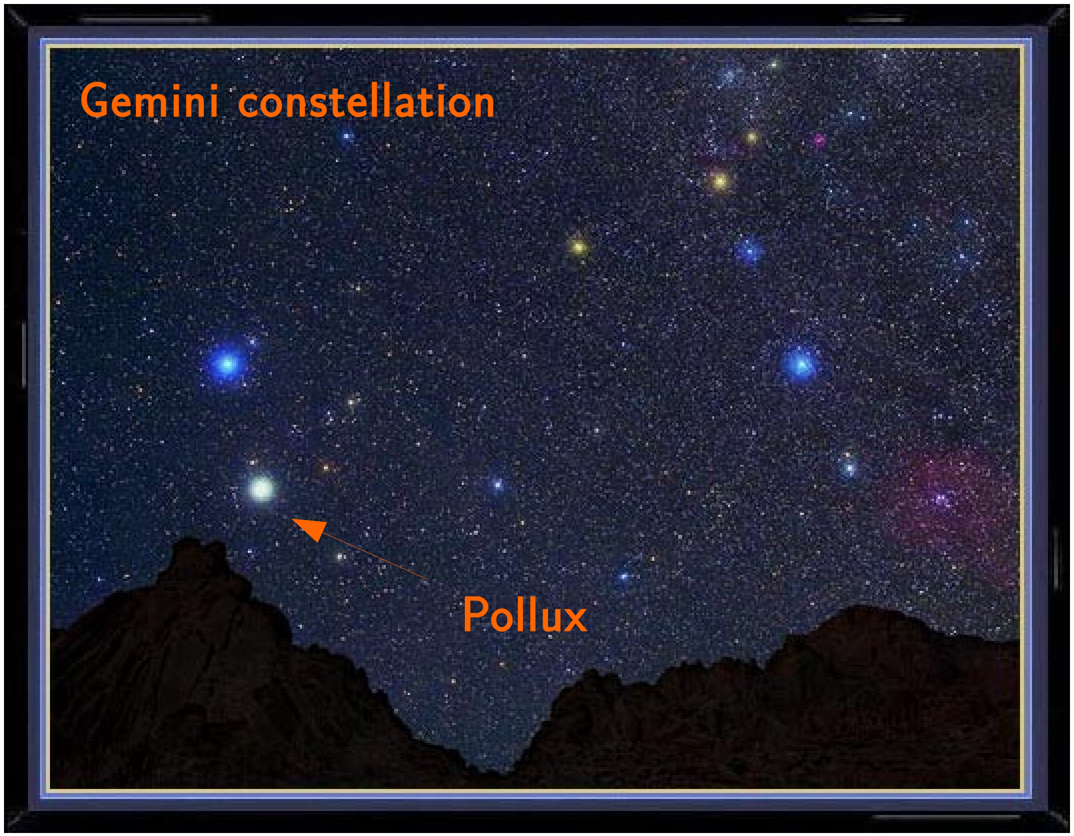
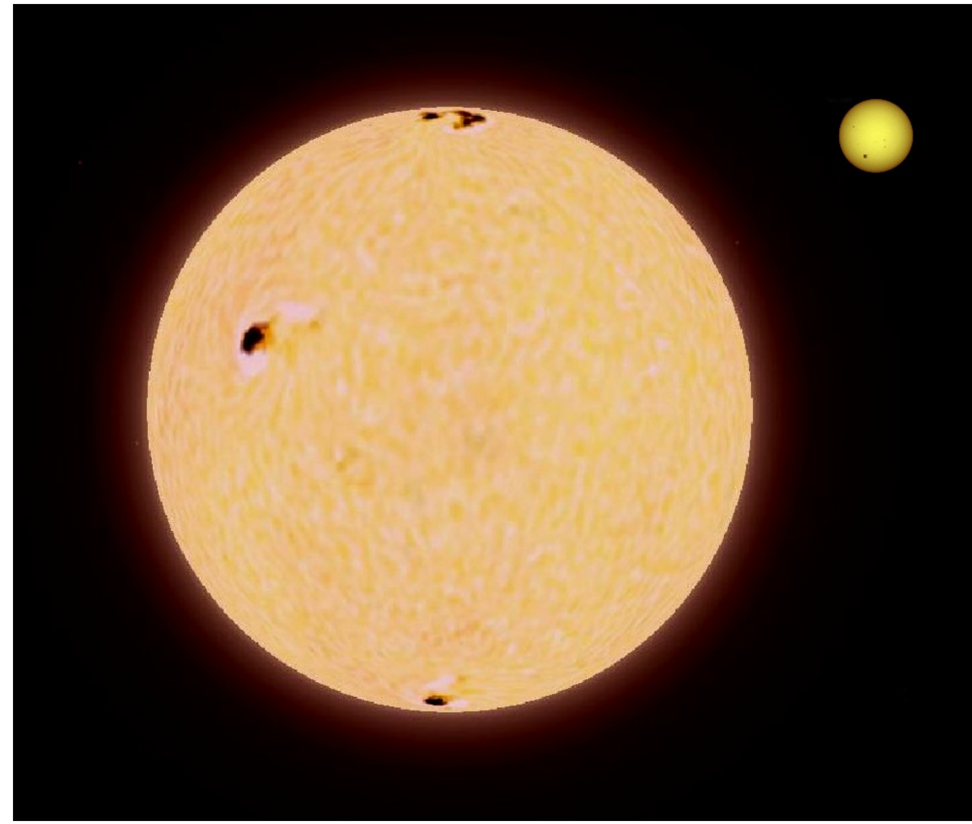
# Magnetism of red giants stars

# The case of the slow rotator, weakly magnetic giant POLLUX







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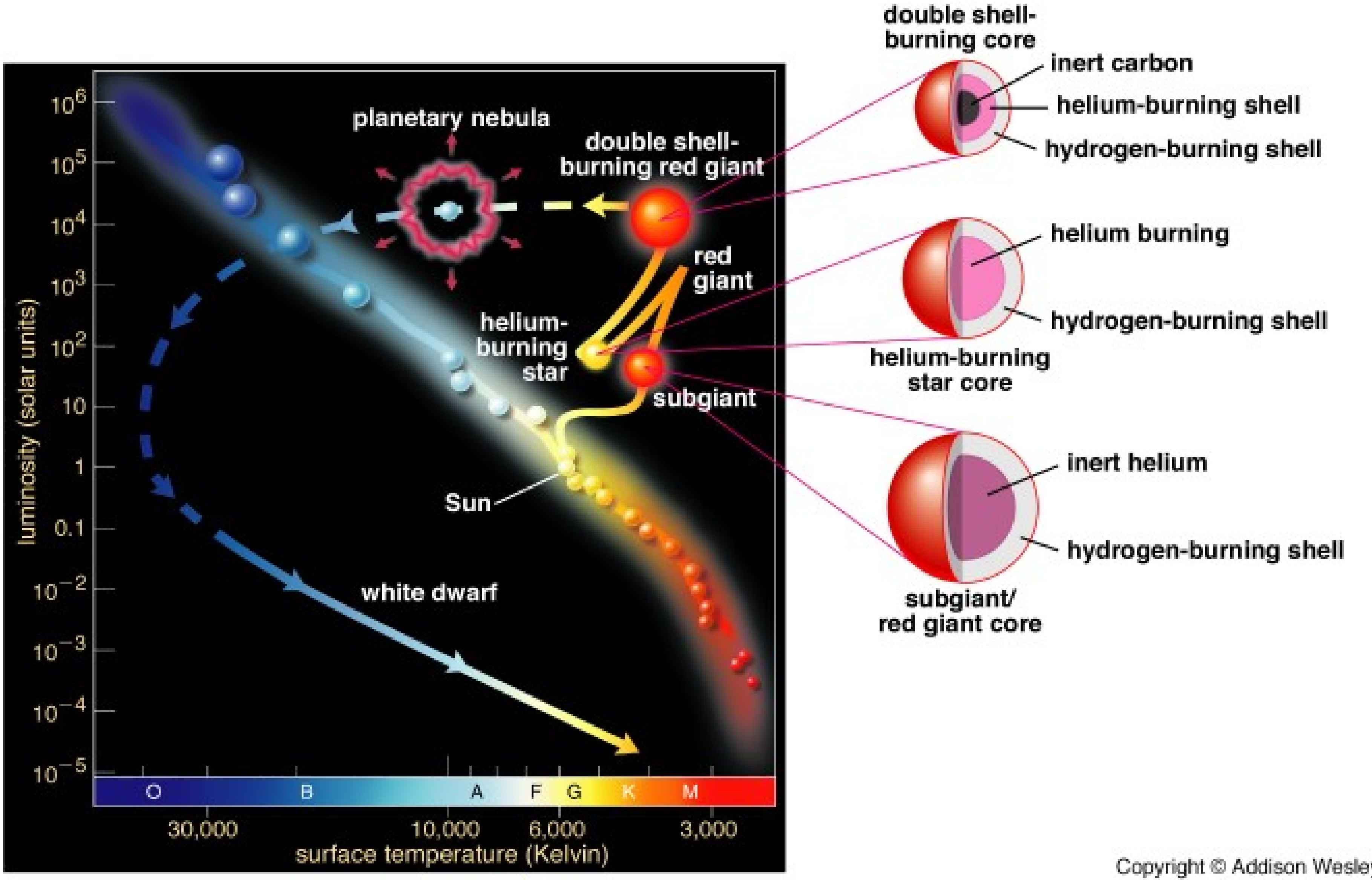
# Outline

- Some basics about red giants
- Magnetism of single giants (Aurière/Konstantinova-Antova group)
- The case of the weak-field giant Pollux
- 3D MHD simulations of the CE of Pollux
- Evolution of hydrodynamical quantities
- Evolution of magnetic field
- Impact of parameters : preliminary results

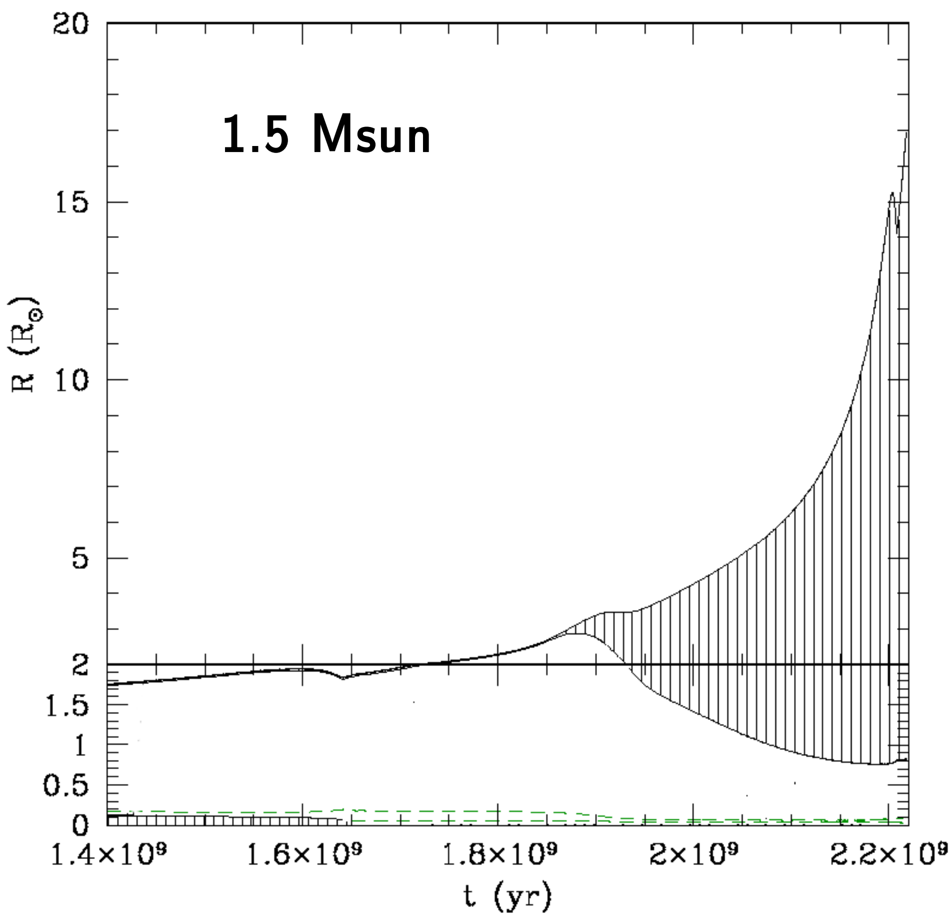
# Red giant branch stars

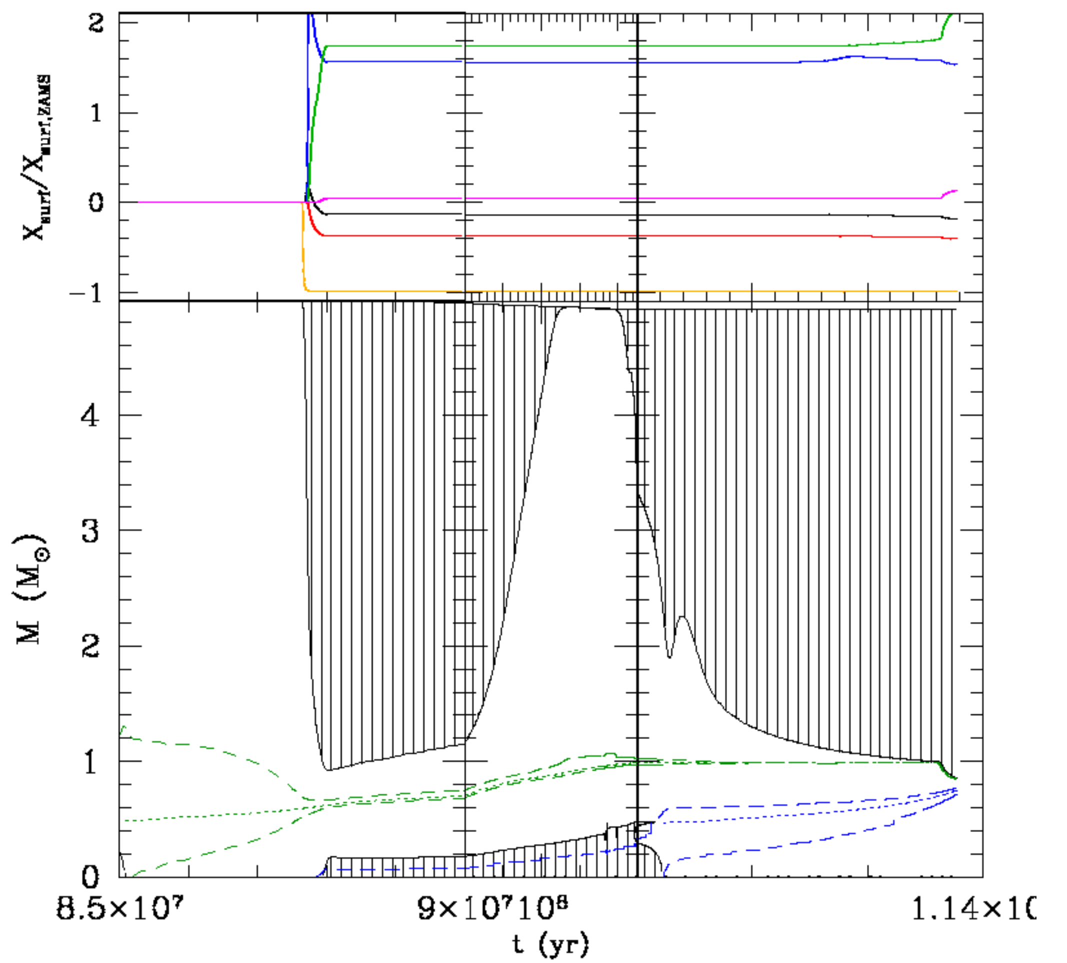
Changing structure along evolutionary path : good laboratories to study dynamo



