Exploring the Role of a Tachocline in M-Dwarf Magnetism

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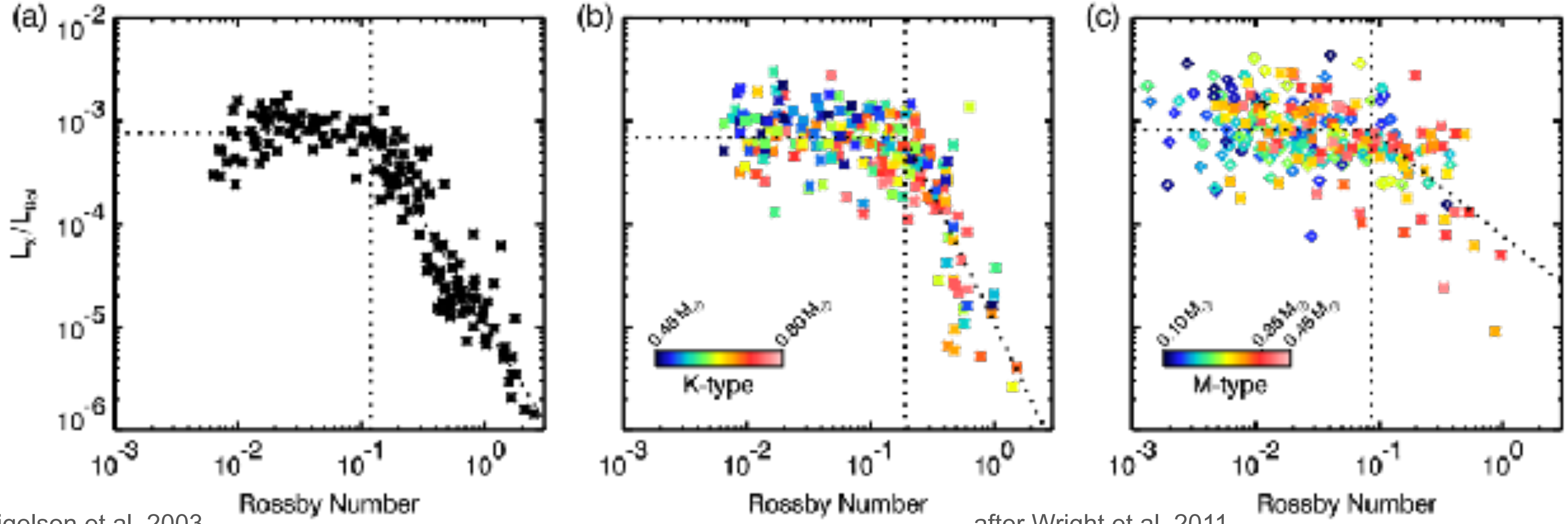
Why M-Dwarfs?

- Strong candidates in exoplanet searches
- Flare stars
- Rotation - Activity relation
- Spectral type - Activity relation?

