Institute for Advanced Study

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The formation of multi-planetary systems

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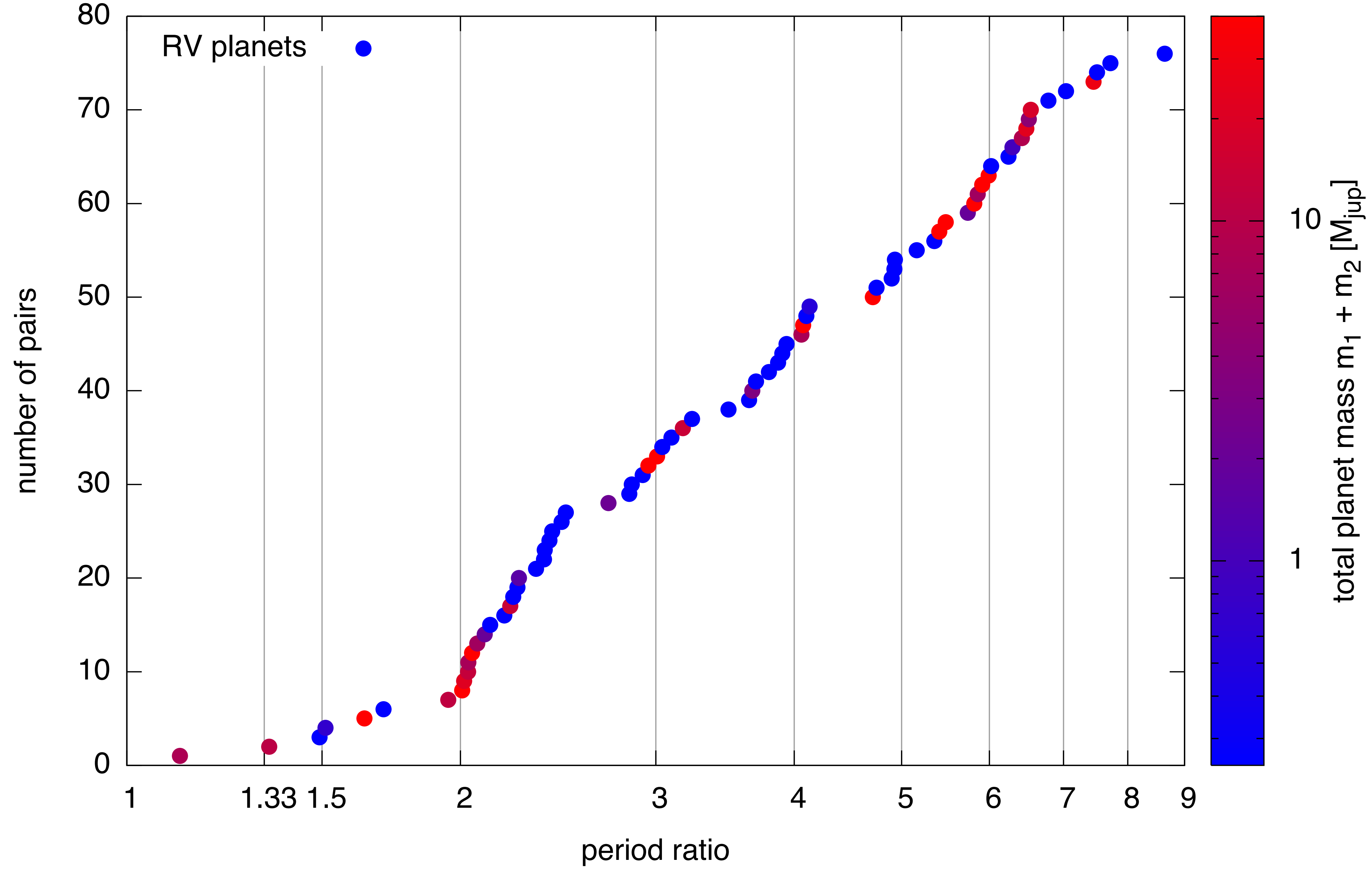
Extra-solar planet census


Carrier
8:57 PM
Exoplanet
Confirmed exoplanets: 831
Selected planets: 840
Database
Milky Way
Exoplanet News
Correlation Diagrams
Background Information
About / Add-ons

Period ratio distribution



Rein, Payne, Veras & Ford (2012)

