Benchmarks for Extreme Space Weather Events Part 2 A Demonstration Case

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Things To Consider

* integral flux or differential flux?
* what energies?
* what orbits?
* what time resolution? (daily averages < peak 5 min fluxes)
* how many benchmarks and how complicated?
* demonstration (use) cases would be useful and could provide a target for operationally-predictable scales
* benchmarks must be consistent as well as accurate

Phase I Benchmarks Need To Be Reviewed for Consistency: E.G. Parameters & Values

Statistical Maxima

Electron Radiation Belt Flux		
Location	Energy	Differential Flux (cm^{-2} s^{-1} $sr^{-1}MeV^{-1}$)
GEO (LANL)	2.65 MeV	5.9 [4.7, 7.3] × 10^4
	625 keV	4.1 [3.2, 5.2] × 10^6
	270 keV	2.0 [1.5, 2.6] × 10^7
INTEGRAL/IREM at L*=6.0	1.82 MeV	1.98 x 10^5
	1.27 MeV	8.11 x 10^5
	690 keV	4.82 x 10^6
INTEGRAL/IREM at L*=4.5	2.05 MeV	6.08 x 10^5
	1.82 MeV	8.10 x 10^5
	1.27 MeV	4.74 x 10^6
	690 keV	1.51 x 10^7

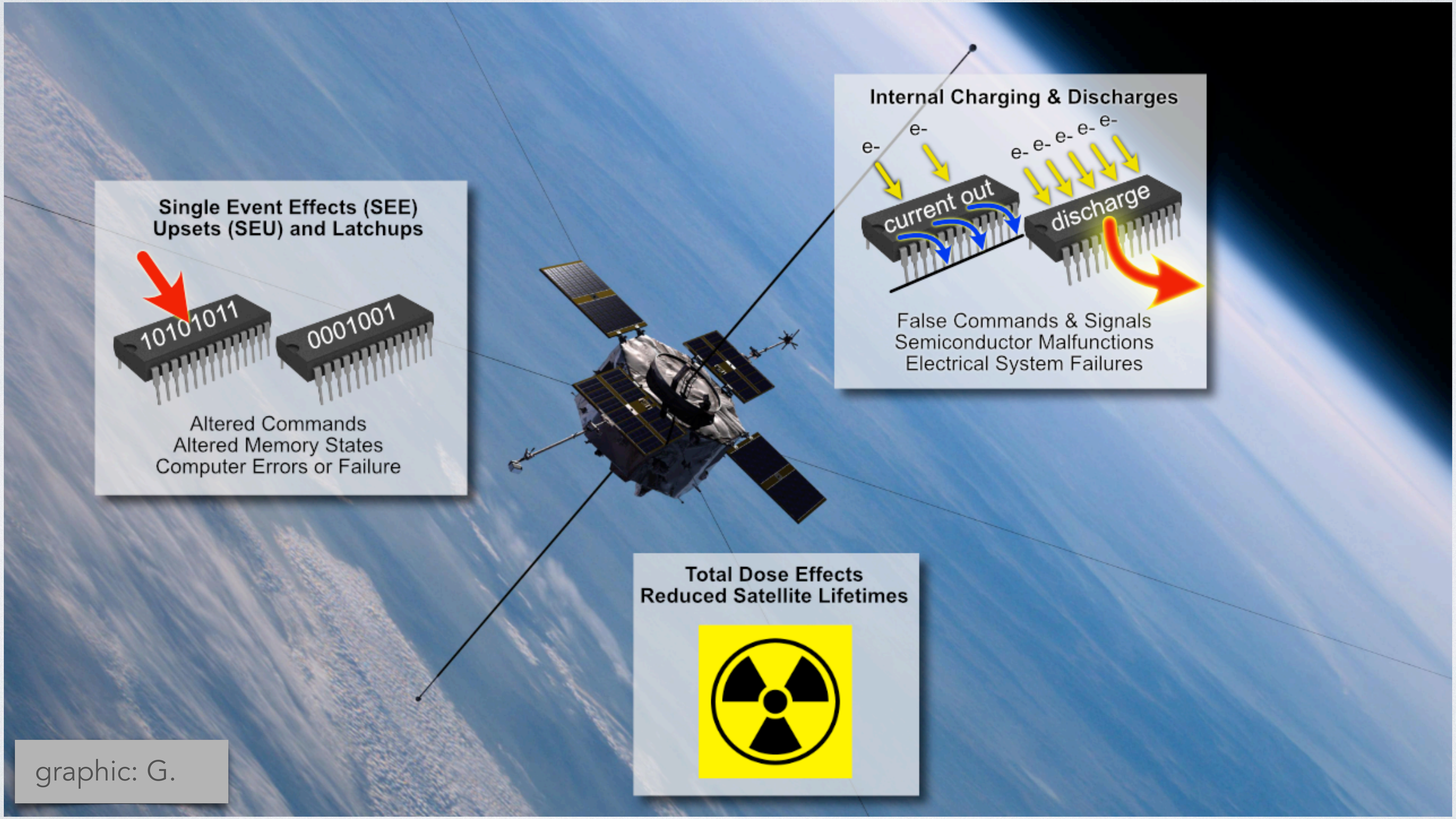
1-in-100 Year

Electron Radiation Belt Flux		
Location	Energy	Differential Flux (cm^{-2} s^{-1} $sr^{-1}MeV^{-1}$)
INTEGRAL/IREM at L*=6.0	2.05 MeV	1.58 × 10^5
	1.82 MeV	1.76 × 10^5
	1.27 MeV	5.99 × 10^5
	690 keV	4.68 × 10^6
INTEGRAL/IREM at L*=4.5	2.05 MeV	5.79 × 10^5
	1.82 MeV	7.29 × 10^5
	1.27 MeV	2.52 × 10^6
	690 keV	1.46 × 10^7

