Probing Young Planetary Systems From Their Debris Disks

Are Our Inferences Compromised By Unseen Planets?

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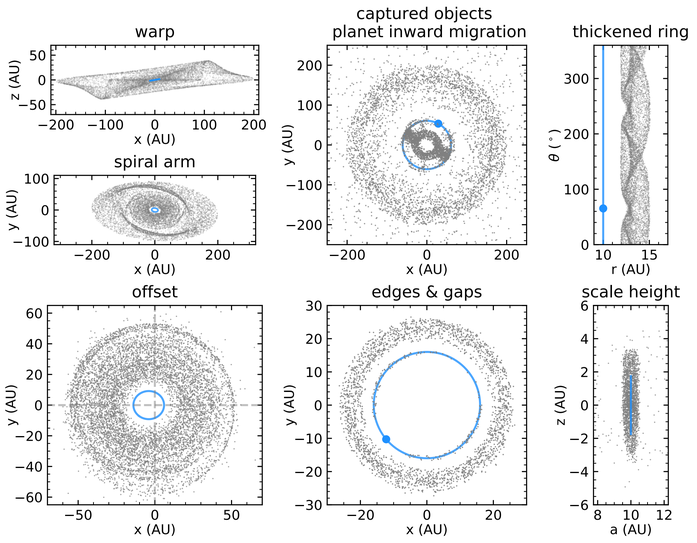
New Horizons in Planetary Systems
Victoria, BC May 13-17, 2019

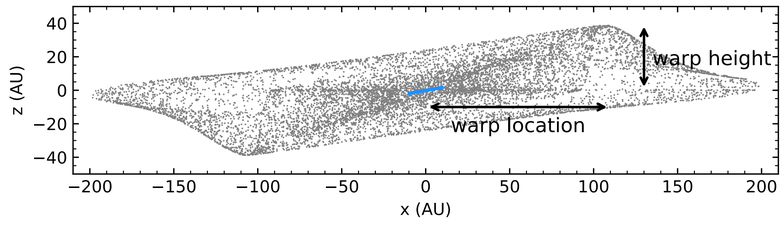
Single-planet model or multi-planet model?

Planets gravitationally sculpt various features in debris disks.



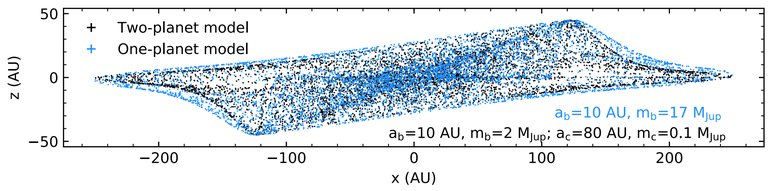
Young planetary system properties can be inferred from resolved debris disk features.

For example, for a warped disk, we can measure its warp location and height.



- The posited Planet b's mass m_b and semi-major axis a_b can be constrained from the warp location (with degeneracy).
- The posited Planet b's inclination i_b can be inferred from the warp height.

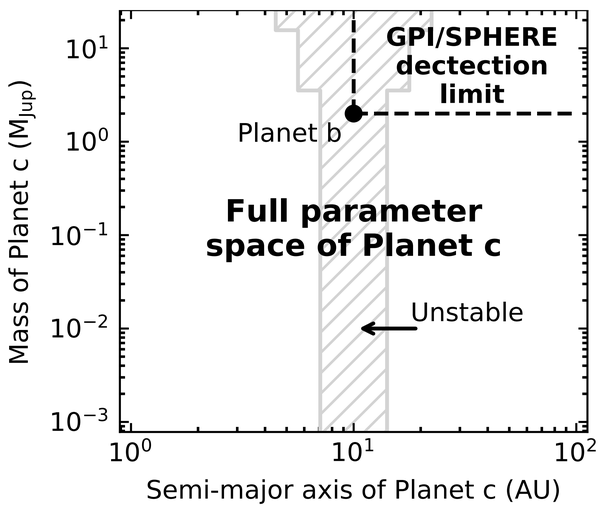
Most existing models characterize planet properties using a **single-planet model**. However, observations of mature planetary systems have revealed many planets reside in **multi-planet** systems.



What if there is a **hidden** Planet c?

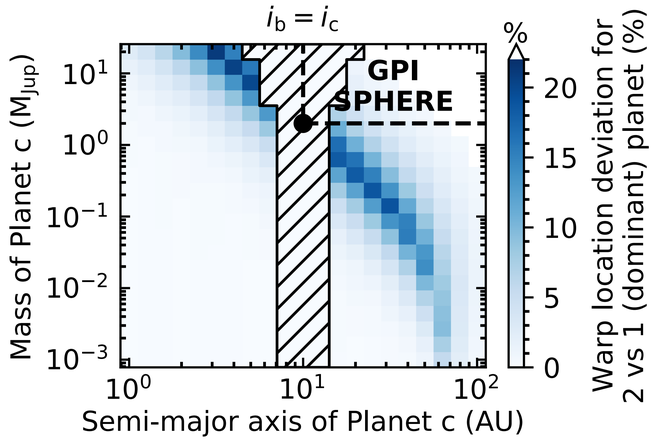
Question Are our inferences compromised by a hidden Planet c?

