PF-08-0003

Planet formation in an evolving disk with disk winds and photoevaporation

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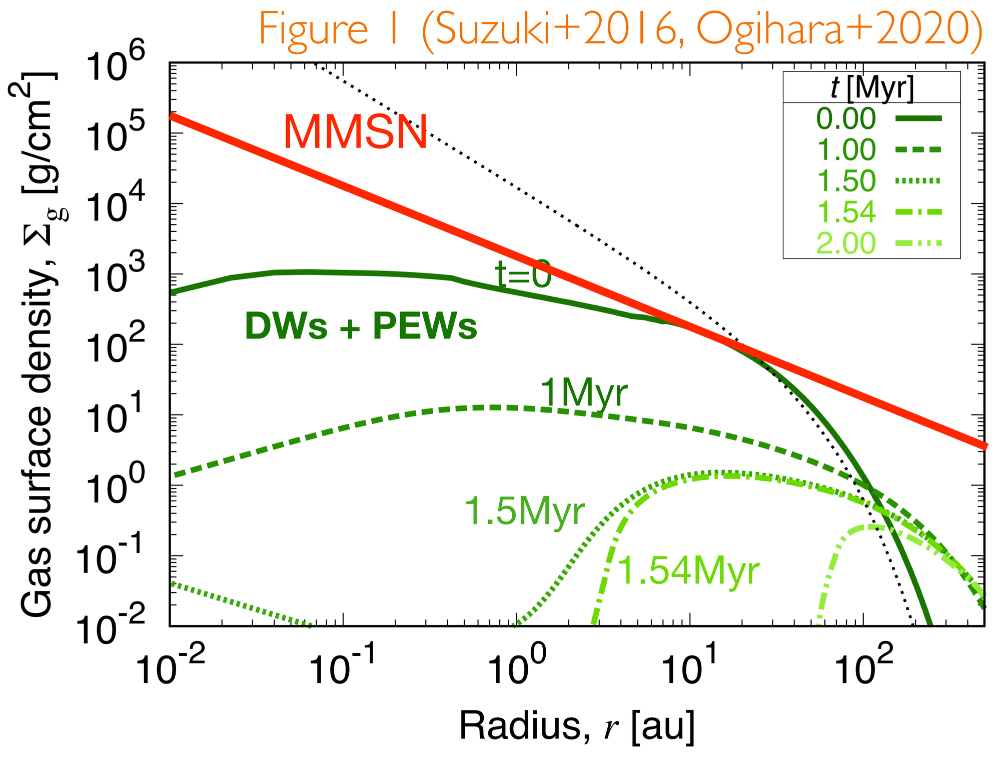
1. Backgrounds/Disk evolution

- MHD disk winds and photoevaporation affect the evolution of PPDs (Chapters 12, 13, 15, 16).
- Specifically, MHD disk winds can change the gas surface density profile, and photoevaporation can cause rapid disk dispersal.
- Since the evolution models of PPDs can have a significant impact on planet formation (Chapters 15, 16, 17, 19, 20), in this study we investigate the formation of super-Earths/sub-Neptunes (SENs), hot/warm-Jupiters (HWJs), and the solar system's terrestrial planets using *N*-body simulations.
- The disk model used is shown in Fig.1, based on Suzuki+(2016) and Ogihara+(2020), which is very different from previous power-law disk models (eg, MMSN).

Figure 1 (Suzuki+2016, Ogihara+2020)



2. Super-Earths/sub-Neptunes: Migration, Period-ratio

Figure 2 (Ogihara+2015)

