MADAWG activities and Metis contributions

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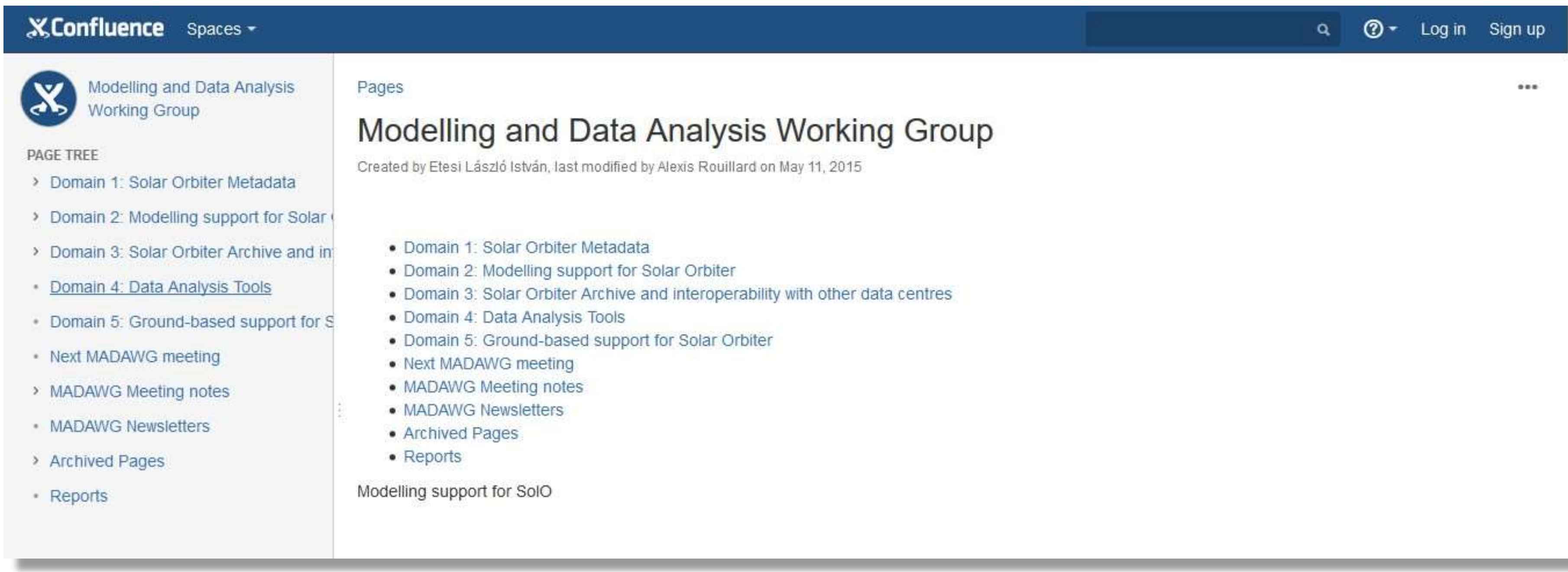
OUTLINE

- MADAWG & Metis
- Metis quick data reduction (level 2 → level 3)
- Future perspectives:
  - Metis advanced data reduction (level 3 → «level 4»)
  - Use of Metis data to derive temperatures
  - Combining remote sensing and in situ data
  - Retrieving the Parker spiral with remote sensing data
- Conclusions

MADAWG

The Modelling and Data Analysis Working Group (MADAWG) is a team of scientists and engineers working on:

- coordinating modelling and theoretical support for Solar Orbiter science,
- preparing data analysis tools to relate different Solar Orbiter datasets,
- defining the format of datasets and their metadata from Solar Orbiter.
- defining how data archives will exchange Solar Orbiter data.



https://stix.cs.technik.fhnw.ch/confluence/display/DAWG/Modelling+and+Data+Analysis+Working+Group

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Solar Probe Plus Representatives:

Solar Wind Electrons, Alphas and Protons (SWEPS; Justin Kasper)
Fields Experiments (FIELDS; Stuart Bale, Marc Pulupa, Keith Goetz)
Wide-field Imager (WISPR; Russ Howard, Angelos Vourlidas, Denis Wang)
Heliospheric Origins with Solar Probe Plus (Marco Velli)

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MADAWG Meetings

Next MADAWG meeting: ESAC (near Madrid) on 24th and 25th of January 2019 following the SOWG (21st-23rd).

Focus: application of the MADAWG tools to PSP's first perihelion and lessons learnt from the support of Hinode-PSP synergies.

- **27/09/2018:** Connectivity tools and flare/CME forecasting capabilities, Athens, Greece
- **22/01/2018:** Integration of PHI data into modelling and data analysis tools, IRAP, Toulouse, France
- **10/07/2017**: Modelling support for Solar Orbiter, ESAC, Madrid, Spain
- **15/11/2016**: Forecasting requirements for Solar Orbiter mission ops., ESWW13, Ostende, Belgium
- **11/04/2016:** Data exploitation testing moels with imagery, Alcalà, Spain
- **19/11/2015:** Modelling support for Solar Orbiter: ROB, Bruxelles, Belgium
- **07/07/2015**: Completion of generic METADATA document, ESAC, Madrid, Spain
- **11/02/2015:** Modelling support for Solar Orbiter: MPS, Gottingen, Germany
- **19/01/2015**: Interactions between data centers: ESAC, Madrid, Spain
- **02/12/2014:** Definition of METADATA document: FHNW, Basel, Switzerland

Presentations and Minutes available at the FHNW Confluence Page

MADAWG Metis activities

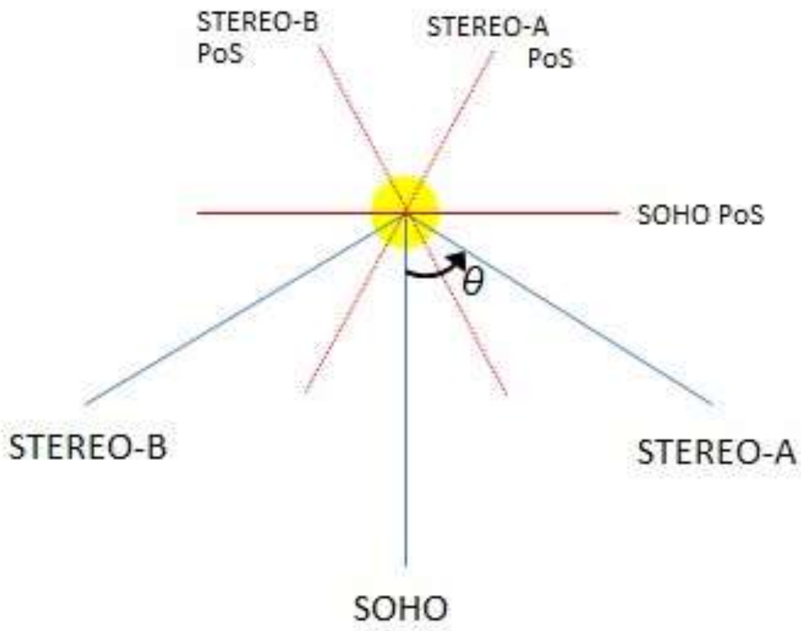
After MADAWG meeting in Bruxelles (Nov. 2015) 2 tasks were assigned to our Team (extracted from the meeting minutes):

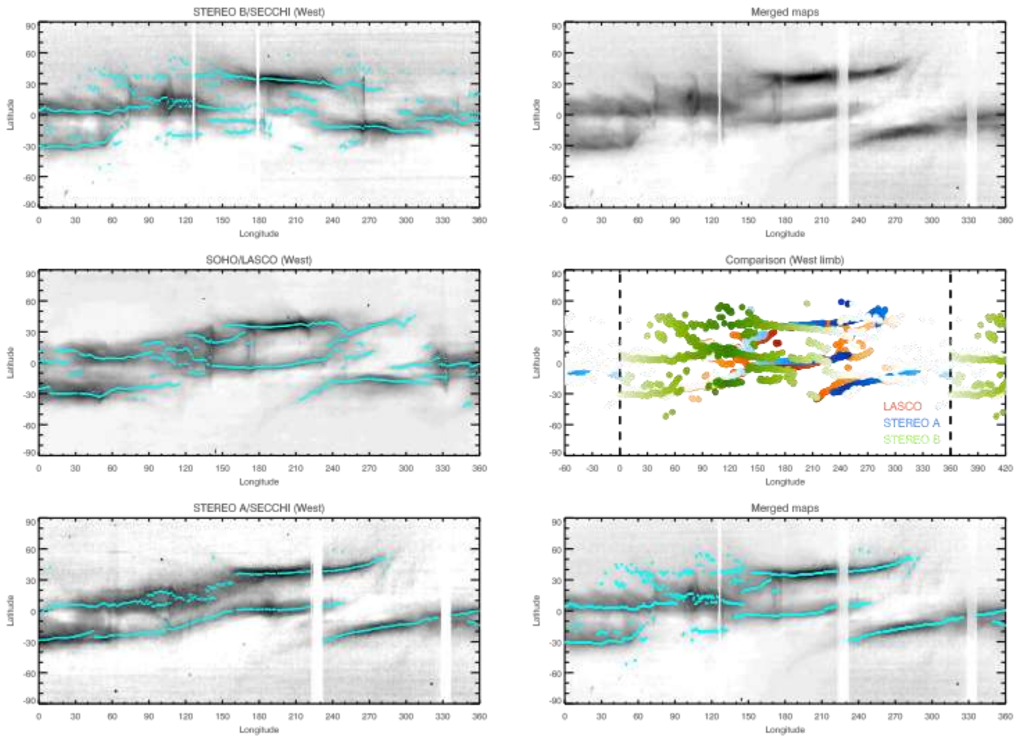
Task 1.5: Alessandro/Russ: Would it be possible to derive a synchronous white- -light map from STEREO/SOHO combined? How would we do that? >> Find out which rotation has a nice coronal hole/simple streamer structure/few CMEs, >> Investigate comparison with tomographic techniques (ask Joe Davila and Judith De Patoul for white---light and Huw Morgan and Mario Bisi for IPS, and Chloé Guennou for EUV): Judith, Huw and Mario should be contacted.

Task 2.3: Alessandro: Feasibility study: Can the methodology proposed by the METIS team to derive the solar wind speed variations in the METIS field of view be used for our forecasting needs? >> can we predict the shape of the spiral arm in that critical region located between the source surface and the inner boundary of the MHD models (21.5Rs).

Over the **last 3 years** lot of work has been performed in the Team to demonstrate in particular how future Metis data will possibly provide **constraints for connectivity tools**.

