Search for the Common Power Law Spectrum in Parker Solar Probe's IS⊙IS-EPILo Data

Asher Merrill
Advisors: Dr. Jonathan Niehof and Dr. Nathan Schwadron

University of New Hampshire

Abstract

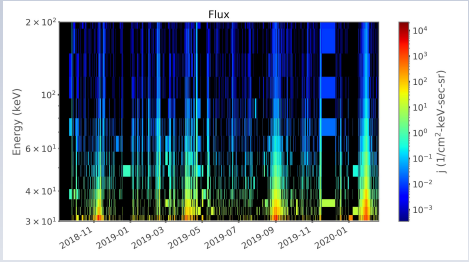
I investigate the first year and a half of Parker Solar Probe's data to find evidence of the common power law spectrum of ions proposed by Gloeckler et. al. (2000) within 0.3 AU. I find weak evidence to suggest the existence of a common spectrum of protons from ~60 keV to 200 keV inside the region being studied. Further work is required to elucidate the phenomena in this region that determine the shape of the solar wind spectra.

Introduction

The Advanced Composition Explorer and the Ulysses spacecraft revealed the presence of a common power-law spectrum of ions in the solar wind, the shape of which is independent of solar activity. The highest energy particles in this distribution are a direct interest to human affairs as they can serve as the seed population for large, destructive events that can harm ground- and air-based equipment. The mechanisms that create this common distribution are unknown, but by studying the behaviour of the spectrum at closer radii more can be learned about their origin. Furthermore, this relationship is altogether poorly studied within 1 AU.

Parker Solar Probe (PSP) provides a new platform to probe this relationship. PSP flies within approx. 0.05 AU of the sun, far closer than any previous spacecraft. Additionally, the mission carries newer and more sensitive instruments, improving on previous measurements and collecting new high-resolution data in not-previously-explorer regions.

The seed population of particles is of interest because it contributes to phenomena such as diffusive shock acceleration, which is capable of accelerating ions from the keV to MeV energy range. It is these particles carried by diffusive shock acceleration that are dangerous.



Left: "map" of flux across various energies and dates. Due to the format constraints of this poster, you're probably unable to see most events as they're only a day or two wide.

Analysis

Event Selection

It is necessary to identify solar wind events in order to have significant counting statistics above background. Solar wind events were identified by eye.

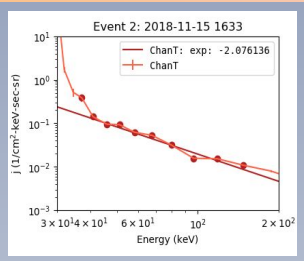
Fitting

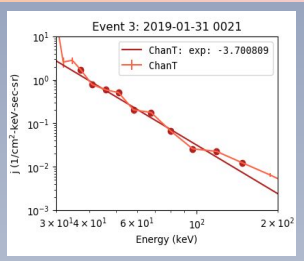
Fisk & Gloeckler (2006) suggest a model of compressional acceleration in solar wind turbulence that predicts a functional dependence of flux on energy as shown above. For each event, the flux was averaged along time, and then a fit to this model was applied between ~60 keV and 200 keV, depending on data source.

$$j = j_0\, T^{-3/2}$$

Event Type Analysis

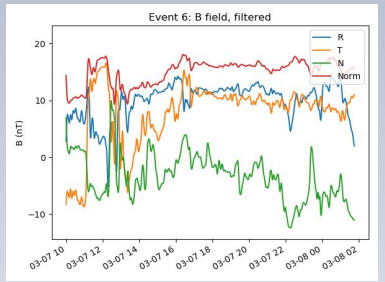
It became evident from the set of fits that events needed to be distinguished based on type in order to see similarities between events of the same nature, (ie., CIR, CME, solar flare, etc…). Various characteristics for event classification were considered, as indicated in in the figures below and to the right.

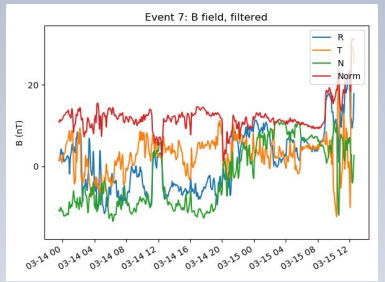


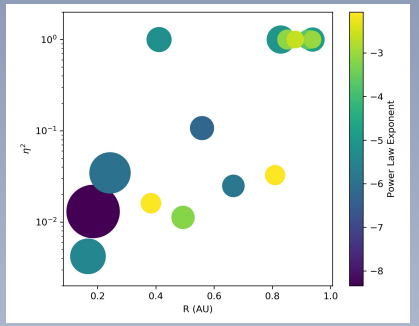


Fits of Events 2 and 3. Notice neither fit agrees with Fisk & Gloeckler (2006) suggesting $T^{-3/2}$.

