3D simulations of planetesimal formation in vortices

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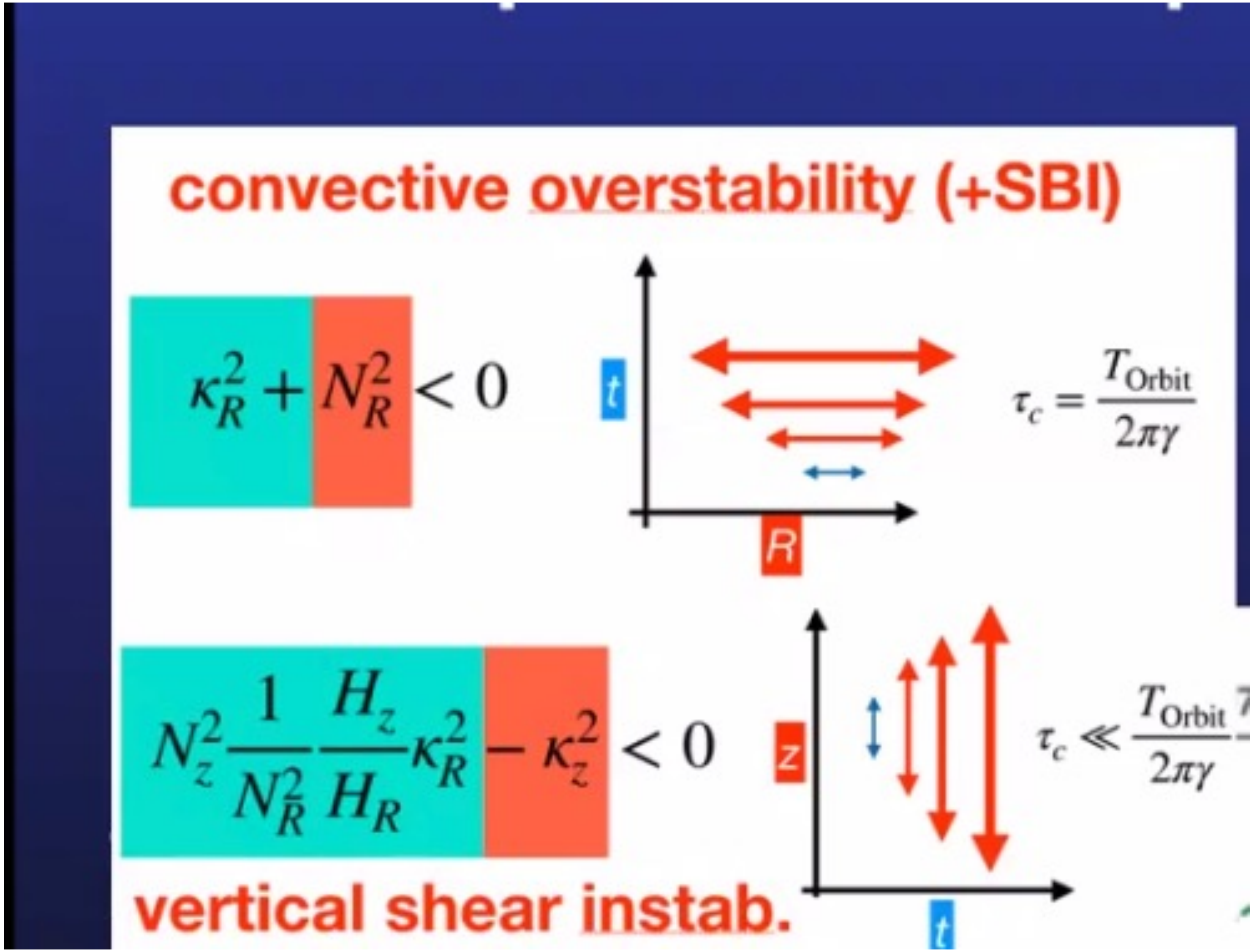
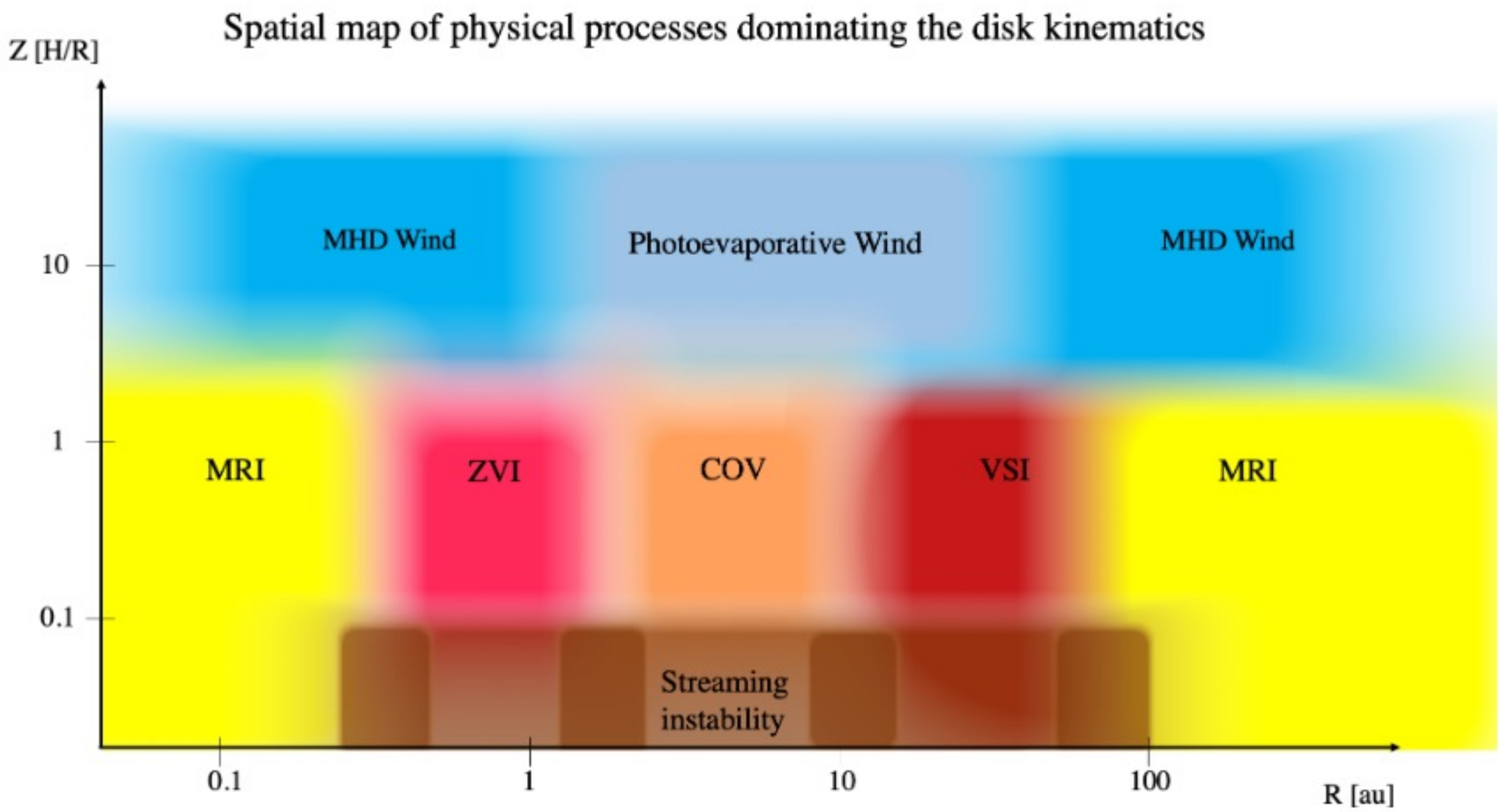
From Hubert's talk



Instability Map

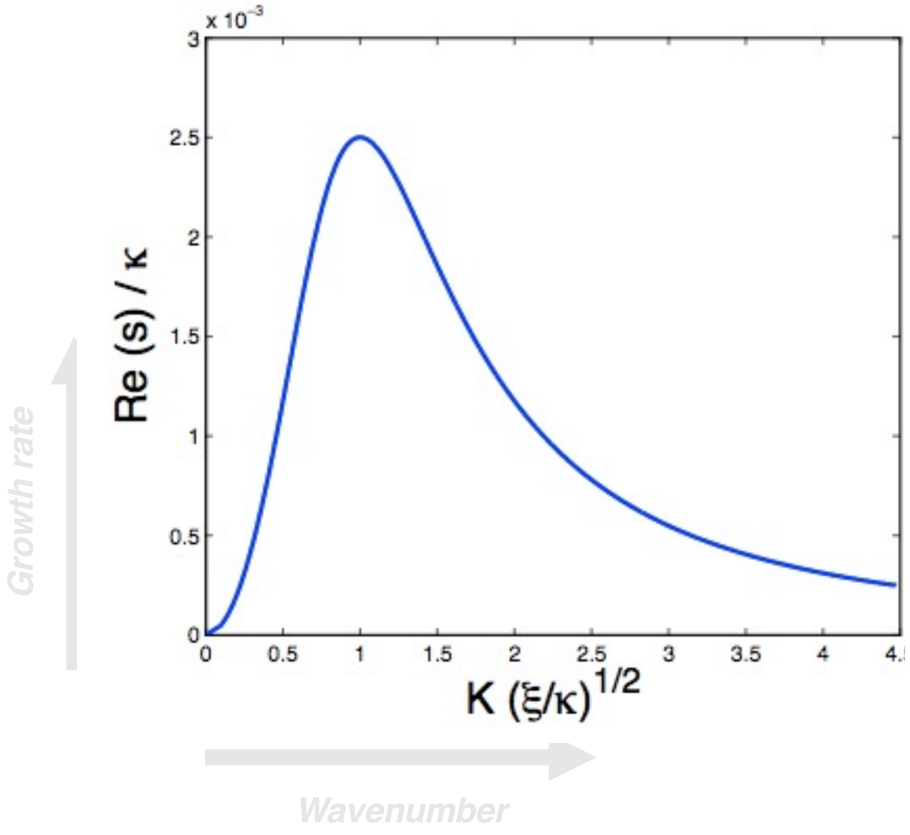


Lesur et al. (2021)

