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Microbursts vs Curtains: Similarities and differences complicating identification and potential sources.

Similarities and differences complicating identification and potential sources.

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ABSTRACT

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1. Introduction

The discovery of electron precipitation associated with the aurora and the Earth's radiation belts have fueled much of the research within space physics and in particular, magnetospheric physics over the last 70 years. Microbursts are a common thread and have been hypothesized to explain the near complete loss of the radiation belts during geomagnetic storms as well as small scale features in the diffuse and pulsating aurora (e.g. Lorentzen et al., 2001; Miyoshi et al., 2015; Greeley et al., 2019). Obtaining a better understanding of radiation belt and auroral dynamics may eventually lead to improvements in space weather tools and analysis. Specifically, if microbursts play a large role in radiation belt dynamics or energy deposition into the ionosphere and upper atmosphere, understanding their impact and occurrence will become important. However, in the near term, understanding the microphysics of microbursts and their wave-particle interactions will improve our fundamental understanding of some of the potentially dominate mechanisms controlling the dynamics of the radiation belt and aurora.

The relatively new ability of flying constellations of LEO CubeSats have also helped to identify a similar phenomenon to microbursts. Curtains are similar in scale size of microbursts but have some clear characteristic differences as will be outlined within Section 1.2 (Blake and O'Brien, 2016). Little research has been completed on Curtains. The current identification of their characteristics suggests that they may have a similar source, however outstanding issues still persist.

1.1. *Initial balloon observation of microbursts:*

Since the start of balloon bourn observations of ?auroral? precipitation, microbursts have fascinated researchers and provided a potential explanation for energy loss into the upper atmosphere. One of the first observations of microbursts were observed with the energetic electron precipitation during a geomagnetic storm on September 25th, 1961 (Winckler et al., 1962). Winckler et al. (1962) reported a new result of observations of bursts in the 0.1 - 0.2 second range.

Shortly after, Anderson and Milton (1964) looked statistically at these sub-second precipitation events and started to catalog their characteristics. Within Anderson and Milton (1964), microbursts are defined as a burst of X-rays from auroral regions of about 0.25 second duration. They also noted that when patches of microbursts were observed, they were observed for about 1.5 hours at a time with the frequency of the bursts increasing to about 1 per second before weakening and decaying back into the background noise. These patches were observed during daylight hours but most often in the dawn regions. Microbursts were found to primarily occur in trains, multiple peaks separated by $\sim$ 1second without changing characteristics. Parks et al. (1965) also confirmed these results, further suggesting that these trains were due to bouncing packets of electrons. While Anderson and Milton (1964) saw many microbursts occurring within these patches and/or trains, there were some microbursts which were identified at times on their own. Often the microbursts were found to be superposed on top of smooth background X-ray flux. During these events, the microburst intensity was found to significantly enhance the counting rate when averaged over longer periods of time. Anderson and Milton (1964) found that the energy spectrum of the microbursts was harder (more energetic) than the background precipitation. However, this was later contradicted by Hudson et al. (1965) where they determined that the energy spectrum of the microbursts were similar to that of the background energetic electron precipitation. Anderson and Milton (1964) also reported that the energy spectra was observed to change throughout the event with a higher characteristic energy at the start of the microburst. Many of these attributes have been found to hold with recent observations and studies of microbursts from similar balloon missions such at BARREL (e.g. Woodger et al., 2015). **** Need to add citation Brett's paper maybe? ****

In order to help determine the spatial scale size of a microburst, Parks (1967) launched a balloon with four narrowly collimated X-ray detectors. During the balloon flight approximately 1400 microbursts were observed with similar features to those observed by Anderson and Milton (1964). Parks found that the region of interaction in the upper atmosphere (~80 - 110 km altitude) for the individual microburst was around 40 km ±14 km. It was clear that for some events, this distance was smaller. Parks also suggested that microbursts are a result of a plasma instability which may initially be triggered by an electromagnetic wave. He did not see a time displacement of the high and low energy electron arrivals so concluded that the source must be local and the interaction instantaneous.

