Institute for Advanced Study

One at a time or all at once: Simulating the formation of Kepler systems

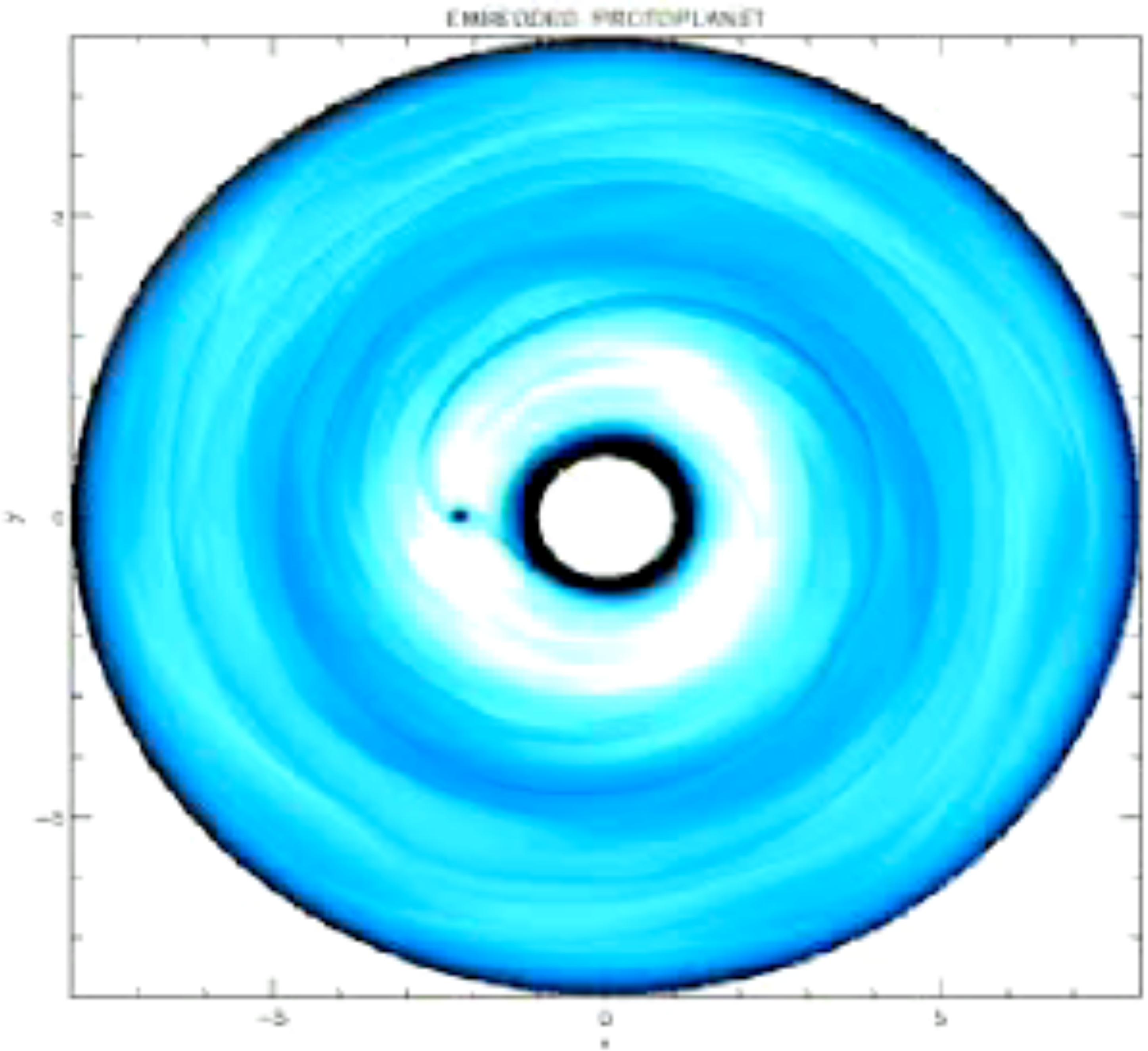
Hanno Rein

Evolution of planets, the simplest case

1. Planets form in a protoplanetary disk
2. Planets form beyond the snowline
3. Planets interact with the disk in which they formed

