Radial Drift and Concurrent Ablation of Boulder-Sized Objects

Dust, Pebbles and Minor Bodies 2019 – NCCR PlanetS Workshop Bern

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Introduction

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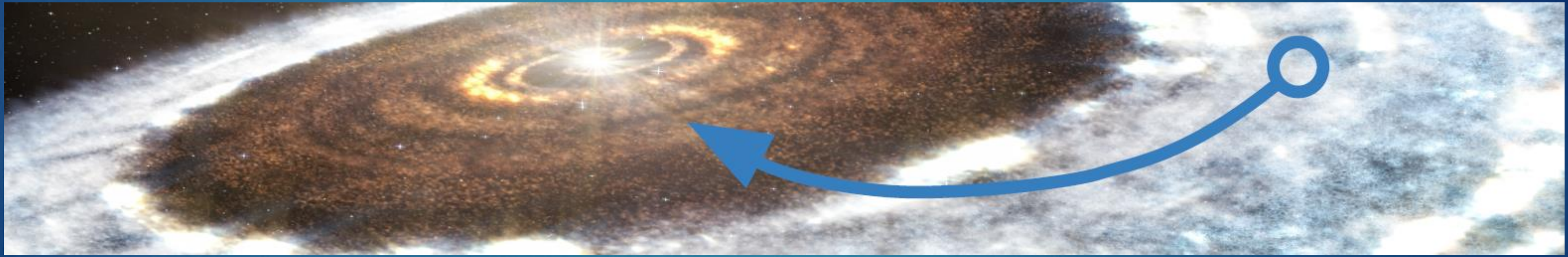
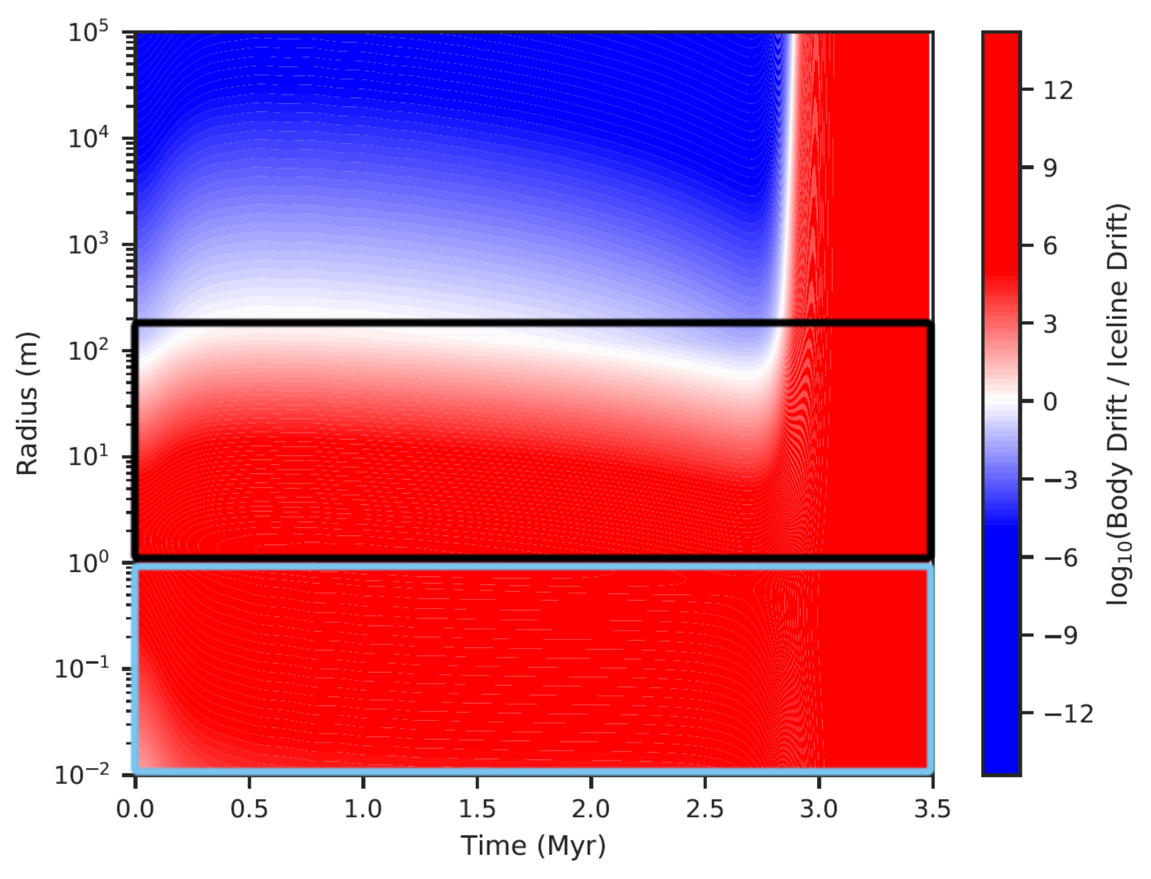
Introduction

- Icy bodies crossing the snowline due to radial drift
  - Caused by gas drag
  - Quantify efficiency of water transport
- Focus on H_2O ice line (i.e. the snowline)



Boulder size range

- Pebbles and Cobbles sublimate fast and drift slow (e.g. Schoonenberg, Ormel 2017, Drazkowska 2017)
- Boulders with r ≳ 1m drift fast and take longer to lose ice
- Planetesimals (r ≳ 200m) drift slower than snowline
  - They never cross it by gas induced drift



