Nonlinear interactions in turbulent stellar dynamos

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Recent spectropolarimetric observations of low-mass stars show that large-scale components of their magnetic fields can exhibit cyclic variations or reversals [1] ; it is yet unclear how low-mass stars with strong convective turbulence and relatively slow rotation are able to maintain coherent large-scale magnetic activity. In convective flows, magnetic fields are created through dynamo action - systematic stretching and twisting of magnetic field lines by helical vortices. Dynamo is intrinsically nonlinear process ; its saturated states depend on the interplay between magnetic induction and the feedback on the flow from magnetic tension. In this work, we developed direct numerical models of convective zones of low-mass stars with their key ingredients - high density contrast and strongly supercritical turbulent convection. Our models reproduce stellar topologies commonly observed in low-mass stars and their dynamic behaviour - reversals and transitions between dipolar and multipolar magnetic states. The strength of dipolar component is increasing with both stratification and turbulence level. Our analysis suggests that magnetic pumping mechanism is responsible for this effect : small-scale magnetic flux, generated by small-scale turbulence in the outer flow regions with low density, is systematically transported into more quiescent inner regions. Furthermore, we found that the key ingredient of destabilization of dipolar fields in our models is their nonlinear interaction with axisymmetric (zonal) flows, resulting in bi-stable behaviour with transitions between high- and low-energy dynamo states mediated by magnetic Lorentz force.

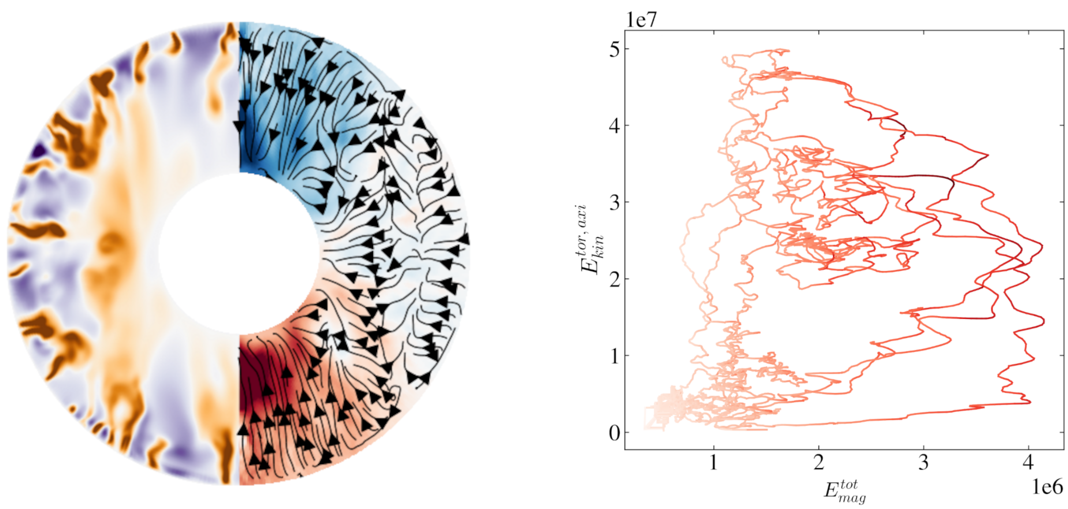

Figure 1. On the left, a snapshot of radial velocity of the turbulent multi-scale convection in simulations, together with the mean dipolar magnetic field (in color). Solid lines of magnetic flux illustrate magnetic pumping effect. On the right, dynamo flow trajectories in the space of total magnetic energy and the energy of axisymmetric (zonal) flow ; color - magnetic Lorentz force.

Références

1. Jeffers, S.V. et al, *Space Science Reviews*, **219**, 54 (2023).

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