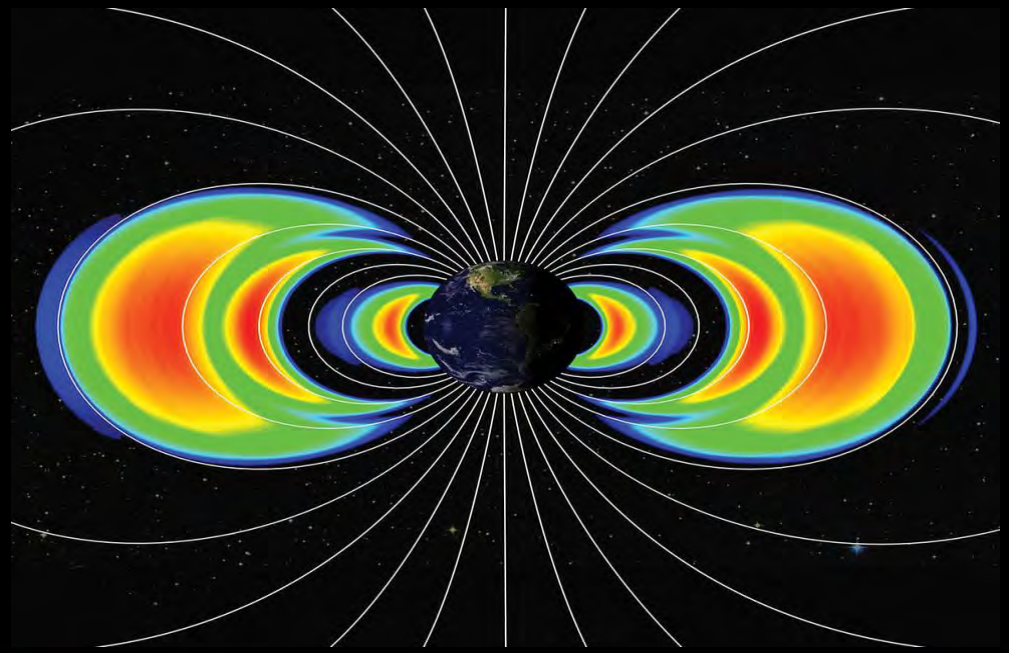
Identifying Cases of Radial Diffusion Driven Acceleration in Earth's High-Energy Radiation Belts

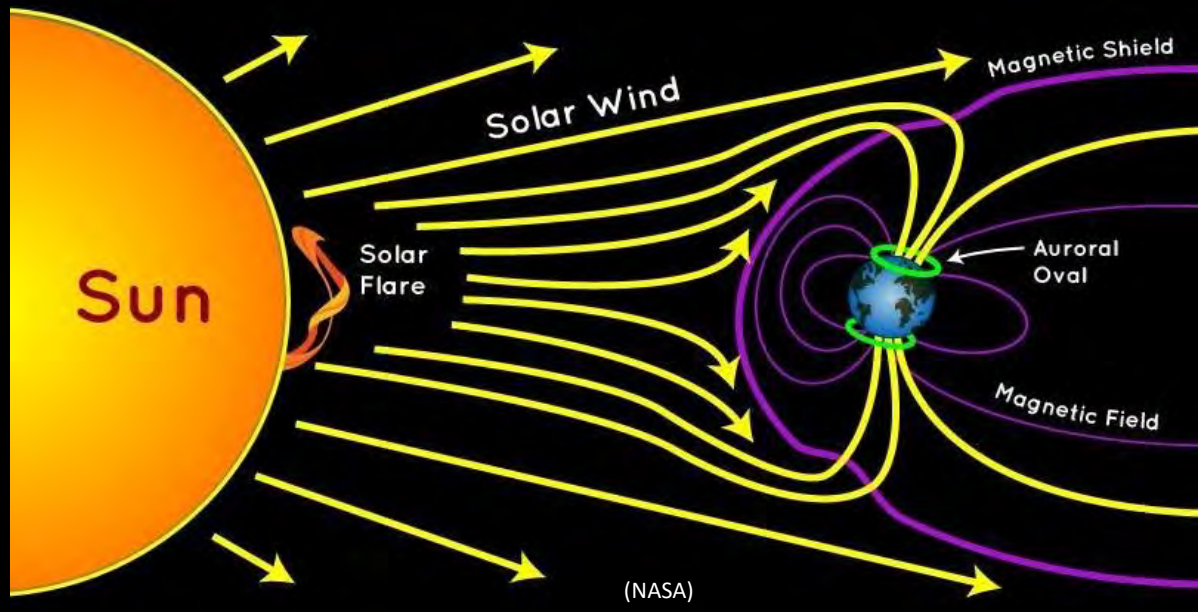
Joshua Doucette

Mentor: Allison N. Jaynes

Introduction

- The radiation belts are regions of Earth's magnetosphere filled with highly energetic electrons, protons, and photons.
- Electrons and ions become "trapped" on the magnetic field lines around the earth.
- Radiation in the belts is intense enough to cause fatal damage to persons and hardware having to pass through.





(NASA)

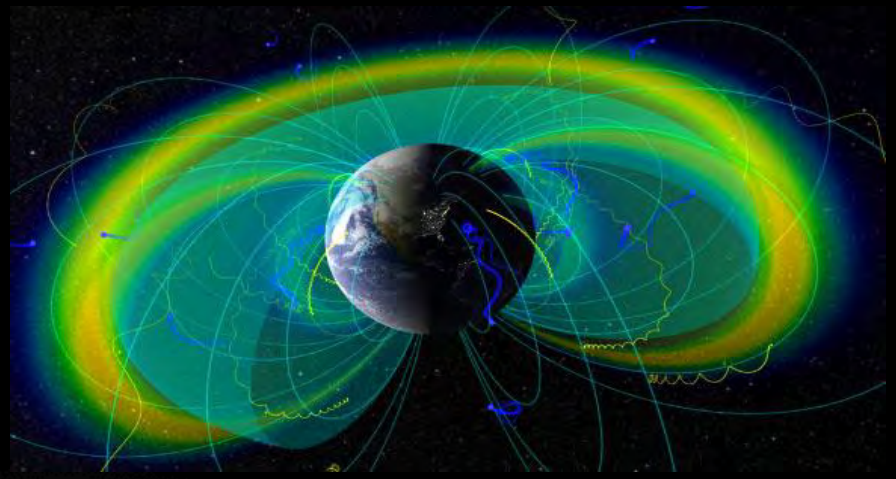
Periodic Motions in Plasmas:

- Particles in the radiation belts are not static.

