Temporal evolution of ion spectral structures during a geomagnetic storm: Observations and modeling

Poster #19

Cristian P. Ferradas[1] (cpi66@wildcats.unh.edu), J.-C. Zhang[1], H. E. Spence[1], L. M. Kistler[1], B. A. Larsen[2], G. Reeves[2], R. Skoug[2], and H. Funsten[2]

University of New Hampshire

[1] Space Science Center and Physics Department, University of New Hampshire, Durham, NH 03824, USA

[2] ISR Space Science and Applications, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

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1. Abstract

During the last decades several missions have recorded the presence of dynamic spectral features of energetic ions in the inner magnetosphere. We present a case study of the temporal evolution of ion spectral structures throughout the geomagnetic storm of 2 October 2013. We use data from the HOPE instrument onboard Van Allen Probe A to analyze the spectral structures in the energy range of 1-~50 keV. We find that the characteristics of the ion structures follow a cyclic pattern, the observed features changing dramatically as the storm starts and then returning to its initial pre-storm state. Before and after the storm, ion access to the lowest L values is limited to narrow energy bands corresponding to nose structures, whereas storm-time access is observed at a wide energy range. We use a model of ion drift and losses due to charge exchange to reproduce the spectral features.

2. Introduction

- Over the last 40 years several magnetospheric missions have detected ion structures which in the energy-time spectrograms appear as narrow energy bands, or "nose-like" structures [*Smith and Hoffman*, 1974; *Vallat et al.*, 2007; *Dandouras et al.*, 2009].
- The formation of these structures is credited to the combined effects that the electric and magnetic fields, ion losses, and changes in the plasma sources and field configuration have on the particles being injected into the inner magnetosphere.
- Several studies of nose structures have found a dependence on geomagnetic activity, with multiple noses been observed more often during quiet times [*Fennel et al.*, 1998; *Li et al.*, 2000; *Buzulukova and Vovchenko*, 2008; *Ferradas et al.*, 2016]. However, no analysis of nose structures over a geomagnetic storm has been done.

