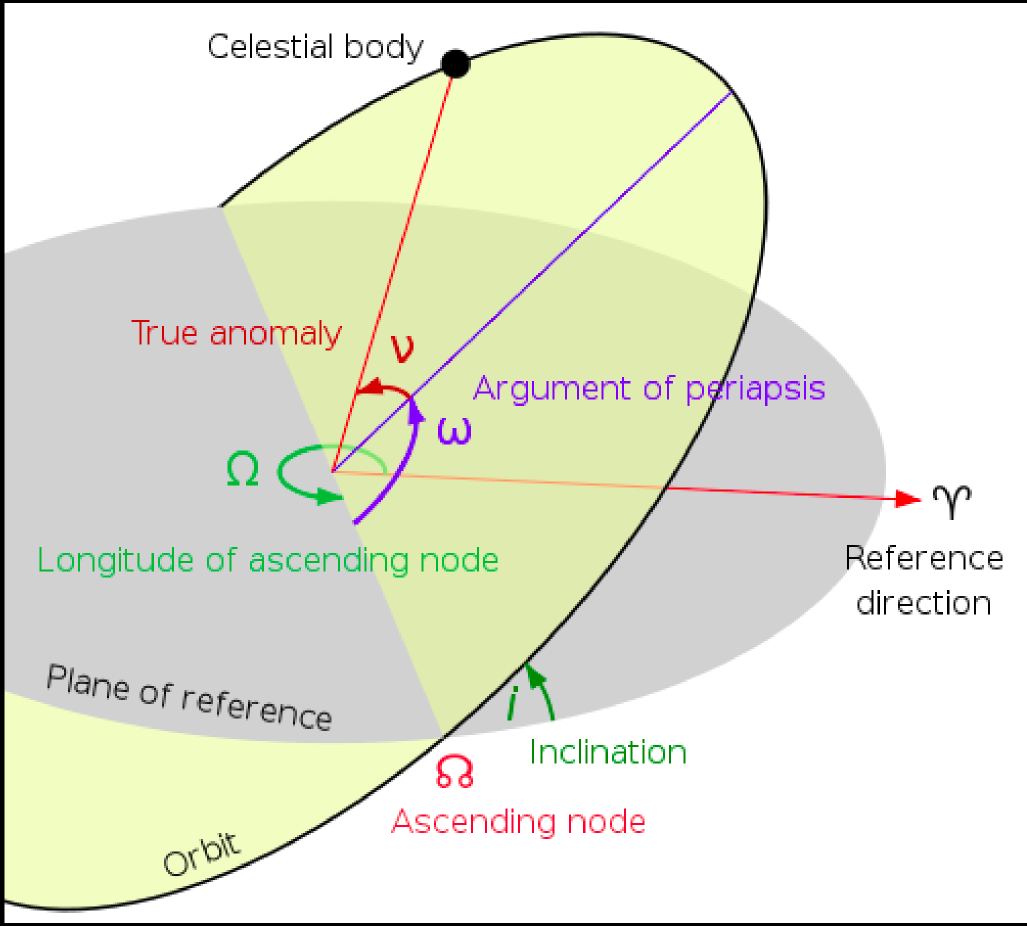
Keplerian orbital elements

Six Keplerian orbital elements is standard set of parameters used to described an elliptic motion.

These orbital elements are however constant only in a gravitational 2-body problem



Osculating orbital elements

- Computed from the observations
- Defined for a specific epoch
- Continuously change in time

4 Vesta (A807 FA)

Classification: Main-belt Asteroid **SPK-ID:** 2000004

[Ephemeris | Orbit Diagram | Orbital Elements | Mission Design | Physical Parameters | Discovery Circumstances]

[show orbit diagram]

Orbital Elements at Epoch 2458600.5 (2019-Apr-27.0) TDB
Reference: JPL 35 (heliocentric ecliptic J2000)

Element	Value	Uncertainty (1-sigma)	Units
e	.08872145978916499	2.3321e-10	
a	2.361417893971132	1.5143e-09	au
q	2.151909451245757	1.9286e-09	au
i	7.141771087953539	2.1706e-07	deg
node	103.8108039679376	3.8808e-07	deg
peri	150.7285410950405	1.7893e-07	deg
M	95.86193772405923	1.2068e-06	deg
t_p	2458247.559575009090 (2018-May-09.05957501)	4.1037e-06	TDB
period	1325.432763131374	1.2749e-06	d
	3.63	3.49e-09	yr
n	.2716094018601813	2.6125e-10	deg/d
Q	2.570926336696506	1.6486e-09	au

Orbit Determination Parameters

# obs. used (total)	9397
# delay obs. used	2977
# Doppler obs. used	0
data-arc span	25372 days (69.46 yr)
first obs. used	1950-09-23
last obs. used	2020-03-11
planetary ephem.	DE431
SB-pert. ephem.	SB431-N16
condition code	0
norm. resid. RMS	.3998
source	ORB
producer	Davide Farnocchia
solution date	2020-Apr-06 17:19:16

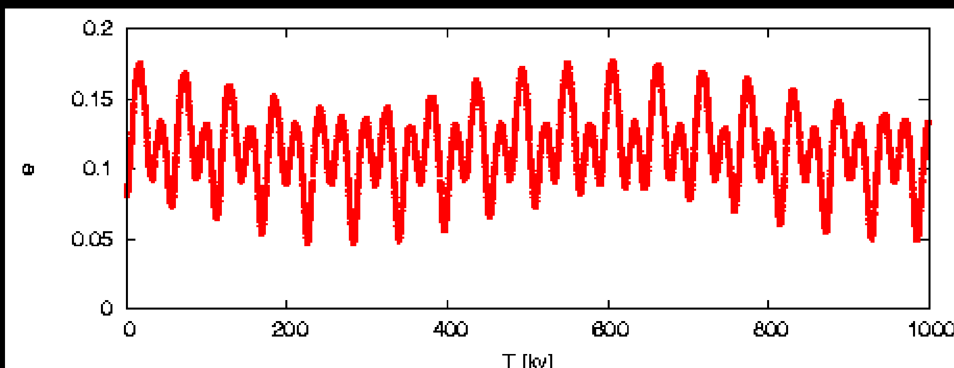
Additional Information

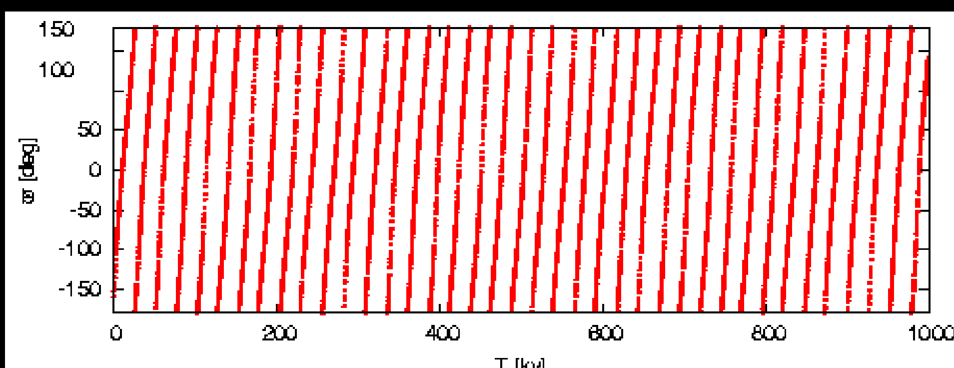
Earth MOID = 1.13948 au
Jupiter MOID = 2.46988 au
T_jup = 3.535

