Importance of Understanding the CME Three-Part Structure and Its Implication to the CME Radial Expansion

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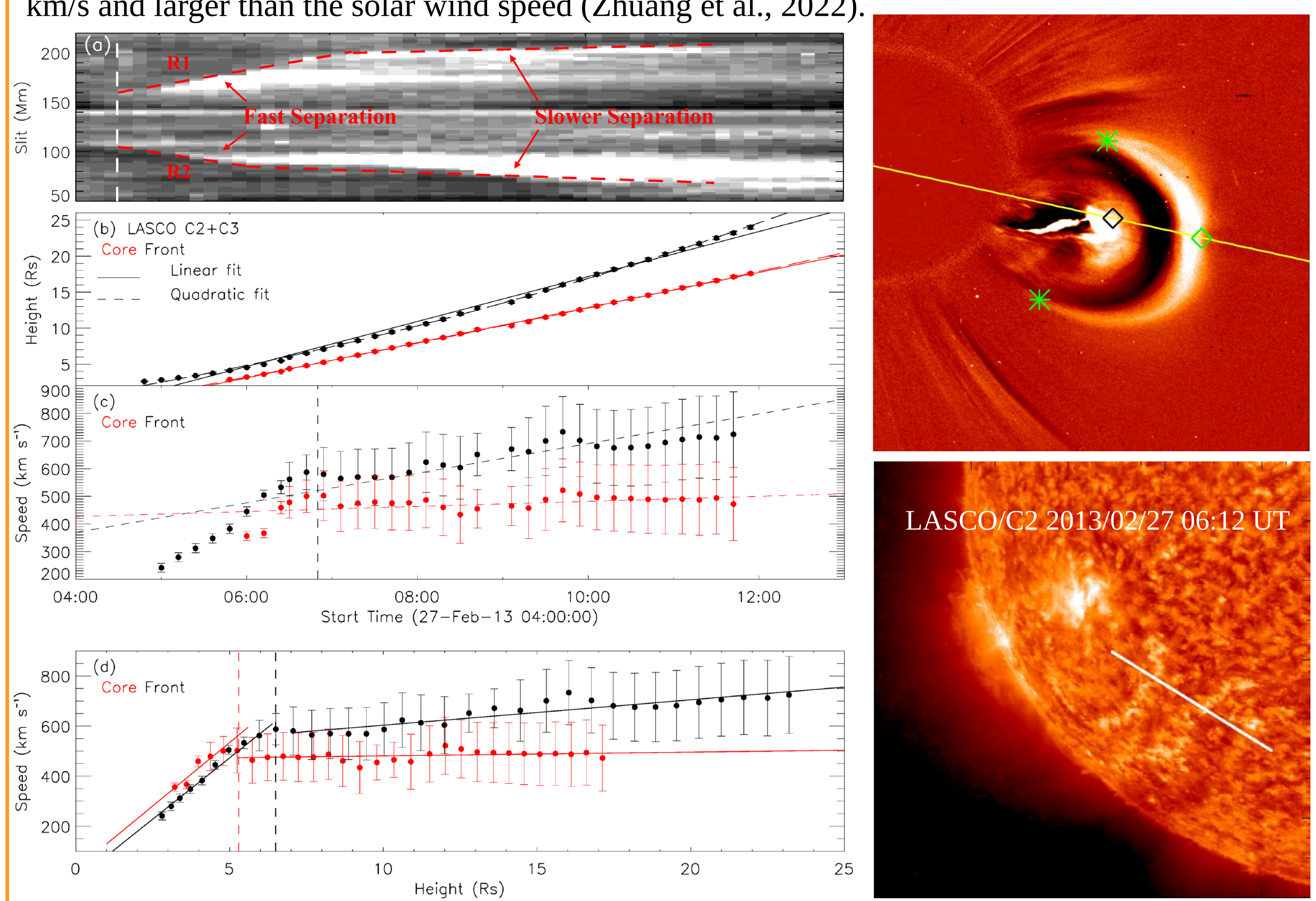
To be discussed

