4^{th} Eddy NASA Symposium

In-situ observation of Alfvén ion cyclotron waves in ICME magnetic clouds at 1 AU

Presented By
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Coronal mass ejections (CMEs)

Secret??

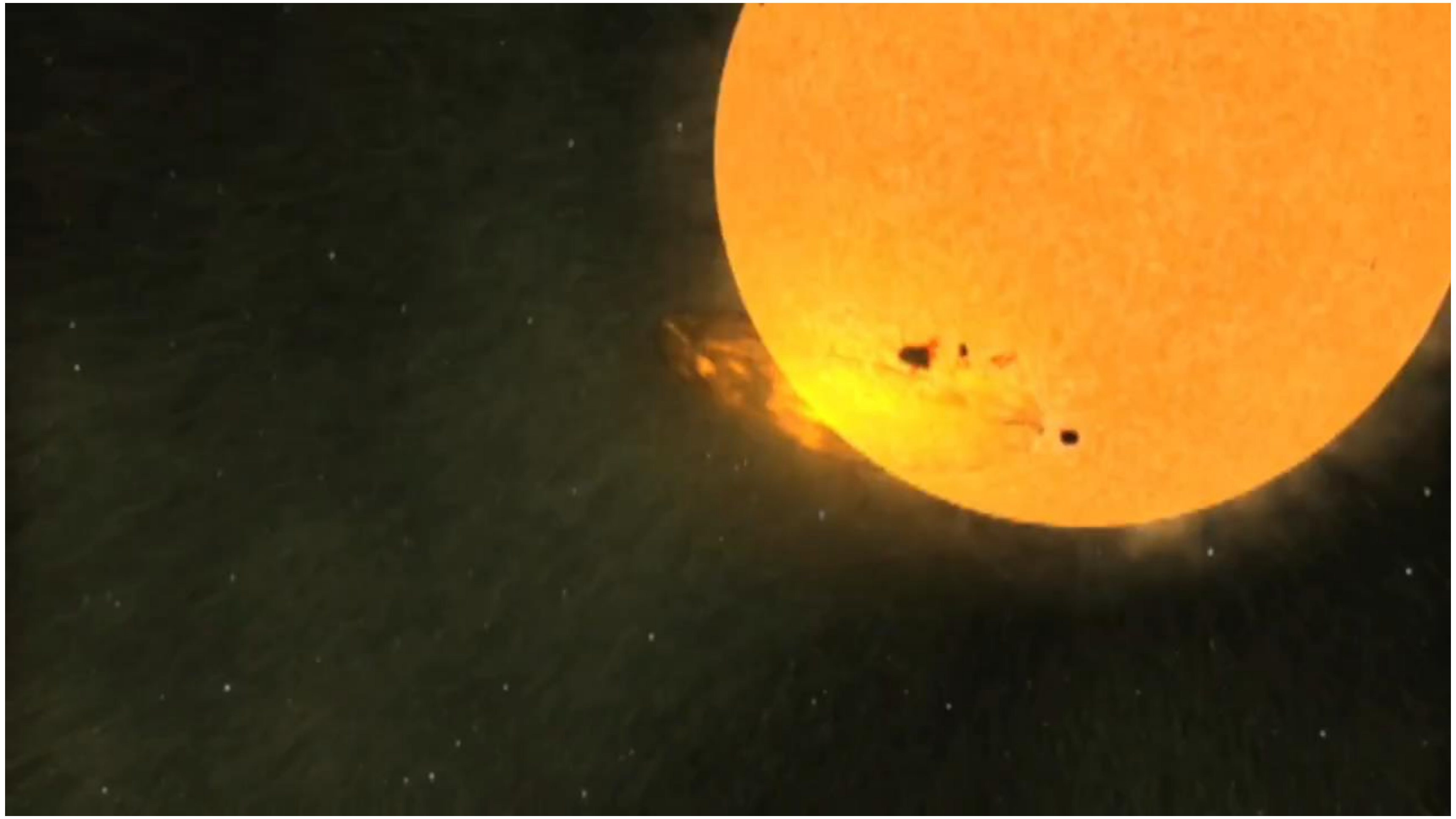


Image credits: https://soho.nascom.nasa.gov/

Interplanetary Coronal Mass Ejections (ICMEs)

Burlaga et.al. 1981,1987; Bothmer et al., 1997, Cane et al., 1993, 2000; Zurbuchen et.al., 2006; Richardson et.al.,2010,2011, Kilpua et al., 2017.

❖ Important features:

- Shock front (Sudden transient)
- Shock-sheath (Turbulent Plasma)
- Magnetic cloud (MC) (Ordered structure)

