Forecasting SEP Events with Solar Radio Bursts

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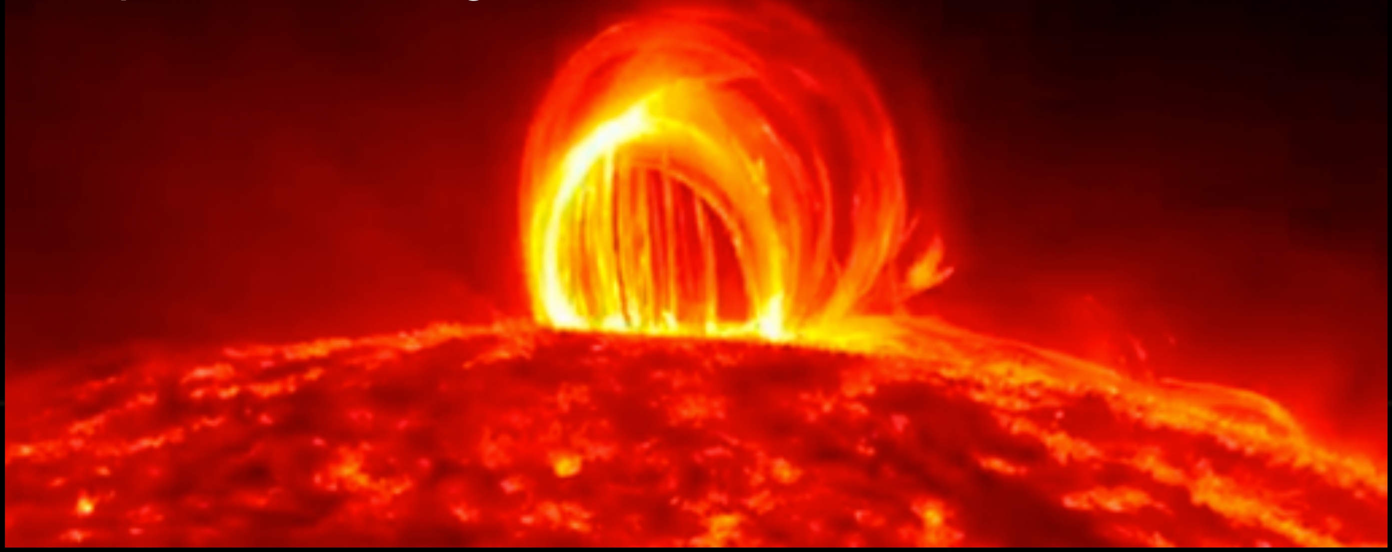
aer

Atmospheric and Environmental Research

- Helps government agencies and companies better anticipate climate and weather related risks
- Agencies include NOAA, NASA, Department of Defense
- Strive to better understand atmospheric, climate, weather, oceanic, and planetary sciences

Solar Energetic Particle (SEP) Events

- Occur when particles associated with solar bursts (like flares or CMEs) are propelled at high energies into space
- Can be substantially harmful to objects in their paths – can penetrate into spacecraft and satellites and cause radiation damage
- If strong enough, SEPs cause aurora and can pose a radiation threat on polar airline flights



TYPE II AND TYPE III RADIO BURSTS AND THEIR CORRELATION WITH SOLAR ENERGETIC PROTON EVENTS

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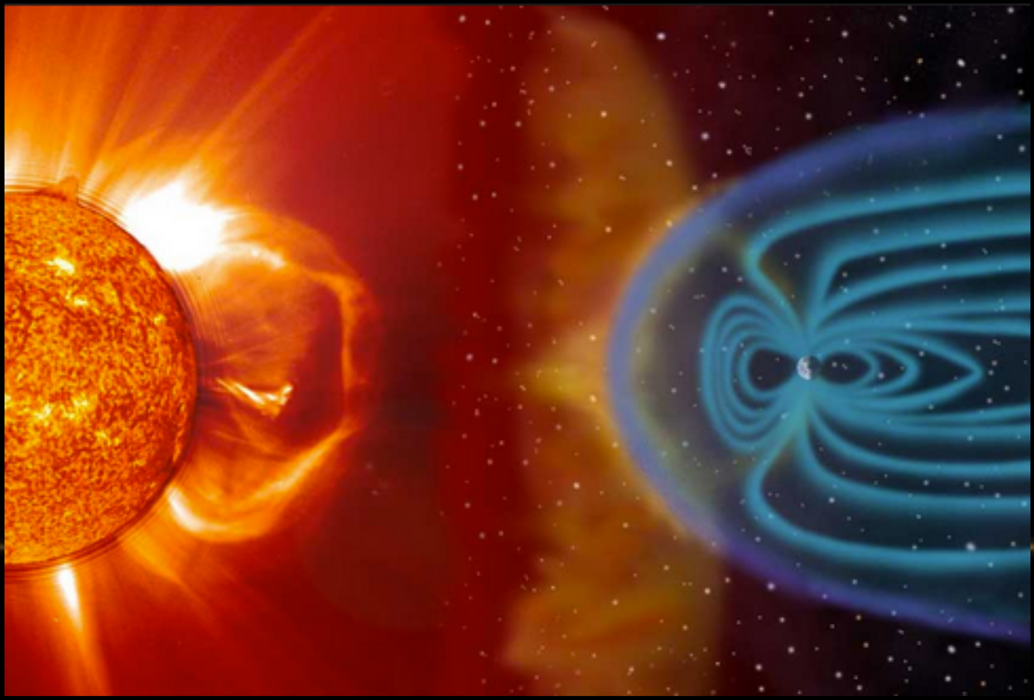
- Previous study (accepted to the Astrophysical Journal) analyzed radio bursts from the Sun (type II and type III), measured from WIND-WAVES
- Measured multiple parameters to see how correlated they were with SEP events
- Goal was to see if these parameters could be used to forecast an SEP event

Type II Bursts

- Indicators of CME's (Coronal Mass Ejections)
- Relatively longer bursts (extreme events can last up to several days)
- In frequency vs time plots, can be identified as horizontal features



Type III Bursts

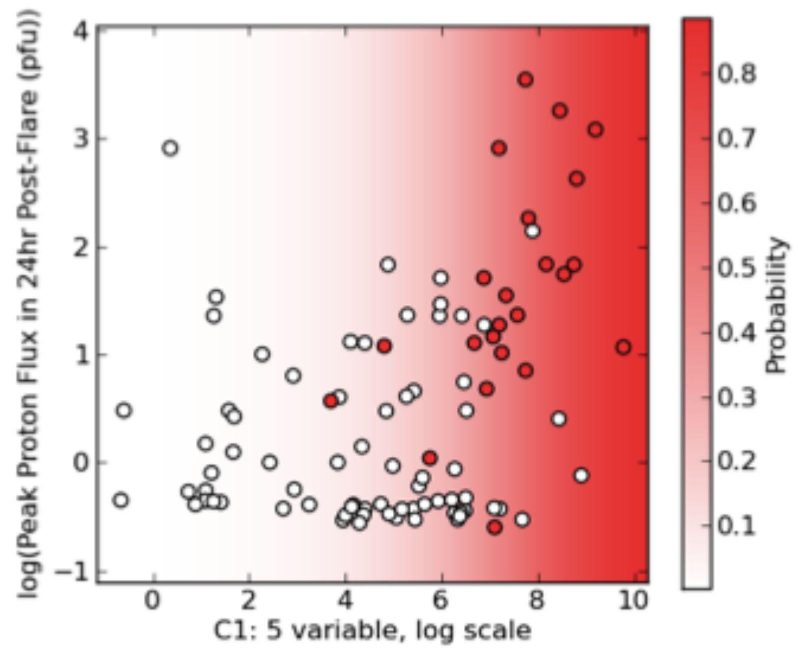
- Indicators of solar flares
- Shorter and faster events
- In frequency vs time plots, can be identified as vertical features

Current Solar Cycle - Cycle 24

- Previous study analyzed data from the current solar cycle
- 2010 – 2013
- Measurements were taken from radio bursts corresponding to 25 SEP events (27 total SEP events in cycle 24)
- Parameters on these bursts measured included:
  - Duration of type III burst
  - Peak of type II intensity
  - Integral of type III intensity
  - Integral of type II intensity
  - Peak Langmuir wave – associated with a large flux of protons

Previous Results

- From the five parameters, a radio index was created from a principal component analysis – gave a different weighting to each parameter
- The radio index itself can indicate the probability of a burst being associated with an SEP event
- May additionally help predict the peak flux of that event



