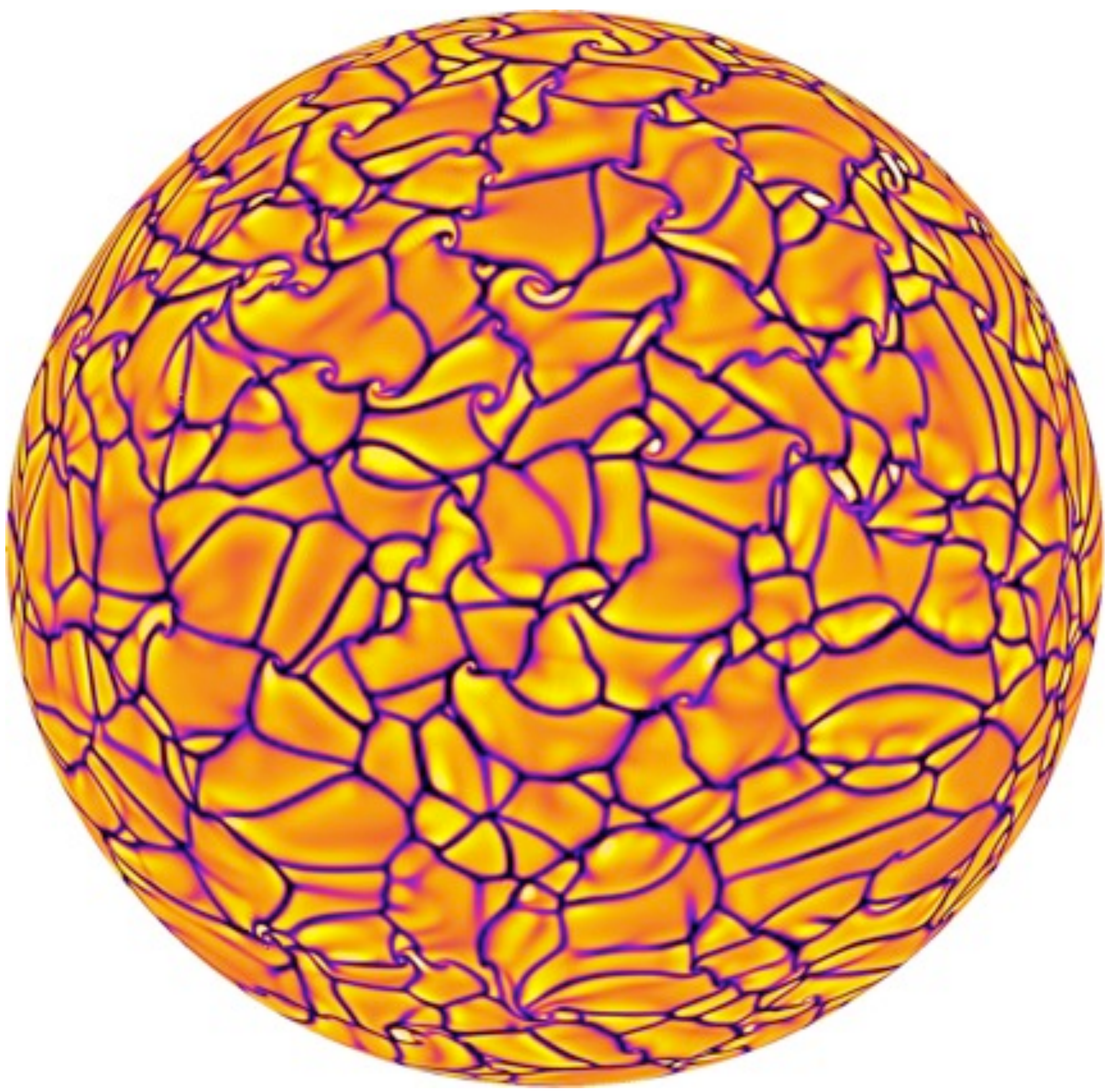
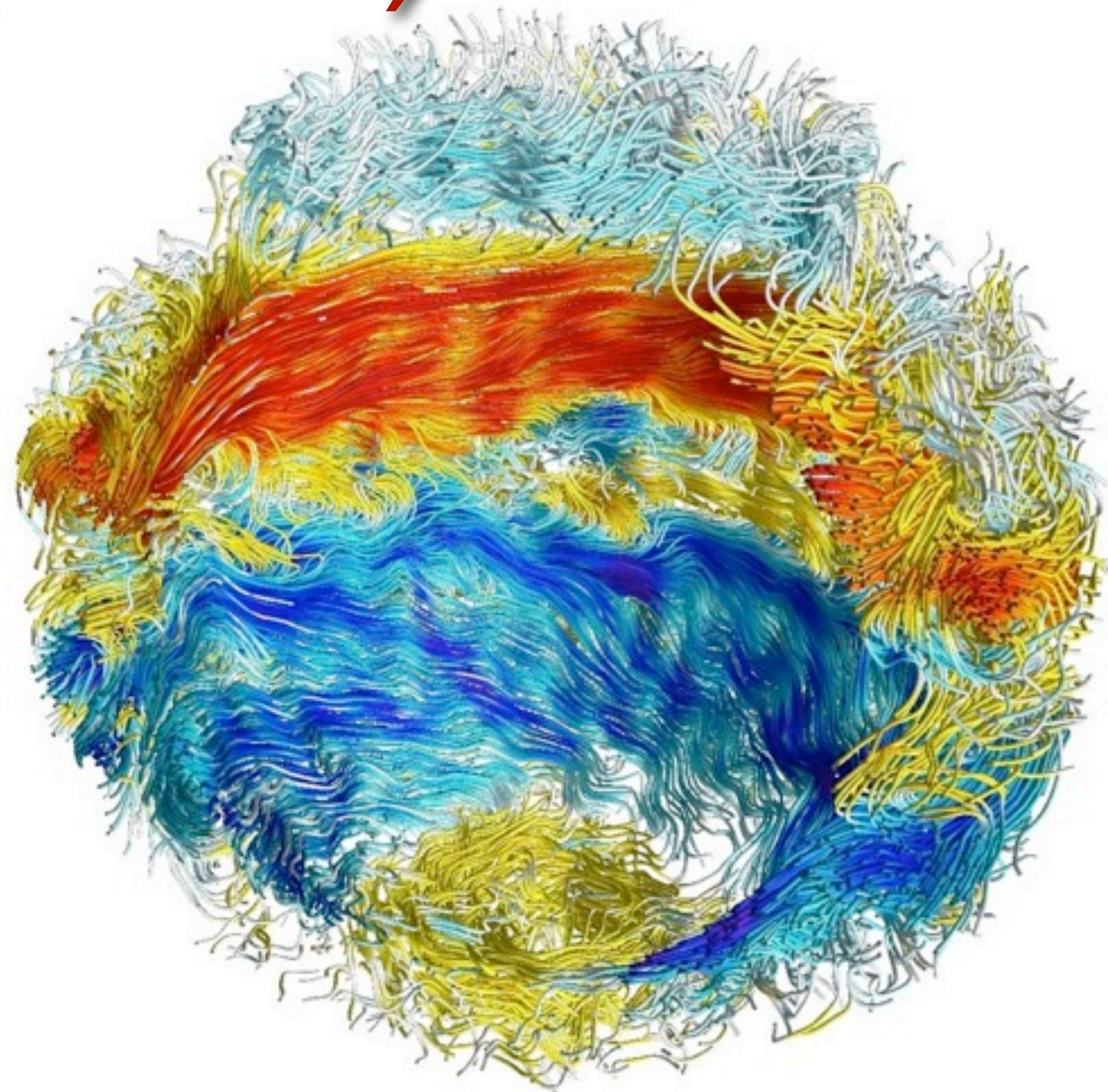
Convection in Main-Sequence Stars (Part I)





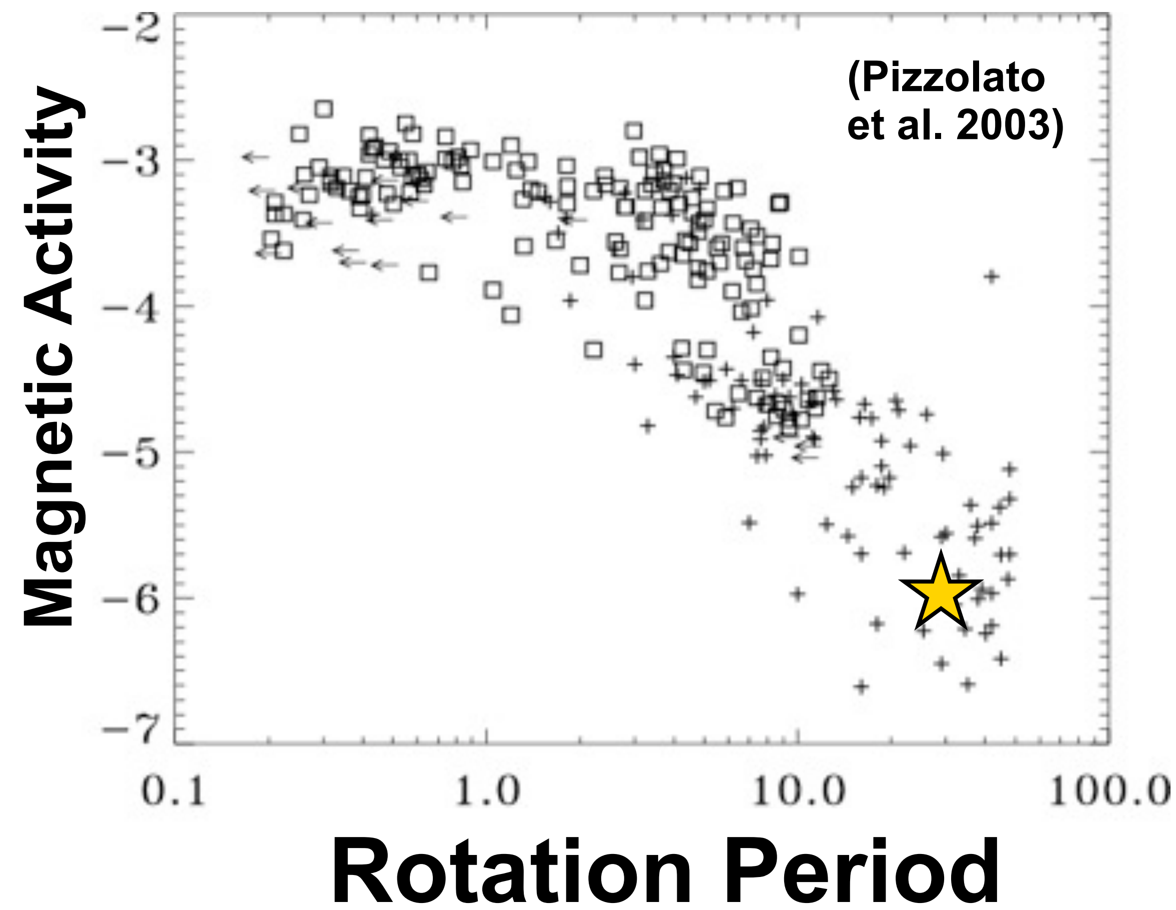
w/ Browning, Brun, Miesch, Toomre, Zweibel

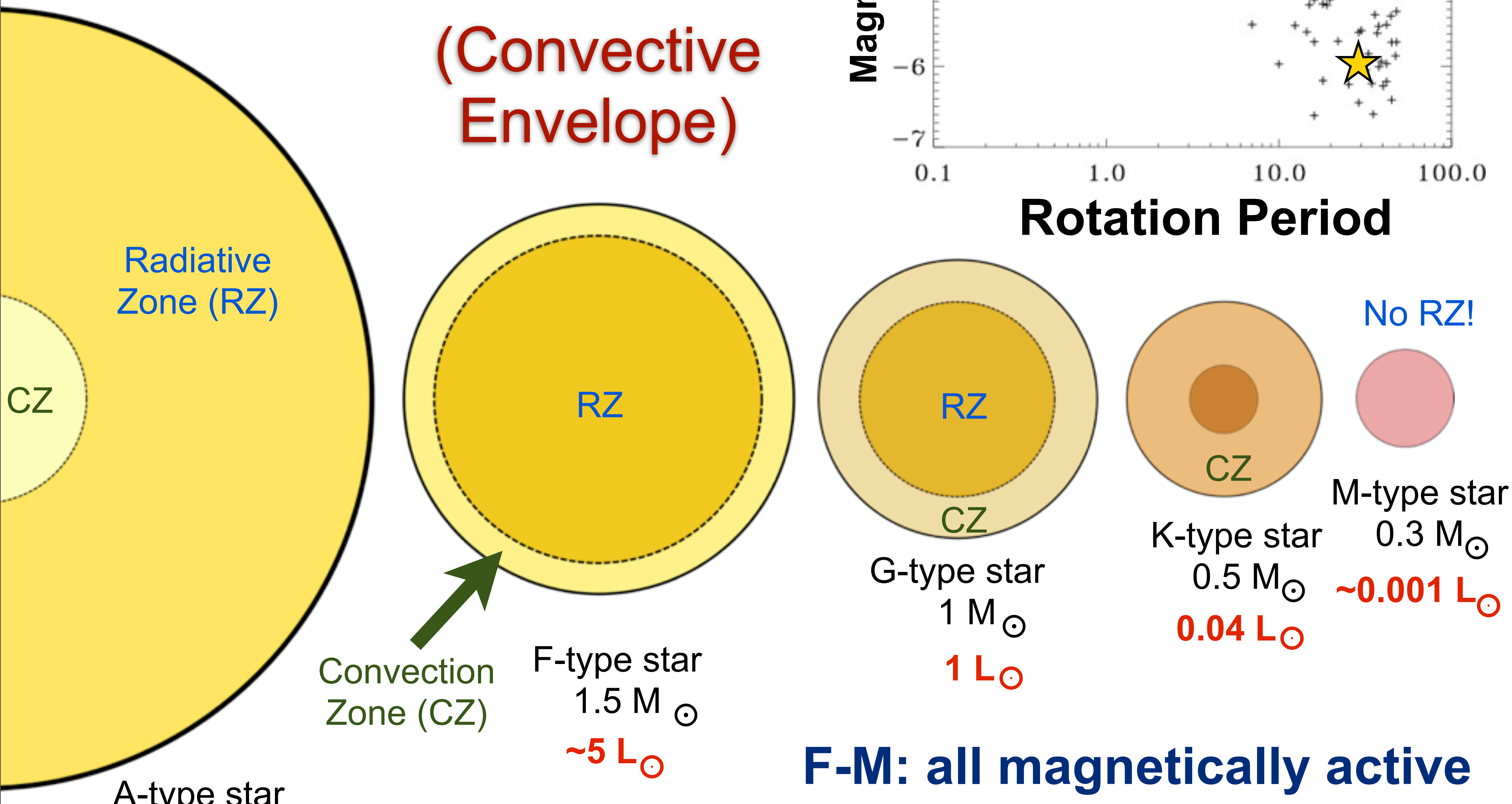
Ben Brown
Univ. Wisconsin Madison

(CMSO & NSF AAPF)

Magnetic Activity in Solar-like Stars

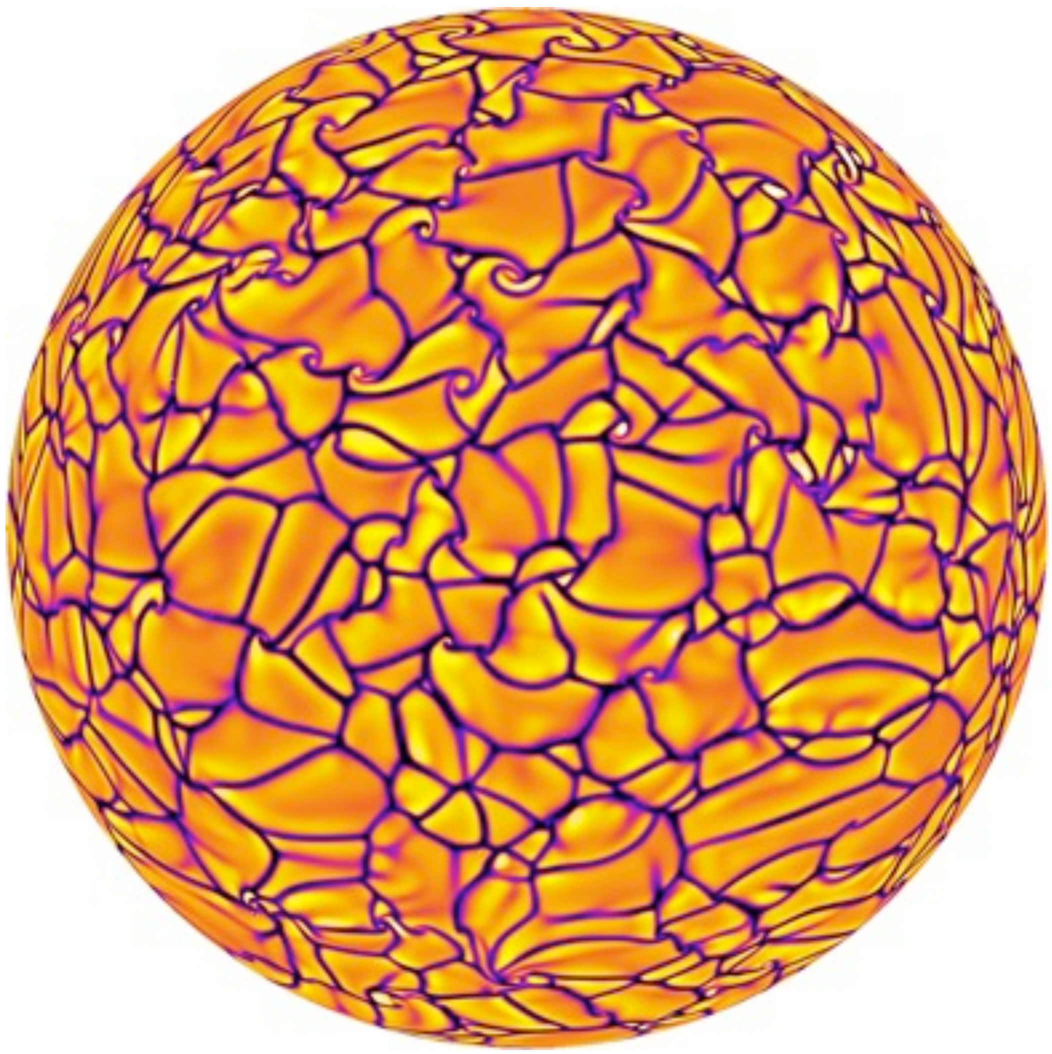
(Convective Envelope)





F-M: all magnetically active

Anelastic Spherical Harmonic (ASH) Simulations



Solar convection
(Miesch et al. 2008)

- Capture 3-D MHD convection at high resolution on massively-parallel supercomputers (~1000 processors for ~1 year)
- Study turbulent convection interacting with rotation in bulk of solar CZ: 0.72 *R* - 0.97 *R*
- Realistic stellar structure
- Simplified physics: perfect gas, radiative diffusivity, compressible, subgrid transport, MHD
- Correct global spherical geometry
- Now can study similar stars too

