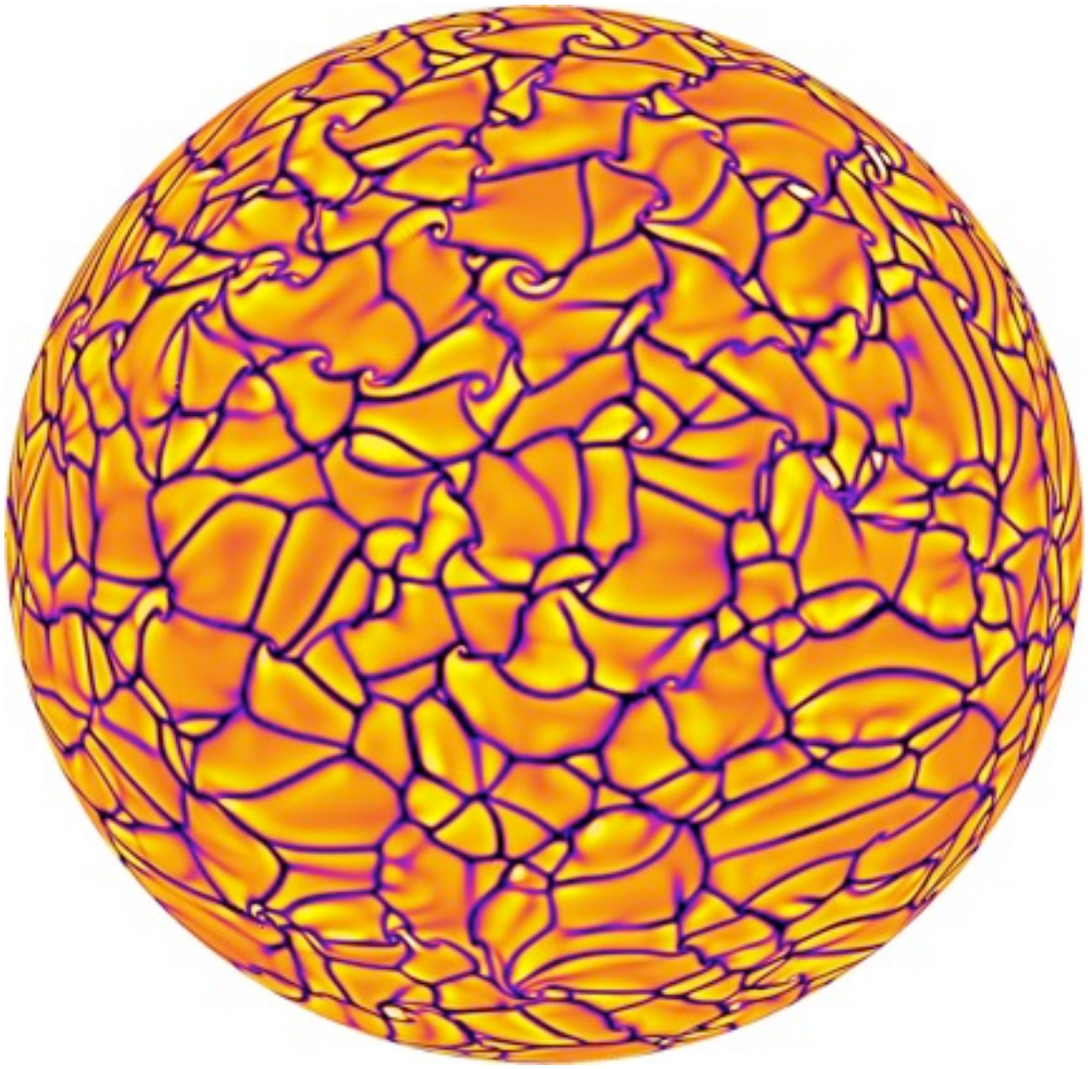
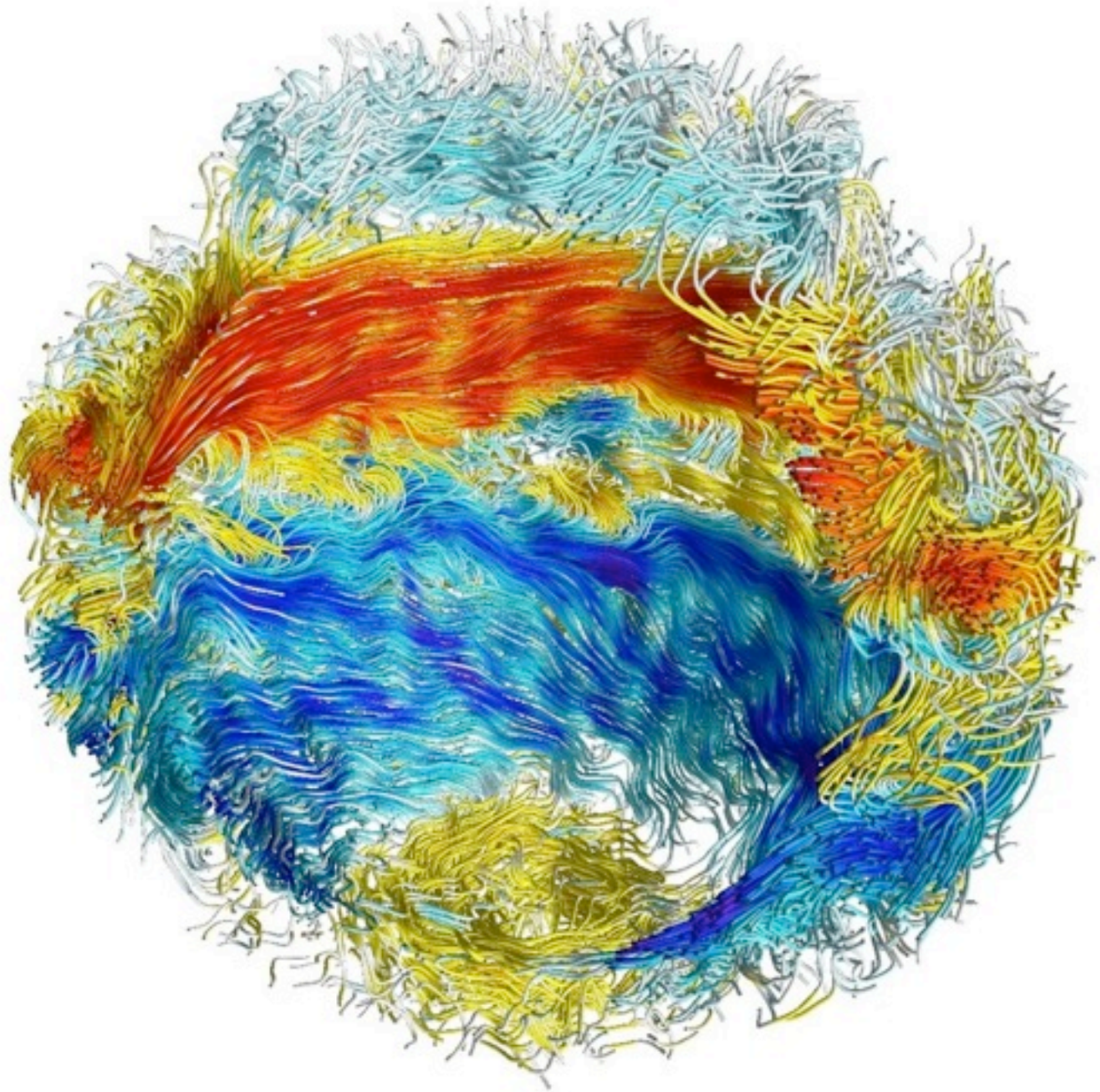
Global-scale Simulations of Stellar Convection



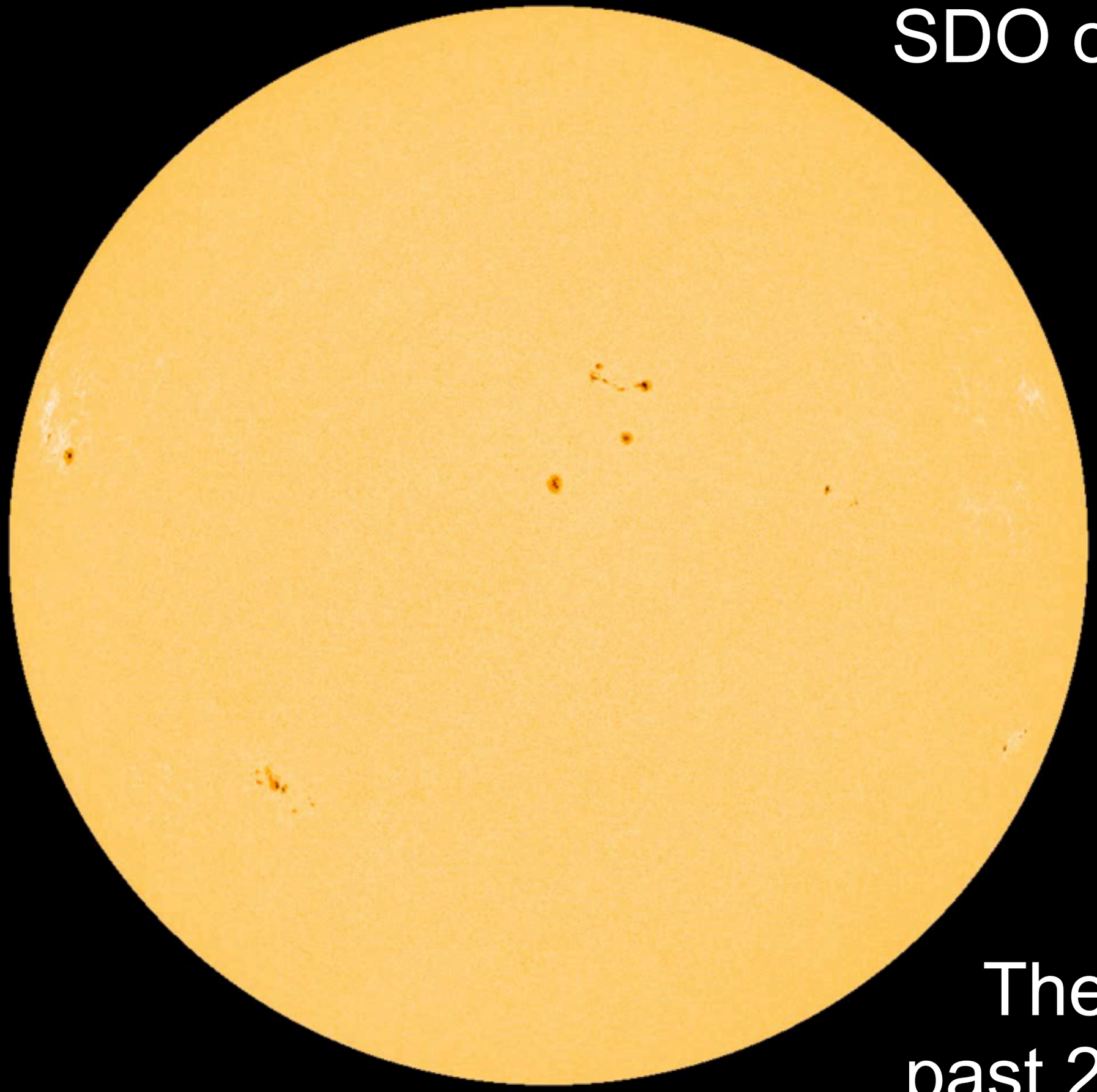


w/ Browning, Brun, Miesch, Toomre, Vasil, Zweibel

Ben Brown
Univ. Wisconsin Madison

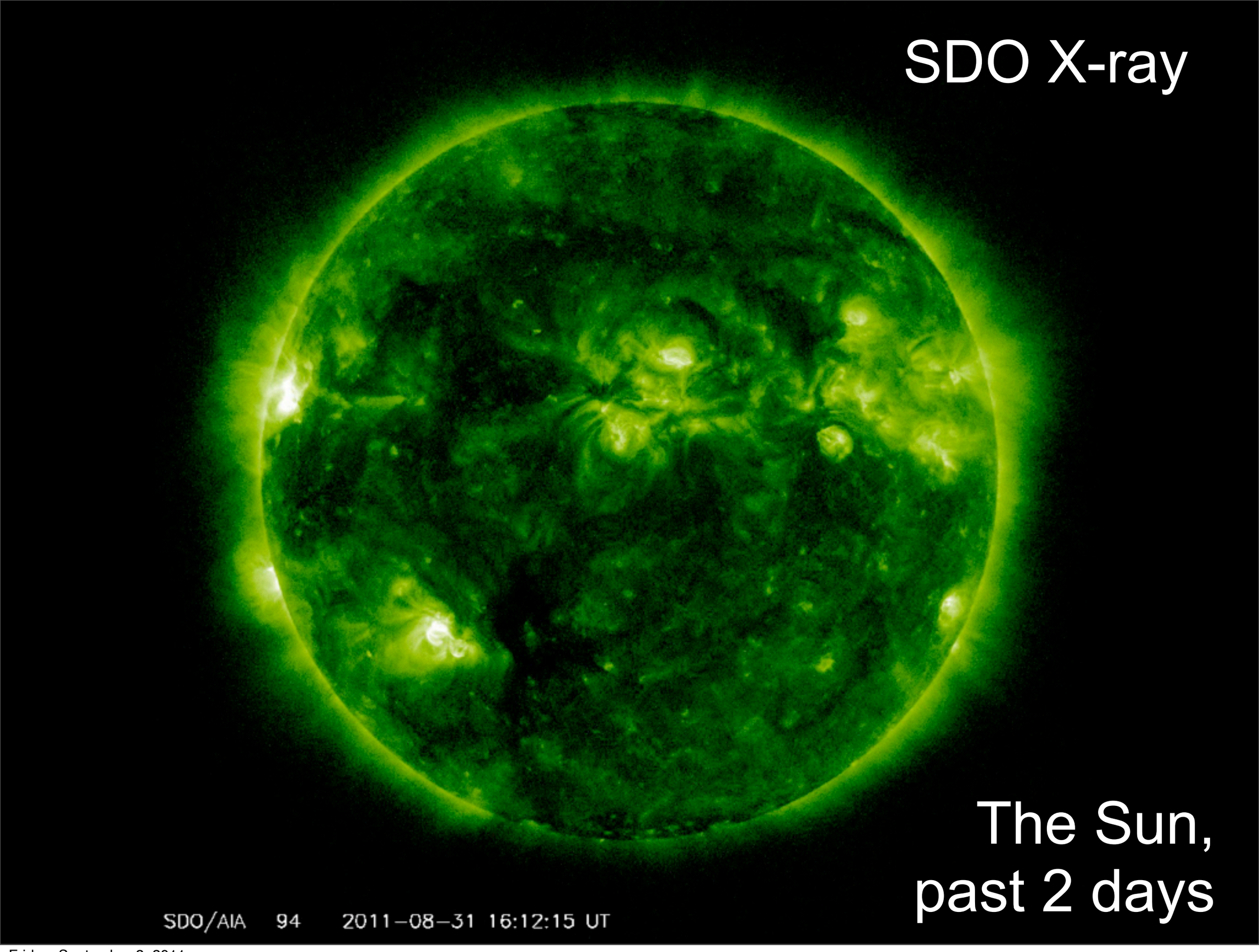
(CMSO & NSF AAPF)

SDO optical



The Sun,
past 2 days

SDO X-ray



The Sun,
past 2 days

The Sun

EIT 304
(He II)

