Departement
WISKUNDE

CME generated MHD shocks: creation, evolution, and impact

S. Poedts, B. van der Holst, I. Chattopadhyay, D. Shergelashvili, D. Banerjee, R. Keppens (FOM), and H. Deconinck (VKI)

Celestijnenlaan 200 B,
B–3001 LEUVEN
BELGIUM

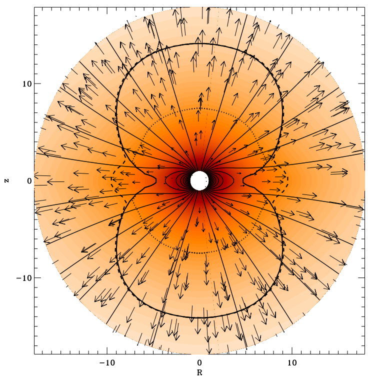
Motivation and context

The shocks in the solar corona caused by fast CMEs and the shock at the Earth's magnetosphere caused by the corresponding magnetic clouds (superposed on the solar wind) are studied in the framework of computational magnetohydrodynamics (MHD). Due to the presence of three characteristic velocities and the anisotropy induced by the magnetic field, MHD shocks can have a complicated structure including secondary shock fronts, overcompressive and compound shocks, etc.
The CME shocks are simulated superposed on the background solar wind. Special attention is given to interactions of two subsequent CME shocks in the IP medium and to the interaction of a CME/magnetic cloud with the bow shock at the Earth's magnetosphere. The change of the topology of the shock at the Earth's magnetosphere at the impact of a magnetic cloud is important for the **'geo-effectiveness'** *of the magnetic storms.*

Numerical method(s)

In addition to our state-of-the-art FVM codes (with standard Riemann solvers), we extended recent innovative CFD techniques (VKI) to computational (ideal) MHD including: a compact finite element multi-D upwind CRD ('Conservative Residual Distribution') discretization, *unstructured* adaptive meshes, and parallel implicit solvers. These novel techniques have excellent shock capturing properties and a narrower stencil than the standard FVM schemes which is CPE time and memory saving in demanding (large-scale, 3D, implicit) calculations.

Background solar wind



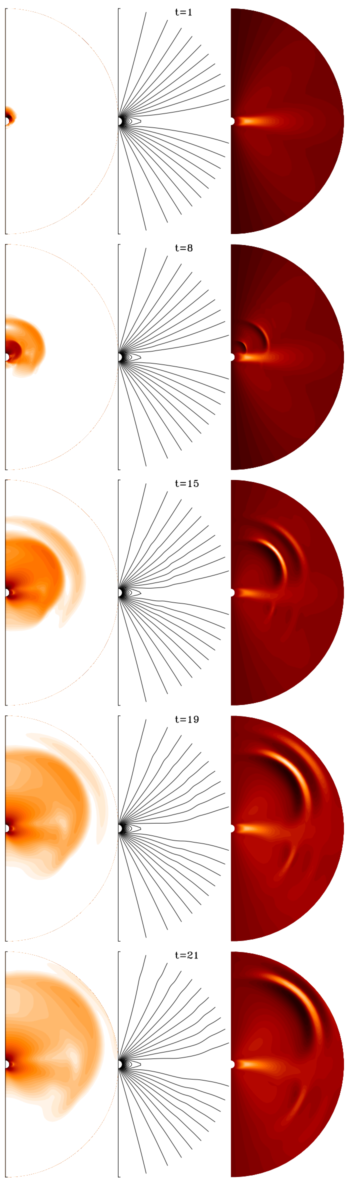
The 2D MHD wind solution (extension of Keppens et al. '00).

The gross macroscopic behaviour of the solar wind can be qualitatively described by the MHD equations. The stationary background wind solution is modelled modelled by choosing at the reference position $r_* = 1.25\,R_\odot$: the temperature $T_0 \approx 1.5\times10^6$ K, the number density $N_0 \approx 10^8$ cm^{-3}, the angular velocity $\Omega \approx 3\times10^{-6}$ s^{-1}, and the radial magnetic field $B_r \approx 2$ G. Far away from the sun the plasma outflow is superfast and continuous. Here, we assume a polytropic state, $p/p_0 = (\rho/\rho_0)^\alpha$, where p is the plasma pressure, ρ the density, and α the polytropic index taken to be 1.13.

