Deceleration of CMEs between Mercury and Earth tested by Icarus (EUHFORIA) MHD simulations

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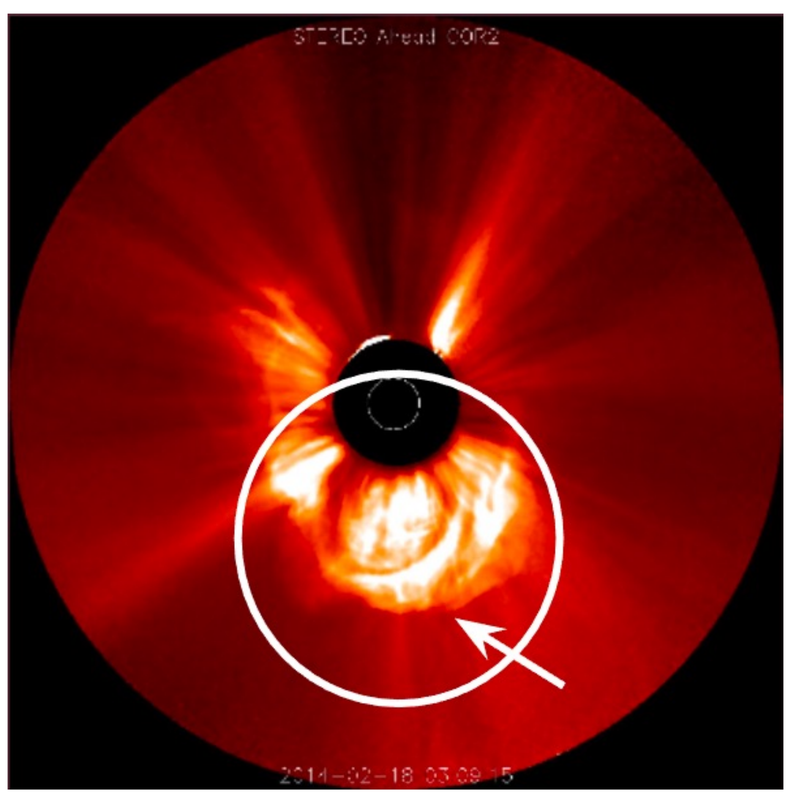
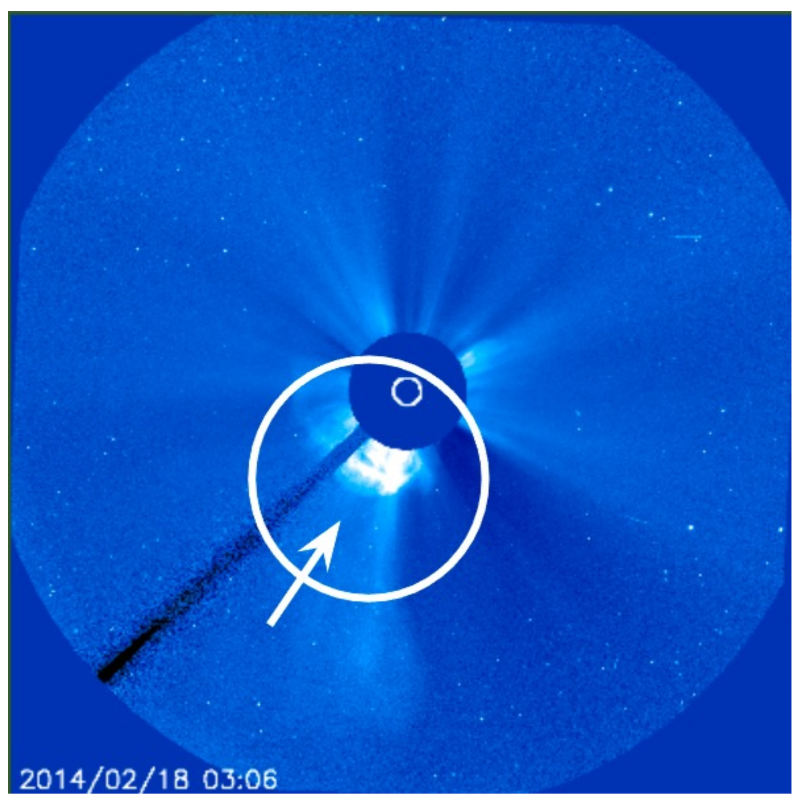
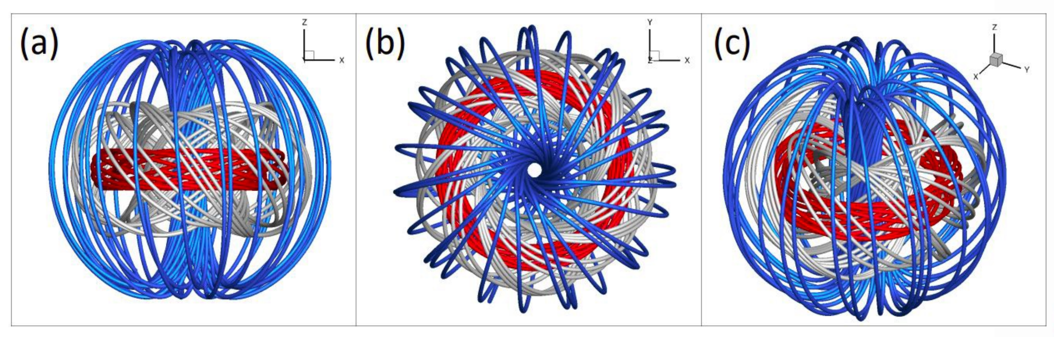
Abstract: Coronal Mass Ejections (CMEs) are the main drivers of the disturbances in interplanetary space. Then, understanding CMEs is crucial for advancing space weather studies. Assessing the numerical heliospheric model capabilities is crucial, as understanding the nature and extent of the limitations can be used for improving space weather predictions. In a statistics study it was shown that among 28 cases observed by the two spacecraft located near Mercury (MESSENGER) and Earth (ACE), 22 cases show a deceleration of 160 km/s. We test this result by considering two cases using the advanced 3D MHD heliospheric modeling tool Icarus recently developed at CmPA, KU Leuven. Icarus applies the radial grid stretching and adaptive mesh refinement to the computational domain to obtain fast simulations. The source regions for the CMEs were identified, and the CME parameters were calculated and optimized. The results were compared to in situ measurements.