Planet formation

Planet formation

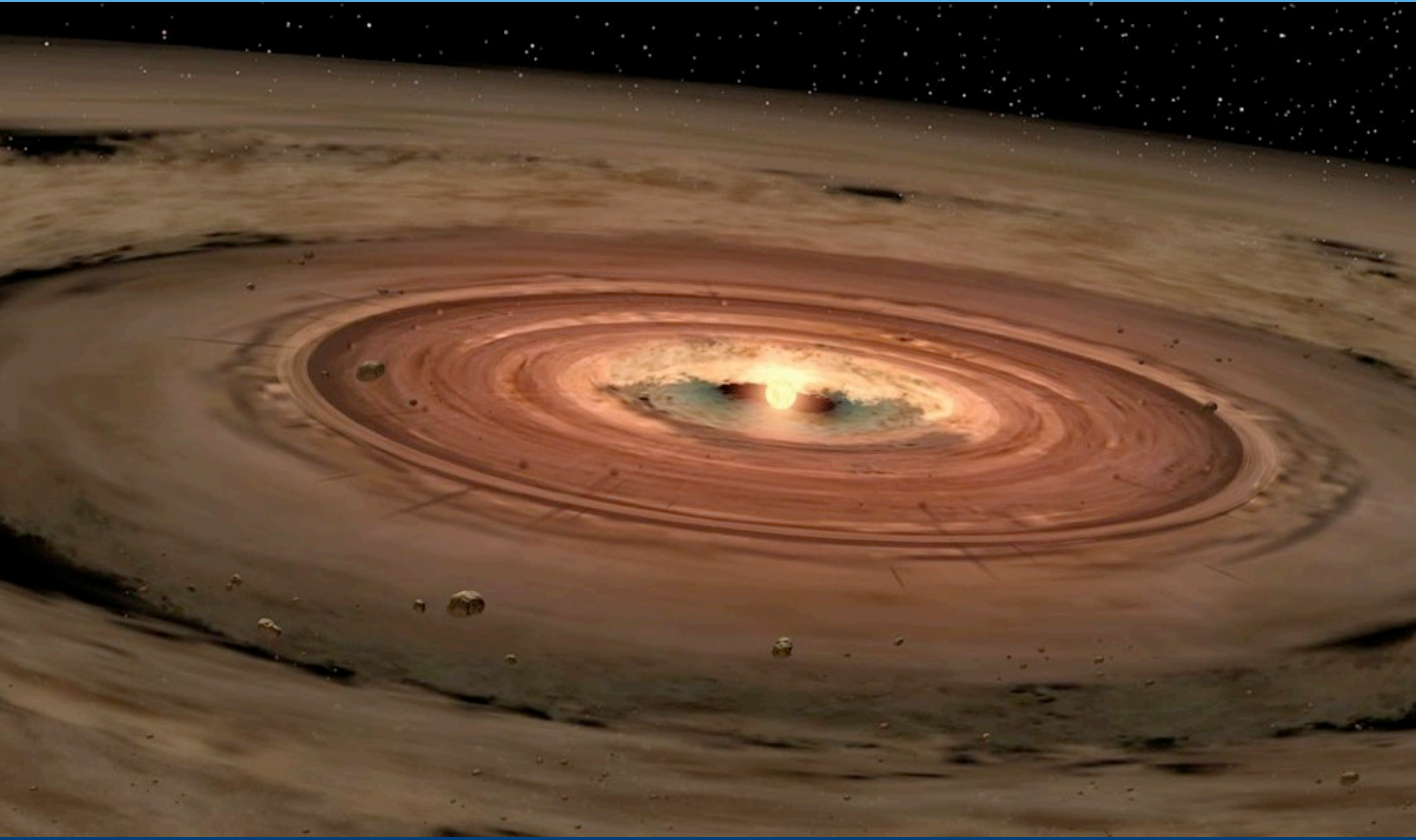
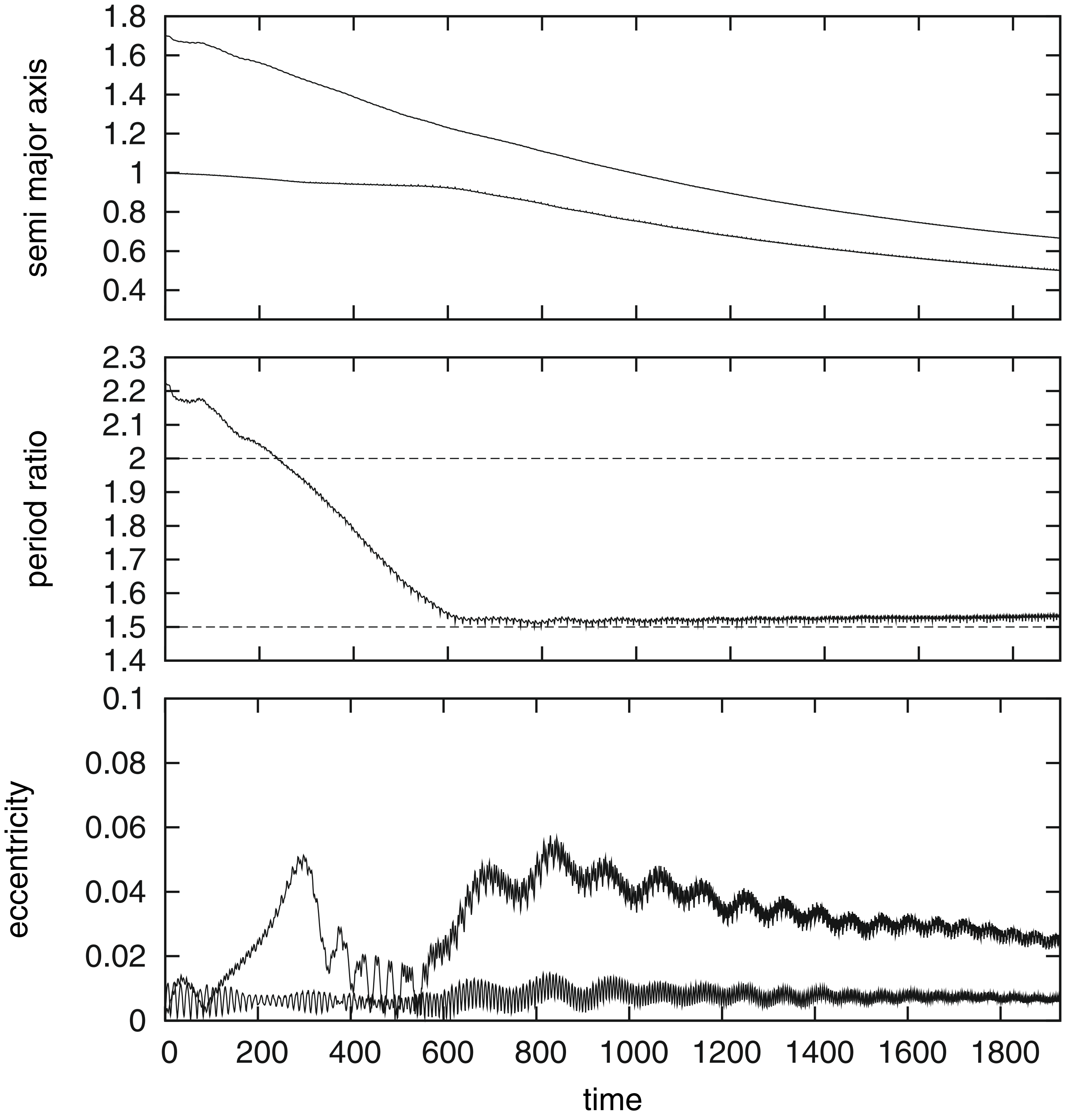


