Institute for Advanced Study

I. Formation of multi-planetary systems
II. Open Exoplanet Catalogue

Hanno Rein @ Niels Bohr Institute, Copenhagen, February 2013


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

Formation of multi-planetary systems

Planet formation

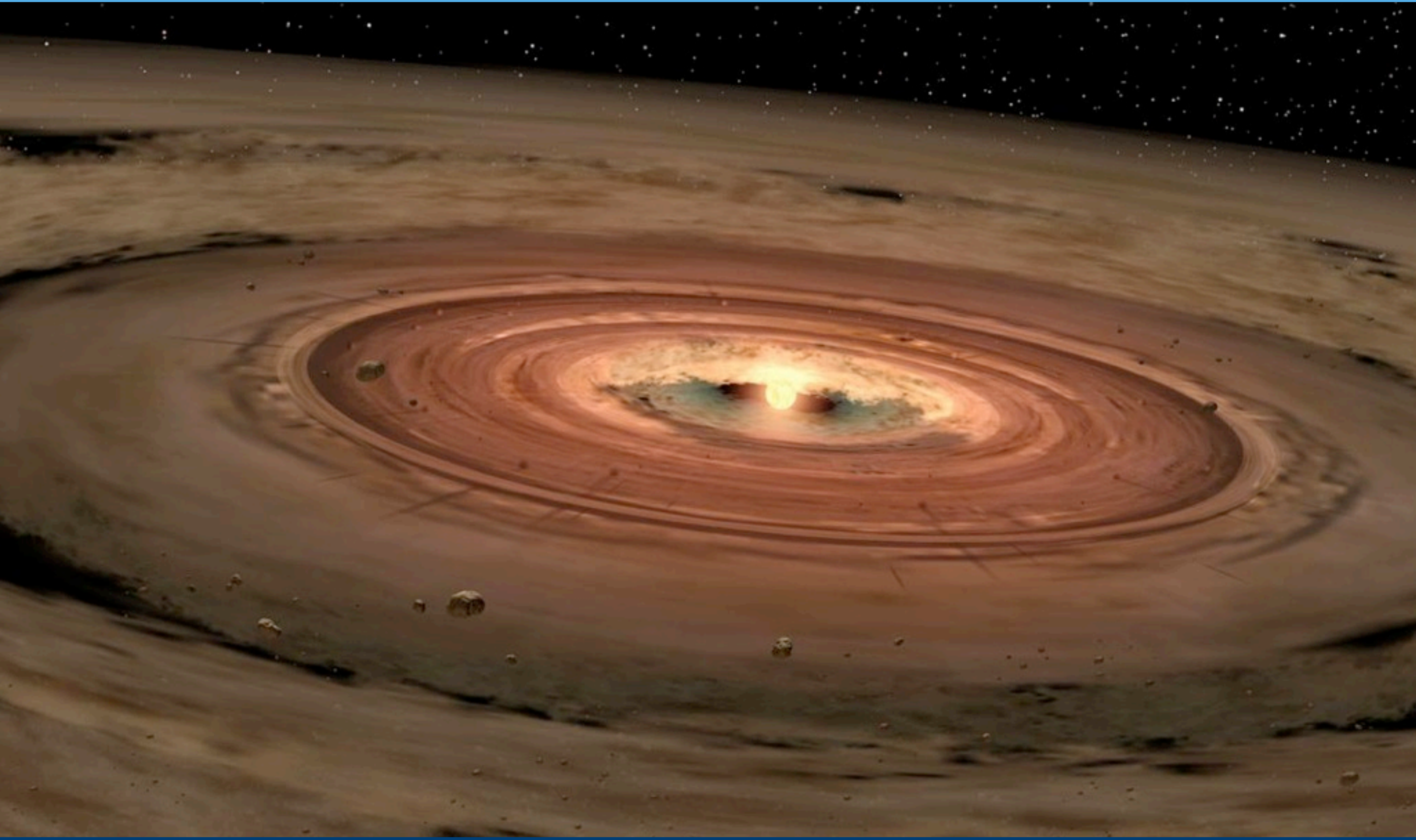
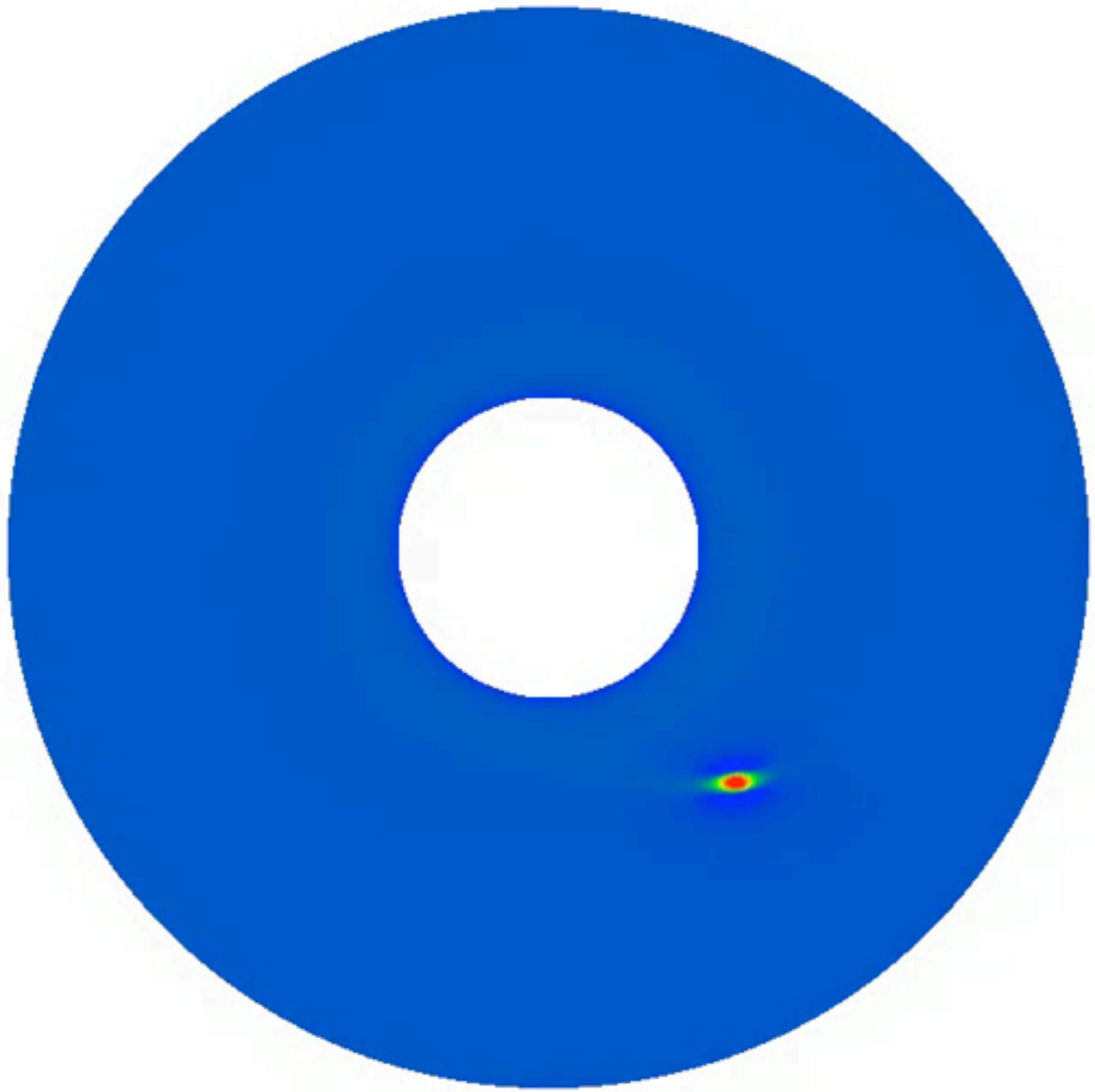


