Ion's Energy Spectra at Earth's Bow Shock

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Abstract

Ions are accelerated to very high, cosmic ray energies in space, solar, and astrophysical plasma environments. While the so-called diffusive shock acceleration has been the standard model of ion acceleration, it still remains unclear how ions are accelerated from thermal to non-thermal energies and how an ion energy spectrum looks like. Here we show, based on the state-of-the-art observation by NASA's MMS mission, that the ion energy spectrum exhibits a power-law form that extends smoothly from the thermal component up to > 100 keV at the Earth's bow shock. The intensity of this non-thermal component depends on the shock angle. However, the energy spectrum is often confounded by the presence of high energy ions from a different source possibly the magnetosphere. We envision that more detailed and careful analysis of ion spectra would lead to a better understanding of how ions are accelerated from thermal to non-thermal energies at not only Earth's bow shock but also in other space and astrophysical shocks.

Introduction

- High energy, ion collisions on the Earth's bow shock can vary depending on the shock angle of the shock crossing event.
- It is unclear how ions are accelerated from thermal to non-thermal energies. One source that cause these accelerated ions may be connected to the magnetosphere.
- However, the primary focus of this research is the shock front of Earth's bow shock.
- The main goal of this research project is to study how much energy ions can gain. We hope to see a clear power-law within the plots from various shock angles.
- In addition, we also want to connect the Diffuse Shock Acceleration Theory (DSA) into the Earth's bow shock. In which would mostly apply to lower shock angles. DSA explains in how cosmic rays are generated in astrophysical objects; however, there has not been any direct connections of DSA to Earth's bow shock.

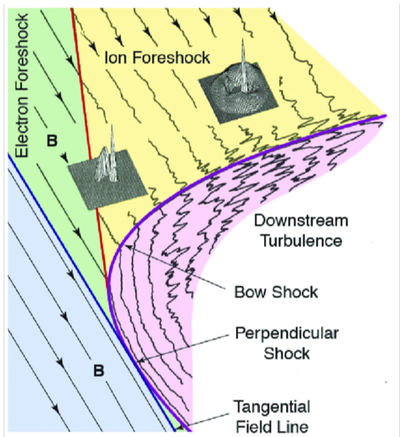


Figure 1. *This figure shows a representation of upstream ions colliding with the Earth's bow shock at different shock angles. With the perpendicular shock not encountering any ion particles. As opposed to the more quasi-parallel shock, in which receives countless of ion particles. Image credit: [2]Burgess et al. 2012.*

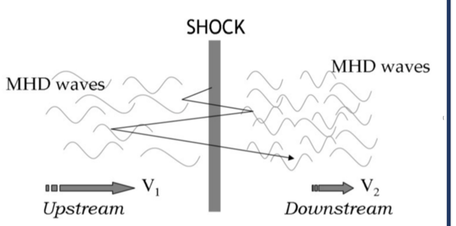
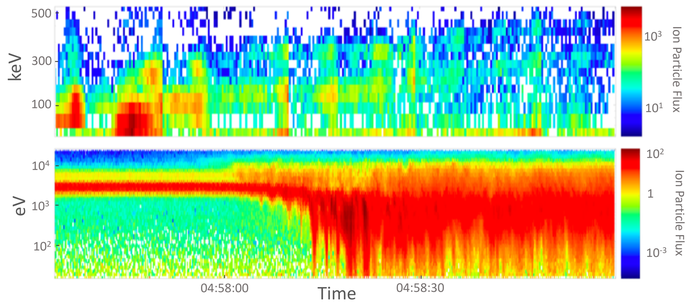


Figure 2. *This schematic illustration of Diffuse Shock Acceleration (DSA) shows how ion energy spectrum behaves in a shock front.*

