Multi-ensemble MHD coronal modelling to improve background wind for CME propagation for EUHFORIA 2.0

By Dr. Barbara PERRI[1]

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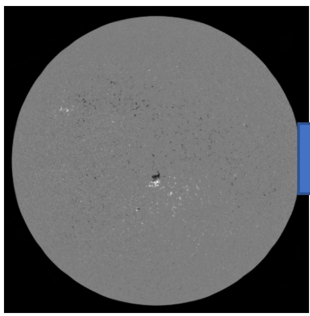
Horizon 2020

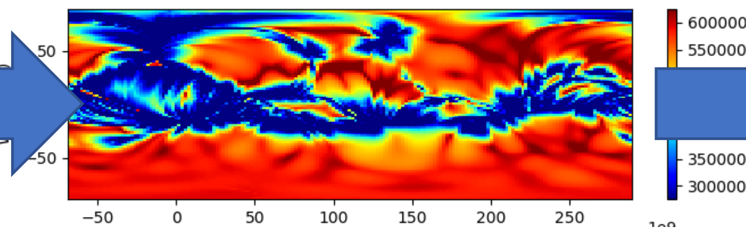
EUHFORIA 2.0

Chain of data-driven heliospheric simulations from the solar surface to the Earth

[SDO/HMI]

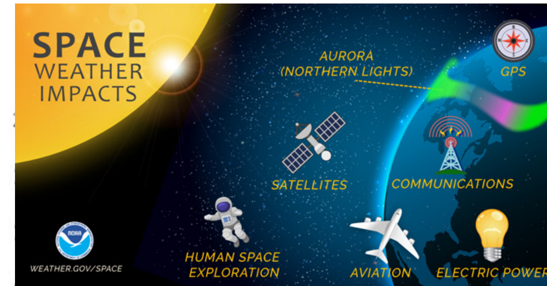


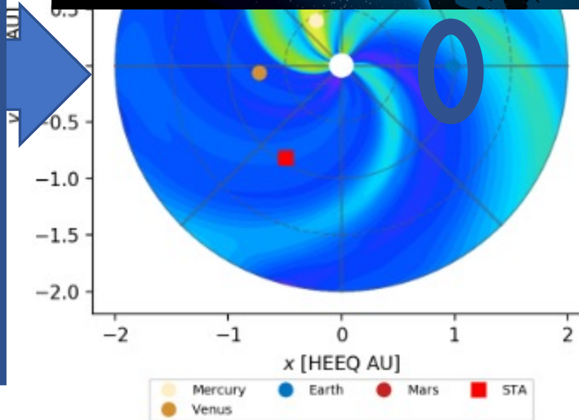
$1\ R_\odot$



$20\ R_\odot$

[NASA]





$20\ R_\odot - 2\ UA$

The extrapolations from 1 to 20 solar radii are semi-empirical

→ this is where most of the structures are created!

→ we want to replace it with a more physical code (MHD) BUT still fast!

Wind-Predict

Numerics :

- Based on the **PLUTO code** (Mignone+2007)
- Solves the set of **ideal conservative MHD** equations:

$$\frac{\partial}{\partial t}\rho + \nabla \cdot \rho \mathbf{v} = 0$$

$$\frac{\partial}{\partial t}\mathbf{m} + \nabla \cdot (\mathbf{m}\mathbf{v} - \mathbf{B}\mathbf{B} + \mathbf{I}p) = \rho \mathbf{a}$$

$$\frac{\partial}{\partial t}E + \nabla \cdot ((E+p)\mathbf{v} - \mathbf{B}(\mathbf{v}\cdot\mathbf{B})) = \mathbf{m}\cdot\mathbf{a}$$

