How planetesimal accretion affects the composition of gas giants

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Can we find tracers to distinguish the formation pathway of a planet?

Planets form in discs in which pebbles drift inwards crossing various evaporation lines and enrich the gas in the inner disc in volatiles (Figure 1). The planetary embryo migrates through the disc accreting pebbles and planetesimals, whose composition depends on the location in the disc (Figure 2). Once the planet reaches pebble isolation mass (Figure 3), it accretes planetesimals and gas that has been enriched in volatiles by evaporating pebbles.

Methods: We performed a semi-analytical 1D simulation of a set of forming planets using the chemcomp code in [1] considering 3 different scenarios: pebble accretion, planetesimal formation, pebble and planetesimal accretion. By analysing the atmospheric composition of the planet we try to answer the question: can we find a tracer to tell the formation scenarios apart?

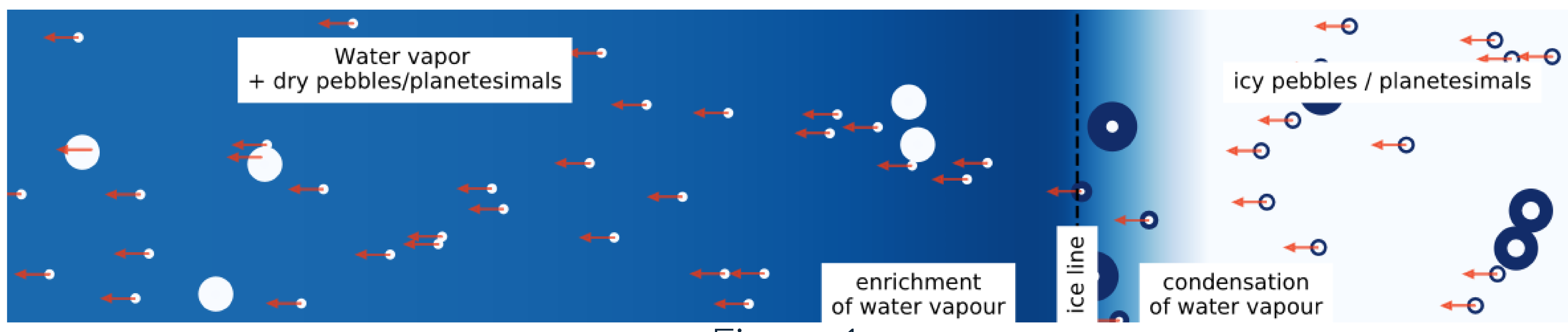


Figure 1

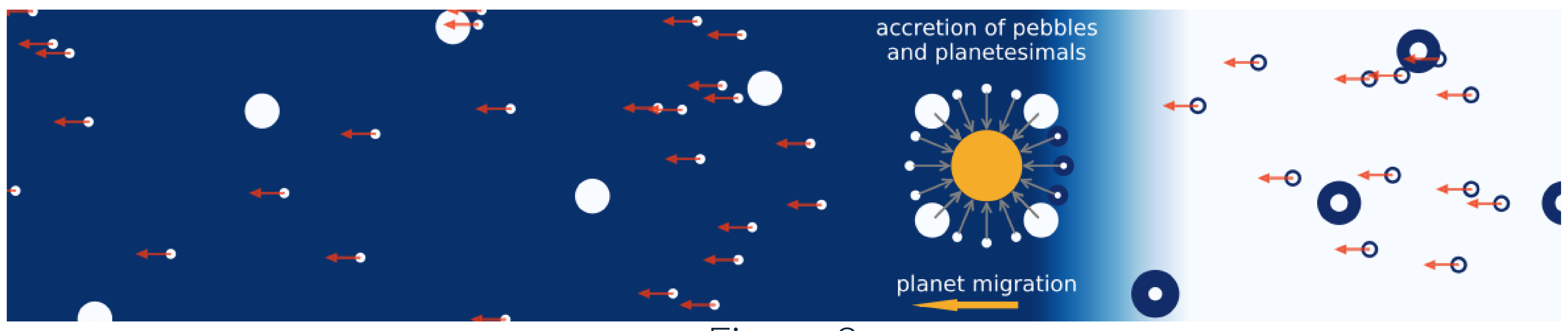


Figure 2

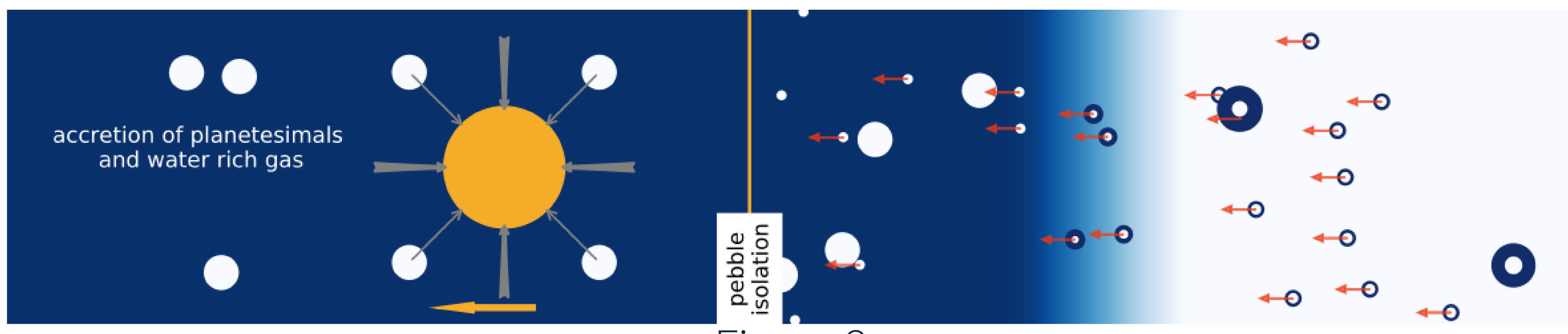
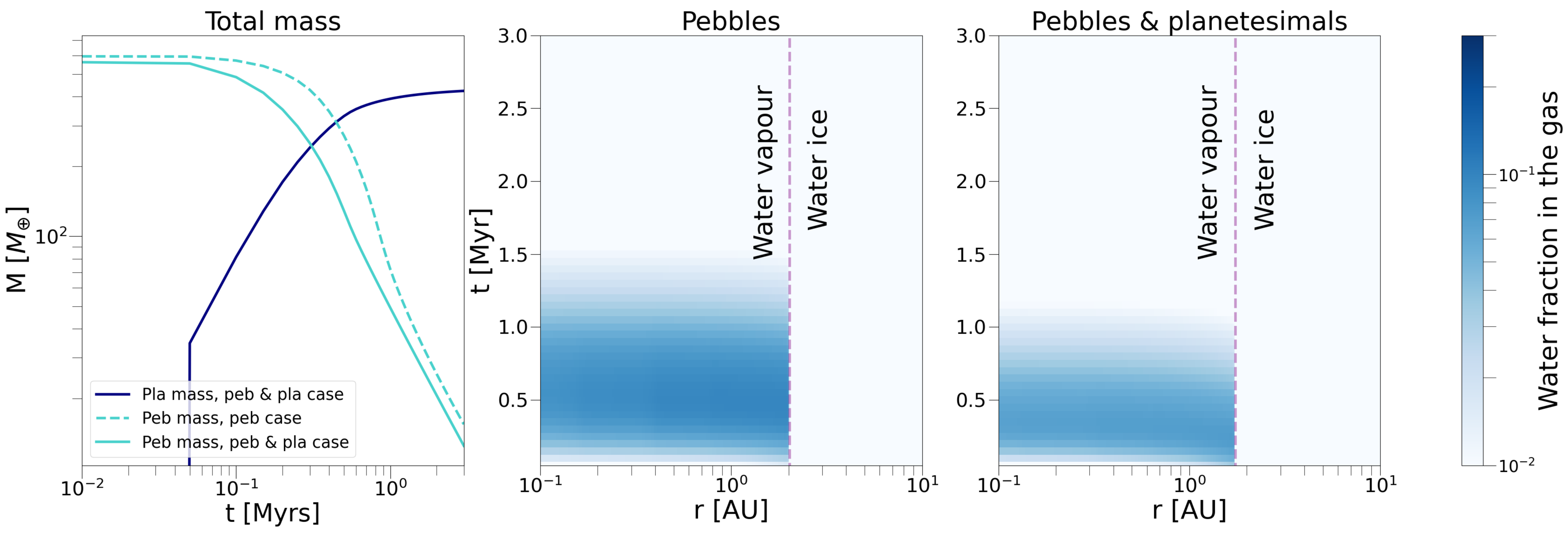