# Internal structure of red giant stars

Very extended convective envelopes, low density, essentially slow rotation (challenged by asteroseismology

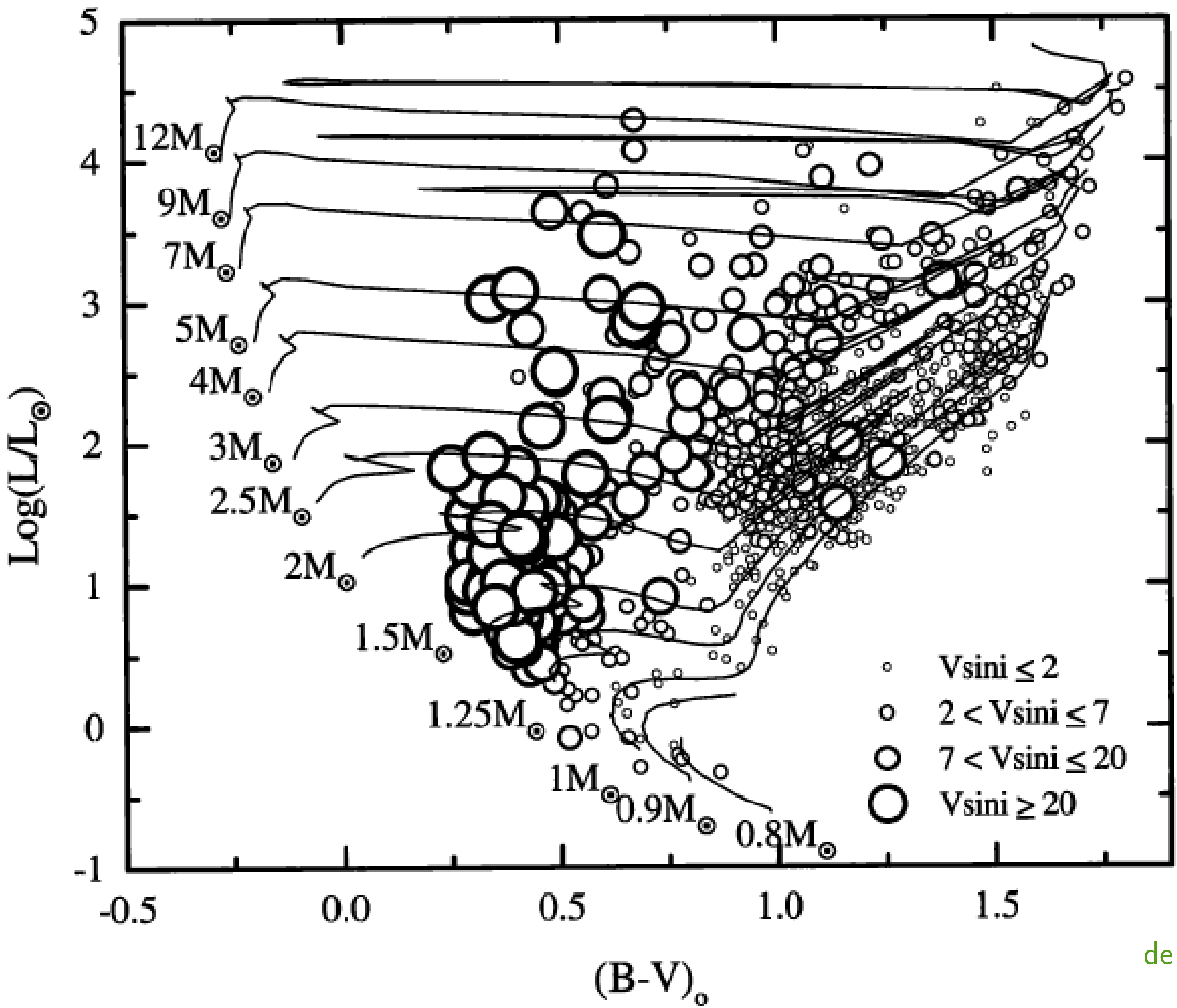



5 Msun

# Observed rotation for red giant stars from spectroscopy

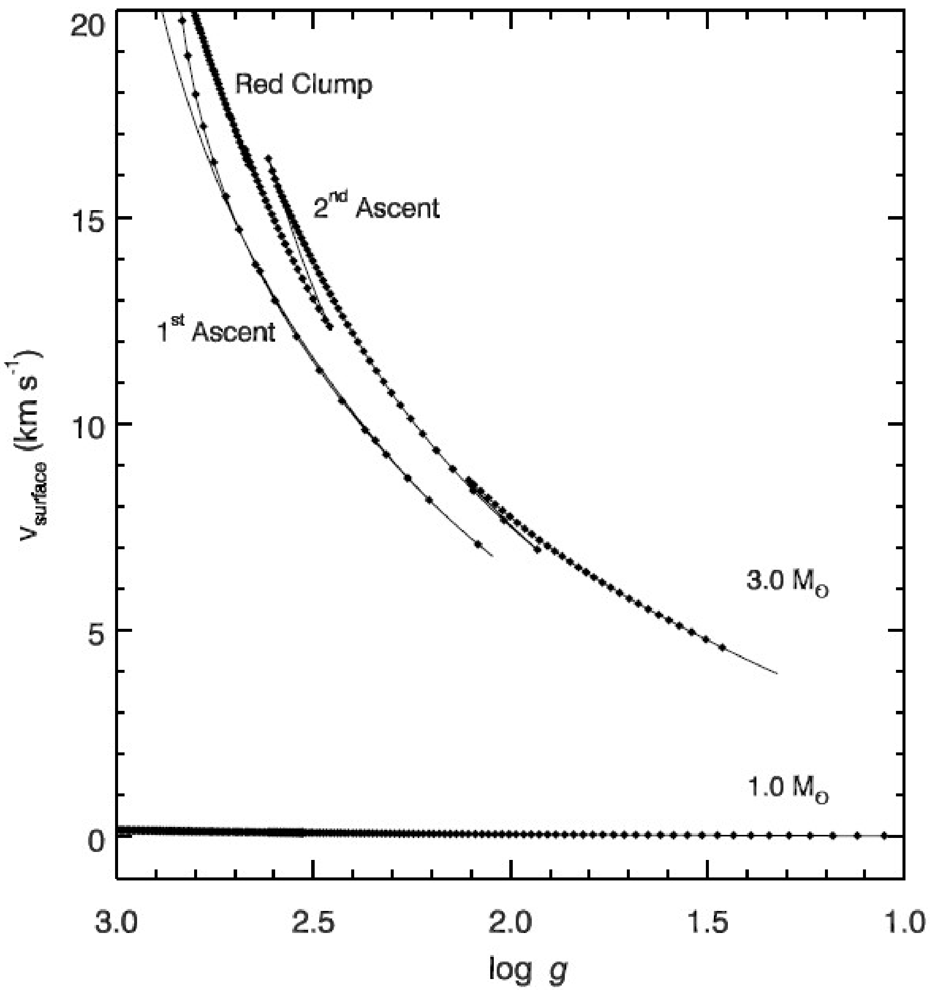
Essentially slow rotation on RGB/AGB with some exceptions

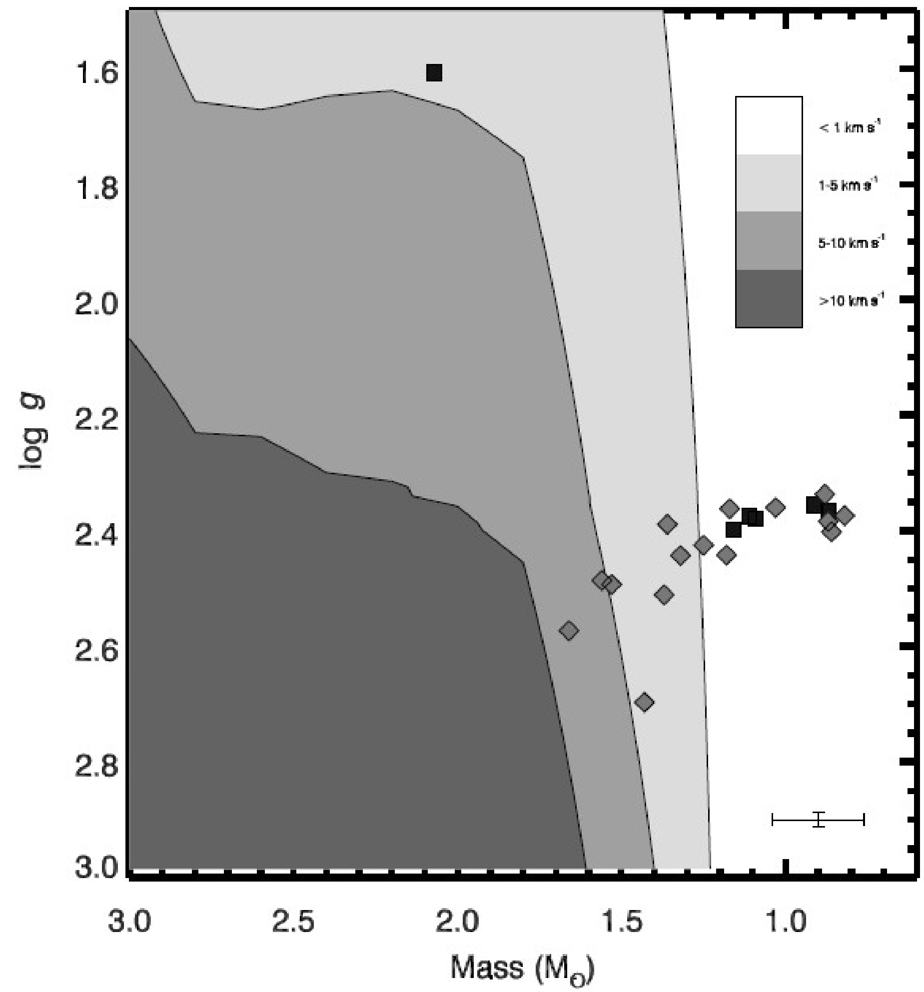



de Medeiros 2004, IAUS 215

# Predicted rotation of red giant stars

Surface velocity expected to decrease as the stars ascend the RGB (then AGB) with possible acceleration at clump due to overall contraction during CheB phase.



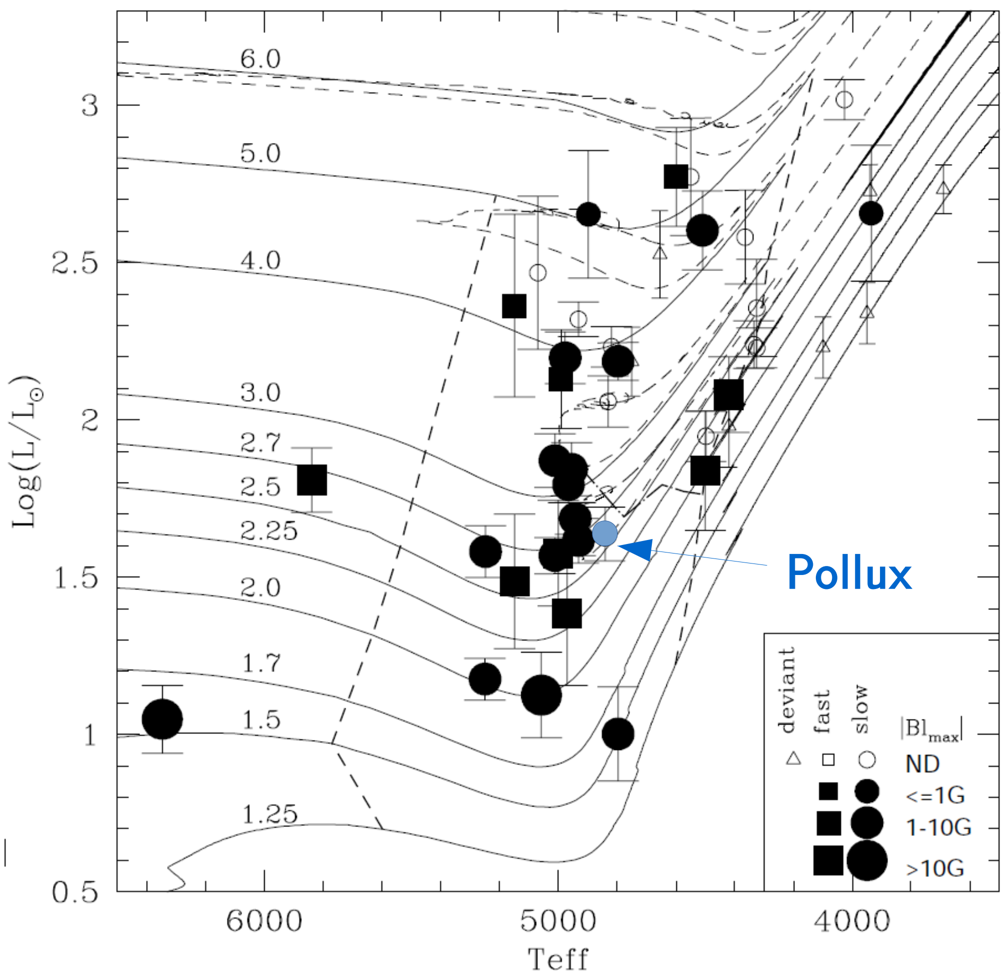




Tayar et al. 2015

# Magnetism of RGB stars

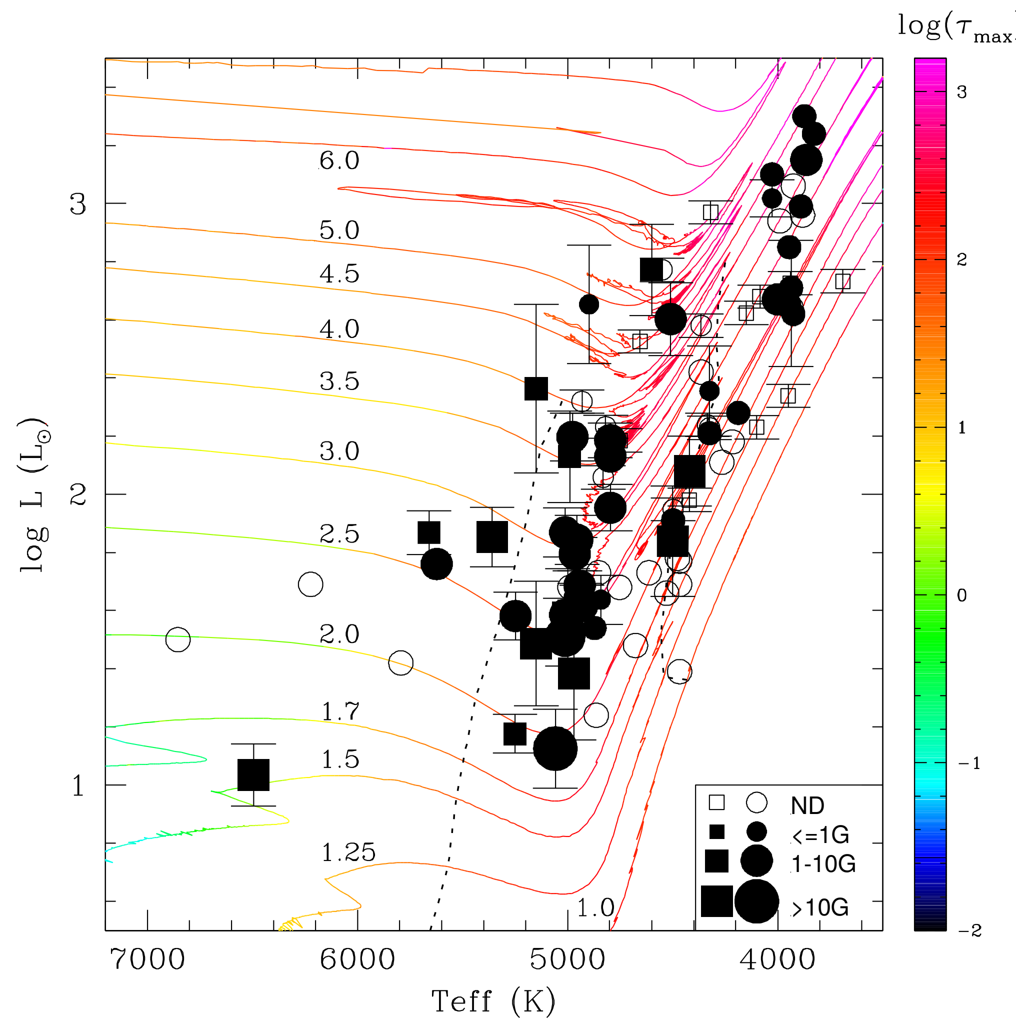
Two large spectropolarimetric surveys of single red giants in Stokes I and V by french-bulgarian team.

