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Gas Accretion by Giant Planets : a study with 3D inviscid hydrodynamical simulations

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Abstract

We investigate the properties of the circumplanetary disc (CPD) of a Jupiter-mass planet with a three-dimensional hydrodynamical nested grid code. We perform isothermal simulations of a large radial portion of the circumstellar disc and, with the help of a system of 8 nested grids, we zoom into the planet's vicinity. Since giant planets are thought to form in a dead zone, we do not use any prescribed viscosity in the fluid-dynamics equations.

We discuss in details the geometry of the circumplanetary disc, and especially focus on the role of the polar inflow. As in [7], we find that vertical inflow from the envelope to the circumplanetary disc determines both the shape of the disc and the accretion rate. In fact, the vertical inflow provides most of the gas to the CPD.

Overall, our simulations lead to $\dot{M} = 10^{-4} M_J/year$. We argue that most of this high accretion rate is due to numerical viscosity, which is particularly high in the CPD due to the Cartesian geometry of the grids close to the planet. Thus, from a detailed analysis of the dynamics, we identify the viscosity-independent accretion mechanisms (the planet's polar inflow and the stellar torque exerted on the CPD). We find that these mechanisms alone should result in an accretion rate that is at least 40 times smaller than that observed in the simulation.

1. Introduction

How exactly the giant planets form is still one of the most puzzling questions in today's planetary science with lots of dark patches in the picture. One of the main open issues is the following : according to the standard core accretion model [5] the capture of gas by a solid core eventually enters in a runaway phase. This phase should not stop until the planet has acquired a mass of several Jupiter masses [1, 2], i.e. until a deep gap around the orbit of the planet is formed. If this were true, there should be a dichotomy in the mass distribution of planets : planets should be either smaller than $\sim$ 30 Earth masses (those that did not reach the phase of runaway gas accretion) or of multiple Jupiter-masses (those that entered and completed the fast runaway gas accretion). Planets in between these two mass categories should be extremely rare, conversely to what is observed [4].

A very likely possibility, however, is that the circumplanetary disc acts as a regulator of the rate of gas accretion onto the planet. In particular, if the circumplanetary disc (CPD) has a very low viscosity [8], then the transport of angular momentum through this disc can be very inefficient and gas can only accrete onto the planet at a very slow rate. In this situation the observed mass spectrum of the giant planets may be set by the competition between gas accretion and gas dissipation [6].

In this talk thus we present our study of the CPD structure and of the accretion of a Jovian-mass planet in simulations with no prescribed viscosity. Unfortunately these simulations are nevertheless affected by a large numerical viscosity. Thus, we also try to distinguish between the different accretions processes and quantify those that are truly viscosity independent.

2. Results

Our simulations are similar to those in [7] with one main difference : instead of a local shearing sheet, we perform global disc simulations. Consequently, the planet can open a gap around its orbit (see Fig. 1). The nested-grid scheme ensures high-enough resolution of the flow in the vicinity of the planet. Our finest grid has a resolution smaller than the current Jupiter's radius. We use the code Jupiter[1], developed by F. Masset.

Fig. 1 shows that the density wave launched by the planet in the circumstellar disc smoothly joins the

[1] http://jupiter.in2p3.fr

CPD and spirals into it, down to the planet. With the help of a few streamlines, it can be seen that gas flows in the midplane from the circumstellar disc into the CPD. [7] found outward flow in the midplane of the CPD. We recover their result when we impose a prescribed viscosity ($\alpha = 0.04$). Instead, in inviscid simulations as that illustrated in Fig. 1 the gas loses angular momentum due to shocks suffered when crossing the spiral density wave. This mechanism promotes the inflow. Nevertheless, we find that this midplane inflow accounts only for ($\sim 10\%$) of the total mass flux into the CPD, the rest coming via the vertical inflow.