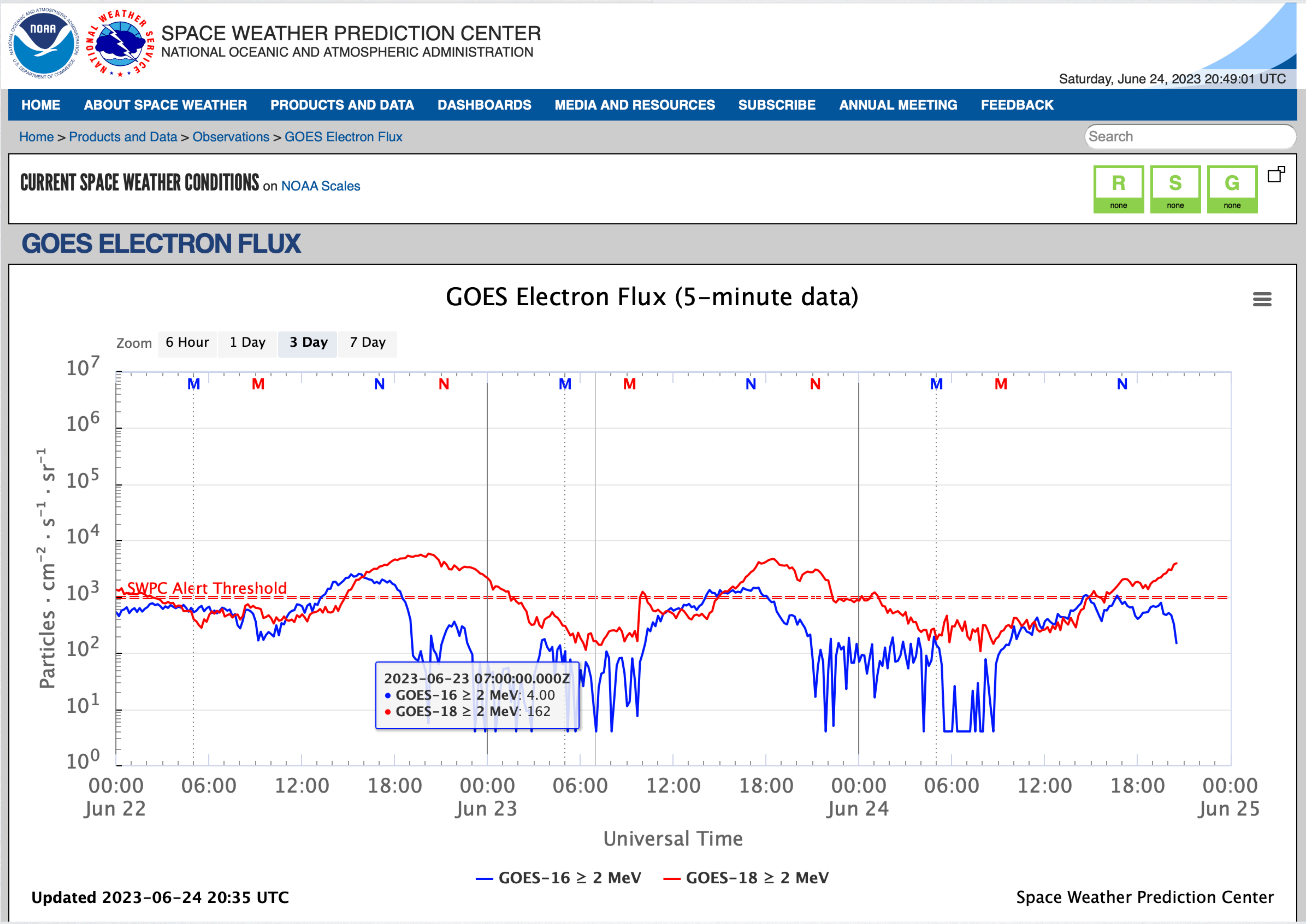
Maximum and Extreme values cite different energies

Some Theoretical Maximum values are less than the 1-in-100 year values

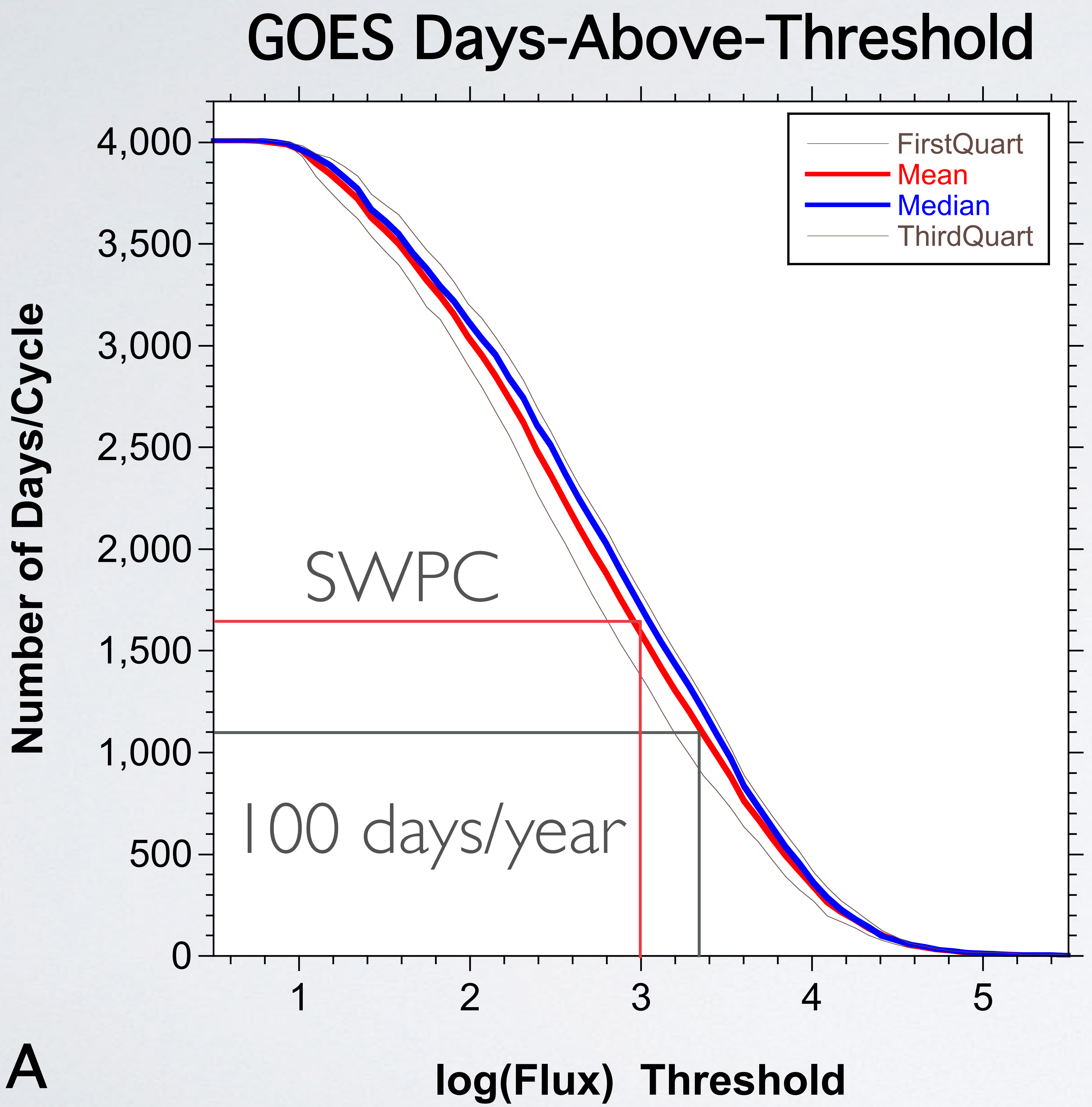
A Deeper Dive Into
Radiation Belt Electron Benchmarks & Scales

