Identifying Cases of Radial Diffusion Driven Acceleration in Earth's High-Energy Radiation Belts

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Introduction

This study was done to determine which wave-particle interactions are involved in radiation belt electron enhancements. Prior to this study, three schools of thought existed to explain how radiation belt electrons gained significantly high energies (> ~2 MeV):[1]

1. Local Acceleration by electromagnetic chorus waves at the same frequency as the doppler-shifted gyro frequency of the electron. This causes the energy of the electron to increase quickly at the location of the interaction.
2. Perturbation by electromagnetic ultra-low frequency (ULF) waves that cause the electrons to move towards earth, followed by radial diffusion; a process that causes the momentum of the electrons to slowly increase as the magnetic field increases smoothly by conserving adiabatic invariants.
3. A combination of the above two acceleration processes in some sort of two step mechanism.

This study set out to find indisputable evidence of electron enhancements without the presence of chorus, and show that the events possess characteristics expected from an acceleration caused by ULF wave instigated radial diffusion. This would determine the importance of ULF waves in simulating Earth's radiation belts.

Methods

This study uses physics-based techniques and data sets collected by RBSP / Van Allen Probes, NOAA's POES, EUMETSAT's MetOp, and NOAA's GOES satellites.

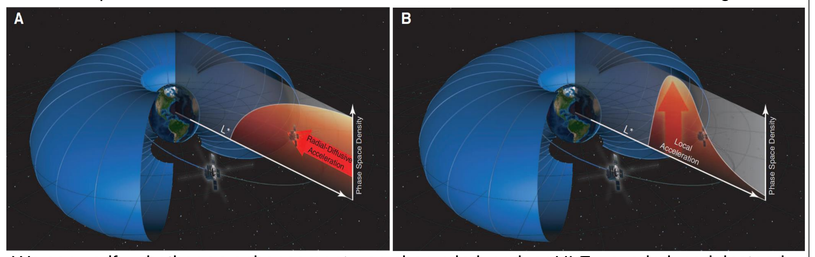
The methods used to obtain the plots of the inferred chorus for the following events can be found in Chen, Y., et al. (2014).[2] Where it should be noted that equation (1):

$$j(L,MLT) = B_w^2(L,MLT) * P * \left[(L-3)^2 + 0.03\right]$$

Is solved for the wave power B_w, and a value of 15 for the fitting parameter P is used. This overestimates the chorus for almost all events. Then solar proton events (> 10 MeV) are removed using the solar proton data collected by GOES.

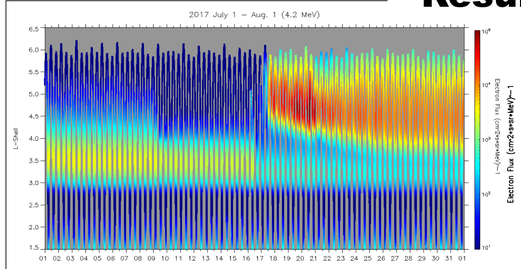
We call an event an electron enhancement if the electron flux collected by REPT on RBSP is at least 3 times greater than the day before. For each energy channel recorded by REPT, we find enhancements for L bins of size 0.02, in intervals of 0.5L, from 4L to 6L. By comparing the found enhancements to the graphs of inferred chorus, we can select the enhancements with little to no chorus.

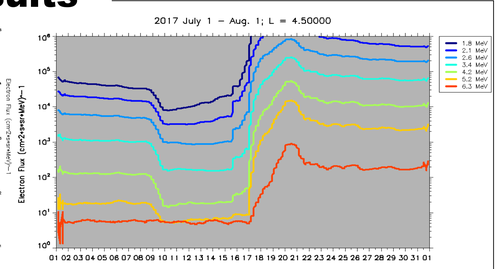
Using the method of calculating Phase Space Density (PSD) outlined in Chen Y., et al. (2005)[3], and noting the images below from Reeves, et al. (2013)[4], which show the PSD over L* profiles for Radial Diffusion on the left, and for Local Acceleration on the right:



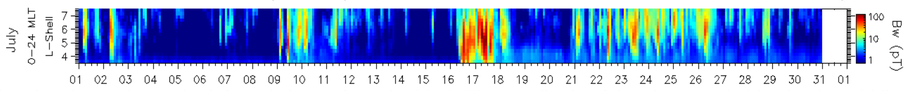
We can verify whether an enhancement was chorus induced, or ULF wave induced; instead of relying on the inferred chorus graphs. The arrows indicate how the PSD should evolve over time.