Image credit: NASA/JPL-Caltech

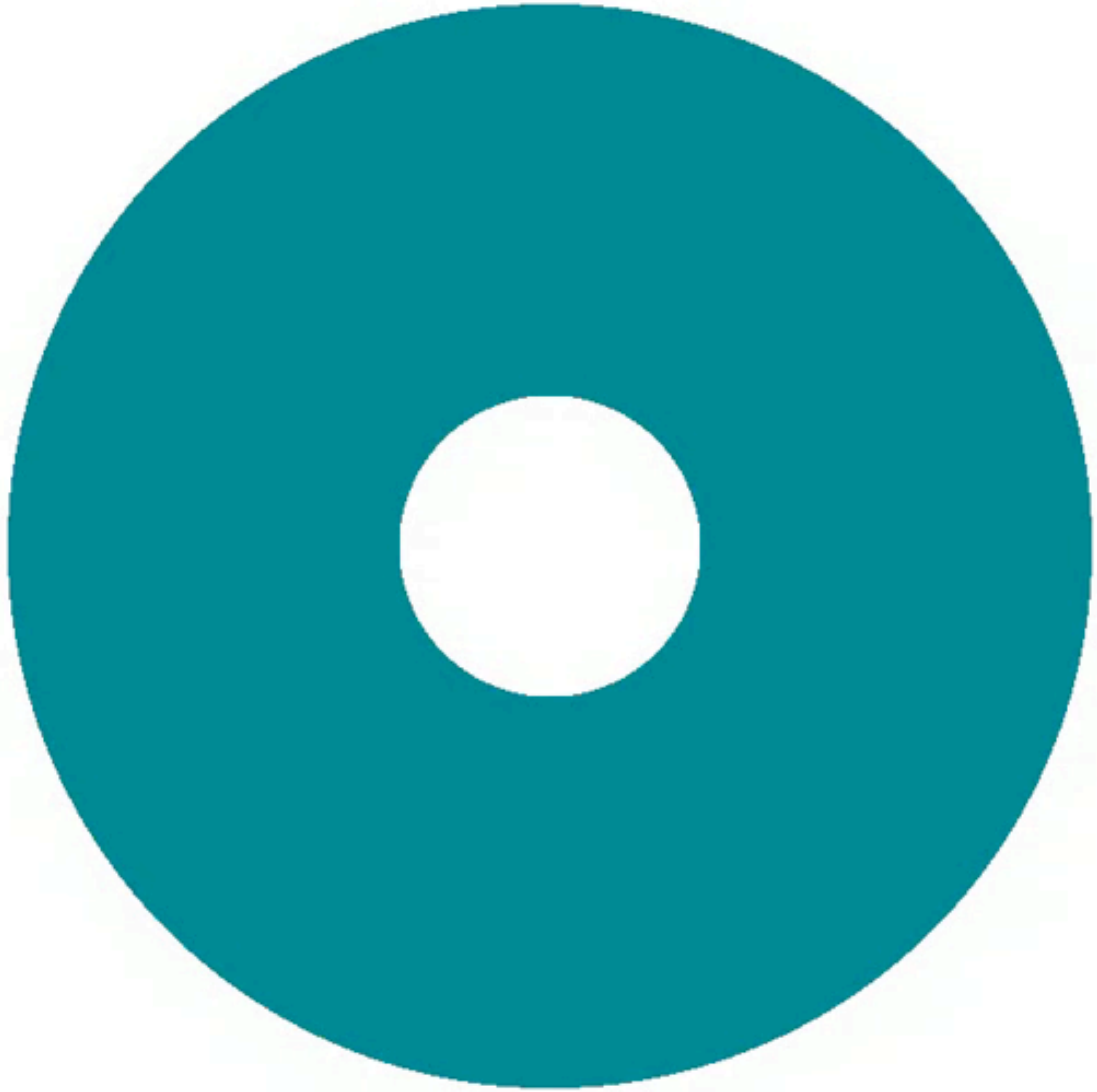
Migration - Type I

- Low mass planets
- No gap opening in disc
- Migration rate is fast
- Depends strongly on thermodynamics of the disc



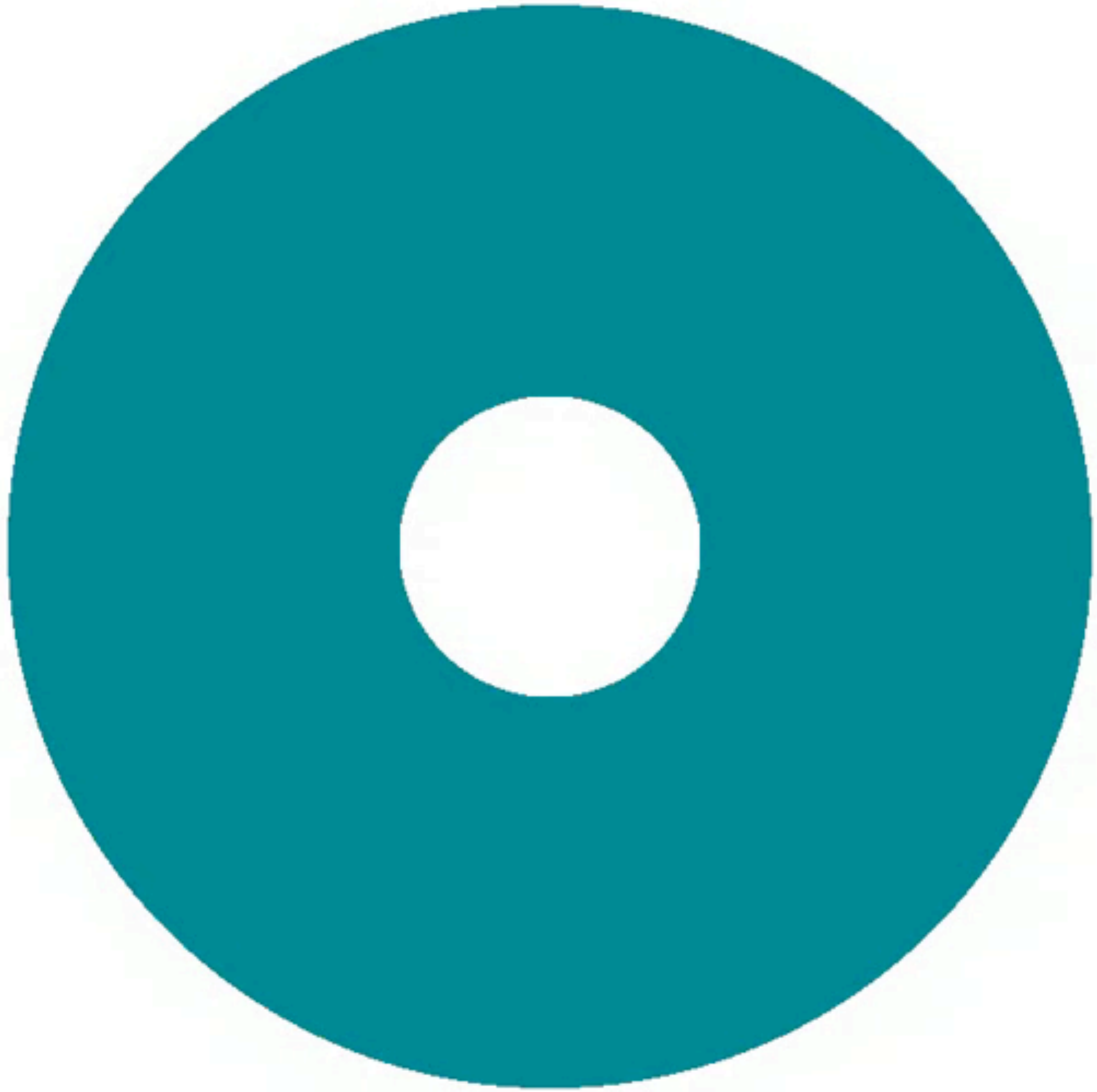
Migration - Type II

- Massive planets (typically bigger than Saturn)
- Opens a (clear) gap
- Migration rate is slow
- Follows viscous evolution of the disc



Migration - Type III

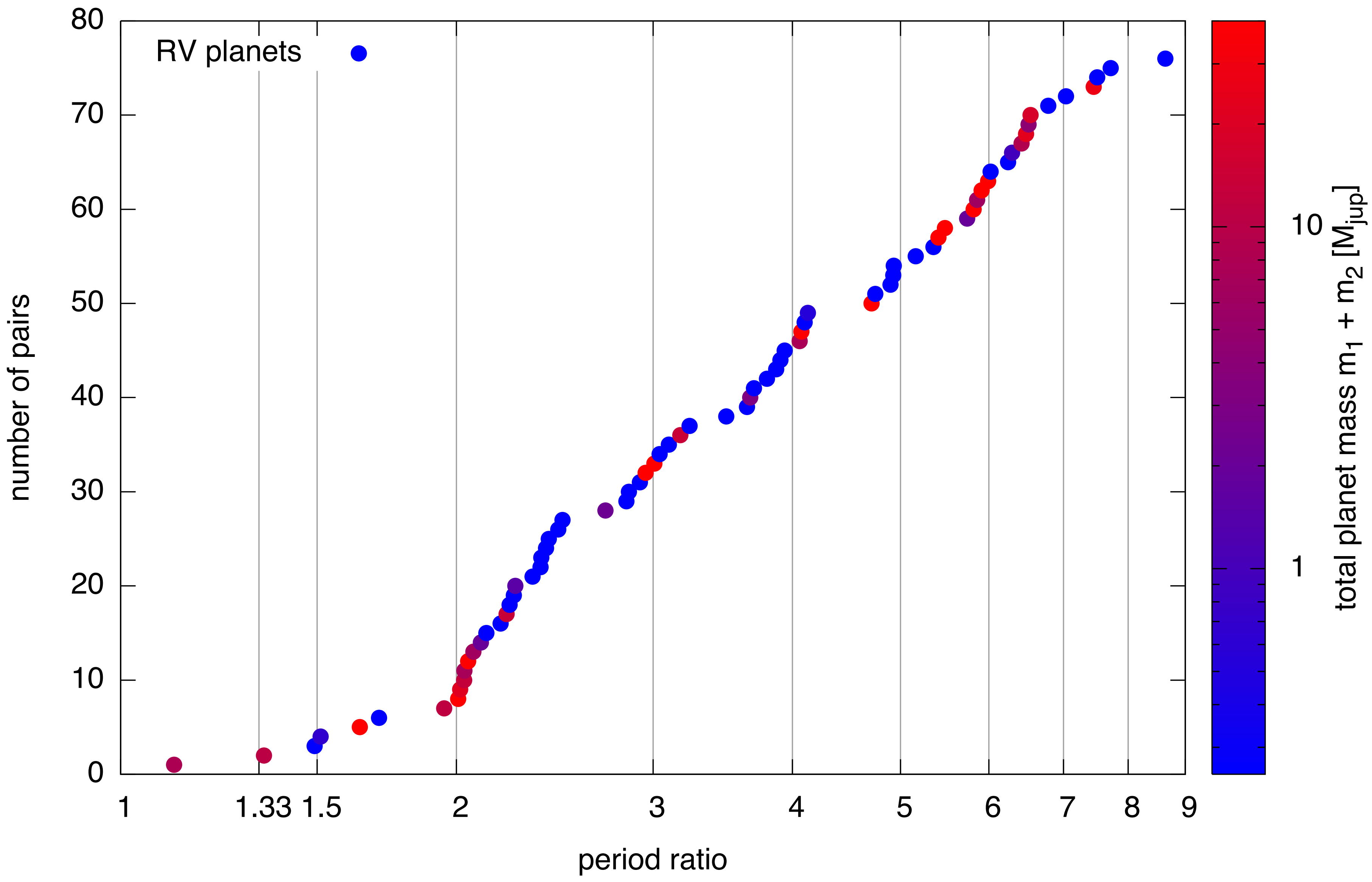
- Massive disc
- Intermediate planet mass
- Tries to open gap
- Very fast, few orbital timescales



