Joint investigation of coronal mass ejections with Metis observations, numerical simulations and in situ spacecraft data

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Outline

A new research project, entitled "Heliospheric shocks and space weather: from multispacecraft observations to numerical modeling", has been funded by the Italian MUR

a) Objectives of the research project

b) Sample events under study (preliminary stage):

   1. CME of 5 September 2022

   2. CME of 4 November 2023

First objective, to determine physical properties of shocks and CME from remote observations

To use data from EUV imagers (SDO/AIA, PROBA2/SWAP, STEREO/SECCHI-EUVI, SOLAR ORBITER/EUI), white light (WL) and UV coronagraphs (SOHO/LASCO, STEREO/SECCHI/COR1-2, Solar Orbiter/Metis), and radio spectra and/or radio heliographs to study the origin and the early evolution of interplanetary shocks

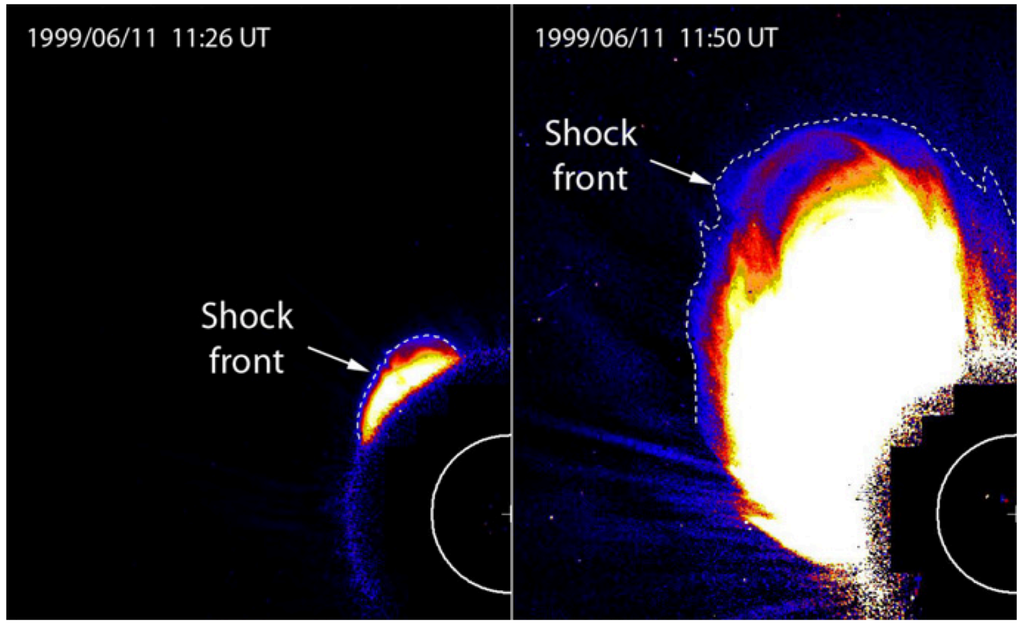
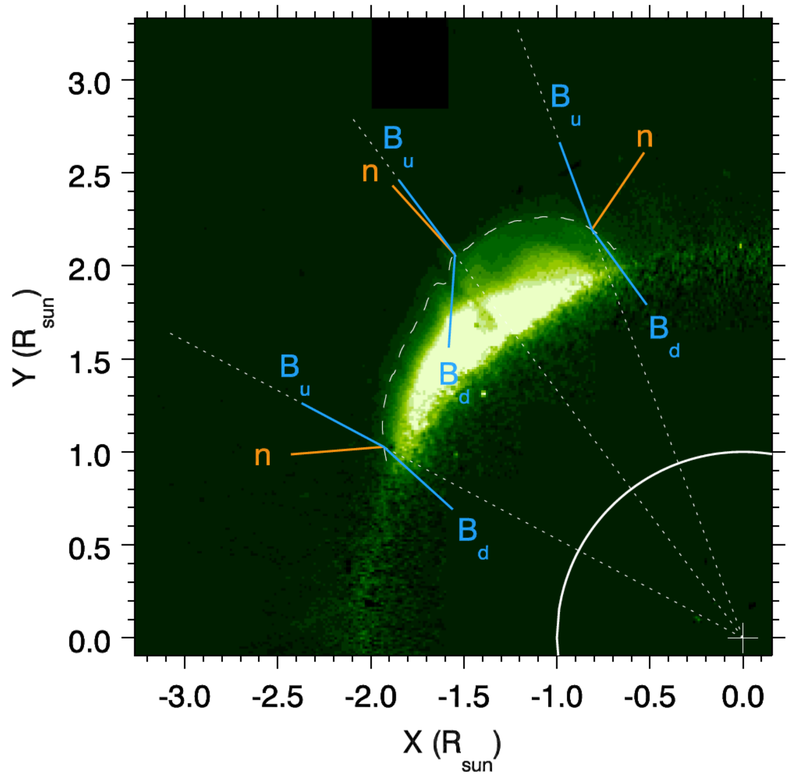


Figure 1. Base difference LASCO/C2 images showing the location of the CME-driven shock front (dashed lines) at 11:26 UT (left) and 11:50 UT (right).

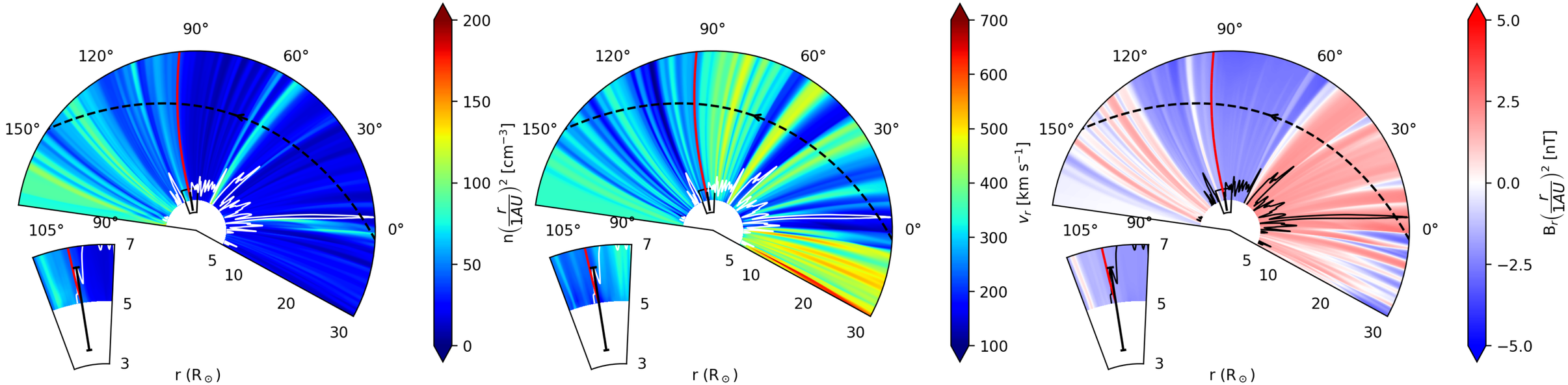
Bemporad and Mancuso, ApJL (2011)



Bemporad et al., ApJ (2014)

Second objective, to trace the generation and evolution of the CME-driven shocks and particle acceleration from the source to the interplanetary space, for multi-spacecraft detection and with the support PLUTO simulations