Results



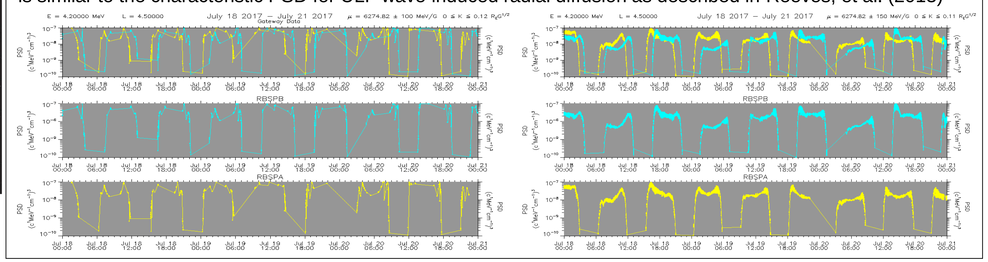


Here we showcase electron enhancements for 4.2 MeV at L = 4.5 on July 18-20, 2017. The plots above use the REPT Data for RBSP-B. For multiple energies, we see the electron flux increased a few orders of magnitude.



The plot above shows the inferred chorus for July, 2017. The amplitude of the chorus subsides by the middle of the 18th; however, we still see electron enhancements in multiple channels until the end of the 20th. To determine whether the enhancements were caused by radial diffusion, we turn to plots of the phase space density below.

Shown on the left is the PSD vs L* using the PSD available on the RBSP Science Gateway. On the right, the PSD over L* graphs using the PSD calculated with the method in Chen, Y., et al. (2005)[3]. In both cases the profile is similar to the characteristic PSD for ULF wave induced radial diffusion as described in Reeves, et al. (2013)[4]



Conclusions

In this study we investigated all of the electron enhancements between September of 2012, and October of 2019. We report the following conclusions:

- 146 electron enhancements on 49 dates were identified having little to no inferred chorus amplitude.
- 73% of the 49 dates displayed inferred chorus subsiding within a half a day before the enhancements.
- Of the 146 electron enhancements, the majority, 25%, were in the 3.4 MeV channel; and 64% between 2.6 MeV and 4.2 MeV.
- 56% of the enhancements occurred at or below L = 5.0, and the majority of 27% occurred at L = 5.0.

We are only able to see these enhancements using the twin spacecraft RBSP in their elliptical orbits and from the PSD values that we derive from them. This study was not possible before the Van Allen Probes mission.

Limitations and Future Studies

RBSP or the Van Allen Probes are now dead after 7 years of operation. As a result, future studies can only investigate enhancements between September, 2012 and October, 2019. The research presented on this poster, and future studies, will be benefited from the launch of a new set of satellites with instrument packages similar to RBSP's but capable of:

- Measuring the electron flux in more energy channels separated by a smaller energy difference.
- Measuring the electron flux over more pitch angles separated by a smaller pitch angle difference.

Future studies will also benefit from more LEO satellites with the SEM-2 or similar instrument package to gain a better resolution of the inferred chorus, as the current number leaves gaps in the covered L - MLT sectors.

It is also crucial for the future of research in this area to see:

- Uniformity in the methods and data used to calculate and display PSD.

Sources and Citations:

[1] Li, W., et al. (2016), J. Geophys. Res. Space, Physics, 121, 5520–5536, doi:10.1002/2016JA022400.

[2] Chen, Y., et al. (2014), Geophys. Res.Lett., 41, 755–761, doi:10.1002/2013GL059181

[3] Chen, Y., et al. (2005), JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110, A10210, doi:10.1029/2004JA010895, 2005

[4] Reeves, et al. (2013), Published online 25 July 2013; 10.1126/science.1237743