Estimating magnetospheric currents and geoeffectiveness of interplanetary CMEs with magnetohydrodynamic simulations

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Abstract

The high energetic plasma and the embedded magnetic field of coronal mass ejections interact with planetary magnetospheres giving rise to transient perturbations such as geomagnetic storms. Predicting the geomagnetic impact of such interplanetary coronal mass ejections (ICME) is of utmost importance for the protection of our technological infrastructure that is affected by space weather. We use 3D compressible magnetohydrodynamic simulation of a star-planet system to model and study an ICME-Earth interaction event of 20th November 2003. In the modelled interaction, we observe a change in magnetopause shape and stand-off distance on ICME impact, day and night side reconnections and induction of high currents in the magnetosphere. We also notice the formation of a ring of strong equatorial current around the Earth, leading to a reduction of the geomagnetic field. We calculate the simulated reduction in the magnetic field and compare that to the observed geomagnetic indices in order to establish a predictive approach for geomagnetic storms. These simulations are expected to illuminate the physical processes that result in space weather impacts of stellar magnetic storms in planetary and exoplanetary systems.

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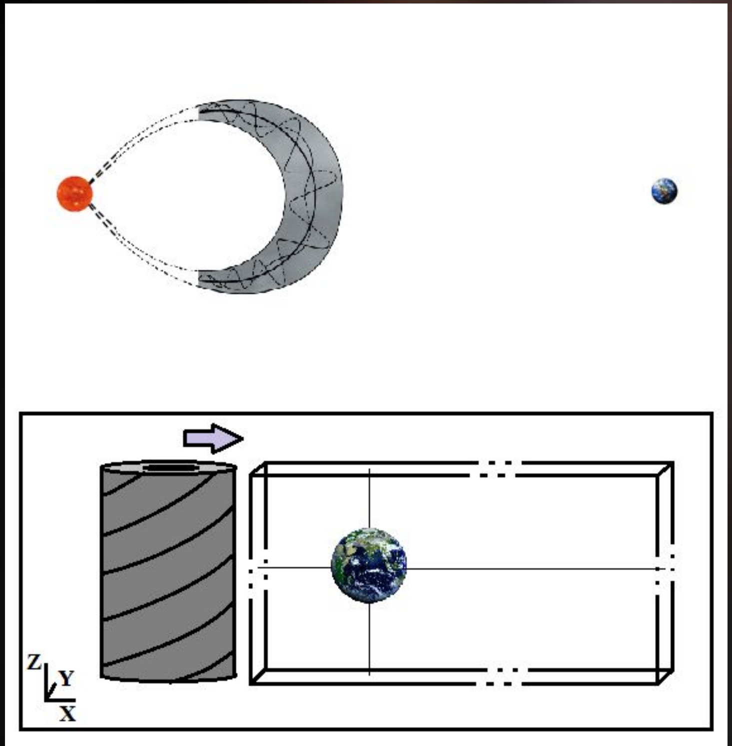
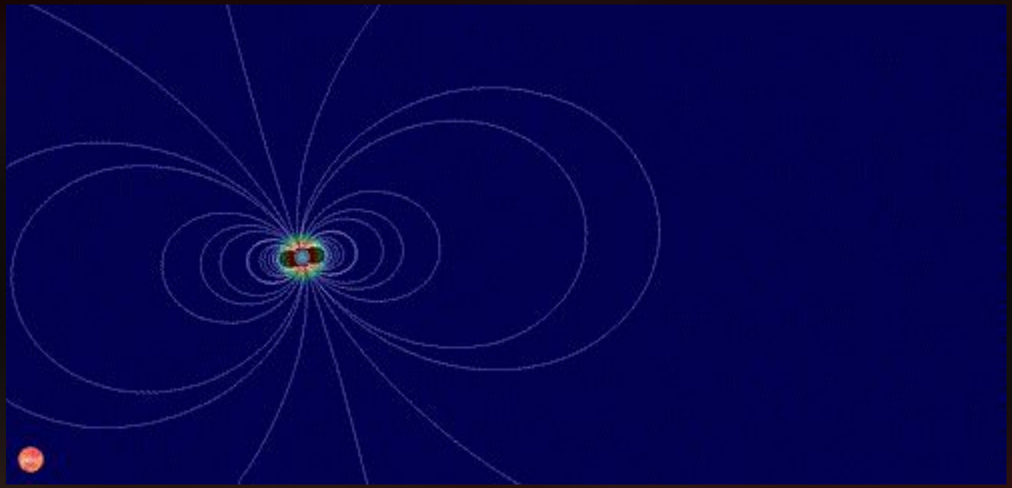
Geomagnetic Impact of Interplanetary CME using CESSI-STROMI

