Celestial Mechanics: from Asteroids to Extrasolar Planets

23.06.2010 :: Florian Freistetter :: OATS

Orbital Dynamics: Order and Chaos

- since Poincaré (1889) we know that the n-body problem (n>2) can not be solved analytically and can give chaotic solutions

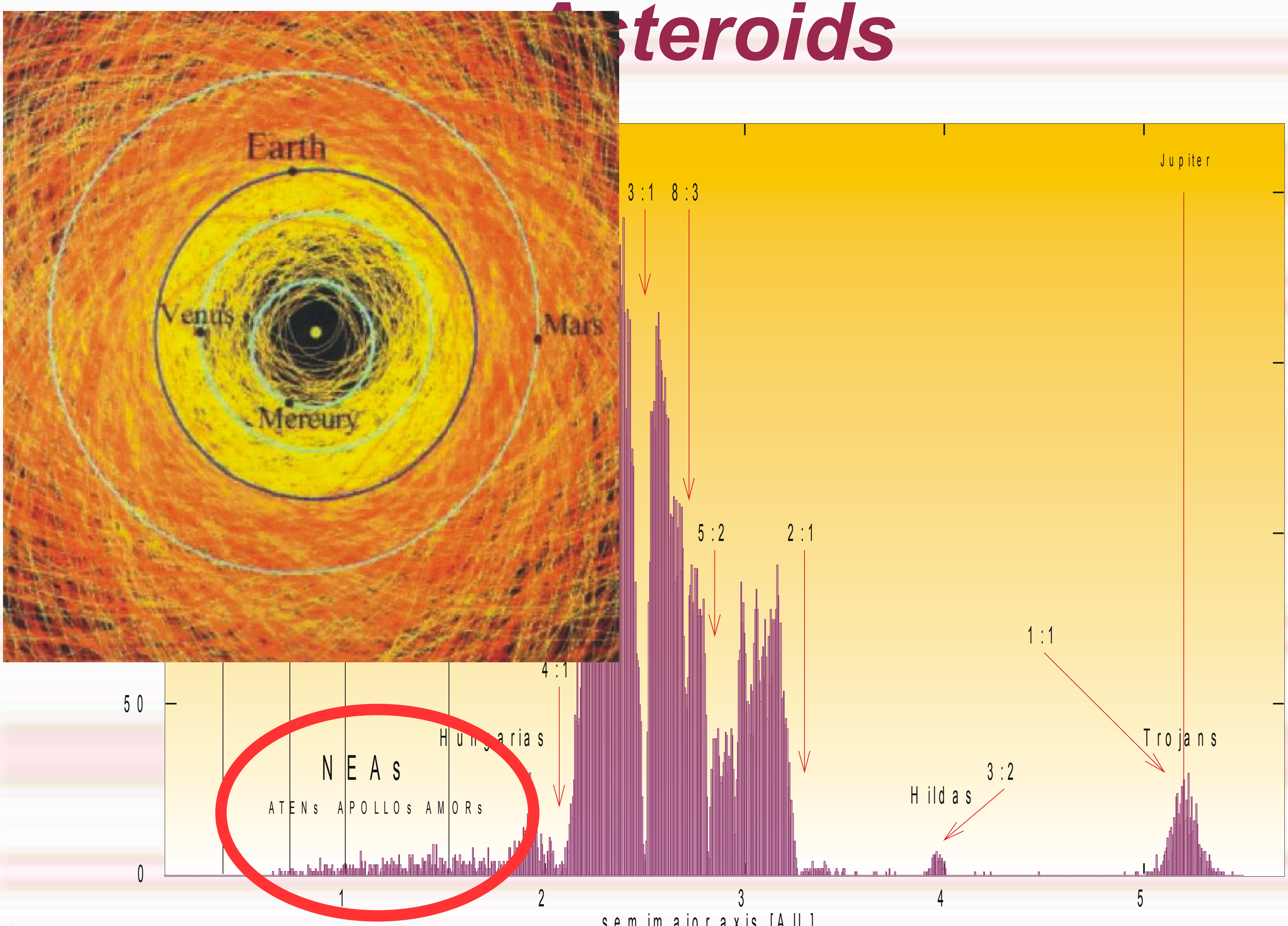
→Part I: Chaotic Orbits of Near Earth Asteroids

- during the last 15 years ~450 extrasolar systems were discovered – but it is still almost impossible to detect terrestrial planets

→Part II: Stability of potential terrestrial planets in extrasolar systems

→Part III: Planets and Asteroids in the disk of Beta Pictoris

Asteroids

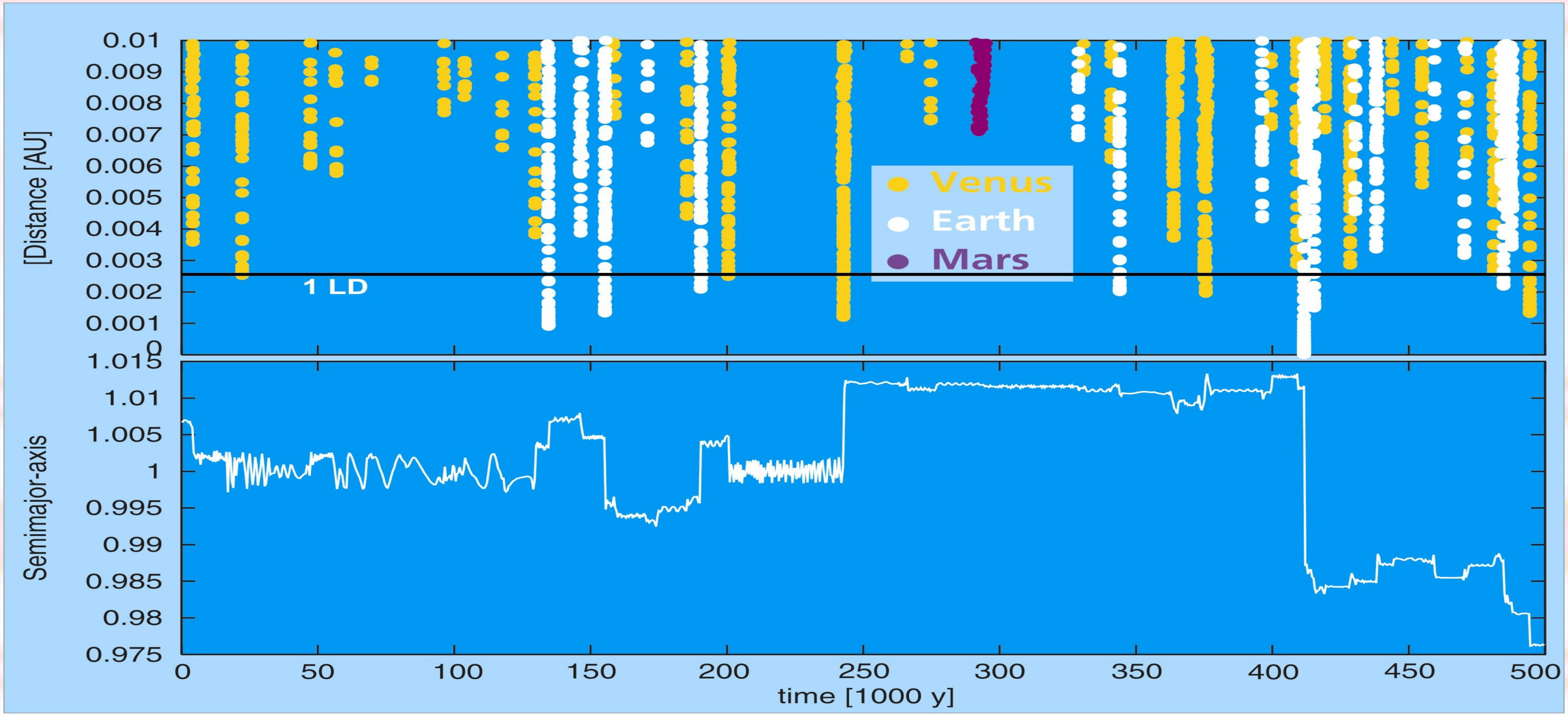


Earth
Venus
Mars
Mercury
Jupiter
3:1
8:3
5:2
2:1
4:1
1:1
3:2
Hungarias
NEAs
ATENs APOLLOs AMORs
Hildas
Trojans
50
0
1
2
3
4
5
semimajor axis [AU]

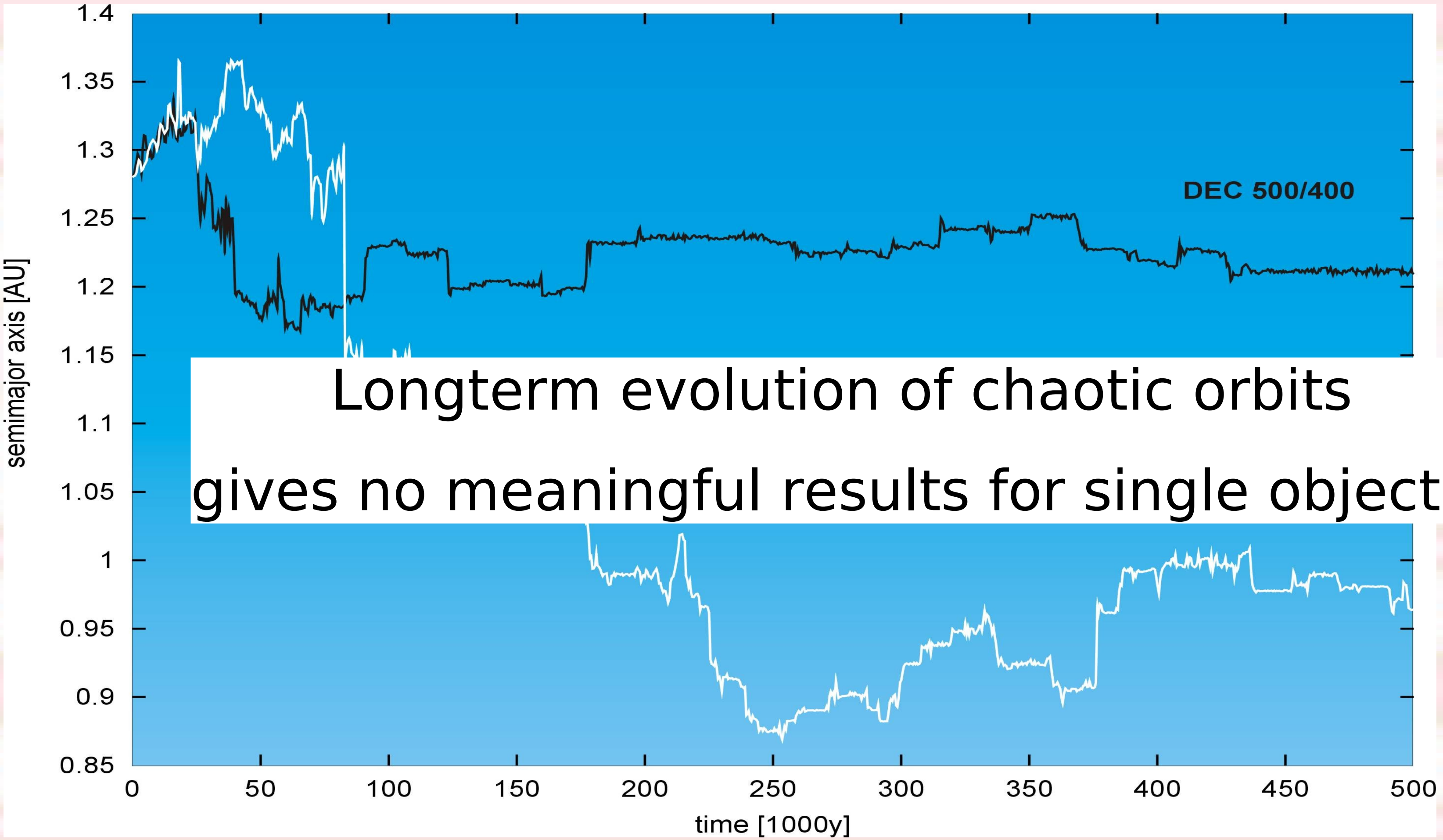
Chaotic Motion of NEAs

- Close encounters -> Chaos!