Colliding CME shocks

According to Burlaga ('01) *two thirds of the interplanetary ejecta are complex*, i.e. last several days and may consist of two or more CMEs coming together. Gopalswamy ('01) made a detailed and *careful analysis of radio observations of two CMEs* at different speeds originating from different regions on the Sun. We initiated a study of interacting CMEs. Preliminary results are shown here. The CMEs are simulated by means of injections of high density, high momentum plasma blobs superposed on the background solar wind (see above).

CME	g (in g/s)	t	τ	θ	a
CME$_1$	1.458×10^{12}	0	1	30°	36°
CME$_2$	5.299×10^{12}	5	1	30°	36°

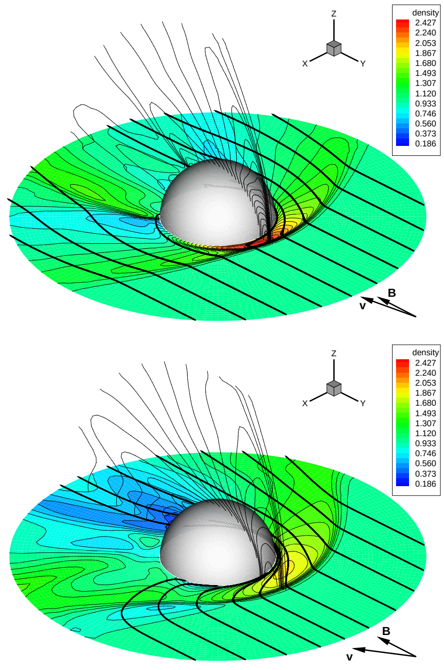


Five snapshots of the evolution of 2 subsequent CMEs. Left: the density difference between the evolving mass ejection and the background solar wind. Middle: the magnetic field structure. Right panel: the toroidal velocity component v_ϕ. Time is normalized: $1 = 87$ min. The simulation domain reaches from 1.25 up to roughly 36 solar radii. Results from the VAC code.

In 3D flows too, the shock front can not be entirely of the fast shock type near a perpendicular point with a fast switch-on shock (discontinuity). The magnetized flow needs a complex shock front to get around the sphere.

Earth bow shock topology

It is very likely that *during the impact of a magnetic cloud* the conditions for fast switch-on shocks are met. Simulations show that in that case the plasma flow needs a complex bow shock topology to get around the Earth's magnetosphere. Some recent 3D results from the EUPHORIA code. . .



Above: Earth bow shock during CME impact for $\theta_{vB} = 5^\circ$. Below: the same for $\theta_{vB} = 30^\circ$.

Conclusions

State-of-the-art FVM and innovative multidimensional upwind CRD schemes are exploited to solve the ideal MHD equations. The interaction of two subsequent CMEs in the IP medium superposed on the solar wind has been simulated in 2D MHD. The collision of the corresponding shocks is studied. During impact of the magnetic clouds on the Earth's bow shock *complex shock topologies with intermediate shock fronts* are formed. *The secondary shocks certainly affect the geo-effectiveness of magnetic storms:* the associated switching back of the magnetic field lines must influence the reconnection process at the terrestrial magnetopause. However, much more modelling and parameter studies are required

Some references

- H. De Sterck, B.C. Low, and S. Poedts: *Phys. Plasmas* **6 (3)**, 954–969 (1999).
- H. De Sterck and S. Poedts: *J. Geophys. Res.* **104 (A10)**, 22401 - 22406 (1999).
- A. Csík, H. Deconinck, and S. Poedts: *AIAA journal*, **39 (8)**, 1532–1541 (2001).
- H. De Sterck and S. Poedts, *J. Geophys. Res.* **106 (A12)**, 30023–30037 (2001).