Statistical Properties of Curtain Electron Precipitation Derived with AeroCube-6

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Key Points:

- We used the dual AeroCube-6 CubeSats to identify stationary, narrow, and persistent > 30 keV precipitation in low Earth orbit
- A single low Earth-orbiting spacecraft can easily misidentify curtains as microburst precipitation
- A few curtains were persistently scattered into the atmosphere for at least six seconds

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Abstract

Abstract here

1 Plain Language Summary

2 Introduction

Outline

1. Introduce various particle loss mechanisms
2. Introduce microbursts and their effect on atmospheric chemistry. Maybe mention how there is an unexplained source of HOX and NOX?
3. Introduce curtains and the prevailing hypothesis linking curtains to microbursts
4. If curtains are drifting then we have overestimated the atmospheric losses due to microbursts
5. Our goal is to study three statistical properties of curtains: location, spatial width, and preferred geomagnetic conditions. Lastly we will use the SAA to determine if some curtains were drifting around the Earth or locally and persistently precipitating
6. Explain DLC and BLC. DLC description from Comes 2003 paper and maybe something from Craig Rogers group.
7. Maybe cite the curtain paper from 2000 that relates them to lightning? Title: Trapped energetic electron curtains produced by thunderstorm driven relativistic runaway electrons

Double check that I am citing correct references One of the important loss mechanisms of radiation belt electrons and protons is wave-particle scattering. A few wave modes have been extensively studied to scatter waves, EMIC, hiss, and chorus waves. EMIC wave excitation is believed to be caused by anisotopic distributions of ≈ 10 keV protons injected from the magnetotail; while chorus waves are excited by ≈ 10 keV electrons. Once excited, these waves scatter inner magnetosphere particles into the atmosphere. One form of precipitation that is widely believed to be caused by scattering between chorus waves and electrons in the outer radiation belts is microbursts. Microbursts are a spiky increase of electrons observed for shorter than a second. They have been studied since the mid 1960s with high altitude balloons and satellites (e.g. Anderson & Milton, 1964; Lorentzen et al., 2001; O'Brien et al., 2003; Douma et al., 2017). The microburst impact on the environment has been estimated to be substantial. Douma et al. (2019) and Breneman et al. (2017) shown that microbursts can deplete the outer radiation belt electrons in around a day. Furthermore, Seppälä et al. (2018) modeled a 6 hour microburst storm and concluded that microbursts depleted mesospheric ozone by roughly 10%.

With one spacecraft in low Earth orbit (LEO), moving at a typical 7.5 km/s velocity, it is impossible to differentiate between a microburst that gets scattered and lost in less than a second (temporal), and a stationary spiky feature that is narrower than 7 kilometers. Two identically-instrumented spacecraft orbiting in proximity can successfully differentiate between the two realities. One such mission is the dual AeroSube-6 (AC6) CubeSats that measured electrons and protons together in LEO between 2014 and 2017. With AC6 both structures were readily observed and studied: microbursts in Shumko et al. (2019), and recently discovered stationary, narrow, and spiky precipitation features called curtains that were first reported by Blake and O'Brien (2016).

2.1 Curtain Hypothesis

Besides a brief description of curtains in Blake and O'Brien (2016), not much is known about about them. Blake and O'Brien (2016) proposed an outstanding hypothesis that curtains are remnants of microbrusts that are not completely scattered into the atmosphere and over time the packet of microburst electrons is smeared out (bounce phase averaged) along the magnetic field line between the two hemispheres. Since different energy electrons drift around the Earth at different speeds, the electrons are not only smeared out along one field line, but also stretched out along the electron drift orbit into a curtain shape. In most regions in LEO where AC6 observes curtain electrons, these electrons are drifting east in the drift loss cone until they are scattered into the South Atlantic Anomaly (SAA).

drifting to the east around the earth in the drift loss clone. The drift loss cone is

