Resonancias orbitales

Tabaré Gallardo

www.fisica.edu.uy/∼gallardo

Facultad de Ciencias
Universidad de la República
Uruguay

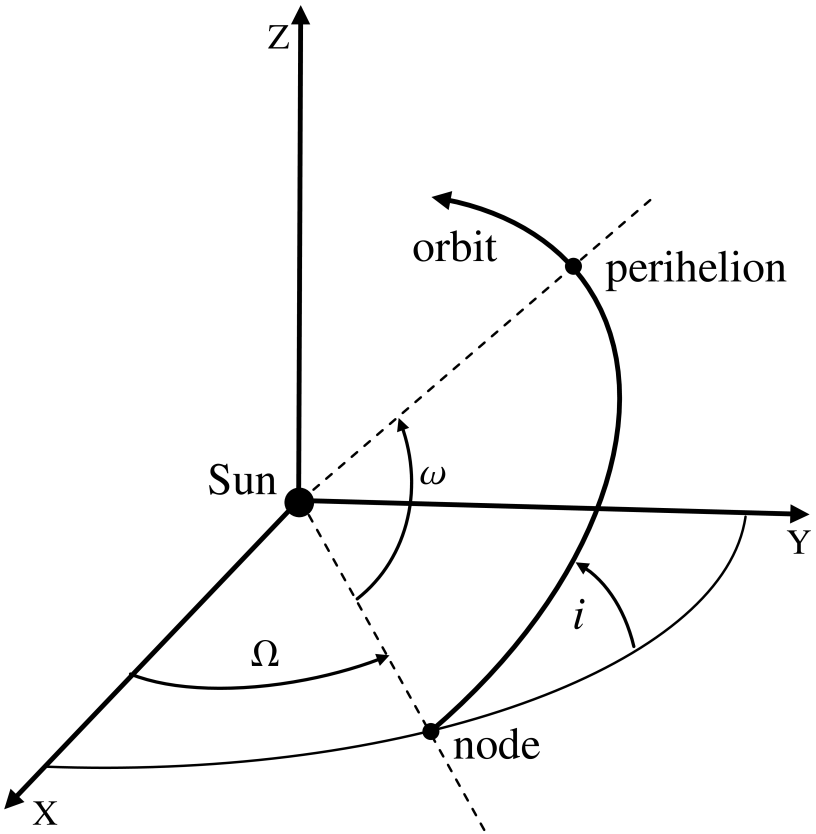
Curso Dinámica Orbital 2018

Orbital motion

Oscillating planetary orbits

Orbital Resonances

Commensurability between **frequencies** associated with orbital motion: mean motion, nodes and pericenters

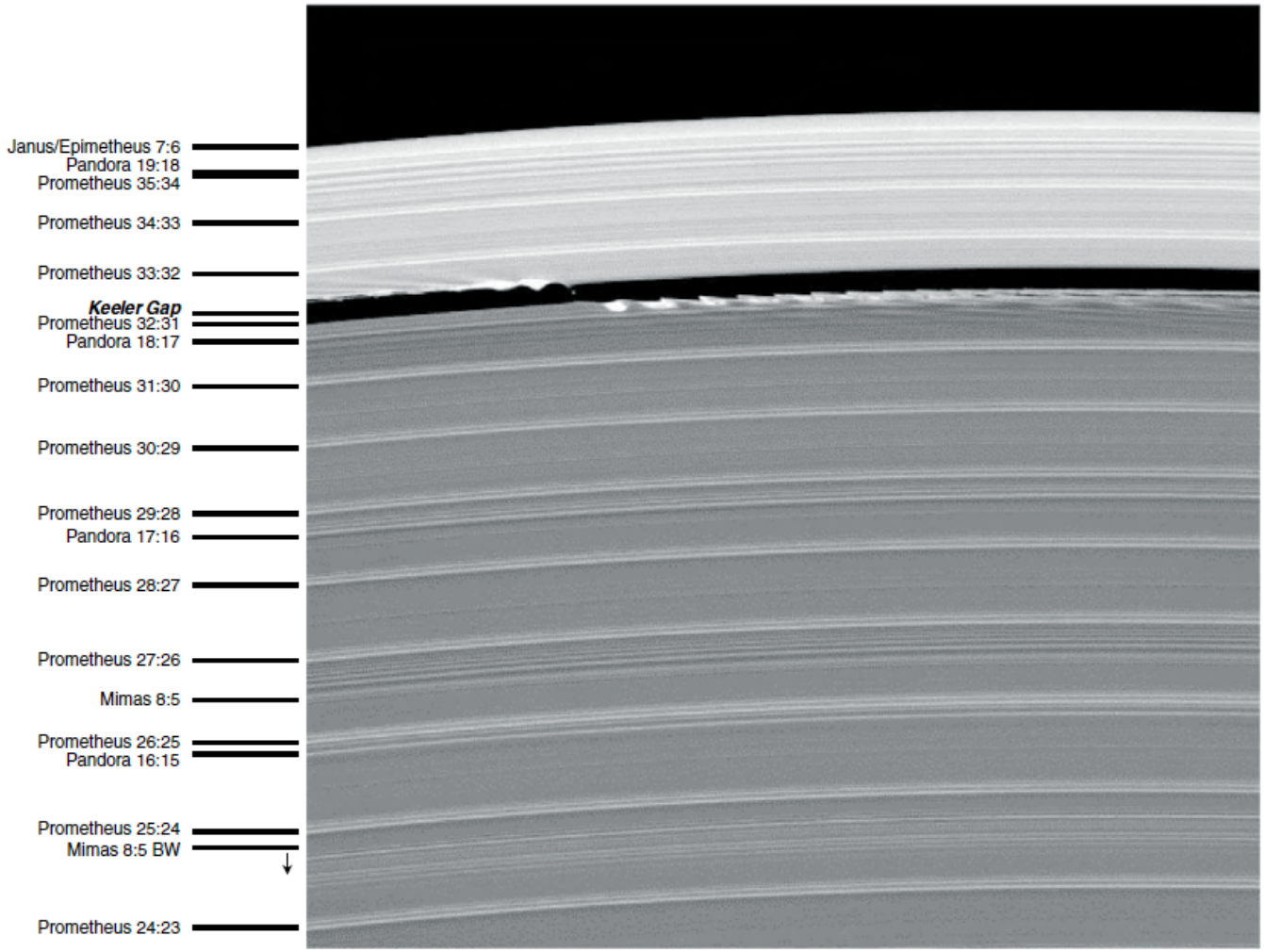


- two-body resonances (λ, λ_p)
- three-body resonances $(\lambda, \lambda_{p1}, \lambda_{p2})$
- secular resonances (Ω, ϖ)
- Kozai-Lidov mechanism (ω)

Some examples

- Io-Europa-Ganymede
- Saturn satellites
- Saturn rings
- Uranus satellites
- asteroids with Jupiter, Mars, Earth, Venus...
- Trans Neptunian Objects with Neptune
- Pluto - Neptune
- comets - Jupiter
- Pluto satellites: Styx, Nix, and Hydra

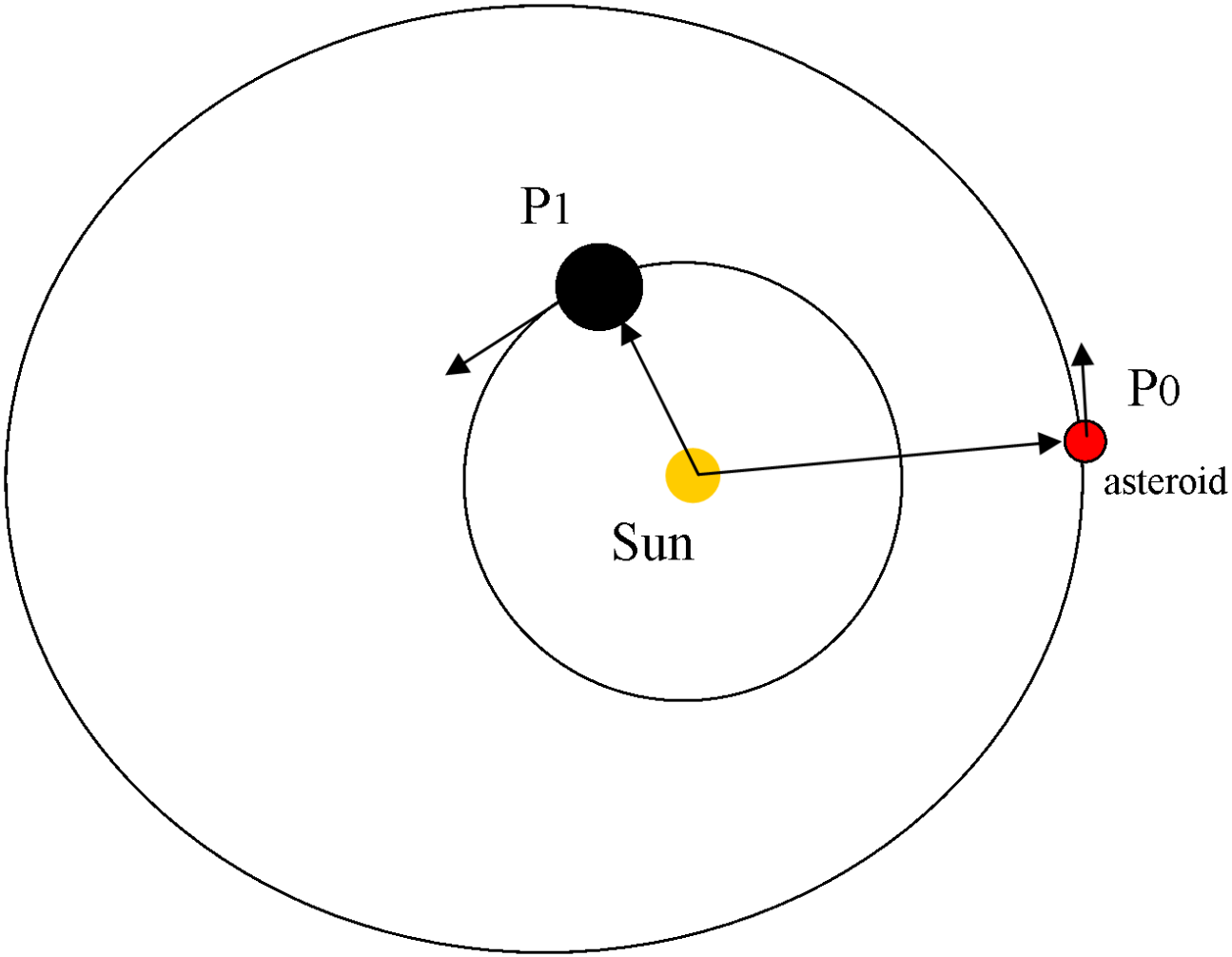
Saturn rings



Lissauer and de Pater, Fundamental Planetary Science

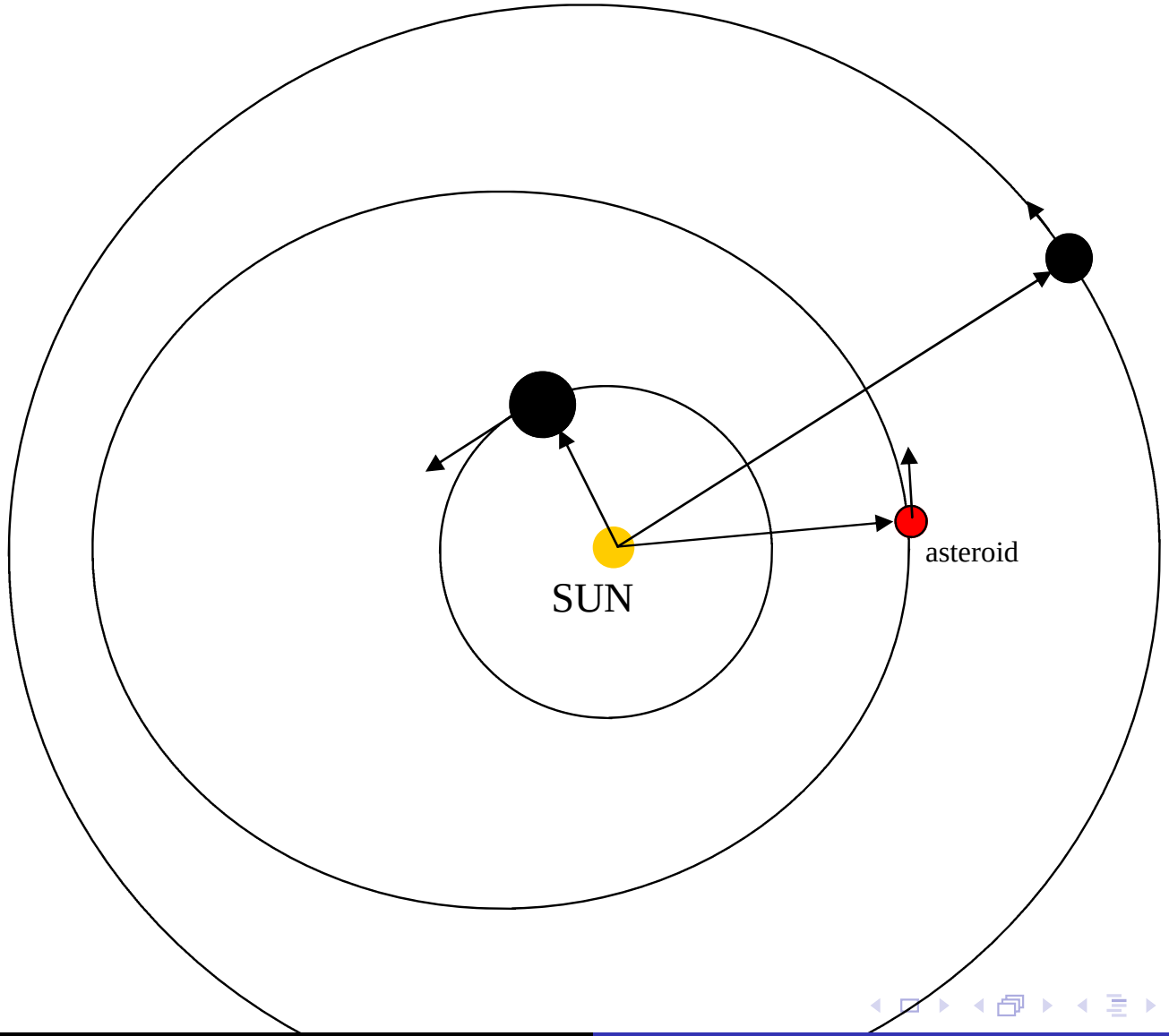
Two-body resonance

$k_0 n_0 + k_1 n_1 \simeq 0$



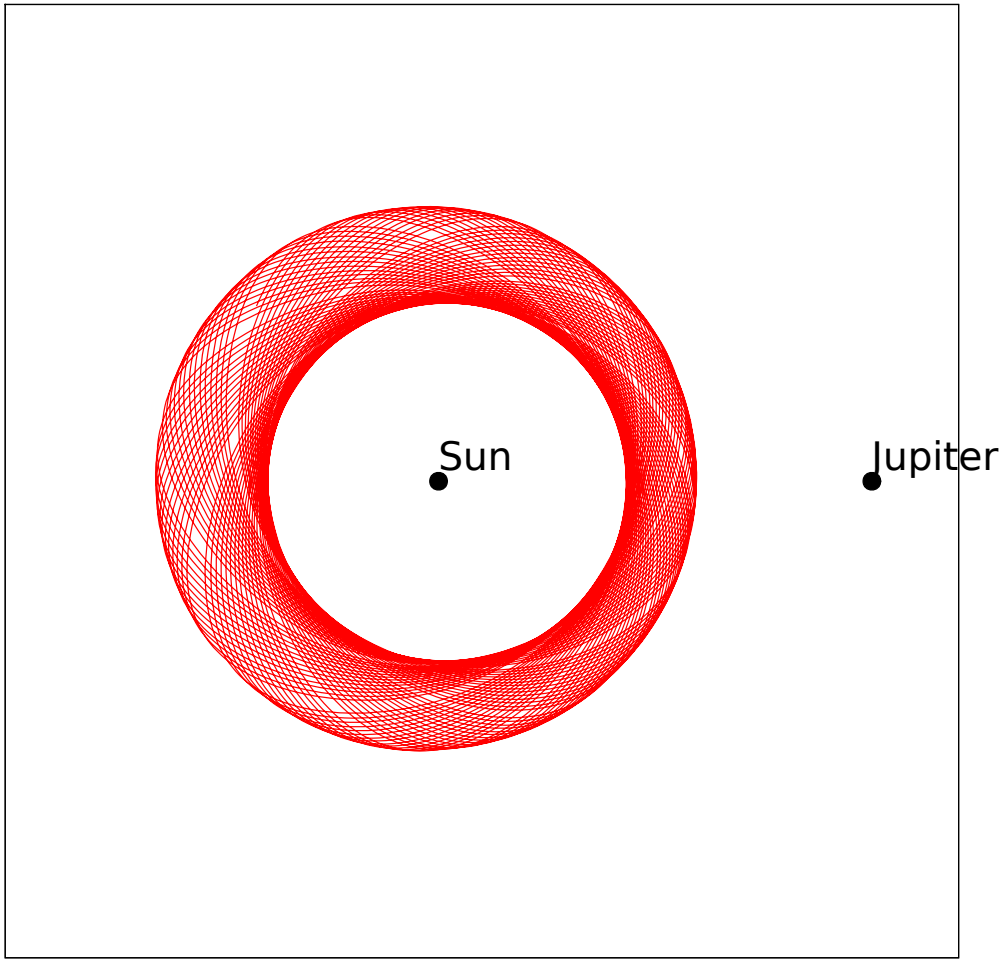
Three-body resonance

$k_0 n_0 + k_1 n_1 + k_2 n_2 \simeq 0$ only the asteroid feels the resonance



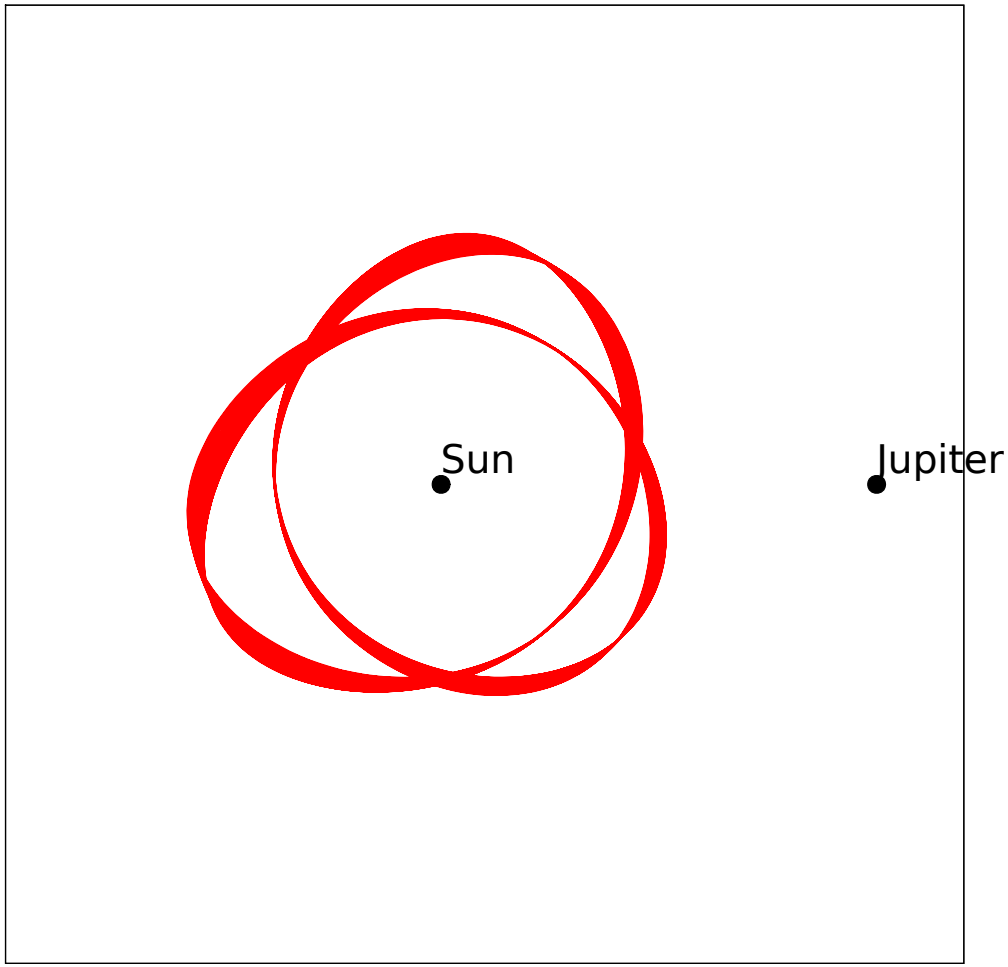
Non resonant asteroid: relative positions