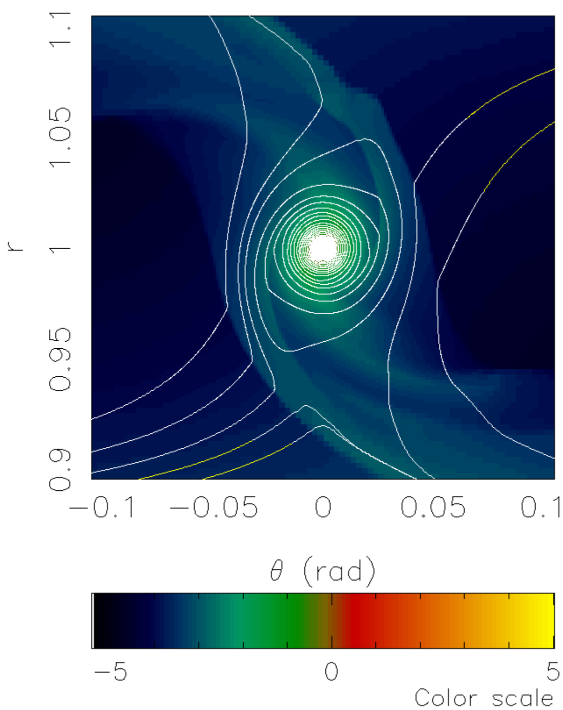

Figure 1: Density map on the midplane in the vicinity of a Jupiter-mass planet for a simulation with no prescribed viscosity. A few streamlines are also shown. One of them shows clear shocks when crossing the spiral density wave, thus losing angular momentum and spiralling down to the planet.

The vertical structure of the disc is also very interesting. As pointed out in [7] the CPD is bounded by a shock front generated by the vertical influx. We find that the CPD is not in hydrostatic equilibrium due to the pressure exerted by the vertical inflow. Its aspect ratio changes wildly with azimuth, from $\sim 20\%$ till $> 100\%$. This is because the vertical inflow is not uniform and the CPD is more compressed where the inflow is maximal, i.e. along the spiral wave.

We measure the mass flux into the inner eight cells around the point-mass planet as an estimation of the planet's accretion rate. For numerical reasons we have to limit the maximum density in these cells, therefore it is easy to measure how much mass we remove in each timestep. We find a large accretion rate, namely : $\dot{M} = 10^{-4} M_J/yr$. We argue that this high accretion rate is due to the large numerical viscosity in the inner part of the CPD, due to the Cartesian geometry of the nested grids.

In an ideal inviscid disc (i.e. with no numerical viscosity), planet accretion can occur only via two mechanisms. One is direct polar inflow, corresponding to the fraction of the vertical inflow onto the CPD that has a specific angular momentum smaller than that of an orbit at the distance of one planet's radius. We measure that the accretion rate due to this mechanism is only $\dot{M} = 6 \times 10^{-7} M_J/yr$. This is one order of magnitude less than in [7], due to the gap opened by Jupiter around its orbit. The second mechanism is the loss of angular momentum in the CPD due to the torque exerted by the star, which is non-zero due to the spiral density wave [3, 6]. With the method described in [6], we derived that the stellar torque promotes the accretion of 2.5×10^{-4} of the mass of the CPD per year. The mass of the CPD in our simulation is only $4 \times 10^{-4} M_J$. However, if the disc could not accrete onto the planet as fast as in our simulation due to the lack of viscosity, the gas would pile up into the disc, increasing the CPD mass. How massive the disc can become cannot be studied using isothermal simulations and will be the object of a future study.

In [6] it was estimated analytically that the maximum mass in the CPD can achieved before its pressure gradient becomes large enough to stop the vertical inflow is $\sim 10^{-3} M_J$. This estimate is probably valid only at the order of magnitude level. However, even assuming a CPD mass of $0.01 M_J$, the stellar torque would imply an accretion rate of only $2.5 \times 10^{-6} M_J/yr$, i.e. a mass doubling time of 400,000 years. This timescale is comparable to that of the photoevaporation of the circumstellar disc. Hence, if giant planets form towards the end of the disc's lifetime, the competition between the planet's accretion timescale and the disc removal timescale might explain the wide range of masses observed for giant planets.

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References

[1] Kley, W., 1999, MNRAS, 303, 696

[2] Lubow, S. H., & D'Angelo, G., 2006, ApJ, 641, 526

[3] Martin, R. G., & Lubow, S. H., 2011, MNRAS, 413, 1447

[4] Mayor, M., Marmier, M., Lovis, C., et al., 2011, arXiv:1109.2497

[5] Pollack, J. B., Hubickyj, O., Bodenheimer, P., et al., 1996, Icarus, 124, 62

[6] Rivier, G., Crida, A., Morbidelli, A., & Brouet, Y., 2012, A&A, 548, A116

[7] Tanigawa, T., Ohtsuki, K., & Machida, M. N., 2012, ApJ, 747, 47

[8] Turner, N. J., Carballido, A., & Sano, T., 2010, ApJ, 708, 188