Polytropic behavior in the substructure of interplanetary coronal mass ejections

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The polytropic process is a quasi-static thermodynamic state that characterizes space plasma populations described by kappa distributions. The polytropic index, γ, is particularly important as it describes the thermodynamic behavior of the system by quantifying the changes in temperature as the system gets compressed or expands. Using Wind spacecraft plasma and magnetic field data during 02/1995 – 12/2015, we investigate the thermodynamic evolution in 336 Interplanetary Coronal Mass Ejection (ICME; [1]) events. For each event, we derive the polytropic indices (e.g., [2]) in the sheath and magnetic ejecta structures, along with the pre- and post- event regions. We then examine the distributions of these indices in the four identified regions and connect their properties with derived entropy [3,4] and turbulent heating [5] gradients. We find that in the ICME sheath region where wave turbulence is expected to be highest, the thermodynamics takes longest to recover into the original quasi-adiabatic process, while it recovers faster in the quieter ejecta region. This pattern creates a thermodynamic cycle, featuring a near adiabatic value $\gamma \sim \gamma_a = 5/3$ upstream of the ICMEs, $\gamma_a - \gamma \sim 0.26$ in the sheaths, $\gamma_a - \gamma \sim 0.13$ in the ICME ejecta, and recovers again to $\gamma \sim \gamma_a$ after the passage of the ICME. These results expose the turbulent heating rates in the ICME substructures. The lower the polytropic index from its adiabatic value, the larger the rate of turbulent energy that heats the ICME plasma. In other words, increased energy absorption in the sheath driven by its fast expansion would result in a low polytropic index.

For full details, see Dayeh and Livadiotis, 2022 [6].

References

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