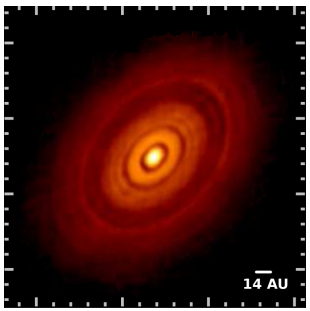
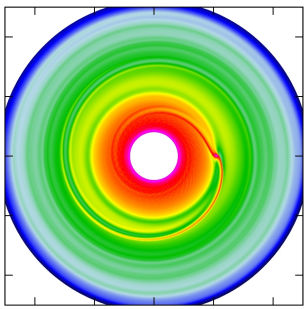
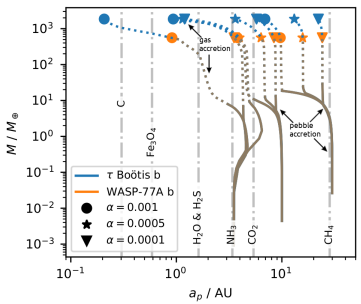
Chemcomp: Calculating disc and planetary compositions

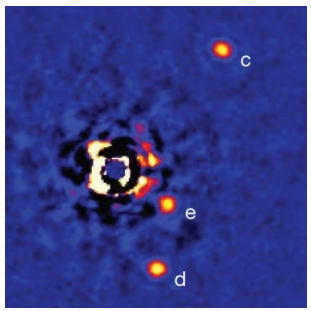
Bertram Bitsch

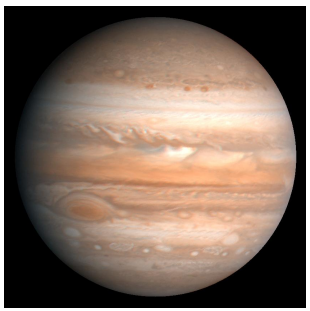
UCC
Coláiste na hOllscoile Corcaigh
University College Cork, Ireland



