

Modeling and Data Analysis Tools in preparation for solar wind studies with Solar Orbiter

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Connectivity Tool

- . past and future spacecraft – solar surface connectivity

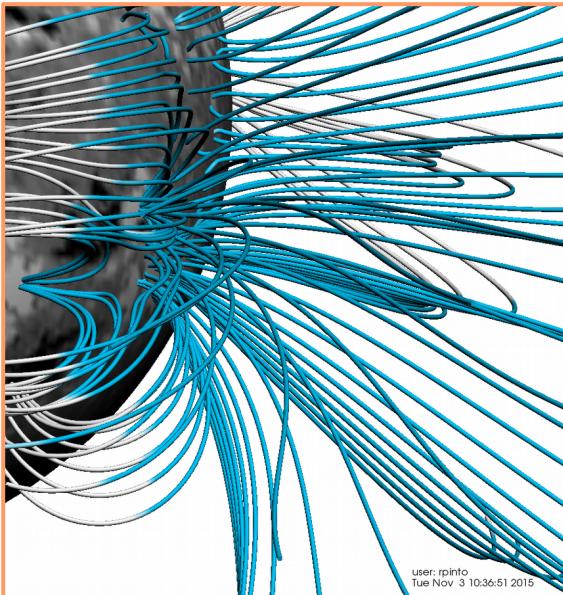
Accurate background solar wind simulations

- . physics based modeling, alternative to semi-empirical (WSA)
- . data driving, full set of background wind properties (speed, density, etc)
- . flexible setup: full 3D, plane-of-sky, orbit, etc.
- . Interface with ConnectTool, PropagationTool, etc.

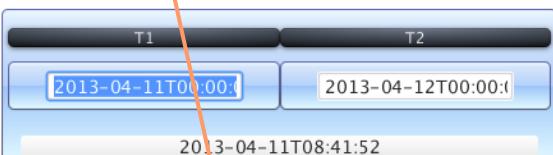
MADAWG (Modeling and Data Analysis WorkGroup)

STORMS (Solar Terrestrial ObseRvations and Modeling Service)

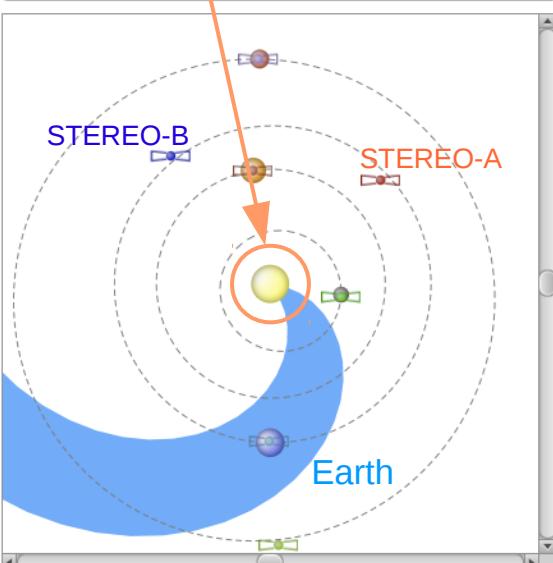
Connectivity Tool



- **Paths** and **delays** of propagation Sun – spacecraft
(wind flows, CME, shocks, energetic particles)



- **Use many models:** forecast redundancy
(but keep it simple!)



- **Planning and management of campaigns**
exploit synergies between multiple s/c.

- **Scientific exploitation**
past data: post-event analysis relating in-situ ↔ remote,

Connectivity Tool

Layout of the connectivity tool

1. Chose mode of operation

Post-event analysis

Forecast

2. Choose date or s/c position

3. Trace down magnetic field-line

i) Parker spiral or heliospheric model

use measured wind speed

use estimated wind speed

ii) Coronal field reconstruction

(PFSS, NLFFF, MHD, ...)

use HMI magnetograms

use ADAPT magnetograms

4. Find connectivity points at the surface

Take into account propagation delays (wind, particles)

Plot maps at slow/fast wind / SEP launch times + target time

Compare instrument FOV, estimate uncertainties

Connectivity Tool

Home Help Contacts

Prototype webpage <http://storms-connectsolo.irap.omp.eu/>

Solar Orbiter / Solar Probe Plus Connectivity Tool

Select date/time
at spacecraft

Date

2020-05-01 00:00

Select coronal
model

Coronal magnetic field

PFSS

Mode

SCIENCE

Select Science/
Forecasting Mode

Interplanetary magnetic field

PARKER

Select interplanetary
model

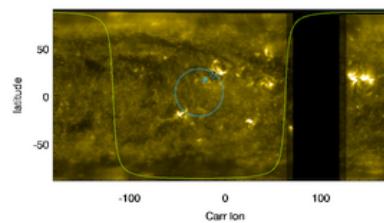
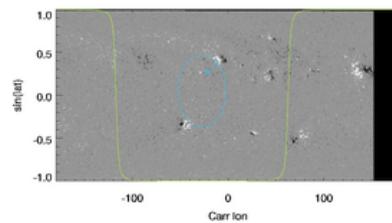
SEARCH

Time reference

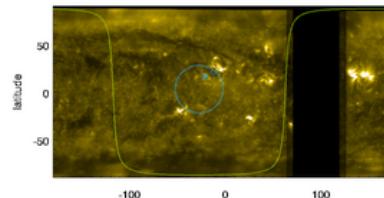
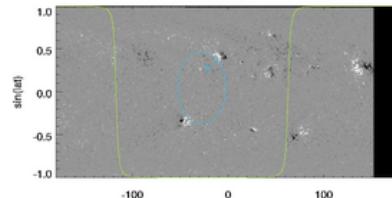
SDO/HMI

SDO171

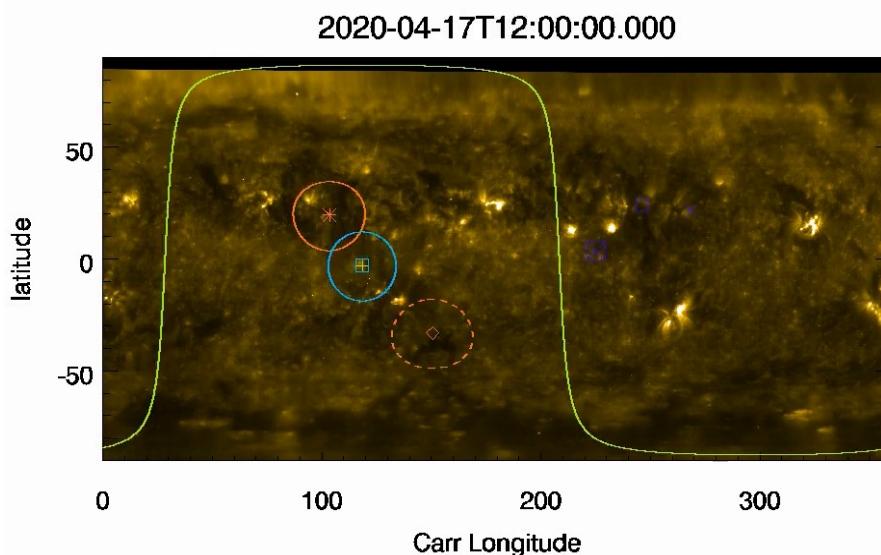
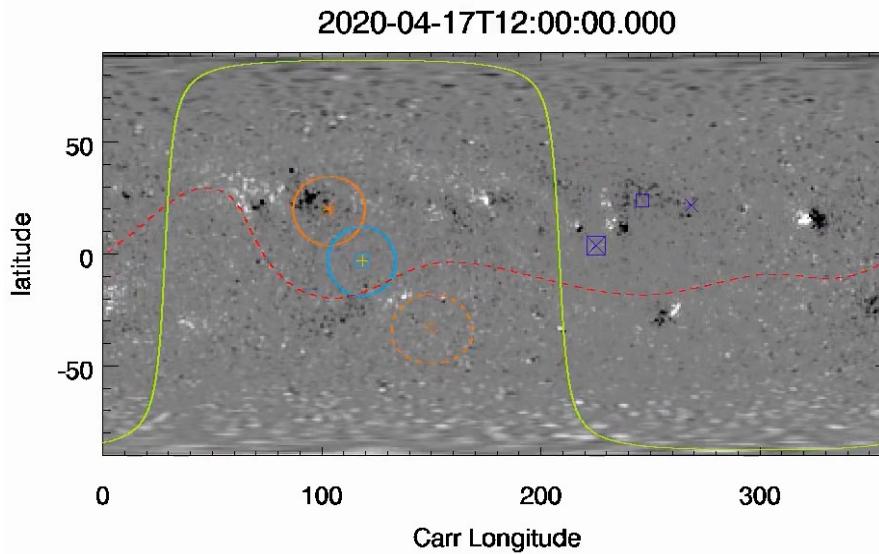
Carrington maps
at plasma impact ➤ Spacecraft
time



