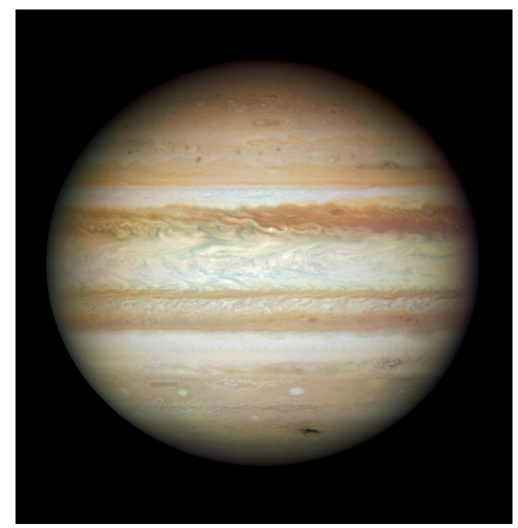
Ice condensation as a planet formation mechanism



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Instabilities and structures in protoplanetary discs, September 19th 2012

Why ice condensation?

- Pebbles to planetesimals: possible by clumping events and gravitational collapse

  Vortices, streaming instability...
  (Barge & Sommeria, 1995; Lyra et al., 2009; Johansen, Oishi et al., 2007)

- Giant planet formation by pebble accretion
  (talk by Michiel Lambrechts)

- ***Need pebbles to start with!***

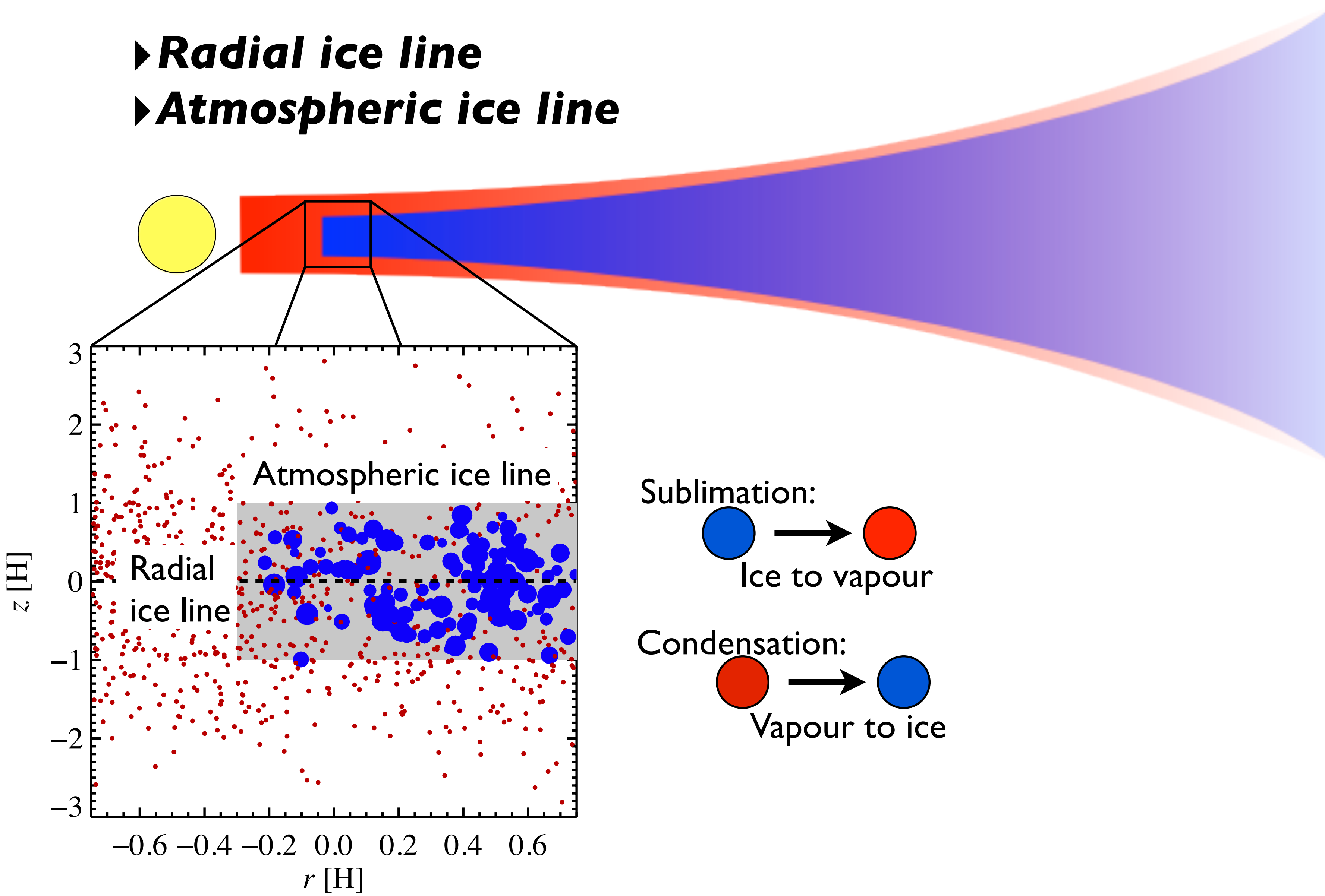
- Coagulation is efficient for up to mm-sized particles
  (Brauer et al., 2008; Blum & Wurm, 2008; Windmark et al., 2012)

- ***Condensation can form cm-dm sized pebbles!***

Overview of model

Inwards temperature gradient
Cold midplane - hot outer layer (Dullemond & Dominik, 2004)

