3D Rossby vortices in protoplanetary discs

Héloïse Meheut

Center for Space and Habitability
University of Bern

In collaboration with:

Willy Benz
Fabien Casse
Rony Keppens
Dong Lai
Zakaria Meliani
Michel Tagger
Peggy Varnière
Cong Yu

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Why vortices as planet nursery?

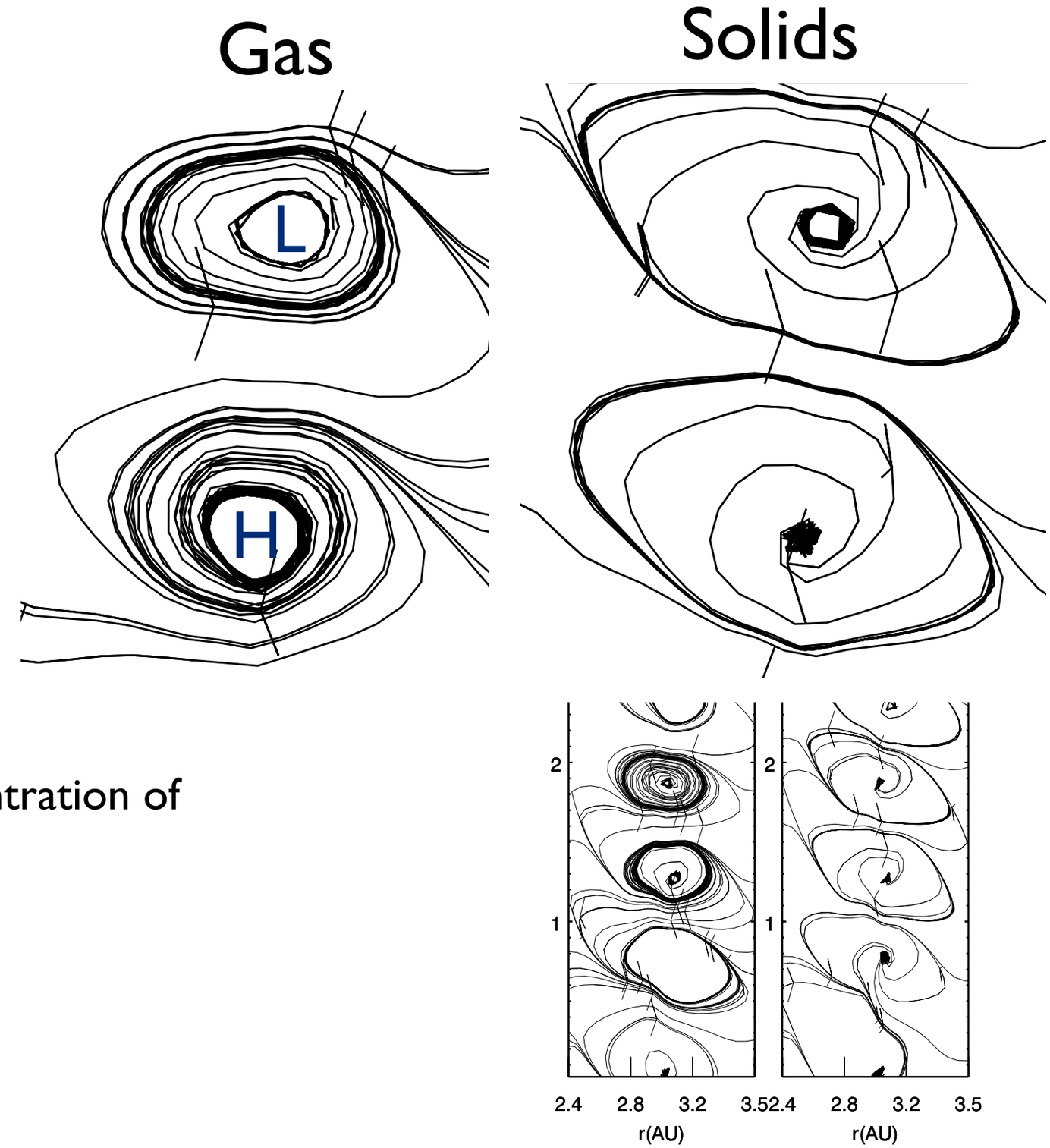
- Timescale problem for grains growt

- Vortices concentrate solids in their
  - Fluid: in equilibrium with pressu
  - Solids: no pressure

  ⟶ Barge & Sommeria, 1995

- Numerical simulations show concentration of solids (e.g. Johansen et al. 2004)

- How to form vortices?



Rossby wave instability (RWI)