Ten minute filtered views of the magnetic field during events 6 and 7. Some features of note exist, but are altogether hard to see.







Analysis of variance of magnetic field vs radial distance. Schwadron et. al. (1996) propose magnetic variance can be a proxy for plasma turbulence. Color indicates spectrum hardness, (brighter is harder spectrum, darker is softer), size indicates peak flux. A possible trend exists such that events closer to the sun have less variance in the magnetic field.

Discussion and Conclusions

The tail described by Fisk & Gloeckler (2000, 2006) is noted to appear during quiet-time solar activity. Accordingly, it is necessary to distinguish between compressional events and other sources of acceleration.

- Ultimately, the events over which data was collected do not represent a significant sample. More data is needed.
- Further work is required to determine if a common power law tail exists in the regime <0.3 AU.
- This work may be aided by using data from missions such as SOHO and STEREO to determine the type of event, which can aid in the recognition of phenomena observed by PSP.

References

Fisk, L. A., & Gloeckler, G. (2006). *The Common Spectrum for Accelerated Ions in the Quiet-Time Solar Wind.* The Astrophysical Journal, 640(1), L79–L82.

Gloeckler, G. (2000). *Sources, injection and acceleration of heliospheric ion populations.* AIP Conference Proceedings. (ACE-2000 symposium).

Schwadron, N. A., Fisk, L. A., & Gloeckler, G. (1996). *Statistical acceleration of interstellar pick-up ions in co-rotating interaction regions.* Geophysical Research Letters, 23(21), 2871–2874.

Acknowledgements

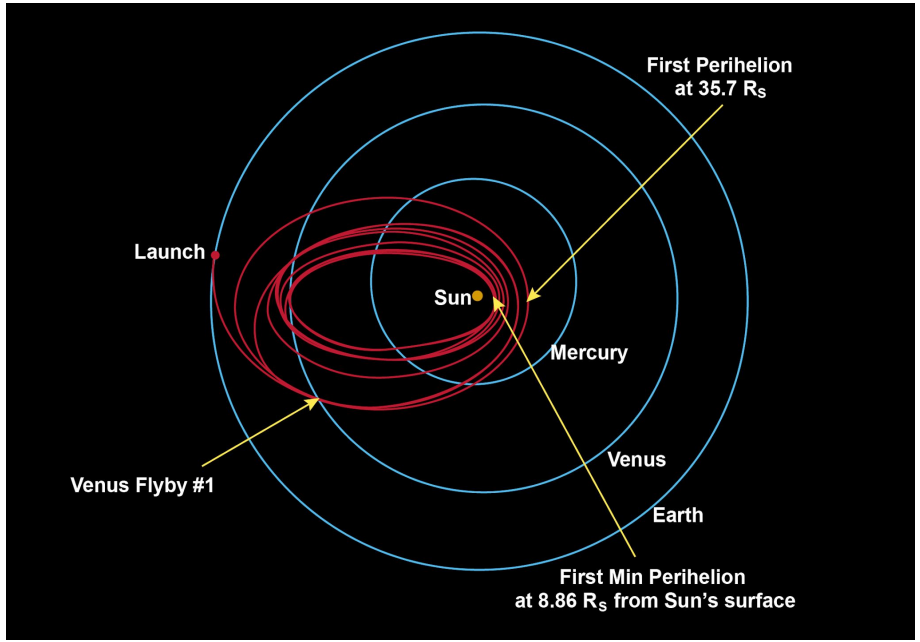
- Dr. Niehof and Dr. Schwadron for their incredible patience and help throughout this project.
- The IS⊙IS and FIELDS teams for the titanic effort of getting data from instrumental readings.
- This work was supported by NASA Prime Contract No. 136435.

Search for the Common Power Law Spectrum in Parker Solar Probe's IS⊙IS-EPILo Data

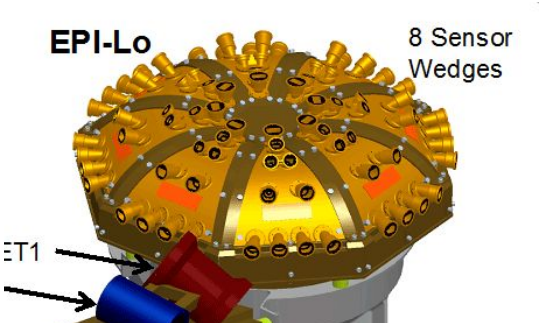
Asher Merrill
Advisors: Dr. Jonathan Niehof and Dr. Nathan Schwadron

Introduction

- The Advanced Composition Explorer and Ulysses found a common spectrum of ions in the solar wind in regions > 1 AU (Gloeckler 2000, Fisk & Gloeckler 2006).
    - The population of ions at the top of this distribution can spark phenomena that are dangerous to humans and our stuff.
- Parker Solar Probe is exploring 0.05 < r < 1 AU. Will we see the common spectrum here?