3 Instrumentation

Think about the flow, and avoid plagiarizing myself

The AC6 mission was a pair of 0.5U (10x10x5 cm) CubeSats built by The Aerospace Corporation designed to measure the electron and proton environment in low Earth orbit (O'Brien et al., 2016). AC6 was launched on 19 June 2014 into a 620x700 km, 98° inclination orbit. The AC6 orbit over the three year mission lifetime was roughly dawn-dusk, and precessed only a few hours in MLT; 8-12 MLT in dawn and 20-24 MLT in dusk. The two AC6 spacecraft, designated as AC6-A and AC6-B, separated after launch and were in proximity for the duration of the three year mission—maintained by an active attitude control system. The attitude control system allowed then to precisely control the amount of atmospheric drag experienced by each AC6 unit using the surface area of their solar panel "wings". By changing their orientation, AC6 was able to maintain a separation between 2-800 km, confirmed with the Global Positioning System. The two AC6 units were in a string of pearls configuration so one unit, typically unit A, was leading the other by an in-track lag—the time it would take the following spacecraft to catch up to the position of the leading spacecraft. To convert between the AC6 in-track separation and in-track lag, we assume a typical 7.5 km/s orbital velocity of LEO spacecraft. The in-track lag was readily available with the Global Positioning System which makes it easy to study precipitation phenomena observed at the same time, and at the same position by shifting one time series by the in-track lag.

Each AC6 unit contains three Aerospace microdosimeters (licensed to Teledyne Microelectronics, Inc) that measure the electron and proton dose in orbit (O'Brien et al., 2016). The dosimeter used for this study is dos1 with a 30 keV electron threshold. dos1 is used for this study because the other dosimeters were not identical between unit A and B. All dosimeters sample at 1 Hz in survey mode, and 10 Hz in burst mode. 10 Hz data was readily available from both AC6 units from June 2014 to May 2017 while their in-track lag was less than 65 seconds, and at times was a fraction of a second. Show a distribution of the in-track lag when they had 10 Hz data? The variety of AC6 separations and data availability over the three-year mission makes it possible to study tranisent electron microburst precipitation (Shumko et al., 2019) and now stationary electron curtain precipitation.

4 Methodology

4.1 Curtain Identification

Outline

1. Various parameters were explored and we tuned it to have as many candidate events as possible while being feasible to inspect every detection.
2. Baseline sensitivity decreases with larger structures, depending on the curtain amplitude, background level, and baseline width. Sensitivity begins to rapidly dimin-

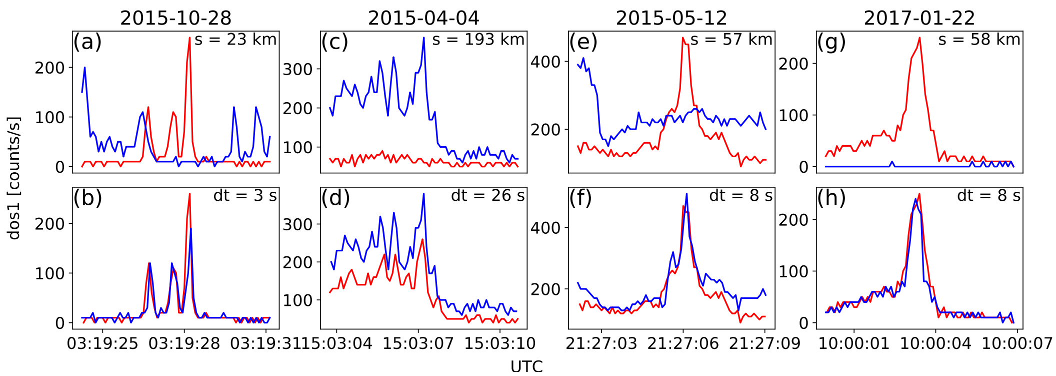

Figure 1. Four examples showing the AC6 > 30 keV electron data taken by AC6 at the same time in the top row and at the same position in the bottom row. AC6-A, whose data is shown with red curves, was s kilometers ahead of AC6-B. To show the data at the same position the time series data from one spacecraft was shifted by the in-track lag and annotated by dt. These examples show curtain precipitation that was highly correlated for up to 26 seconds.

ish for widths close to half of the baseline width—around five seconds, correspondent to 38 km size, for this identification criteria.

The 10 Hz data was used to identify curtains with the following two criteria: a high spatial correlation, and bursty. The first criterion quantifies the similarity of the feature between both AC6 units, and the second criterion checks that highly correlated times were bursty. Before we we applied the identification criteria, the AC6-B time series was shifted by the in-track lag to spatially align it with the AC6-A time series.

The first identification criterion is a 1-second rolling Pearson correlation applied to both time series. Spatial features with a correlation greater than 0.8 were considered highly correlated and saved.

The second identification criterion checks for locations where both AC6 units observed bursty precipitation. Similar to how precipitation bands were identified in Blum et al. (2015) and microbursts in Greeley et al. (2019), we find bursty precipitation by estimating the number of Poisson standard deviations, σ, that a dos1 count rate is above a centered 10-second running average, B_{10}. Locations where the count rates are at least two σ above B_{10} are bursty.