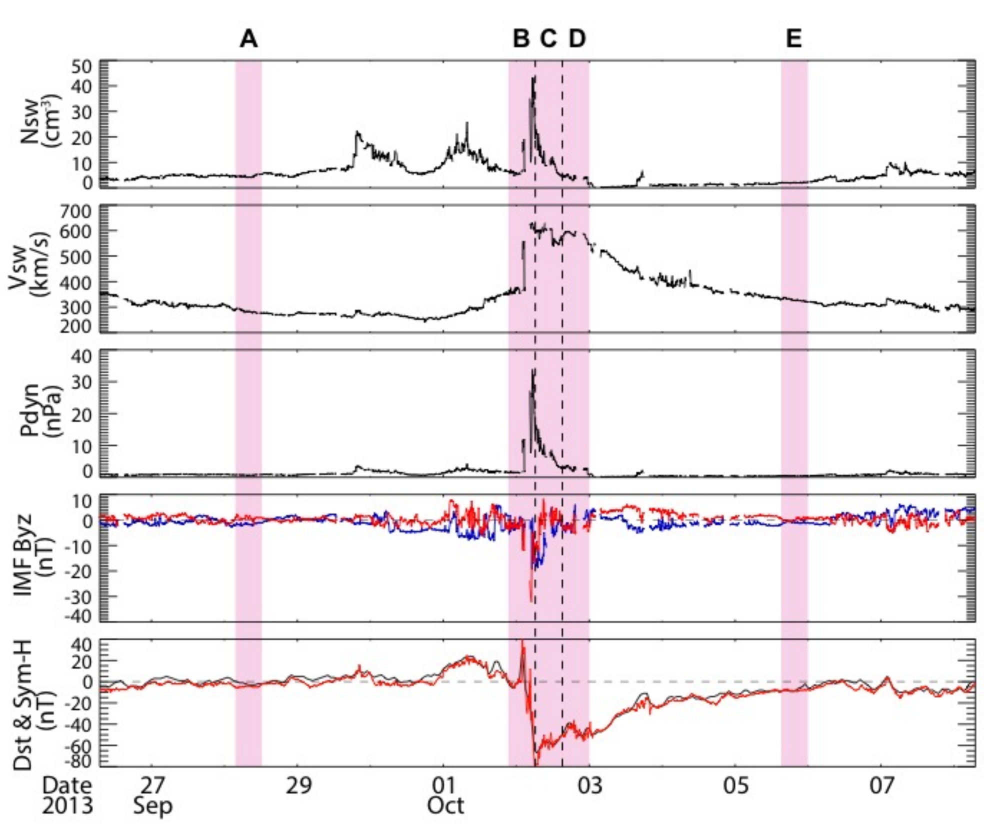
3. Motivation

- Report a case study of the temporal evolution of ion spectral structures during a geomagnetic storm.
- Validate the effectiveness of a model of ion drift and loss in the inner magnetosphere, using a dipole magnetic field and an empirical electric field model, to reproduce the ion structures.
- Investigate the storm-time access of ions to the inner magnetosphere.

4. Instrumentation

- The Van Allen Probes mission (2012-present) consists of two spacecraft (Probes A and B) in almost the same highly elliptical, low inclination (10°) orbits with a perigee of 1.1 R_E, an apogee of 5.8 R_E, and a period of 9 hours.
- The Helium, Oxygen, Proton, and Electron (HOPE) mass spectrometer [*Funsten et al.*, 2013] in the Energetic Particle Composition and Thermal Plasma (ECT) suite [*Spence et al.*, 2013] measures electrons and ions in the energy range of ~1 eV-~50 keV and distinguishes composition of three major ion species, H^+, He^+, and O^+.

5. Ion Spectral Structures



Geomagnetic Storm of 2 October 2013

Solar wind parameters and *Dst* and *Sym-H* indices during the storm. The shaded regions correspond to 5 orbits of Van Allen Probe A.

A: Pre Storm

- Probe A measured fine spectral structures: two in the inbound pass and two in the outbound pass.
- Heavy ion structures reach deeper inward than H^+ structures.
- The data-model discrepancy at low energies suggests that these ions are lost via a different loss mechanism.

B: Main Phase

- The newly transported plasma can be noticed on the outbound pass.
- A similar extent of access for all ion species is observed.
- The model reproduced well the inner extent of access.

C: Early Recovery

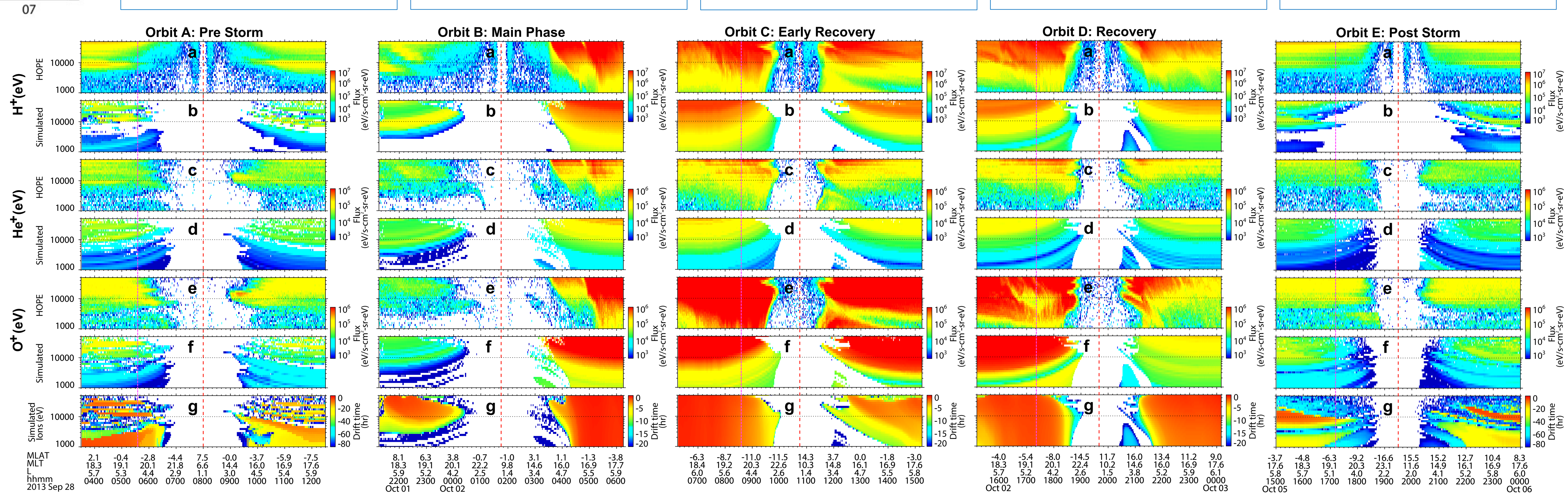
- Following the transport of new plasma, the inner edge of the plasma sheet shows only one nose structure.
- The model reproduced the only nose present in both the inbound and outbound passes.