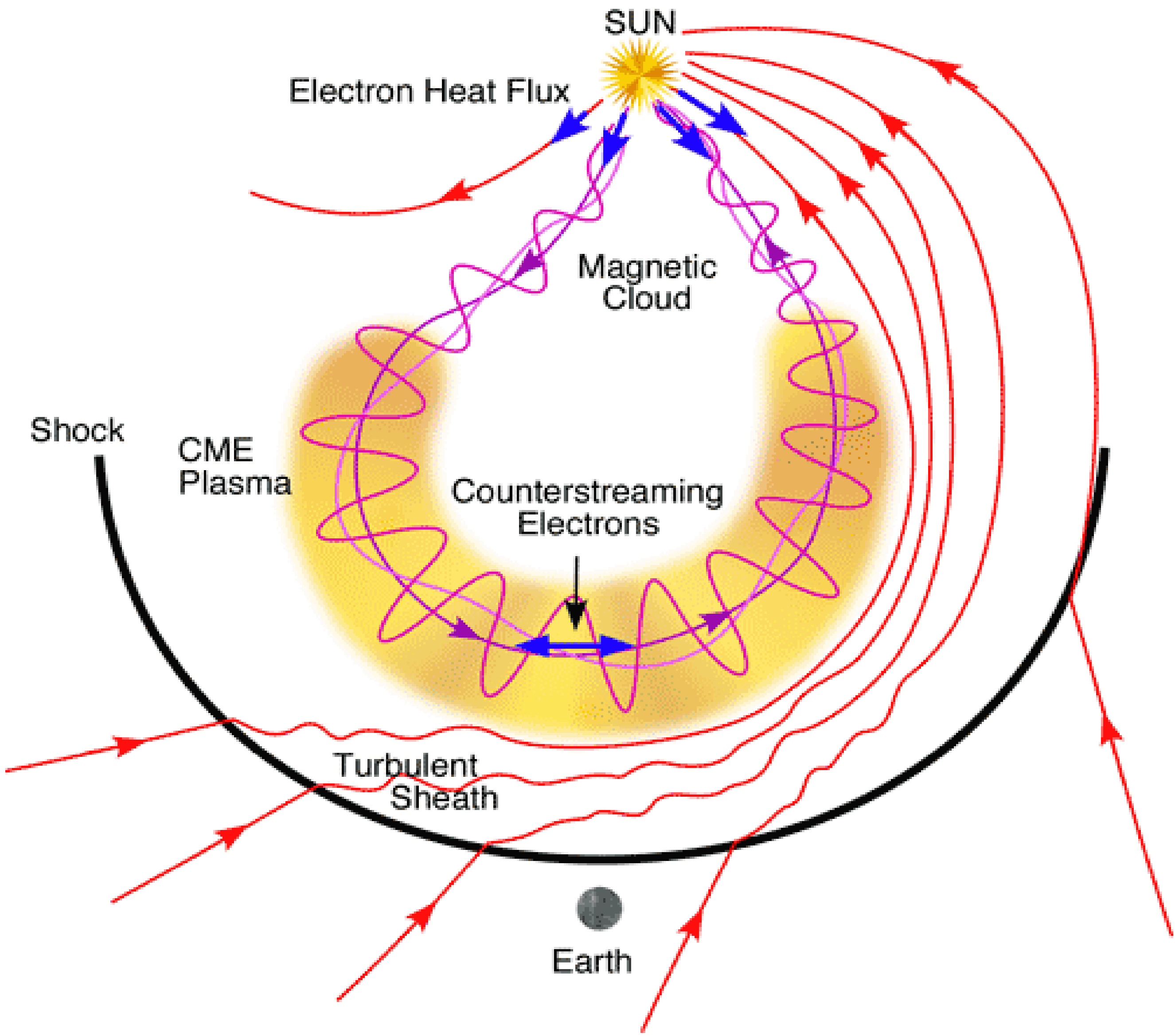


Image Courtesy: Deborah Eddy and Thomas Zurbuchen

- The observation of Alfvén waves during the interaction of ICME-ICME and ICME-HSS
- Change in Polytropic index
- Expansion, formation of complex ejecta, sudden deflection, and disruption

- *Raghav et al. , MNRAS, 495, 2, (2020)*
- *Raghav & Shaikh, MNRASL, 493, 1, (2020)*
- *Shaikh & Raghav et. al., MNRAS, 494, (2), 2020.*
- *Shaikh, Raghav, & Vichare, MNRAS, 490 (2), 2020.*
- *Shaikh & Raghav et. al., MNRAS, 490 (3), 2020.*

- Co-existence of Alfvén wave and PMS in ICME shock-sheath
- Deceleration of fast CMEs and acceleration of slow CMEs in the solar wind
- Rise in temperature anisotropy and kinetic scale wave generation

- *Raghav & Kule, MNRASL, 476, (1), 2018.*
- *Raghav & Kule, MNRASL, 480, (1), 2018.*
- *Shaikh, Raghav, & Bhaskar, ApJ, 844, 2, (2017).*
- *Dhamane et al 2023 Solar Physics*

CME-CIR interaction

CME-HSS interaction

Interaction with solar wind

CME-CME interaction

Internal disturbances

Factors affecting the ICME

Plasma waves in ICME

Observation of MHD scale waves

- Observation of Alfvén waves in small scale flux rope.
- Observation of torsional Alfvén waves.
- Surface Alfvén waves embedded in ICME flux rope
- Inward directed Alfvén waves due to ICME-HSS interaction

1. *Gosling et. al, 2010*
2. *Raghav and kule MNRASL 2018*
3. *Raghav and Kule, MNRASL, 2018*
4. *Raghav el.al, 2023 APJ*
5. *Dhamane et al. Solar Physics, 2023*

Observation of kinetic scale waves

- Alfvén ion cyclotron waves (AIC) observed in the ICME sheath region and the occurrence of the AIC wave is highest near the shock front, whereas the rate decreases as we move closer to the ICME MC leading edge.

Al-Lahti et.al.2019 JGR

Is Kinetic scale waves possible in magnetic cloud ????

