The emerging field of planets in binaries

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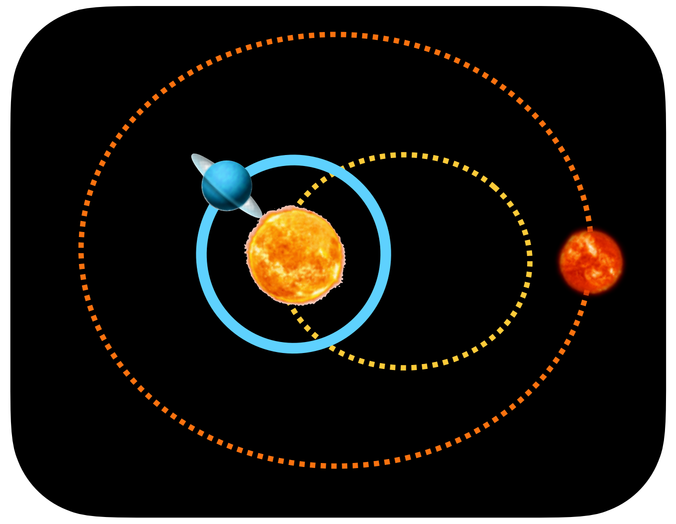
51 Peg b 30th Birthday: Cool Giant Exoplanets & Their Systems — OHP — Oct. 6th to 10th, 2025.

