From the tachocline into the heliosphere

Coupling a 3-d kinematic dynamo to coronal models

Anthony Yeates
with Andrés Muñoz-Jaramillo (Montana State University)

"CAJ65" Meeting, Newcastle, 29-Aug-14

Summary

- Developed a 3-d kinematic dynamo model.

- True Babcock-Leighton model with no parametrised/microscopic α-effect.

- Advantages:

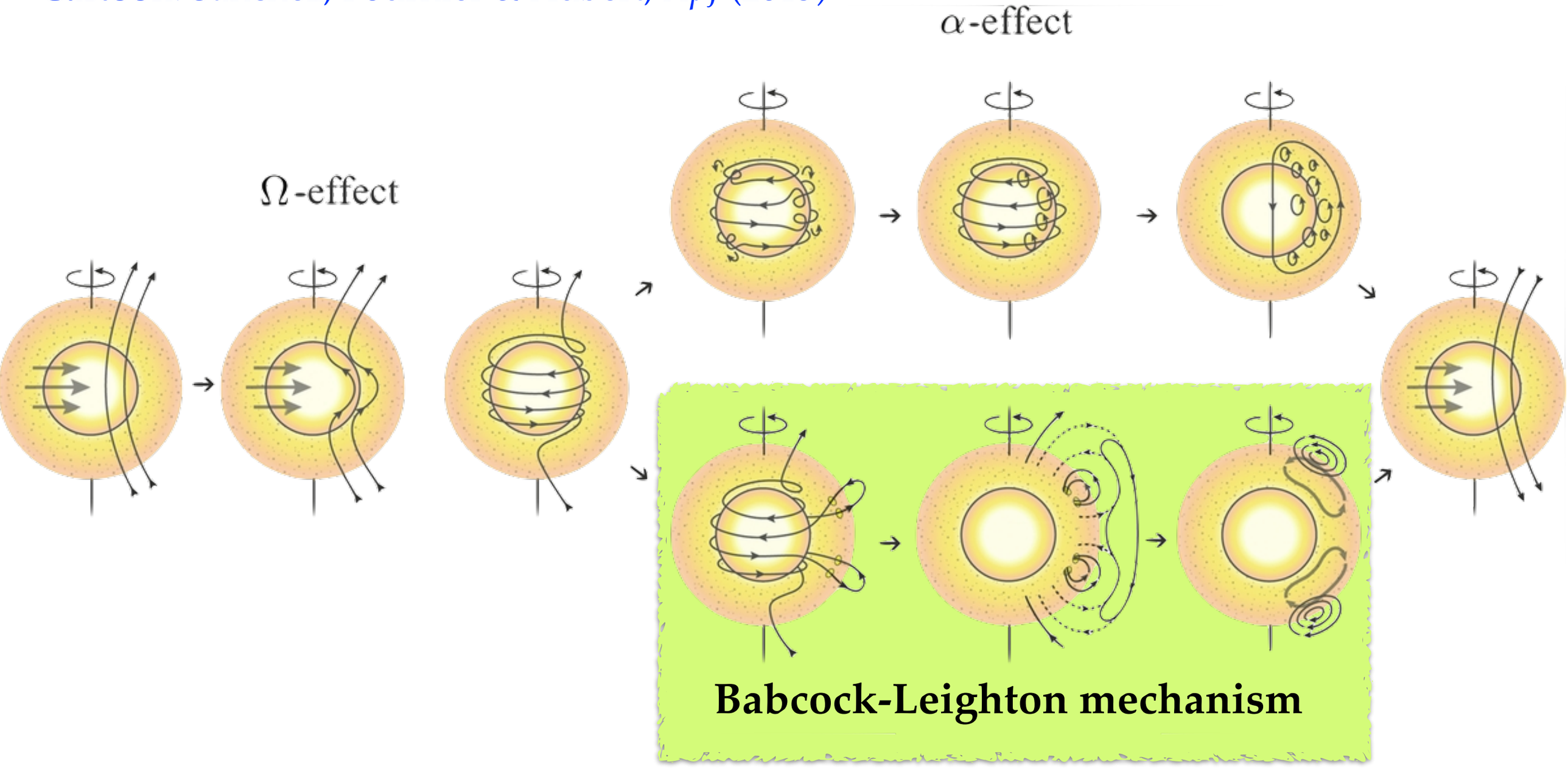
  1. More consistent treatment of the B-L process.

  2. Interfaces with coronal and heliospheric magnetic models.

Yeates & Muñoz-Jaramillo, *MNRAS* (2013)

Completing the solar cycle

Cartoon: Sanchez, Fournier & Aubert, *ApJ* (2013)

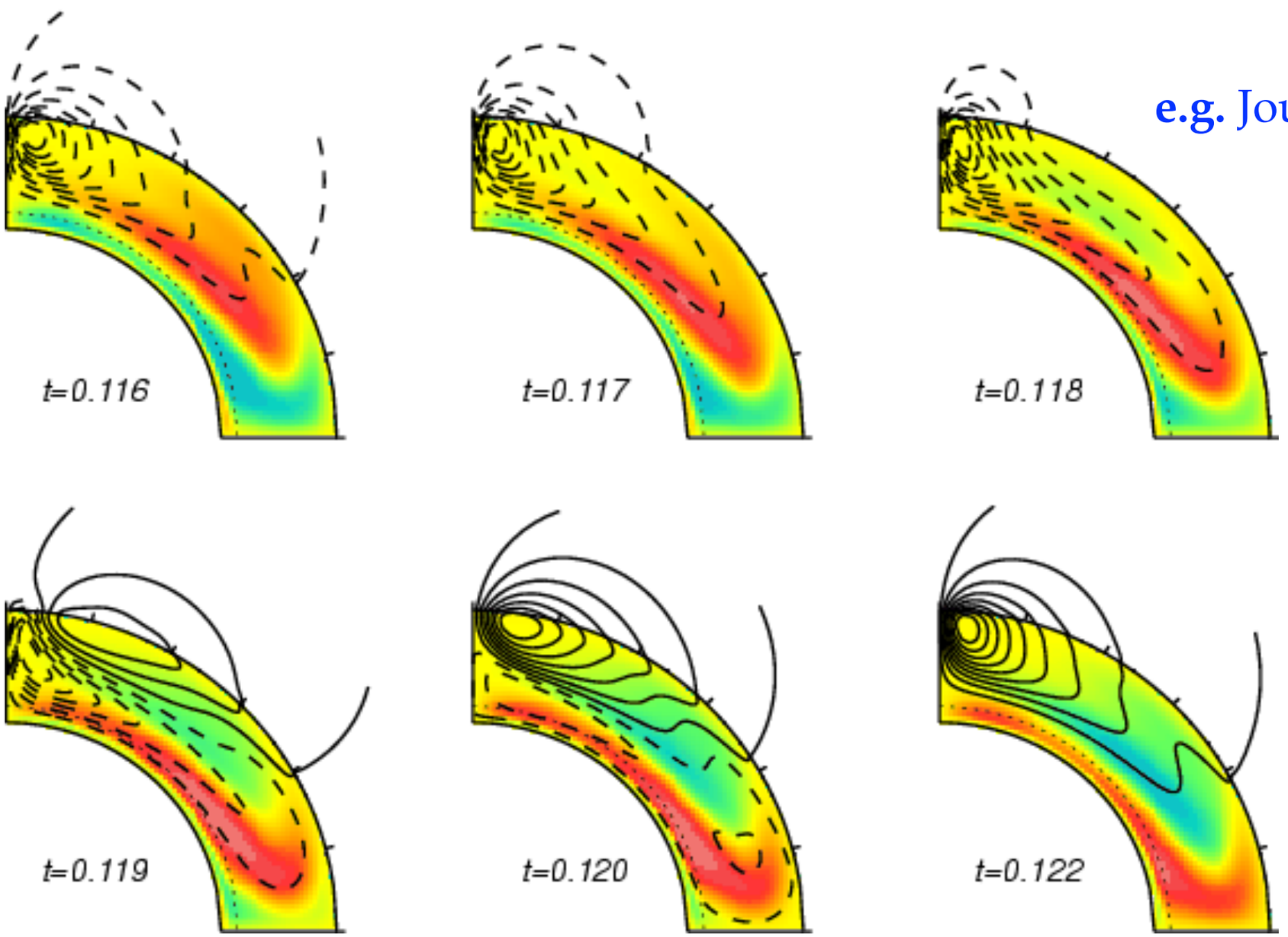


Babcock, *ApJ* (1961); Leighton, *ApJ* (1969)

Charbonneau, *Adv. Space Res.* (2007)

Completing the solar cycle

- Primary tool has been axisymmetric, kinematic models, where the B-L process is parametrised by a **nonlocal source term**.



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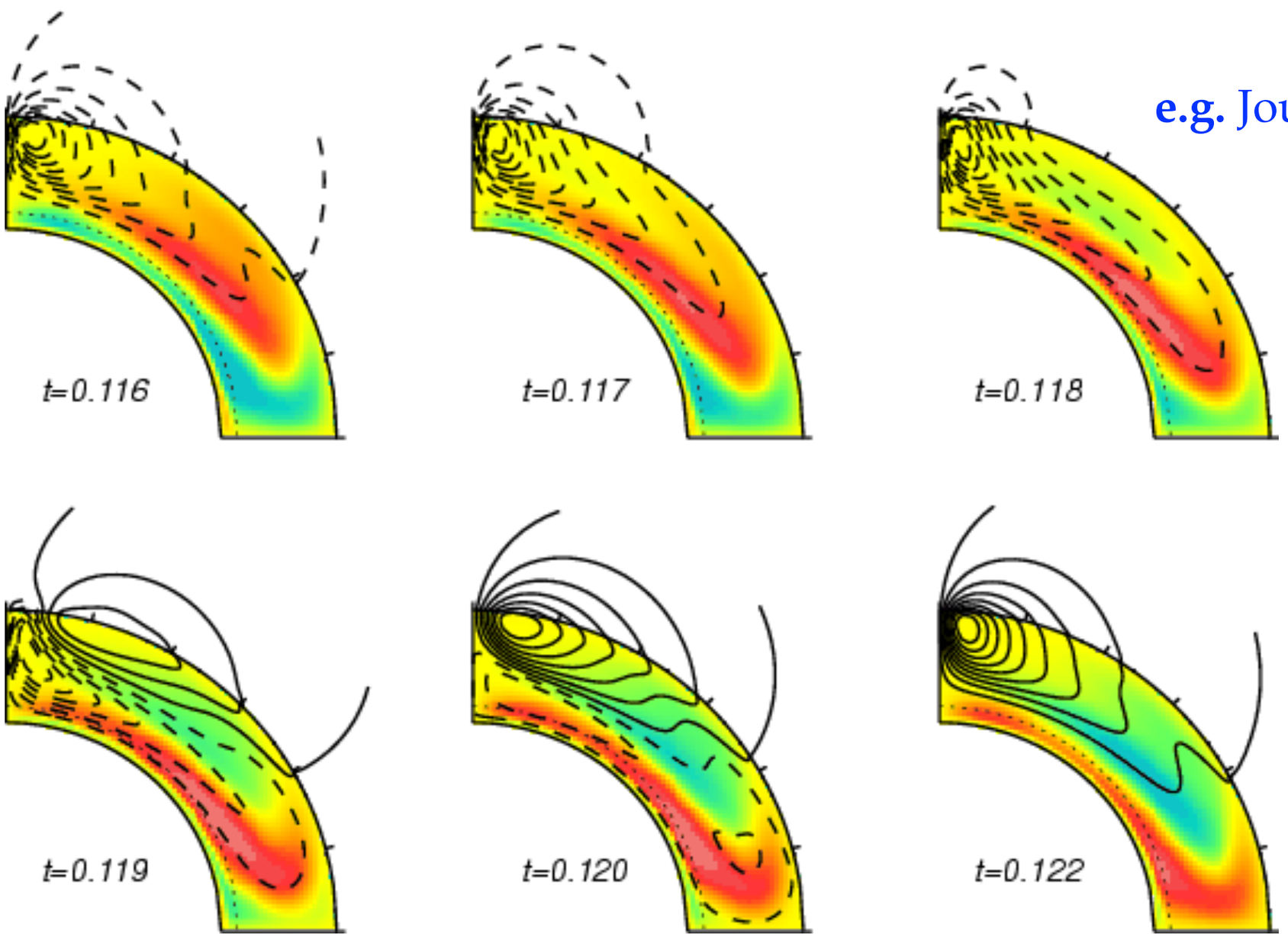