Motivation behind study

- Study plasma turbulence in ICME magnetic cloud.
- Connections between the large and small scale characteristics of magnetic field fluctuations across frequency break.
- To verify, whether Alfvénic fluctuations can affect polarization of magnetic field fluctuations
- Aim to interlink specific turbulence state within the inertial range of fluctuations to the polarization of magnetic field fluctuations at dissipative scales

Methodology

Power Spectral Density

1. Fast Fourier Transform Algorithm is used
2. IMF 11 Hz data used for analysis
3. Shortlisted event which having explicit hump

Bruno & Carbone 2013, Solar Physics review
Tu and Marsch 1995, space science reviews
Vlahos & Cargill 2009, Turbulence in Space Plasmas

Normalized magnetic Helicity

1. $\sigma_m(\omega) = \frac{2Im[Y^* (\omega)Z(\omega)]}{E_B}$
2. Criteria $\sigma_m \geq |0.5|$
3. 11 Hz data is used.
4. $\sigma_m(\omega)$= 0 for plane polarized wave.
5. $\sigma_m(\omega)$=± 1 for circularly polarized waves.
6. Shortlisted 14 events

Telloni D. 2020, Atmosphere
Goldstein et.al, 1994 JGR
Telloni et. al, 2019 APJ
Telloni et. al, 2012 APJ

Walén Test

1. Alfvén Velocity: $V_A = B/\sqrt{\mu_0 \rho}$
2. 4th order band pass Butterworth filter is applied.
3. Walén relation: $\Delta V = |R_H| \Delta V_A$
4. 3 sec wind MFI and 3DP data are used.
5. Criteria Correlation Coefficient ≥ |0.7|
6. Shortlisted 5 events out of 14

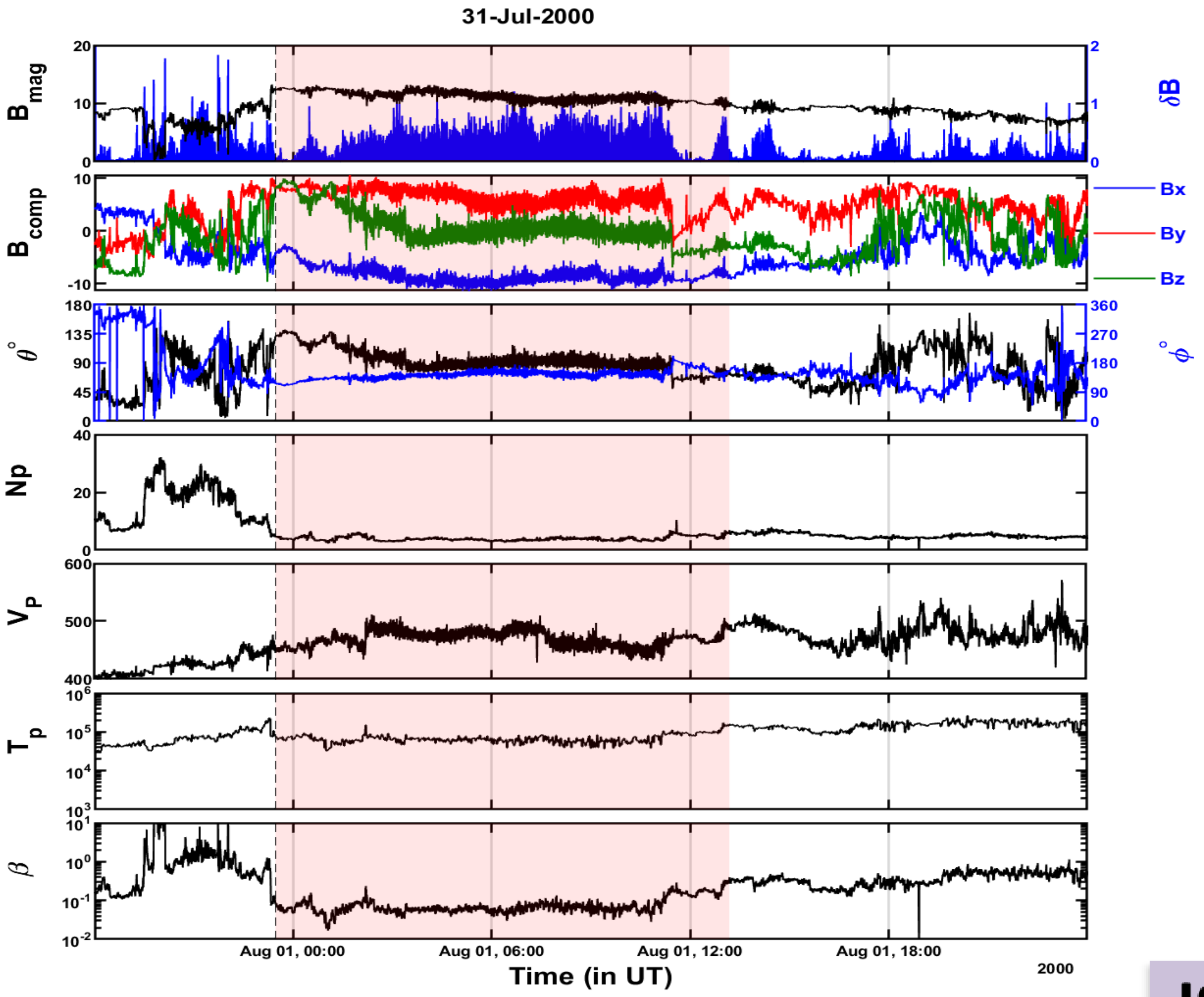
Hannes Alfvén and B Lindblad. MNRAS, 107(2)..211-219
Yang et al ApJ , 817(2):178, 2016.
Dhamane et. al. 2023 Solar Physics

θ_{VB} Test

1. Angle between IMF vector and solar wind velocity $\theta_{VB} = cos^{-1}[-B_x/B_{mag}]$
2. Criteria for quasi parallel flow $\theta_{VB} \leq 40^\circ$
3. Criteria for quasi anti parallel flow $\theta_{VB} \geq 140^\circ$
4. 2 event shows quasi parallel nature and 3 shows quasi- anti-parallel nature