Selection of active and fast rotating red giants




Konstantinova-Antova, et al. 2012

all single G, K and M giants up to 4 mag in the Solar vicinity observable from Pic du Midi

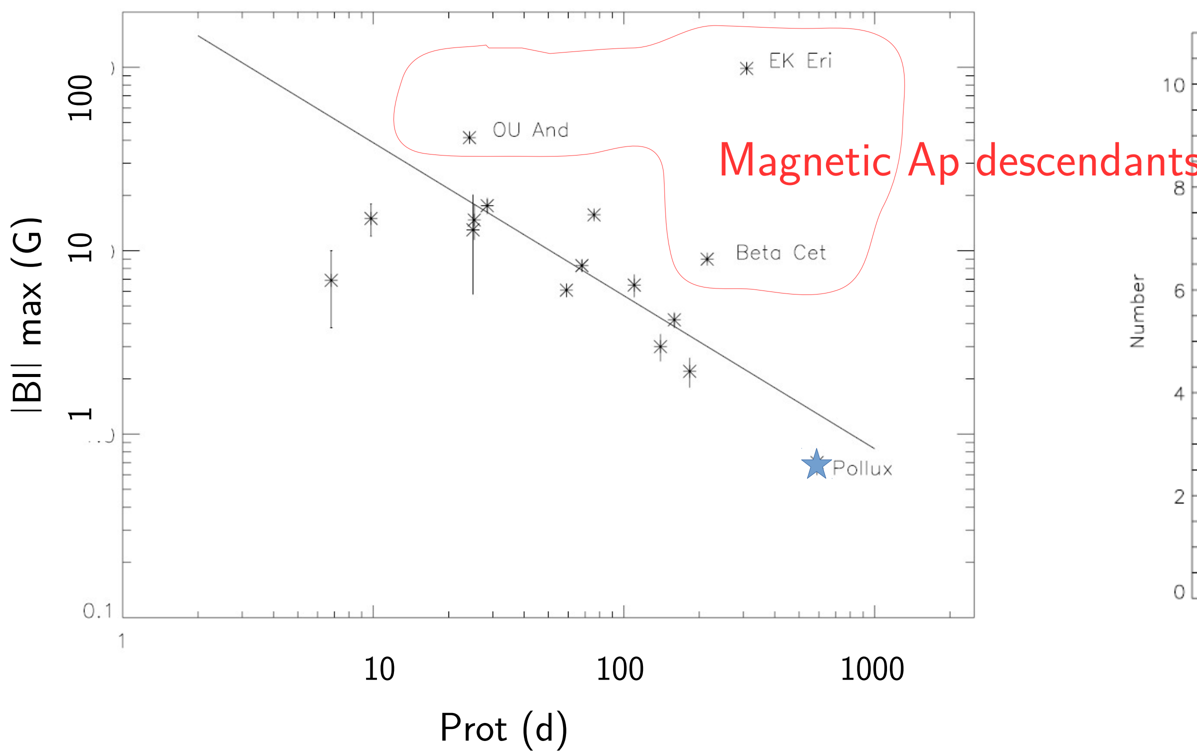


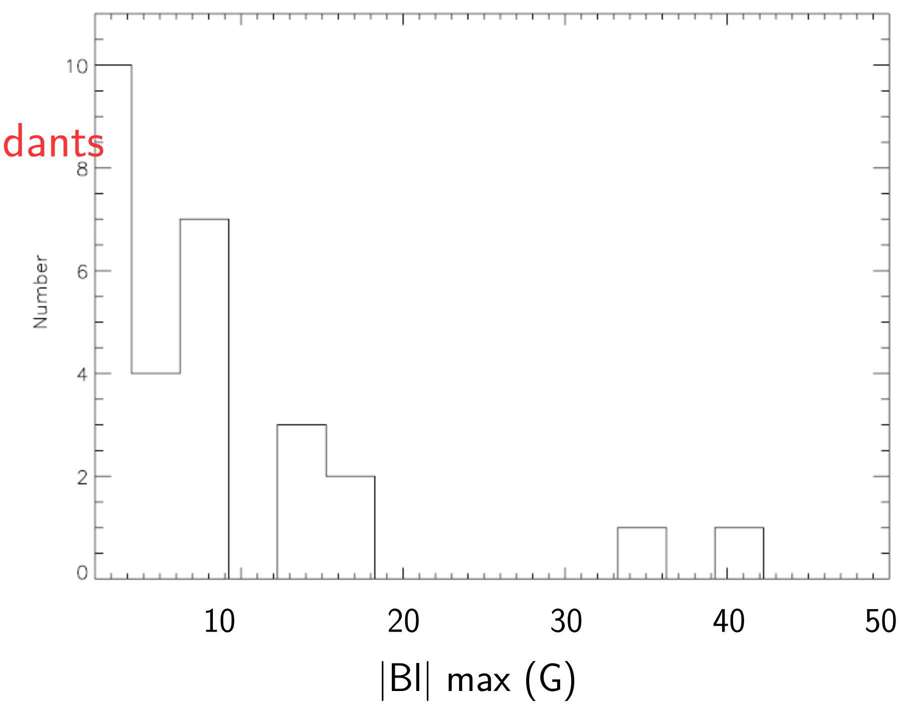

Aurière et al. 2015

# Magnetism of RGB stars – Main results from Aurière+ 2015

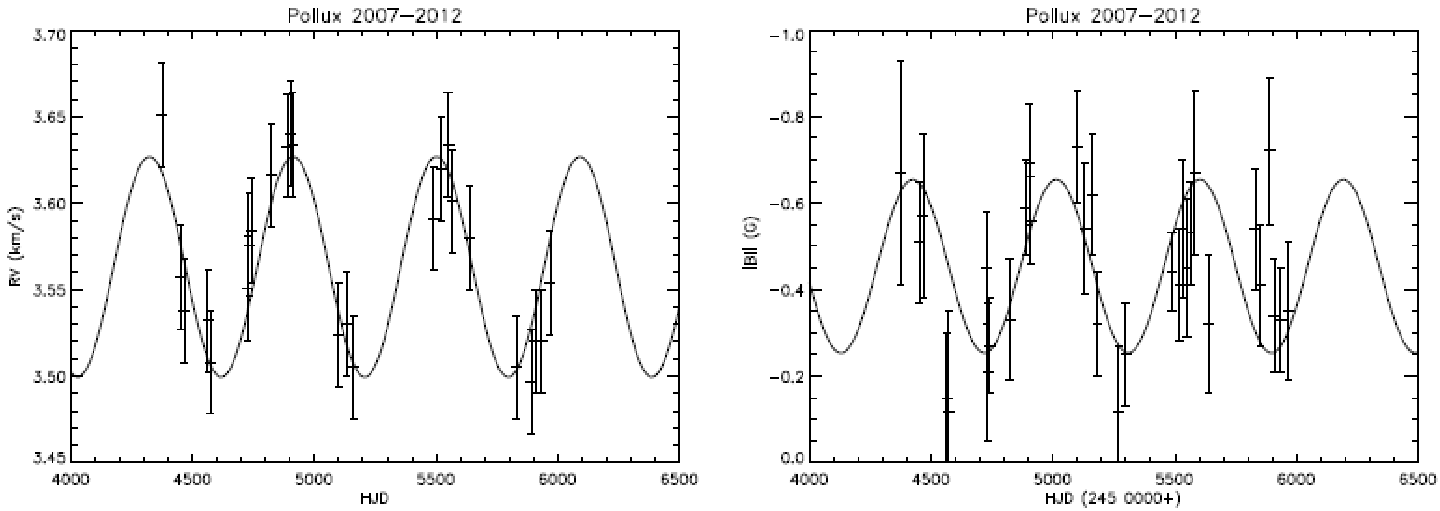
- 29 of the 48 giants in the unbiased sample Zeeman detected in Stokes V
- 23 out of 24 active giants Zeeman detected

- Most of detected giants in magnetic strips where convective turnover timescale is maximum
- The longer the rotation period the smaller the large scale longitudinal field



# The case of the weak-field magnetic giant Pollux




Aurière et al. 2014, IAUS Conf. Proc. 302

**Figure 1.** Variations of RV (left plot) and of $B_l$ (right plot) with HJD (245 0000+) in 2007-2012. A sinusoid with P= 589.64 d is fitted for each parameter.

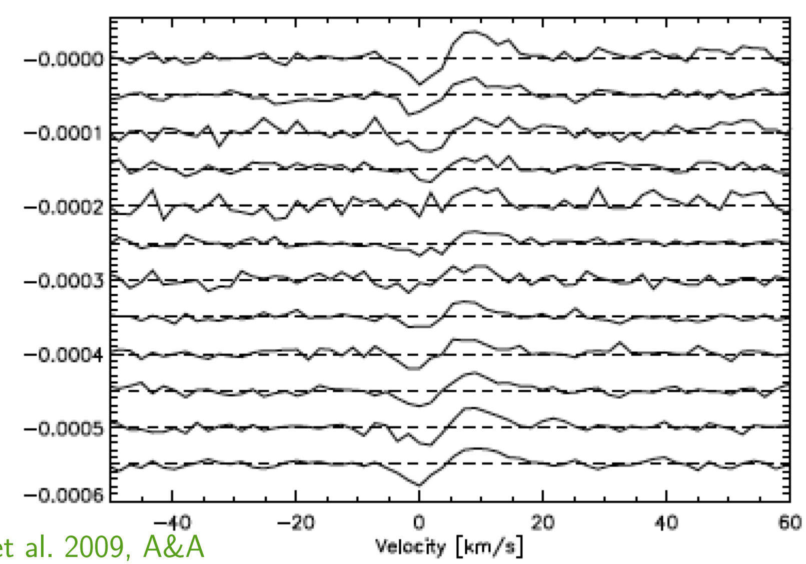
**Table 2.** Magnetic strength of red giants with available magnetic field models from ZDI.

Aurière et al. 2015, A&A

| HD | Name | $v \sin i$ km s$^{-1}$ | $P_{rot}$ day | $\|B_l\|_{max}$ G | $B_{mean}$ G | Ref. |
|---|---|---|---|---|---|---|
| 11812 | 31 Com | 67 | 6.8 | 9.9 | 32 | (1) |
| 33798 | V390 Aur | 29 | 9.8 | 13 | 26 | (2) |
| 223460 | OU And | 21.5 | 24.2 | 36 | 68 | (1) |
| 112989 | 37 Com | 11 | 111 | 6.5 | 10.8 | (3) |
| 9746 | OP And | 8.7 | 76 | 16 | 15 | (4) |
| 4128 | $\beta$ Cet | 5.8 | 215 | 8 | 10 | (5) |
| 27536 | EK Eri | 1 | 308.8 | 99 | 94 | (6) |
| 62509 | Pollux | 2.8 | 590 | 0.7 | 0.6 | (7) |

**Notes.** References for $B_{mean}$: (1) Borisova et al. (in prep.); (2) Konstantinova-Antova et al. (2012); (3) Tsvetkova et al. (in prep.); (4) Konstantinova-Antova (in prep.); (5) Tsvetkova et al. (2013); (6) Aurière et al. (2011); (7) Aurière et al. (2014 and in prep.).

Very weak longitudinal field revealed by spectropolarimetry and long rotation period. ZDI reconstruction favours a strong dipole.