Carrington maps
at plasma release
time ➤ Sun



Solar Orbiter CONNECTIVITY TOOL



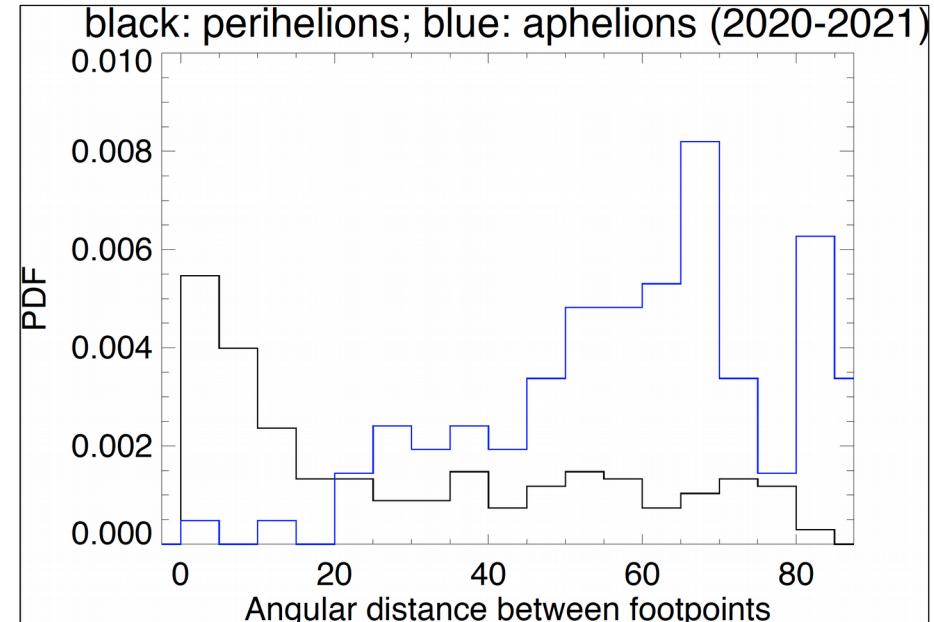
HMI magnetograms (time-evolved) EIT 171 Å

Limb as seen from Solar Orbiter
Neutral line

EUI FOV centered on Solar Orbiter position
EUI FOV centered on Solar Orbiter footpoints
(slow wind and fast wind)

Position and footpoints of Parker Solar Probe

Solar Orbiter footprint separation



Connectivity maps

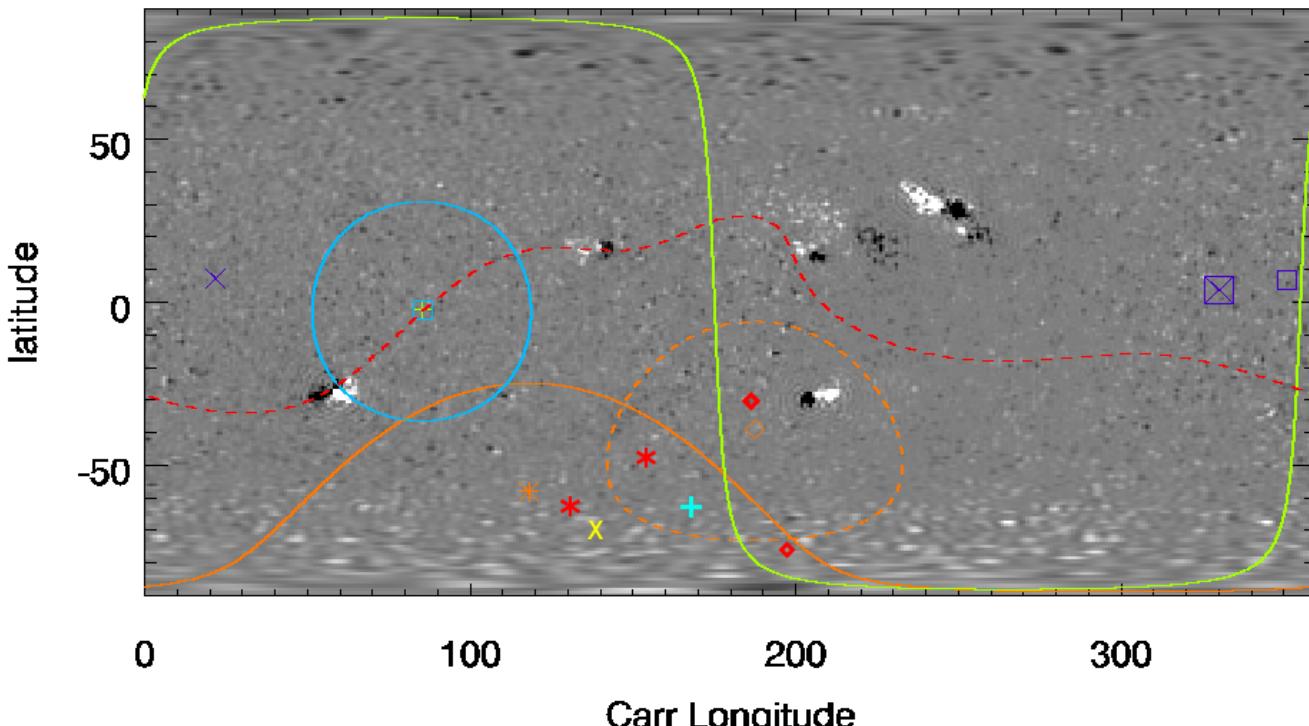
Forecasting: testing different approaches

Corona:

ADAPT+PFSS, ADAPT+NLFFF (maybe)

Heliosphere:

PARKER, EUHFORIA, ENLIL



asterisks/diamonds: fast, slow wind ADAPT; X cross: EUHFORIA; + cross MULTI-VP

End data product:

probability distribution of connectivity
(positions + sizes of distributions vs. FOV)

Souces of scatter :

- different magnetogram sources
- magnetic field extrapolation methods
- assumed/forecasted wind profile

Tasks :

- cross-calibrate different magnetograms
(cf. Riley et al, 2014, Linker et al 2017)
- integrate fresh SolO/PHI data into the modelling
- synoptic → synchronic maps (e.g. Henney, et al)
- integrate other models from the community

SWiFT / MULTI-VP Data-driven solar wind model

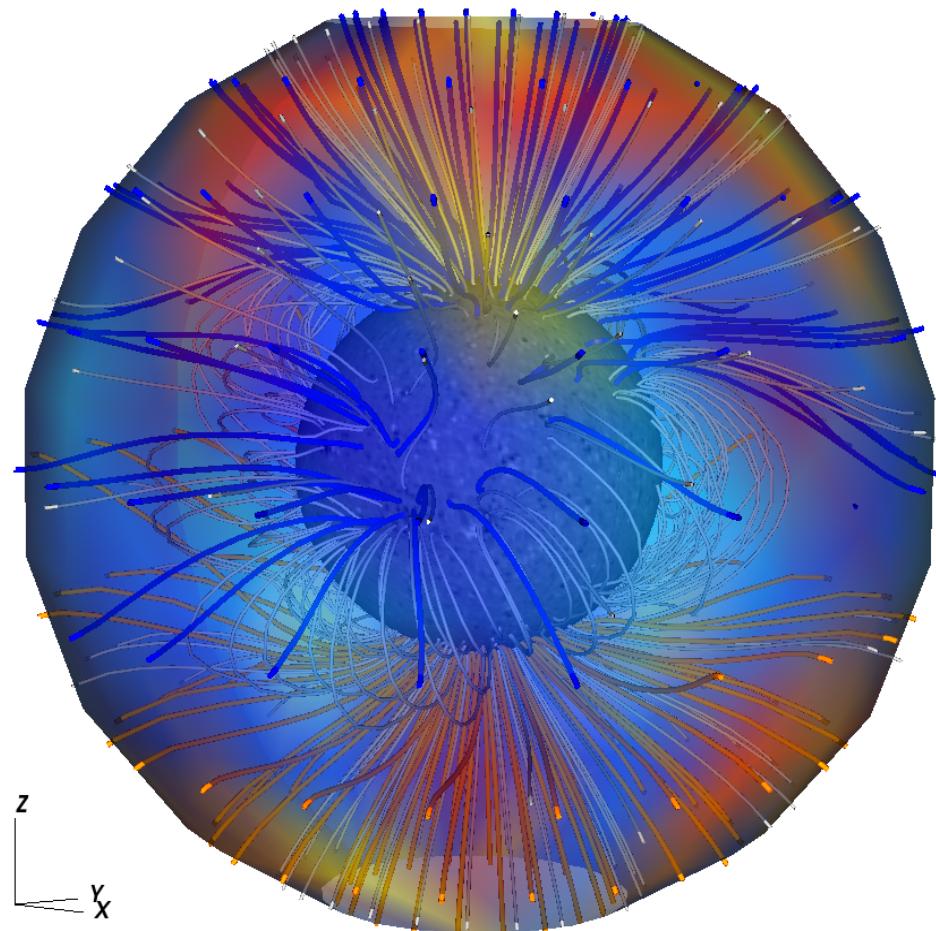
Sun / surface observations
(magnetograms: HMI, WSO, ADAPT)

Coronal field reconstruction
(PFSS, NLFFF, etc)

MULTI-VP

Heliospheric propagation
(ENLIL, EUHFORIA, SW1D)

Earth / interplanetary medium
(S/C data, heliospheric imaging)