Convective Overstability

Cooling renders the 2nd Solberg-Hoiland criterion irrelevant

$$\kappa_{eq}^2 + N_R^2 > 0,$$



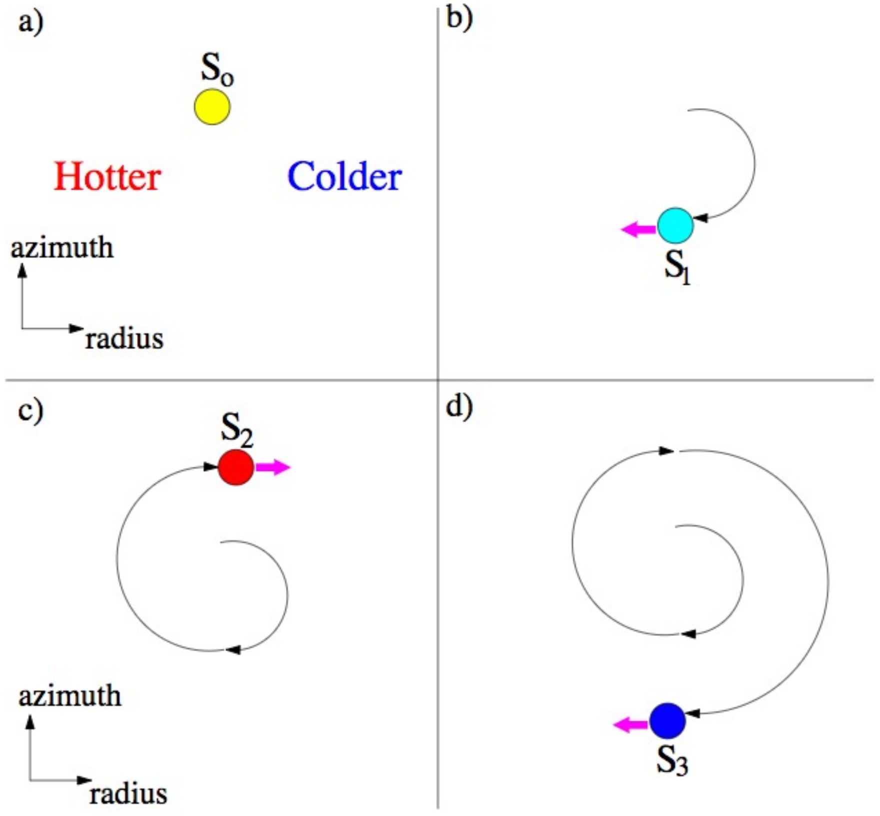
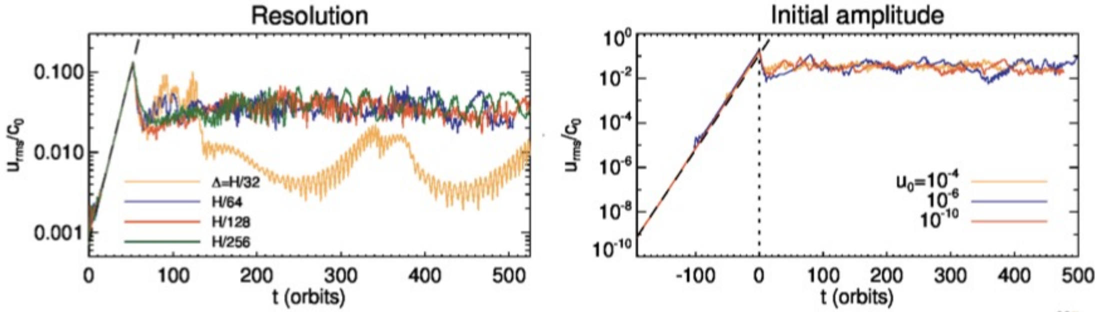


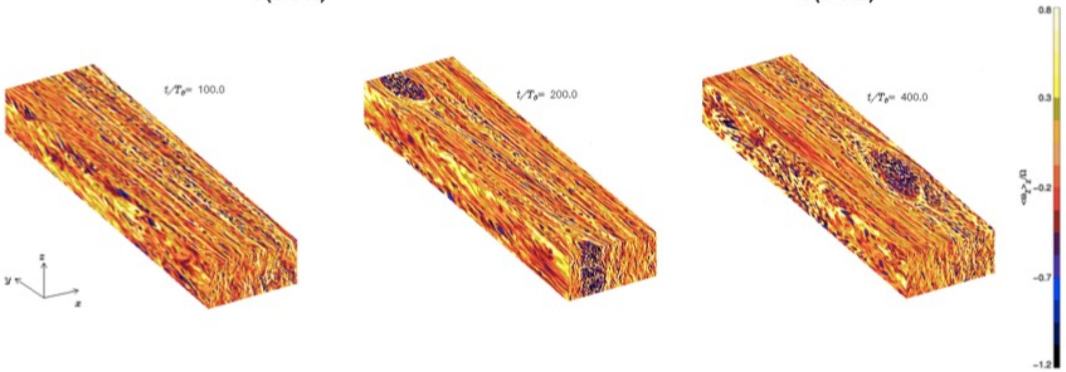
Figure 2. Four panels indicating the convective overstability mechanism. In panel (a) a fluid blob is embedded in a radial entropy gradient. In panel (b) it undergoes half an epicycle and returns to its original radius with a smaller entropy than when it begun $S_1 < S_0$. It hence feels a buoyancy acceleration inwards and the epicycle is amplified. The process occurs in reverse once the epicycle is complete, shown in panel (c), where now $S_2 > S_0$. The oscillations hence grow larger and larger.

Latter (2016), Teed & Latter (2021)

Convective Overstability

Klahr & Hubbard (2014), Lyra (2014), Latter (2016)





$$\tau_{\max} = \frac{1}{\gamma\Omega};$$

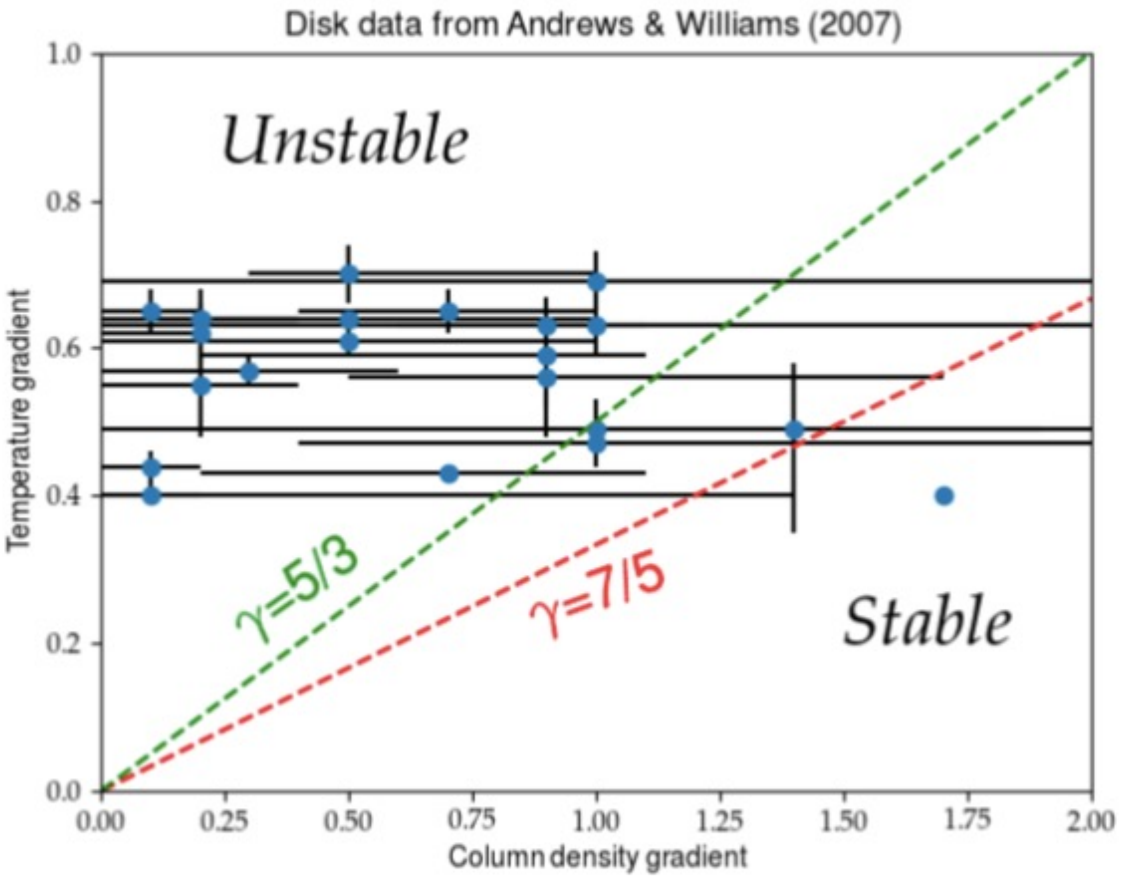
Cooling time
of maximum growth

$$\sigma_{\max} = -\frac{N^2}{4\Omega}.$$

Growth rate

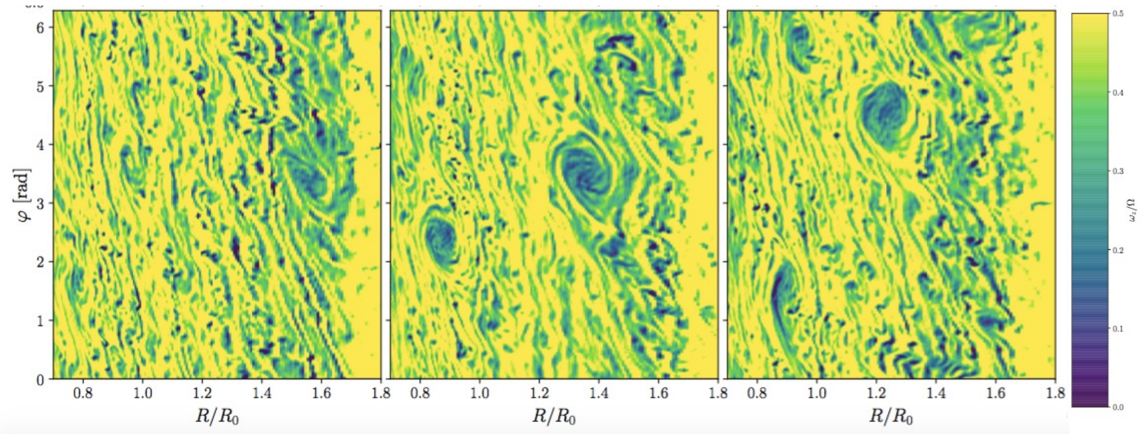
Lyra (2014)