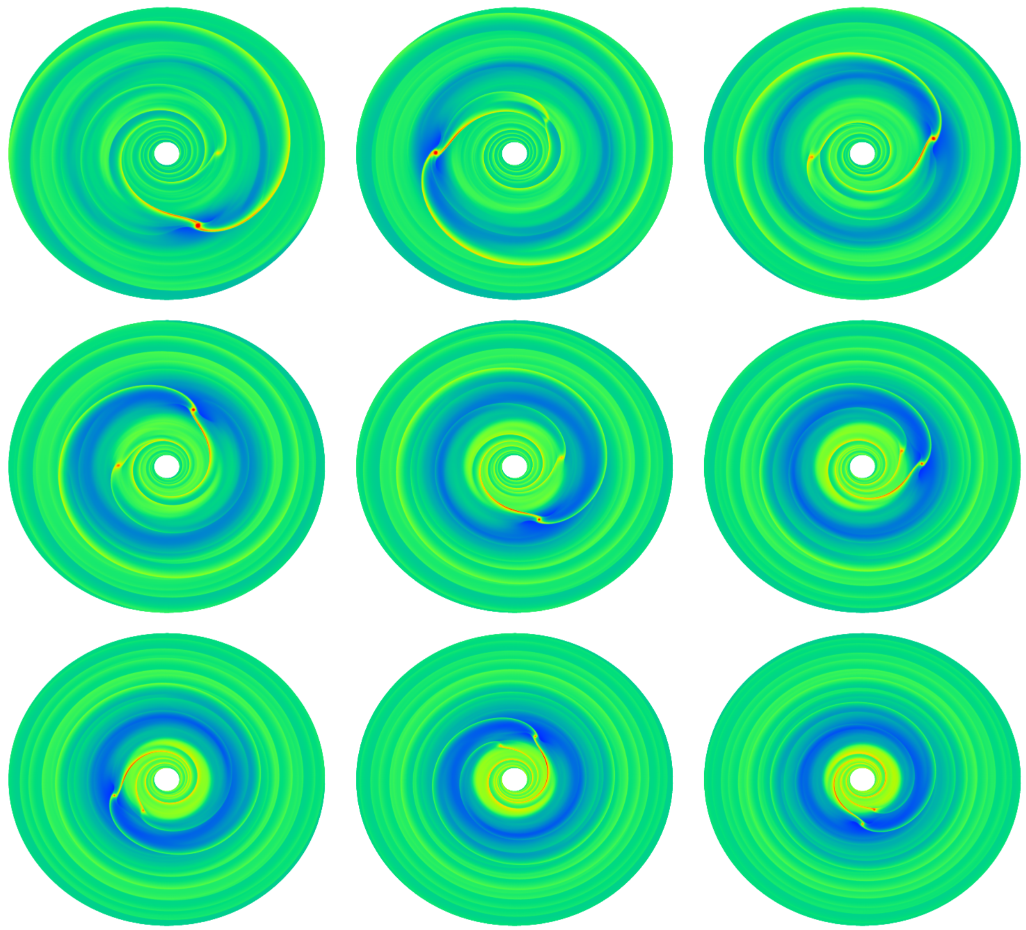
Image credit: NASA/JPL-Caltech

Planet migration

Low mass planet, type I migration, Prometheus code

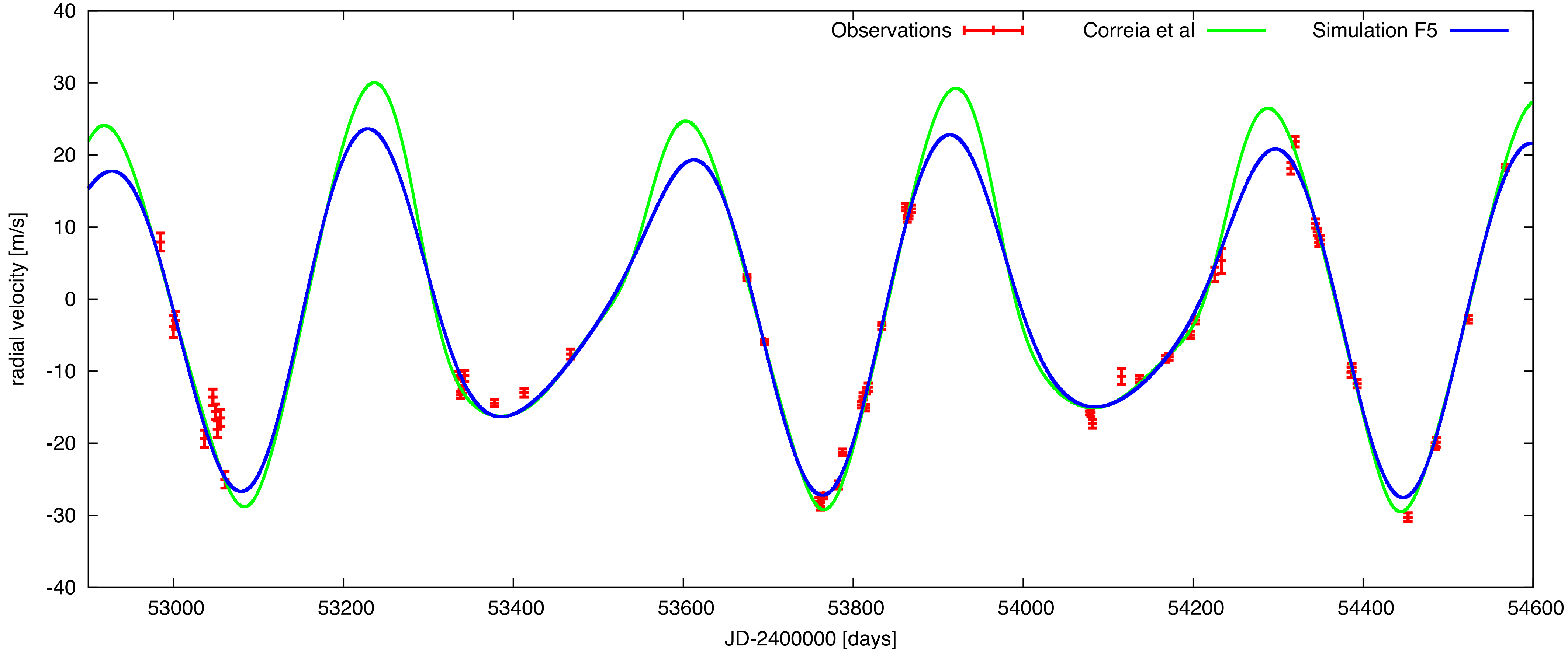
Formation scenario for HD45364





Rein, Papaloizou & Kley 2010

