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AOE 5654: SPACE SCIENCE I: THE SOLAR WIND & MAGNETOSPHERE

Unexpected Coronal Mass Ejection: Understanding effect of Geomagnetic Storm Causing Orbital Re-entry of satellites

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Abstract / Introduction

1 The unexpected coronal mass ejections triggered a moderate magnetic storm that de-orbited 40 out of 49 commercial Starlink satellites launched by SpaceX on February 3rd, 2022. The arrival of this unforeseen plasma led to the expansion of denser gases, increasing atmospheric drag and ultimately causing the satellites to fall back to Earth. This incident raises significant concerns, as satellites represent a substantial financial investment, and such sudden failures could pose risks to life and safety. While the magnetic storm was neither massive nor rare, its impact on low Earth orbit (LEO) satellites highlights the vulnerabilities of our space assets. A deeper understanding of coronal mass ejections is essential, particularly regarding their effects on the modern satellite era, which encompasses various atmospheric monitoring capabilities, especially in LEO. For this analysis, three missions were chosen: OMNI, TIMED, and DSCOVR. Together, these missions contribute to a better understanding of Coronal mass ejections and help in better analyzing preventive measures considering the modern age of launching satellites.

2 **Impact of Magnetic Storms on LEO Satellites**

- Raises concerns about the resilience of space assets, especially newer smaller/cube sats in the modern satellite era (supporting communication, GNSS… etc)

3 **Missions Chosen for Analysis**

1.OMNI Mission:

Provides comprehensive solar wind data essential for analyzing the impact of space weather on Earth's environment.

2.NASA's TIMED Mission & STEREO Mission:

Captures dynamics within Earth's upper atmosphere, focusing on the mesosphere, thermosphere, and ionosphere.

3.NOAA's DSCOVR Mission:

Critical for weather forecasting and live solar wind monitoring to predict space weather impacts.

4 **Importance of Understanding Coronal Mass Ejections**

- Modern satellites in LEO are integral to various applications, including atmospheric monitoring, communication, and navigation.

Image of the satellites de-orbiting due to increased drag (Image credit: Eddie Irizarry/Sociedad deAstronomia del Caribe (SAC))

Mission Overview

OMNI
L1 orbit mission, to understand magnetic field variation with understanding of plasma properties.

TIMED
Studying the suns effect in the mesosphere and lower thermosphere/ionosphere.

STEREO
Observation of the CME's from the heliocentric region

DSCOVR
Observatory that focuses on space-weather alerts.

Objectives

1. Investigate the onset of unexpected geomagnetic storms caused by coronal mass ejection structures (Proton Density, IMF, Solar Wind Density, Solar Wind Speed, AL Index, and so on)

2. Explore the relationship between geomagnetic disturbances and variations in atmospheric mass densities

3. Analyze the impact of geomagnetic storms on satellite altitude and their susceptibility to these events

Datasets

Spacecraft Mission:

Office of Naval Research (ONR) Multi-Instrument Network (OMNI), Deep Space Climate Observatory (DSCOVR) and Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED)

- **Data set 1 :** OMNI2_H0_MRG1HR

  OMNI Combined, Definitive, Hourly IMF and Plasma Data, and Energetic Proton Fluxes, Time-Shifted to the Nose of the Earth's Bow Shock, plus Solar and Magnetic Indices - J.H. King,N. Papitashvili (ADNET, NASA GSFC)

- **Data set 2 :** DSCOVR_H0_MAG

  DSCOVR Fluxgate Magnetometer 1-sec Definitive Data - A. Koval (UMBC,NASA/GSFC) DSCOVR_AT_DEF]

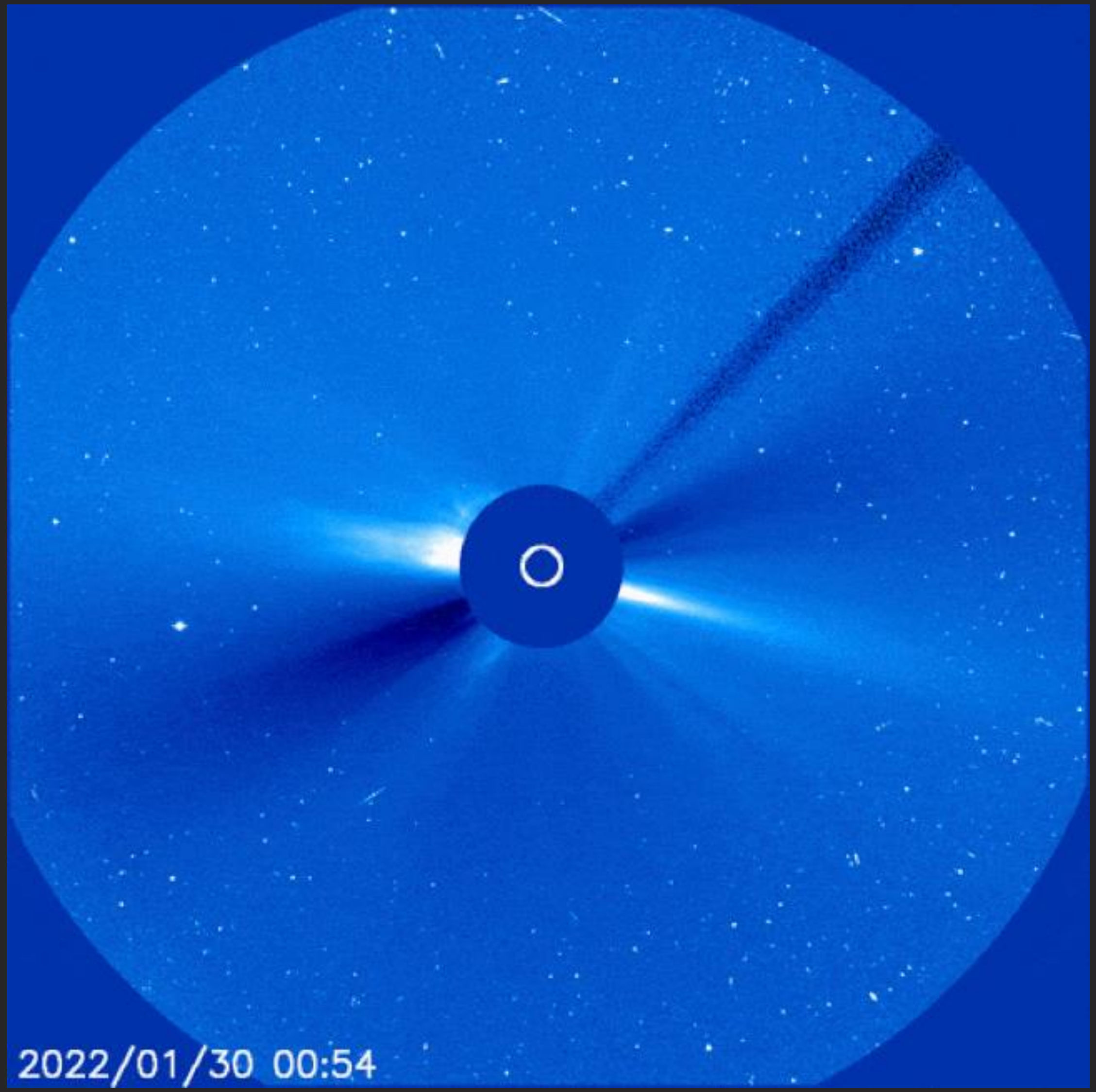
- Data set 3 : TIMED_L1BV20_SABER

  DIR Radiances in 10 channels (1.27 to 17ym) from 0 to 150 km, Version1.07, - James Russell III (Hampton University)

