EGU General Assembly 2021

EGU21-10578, updated on 25 May 2022
https://doi.org/10.5194/egusphere-egu21-10578
EGU General Assembly 2021

The three-dimensional density compression ratio of shock fronts observed as halo coronal mass ejections

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We present a novel method to derive the shock density compression ratio of coronal shock waves that are occasionally observed as halo coronal mass ejections (CMEs). Our method uses the three-dimensional (3-D) geometry and enables us to access the reliable shock density compression ratio. We show the 3-D properties of coronal shock waves seen from multiple vantage point observations, i.e., geometry, kinematics, and compression ratio (Mach number). The significant findings are as follows: (1) Halo CMEs are the manifestation of spherically shaped fast-mode waves/shocks, rather than a matter of the projection of expanding flux ropes. The footprints of halo CMEs on the coronal base are the so-called EIT/EUV waves. (2) These spherical fronts arise from a driven shock (bow- or piston-type) close to the CME nose, and it is gradually becoming a freely propagating (decaying) fast-mode shock wave at the flank. (3) The shock density compressions peak around the CME nose and decrease at larger position angles (flank). (4) Finally, the supercritical region extends over a large area of the shock and lasts longer than past reports. These results offer a simple unified picture of the different manifestations for CME-associated (shock) waves, such as EUV waves and SEP events observed in various regimes and heliocentric distances. We conclude that CME shocks can accelerate energetic particles in the corona over extended spatial and temporal scales and are likely responsible for the wide longitudinal distribution of these particles in the inner heliosphere.