Imperial College London

Formation and Astrometric Detection of Mean Motion Resonances in Giant Planets

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I. Formation of Giant Planet Resonances

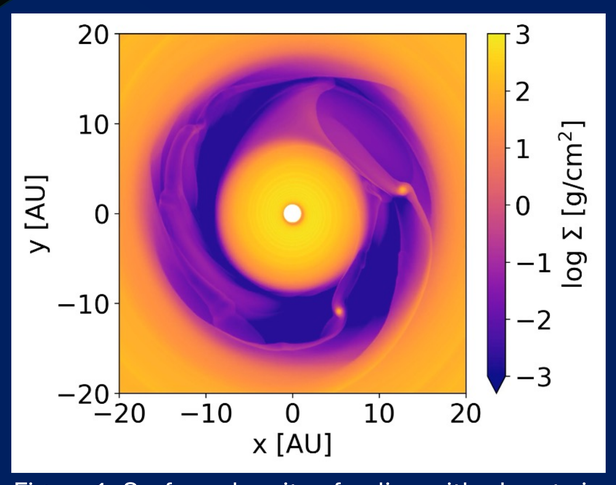

Figure 1: Surface density of a disc with planets in resonance in a common gap. Photoevaporation depletes gap material.

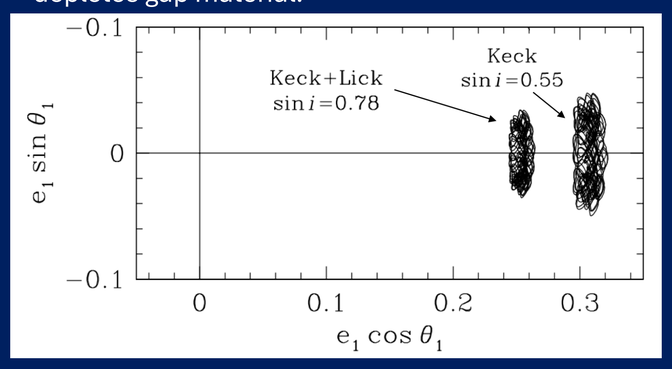

Figure 2: Small observed librations for GJ 876 planets b and c caught in deep 2:1 resonance. Figure from (Lee & Peale 2002)

- It is **poorly understood** as to how giant planets end up with their orbital parameters such as eccentricity.
- **Migration theory** predicts that **resonant chains** are likely to form yet very few exact resonances are observed for high mass planets.
- Very few systems such as Gliese 876 are nonetheless observed with giant planets definitively in resonance (Fig. 2).
- We expect more data on this matter in the next few years with the **Gaia catalogue** release.
- The protoplanetary system is a **dynamically evolving** environment, with orbital parameters influenced by **planet-disc interactions**.
- **Disc photoevaporation** from the central star is an additional mechanism that becomes significant in the presence of **gaps** and is not yet well studied in the context of **migration**
- To investigate **resonance formation** in the context of giant planets, run long-term **hydrodynamical simulations** using FARGO3D (Fig.1)

<u>Result 1</u> : We find the **resonances to break gradually** due to **planet-disc interactions** over long timescales (Fig. 3). **Disc photoevaporation** is also considered as an additional mechanism that makes resonances more **robust**, due to the additional depletion in the common gap region. Thus, we might expect many cool **giant planets to be found in resonance**

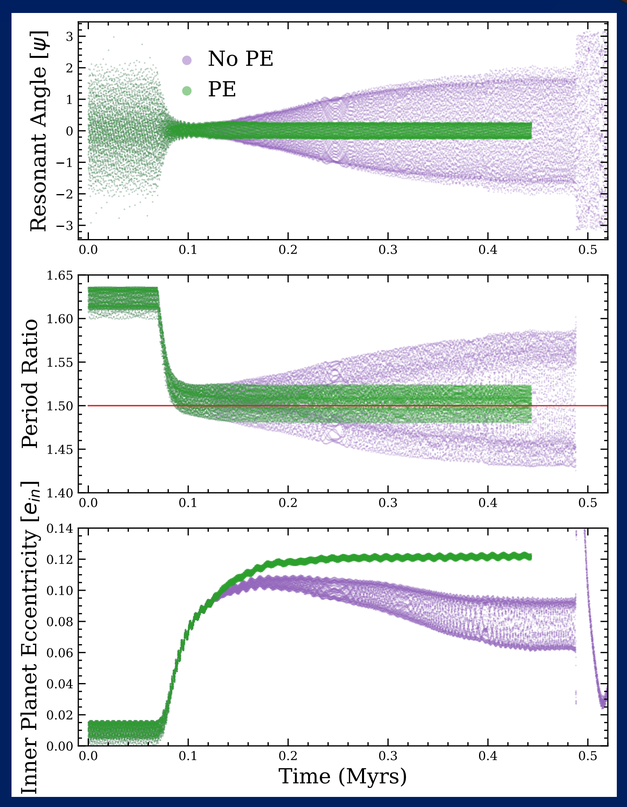

Figure 3: Evolution of the resonant angle (top), planet period ratio (middle) and inner planet eccentricity for planets in 3:2 resonance. Photoevaporation limits all resonance breaking effects, with the eccentricity climbing and the resonance remaining stable until the inner disc dissipates. (<u>Greenfield & Owen</u>, <u>subm</u>.)