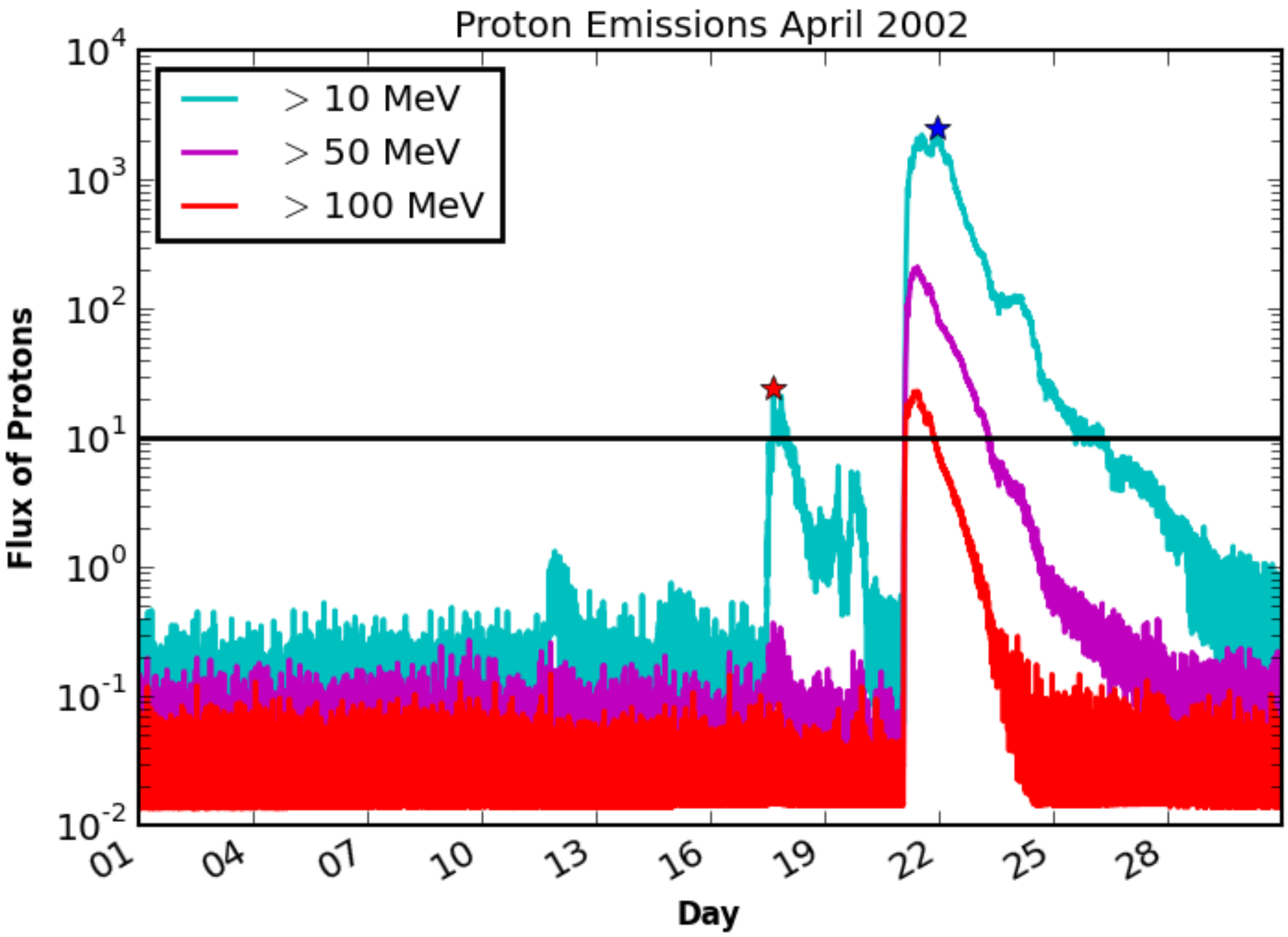
$$C1 = T_{III} \times 0.370 + I_{II\ Peak} \times 0.424 + I_{III\ Integral} \times 0.642 + I_{L\ Peak} \times 0.380 + I_{II\ Integral} \times 0.356.$$

Cycle 23

- Dates for events ranged from 2000-2003
- Much more active cycle – many more SEP events and radio bursts
- 41 bursts associated with SEP events were measured (63 SEP events total)
- Analyzed SEP events with corresponding bursts – but it is possible all bursts were not documented in the Wind/WAVES catalog
- Goal was to analyze these bursts and find the same parameters to see the results on a different (more active) solar cycle

Proton Data from GOES08 and GOES11 –SEP events

- Gathered monthly proton data to find SEP events from 2000 to 2003 and compared my finding to NOAA SWPC's SEP catalog
- SEP event defined by NOAA as having a flux of protons greater than 10 pfu at energies > 10 MeV
- Analyzed the proton data at energy levels > 10MeV, >50MeV, and >100MeV


Proton Emissions April 2002
> 10 MeV
> 50 MeV
> 100 MeV
Flux of Protons
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
01
04
07
10
13
16
19
22
25
28
Day

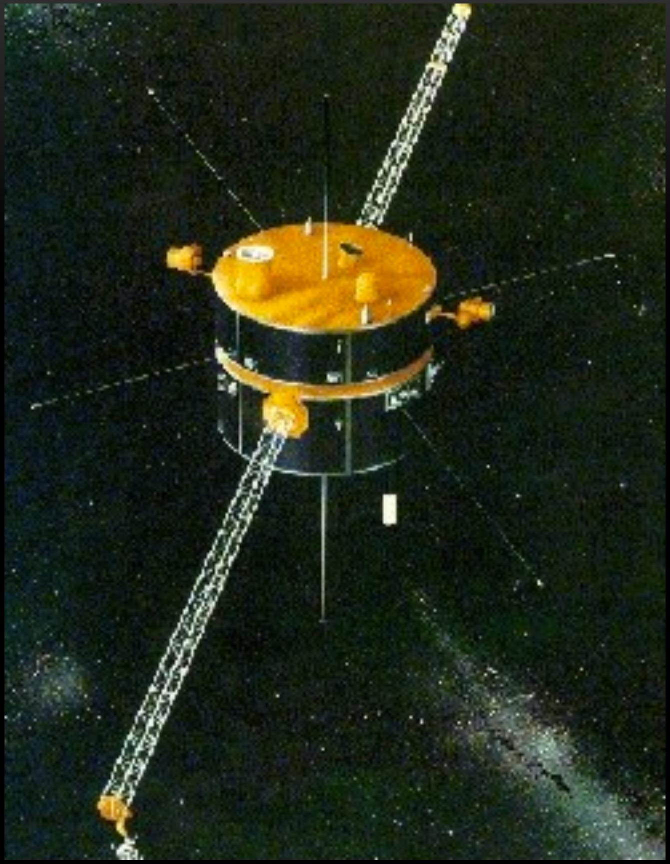
Radio Data – Measuring Solar Bursts

- Radio Data from Wind-Waves
- Radio Receiver Band 1 (RAD1), frequencies measured from 20kHz to 1,040 kHz
- Radio Receiver Band 2 (RAD2), frequencies measured from 1.075 MHz to 13.825 MHz
- Thermal Noise Receiver (TNR), frequencies measured from 4 kHz to 256 kHz
  - Did not have time to measure this data, principal component analysis was recalculated without this data

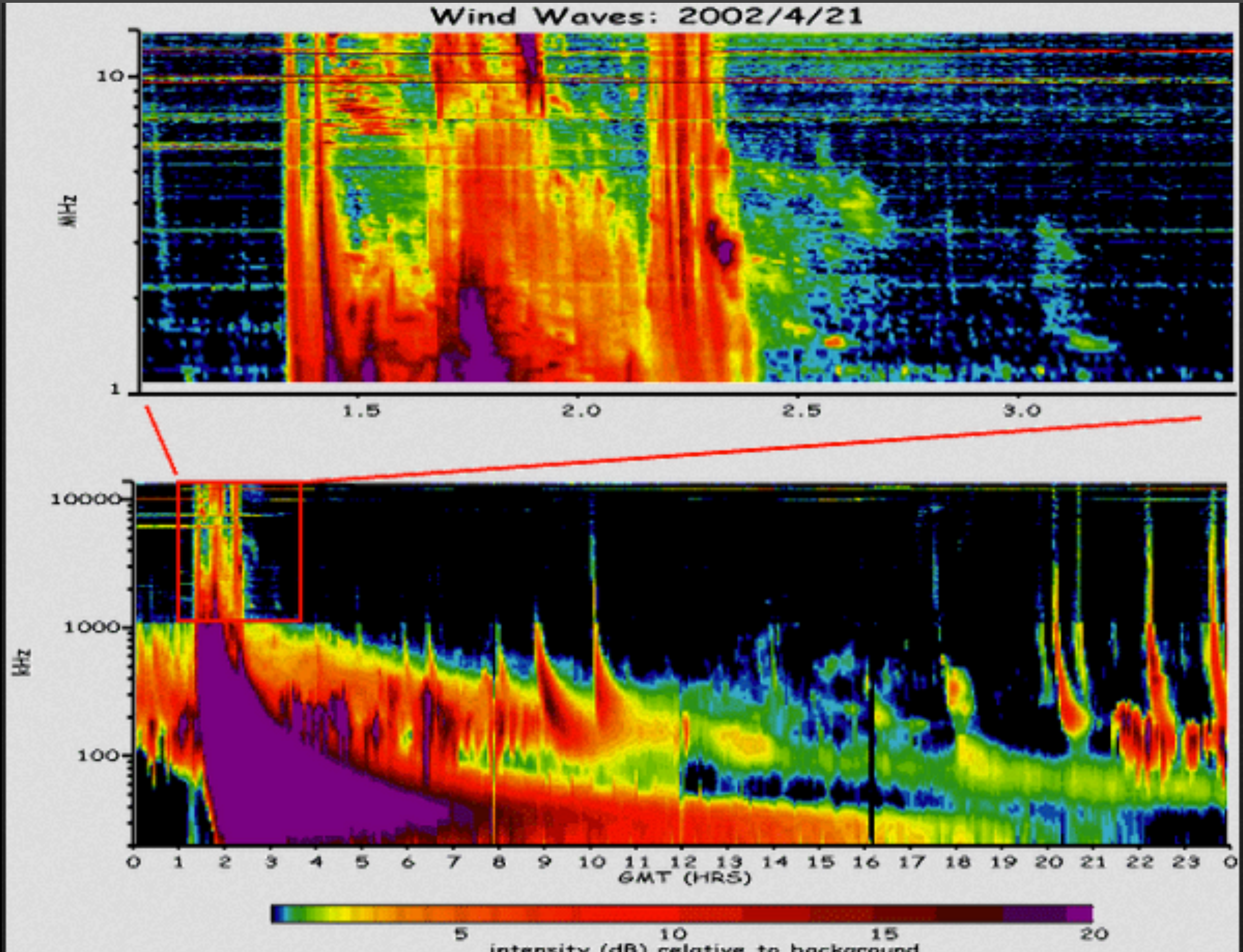
$$C1 = 0.16457 * T\_III + 0.1350 * I\_II\ Peak + 0.9686 * I\_III\ Integral + 0.1283 * I\_II\ Integral$$

