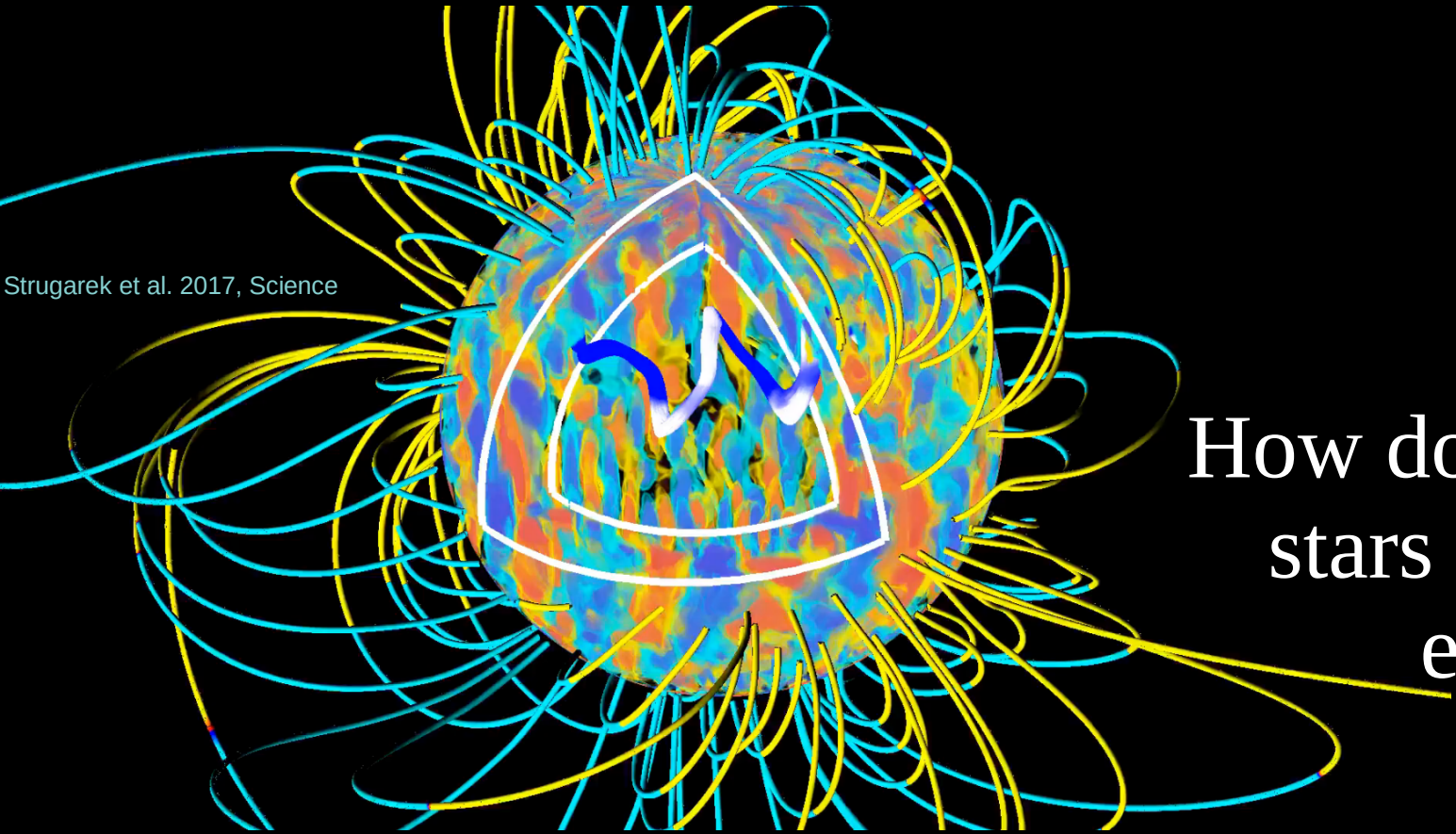
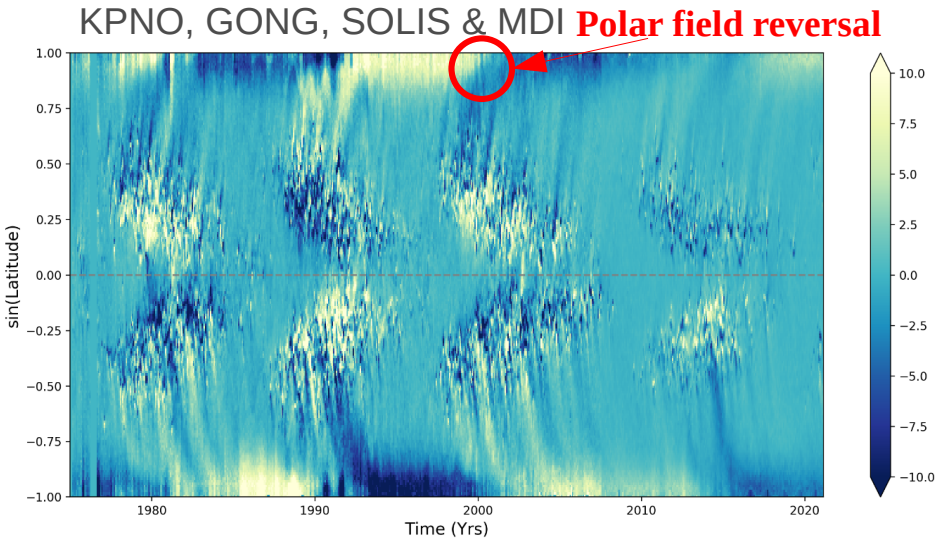
PLATO Conference 2021 - Quentin NORAZ, Allan Sacha BRUN & Antoine STRUGAREK



Strugarek et al. 2017, Science

How does solar-type stars magnetism evolve?

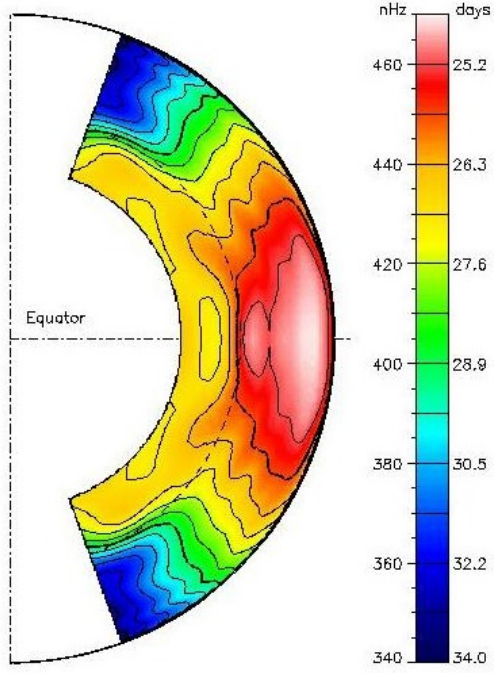
Current Observations :



- 11-years activity cycle
- Migration of structures toward equator
- Opposite hemisphere polarities
- Alternating dipole/quadrupole
- 22-years magnetic cycle

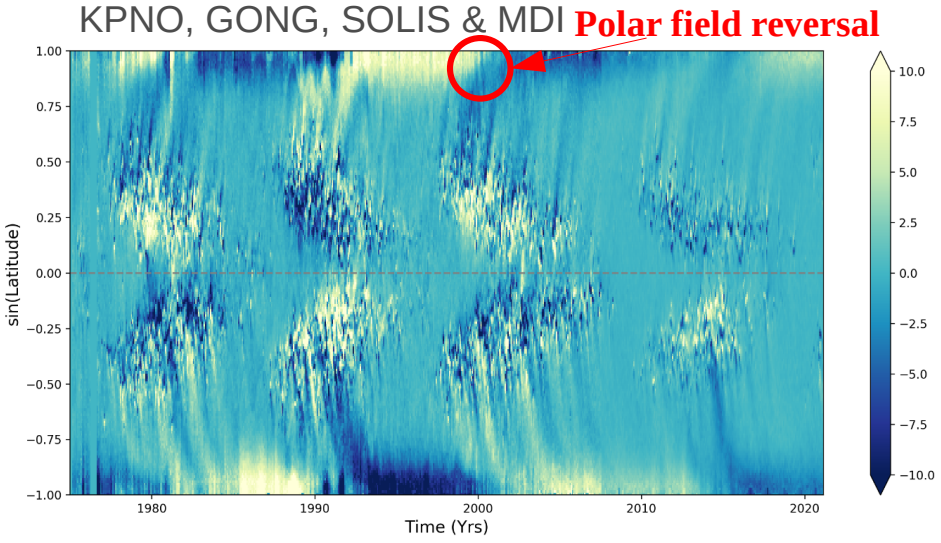
A solid-body rotation of the radiative core, surrounded by a differentially rotating convective envelope

Thompson et al. (2003)



Our star: the Sun

Current Observations :



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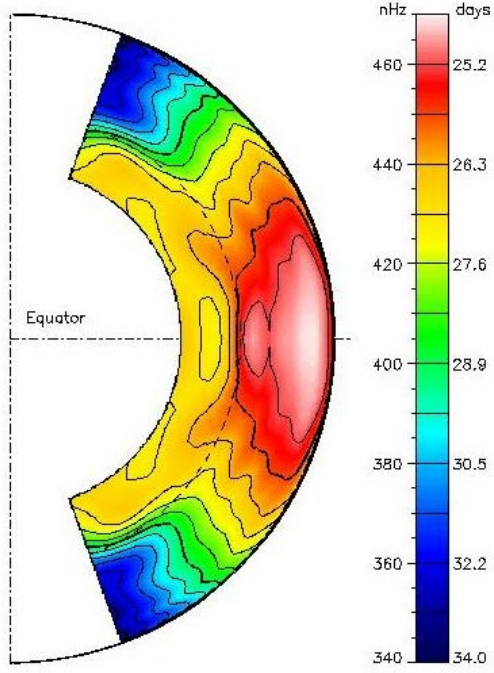
A solid-body rotation of the radiative core, surrounded by a differentially rotating convective envelope

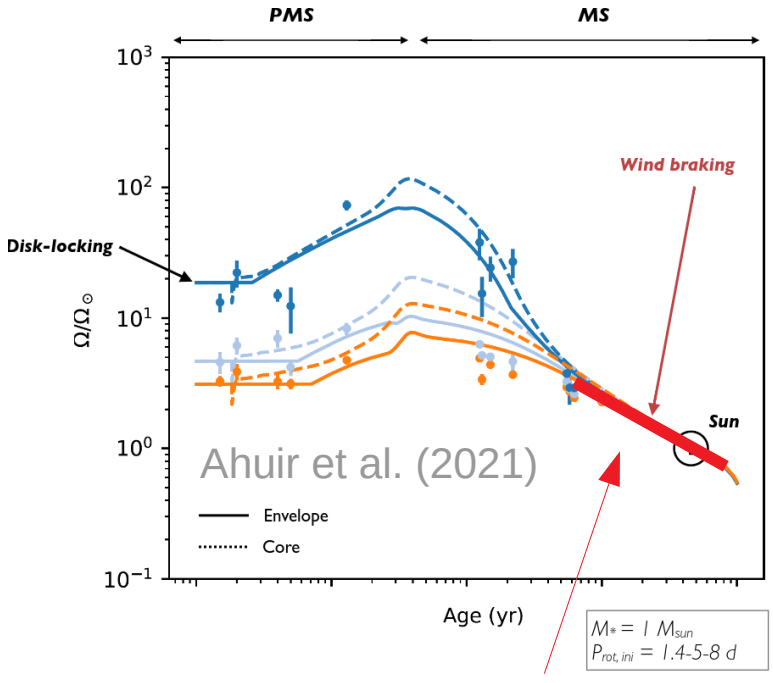
Thompson et al. (2003)

