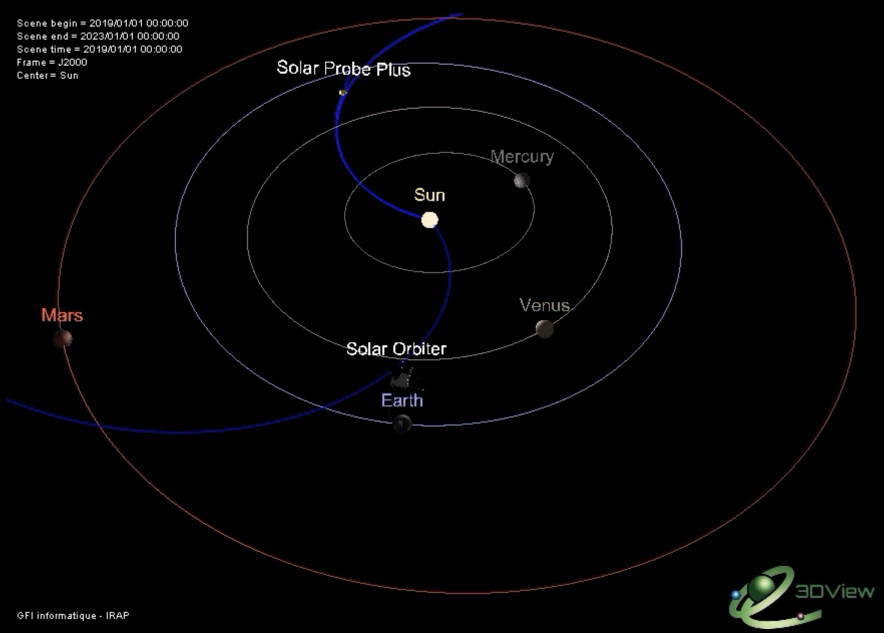
Modelling and Data Analysis Tools for Solar Orbiter and Parker Solar Probe

Alexis P. Rouillard

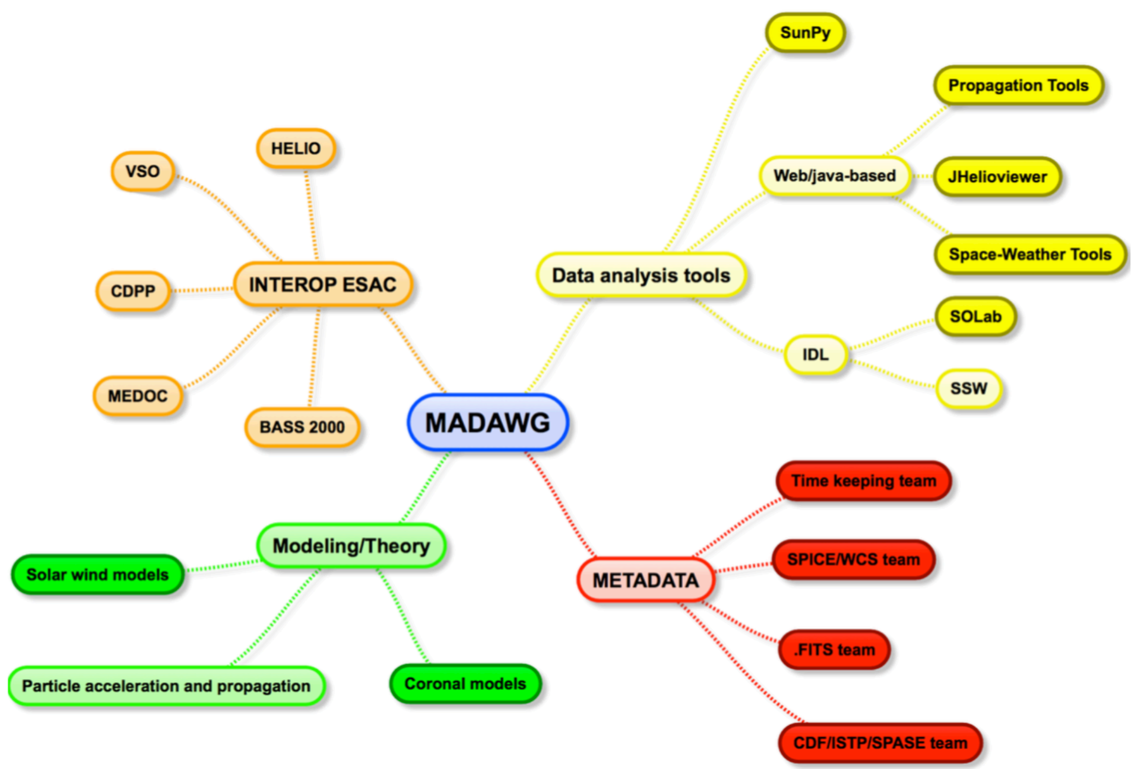
(CNRS/IRAP/CNES)

and ESA's Modelling and Data Analysis Working Group (MADAWG)



Talk describes work in preparation for Solar Orbiter in

- the heliophysics team in Toulouse
- ESA's Modelling and Data Analysis Working Group (MADAWG)



Support for Solar Orbiter/Parker Solar Probe

To support fundamental research on coronal heating, solar wind research CMEs, SEPs we need to know:

-> some basic properties of the background corona (3-D magnetic vector field, temperature, density, plasma speed distribution) and the associated uncertainties in this derivation,

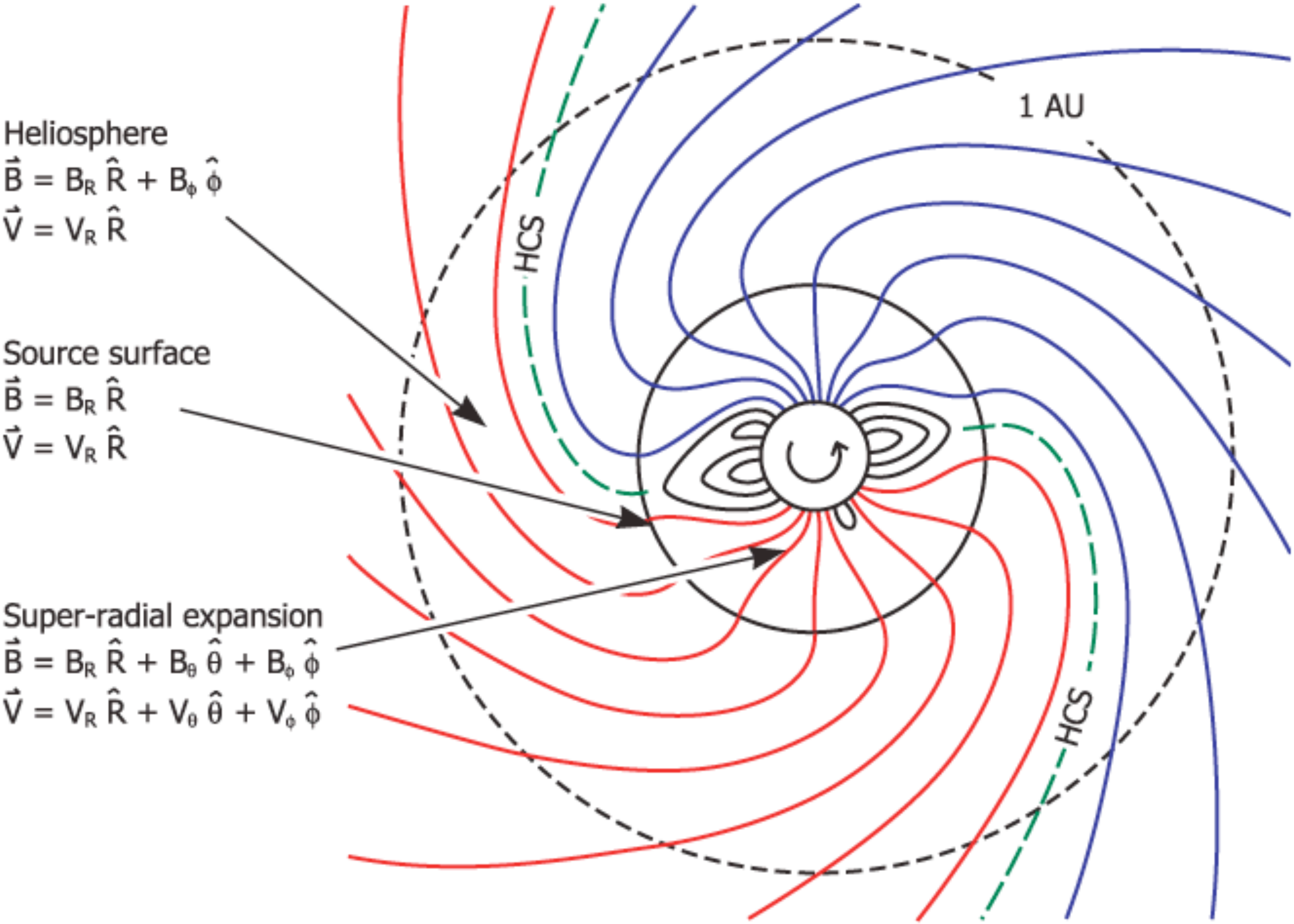
-> to provide advanced catalogues (3-D cubes,…) with the necessary visualisation tools.