Comparing magnetic field extrapolations with multi-spacecraft WL Carrington maps



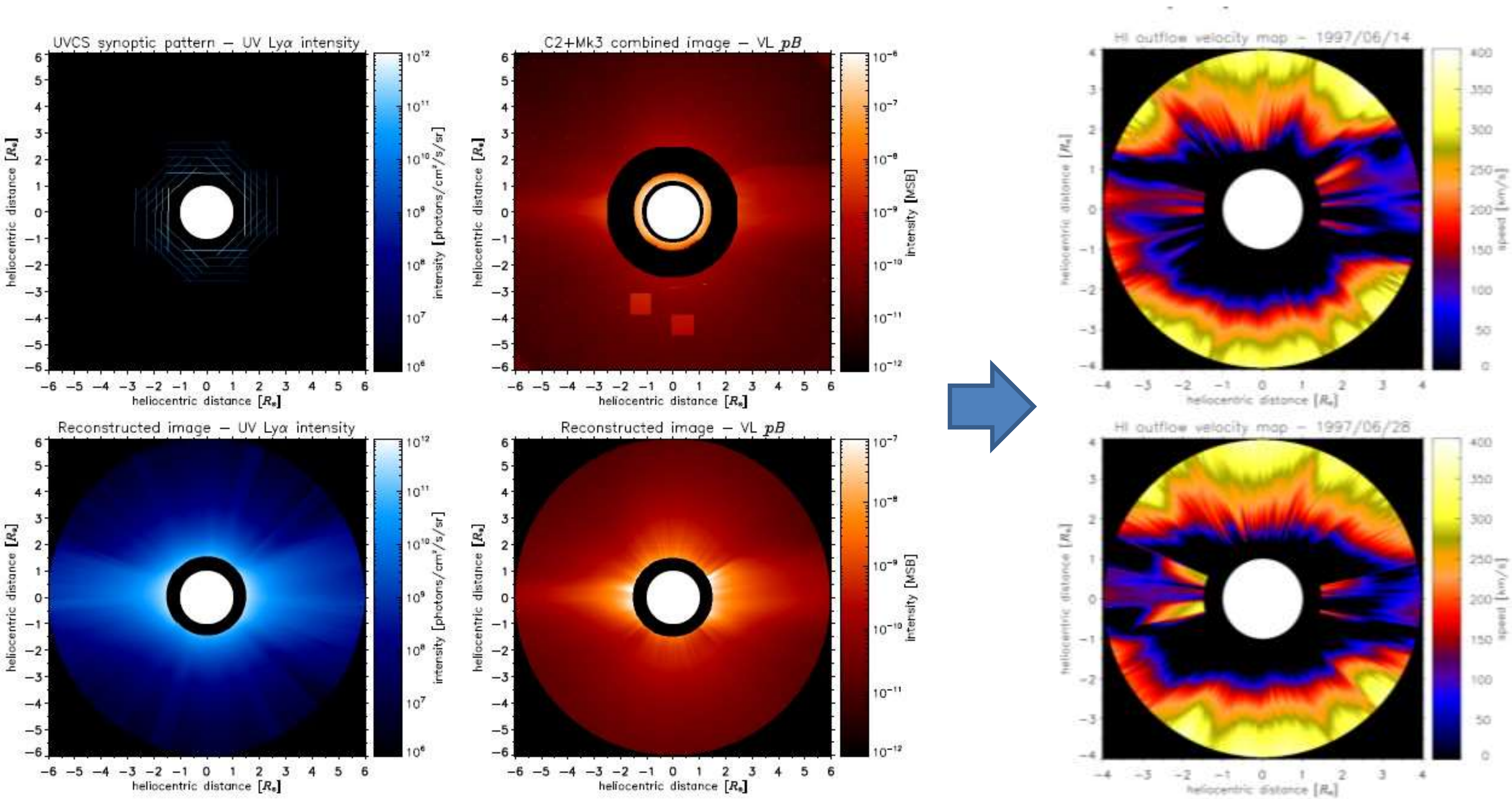


Aim is to verify if this comparison can be a fast method to check systematically the reliability of the many methods available to reconstruct the coronal magnetic field.

Results show that the location of coronal streamers can provide important indications to discriminate between different magnetic field extrapolations.

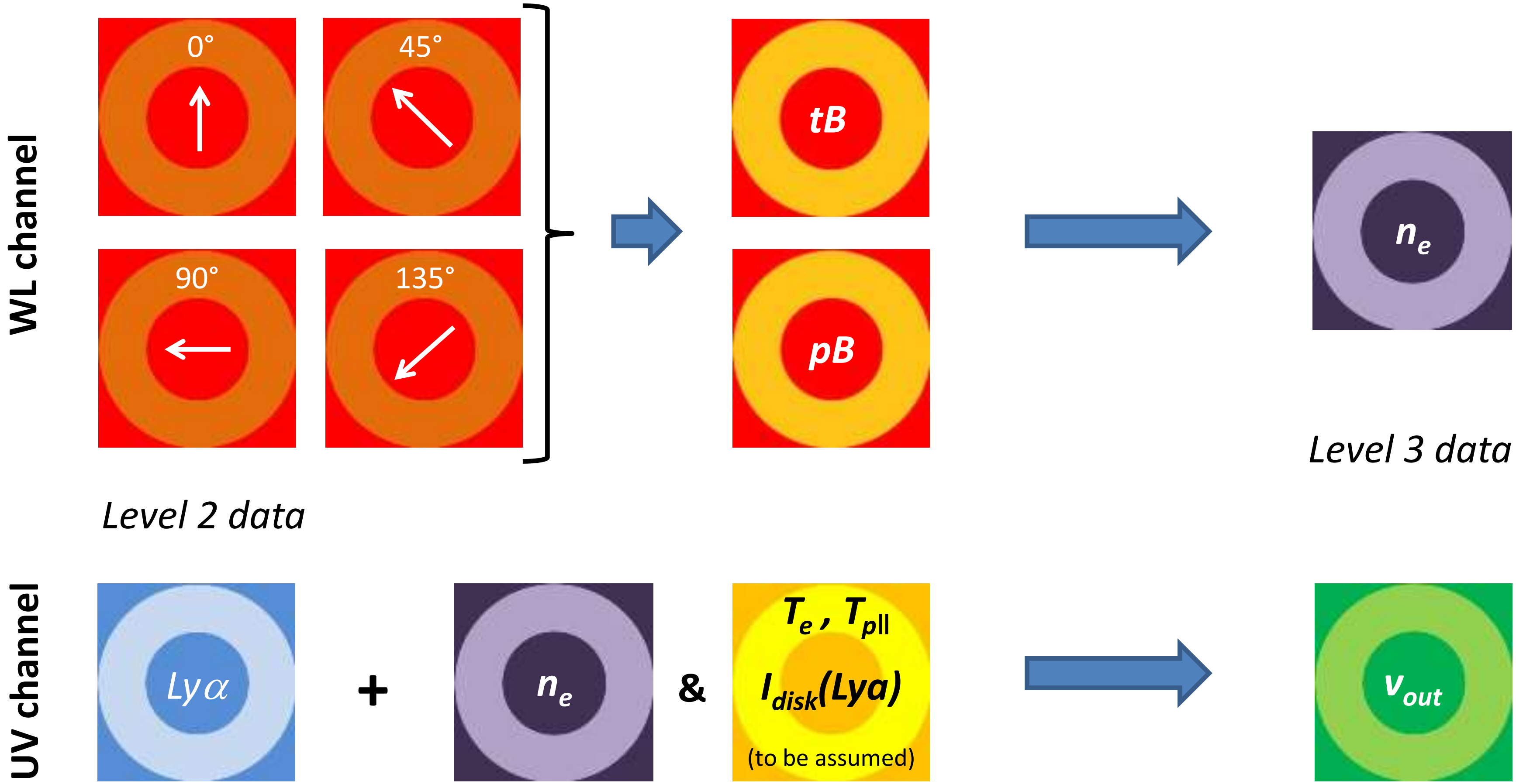
(Sasso et al. 2019, under review)

Mapping the solar wind HI outflow velocity by coronagraphic UV and WL observations



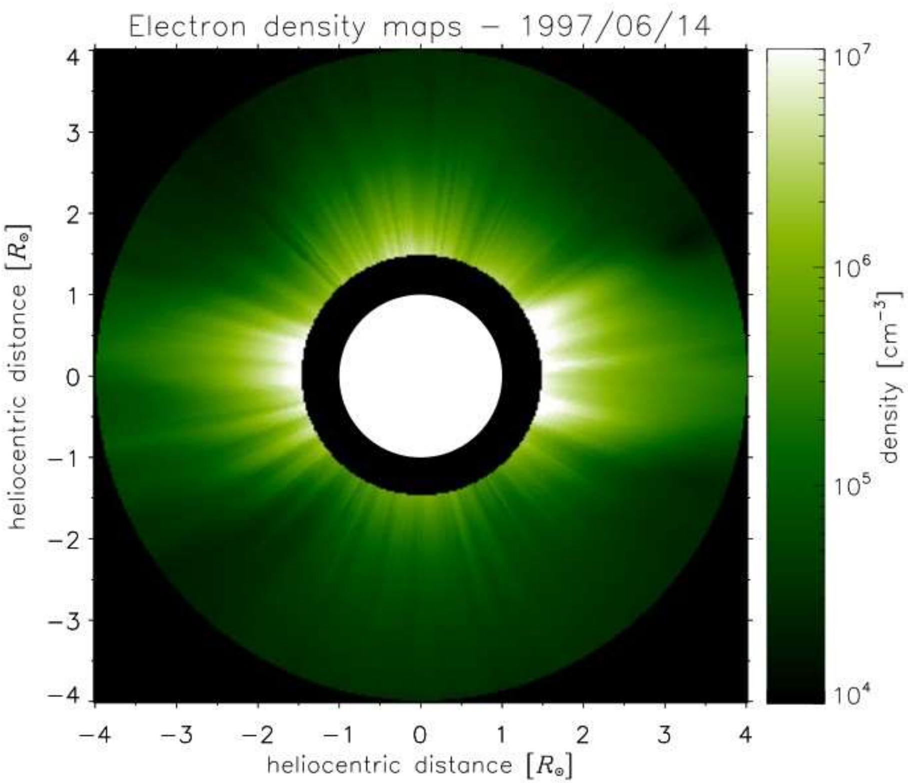
(Dolei et al. 2018; Dolei et al. 2019 in prep.)

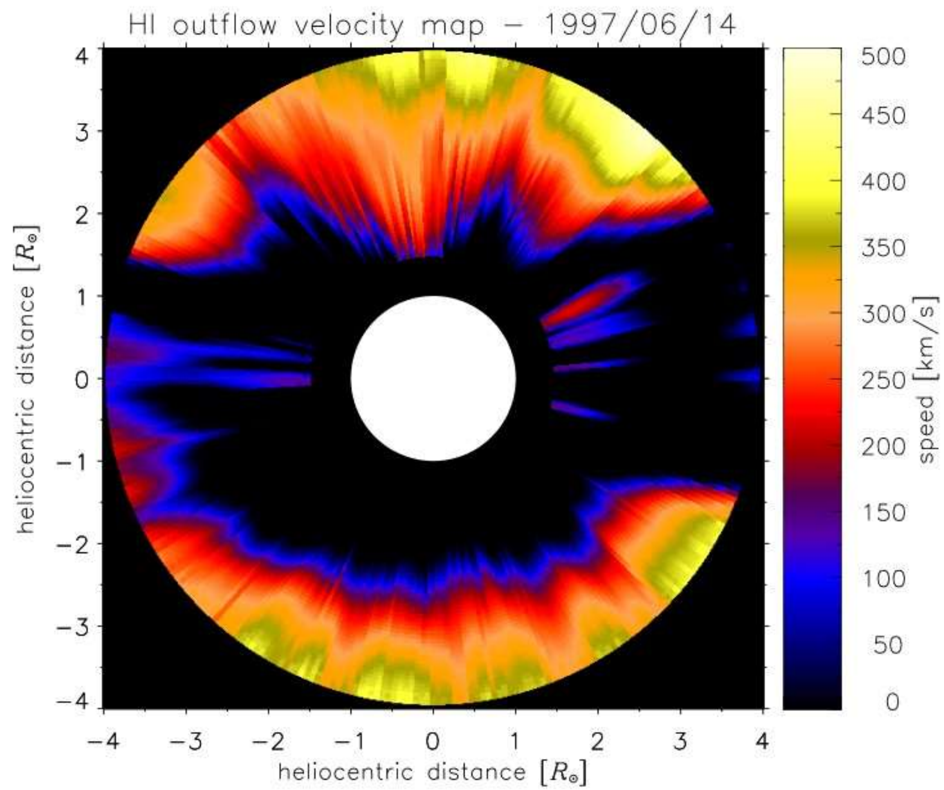
Metis quick data reduction: concept



Derivation of n_e and v_{out} 2D maps (Level 3 data) can be implemented with automatic routines running as soon as the data are available.

