Wreathes of Magnetism in Rapidly Rotating Stars

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1. MOTIVATION Early in its life our sun rotated much more rapidly. Observations of young, rapidly rotating stars indicate that magnetic activity and possibly dynamo action are stronger with more rapid rotation. Continuing our earlier work on rapidly rotating suns [1], we here explore dynamo action in a simulation of a younger sun rotating at three times the current rate. A striking finding is that coherent magnetic structures arise in the midst of the turbulent convection zone. These wreathes of toroidal field persist for long periods of time.

2. APPROACH Our 3-D simulations of compressible MHD turbulent convection are carried out with the anelastic spherical harmonic (ASH) code on massively parallel supercomputers. For simplicity we adopt the radial stratification of the present-day sun and examine global scale convection in a spherical shell extending from 0.72 to 0.97 solar radii. The simulation is evolved for over 7000 days with the ohmic diffusion time about 1300 days. Pm = 0.5 and Re'=172, Rm'=86, Ro'=0.26

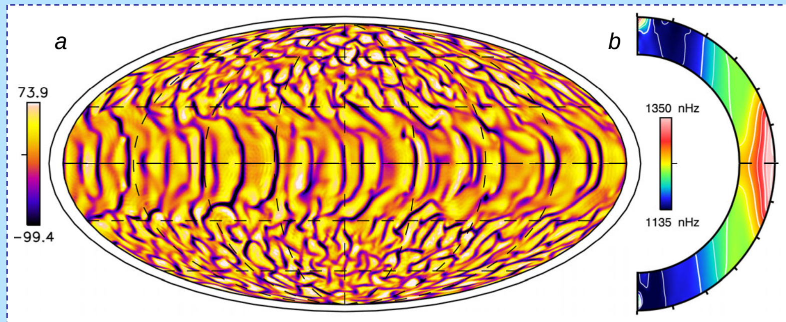

Figure 1. (*a*) Radial velocities near top of convection zone with downflows dark and (*b*) mean profile of angular velocity with fast prograde equator.

