Concentration of solids in 3D Rossby vortices

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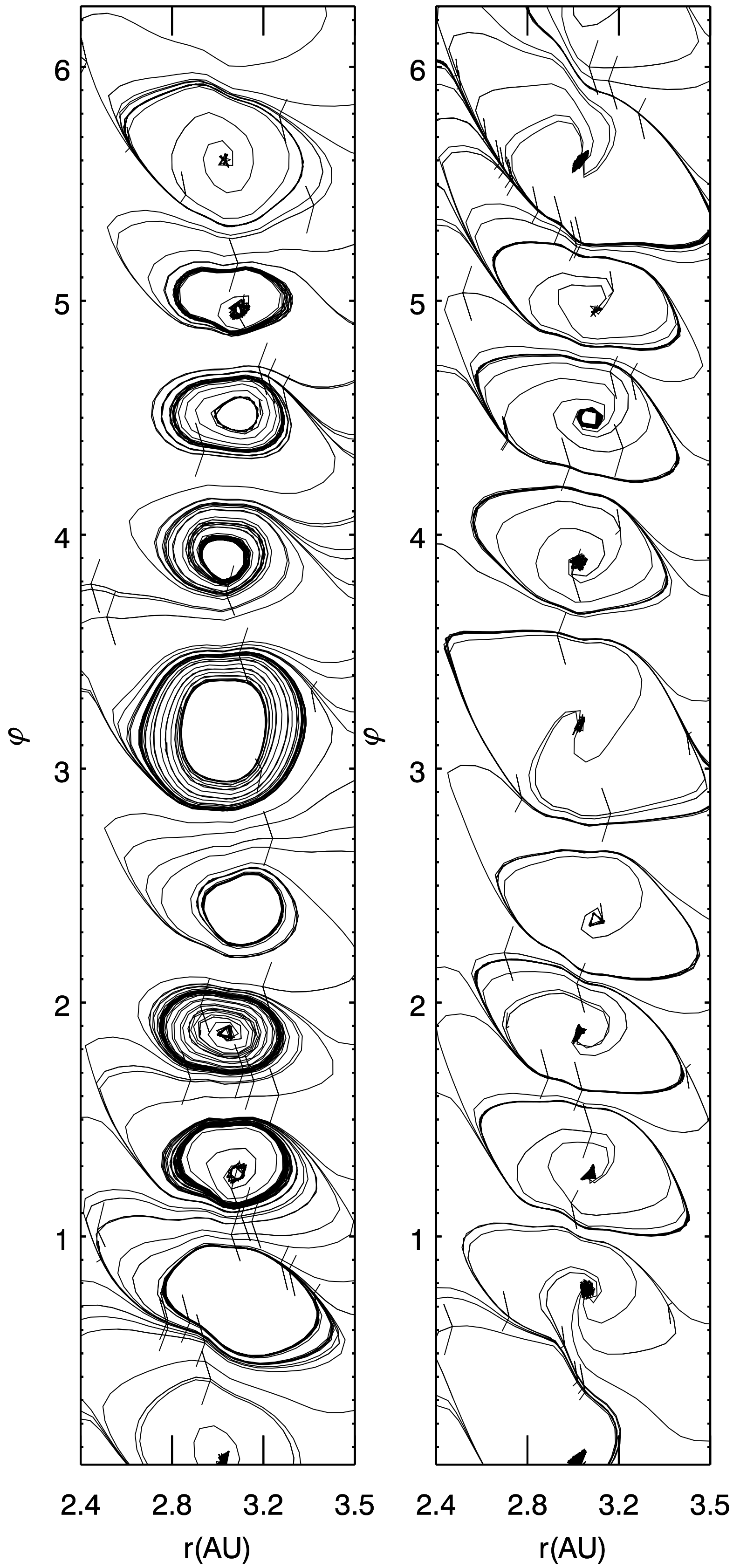
