



Effect of the Solar Cycle on Typical CME Properties During 1995-2024

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1. Introduction

Coronal Mass Ejections (CMEs) are violent events corresponding to strong magnetic structures erupting from the outermost part of the Sun: the corona.

The CMEs observed in the interplanetary medium have been cataloged in Helio4Cast catalog which covers nearly three decades (1995 - 2024) of in situ measurements taken by many interplanetary and planetary probes from 0.2 to 1.2 au (Mostl et al. 2020).

We analyze this large dataset of CMEs to investigate the evolution of their properties with heliocentric distance and with the phase of the solar cycle.

2. Active phase (AP) and quiet phase (QP) CME

We group the events as Active Phase (AP) events (457) and Quiet Phase (QP) events (335) based on the phase of the solar cycle they occur in, and we performed a superposed epoch analysis to obtain the statistical mean and median profiles of the CMEs in each phase.

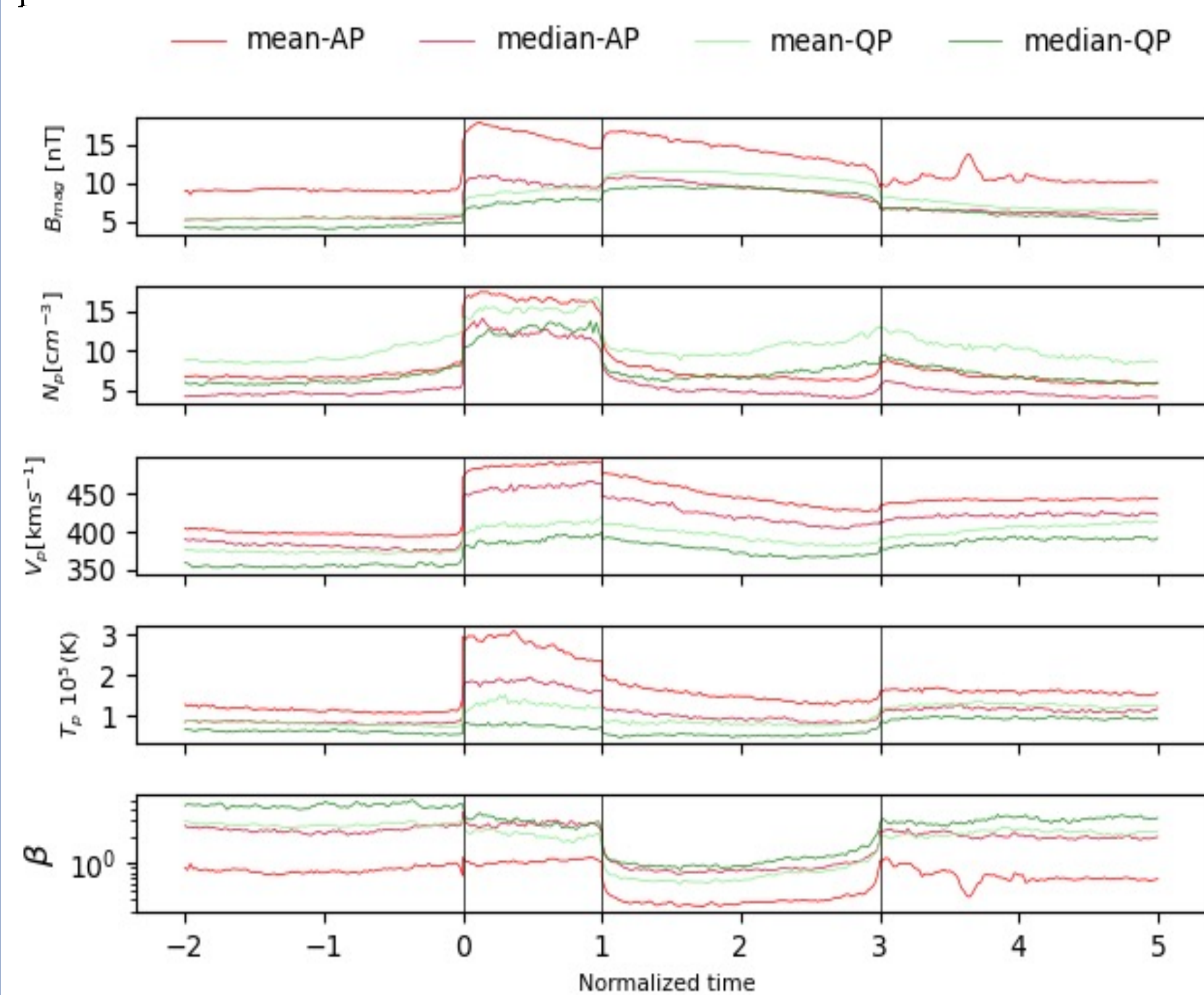


Figure 1: Superposed epoch analysis of CME events based on solar cycle phase. From the left: pre-solar wind, sheath, magnetic ejecta (ME) and the wake region respectively.

We study the variation of the CME properties with heliocentric distance. We perform a superposed epoch analysis on the magnetic field components, B_k and B_j , obtained from the minimum variance analysis (MVA).