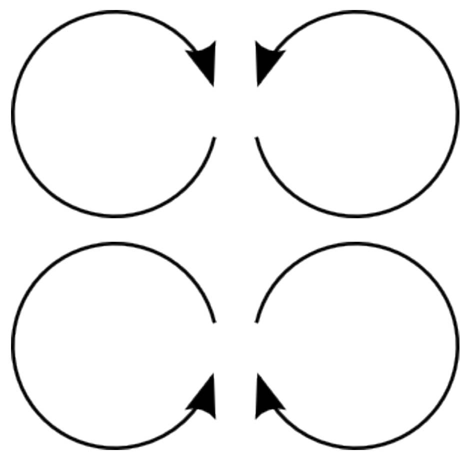
- ***Radial ice line***
- ***Atmospheric ice line***



Model - dynamics

Small particles (<mm)

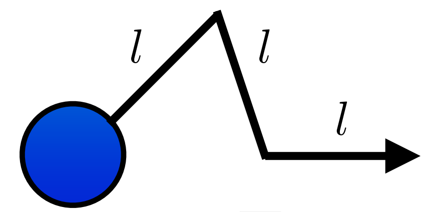
- Turbulent diffusion modelled as a random walk



$$\tau = \frac{l}{v} = \Omega^{-1}$$

$$D \sim v \times l$$

$$D = \sqrt{\alpha} c_s \sqrt{\alpha} H = \alpha c_s H$$



$$l \sim \sqrt{\alpha} H$$

Larger particles (>mm)

- Decoupling from gas - sedimentation towards the midplane
- Move shorter distance each time step

All particles

- Gas density decreases with height above the midplane - particles move shorter distance each time step

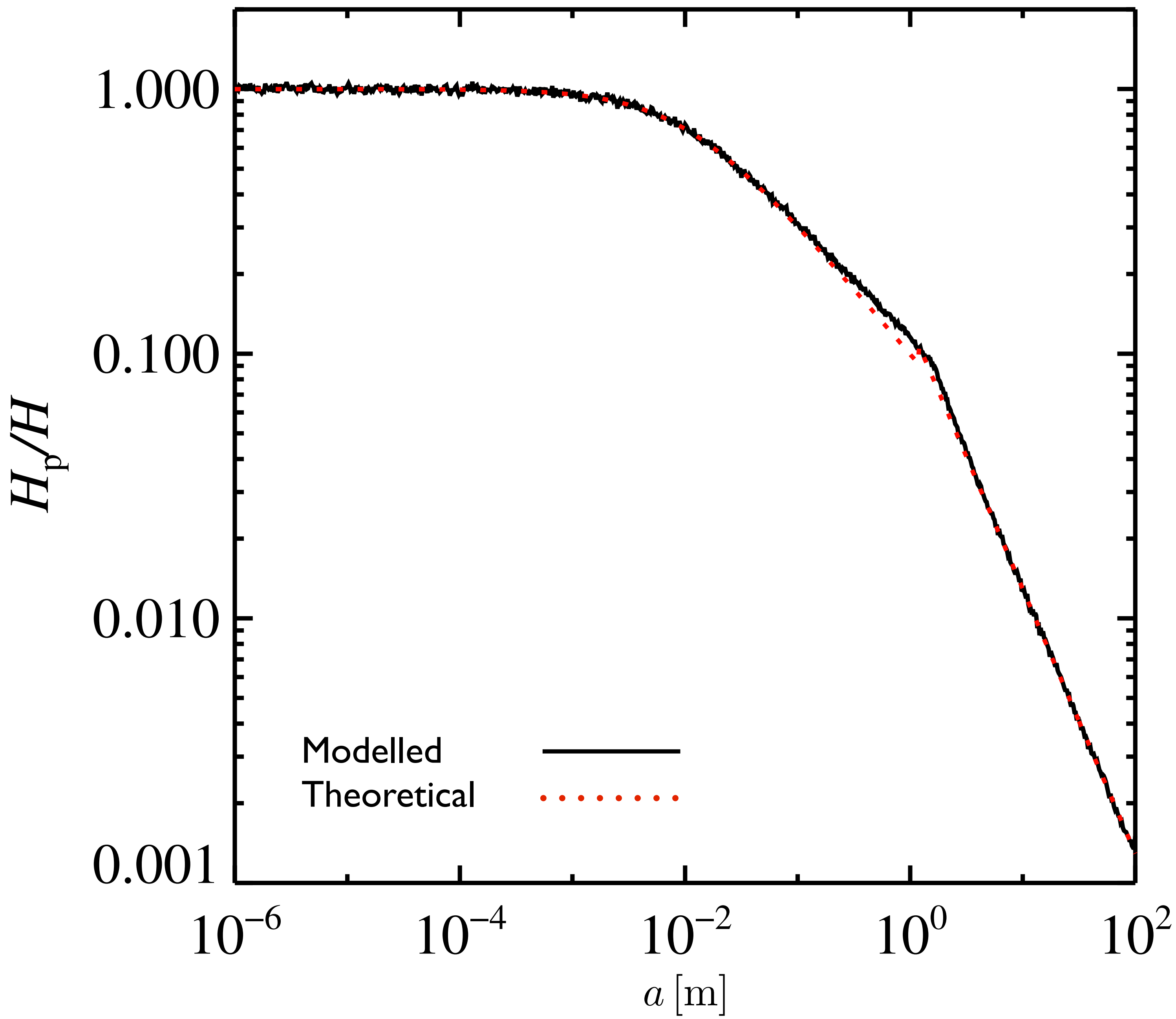
Not yet included:

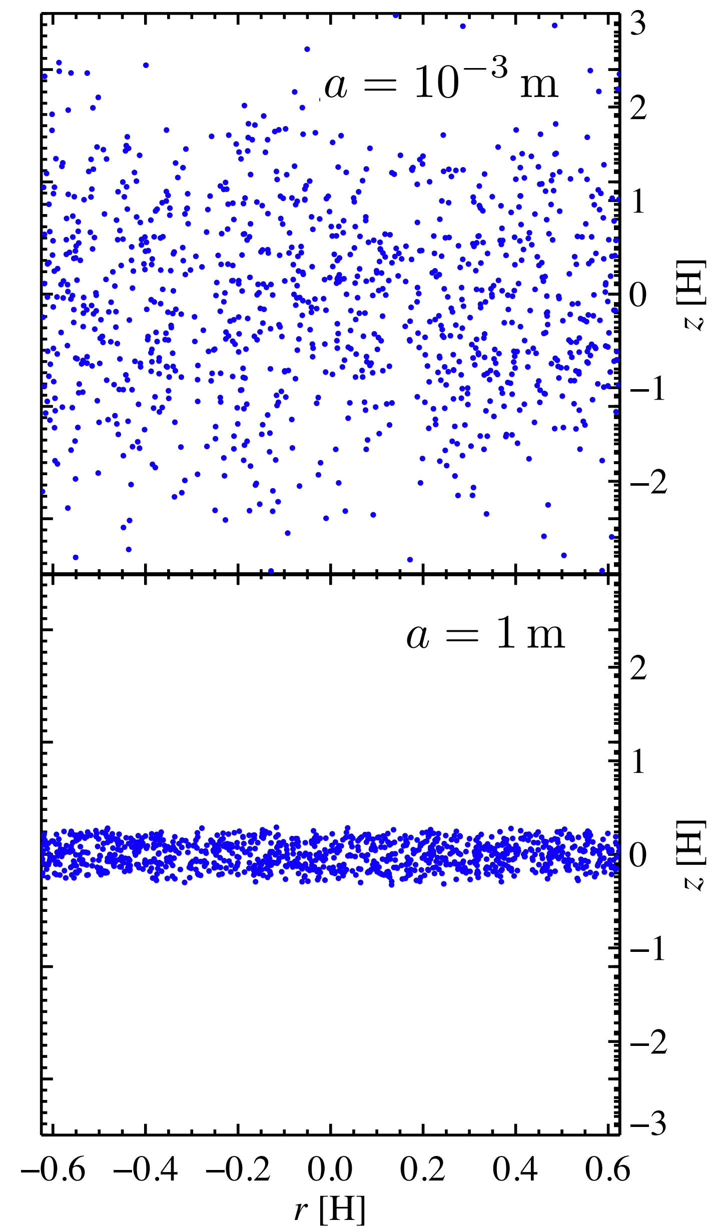
- collisions
- refractory core

Dynamics - test problem

Comparison to sedimentation - diffusion equilibrium

(Carballido et al., 2006, Youdin & Lithwick 2007)





Model - condensation

Condensation time scale

$$\tau_{\rm c} = \frac{R\rho_\bullet}{v_{\rm th}\rho_{\rm v}}$$

Sublimation time scale

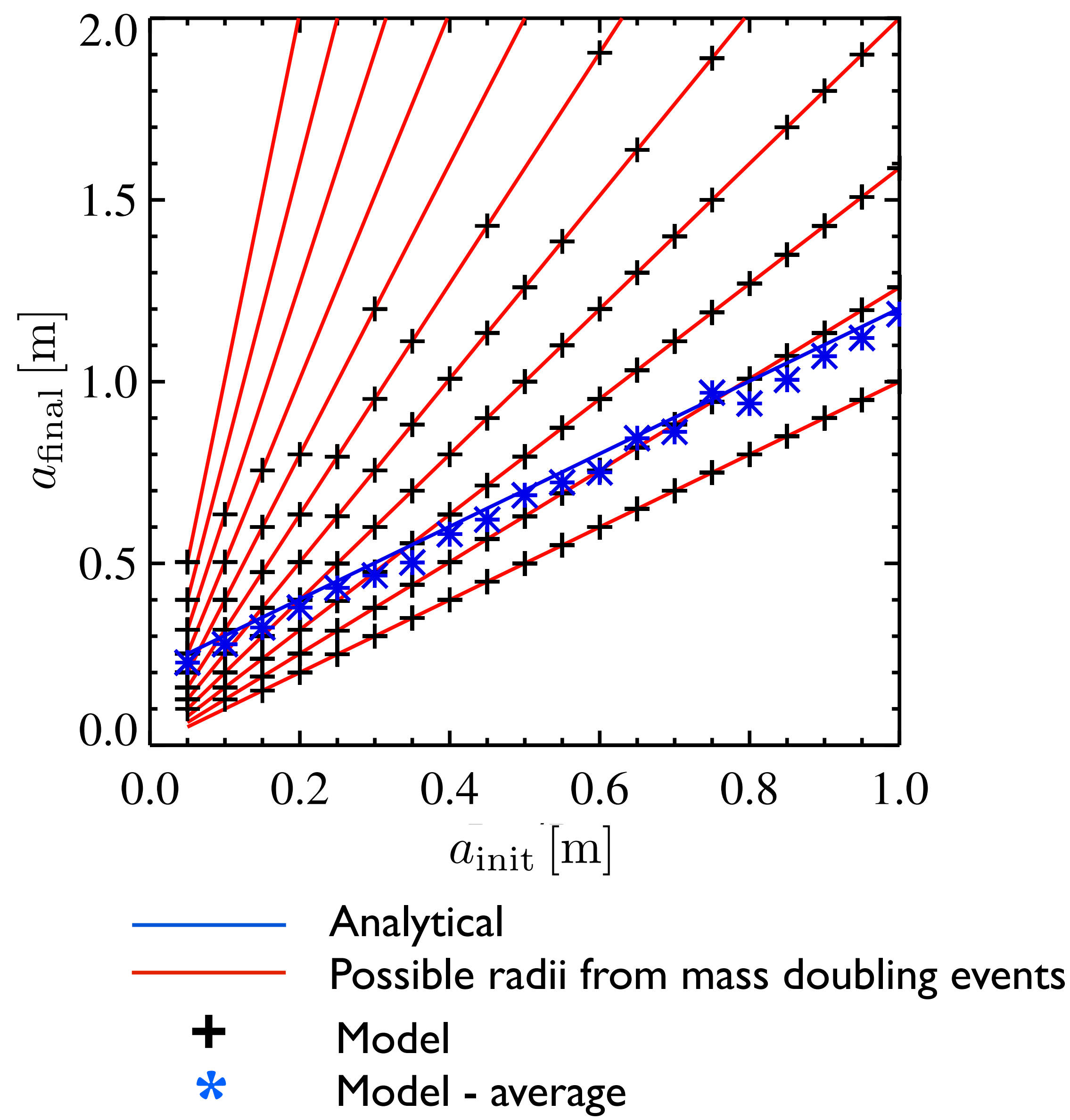
$$\tau_{\rm s} = \frac{R\rho_\bullet}{v_{\rm th}\rho_{\rm sat}}$$