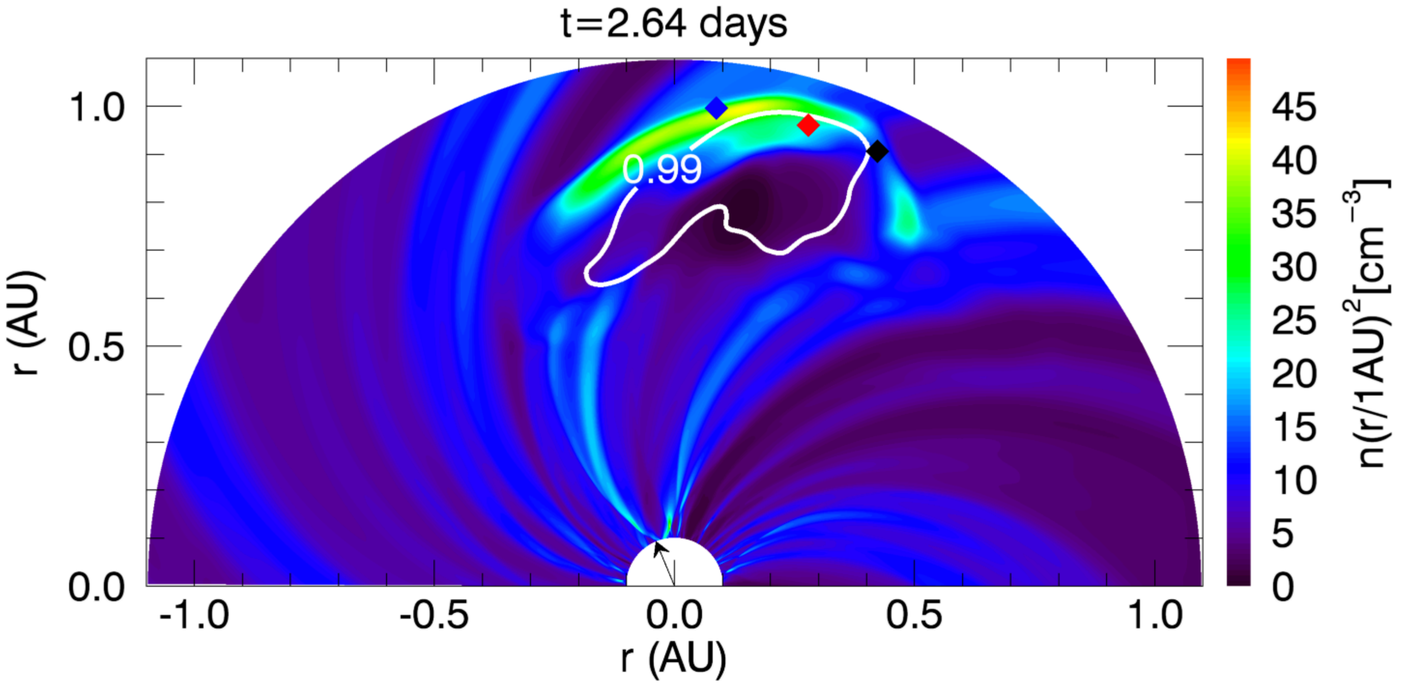
In particular, the recent RIMAP, Reverse In situ data and MHD Approach, will be used. RIMAP is a new way to reconstruct the Parker spiral from MHD modelling. The model uses in situ measurements at 1 AU as input to reconstruct the density structure of the Parker spiral

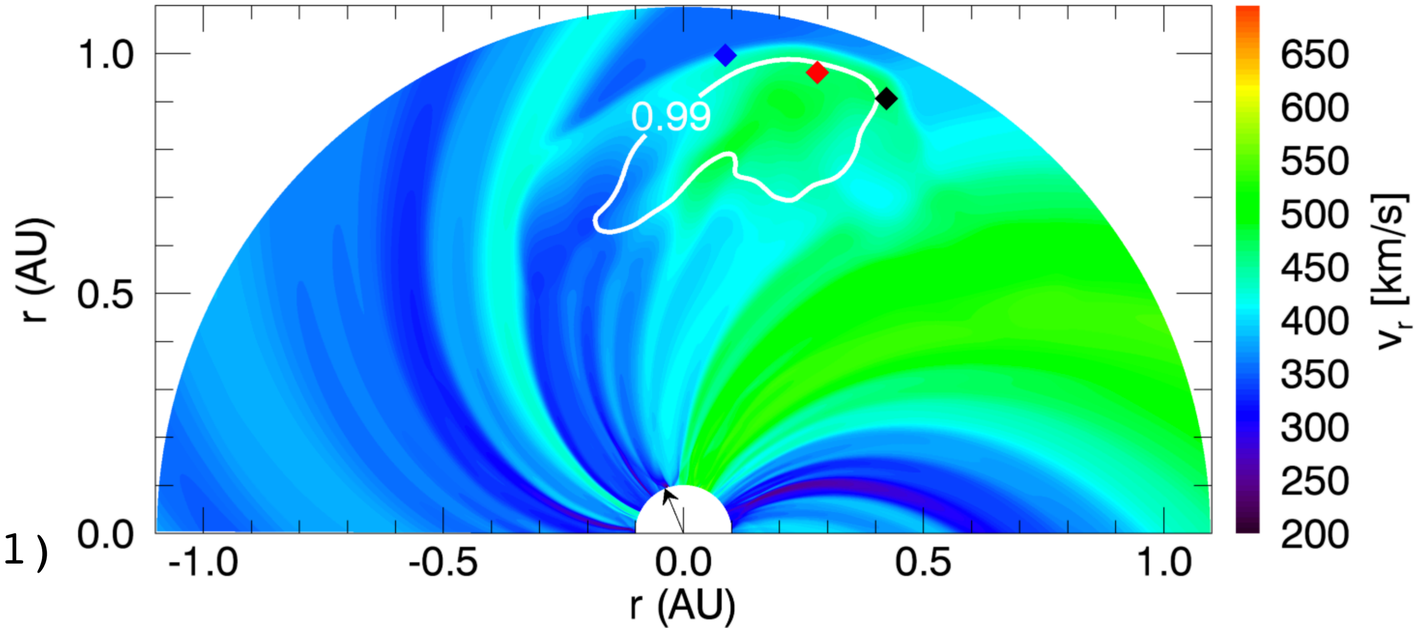


(Biondo et al., A&A, 2022)

Sample numerical simulation of a CME evolution

The structure of the ICME is influenced by the pre-existing density and magnetic field structures