Mean perturbation is radial: Sun-Jupiter

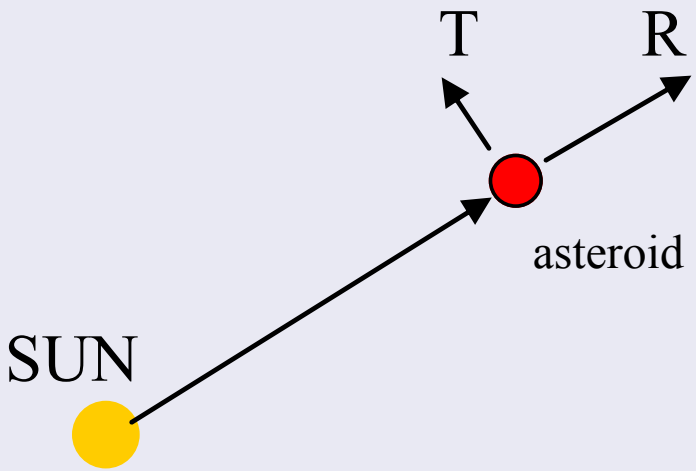


Resonant asteroid

Mean perturbation has a **transverse** component.



from Gauss equations



$$F_{perturb} = (R, T, N)$$

$$\frac{da}{dt} \propto (R, T)$$

$$< \frac{da}{dt} > \propto T$$

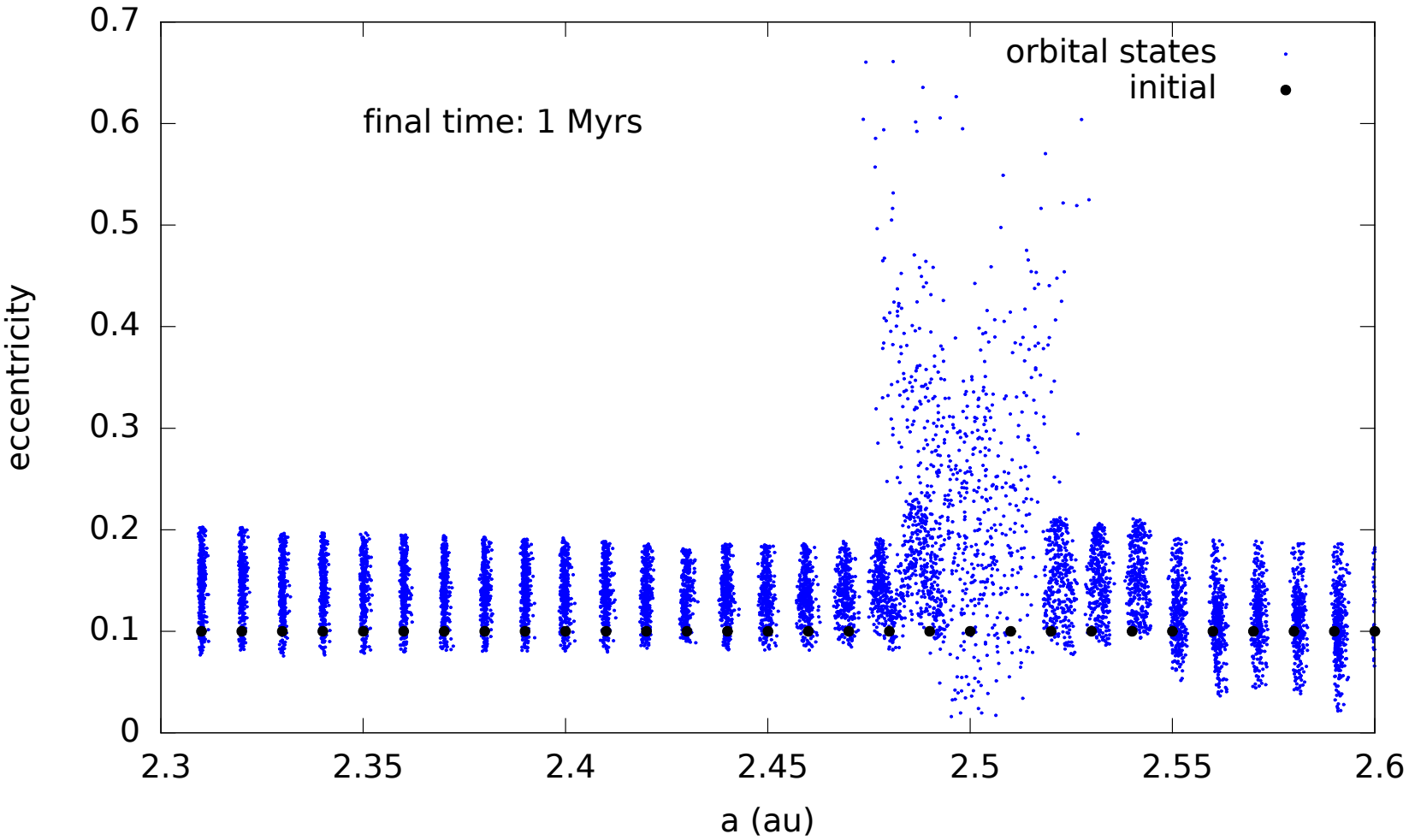
Non resonant

$T = 0 \Rightarrow a =$ constant

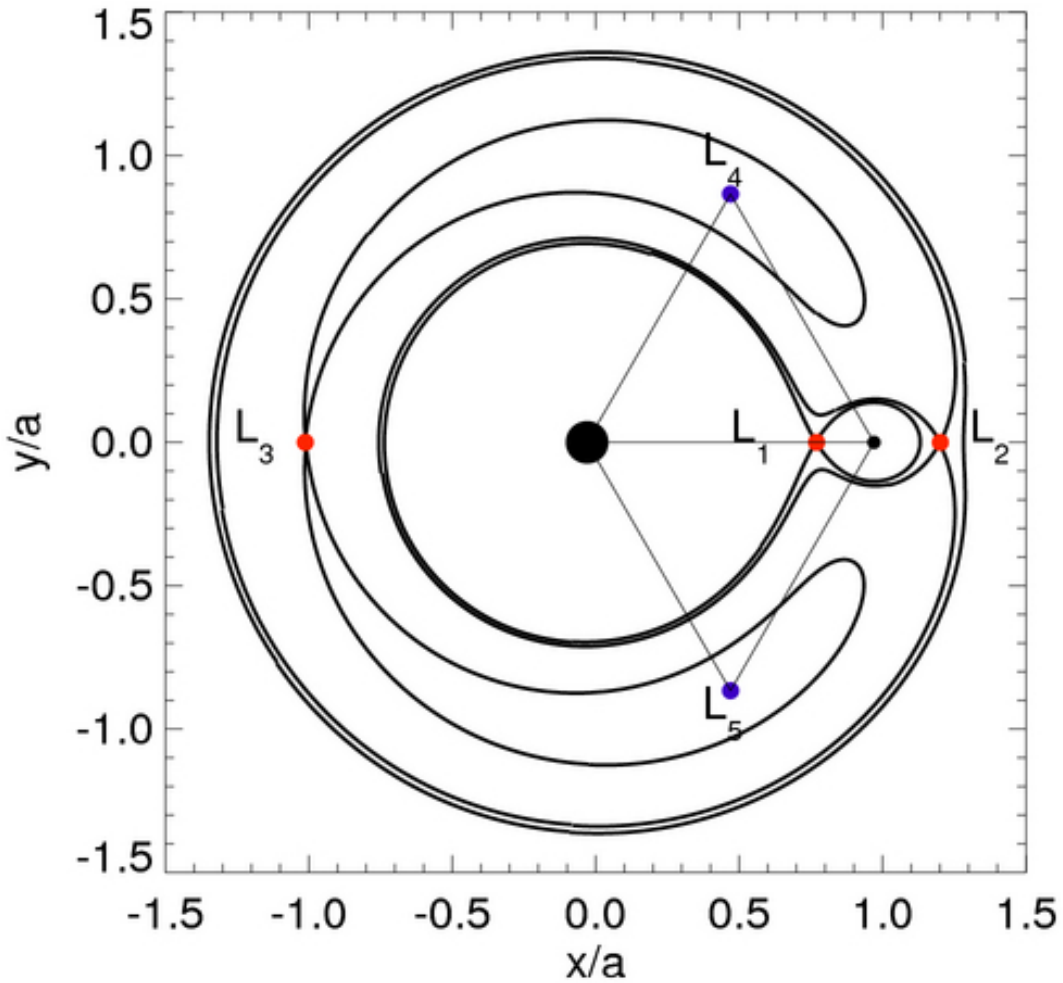
Resonant

$T \neq 0 \Rightarrow a =$ oscillating

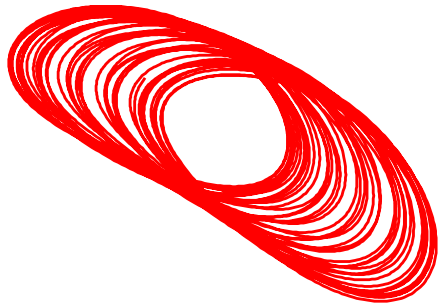
Dynamical effects: a numerical exercise



1772: Lagrange equilibrium points



1906: (588) Achilles by 500 yrs



Sun

Jupiter

1784: Laplacian resonance

$$3\lambda_{Europa} - \lambda_{Io} - 2\lambda_{Ganymede} \simeq 180^\circ$$

$$3n_{Europa} - n_{Io} - 2n_{Ganymede} \simeq 0$$

They are also in commensurability by pairs:

$$2n_{Europa} - n_{Io} \simeq 0$$

$$2n_{Ganymede} - n_{Europa} \simeq 0$$

$$\Downarrow$$

It must be the consequence of some physical mechanism.

1846: discovery of Neptune

quasi resonance Uranus - Neptune:

$$n_{Uranus} \sim 2n_{Neptune}$$

quasi resonance Saturn - Uranus:

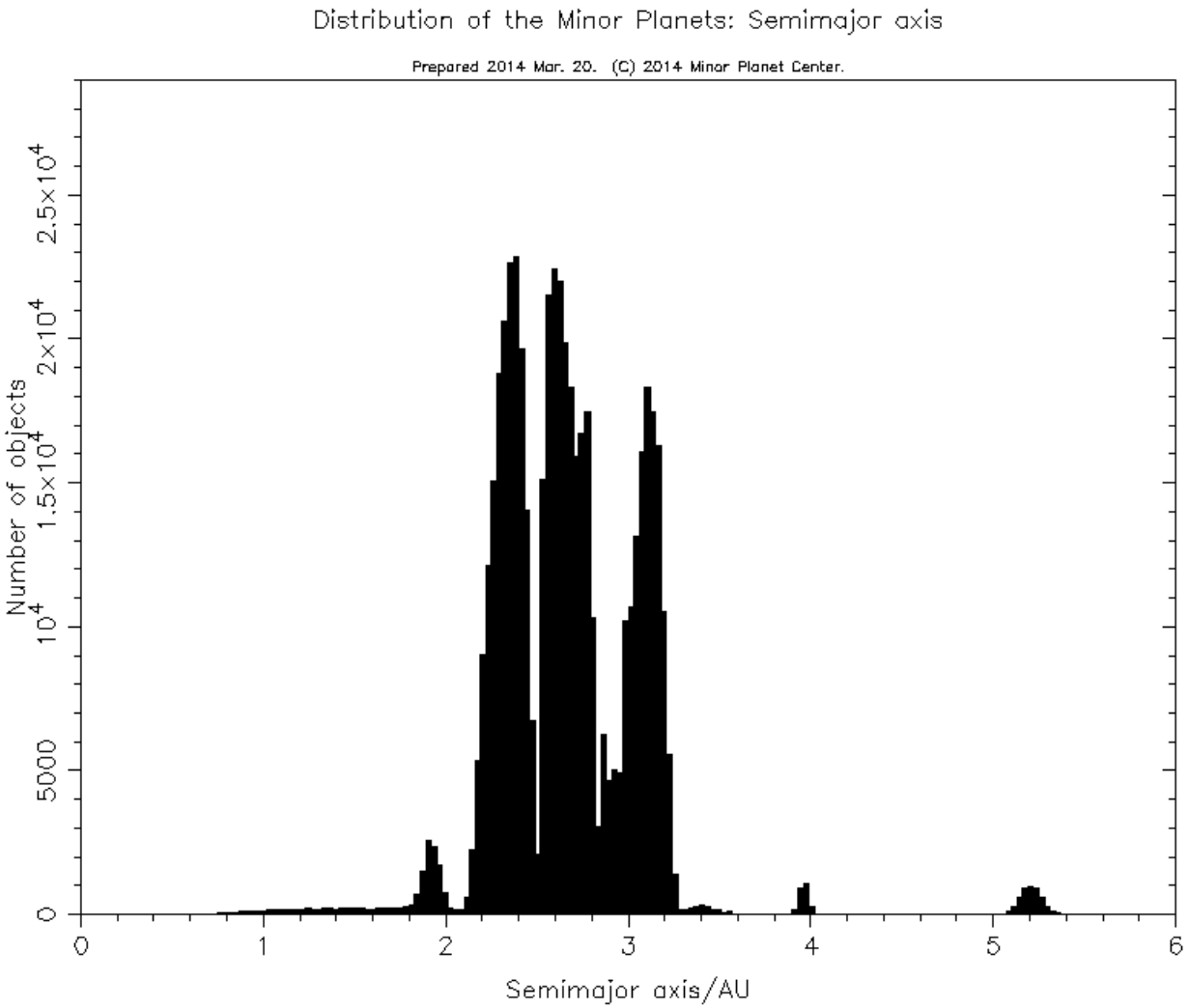
$$n_{Saturn} \sim 3n_{Uranus}$$

quasi resonance: Jupiter - Saturn

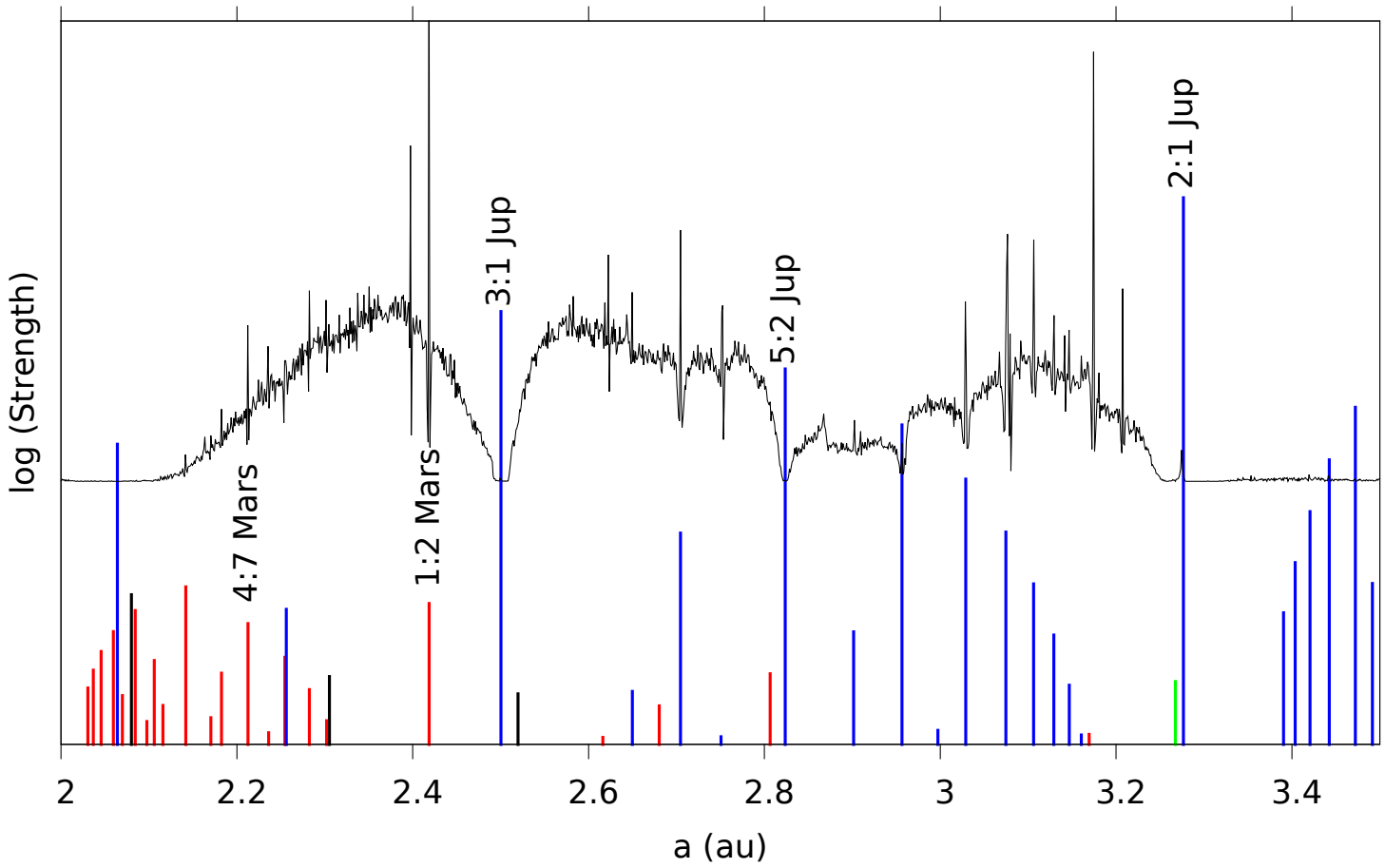
$$2n_{Jupiter} \sim 5n_{Saturn}$$

Why the planets are close to resonance?
Hint: **planetary migration**

1866: Kirkwood gaps



Kirkwood gaps at present



Main belt of asteroids is *sculpted* by resonances.

Resonance locations

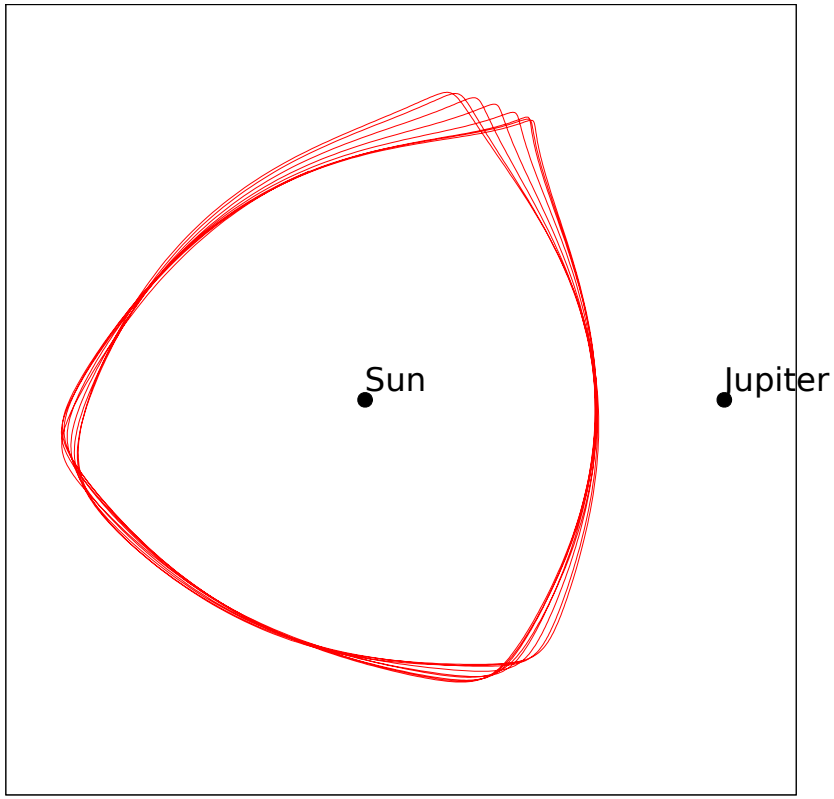
$$k_0 n_{ast} = k_1 n_{Jup}$$

$$a_{ast} \simeq (\frac{k_0}{k_1})^{2/3} a_{Jup}$$

There is an infinite number of resonances...