- **Additional Data**: STEREO, STA_C0H01HR_MERGED_MAG_PLASMA

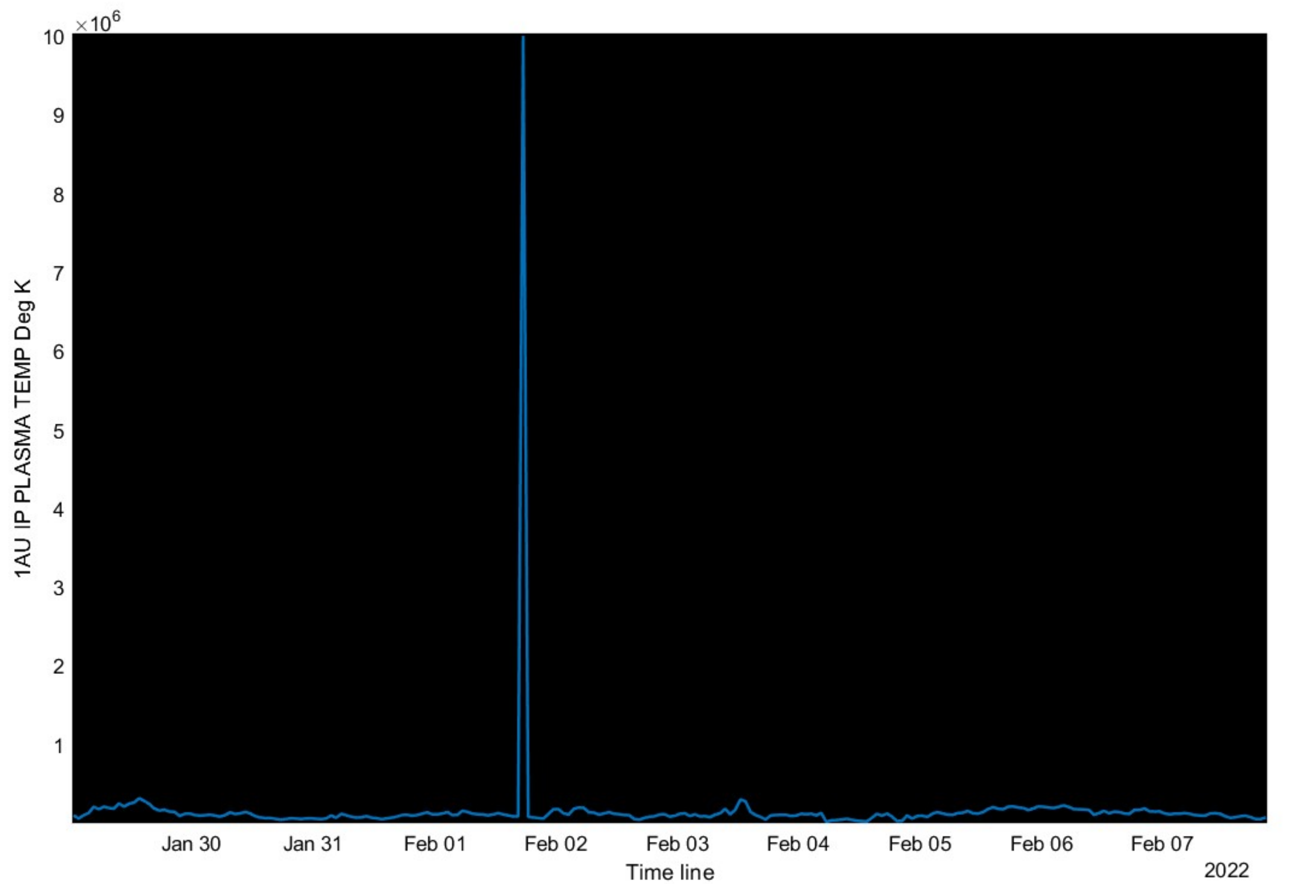
  Genesis Ion Monitor Experiment - Roger C. Wiens (LANL)

Selected Time Range: Jan 29th, 2022, to Feb 8th, 2022 [10 days]