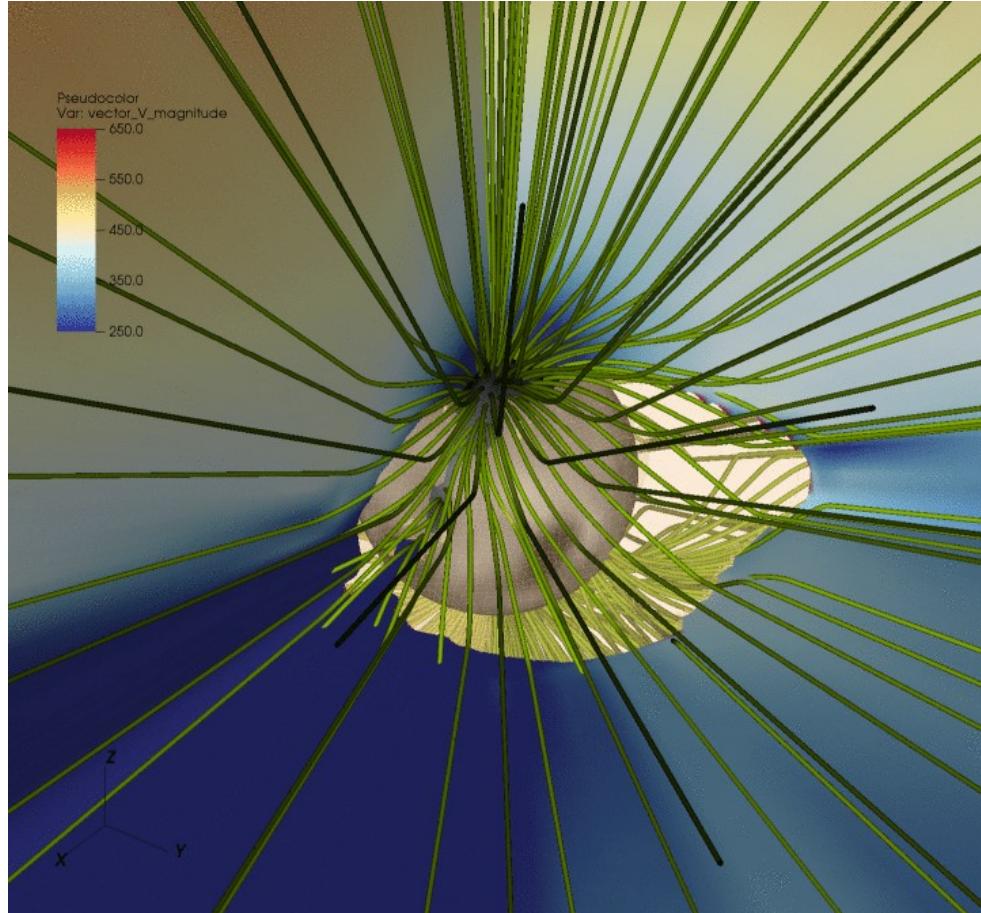
PFSS field lines: positive / negative polarity
Wind speed: 300 / 700 km/s

→ SWiFT framework pipeline

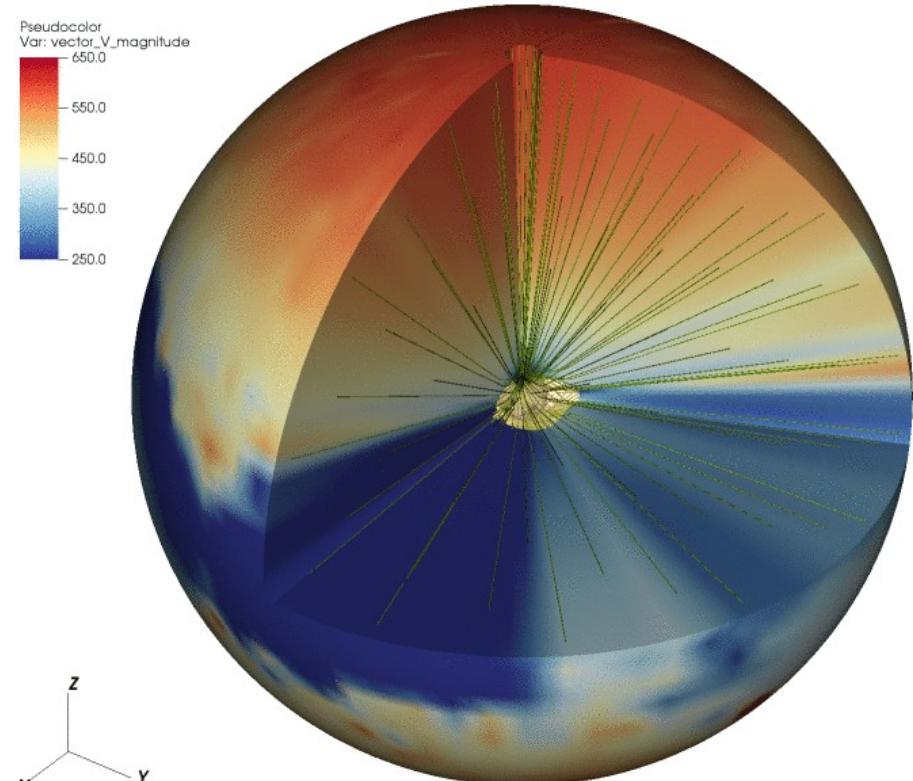
→ see poster X4.205 by R. Pinto

MULTI-VP Data-driven solar wind model

CR 2055 - 2139 (yrs 2008 - 2012)



Low corona (close-up view)



High corona (1 – 15 R_{sun})

PFSS magnetic field extrapolations

(but could be PFSS+SCS, NLFFF, SolarModels, etc)

Open magnetic fieldlines ("coronal holes")