10563 Izdhubar



Chaotic Motion of NEAs



Longterm evolution of chaotic orbits

gives no meaningful results for single objects !

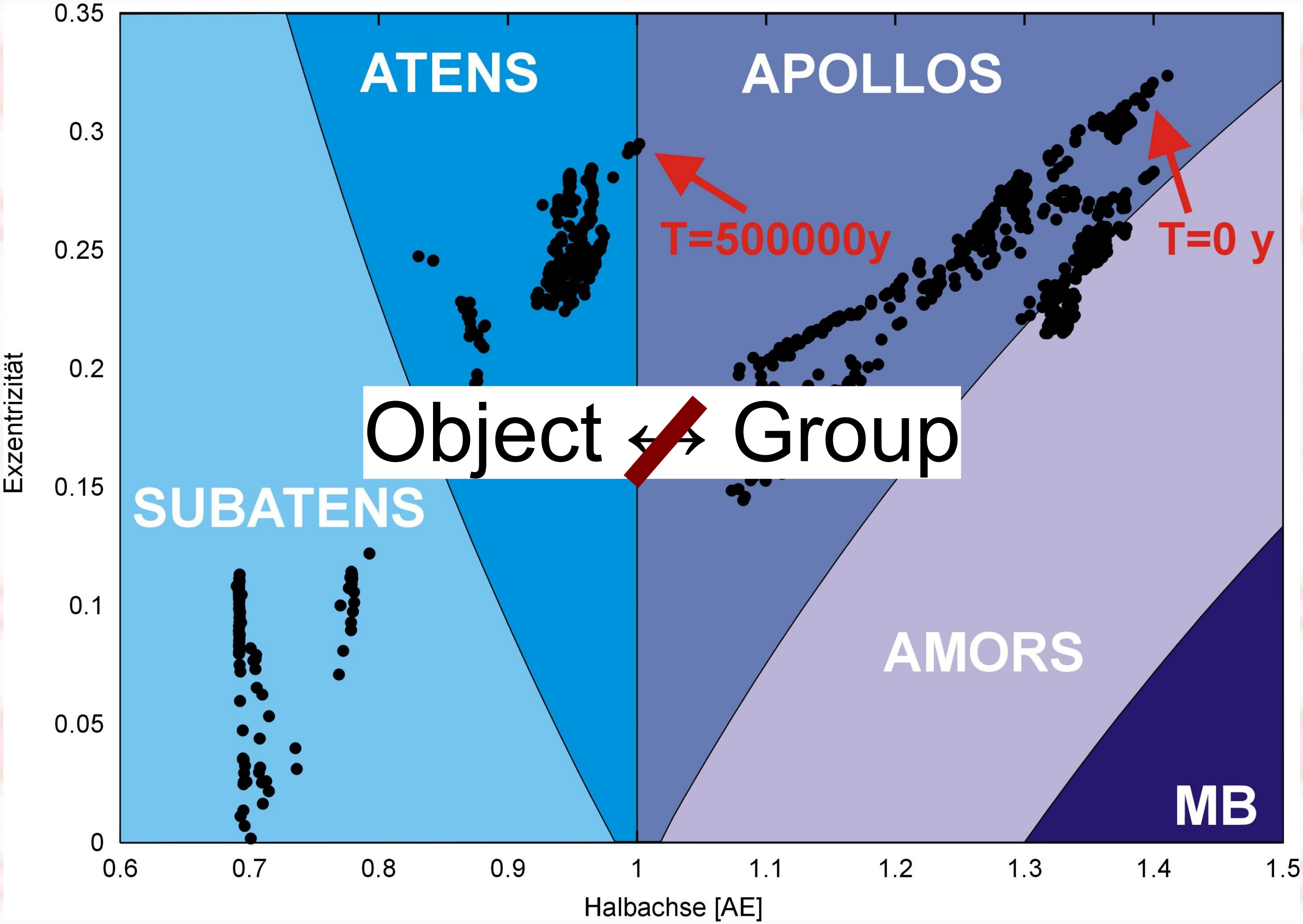
NEA Groups

- 2 important classifications:
- Shoemaker et al. (1973):
  - Aten :: Apollo :: Amor
  - a, e (crossing behaviour)
- Milani et al (1989)
  - 7 classes
  - Dynamical behaviour (encounters, etc)
- How does Chaos effect the groups?

Mixing!

- Chaos + Long Timescales = Problems!

Mixing

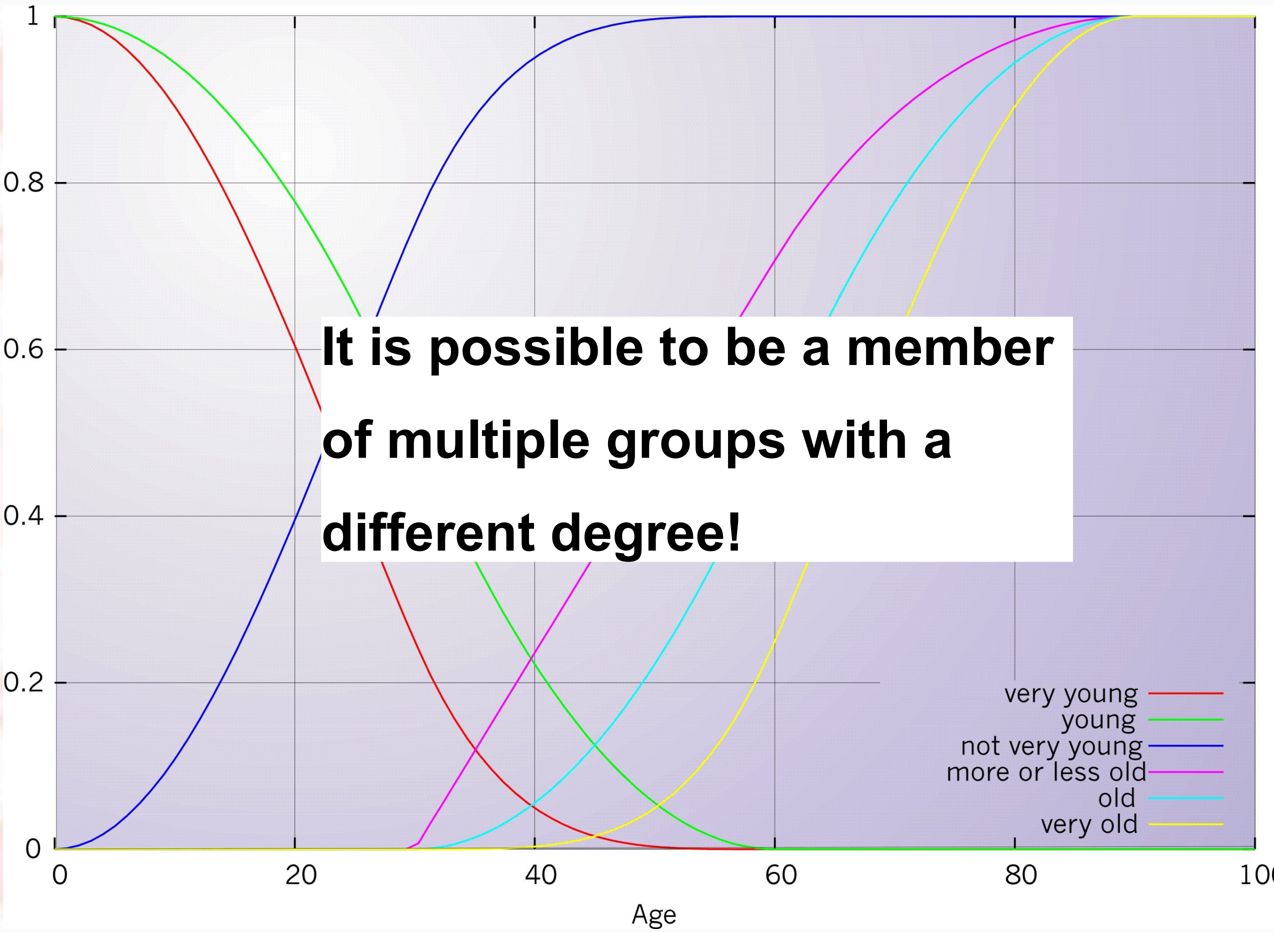


ATENS
APOLLOS
SUBATENS
AMORS
MB
T=500000y
T=0 y
Object ↔ Group
Exzentrizität
Halbachse [AE]
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5

Mixing

- How much time does a NEA spend in its initial group?
  - **69.86 %** (Shoemaker et al. classification) *(Dvorak & Freistetter 2001, Freistetter 2009)*
  - **65.72 %** (Milani et al. classification) *(Dvorak & Freistetter 2001, Freistetter 2009)*
- Need a new way of classification: Fuzzy Logic!

Fuzzy Logic



It is possible to be a member of multiple groups with a different degree!