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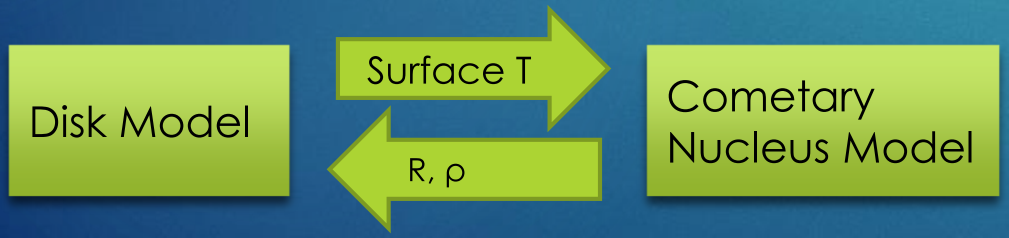
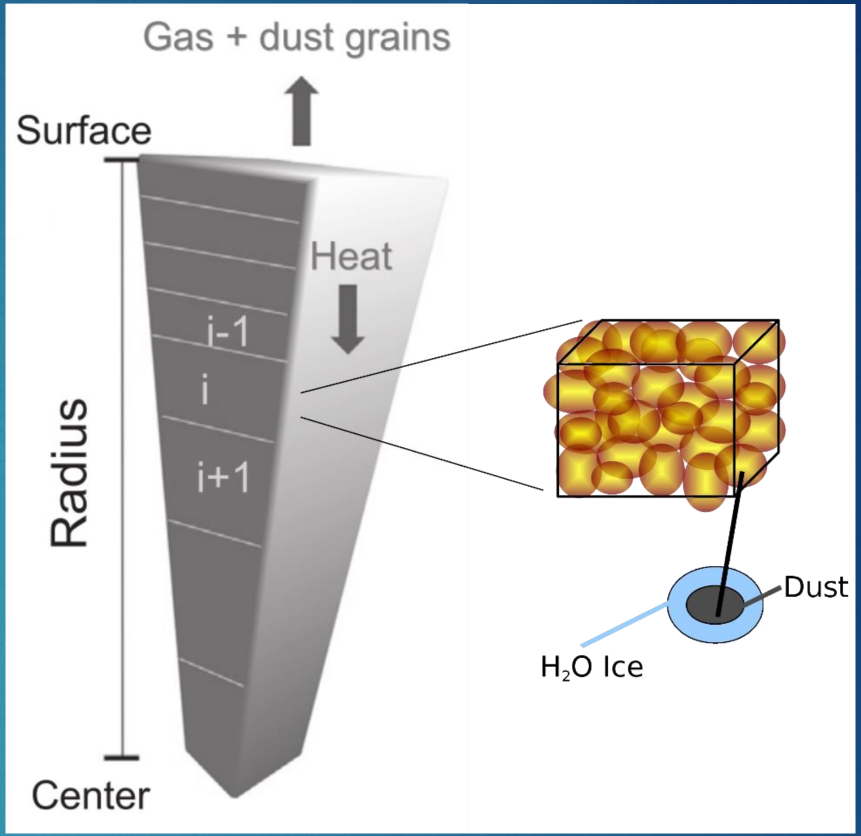
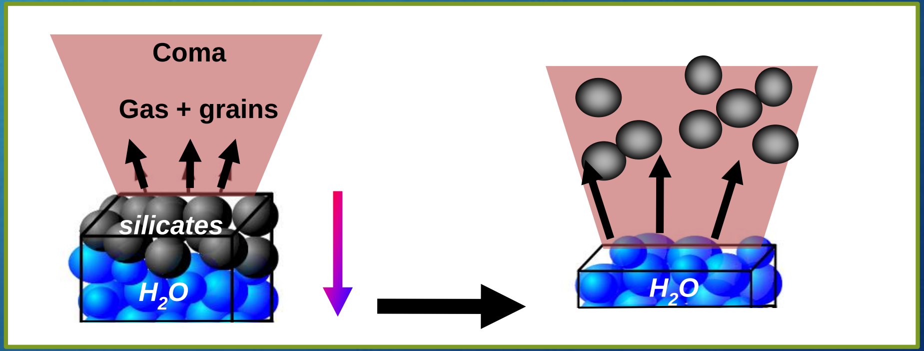
Methods

Cometary Nucleus Model

- Model from Marboeuf 2008, Marboeuf et al., 2012
  - 1-D mode used
  - Heat, gas and dust grain transport
  - Sublimation/Condensation of volatiles
  - Dust mantle formation / removal possible







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Radial Drift

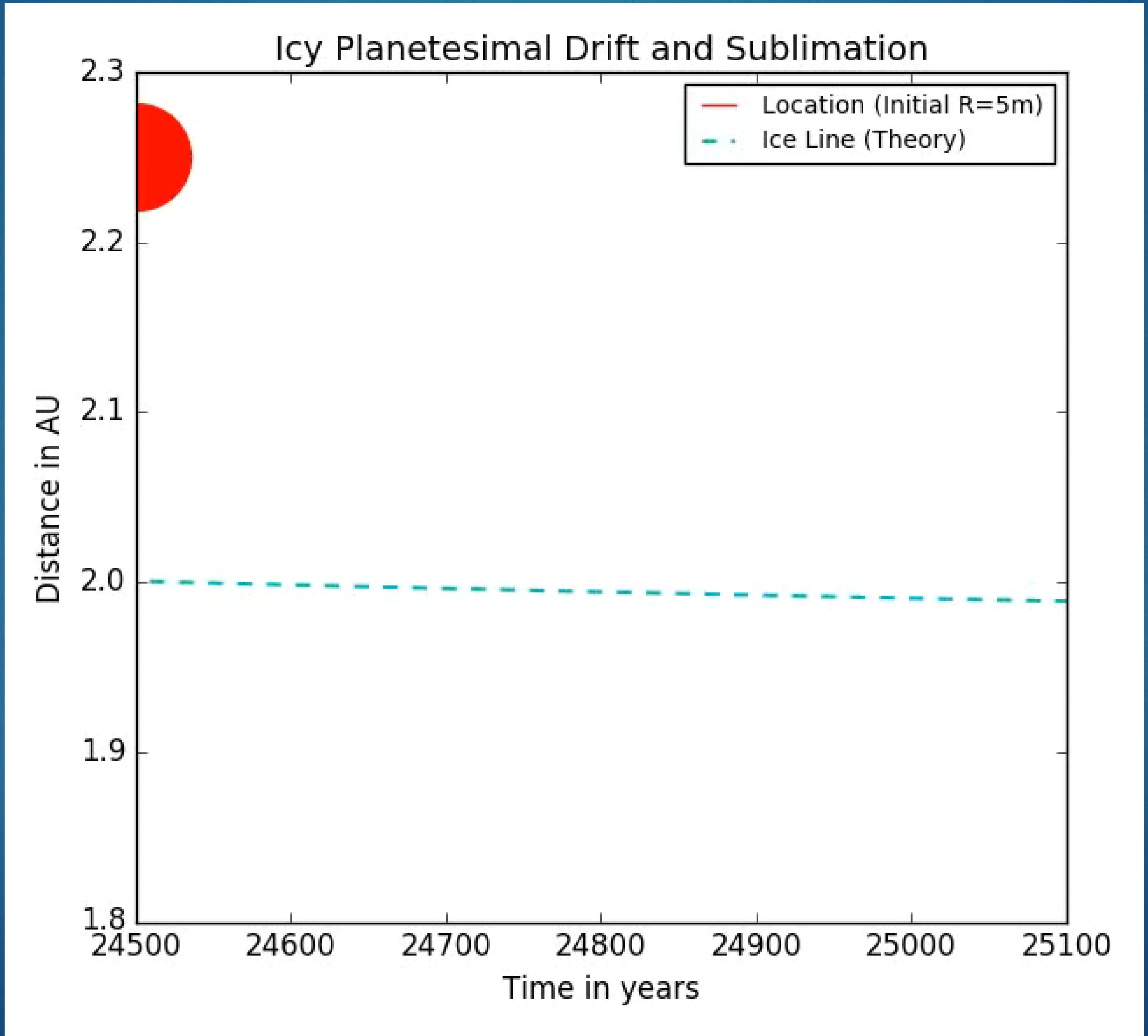
$$\frac{da}{dt} = \begin{cases} -\frac{2a\eta\Omega}{s} & \text{Quadratic Regime} \\ -\frac{2a\eta\Omega}{s}\left(\frac{s^2}{1+s^2}\right) & \text{Epstein or Stokes (laminar) Regime} \end{cases}$$

