Vortex formation and evolution in discs under thermal relaxation and with a high mass planet embedded

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Abstract

Vortices are structures that can be formed in several fluid systems. In the particular case of a protoplanetary disc they are known to play a role for planet formation, angular momentum transport, and type I migration. In this project we study the formation and evolution of vortices induced by a high mass planet embedded in a disc under thermal relaxation. For this purpose we perform 2D–HD simulations of planet–disc interaction using the PLUTO code. We study the lifetime of vortices as a function of the cooling timescale. Additionally we model the Oph IRS 48 system, a place where a vortex is claimed to be detected by the Atacama Large Millimeter/submillimeter Array (ALMA).

Why are vortices important?

- Planet formation
  Possible solution for the radial drift barrier.
- Angular momentum transport
  Responsible for turbulence in dead zones.
- Type I migration
  Trap planet cores, reducing migration rate.

Observational evidence

Dust asymmetries observed with ALMA in the systems:

- LkHα (Isella et al. 2013)
- Oph IRS48 (van der Marel et al. 2013)
- HD 142527 (Casassus et al. 2013; Fukagawa et al. 2013)
- SAO 206462 (Pérez et al. 2014)
- SR 21 (Pérez et al. 2014)

Simulations

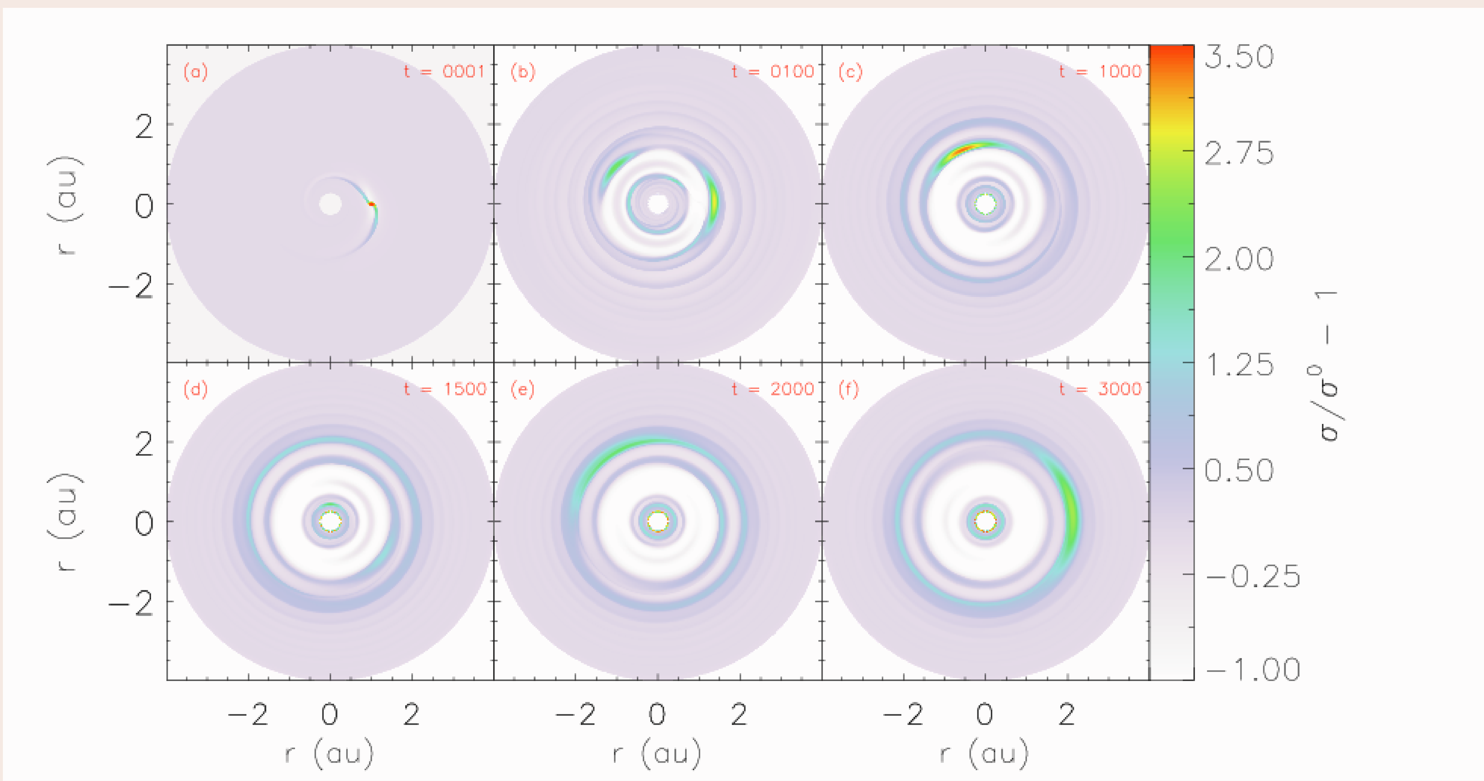
- PLUTO code (Mignone et al. 2007)
- Global hydrodynamical (HD) simulations
- Planet–disc approach from Uribe et al. (2011) + thermal relaxation
- 2D in polar coordinates
- Resolution: $(N_r, N_\phi) = (512, 1024)$
- Disc: $\sigma \propto r^{-\delta}$, $c_s \propto r^{-\beta}$, and $H/R = 0.05$