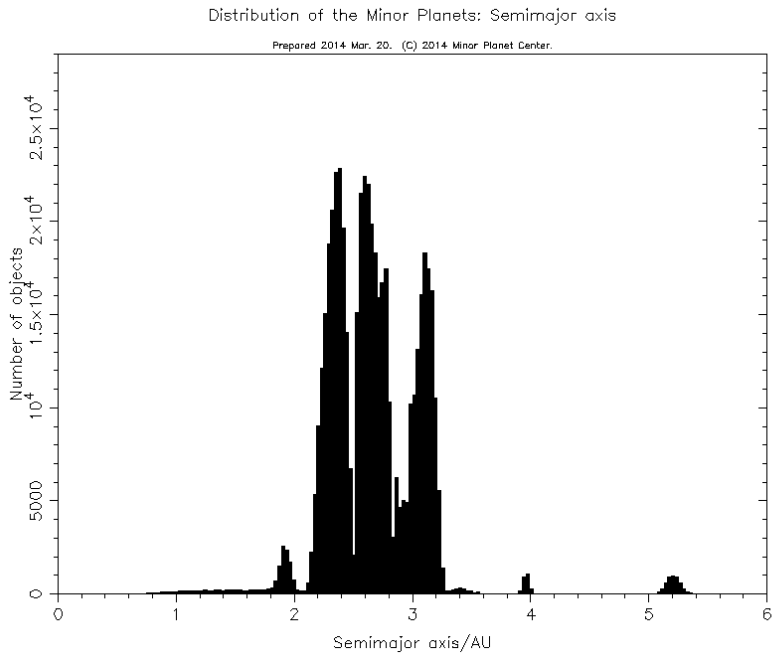
which are the relevant ones?

1875: resonant asteroids (153) Hilda 3:2



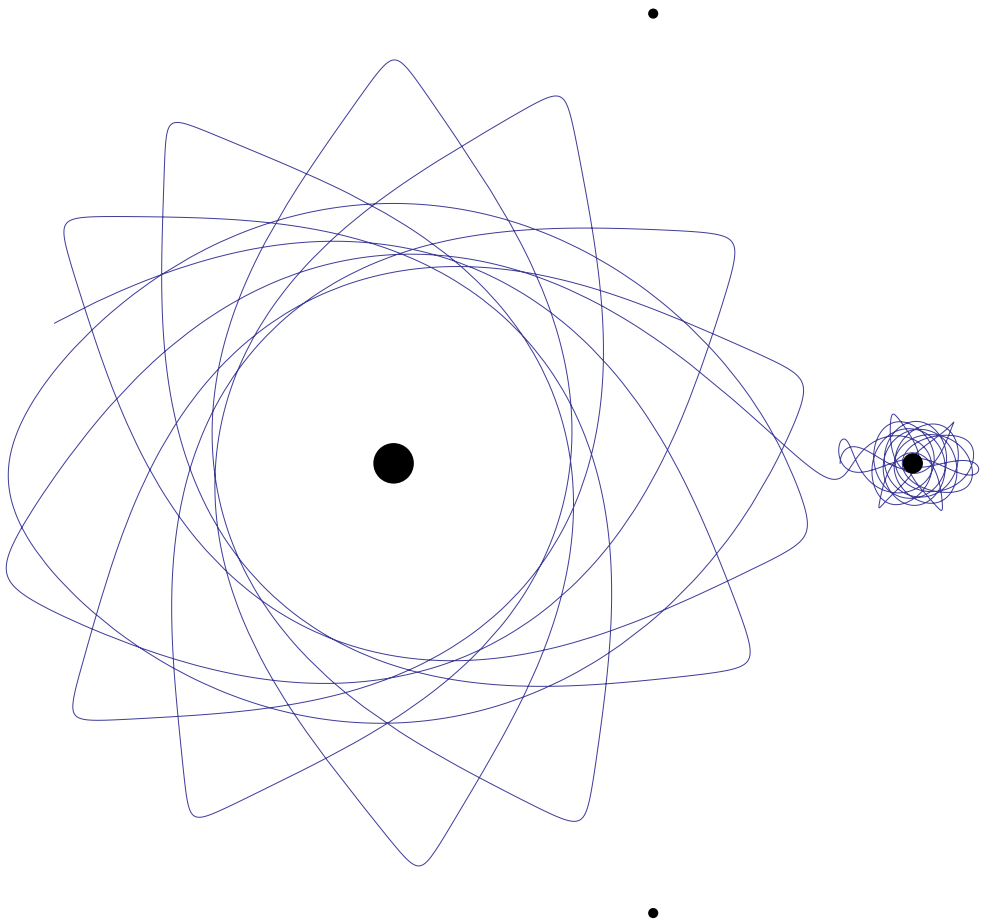
$$2n_{Hilda} = 3n_{Jup}$$

$$a_{Hilda} = (\frac{2}{3})^{2/3} a_{Jup} = 3.97\text{ua}$$



Hildas and Trojans

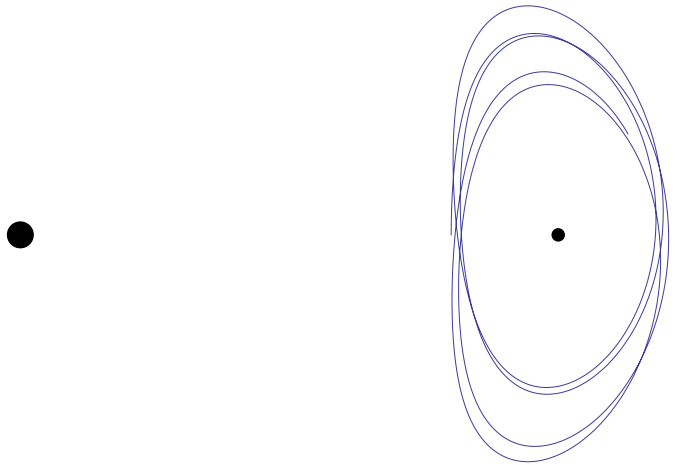
Temporary satellite capture



the most probable origin of the irregular satellites

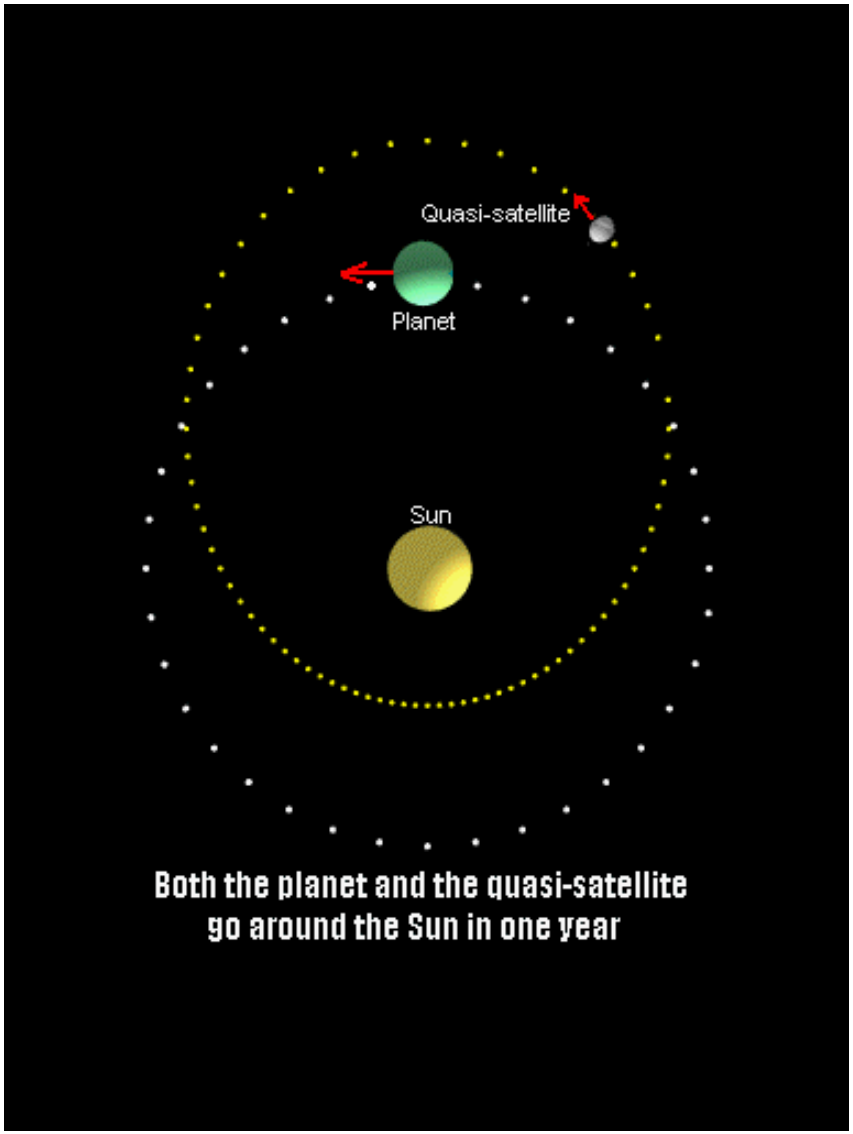
Quasi satellite, resonance 1:1

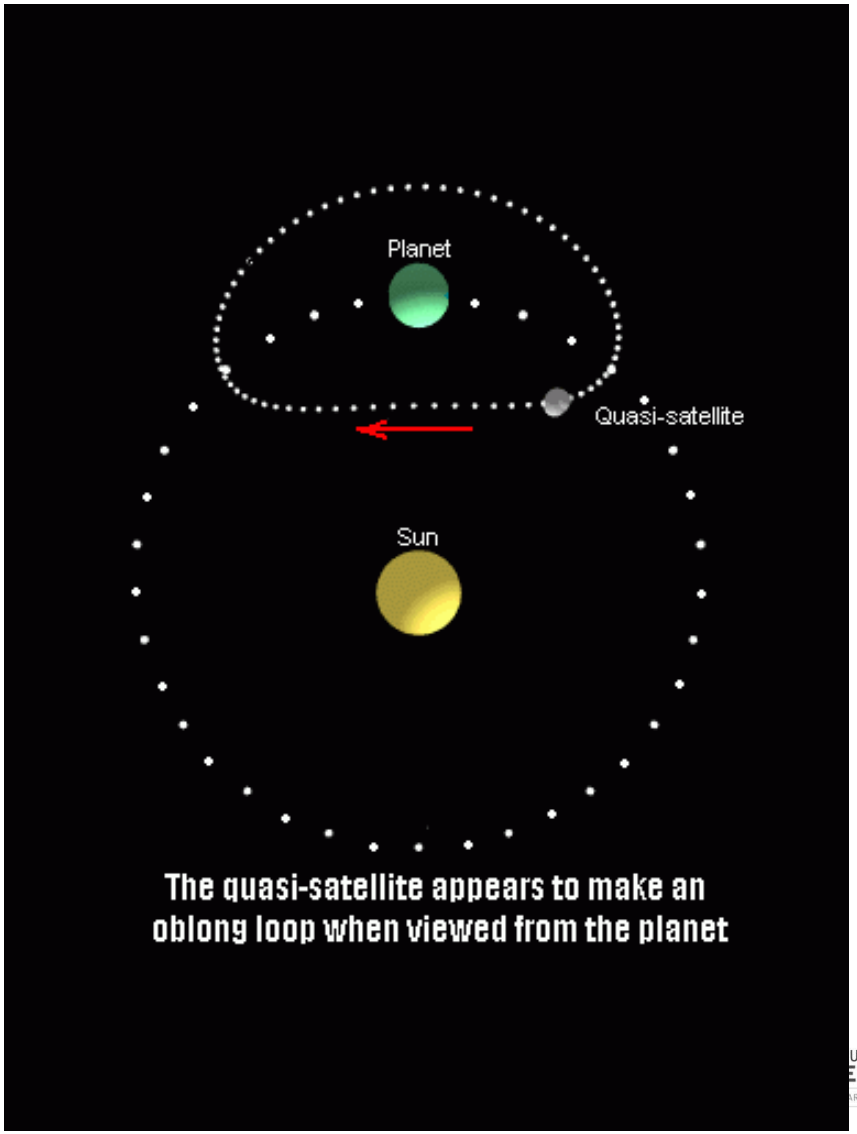
it is not orbiting around the planet, it is synchronized 1:1 with the planet



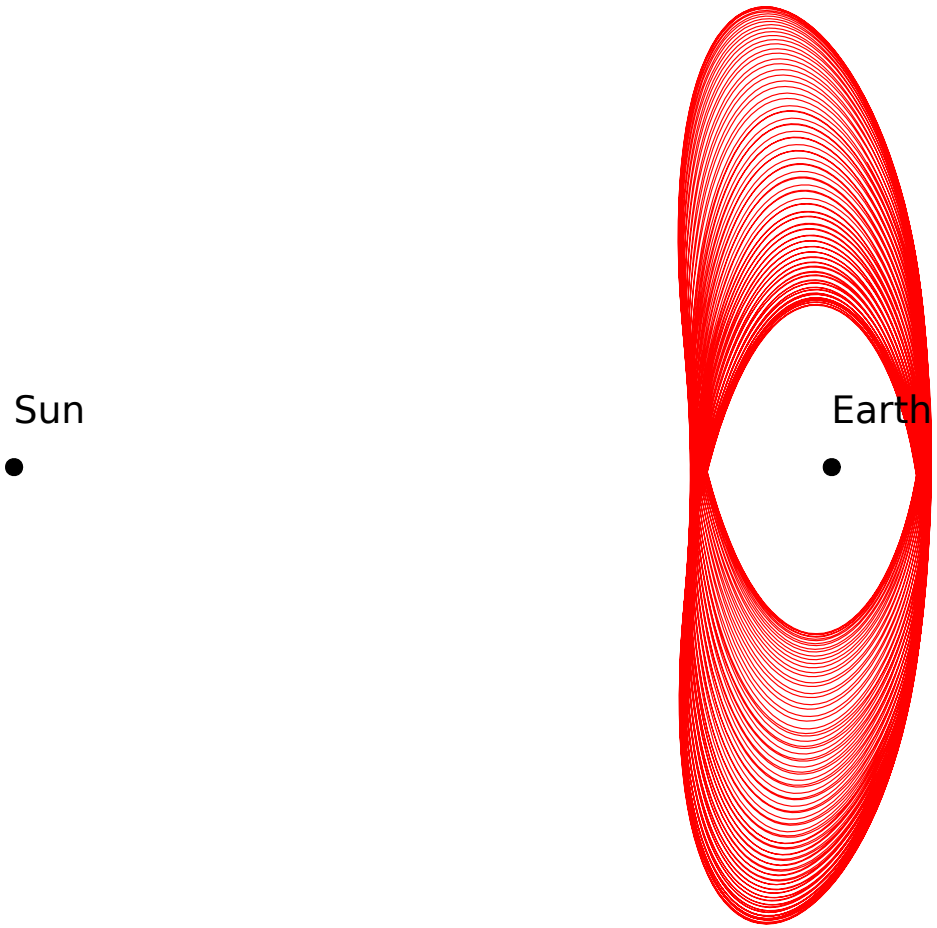
Quasi satellite

from Wiegert website:

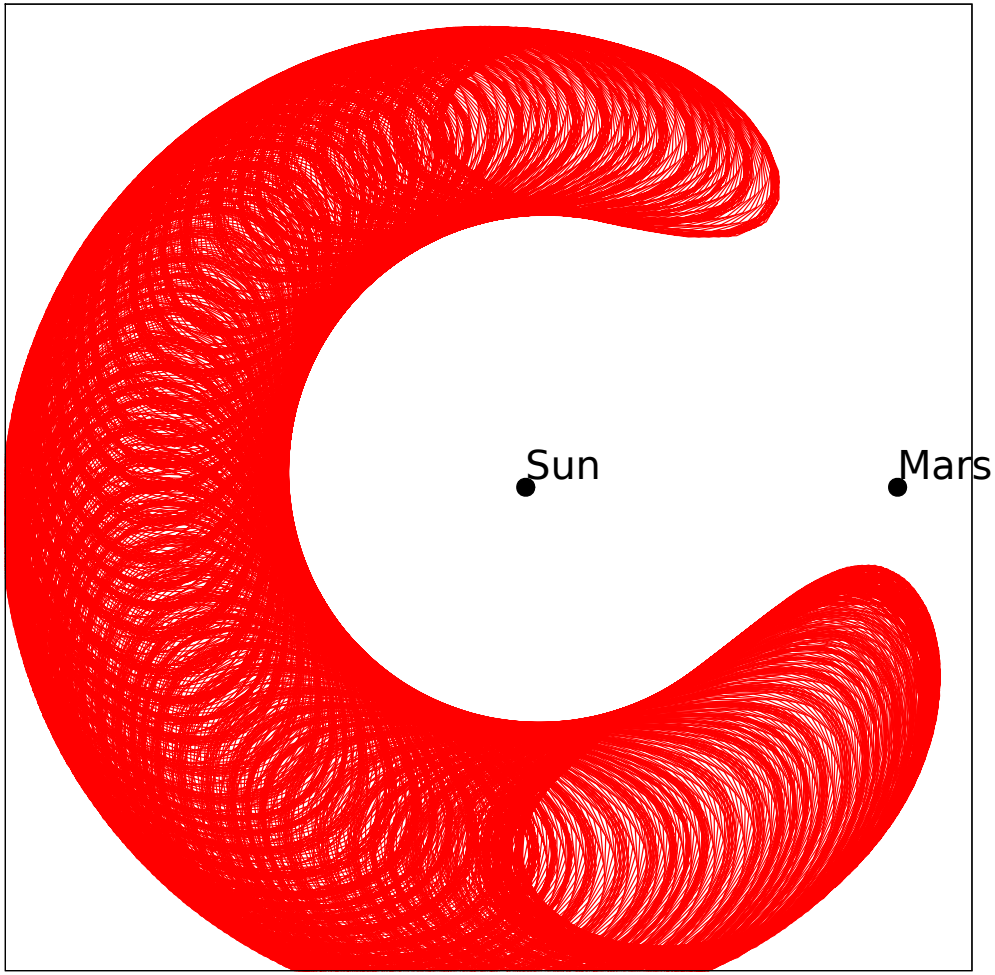




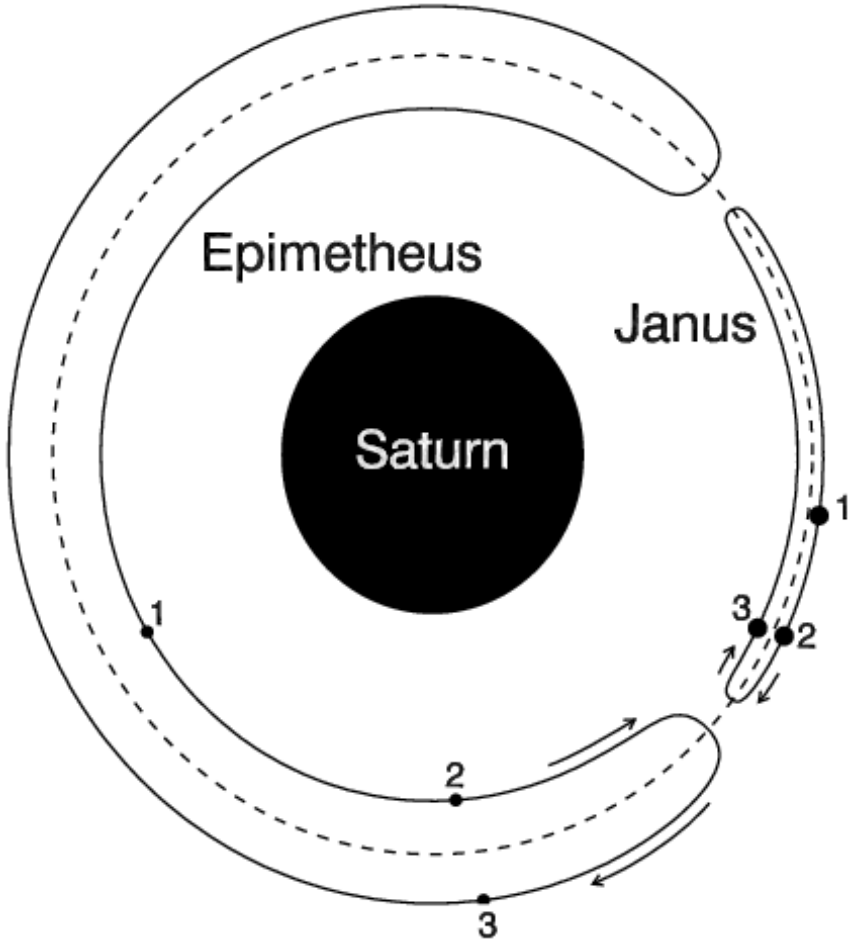
2004 GU9: Earth quasi satellite, resonance 1:1