Streamer / coronal hole boundaries

Fast wind

Slow wind

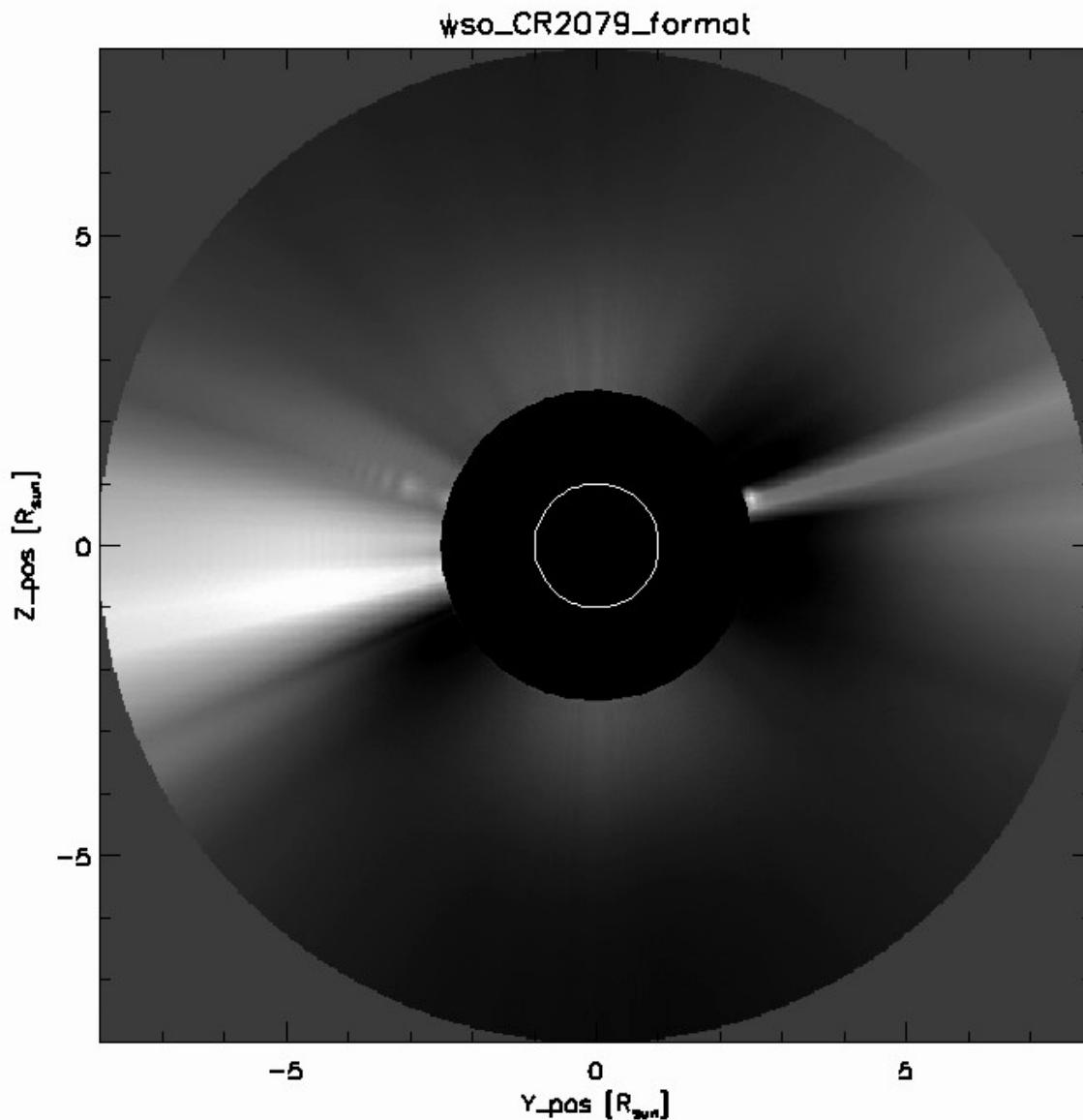
MULTI-VP Data-driven solar wind model

Synthetic images of the corona

CR 2079 - 2080

MULTI-VP + FORWARD

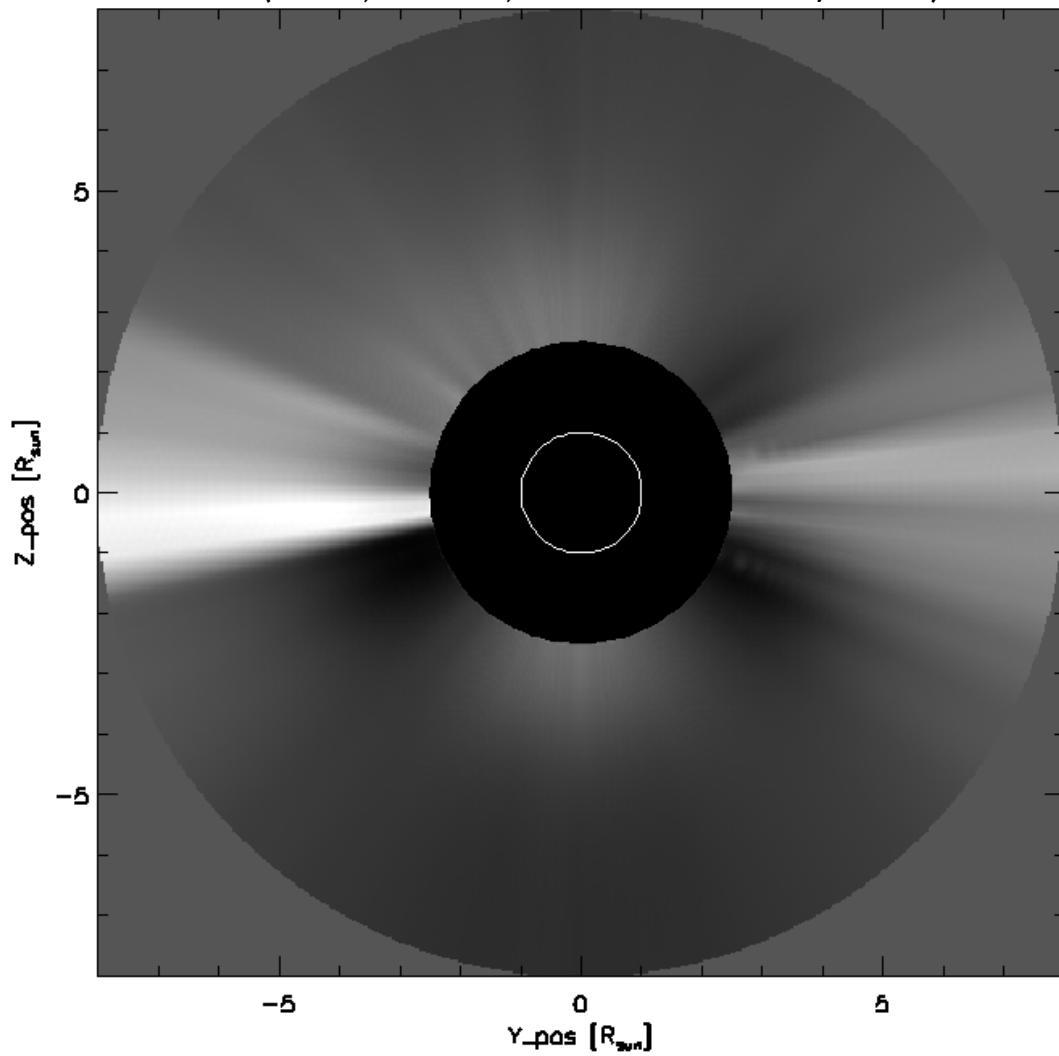
(NRGF-filtered, ~C2 FoV)



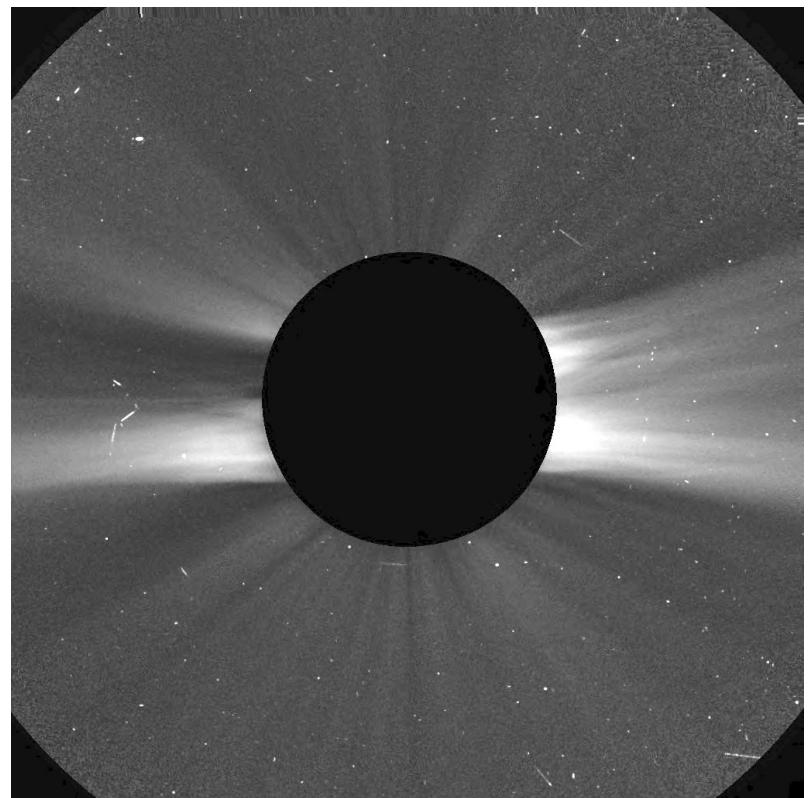
MULTI-VP Data-driven solar wind model

Synthetic images of the corona

CR 2079 (Earth, mid-CR, MULTI-VP NRGF-filtered)

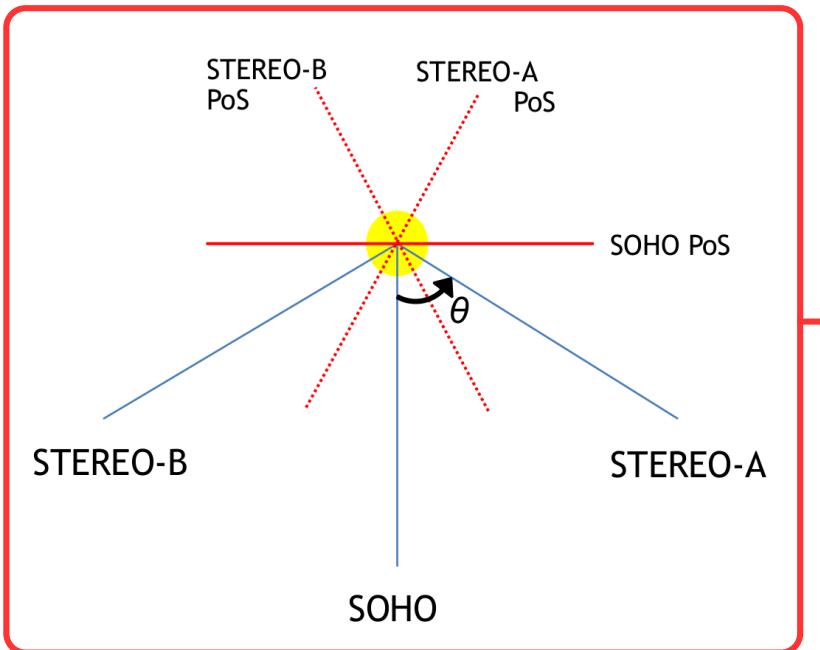


CR 2079 (L1, mid-CR, LASCO C2)