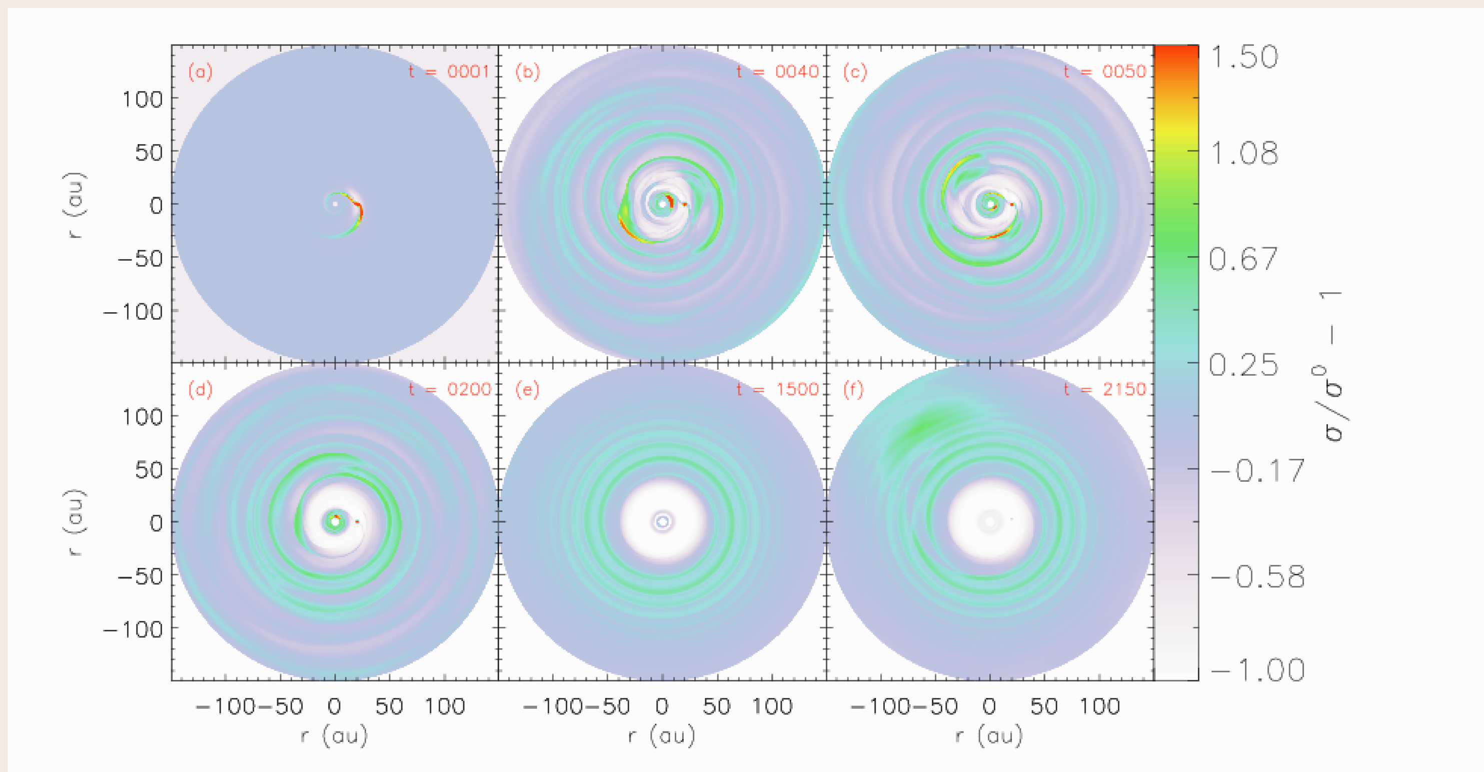
Label	M_*/M_p	R_p (au)	$\tau_{\rm relax}$ $(2\pi/\Omega_o)$	δ	β	$(R_{in}, R_{out})(au)$	time $(2\pi/\Omega)$
TR001	1×10^{-3}	1.0	0.01	1.5	0.5	(0.25,4.0)	3000
TR01	1×10^{-3}	1.0	0.1	1.5	0.5	(0.25,4.0)	3000
TR1	1×10^{-3}	1.0	1.0	1.5	0.5	(0.25,4.0)	3000
TR2	1×10^{-3}	1.0	2.0	1.5	0.5	(0.25,4.0)	3000
TR5	1×10^{-3}	1.0	5.0	1.5	0.5	(0.25,4.0)	3000
TR10	1×10^{-3}	1.0	10.0	1.5	0.5	(0.25,4.0)	3000
OphIRS48	5×10^{-3}	20.0	1.0	1.0	0.25	(2.0,150.0)	2150

Goal

Vortices interact with their surrounding fluids in many ways, in an ideal steady–state system they can live forever, however in a viscous system the energy of the vortices can be dissipated and they eventually get damped. Fu et al. (2014) studied the long term evolution of vortices depending on the disc viscosity, disc temperature, and planet mass. In this work we study how cooling, which can also dissipate energy, affects the vortex formation and evolution.