Parker Solar Probe's orbit plotted out to 2025.
Image credit: NASA/JPL Mission Site.



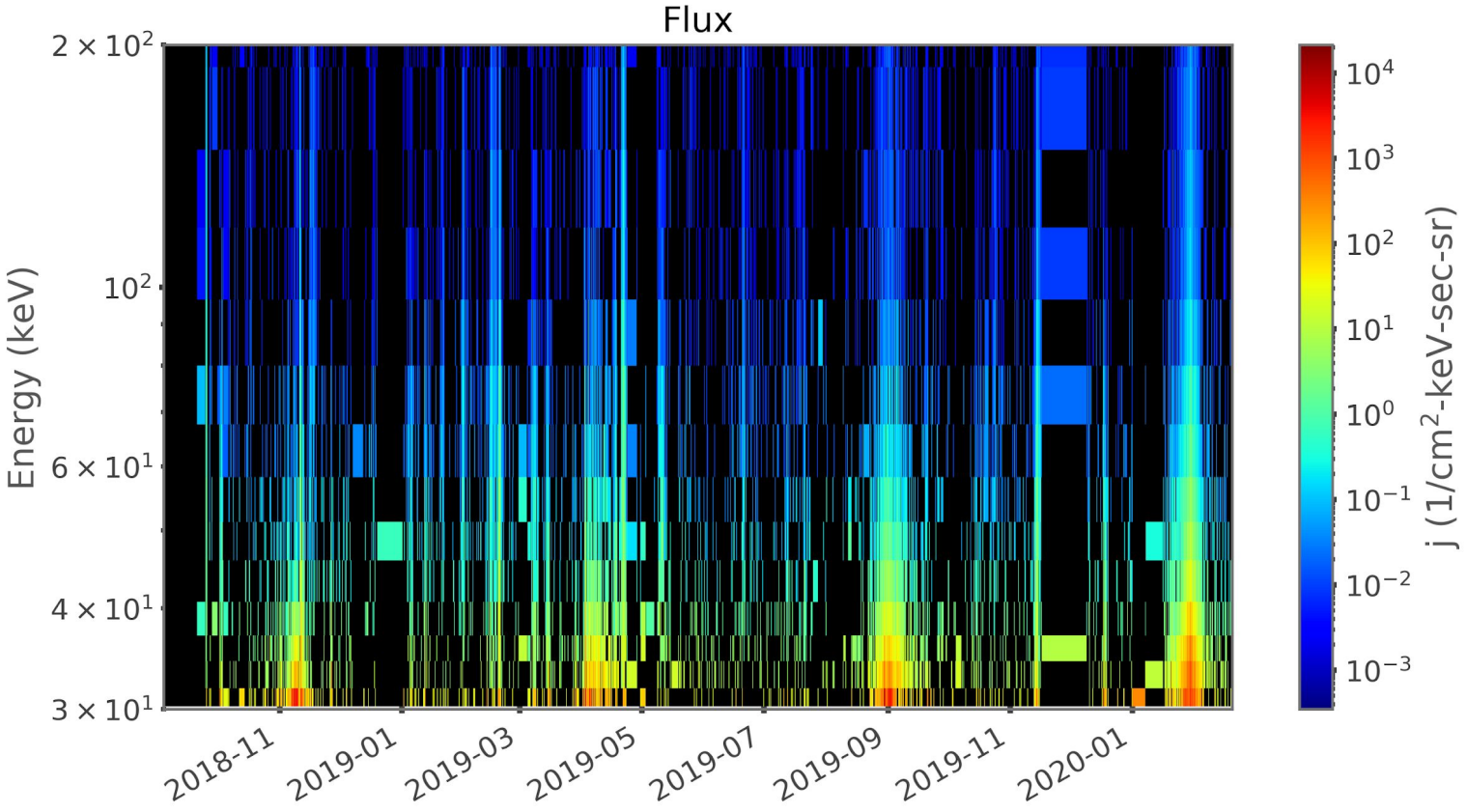
Parker Solar Probe's IS⊙IS-EPILo instrument.
Image credit: [also] NASA/JPL Mission Instruments Site.