1996

1997

1998

1999

2000

2001

2002

2003

2004

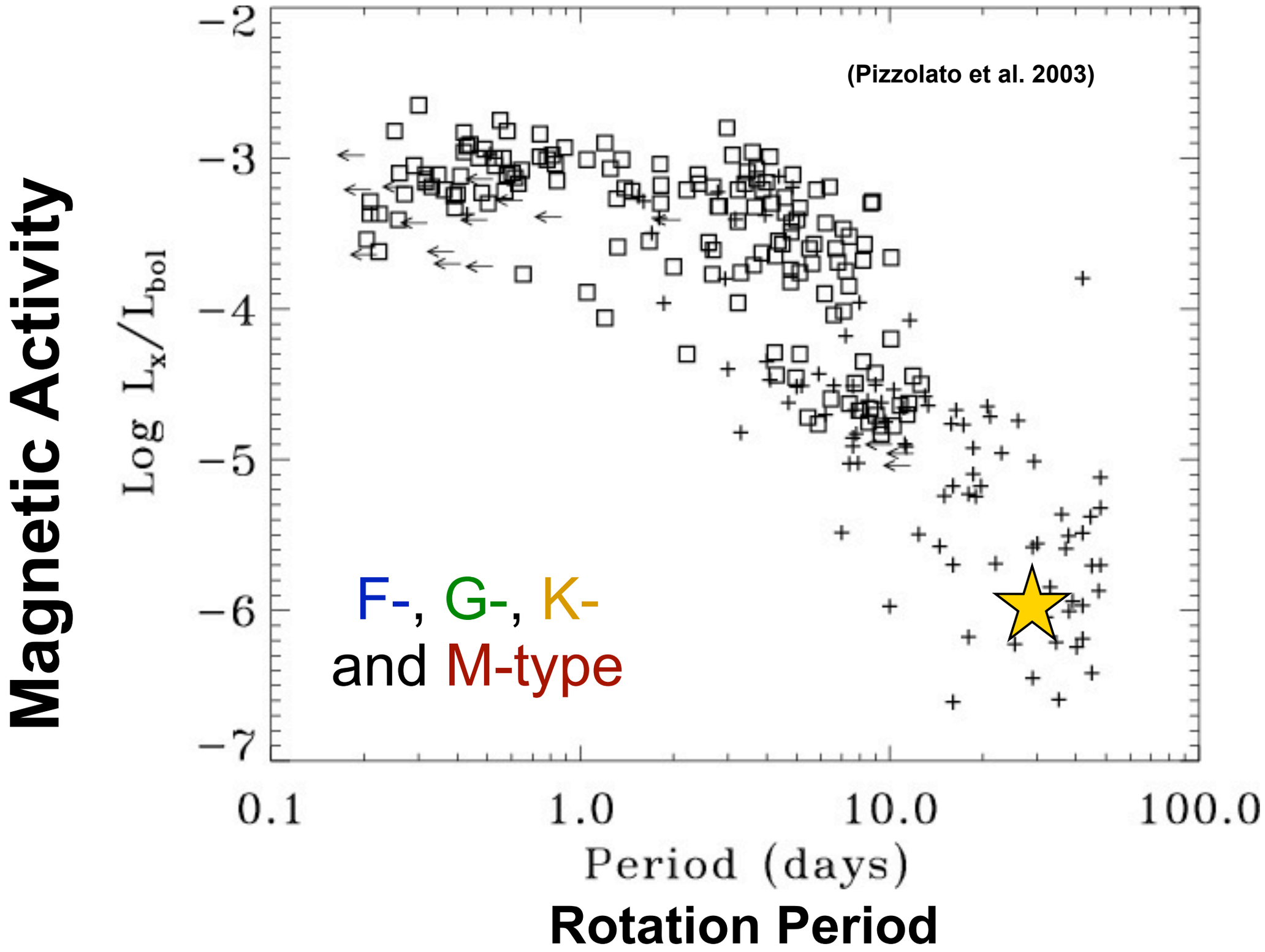
2005

2006

11-year
cycle

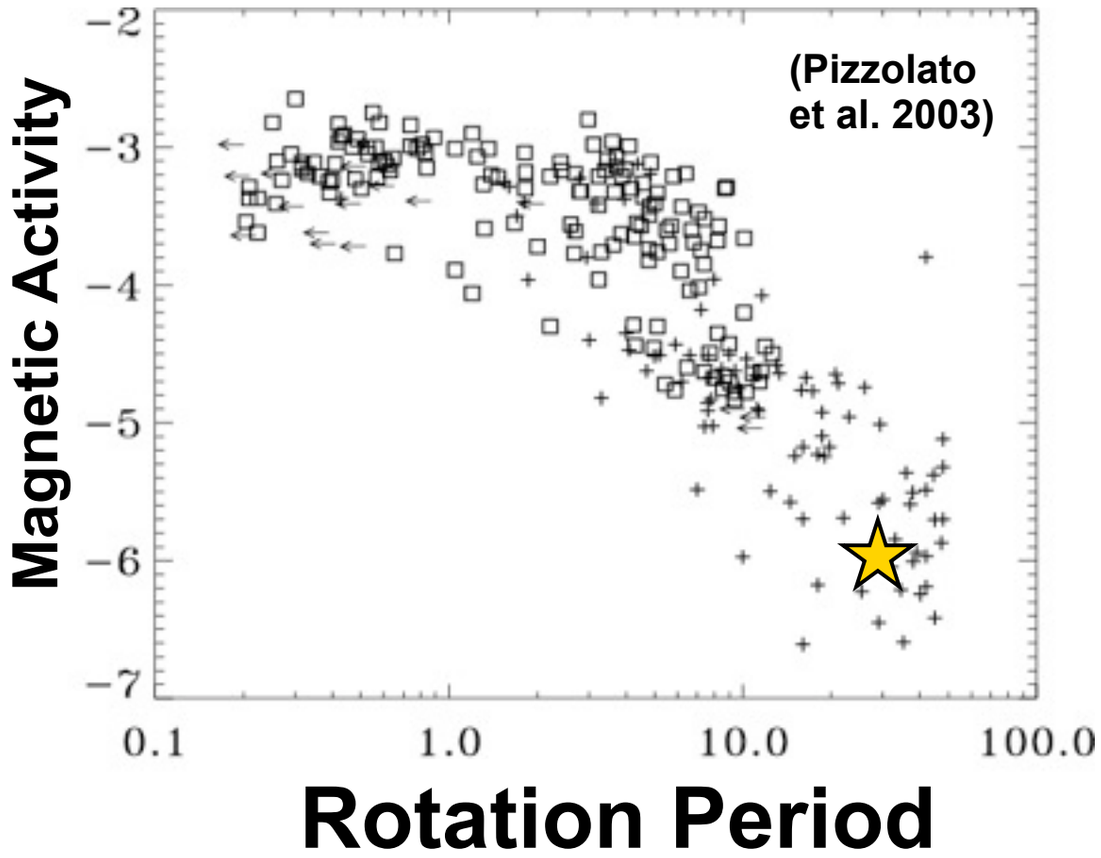
SOHO

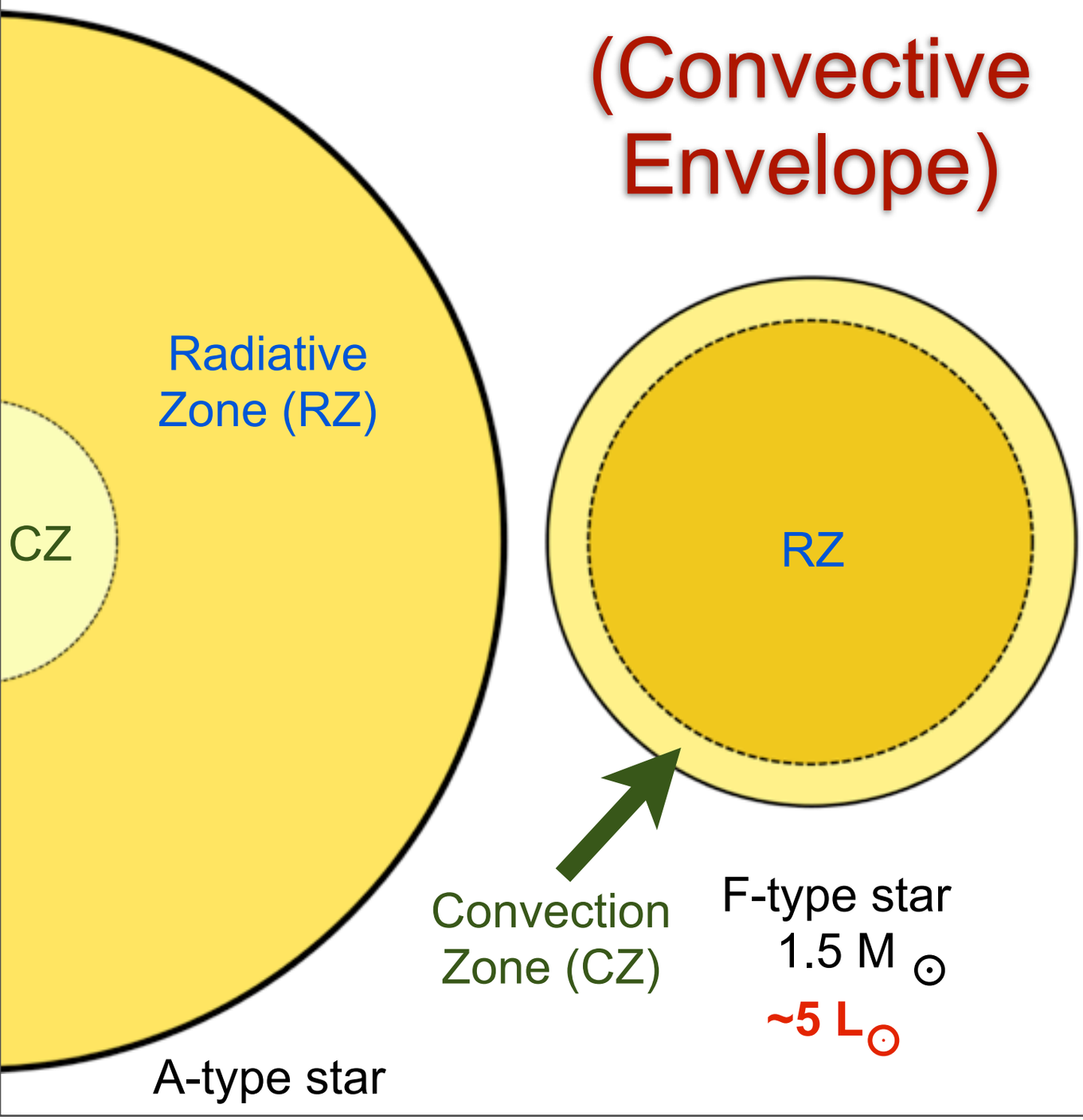
Magnetic Activity in Other Suns



Magnetic Activity in Solar-like Stars

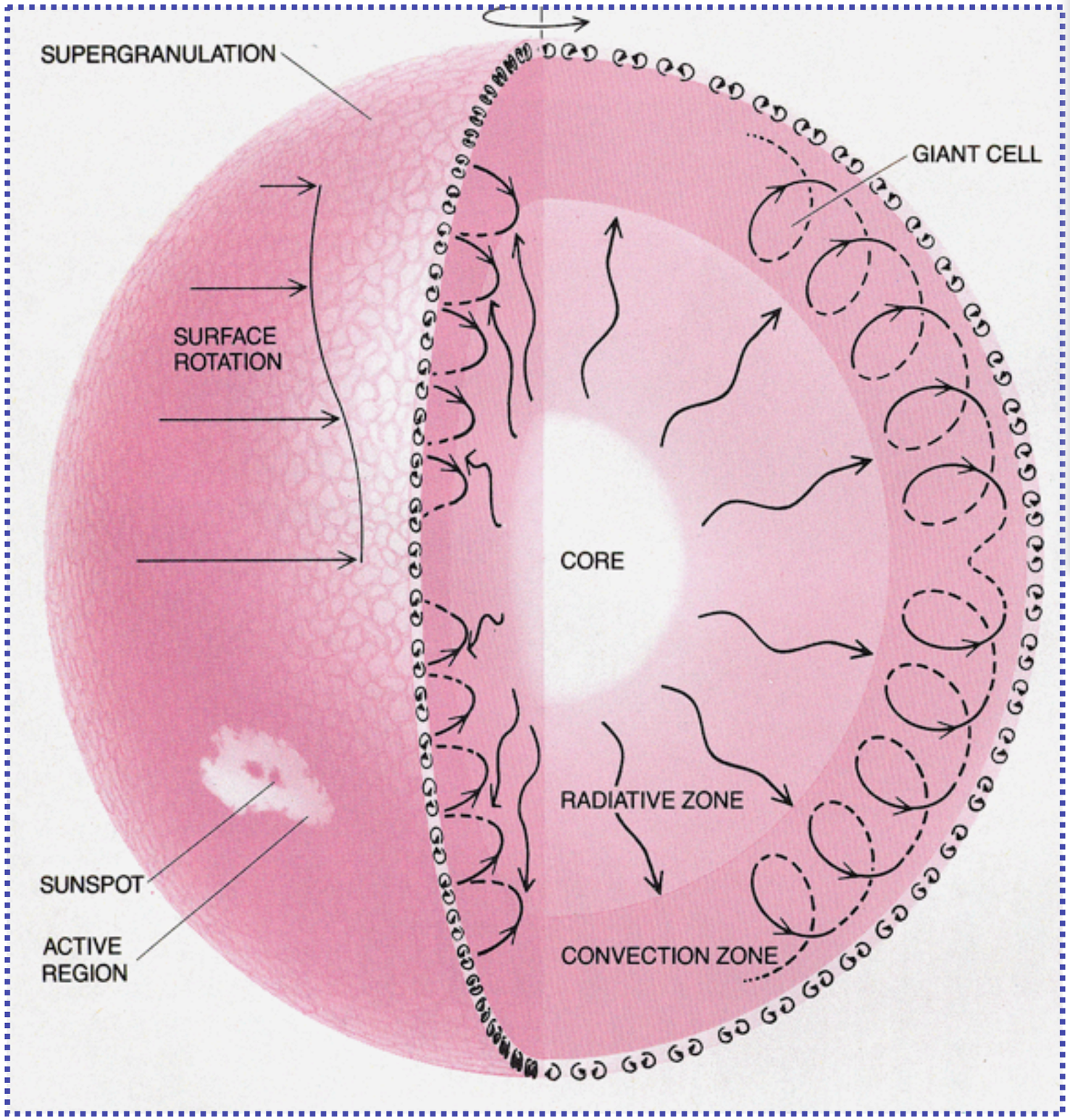
(Convective Envelope)

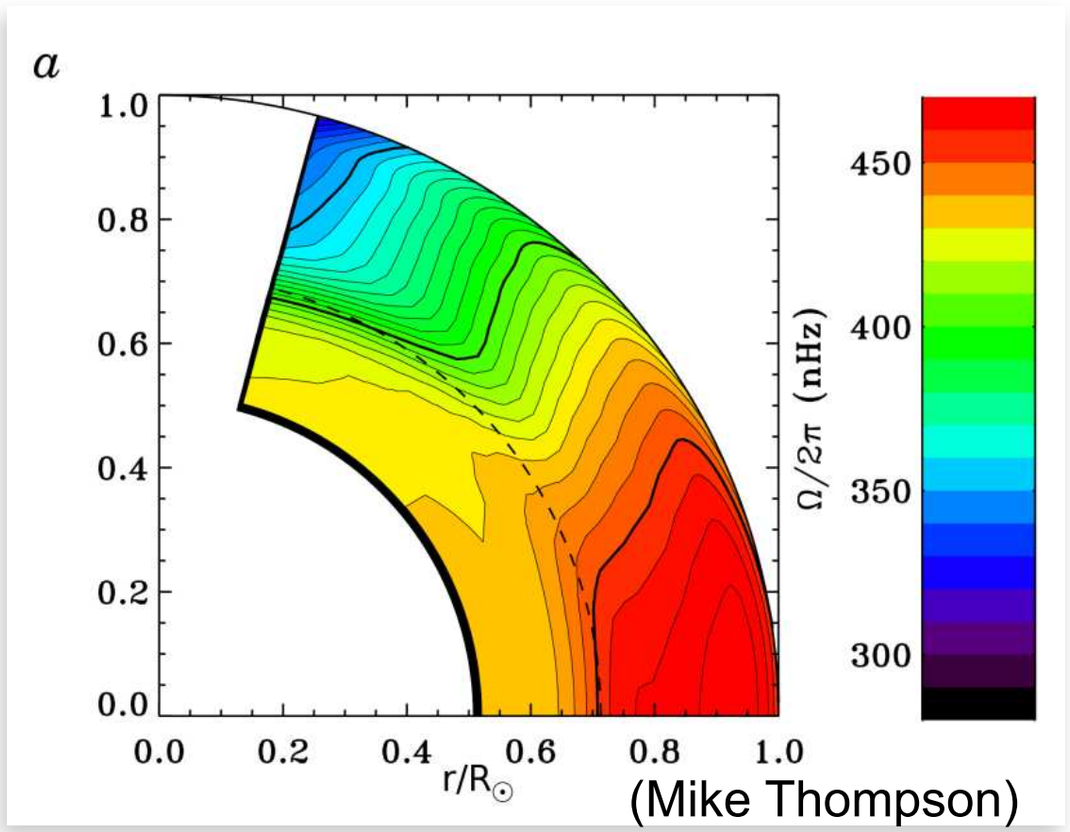




F-M: all magnetically active

Inside the Sun





(Mike Thompson)