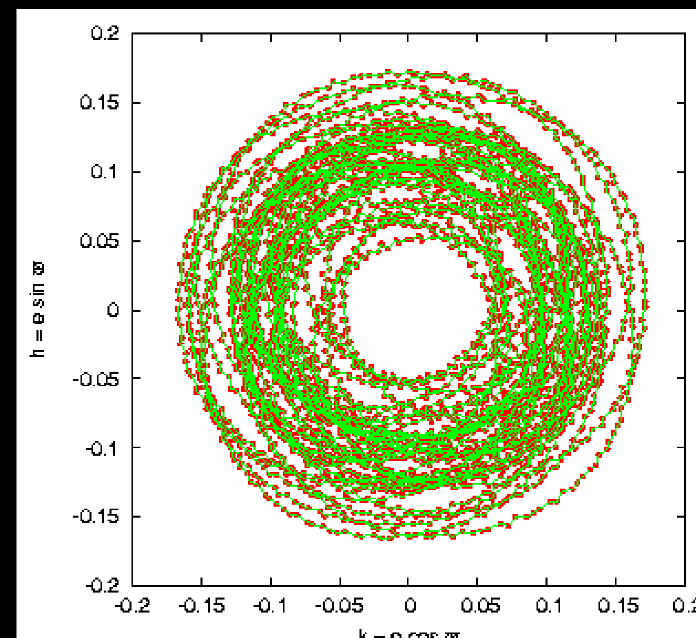
Typical Orbital Evolution in the Asteroid Belt

Example: (32) Pomona; osculating orbital elements

a = 2.59 AU, e = 0.083, *i* = 5.53 deg







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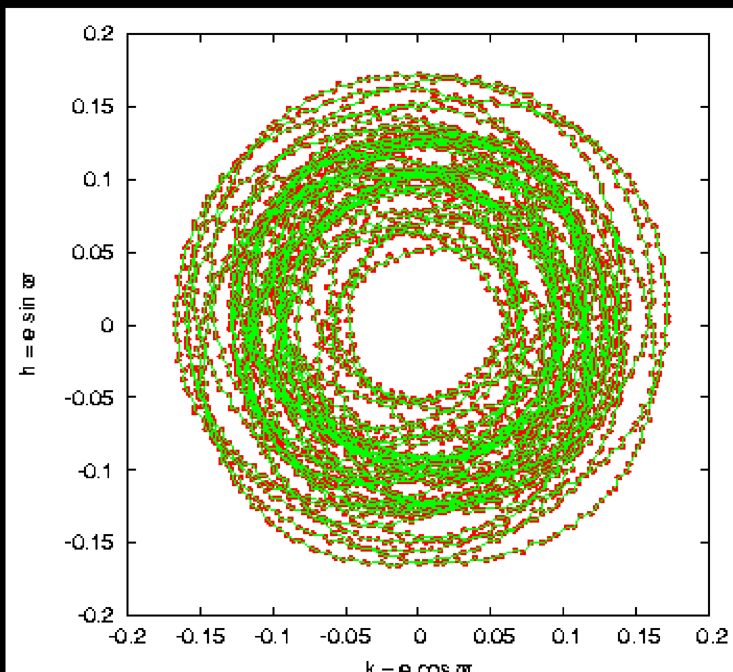
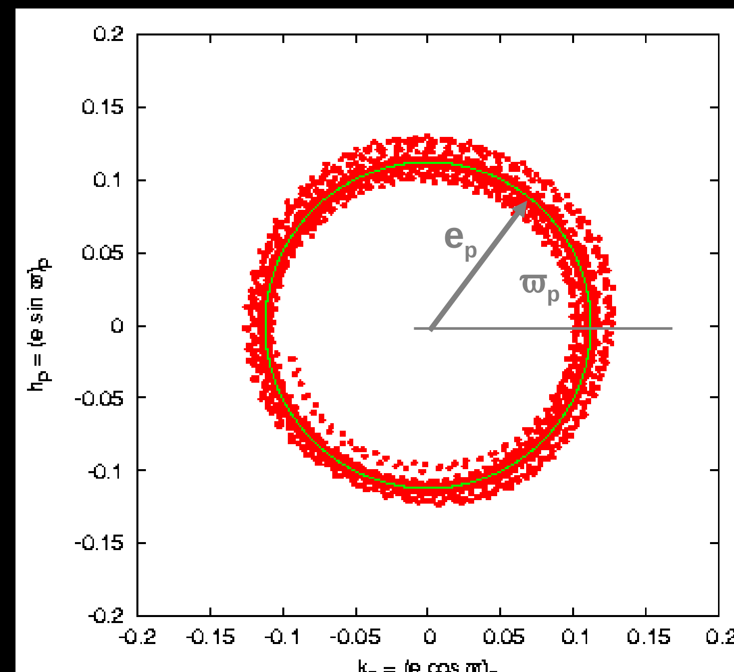
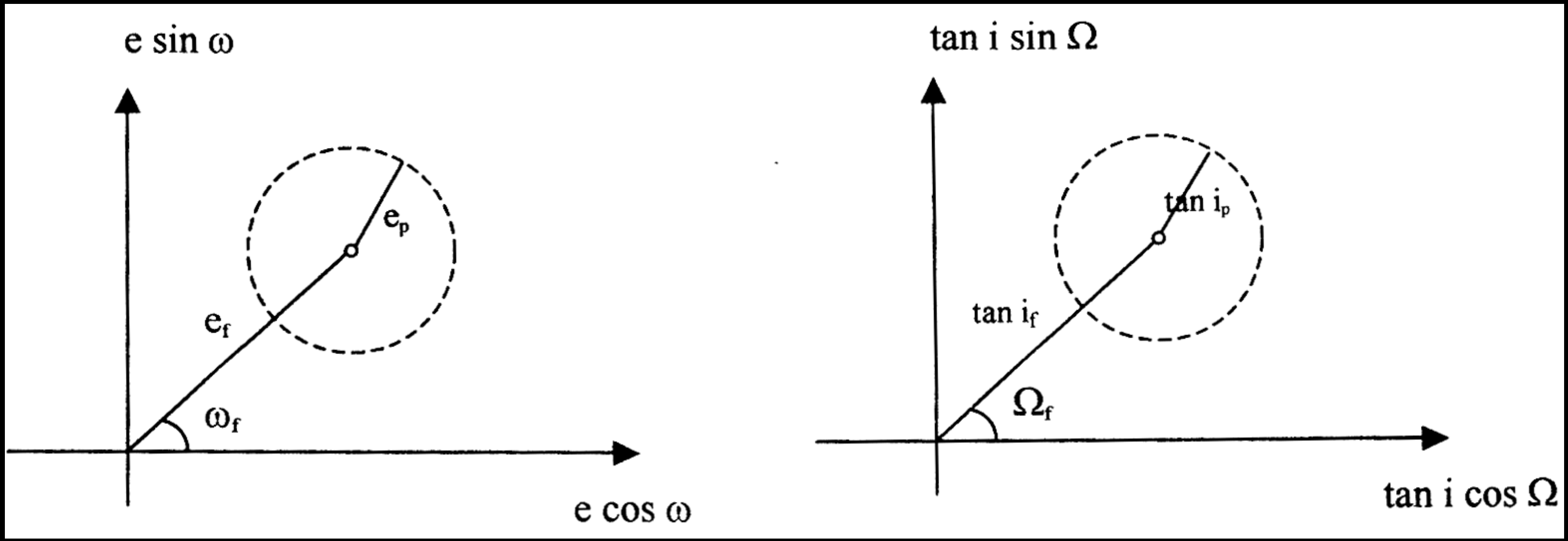