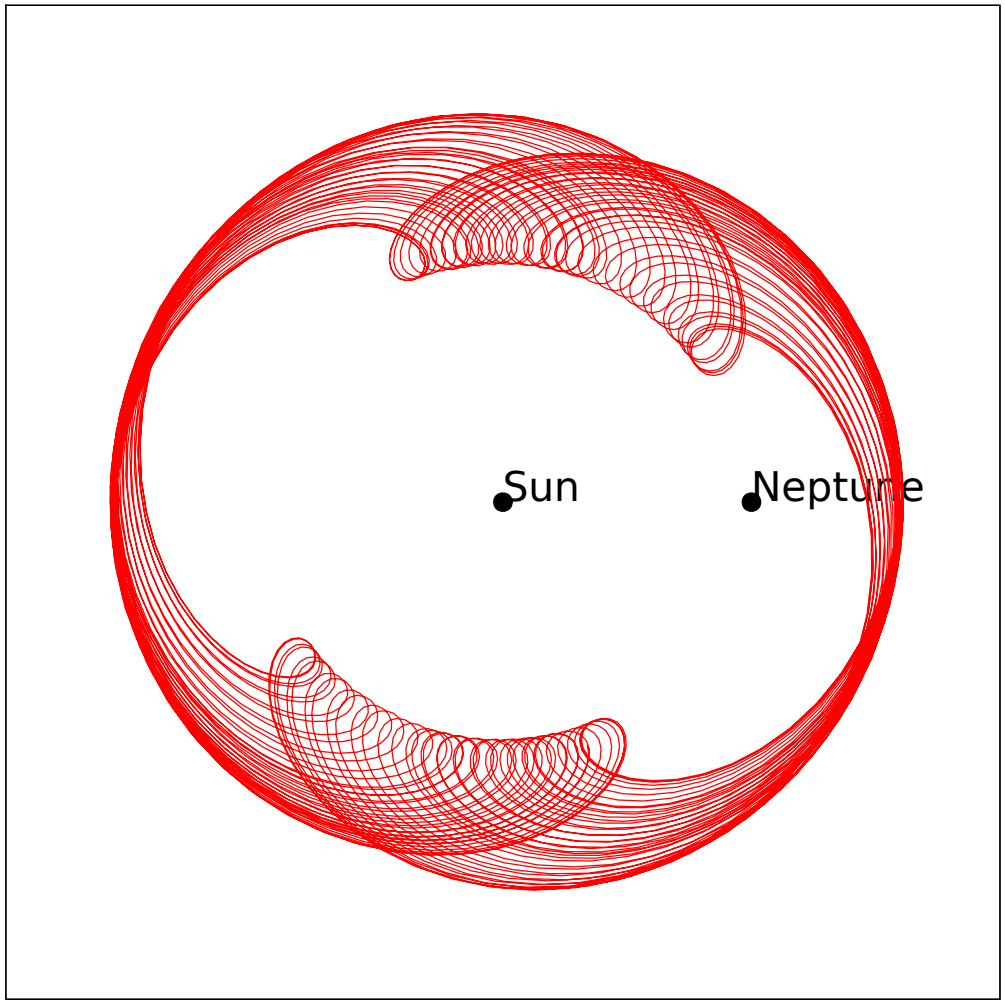
1999 ND43: Mars horseshoe, resonance 1:1



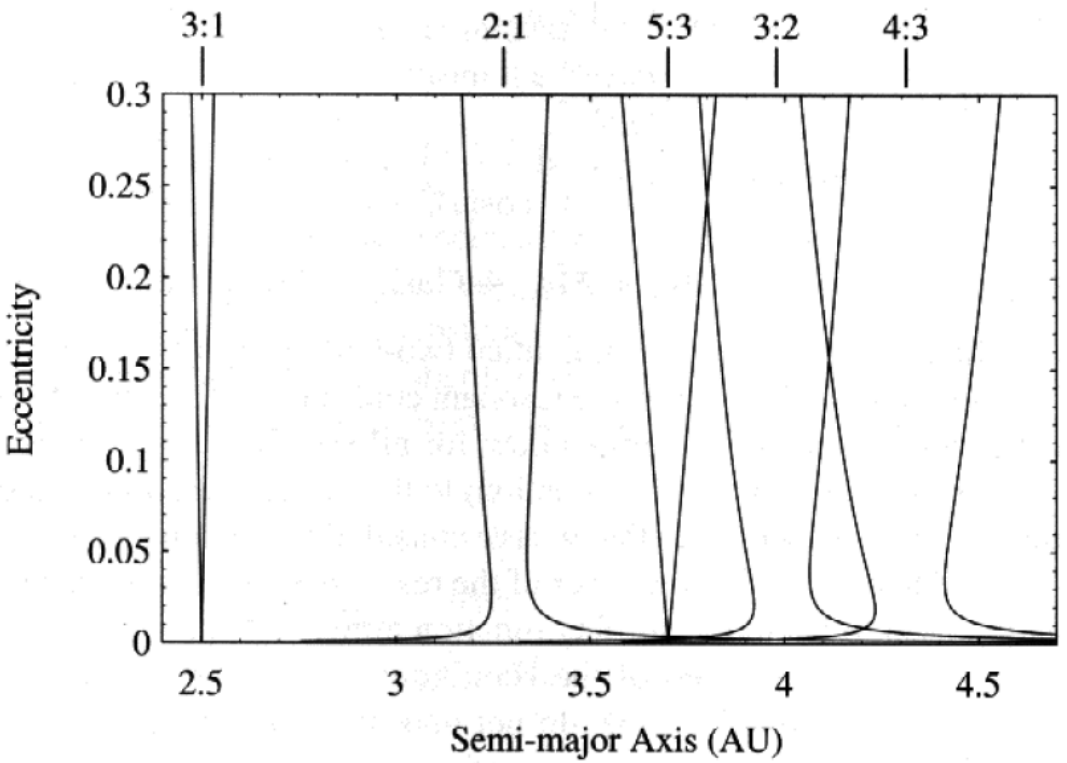
Janus - Epimetheus 1:1



(134340) Pluto in exterior resonance 2:3



Widths

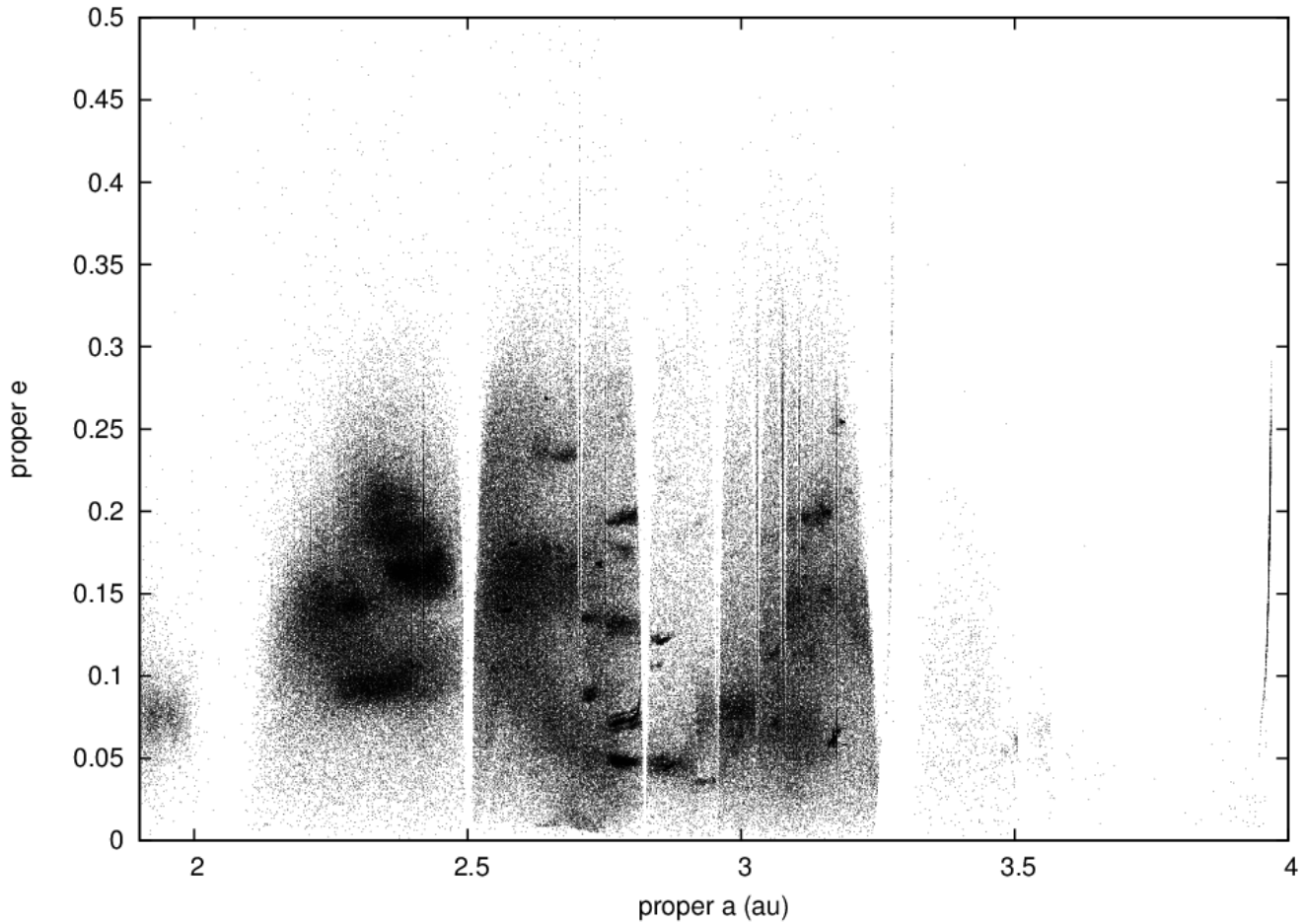


Murray and Dermott in Solar System Dynamics

Chaos:

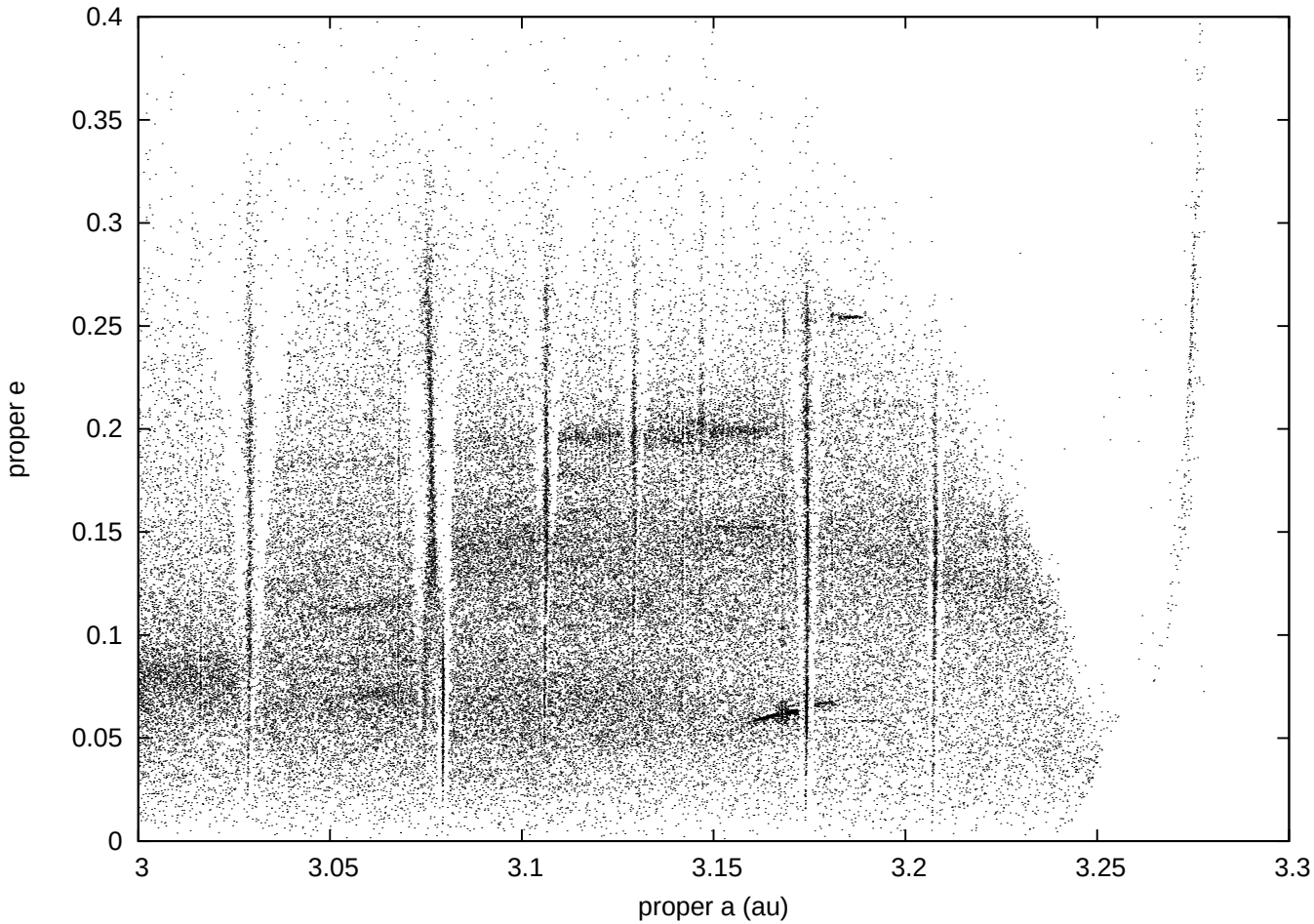
- at resonance borders
- superposition of resonances

350.000 asteroids (proper elements)



AstDyS database

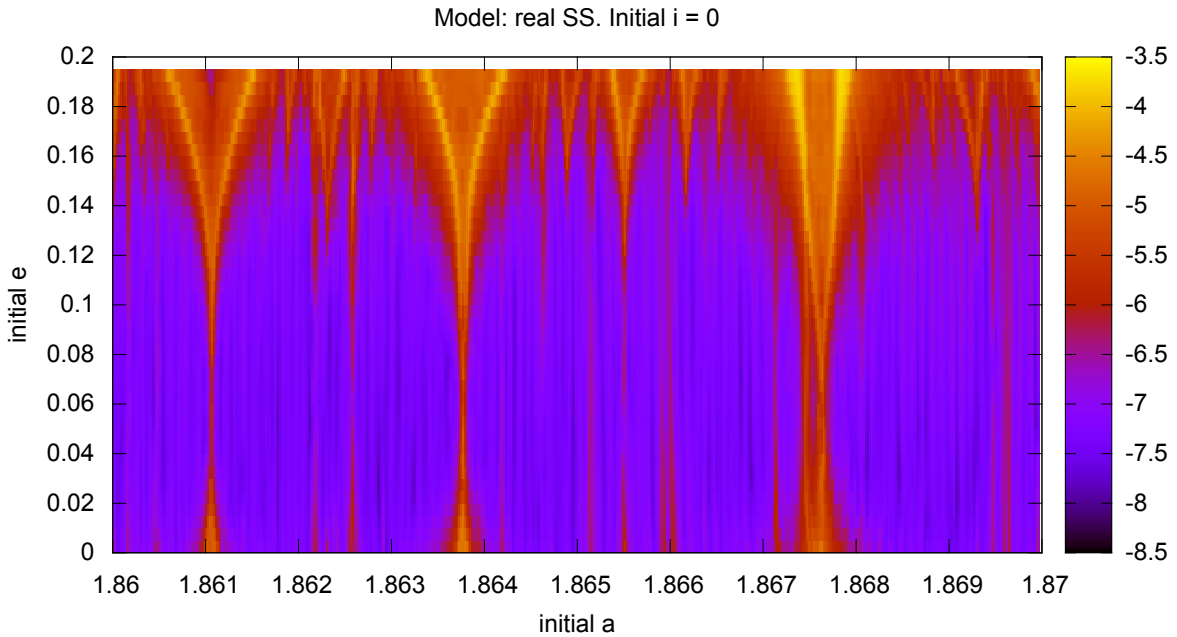
Resonant structure (zoom)



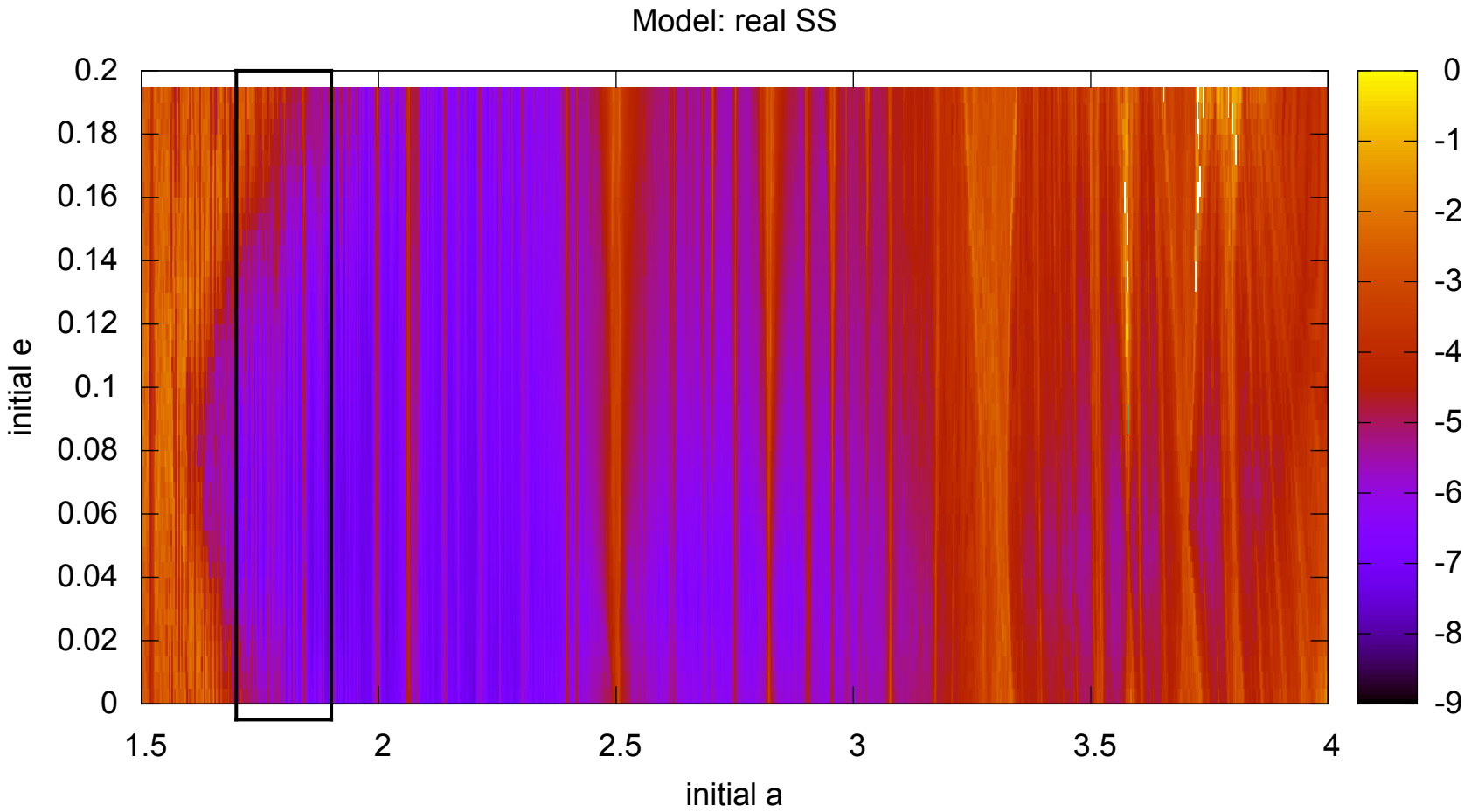
AstDyS database

Dynamical Maps

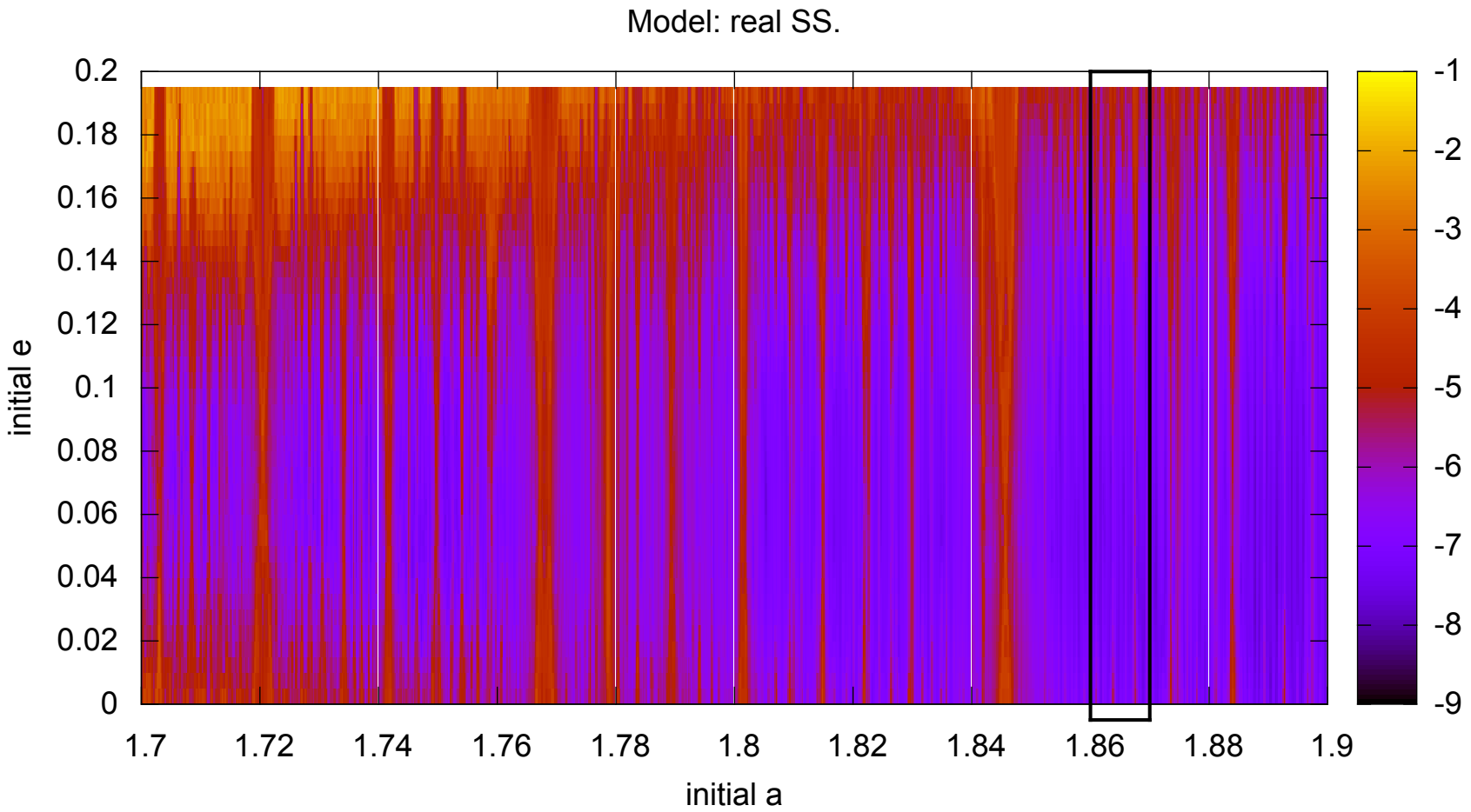
- take set of initial values (a, e)
- integrate for some 10.000 yrs
- surface (color) plot of $\Delta a(a, e)$



