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2D simulations of dust trapping by self-gravitating vortices

Self-gravity in 2D simulations

To mimic protoplanetary discs evolution, 2D simulations with self-gravity must introduce a softening prescription of the gravitational potential which is proportional to the gas scale height **[1]**.

How correct is this approximation ? Can it be generalised when dust is included ? [2]

From 3D self-gravity to 2D: the smoothing length approach

2D force = Vertical average of the 3D force

$$f_{2D}^{a\to b}(\boldsymbol{r}) = \int_{z=-\infty}^{\infty} f_{3D}^{a\to b}(\boldsymbol{r}, z)\, dz = -\frac{G}{\pi}\Sigma_b(\boldsymbol{r}) \iint_{disc} \frac{\Sigma_a(\boldsymbol{r}')}{H_g(\boldsymbol{r})\, s} L_{sg}^{ab}(d_g, d_b, \eta)\, \boldsymbol{e}_s\, d^2\boldsymbol{r}'$$

with: $d_b = \|\boldsymbol{r}-\boldsymbol{r}'\| / H_b$: normalised distance

*Self-gravity force correction (**SGFC**): exact quantity*

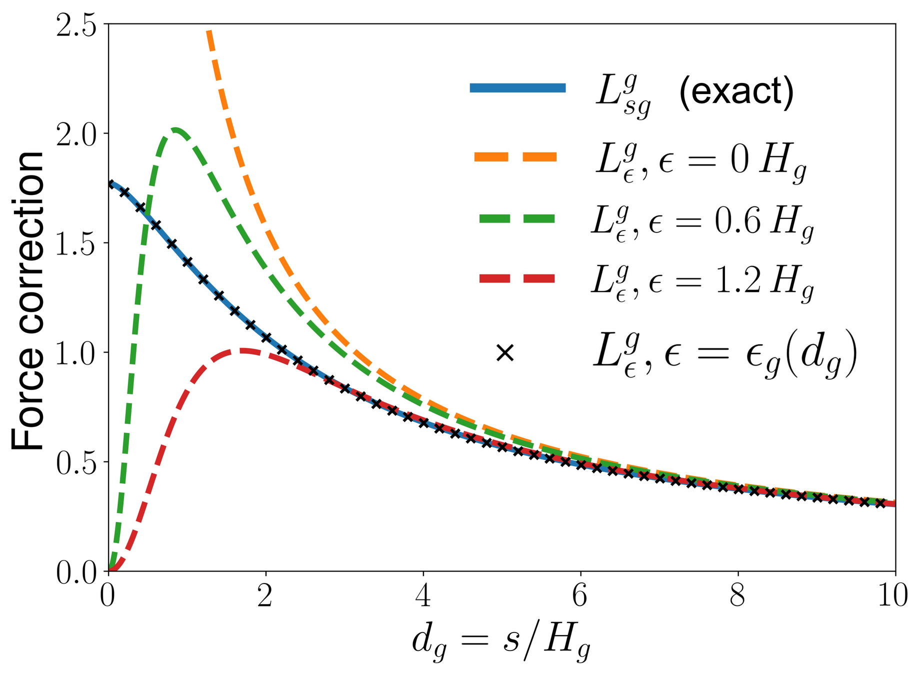
$$L_{sg}^{ab}(d_g, d_b, \eta_{ab}) = \frac{1}{2}\frac{d_b^3(\boldsymbol{r})}{d_g(\boldsymbol{r})} \iint_{u,v=-\infty}^{+\infty} \frac{e^{-\frac{u^2}{2}} e^{-\frac{v^2}{2}}}{[d_b(\boldsymbol{r})^2 + (u-\eta_{ab} v)^2]^{3/2}}\, du\, dv$$

*Smoothing length force correction (**SLFC**): approximation to the SGFC*

$$L_{\epsilon}^{ab} = \frac{\pi d_g^2}{\left[d_g^2 + (\epsilon_{ab}(d_g)/H_g(\boldsymbol{r}))^2\right]^{3/2}}$$