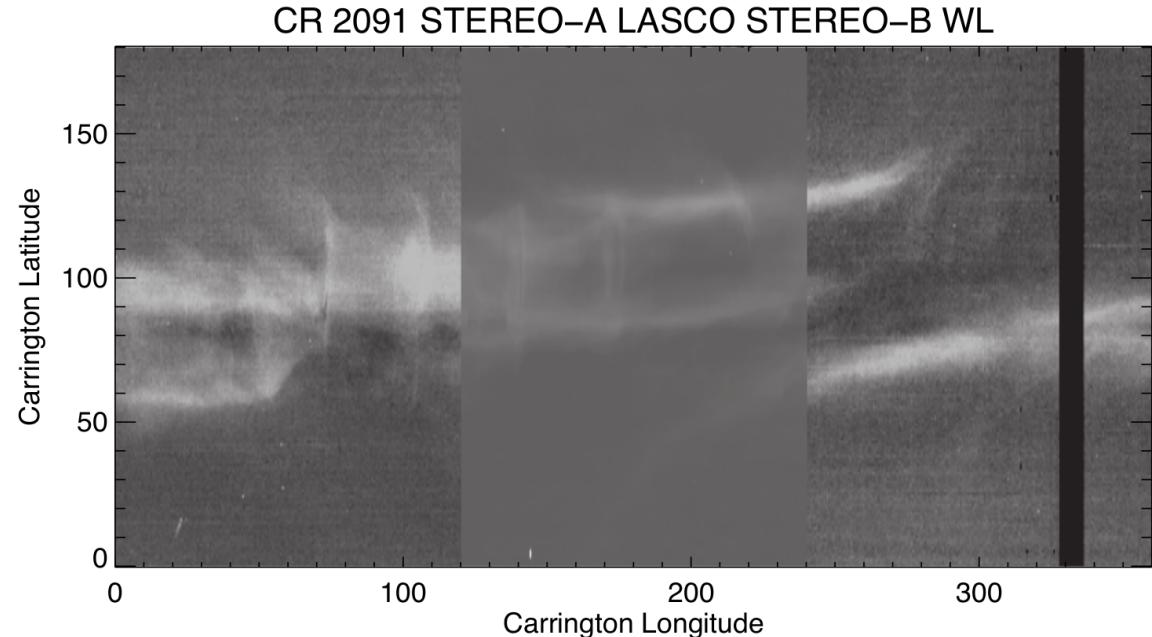


MULTI-VP Data-driven solar wind model

White-light images of the corona – combining multiple points of view



(Sasso, Pinto, et al, in prep)

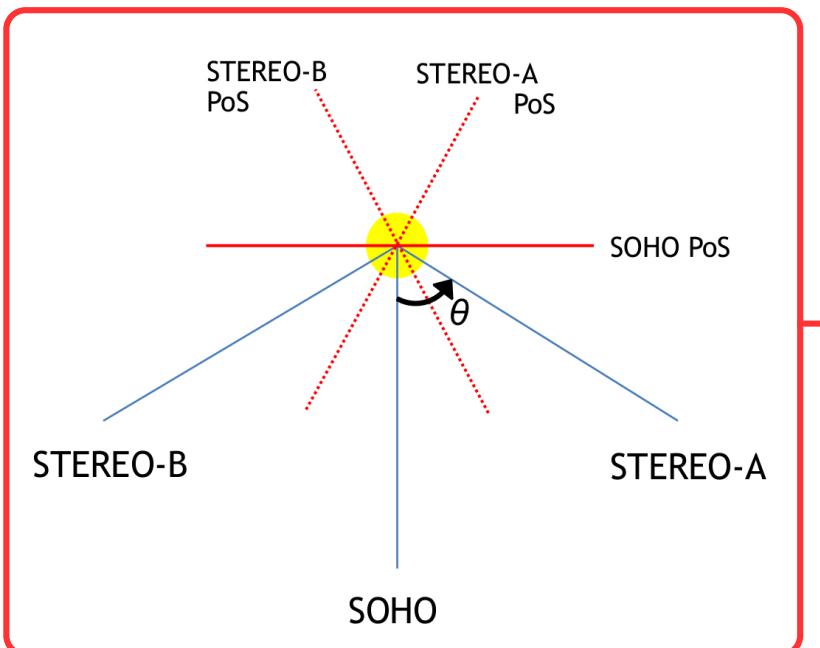


Goal:

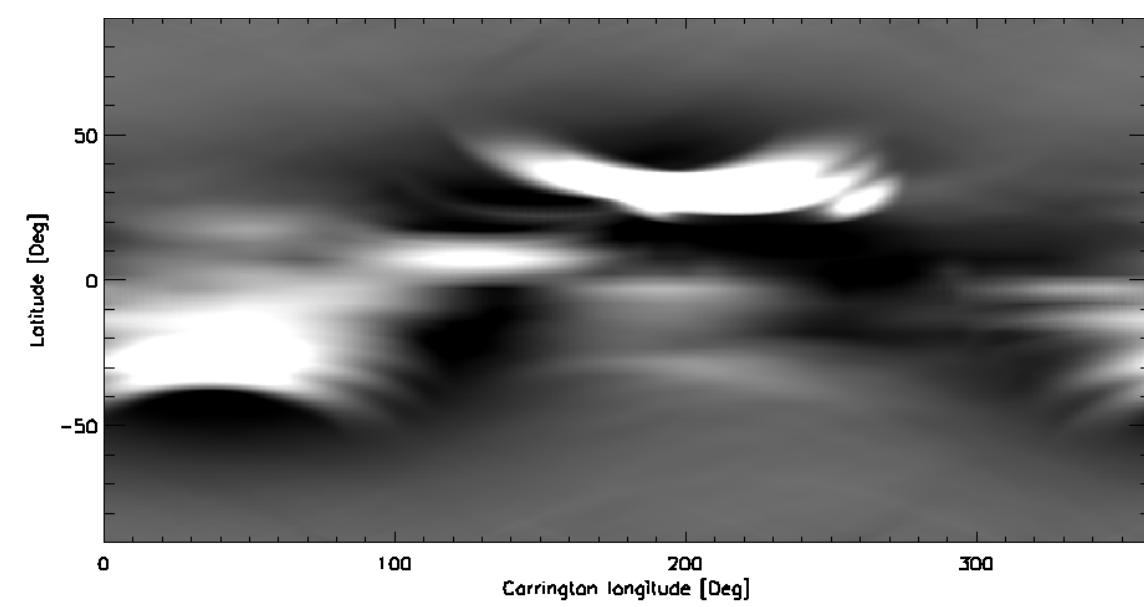
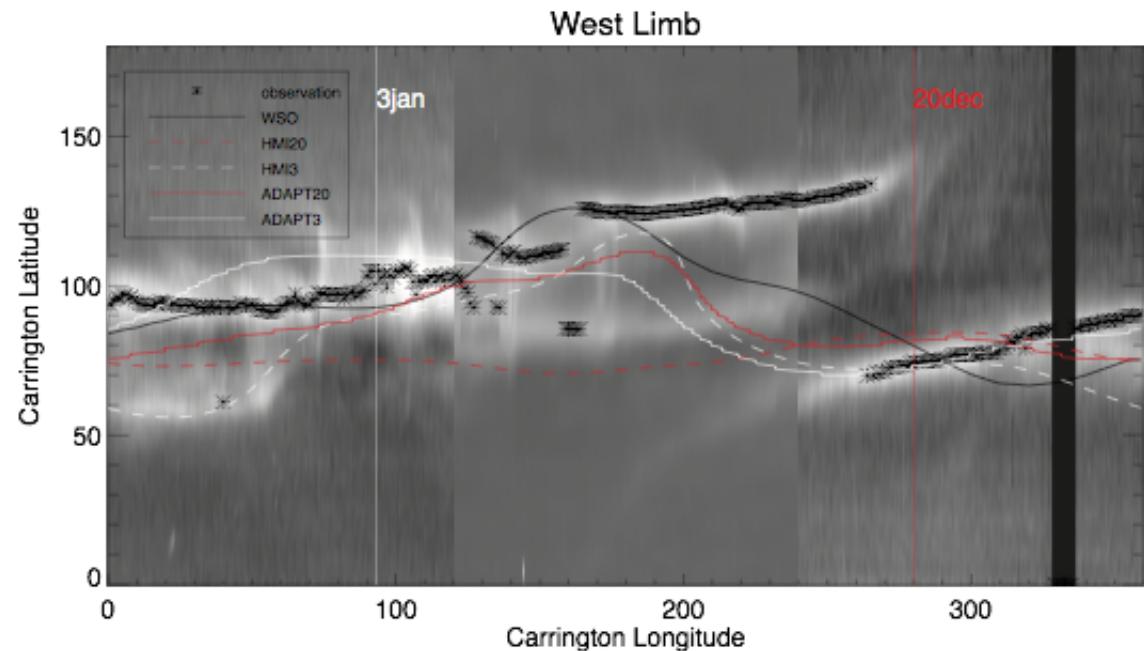
detect main magnetic features of the corona from WL maps
(e.g. positions of HCS and pseudo-streamers)