<u>Fundamental at all stages of the data acquisition and analysis process</u>

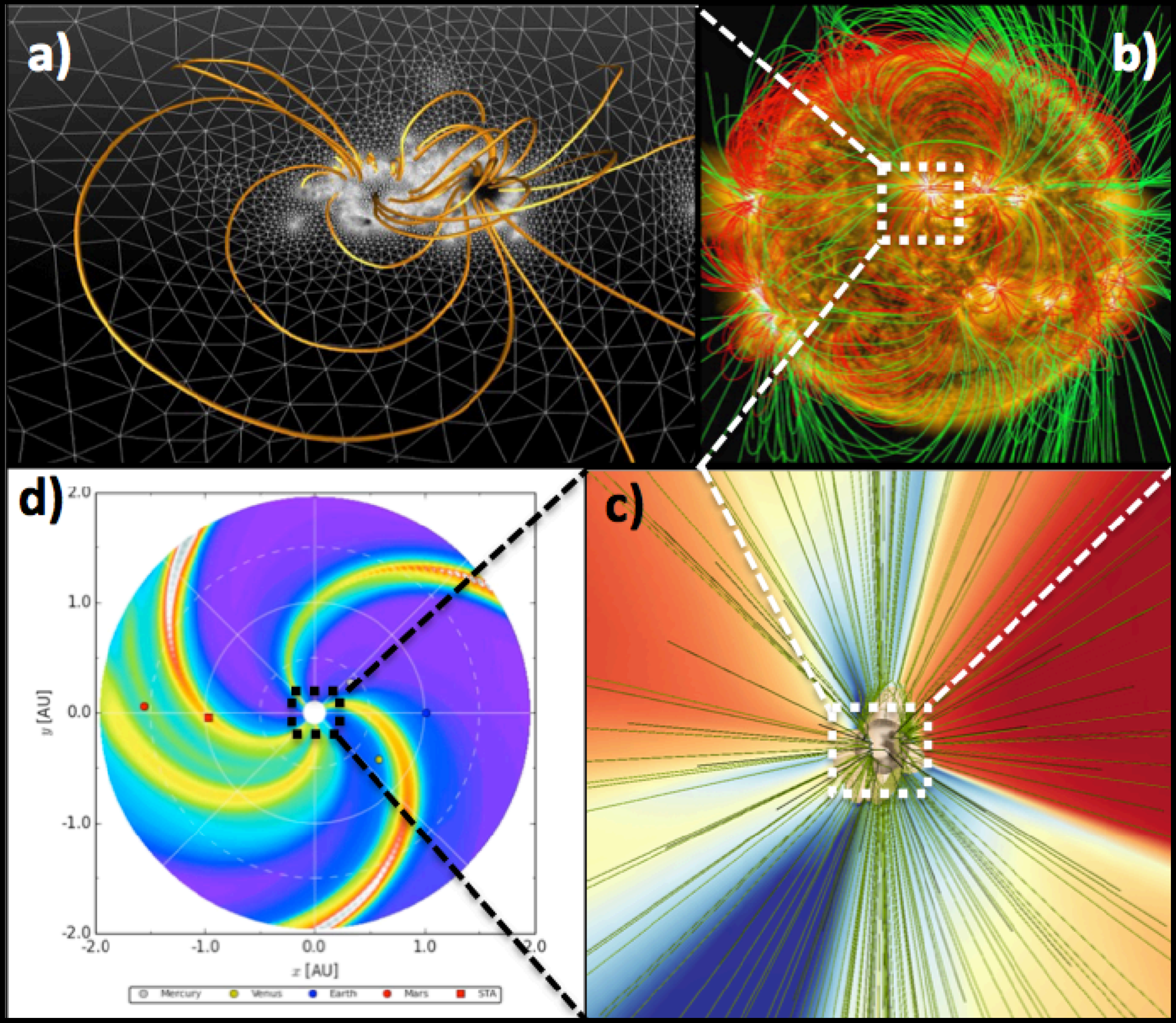
Role of modelling in Solar Orbiter

Coronal + heliospheric models will play key role in SolO science planning for:

- **Forecasting – VSTP cycle support**:
  - Establishing the most likely connection between S/C and solar source region
  - Choice of targets and pointing updated
- **Data management onboard:**
  - Models will help us interpret the daily LowLatency data and to decide which onboard data to select or prioritize for downlink (for those instruments with internal-storage, or those IS instruments using selective)
- **Data analysis** afterwards:
  - Establishing the link between the remote-sensing observations and the in-situ measurements
  - = One of Solar Orbiter's main science goals!!



Owens and Forsyth 2013



a)
b)
c)
d)
2.0
1.0
0.0
-1.0
-2.0
y [AU]
-2.0
-1.0
0.0
1.0
2.0
x [AU]
Mercury
Venus
Earth
Mars
STA

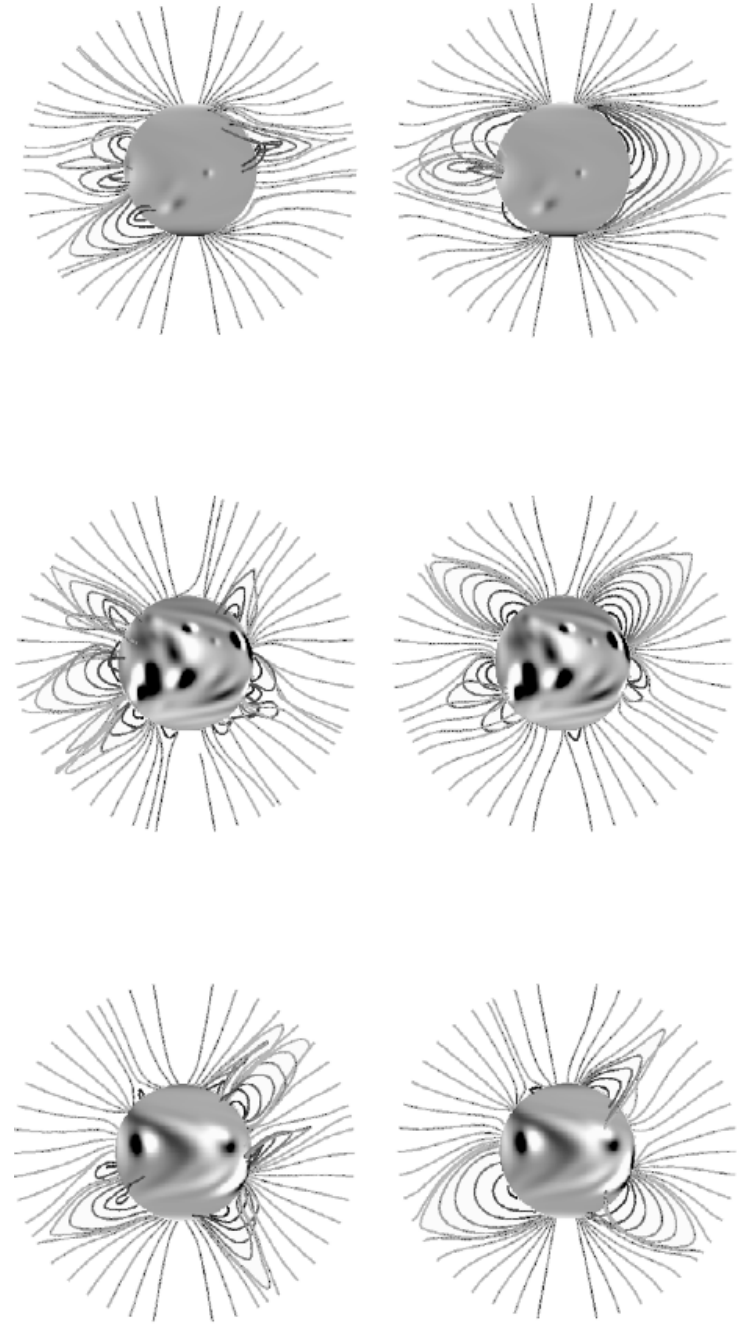
Problems of models to derive coronal magnetic fields:

- The extrapolated field is strongly model-dependent.