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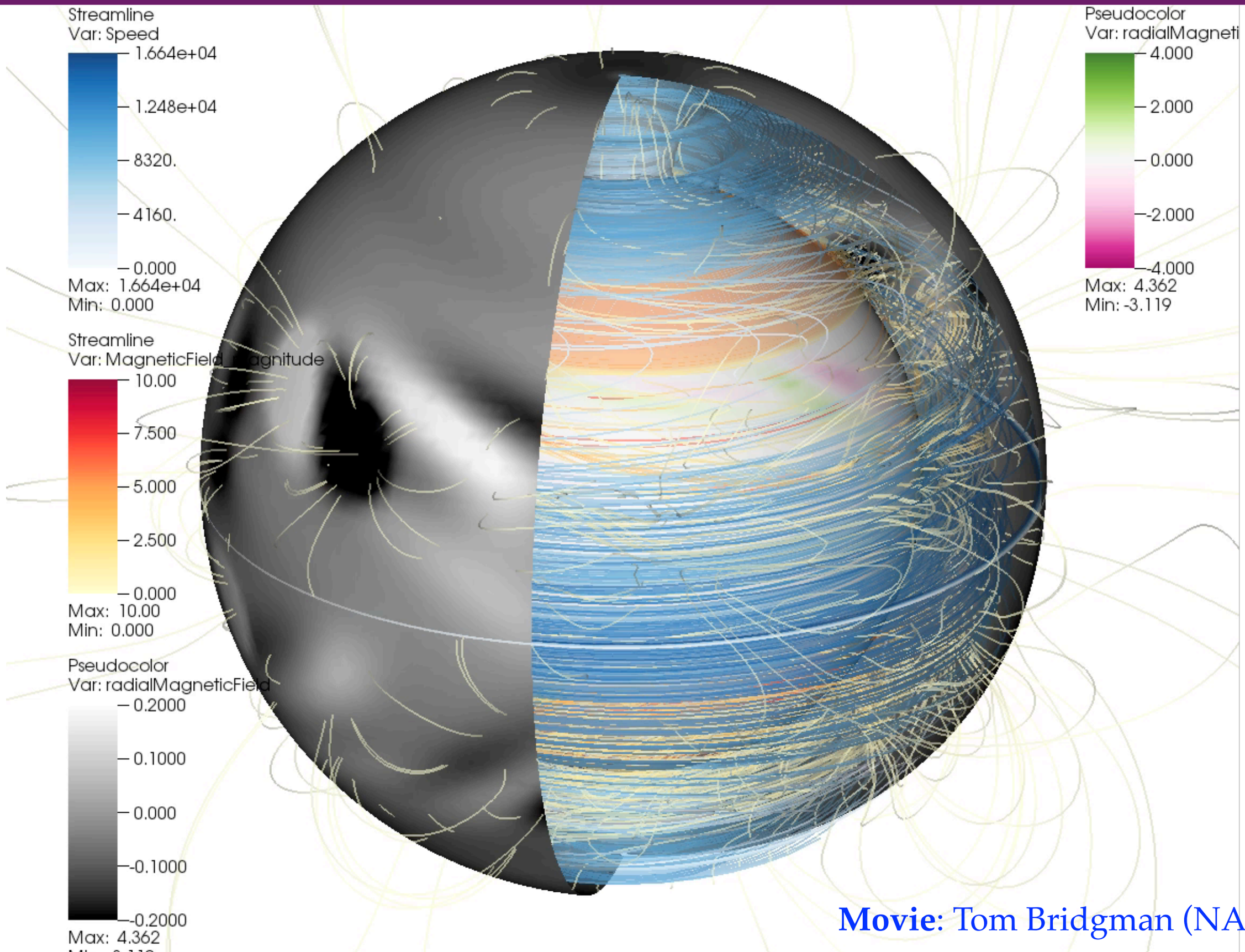
Now in 3-d: Miesch & Dikpati, *ApJ* (2014)

Our new model



Movie: Tom Bridgman (NASA).

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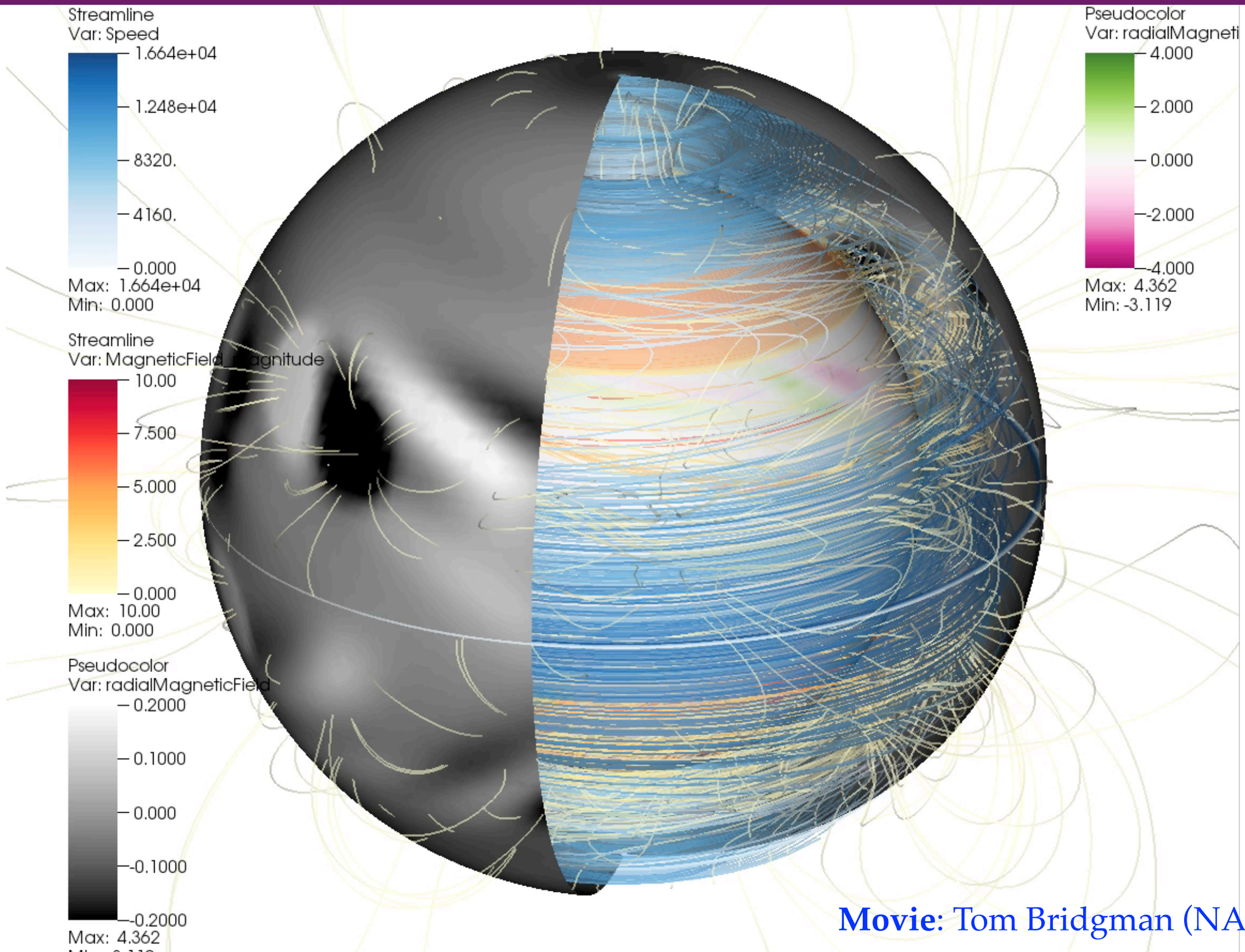

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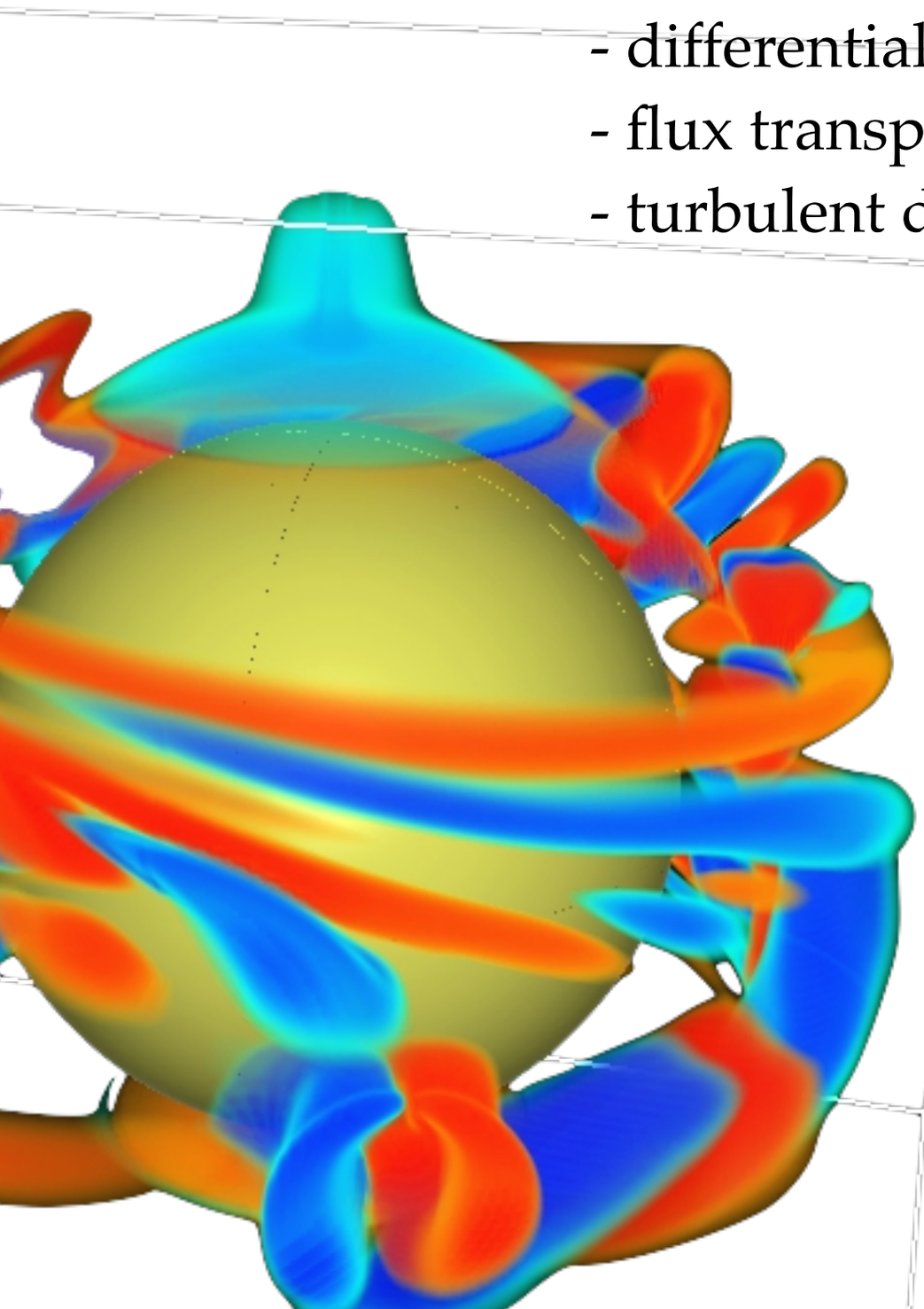
Features of our new model