Prevalence of Convective Overstability in actual disks



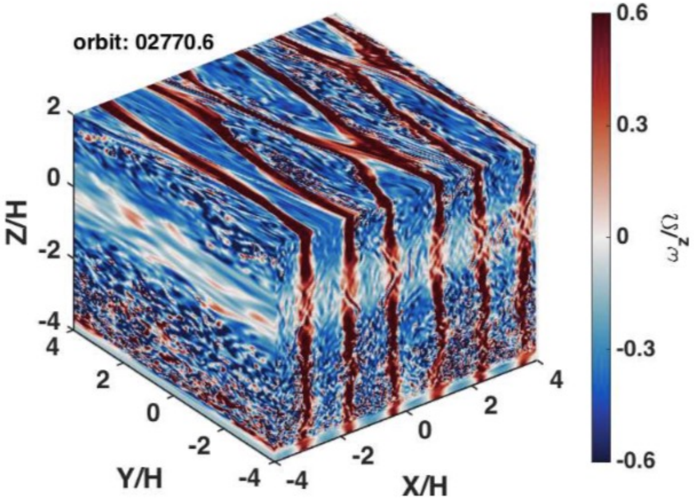
Lyra & Umurhan (2019)

Saturation – vortices and α between 10^{-4} and 10^{-3}



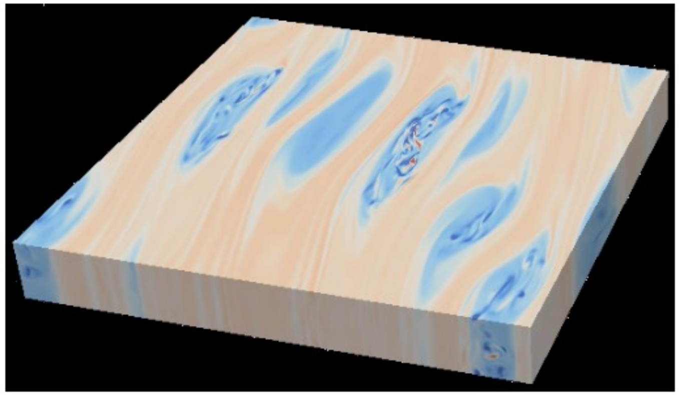
Manger & Klahr (2018)

VSI saturates into vortices



Barranco et al. (2019)

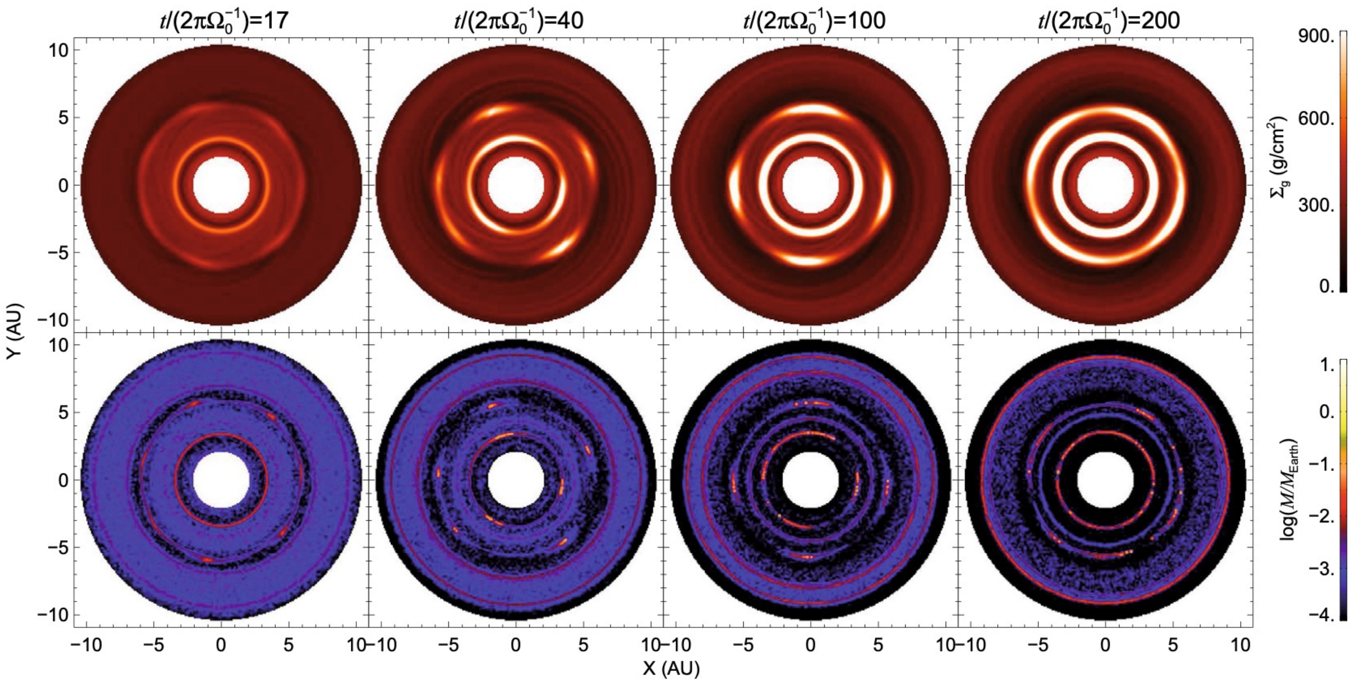
ZVI saturates into vortices

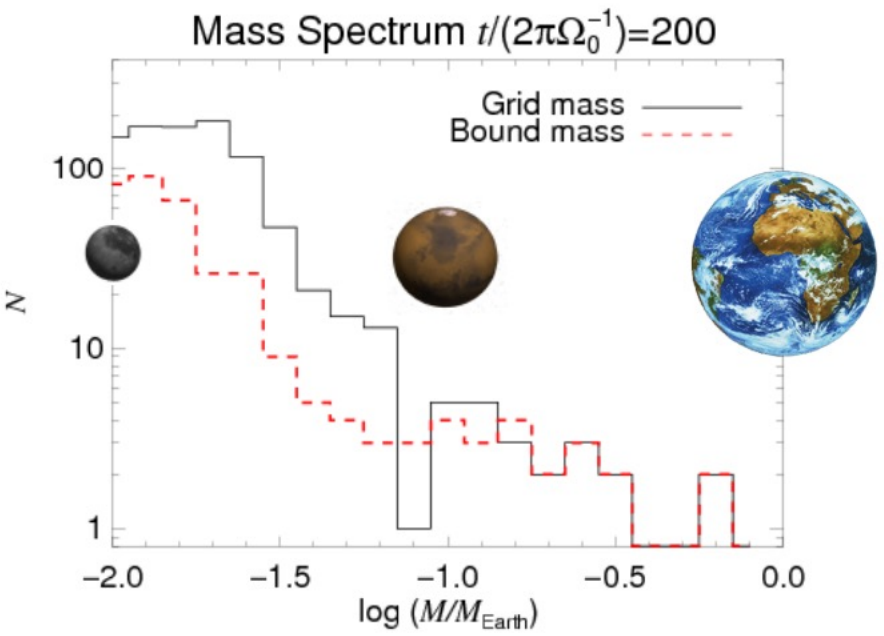


Lesur & Papaloizou (2010)