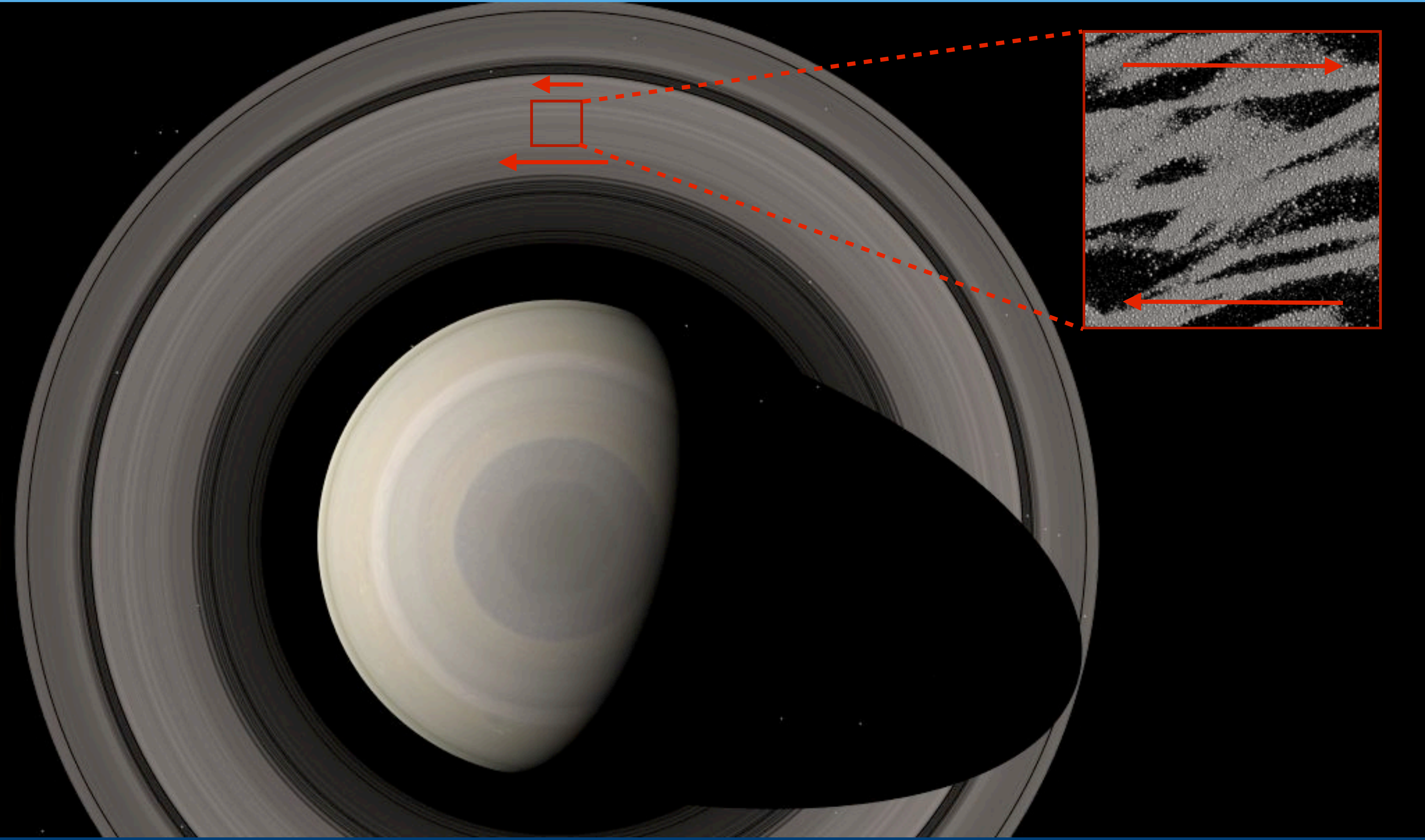
Formation scenario leads to predictions



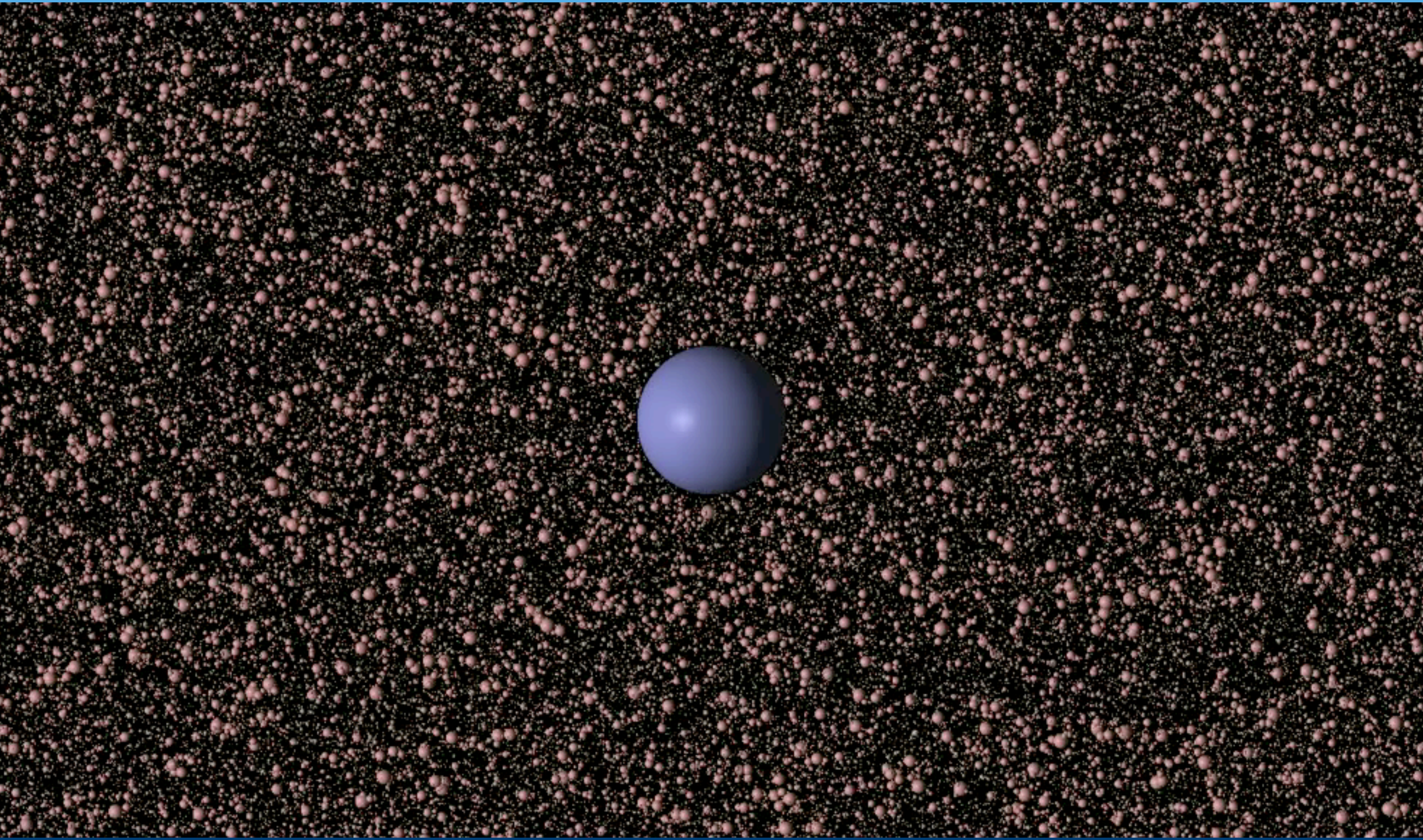
Parameter	Unit	Correia et al. (2009) b	c	Simulation **F5** b	c
$M \sin i$	$[\mathrm{M_{Jup}}]$	0.1872	0.6579	0.1872	0.6579
M_*	$[M_\odot]$	0.82		0.82	
a	[AU]	0.6813	0.8972	0.6804	0.8994
e		0.17 ± 0.02	0.097 ± 0.012	0.036	0.017
λ	[deg]	105.8 ± 1.4	269.5 ± 0.6	352.5	153.9
ϖ^a	[deg]	162.6 ± 6.3	7.4 ± 4.3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

