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3D simulations of dust trapping in gaseous vortices

Astronomical context

3D vortices generation

Dust **trapping** by **3D vortices**

Possible **observations of vortices**

Tool presentation **RoSSBi 3D**

Bibliography and **acknowledgments**

Aix-Marseille université initiative d'excellence
cnrs
cnes

Astronomical context

Context and challenges

How **gaseous vortices** contribute to build planetesimals and/or gas giants ?

- Before pebbles fall onto the star ? (fragmentation, meter barrier, coagulation)
- Before gas dissipation (few Myr)

Why **vortices** ?

- Natural outcome of hydrodynamical instabilities (RWI, baroclinic, Vertical Shear instability …)
- Persistent quasi-steady structures (more than 1000 orbits) (1)
- Very efficient dust traps (x1000 in vortex center) (2)

Some drawbacks ...

- Dust back-reaction weakens or destroy **2D** vortices if $\sigma_{gas}/\sigma_{dust} \sim 1$ (3)
- **3D** vortices are unstable under elliptical instability (**EI**) for $\chi \lesssim 6$ (4)

But ...

- Destruction vs generation mechanisms ? (5)
- SG can inhibit **EI** in 3D (6)
- **3D vortices are not destroyed by dust back-reaction (7)**
- Existence seems comforted by the observations

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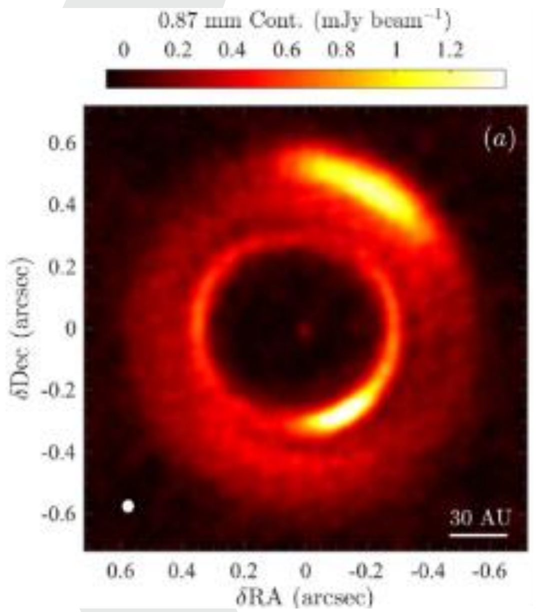
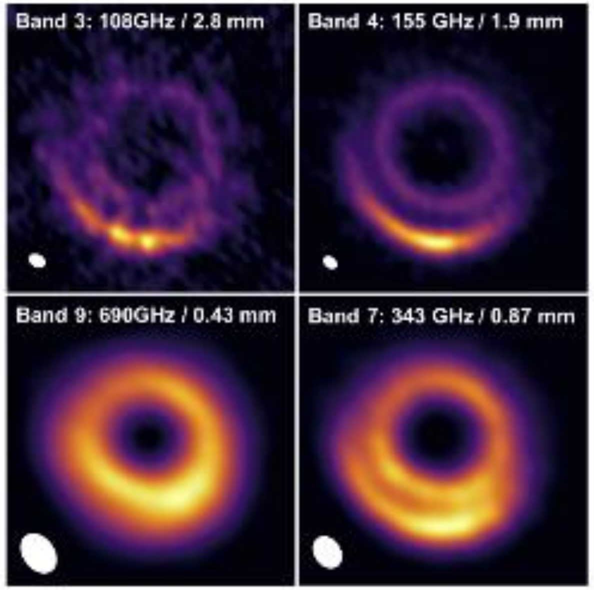
Possible observations of vortices

Excess emissions in the submillimeter-millimeter wavelengths exhibit lopsided regions



(1)



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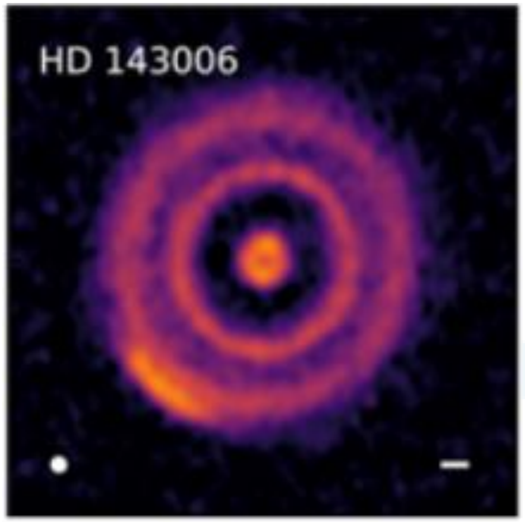