- **Osculating elements**
- **Proper elements**

Proper Orbital Elements

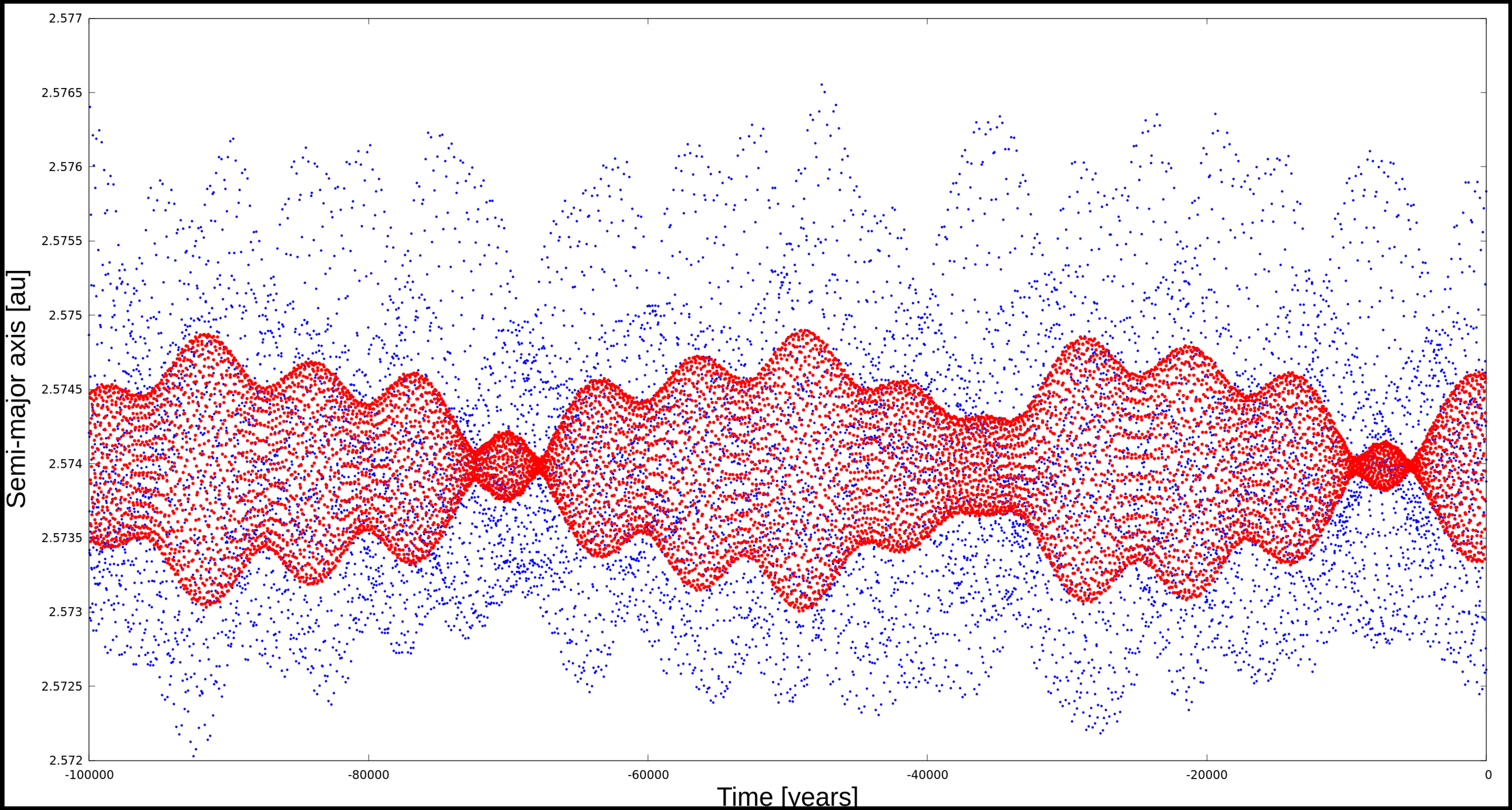


Proper orbital elements

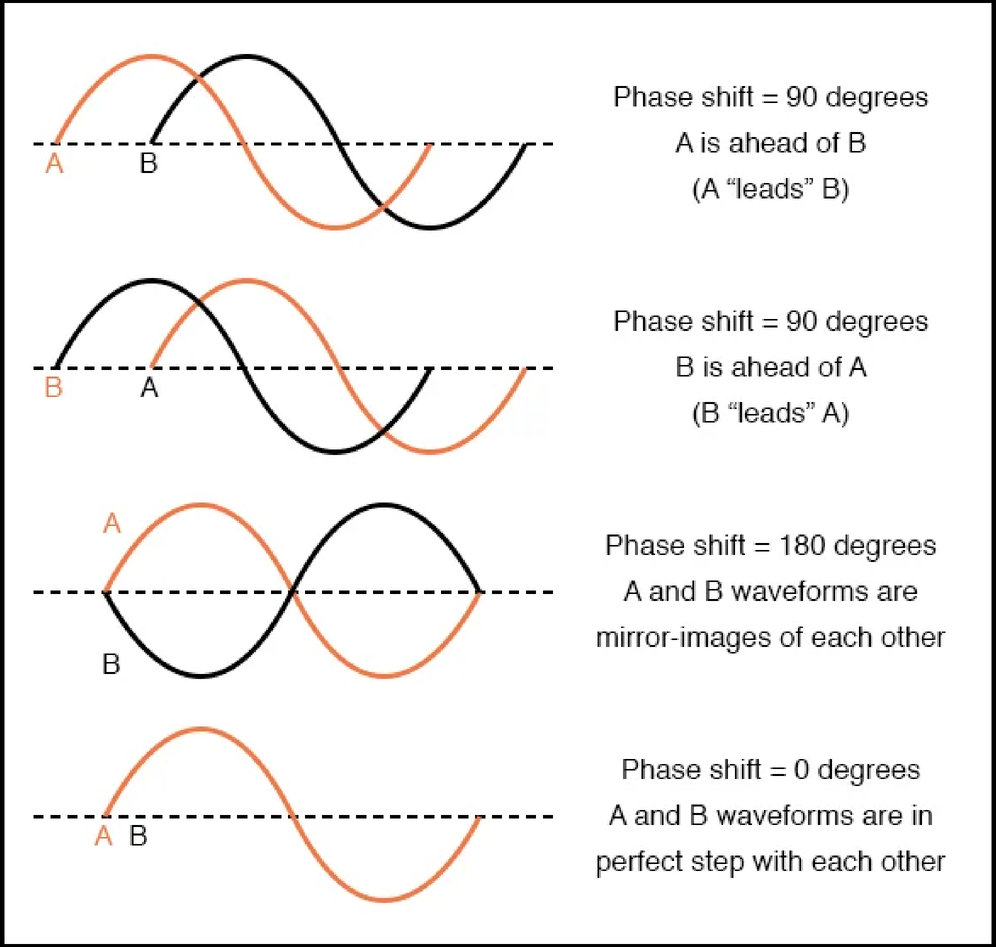
- Computed from the osculating elements by removing short- and long periodic oscillations
- They represent a kind of “average” characteristic of motion
- The proper elements are typically stable (constant) over long time scales: millions of years, or even more

