Evolution of CME Properties Through Superposed Epoch Analysis from 0.2 to 2.2 au.

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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)**.

In this work, we study evolution of CMEs from 2 perspectives:
A: Solar Cycle phases
B: Heliocentric distances from the Sun.

2. Effect of Solar Cycle on CME Properties

We group the events from Helio4Cast catalog 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 (SEA) to obtain the statistical mean and median profiles of the CMEs in each phase.

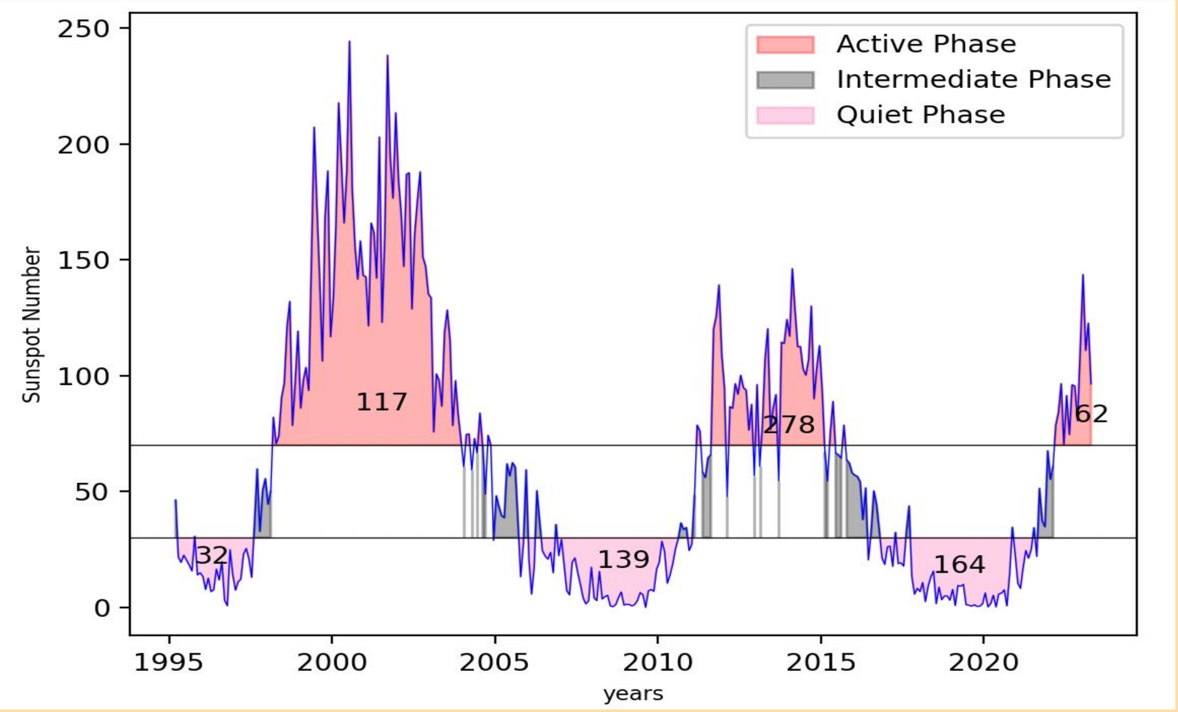

Figure 1: Sunspot plot classifying the Active CME phase (AP), intermediate phase and Quiet CME phase (QP) respectively for events in Helio4Cat Catalogue.