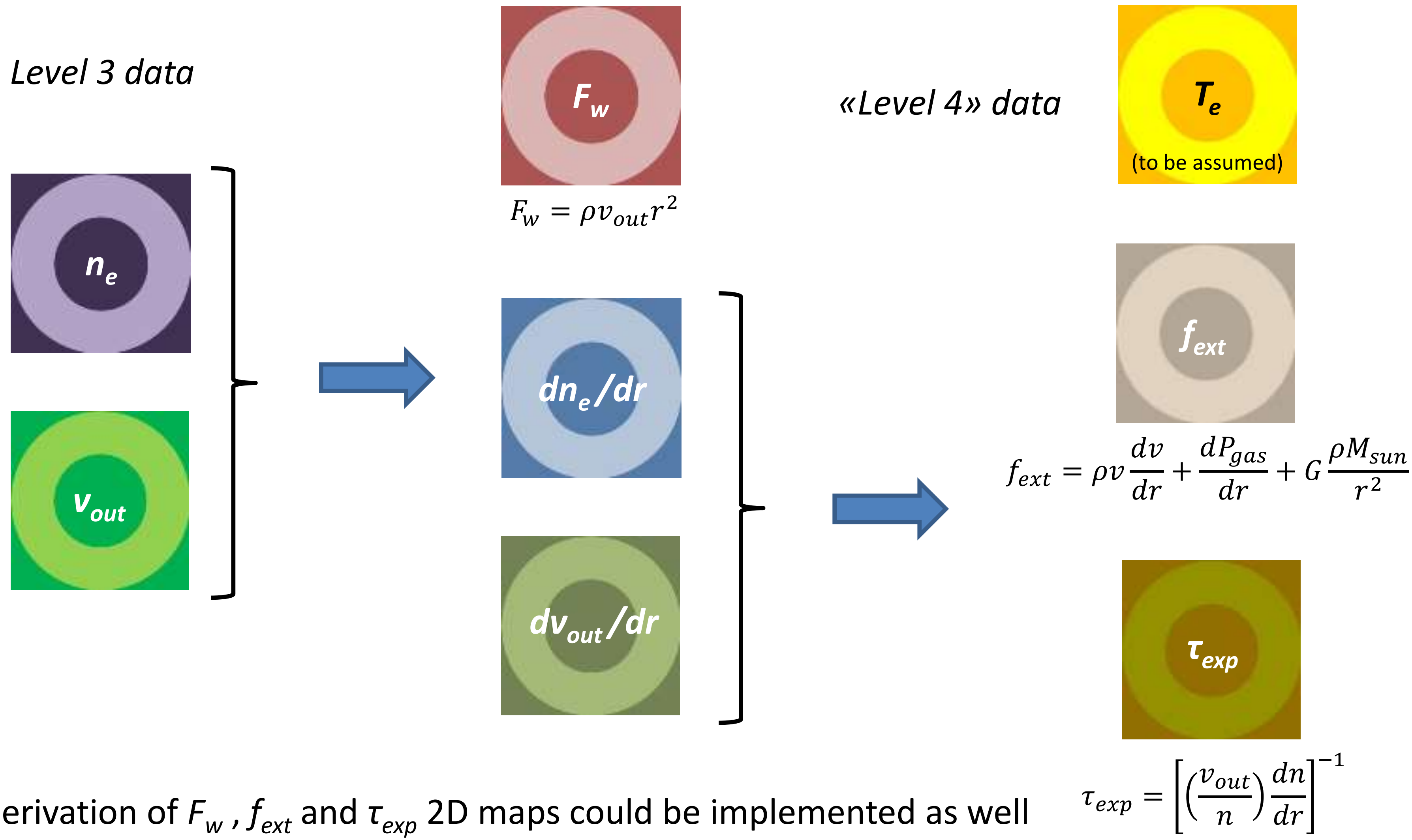
Metis quick data reduction: example





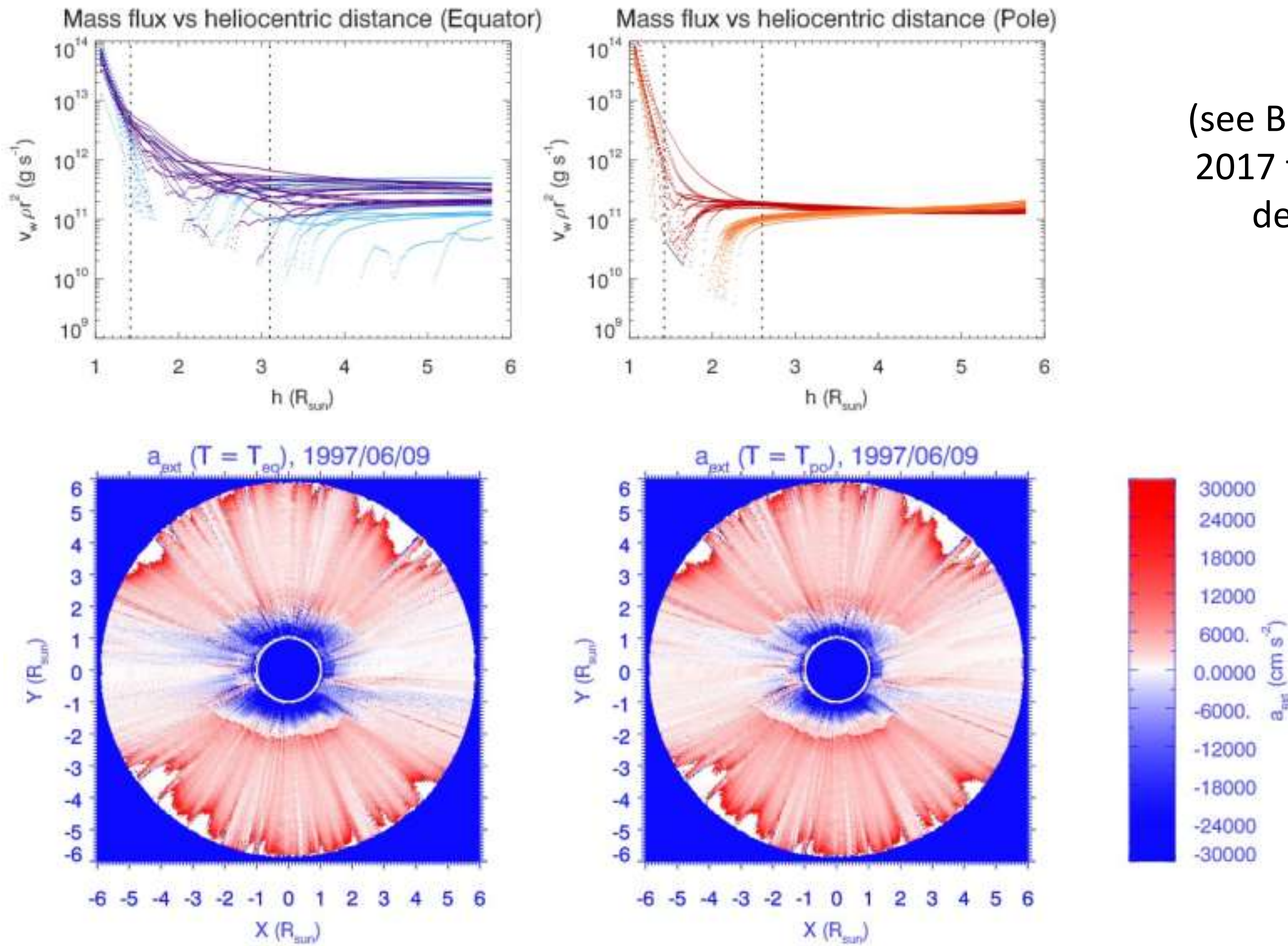
FUTURE PERSPECTIVES

Metis advanced data reduction: concept



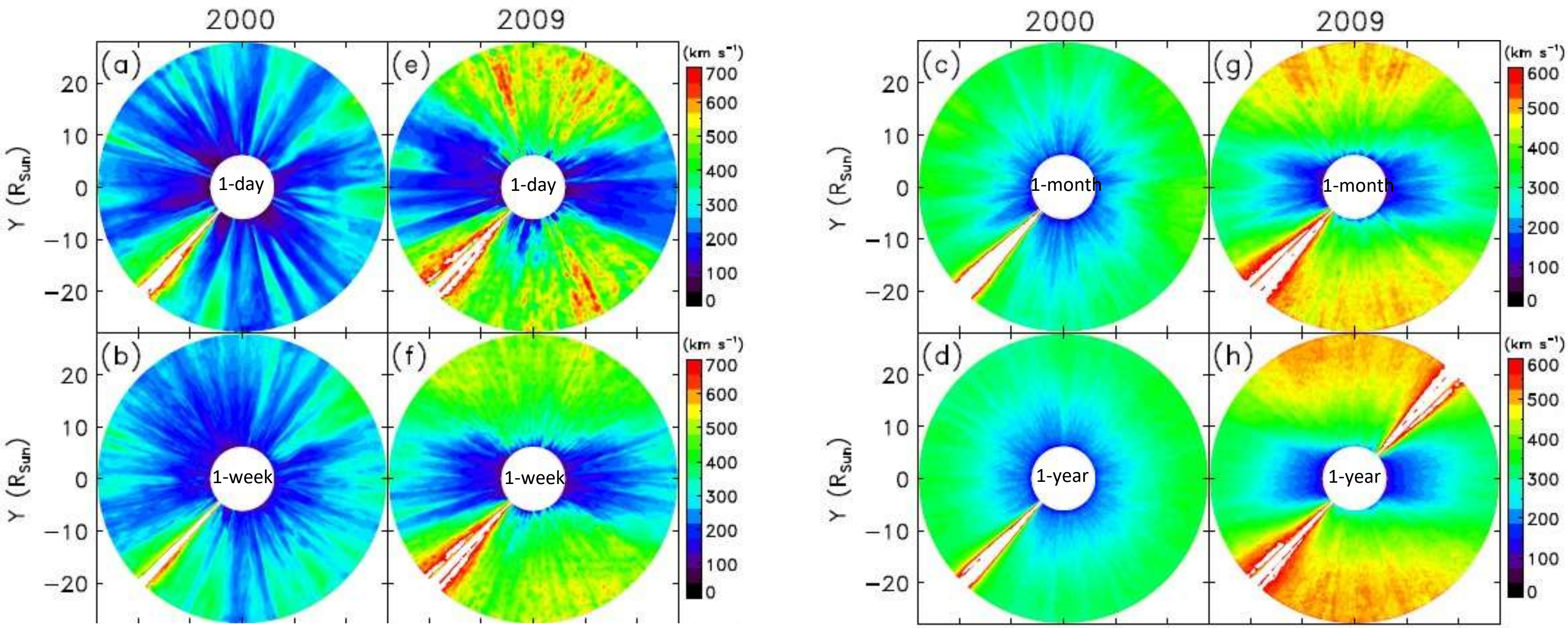
Derivation of F_w , f_{ext} and τ_{exp} 2D maps could be implemented as well with automatic routines running as soon as the data are available.

Metis advanced data reduction: example



(see Bemporad 2017 for more details)

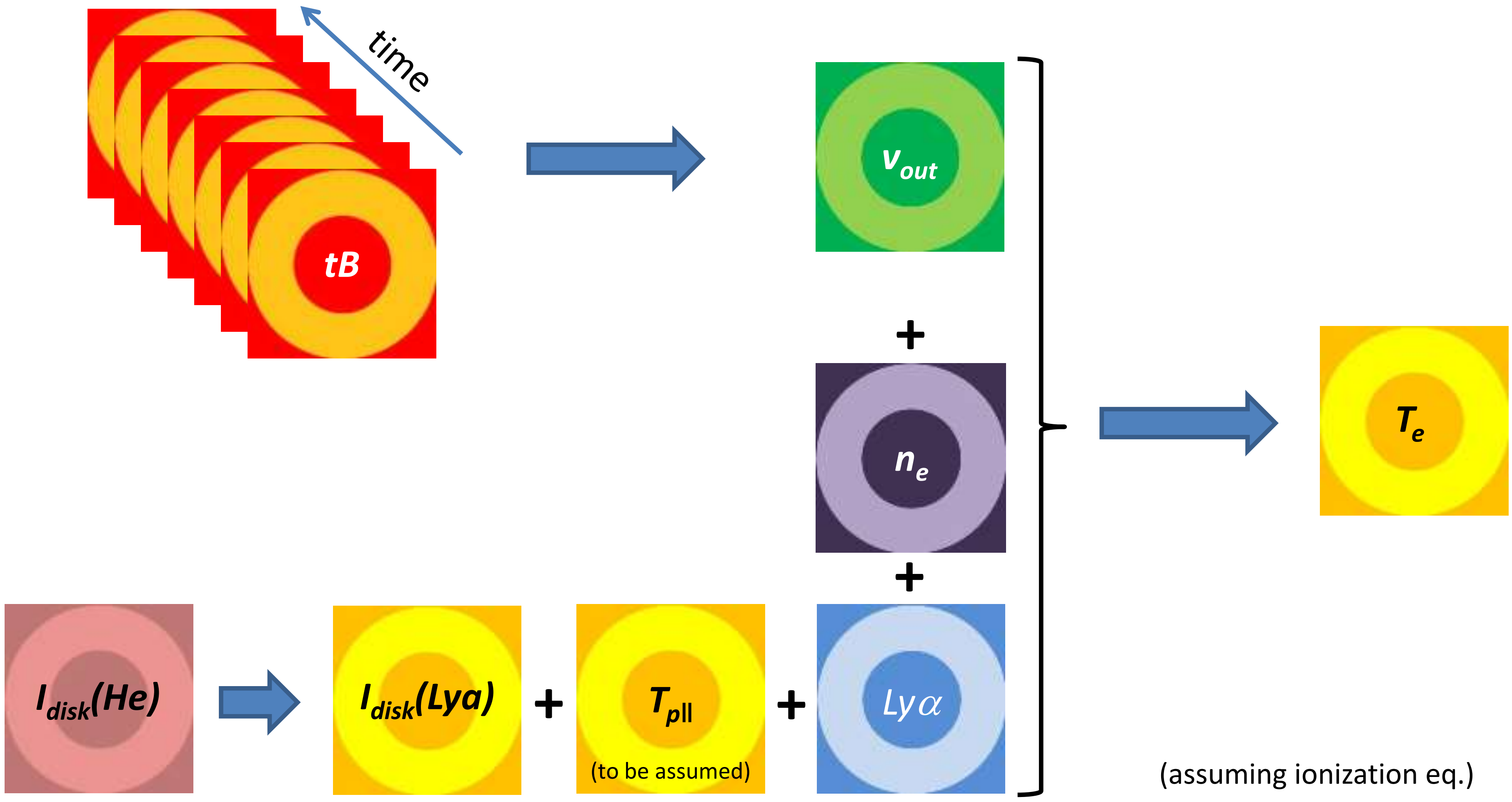
Future perspectives: measuring coronal temperatures with Metis data? (1/3)



Recently **Cho et al. (2018)** showed that 2D solar wind speeds can be measured from 6 to 26 solar radii by applying Fourier motion filters to SOHO/LASCO C3 image sequences observed from 1999 to 2010.