Osculating vs Mean Elements

Mean elements are obtained from the osculating elements by removing short periodic oscillations.



Mean vs Proper Elements

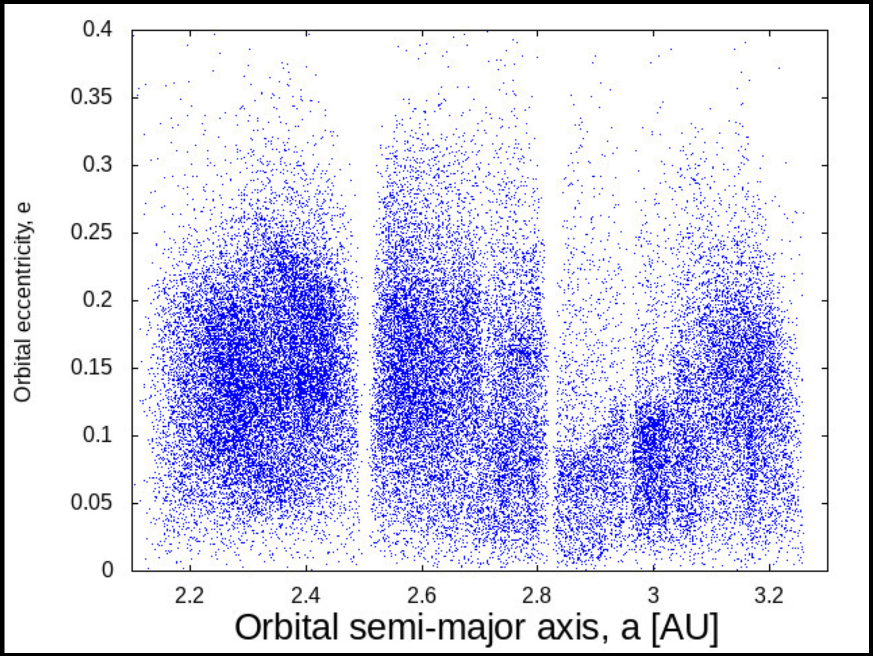


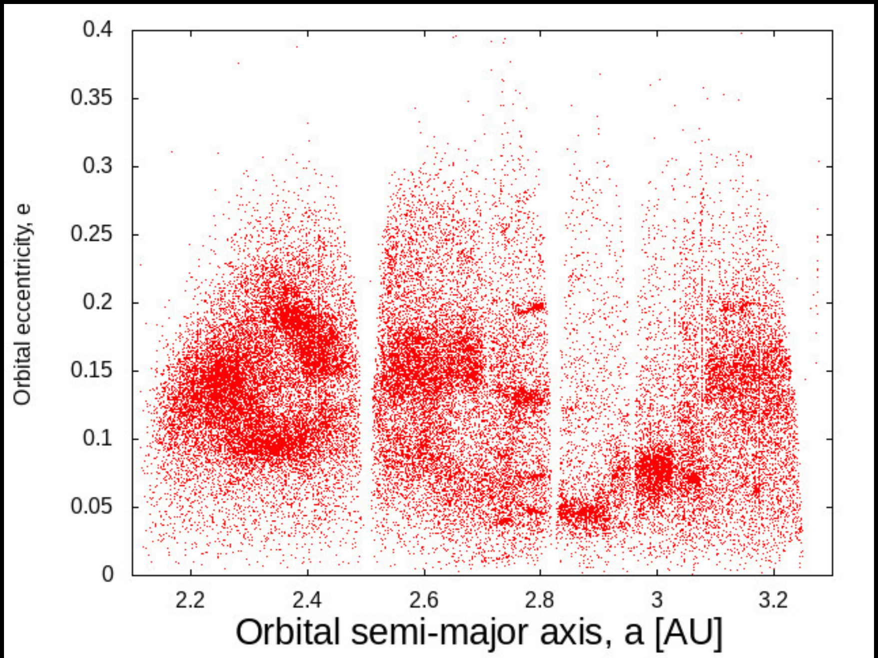
“Nearby” asteroids oscillates around the similar points, but their oscillations could be significantly phase shifted!

Therefore, by removing periodic oscillations we bring the nearby asteroids close to each other in orbital space!

Structure of the asteroid belt

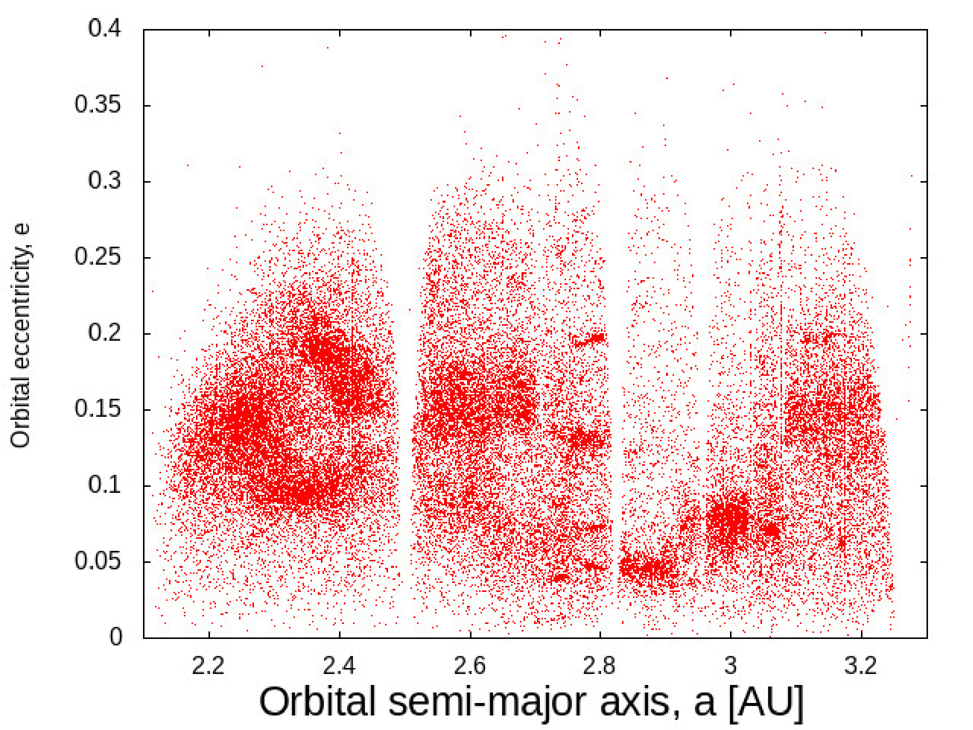
Osculating vs Proper orbital elements





What is responsible for patterns seen in the proper orbital elements space?