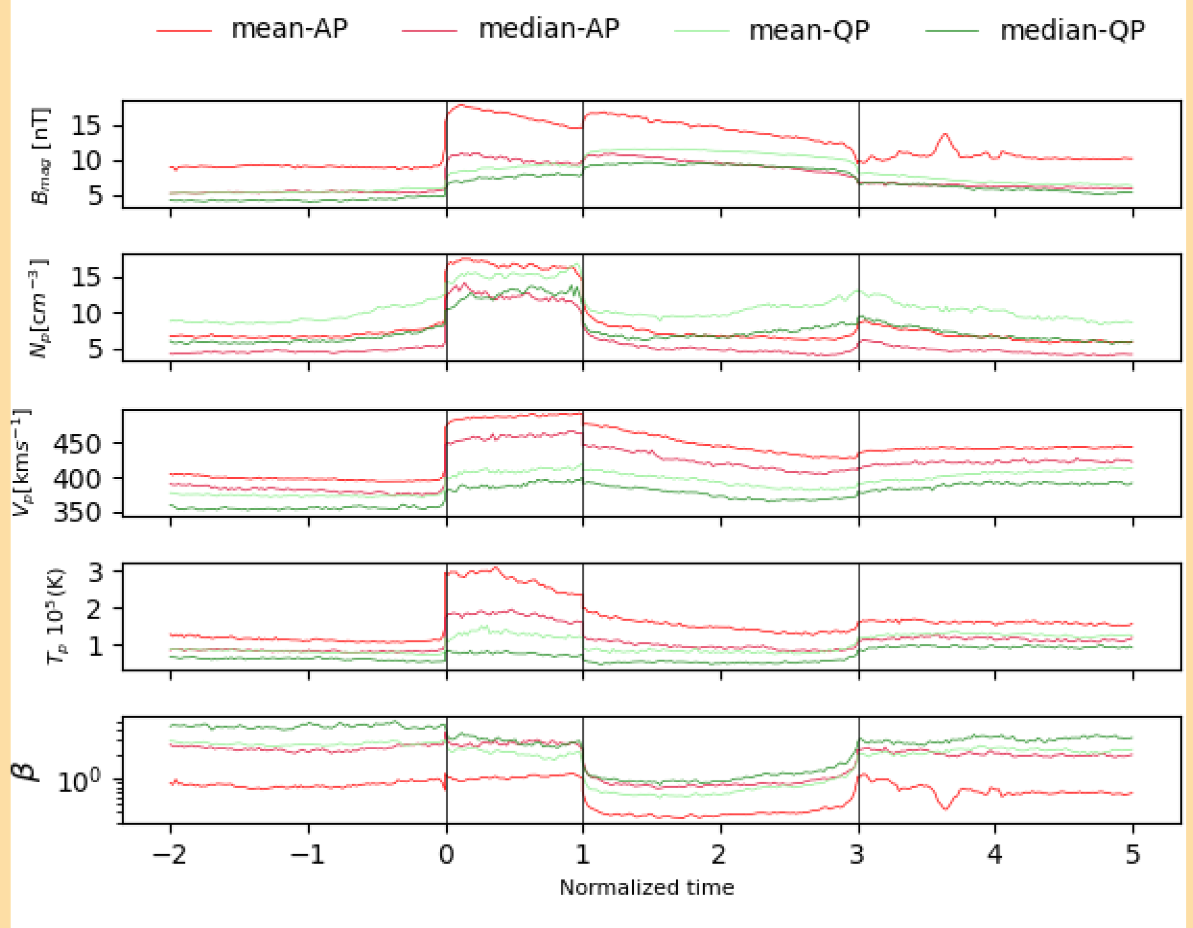

Figure 2: Superposed epoch analysis of CME events based on solar cycle phases (AP & QP). From the left: pre-solar wind, sheath, magnetic ejecta(ME) and the wake region respectively.

3. CME Study at different heliocentric distances

We study the variation of the CME (properties) from Helio4cat catalogue and JUNO datasets with heliocentric distance. We perform a superposed epoch analysis on the magnetic field components, B_ϕ and B_z, obtained from the minimum variance analysis (MVA). Figures (4,5,6) shows the SEA for Bin 19, average magnetic field profiles, and Ransac fitting for axial and poloidal magnetic field components respectively.

