Modeling the Lunar Wake Response to a CME Using a Hybrid-PIC Model

A. P. Rasca[1], S. Fatemi[2,3], and W. M. Farrell[1]

[1]*NASA/Goddard Space Flight Center, Greenbelt, MD, USA,* [2]*Swedish Institute of Space Physics, Kiruna, Sweden* [3]*Department of Physics, Umeå University, Sweden*

I. Abstract

In the solar wind, low density wake regions form downstream of the nightside lunar surface surface. This wake region affects the surface potentials across the nightside region of the Moon. In this study, we use a series of 3-D hybrid-PIC simulations to model the response of the lunar wake to a passing coronal mass ejection (CME). Average plasma parameters are extracted from the Wind spacecraft located at 1 AU during three distinct phases of a passing halo (Earth-directed) CME on 22 June 2015. Each set of plasma parameters, representing the shock/plasma sheath, a magnetic cloud, and ICME, are used as the time-static upstream boundary conditions for three separate simulations and are compared with results that use nominal solar wind conditions. Results show a shortened plasma void and distinctive rarefaction cone originating from the terminators during the plasma sheath phase, while a highly elongated plasma void reforms during the magnetic cloud and ICME phases. Intense electric and magnetic field development are also observed during the plasma sheath phase along the central wake.

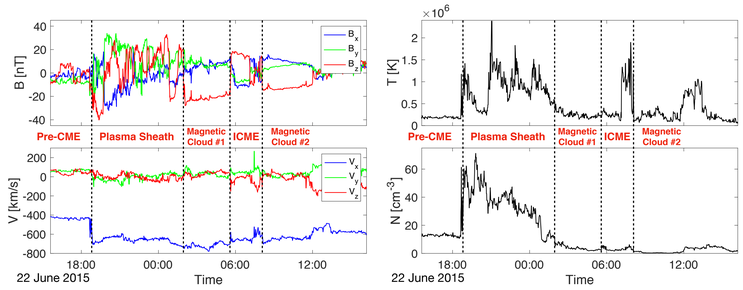
II. Model

- Plasma flows around the Moon are modeled using the Advanced Modeling Infrastructure in Space Simulation (Amitis) code by Fatemi et al. (2017). Amitis solves a 3-D hybrid model by treating electrons as a massless fluid and ions as particles, ideal for scale lengths between the gyro-radii of solar wind electrons and ions.

III. Input Data

- The CME was observed by the Wind spacecraft at the L_1 Lagrangian point near 1 AU. The initial shock was was detected around 18:00 on 22 June 2015, followed by a plasma sheath and two magnetic cloud structures.
- Average plasma parameters from four phases of the event—pre-CME, plasma sheath, first magnetic cloud, and the brief ICME phase separating the two magnetic clouds—are used as time-independent upstream input for a series of hybrid simulations.

Wind Observations, 22-23 June 2015



Upstream Plasma Parameters for Hybrid Simulations

	Pre-CME	Plasma Sheath	Mag. Cloud #1	ICME
n_i (cm^{-3})	13	39	4	3
T (K)	2×10^5	9×10^5	2.5×10^5	5×10^5
V (km/s)	440	650	720	650
B (nT)	$[-1.8, -5.8, -2.7]$	$[-6.4, -11.2, 4.2]$	$[6.3, 7.3, -21.5]$	$[-3.9, -3.4, 9.7]$

Acknowledgments

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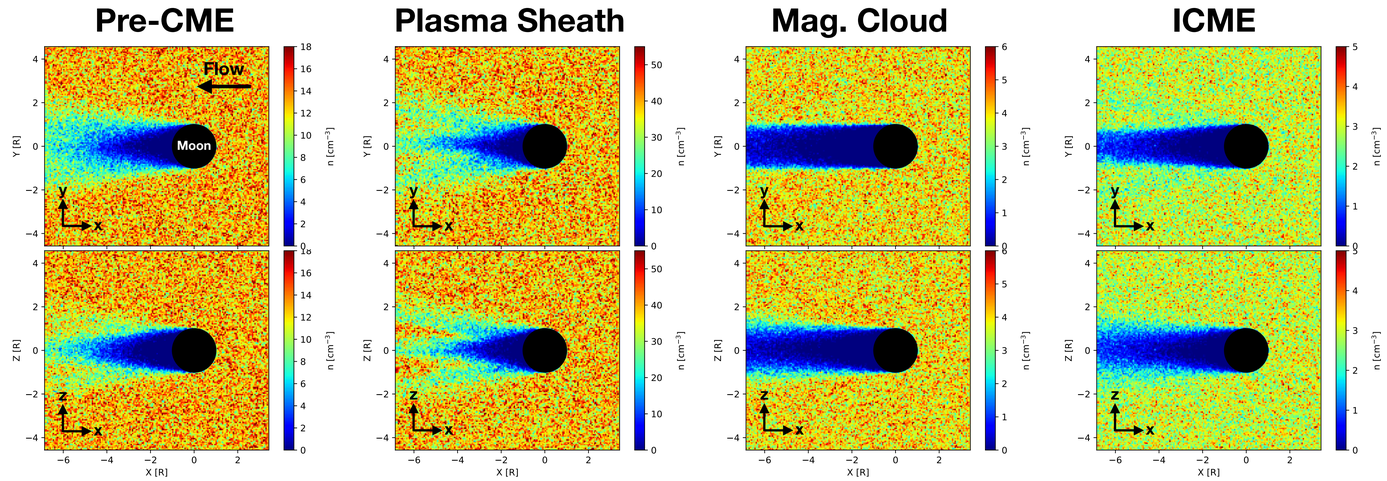
IV. Simulation Results

