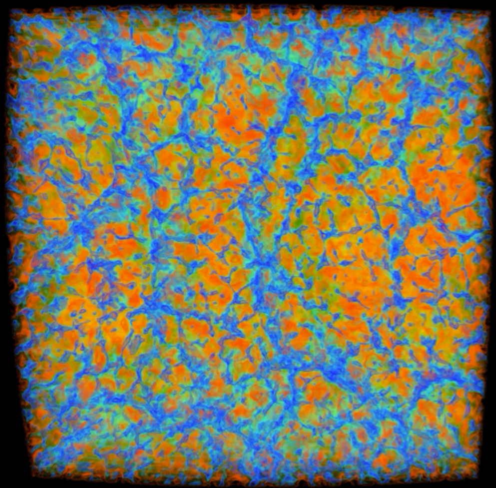
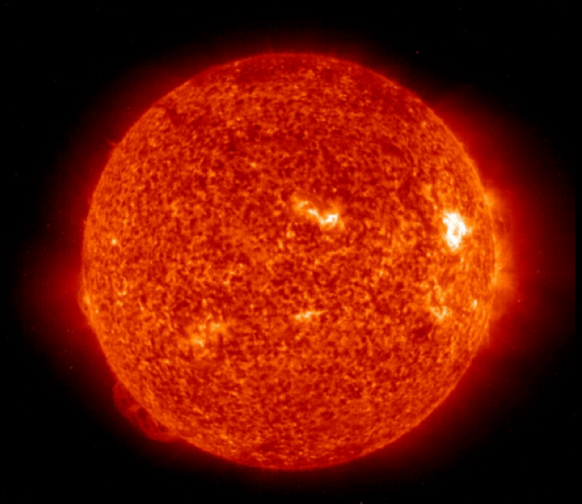
Simulations of Flux Emergence in Cool Stars: What's Convection, Rotation, and Stellar Structure got to do with it?