Analysis

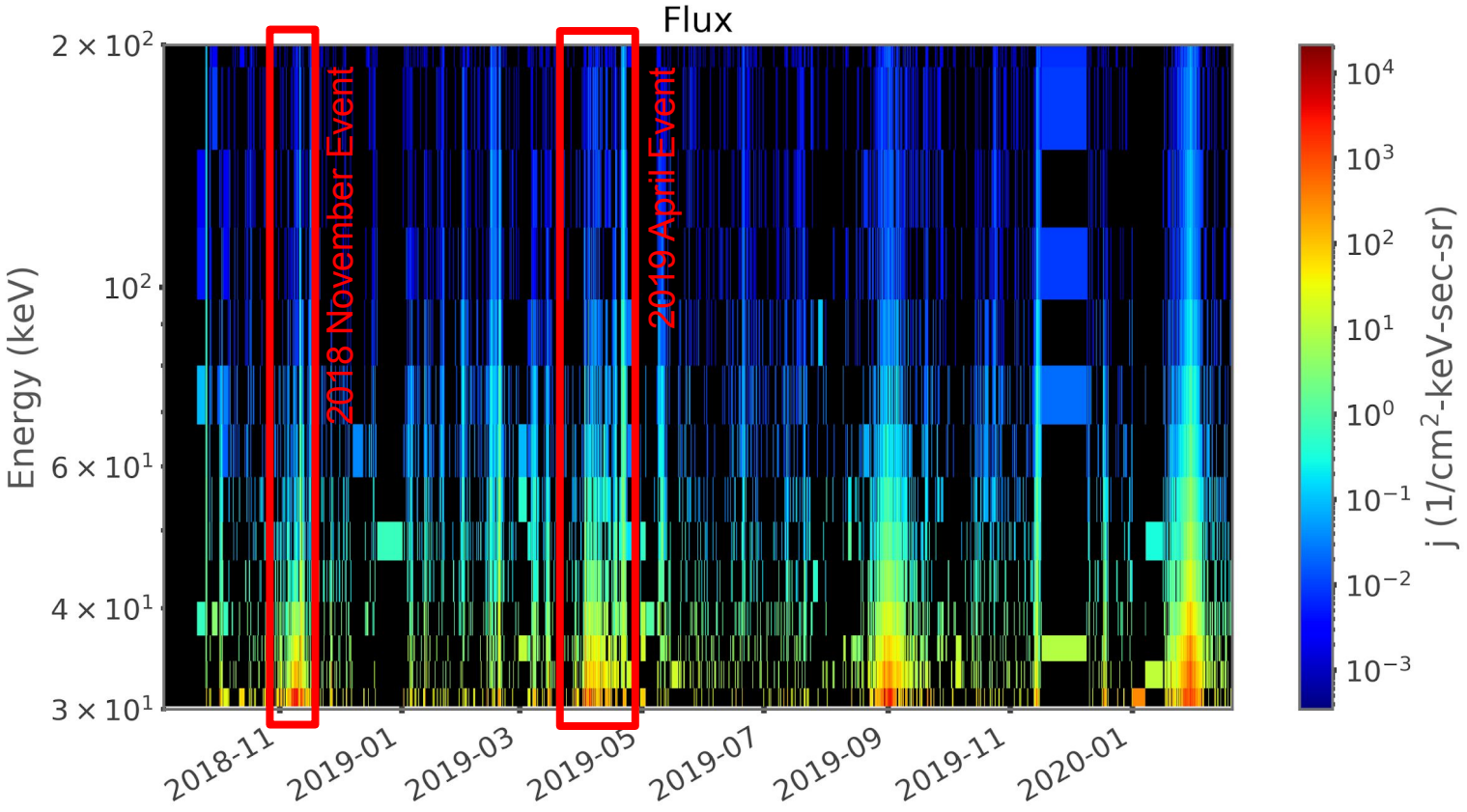
- What do we need in order to compare?
  - Need **time periods with high enough counting statistics,** (ie., something needs to happen, otherwise we just have background).
  - Fisk & Gloeckler (2006) model, (they have some more elegant stuff, but the distribution they describe can be modeled by this):