The method measures 2D solar wind speeds from 1-day to 1-year timescales and their variation in solar cycle 24.

Future perspectives: measuring coronal temperatures with Metis data? (2/3)



Future perspectives: measuring coronal temperatures with Metis data? (3/3)

For long time the «scale-heigth» temperatures have been inferred from densities in hydrostatic equilibrium hypothesis.

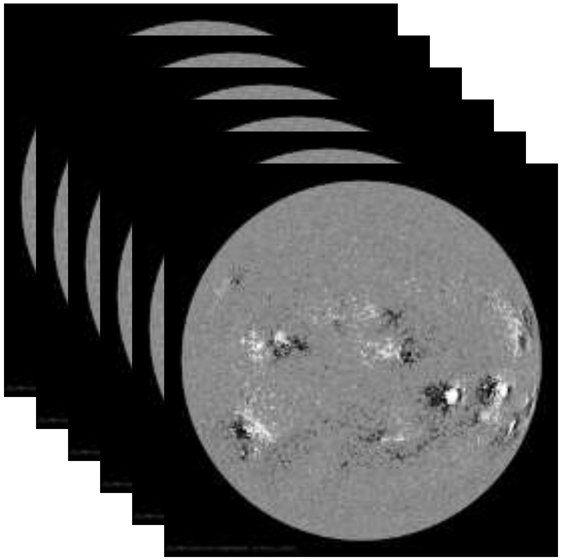
Recently **Lemaire & Stegen (2016)** showed that by starting with the (1-D single fluid) momentum equation, and by assuming mass flux conservation along flowtubes (≠ mag. fluxtubes) up to 1 AU with prescribed radial variation ***A(r)*** of the cross-sectional area (from Kopp & Holzer 1976), it is possible to derive from the observed radial density profile ***n(r)*** the radial velocity profile ***u(r)***, and this can be used to estimate (with numerical integration) the temperature profile ***T(r)*** as

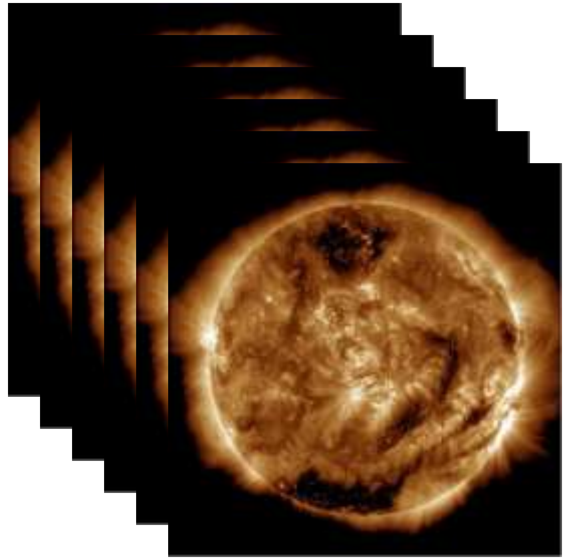
$$T(r)/T^* = -[1/n_e(r)] \int_\infty^r [n_e(r')/r'^2][1+F(r')]\mathrm{d}r'$$

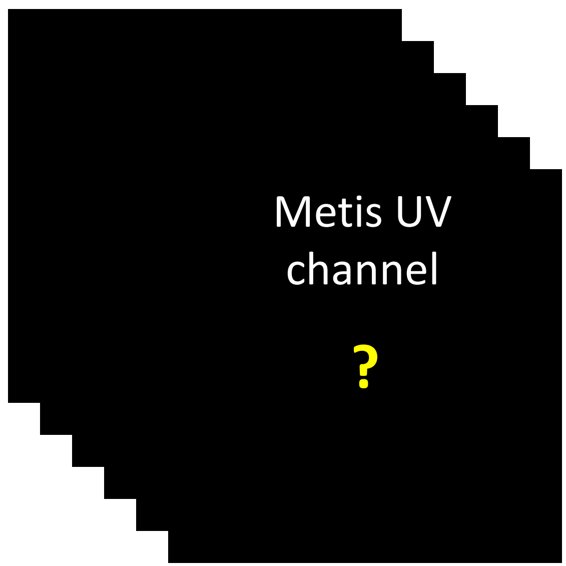
$$F(r) = r^2 u(\mathrm{d}u/\mathrm{d}r)/g_0 \mathrm{R}_\odot$$

$$T^* = \mathrm{GM}_\odot \mathrm{m_H} \mu / \mathrm{k R}_\odot$$

Future perspectives: testing Metis data tools







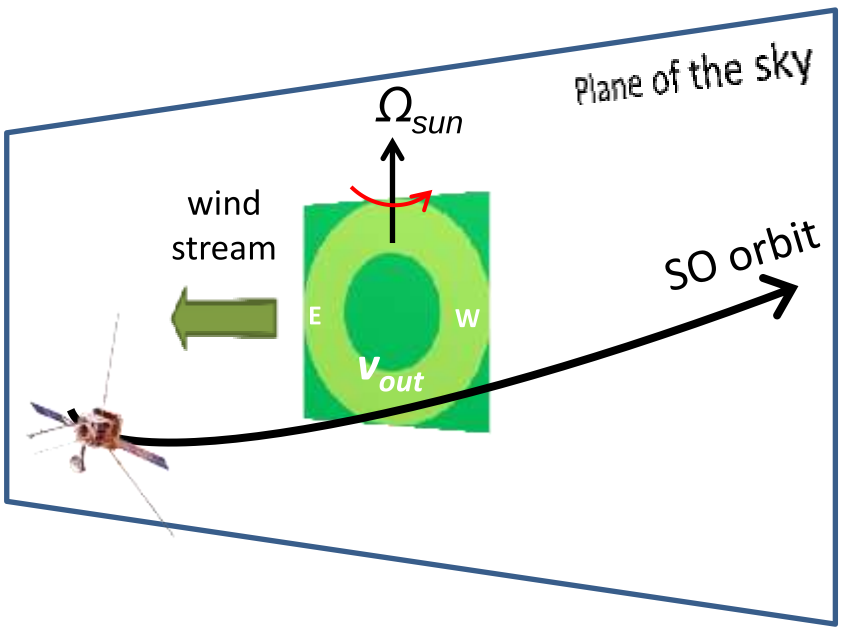
Lot of available data for magnetograms and EUV images → baseline for the development of data analysis tools → capability to test future tools for planning and science purposes.

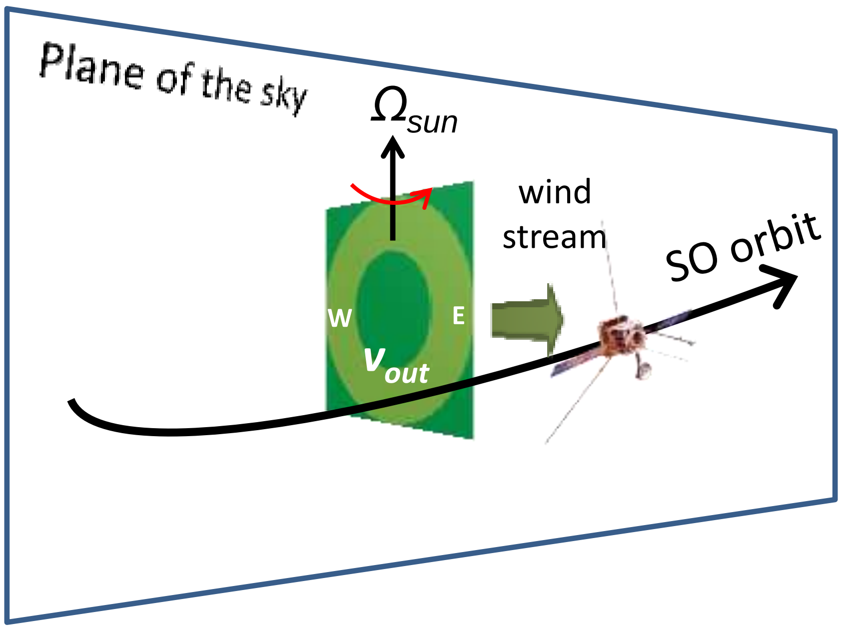
The same baseline of data exists only for Metis WL channel, while sparse observations (limited to UVCS field-of-view) are available for Metis UV Lyα channel.

The **FORWARD** package has been developed by HAO and distirbuted under SolarSoftware → capability to load numerical coronal models (e.g. PFSS, MAS, etc…) and simulate coronagraphic images.

The idea: use FORWARD to create a baseline of WL and UV coronagraphic images representative of different S/C distances and periods of solar activity cycle to test data analysis tools.

Combining SO remote sensing and in situ data



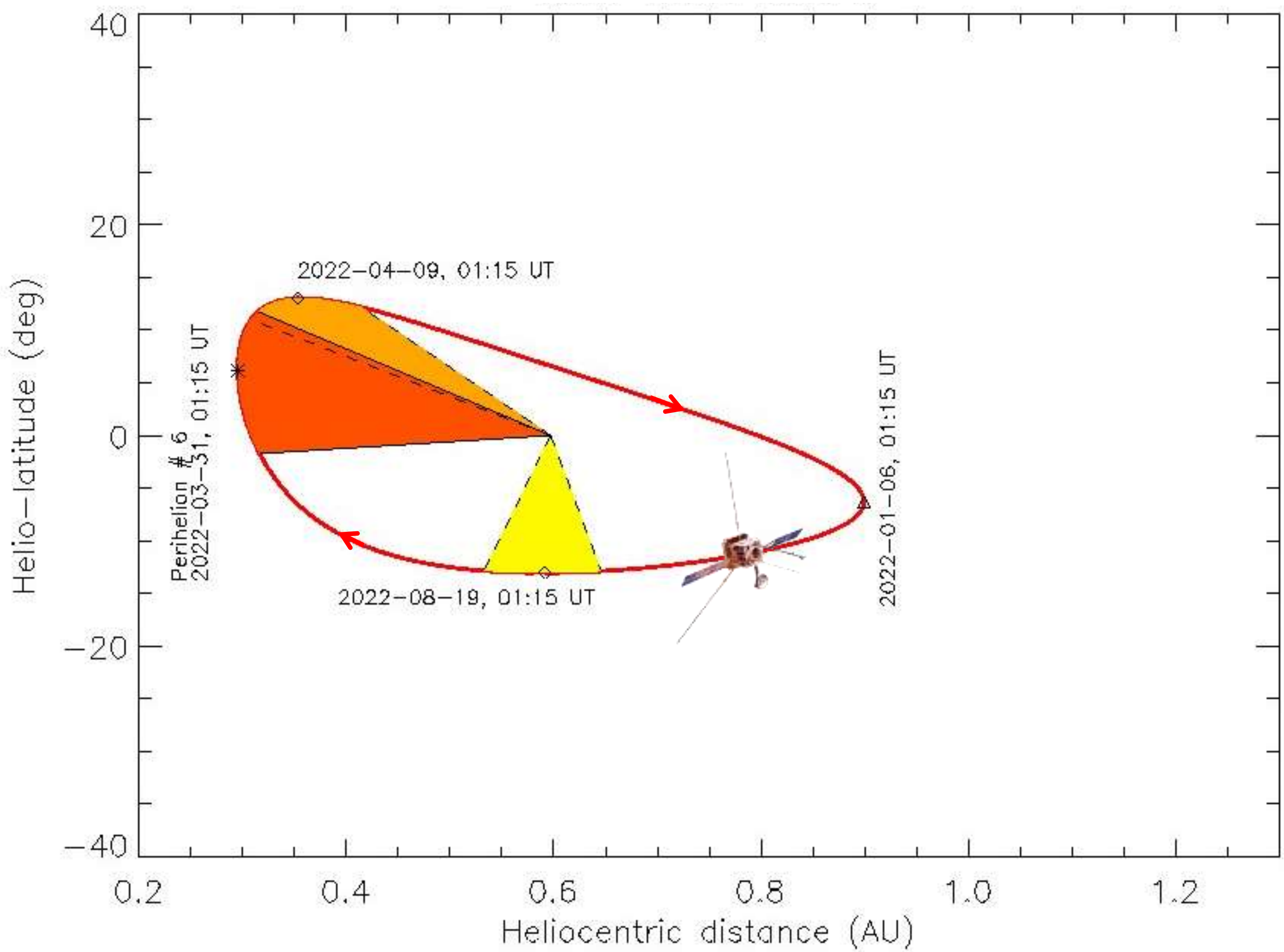


DAY 1: coronal streamers / holes sampled by Metis with remote sensing → slow / fast wind regions determination