The locations where the two criteria are met are curtain candidates and the time of the peak count rates are saved. To check the quality of the data set, one author visually checked every candidate curtain and 1634 curtains were confirmed. Four curtain examples are shown in Fig. 1. In these examples the unmodified time series is in the top row and the corresponding spatially-aligned time series is in the bottom row. The in-track lag used to shift the bottom row is annotated by dt, corresponding to an AC6 in-track separation annotated by s. The top row is uncorrelated; thus these events were not microbursts. The bottom row is correlated after 3 to 26 seconds. The correlated curtains in the bottom row are peculiar—they have a fine structure on a 10-kilometer scale that we have shown to persist for at least 26 seconds.

5 Results

Outline

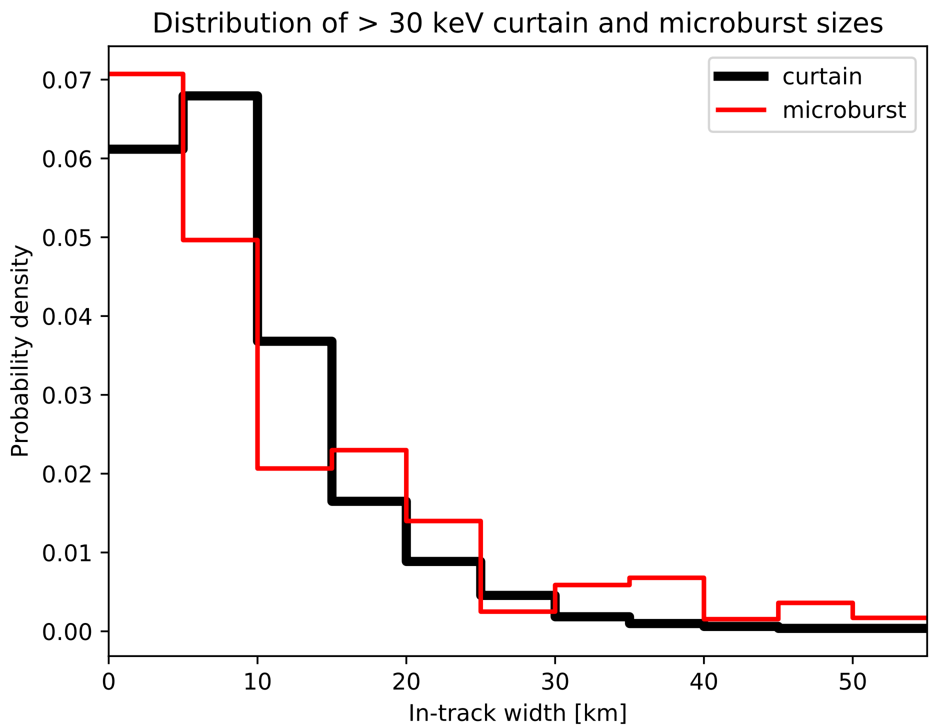

Figure 2. Size distributions of curtains (AC6 in-track separation mostly in latitude) in black and microbursts in red as a function of AC6 in-track width. Microburst distribution adopted from Shumko et al. (2019).

1. Show curtain width and comment how narrow they are. Whether they are drifting or locally precipitating, they must have a very filamentary structure that persists for multiple seconds
2. Figure out how the detection bias affects the width distribution
3. Show, and comment on the Auroral electroject strengths when each curtain was observed. Curtains are more likeliy to be observed during disturbed times.
4. Discuss the SAA, BLC, and show the curtains the the BLC plot. Mention how these electrons must have been precipitating for multiple seconds, over an order of magnitude longer than typical microbursts.

In the spirit of brevity, we limited the scope of these results to answer the following three questions:

1. how narrow are curtains,
2. when and where are curtains observed, and
3. are curtains drifting or locally precipitating?

