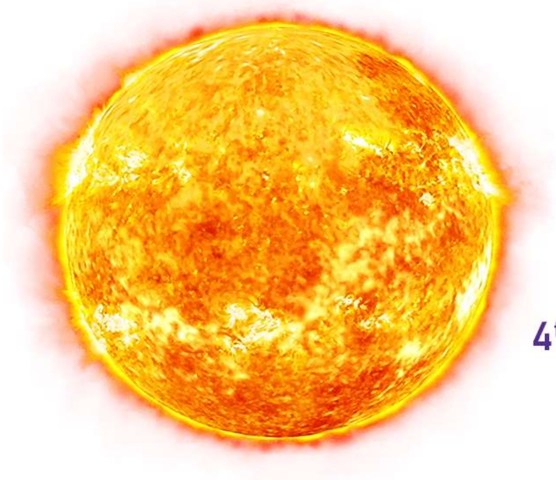
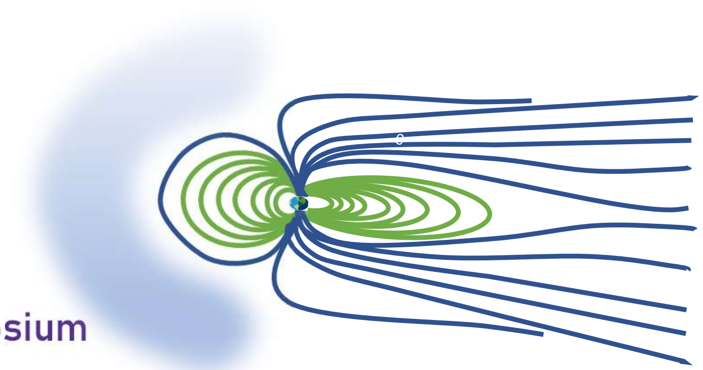
ICME-Driven Geoeffectiveness: Insights from Planar Magnetic Structures



By
Mr. Kalpesh Ghag
Department of Physics,
University of Mumbai

Presentation at
4th Eddy Cross –Disciplinary Symposium
Oct. 29 to Nov. 3, 2023
GOLDEN, CO



Contributing Authors : Anil Raghav, Ankush Bhaskar, Zubair Shaikh, Omkar Dhamane, Bhagyashri Sathe

Space weather effects

Mar 13, 2009

The Day the Sun Brought Darkness

Quebec Blackout (March 13, 1989)

News > Science & Astronomy

Solar Radio Bursts Could Cripple GPS

By Ker Than published April 04, 2007

New Mexico and Colorado (December 6, 2006)

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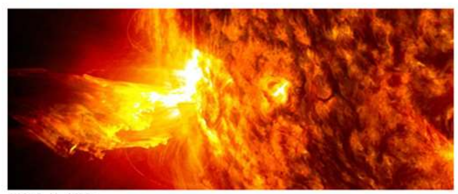
Solar flares will disrupt GPS in 2011

By Jeff Hecht

29 September 2006

We Just Got Evidence For One of The Biggest Solar Storms to Ever Blast Earth

SPACE 12 March 2019 By DAVID NIELD



Turns Out, We Have No Idea Why The Northern Lights Wreak Havoc on Our Satellite Technology

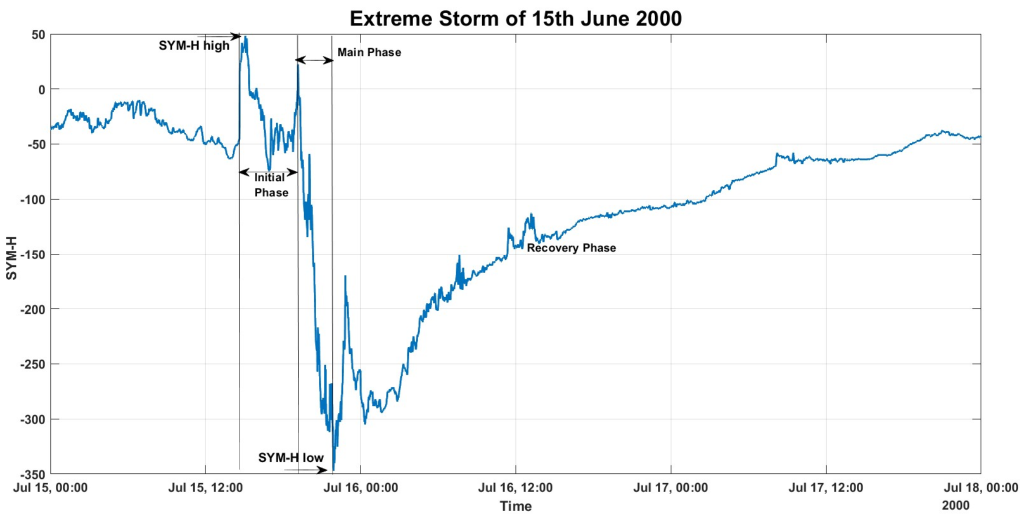
SPACE 15 March 2017 By BEC CREW

May 15, 1921 - The entire signal and switching system of the New York Central Railroad below 125th street was put out of operation, followed by a fire in the control tower at 57th Street and Park Avenue. The cause of the outage was later ascribed to a "ground current" that had invaded the electrical system. Brewster New York, railroad officials formally assigned blame for a fire destroyed the Central New England Railroad station, to the aurora. [NYT,1921]

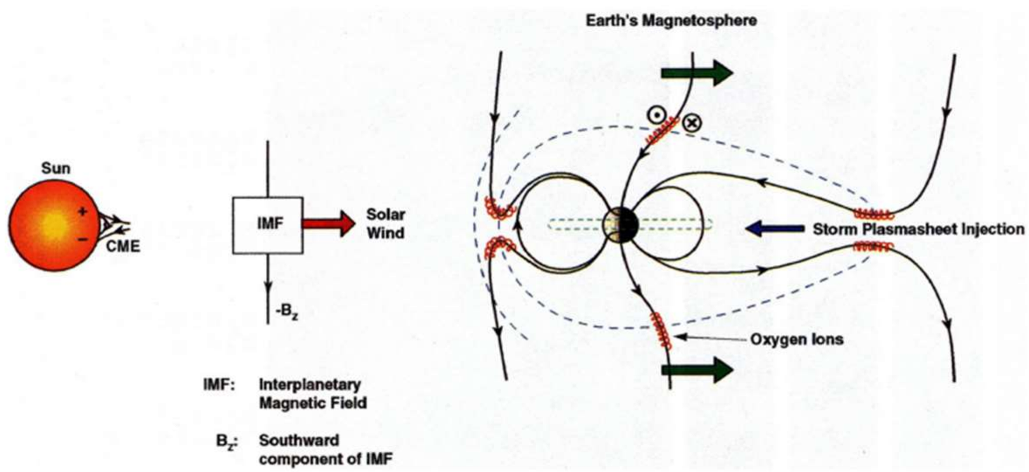
October, 2003 - South Africa Transformer Damage. The ESKOM Network reported that 15 transformers were damaged by high GIC currents. Figure 6 shows one of the transformers in a view reminiscent of the legendary images of the 1989 Quebec transformer failure. [Murtagh,2009]