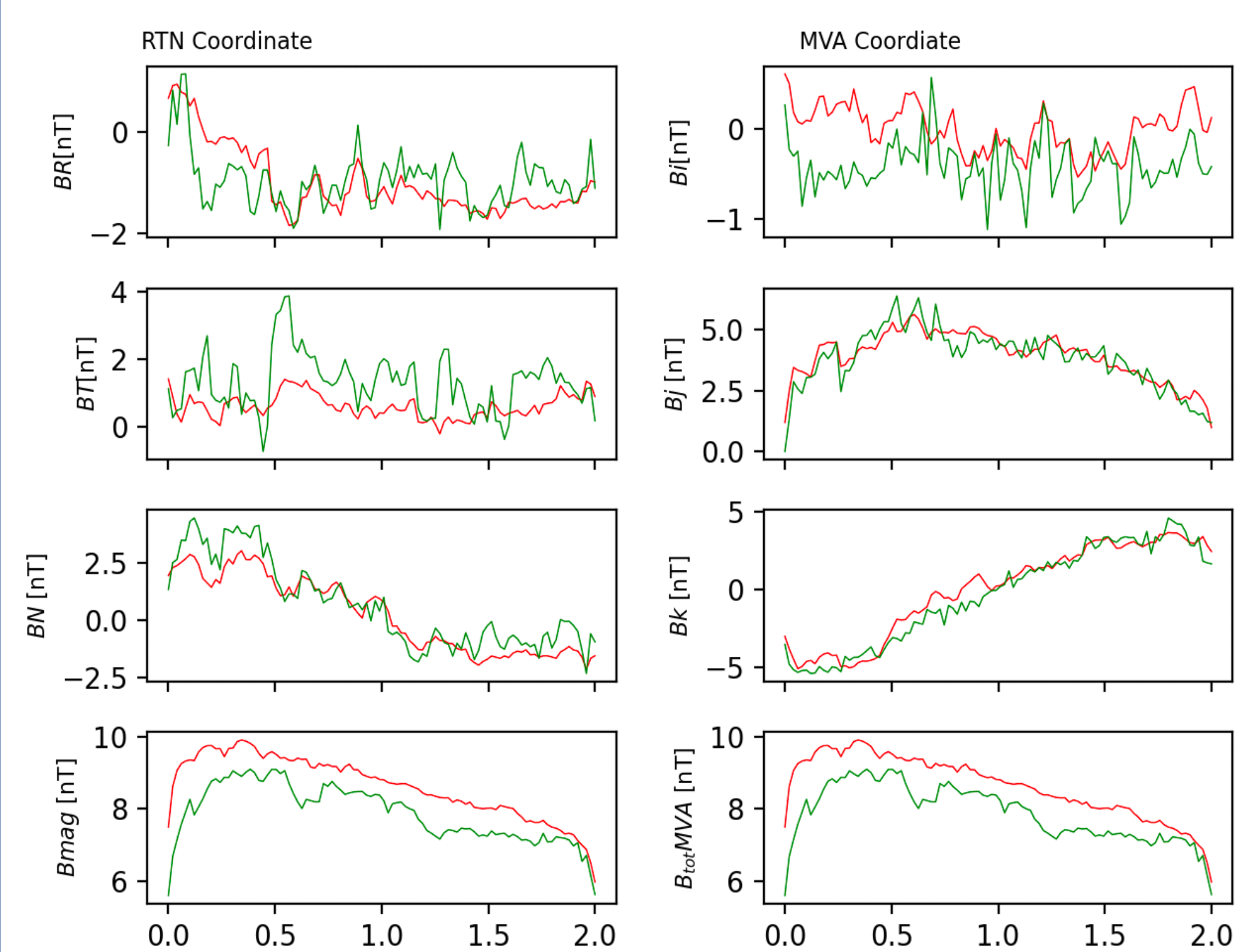


Figure 2: SEA for the magnetic field components in RTN vs MVA coordinates for all CMEs within bin 19 (1.08 - 1.14 au).

3. CMEs at different heliocentric distances

The database has enough CMEs to investigate the changes of properties with heliocentric distance. Figures (3,4,5) shows the expansion speed, Distortion Parameter (DiP) and magnetic field profiles respectively.

The ME average magnetic field as function of heliocentric distance for the mean profile (slope = -1.49) decrease at about the same rate as what was found in Davies et al. 2022 and less rapidly as compared with Winslow et al. 2015 (slope = -1.95).