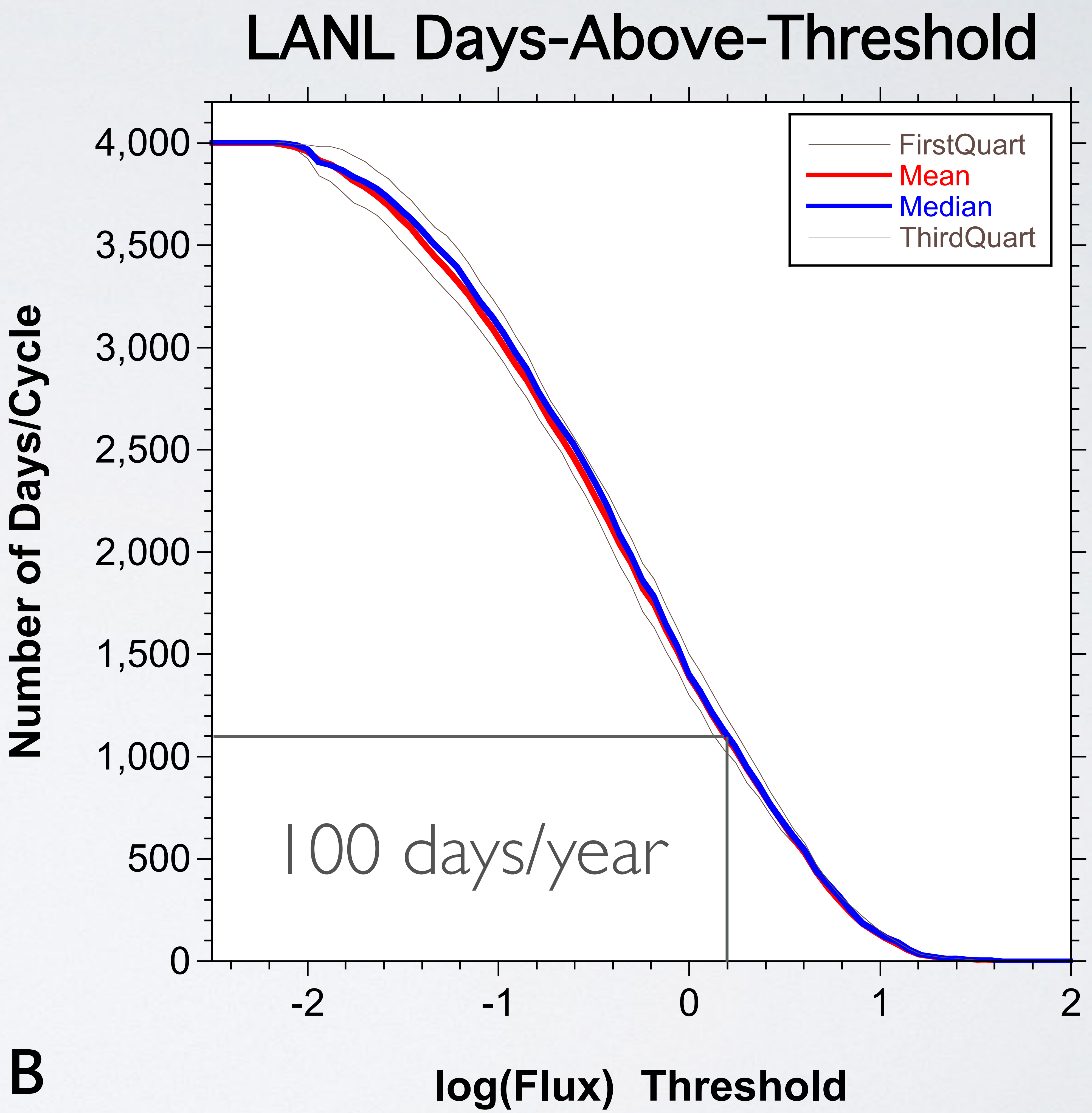


SWPC Warning = 1,000 $(Cm^2\text{-}S\text{-}Sr)^{-1}$



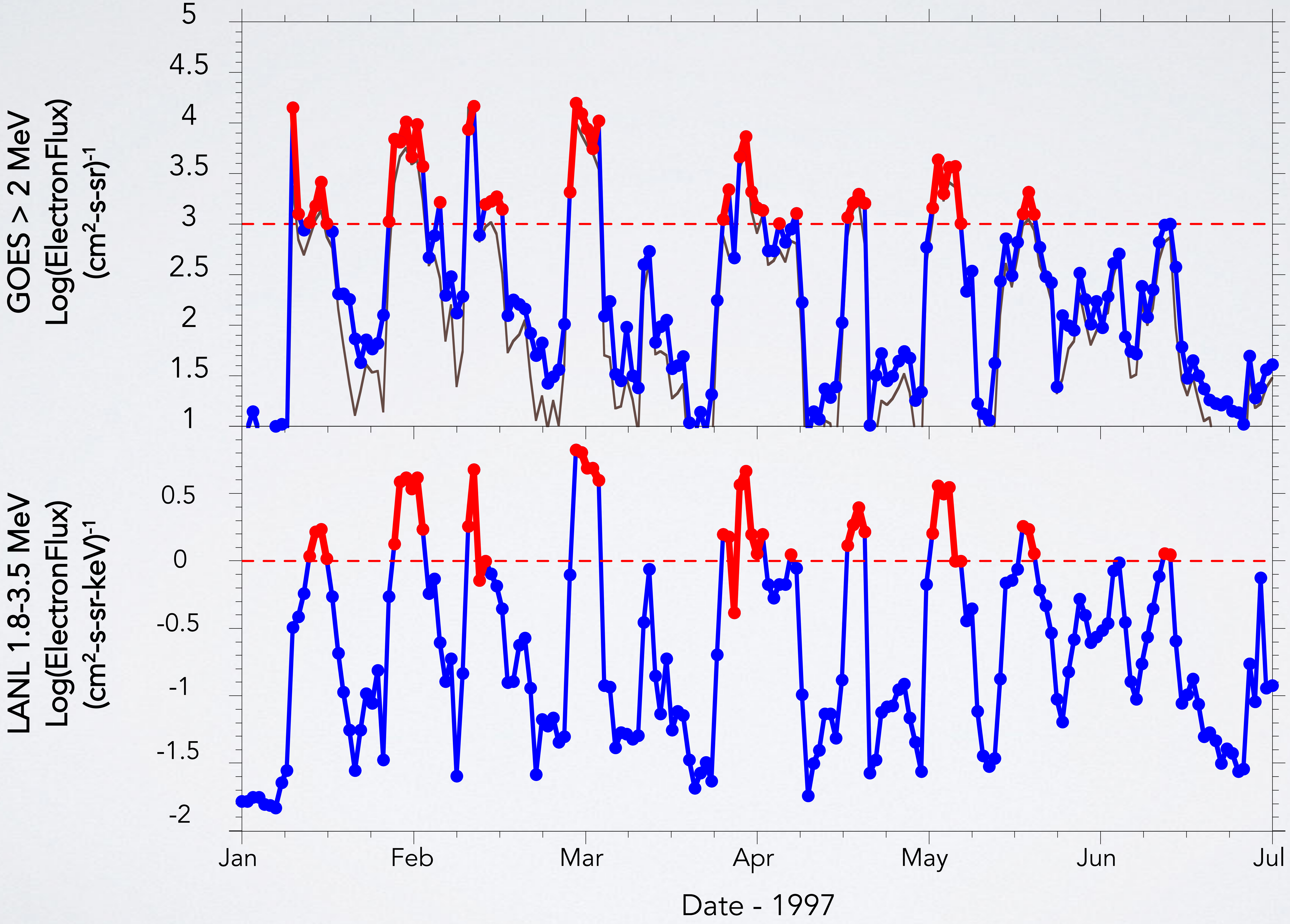
Statistics Normalize Different Data Sources