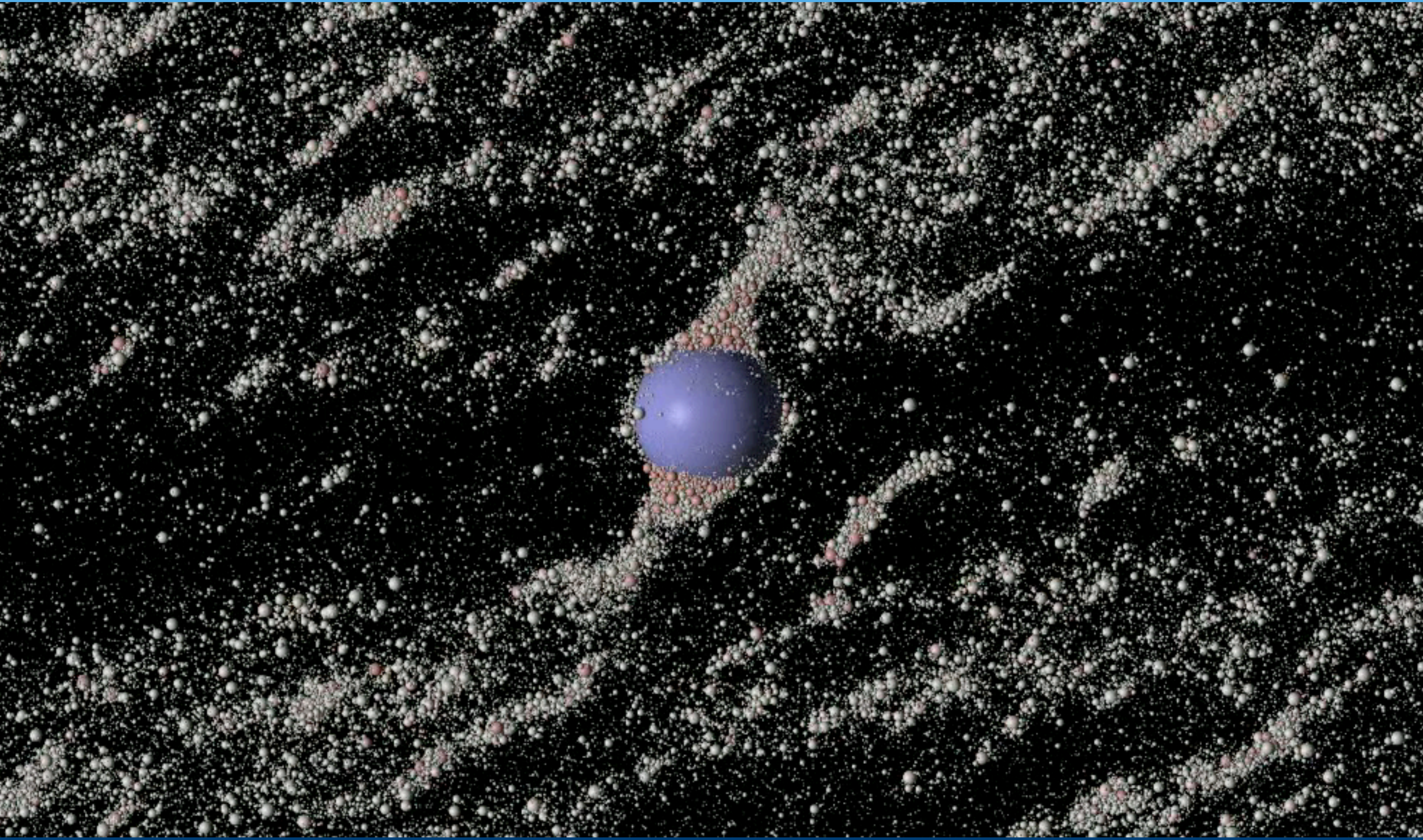
Turbulent disk

- Measured angular momentum transport requires some sort of turbulent transport
- Magnetorotational instability (MRI)
- Stochastic forces lead to random walk of the planet