Familiar

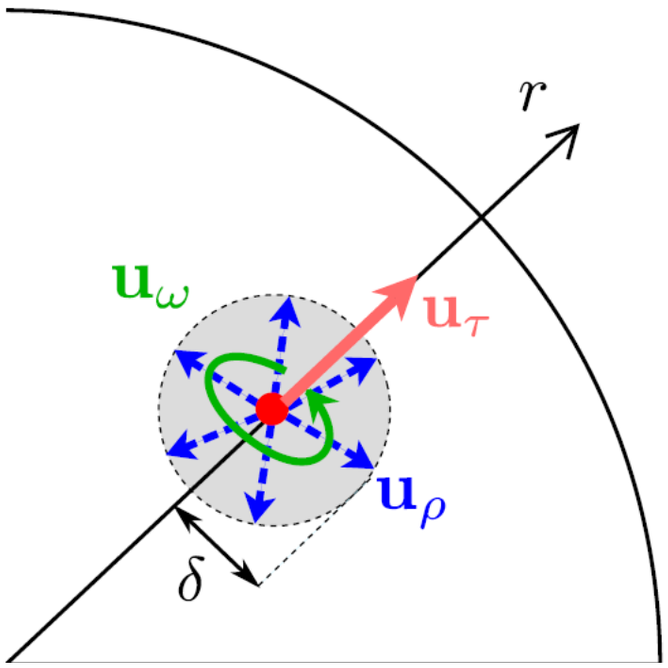
- kinematic mean-field induction equation
- differential rotation
- flux transport (meridional circulation, turbulent pumping)
- turbulent diffusion

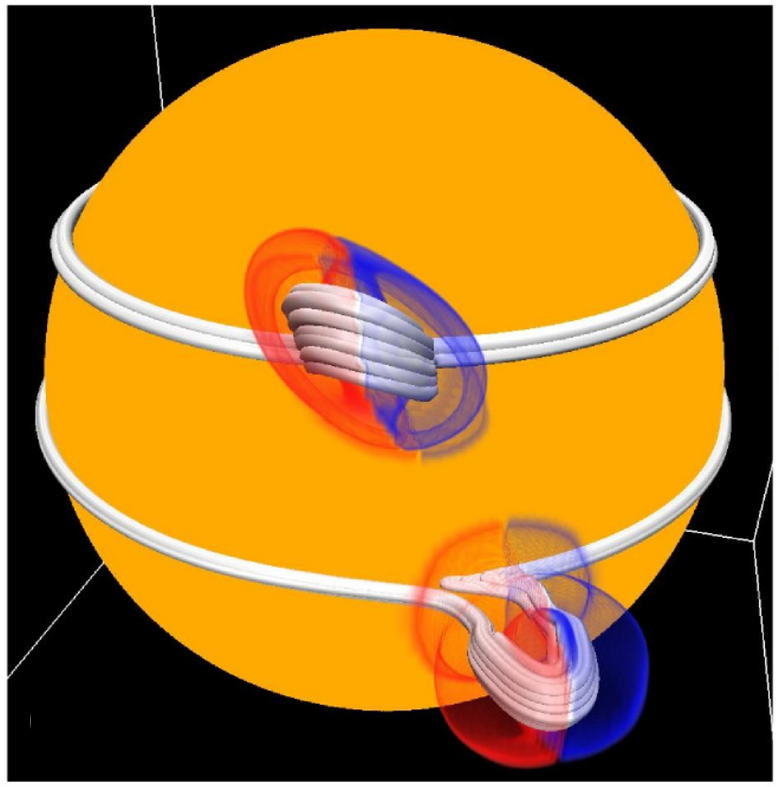
Novel

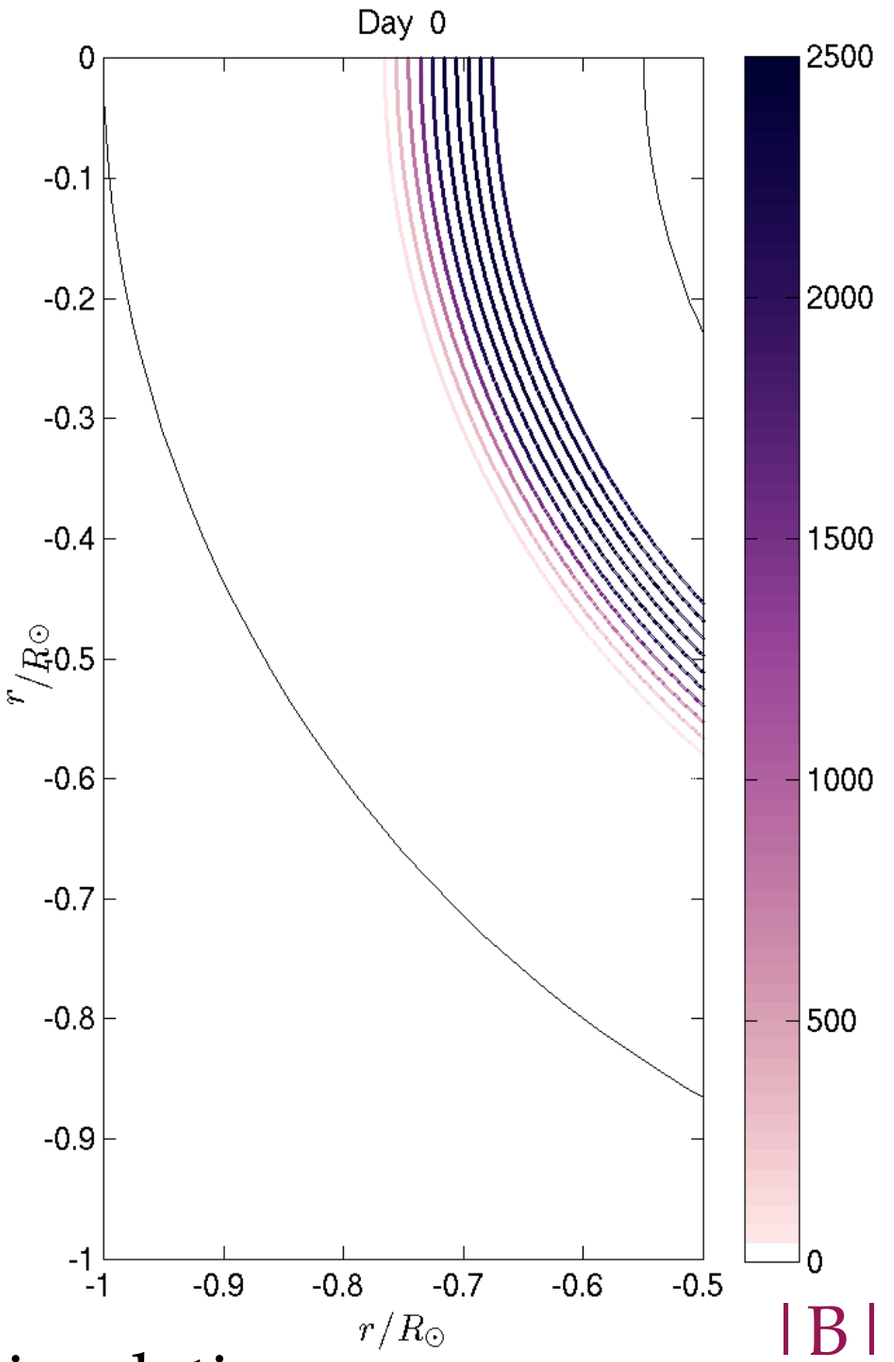
- fully three-dimensional
- no parametrised α-effect
- kinematic emergence of individual flux tubes

Kinematic flux tube emergence

- Individual Ω-loops are created by localised **velocity** perturbations.







- Informed by thin flux tube and anelastic-MHD simulations.

e.g. Fan, *ApJ* (2008), Nelson et al., *ApJ* (2011), Jouve, Brun & Aulanier, *ApJ* (2013).

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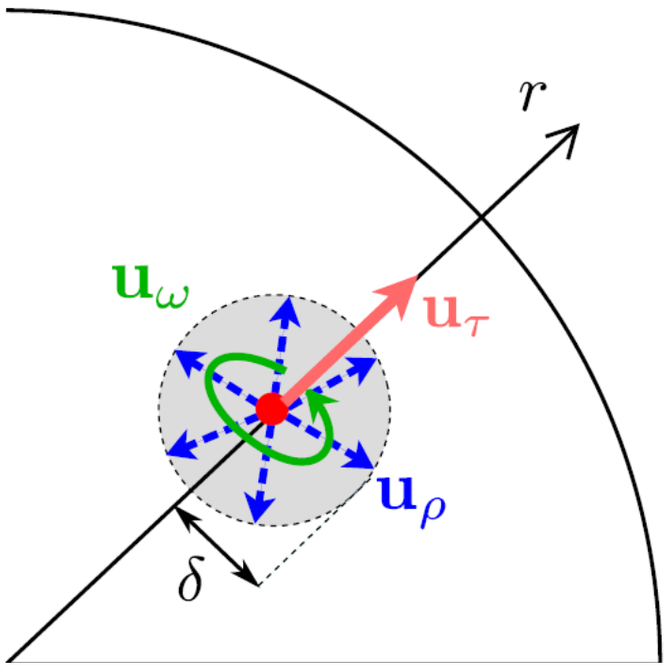