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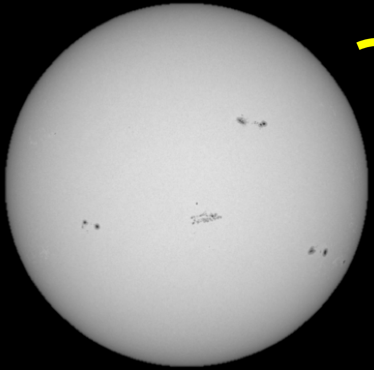
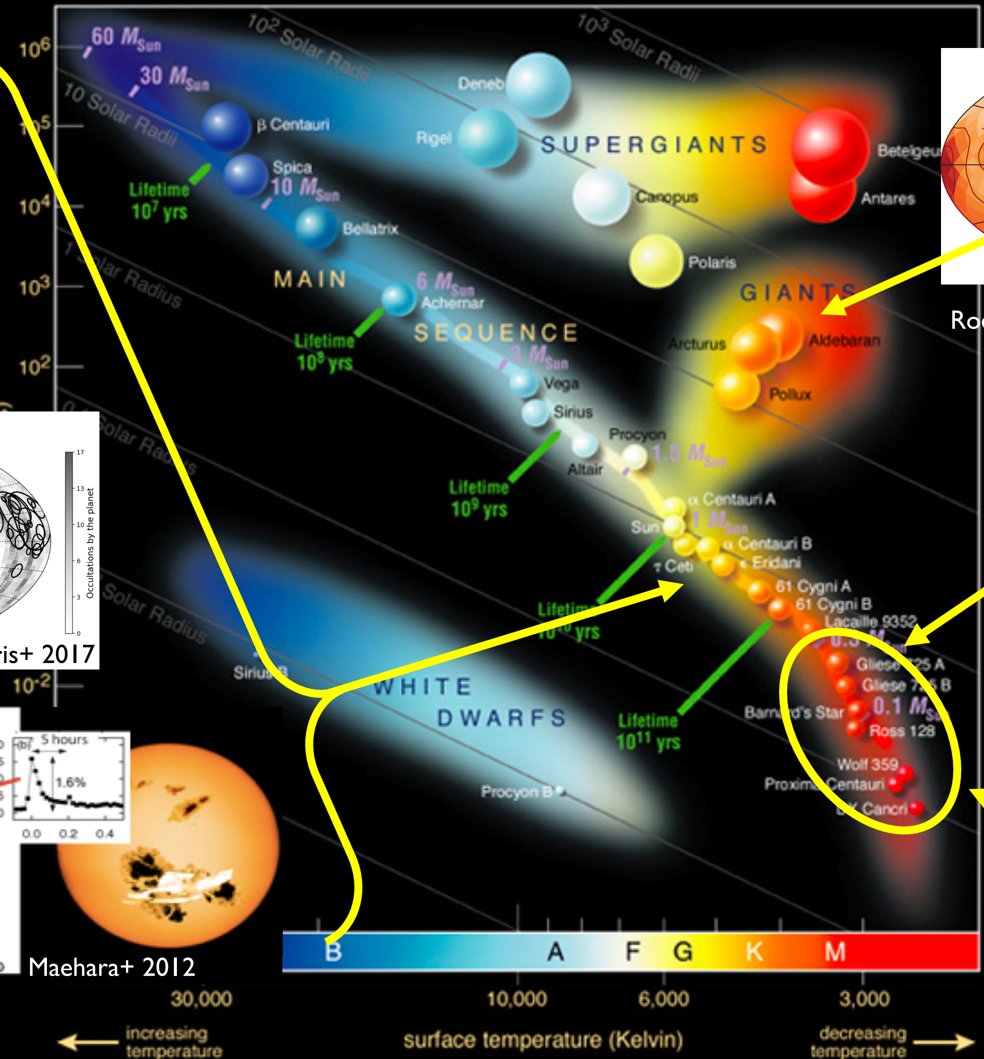
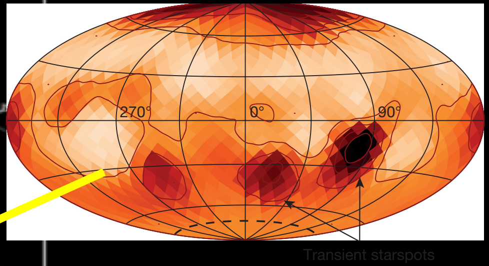
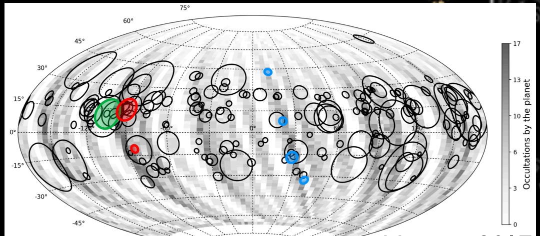


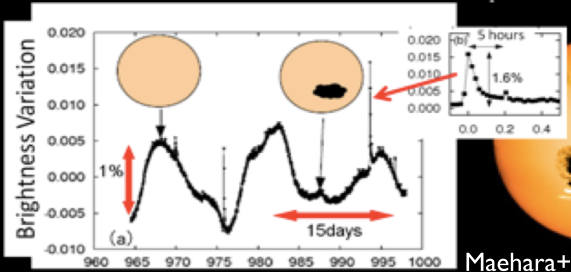




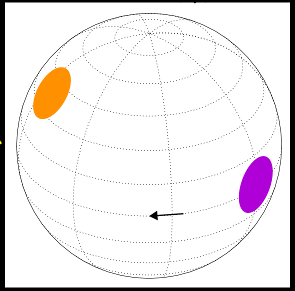
Roettenbacher+ 2016



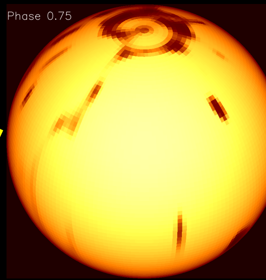
Morris+ 2017



Maehara+ 2012



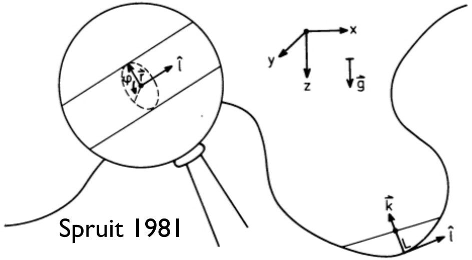
Davenport+ 2015



Barnes+ 2015

Model Schematic:

TFT Approximation → Initial Conditions → Stellar Structure → Convective Velocity Field