- The extrapolated field is static.

- Realistic extrapolations also require difficult horizontal photospheric field measurements and strong assumptions about critical but unobserved quantities (e.g. magnetic field at the low-β coronal base is assumed to be the same as in the high-β photosphere).

- The extrapolated field cannot always reproduce accurately complex magnetic configuration of the solar corona.

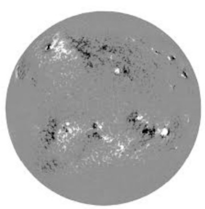


Yeates et al. 2010

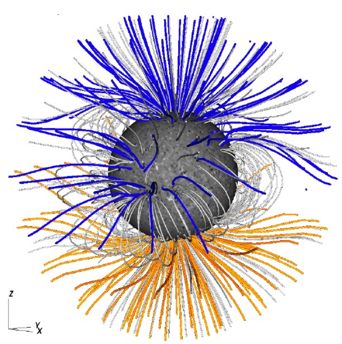
Solar Orbiter / Parker Solar Probe Connectivity Tool

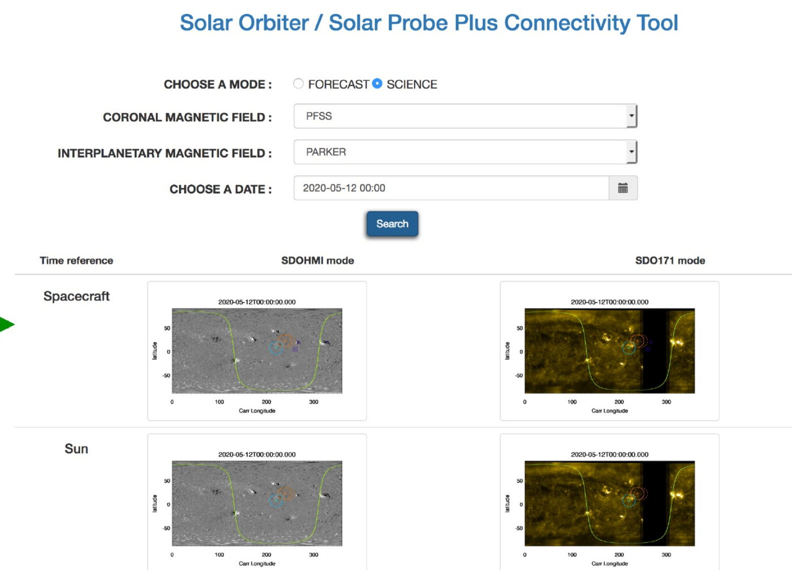
- Aim is to deploy the SolO/PSP magnetic connectivity tool: will provide estimates of where the two spacecraft connect to on the solar surface either using past data (for science purposes) or else using forecasts of the solar magnetic field (for operational purposes).
- In its forecasting mode the tool would estimate where SolO connects to the solar surface in order to decide where the remote-sensing instruments should point. Forecasted magnetograms can be ADAPT maps and Toulouse is putting in place a flux-transport model running on SDO magnetograms.

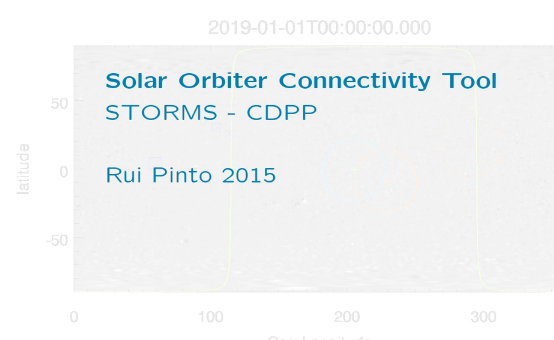
FLUX TRANSPORT



PFSS, NLFF, MHD



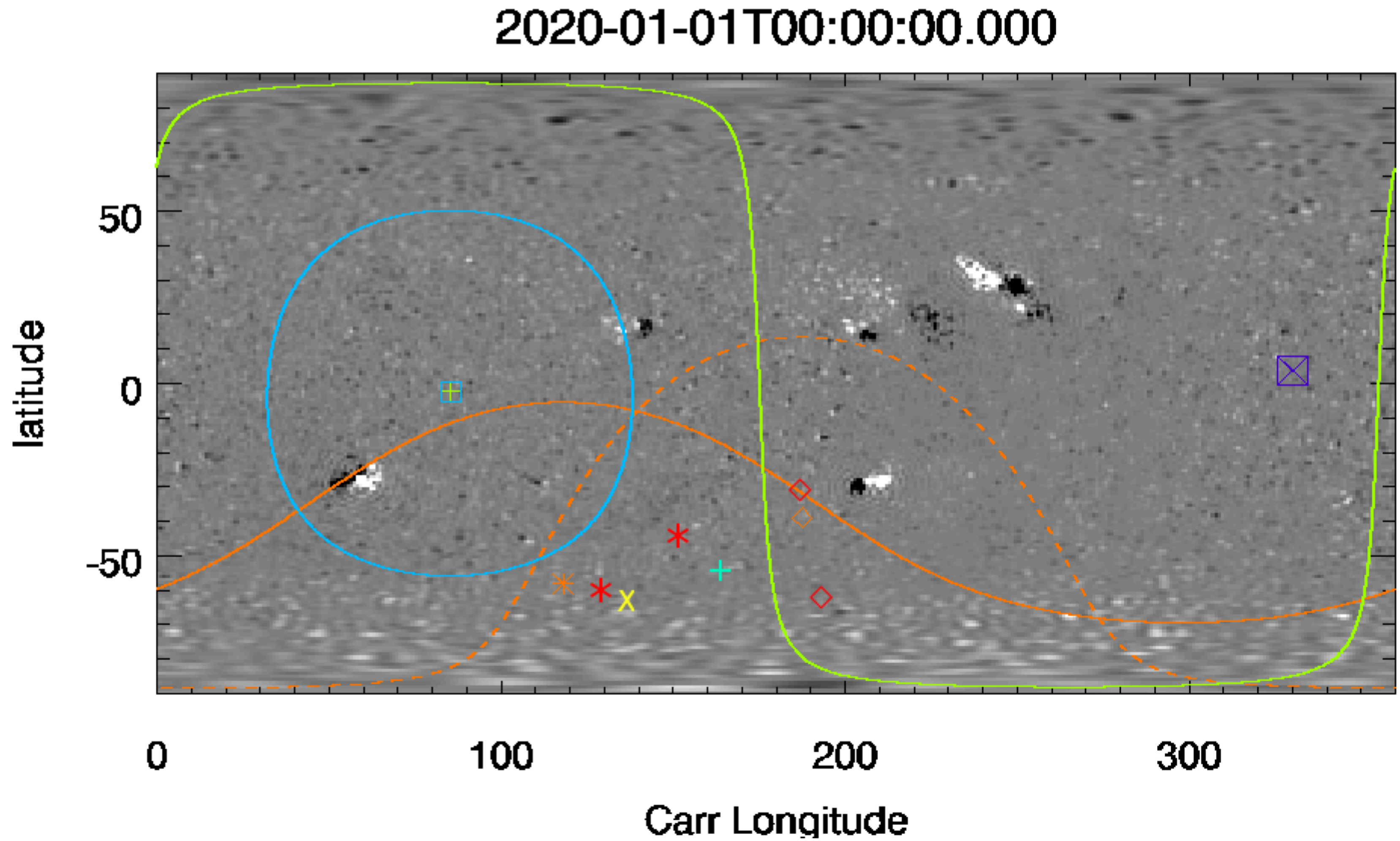




Forecasting: testing different approaches

Corona:
ADAPT+PFSS, ADAPT+NLFFF (maybe)

Heliosphere:
PARKER, EUHFORIA, ENLIL



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

(Courtesy of Paolo Pagano)