- Dynamical and collisional evolution of the asteroid belt
- Procedures to compute proper elements



Asteroid Families

What are they?

Asteroids Orbital Velocities

Table 25 Planets' Orbital Velocities and Distances from the Sun

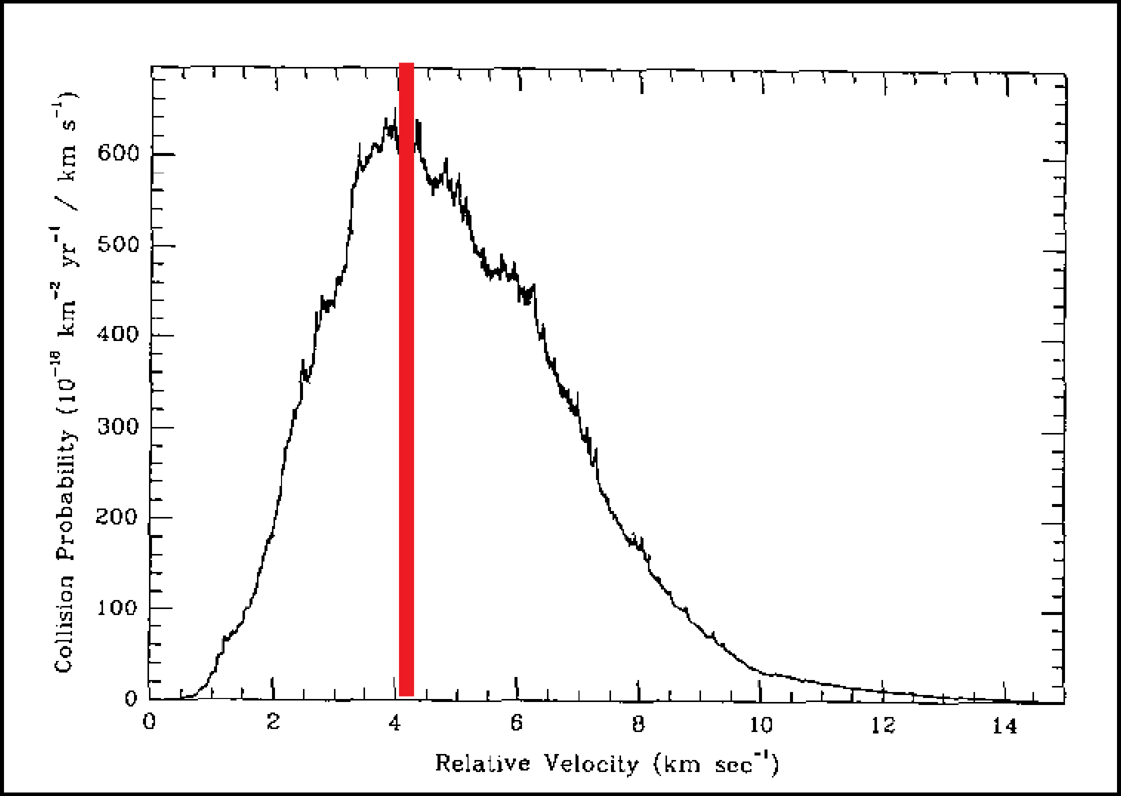
Planet	Mean Distance from Sun (million km)	Orbital Velocity (km/s)
Mercury	57.9	47.4
Venus	108.2	35.0
Earth	149.6	29.8
Mars	227.9	24.1
Jupiter	778.6	13.1
Saturn	1433.5	9.7
Uranus	2872.5	6.8
Neptune	4495.0	5.4

Source: *NASA*

Asteroids

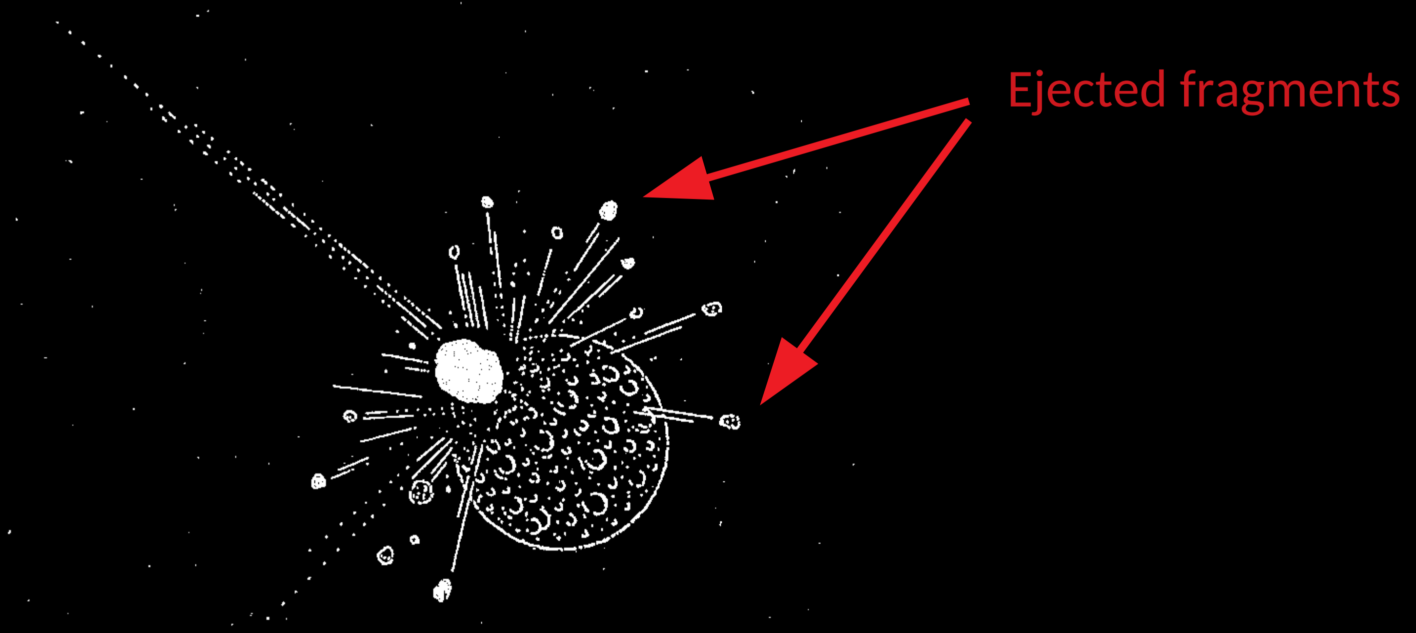
- Orbital velocities of Main Belt asteroids: ~20km/s

