Institute for Advanced Study

The dynamics of extra-solar planets

Hanno Rein @ Franklin Institute, November 2011

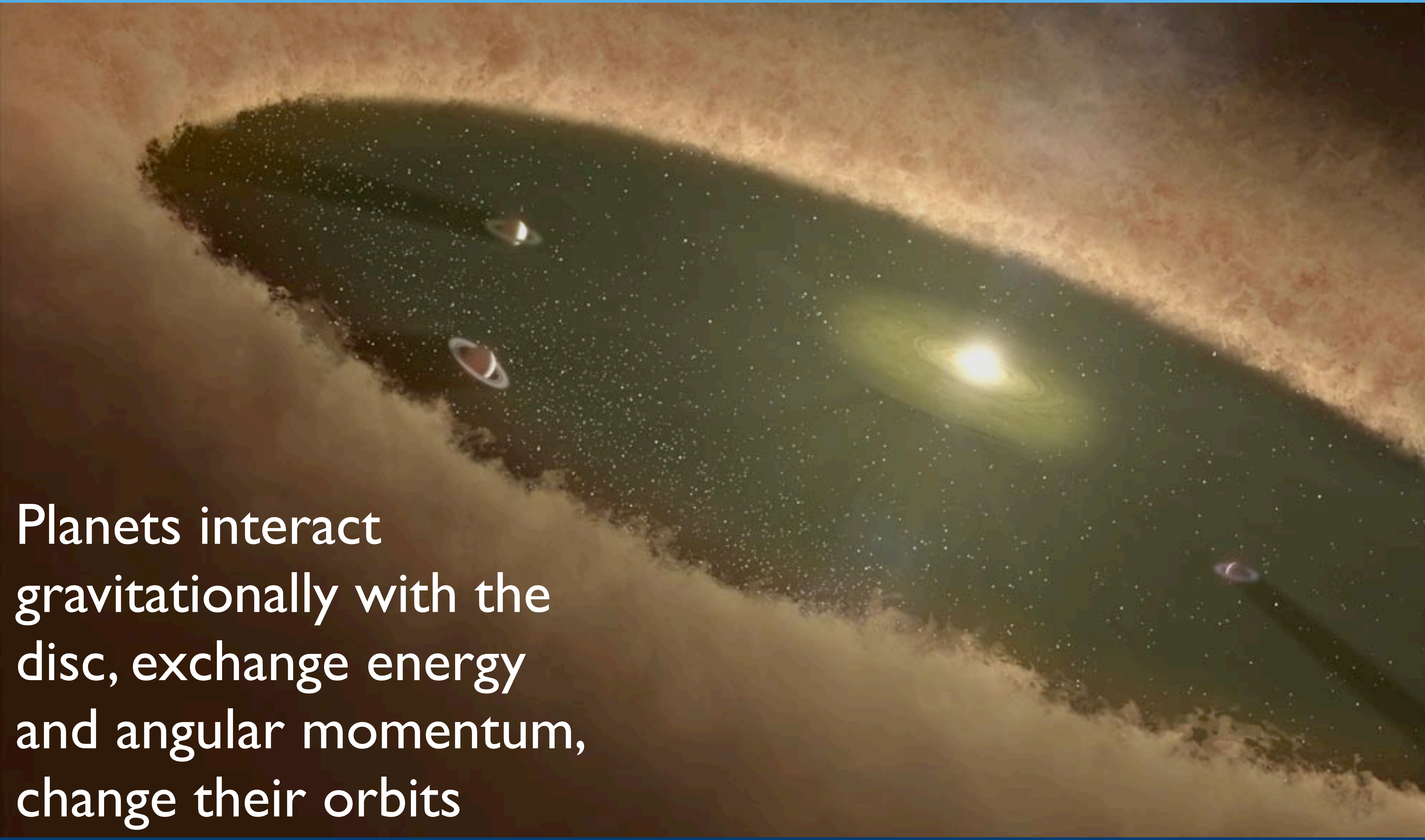
Planet formation

Planet formation

Credit: NASA/JPL-Caltech/T. Pyle (SSC)

Planet Migration

Planet Migration



Planets interact gravitationally with the disc, exchange energy and angular momentum, change their orbits

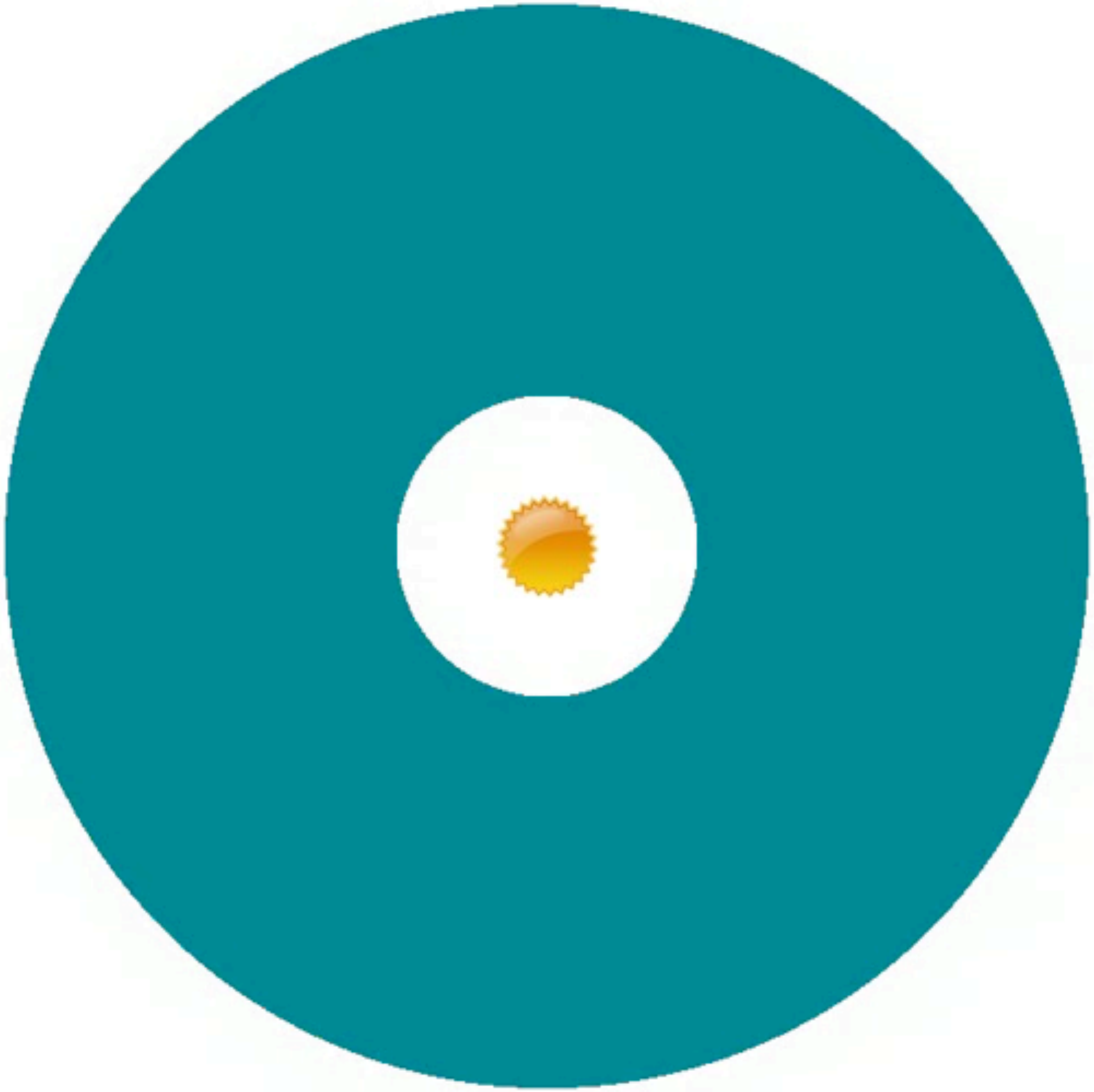
Credit: NASA/JPL-Caltech

Planet Migration - Type I

- Low mass planets, Earth, Mars, Venus, (Saturn)
- Not massive enough to open gap in disc
- Migration rate is fast
- Details are very complicated and not completely understood yet
- Strong dependence on gradients and thermodynamics

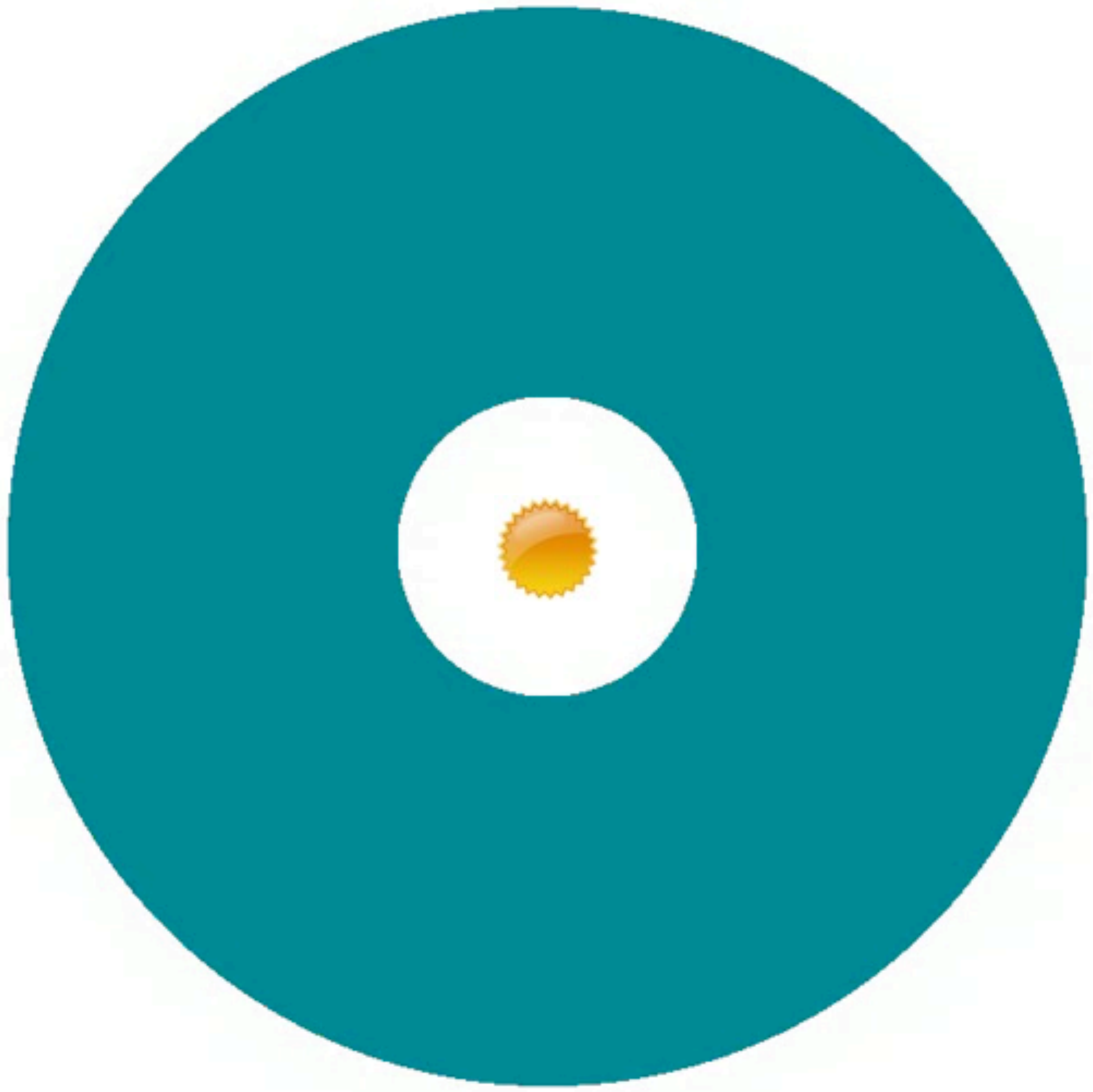
Planet Migration - Type II

- Massive planets, (Saturn), Jupiter, and above
- Planets are so big that they strongly perturb the disc and open a gap
- That changes the migration rate, slows it down
- Planets follow the evolution of the disc