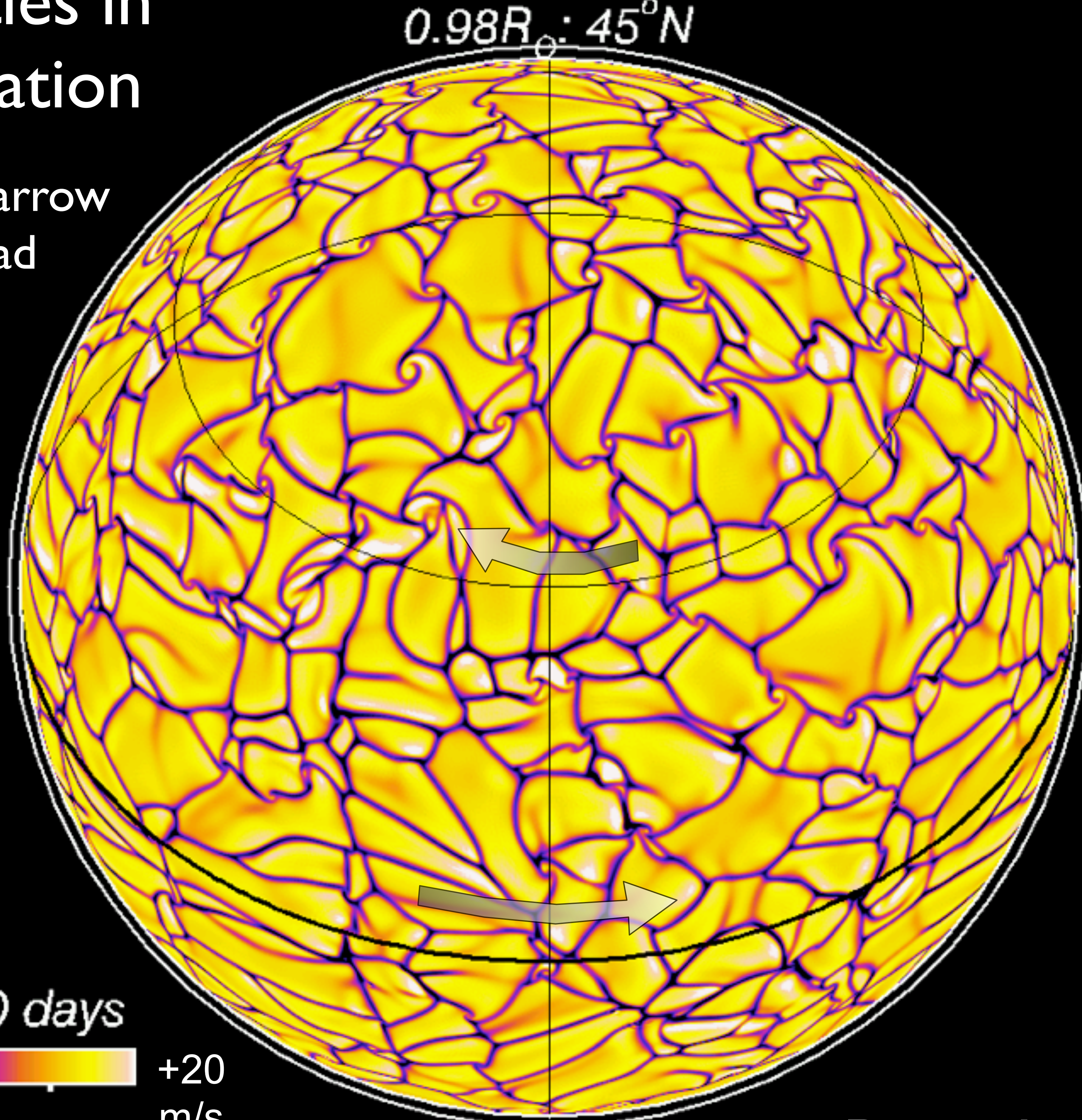
Radial Velocities in a solar simulation

Downflows: fast, narrow
Upflows: slow, broad

Swirling, vortical convection near polar region

Sweeping cells near equator

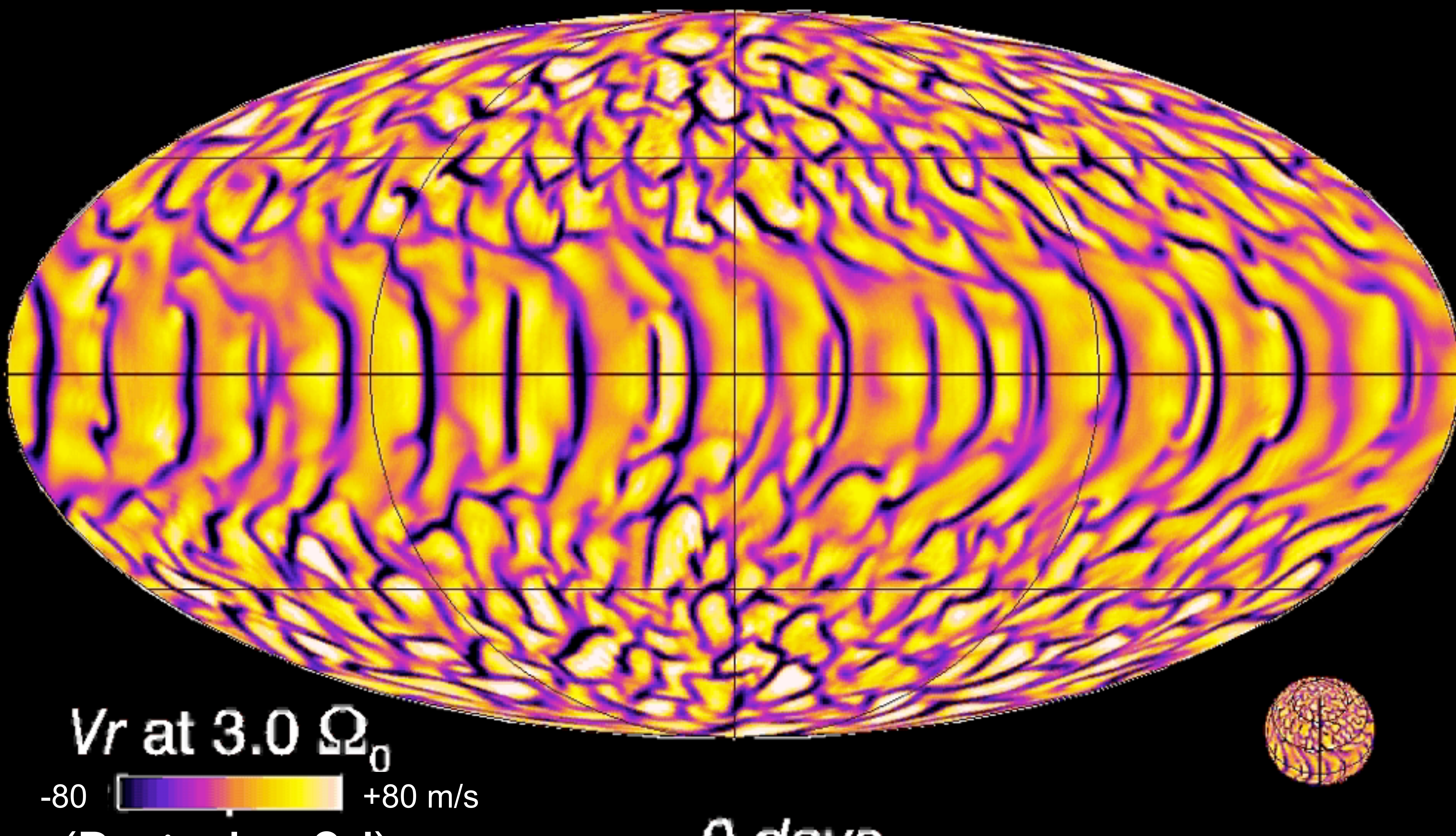
Shown near the solar surface (2%)



(based on Miesch et al. 2008)

Period ~ 28d

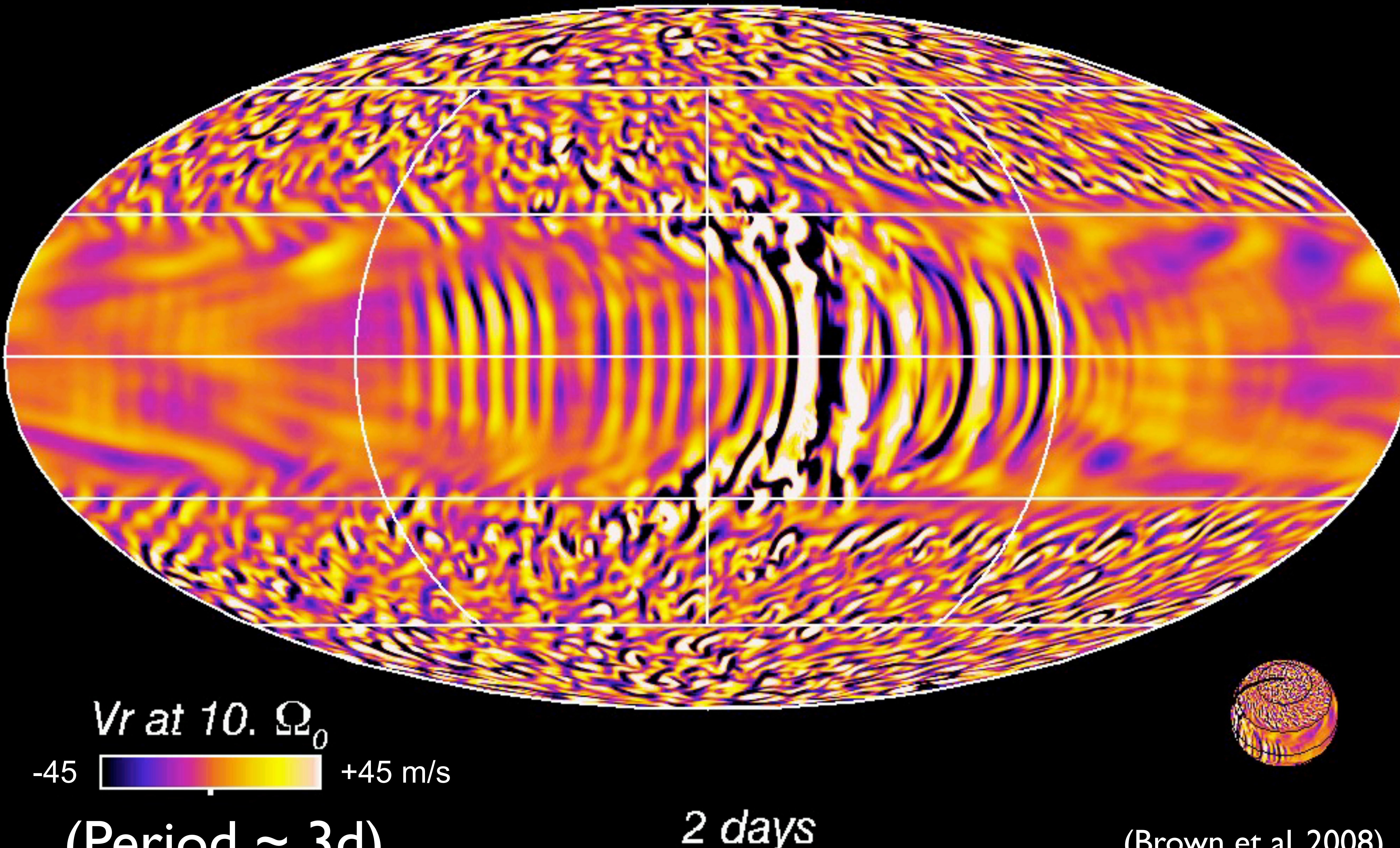
Rapidly Rotating Suns: Convective Flows



(Period ~ 9d)

(Brown et al. 2008, 2010)

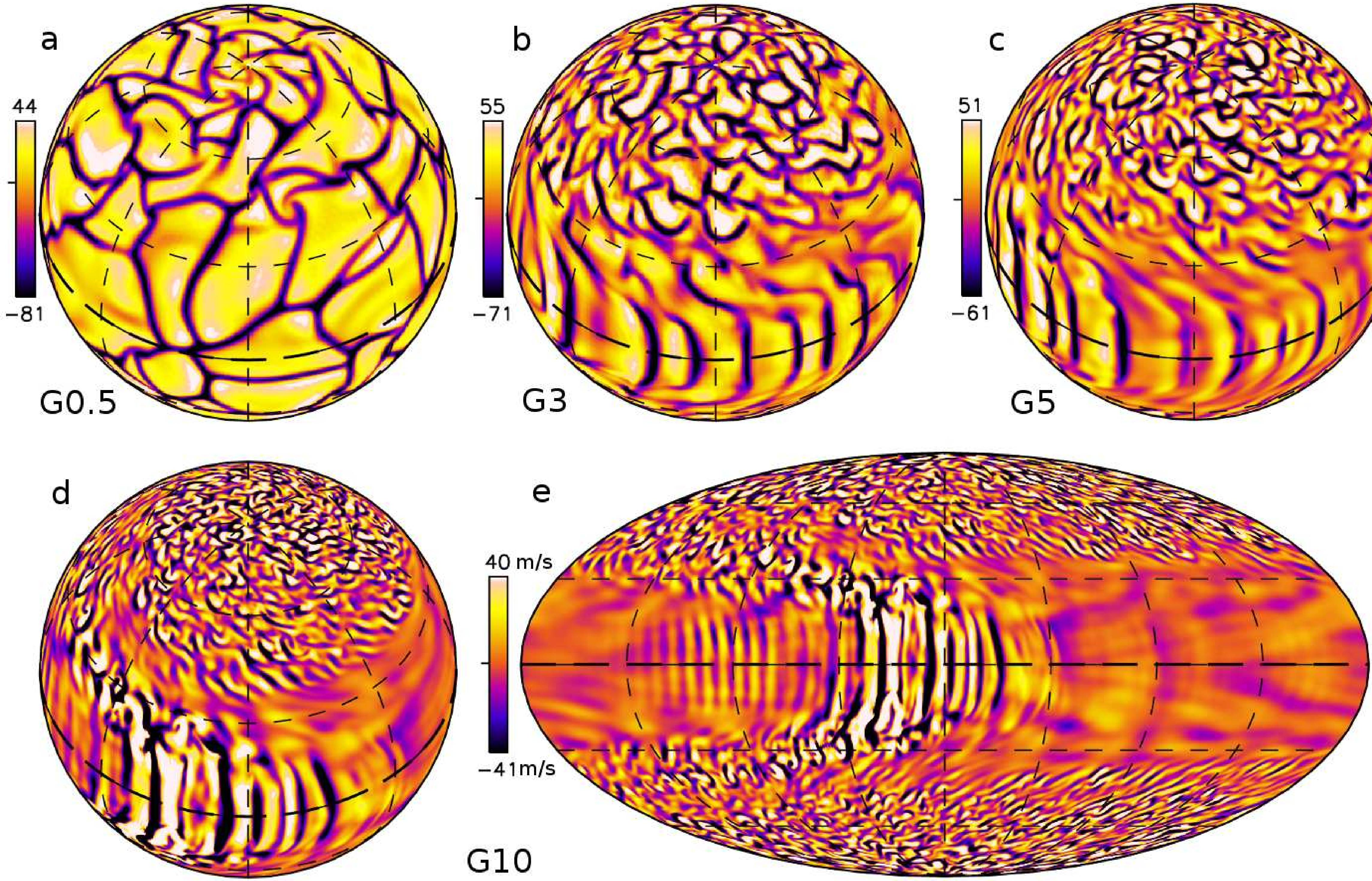
Flows in a very rapidly rotating star



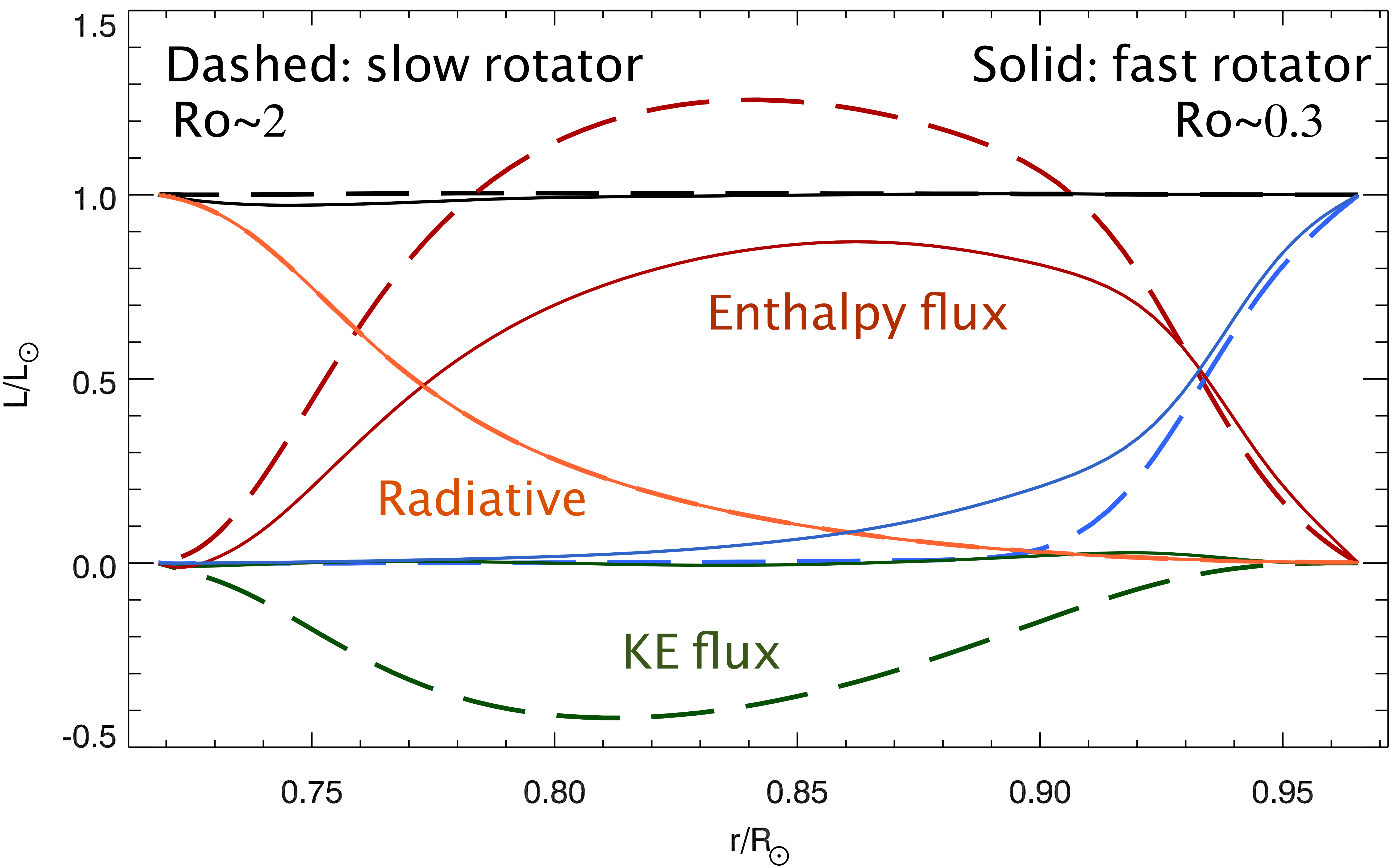
(Period ~ 3d)

(Brown et al. 2008)