Predicting Eruptivity of active region magnetic fields

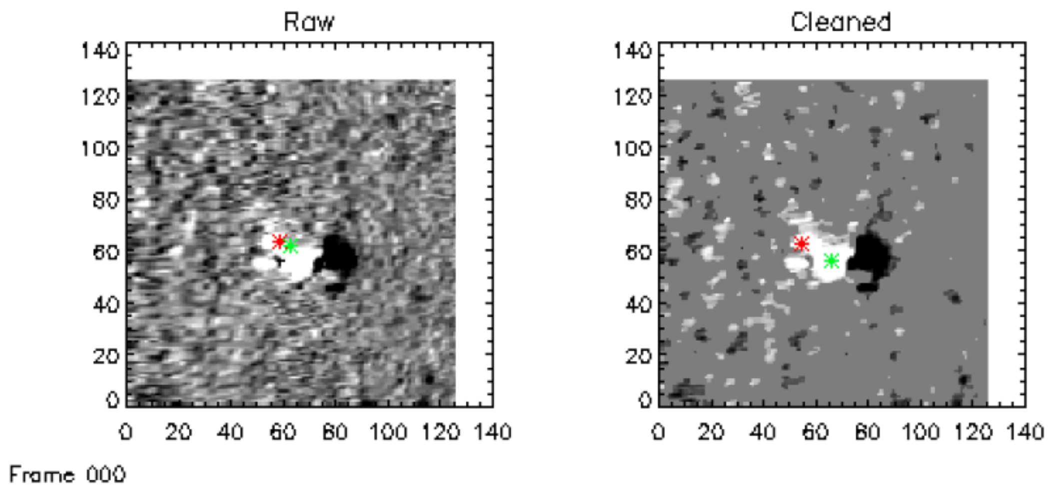
Surface potential vector evolution

$$\frac{\partial \vec{A}}{\partial t} = \vec{v} \times \vec{B}$$

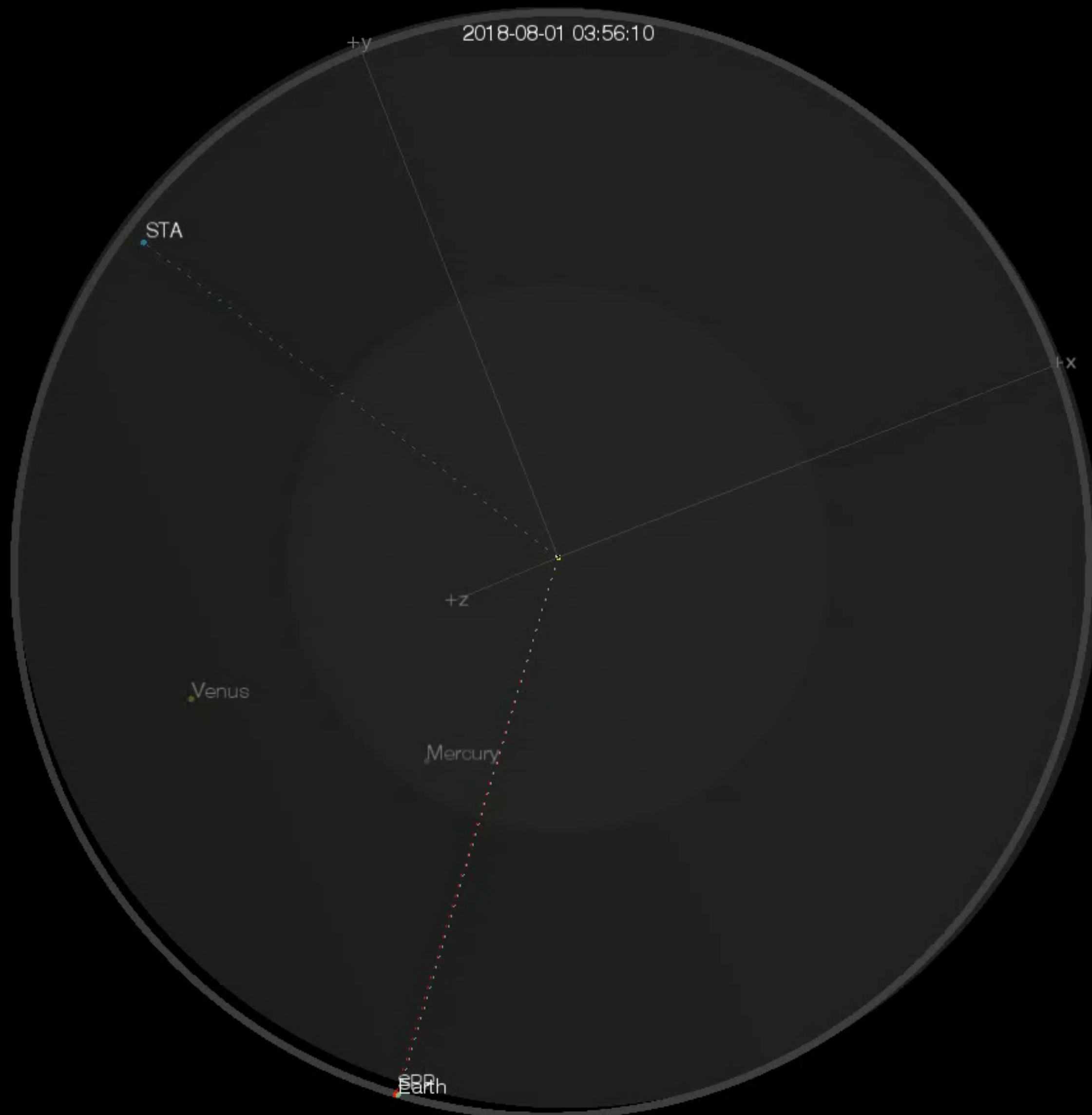
$$B = [0, 0, B_z]$$

We compute $\vec{A}$ and $\vec{B}$ for each magnetogram

$$\frac{\partial \vec{A}_x}{\partial t} = v_y B_z \quad \frac{\partial \vec{A}_y}{\partial t} = -v_x B_z$$



We can compute the velocity field from two subsequent magnetograms and use the velocity field evolution to predict the evolution of the surface field.


2018-08-01 03:56:10
+y
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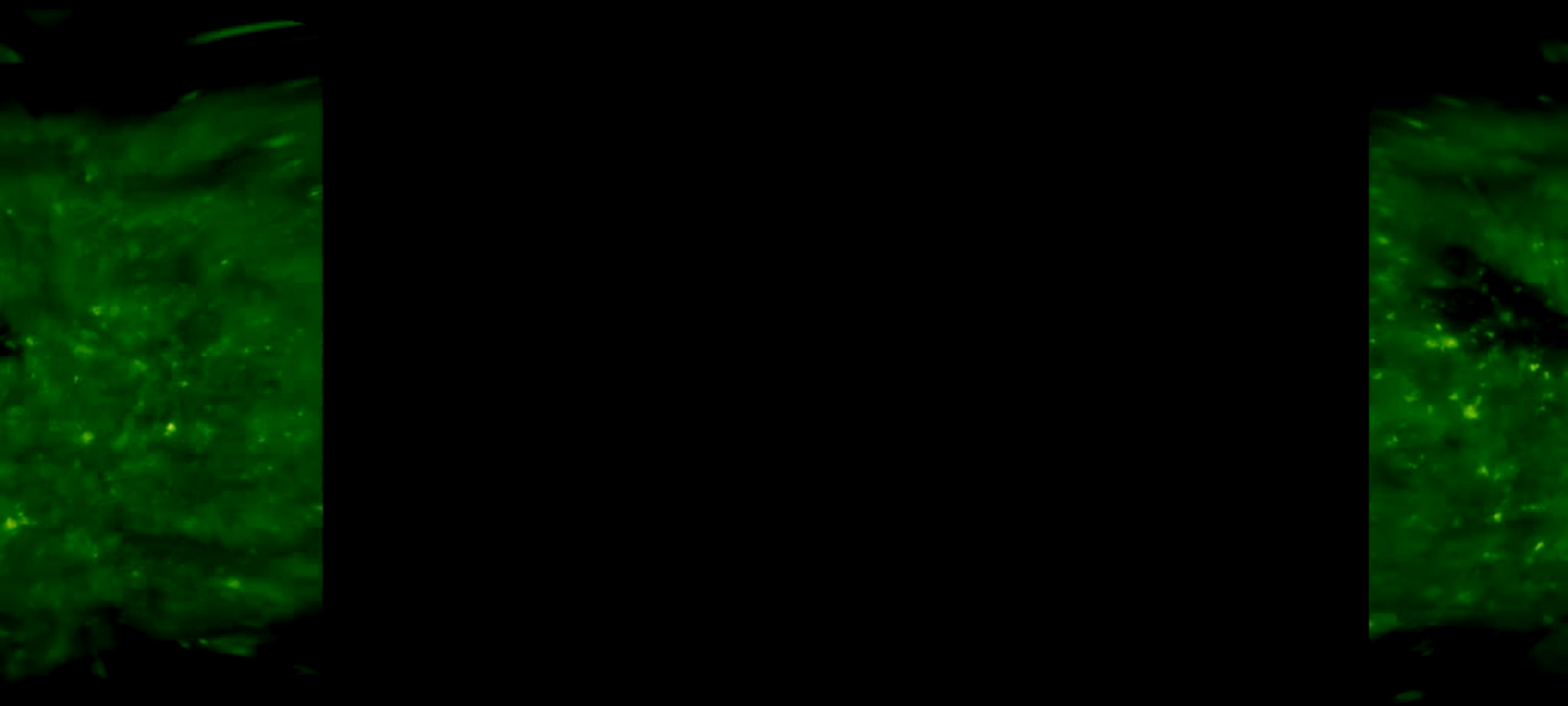
+x
+z
Venus
Mercury
Earth

