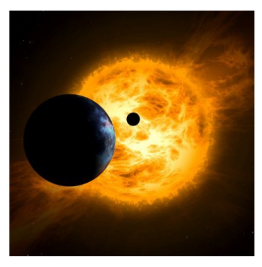
First in-situ evidence of Pancaked ICME and it's Distinct Plasma Characteristics Compare to Non-Pancaked ICME during Solar Cycles 23 and 24

Zubair I. Shaikh*[1], Anil Raghav[2], Geeta Vichare[1]

[1]Indian Institute of Geomagnetism (IIG), New Panvel, Navi Mumbai-410218, India.
[2]University Department of Physics, University of Mumbai, Vidyanagari, Santacruz (E), Mumbai-400098, India.



Abstract

The magnetic topology of an ICME can be cylindrical, toroidal, elongated elliptical, etc. Moreover, several remote observations and models/simulations suggest that ICME can show a 'pancake' structure. For the first time, in-situ observation of pancaked ICME at 1 AU is investigated using the PMS analysis technique. Furthermore, a statistical study of 468 ICME from 1998 to 2017 reveals that $\sim$ 30% ICME shows planar whereas $\sim$ 70% are non-planar signature. The average plasma parameters, i.e., plasma temperature, density, speed, beta, thermal pressure, and magnetic pressure in the planar ICME, are significantly higher than those of non-planar ICME. It indicates that planar MCs are highly compressed. The double-strength of the southward/northward magnetic field component associated with planar ICME implies that it is more geo-effective than the non-planar ICME. We believe that the above study is beneficial for ICME arrival time predication, solar-terrestrial physics, space weather physics, etc.