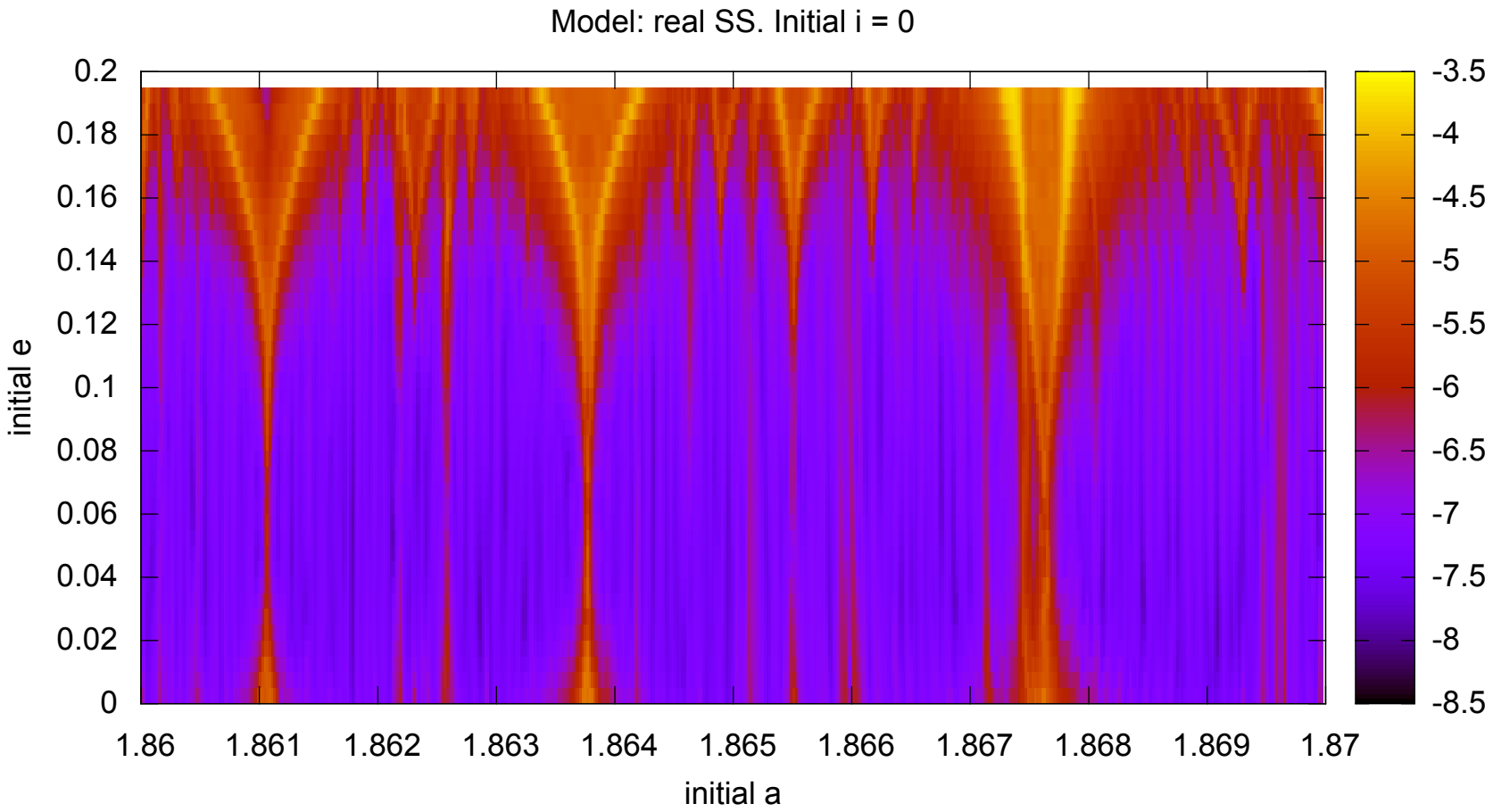
Asteroid region



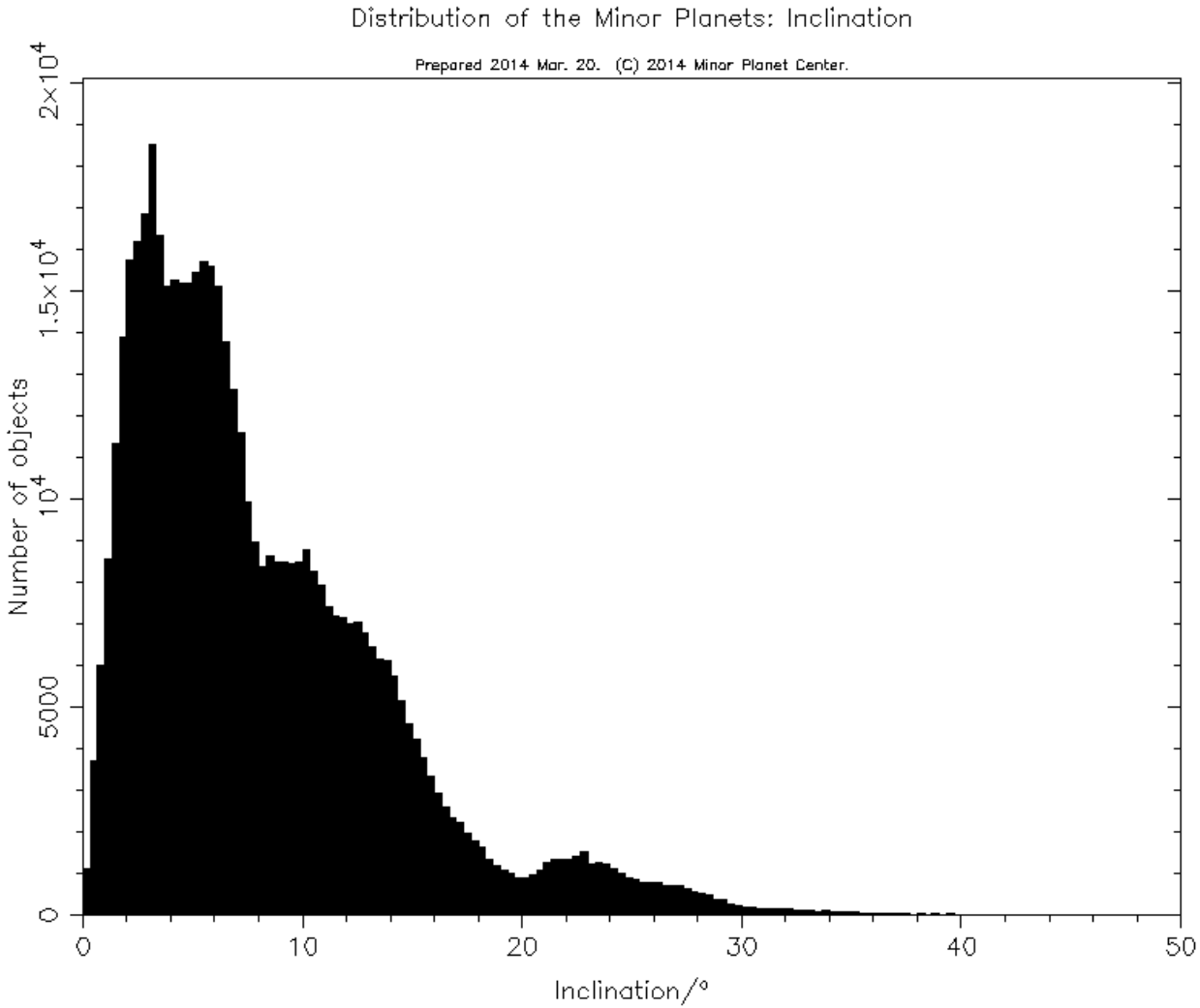
Zoom


Model: real SS.
initial e
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
initial a
1.7
1.72
1.74
1.76
1.78
1.8
1.82
1.84
1.86
1.88
1.9
-1
-2
-3
-4
-5
-6
-7
-8
-9

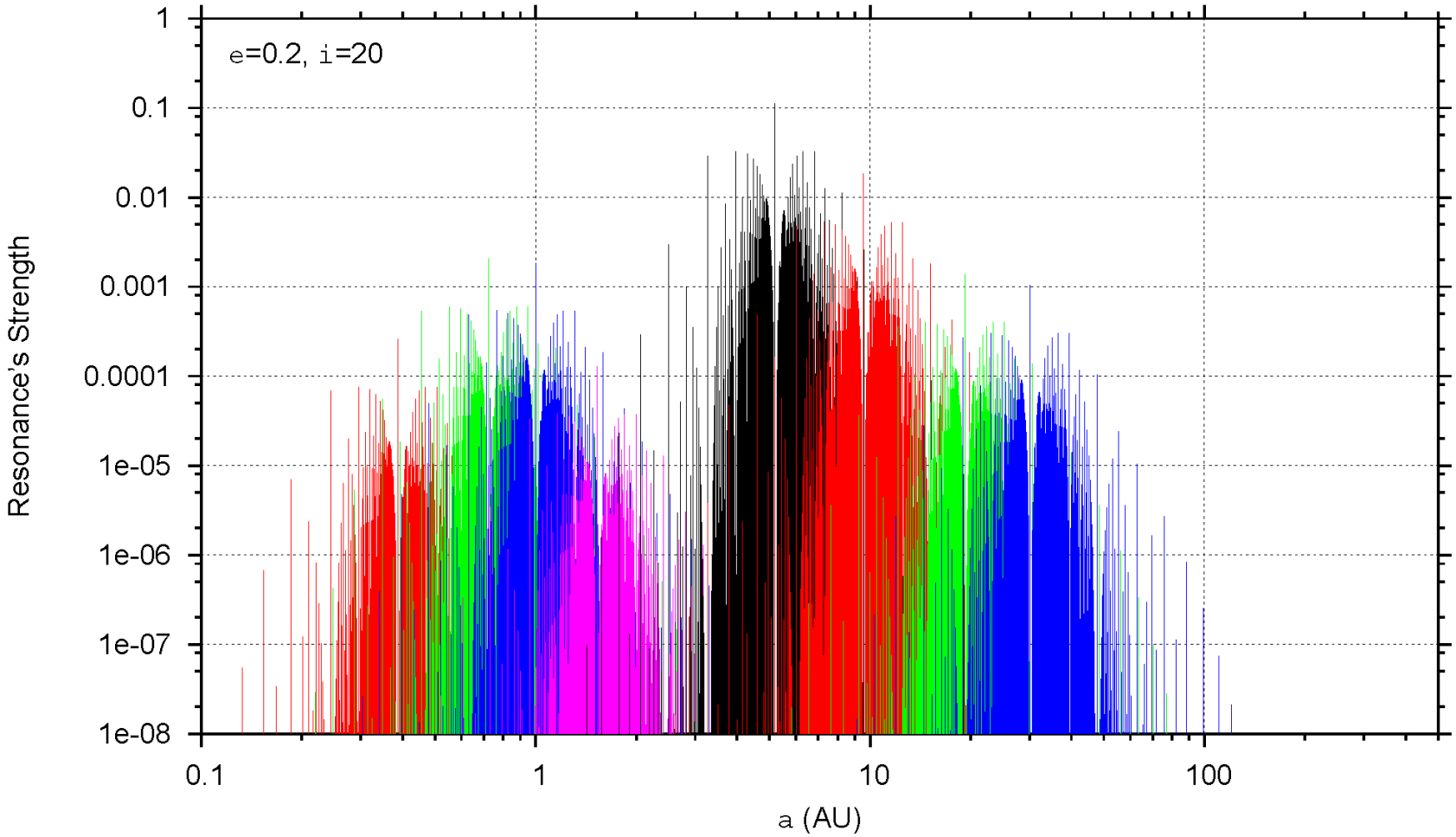
Zoom


Model: real SS. Initial i = 0
initial e
initial a
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1.86
1.861
1.862
1.863
1.864
1.865
1.866
1.867
1.868
1.869
1.87
-3.5
-4
-4.5
-5
-5.5
-6
-6.5
-7
-7.5
-8
-8.5

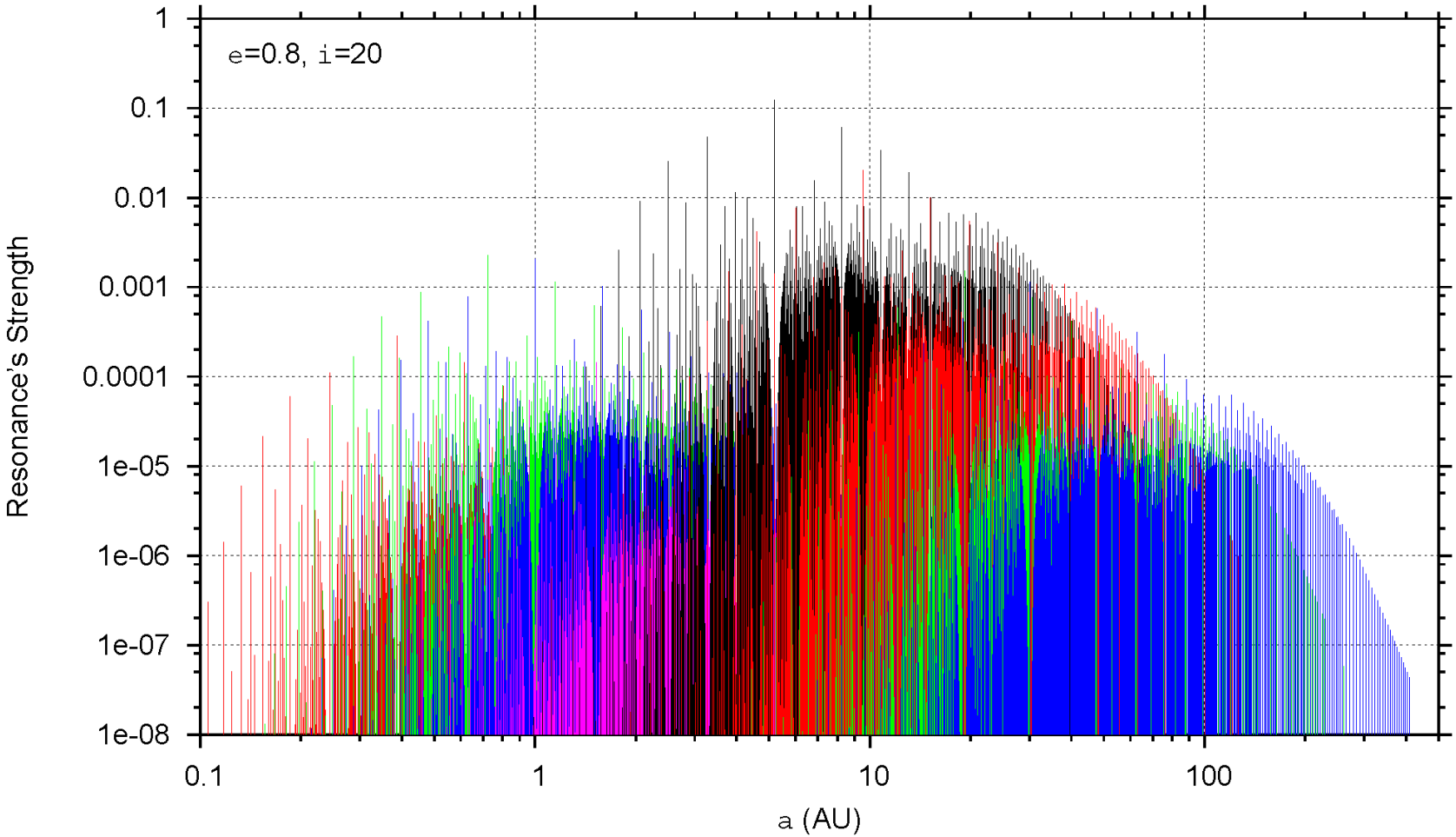
Orbital inclinations of asteroids



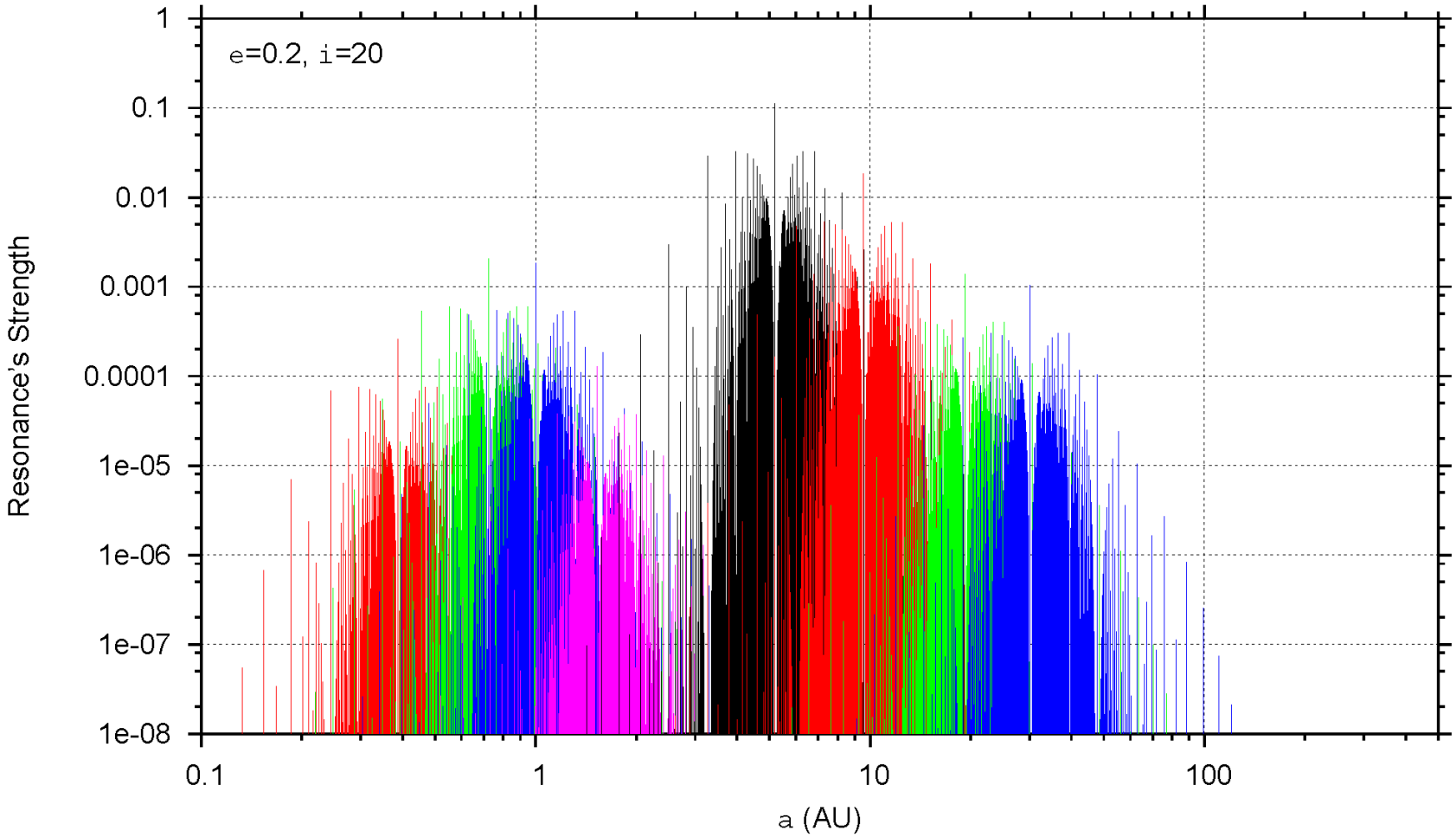
Atlas of resonances in the Solar System, low *e*