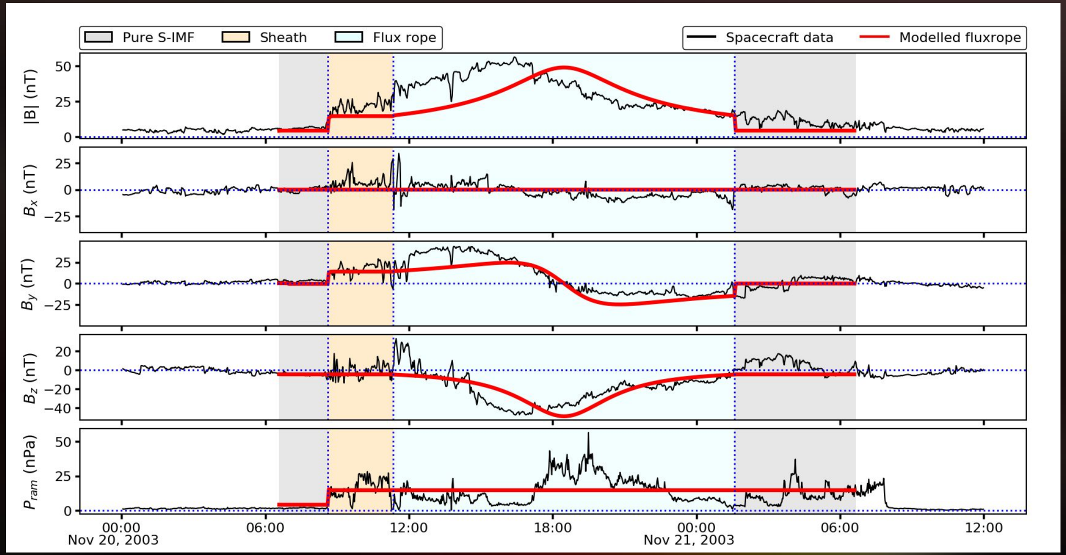
STROMI or the Storm interaction module:

- 3D MHD simulation of star-planet interaction using PLUTO architecture.
- Interplanetary CME with cylindrical Gold-Hoyle (GH) type magnetic flux rope.





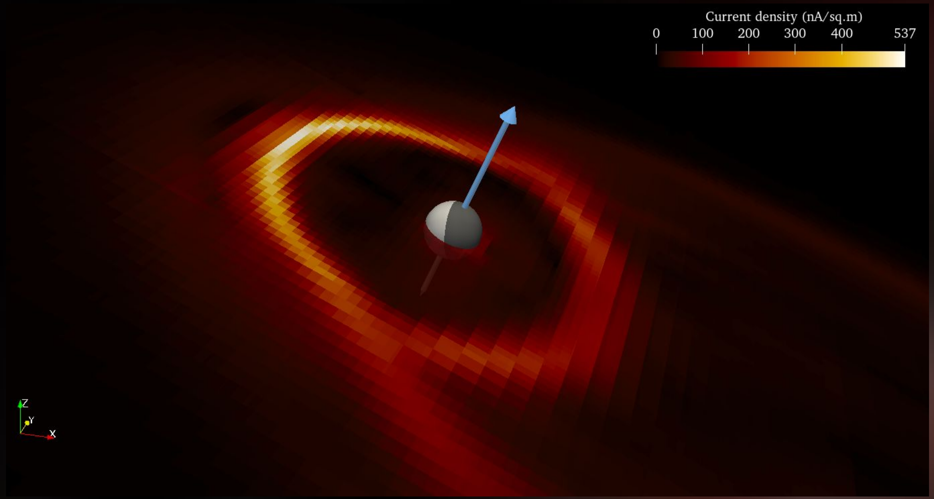
Modelling the 20-Nov-2003 storm event:

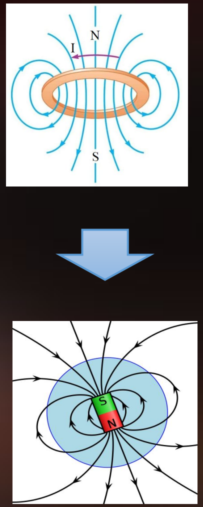


Data source: https://spdf.gsfc.nasa.gov/index.html

Induced Currents and Prediction of Geoeffectivenss

Current ring around Earth:



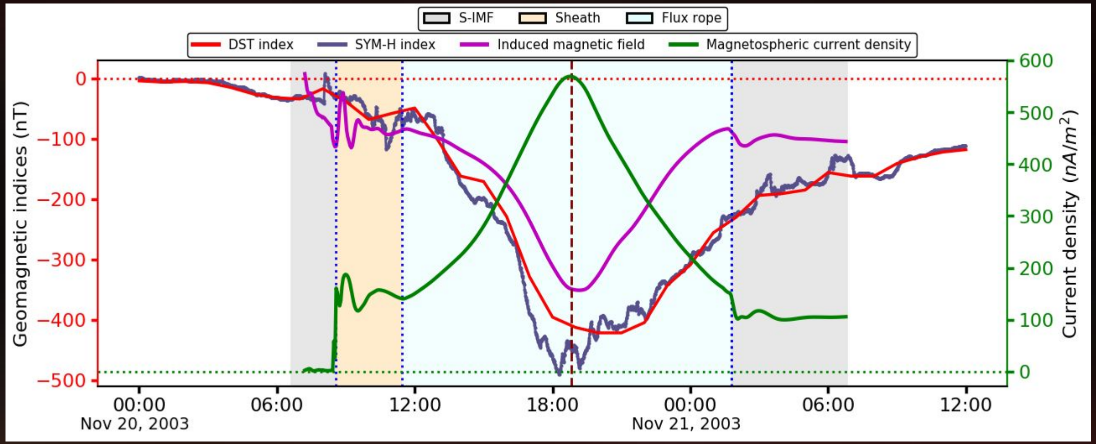


Geo-magnetic Indices:

- Information about the strength of the ring current around Earth
- Measure disturbance in terms of horizontal magnetic field H
- Disturbance Storm Time or DST Index (4 Observatories) and SYM-H Index (11 observatories)

Higher Ring Current → **Weaker Geo-magnetic Field** → **Negative Indices**

Prediction Result:



Data source: https://spdf.gsfc.nasa.gov/index.html

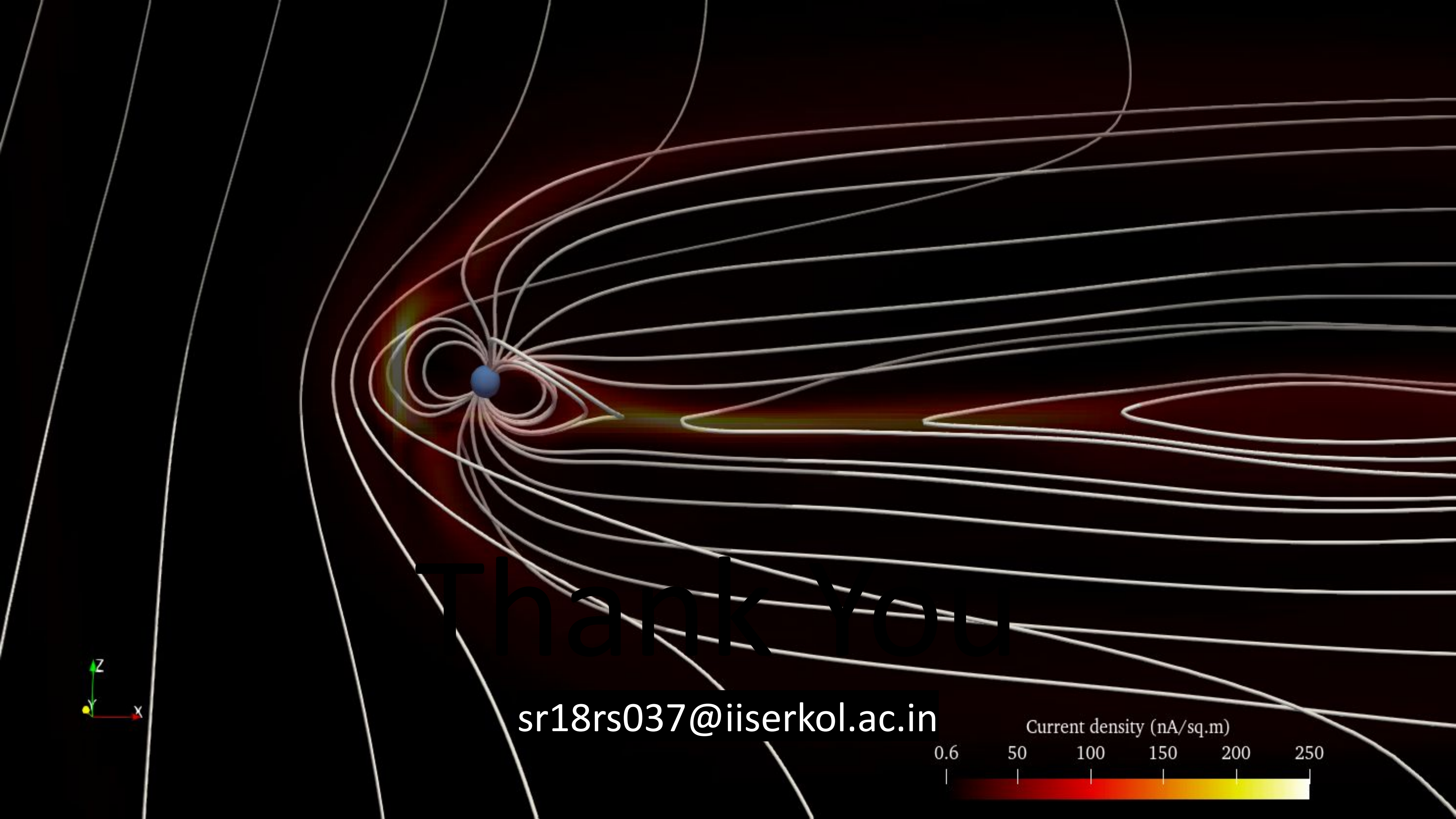
Statistical analysis:

Parameters	DST Index	SYM-H Index
1. Linearity Modelled = Slope x Observed + Intercept	Slope = 0.56 (σ = 0.02) Intercept = -25.99 nT (σ = 4.12)	Slope = 0.55 (σ = 0.01) Intercept = -24.06 nT (σ = 3.61)
2. Pearson coefficient (R)	0.85 (99.99%)	0.88 (99.99%)

Conclusion:

- Understanding and predicting the geomagnetic impact of solar storms with 60% overall accuracy for both DST and SYM-H.
- Room for improvisation as a potential prediction module.

Thank You



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