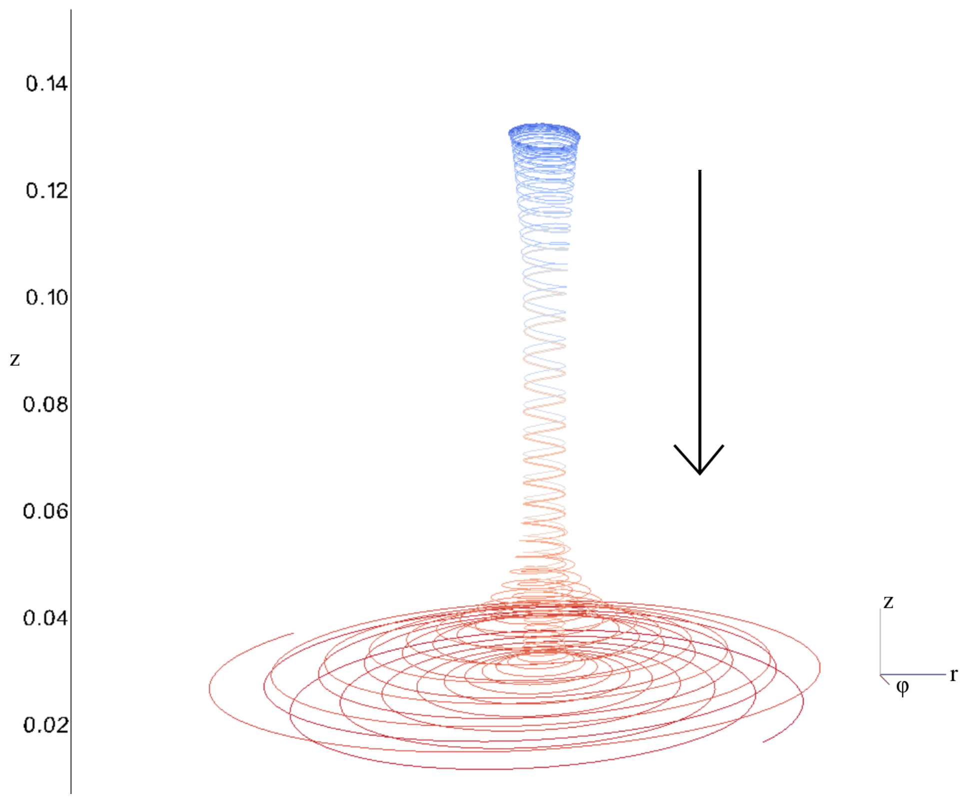
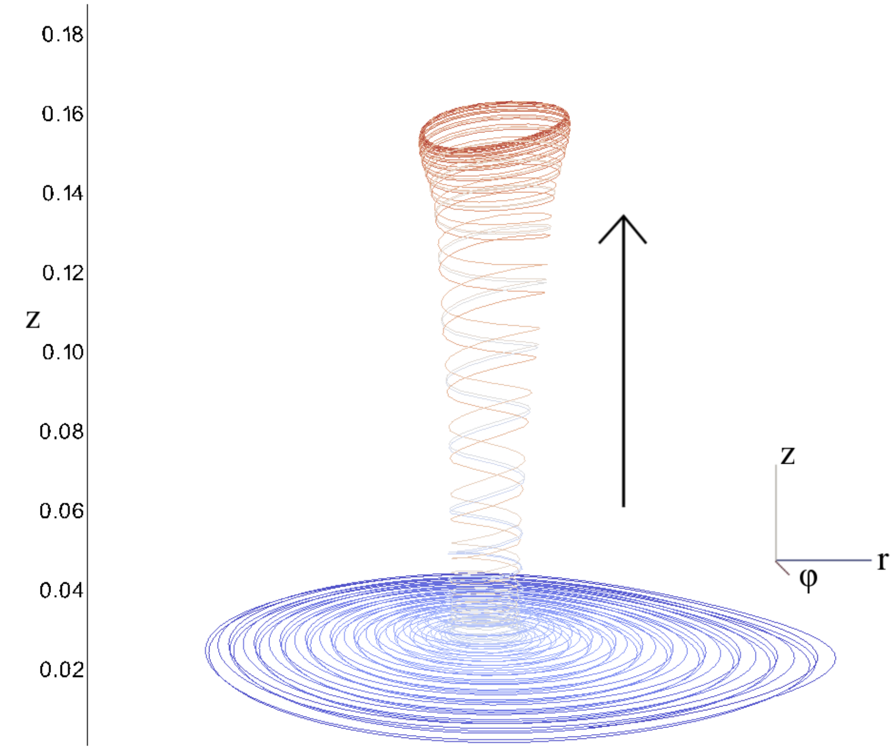
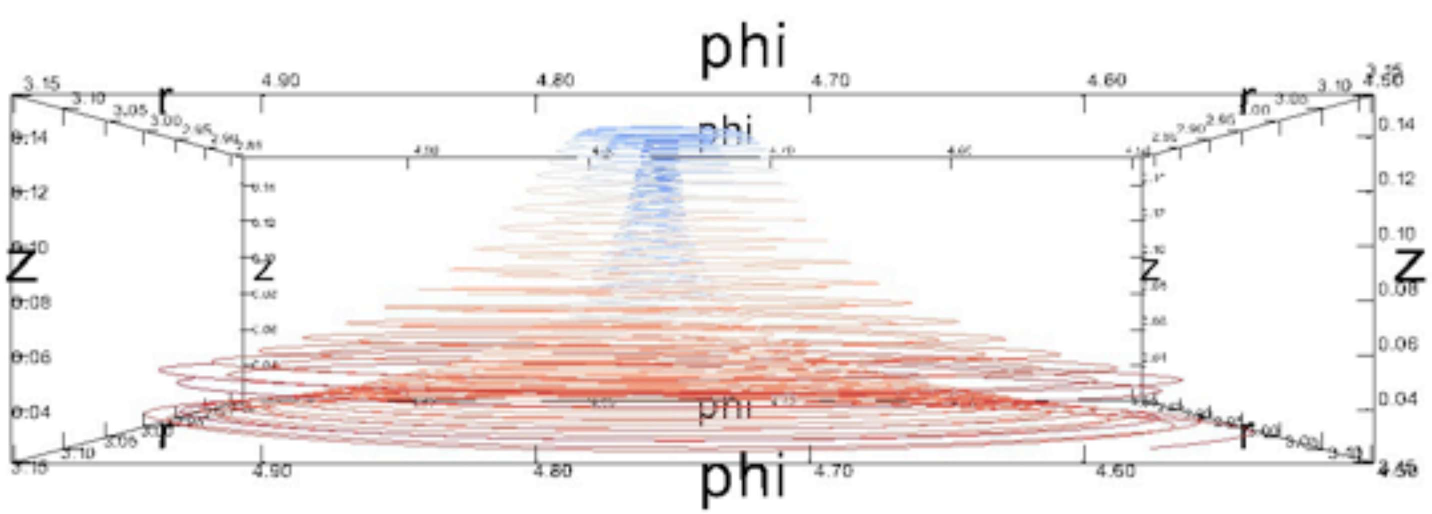
Rossby vortex: 3D streamlines