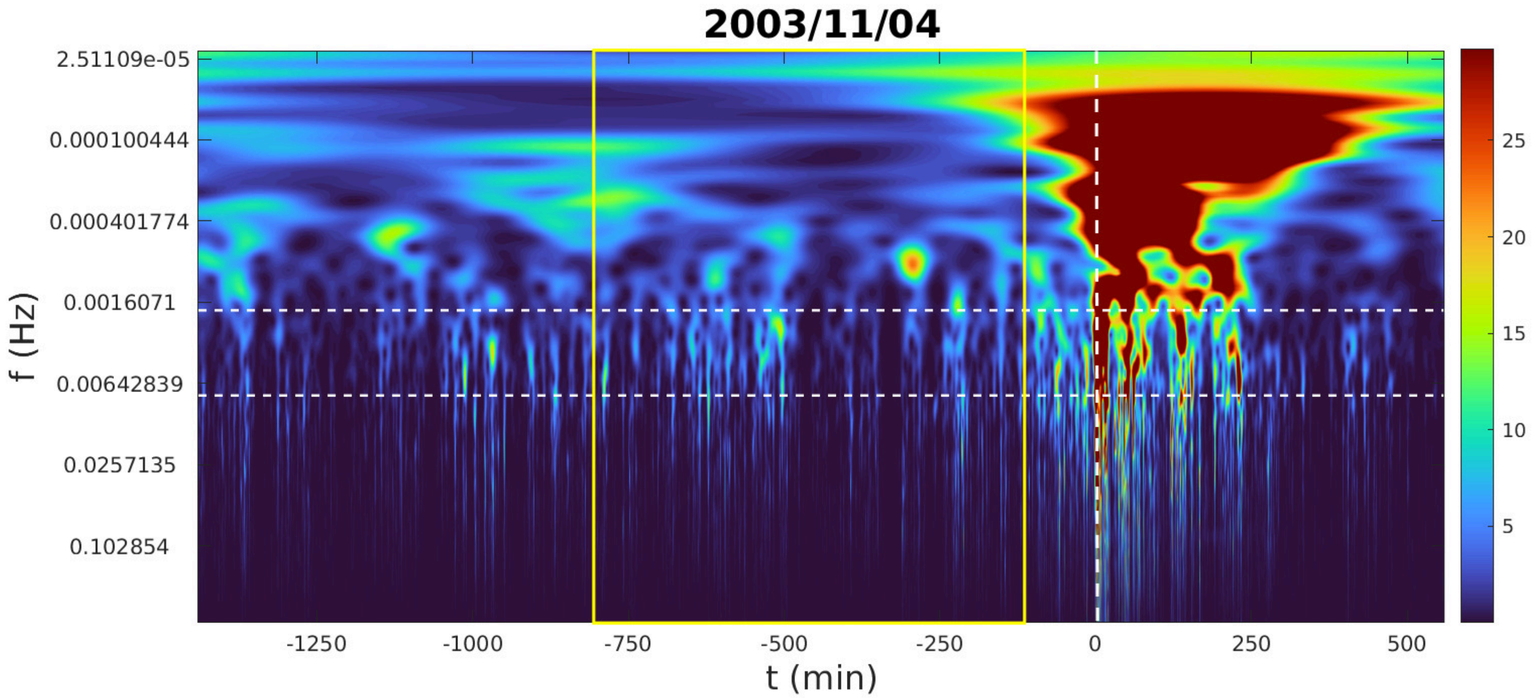


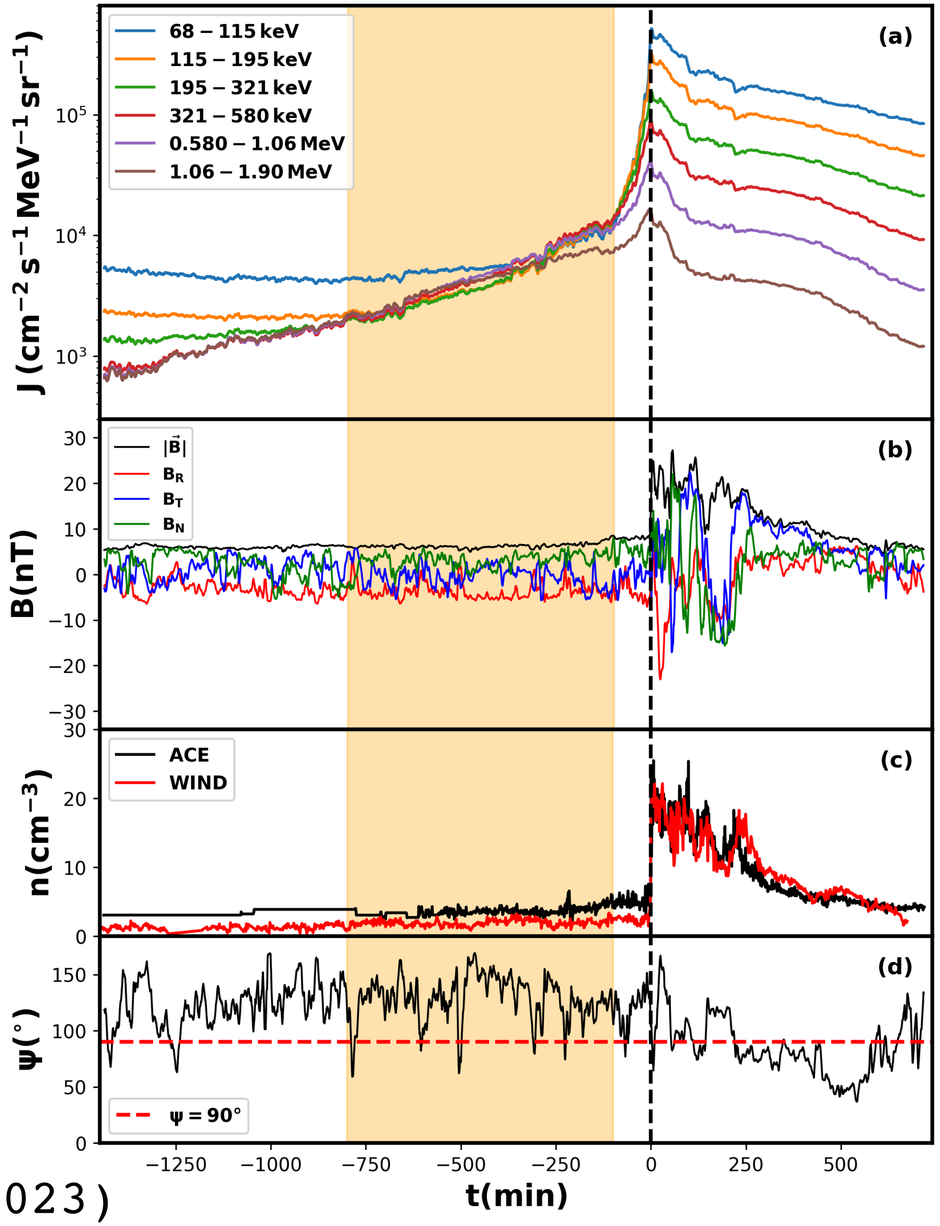


(Biondo et al., A&A, 2021)

Third objective, shock evolution in the interplanetary medium and particle acceleration

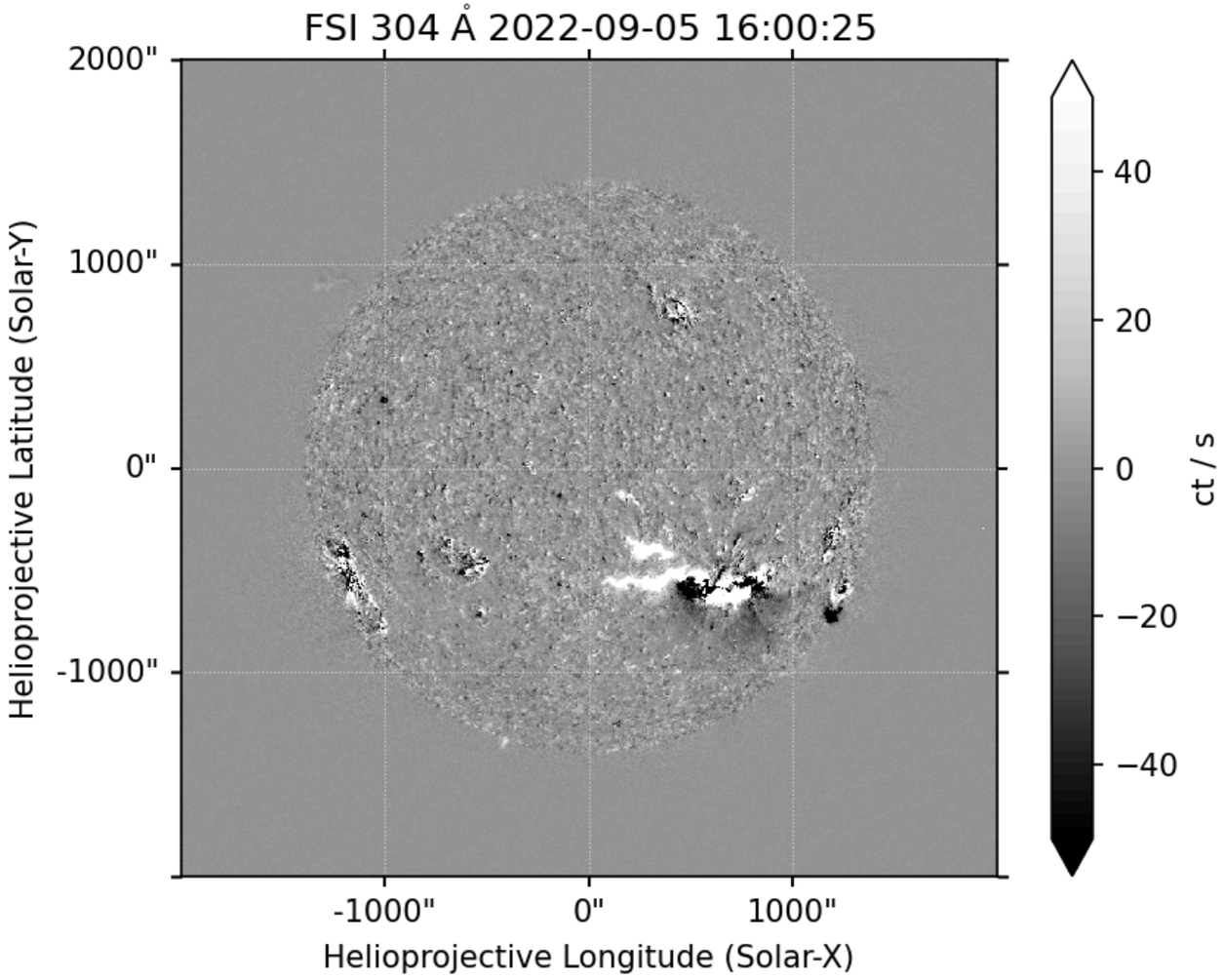
We aim at investigating the evolution of shocks observed both in corona and in the interplanetary medium, also in order to understand their role in accelerating particles to supra-thermal energies. This is going to be accomplished by analysis of in-situ data, too, for the determination of energetic particle transport and acceleration upstream of shocks



