PEBBLE DRIFT IN HD 163296

Constraining the mass of dust and ice reaching the terrestrial planet formation region

UKI Discs 2024

Credit: NASA/JPL-Caltech

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WHY PEBBLE DRIFT?

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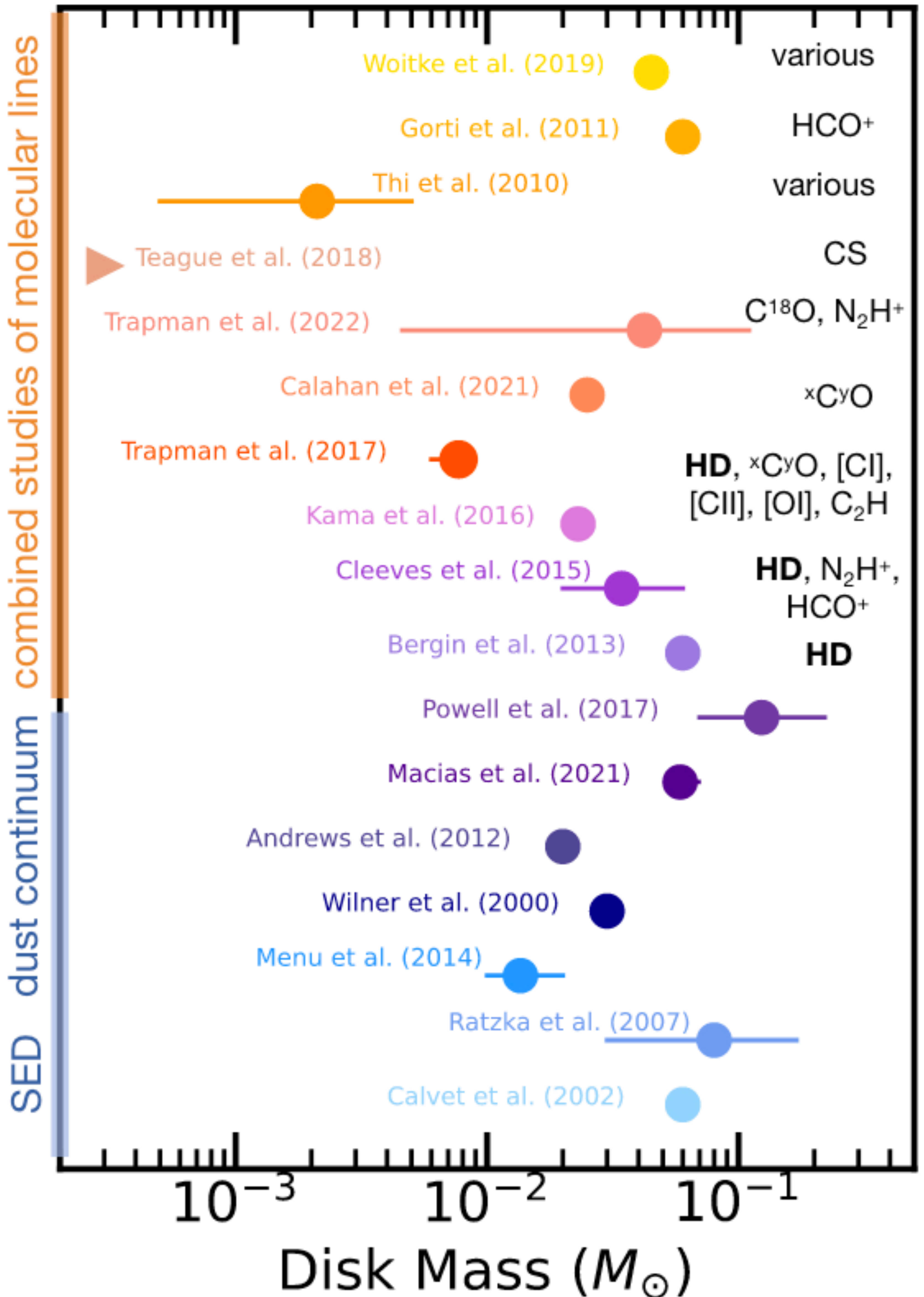
- Pebbles build planets (e.g. Lambrechts & Johansen 2017)
- Pebble **drift** is dominated by **disk mass**
  - Other parameters (disk radius, turbulence…) matter less
- Disk mass is ***very* hard** to constrain

Can we constrain **disc birth conditions (mass, radius)** using pebble drift?

Miotello+22



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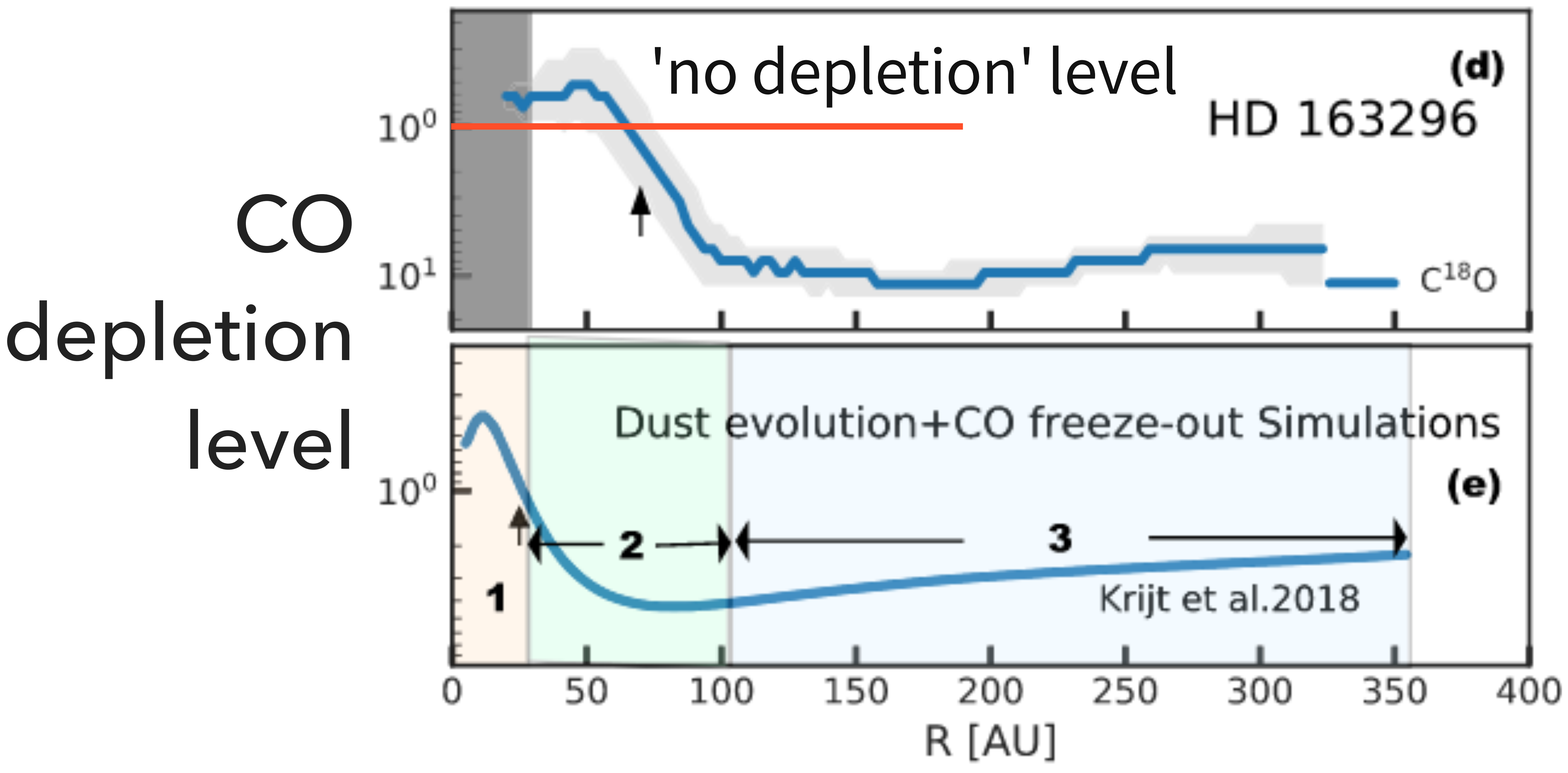
WHY HD 163296?

- CO enhancement within snowline, with C/H ratio 1.8 - 8 times ISM value
- Requires delivery of **150 - 600 $M_{\oplus}$ of material within 5-10 Myr through CO snowline** (Zhang+20)
- We can study this with **pebble drift models**



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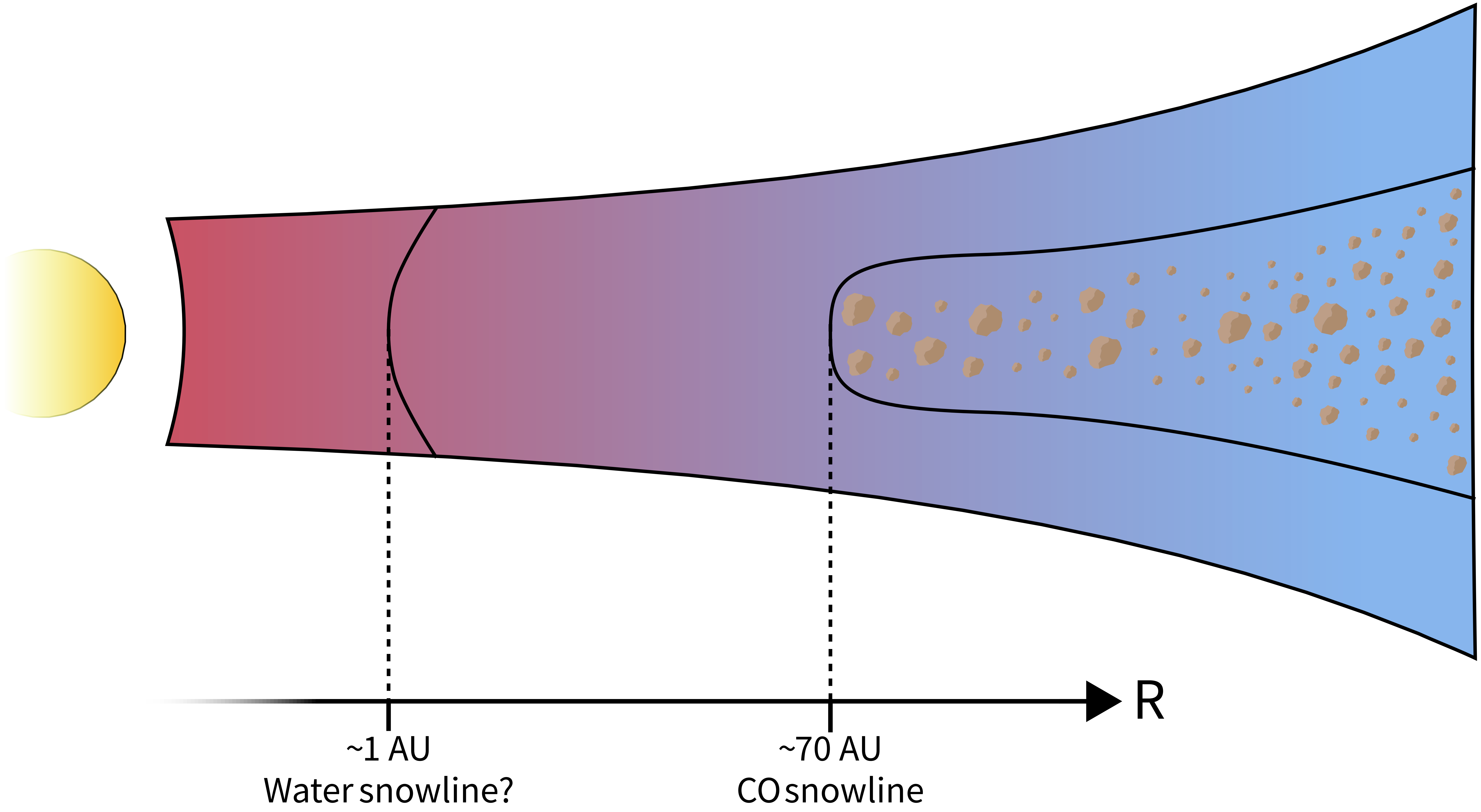
CO ENHANCEMENT CONSTRAINT

Williams & Krijt (in prep.)