Advanced data products: creating synchronous maps from multiple view points, getting ready for Solar Orbiter EUI



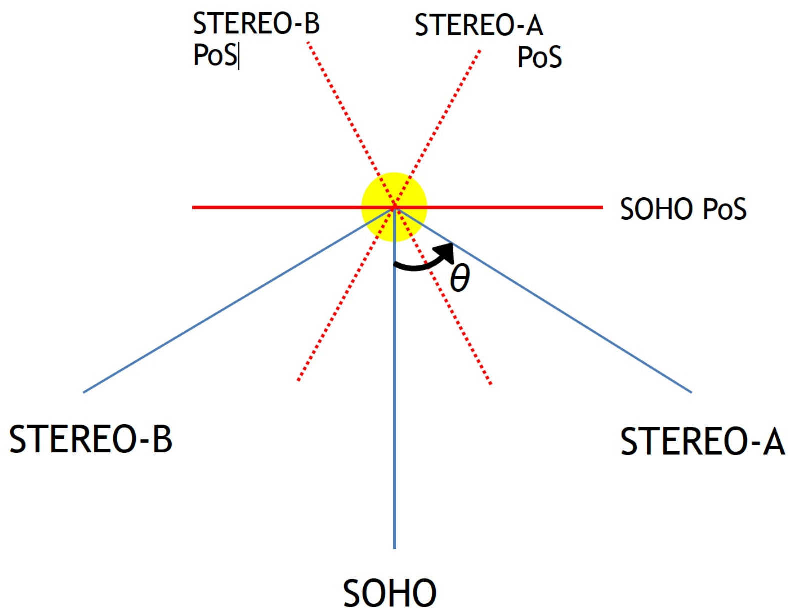
With multi- instrumental and multi-spacecraft studies we immediately face the problem of **<u>synchronicity</u>** and **<u>spatial variability.</u>**

Advanced data products: creating synchronous maps from multiple view points….

Clementina Sasso – INAF/OAC

Rui Pinto, Russ Howard and METIS team

The idea: to combine SOHO and STEREO –A and –B Carrington maps at given altitude to have an almost «instantaneous» picture of coronal structures → compare locations of streamer belt, streamer boundaries, coronal holes with extrapolated location of magnetic neutral line, closed/open field boundaries, etc… at the same altitude.

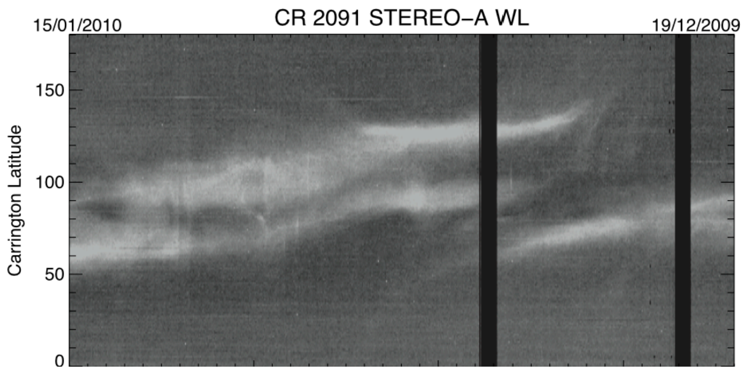


For CR2091 the STEREO-SOHO separation angles were 64° (ST-A) and 68° (ST-B).

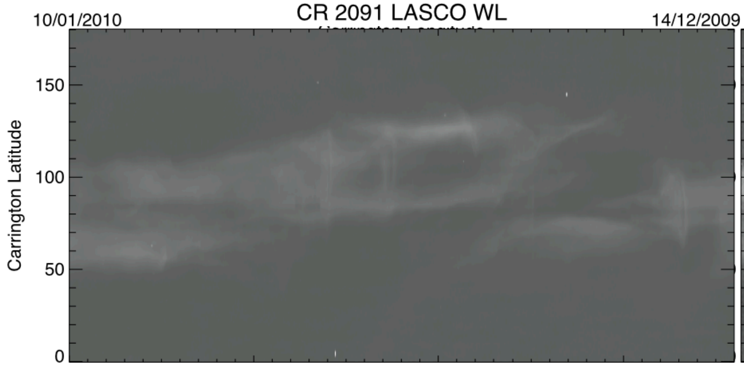
If θ ~ 60° → after ~ 4.5 days the same structures seen by SOHO start to be observed by STEREO-B and were observed 4.5 days before by STEREO-A → need only 13.5 days (instead of 27 days) of data to see one full coronal rotation.

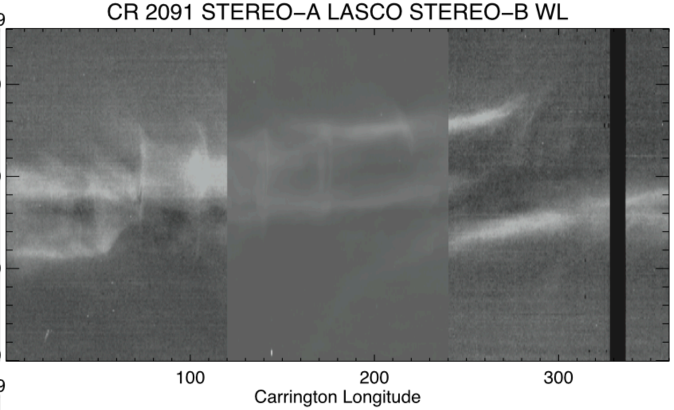
Advanced data products: creating synchronous maps from multiple coronagraphic views….

+4.5 days

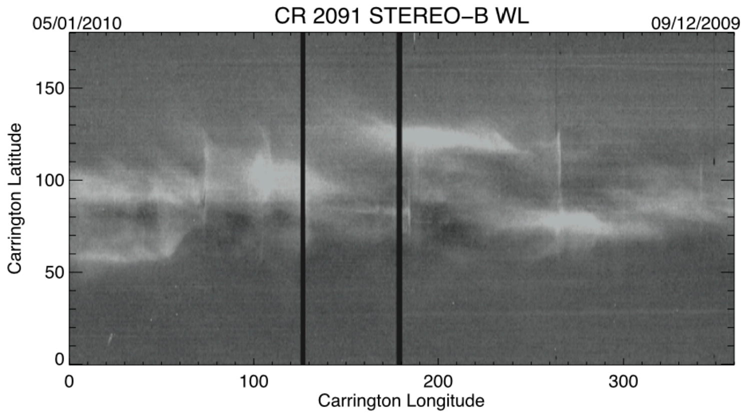


Time
<—





-4.5 days

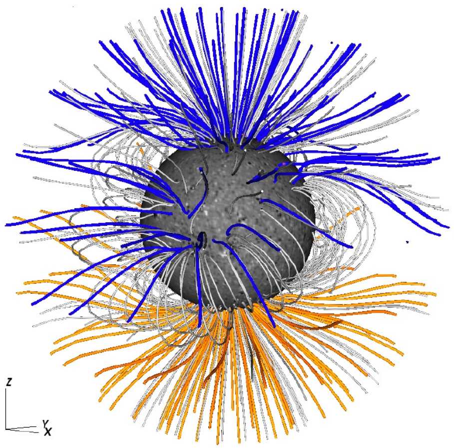


STEREO-B + SOHO + STEREO-A combination guarantees the minimum amount of temporal evolution in the maps as possible.