$$\tau_{\rm s} \ll \tau_{\rm c}$$

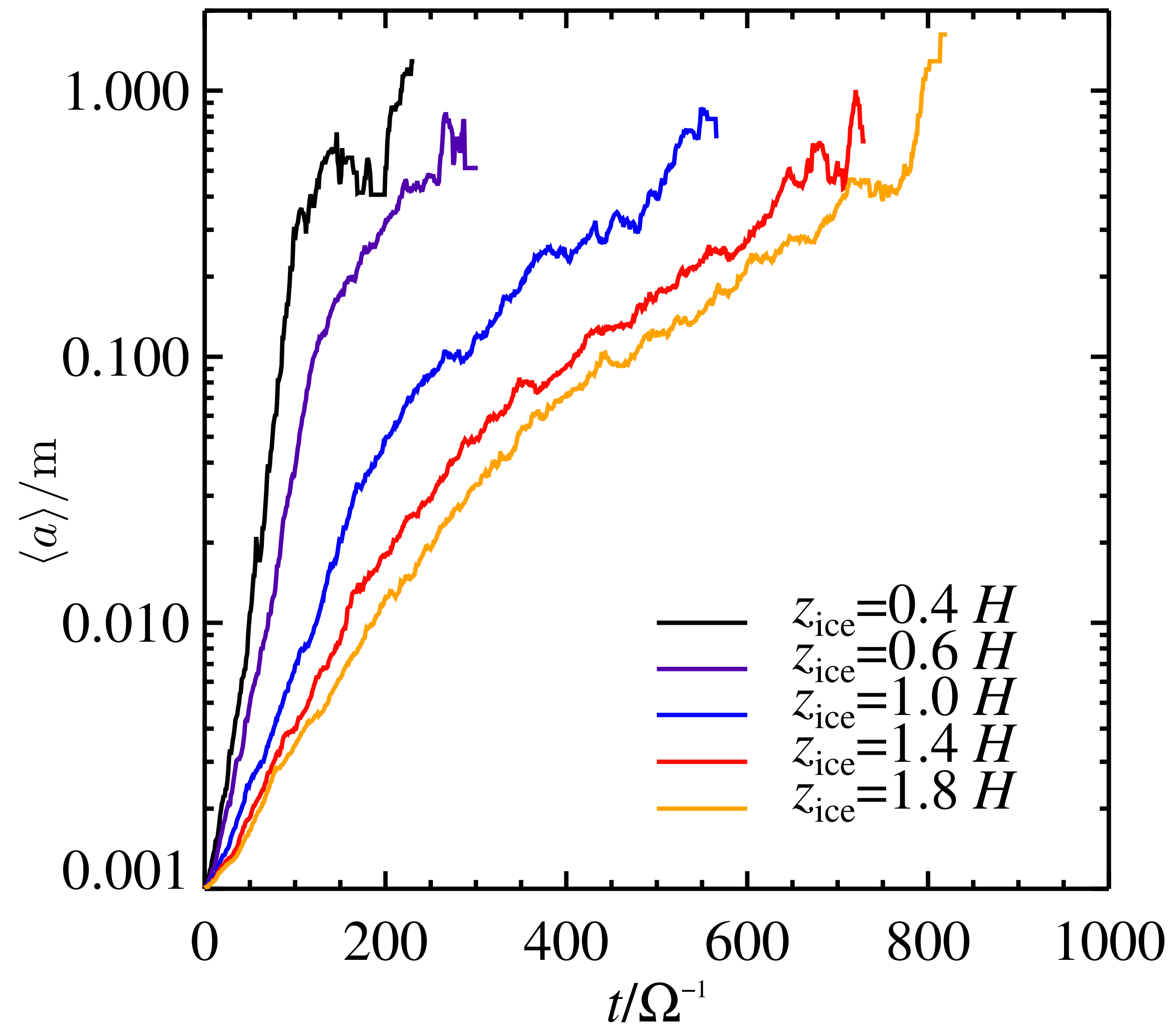
- Sublimation: instantaneous process

- Condensation: Monte Carlo scheme with superparticles (Zsom & Dullemond, 2008)
- condensation probability proportional to surface area