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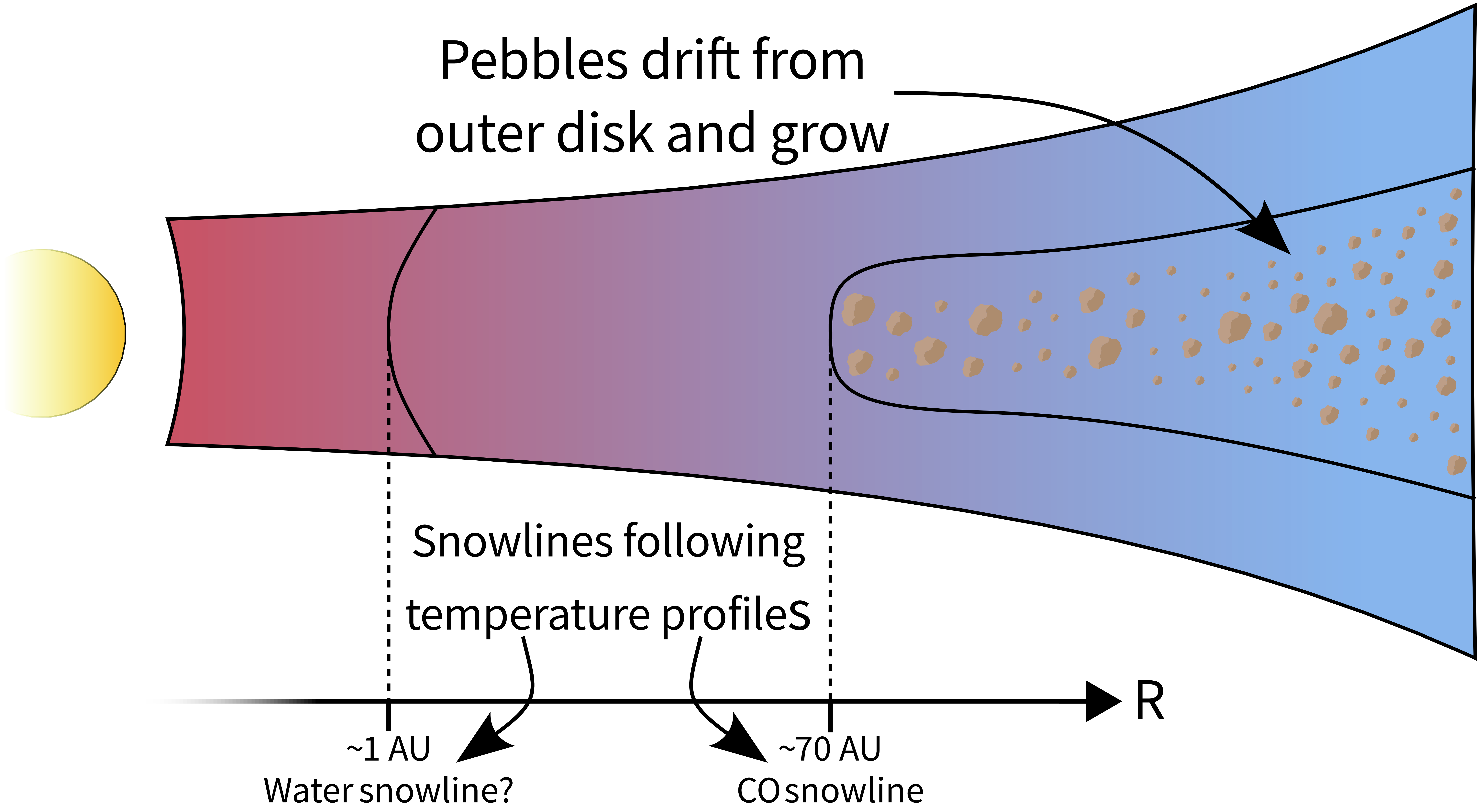

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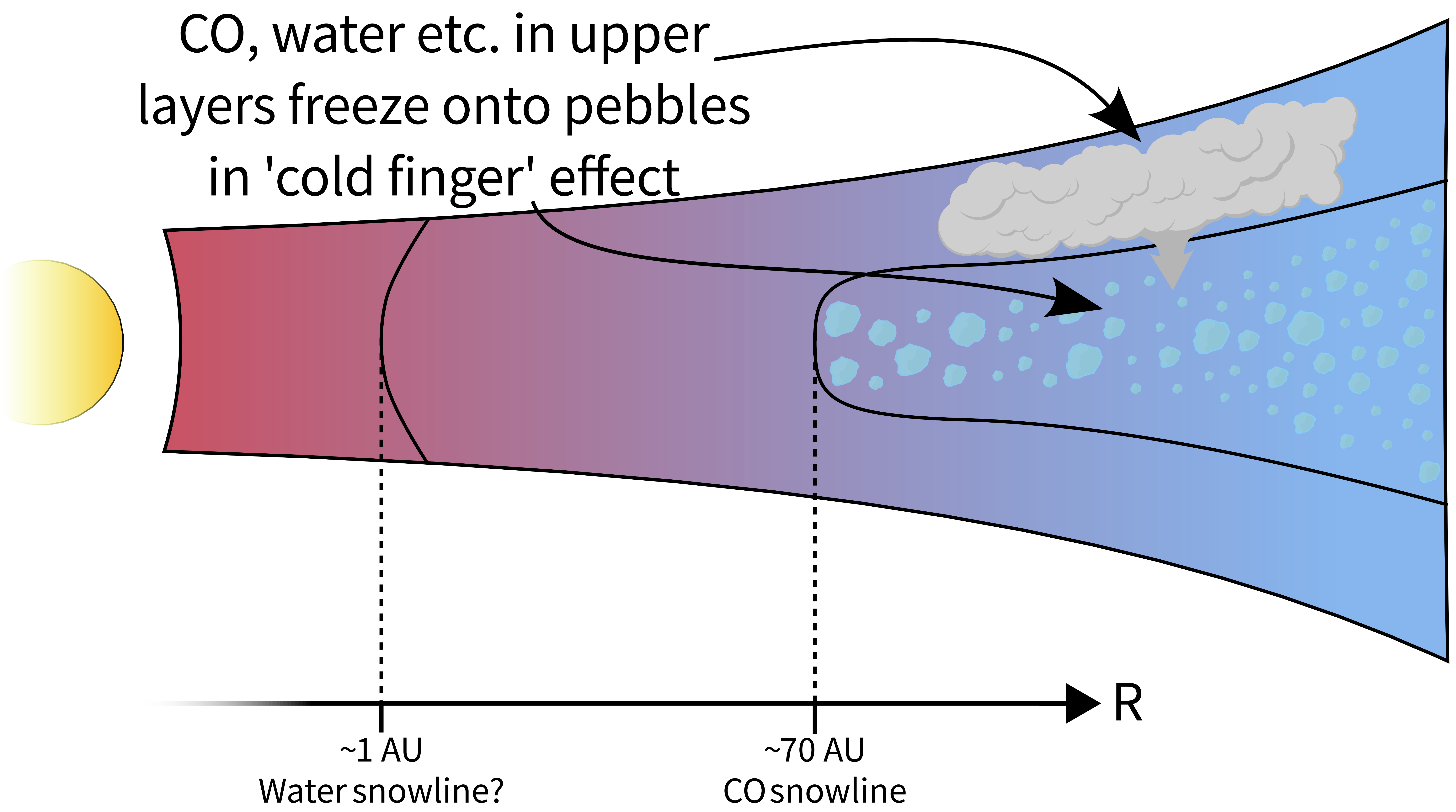

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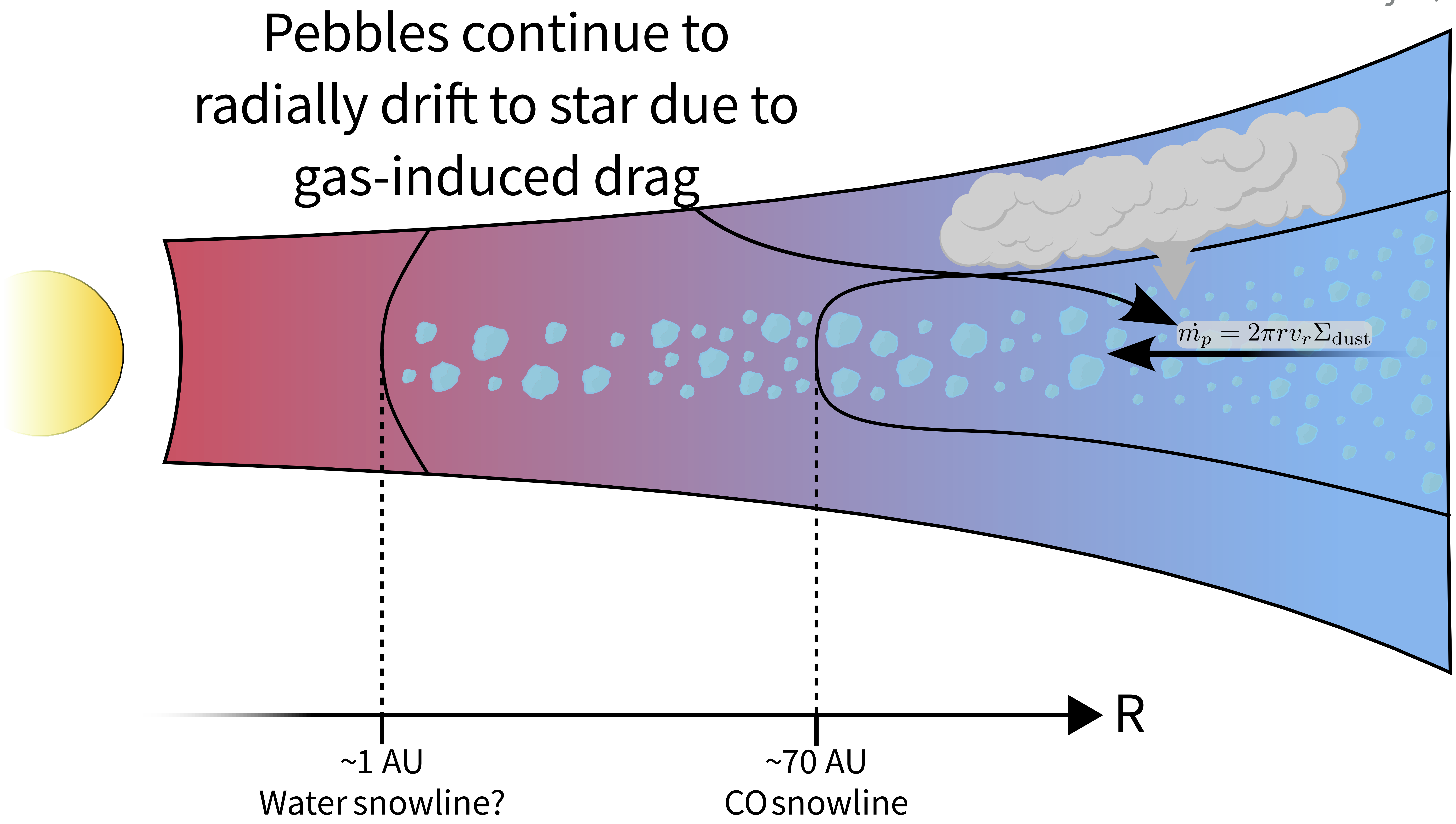

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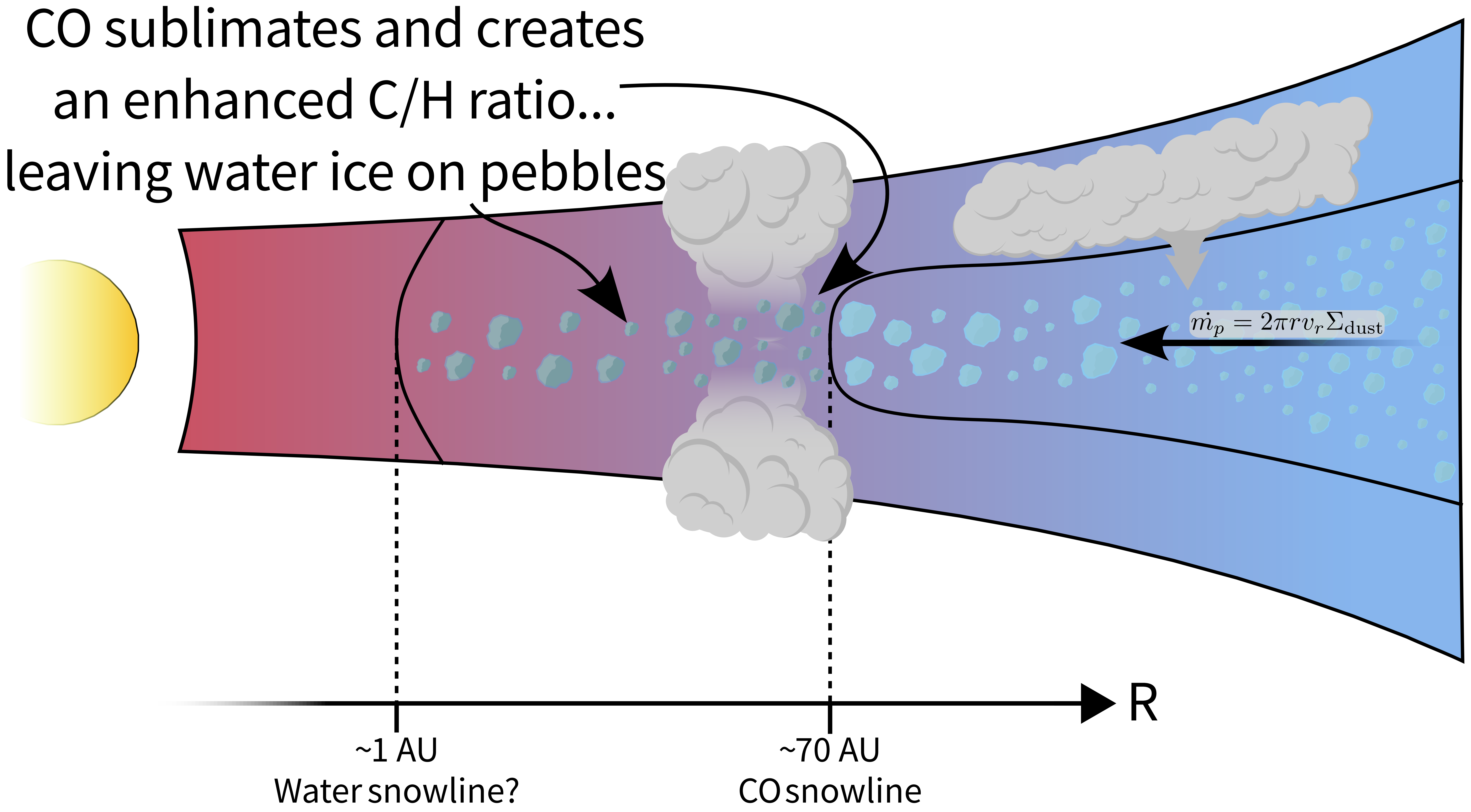