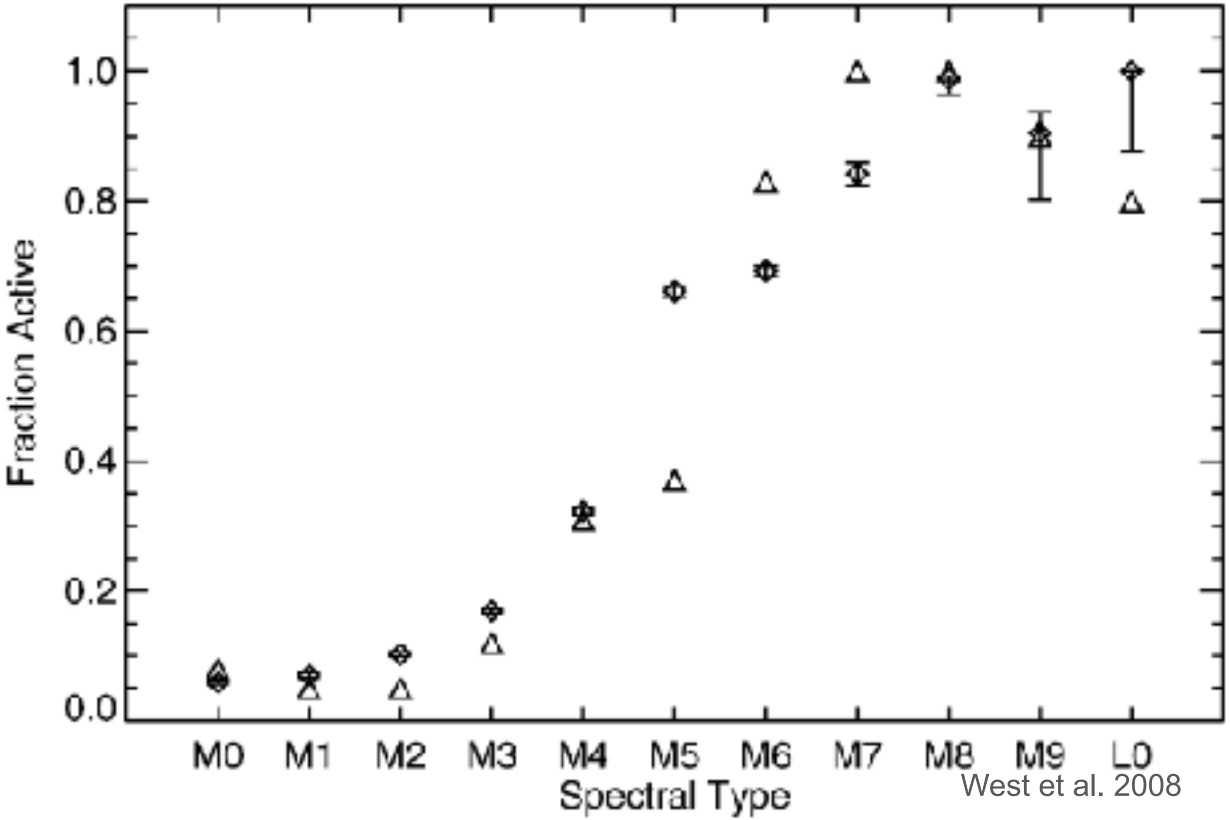


Feigelson et al. 2003

after Wright et al. 2011

The Tachocline Divide

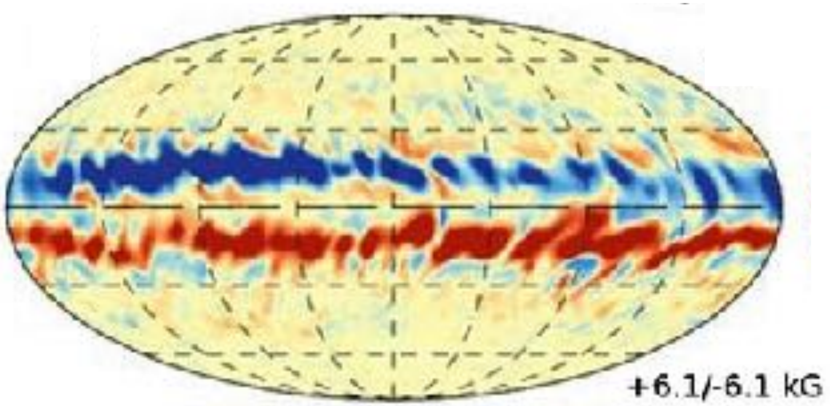
- >10% active earlier than M3
- ~90% active later than M6
- Current activity may reflect different spin-down histories
- Fully convective below M3.5