Podesta and Garry 2011, APJ

Event Analysis: 31 July 2000

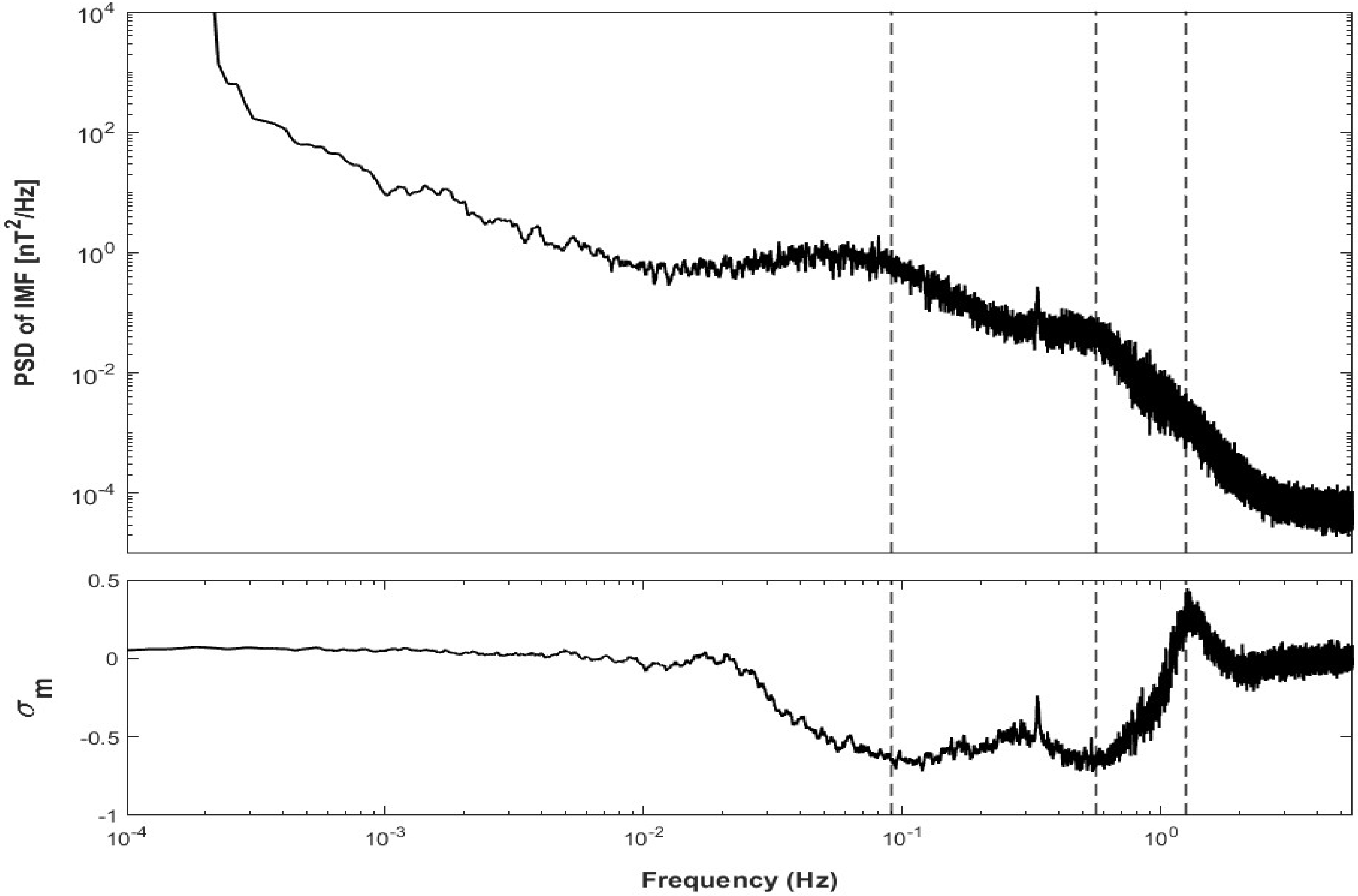


IP Parameters

❖ Features

- ✓ No Sheath
- ✓ Outer layer is free from fluctuations
- ✓ Inner layers are highly fluctuating
- ✓ 92 sec data won't show any fluctuation
- ✓ 3 sec data used for analysis

ICME catalog available at
https://wind.nasa.gov/ICME_catalog/ICME_catalog_viewer.php