<u>Age: 32 years</u>

- very young: 25%
- young: 50%
- not very young: 75%
- more or less old: 2%
- old: 0%
- very old: 0%

Fuzzy Classification

Name	a	e	i	G1	G2	G3	G4
2000GD2	0.757928	0.4765	32.14639	1	0.7585	0.9407	0
2000HB24	0.815912	0.4302	2.669175	1	0.9852	0.9895	0
2000HO40	0.743917	0.5241	5.981537	1	0.9951	1	0
2000LG6	0.916167	0.1121	2.829914	0.0164	0	0.9973	0
2000NL10	0.914292	0.8171	32.51204	1	0.3271	0.436	0.0147
2000OK8	0.984809	0.2211	9.985352	0.7272	0	0.9299	0.6993
2000PH5	1.000608	0.2301	1.71175	0.1708	0.9962	0.9792	0
2000PJ5	0.8727	0.3736	51.18267	1	0.9742	0	0
2000QP	0.847462	0.4631	34.7466	0.9008	0.9559	0	0
2000RH60	0.825892	0.5513	19.64366	1	0.9403	0.9191	0
2000RN77	0.951245	0.3184	16.0945	0.8264	0.9503	0.7779	0.7791
2000SG344	0.977357	0.0669	0.109731	0.0113	0.9929	0.9972	0
2000SP43	0.811372	0.4669	10.35569	1	0.9558	0.9378	0
2000SY2	0.858743	0.6426	19.23634	1	0.7415	0.7198	0.8302
2000SZ162	0.929366	0.1674	0.896554	0.2561	0.0126	0.9818	0.7287
2000UH11	0.870267	0.4223	32.21665	1	0.7179	0.6956	0
2000UK11	0.884688	0.2482	0.776174	0.9256	0.4127	0.9816	0.4049
2000UR16	0.903661	0.4387	11.74411	1	0.9341	0.8863	0
2000WC1	0.879512	0.2626	17.40797	0.8512	0.9356	0.8146	0
2000WO107	0.911347	0.7806	7.784174	1	0.9192	0.91	0.9963
2000WP19	0.854492	0.2886	7.678904	0.6033	0.9773	0.9227	0
2000YS134	0.85736	0.2242	3.500566	0.8264	0.9981	0.7895	0
2001AF2	0.953982	0.5953	17.8175	0.0692	0.7104	0.6852	0.8186
2001BA16	0.940225	0.1374	5.768623	0.3057	0.9977	0.9806	0
2001BB16	0.854463	0.1723	2.026138	0.6033	0.9919	0.9797	0
2001BE10	0.823508	0.369	17.50827	1	0.9358	0.9119	0
2001CK32	0.725401	0.3826	8.137319	0.3553	0.9747	0.7198	0
2001CP36	0.714308	0.4077	10.53547	0.4545	0.9642	0.955	0

- Comparison with Milanis Classification

http://www.celestialmechanics.eu/neas/

Fuzzy Classification

• compare the classification data with the Spaceguard classes

Geographos group

• many close approaches with Earth

• some close approaches with Venus

Oljato group

• chaotic orbits

• large eccentricities

ets

Fuzzy Classification works!

(1620) Geographos:

• G1 (no mixing): 1

• G2 (Venus): 0.03

• G3 (Earth): 0.76

(2201) Oljato:

• G1 (no mixing): 0.04

• G2 (Venus): 0.38

• G3 (Earth): 0.36

• G4 (Mars): 0.28

Extrasolar Planets

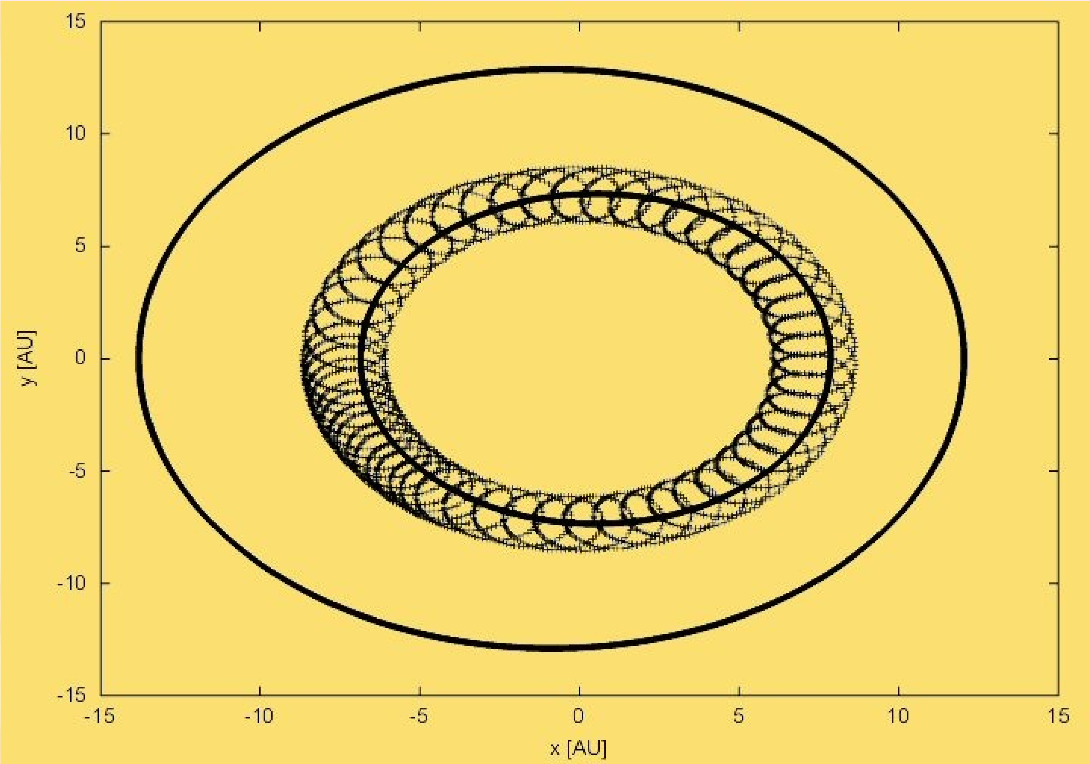
- Observation of terrestrial planets?
- -> Theoretic simulations
- Stability in the habitable Zone

HD 41004 A

Star 1
M_{star1} = 0.7 M_{Sun}

Star 2
m = 0.4 M_{Sun}
a = 21 AU
e = 0.1

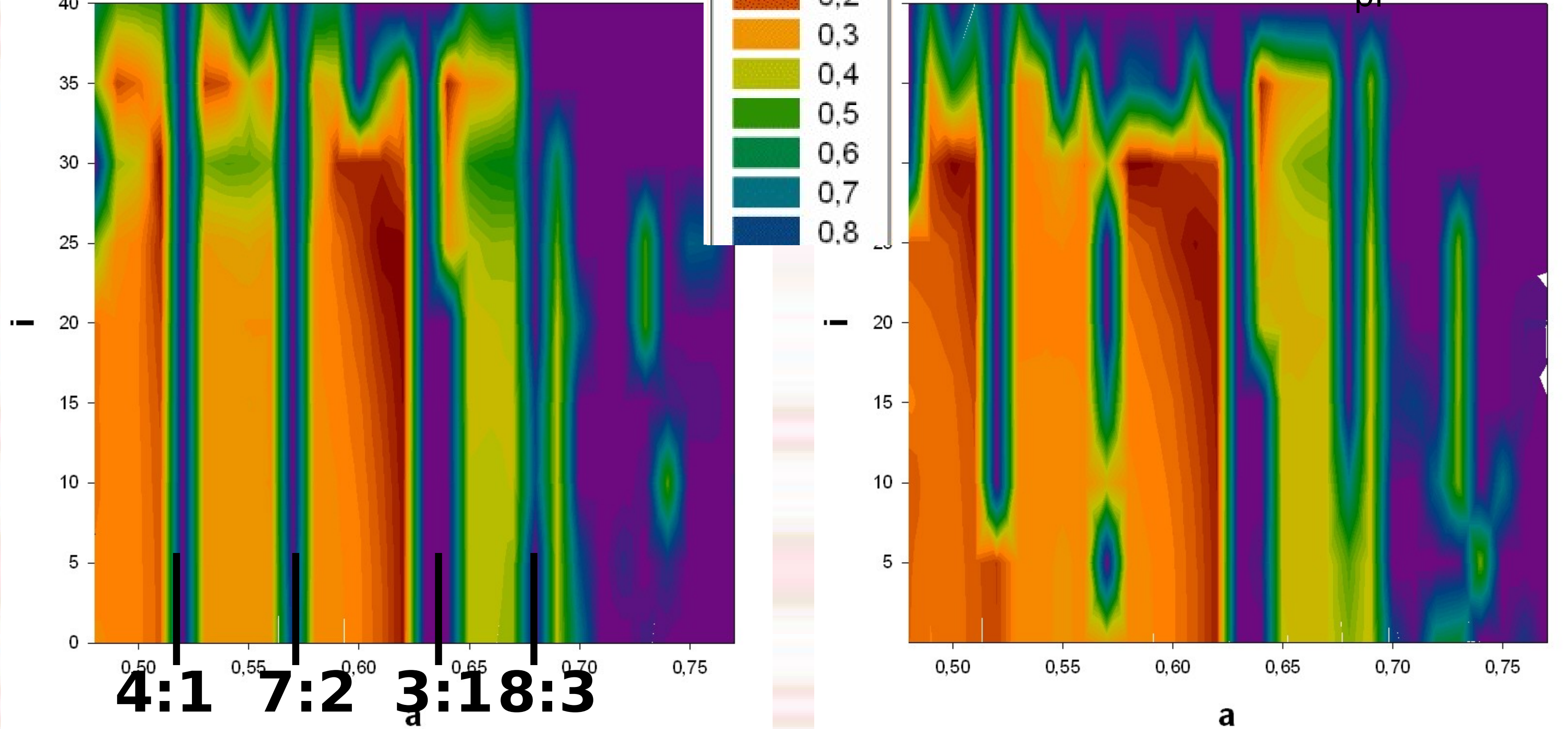
Planet
m sin i = 2.3 M_{jup}
a = 1.31 AU
e = 0.39 $\pm$ 0.17
$\omega \approx$ 114°



