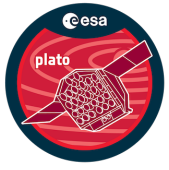
Understand the magnetic field of the Red Giant Pollux thanks to 3D MHD simulations

Louis Amard

with A.S. Brun - A. Palacios

Prospective du PNPS 2024

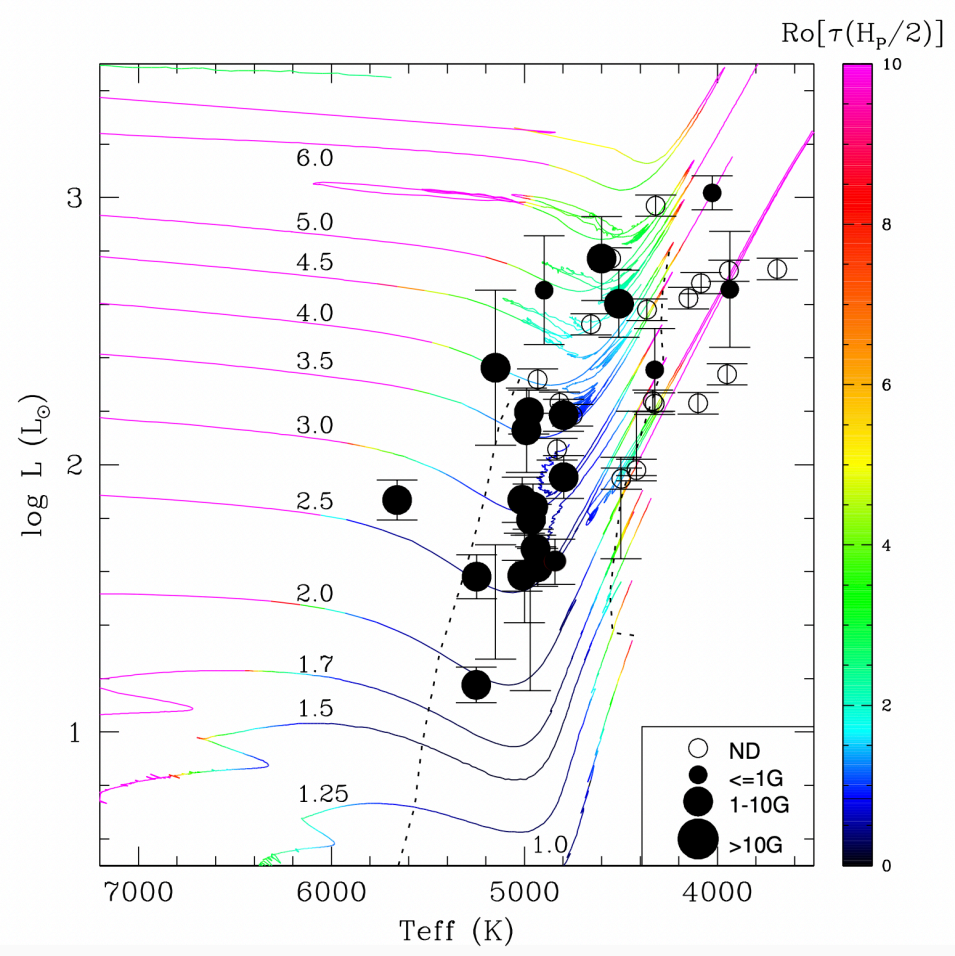
9 Janvier 2024



Red giants with magnetic field

Active giants : Konstantinova-Antova et al. (2014, 2023), Aurière et al. (2015)
Observational features :

- Located in the magnetic strip
- 2 magnetic strips (Konstantinova-Antova et al. 2023)
- Weakly magnetised ($\sim 10sG$)

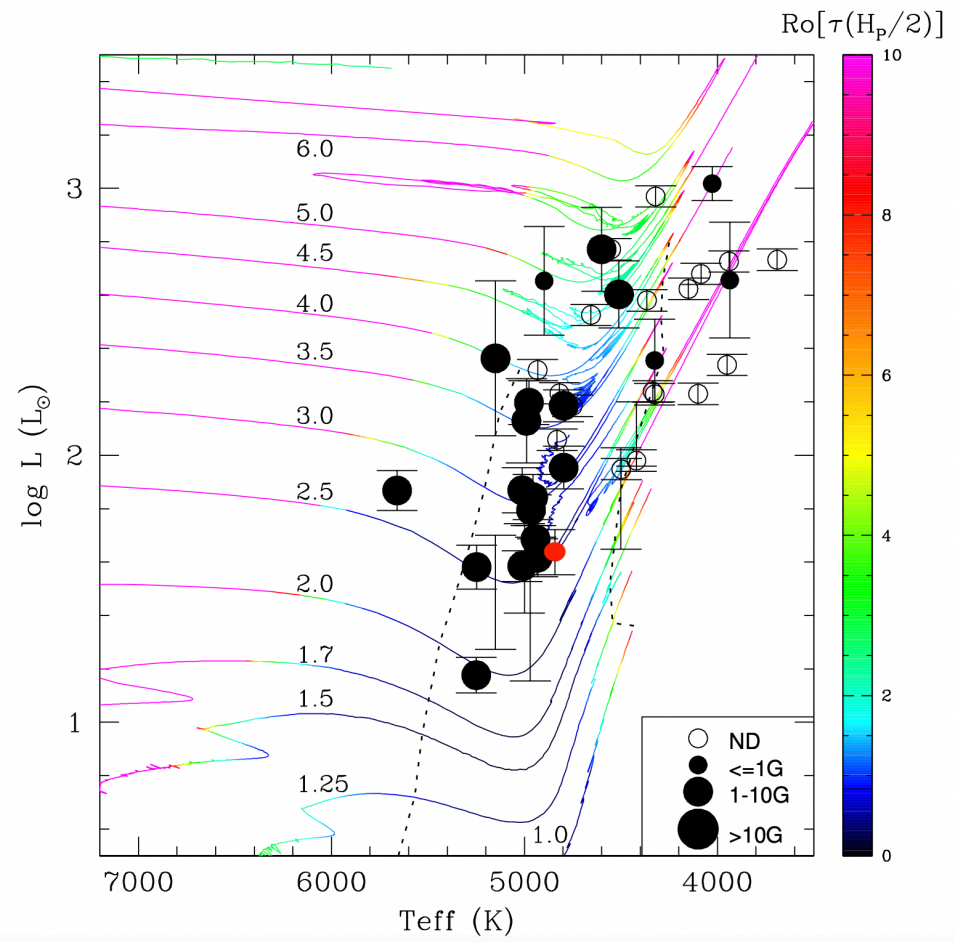


Aurière et al. (2015), Charbonnel et al. (2017)

Pollux as a star

Pollux is a Red Giant Branch star with the lowest measured mean magnetic field strength (Aurière et al 2009, 2015, 2021)

- $M = 2.5\ M_\odot$
- $R = 9.3\ R_\odot$
- $L \sim 43\ L_\odot$
- logg $\sim$ 2.9
- [Fe/H]=-0.07
- $T_{eff} = 4842K$
- $P_{rot} = 590$ days
- $\tau_c = 330$ days (Lagarde et al. 2012)
- $B_l \leq 0.7$ G



Aurière et al. (2015), Charbonnel et al. (2017)

Pollux : Magnetic field observations

Aurière et al. 2021 :

- $|B_l|$ ∼0.5G
- Mostly dipolar
- Origin of the magnetic field cannot be from Ap progenitor
- Presence of possible planet (?)