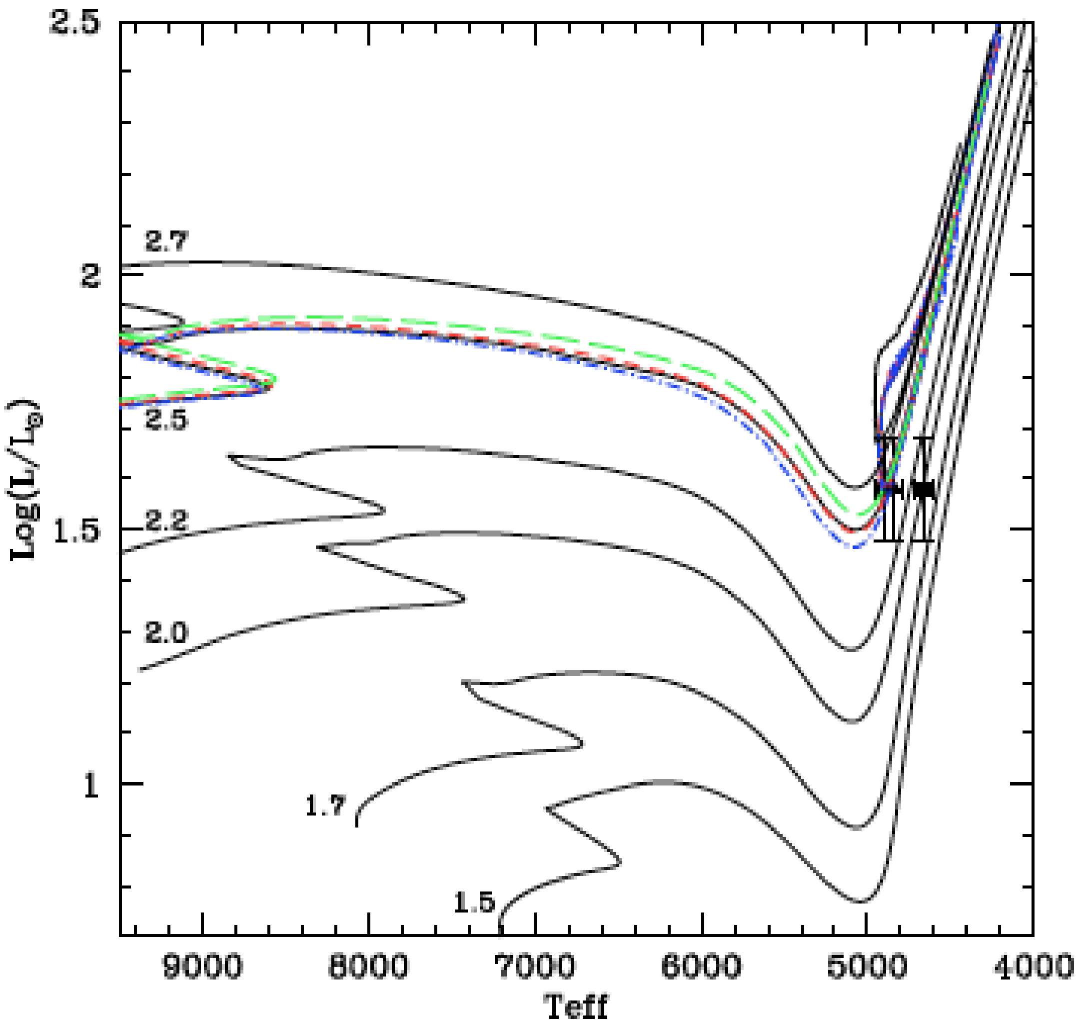

Aurière et al. 2009, A&A

# Pollux – β Geminorum

RGB star K0III @ 10.3 pc of the Sun

$M_* = 2.5\ M_{sol}$   $L_* = 40\ L_{sol}$   $R_* = 9\ R_{sol}$

**Progenitor: 2.5 $M_{sol}$ A2V star**



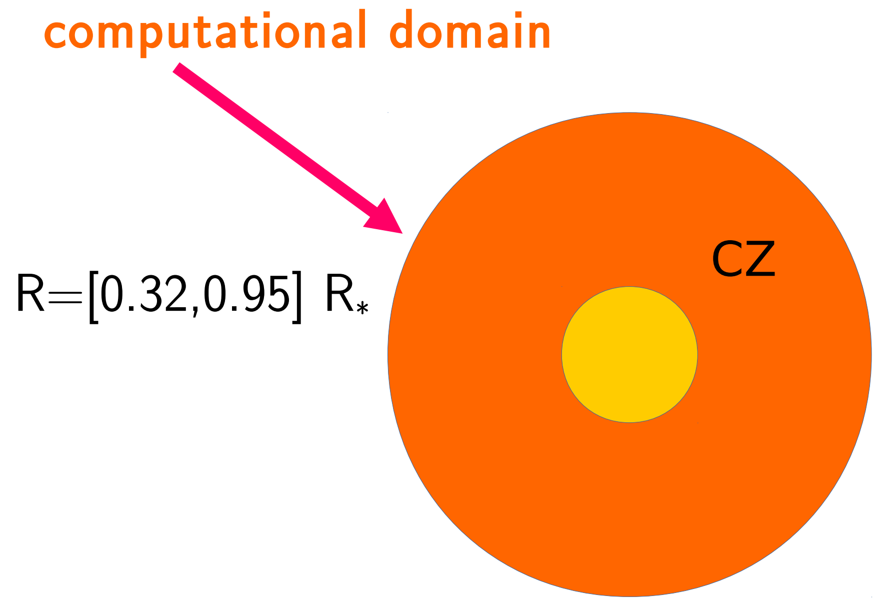

Aurière et al. 2009

# ASH simulations

3D MHD simulations in the anelastic approximation using the ASH (Anelastic Spherical Harmonics) code *(Clune et al. 1999, Brun et al. 2004, Featherstone et al. 2013)*

MHD runs based on converged hydrodynamical runs in which a magnetic multipole seed is included

- L ≈ constant in model
- $\rho \sim [0.02;\ 10^{-5}]$ g/cm$^3$ or 7.4 $N\rho$
- $\Omega = \Omega_\odot/20 = 1.23\ 10^{-7}$ rad s$^{-1}$
  or $P_{rot} = 590$ days
- Resolution : $N_r x N_\theta x N_\varphi = 513x512x1024$




Rigid stress free boundaries, Fixed Flux
Perfect conductor (bottom) &
potential field (top)

Prandtl number $\frac{\kappa}{\nu} = 1/8$

Magnetic Prandtl number $\frac{\nu}{\eta} = 2$

Case A : initial high degree multipole $l = 10$, $m = 7$ , $Re = 238$ , $Ro = 2.35$

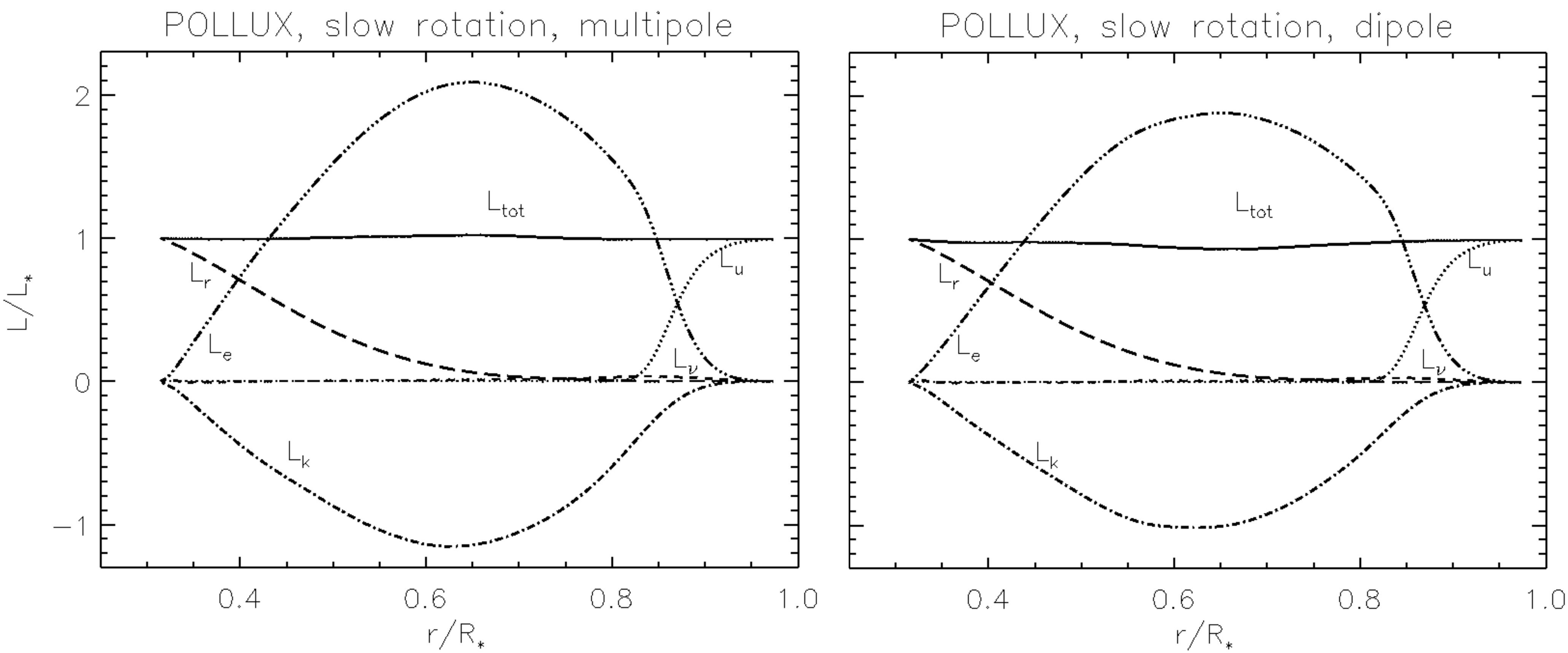
Case B : initial dipole $l = 1$, $m = 0$

# Energy budget

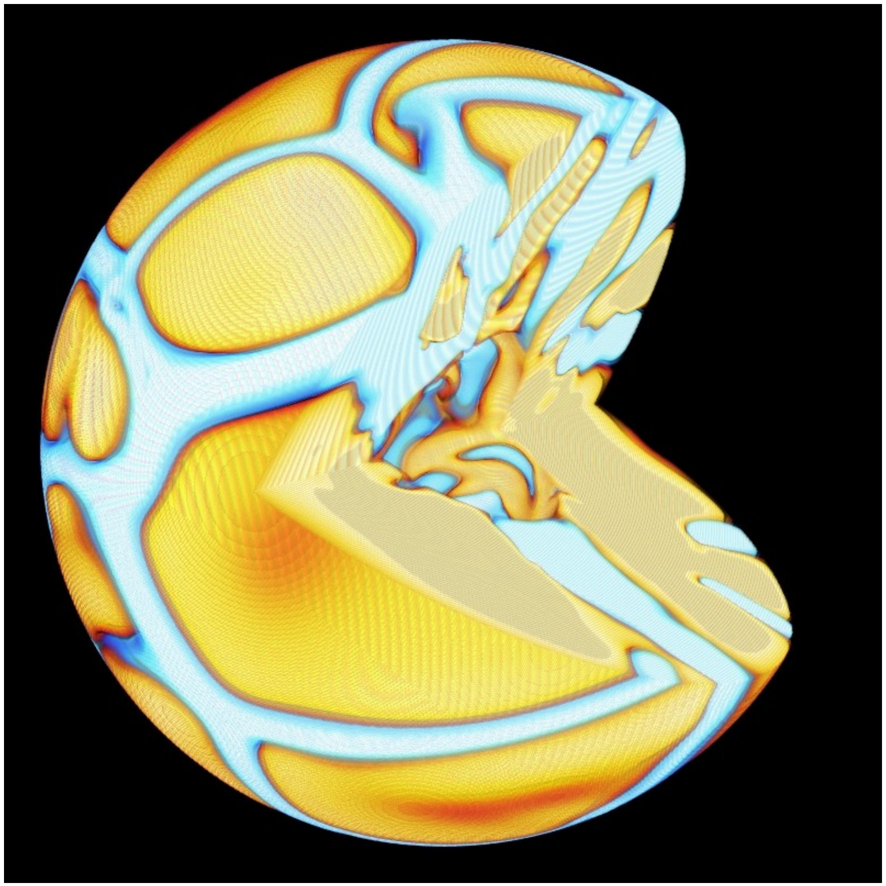
Convective luminosity $> L_*$ to compensate the negative kinetic luminosity

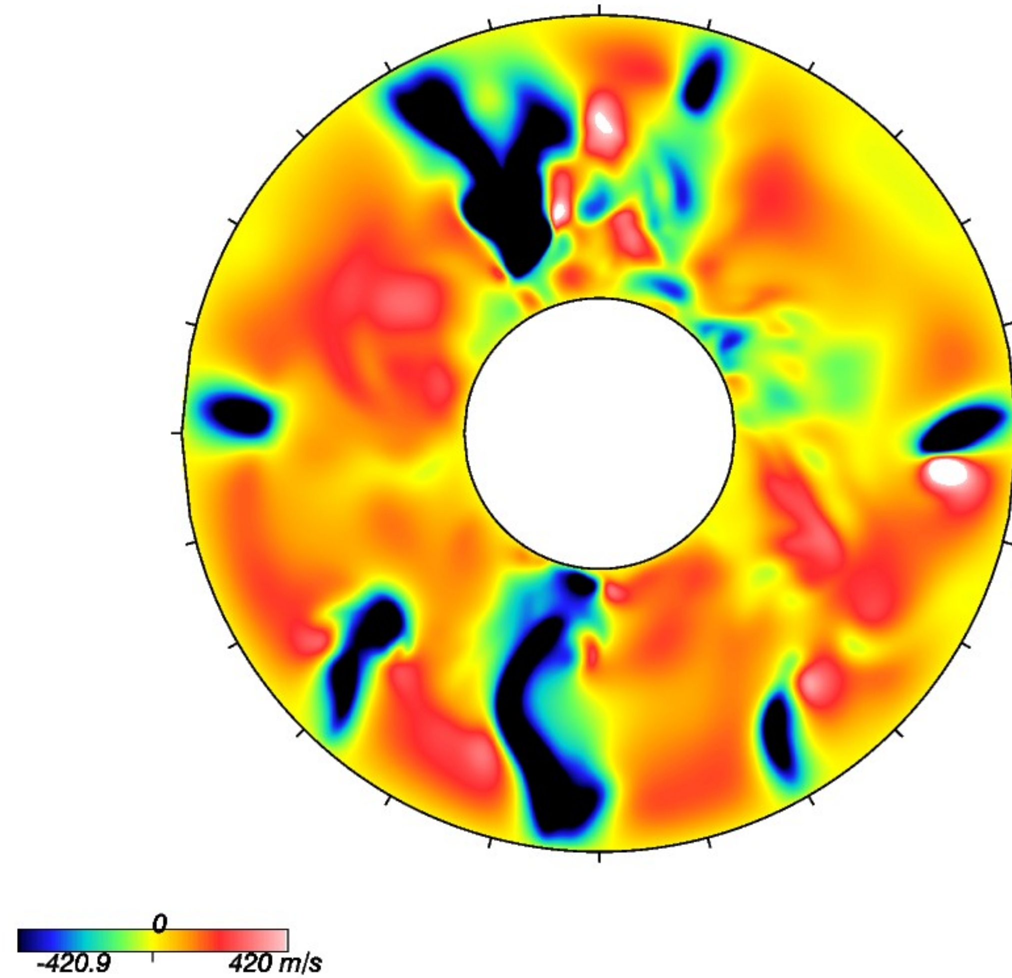
$\rightarrow$ differs from MLT predictions

Negative kinetic energy represents up to 100% of the flux in the inner part of the domain