5.1 Local Atmospheric Precipitation

6 Discussion

Outline

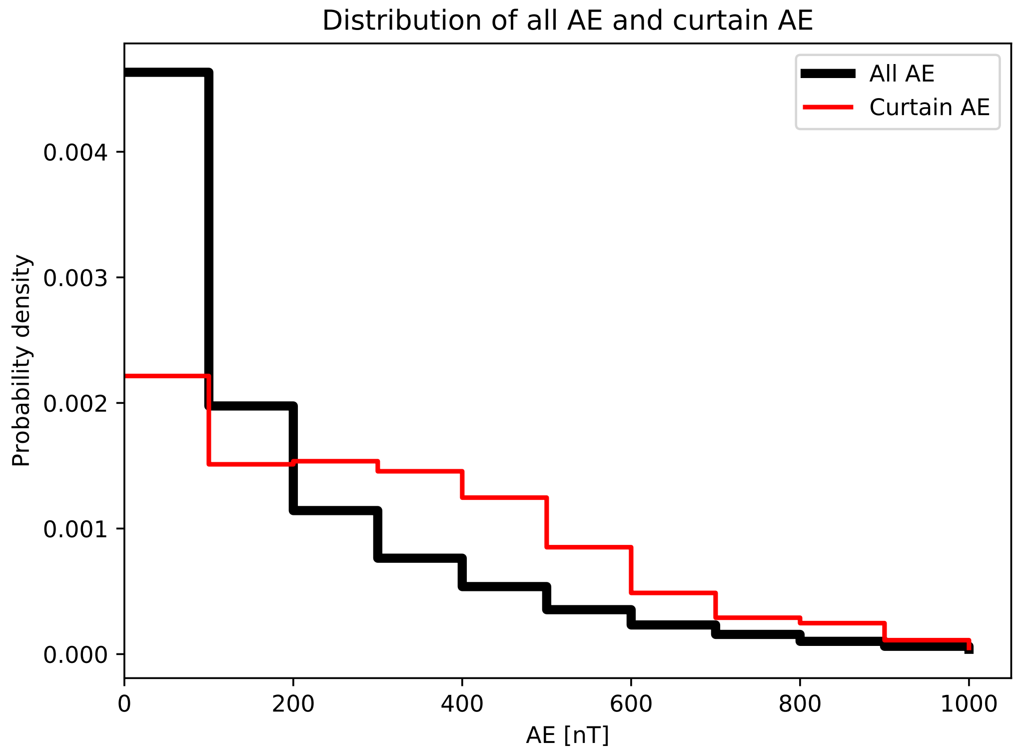

Figure 3. The distribution of the Auroral Electroject index from 2014 to 2017 shown by the thick black curve, and the Auroral Electroject index when curtains were observed by the red curve.

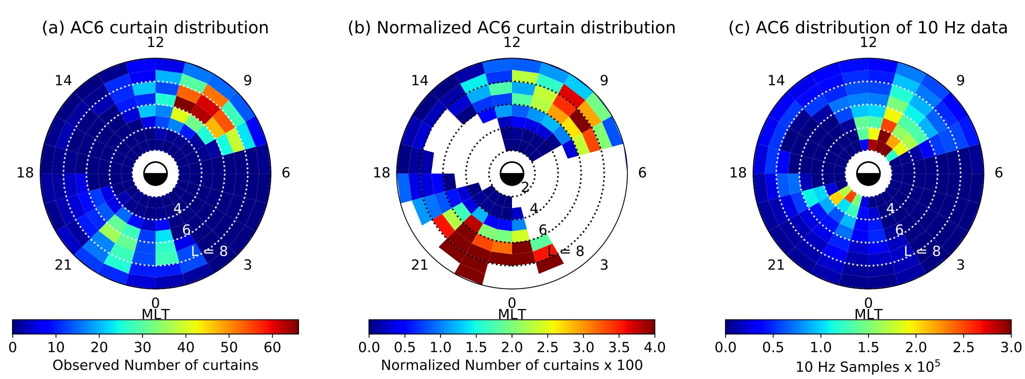

Figure 4. Distribution of curtains as a function of L and MLT. To avoid noisy normalization scaling, bins with less than $10,000$ 10 Hz samples were not normalized in panel b.