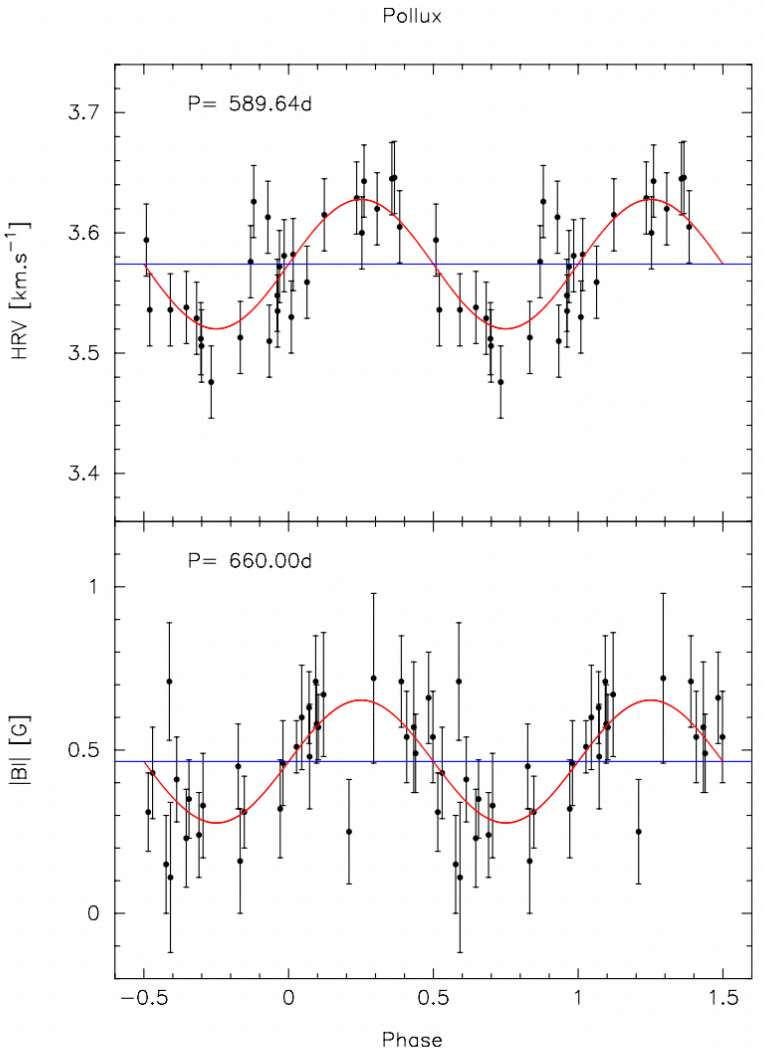


Fig. 2. Radial velocity (*upper plot*) and unsigned B_ℓ (*lower plot*) of Pollux phased with the 589.64 d and 660 d periods, respectively. The mean value of RV and $|B_\ell|$ are shown. Two periods are plotted for clarity.

Pollux Simulations : The setup

The setup

Same initial input as in Palacios & Brun (2014), Brun & Palacios (2015)

- ASH Code (Anelastic Spherical Harmonics, e.g. Brun+02,04)
- Resolution 256 x 512 x 1024

	P2M2	P3M2
Pr	1/8	1
Pm	2	2
N_ρ	7.4	7.4
Re	237	201
Ro_c	0.99	1.19

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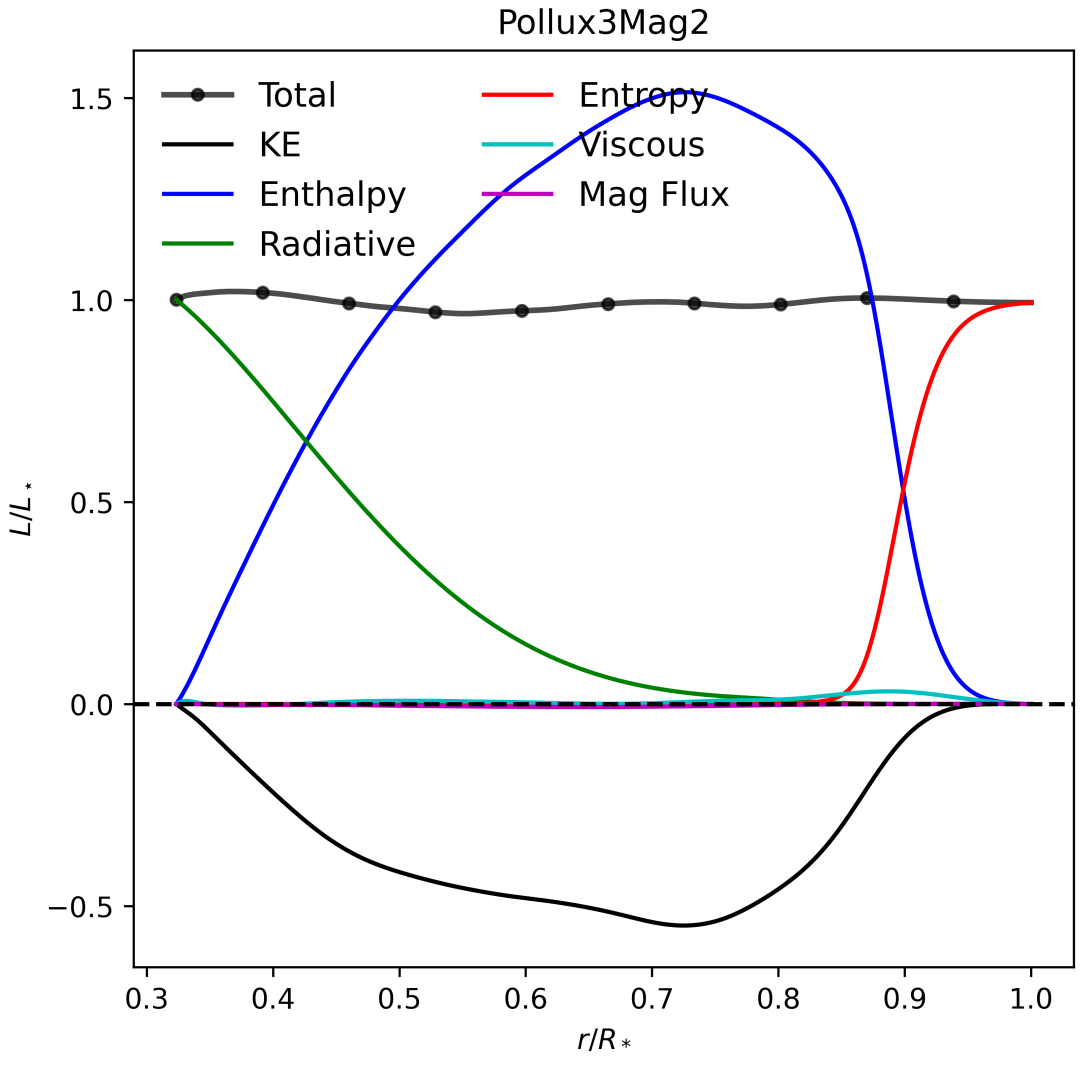
MHD simulation