RWI vortices: vertical velocity



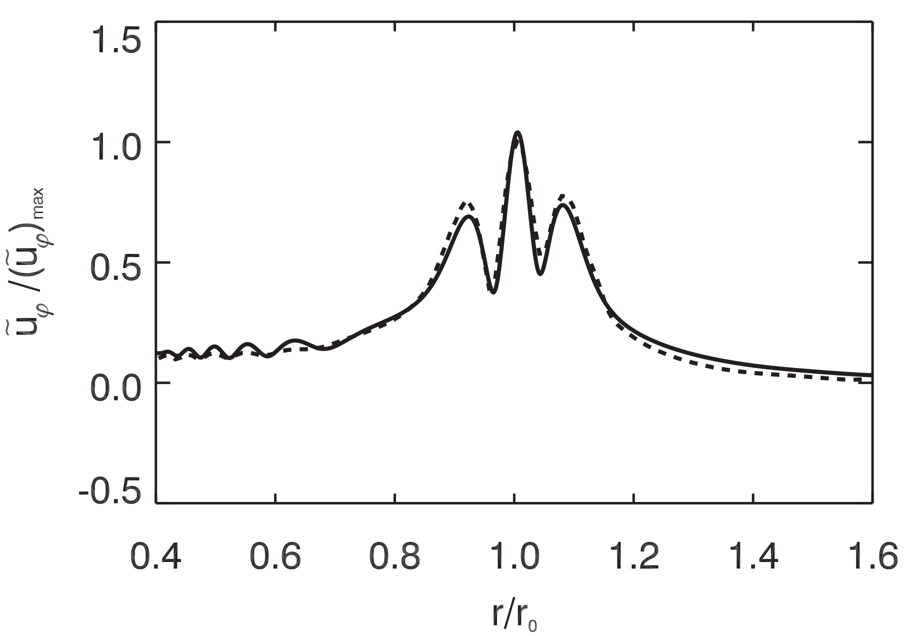


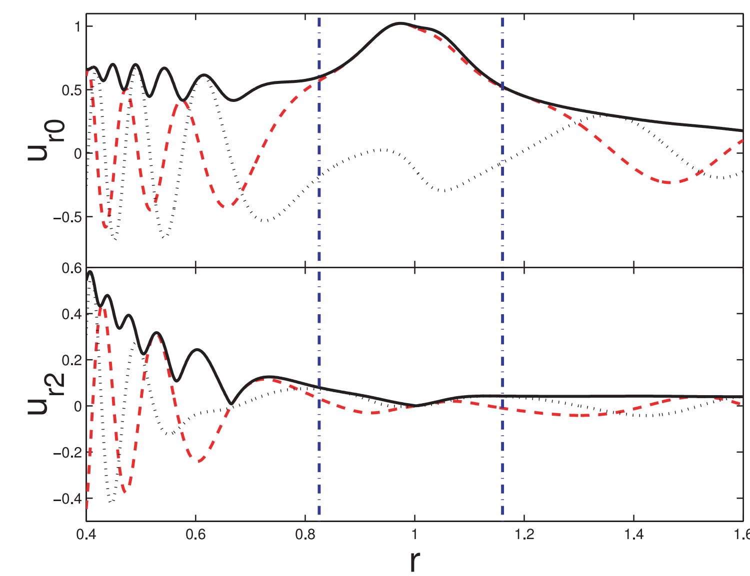


A linear approach

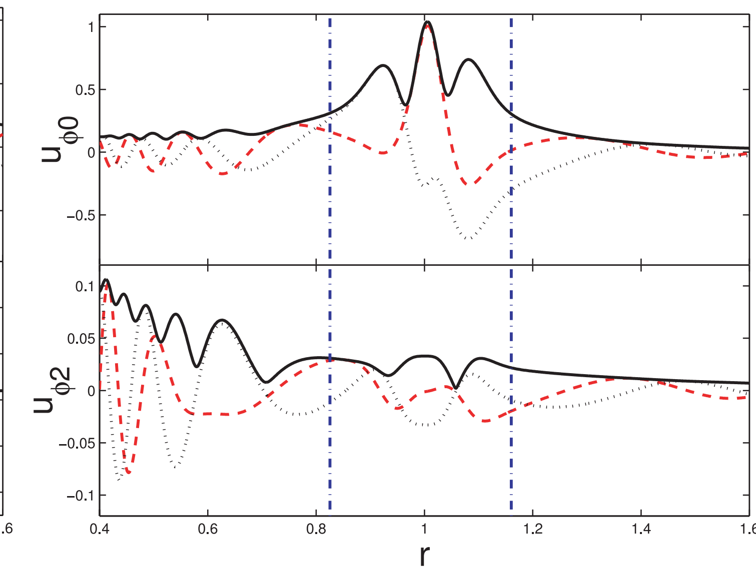
- Linearized equations
- Isothermal disk
- Hermite polynoms in vertical direction