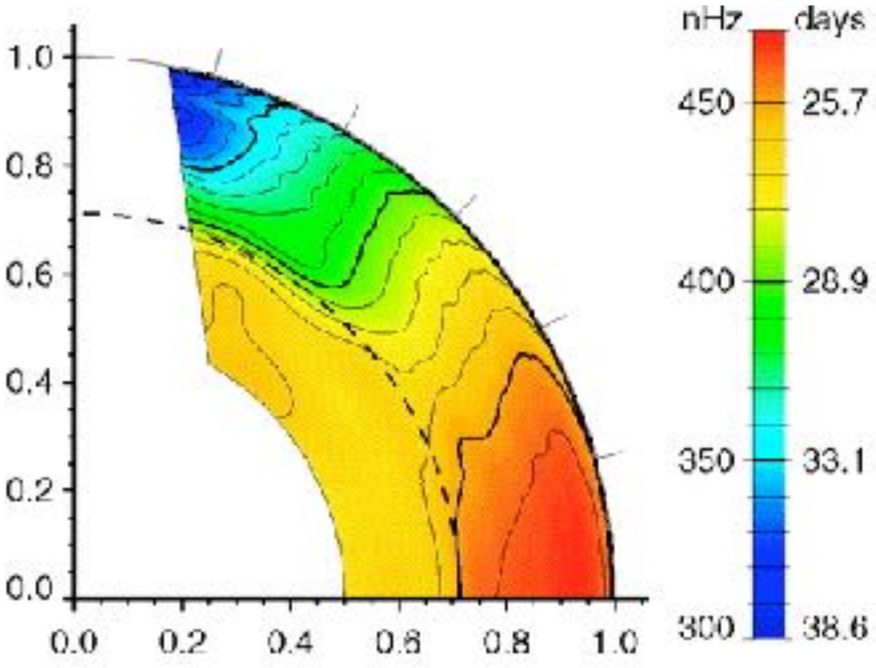
West et al. 2008

The Solar Tachocline

- Helioseismology reveals a shear layer separating RZ and CZ in the Sun
- Can store and amplify wreathy fields generated in the bulk of the CZ