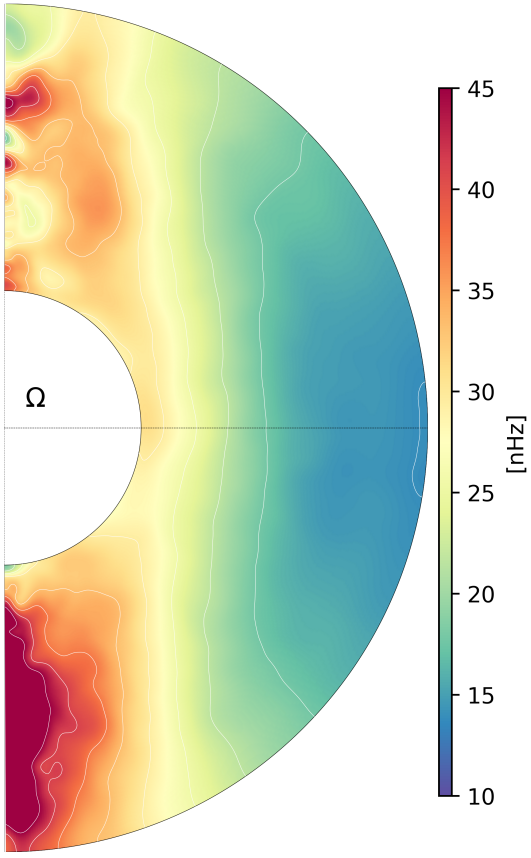
Flux Balance



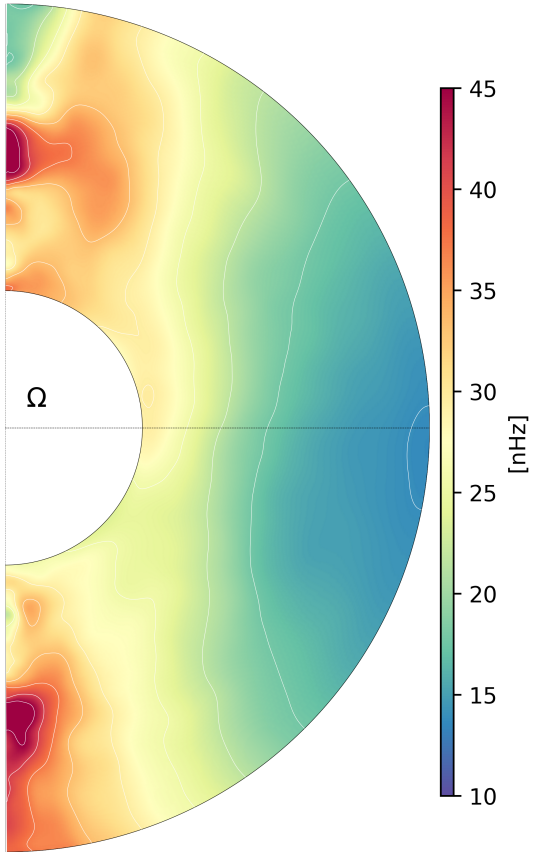
Comparison to hydrodynamic simulation

Rotation profile

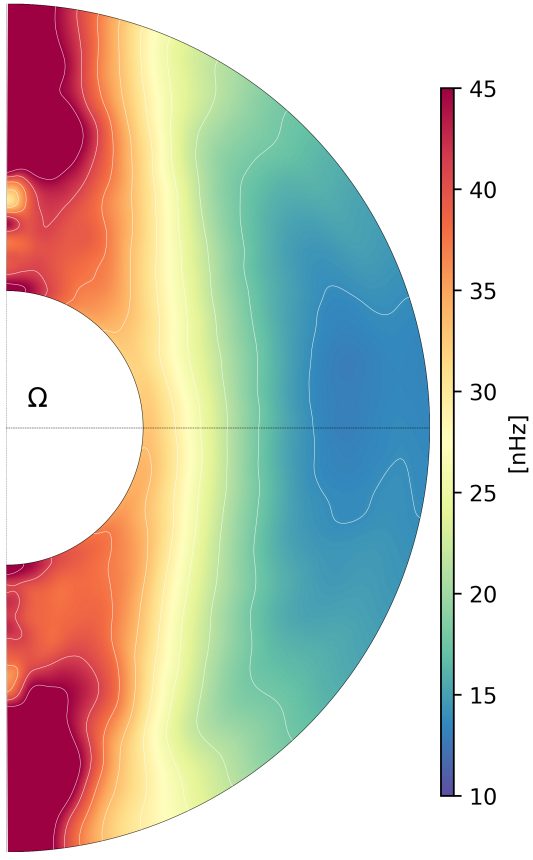
Hydro (Pr=1/8)



P2M2 (Pr=1/8)

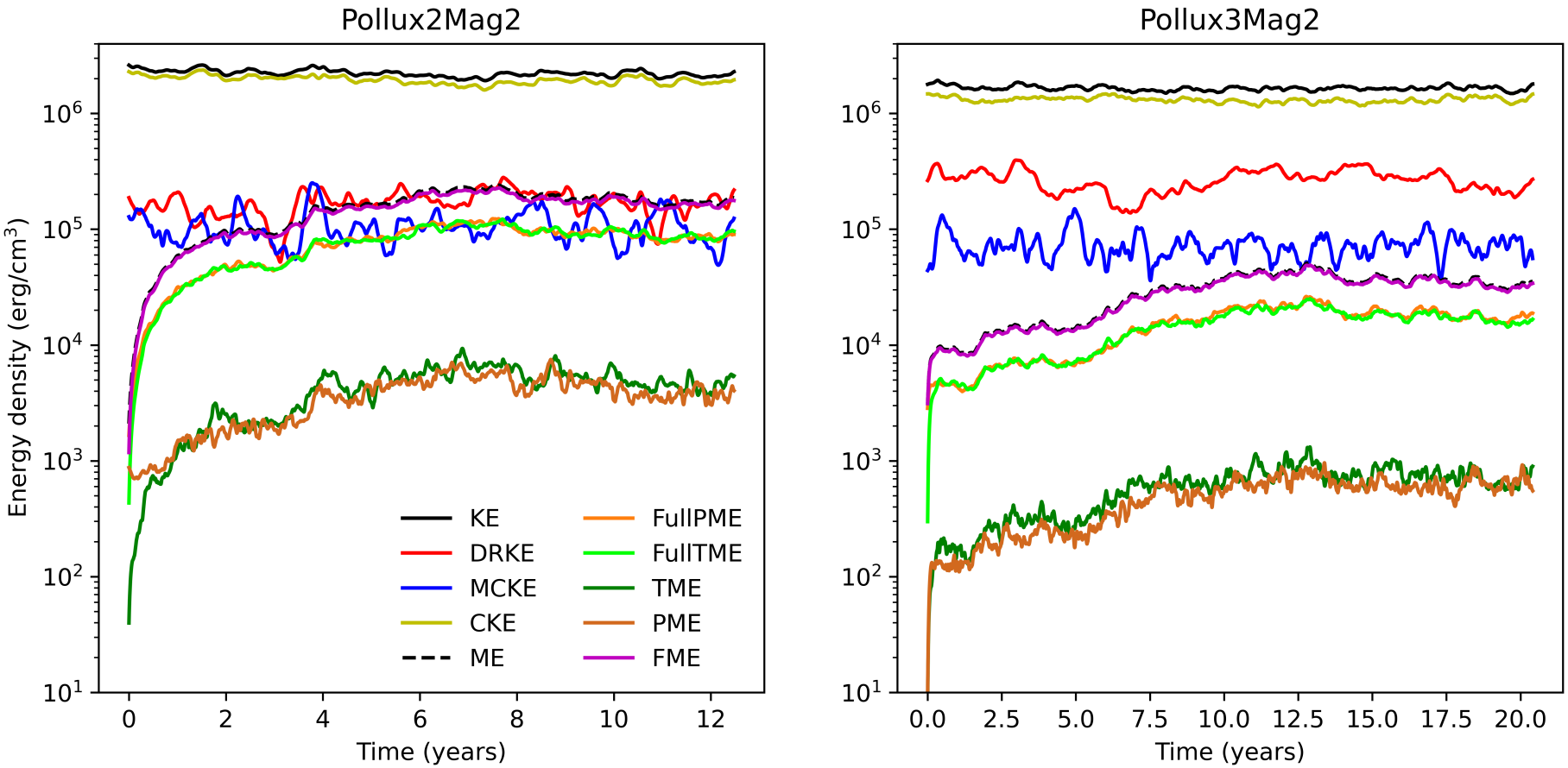


P3M2 (Pr=1)