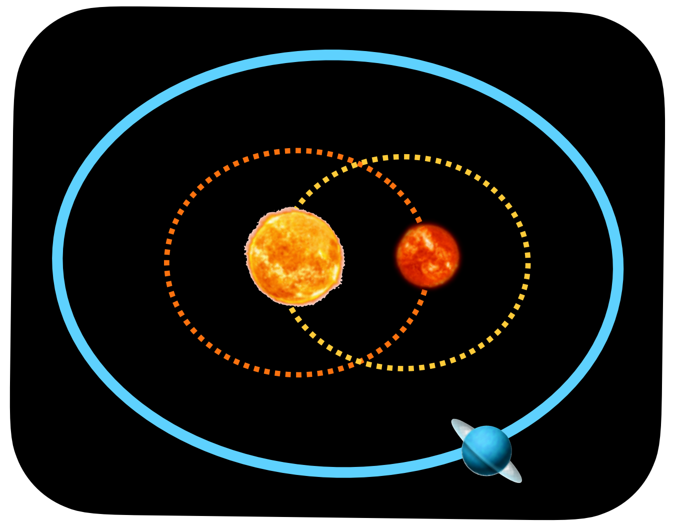
Planets in binaries

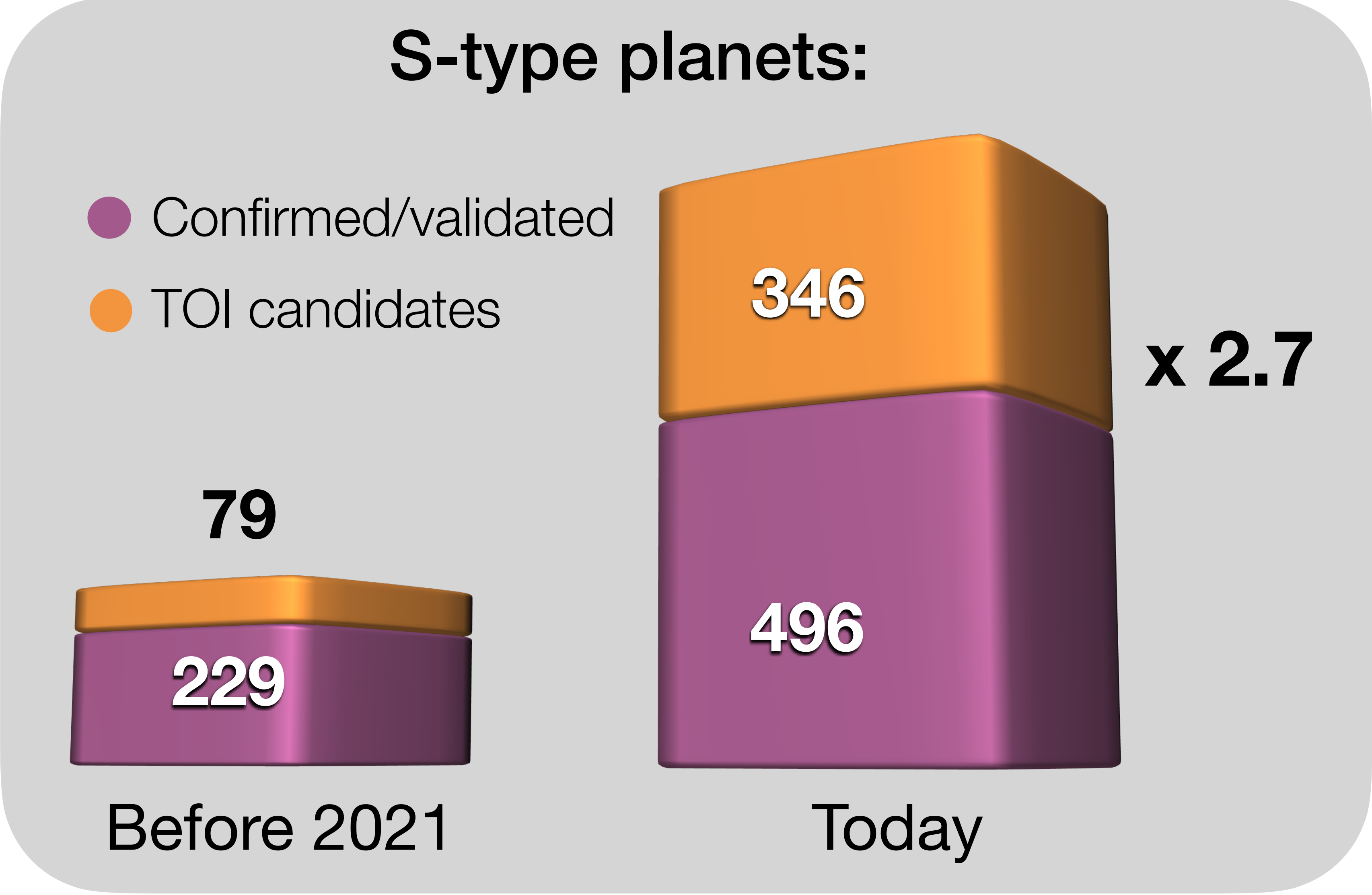
Raghavan+2010

S-type or circumstellar

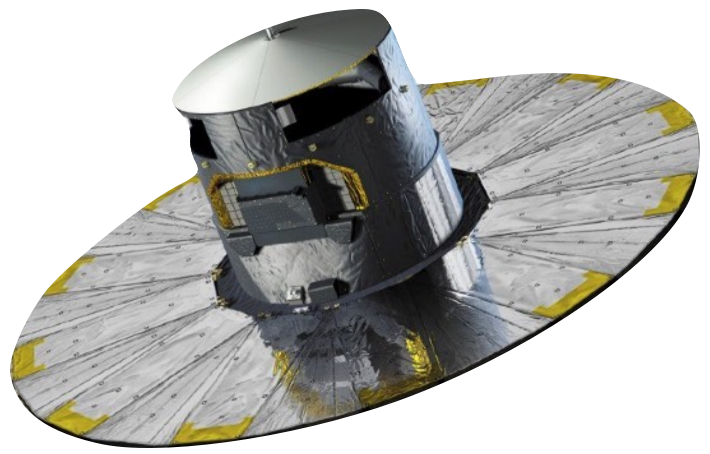


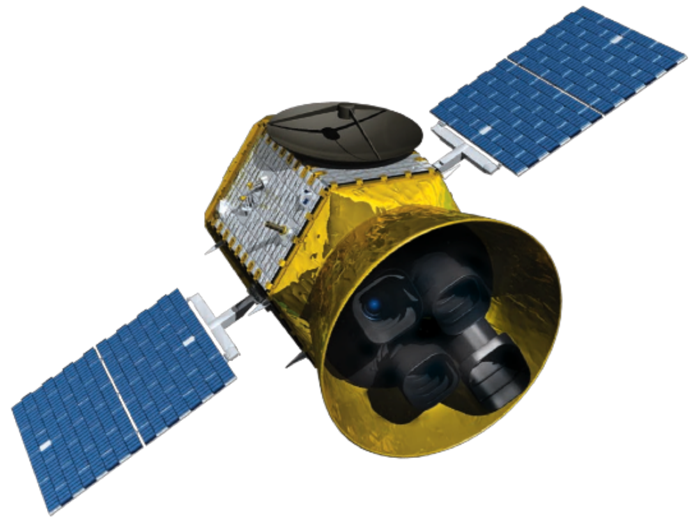
P-type or circumbinary

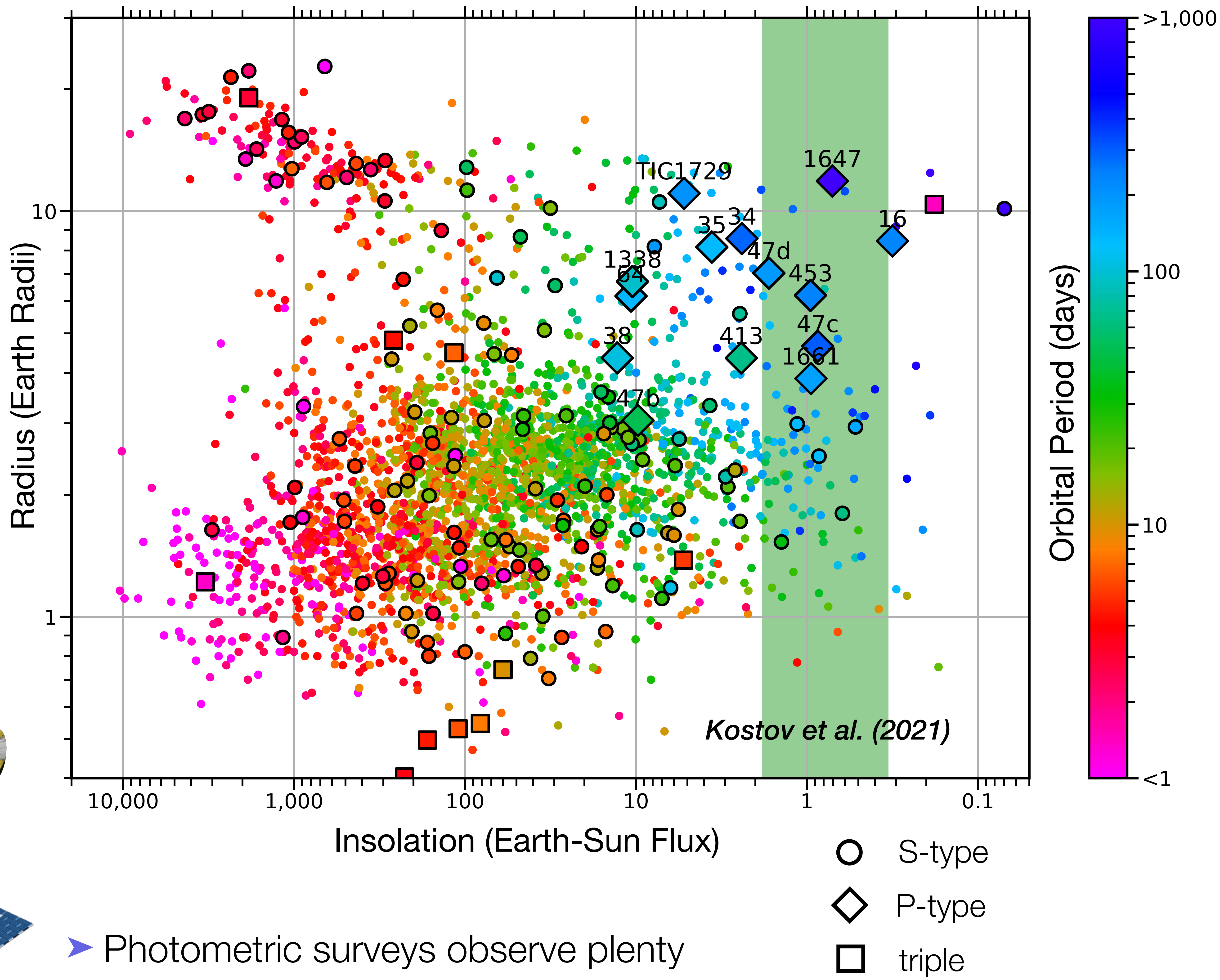




NASA Archive, Mugrauer+2021,2023, Behmard+2022, Lester +2022



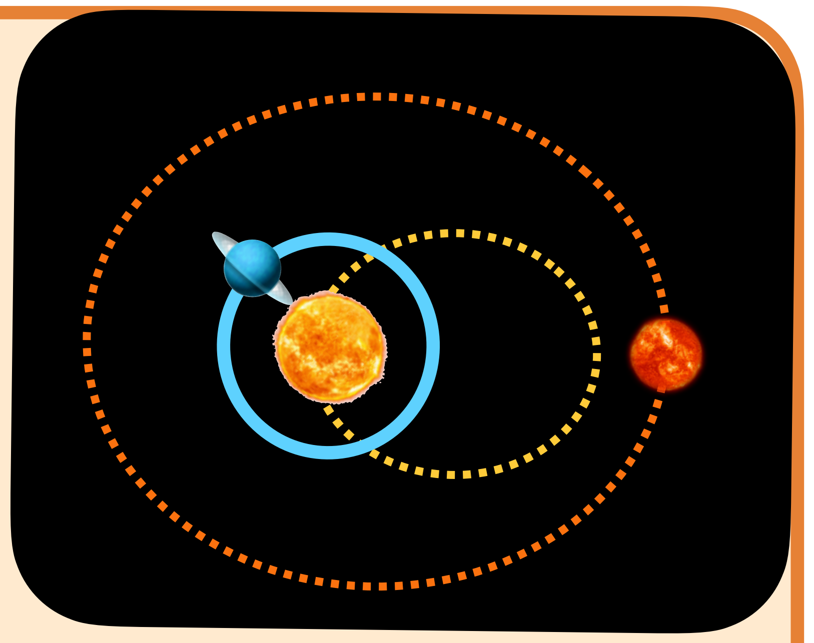




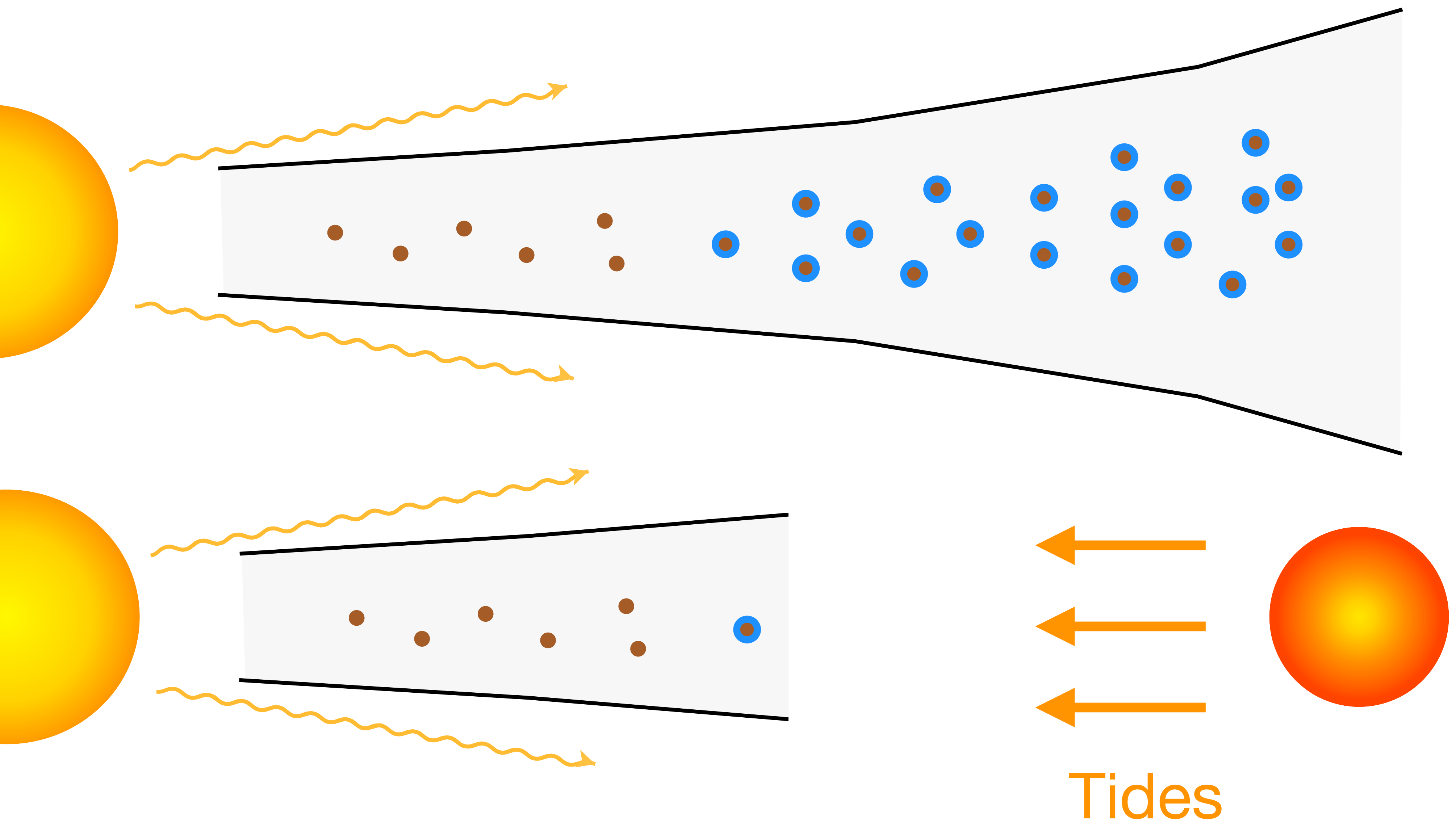
➤ Photometric surveys observe plenty of binaries => many transiting planets were detected in systems which were later revealed as binaries by *Gaia*.

S-type planets: what do we know?

Observed statistical differences between S-type planets and single stars:



- Distribution of **planet mass and semi-major axis** is **different from single-stars for a_{bin}≲1000 au** *(Fontanive et al. 2021)*.
- **Occurrence rate of giant planets drastically decreases for a_{bin} ≲100 au (from 20% to 4%)** *(Hirsch et al. 2021)*.
- Binaries hosting S-type planets (with a_{bin}<1000 au) have the **peak of binary separation at 100 au,** while for **field binaries the peak is at 50 au** *(Lester et al. 2021)*.
- The **population of mini-Neptunes seems to be suppressed for a_{bin} ≲100 au compared to single stars** *(Sullivan et al. 2024)*.



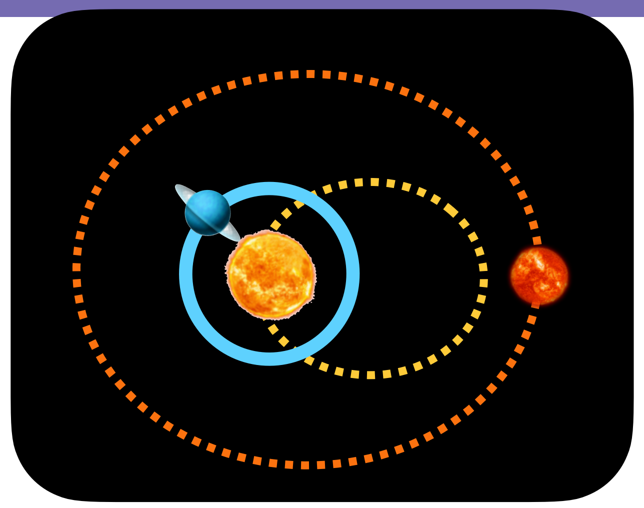
- The environment where S-type planets form can be very different from the single-star case:
  - **Disc truncation** and **heating** induced by the **tides of the stellar companion.**
  - **Gravitational perturbation from the stellar companion.**

➡ **Affects the outcome of planet formation and the long-term dynamical evolution**

(e.g. Kley & Nelson 2007, Alexander et al. 2011, Zagaria et al. 2021, Ronco et al. 2021, Venturini et al. subm., Nigioni et al. subm.)

The PAIRS project: Planet formation Around bInaRy Stars

Goal: to adapt the ***Bern Model*** of planet formation and evolution *(Alibert et al. 2005, Mordasini et al. 2009, Fortier et al. 2013, Emsenhuber et al. 2021)* to **binary stars to conduct population synthesis** studies.



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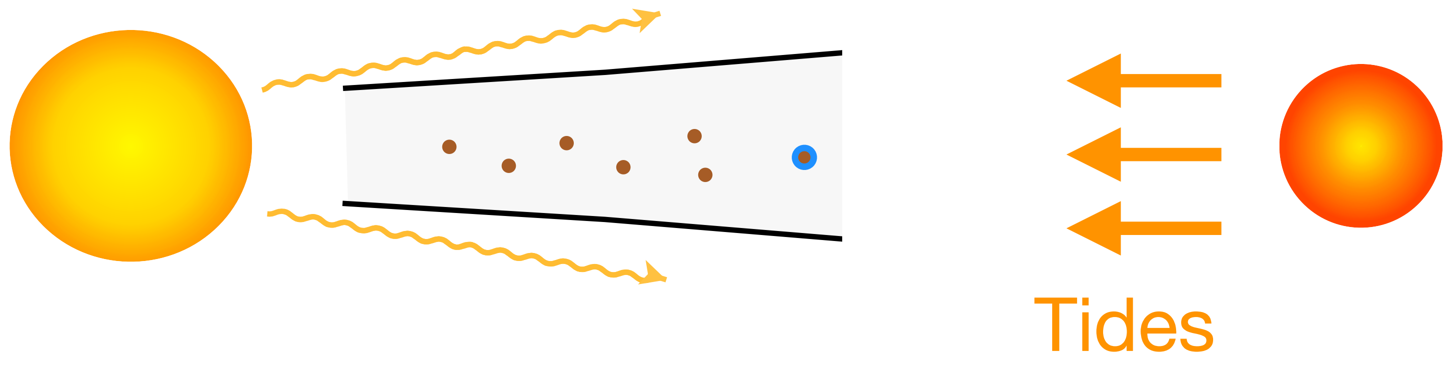
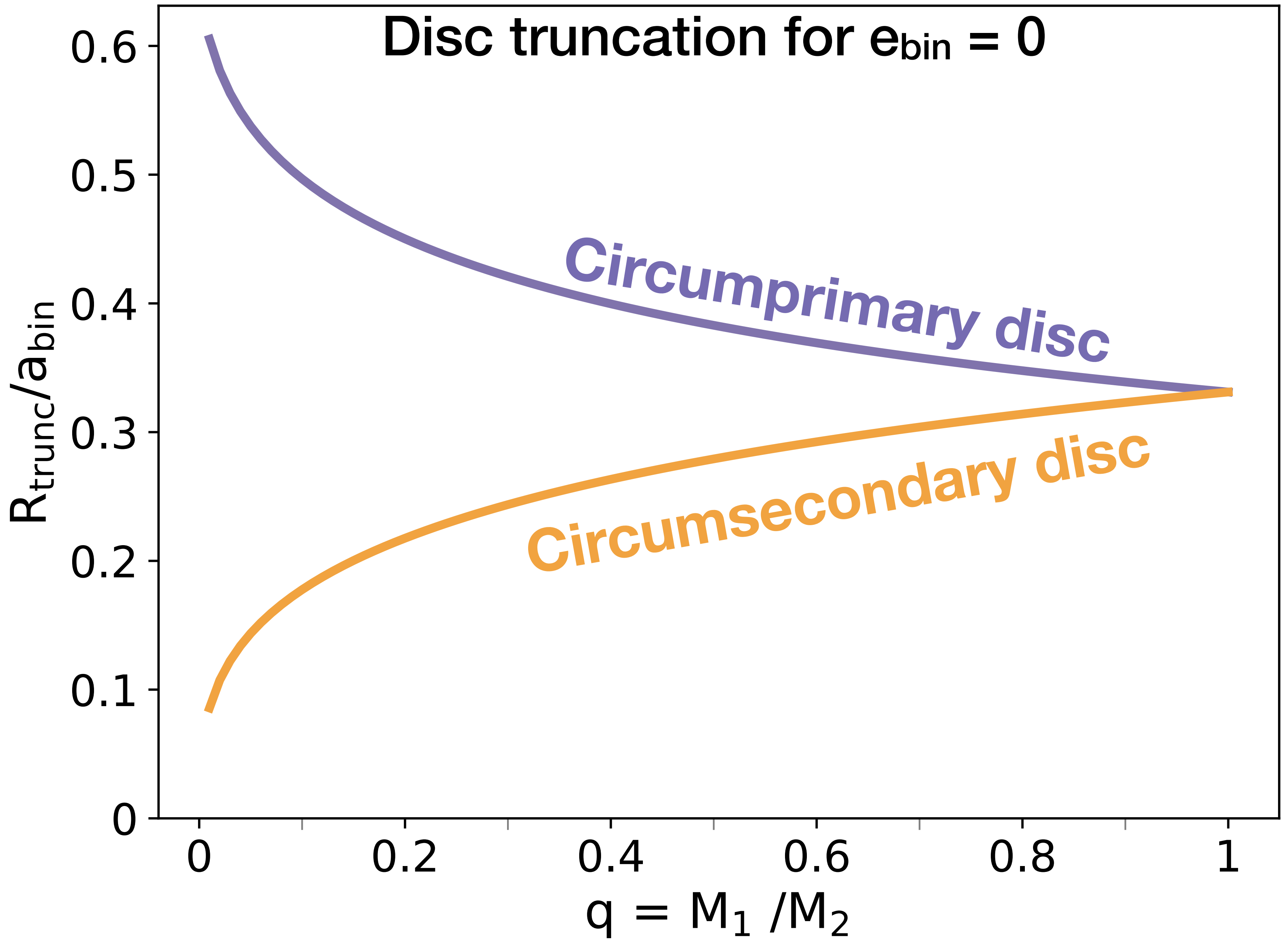
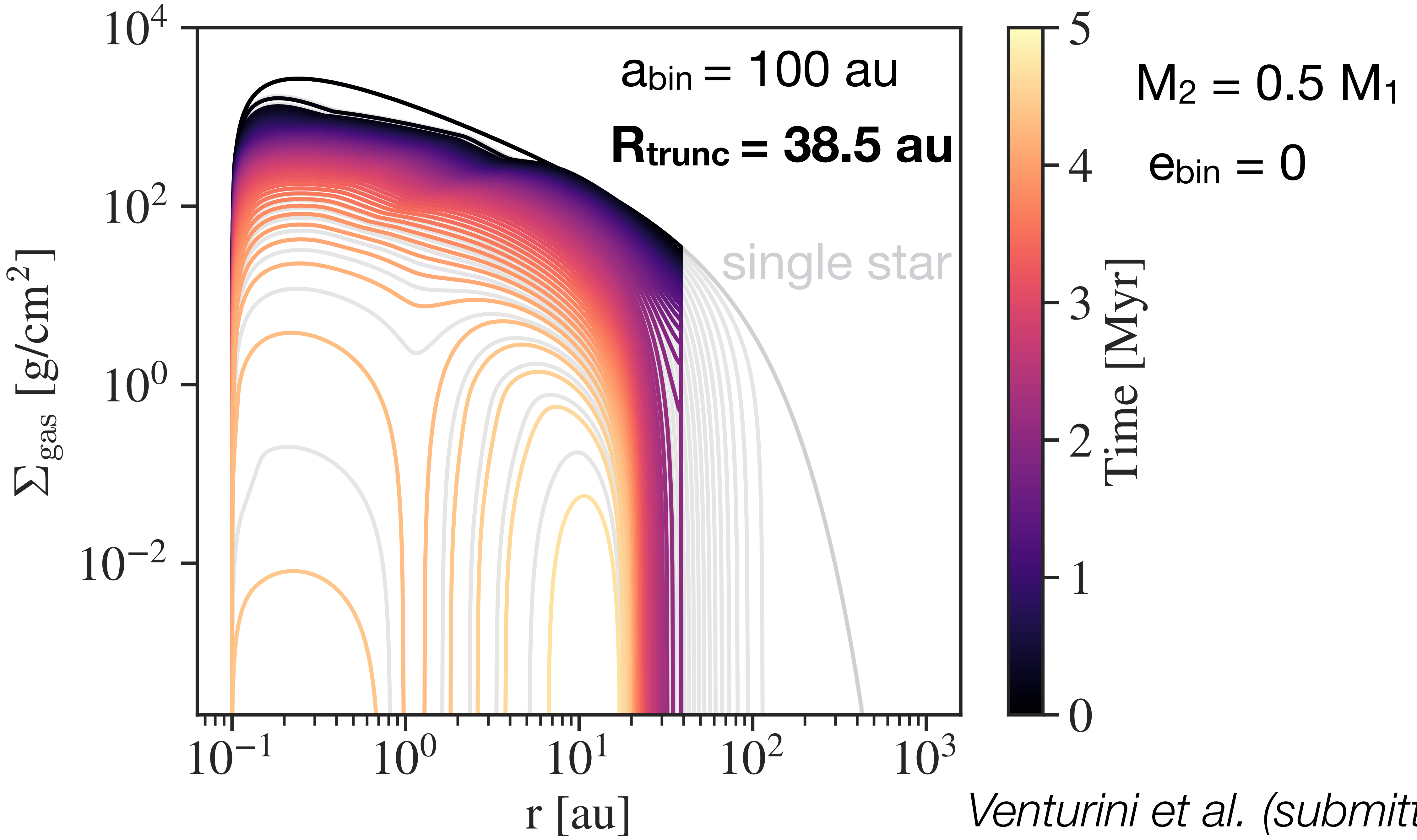