Equation of Motion:

$$\rho \frac{d\mathbf{v}}{dt} = -2\rho(\boldsymbol{\Omega_0} \times \mathbf{v}) - (\rho_e - \rho)\mathbf{g} + \mathbf{l}\frac{\partial}{\partial s}\left(\frac{B^2}{8\pi}\right) + \frac{B^2}{4\pi}\mathbf{k}$$

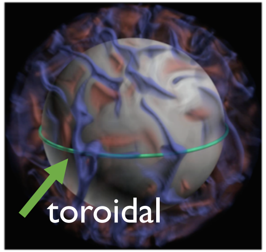
$$-C_d \frac{\rho_e |(\mathbf{v} - \mathbf{v}_e)_\perp|(\mathbf{v} - \mathbf{v}_e)_\perp}{(\pi\Phi/B)^{1/2}}$$

B_0

r_0

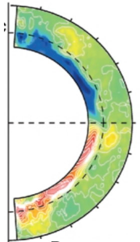
θ_0

Φ



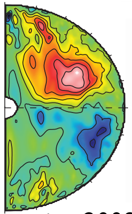
Solar $1\Omega_\odot$, $5\Omega_\odot$

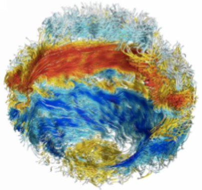
Tachocline interface dynamo



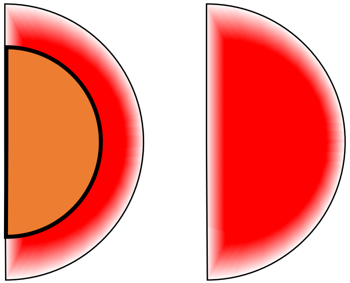
M dwarf, Solar $3\Omega_\odot$

Distributed dynamo

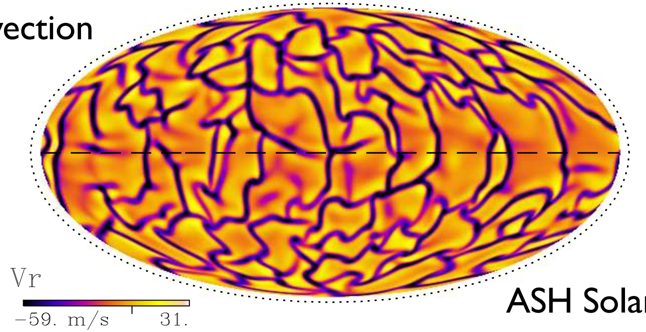




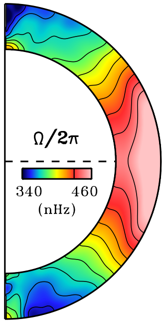
Sun $0.3M_\odot$ M Dwarf



Convection

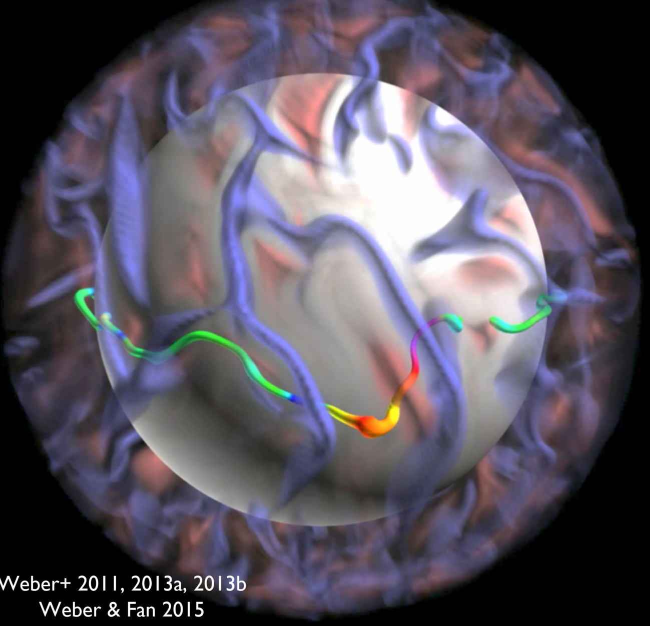


ASH Solar



Convection modulates flux emergence

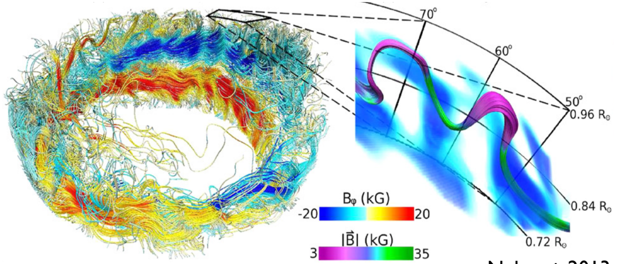
Sun-like stars



Weber+ 2011, 2013a, 2013b
Weber & Fan 2015

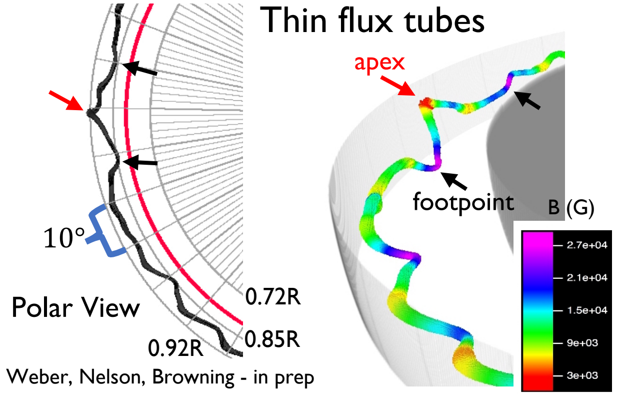
- Convection & magnetic buoyancy work in concert to promote flux emergence