Convection in G-type stars



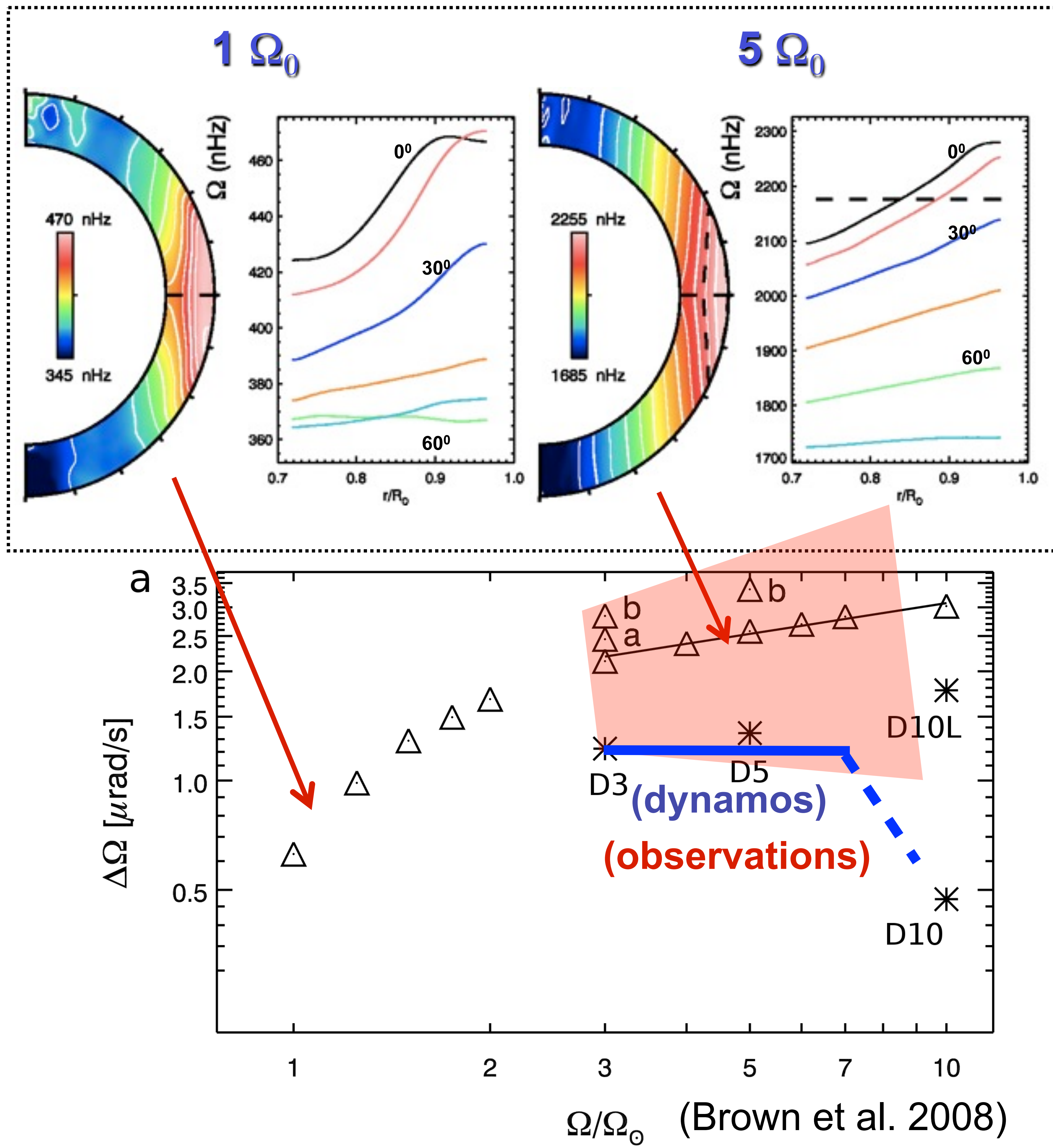
Convective fluxes (G-type)



Differential Rotation in Other Suns (G-type)

More rapidly rotating suns look much like the Sun, but with stronger overall DR contrast

Decent agreement with observations

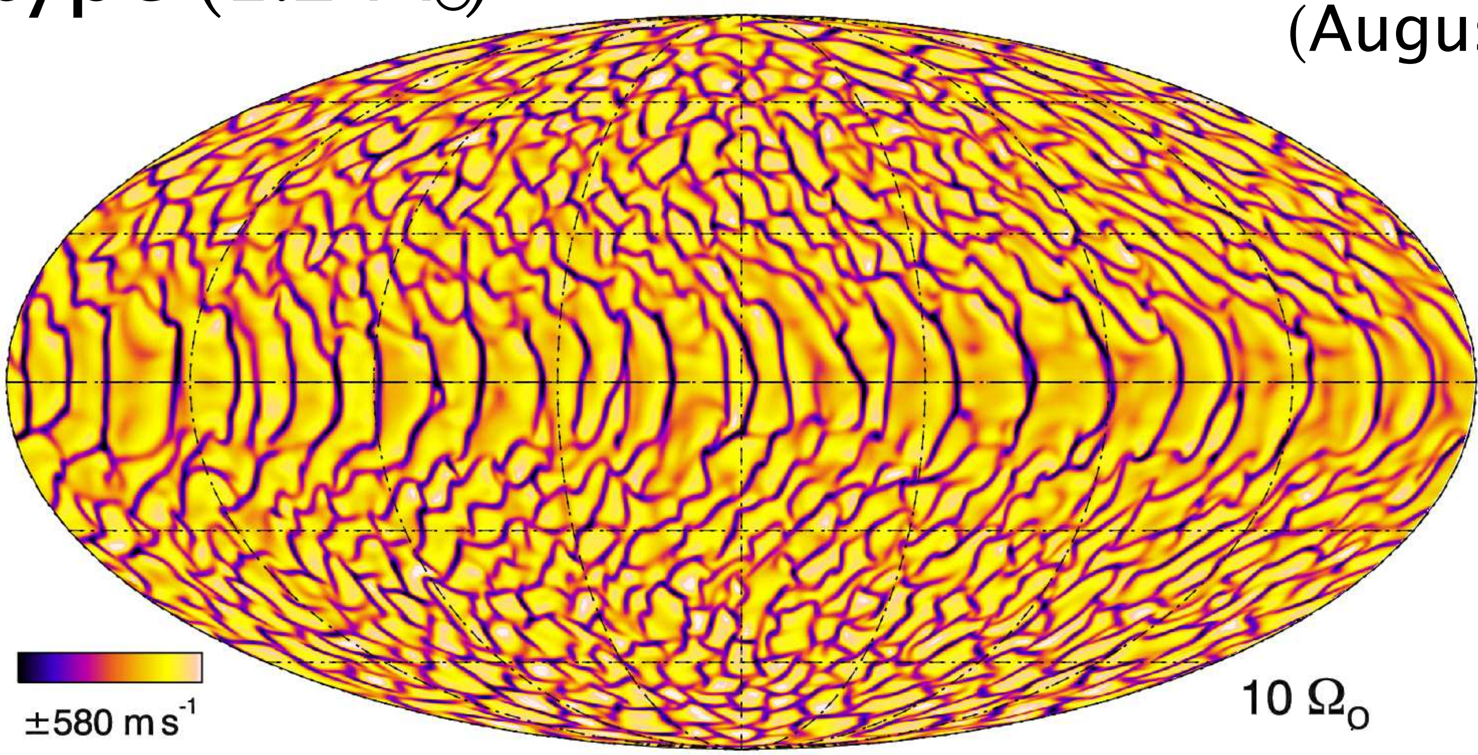


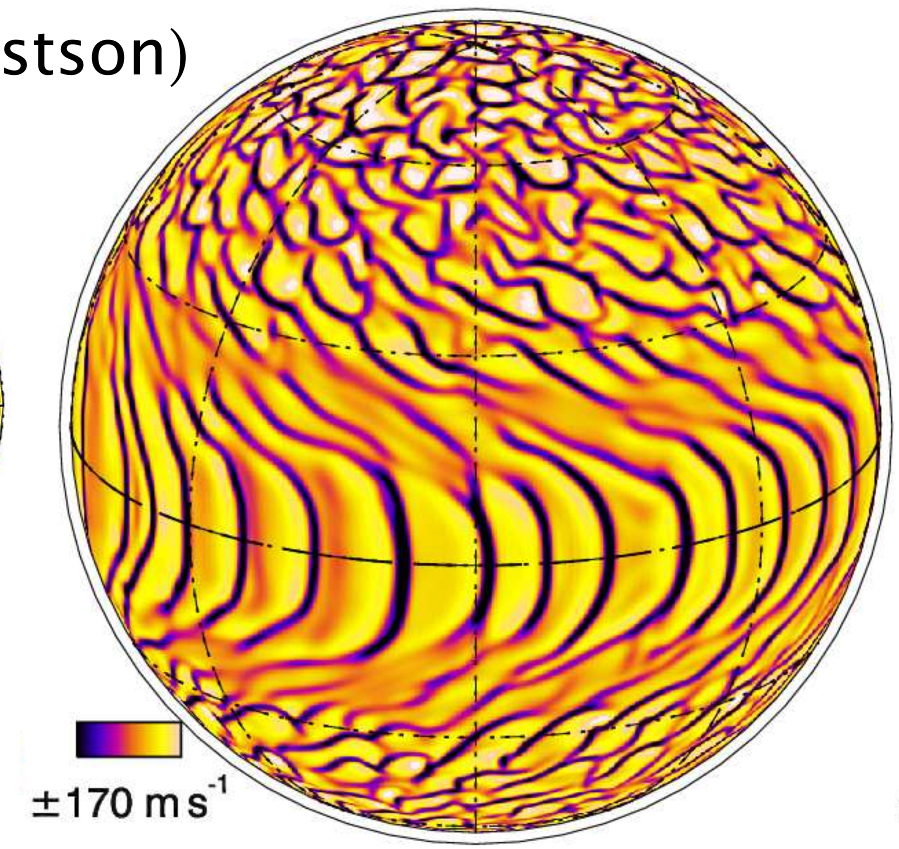
(Brown et al. 2008)

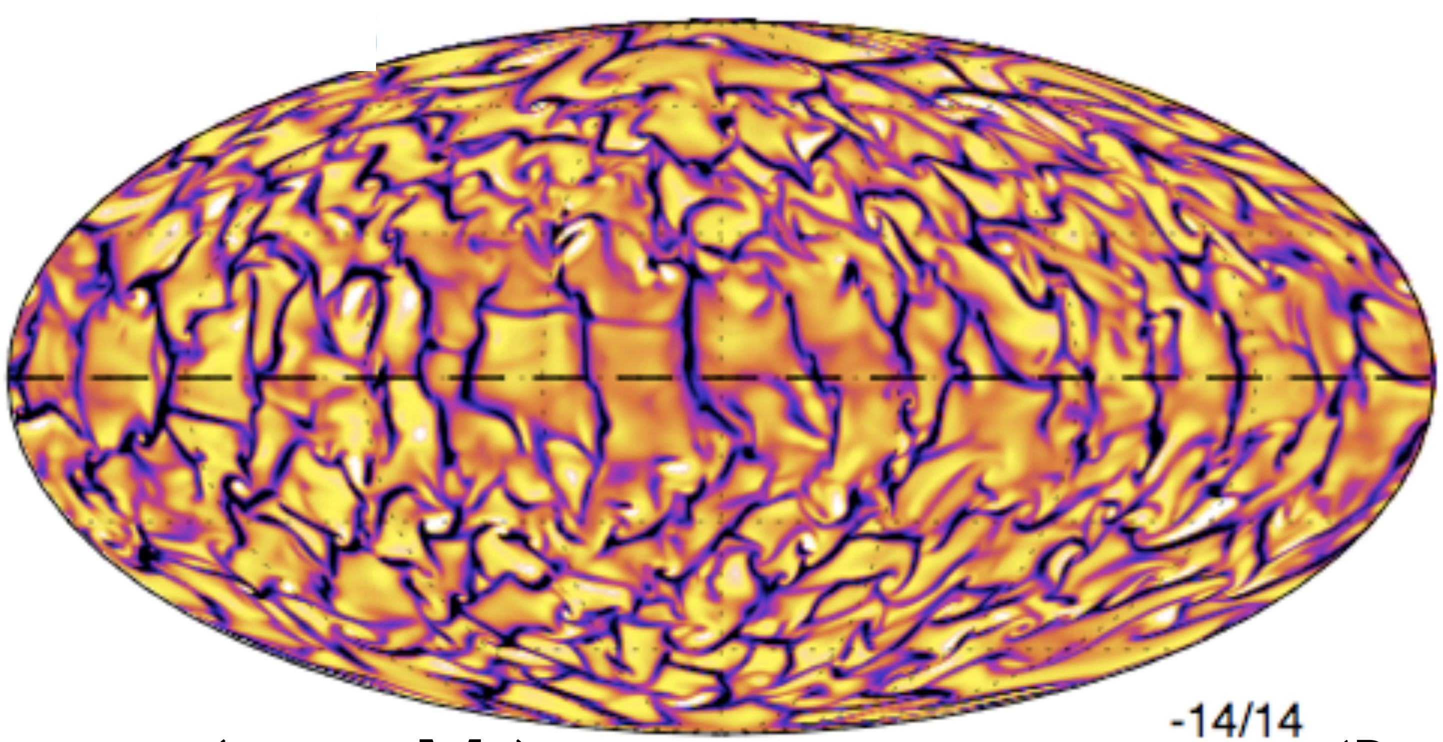
Flows in F- and M-type stars

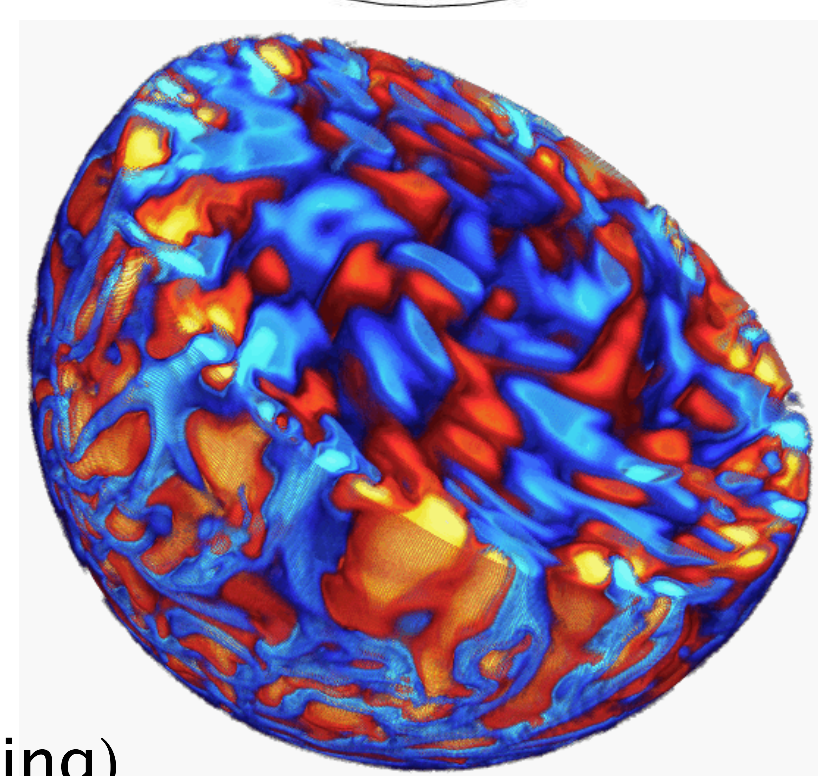
F–type (1.2 $M_\odot$)

(Augustson)





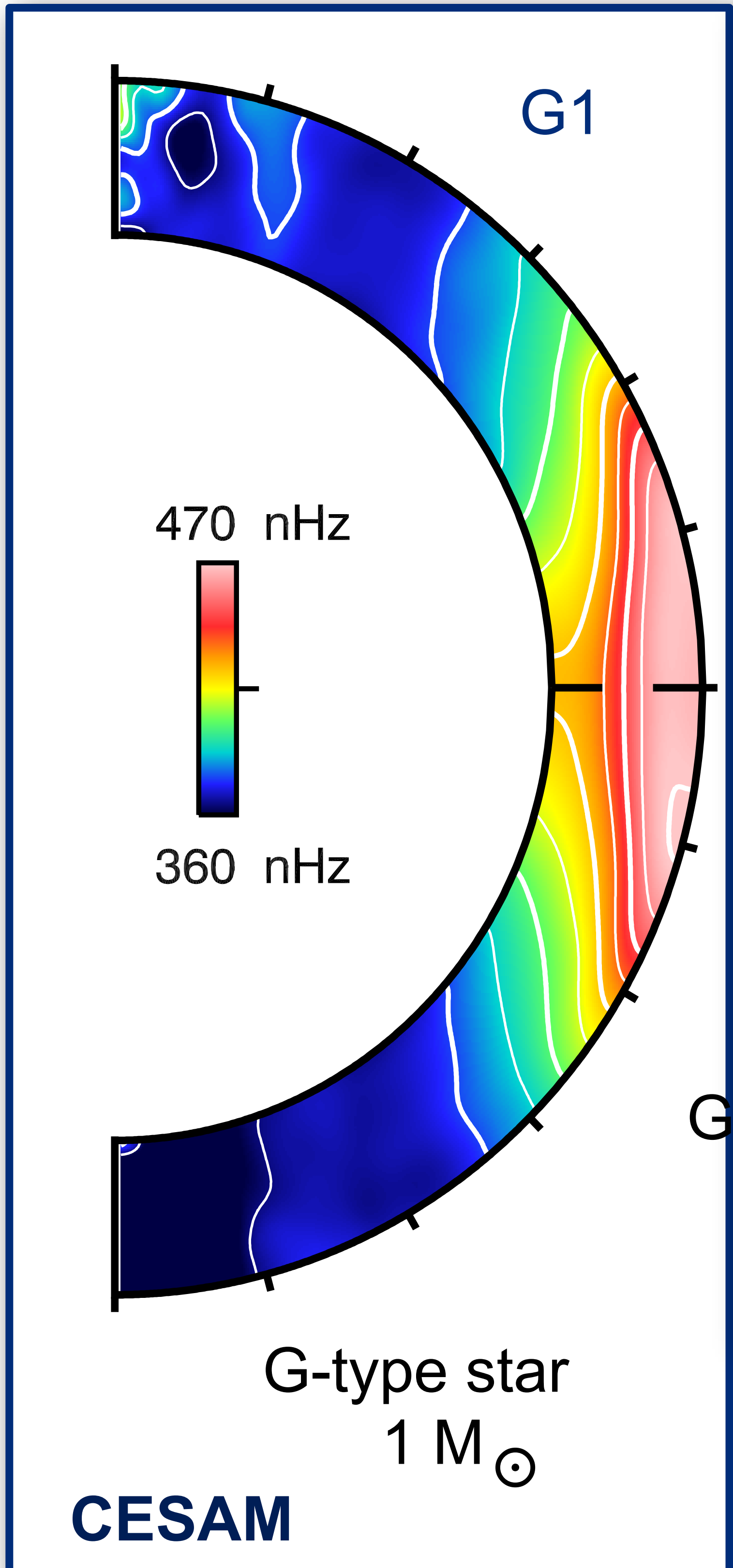


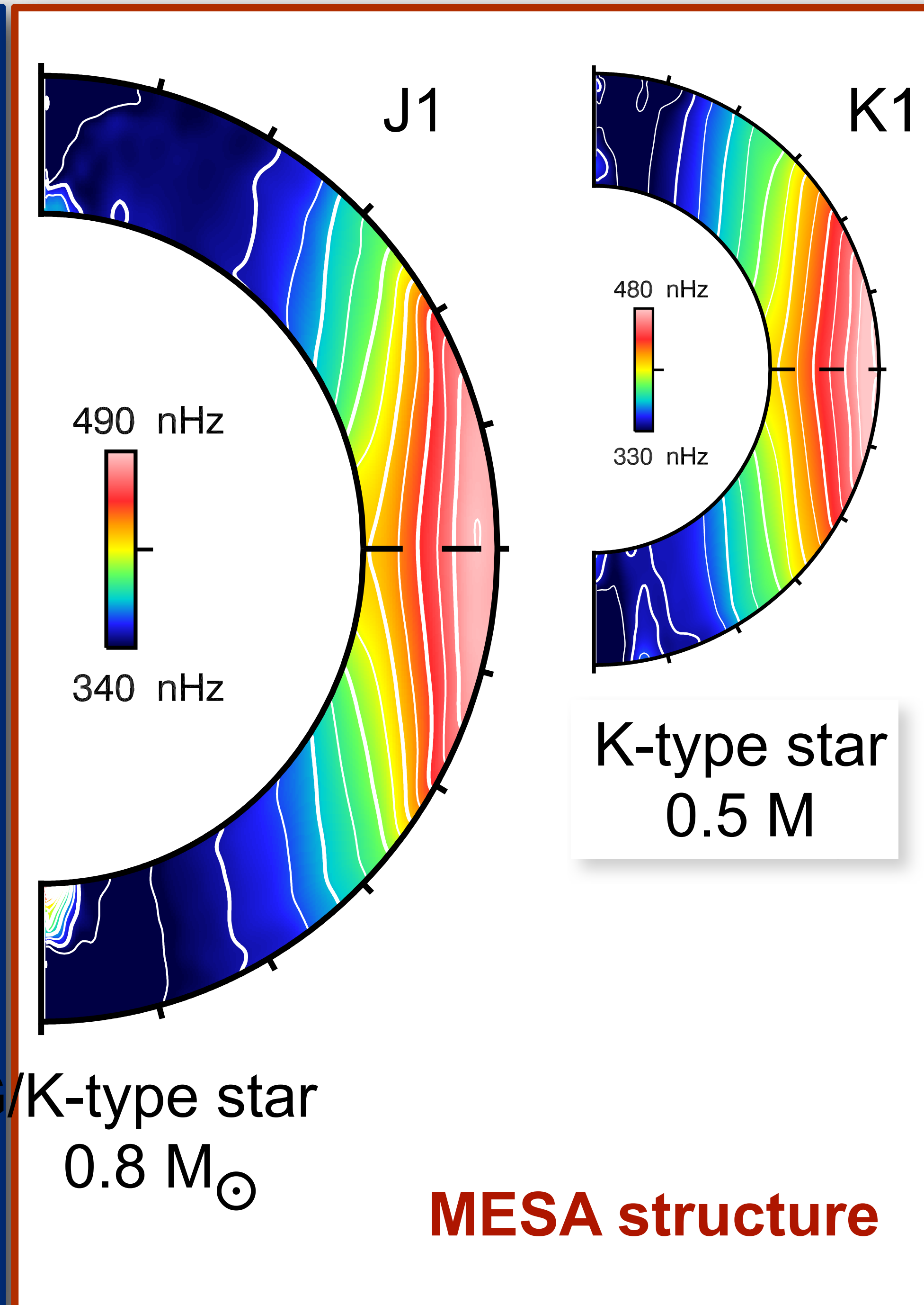


M–type (0.35 $M_\odot$)