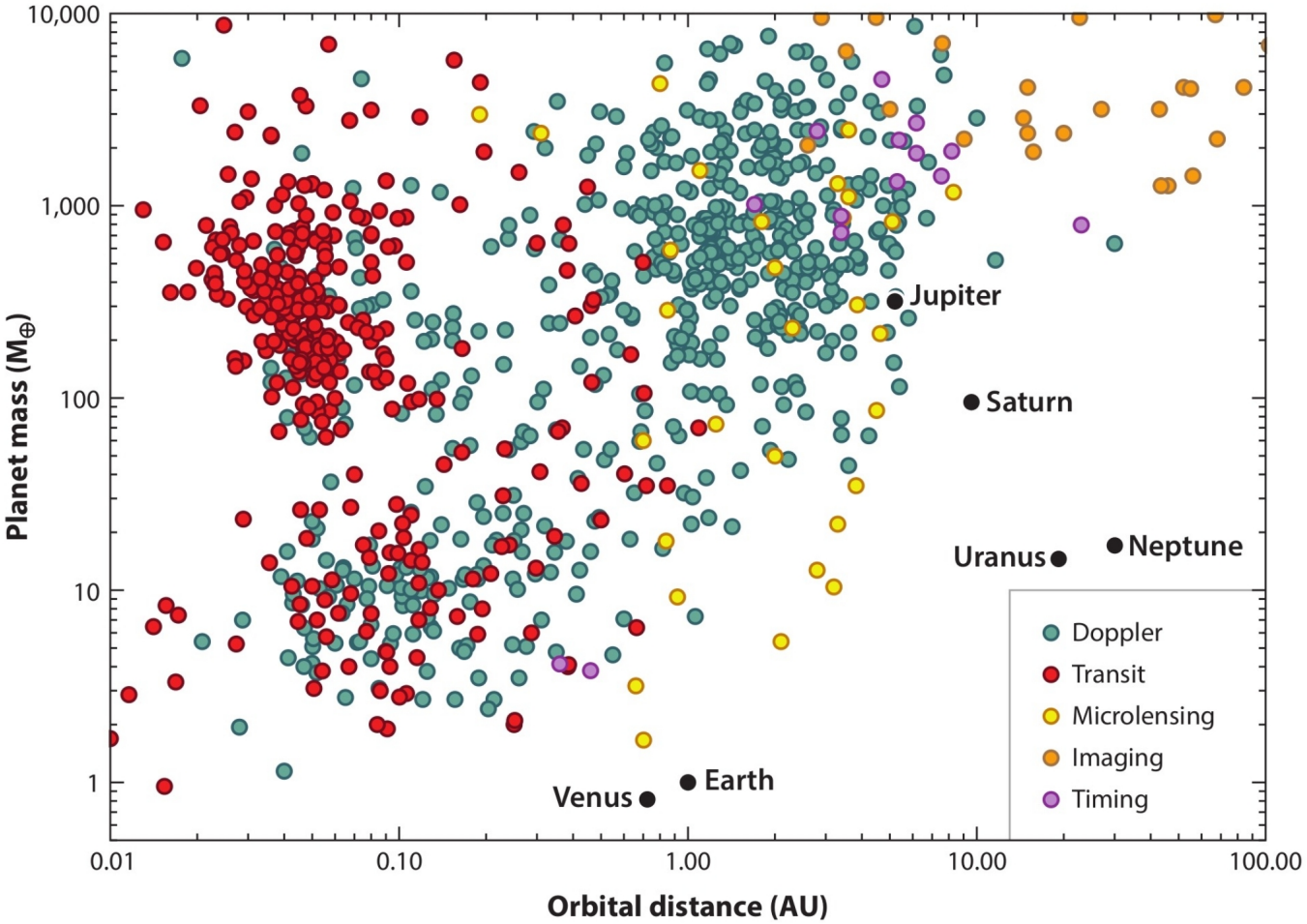






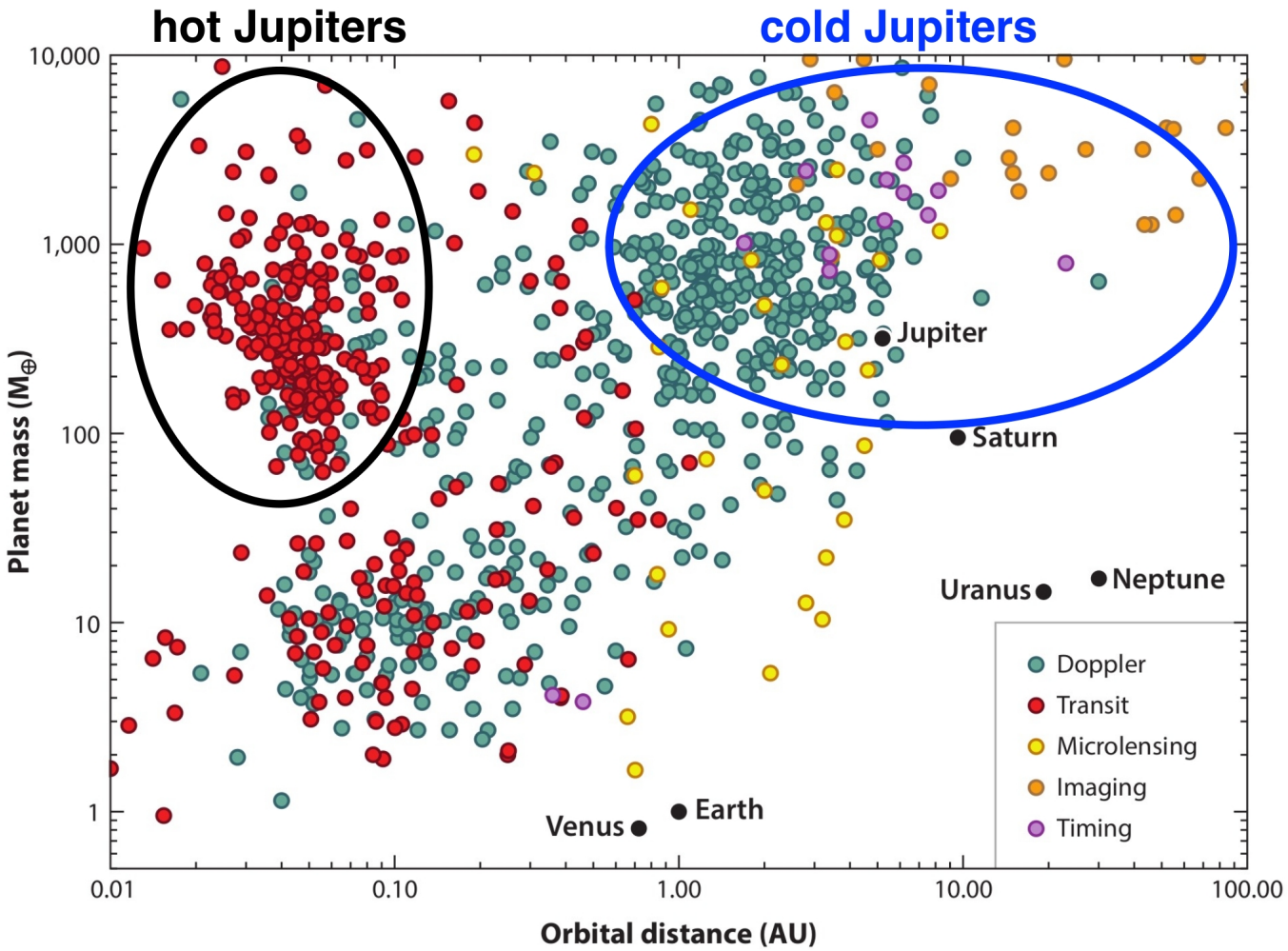


Observations of planets



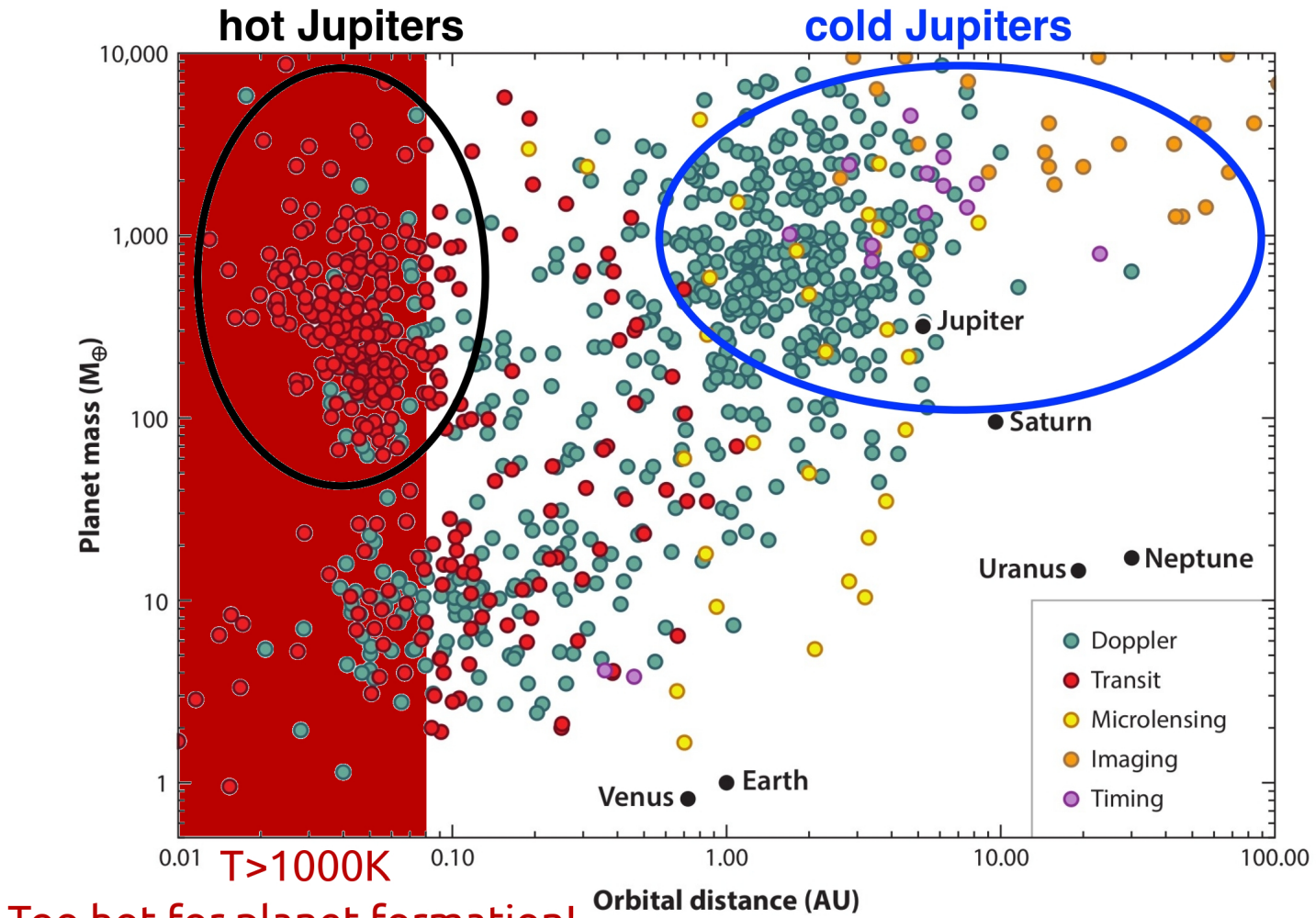
(*Winn & Fabrycky 2015*)

Observations of planets



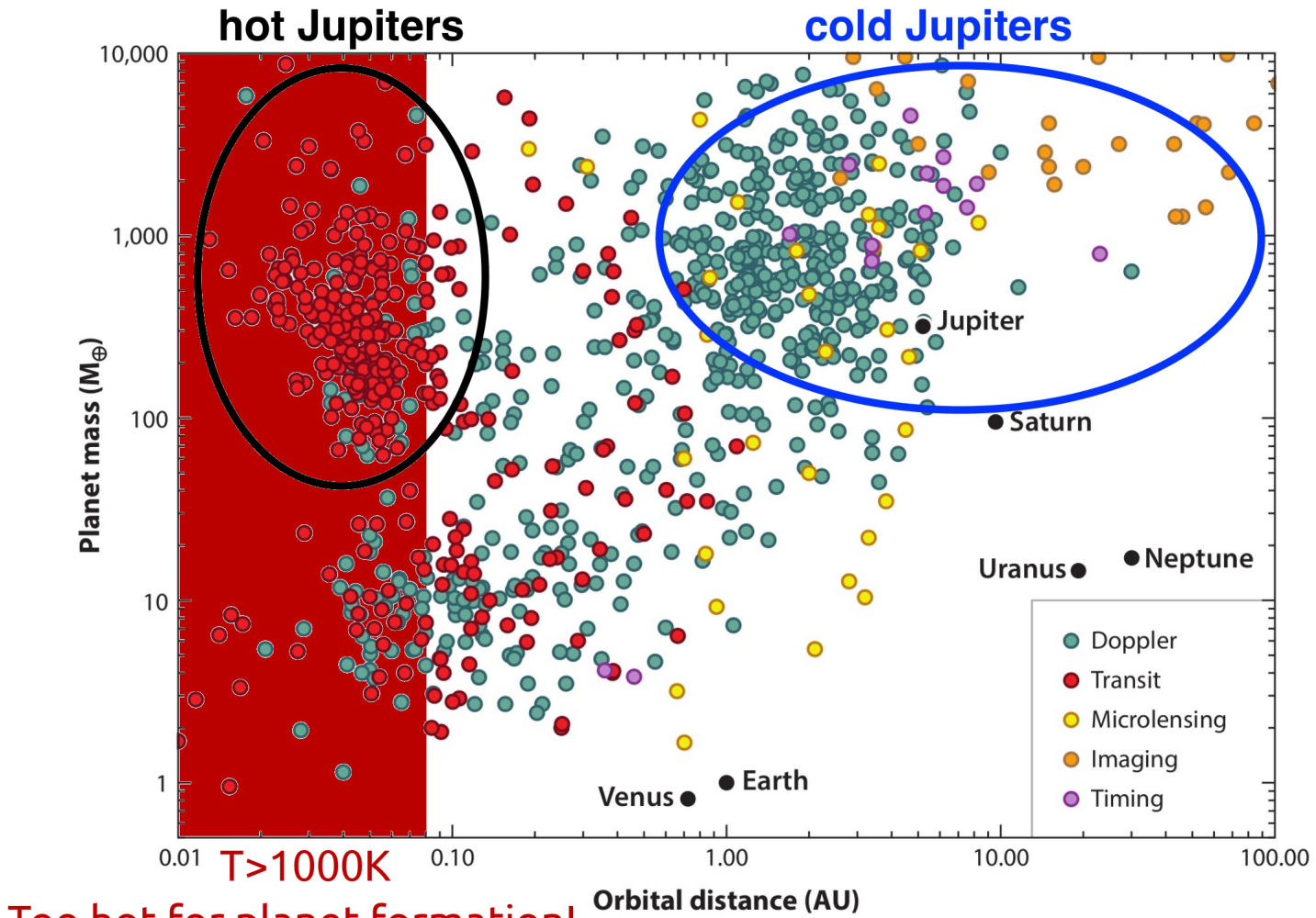
(*Winn & Fabrycky 2015*)

Observations of planets



(*Winn & Fabrycky 2015*)

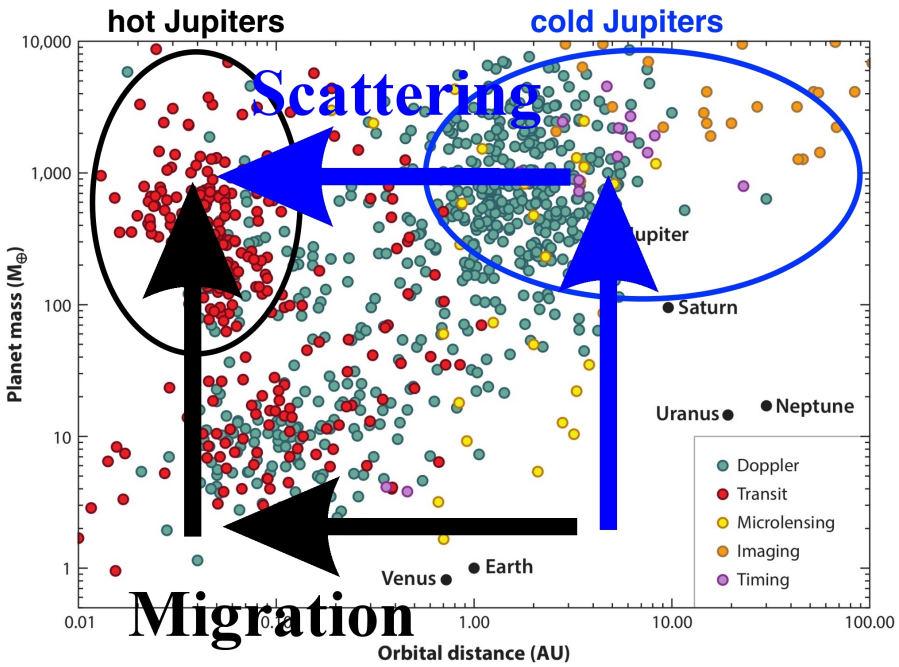
Observations of planets



(*Winn & Fabrycky 2015*)