Ref : http://www.spaceweather.org/ISES/swxeff/swh.html

Geomagnetic storm



Geomagnetic storm profile of extreme storm of 15th June 2000



Schematic physical process for geomagnetic storm as per Dungey 1961

CME's and ICME's

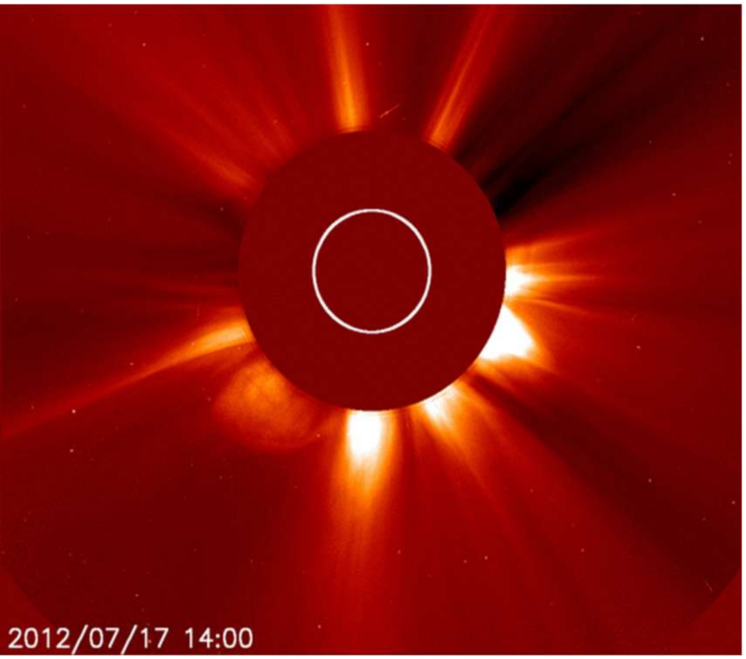
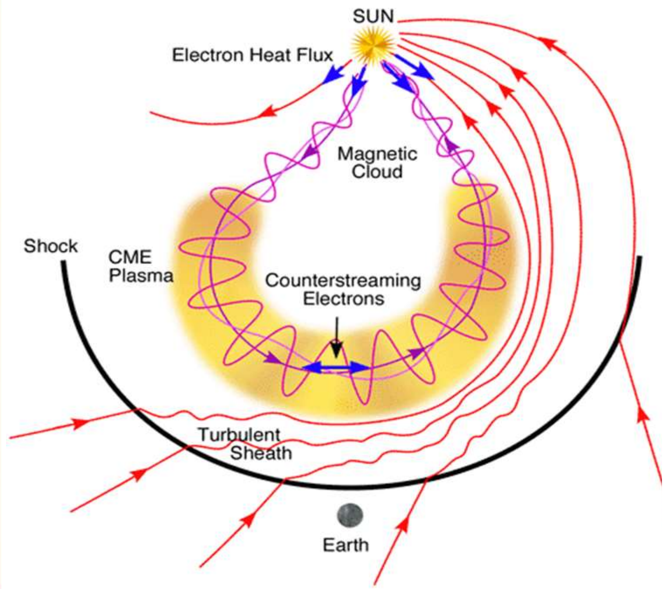


Image credits: https://soho.nascom.nasa.gov/



Burlaga et.al. 1981,1987; Cane et al., 1993, 2000; Zurbuchen et.al., 2006; Richardson et.al.,2010,2011, Kilpua et al., 2017; Ghag et.al. 2023