- Stokes Number $s = t_s\Omega = \frac{\rho_s R\Omega}{\rho_g v_{therm}} \left(\times \left\{1, \frac{2R}{3\lambda}, \frac{6v_{therm}}{\Delta v}\right\}\right)$

Results

(BURN ET AL. SUBMITTED TO A&A)

Single Boulder



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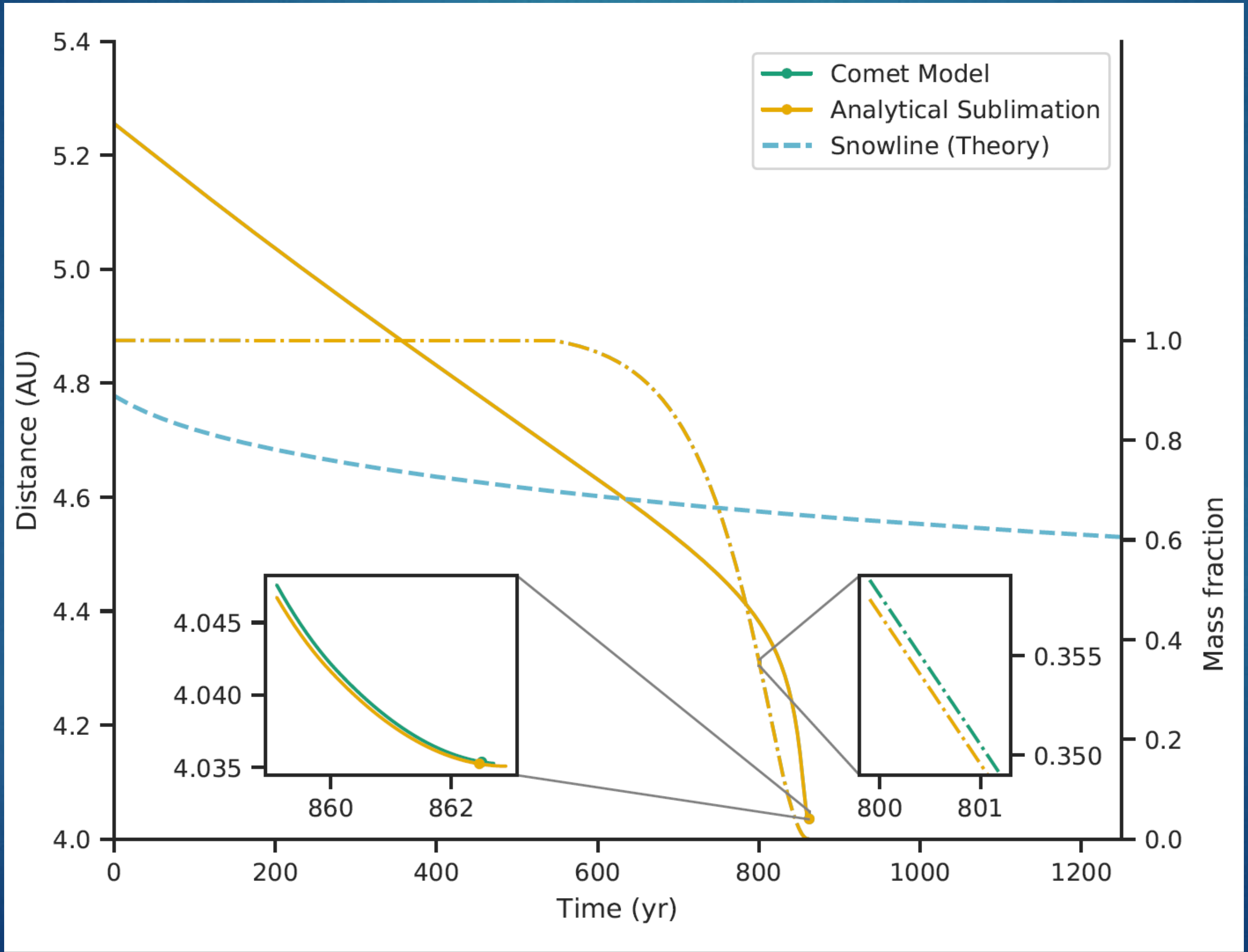
Sublimation Model



