Building and maintaining a solar tachocline through convective dynamo action

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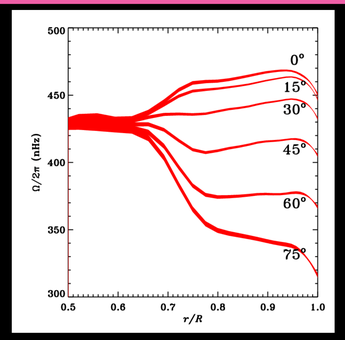
1. The thin solar tachocline

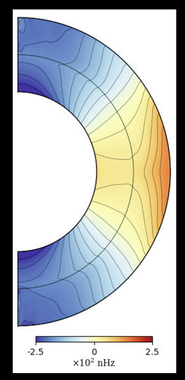
- Helioseismology revealed a tachocline, thickness < 5% $R_\odot$ (Howe et al. 2000)
- Spiegel & Zahn (1992) showed DR should have spreadby ~40% $R_\odot$
- Some other mechanism must transport angular momentum from equator to pole

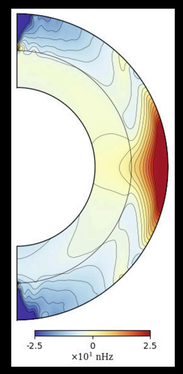


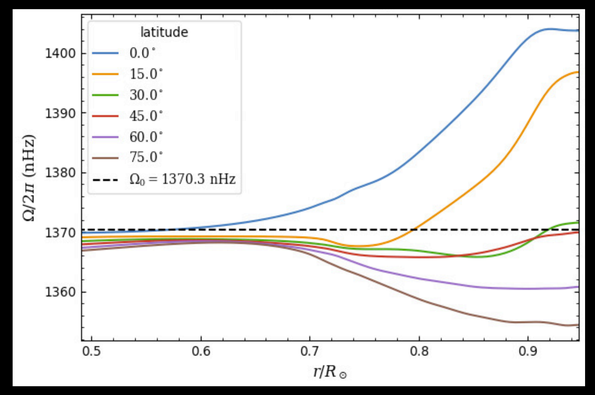
- Mechanism #1 (**Fast tachocline, Spiegel + Zahn 1992**): anisotropic turbulence
- Mechanism #2 (**Slow tachocline, Gough + McIntyre 1998**): primordial magnetic field
- **Neither mechanism has been shown to fully work**

3. Tachocline-like shear layer

- In hydro system, diff. rot. mprints viscously from CZ onto RZ (left)
- For dynamo case, RZ is forced into solid-body rotation (middle and right)
- Roughly solar-like differential rotation in CZ, but highly diminished

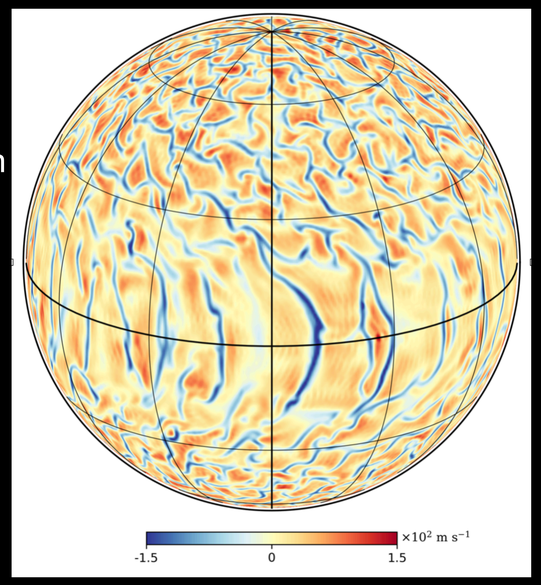






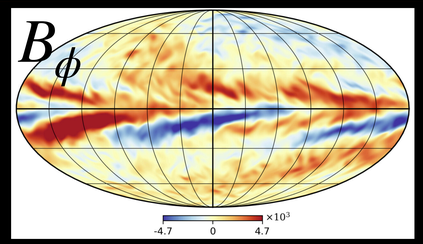
2. Numerical experiment

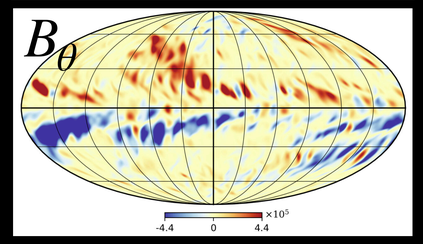
- Hydro simulations with convection zone (CZ) overlying radiation zone (RZ)
- Rotate 3 x solar Carrington
- Atmosphere has ds/dr = 0 in CZ joined quartically to ds/dr > 0
- **Thermal** Pr = 1, $\nu = \kappa \propto \rho^{-1/2}$)
- Boundary conditions: fixed thermal energy flux, impenetrable, stress-free
- After equilibration add small random B (~ 1 G)

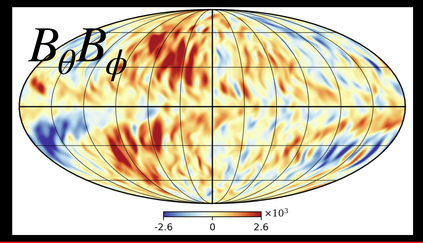


4. Lorentz torques maintain shear

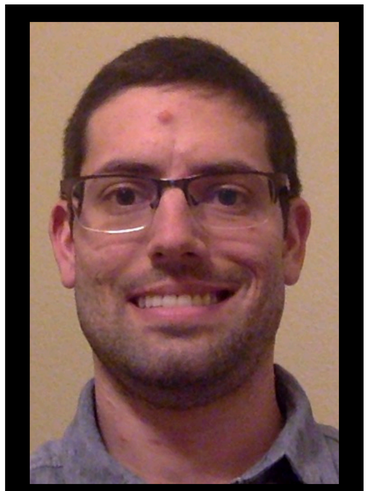
- m = 1 or 2 $B_\theta \rightarrow$
- m = 1 or 2 B_ϕ (through **latitudinal** shear)
- Correlation $B_\theta B_\phi$ sends angular momentum poleward
- Like **Ferraro's Law of Isorotation ($\mathbf{B}_{\rm pol} \cdot \nabla \mathbf{\Omega} = 0$)**
- This new magnetic confinement scenario does not rely on primordial field
- Note the similar timescales for Eddington-Sweet and Magnetic diffusion: $\sim 10^{11}$ yr







5. Contact



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