$$j = j_0 \, T^{-3/2}$$

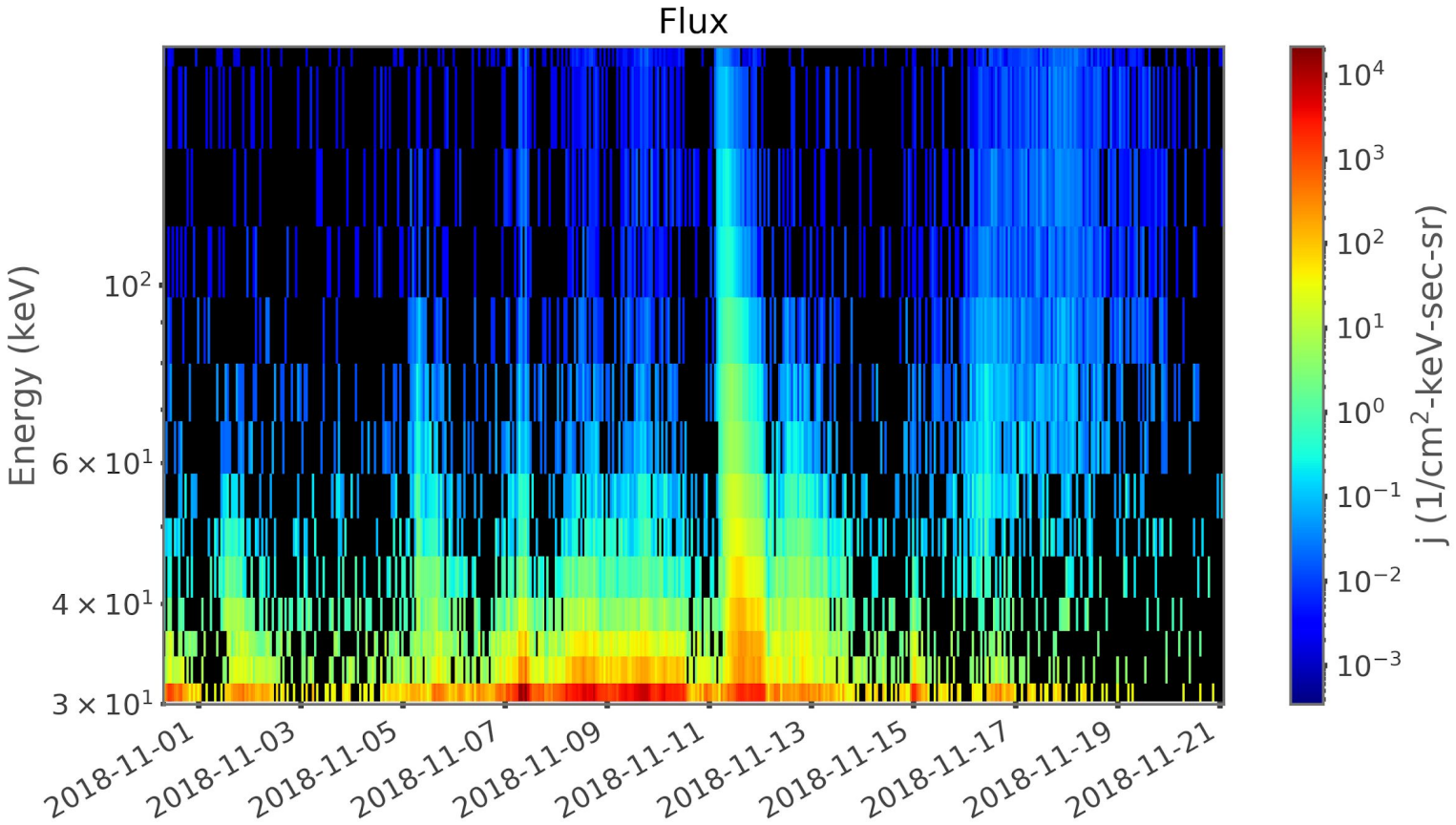
Analysis


Flux
Energy (keV)
2×10^2
10^2
6×10^1
4×10^1
3×10^1
2018-11
2019-01
2019-03
2019-05
2019-07
2019-09
2019-11
2020-01
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
j (1/cm^2-keV-sec-sr)

Analysis

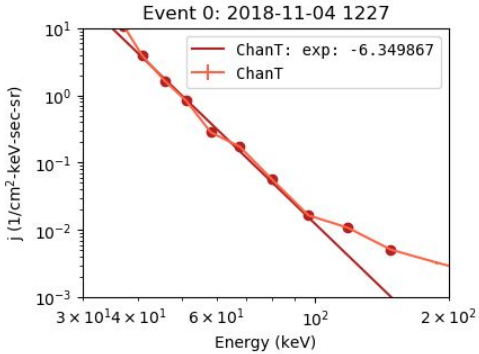

Flux
2 × 10^2
10^2
6 × 10^1
4 × 10^1
3 × 10^1
Energy (keV)
2018 November Event
2019 April Event
2018-11
2019-01
2019-03
2019-05
2019-07
2019-09
2019-11
2020-01
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
j (1/cm^2-keV-sec-sr)