The first CME case erupted on SOL2013-07-09T15:24. The modeled time series were in good agreement with the observations both at MESSENGER and ACE. The second CME case, starting on SOL2014-02-16T10:24 was more complicated, three CME interactions have to be taken into account. The CME-CME interactions were modeled in the Icarus simulations, which reconstructed the observed time series much better than considering only one CME. The deceleration of the CMEs observed between Mercury and Earth and attributed to the accumulation of the solar wind plasma upstream of the ICME was not retrieved in the simulations. The modeled time-series and observations are compared for both CME events. The results of the 3D heliospheric model are presented.



2014-02-16 09:30:00 (UTC)





Linear Force-Free Spheromak (LLF-Spheromak) is a magnetized (divergence- and force-free) CME model (Scolini et al 2019).

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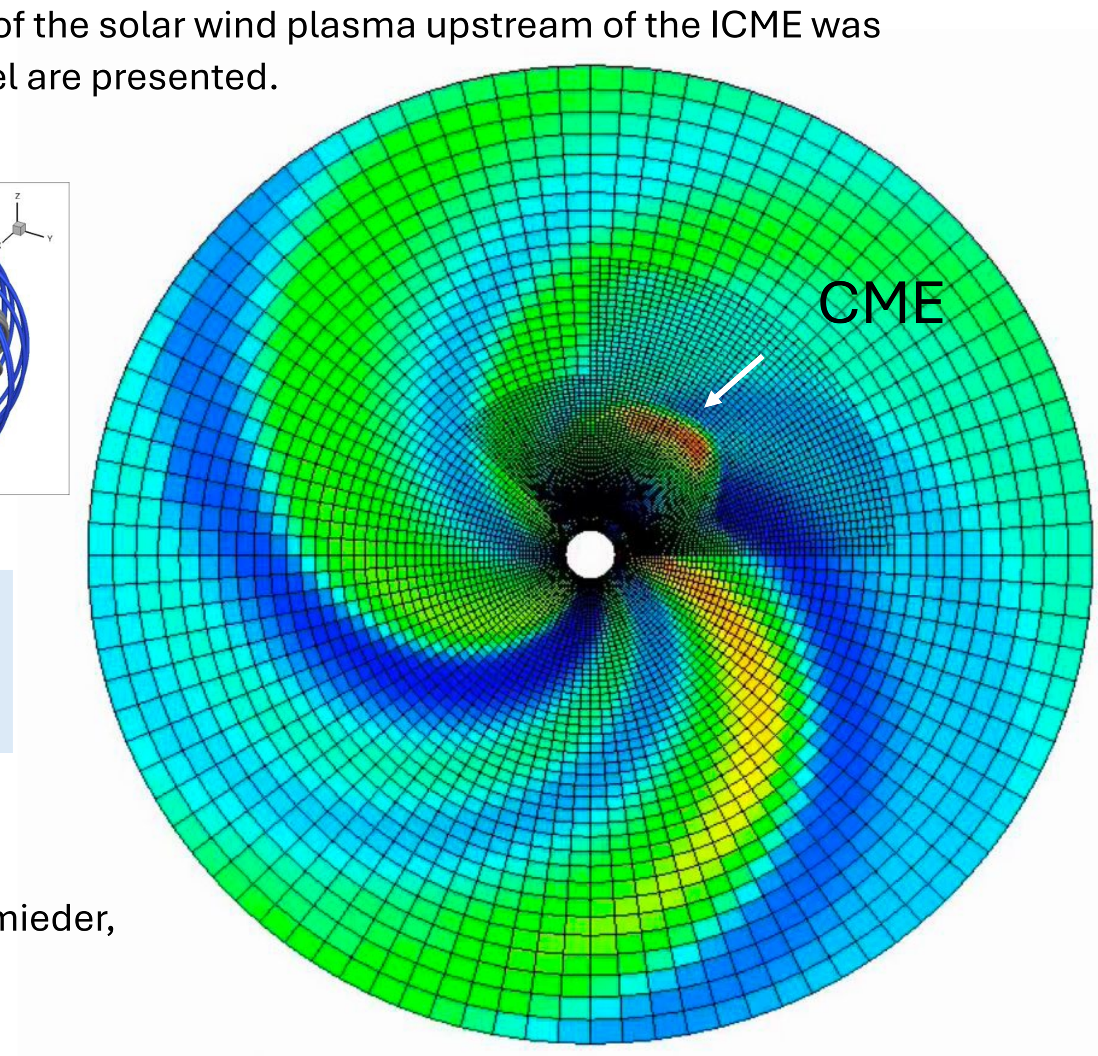
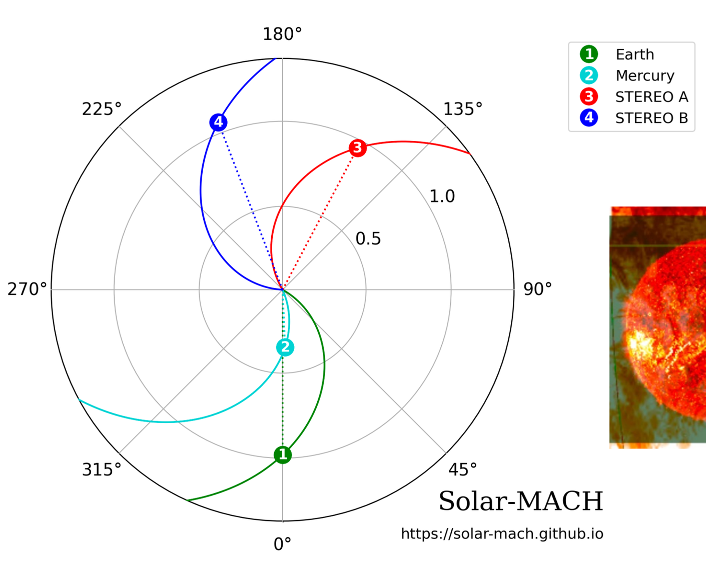
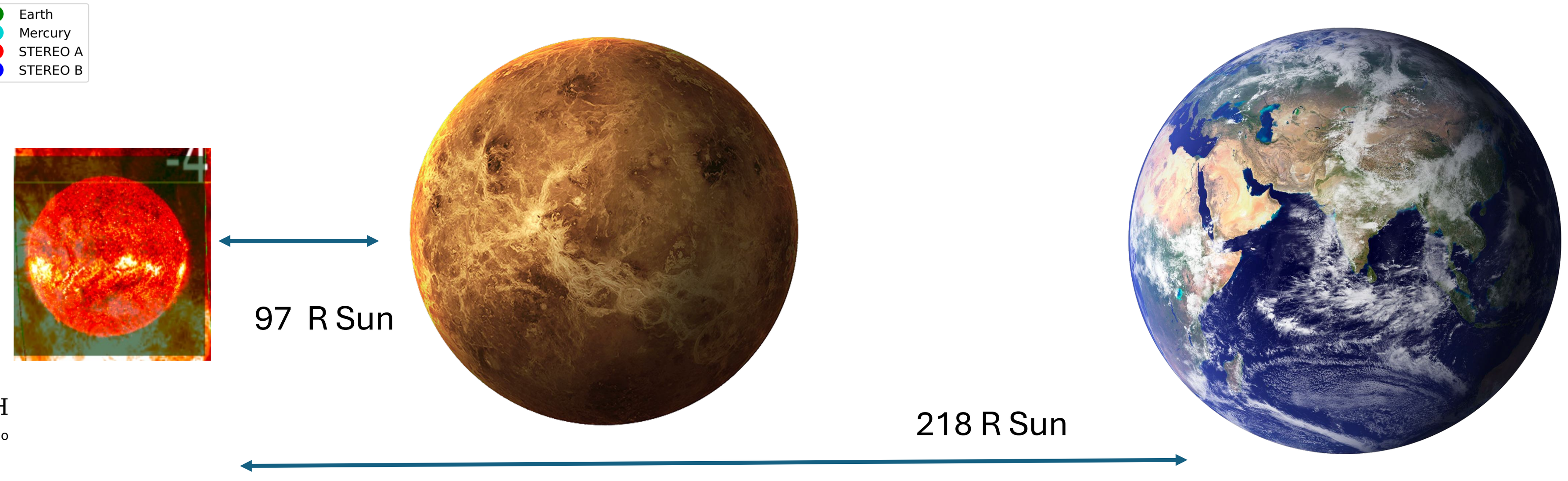