Physical effects included:

- **Tidal disc truncation** and **heating** induced by the **stellar companion** *(Venturini et al. subm.)*
- **Gravitational interaction with the stellar companion** *(Nigioni et al. subm.)*

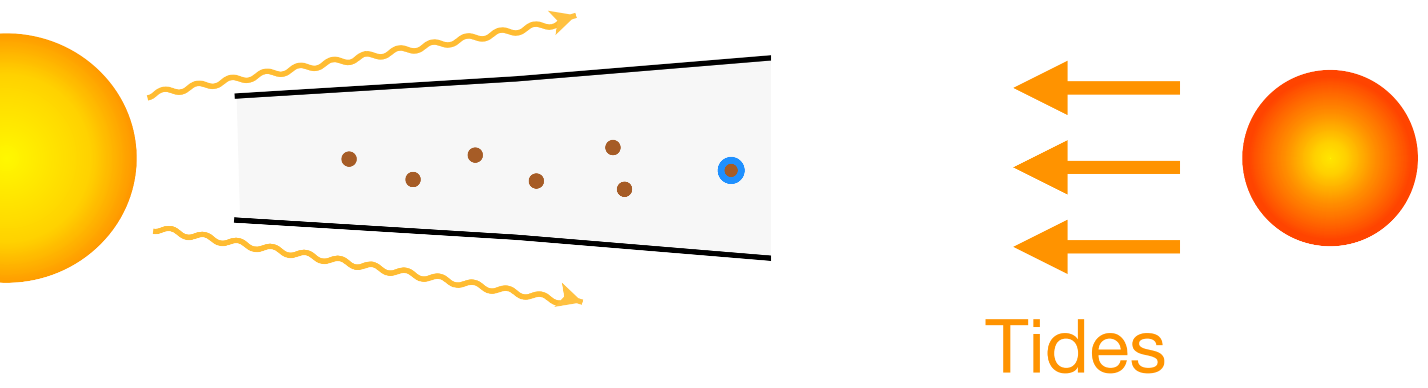


Fits from Manara et al. 2019, based on calculations of Artymowicz & Lubow 1994



Venturini et al. (submitted)

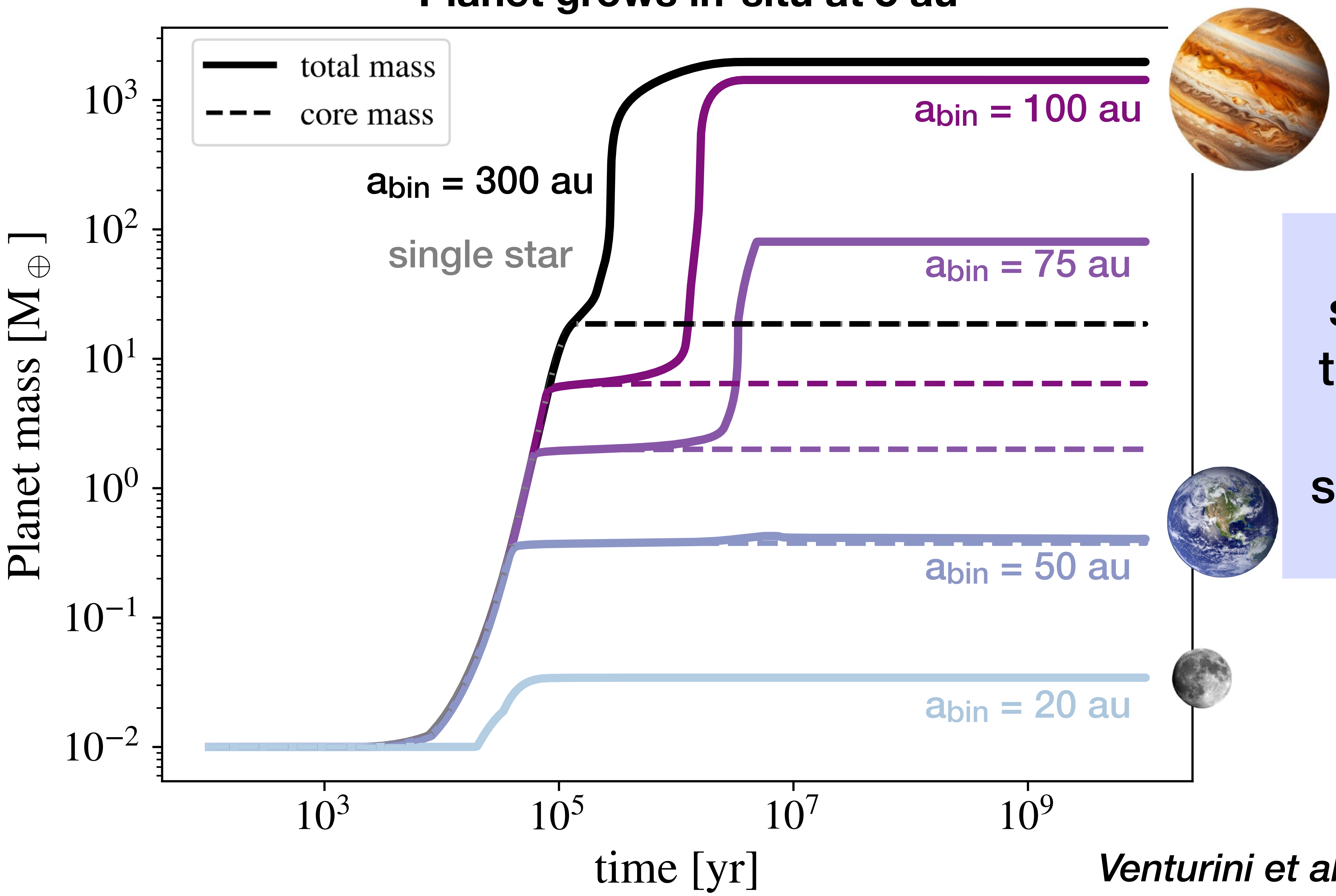
Effect of disc truncation on planet growth: shut-off of pebble supply



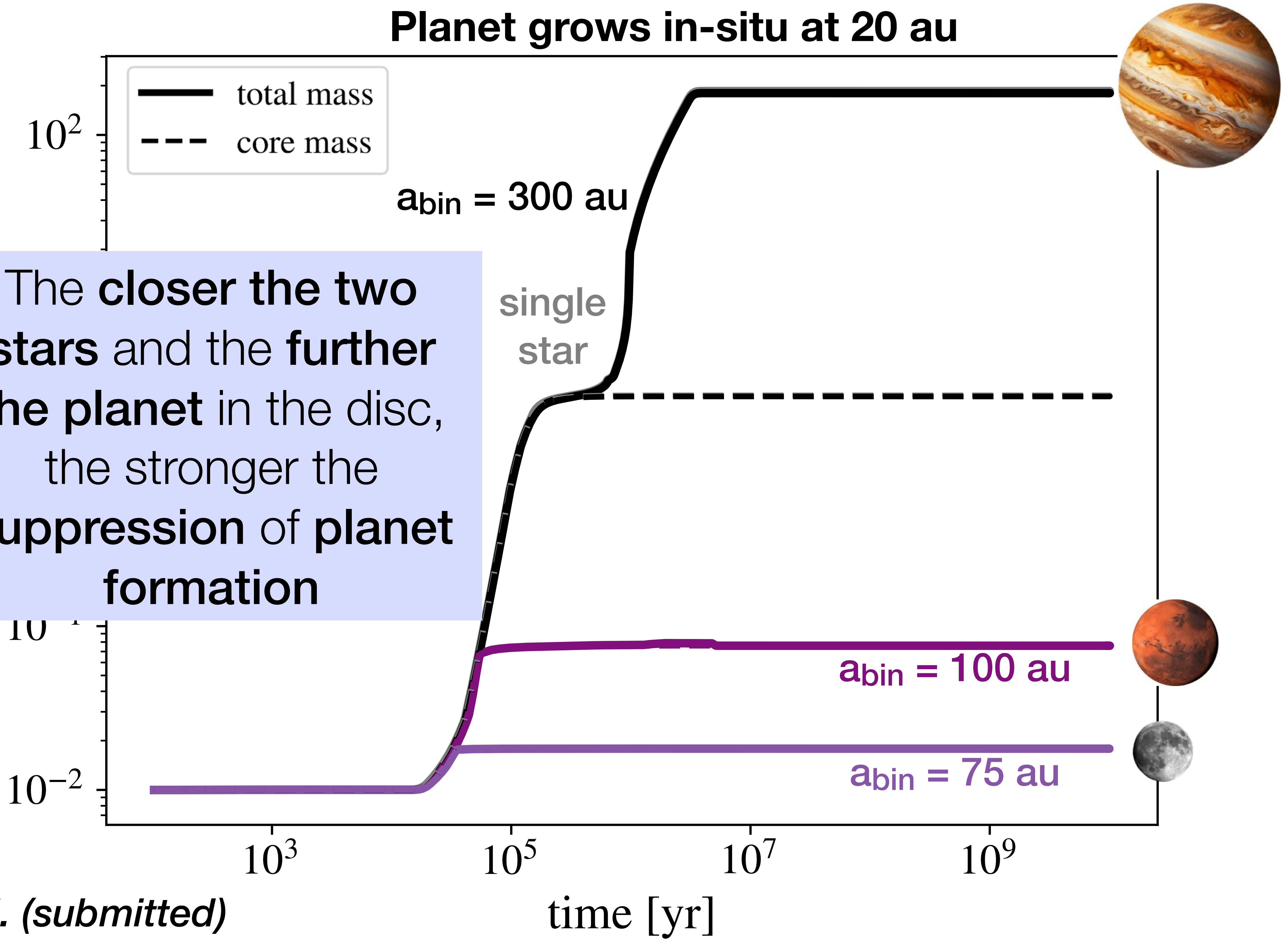
- Disc gas evolution with disc truncation + tidal heating + direct irradiation from secondary.
- Dust evolution (from μm- to pebble-sizes, *Birnstiel+2011*).
- Moon-mass embryo grows by pebble and gas accretion (envelope opacities: 0.01x BL94).

$M_1 = 1\ M_\odot$
$M_2 = 0.5\ M_\odot$
$M_{disc} = 0.1\ M_\odot$
$\alpha = 10^{-3}$

Planet grows in-situ at 5 au



Planet grows in-situ at 20 au



The **closer the two stars** and the **further the planet** in the disc, the stronger the **suppression** of **planet formation**

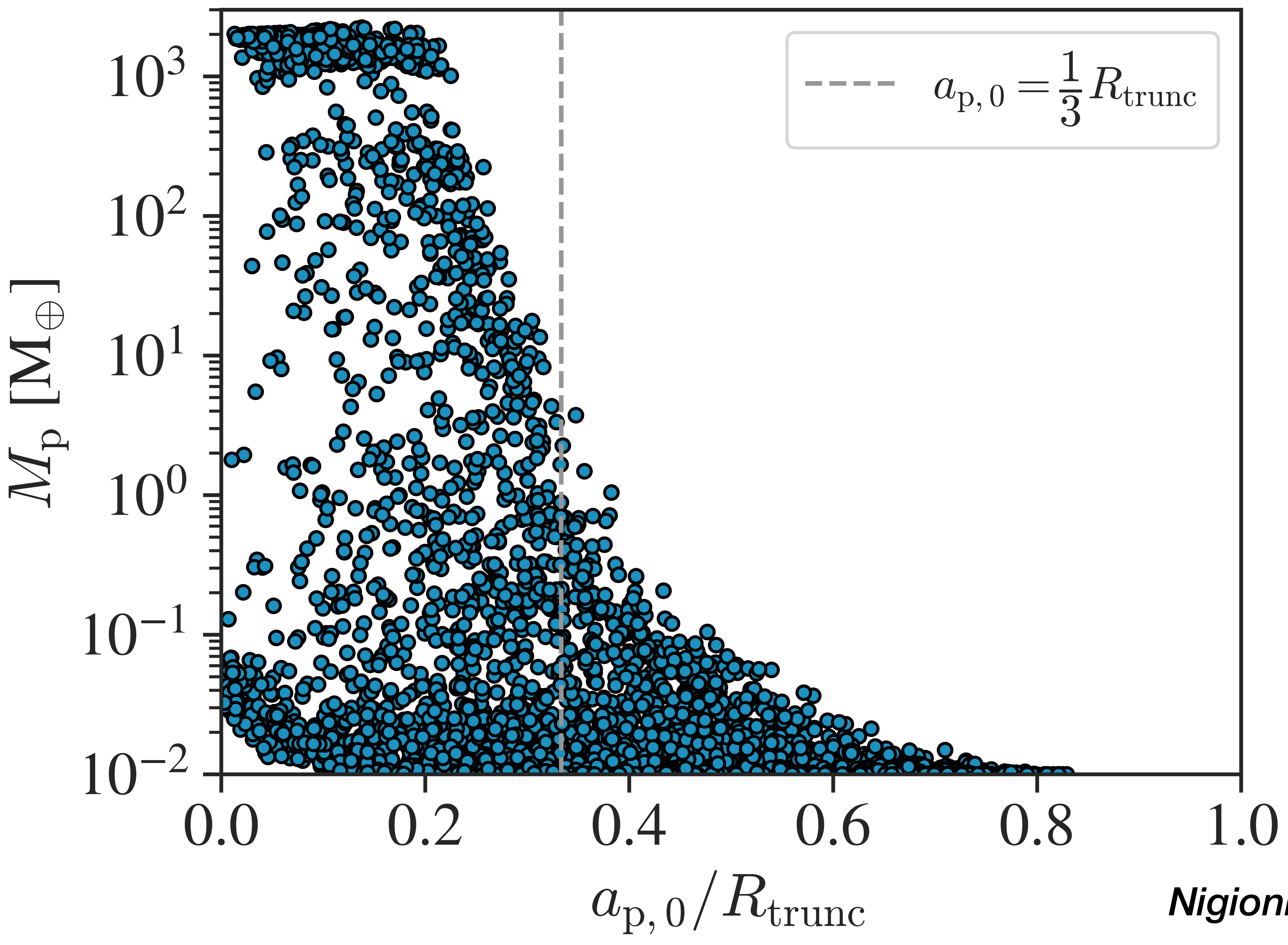
Venturini et al. (submitted)