1.2. *In situ observations of microbursts*

Soon after the initial microbursts observations from balloons, rocket and satellite measurements were used to determine the source of the microbursts phenomena. Lampton (1967) launched a rocket with a pair of plastic phosphor scintillation counters. Each scintillator was oriented to view the precipitating electrons in the parallel and perpendicular direction to the rocket spin axis with three energy channels between $\sim$ 60 - 300 keV. During the September 17, 1965 flight the rocket reached an altitude around 160 km. Using the two detectors, Lampton (1967) was able to determine that the pitch angle distribution was strongly peaked at the local 90 degree. They note that prompt appearance of the microbursts signatures at a large range of energies suggests that their source is local and synchronous. They also determined that for the weak microbursts observed during the flight, which did show energy dispersion, must have initiated a a much further distance away. The weaker microbursts were thought to have potentially bounced at least once along a closed field line. These results are consistent with more recent observations discussed below (e.g. Shumko et al., 2018).

Milton and Oliven (1967) attempted to gather simultaneous results from stratospheric balloons and INJUN 3. During the near conjugate pass the balloon and satellite were separated in longitude by less than 550 km. The balloon was at an altitude of 35 km and the satellite 2350 km. During this study, no simultaneous measurements of microbursts were able to be confirmed. However, there was a correlation found between the two platforms for longer period precipitation phenomena. Similar studies have since been completed to further constrain both the size of a single microbursts as well as the larger region of precipitation ***********Cite here Aaron's, Brett's, Mark's?******** Milton and Oliven (1967) stated that their lack of one-to-one correspondence of microburst observations is perhaps not unexpected as Parks (1967) had previously found that the source region of a microburst is approximately 20 km at the expected loss height of 80 km.

Oliven and Gurnett (1968) used INJUN 3 VLF records to show the simultaneous occurrence of chorus waves and microbursts. They note that chorus waves were often observed in the dawn and pre-noon sector(Oliven and Gurnett, 1968). They determined that for all microbursts episodes that they observed, VLF chorus emissions were present. However, they were not able to show a one-to-one, burst-to-burst correlation between an individual microburst and a specific chorus burst. However, they concluded that the chorus waves and microbursts must have a similar origin.

During the following decade many more observations of microbursts were collected and ultimately compiled by Parks (1978, and references therein).

- Duration of microbursts - 0.1 - 0.6 seconds with 85% occurring with a duration of 0.1 - 0.3 seconds.
- Microbursts occur individually, in pairs, and in trains with a quasi periodicity of ~ 0.6 seconds.
- Microbursts are often superposed on 5 - 15 second periodic X-ray pulsations.
- Rocket experiments show a substructure on the order of 10 ms.
- In situ satellite data show microbursts occurring within all pitch angles.
- Microburst are primarily observed between ~ 0600 - 1800 MLT.
- Patches of microbursts can be observed over a few-MLT hour region.
- Individual microbursts are highly localized, 10s km at the loss height.
- not yet confirmed if microbursts or patches of microbursts drift from west to east as suggested in Parks (1967)
- Microbursts do not affect strongly the observed pitch angle distribution.

– The energy spectra of microbursts often agree with the energy spectra of the background precipitation. (characteristic energy of ~ 30 keV)

– The higher energy electrons within the microburst were found to arrive slightly ahead of the lower energies suggesting energy dispersion from a bouncing packet.

– A strong correlation between microbursts and VLF waves, specifically rising tone chorus waves, have been identified.

– Microburst activity increases during substorms.

Many of these findings continue to hold today with more recent balloon and in situ observations.

As more satellites were launched, and higher energy ranges were observed, there appeared to be two populations of microbursts, energetic electron and relativistic electron microbursts. These two different populations have potentially different impacts within the radiation belt and ultimately space weather impacts. Do we want to say anything here about loss of the source population and the different impacts. The lower energy electrons may have a larger impact on the ionosphere vs the relativistic stuff???? O'Brien et al. (2004) looked at whether microbursts in the recovery phase resulted in less electron loss from microbursts occurring during the main phase. Specifically, and unlike the previous studies mentioned which were considering 10s keV electron precipitation during a microburst, O'Brien et al. (2004) were focusing on MeV microbursts. It should be noted that while MeV microbursts have been observed in situ, they are extremely rare (1 reported incident by the GRIPS team known by this author at the time of writing) within the atmosphere. They found that it was possible for microbursts to account for the loss of the radiation belts during the main phase. Each of the periods of strong microbursts activity, and thus loss, were accompanied by substorm and storm time injections. These results, and others cited within O'Brien et al. (2004), also suggest that chorus (non-linear) wave-particle interactions are the driver of relativistic microbursts.