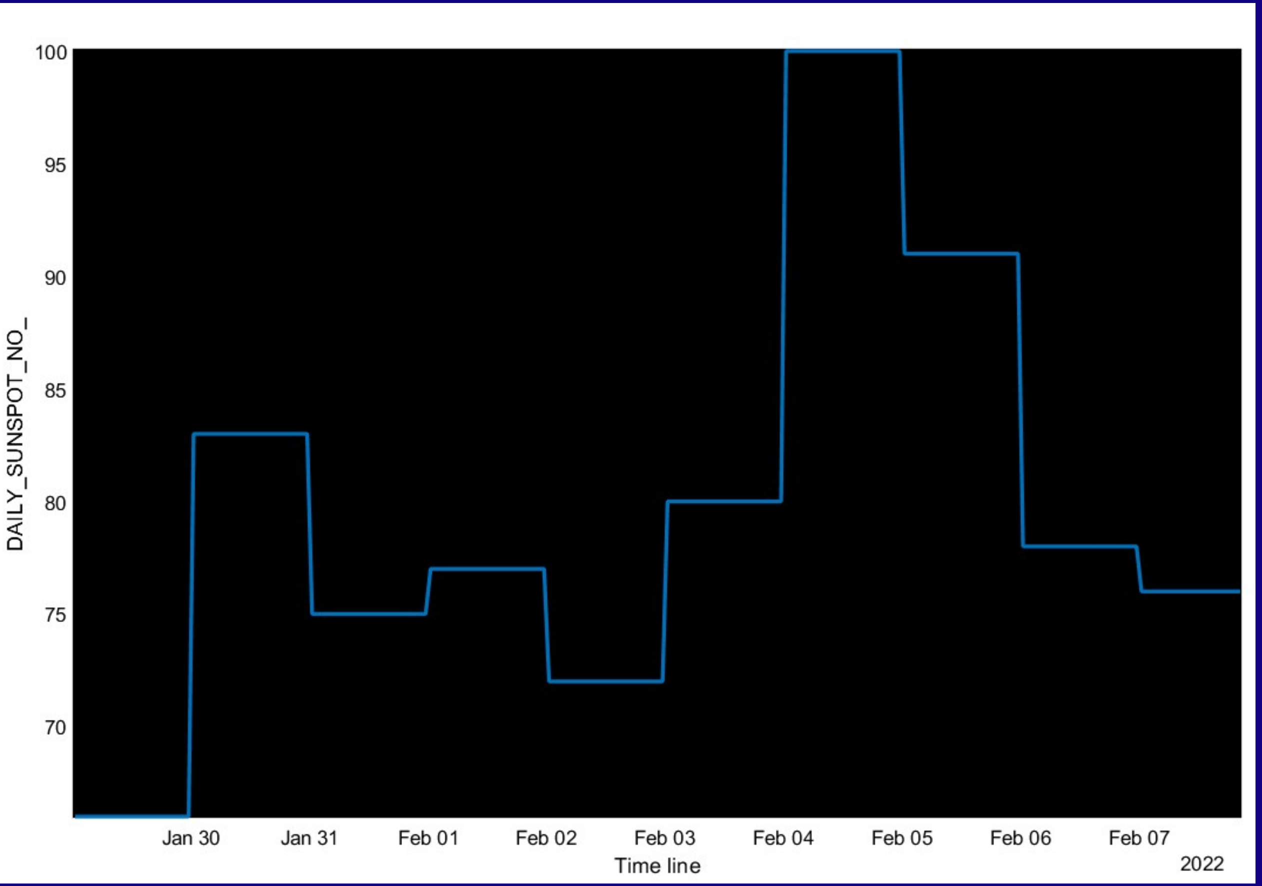


GIF of Coronal Mass ejection from the sun on January 30, 2022

Results & Findings : OMNI

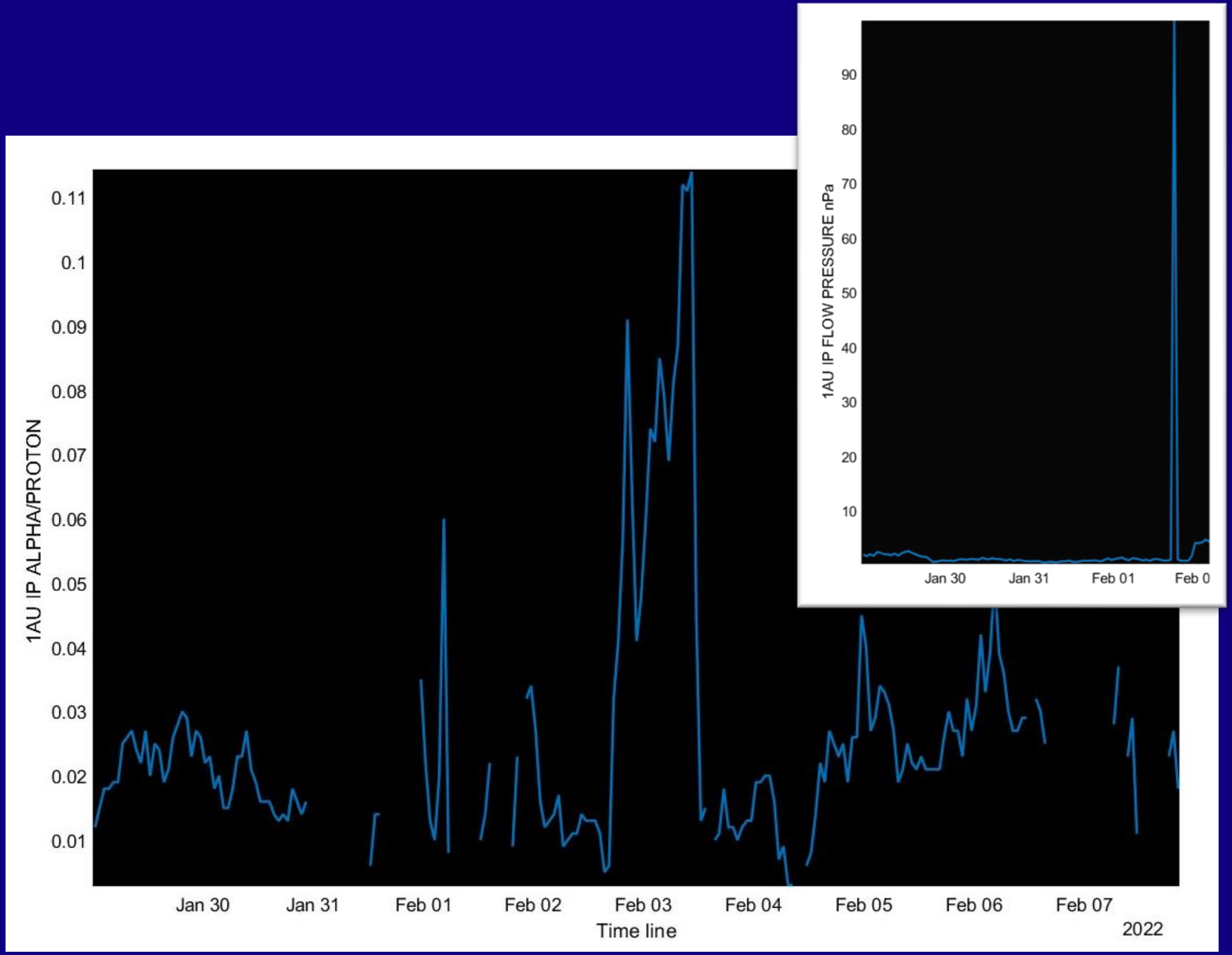


At first, we observe the early onset using OMNI's readings of the change in plasma. Here the plasma around earth shows a sudden spike about a day before the launch of the satellites, and the Geomagnetic storm hitting earth.