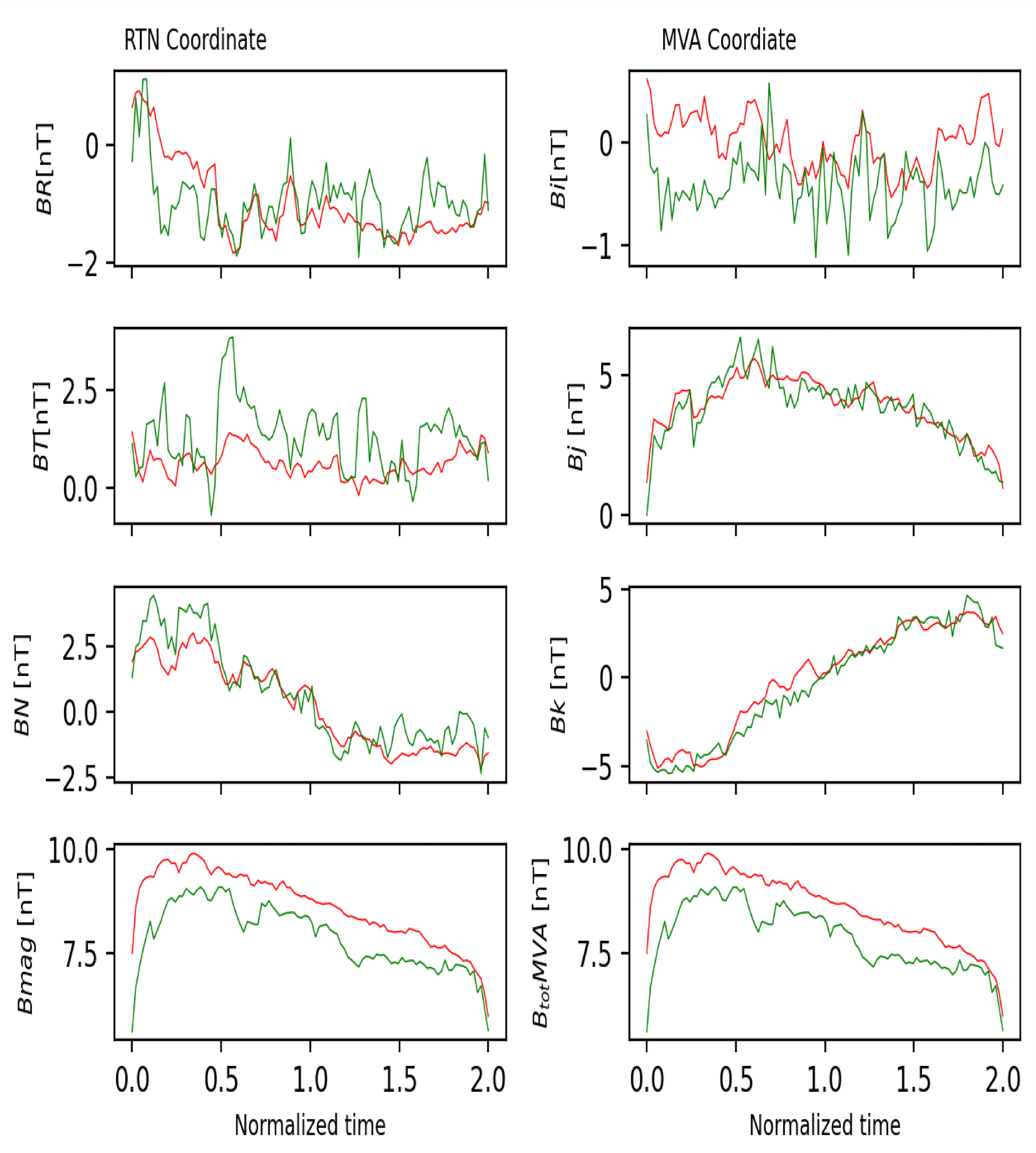

Figure 3: Sample SEA result (Bin 19) for magnetic field components in RTN vs MVA coordinate.

