Planet migration with gravitationally unstable gaps

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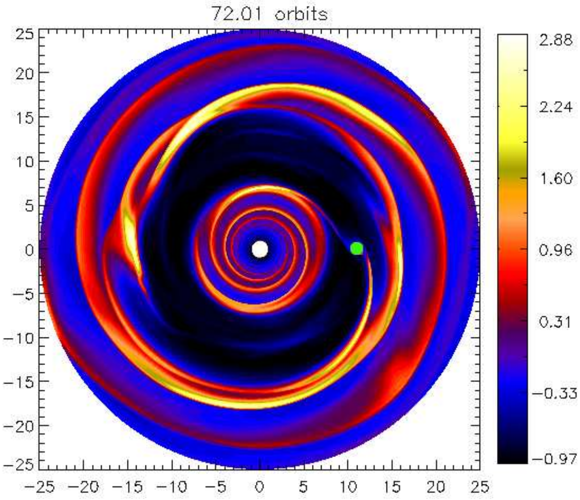
Last time



- Massive planet & massive disc
- Planet migrates *outwards*

Outline

Part I:

- Review of instability
- Numerical results
- A fiducial case
- Discussion and future work

Part II:

- Validating the use of 2D discs

Gravitational instability in structured discs

- Level of self-gravity (SG) usually measured by Toomre Q:

$$Q \equiv \frac{c_s \kappa}{\pi G \Sigma}$$

- Locally Toomre unstable if $Q \lesssim 1$.

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- Level of self-gravity (SG) usually measured by Toomre Q:

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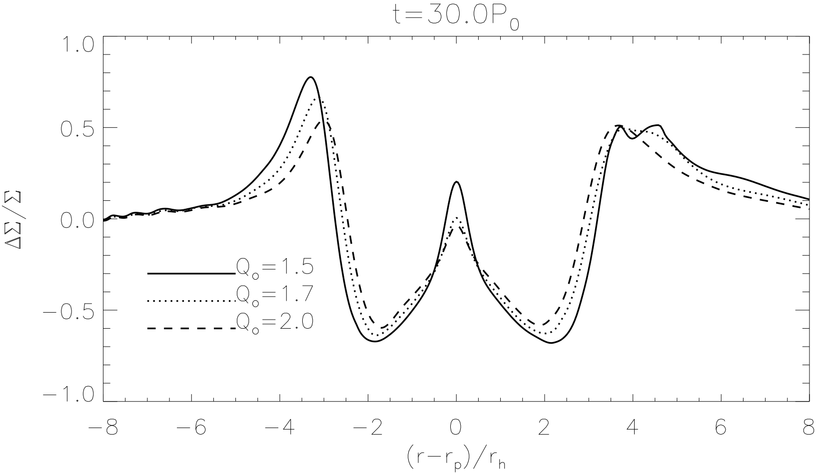
- Locally Toomre unstable if $Q \lesssim 1$.
- Discs can be unstable if it has radial structure. An important quantity is the vortensity profile η:

$$\eta \equiv \frac{\kappa^2}{2\Omega\Sigma}$$

- Instabilities associated with $\min(\eta)$ or $\max(\eta)$.

Application to planetary gaps

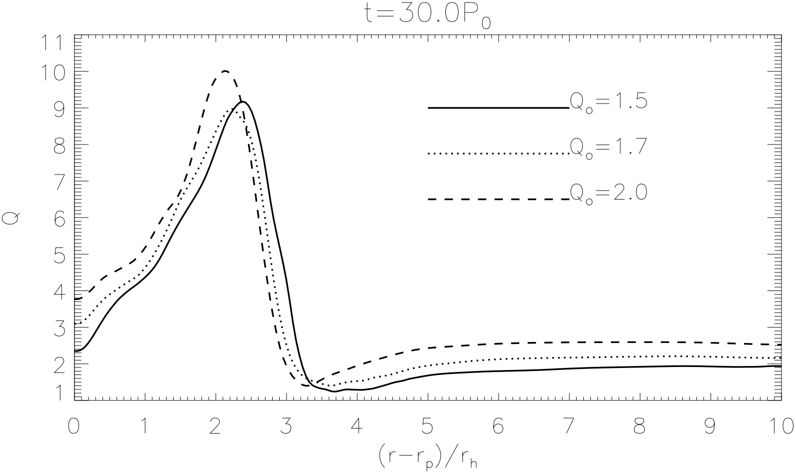


Q_o paramterises disc models (inversely proportional to disc mass).