Dynamo-generated magnetic loops



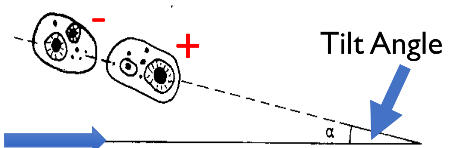
Nelson+ 2013

Thin flux tubes



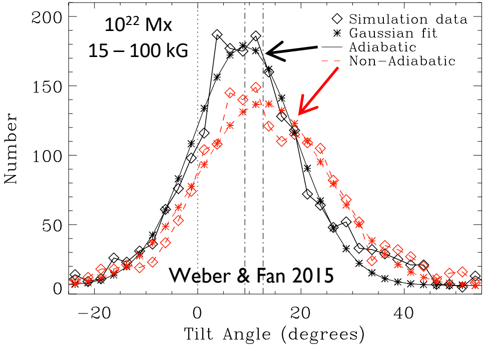
Weber, Nelson, Browning - in prep

- Downflows naturally induce loops ~15° – 20° apart

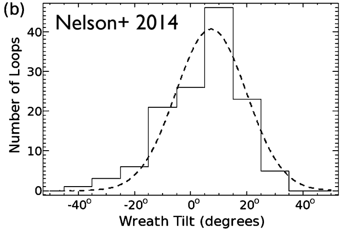


adapted from Schrijver & Zwaan 2000

TFT+convection



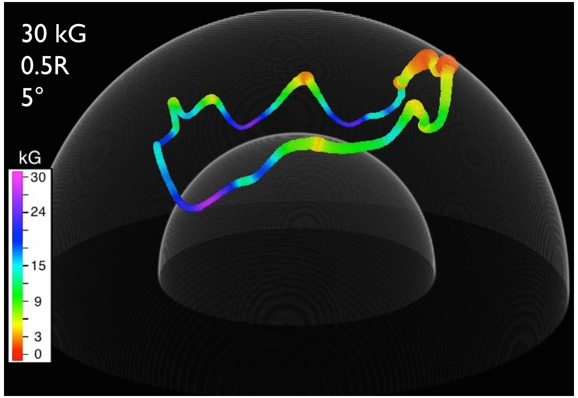
Dynamo-generated loops

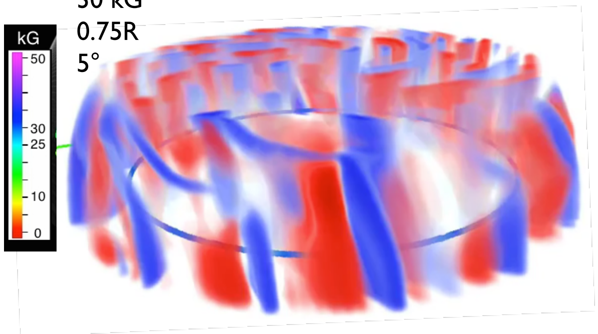