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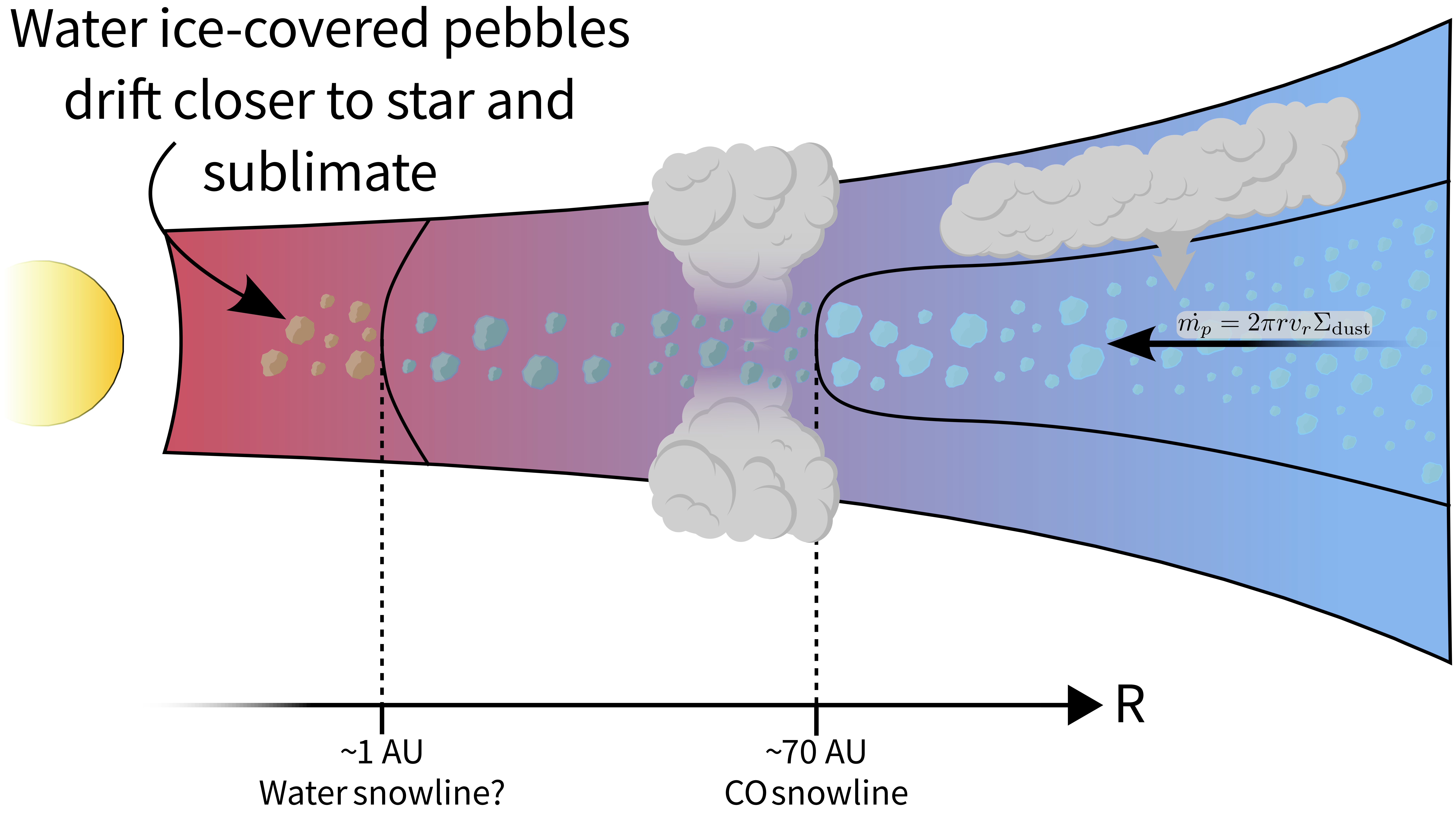

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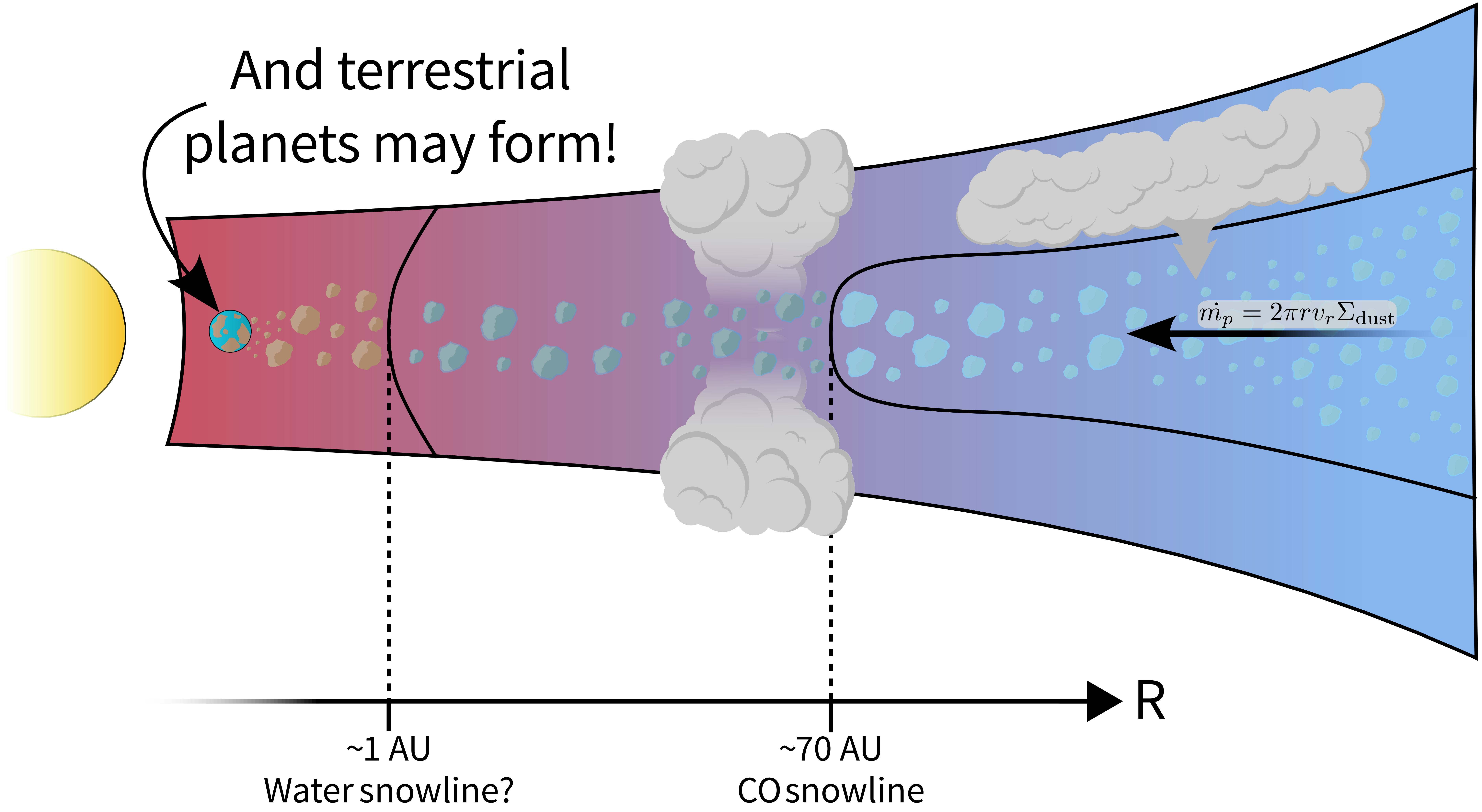

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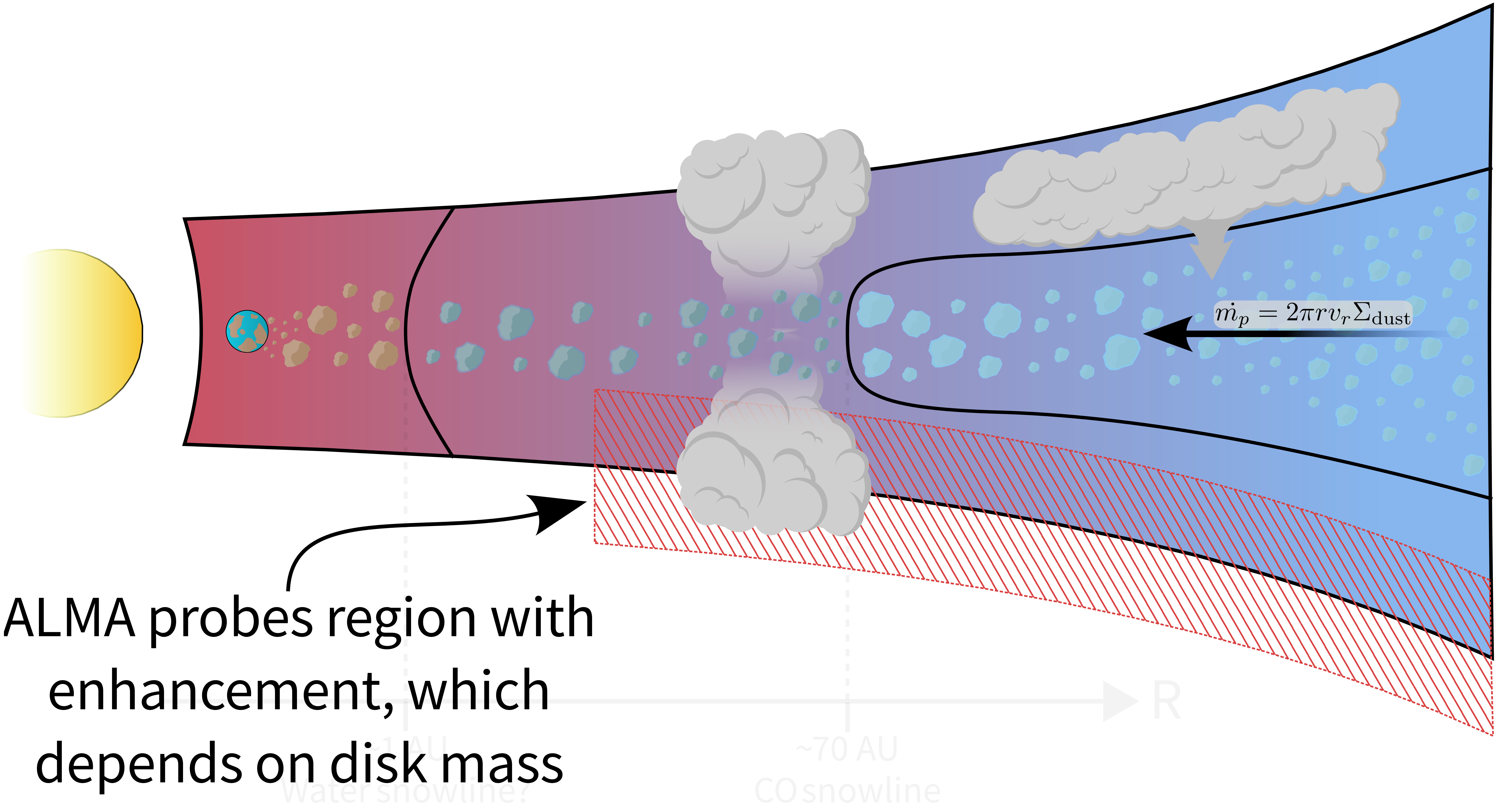

