Dipole Collapse and Dynamo Waves in Global Direct Numerical Simulations

Martin Schrinner, Ludovic Petitdemange, Emmanuel Dormy

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Magnetic fields of low-mass stars and planets are thought to originate from self-excited dynamo action in their convective interiors. Observations reveal a variety of field topologies ranging from large-scale, axial dipole to more structured magnetic fields. In this article, we investigate more than 70 three-dimensional, self-consistent dynamo models obtained by direct numerical simulations. The control parameters, the aspect ratio and the mechanical boundary conditions have been varied to build up this sample of models. Both, strongly dipolar and multipolar models have been obtained. We show that these dynamo regimes can in general be distinguished by the ratio of a typical convective length scale to the Rossby radius. Models with a predominantly dipolar magnetic field were obtained, if the convective length scale is at least an order of magnitude larger than the Rossby radius. Moreover, we highlight the role of the strong shear associated with the geostrophic zonal flow for models with stress-free boundary conditions. In this case, the above transition disappears and is replaced by a region of bistability for which dipolar and multipolar dynamos co-exist. We interpret our results in terms of dynamo eigenmodes using the so-called test-field method. We can thus show that models in the dipolar regime are characterized by an isolated 'single mode'. Competing overtones become significant as the boundary to multipolar dynamos is approached. We discuss how these findings relate to previous models and to observations.

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