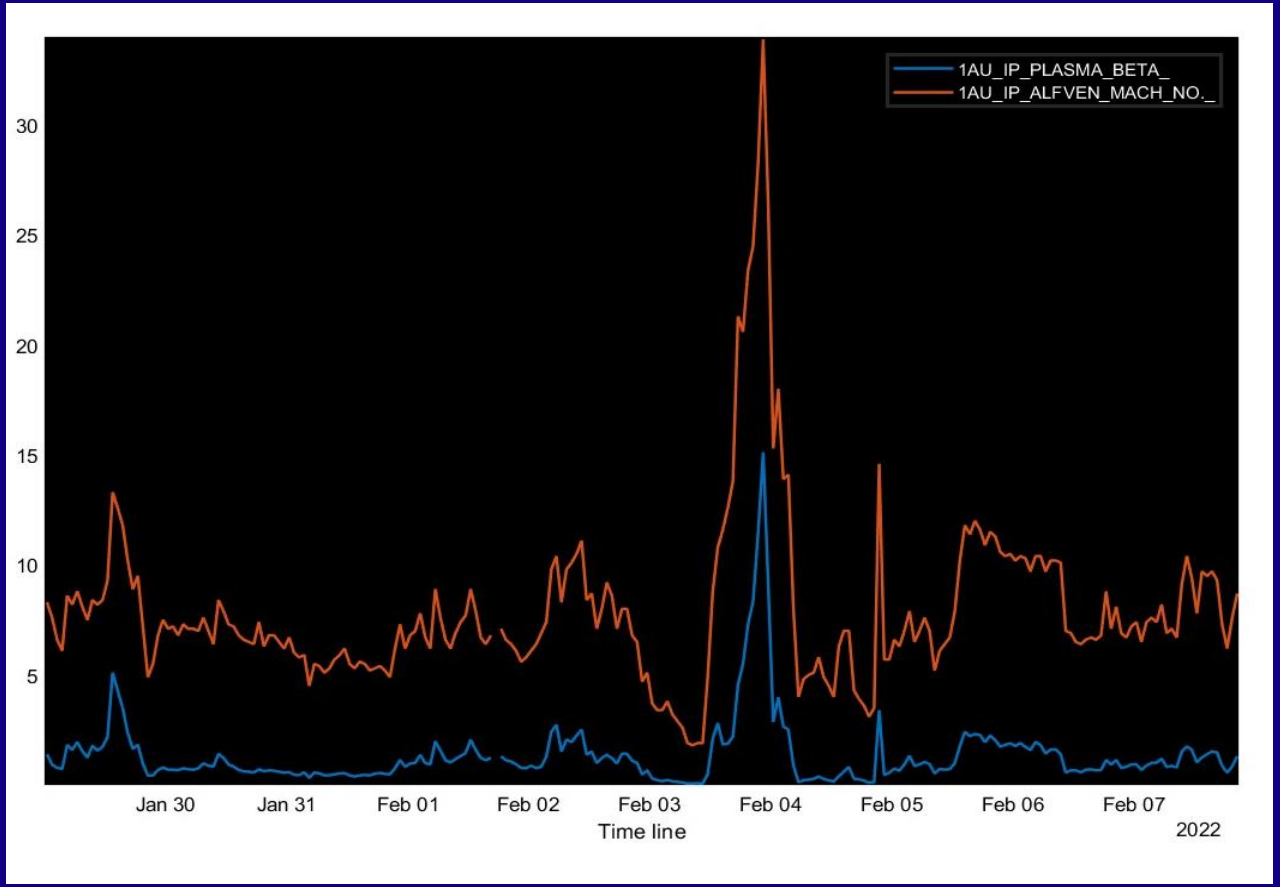


This plot is one of the best indicators of the mild storm from the date of the CME to the geomagnetic storm hitting. On Jan 30, when the CME is released, the number of sunspots increased up until after the day of the storm and reduced as it passed.

Results & Findings : OMNI

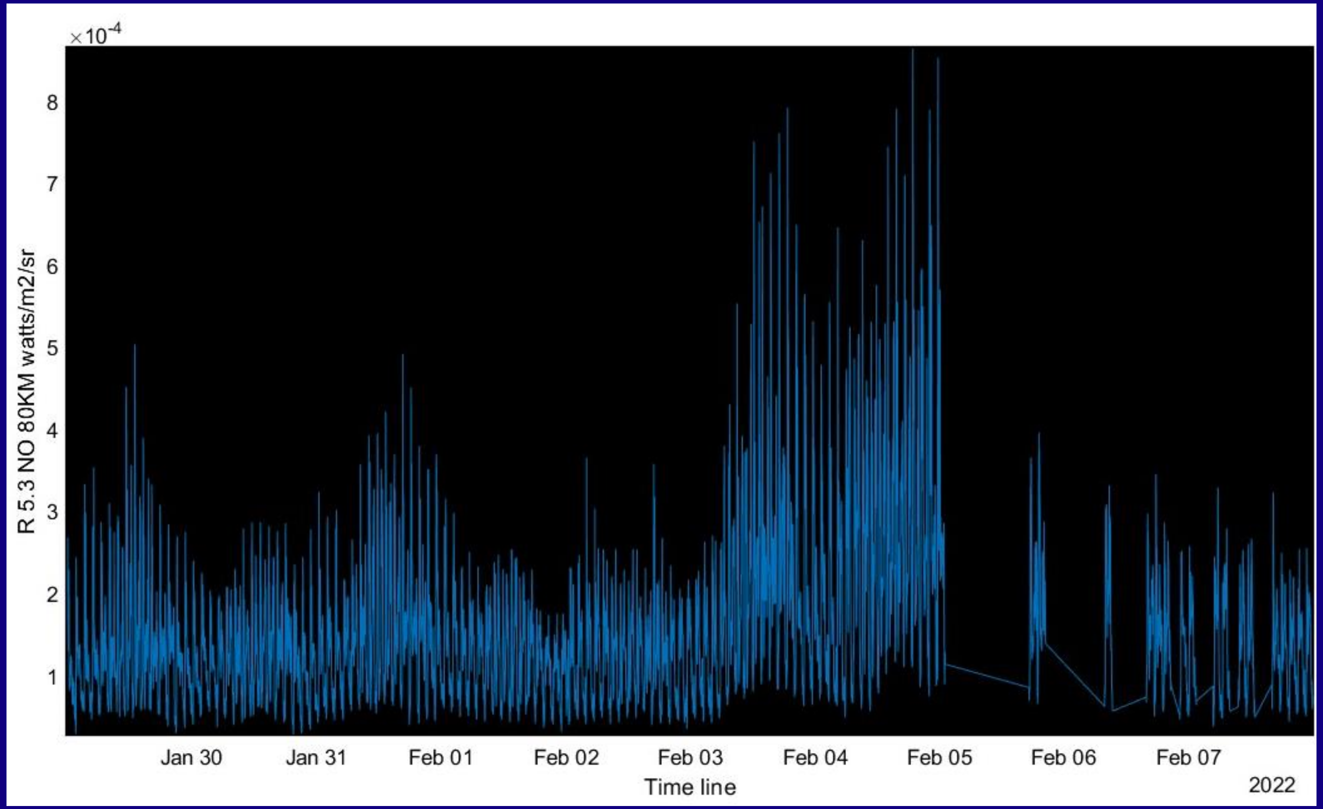


The IP alpha/proton ratio peaks around the same day the IP flow pressure and the RMS deviation of the plasma temperature and ion number density, both showing peaks in the latter on Feb 3rd. while the alpha/proton ratio and the flow pressure are a bit wide.