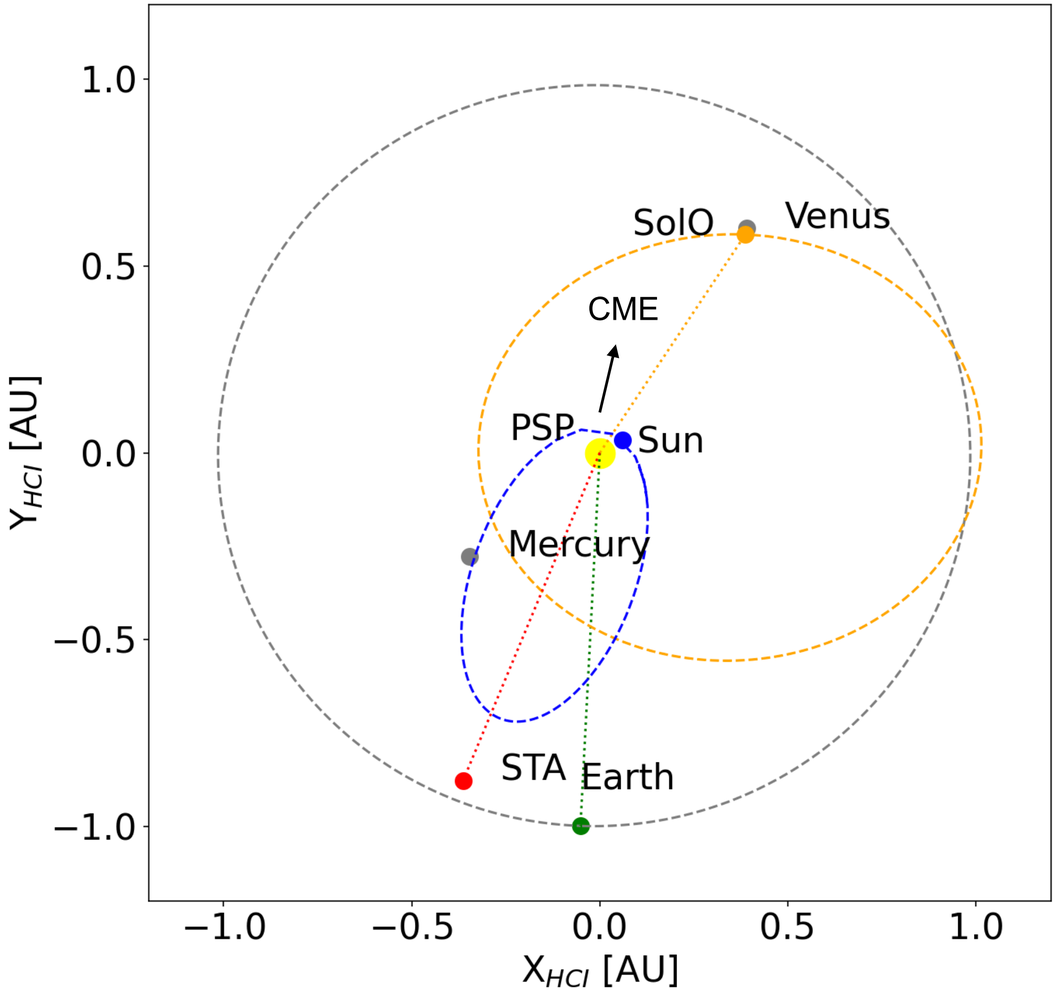


(Perri et al., 2023)