II. Detections with Gaia astrometry

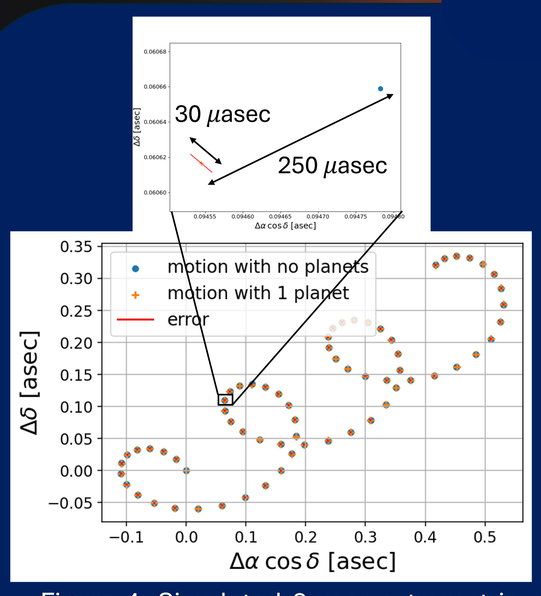

Figure 4: Simulated 3-year astrometric signal for Jupiter, with associated uncertainties

- The Gaia data is precise to 30 μas, which is sufficient to detect single planetary signals (Fig. 4)
- The detection space for Gaia will allow to expand on our limited knowledge of cold giant planets beyond 10 AU and obtain data on planets similar to Jupiter and Saturn (Fig. 5)

<u>Questions</u>:

1. **Can Gaia detect two planets in the same system?**
2. **Can we quantify when the two planet model is more appropriate to fit a signal?**
3. **Can the regular signal due to resonances enhance planet detection?**

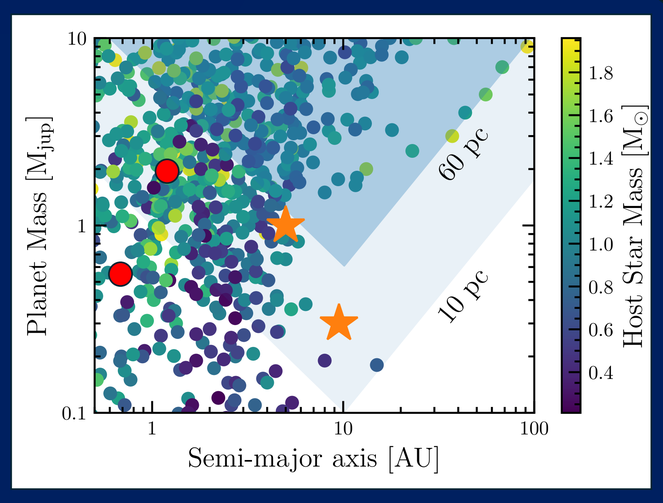

Figure 5: Detection space for Gaia and known giant planets. Stars represent Jupiter and Saturn. Red dots represent the system detected in Fig. 7