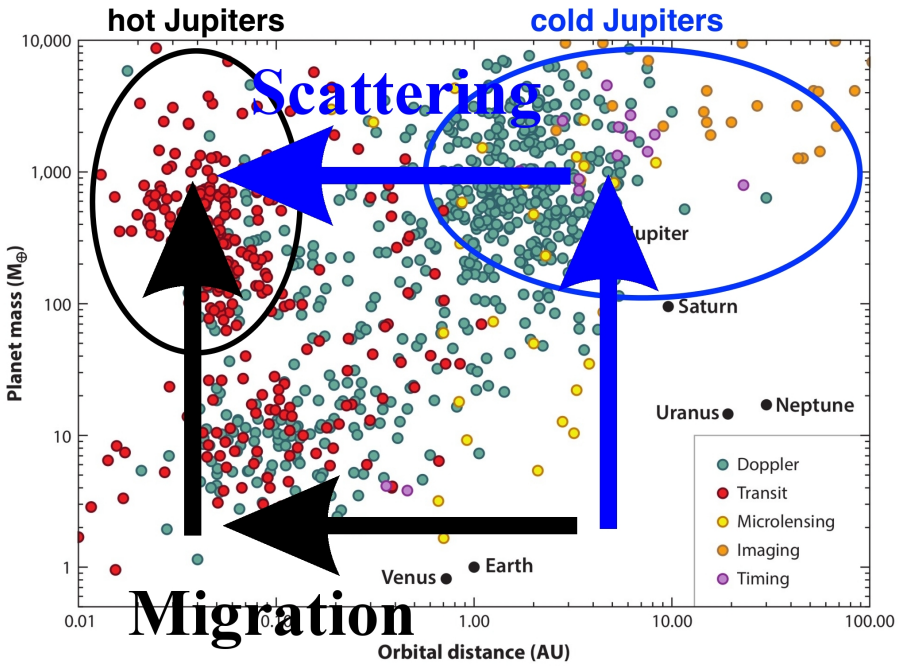
$\Rightarrow$ Where do giant planets form?

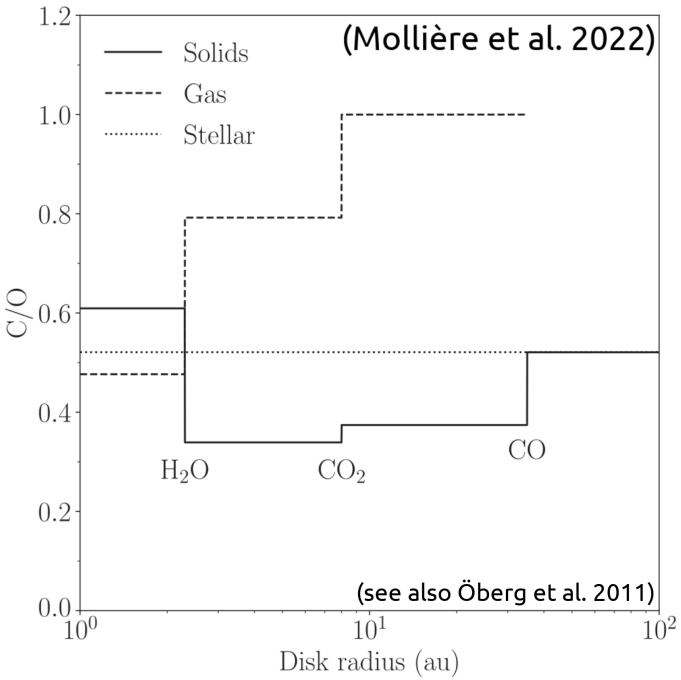
Where did the giant planets form?



- Where did the giant planets form?

Where did the giant planets form?

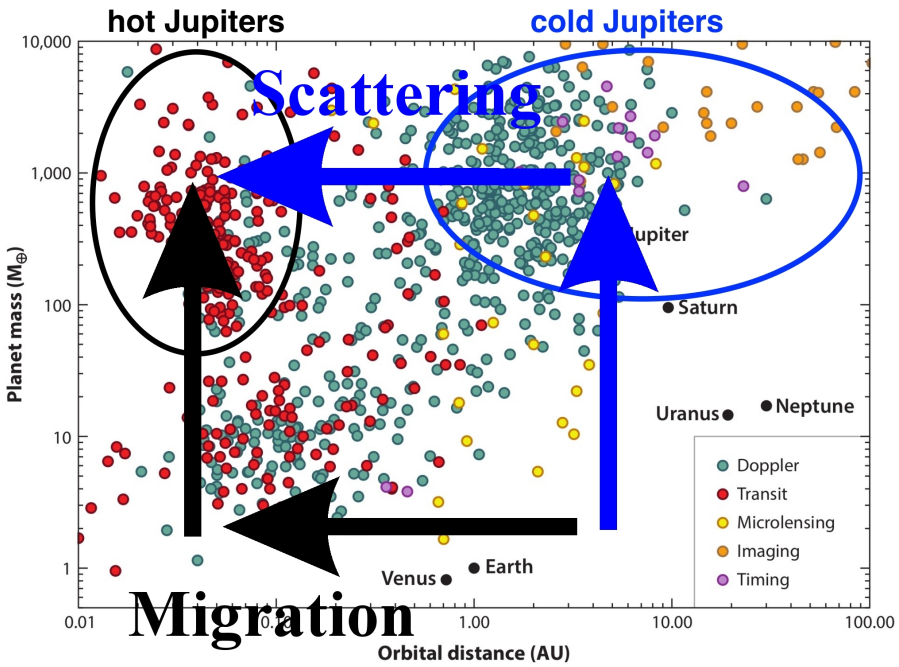


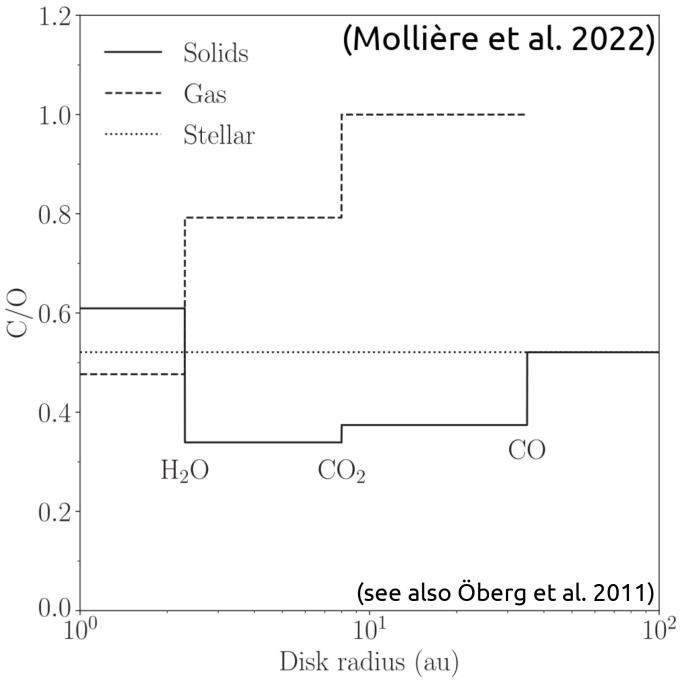


- Where did the giant planets form?

$\Rightarrow$ The disc's C/O ratio changes with distance, potentially suggesting that we can constrain planet formation via atmospheric C/O ratios

Where did the giant planets form?





- Where did the giant planets form?