Radio Data – Cleaning

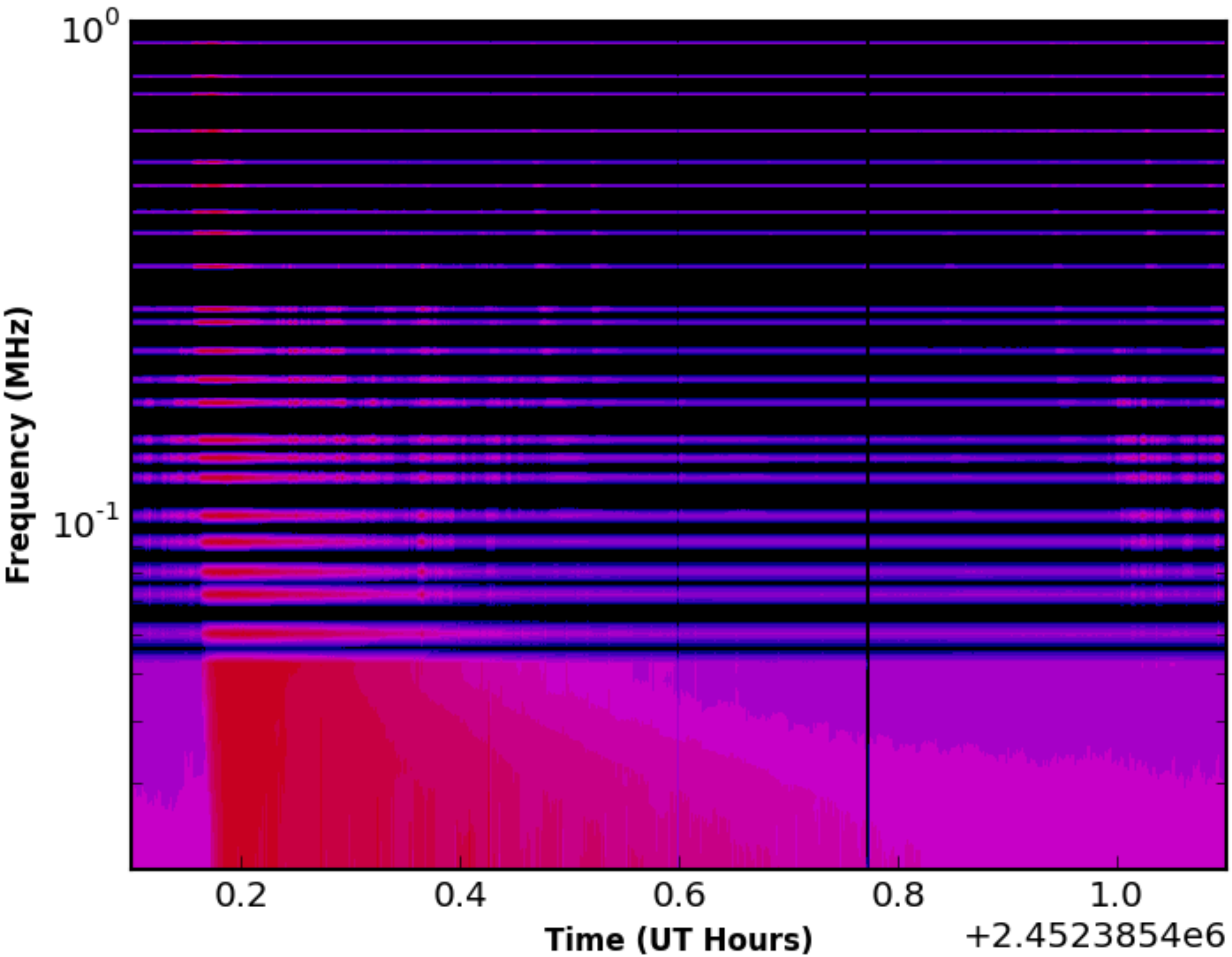
- Lots of gaps in original data where the measurements were not taken
- Important to have clear structures for analysis
- Created code to do a linear interpolation on data to clean up gaps (not done on previous study)



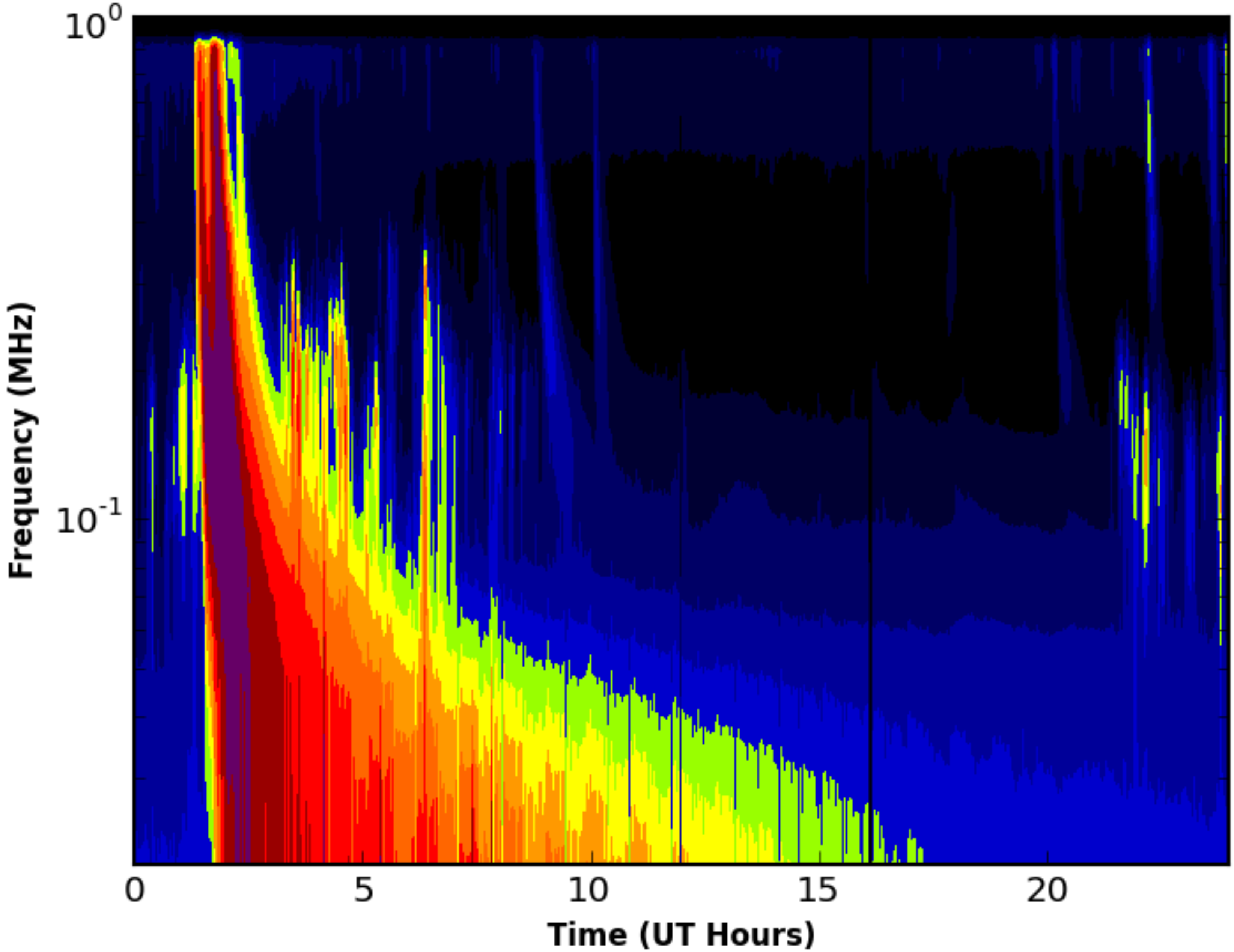
WIND



Wind Waves: 2002/4/21
MHz
10
1
1.5
2.0
2.5
3.0
kHz
10000
1000
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 0
GMT (HRS)
5
10
15
20
intensity (dB) relative to background

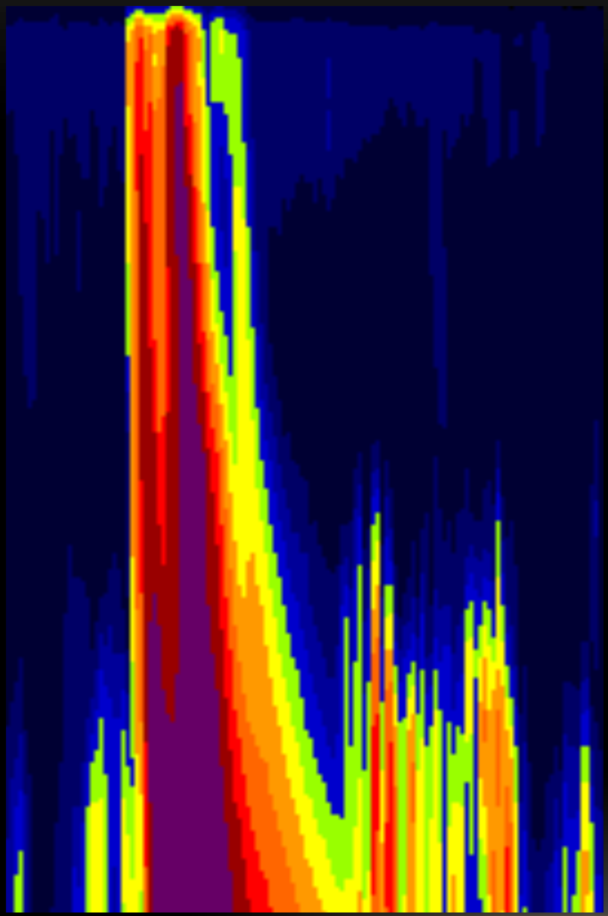


10^0
10^{-1}
Frequency (MHz)
0.2
0.4
0.6
0.8
1.0
Time (UT Hours)
+2.4523854e6



10^0
10^{-1}
Frequency (MHz)
0
5
10
15
20
Time (UT Hours)