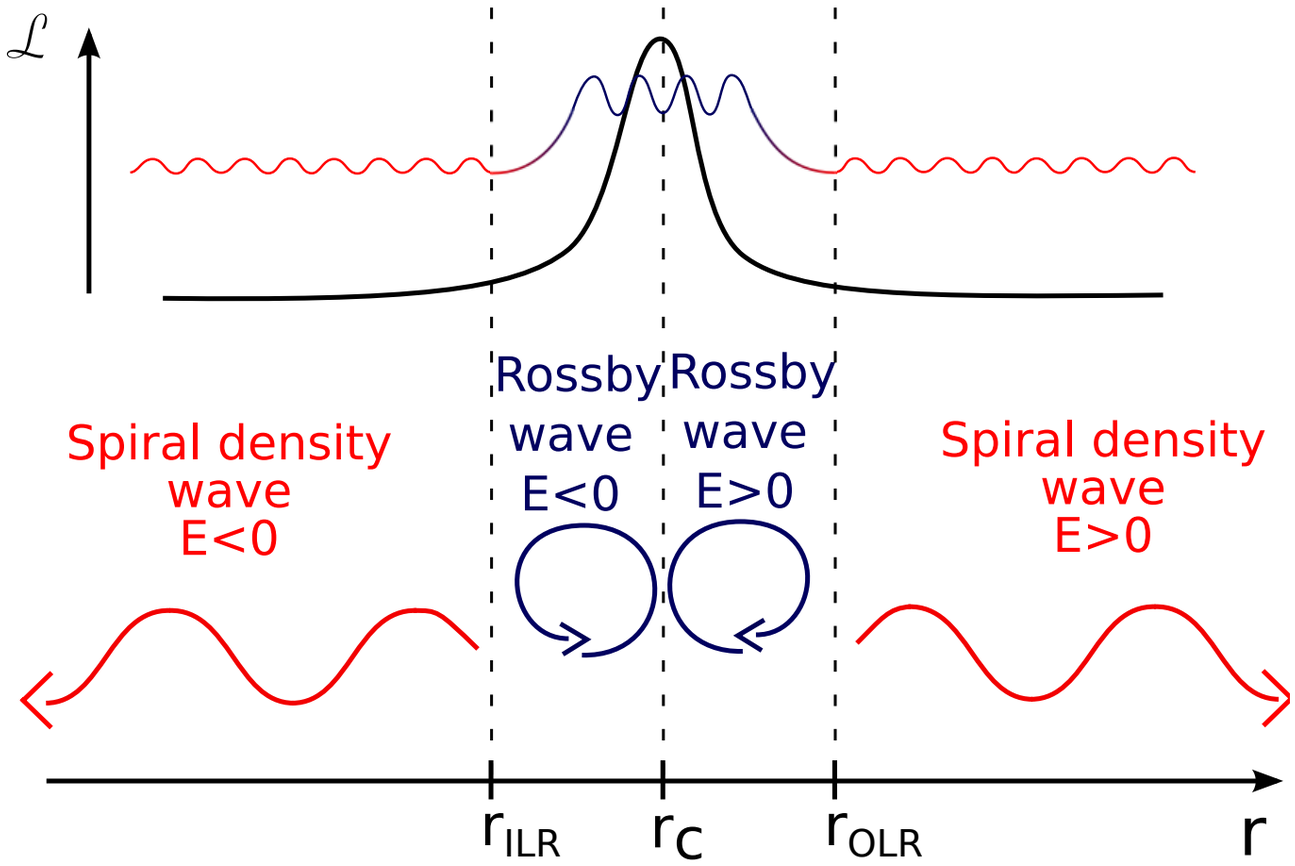
Lovelace et al., 1999 - Li et al., 2000 & 2001