CME event of 5 September 2022



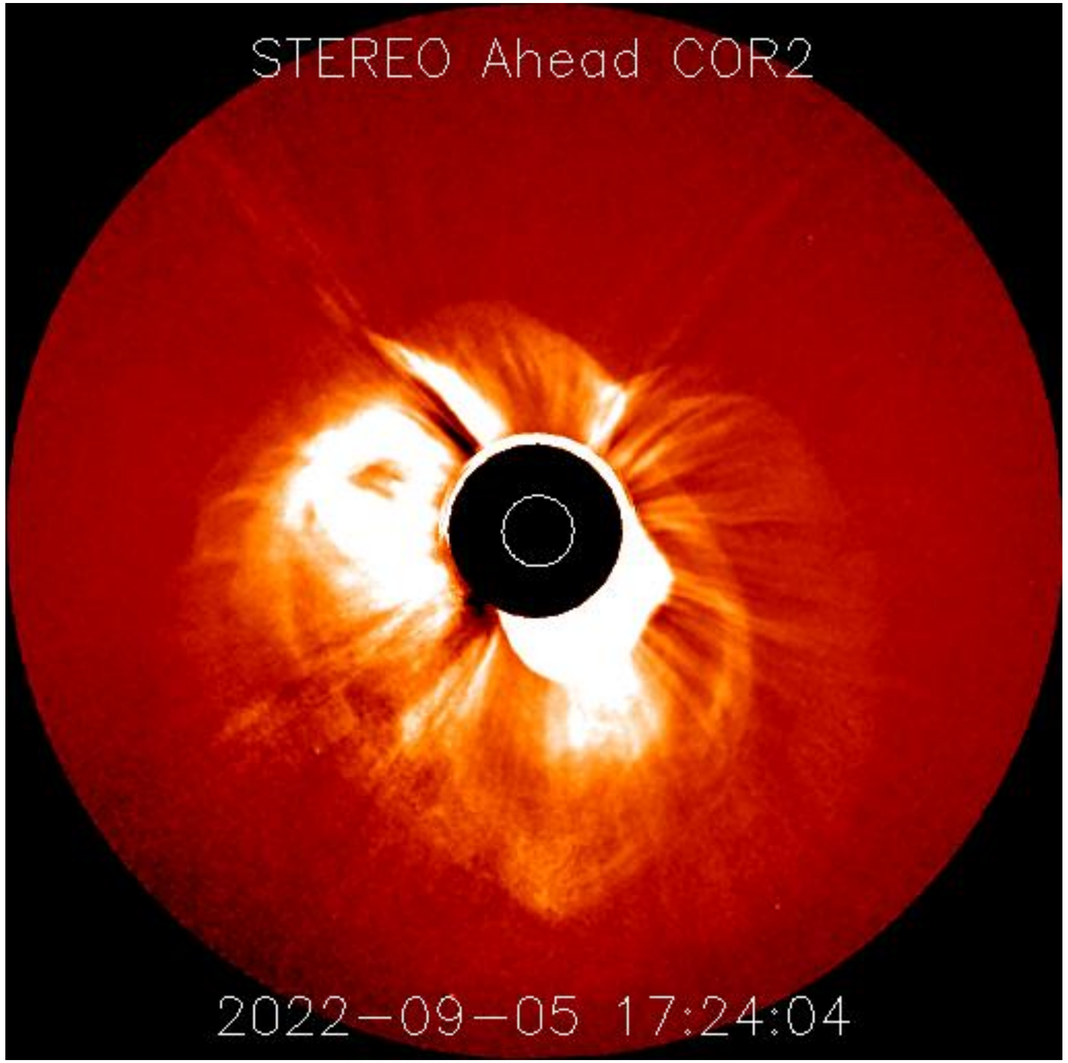
EUV image by Solar Orbiter/FSI at 304 A

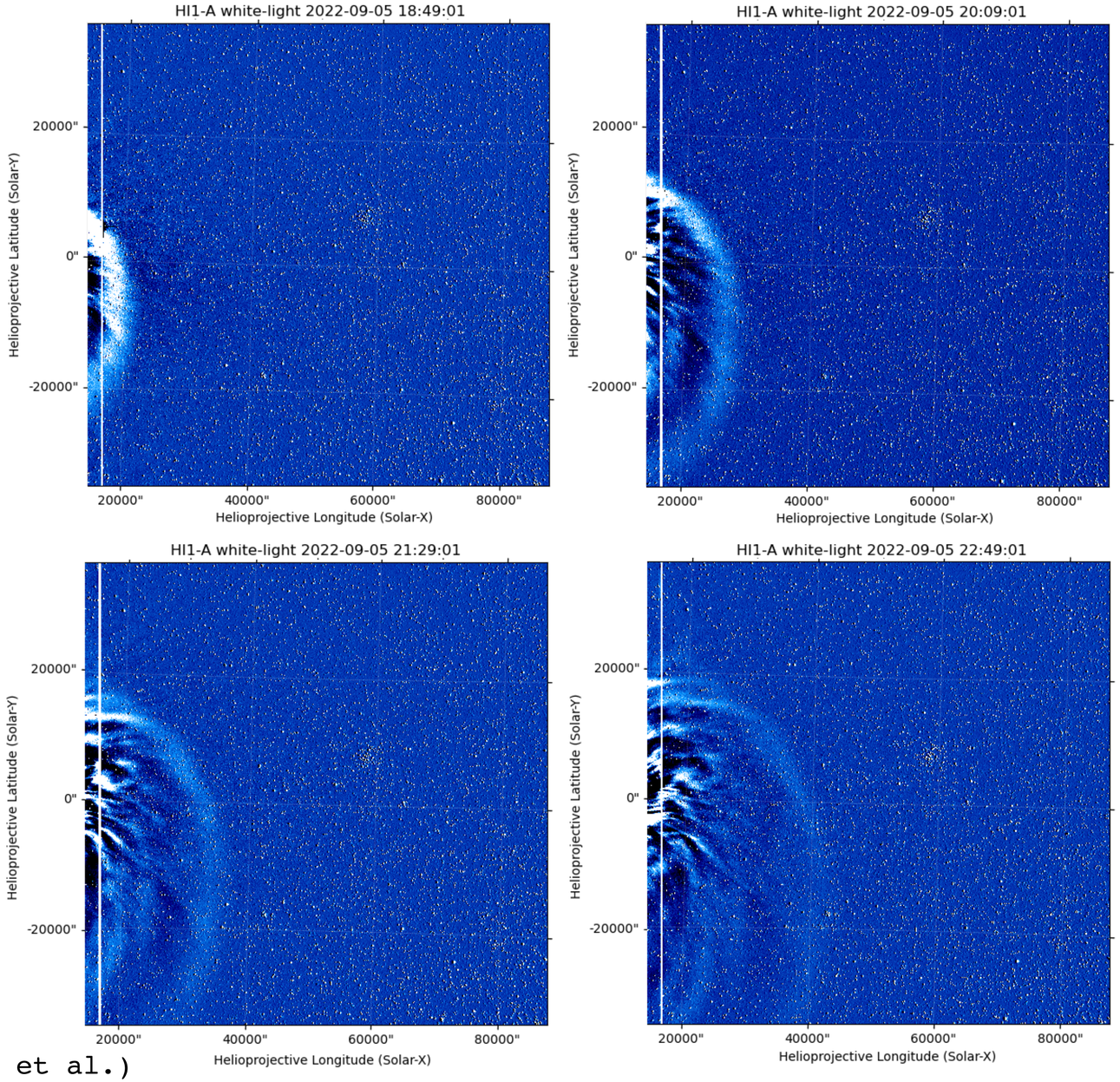


Spacecraft positions on 5/09/22

This event was well visible from STEREO-A/COR2 and PSP/WISPR

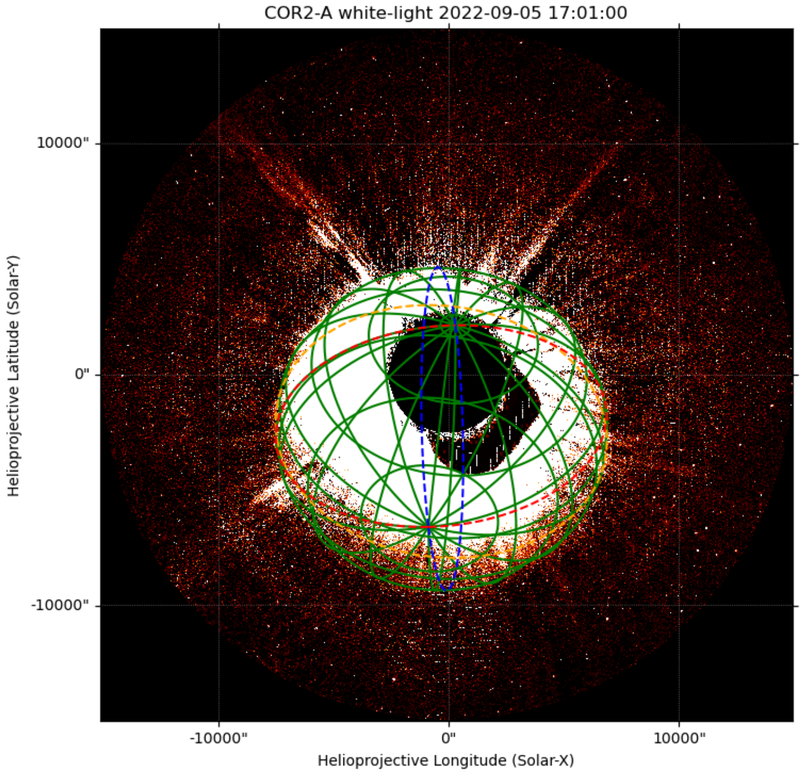
Lasco and Metis data are not available for this event