COV saturates into vortices

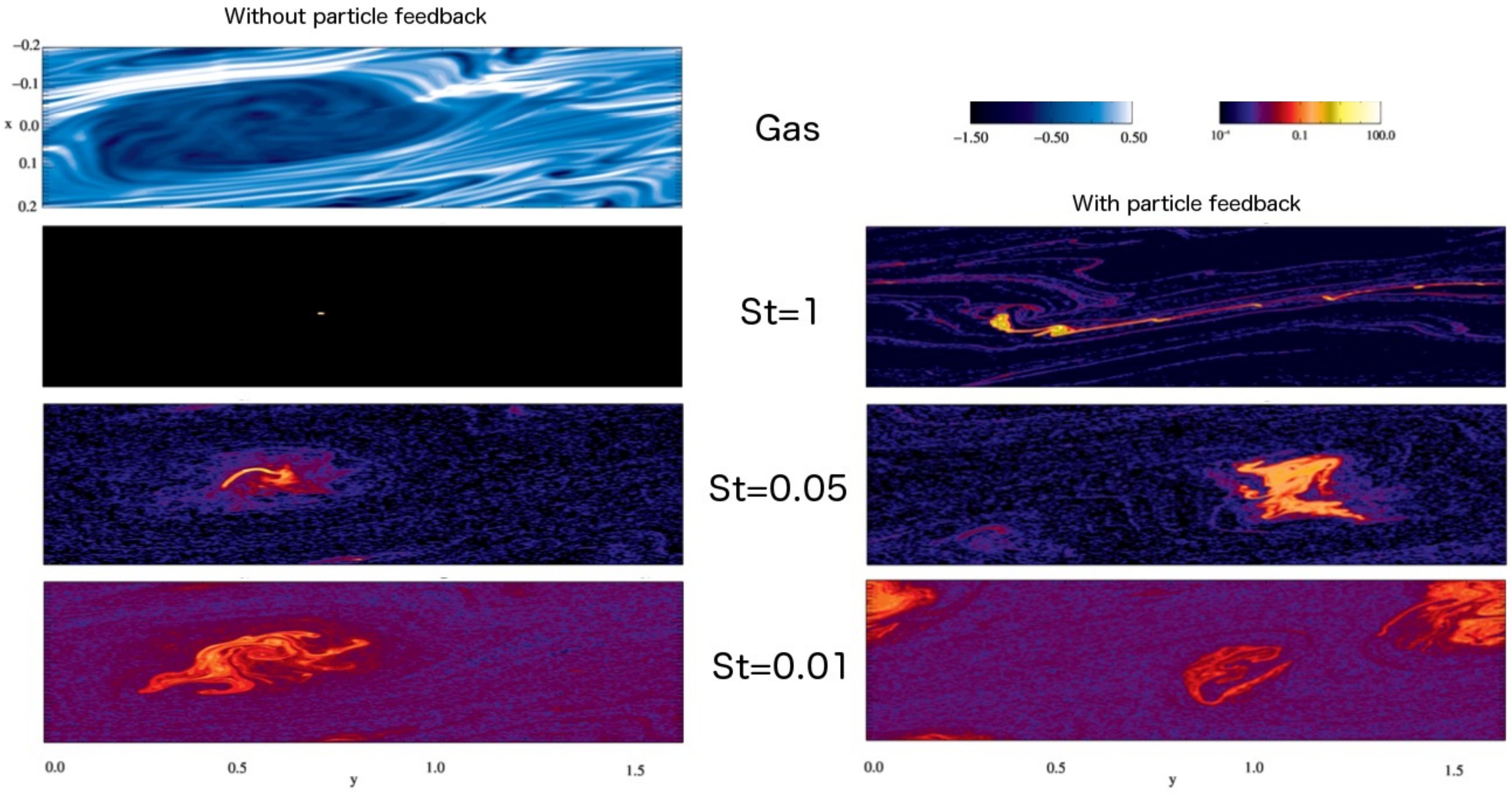
Vortices and Planet Formation





Lyra et al. (2008)

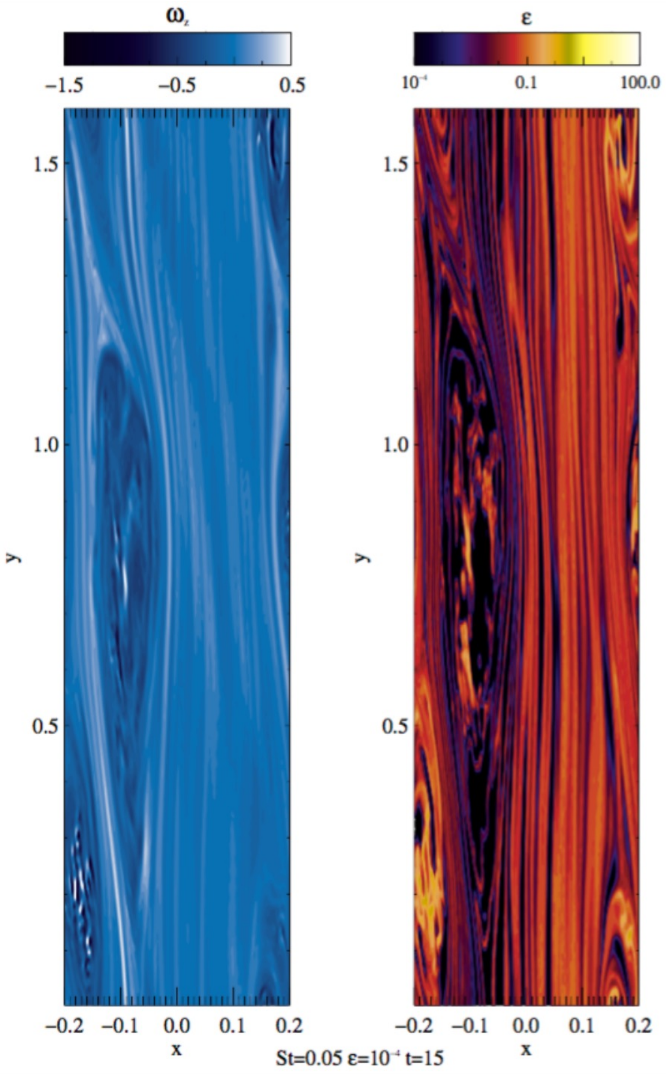
Pebble trapping in vortices in LOCAL models



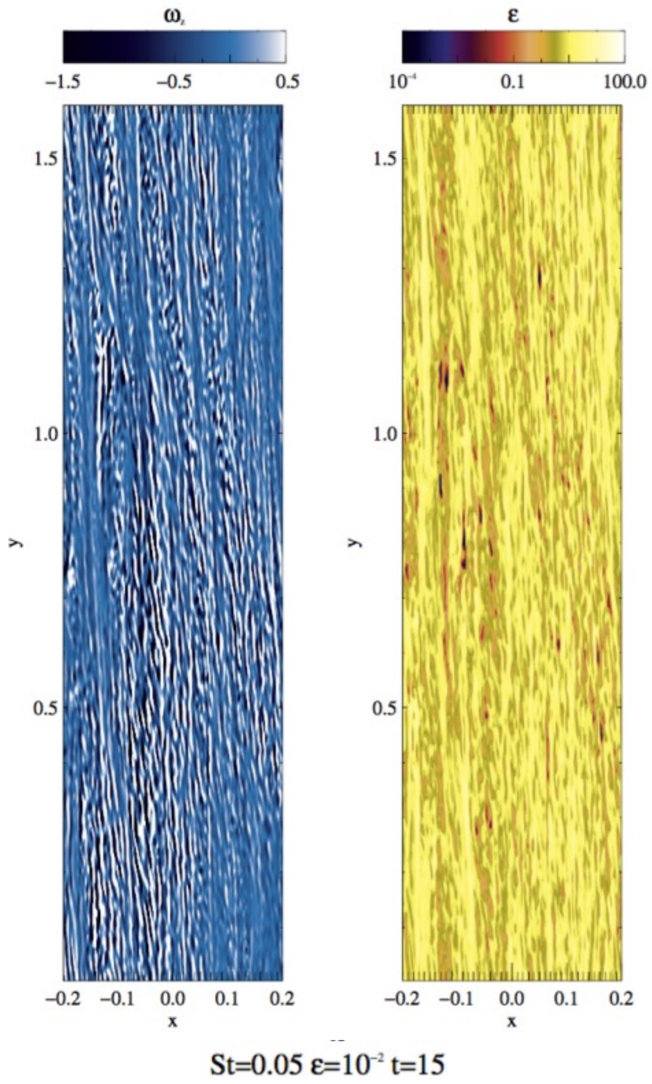
Raettig et al (2015)

Vortex destruction at high dust load?