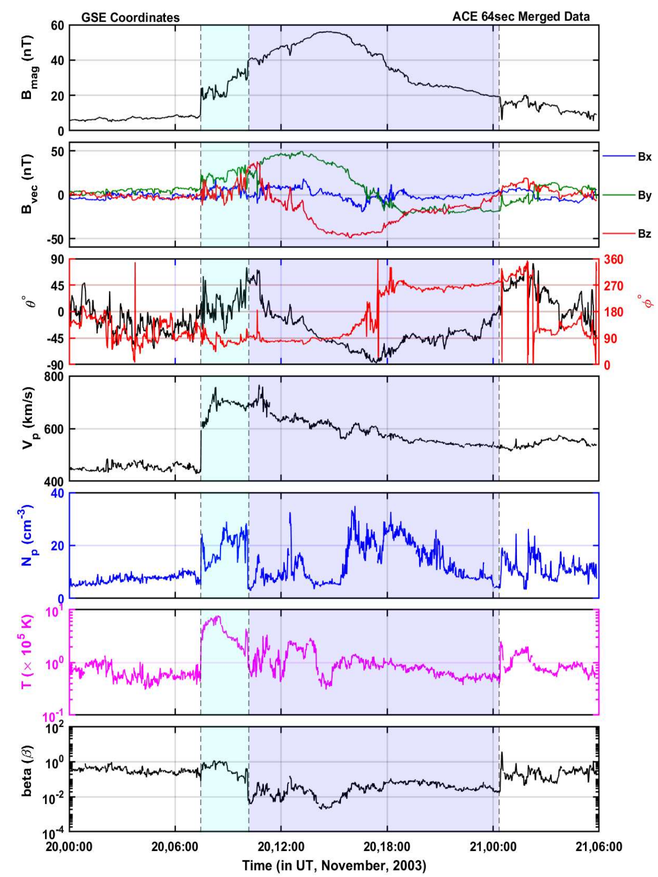


Figure credits: Raghav & Shaikh (2020), MNRASL

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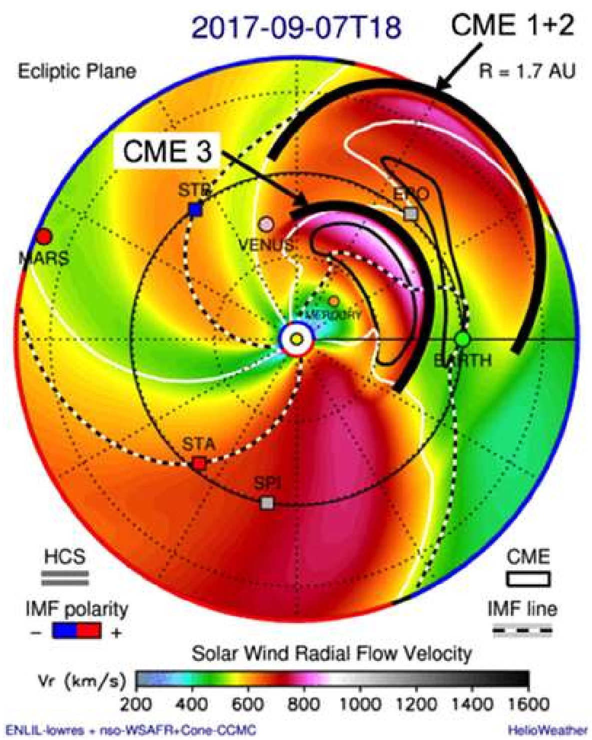
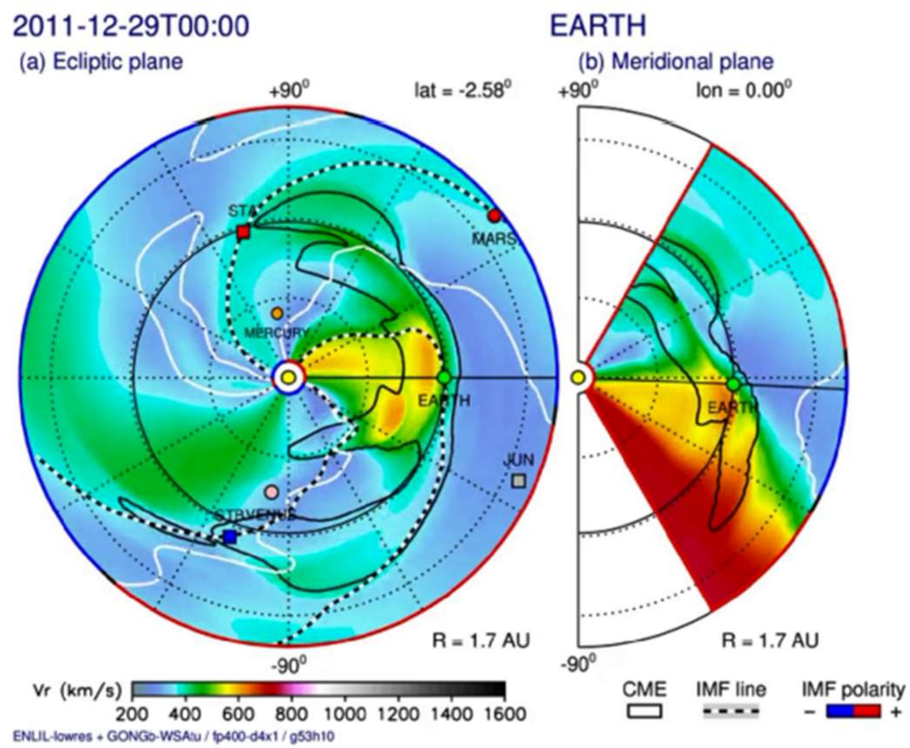
Interaction of ICME's