D: Recovery

- Observed H^+ spectral structures are simple, without traces of nose structures.
- Heavy ion spectra show structures that increase in energy with decreasing L value.
- The model predicts the observed heavy ion spectral structures.

E: Post Storm

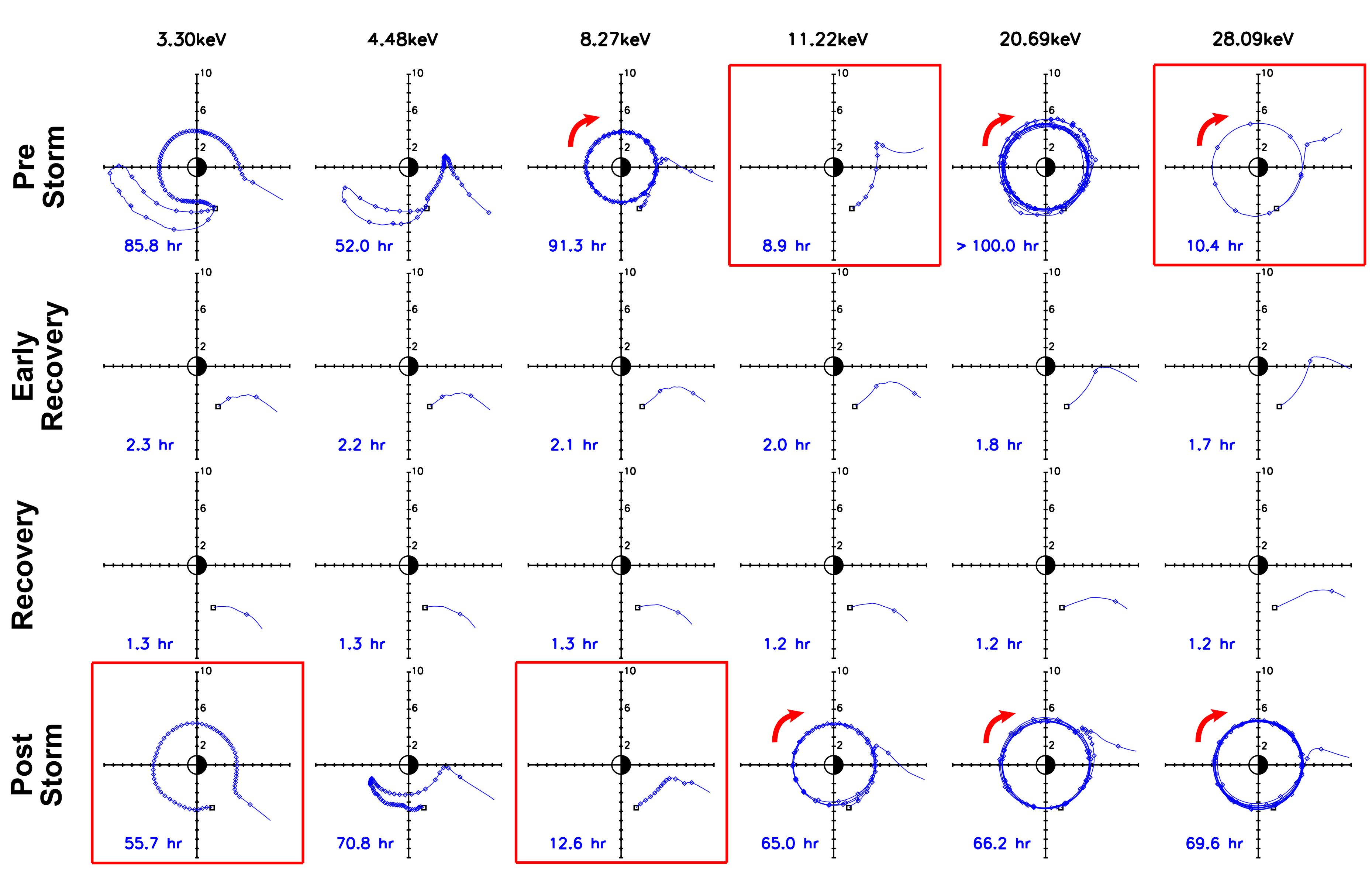
- As geomagnetic conditions become quieter after the storm, fine spectral structures are visible once again
- A main nose is observed at ~10 keV.
- Heavy ion structures reach deeper once again.
- The model reproduces the fine structures.