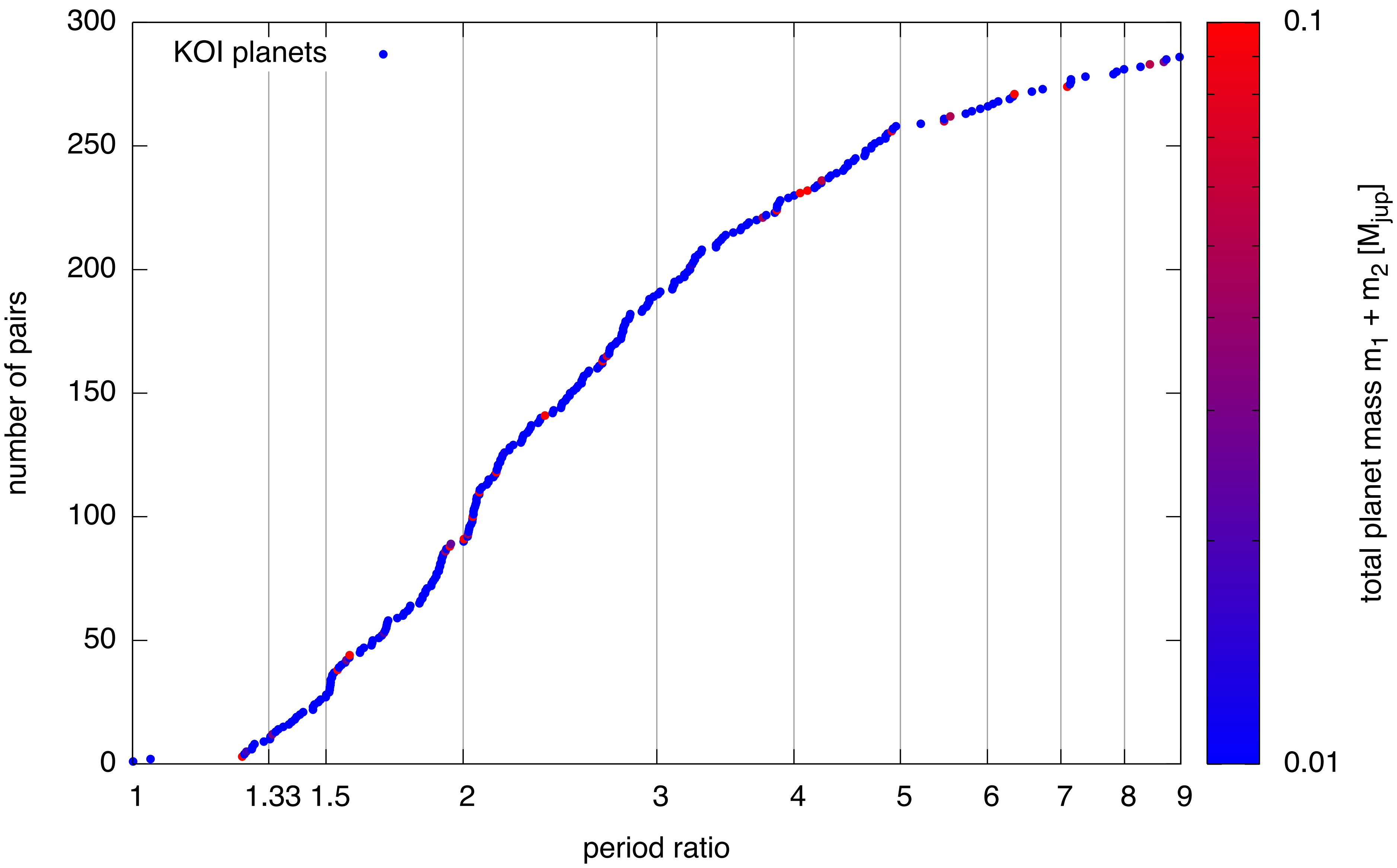
Animation from Nelson & Papaloizou 2004
Laughlin et al. 2004, Nelson 2005, Oischi et al. 2007, Rein & Papaloizou 2009