Take home message I

planet + disc = migration

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

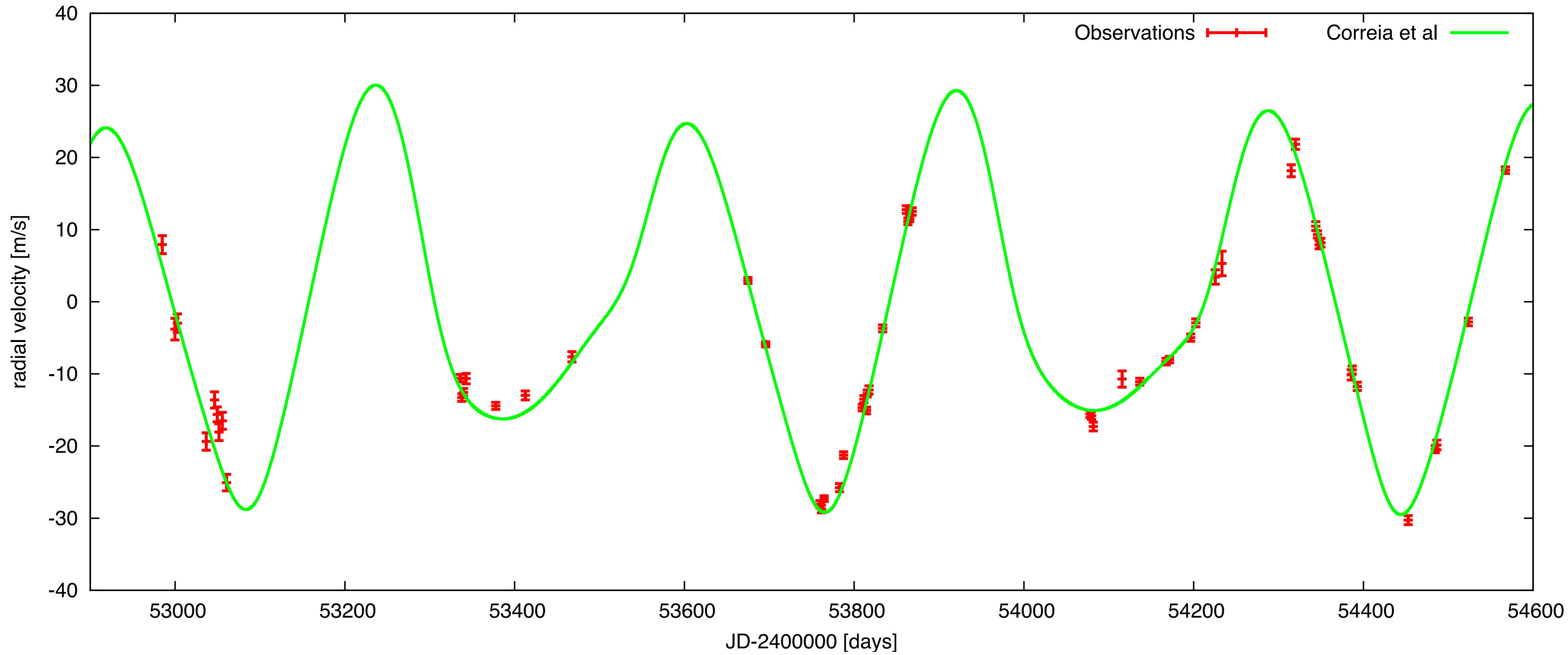
Rein, Payne, Veras & Ford (2012)