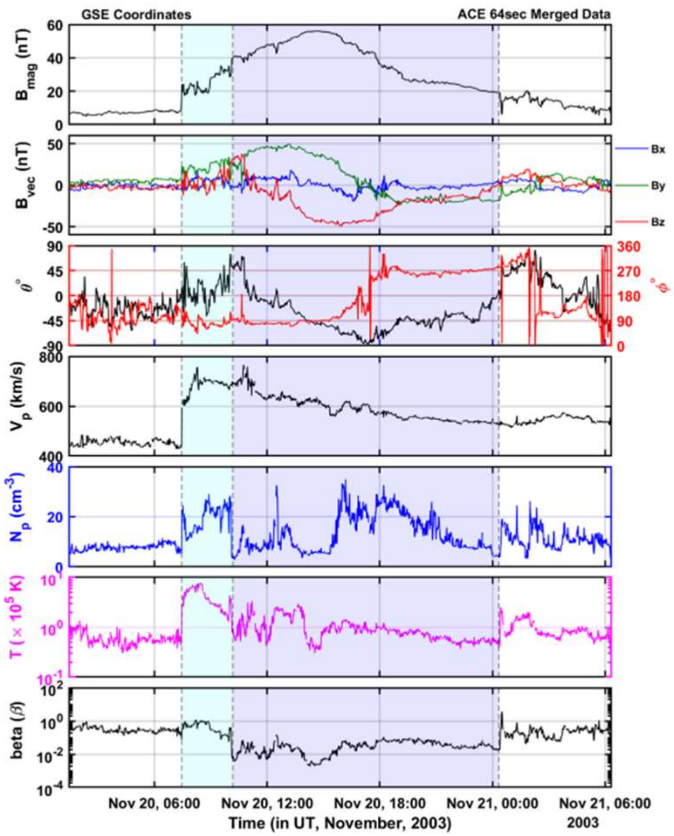


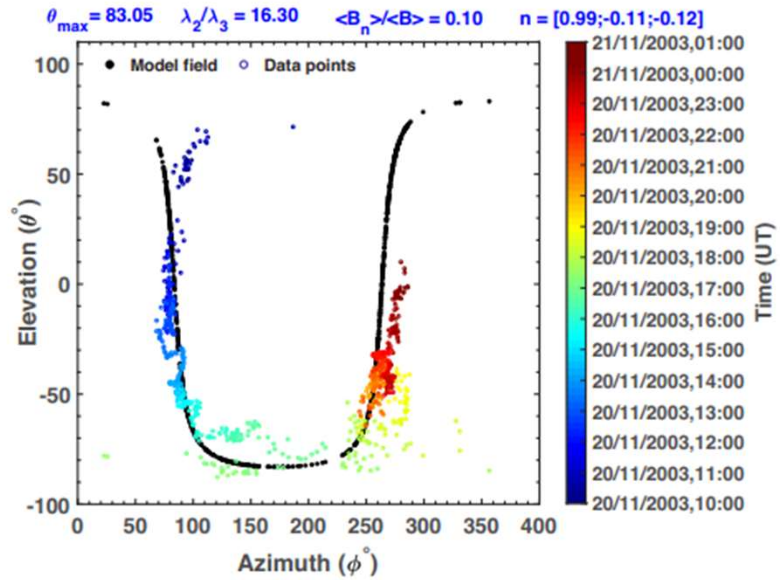
Werner et al. (2019) *Space Weather*

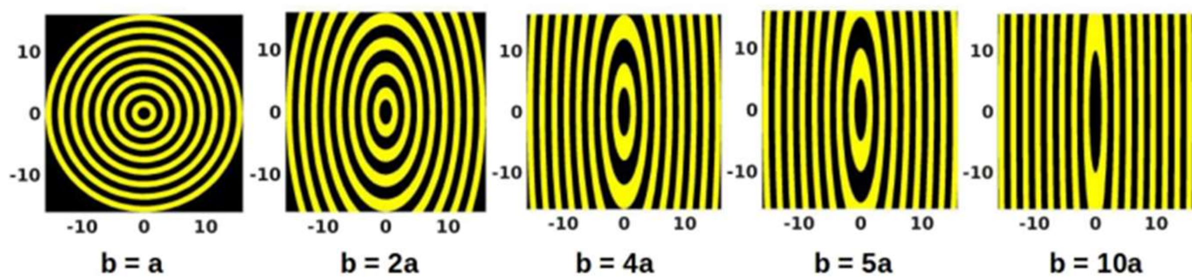


Y. Shugay et al (2018) J. Space Weather Space Clim

Pancaking of ICME

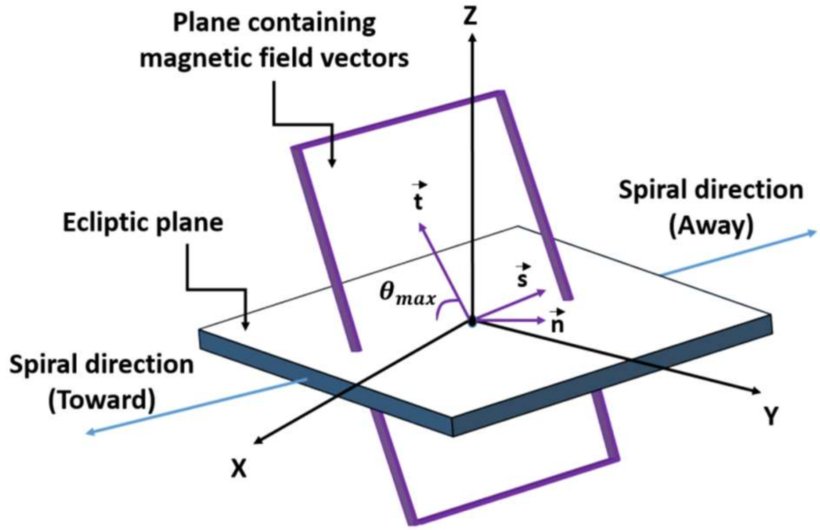


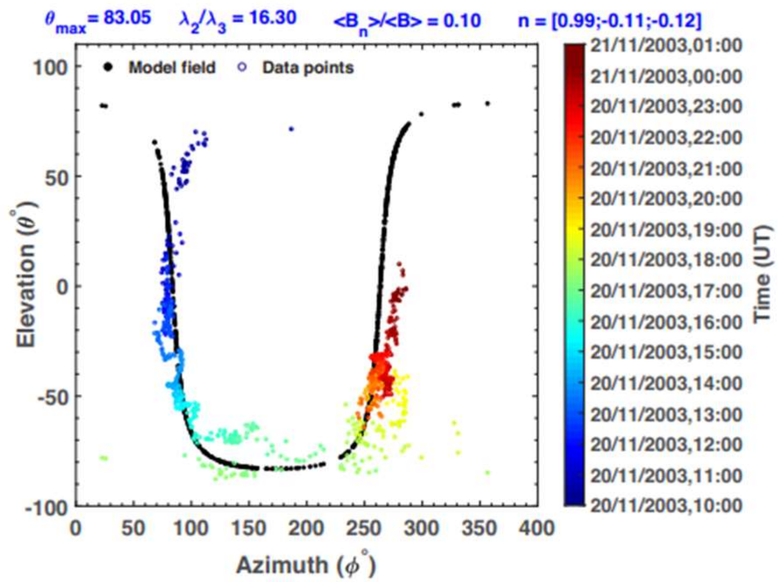




Raghav and Shaikh et al. (2020) MNRASL

Planar Magnetic Structures(PMS)