Random walk in Saturn's Rings: Propellers



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

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

Rein, Payne, Veras & Ford (2012)

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

Advantages

Comparison of statistical quantities

- Period ratio distribution
- Eccentricity distribution
- TTVs

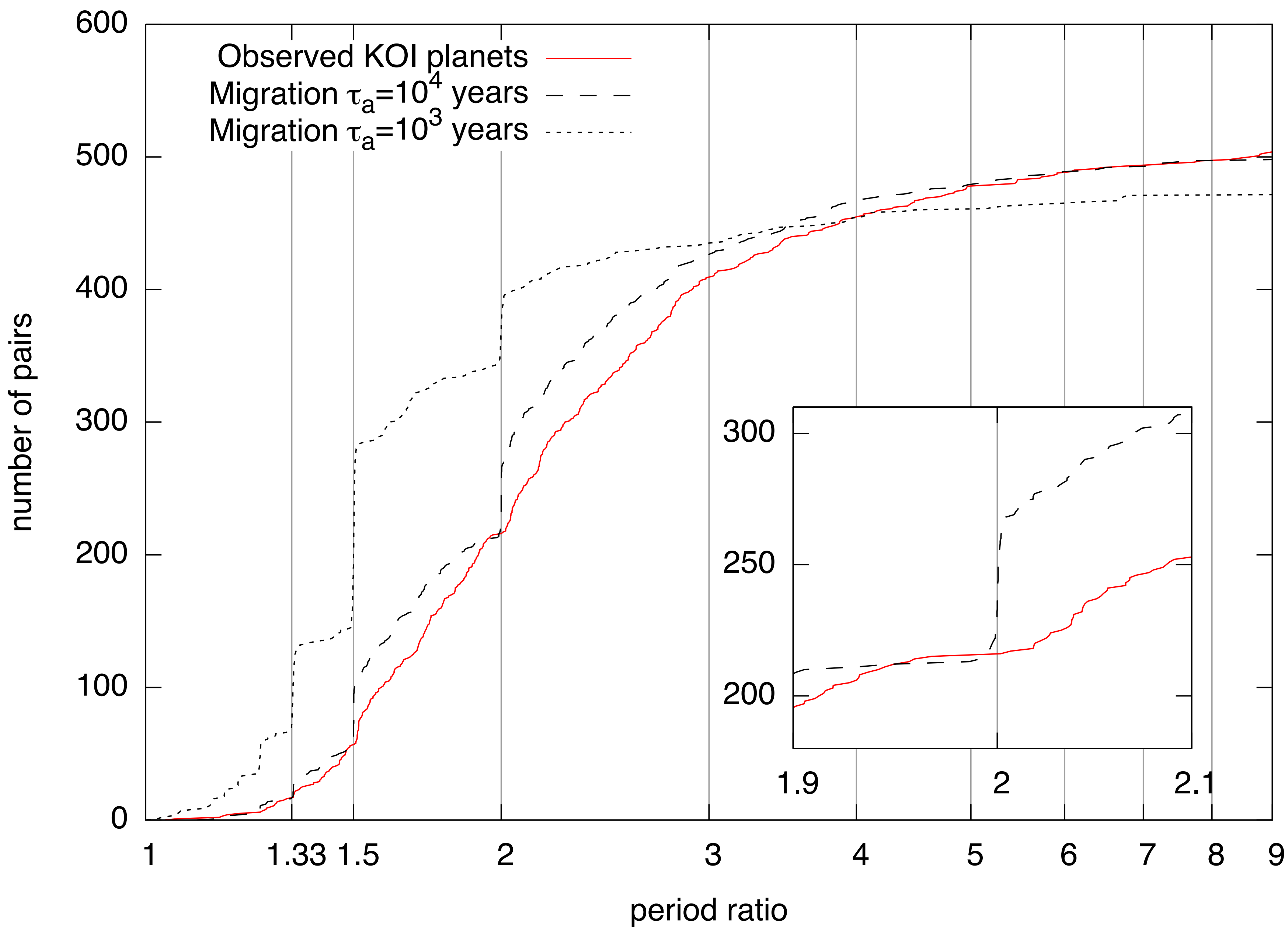
Comparison of individual systems

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

No synthesis of a planet population required

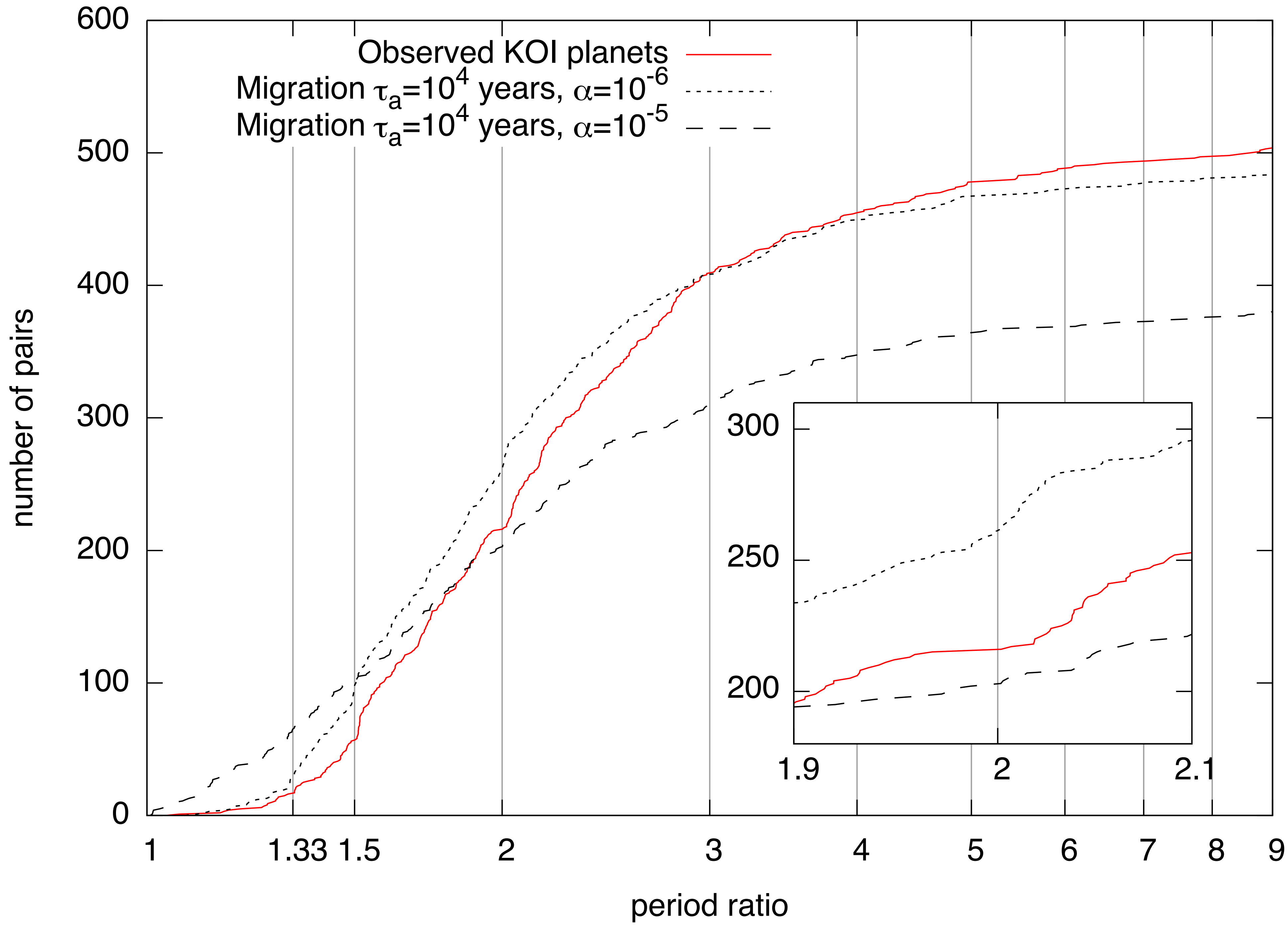
- Observed masses
- Observed architectures