Take home message II

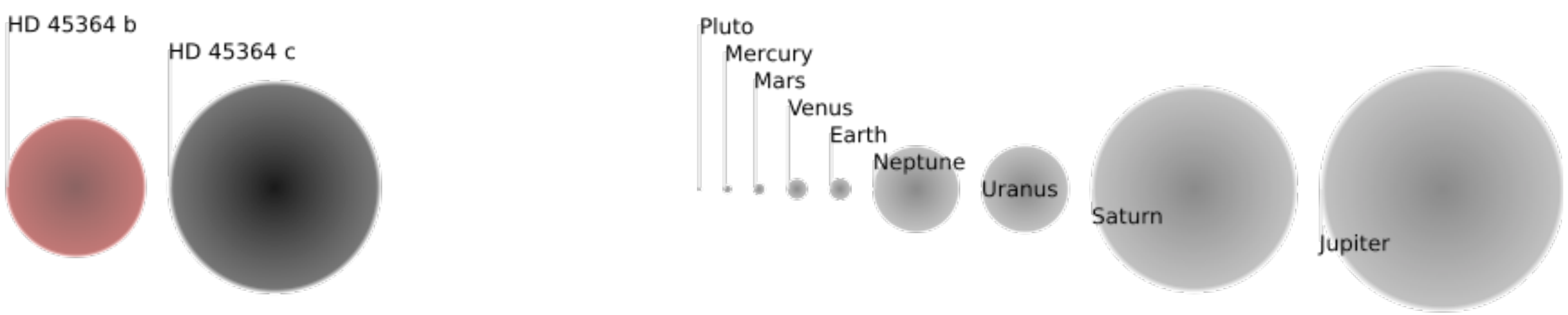
2 planets + migration = resonance

HD45364

HD45364

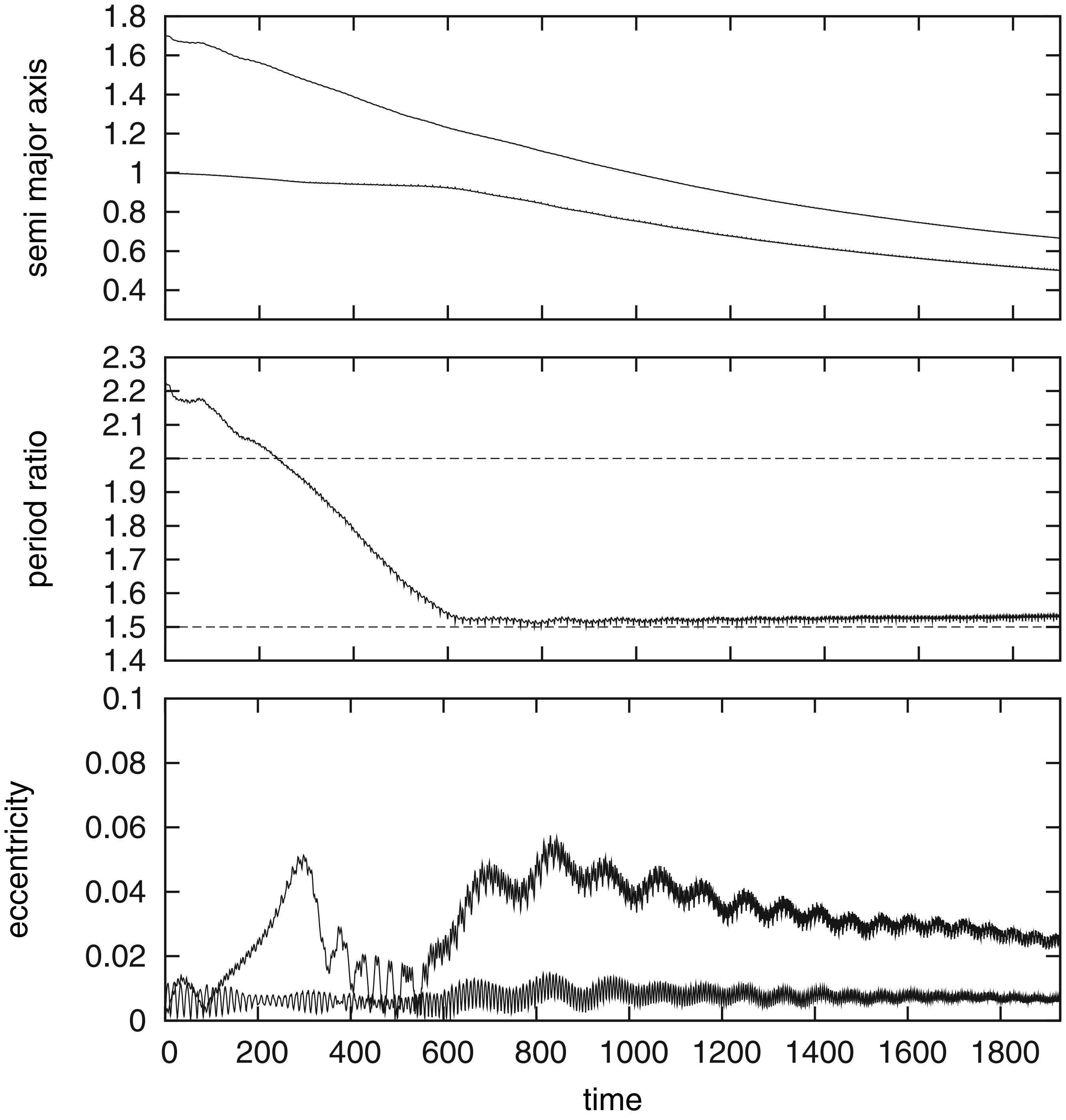


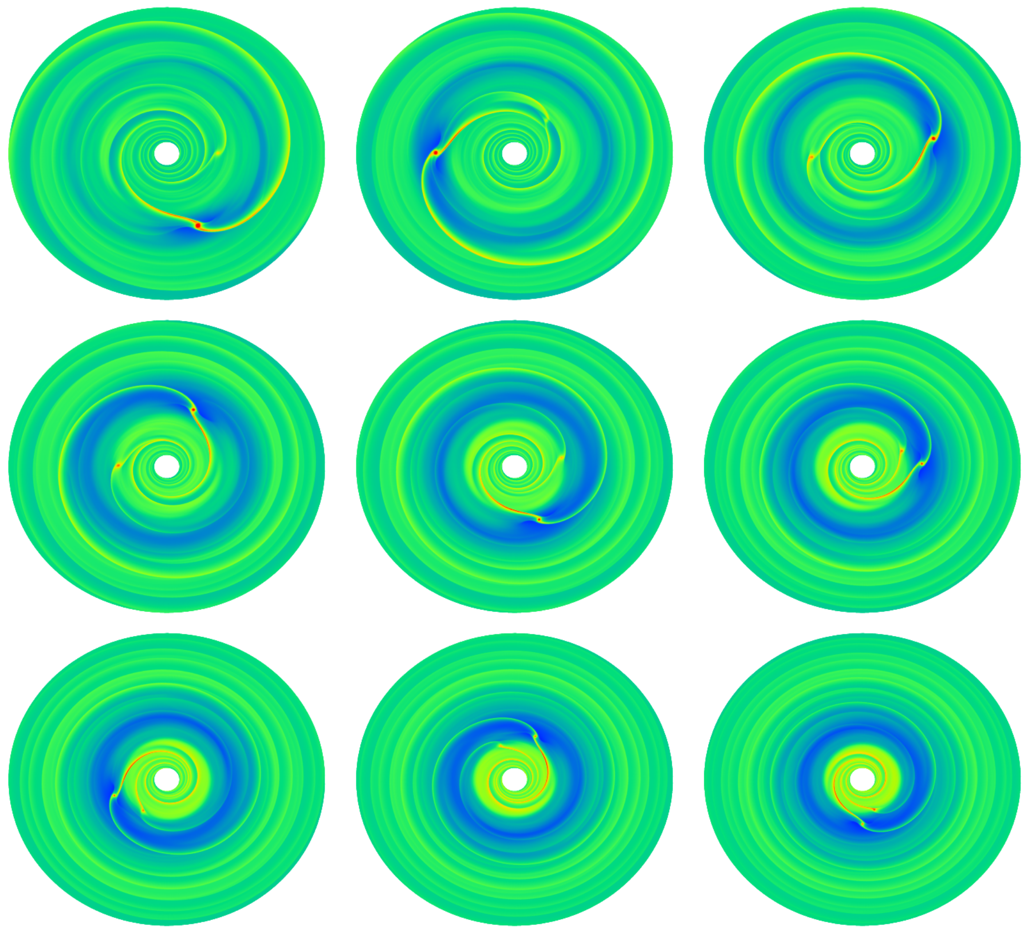
Observations
Correia et al
radial velocity [m/s]
JD-2400000 [days]
40
30
20
10
0
-10
-20
-30
-40
53000
53200
53400
53600
53800
54000
54200
54400
54600



HD 45364 b
HD 45364 c
Pluto
Mercury
Mars
Venus
Earth
Neptune
Uranus
Saturn
Jupiter

Formation scenario for HD45364





Rein, Papaloizou & Kley 2010

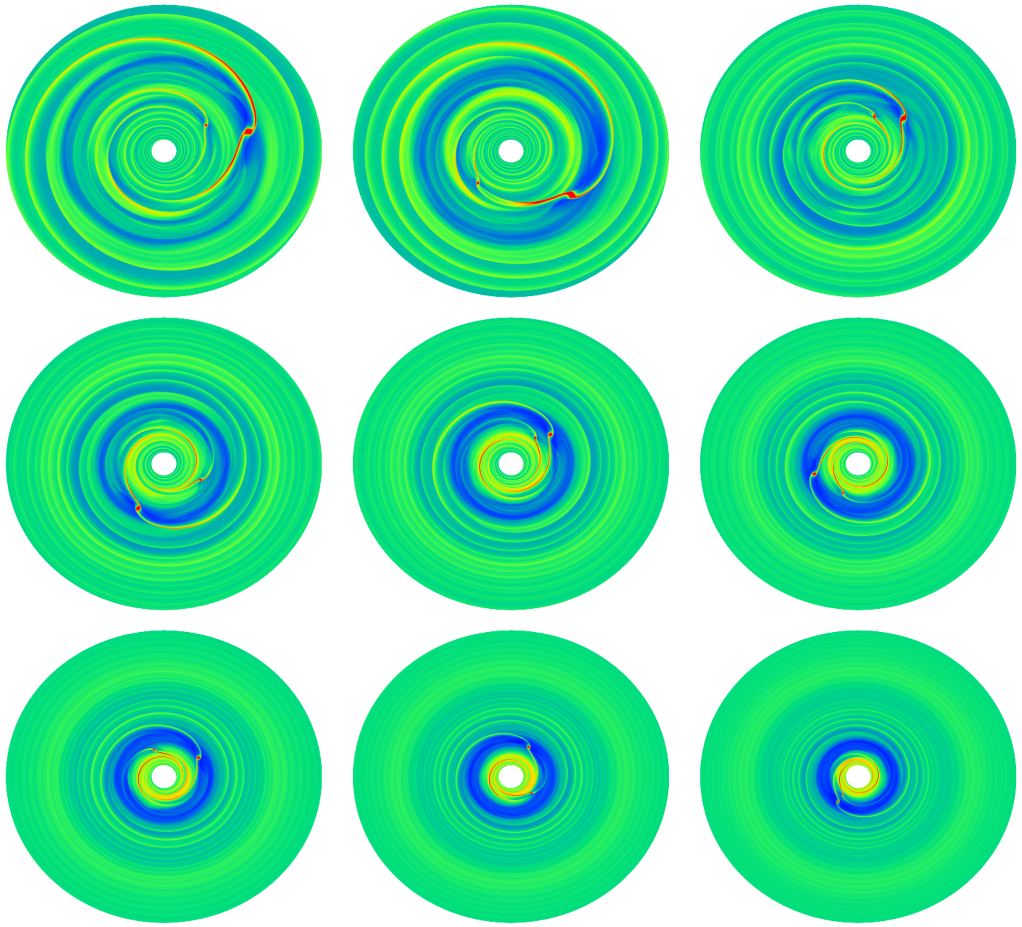
Formation scenario for HD45364

Massive disc (5 times MMSN)