Figure 3

Take home message

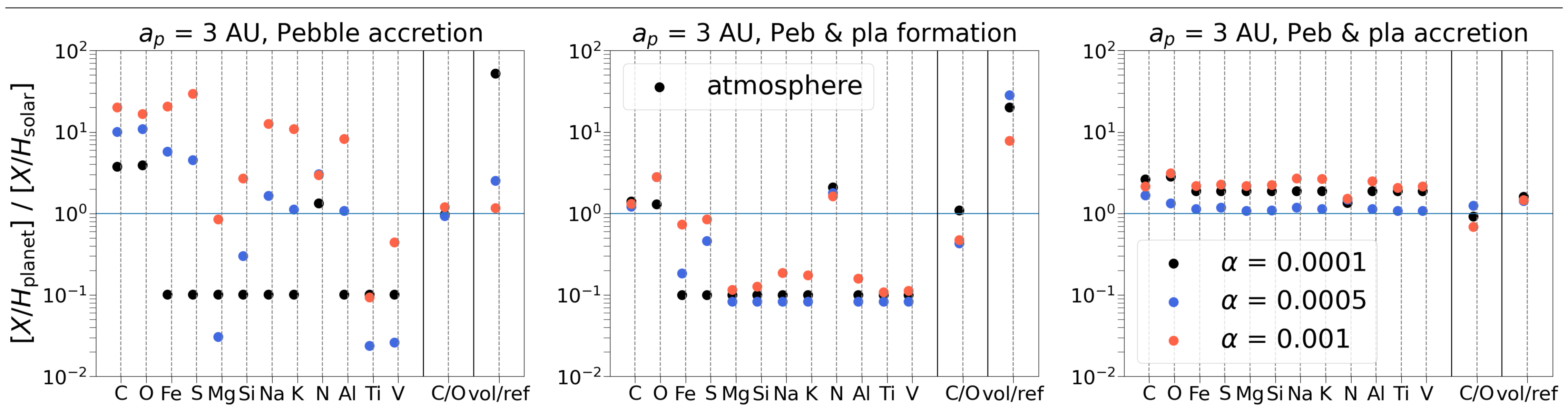
- The pebble accretion scenario creates planets with higher heavy element content, that are mainly accreted as vapor through the gas accretion phase.
- Planetesimal formation locks pebbles away and thus decreases the enrichment of the disc in volatiles.
- Planetesimal accretion results in lower volatile-to-refractory ratios in the atmosphere, implying that this tracer could constrain the amount of planetesimals accreted by giant planets.

Total pebble and planetesimal mass and water fraction in the gas of the protoplanetary disc