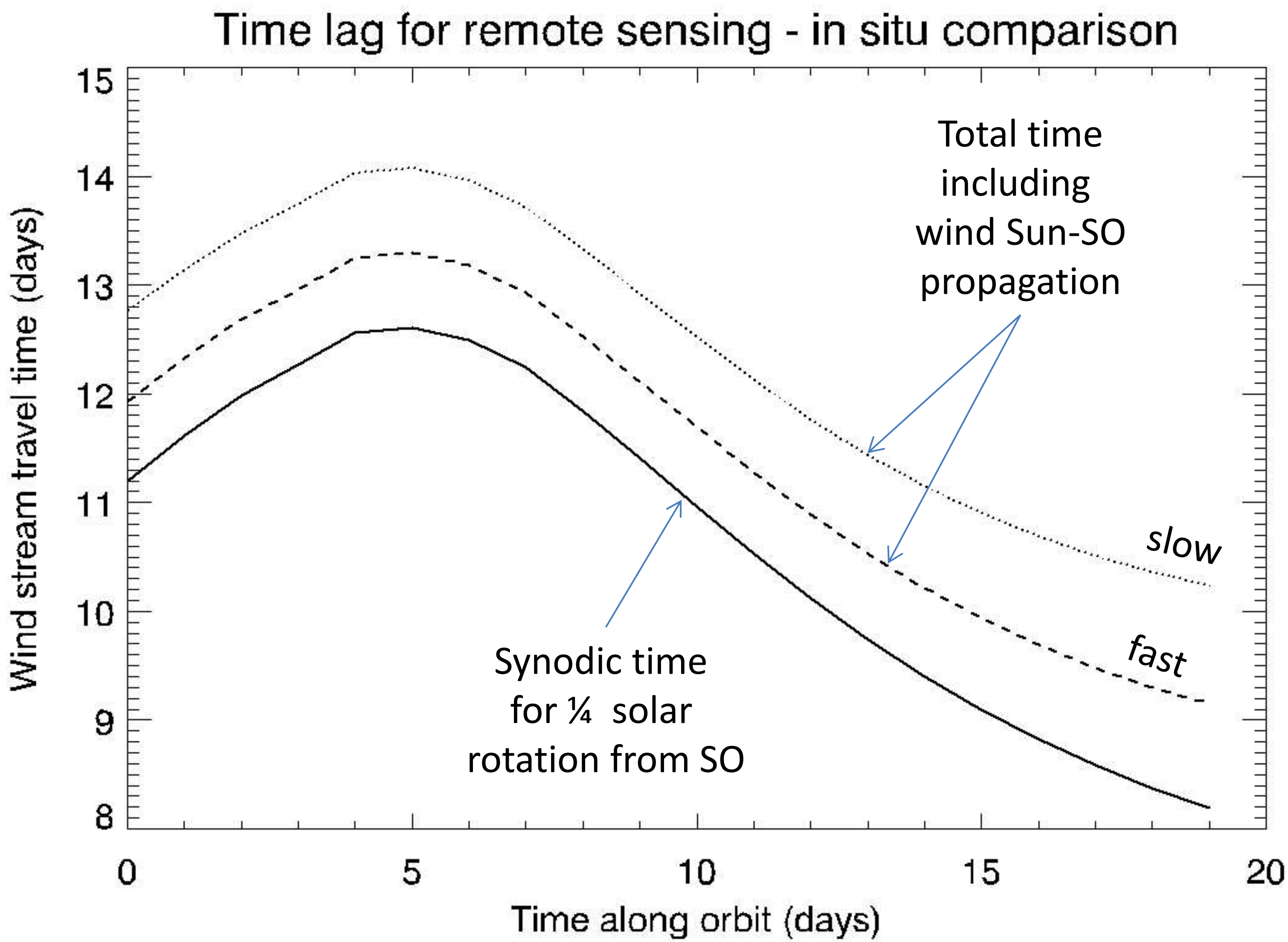
DAY 1 + Δt: assuming a stationary corona over time Δt the same wind stream are sampled by in situ instruments

Examples with a specific orbit

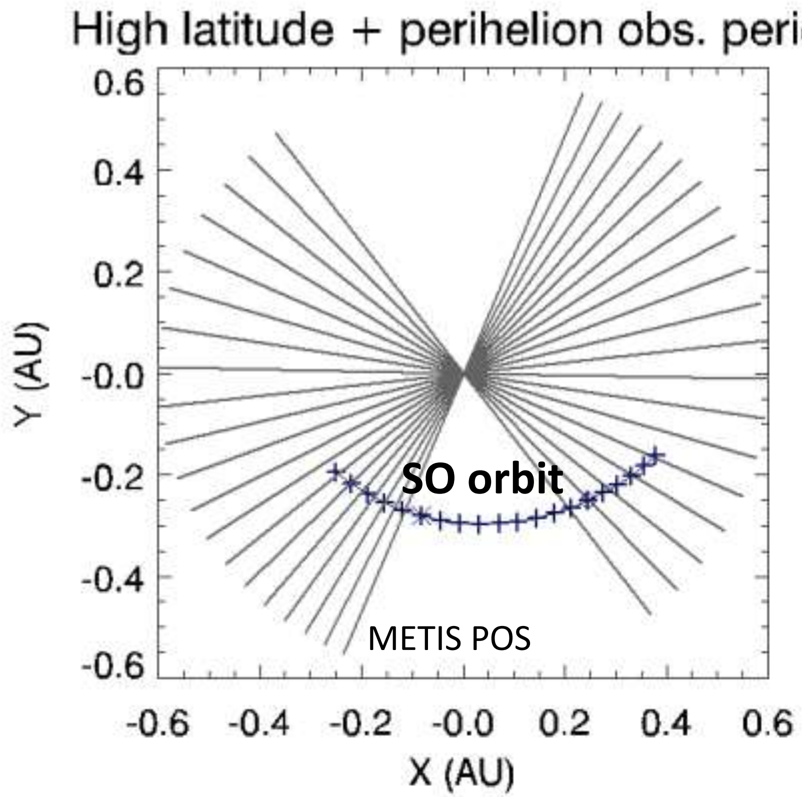
2nd SO orbit in the Nominal Mission phase

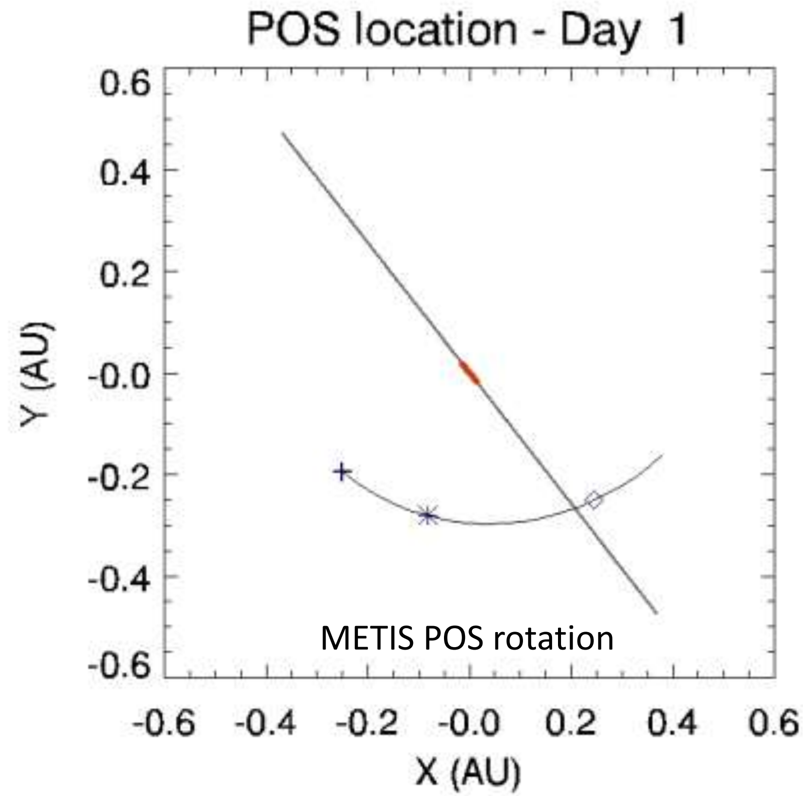


Wind stream: perihelion + high latitude intervals



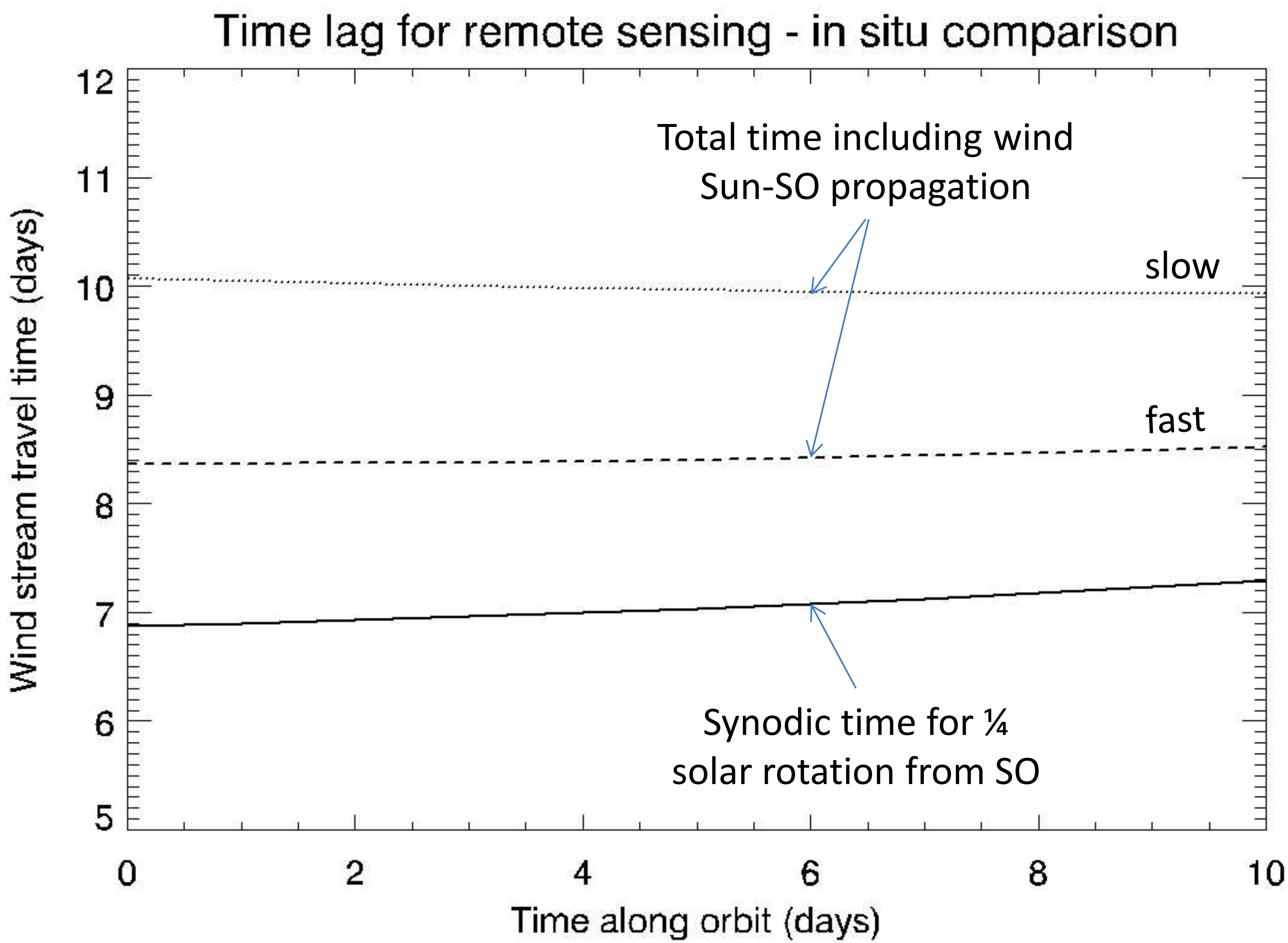
Wind stream: perihelion + high latitude intervals