- Gap GI first suggested by Meschiari & Laughlin (2008)
- Explicitly confirmed by Lin & Papaloizou (2011a)

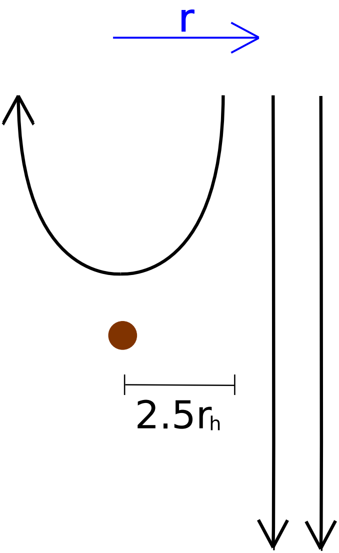
Application to planetary gaps

- Global instability associated with $\max(\eta)$, equivalent to $\max(Q)$ for gaps.



- Disturbances inside the gap edge

The co-orbital region



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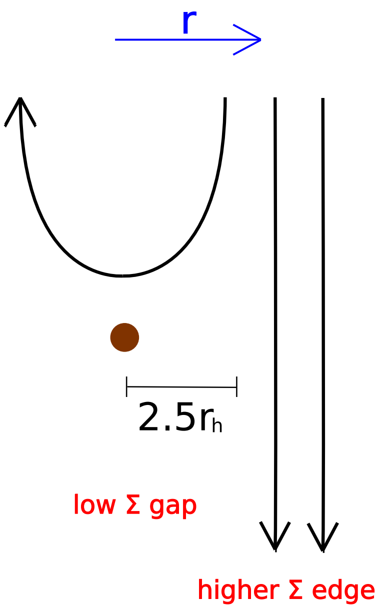

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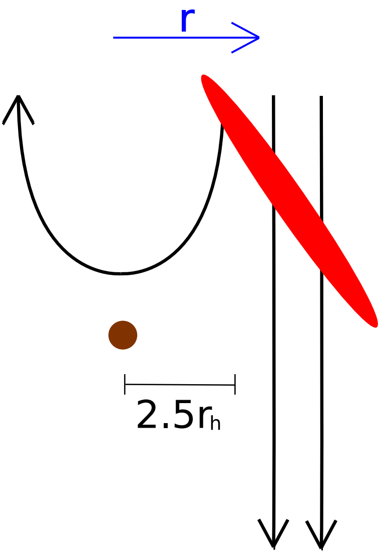
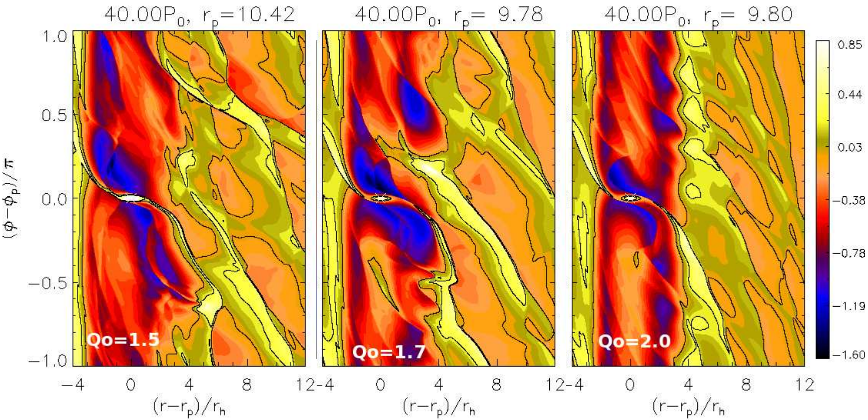