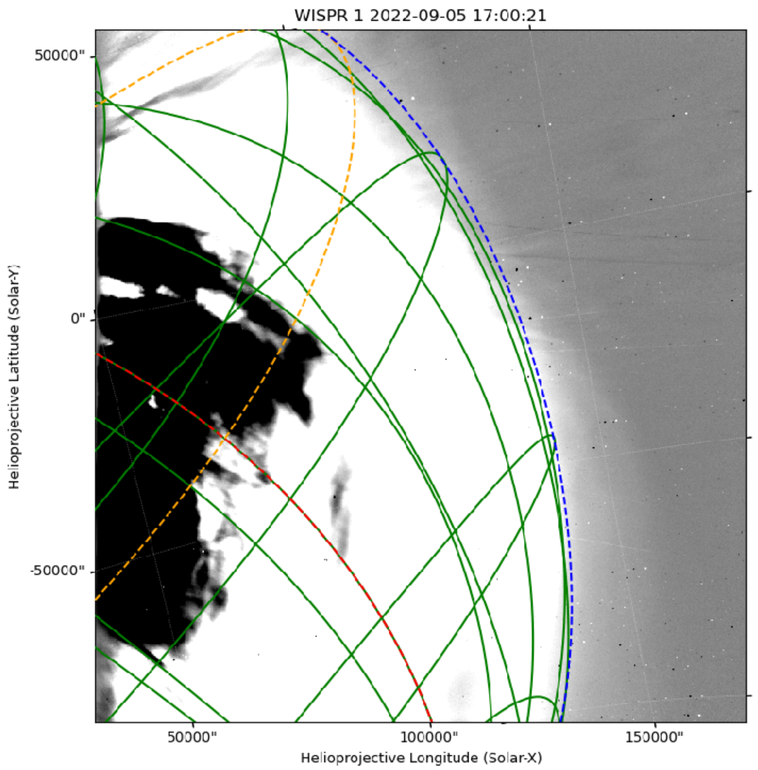


(Mesoraca et al.)

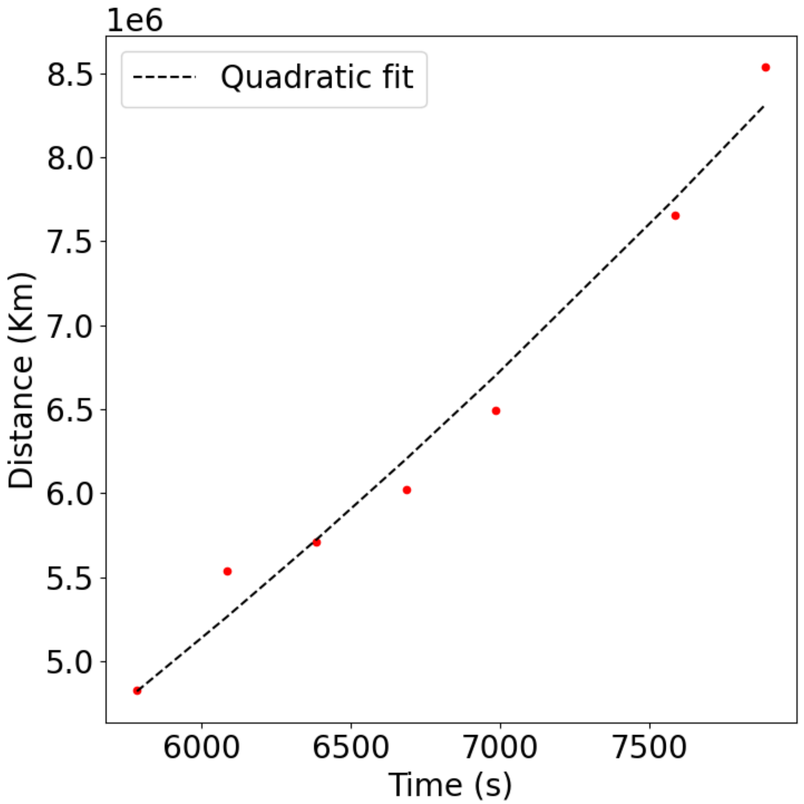
A 3D reconstruction is being carried out (Mesoraca et al. in prep.)



STEREO-A



PSP

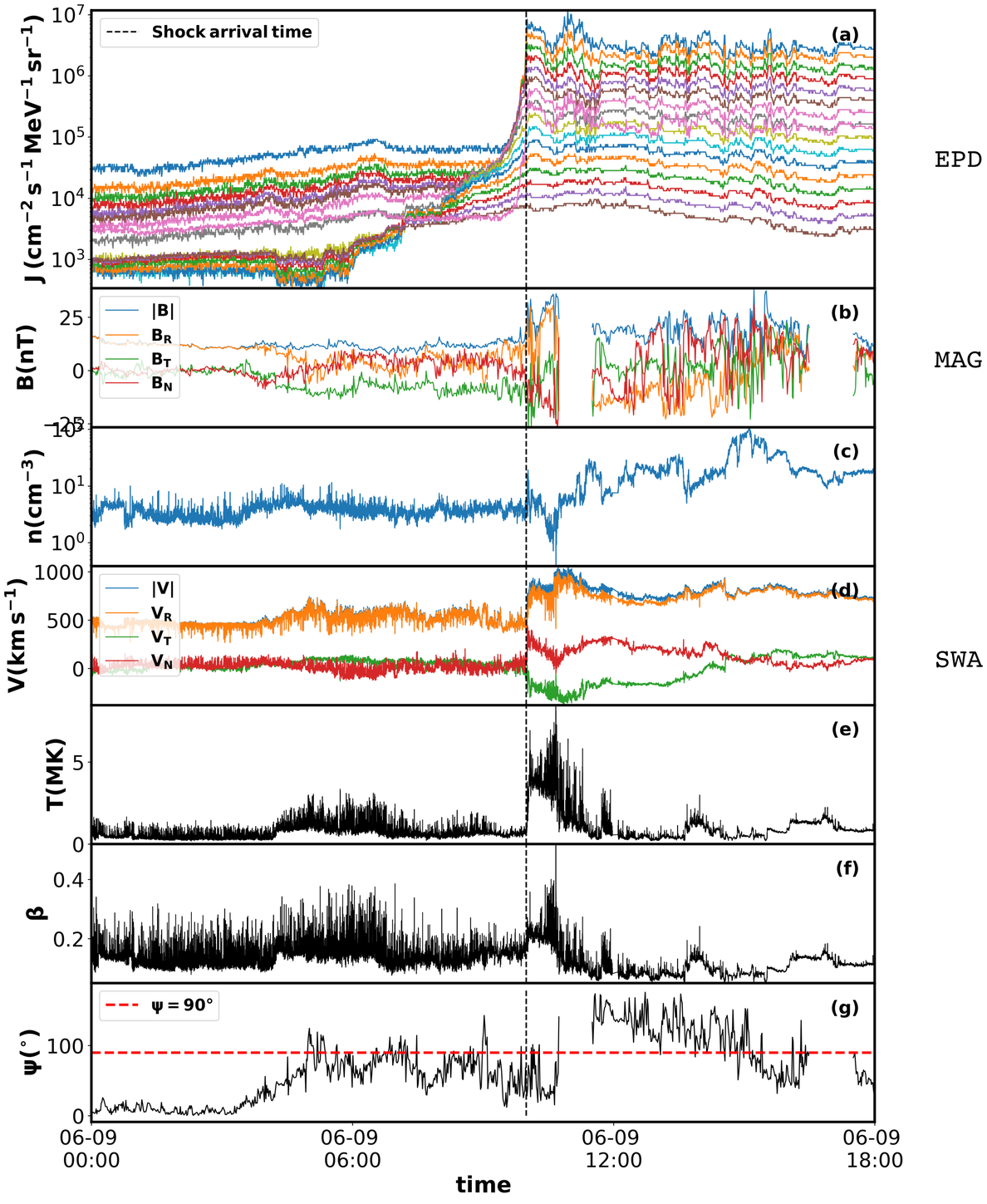


Quadratic fit at a specific position (Mesoraca et al., in preparation)