⟶ vertical velocity

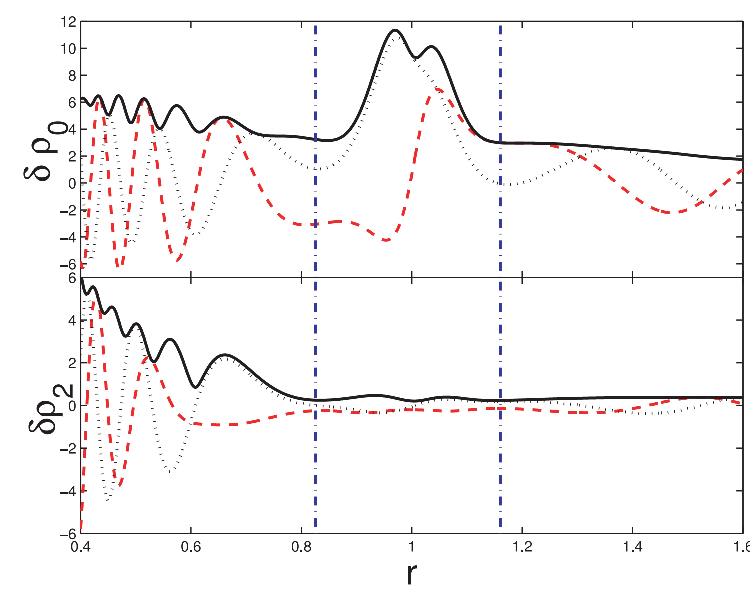




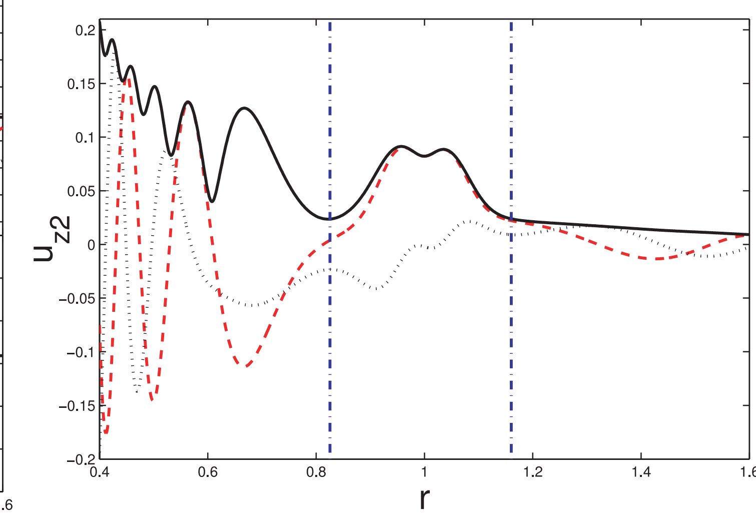
(a) Radial velocity



(b) Azimuthal velocity



(c) Densitiy



(d) Vertical velocity

Meheut, Yu & Lai, 2012

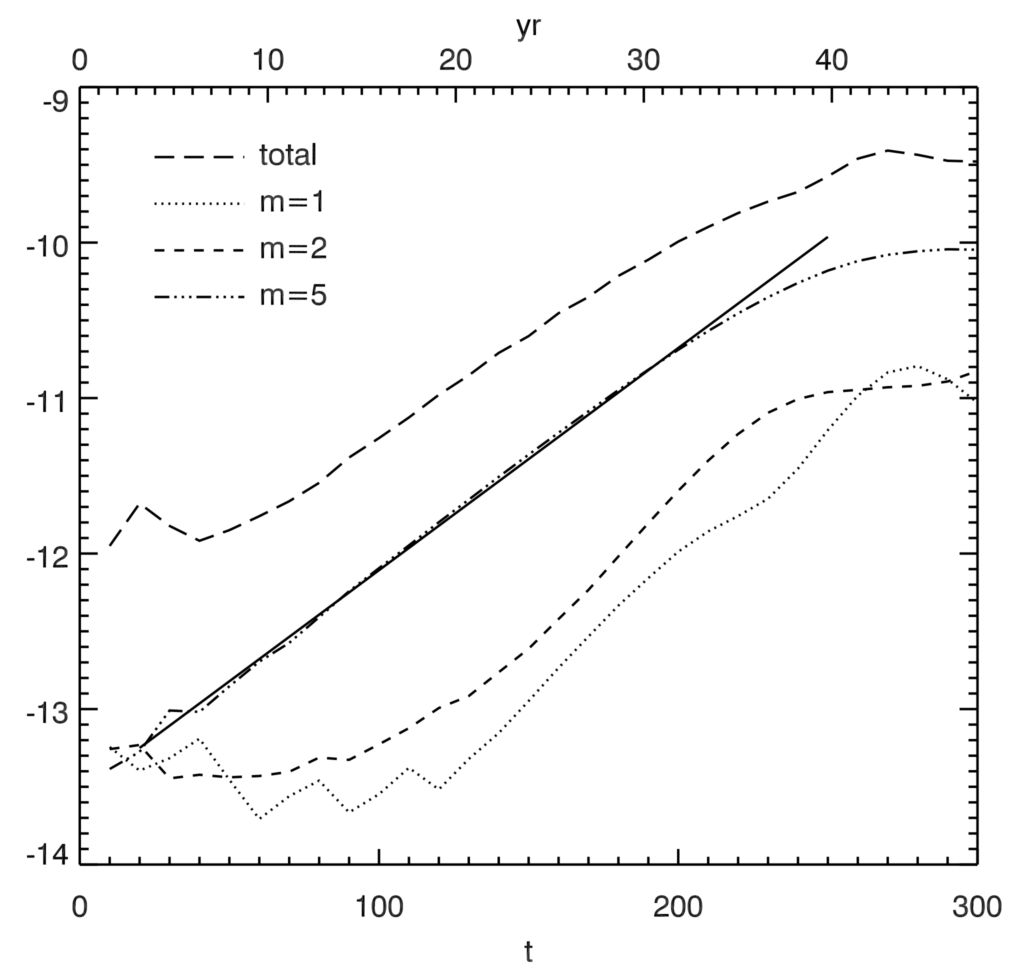
Bi-fluid simulations

- Hydro simulation of the RWI
- Solids added at saturation

$$\begin{cases} \partial_t \rho + \boldsymbol{\nabla} \cdot (\rho \boldsymbol{v}) = 0 \\ \partial_t \rho \boldsymbol{v} + \boldsymbol{\nabla}(\boldsymbol{v} \cdot \rho \boldsymbol{v}) + \boldsymbol{\nabla} p = -\rho \boldsymbol{\nabla} \Phi_G + \rho_d \boldsymbol{f}_d \\ \partial_t \rho_d + \boldsymbol{\nabla} \cdot (\rho_d \boldsymbol{v}_d) = 0 \\ \partial_t \rho_d \boldsymbol{v}_d + \boldsymbol{\nabla}(\boldsymbol{v}_d \cdot \rho \boldsymbol{v}_d) = -\rho_d \boldsymbol{\nabla} \Phi_G - \rho_d \boldsymbol{f}_d \end{cases}$$

