Geophysical Research Abstracts
Vol. 18, EGU2016-4752-2, 2016
EGU General Assembly 2016

Lagrangian MHD Particle-in-Cell simulations of coronal interplanetary shocks driven by observations

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In this work, we compare the spatial distribution of the plasma parameters along the June 11, 1999 CME-driven shock front with the results obtained from a CME-like event simulated with the FLIPMHD3D code, based on the FLIP-MHD Particle-in-Cell (PiC) method. The observational data are retrieved from the combination of white-light (WL) coronagraphic data (for the upstream values) and the application of the Rankine-Hugoniot (RH) equations (for the downstream values). The comparison shows a higher compression ratio X and Alfvénic Mach number MA at the shock nose, and a stronger magnetic field deflection d towards the flanks, in agreement with observations. Then, we compare the spatial distribution of MA with the profiles obtained from the solutions of the shock adiabatic equation relating MA, X, and the angle between the upstream magnetic field and the shock front normal for the special cases of parallel and perpendicular shock, and with a semi-empirical expression for a generically oblique shock. The semi-empirical curve approximates the actual values of MA very well, if the effects of a non-negligible shock thickness and plasma-to magnetic pressure ratio are taken into account throughout the computation. Moreover, the simulated shock turns out to be supercritical at the nose and sub-critical at the flanks. Finally, we develop a new 1D Lagrangian ideal MHD method based on the GrAALE code, to simulate the ion-electron temperature decoupling due to the shock transit. Two models are used, a simple solar wind model and a variable-gamma model. Both produce results in agreement with observations, the second one being capable of introducing the physics responsible for the additional electron heating due to secondary effects (collisions, Alfvén waves, etc.).

Work supported by the European Commission under the SWIFF project (swiff.eu)