Influence of the companion

$e_{bin}=0.1$ $e_{pl}=0.22$

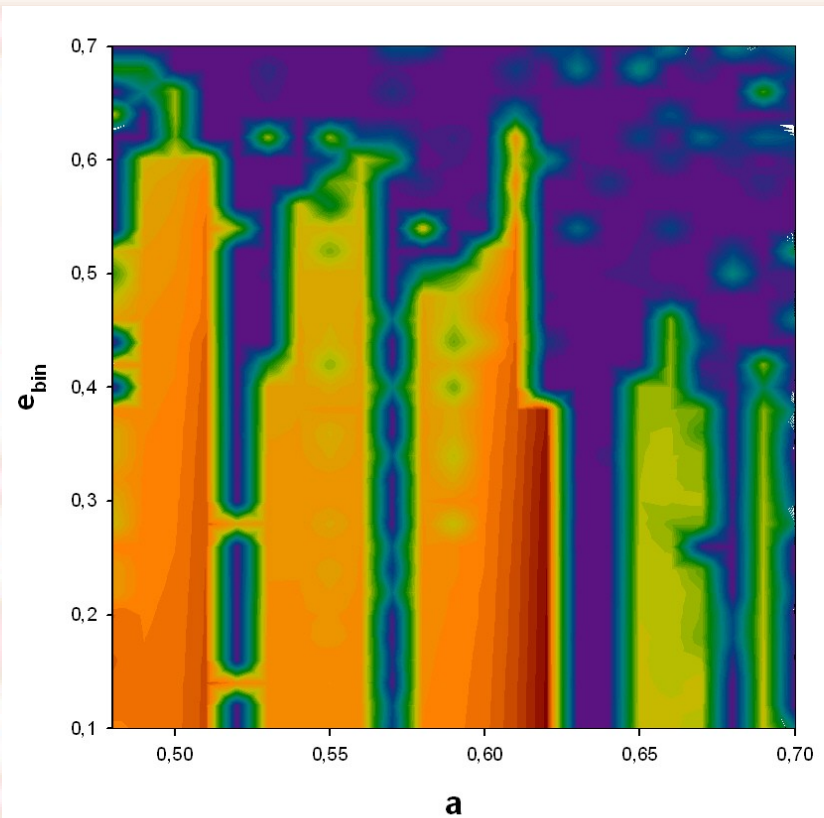
no secondary $e_{pl}=0.22$



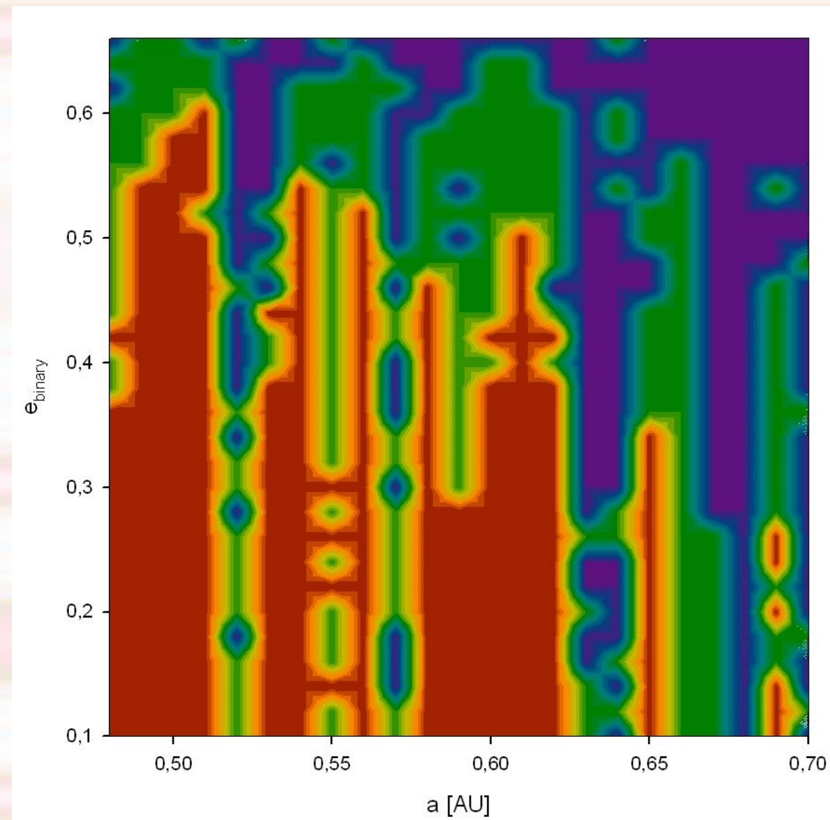
Different Methods

e_{pl}=0.22

MEM

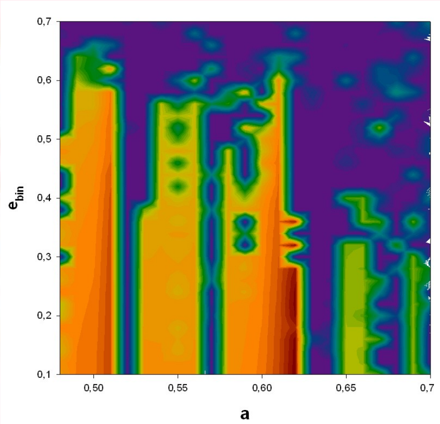


FLI

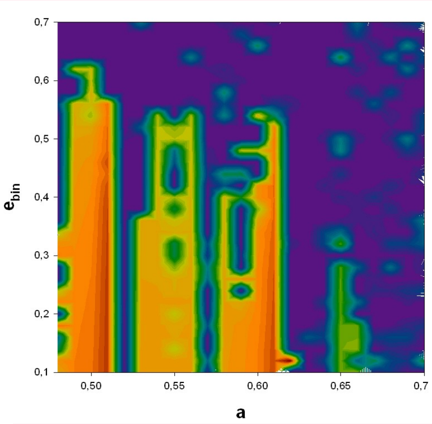


Importance of observations

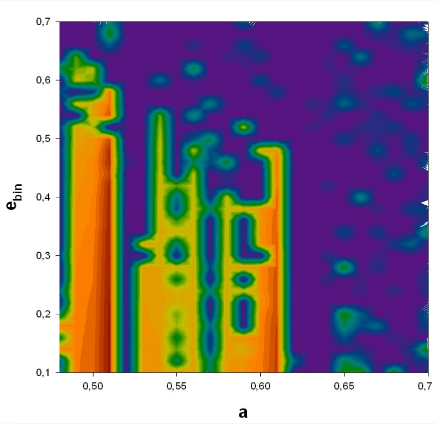
e_{pl}=0.24



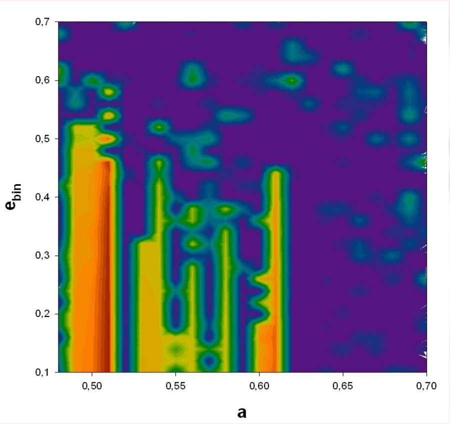
e_{pl}=0.26



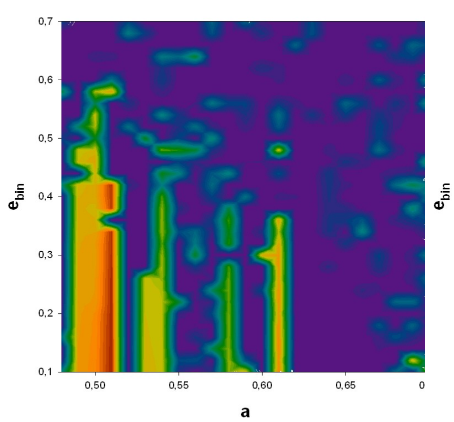
e_{pl}=0.28



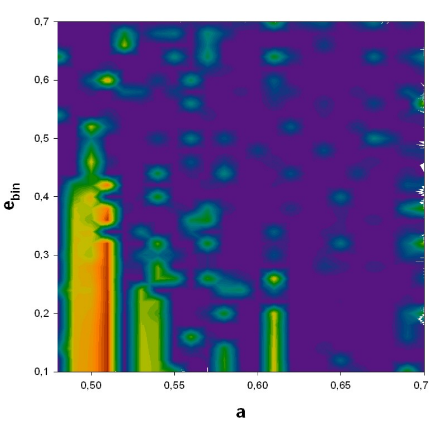
e_{pl}=0.30



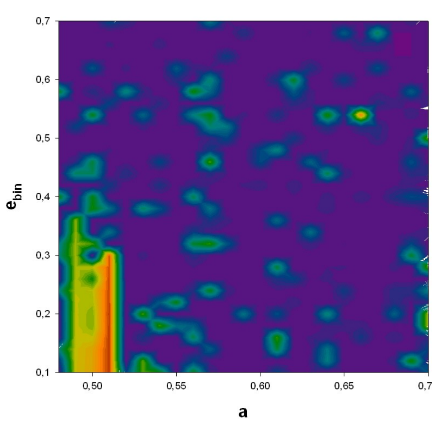
e_{pl}=0.32



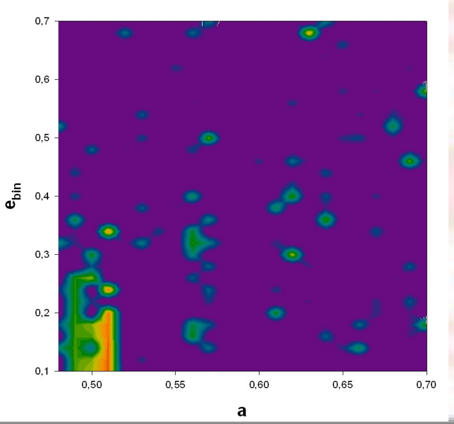
e_{pl}=0.34



e_{pl}=0.36

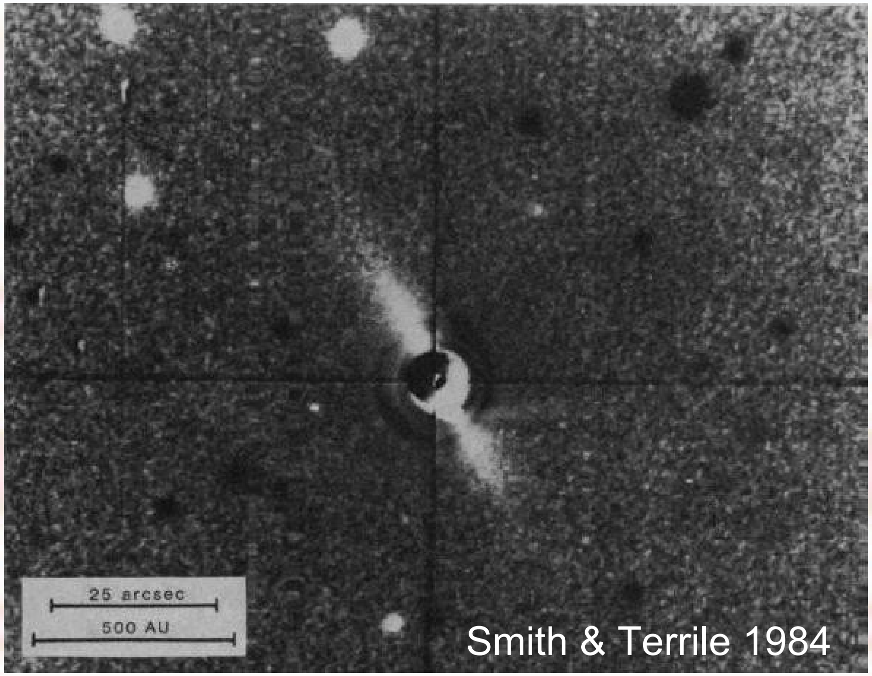


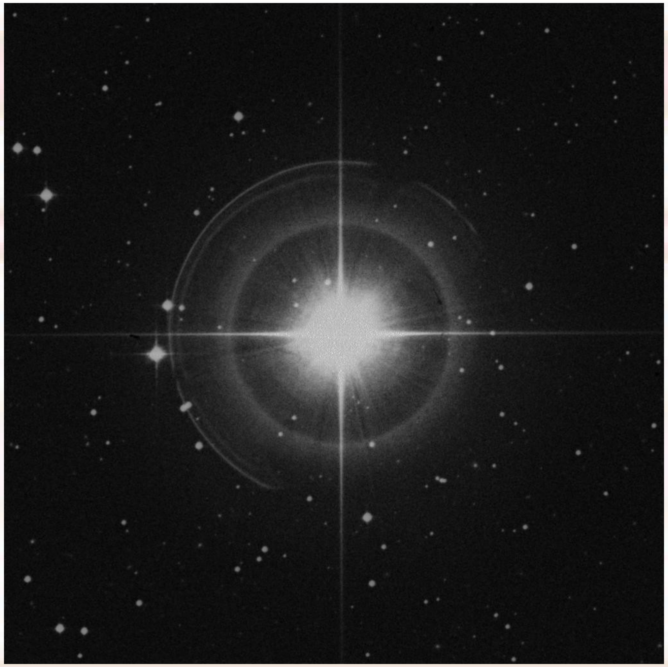
e_{pl}=0.38



b Pictoris

- spectral type: A5 V star
- age: ~20 Myrs
- mass: 1.75 M_{SUN}
- 1984: debris disk!