Reeves et al., SW, 2020

Severe electron environments occur as Events
Daily fluxes are not Statistically Independent



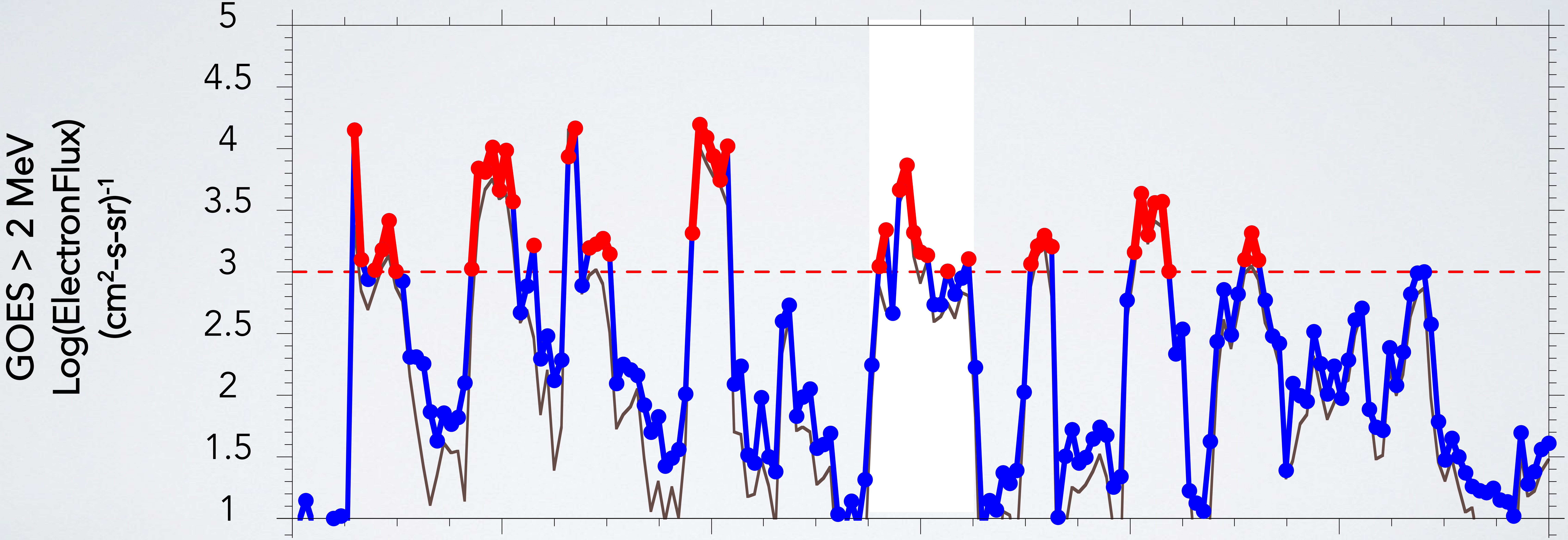
Reeves+ Definition of an Event

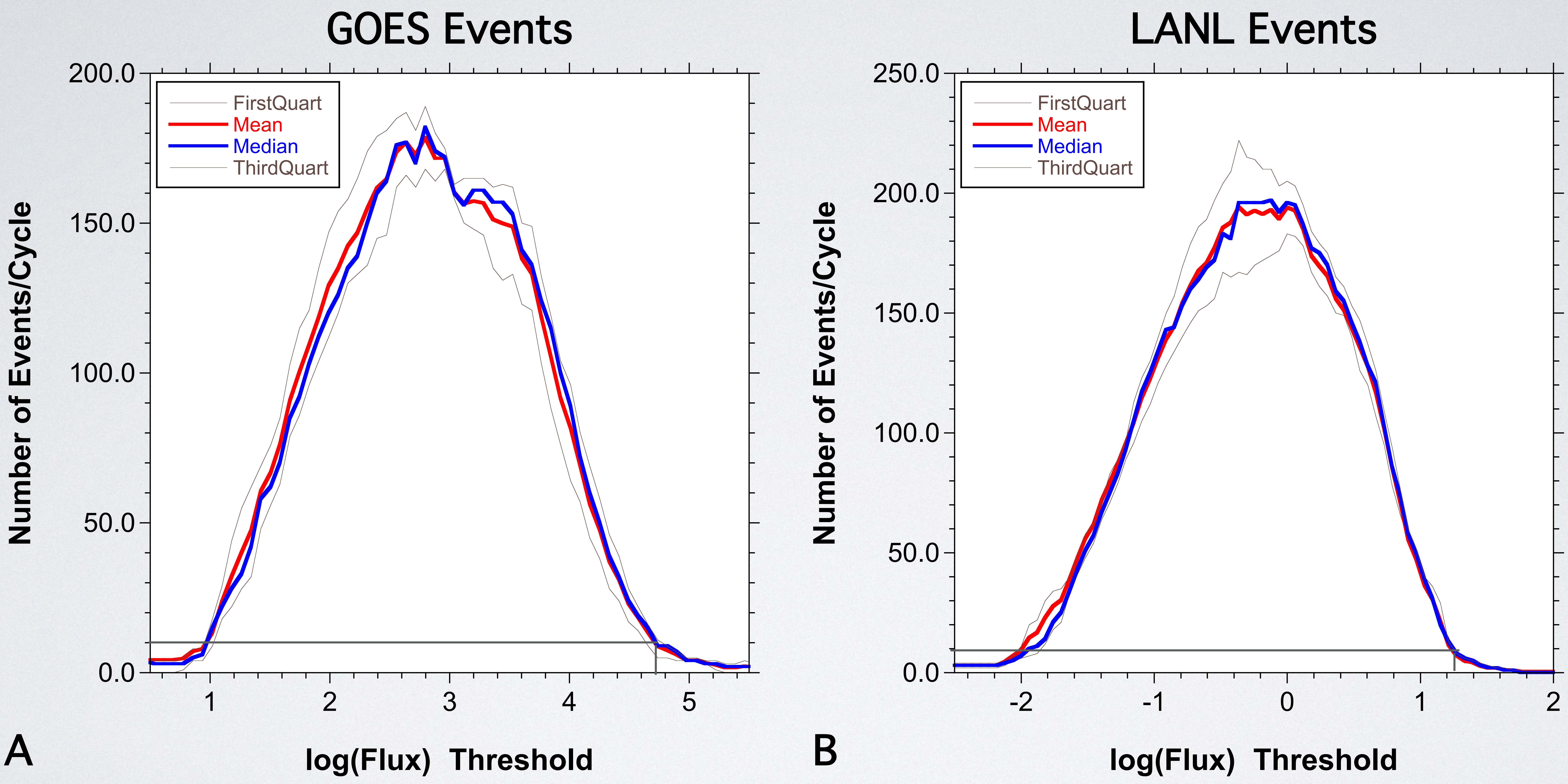
- Event starts when fluxes cross a particular threshold
- Threshold can be varied continuously

- Event ends when fluxes drop back below the threshold <u>and</u> remain below the threshold for 3 continuous days

- Statistics use a sliding window to define 1-in-N year events Reeves et al used 11 years. 10, 20, 30 years is better.