ALMA probes region with enhancement, which depends on disk mass

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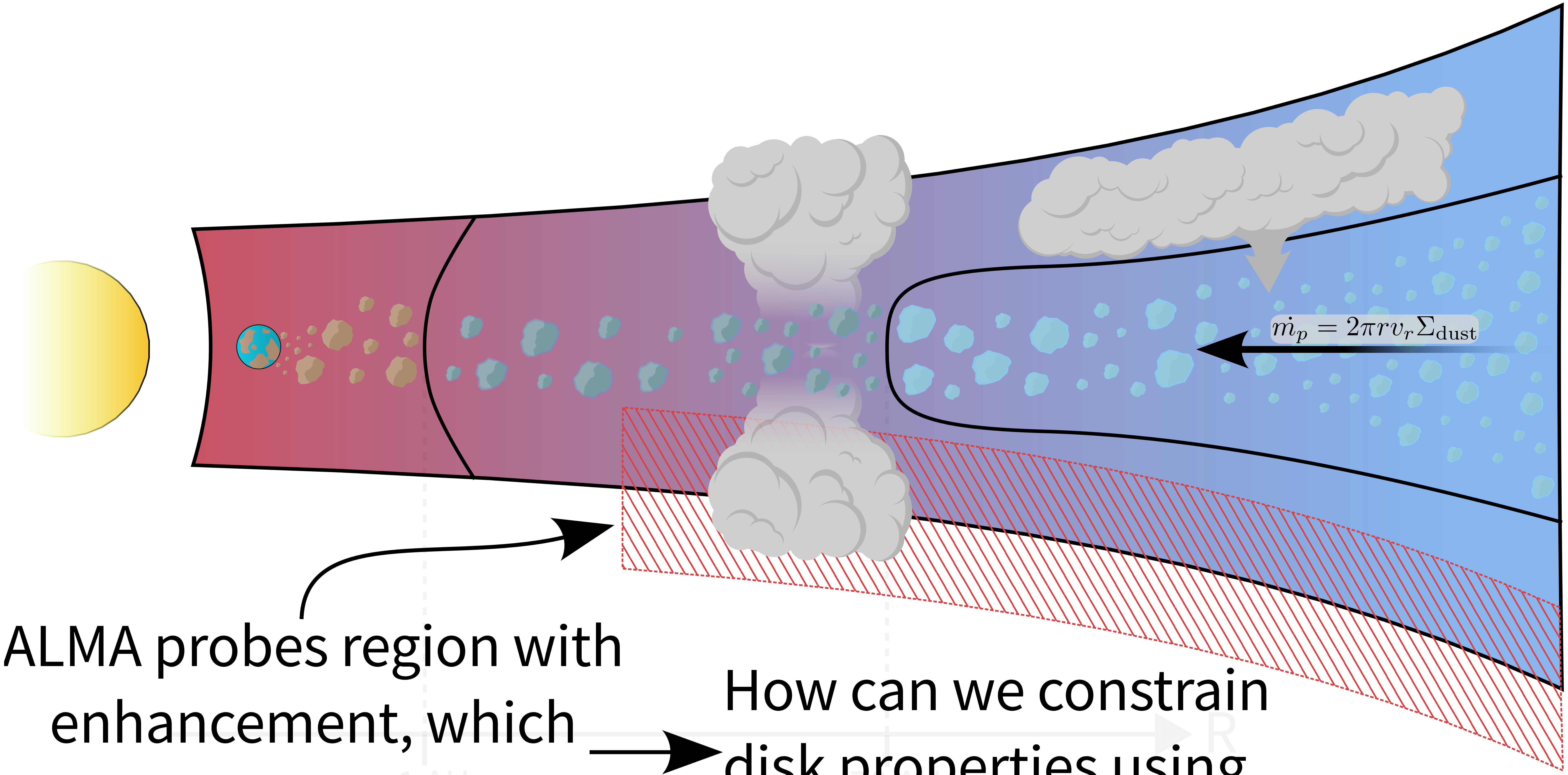

ALMA probes region with enhancement, which depends on disk mass

How can we constrain disk properties using this enhancement?

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NUMERICAL APPROACH (PYTHON)

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`pebble predictor` *Drążkowska et al. 2021*	1D disk dust simulator based on pebble drift
`emcee` *Foreman-Mackey et al. 2013*	Markov chain Monte Carlo ensemble sampler

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NUMERICAL APPROACH (PYTHON)

University of Exeter

Predicted cumulative pebble flux: **375 ± 125 $M_\oplus$** (Zhang+20)

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↓

Rapidly calculate cumulative pebble flux with simulator for given disk parameters

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Use **`emcee`** to sample the posterior distribution of disk parameters

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↓

Rapidly calculate cumulative pebble flux with simulator for given disk parameters

↓

Use **`emcee`** to sample the posterior distribution of disk parameters

↓

Deduce parameters **most likely to produce observations**

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TRIALLING A SYNTHETIC DISK

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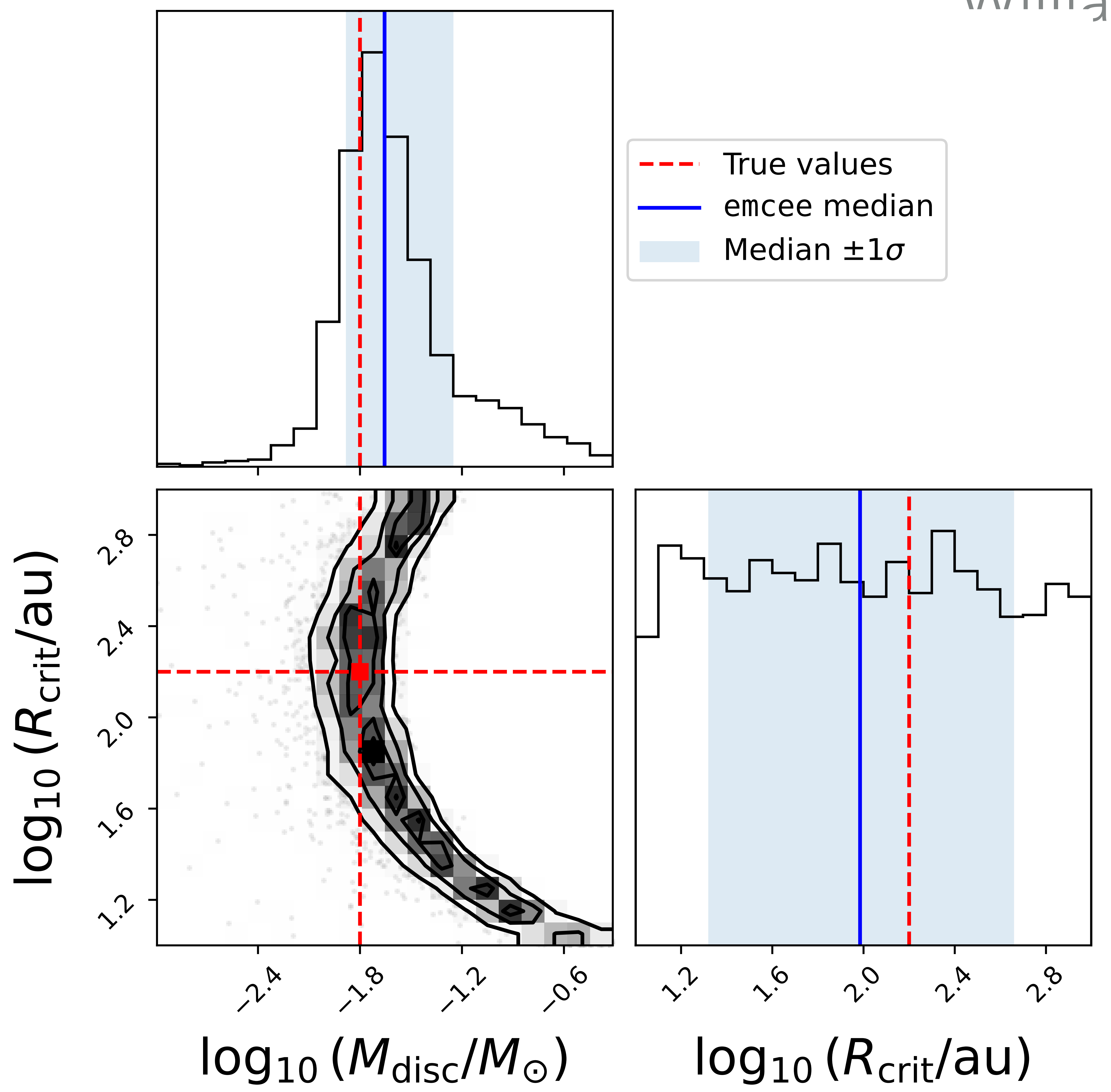
Williams & Krijt (in prep.)



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SOLUTIONS FOR HD 163296

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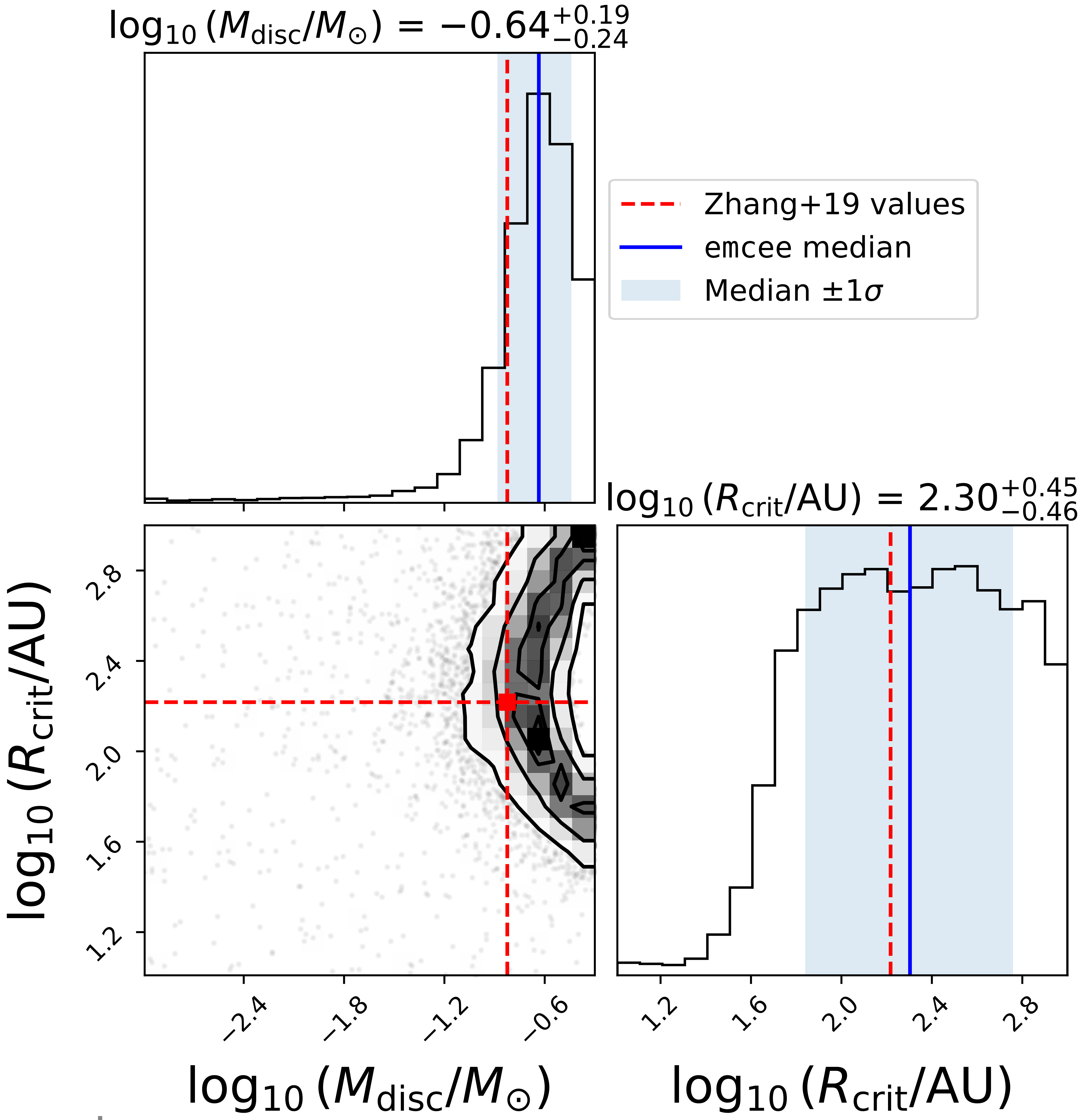

Williams & Krijt (in prep.)