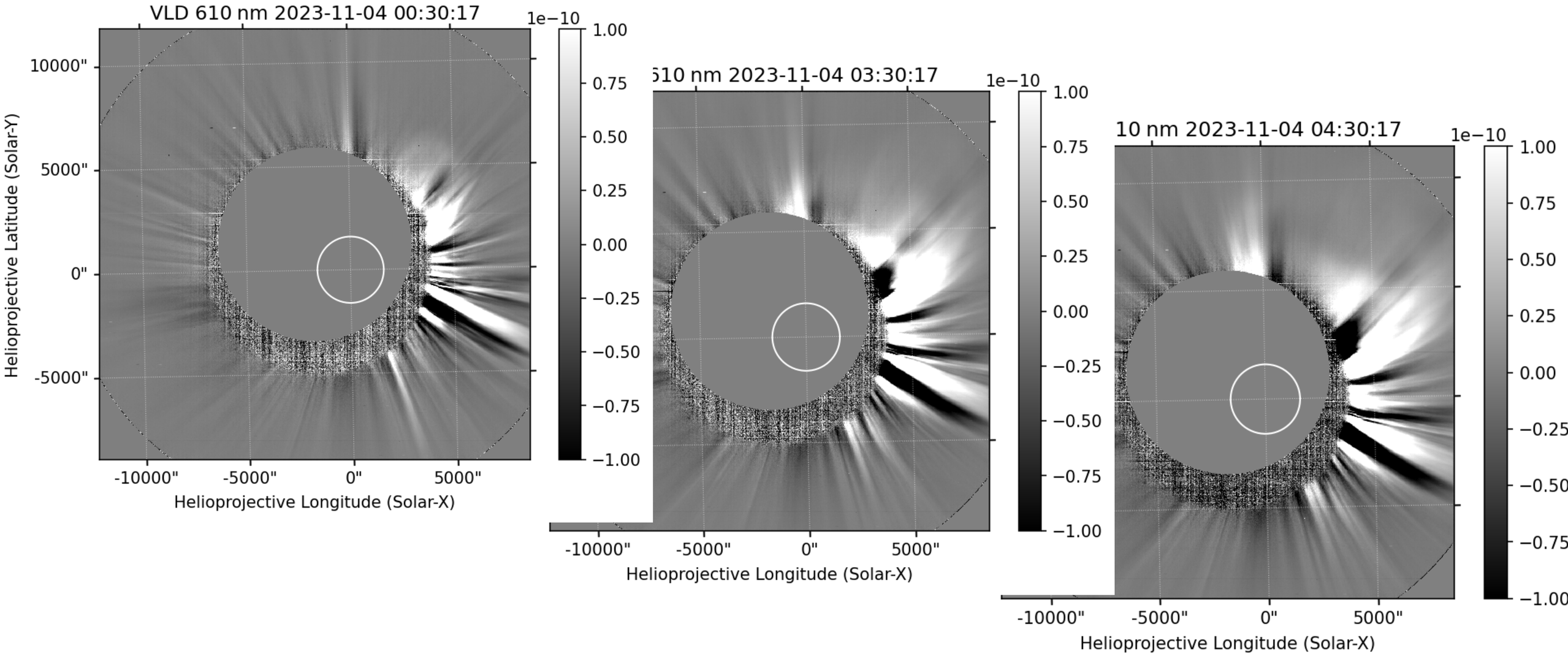
The parameters obtained from the fit of the 3D reconstruction are going to be given as an input to the RIMAP simulation.

Solar Orbiter was able to observe the interplanetary CME in situ on 06/09/22.

Beside the MHD shock, several interesting features were observed, like high fluxes of energetic particle and a changing direction of the upstream IMF, well before the shock arrival.