Differential rotation plays a key role for **dynamo mechanism**



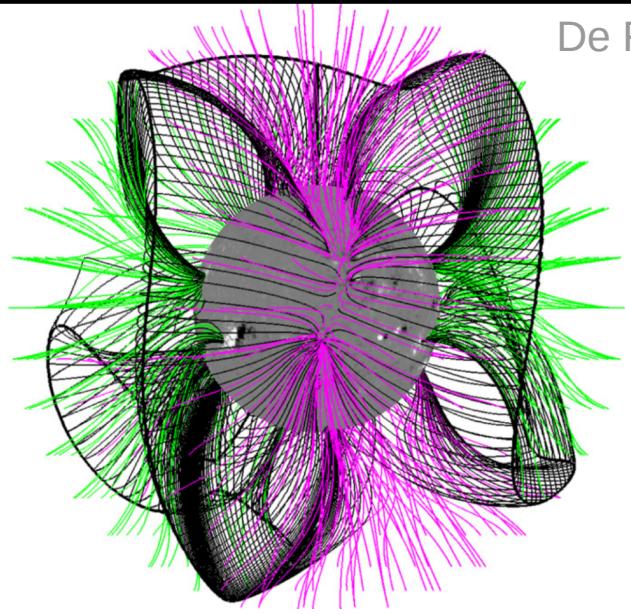
Sun in time: Rotation/Magnetism Retroaction

Stellar rotational evolution model



Dynamo

Wind



De Rosa et al. (2012)

Magnetic activity

Skumanich law: $\Omega(t) \propto t^{-1/2}$

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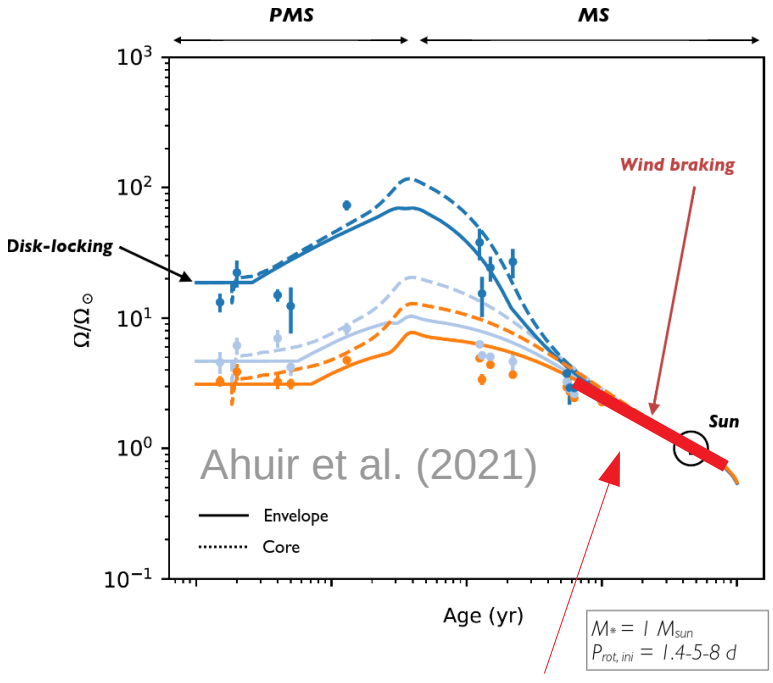

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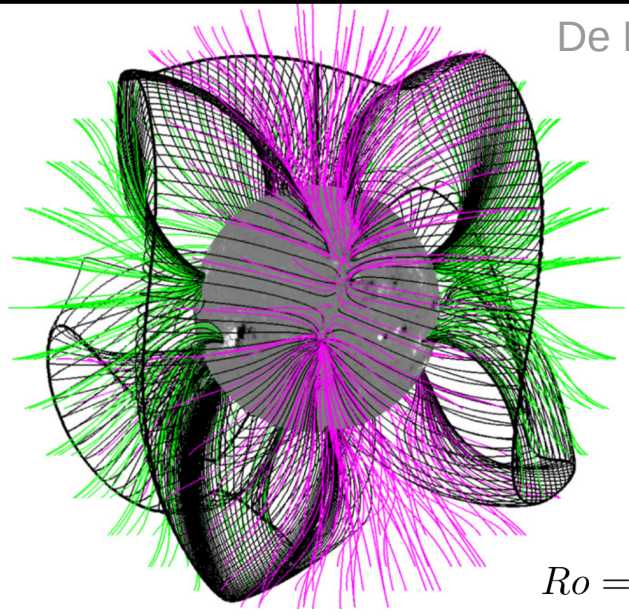


De Rosa et al. (2012)

Magnetic activity

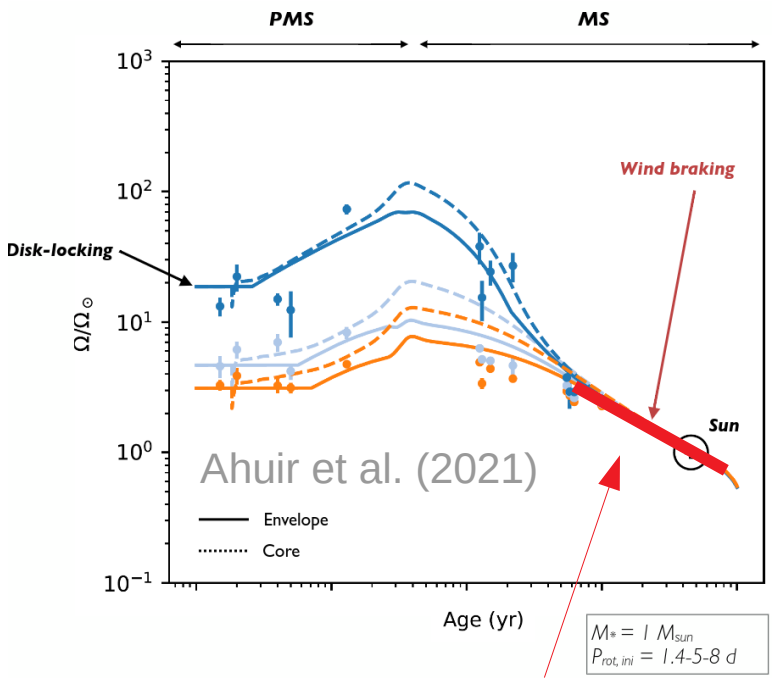
$B_{ZDI} \propto Ro^{-1.4}$

See et al. (2019)
Vidotto et al. (2021)

$$Ro = \frac{v}{2\Omega L} \sim \frac{\text{Advection}}{\text{Coriolis}}$$

Sun in time: Rotation/Magnetism Retroaction

Stellar rotational evolution model



Ahuir et al. (2021)

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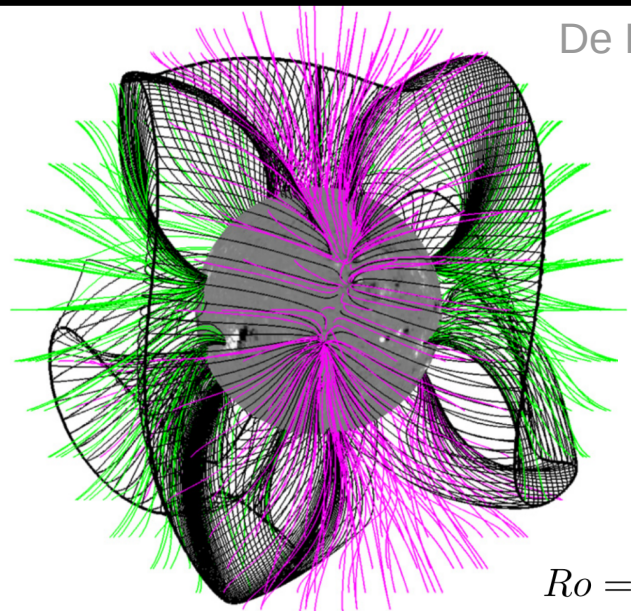

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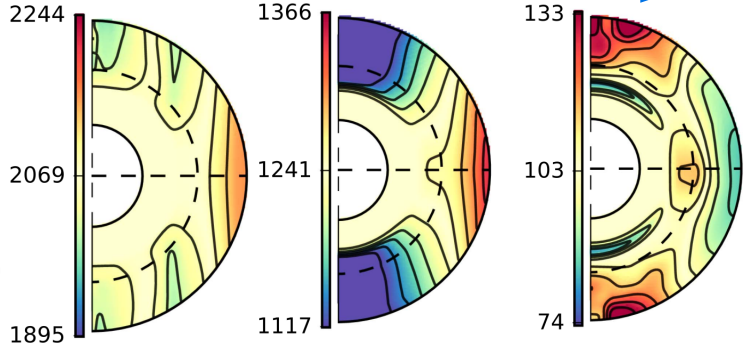
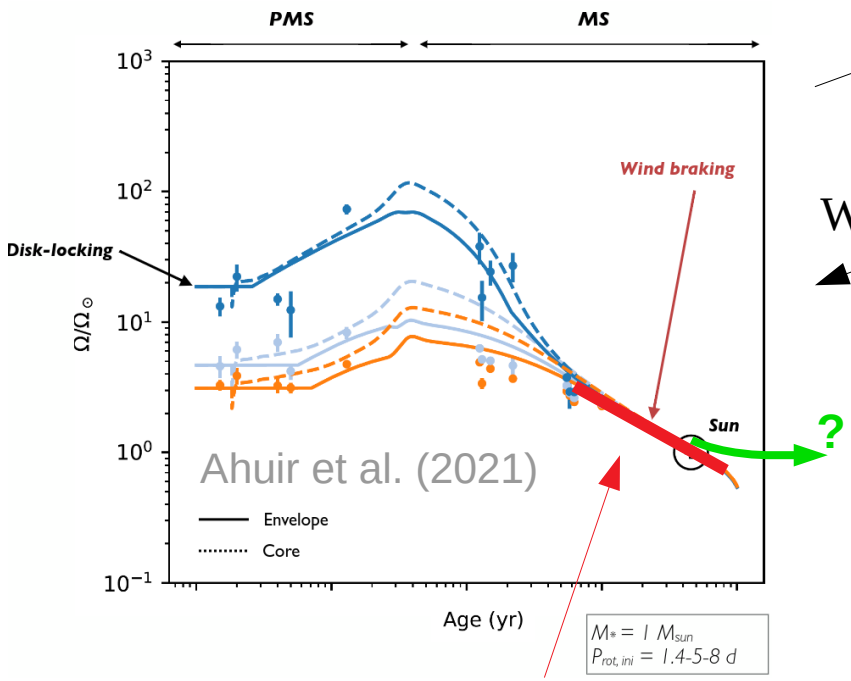


Brun et al. (2017)

Sun in time: Rotation/Magnetism Retroaction

Stellar rotational evolution model



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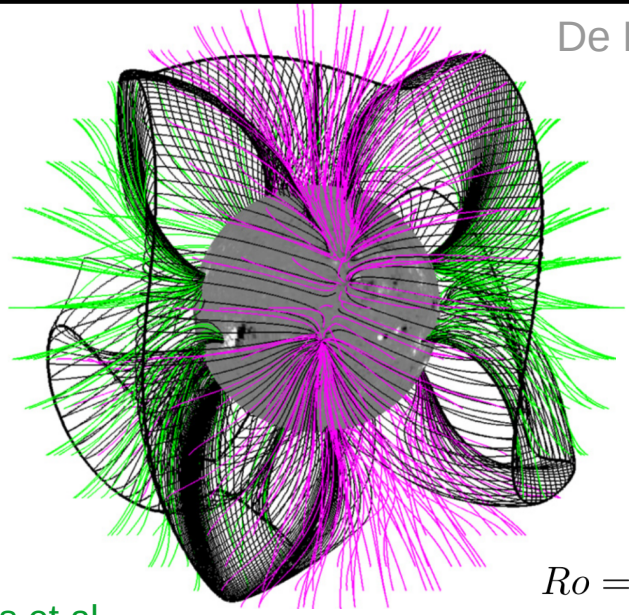
Dynamo

Wind

van Saders et al. 2016

?