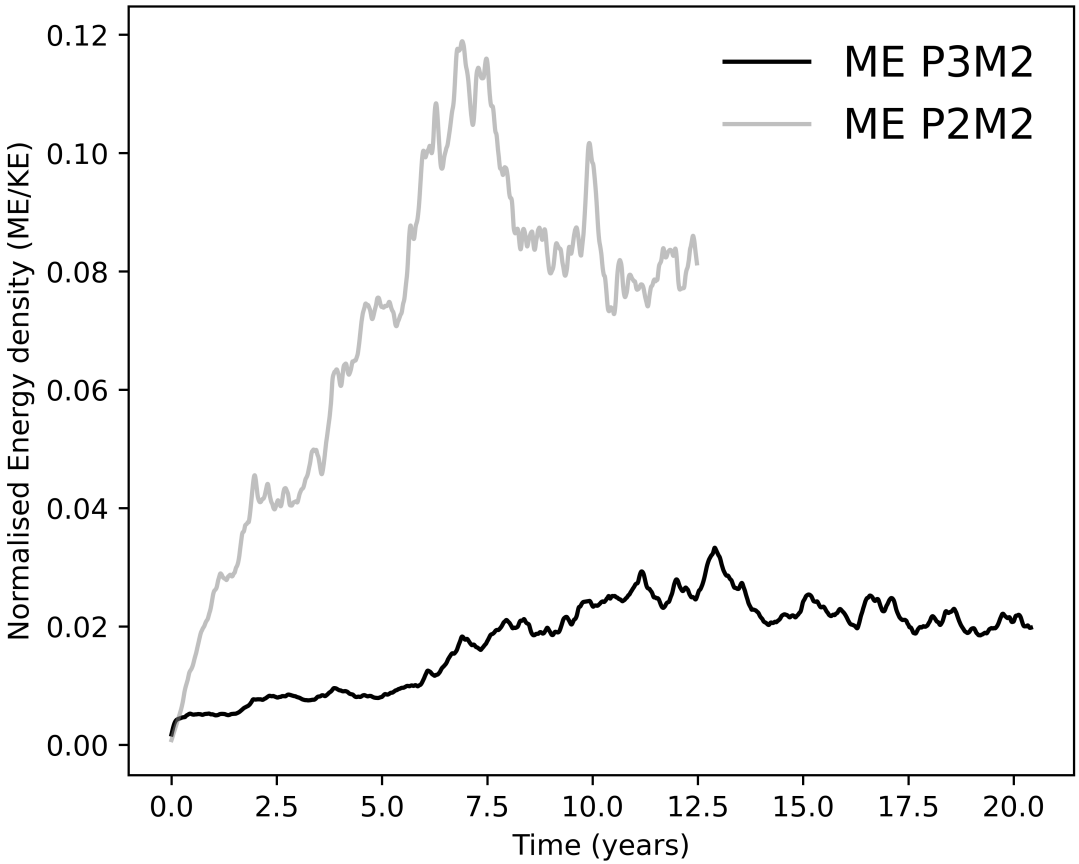
MHD simulation

Energy evolution



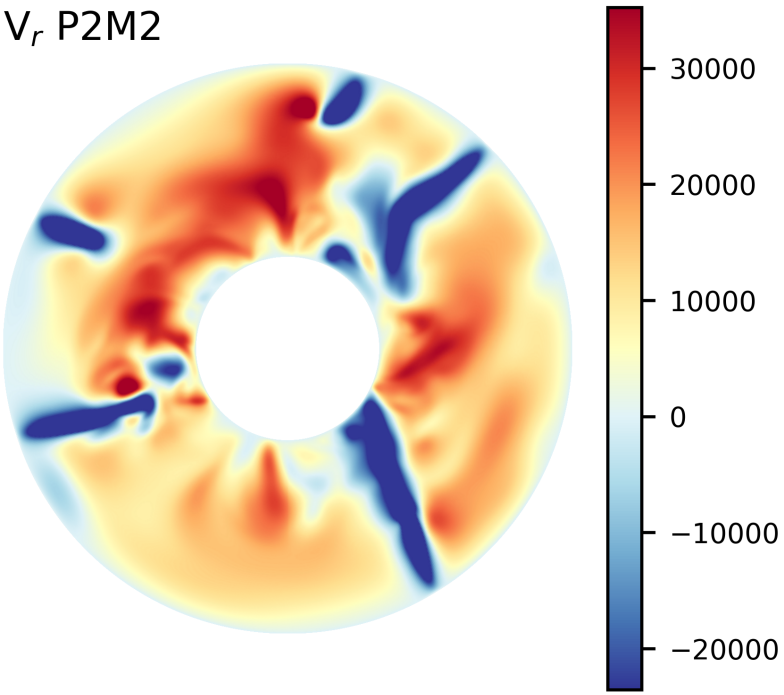
MHD simulation

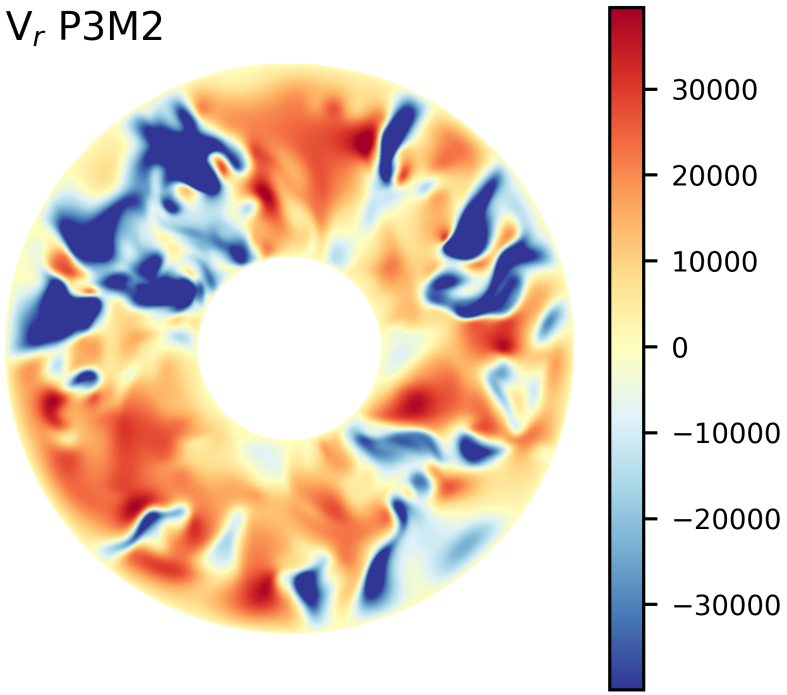
Magnetic to Kinetic Energy evolution



MHD simulation

Equatorial Slices





MHD simulation

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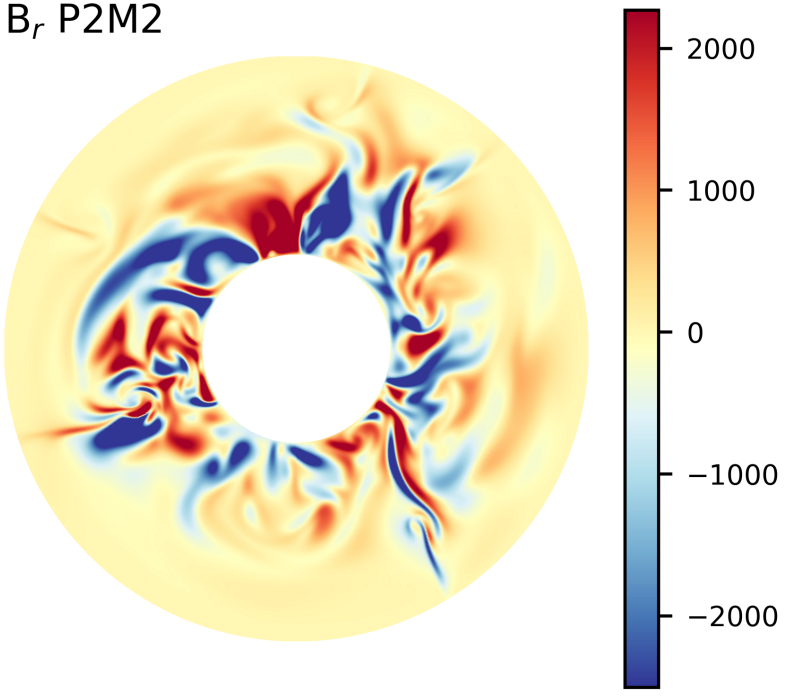