Introduction and Motivation

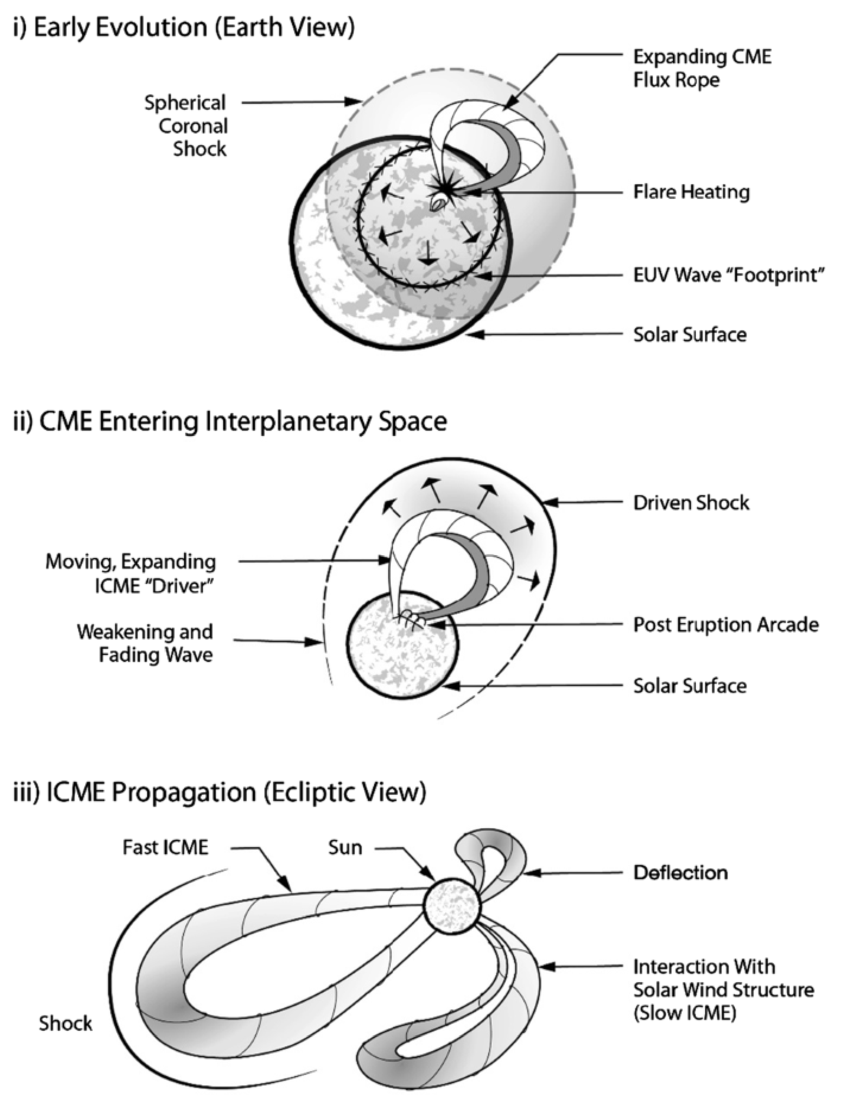


Figure 1: Artistics way to represent the global Coronal mass ejection evolution from the Sun to interplanetary