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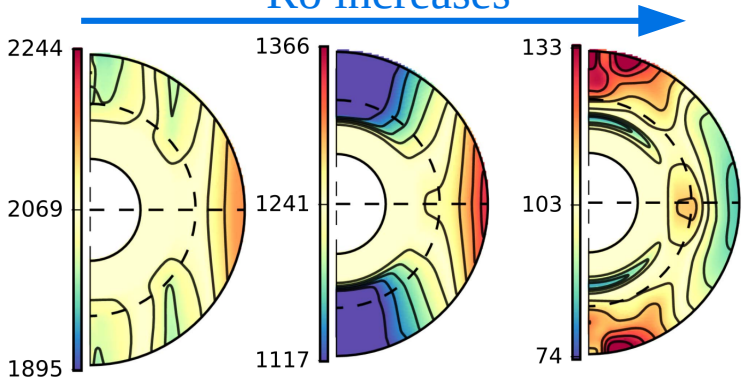

Brun et al. (2017)

Dynamo Mechanism

Dynamo effect:
The ability of a conductive fluid (plasma) to amplify and maintain a magnetic field against its ohmic dissipation.

$$\frac{\partial \mathbf{B}}{\partial t} = \boxed{\nabla \times (\mathbf{v} \times \mathbf{B})} - \boxed{\nabla \times (\eta \nabla \times \mathbf{B})}$$

Induction

Dissipation

Dynamo Mechanism

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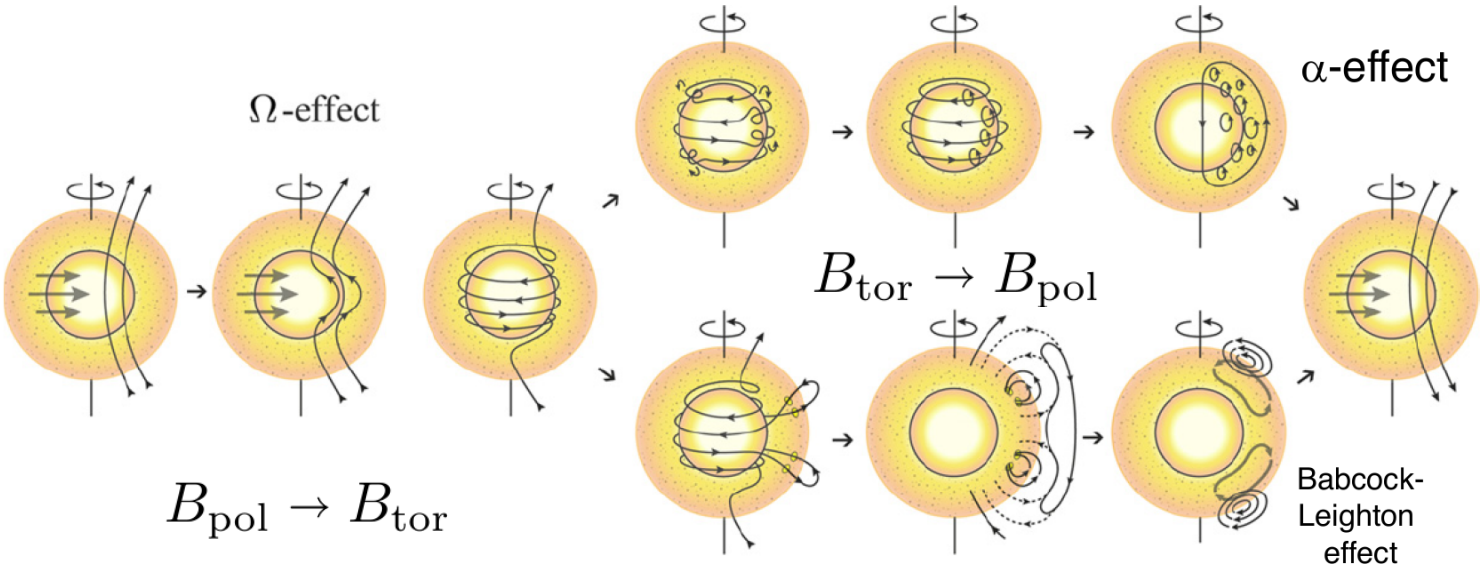
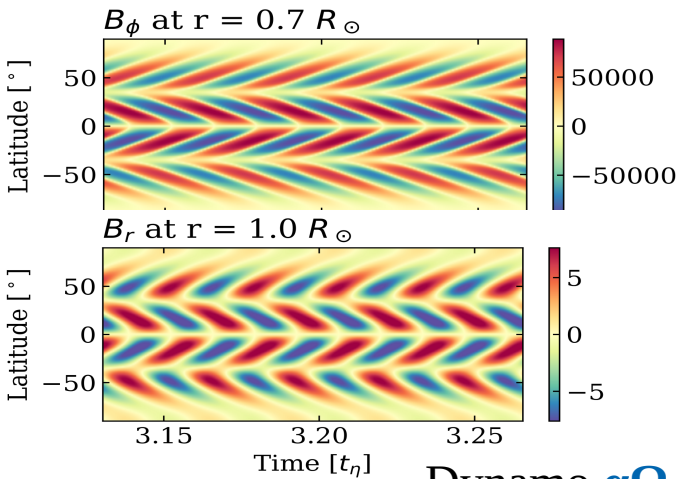
Induction Dissipation



Sanchez et al. (2014)

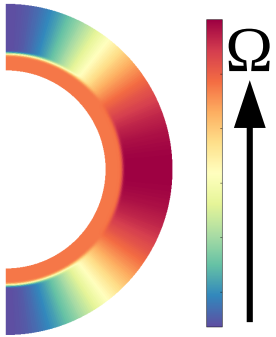
2D Kinematic Approach: Solar reference cases



Dynamo **αΩ**

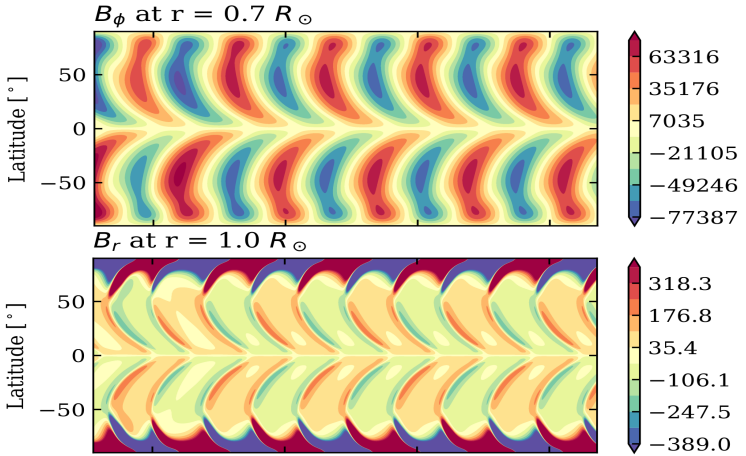
$$\boldsymbol{s} = r \sin\theta \alpha \cdot \boldsymbol{e}_\phi \times \nabla\Omega$$

Parker-Yoshimura

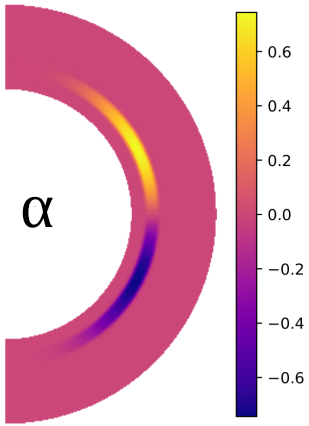


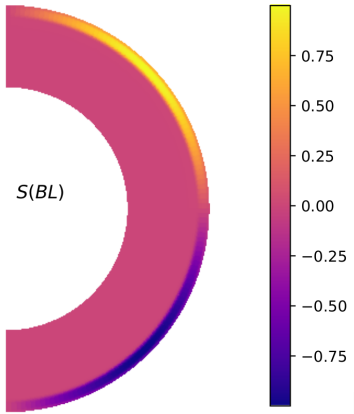
Solar

Rotation profile



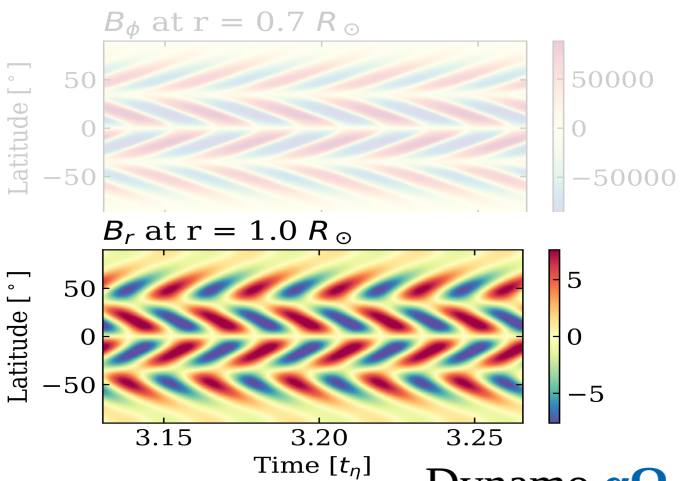
Dynamo Babcock-Leighton + MC





Noraz et al. (submitted)

2D Kinematic Approach: Solar reference cases



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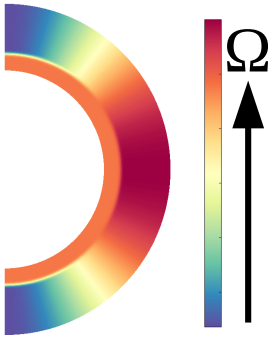
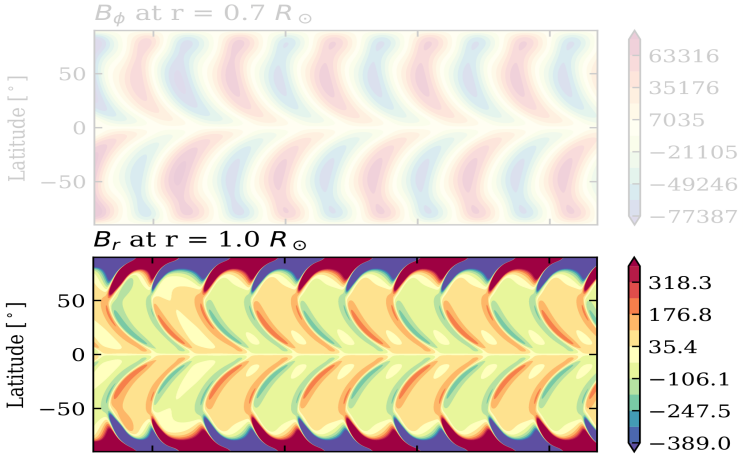
Parker-Yoshimura



