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Adaptive-mesh MHD simulations of a jet emerging from a circumplanetary disc embedded in a protosolar nebula

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Abstract

We perform magnetohydrodynamic computer simulations of a semi-global protoplanetary disc section with an embedded planet core. The disc model assumes a self-consistent and dynamically evolving Ohmic resistivity, which is derived from a sophisticated ionisation model [5, 9] resulting in a dead-zone comparable to our previous local shearing box models [4]. Before the insertion of the planet core, the resulting configuration consists of a magnetically inactive dead zone and turbulent surface layers. When the embedded planet core of initially 100 earth masses has opened a gap in the disc, we study the ionisation structure and turbulent state of this region, including the circumplanetary disc which has formed around the planet. By determining accretion rates and analysing the flow structure in the vicinity of the planet, we aim to address the important question of what limits the growth of gas giant planets in the classic core-accretion picture.

1. Introduction

Gas giant planets, like Jupiter and Saturn as well as the observed exoplanet population of *Hot Jupiters*, are believed to form within a protoplanetary disc (PPD) via accretion of surrounding gas onto a rocky core of at least several earth masses (i.e., for a solar-type parent star). Given the diversity of masses within the gas giant planets observed to date, it is an interesting question to pose whether there are generic mechanisms that determine the total amount of gas accreted. A key role in regulating the mass flow onto the planet core is usually ascribed to the circumplanetary disc (CPD) forming around the growing planet. To asses whether this is indeed the case, and to test a potential influence of magnetic forces in the accretion process, we perform magnetohydrodynamic (MHD) simulations of the core accretion stage of giant planet formation.

2. Results

The complex results of the presented MHD simulation (and of further fiducial hydrodynamic reference simulations) will be presented elsewhere. Here we focus on aspects of the time variability of the CPD environment introduced by the magnetic tension forces and the self-consistent emergence of a proto-jovian jet.

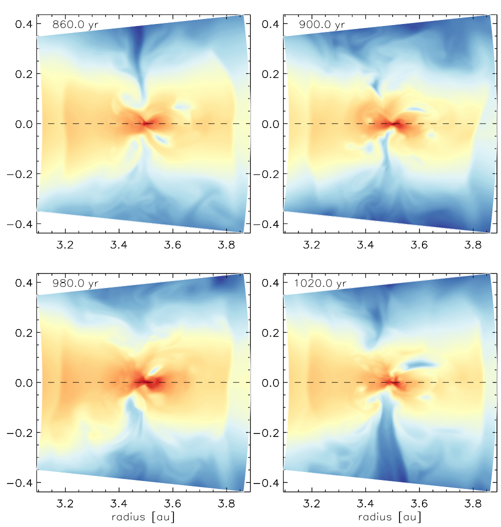

Figure 1: Time sequence of vertical slices through the CPD. Colours indicate logarithmic gas density, with blue (red) indicating low (high) values. The last panel corresponds to the same time as in Fig. 2 below.

As is shown in Fig. 1, the disc that has formed within the Hill sphere of the planet is subject to stochastic variations in its inclination (up to $\sim 15°$). Thin funnels seen in the polar region above and below the planet are generally related to in-fall of low-angular-momentum material. Part of this material is "recycled" in poloidal vortices around low density voids seen at different locations in the four panels. In contrast to the described funnel-like structures (seen most prominently in the upper half of the first panel in Fig. 1), the wider, cone-like structure in the lower half of the last panel is in fact associated with a magnetically collimated *outflow*.

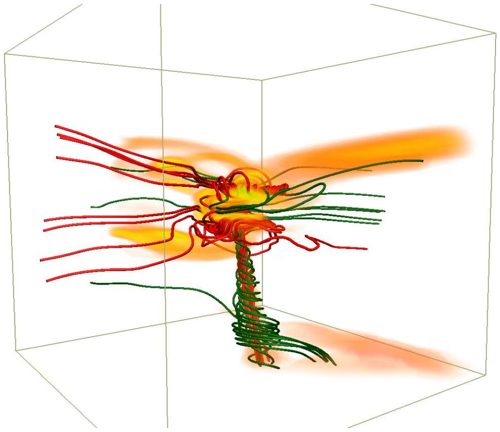

Figure 2: Close-up of the region containing the CPD ($1.5\,\mathrm{au}$ on edge). Selected flow lines originating in the vicinity of the planet (red) show a one-sided, collimated outflow with helical magnetic field lines (green) tightly wrapped around. The volumetric rendering indicates regions of strong Ohmic dissipation.

Evidence for the *magnetic collimation* is presented in Fig. 2, where we plot stream lines (red) and magnetic field lines (green), which are tightly draped around the outflow cone. While standard theory [1] typically predicts bi-polar jets, we do not find any evidence for even a weak counter-jet. This possibly indicates that the conditions for jet formation are only marginally met in our simulations. It is interesting to note that, as a result of its high column density (efficiently shielding external ionising radiation), the CPD itself is only weakly ionised and hence subject to high magnetic diffusivities. This may in turn affect the topological reconnection of field lines required for the jet to operate. In our current simulation, the appearance of the jet is very sporadic. To establish its universality will demand for a dedicated exploration of the conditions conductive to jet formation.

3. Conclusions

Confirming previous three-dimensional hydrodynamic models [8], we identify that the bulk of the mass accretion onto the core appears to happen from mid-latitudes. As a consequence, viscous mass transport through the CPD [7] would not be expected to play a significant role in explaining the diversity of masses observed in existing samples of extrasolar planets.

The main finding of our simulation, however, is the self-consistent emergence of a magnetically collimated outflow from the CPD. Such a phenomenon has been predicted based on theoretical scaling arguments more than a decade ago [3, 6]. Even though, from a first analysis, the mass loading appears rather low, future research will show whether such a magnetically induced outflow can potentially limit the mass accretion rate onto the embedded planet core.

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References

[1] Blandford R. D., Payne D. G., 1982, MNRAS, 199, 883

[2] Clyne J., Mininni P., Norton A., Rast M., 2007, NJPh, 9, 301

[3] Fendt C., 2003, A&A, 411, 623

[4] Gressel O., Nelson R. P., Turner N. J., 2011, MNRAS, 415, 3291

[5] Ilgner M., Nelson R. P., 2006, A&A, 445, 205

[6] Quillen A. C., Trilling D. E., 1998, ApJ, 508, 707

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

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

[9] Turner N. J., Drake J. F., 2009, ApJ, 703, 2152

[10] Ziegler U., 2004, JCoPh, 196, 393

[11] Ziegler U., 2011, JCoPh, 230, 1035