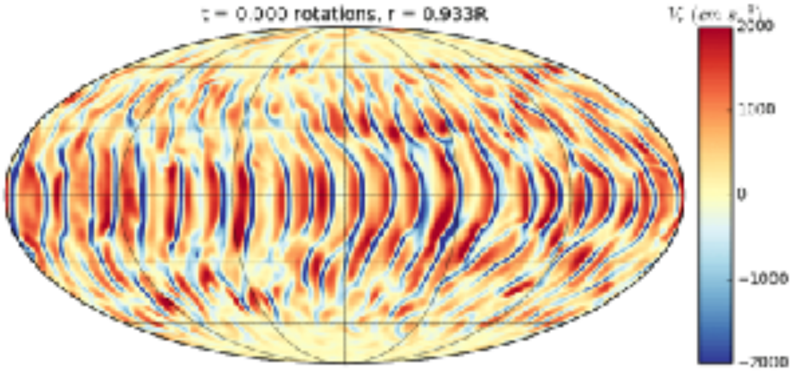
Brown et al. 2010



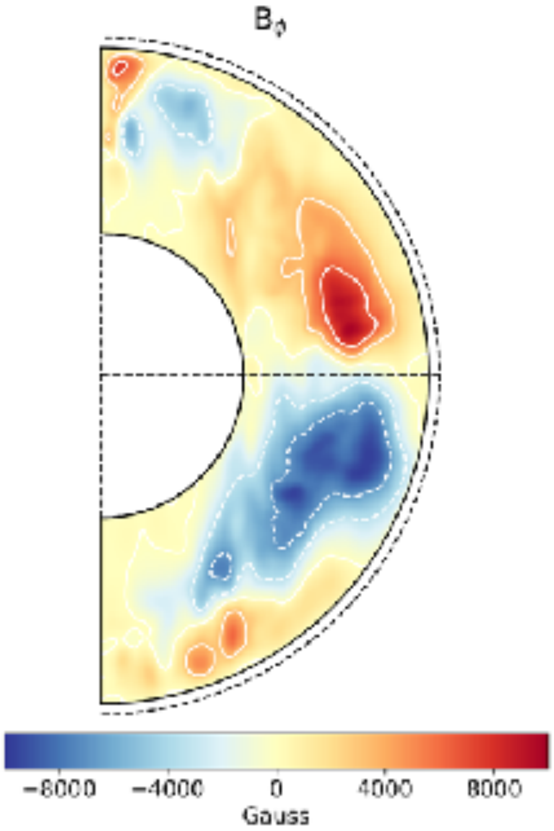
SOI-MDI

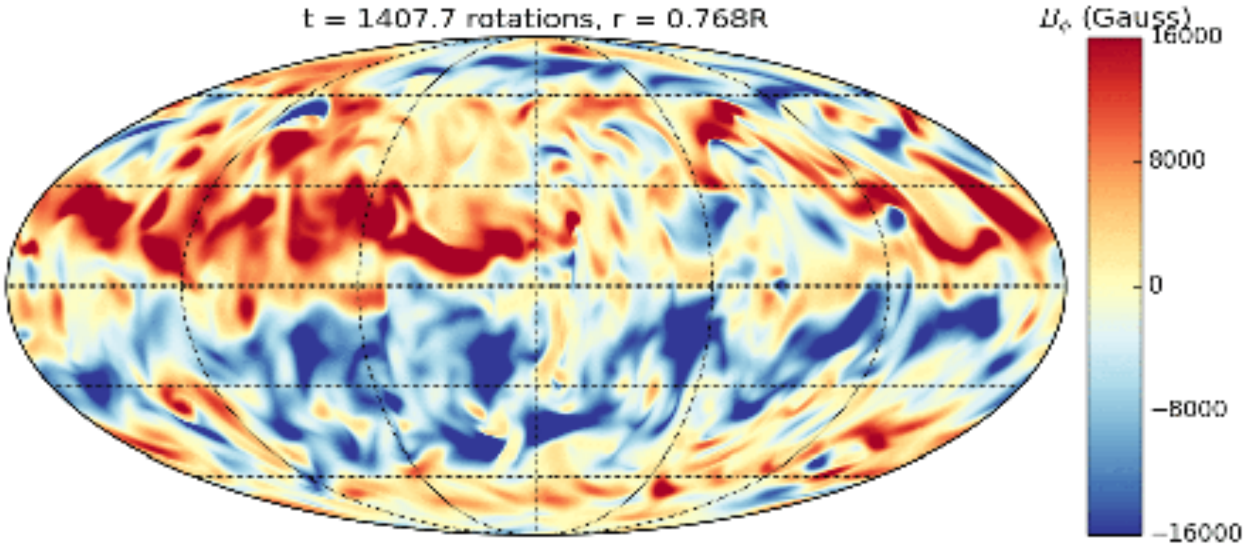
Computing Setup - Rayleigh

- Open source code developed by Nick Featherstone with NSF support through the Computational Infrastructure for Geodynamics (CIG)
- Anelastic MHD in rotating spherical shells
- Pseudospectral
  - Chebyshev polynomials
  - Spherical harmonics
- Background states taken from MESA
  - 0.4 $M_\odot$ rotating at 2 $\Omega_\odot$
  - Include / exclude stable layer below CZ
- Simulations here use 4096 cores on Pleiades
  - Efficient scaling to $O(10^5)$



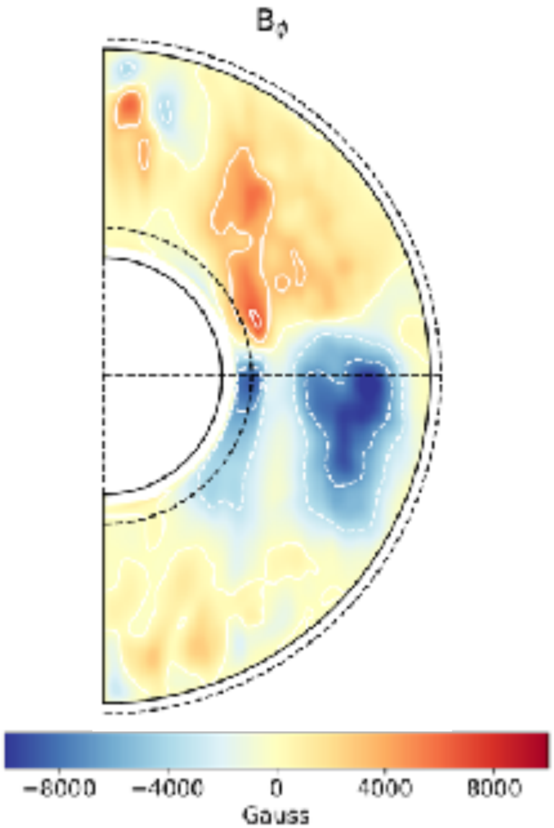
Toroidal Field Structure - No Stable Layer