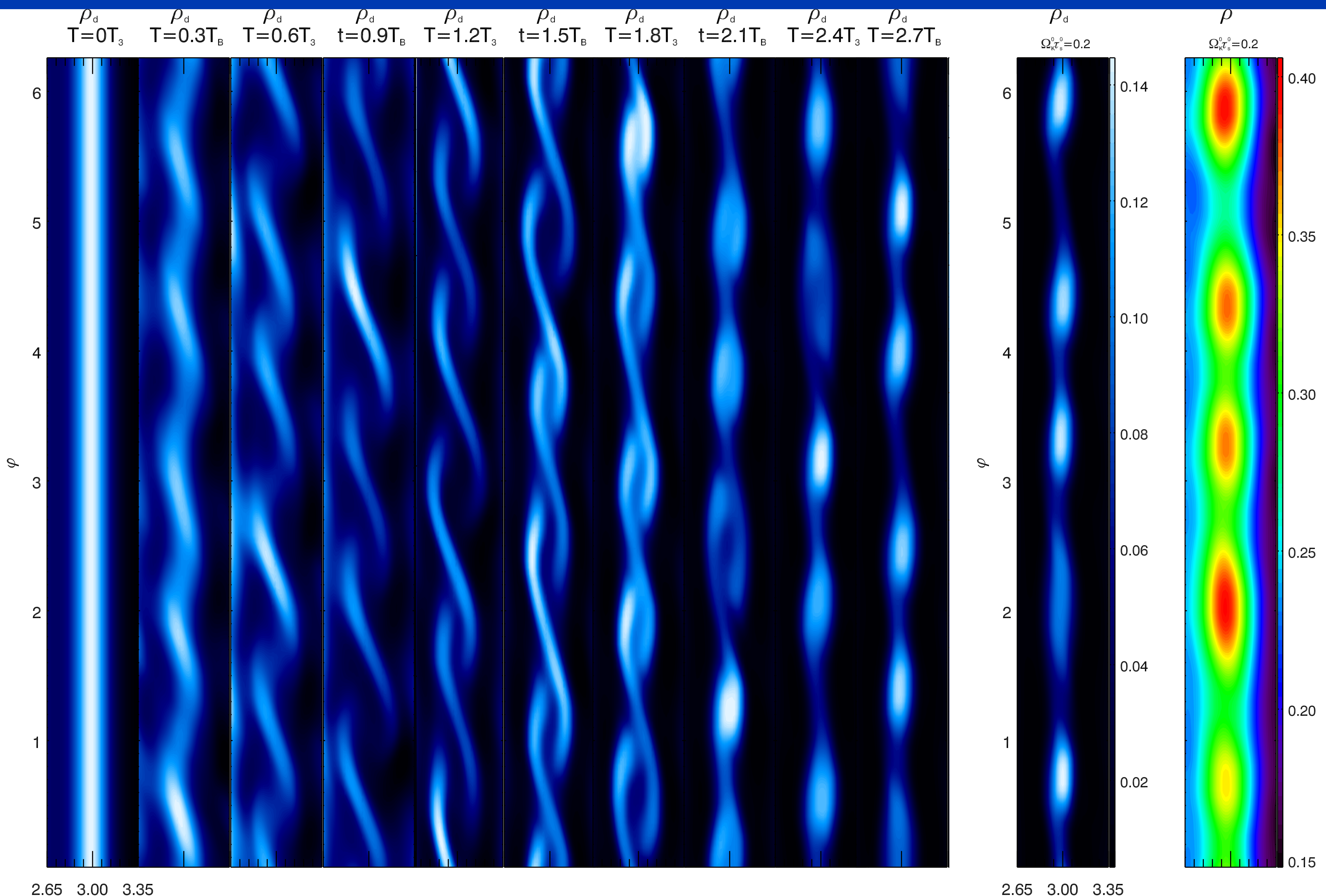
$$\rho_d \boldsymbol{f}_d = \frac{\rho_d}{\tau_s}(\boldsymbol{v} - \boldsymbol{v}_d)$$

Population	$\Omega_K^0 \tau_s^0$	$\Omega_K^{r_B} \tau_s^{r_B}$	s(cm)
1	0.010	0.009	0.1
2	0.020	0.017	0.2
3	0.030	0.026	0.3
4	0.050	0.042	0.5
5	0.100	0.085	1
6	0.200	0.17	2
7	0.300	0.256	3
8	0.500	0.427	5