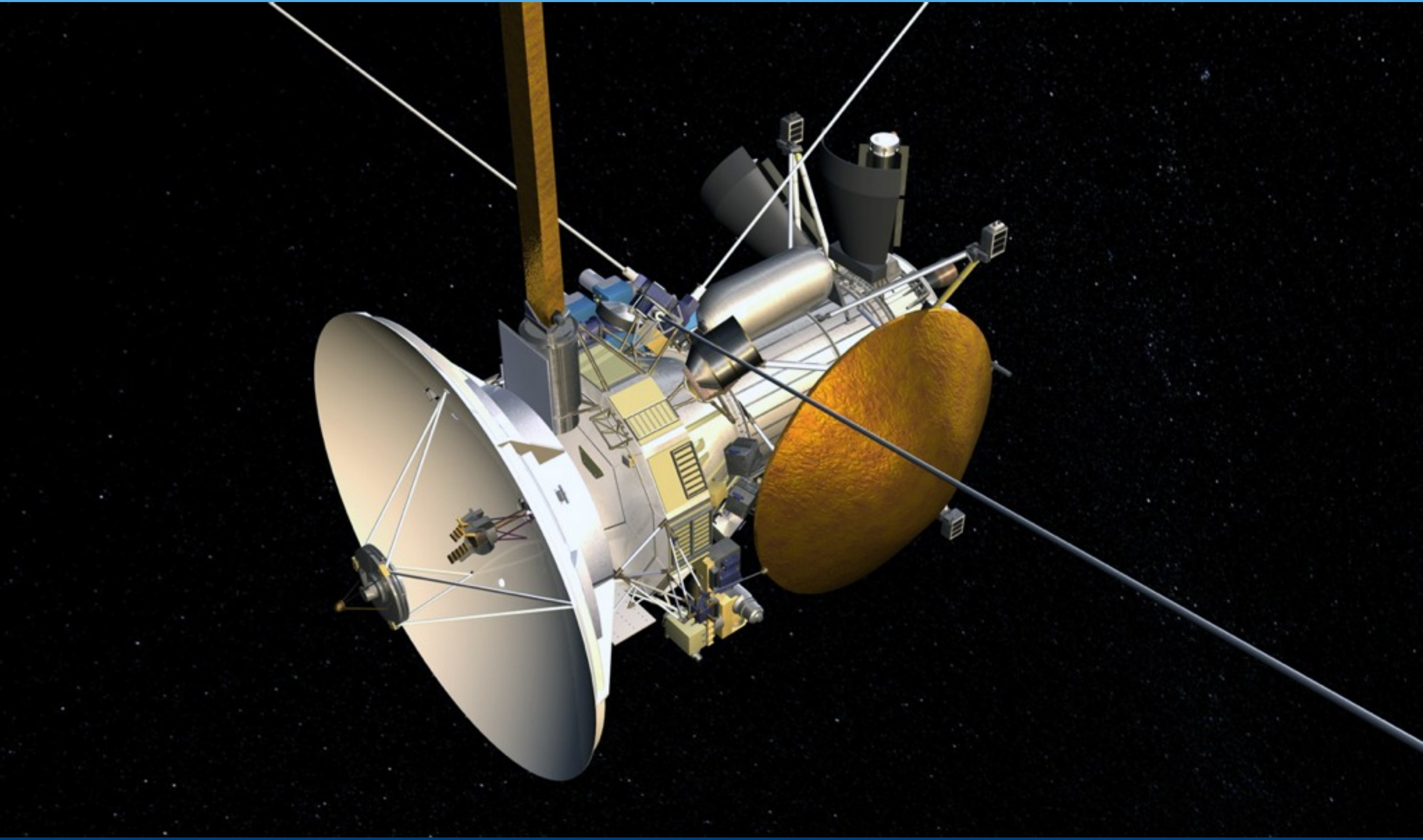
Planet Migration - Type III

- The extreme case
- Massive planets, Jupiter and above
- Massive proto-planetary disc
- Planet tries to open a gap, but can't do it fast enough
- Planet migrates inwards very quickly