The whole white area here is one event even though some days drop below threshold





1 event per 11-year cycle

1-in-N year Thresholds

	100 Events-per-Cycle	10 Events-per-Cycle	1 Events-per-Cycle
LANL-GEO Average Flux	5.37 $(cm^2\text{-}s\text{-}sr\text{-}keV)^{-1}$	17.8 $(cm^2\text{-}s\text{-}sr\text{-}keV)^{-1}$	46.7 $(cm^2\text{-}s\text{-}sr\text{-}keV)^{-1}$
GOES_max Flux	8,500 $(cm^2\text{-}s\text{-}sr)^{-1}$	62,300 $(cm^2\text{-}s\text{-}sr)^{-1}$	167,000 $(cm^2\text{-}s\text{-}sr)^{-1}$

Moderate = One Hundred / 11 years (~10/year)

Strong = Ten / 11 years (~1/year)

Intense = One / 11years

Strong is only 7 times as high as Moderate

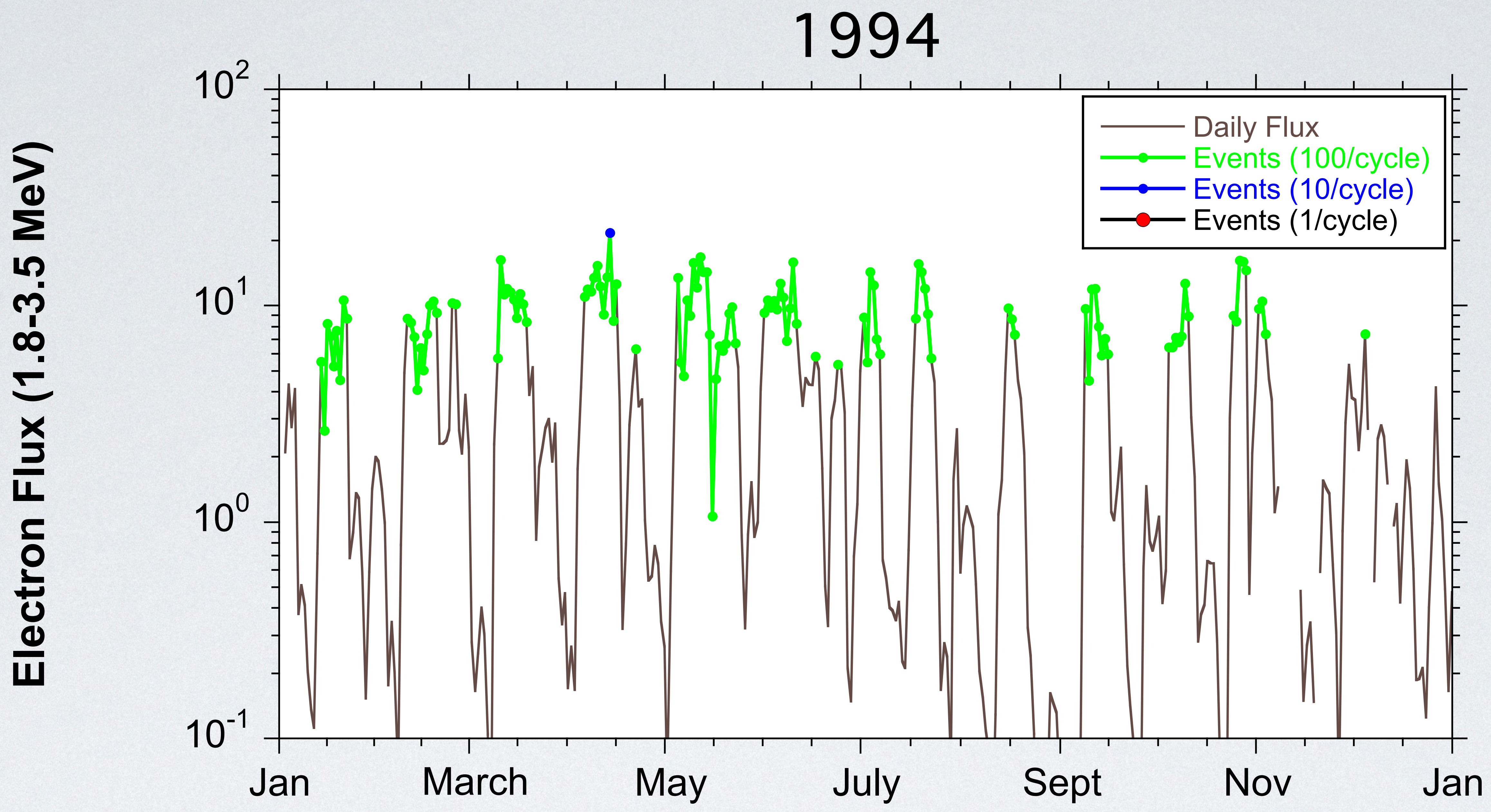
Intense is less than 3 times as high as Strong