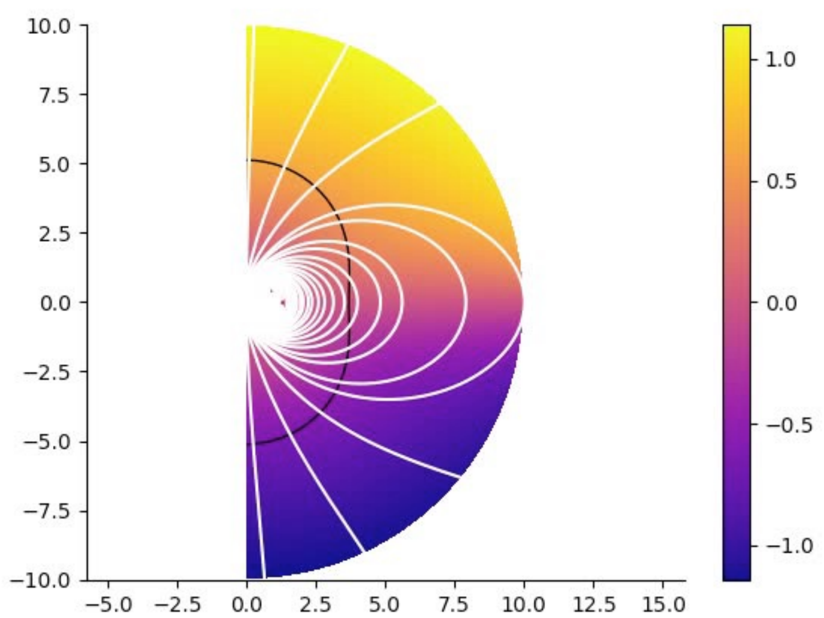
$$\frac{\partial}{\partial t}\mathbf{B} + \nabla \cdot (\mathbf{v}\mathbf{B} - \mathbf{B}\mathbf{v}) = 0$$

- **Finite-volume** method with Riemann solver

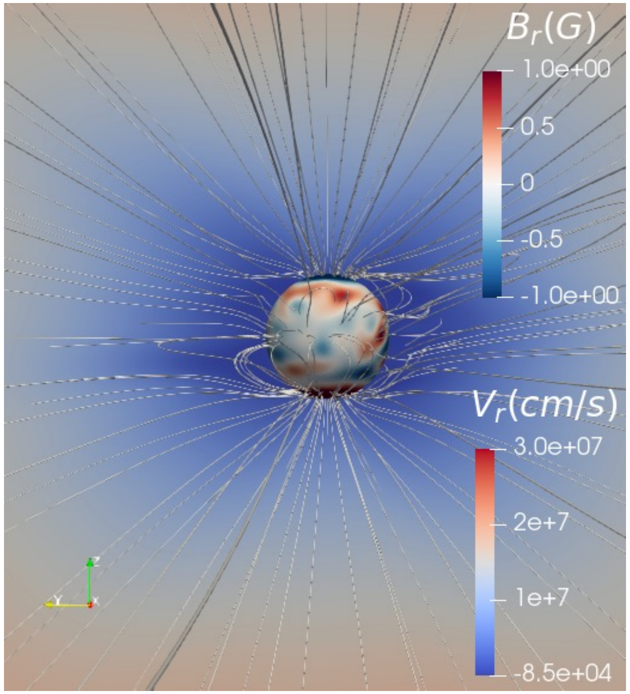
Physics :

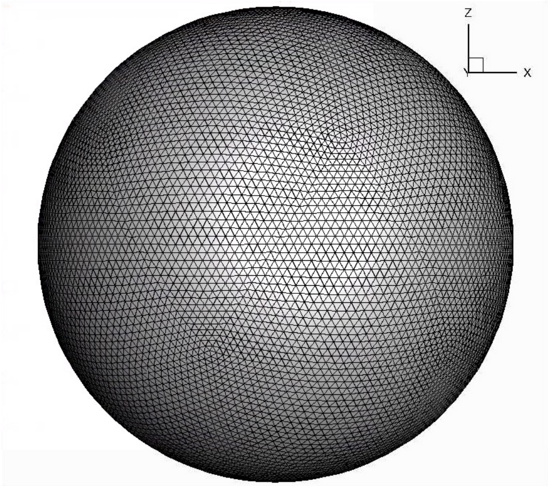
- **Polytropic wind** model with $\gamma = 1.05$
- Rotation of the star and the corona
- Gravity