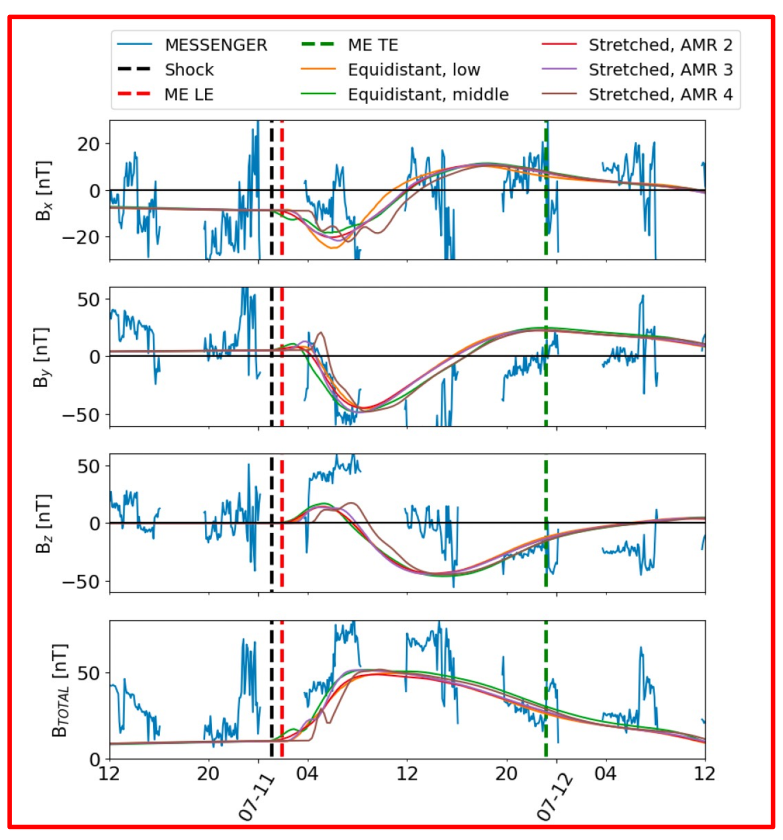
Icarus (Verbeke et al. 2022) is a new heliospheric tool derived from EUHFORIA and implemented in MPI-AMRVAC (Xia et al. 2018).