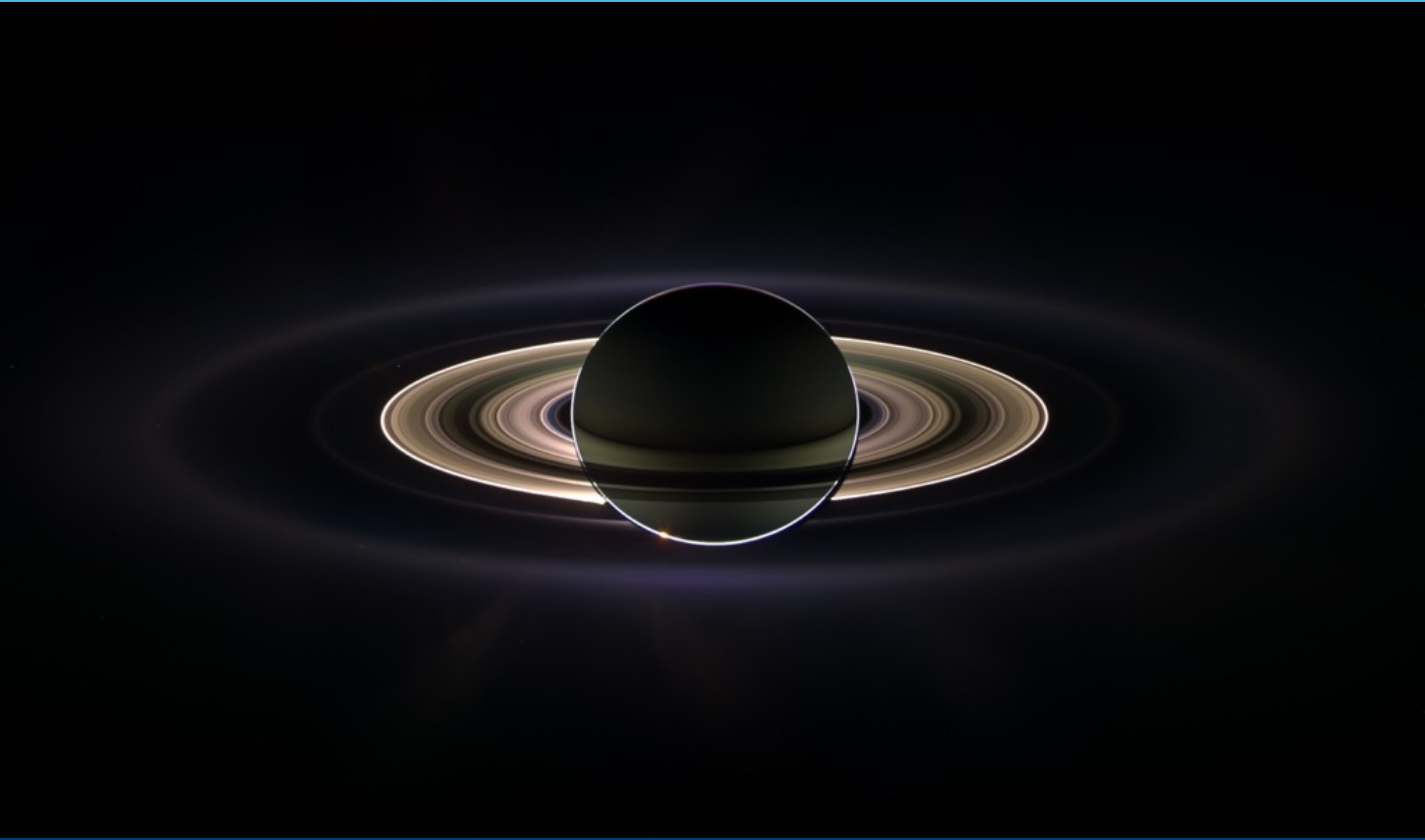
Moonlets in Saturn's Rings

Cassini spacecraft



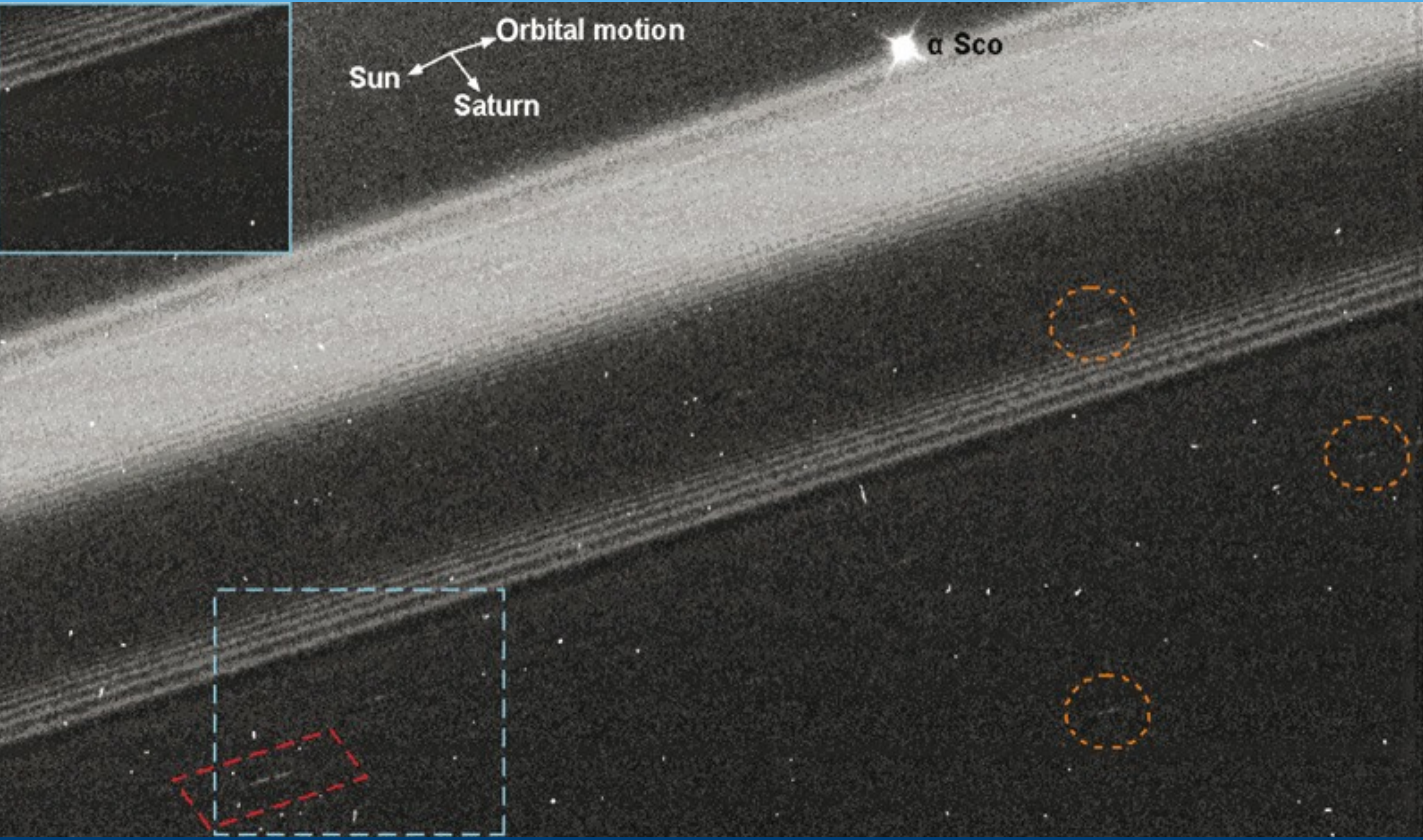
Credit: JPL/Gordon Morrison

The far side of Saturn



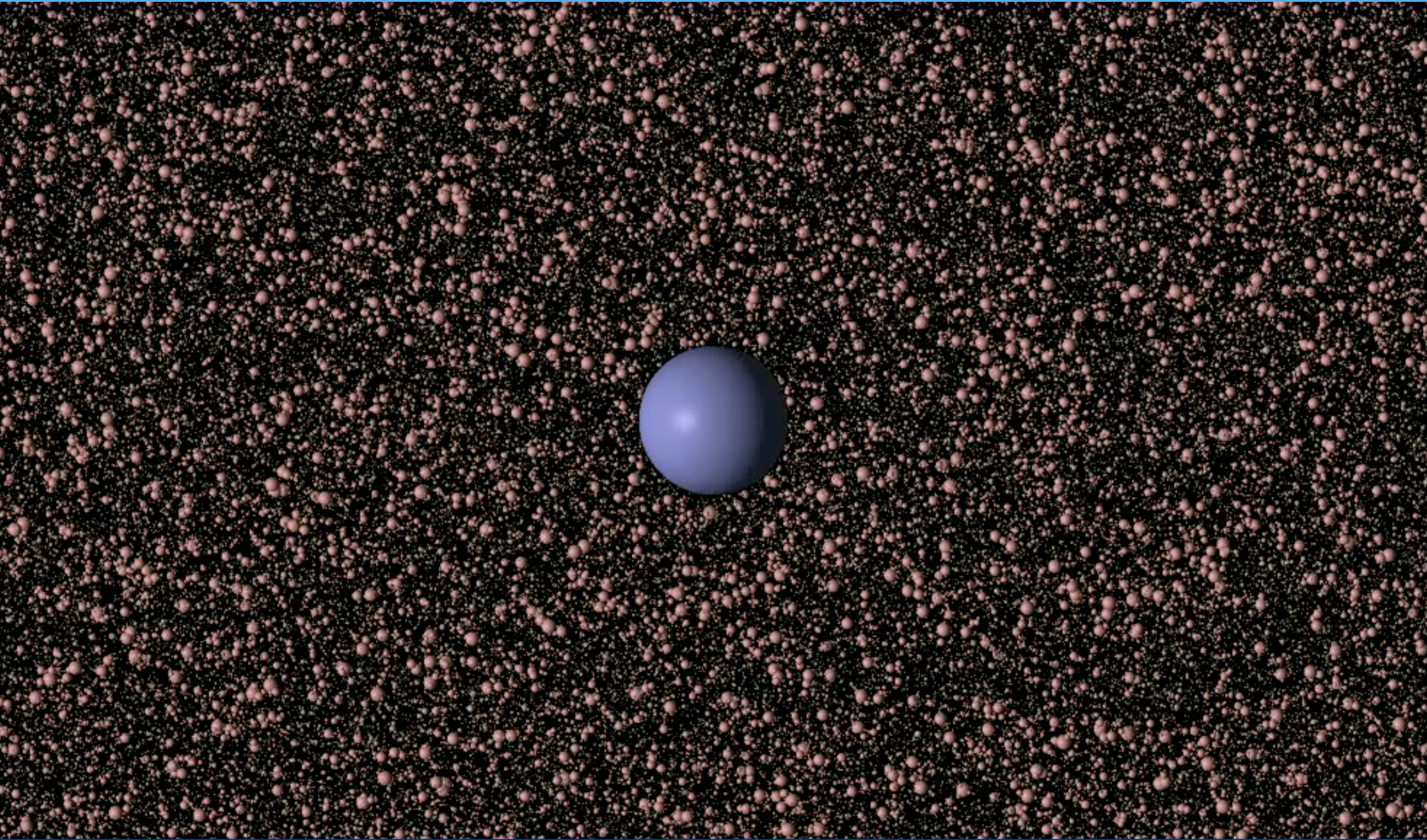
NASA/JPL/Space Science Institute

Propeller structures in A-ring



Porco et al. 2007, Sremcevic et al. 2007, Tiscareno et al. 2006

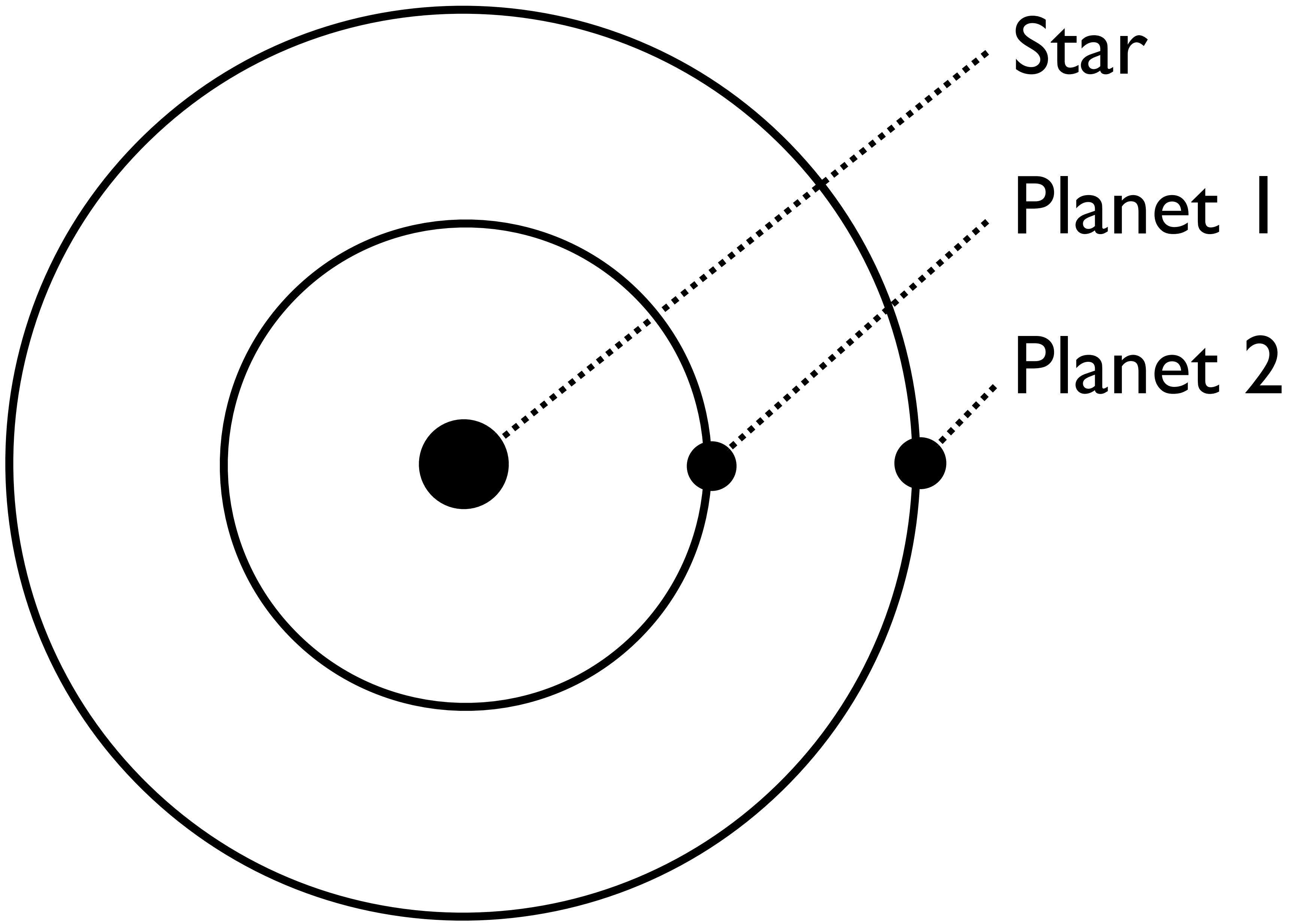
Random walk



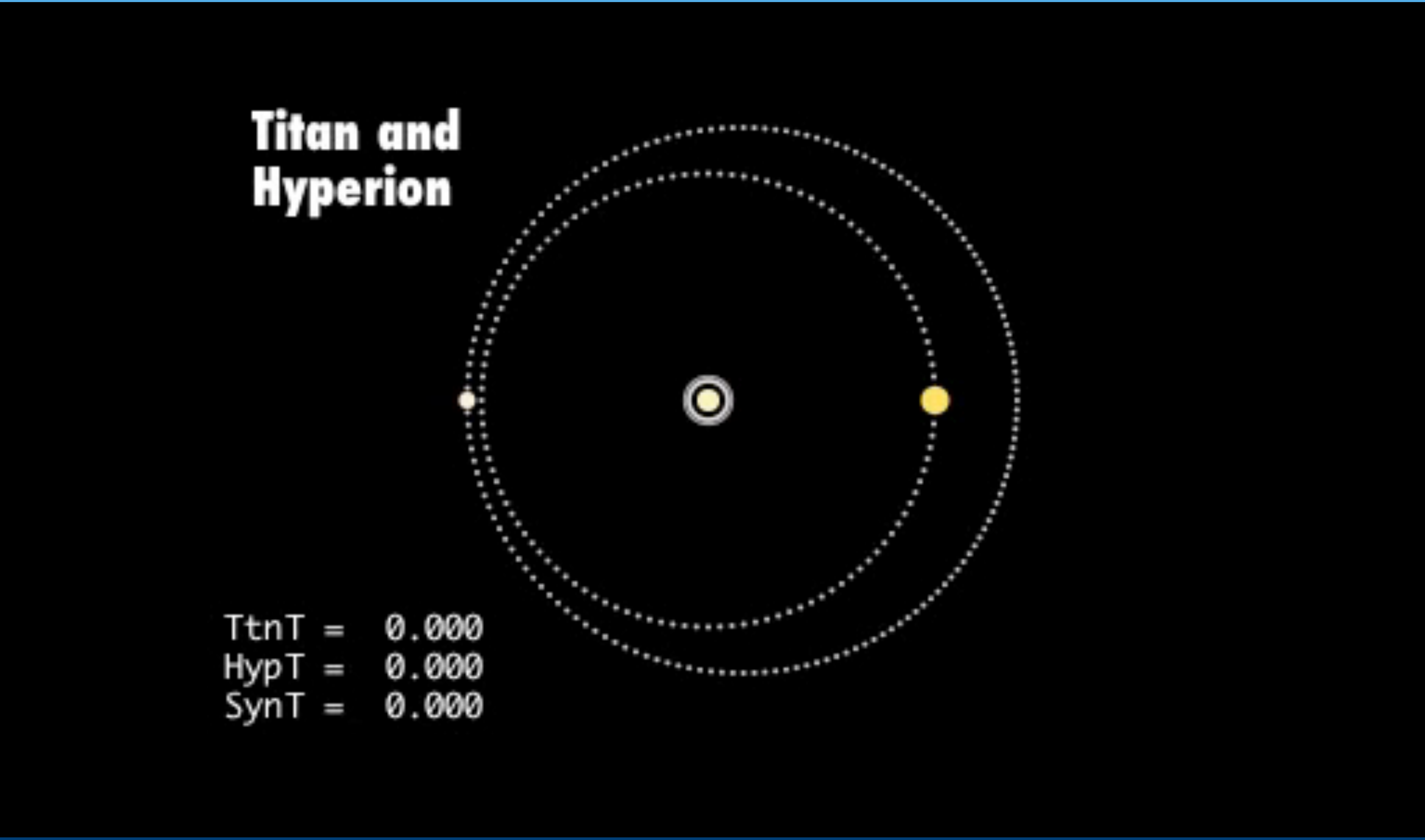
REBOUND code, Rein & Papaloizou 2010, Crida et al 2010