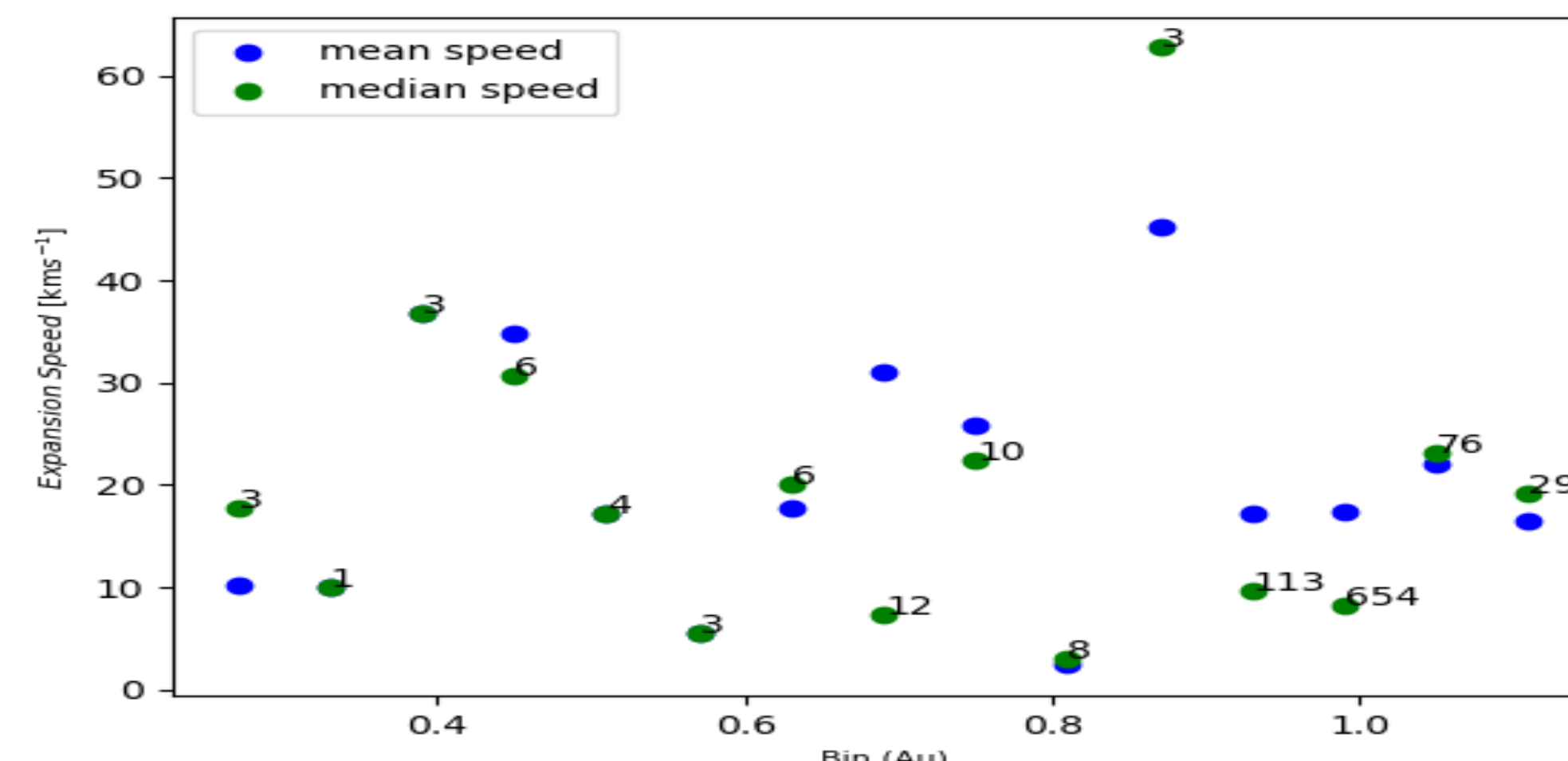


Figure 3: The expansion speed of ME as a function of heliocentric distance. The number of CMEs in each bin is indicated for the median speed.