The CME three-part structure in white-light images has been studied for decades. However, with the recent advanced observations, the traditional relationship between the observed signatures and the CME physical structures has been challenged, e.g., it is under debate whether the bright core consists of the filament material associated with the CME eruption. Here, we discuss the importance of revisiting the CME three-part structure by combining remote-sensing and in-situ observations. First, we study ***a moderately fast CME with a continuous acceleration into the high corona*** (i.e., >20 Rs). We show how the CME three-part structure evolves (with on-going magnetic reconnection processes) as the CME propagate outward. Second, we show a study on ***the CME radial expansion by combining remote-sensing observations and in-situ measurements*** in radial conjunction. We find that the CME radial size and other expansion parameters are not always consistent between the remote and in-situ observations, while the exact identification of the CME trailing edge here acts as one of the reasons of those inconsistencies. In general, investigating the CME trailing edge, whose role was previously neglected, is ***critical*** for further understanding the CME three-part structure and the CME propagation, including their radial expansion.

Continuous acceleration of CMEs in the high corona

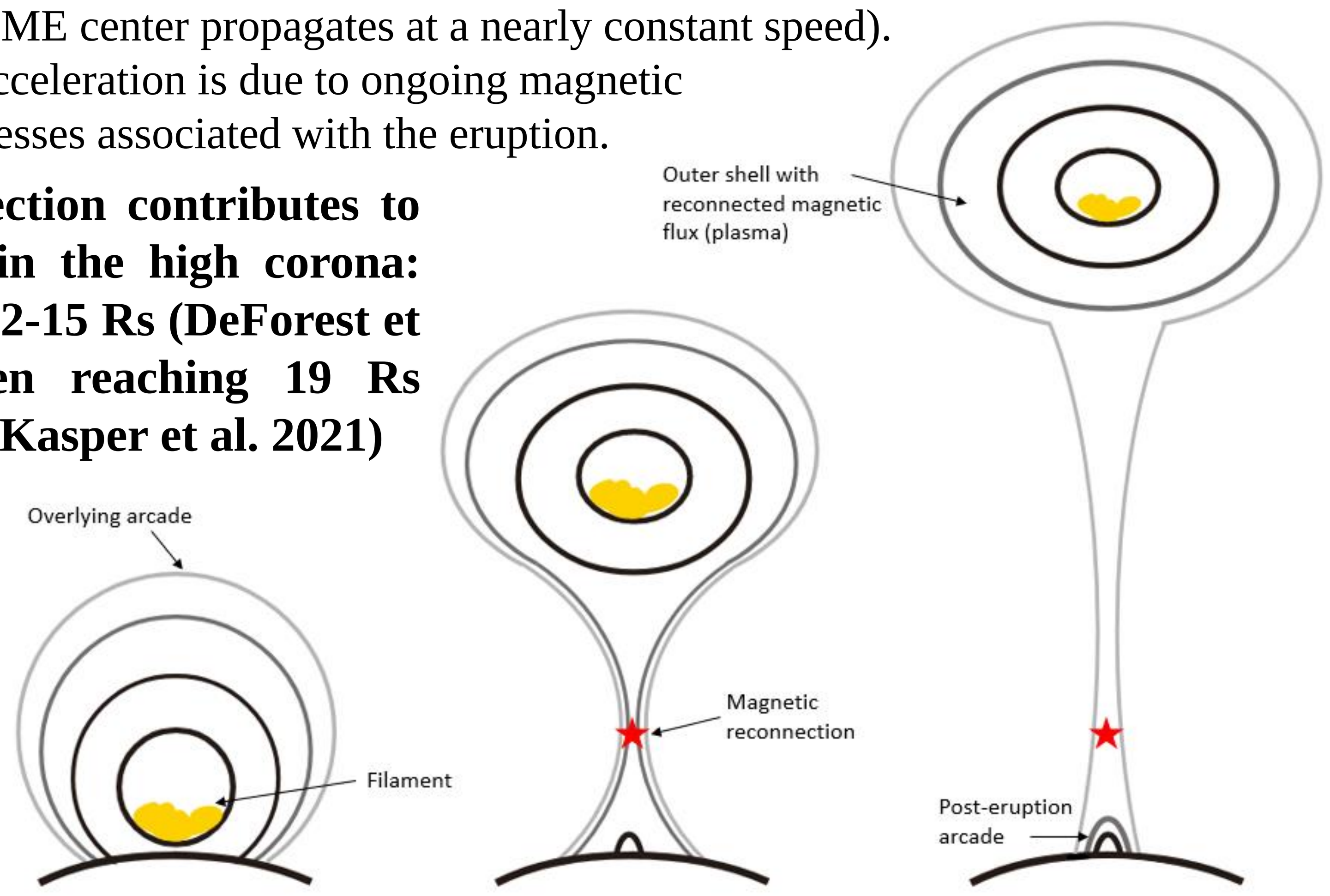
We analyze the dynamics of a moderately fast CME on 2013 February 27, associated with a continuous acceleration of its front into the high corona, even though its speed had reached ~700 km/s and larger than the solar wind speed (Zhuang et al., 2022).