space (Luhmann et al., 2020).

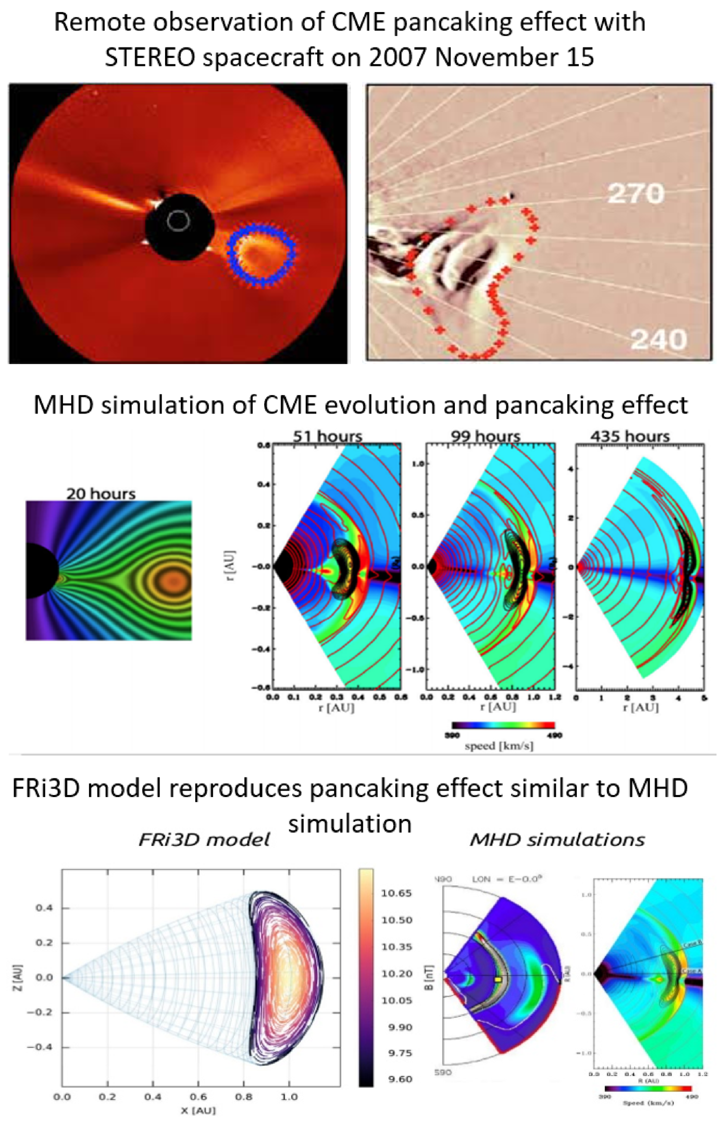


Figure 2: CME or ICME pancaking effect (Savani et al 2010; Riley and Crooker 2004; Isavnin 2016).