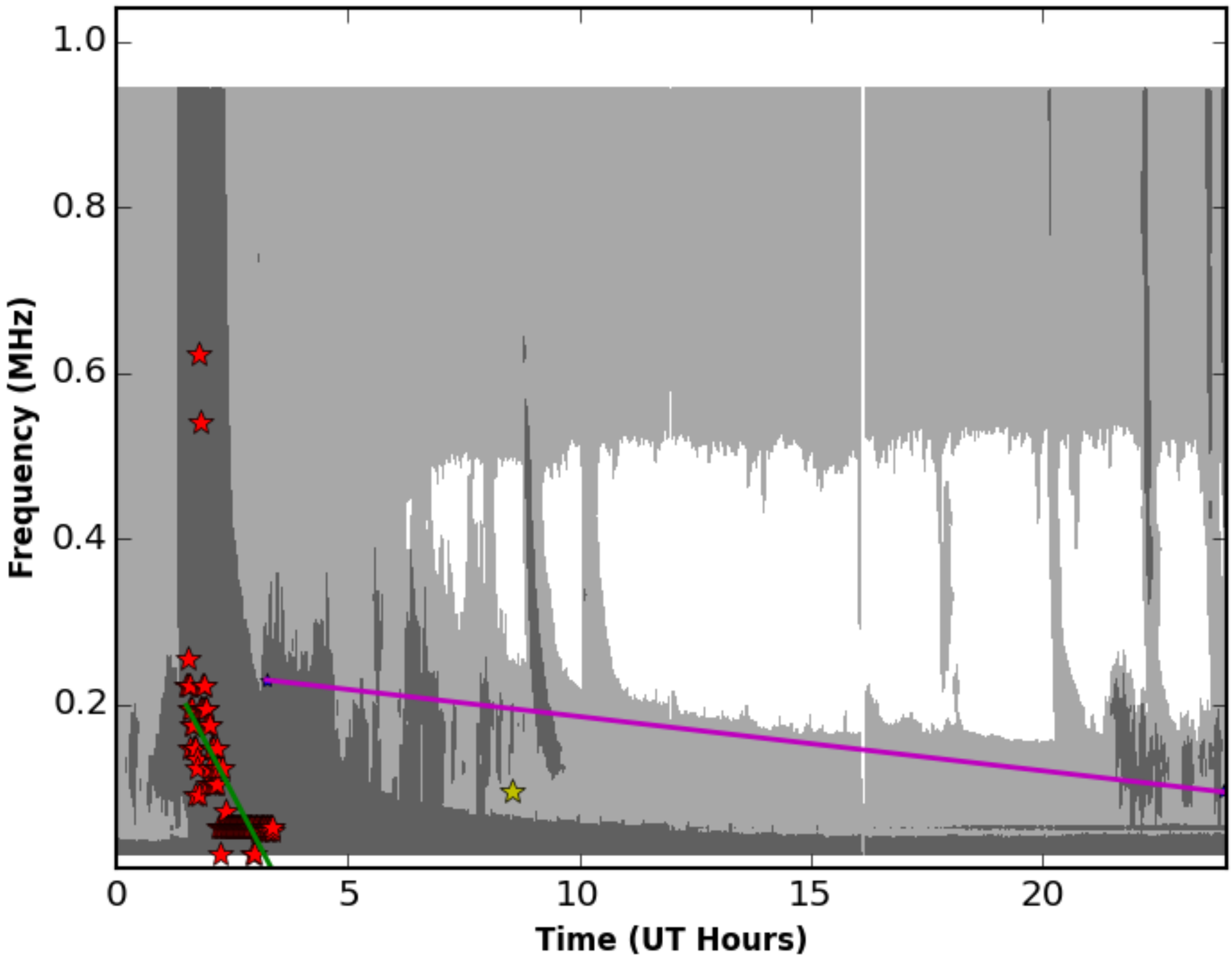
Measuring Parameters



- Duration of type III Burst – measured the extent of the burst until it dropped below 4 times the background flux levels
- Measured through time at close to 1 MHz (near end of RAD1 data and beginning of RAD2 data)

Measuring Parameters – Integral Type II and III Bursts and Type II Peak

- Converted color scale to black and white to easily see the bursts
- For type three – first found peak in the burst and all the local maxima around it (stepping by time) until the flux dropped by 15% of the original peak
- Fit a line to these points and integrated all the fluxes along this line
- For type II – visually inspected and used Wind/WAVES website to identify burst
- Drew a line along the burst and integrated across – if given more time would use a similar approach as type III
- Found peak along this line for type II



1.0
0.8
0.6
0.4
0.2
Frequency (MHz)
0
5
10
15
20
Time (UT Hours)

Results – Proton Data Average Fluxes (pfu)

Cycle 23 – All SEP events	Cycle 23 – SEP events with type II burst	Cycle 23 – SEP events without type II bursts	Cycle 24 – All SEP events
2246.10	2674.68	2460.31	823.77

- Much higher >10 MeV fluxes in cycle 23
- Interesting that the averages for events with and without type II bursts are similar – it is possible that there were bursts but not cataloged
- Future work would include going through and measuring these bursts

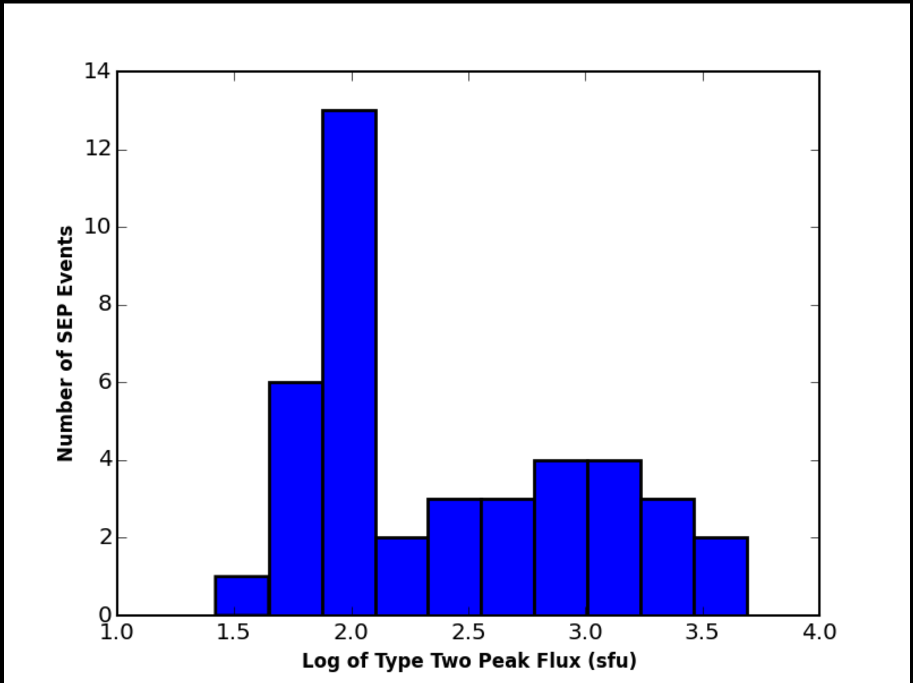
Radio Parameters – Type II Peak

	Cycle 23	Cycle 24
Log of Average (sfu)	2.42	--
Log of Median (sfu)	2.11	2.949
Log of Standard Deviation (sfu)	0.59	4.85

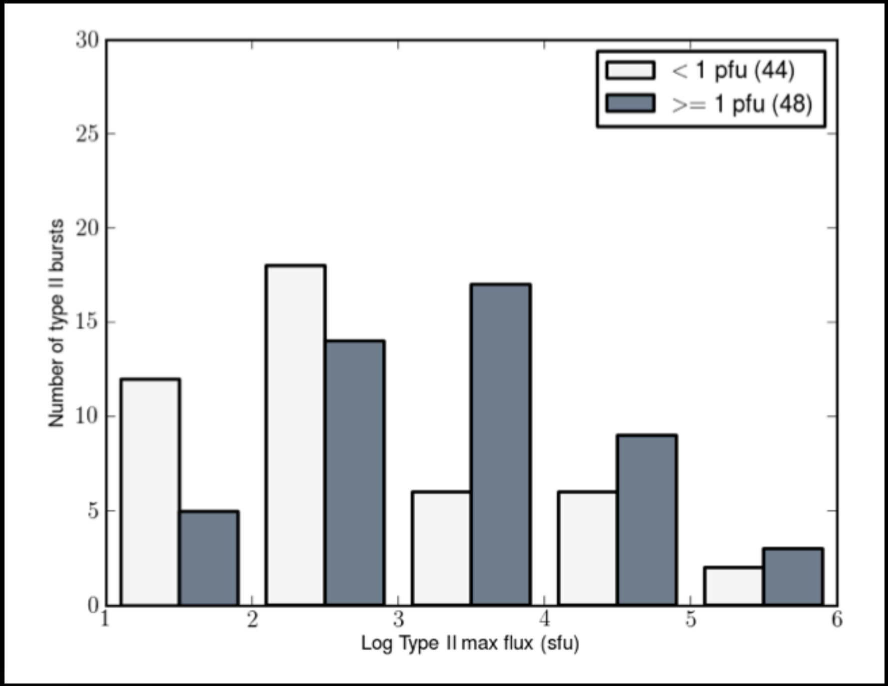
- Interesting that cycle 23 had significantly lower peak values
- Could be due to measurements made by visual inspection instead of previous study's technique

Radio Parameters – Type II Peak

Cycle 23



Cycle 24



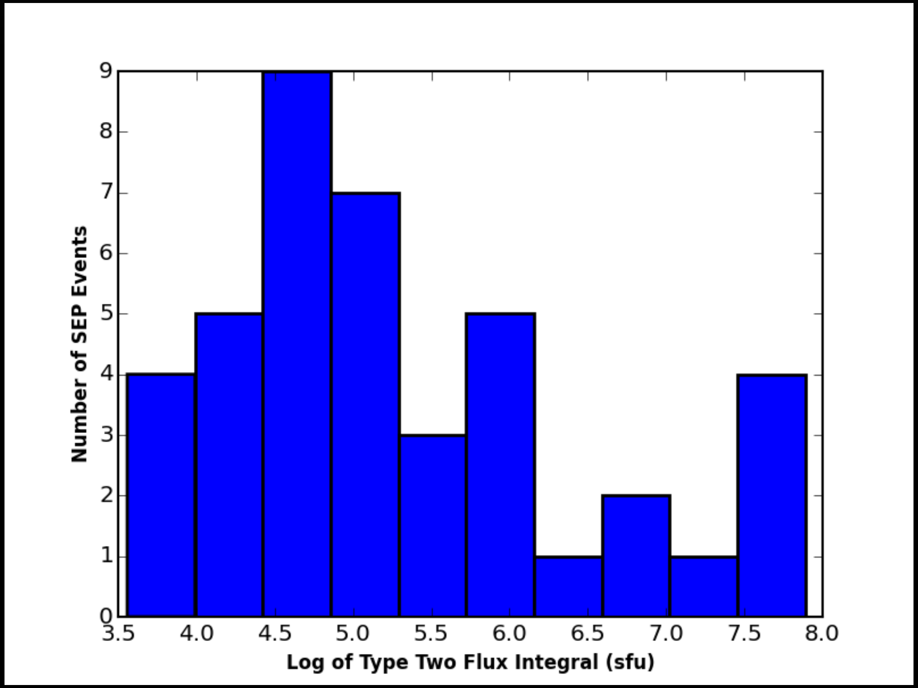
Radio Parameters – Type II Integral

	Cycle 23	Cycle 24
Log of Average (sfu)	5.33	--
Median (sfu)	5.08	3.57
Log of Standard Deviation (sfu)	1.13	4.84

