Accretion of Jupiter-mass Planets in the Limit of Vanishing Viscosity

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ABSTRACT

Motivation: the rate of gas accretion by the giant planets is crucial to understand their mass distribution. Too fast runaway accretion leads to too massive planets.

Method: we investigated the characteristics of the circumplanetary disc (CPD) of a Jupiter-mass planet with a three-dimensional hydrodynamical nested grid code. We looked for the accretion mechanisms operating in inviscid (MRI inactive) CPD.

Main results: 1) the main accretion mechanism from the CPD to the planet is the stellar tide

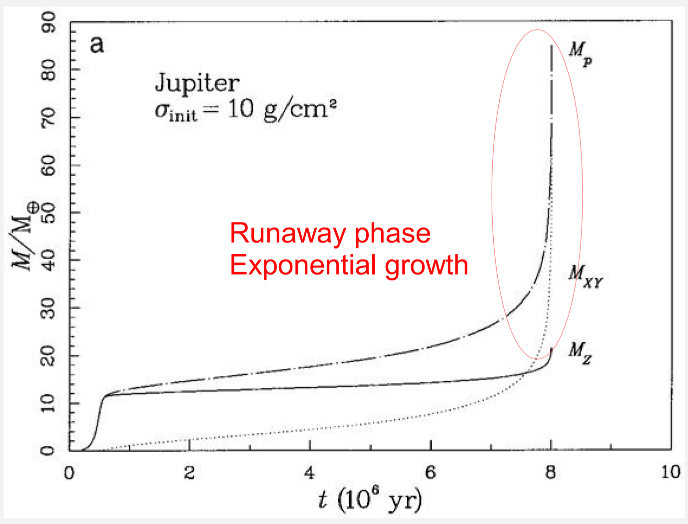
2) Jupiter's accretion rate could be >10x slower than previously thought

3) runaway growth could happen on a timescale comparable to the disc's lifetime

1) MOTIVATION

The core accretion model by Pollack e al. 1996 predicts runaway accretion → planets of several Jupiter-masses ↔ conflict with the observations

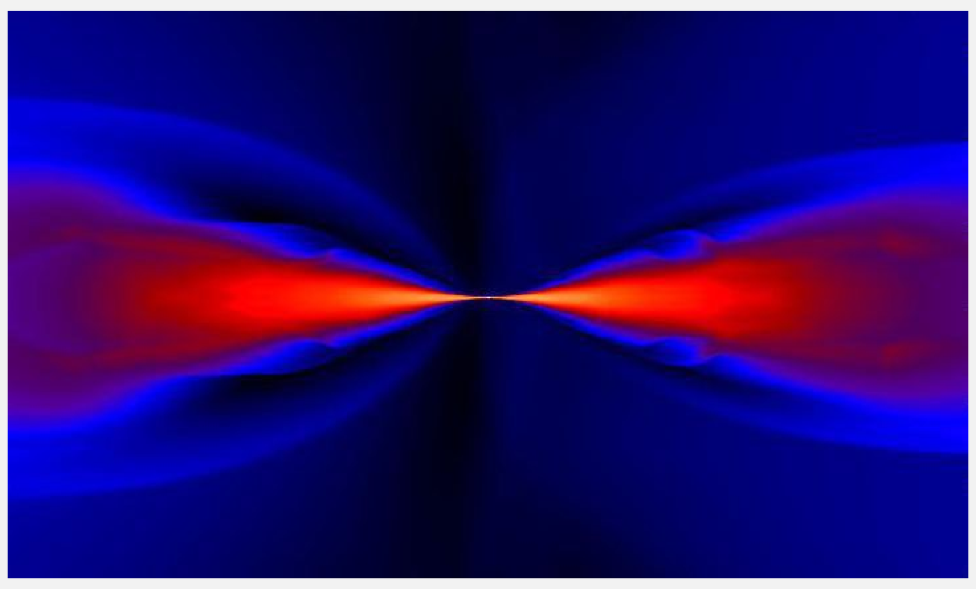
The circumplanetary disc might regulate the gas accretion rate!