Asteroids Relative Velocities



- Collision between asteroids: ~4-5 km/s

Collision Ejection Velocities



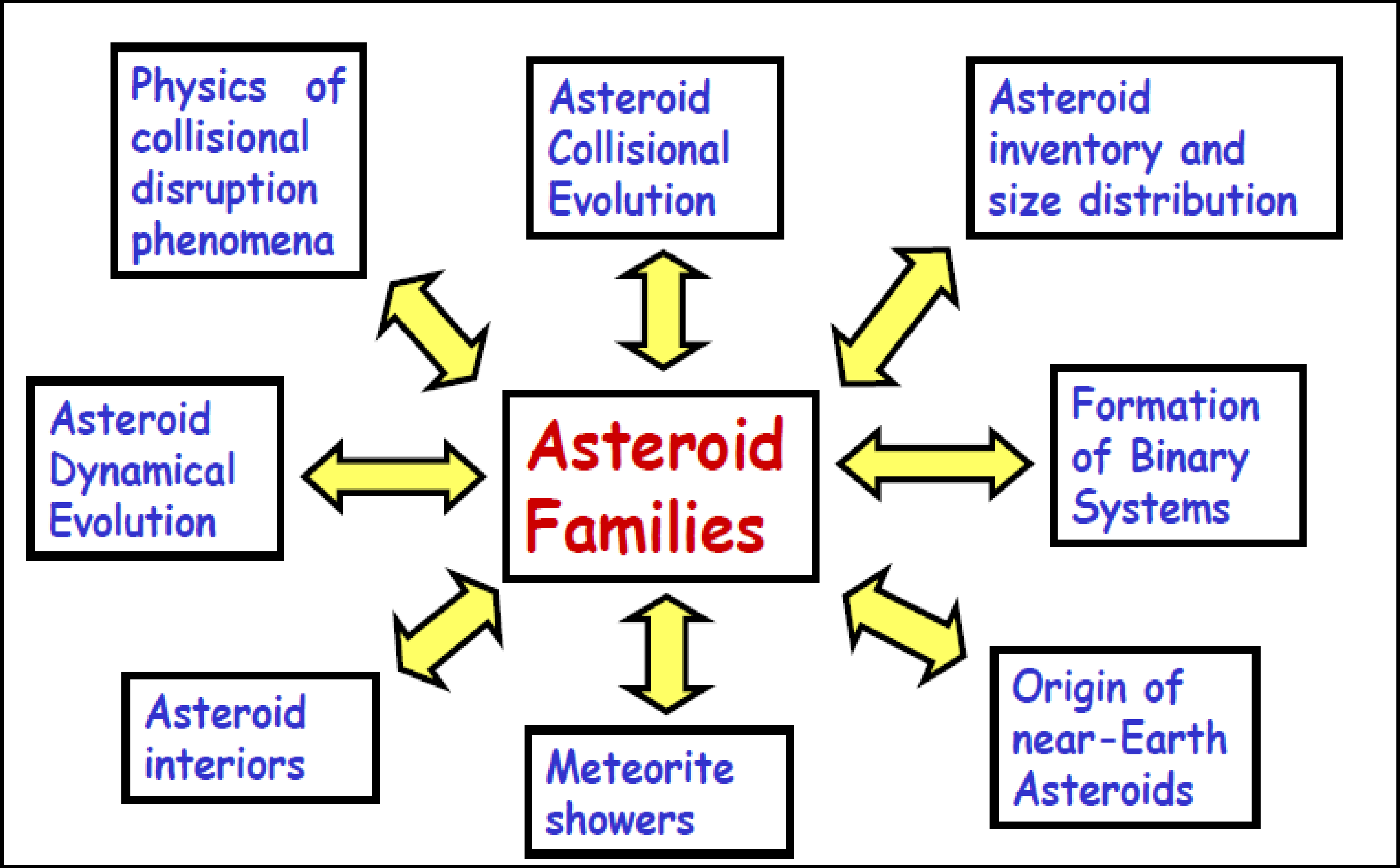
- Fragments ejection velocities during collision between asteroids:

10 – 100 m/s

Asteroid Families

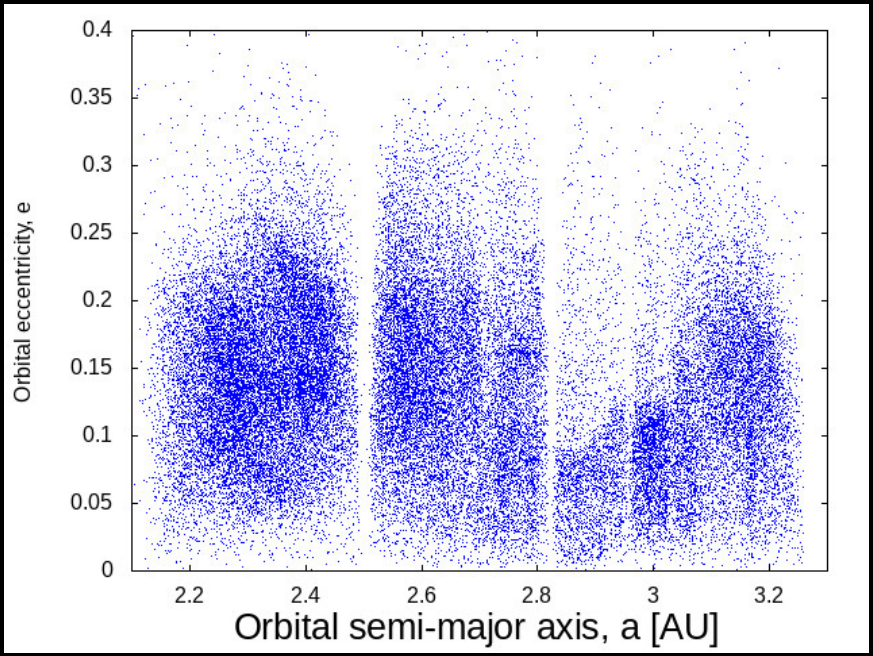
- An asteroid family is a population of asteroids that share similar proper orbital elements, and which are thought to be fragments of past asteroid collisions.
- The sites of such cosmic accidents are filled with debris that drift away at speeds that are roughly commensurate with the escape speed from the original target body
- Daughter fragments produced by breakup of a parent asteroid will appear as a group in space of the proper elements even gigayears after the original collision.