- Initialization with a Parker solution
- Relaxation to reach **stationnary state**



[Perri+2022a] (under review)





[Brchnelova+2022]

COCONUT

COolfluid COronal uNstrUcTured

→ Based on the **COOLFluiD** framework

[Lani+2005/2006, Kimpe+2005, Maneva+2017]

Ideal MHD model for the solar wind in the corona (from 1 to 25 solar radii):

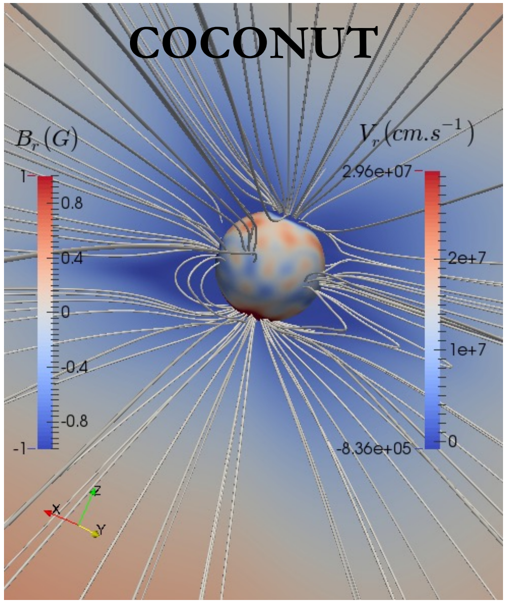
- Cartesian geometry
- Finite volume + Riemann solvers
- Polytropic heating

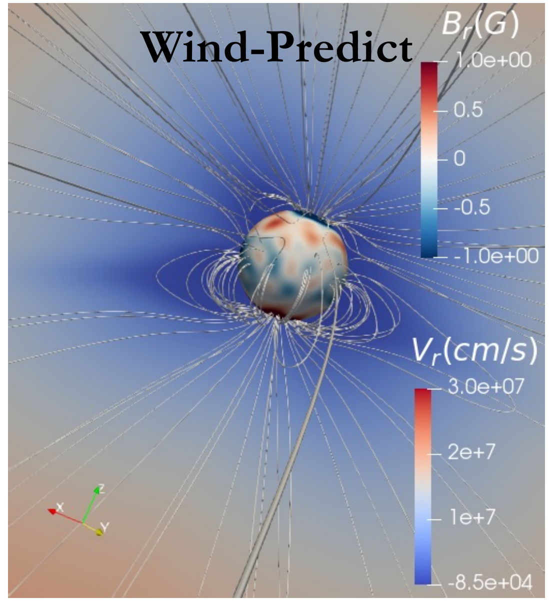
Advantages:

- **Unstructured** mesh → **no singularity** at the solar poles
- **Implicit** solving method → **fast** and accurate

[Perri+2022a] (under review)

Validation of the new code





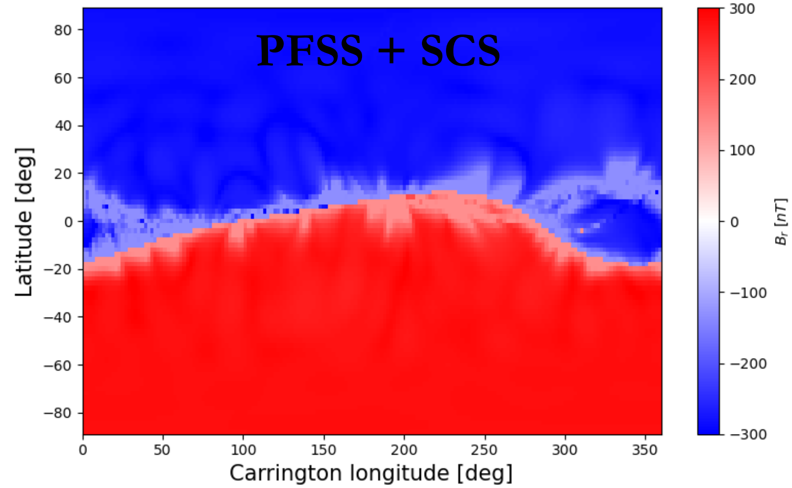
[Réville+2015a, Perri+2018]