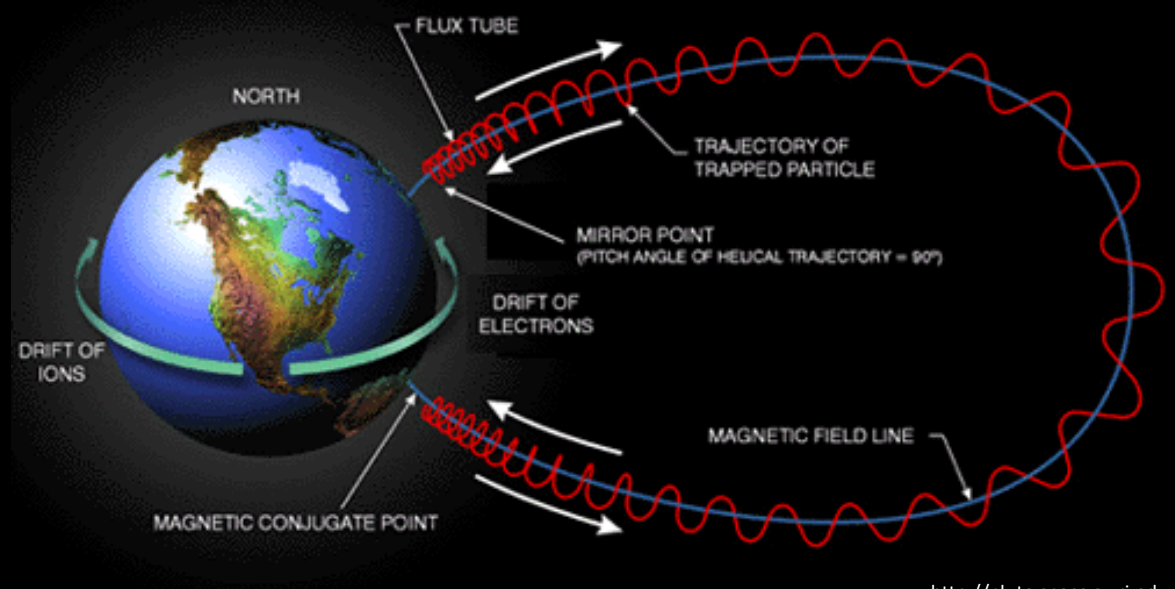
Three main types of motion exist:

- Cyclotron motion around field line
- Bounce motion between mirror points
- Precession motion around Earth: Drift

- Small enough pitch angles can lead to precipitation in the low atmosphere, while larger pitch angles reflect the bounce motion.

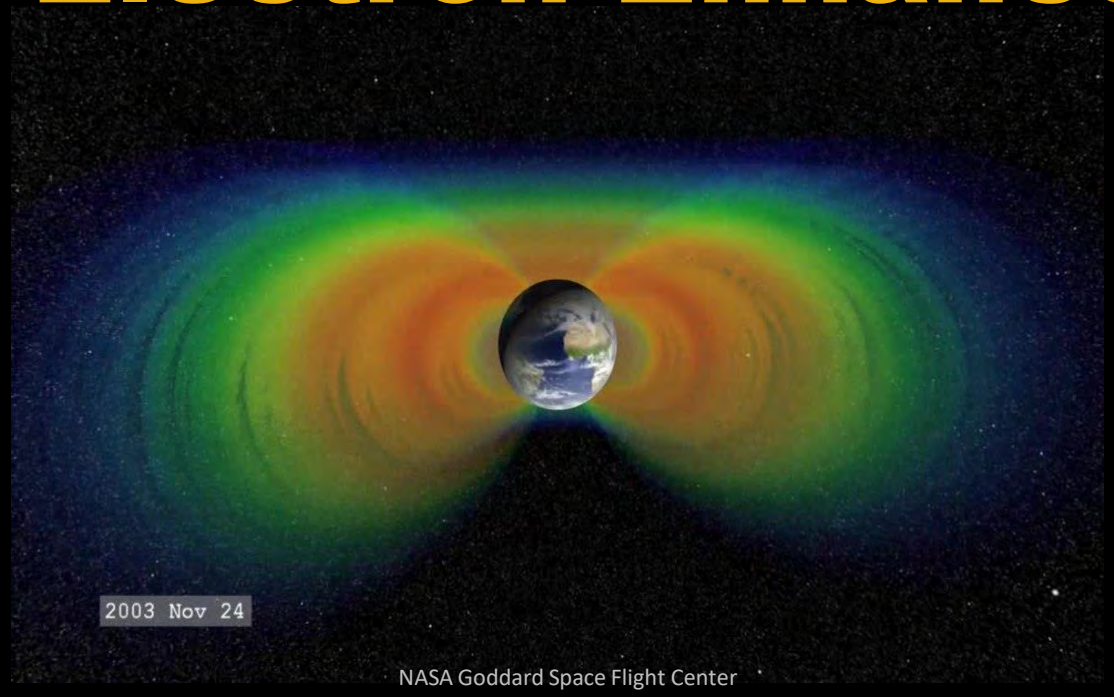


NASA



http://pluto.space.swri.edu

Electron Enhancements



- We want to know how an electron gains momentum perpendicular to their magnetic field line.

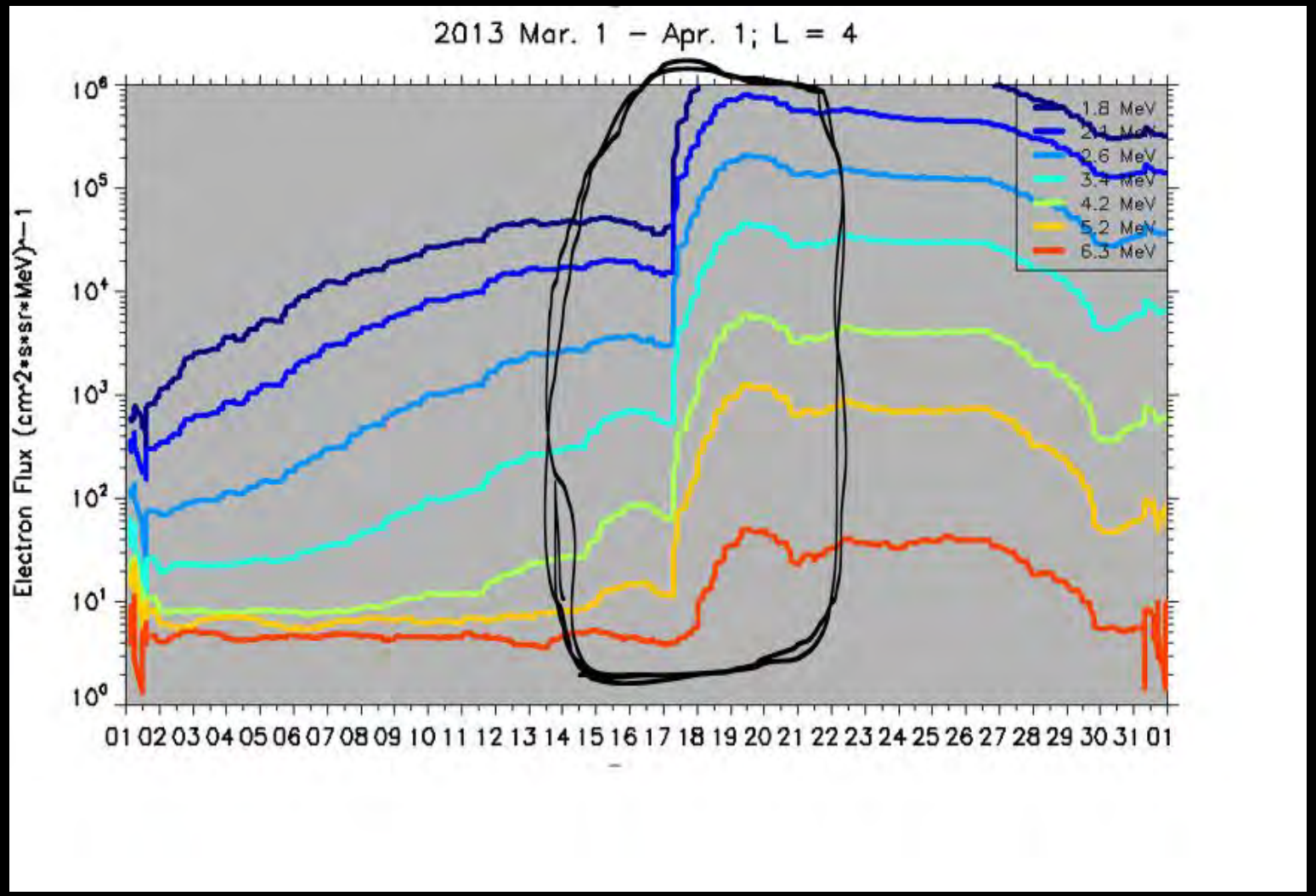
Prior to this study, three schools of thought existed to explain how radiation belt electrons gained significantly high energies (> ~2 MeV):