- The front of the CME has a continuous acceleration lasting for ~5 hours and up to >20 Rs even the CME speed is ~700 km/s and larger than the solar wind speed (~300 km/s).
- The apparent acceleration of the CME front is related to the CME expansion in the radial direction (as the CME center propagates at a nearly constant speed).
- This continuous acceleration is due to ongoing magnetic reconnection processes associated with the eruption.

Magnetic reconnection contributes to CME expansion in the high corona: Alfvén point at ~12-15 Rs (DeForest et al. 2014) or even reaching 19 Rs observed by PSP (Kasper et al. 2021)

Filament is near the CME center in the higher corona.



In the future

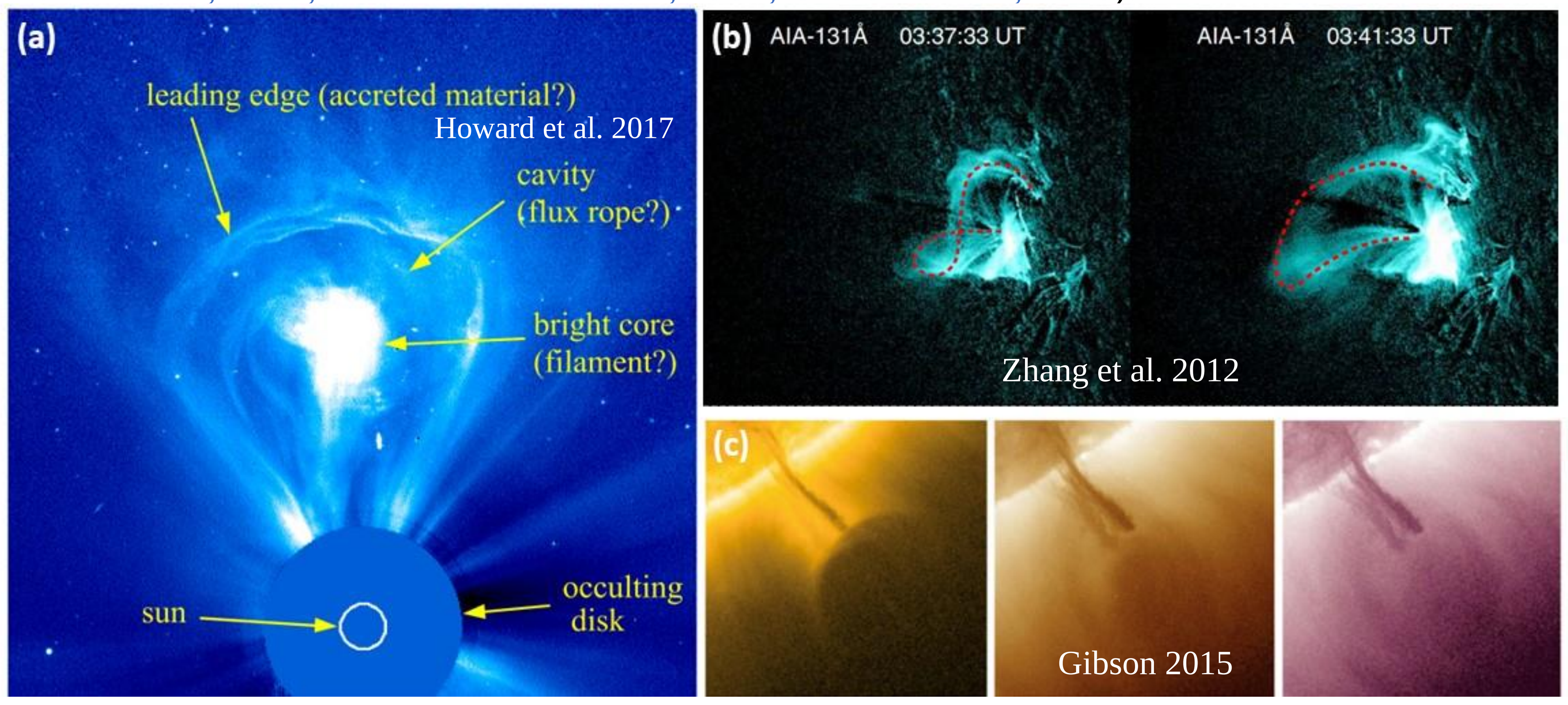
Revisiting the CME three-part structure by continuously tracking not only the morphology but also the **kinematics** of the CME from the low corona (EUV, e.g., SDO, **SUVI**) to the high corona (coronagraph), or even to interplanetary space by using heliospheric imagers and in situ measurements from PSP and Solar Orbiter when they are close to the Sun.