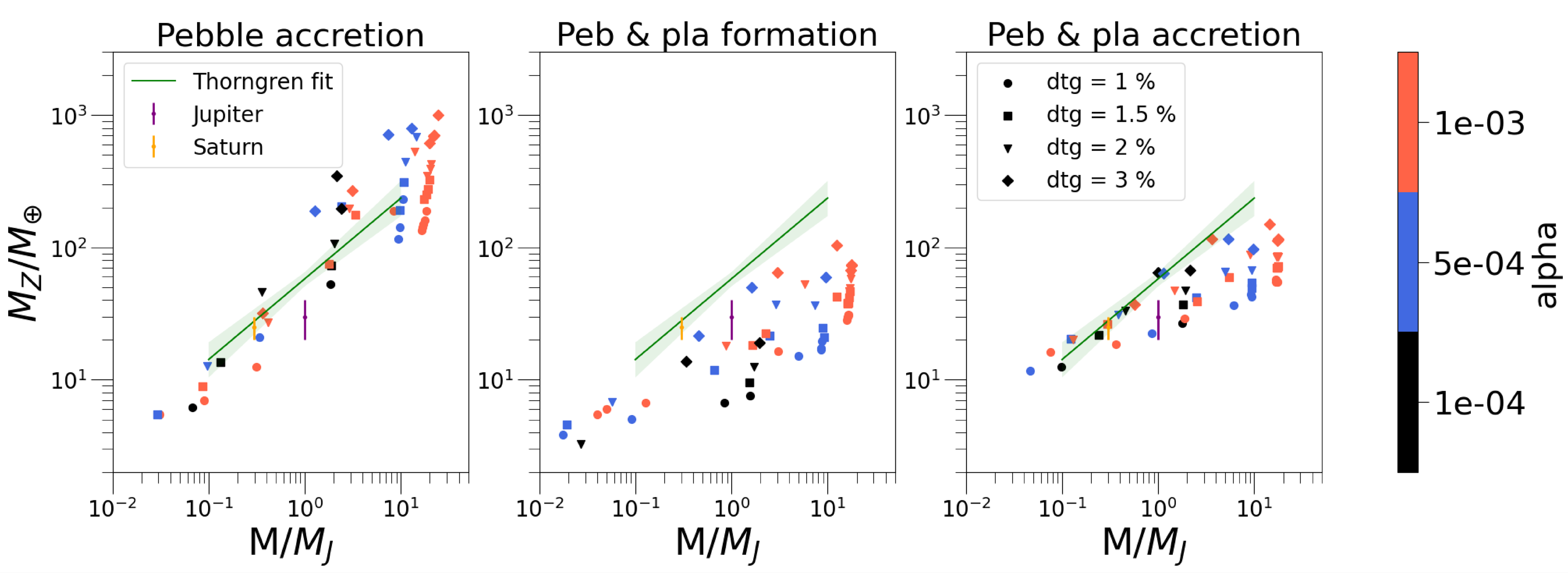
- The total pebble mass decreases with time (left panel, turquoise line), where planetesimal formation locks pebbles away, decreasing the pebble mass even further (solid vs dashed line).
- Inward drifting pebbles enrich the disc with volatiles, here illustrated for water vapour but it applies to all the elements and their respective evaporation fronts.
- Planetesimal formation locks pebbles way, leaving less material to drift and evaporate in the disc, resulting in a lower water vapour enrichment.

Atmospheric elemental composition of a 3 AU planet



- The atmospheric composition of planets forming in the pebble accretion scenario are dominated by volatiles that are accreted through gas accretion.
- Planetesimal formation (central panel) hinders disc enrichment with volatiles, thus the planet is depleted in voltiles.
- Adding planetesimal accretion (right panel) enhances again the planet abundances but still less than the pebble case.
- The big difference is in the volatile-to-refractory ratio: it is depleted in the planetesimal accretion case → possible formation pathway tracer.

Heavy element content of the simulated planets



- Heavy element content of planets with final mass $M > 5M_\oplus$ and $a_p < 1$ AU. The pebble accretion scenario is the only one that is able to easily produce planets with high heavy element content.
- Higher disc viscosities generate more massive planets.

References

[1] A. D. Schneider and B. Bitsch. How drifting and evaporating pebbles shape giant planets. I. Heavy element content and atmospheric C/O. *Astronomy and Astropysics*, 654:A71, Oct. 2021.

[2] A. D. Schneider and B. Bitsch. How drifting and evaporating pebbles shape giant planets. II. Volatiles and refractories in atmospheres. *Astronomy and Astrophysics*, 654:A72, Oct. 2021.