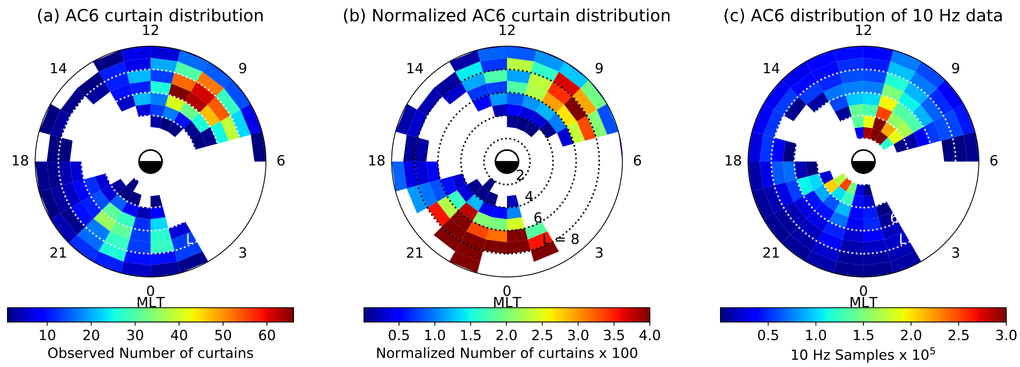

Figure 5. Distribution of curtains as a function of L and MLT. White bins in panels a and c have 0 curtain detections or 10 Hz samples. To avoid noisy normalization scaling, bins with less than 10,000 10 Hz samples were not normalized in panel b. Or show this version?

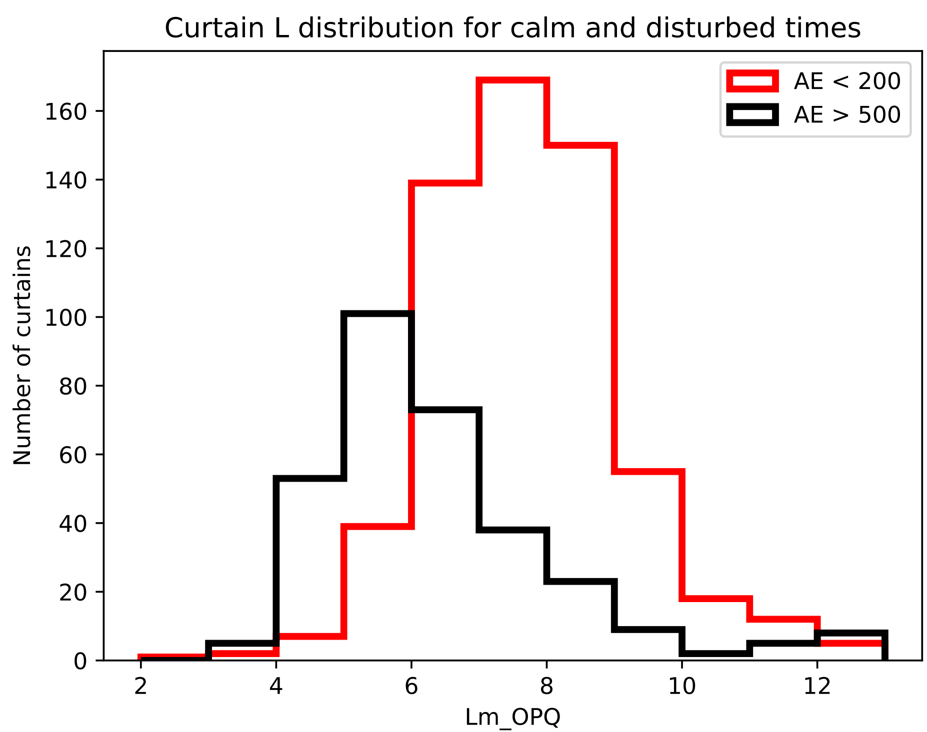

Figure 6. What about this figure?