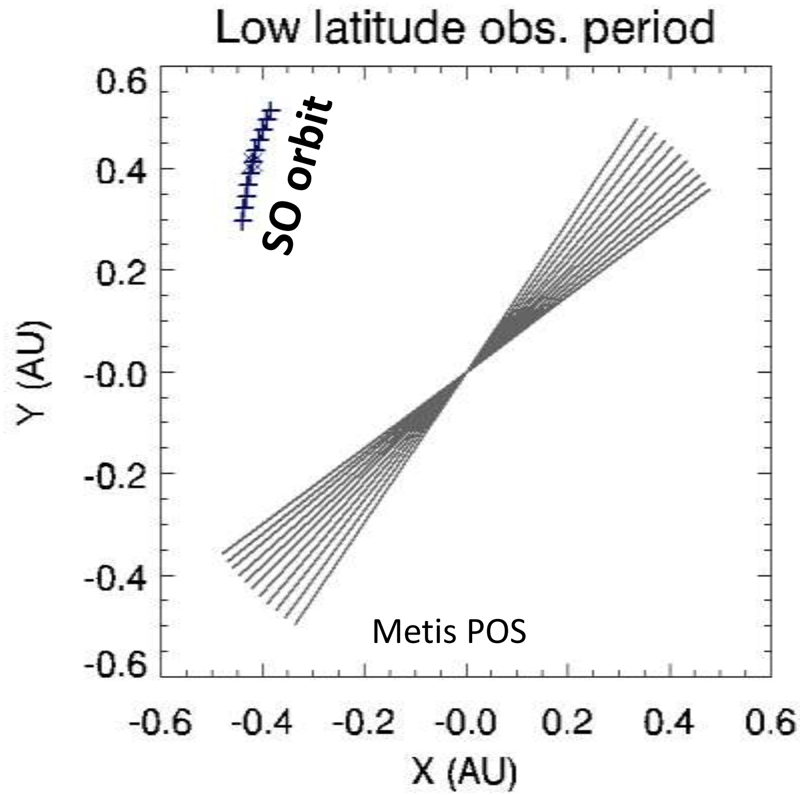


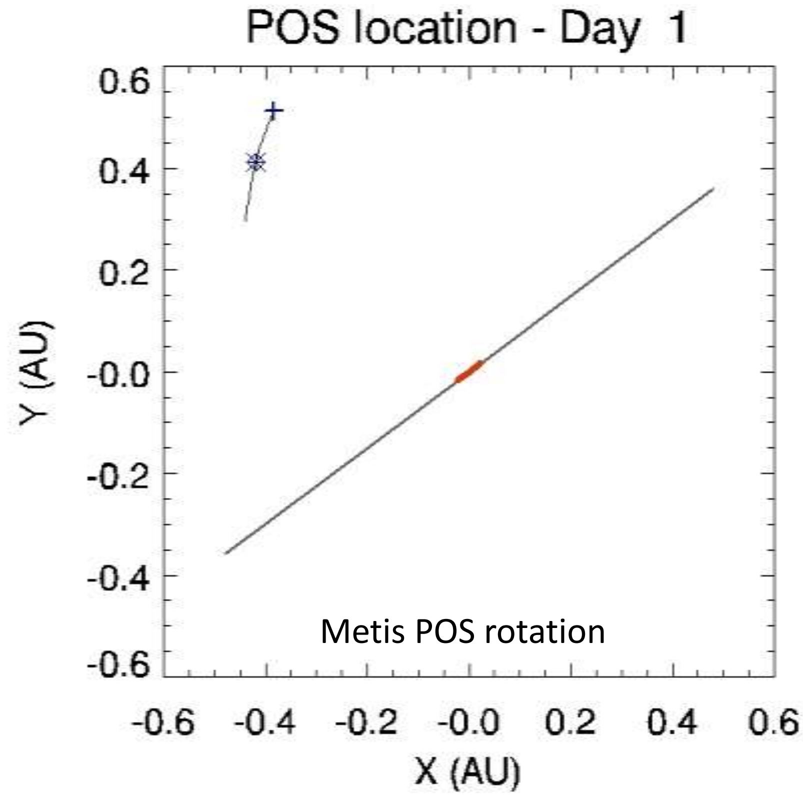
After about 13 days the in situ instruments will measure the same wind stream observed with remote sensing by Metis at the beginning of the remote sensing window.

Wind stream: low latitude interval



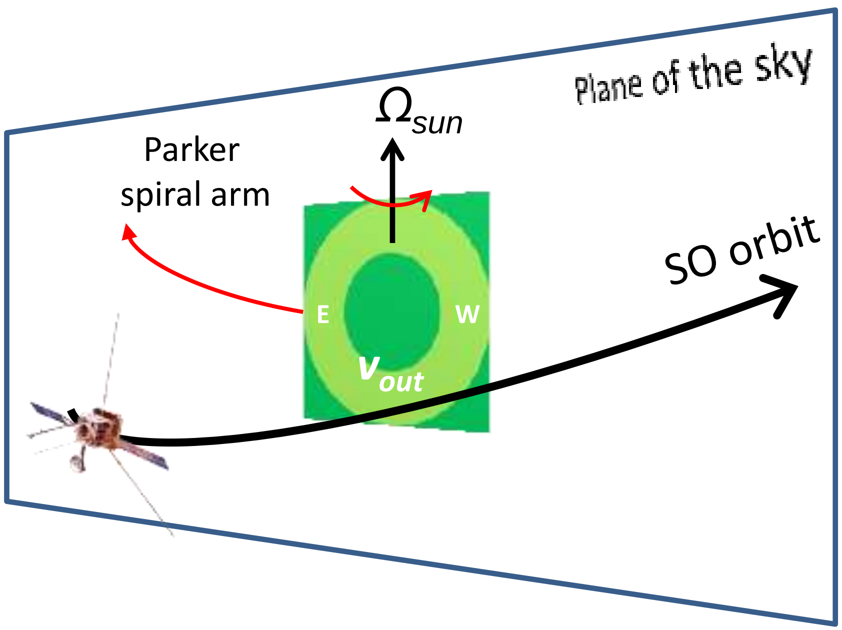
Wind stream: low latitude interval

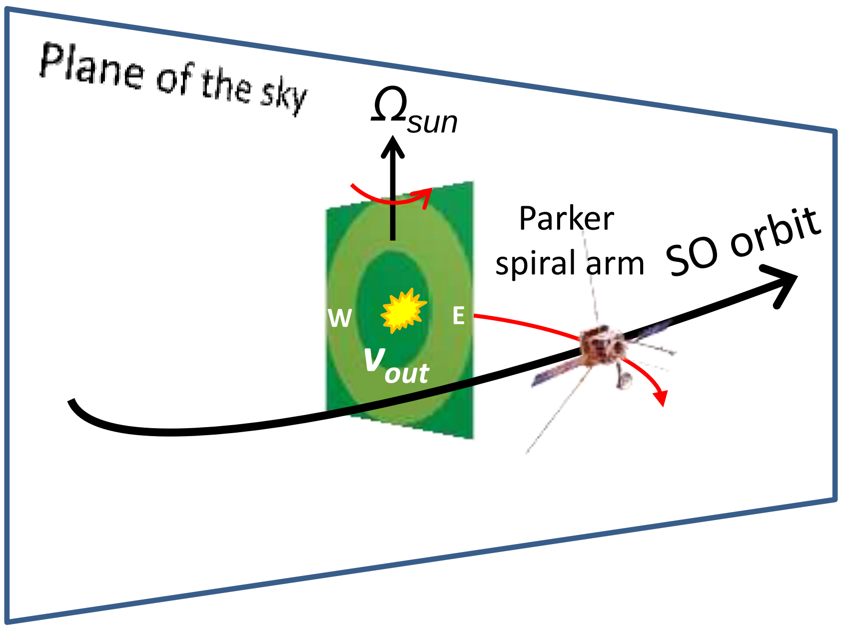




After about 9 days the in situ instruments will measure the same wind stream observed with remote sensing by Metis at the beginning of the remote sensing window.

Combining SO remote sensing and in situ data

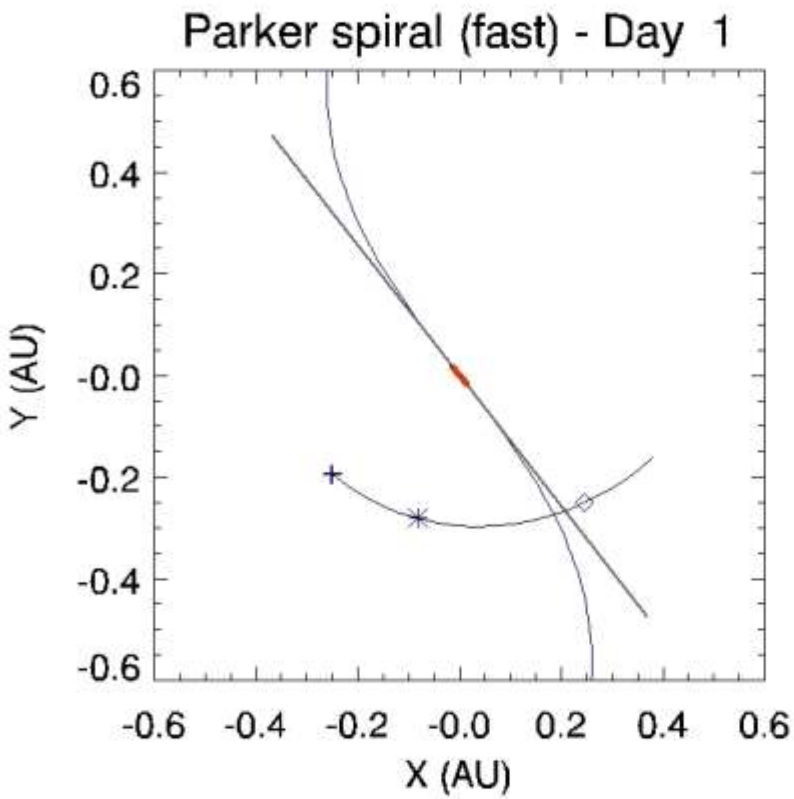


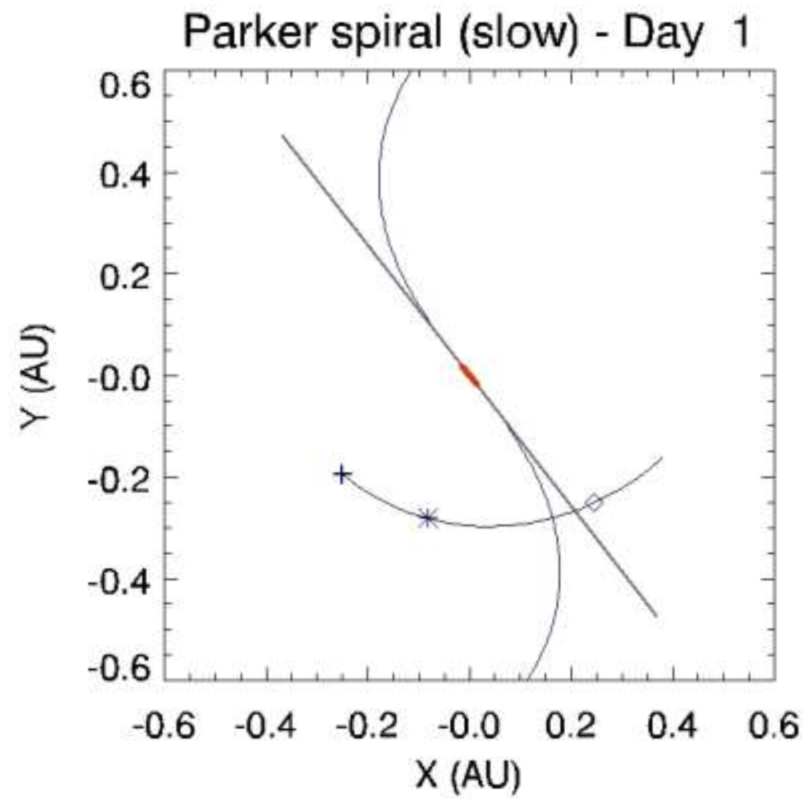


DAY 1: coronal streamers / holes sampled by Metis with remote sensing → determination of the inclination of different Parker spiral arms