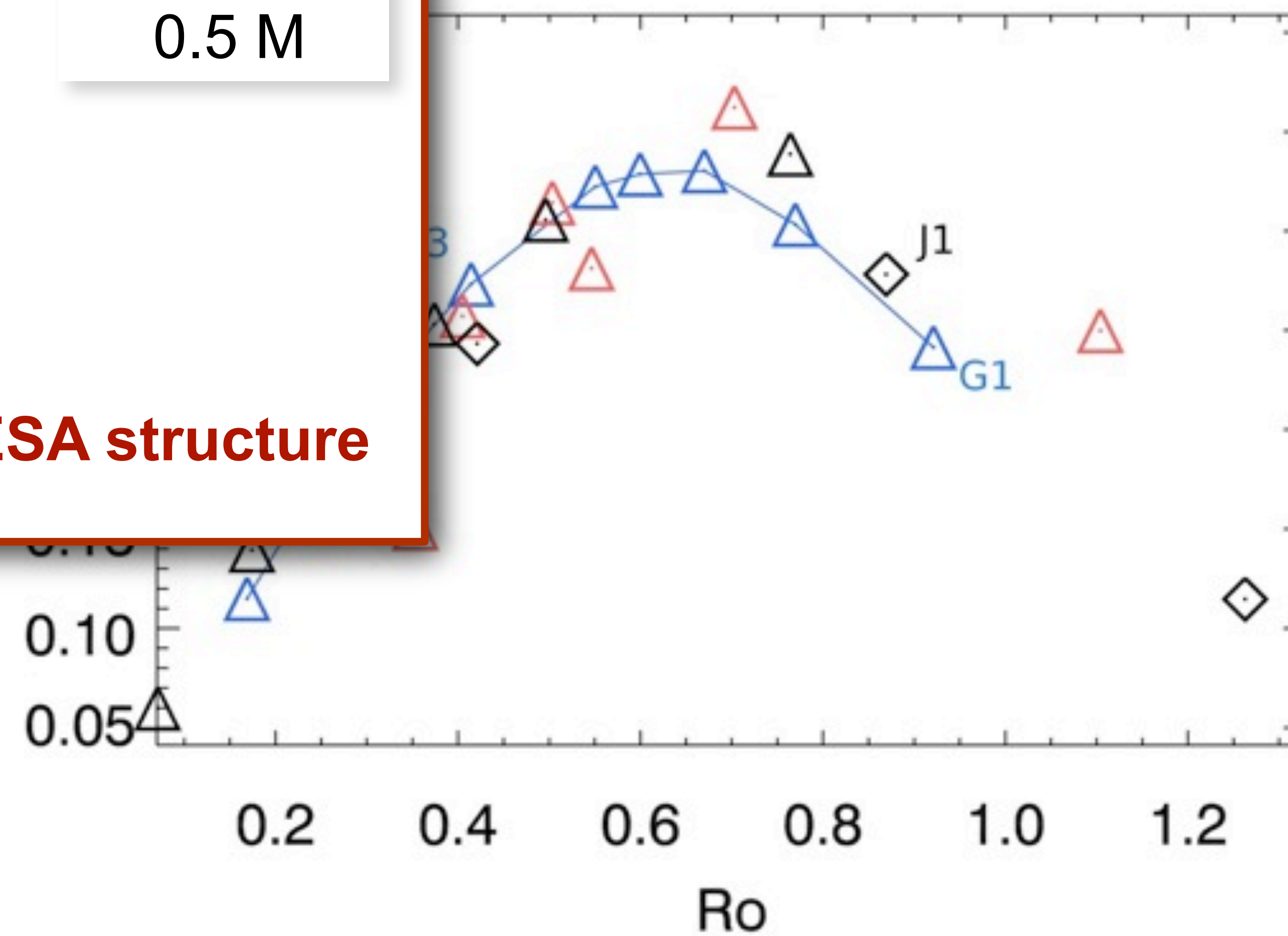
(Browning)

Differential Rotation in Other Stars



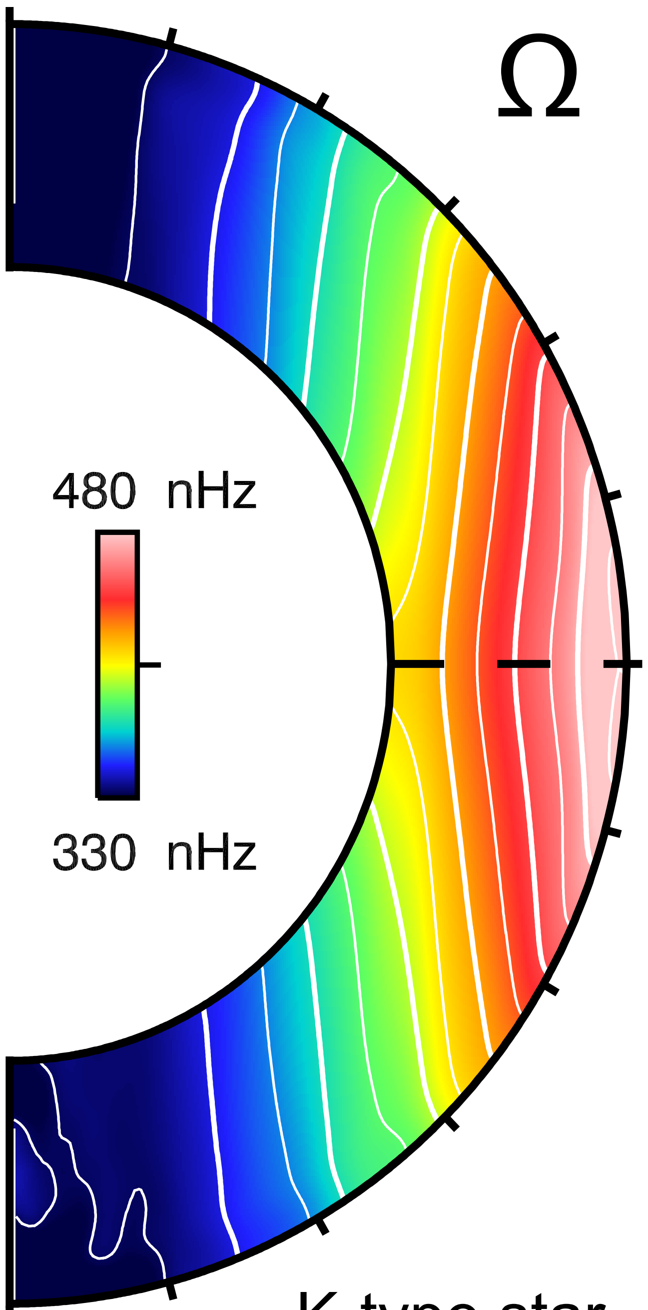


Different masses, same rotation rate, very similar profiles of DR.

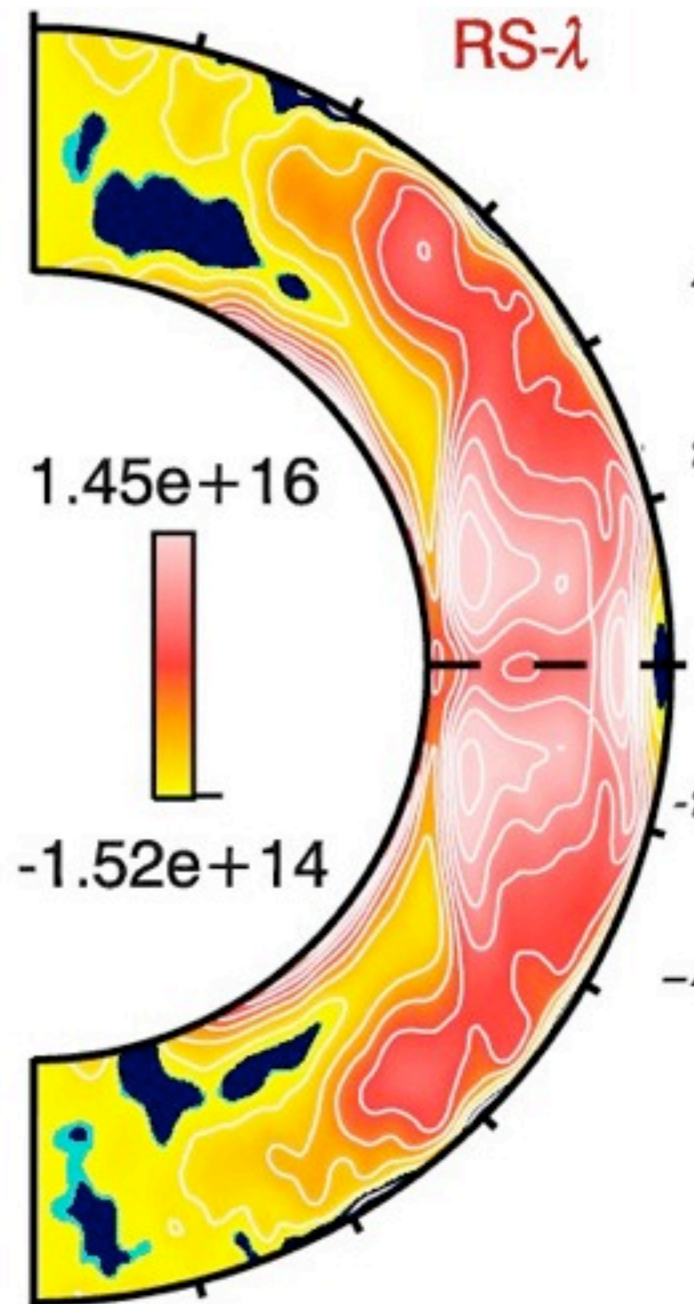


All three stars rotating at solar rate (P~28d)

How is this Differential Rotation Maintained?

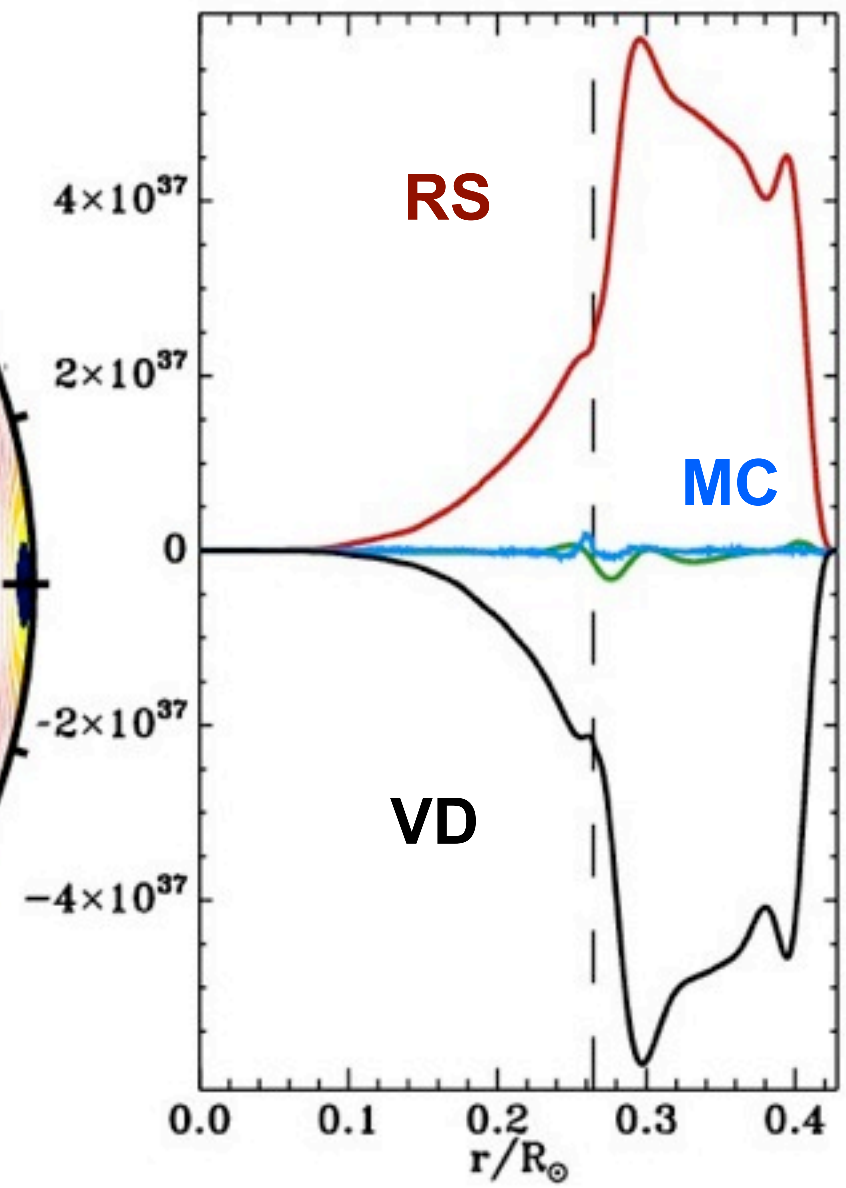


K-type star
0.5 $M_\odot$
1.0 $\Omega_\odot$



Reynolds Stresses
(cylindrical transport)