Benchmark with both **simulations** (Wind-Predict) and **observations** (WL + EUV)

Verification of the speed-up of the implicit solver → **operational running times**

Configuration	COCONUT running time
Dipole	5.9 min
Quadrupole	11.9 min
Magnetic map ($l_{max} = 15$)	87.5 min (1h28)
Magnetic map ($l_{max} = 30$)	86.8 min (1h27)

Coupling to EUHFORIA



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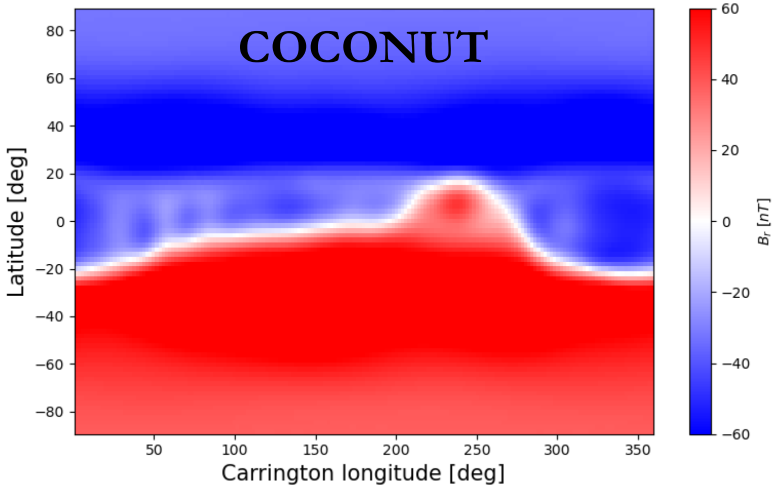
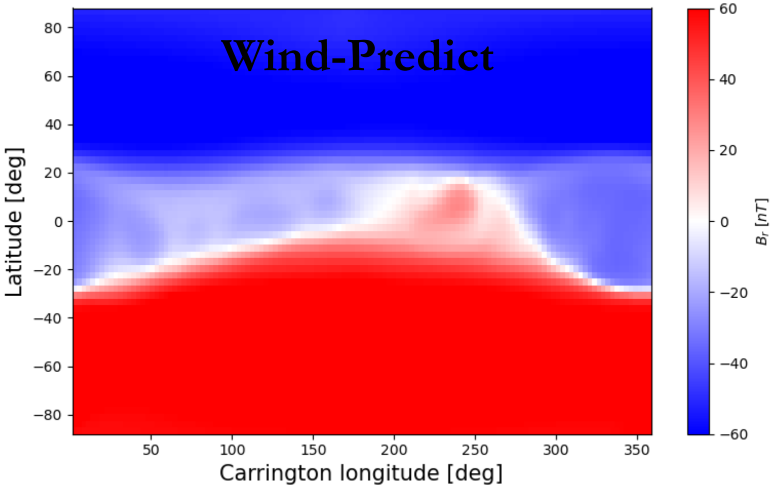