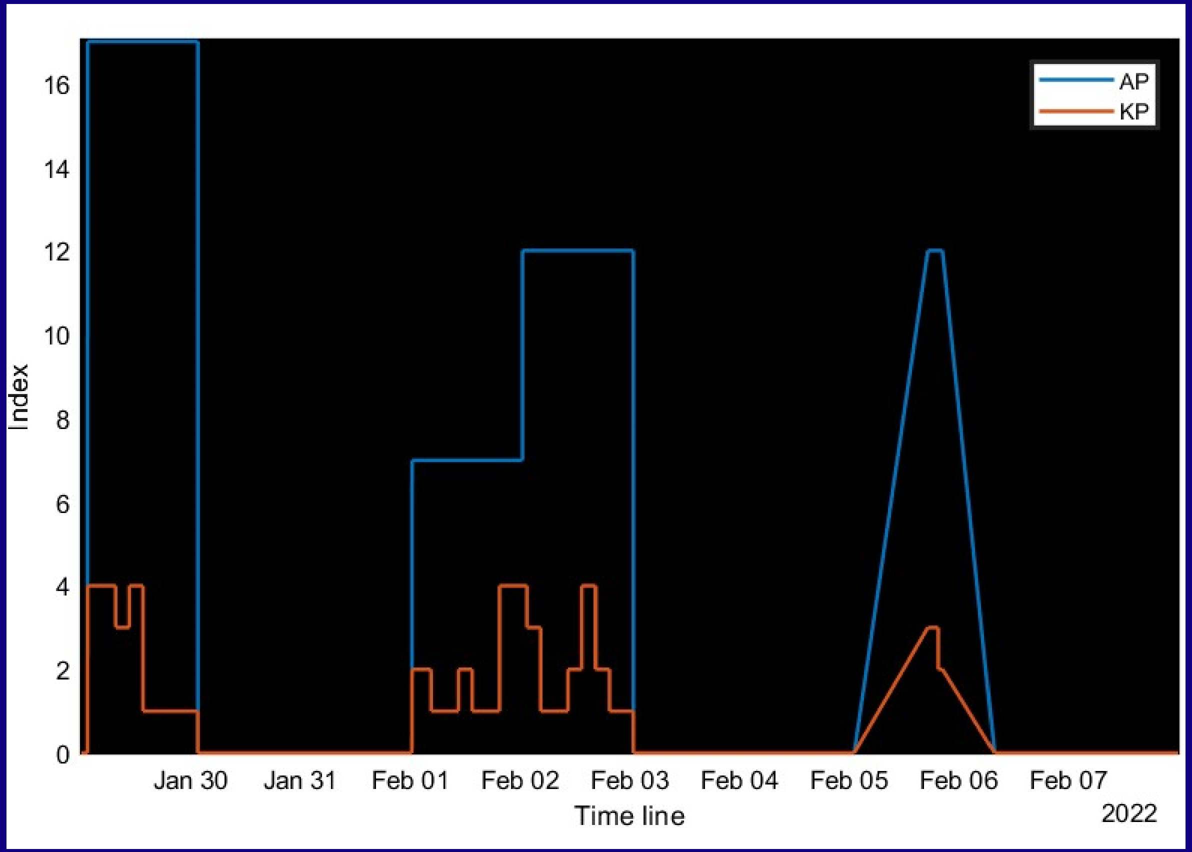


The High plasma beta means that the thermal pressure dominates while the high Alfven mach no. means solar wind velocity is greater than the Alfven speed, it could enter the earths magnetic field more easily.

