Global Magnetic Oscillations in a Rapidly Rotating Sun

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Motivation:

Global MHD simulations of the solar convection zone and tachocline reveal that global wreathes of toroidal magnetic field can be realized in the tachocline (Browning et al. 2006). Recent simulations of more rapidly rotating sun-like stars (without tachoclines) have shown that magnetic wreathes can also be achieved in the bulk of the convection zone itself (Brown et al. 2007). Here we simulate a rapidly rotating sun at a higher turbulence level (again without a tachocline), finding toroidal magnetic wreathes that vary in time. These tubular wreathes can undergo large oscillations in magnetic field strength and even a reversal of global magnetic polarity.

Method:

We use the 3-D anelastic spherical harmonics (ASH) code to solve the full, anelastic MHD equations in a rotating spherical shell. Here we have modeled the convective interior (from 0.72 to 0.97 R_{sun}) of a solar-type star rotating at 3 times the solar rate with the following fluid parameters: Pr = 0.25, Pm = 0.5, Re = ~242. The simulation has a resolution of 96 radial, 256 meridional, and 512 azimuthal points.

Results:

We find that strong dynamo action produces magnetic structures in the bulk of the convection zone that vary with time (Fig. 1). Additionally, this dynamo undergoes large oscillations in global magnetic field strength which influence the differential rotation of the star without significantly altering the convection (Fig. 2). The system also achieves a reversal of the average poloidal magnetic field and the polarity of the toroidal magnetic wreathes in each hemisphere (Fig. 3). These striking changes in magnetic field strength and global polarity demonstrate that organized oscillatory dynamo action can be realized in rapidly rotating suns even without a tachocline of shear.