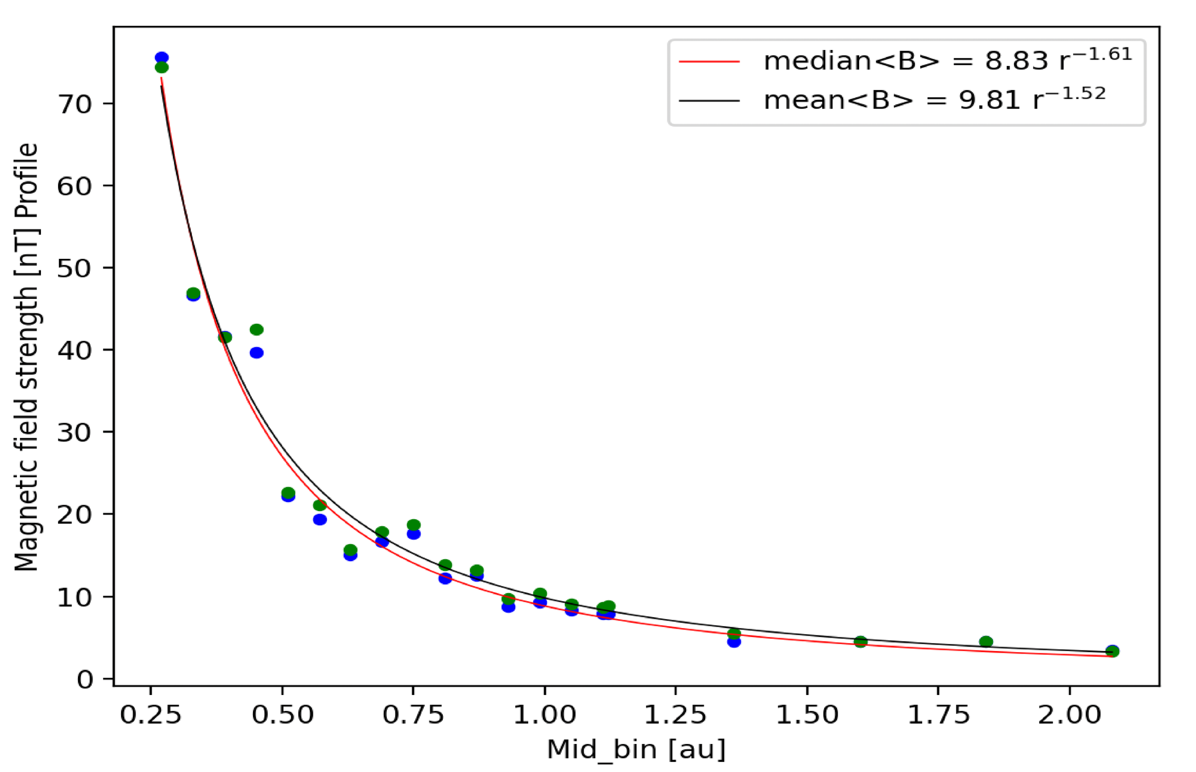

Figure 4: The ME average magnetic field as function of heliocentric distance for the mean profile (slope = -1.52) decrease at about the same rate as what was found in **Davies et al. 2022** and less rapidly as compared with **Winslow et al. 2015** (slope = -1.95).