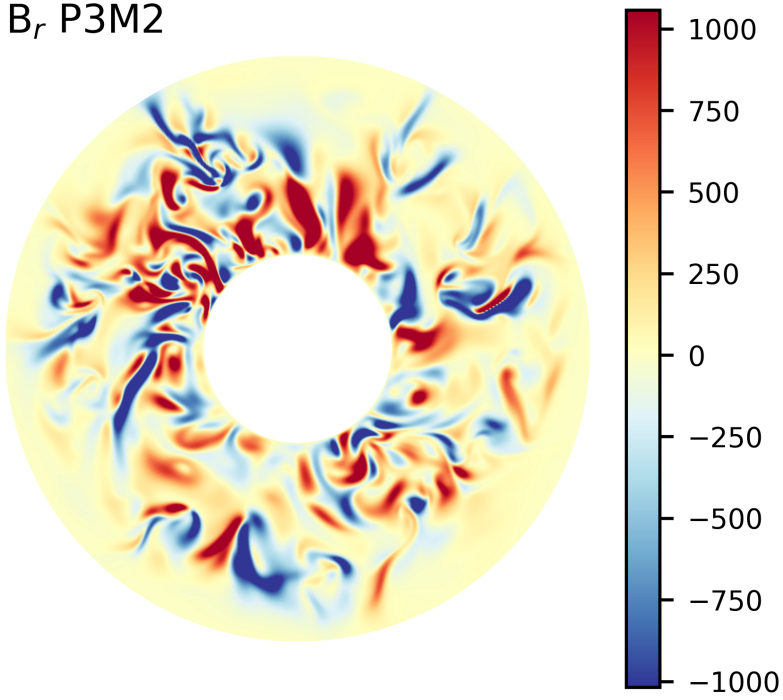

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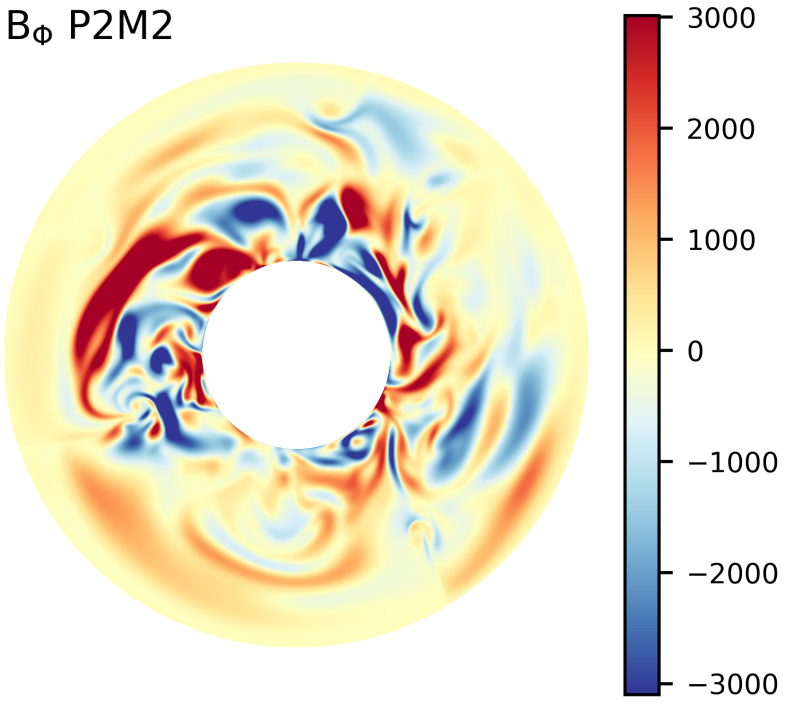
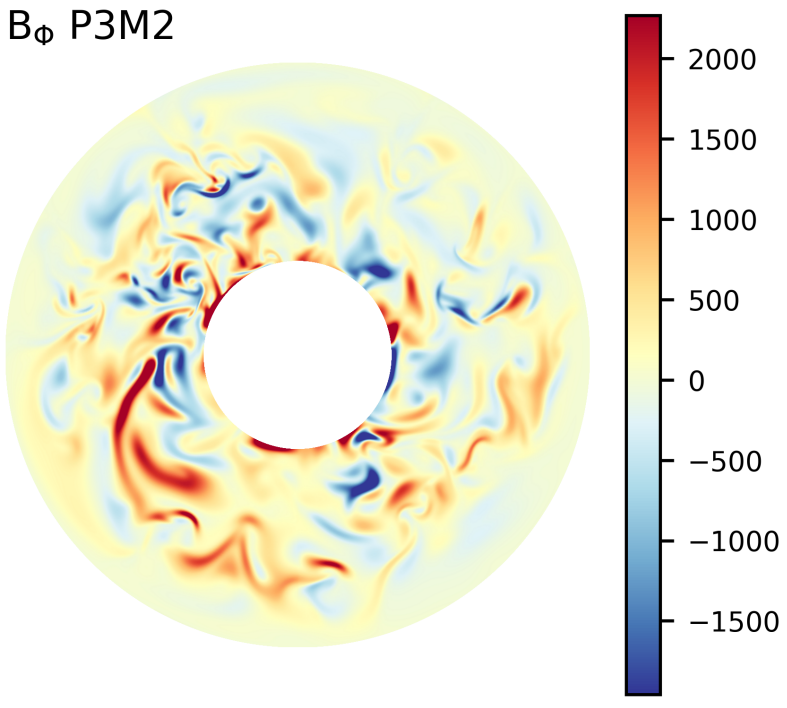
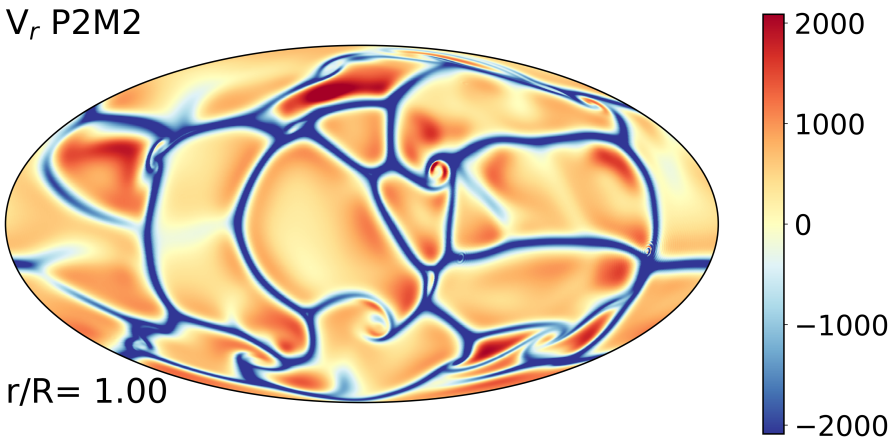
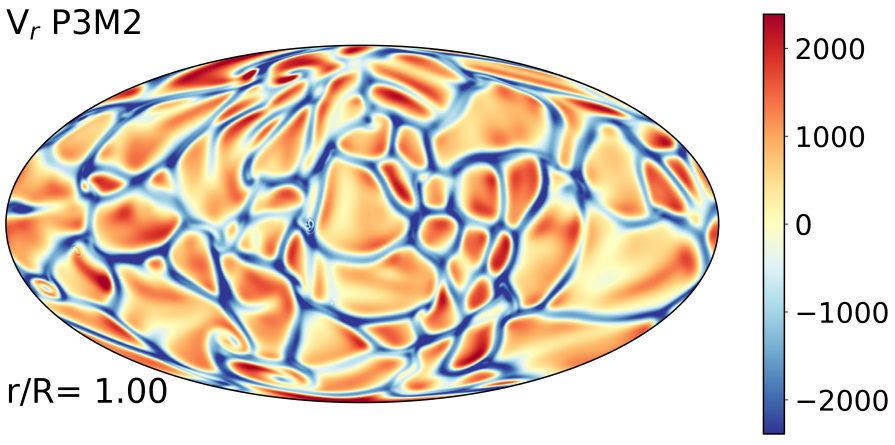




MHD simulation

Shell Slices





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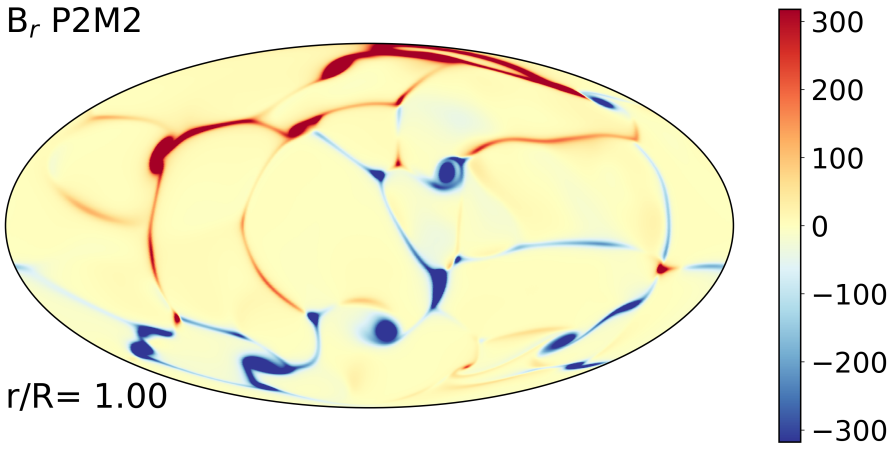