- Local Acceleration by Chorus Waves.
- ULF Wave perturbation then Radial Diffusion.
- A combination of the two above.

- In this study, an electron enhancement is when the electron flux recorded from REPT on RBSP increases by a factor of three from the day before.

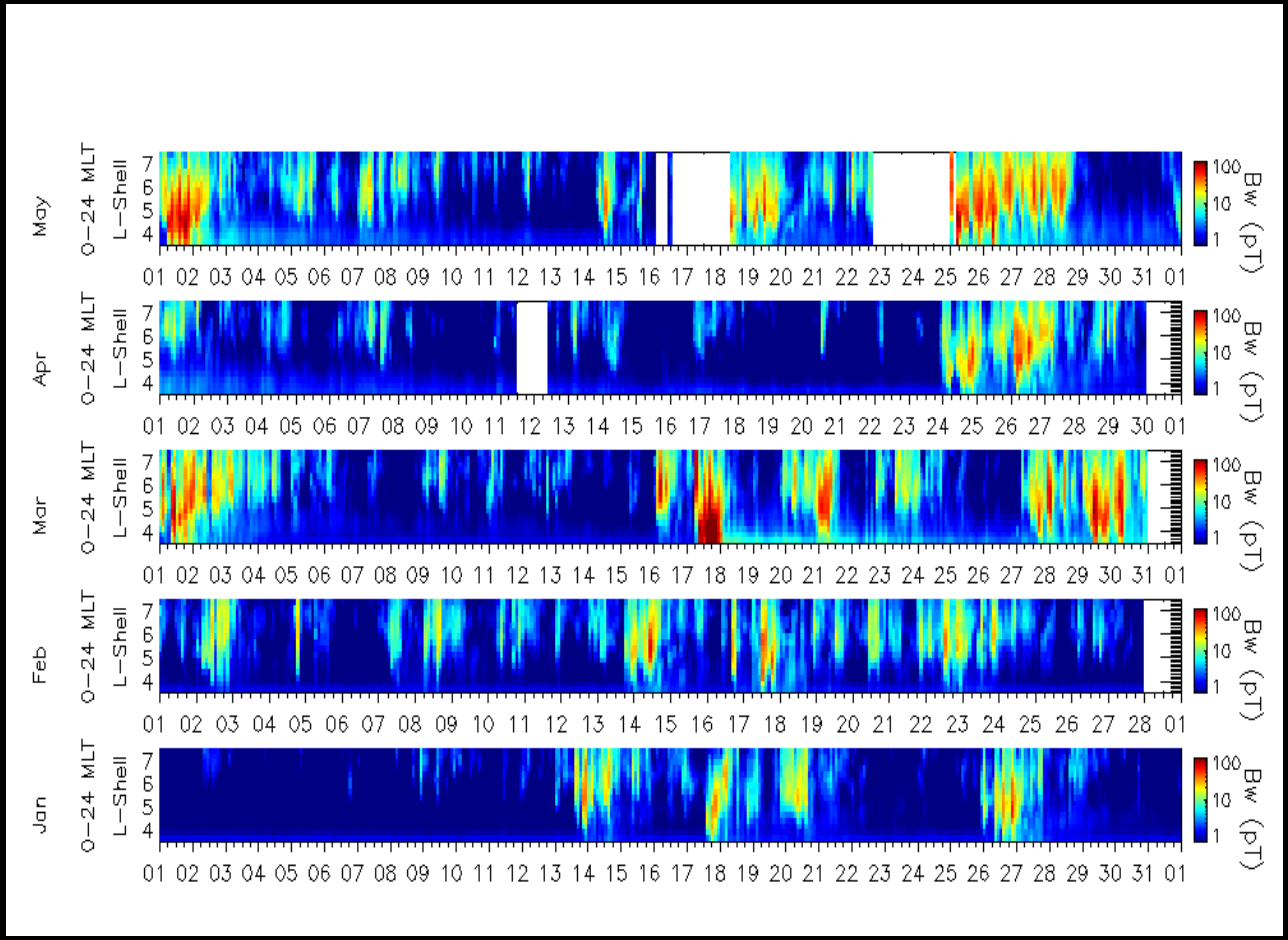
Electron Enhancement Example:

- Here we showcase an electron enhancement at L = 4.0 for the March, 2013 storm.
- This study sought to determine the existence of electron enhancements caused by radial diffusion from ULF waves.



