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
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
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 $B_\phi$
- Pure convection has reversals every 100-200 rotations
- Model with sub-adiabatic layer has cycle period $T \sim 220$ rotations
Emergent Field

- 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

<table>
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<th>Case</th>
<th>(N_r, N_\theta, N_\phi)</th>
<th>(N_\rho)</th>
<th>(\Omega_0/\Omega_\odot)</th>
<th>(\nu , cm^2 s^{-1})</th>
<th>(Pr)</th>
<th>(Prm)</th>
<th>(Raf)</th>
<th>(Ta)</th>
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Values quoted at 0.7R.