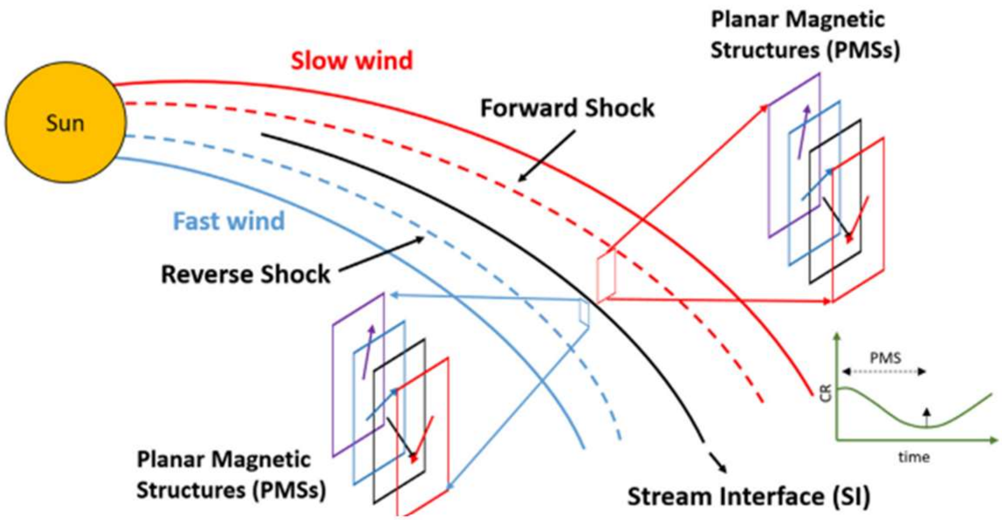


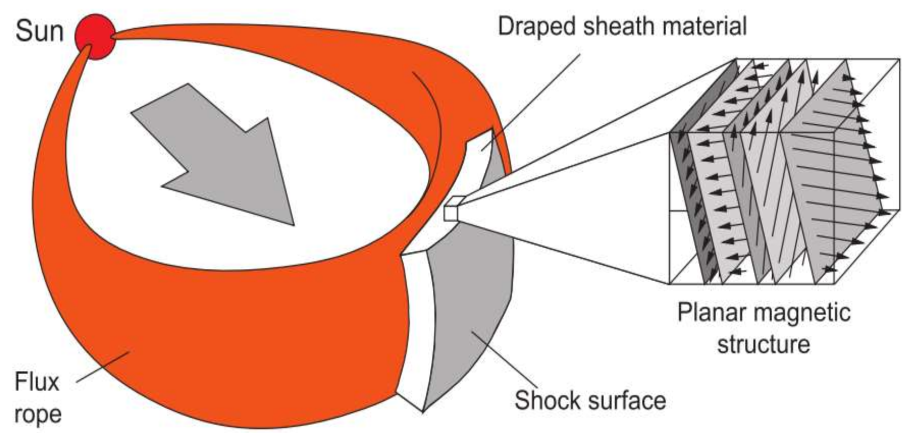


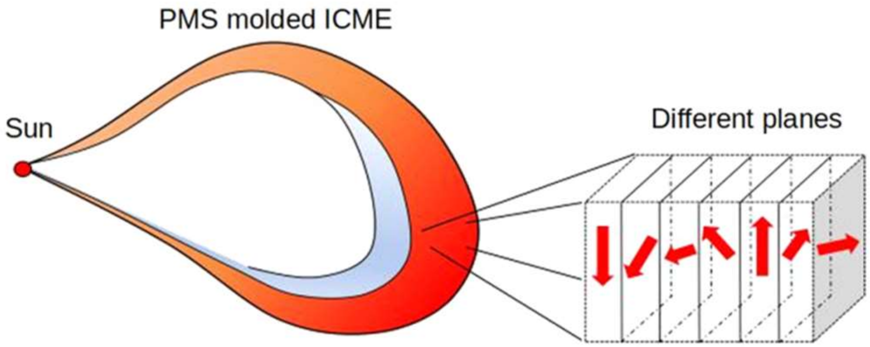
$$\theta = arctan\left[-\frac{(n_x cos\phi + n_y sin\phi)}{n_z}\right]$$

Nakagawa et al (1993), Palmerio et al (2016) , Raghav et al (2022), Shaikh et al (2020, 2022)

PMS in interplanetary space







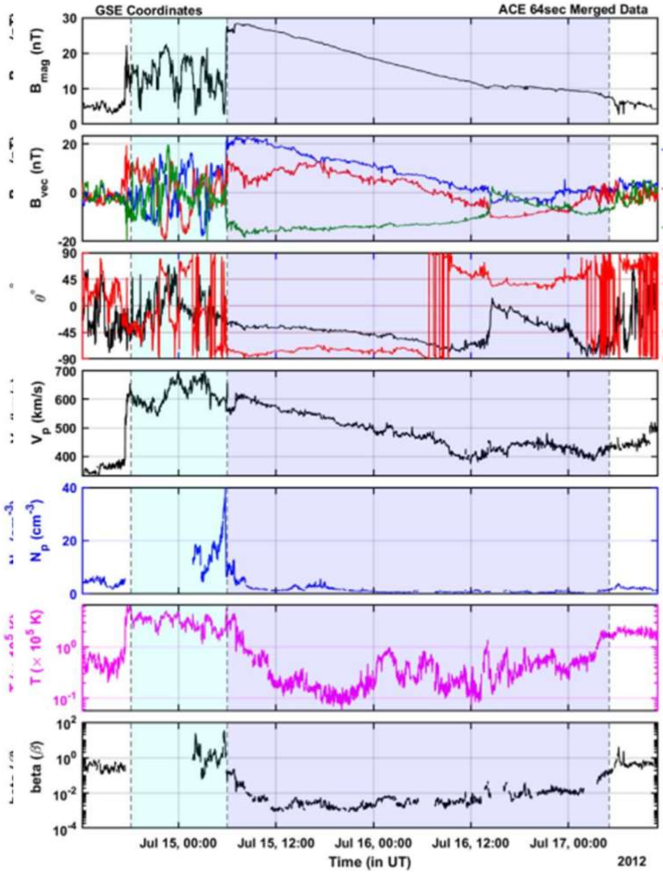
Palmerio et al (2016), In Annales Geophysicae

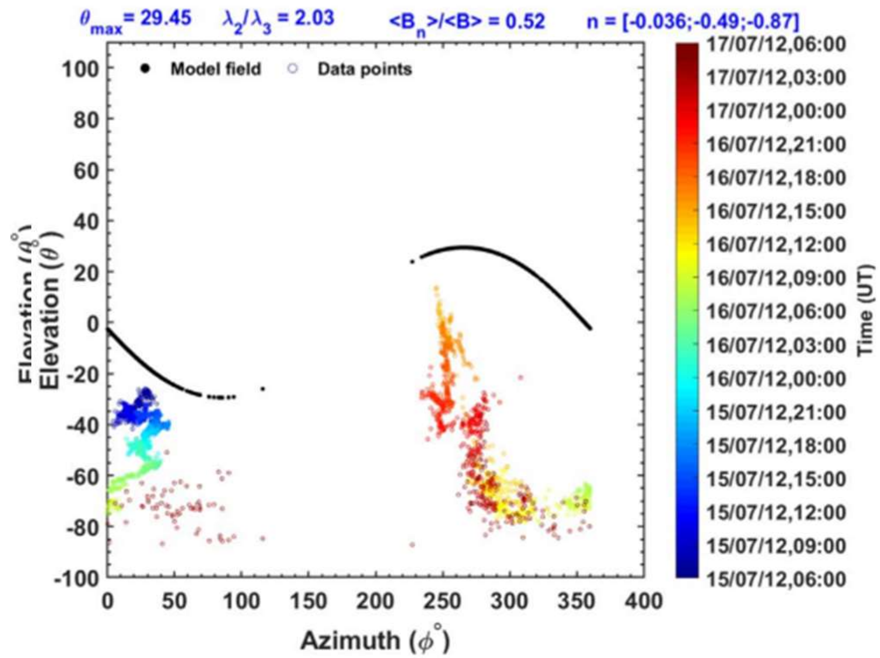
Shaikh et al (2020a), MNRS

Shaikh et al (2022), ApJ

Shaikh et al (2020b), MNRS

Magnetic cloud as PMS





Shaikh and Raghav (2022) suggest that 121 (29%) ICME MCs are planar, whereas 299 (71%) are non-planar.