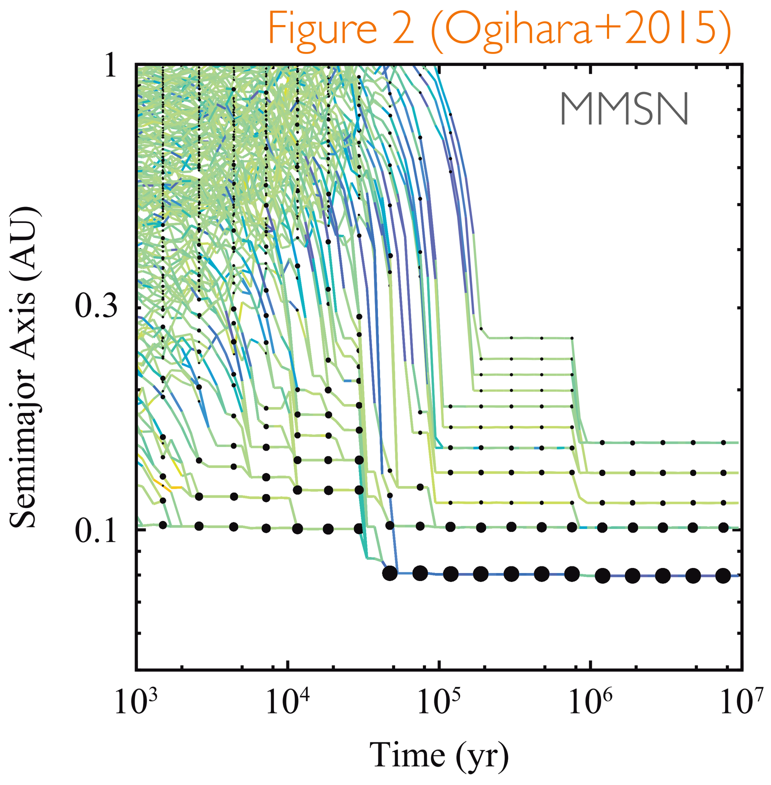


Figure 3 (Ogihara+2018b)