Dust to gas ratio 10^{-4}

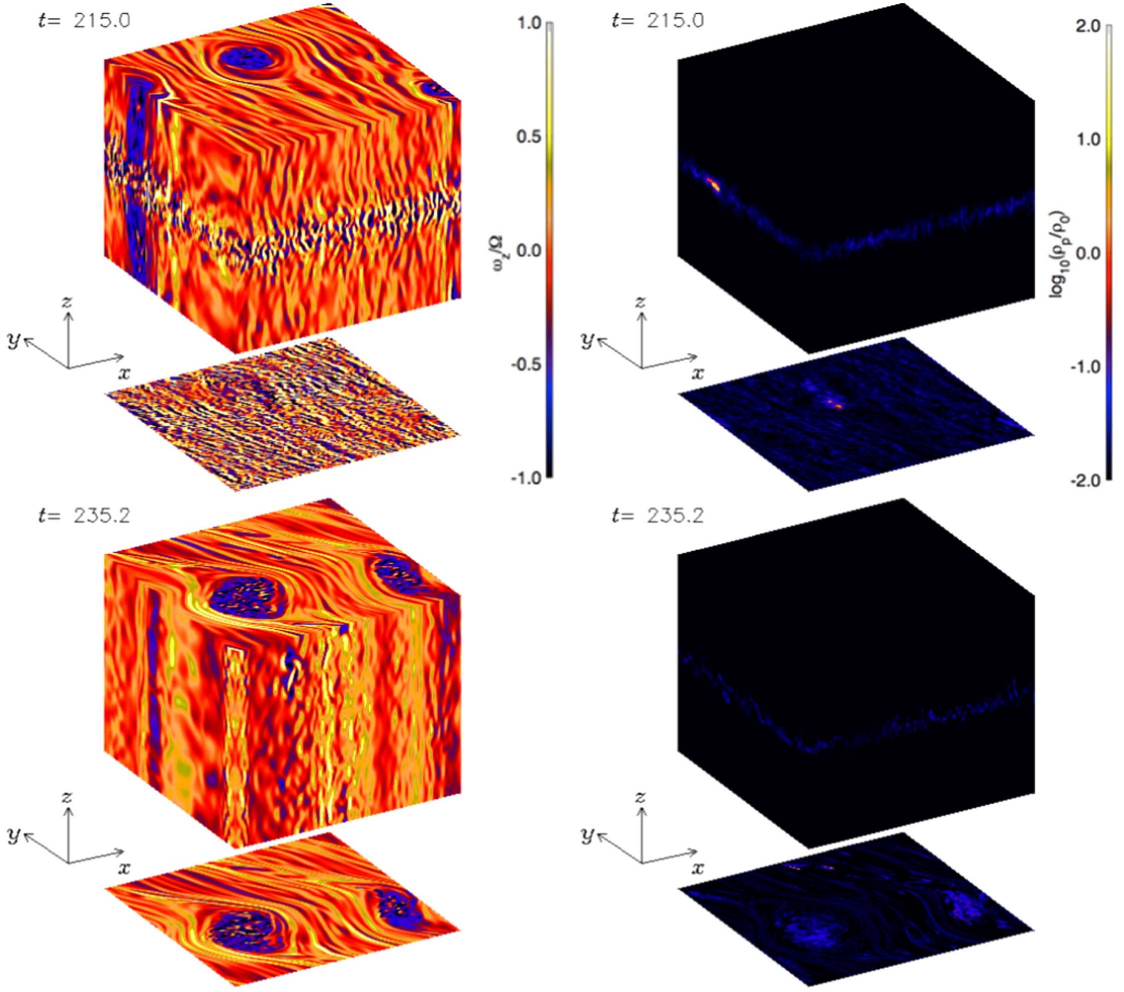


Dust to gas ratio 10^{-2}



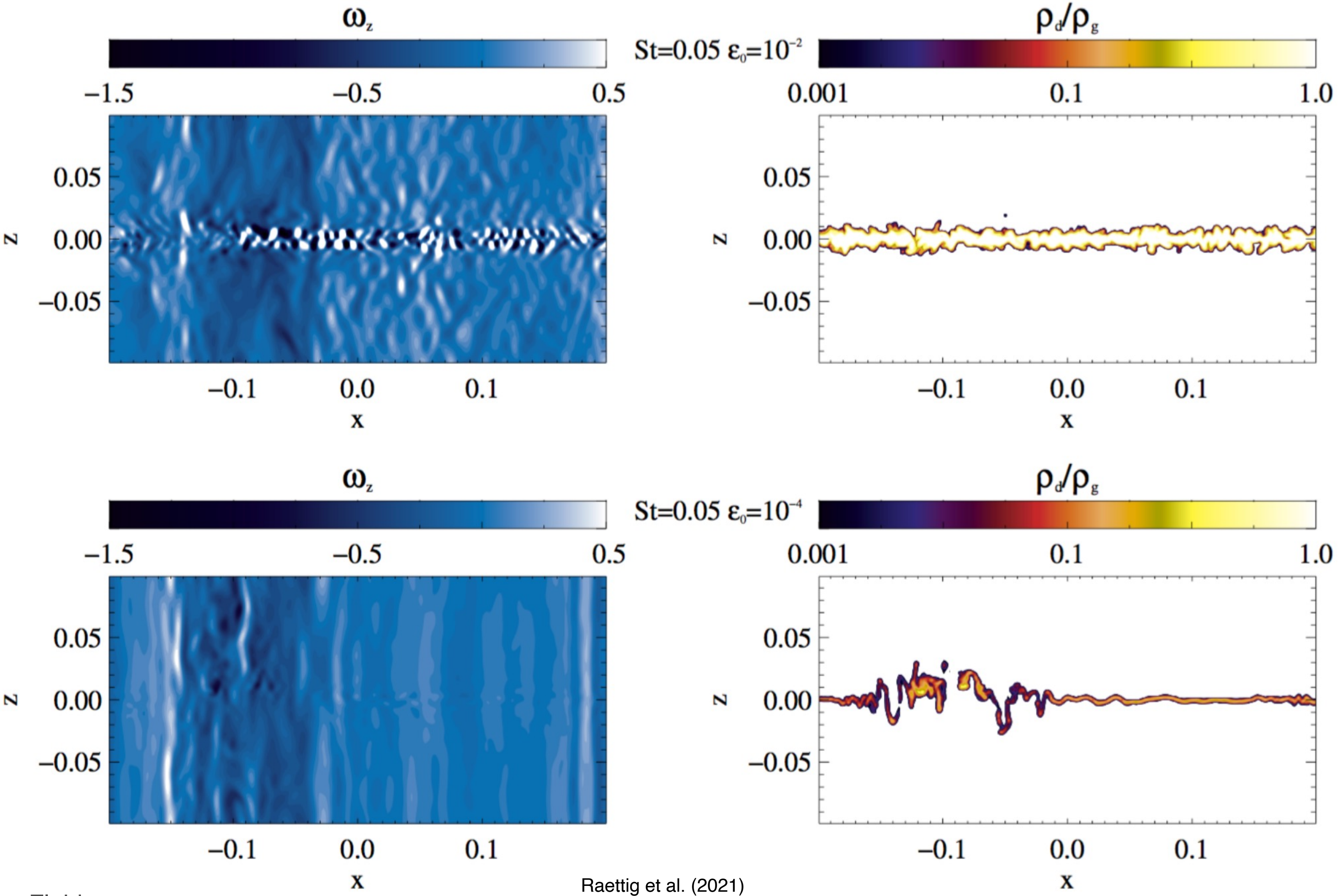
Raettig et al (2015)

Pebble trapping does not destroy vortices



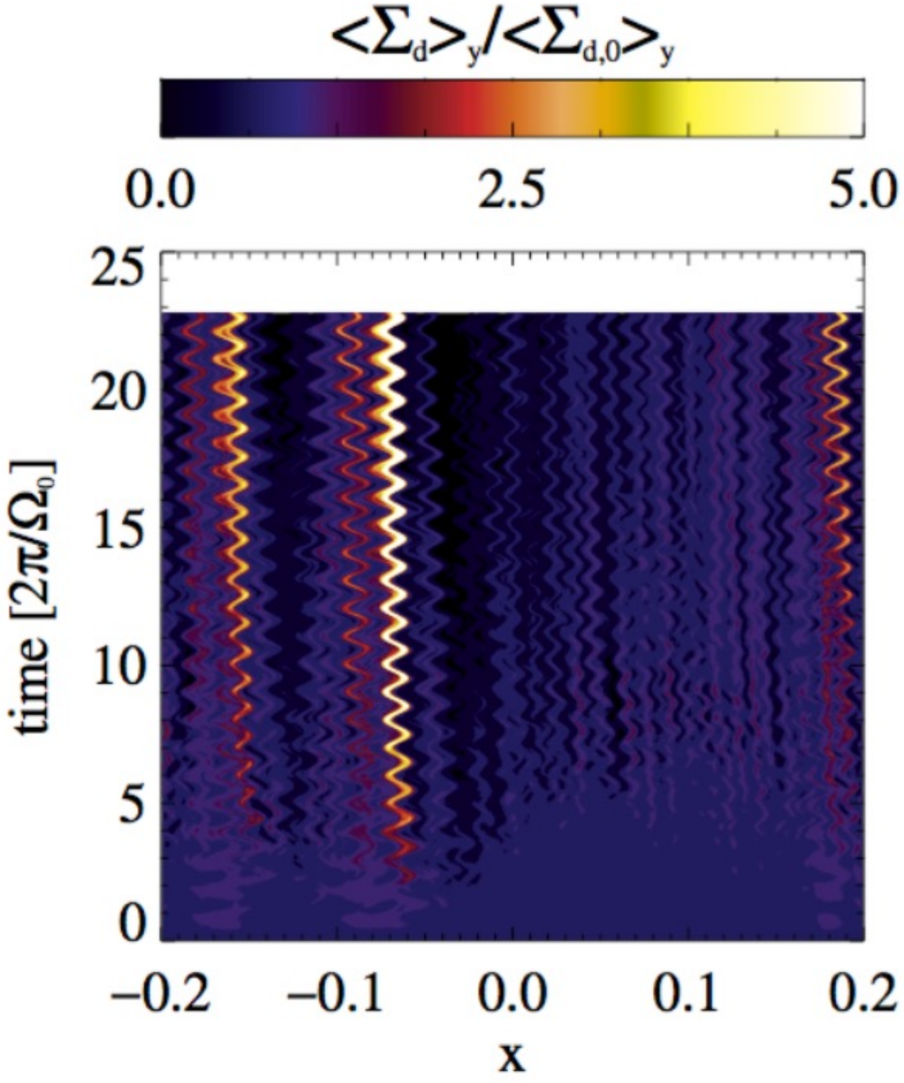
Lyra et al. (2018)

Vortex column disrupted only around the midplane



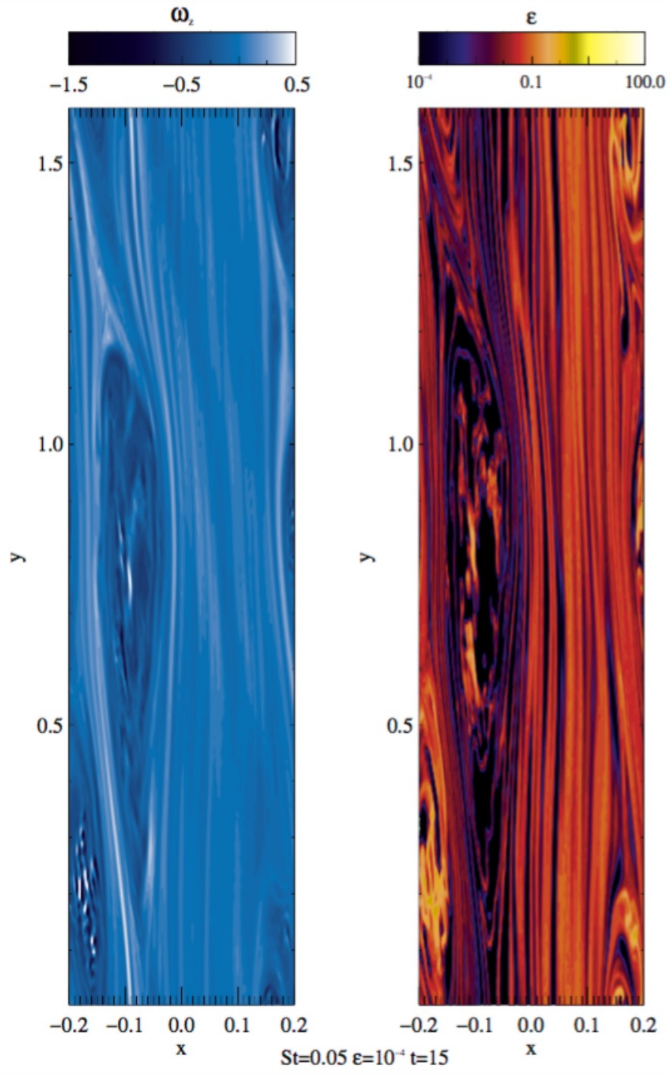
Raettig et al. (2021)