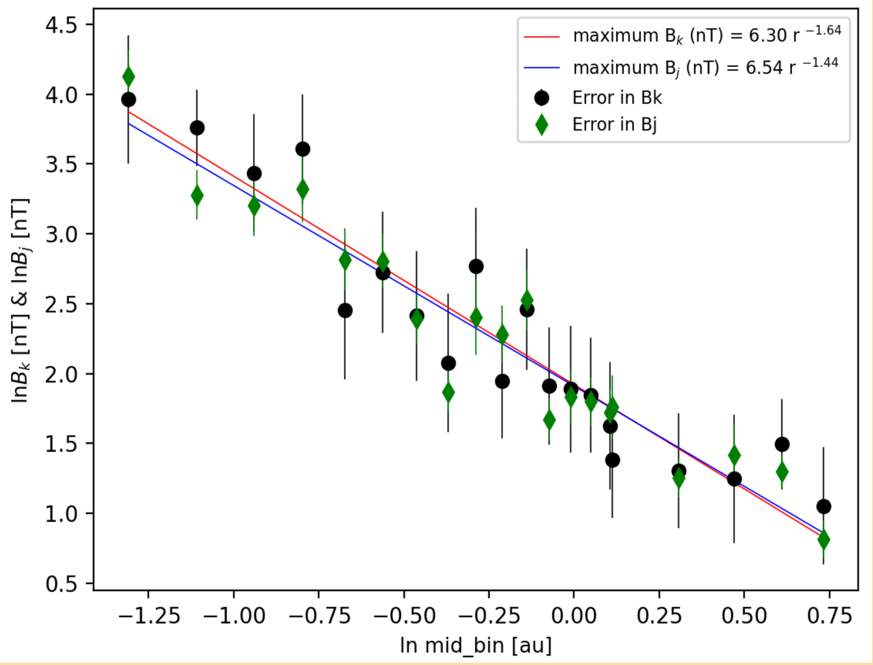

Figure 5: The plot of ln maximum B_k & ln maximum B_j (nT) as a function of heliocentric distance [ln mid_bin (au)]

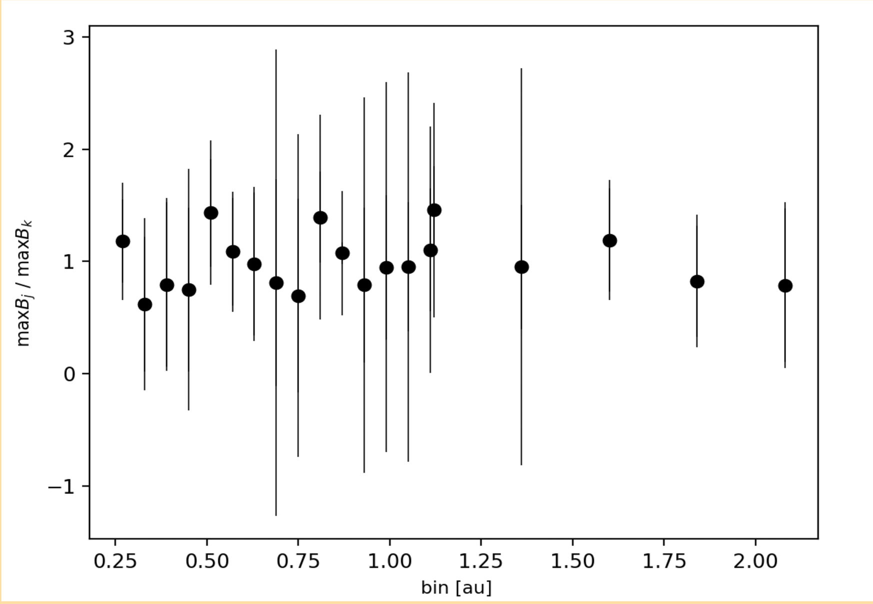

Figure 6: The ratio of maximum B_j to maximum B_k as a function of heliocentric distance [bin (au)]