Solar

Rotation profile



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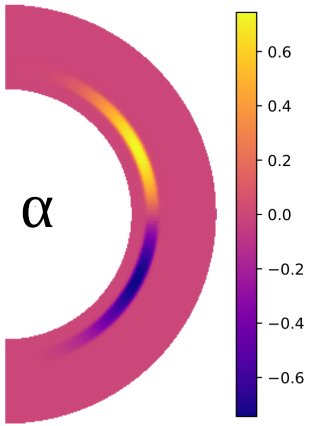
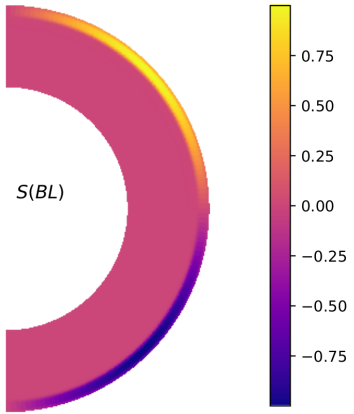
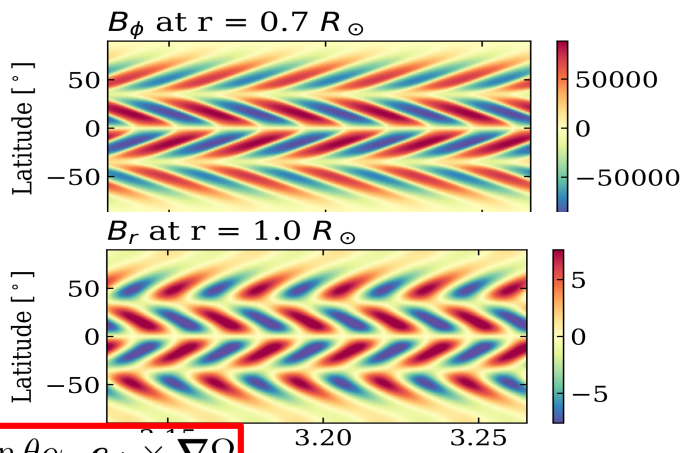




Noraz et al. (submitted)

2D Kinematic Approach: Application to the anti-solar DR



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Parker-Yoshimura

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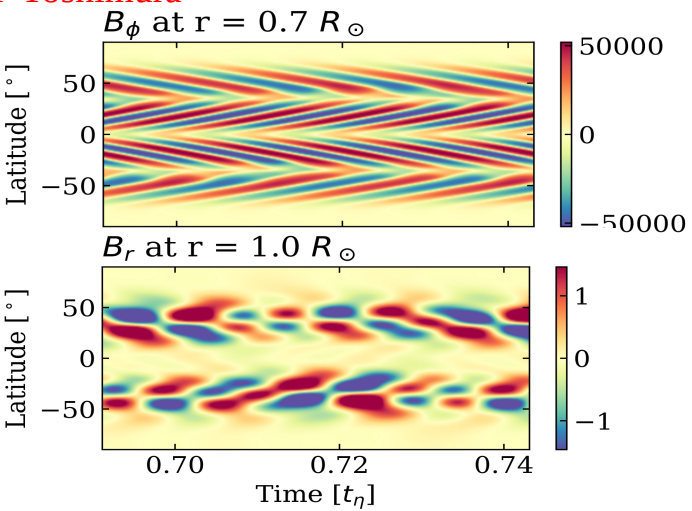

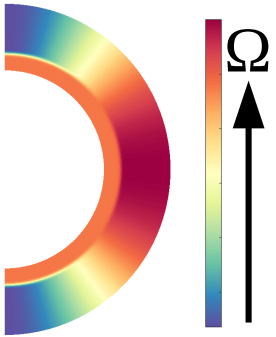

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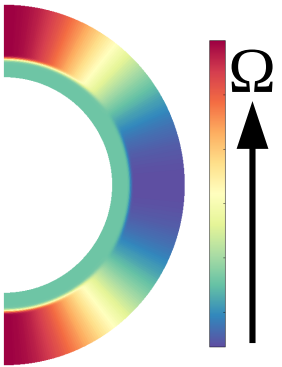
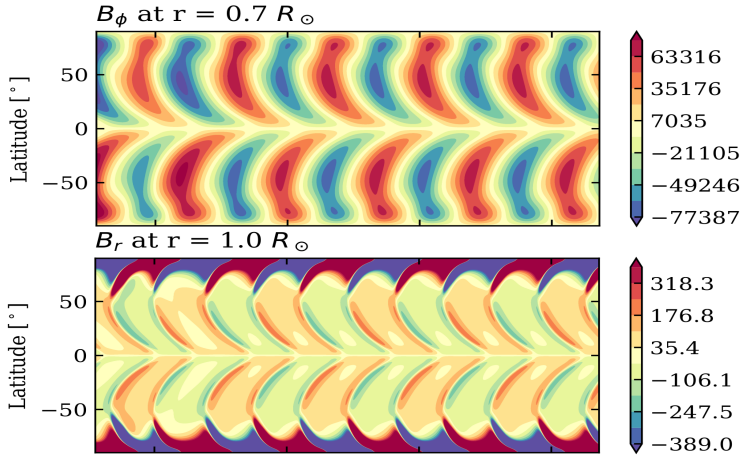
Rotation profile



Anti-solar

Rotation profile



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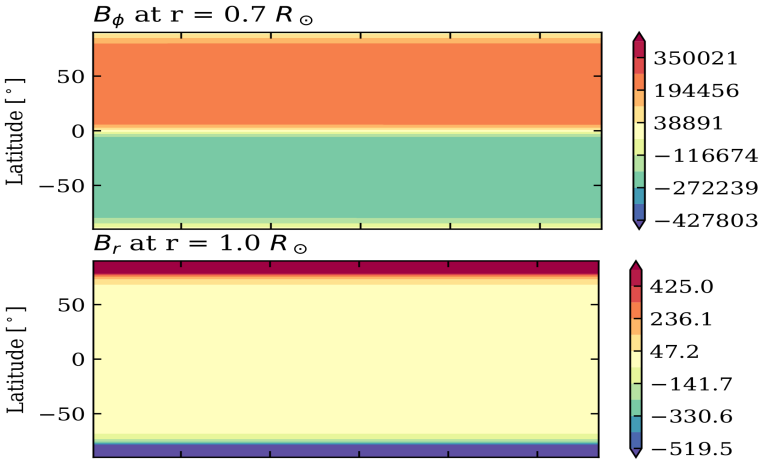
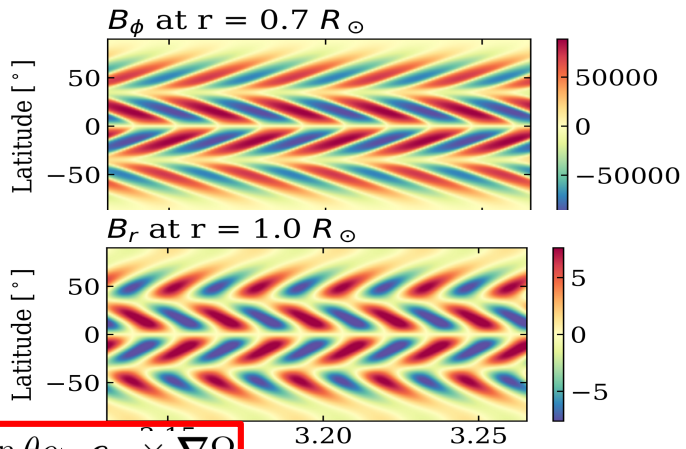


Noraz et al. (submitted)

2D Kinematic Approach: Application to the anti-solar DR



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Parker-Yoshimura

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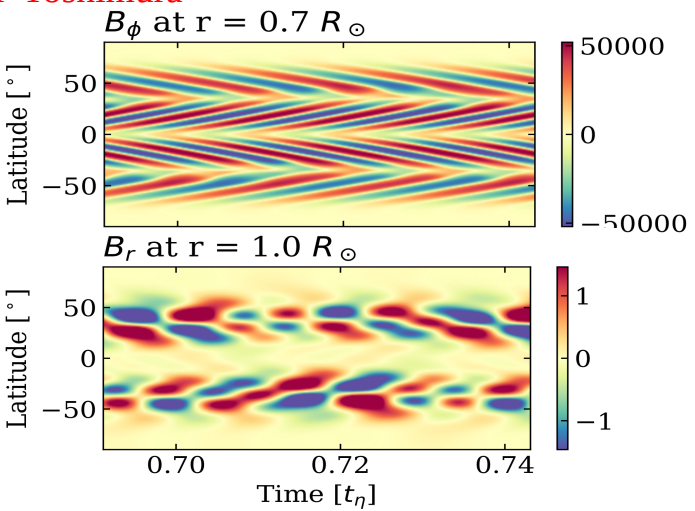

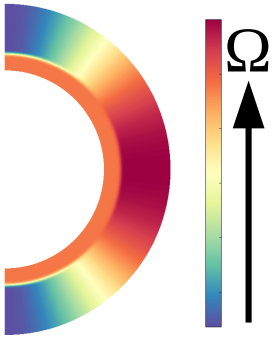

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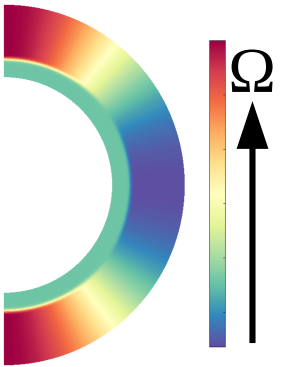


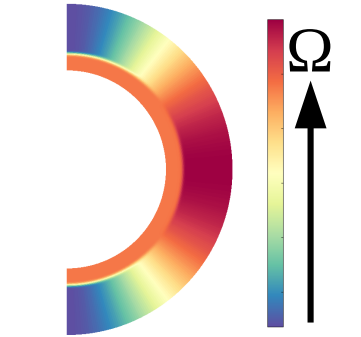
Anti-solar

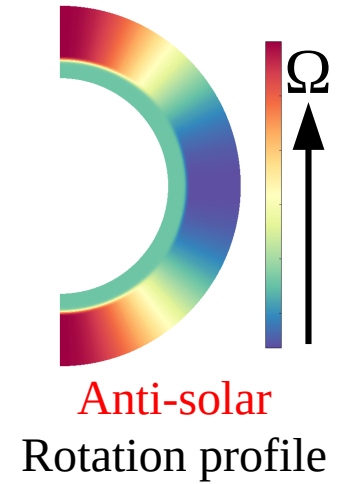
Rotation profile

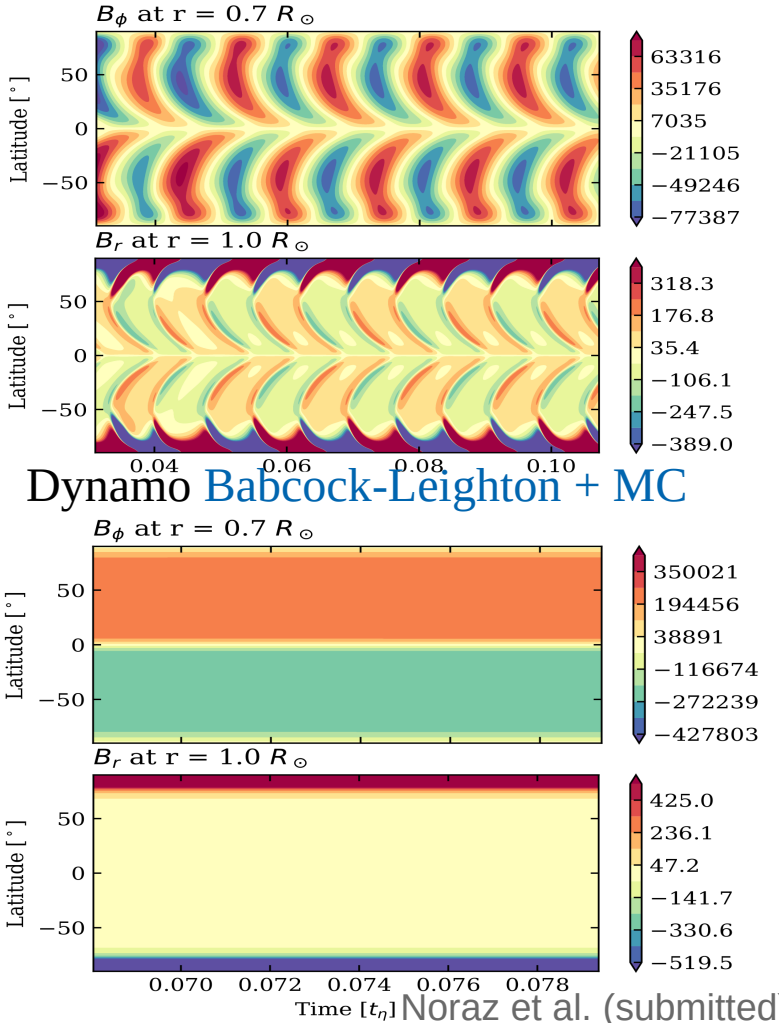
Dynamo Babcock-Leighton + MC

Noraz et al. (submitted)