Effect of gravitational perturbation from the secondary

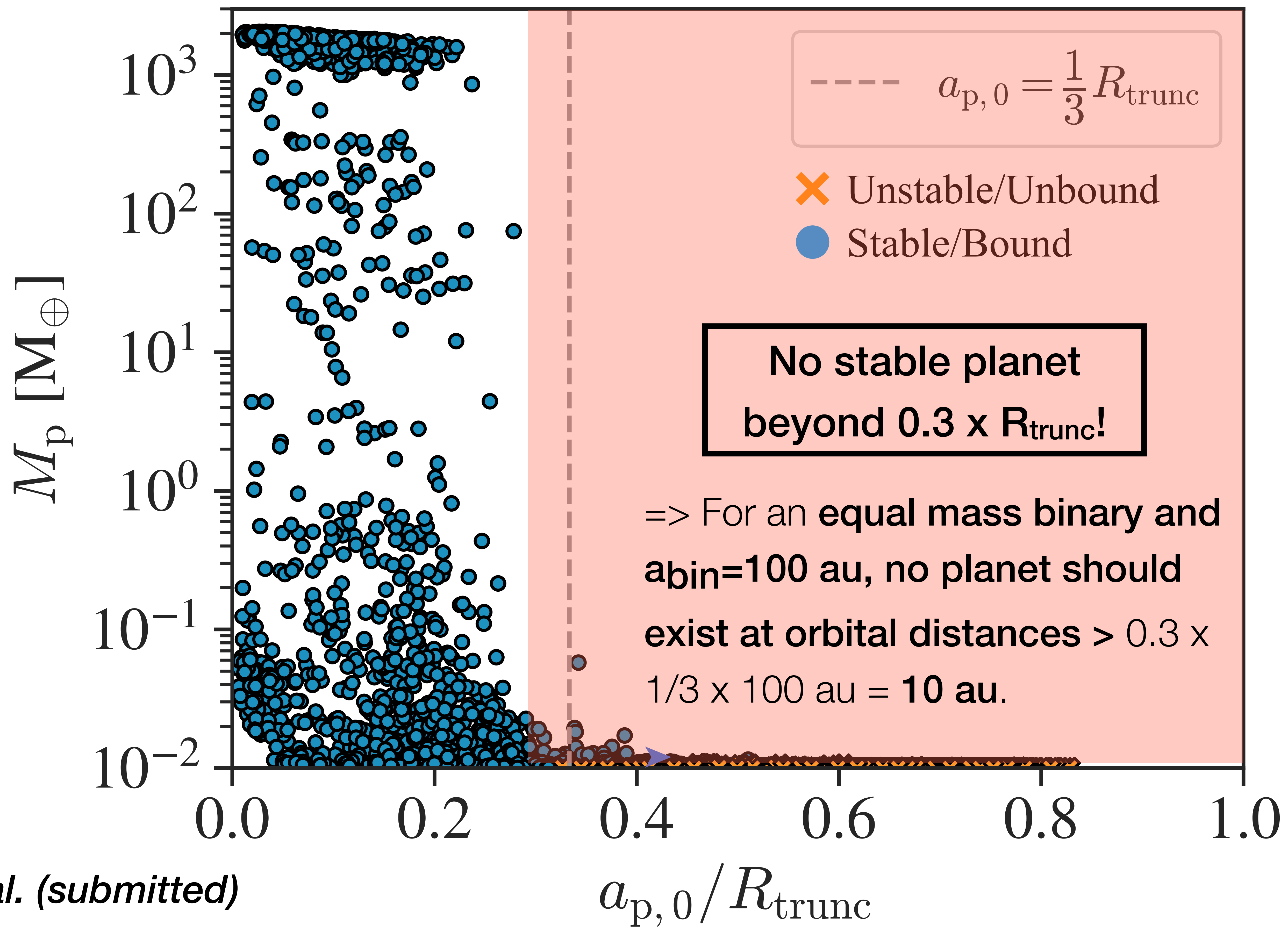
- **In-situ**, grid of 5000 simulations, 1 embryo per system.

$M_1 = 1\ M_\odot$ $M_2 = 0.1$ - $1\ M_\odot$ $a_{bin} = 10$ - 1000 au $e_{bin} = 0$ - 0.9 $M_{disc} = 0.1\ M_\odot$ $\alpha = 10^{-3}$ 1 embryo

Truncation only

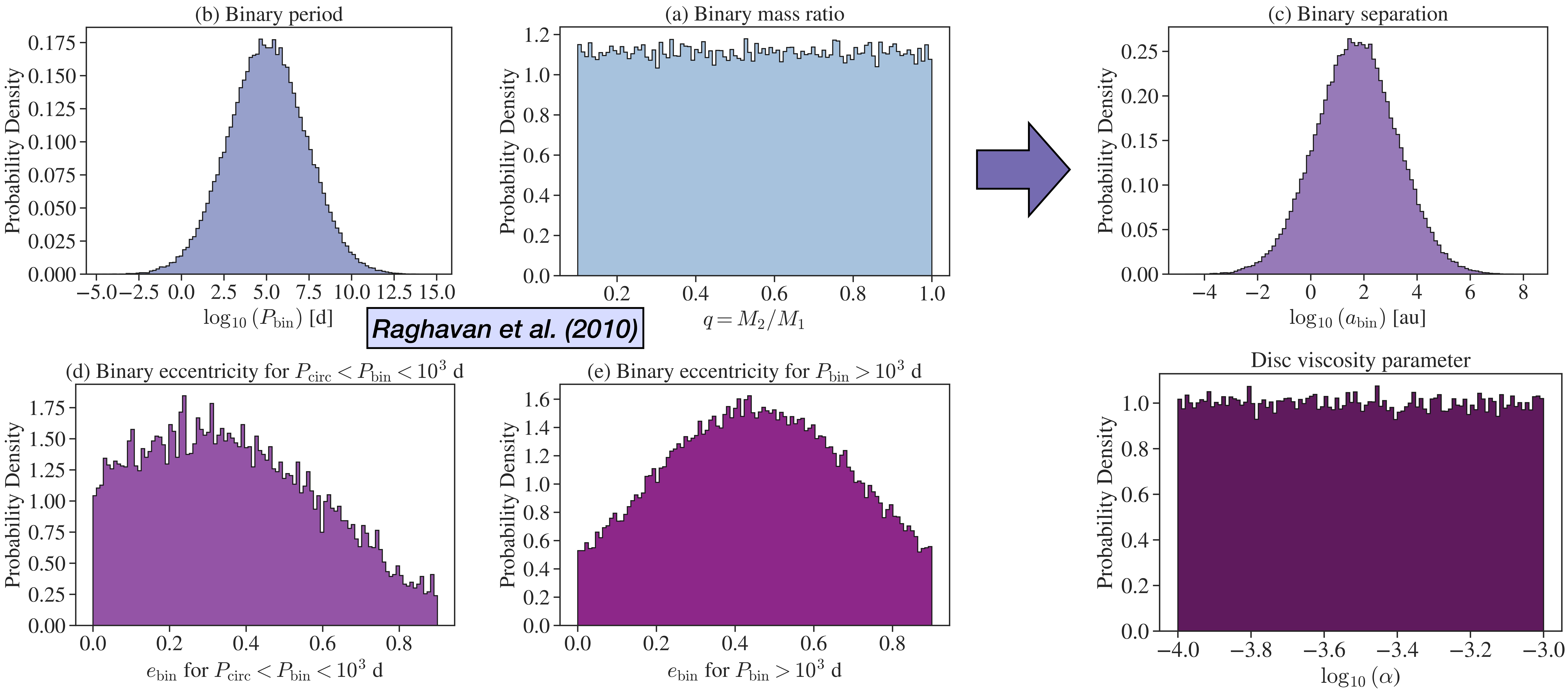


Truncation + gravitational interaction



Nigioni et al. (submitted)

Population synthesis: distributions of binary parameters (initial conditions)



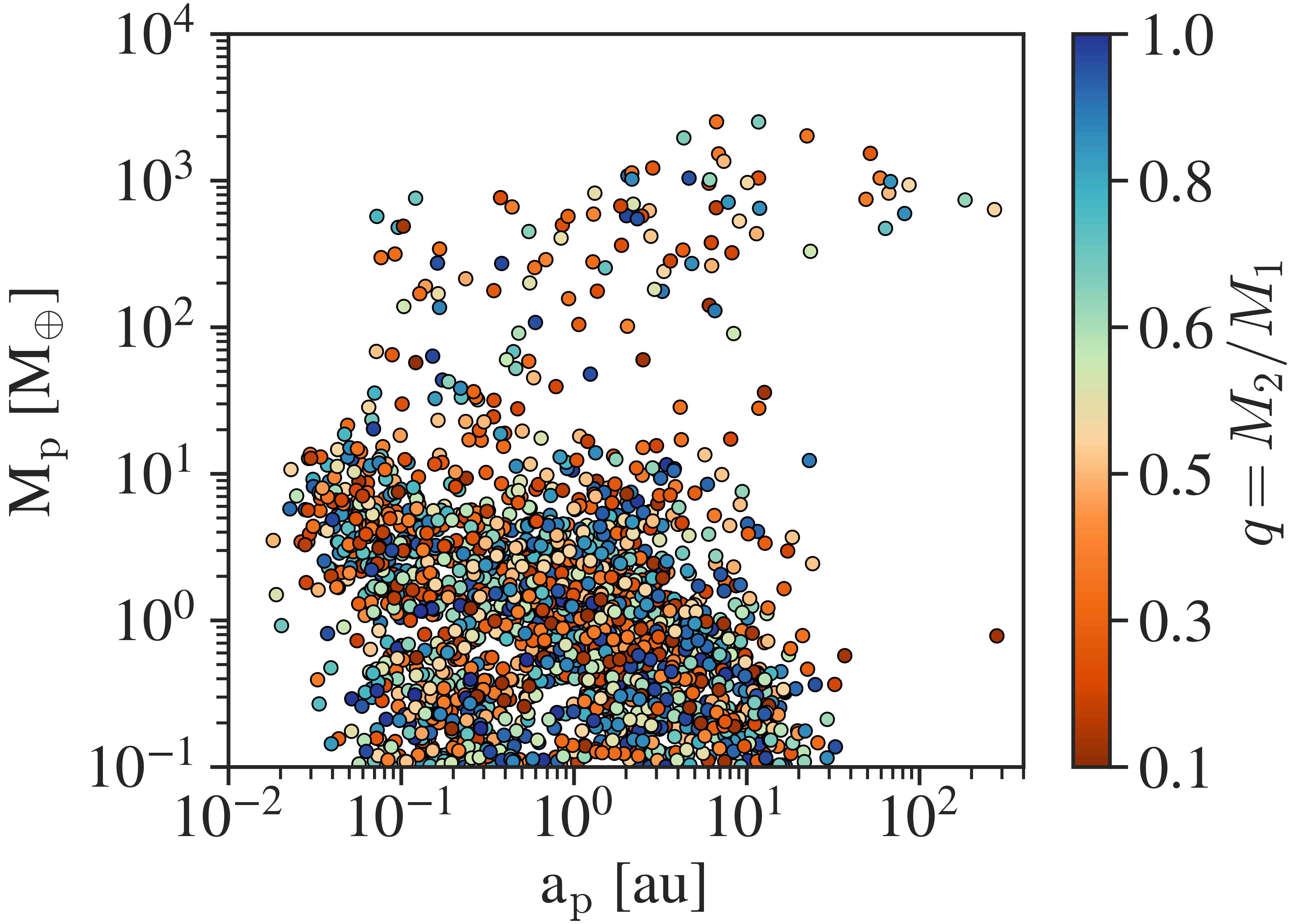
<u>**1000 systems, 20 embryos per system:**</u>