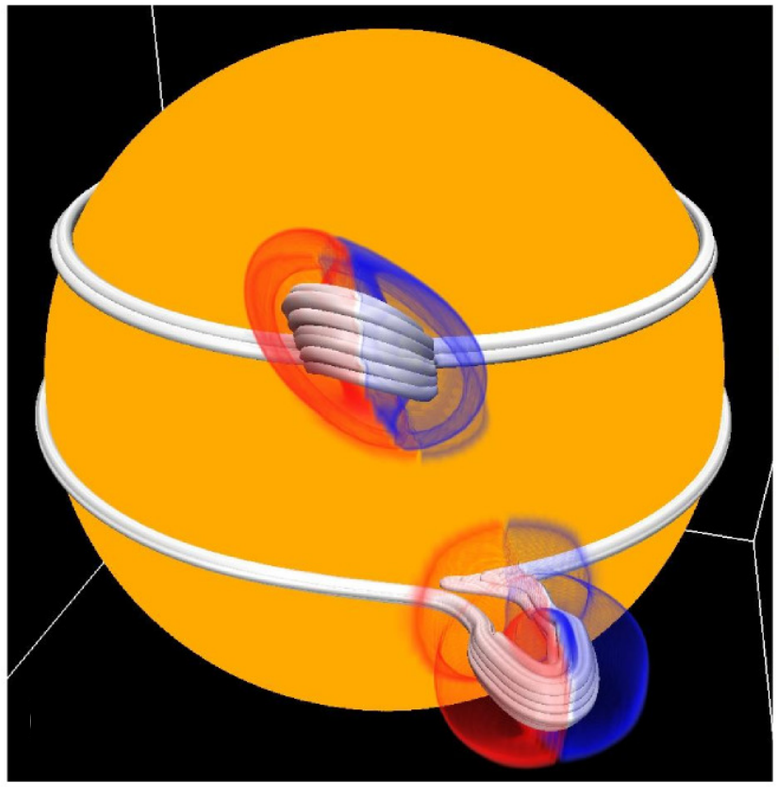

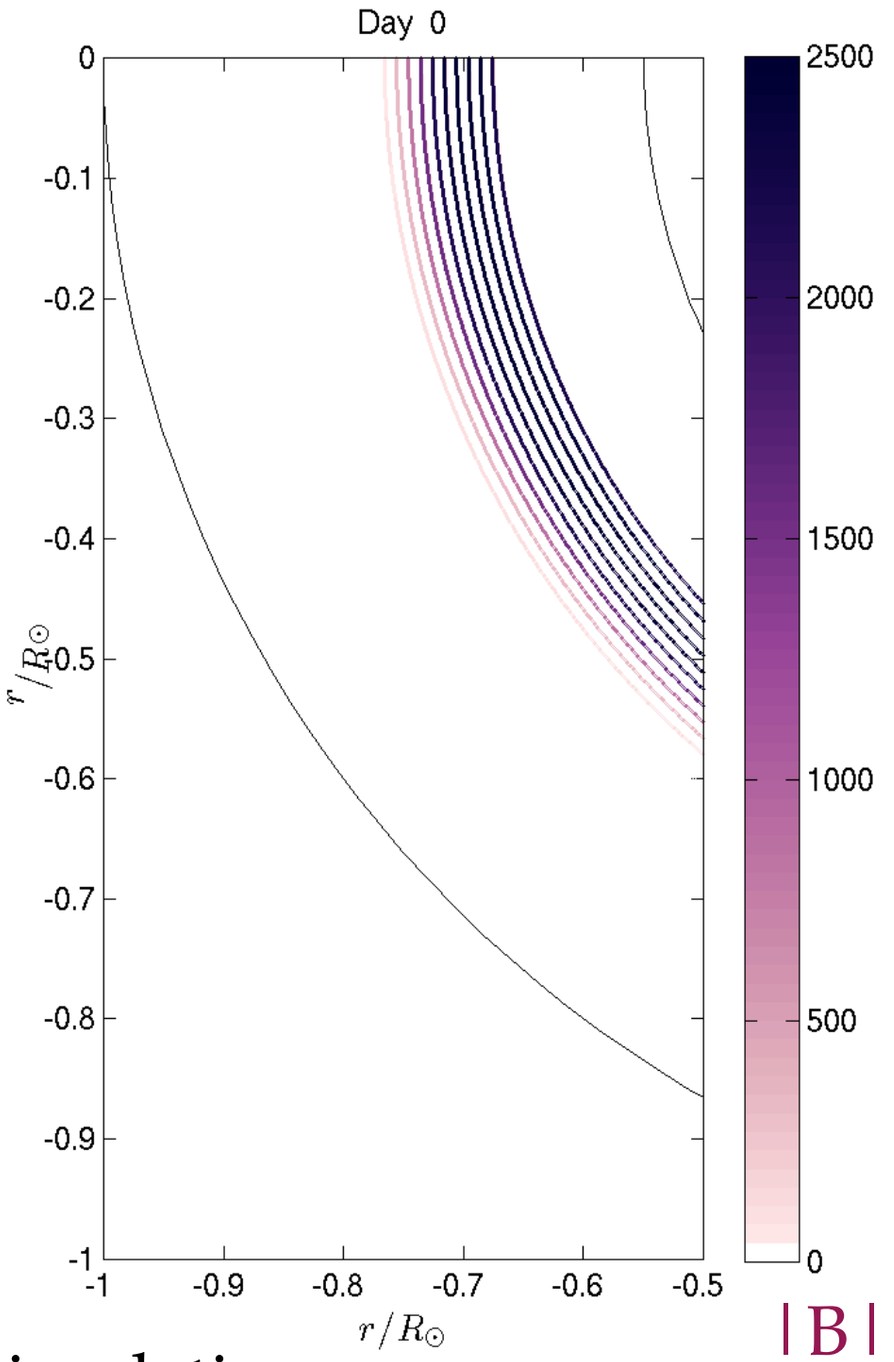

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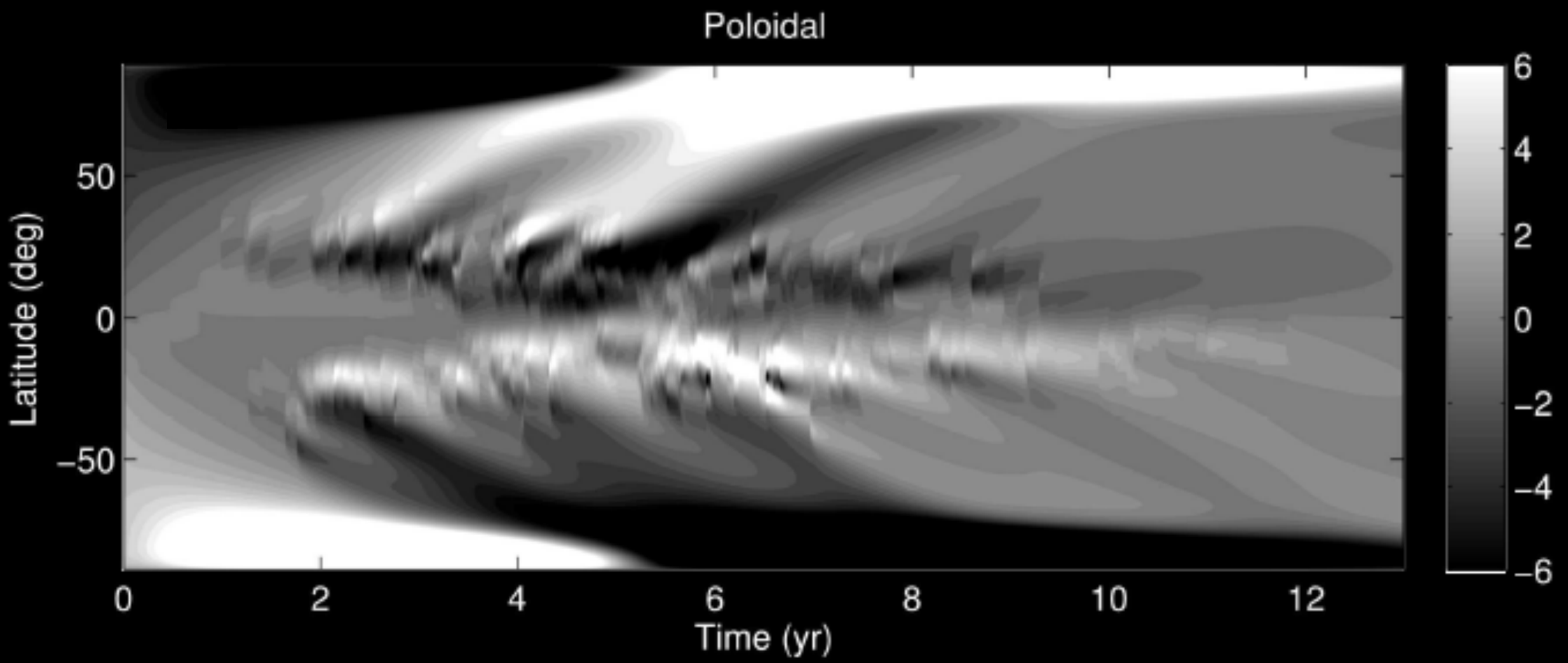

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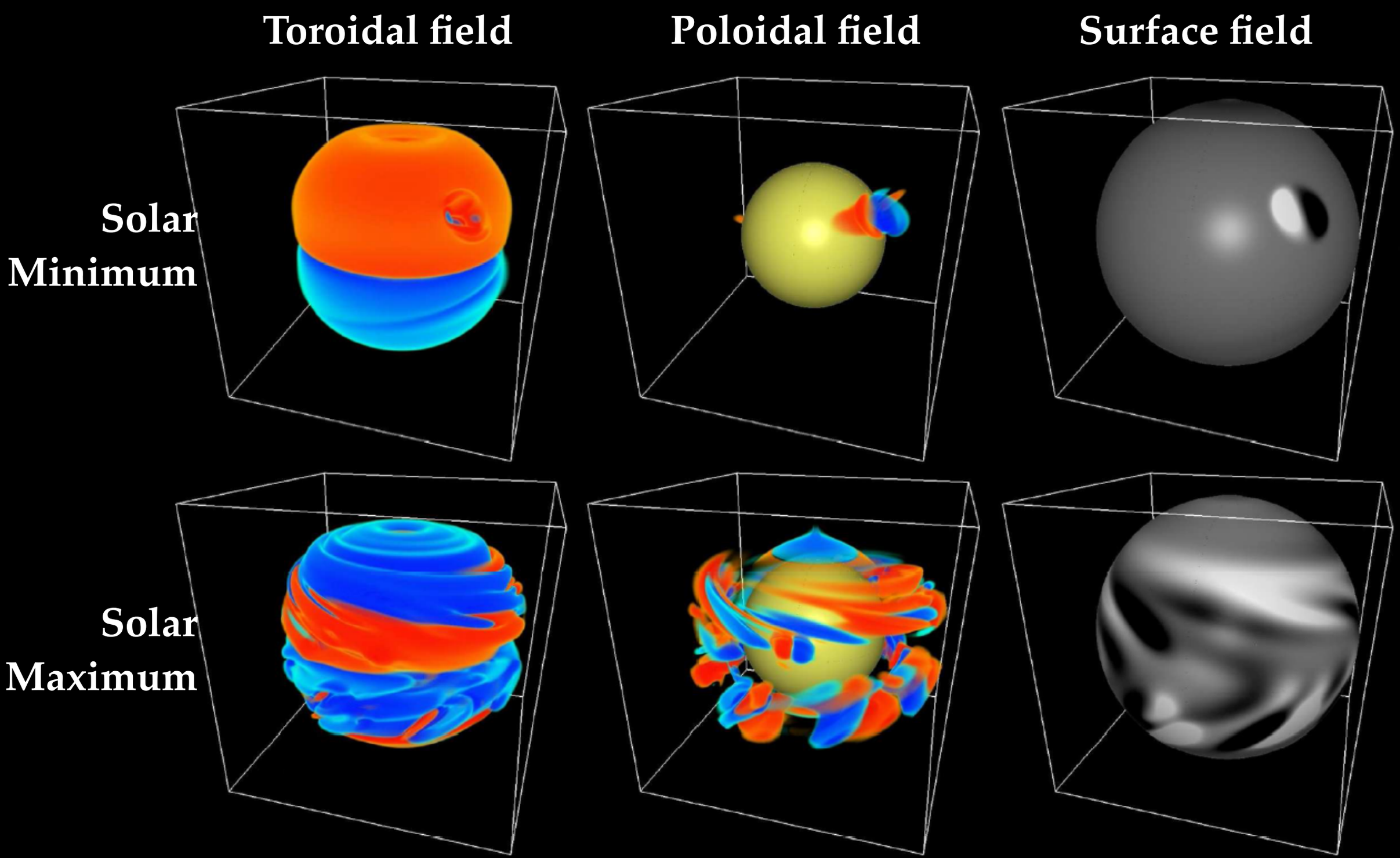
Yeates & Muñoz-Jaramillo, *MNRAS* (2013)