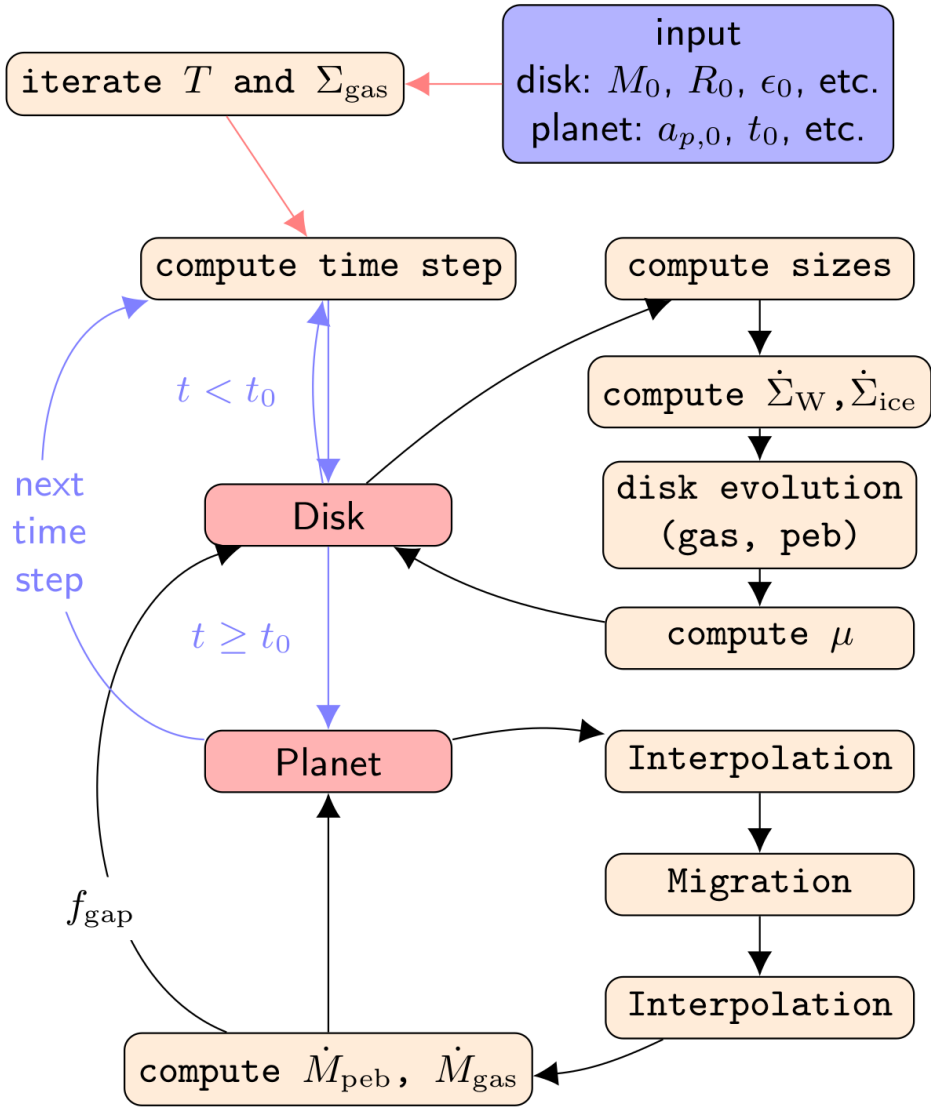
$\Rightarrow$ The disc's C/O ratio changes with distance, potentially suggesting that we can constrain planet formation via atmospheric C/O ratios

$\Rightarrow$ Is it really that simple?

Model: Chemcomp

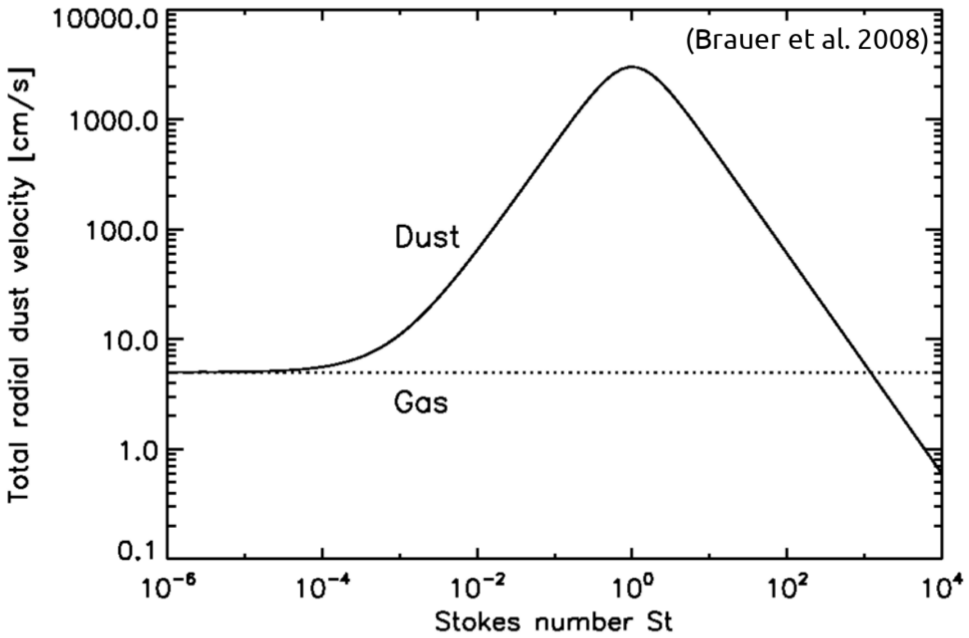
- Viscous disc evolution
- Pebble growth and drift
  (*Birnstiel et al. 2012*)
- Pebble evaporation and recondensation at ice lines
- Chemical partitioning model: No chemical evolution
  (*Booth & Ilee 2019, Eistrup & Henning 2022*)
- Pebble accretion
  (*Johansen & Lambrechts 2017*)
- Gas accretion, limited by $\dot{M}_{\mathrm{disc}}$
  (*Ndugu et al. 2021*)
- Type-I migration
  (*Paardekooper et al. 2011*)
- Type-II migration
  (*Ndugu et al. 2021*)

$\Rightarrow$ Code now publicly available!

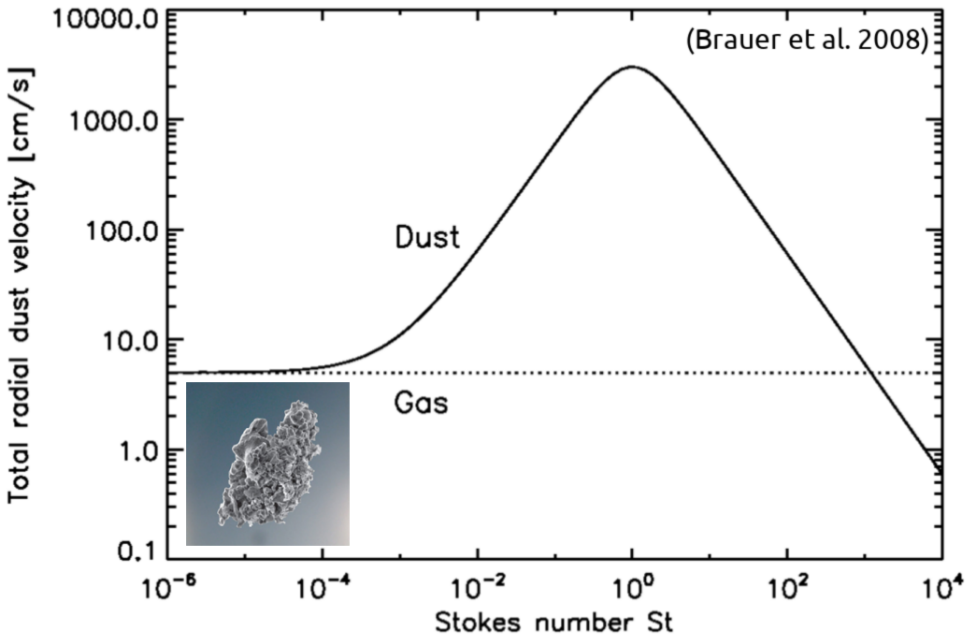


(*Schneider & Bitsch, 2021a, 2024*)