CONVECTION ZONE

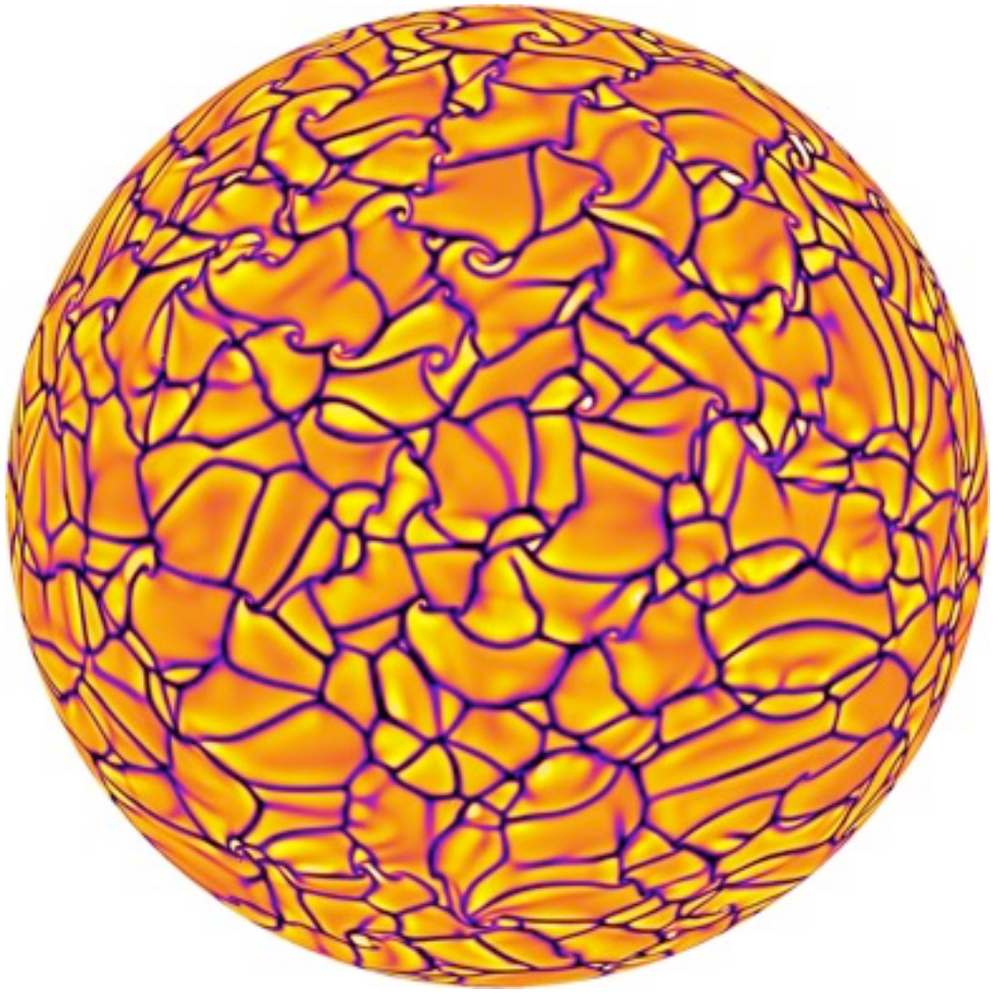
VERY TURBULENT

(depth of 200 Mm)

Re ~ 10^{15}

Stratified, Rotating and Magnetic

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 <u>turbulent convection interacting with rotation</u> in bulk of solar CZ: 0.72 *R* - 0.97 *R*
- Realistic stellar structure
- <u>Simplified physics</u>: perfect gas, radiative diffusivity, compressible, subgrid transport, MHD
- <u>Correct global spherical geometry</u>
- Now can study similar stars too

Radial Velocities in a solar simulation

(based on Miesch et al. 2008)

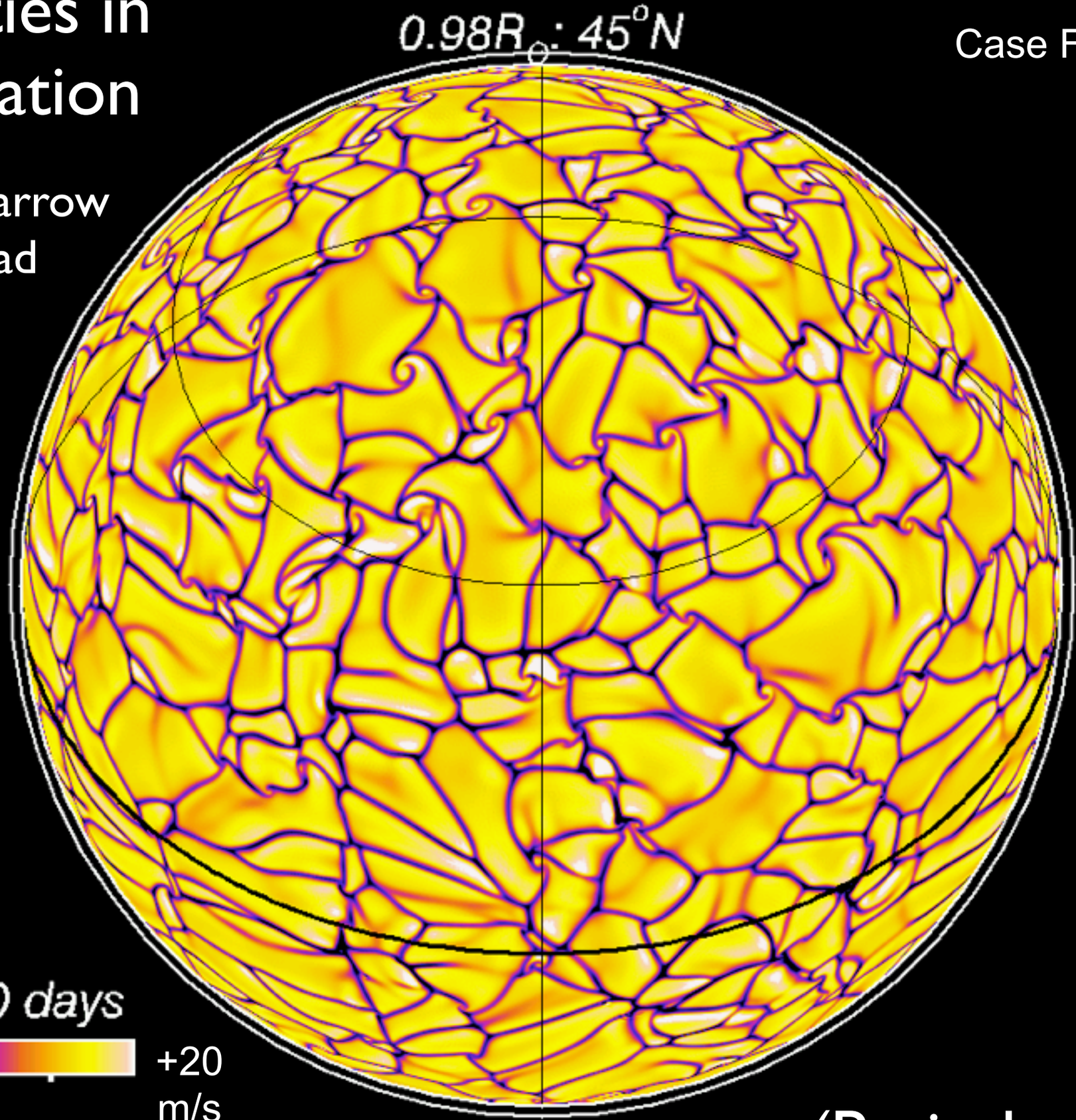
Case F

Downflows: fast, narrow
Upflows: slow, broad

Swirling, vortical convection near polar region

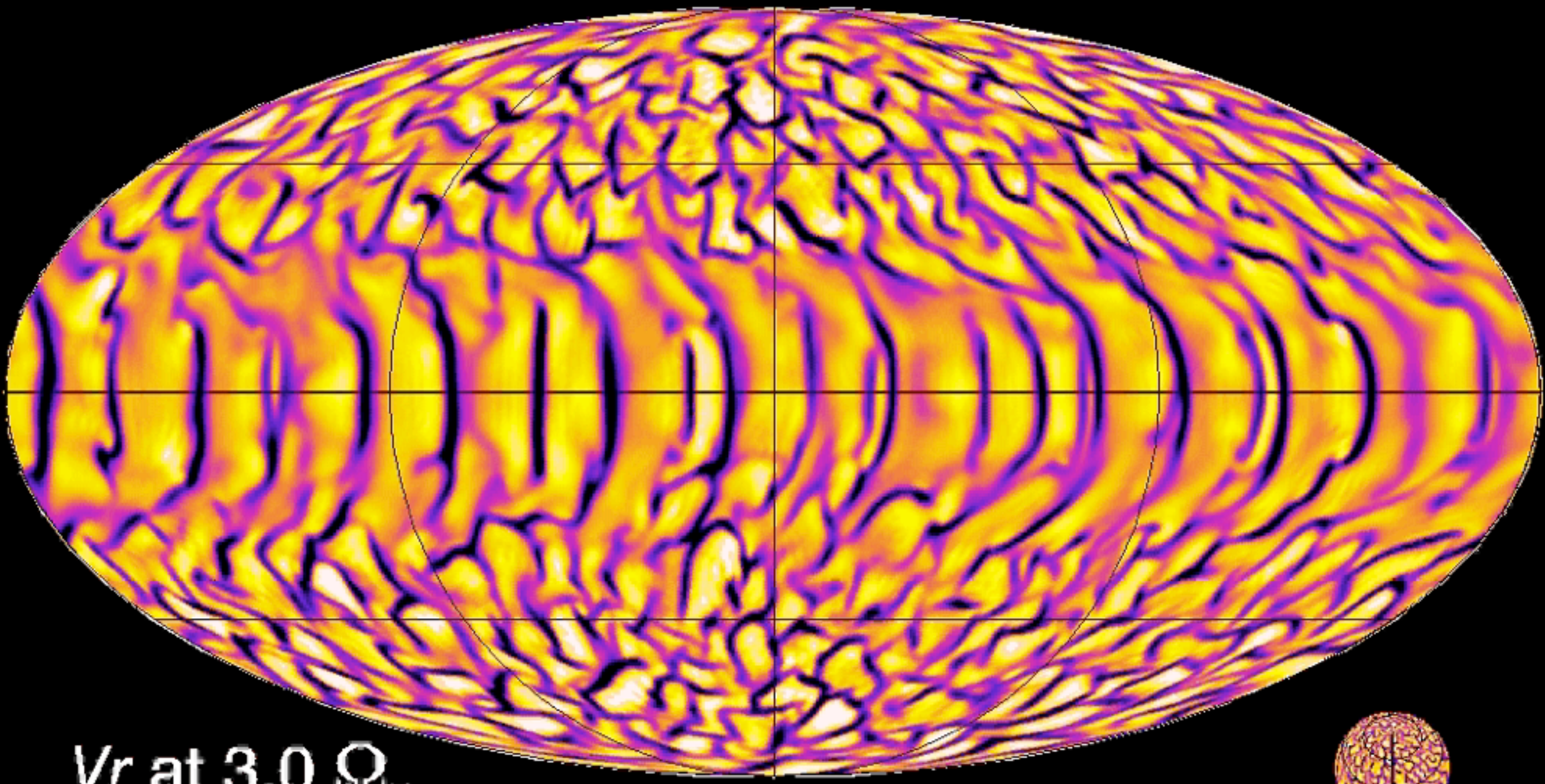
Sweeping cells near equator

Shown near the solar surface (2%)



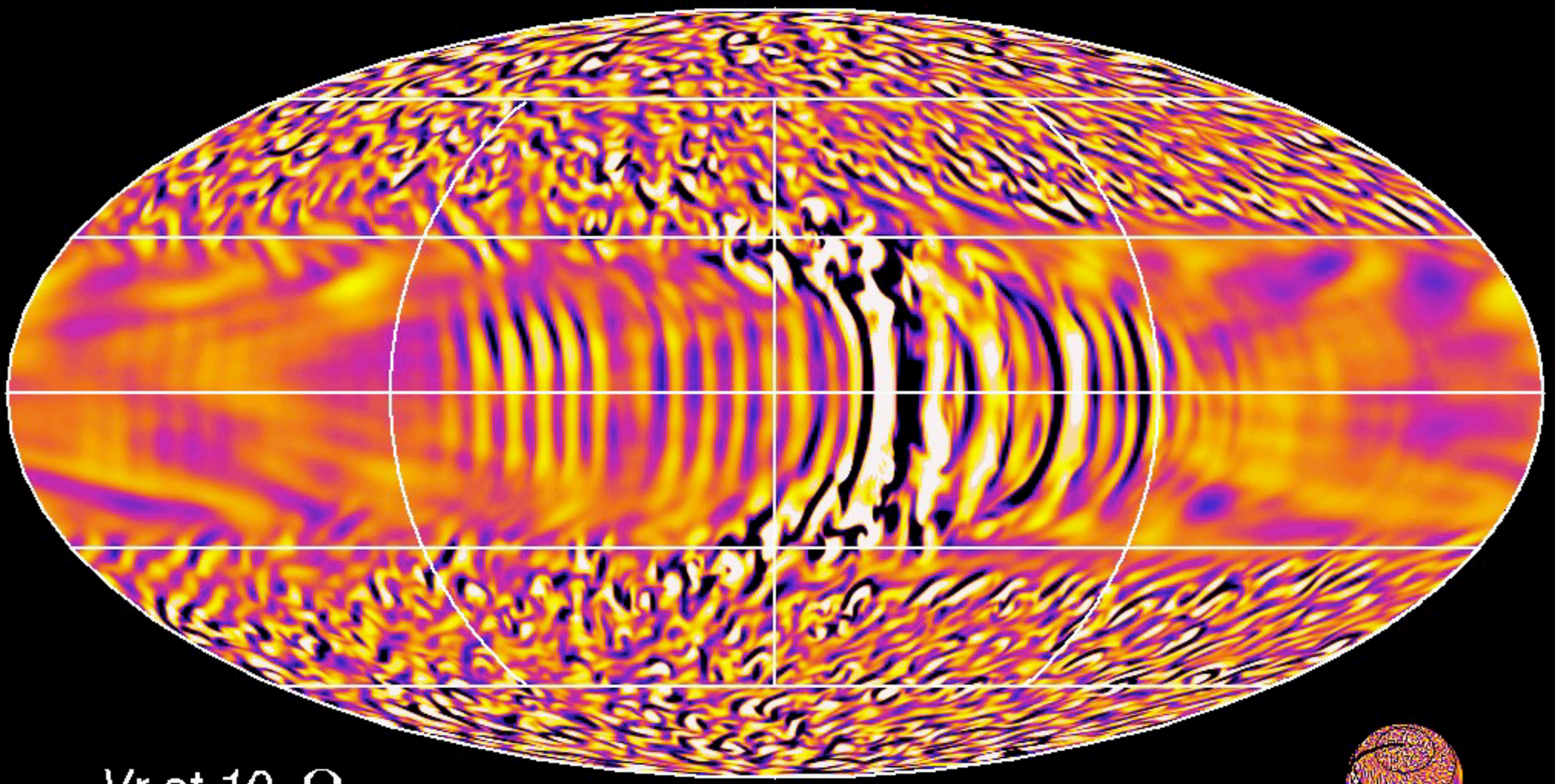
(Period ~ 28d)

Rapidly Rotating Suns: Convective Flows



(Brown et al. 2008, 2010)