Numerical experiments

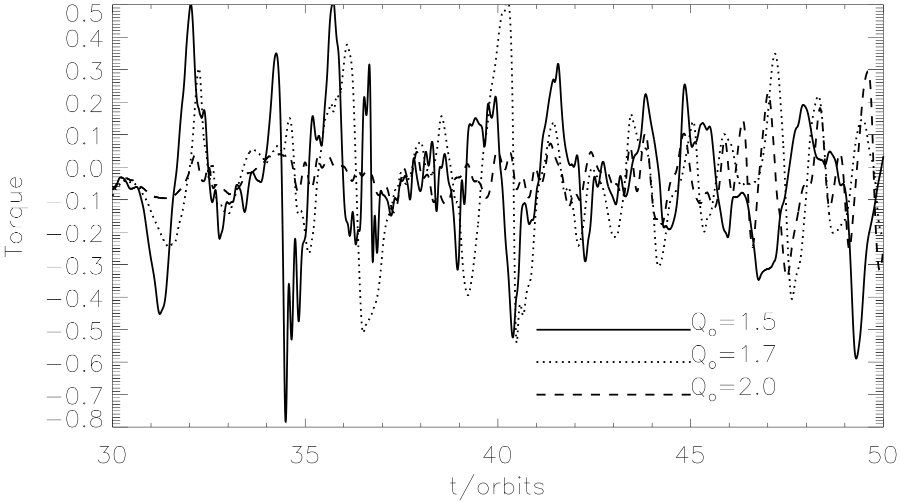
- 2D self-gravitating disc-planet simulations
- Three disc masses: $M_d/M_* = 0.06,\ 0.07,\ 0.08$
  $(Q_o = 2.0,\ Q_o = 1.7,\ Q_o = 1.5)$
- 2-Jupiter mass planet $(M_p/M_* = 0.002)$ initially at $r = 10$
- Domain $r = [1, 25]$, resolution $N_r \times N_\phi = 1024 \times 2048$ (28 cells per Hill radius)