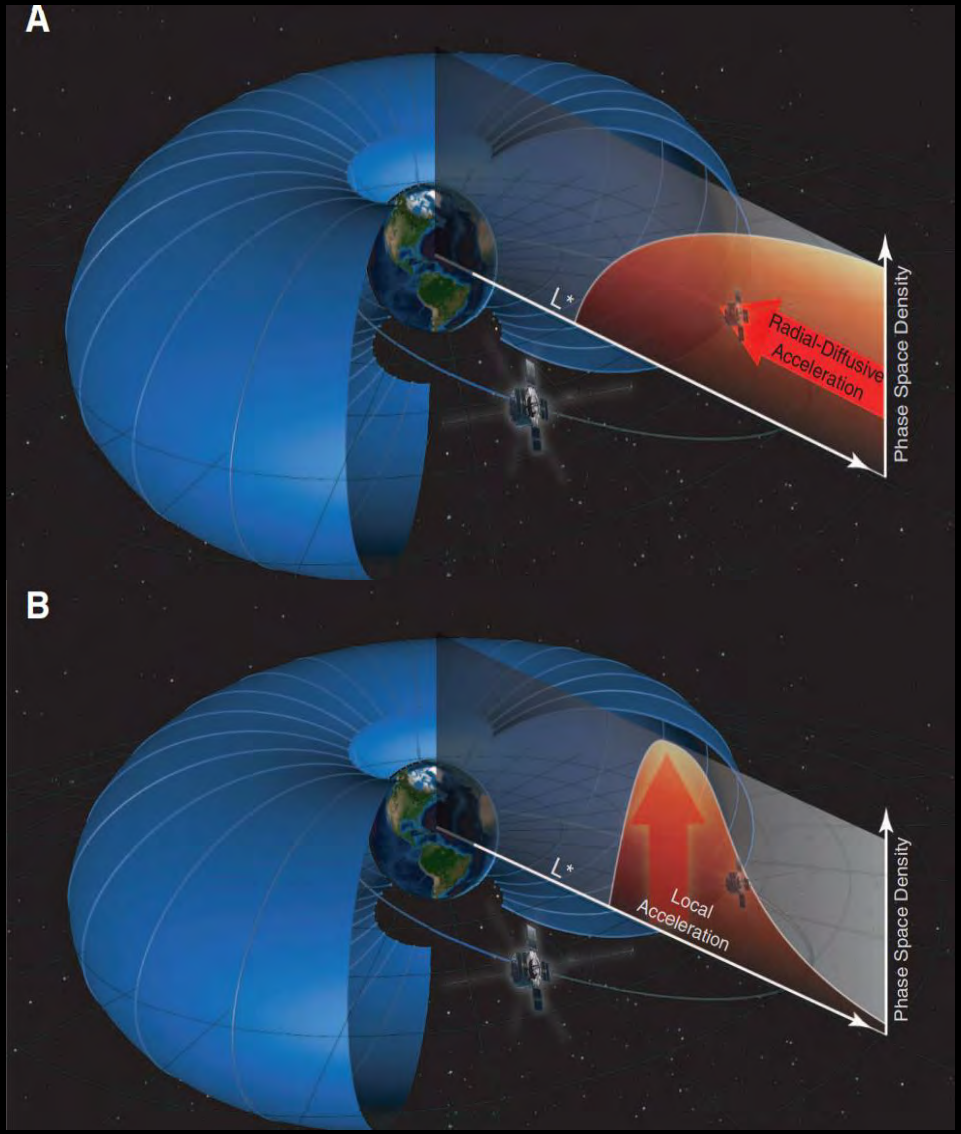
How to determine the cause of an enhancement:

- Solar Proton Events are removed using data from GOES.
- Graphs of inferred chorus can be created using a method described in Chen Y., et al. (2014).
- If no chorus is found on the date of an enhancement, the event is flagged to be reviewed further.
- To determine which of the flagged events are consequences of Radial Diffusion or Local Acceleration, we turn to graphs of the Phase Space Density.



Phase Space Densities:

- Phase Space Density can be found for each enhancement using a method in Chen Y., et al. (2005), and the data collected by RBSP.
- Note the characteristic profiles of PSD for Radial Diffusion and Local Acceleration displayed in an image to the right from Reeves, et al. (2013).
- We can only be sure whether each event was chorus induced or ULF wave induced using the PSD vs L* graphs for each event.
- Next we show the instruments necessary to conduct such a study.



POES (Polar Orbiting Environmental Satellites)

- Launched by NOAA and NASA
- Orbital period ~90 min
- Altitude ~ 800 km
- SEM-2 instrument package is capable of measuring flux from energetic ions and electrons near altitude of the satellite.
- MEPED (Medium Energy Proton and Electron Detector), has two electron solid-state detector telescopes, one pointed along zenith, other is orthogonal. Three energy bands are measured (>30 keV, > 100 keV, and > 300 keV).

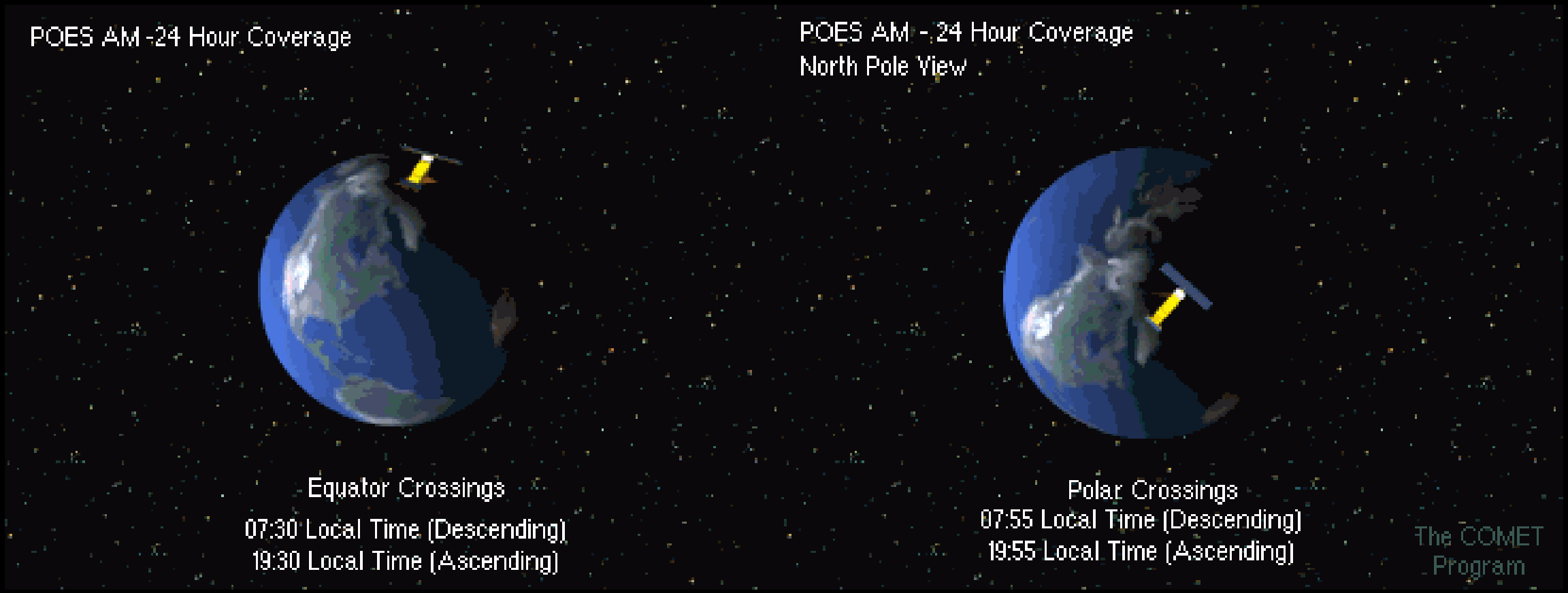
Image courtesy of NOAA.

MetOp Satellites

- Developed by European Space Agency and operated by European Organization for Exploitation of Meteorological Satellites.
- Orbital period ~ 100 min
- Altitude ~ 800 km
- SEM-2 has also been added to these polar orbiting satellites.