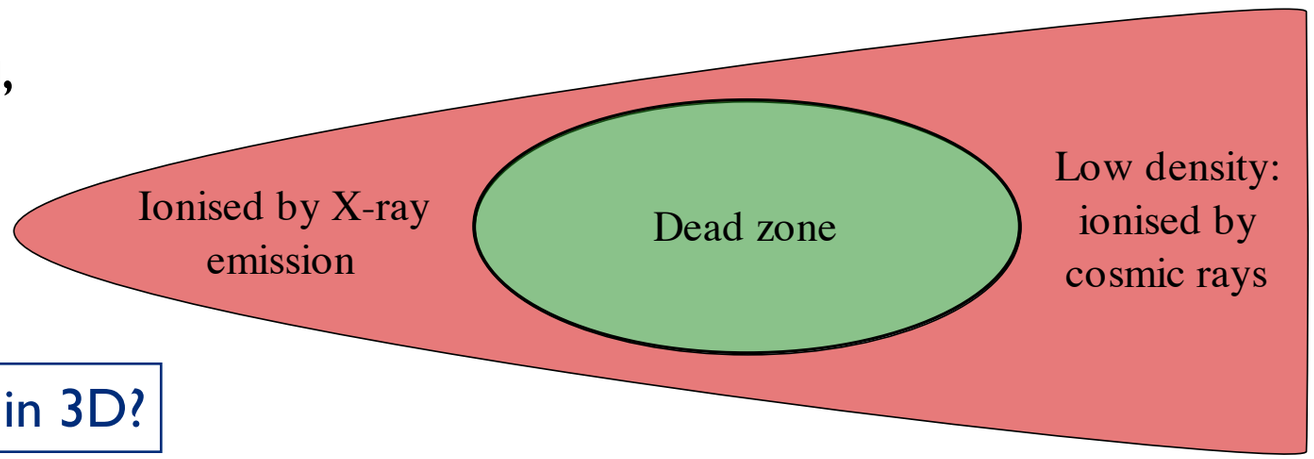
- RWI requires an extremum of

$$\mathcal{L}^{-1} \propto \frac{(\nabla \times v)_z}{\Sigma}$$

in barotropic disks

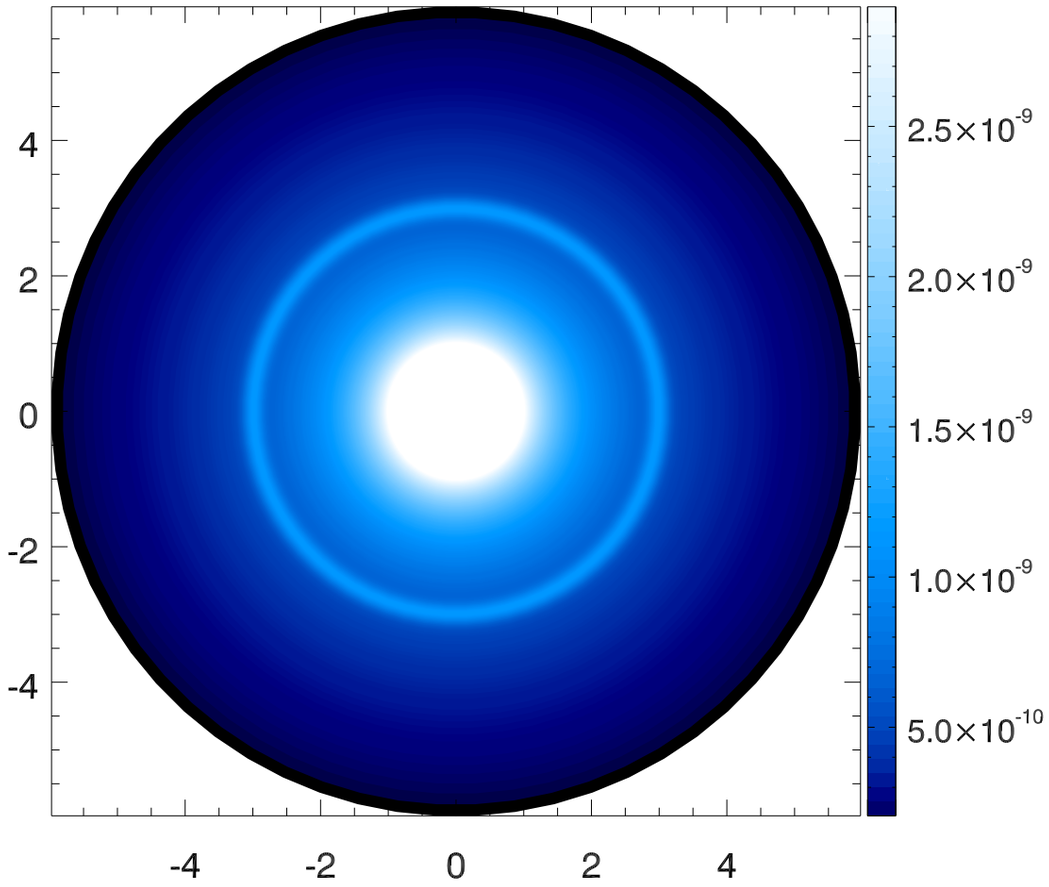
- Extremum of density:
  - Borders of the dead zone (e.g. Lyra & Mac Low, 2012)
  - Ice line (Kretke & Lin, 2007)
  - Planet gap (Lin & Papaloizou, 2011)



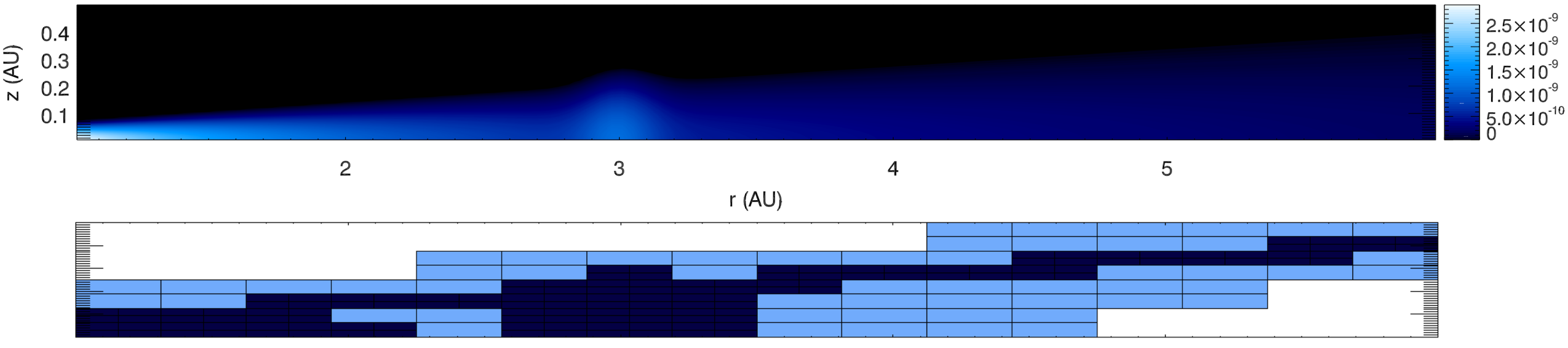


Do the vortices survive on long timescales in 3D?

Simulation with MPI-AMRVAC



- MPI-AMRVAC (*Keppens et al. 2012*)
- Initial conditions:
  - $\rho \propto r^{-1/2}$ & bump
  - barotropic disk
  - gas in sub-keplerian rotation
  - random radial velocity perturbations (10^{-4})