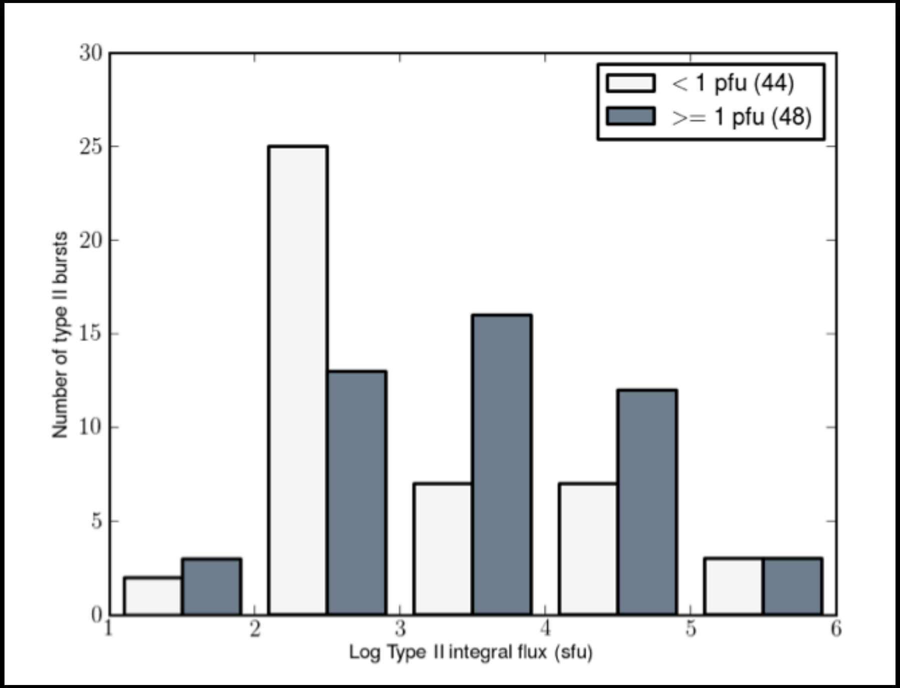
- Much higher type II integral values from cycle 23

Radio Parameters – Type II Integral

Cycle 23



Cycle 24

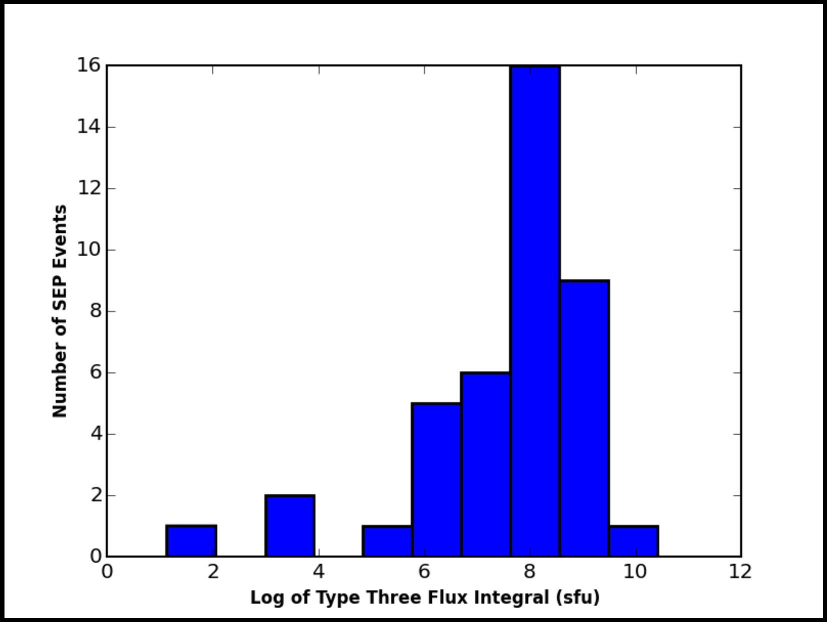


Radio Parameters – Type III Integral

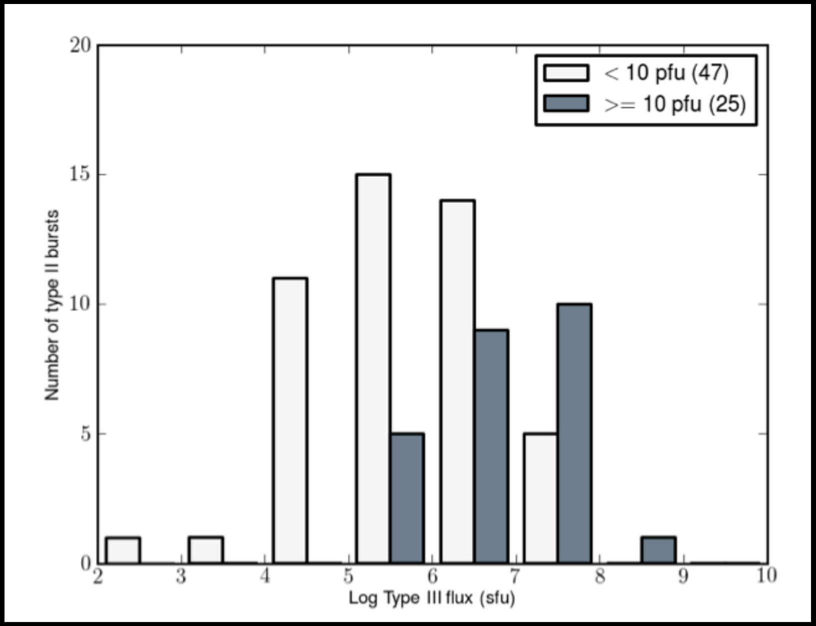
	Cycle 24
Log of Average (sfu)	7.53
Log of Median (sfu)	8.00
Log of Standard Deviation (sfu)	1.76

Radio Parameters – Type III Integral

Cycle 23



Cycle 24



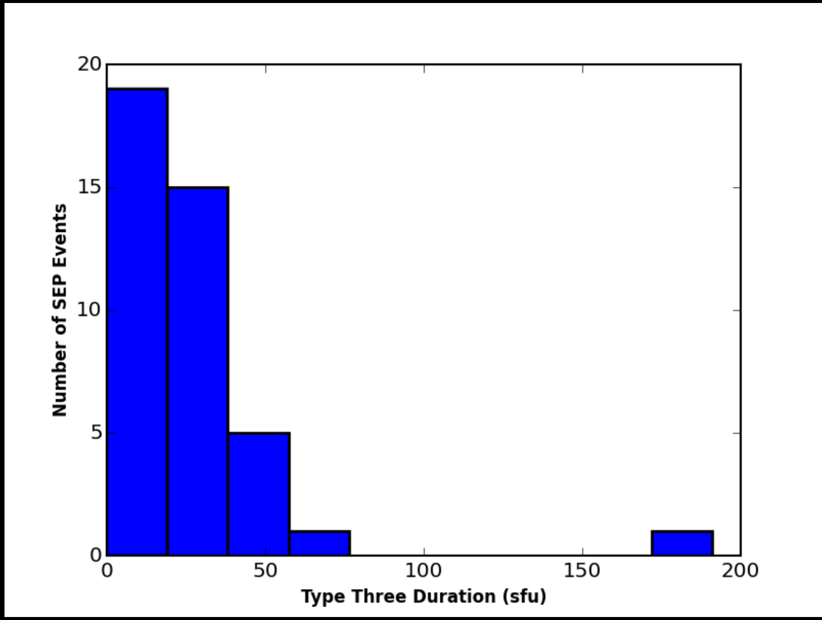
Radio Parameters – Type III Duration

	Cycle 23	Cycle 24
Average (min)	26.08	--
Median (min)	22.00	13.00
Standard Deviation (min)	29.71	11.8

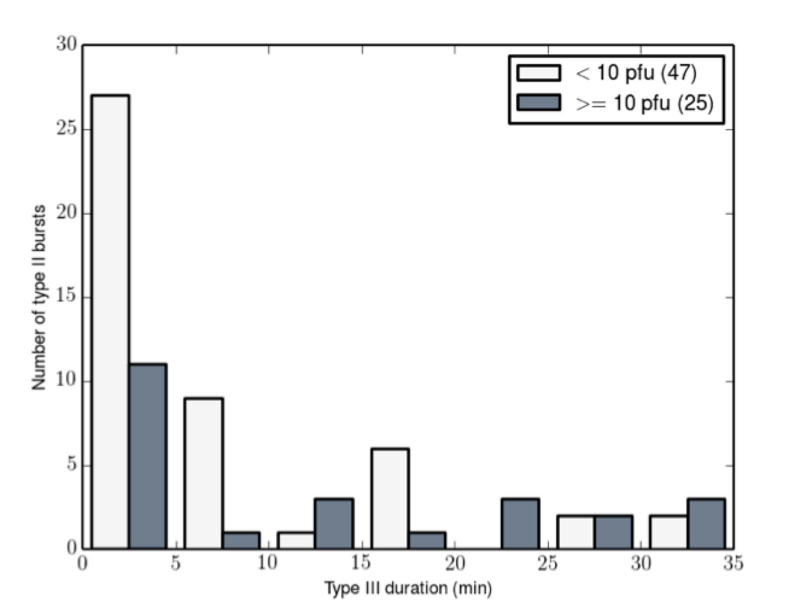
- Overall, in a more active solar cycle we see longer durations and brighter bursts