With the polytropic assumption, only the magnetic field to compare for now

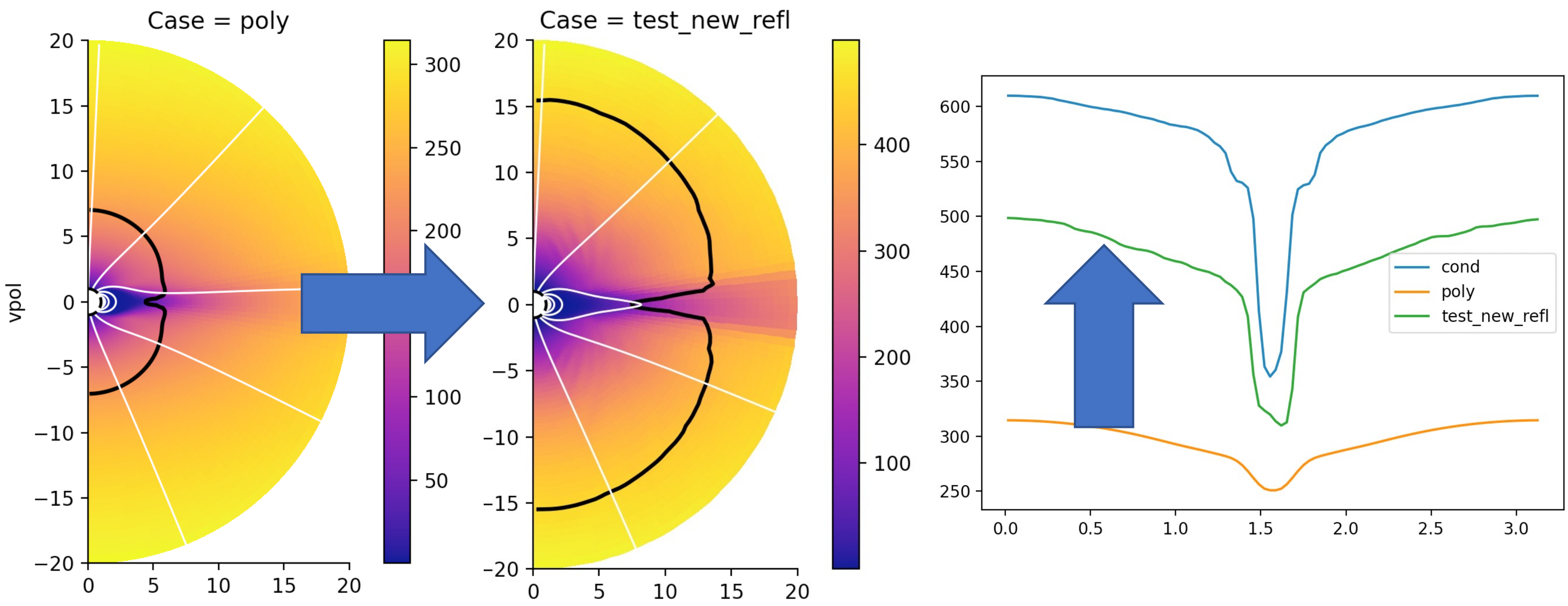
→ More precise current sheet, but field amplitude reduced

→ Assessment on the impact on connectivity (in prep.)

Improvement of the codes

Improvement of the coronal heating to capture bimodality:

- COCONUT → thermal conduction + radiative cooling + Manchester term
- Wind-Predict → Alfvén waves



→ Possibility to capture CIRs and HSSs

Magnetic map sensibility

[Perri+2022b] (submitted)