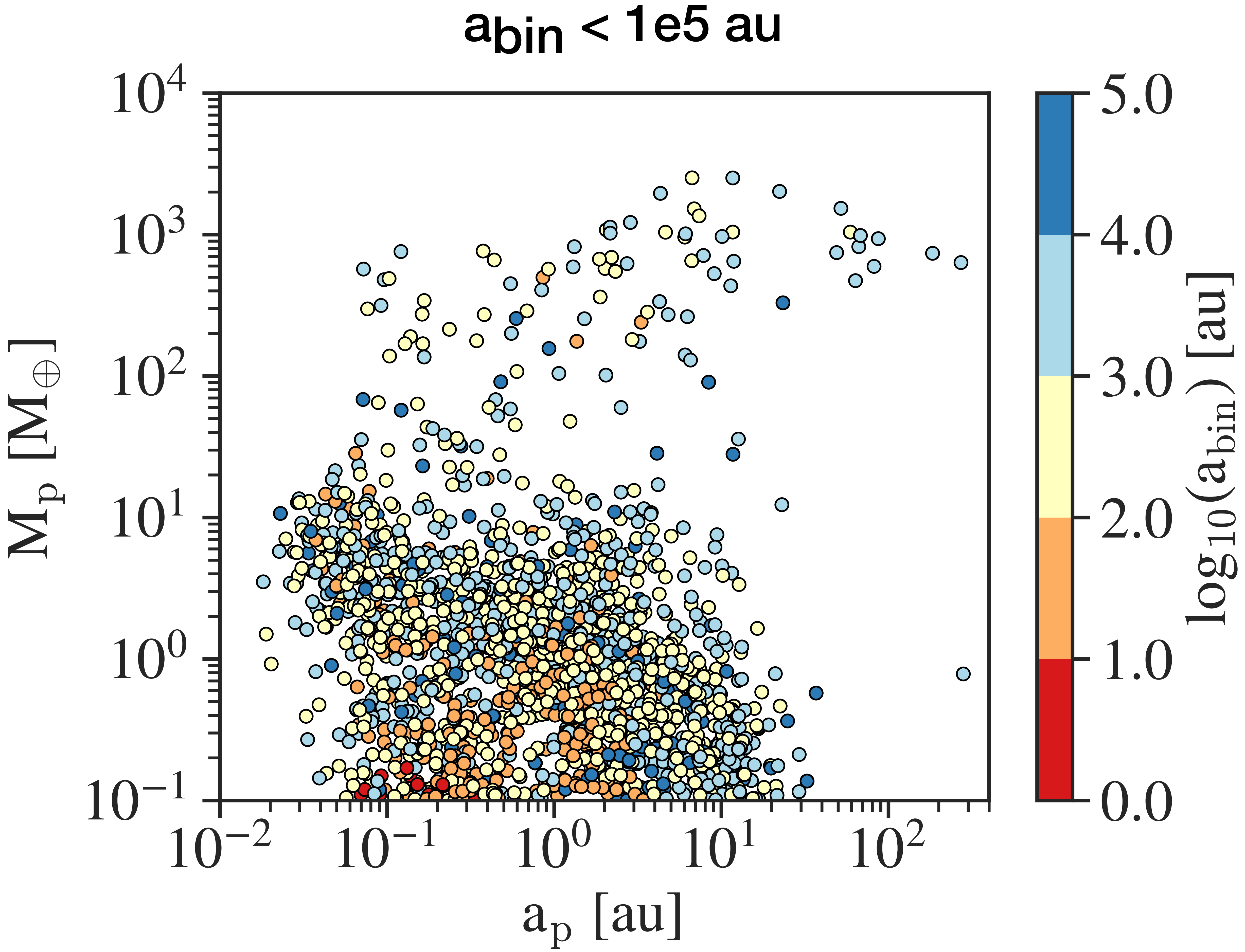
- Still running: 84 systems
- **No gas disc:** 128 simulations —> abin < 3 au.
- 81 simulations with errors

- **707 analysed systems** -> 14048 planets (all Mp, stable or ejected) —> **2049 planets (with Mp > 0.1 ME and stable)**

Population synthesis: output after formation + evolution

- Formation until disc dispersal
- 20 Myr of N-body
- 10 Gyr evolution with photoevaporation





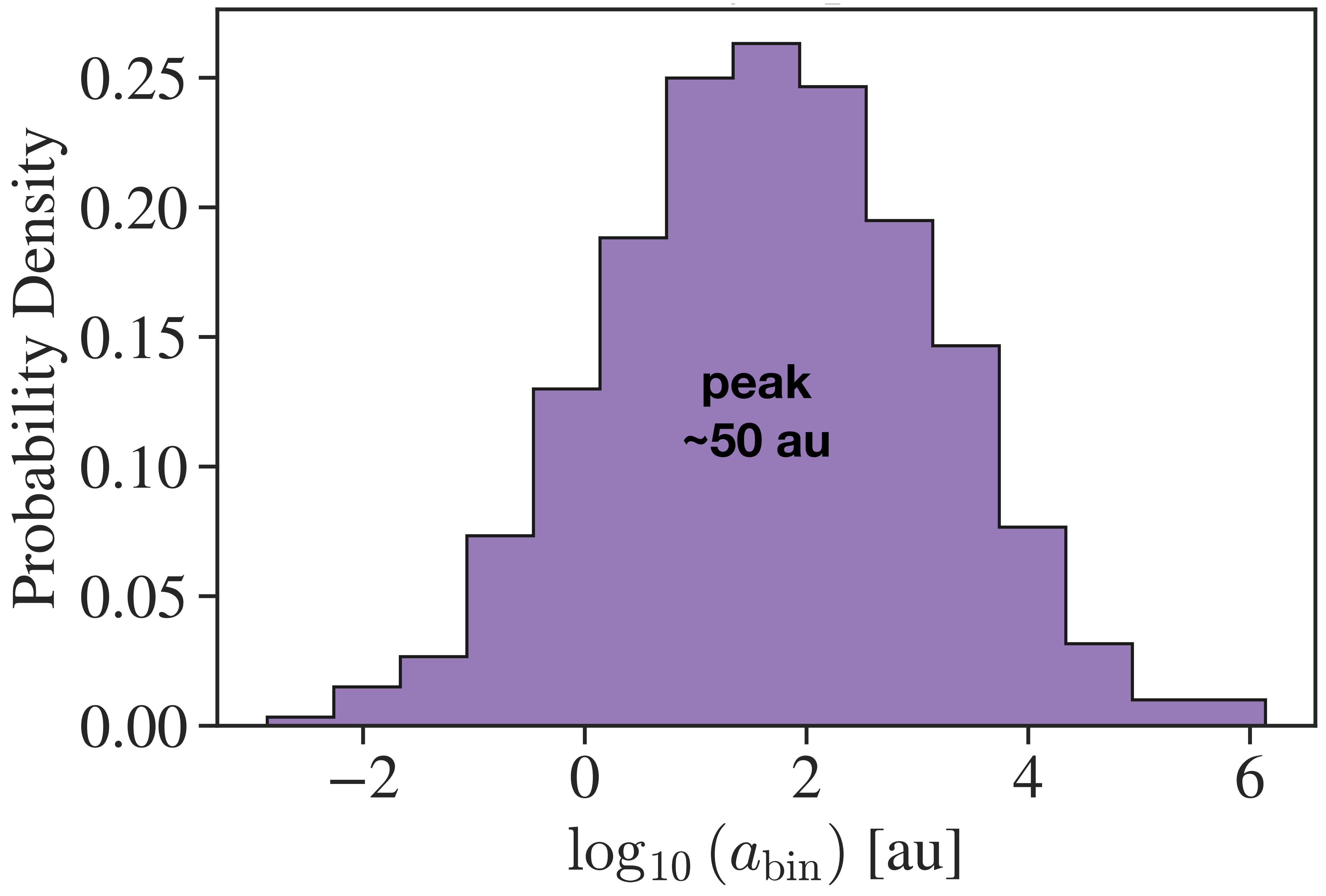
16.5 % of systems are missing

Nigioni, Venturini et al. in prep.

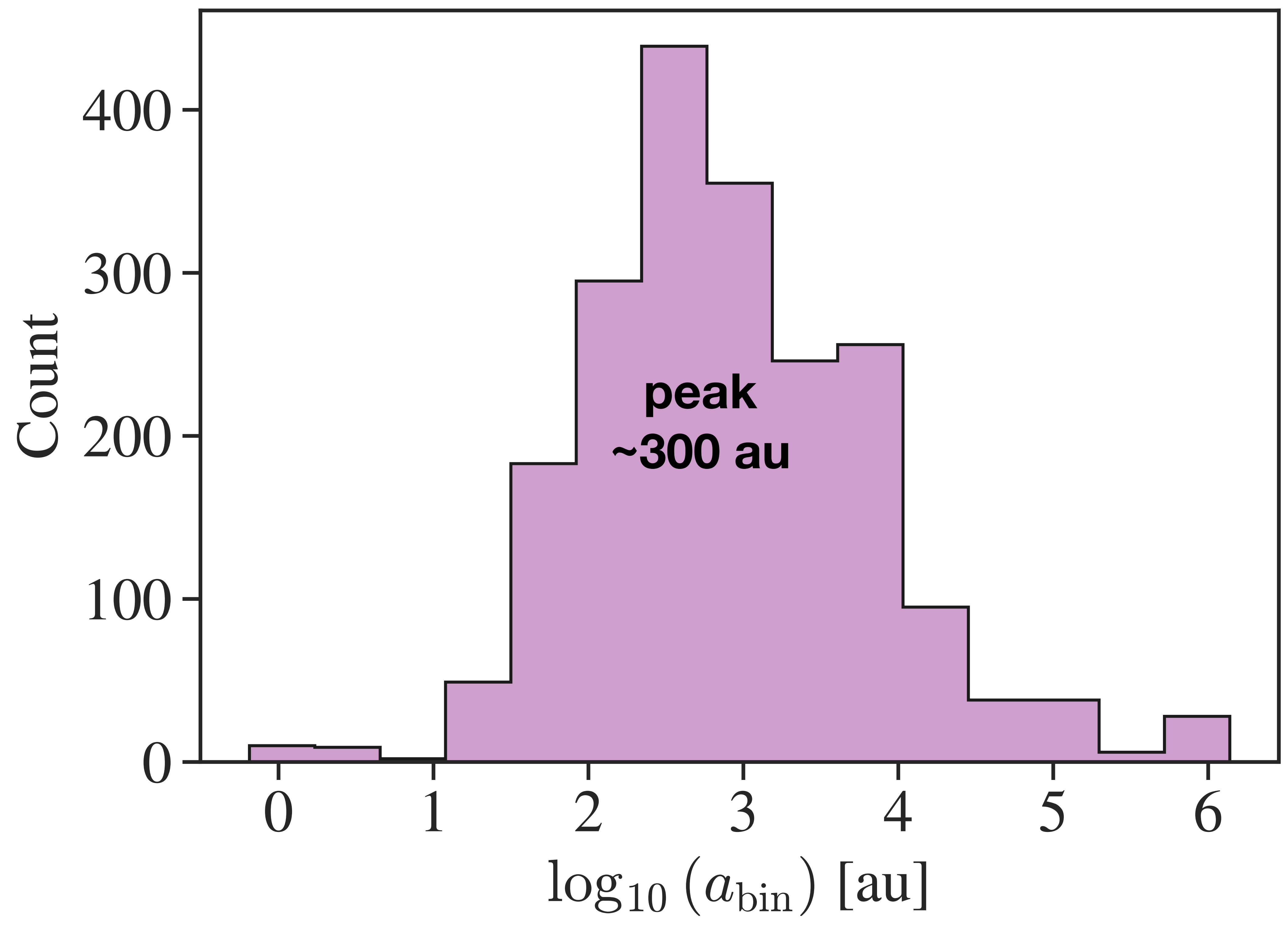
Population synthesis: output after formation + evolution

Distribution of binary semi-major axis

All binaries (initial conditions)