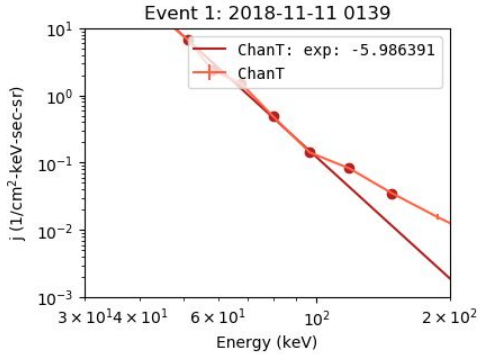
Analysis: November 2018

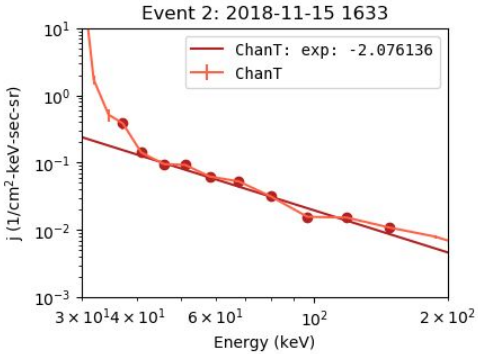


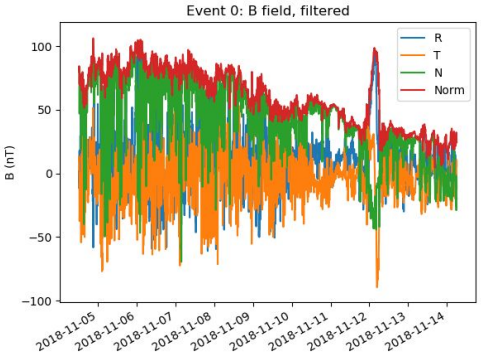
Analysis

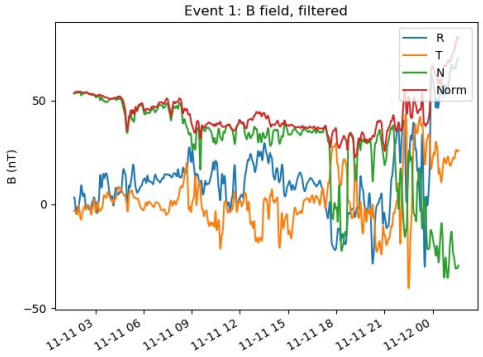
- Let's make some spectra!

