EPSC Abstracts
Vol. 6, EPSC-DPS2011-1059, 2011
EPSC-DPS Joint Meeting 2011

Structure of three dimensional Rossby vortices

H. Meheut (1), P. Varniere (2), F. Casse (2) and M. Tagger (3)
(1) Physikalisches Institut, Universität Bern, 3012 Bern, Switzerland (meheut@space.unibe.ch), (2) AstroParticule & Cosmologie (APC), UMR7164, Université Paris Diderot, 10 rue Alice Domon et Leonie Duquet, 75205 Paris Cedex 13 (3) Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E), Université d'Orléans/CNRS, France

Abstract

Vortices have been proposed as a solution to the "meter-size barrier" in the context of planetesimals formation. Indeed vortices may concentrate the solids in their centres and accelerate grain growth. By this mean, grains may overcome this size barrier without falling onto the central star due to gas drag. The Rossby Wave Instability (RWI) may be a solution to form such vortices again the destructive effect of differential rotation. We present here the first three dimensional (3D) simulations of the instability with an adaptive mesh refinement (AMR) code.

1. Introduction

One of the most unclear stage for planet formation in the core accretion scenario is the formation of planetesimals. The difficulty resides in the rapid drift of solid grains toward the central star, on a timescale highly to small to explain their growth up to size where the velocity drift starts to decrease. One of the proposed solution postulates the trapping of dust in vortices [1, 2]. However the differential rotation tears the vortices away and one need a stabilising mechanism such as the RWI [4]. Previous studies have shown that this instability can grow at the edge of the poorly ionised region of the disc ("dead-zone") [7] and that the Rossby vortices effectively concentrate the grains [5]. But it is only recently that a full 3D approach has been proposed [6], and it is a more detailed study that we present here.

2. Methods

The initial conditions are similars to the ones presented in [6]. It is an axisymmetric disc with a density decreasing with radius: $\rho = \rho_i/\sqrt{r}$ on top of which we added a gaussian bump at a radius of $3r_i$. The density is normalised to its value ρ_i at the inner edge of the simulation (r_i). We use cylindrical coordianates (r, ϕ, z). The vertical structure of the disc is determined by hydrostatic equilibrium. The poloidal velocity is chosen to balance the central star gravitational potential and the pressure gradient. There is no initial vertical velocity, and small perturbations are introduced in the radial velocity as a sum of the first five modes with an amplitude $v_r/v_\phi(r_i) = 10^{-3}$. The fluid equations are solved with MPI-AMRVAC [3] with 3 levels of refinement and a maximum resolution corresponding to $(256, 64, 64)$ in the region of the bump. The evolution of the instability is computed over $\sim$ 128 orbits at the inner edge which correspond to $\sim$ 40 orbits at the bump radius.

3. The Rossby Wave Instability

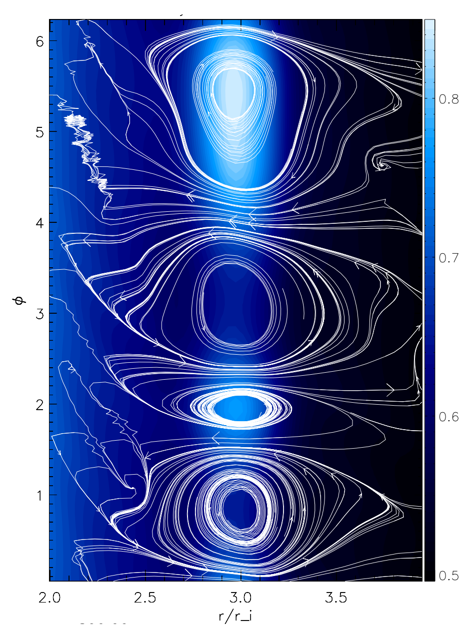

Figure 1: Structure of the vortices in the disc midplane after $\sim$ 40 orbits: *in colors* gas density and *in white* perturbed velocity streamlines.

Fig. 1 show that the nearly axiymetrical initial conditions have lead to the formation of vortices due to the RWI. The anticyclonic vortices are rotating clockwise and are at the location of high density regions.