Unstable gaps & migration

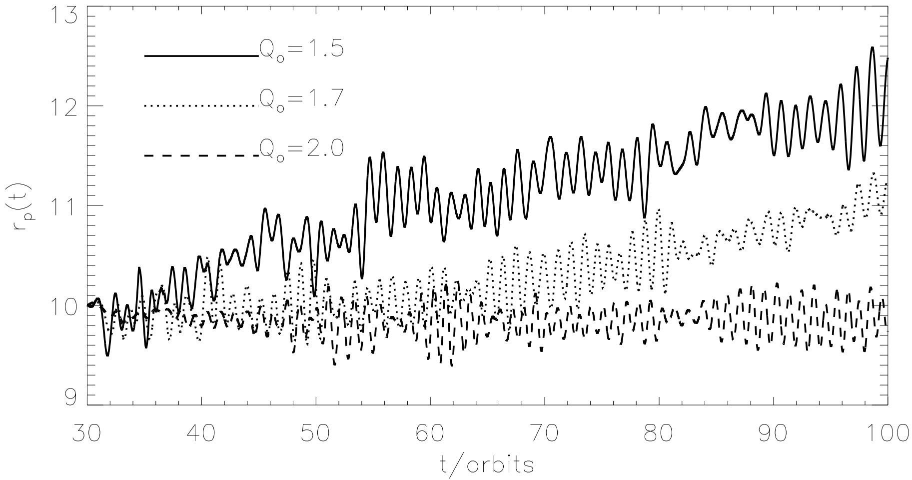


- $\log\left[\Sigma/\Sigma(t=0)\right]$ plotted

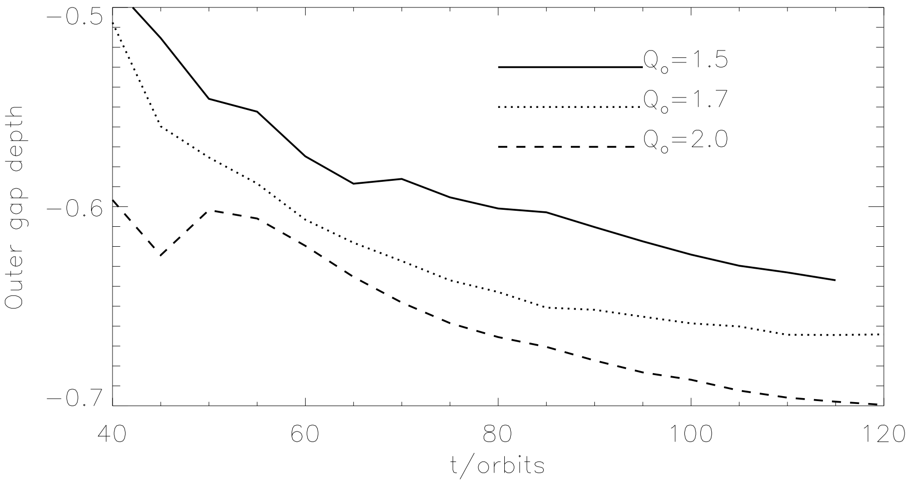
Unstable gaps & migration



Unstable gaps & migration

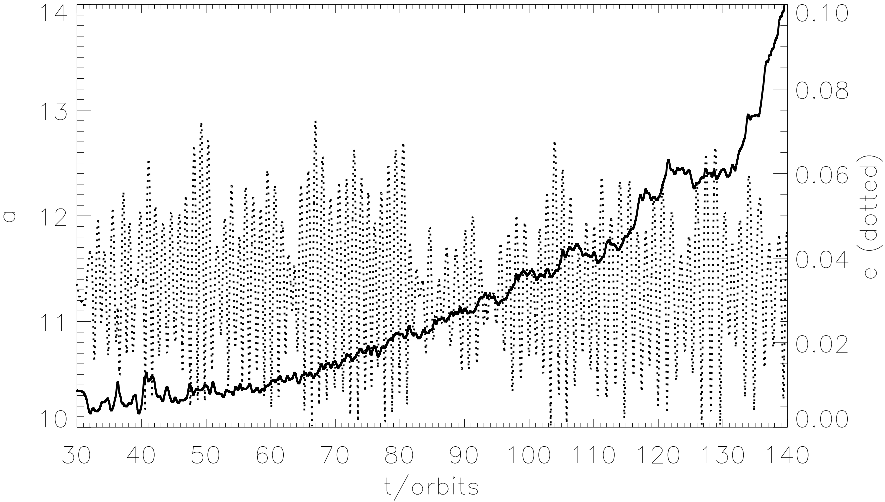


Gap evolution

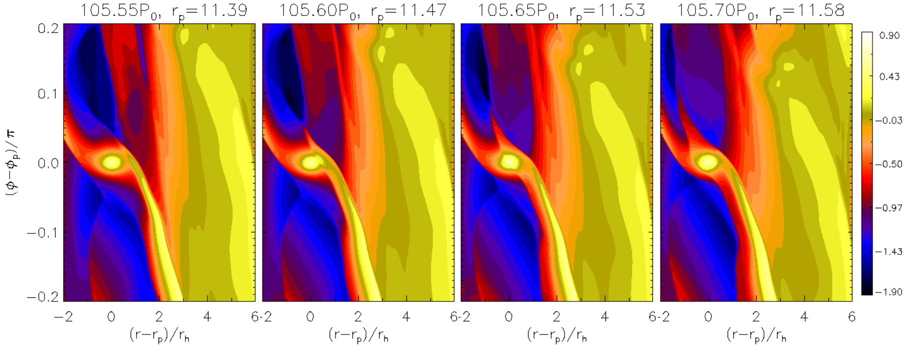


- Gap is more shallow with increasing instability

The $Q_o = 1.7$ case

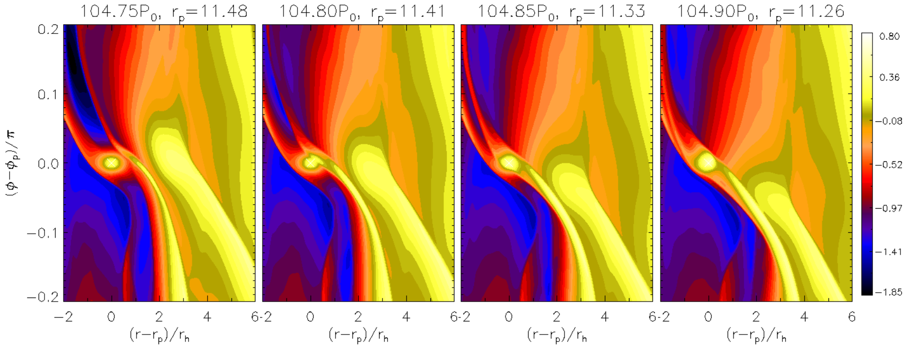


Passage of spiral arms



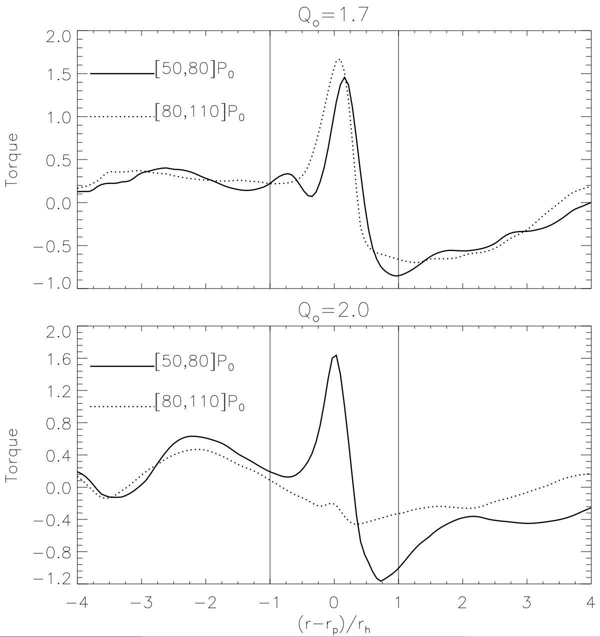
- Instability sends material to the planet for interaction

Passage of spiral arms



- Show movie

Co-orbital torques