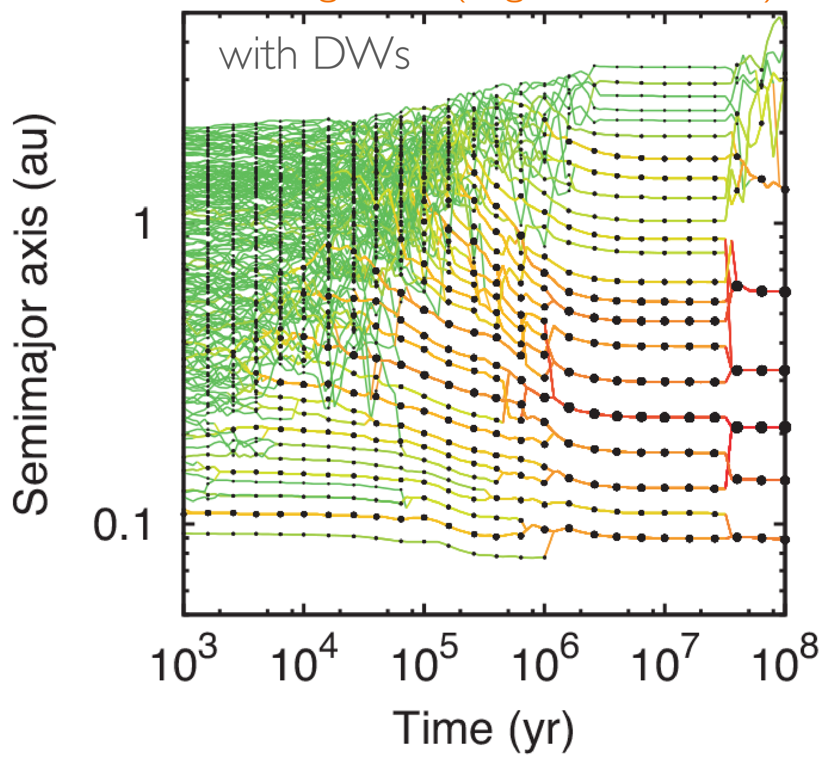
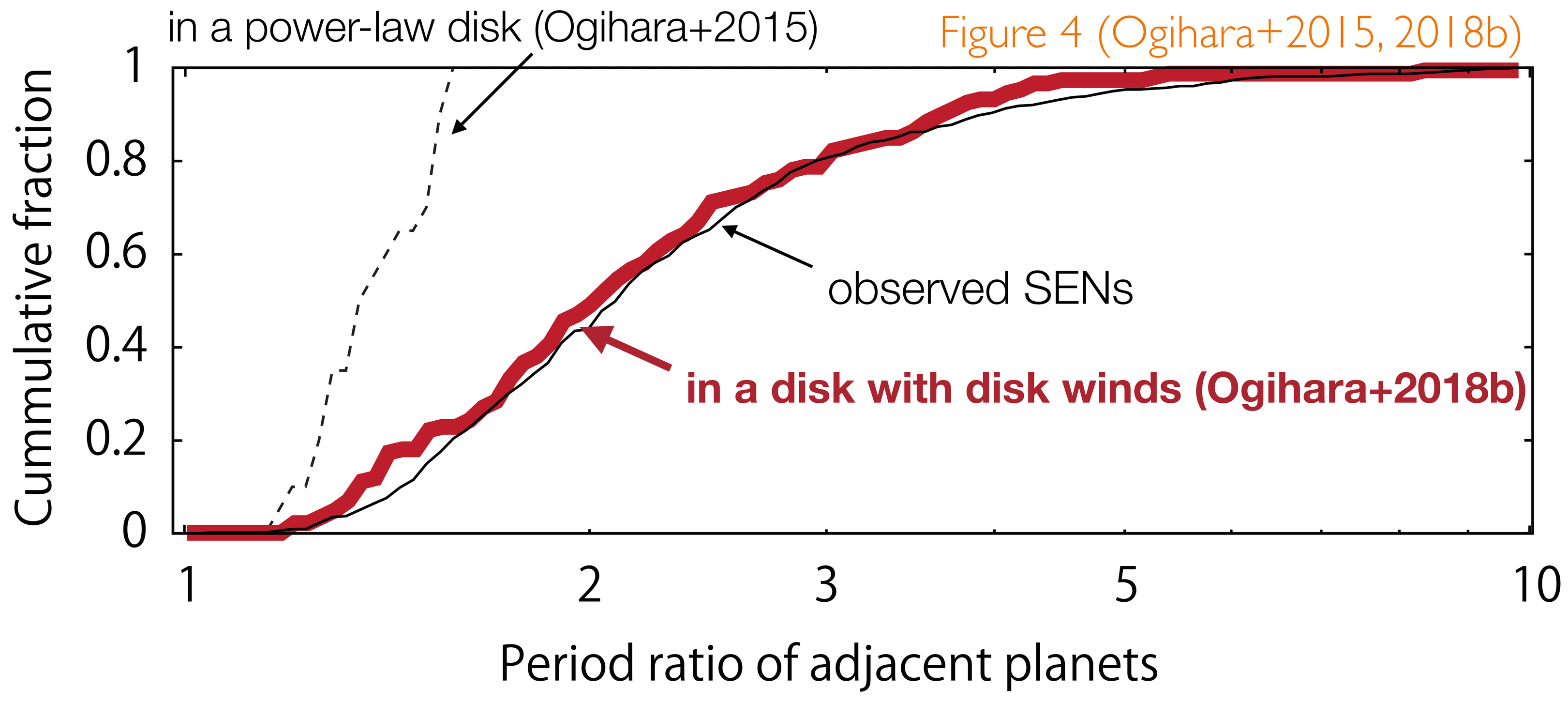