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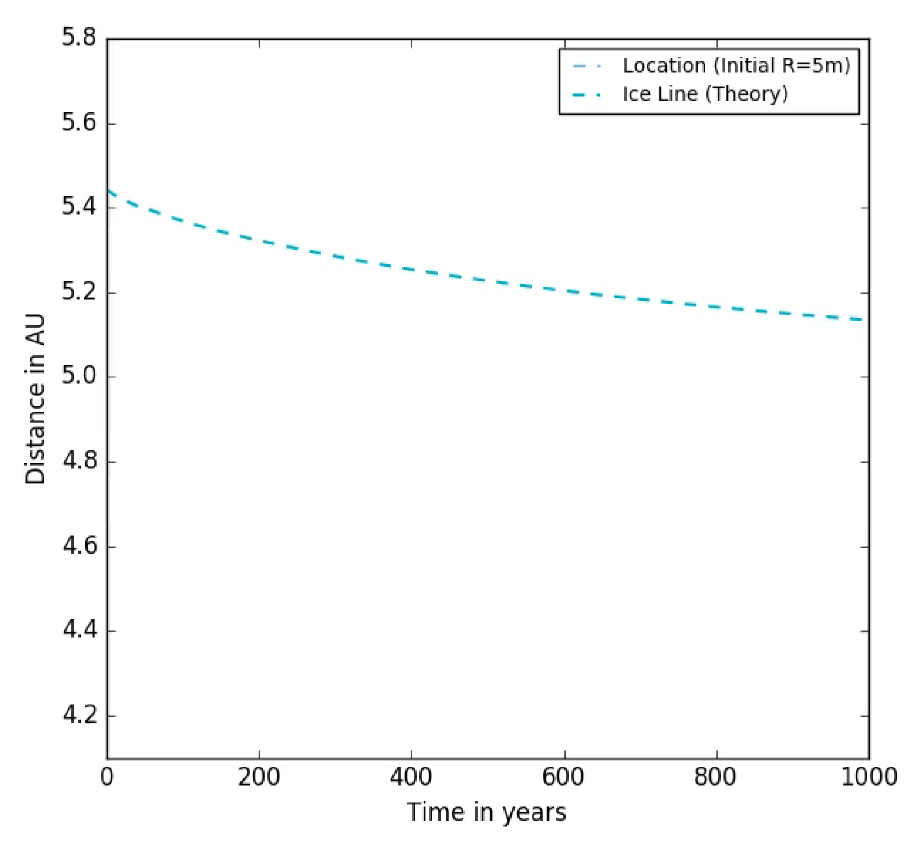
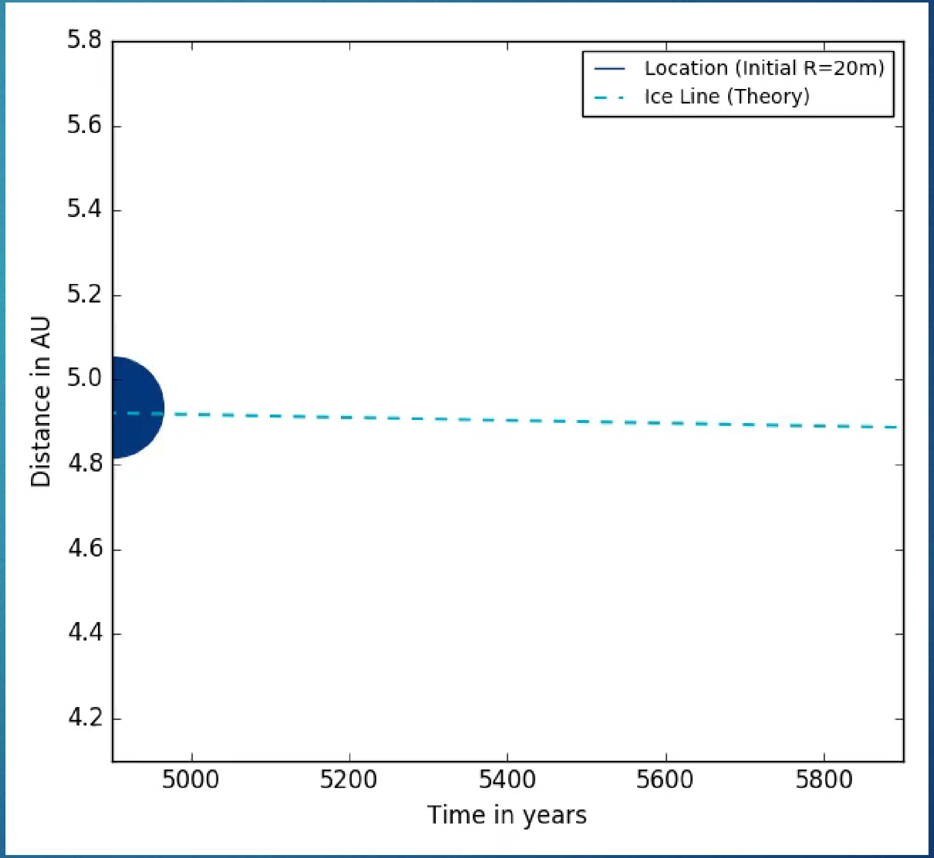
Size Dependence





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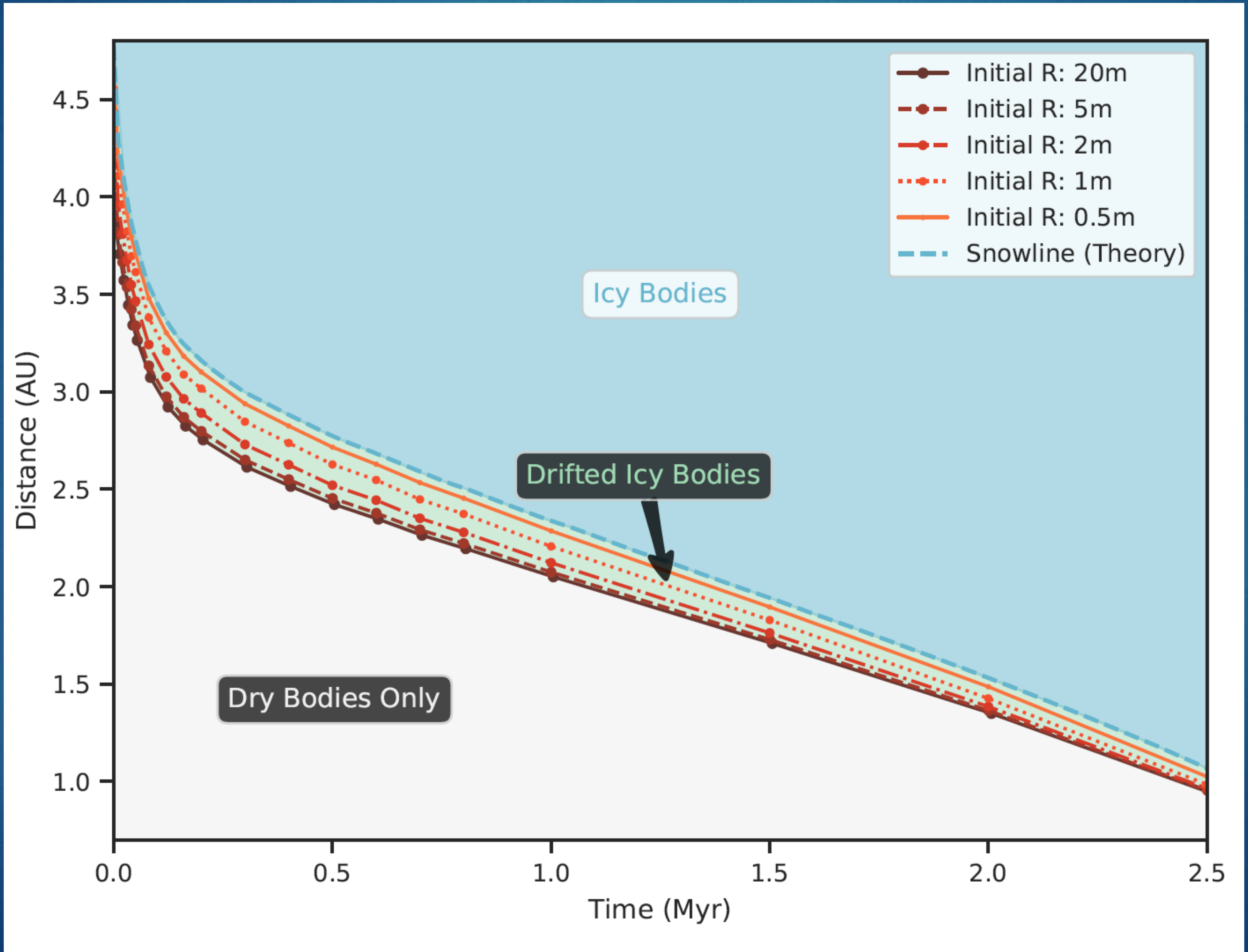