CME Evolution: kinematic expansion + dynamic evolution

At 1AU the flux rope cross-section is non-circular, also it is not elliptical but concave-outward. Such deformed ICME cross-section called '**pancake**' structure.

Pancaking nature of ICME cross-section were confirmed by the; (1) Remote observation (Savani et al 2016), (2) MHD simulation (Riley and Crooker (2004)), and (3) FRi3D model (Isavnin 2016).

Very recently, Raghav et al. 2020 gave first in-situ observation of such 'Pancaked' ICME using planar magnetic structure (PMS) analysis technique.

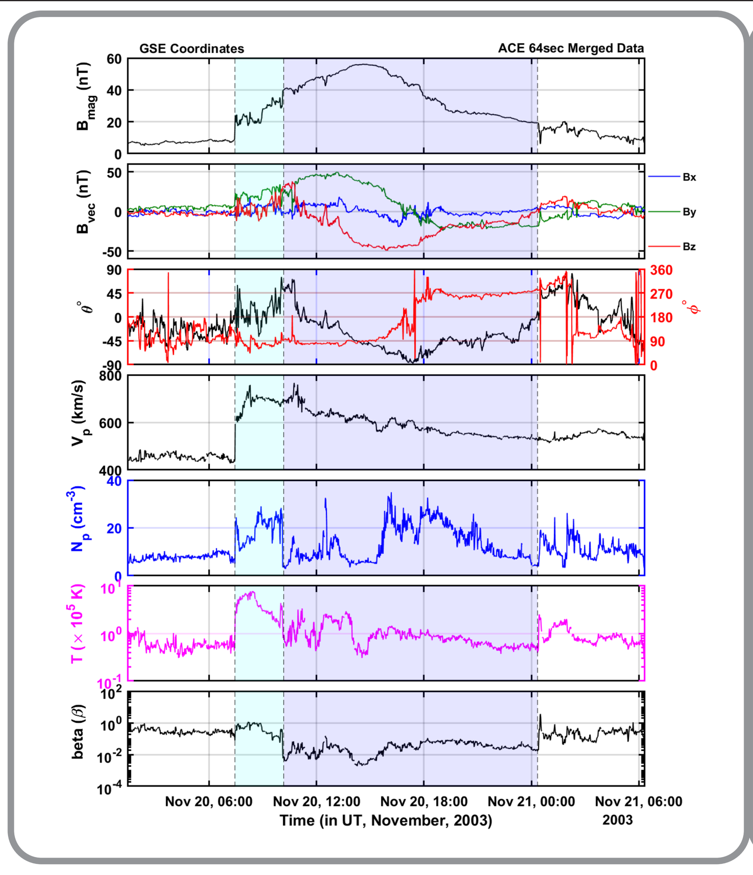
PMSs is a laminar structure, which consists of different parallel sheets containing differently oriented IMF (Nakagawa et al 1989).

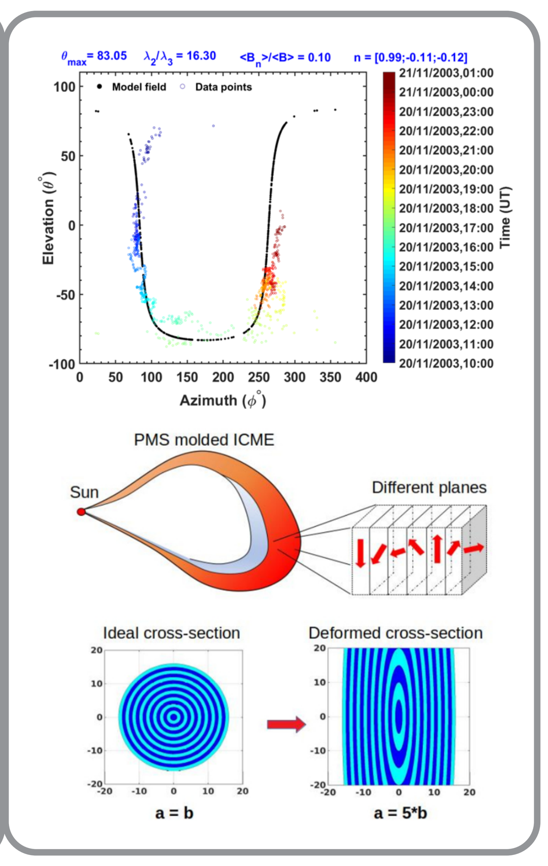
Here, for first time,
1. we gave the detailed comparative plasma characteristics of planar and non-planar ICME using in-situ data at 1AU.
2. Additionally, we gave first global pancaked evidence using multi-spacecraft data