Flows in a very rapidly rotating star

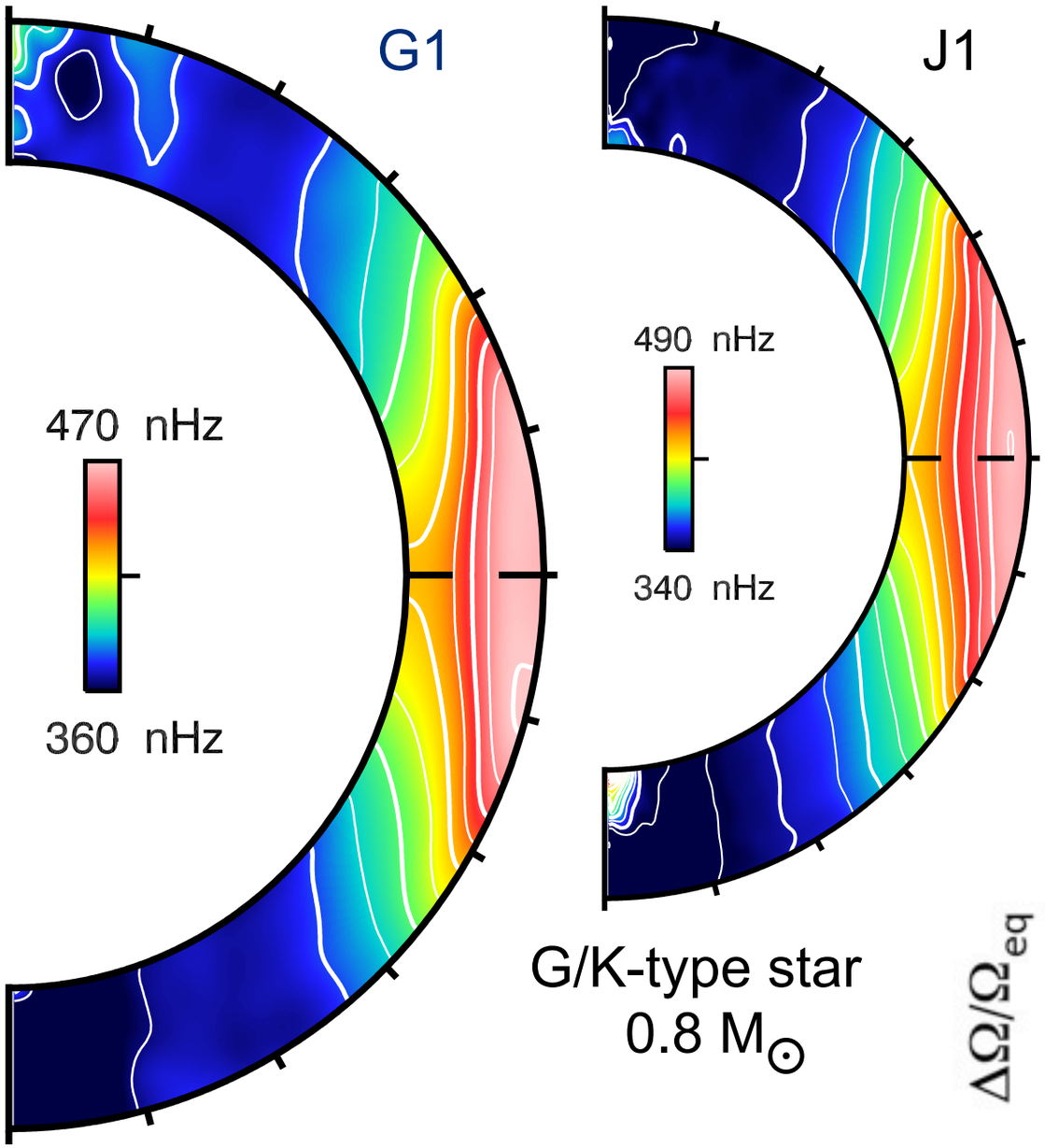


(Period ~ 3d)

2 days

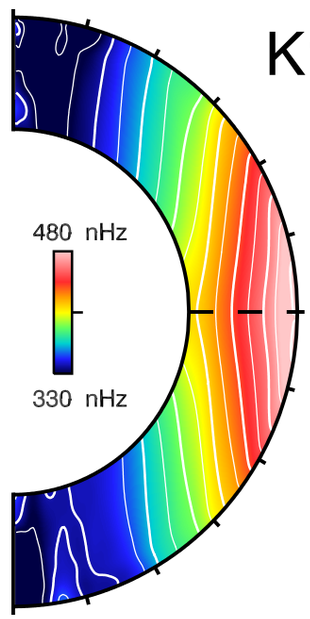
(Brown et al. 2008)

Differential Rotation in Other Stars



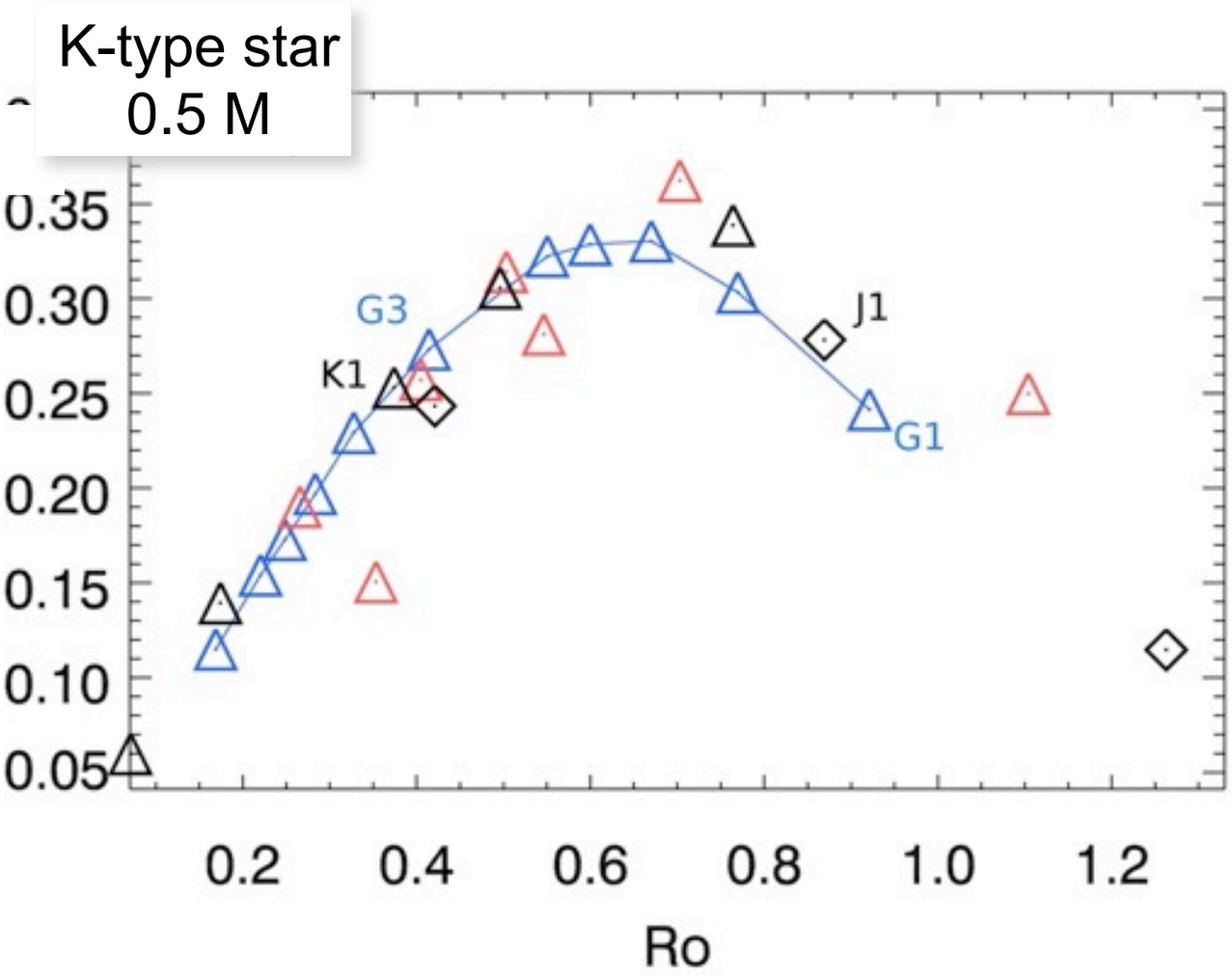
G-type star
1 $M_\odot$

G/K-type star
0.8 $M_\odot$

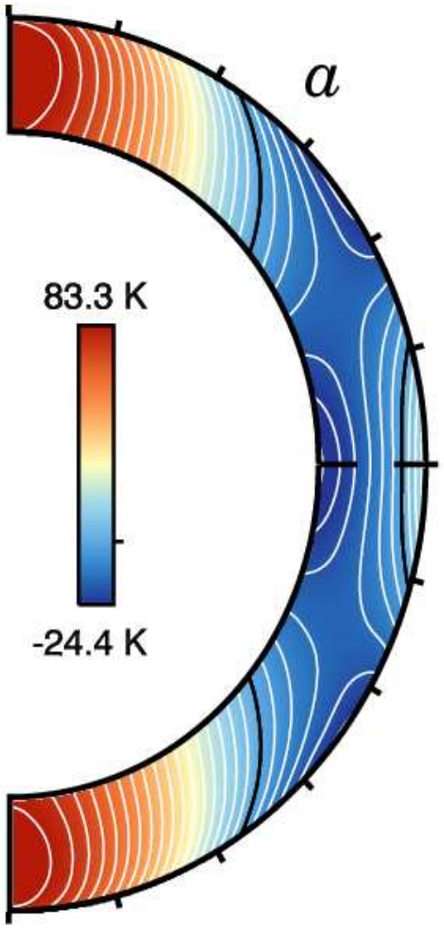


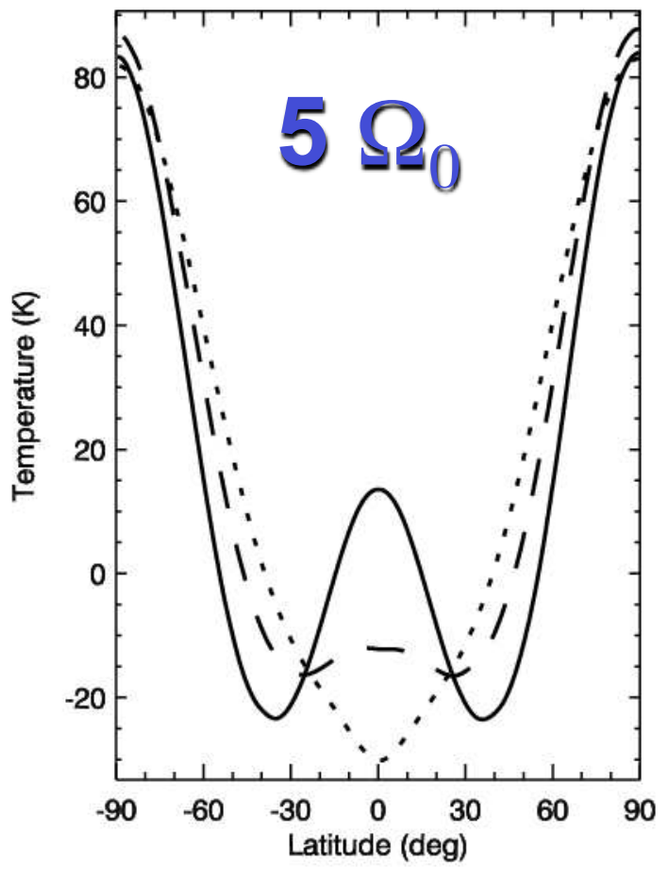
Different masses, same rotation rate, very similar profiles of DR.

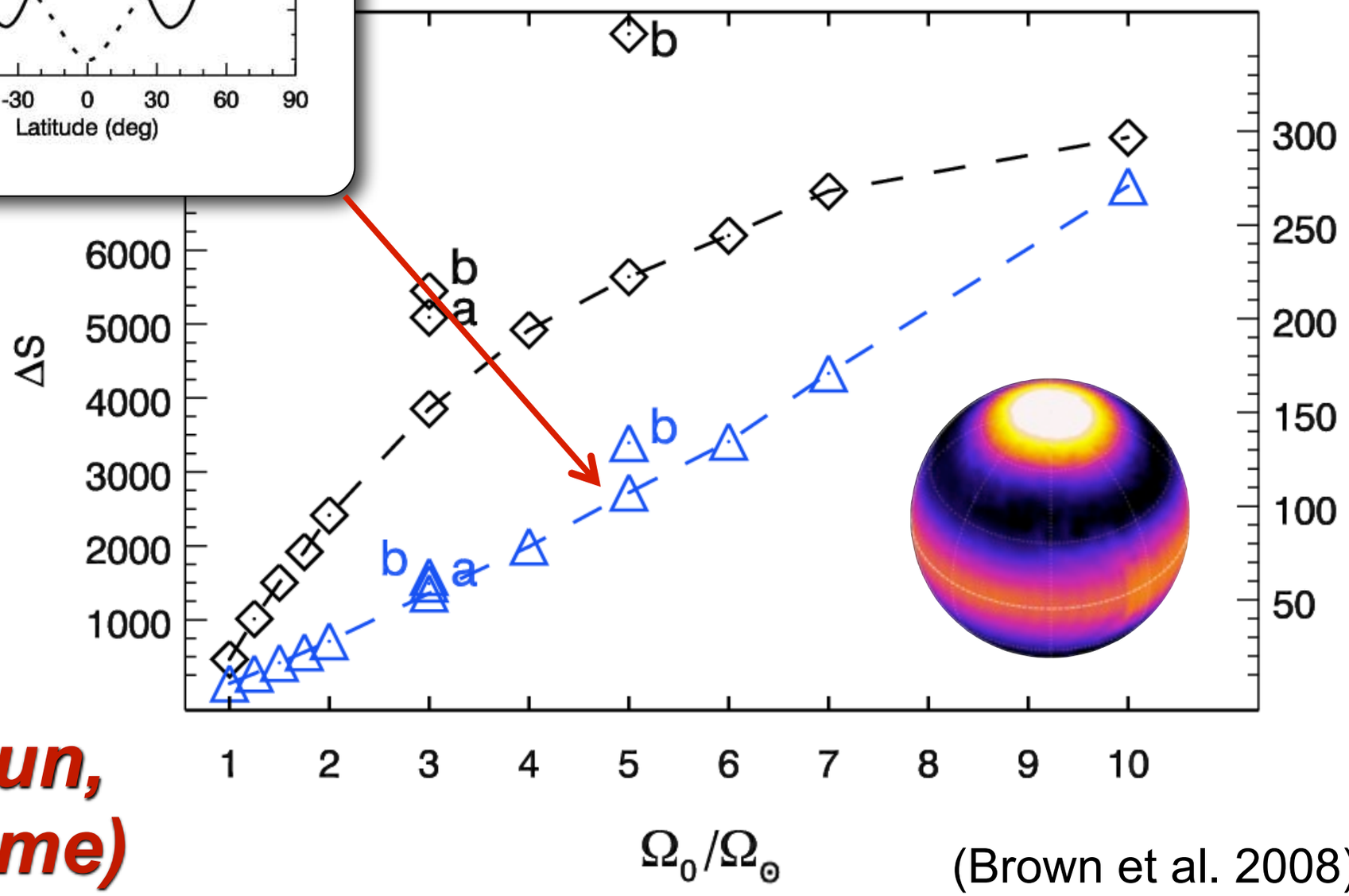
All three stars rotating at solar rate (P~28d)