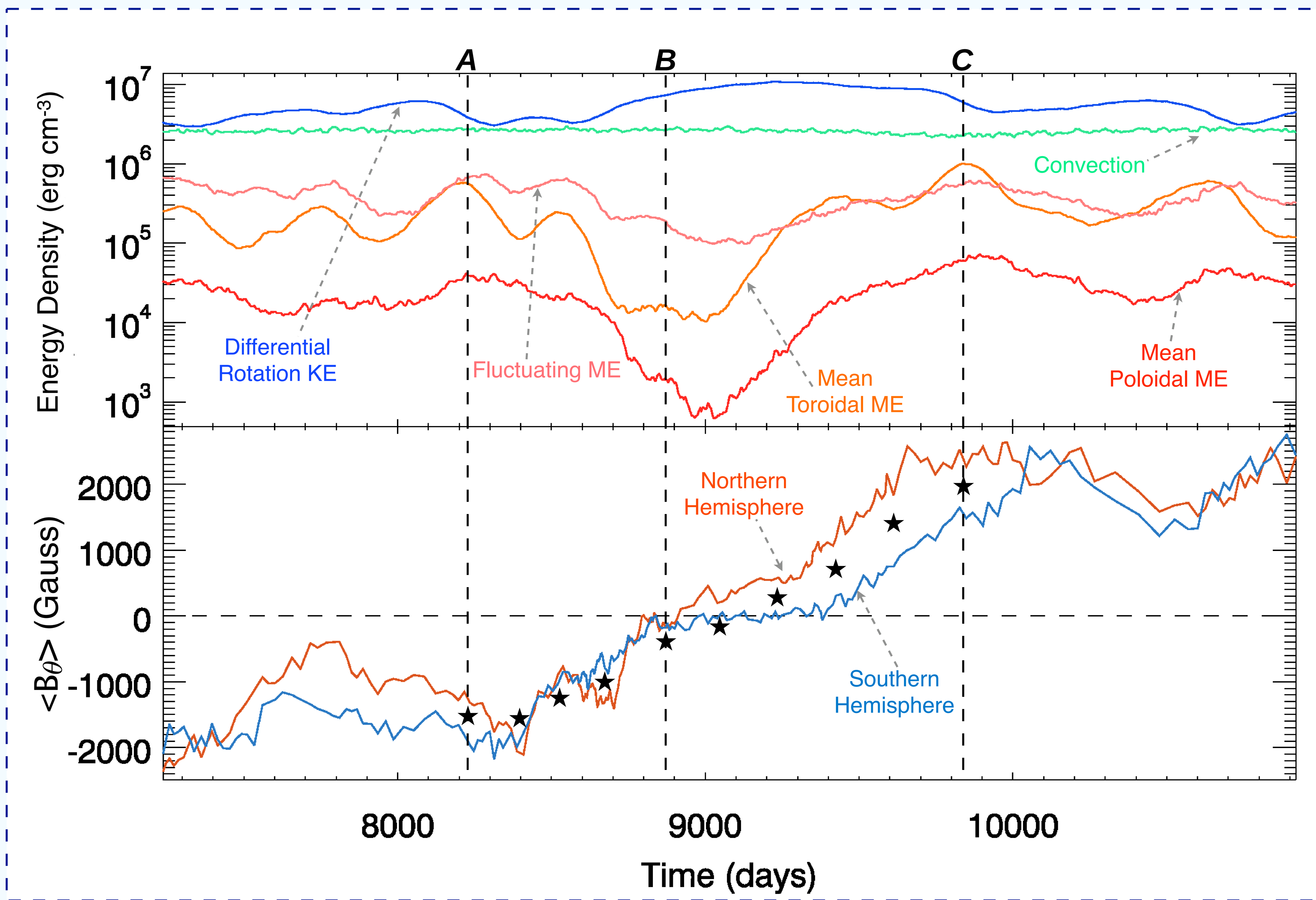

Figure 2: Time history of kinetic (KE) and magnetic (ME) energy densities in the convection zone (upper panel), and polarity reversal of mean latitudinal magnetic field near base of convection zone in each hemisphere (lower panel). Samplings A, B, & C for Fig. 1 are indicated, and stars indicate times sampled in Fig. 3.

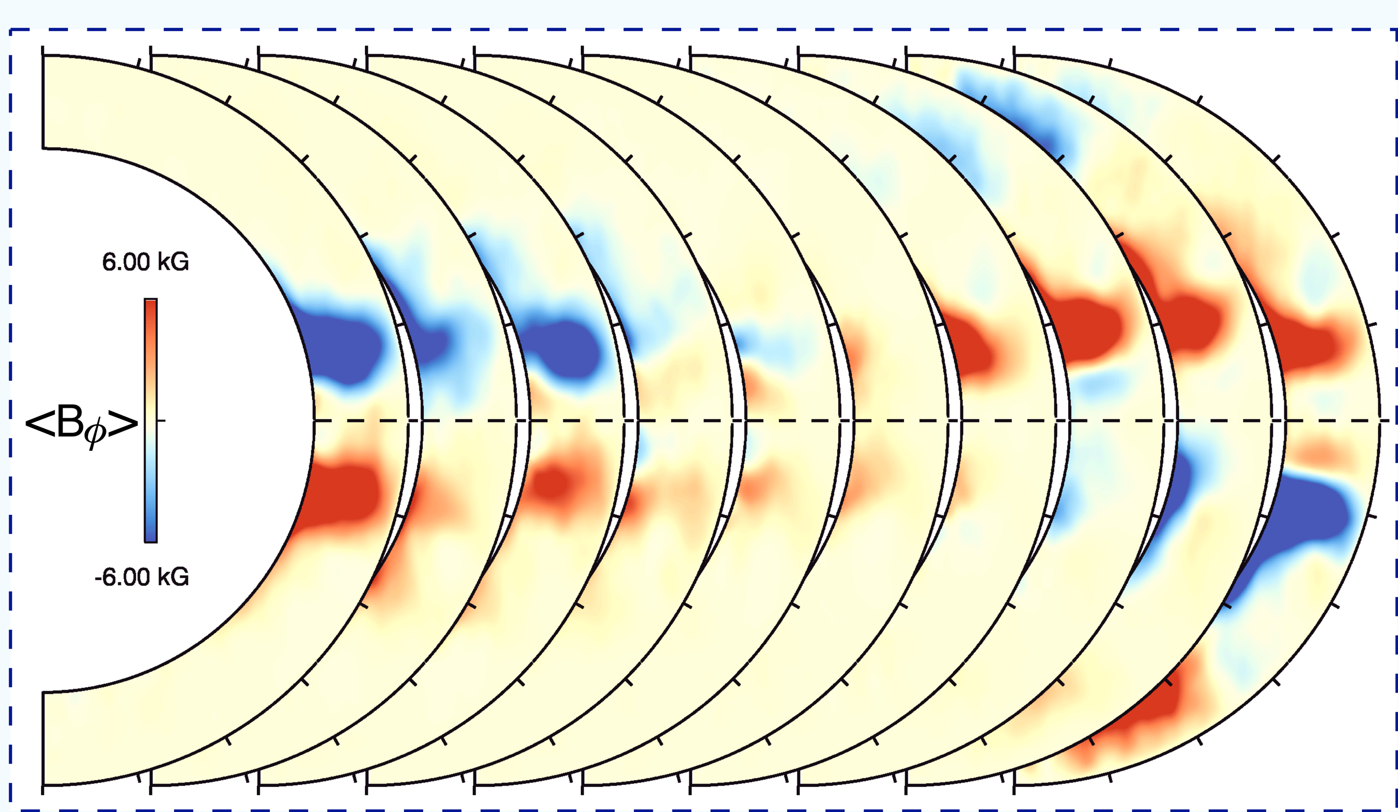

Figure 3: Evolution of magnetic structures in the convection zone, shown in a temporal sequence of azimuthally averaged snapshots of B_ϕ. Magnetic wreathes, seen in cross section, oscillate in field strength and even reverse polarity. Peak $<B_\phi>$ is 27 kG. Comparing Fig. 2, the poloidal field reversal leads that of the toroidal field.