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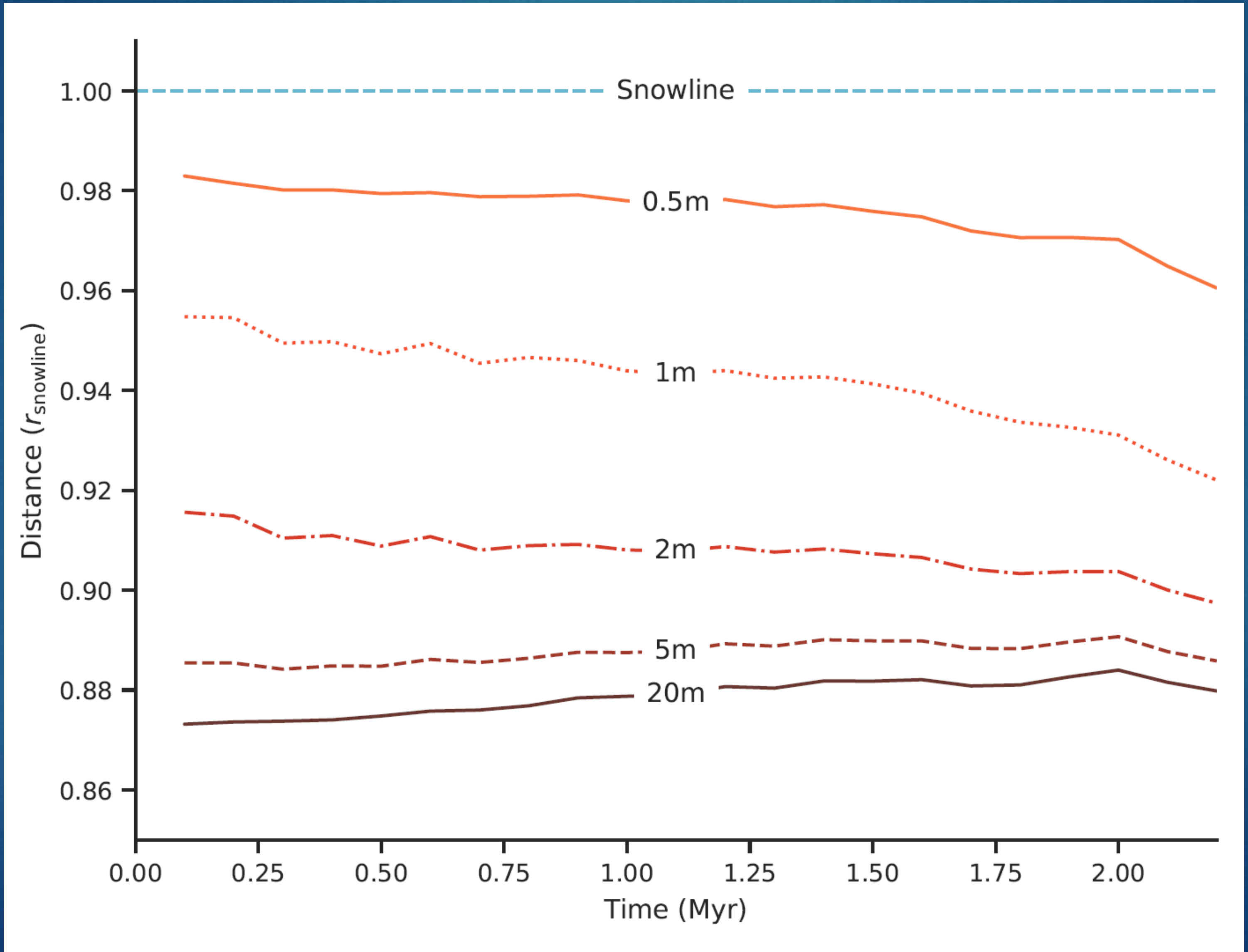

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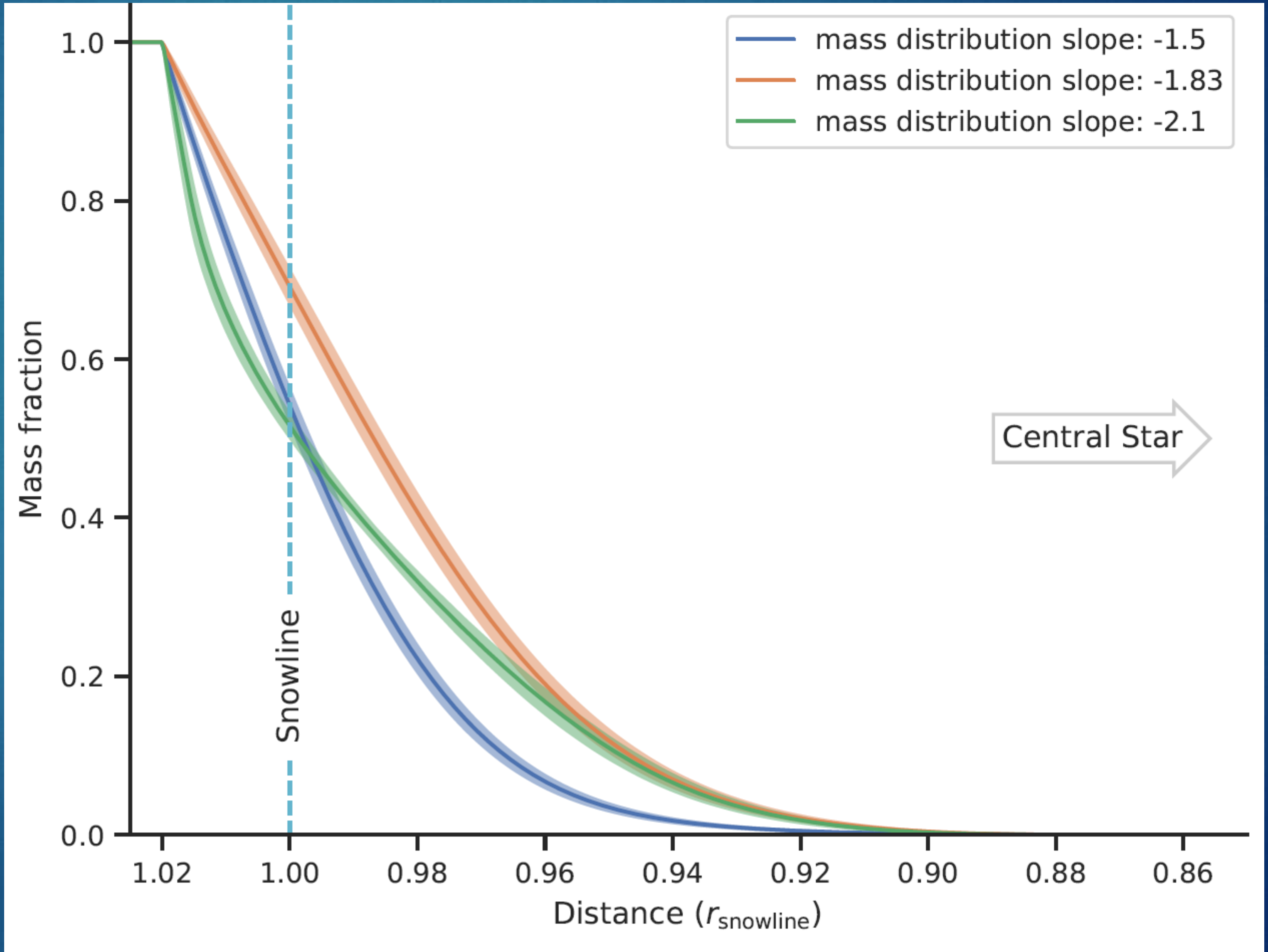
Size Dependence