Pole-to-Equator Temperature: Thermal Wind





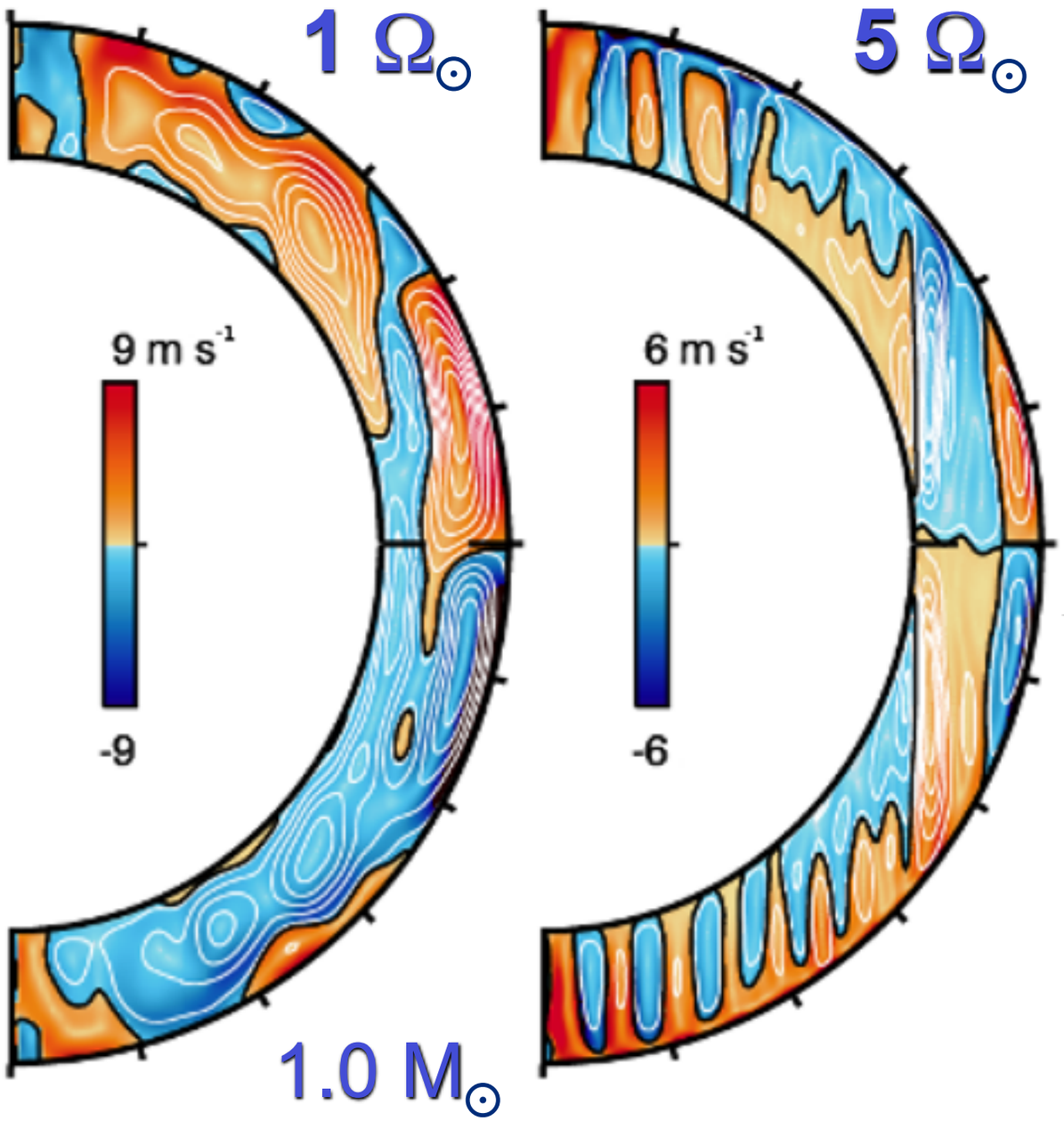


Temperature contrast in latitude grows substantially with fast rotation

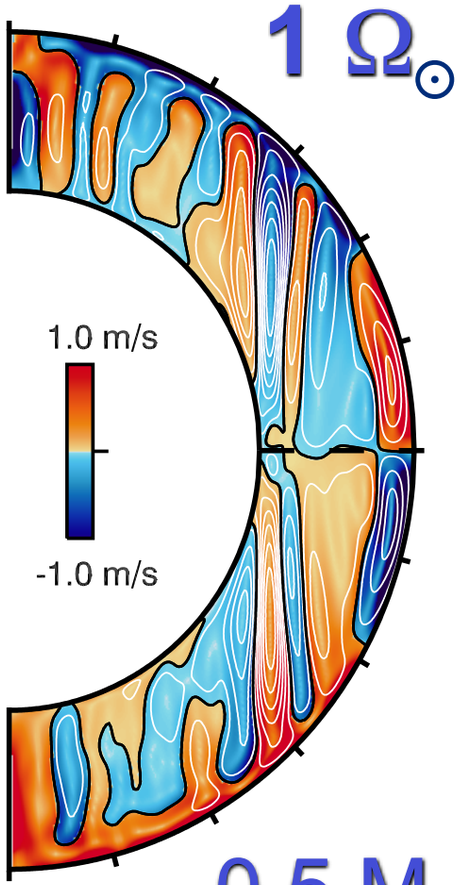
(few K in the Sun, few 100 K in some)

(Brown et al. 2008)

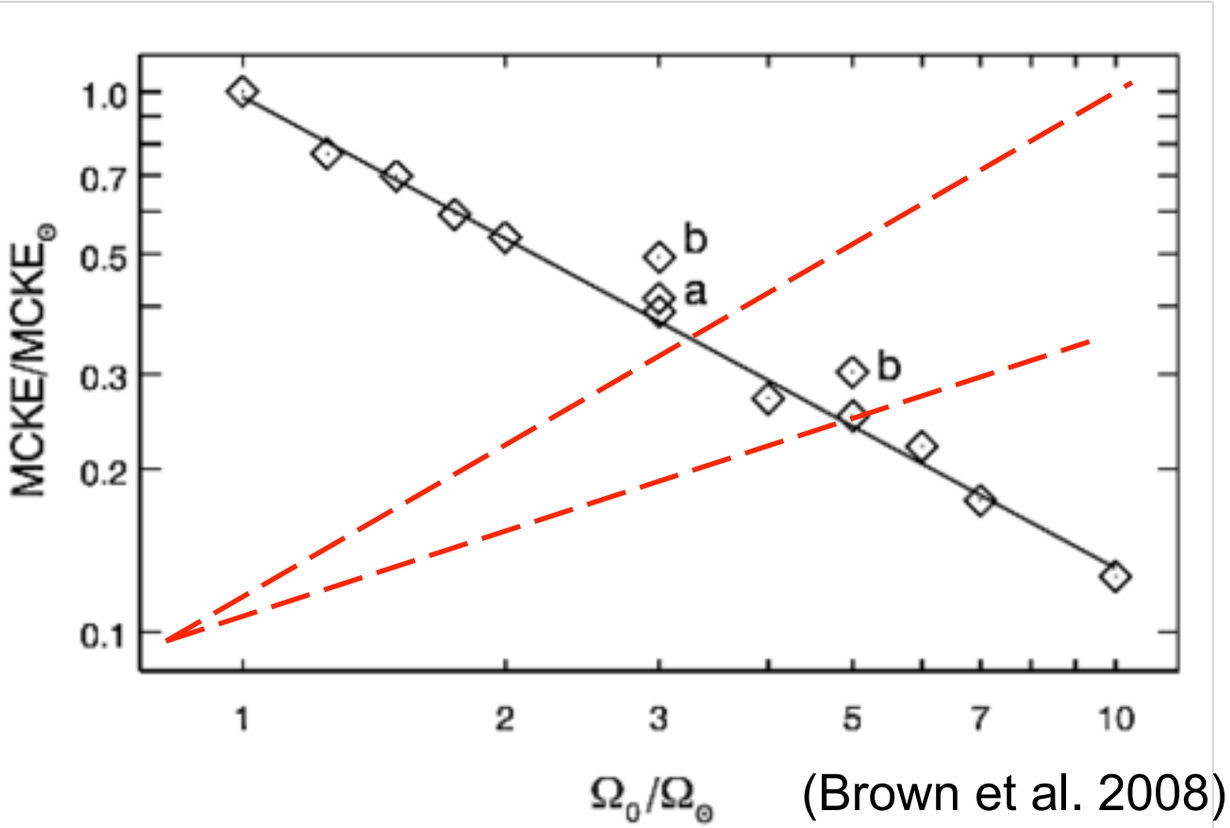
Meridional Circulations



In contrast, meridional circulations are weaker and mutli-celled



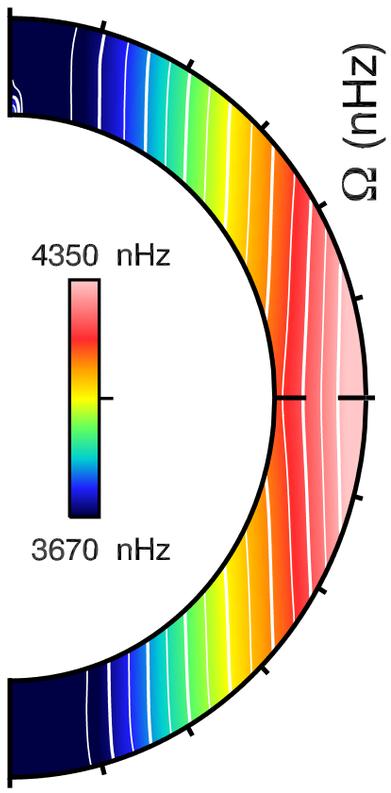
Disagreement with expectations

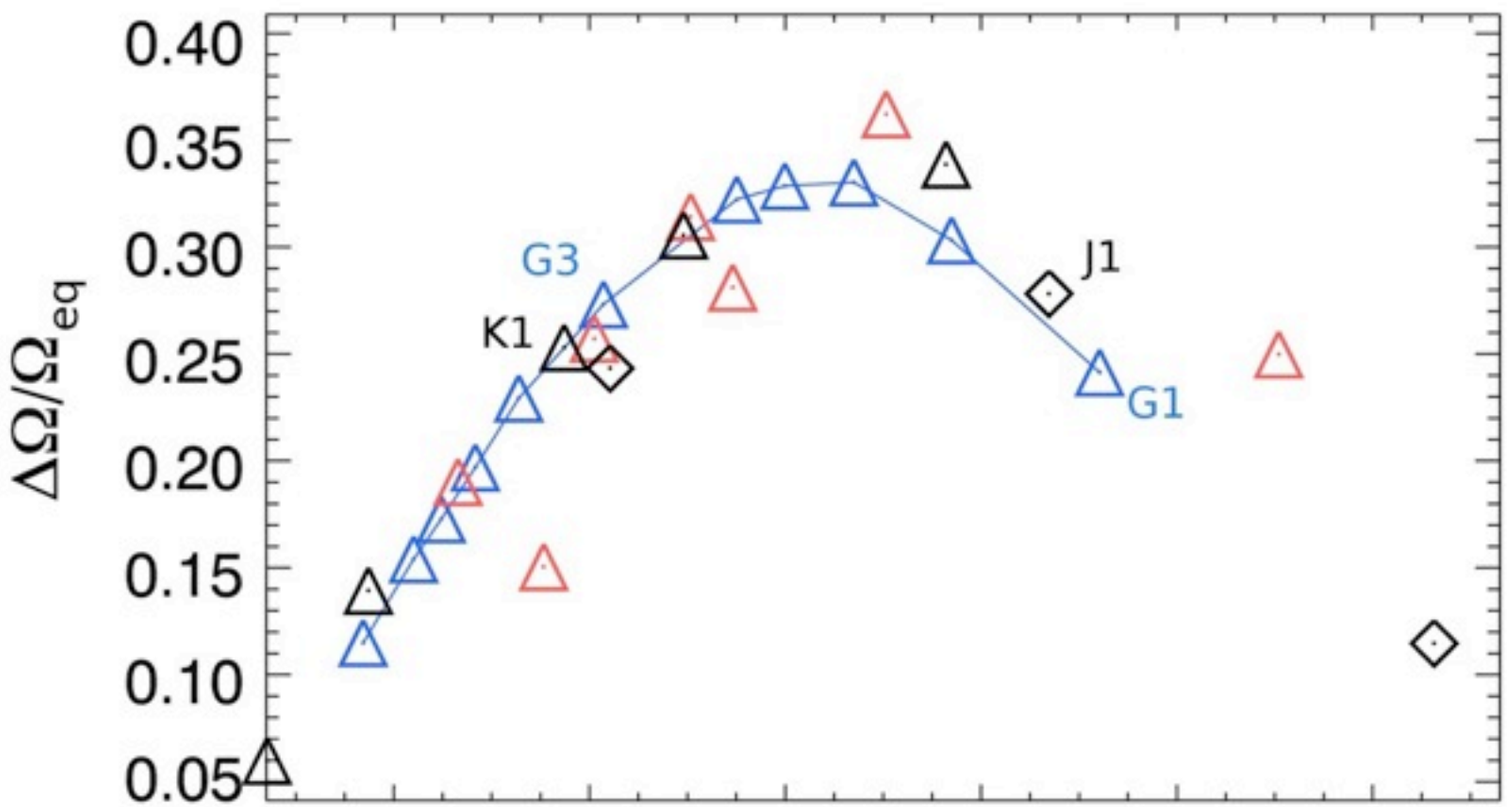


(Brown et al. 2008)