MULTI-VP Data-driven solar wind model

White-light images of the corona – combining multiple points of view



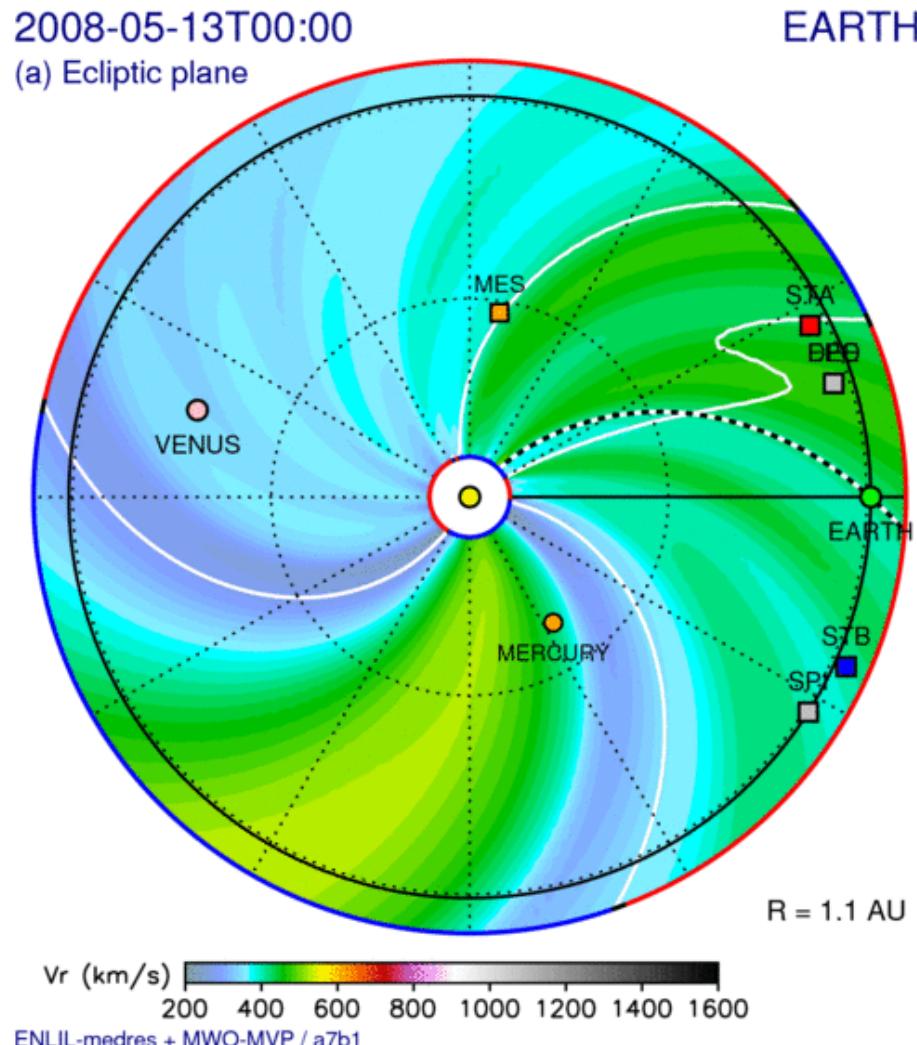
(Sasso, Pinto, et al, in prep)



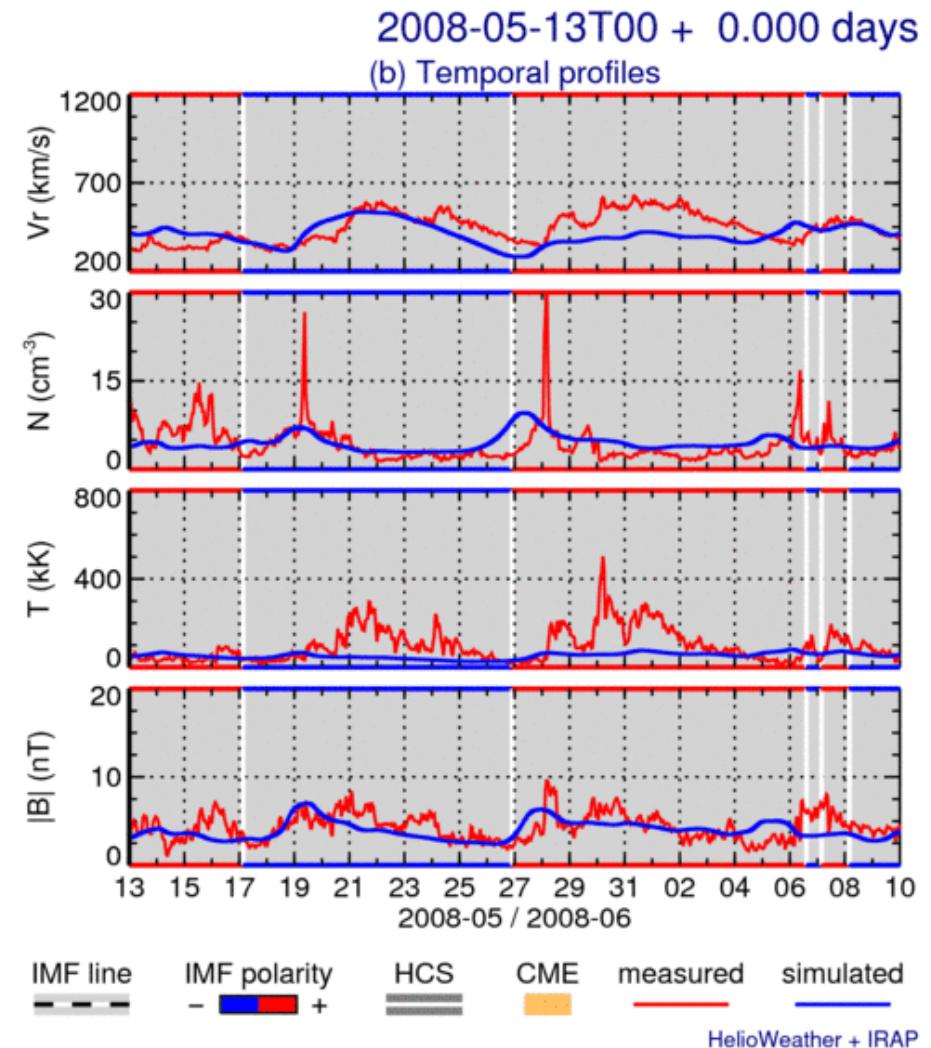
MULTI-VP

Predicting the solar wind conditions at 1 AU

Interplanetary medium, in-situ data



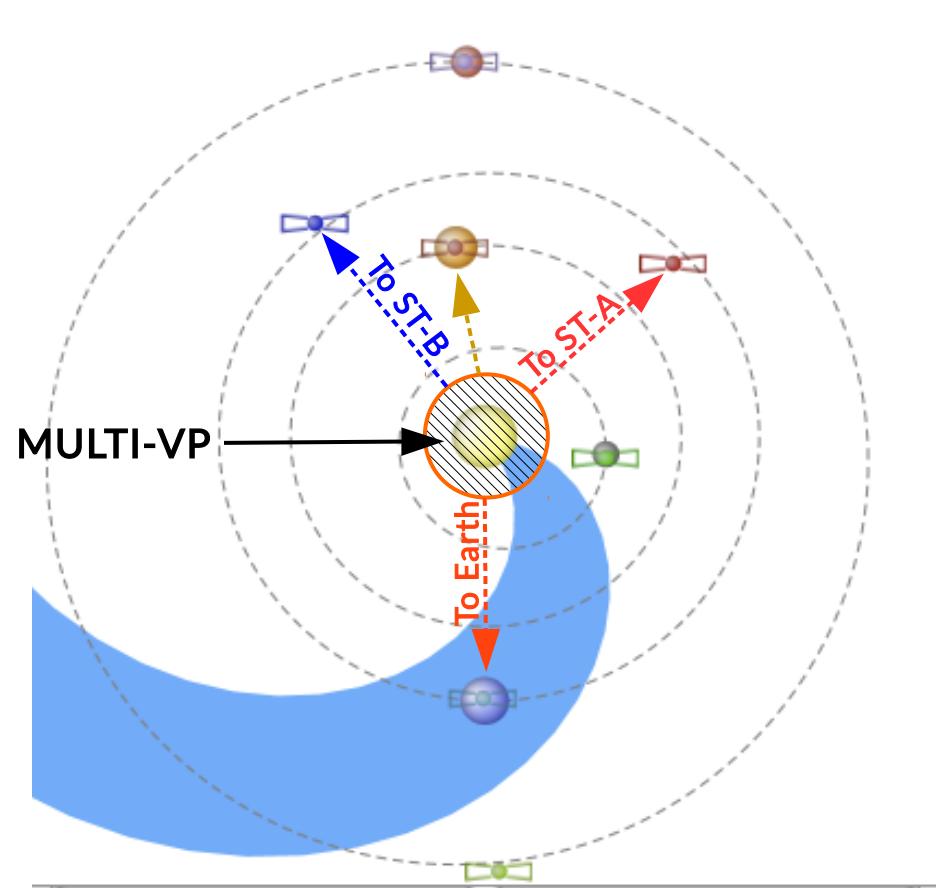
MULTI-VP maps
at 21.5 Rsun → ENLIL, EUFORIA