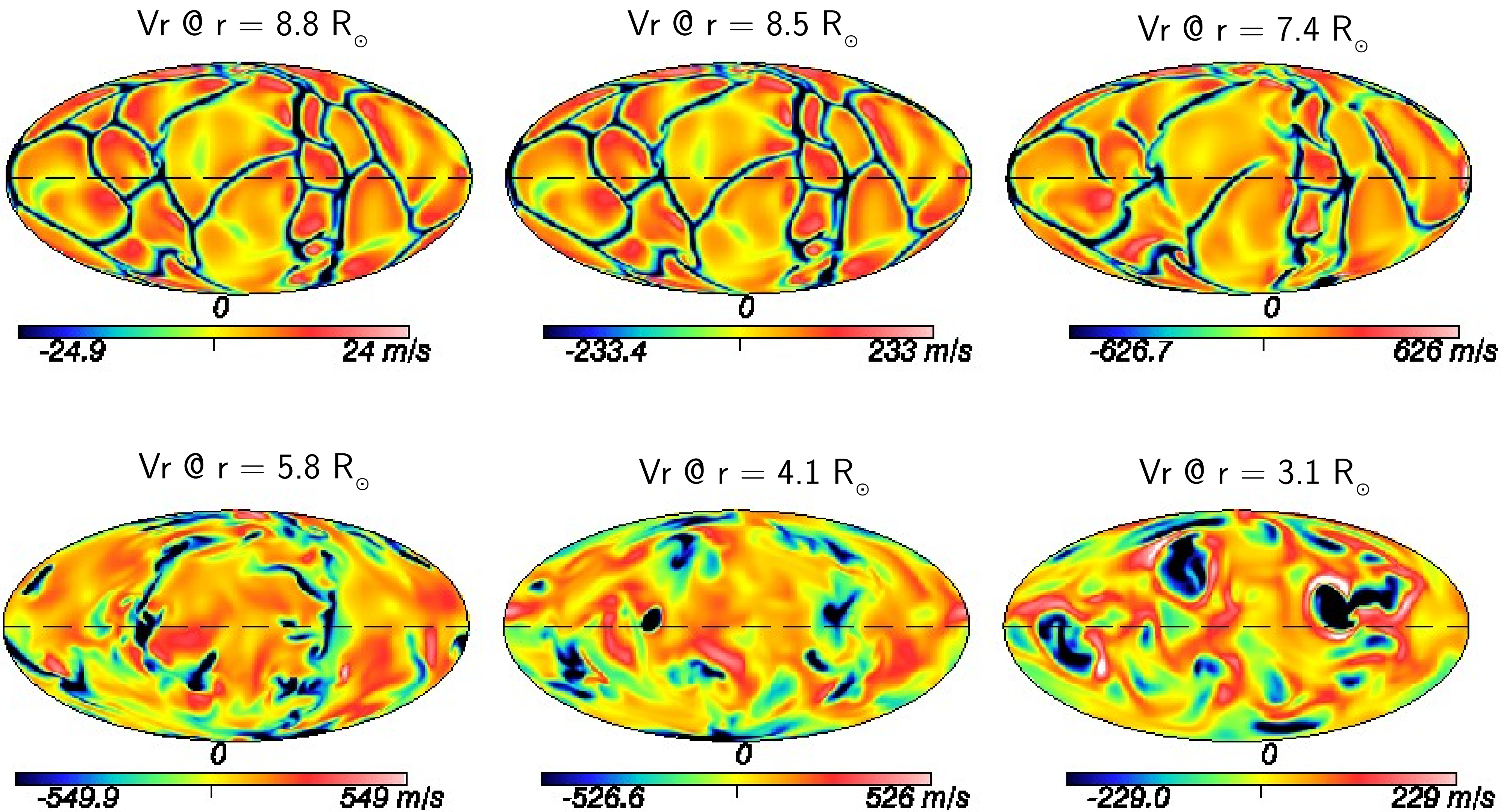
# Convective motions





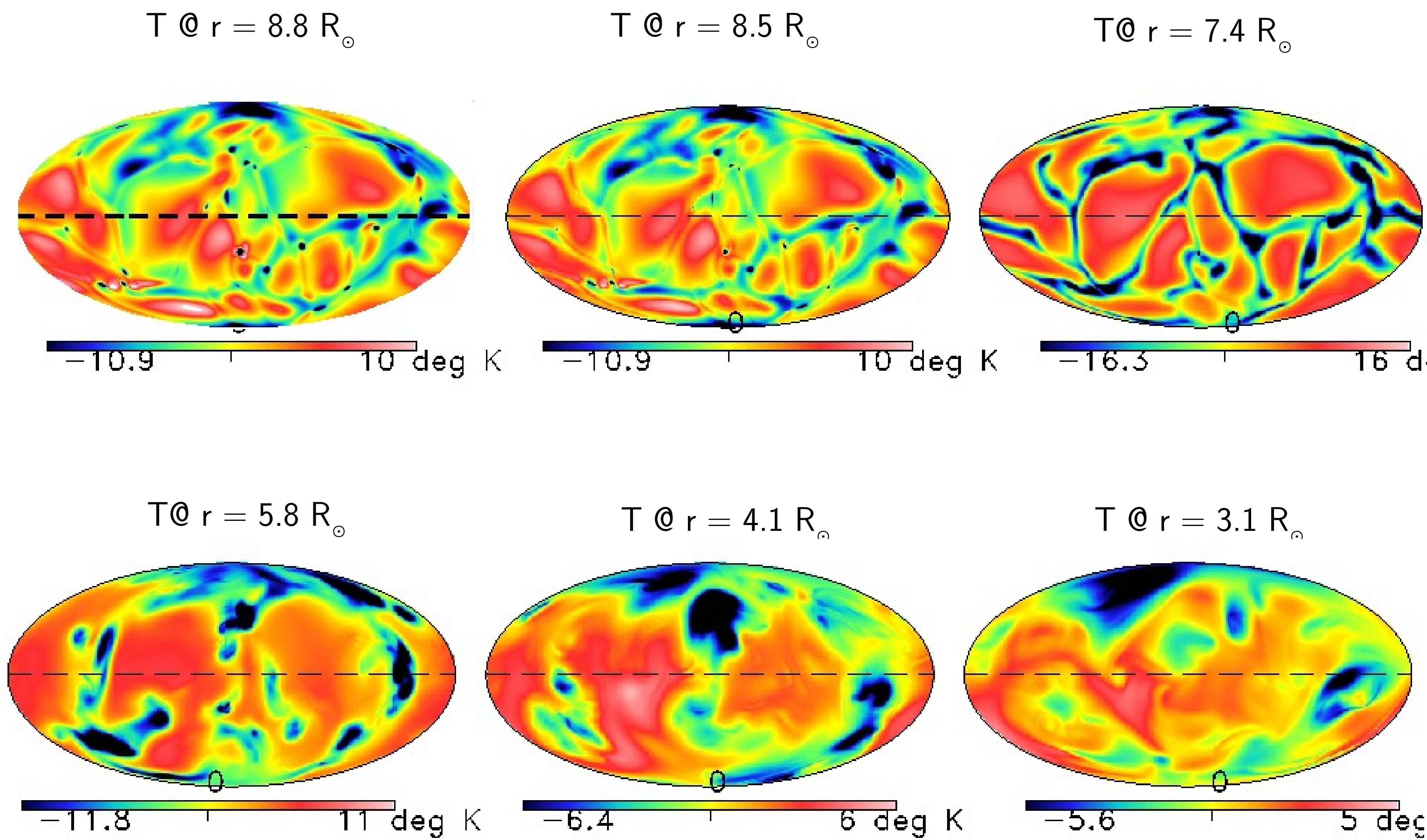

Vr

# Convective motions – Radial velocity fluctuations




Case A – Similar pattern and values for case B

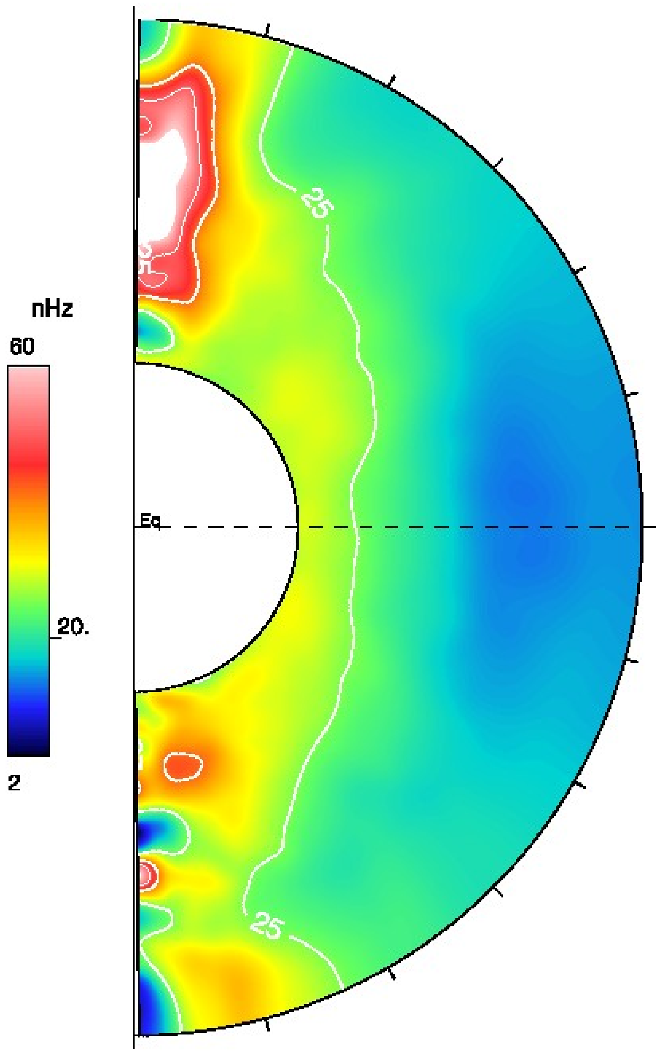
# Convective motions – Temperature fluctuations

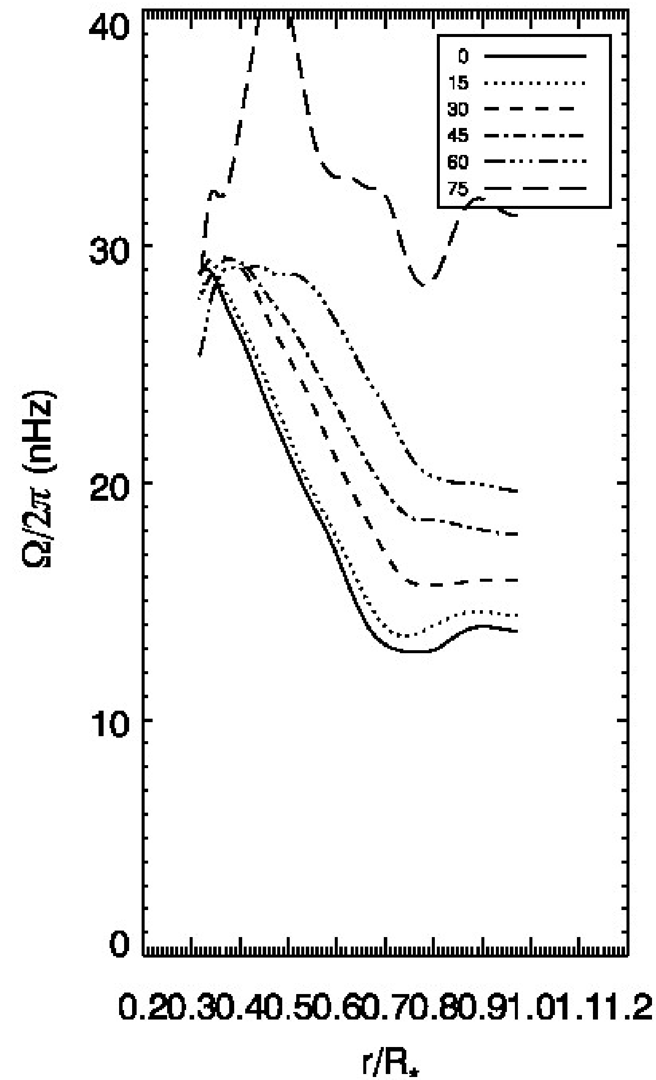



**Case B – Similar pattern and values for case A**

# Rotation

Moderate differential rotation in the radial direction, moderate in latitude.