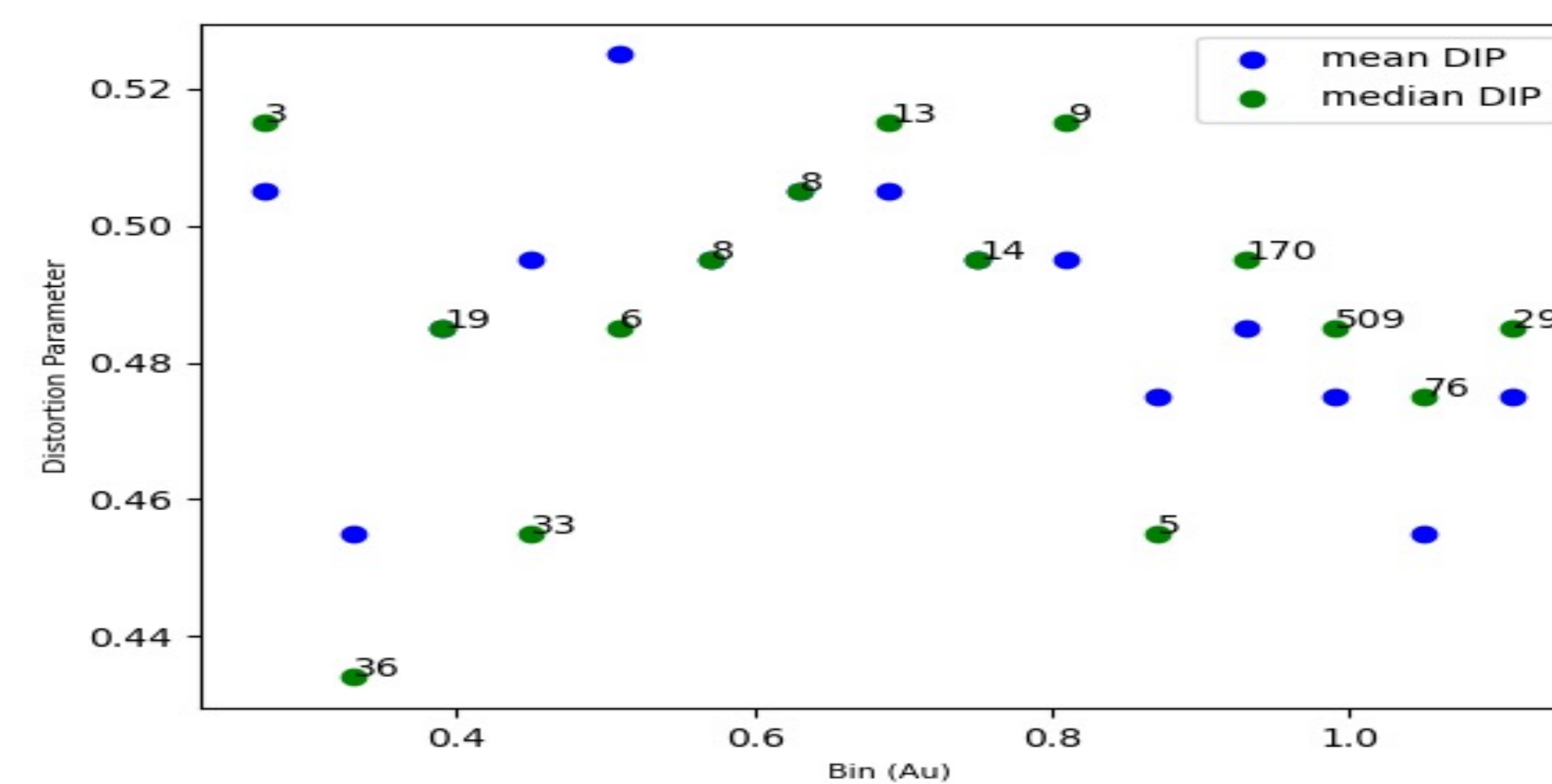


Figure 4: The Distortion Parameter (DiP, see Nieves-Chinchilla et al. 2018) of the ME as a function of heliocentric distance (au).