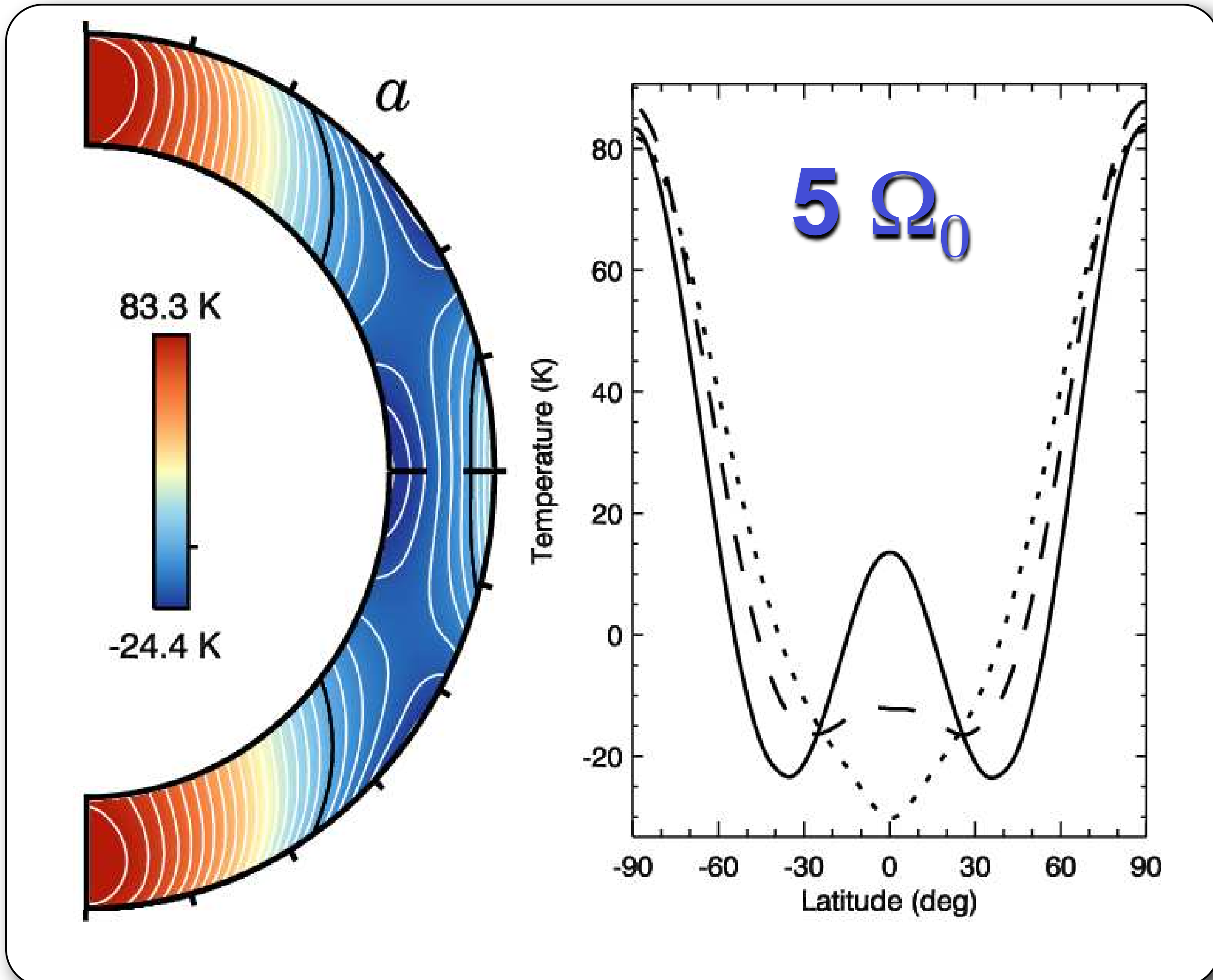
RS balances VD



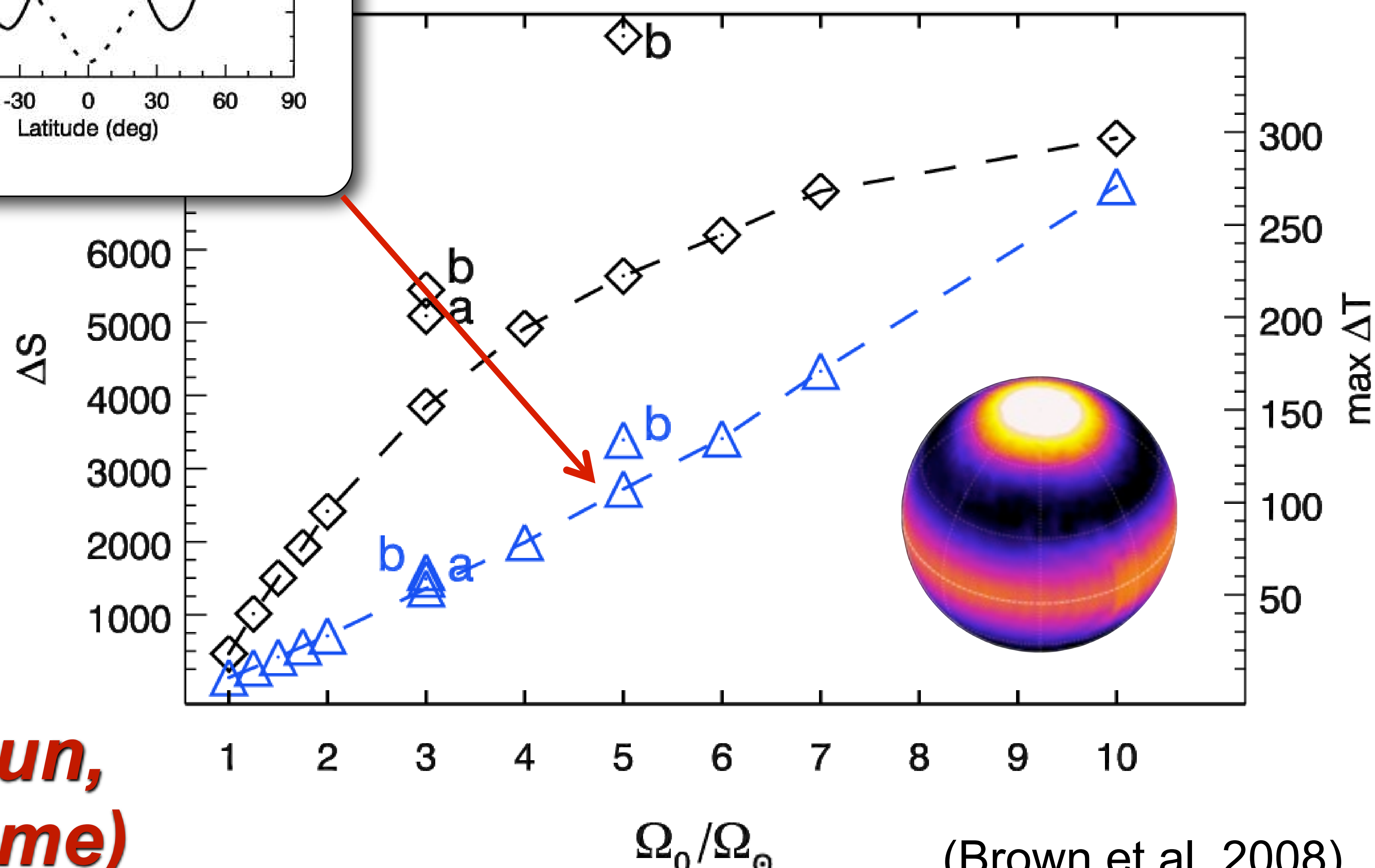
Integrated on cylinders

This balance seems to generally hold in low-Ro, hydrodynamic cases.

$\ell_{\max} = 170$



Pole-to-Equator Temperature: Thermal Wind

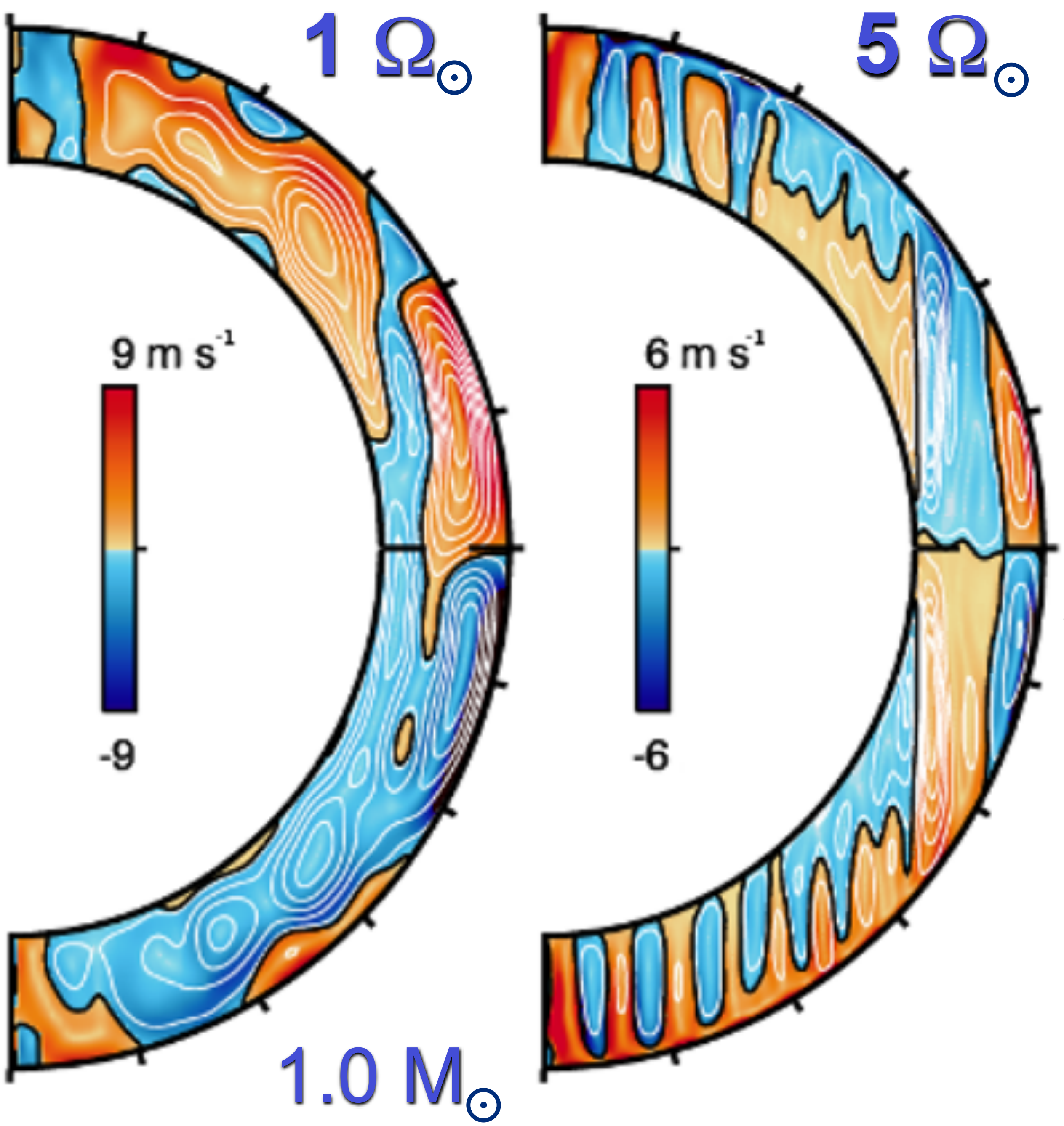


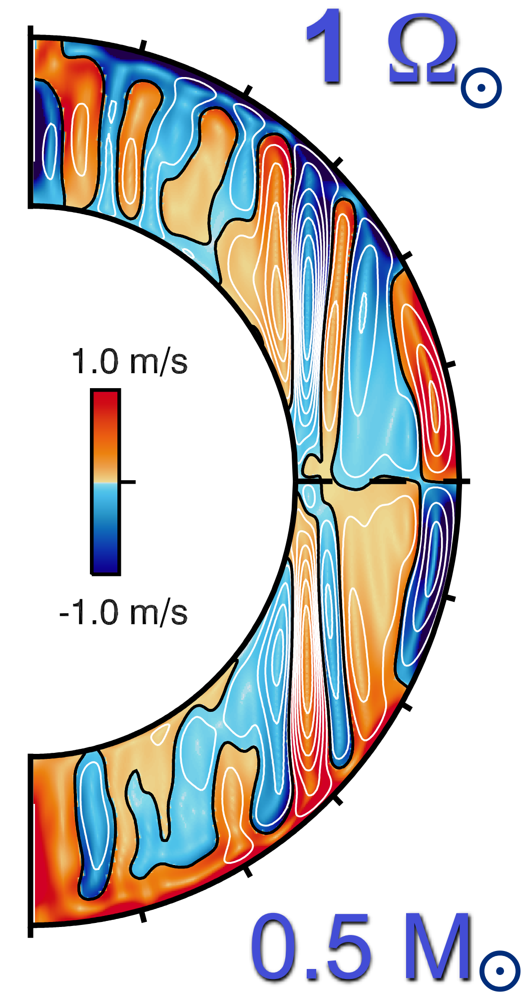
Temperature contrast in latitude grows substantially with fast rotation

(few K in the Sun, few 100 K in some)

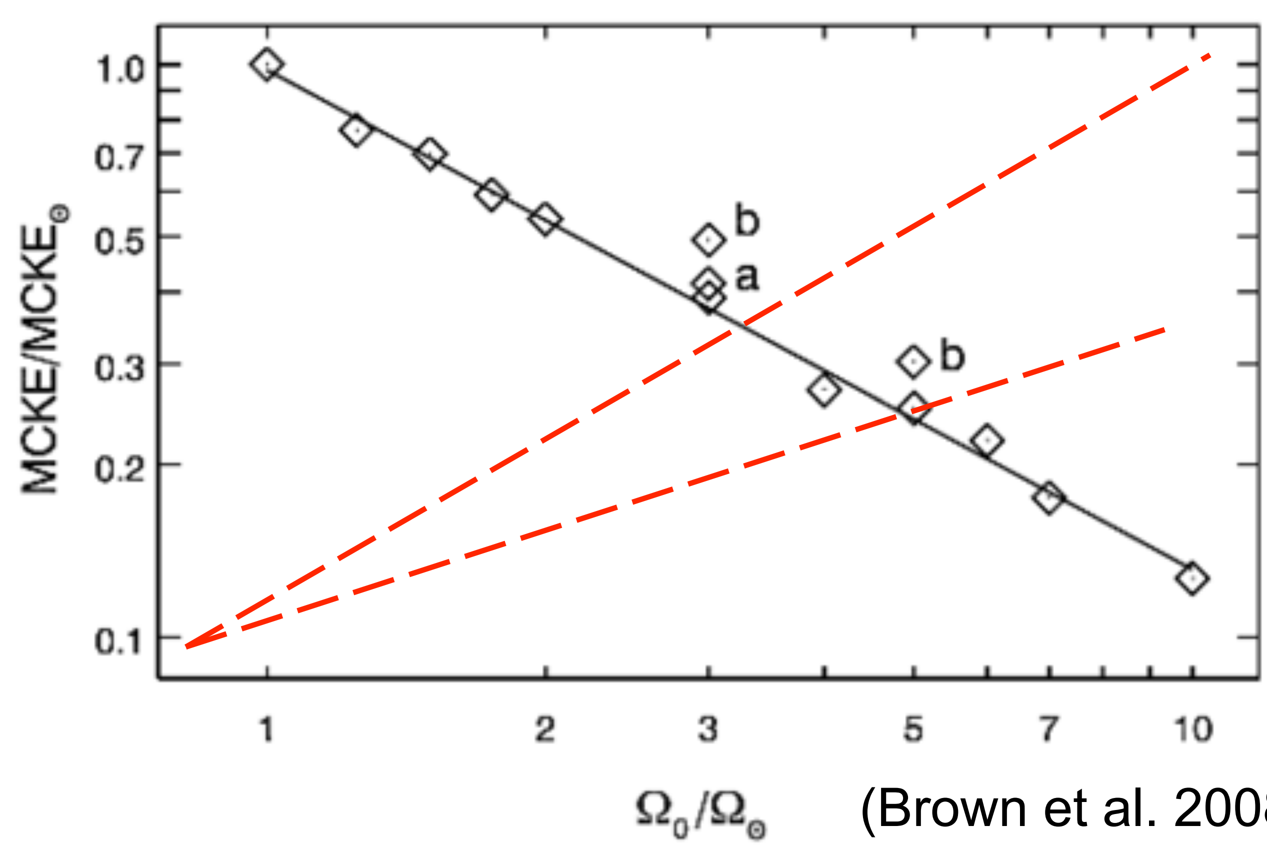
(Brown et al. 2008)

Meridional Circulations





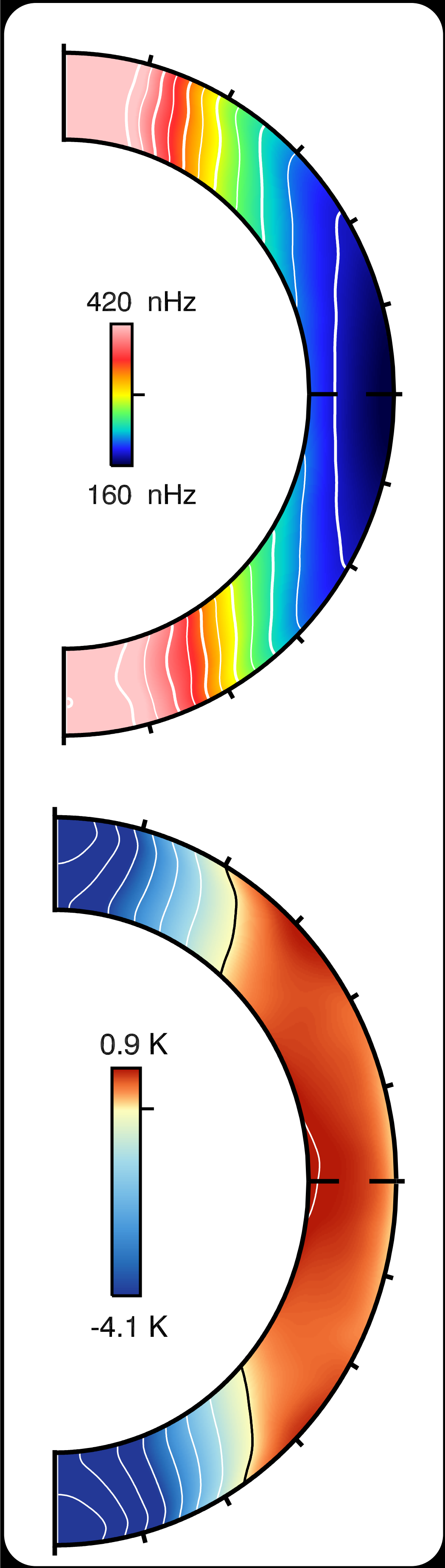
In contrast, meridional circulations are weaker and mutli-celled

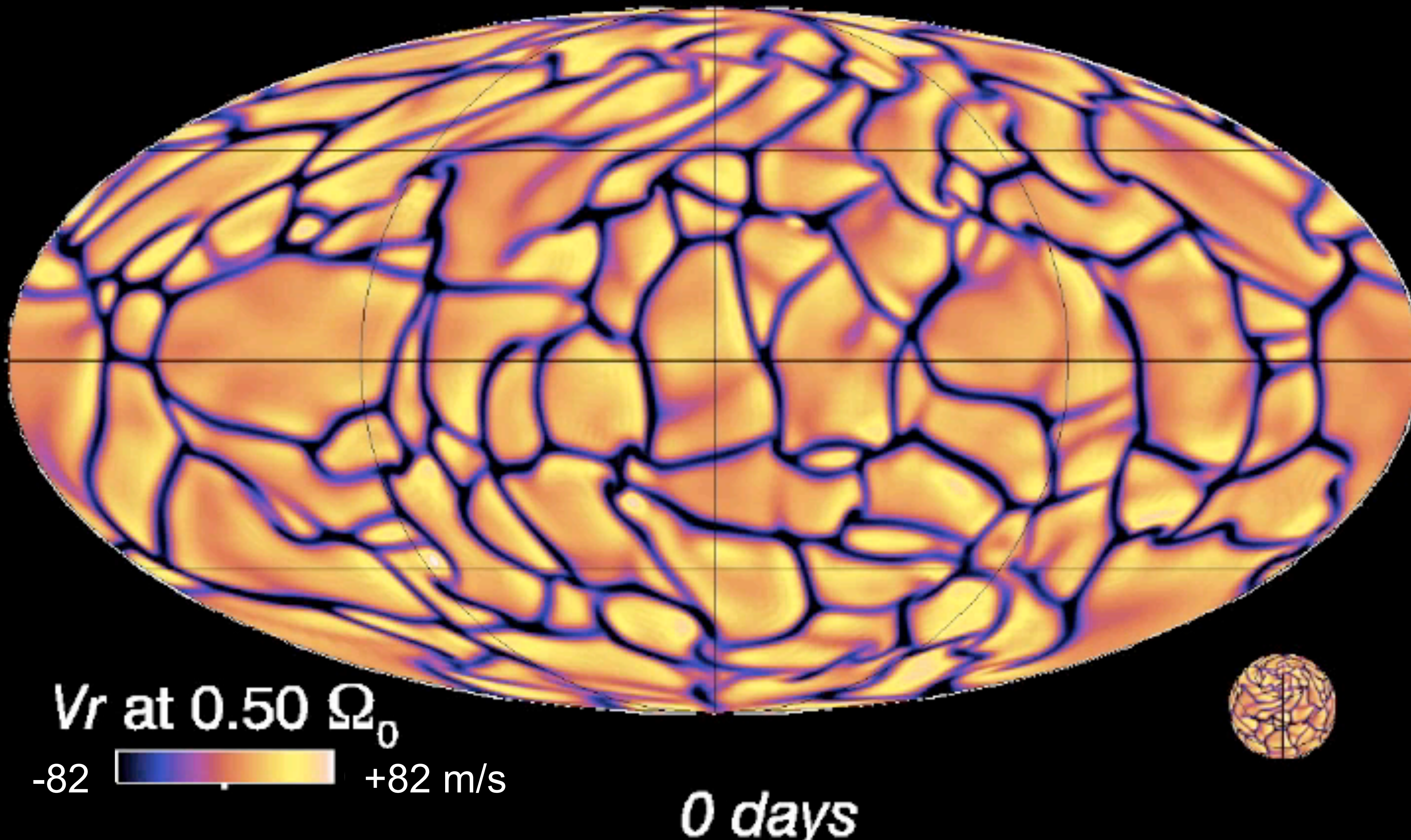


(Brown et al. 2008)

Disagreement with expectations

Slowly Spinning Suns:
anti-solar DR



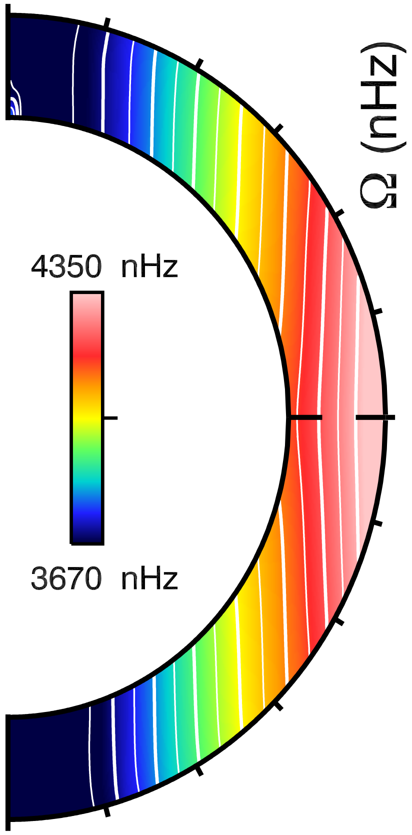


(Period ~ 56d)