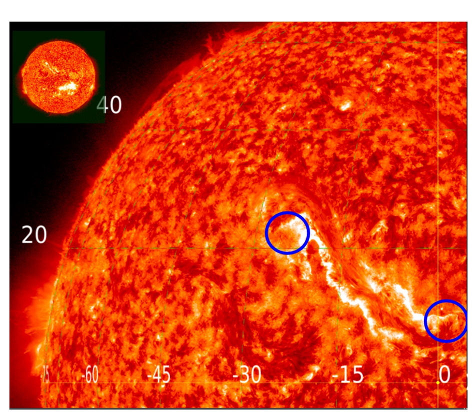
Advanced numerical techniques, such as solution adaptive mesh refinement (AMR) and radial grid stretching are implemented with different criteria (Baratashvili et al. 2022).

RESULTS AT Mercury

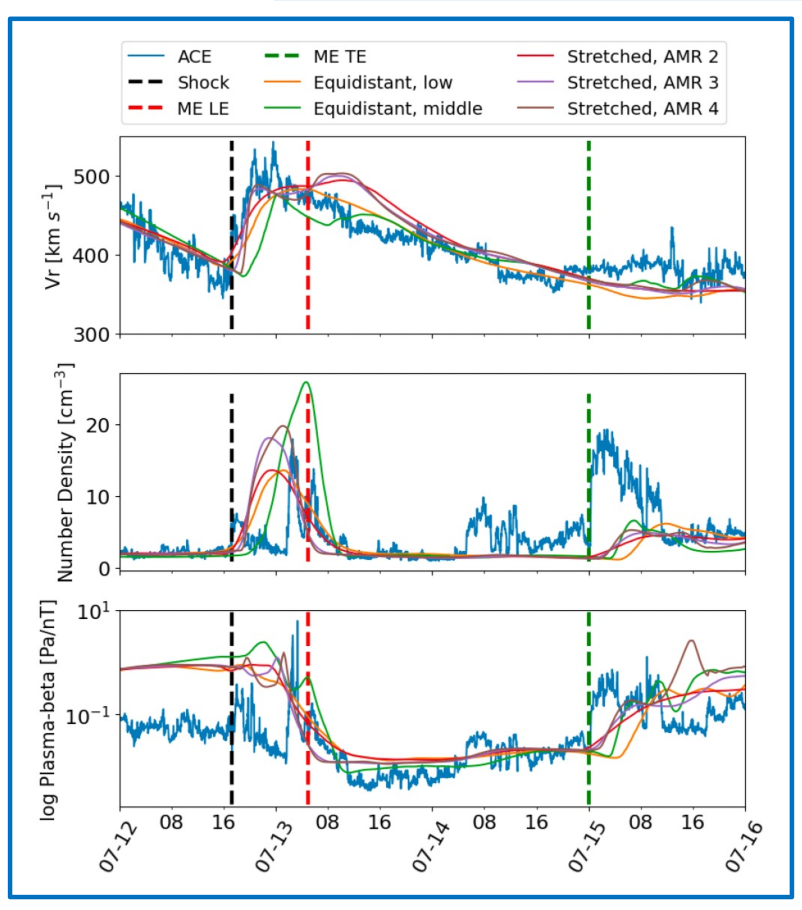
CASE I : One CME (9 July 2013)