2D Kinematic Approach: Application to the anti-solar DR







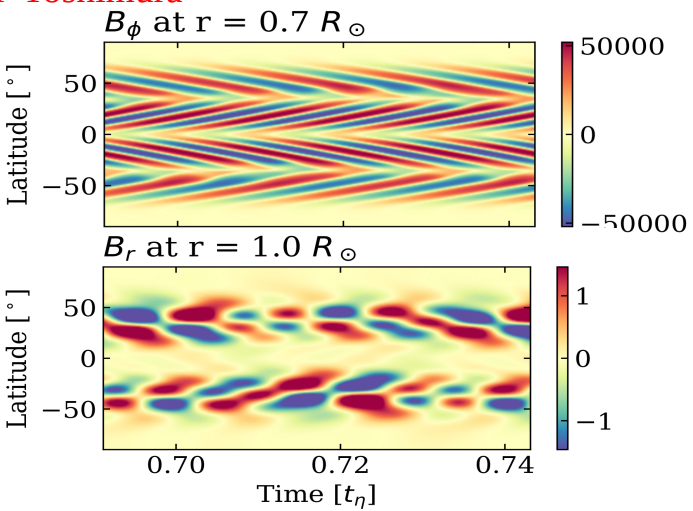
2D Kinematic Approach: Application to the anti-solar DR

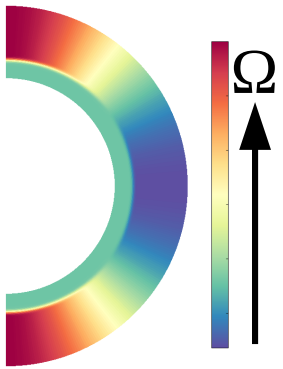
The dynamo still occurs,
but how is the magnetic cycle lost?

$$\boldsymbol{s} = r \sin\theta \alpha \cdot \boldsymbol{e}_\phi \times \boldsymbol{\nabla}\Omega$$

Parker-Yoshimura

Dynamo **αΩ**





Anti-solar

Rotation profile

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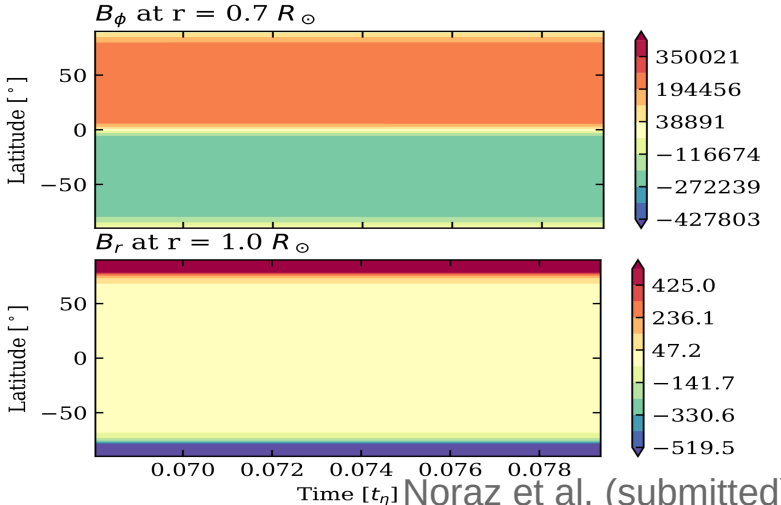
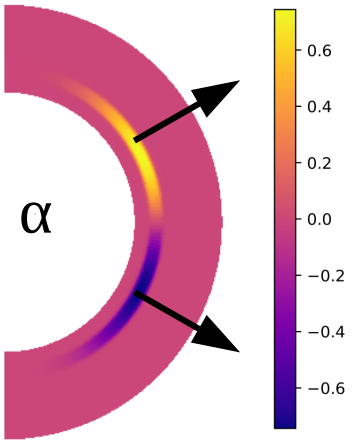
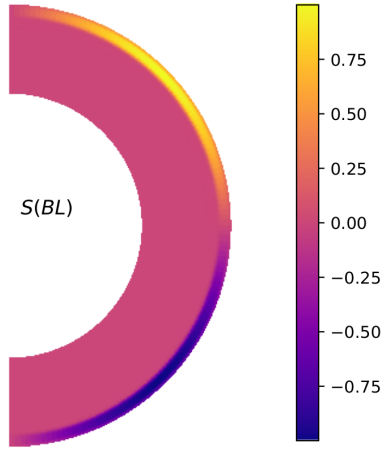


Noraz et al. (submitted)

2D Kinematic Approach: Localisation of the Dynamo



α-effect location:
From the tachocline to the surface



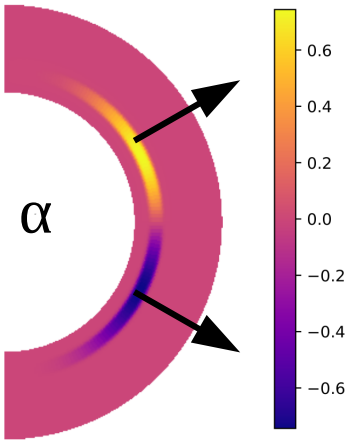
α-source

Babcock-Leighton source

Noraz et al. (submitted)

2D Kinematic Approach: Localisation of the Dynamo

For **anti-solar DR** the dynamo becomes **stationnary** once
α is leaving the tachocline (*ie*. the radial shear)



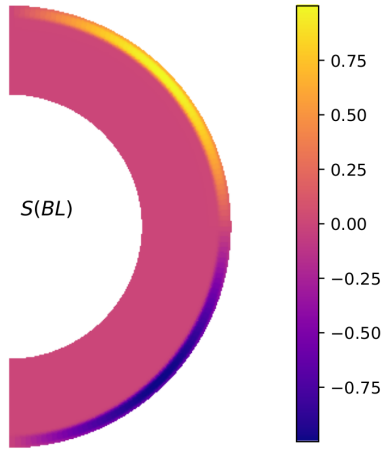
α-source

r_1 - r_2	⊙	anti-⊙
0.9 - 1	7.3	×
0.8 - 1	25.1	×
0.7 - 1	32.4	×
0.8 - 0.9	15.5	×
0.7 - 0.9	26.8	×
0.7 - 0.8	64.9 (9.7)	×
0.68 - 0.74	15.8	9.0
0.67 - 0.73	**31.8**	**17.7**

CZ

tachocline

Table 3. The α-effect is spread through the tachocline and CZ for solar and anti-solar DR regimes. Magnetic cycle periods are expressed in years.

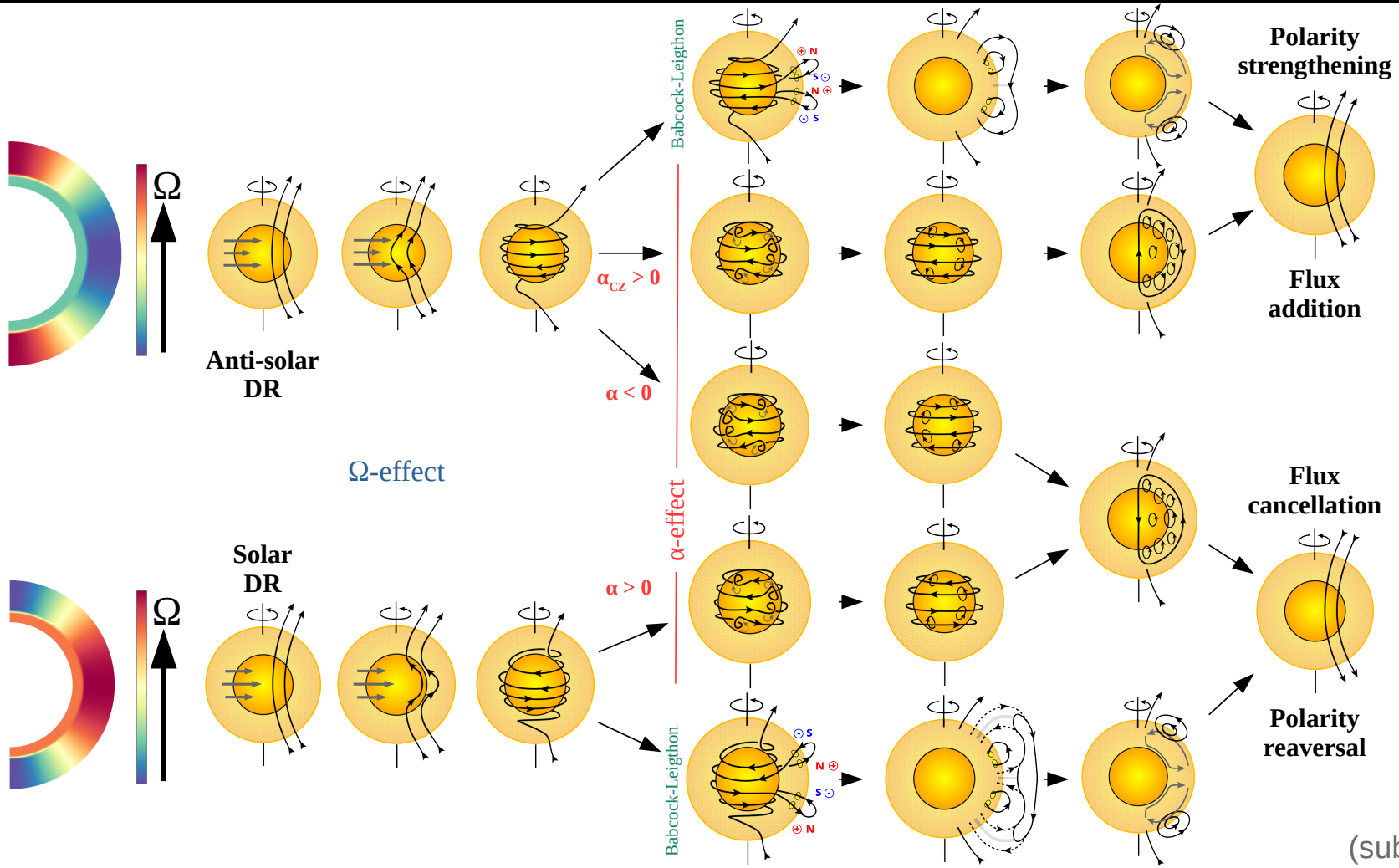


Babcock-Leighton source

Robustness over other parameters change
(Meridional circulation, diffusion, shear or process amplitudes...)