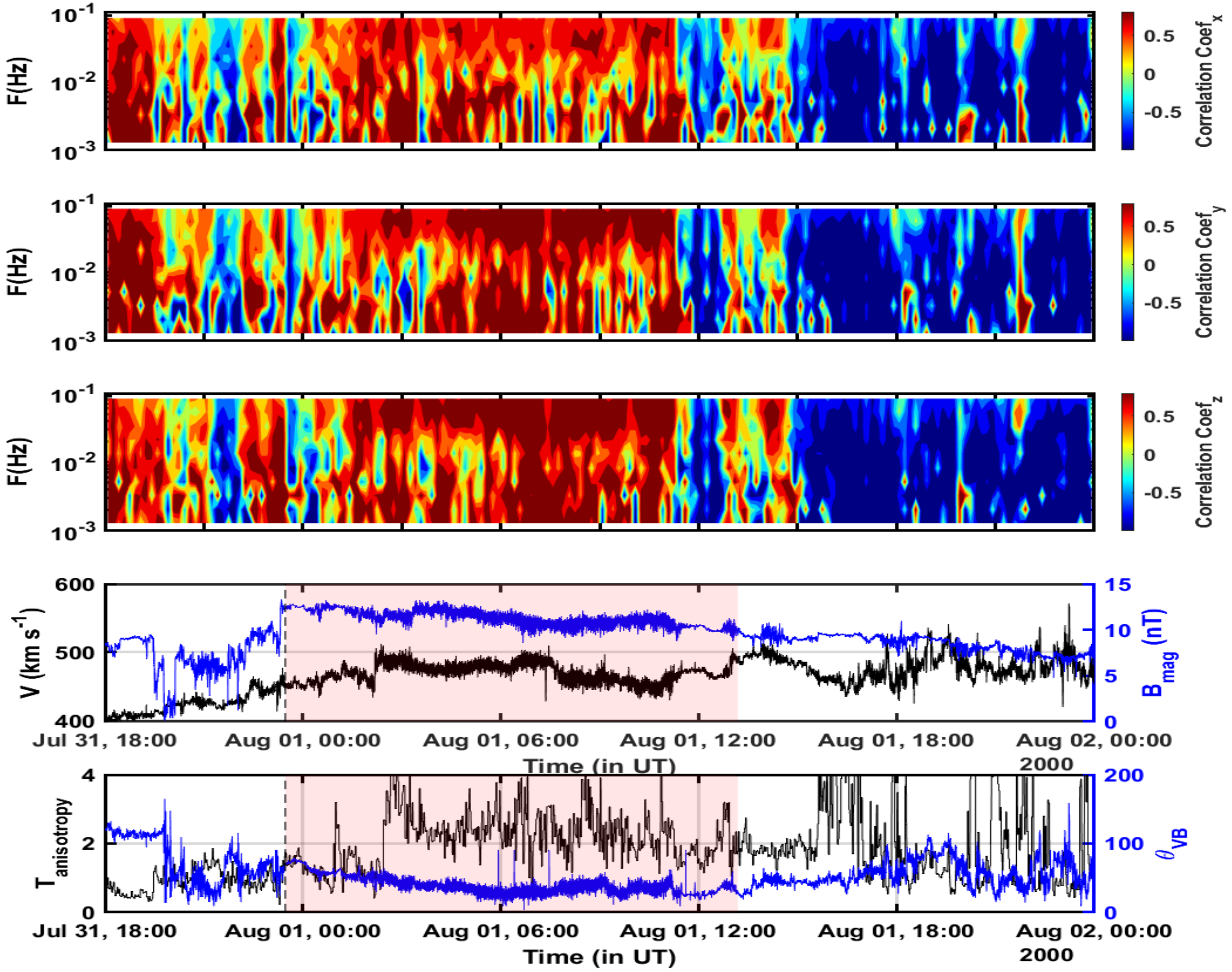


❖ Features

- First hump near 0.1 Hz
- Second hump at 0.6 Hz (gyro- frequency)
- Third hump at 1.24 Hz
- Negative value of σ_m
- Possible signature of kinetic scales waves.
- 11 Hz MFI data used for analysis.

Telloni et. al, 2019 APJ
Telloni et. al, 2012 APJ
Telloni et. al. 2013 APJ

PSD and normalized helicity analysis

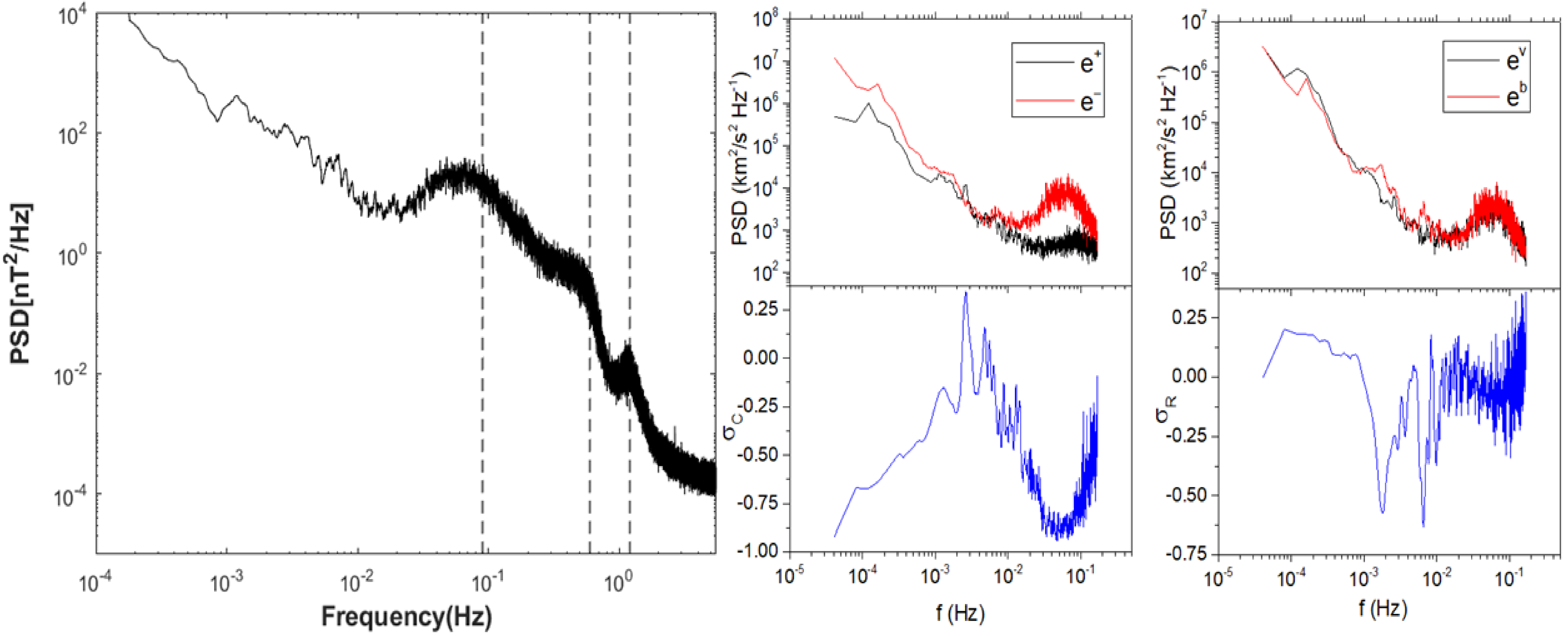


❖ <u>Features</u>:

