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Simulations on the origin of magnetic flux ropes in quiescent and active regions on the Sun

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Helical magnetic flux ropes (MFRs) are the core structure and main driver of solar eruptions. They are magnetic skeletons of most solar prominences in a range of scales. Their formation in solar corona, which stores magnetic helicity and magnetic free energy to be released in solar eruptions later on, is still elusive and has been intensively studied. While previous numerical models rely on shearing and converging photospheric velocity driving on smooth bipolar magnetic field, or equivalent processes in a flux rope emergence, to form MFRs mostly near active regions, large scale MFRs in quiescent regions above fragmented magnetic network cannot be produced by these models. Using three-dimensional magnetofriction simulations in a spherical subdomain, we simulate time-dependent photospheric supergranular motions with and without Coriolis forced rotation to drive the formation of a MFR above photospheric magnetic network from an initially smooth bipolar magnetic region. We find the Coriolis effect inject negative helicity from magnetic network into corona and the helicity condensation gather the negative helicity along the polarity inversion line (PIL) creating strongly sheared magnetic arcades. The diverging supergranular flows at two sides of the PIL converge footpoints of the sheared arcades and magnetic reconnection links the sheared arcades to a large MFR. Without Coriolis effect, the differential rotation cannot inject helicity quickly enough to be condensed along PIL and neither sheared arcades nor MFRs form. In a flare productive quadrupolar active region like AR11158, we solve 0-beta MHD equations to simulate the collisional shearing between opposite polarities belonging to different bipolar magnetic regions and find the two successive MFR formation and eruption. Topology transition from bald patch to hyperbolic flux tube of the MFRs starts from the middle part of the MFR with a current sheet with magnetic reconnection underneath the MFR. Enough magnetic helicity injected by Coriolis rotation in quiescent regions and shearing/rotation in active regions is a prerequisite for the formation of MFRs and photospheric magnetic reconnection (flux cancellation) is the key process changing sheared loops into MFRs.

References
Liu, Q.J., Xia, C. 2022 ApJL under review
Xia, C., Keppens, R., Guo, Y. 2014 ApJ 780, 130

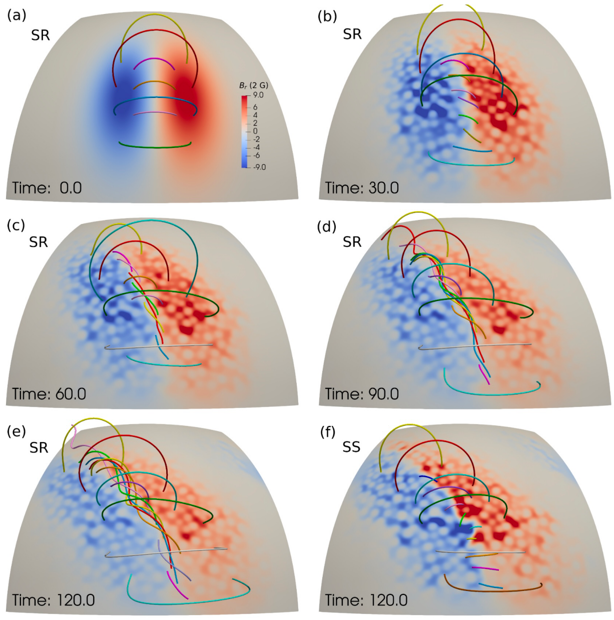

Figure 1 Evolution of magnetic field lines above photospheric magnetogram of model SR with Coriolis effect (a)-(e), (f) model SS without Coriolis effect.

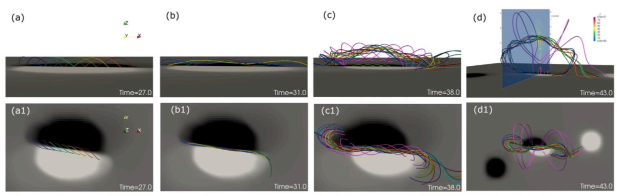

Figure 2 Side views (top row) and top views (bottom row) of the formation of a MFR driven by collisional shearing photospheric motions.