Orbital Resonances

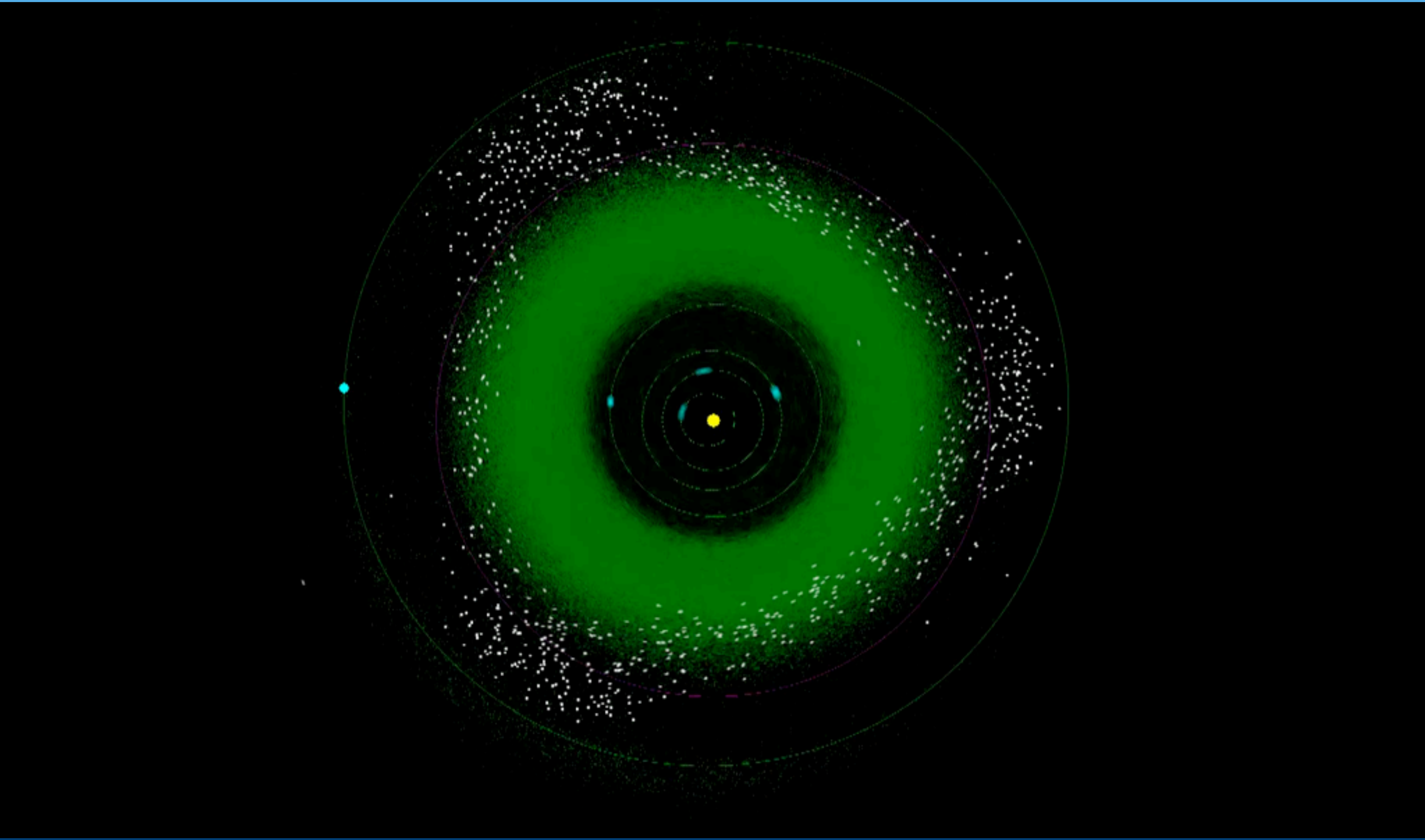
2:1 Mean Motion Resonance



Resonances in the Solar System



Resonances in the Solar System



Extra-solar planets: Gliese 876

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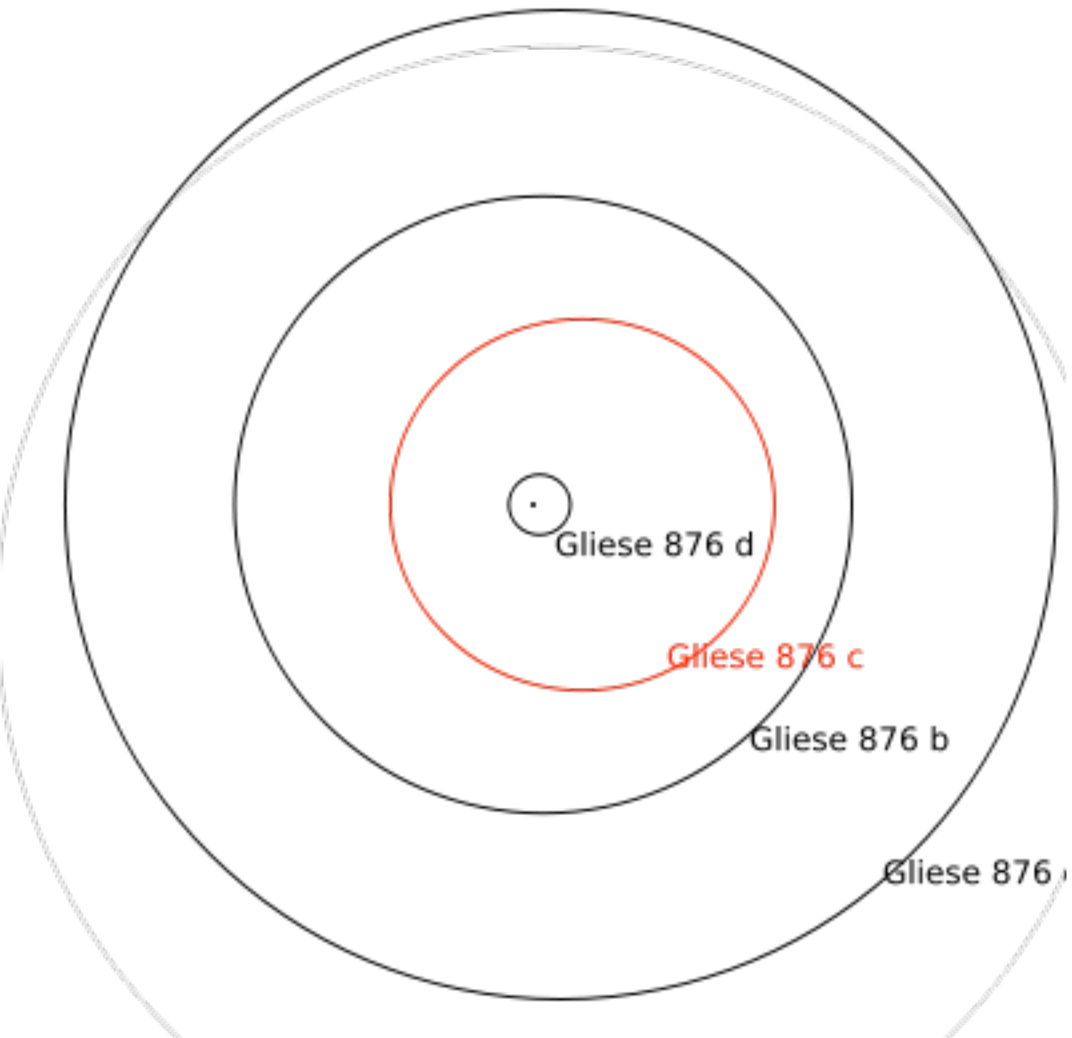
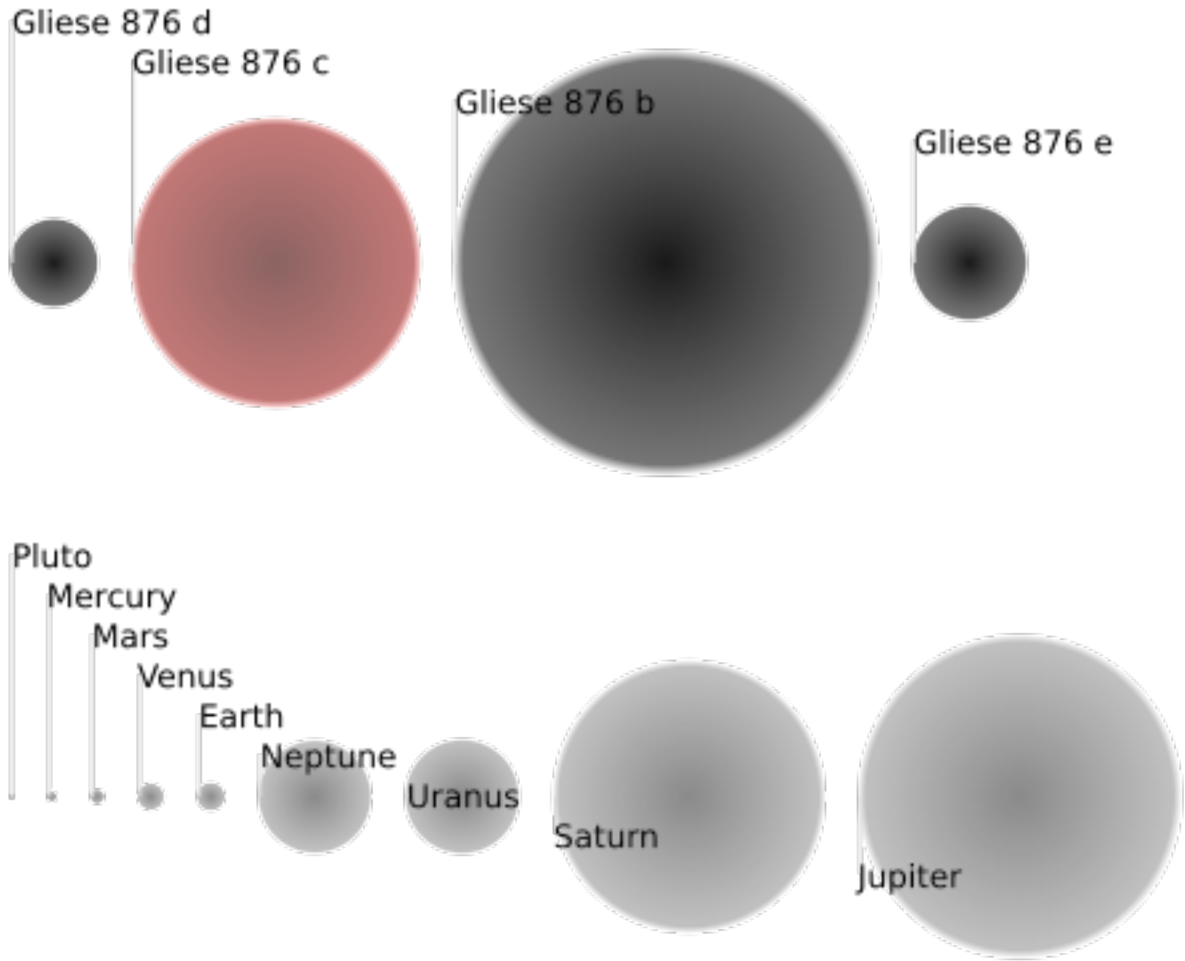
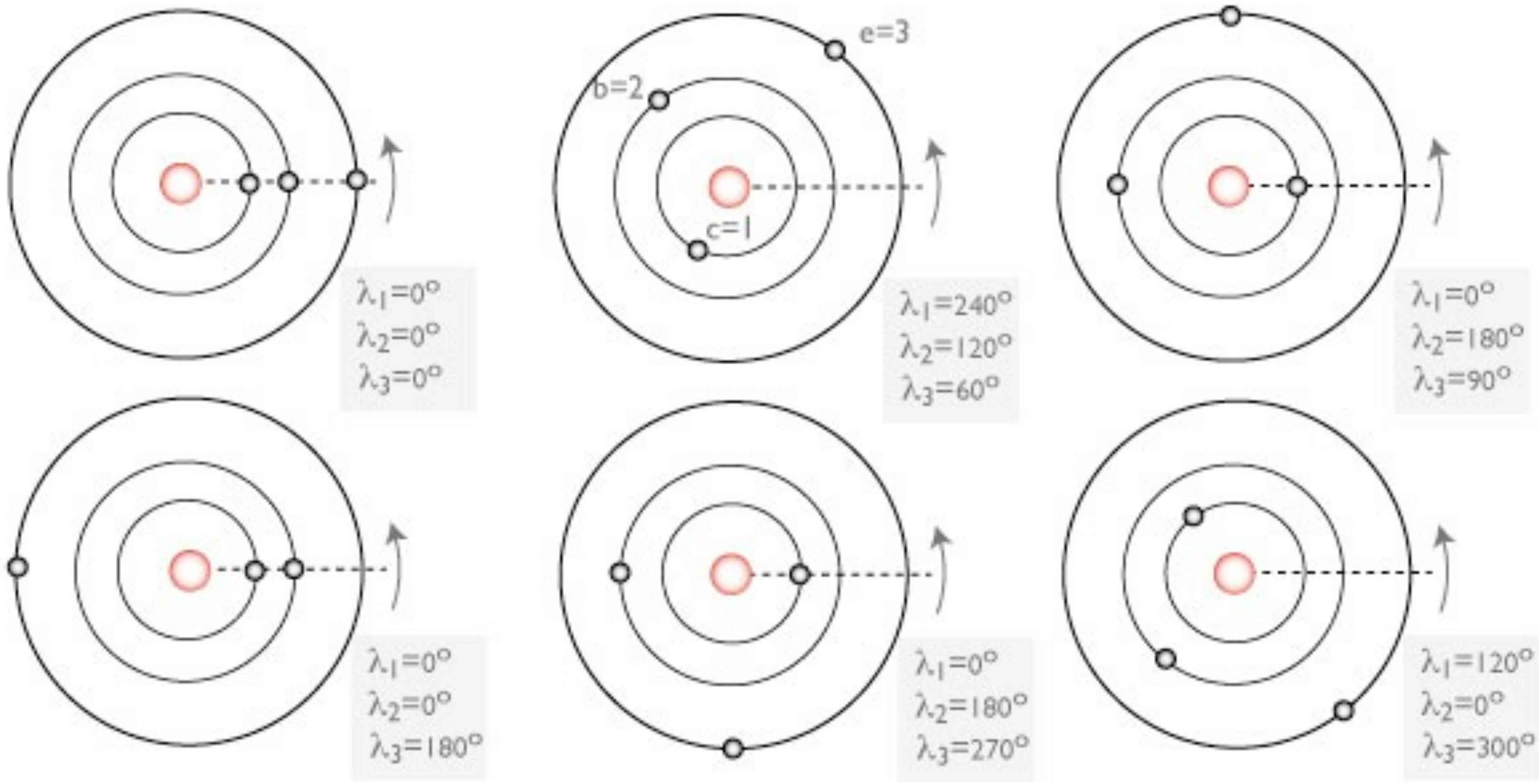