We **can** constrain disk birth conditions!

What else can we do?

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MASS HISTORY & GRAIN FRAGILITY

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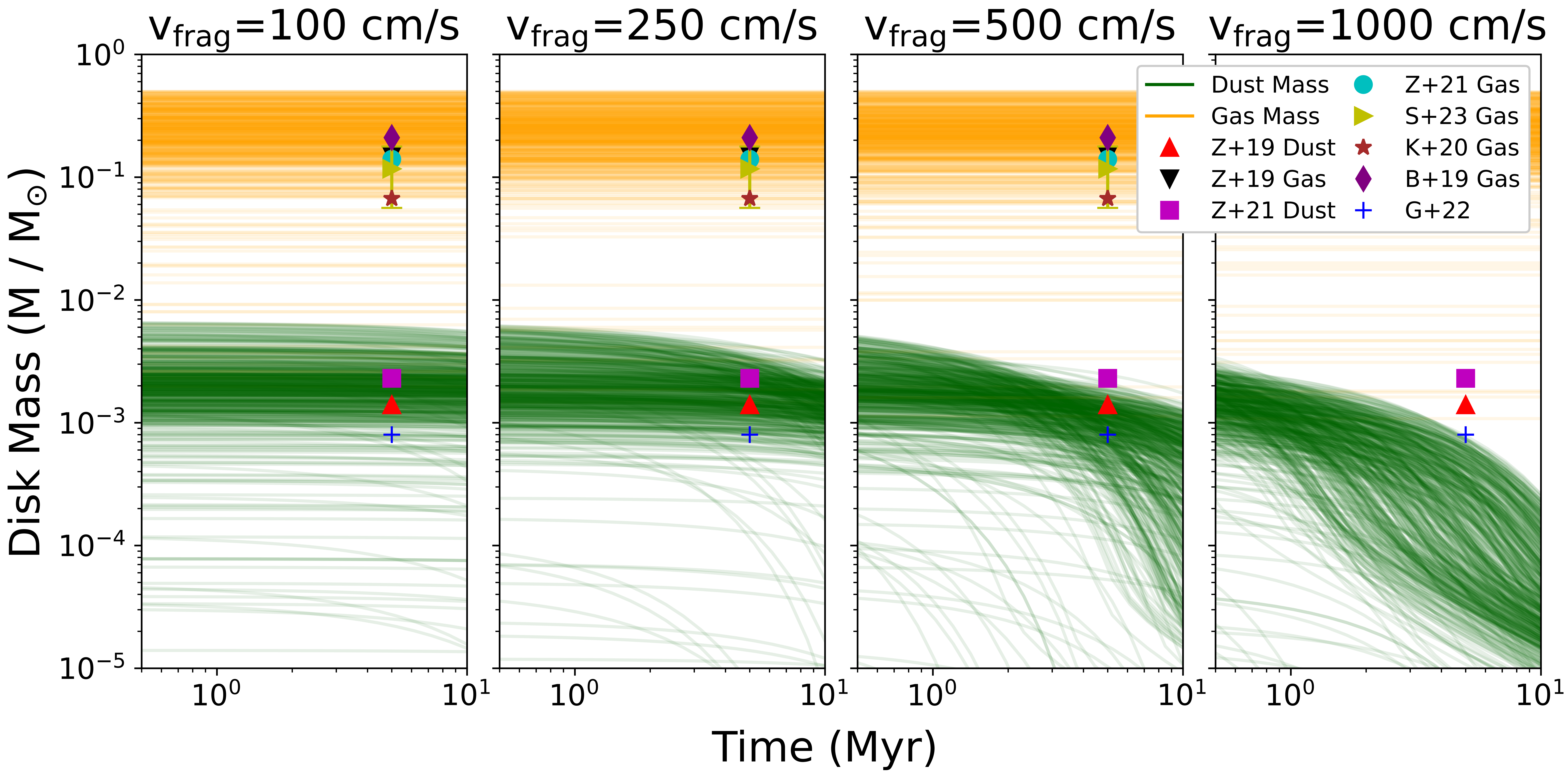
Williams & Krijt (in prep.)



Zhang+19
Zhang+21
Stapper+22
Stapper+23
Kama+20
Booth+19
Guidi+22

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DISTRIBUTION OF SOLUTIONS – 100 CM/S

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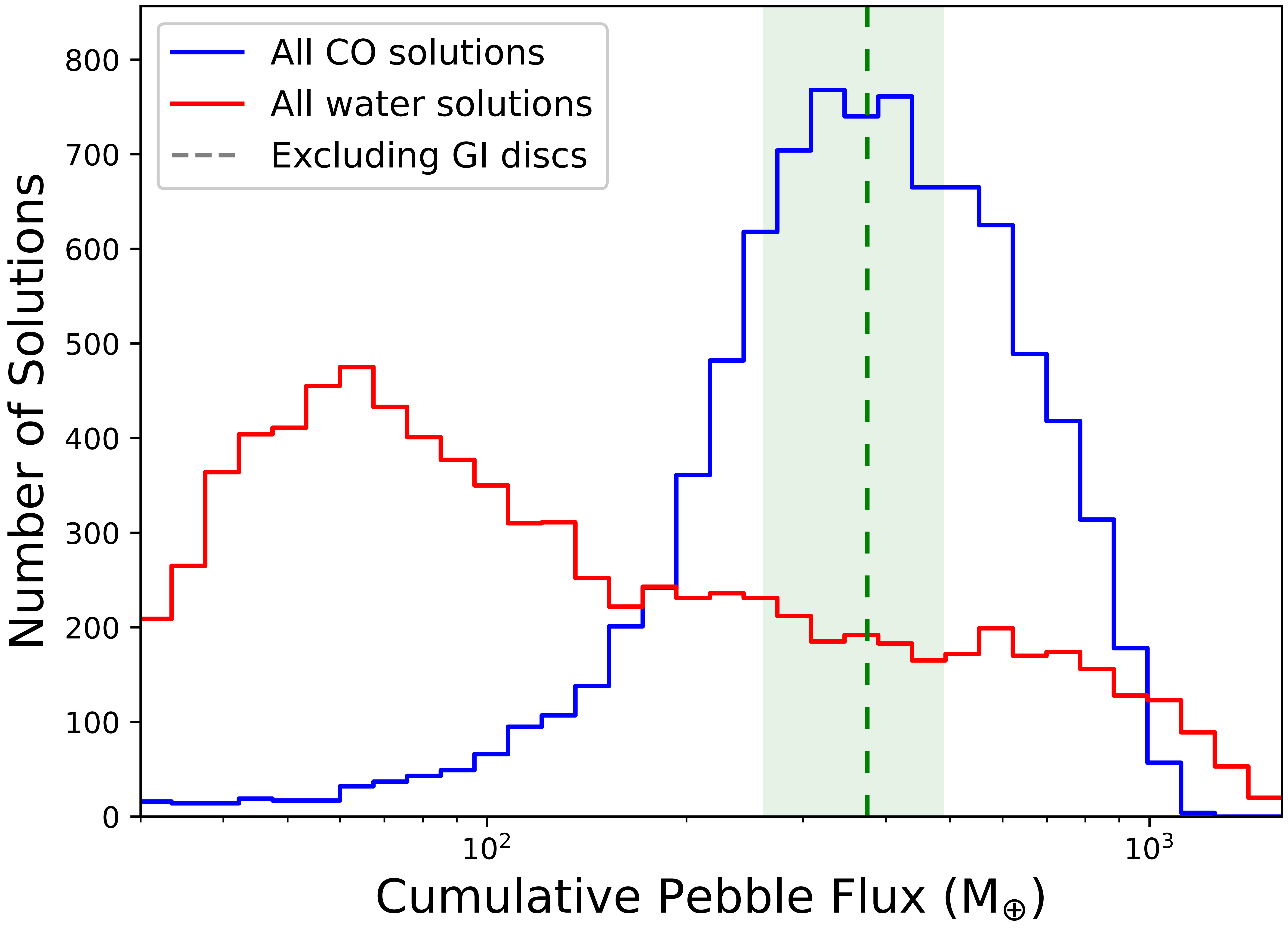
Williams & Krijt (in prep.)

Target 375 ± 125 $M_\oplus$



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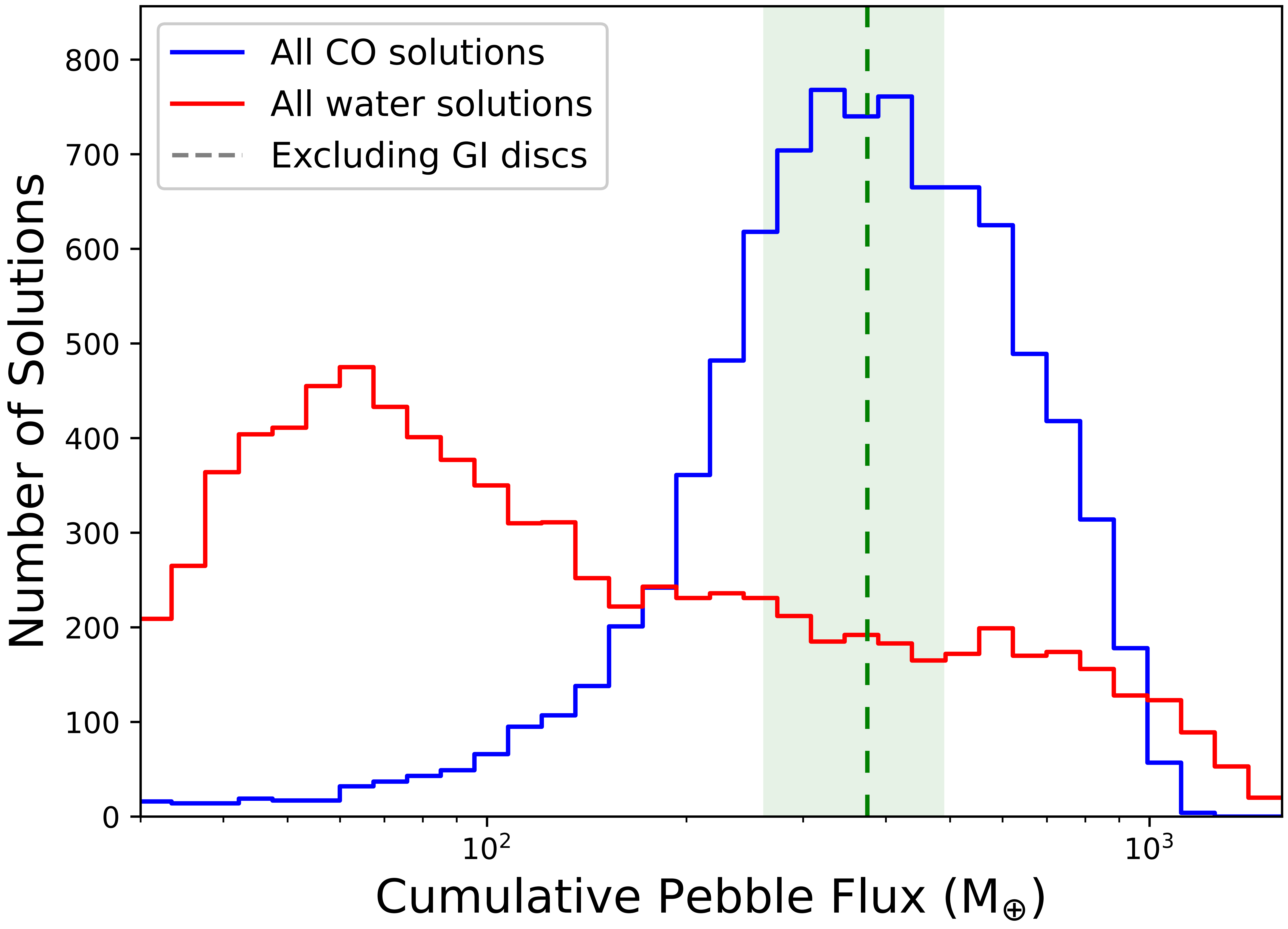

Target 375 ± 125 $M_\oplus$

But what about the terrestrial planet region?