DAY 1 + Δt: assuming a stationary corona over time Δt the same Parker spiral arm will cross SP → if a flare/CME occurs the path followed by SEP will be constrained

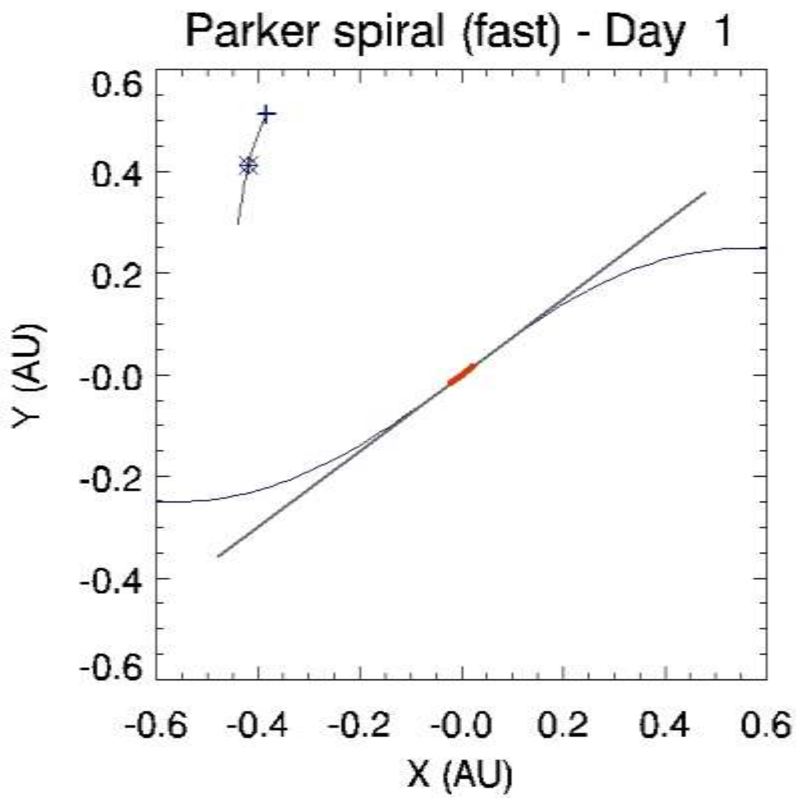
Parker spiral: perihelion + high latitude intervals

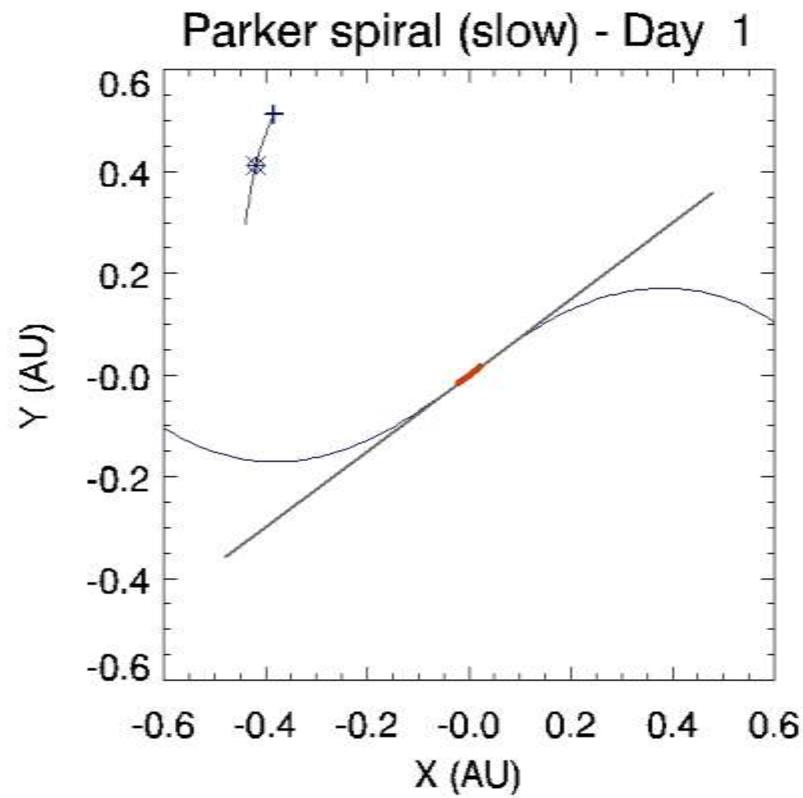




After about 13 days the in situ instruments will connected via the Parker spiral with the same solar limb observed with remote sensing by Metis at the beginning of the period

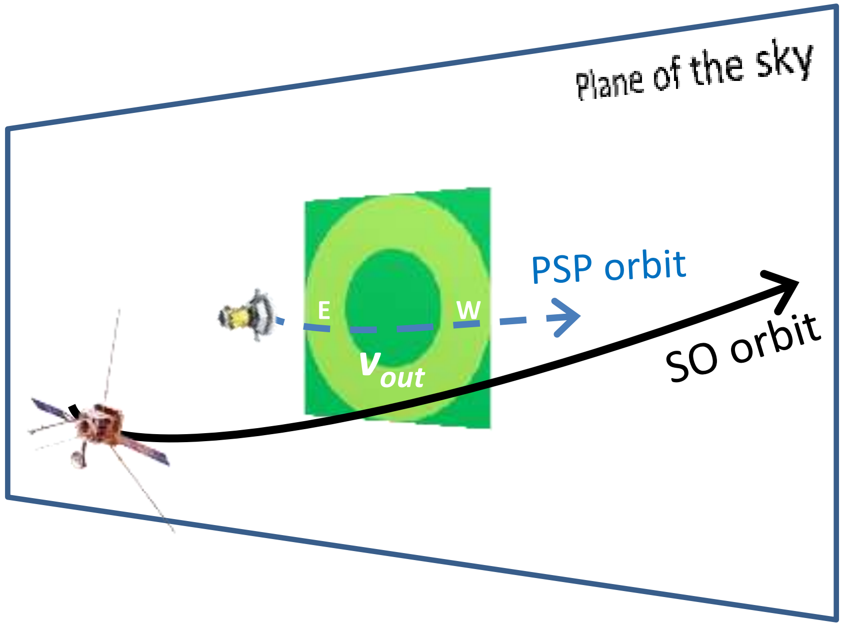
Parker spiral: low latitude interval





After about 9 days the in situ instruments will connected via the Parker spiral with the same solar limb observed with remote sensing by Metis at the beginning of the period

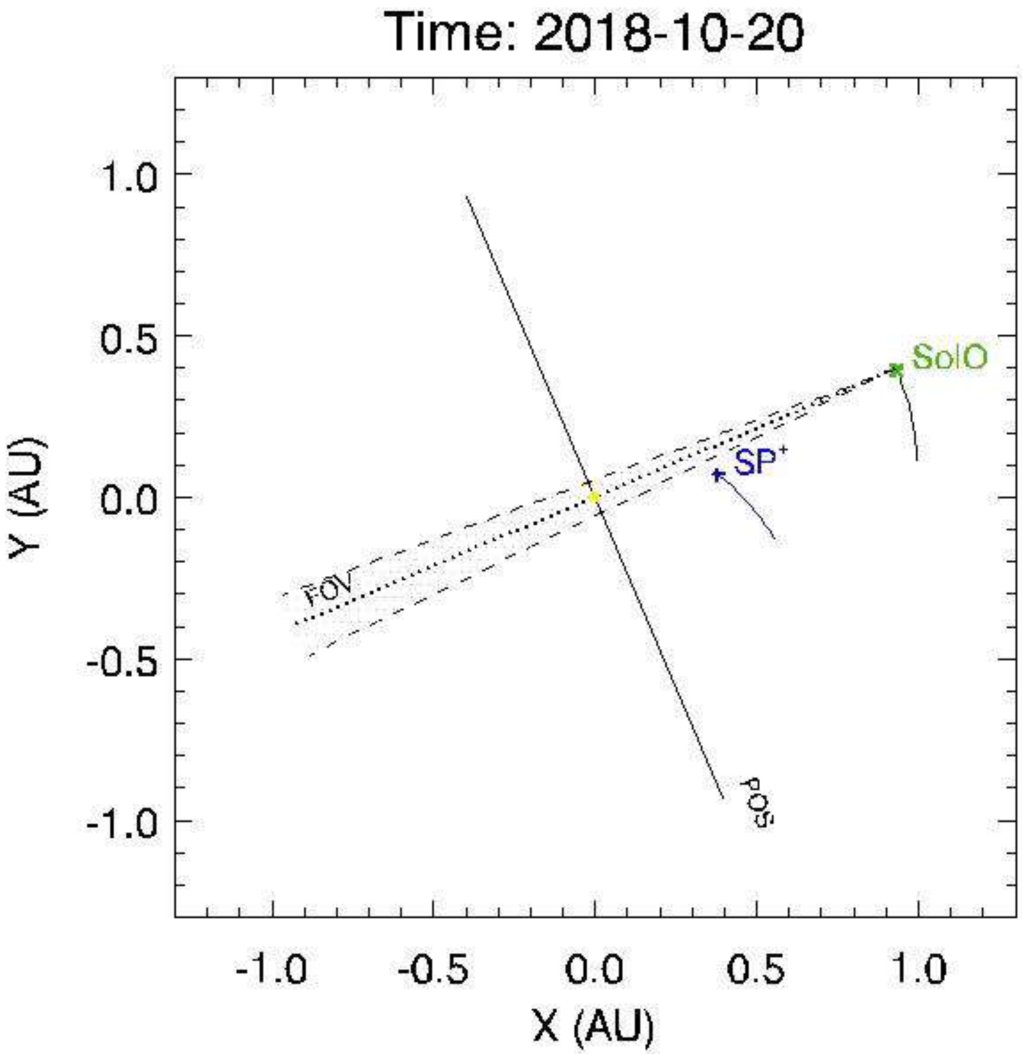
Combining SO remote sensing and PSP in situ data

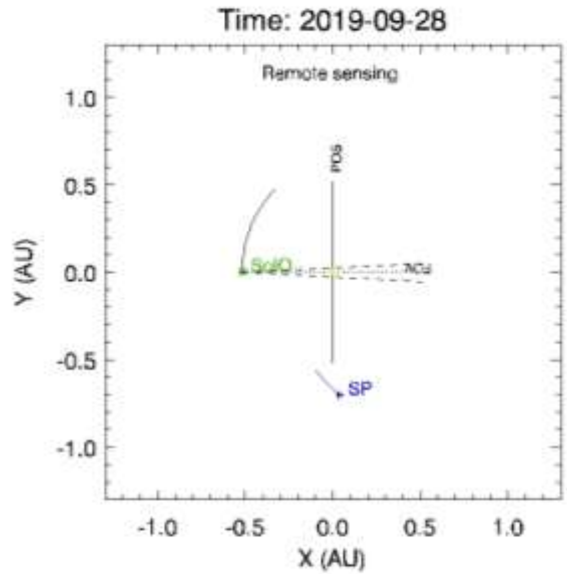


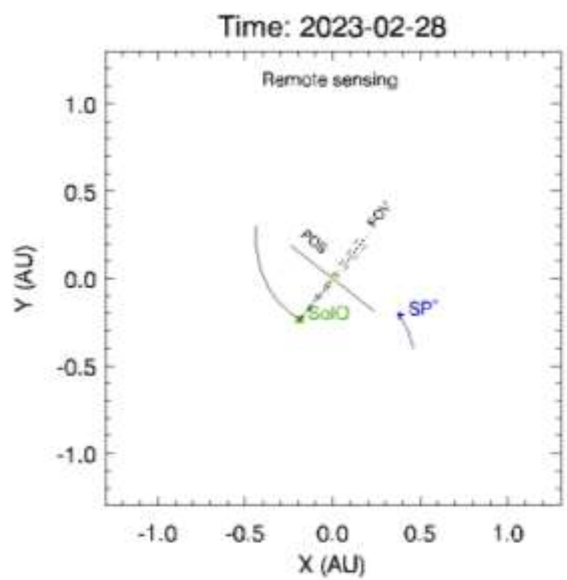
Many different possible configurations:

- Quadratures → study of the same wind stream and solar eruptions with SO remote sensing and PSP in situ & remote sensing instruments
- alignements along the same radial → study of the same wind stream and solar eruptions with SO and PSP in situ instruments
- alignements along the same Parker-spiral arm → study of the same SEPs with SO and PSP in situ instruments