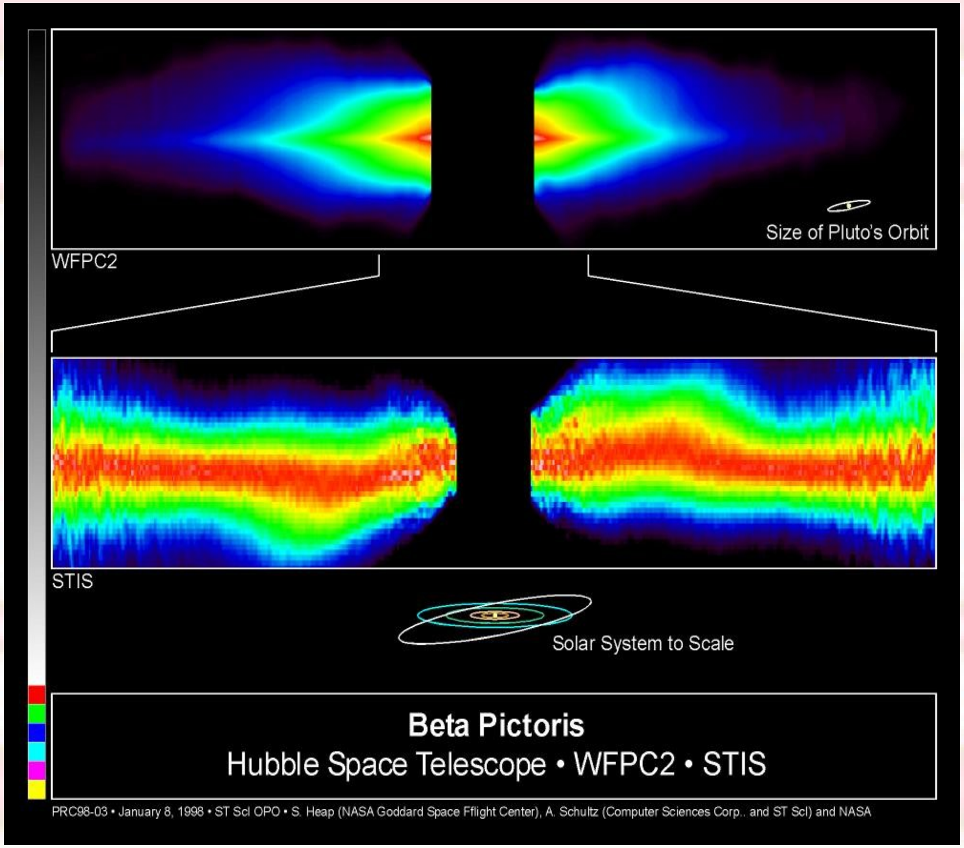




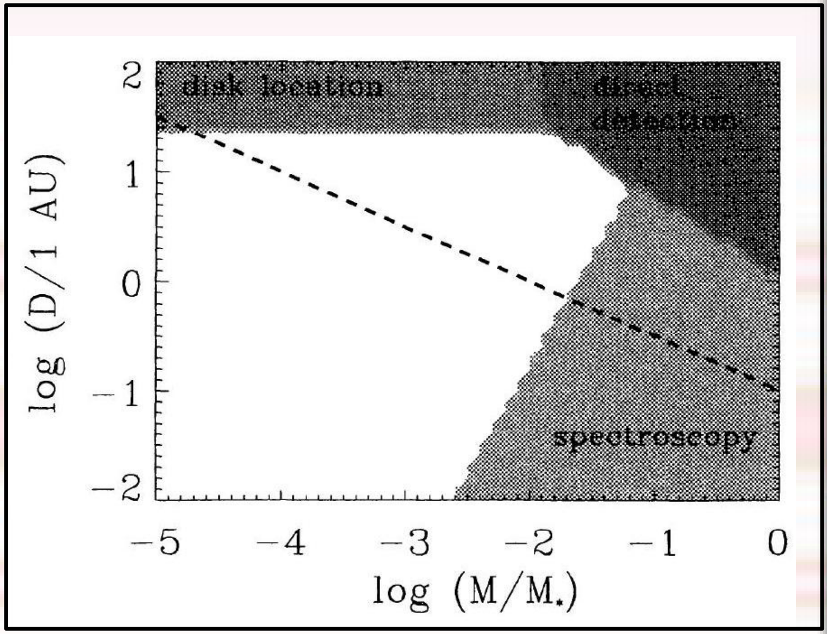
- first debris disk
- some 100 articles

The disk of b Pictoris

- many interesting structures:

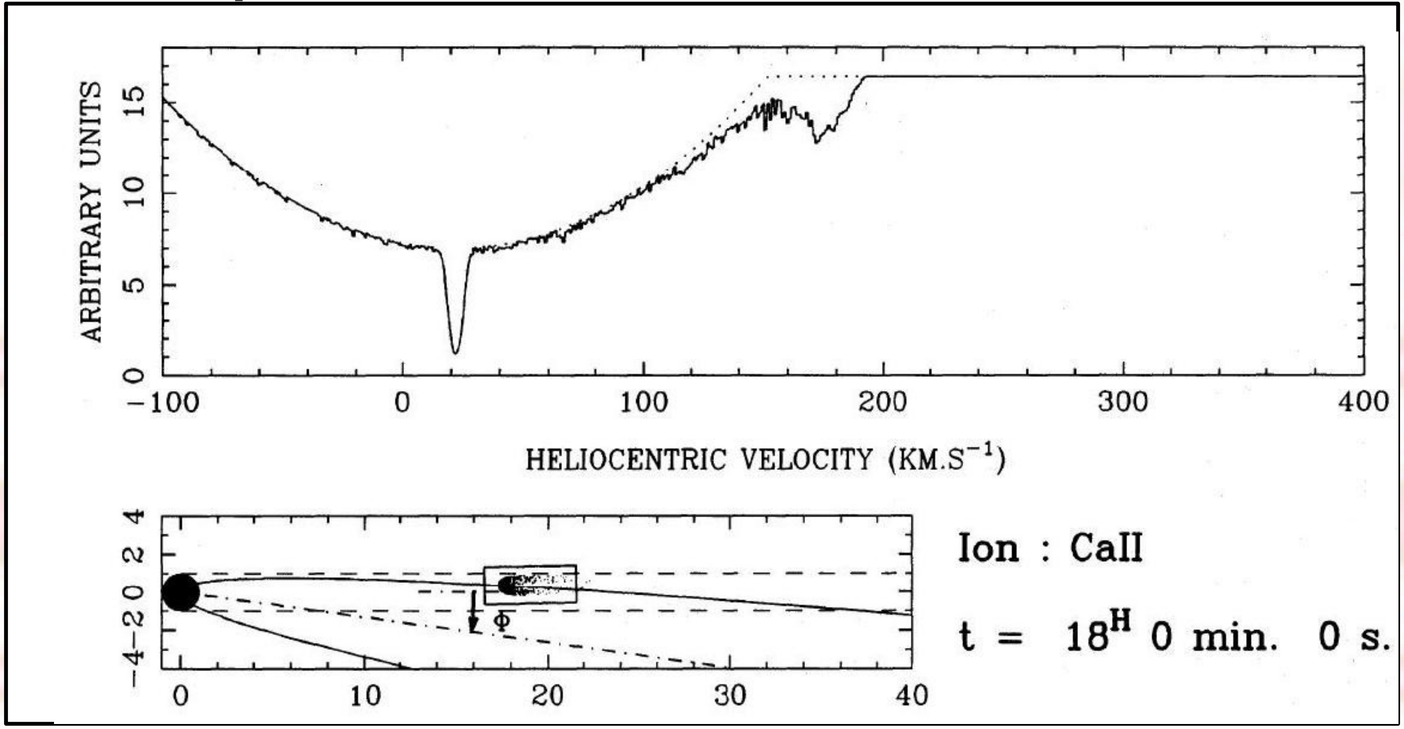


- warp:
- → inclined planet?
- Mouillet et al.:



The disk of b Pictoris

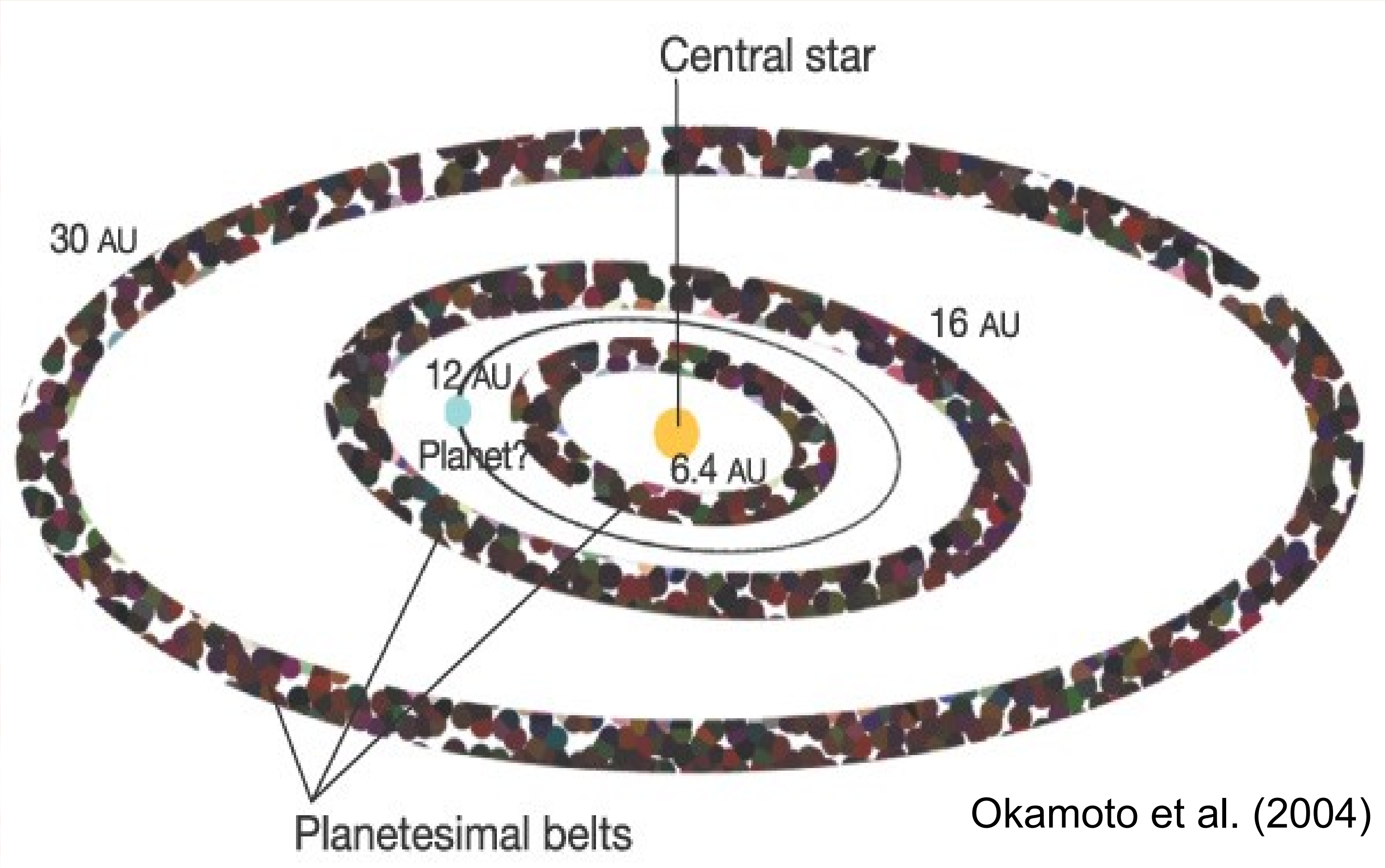
- "Falling Evaporating Bodies (FEBs)":
- variations in spectral lines
- → small bodies fall onto the star
- → planet has to disturb these bodies



