Magnetic Fields and Accreting Giant Planets around PDS 70

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Abstract

The recent high spatial/spectral resolution observations have enabled constraining formation mechanisms of giant planets, especially at the final stages. The current interpretation of such observations is that these planets undergo magnetospheric accretion, suggesting the importance of planetary magnetic fields. We explore the properties of accreting, magnetized giant planets surrounded by their circumplanetary disks, using the physical parameters inferred for PDS 70 b/c. We compute the magnetic field strength and the resulting spin rate of giant planets, and find that these planets may possess magnetic dipole fields of either a few 10 G or a few 100 G; the former is the natural outcome of planetary growth and radius evolution, while the resulting spin rate cannot reproduce the observations. For the latter, a consistent picture can be drawn, where strong magnetic fields induced by hot planetary interiors, lead both to magnetospheric accretion and to spin-down due to disk locking. We also compute the properties of circumplanetary disks in the vicinity of these planets, taking into account planetary magnetic fields. The resulting surface density lies between the predictions of two empirically derived models of circumplanetary disks:the minimum mass subnebula model and the gas-starved model. Our model predicts a positive gradient of the surface density, which invokes the traps for both satellite migration and radially drifting dust particles. This work thus concludes that the final formation stages of giant planets are similar to those of low-mass stars such as brown dwarfs, as suggested by recent studies.

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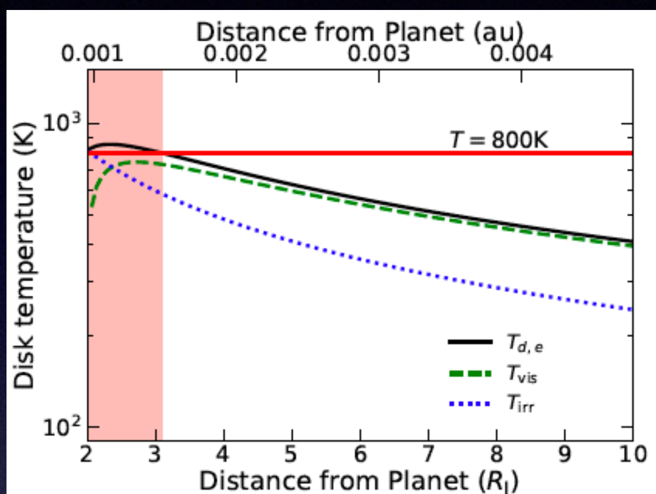
1. Energy budget

The inner edge region can be MRI active due to thermal ionization



3. The inner edge properties of circumplanetary disks

Planetary magnetic fields & non-ideal MHD effects play an important role

$$\Sigma \simeq 4.0 \times 10^4 \text{ g cm}^{-2} \left(\frac{M_p}{10 M_J}\right) \left(\frac{\dot{M}_p}{10^{-7} M_J \text{ yr}^{-1}}\right)^{2.9} \times \left(\frac{R_p}{2R_J}\right)^{-12} \left(\frac{T_{p,e}}{1200 \text{ K}}\right)^{-0.5} \left(\frac{B_{ps}}{130 \text{ G}}\right)^{-3.9} \left(\frac{r}{6R_J}\right)^{4.8}, \quad (22)$$

The resulting surface density lies between two empirically derived models: the minimum mass *sub*nebular model and the gas-starved one

The positive radial gradient invokes traps for both satellite migration and radial dust drift

2a. Weak magnetic fields

Magnetospheric accretion becomes possible when planetary magnetic fields are

$$20 \text{ G} \lesssim B_{ps} \lesssim 40 \text{ G},$$

This field strength is predicted for rapid rotators

Disk locking leads to the spin rate of ~ 84 % of the break-up limit

Giant planets very likely undergo magnetospheric accretion, following mass growth and radius evolution

2b. Strong magnetic fields

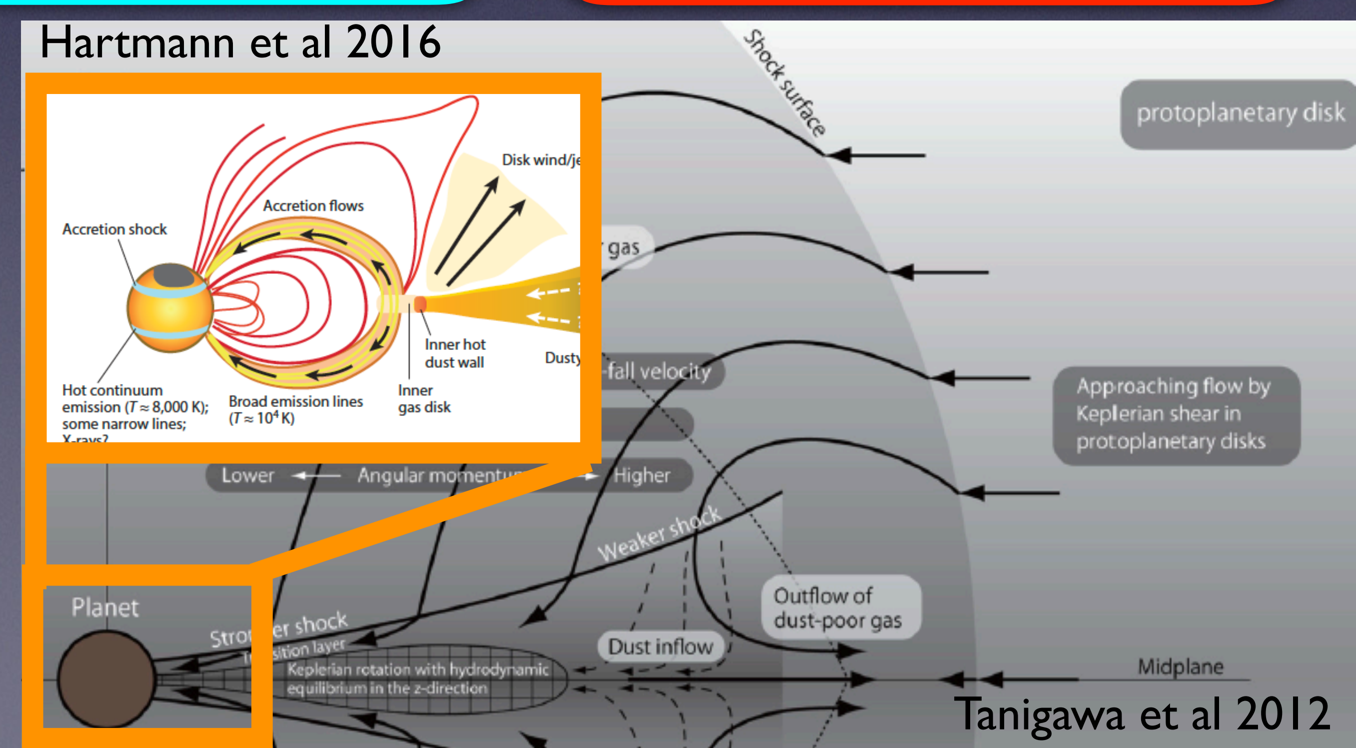
Thermodynamically available internal energy generates planetary magnetic fields:

$$1.3 \times 10^2 \text{ G} \lesssim B_{ps} \lesssim 5.0 \times 10^2 \text{ G},$$

The same scaling law can reproduce indirect measurements of B-fields for hot Jupiters

Disk locking leads to the spin rate of ~ 14 % of the break-up limit, which is consistent with the recent observations

Hartmann et al 2016



Tanigawa et al 2012