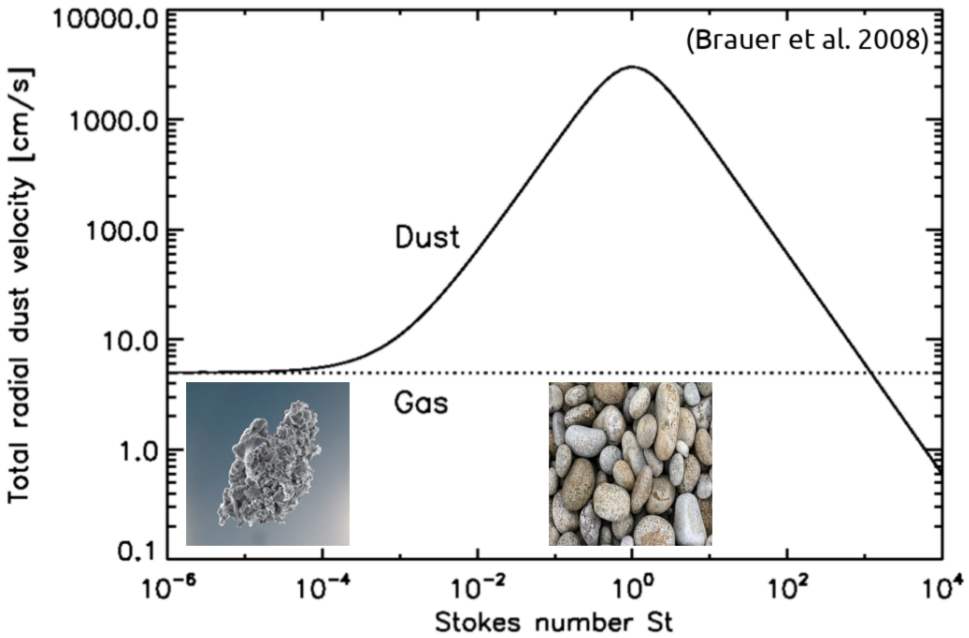
Effects of pebble drift and evolution



Effects of pebble drift and evolution

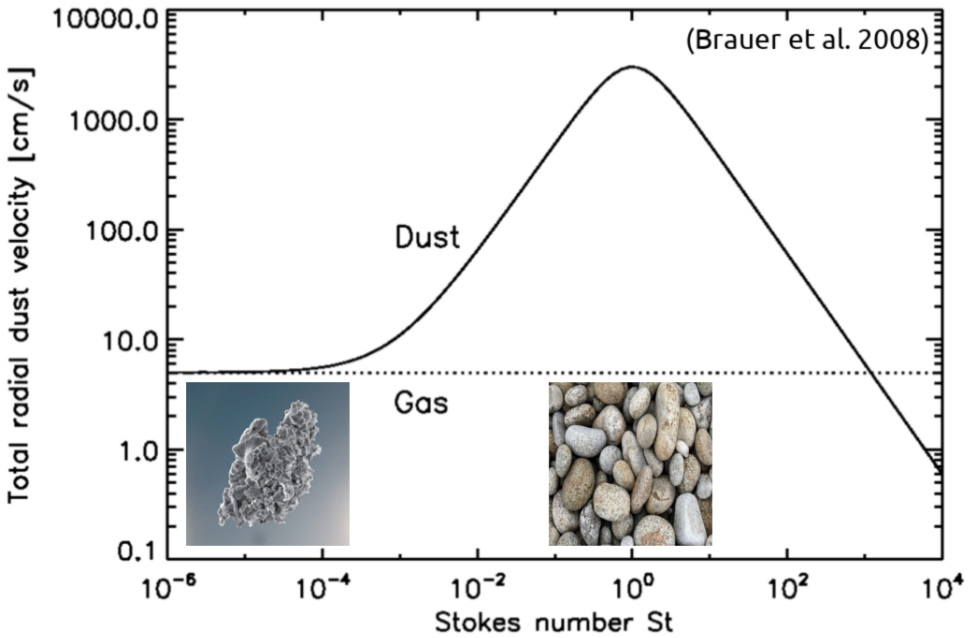


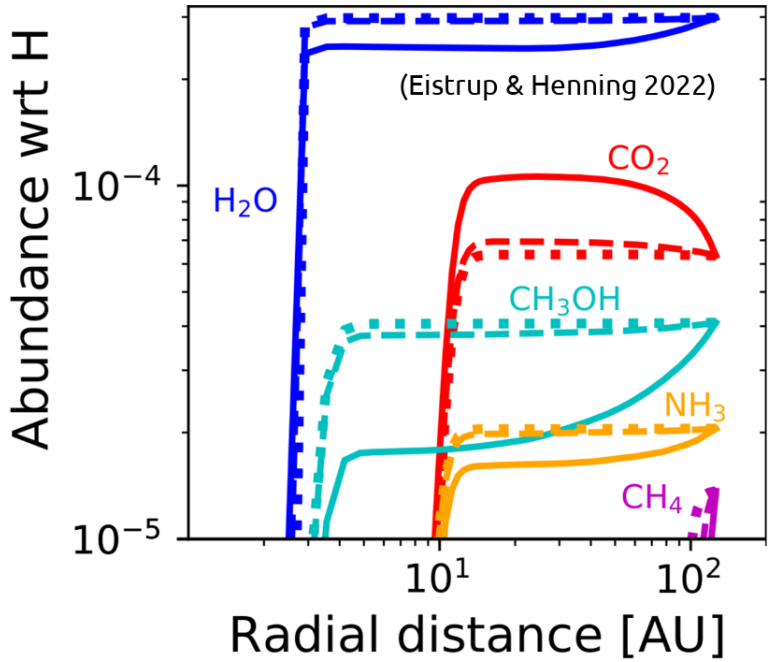
Effects of pebble drift and evolution



- Pebbles drift inwards faster than the gas moves!

Effects of pebble drift and evolution

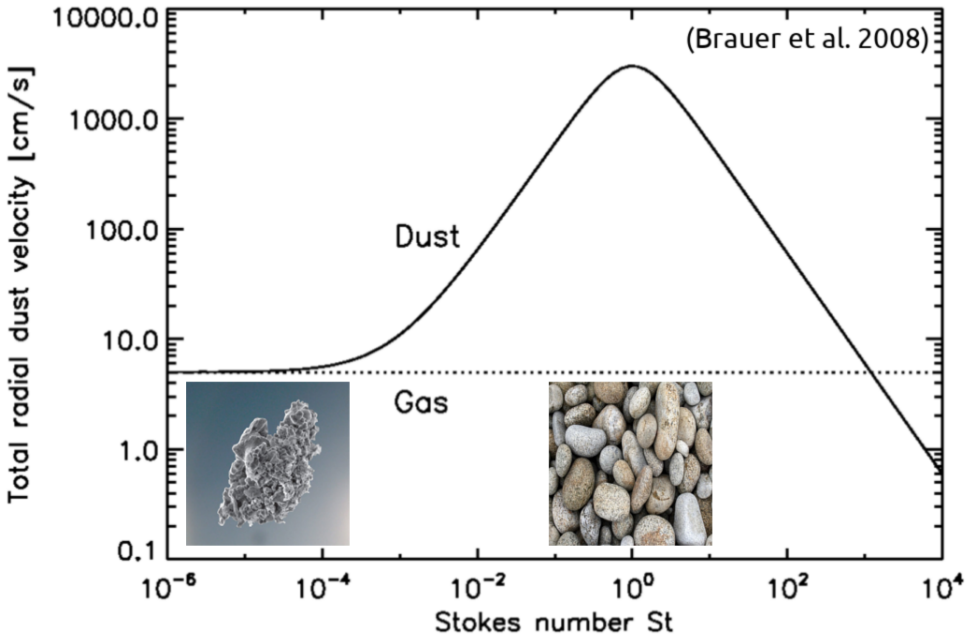


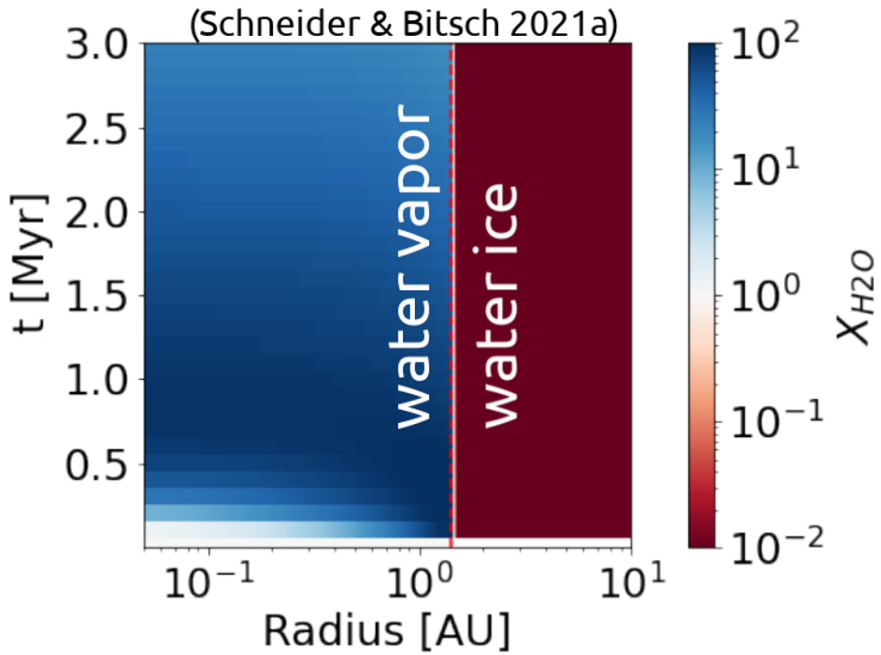


- Pebbles drift inwards faster than the gas moves!

$\Rightarrow$ Pebble composition is unaltered during drift
(e.g. *Booth & Ilee 2019, Eistrup & Henning 2022*)