Pay attention to the CME trailing edge, and it is critical to understand the CME size, expansion and morphology!

More information in two papers: Zhuang et al. (2022) accepted by ApJ, and Zhuang et al. 2022, in preparation.

Background

Coronal mass ejections (CMEs) can appear as the classic three-part structure, including a bright leading edge followed by a dark (low-density) cavity and a bright core (e.g., Illing & Hundhausen, 1985; Webb & Hundhausen, 1987; Gibson & Fan, 2006).



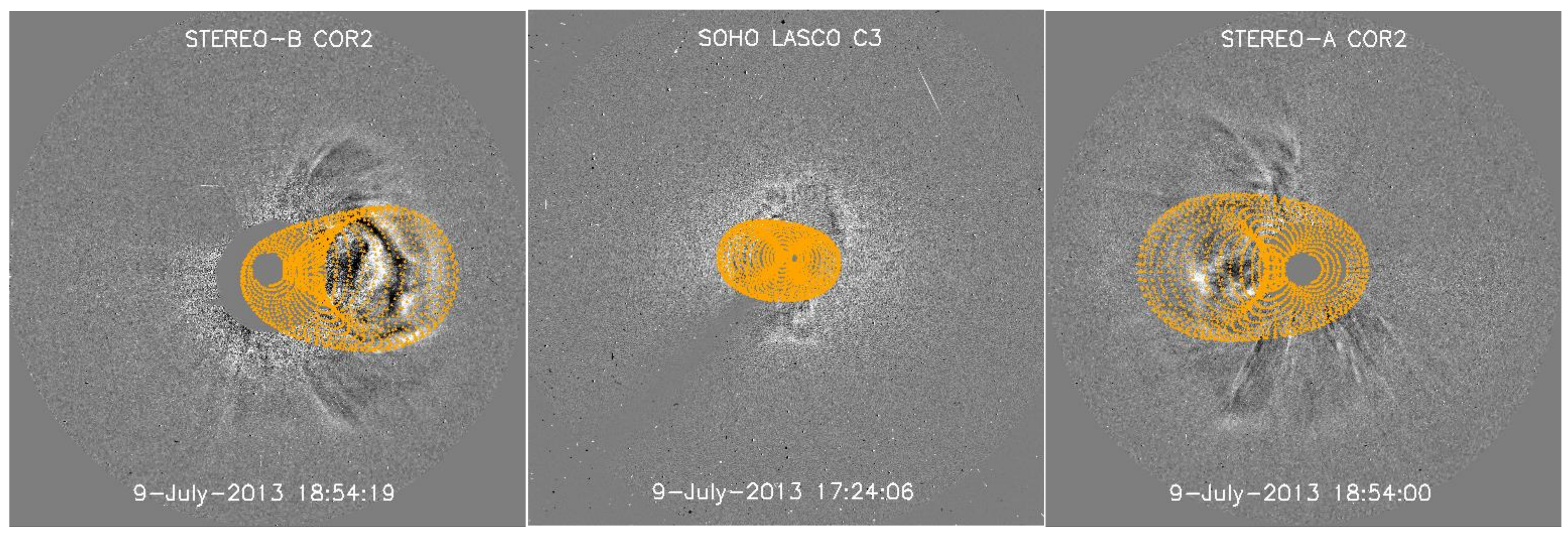
- Traditionally, in white-light coronagraphs, the dark cavity corresponds to the CME magnetic flux role (MFR), and the bright core represents the associated filament material contained in the trailing part of the MFR.
- Howard et al. (2017) challenged this view and found that 69% of 42 CME events showing that the bright core is not associated with a filament eruption. They proposed that the bright core can be related to the projection effects on a writhed and twisted MFR.
- Association between bright core and flux rope structure was also studied by, e.g., Song et al. 2017, 2019, and Veronig et al. 2018.