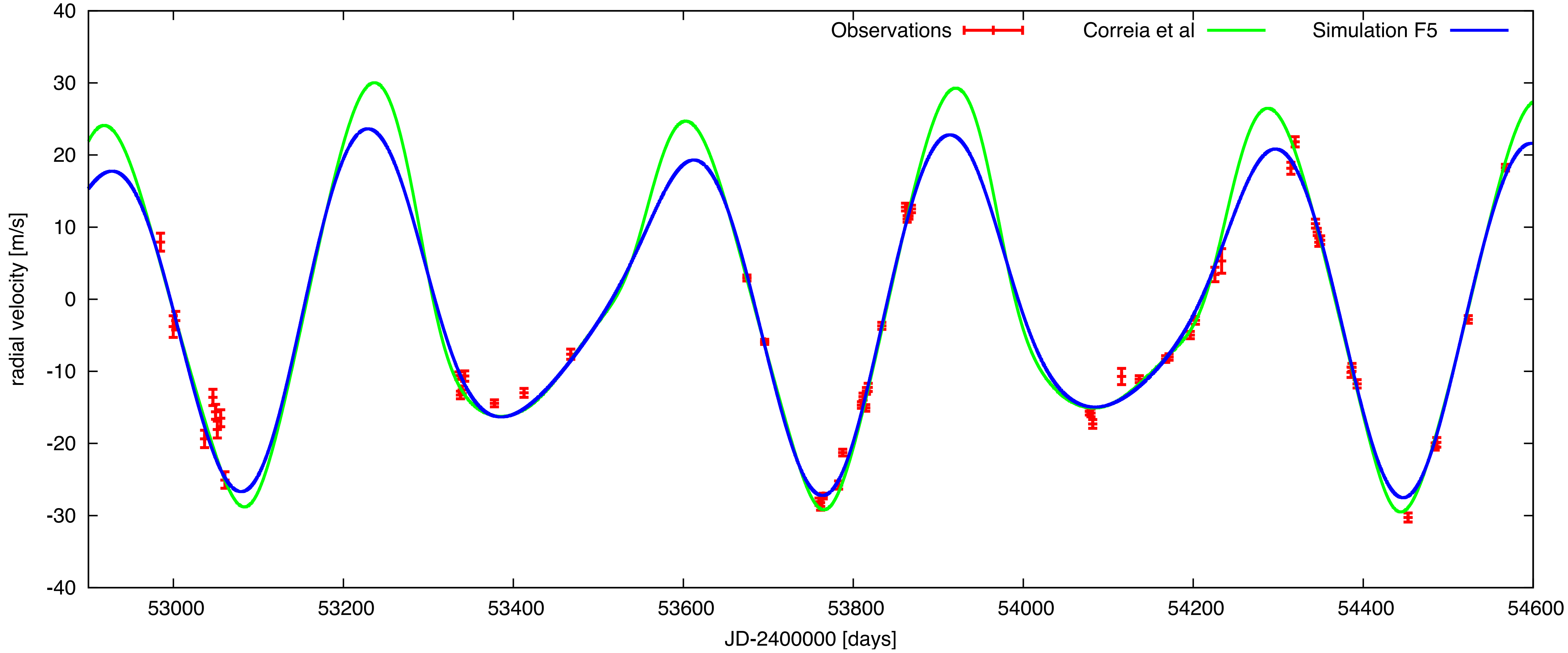
- Short, rapid Type III migration
- Passage of 2:1 resonance
- Capture into 3:2 resonance

Large scale-height (0.07)

- 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	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

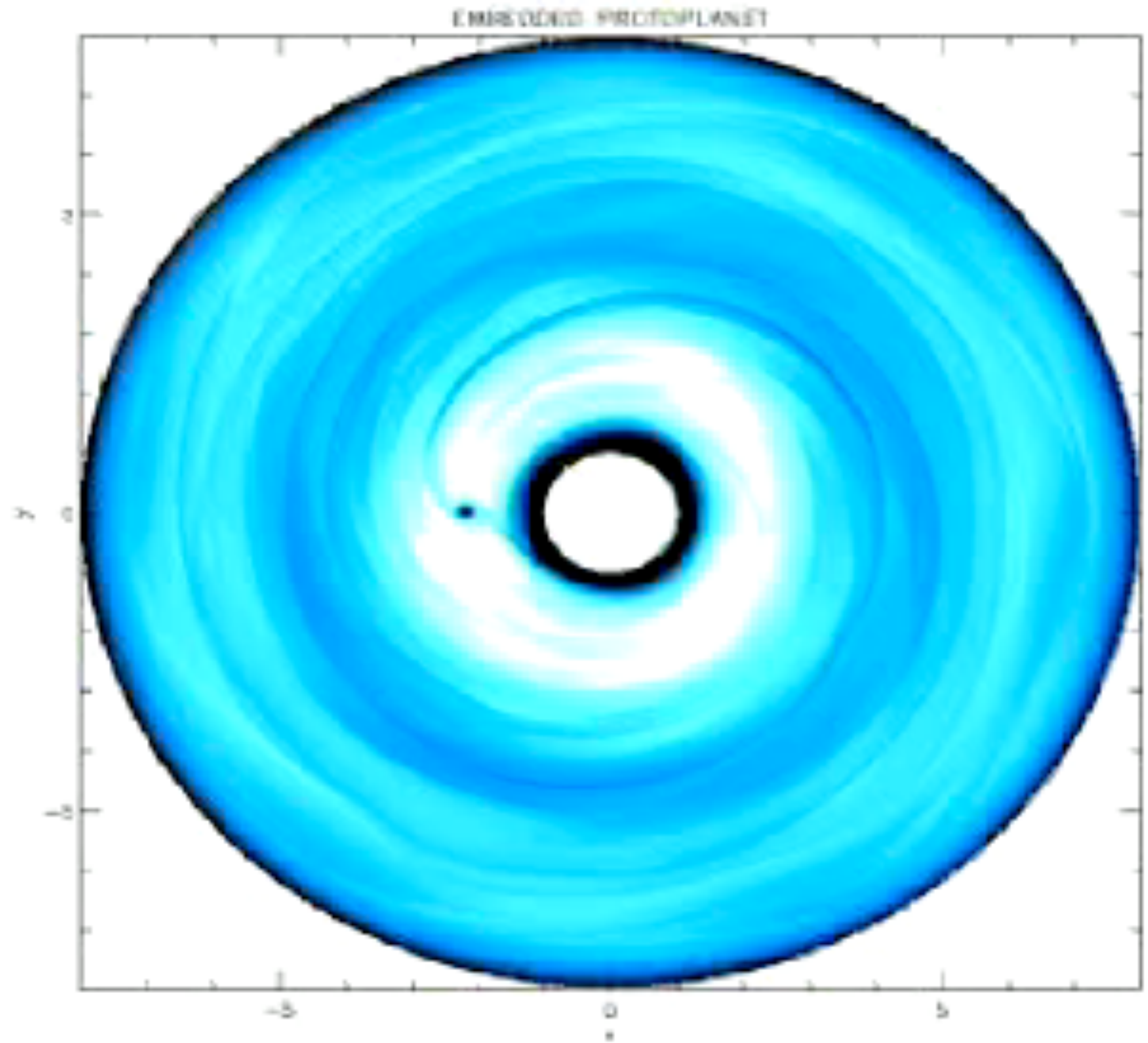
Take home message III

Resonant systems tell us something about the (currently) unobservable formation phase.

Migration in a turbulent disc

Turbulent disc

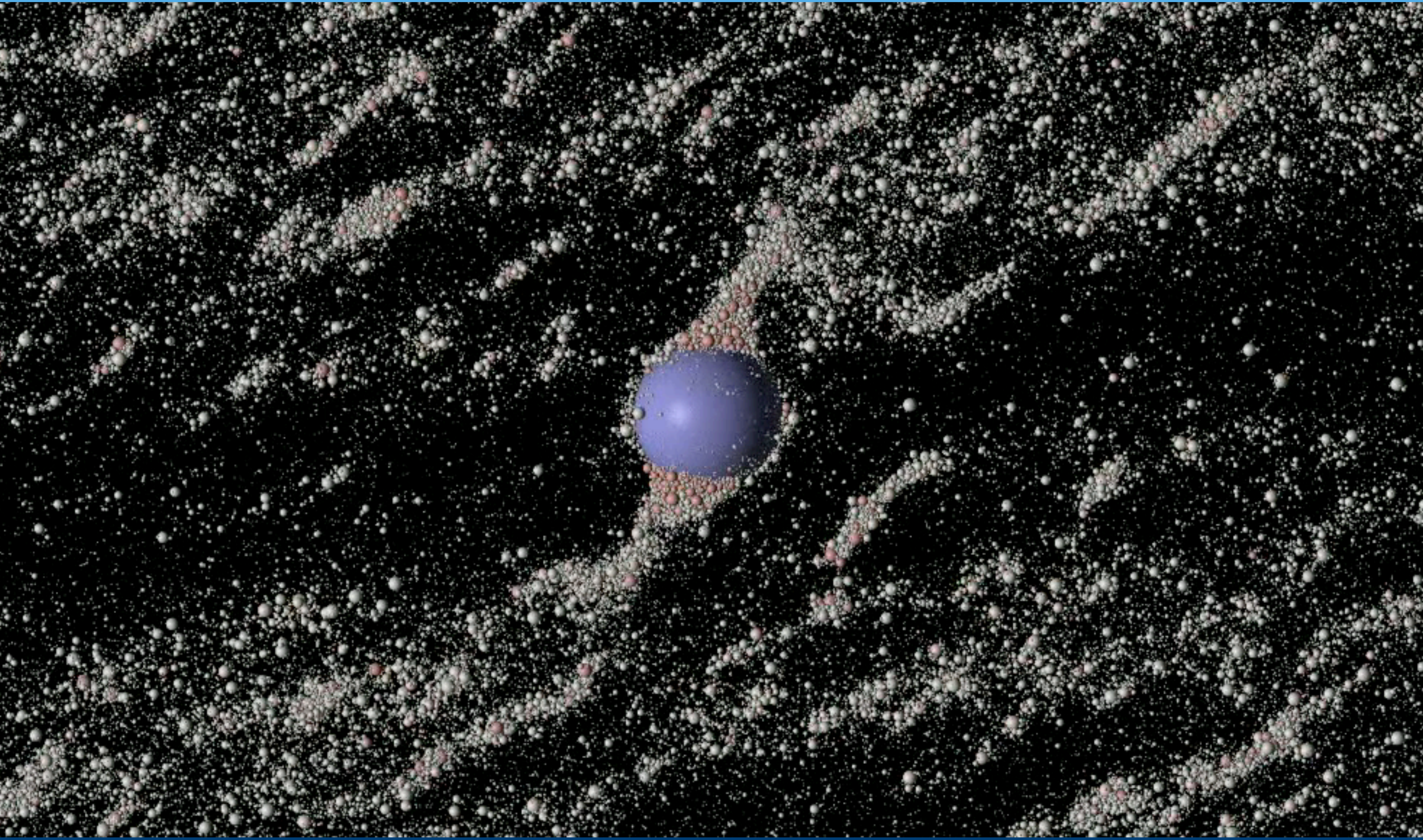
- Angular momentum transport
- Magnetorotational instability (MRI)
- Density perturbations interact gravitationally with planets
- Stochastic forces lead to random walk
- Large uncertainties in strength of forces