Binaries that formed planets



1000 binary systems, 20 embryos per system

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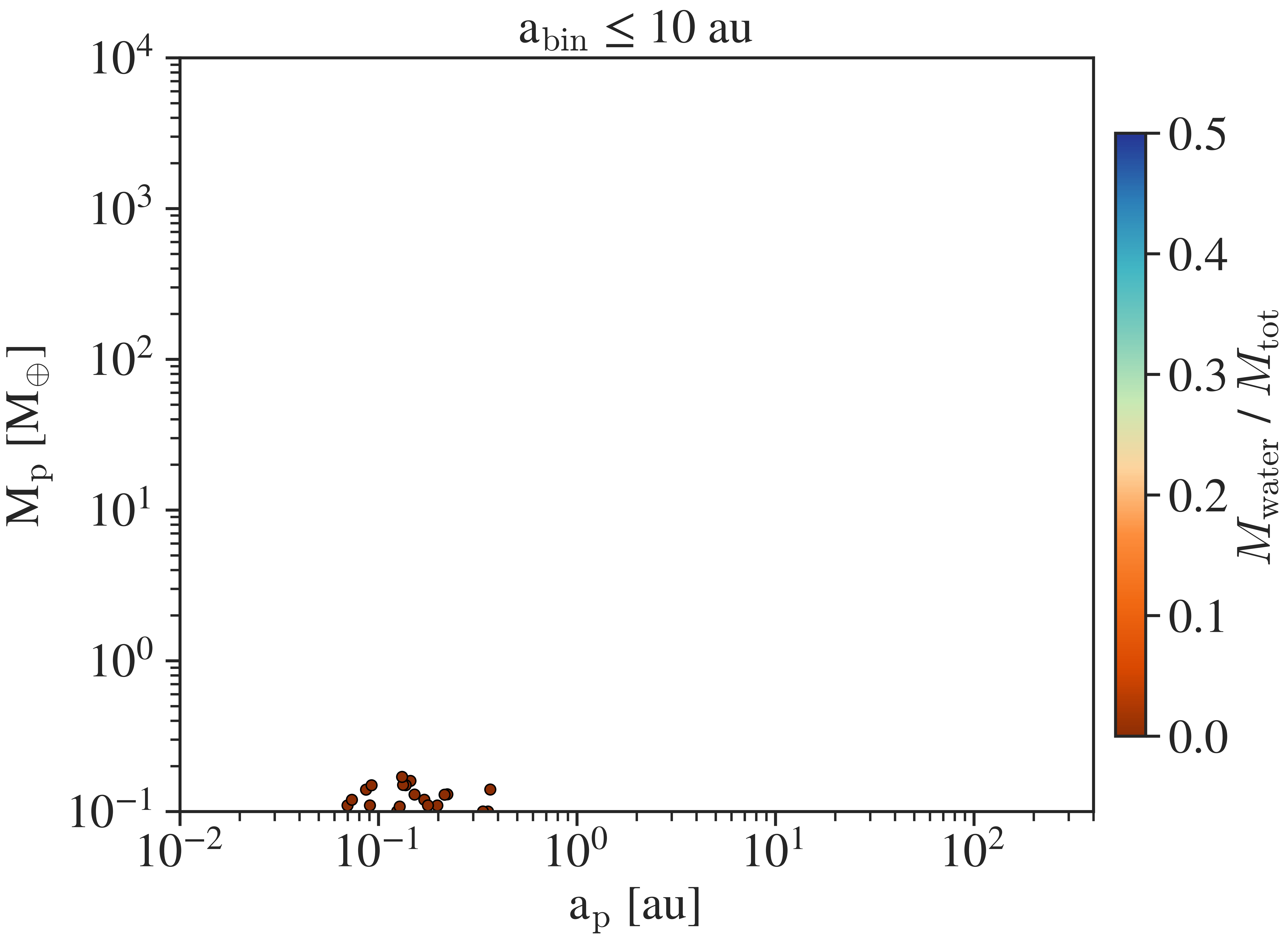
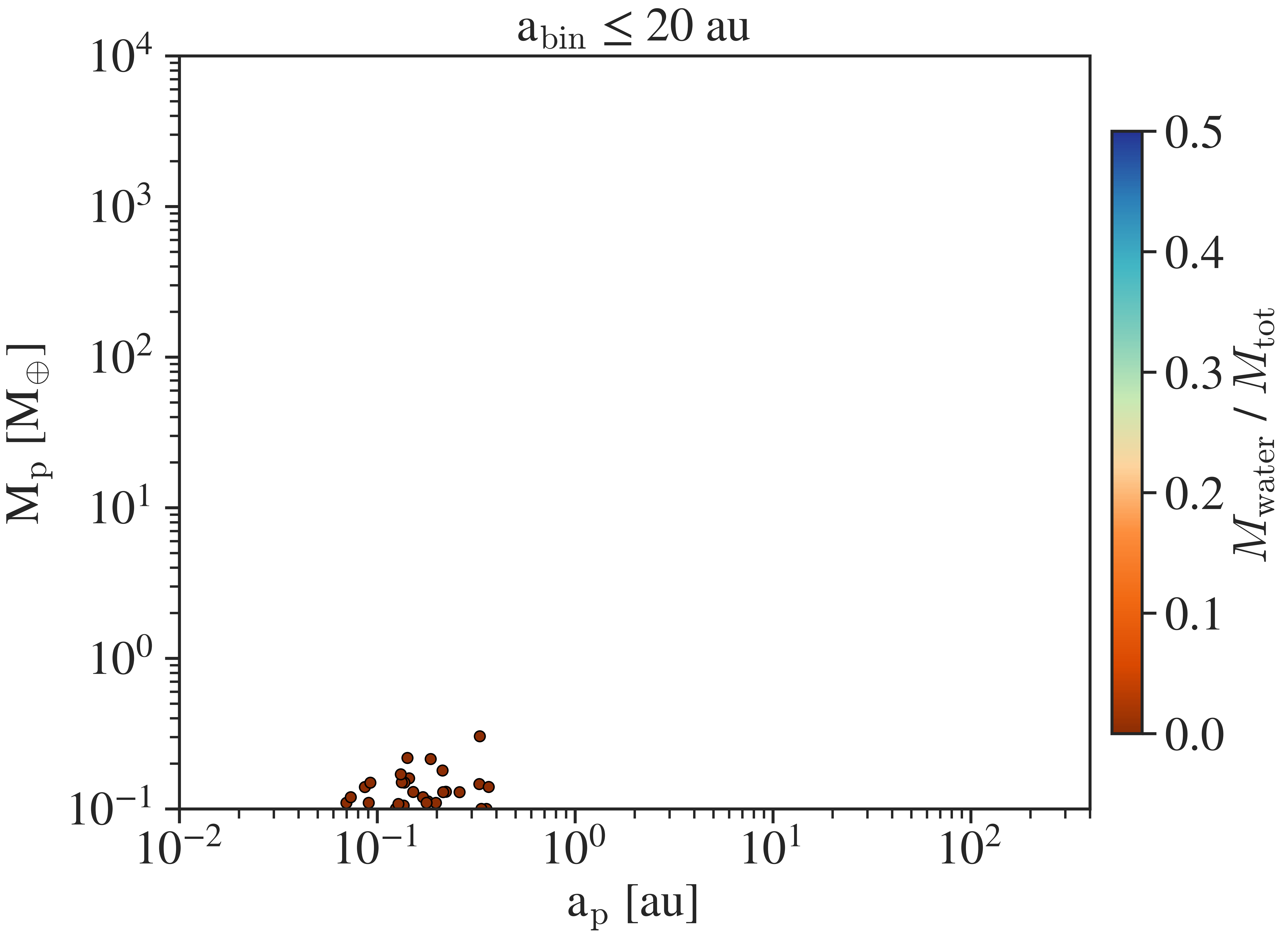
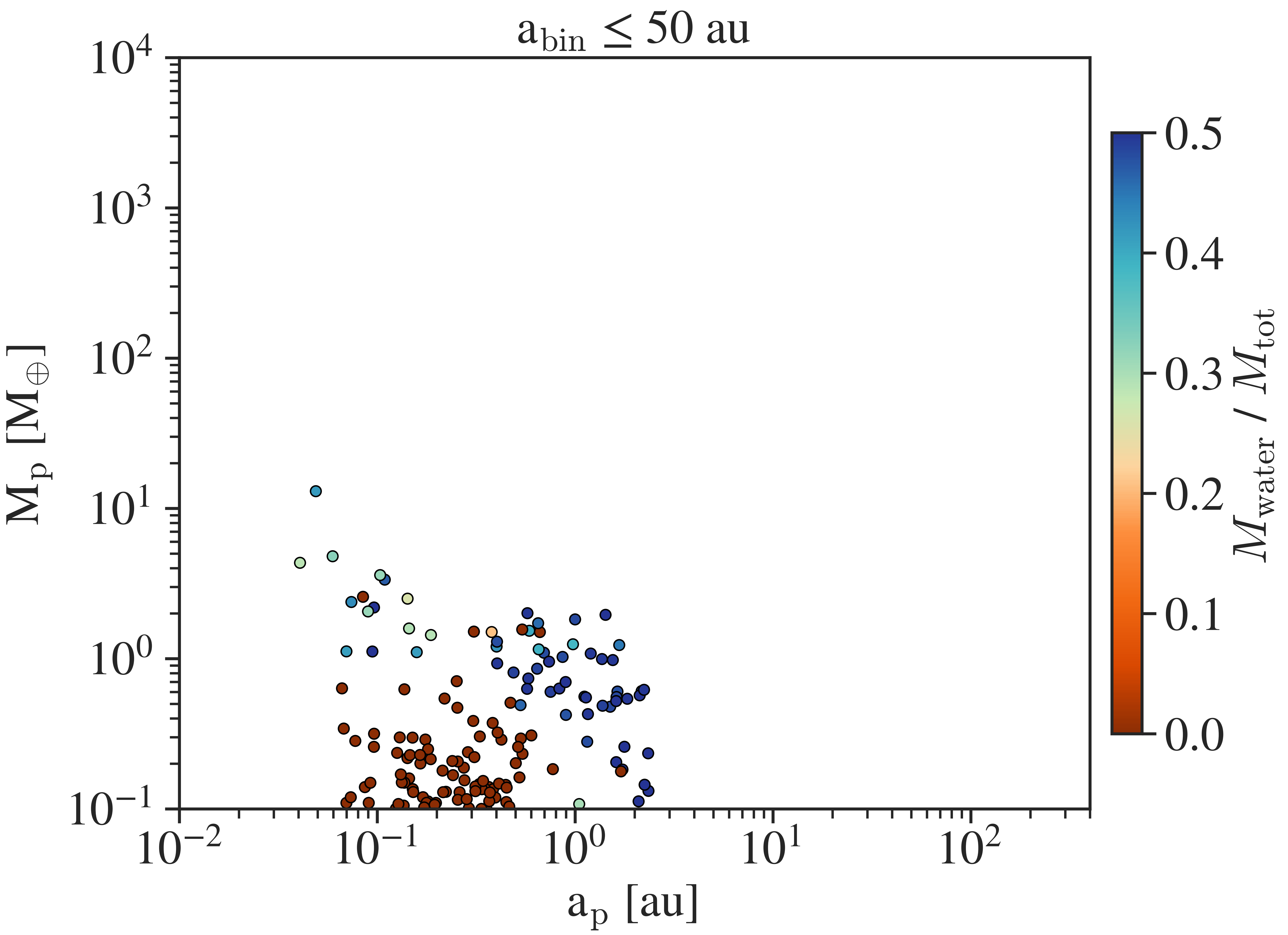
Population synthesis: output after formation + evolution



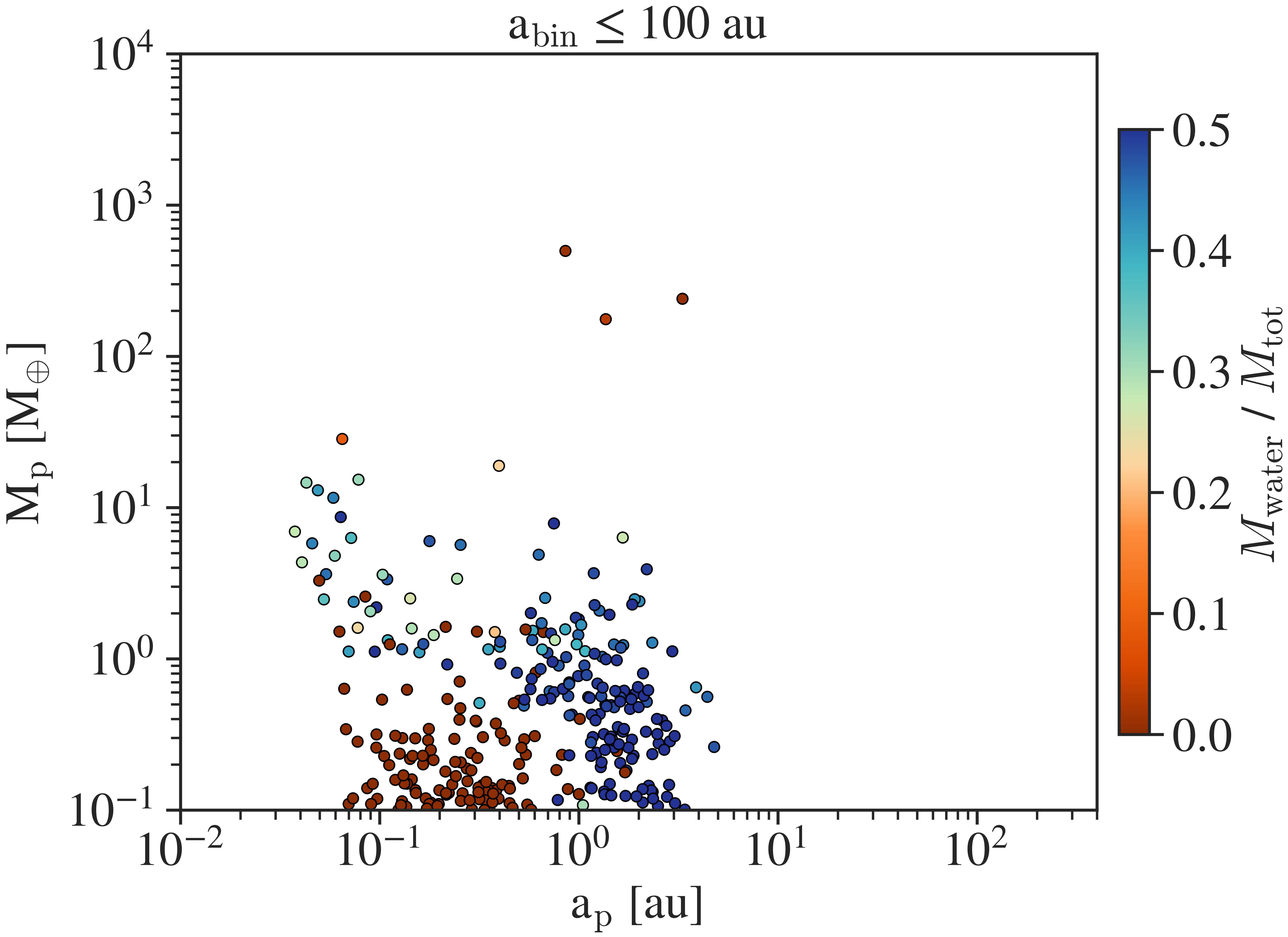
Population synthesis: output after formation + evolution



Population synthesis: output after formation + evolution



Population synthesis: output after formation + evolution



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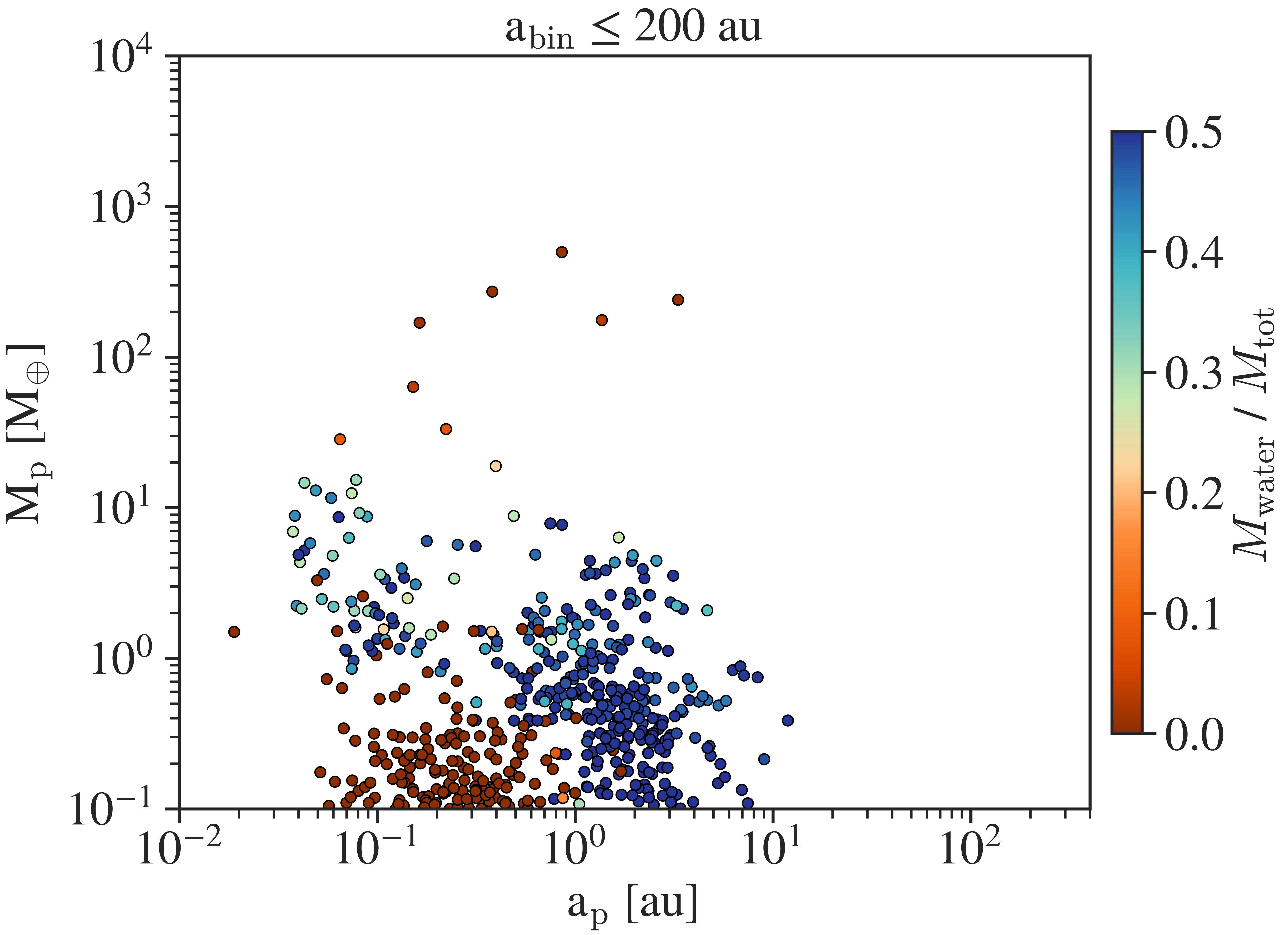