- Assume a size distribution

$$n(m)dm = \begin{cases} Am^{\alpha} & \text{for } m \in [c_l, c_u] \\ 0 & \text{else} \end{cases} dm$$

- $c_l = 1\ \mathrm{kg}$
  $c_u = 1 \times 10^9\ \mathrm{kg}$
- Integral over all included masses
- Mean in time evolution of the disk



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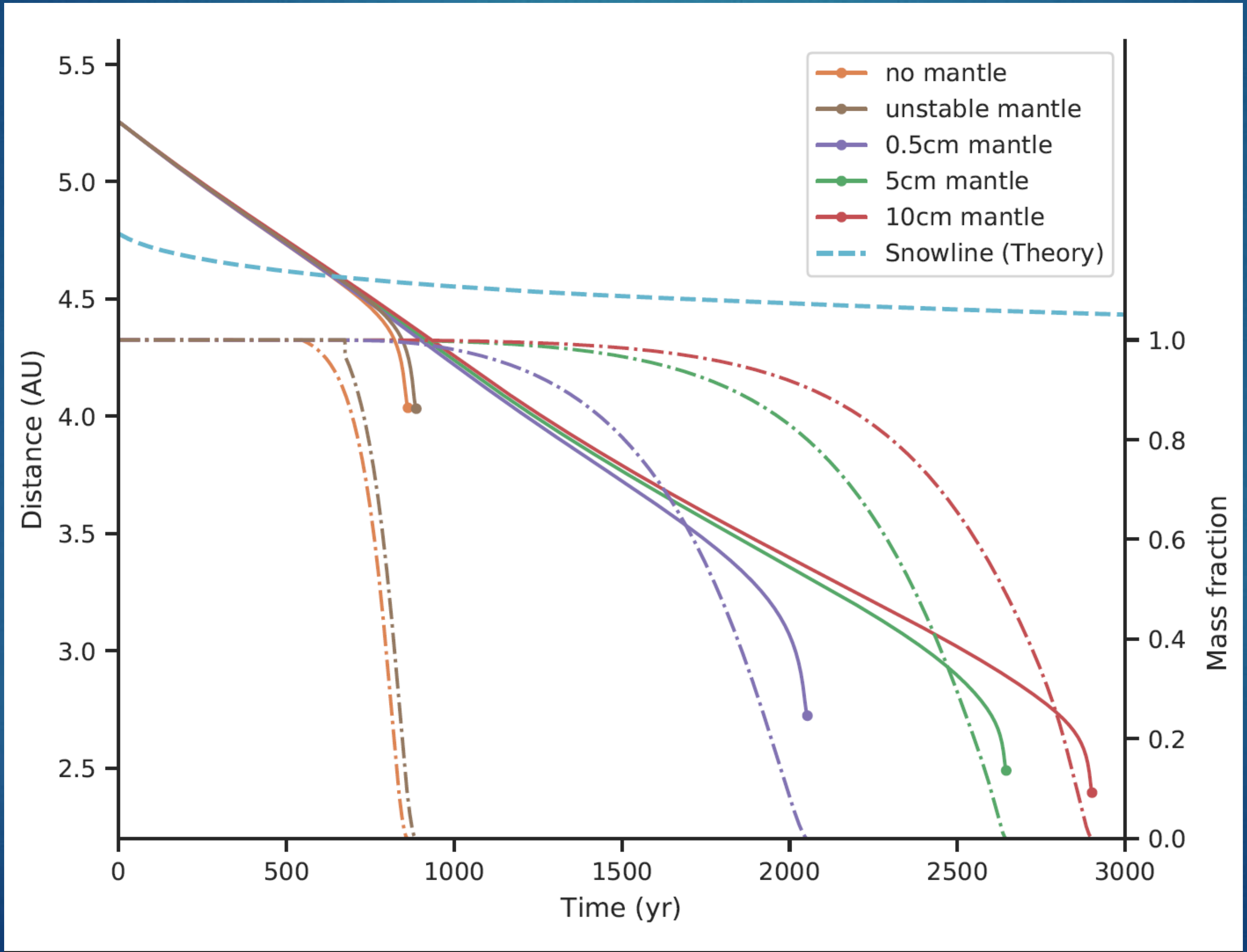
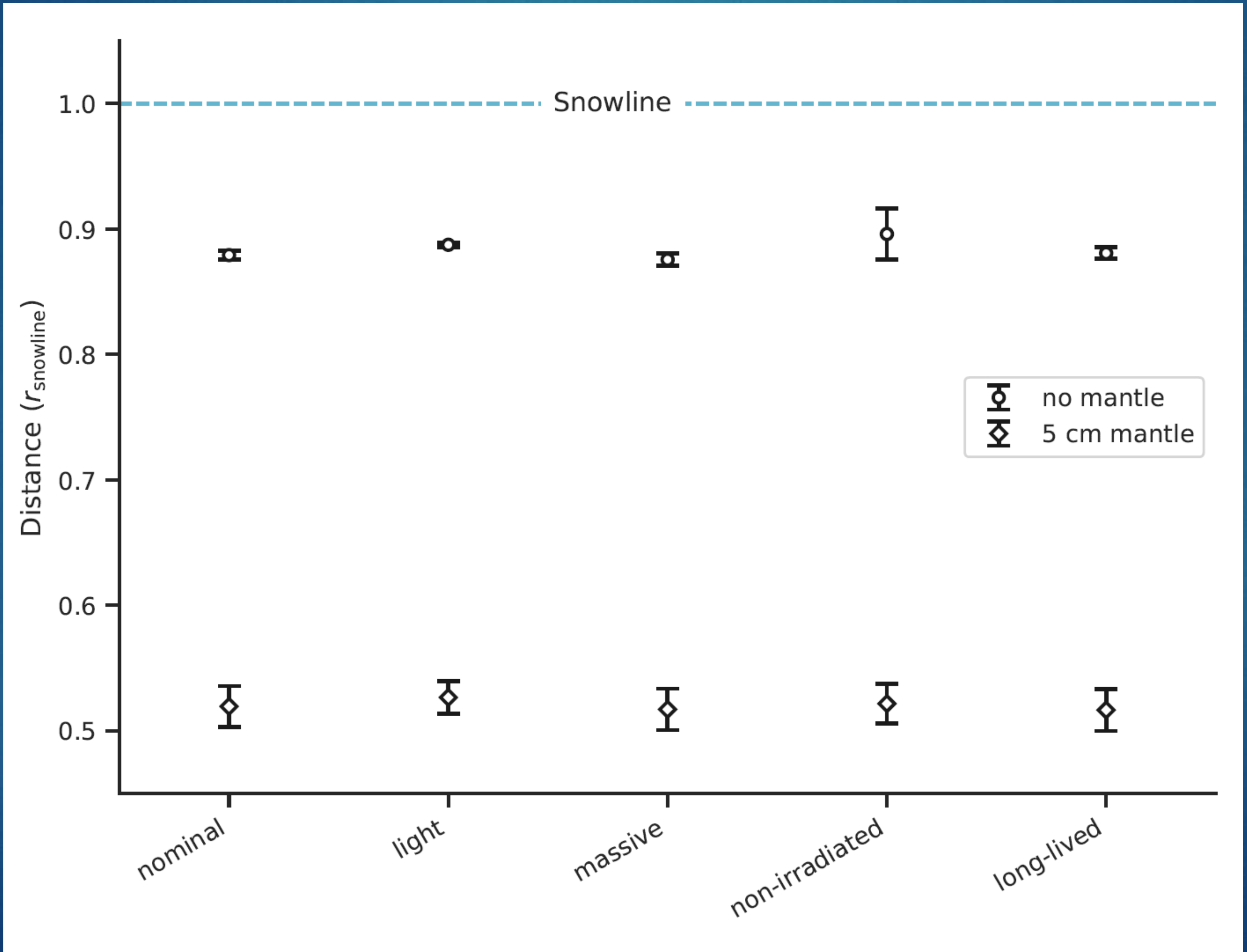
Dust Mantle