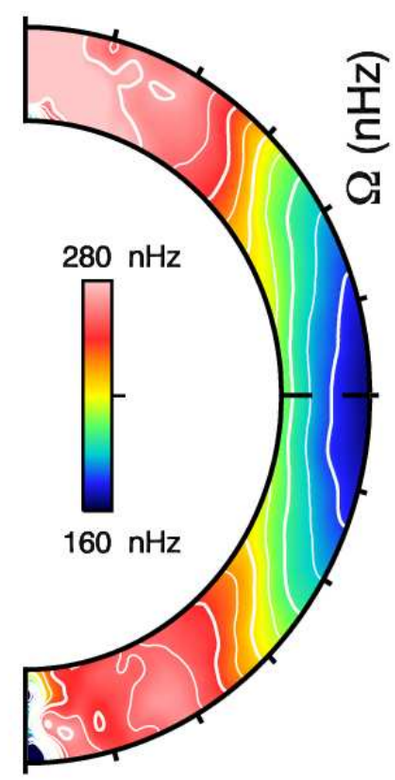
Observables

Rapid Rotators

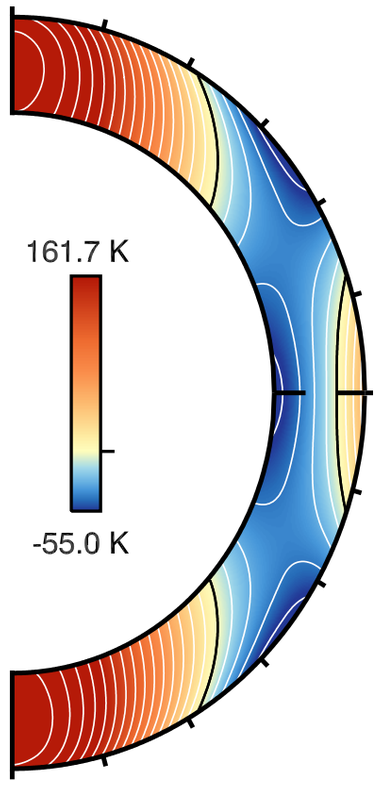


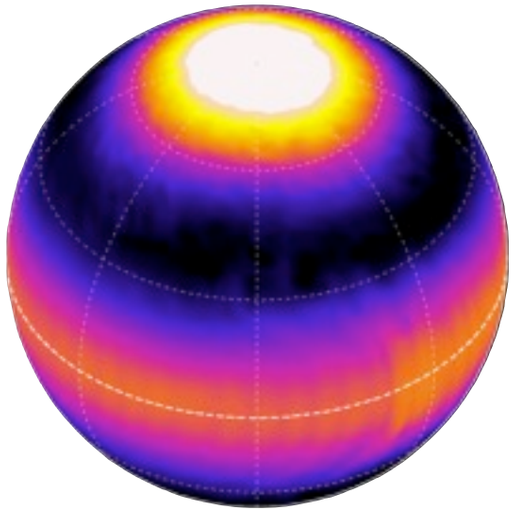


Slow Spinners

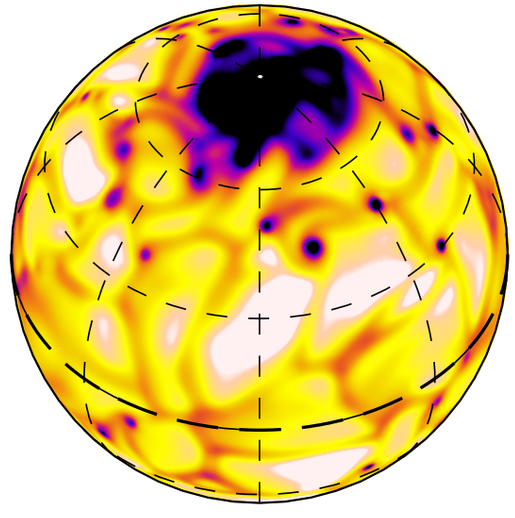


Hot poles

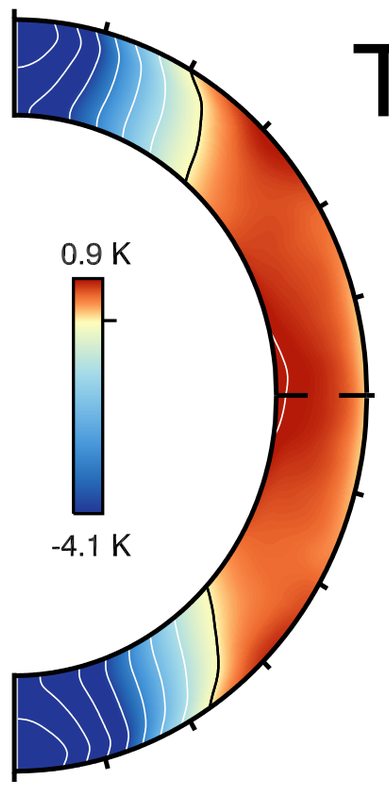




BB flux map with 5-10% variation

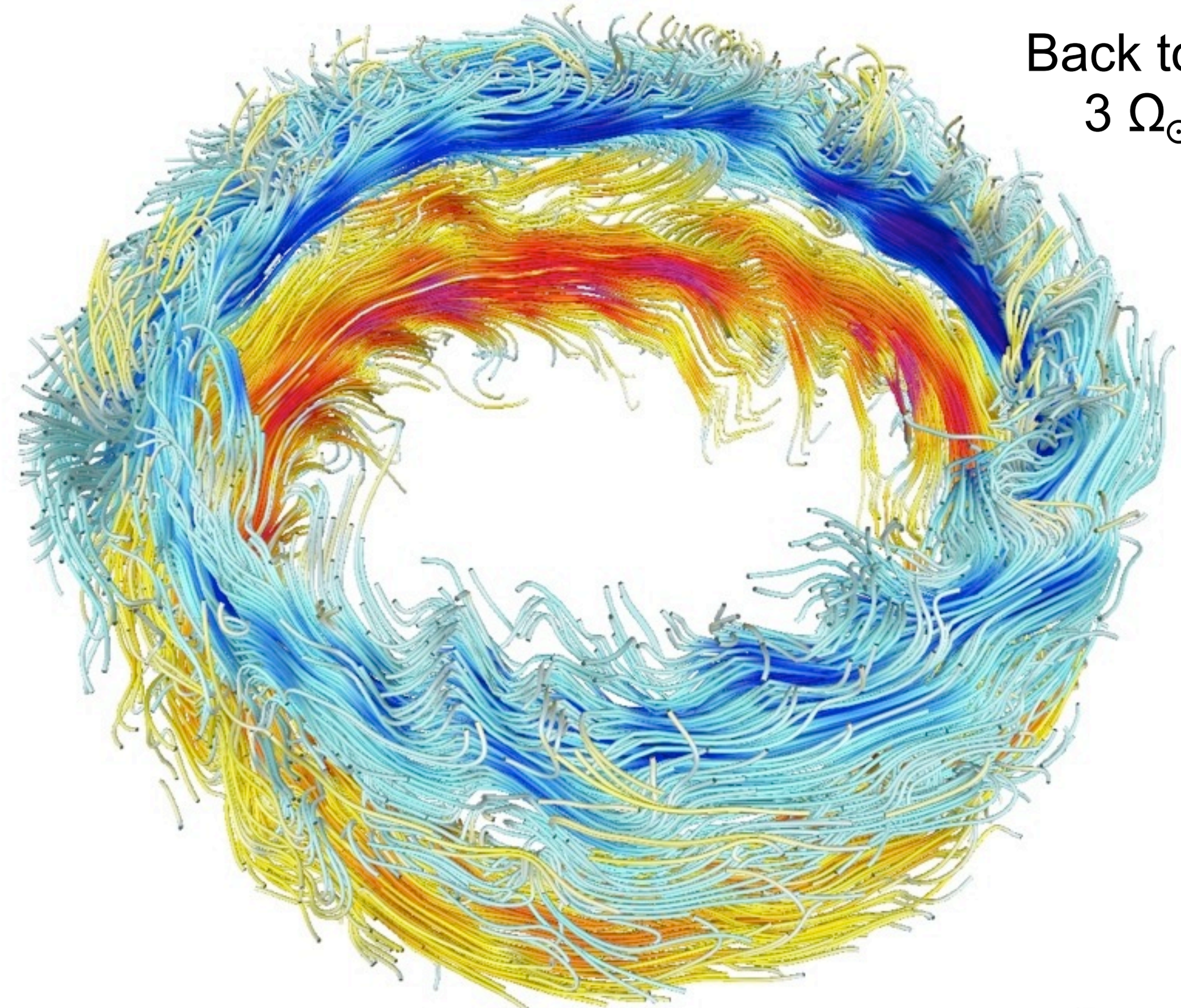


Cold poles



Strong DR → Wreath-building Dynamo

Back to low Ro
3 $\Omega_\odot$ Ro~0.4

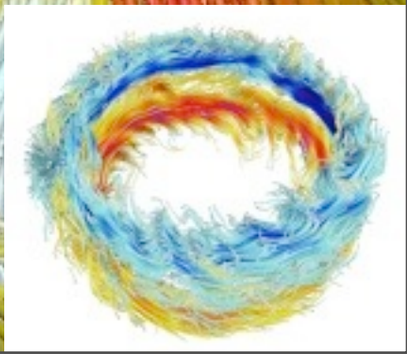


(Brown et al. 2010)

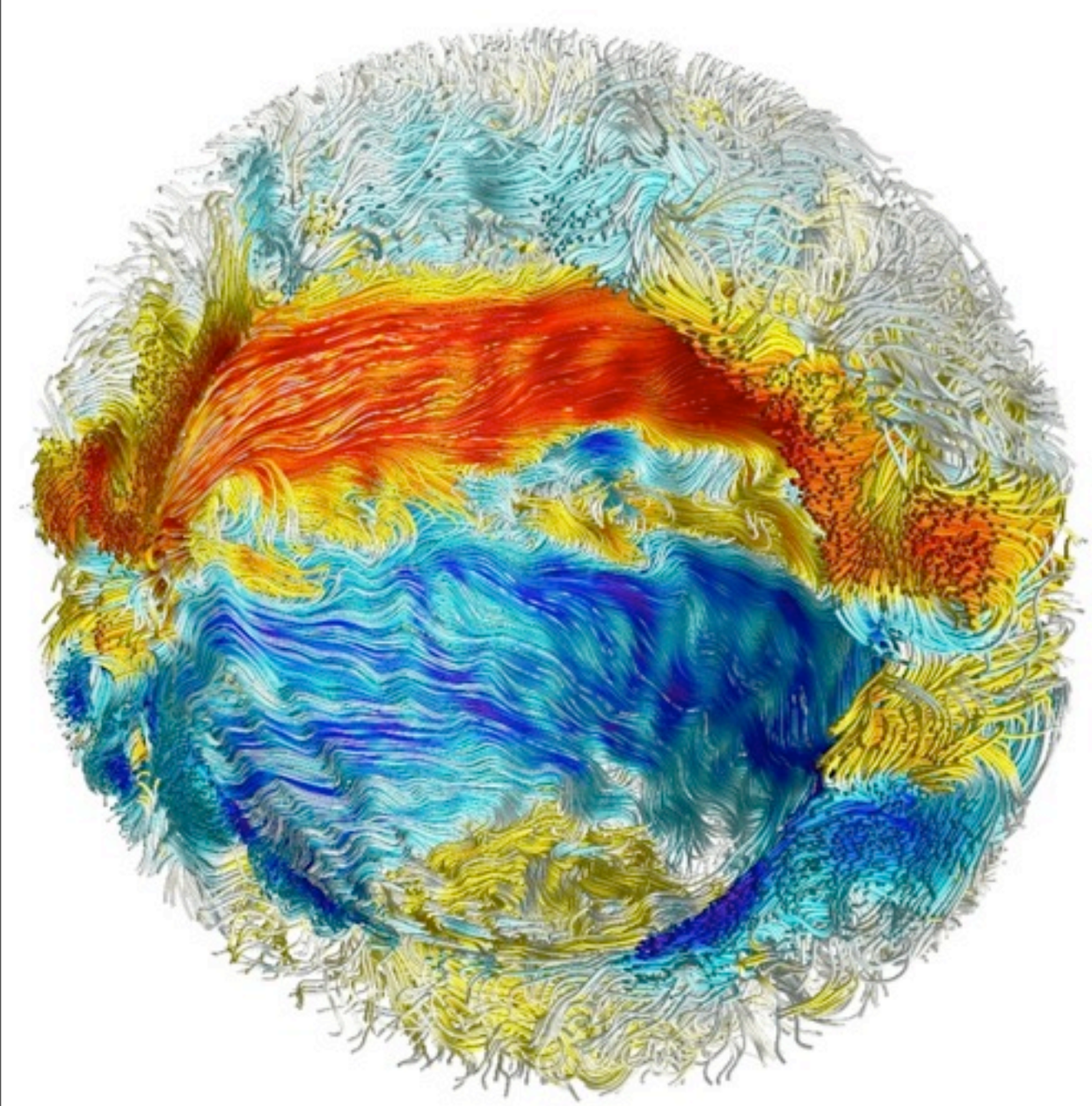
Poloidal Regeneration region

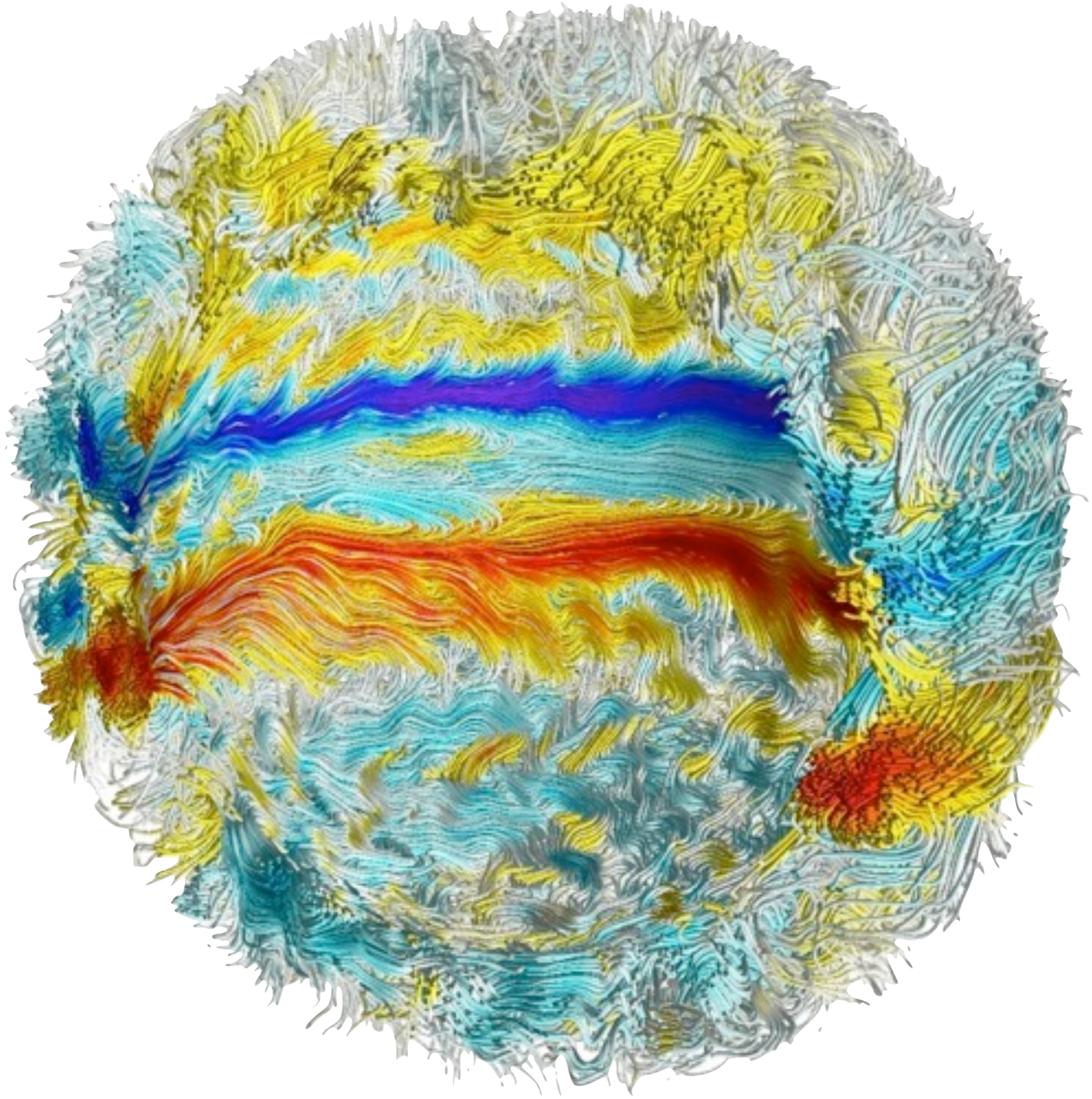
Toroidal Regeneration region

Poloidal Regeneration region



More Turbulent Dynamos: Magnetic Wreaths and Global-scale Reversals

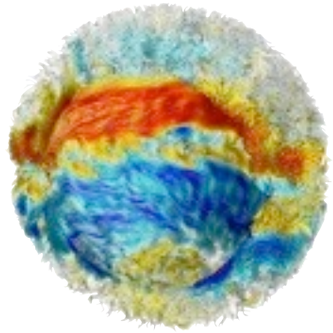




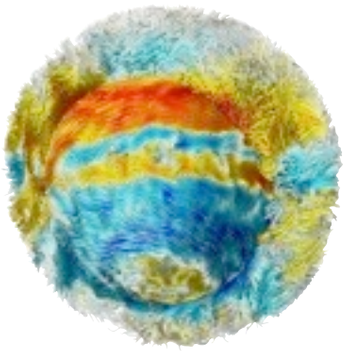
Shortly before (Brown et al. 2011) Long after