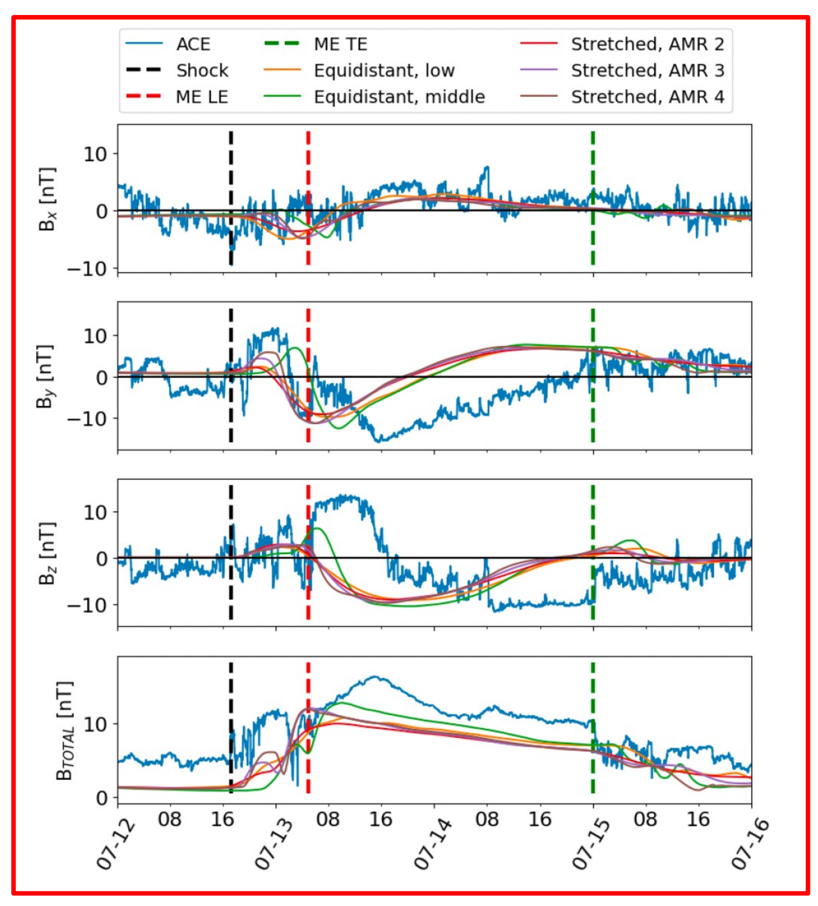
RESULTS at EARTH



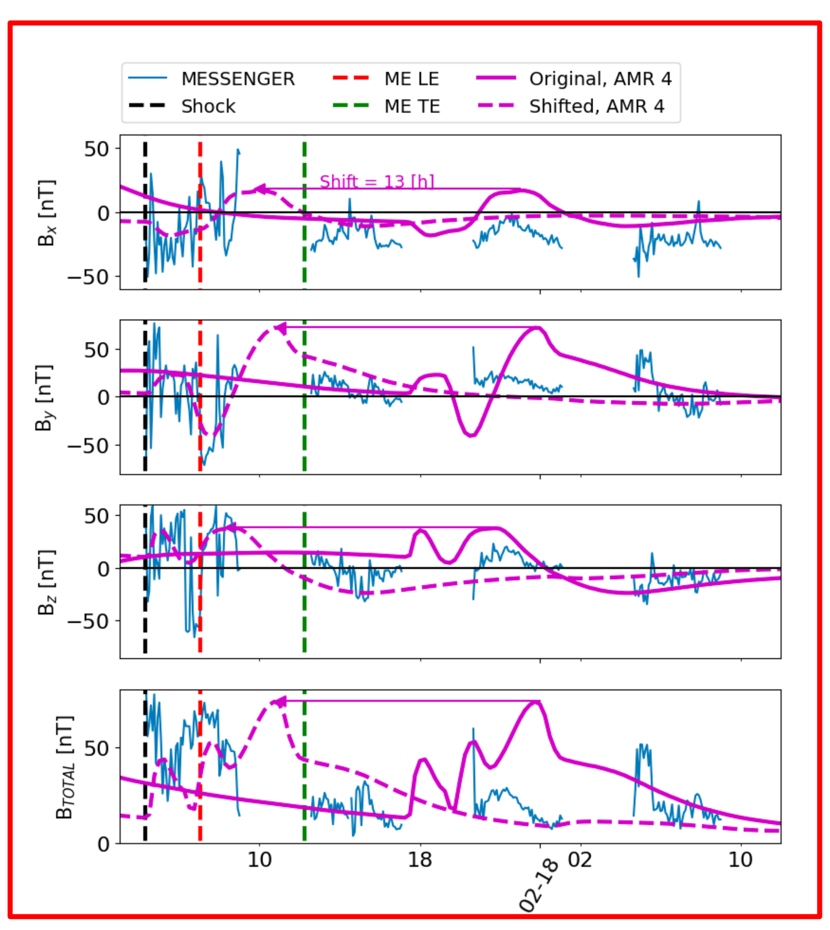


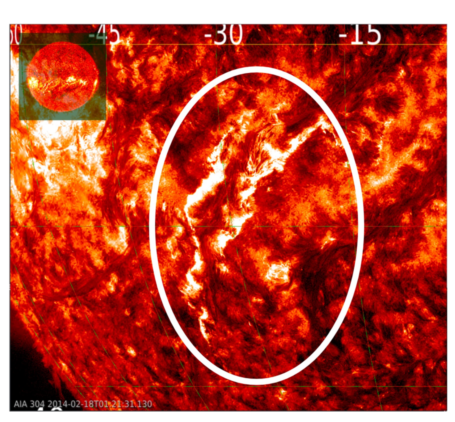
For this case the Icarus simulations were perfect for reproducing the in situ measurements of Messenger and ACE (Baratashvili et al 2024).