- Strong Alfvénic Correlation is observed in frequency range 10^{-3} - 10^{-1} Hz.
- High Temperature Anisotropy is observed in the in inner layer of cloud.
- θ_{VB} is almost below 40 $^{\circ}$ in high fluctuating region.
- 92 sec SWE data is used to study temperature anisotropy.

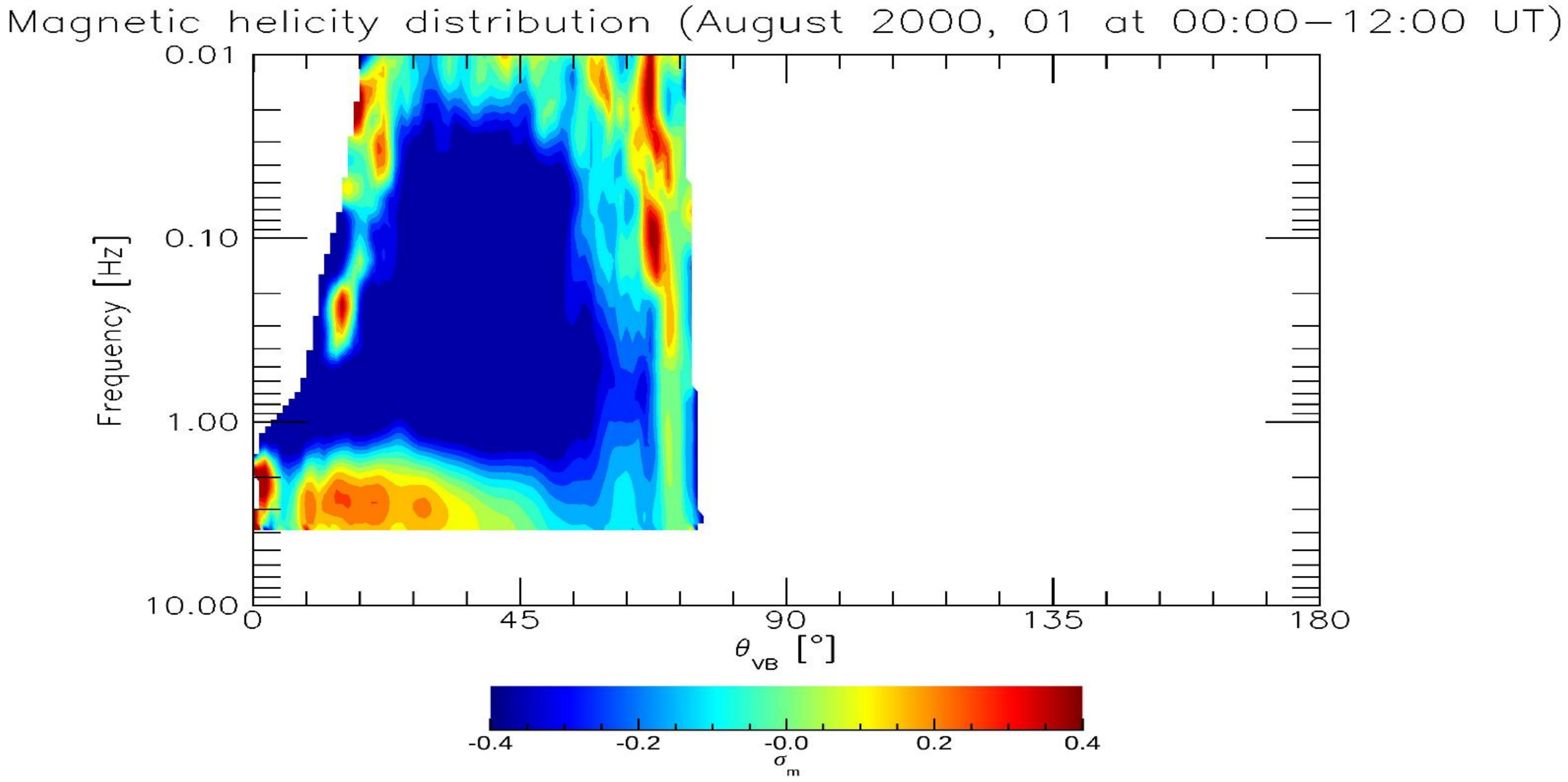
Dhamane et. al. 2023 Solar Physics
Raghav et. al. 2023 APJ
Raghav et. al. 2018 MNRASL
Yang et al ApJ , 817(2):178, 2016.

Walén Test



(a) (b) (c)

Spectral Analysis



Angle between the solar wind velocity and magnetic field

Conclusion

- The coupling of fluid and kinetic scales
- Generation of left-hand-polarized parallel-propagating AIC
- The gyro-frequency at which we found the energy exchanges between wave and particle
- The perpendicular signature is much more effective

What Next?