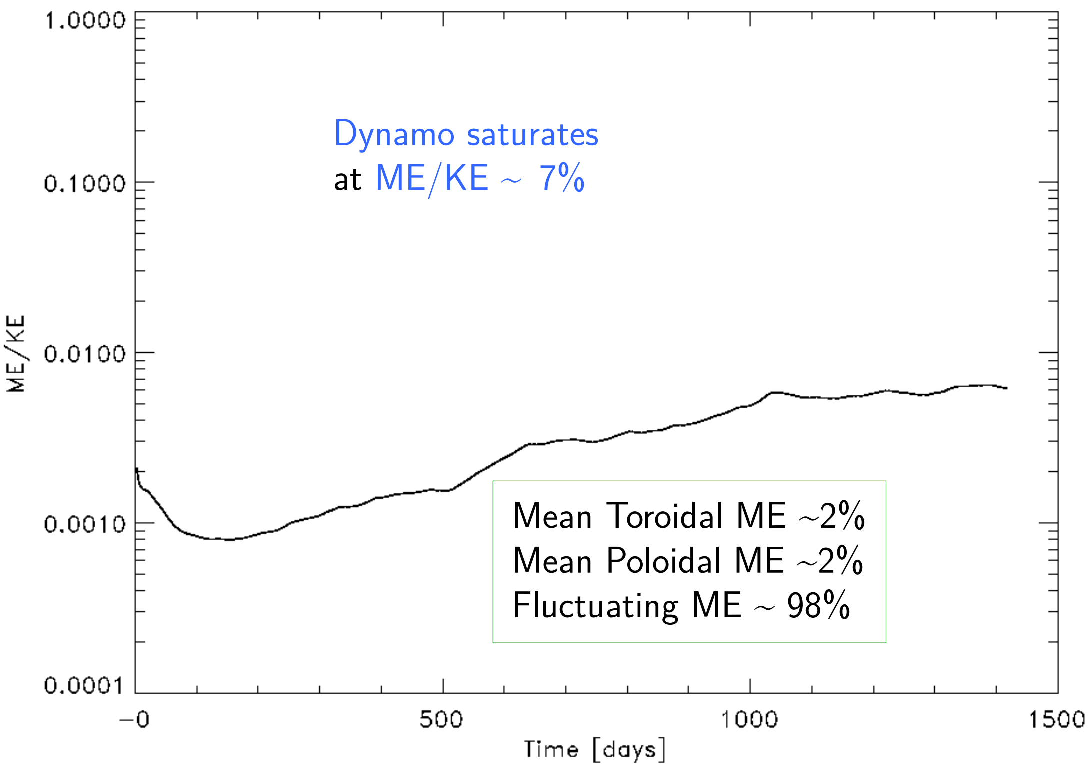


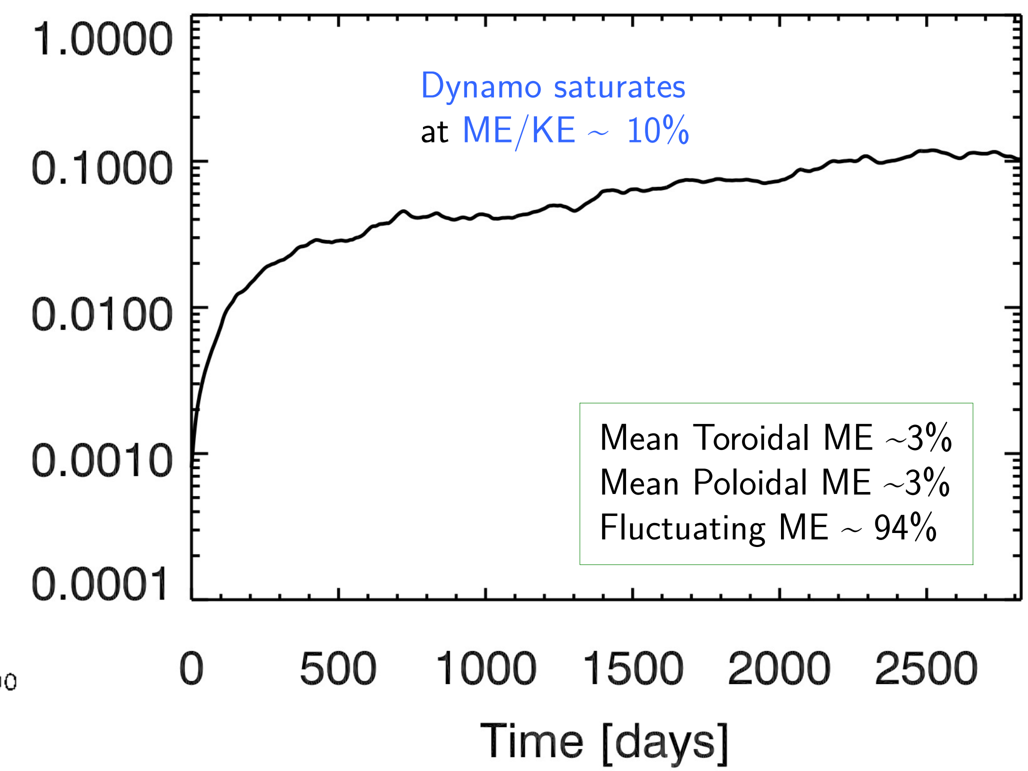

Mean over 1 $P_{rot}$ – Case A

# Dynamo action starting with seeds of different topologies

Case A : seed multipolar field

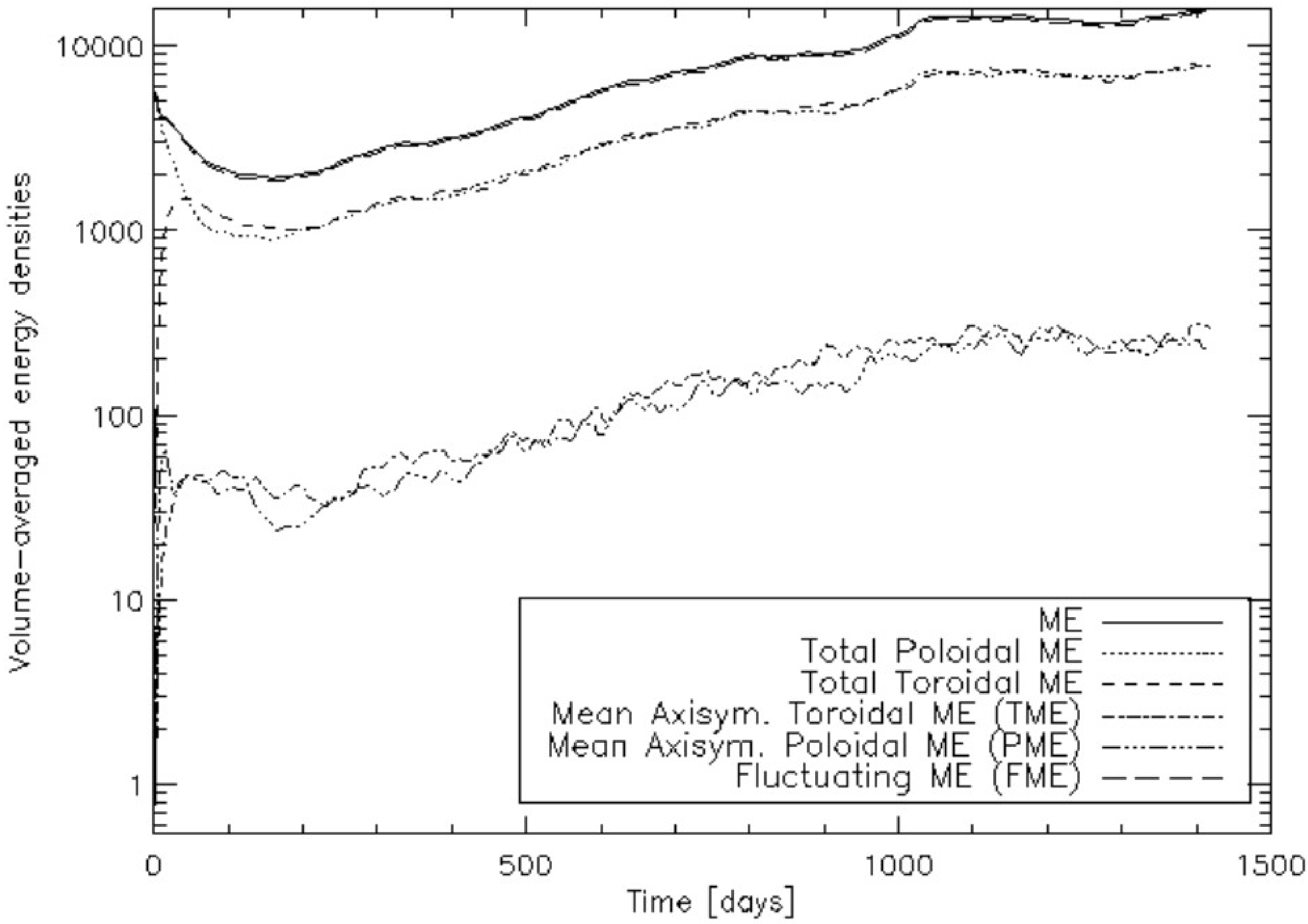



Case B : seed dipolar field

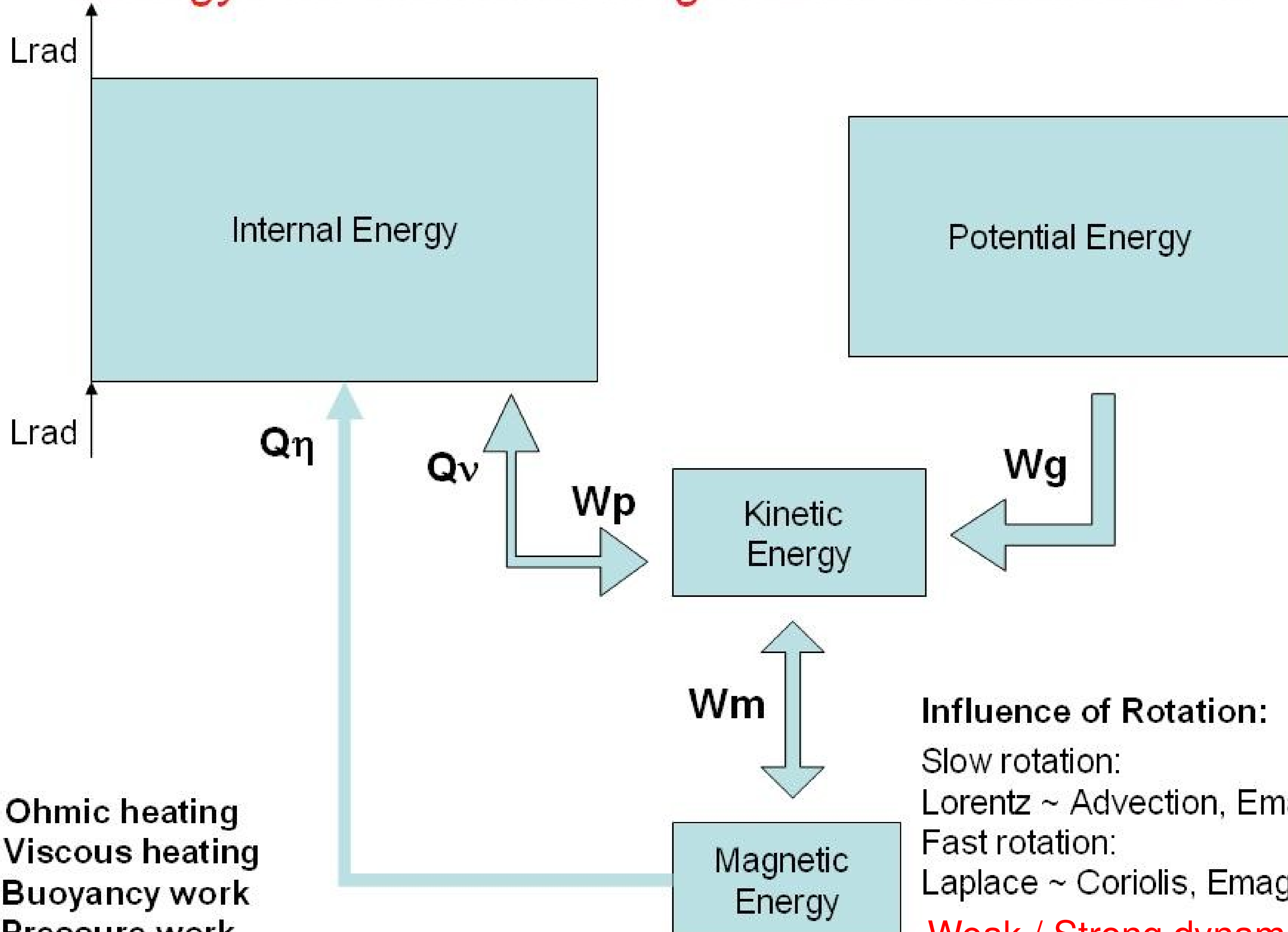



Initial ME/KE $< 0.1\%$

# Evolution of magnetic energies in simulation A



# *Energy Reservoirs in a Magnetized Convection Zone*




**Qη: Ohmic heating**
**Qν: Viscous heating**
**Wg:Buoyancy work**
**Wp:Pressure work**
**Wm: Lorentz force work**

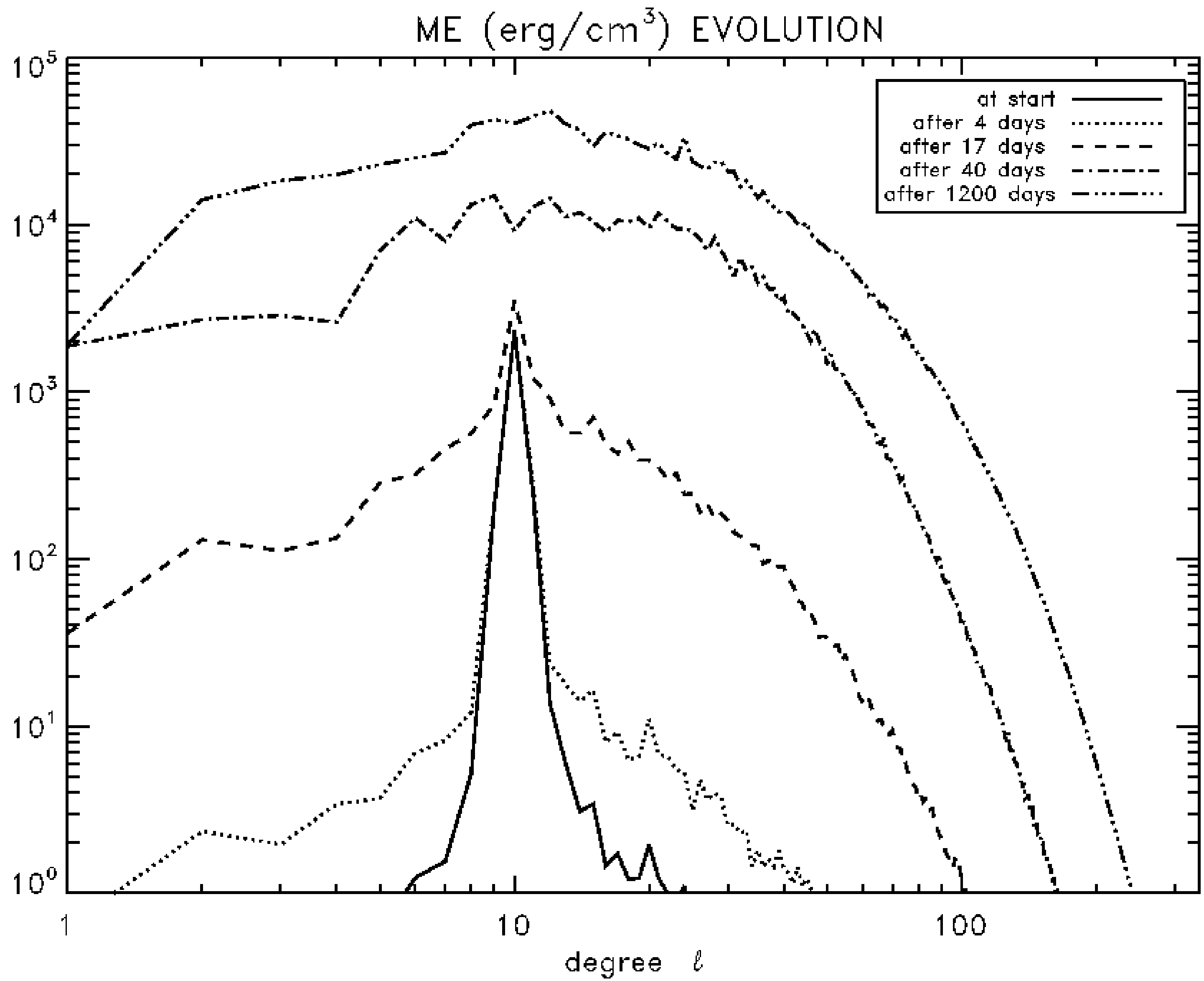
**Influence of Rotation:**

Slow rotation:
Lorentz ~ Advection, Emag ~ Eke
Fast rotation:
Laplace ~ Coriolis, Emag > Eke

Weak / Strong dynamo regime

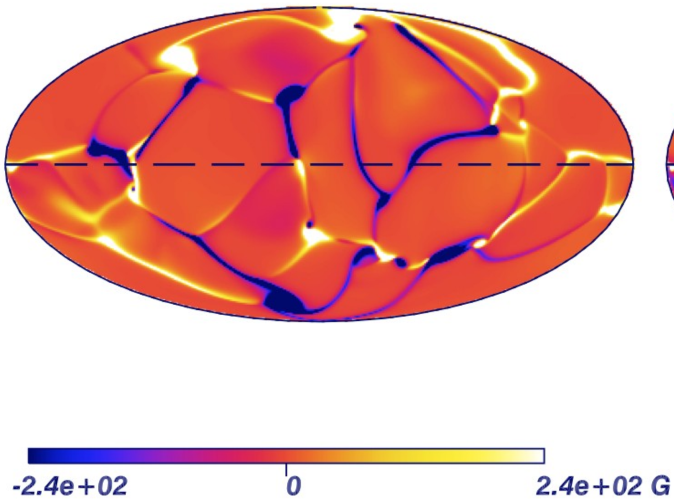
(Brandenburg et al. 1996, Brun et al. 2004) Simitev & Busse 2009