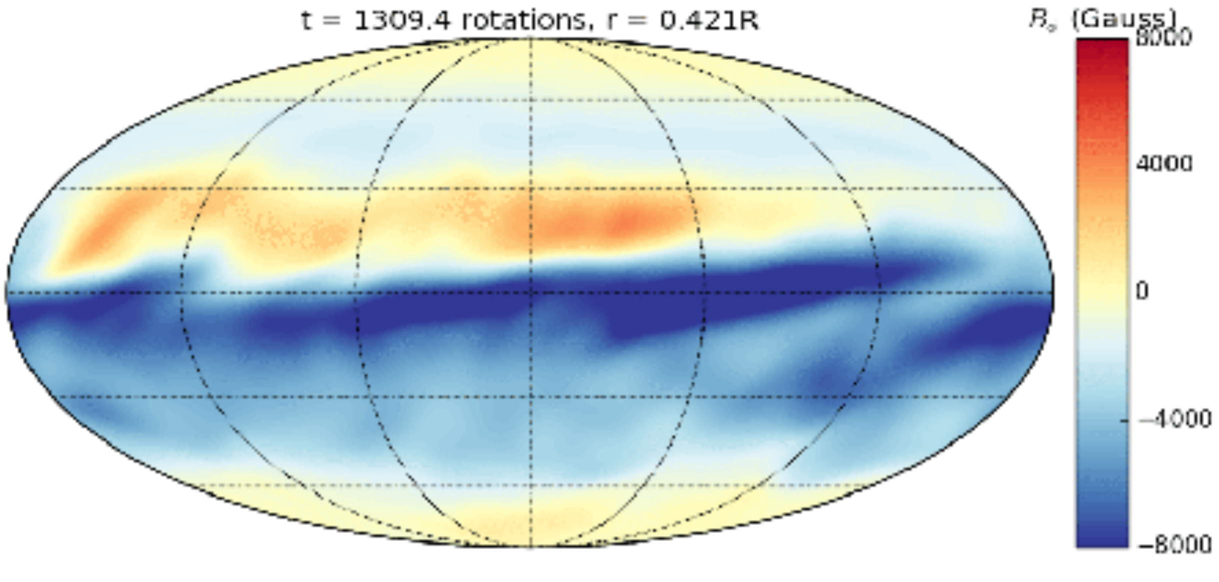




- Helical generation
- Quenched Diff. Rotation

Toroidal Field Structure - Stable Layer

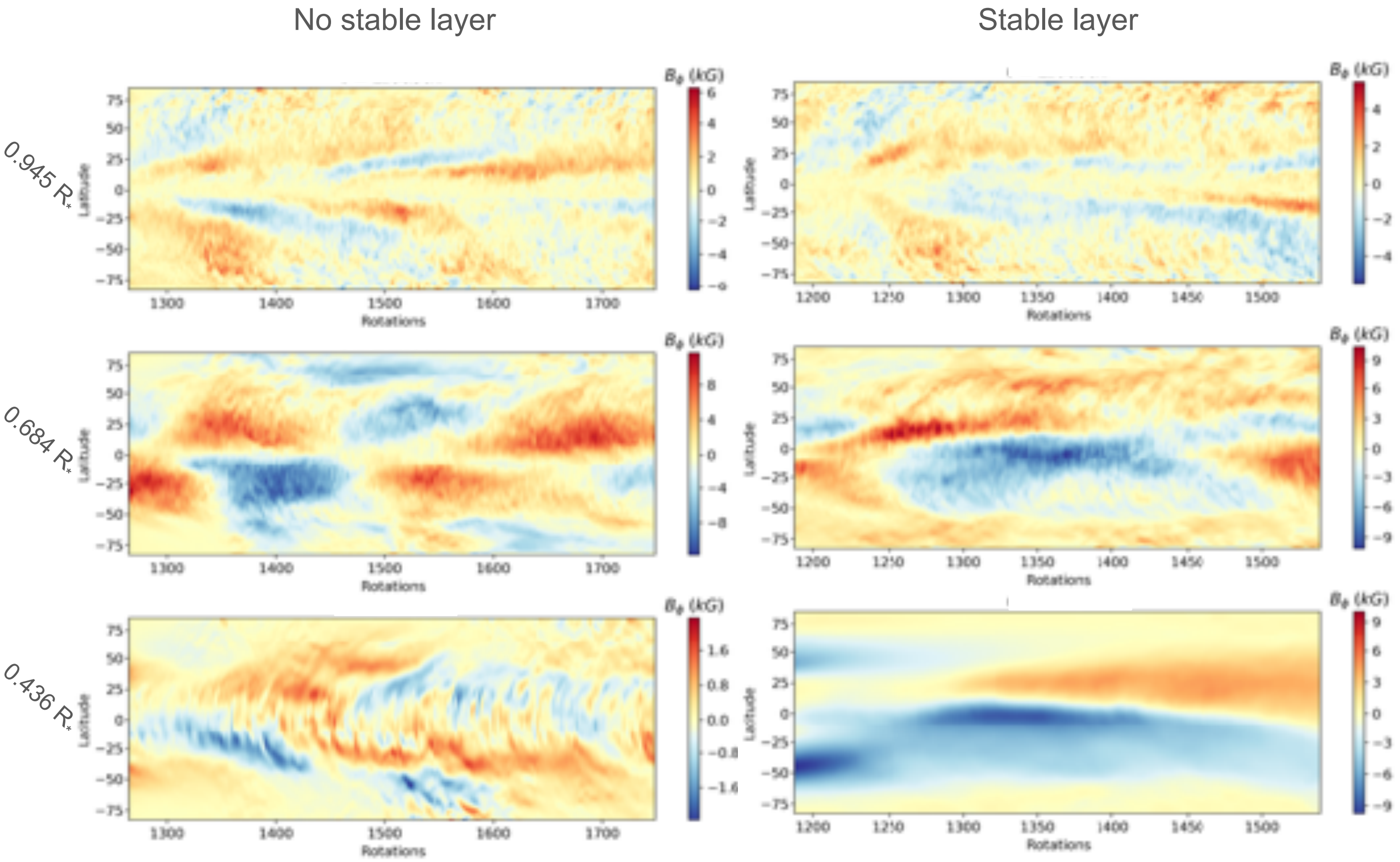




- Secondary site
- Powered by mean shear