Beust et al. 1990

The disk of b Pictoris

- clumps in the disk



Okamoto et al. (2004)

Belt structures in the b Pic-disk

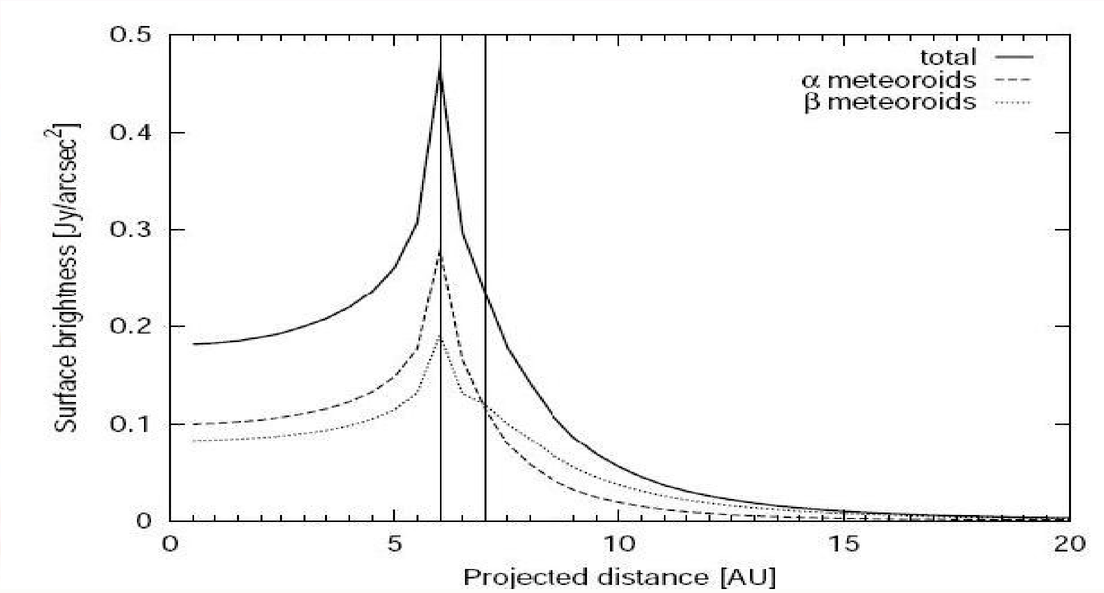
- A: ~6.4 AU [2]
- B: ~16 AU [1,2,4]
- C: ~32 AU [1,2,4]
- D: ~52 AU [1,3,4]
- structures in the outer disk

> - Can these clumps be caused by planetesimal belts?
> - What planets are needed to confine such belts?

[1] Wahhaj et al 2003 [2] Okamoto et al. 2004
[3] Telesco et al. 2005 [4] Golimowski et al. 2006

Planetesimal belts

- objects from 0.15 μm – 7 km
- $M_{tot} = 0.3M_{EARTH}$
- a = 6 - 7 AU
- e = 0 - 0.1
- → evolution of dust particles → Brightness

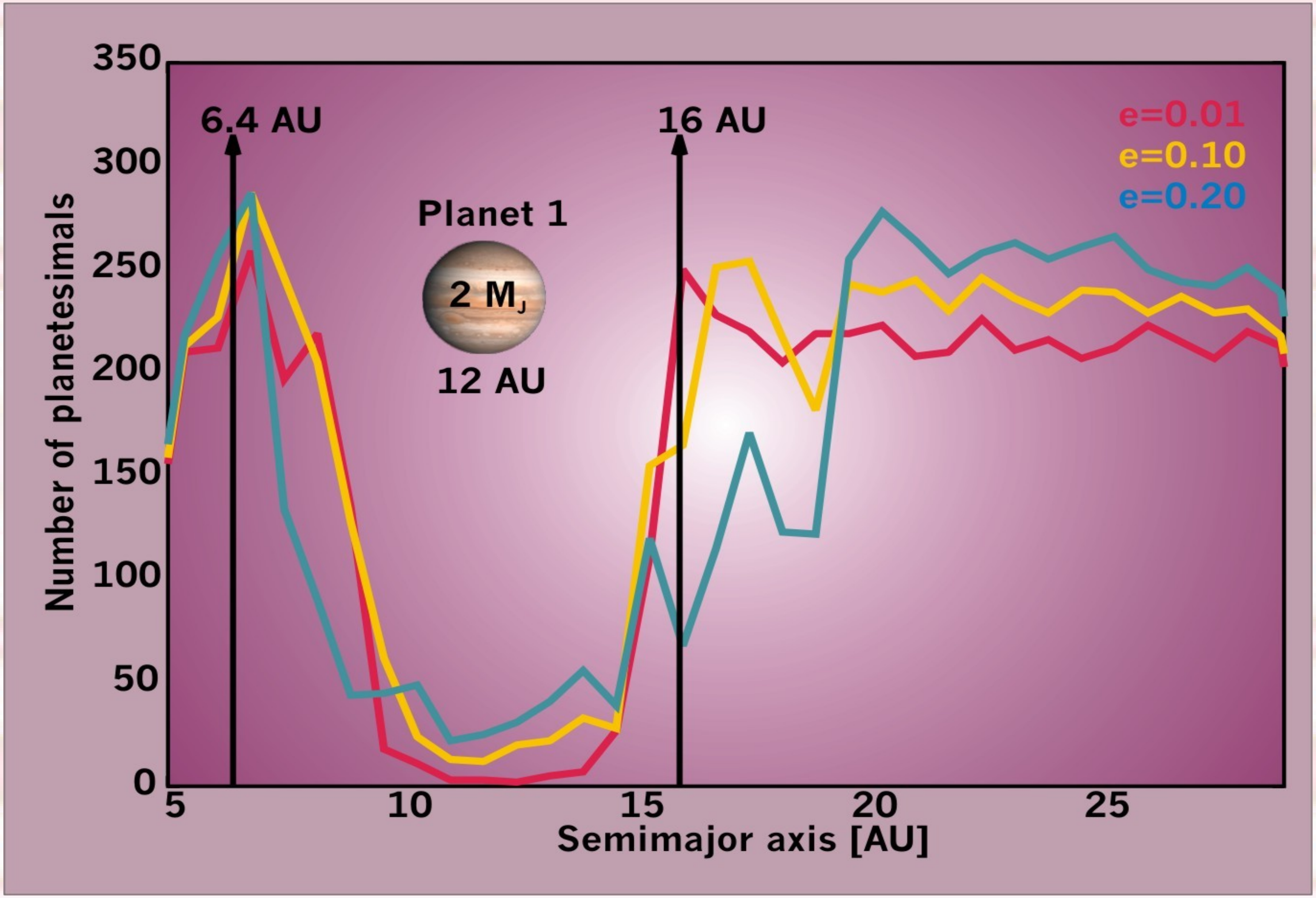


→ observed peaks can be due to planetesimal belts!

Planets

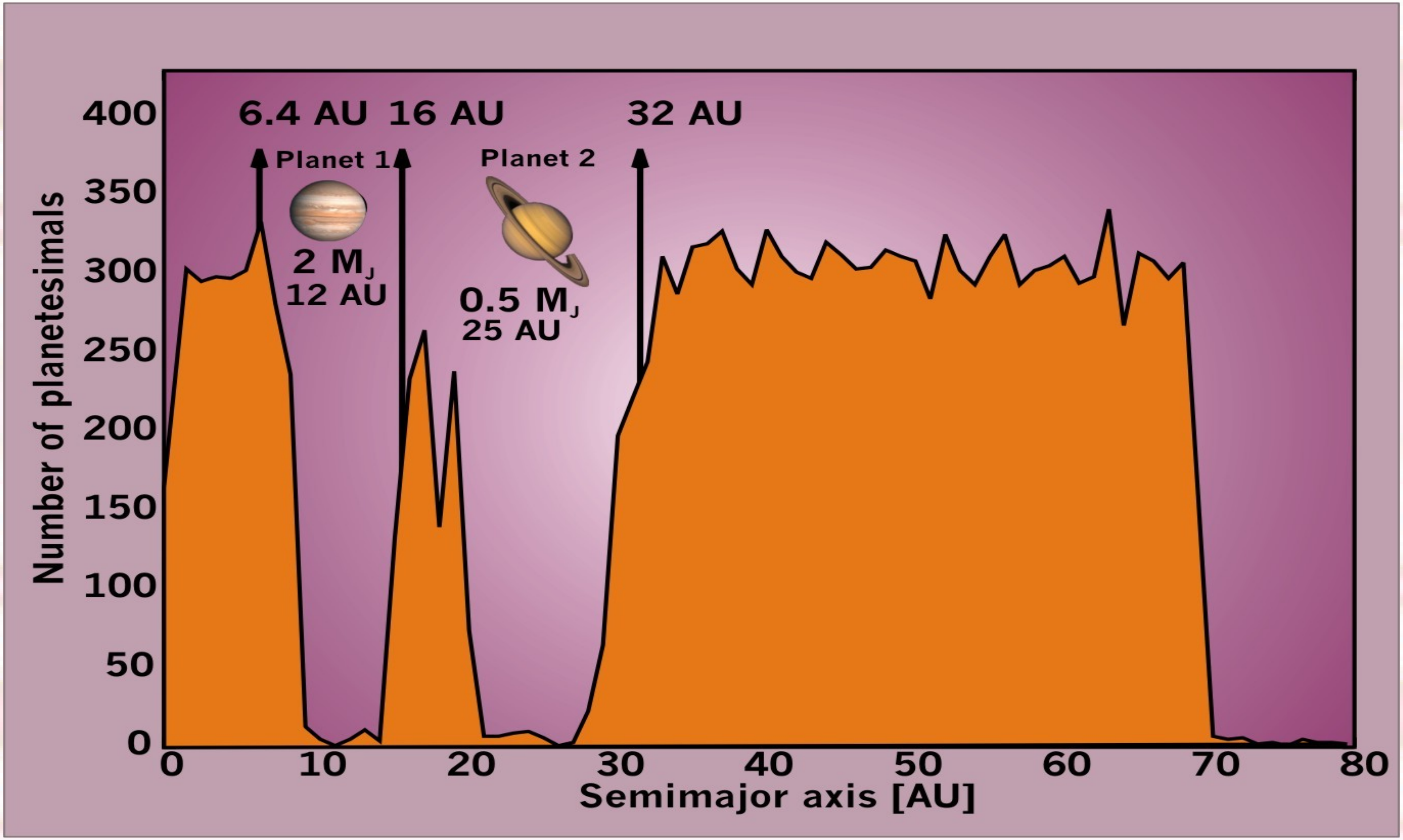
- belts are confined by planets
- What are the parameter of the planet(s) so that the perturbations cause the observed clumps?
- simulations with 1 – 3 planets
- parameters (M, a, e, i) very varied