Radio Parameters – Type III Duration

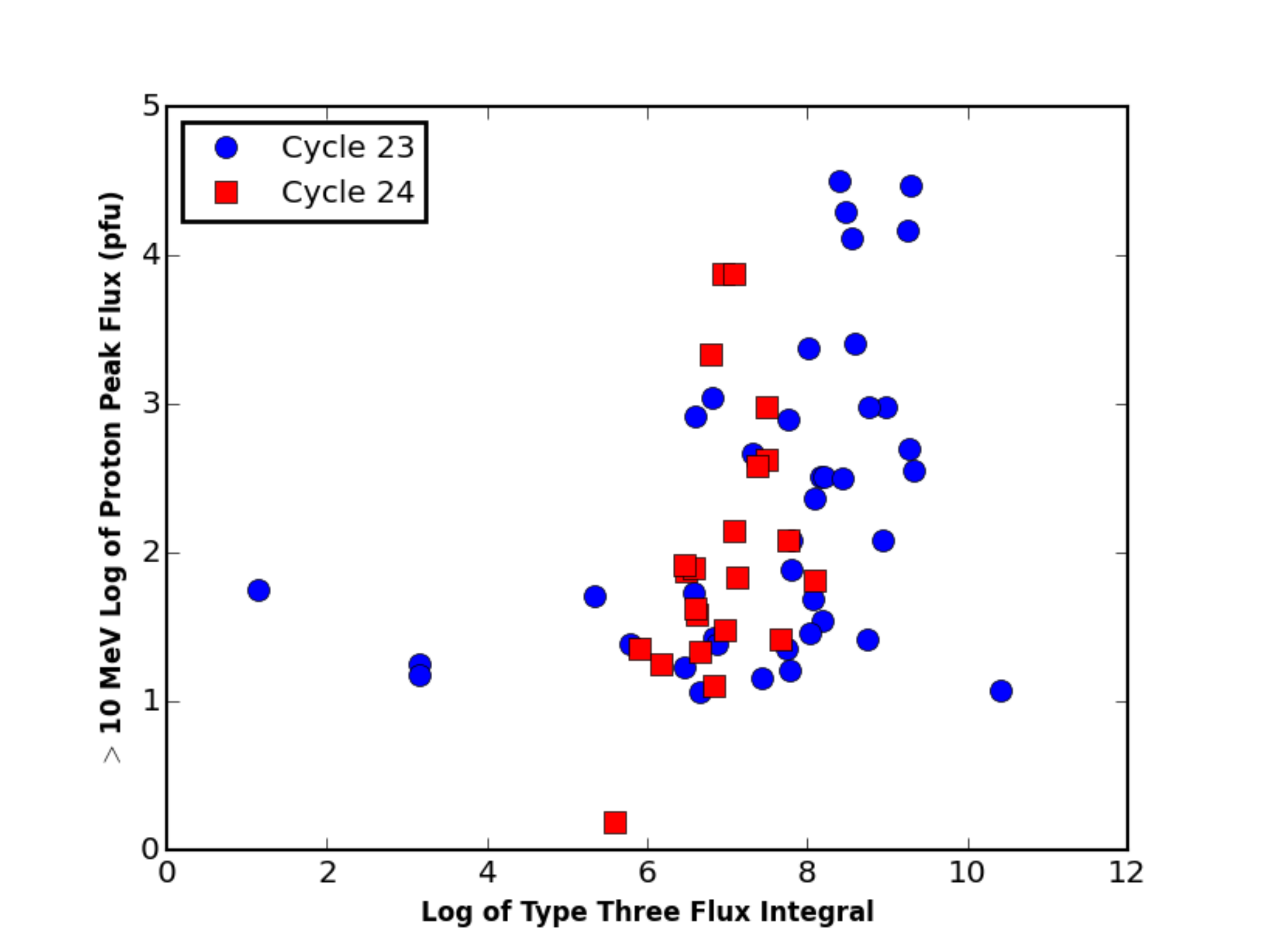
Cycle 23



Cycle 24



Results – Proton and Radio Data



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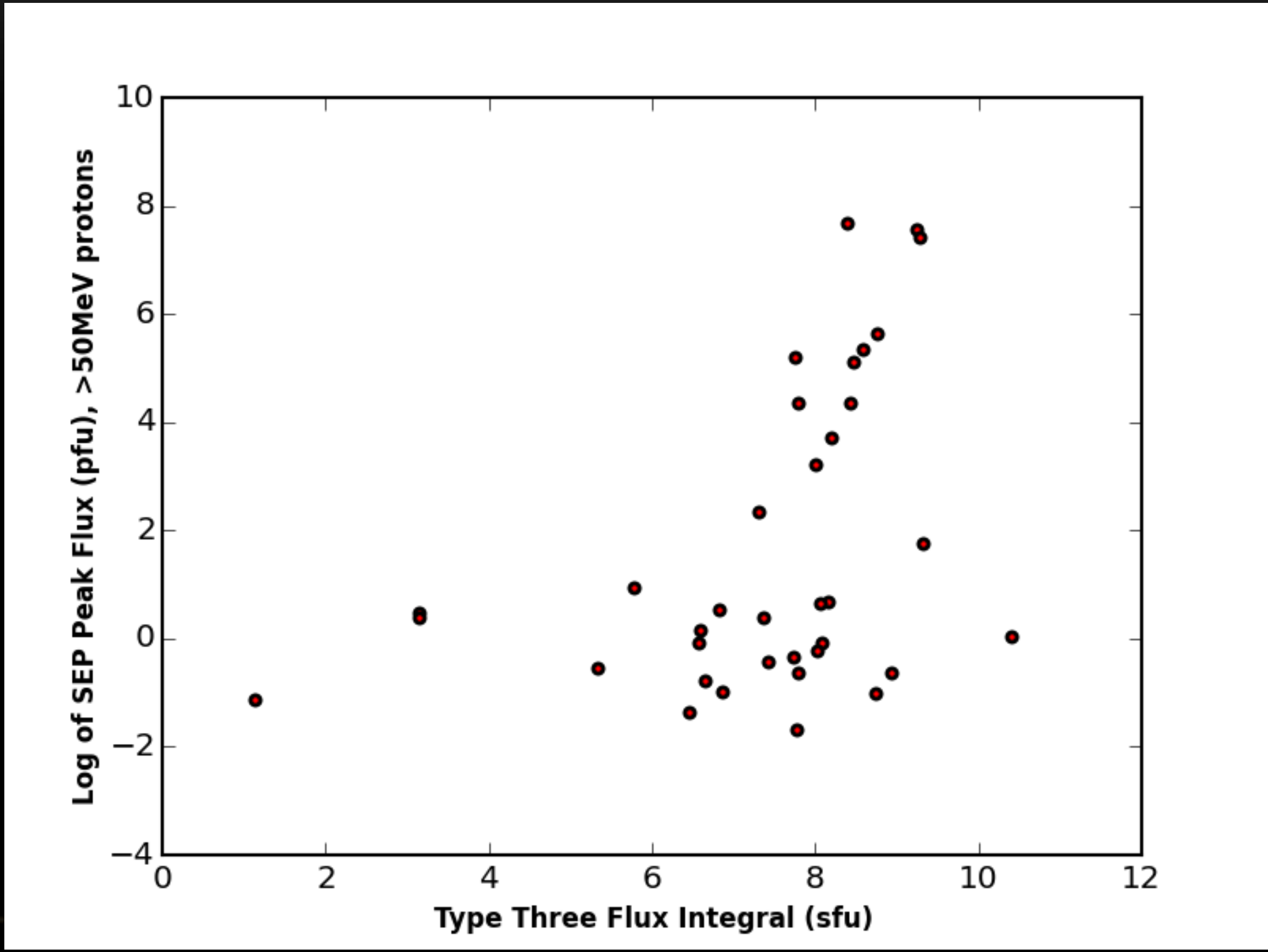

