Detection and Dynamics of Exoplanets (DDE): Interplay between theory and observations

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Planetary Dynamos in Evolving Cold Gas Giants

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Magnetic fields remain one of the least understood aspects of exoplanetary systems. A deeper understanding of planetary dynamos and the evolution of surface magnetic properties throughout a planet's lifetime is a key scientific purpose, with implications for planetary evolution, habitability, and atmospheric dynamics. This study models the evolution of magnetic fields generated by dynamo action in cold giant gaseous planets. We solve the resistive magnetohydrodynamic (MHD) equations under anelastic approximation with a 3D pseudo-spectral spherical shell MHD code. We employ 1D thermodynamical hydrostatic profiles taken from gas giant evolutionary models as the background states of our MHD models. Numerical integration leads to saturated dynamo solutions. Such calculations are performed with radial profiles corresponding to different planetary ages so that we can interpret them as different snapshots of the magnetoconvection evolution during the long-term planetary evolution. We characterize magnetic fields across different evolutionary stages of a cold gaseous planet in terms of topology and strength. We find the occurrence of a transition from multipolar to dipolar-dominated dynamo regime throughout the life of a Jovian planet. During the planetary evolution and the cooling down phase, we observe a decrease in the average magnetic field strength near the dynamo surface as ~t−0.2−t−0.3, a trend compatible with previously proposed scaling laws. We also find that some dimensionless parameters evolve differently for the multipolar to dipolar branch, possibly reflecting a force balance change. This approach can be extended to study hot gaseous planets, offering a versatile tool for interpreting the magnetic properties of giant planets.

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