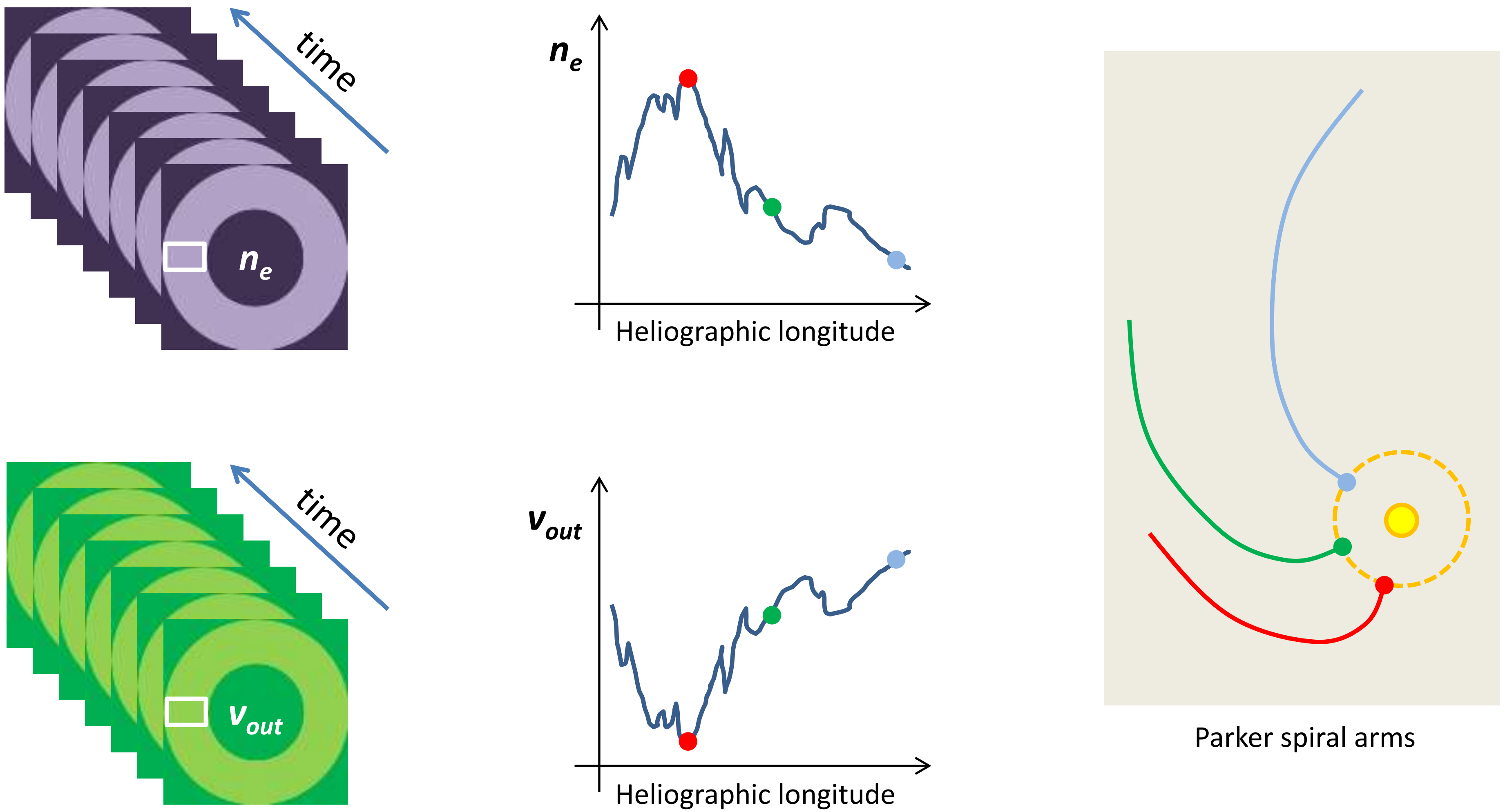
Example: SO and PSP quadratures



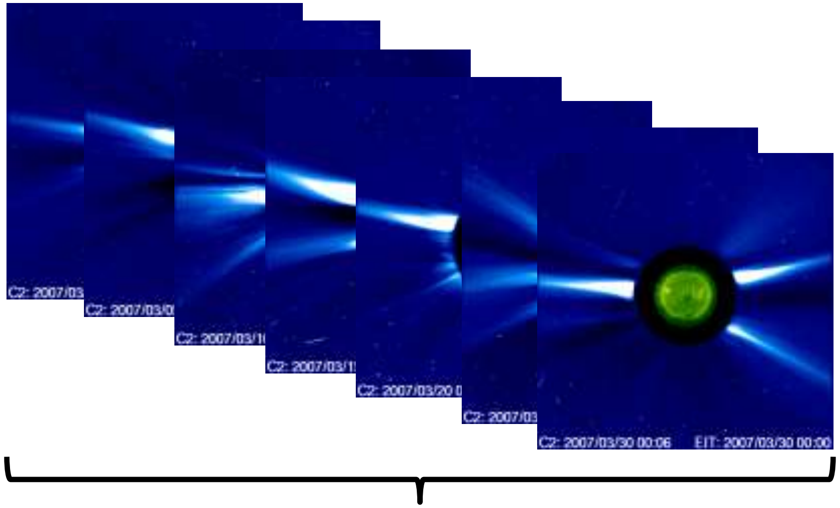




Retrieving the Parker spiral with Metis data: concept



Retrieving the Parker spiral with Metis data: example



Analyzed data: one full Carrington rotation (~ 27.3 days) of LASCO/C2 images (March 2007) → about 1500 total Brightness images (*in collaboration with L. Zangrilli*)

Wind speed profiles inside single fluxtubes: derived with solution of Parker equation

Wind density profiles inside single fluxtubes: given by mass flux conservation

$$n(r)v(r)r^2 = n(R_0)v(R_0)R_0^2$$

$$R_0 = 6R_{sun}$$

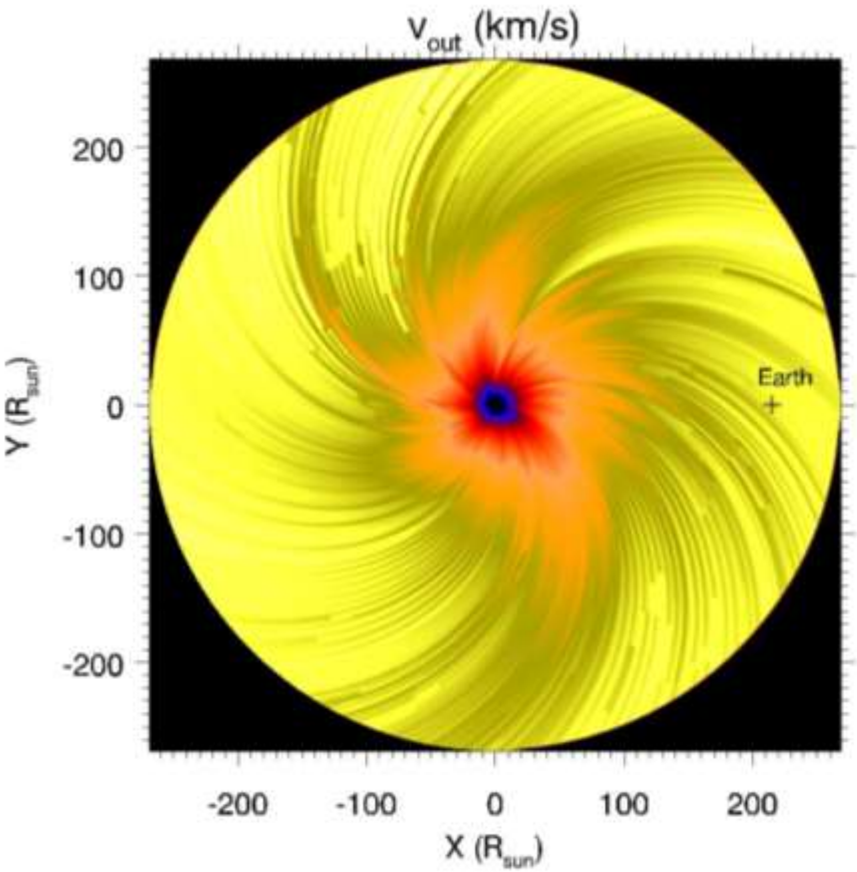
Electron density on the ecliptic plane at 6 R_{sun}

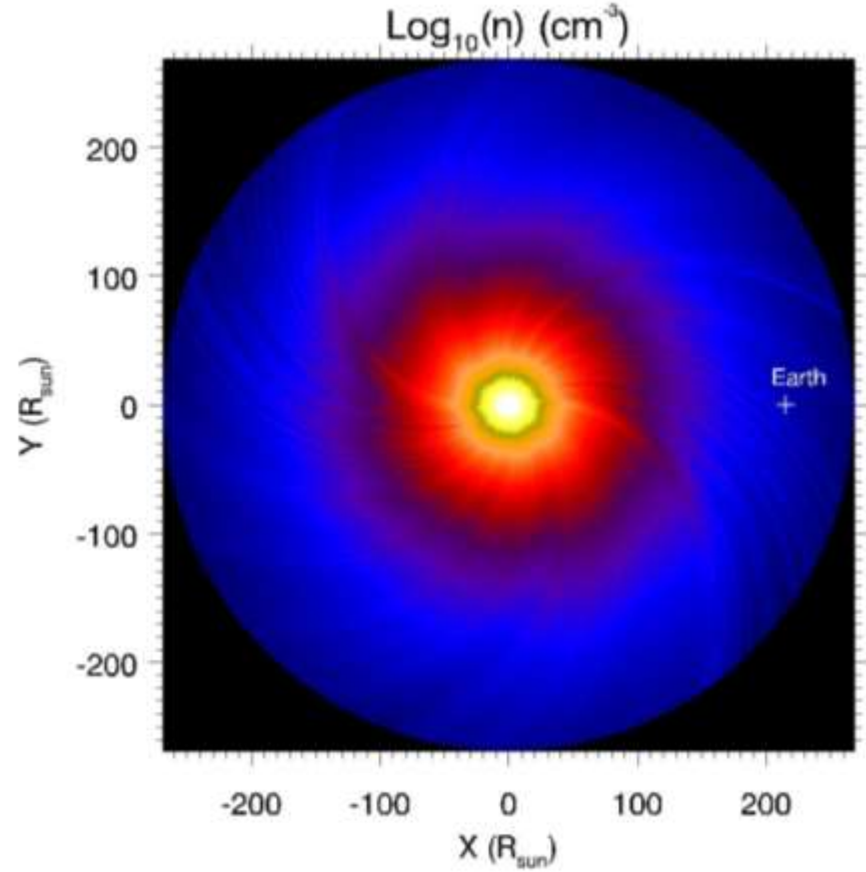
- one full Carrington rotation of LASCO/C2 total Brightness images are downloaded and calibrated;
- a model for F-corona brightness is removed from each image
- coronal electron density around the ecliptic plane is derived

Outflow speed on the ecliptic plane at 6 R_{sun}

- by applying an empirical relationship between n_e and v_{out} (~ anti-correlated, see Bemporad 2017)

Retrieving the Parker spiral with Metis data: example





Results: first 2D maps of Parker spiral wind speed (left) and plasma density (right) from the analysis of coronagraphic (LASCO/C2) data.

Similar methods could be applied starting from sequences of density and speed images provided with analysis of Metis data.

SUMMARY

- Work has been performed by people in Metis Team to show how the instrument could provide possible constraints for tools that are under development for planning under MADAWG.
- Quick Metis data inversion will allow to derive **2D maps** of **coronal density** and **outflow velocity** on the actual plane of the sky (POS) → **Level 3 data**
- Further analysis will allow also to quantify other important properties of solar wind (mass flux, coronal expansion time, solar wind «external force», etc…) → **«Level 4» data**
- A **baseline of Metis WL+UV channel images** could be provided by using FORWARD package to test future data analysis tools.
- Solar rotation + stationary state of corona → SO will cross the same wind streams and Parker spiral arms observed on the POS ~ 9-13 days before → **link between Metis remote sensing and SO in situ data**
- SO – PSP quadratures → PSP spacecraft will cross the same POS sampled at the same time by Metis → **link between METIS remote sensing and PSP in situ & remote sensing data**
- PSP will cross Parker spiral arms formed by wind streams sampled by Metis → **get information on PSP magnetic connectivity with the Sun**
- **Analysis of Metis data can provide unique information on the orientation of Parker spiral thus helping to understang connections between remote sending and in situ observations.**