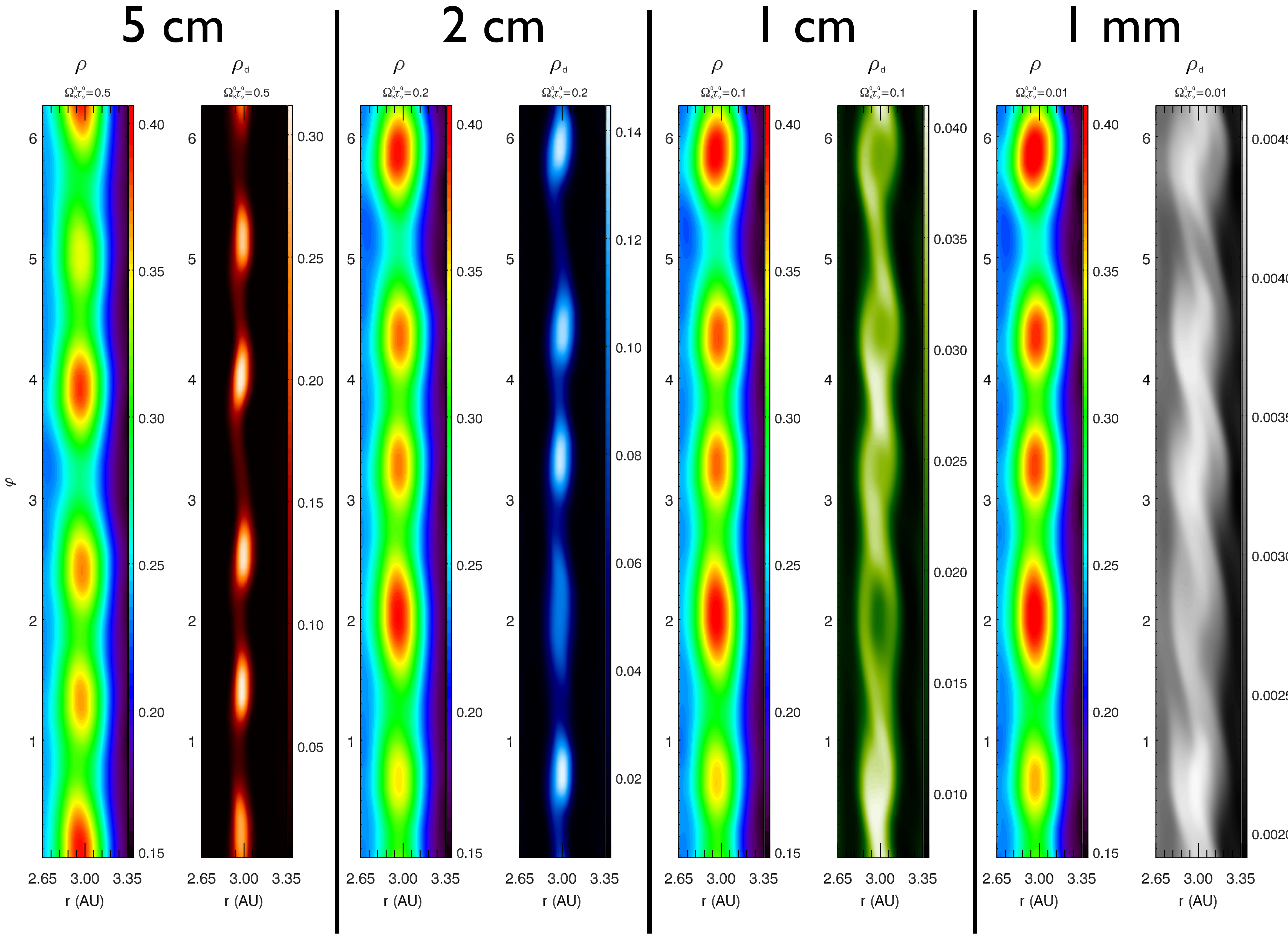


- Epstein regime
- Initial dust-to-gas ratio: 10^{-2}

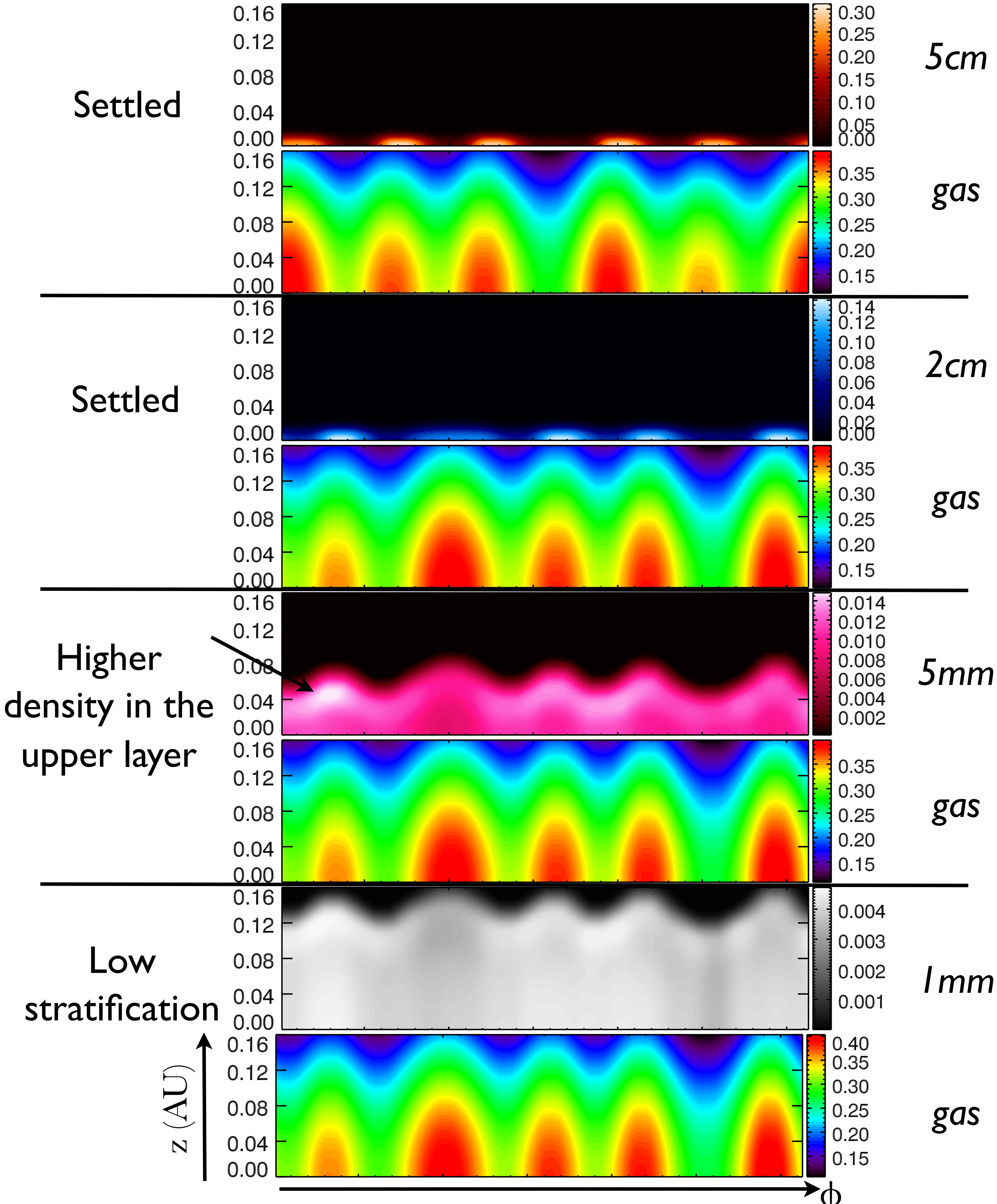
Midplane density: time evolution



Solids size



Vertical stratification

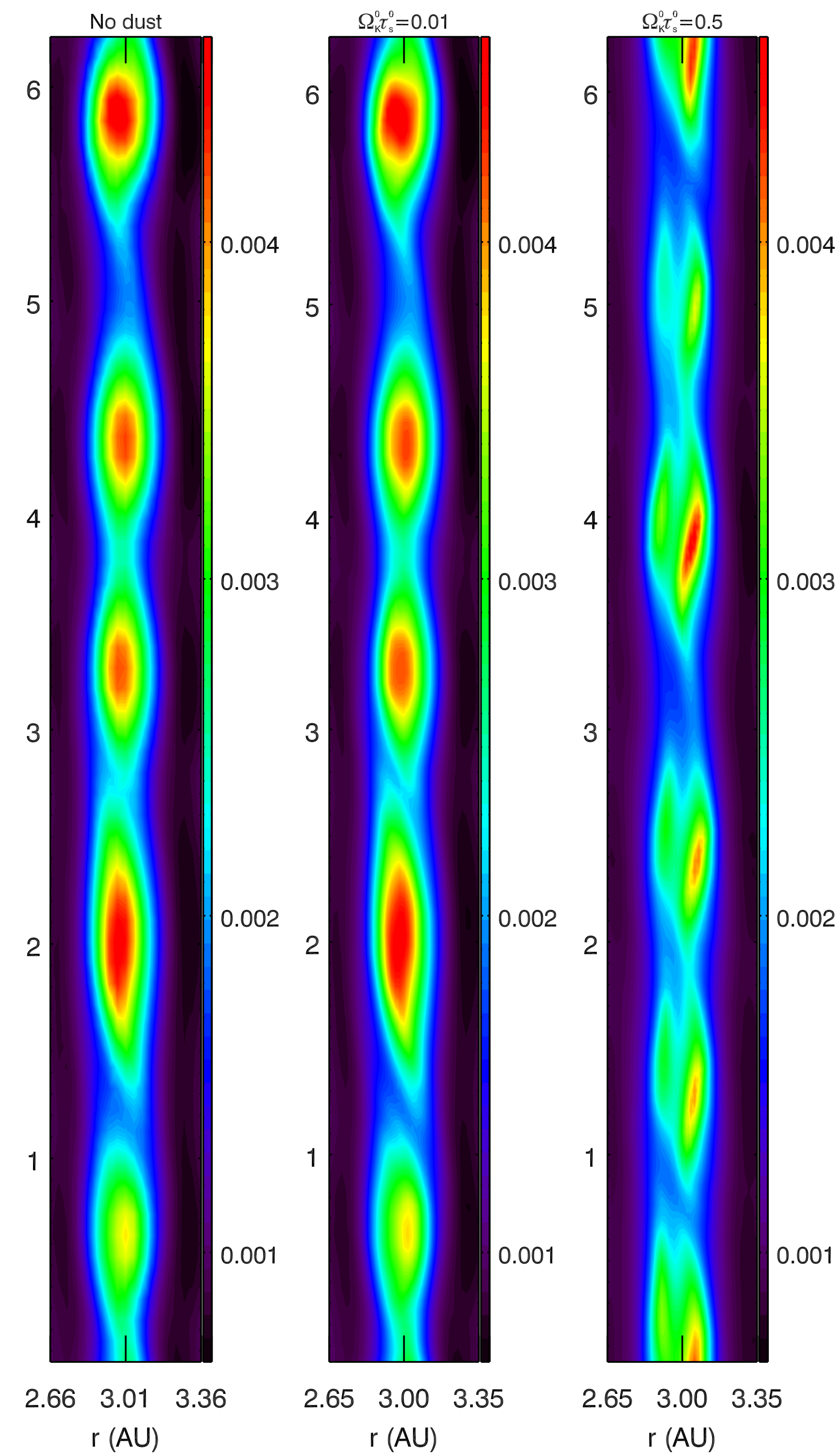


Meheut, Meliani, Varniere & Benz 2012

Summary

- 3D Rossby vortices do accumulate solid grains
- Dust-to-gas ratio reaches ~ 1 for larger solids