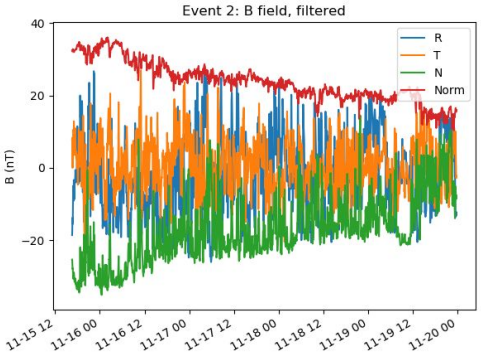




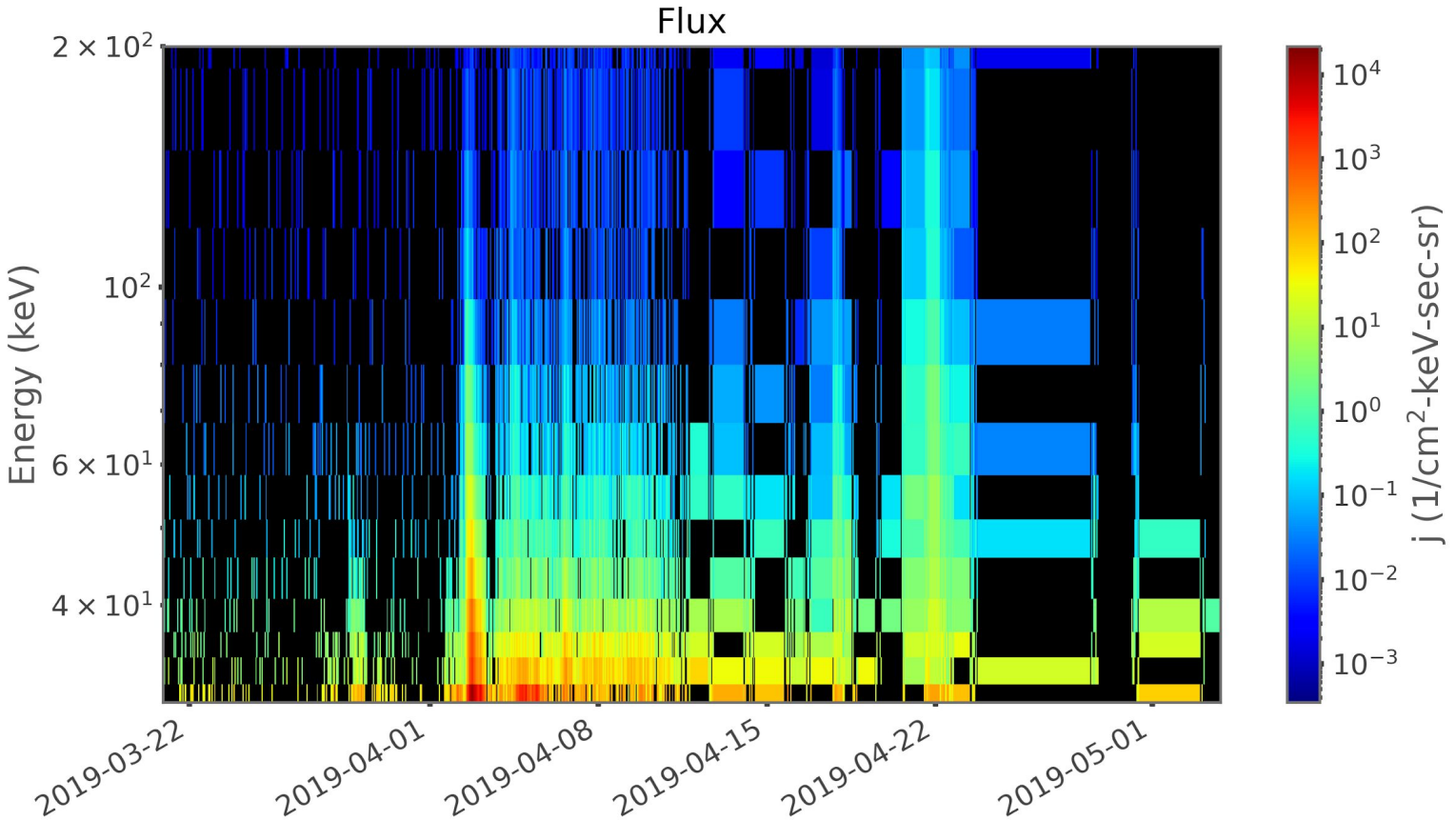






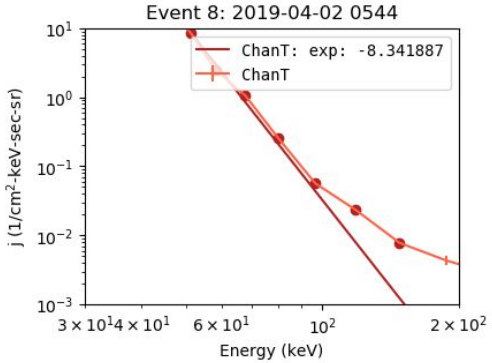


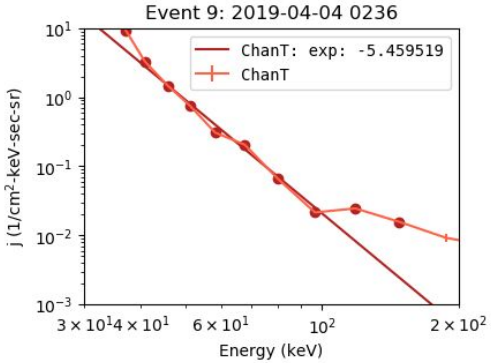
Analysis: April 2019

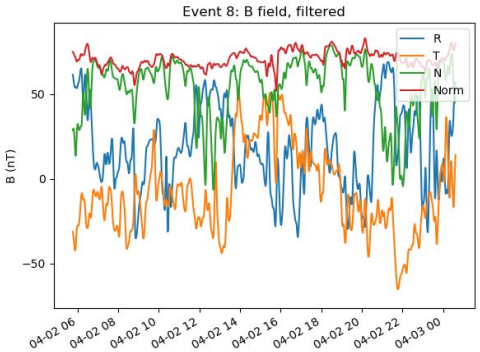


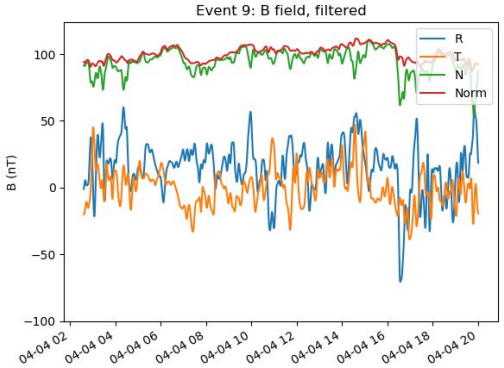
Analysis

- We see some similar behavior as before...