Discussion & future work

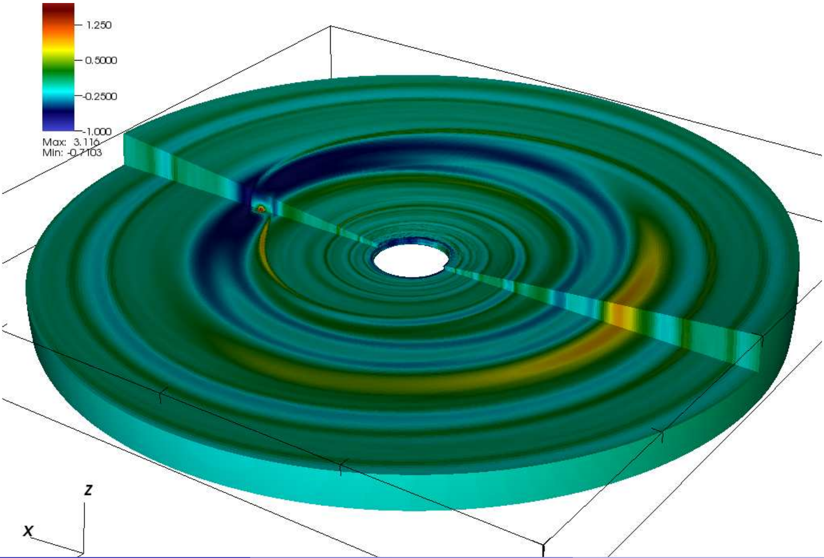
- Migration in massive discs: Baruteau et al. (2011); Michael et al. (2011)
- Migration of stars in black hole accretion discs (e.g. McKernan et al., 2011)
- Parameter study

Three-dimensional discs

- All previous works on gap stability use 2D disc models (Lin & Papaloizou, 2010, 2011a,b)
- Verify with counterpart 3D simulations
- `ZEUS-MP` code: add planet and boundary potential solver

Vortex-induced migration

- Lin & Papaloizou (2010): vortex formation at gap edges in low viscosity discs
- Non-monotonic migration: discrete jumps in orbital radius