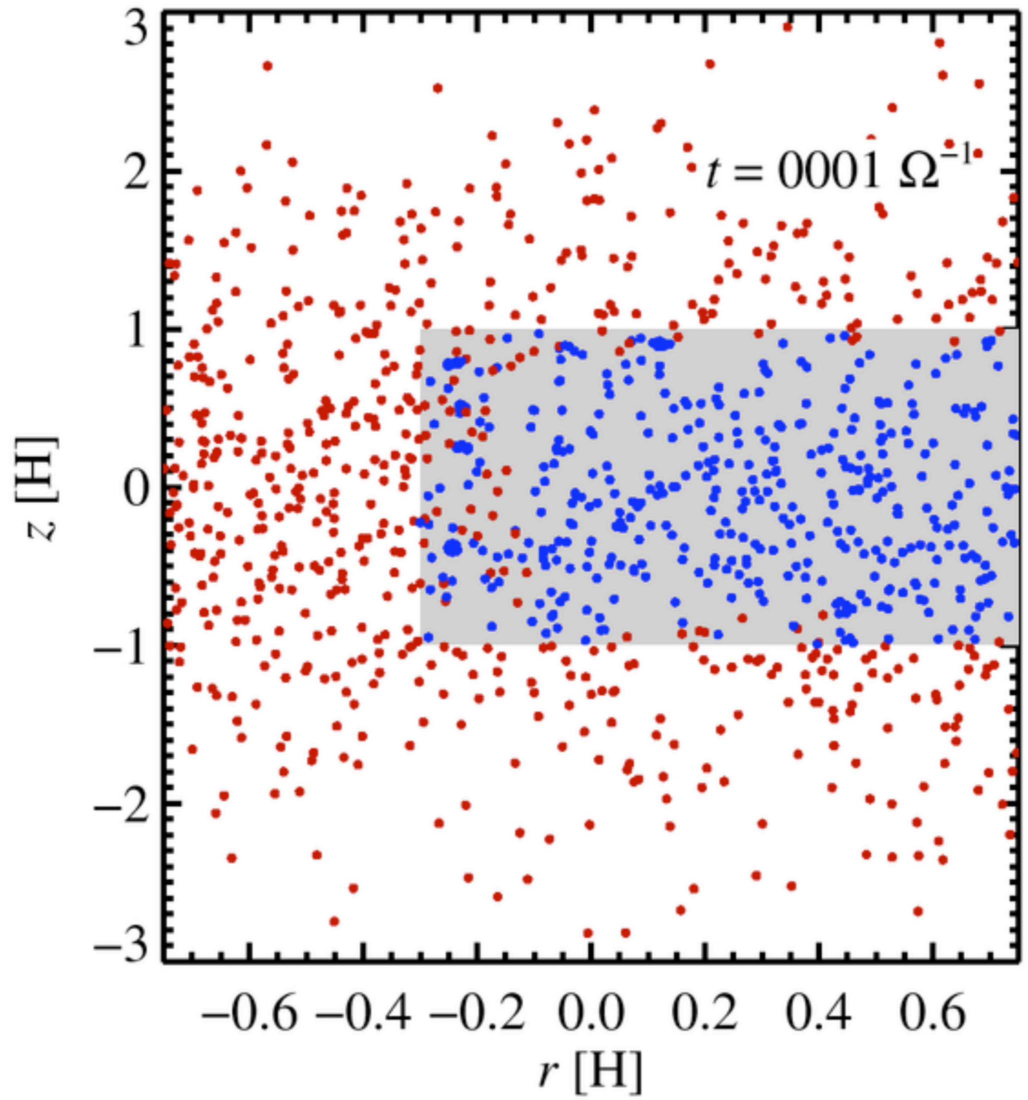
Comparison to expected particle growth

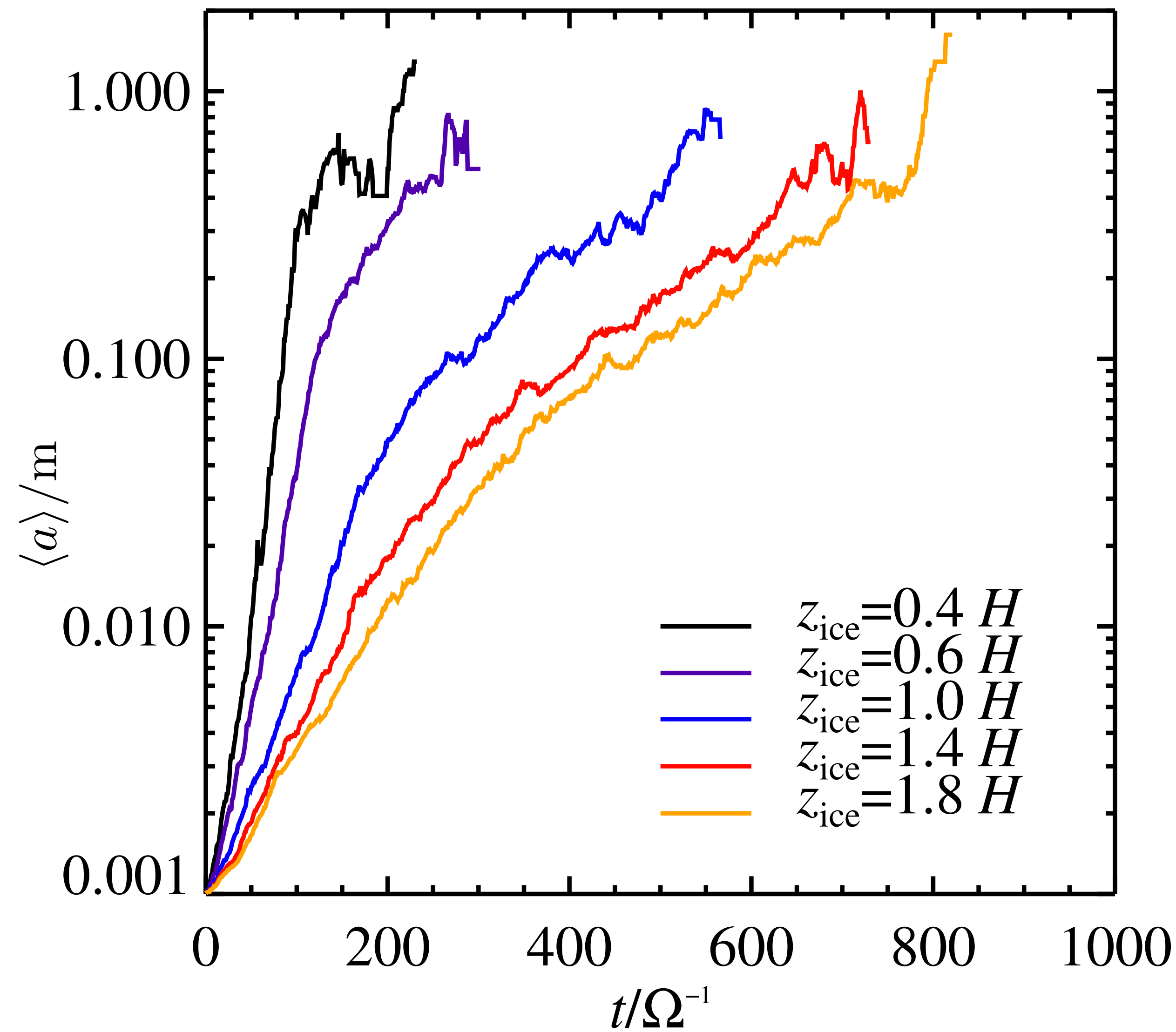


Results - varying the ice line position