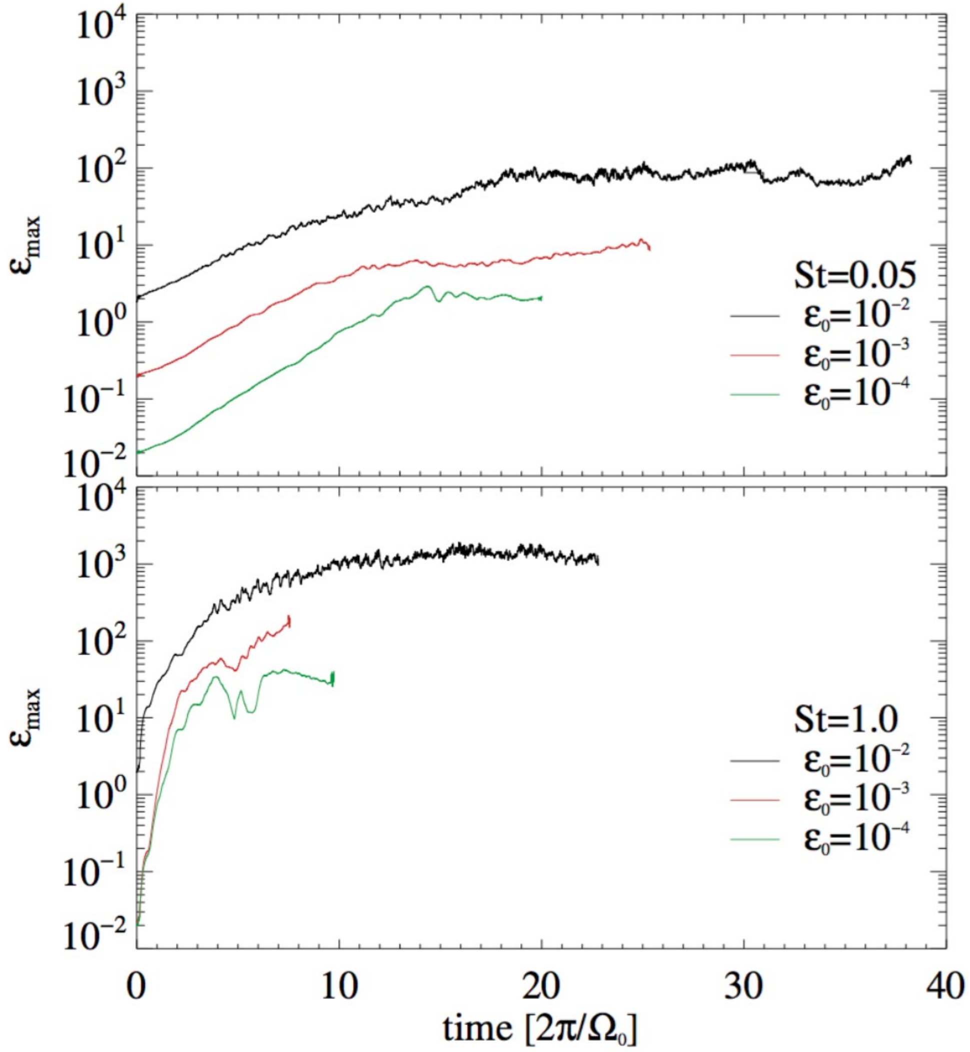
Pebble drift: follows vortex



Raettig et al. (2021)

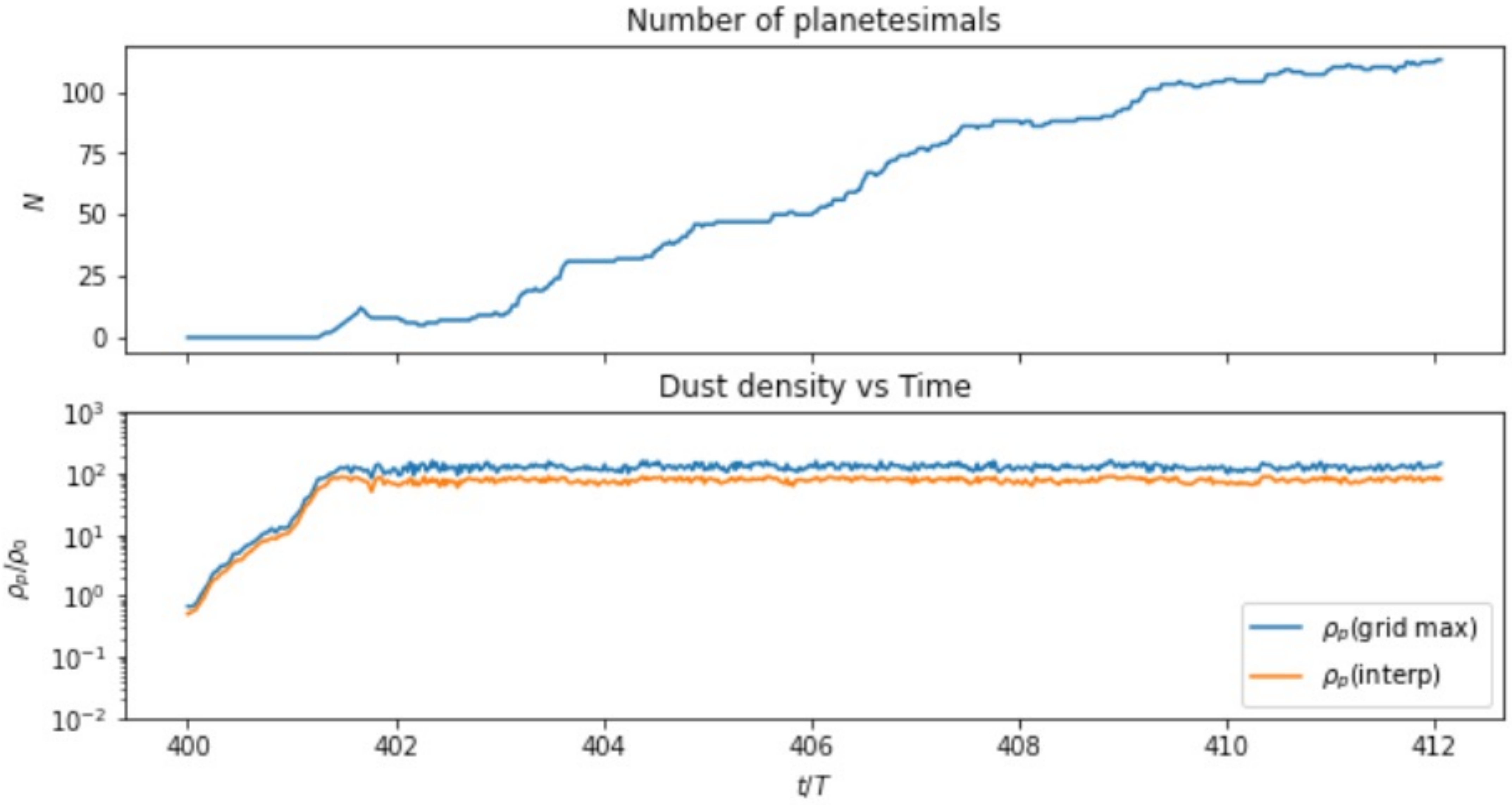
Pebble trapping in 3D vortices





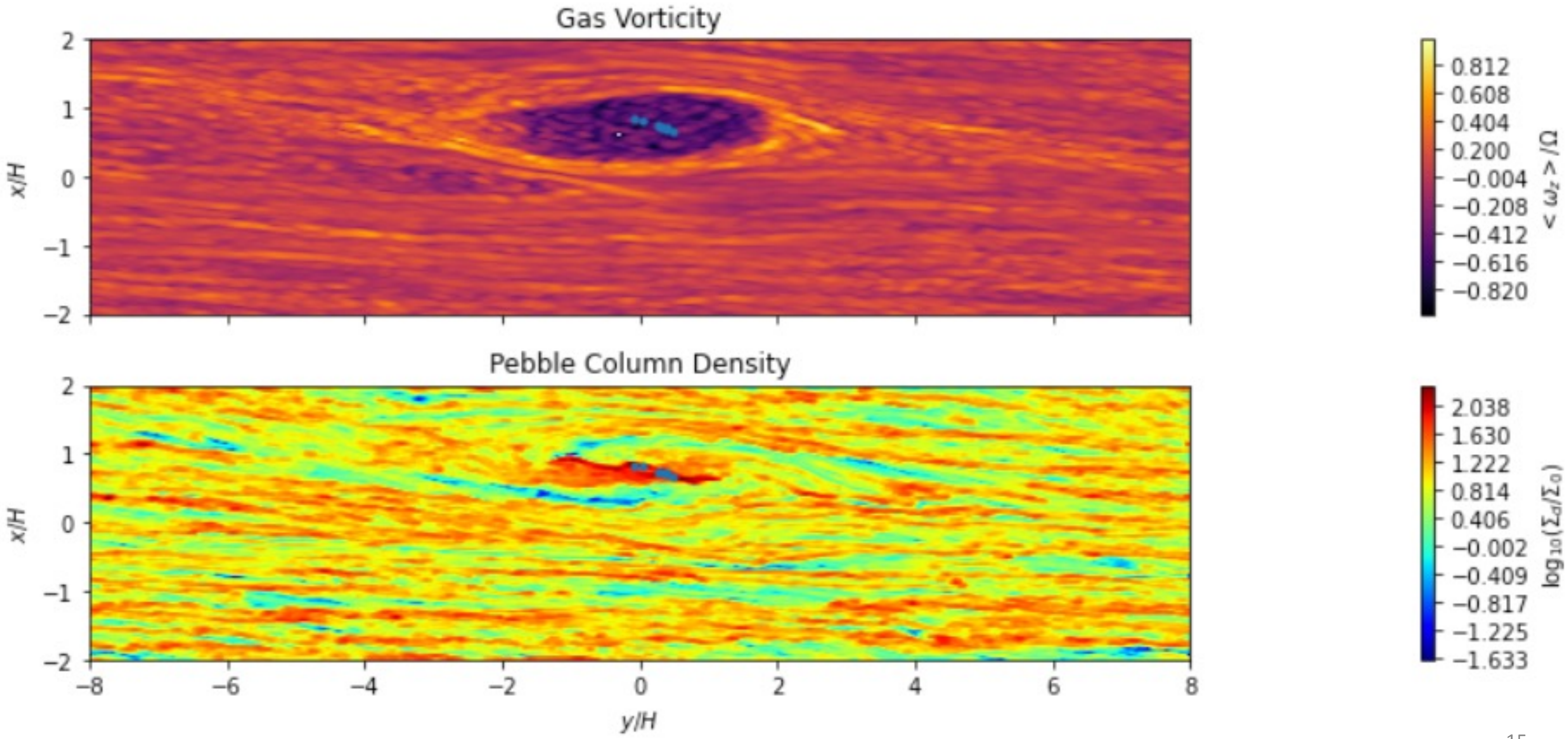
Raettig et al. (2021)