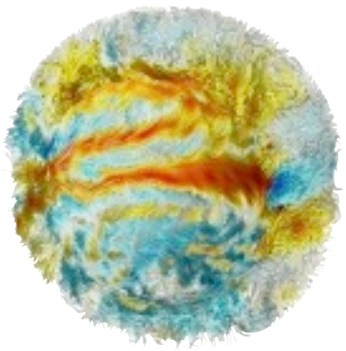
$5\ \Omega_0$

A Global-scale reversal

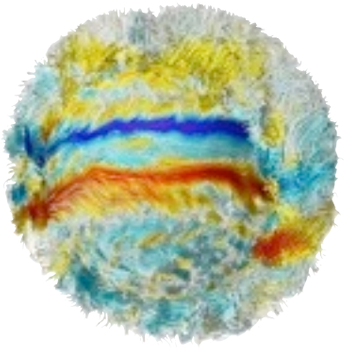


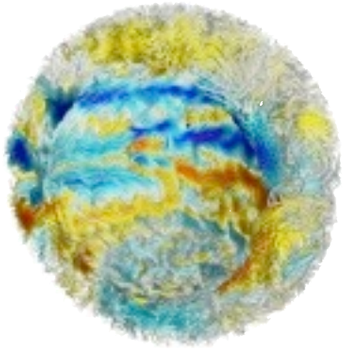
Shortly before





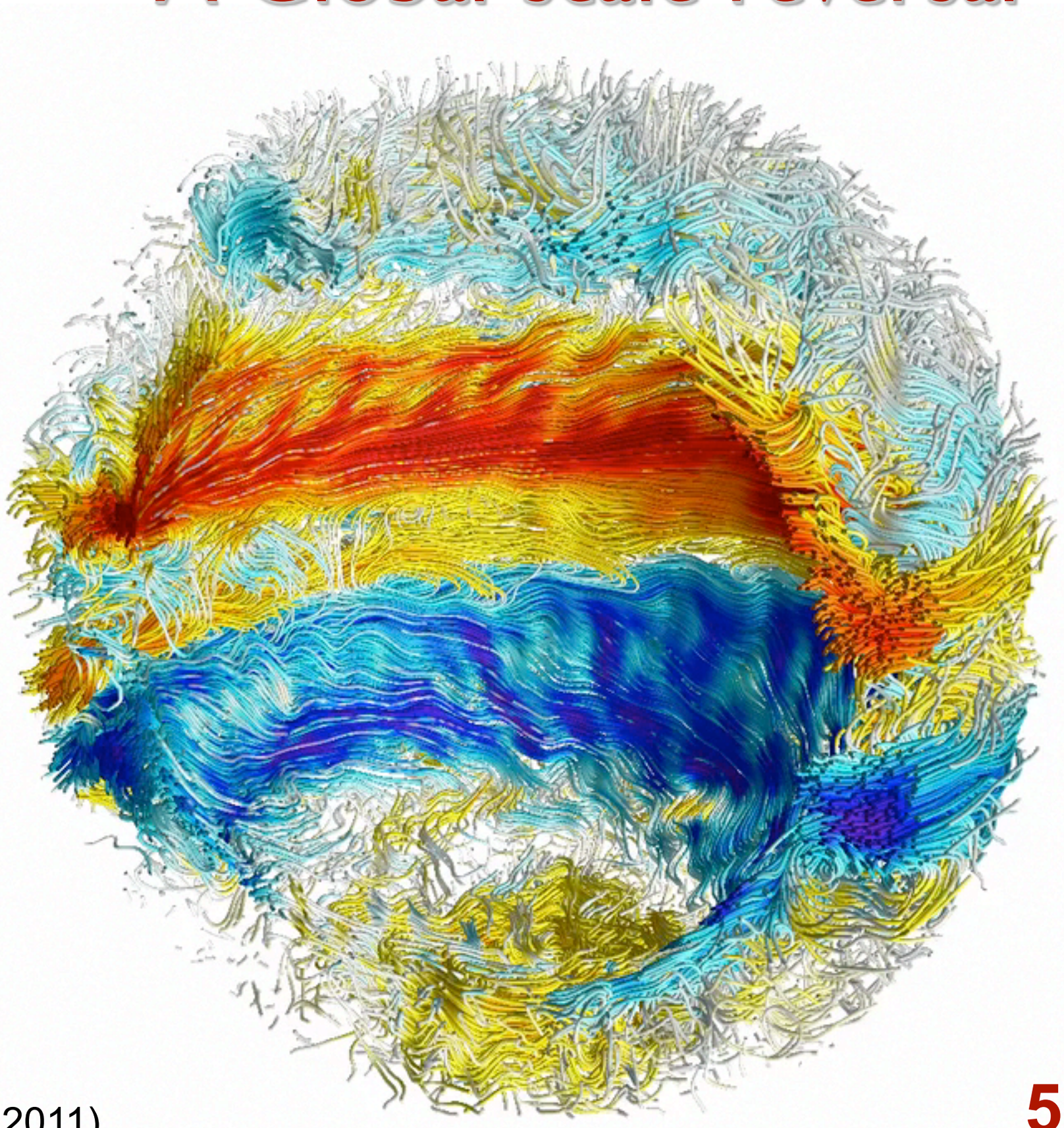
During reversal



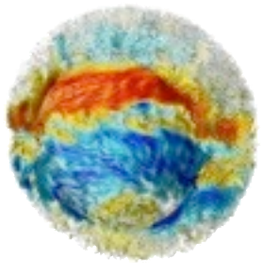


Long after

(Brown et al. 2011)



$5\ \Omega_0$



5 Ω

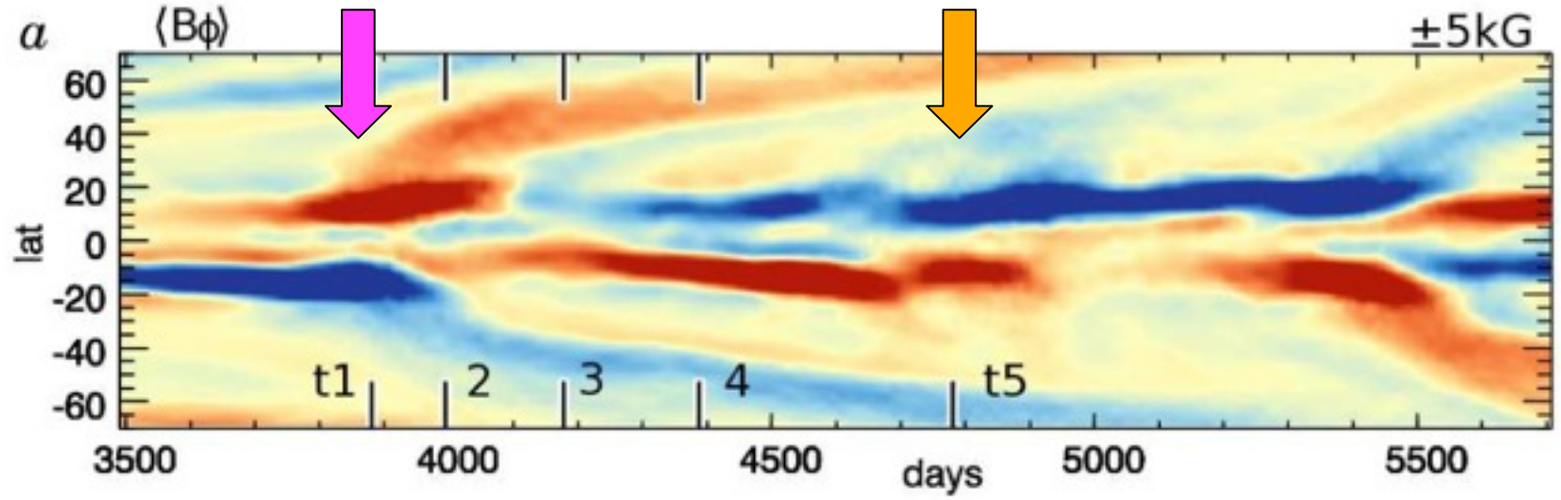
Time-latitude map of Bϕ

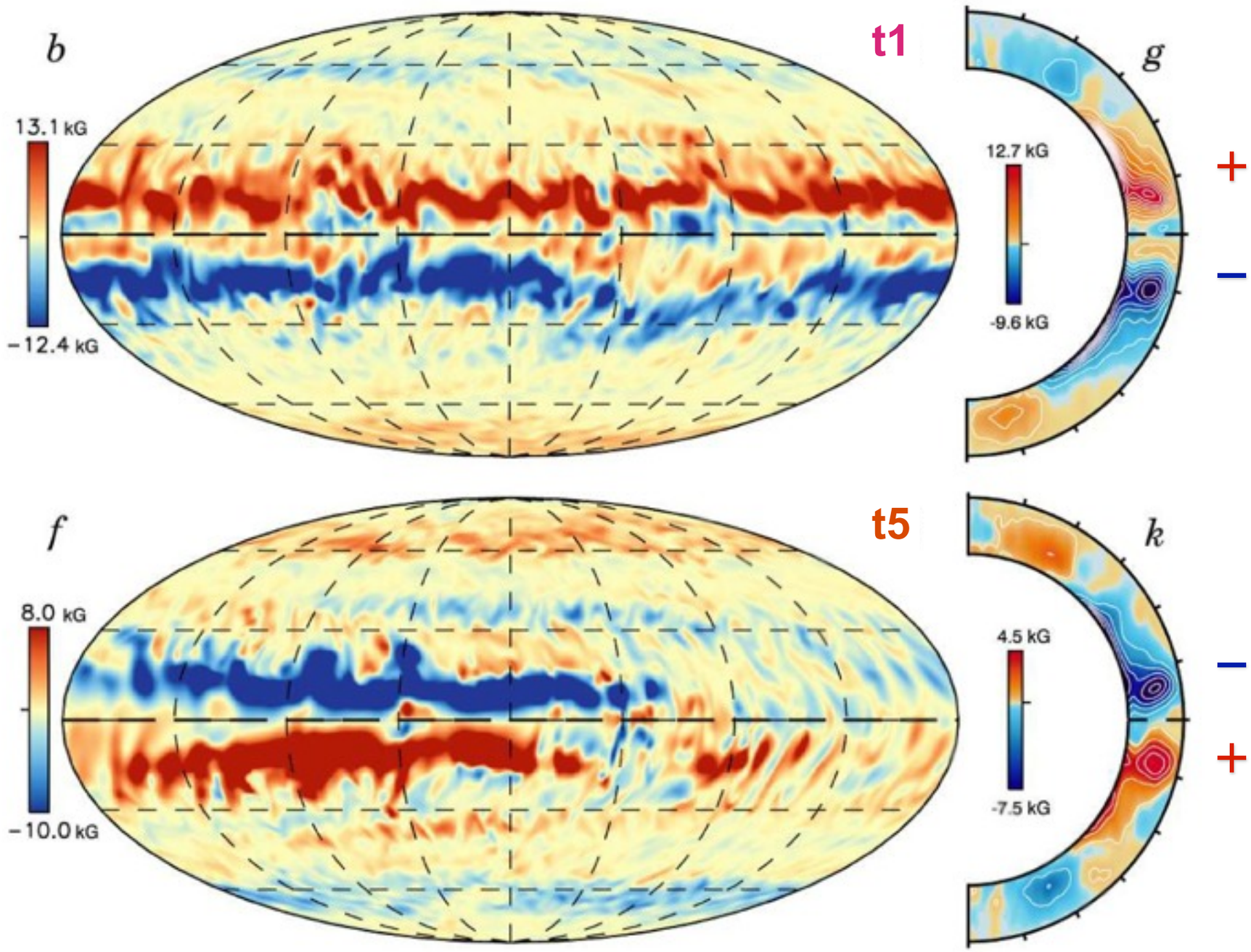
Torroidal field …

flips!

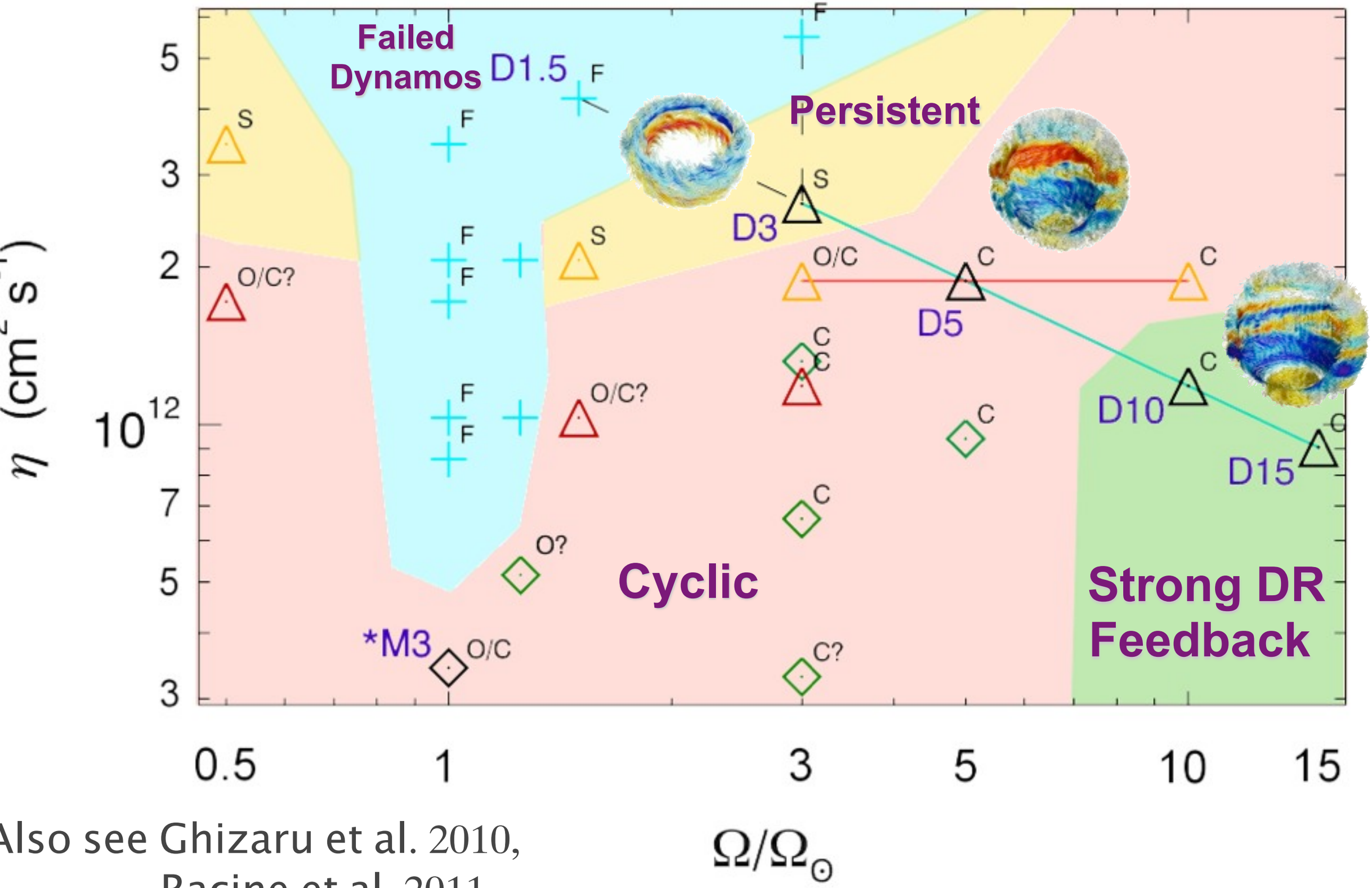
(shown here at mid-CZ)

(Brown et al. 2011)