Rein, Papaloizou & Kley 2010

Saturn is a smaller version of the Solar System

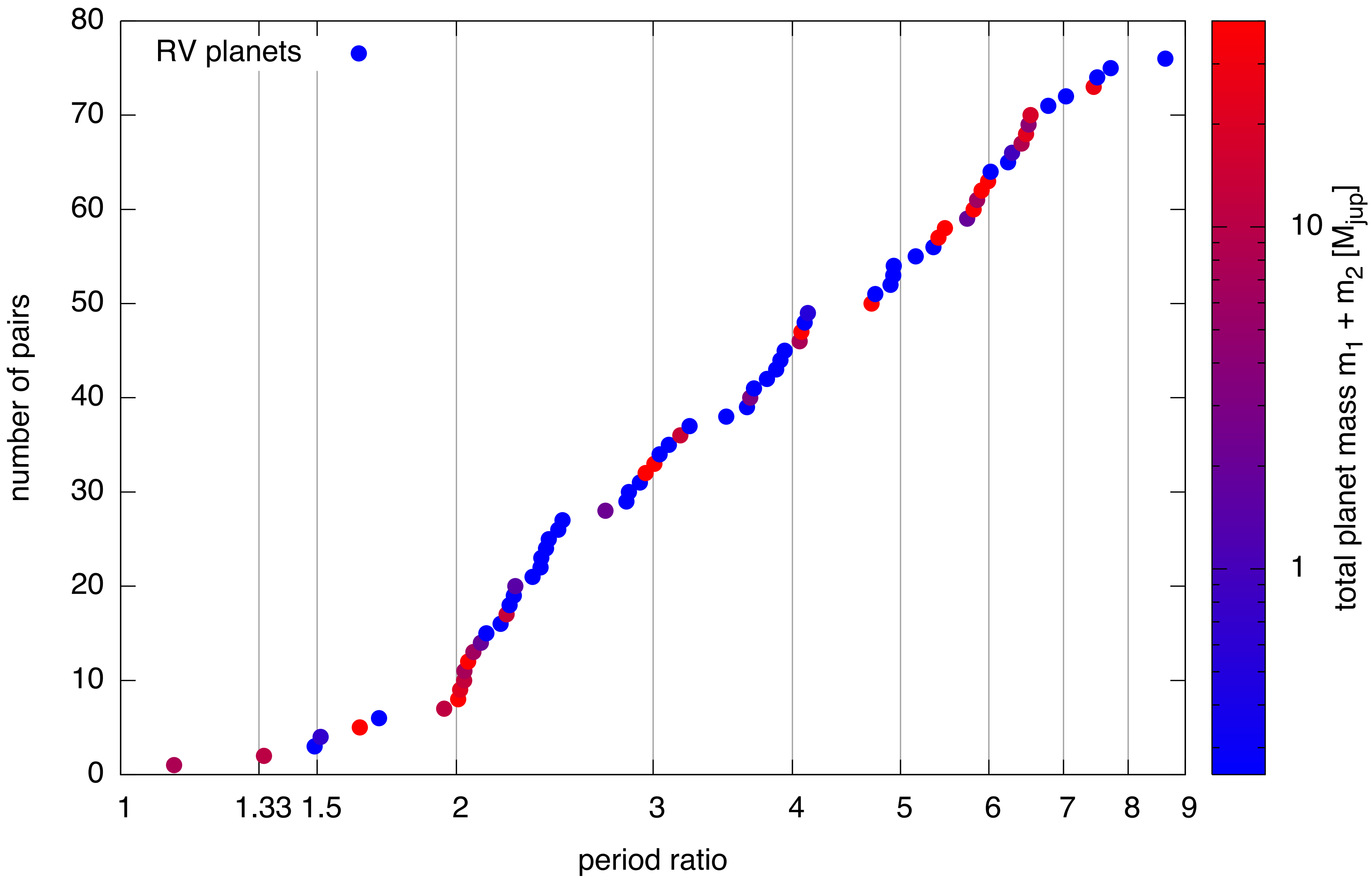


Stochastic Migration



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

Radial velocity planets

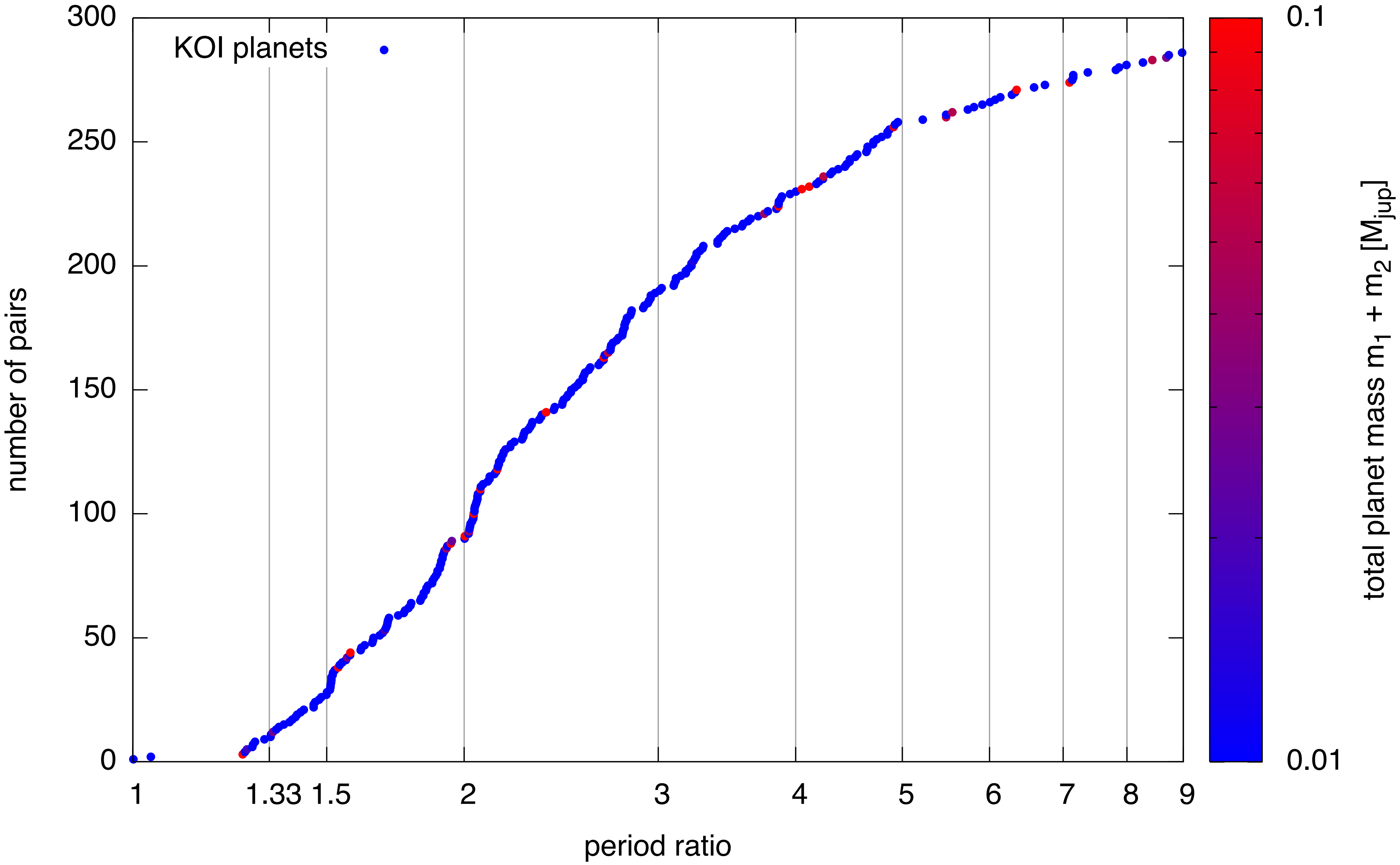


Cumulative period ratio in multi-planetary systems

- Periods of systems with massive planets tend to pile up near integer ratios
- Most prominent features at 4:1, 3:1, 2:1, 3:2

Rein, Payne, Veras & Ford (2012)

Kepler's transiting planet candidates



- Period ratio distribution much smoother for small mass planets
- Deficiencies near 4:3, 3:2, 2:1
- Excess slightly outside of the exact commensurability