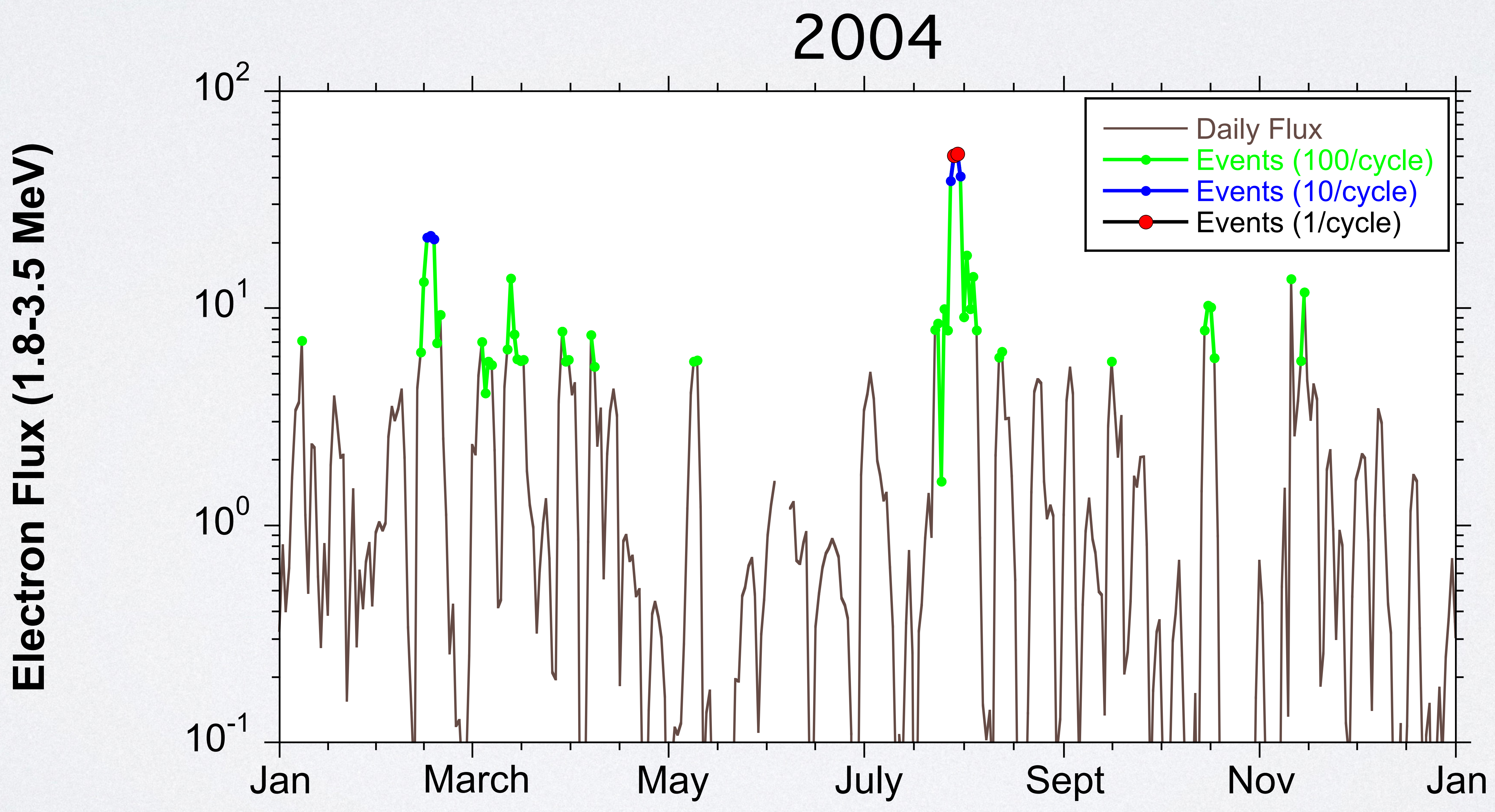
Internal Charging effects are linear

Catalog of Events

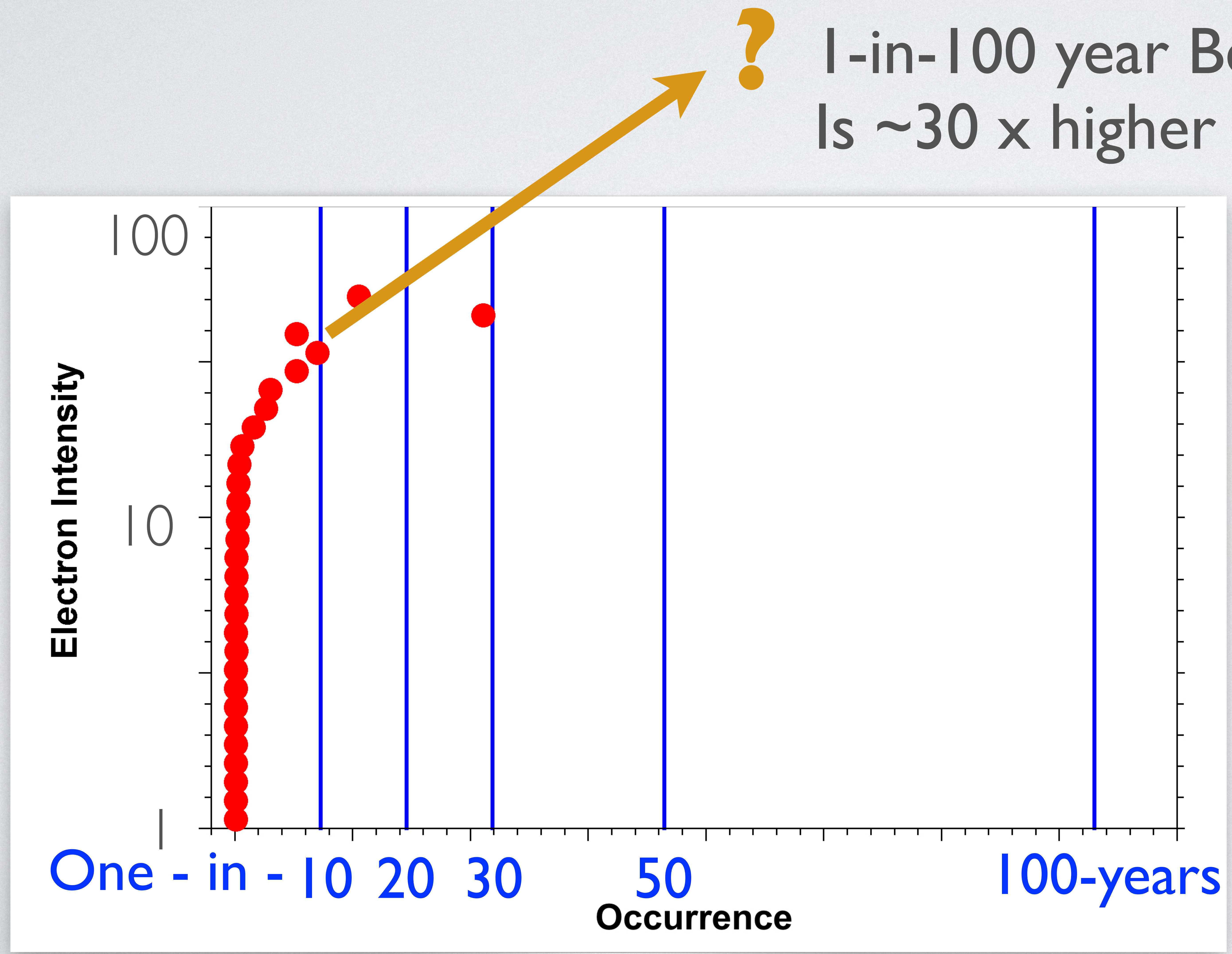
Strong Events

Event	Start Date	Stop Date
S1	1991-03-29	1991-03-31
S2	1992-05-12	1992-05-17
S3	1992-09-07	1992-09-07
S4	1992-10-03	1992-10-04
S5	1993-06-10	1993-06-10
S6	1993-08-22	1993-08-23
S7	1994-04-14	1994-04-14
S8	1995-03-16	1995-03-16
S9	1995-04-14	1995-04-16
S10	2003-08-27	2003-08-27
S11	2003-09-20	2003-09-20
S12	2004-02-16	2004-02-18
S13	2004-07-28	2004-07-31
S14	2005-05-17	2005-05-19
S15	2005-08-08	2005-08-09
S16	2005-09-14	2005-09-21
S17	2006-04-16	2006-04-17
S18	2010-04-08	2010-04-11
S19	2017-04-27	2017-04-27