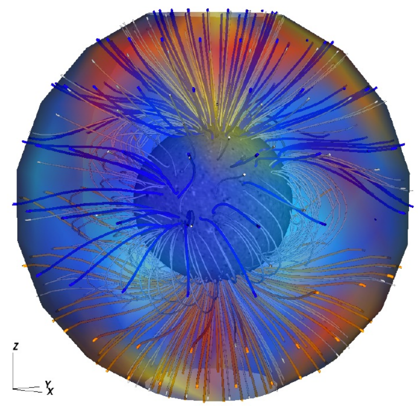
Photosphere to corona solar wind models run with realistic thermodynamics and high-resolution magneto-static models (PFSS, NLFF):

-> provides simulated 3-D cubes of N,T,V to compare with observations either via forward modeling (synthetic imagery) or inversion of imagery (N,T,V).

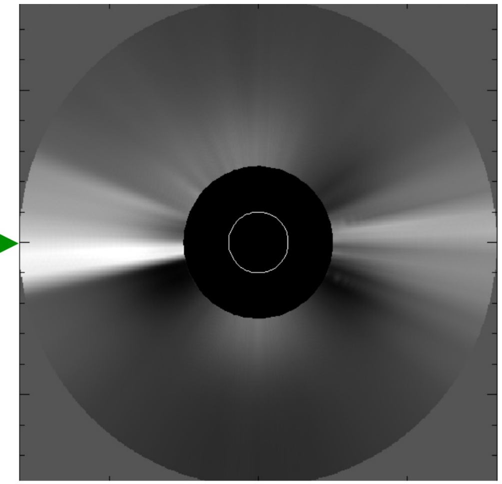
-> next step: transition to multi-species models (electron, proton, alphas and heavier ions)



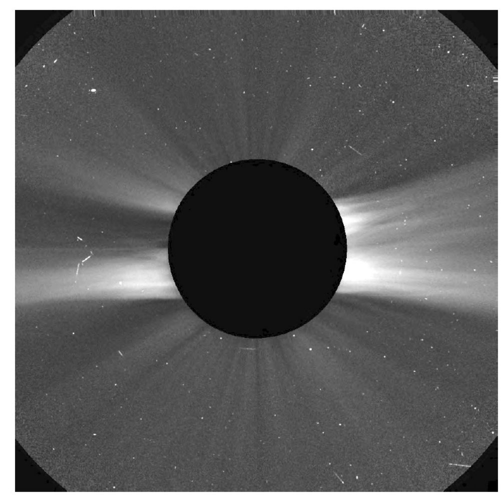
PFSS (or NLFF)



3-D solar wind plasma



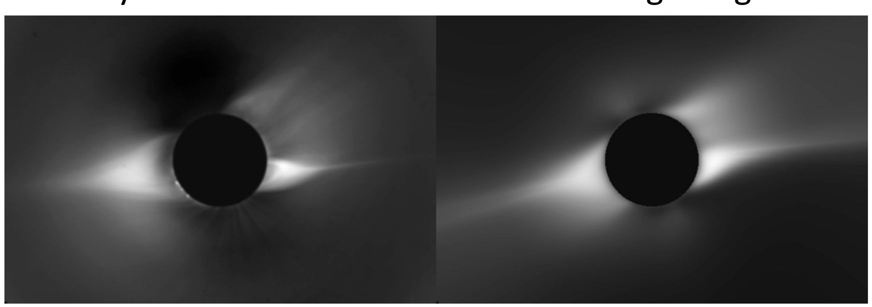
Synthetic imagery



SOHO C2

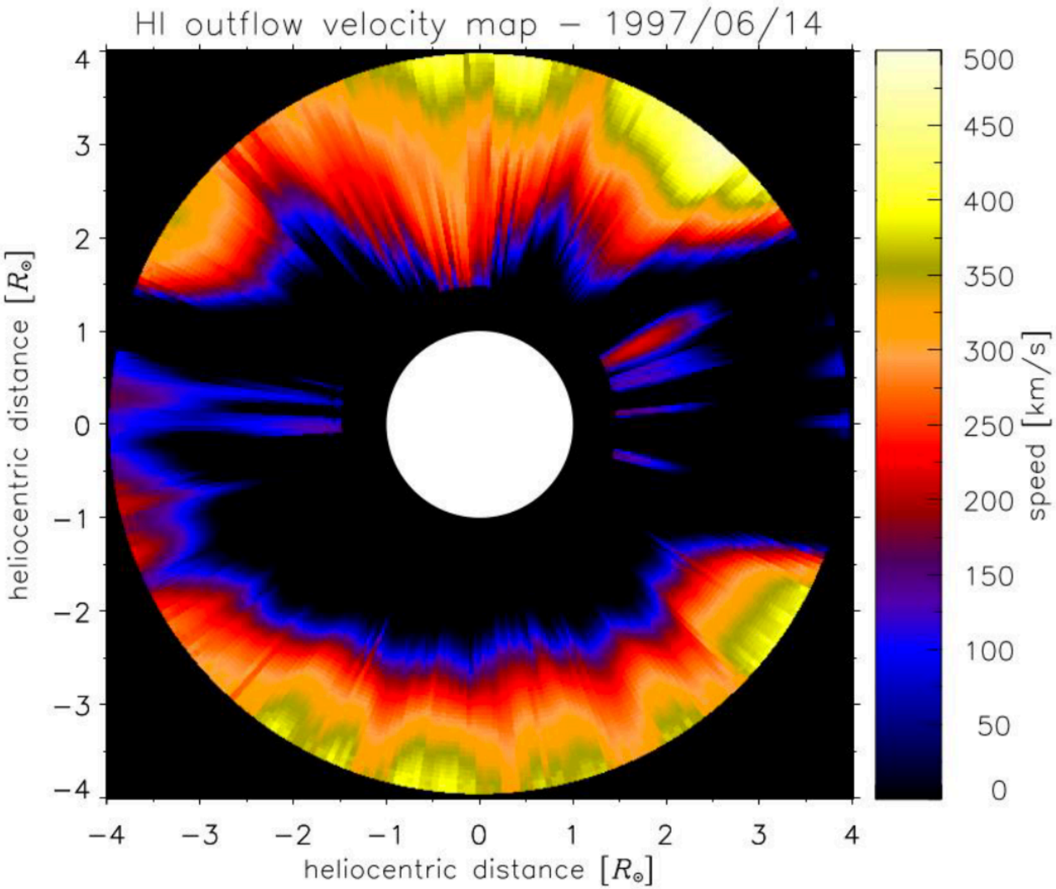
Pinto and Rouillard (2017)

Done by MHD modellers on smoothed magnetograms:



PSI Inc. (Linker et al. 2009, Downs et al. 2010)