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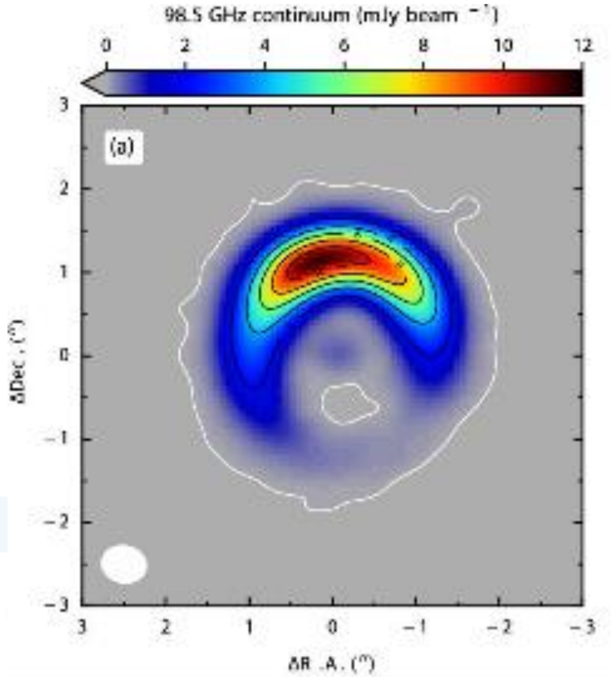

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Tool presentation : RoSSBi* 3D

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Physics

- Fully **compressible inviscid** Euler's equations and continuity equations solved in polar coordinates for an ideal gas.
- **Pressureless particles** in a fluid approximation

Solver

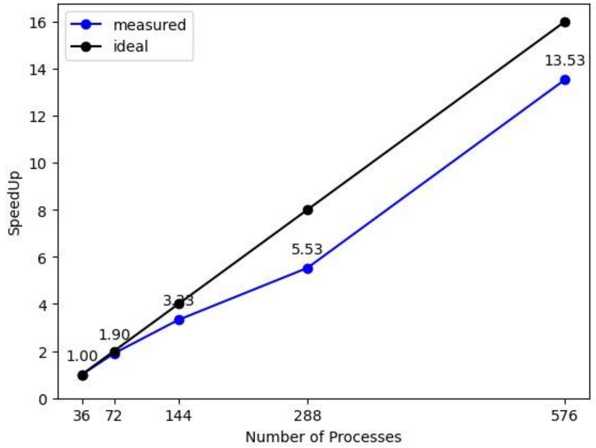
- **Finite volume** method
- **Exact Riemann solver**
- **Second order** Runge-Kutta method
- **Parallelized** in all **3 directions**

Boundary conditions (BC)

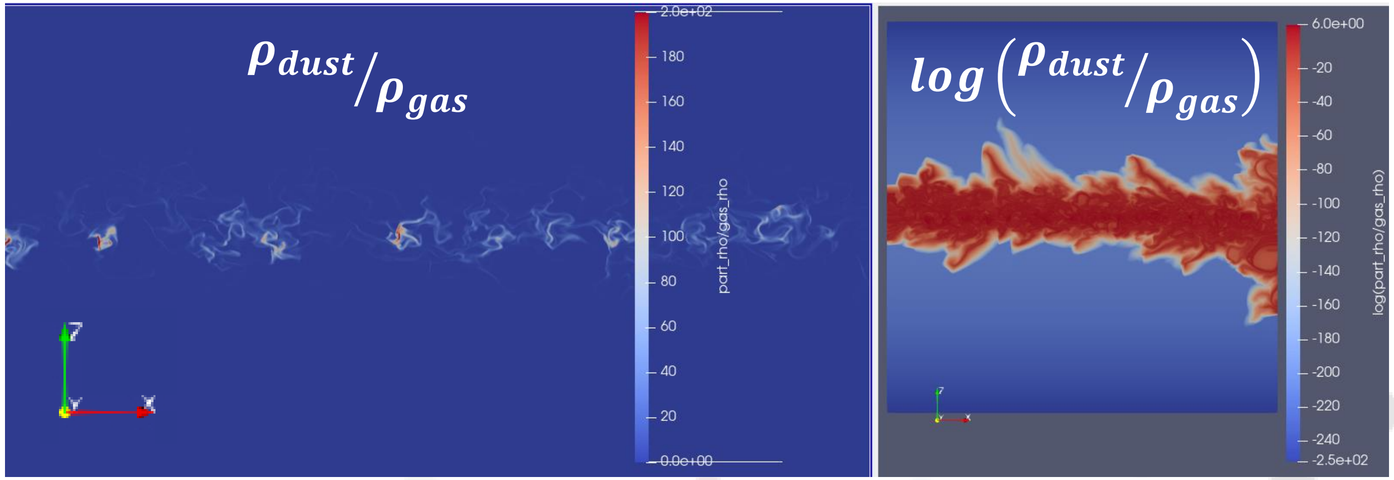
- Radial : 4 ghost cells at each radial numerical domain + **sheared damped** BC
- Azimuth : periodical
- Vertical : **damped** BC/**free** BC