PMS properties

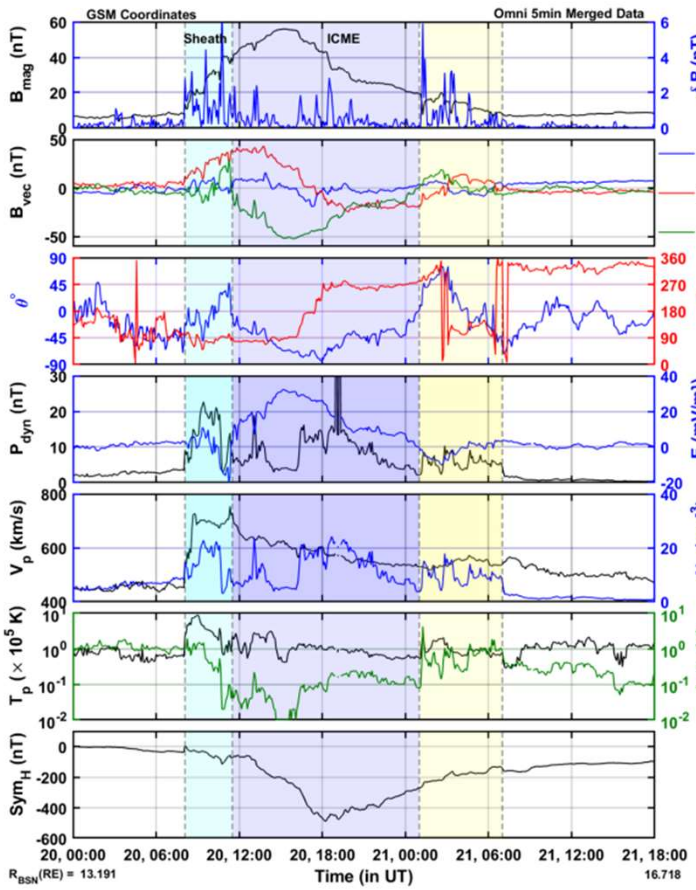
Shaikh et al. (2020) suggest that out of 420 ICME events, 147 (35%) ICME-driven sheaths are planar, whereas the remaining 273 (65%) are non-planar.

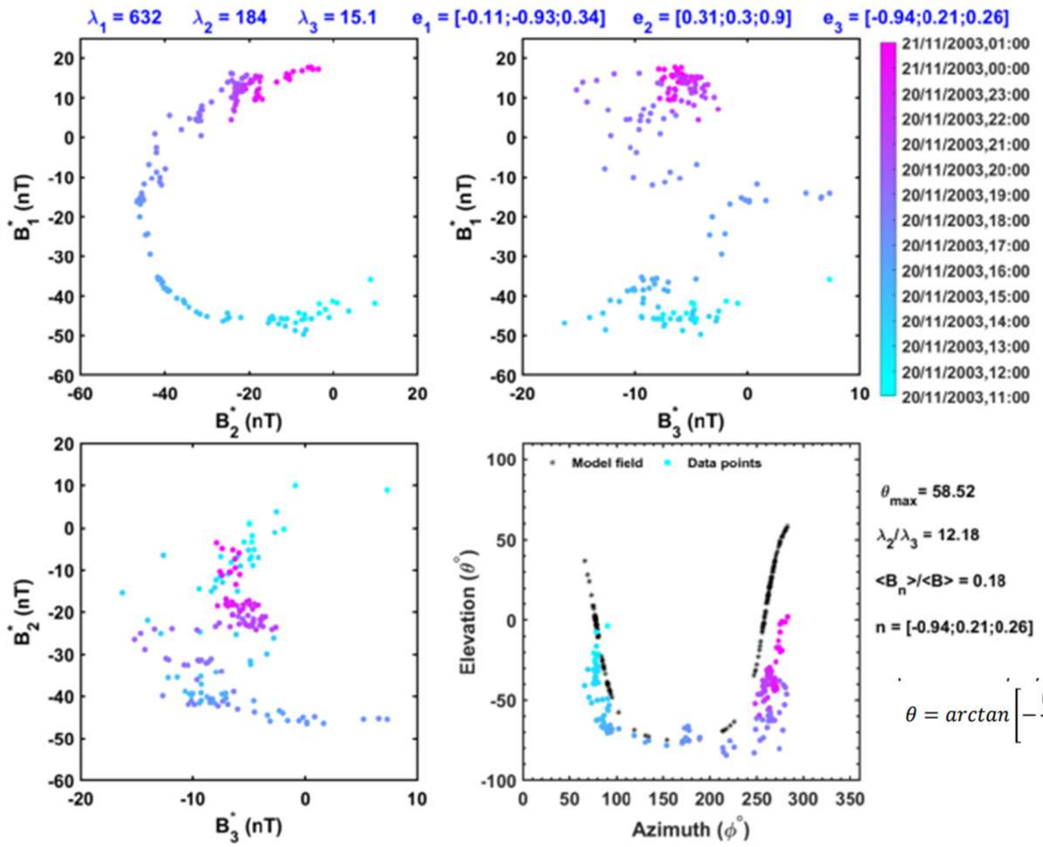
Shaikh and Raghav (2022) suggest that 121 (29%) ICME MCs are planar, whereas 299 (71%) are non-planar.

	ICME Sheath		ICME Magnetic Cloud	
	Non-Planar	Planar	Non-Planar	Planar
B (nT)	9.17	13.57	8.66	12.20
Bz_{min} (nT)	−6.91	−15.43	−9.46	−13.67
Bz_{max} (nT)	7.71	14.71	8.09	13.10
Np (cc^{-1})	9.66	13.41	6.22	8.40
Vp (kms^{-1})	482.79	510.80	458.95	451.79
Tp ($\times 10^5$ K)	1.37	1.97	0.52	0.51

Comparison of different plasma parameters in planar and non-planar ICME sheath and magnetic cloud taken from Shaikh et al (2020) and Shaikh and Raghav (2022).