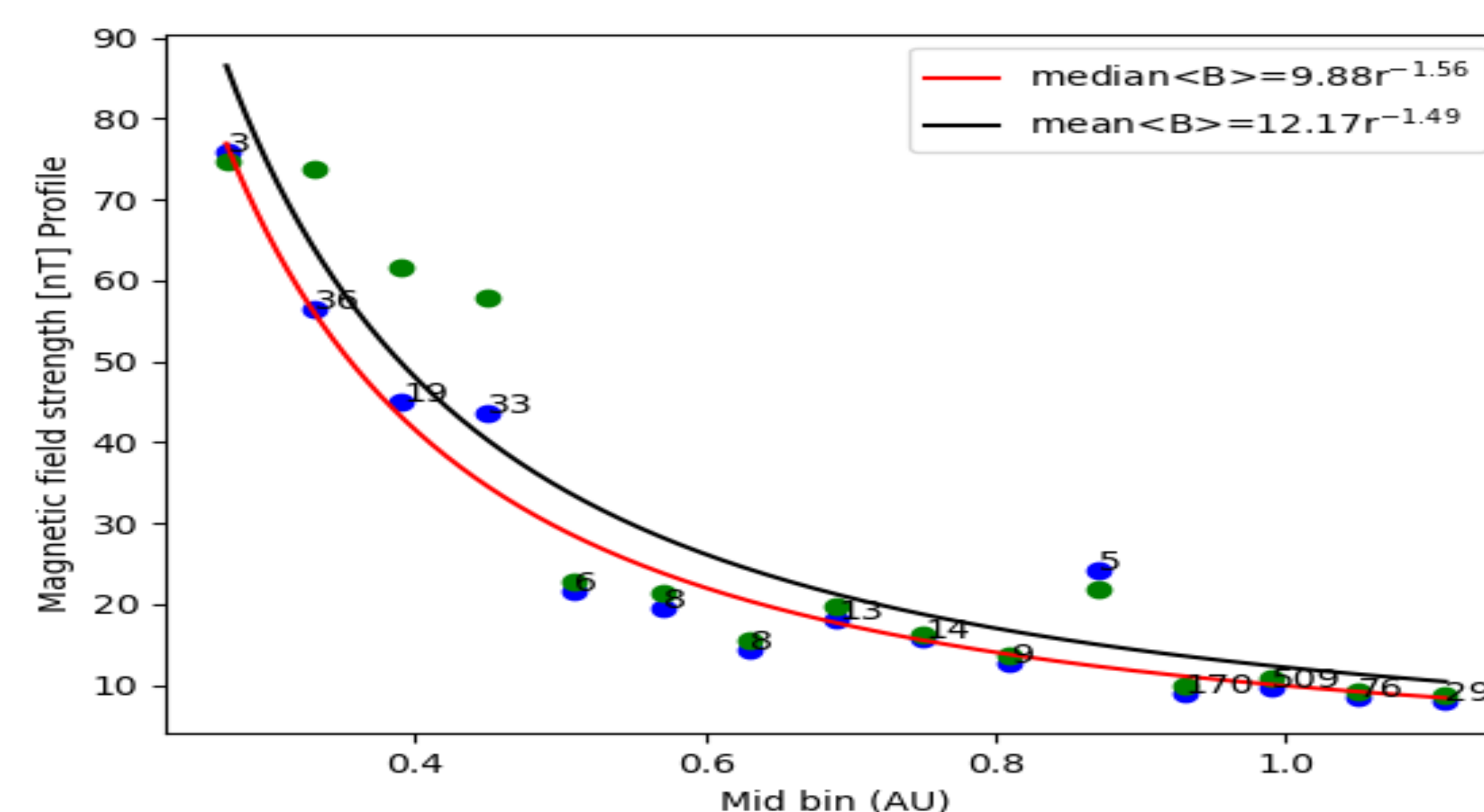


Figure 5: The average magnetic field strength (nT) in ME for mean and median profile as a function of heliocentric distance (au).