In practice, $\epsilon_{ab}/H_g = const. = 0.3 - 0.6$

The standard smoothing length highly underestimates self-gravity



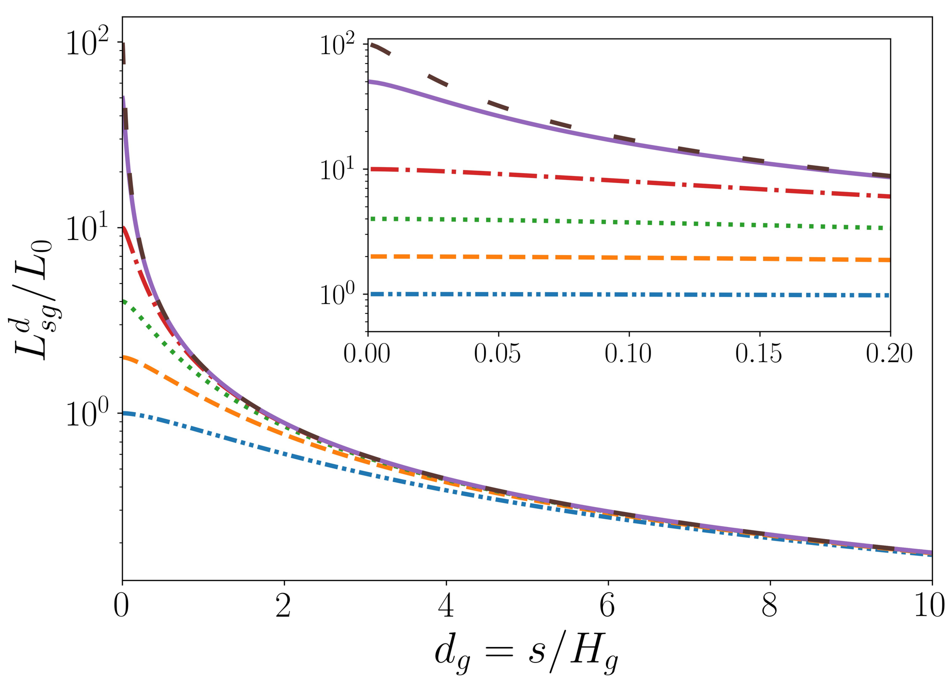
Self-gravity approximation with different smoothing lengths

Standard approx. $\epsilon_{ab}/H_g = const.$ → Two fluid elements separated by less than $1.5\, H_g$ don't feel their mutual gravity !

A space varying smoothing length should be used instead

$$\epsilon_g(d_g) = \sqrt{2}\, H_g(\boldsymbol{r}) \left[1 - \exp\left(-\frac{\epsilon_{g,0}}{\sqrt{2}} d_g^{2/3} - \alpha d_g^n\right)\right]$$

Generalisation of the smoothing length approach to bi-fluids



Dust self-gravity with respect to the gas-to-dust scale height η

Dust self-gravity is proportional to: $\eta = H_g/H_d$

→ Dust self-gravity is high for thin discs (low viscosity)

Take-home messages

- Self-gravity underestimated
- Corretion requires a space varying smoothing length
- If dust: two additionnal smoothing lengths
- Planet migration: adjustment factor $\epsilon/H_g = 0.3$ convenient ?