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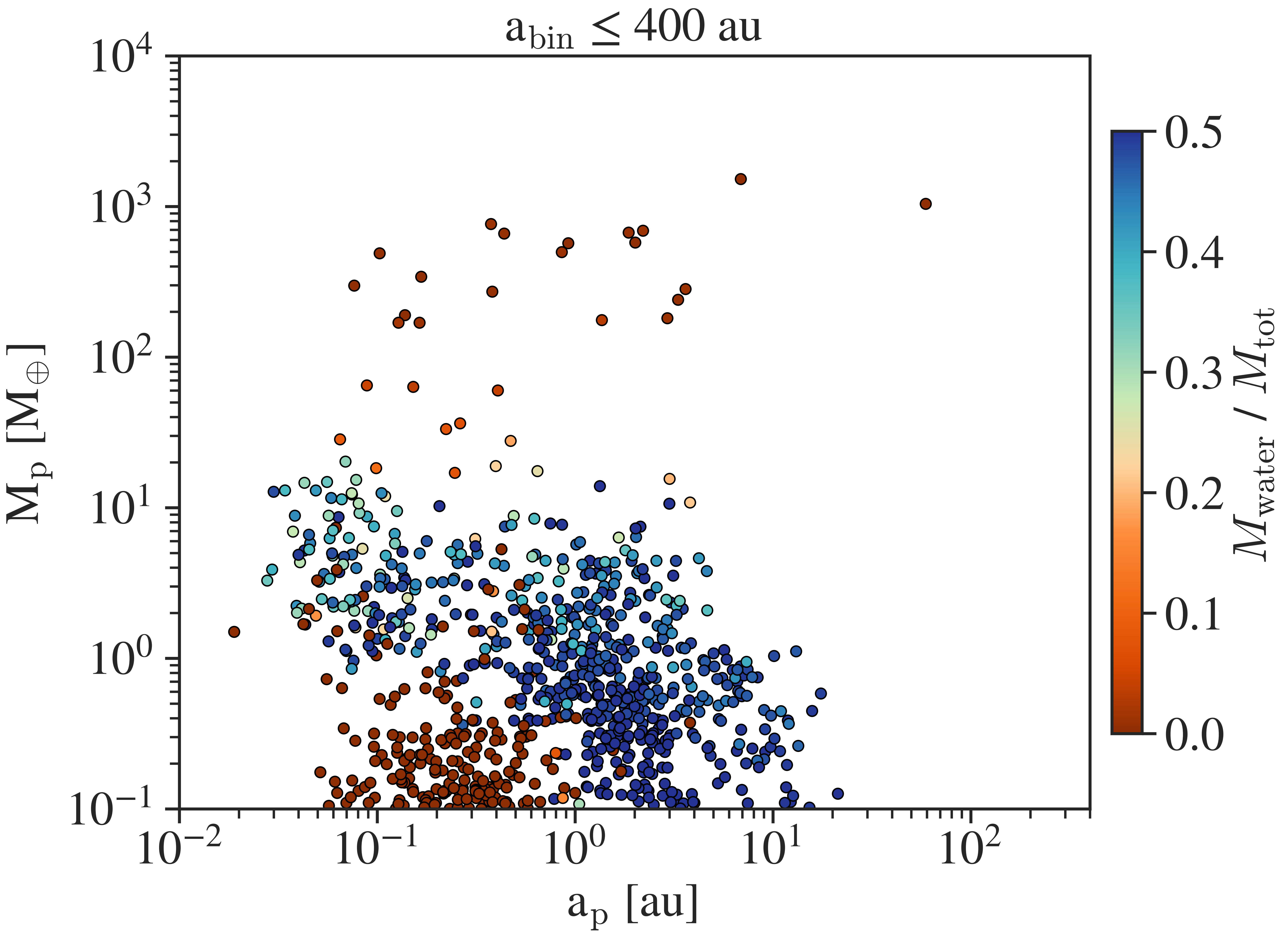

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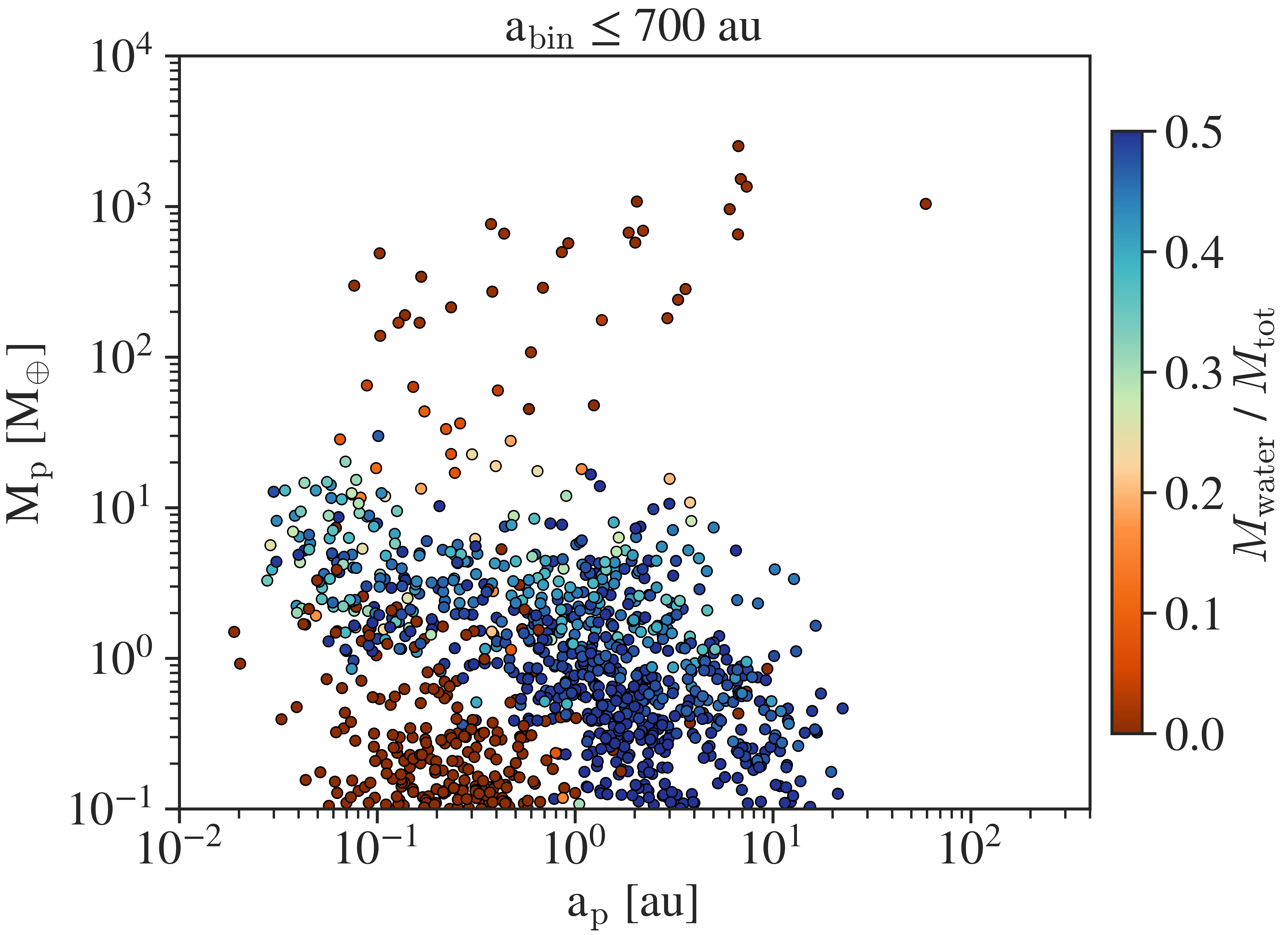
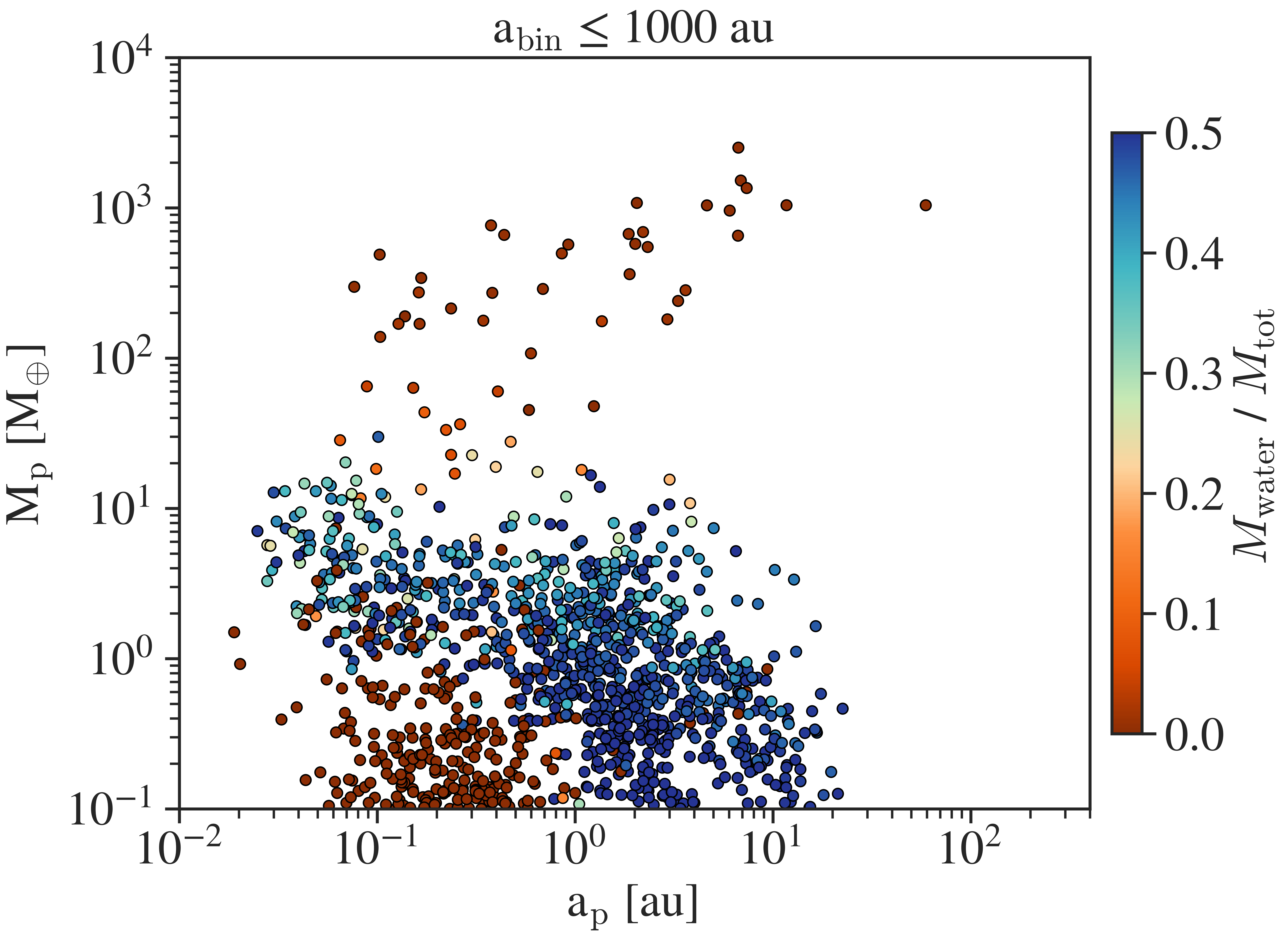