Unsolved Questions

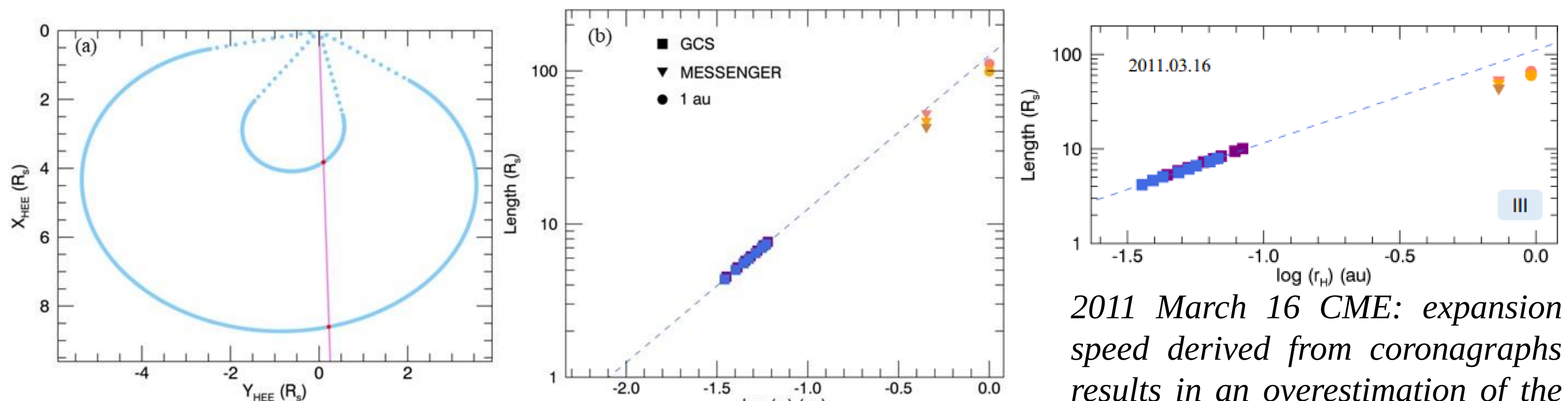
1) **What and where are the CME MFR structure and filament material observed in white-light coronagraphs?**
2) **Where is the CME trailing edge?**
3) **Is the CME structure, size and morphology observed remotely consistent with that observed in-situ, and vice versa?**

CME radial expansion studied by combining remote and in-situ data

We study the radial expansion of 22 CME events during 2010 and 2014, which were well observed by three coronagraphs and by two and/or three spacecraft in radial conjunction.