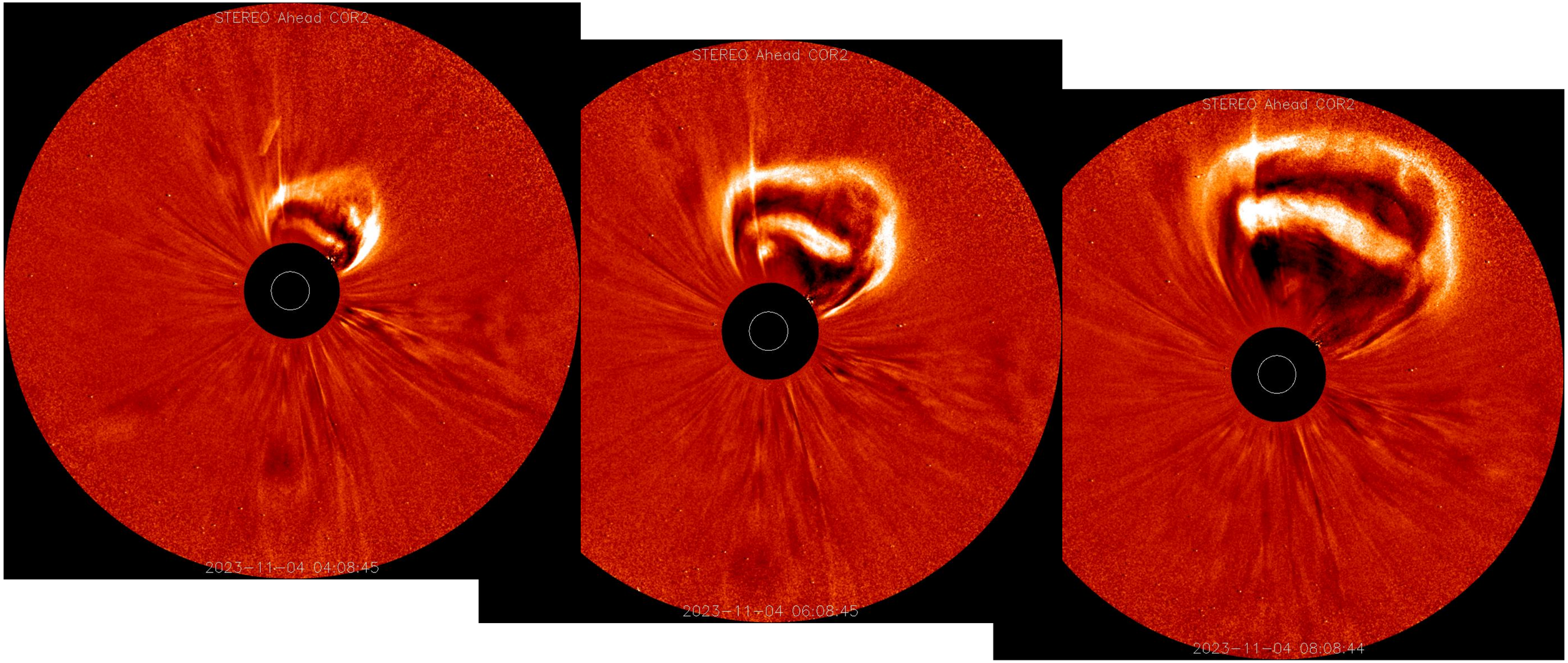


CME event of 4 November 2023

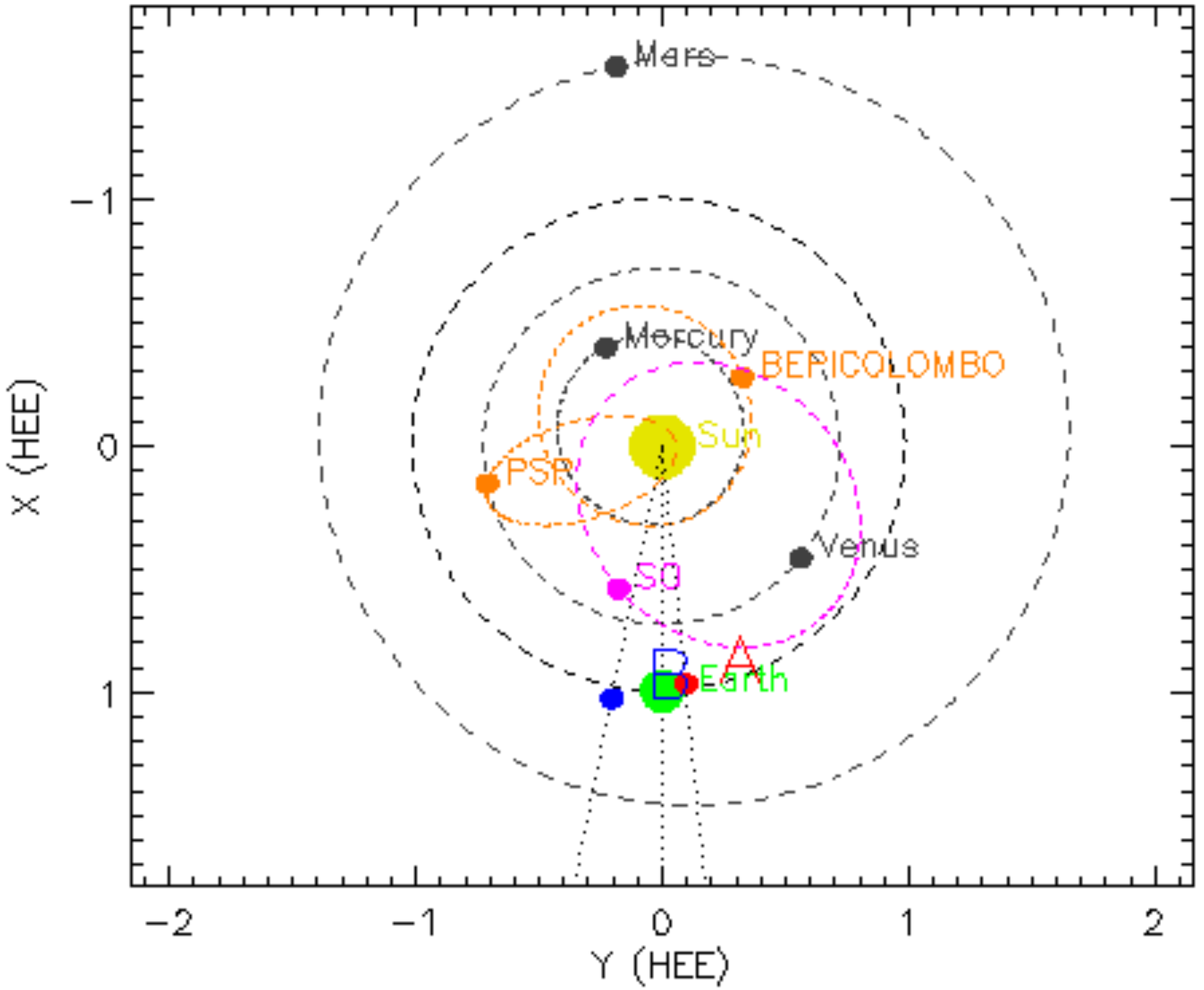


Metis data on 04/11/23. Not yet for distribution

CME of 04/11/2023 in STEREO-A/COR2

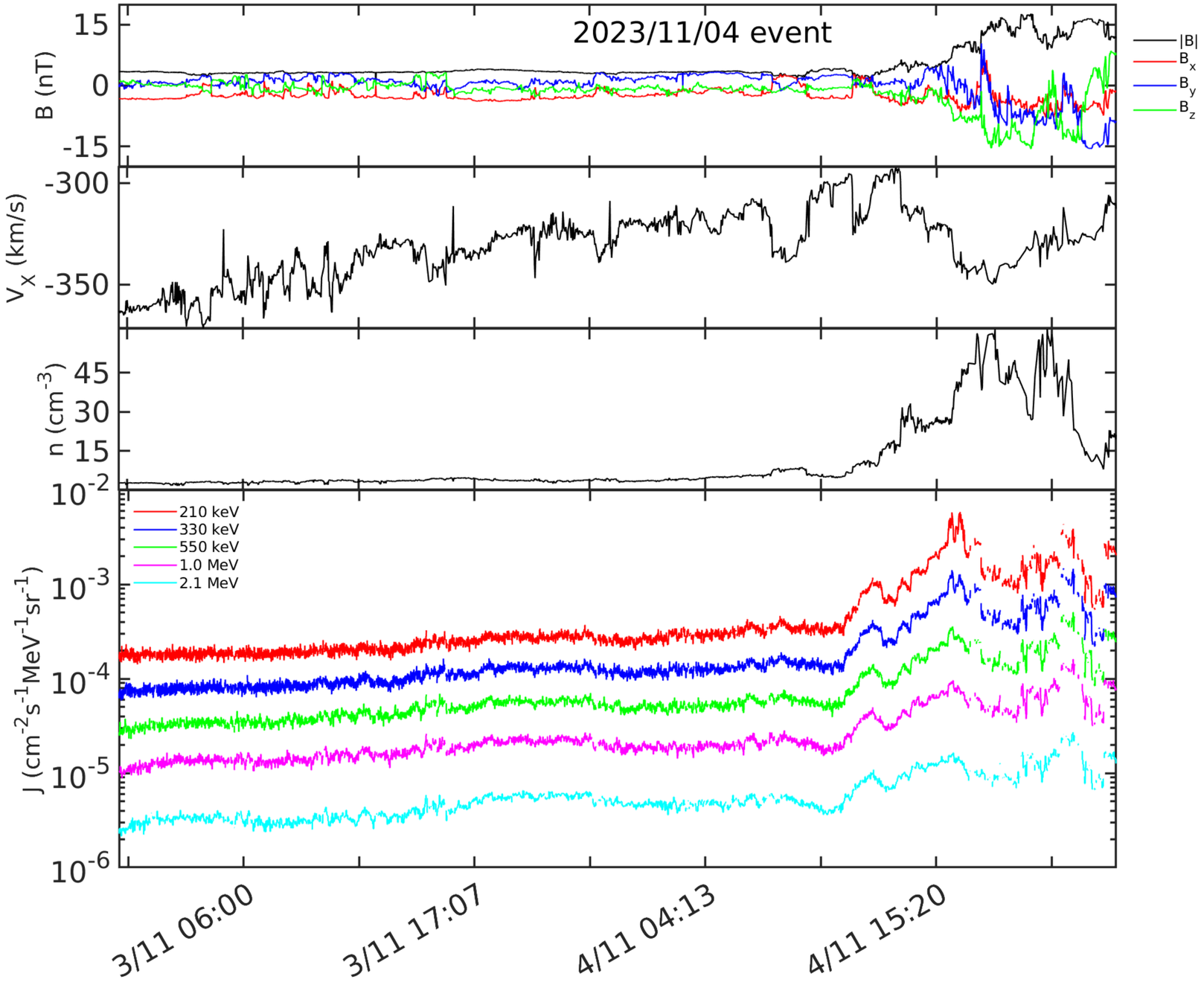


Spacecraft positions on 4 November 2023



For this event, in situ WIND data only is available at this time.

Apparently, the perturbation flank reached WIND, causing a gradual increase in energetic particles, and a gradual change in the MHD parameters.



Conclusions

We have presented the working methods to be integrated in this new research project, which involves both remote and in situ observations in the heliosphere, and which are going to be linked by RIMAP numerical simulations.

We have shown preliminary investigations for the CME events of 5 September 2022 and 4 November 2023. Both remote and in situ data are available for these events.

These events promise to be very useful for the planned integrated approach. This is going to lead to an improved understanding of CME and shock propagation from the corona to the heliosphere, and of particle acceleration processes.