4:2:1 Laplace resonance in Gliese 876

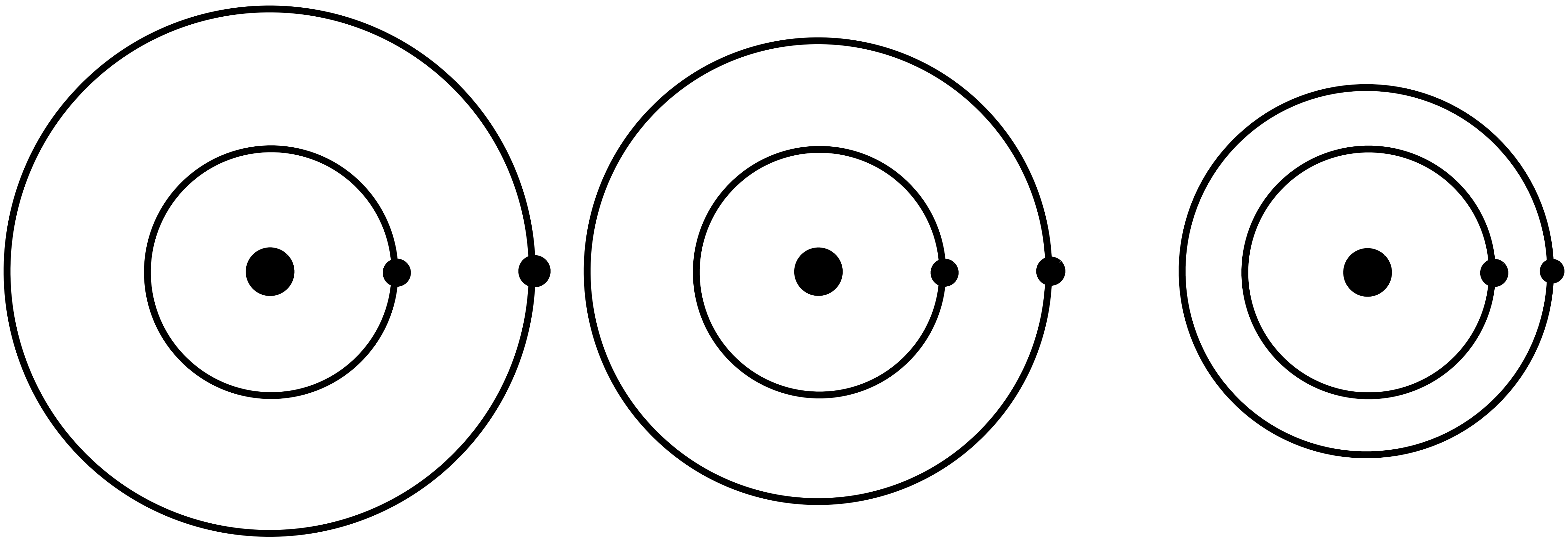


Credit: oklo.org

The formation of Gliese 876

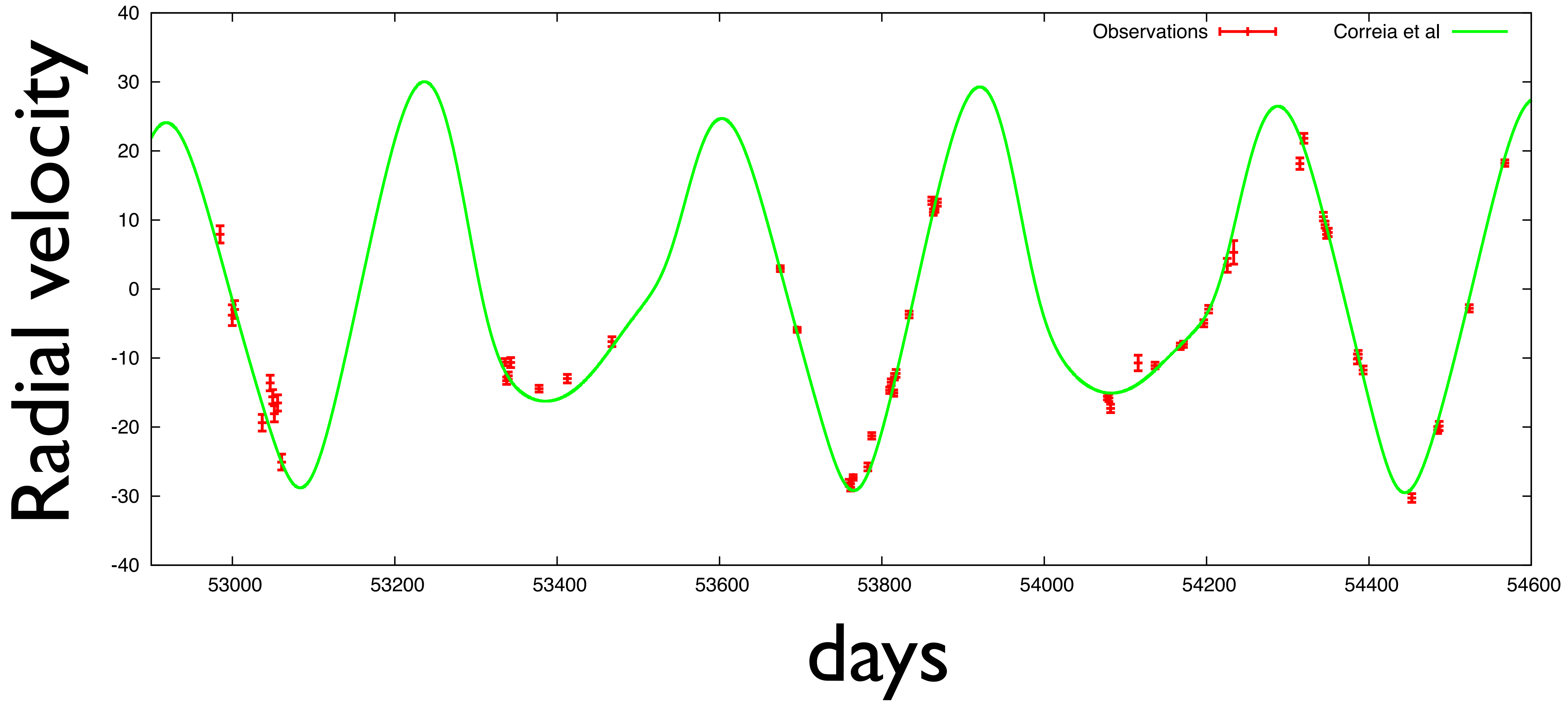
- Resonance structure is key to understanding the formation
- Dissipative processes lead to resonance capture
- Indirect evidence for planet-disc interaction