Result 1: Smooth migration alone is not enough



Rein 2012

Result II: Stochastic migration works much better



Conclusions

1. Simplest scenario seems to work without fine-tuning.
2. This method can easily be extended to study other ideas such as stellar tides, secular chaos, etc.
3. This method allows the simultaneous comparison of individual and ensemble quantities.

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Open Exoplanet Catalogue

Hanno Rein

Why do we need another exoplanet catalogue?

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

Demo

Example of a python script parsing all systems

```
import xml.etree.ElementTree as ET, glob
for filename in glob.glob("*.xml"):
  tree = ET.parse(open(filename, ’r’))
  planets = tree.findall(".//planet")
  for planet in planets:
    print planet.findtext("./name")
    print planet.findtext("./mass")
```

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

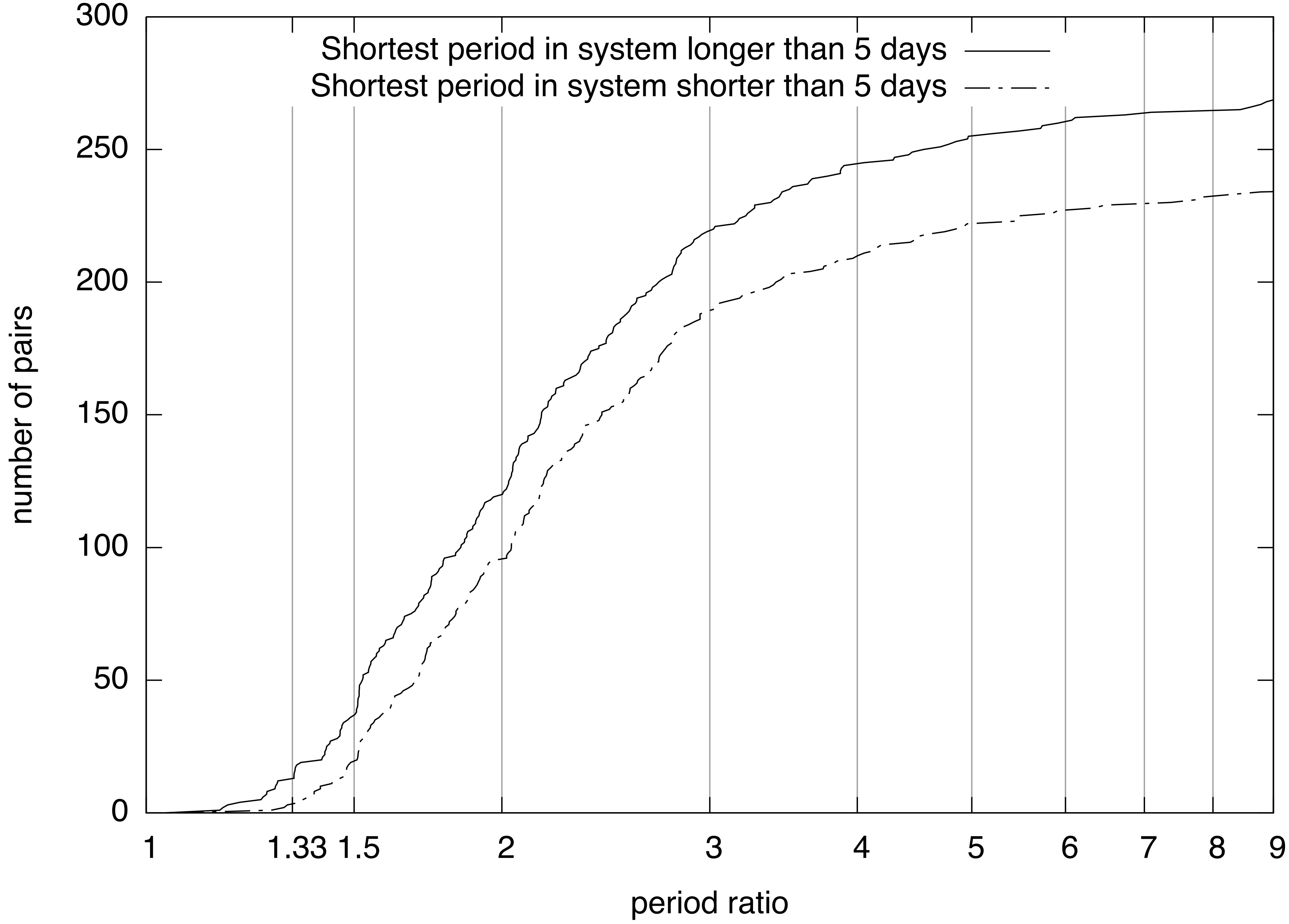
- Uses plain XML
- Can represent arbitrary configurations in systems with stellar multiplicity >1
- Extremely easy and intuitive to parse in almost any language
- Compresses extremely well
- size ~ 100KB