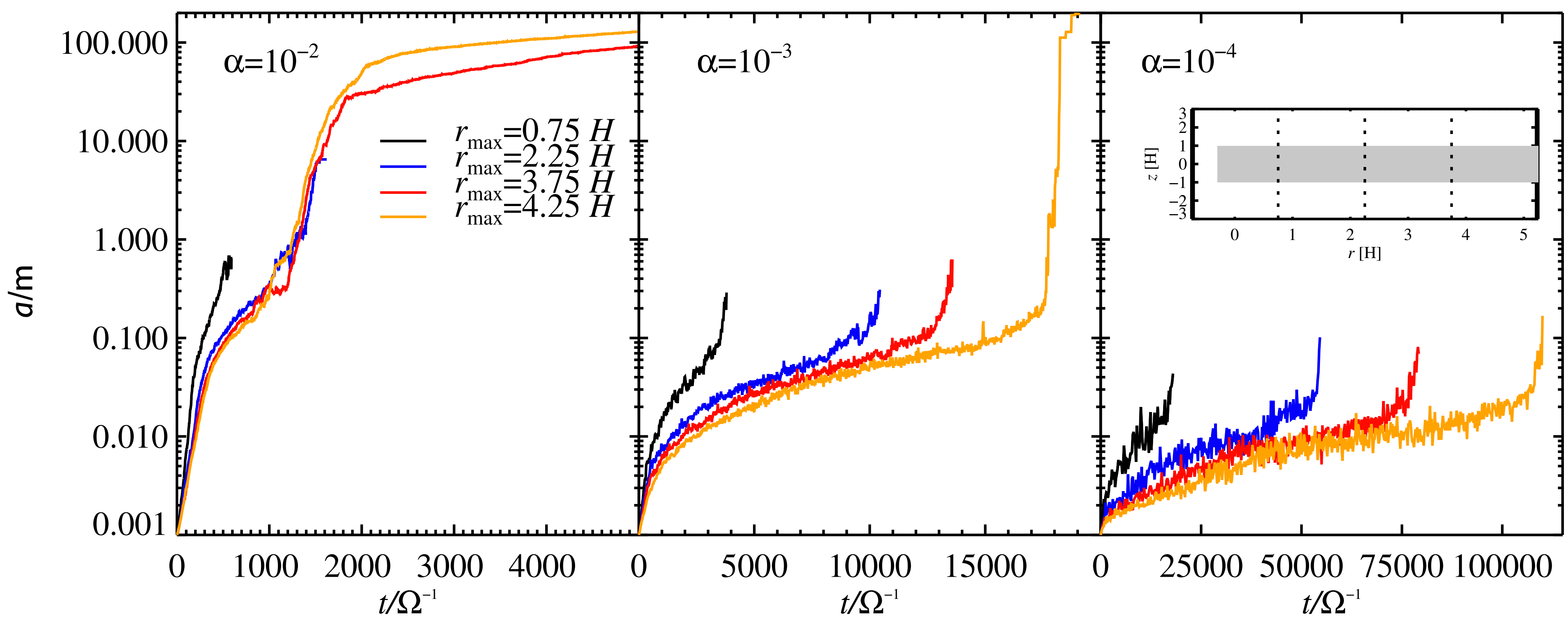


Results - varying the ice line position





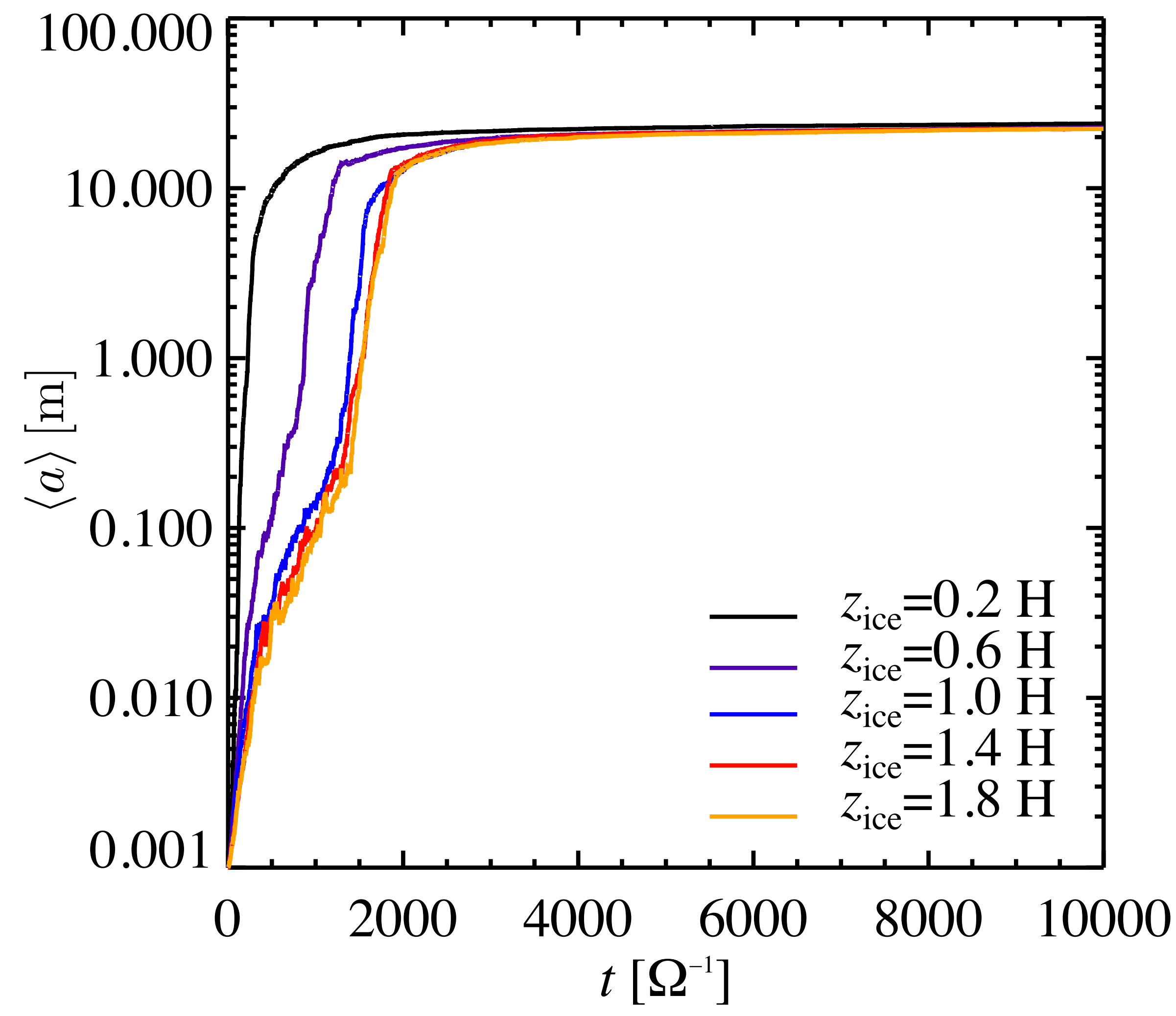
Results - varying the turbulence



- Even weak turbulence leads to particle growth
- Moderately strong turbulence lets particles grow past the meter-barrier