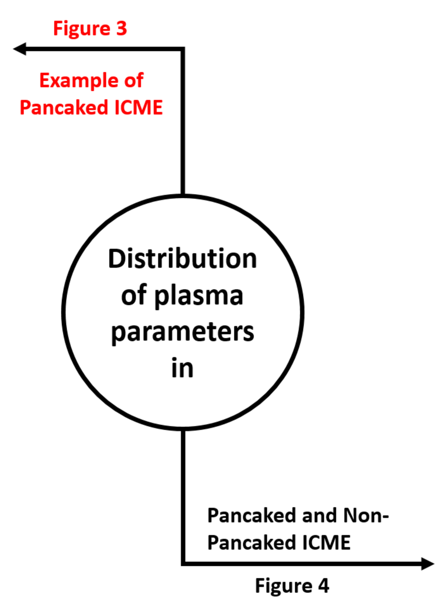
Methodology

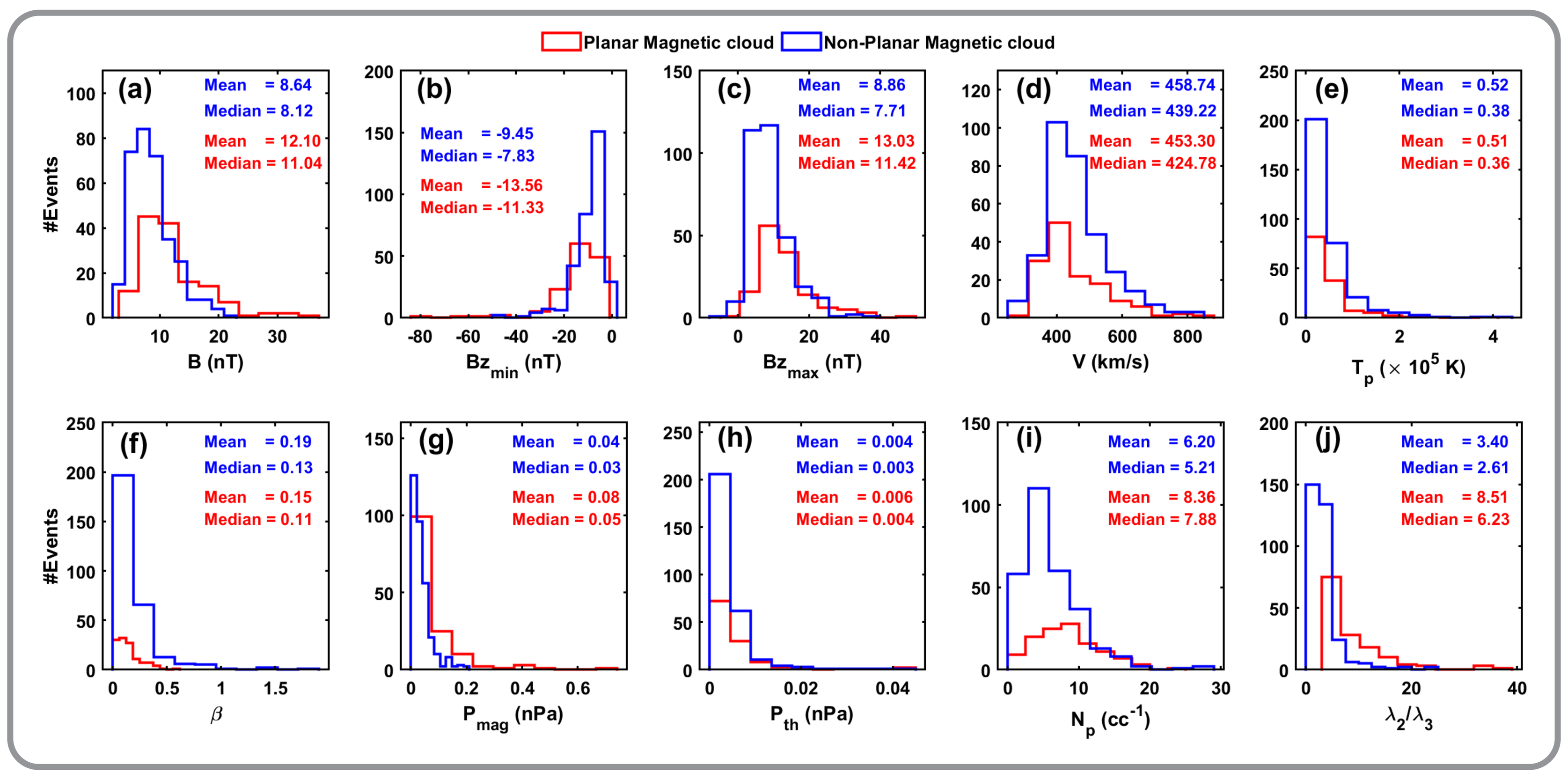
- **Data used:** 64 sec time cadenced magnetic field and plasma parameter from **ACE spacecraft**.
- **Minimum Variance Analysis (MVA):** Gives three eigenvalues ($\lambda_1 > \lambda_2 > \lambda_3$) and corresponding eigenvector (e_1, e_2, e_3).
- **Structure will be planar if:**
  1. **Azimuth angle, i.e.,** $0 < \phi < 360$.
  2. **Good planarity:** $|B_n|/B \leq 0.25$, where, $B_n = \vec{B}.\vec{n}$ (for perfect plane $B_n = 0$).
  3. **Good efficiency:** $\lambda_2/\lambda_3 \geq 3$.
- When IMF vector $\vec{B} = (B_x, B_y, B_z) \equiv (Bcos\theta cos\phi, Bcos\theta sin\phi, Bsin\theta)$ is parallel to a plane whose normal is $\vec{n} \equiv (n_x, n_y, n_z)$, the relation between ϕ and θ is given as: $n_x cos\theta cos\phi + n_y cos\theta sin\phi + n_z sin\theta = 0$.