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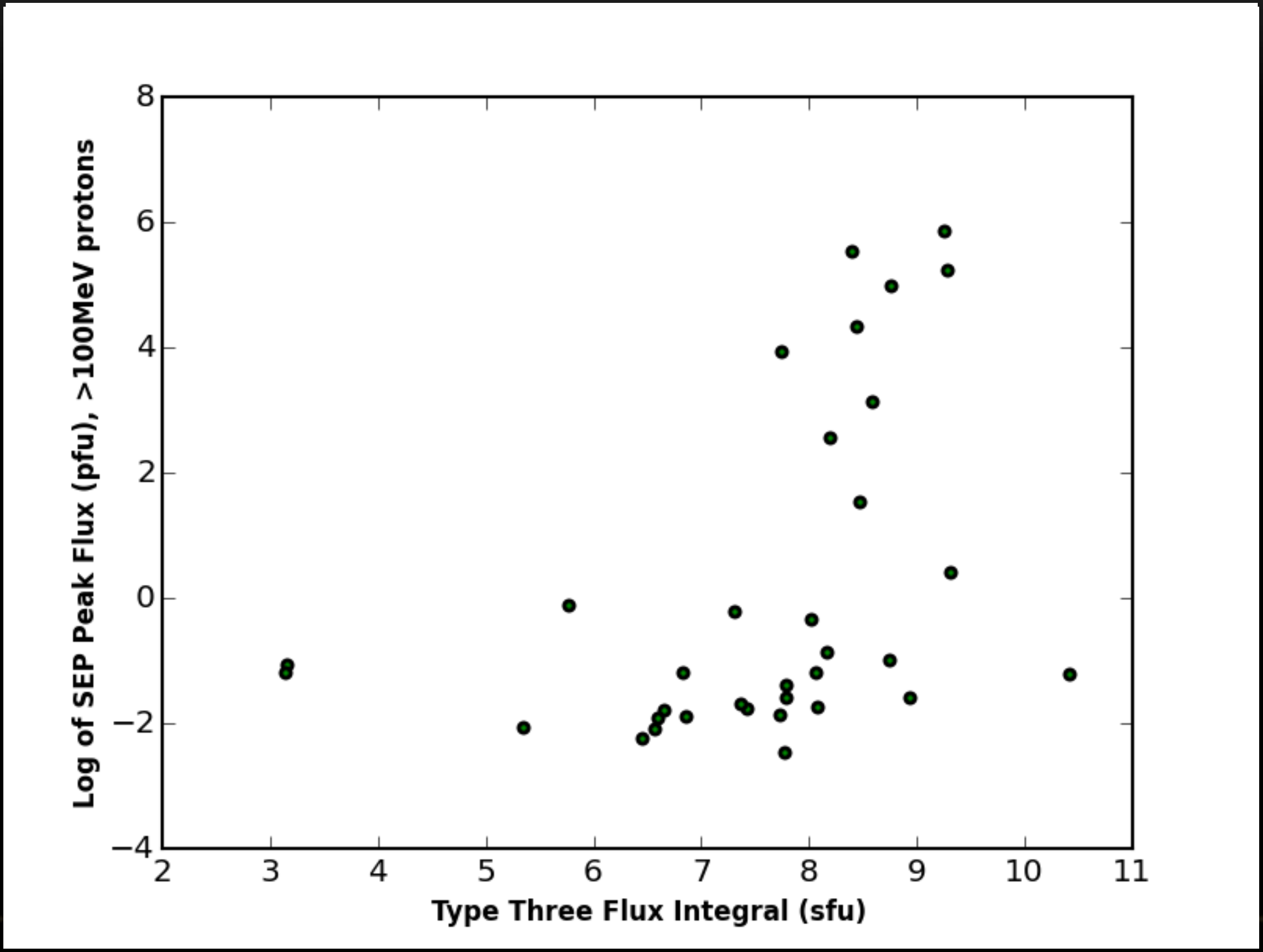
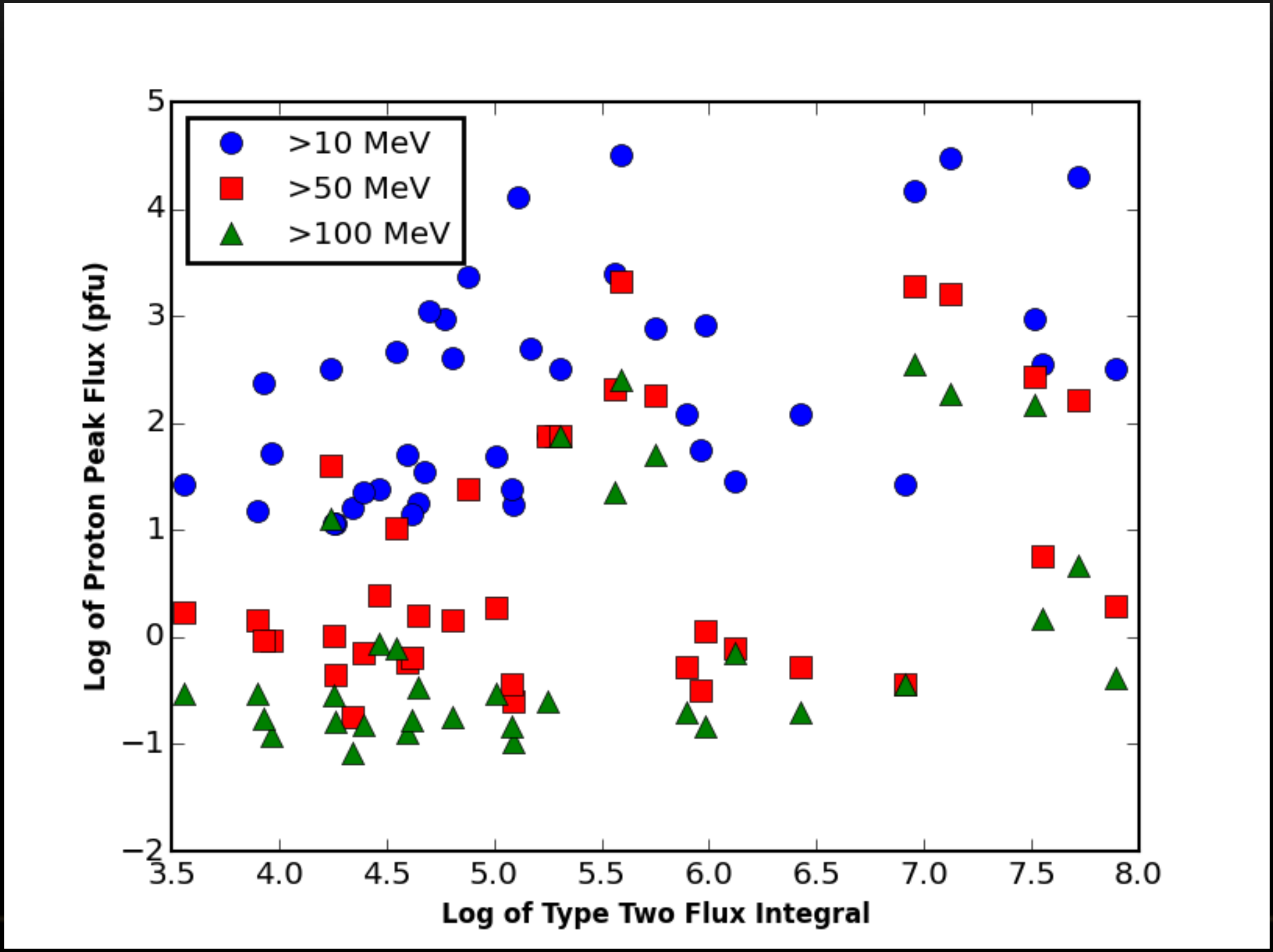
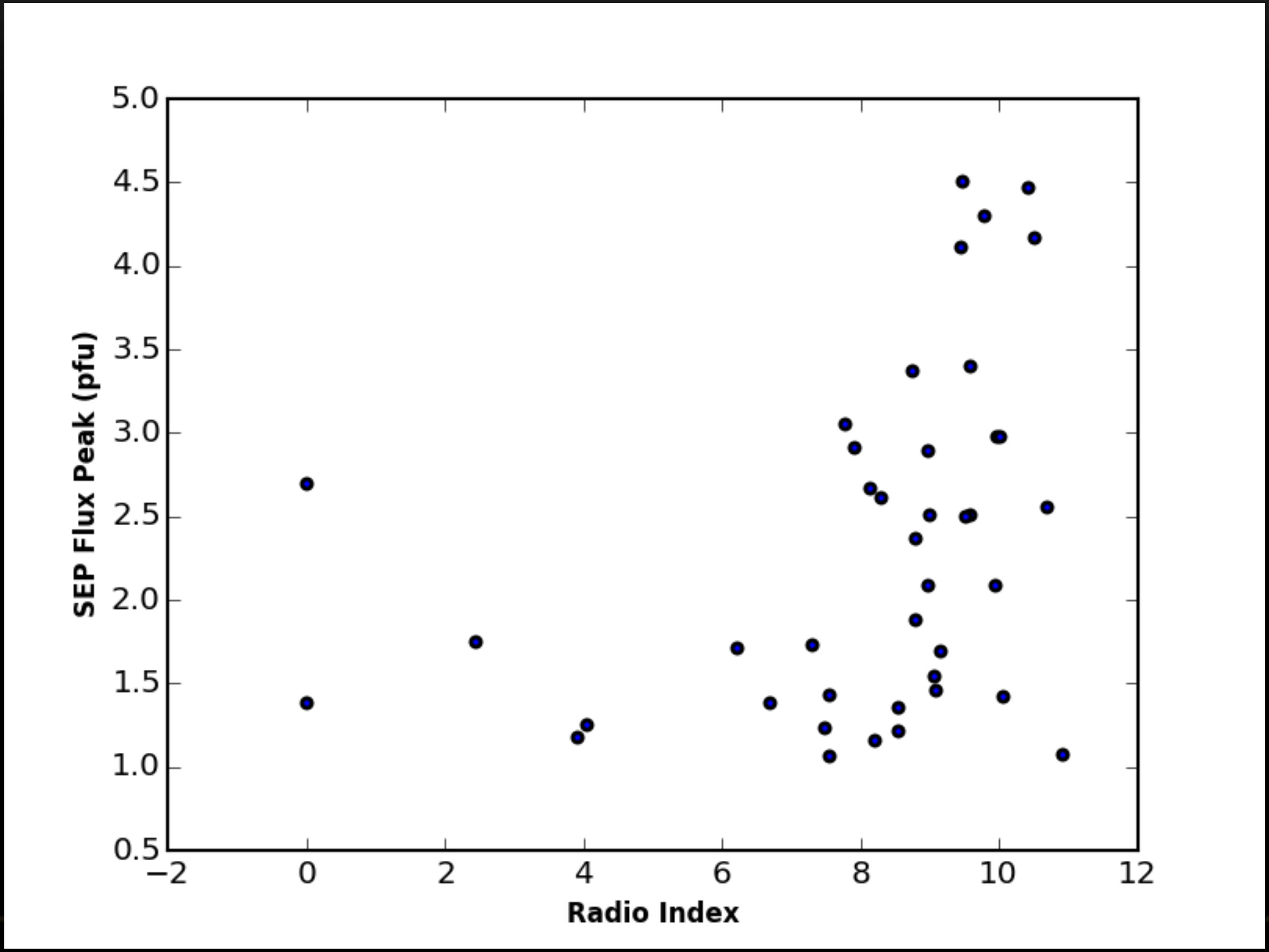


Results – Proton and Radio Data



Radio Index – What we've been waiting for!