Effects of pebble drift and evolution



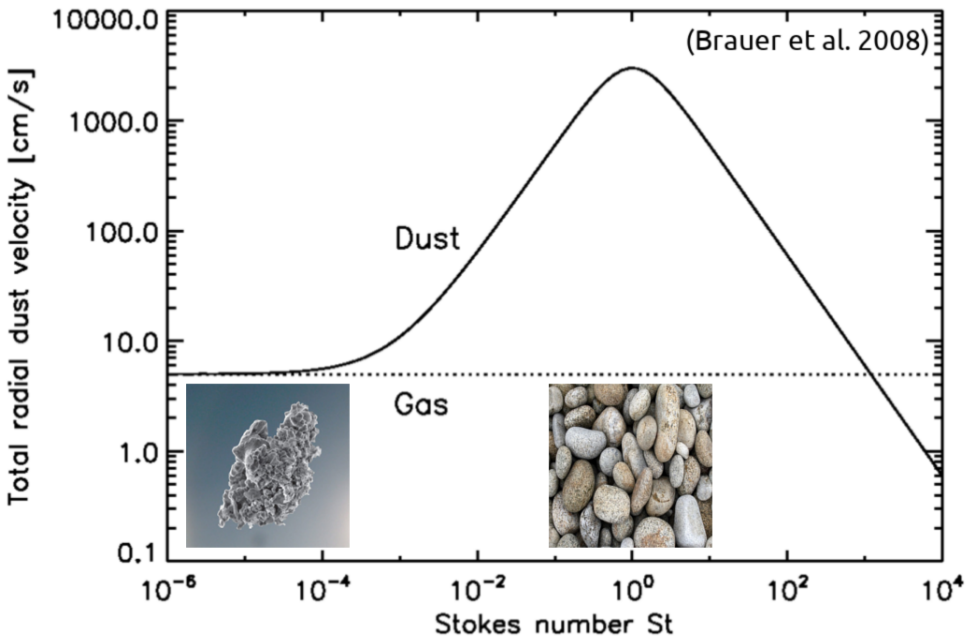


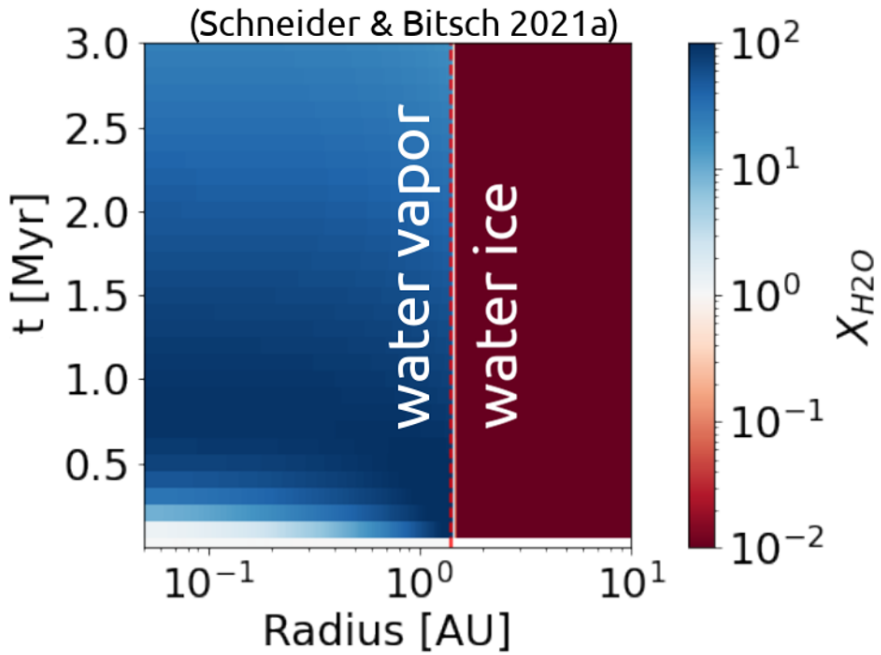
- Pebbles drift inwards faster than the gas moves!

$\Rightarrow$ Pebble composition is unaltered during drift
(e.g. *Booth & Ilee 2019*, *Eistrup & Henning 2022*)

$\Rightarrow$ Pebble drift and evaporation can lead to a pile-up of volatile vapor!
(e.g. *Booth et al. 2017*, *Aguichine et al. 2020*, *Schneider & Bitsch 2021a,b*, *Kalyaan et al. 2023*)

Effects of pebble drift and evolution





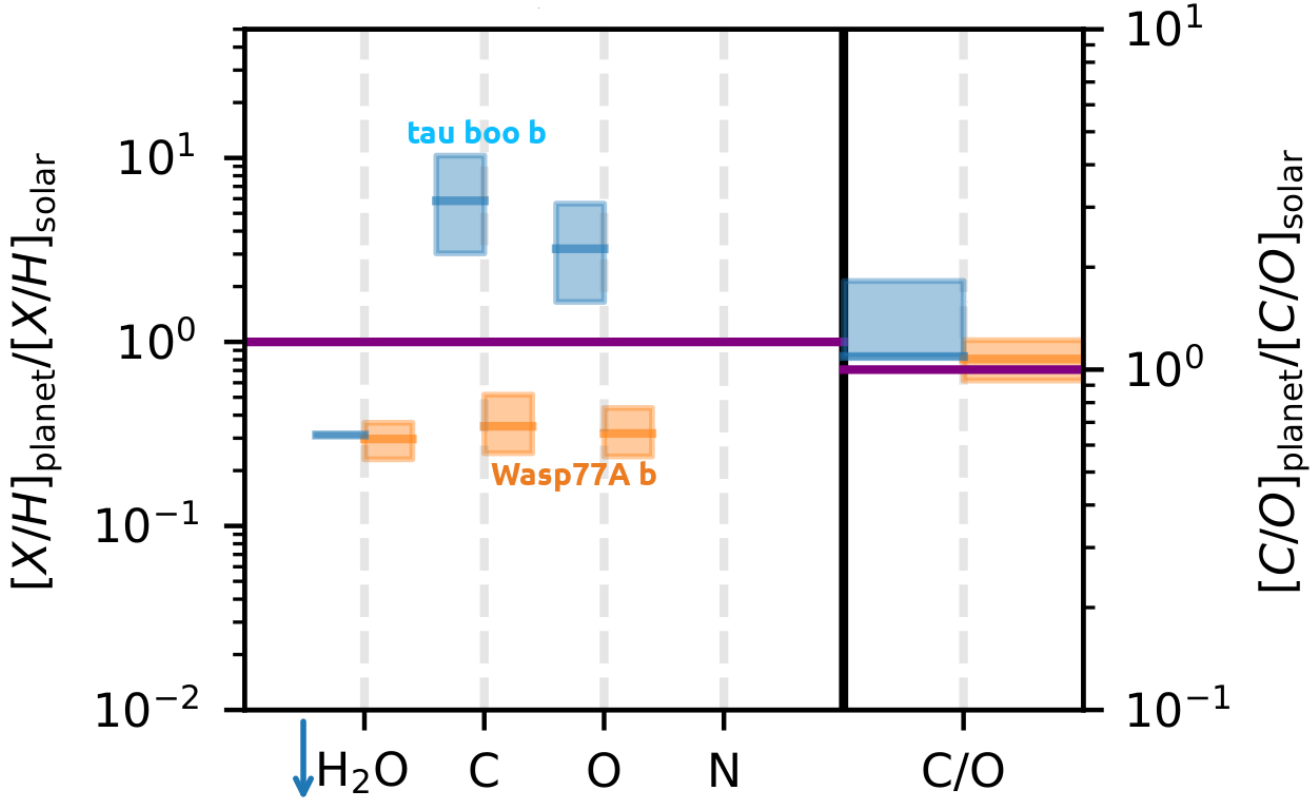
- Pebbles drift inwards faster than the gas moves!

$\Rightarrow$ Pebble composition is unaltered during drift
(e.g. *Booth & Ilee 2019, Eistrup & Henning 2022*)

$\Rightarrow$ Pebble drift and evaporation can lead to a pile-up of volatile vapor!
(e.g. *Booth et al. 2017, Aguichine et al. 2020, Schneider & Bitsch 2021a,b, Kalyaan et al. 2023*)

$\Rightarrow$ Disc composition evolves with time (unlike Öberg et al. 2011)!

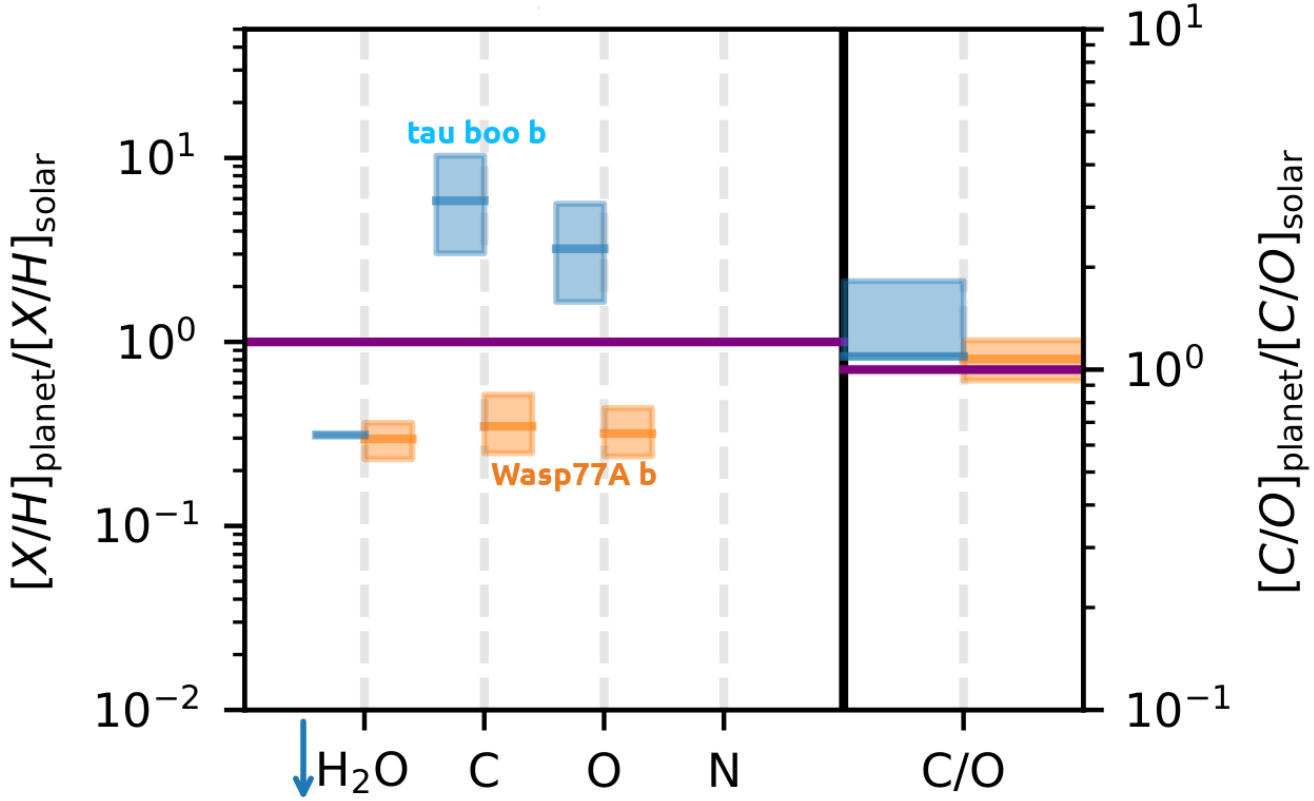
Planetary atmospheres of WASP77-A b and τ Boötis b