- Convection introduces a statistical spread in tilt angles

Convection can also suppress flux emergence

Fully convective M dwarf

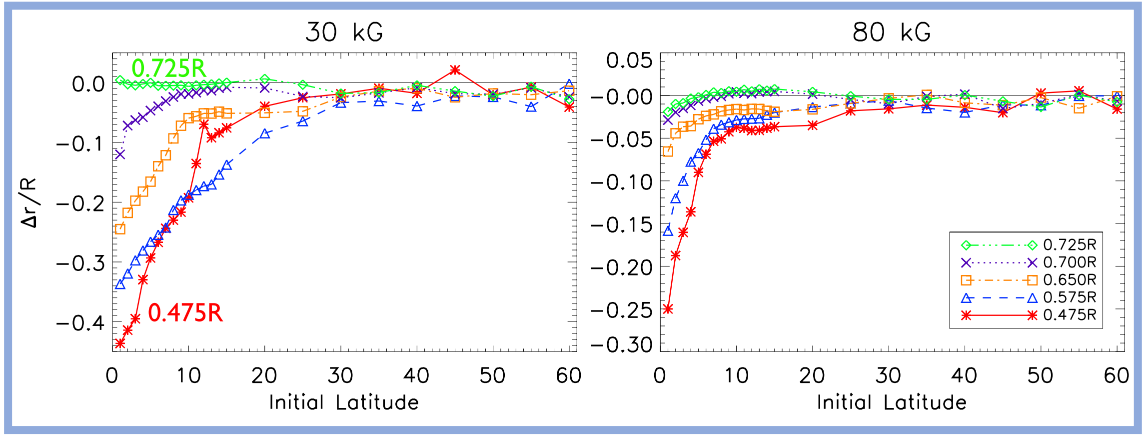




Weber & Browning 2016, Weber+ 2017

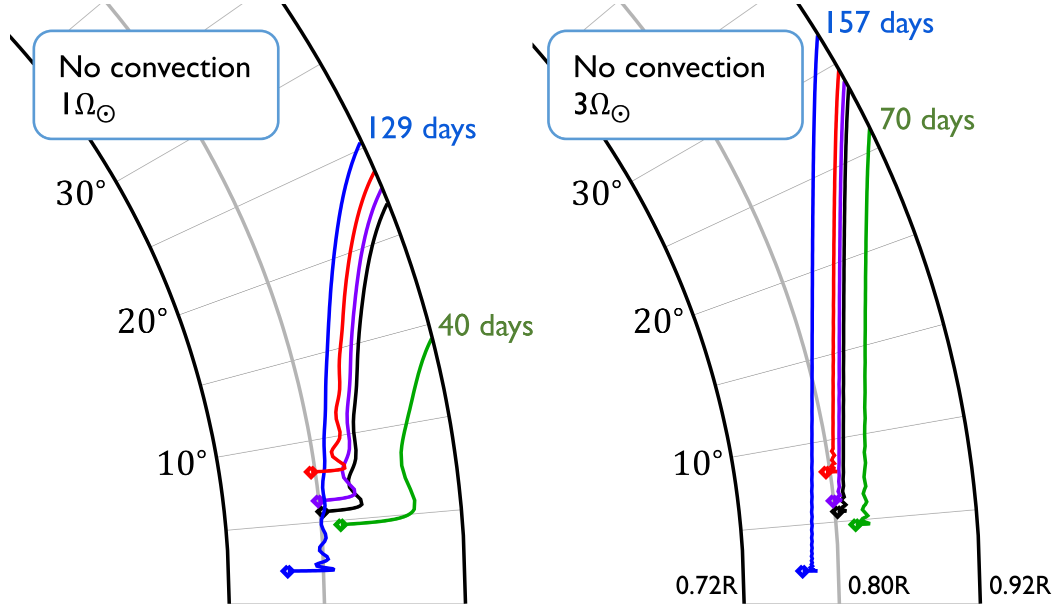
Average 'suppression depth' Δr

Weber+ 2017



- The global rise of TFTs is more strongly suppressed by convective flows when the flux tube is initiated:
  - in the deeper interior
  - at lower latitudes
  - with a weaker magnetic field strength