Time Variability

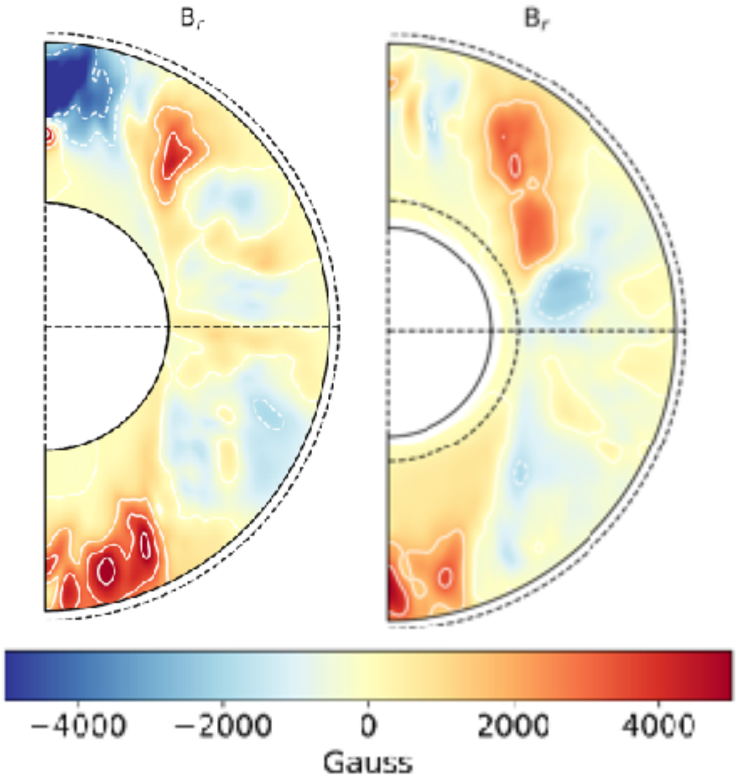
- Poleward migration of B_ϕ
- Pure convection has reversals every 100-200 rotations
- Model with sub-adiabatic layer has cycle period T~220 rotations