In-situ observation and plasma properties of Planar and Non-planar ICME Sheaths









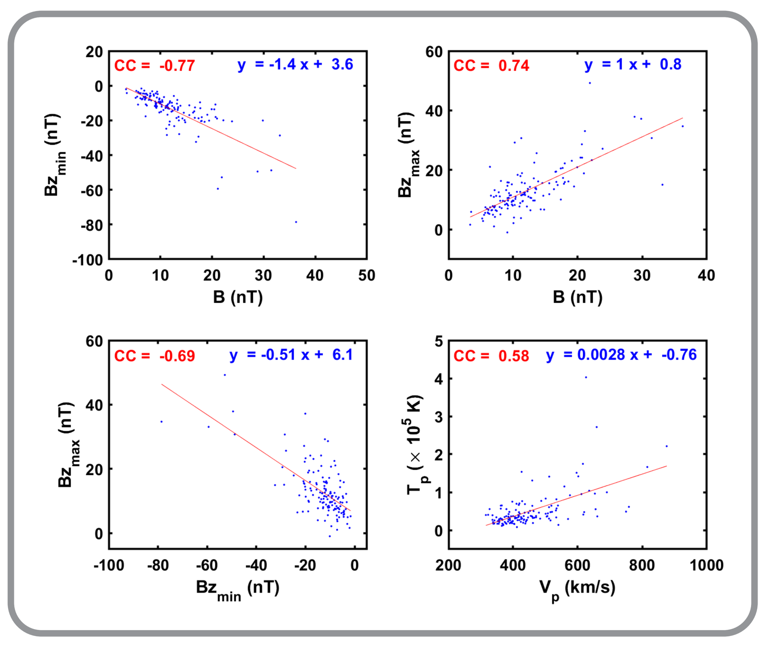
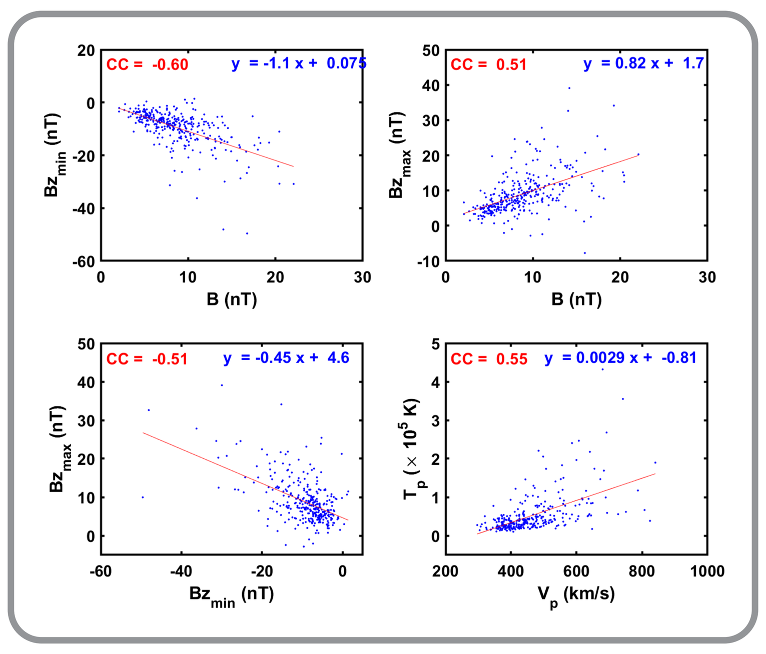


Figure 5: Pearson correlation and regression analysis for pancaked ICME

Figure 6: Pearson correlation and regression analysis for non-pancaked ICME



- Study demonstrates that the B is 41%, T_p and V_p is nearly 2%, N_p is 35%, and β is 21% higher while P_{mag} & P_{th} are about 2 and 1.5 times higher in pancaked ICME as compared to non-pancaked ICME.
- Pancaked ICME has strong southward/northward IMF and is likely to be more geo-effective compare to non-pancaked ICME.

Discussion and Conclusion

- Study reveals that 142 out of 469, i.e., 30 % of ICME magnetic cloud are converted into PMSs.
- Conversion of ICME into PMS may be due to;
  1. High compression by fast solar wind stream
  2. High compression by ICME-ICME or ICME-CIR interaction
- Significantly high plasma parameters within planar ICME suggest that compression plays a very important role in planar nature of ICME.