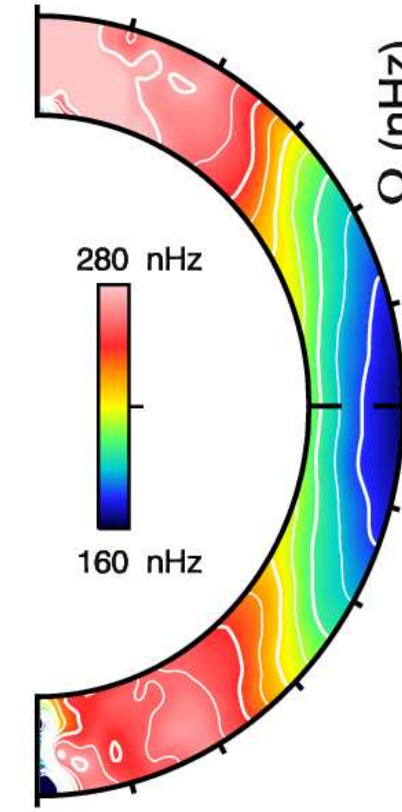
Ro~2

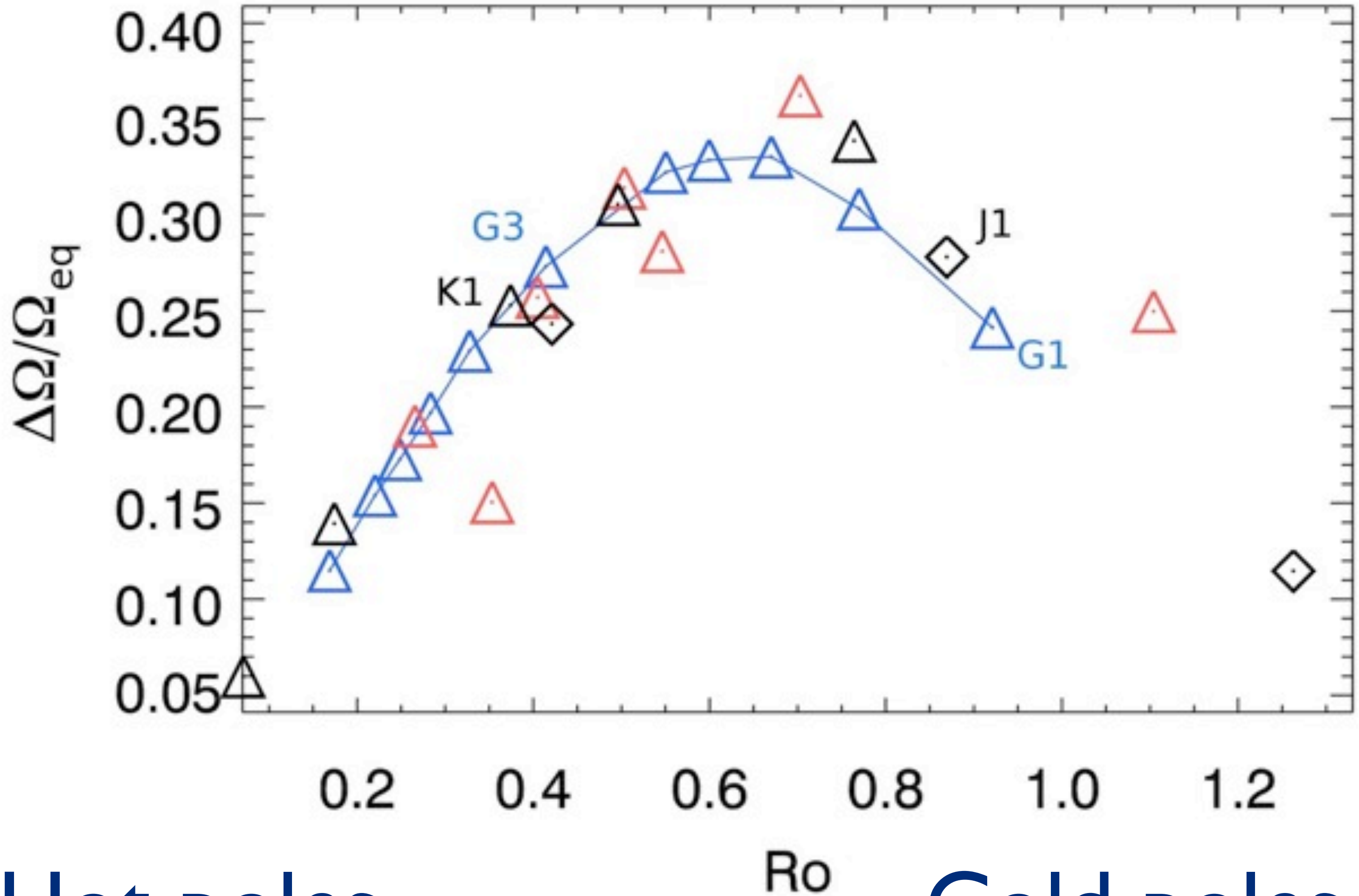
Observables

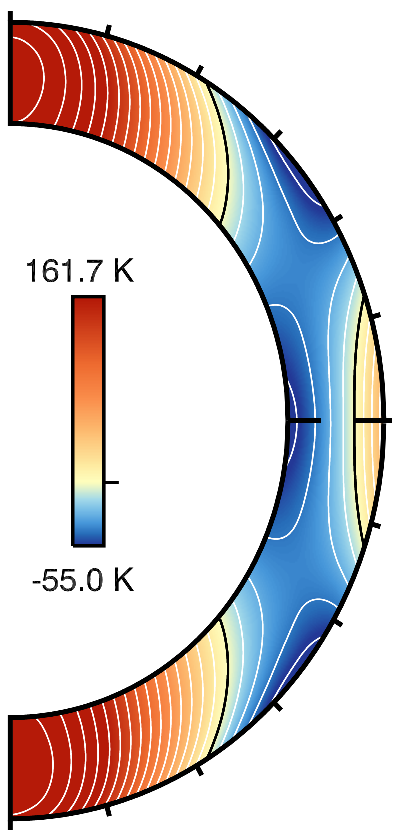
Rapid Rotators



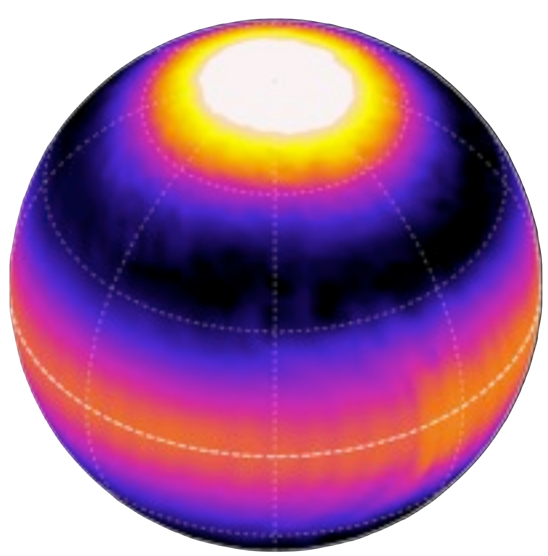
Slow Spinners





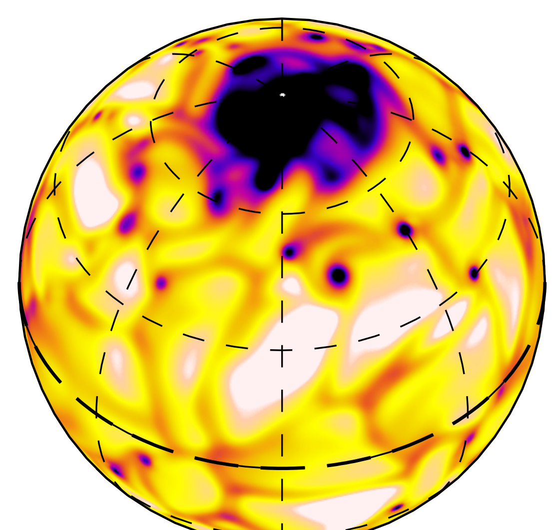


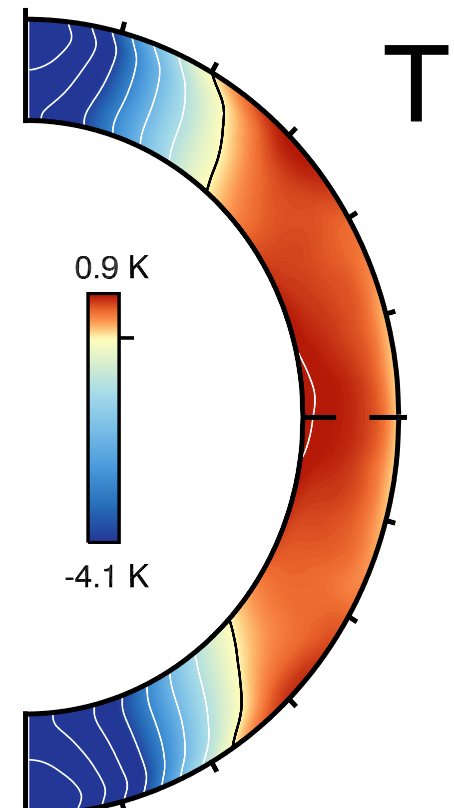
Hot poles



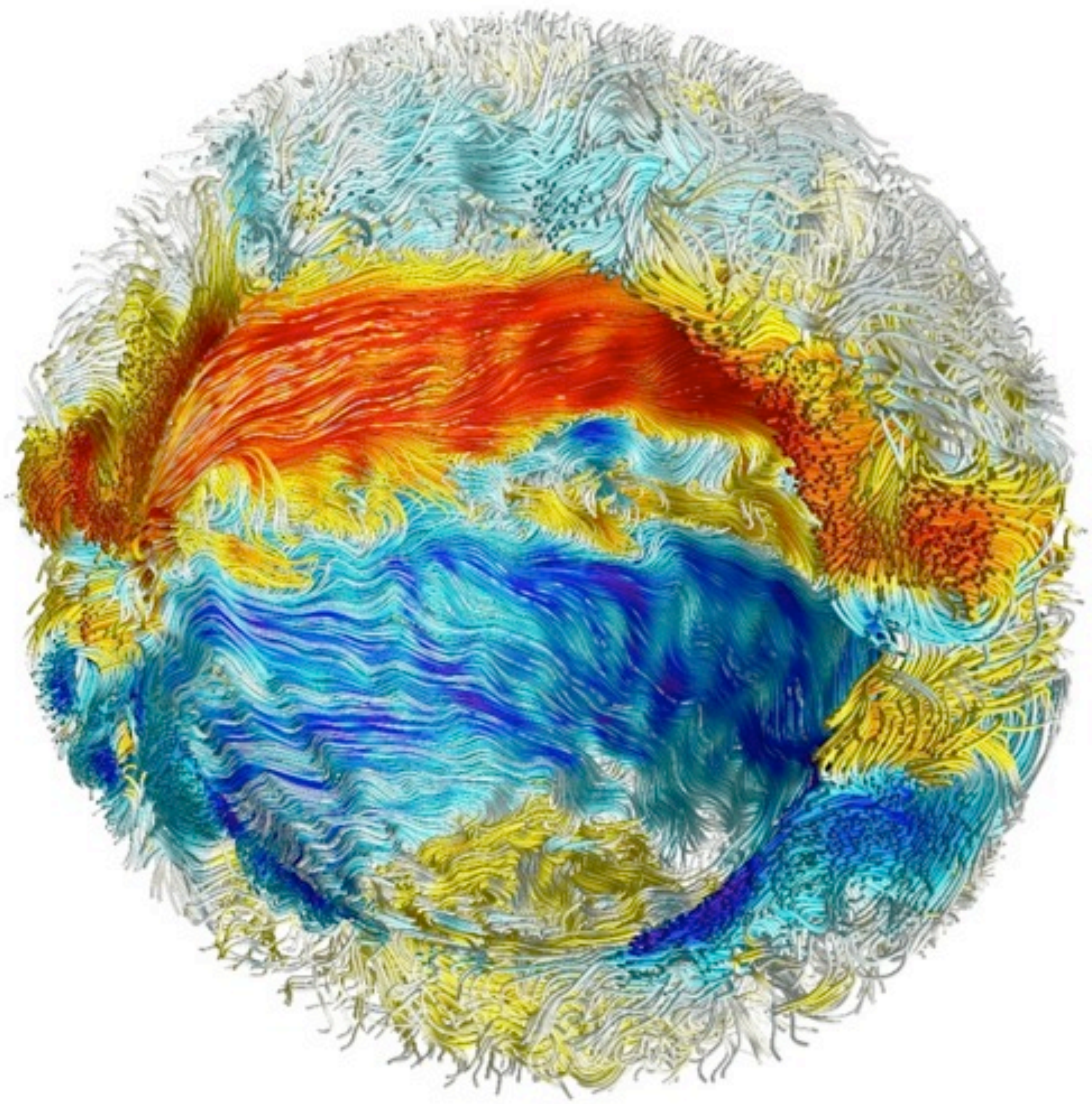
BB flux map with 5-10% variation

Cold poles

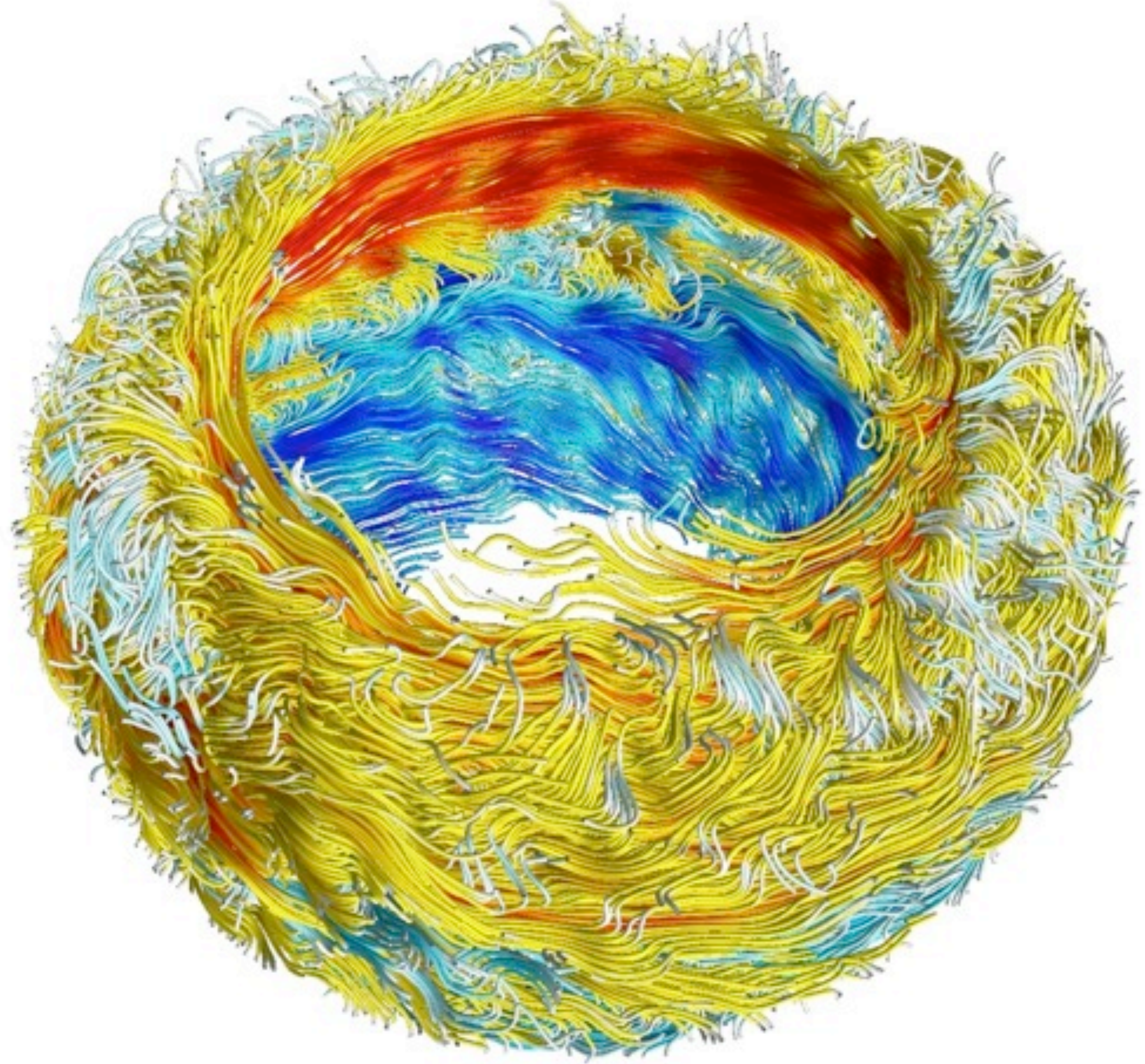




Convection Zone Dynamos: Magnetic Wreaths



Hemisphere view