1994
Electron Flux (1.8-3.5 MeV)
10^2
10^1
10^0
10^{-1}
Jan
March
May
July
Sept
Nov
Jan
Daily Flux
Events (100/cycle)
Events (10/cycle)
Events (1/cycle)


2004
Electron Flux (1.8-3.5 MeV)
10^2
10^1
10^0
10^{-1}
Jan
March
May
July
Sept
Nov
Jan
Daily Flux
Events (100/cycle)
Events (10/cycle)
Events (1/cycle)

2 MeV Geosynchronous Electron Fluxes



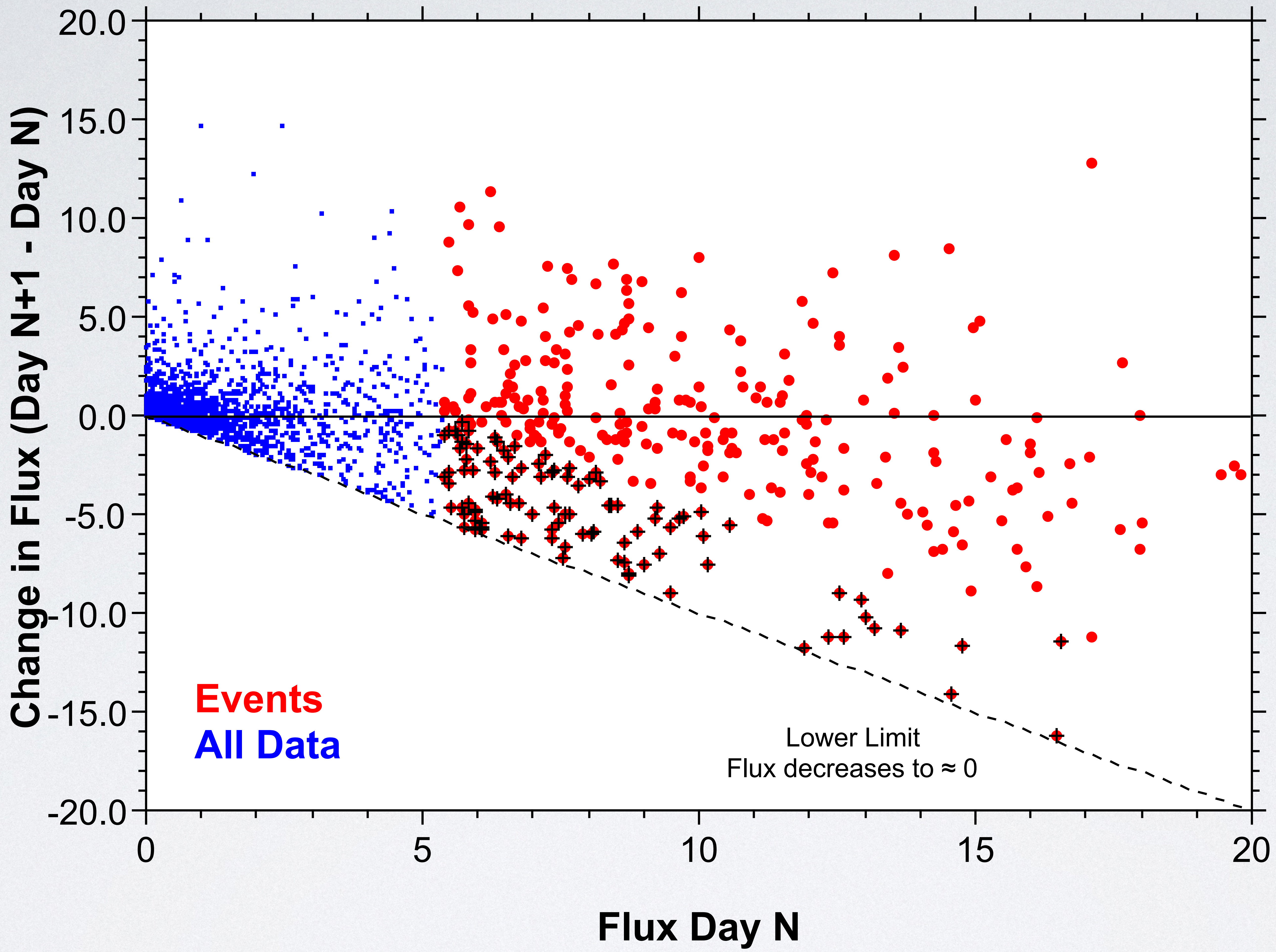
1-in-100 year Benchmark = 1,500 (cm^2-s-sr-keV)$^{-1}$
Is ~30 x higher than Max Observed Flux