Results & Findings : TIMED

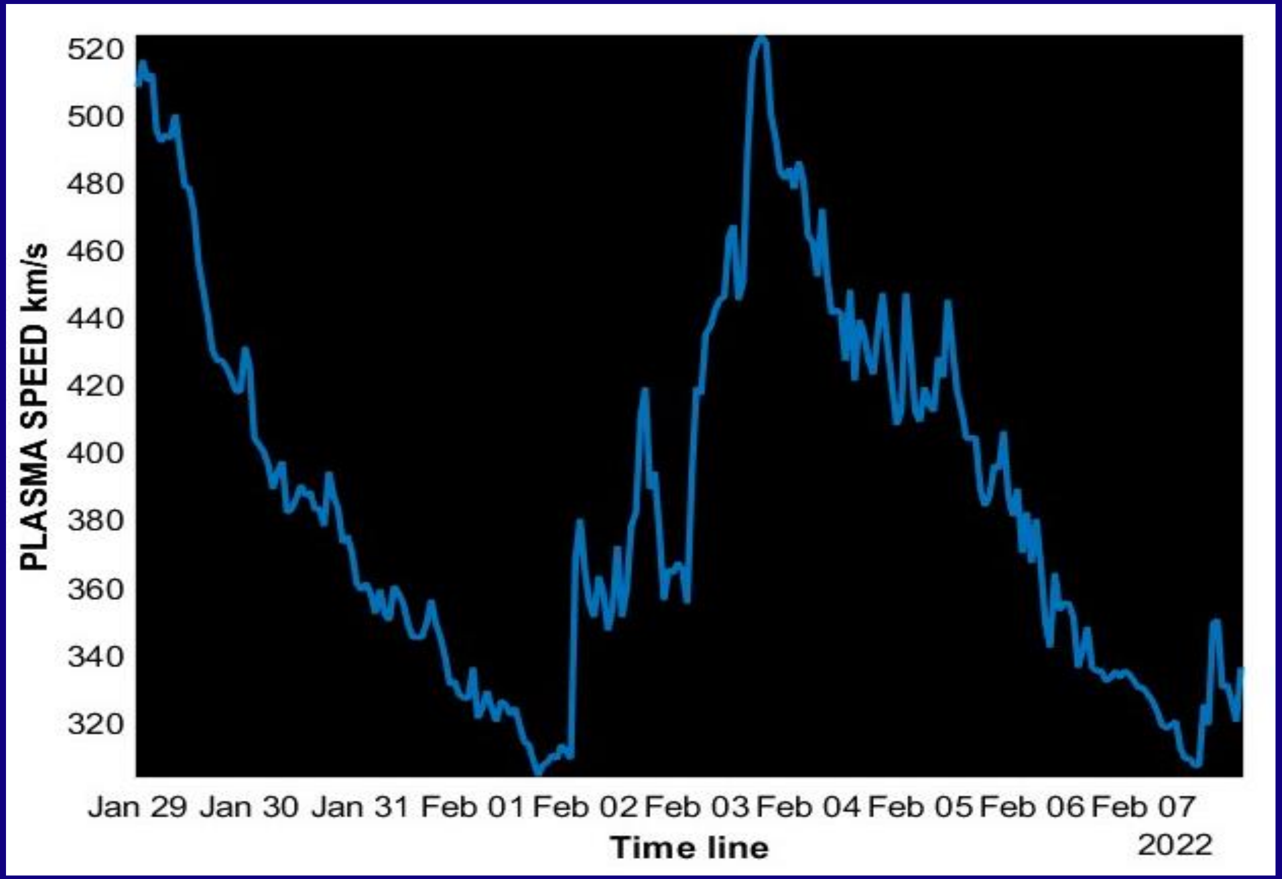


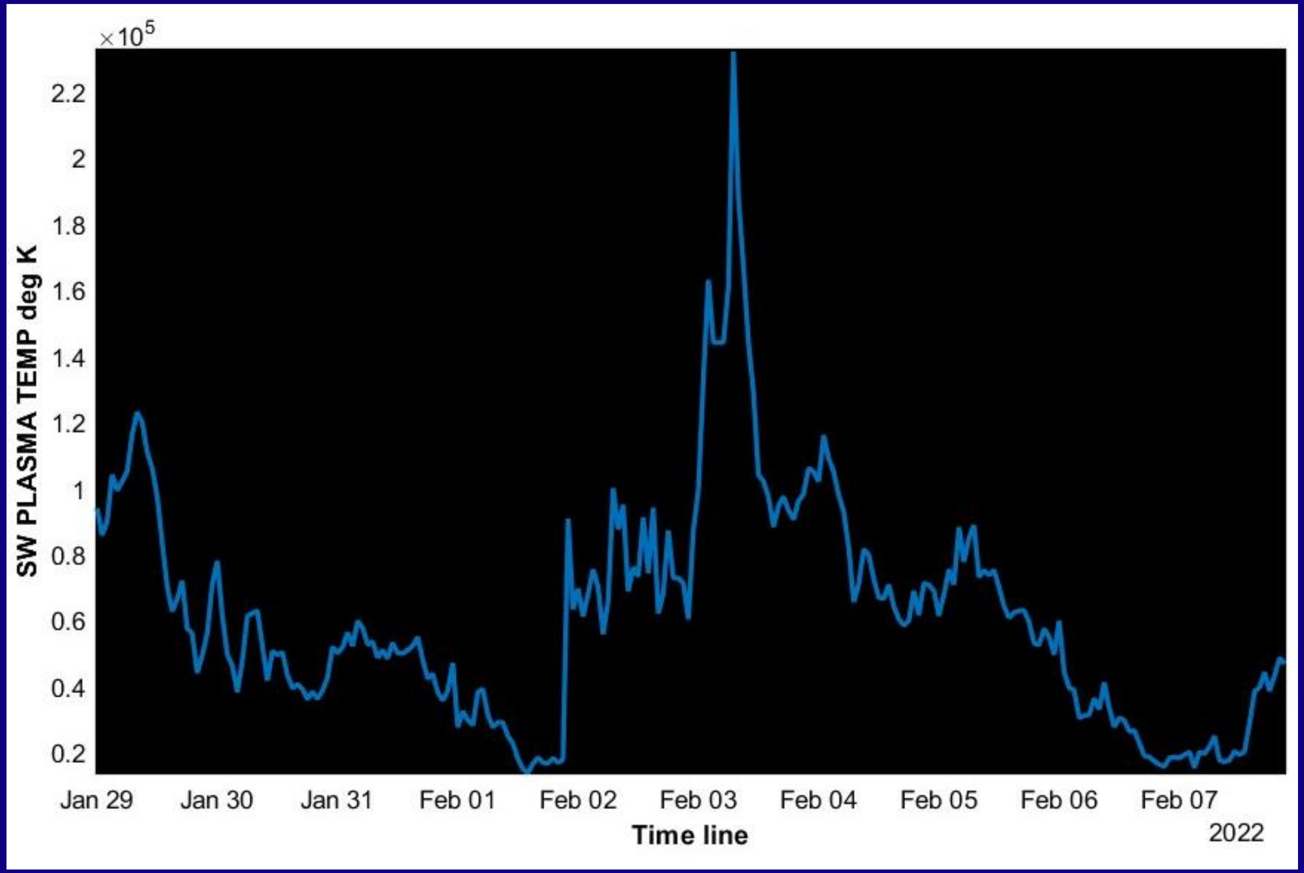
The calibrated radiance at 5.3 um (NO)) at 80km shows a brief period of rise and fall after the magnetic storm has hit.



The Ap and Kp values peak right before the Geomagnetic storms hit meaning the onset of the storms, where we know Kp indicates short-term fluctuations but shows overall activity level of geomagnetic in the magnetosphere-ionosphere system, and Ap is the daily average of these geomagnetic disturbances.