- Does the transverse propagating kinetic scale exist in magnetic cloud?
- How it contributes to the heating in magnetic cloud?
- What is source of high temperature anisotropy in the inner layer of cloud? Is it locally generated or from their point of origin in the solar corona.

Published Article

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Observation of Alfvén Ion Cyclotron Waves in ICME Magnetic Clouds at 1 au

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Abstract

Waves in plasma play an essential role in the energy transfer and plasma-heating processes. This article discusses the in situ observation of Alfvén ion cyclotron (AIC) waves and their characteristics within interplanetary coronal mass ejection (ICME) flux ropes. We analyzed 401 ICME flux ropes, observed by WIND spacecraft from 1995 to 2021 at 1 au. We found only five ICME flux ropes that show an explicit presence of AIC waves; two have normalized magnetic helicity $\sigma_m \leqslant -0.5$, and the remaining three show $\sigma_m \geqslant 0.5$ polarization. The angle between velocity and magnetic field ($\theta_{\rm VB}$) for $\sigma_m \leqslant -0.5$ is $<40°$, whereas for $\sigma_m \geqslant 0.5$, $\theta_{\rm VB} > 140°$. This result supports the existence of quasi-parallel and quasi-antiparallel left-handed polarized AIC waves within ICME flux ropes. We suggest that AIC waves are possibly triggered by (i) proton temperature anisotropy $Tp_\perp / Tp_\parallel > 1$ driven by cyclotron instability and (ii) low-frequency Alfvén waves through the magnetohydrodynamic turbulent cascade. This study shows evidence of fluid and kinetic scales coupling in the ICME flux rope.

Unified Astronomy Thesaurus concepts: Magnetohydrodynamics (1964)

Thanks to Collaborators

- ✓ Dr. Daniele Telloni -NIA, Astrophysical Observatory of Torino, Italy
- ✓ Prof. Raffaella D'Amicis, INAF, Institute for Space Astrophysics and Planetology, Italy
- ✓ Dr. Zubair Shaikh, Space Sciences Laboratory, University of California
- ✓ Dr. Ankush Bhaskar, SPL, ISRO, India
- ✓ Dr. Robert Wicks, Northumbria University, UK
- ✓ Dr. Georgios Nicolaou – MSSL, UK

Publications

- **Dhamane, Omkar, et al. "In-situ observation of Alfvén ion cyclotron waves in ICME Magnetic clouds at 1AU ." The Astrophysical Journal**
- **Raghav, Anil, et al. "First Analysis of In Situ Observation of Surface Alfvén Waves in an ICME Flux Rope." The Astrophysical Journal 945.1 (2023): 64.**
- **Dhamane, Omkar, et al. "Observation of Alfvén Waves in an ICME-HSS Interaction Region." Solar Physics 298.3 (2023): 34.**

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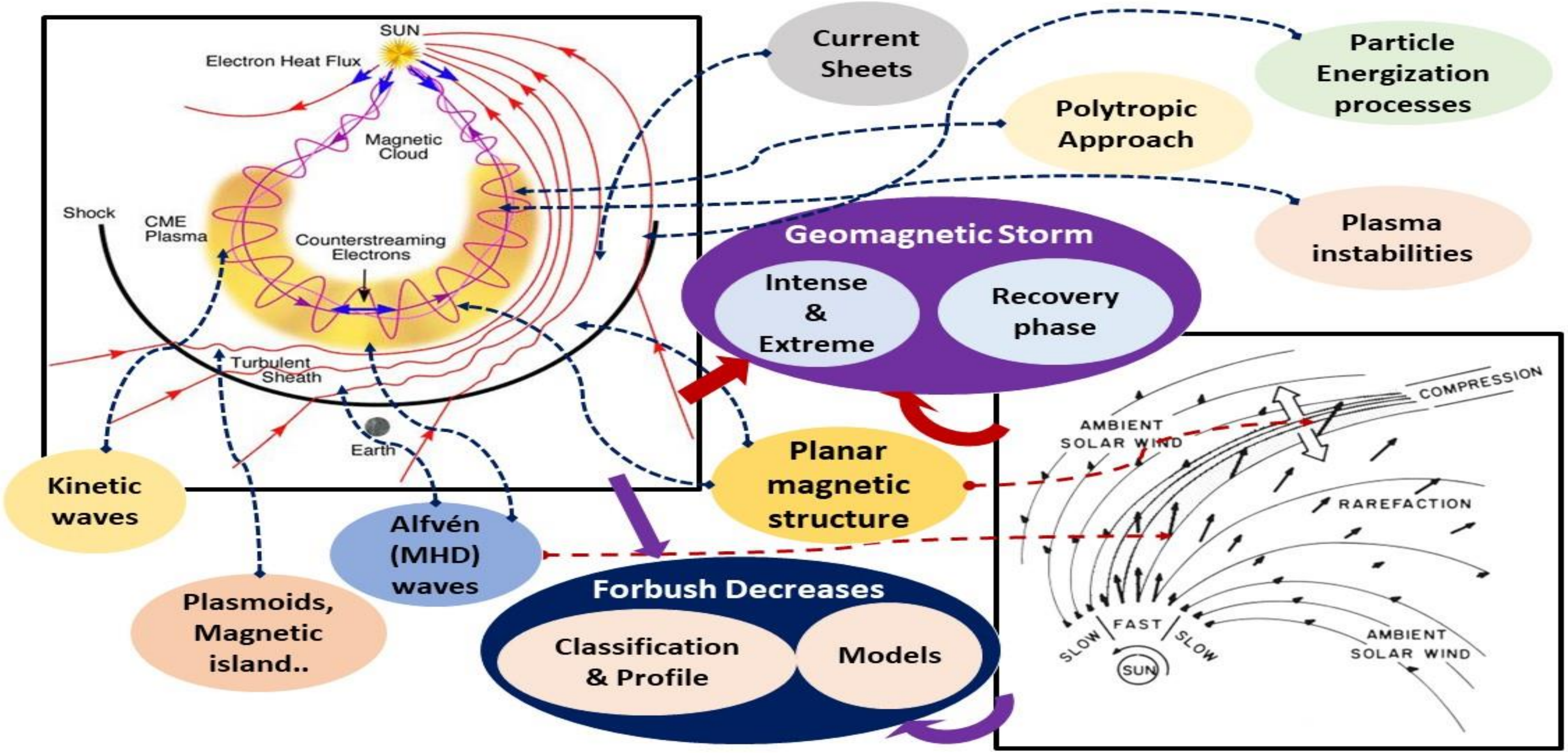
What we are doing?