OpenExoplanetCatalogue.com

arXiv:1211.7121

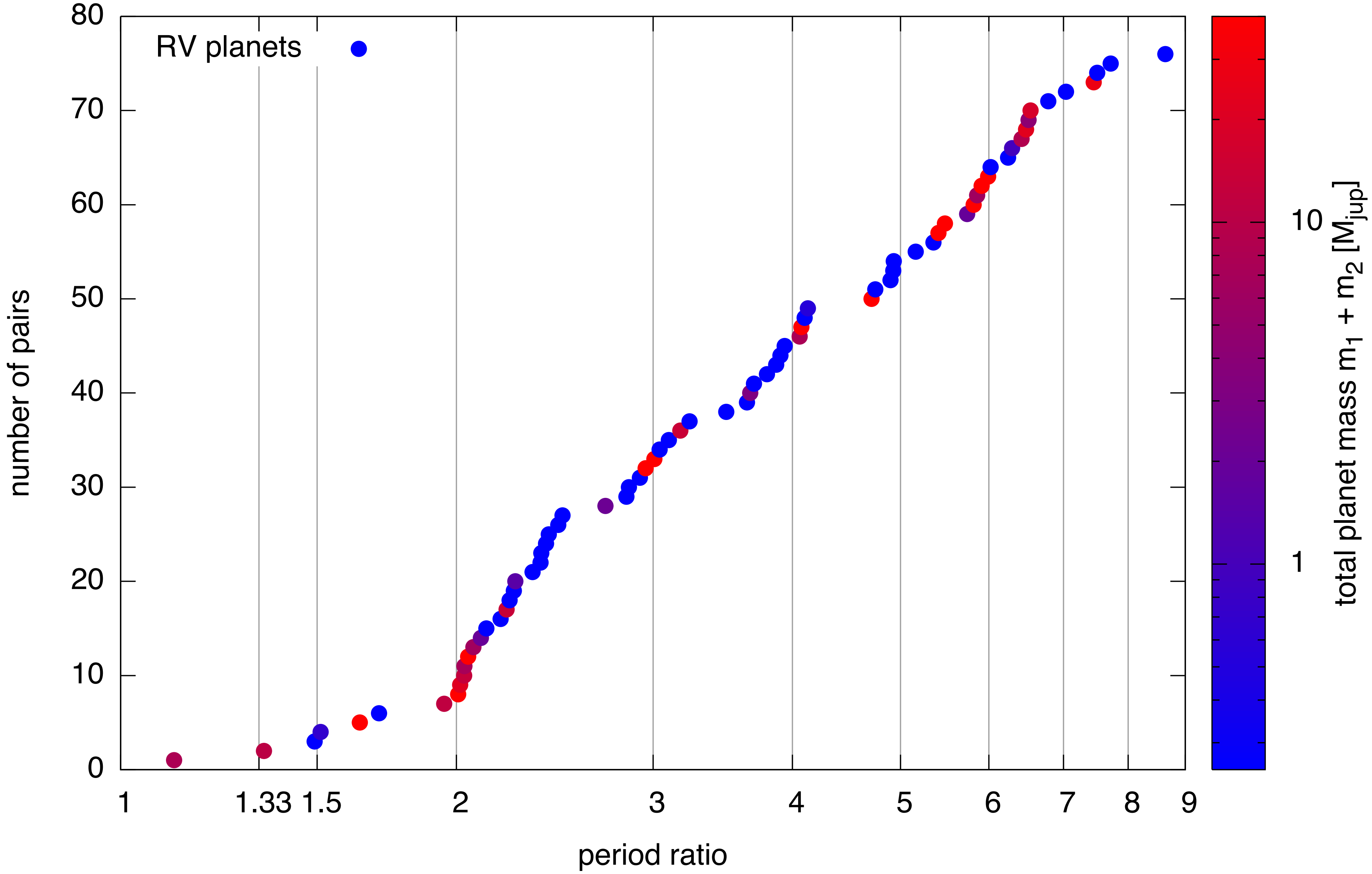
Backup slides

No different for close-in/far-out planets



Rein 2012

Radial velocity planets



- 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

Example of a system file: 42 Dra b

```xml
<system>
    <name>42 Dra</name>
    <rightascension>18 25 59</rightascension>
    <declination>+65 33 49</declination>
    <distance>97.3</distance>
    <star>
        <mass>0.98</mass>
        <radius>22.03</radius>
        <magV>4.83</magV>
        <metallicity>-0.46</metallicity>
        <spectraltype>K1.5III</spectraltype>
        <planet>
            <name>42 Dra b</name>
            <list>Confirmed planets</list>
            <mass>3.88</mass>
            <period>479.1</period>
            <semimajoraxis>1.19</semimajoraxis>
            <eccentricity>0.38</eccentricity>
            <description>42 Draconis is a metal poor star.</description>
            <discoverymethod>RV</discoverymethod>
            <lastupdate>09/03/23</lastupdate>
            <discoveryyear>2009</discoveryyear>
            <new>0</new>
        </planet>
        <name>42 Dra</name>
    </star>
</system>
```

Example of an HTML site parsing all systems

```
<html>
    <head>
        <script type="text/javascript" src="./js/d3.v3.min.js"></script>
        <script type="text/javascript" src="./js/jquery.min.js"></script>
    </head>
    <body>
        <table>
            <thead><tr><th>Name</th><th>Mass [MJup]</th></tr></thead>
            <tbody id="tablebody"></tbody>
        </table>
        <script type="text/javascript">
            d3.xml("systems.xml", "application/xml", function(xmldata) {
                var planets = $("planet",xmldata);
                var tr = d3.select("#tablebody").selectAll("tr")
                    .data(planets).enter().append("tr");
                tr.append("td").text(function(planet){
                        return $("name:first",$(planet)).text();
                    });
                tr.append("td").text(function(planet){
                        return $("mass",$(planet)).text();
                });
            });
        </script>
    </body>
</html>
```