GIANT PLANETS

Magnetic brake

Gas giants like Jupiter and Saturn are fast rotators, having day lengths of 9.9 and 10.7 hours, respectively. However, according to the core accretion theory of planetary formation, they should spin even faster. In fact, the runaway accretion of gas (and related angular momentum) during the last phase of their formation, followed by gravitational contraction of the gaseous envelope, should bring the final rotation rate very close to the breakup velocity. Instead, Jupiter and Saturn rotate at only 28 and 37% of their breakup velocities. Recent measurements indicate that gaseous exoplanets behave in the same fashion (M. L. Bryan et al. *Nat. Astron.* 2, 138–144; 2018).

Konstantin Batygin proposes a solution to this outstanding question of planetary formation (*Astron. J.* 155, 178; 2018). He develops a semi-analytical model that includes two interacting objects in the late stages of accretion: the planet itself, a proto-Jupiter (with a radius of $2R_{\text{Jup}}$ and a mass of M_{Jup} , where R_{Jup} and M_{Jup} are the radius and mass of Jupiter, respectively) with a convective dynamo that generates an intense magnetic field (~ 500 gauss), and a circumplanetary gaseous disk with solar elemental abundances. The disk, by virtue of the strong luminosity emitted by the planet, can reach temperatures greater than $\sim 1,000$ K — sufficient to ionize alkali metals contained in it and making it electrically conductive.

Batygin's scenario is masterfully summarized in the illustration (figure 2 in the paper). The magnetic field naturally clears the region within $\sim 4\text{--}5 R_{\text{Jup}}$ of the planet, truncating the disk and triggering meridional flows (white arrows) that either accrete material onto the planet or deflect it back into the disk and ultimately to the protoplanetary nebula (the 'de-cretion

Credit: AAS/IOP; illustration by James Tuttle Keane, Caltech

disk' effect indicated in the illustration). Meanwhile, magnetic induction couples the planetary magnetic field (red lines) to the disk, creating a secular transfer of angular momentum from the faster-rotating planet to the slower disk (yellow lines). The meridional flows that recycle the circumplanetary material into the protoplanetary nebula thus induce a net loss of angular momentum. Interestingly, the main factor that regulates the final spin value seems to be the truncation radius of the disk (which in turn depends on the planet's radius).

This approximate model gives numerical results in agreement with observations

and can explain in broad strokes both the slow spin rate and (through the truncation of the disk) the final mass of the planet, which is the other outstanding problem of the formation of gas giants. The model is also only weakly dependent on poorly constrained parameters like the mass accretion rate or the surface field strength, so it is a strong baseline for more refined magnetohydrodynamic models applied to planetary formation. $\square$

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