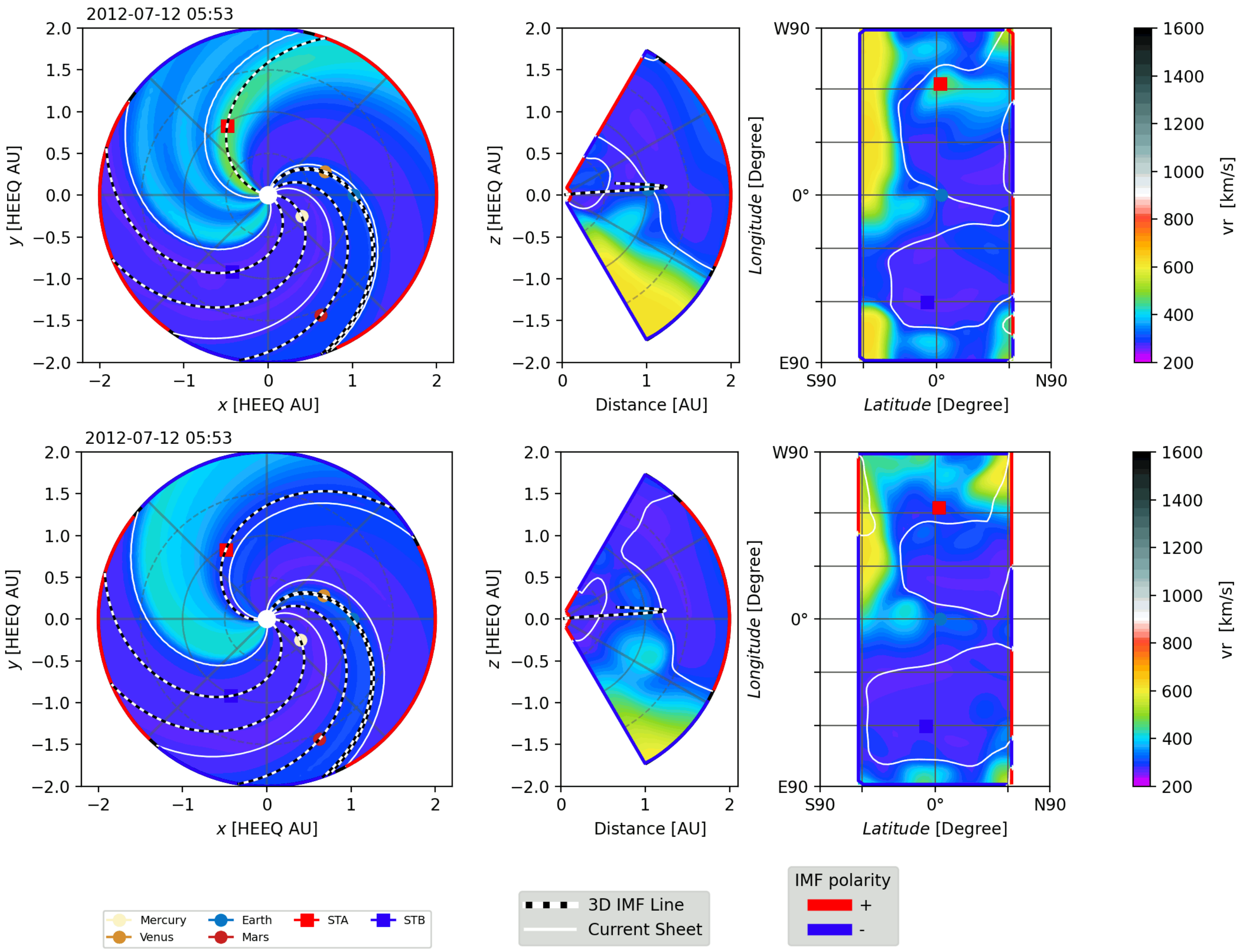
Map	Streamers ratio	Polar CH ratio	Eq. CH ratio	SB deviation
WSO	left: 28.0%, right: 24.0%	North: 72.8%, South: 33.7%	10.7%	$\delta_{max} = 30.8°$, $\delta_{mean} = 9.22°$
HMI	left: 84.2%, right: 74.7%	North: 86.1%, South: 40.6%	37.4%	$\delta_{max} = 17.5°$, $\delta_{mean} = 4.88°$
GONG (mrmqs)	left: 54.4%, right: 37.7%	North: 87.1%, South: 23.9%	8.8%	$\delta_{max} = 27.9°$, $\delta_{mean} = 11.9°$
GONG (mrnqs)	left: 74.9%, right: 65.6%	North: 86.2%, South: 42.0%	26.2%	$\delta_{max} = 19.1°$, $\delta_{mean} = 4.98°$
HMI (daily)	left: 66.2%, right: 70.1%	North: 86.3%, South: 40.1%	65.5 %	$\delta_{max} = 16.1°$, $\delta_{mean} = 4.30°$
GONG (mrbqs)	left: 39.1%, right: 41.6%	North: 80.3%, South: 33.9%	11.6%	$\delta_{max} = 23.9°$, $\delta_{mean} = 7.35°$
GONG (mrbqj)	left: 47.3%, right: 32.8%	North: 79.2%, South: 32.5%	11.4%	$\delta_{max} = 20.5°$, $\delta_{mean} = 6.43°$
GONG (mrzqs)	left: 29.1%, right: 53.6%	North: 85.2%, South: 39.2%	20.4%	$\delta_{max} = 19.7°$, $\delta_{mean} = 4.66°$
ADAPT (1)	left: 64.3%, right: 77.8%	North: 88.1%, South: 44.4%	0.0%	$\delta_{max} = 10.5°$, $\delta_{mean} = 5.36°$
ADAPT (2)	left: 61.7%, right: 77.1%	North: 87.9%, South: 44.1%	0.0%	$\delta_{max} = 9.99°$, $\delta_{mean} = 5.60°$
ADAPT (3)	left: 69.4%, right: 72.4%	North: 88.3%, South: 44.0%	0.0%	$\delta_{max} = 10.5°$, $\delta_{mean} = 5.57°$
ADAPT (4)	left: 77.0%, right: 85.5%	North: 87.9%, South: 43.9%	0.0%	$\delta_{max} = 9.69°$, $\delta_{mean} = 4.76°$
ADAPT (5)	left: 61.4%, right: 79.5%	North: 87.8%, South: 44.5%	0.0%	$\delta_{max} = 9.84°$, $\delta_{mean} = 5.09°$