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DISTRIBUTION OF SOLUTIONS – 100 CM/S

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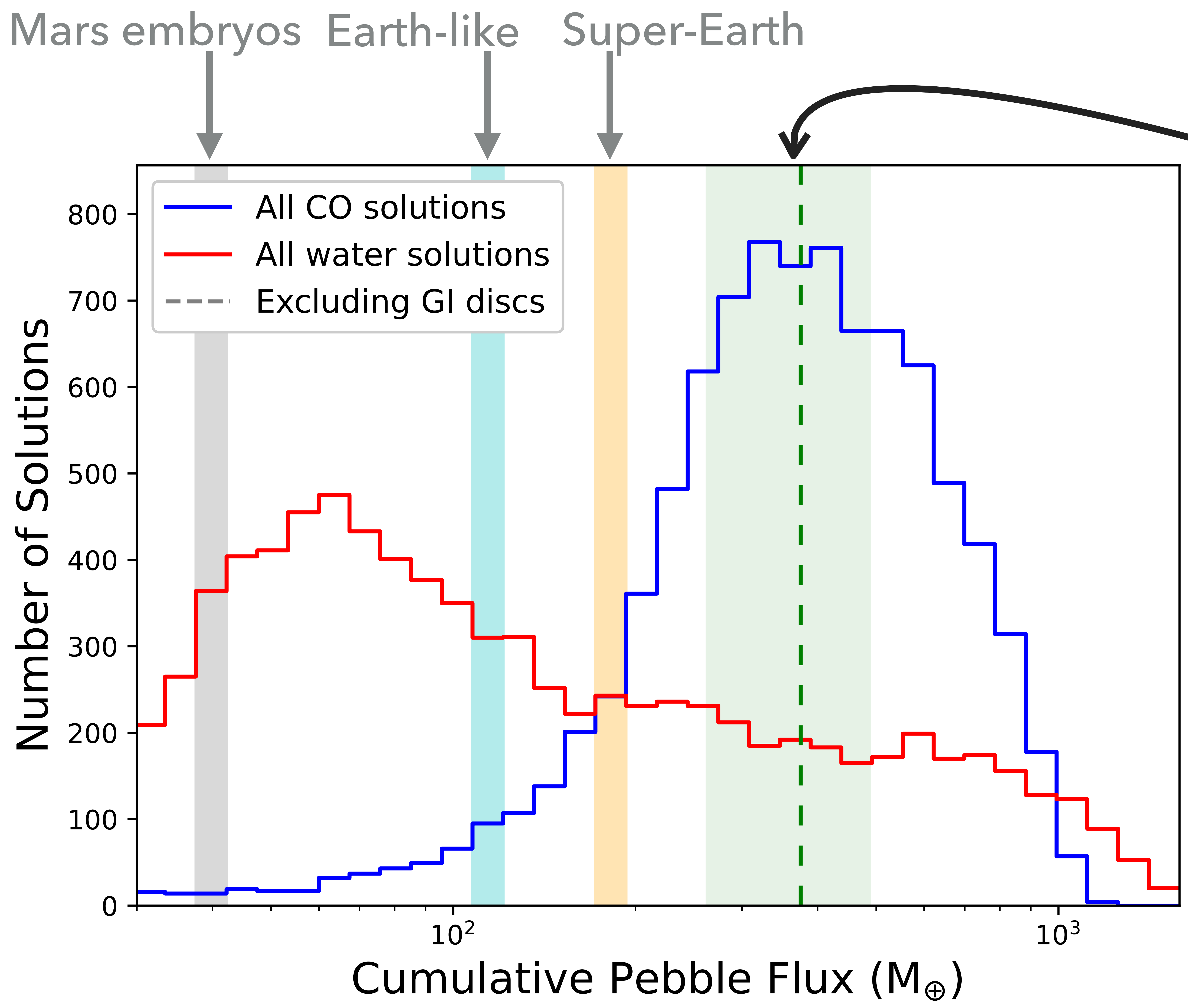

Target 375 ± 125 $M_\oplus$

Based on architecture predictions from Lambrechts et al. 2019:

Most likely to produce **Mars-like to terrestrial planets** (41% of solutions in this range)

… but can't rule out super-Earths (34% of solutions above this band)

See talk Morgan Williams later today for formation mechanisms!

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WHAT'S NEXT?

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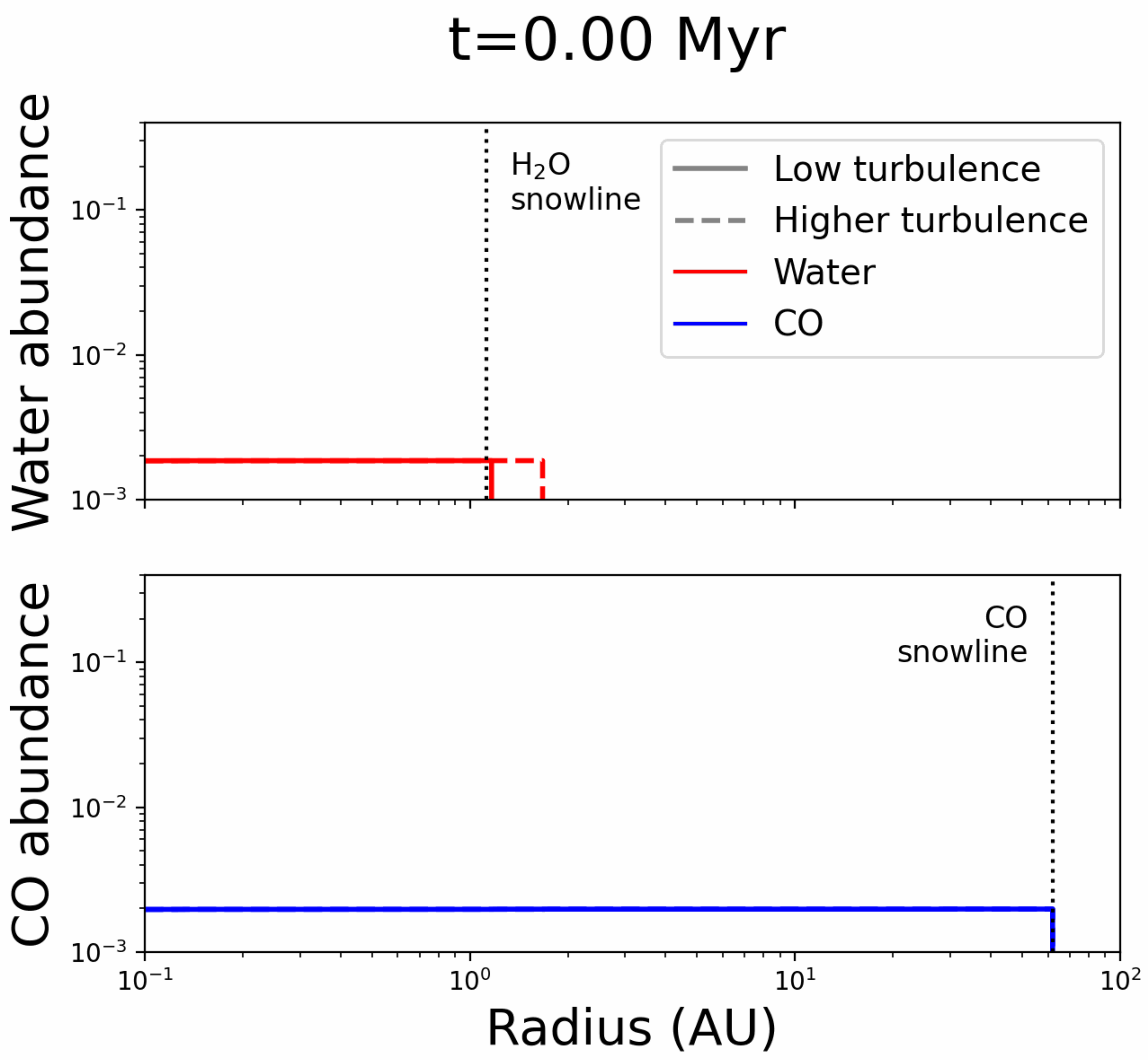
- More complex observations - radially resolved CO enhancement?
- Other disks?
- Other molecular tracers?
  - Using JWST to probe water content (e.g. Banzatti+23)



Produced with `chemcomp` (c.f. talk by Bertram Bitsch yesterday!)

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CONCLUSION

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Take-aways	Future questions
New way to constrain disk birth conditions using pebble flux	What about the effect of disk substructure? (e.g. Stammler+23)
Predicting solid and ice flux to terrestrial planet region	Would planet formation have a significant impact?
Fragile grains reproduce observations best	Can we use other disks and molecular tracers?

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BONUS SLIDES

SOLUTIONS FOR HD 163296 WITH TABLE

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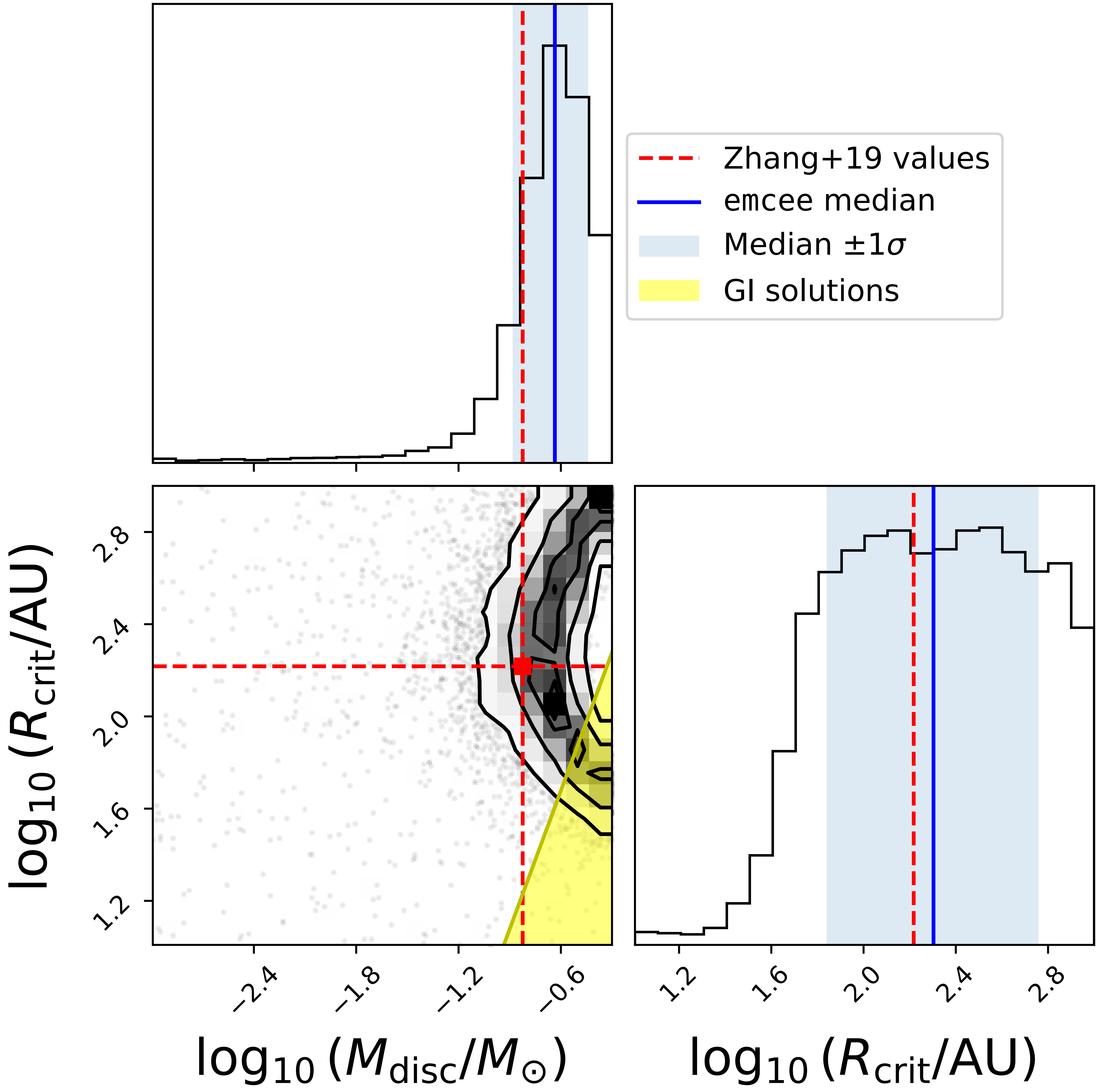
Parameter	Literature value	Found value
$\log_{10}(M_{\rm disk}/M_\odot)$	-0.82	$-0.64^{+0.19}_{-0.24}$
$\log_{10}(R_{\rm crit}/{\rm AU})$	2.22	$2.30^{+0.45}_{-0.46}$

- Gravitational stability

Williams & Krijt (in prep.)