Animation from Nelson & Papaloizou 2004

Random forces measured by Laughlin et al. 2004, Nelson 2005, Oischi et al. 2007

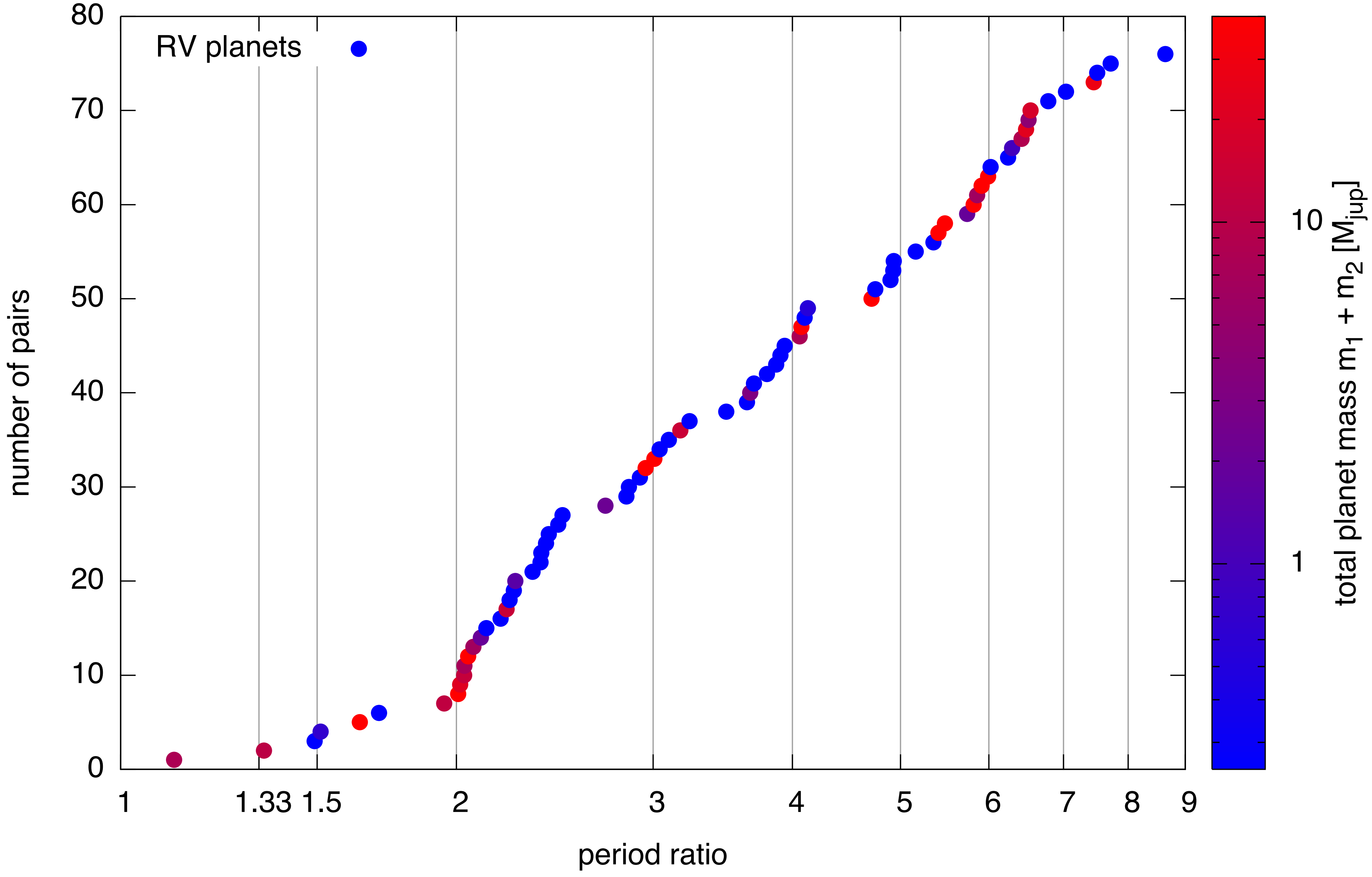
Stochastic Migration



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

REBOUND Demo

Radial velocity planets

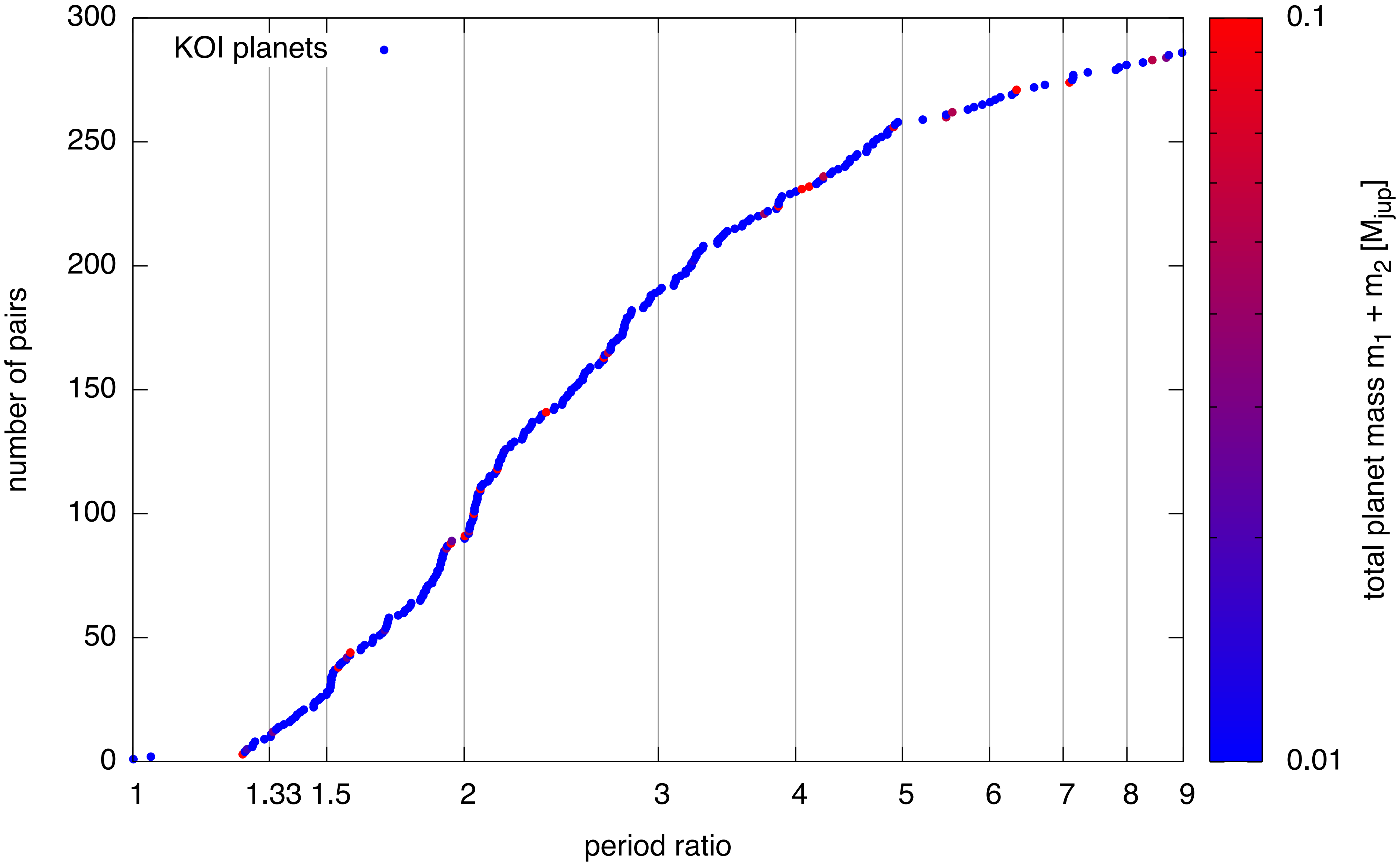


Cumulative period ratio in multi-planetary systems

- 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

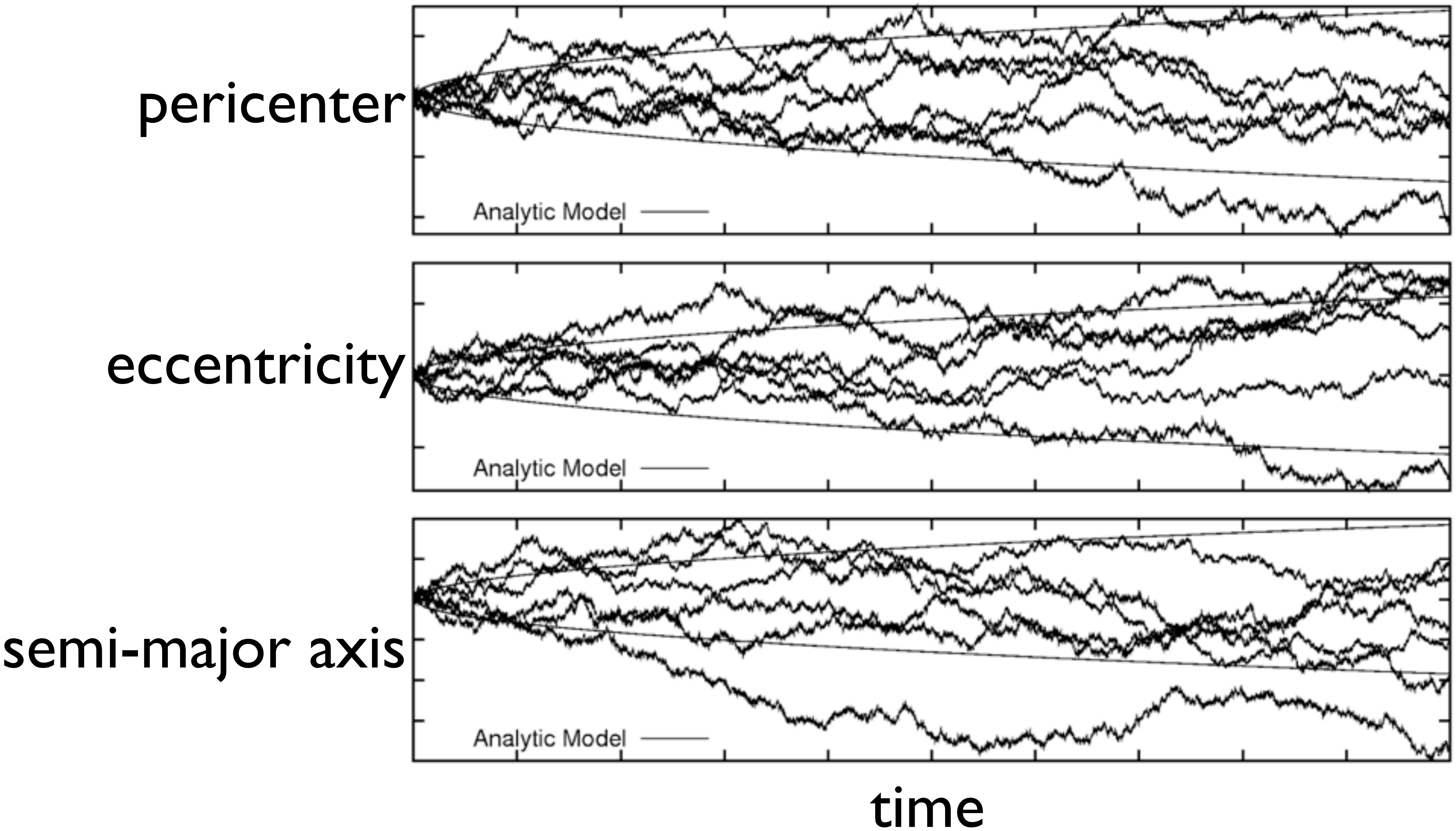
Rein, Payne, Veras & Ford (2012)