Confirmation of case tests

- Code tested with streaming instability (**SI**) , RWI and dust trapping mechanism



3D code scalability
(POP2 audit)



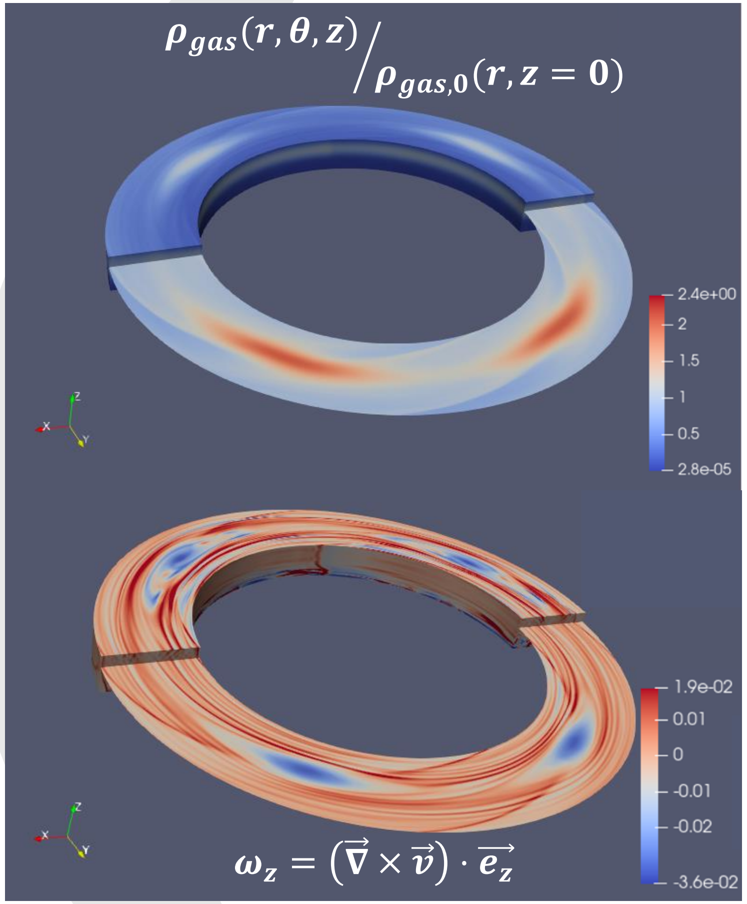
Confirmation of the code validity by a test case : SI

Dust-to-gas ratio. Left : Zoom in the midplane region.
Right : Same but for all the simulation box and in log scale.

*Rotating Systems Simulation Code for Bi-fluids

3D Vortices generation

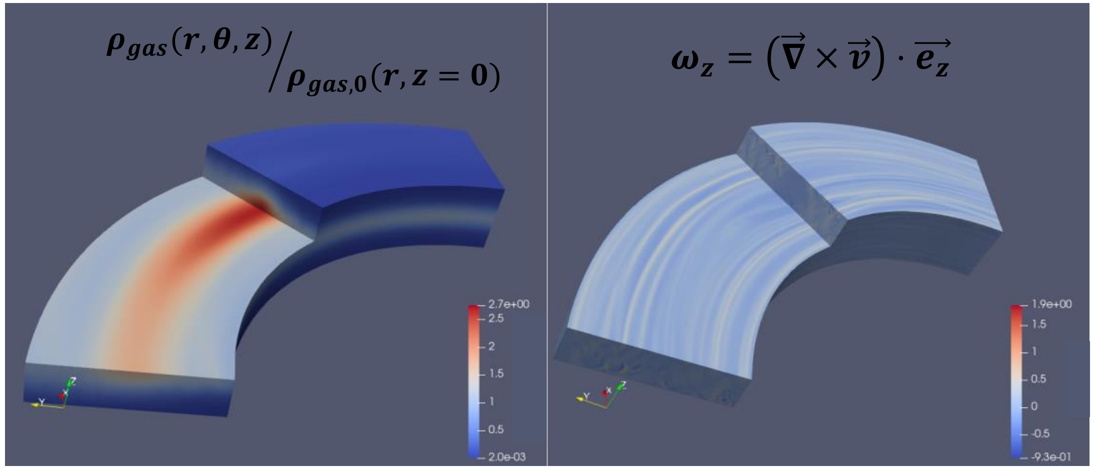
Rossby Wave Instability (RWI)