- Intermediate size solids are lifted above the midplane by the vortices
- Vortices survive for low grain density
- High grain density: vortices are dragged

- How strong are the Rossby vortices?



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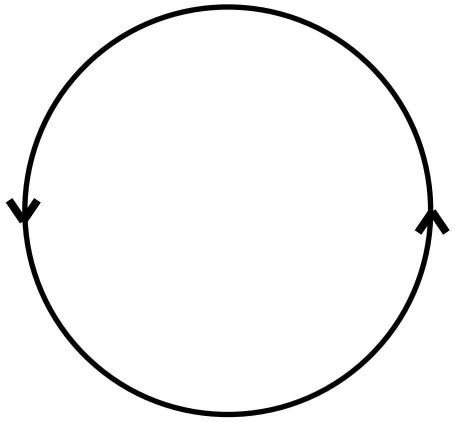
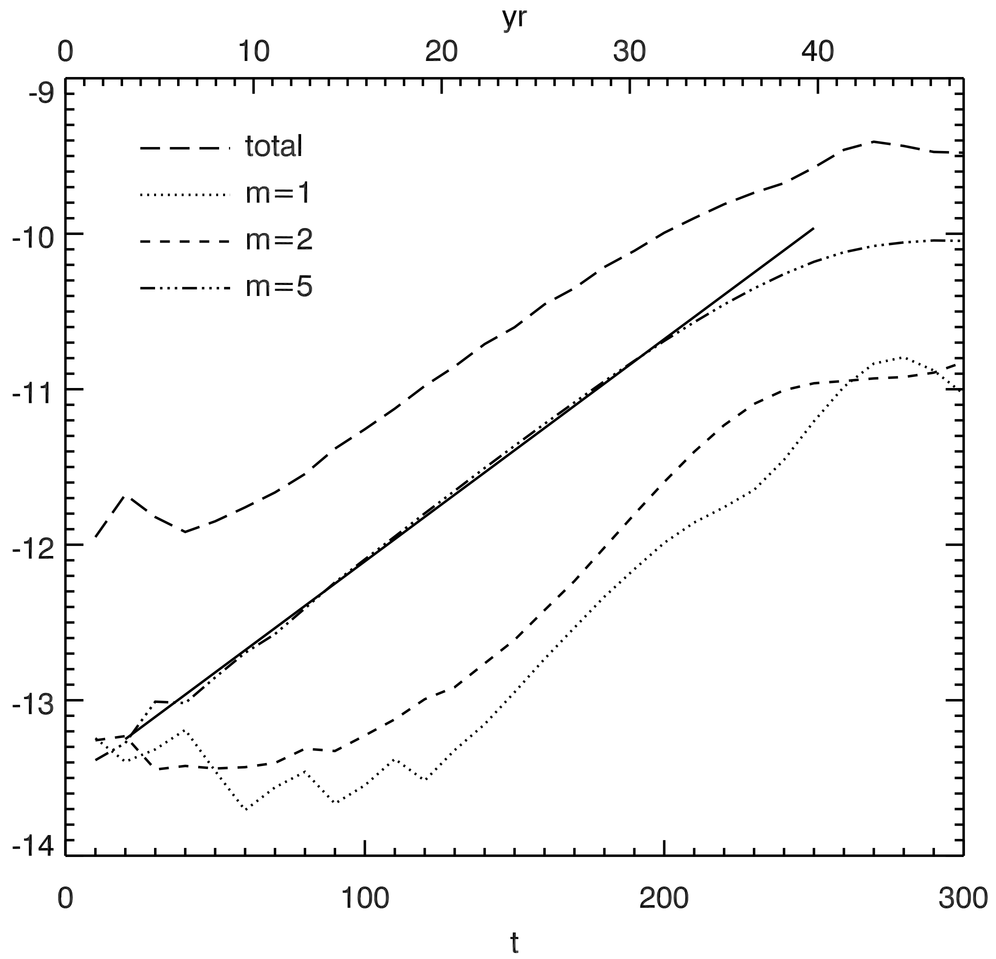
How strong are the Rossby vortices?