One Planet



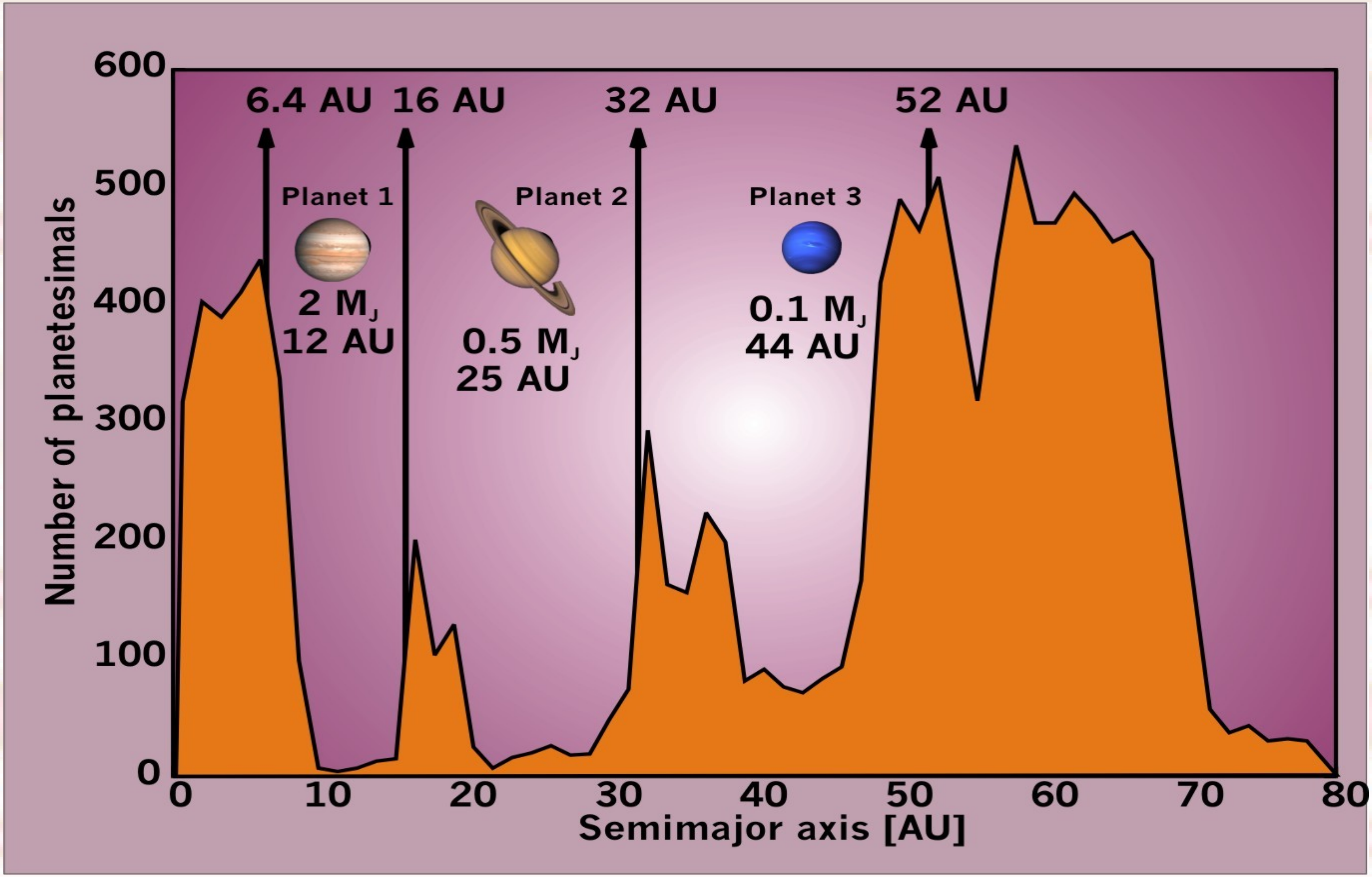
6.4 AU
16 AU
Planet 1
2 M_J
12 AU
e=0.01
e=0.10
e=0.20
Number of planetesimals
350
300
250
200
150
100
50
0
5
10
15
20
25
Semimajor axis [AU]

Two Planets

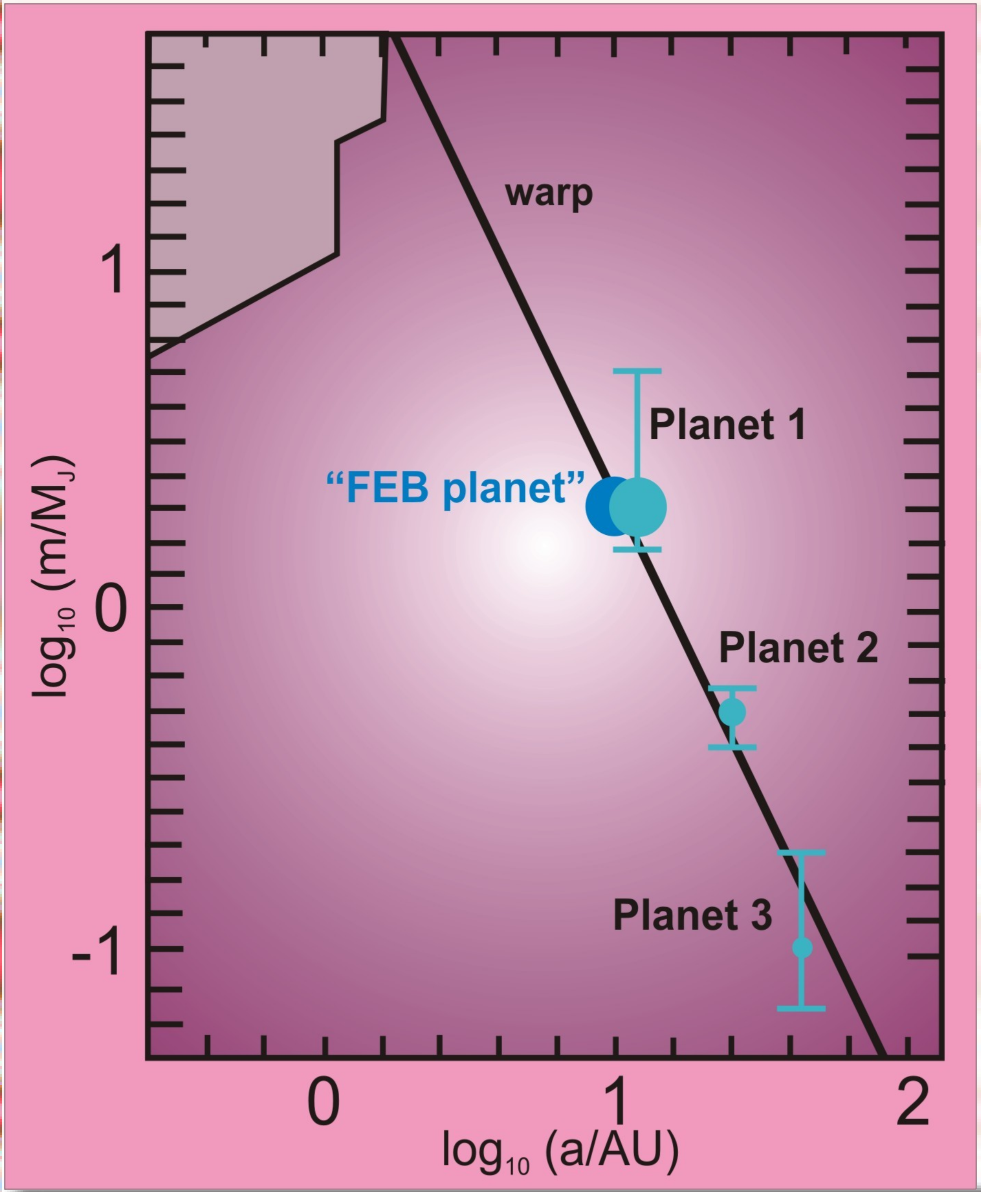


6.4 AU
16 AU
32 AU
Planet 1
2 M_J
12 AU
Planet 2
0.5 M_J
25 AU
Number of planetesimals
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
Semimajor axis [AU]