Image courtesy of Airbus Defense and Space

POES and MetOp Orbits:

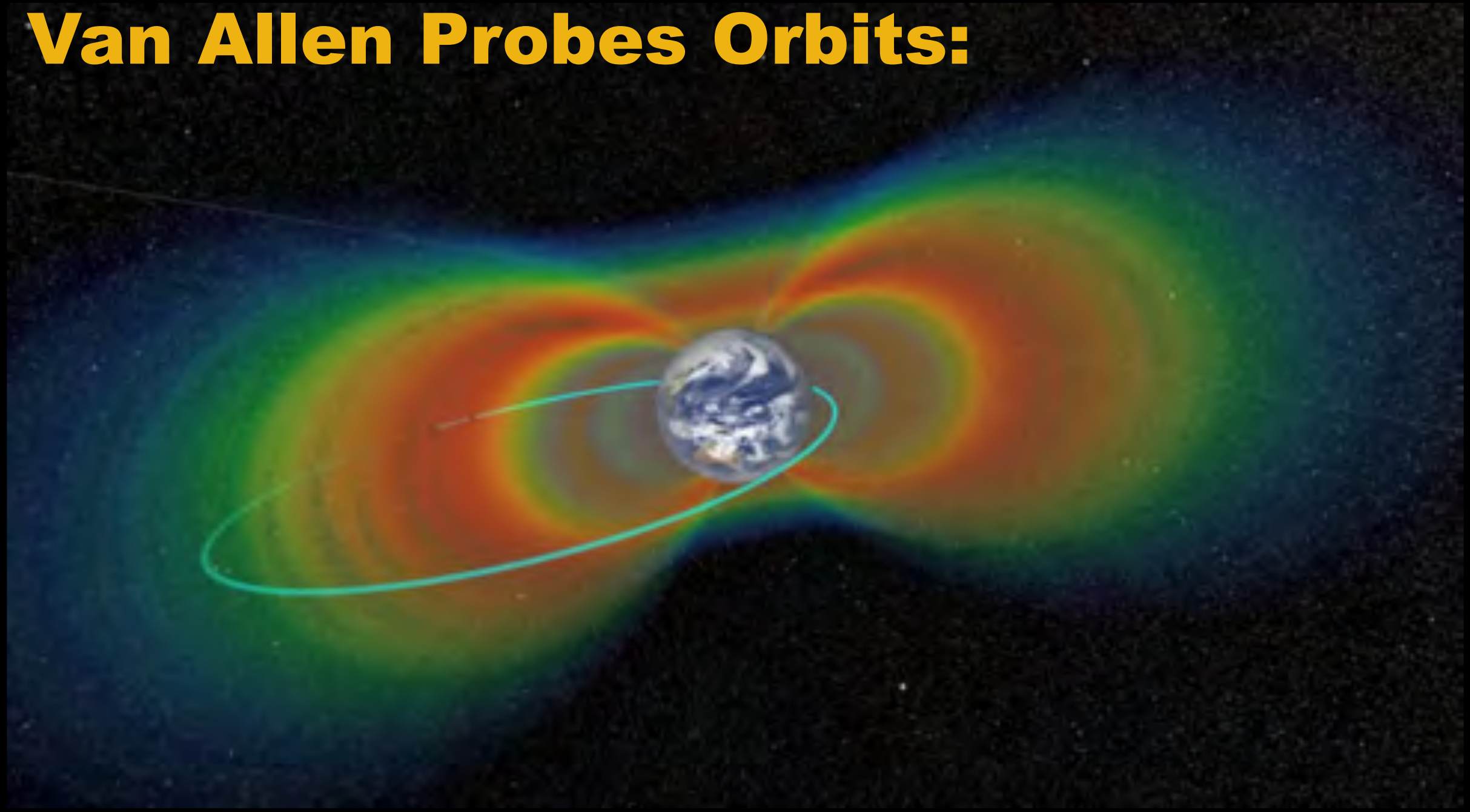


Radiation Belt Storm Probes

- These twin satellites are also named the ‘Van Allen Probes’ after physicist James Van Allen, who discovered the radiation belts.
- Launched in August, 2012
- De-orbited ~ October, 2019
- Perigee: ~620 km; Apogee: ~5.8 Earth Radii
- EMFISIS instrument suite on-board takes detailed electric and magnetic field measurements, measuring waves between 10 Hz and 400 kHz.

Van Allen Probes (John Hopkins Applied Physics Laboratory)

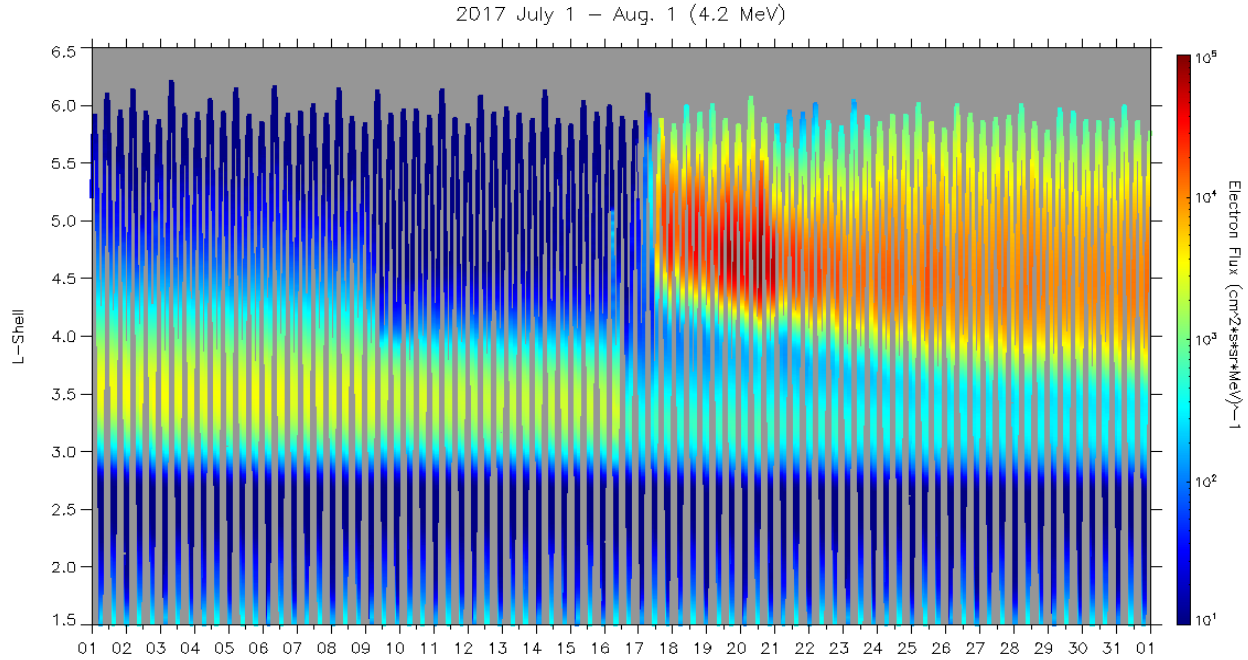
Van Allen Probes Orbits:



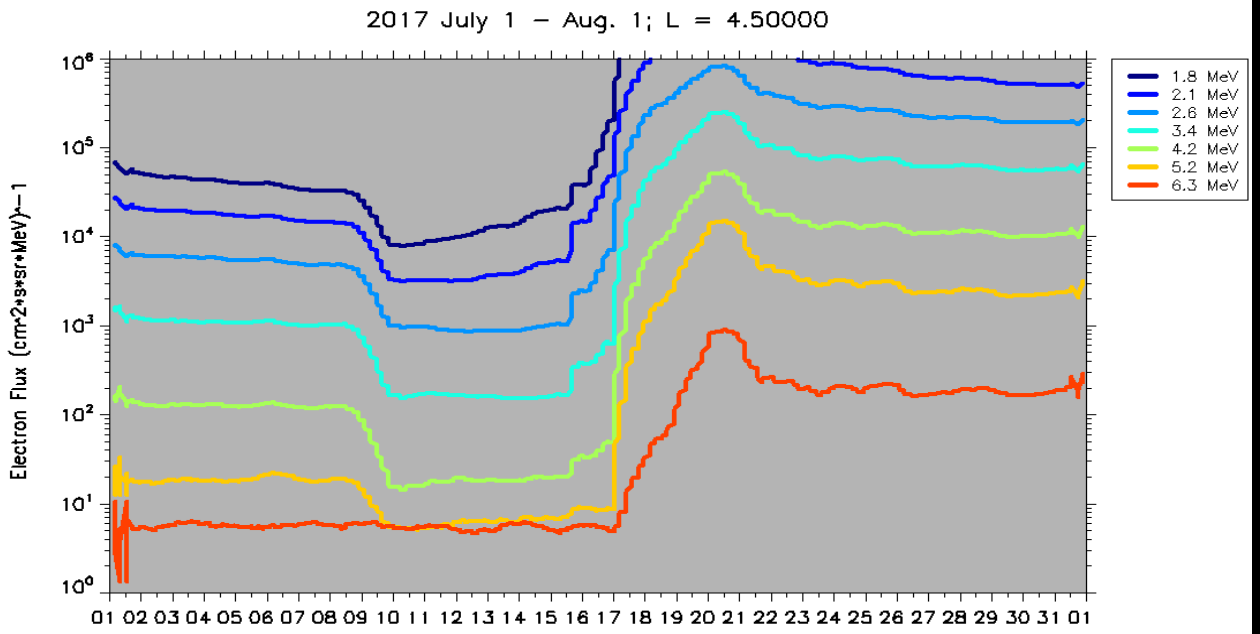
NASA Goddard Space Flight Center

Radial Diffusion by ULF waves:

- Here we showcase electron enhancements on July 18, 19, and 20 in 2017.
- During this period there were repeated electron enhancements at L=4.5 for the 4.2 Mev, 5.2Mev and 6.3Mev channels.