Population synthesis: output after formation + evolution



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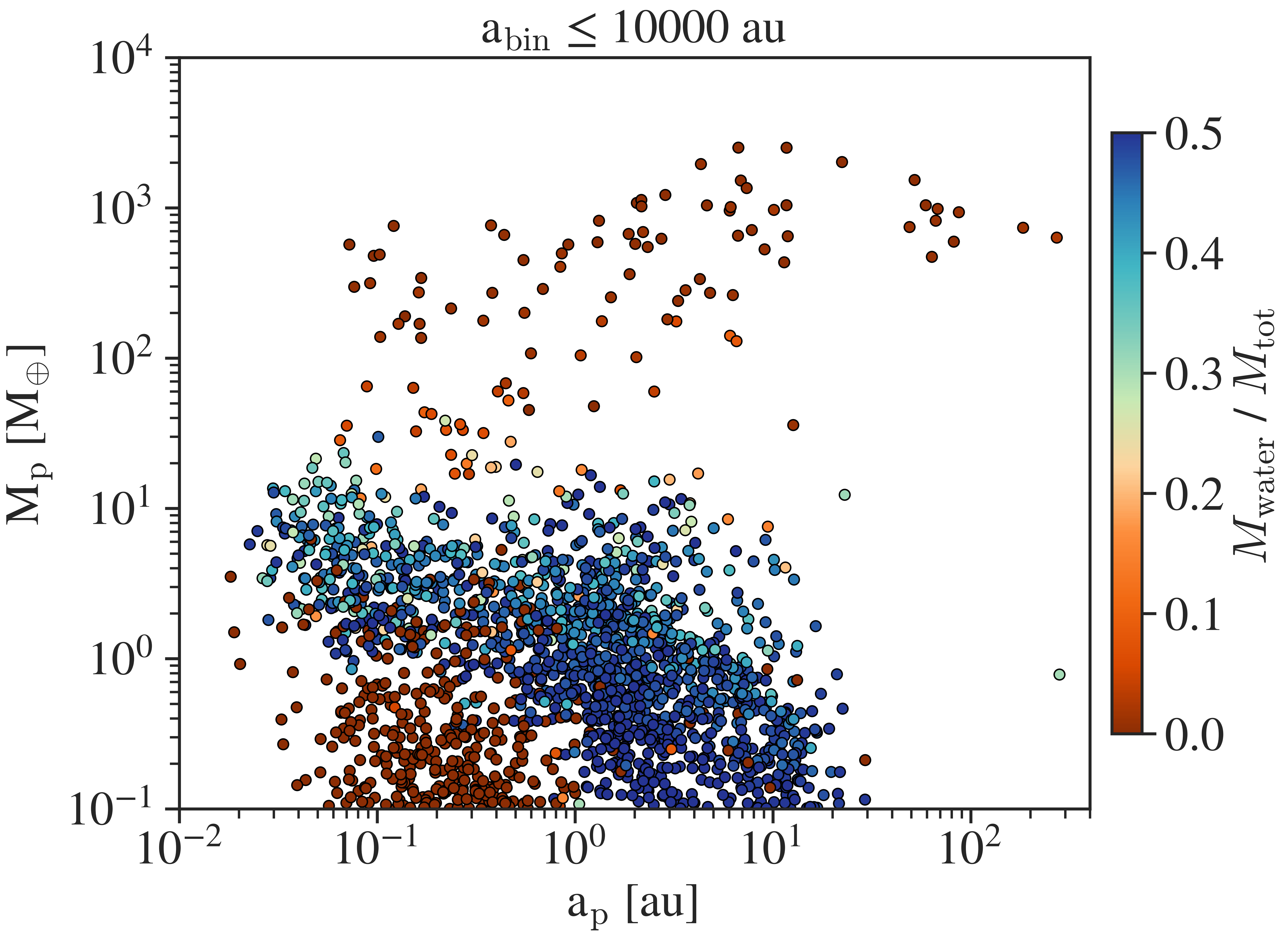


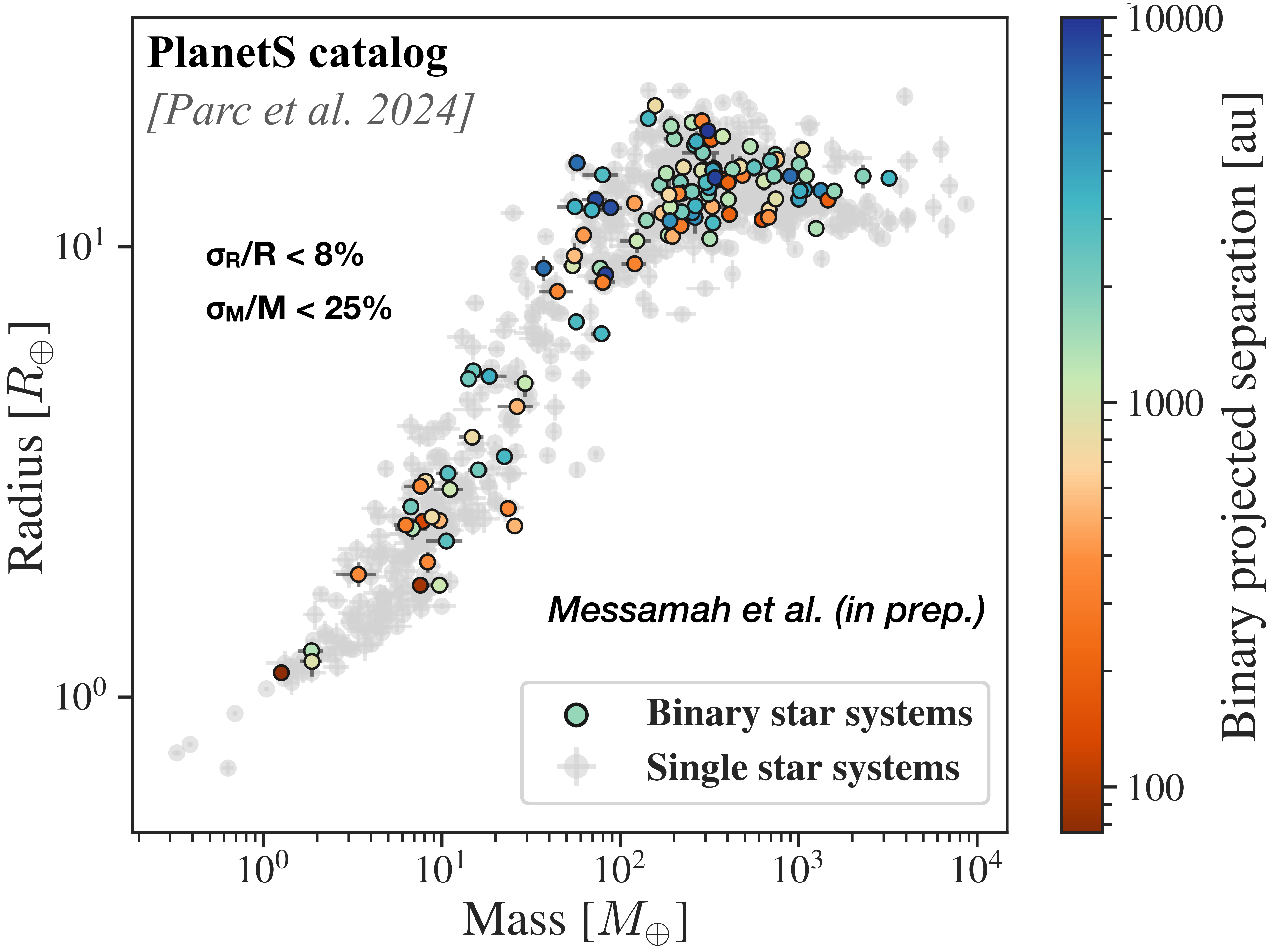
S-type planets with NIRPS & PlanetS catalog

Lina Messamah

F. Bouchy

PlanetS
National Centre of Competence in Research

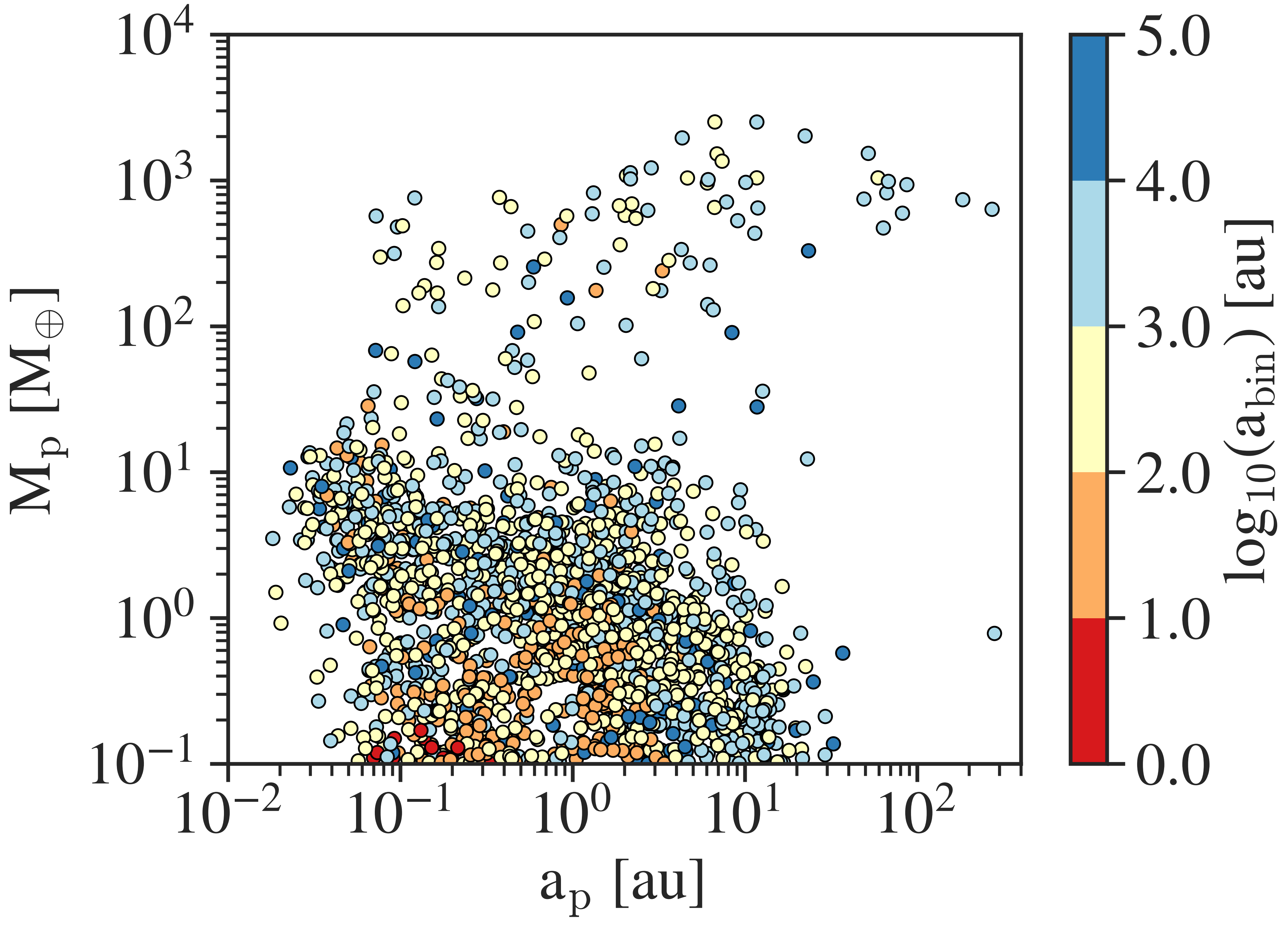
- Ongoing efforts to expand the planets in binary sample at angular separations < 2” with NIRPS.
  - Targets: transiting S-type planet candidates **around K- to M-dwarf hosts.**
  - High-resolution follow-up to confirm new S-type planets.



Summary

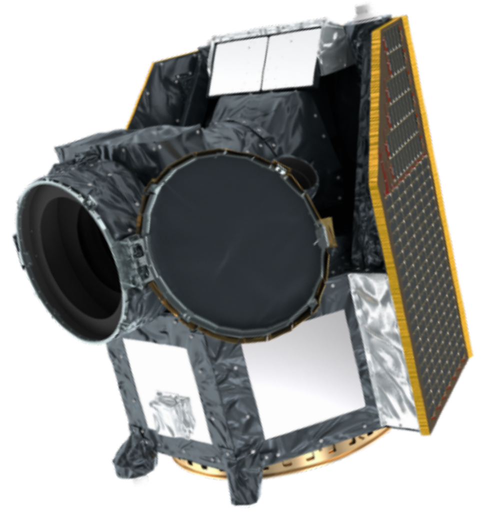
Theory:

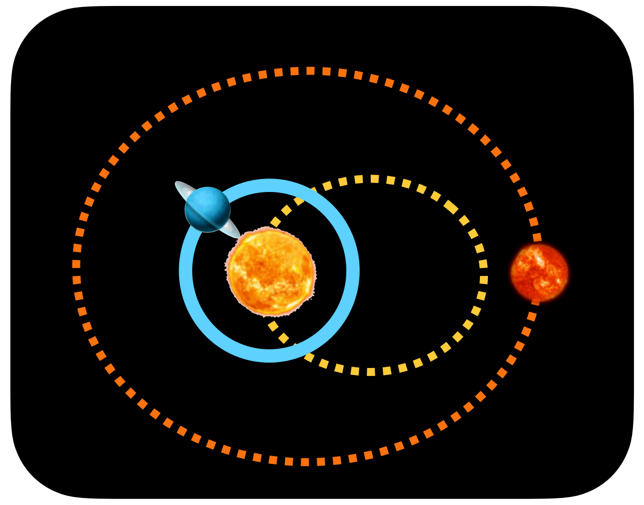
- **S-type planet formation by pebble accretion is severely affected by disc truncation for a_{bin} < 50-100 au.**
- During formation, the S-type planets become unstable if located beyond ~0.3 x $R_{trunc.}$ => Outer limit to S-type planetary systems that can be tested observationally.
- **(Preliminar) Pop. Synthesis:**
  - **min. a_{bin} to form Earth-mass planets:~30 au**
  - **min. abin to form giant planets (Mp>100 ME): ~ 80 au**
  - **Far-out giant planets (ap ~ 50 -300 au) appear for a_{bin}~ 1000 -10'000 au**
    —> to be investigated!



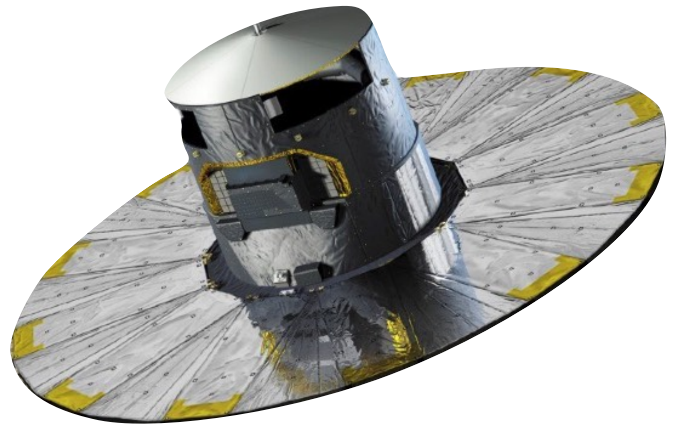
Observations:

- **CHEOPS** is allowing to identify the planet-hosting star in S-type binaries and to refine the planet radius.
- Ongoing efforts with **NIRPS** to confirm S-type planets around M- and K-dwarfs for angular separations < 2".





- **WG on S-type planets** within the **PLATO** Consortium: synergy with **GAIA DR4**.



Thank you for your attention!