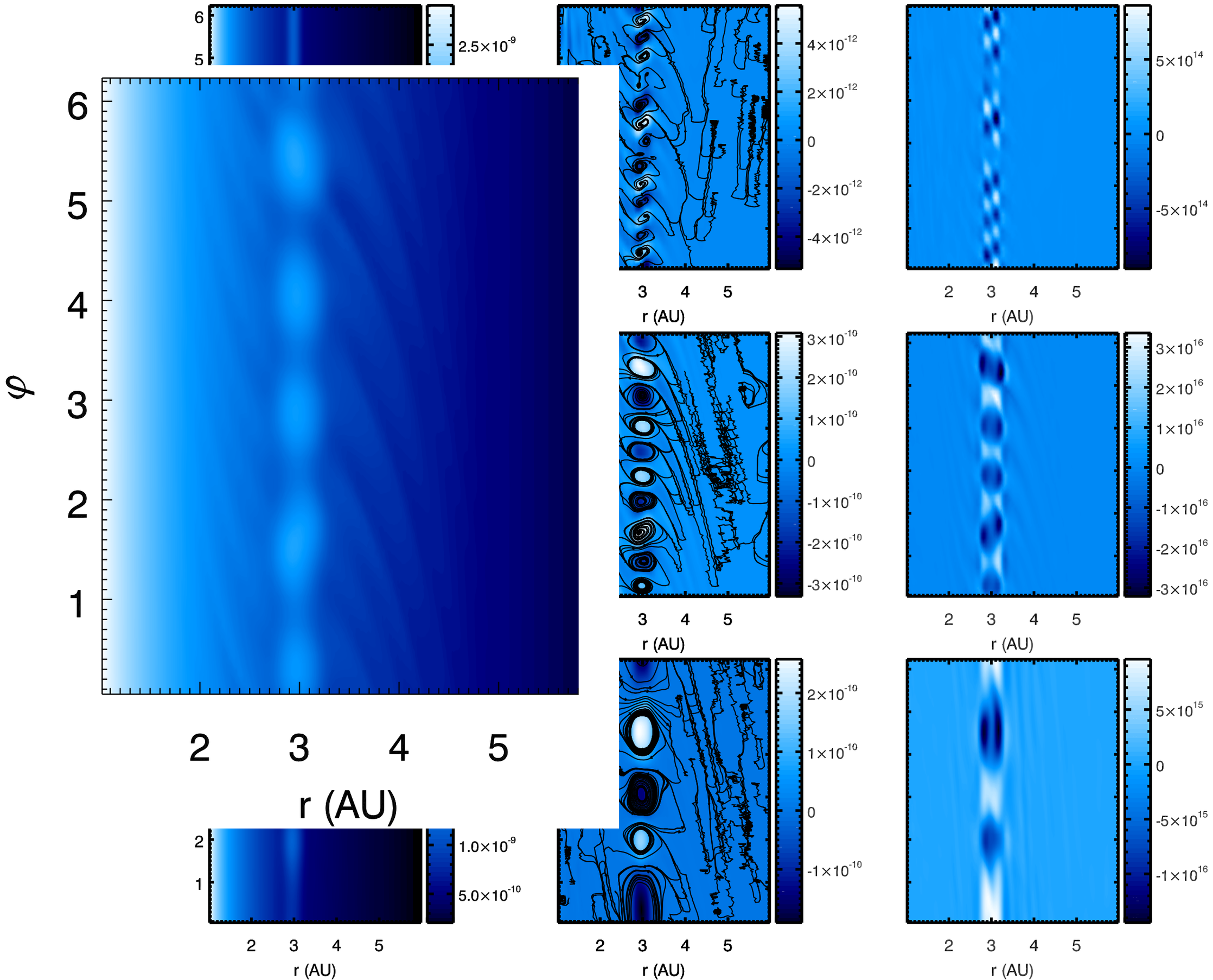


heloise.meheut@space.unibe.ch

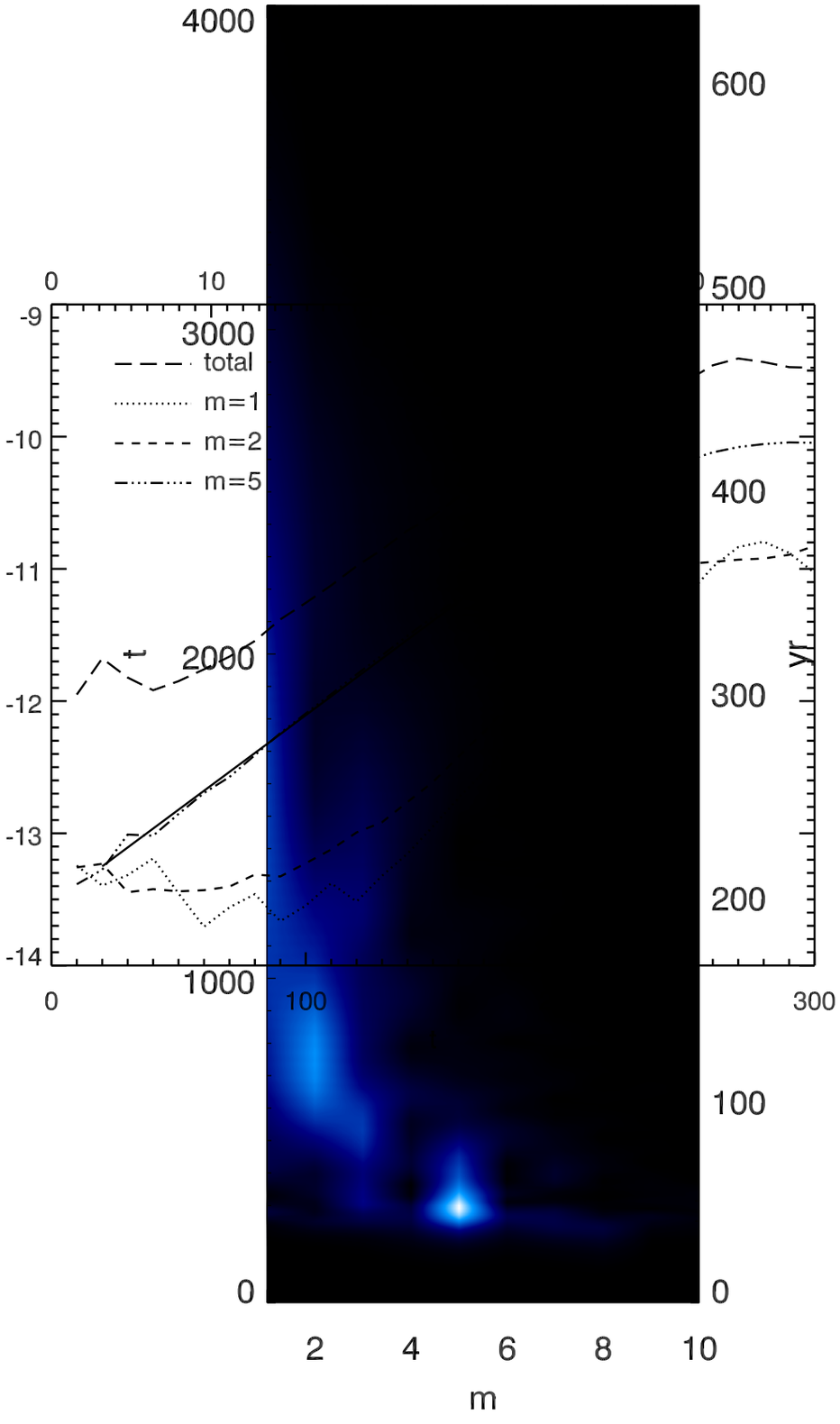
ρ

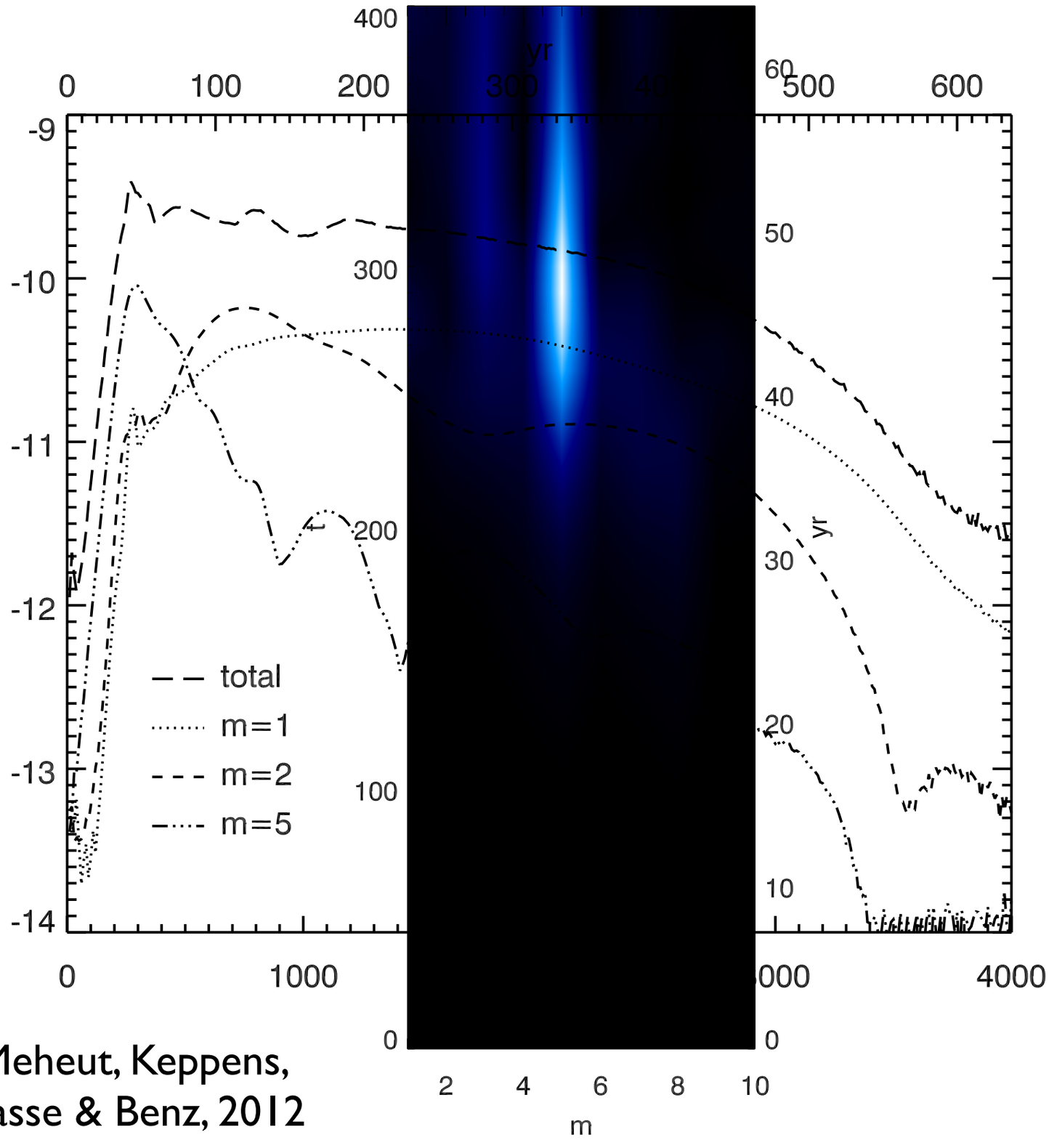
$\rho - \rho_0$
& perturbed streamlines

vortensity