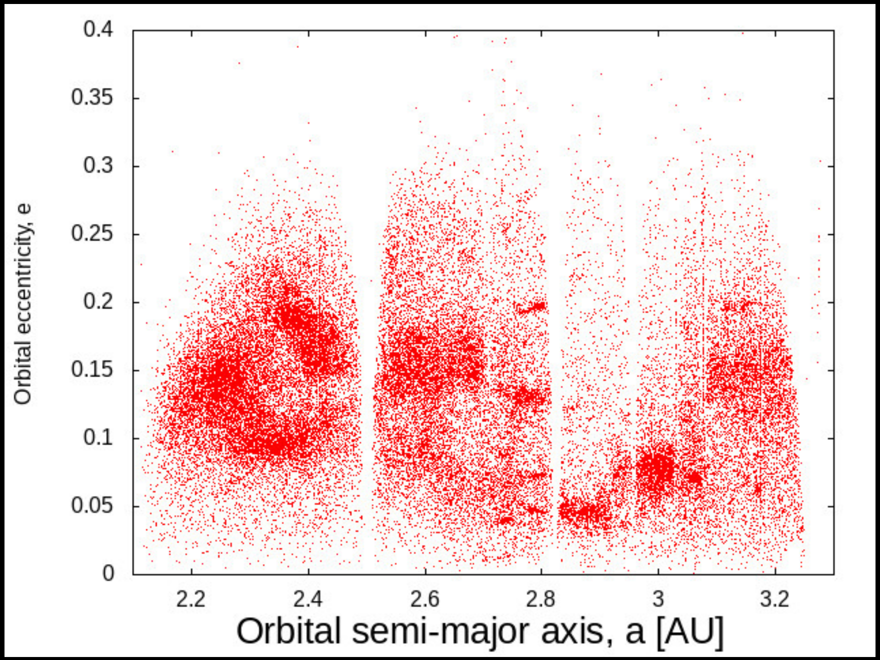
Why to study families?



Identification of Asteroid Families

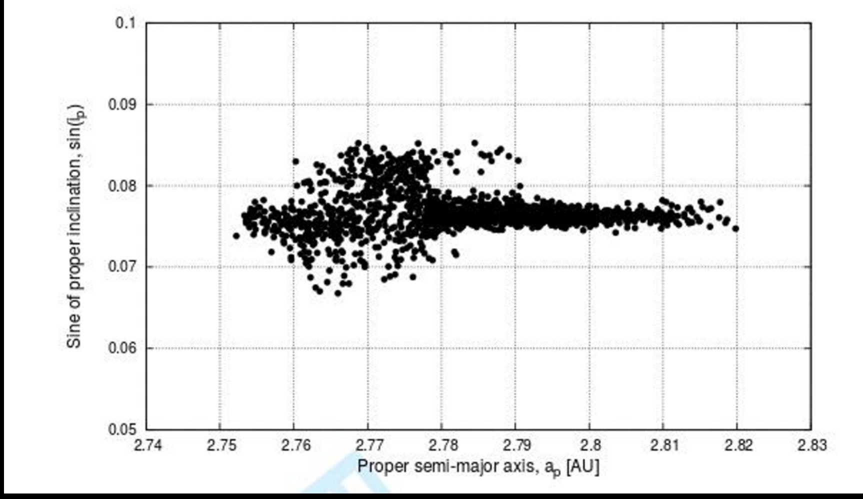
Osculating vs Proper orbital elements



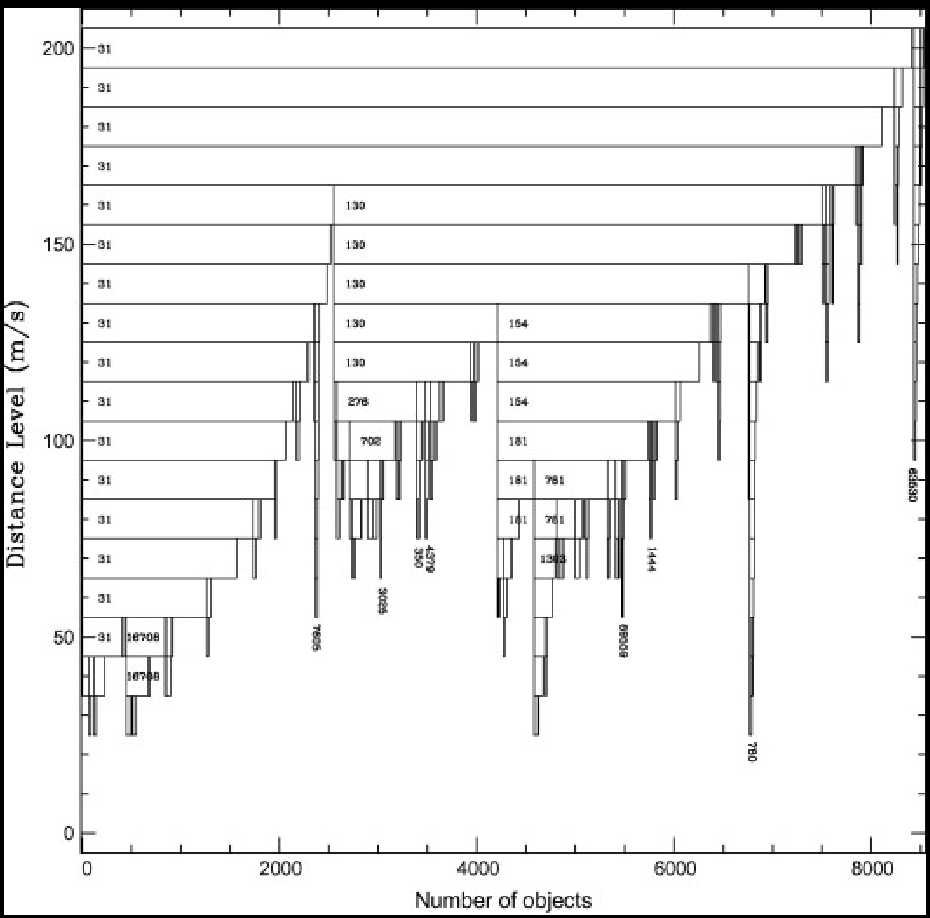


Asteroid Families Identification Challenges

- Number of families is not known a priory
- Even proper orbital elements change over long time scales
- Families are located in different dynamical environments (non-homogen phase space density)
- Families are often irregularly shaped



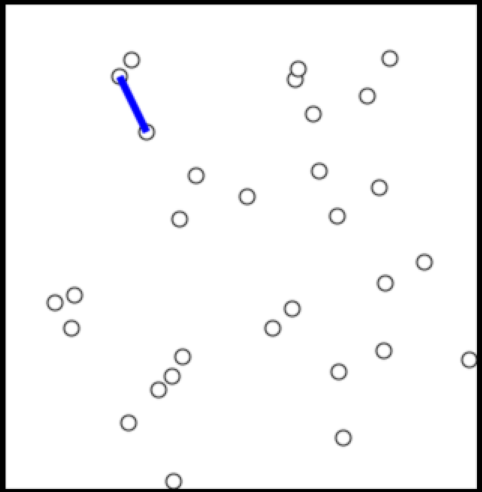
Asteroid Families: Identification technique