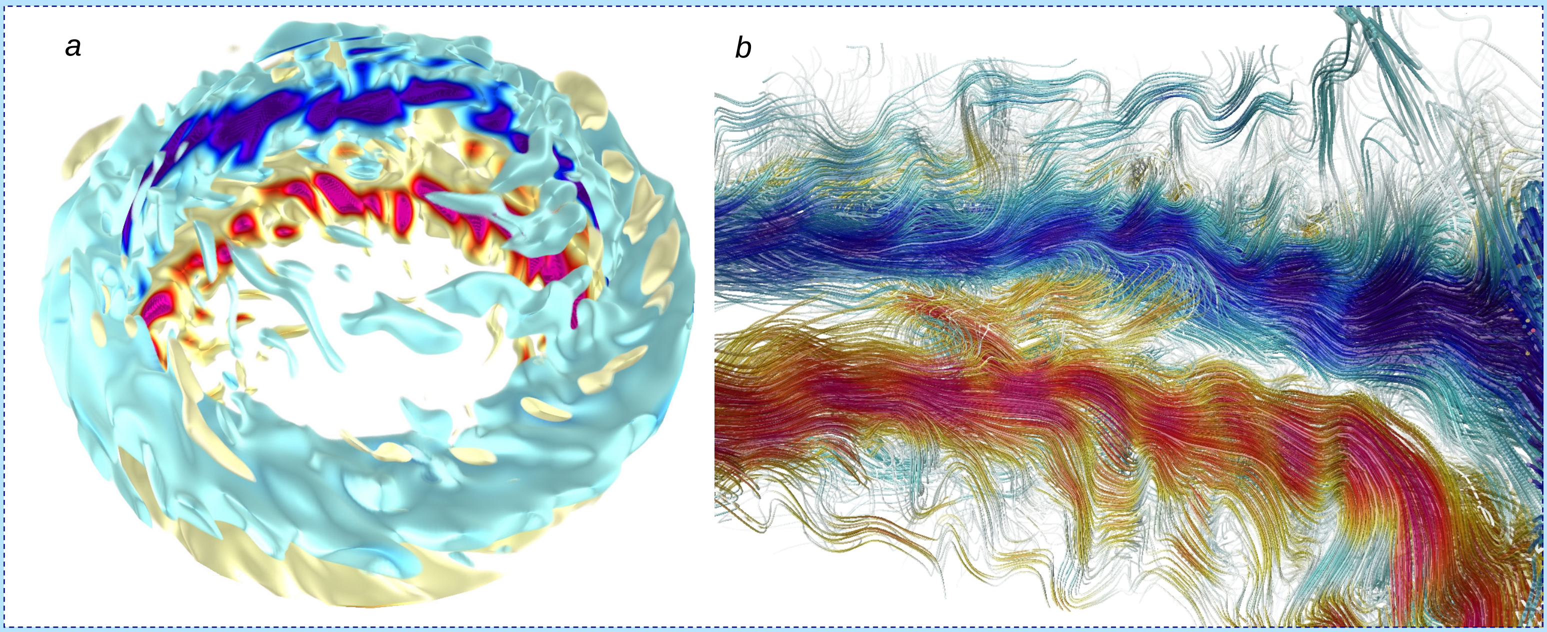

Figure 2. (*a*) Volume rendering of toroidal magnetic field with blue (red) indicating negative (positive) B_ϕ. Large coherent magnetic structures fill the convection zone, with opposite polarities above and below the equator. Peak field strengths in these wreathes are over 40 kG. (*b*) Field lines in a portion of the domain reveal that the wreathes are leaky structures, with field wound up in the vortical downflows at higher latitudes. The upflows and downflows of convection distort the wreathes but do not shred and destroy the structures.

3. RESULTS Vigorous convection and a strong differential rotation are achieved in the simulation (Fig. 1). Filling the convection zone are coherent structures of toroidal magnetic field. These wreathes look superficially like idealized flux tubes, but in reality they are much more complex structures with significant field threading in and out of the wreathes (Fig. 2). These wreathes have peak field strengths of 40 kG and average field strengths of over 10 kG. These structures persist for thousands of days with same polarity and similar structure. There is a complex balance between the strong differential rotation which rebuilds the wreathes and the turbulent convection that shreds them apart and sweeps them into other portions of the convection zone (Fig. 3). Compressible effects enhance the regeneration of the mean radial magnetic field while the mean meridional field is regenerated by fluctuating shear and advection.

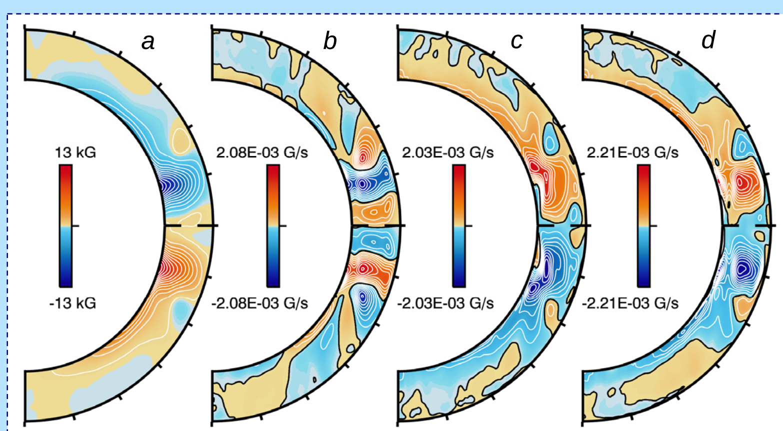

Figure 3. Mean profiles of (*a*) B_ϕ and magnetic production terms from (*b*) mean shear which maintains the wreathes and (*c*) fluctuating shear and (*d*) fluctuating advection which act to disassemble them. Other terms such as diffusion and compressible effects are smaller.

REFERENCES

[1] Brown, B., Browning, M., Brun, A.S., Miesch, M. & Toomre, J. 2008, "Rapidly rotating suns and active nests of convection", ApJ, in press.

[2] Brown, B., Browning, M., Brun, A.S., Miesch, M. & Toomre, J. 2008, "Magnetic Wreathes in Rapidly Rotating Suns", to be submitted to ApJ.

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