(*Bitsch et al. 2022*)

- WASP77-A b: sub-solar C/H, O/H with solar C/O
  (*Line et al. 2021*)
- τ Boötis b: super-solar C/H, O/H with slightly super-solar C/O
  (*Pelletier et al. 2021, Webb et al. 2022*)

Planetary atmospheres of WASP77-A b and τ Boötis b

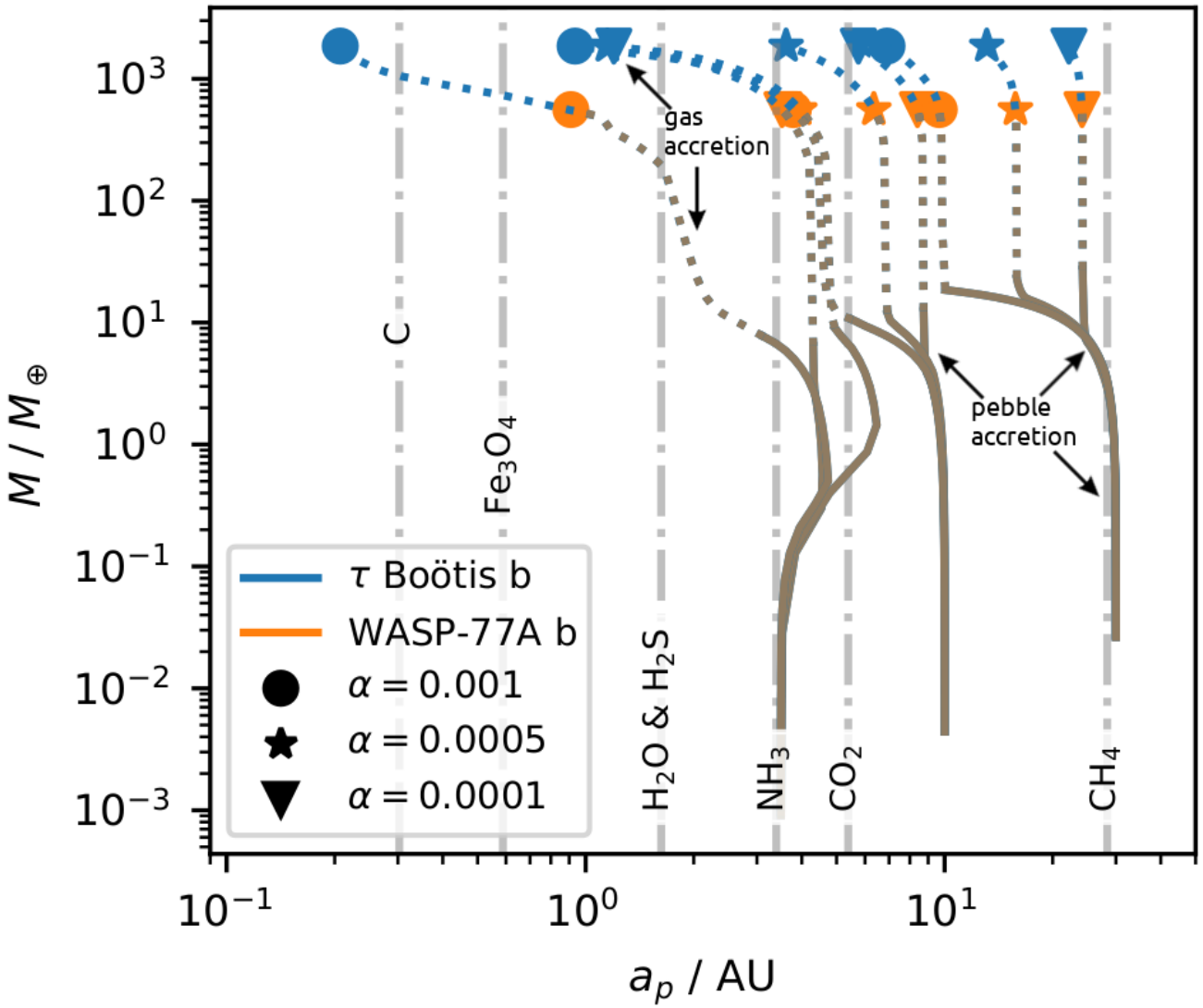


(*Bitsch et al. 2022*)

- WASP77-A b: sub-solar C/H, O/H with solar C/O
  (*Line et al. 2021*)
- τ Boötis b: super-solar C/H, O/H with slightly super-solar C/O
  (*Pelletier et al. 2021, Webb et al. 2022*)

$\Rightarrow$ Where in the disc did these planets form?

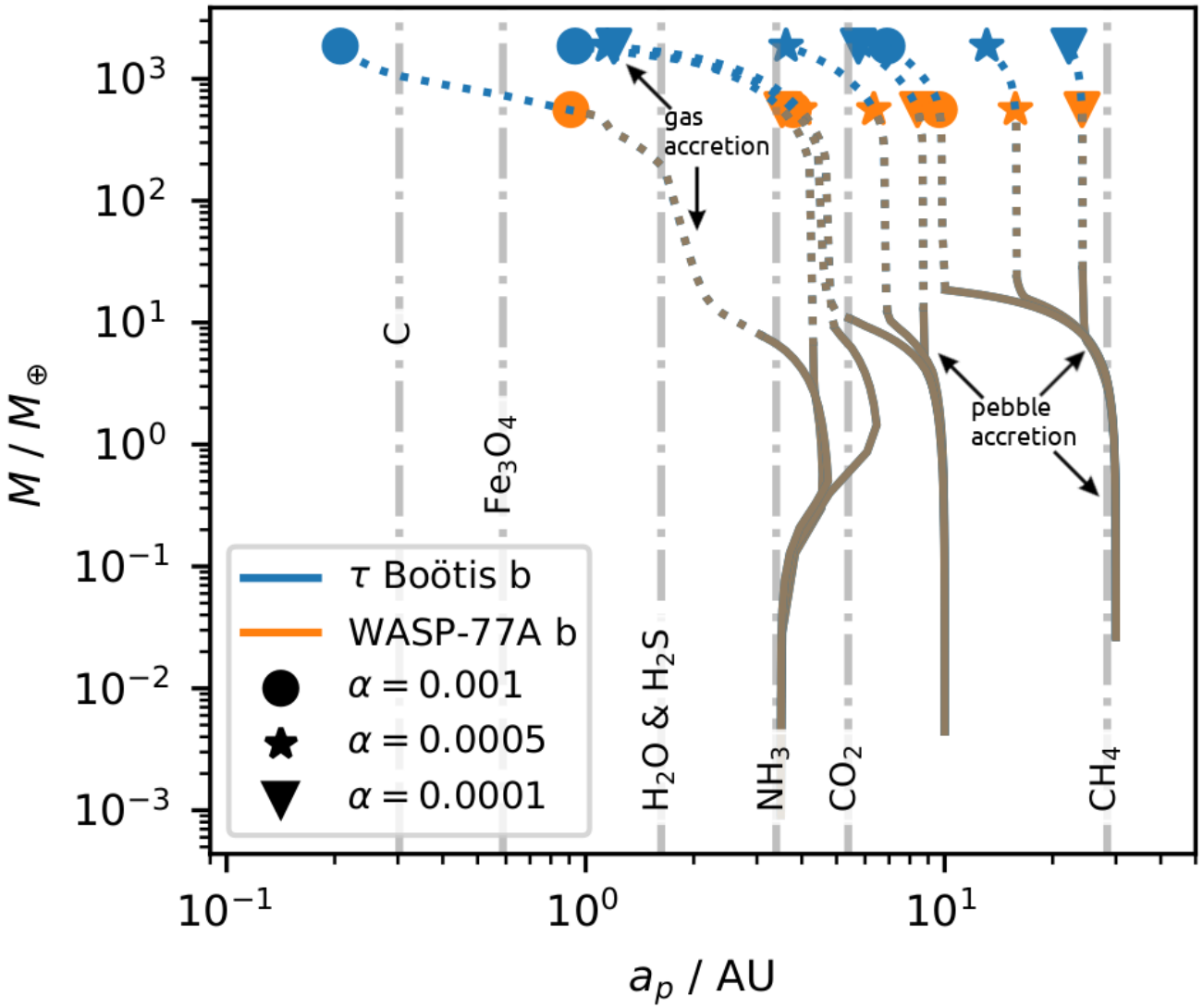
Growth tracks



(*Bitsch et al, 2022*)

⇒ Planets cross various evaporation fronts during their migration!