Observed and Simulated Ion Spectra

- Five entire orbits of Van Allen Probe A before, during, and after the geomagnetic storm.
- Panels a-f show the measured and simulated H^+ (a-b), He^+ (c-d), and O^+ (e-f) energy flux.
- Panel g shows the simulated ion drift time to L=10.
- The simulations were carried out using the Weimer 1996 convection electric field model [*Weimer*, 1996] and a dipole magnetic field model assuming losses due to charge exchange.

6. Ion Access to the Inner Magnetosphere



Simulations for ions with PA = 90°. Start location at: L = 4.9

Pre Storm:

- Ion access is limited to discrete energy bands corresponding to multiple nose structures (11.22 and 28.09 keV).
- Ions with other energies either have no access (20.69 keV) or are lost via charge exchange collisions along the way due to their long drift time (3.30, 4.48, and 8.27 keV).
- Ions composing both noses have a comparable drift time but encircle the Earth a different number of times.

Early Recovery:

- Ion access occurs at a wide energy range.
- All ions have direct access from the source and due to enhanced convection, they take very short time to drift to the inner magnetosphere.

Recovery:

- Ion access occurs at a wide energy range.
- Strong convection persists, as seen by the very short drift time.

Post Storm:

- Ion access is similar to the Pre Storm case: it is limited to discrete and narrow energy bands corresponding to multiple nose structures (3.30 and 8.27 keV).
- Ions composing the secondary nose have a significantly longer drift time than main-nose ions.

7. Summary and Discussion

- A first study of the time evolution of ion spectral structures observed by the ECT-HOPE instrument onboard Van Allen Probe A during the geomagnetic storm of 2 October 2013 has been performed.
- The characteristics of the ion spectral structures throughout the storm follow the intensity of the convection electric field, and are as follows:
  - Pre Storm: Spectral features are characterized by fine nose structures, with a main nose centered at around 10 keV.
  - Main Phase: Ion access to the low L values occurs in a broad energy range.
  - Early Recovery: Ion access reaching L~2.5 at a broad energy range.
  - Recovery: Simple nose structures begin to appear again.
  - Post Storm: Fine nose structures are observed again.
- Pre- and post-storm ion access to the inner magnetosphere is limited to discrete energy bands, whereas during storm-time ion access occurs at a wide energy range.
- The range of access is more clearly species dependent during the Pre Storm and Post Storm orbits, owing to charge exchange loss effects.

8. References

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9. Acknowledgements

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