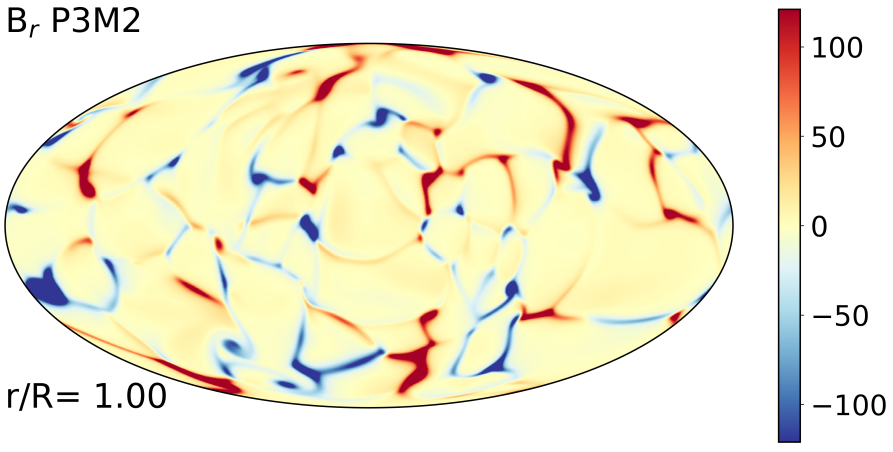

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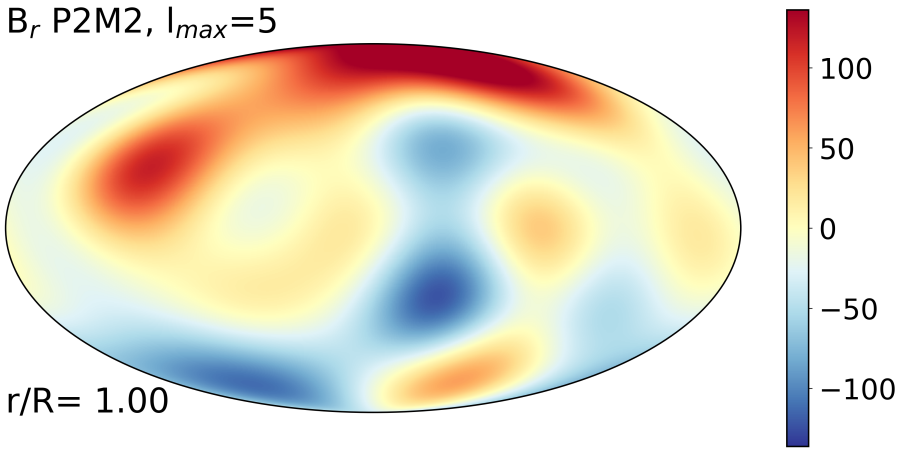
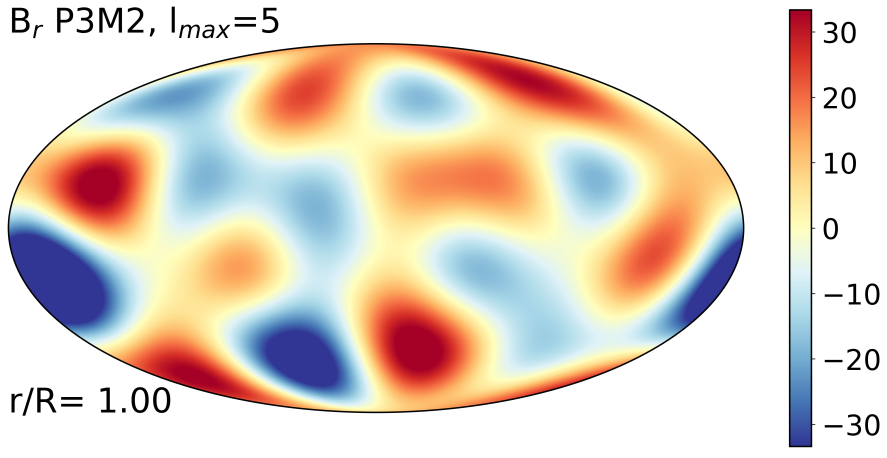
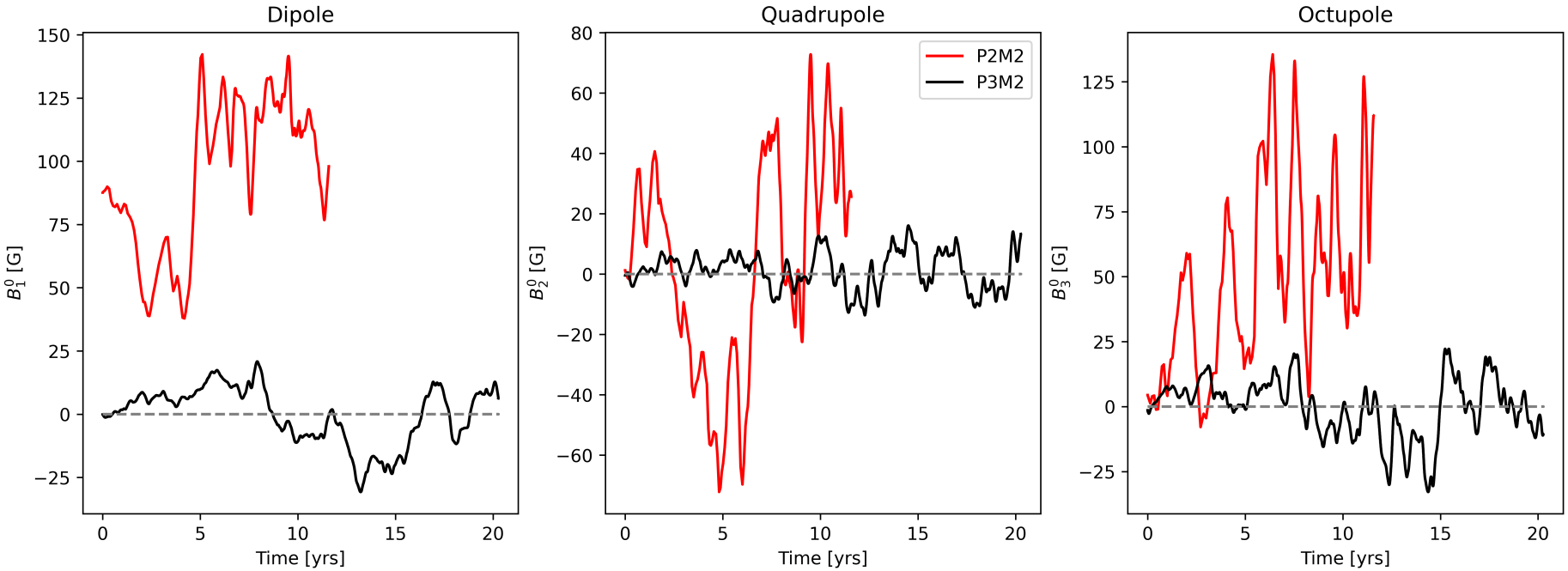