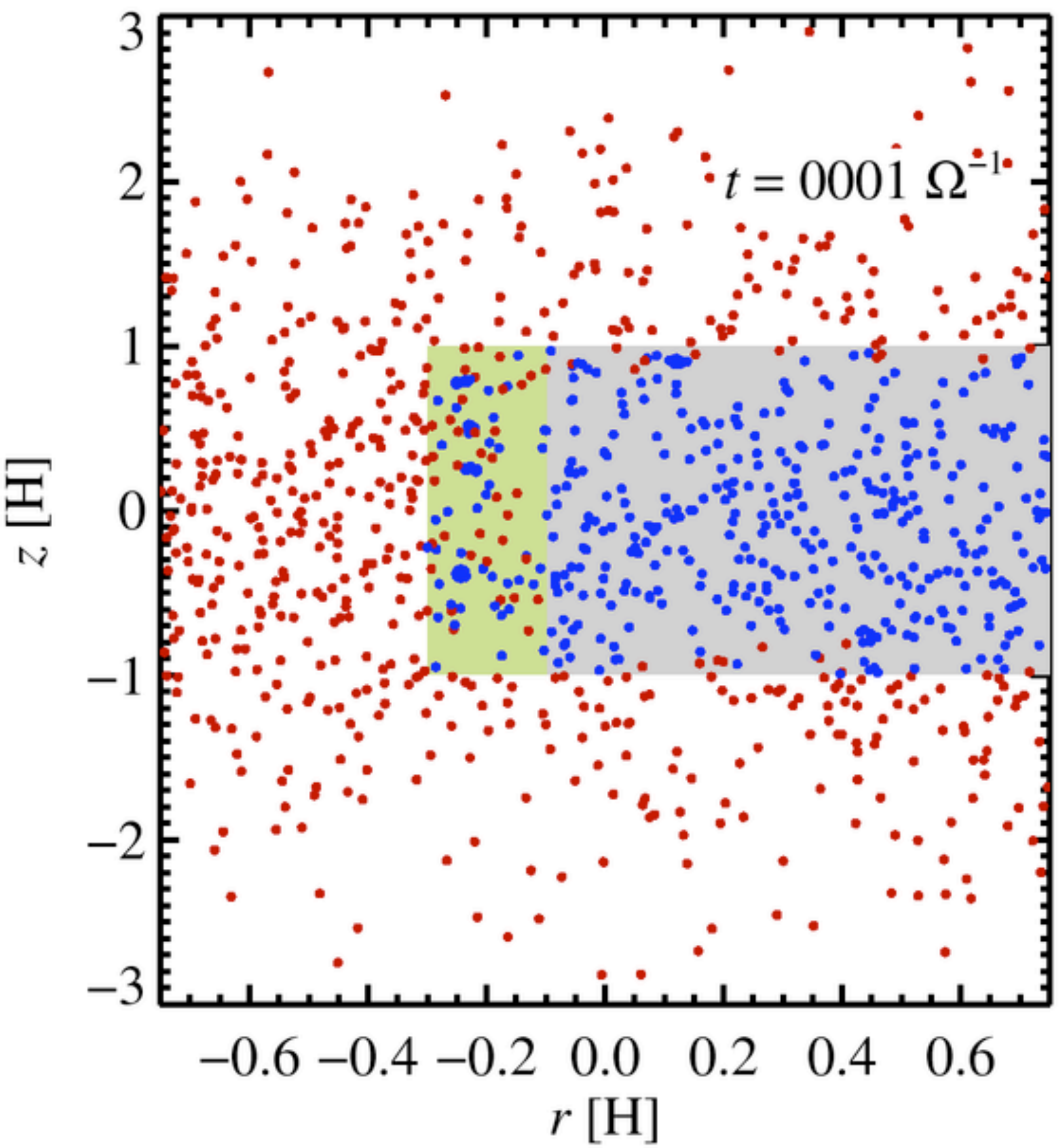
Results - trapping in pressure bump

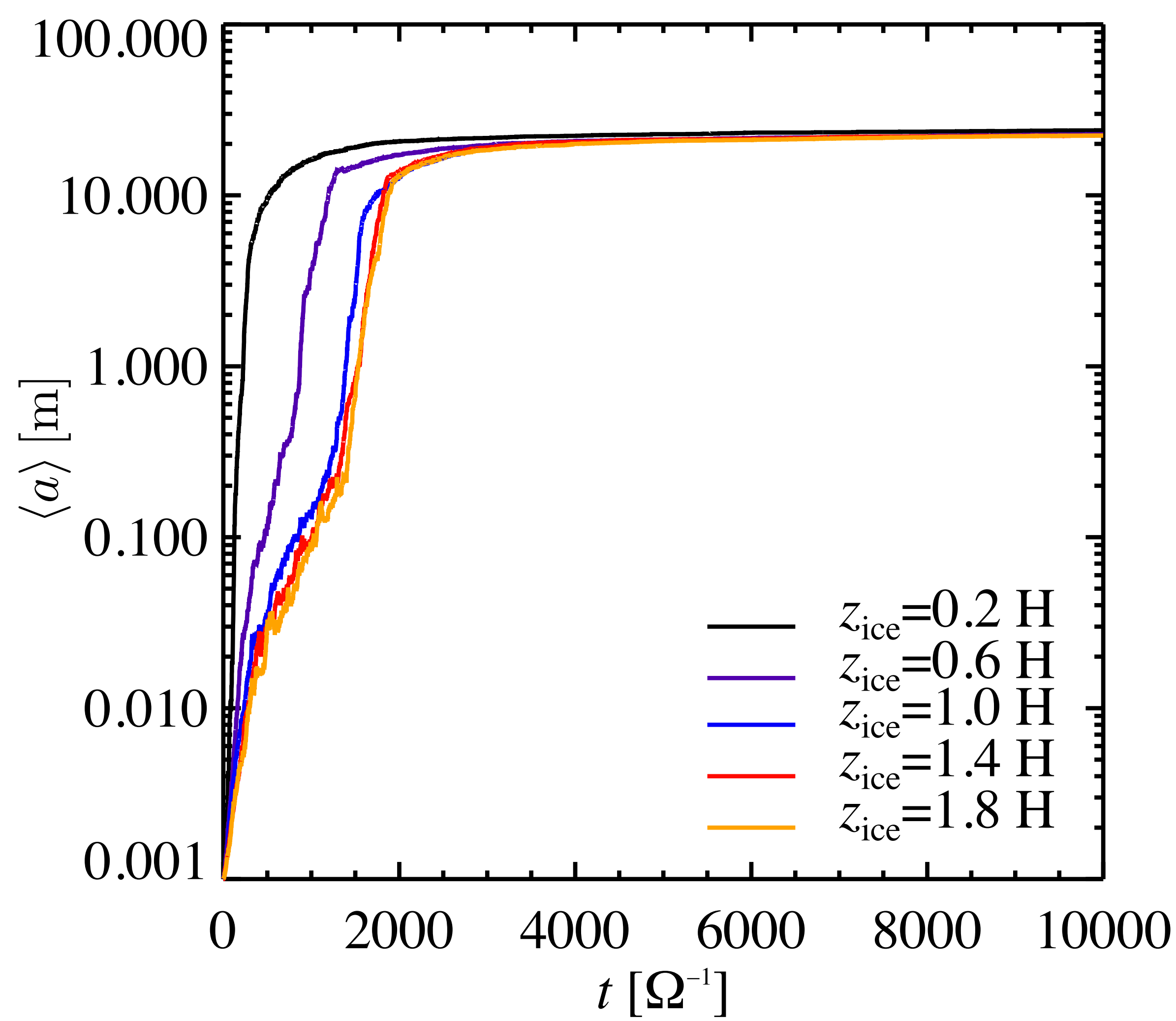
Pressure bump outside of the ice line (Kretke & Lin 2007)



Results - trapping in pressure bump

Pressure bump outside of the ice line (Kretke & Lin 2007)





Conclusions

- Growth from dust (mm) to large pebbles (cm - dm)
- Time scale ~ 1000 years
- Growth stopped by sedimentation towards the midplane, radial drift and/or decoupling from turbulent gas
- Growth past the meter-barrier is possible with pressure bump or moderately strong turbulence
- Particles grow large enough to facilitate further growth into planetesimals via clumping and gravitational collapse