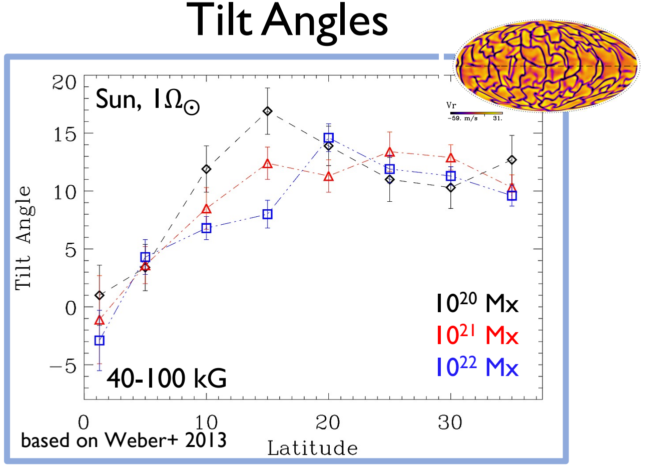
Rotation alters emergence properties

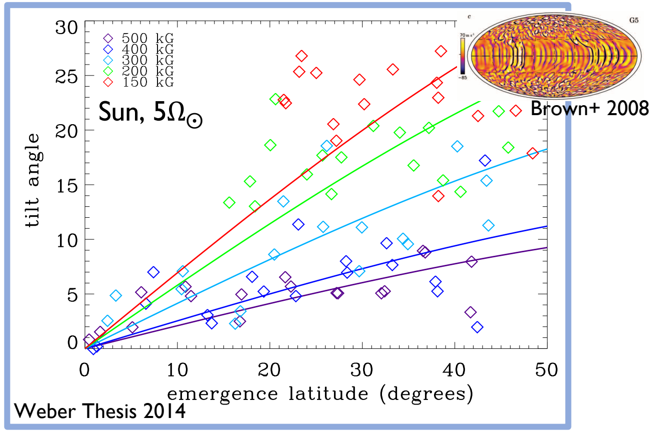


Weber, Nelson, Browning - in prep

- Due to the Coriolis force, more rapid rotation:
  - Lengthens the rise time
  - Leads to poleward deflection
  - Increases tilt angles