- When does the linear theory break?
- Turnover timescale of the order of growth timescale
    - Landau damping breakdown due to particle trapping

Lovelace et al. 2009

- Turnover timescale ~ half the vorticity





Meheut, Lovelace & Lai, in prep.

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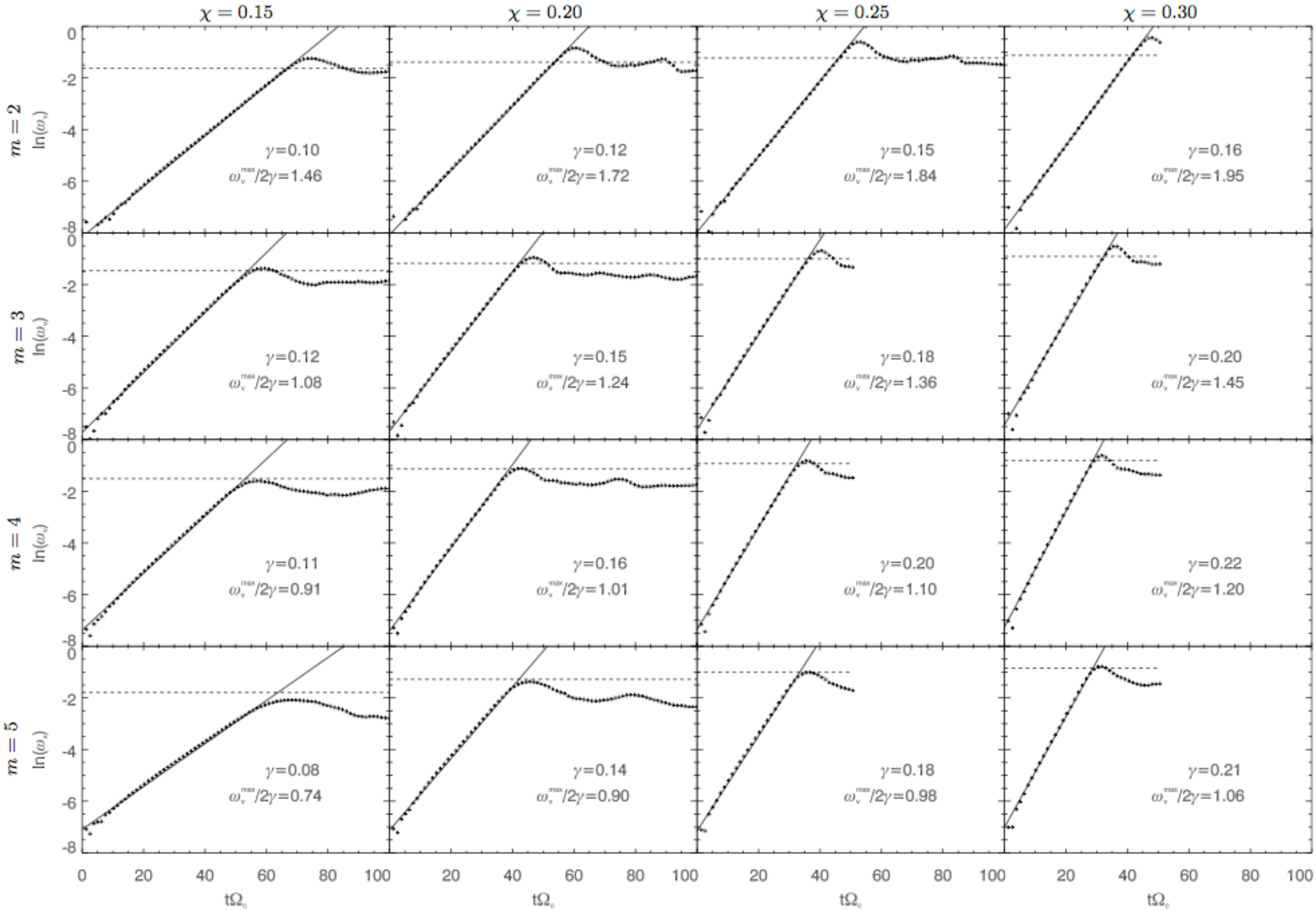
$\chi = 0.15$
$\chi = 0.20$
$\chi = 0.25$
$\chi = 0.30$
$m = 2$
$m = 3$
$m = 4$
$m = 5$
$\ln(\omega_v)$
γ=0.10 $\omega_v^{max}/2\gamma$=1.46
γ=0.12 $\omega_v^{max}/2\gamma$=1.72
γ=0.15 $\omega_v^{max}/2\gamma$=1.84
γ=0.16 $\omega_v^{max}/2\gamma$=1.95
γ=0.12 $\omega_v^{max}/2\gamma$=1.08
γ=0.15 $\omega_v^{max}/2\gamma$=1.24
γ=0.18 $\omega_v^{max}/2\gamma$=1.36
γ=0.20 $\omega_v^{max}/2\gamma$=1.45
γ=0.11 $\omega_v^{max}/2\gamma$=0.91
γ=0.16 $\omega_v^{max}/2\gamma$=1.01
γ=0.20 $\omega_v^{max}/2\gamma$=1.10
γ=0.22 $\omega_v^{max}/2\gamma$=1.20
γ=0.08 $\omega_v^{max}/2\gamma$=0.74
γ=0.14 $\omega_v^{max}/2\gamma$=0.90
γ=0.18 $\omega_v^{max}/2\gamma$=0.98
γ=0.21 $\omega_v^{max}/2\gamma$=1.06
$t\Omega_c$