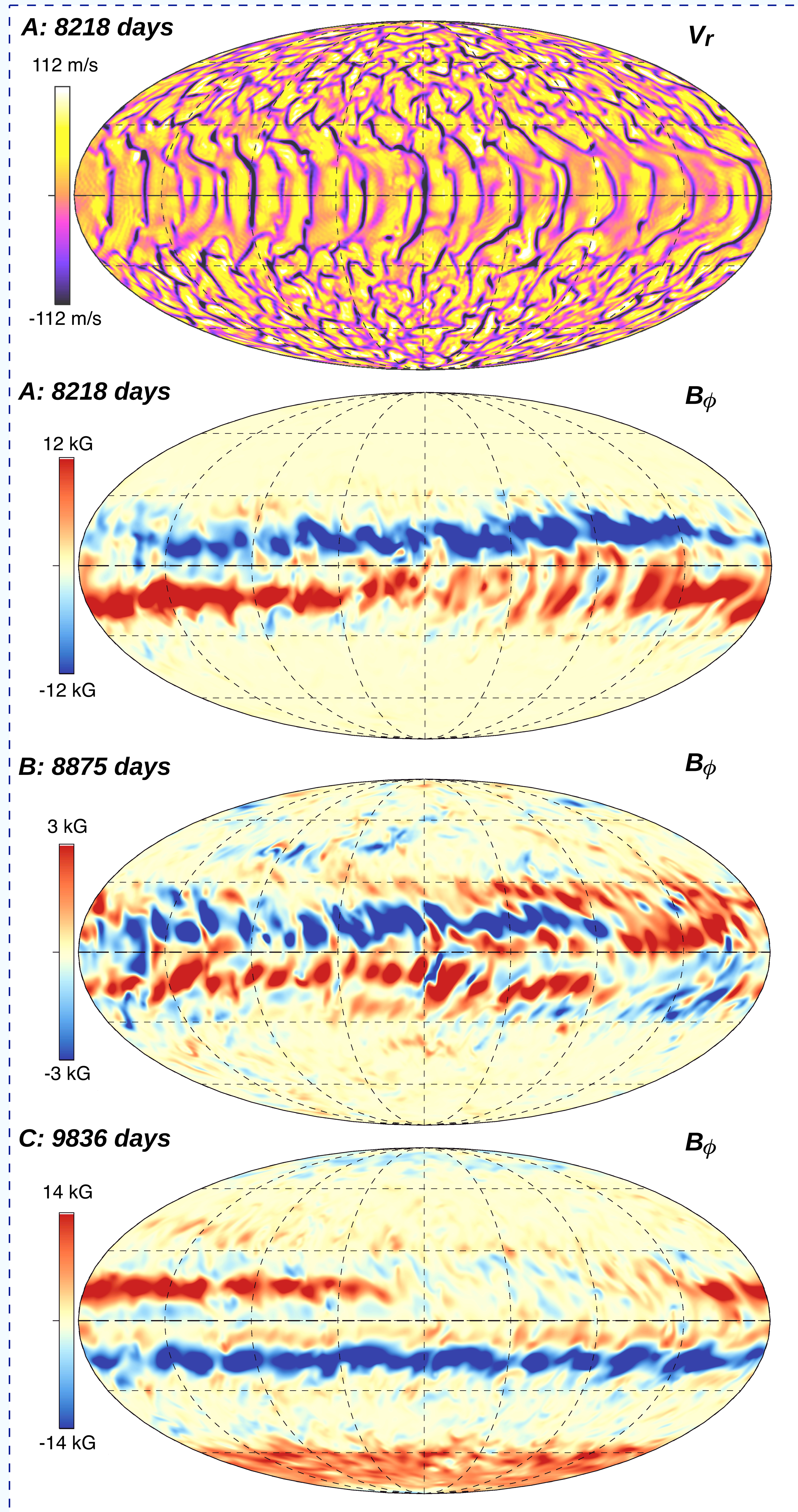

Figure 1: Radial velocity (V_r) at top of convection zone shown in Mollweide projection, with broad upflows and networks of sharp downflows as sampled at time A: day 8218 (also labeled in Fig. 2). Toroidal magnetic field (B_ϕ) at mid-convection zone shown at the same instant, with two strong bands of magnetic field of opposite polarity in the northern and southern hemispheres (peak B_ϕ, 33 kG). At time B: day 8875 the magnetic structures have weakened considerably (peak B_ϕ, 10 kG). At time C: day 9836 the bands of toroidal field have re-established themselves (peak B_ϕ, 34 kG) but with opposite polarity.

References:

- Brown, B.P., Browning, M.K., Brun, A.S., Miesch, M.S., Nelson, N.J., & Toomre, J. 2007, in "Unsolved Problems in Stellar Physics", AIP, 948, 271.
- Browning, M.K., Miesch, M.S., Brun, A.S., & Toomre, J. 2006, ApJ, 648, L157.

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