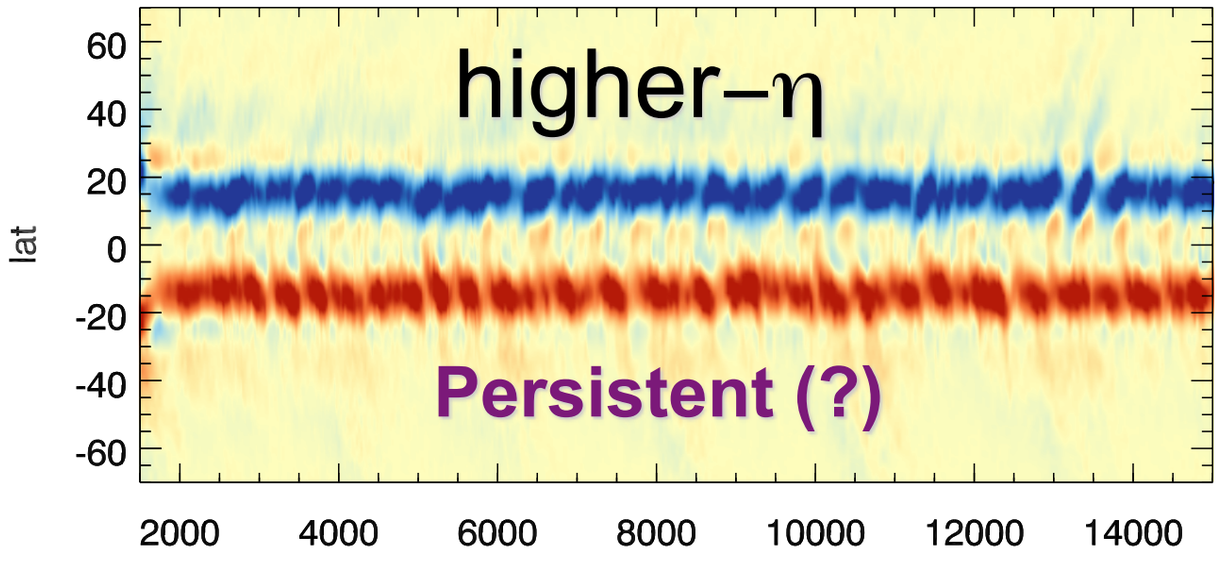


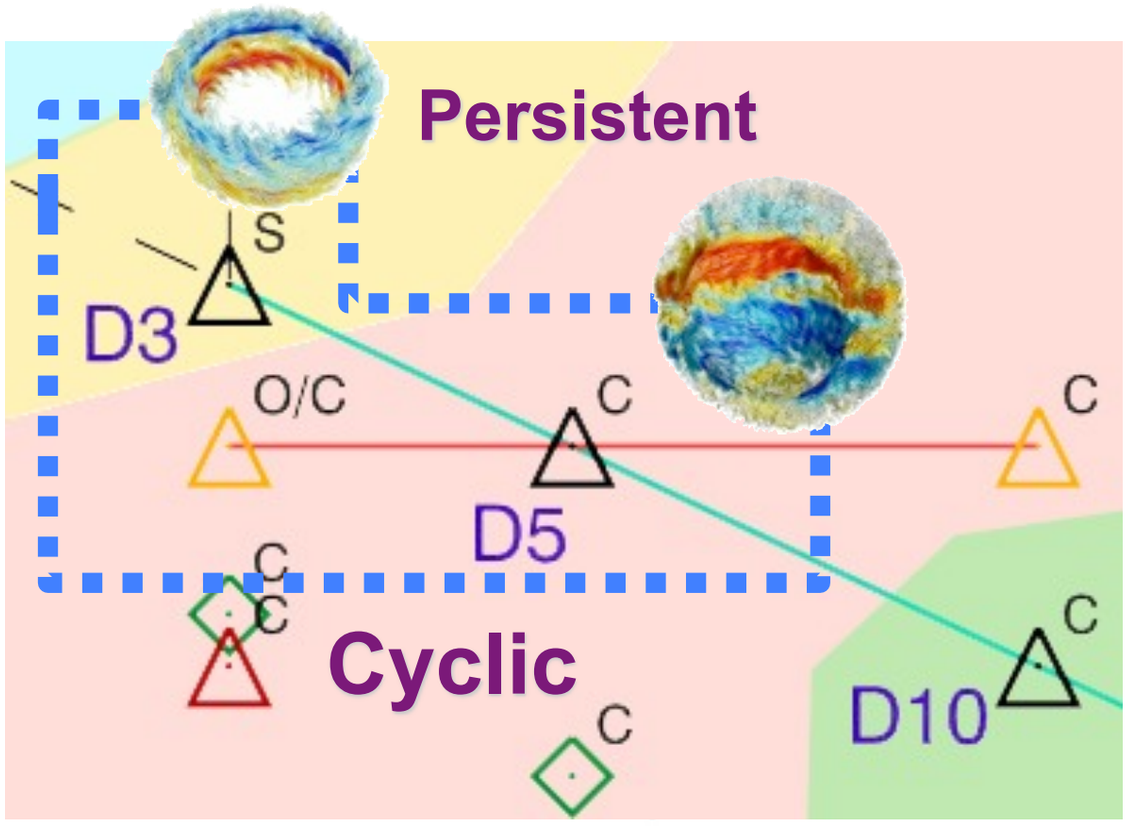
Cyclic Activity: Nearly Ubiquitous

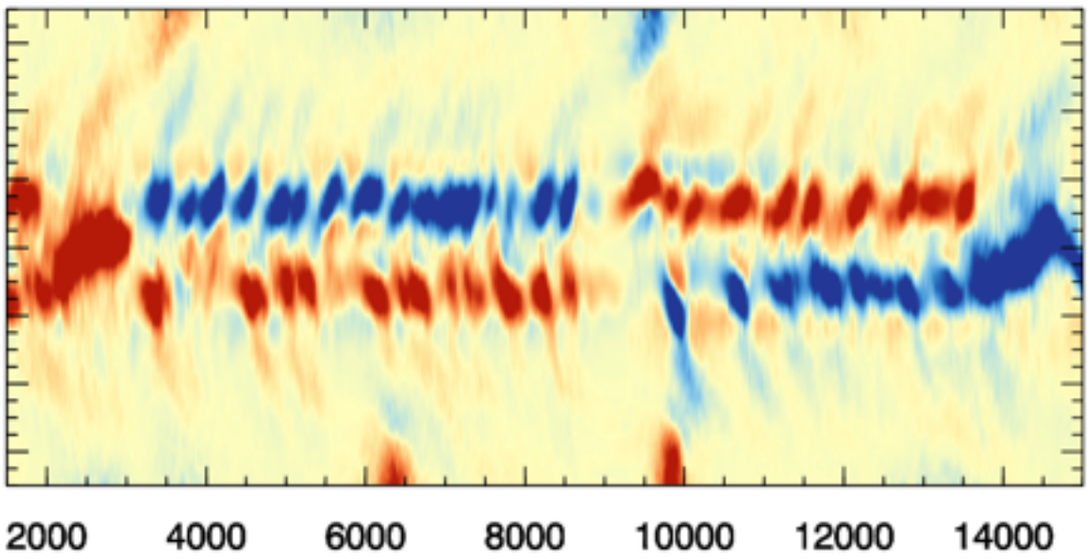


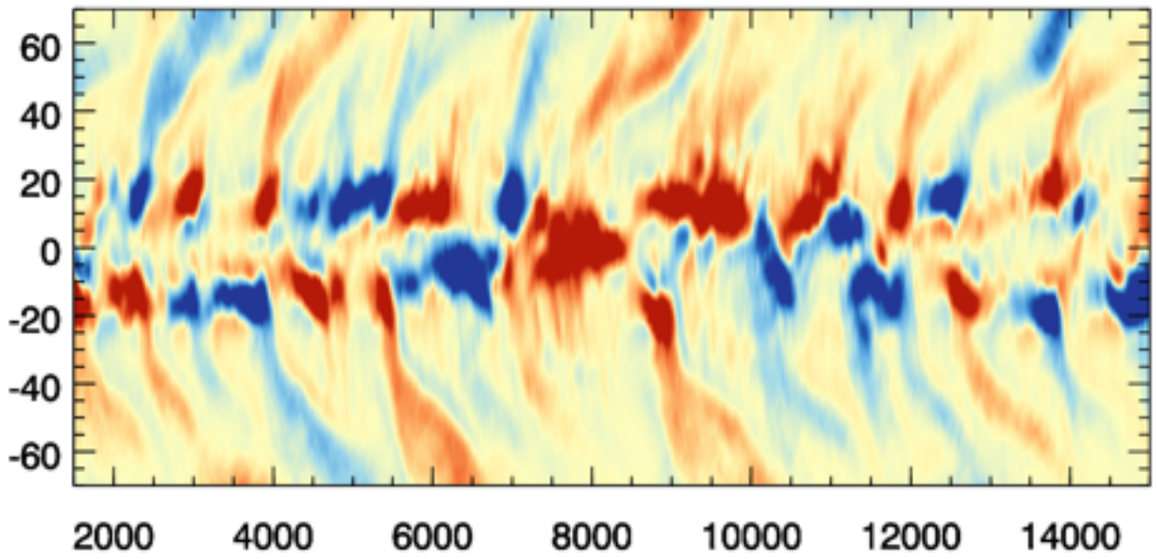
Also see Ghizaru et al. 2010, Racine et al. 2011

Rotation and Turbulence





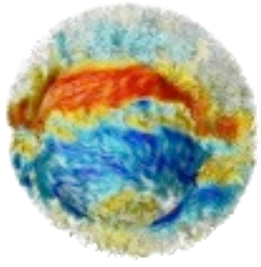




3 Ω

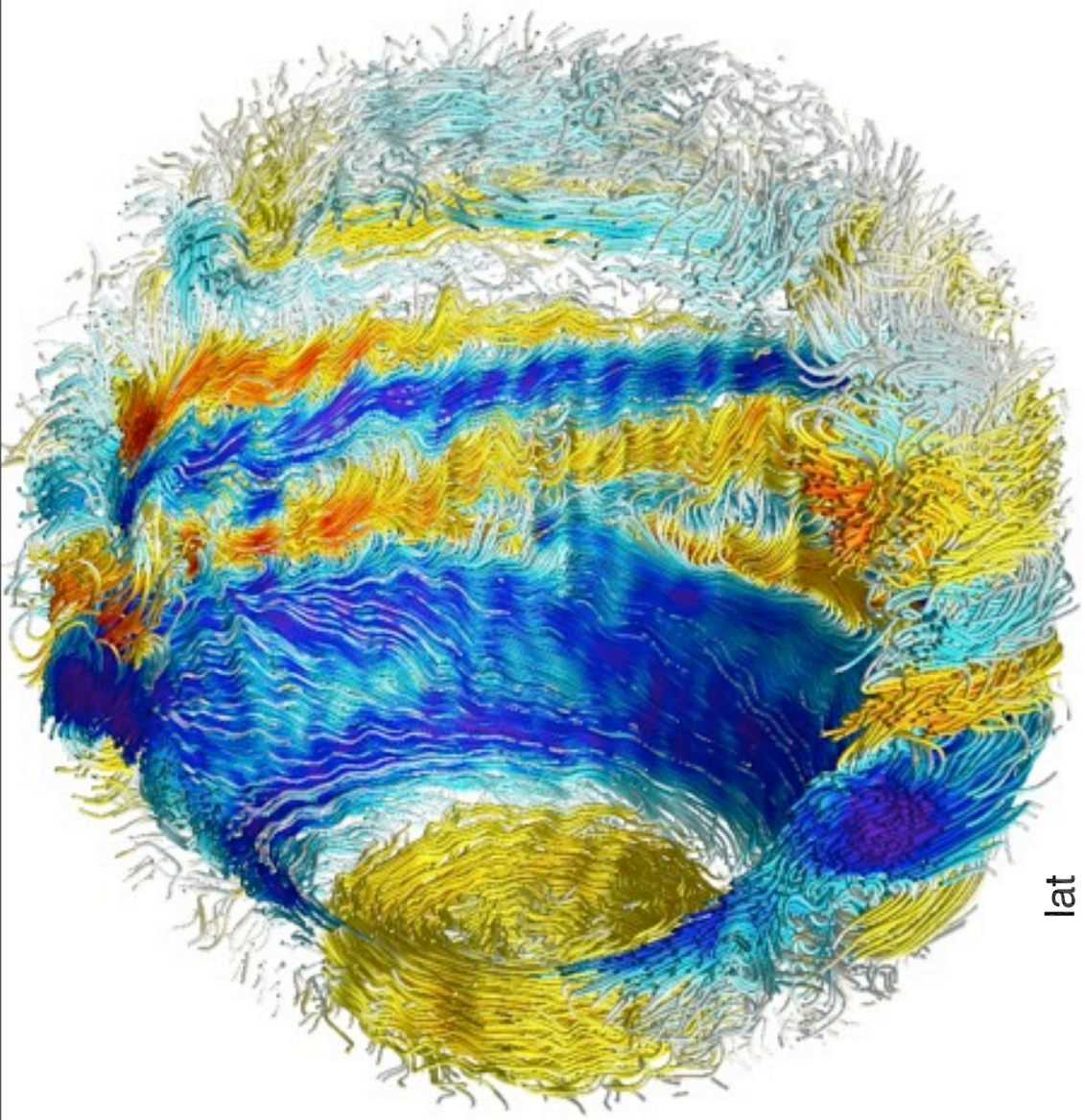
lower–η

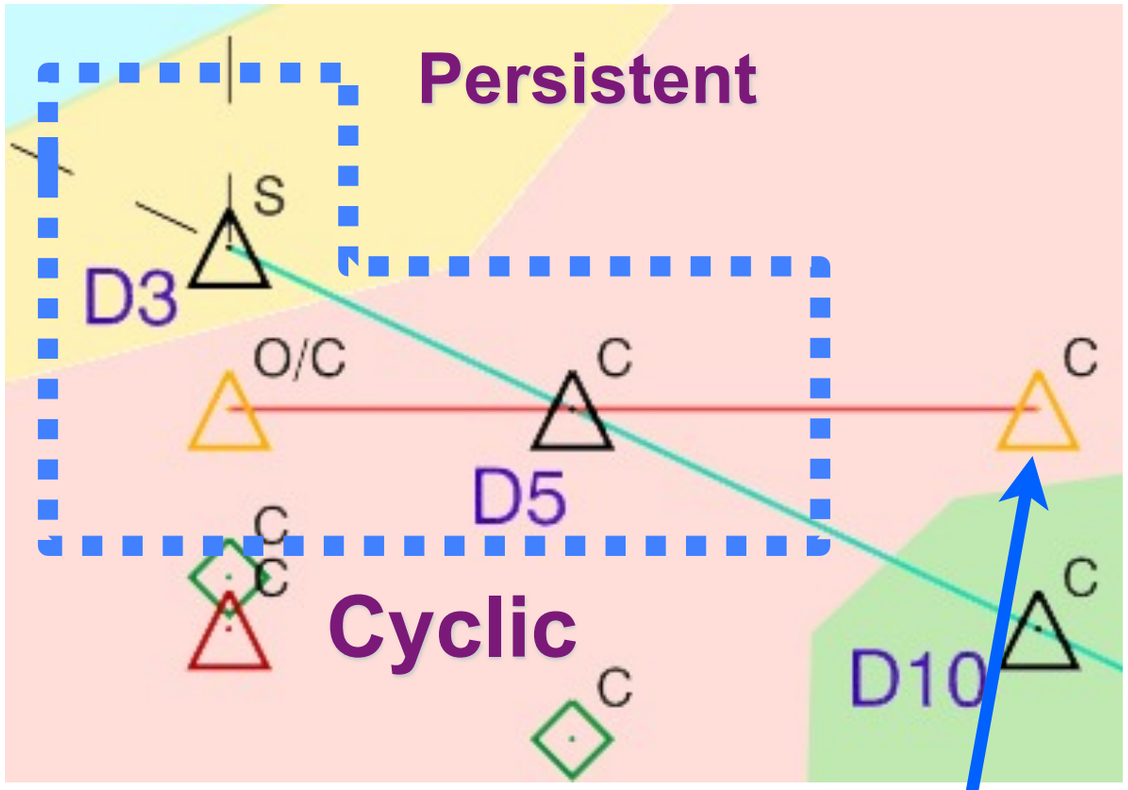
Cyclic

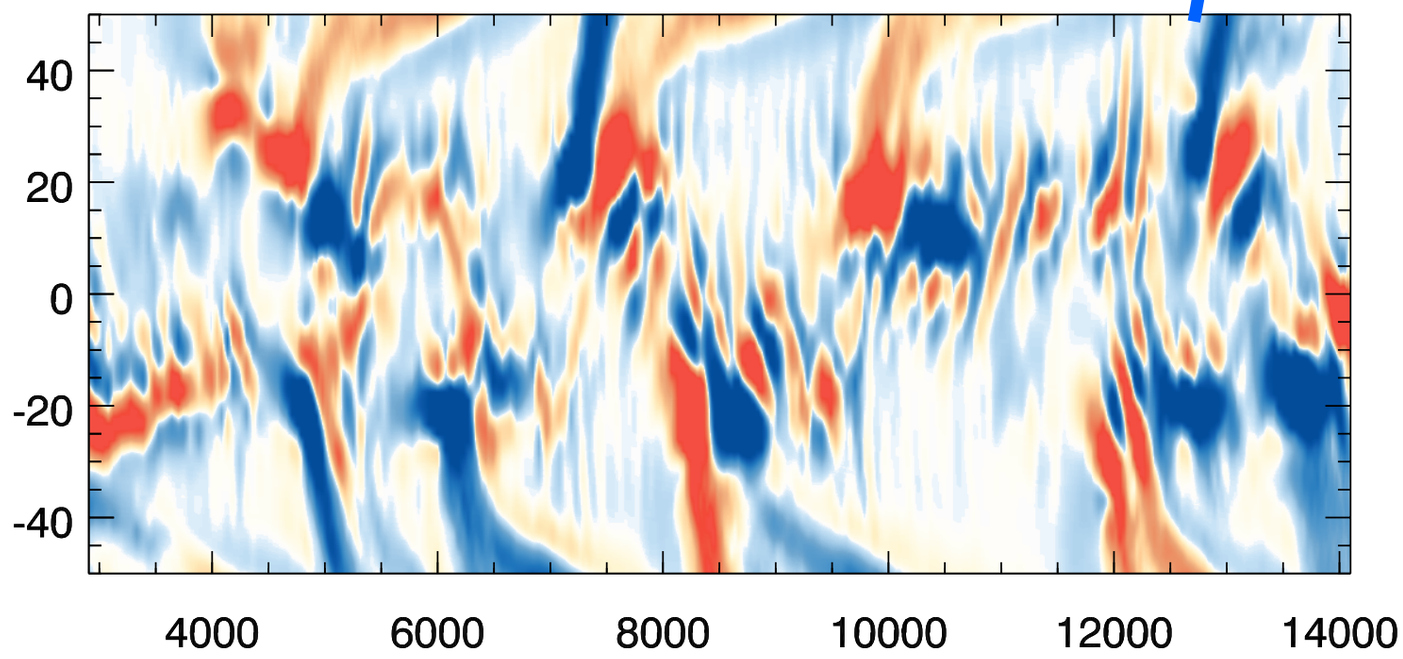


5 Ω

Rotation and Turbulence







Hemispheric dynamo

10 Ω