Solar wind HI outflow velocity

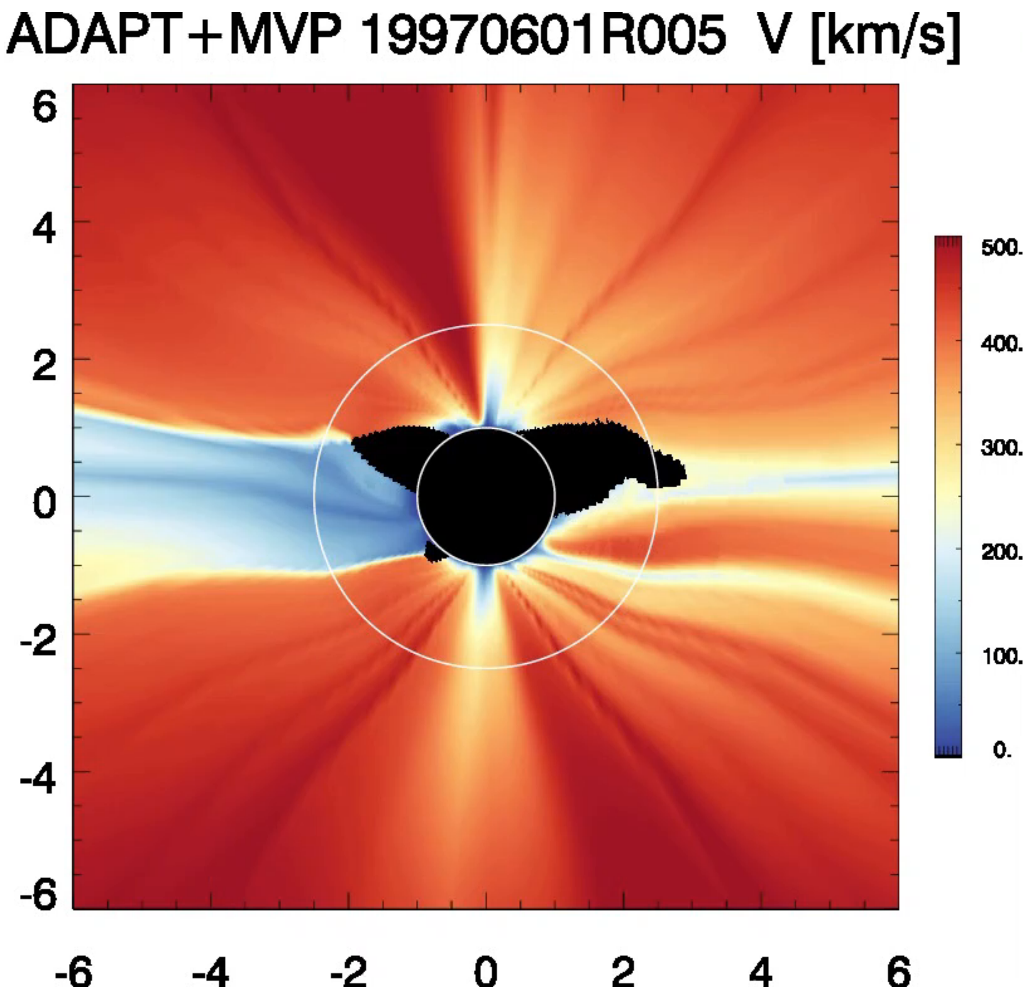


daily maps from 1° to 28° June 1997 of the solar wind speed distribution on the plane of the sky

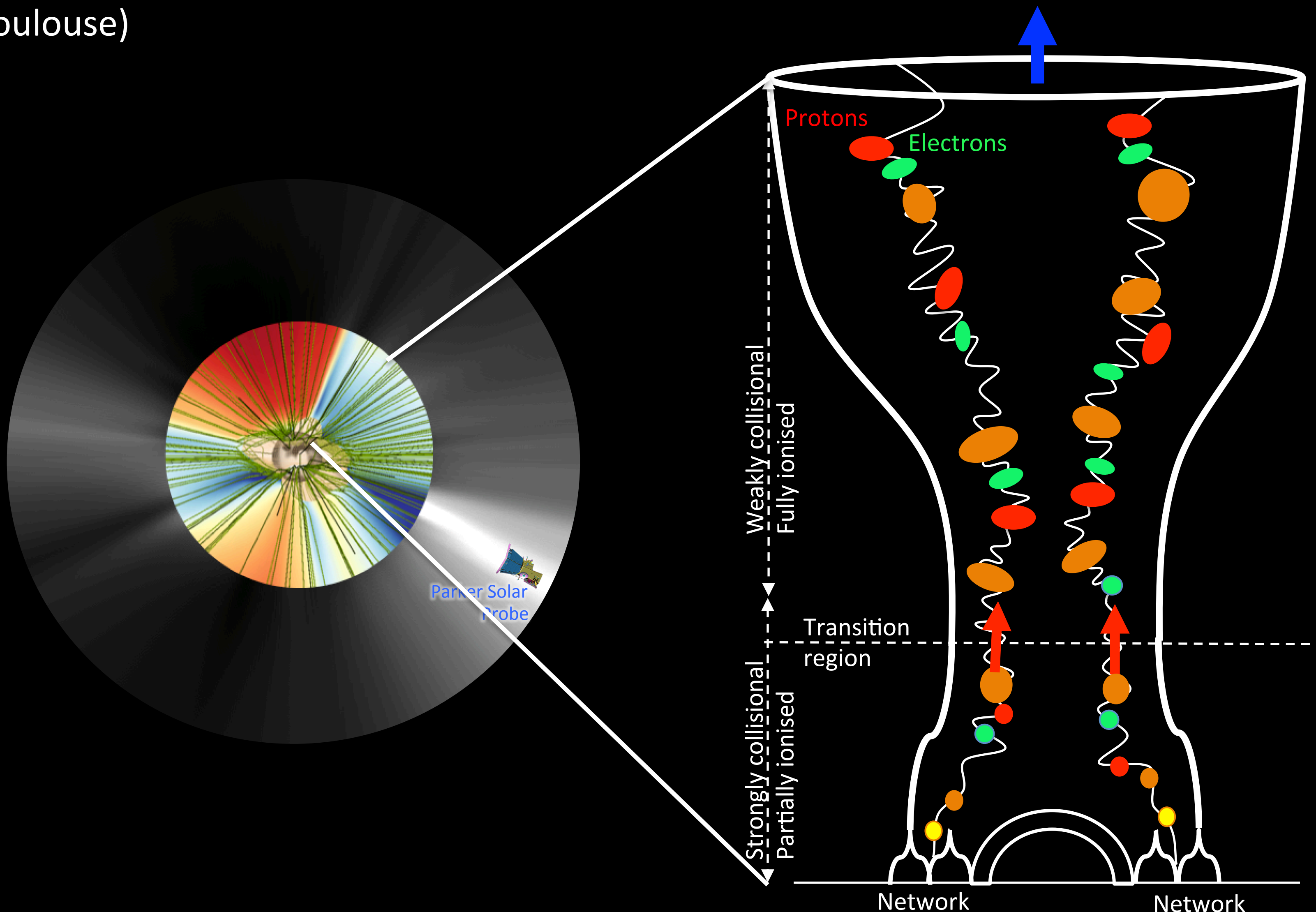
OHB CGS ThalesAlenia Space IFN ASF ifsi OAC OACt OAPA OATs MPS LAM

New modelling capability put in place by IRAP (R. Pinto)

-> to extract solar wind along field lines in the plane of the sky
-> compare directly with METIS-SolOHI data

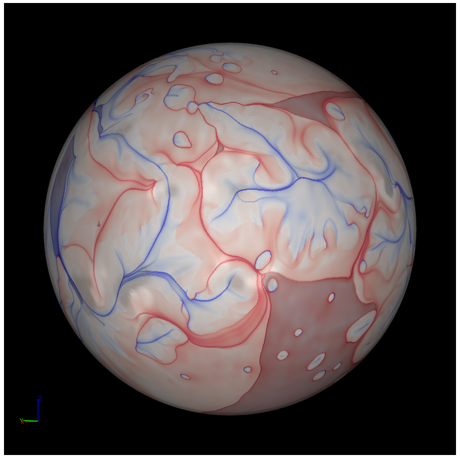


Moving to global multi-species and multi-temperature models:
(IRAP Toulouse)



We need simulated or inferred physical parameters of the corona (magnetic fields, speeds, density, temperatures) for all topics(SEPs, solar wind, CMEs)

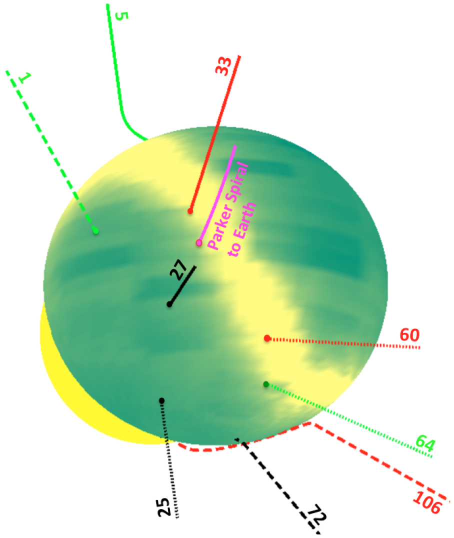
Slow solar wind



Squashing factor

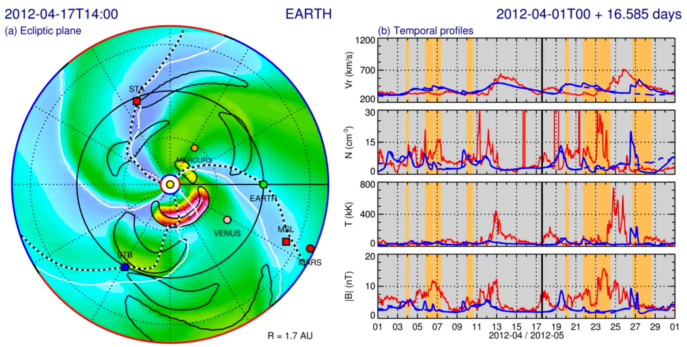
Q-maps
(PSI, Polytechnique)