ADAPT (6)	left: 66.3%, right: 78.1%	North: 87.5%, South: 44.1%	0.0%	$\delta_{max} = 10.0°$, $\delta_{mean} = 5.84°$
ADAPT (7)	left: 72.1%, right: 78.5%	North: 87.2%, South: 43.6%	0.0%	$\delta_{max} = 10.4°$, $\delta_{mean} = 6.20°$
ADAPT (8)	left: 61.9%, right: 87.9%	North: 87.4%, South: 45.3%	0.0%	$\delta_{max} = 9.63°$, $\delta_{mean} = 5.75°$
ADAPT (9)	left: 75.4%, right: 77.6%	North: 87.7%, South: 43.4%	0.0%	$\delta_{max} = 10.3°$, $\delta_{mean} = 5.91°$
ADAPT (10)	left: 61.3%, right: 80.5%	North: 88.0%, South: 44.9%	0.0%	$\delta_{max} = 9.39°$, $\delta_{mean} = 4.99°$
ADAPT (11)	left: 80.0%, right: 64.1%	North: 88.1%, South: 44.7%	0.0%	$\delta_{max} = 10.4°$, $\delta_{mean} = 5.73°$
ADAPT (12)	left: 76.1%, right: 85.8%	North: 87.9%, South: 44.5%	0.0%	$\delta_{max} = 10.0°$, $\delta_{mean} = 5.52°$

→ HMI and GONG-ADAPT perform the best

→ WSO and GONG should not be used without the proper corrections!

Impact on CMEs

Propagation of the same CME with different wind backgrounds (maps) (in prep.)



Conclusion and perspectives

Conclusions:

- We have coupled **two new coronal models** to EUHFORIA
- We can then better quantify the impact of the **coronal magnetic field** on space weather previsions (**HMI** > GONG-ADAPT > GONG)

Perspectives:

- **Impact on transient** propagation and connectivity
- **Comparisons between models** to better understand the underlying physics
- International standards to validate and quantify models (**ISWAT**)

Papers:

- Perri+2022 (arxiv: https://arxiv.org/pdf/2205.03341.pdf)
- Brchnelova+2022 (JPlPh, doi:10.1017/S0022377822000241)
- Samara+2021: (A&A, doi:10.1051/0004-6361/202039325)

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