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Drag Force in Coronal Mass Ejections: Propagation and Morphological Evolution During the Solar Minimum

'Coronal Mass Ejections (CMEs) constitute magnetised plasma volumes expelled from the inner corona that propagate through the heliosphere under quasi-ballistic kinematics initially, before entering a drag-dominated regime imposed by the ambient solar-wind (SW) flow. To parameterise this magnetohydrodynamic drag, we compute the retarding force exerted by the bimodal SW typical of solar-minimum conditions and solve the associated equation of motion for three velocity–mass archetypes—slow ($v_0 < 400\ \mathrm{km\ s^{-1}};\ \ m \sim 10^{11}$ kg), intermediate ($400 \leq v_0 \leq 1000;\ \mathrm{km\ s^{-1}};\ m \sim 10^{12}$ kg) and fast ($v_0 > 1000\ \mathrm{km\ s^{-1}};\ m \sim 10^{13}$ kg) events. The model treats the CME as either a self-similar sphere or an expanding prolate ellipsoid, allowing the instantaneous drag coefficient C_D to be expressed explicitly as a function of the evolving cross-sectional area and aspect ratio. Numerical integration reveals that, irrespective of launch speed, the CME velocity asymptotically relaxes toward the local SW speed on heliocentric scales
$gtrsim0.3\,\mathrm{au}$, with convergence timescales inversely proportional to the size-to-mass ratio. The spherical-to-ellipsoidal transition amplifies the effective C_D by up to an order of magnitude, highlighting the critical role of morphological evolution. Finally, we analyse each kinematic class for susceptibility to Kelvin–Helmholtz and Rayleigh–Taylor modes during CME–SW coupling, identifying fast-massive ellipsoidal CMEs as the most instability-prone scenario under typical solar-minimum parameters.

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