Including selfgravity: Planetesimal Formation



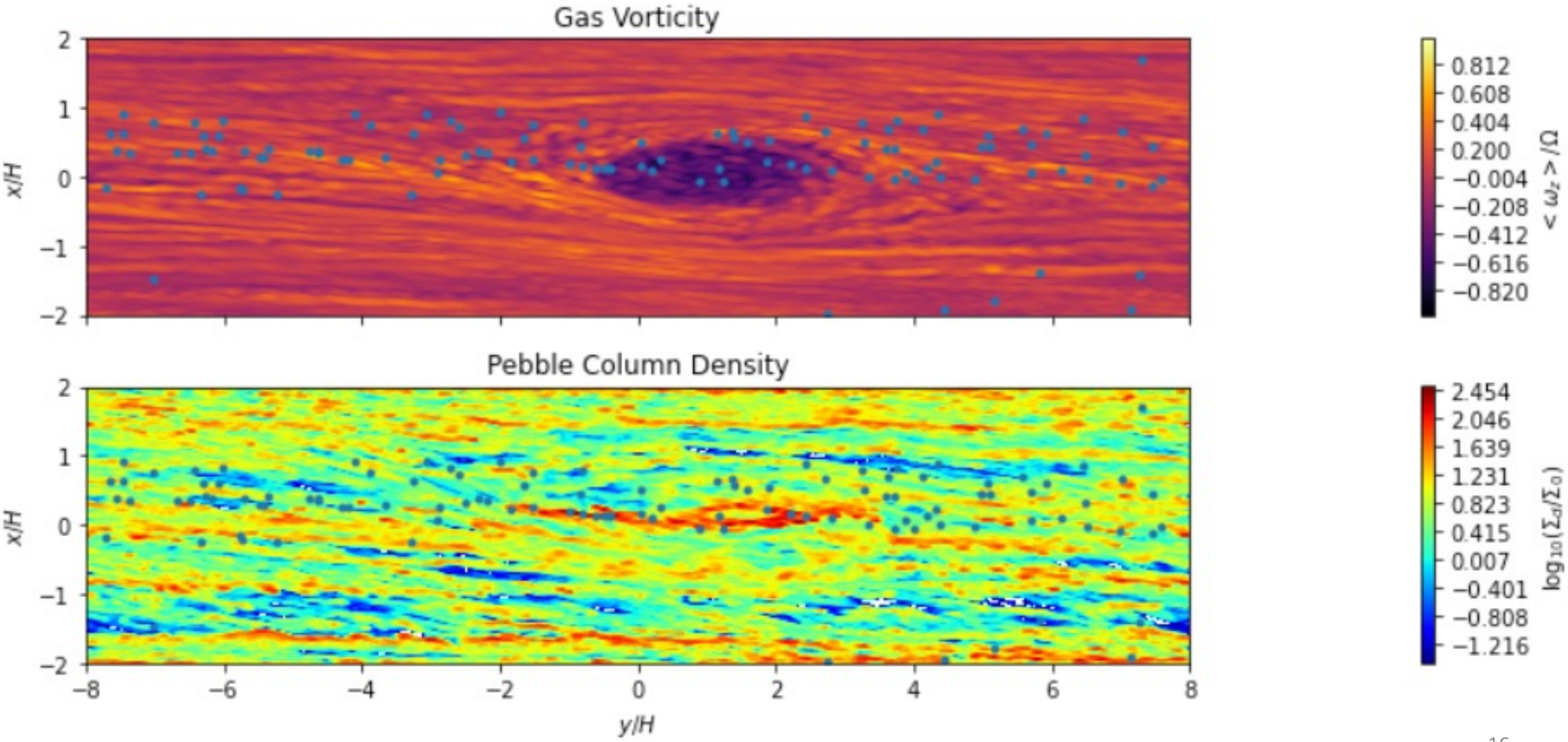
Lyra et al. in prep

Including selfgravity: Planetesimal Formation



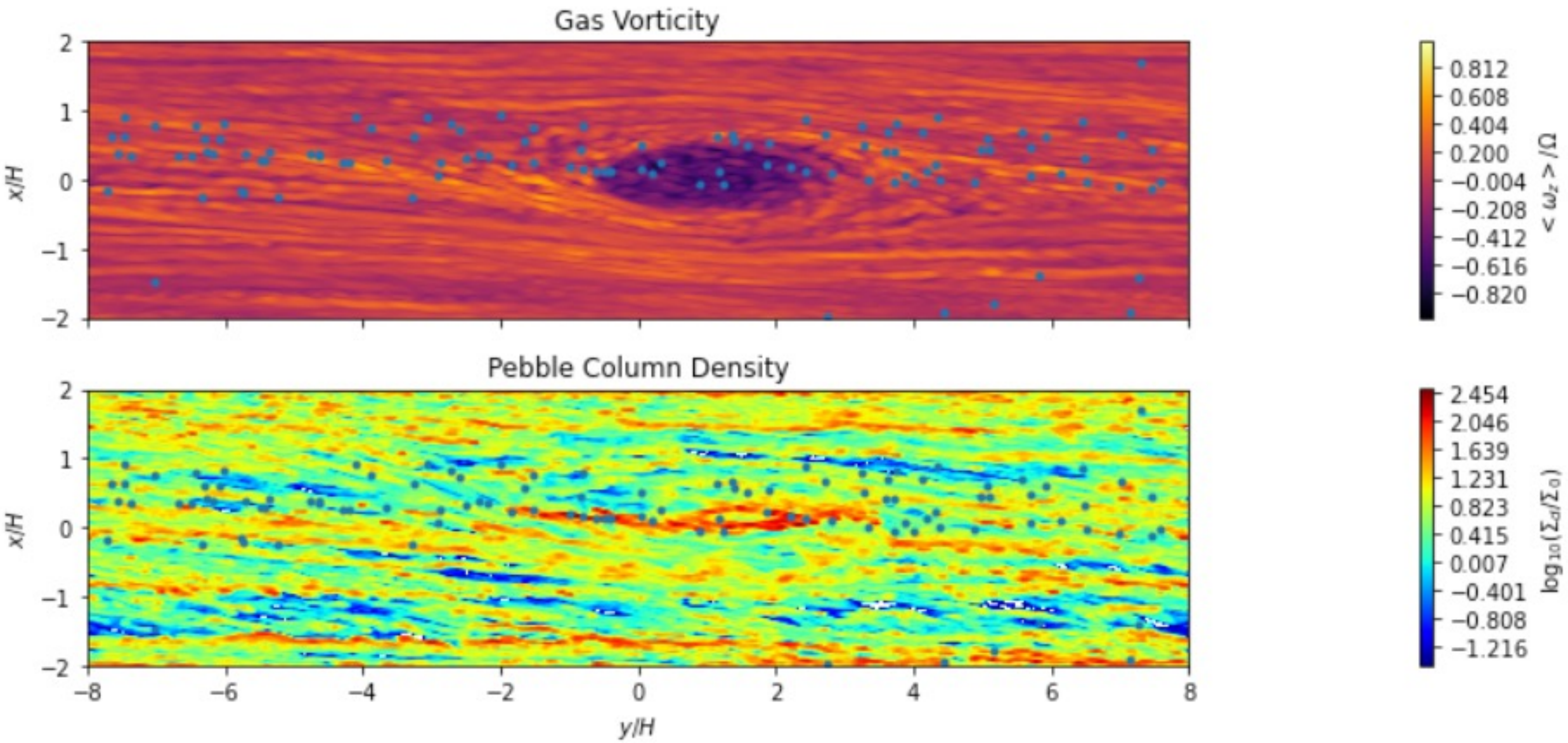
Lyra et al. in prep

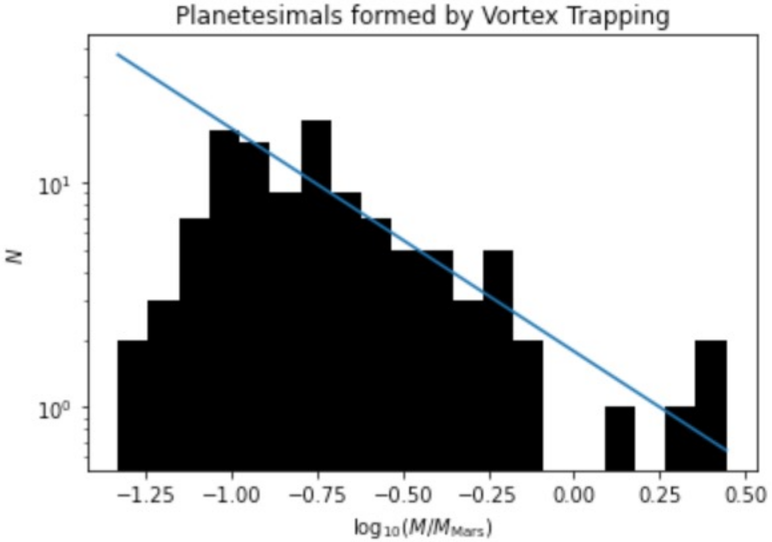
Including selfgravity: Planetesimal Formation