System evolution





Evolution for model TR01:

(a) Spiral waves are formed.
(b) The planet already opened a notable gap;
  Small vortices are formed in the outer edge of the gap.
(c) The small vortices merged into a big one;
  A second gap, carved by the big vortex, stars to be noticeable;
  Accumulation of material in the outer edge of the vortex gap.
(d) The big vortex is almost totally damped.
(e) A vortex–like structure is formed in the outer edge of the vortex gap.
(f) The outer vortex still survive and is even stronger;
  The new vortex is more spread in the azimuthal direction;
  The new vortex is weaker than the inner one was.
  * The other models present similar behavior.

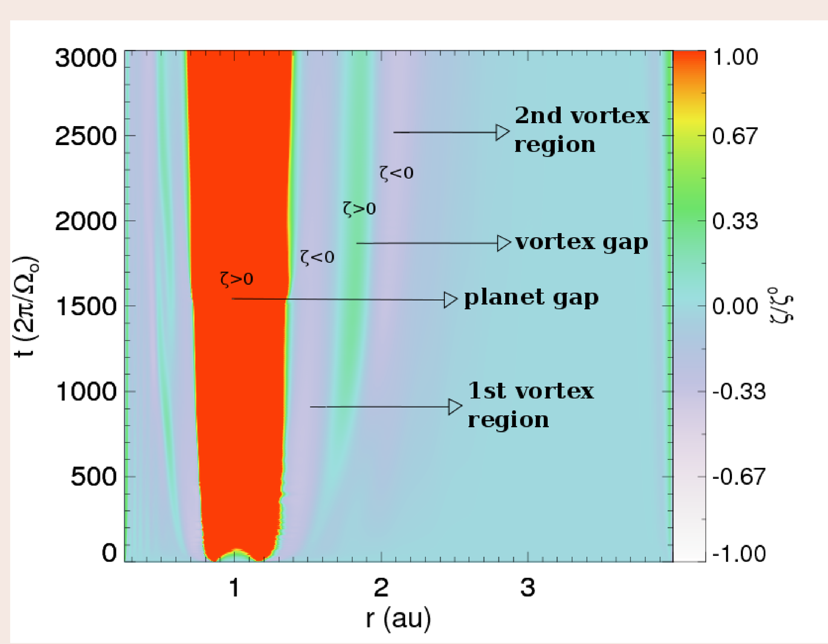
Evolution for model OphIRS48:

(a) Spiral waves are formed.
(b) The planet gap is noteable;
  Two vortices are formed in the outer edge of the gap.
(c) The vortices did not merge, but already decrease intensity.
(d) The vortices are almost totally damped;
  The material is distributed in rings.
(e) The material in the rings is uniformly distributed in azimuth.
(f) An outer vortex covering a very large radius interval is formed;
  The new vortex is not so much spread in the azimuthal direction;
  The new vortex is just a bit weaker than the inner ones were.

Vortex formation

- Product of the Rossby wave instability (RWI).
- How to trigger the RWI?
  - Strong gradient and an inflexion point in the disc's radial potential vorticity (ζ) profile.
  - Physically it can be achieved at:
    ⇒ Edge of a planet gap (de Val-Borro et al. 2007);
    ⇒ Edge of a dead zone due to sharp viscosity transition (Lyra & Mac Low 2012).
- In the space–time evolution plot of ζ (in the right) we can see the two conditions being fulfilled.
  - The second vortex is created not because of a planet gap, but due to a vortex gap.

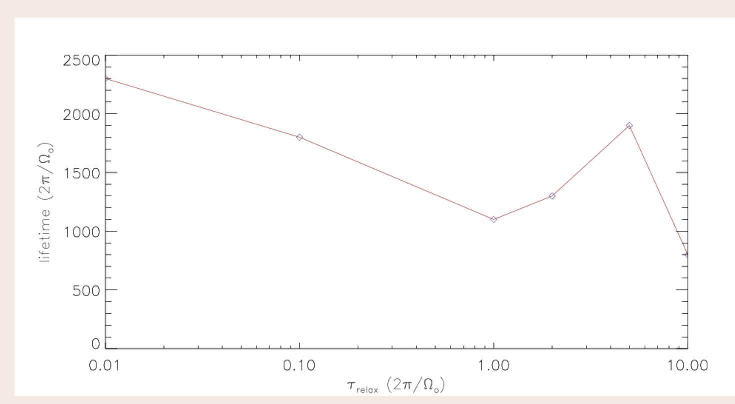
TR01



Vortex lifetime

- Maximums:
  - τ_{relax} very small ("quasi-isothermal");
  - $\tau_{relax} \simeq 5.0$.
- Minimums:
  - $\tau_{relax} \simeq 1.0$;
  - τ_{relax} very high.
- Oph IRS 48:
  - Vortex damped after ~ 200 orbits;
  - Lifetime ~ 0.1 Myrs.

Lifetime of the inner vortex



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