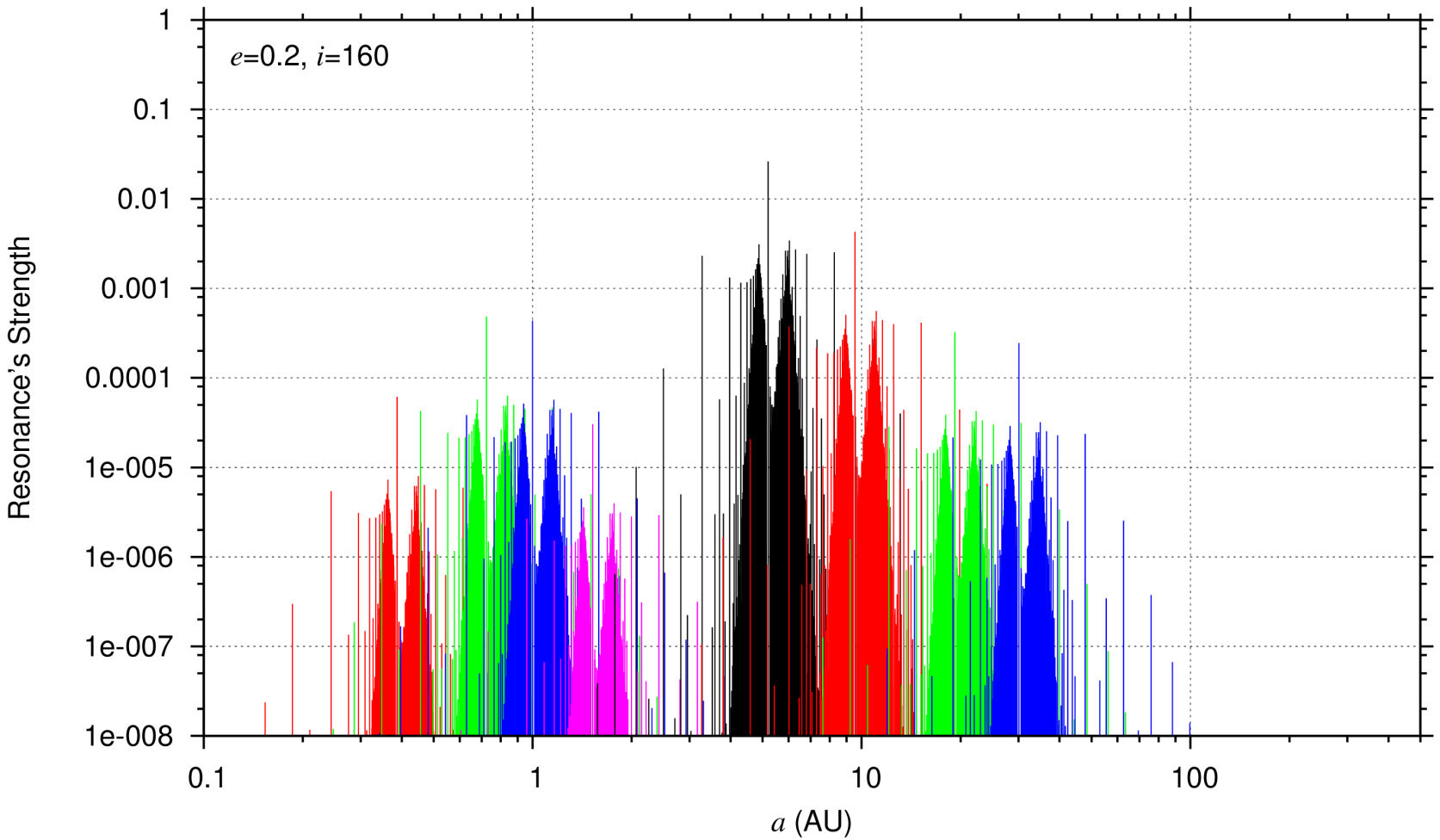
Atlas of resonances in the Solar System, high *e*



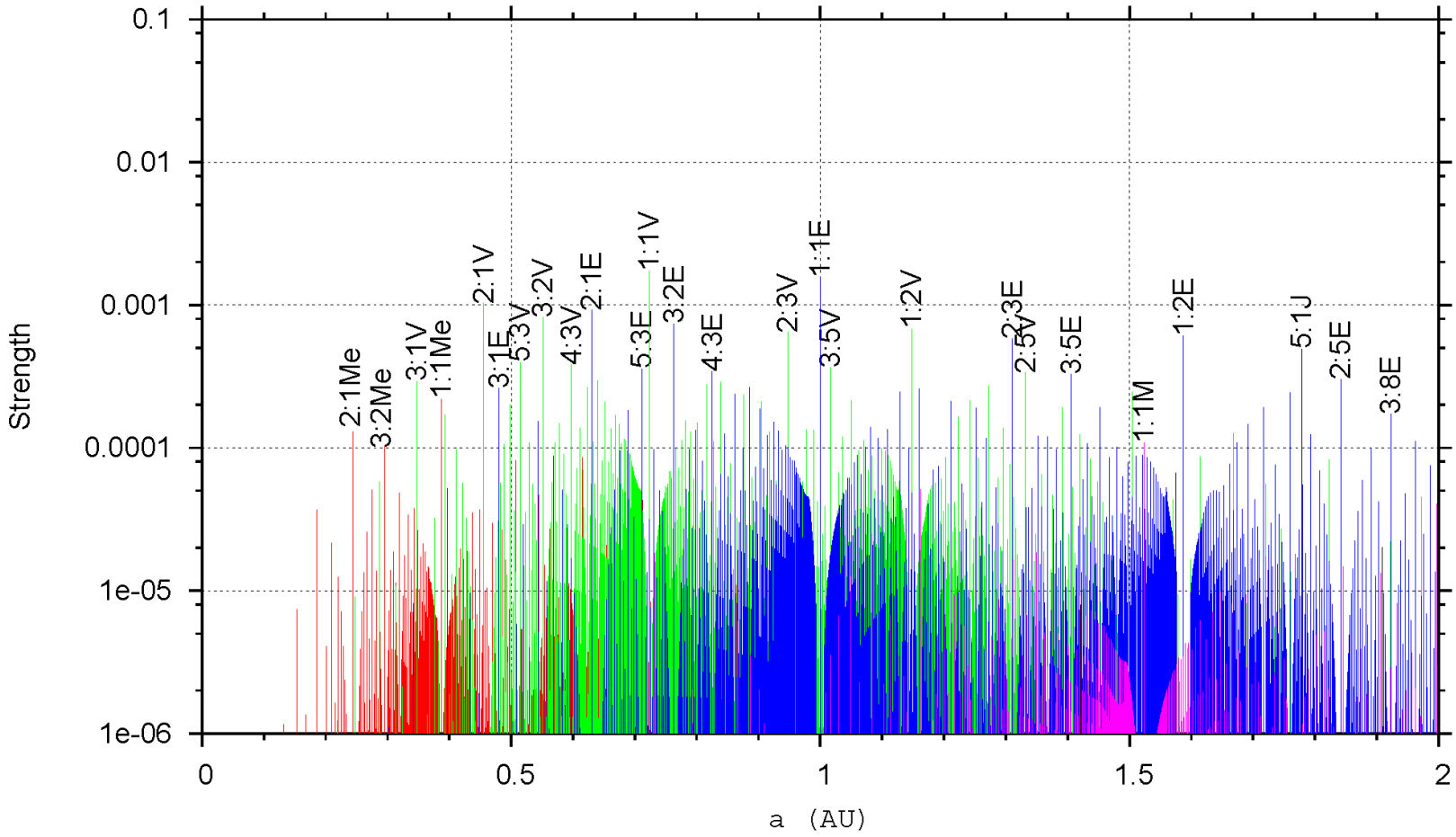
Atlas for DIRECT orbits



Atlas for RETROGRADE orbits



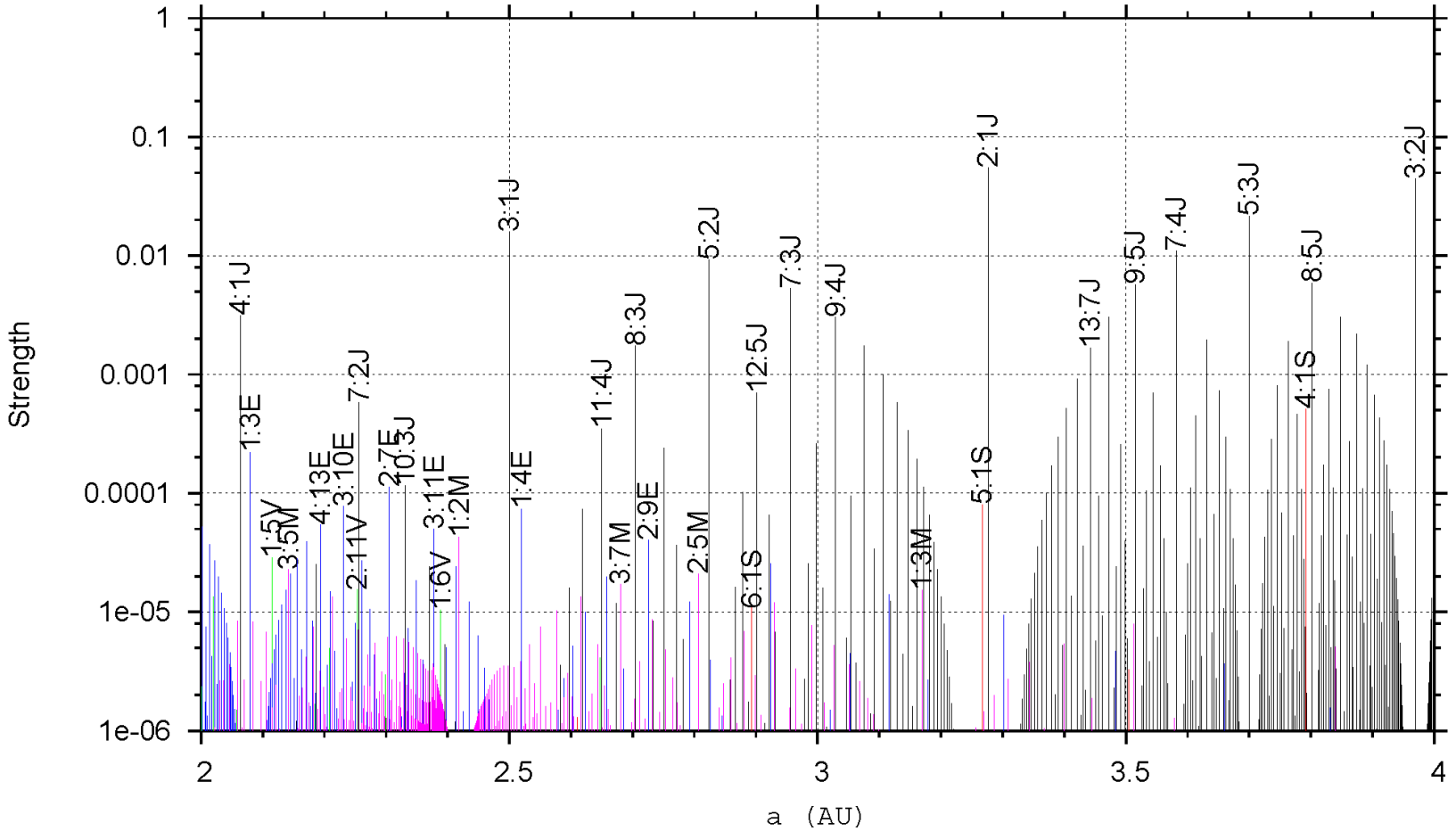
Atlas from 0 to 2 au



Gallardo 2006

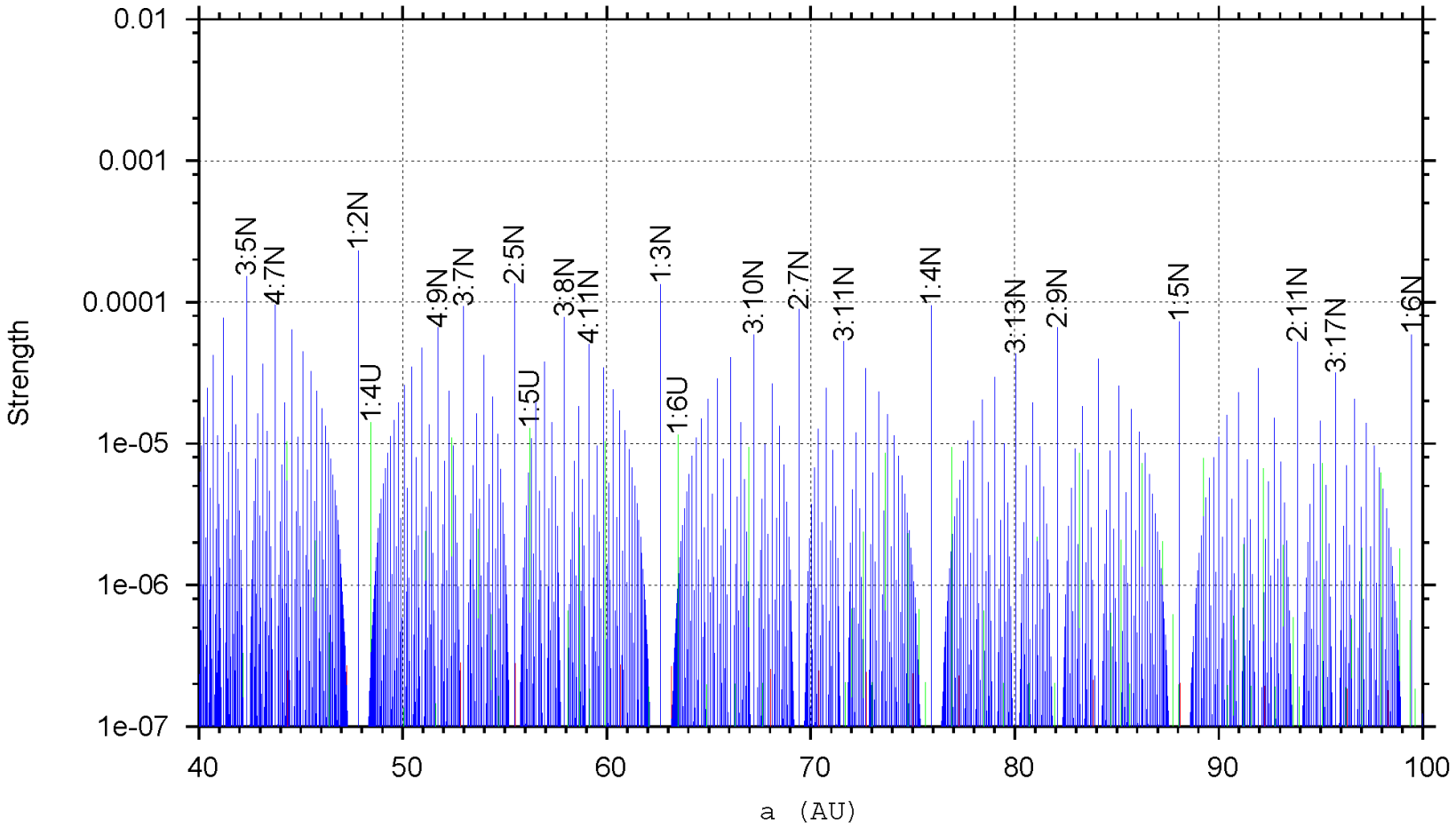
FACULTAD DE CIENCIAS
UDELAR | fcien.edu.uy