$$P_1/P_2 = 3.754 \longrightarrow P_1/P_2 = 2.335 \longrightarrow P_1/P_2 = 2.000$$



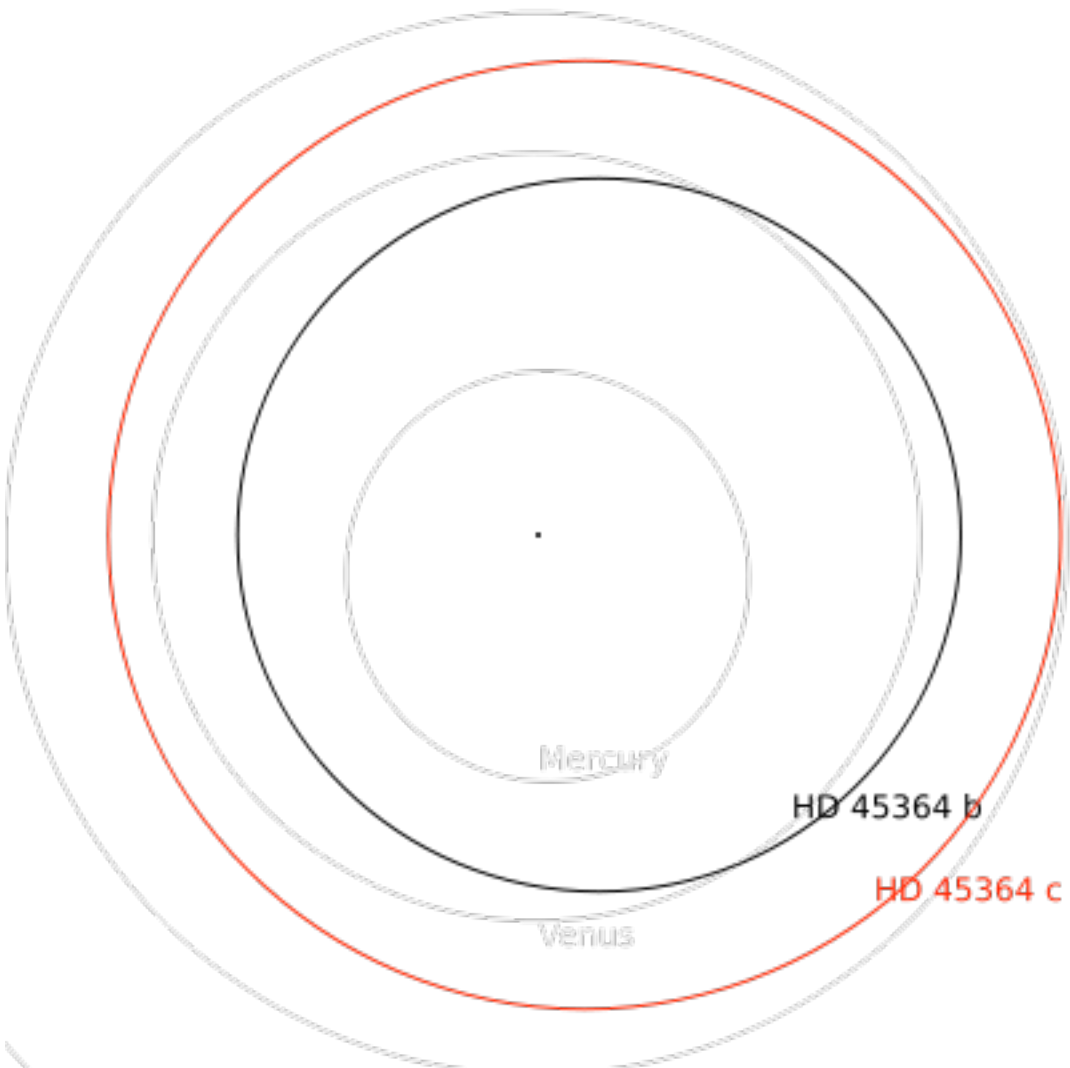
Extra-solar planets: HD 45364

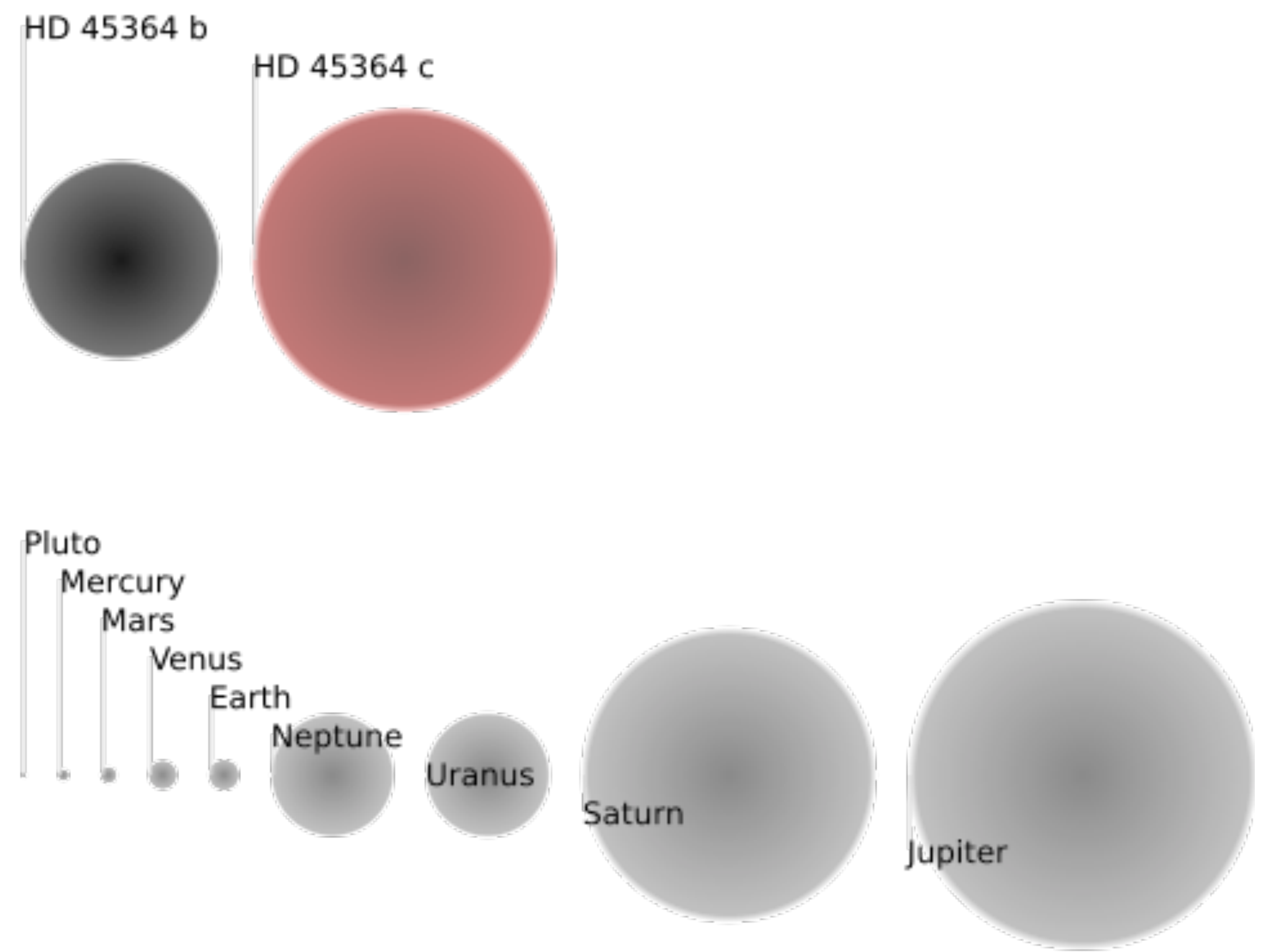
Extra-solar planets: HD45364



Correia et al 2009

Extra-solar planets: HD45364



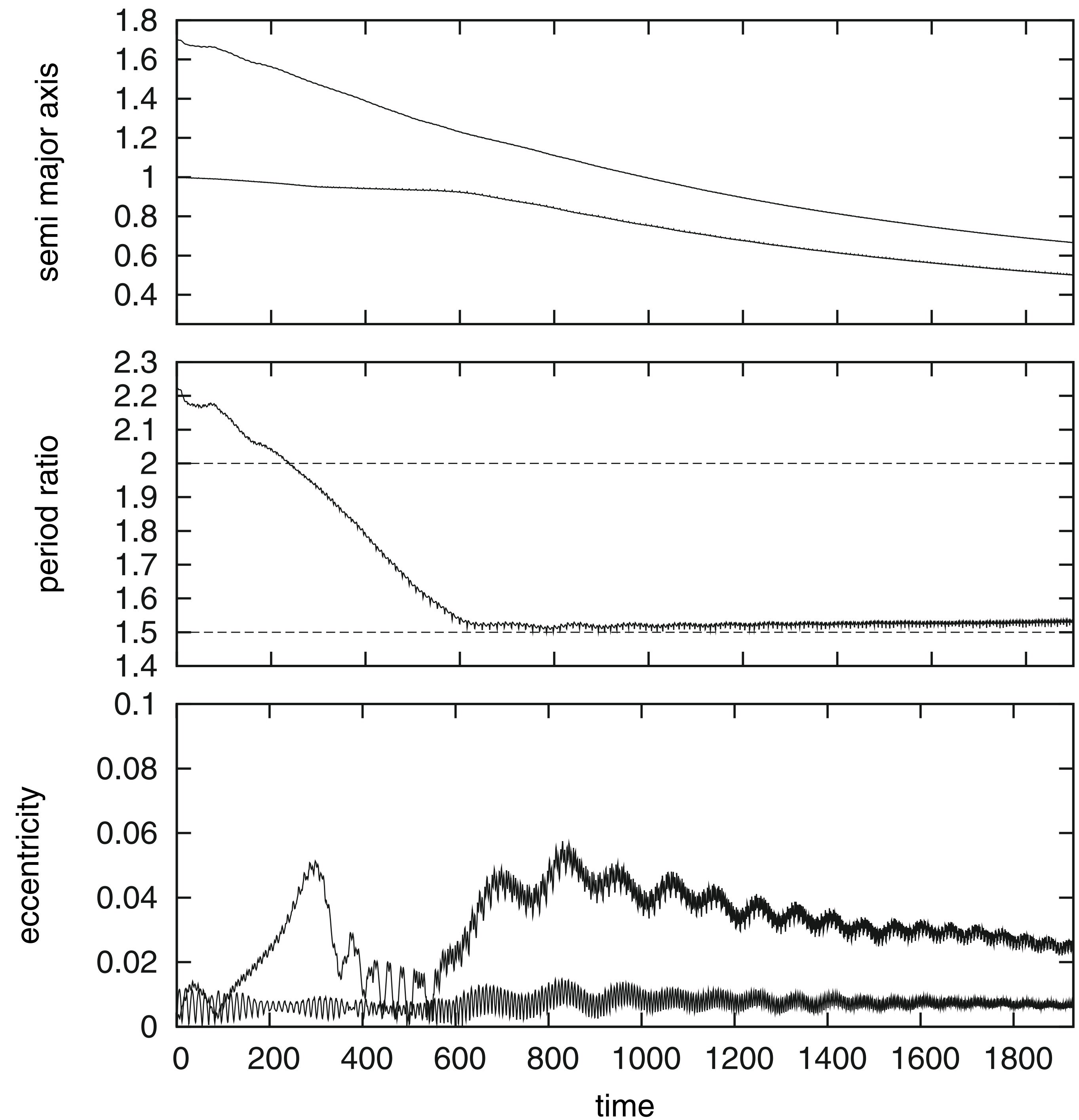


Formation scenario for HD45364

- Two migrating planets but an infinite number of resonances

3:2 1:4 1:2 1:3 7:8

- Migration speed is crucial