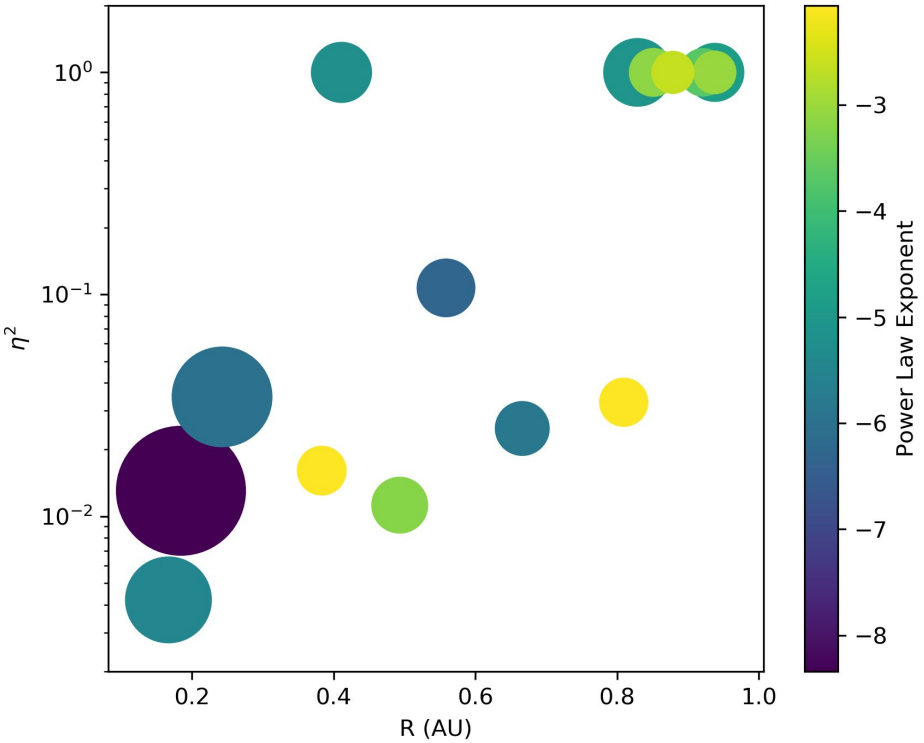


Analysis

- These numbers don’t look like -1.5...
    - Maybe we need to look at the type of event.
    - Would help to distinguish between compressional acceleration and quiet time solar wind.

Analysis

Schwadron et. all (1996) demonstrate magnetic variance can be a proxy for plasma turbulence, a hallmark of compressional acceleration.



Size corresponds to peak flux.

Discussion & Conclusion

The tail described by Fisk & Gloeckler (2000, 2006) is noted to appear during quiet-time solar activity. Accordingly, it is necessary to distinguish between compressional events and other sources of acceleration.

- Ultimately, the events over which data was collected do not represent a significant sample. More data is needed.
- Further work is required to determine if a common power law tail exists in the regime <0.3 AU.
- This work may be aided by using data from missions such as SOHO and STEREO to determine the type of event, which can aid in the recognition of phenomena observed by PSP.

Acknowledgements

- Dr. Niehof and Dr. Schwadron for their incredible patience and help throughout this project.
- The IS⊙IS and FIELDS teams for the titanic effort of getting data from instrumental readings.
- This work was supported by NASA Prime Contract No. 136435.

References

Fisk, L. A., & Gloeckler, G. (2006). *The Common Spectrum for Accelerated Ions in the Quiet-Time Solar Wind*. The Astrophysical Journal, 640(1), L79–L82.

Gloeckler, G. (2000). *Sources, injection and acceleration of heliospheric ion populations*. AIP Conference Proceedings. (ACE-2000 symposium).

Schwadron, N. A., Fisk, L. A., & Gloeckler, G. (1996). *Statistical acceleration of interstellar pick-up ions in co-rotating interaction regions*. Geophysical Research Letters, 23(21), 2871–2874.