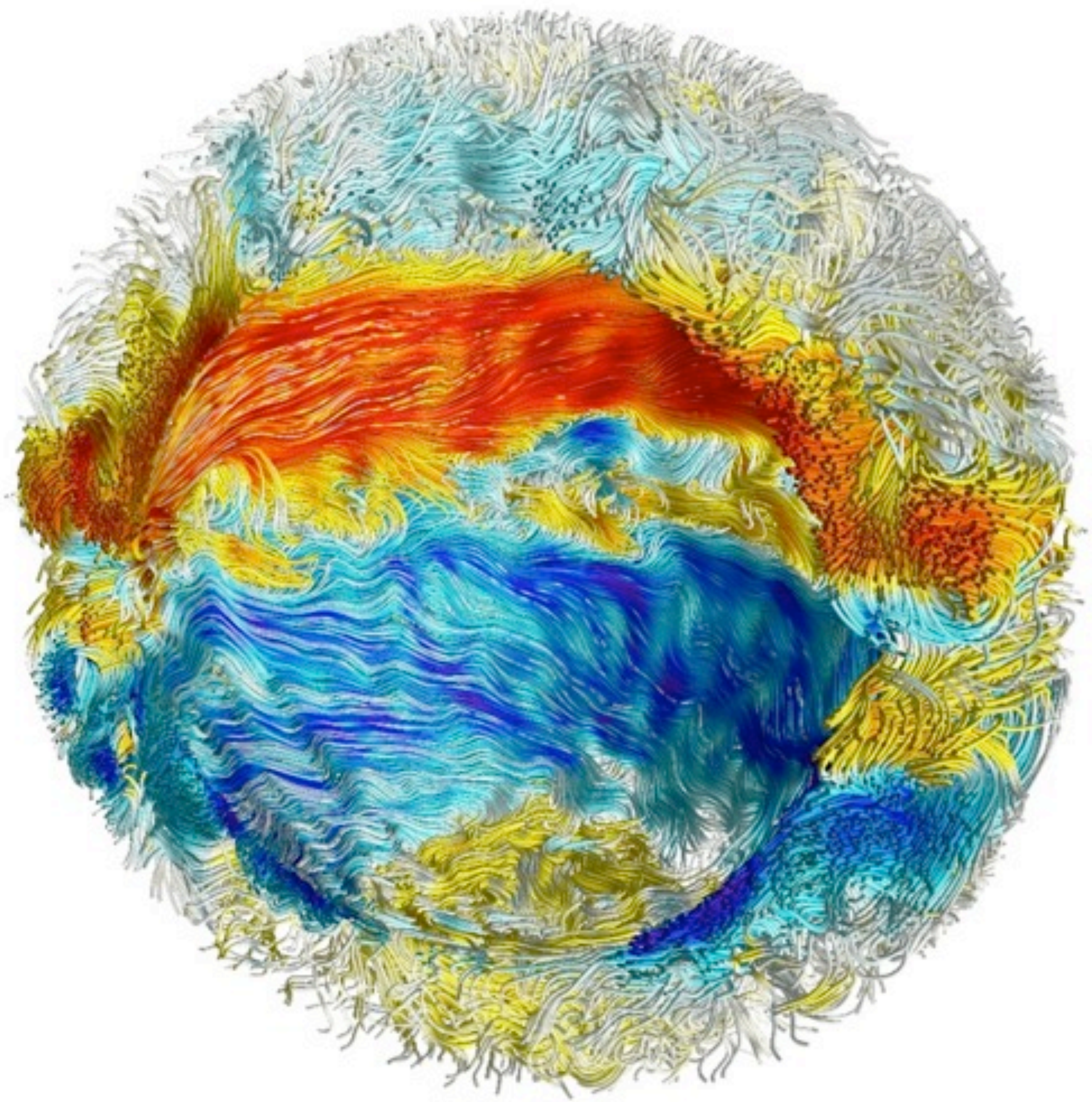


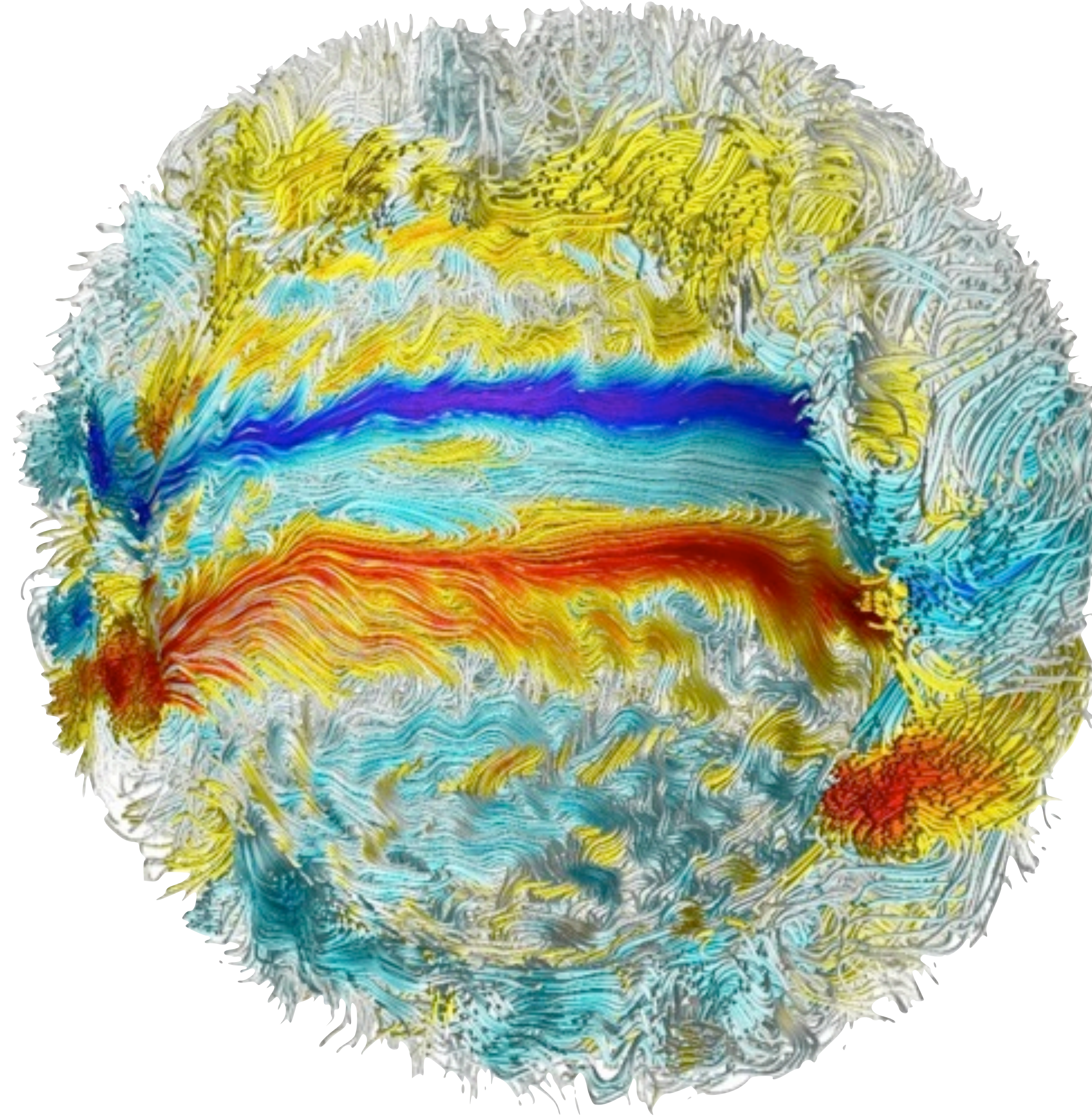
Equatorial view

(Brown et al. 2011)

$5\ \Omega_0$

Convection Zone Dynamos: Magnetic Wreaths and Global-scale Reversals

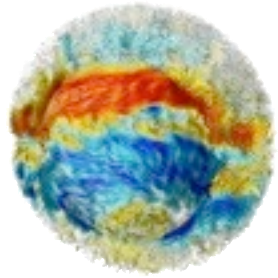


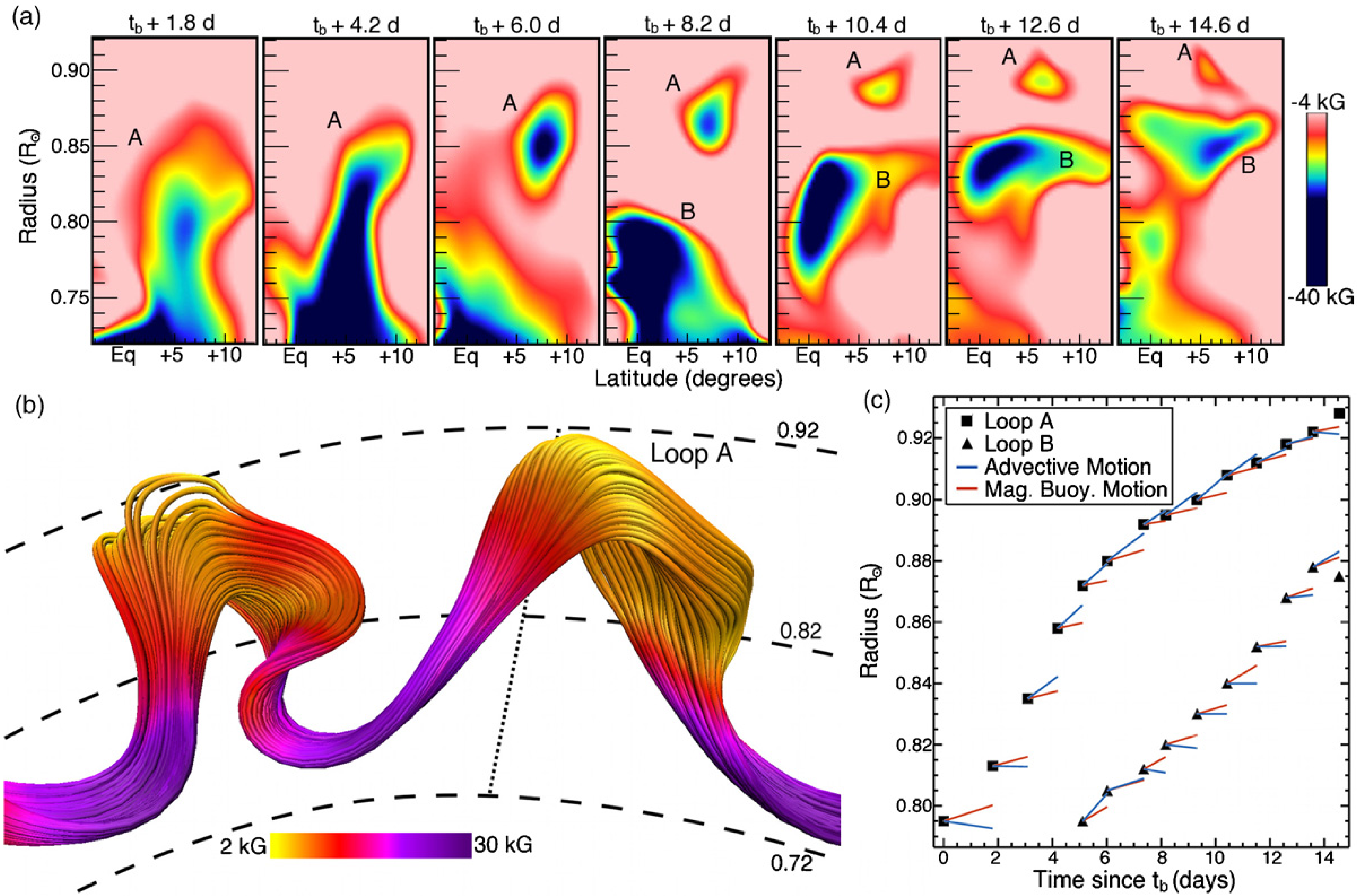


Shortly before (Brown et al. 2011) Long after

5 Ω_0

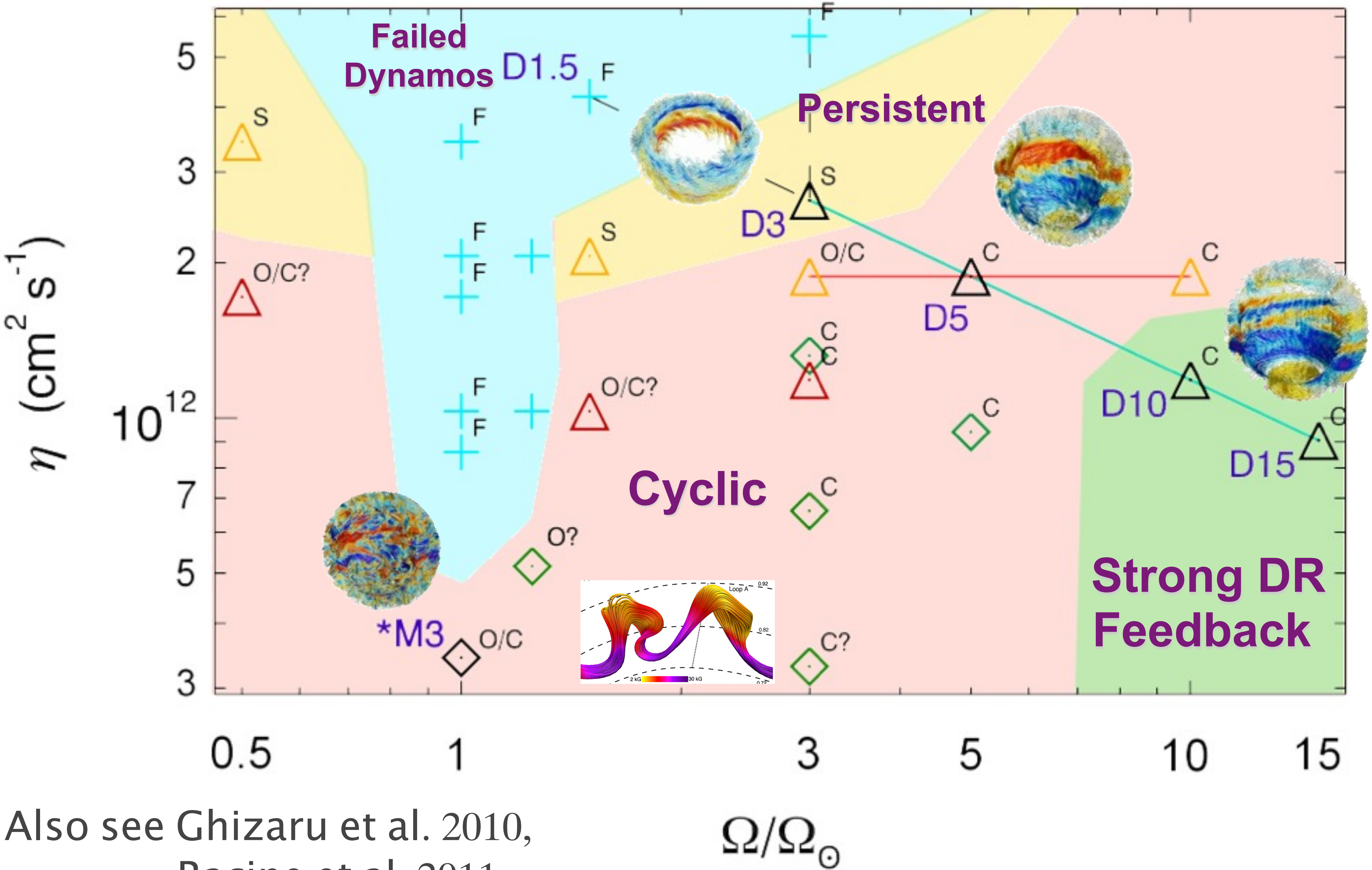
Next Step: Sunspots and Buoyant Magnetic Loops?





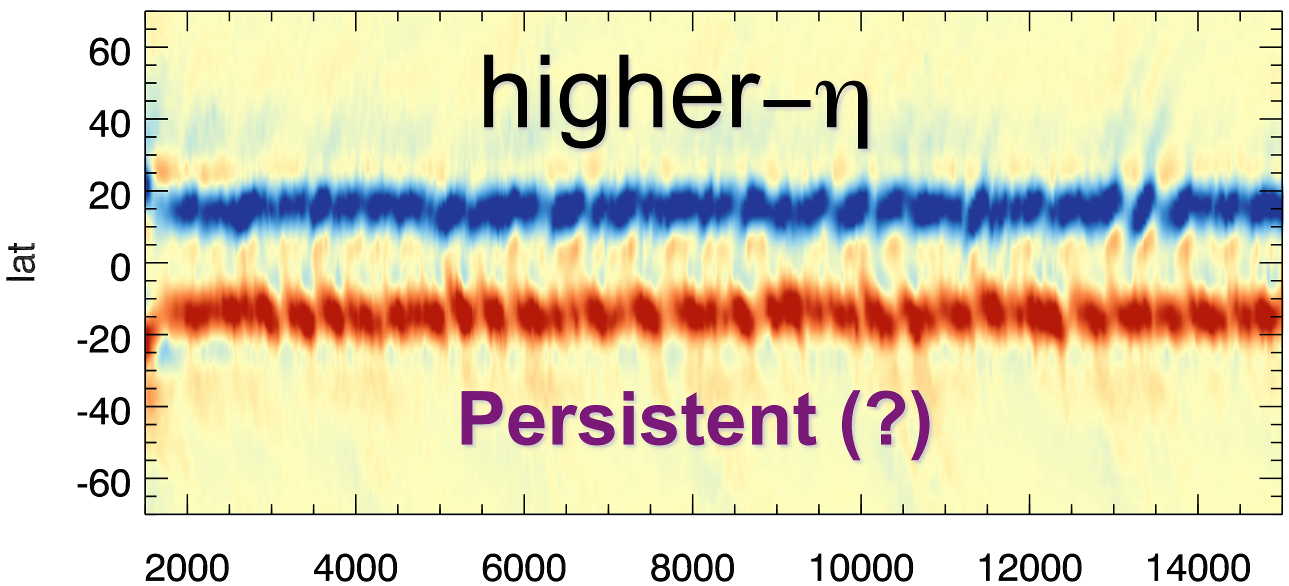
(Nelson et al. 2011, ApJL)