Geoeffectiveness of PMS – A case study



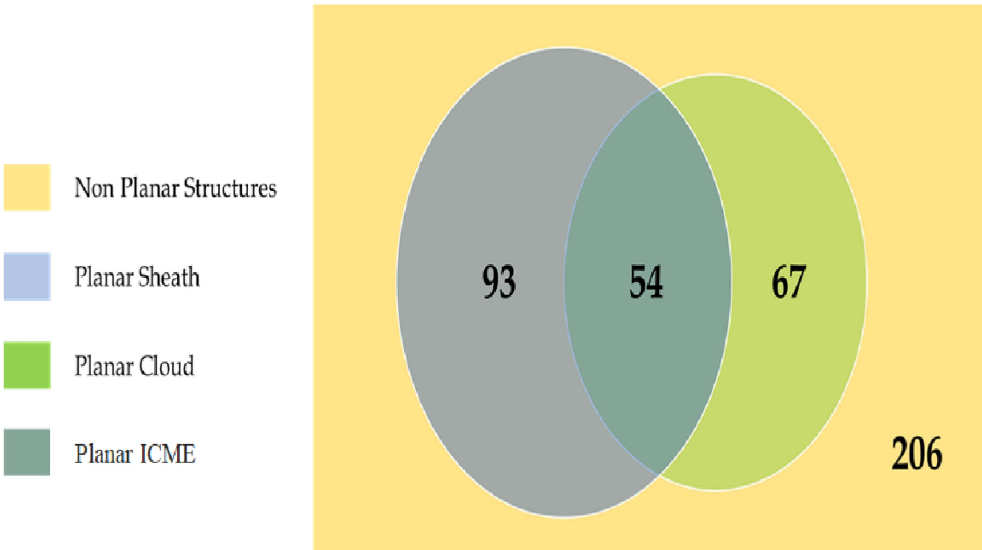


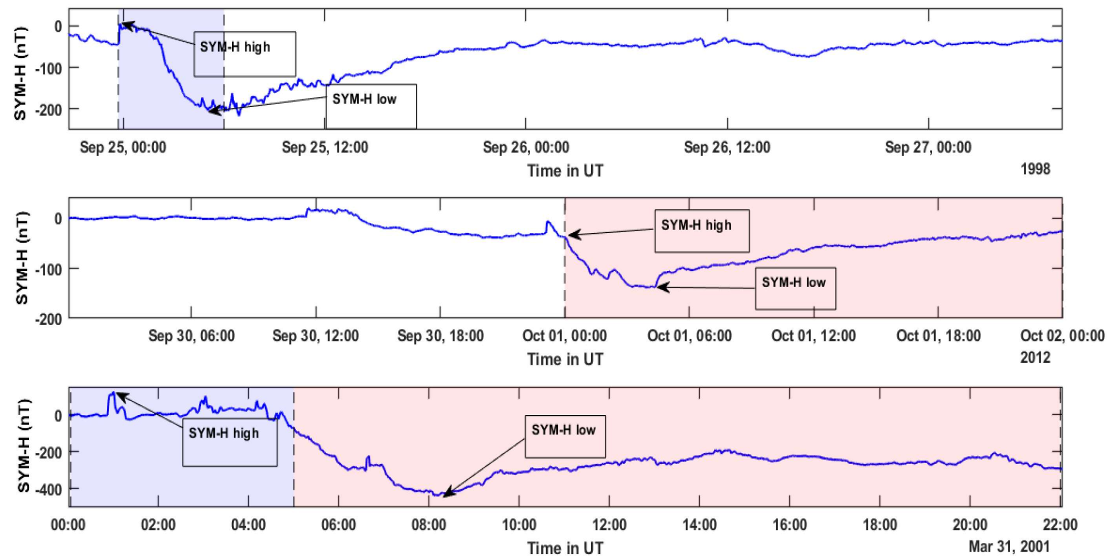
$$\theta = arctan\left[-\frac{(n_x cos\phi + n_y sin\phi)}{n_z}\right]$$

Raghav et al (2022)

Kalpesh Ghag (UDP-MU)   kalpesh.ghag@physics.mu.ac.in

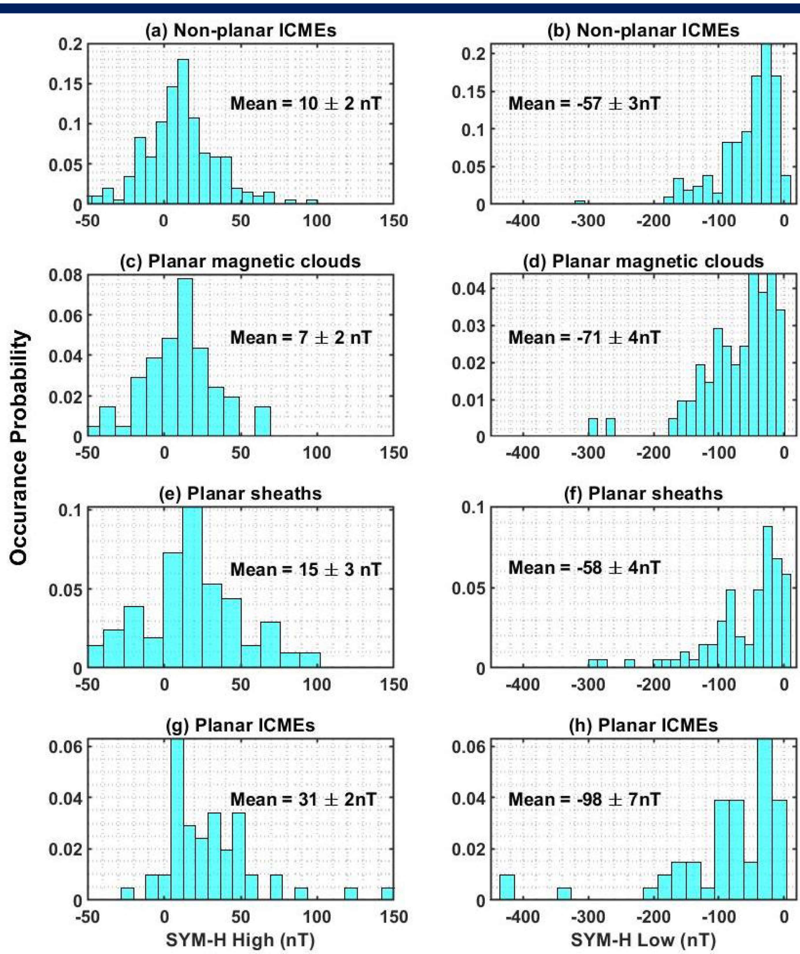
Statistical study of PMS





Ghag et al. (2023), Universe

Statistical study of PMS



Groups	Weak (>−50 nT)	Moderate (−50 nT to −100 nT)	Intense (−100 nT to −200 nT)	Extreme (>−200 nT)
Planar ICMEs	38.88%	25.92%	25.92%	9.25%
Planar MCs	43.28%	31.34%	22.38%	2.98%
Planar sheaths	58.06%	22.58%	13.97%	5.37%
Non-Planar ICMEs	54.85%	30.58%	14.07%	0.48%

Contribution of PMS into different categories of geomagnetic storms

Ghag et al. (2023), Universe

Major Findings

- Our study statistically confirms the hypothesis that ICMEs that are transformed into PMS are more geoeffective than non-planar ICMEs.
- The combined enhancement in the magnetic field components and plasma parameters is found in the planar sheath and MCs
- The enhancement in the magnetopause current and ring current due to enhanced plasma conditions could be the main reason for the high geoeffectiveness of planar ICMEs.

What next?

It is indeed fascinating to investigate the degree to which planarity amplifies the geoeffectiveness of sheaths, considering that sheaths are already acknowledged as impacting Earth's geomagnetic activity.