- Different migration types give different migration speeds



Rein, Papaloizou & Kley 2010

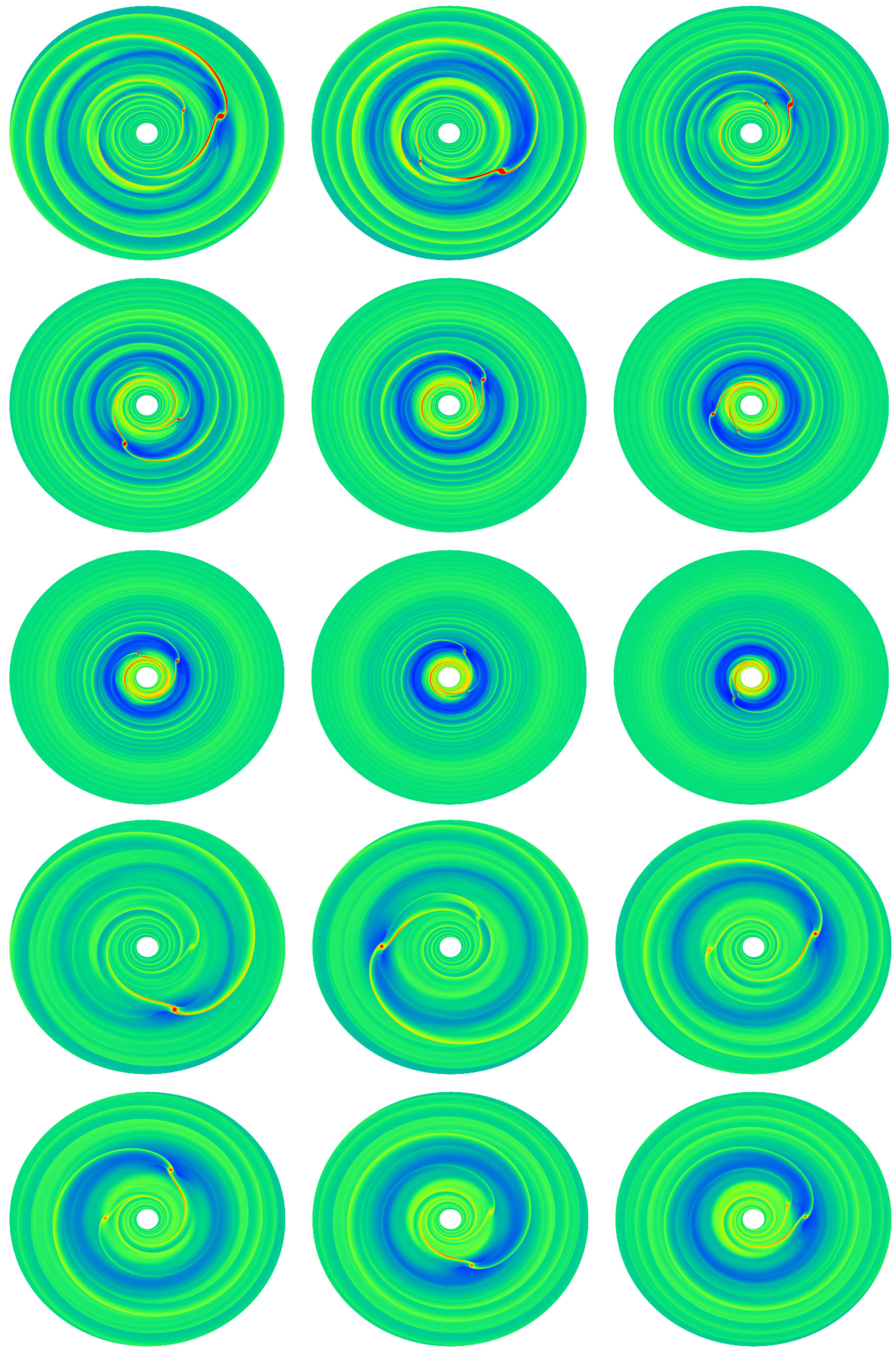
Formation scenario for HD45364

Massive disc

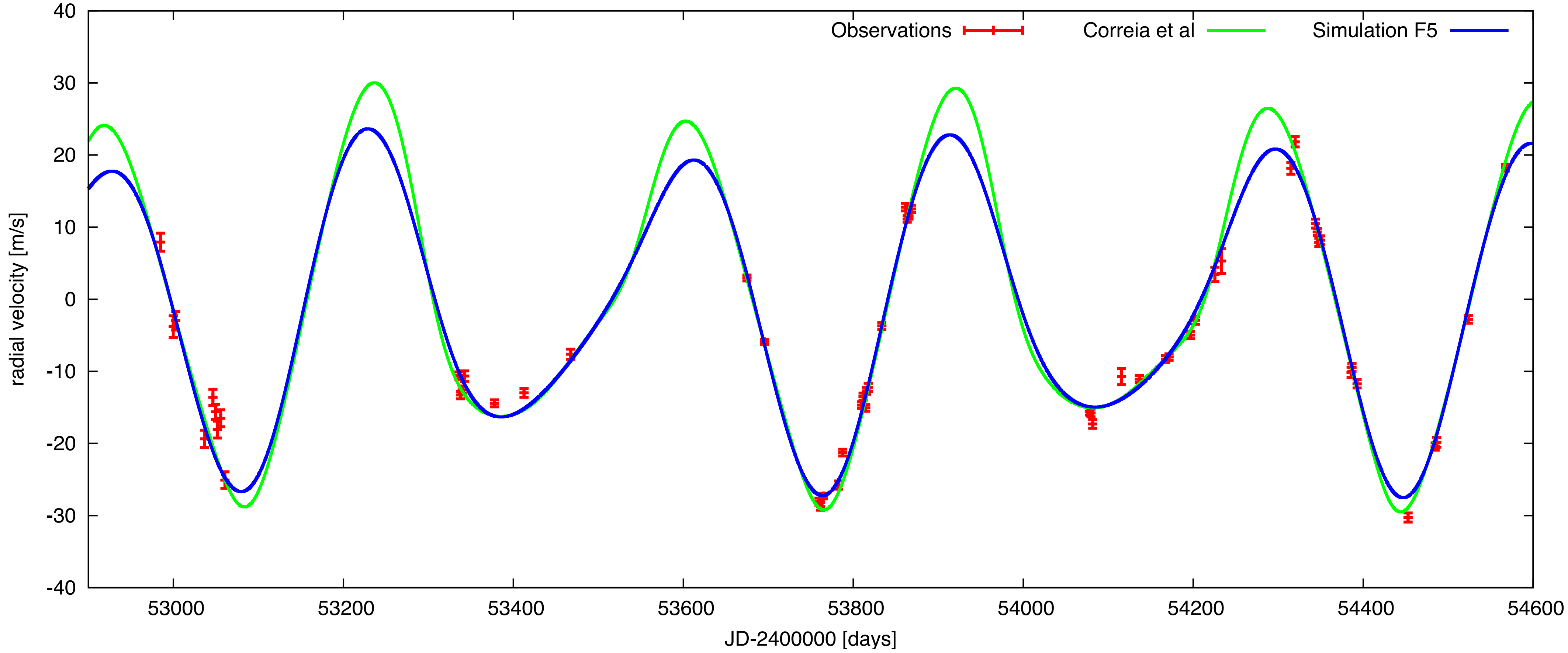
- Short, rapid Type III migration
- Passage of 2:1 resonance
- Capture into 3:2 resonance

Thick disc

- Slow Type I migration once in resonance
- Resonance is stable
- Consistent with radiation hydrodynamics



Formation scenario leads to a better 'fit'