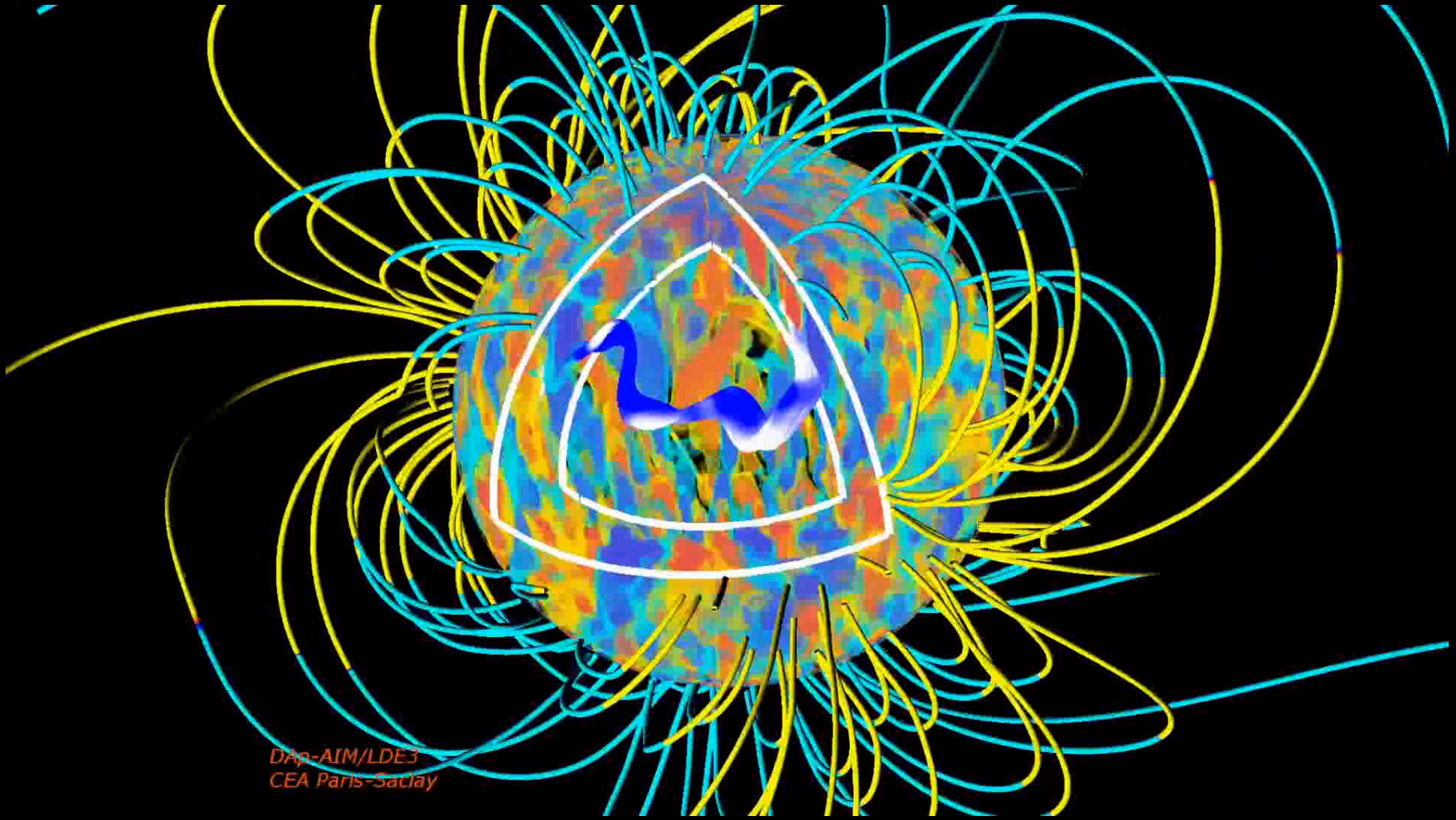
Noraz et al. (submitted)

2D Kinematic Approach: Localisation of the Dynamo

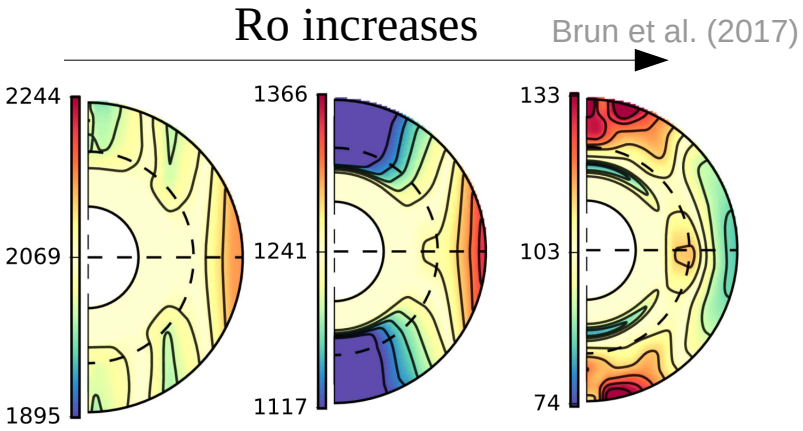


Noraz et al. (submitted to A&A)

From 2D Kinematic to Global 3D MHD turbulent dynamo



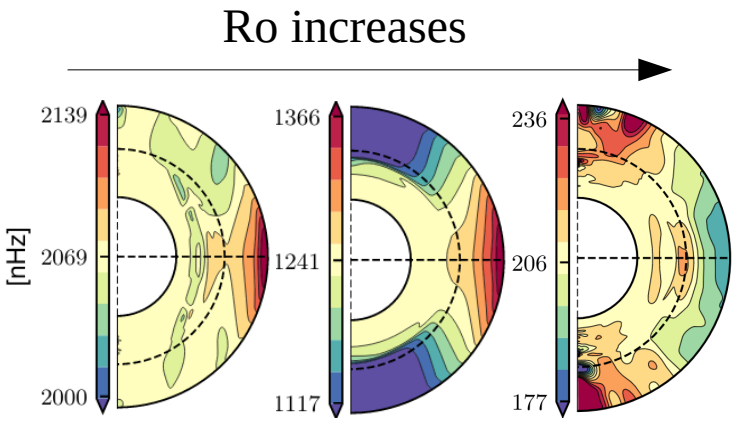
Differential Rotation along the Rossby number

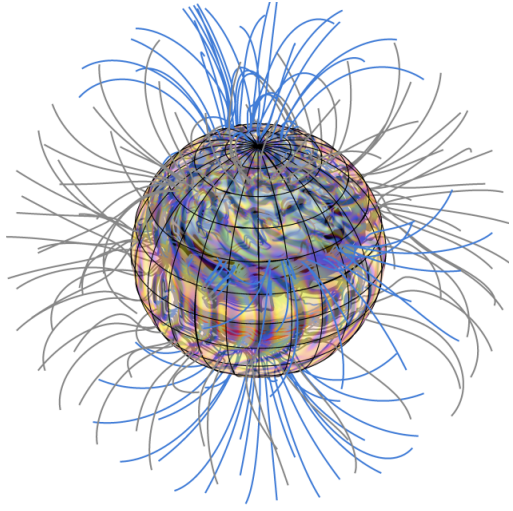


Brun et al. (2017)

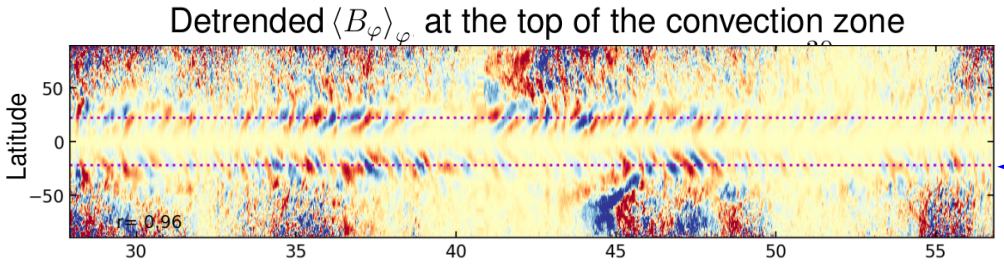
MHD

Brun et al. (2021)

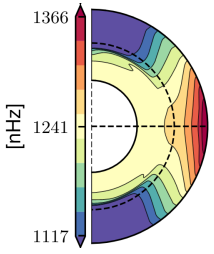


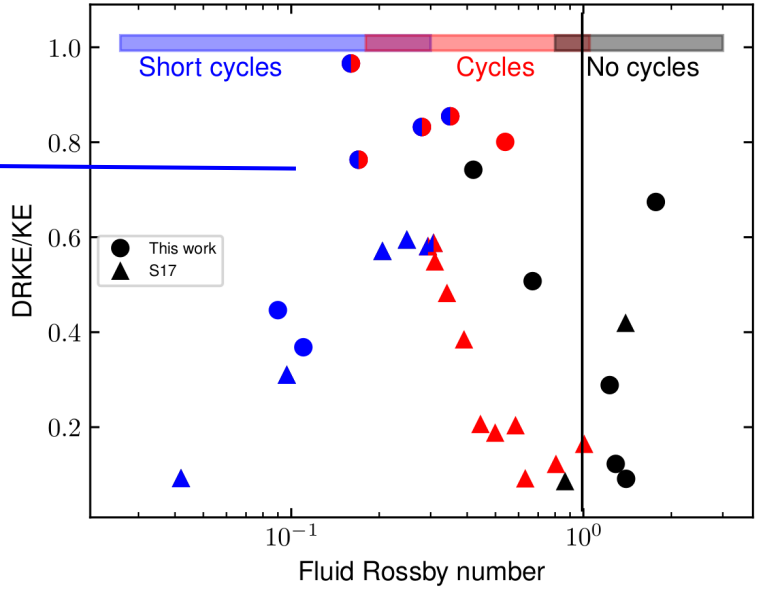


Role of the rotation on dynamos



- short cycles (~year) ; **quasi-biennial oscillations ?**
- surface dynamo
- Parker-Yoshimura type





Brun et al. (2021)

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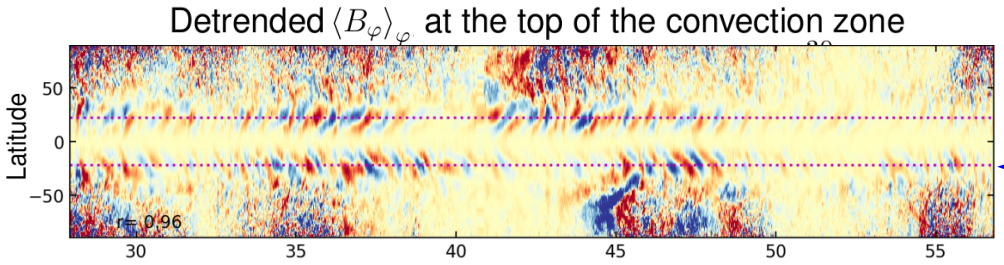