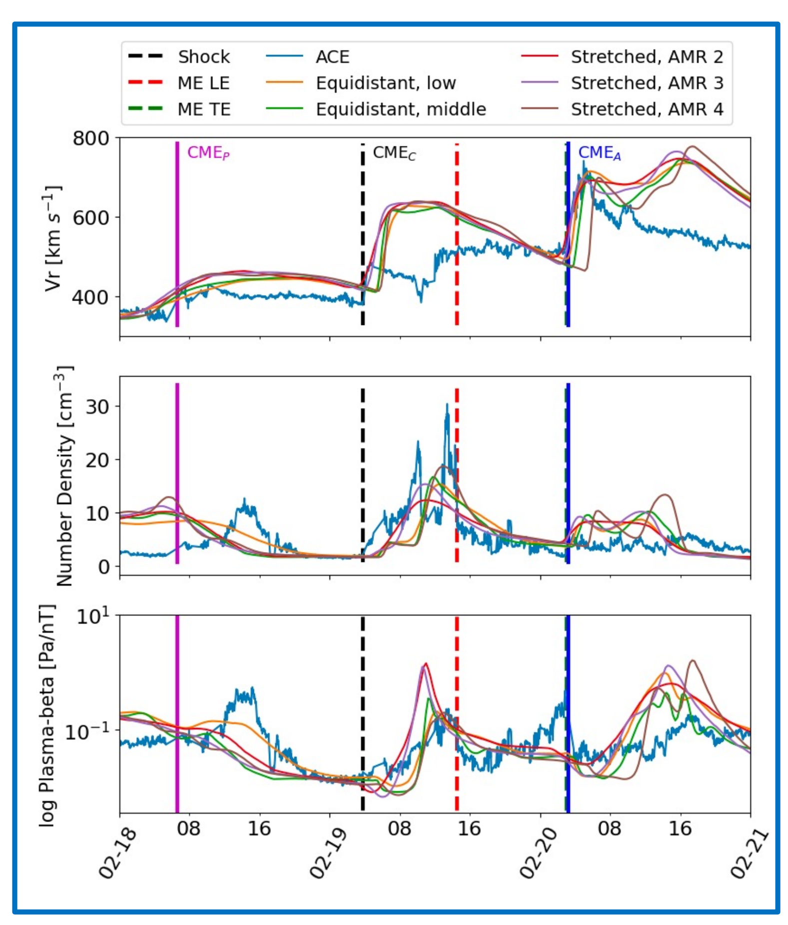


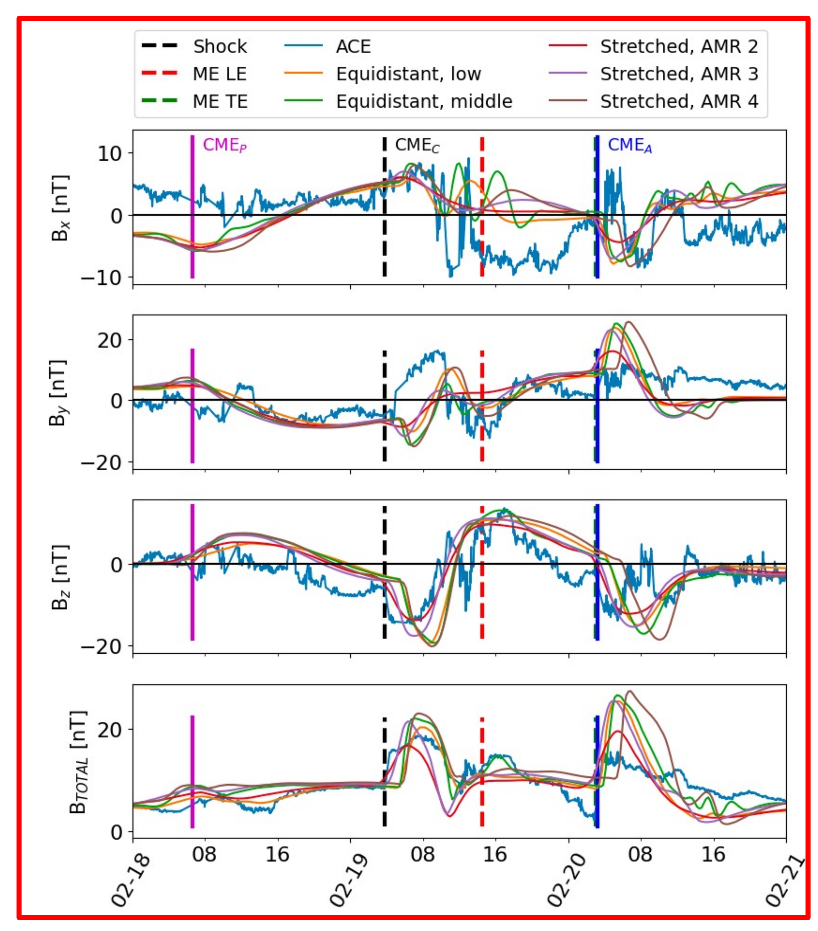
CASE II : Three solar CMEs. (16 February 2014)





For this case we need to take into account three CMEs. The Icarus simulations reproducesperfectly the in situ measurements of ACE.
Between Mercury and Earth a decelaration was certainly the reason of the late arrival of the CME at Mercury as we have a constant speed during 218 solar radius in the simulations (Grison et al 2018, Baratashili et al 2024).





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