THANK YOU

University of Mumbai (INDIA)

In situ data measurement

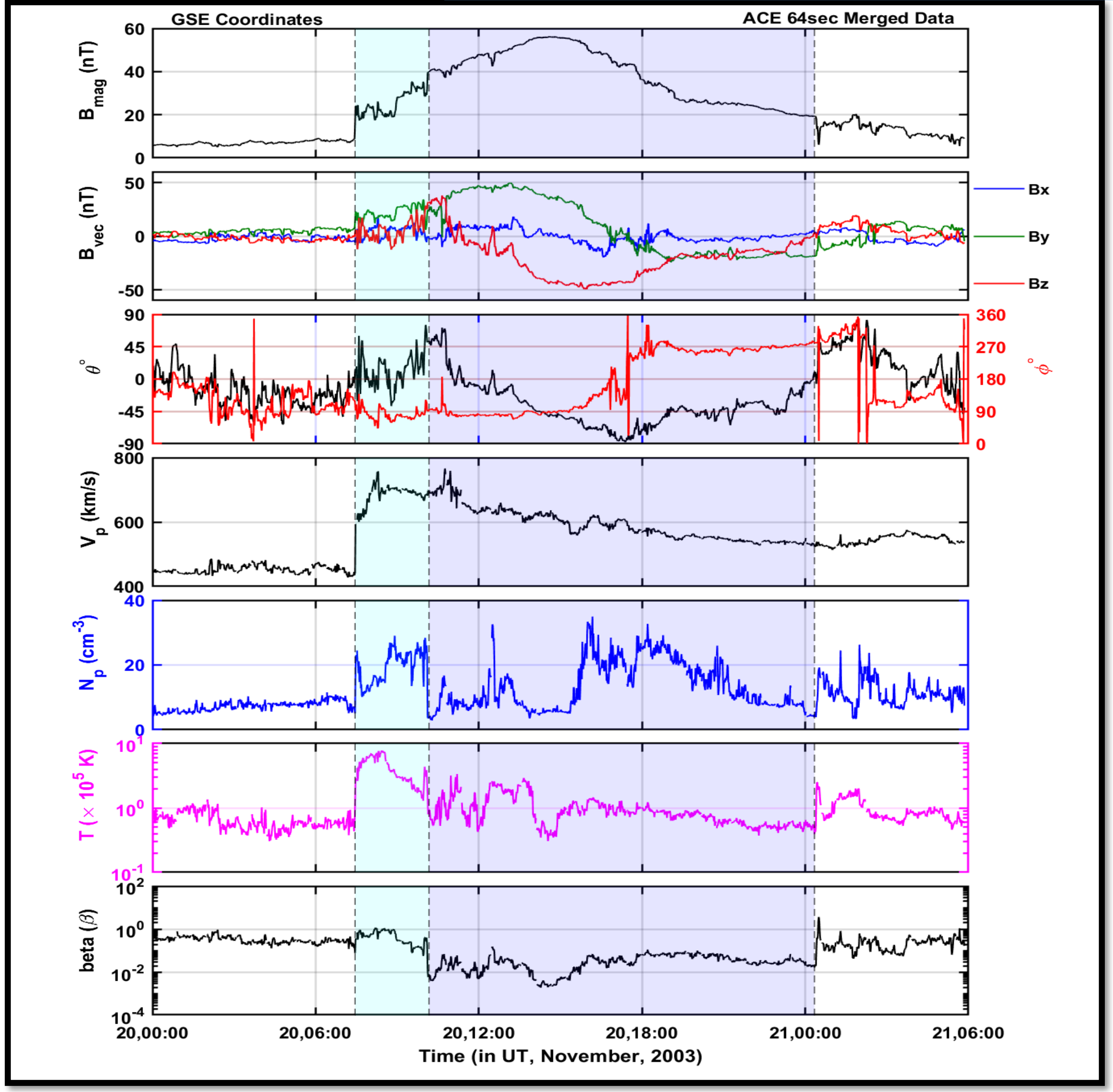


Figure credits: Raghav & Shaikh (2020), MNRASL

The ICME transit on 20 November, 2003 measured by Wind spacecraft.

- ✓ Cyan shade – shock-sheath
- ✓ Blue shade – MC/ flux rope
- ✓ Criteria for identification of flux-rope:
  - ✓ Enhanced IMF
  - ✓ Rotation of IMF vector
  - ✓ Gradual decrease in solar wind speed
  - ✓ Low plasma beta
  - ✓ Low proton Temperature
  - ✓ Low proton density
  - ✓ Bidirectional electron flow

Zurbuchen & Richardson 2006; Chi et al. 2016; Kilpua et al. 2017)