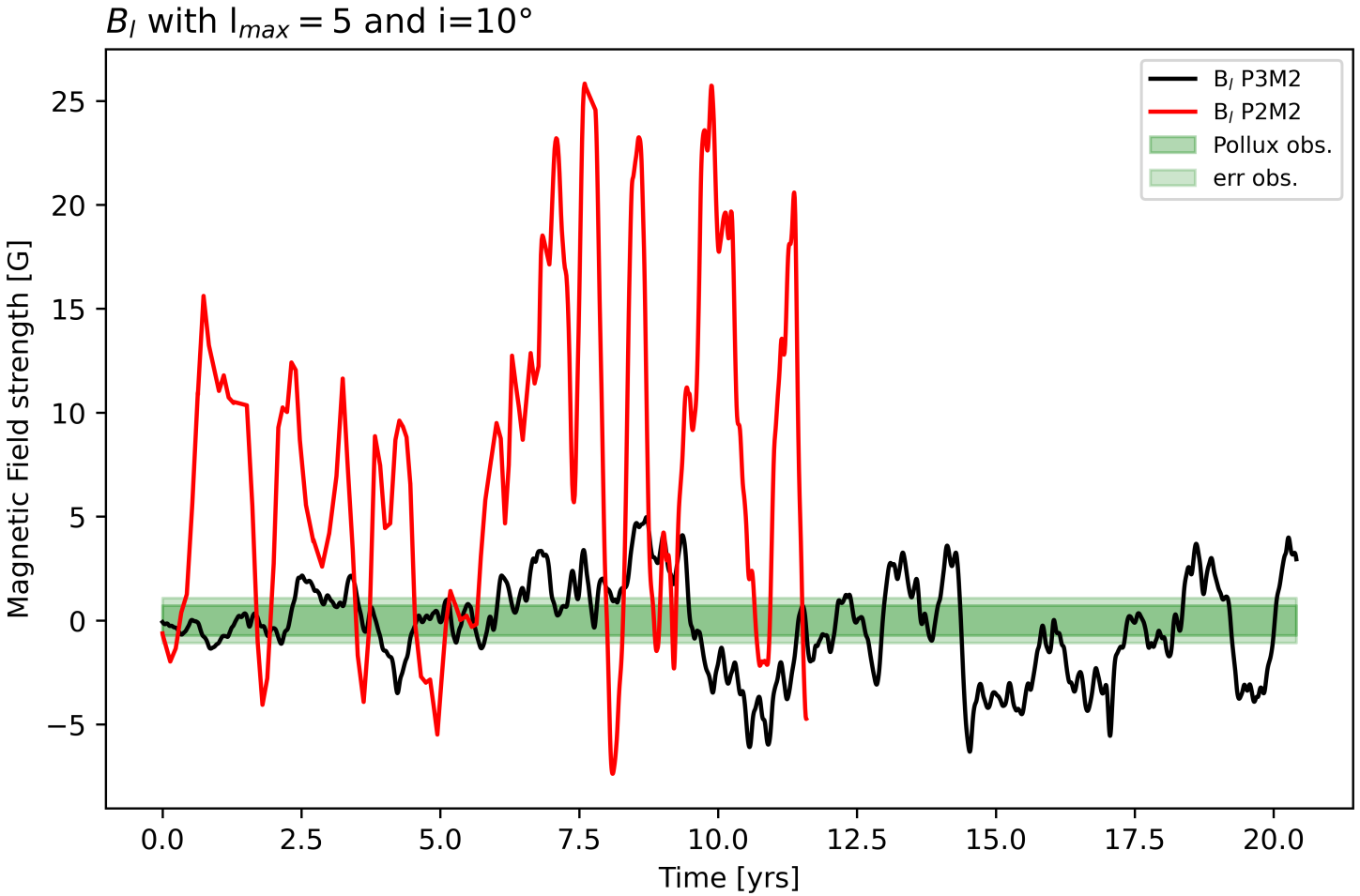
Comparison to observations

Multipolar components



Comparison to observations

Mean B_l

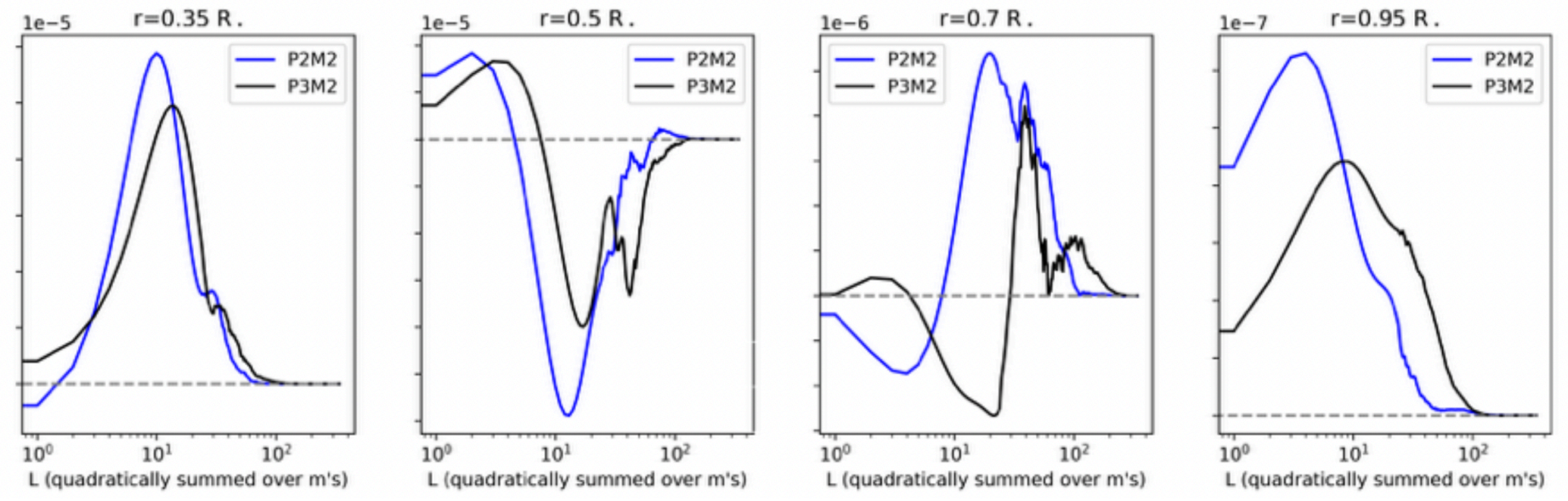


Dynamo process

Spectrum of the induction term

$$\partial_t \mathbf{B} = \nabla \times (\mathbf{U} \times \mathbf{B}) - \nabla \times (\eta \nabla \times \mathbf{B})$$

$\rightarrow$ Take the spectrum at various depth in the convective region to estimate the contribution of each scale to the magnetic field generation (See Strugarek et al. 2013)



Conclusion

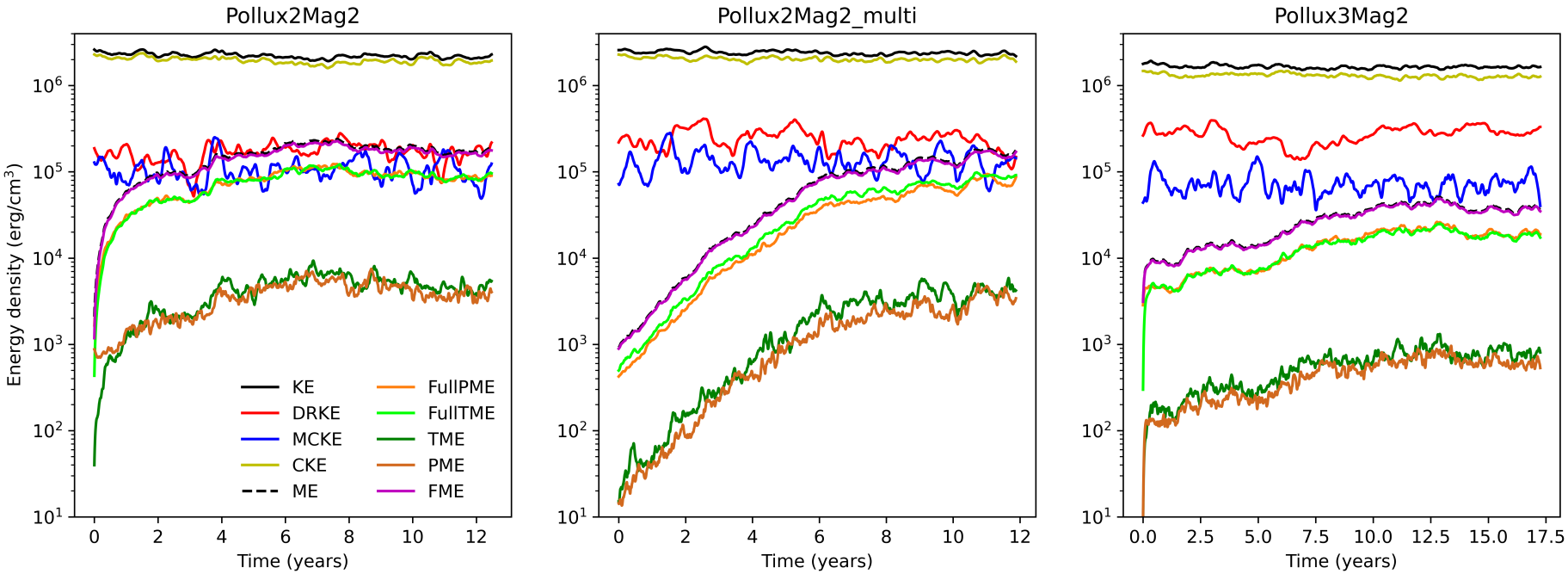
- Very few to no dynamo simulations of red giants
- Larger convective cells appear to be associated to the generation of more intense magnetic field at larger scales
- In the case of Pollux, we did not manage to exactly reproduce the observed magnetic field but found a direction to follow
- Red giants will definitely contribute to the global understanding of the dynamo process !

Recommendations ?

- More observations, keep monitoring the ones we already have (even if scarcer)
- The simulations are heavy and take a long time to run, carefully chose what we want to model
- Explore the Range of even smaller Prandtl number to verify if the trends are still valid