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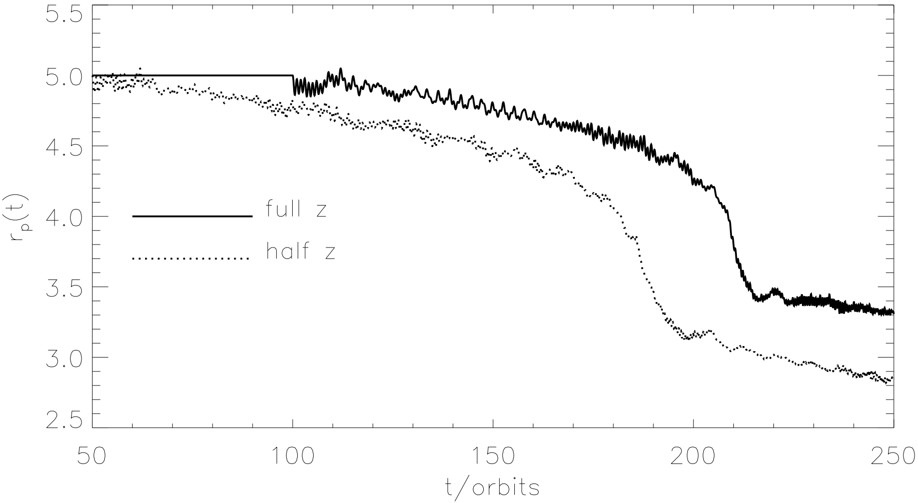

Vortex modes in 3D self-gravitating discs

- Lin & Papaloizou (2011b): more vortices with increasing SG, and
- Resisted vortex merging with increasing SG

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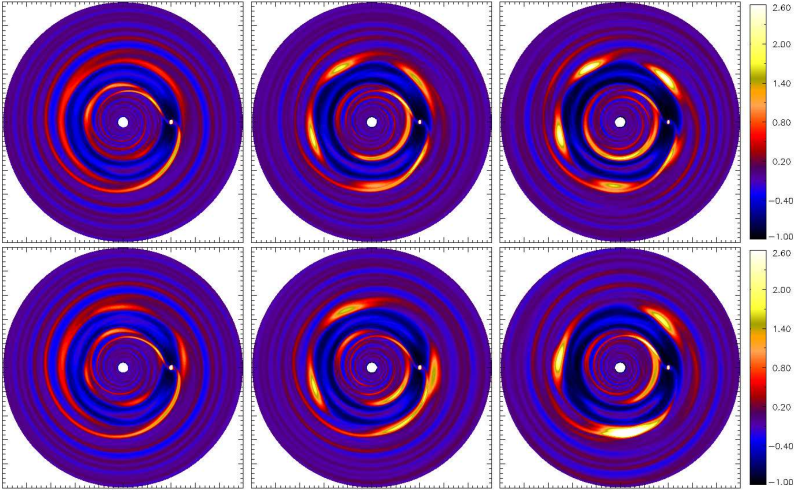
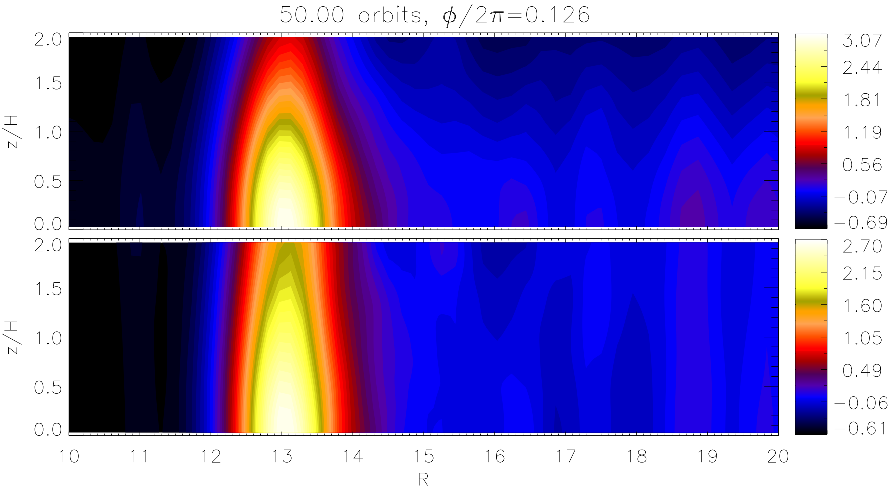


- Top: $Q_o = 4.0$, bottom $Q_o = 8.0$.