WIP: SWiFT with 1D propagation and EUHFORIA

1D Heliospheric SW propagation

Multiple wind propagation paths



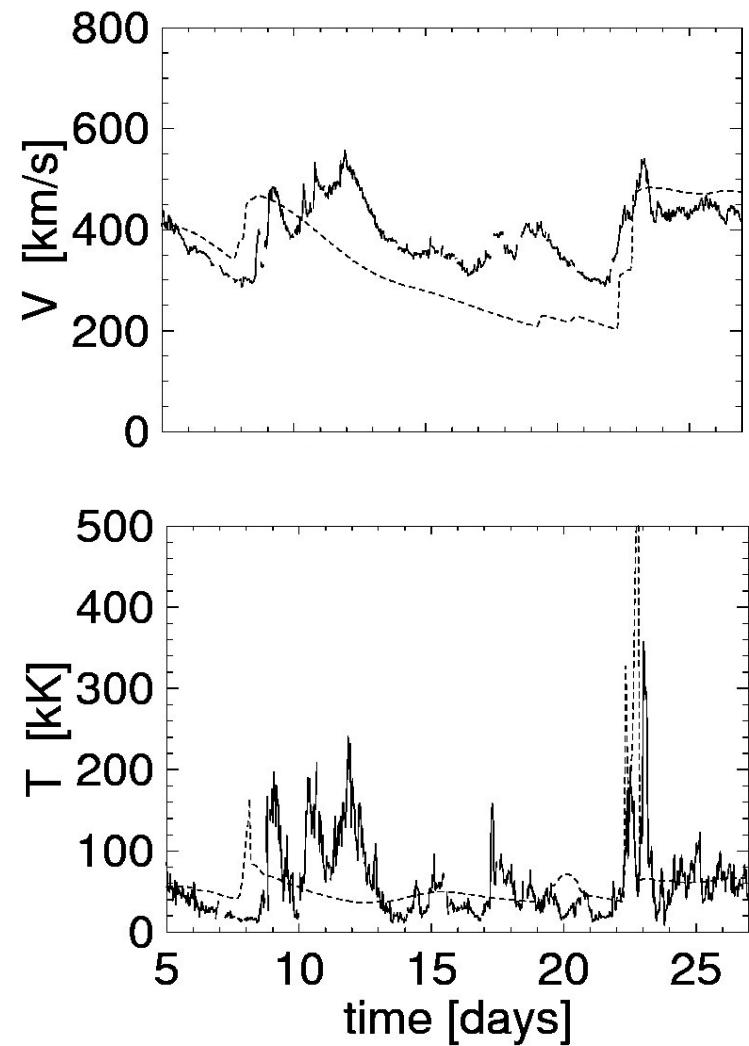
propagationtool.cdpp.eu

(propagation method from Tao et al, 2005)

Forward propagation from output of MULTI-VP
(arbitrary radial paths, any latitude or longitude)

Multiple time-series, at different orbital positions,
rotation + background field evolution

Simulation vs. OMNI (CR 2055)



EUHFORIA

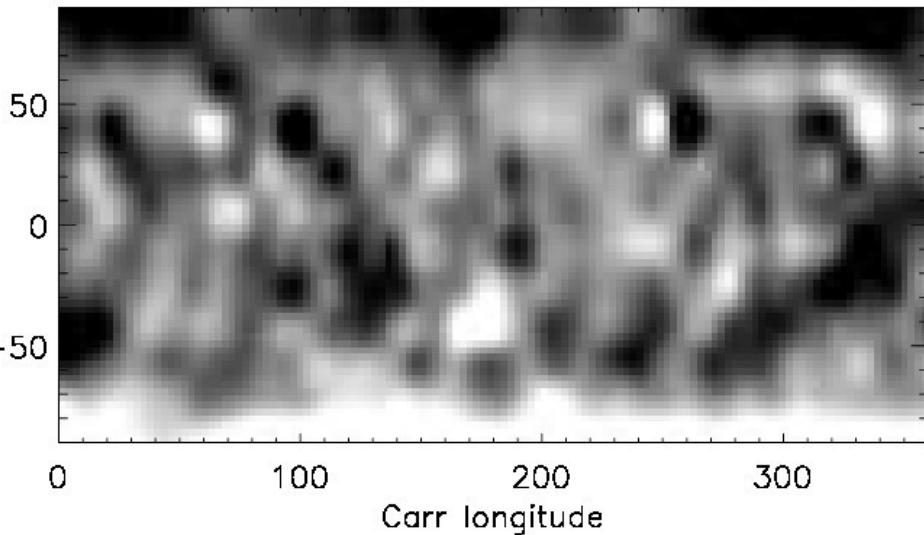
Full MHD heliosphere, interface with coronal models
(Pomoell, Poedts, et al)

Synchronous magnetograms

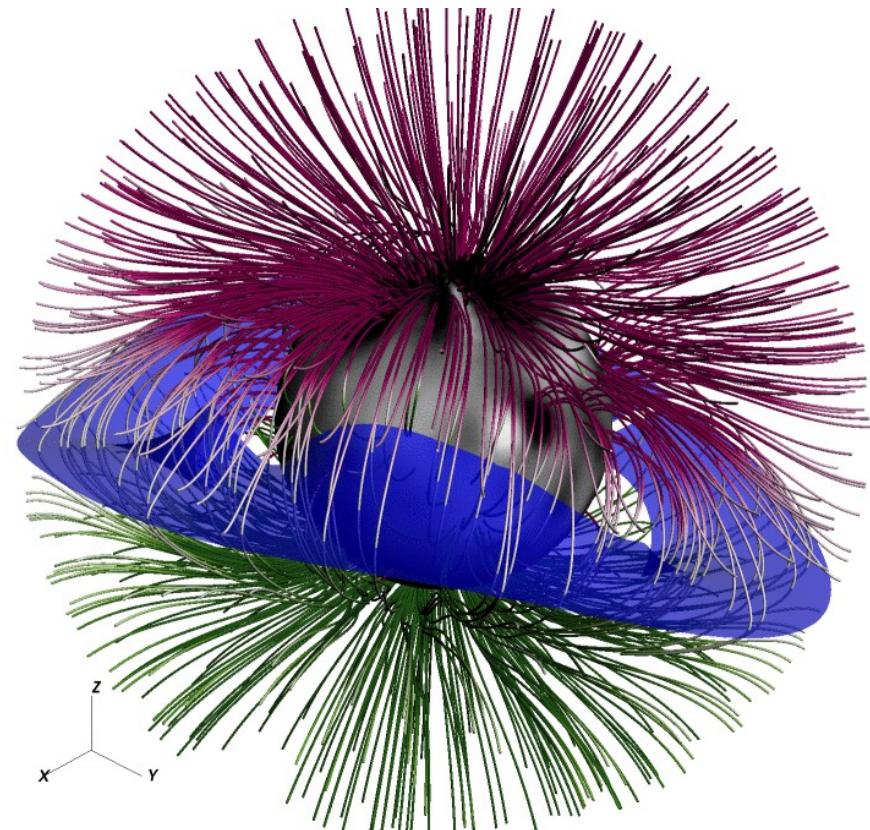
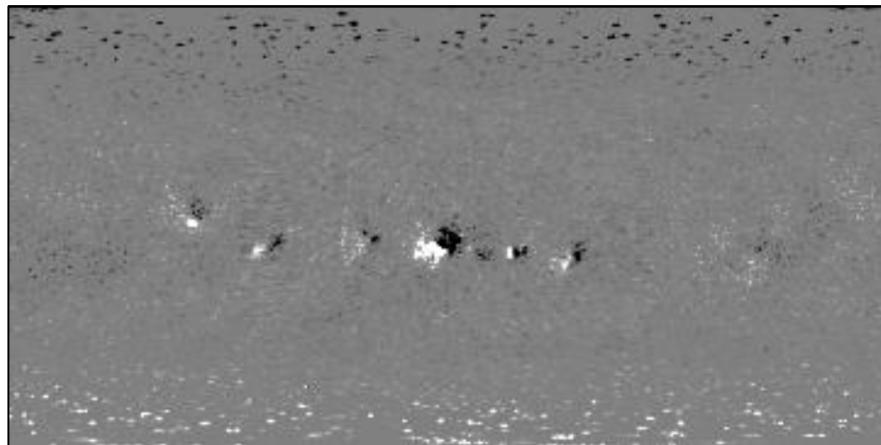
Surface flux-transport methods to evolve magnetograms (full disk)

Simple large-scale shear+diffusion (cf. Wang et al)

wso2079 + 1 d



ADAPT ensemble maps (Henney, Arge, et al)



Synchronous wind runs (ADAPT + PFSS-SCS + MULTI-VP)

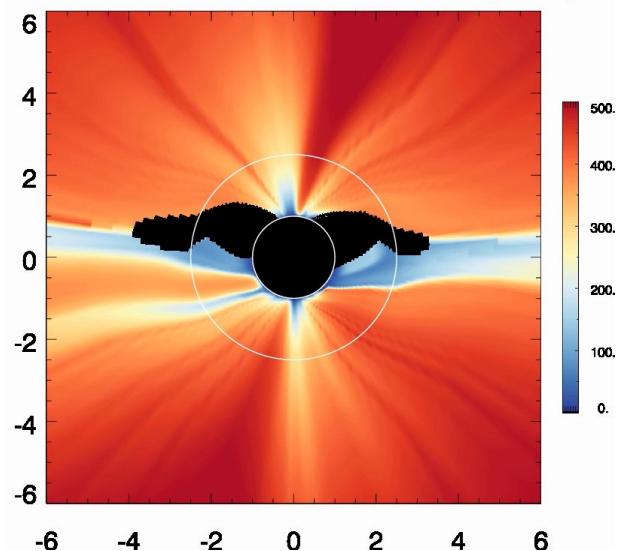
MULTI-VP (plane-of-sky only)