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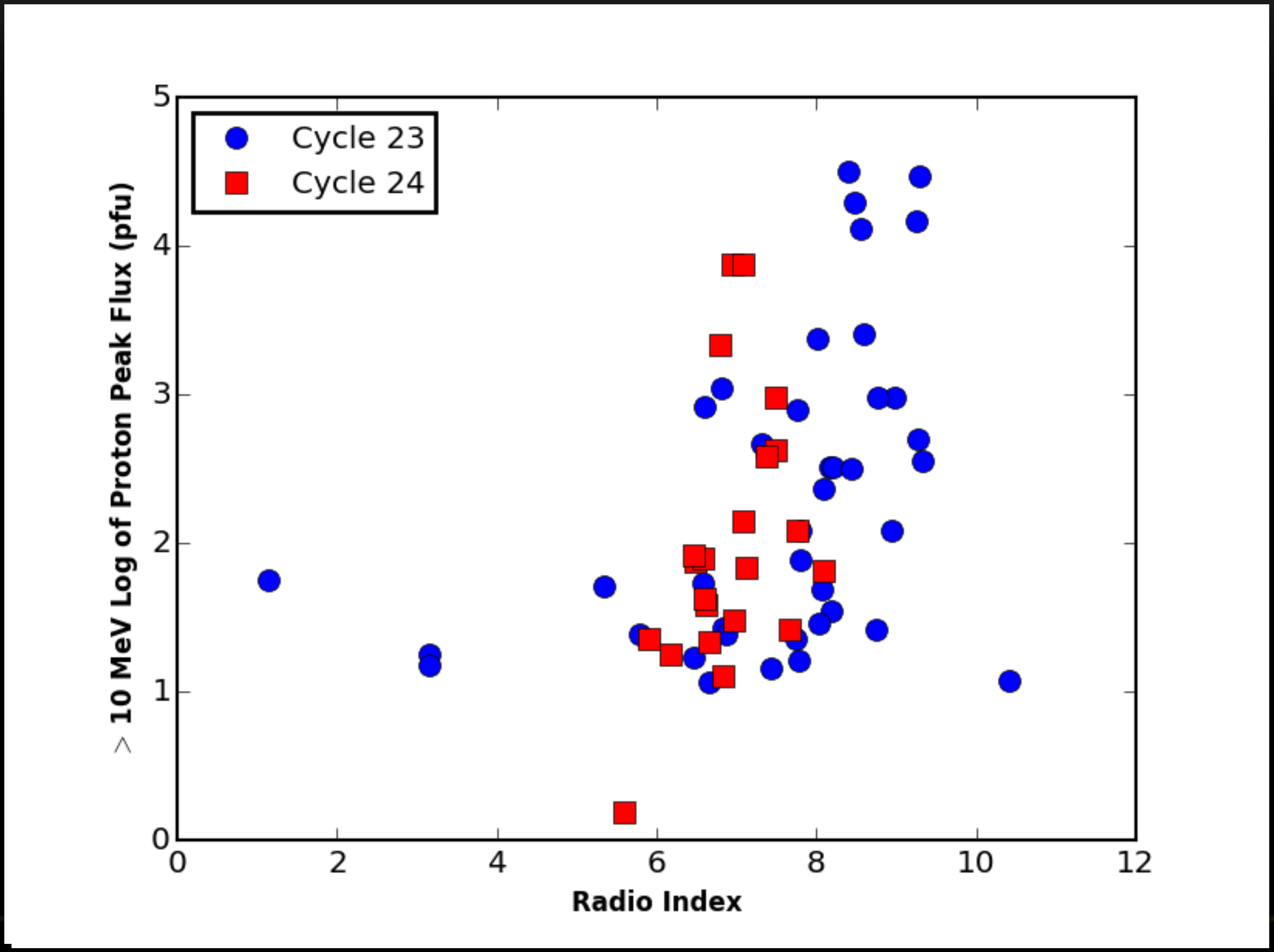

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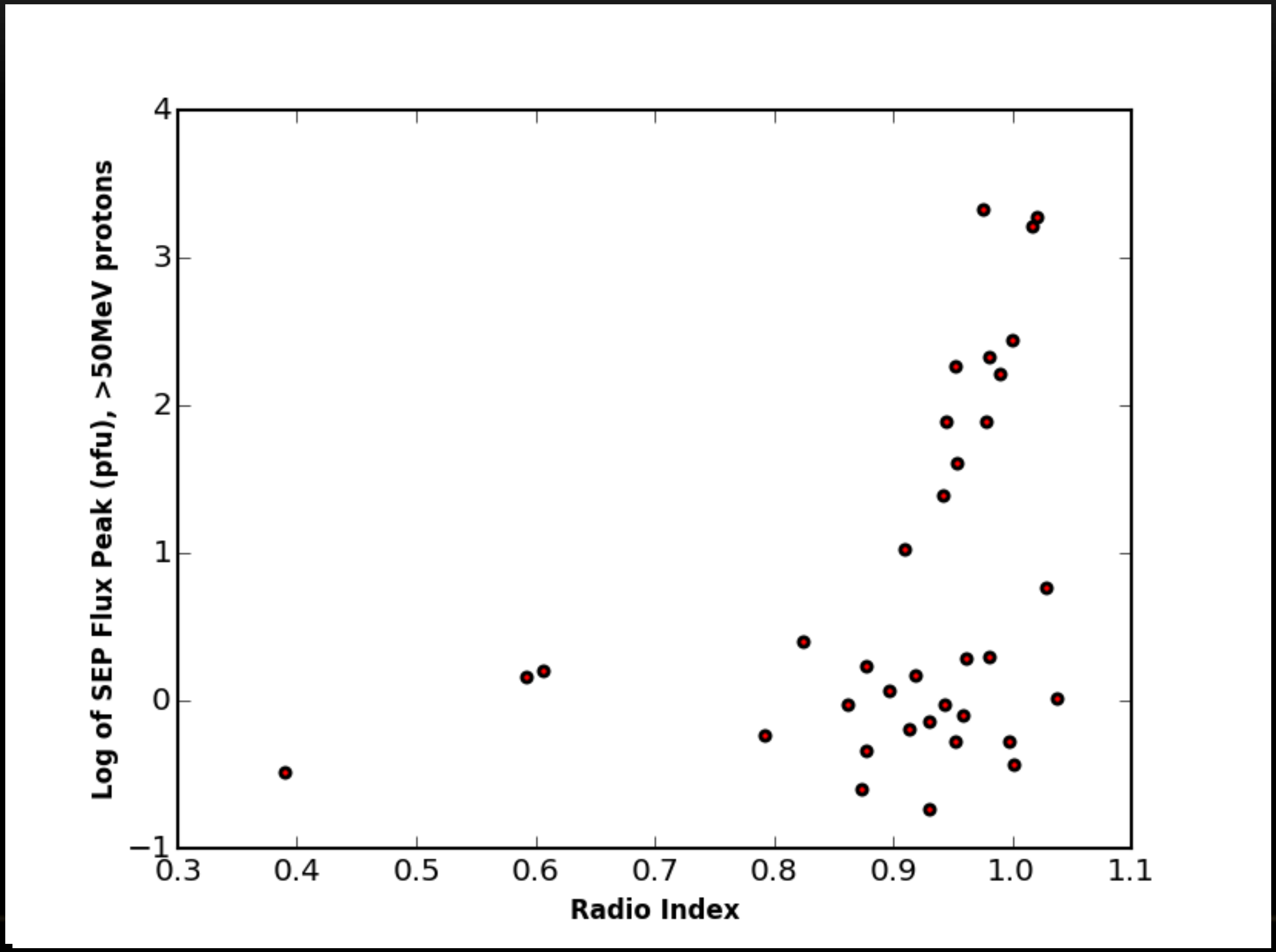

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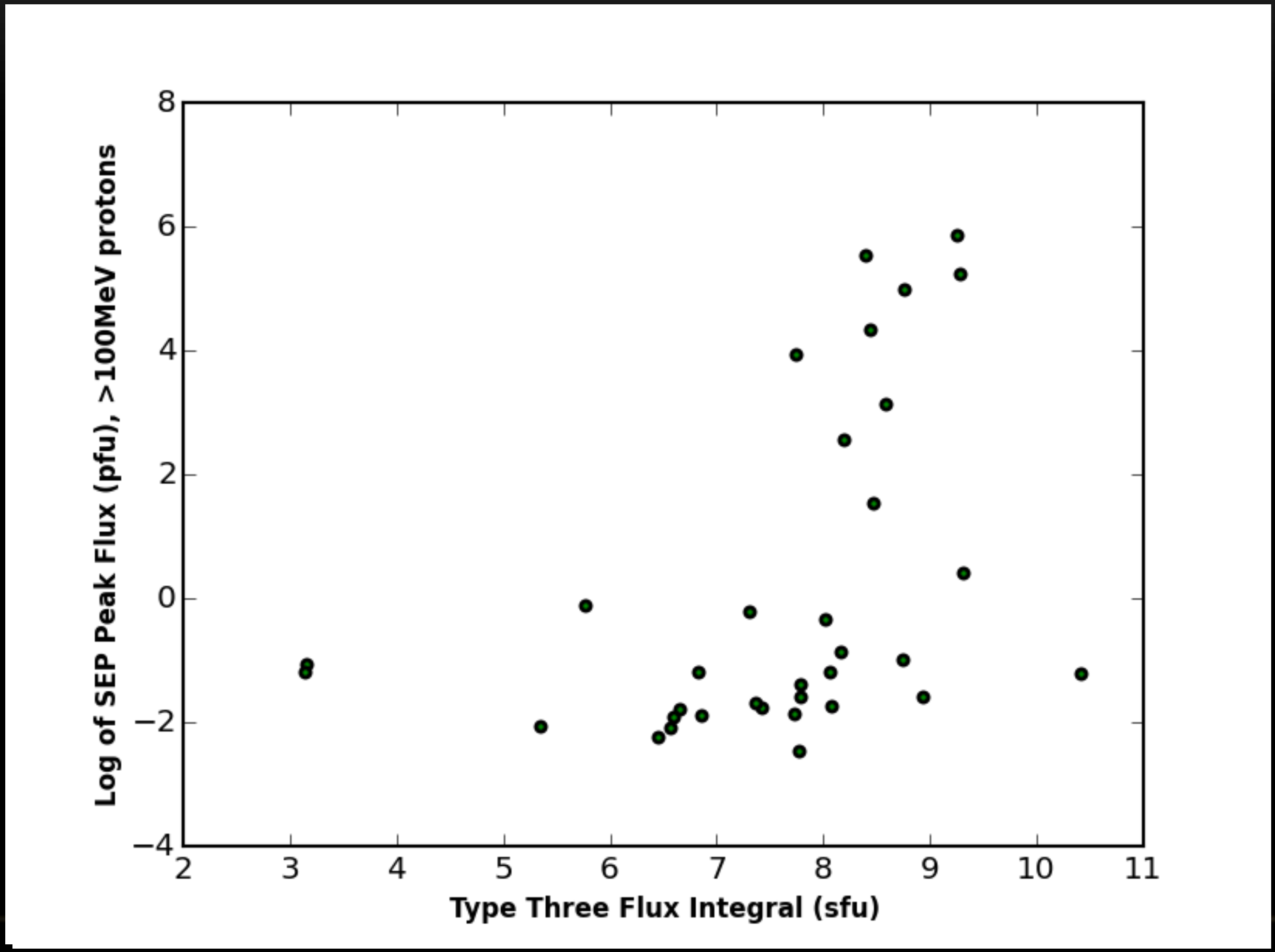

Conclusions

- Questions at the beginning of the study:
  - How does a more active solar cycle differ in terms of proton and radio emissions from a less active solar cycle?
  - Can we use the analysis found in a previous study to forecast a different and more active solar cycle?
- Conclusions we can draw
  - Along with more SEP events and solar bursts, we see greater proton fluxes, and longer and brighter bursts
  - the higher the radio index the higher the peak proton flux will be following the burst
  - The radio index successfully predicts the occurrence of SEPs for the events in the more active solar cycle 23 (YAY!)

Questions?