Figure 4 (Ogihara+2015, 2018b)



- Using power-law disk models, planetary embryos experience rapid inward migration (Fig.2). As a result, SENs form in a very compact configuration at the inner edge of the disk, captured in mean-motion resonances (MMRs).
- In disks with (near) flat surface density profiles due to disk winds, embryos can avoid rapid migration (Fig.3). As a result, orbital instability (or giant impacts) occurs during the disk dissipation phase, and SENs form out of MMRs with some orbital separation.
- Orbital period ratios formed after undergoing rapid migration do not match the observed orbital period distribution of observed SENs (Fig.4, dashed black), while those that avoid rapid migration reproduce the observed orbital period ratios well (Fig.4, thick red). Other features (eg, size dispersion, orbital separation ~10-30 mutual Hill radii, eccentricity; Chapters 23 and 24) are also consistent.

3. Super-Earths/sub-Neptunes and hot/warm Jupiters: Atmospheres/Envelopes

Figure 5 (Ogihara & Hori 2020, Ogihara+2020)

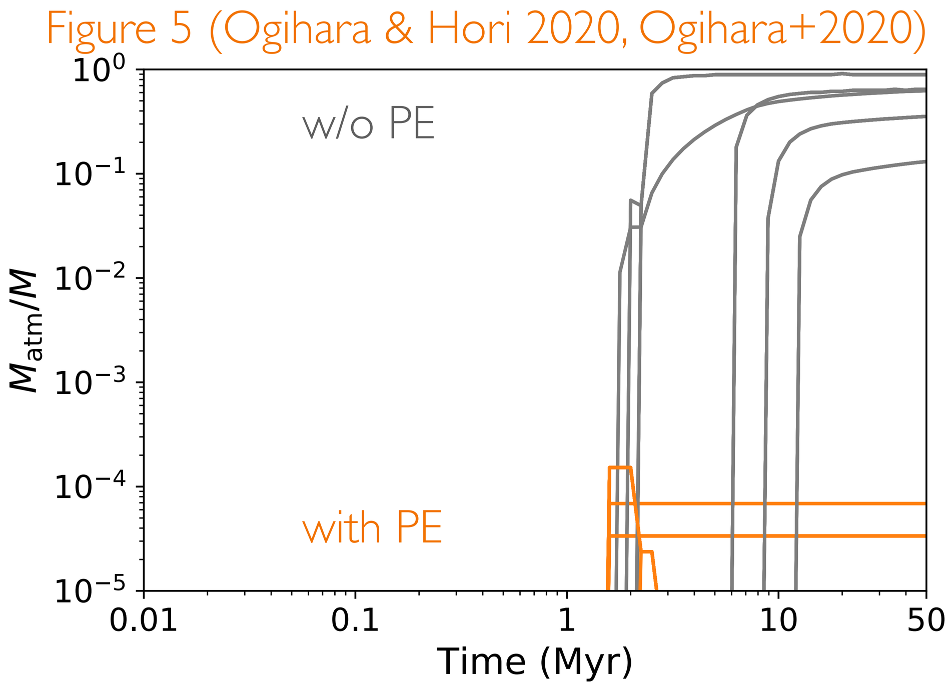


Figure 6 (Ogihara+2021)

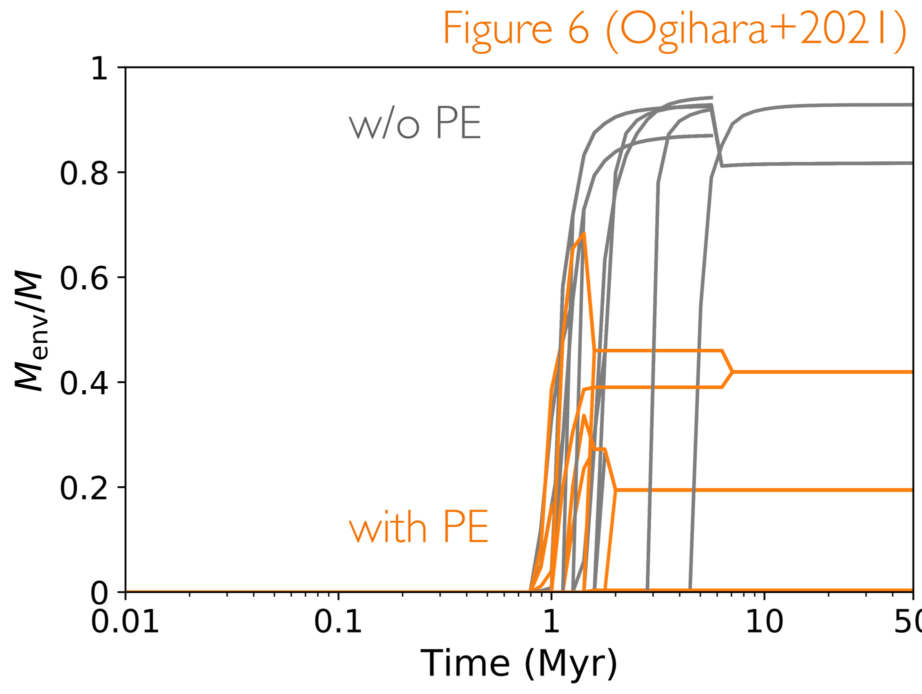
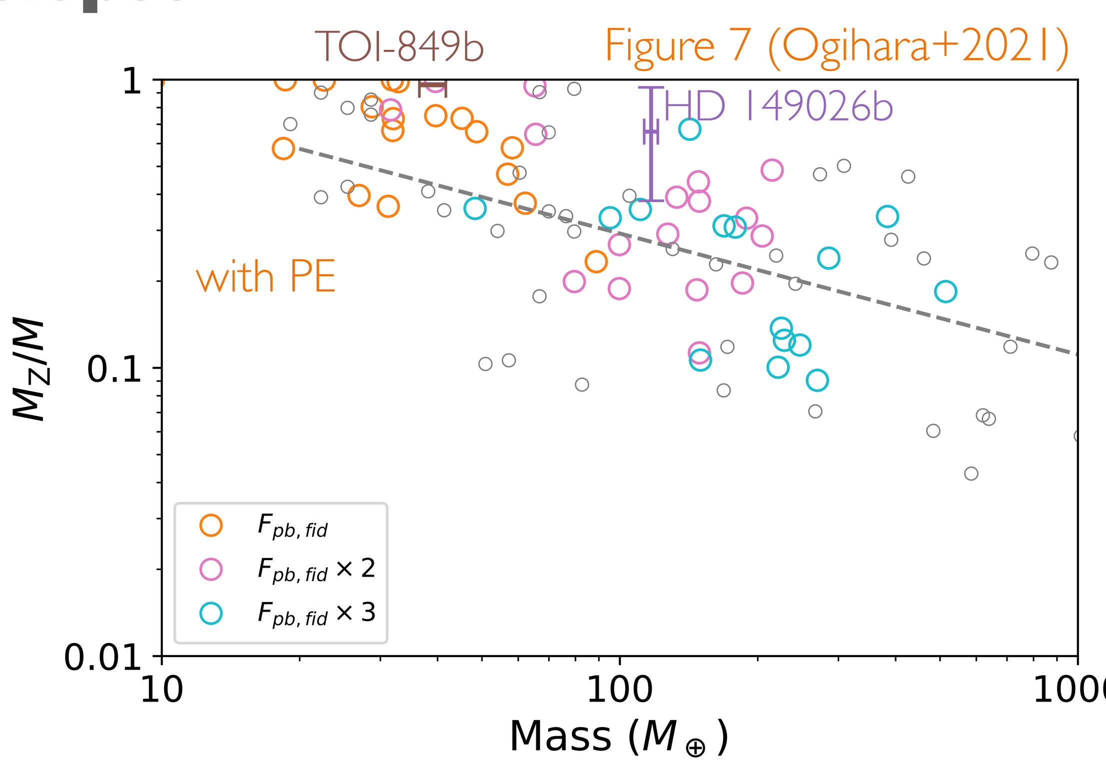