Atlas in the asteroids region



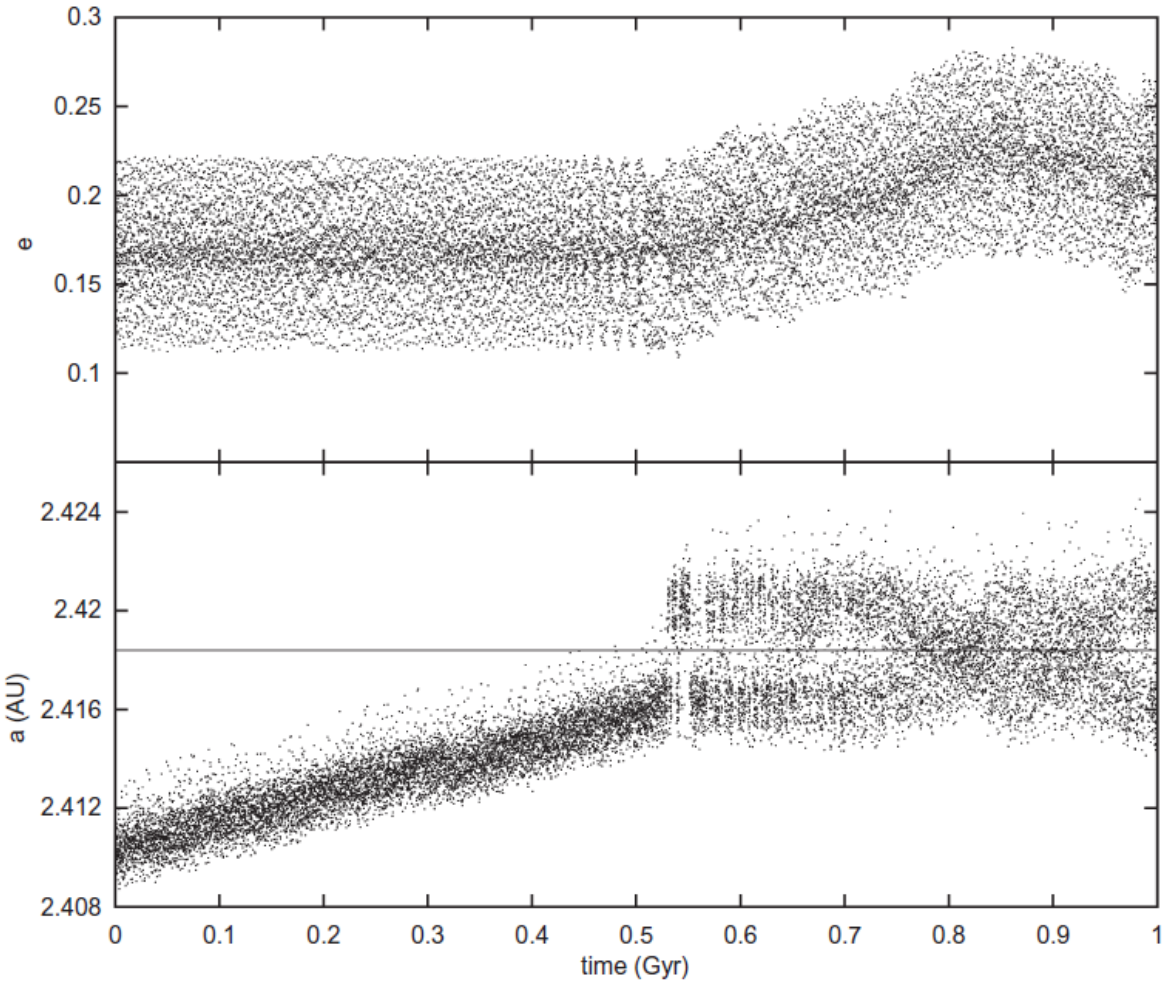
Gallardo 2006

Atlas in the trans-Neptunian Region



Gallardo 2006

Stickiness: ability to capture particles

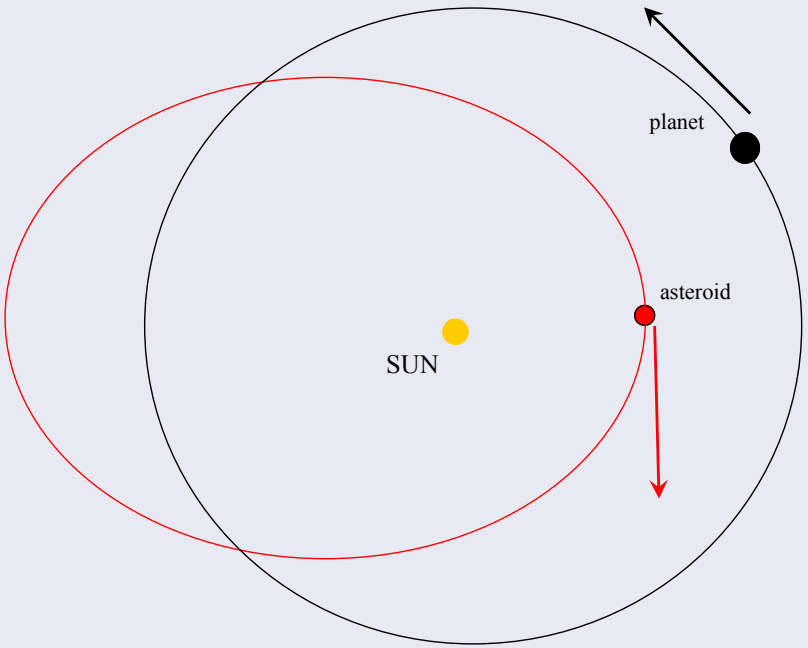


Gallardo et al. 2011

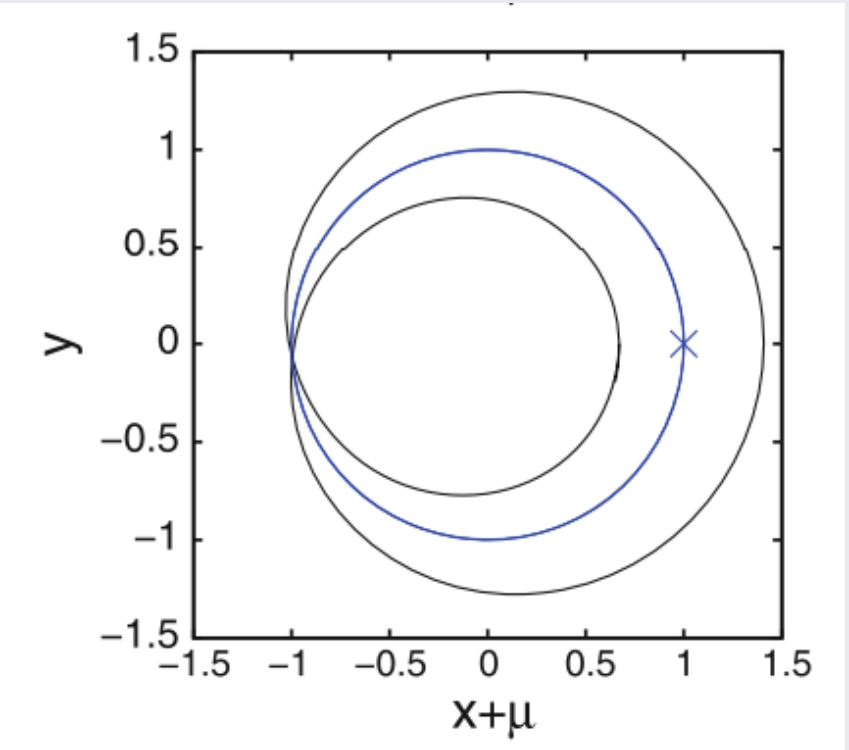
Bizarre worlds...

