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Coronal Mass Ejections (CMEs) are critical drivers of space weather, whose evolution in the heliosphere is shaped by interactions with the ambient solar wind and other CMEs. These interactions can lead to significant deformations and changes in CME properties, which have substantial implications on their geoeffectiveness. However, the complex interplay between CME and the surrounding solar wind, as well as CME-CME interactions, remains inadequately explored, particularly from a quantitative perspective.

This work leverages the MHD-based SWASTi framework to investigate the changes in the trajectory, structure and internal properties of CMEs as they propagate in the inner heliosphere. The model incorporates a modified WSA relation to set realistic solar wind conditions and includes flux rope CME. A unique passive scalar tracing methodology is employed to isolate CME structures and analyze their interactions within the heliosphere.

The following key aspects of the study will be presented:

1. CME-Solar Wind Interaction: Simulations demonstrate how variable solar wind properties modulate the expansion, shape, and pressure profiles of CMEs. Synthetic benchmarks with uniform solar wind conditions are used to isolate the influence of ambient wind variability.

2. CME-CME Interaction: Multiple interaction scenarios highlight non-uniformity across CMEs due to the inherent inhomogeneity of the heliospheric environment. Reverse shocks, compression zones, and drag forces significantly alter CME trajectories and dynamics.

3. Quantitative Insights: Detailed analyses of thermal, magnetic, and kinetic pressures during CME evolution reveal a non-fractal power-law expansion of CME volume, eventually reaching a balanced state.

The findings offer new insights into CME evolution and deformation, laying the groundwork for improved space weather prediction models. Additionally, this study offers a promising pathway for using PUNCH mission observations to validate and refine simulation outputs. By combining PUNCH's high-resolution imaging of the inner-heliospheric environment with SWASTi's detailed modeling capabilities, a comprehensive understanding of CME dynamics can be achieved.
Presentation file
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