# Evolution of magnetic energy spectrum in case A

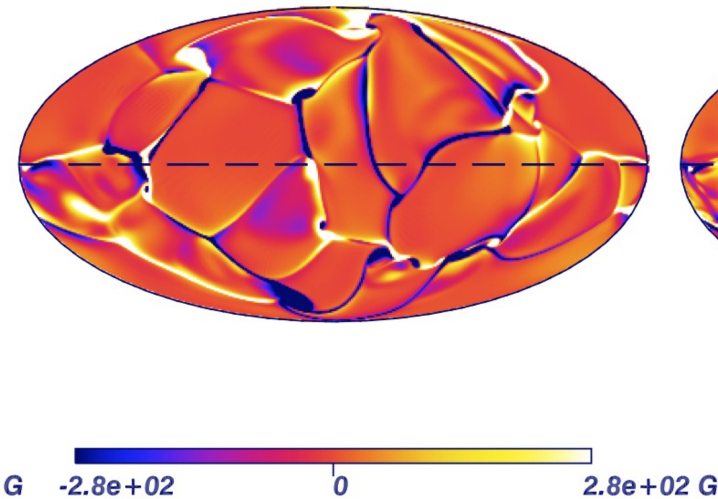


# Magnetic field – radial component Br

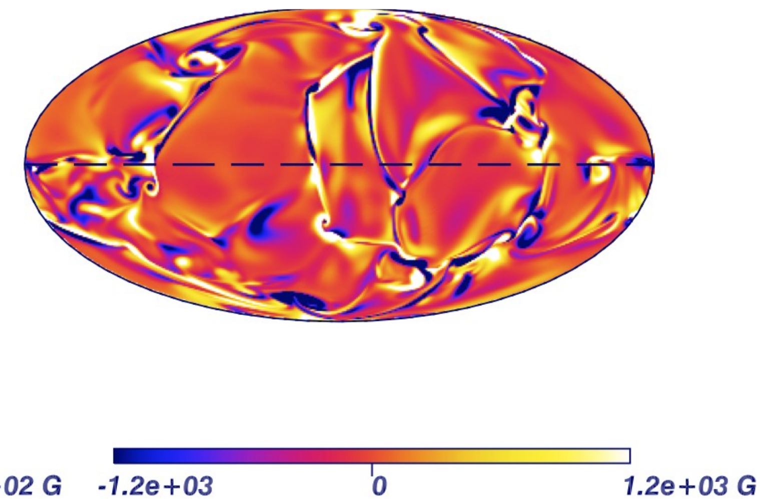
Br @ r = 8.8 $R_\odot$




Br @ r = 8.5 $R_\odot$

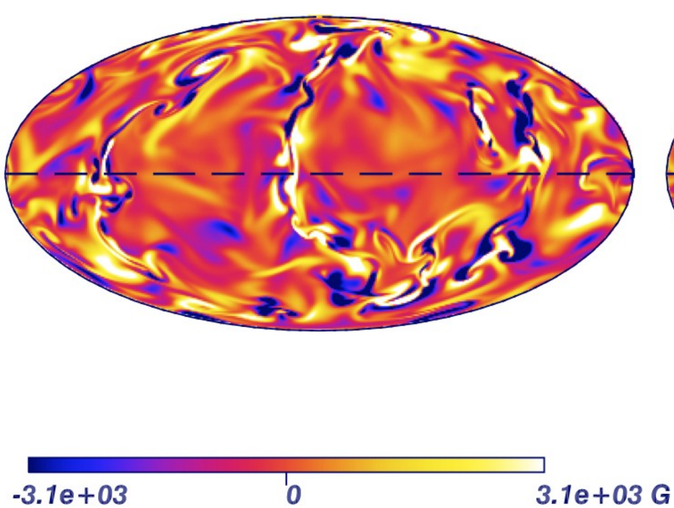



Br @ r = 7.4 $R_\odot$

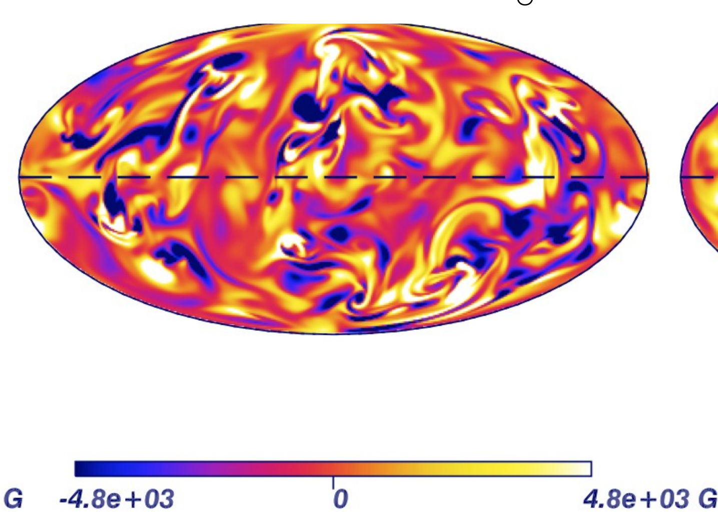



## case B

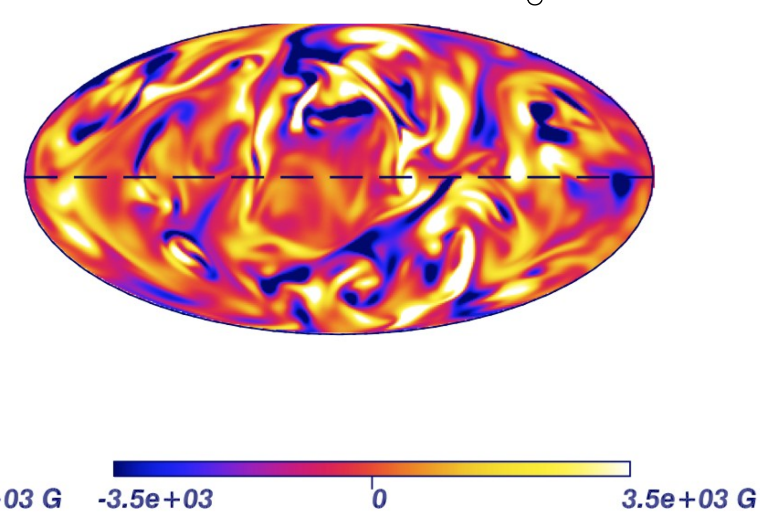
Br @ r = 5.8 $R_\odot$



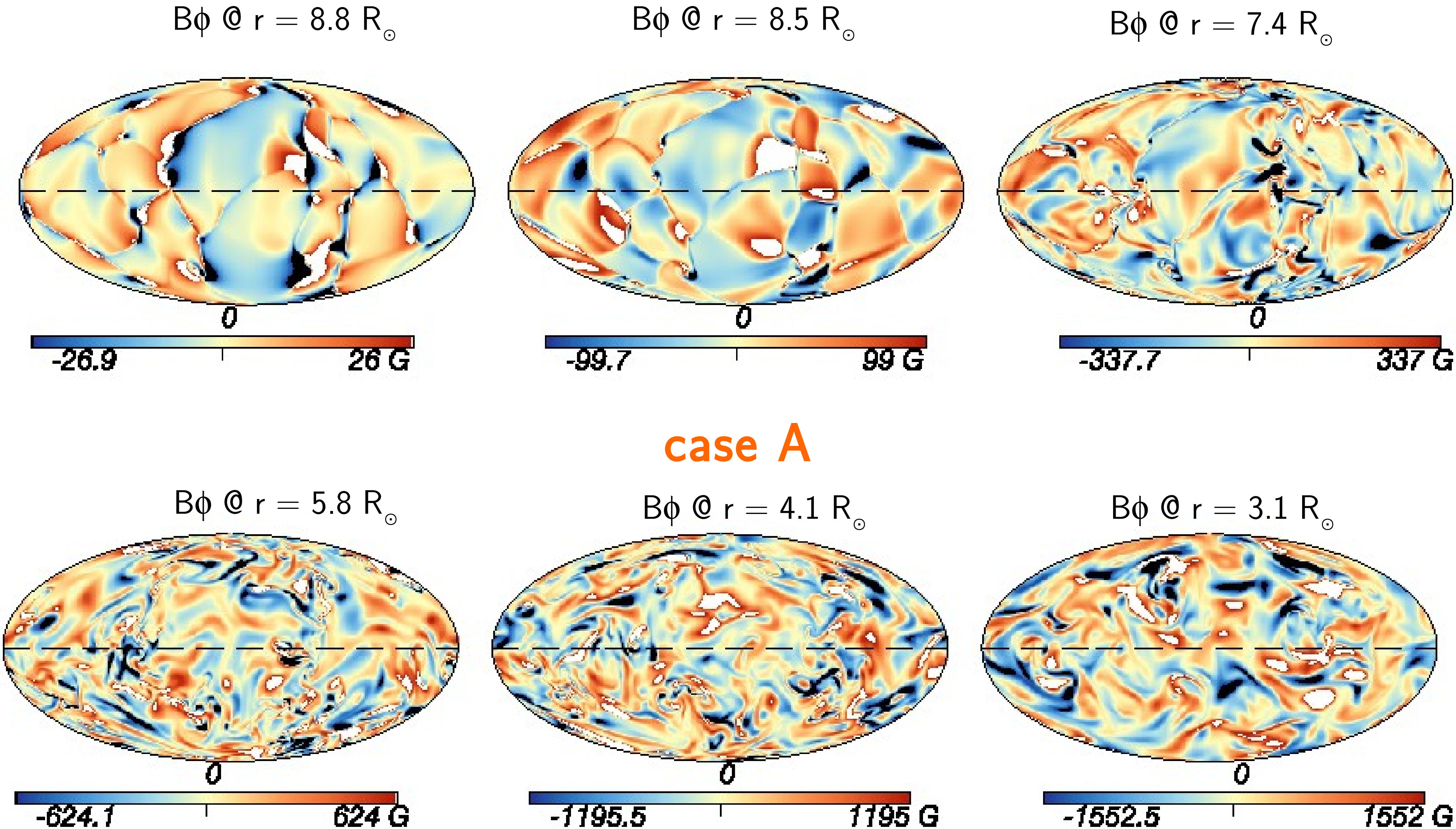

Br @ r = 4.1 $R_\odot$




Br @ r = 3.1 $R_\odot$

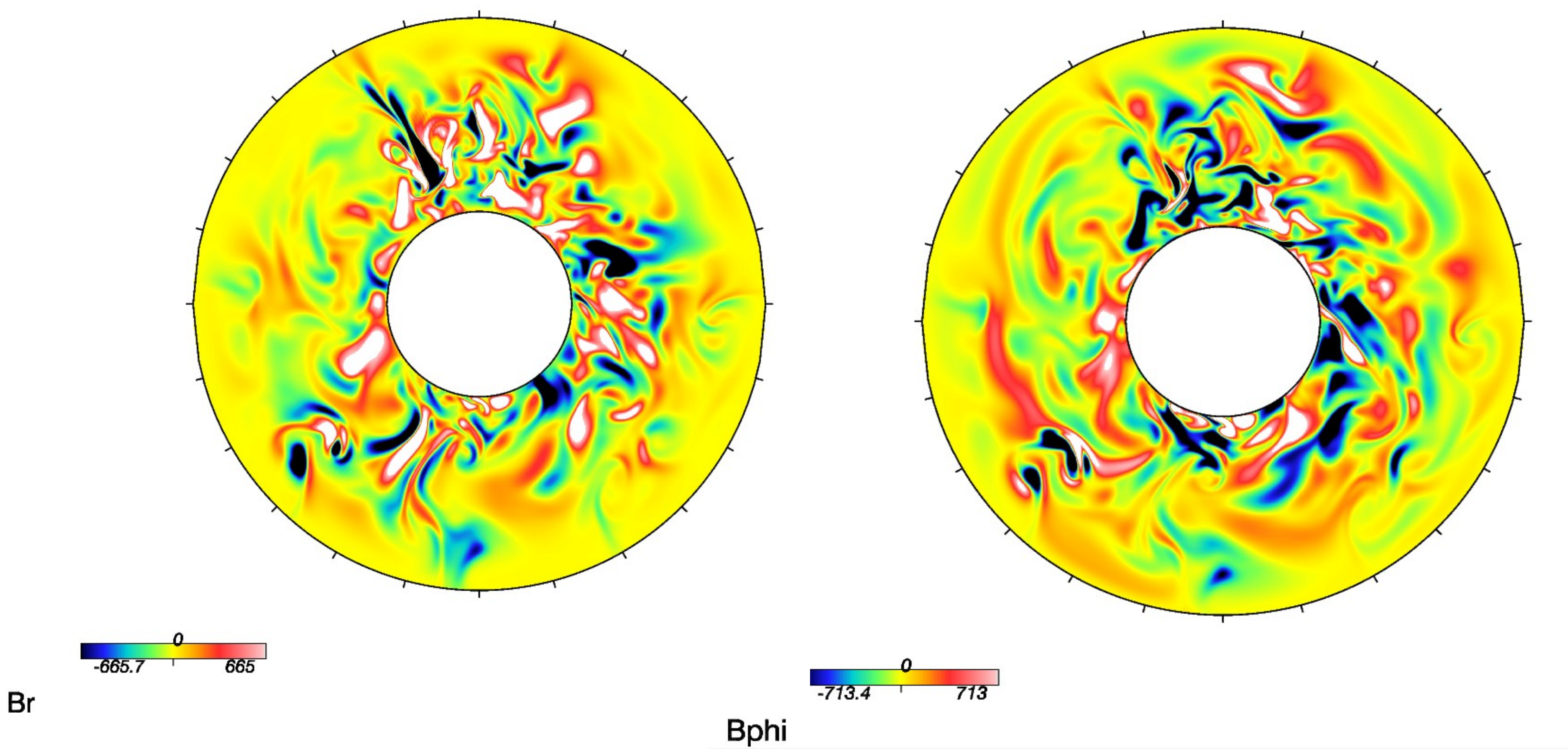


# Magnetic field – azimuthal component Bphi



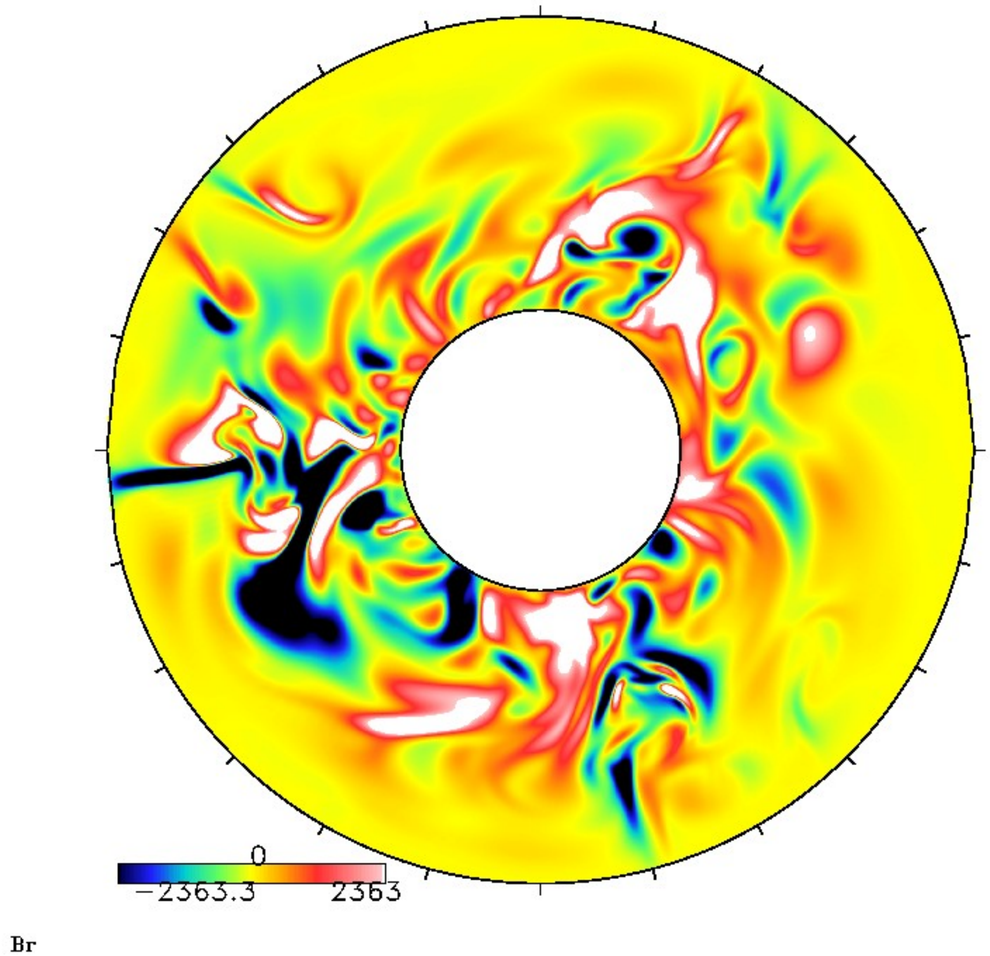
# Magnetic field – radial and azimuthal euqatorial slices