CubeSats have greatly expanded the ability to study energetic electron precipitation (e.g. Crew et al., 2016). This low cost access to space has provided the opportunity to regularly observe microbursts from multiple in situ platforms. FIREBIRD-II was one of the first CubeSats to look at energetic electron precipitation and specifically microbursts (Crew et al., 2016). Shumko et al. (2018) looked at an event which initially looks like a series of microburst and determined that it corresponded to a bouncing packet of electrons. As time increased, the higher energy electrons were found to arrive first. This suggest that while some electrons were lost to the atmosphere, another population remained trapped. Using the two CubeSats, they were able to constrain the size of the microburst showing that at the height of the satellite the latitudinal distance was 29 +/- 1 km and longitudinal distance of 51 +/- 1 km. This results agrees incredibly well with previous observations (e.g. Parks, 1967; Lampton, 1967; Milton and Oliven, 1967; Parks, 1978, and references therein).

******* Add in observations from Van Allen Probes*************** Add in here the the van allen sat and balloon conjunction studies

Throughout much of the last 70 years, instrumentation to look for microbursts within the equatorial regions have not existed. It is exceedingly difficult to resolve the loss cone at the magnetic equator. However, Shumko et al. (2018) were able to result what appears to be a microbursts on March 31 2017 from the Van Allen Probes. The characteristic energy of the microbursts were between 25 and 35 keV with an upper limit of 92 keV. The duration of these events was 0.15 - 0.5

seconds and had a clear lack of energy dispersion, suggesting the source mechanism was local. A chorus wave was observed at the same location and they were able to determine that quasi-linear wave-particle interactions were not sufficient to describe the observations. Thus, the observations at the magnetic equator - assumed to be within the generation region - suggest that non-linear interactions may be necessary to generate microbursts.

1.3. A new phenomena: Curtains

Blake and O'Brien (2016) found a similar type of phenomena to microbursts. Prior to this point many in situ microburst studies used observations from a single satellite. This has made differentiating between spatial and temporal features difficult. Blake and O'Brien (2016) found what initially appeared to be microbursts, similar in scale size, but they can last for minutes. Interestingly, the fine scale structure appears to remain consistent with a lack of energy dispersion, contrary to prior observations of microbursts or bouncing packets of electrons. It is yet unclear what may be the source of the fine scale structure.

1.4. Wave-particle modeling of chorus and microbursts

Pervious work to model the potential wave-particle interactions generating microbursts have been performed. (Hikishima, Omura, & Summers, 2010) used a self-consistent full particle simulation to show that the low energy microbursts (10 ? 100 keV) may be caused by discreate bursts of chorus wave emissions. They assume that the chorus wave generation region is at the magnetic equator and use a relatively low temperature anisotropy, A = 1.1. However, their simulation generates quite large chorus wave amplitudes of 4.8 nT which would impact the strength of the wave-particle interactions leading to a higher flux of particle precipitation or acceleration within their simulations.

(Hikishima, Omura, & Summers, 2010)?s simulations showed a one-to-one correspondence between electron microbursts with energies between 10 ? 100 keV electrons and the generation of discrete chorus elements. Throughout the simulation time (Hikishima, Omura, & Summers, 2010) found that the precipitating electron energies slowly decrease. This may in part be due to electrons with lower parallel velocities decreasing with the increasing wave frequencies of the rising tone chorus. The wave-particle interactions cause changes to the anisotropy and thus wave growth and wave characteristics. This leads to potential differences in the precipitation expected to be observed in the northern and southern hemisphere. Of course, the wave-particle interactions described in (Hikishima, Omura, & Summers, 2010) are not the only potential sources of microbursts or causes of electron precipitation (e.g. interactions at higher altitudes) within this energy range.

1.5. Scale size and characteristics of chorus waves

Thus far we have shown a growing about of evidence that microbursts are generated by wave-particle interactions with chorus waves. The scale sizes and temporal features of microbursts should then compare to those of chorus waves. (Agapitov, Blum, Mozer, Bonnell, & Wygant, 2017) completed a survey of

2. Conclusions

1. Microbursts have historically, and recently been shown to theoretically and observationally correlate strongly with chorus wave activity

2. Curtains have many similar spatial characteristics to Microbursts

3. Curtains contain many puzzling attributes including a lack of clear energy dispersion suggesting that they are not generated from a single incident of wave-particle interactions such as suggested with microbursts and rising tone chorus waves.

Acknowledgements. ***** Include acknowledgements here ******

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