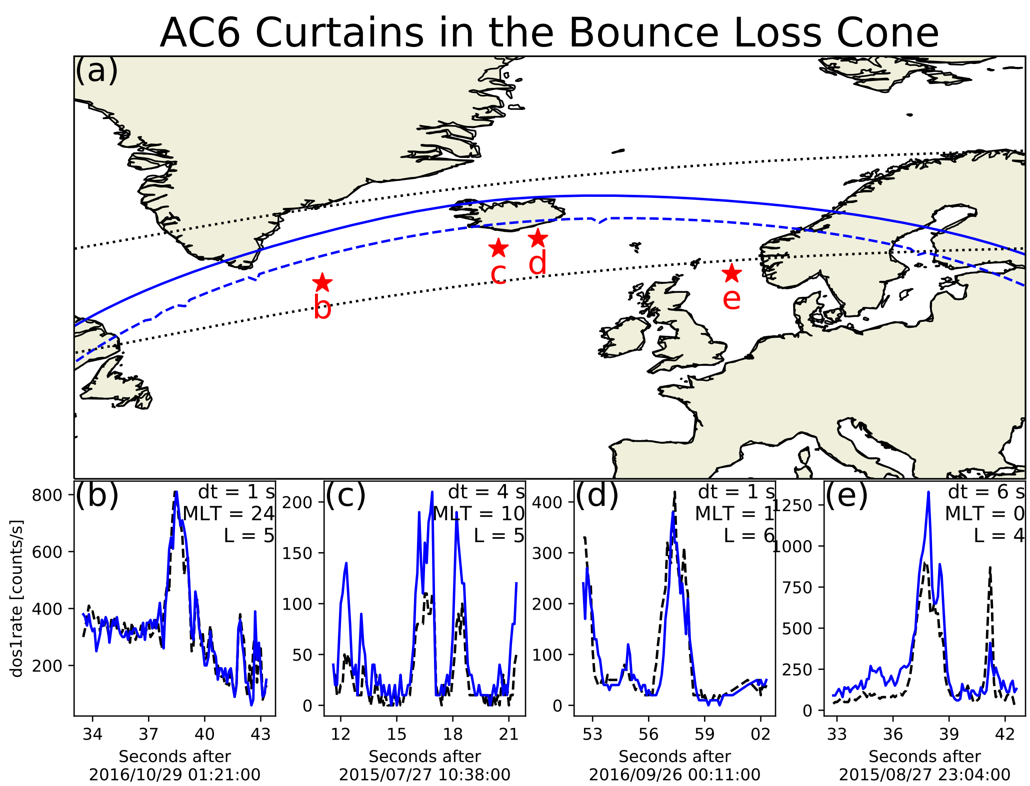

Figure 7. Curtains observed inside the bounce loss cone. Refrence Comess 2013 and DIETRICH 2010 paper that shows a similar BLC region.

1. Curtains are spatially small and must be around a few hundred km at the equator
2. curtain phenomena originates in the outer radiation belt, and observed relatively more in the evening than morning regions. Limited AC6 coverage prevents a complete MLT distribution
3. preference to disturbed conditions
4. some curtains locally precipitate for an extended period of time so there must be a sustained parallel electric field. Show the derivation and estimated potential.
5. AC6 can't answer this question, but curtains could provide a substantial source of HOx and NOX molecules responsible for destroying ozone. We need AC6 with energy and pitch angle resolution.

7 Conclusions

Acknowledgments

This work was made possible with the help from the many engineers and scientists at The Aerospace Corporation who designed, built, and operated AC6. M. Shumko was supported by NASA Headquarters under the NASA Earth and Space Science Fellowship Program - Grant 80NSSC18K1204. D.L. Turner is thankful for support from the Van Allen Probes mission and a NASA grant (Prime award number: 80NSSC19K0280). The work at The Aerospace Corporation was supported in part by RBSP-ECT funding provided by JHU/APL contract 967399 under NASA's Prime contract NAS501072. The AC6 data is available at http://rbspgway.jhuapl.edu/ac6 and the IRBEM-Lib version used for this analysis can be downloaded from https://sourceforge.net/p/irbem/code/616/tree/.

8 Homeless Words

Title: Statistical Properties of Curtains–Latitudinally-Narrow and Persistent Electron Precipitation Phenomena

This study leverages AC6, a multi-spacecraft mission, to interpret and understand particle precipitation in a way that is impossible with a single spacecraft.

This study leverages the asymmetry in Earth's magnetic field. The asymmetric magnetic field results in the SAA and the BLC, two very related and unique regions

Particles that impact the atmosphere are lost during that bounce motion. We found curtains in the bounce loss cone, a region in the North Atlantic near and above Iceland.

The bounce loss cone is magnetically connected to the SAA, where Earth's magnetic field is weakest near Earth's surface. A particle observed in the blc in the northern hemisphere will descend below 100 km altitude. At sub-100 km altitudes the particle has a high chance of encountering and scattering with the atmosphere and be lost.

We found curtain electrons that, when given the chance to execute their cyclical bounce motion, will descend below Earth's surface in the SAA. An electrons can not survive that trip.

Write the paper and ask the question: "What is this paper really about?" Not just curtains, but uncovering something unexpected that has been observed and overlooked for decades.

Are curtains related to aurora? This is a good question—one that is not pertinent here (idea from The Elements of Style p.68).

Here are two parting questions that are not considered here. Why were some curtains shifted slightly? Perhaps it was due to the movement of the magnetic field lines. Also do curtains have a corresponding visual signature on the ground? The answer to this question will show if curtains are related to the aurora.

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