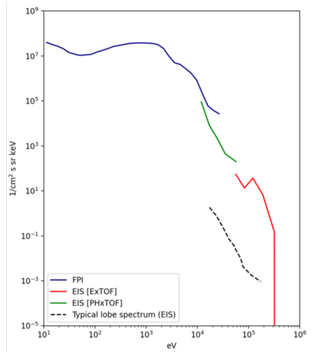
Methods & Results

- For this research project I utilized Python to retrieve data from the Magnetospheric Multiscale Mission (MMS) spacecraft. Furthermore, the instruments I used to retrieved data were from the Fast Plasma Investigation (FPI), The Fly's Energetic Particle Spectrometer(FEEPS) and Energetic Ion Spectrometer (EIS).
- I developed a code in where I gathered data and created plots from a list of shock crossing events. Therefore, with the created plots, I separated them from their respective shock angles, in which were <= 45° and > 45°.
- Moreover, I also plotted a particular shock crossing event that occurred on November 4th, 2015, that showed high energy ions in a perpendicular shock angle.
- I have analyzed and compared the events of November 4th, 2015 to other dates with a lower shock angle; and results for this comparison showed that ions crossing the shock front gave a much higher energy output when the shock angle was lower.
- Since the November 4th, 2015 event showed high energy ions at a perpendicular angle of 83.9, it was unsual that high energy ions were present at the perpendicular shock because ions from the upstream are not known to collide the shock front at such a high shock angle.
- The plots and analysis of the day of and prior to November 4th, 2015 showed similar high energy ion activity. This led us to ultimately believe that it was caused by the magnetosphere, not the bow shock itself. And we decided to look in detail other shock crossing events at different angles.

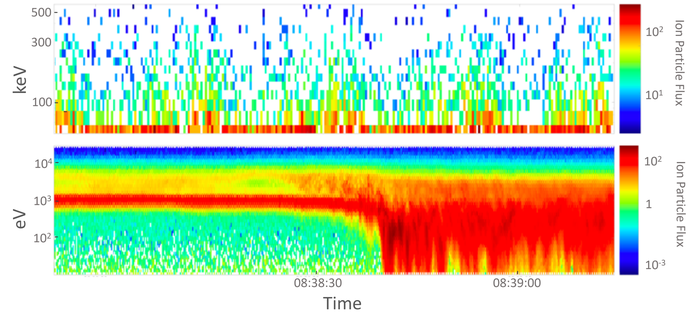
Event date: 2015-11-04 / 04:57:50 - 04:59:00
Shock angle at 83.9
Mach number 10.9



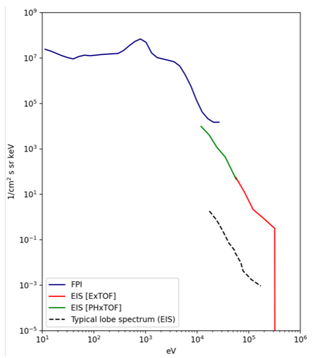
Interval: 04:58:05 - 04:58:25



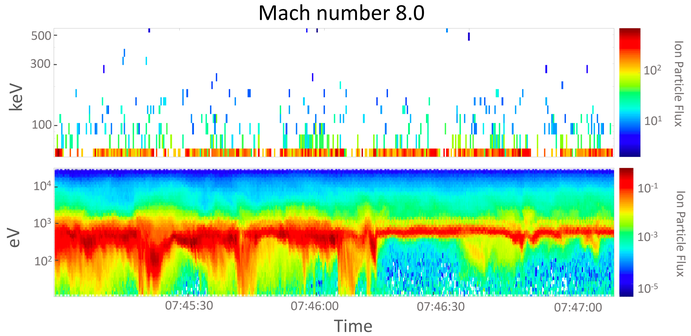
Event date: 2015-10-25 / 08:37:45 - 08:39:30
Shock angle at 55.1
Mach number 9.0



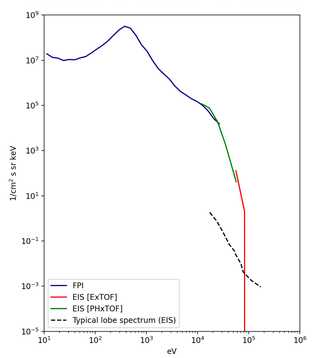
Interval: 08:38:25 - 08:38:45



Event date: 2015-10-21 / 07:45:04 - 07:47:00
Shock angle at 29.1
Mach number 8.0



Interval: 07:45:53 - 07:46:13



The spectrograms above shows in how the shock angle can alter the accelerations of ions which can determine the ion's acceleration.

Ion energy spectrums intervals above clearly shows the power-law.

Future Work and Conclusions

For our conclusions, we have reassured that the shock angle of the Earth's bow shock can determine the acceleration for ion particles. Ultimately, ion acceleration can cause high energy ions in where they gyrate back and forth through the Earth's bow shock. Furthermore, future work will consist of analyzing other shock crossing events and further investigate how ions behave in order to understand and hopefully fill the gap of thermal and non-thermal components.

References

[1]Oka, Mitsuo, 2019, ApJ 886:53;
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