Three Planets

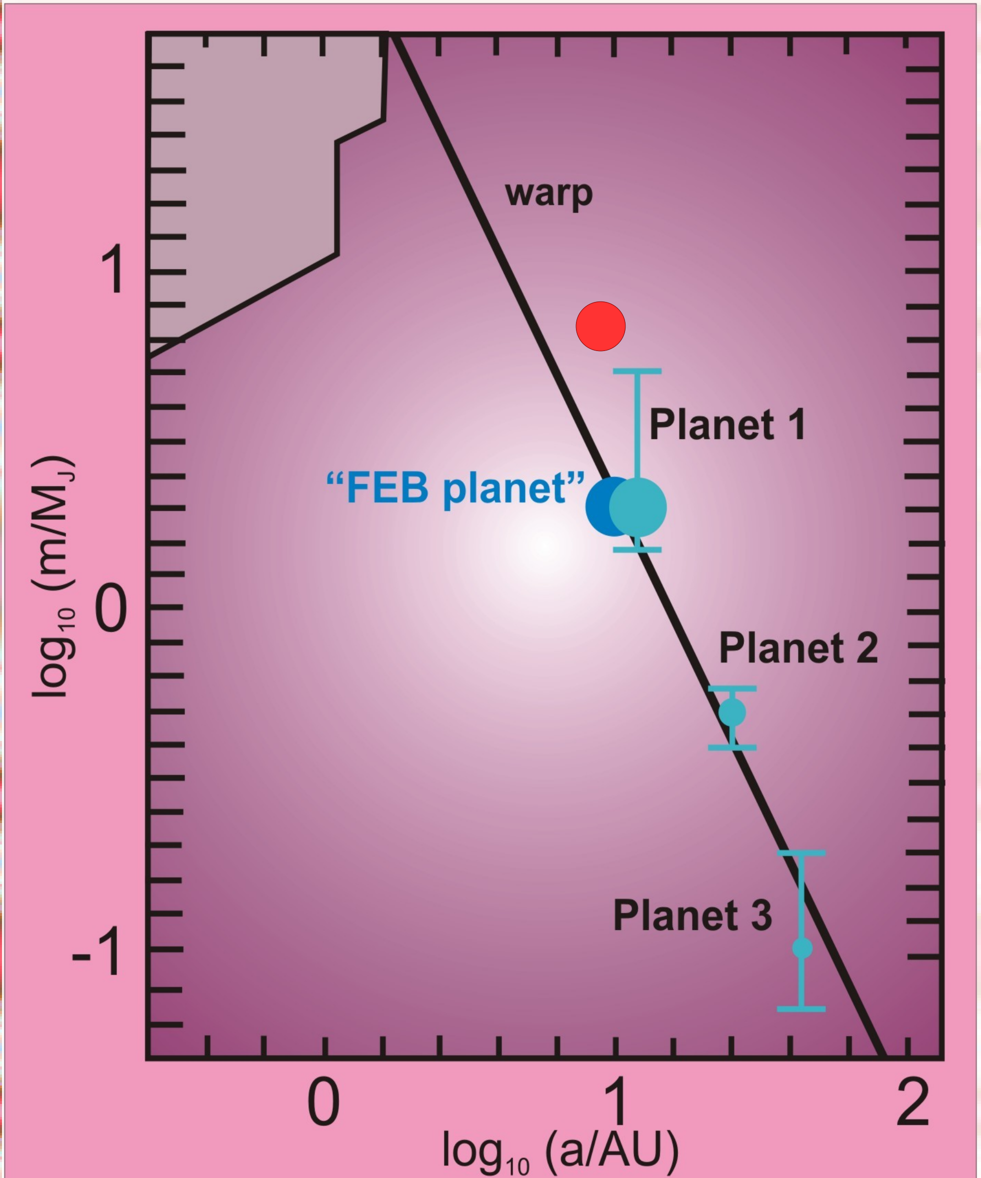


Summary

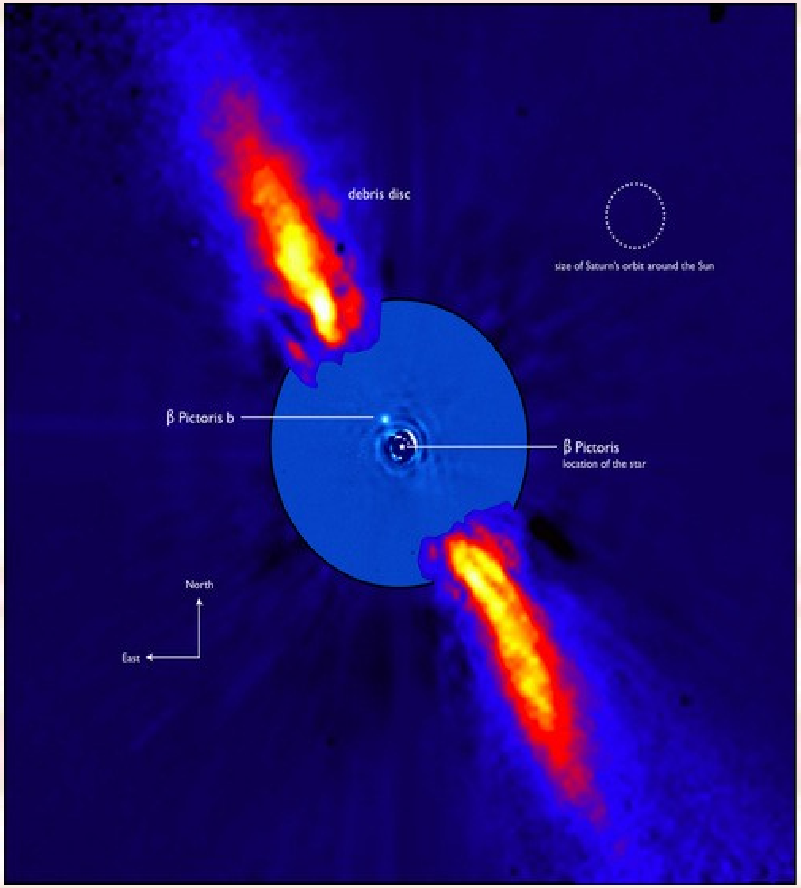


- Confirmation of previous results
- Additional restrictions for planetary parameters
- At least 3 planets are needed to explain observations
- The planetary system could be resonant

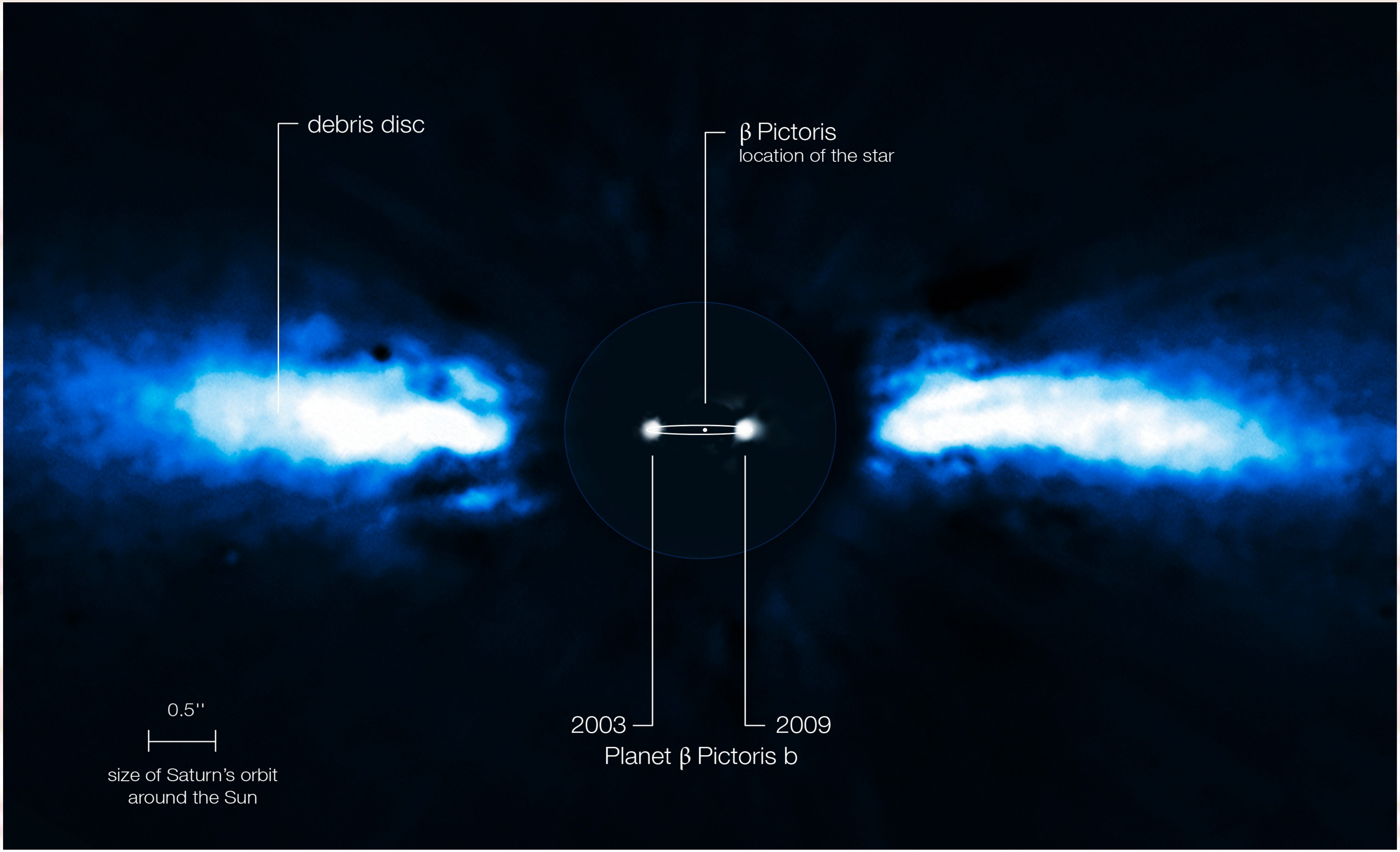
Beta Pictoris b

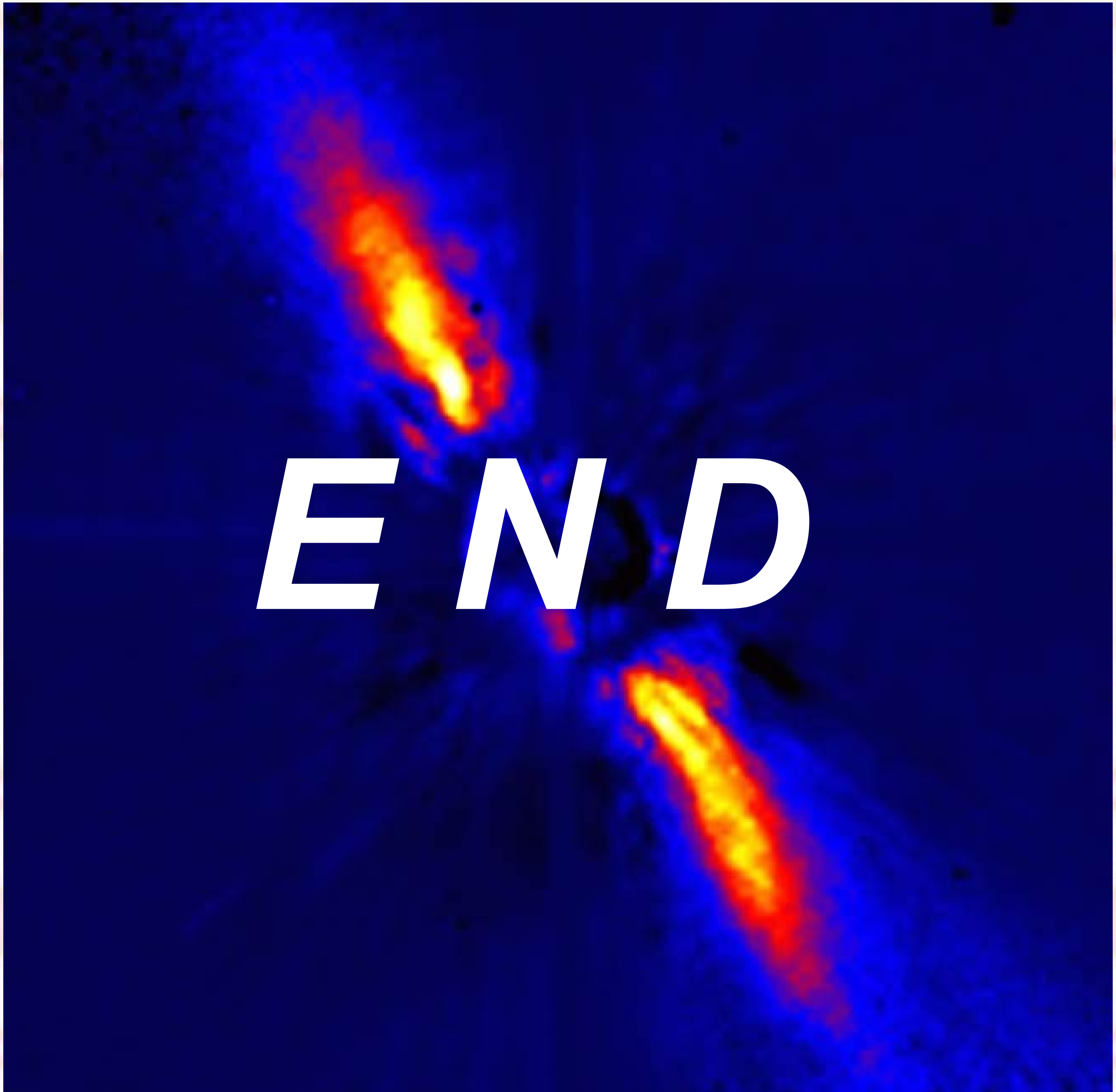


- Do the planets exist?



Beta Pictoris b

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