III. Resonances might enhance detections

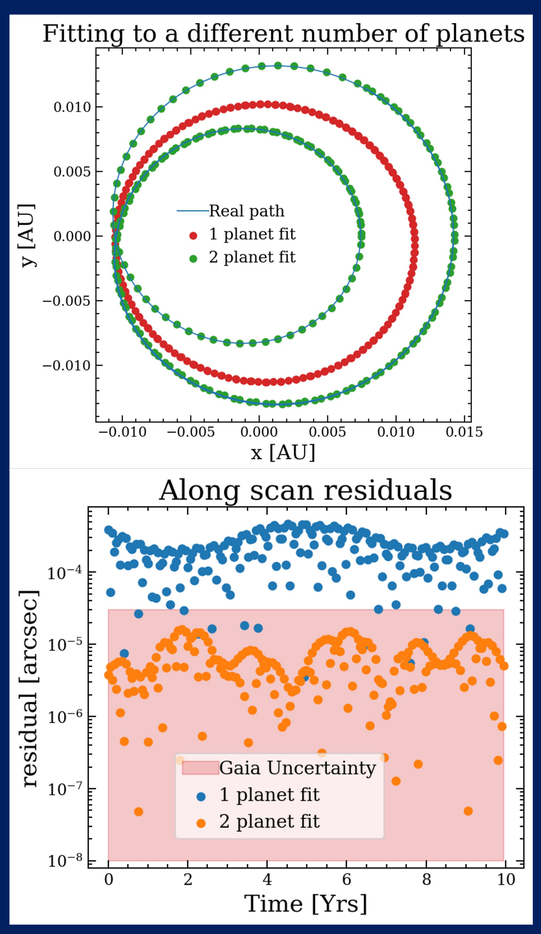

Figure 6: Best fit to a 2-planet signal using planet and 2 planet models. Uncertainties in the fit are compared to Gaia's uncertainties

- We simulate a **10-year Gaia signal** from two planets using a **N-body simulation** (REBOUND)
- We use **nested sampling** to fit the data (dynesty)
- Erroneous fitting of **a single planet** to a multi planet system will result in **erroneous** orbital parameter retrieval. We can see that in this case the residuals are larger than the Gaia uncertainty (Fig. 6)
- The signal shape is different depending on whether the two planets are in resonance or not. Resonances lead to a **characteristic overdensity** in the signal at the point of conjunction between the planets. (Fig. 7)
- We find that it is **easier to recover** an inner planet that is on the edge of the detectability region when it is in resonance with an outer planet

<u>Result 2</u>:

- Systematically fitting a **single planet** to the data might yield **incorrect results**
- **Resonances** create a **clustered pattern** in the signal that is easier to detect
- This might allow for us to detect planets that would not be detectable on their own

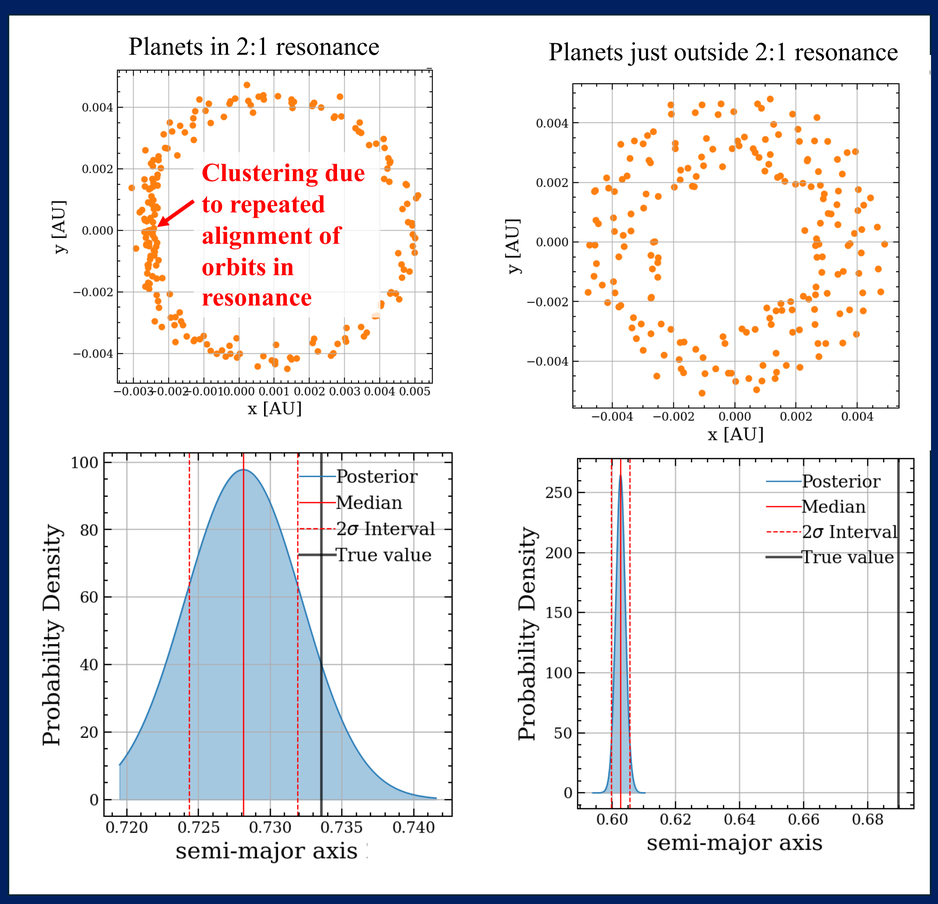

Figure 7: Planetary signal (top) and retrieved semi-major axis (bottom) for the inner planet, in the case where the 2 planets are in resonance (left) and just out of resonance (right). Detections are more accurate when the planets are in resonance