1 – 30 June 1997

ADAPT / KPVT maps, PFSS + SCS coronal field reconstruction

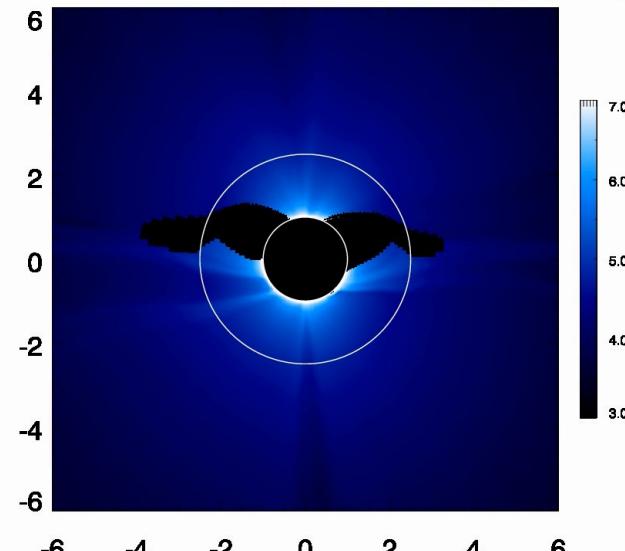
Speed

ADAPT+MVP 19970616R005 V [km/s]



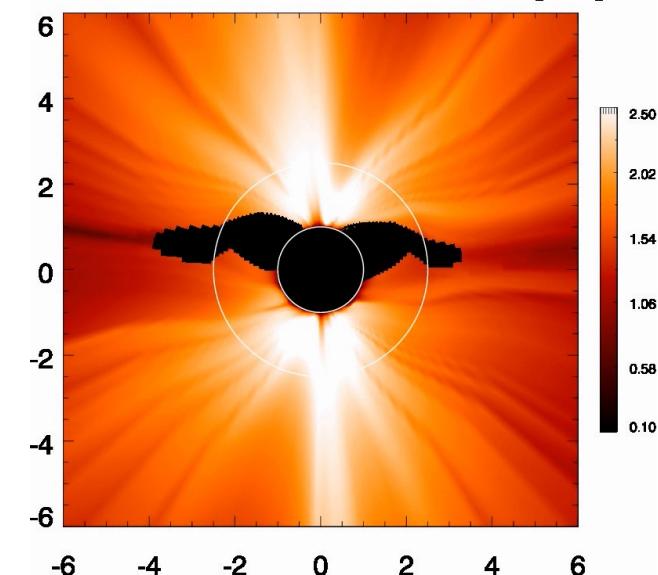
Density

ADAPT+MVP 19970616R005 $\log(n)$ [cm^{-3}]



Temperature

ADAPT+MVP 19970616R005 T [MK]



dark patches: streamers, data gaps
white lines: surface, source-surface

- ADAPT-WSA vs. MULTI-VP vs. UVCS data
- synchronic magnetic maps are required
- preparation for Solar Orbiter/METIS

(Pinto, Bemporad, Arge, *in prep*)

WIP: Continuous solar wind monitoring and forecasting

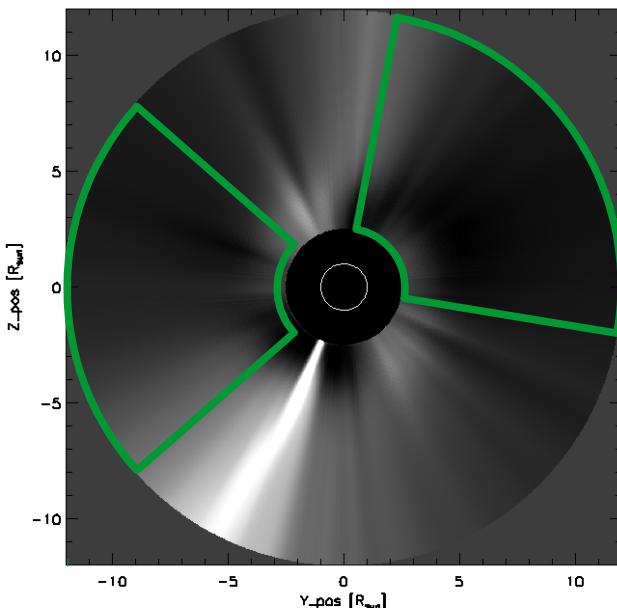
1. Early-on/forecast magnetogram data

2. East/west limb WL nowcast

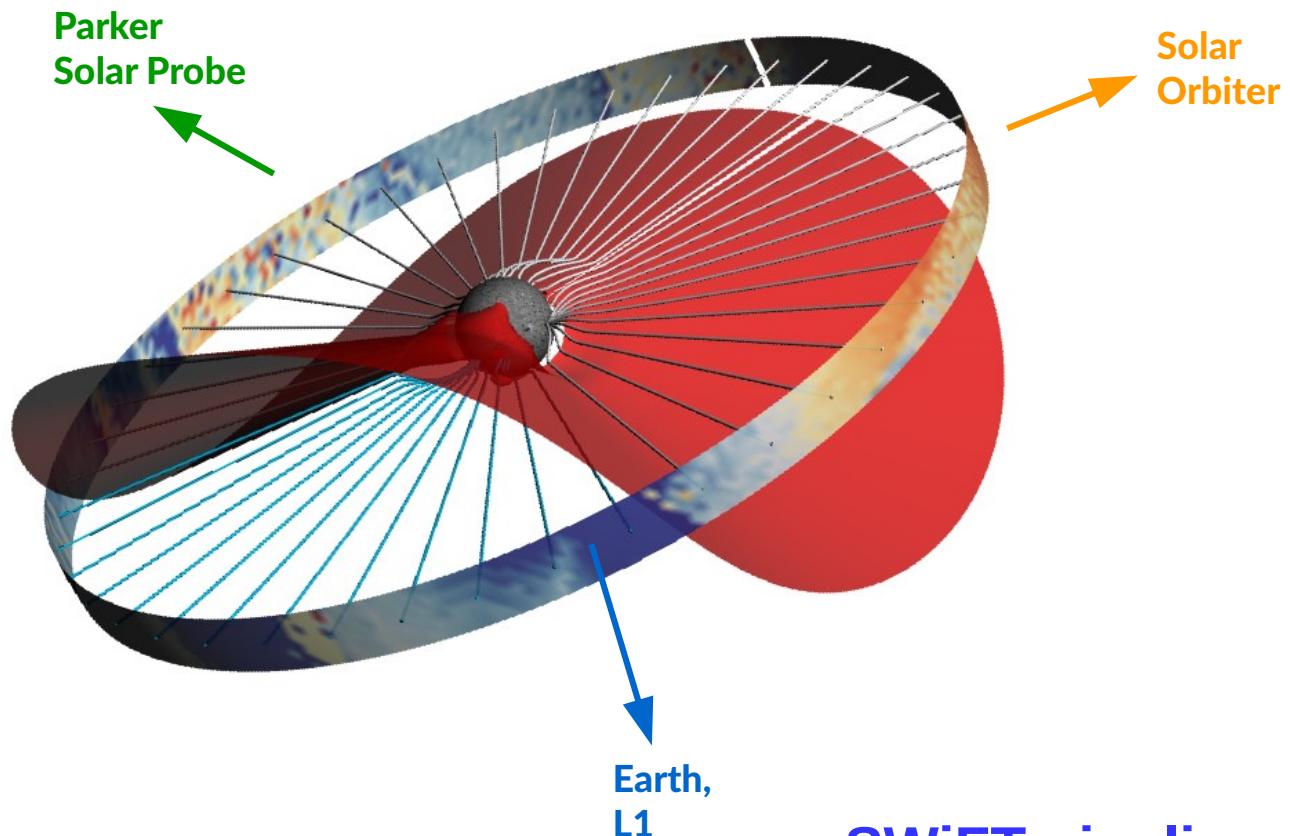
synthetic vs. real coronographic imagery
calibration, re-iteration, forecast quality flags

3. Intermediary in-situ cross-check
verify and (re-)flag propagated wind solutions

4. Sun-spacecraft path on Cor/HI fov
real-time monitoring



East/west limb nowcast
(synthetic coron. imaging)



SWiFT pipeline

Conclusions

Connect Tool: Determine surface – s/c connectivity, multiple methods
Testing with SolO orbit, SDO data with 10 yrs offset
Issues: quantify uncertainties, criteria for forecast quality

SWiFT/ MULTI-VP: global wind model ($1 - 32 R_{\text{sun}}$), fast computation,
alternative to semi-empirical (WSA) and full 3D MHD models
Multi-fluid and kinetic fluid winds → see poster by M. Lavarra (X4.87)

Full set of background solar wind properties,
at all latitudes and azimuths, coronal rotation

Diagnostics (e.g white-light, EUV, in-situ; pre/intermediate/final checkpoints)

Corona to Heliosphere (ENLIL, EUFHORIA, SW1D)

Work-in-progress:

Validation of background SW model: multi-point in-situ and coronography
Data-driving: synoptic to synchronic magnetic maps
Forecast mode: continuous few-days forecast at s/c position