Testing stochastic migration: Method

Architecture and masses from observed KOIs

Placing planets in a MMSN, further out, further apart, randomizing all angles

N-body simulation with migration forces

Testing stochastic migration: Advantages

Comparison of statistical quantities

- Period ratio distribution
- Eccentricity distribution
- TTVs

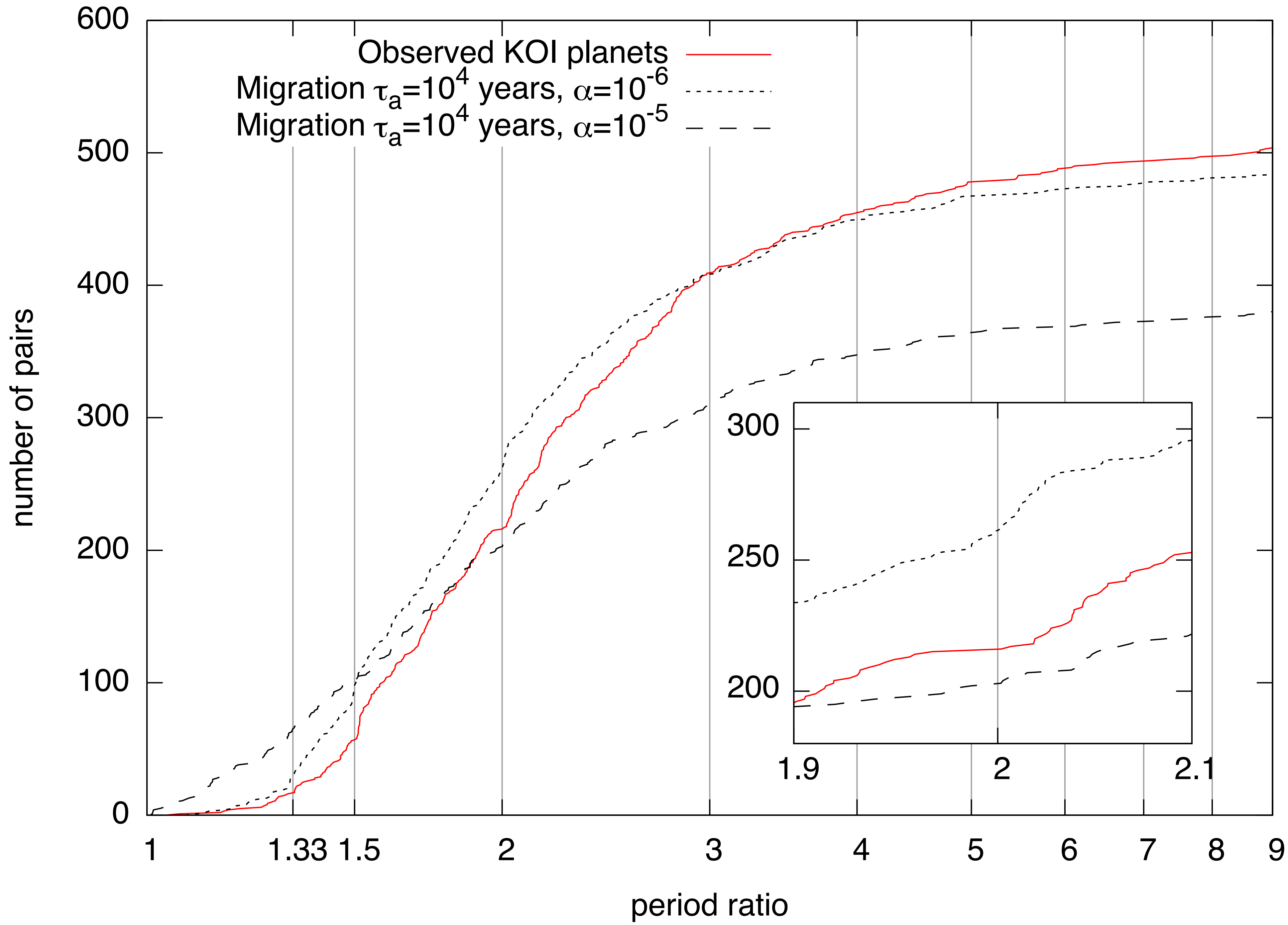
Comparison of individual systems

- Especially interesting for multi-planetary systems
- Can create multiple realizations of each system

No synthesis of a planet population required

- Observed masses, architectures
- Model independent

Preliminary results



Rein 2012, Rein & Papaloizou 2009

Future work

Planet formation models

Physical disk model

- 1D hydrodynamic simulation
- Coupled to N-body simulations

GPU based integrators

- Allows for much bigger samples

Other physical effects

- Tidal damping

Statistical comparison

- Eccentricity, TTV, etc

Other projects

REBOUND

- The only publicly available collisional N-body code
- Hybrid MPI/OpenMP parallelization
- Open Source
- Built-in real-time 3D visualization

Saturn's rings

- Large scale collisional N-body simulations to model the densest parts of the rings
- Radial structure created by the viscous overstability

Exo-moons

- Stability and evolution of exo-planet moons

Symplectic integrators

- First symplectic integrator for shearing sheet (Hill's approximation)
- High precision numerical integrator for different problems

Debris discs

- New REBOUND module to study planet signatures in debris discs

Open Exoplanet Catalogue

- Collaborative project to keep track of all planet discoveries
- Open source, distributed, version controlled

Summary

The formation of multi-planetary systems

Multi-planetary systems provide the richest, most interesting dataset related to extra-solar planets.

This data is essential when we want to explaining the otherwise unobservable formation phase of planets.

We already learned a lot. For example, the system HD45364 formed in a massive, thick disk via fast migration. Other systems: HD128311, HD200964, Kepler-36.

Very soon, we will understand how planets in the Kepler sample formed. The most promising idea involves a turbulent protoplanetary disk and stochastic migration.

Other ongoing/future projects

REBOUND Code
Symplectic integration methods
Saturn's Rings

Open Exoplanet Catalogue
Exo-moons and Exo-Saturns
Debris discs