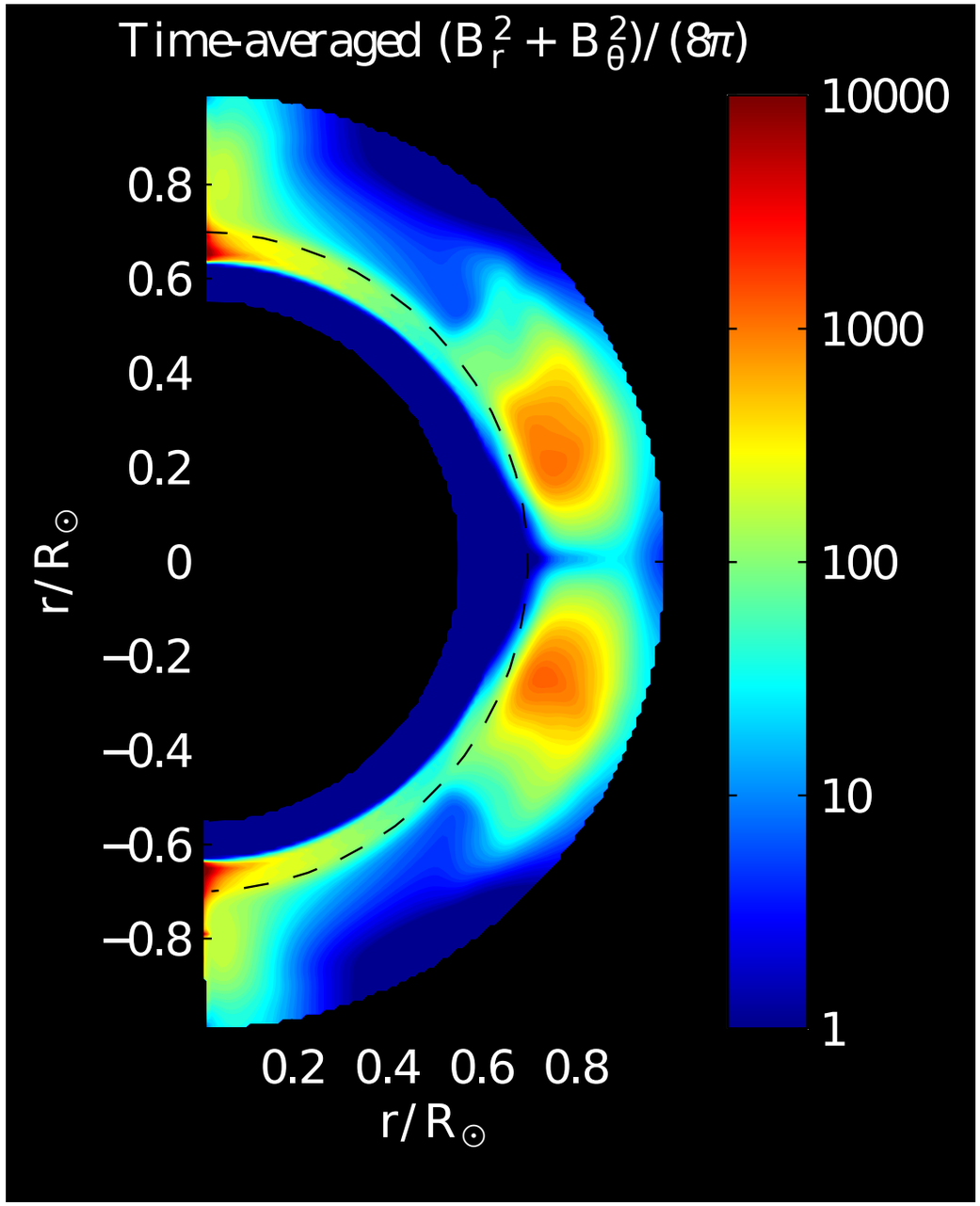
Self-consistent treatment of B-L process

- Magnetic flux is conserved and tubes retain connection to their roots.



Self-consistent treatment of B-L process

- Poloidal magnetic energy is strongest in the middle of the convection zone…



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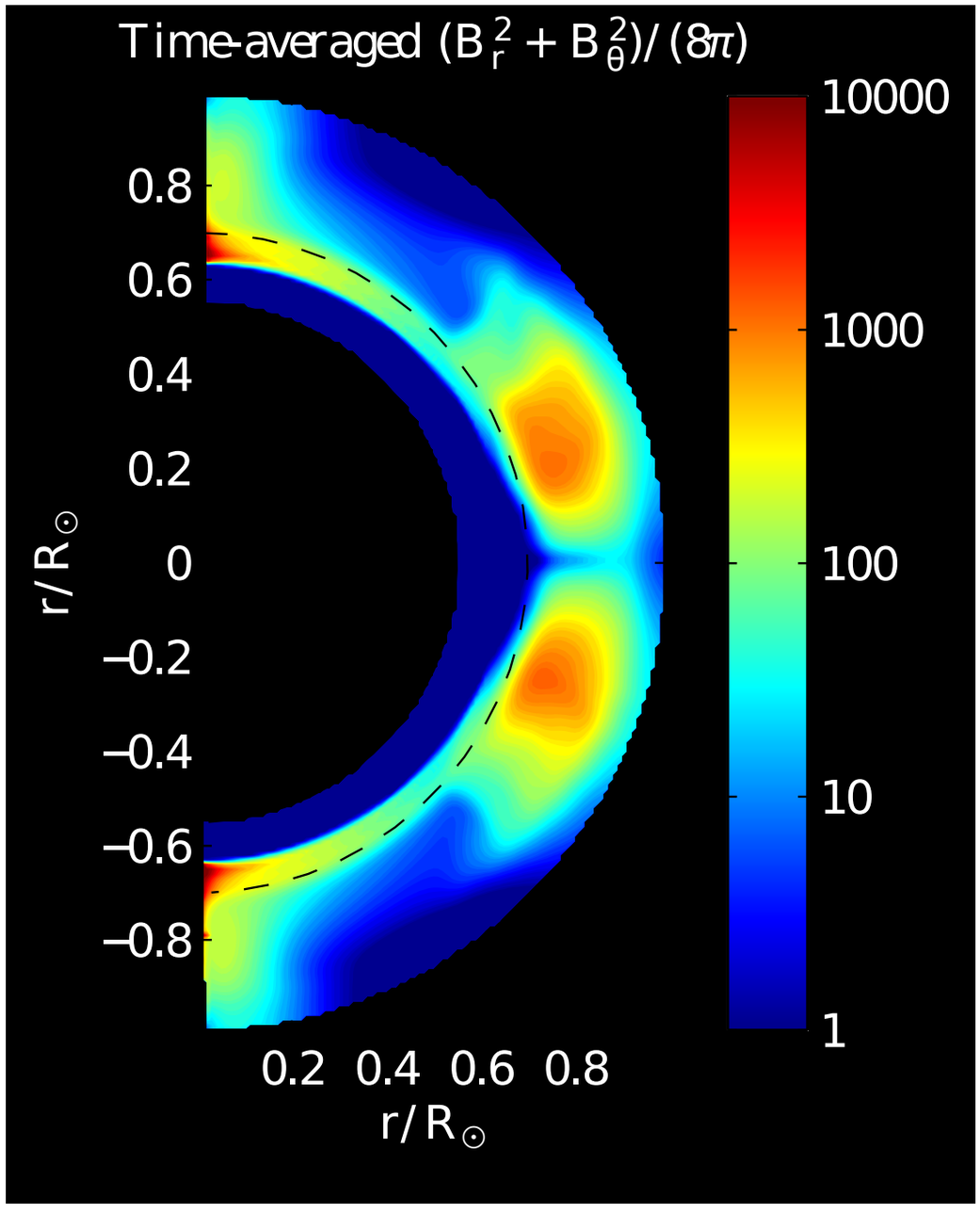
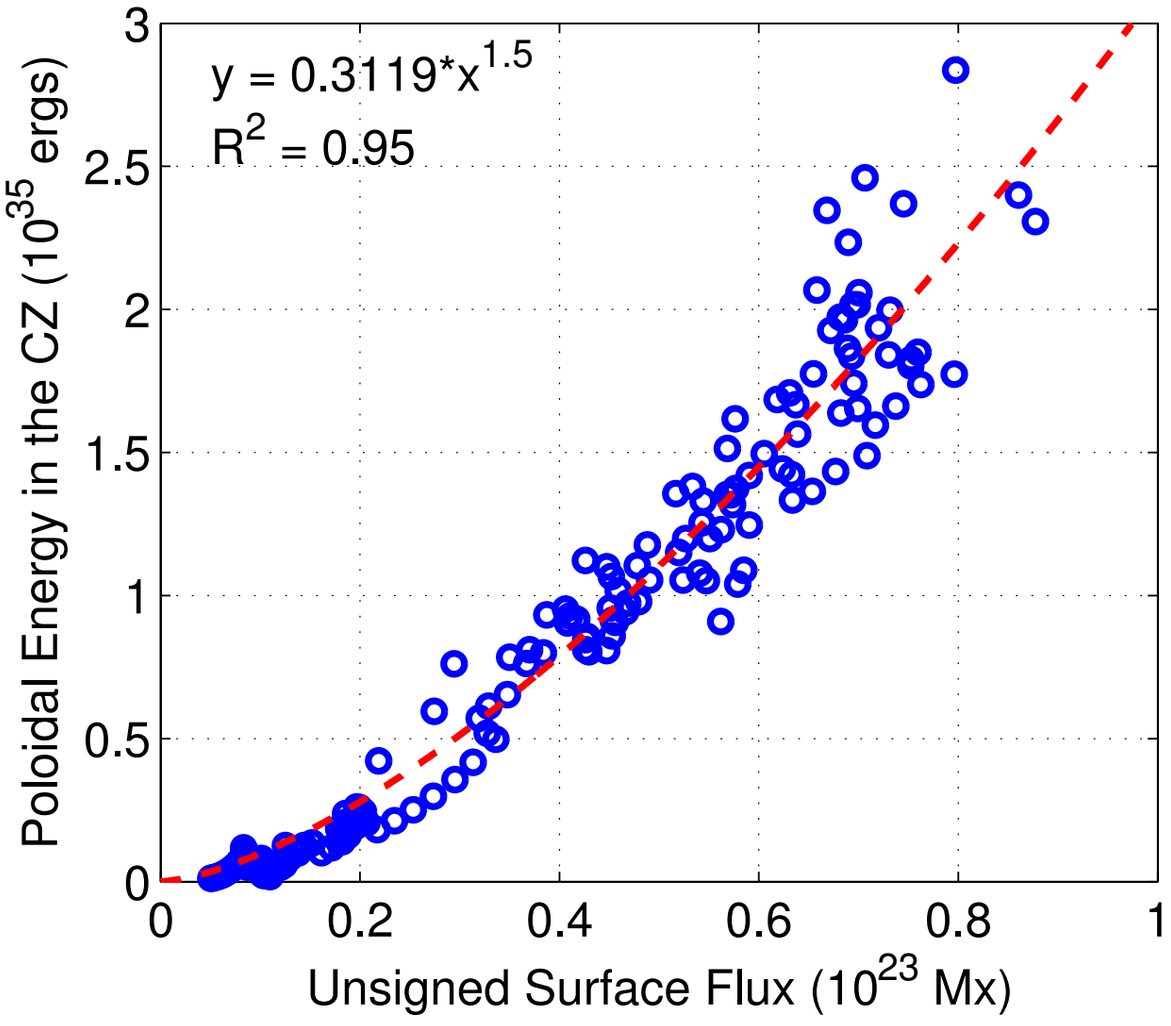
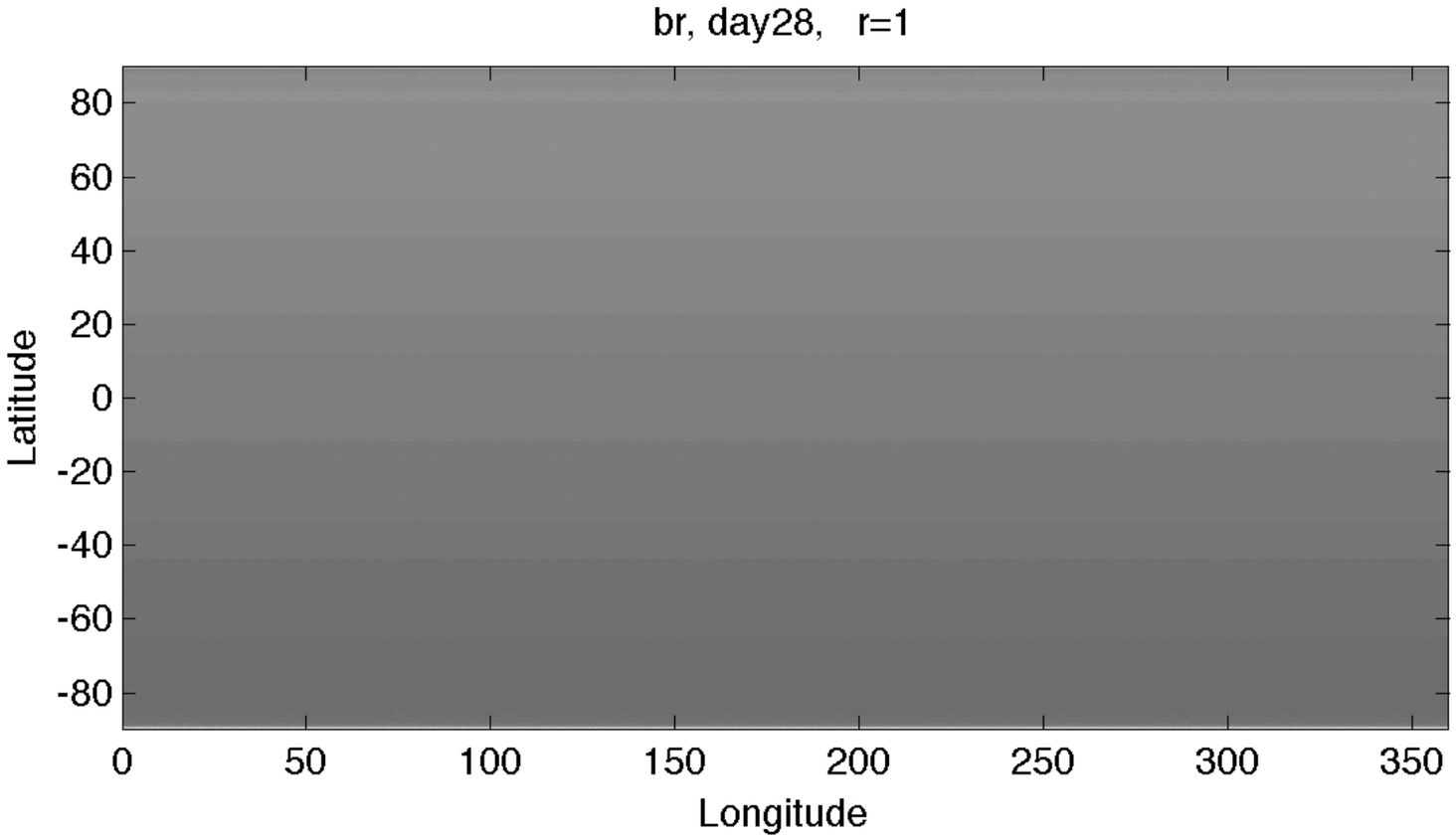