Annexe

Energies evolution with multipolar case



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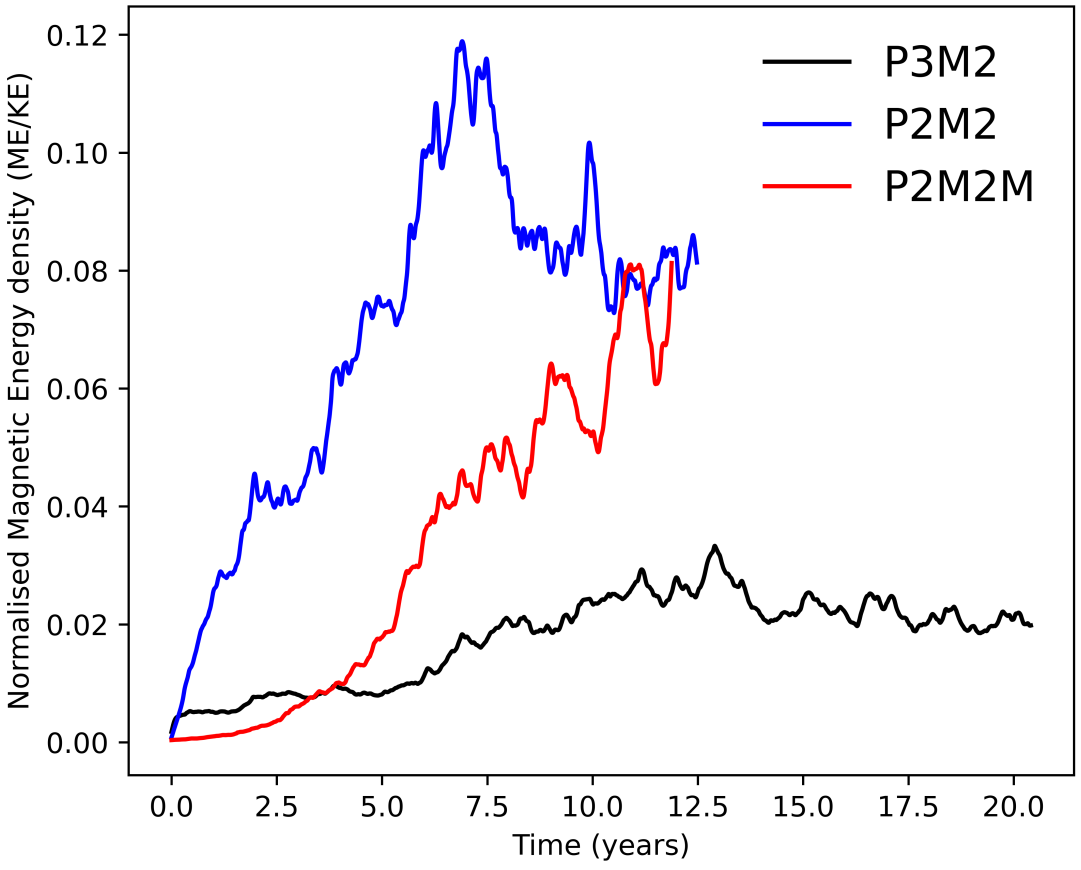
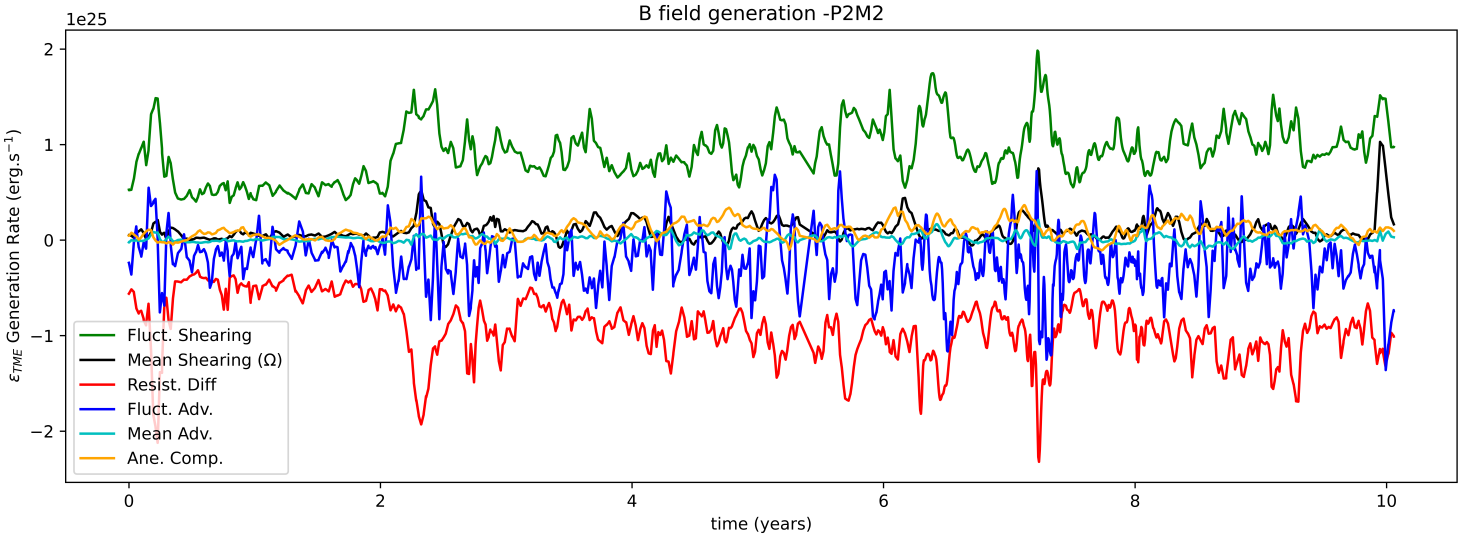
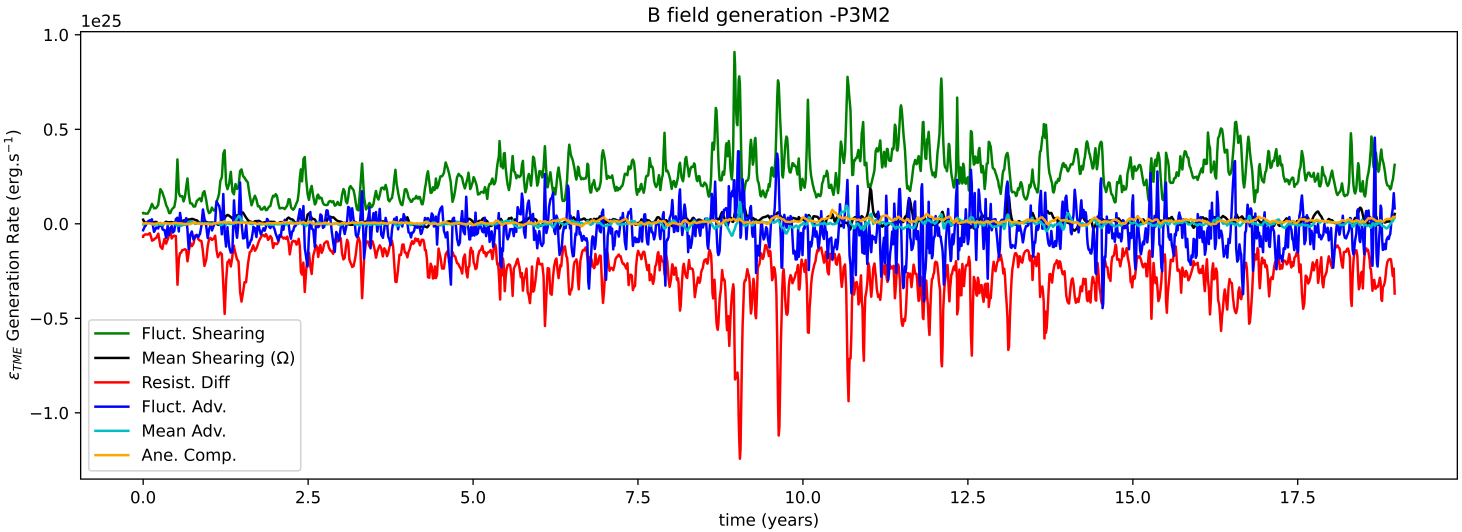


Annexe

B production terms





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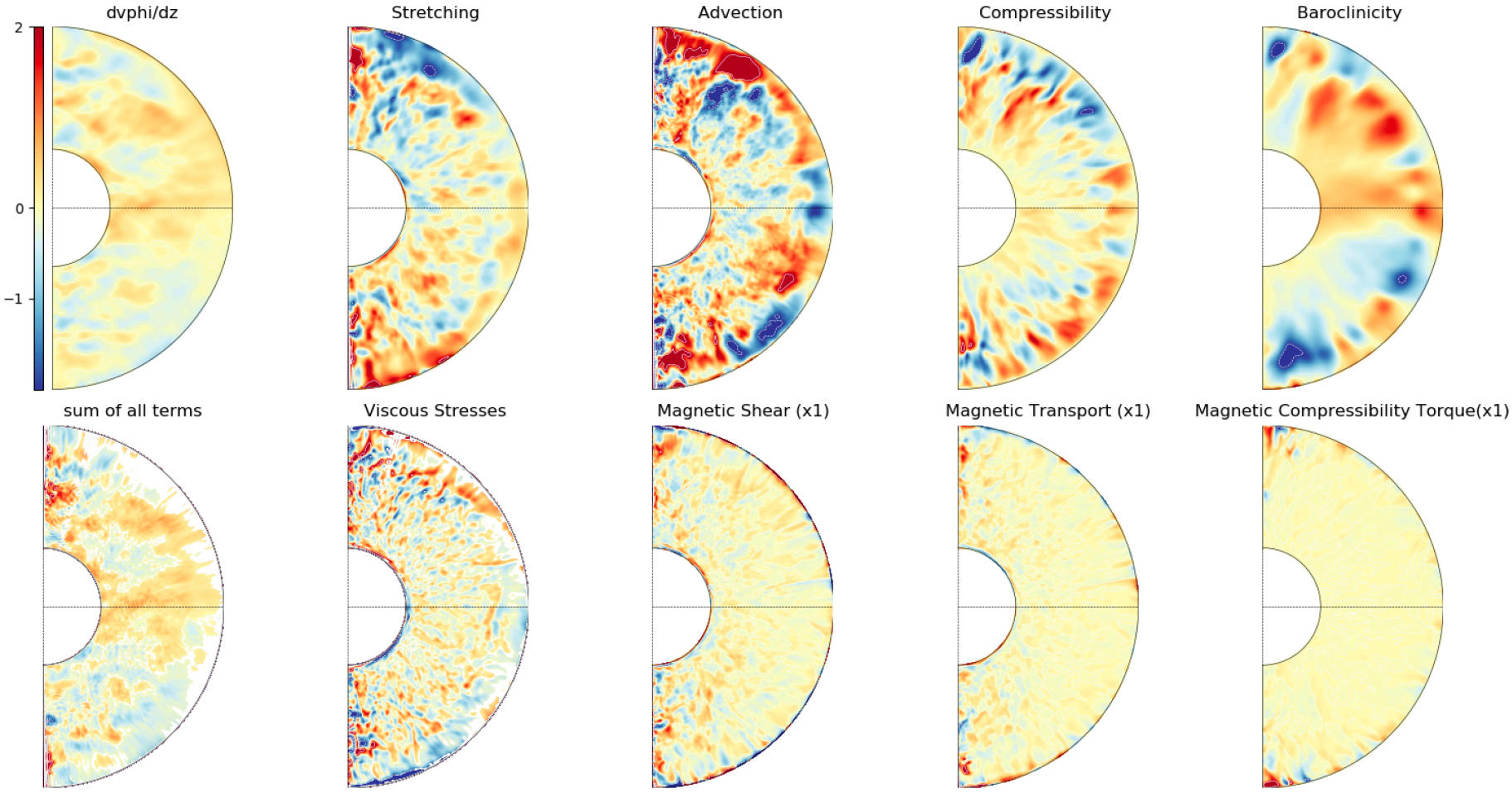
Thermal wind balance P2M2



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