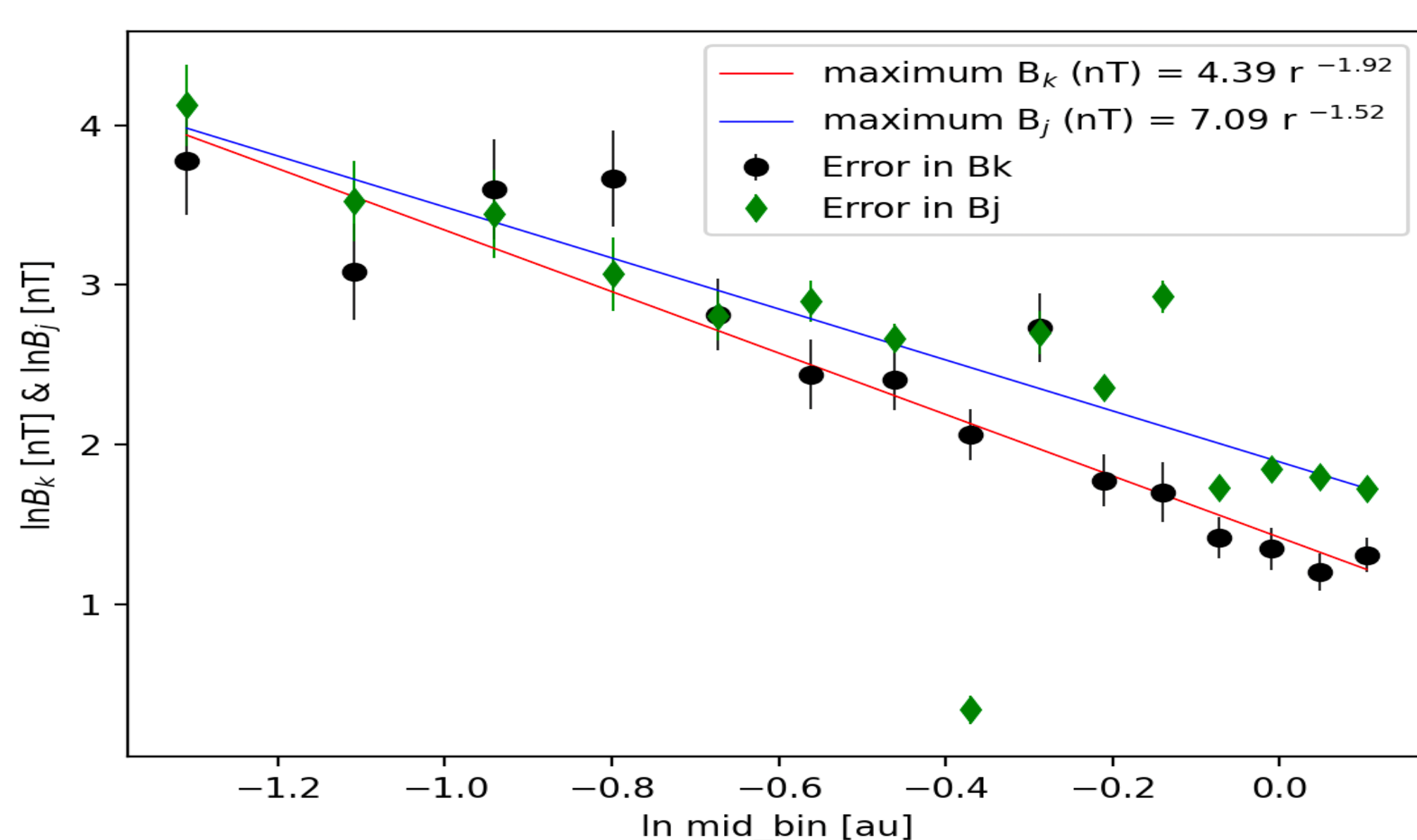


Figure 6: The ln maximum B_k and ln maximum B_j as a function of heliocentric distance (au) [ln Mid bin].