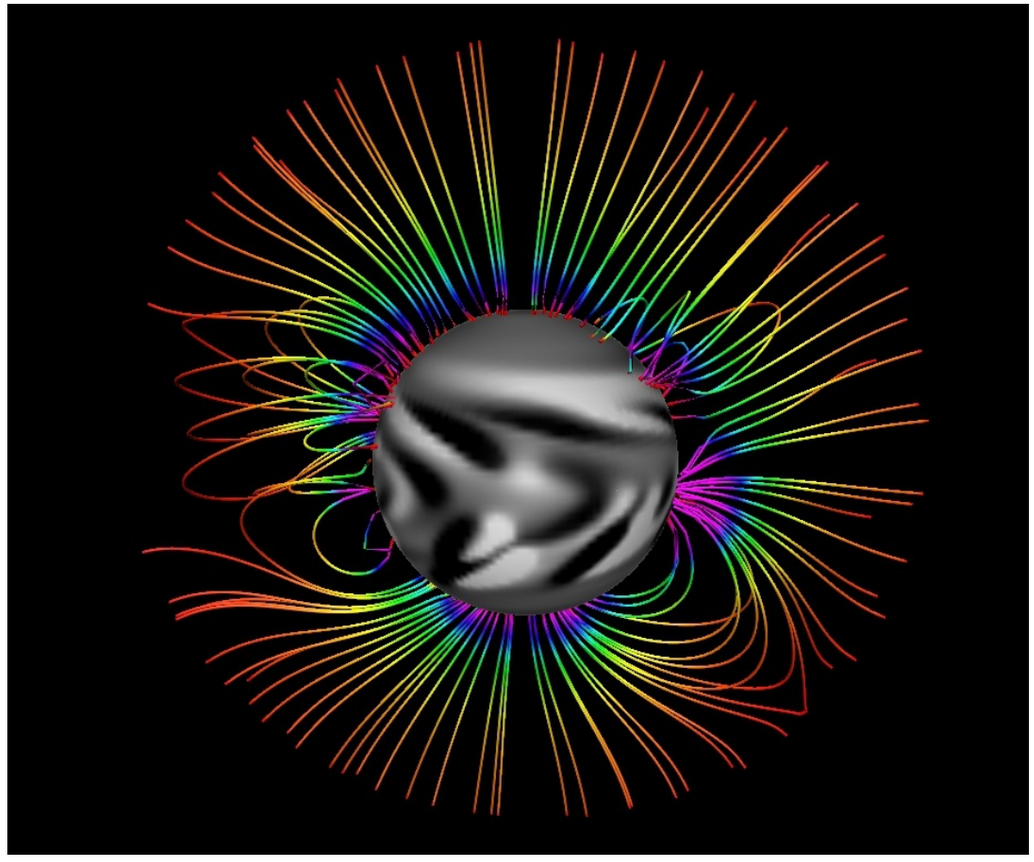


…but is well-correlated to unsigned **photospheric** flux.

Interface with coronal/heliospheric models

- Photospheric “output” can drive coronal magnetic models.





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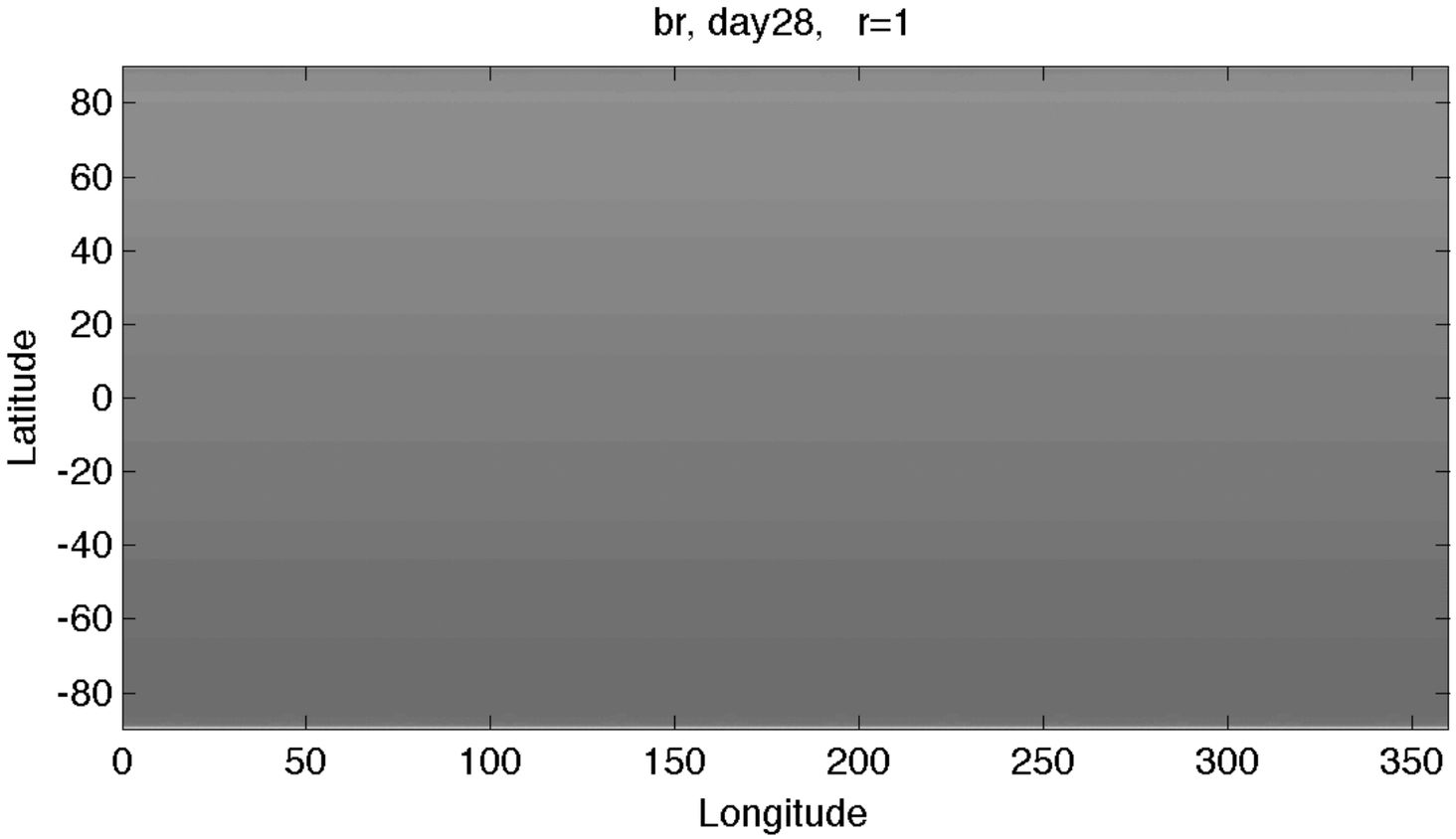