3.1. Growth

The different stages of the instability are shown on Fig. 2. In the first stage, the initial perturbations corresponding to stable modes decrease whereas the unstable modes start to grow. When the unstable modes overcome the others, the instability reaches the linear phase corresponding to an exponential growth. A fit of the exponential growth is given in Fig. 2, with a growth rate of 0.29. Then, when the perturbations reach high amplitude (a few % of the unperturbed density), the instability becomes non linear and saturates.

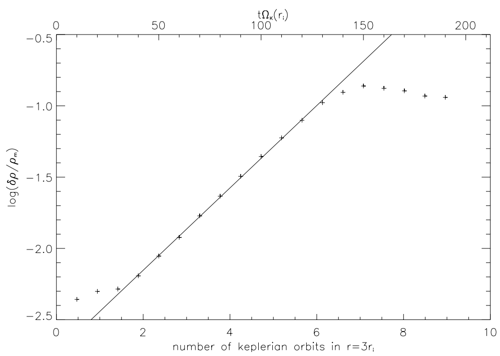

Figure 2: The three stages of the instability. This figure shows the amplitude of the perturbations in a logarithmic scale in function of time. The linear phase is fitted with a growth rate of $0.29\ \Omega_K(r_i)$.

3.2. Vertical structure

This 3D simulations allow to investigate the verticale structure of the vortices. The Rossby vortices appeared to have a full 3D structure that can not be reduced in a bi-dimensional approximation. Vertical movements exist in these structure with upstream velocity in the anticyclonic vortices and downstream velocity in the others. Moreover vertical rolls appear inside the vortices structure as can be seen on Fig. 3.

4. Summary

This new simulations have shown the 3D structure of the Rossby vortices, including vertical displacements inside the vortices. Such structures are of peculiar interest in the context of planetesimals formation as they

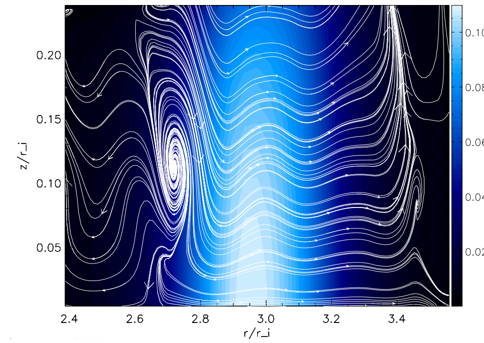

Figure 3: Vertical cut in the middle of a vortex: density and perturbed velocity streamlines in the plane (r,$\phi \sim 5.5$,z). The vertical direction is stretched to have a better visualisation of the structures.

can modify our understanding of solid concentration in vortices. The use of an adaptive mesh refinement code open the possibility to have very high resolution vortices and if couple to a bi-fluid module to follow the evolution of solids in 3D with high precision.

References

[1] P. Barge et J. Sommeria. Did planet formation begin inside persistent gaseous vortices? *A & A*, 295:L1–L4, 1995.

[2] A. Johansen, A. C. Andersen, et A. Brandenburg. Simulations of dust-trapping vortices in protoplanetary discs. *A & A*, 417:361–374, 2004.

[3] R. Keppens, Z. Meliani, A. van Marle, P. Delmont, A. Vlasis, and B. van der Holst. Parallel, grid-adaptive approaches for relativistic hydro and magnetohydrodynamics. *Journal of Computational Physics*, In Press, Corrected Proof:–, 2011.

[4] R. V. E. Lovelace, H. Li, S. A. Colgate, et A. F. Nelson. Rossby Wave Instability of Keplerian Accretion Disks. *ApJ*, 513:805–810, 1999.

[5] W. Lyra, A. Johansen, A. Zsom, H. Klahr, et N. Piskunov. Planet formation bursts at the borders of the dead zone in 2D numerical simulations of circumstellar disks. *A & A*, 497:869–888, 2009.

[6] H. Meheut, F. Casse, P. Varniere, et M. Tagger. Rossby wave instability and three-dimensional vortices in accretion disks. *A & A*, 516:A31+, 2010.

[7] P. Varnière et M. Tagger. Reviving Dead Zones in accretion disks by Rossby vortices at their boundaries. *A & A*, 446:L13–L16, 2006.