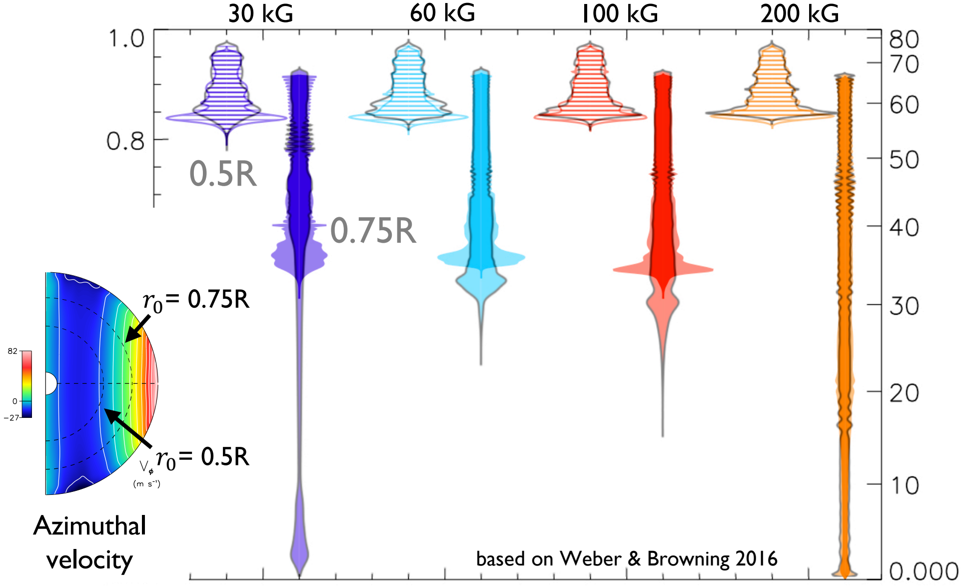
Tilt Angles



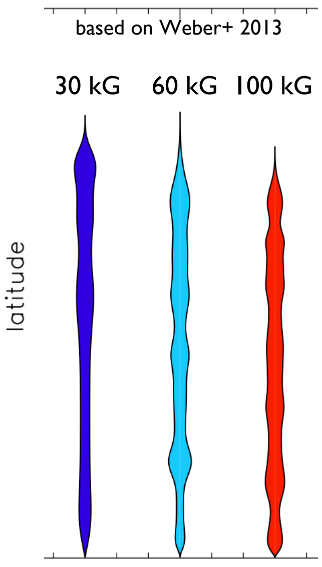


Stellar structure impacts emergence latitudes and more

Emergence Latitude Probability Functions

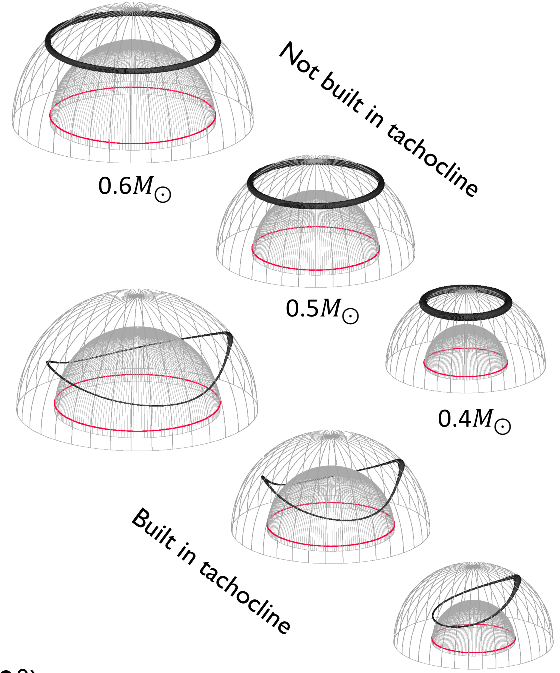


Fully Convective M Dwarf, $\theta_0 = 1° - 60°$



Sun, $\theta_0 = 2° - 40°$

Tachocline or not?

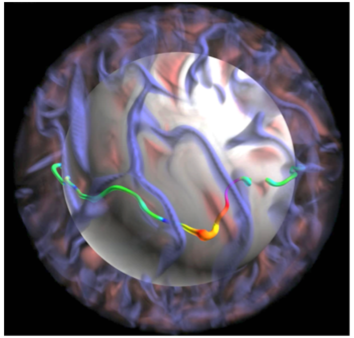


- Unlike solar case, in M dwarf there is a tendency for high latitude emergence (> 30°)
- Exceptions when flux tubes initiated closer to the surface and of sufficiently weak (≤30 kG) or strong field strengths (≥200 kG)
- Increased density in M dwarfs leads to longer flux tube rise times by ≤ 10x

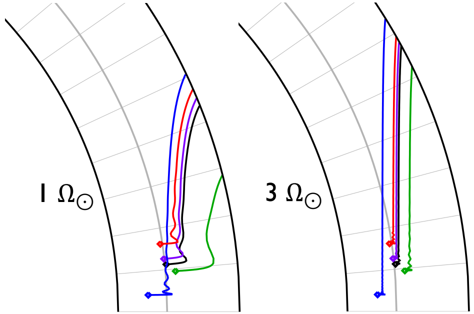
- Assumption of flux tube generating region, and thereby initial thermodynamic properties, matter

Summary

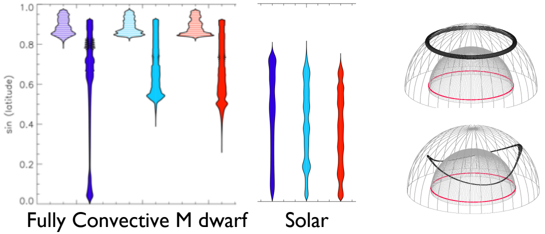
Convection, rotation, and stellar structure are all important contributing factors to the overall trend of flux emergence.



- Convection modulates flux emergence
- Fluid motions both suppress and promote the rise of magnetism
- Convection introduces a statistical spread in emergence properties



- Due to the Coriolis force, rapid rotation:
  - Lengthens the rise times
  - Leads to poleward emergence
  - Increases tilt angle



- Tendency for polar flux emergence in M dwarfs, unlike in solar-like stars
- Increased density in M dwarfs leads to longer rise times
- Assumptions about flux tube generating region (i.e. tachocline or not) has consequences for flux emergence

This work is a step toward linking magnetic flux emergence, convection, and dynamo action along the lower end of the main sequence.