Multi-planetary systems

Hanno Rein

@University of Toronto, Scarborough, March 2013
Projects that I will not talk about today

- Symplectic integrators
- Parallel tree codes
- Open Exoplanet Catalogue
- Viscous overstability
- Stability of exo-moons
- Simulations of dense rings
All discovered extra-solar planets

869 confirmed extra-solar planets

- Super-Jupiters
- (Hot) Jupiters
- Neptunes
- Super-Earths
- Earth-size planets
All multi-planetary systems

869 confirmed extrasolar planets

- Super-Jupiters
- (Hot) Jupiters
- Neptunes
- Super-Earths
- Earth-size planets
There are a lot of planets.
Exoplanet
Confirmed exoplanets: 831
Selected planets: 840

Database
Milky Way
Exoplanet News
Correlation Diagrams
Background Information
About / Add-ons

Exoplanet App by Hanno Rein
Available on the Apple AppStore
Take home message II

The variety of planets and planetary systems is enormous.
Recipe:
1. Planet migration
2. Resonances
1. Planet migration
Planet formation

Image credit: NASA/JPL-Caltech
Smooth migration

2D hydro code Prometheus (Rein 2010)
Stochastic migration

Animation from Nelson & Papaloizou 2004
planet + disc = migration
2. Resonances
2:1 Mean Motion Resonance
Asteroids in resonance with Jupiter
Saturn’s rings are sculpted by resonances
The system Gliese 876

- Massive planets.
- Locked in a resonance.
- Observed with high accuracy.

Open Exoplanet Catalogue (Rein 2012b)
Resonances are special dynamical configurations.
Formation of GJ 876: Resonance capture

- Migration can explain this special resonant configuration
- Both the period ratio and the eccentricities are reproduced
2 planets + migration = resonance
The case of Kepler-36
Kepler-36 c as seen from Kepler-36 b

- Would appear 2.5 times the size of the Moon
- Very close orbits, near a 7:6 resonance
- Very different densities

Carter et al (2012), Frank Melchior, Eric Agol
Snow line

Rocky material

Icy material

Image credit: NASA/JPL-Caltech
Convergent migration in Kepler-36

Successful formation scenario for Kepler-36

- Getting planets of different origin (composition) close together
- Forming stable high order resonances
- Capture probability greatly enhanced by adding a small amount of stochastic migration

Paardekooper, Rein & Kley (in prep)
We find planets where they didn’t form. This is a result of migration.
The formation of HD45364
HD45364

Observations

Formation scenario for HD45364

The semi-major axes, period ratios, and eccentricities for the two planets are shown in the figure. The top panel displays the semi-major axes as a function of time, with the inner planet's semi-major axis decreasing significantly. The middle panel shows the period ratio, where the ratio values are indicated by dashed lines, suggesting a change in migration pattern. The bottom panel illustrates the eccentricity over time, with periods of increased eccentricity indicated, particularly in the early stages.

The simulation uses a disc aspect ratio of $a_1/D_{	ext{grid}}$ with a disc aspect ratio of 0.02, and the disc aspect ratio is a factor that affects the migration rates as the planets grow. The inner planet is embedded and interacts strongly with the inner disc, and after the planets went into divergent migration, the inner planet is not in a rapid accretion phase.

The total planet mass depends on the boundary conditions, here determined by the mass of the inner planet. The semi-major axes and period ratios are plotted for different times, showing the evolution of the system. The eccentricity plots indicate periods of increased eccentricity, which are significant for the evolution of the planetary system.

The simulations are consistent with theoretical predictions and observations, providing insights into the dynamical origin of HD 45364.
Lessons learned from HD45364

Massive disc (5 times MMSN)

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

Large scale-height (0.07)

- Slow migration once in resonance
- Resonance is stable

Rein, Papaloizou & Kley 2010
Migration scenarios provide us with valuable information about the environment of planet formation.
Our formation model predicts a specific set of orbital parameters
• Consistent with current observations
• Testable with just a few well-timed radial velocity data points.
HD200964
The impossible system?
HD200964

- Two massive planets $1.8 \, M_{\text{Jup}}$ and $0.9 \, M_{\text{Jup}}$
- Period ratio close to 4:3
- Another similar system, to be announced soon.
Stability of HD200964

2:1 unstable

3:2 unstable

4:3 unstable

5:2 unstable

eccentricity $e$

semi-major axis $a_2$ [AU]

We don't understand everything*. 

*just yet
Saturn’s Rings
Saturn is a smaller version of the Solar System
Stochastic Migration

REBOUND code, Rein & Papaloizou 2010, Crida et al 2010
The formation of multi-planetary systems

Many planets are in systems where multiple planets orbit the same star.

By studying the current dynamical configuration we can learn a lot about the physical environment at the time when the planets formed.

- **Gliese 876**: Best example for the effects of dissipative planet migration.
- **Kepler-36**: Very different composition, brought onto close orbits by migration.
- **HD45364**: Had to form in a massive disc.
- **HD 200964**: We have no clue (yet).

The big picture

Understanding the formation of multi-planetary systems is essential if we want to know if the Solar System is special, if life is special.
Exoplanet Visualization Contest

The 2013 Exoplanet Visualization Contest

Create visualizations of real exoplanet data and win up to $1500.

The Contest

Extraterrestrial planets, or exoplanets, are planets beyond our own Solar System. With the prospect of finding potentially habitable planets, this is one of the most exciting scientific areas of the 21st century. Space and ground-based observing campaigns such as the Kepler mission have already found over 800 planets, and new planets are discovered almost every week.

If you want to take part in this contest and have a chance to win up to $1500, download the Open Exoplanet Catalogue and use this dataset of extrasolar planets to create crisp, stunning, and inspiring visualizations. You can use any scripting, programming, or visualization software to produce images, videos, sound files or interactive apps. Be creative!

The Open Exoplanet Catalogue

The Open Exoplanet Catalogue is a new community project that keeps track of all exoplanet discoveries. The dataset is hosted on GitHub and uses human-readable XML files. Simple interfaces in various programming languages (such as Python and JavaScript) have been created to allow easy access. Additional interfaces are currently under development. Why not participate?

Source: