PUNCH and space weather forecasting

Some perspectives gained from the UK SWEEP project

SWEEP team leaders:

PI Huw Morgan, Prifysgol Aberystwyth (Cymru, UK)

Matt Owens (Reading, UK)

Anthony Yeates (Durham, UK)

hmorgan@aber.ac.uk

SWEEP: Space Weather Empirical Ensemble Package

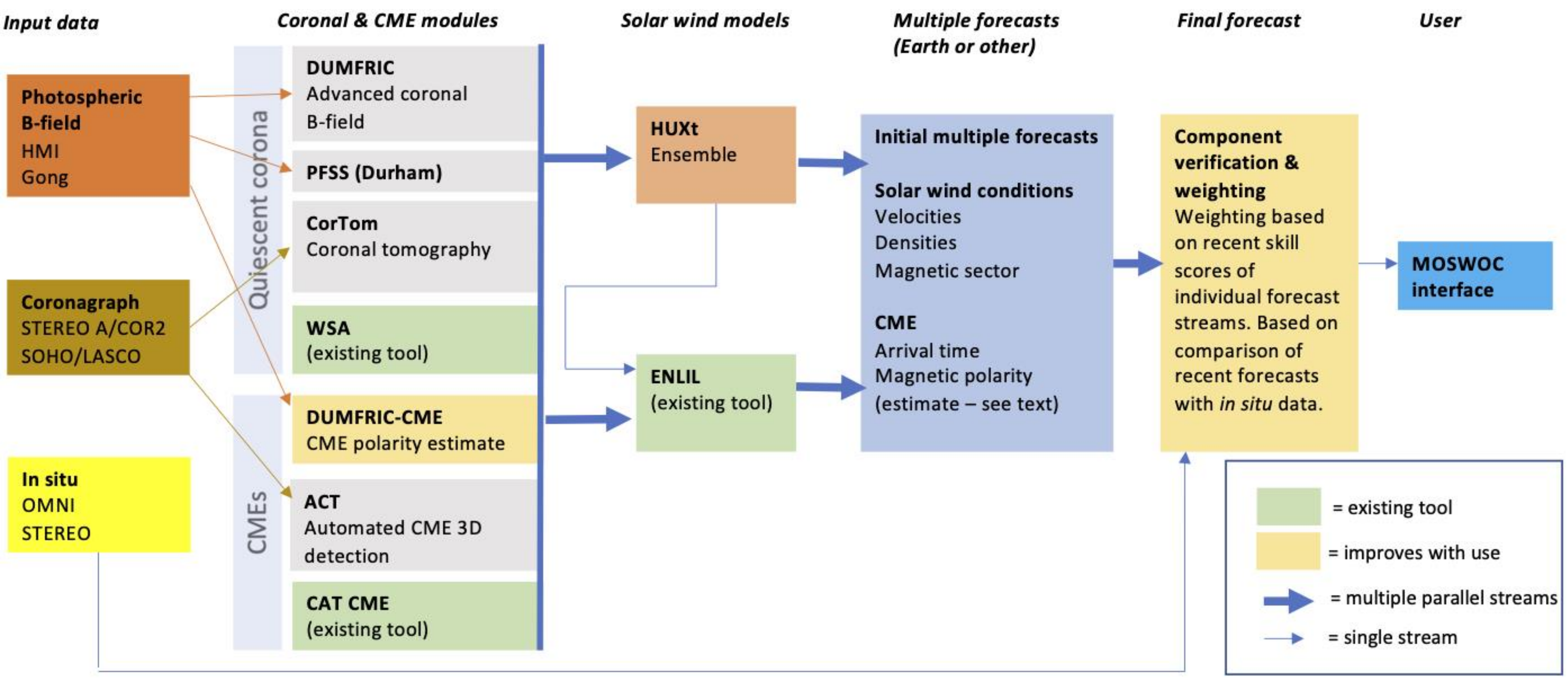
- Funded under UKRI Strategic Priority Funds. *"SWIMMR (Space Weather Instrumentation, Measurement, Modelling and Risk) is a £20 million, four-year programme that will improve the UK's capabilities for space weather monitoring and prediction."* 12 funded projects, one of which is…
- SWEEP, led by Aberystwyth, collaboration with Reading, Durham, Northumbria
- Develop a new space weather forecasting software package for the Met Office Space Weather Operations Centre

SWEEP: Space Weather Empirical Ensemble Package

Remote observations near Sun => Solar wind & CME forecasts at Earth

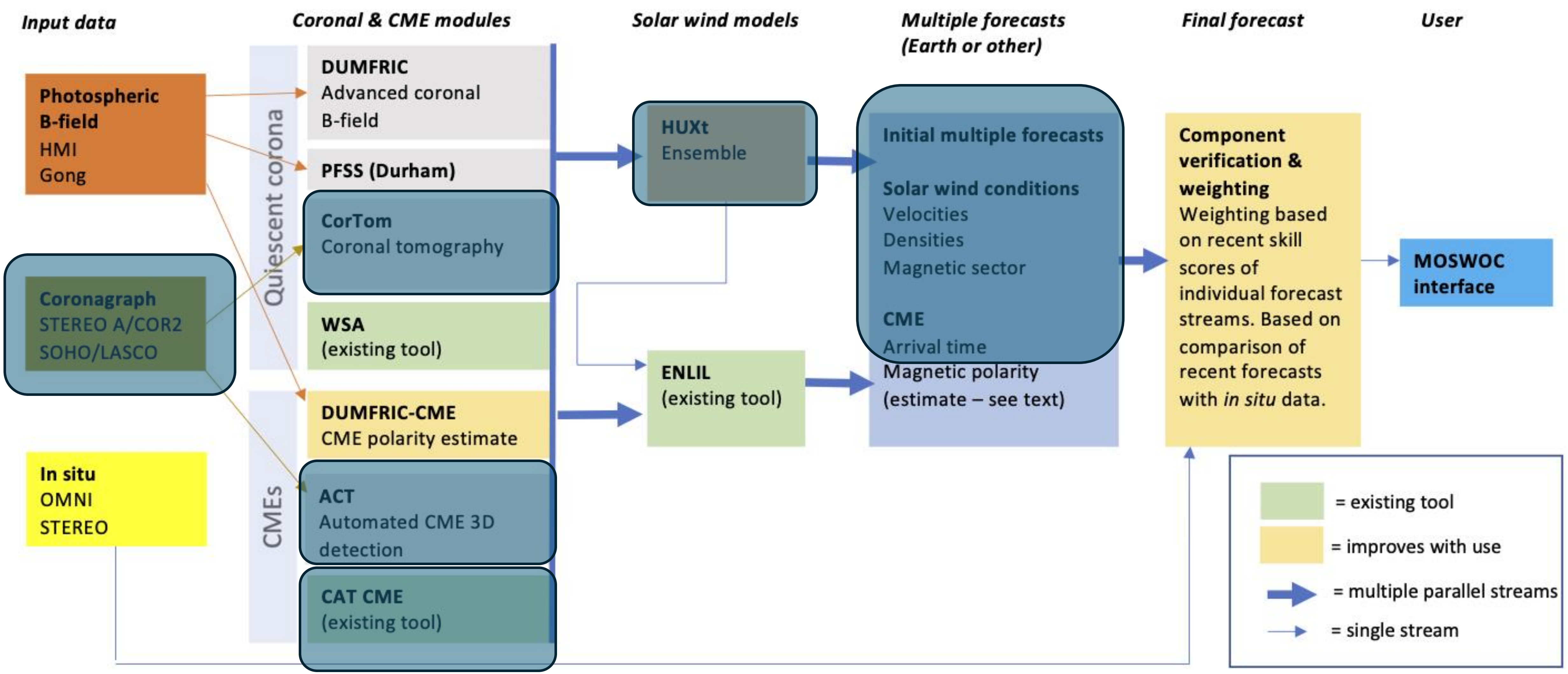
- Merge several existing advanced modelling and analysis tools
- Provide fully-automated, near-real-time (NRT) forecasts of the solar wind and coronal mass ejections (CMEs)
- Confidence limits based on an ensemble approach
- Robust – multiple models and data sources => multiple forecasts
- Hindcasts used to merge multiple forecast streams.
- No new research: packaging of existing tools

SWEEP modules & linkages



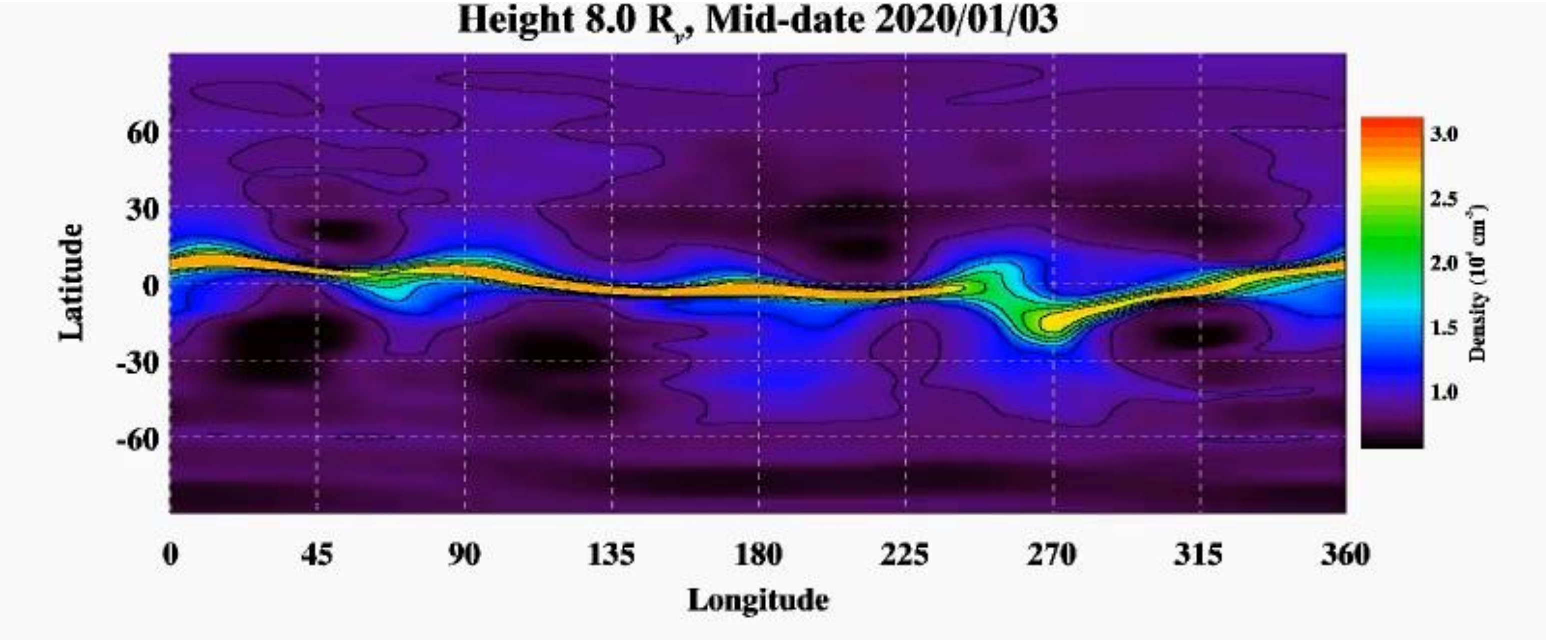
SWEEP modules & linkages

All these based on coronagraph data. Can provide forecasts (ambient solar wind/CMEs) based *only* on coronagraphs!

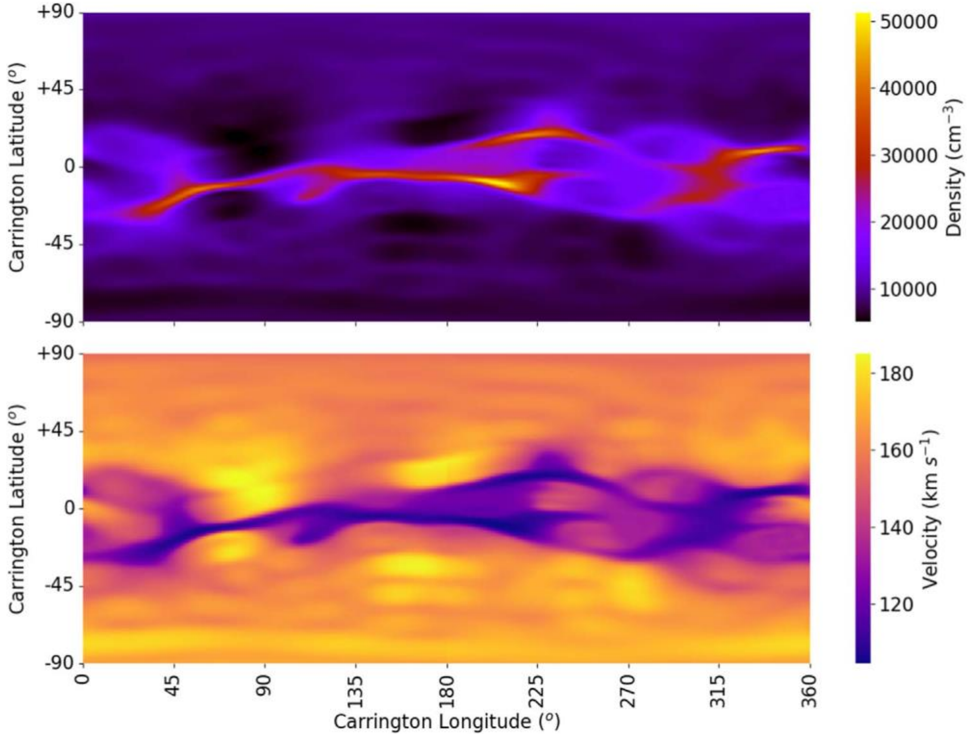


Coronal Tomography (CorTom)

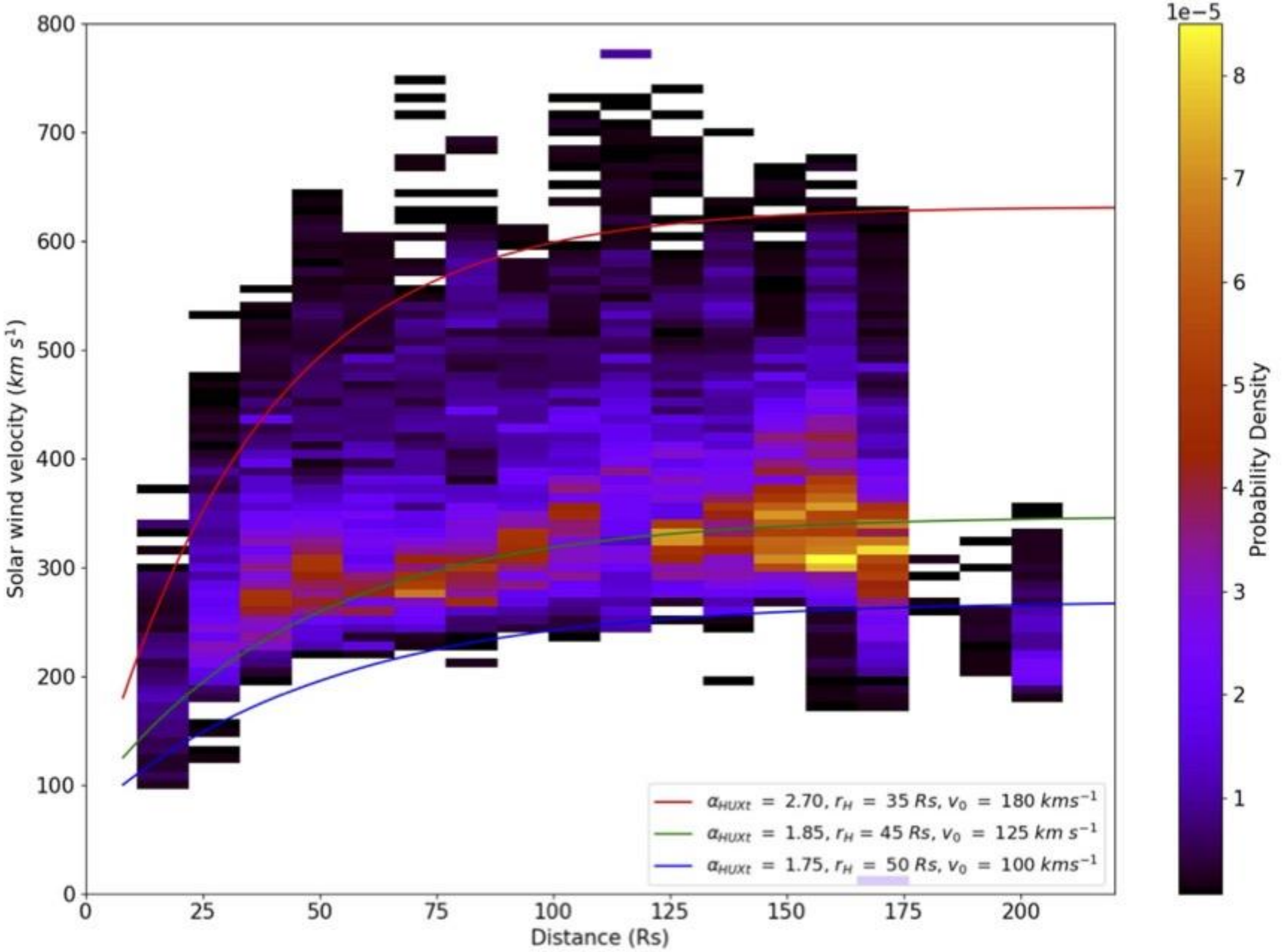
- White light observations of the solar corona are taken by Cor2 onboard STEREO Ahead for approx. ½ of a Carrington rotation.
- Data is processed to reduce CME signals.
- An inversion technique based on spherical harmonics is applied to obtain the 3D density of the solar corona, thus solving the LOS.
- For space weather purposes, we reconstruct density at $r = 8\ R_s$



Density => Velocity



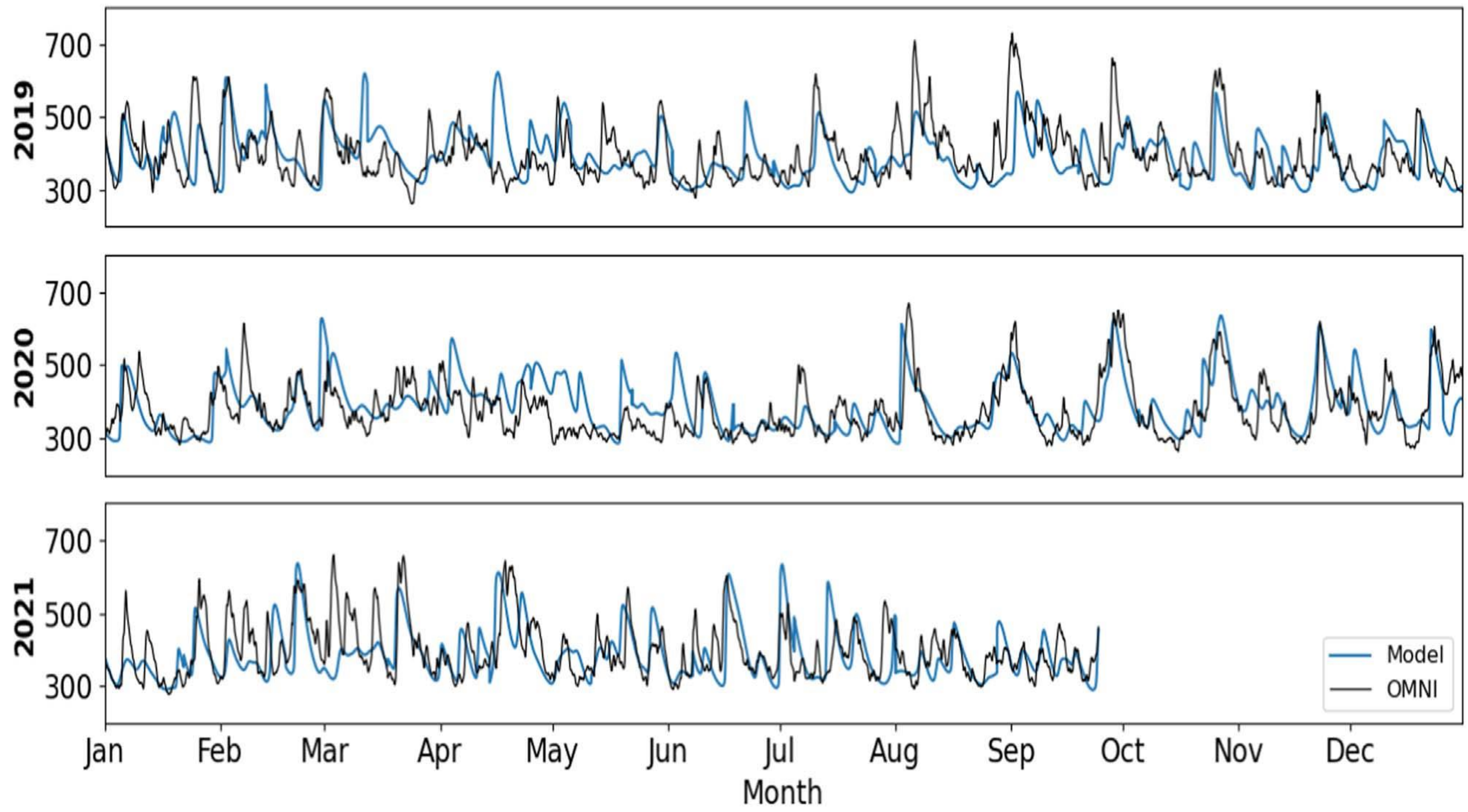
Based on empirical constraints, tomographical density is converted to solar wind velocity *and* acceleration



$$V_0 = (75 * e^{-|5.2*\rho_N|} + 108)$$

$$V(r) = V_0(1 + \alpha_{HP}[1 - e^{(-[r-r_0]/r_H)}])$$

Comparison with in-situ speeds

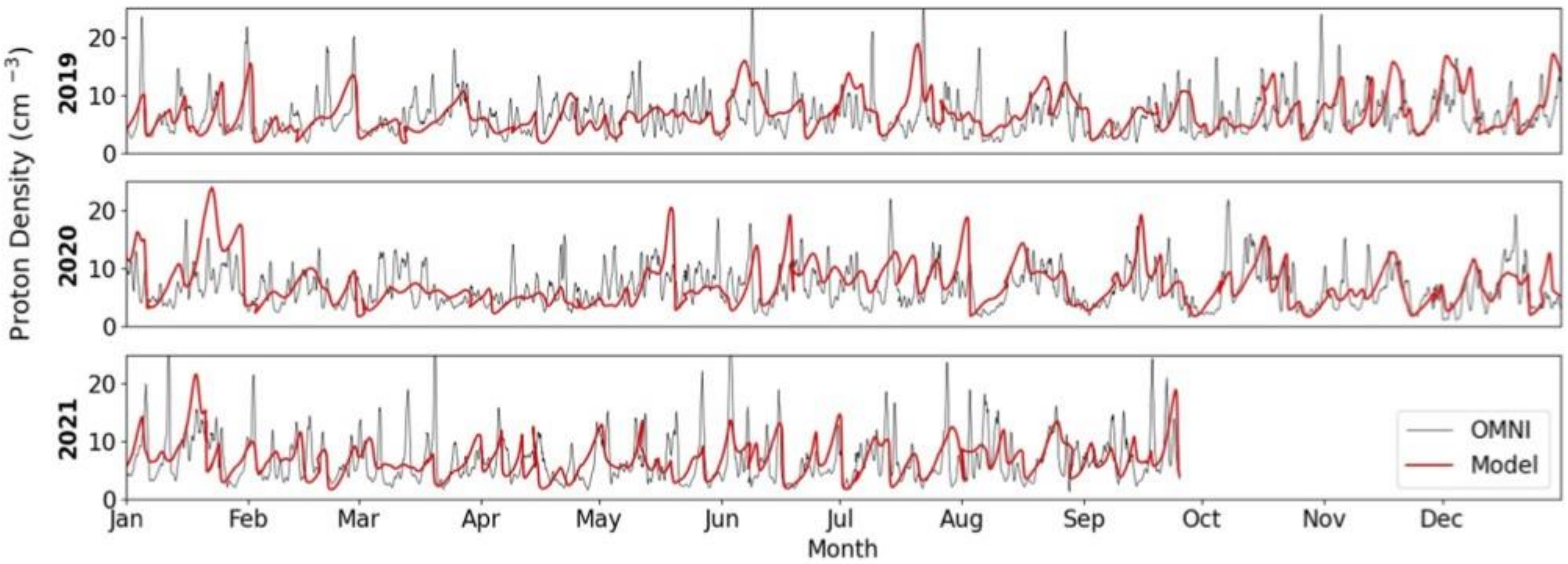


Black = solar wind velocity measured near Earth

Blue = model solar wind velocity (tomography-based)

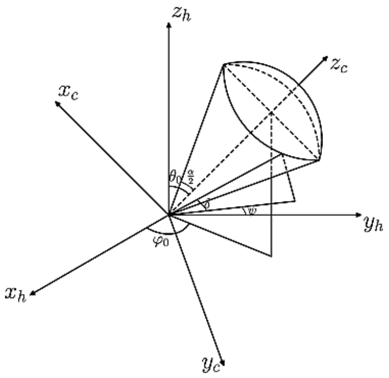
Comparison with in-situ densities

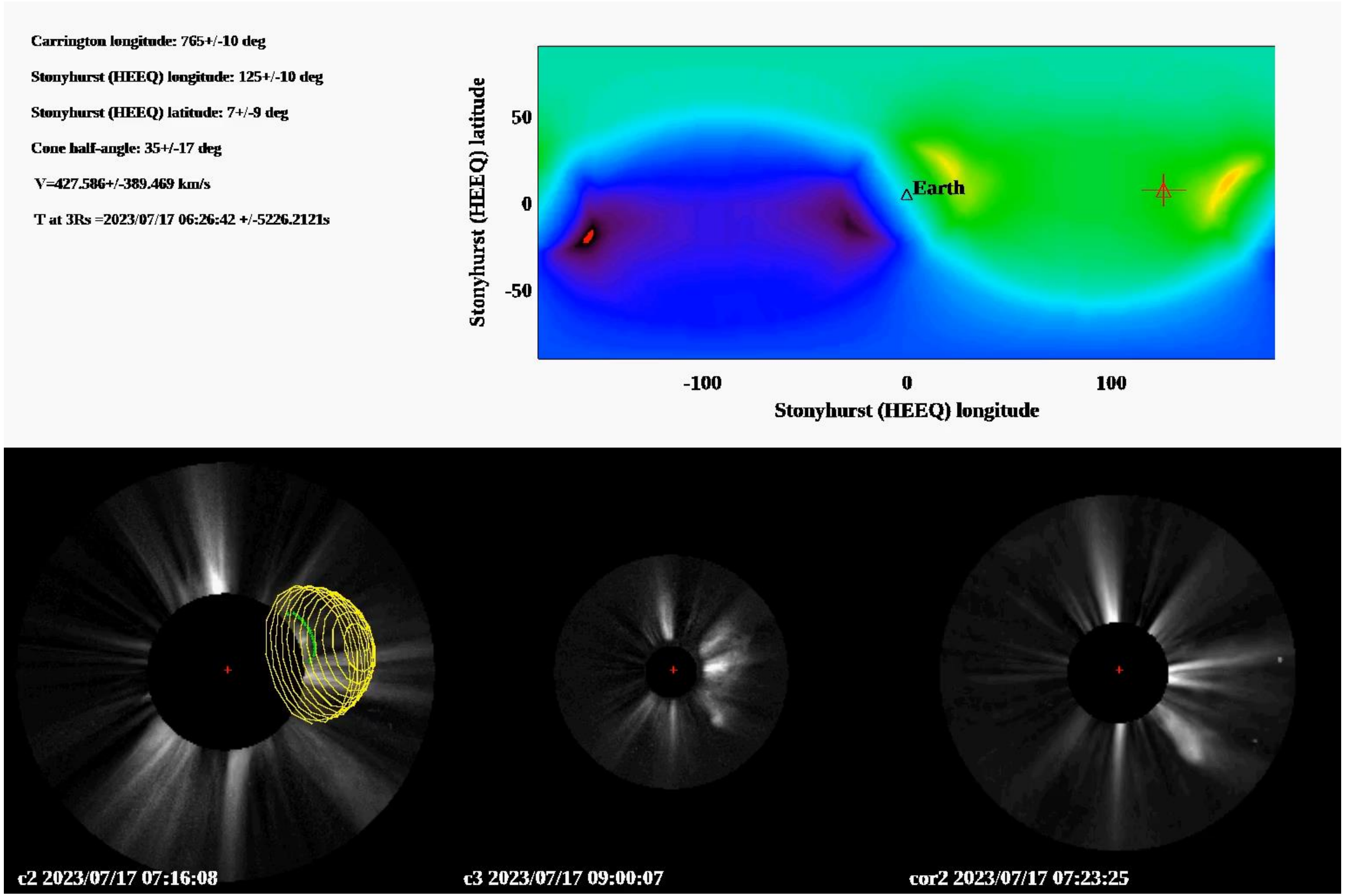
Black = solar wind density measured near Earth
Red = model solar wind density (tomography-based)



- Tomography gives densities *and* velocities near the Sun
- Extrapolate densities outwards based on mass-flux constraints

Automated CME detection



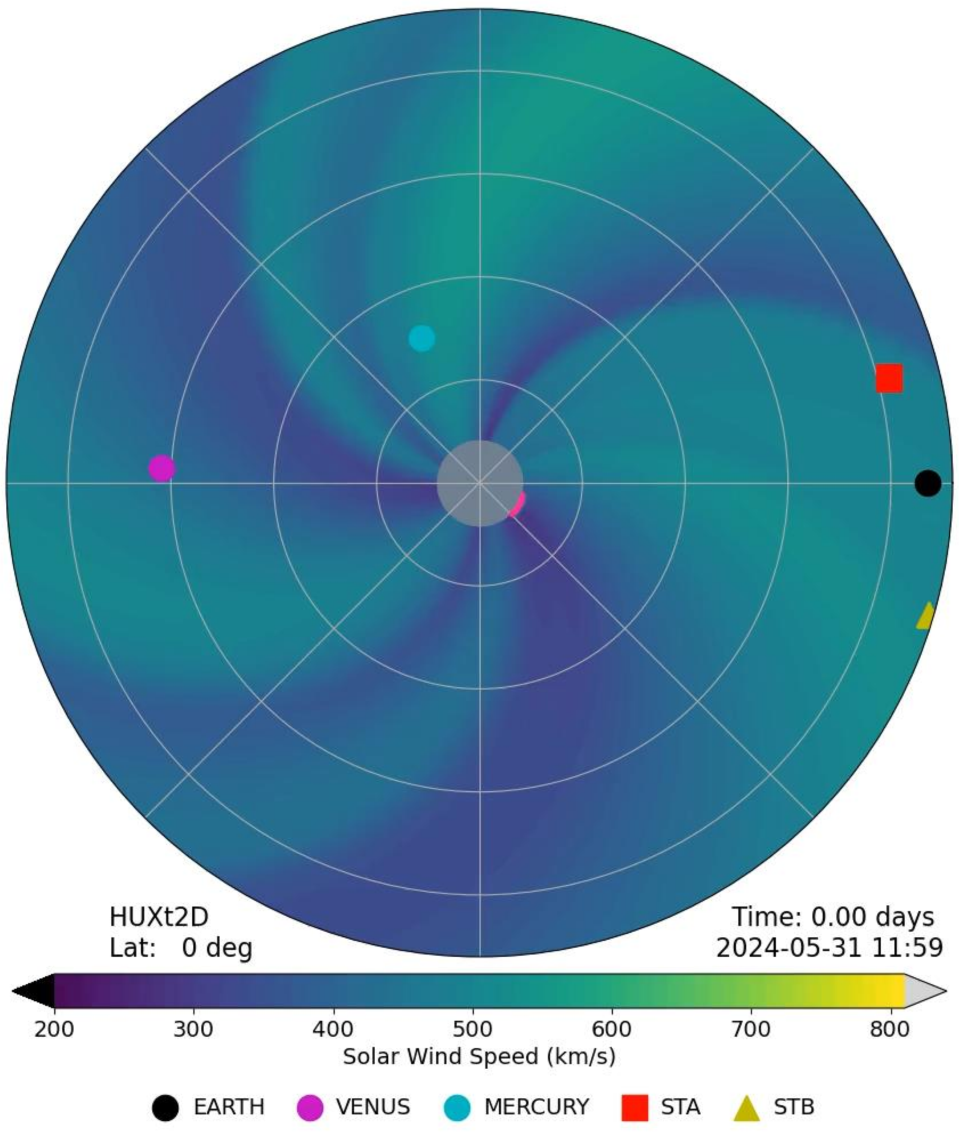


- Reasonable fit of outer edge of cone model to observed CME front edge points.

- Use of Beacon NRT data - challenging

- Performance depends critically on data availability

HUXt solar wind model



Time-dependent, radial solar wind model.

Incompressible hydrodynamic flow.

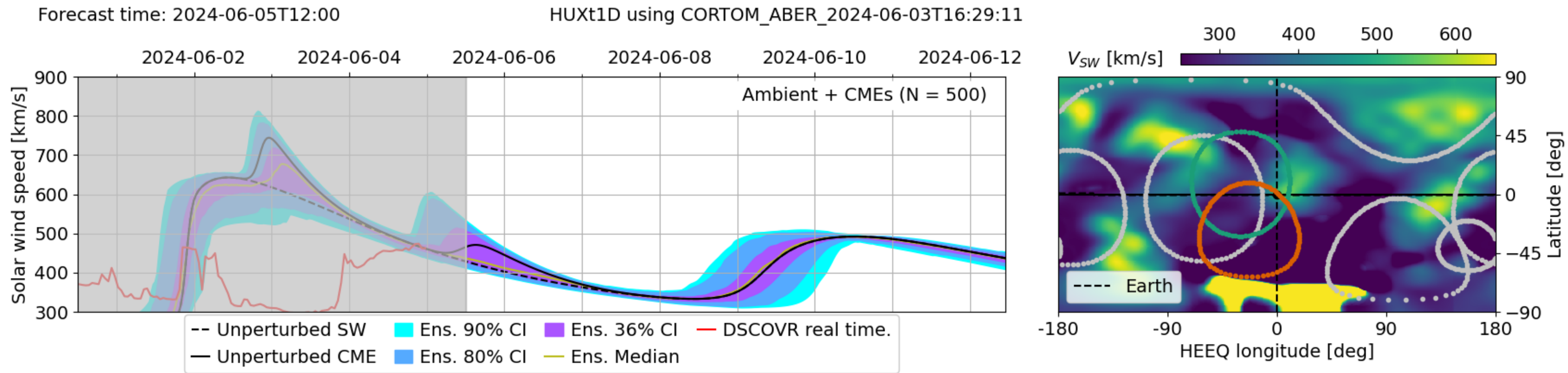
Reproduces 3D MHD solar wind solution to within a few %.

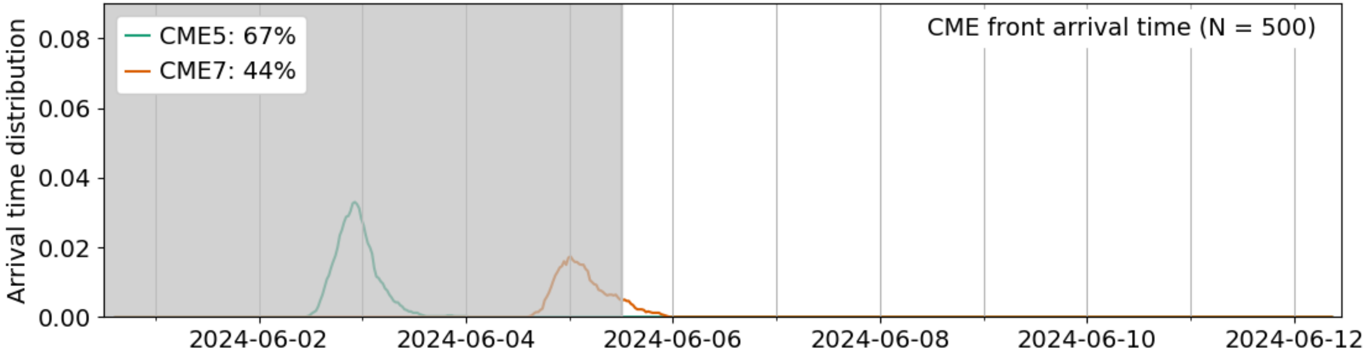
Includes “Cone model” CMEs (c.f. ENLIL etc.)

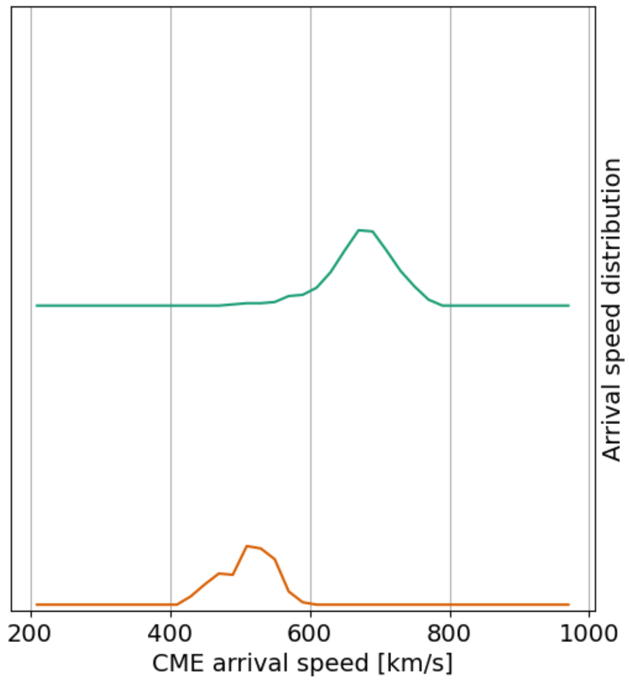
Very efficient: 5 day run in the ecliptic plane takes <1 second on a desktop machine.

Owens et al., *Sol. Phys.*, 2020

A recent forecast - based on coronagraph data only







	Cone CME Time at 21.5 r_S	V [km/s]	Long [deg]	Lat [deg]	Width [deg]	Hit %	Earth arrival time (median)	+/- [hrs]	V [km/s]	+/- [km/s]
CME5	2024-05-31T12:05	710	330	8	80.0	67.0	2024-06-02T21:55	(-5.8,+8.9)	677	(-91,+67)
CME7	2024-06-02T00:48	700	337	-27	72.0	44.4	2024-06-05T01:54	(-6.1,+12.6)	517	(-69,+48)

PUNCH & Space weather: some thoughts

New missions: PUNCH/NASA (2025), Vigil L5/ESA (2031).

These are the likely main missions for space weather forecasting over the next decade.
PUNCH provides an important Earth-based viewpoint to complement Vigil or STEREO.
If LASCO/SOHO and/or STEREO A stop, PUNCH becomes central.

PUNCH will drive different levels of space weather-related activity:

- Research.

  Blue sky. Searching for physical interpretation/models/diagnostics which can instruct/improve future forecasting. Case studies that show promise, proof of concept.
- Method/system development.

  Near-future. Statistical validation. Public codes.
- Operations.

  Use in operational real-world systems. Require compromise: forecasts eventually interpreted by people who are not scientists.
  PUNCH data will immediately feed forecasts for SWEEP

PUNCH & operations: some thoughts

Observations (PUNCH ticks all these boxes):

- *Frequency*: at least hourly.
- *Latency*: ~1-3 hours. *Current coronagraph missions compromise on data quality/validation to provide this*.
- *Regularity*: repeated observations of the same format at regular cadence.

Will PUNCH directly provide higher-level space-weather products to stakeholders?

- Updated tomography-type maps
- CME alerts
- CME characterisation (location, speed, size). *Requires other viewpoint…*
- Higher level solar wind modelling, based on PUNCH data?

Do we have the necessary contact with stakeholders internationally?

- *Important role for science Co-Is*