Coorbital retrograde

heliocentric motion



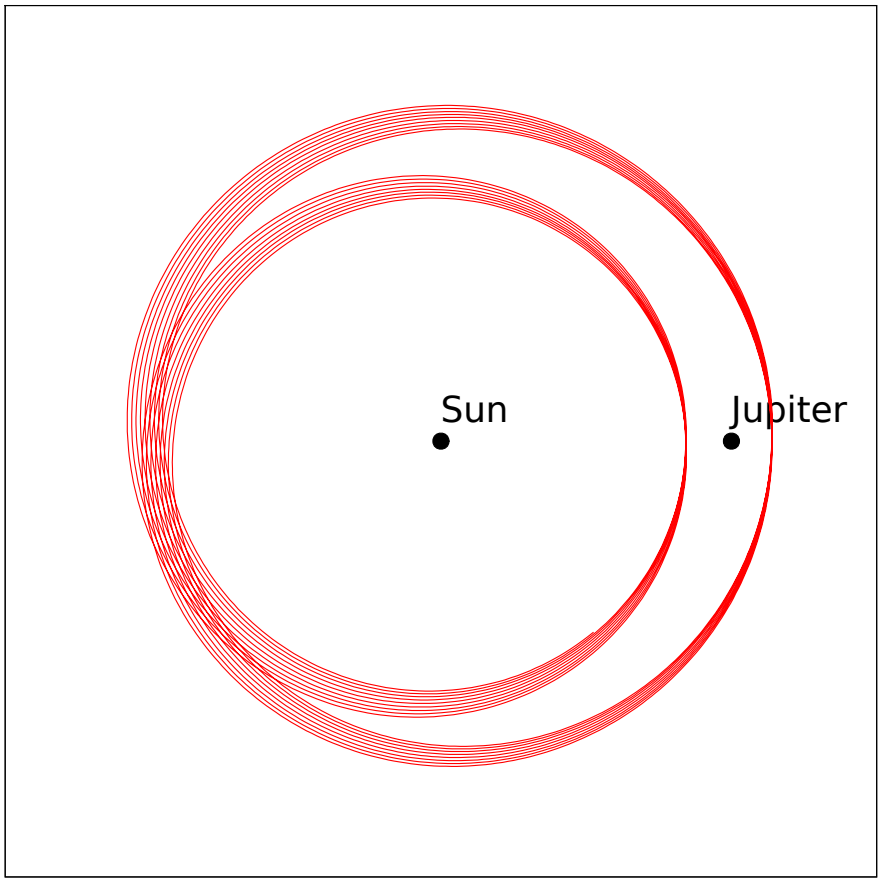
relative motion



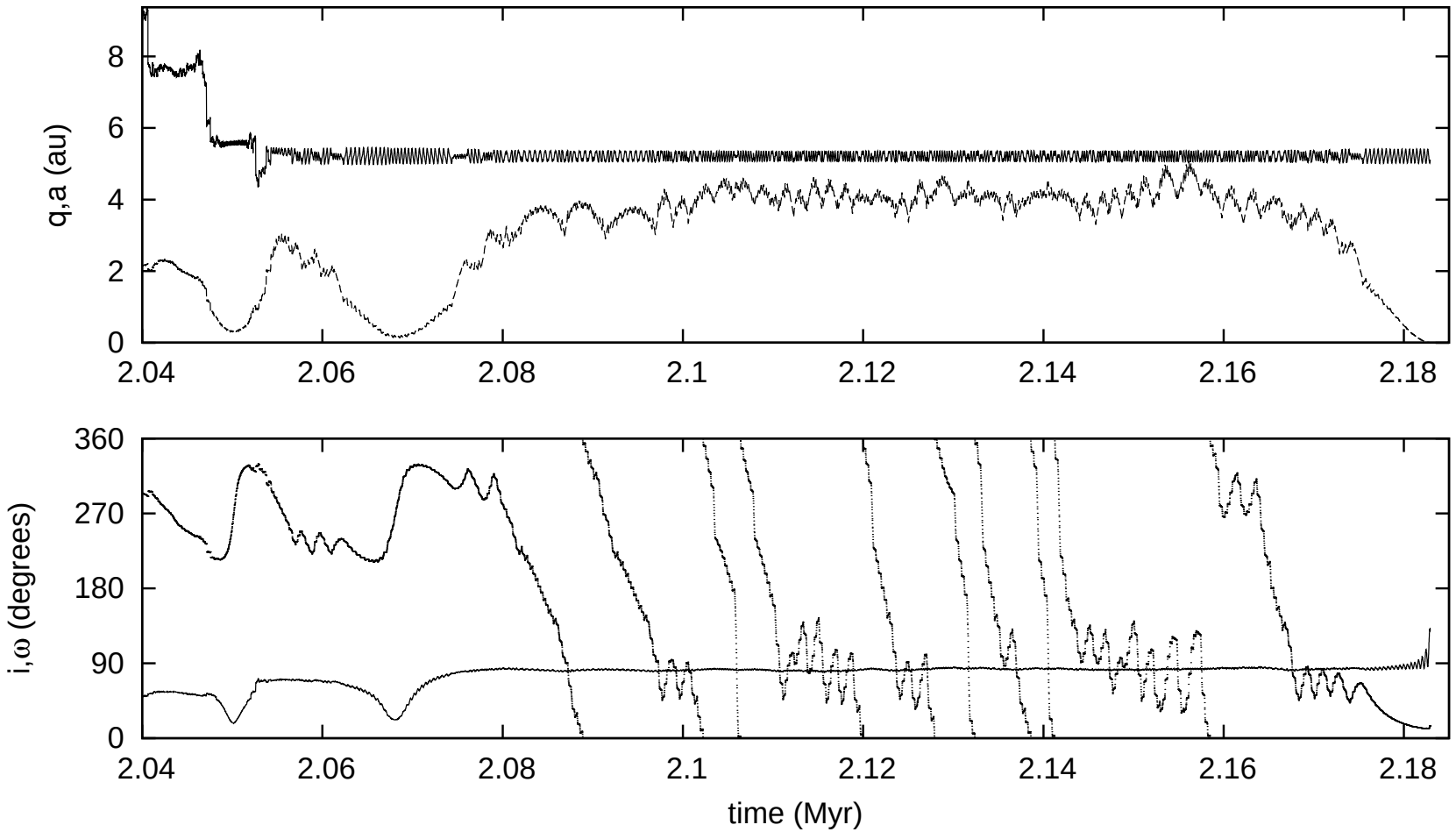
Morais and Namouni 2013

2015 BZ509: discovered in January 2015

$a = 5.12$ au, $e = 0.38$, $i = 163°$

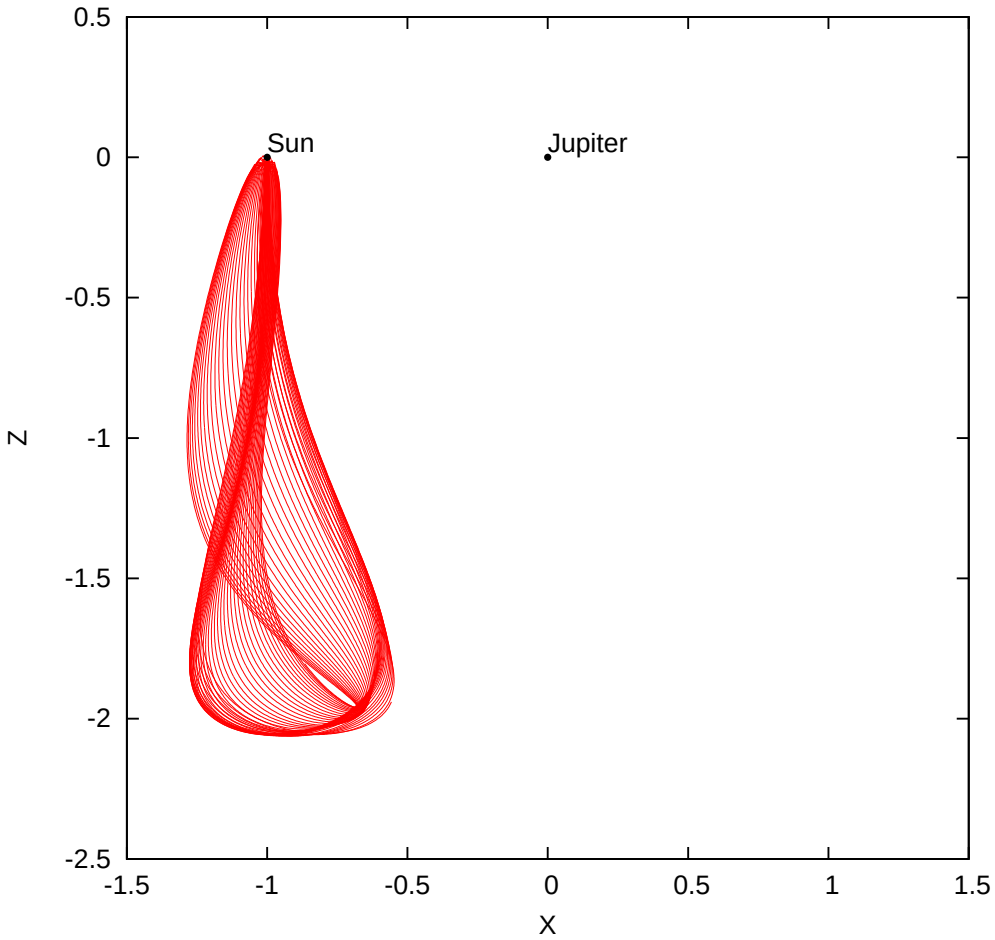


Bizarre extreme: fictitious particle in resonant polar orbit

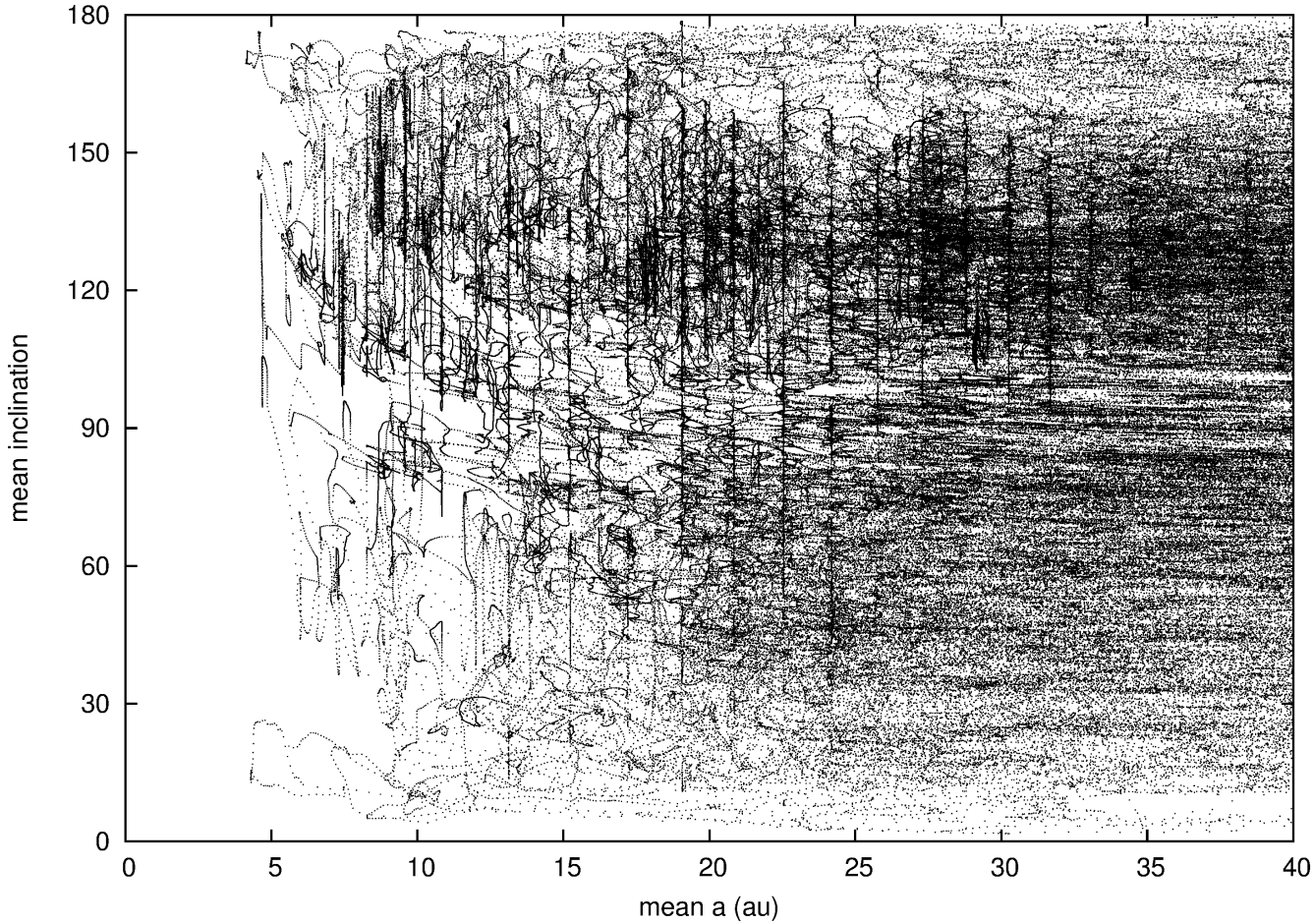


Bizarre extreme: fictitious particle in resonant polar orbit

collision with the Sun in the rotating frame

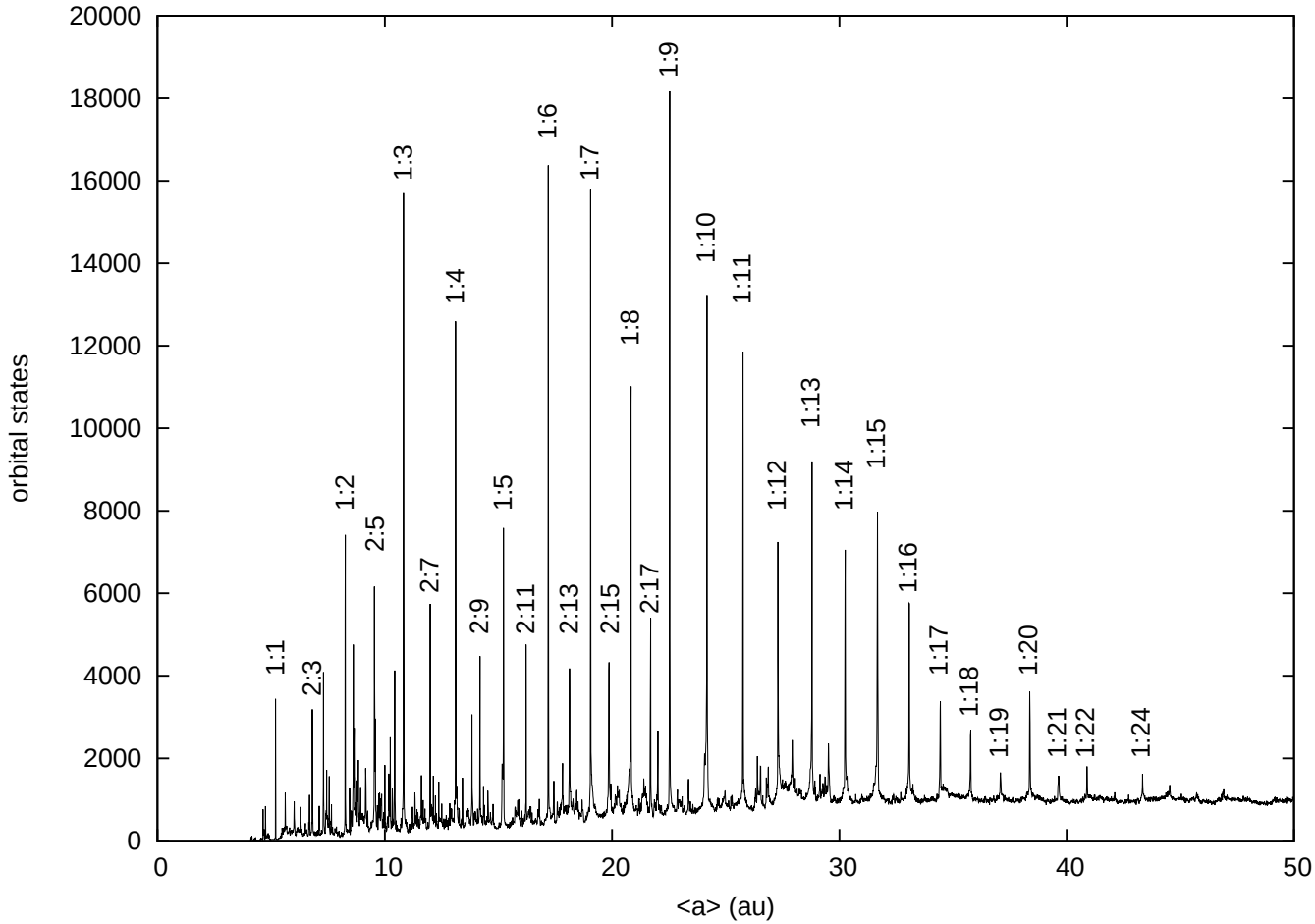


Resonances of Long Period Comets



Fernandez et al. 2016

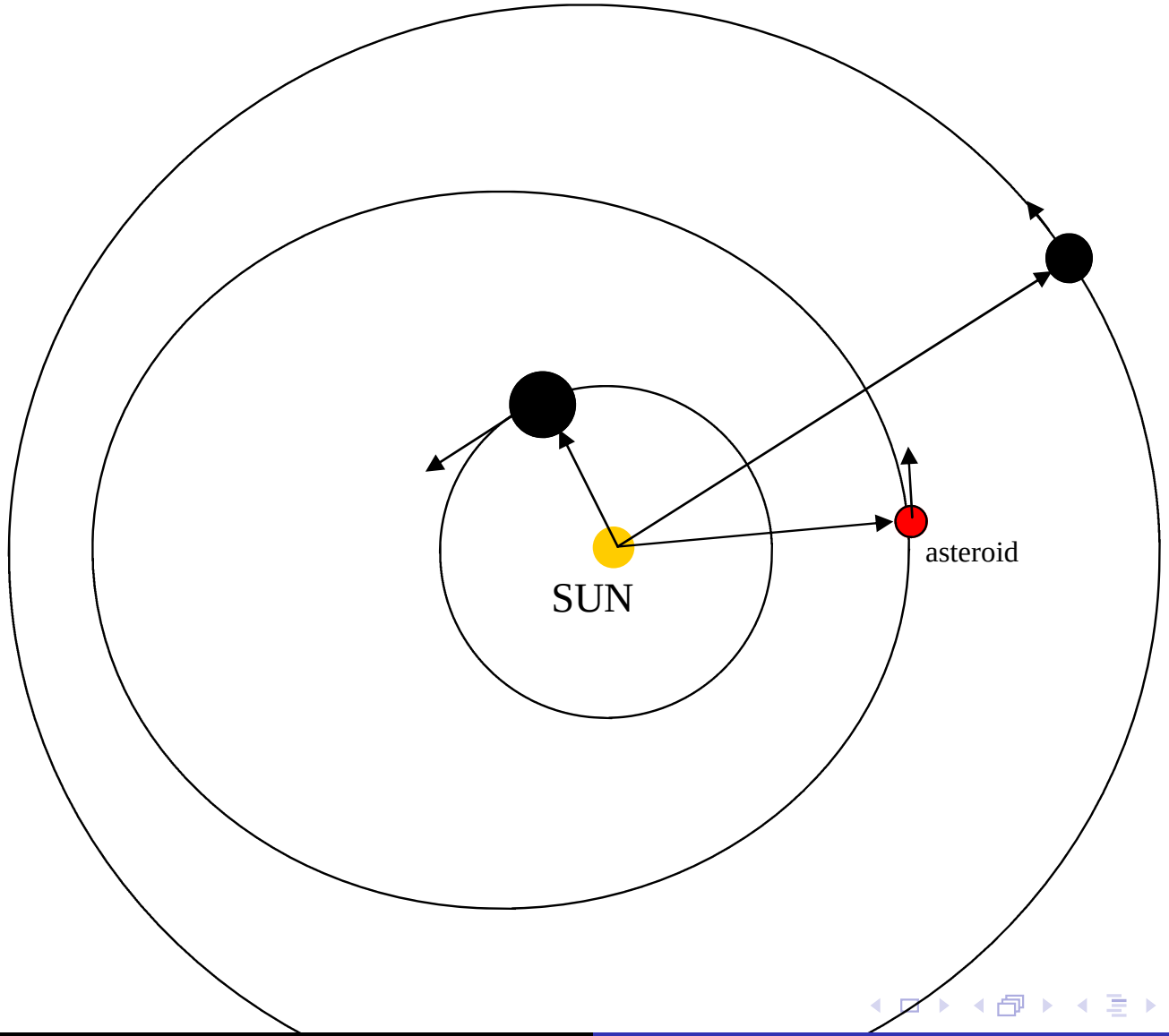
Resonances of Long Period Comets



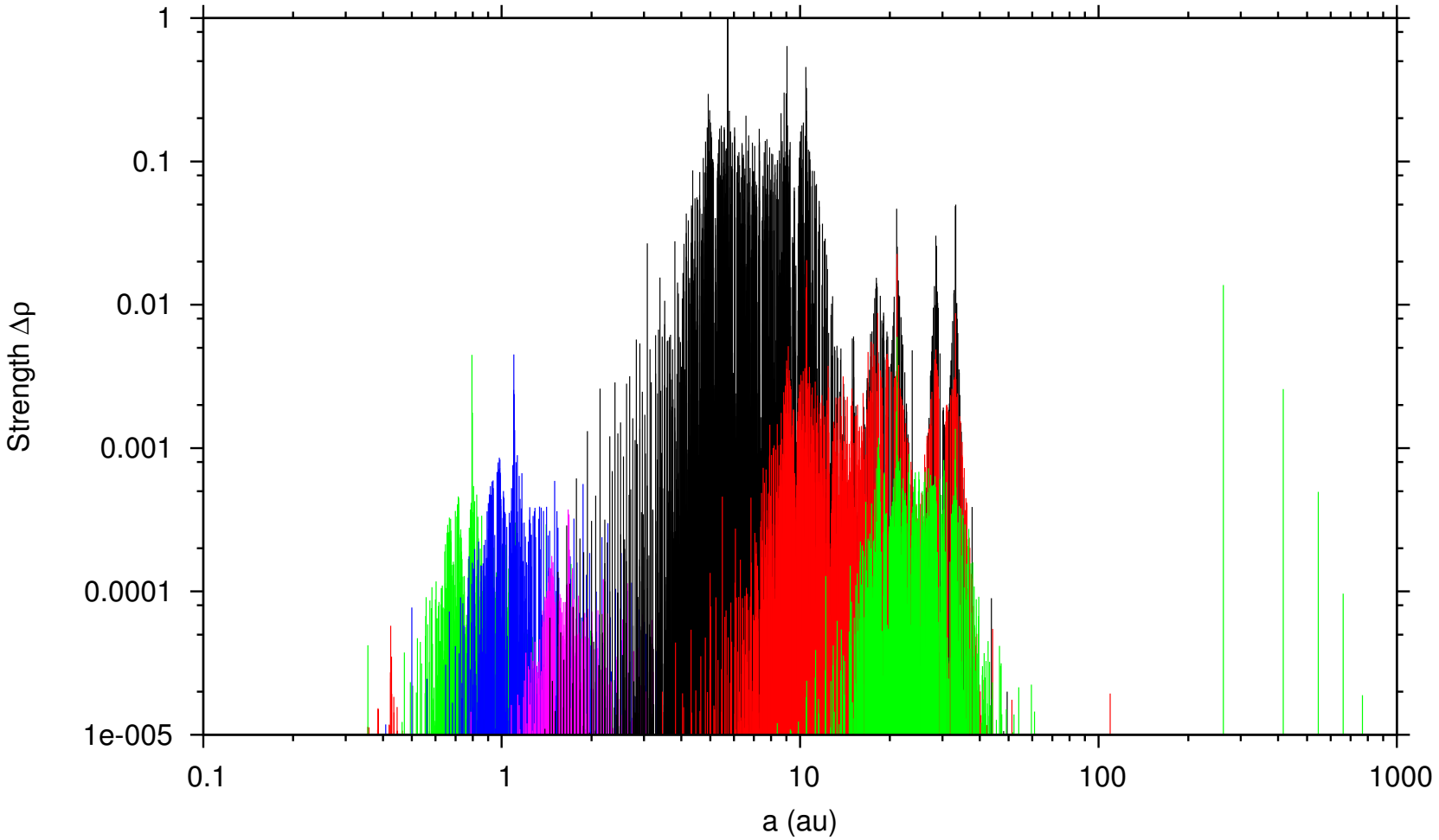
Fernandez et al. 2016

Three-body resonance

$k_0 n_0 + k_1 n_1 + k_2 n_2 \simeq 0$ only the asteroid feels the resonance

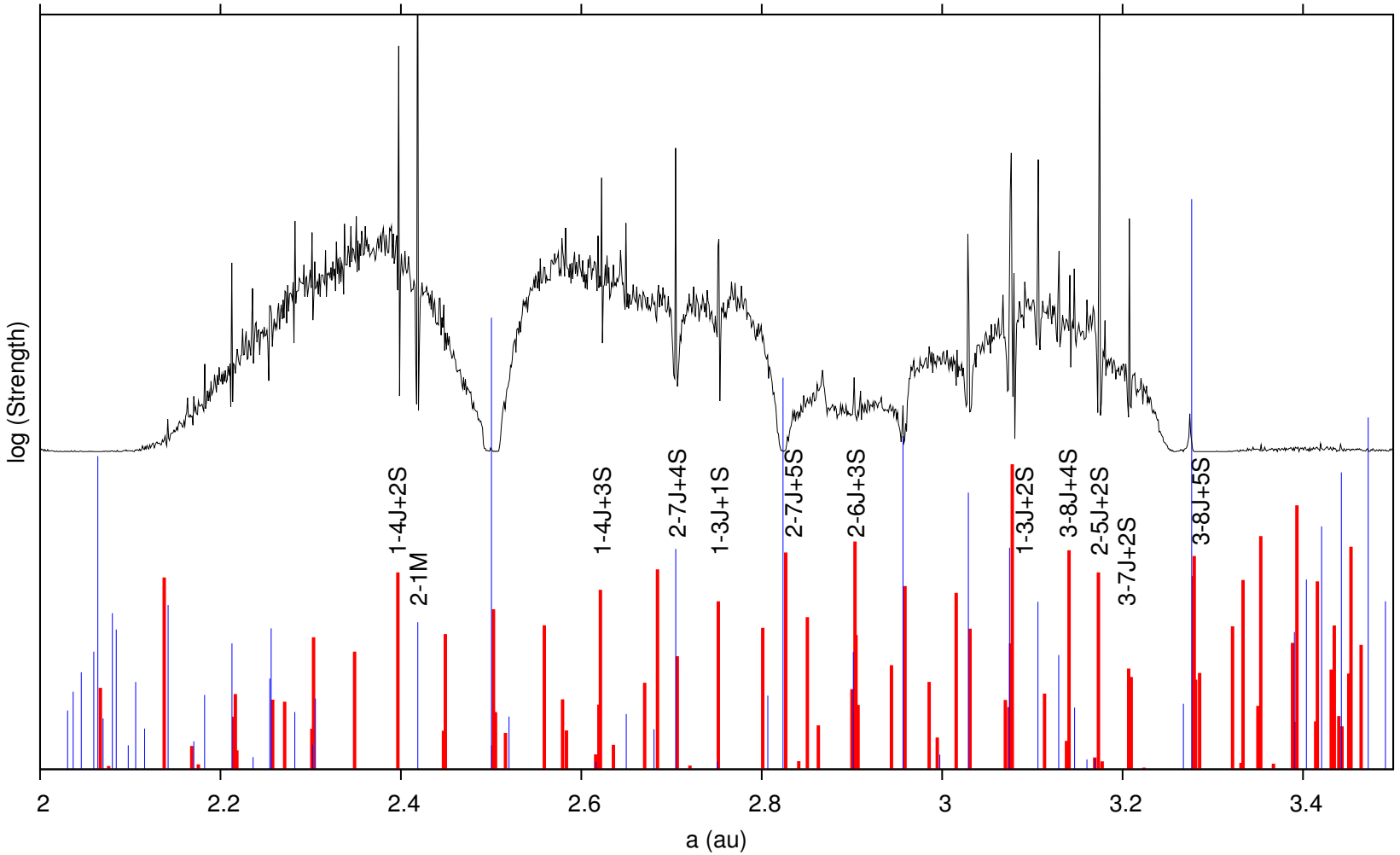


Atlas of TBRs: global view (for $e = 0.15$)



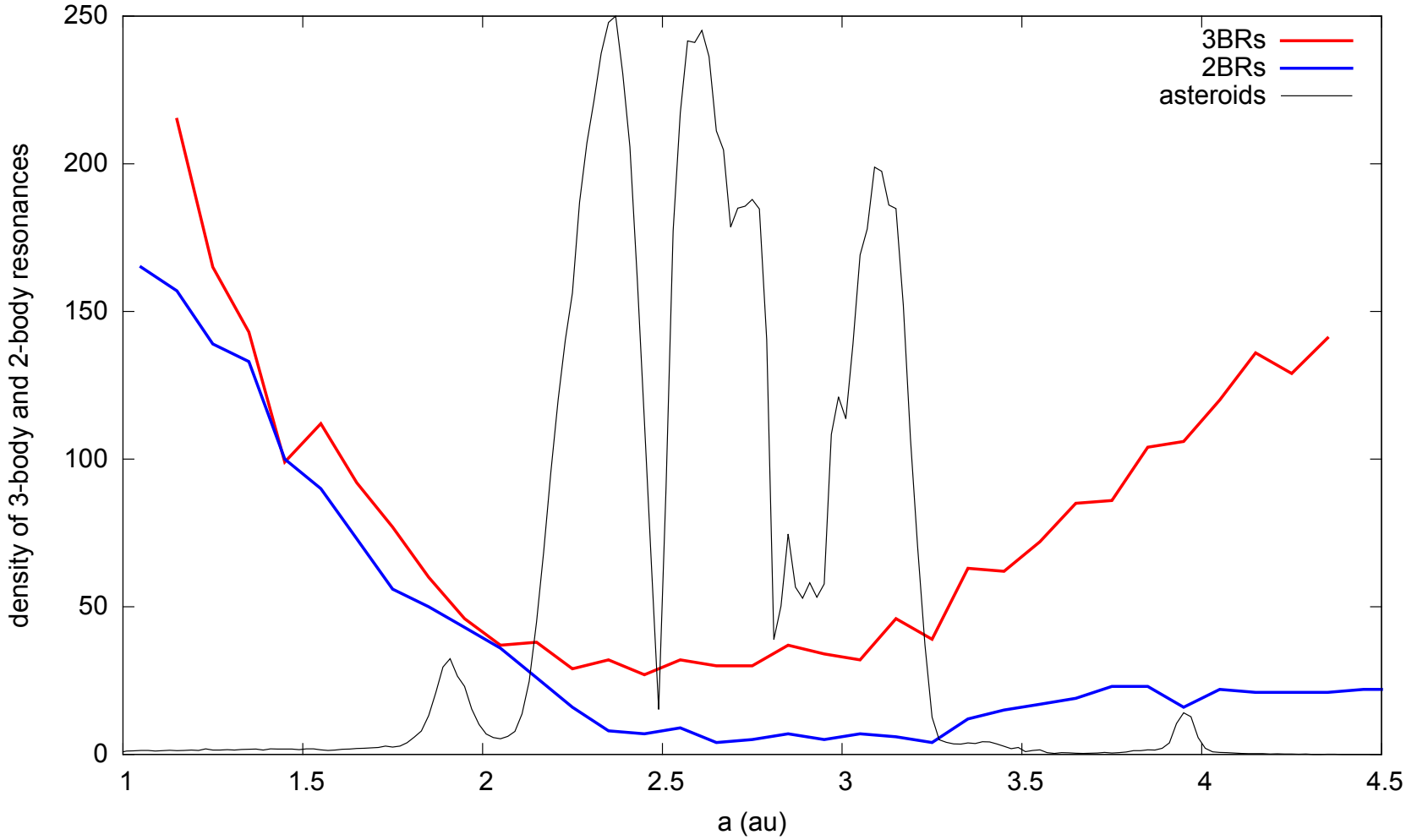
Gallardo 2014

Effects on the distribution of asteroids



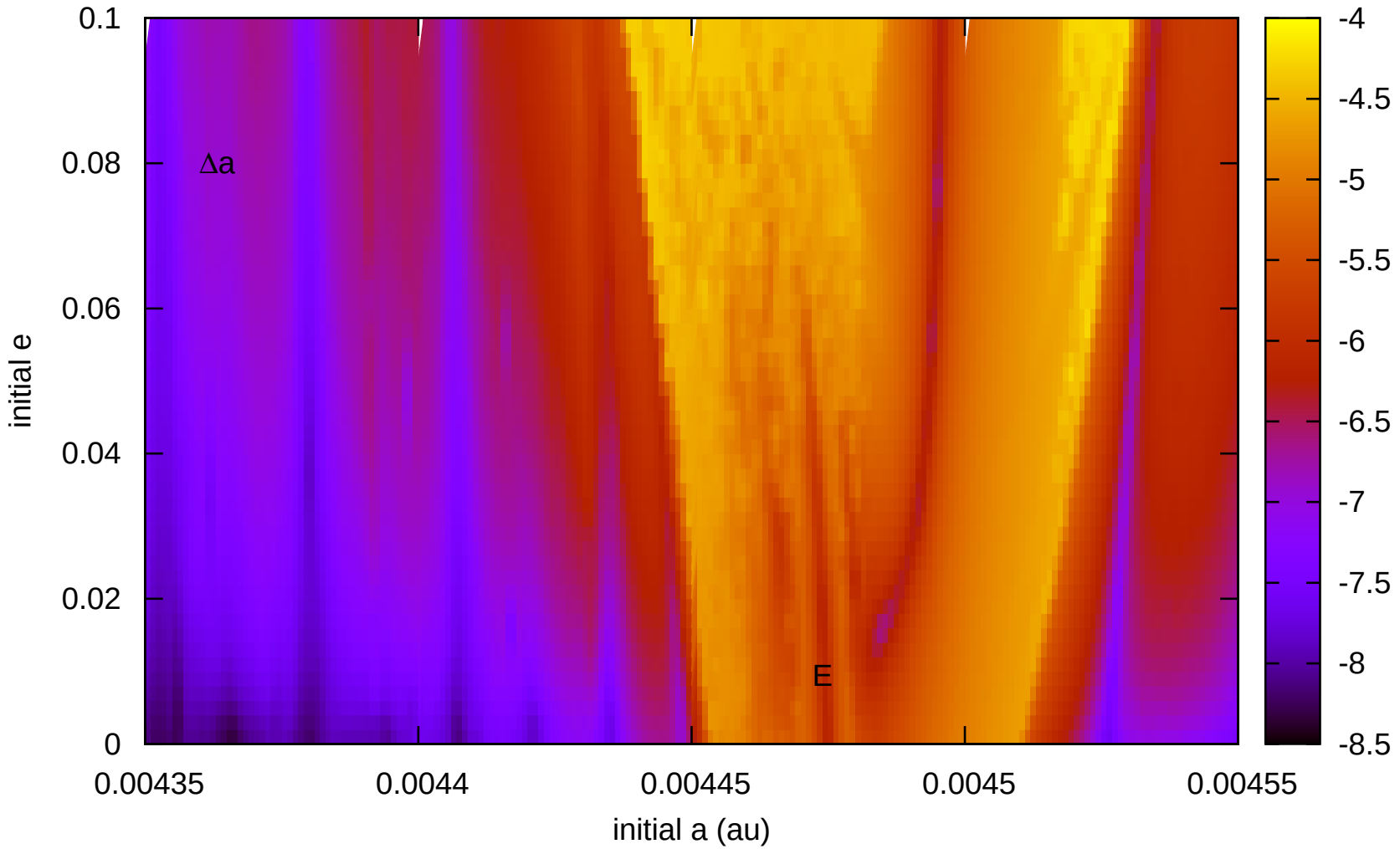
Gallardo 2014

Density of resonances versus density of asteroids



Galilean satellites

Europa: dynamical map



Gallardo 2016

Chronology

- 1772: Lagrange equilibrium points
- 1799: Lagrange planetary equations, stability of the SS
- 1784: Laplacian resonance $3\lambda_E - \lambda_I - 2\lambda_G \simeq 180°$
- Laplace quasi resonances: great inequality $2\lambda_{Jup} - 5\lambda_{Sat}$
- 1846: Neptune discovered
- 1866 Kirkwood gaps
- 1875: first resonant asteroid (153) Hilda 3:2
- 1882: secular resonances (Tisserand, ν_6)
- 1906: first Trojan asteroid (588) Achilles
- 1930: Pluto and exterior resonance 2:3 Neptune-Pluto
- 1962: Lidov-Kozai mechanism
- 1993: resonant TNOs (2:3 plutino)
- planetary systems in 2BRs and 3BRs
- minor bodies in 3BRs
- high inclination resonant orbits
- retrograde resonances

FACULTAD DE CIENCIAS
UDELAR | fcien.edu.uy

Bibliografía

- *Efectos dinámicos de las resonancias orbitales en el Sistema Solar.* Gallardo 2016, BAAA 58, 291.
- *Resonances in the asteroid and TNO belts: a brief review.* Gallardo 2018, Planetary and Space Science 157, 96.
- `http://www.fisica.edu.uy/~gallardo/atlas/`