no mantle
unstable mantle
0.5cm mantle
5cm mantle
10cm mantle
Snowline (Theory)
Distance (AU)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
Mass fraction
1.0
0.8
0.6
0.4
0.2
0.0
Time (yr)
0
500
1000
1500
2000
2500
3000

Different Disks



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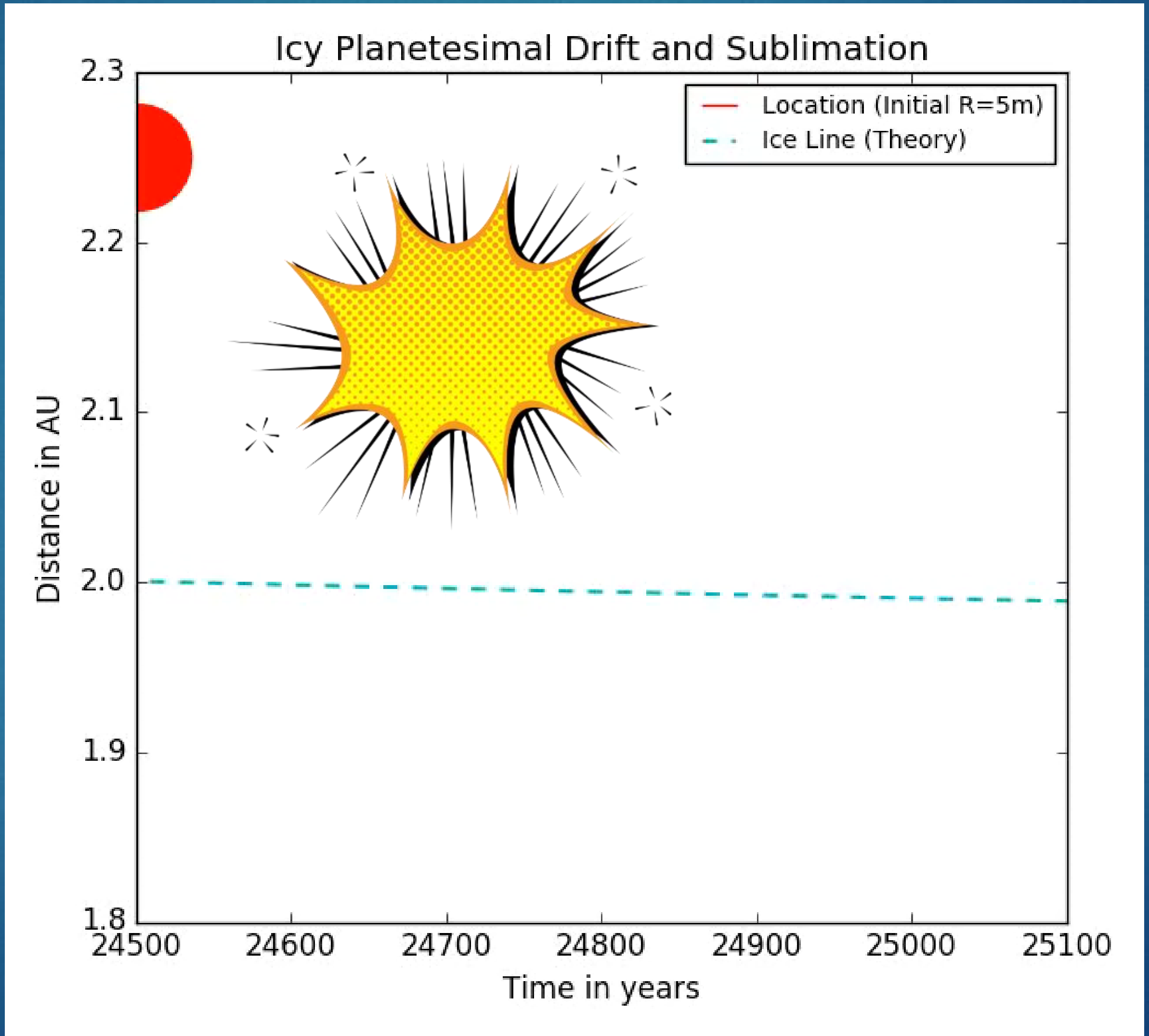
Applicability