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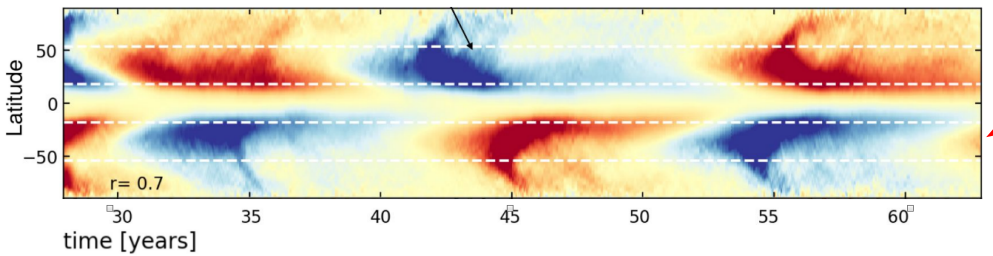
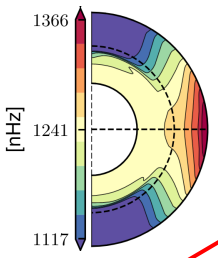
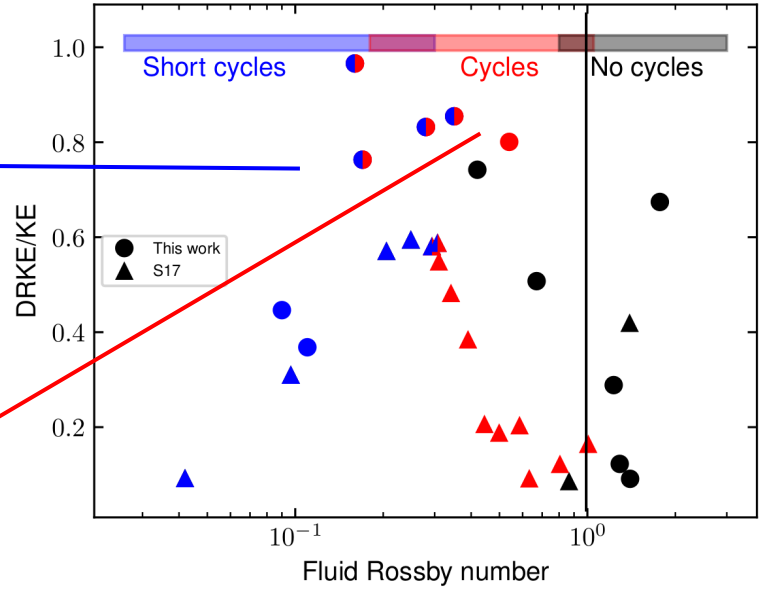


$\langle B_\varphi \rangle_\varphi$ at the base of the convection zone

- long cycles (**decadal solar-like**)
- deeper dynamo
- non-linear retroaction





Brun et al. (2021)

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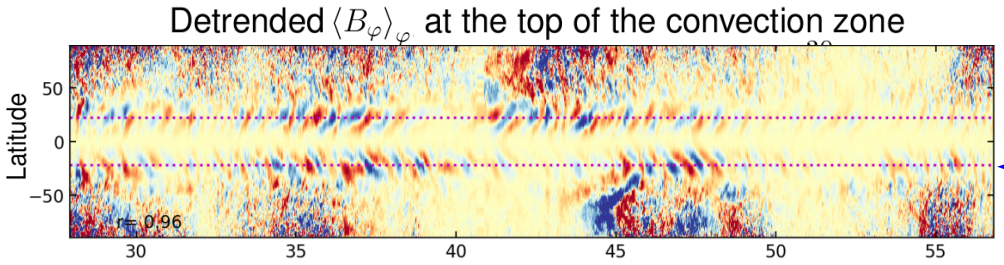

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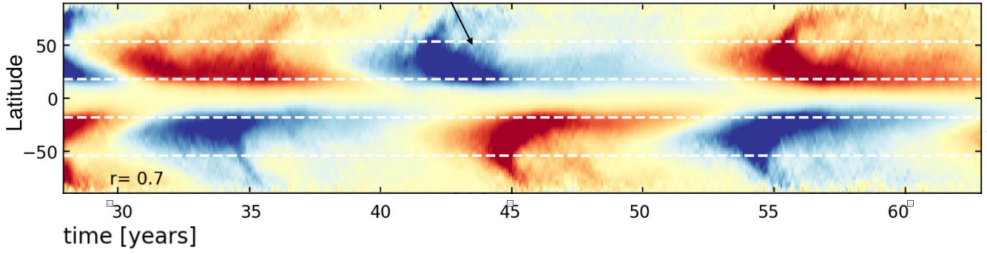

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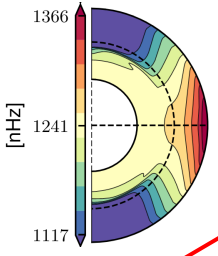
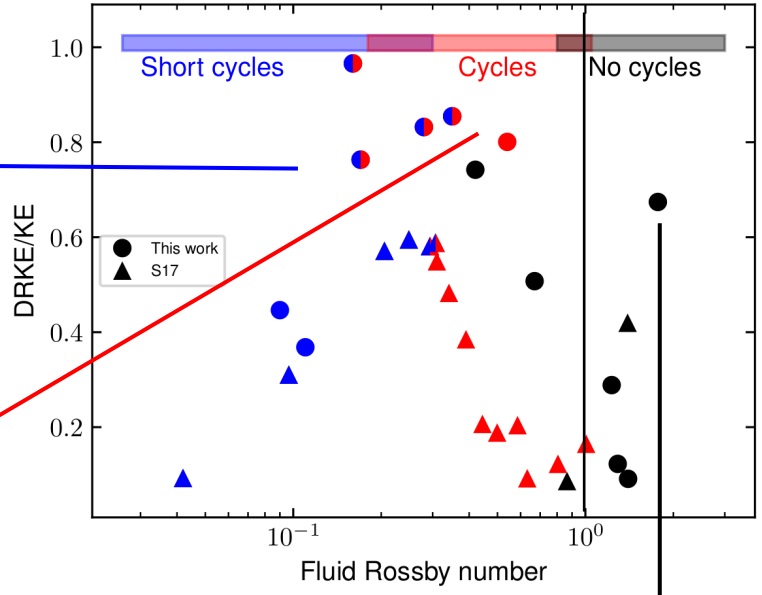
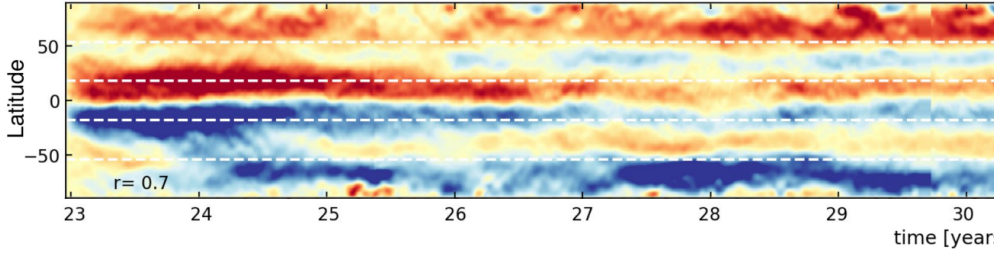
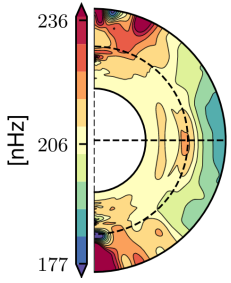




- **Stationnay** dynamo
- Strong deep toroidal field

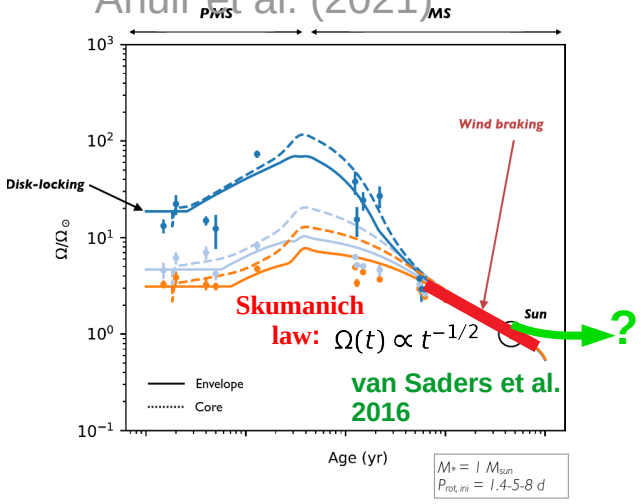




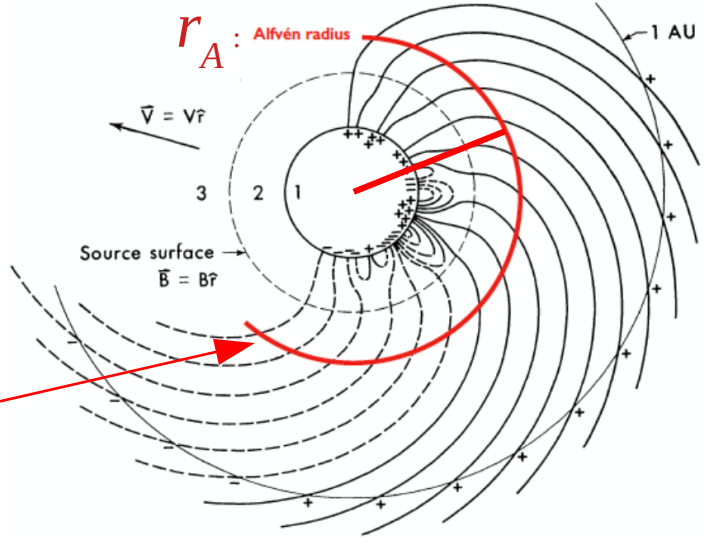
Brun et al. (2021)

Weakened Magnetic Wind Breaking ?

Ahuir et al. (2021)



Schatten et al. (1969)



Angular momentum loss

$$\dot{J} \propto \dot{M}\Omega_* \langle r_A \rangle^2$$

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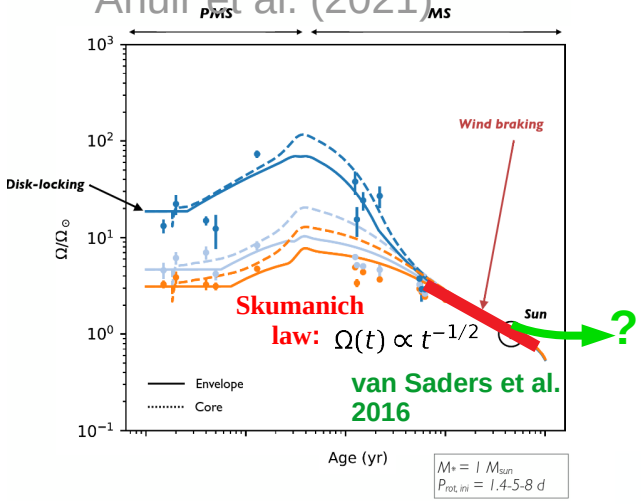
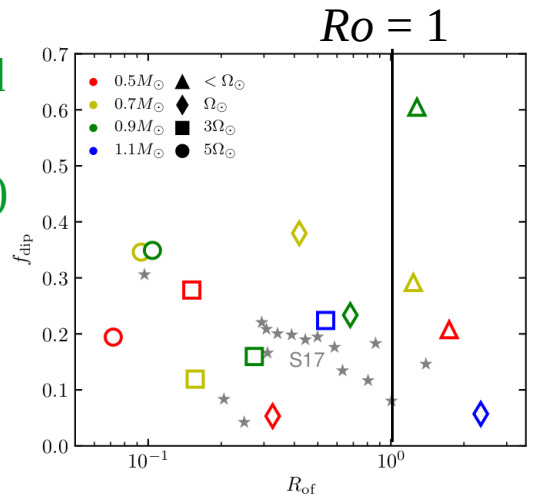


No sign of weakened large-scale field (i.e. no weakened r_A)