2) SIMULATIONS

We performed hydrodynamical simulations with the JUPITER code

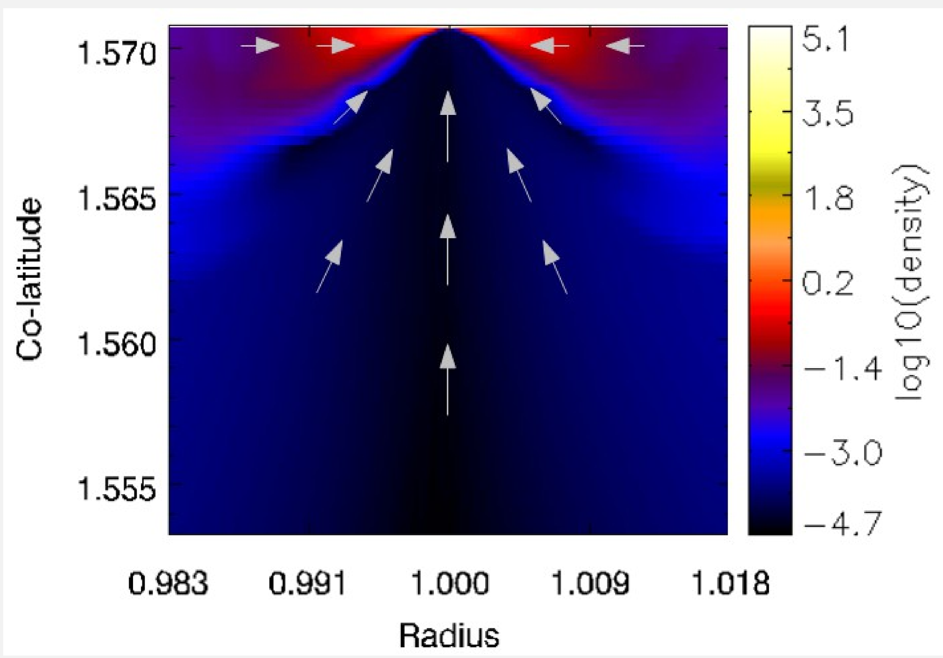
- Riemann-solver
- Nested grids: system of 8 grids zooming onto the planet's vicinity
- 3D
- locally isothermal
- viscous (α=0.004) and inviscid (α=0) simulations
- 2 different resolutions (finest cells 87% and 172% of the present day Jupiter)



3) RESULTS

a) **90% of the accretion occurs from the vertical direction**, the CPD is fed by the vertical inflow;

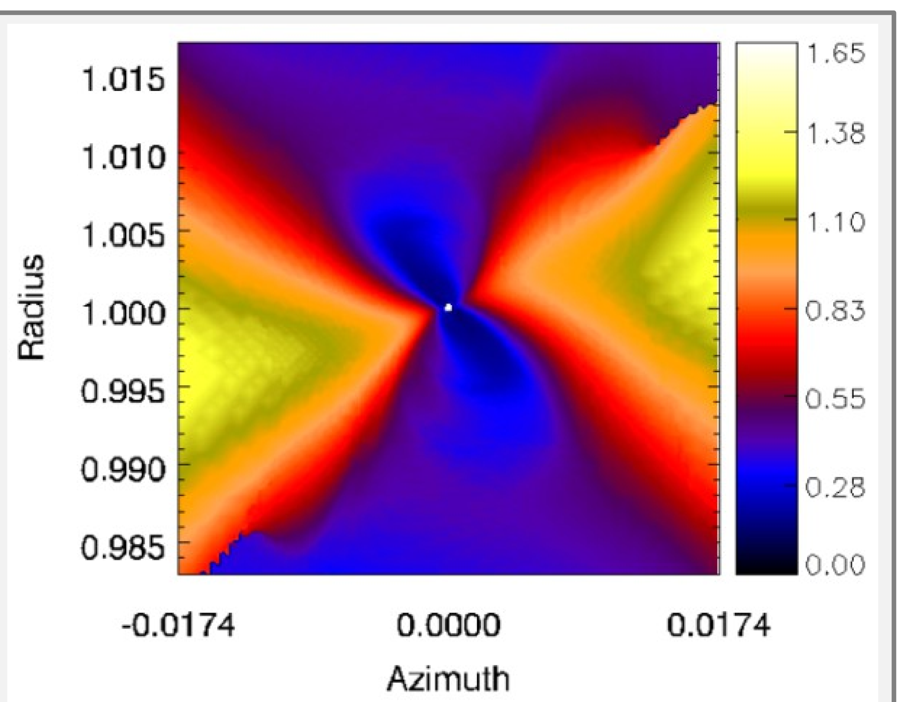
> similarly to the findings of Ayliffe & Bate 2009, Machida et al. 2010, Tanigawa et al. 2012.



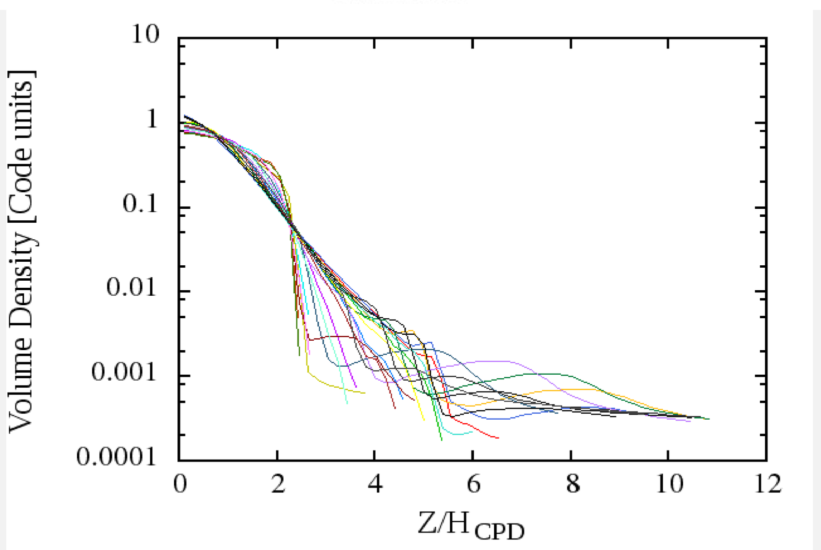
b) The **CPD upper layer is wavy**

> I. e. the aspect ratio of the CPD changes with planetocentric azimuth

↳ due to the pressure of the inhomogeneous vertical inflow.