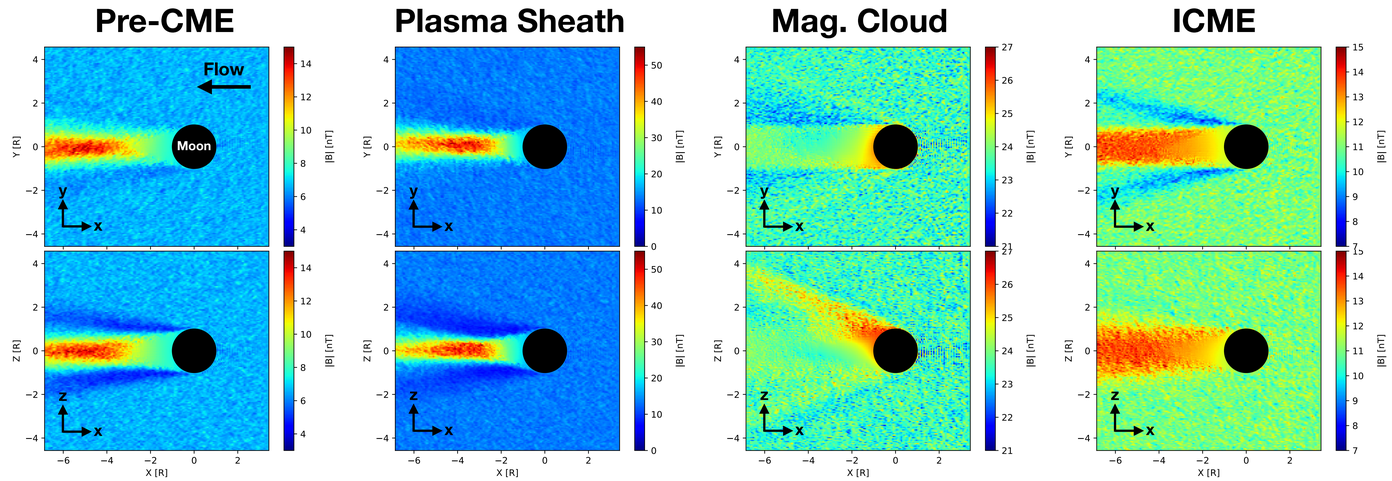
Ion Density

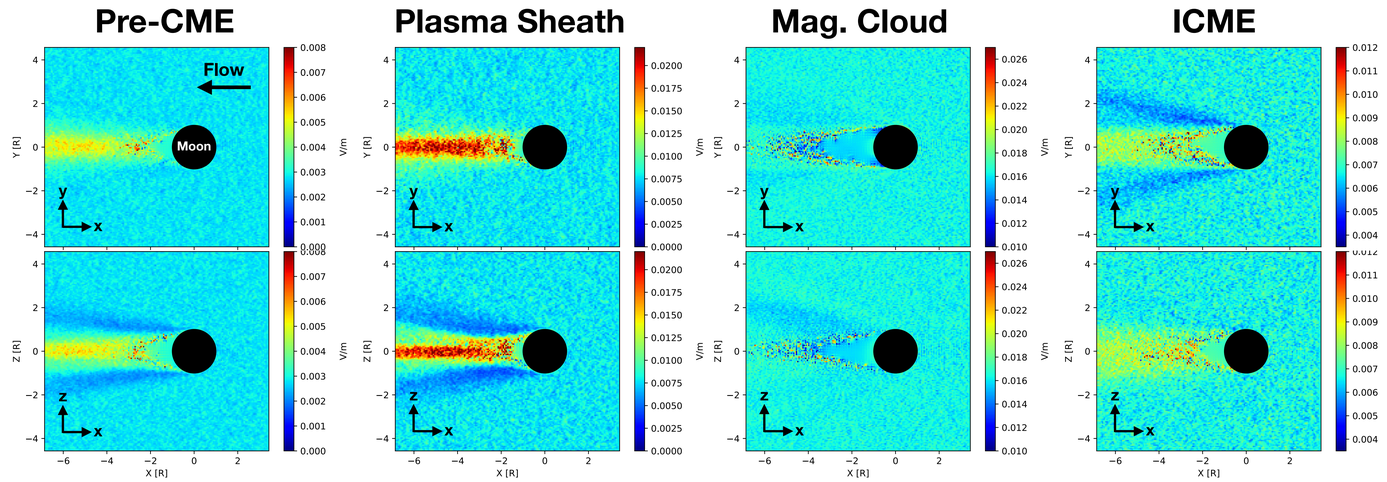
A shortened plasma void and prominent rarefaction cone form as the plasma sheath arrives, followed by an extended wake during the magnetic cloud and ICME.



Magnetic Field Magnitude

We see a compressed magnetic field located downstream in the lunar wake during the plasma sheath phase. During the magnetic cloud, there is a significant shift in the upstream magnetic field, with magnetic compression now occurring very near the nightside surface.



Electric Field Magnitude

An enhanced ambipolar electric field forms in the wake during the plasma sheath phase, but diminishes during the proceeding phases.