Global Pancaking of ICME

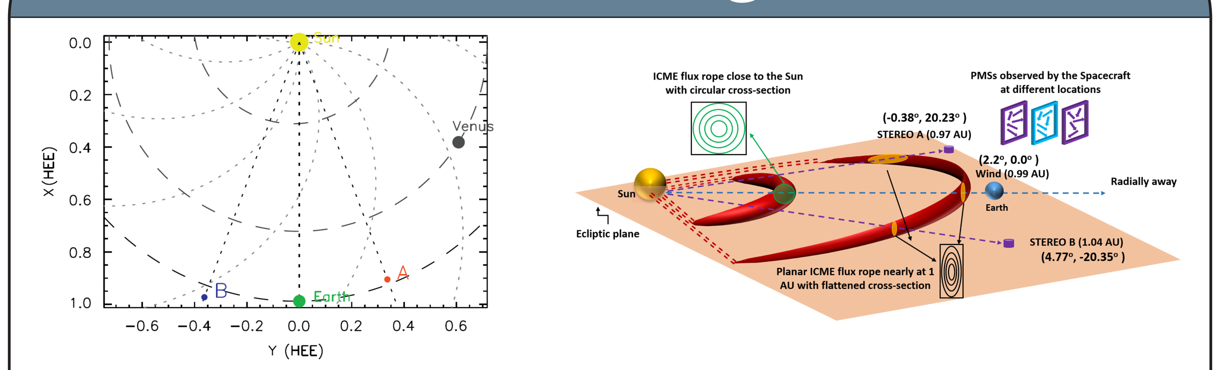


Table 1. List of spacecrafts which observed an ICME crossing on November 19-20, 2007. This table described a plasma properties of an ICME which transformed to PMSs. The PMS plane normal direction is $\vec{n} = (n_x, n_y, n_z)$, eigenvalues are $\lambda = (\lambda_1, \lambda_2, \lambda_3)$ in descending order, λ_1/λ_2 is a ratio of maximum to intermediate eigenvalue, and λ_2/λ_3 is a ratio of intermediate to minimum eigenvalue. Moreover, the average values of the magnetic field and plasma parameters during ICME MC transit are represented as B_{mag}, V_p, β, N_p, and T_p. Further, B_n/B represents planetary of the PMSs and θ_{max} gives inclination angle of the PMS plane with respect to the ecliptic plane.

S/C	Shock onset	MC start	MC end	λ			$\vec{n}$			$\frac{\lambda_1}{\lambda_2}$	$\frac{\lambda_2}{\lambda_3}$	B_{mag}	V_p	N_p	T_p	β	B_n/B	θ_{max}
	date & time	date & time	date & time	λ_1	λ_2	λ_3	n_x	n_y	n_z			(nT)	(kms^{-1})	(cm^{-3})	$(\times 10^4 K)$			(°)
Wind	Nov. 19, 17:22	Nov. 20, 00:20	Nov. 20, 11:40	104.96	17.72	1.93	-0.82	-0.18	0.55	5.92	9.20	18.17	464.83	12.85	2.67	0.04	0.12	52.78
STB	Nov. 19, 13:49	Nov. 19, 23:00	Nov. 20, 07:00	63.81	20.10	1.00	0.66	0.56	0.50	3.17	20.10	13.72	437.26	16.25	4.15	0.81	0.07	43.72
STA	–	Nov., 19, 23:00	Nov. 20, 23:40	38.38	9.07	1.66	-0.87	-0.076	0.49	4.23	5.45	8.99	416.49	7.54	3.22	0.55	0.16	60.66

First multi-spacecraft in-situ evidence of pancaked ICME at 1 AU. This suggest that ICME 'Pancaking' is a global phenomena.

References

[1] Burlaga, L.F., J. Geophys. Res. 93, 7217, (1988).
[2] Zurbuchen, T. H., & Richardson, I. G., (2006).
[3] Shaikh et al, MNRAS, 490(3), 3440-3447, (2019).
[4] Raghav, A. N., & Shaikh, Z. I., MNRAS: Letters, 493(1), L16-L21, (2020).
[5] Shaikh et al., ApJ, 866(2), 118, (2018).
[6] Palmerio E., Kilpua E. K., Savani N. P., Ann. Geophys, 34, 313, (2016).

Acknowledgement

Thanks to ACE, Wind, and STEREO team for making interplanetary data available.

E-mail: zubairshaikh584@gmail.com
Mob No.: 9867064090/8828344940