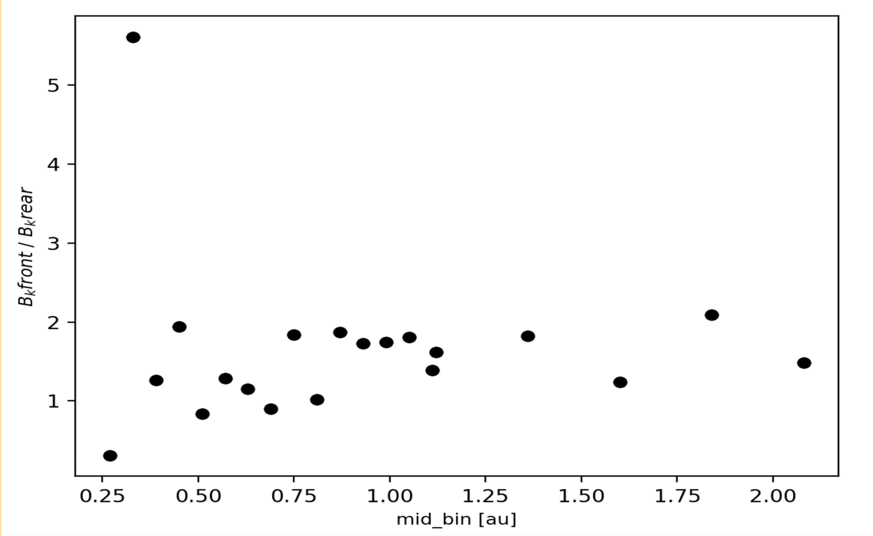

Figure 7: The ratio of B_k front to B_k rear as a function of heliocentric distance [mid_bin (au)].

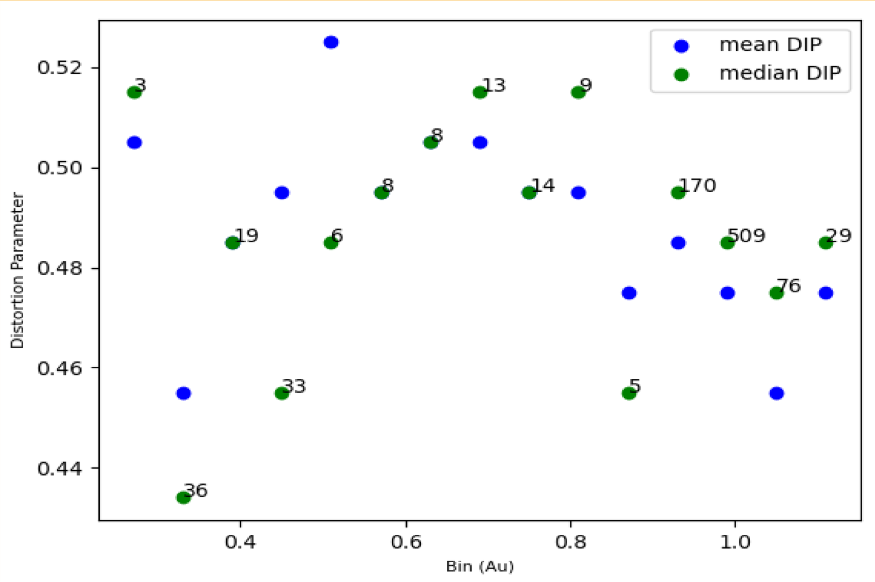

Figure 8: The Distortion Parameter (DiP, see **Nieves-Chinchilla et al. 2018**) of the ME as a function of heliocentric distance (au).

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4. Results

4.1: Active Phase (AP) & Quiet Phase (QP) of the Solar Cycle.

- 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 32km/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.*

4.2: CMEs measured at different heliocentric distances from the Sun

- The expansion speed for all CMEs as a function of heliocentric distance does not have a clear trend. Solar cycle effects may be compounded with 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 (5).**
- The plot of the ratio of front to rear maximum B_k are generally greater than 1. This is due the aging effect (e.g., expansion) of the CMEs as also reported by **Yu et al. 2024** and **Regnault et al. 2024.**
- similar decrease rates of Bj and Bk in figure (6) suggest that the coronal mass ejection (CME) expands at comparable rates along both its radial and axial directions, indicating a uniform expansion behavior in these dimensions.

5. Conclusion

We have used over 1000 CME events from Helio4cast catalogue; classified as Active or Quiet phase CME solar cycle period to perform Superposed Epoch Analysis. This allowed us to study some temporal properties of the CMEs. Adding JUNO dataset to the existing events, we also study some variational properties of CMEs as a function of heliocentric distance from the Sun. Therefore, we consider about 3 decades dataset which is 3 times more CMEs events from multiple spacecraft than what was studied by **(Regnault et al. 2020)** whose measurements was 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 and performed SEA for MVA magnetic field coordinate systems.

Acknowledgement

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Reference

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