If the PMS possesses northward component (+Bz) , what will be the effect on the Earth's magnetosphere?

What is effect of PMS on Ionosphere and magnetosphere coupling?

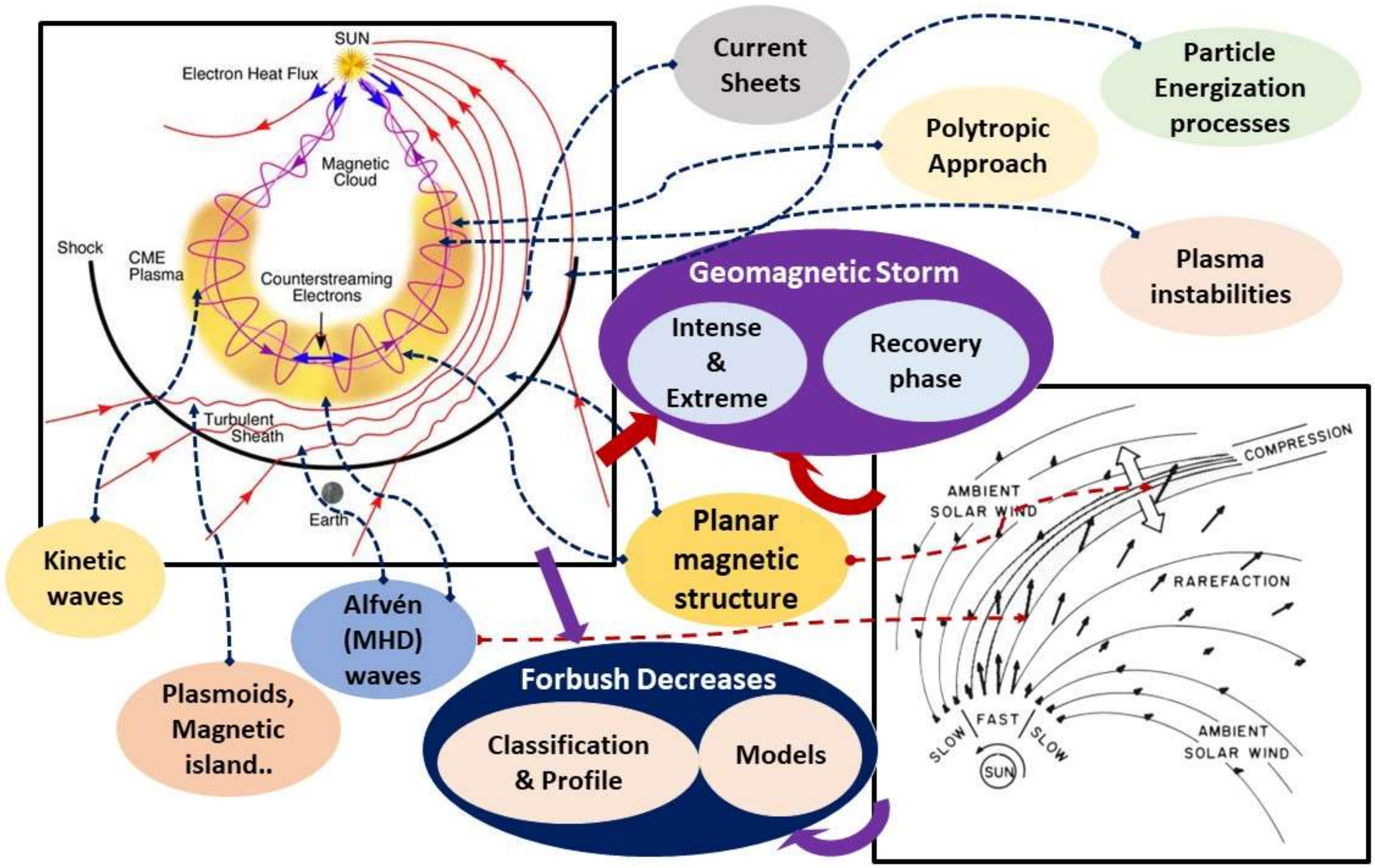
We encourage the inclusion of PMS in modelling and prediction studies of geomagnetic storm.

The role of planar structures in inner and outer magnetosphere dynamics; particle acceleration and wave generation

Publications related to the topics

1. Ghag, Kalpesh, et al. "Statistical Study of Geo-Effectiveness of Planar Magnetic Structures Evolved within ICME's." *Universe* 9.8 (2023): 350.
2. Ghag, Kalpesh, et al. "ICME pancaking: a cause of two-step severe storm ($ Dst\sim-187$ nT) of 25th solar cycle observed on 23 April 2023." arXiv preprint arXiv:2305.05381 (2023).
3. Choraghe, Komal, et al. "Intense (SYM-H⩽-100nT) Geomagnetic Storms Induced by Planar Magnetic Structures in Co-rotating Interaction Regions." Advances in Space Research (2023).
4. Raghav, Anil, et al. "The Possible Cause of Most Intense Geomagnetic Superstorm of the 21st Century on 20 November 2003." Solar Physics 298.5 (2023): 64.
5. Shaikh, Zubair I., and Anil N. Raghav. "Statistical plasma properties of the planar and nonplanar ICME magnetic clouds during solar cycles 23 and 24." The Astrophysical Journal 938.2 (2022): 146.
6. Shaikh, Zubair I., et al. "Comparative statistical study of characteristics of plasma in planar and non-planar ICME sheaths during solar cycles 23 and 24." Monthly Notices of the Royal Astronomical Society 494.2 (2020): 2498-2508.
7. Shaikh, Zubair I., Anil N. Raghav, and Geeta Vichare. "Evolution of planar magnetic structure within the stream interaction region and its connection with a recurrent Forbush decrease." Monthly Notices of the Royal Astronomical Society 494.4 (2020): 5075-5080.
8. Raghav, Anil N., and Zubair I. Shaikh. "The pancaking of coronal mass ejections: an in situ attestation." Monthly Notices of the Royal Astronomical Society: Letters 493.1 (2020): L16-L21.
9. Shaikh, Zubair I., Anil Raghav, and Geeta Vichare. "Coexistence of a planar magnetic structure and an Alfvén wave in the shock-sheath of an interplanetary coronal mass ejection." Monthly Notices of the Royal Astronomical Society 490.2 (2019): 1638-1643.
10. Shaikh, Zubair I., et al. "The identification of a planar magnetic structure within the ICME shock sheath and its influence on galactic cosmic-ray flux." The Astrophysical Journal 866.2 (2018): 118.

What we are doing !



Thanks !