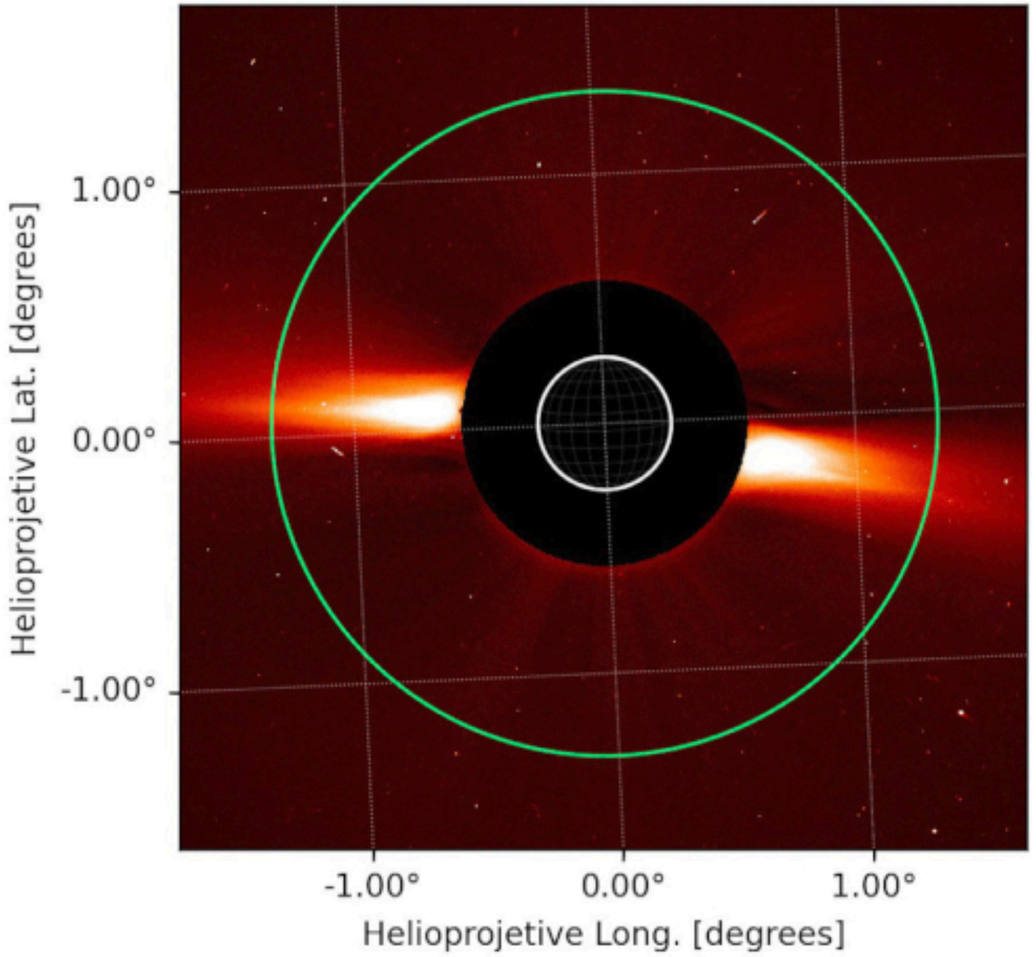
Using white light based coronal models for space weather predictions

V. Réville, A. Rouillard, N. Poirier, A. Kouloumvakos, R. Pinto, N. Fargette, M. Indurain, T. James, R. Pobeda, R. Fournon

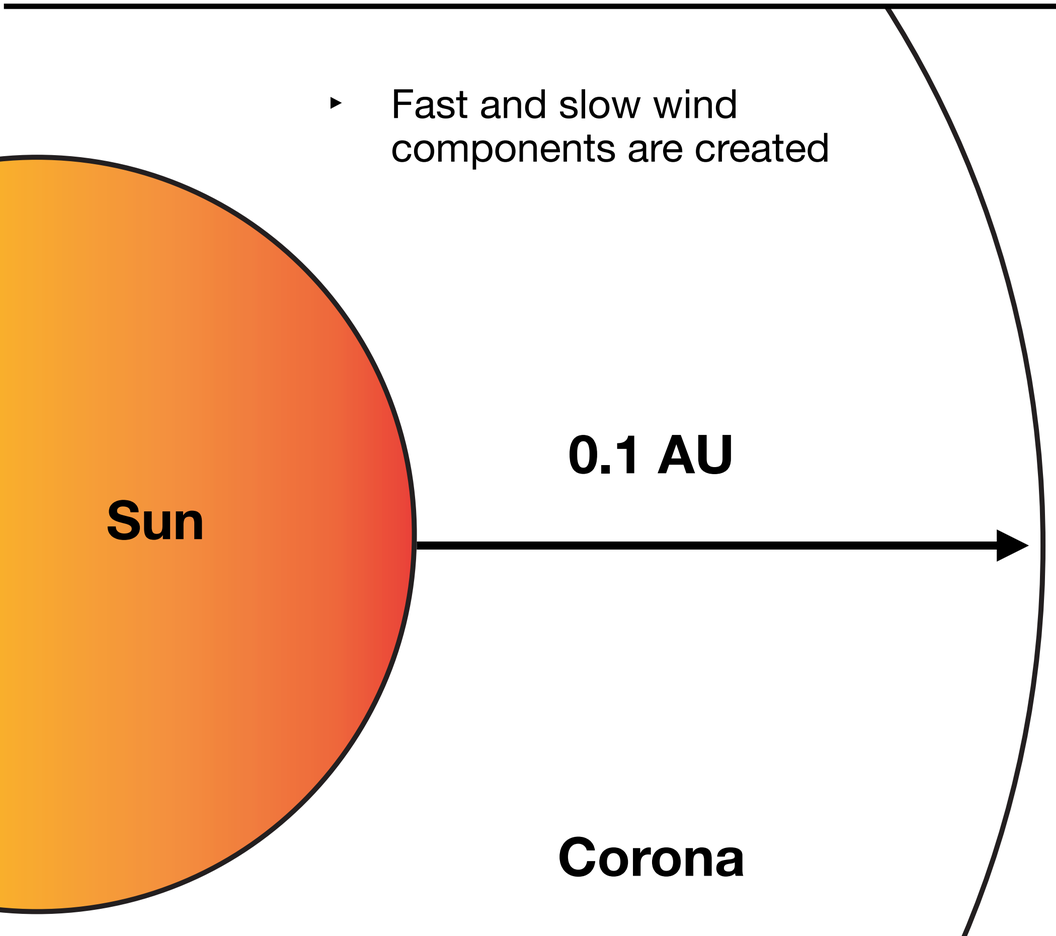


ERC SLOW SOURCE

Colloque PNST, Marseille, 19 Mai 2022

Motivation

Finding accurate and efficient coronal models for the background solar wind

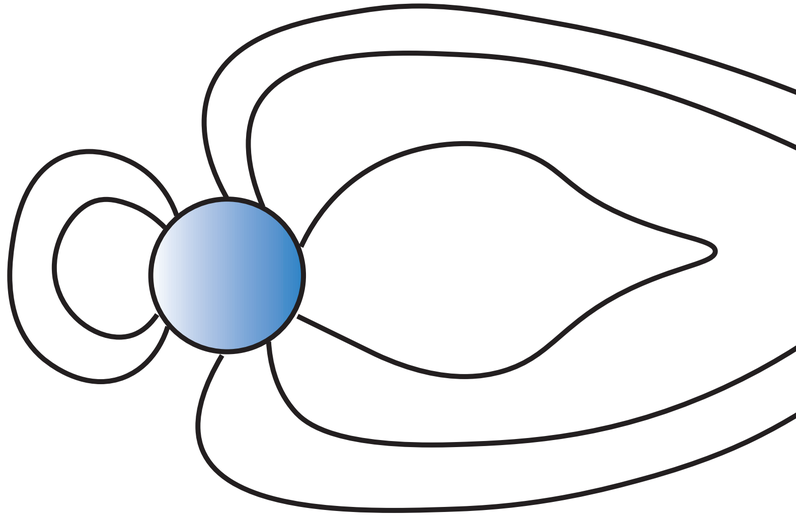


- Fast and slow wind components are created

- High speed streams (HSS) catch up with the slow wind and create compression regions (CIRs).

Heliosphere

- HSS and CIRs drive energetic events (storms) in the magnetosphere and the radiation belts.



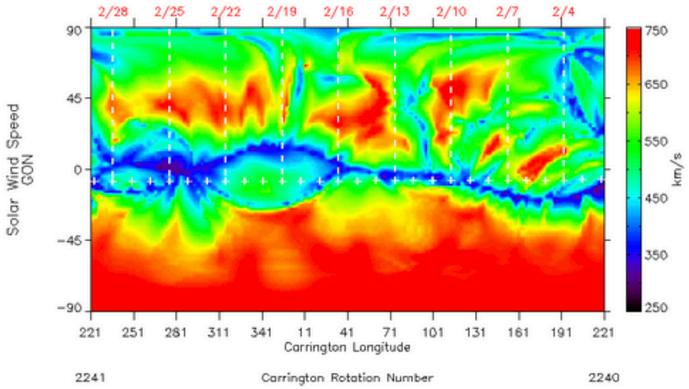
Magnetosphere

Coronal models

Choose your favorite

Wang-Sheeley-Arge (WSA)

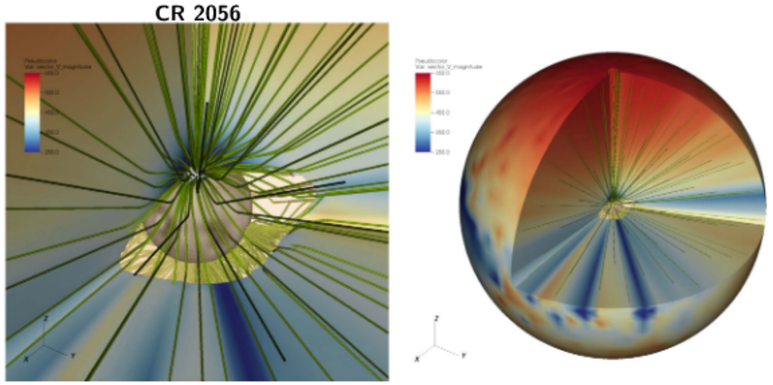
[Wang & Sheeley 1990-91, Arge & Pizzo 2000, Arge et al. 2004]



- PFSS + Schatten Current Sheet model
- Parametrized parameters at 0.1 AU from the B geometry
- Very fast

Multi-VP

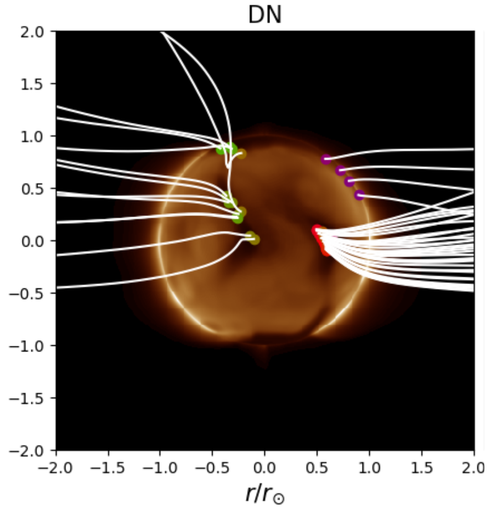
[Pinto & Rouillard 2017, ApJ]



- PFSS model + flux correction
- 1D HD simulations of TR+corona along flux tubes.
- Rather fast (can select resolution/ angular extent)

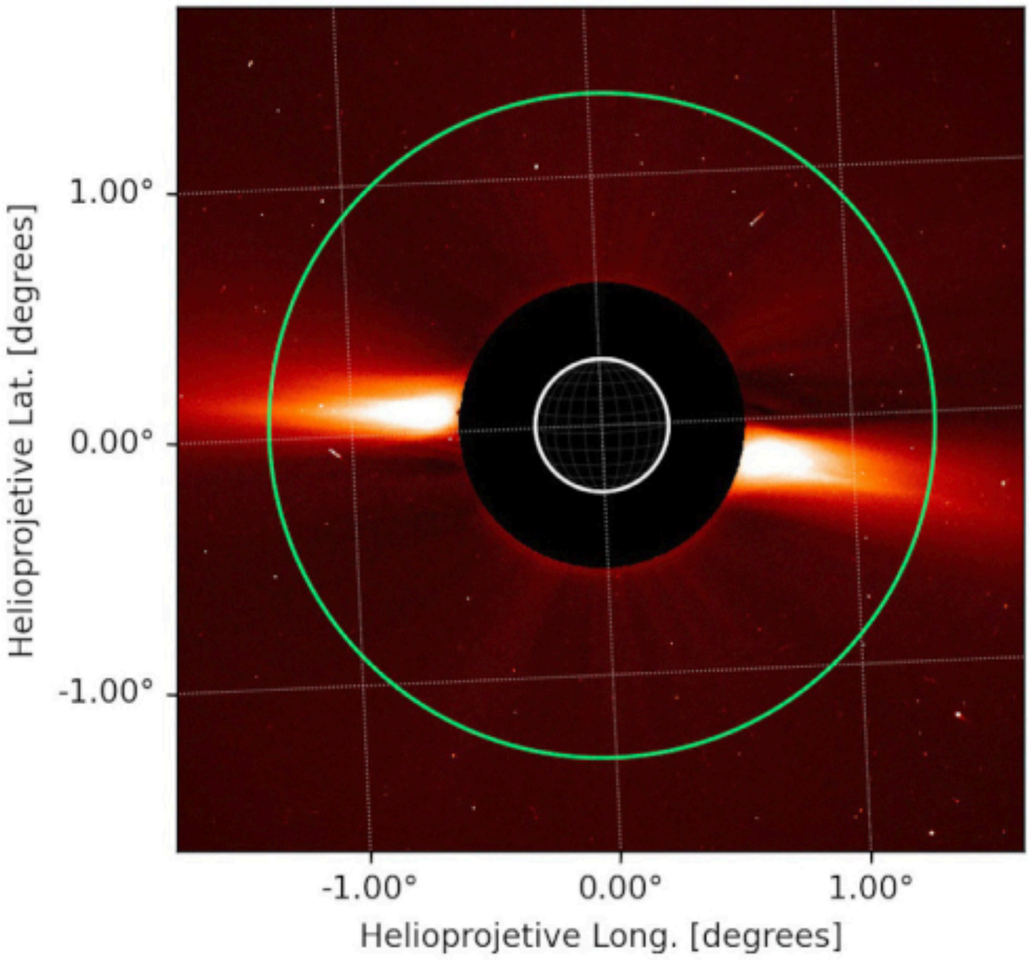
WindPredict-(AW)

[Réville et al. 2020, ApJS, Parenti et al. 2022, ApJ]



- Full MHD model (+ Alfvén driven turbulence phen.)
- All MHD quantities obtained self-consistently
- Validated on in situ and remote data
- Slow to very slow (AW)

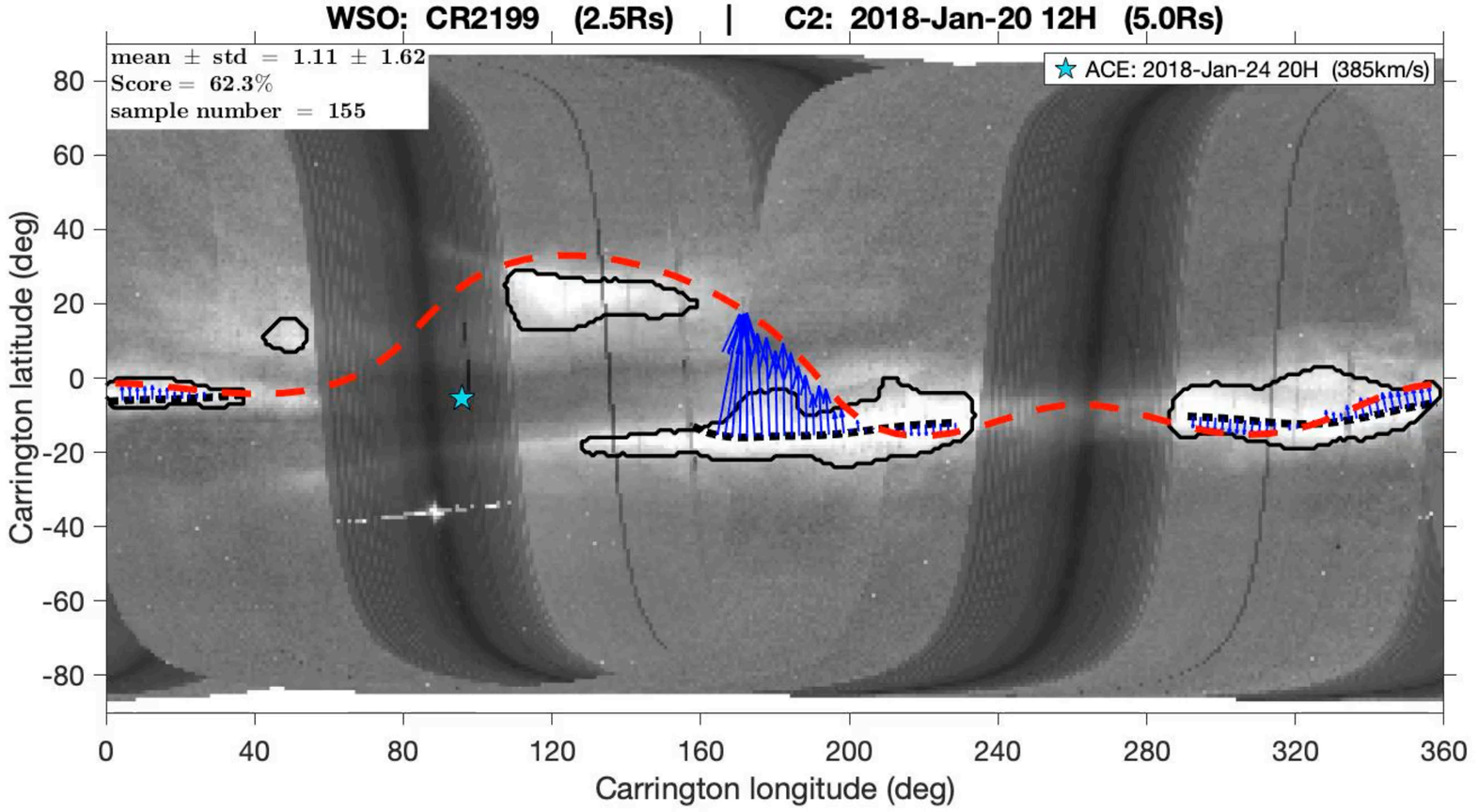
Solar maximum brightness



[Poirier et al. 2021, Frontiers ASpS]

- We use WL observations from SOHO/LASCO-C2
- Observations updated daily to recover the location of the heliospheric current (plasma) sheet.
- We take the maximum brightness as the most likely position of the HCS at 5Rs.
- Connectivity tool uses the algorithm to select best ADAPT magnetogram

Solar maximum brightness



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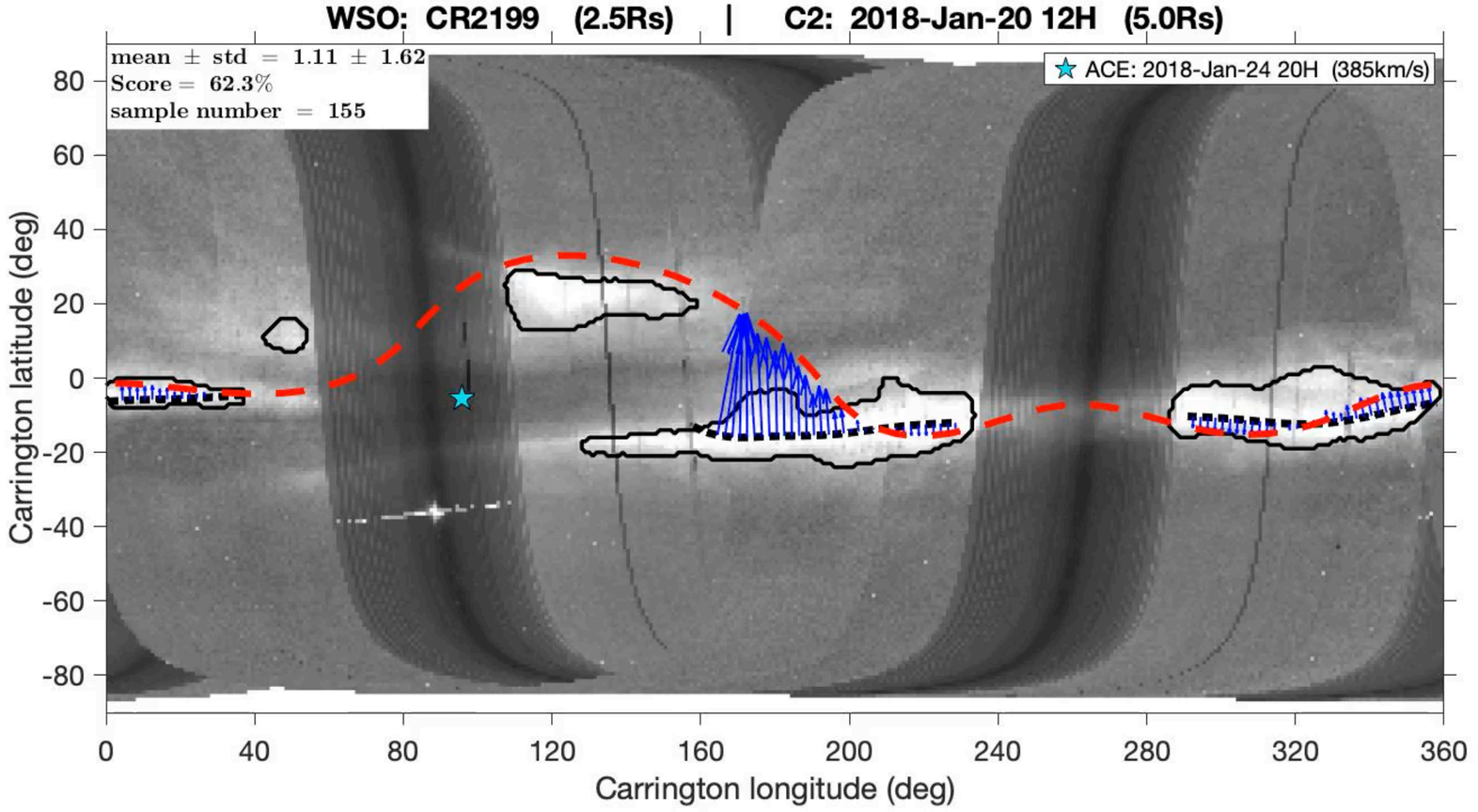

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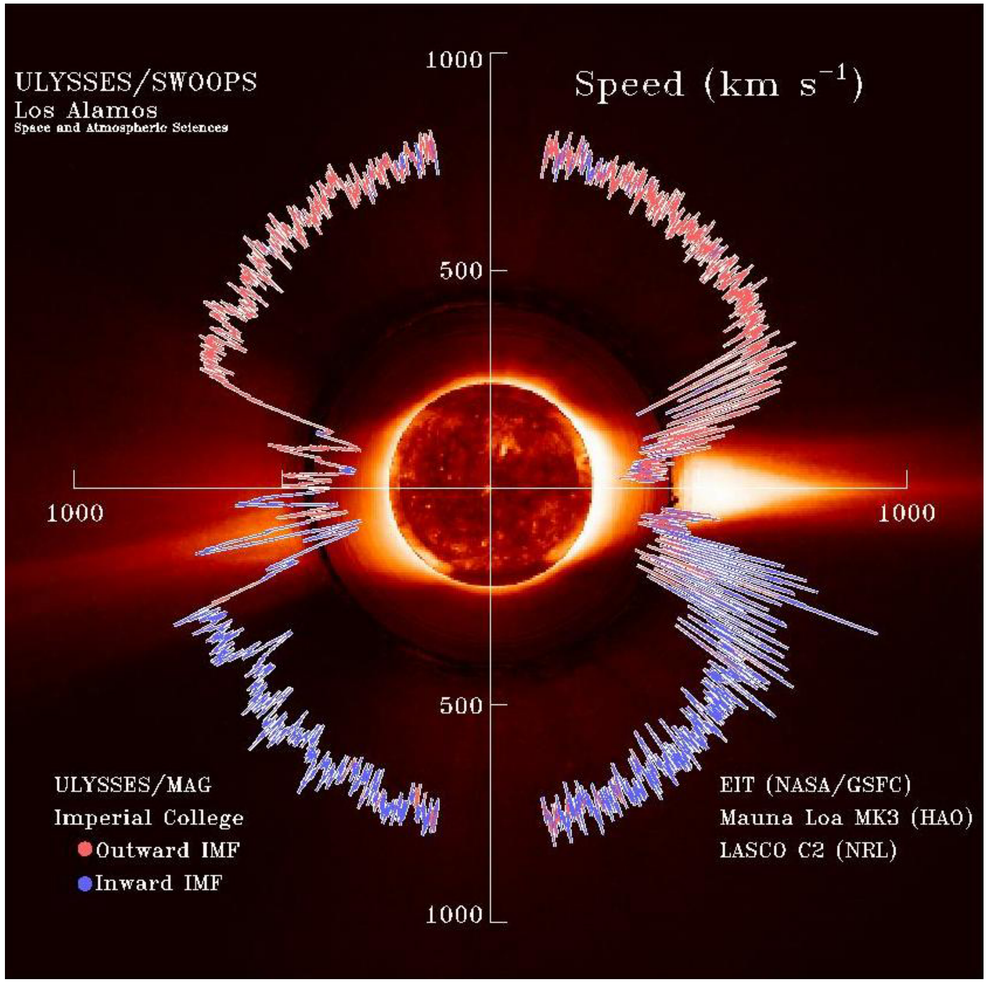
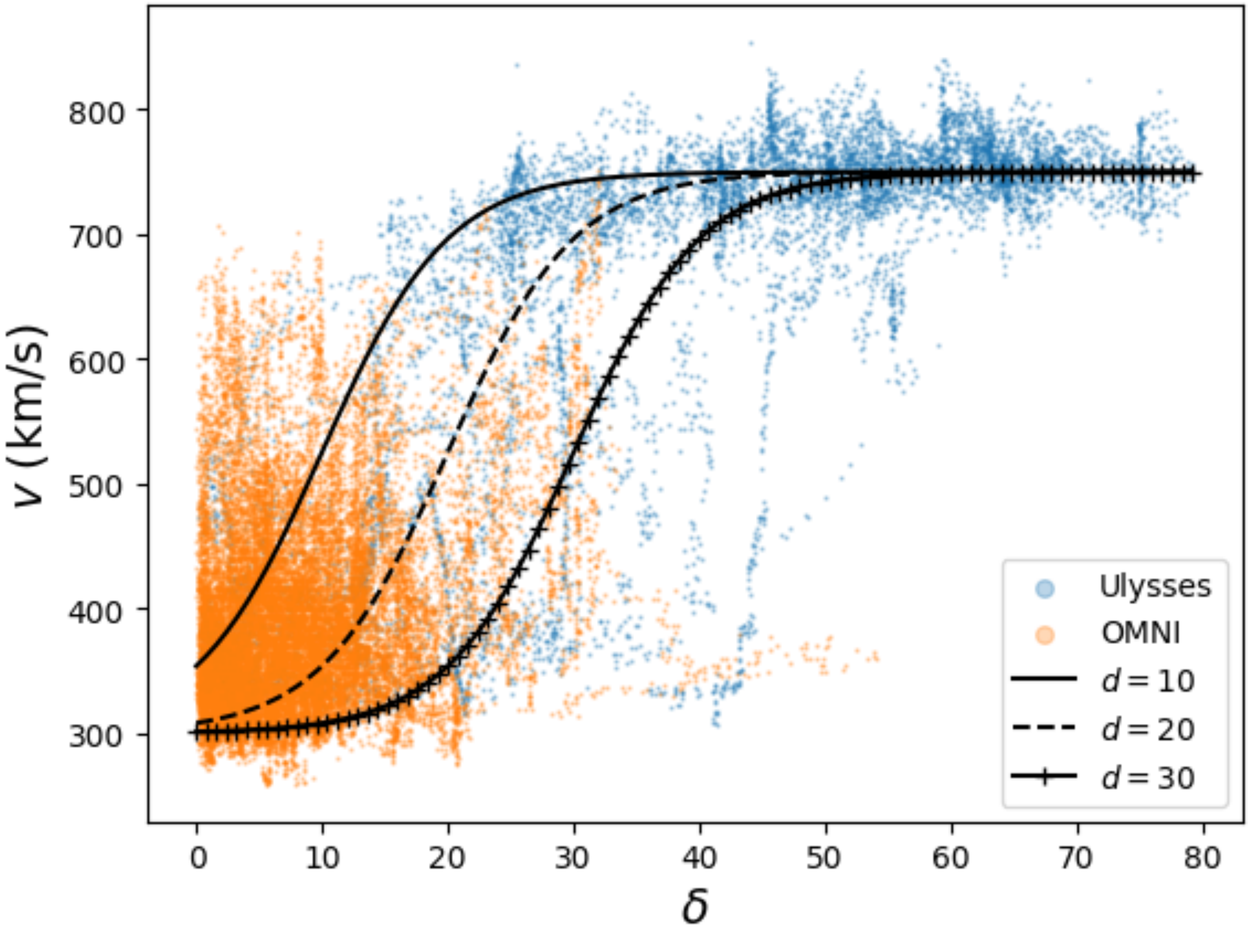
SMB and velocity



$$V(\delta) = 300 + \frac{350}{1 + e^{0.2(\delta - d)}} \text{ km/s}$$

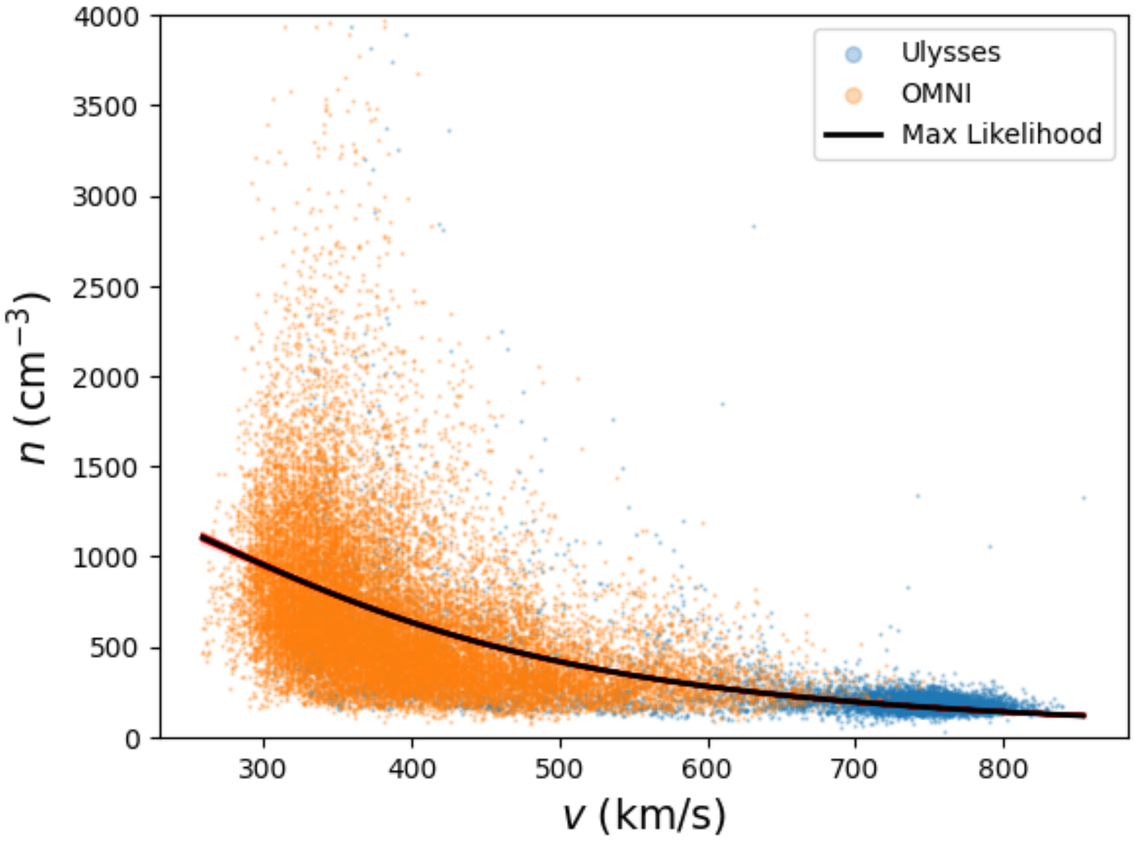


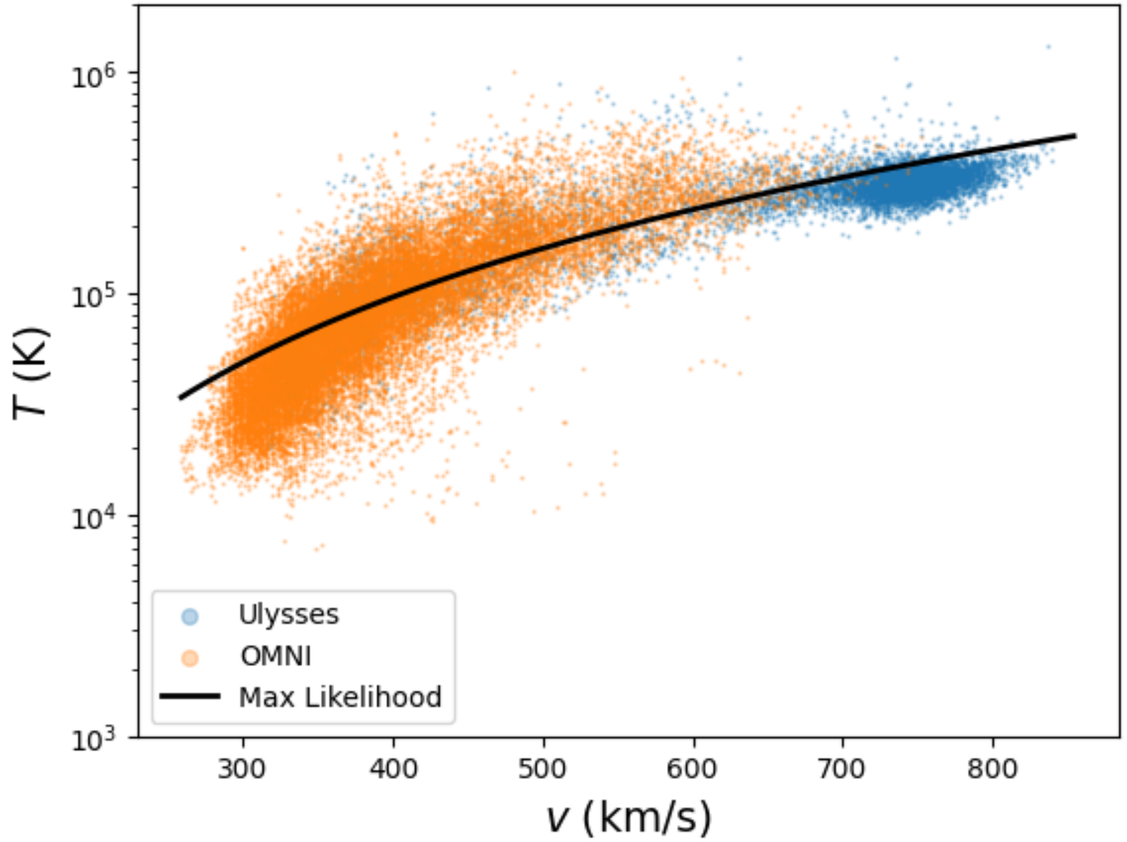
Density / Temperature

Relation with velocity at 0.1 AU

$$n(V(\delta)) = \frac{1582.6}{1 + (V(\delta)/347)^{2.8}} \ \mathrm{cm}^{-3}$$

$$T(V(\delta)) = (0.89 \times V(\delta) - 46)^2$$

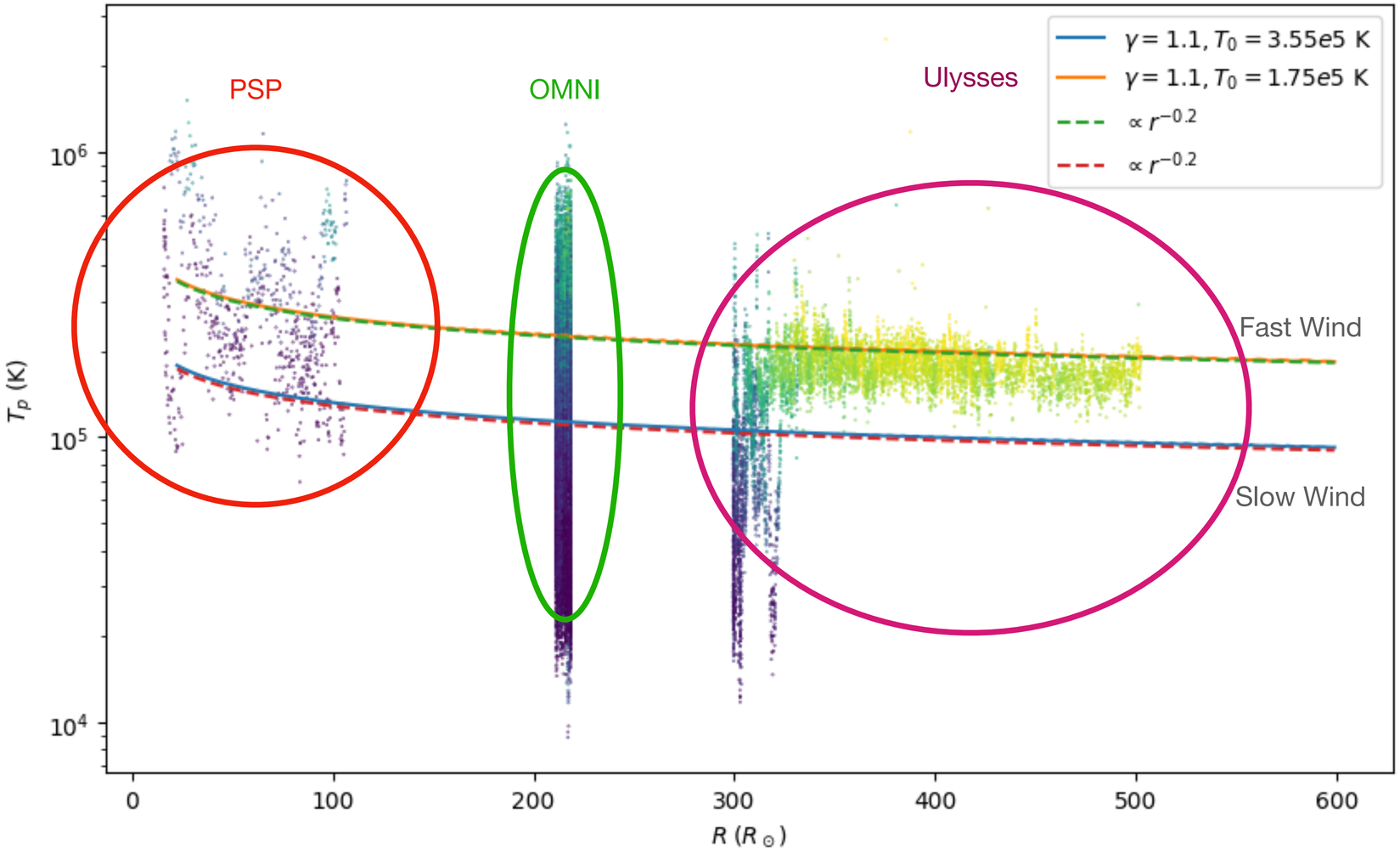




Radial temperature profile

How to extrapolate back to 0.1 AU?

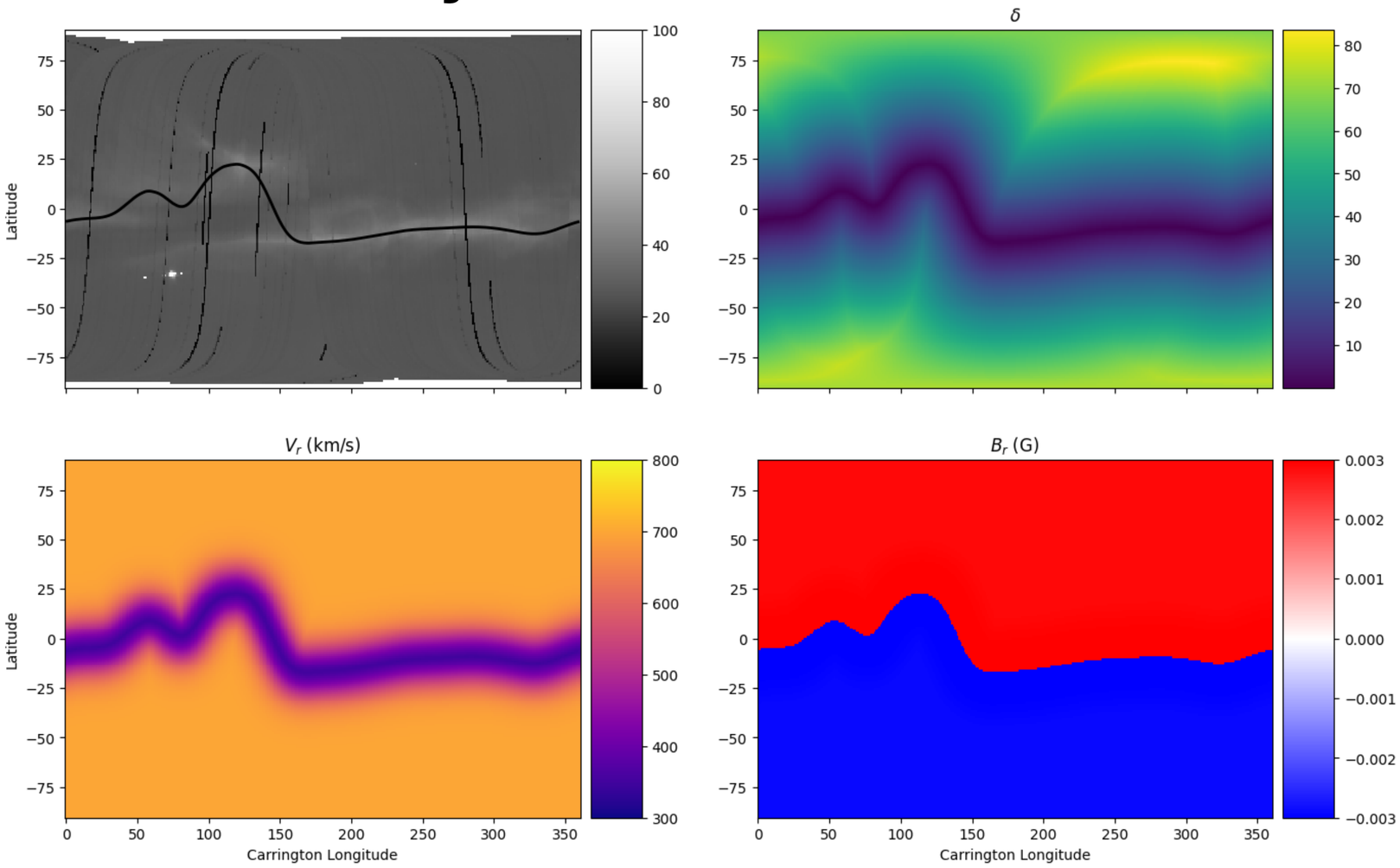
- Proton temperatures for PSP, OMNI, Ulysses
- Radial profiles roughly consistent with a $r^{-0.2}$ decay
- Polytropic wind with gamma=1.1



Empirical SW from SMB

WindPredict-AW & Multi-VP : boundary conditions

- We identify the maximum of the solar maximum brightness with the Heliospheric Current Sheet
- Computes the angular distance delta with the SMB
- Converts delta in velocity, density and temperature
- B (3nT/AU^2) is distributed uniformly on the sphere at 0.1 AU



Inner Heliosphere model

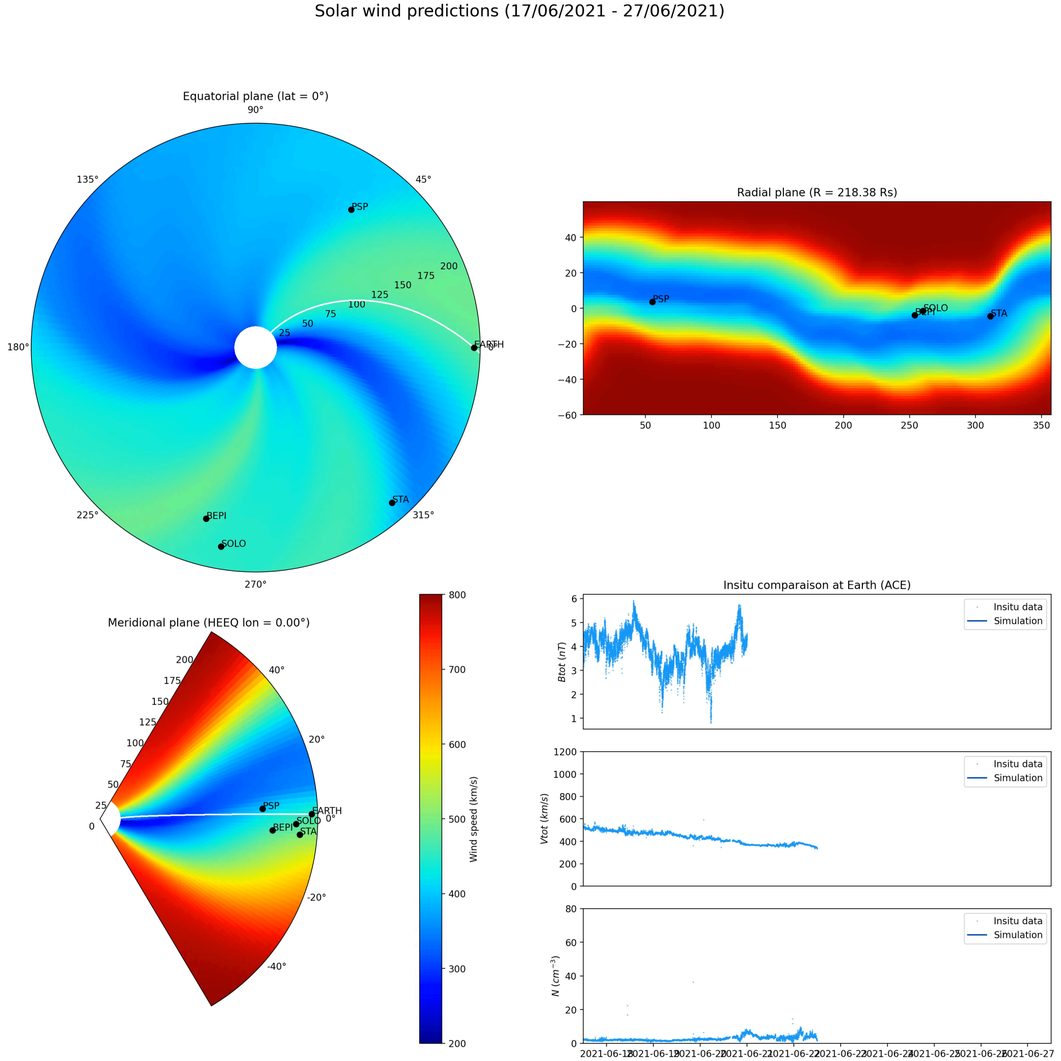
HelioCast

http://heliocast.irap.omp.eu

- Based on the parallel MHD solver PLUTO

  [Mignone et al. 2007, ApJ]

- Godunov type Riemann solvers (HLL)
- Uses time evolving boundary conditions at 0.1 AU (super-Alfvénic regime)
- Polytropic solar wind with gamma=1.1
- Runs +7 days forecasts in a few hours (8 cores)



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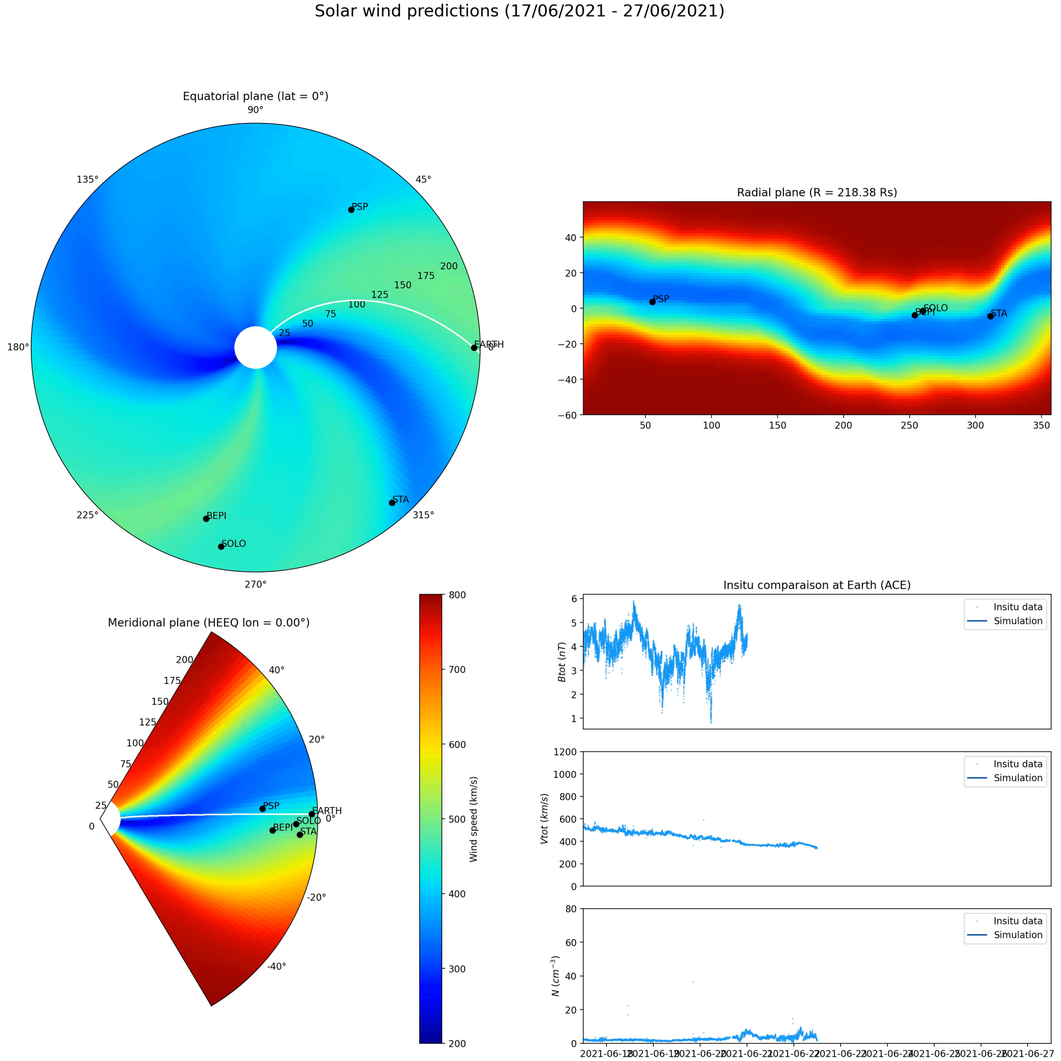
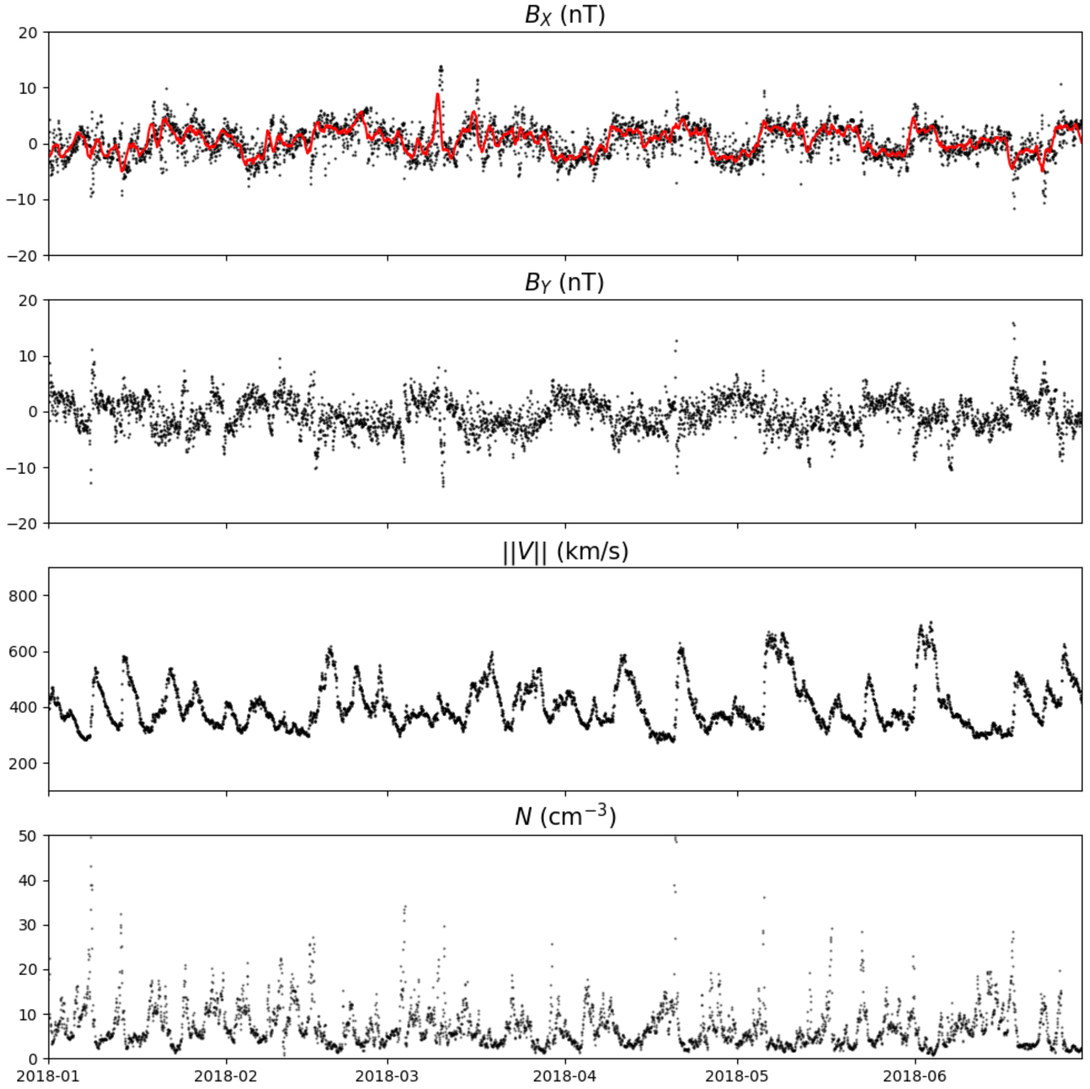


Comparison with in-situu data

How well can we predict SW parameters at Earth?

- HelioCast run with daily update of the solar wind solution from SMB method
- Magnetic properties are mostly good except for some period where the SMB catches quasi-separatrix layers
- Most HSS are recovered
- There is no best model parameter d throughout the period
- Time dependent velocity - distance relation?

[Réville et al. 2022, in prep]



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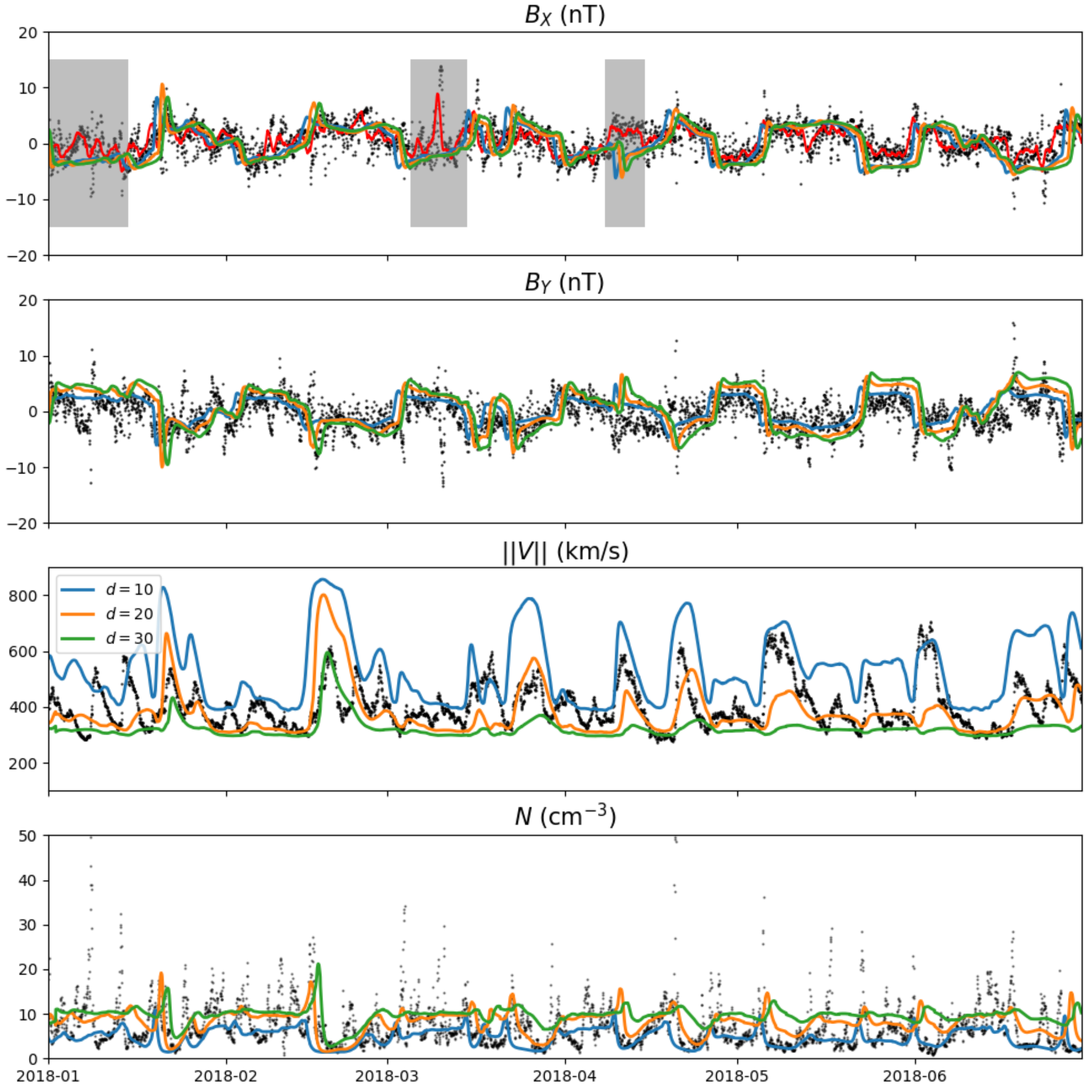
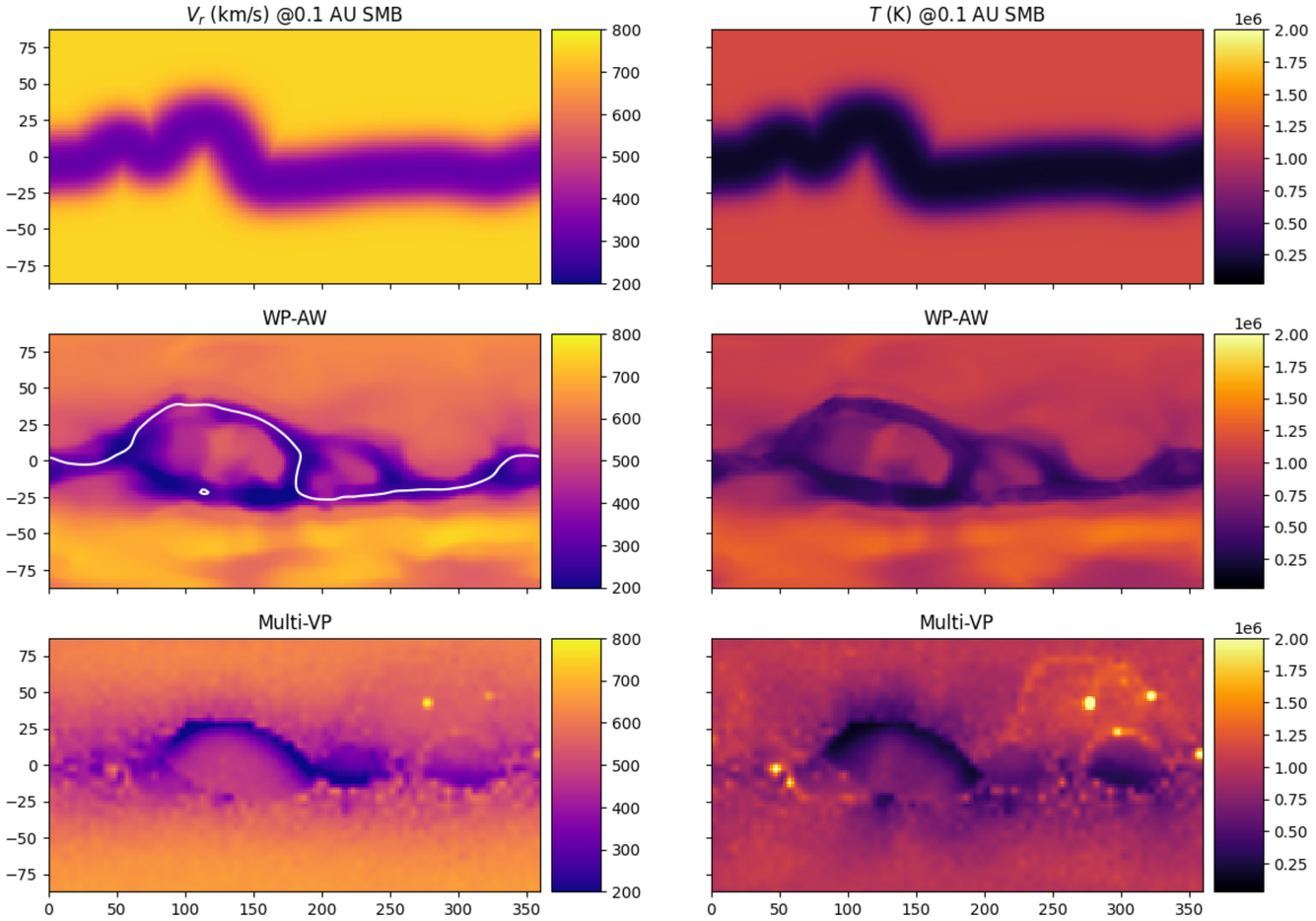


Comparison with other models

WindPredict-AW & Multi-VP: boundary conditions

- Multi-VP models made with WSO Carrington maps
- WindPredict-AW w/ ADAPT GONG synoptic maps
- HCS width in the models depend on the longitude
- Complex structure of slow wind appears in WP-AW and Multi-VP
- Wrong IMF polarity is predicted when the SMB algorithm catches a quasi-separatrix layer instead of the HCS



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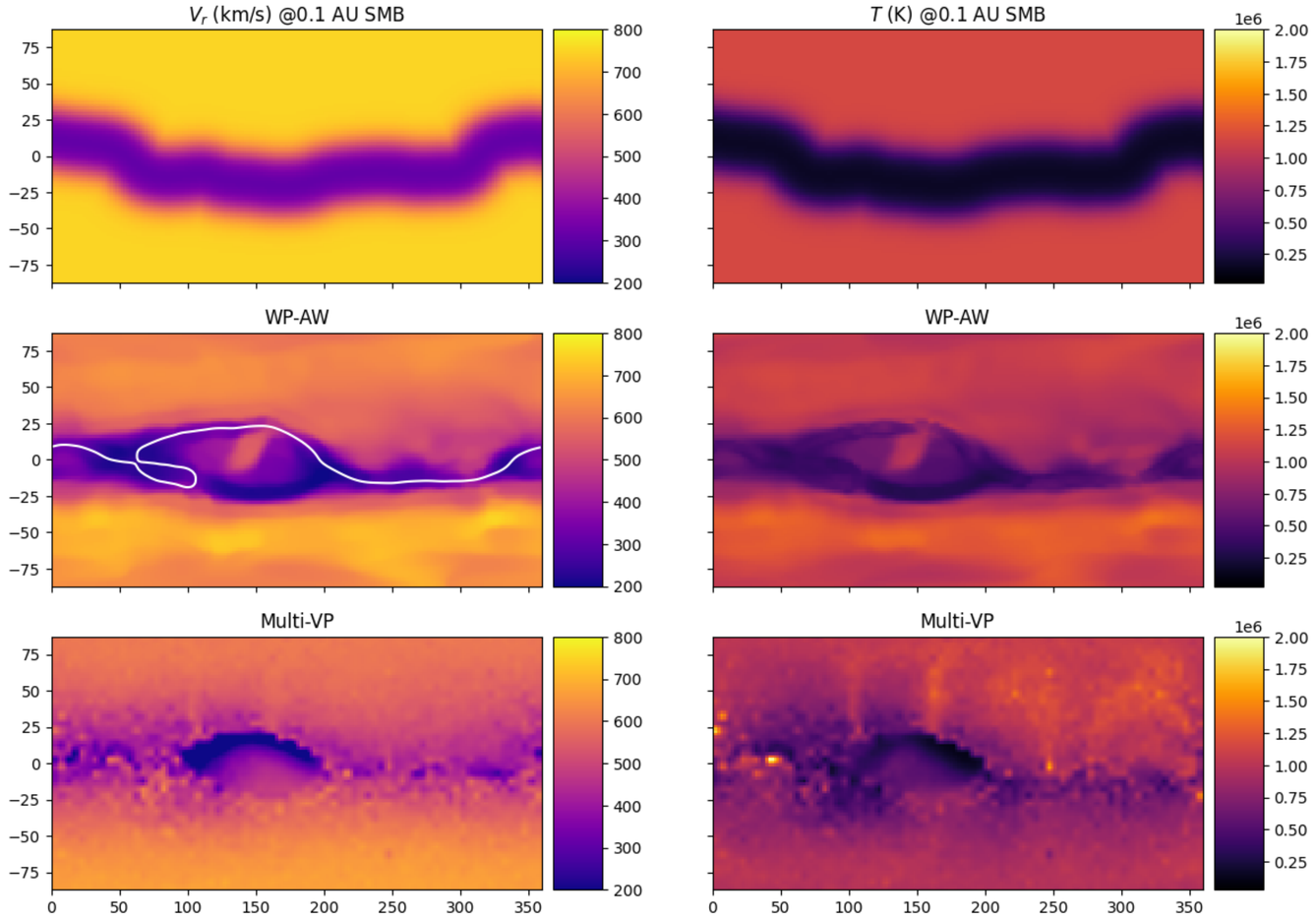
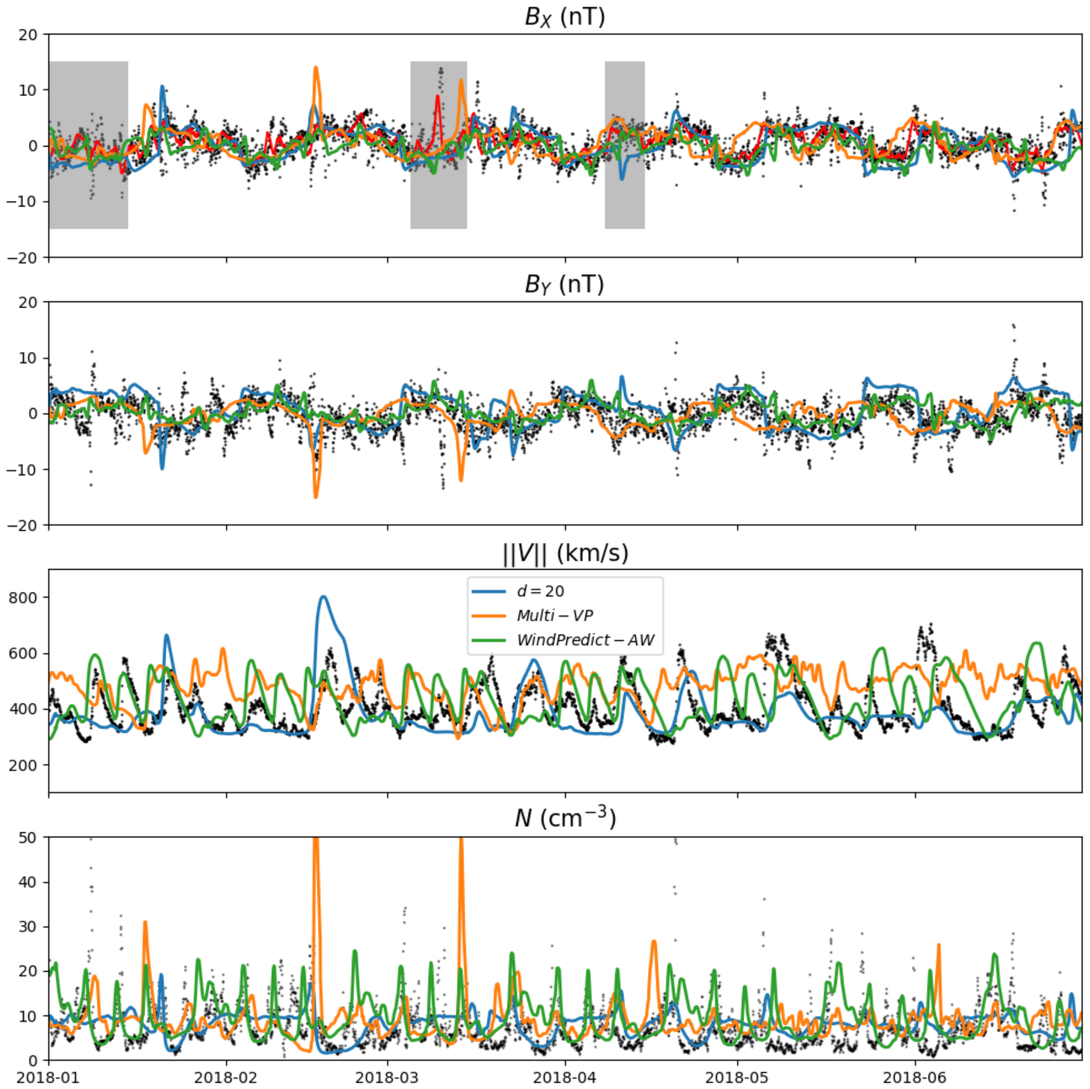


Comparison with other models

WindPredict-AW & Multi-VP: in situ

- 6 Multi-VP run (one per CR)
- 3 WP-AW run (20 Jan-Mar-May)
- Wrong polarities are captured with both MHD models
- HSS are well captured by WP-AW but…
- …faster update seems necessary (daily, weekly ?)

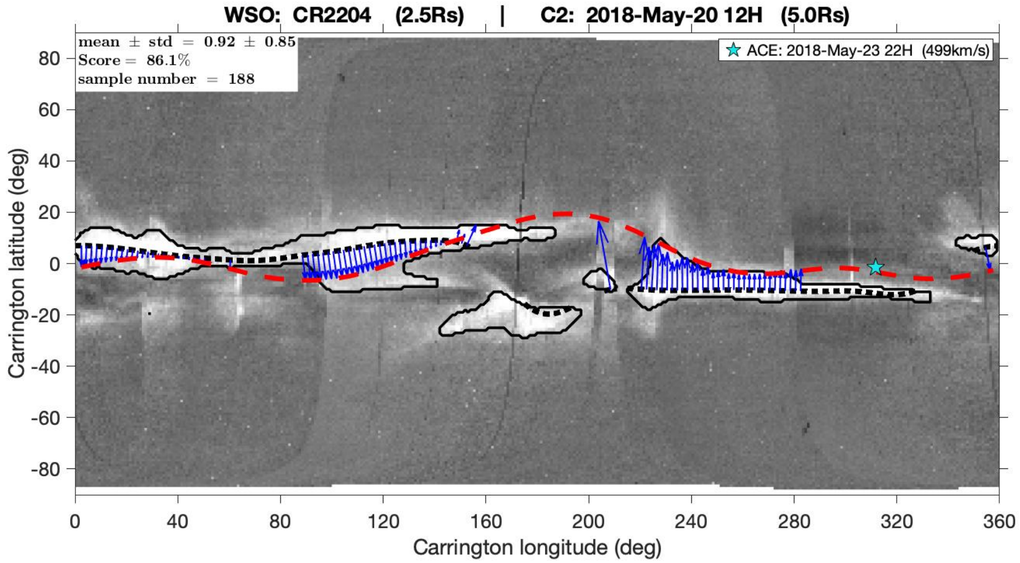
[Réville et al. 2022, in prep]

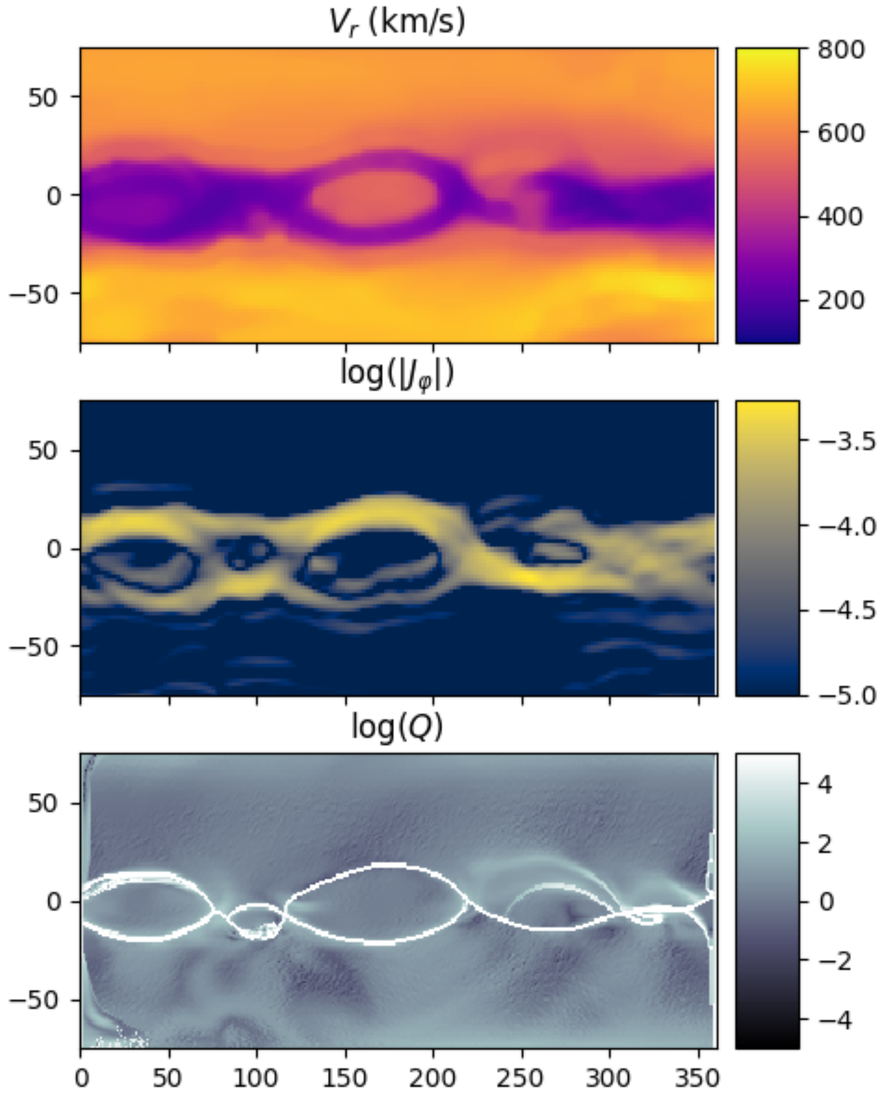


Leads for improvements

Slow wind from quasi-separatrices

- WL structuring corresponds to speed/current squashing factor distributions
- Detecting QSL in the WL would help a lot
- Necessary as we go to activity maximum





Summary

- We developed a novel technique to constrain coronal model and obtain the position of the HCS with WL SMB measurements.
- This technique can also be used to assess empirically the properties of the SW without any magnetogram.
- We propagated these solutions with a 3D MHD model, HelioCast, to 1 AU and find good matches with in situ SW parameters.
- More expensive models improve some aspects, especially reproducing the QSL structures
- Probably possible to improve the algorithm in that direction…

Watch our progress at http://heliocast.irap.omp.eu