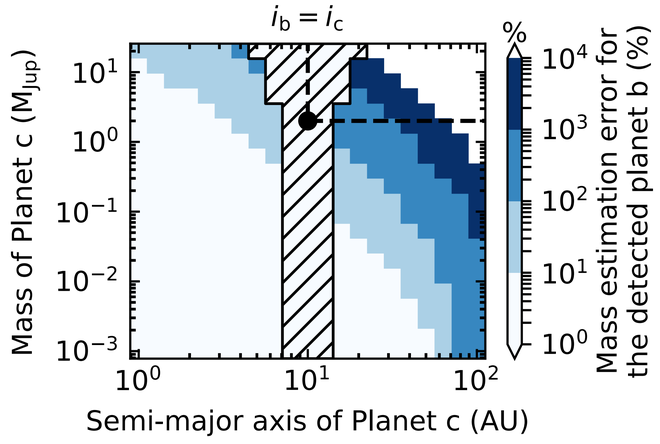
Approach We build a two-planet model: Planet b and c.



- Study planet properties from disks sculpted by either one or two planets.
- Use an analytical solution for **secular** features (warps, spiral arms, offsets)
- Use *N*-body simulations for **resonant** features (gaps, edges, clumps) and **synodic** features (thickened rings, scale heights).

Warps (secular feature)

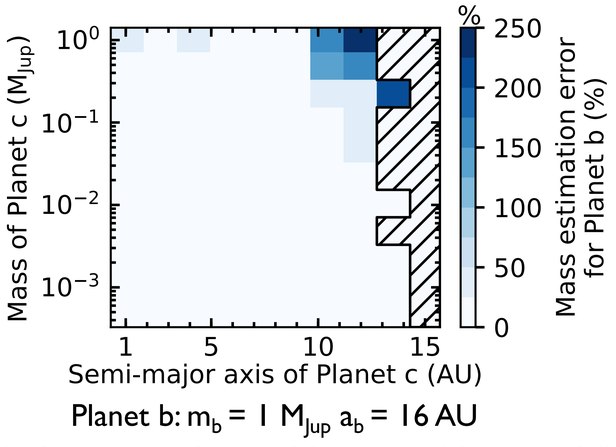




- Warp location is dominated by one planet in most cases.
- Mass estimation error for the detected Planet b could be **huge** in a certain parameter space, **if we do not detect Planet c**.

Edges and gaps (resonant feature)

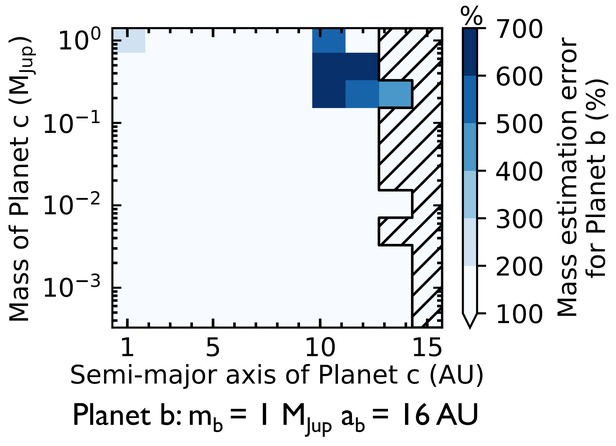
- The chaotic zone width follows the "2/7" law (Wisdom 1980, AJ, 85, 1122), constraining the planet's mass.
- The mass estimation for the detected planet is flawed only for a hidden planet with a comparable mass and orbit to the detected planet.



Simulations (IAS15; Rein & Spiegel 2015, MNRAS, 446, 1424)

Thickened rings (synodic feature)

- Normalized ring width imposes an upper limit of the posited planet's mass (Rodigas et al. 2014, ApJ, 780, 65).
- The mass estimation for the posited planet is severely flawed only for a hidden planet with a comparable mass and orbit to the posited planet.



Simulations (WHFast; Rein & Tamayo 2015, MNRAS, 452, 376)

Summary

- Debris disk features are usually primarily dominated by a **single planet**.
- Use single-planet models with **high risk**: warps and **medium risk**: edges, gaps, and thickened rings.
- Check Dong et al. in prep for a cookbook for observers. Stay tuned!