Growth tracks

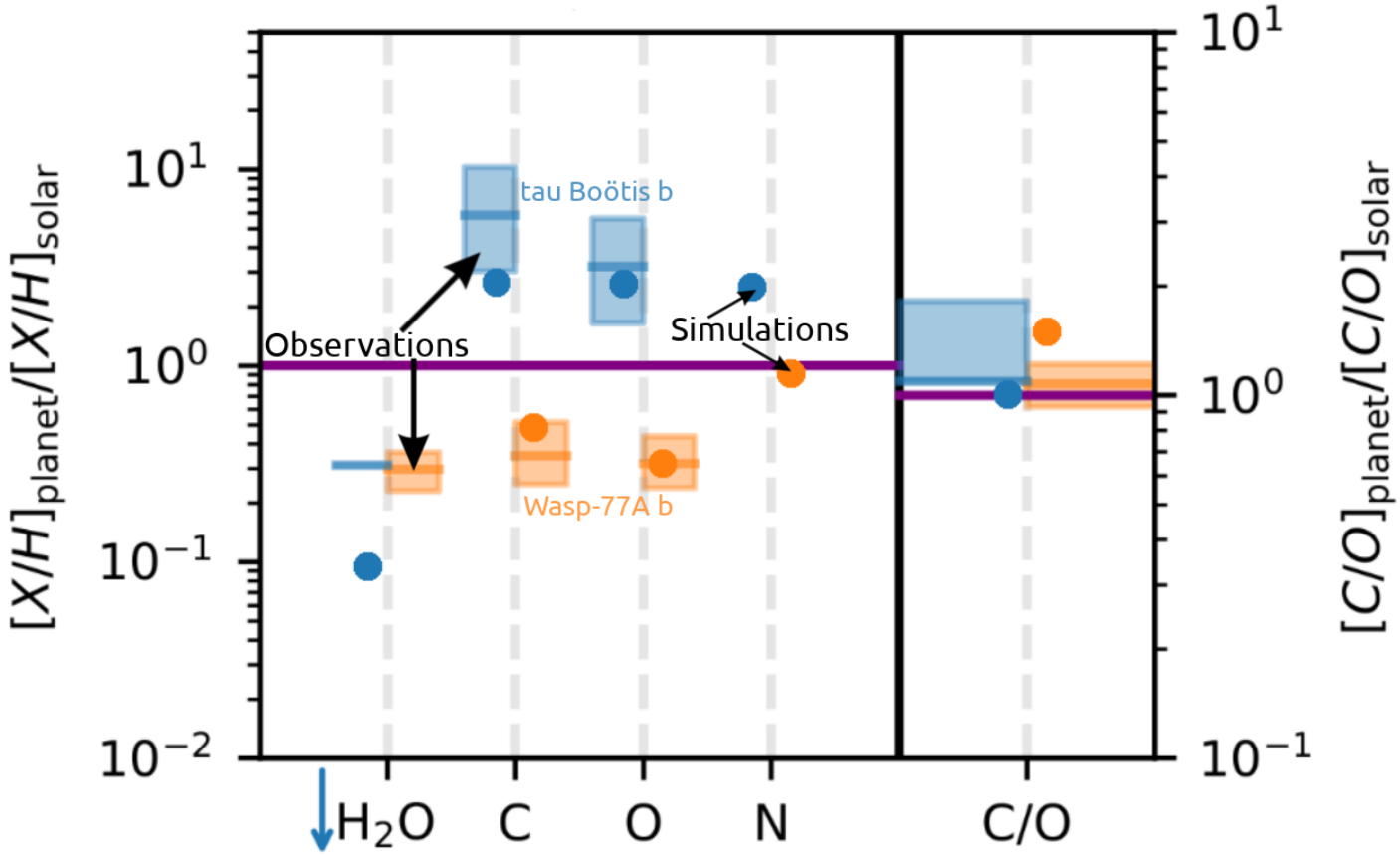


(*Bitsch et al, 2022*)

⇒ Planets cross various evaporation fronts during their migration!

⇒ Test of many parameters to determine the planet's formation location!

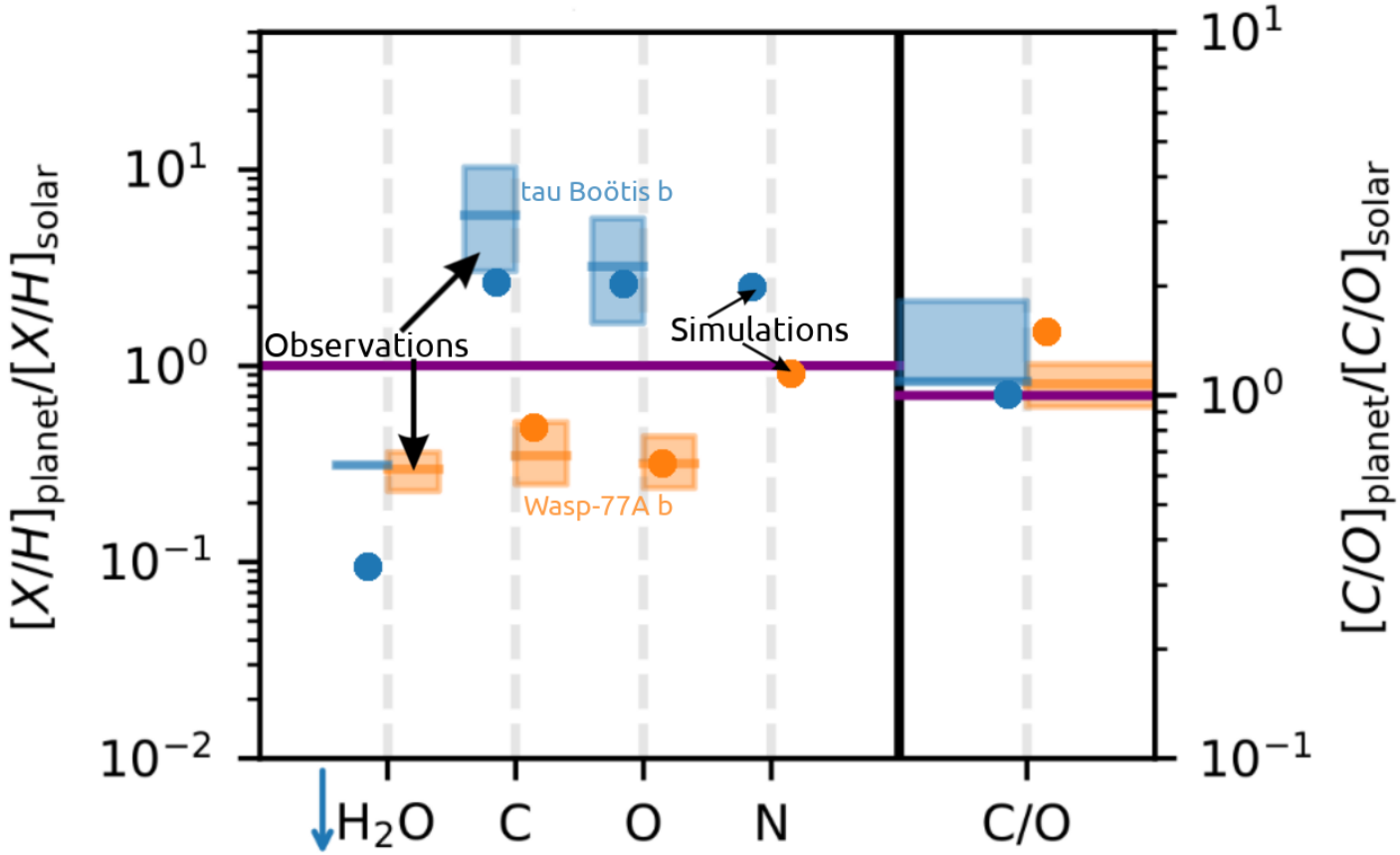
Planetary compositions: **with pebble evaporation**



(*Bitsch et al., 2022*)

⇒ The pebble evaporation model allows **super-/sub-solar** C/H and O/H in planetary atmospheres, if planets form in the **inner/outer** disc!

Planetary compositions: **with pebble evaporation**



(*Bitsch et al., 2022*)

⇒ The pebble evaporation model allows **super-/sub-solar** C/H and O/H in planetary atmospheres, if planets form in the **inner/outer** disc!

⇒ τ Boötis b formed beyond the H_2O evaporation front

⇒ WASP-77A b formed beyond the CO_2 evaporation front

Summary

- Inward drifting pebbles evaporate and enrich the disc
  (e.g. *Booth et al. 2017, Banzatti et al. 2020, Aguichine et al. 2020, Schneider & Bitsch 2021a,b, Bitsch & Mah 2023*)

$\Rightarrow$ The disc's C/O ratio changes in time!

- The C/O ratio alone is **not** a tracer of the planet formation location!
  (e.g. *Turrini et al. 2021, Bitsch et al. 2022, Molliere et al. 2022, Pacetti et al. 2022, Crossfield 2023*)
- `Chemcomp` can calculate the pebble evolution to determine the disc composition
  (e.g. *Schneider & Bitsch 2021a, Bitsch & Mah 2023, Mah et al. 2023, 2024*)
- `Chemcomp` can also include planetary growth and migration to determine the planetary composition
  (e.g. *Schneider & Bitsch 2021a,b, Bitsch et al 2021, 2022, Mah & Bitsch 2023, Savvidou & Bitsch 2023*)
- `Chemcomp` is publicly available here:
  `https://github.com/AaronDavidSchneider/chemcomp`