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WHAT'S NEXT? DIAGRAM

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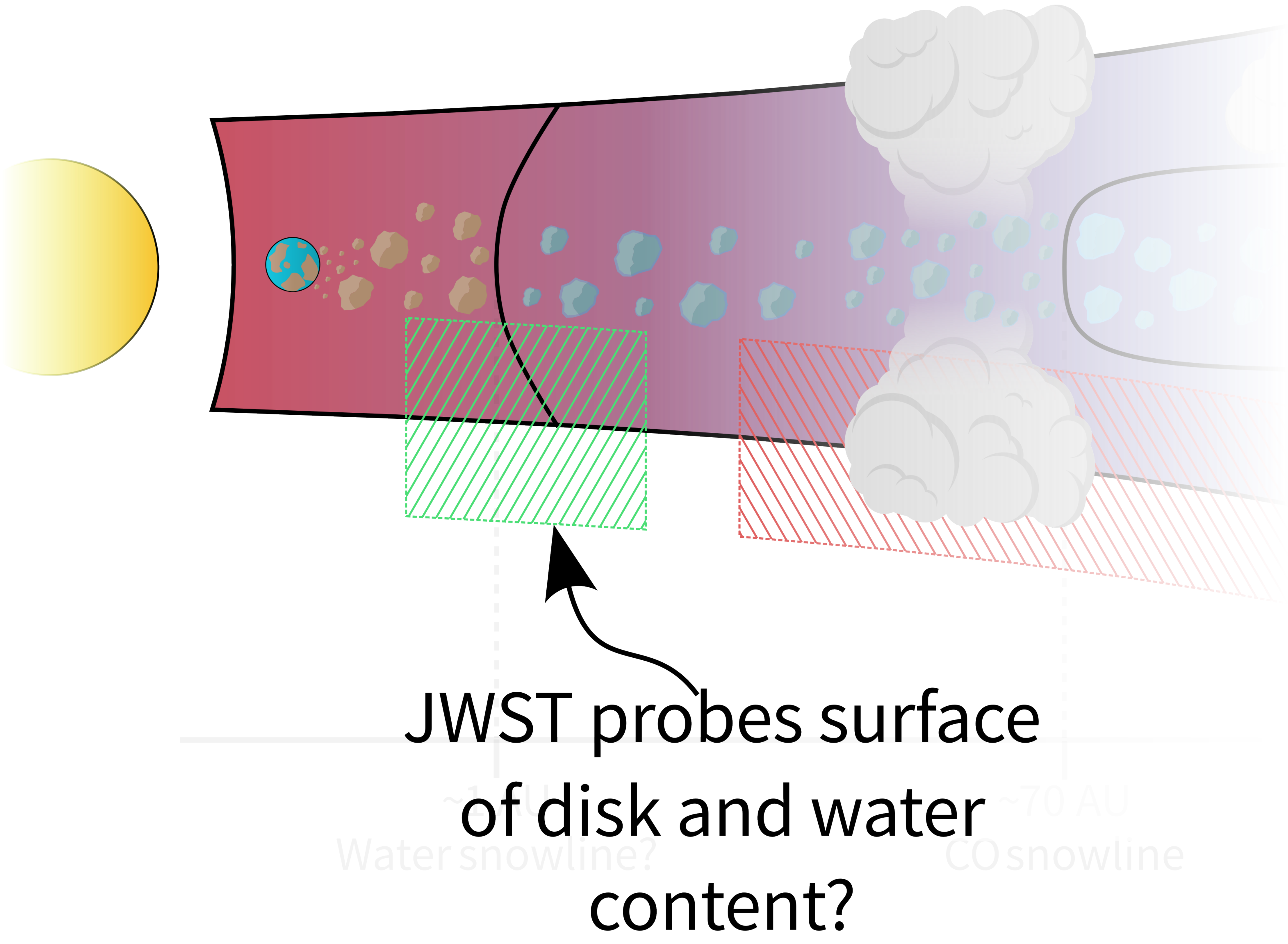
- More complex observations - radially resolved CO enhancement?
  - How does the C/H ratio vary?
- Other disks?
- Other molecular tracers?
  - Using JWST to probe water content (e.g. Banzatti+23)



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MASS HISTORY & GRAIN FRAGILITY

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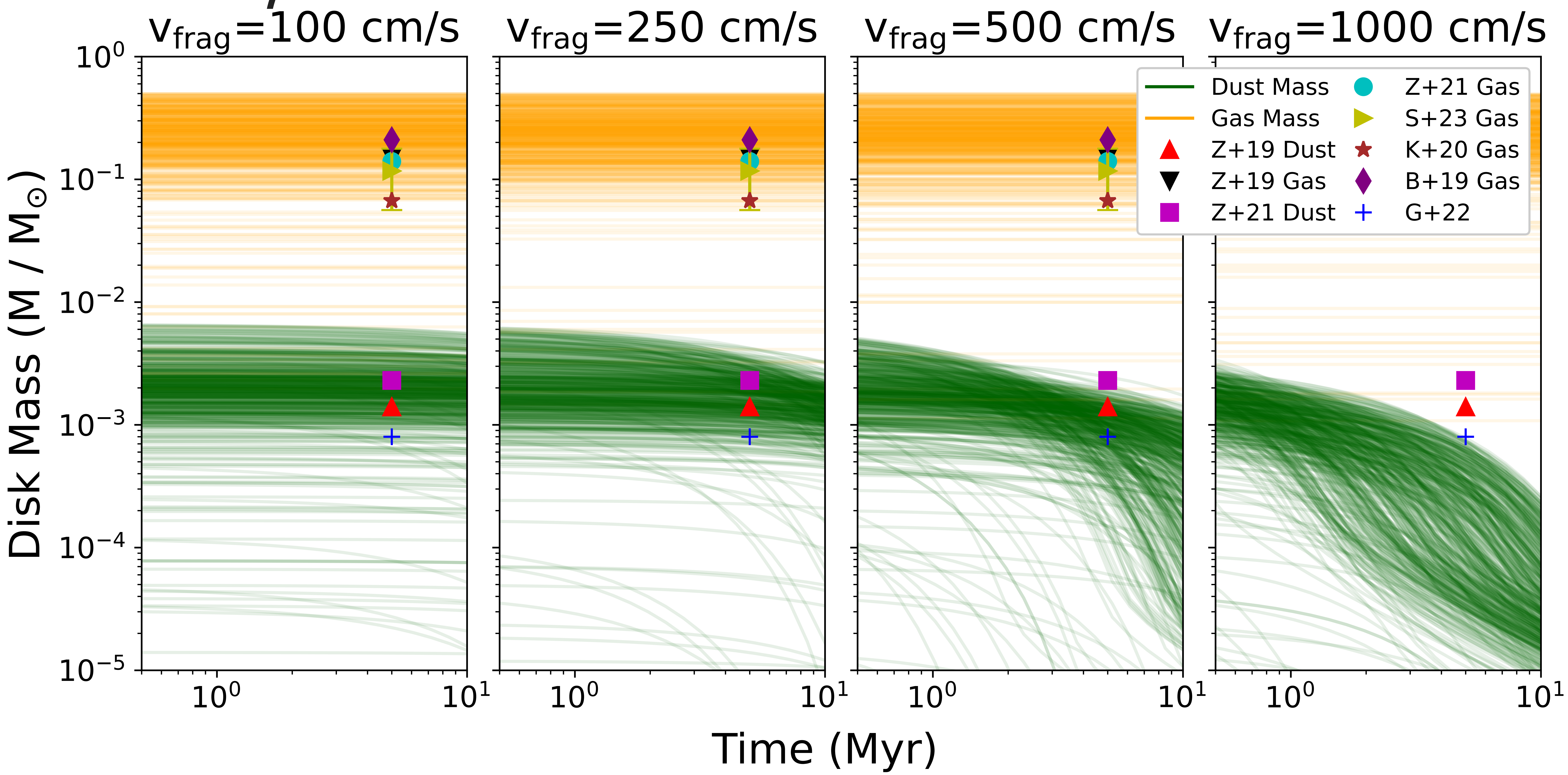
$$\log_{10}(M_{\rm dust}/M_\odot) = -2.95^{+0.22}_{-0.24}$$

Williams & Krijt (in prep.)



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DISTRIBUTION OF SOLUTIONS – 100 CM/S

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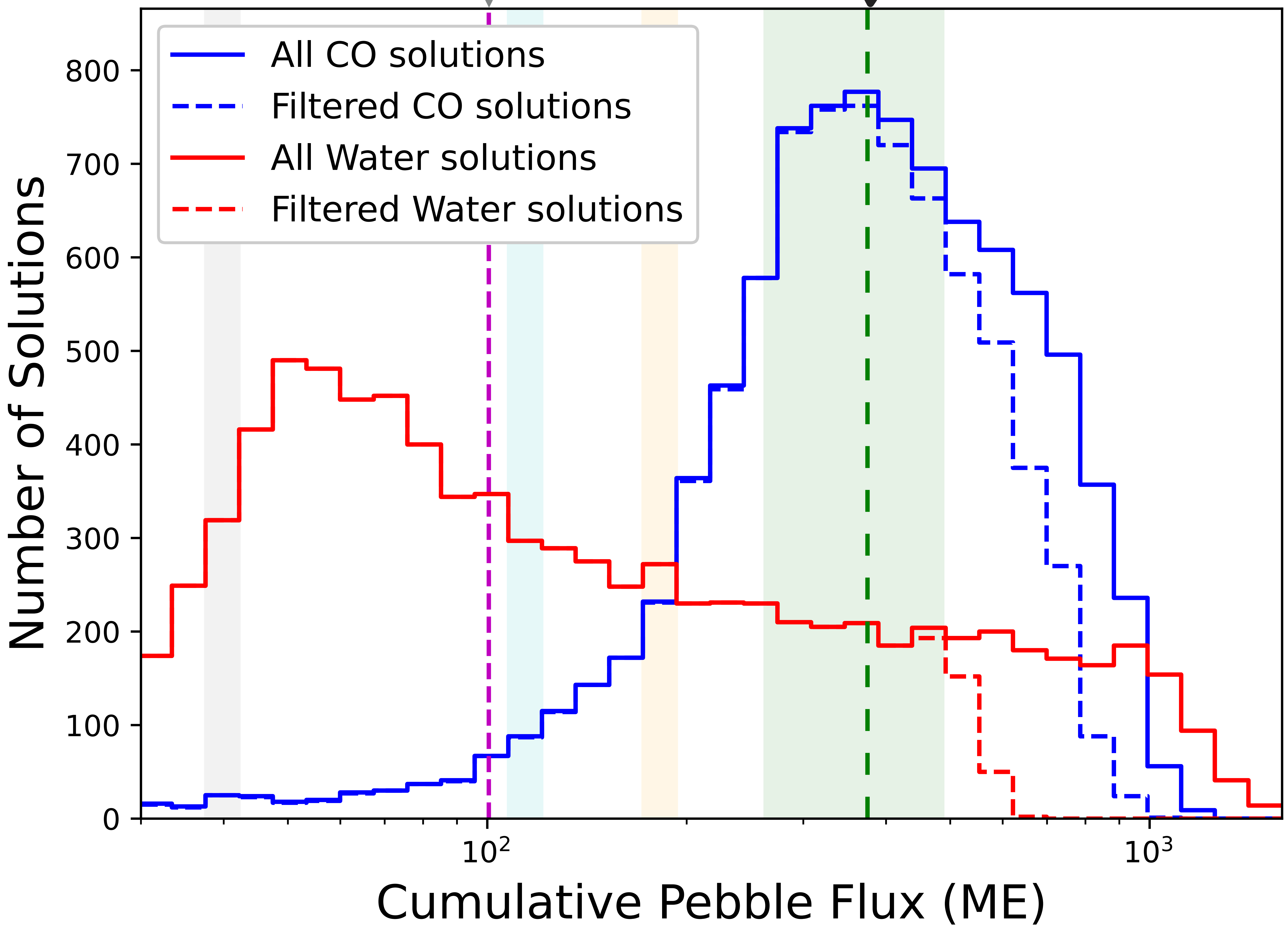
Median solution

Williams & Krijt (in prep.)



Target 375 ± 125 $M_\oplus$

Most ‘likely’ solution?

- 41% between **Mars core** and **Earth-like**
  - **Median solution** is **100 ME** and lies within this region

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DO EMCEE'S SOLUTIONS MAKE PHYSICAL SENSE?