SEP studies



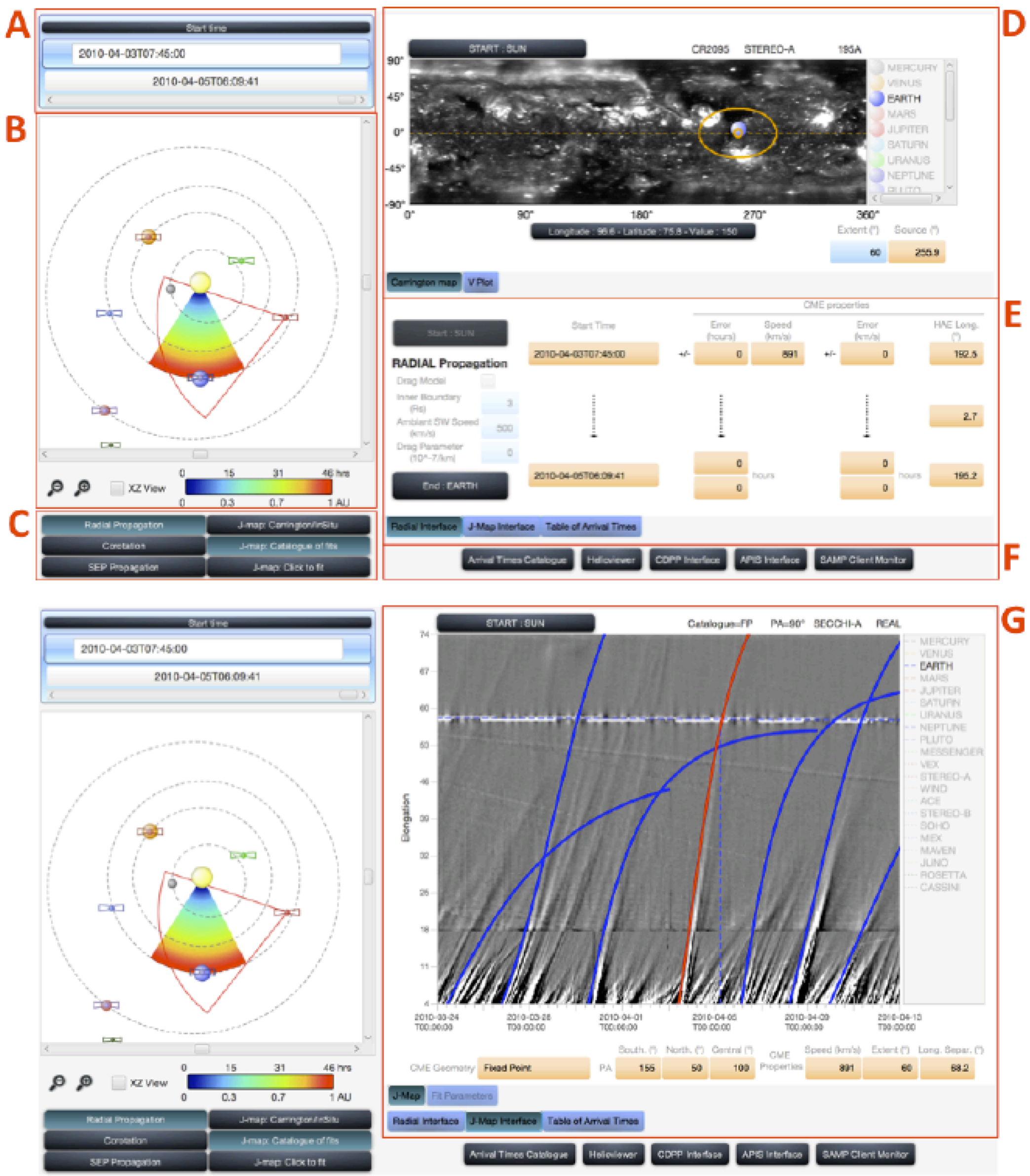
Providing catalogues of shocks
(IRAP-JHAPL collaboration)

CME studies



Catalogues of CME simulations (CCMC, GMU, IRAP)
e.g. HELCATS project

Tool developments to connect in situ and remote-sensing data: moving to 3-D for Solar Orbiter:



propagationtool.cdpp.eu

Rouillard et al. (2017)

- Propagation Tool going 3-D!
- Integration SolO Connectivity Tool

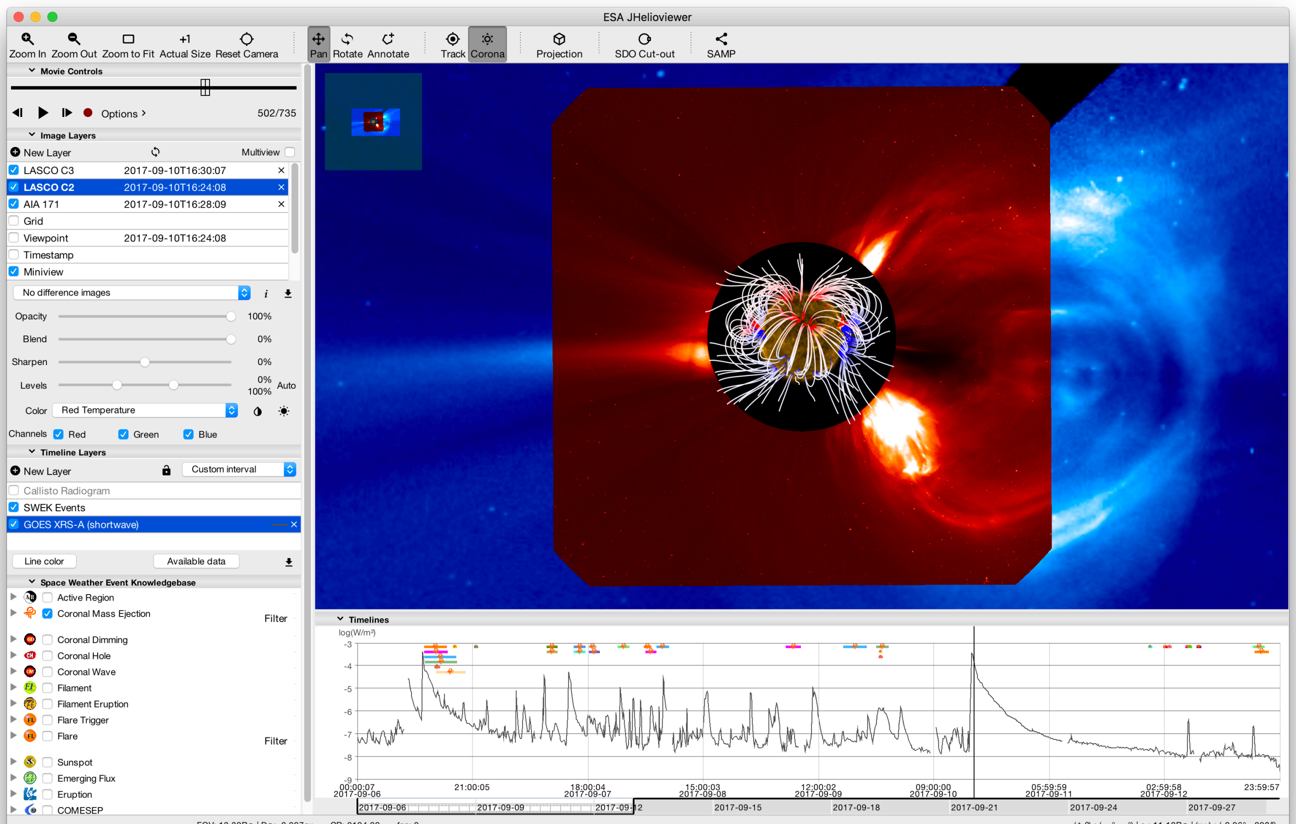
JHelioviewer: Interactively visualize multi-viewpoint data

Today:

- Project solar and heliospheric data in 3D using ephemeris data
- Display 1D and 2D time series
- Overlay PFSS field lines, events from Events databases (HEK, SWEK)
- Difference movies

To be added for SO + PSP:

- In-situ data (time correlation to images requires model)
- Functionality to support SO science planning
- Interface to SO archive + VSO
- Augmented visualization



Müller et al. (2017) A&A **606**, A10

Conclusions:

The preparation of the Solar Orbiter mission involves the development of:

- ‘space-weather tools’ to help mission operations,

- new techniques to exploit remote-sensing and in-situ datasets (for instance to derive the 3-D distribution of coronal plasma parameters at any one time),

- advanced numerical models extending from the photosphere to the solar wind,

- collaborations between Solar Orbiter and other space missions and ground-based instrumentation.