4. Discussion

We used the mean and median values as proxies to better understand the CME behavior during:

5.1: Active Phase (AP) & Quiet Phase (QP) CMEs

- The B_{mag} and plasma parameters in the sheath of AP CMEs show greater enhancement as compared to the QP. This is consistent with the maximum speed of AP ME being on average 32 km/s higher than that of QP ME. Faster CMEs drive stronger sheaths.
- All parameters of AP MEs are higher than QP MEs except for the density n_p which is lower. This is consistent with the results of Regnault et al. 2020. This may reflect differences in initiation mechanisms.
- The ME expansion speed during AP for the mean and median profiles are 42 km/s & 37 km/s and during QP it is 21 km/s & 11 km/s. This suggests that the AP CMEs expand more during their propagation.
- Computing the distortion parameter, the AP mean and median DiP is 0.475, but for QP the mean and median DiPs are 0.505 & 0.495 respectively. This suggests that the MEs during AP are less symmetric than during the QP.

5.2: CMEs measured at different heliocentric distances

- The expansion speed for all CMEs as a function of heliocentric distance does not have a clear trend. Solar cycle effects may be compounded on distance effects.
- The distortion parameter for the CMEs as a function of heliocentric distance for mean profile seems to follow a decreasing pattern with high variability.
- The plot of maximum B_ϕ and B_z as a function of heliocentric distance from the MVA analysis shows a decrease in the axial and poloidal magnetic fields that have a similar power-law index fig(6).

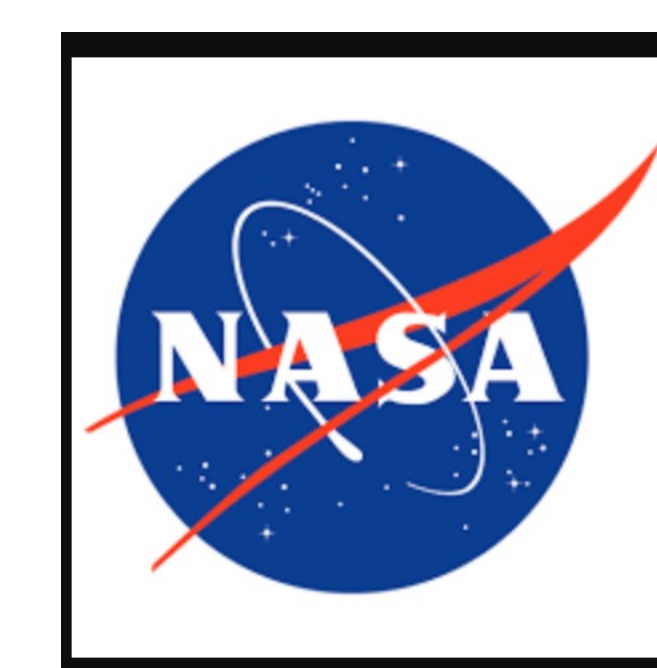
5. Conclusion & Future work

We have used over 1000 CME events classified as Active or Quiet phase CME solar cycle period to perform Superposed Epoch Analysis. This allowed us to study some properties of the CMEs as a function of heliocentric distance from the Sun. Here we consider about 3 decades dataset from multiple spacecraft which is 3 times more CMEs events than what was studied by (Regnault et al. 2020) that were just from a single probe: ACE.

We also group the events into bins of heliocentric distances and study the distance variation of magnetic field components: the axial and the poloidal fields.

7. Acknowledgement

This research is being supported by NSF grant AGS1954983, NASA 80NSSC21K0463 and 80NSSC20K0197.



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