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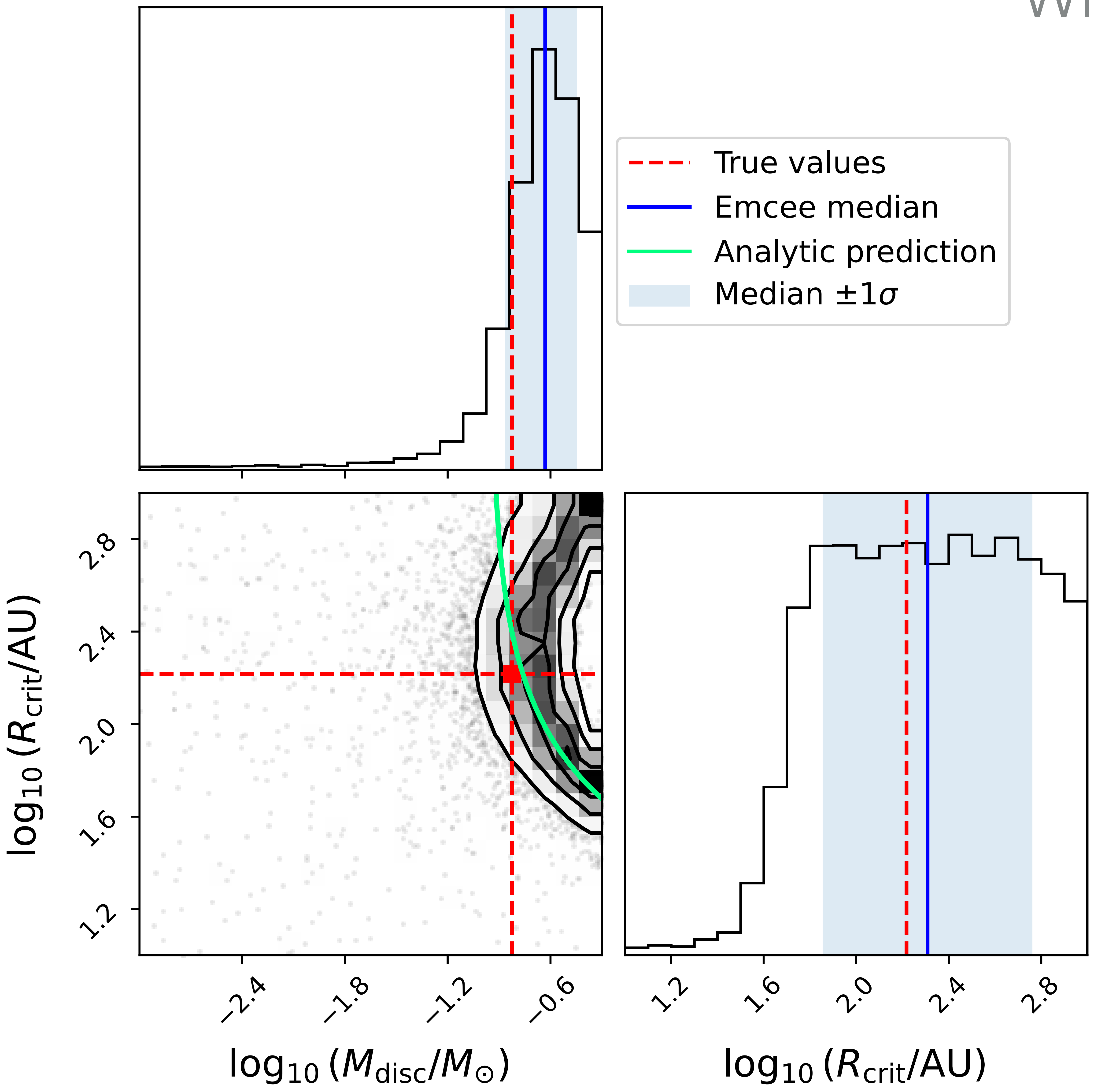

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MARKOV CHAIN MONTE CARLO EXPLAINED

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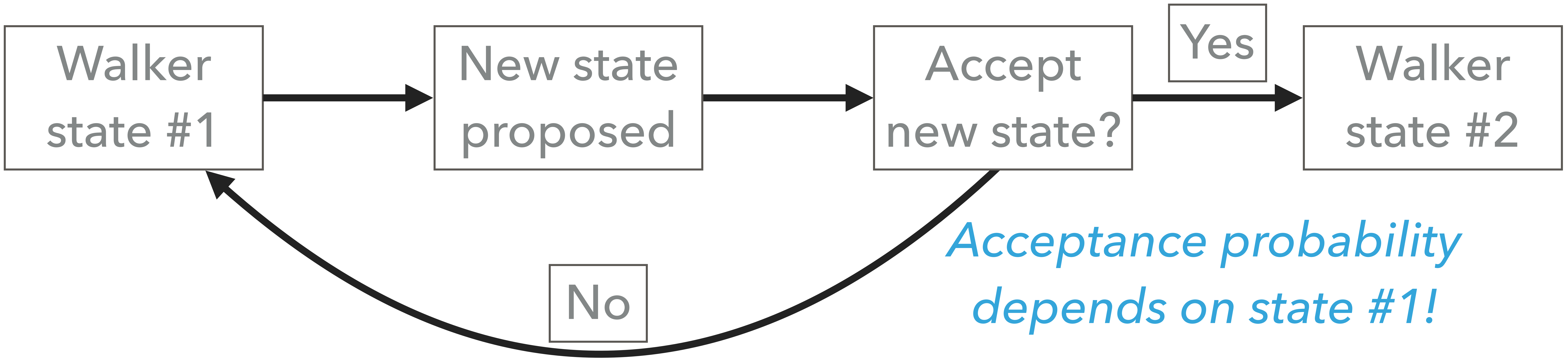
- Uses 'walkers' that explore the parameter space



- Eventually samples states from a stationary distribution when 'detailed balance' is satisfied

- … essentially when the walker states are from a subset of a larger distribution!

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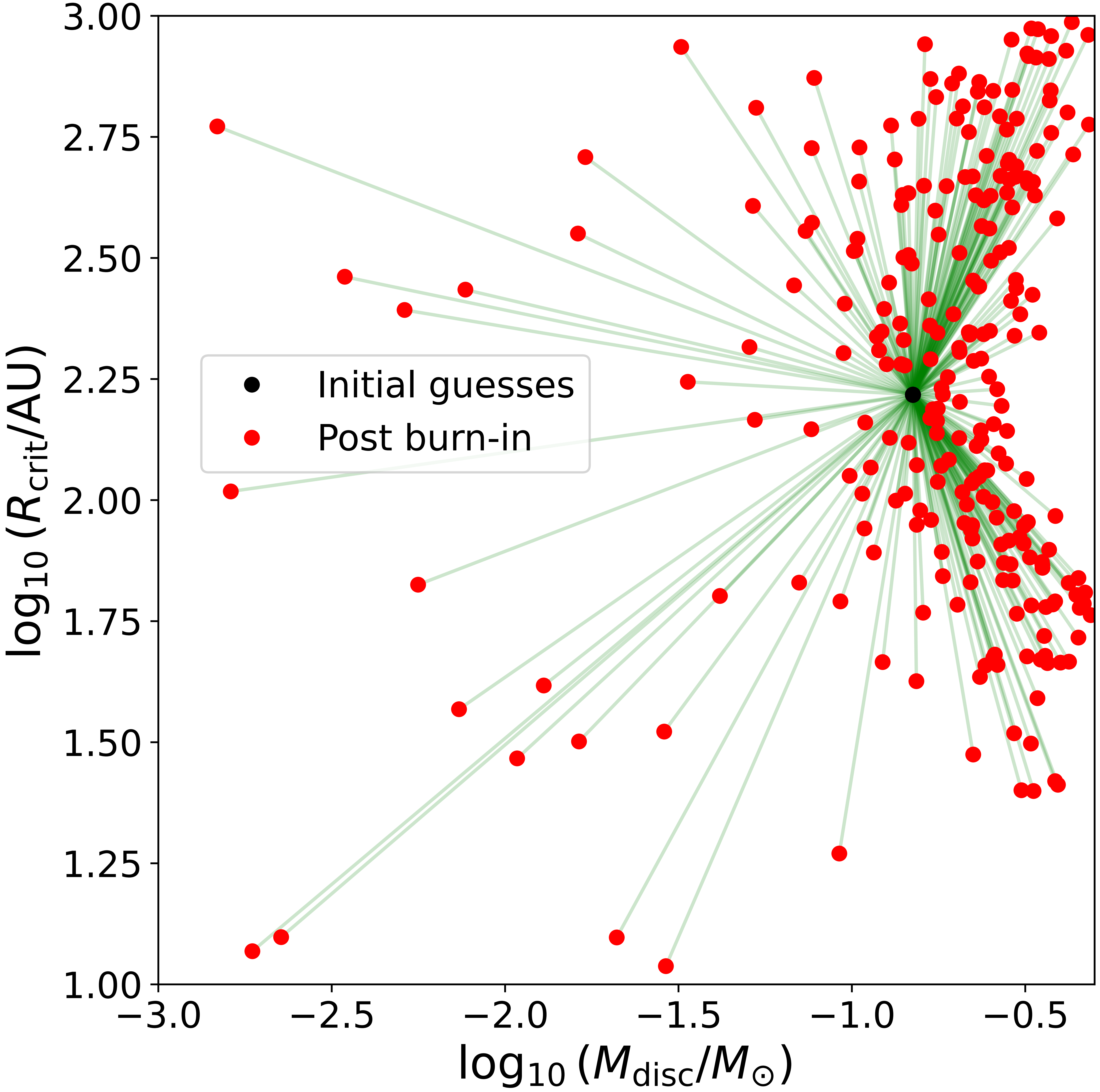
EMCEE WALKERS



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RADIAL DRIFT EXPLAINED

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Gas and dust orbiting star

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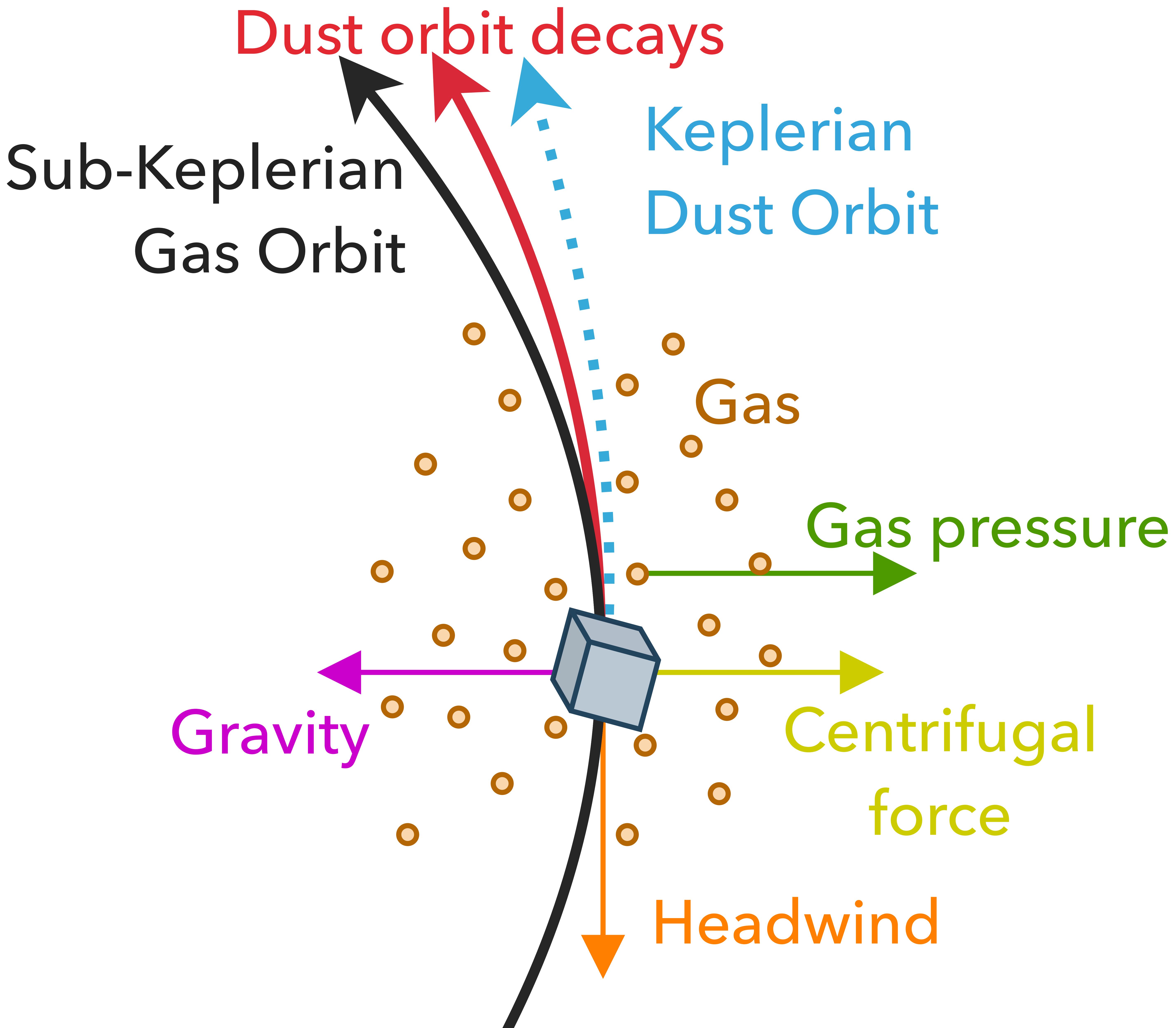
Gas orbits at sub-Keplerian velocity

↓

Dust experiences headwind

↓

Dust drifts inwards



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