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

Random walk



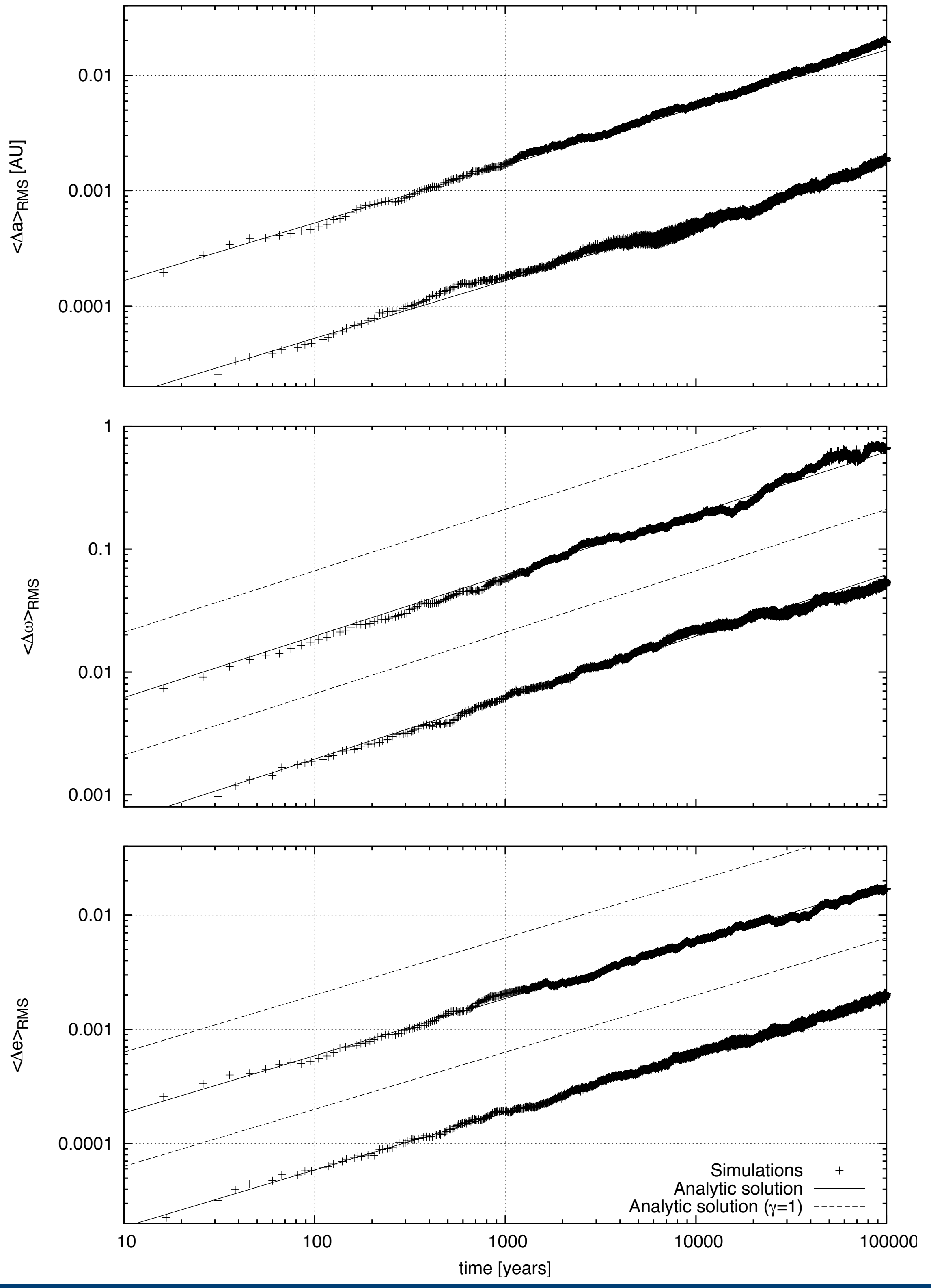
Rein & Papaloizou 2009

Analytic growth rates for 1 planet

$$(\Delta a)^2 = 4\frac{Dt}{n^2}$$

$$(\Delta\varpi)^2 = \frac{2.5}{e^2}\frac{\gamma Dt}{n^2a^2}$$

$$(\Delta e)^2 = 2.5\frac{\gamma Dt}{n^2a^2}$$



Rein & Papaloizou 2009, Adams et al 2009, Rein 2010

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

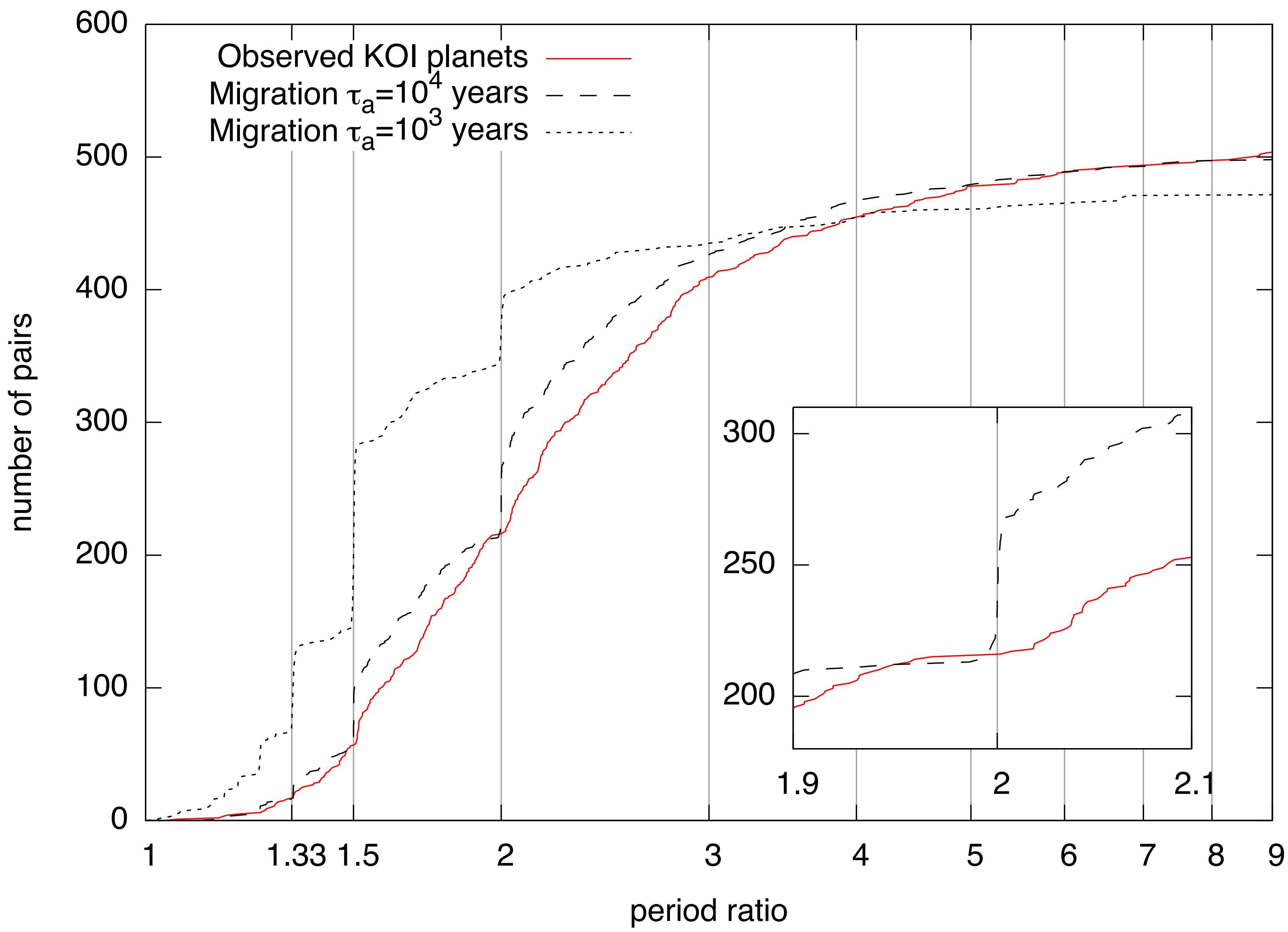
Comparison of individual systems

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

No synthesis of a planet population required

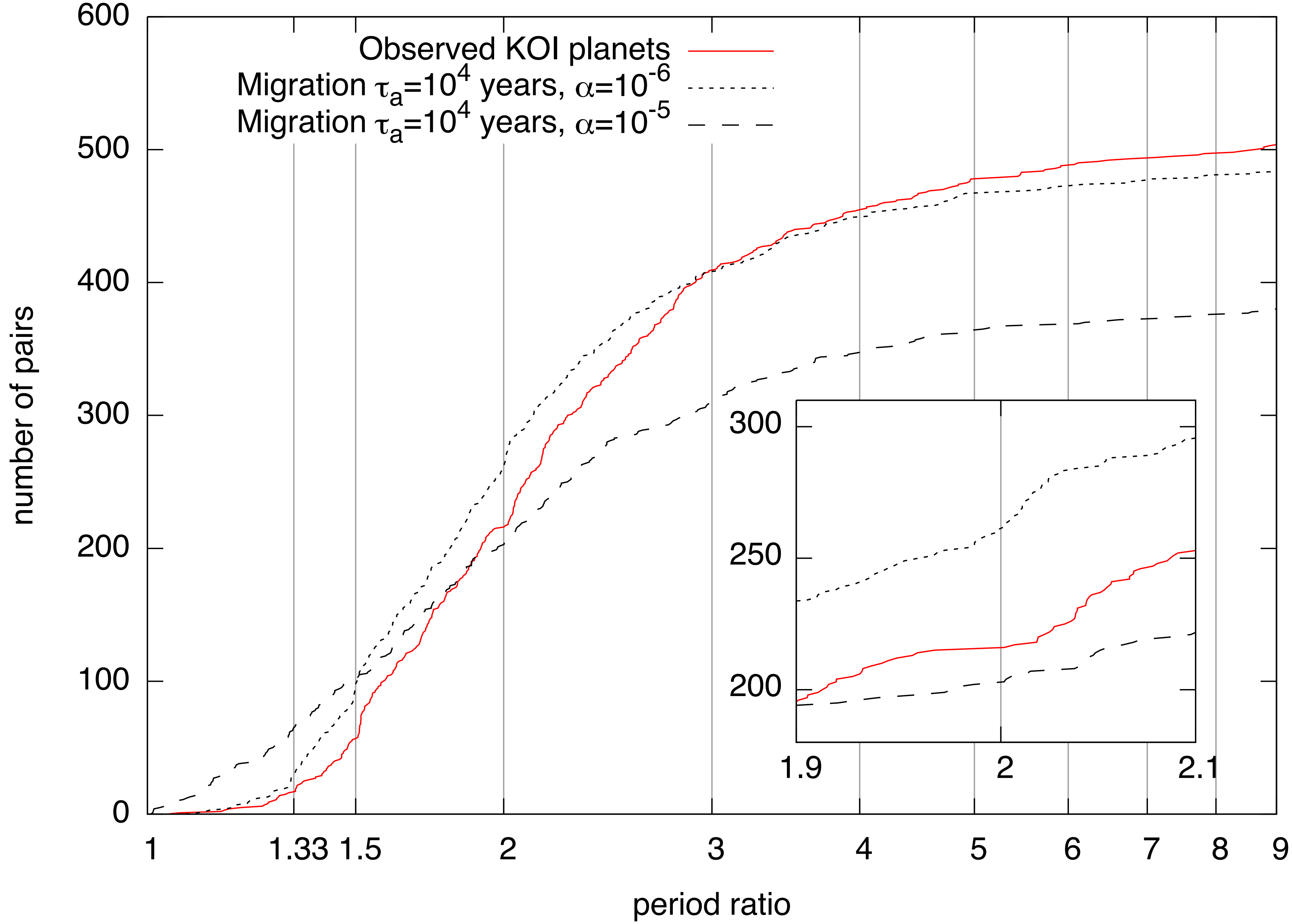
- Observed masses
- Observed architectures

Result 1: Smooth migration alone is not enough



Rein 2012

Result II: Stochastic migration works much better



Rein 2012, Rein & Papaloizou 2009

Take home message IV

Small mass planets might show signs of stochastic migration.

Conclusions Part I

Conclusions

Formation of multi-planetary systems

The number of multi-planetary systems increases almost every week.

Kepler discovered a large number of planets but most are not suitable for a detailed individual analysis.

Multi-planetary system provide insight in otherwise unobservable formation phase.
We already understand many details of the migration history of exoplanets.

GJ876	formed in the presence of a disc with dissipative forces
HD45364	formed in a massive disc
HD128311	formed in a turbulent disc
Kepler planets	formed in a disk, pushed out of resonance by stochastic migration

.... not the end of the story ....