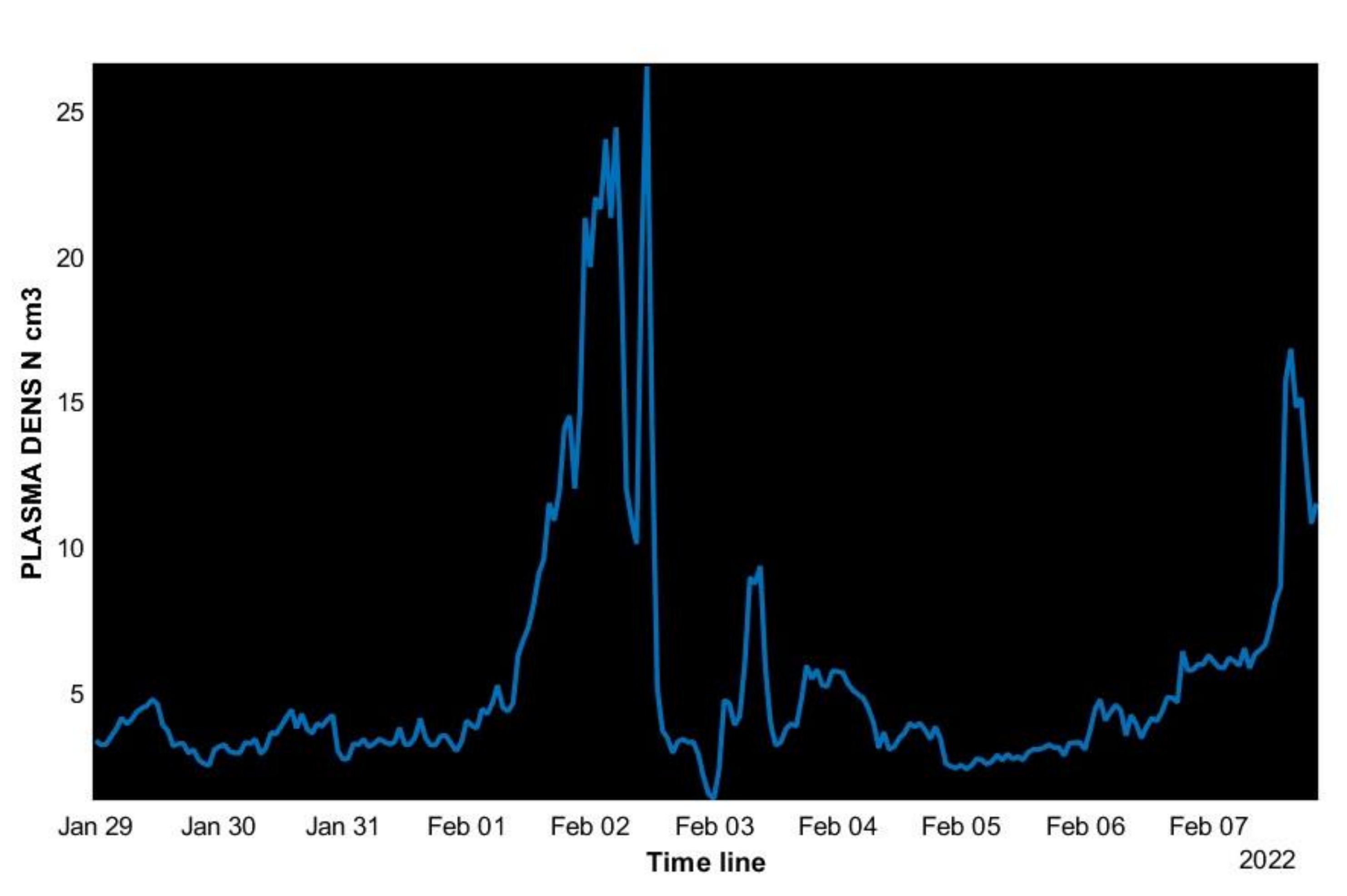
Results & Findings : STEREO





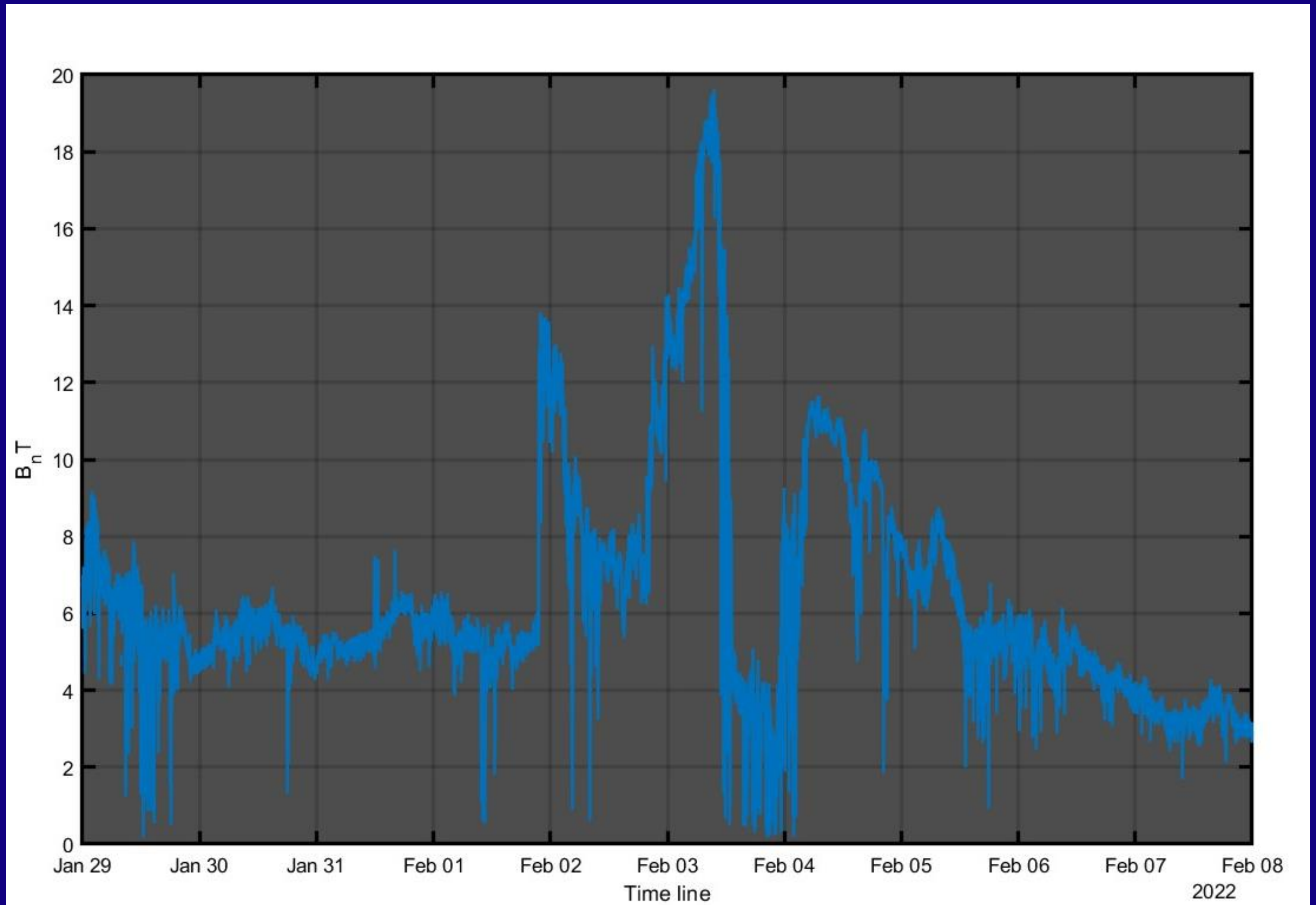
Here plasma temperature can be seen increasing both during when the mass ejections are released and when it hits the LEO. Overall increase in the plasma speed up to 520 km/s and a high Temperature as well, here the temp increase is more during the hit , which can be one of the causes of increasing the air drag.

Results & Findings : STEREO

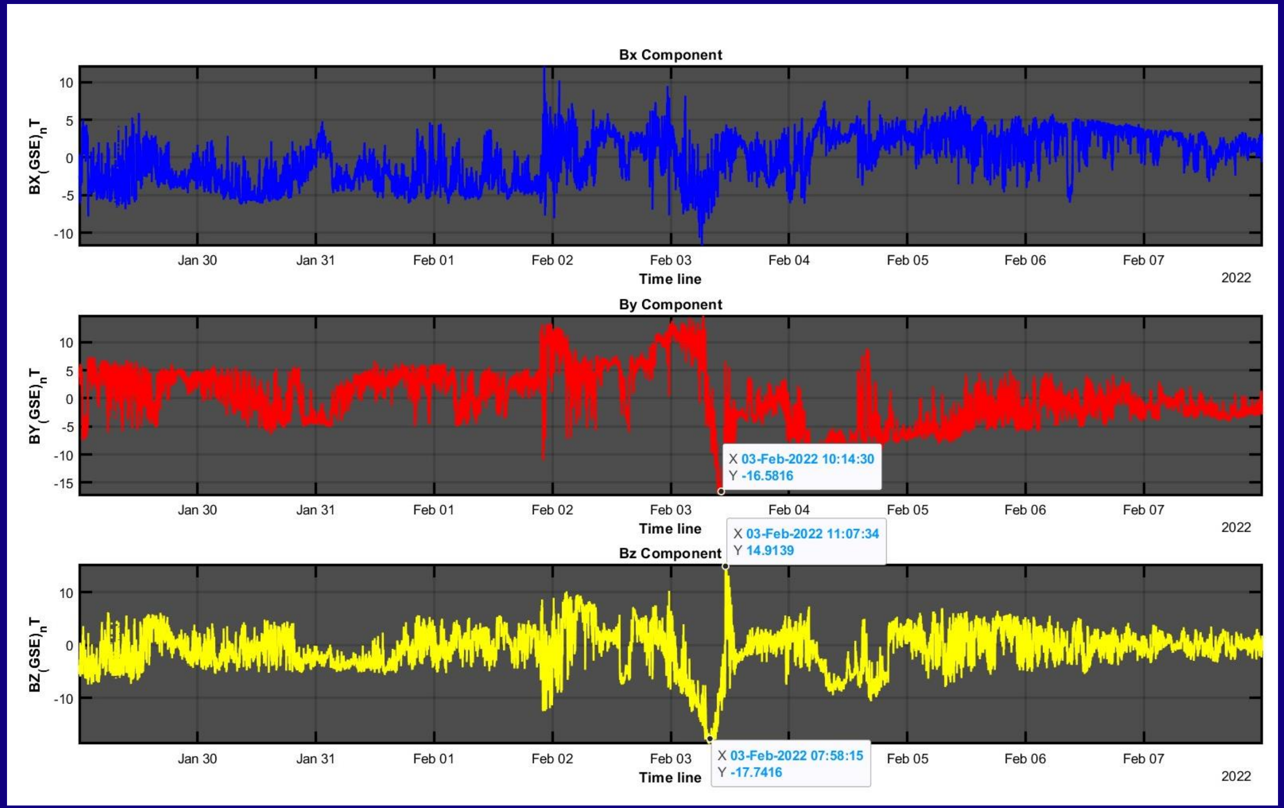


Change in plasma density causing more drag in satellites. Increased densities at altitudes above 200 and below 550km where the LEO exists can cause greater atmospheric drag and orbital decay.