Collisions



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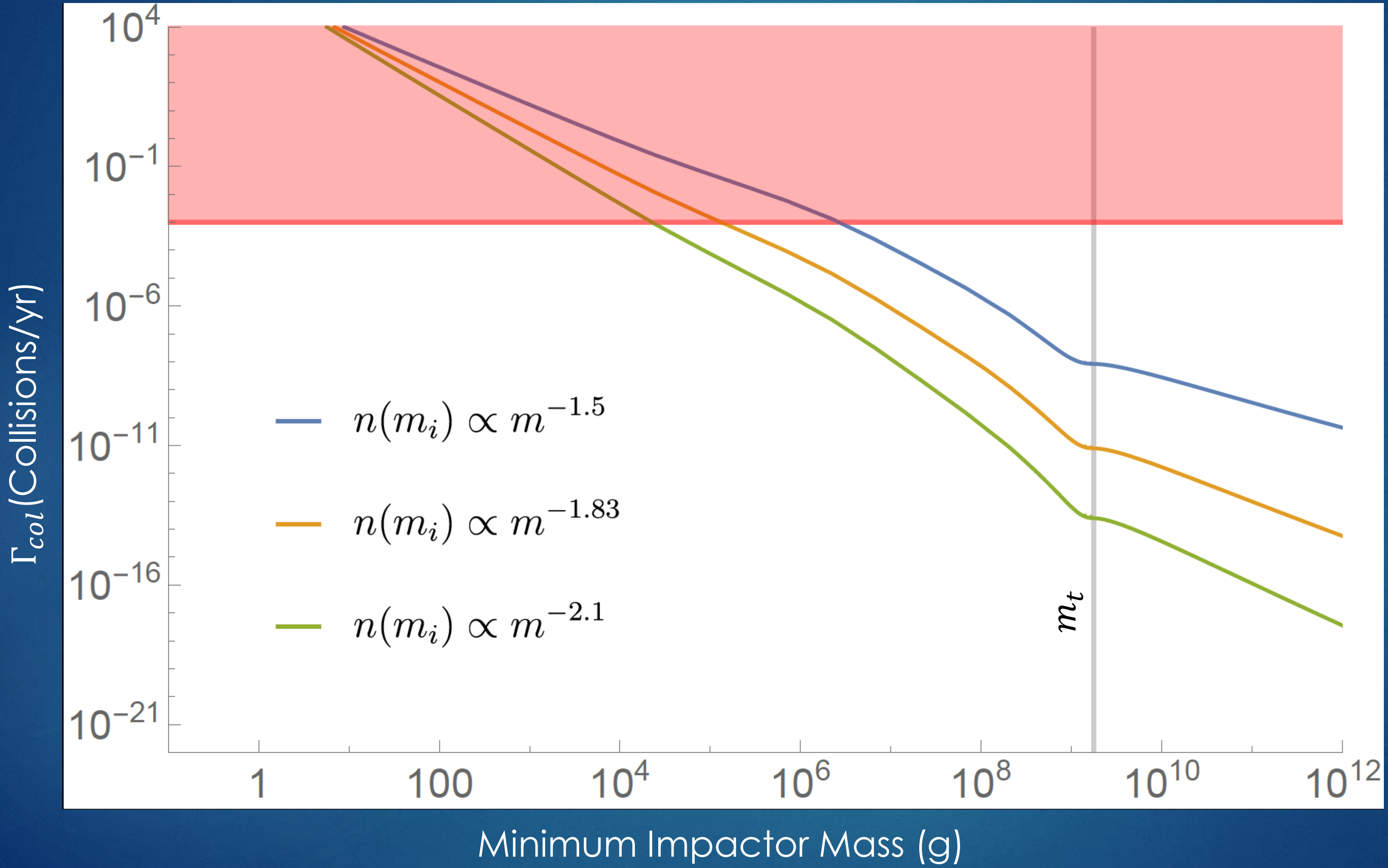
Collision Rate

- «Stokes» collision rate (Safronov 1969)

$$\Gamma_{col} = n_V(m_i)\pi(R_t + R_i)^2\Delta v\left(1 + \frac{v_{esc}^2}{\Delta v^2}\right)$$

  - $v_{esc}^2 = 2G\,\frac{m_t+m_i}{R_t+R_i}$
- Integrate over all masses of impactors m_i
- Dust and larger particles settle to the midplane
  - Balanced by turbulence
- Scale height is suppressed $h_s = h_g\sqrt{\frac{\alpha}{\alpha+s}}$ (Youdin&Lithwick 2007,Fromang&Nelson 2009, Birnstiel 2016)
  - Stop settling at 1% of gas scale height
- Relative velocity Δv depends on radial and azimuthal contributions $\left(\frac{\eta v_k}{1+s^2}\right)$
  - Neglected contributions: Settling speed, Turbulence, Brownian Motion

Collision Rates



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Erosion

- Erosion by collisions with smaller bodies:
  - Total mass erosion rate for a drifting boulder with $r = 10\ \mathrm{m}$
    $$2 - 10 \times 10^{-2}\ \%\ \mathrm{yr}^{-1}$$
  - Timescale of modelled process 100 – 1000 yr

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Conclusions

Conclusion

- Boulders > ca. 10 m reach the same distance to the star (pileup)
- For self-similar size distribution (-1.83) of drifting bodies, the location of 50% water fraction is shifted by 2%
- Water presence limit closer by 15% than the standard one
  - Independent of time and disk initial conditions
- Stable dust mantle has a huge impact on the location
  - 50% closer to the star compared to standard ice line
  - No sublimation from surface layer, need diffusion through surface layer

Outlook

- Take into account pressure of gas disk in a self-consistent way
  - Adding H_2, He to nucleus model
- Eccentric or scattered case
  - Effects for bigger planetesimals
- Additional heating process
  - Heat due to gas drag most significant
- Possible to see signature of this process in the future?
  - Combination with pebble sublimation needed
- CO, CO_2 lines
- Could small boulders keep their size when sublimating (becoming fluffy)?