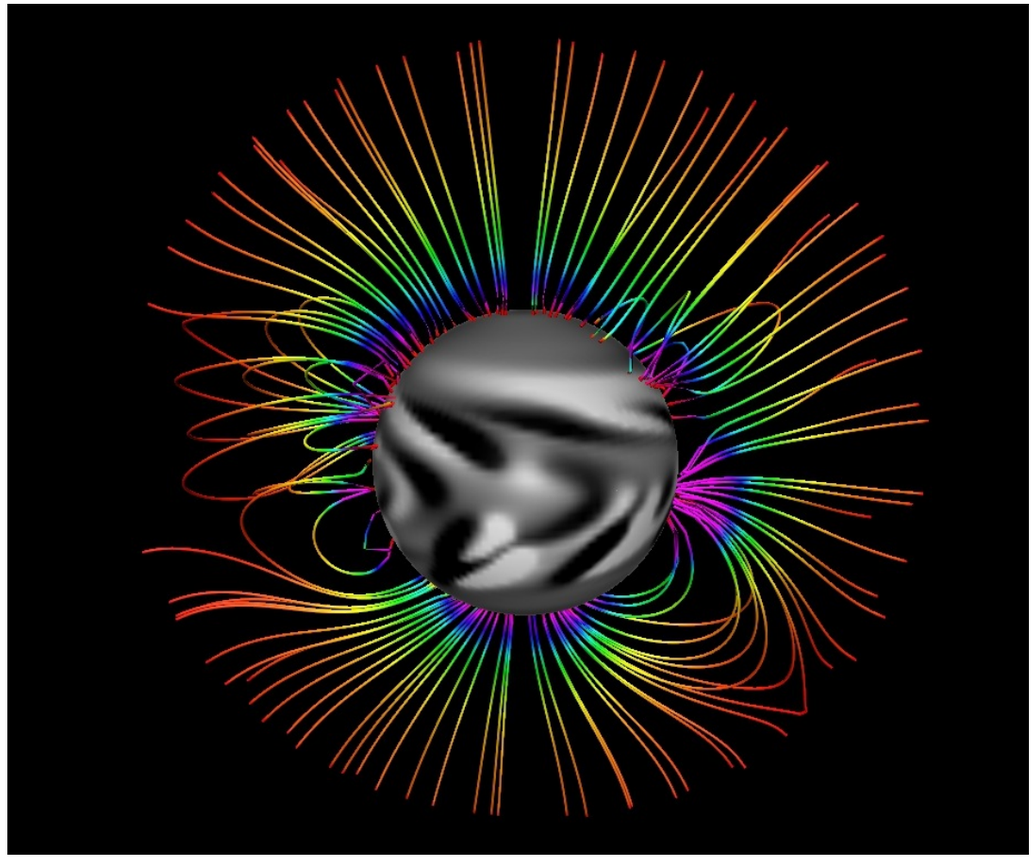

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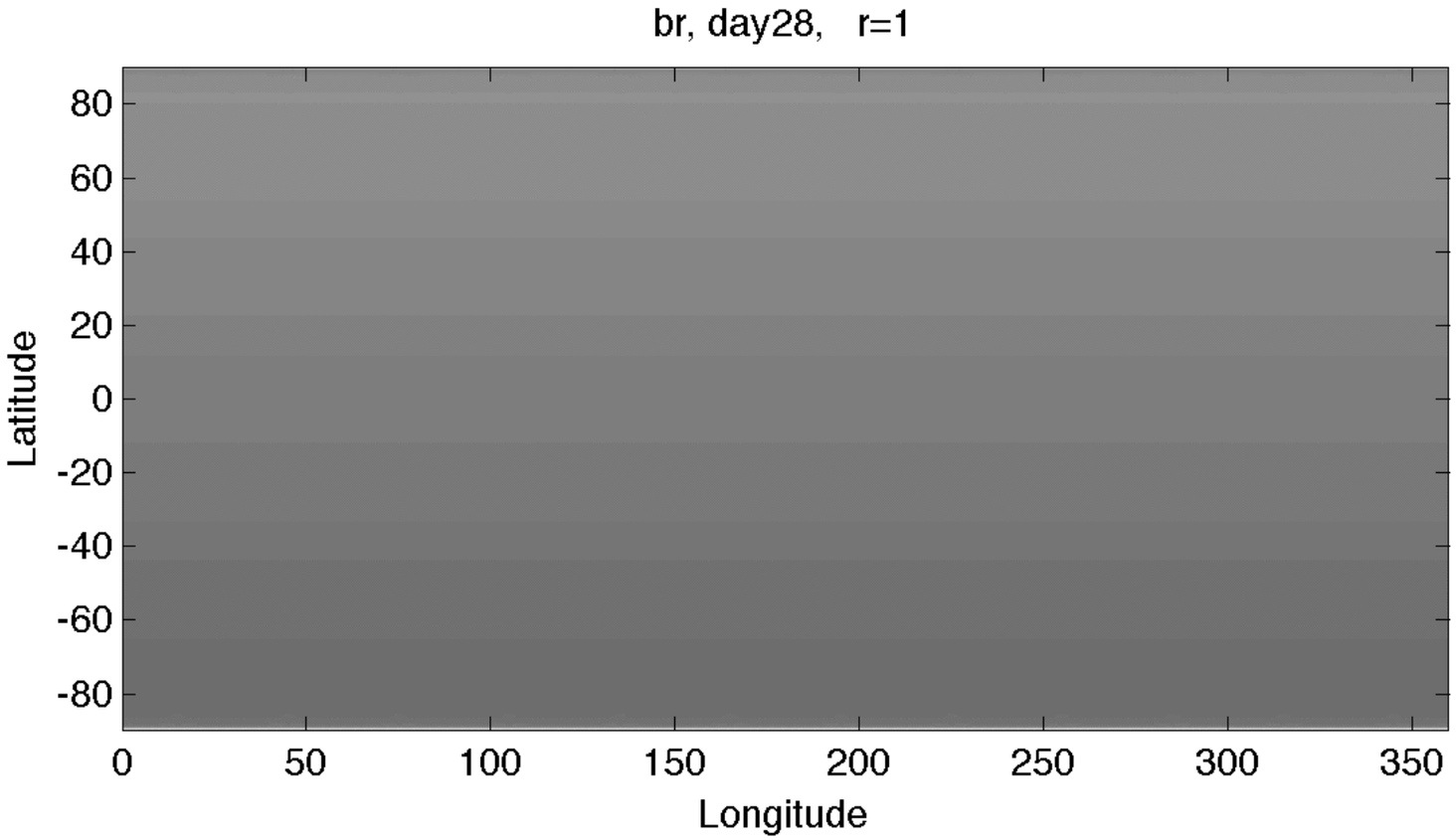
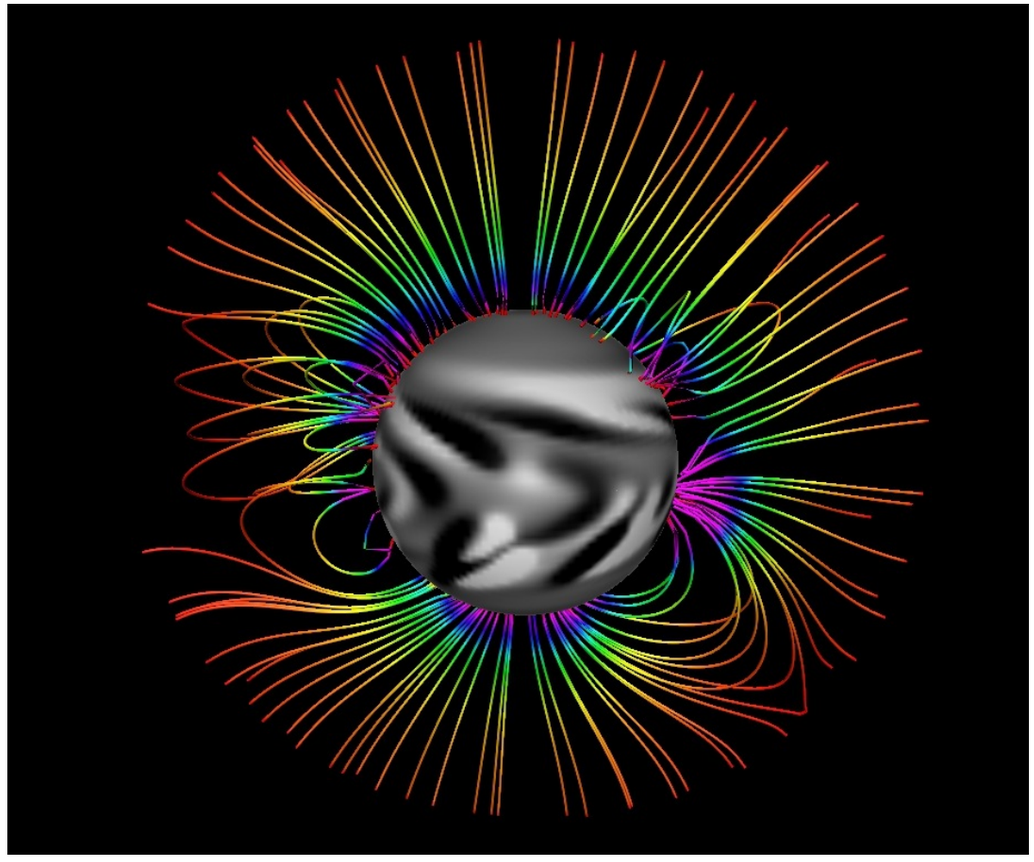


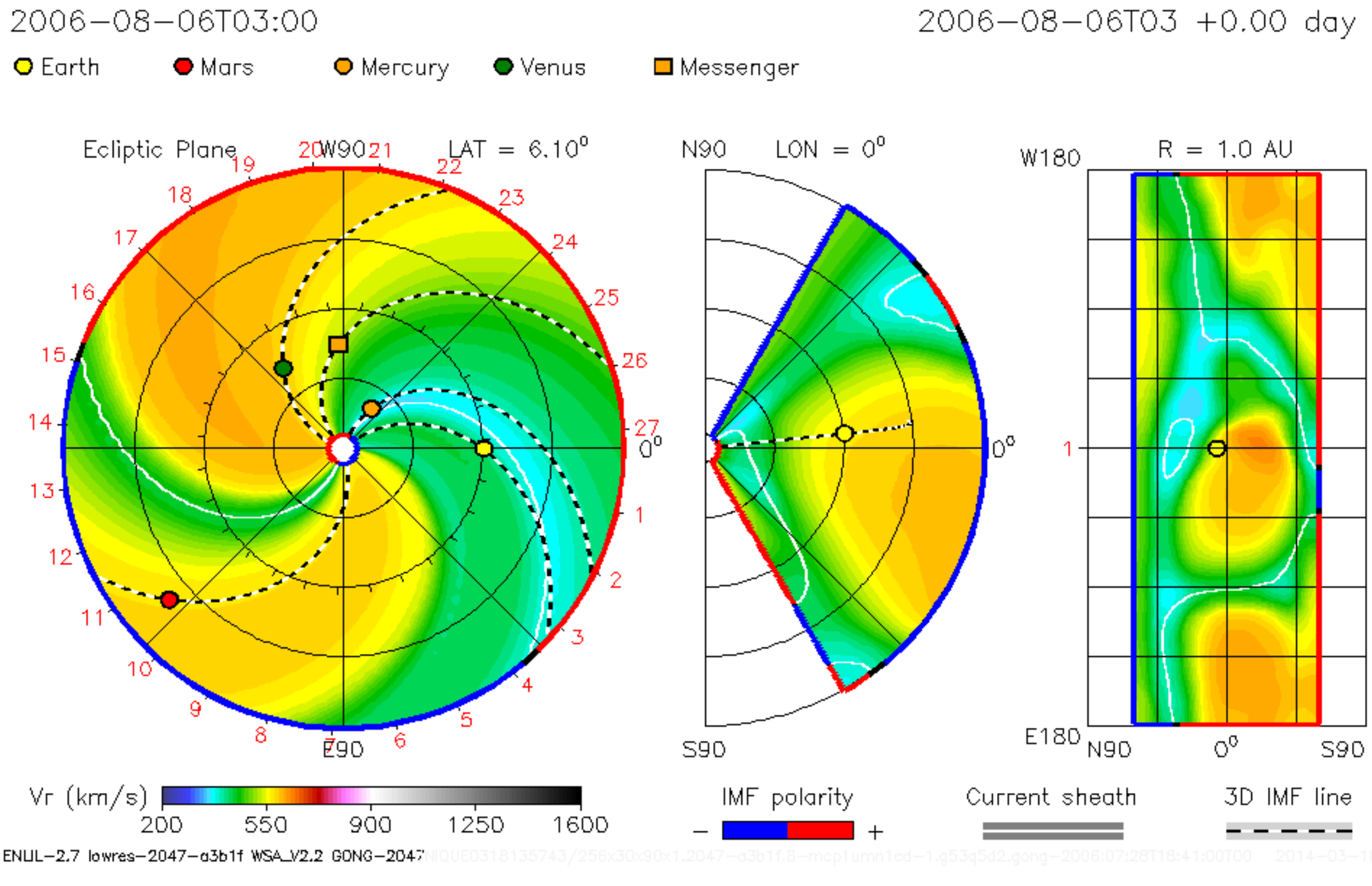


- Includes radial diffusion term missing in surface flux transport models.

Baumann, Schmitt & Schüssler, *A&A* (2006)

Interface with coronal/heliospheric models

Working with CCMC (Community Coordinated Modeling Center) to set up a “theoretical observatory”.