Results & Findings : DSCOVR

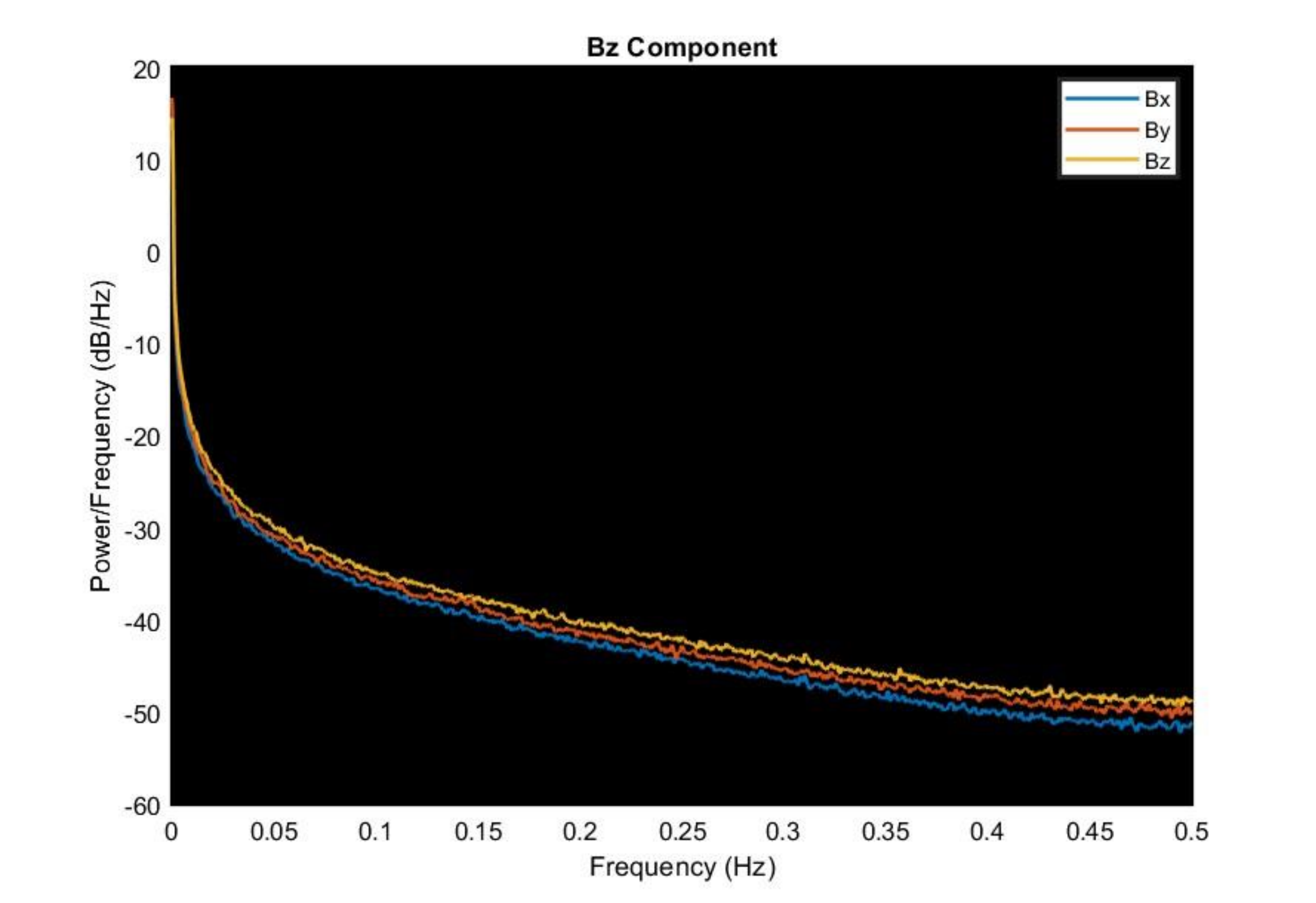


Detail of the change in the magnetic field as seen retrieved by the fluxgate Magnetometer. The onset of the geomagnetic storm is observed in the beginning of Feb 2nd and briefly drops before the main magnetic storm hits during the day of Feb 3rd.



Magnetic Field along the GSE coordinates, with fluctuations seen only in the y and z axis. The z axis shows the magnetic flux moving below the ecliptic plane and then above it during Feb 3rd, while the y axis shows a sharp decline in and is most likely trailing earth.

Results & Findings : DSCOVR



Considering just the GSE coordinates , with the Center assumed to be at the sun. Here Bx shows the least value in the power spectrum and in reference to the plot of the Bx we can see there is no major fluctuations, but there is in Bz along the z axis (magnetic reconnection allowing for the Geostorm) and By along the y axis. These changes in magnetic field can be a factor that creates the initial displacement leading to further changes in the atmospheric conditions.

Discussion

The dip in the one-hour Dst index (can be obtained using OMNI database) indicates the onset of a geomagnetic storm, and the increased densities at altitudes above 200 and below 550km where the LEO exists can cause greater atmospheric drag and orbital decay. Since these were mild it did not have an massive effect but still affected them due to their size and compact nature. Such changes in parameters show that it may impact low earth satellites, maybe radio communication and power infrastructures.

The rise and fall of NO radiance shows how there is heating and then cooling affecting the atmospheric conditions that may account for drag. The increase in plasma density, temperature, speed, and average magnetic strength also add to the effect. The solar wind whose plasma density initially increases and peaks while dropping right immediately before it reaches max speed and max magnetic strength and temperature.

The proton's accelerations (can be obtained using OMNI database) occur due to the strong magnetic fields because of the shock front of the CMES. The disturbance cause can mean that the operators cannot use escape maneuvers with proper predictions. Allowing for safety precautions can be super useful and preparing for better launch dates given the CME had ejected just 3 days ago. These thermal pressure-based fluctuations could have been avoided.

Summary & Conclusion

1 Onset of Geo-magnetic storms

Mild storms need be detected earlier and need to be addressed. Especially when they are seen at short notice and can affect millions of dollars of worth satellites. As satellites get more advance and smaller , they require better protection.

2 Affect in the atmosphere

The Geomagnetic storms affecting the satellites are first studied from their properties that are affecting the space around Earth. The Properties in question are related to the Solar wind properties, the plasma properties, temperatures, and the dominating magnetic properties. Such changes induce higher plasma temp and atmospheric drag.

3 Impact on Satellite altitude

The change in magnetic field along different axes can alter the position of satellites, the affect of CME's at the LEO can then de-orbit vulnerable satellites, providing no escape.

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Merci

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