Based on 30 years of Geosynchronous Observations

graphics based on:
Reeves et al., Space Weather, 2020

Event Days are Different

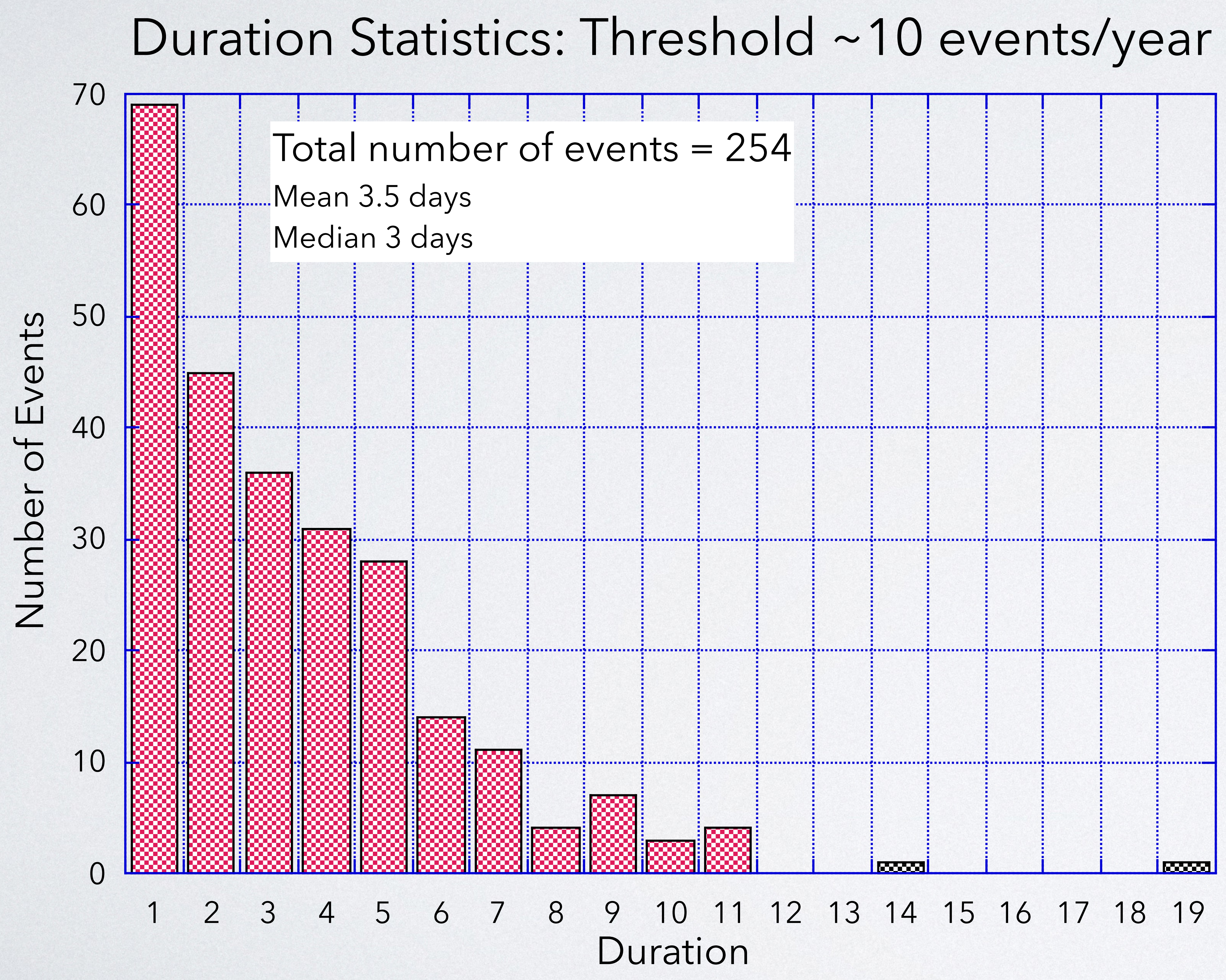
- A number of algorithms have been developed to predict geosynchronous electron fluxes
- But event days (high flux days) are fundamentally different than non-event days. (Similar to storm main phase vs recovery)
- Event days occur when electrons are being accelerated during strong geomagnetic activity
- Non-event days are dominated by quiet or exponentially decaying conditions



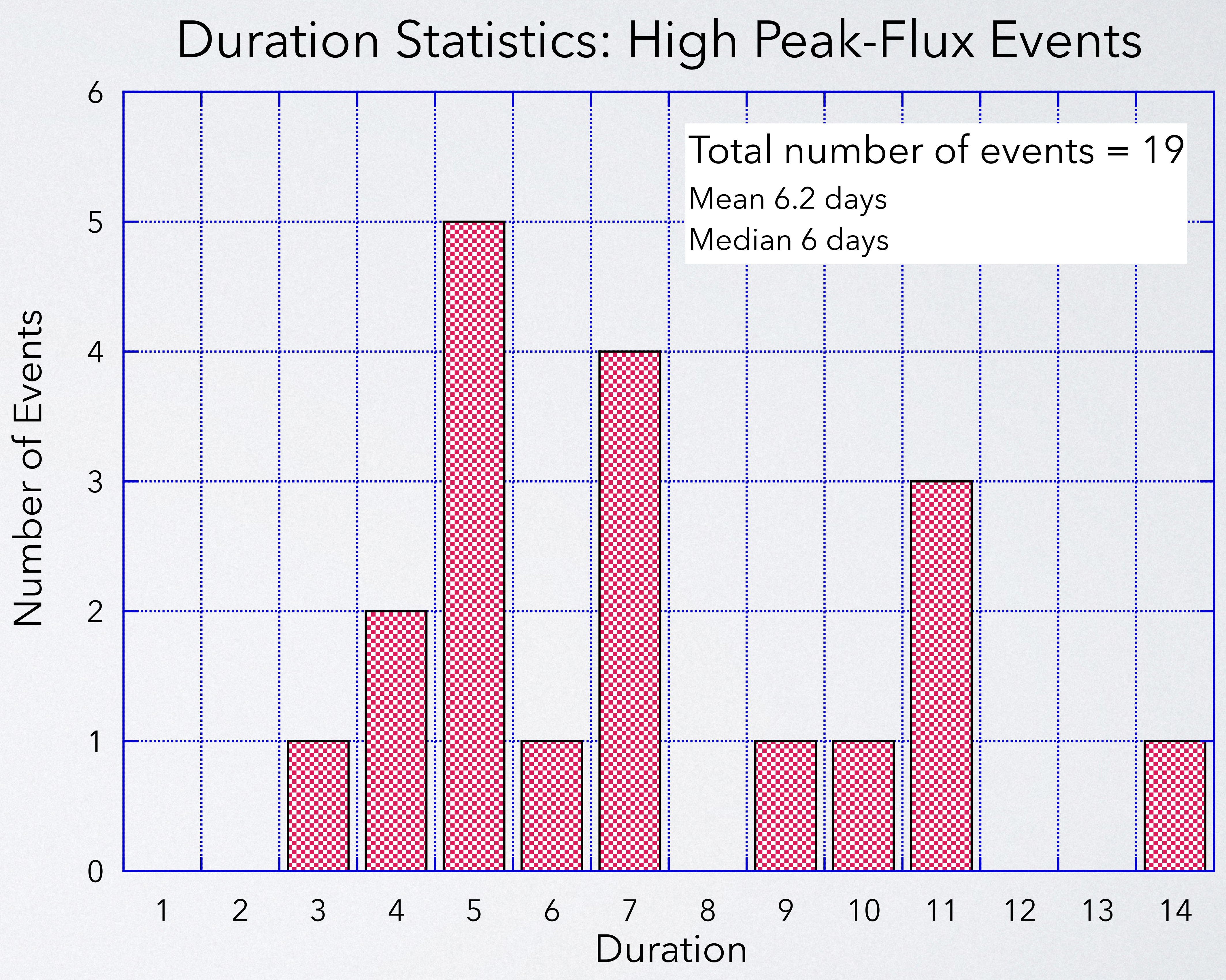
	Events	All Days	Non-Event
small change	36.4%	86.8%	94.7%
positive	19.5%	6.8%	2.8%
negative	44%	6.4%	2.5%

One Example: Event Durations

Duration above 62,300 $(cm^2\text{-}s\text{-}sr)^{-1}$
~10 events/year



Duration above 62,300 $(cm^2\text{-}s\text{-}sr)^{-1}$
if peak flux is > 1 event/year



Conclusions

- Development of benchmarks is different than 'normal' space weather studies. There is more 'what' and less 'why' or 'how'.
- Statistics are key to developing benchmarks
- Statistics allow quantitative benchmarks from heterogeneous data
- 1-in-N year statistics can be directly used to define <u>Scales</u>
- Theis approach can also be a foundation for real-time operational predictions for hazardous events