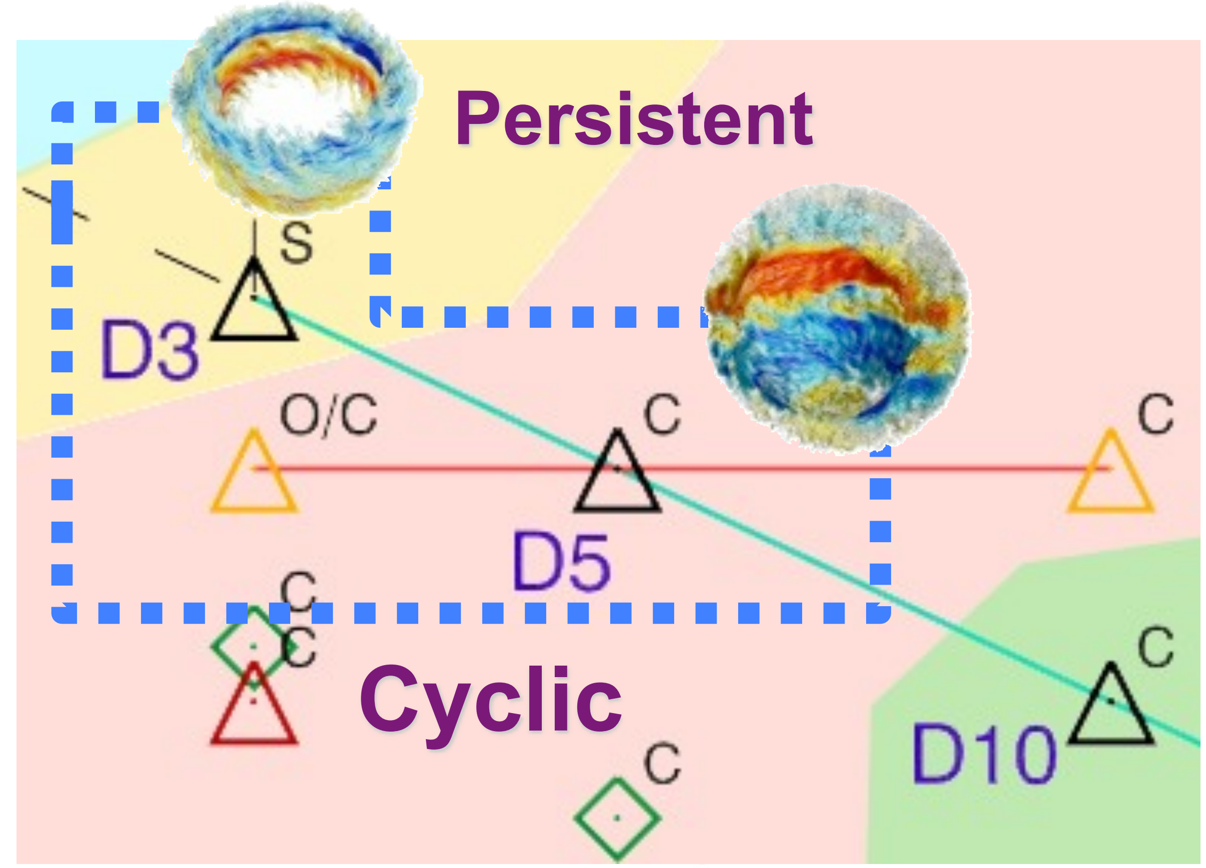
Stellar Dynamos: Many flavors

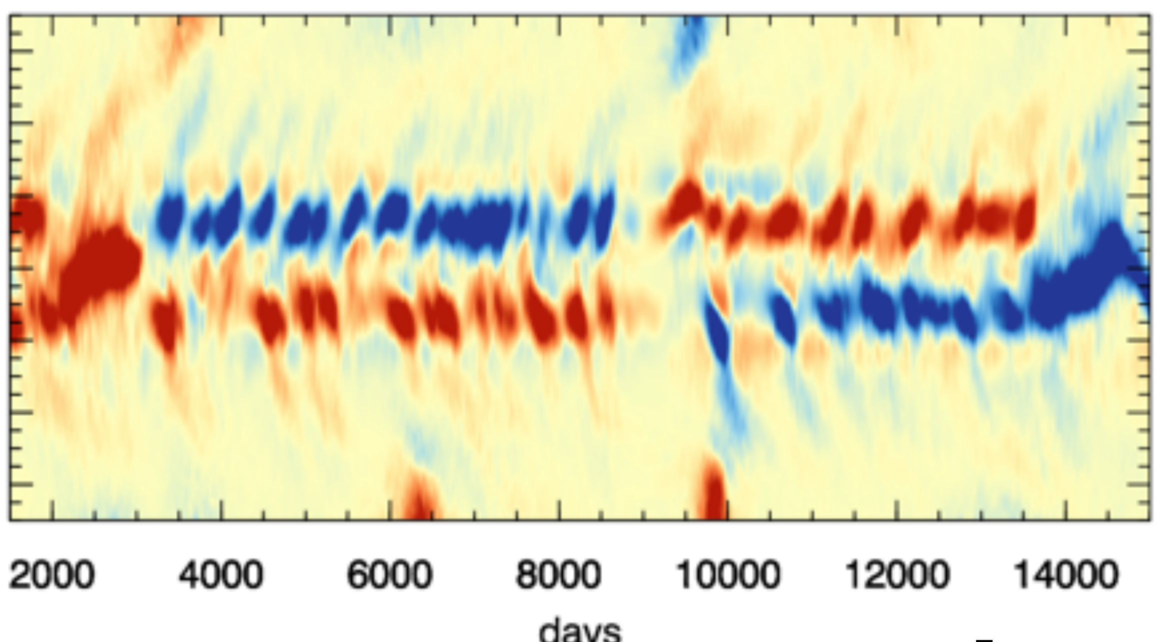


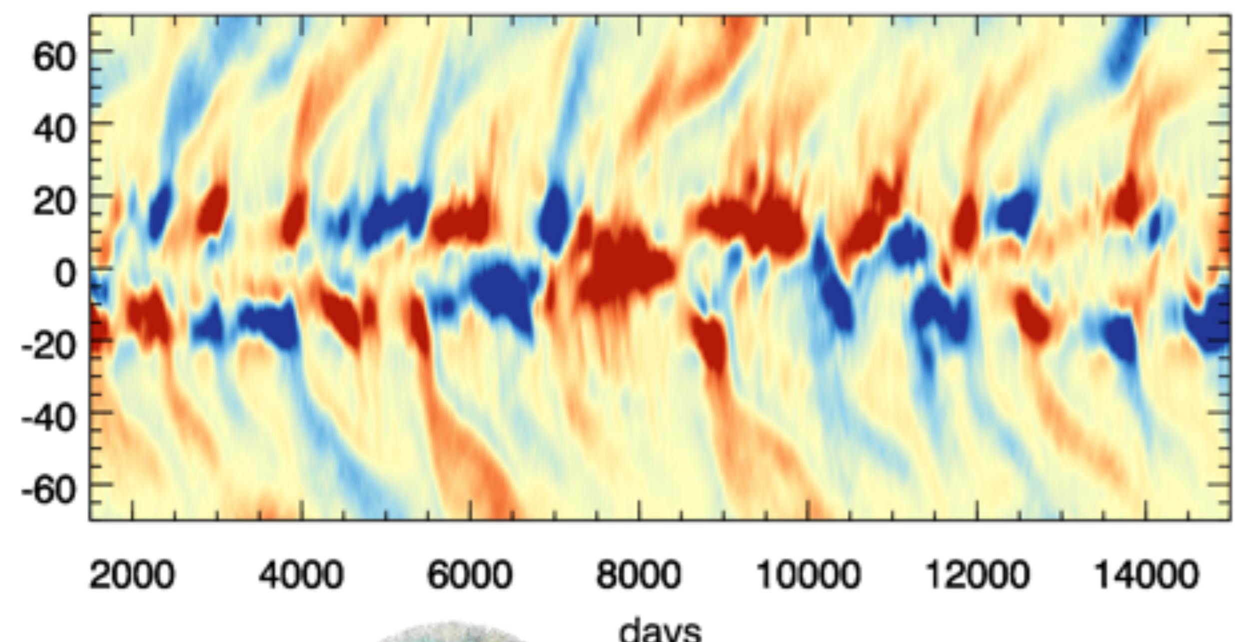
Also see Ghizaru et al. 2010,
Racine et al. 2011

Rotation and Turbulence







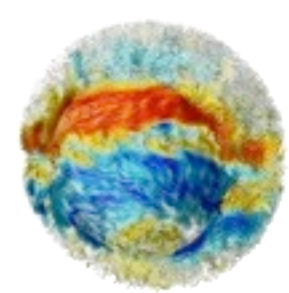


3 Ω

11 yrs ~ 4000 days

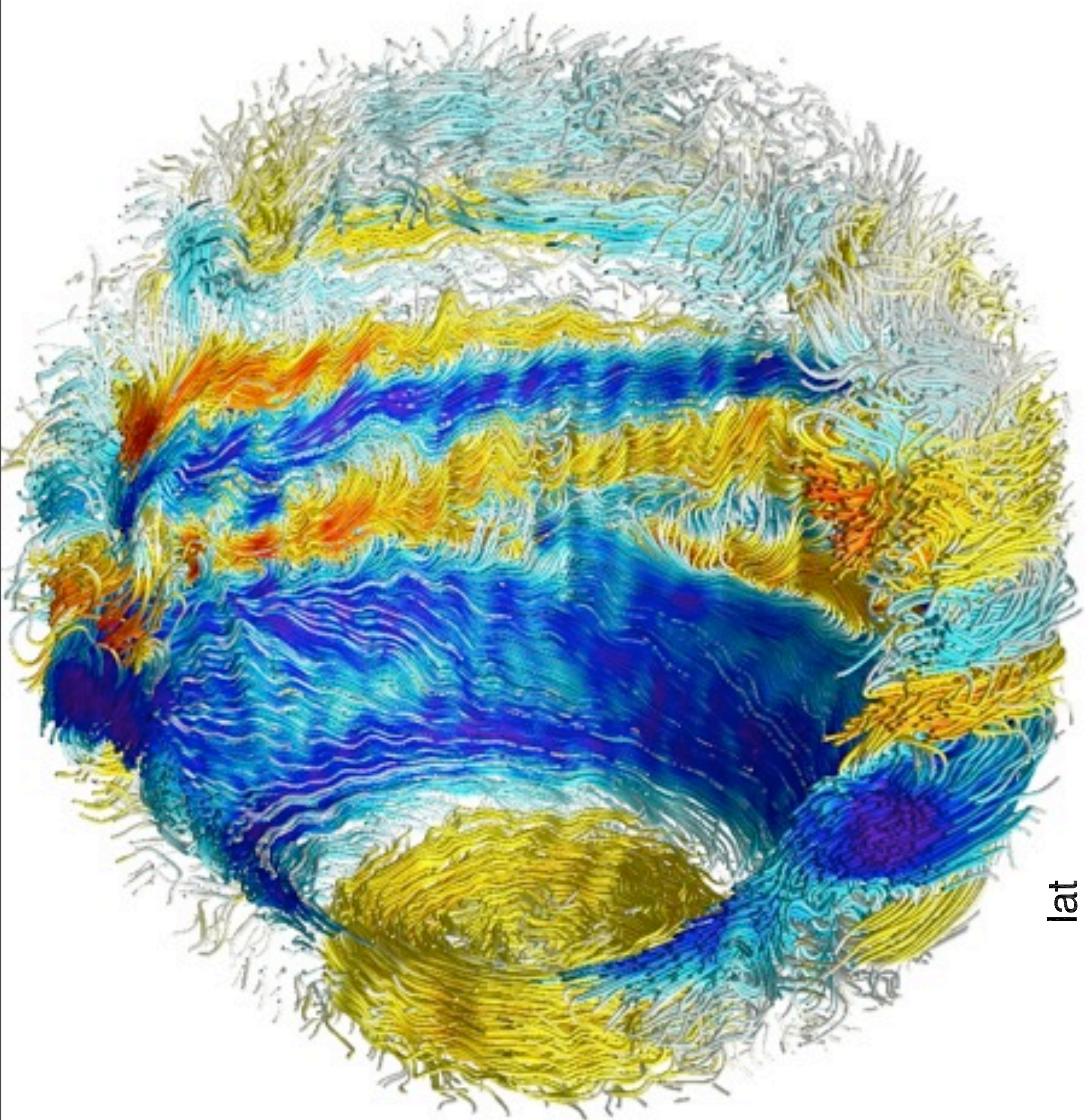
lower–η

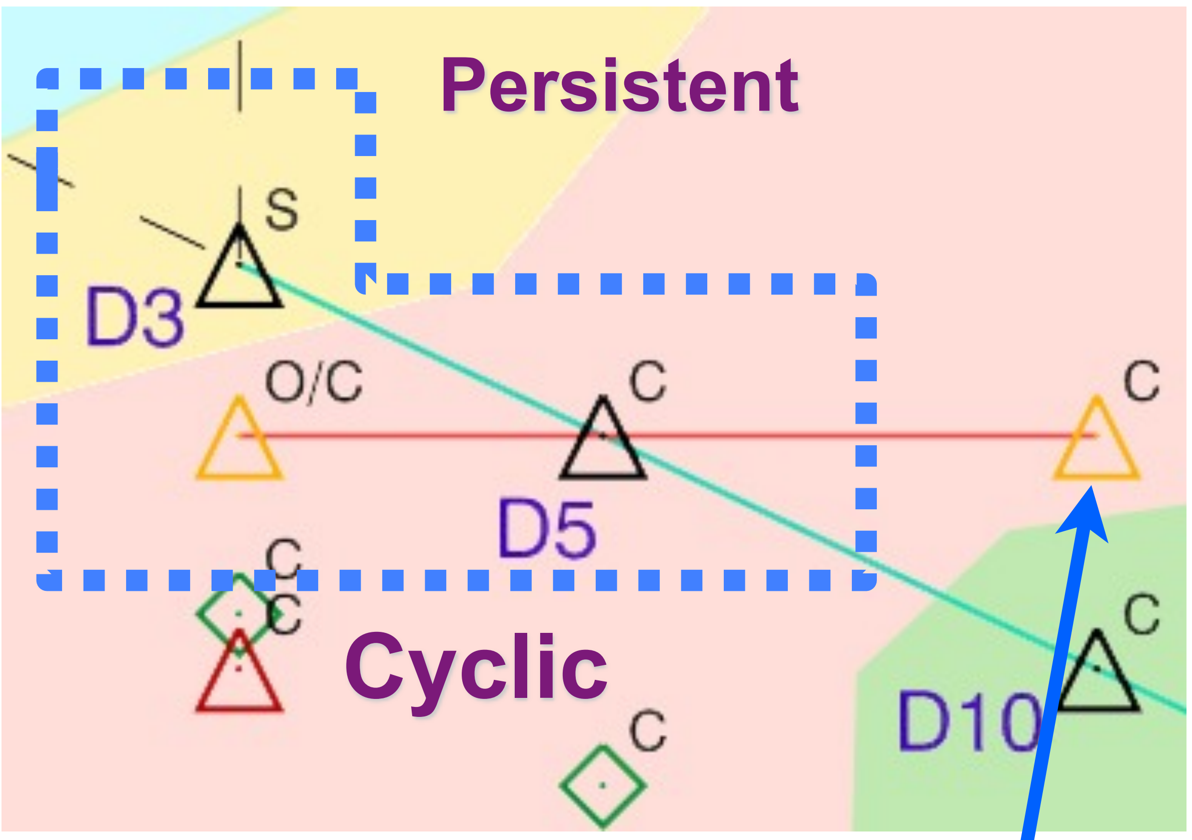
Cyclic

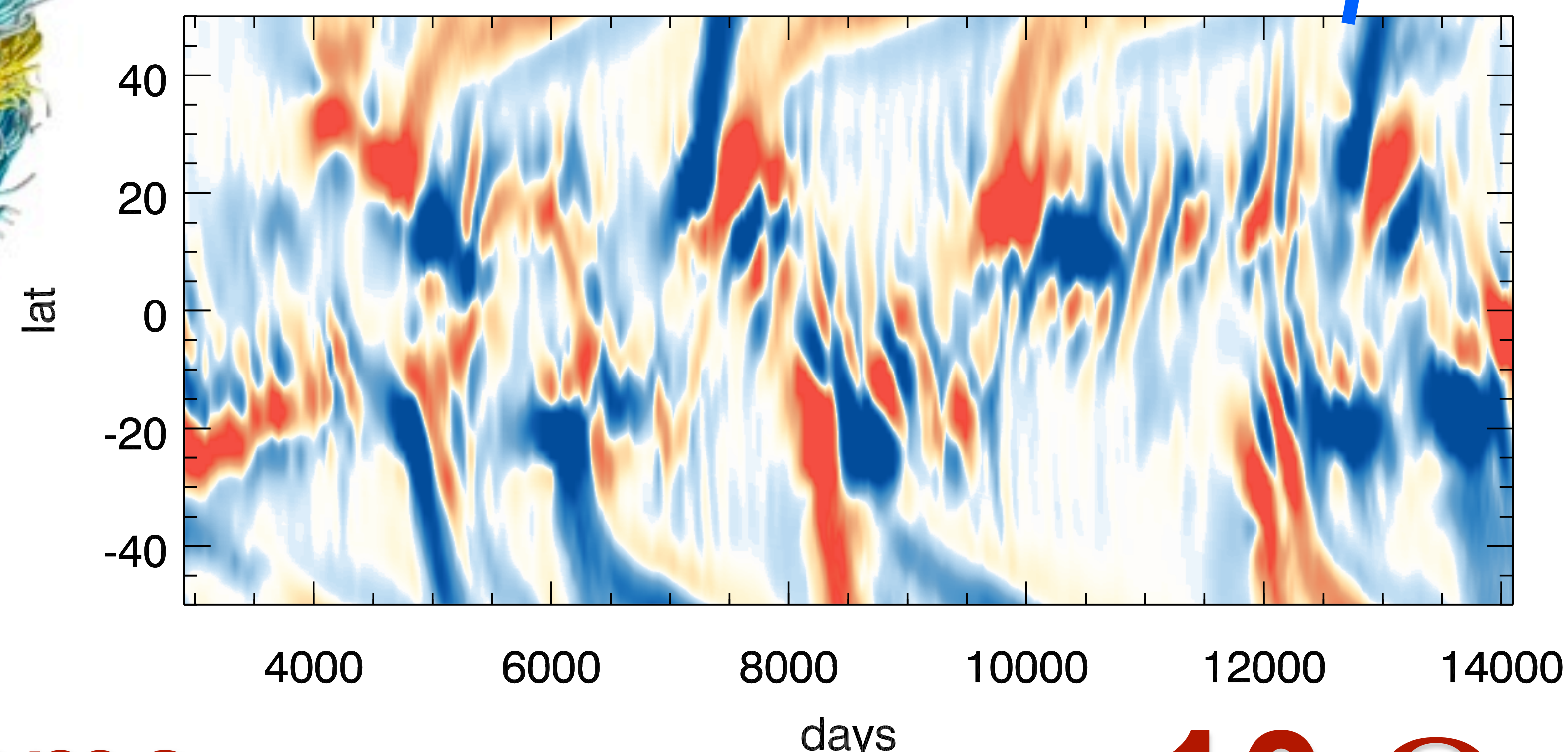


5 Ω

Rotation and Turbulence



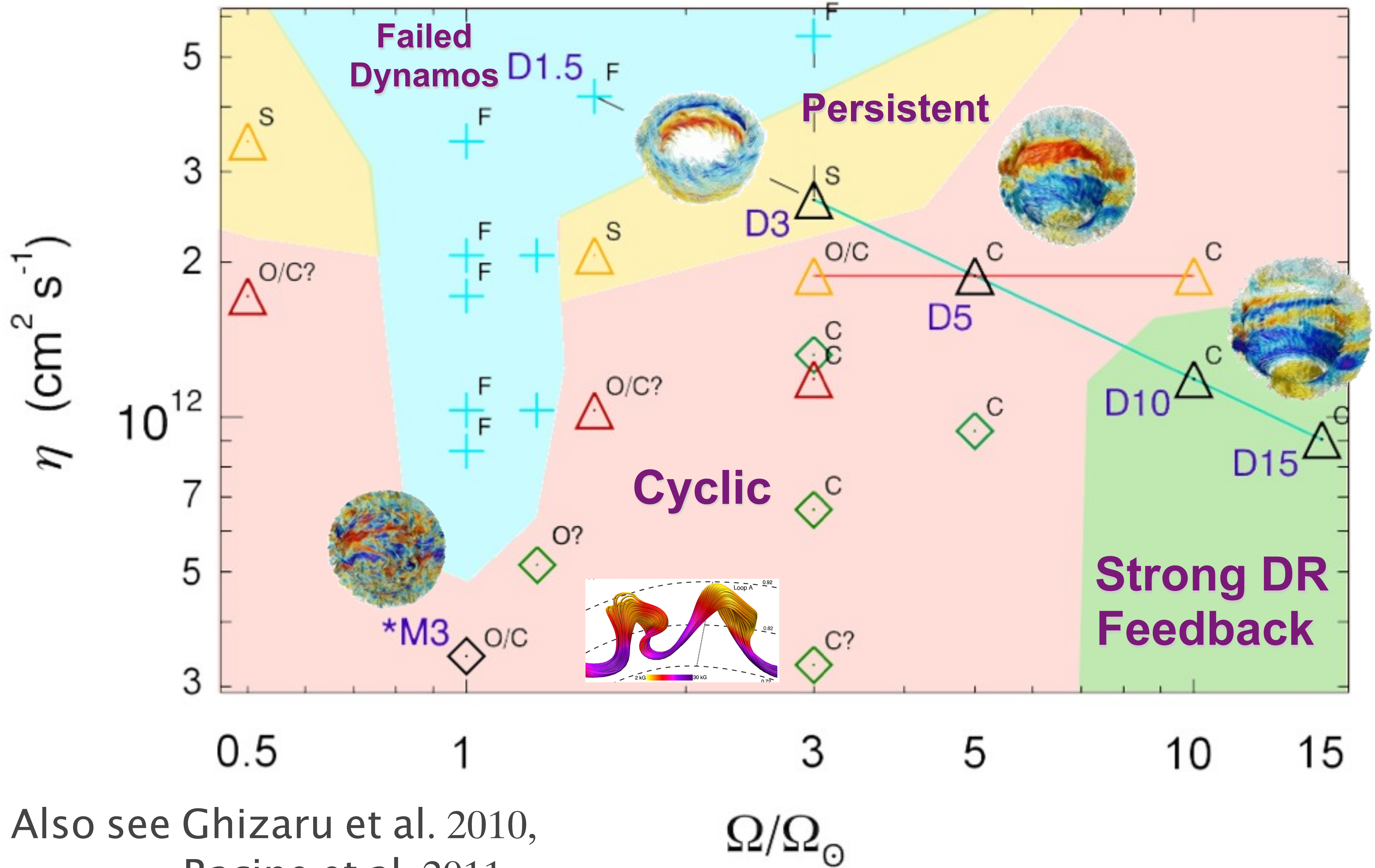




Hemispheric dynamo

10 Ω

Stellar Dynamos: Many flavors



Also see Ghizaru et al. 2010,
Racine et al. 2011