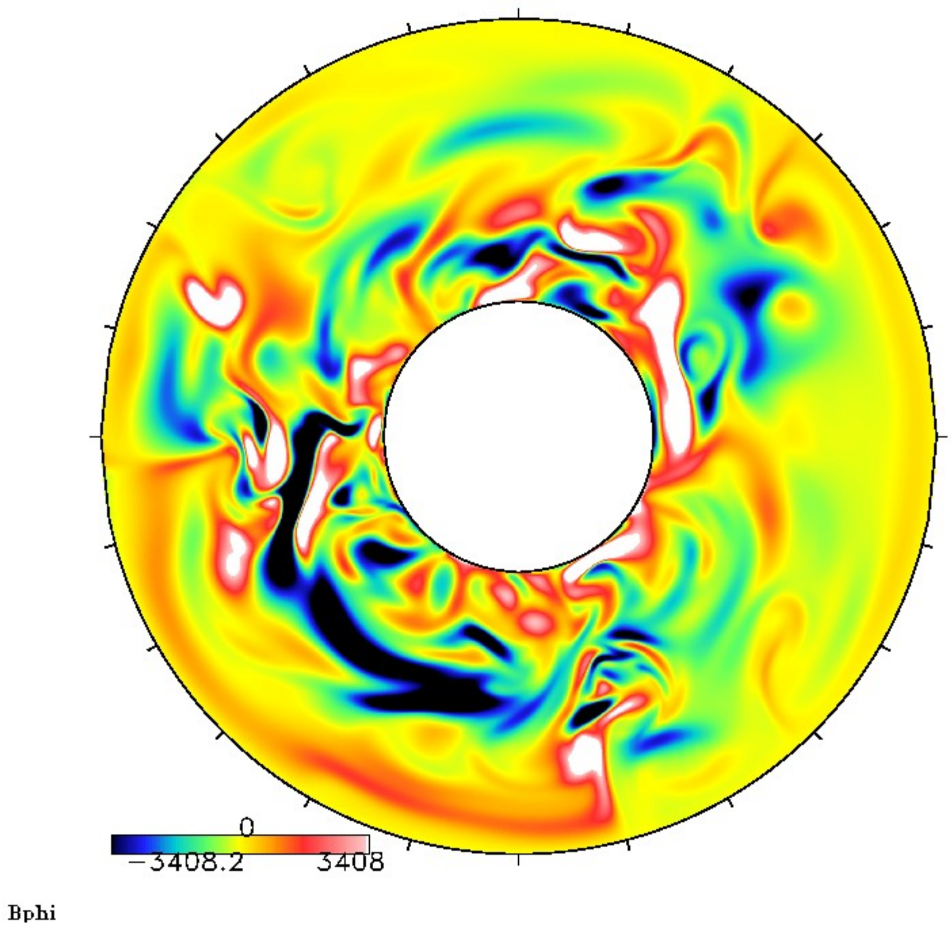
Case A



# Magnetic field – radial and azimuthal equatorial slices

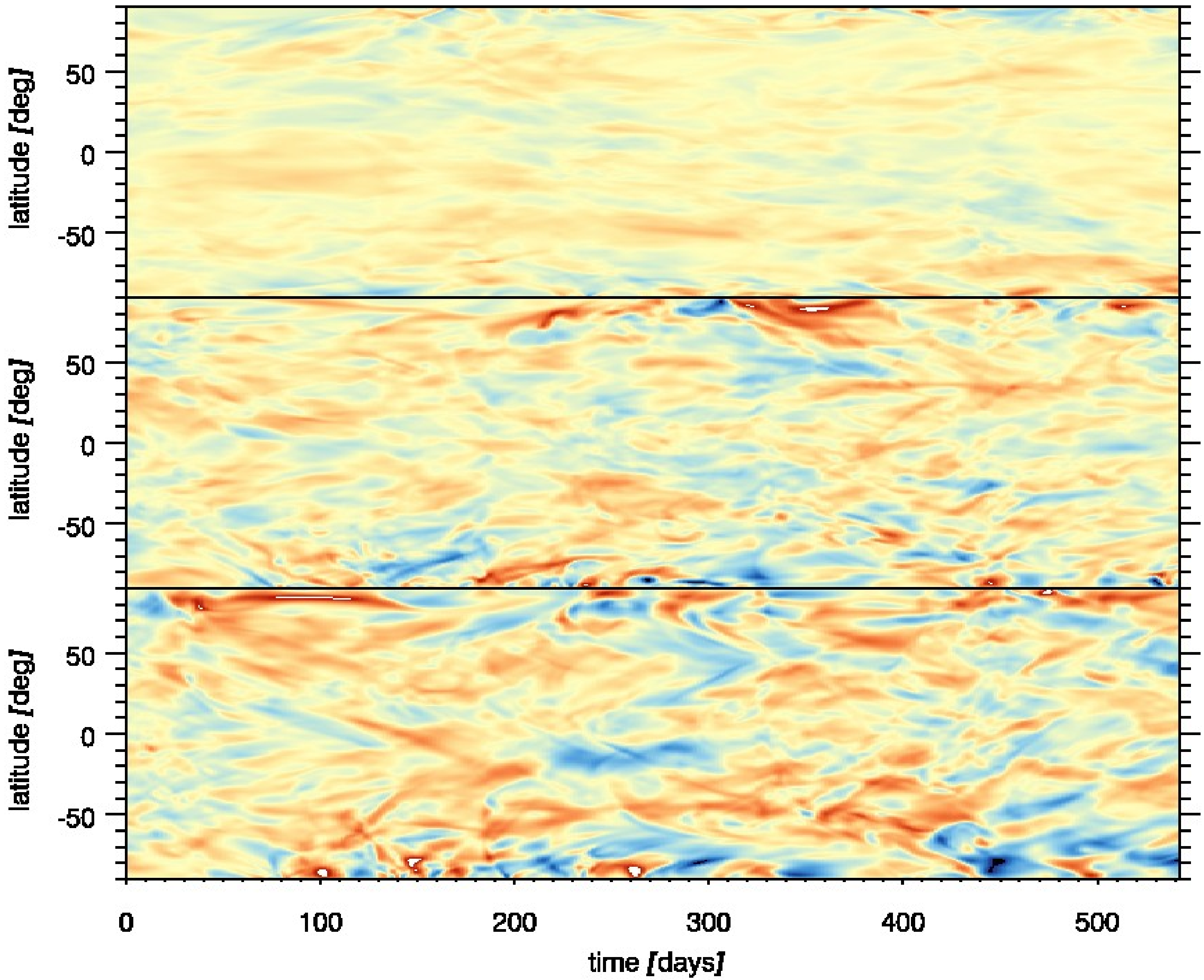
## Case B



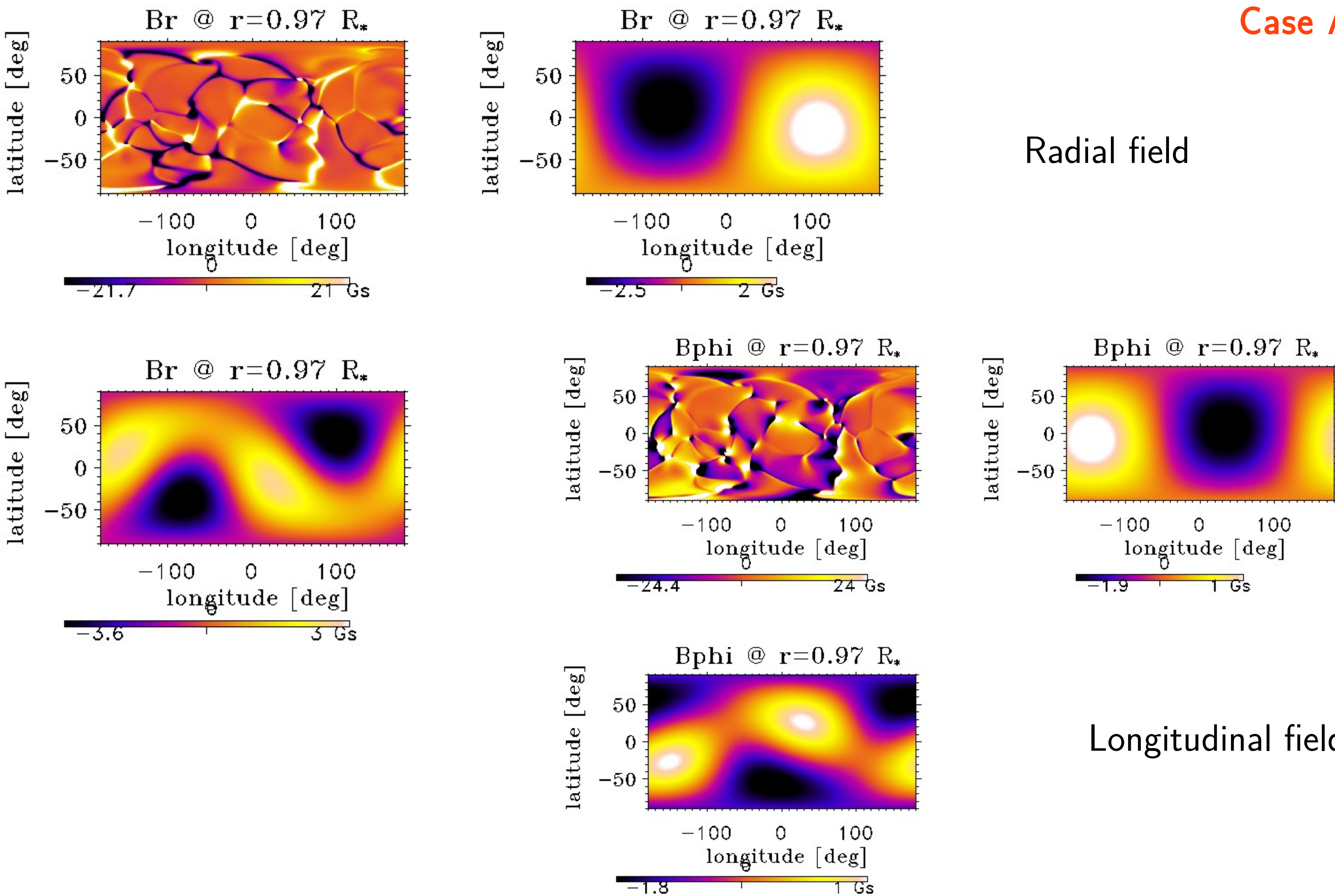
# Evolution of azimuthal magnetic field in case A

Colour scale ± 200 G



# Magnetic field intensity in the dipole and quadrupole

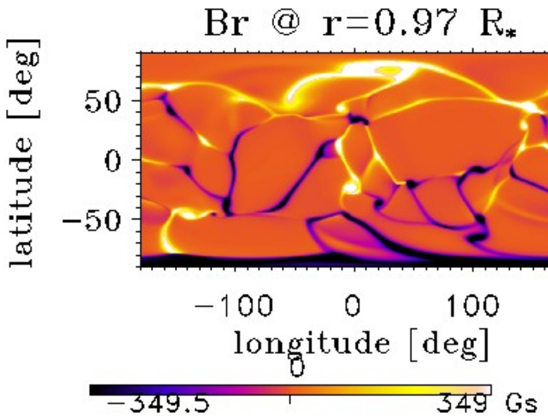
Case A

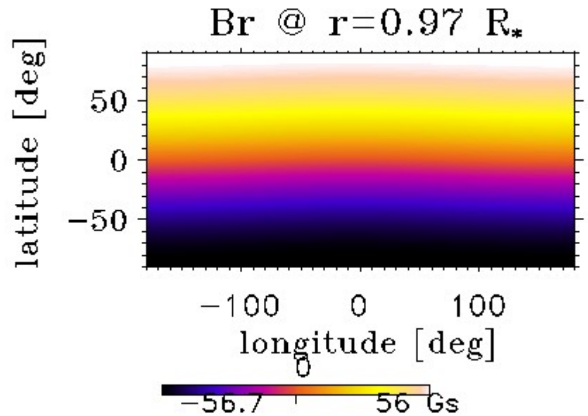



The intensity of the toroidal field in the dipole and quadrupole is compatible with the value of $|B_l|$max derived from Stokes V of about 1 Gauss

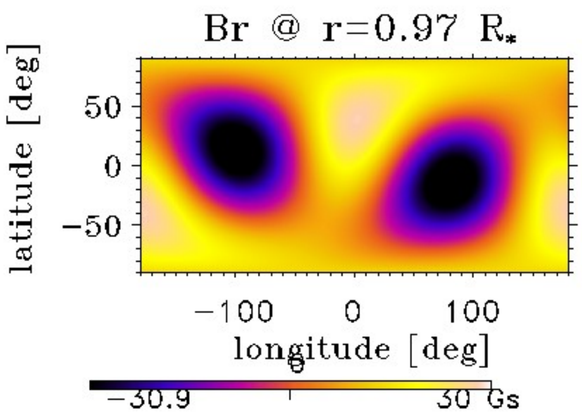
# Magnetic field intensity in the dipole and quadrupole

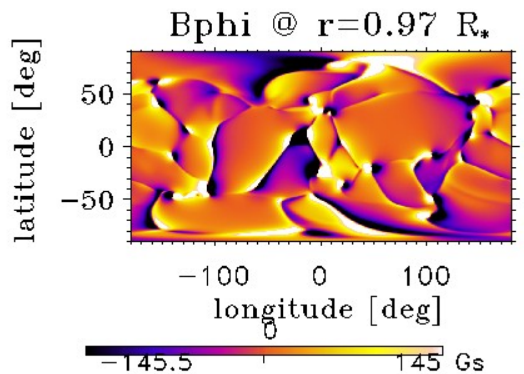
Case B

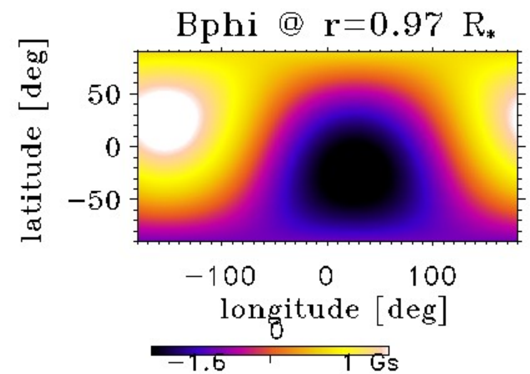


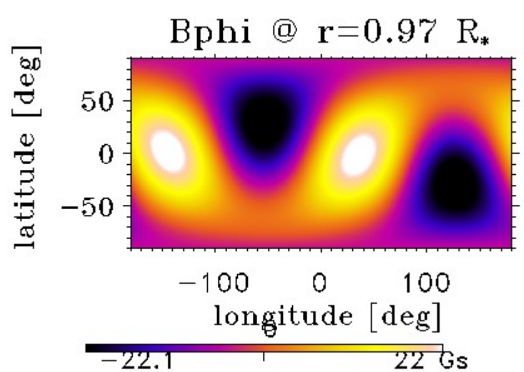




Radial field




Longitudinal field

The intensity of the toroidal field in the quadrupole is much larger for case B (about 20 G) and thus one order of magnitude higher than the |B||max derived from spectropolarimetry

# Take away messages

Slowly rotating RGB star can easily generate magnetic field via dynamo action in their convective envelope

They have some differential rotation mostly radial

Overall field energy is around 10% of kinetic energy

The dipolar and multipolar seeds lead to a dynamo possessing a dipolar mode compatible with that observed

Parameter study will tell us how sensitive it is to initial conditions (A vs Ap star)

# Various Dynamo Regimes and Scalings

Equilibrium field : $B_{eq} \sim \mathrm{sqrt}(8\pi P_{gaz}) \sim \mathrm{sqrt}(\rho_*)$

If magnetic Reynolds number Rm ~1 , $v = \eta/L$, then

Laminar (weak) scaling: Lorentz ~ diffusion →

$$B^2_{weak} \sim \rho \nu \eta / L^2$$

Turbulent (equipartition) scaling: Lorentz ~ advection →

$$B^2_{turb} \sim \rho v^2 \sim \rho \eta^2 / L^2 \Leftrightarrow |B_{weak}| \sim |B_{turb}| P_m^{1/2}$$

Magnetostrophic (strong) scaling: Lorentz ~ Coriolis →

$$B^2_{strong} \sim \rho \Omega \eta$$

With $\rho$ density, $\nu$ kinematic viscosity, $\eta$ magnetic diffusivity, $\Omega$ rotation rate, v, L characteristic velocity & length scales, $P_m = \nu/\eta$ the magnetic Prandtl number

Fauve et al. 2010, Christensen 2010, Brun et al. 2013