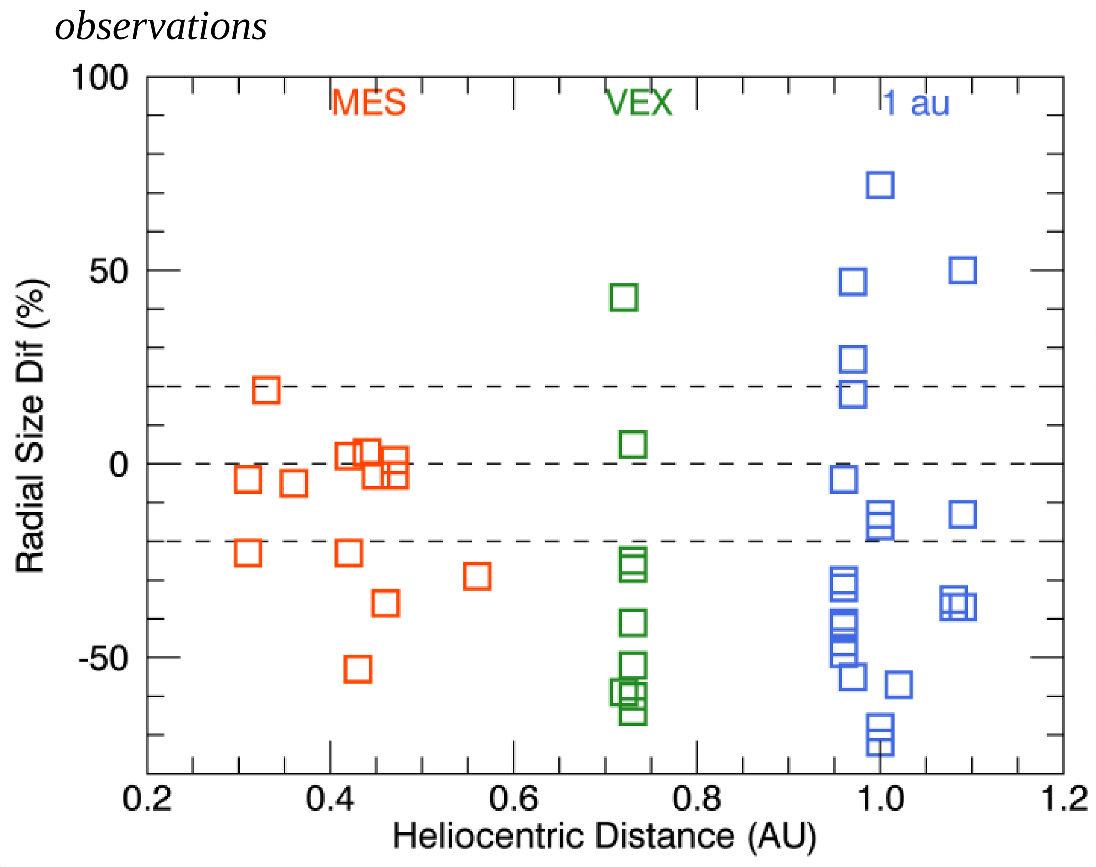


We use the GCS model (Thernisien et al. 2006) to estimate the CME size and radial expansion in the corona. We compare these values to the size and expansion speed at the two spacecraft (MESSENGER, VEX, STEREO, L1). We consider deviations of ±20% to be within the uncertainties of the methods.



2013 July 9 CME: Consistent radial size between remote and in-situ observations

2011 March 16 CME: expansion speed derived from coronagraphs results in an overestimation of the size at VEX and 1 AU.



Radial size is not always consistent between remote observations and in-situ measurements.

Inconsistencies of the CME radial expansion parameters may be caused by:

(1) different mechanisms acting on the CMEs in the inner (CME internal pressure) and outer (solar wind pressure) heliosphere (Lugaz et al., 2020);

(2) difficulties in identifying the CME trailing edge in remote and in-situ observations.