Gas density and vorticity for a 4 mode Rossby Wave Instability

Click on the images for downloading the video

Inject a quasi-steady column solution in a box



Gas density and vorticity for a **column gaussian** vortex

Advantages : control vortex parameters, save computational time (no instability saturation), better azimuth resolution

Many **hydrodynamical instabilities** generate **vortices** in Protoplanetary discs : Convective overstability, RWI (1), Vertical Shear Instability etc. (2)

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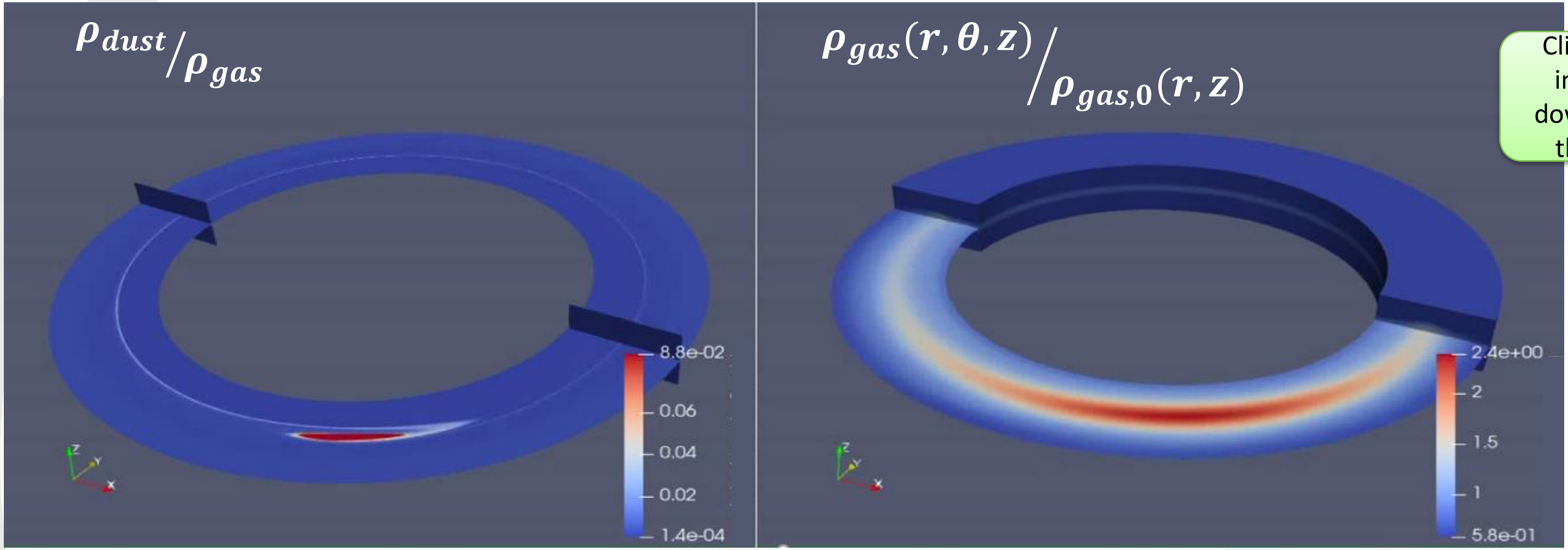
Notes

- Vertically damped BC can affect vortices life-time. Better = free BC
- Reflective BC in z=0 plane
- T_{total} = 185 orbits, $r \in [6,9]$ AU
- $h = H_g/r_0$ = 0.05 : disc flaring

Dust trapping by 3D vortices



Click on the image for downloading the video

Gas density and dust-to-gas ratio with respect to time

Two main steps :

1. Dust sediment in the midplane in a thin layer : $H_d \sim 0.005\ H_g$
2. Sedimented dust is captured by the vortex in the midplane region

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Notes

- The scale is not updated at each frame. At the end the dus-to-gas ratio is 2.7 in the vortex core
- $T_{total} = 148\ T_0$, $r \in [6{,}9]$ AU
- $St = 0.5$: Stokes number
- H_g=0.375 AU : Pressure scale height
- $T_0 = 20.5$ yr
- $h = H_g/r_0 = 0.05$: disc flaring

Bibliography and acknowledgments

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