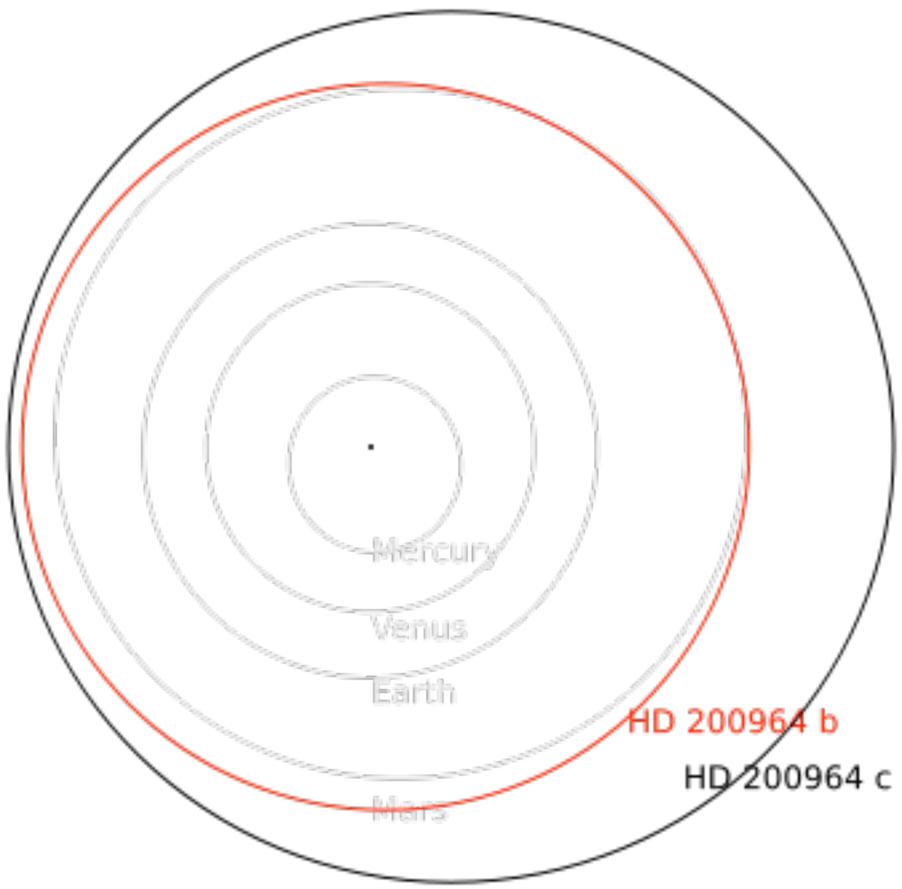


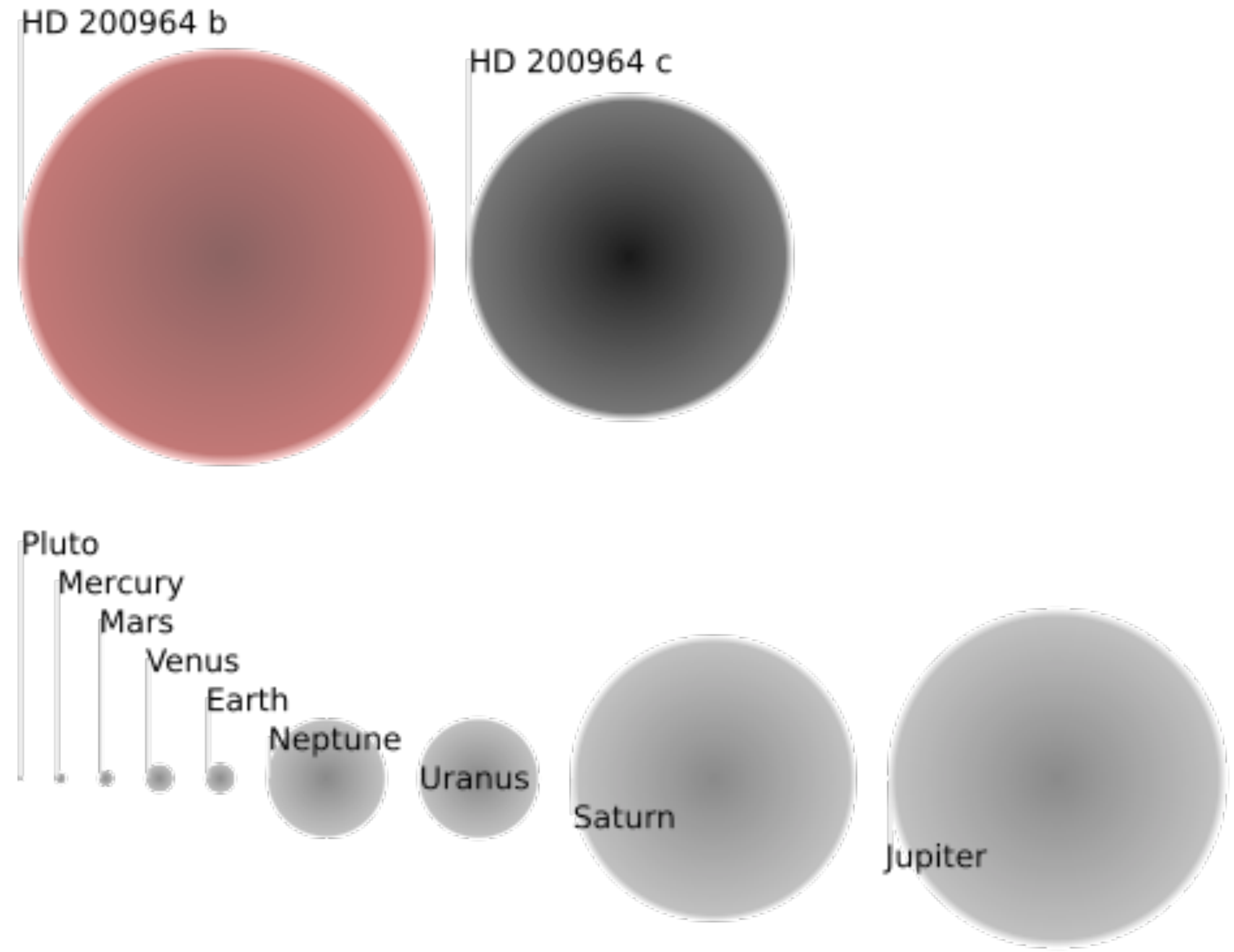
Parameter	Unit	Correia et al. (2009) b	Correia et al. (2009) c	Simulation **F5** b	Simulation **F5** c
$M \sin i$	$[\mathrm{M_{Jup}}]$	0.1872	0.6579	0.1872	0.6579
M_*	$[M_\odot]$	0.82		0.82	
a	[AU]	0.6813	0.8972	0.6804	0.8994
e		0.17 ± 0.02	0.097 ± 0.012	0.036	0.017
λ	[deg]	105.8 ± 1.4	269.5 ± 0.6	352.5	153.9
ϖ^a	[deg]	162.6 ± 6.3	7.4 ± 4.3	87.9	292.2
$\sqrt{\chi^2}$		2.79		2.76^b (3.51)	
Date	[JD]	2453500		2453500	

Rein, Papaloizou & Kley 2010

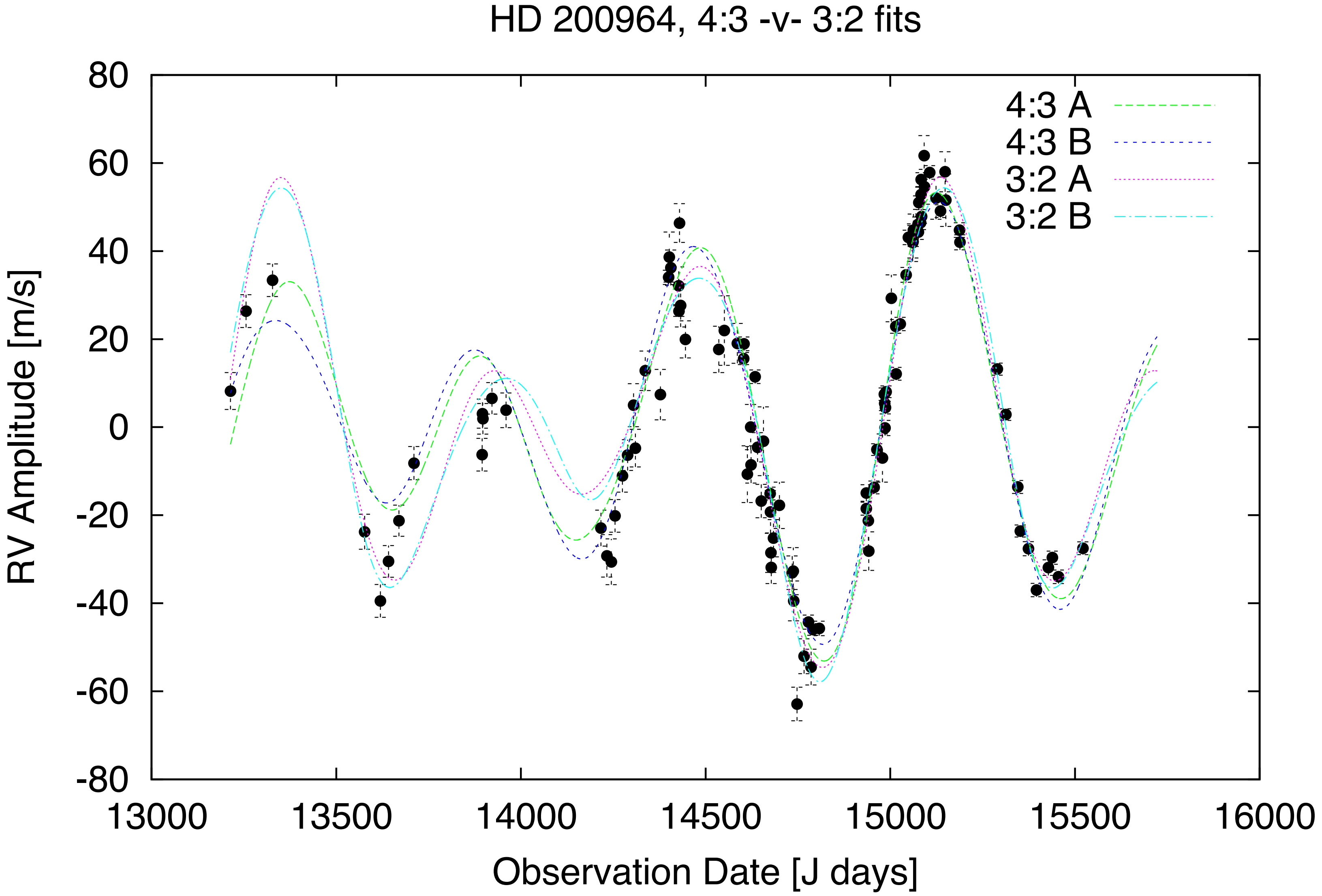
HD200964
The impossible system?

Extrasolar planets: HD200964





Radial velocity curve of HD200964



- Two massive planets 1.8 M_{Jup} and 0.9 M_{Jup}
- Period ratio either 3:2 or 4:3
- Another similar system, to be announced soon
- How common is 4:3?
- Formation?

Plot by Matthew Payne

Outcome for HD200964

Credit: Gemini Observatory/Lynette Cook

Migration does not work for HD200964

- Planets are captured in mean motion resonances
- But not in the observed 4:3 resonance
- Massive planets capture in lower order resonances first: 2:1, 3:2
- 4:3 resonance is very tight
- Probability of planet-planet scattering high
- Ejection of planets from the system

Solutions for HD200964

- In situ formation?
- Main accretion while in 4:3 resonance?
- A third planet?
- Observers screwed up?
- Planet planet scattering?

Planet-planet scattering

Simulation: Eric Ford (UF)

Summary

Conclusions

Planet migration

Planets are formed in a disc around young stars
Planets interact with the disc via gravity
This changes the orbit of the planets over long time-scales

Resonances

A resonance in a multi-planetary system exists when the period of one planet is a multiple of another planet
Many systems are in resonances, in the Solar System and beyond
Resonances are formed when dissipative forces are present, such as planet migration
This allows us to study the unobservable planet formation phase

Moonlets in Saturn’s rings

Small scale version of the planet forming disc
Dynamical evolution can be directly observed with the Cassini spacecraft
Evolution is most likely dominated by random-walk