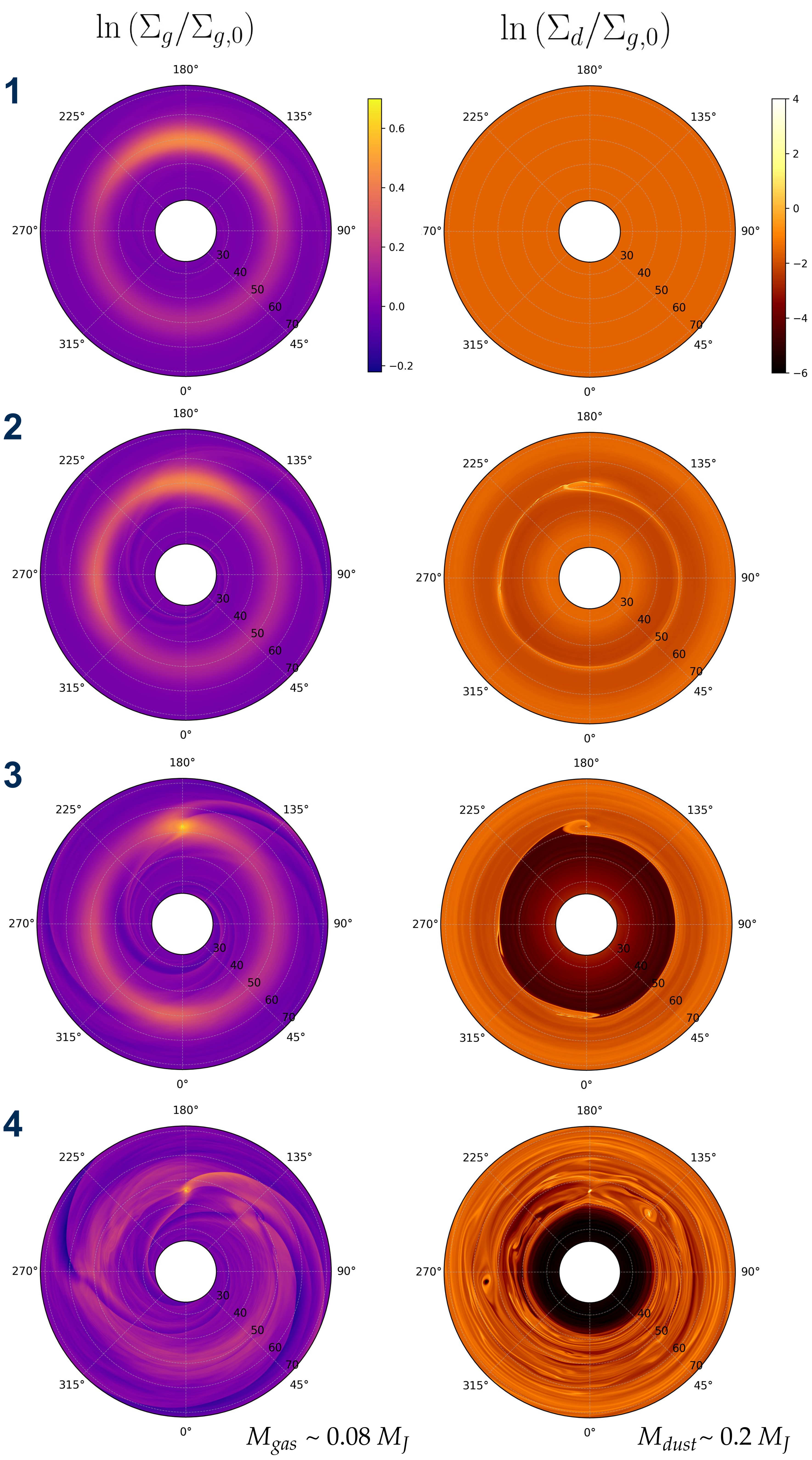
- Correction: clumps formation and gas envelope capture
- Flow circulation in coorbital region, lindblad resonances
- Turbulence ? Migration ? Impact of dust feedback ?

Gas vortices

Large scale vortices are long-lived structures whose main interest is the ability to capture and trap drifting solid particles **[3,4]**. Self-gravity plays a key role in this scenario, since it affects the vortex stability **[5]** and allows captured dust-grains to collapse to form planetesimals or a planet core.

How the smoothing length correction impacts this scenario ?

Global 2D simulations: *RoSSBi3D* [6] (no dust feedback)



1. Initial state: Gaussian vortex + unifrom dust distribution
2. Vortex splitting by a dust clump/filament self-gravity
3. Massive dust clump captures gas envelope
4. Global self-gravitating regime:
- Gas and dust in horseshoe motion
- Lindblad resonances
- Migration ?

References

[1] Müller, et al. 2012, A&A, 541, A123
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[3] Barge, P. & Sommeria, J. 1995, A&A, 295
[4] Fu, W., et al. 2014, ApJ, 795, L39
[5] Rendon Restrepo, S. & Barge, P. 2022, A&A
[6] Rendon Restrepo, S., et al 2022, arXiv

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