Modes growth



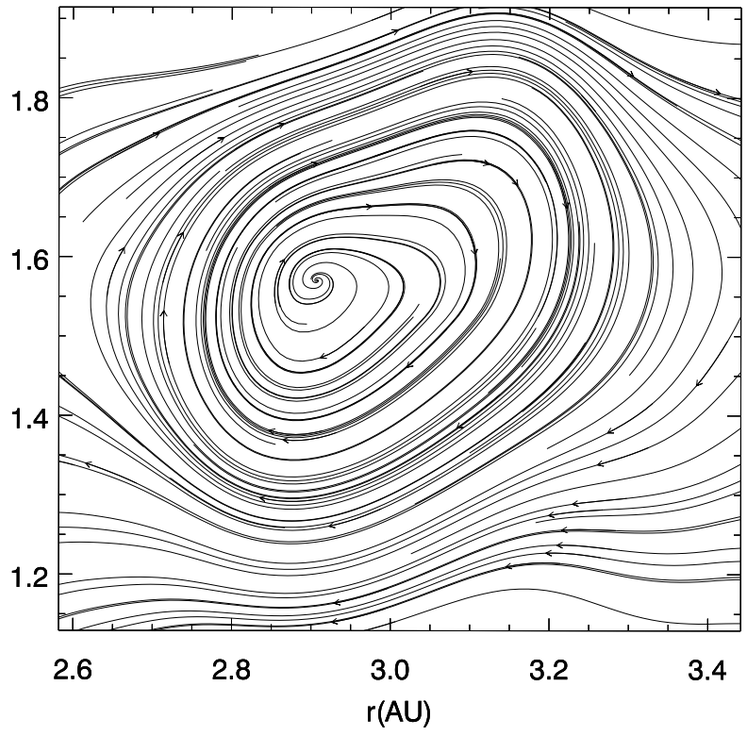


Meheut, Keppens, Casse & Benz, 2012

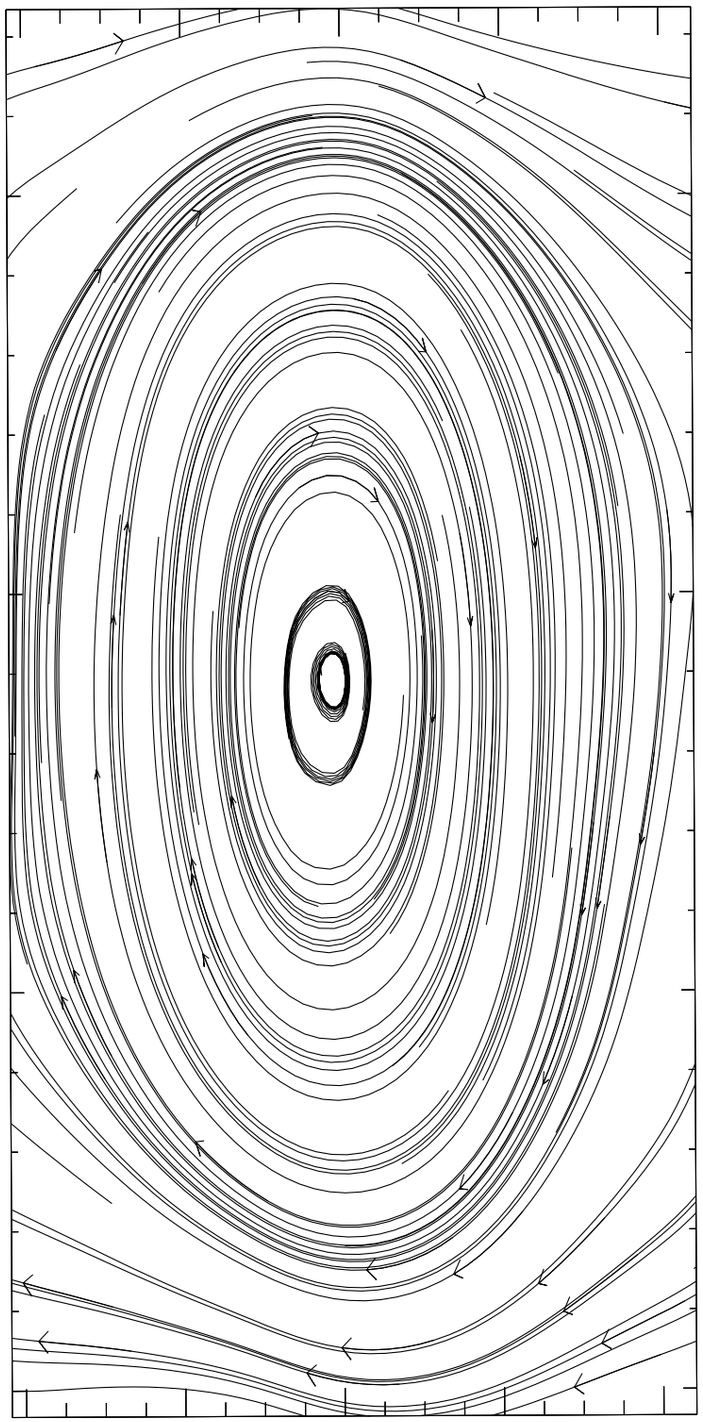
heloise.meheut@space.unibe.ch

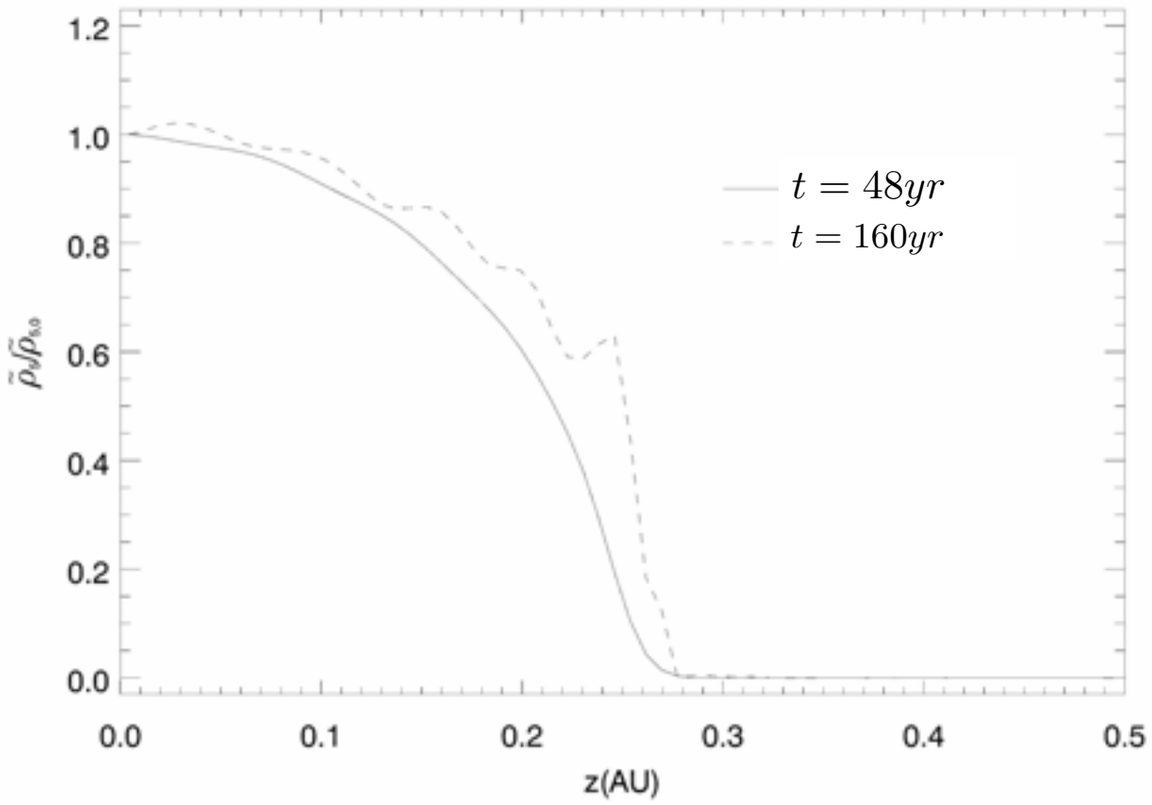