- In a reference frame rotating with the gas around the planet (at a given radius), this pressure exerts a periodic perturbation → **stationary wave in the CPD vertical structure.**

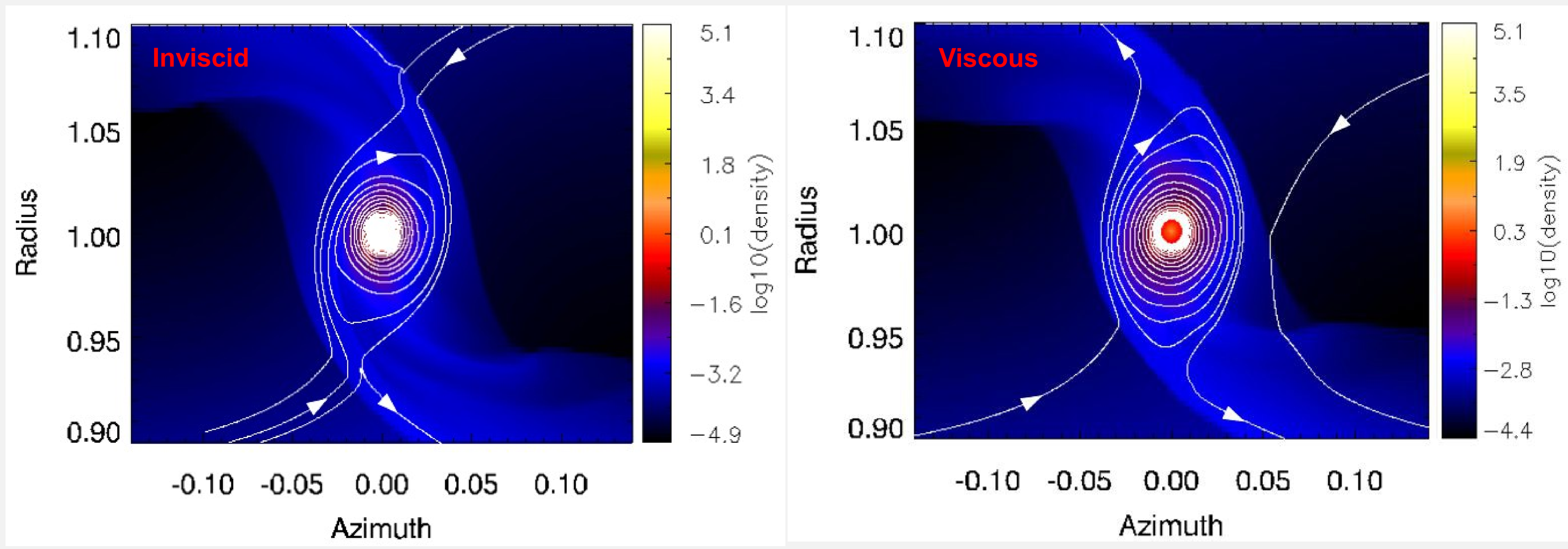


c) **The viscosity determines the directions of the flow in the CPD.**

↳ the flow in the CPD midplane is inwards if α=0.

> the gas flow in the CPD is crossing the spiral density wave twice in every orbit → loss of angular momentum due to a shock --> the flow spirals down to the planet.

↳ In the case of the viscous simulation with α = 0.004, the flow is spiraling outwards in the midplane.



d) **Accretion rate from the simulation: 10^{-4} Jupiter masses per year**

↳ this high rate is due to numerical viscosity

↳ the accretion rate is halved with double resolution

e) In an MRI inactive CPD the main accretion mechanisms would be the torque exerted by the star onto the CPD.

↳ **the stellar torque promotes the accretion of 2.5×10^{-4} of the mass of the CPD per year** (assuming a planet's orbital period of 12 years).

> Assuming a CPD mass of $0.01M_J$, → accretion rate of only 2.5×10^{-6} M_J/year

↳ **= 400,000 years Jupiter mass doubling time**

↳ This timescale is comparable to the removal timescale of the circumstellar disc gas e.g. Koepferl et al. 2013, Gorti et al. 2009.

4) CONCLUSION

gas accretion rate is more then 10x slower than expected

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Jupiter's mass doubling timescale ≈ disc removal timescale

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the competition between the planet's accretion timescale and disc's lifetime could explain the observed, wide range of giant planet masses.

Reference: Szulágyi et al. 2013 (submitted to MNRAS)

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