Hierarchical Clustering Method
+ "standard metrics"

$$\left(\frac{d}{na}\right)^2 = k_a \left(\frac{\delta a}{a}\right)^2 + k_e\ (\delta e)^2 + k_i\ (\delta \sin i)^2$$

(k_a=5/4, k_e=k_i=2, of the order of unity)



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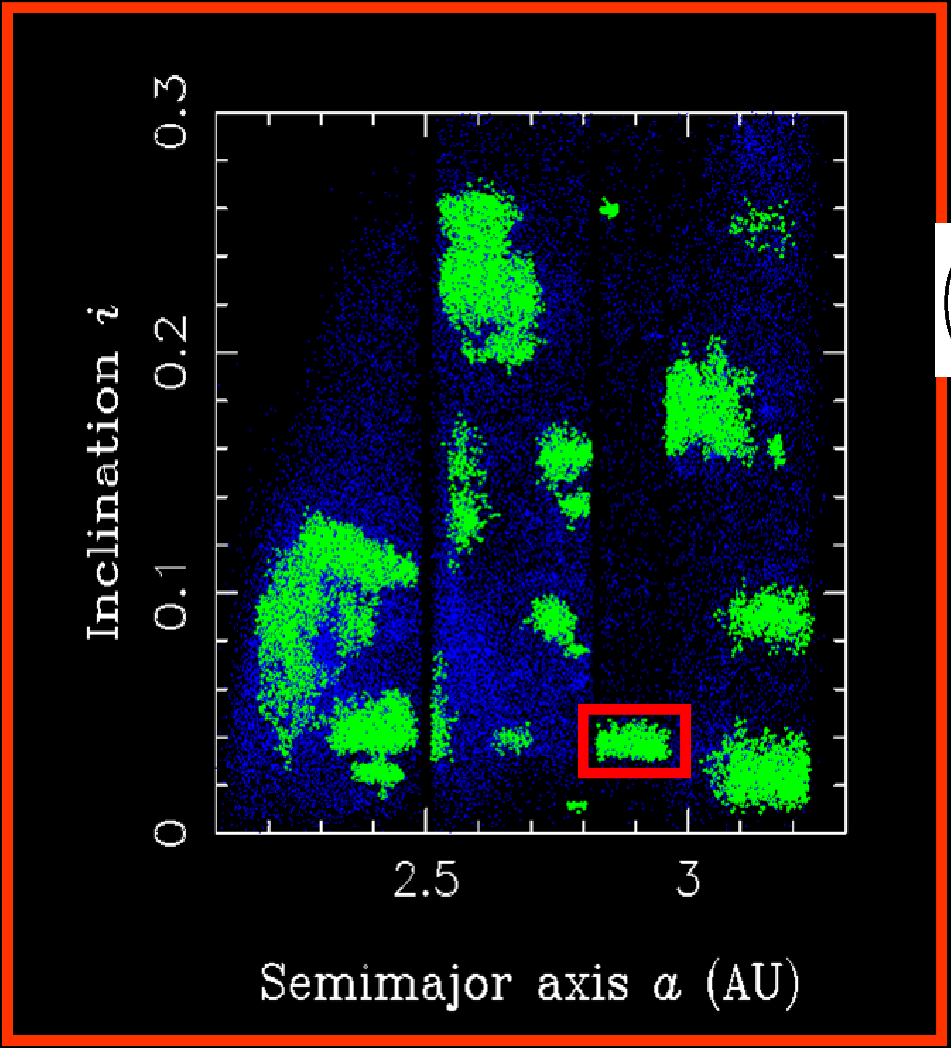

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An example:

Koronis family

as a cluster of objects within a distance 70 m/s from each other

Project overview

Objectives:

- be able to understand the main steps of the procedure to compute the proper orbital elements of asteroids
- be able to understand the main difference between the osculating and proper orbital elements
- learn basics about the codes used to compute the proper elements
- be able to identify the main problems and limitations in the computation and exploitation of the proper elements
- to familiarize themselves with the web-pages providing osculating and proper orbital elements of asteroids, and data on asteroid families
- to apply machine learning tool(s) to classify asteroids into families, using asteroid proper orbital elements
- to understand the main challenges in the identification of asteroid families

Project overview: Main steps

The following steps should be performed:

Step 1: Download a catalog of osculating orbital elements from AstDys web page maintained by University of Pisa. A link to the catalog of numbered main-belt asteroids is this one: https://newton.spacedys.com/~astdys2/catalogs/allnum.cat

Step 2: Download ORBIT9 numerical integrator executable code and necessary input files from https://github.com/stardust-r/LTW-I/tree/master/Asteroid%20Families/Orbit9 To make the code executable on an UNIX machine you may use e.g. chmod +x orbit9 from the command line

Step 3: Pick up randomly 10 asteroids with semi-major axis between 2.3 and 3.2 au, and perihelion distance q = a(1-e) larger than 1.7 au, from allnum.cat. Then propagate the orbits of these objects for 2 Myr (see appendix on basic instructions on how to use the software). To this purpose you should use 7-planets dynamical model (from Venus to Neptune). *This may take about 15-20 minutes!*

Step 4: Redo the integrations for 10 selected asteroids using the 4-planets dynamical model (from Jupiter to Neptune). The other settings should be the same. *But, be careful about the barycentric corrections! This should take some time, but less than the integrations in step 3.*

Step 5: Download PROPSYNTH code from this link.

Step 6: Compute proper orbital elements of 10 selected asteroids using PROPSYNTH code and the numerical integrations produced by ORBIT9 (steps 3 and 4). Compare and discuss the difference in proper elements obtained within two dynamical models. For which asteroids differences are larger and why?

Project overview: Main steps

Step 7: Download a catalog of proper orbital elements from [AFP](http://asteroids.matf.bg.ac.rs/fam/proper/afp.pro) web page maintained by University of Belgrade, available at http://asteroids.matf.bg.ac.rs/fam/proper/afp.pro For information on the afp.pro file format please visit http://asteroids.matf.bg.ac.rs/fam/properelements.php

Step 8: For 10 selected asteroids, compare their proper elements from the catalog, with the ones you computed. Briefly comment on how much (if at all) the results are different, and discuss possible reasons for these differences.

Step 9: Use PYTHON or MATLAB to visualize distribution of asteroids in the proper semi-major axis vs sine of proper inclination and/or proper semi-major axis vs proper eccentricity plane. *Hint: if there are too many points for clear presentation, use only a part of the catalog. Is the distribution uniform? If not, in your opinion, what would be possible explanations?*

Step 10: Use HDBSCAN clustering algorithm to the catalog of asteroid proper elements to classify asteroids into groups. For this purpose extract asteroids from the afp.pro catalogue with proper semi-major axis between 2.5 and 2.82 au, and sine of proper inclination above 0.3.

Project overview

Mentors:

- Bojan Novakovic,
- Zoran Knezevic,
- Victor Rodriguez,
- Marco Fenucci