Vortices shape

$t = 48yr$



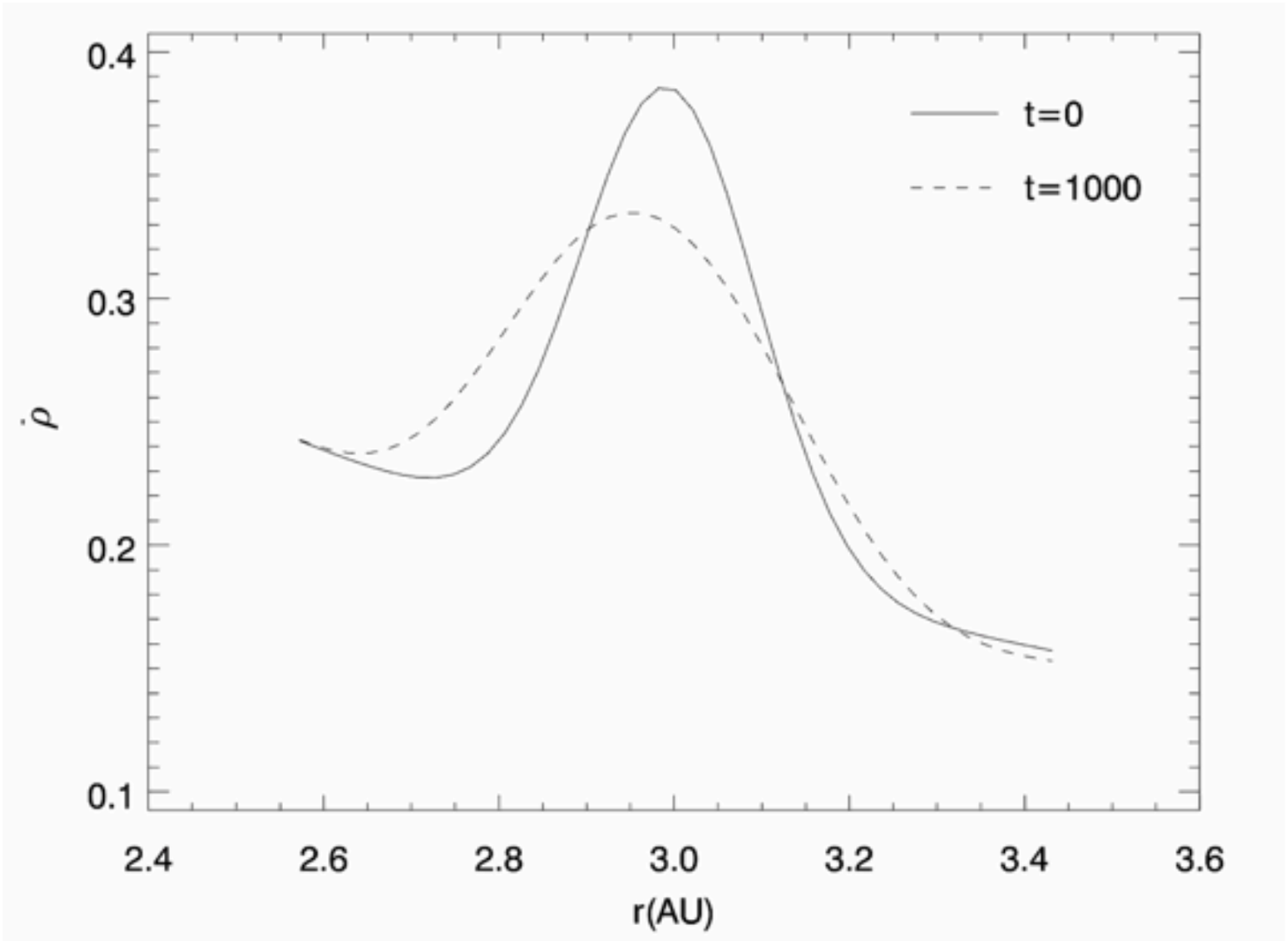
$t = 160yr$



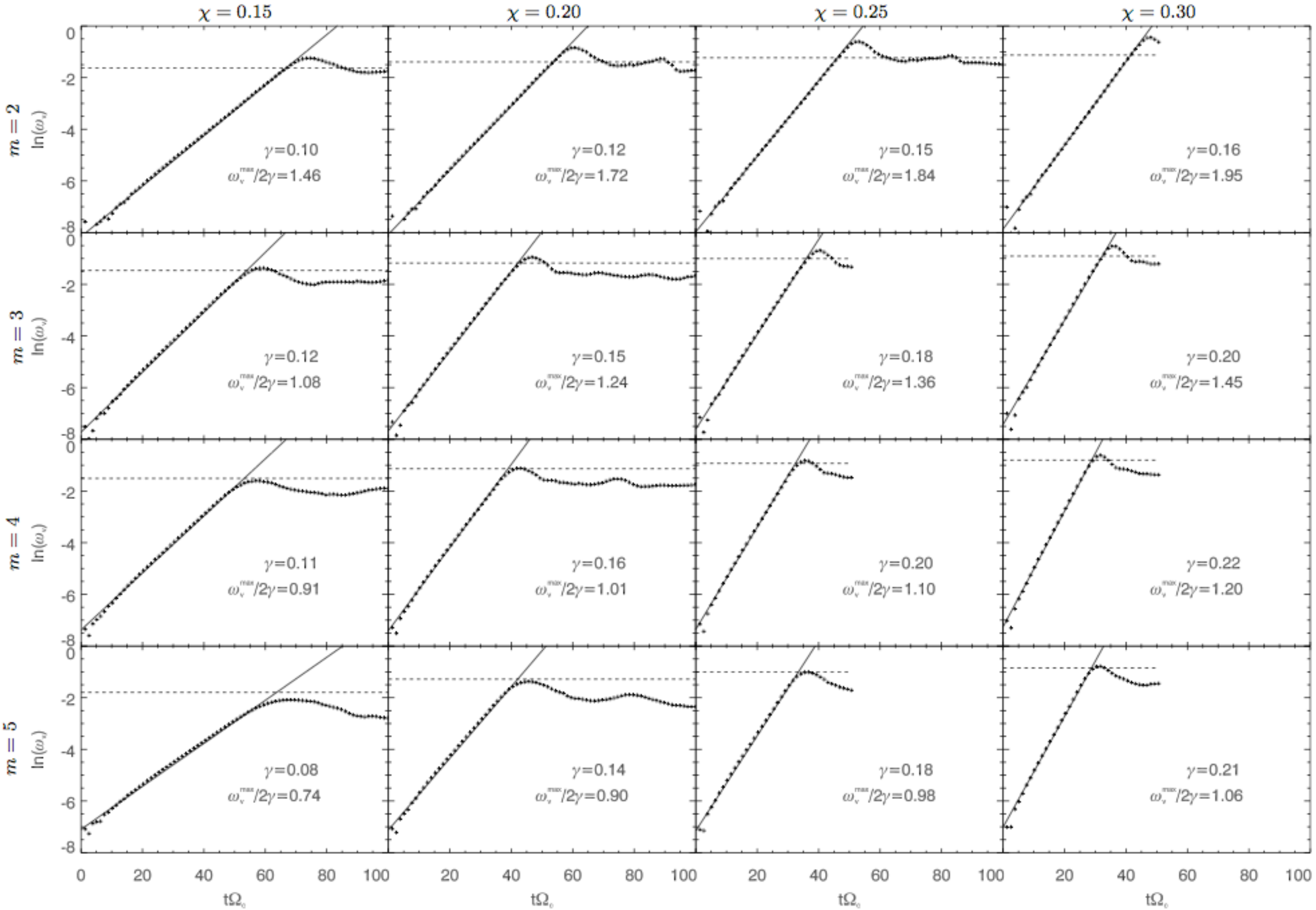


Outlooks

- Rossby vortices can grow and survive in protoplanetary discs
- If RWI sustained, 3D streamlines, no elliptical instability
- No migration



Concentration of solids in the vortices?


$\chi = 0.15$
$\chi = 0.20$
$\chi = 0.25$
$\chi = 0.30$
$m = 2$
$m = 3$
$m = 4$
$m = 5$
$\ln(\omega_v)$
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
0
-2
-4
-6
-8
0
20
40
60
80
100
$t\Omega_0$

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
- Turnover timescale ~ half the vorticity