Lyra et al. in prep

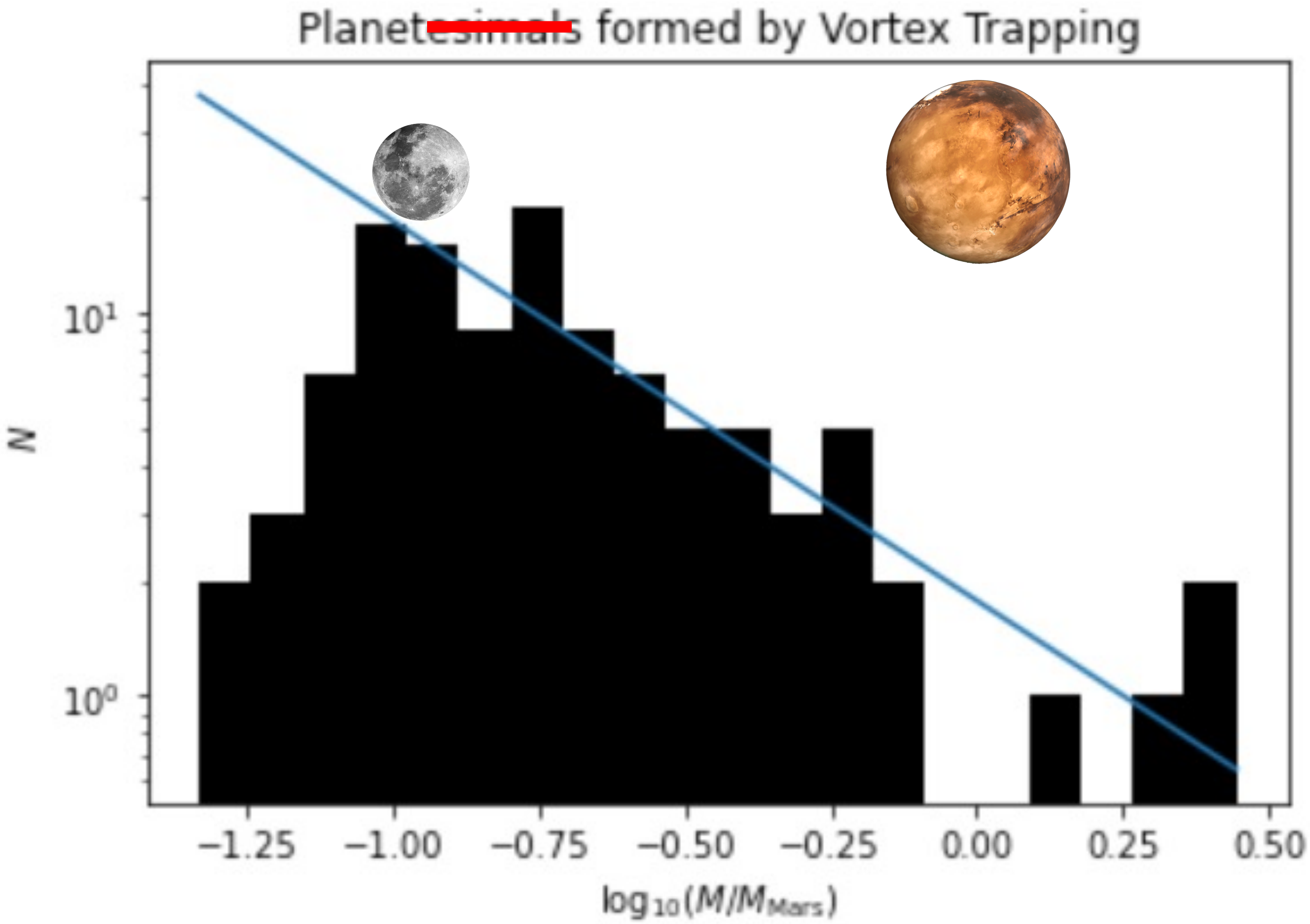
Including selfgravity: Planetesimal Formation





Lyra et al. in prep

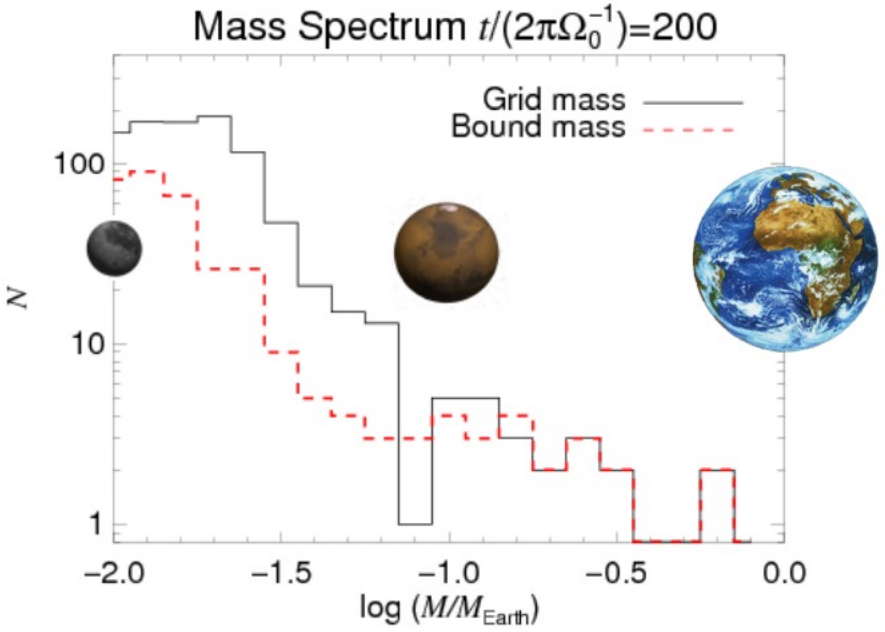
Initial Mass Function

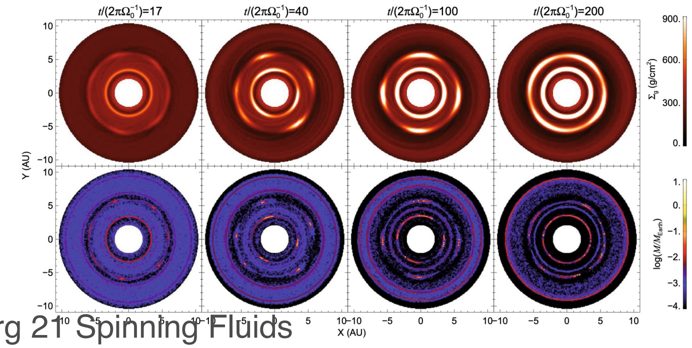


Lyra et al. in prep

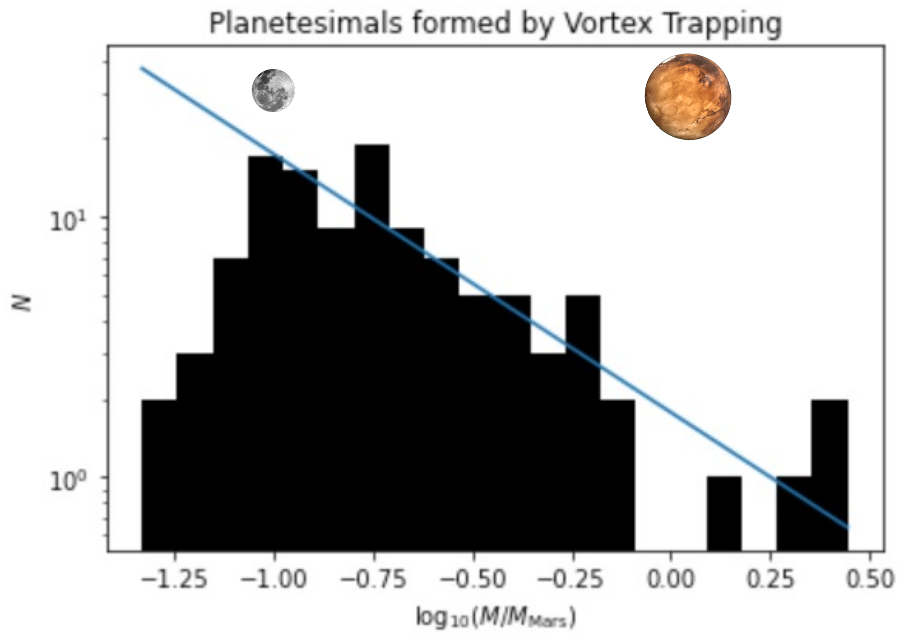
Initial Mass Function

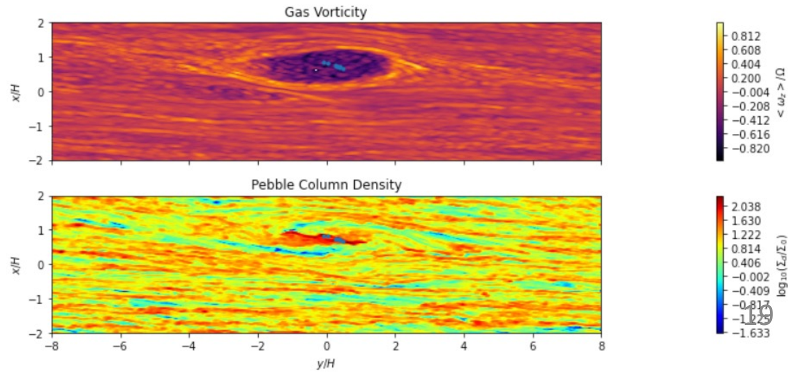
Global 2D, Lyra et al. 2008





Local 3D, Lyra et al. in prep





Conclusions

- ***Convective Overstability may be relevant for planet formation***
  - Finite cooling time + radial entropy gradient
  - Saturates into vortices
  - Happens at 1-10 AU

- ***Vortices are very efficient pebble traps***
  - High particle load disrupts vortical motion around midplane, but not the full column
    - Trapping properties are retained
  - The pebble load is high enough to collapse gravitationally

- ***Planet population is of planetary embryo mass***
  - Moon to Mars mass objects
  - Resolved simulation in both gas and pebbles

- ***Limitations***
  - Streaming Instability not resolved
  - Vertical stratification not included