Figure 7 (Ogihara+2021)



- In disks that dissipate slowly on timescales of a few Myr, SENs can accrete large amounts of atmosphere during the disk dissipation phase (Fig.5, gray). The amount of atmosphere exceeds 10% and is not consistent with the observed SENs (typically less than 10%).
- In disks in which the inner cavity opens quickly (0.1 Myr timescale) due to photoevaporation, SENs can avoid accretion of massive atmospheres (Fig.5, orange).
- The same is true for HWJs, where the inner cavity opens in a rapid disk dispersal, allowing a smaller amount of envelope accretion (Fig.6, orange). This explains the formation of HWJs with large metal mass fractions (eg, HD 149026b and TOI-849b) and the overall distribution of metal mass fractions (Fig.7; see also Chapter 26).

4. Solar system's terrestrial planets: Radial mass concentration

Figure 8 (Ogihara et al. 2018a)

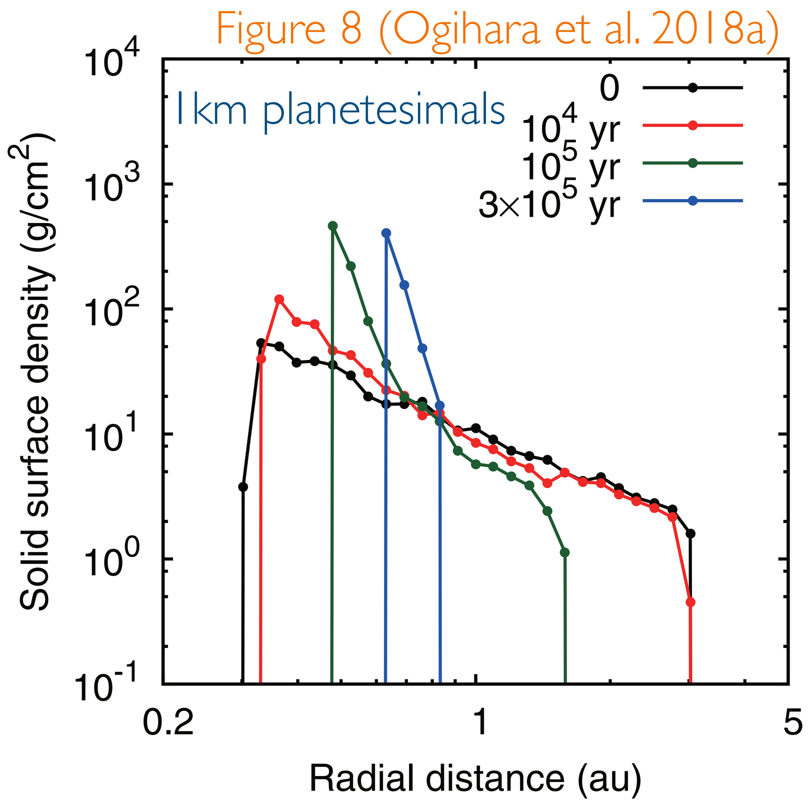
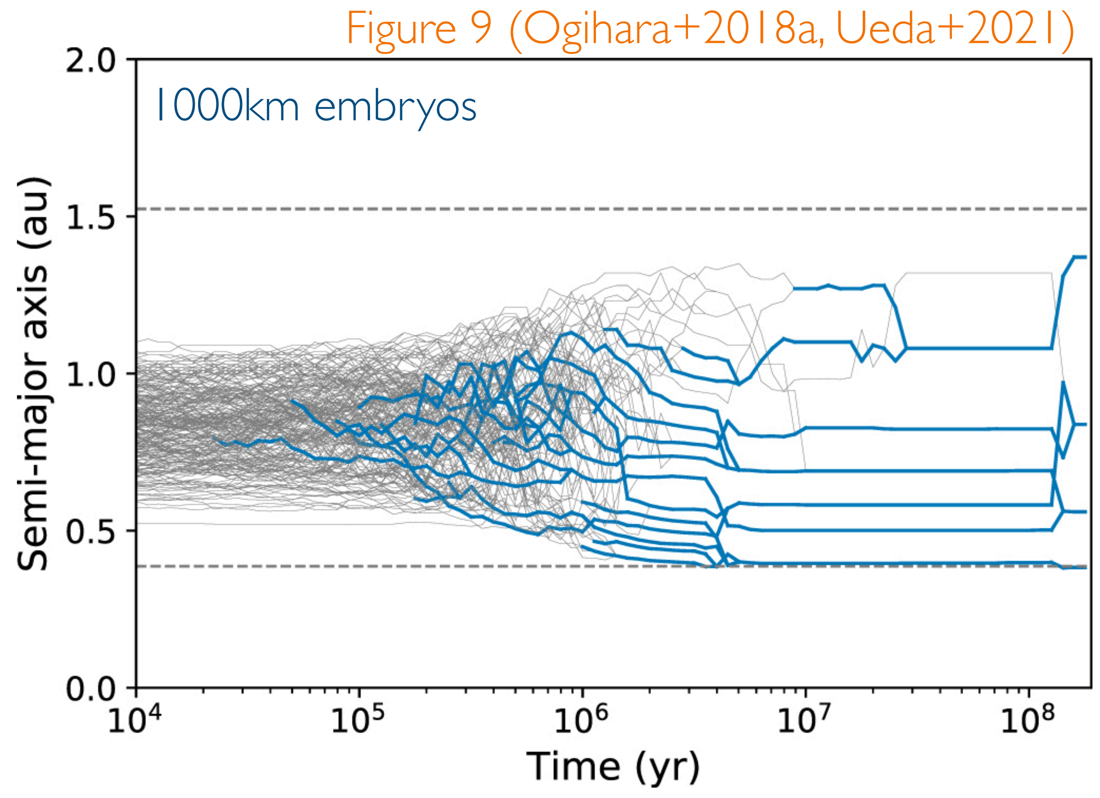


Figure 9 (Ogihara+2018a, Ueda+2021)



- Disks with altered density profiles can be applied to terrestrial planet formation.
- Planetesimals of 1km can drift radially towards 1 au due to gas drag (Fig.8), and embryos of 1000km can avoid migration (similar to SENs) (Fig.9).
- These may be useful for the formation of terrestrial planets, which are radially concentrated around 1 au.

5. Conclusions

- Disks evolving with disk winds and phohtoevaporation can have important effects on planet formation.
- We find that various features of SENs can be reproduced, and such disks are useful to explain the metal mass fraction of HWJs and the radial mass concentration of terrestrial planets.

6. Information

- A.M. is supported by ERC grant: HolyEarth - 101019380
- References

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  - Ogihara et al. (2018a, A&A, 612)
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