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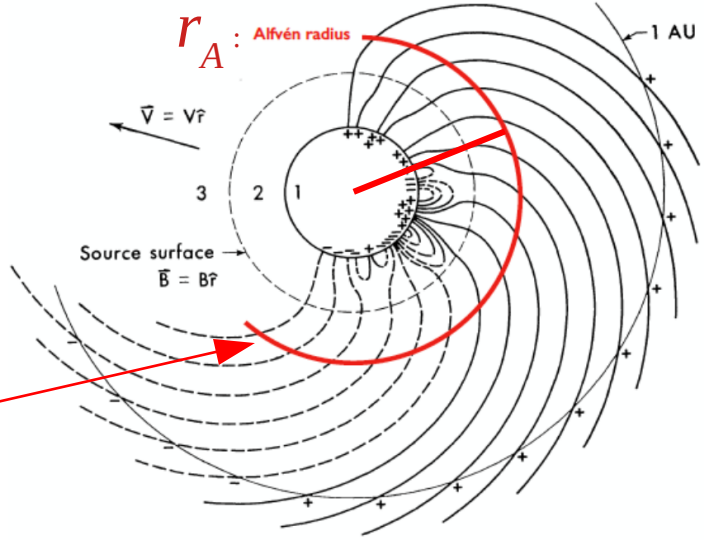

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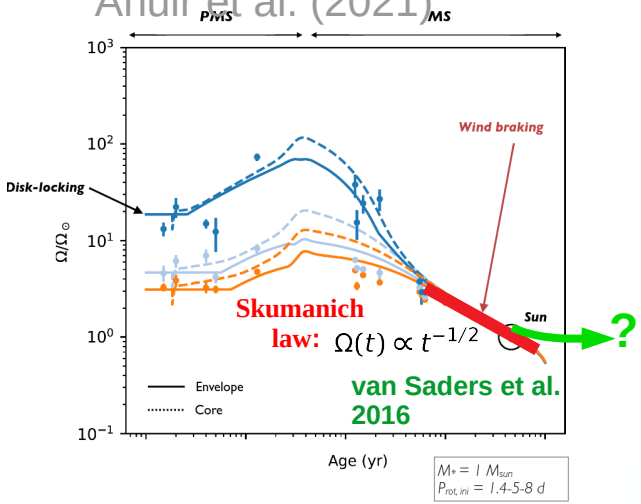

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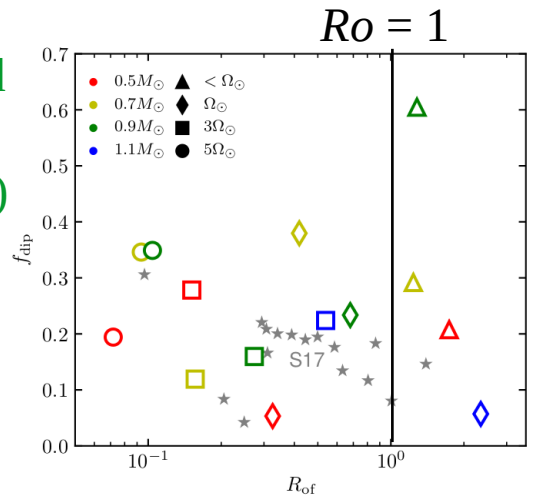

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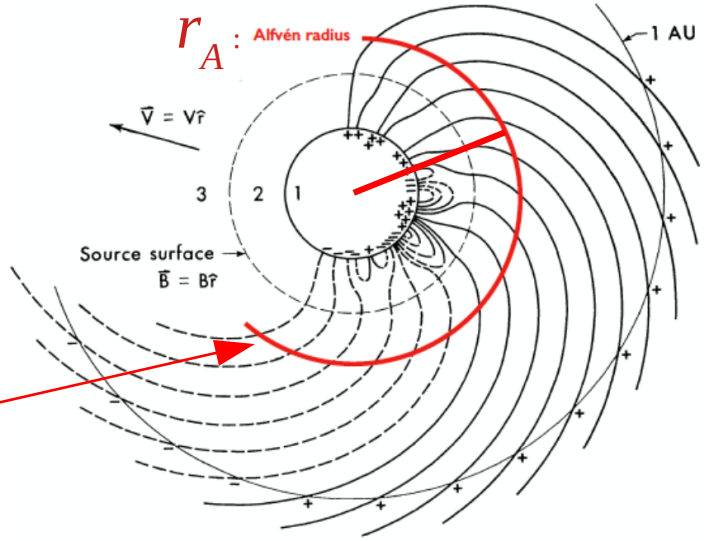
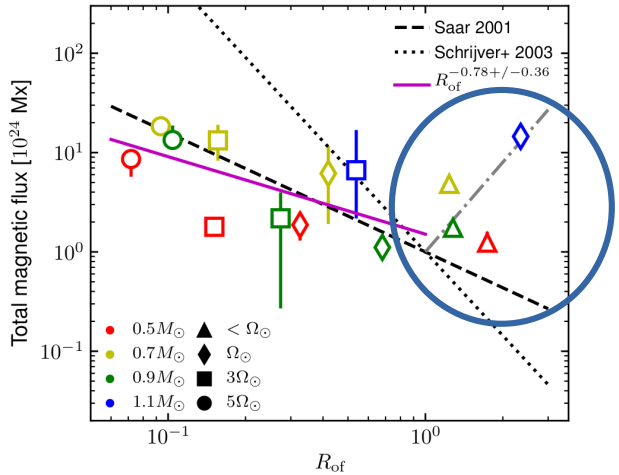


Brun et al. (2021)



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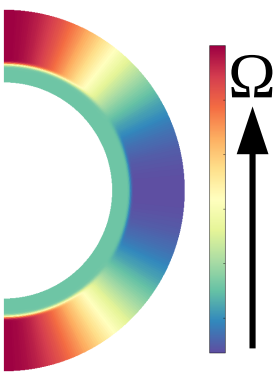
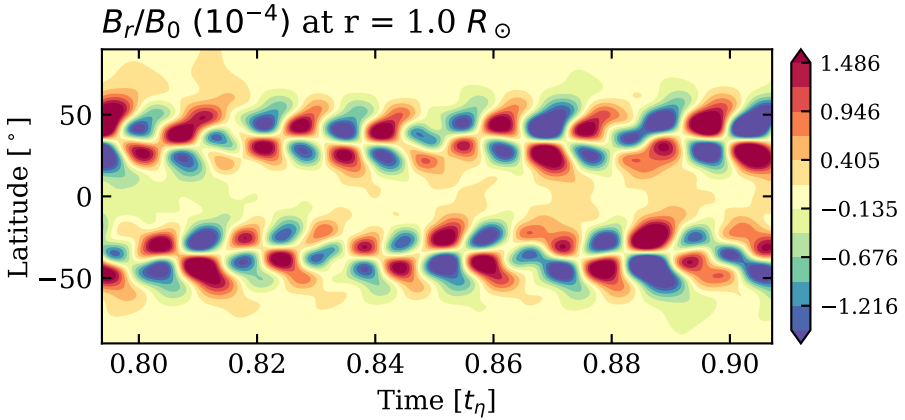
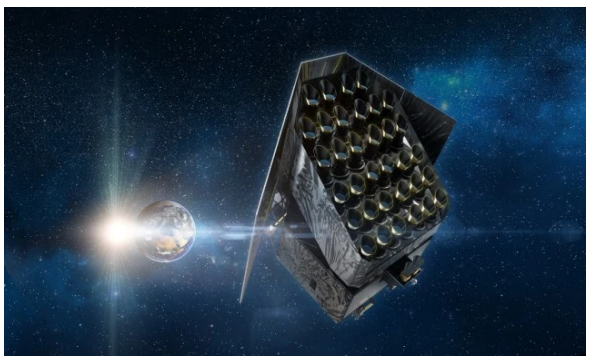
Conclusions

- We present a numerical **multi-D study** with the STELEM and ASH codes to understand the **magnetic field generation** of solar-like stars under **various differential rotation** regimes, and focus on the existence of **magnetic cycles.**

- **Magnetic cycles** can be produced with **anti-solar differential rotation only if the alpha effect is fine tuned** for this purpose in mean-field models.



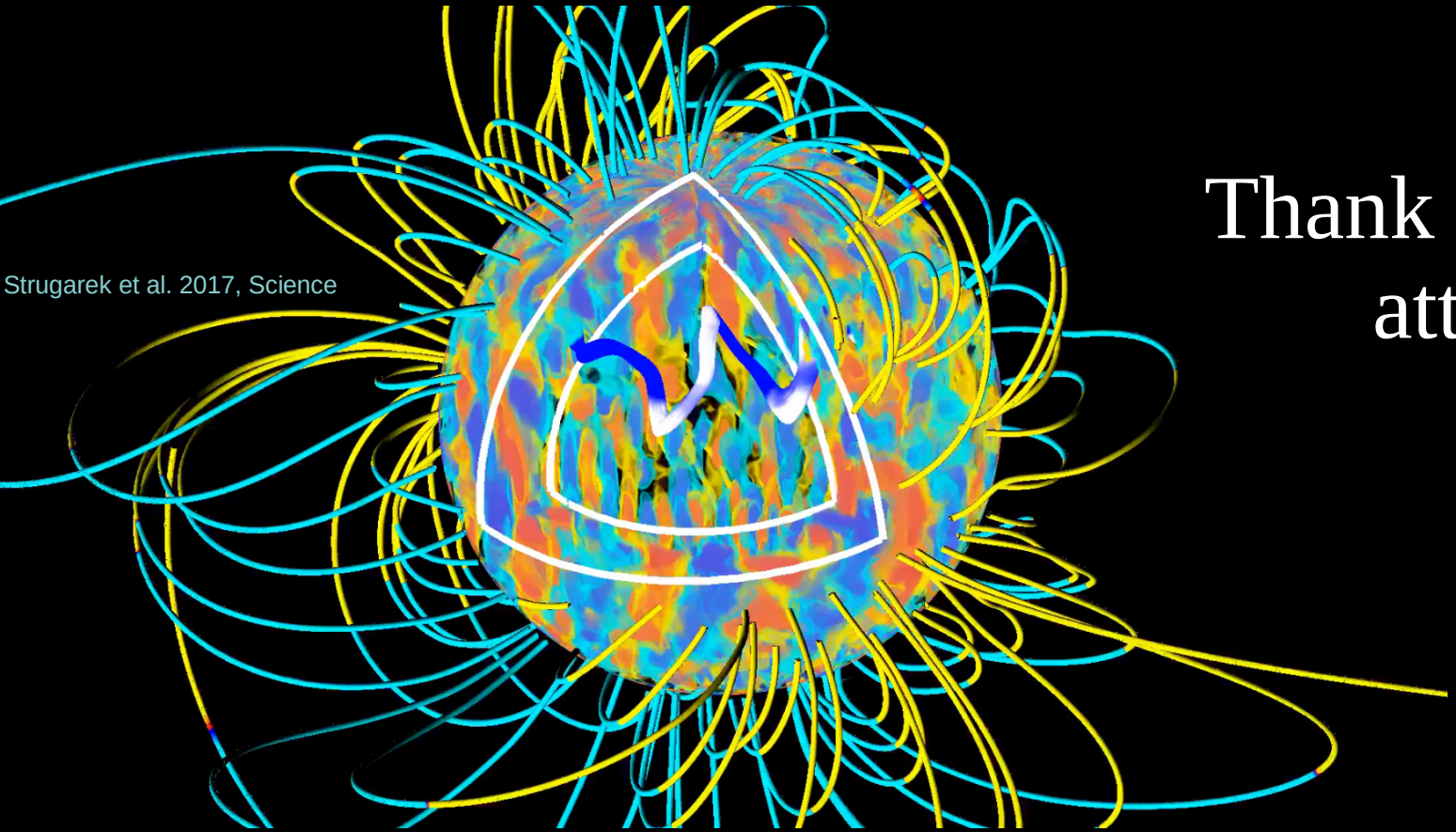




WP123400
differential rotation and dynamo

- A **detection of magnetic cycles for such stars** (or lack of thereof) would therefore be a **tremendous constrain** on deciphering **what type of dynamo** is actually acting in the Sun and solar-type stars.

Brun et al. (2021), Noraz et al. (submitted)



Strugarek et al. 2017, Science

Thank you for your attention !