Vertical structure

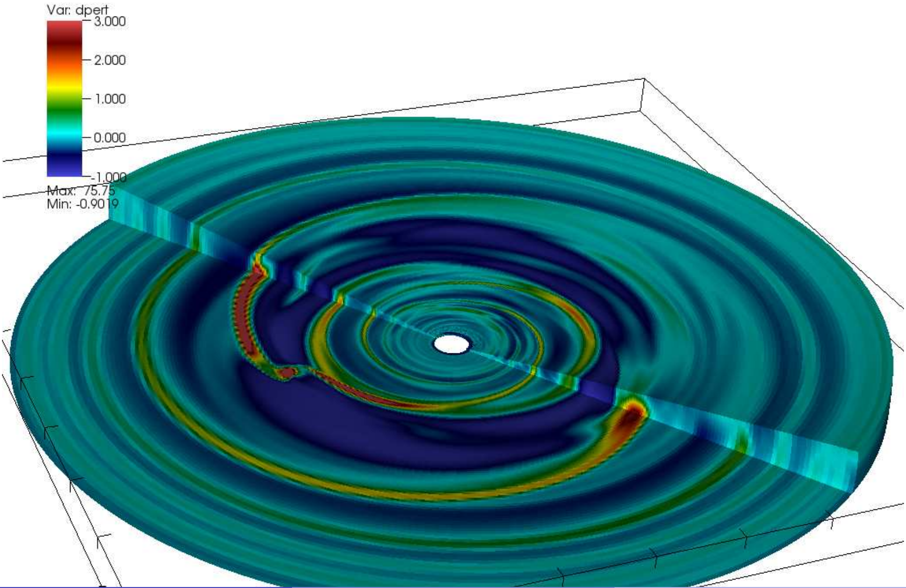
- Relative density perturbation in $R - z$ plane



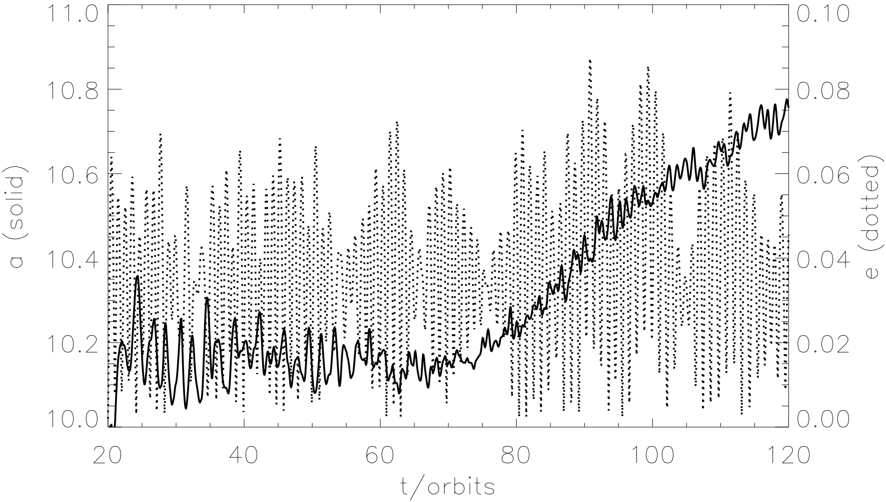
- Top: relative to non-SG background, bottom: relative to SG background

Gravitational instability of gaps

- Lin & Papaloizou (2011a): global spirals attached to gaps in massive discs



Outward migration induced by GI inside gap



Conclusions & future work

- Checked that 2D results persist in 3D

- Vertical boundary conditions
- Self-gravitational collapse of a disc vortex
- Gravitational stability of planetary wakes

- All future simulations will have SG as standard
- Documentation for code modifications

References

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