Institute for Advanced Study

Open Exoplanet Catalogue

Hanno Rein

Other exoplanet catalogues

Centralized

- Impossible to correct typos, add data without sending an e-mail to the person in charge
- Closed ecosystem

Slow and outdated

- It can take days/weeks/months for new planets to be added
- Maintainer can be holiday or abandon the project

Web-based

- Website are badly written
- Requires flash or java plugin
- Need a constant internet connection
- Restricted to a very limited, predefined set of possible queries

Old-fashioned formats

- Static tables are not adequate to represent diverse dataset
- Almost impossible to include binary/triple/quadruple systems
- Not flexible when adding new data
- Unintuitive to parse

Open Exoplanet Catalogue

Open source philosophy

- Unrestrictive MIT license
- Community project
- Everyone can contribute and modify data
- Everyone can expand it
- Distributed, no need for a server/website
- Private clones with confidential data

Based on git

- Distributed version control system
- Used by Linux kernel and most other open source projects
- Every single value, every change ever made is logged, verifiable

Ready to go

- 674 systems, 51 binary system, 870 exoplanets, 9 solar system objects, 2740 KOI objects
- ~10 million users

Hierarchical data structure

- Uses plain XML
- Can represent arbitrary configurations in systems with stellar multiplicity >1
- Extremely easy and intuitive to parse in almost any language
- Compresses extremely well
- size ~ 100KB

Demo

OpenExoplanetCatalogue.com

arXiv:1211.7121