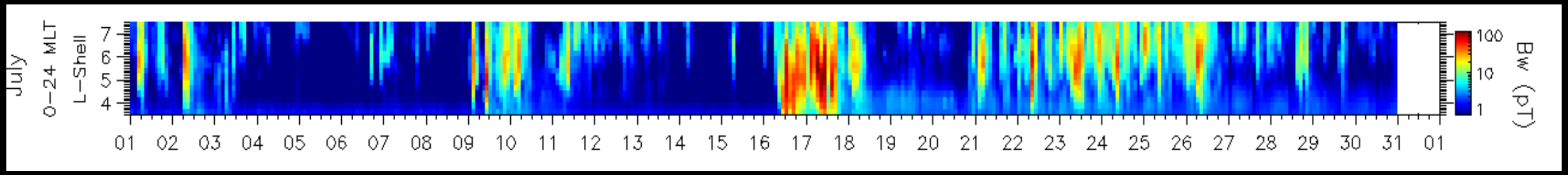


L-Shell vs Time, as Recorded by REPT on RBSP-B

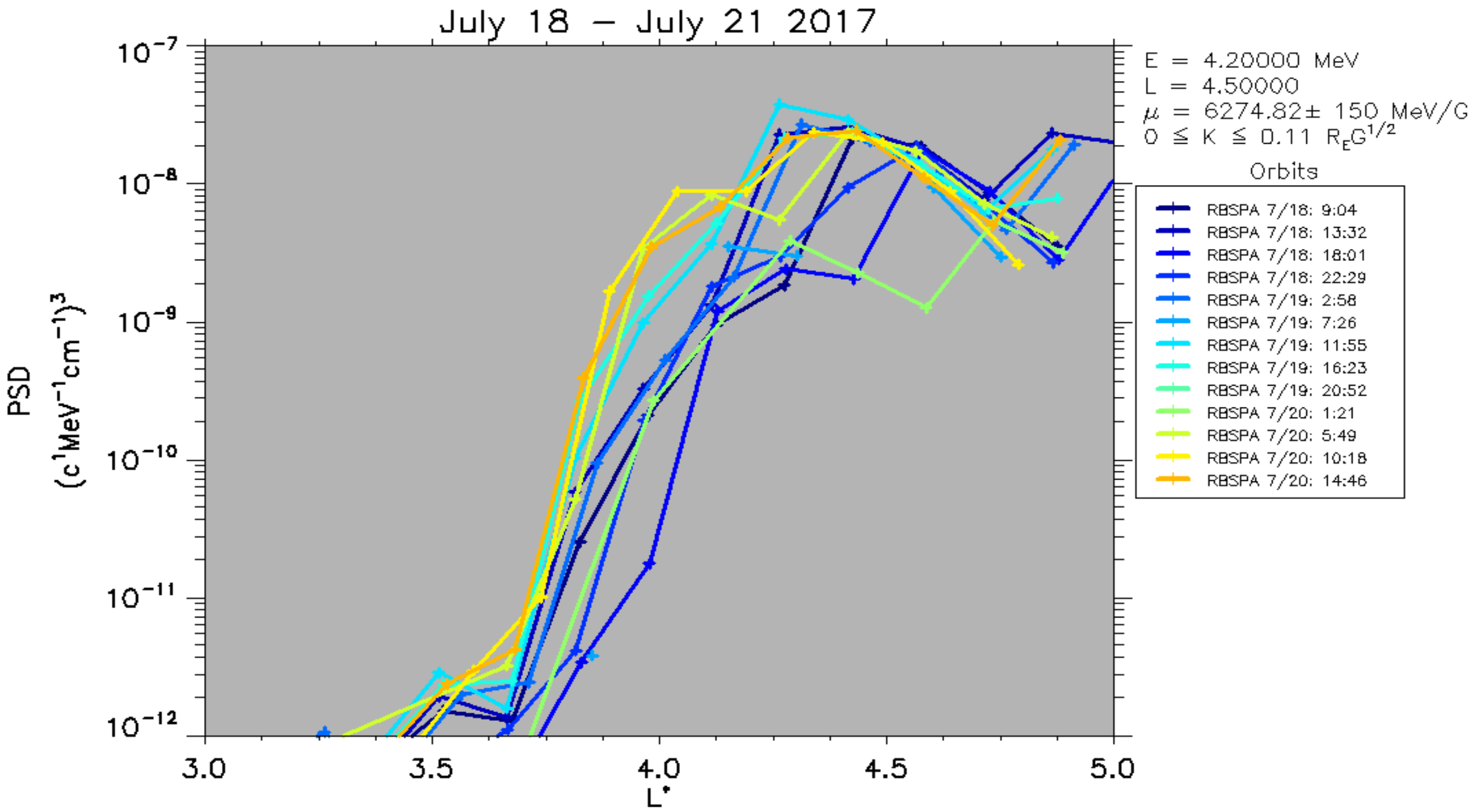


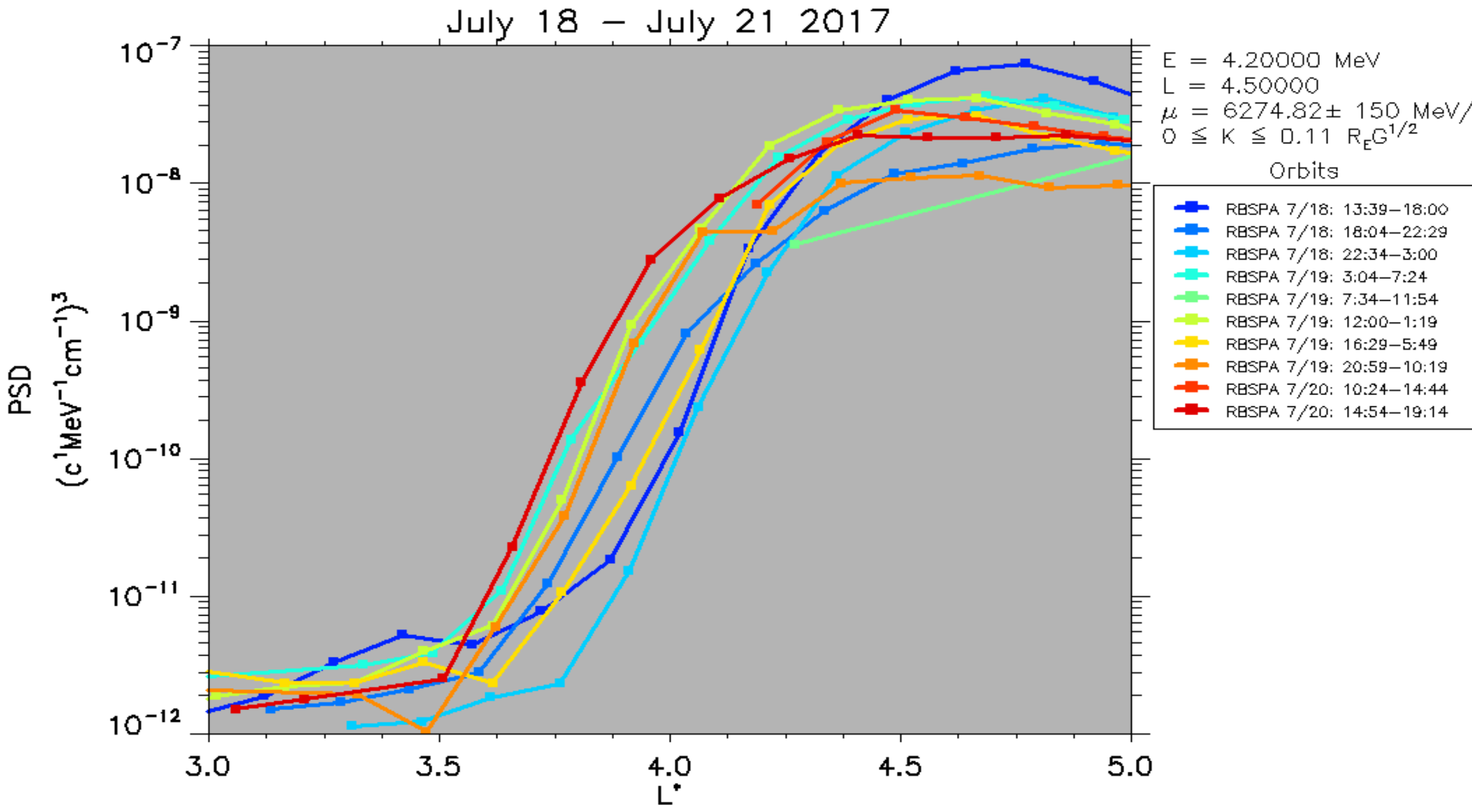
Flux vs Time, as Recorded on REPT by RBSP-B

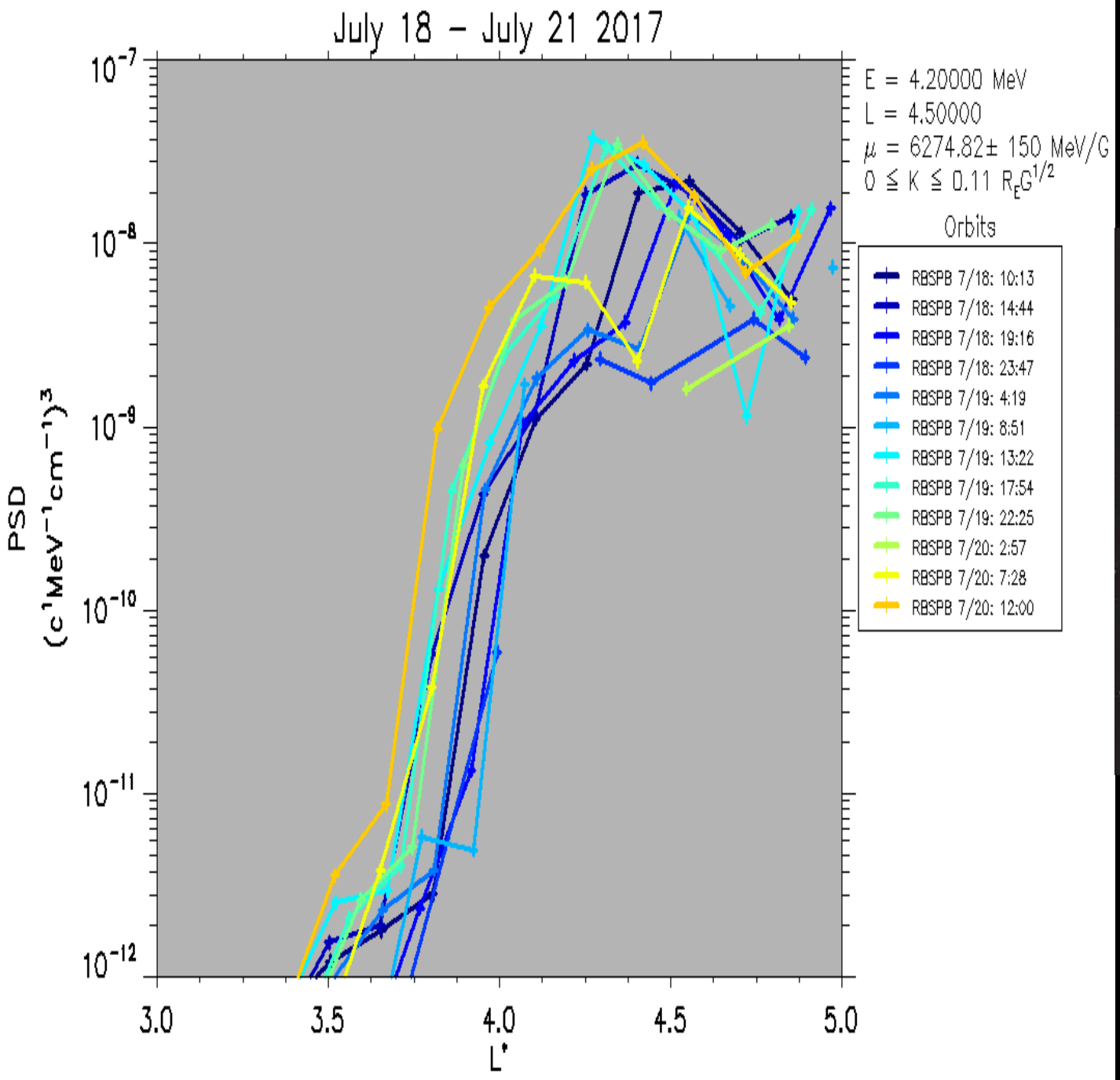
Inferred Chorus for July 18, 19, 20:

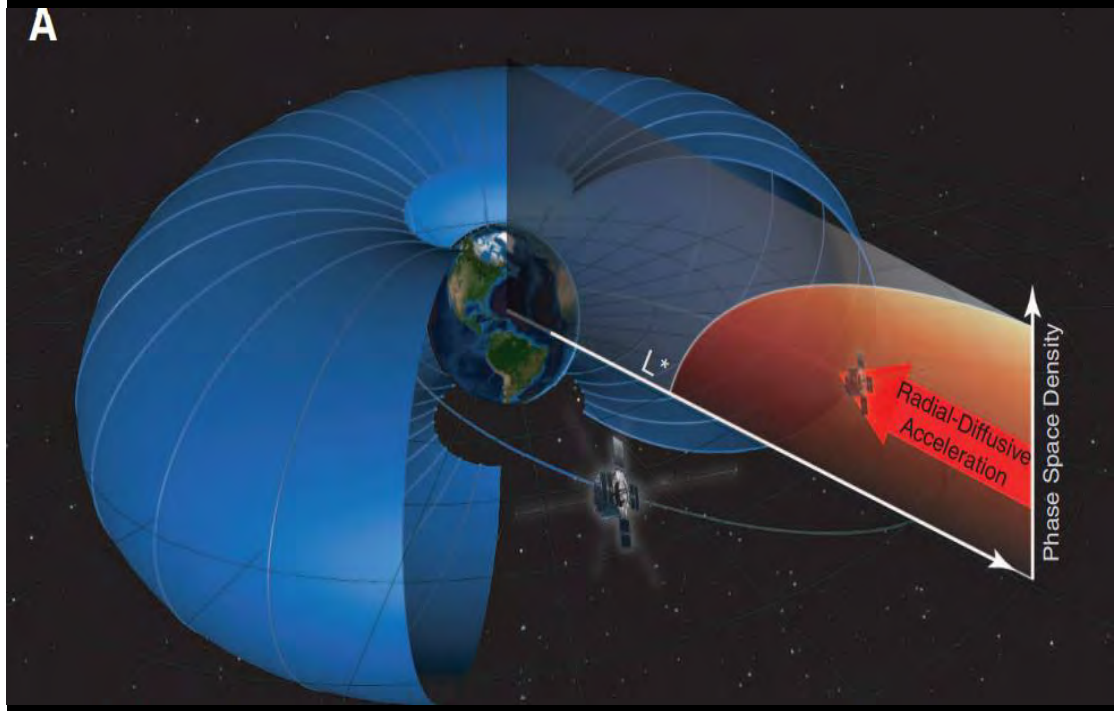


- As can be seen above, the inferred chorus amplitude subsides before the 19th and the 20th. However, we still see enhancements through the 20th.
- Thus we next investigate the PSD vs L* graphs to verify whether or not the acceleration was Radial Diffusion or Local Acceleration.


July 18 – July 21 2017
E = 4.20000 MeV
L = 4.50000
μ = 6274.82± 150 MeV/G
0 ≦ K ≦ 0.11 R_E G^1/2
Orbits
RBSPA 7/18: 9:04
RBSPA 7/18: 13:32
RBSPA 7/18: 18:01
RBSPA 7/18: 22:29
RBSPA 7/19: 2:58
RBSPA 7/19: 7:26
RBSPA 7/19: 11:55
RBSPA 7/19: 16:23
RBSPA 7/19: 20:52
RBSPA 7/20: 1:21
RBSPA 7/20: 5:49
RBSPA 7/20: 10:18
RBSPA 7/20: 14:46
PSD
(c^1MeV^-1cm^-1)^3
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
3.0
3.5
4.0
4.5
5.0
L*


July 18 – July 21 2017
E = 4.20000 MeV
L = 4.50000
μ = 6274.82± 150 MeV/
0 ≦ K ≦ 0.11 R_E G^1/2
Orbits
RBSPA 7/18: 13:39–18:00
RBSPA 7/18: 18:04–22:29
RBSPA 7/18: 22:34–3:00
RBSPA 7/19: 3:04–7:24
RBSPA 7/19: 7:34–11:54
RBSPA 7/19: 12:00–1:19
RBSPA 7/19: 16:29–5:49
RBSPA 7/19: 20:59–10:19
RBSPA 7/20: 10:24–14:44
RBSPA 7/20: 14:54–19:14
PSD
(c^1MeV^-1cm^-1)^3
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
3.0
3.5
4.0
4.5
5.0
L*





- Note the PSD profiles for July 18,19,20 follow the characteristic PSD profile for acceleration by radial diffusion.

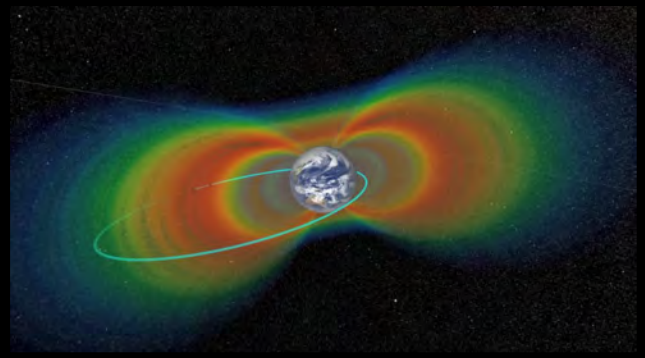
Conclusions:

In this study we investigated all of the electron enhancements between September, 2012, and October, 2019:

- 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.

What is next:

- This study will continue to investigate every event from September, 2012 until October, 2019.
- All enhancements showing the correct PSD profiles and inferred chorus for ULF wave radial diffusion will be flagged.
- All flagged events will under go a statistical analysis involving the investigation of solar wind and magnetic field parameters, and conditions for ULF wave radial diffusion will be found by finding similarities in these parameters.
- A detailed paper on the results will be published with special thanks to NASA, and the Iowa Space Grant Consortium for their funding.



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Sources:

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

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

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