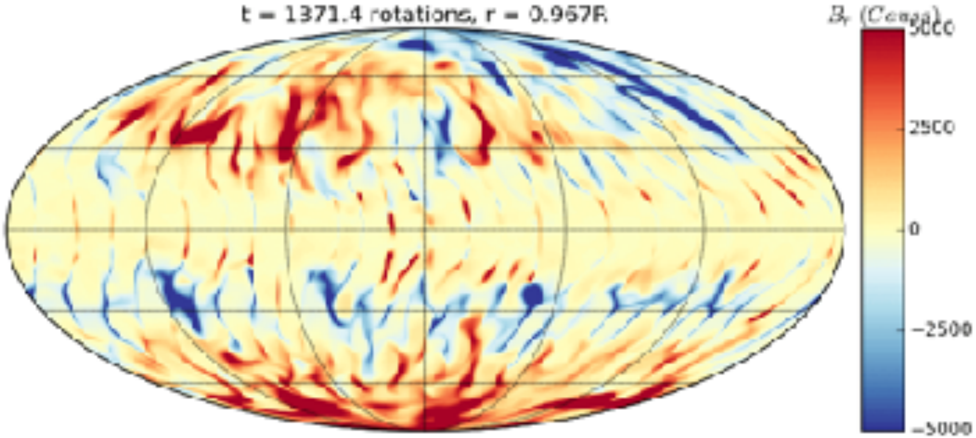


Emergent Field

No stable layer

Stable layer

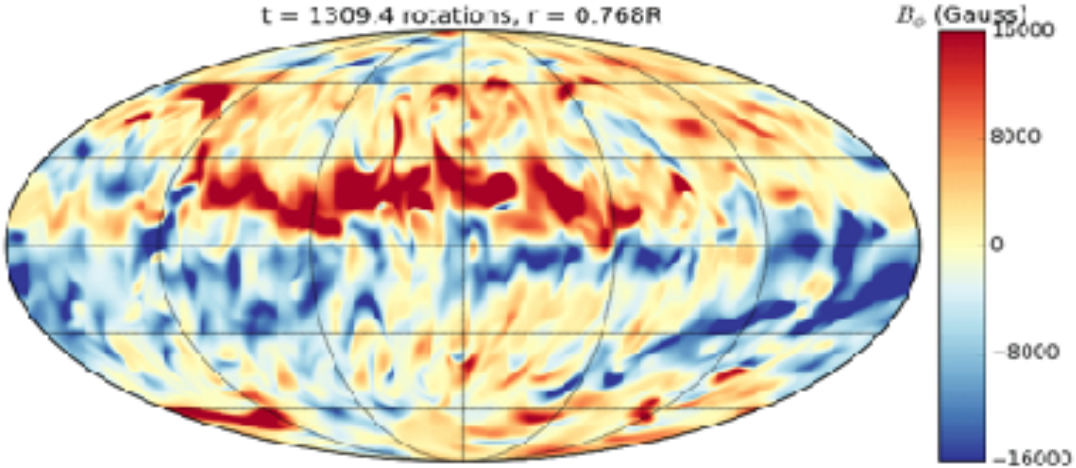




- Dipole much weaker in tachocline model
- Low latitude field builds up in downflow lanes

Conclusions

1. Deep convecting shells can organize very strong mean toroidal fields without need for a stable layer
2. Tachoclines provide even very deep shells an additional site for toroidal field generation with a longer cycling period
3. Early m-dwarfs might actually just “be bad” at building **poloidal** fields -- more simulations are needed.



Computing Setup - Modeling

- MESA reference states
- Fixed entropy gradient boundaries
- Diffuse internal heating
- ~1300x super-critical

Case	N_r,N_θ,N_ϕ	N_ρ	$\Omega_0/\Omega_\odot$	ν cm^2s^{-1}	Pr	Prm	Raf	Ta
H2NT	196×512×1024	5	2	1.02×10^{11}	0.25	-	1.86×10^{10}	4.19×10^8
H2T	(196+48)×512×1024	5	2	1.02×10^{11}	0.25	-	1.87×10^{10}	4.21×10^8
D2NT	196×512×1024	5	2	1.02×10^{11}	0.25	4	1.86×10^{10}	4.19×10^8
D2NTa	196×512×1024	5	2	1.02×10^{11}	0.25	15	1.86×10^{10}	4.19×10^8
D2T	(196+48)×512×1024	5	2	1.02×10^{11}	0.25	4	1.87×10^{10}	4.21×10^8
D2Ta	(196+48)×512×1024	5	2	1.02×10^{11}	0.25	15	1.87×10^{10}	4.21×10^8

Values quoted at $0.7R_*$