Ongoing work

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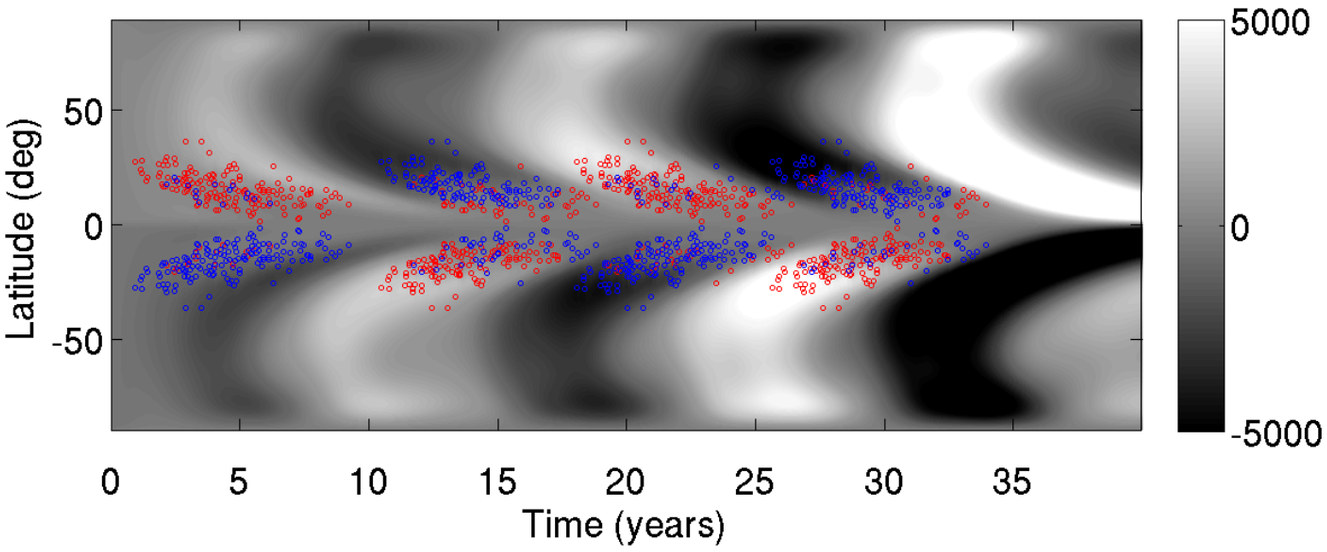
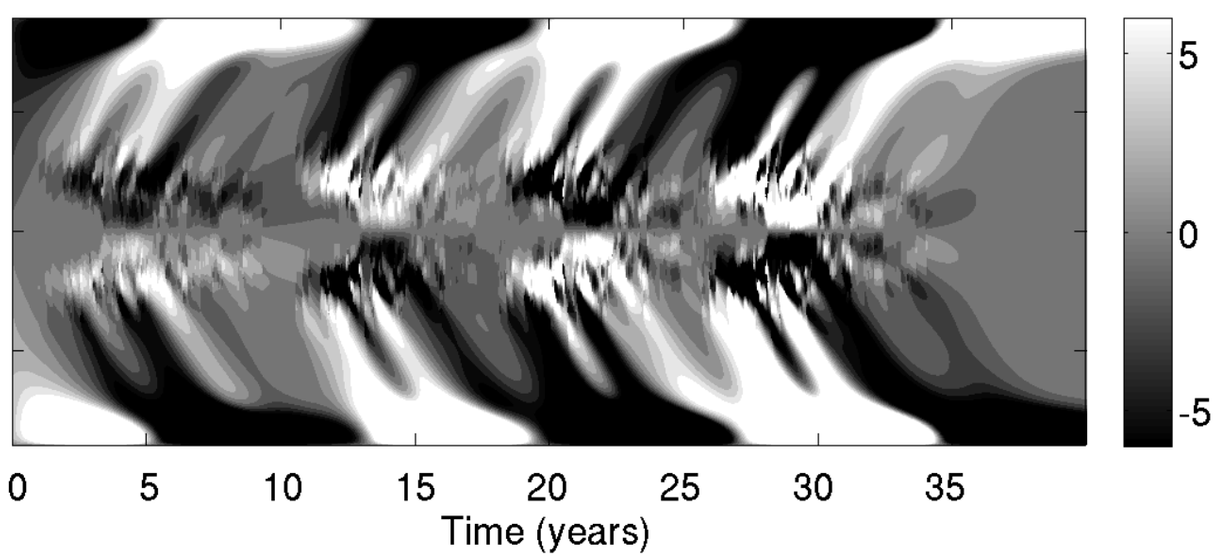
Toroidal field at tachocline



Radial field at photosphere



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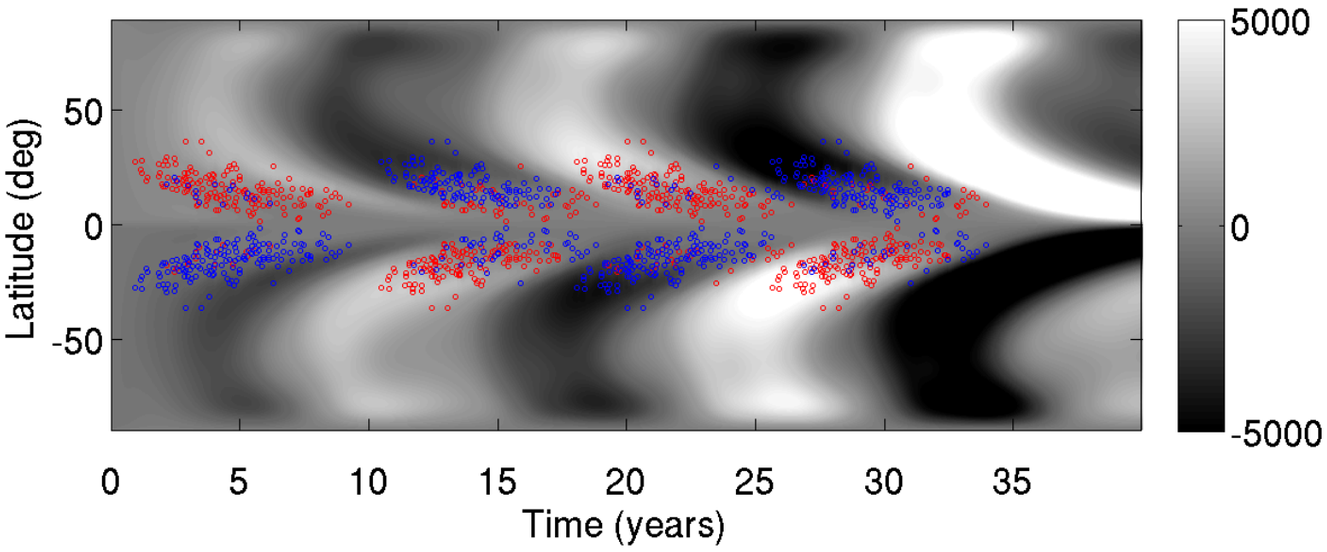

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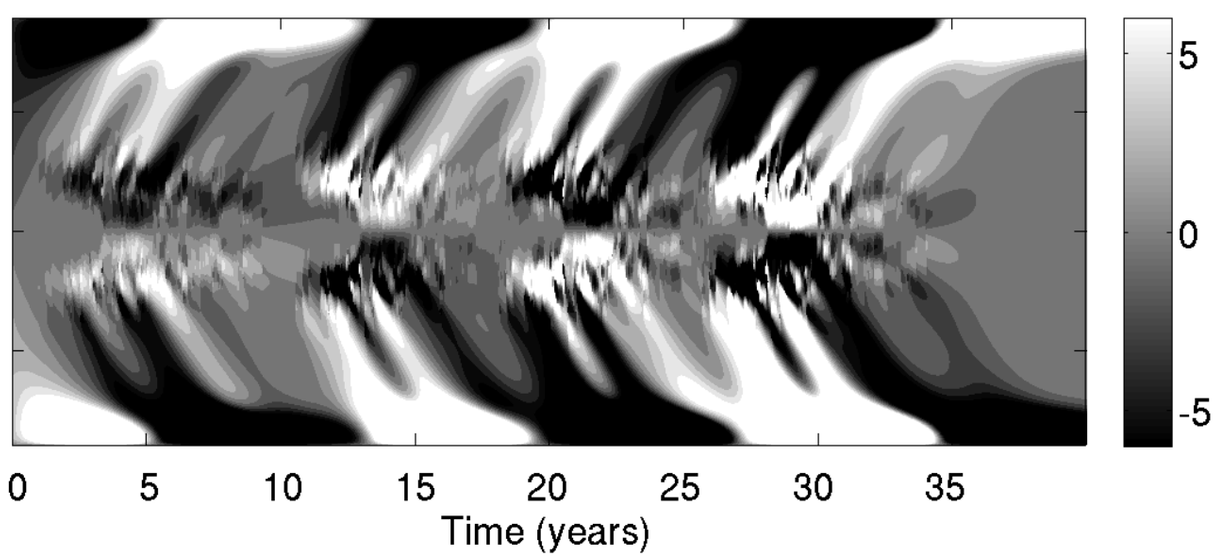

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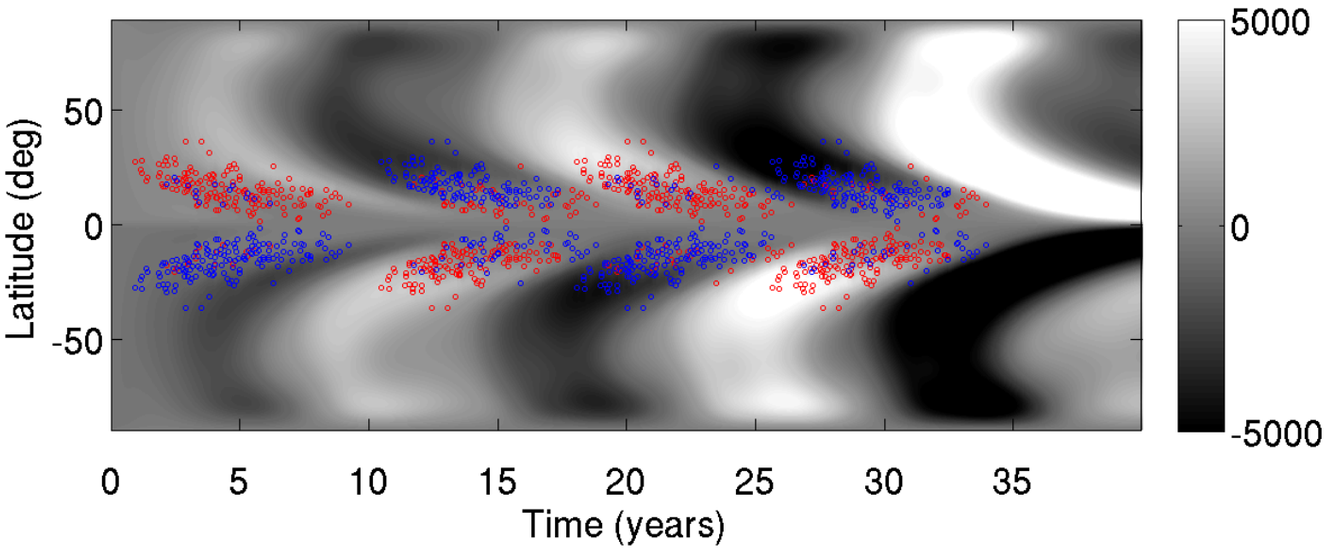

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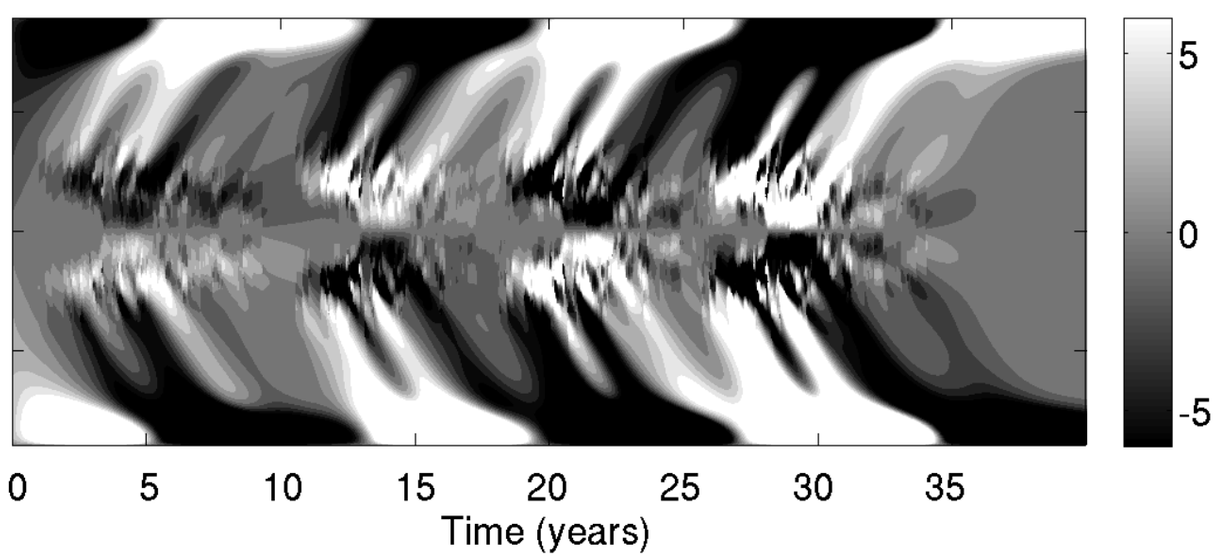

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- NASA Grand Challenges project (PI Piet Martens):
  detailed calibration versus observations and surface models.