On the Probability of Occurrence of Extreme Space Weather Events

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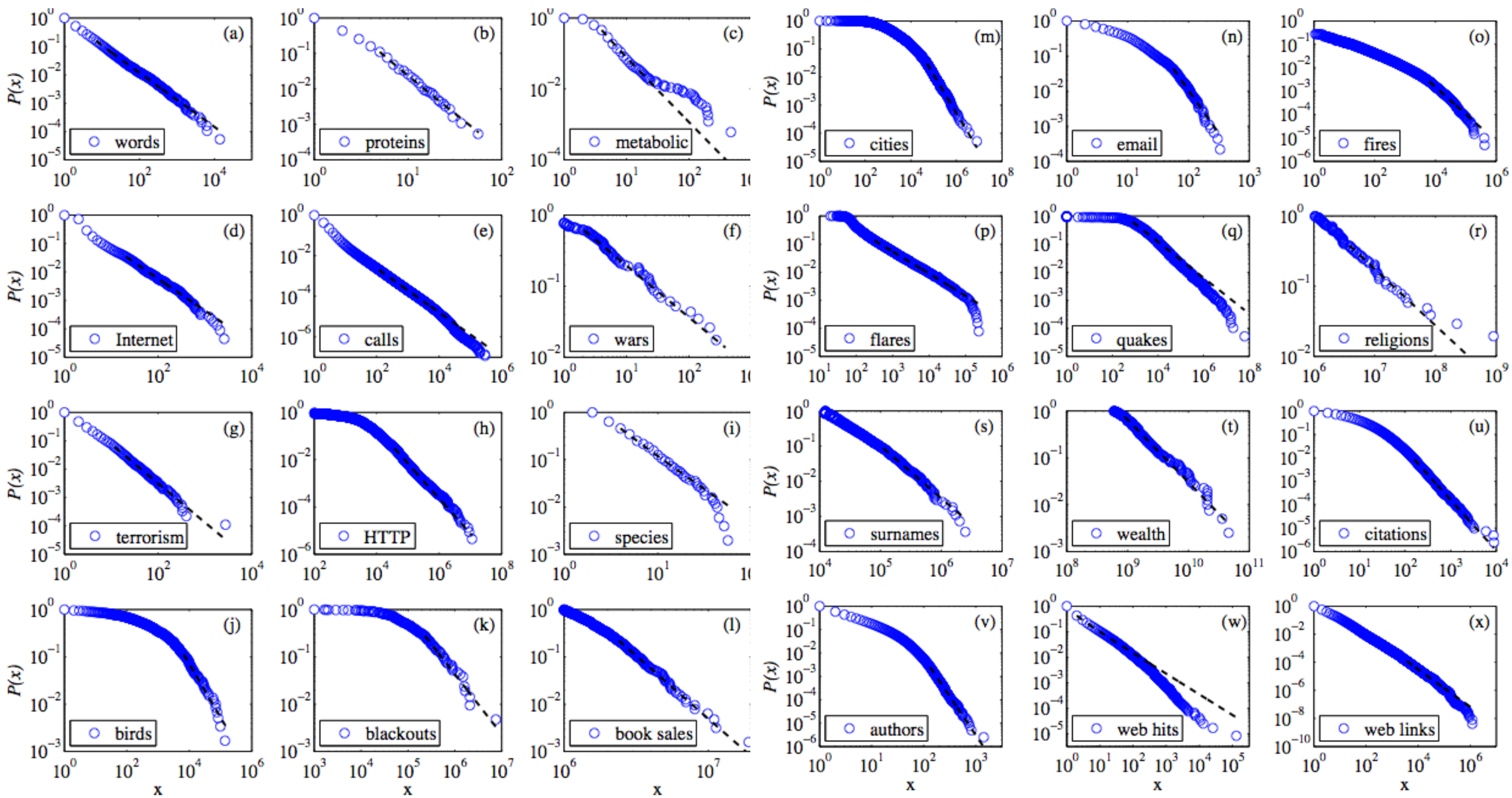
Motivation

What is the likelihood of another Carrington event happening in my lifetime?

Nature loves Power Law Distributions



Clauset et al. (2009)

Mathematical Background

$$p(x) = Cx^{-\alpha}$$

$$P(x \geq x_{crit}) = \int_{x_{crit}}^{\infty} p(x')dx'$$

$$P(x \geq x_{crit}) = \frac{C}{\alpha - 1} x_{crit}^{-\alpha+1}$$

$$\alpha - 1 = N\left[\sum_{i=1}^{N} \ln \frac{x_i}{x_{\min}}\right]^{-1}$$

$$E(x \geq x_{crit}) = NP(x \geq x_{crit})$$

$$P(x \geq x_{crit}, t = \Delta t) = 1 - e^{-N\frac{\Delta t}{\tau}P(x \geq x_{crit})}$$

Reality Check: Time to Event

- For Bernouilli Events,
- with a constant probability of occurrence,
- The probability of occurrence is:

$$P(x) = \frac{1}{1+\tau}$$

- Where τ is time to event.
- E.g., if event occurs every 100 years, the probability of one occurring in the next decade is: 1/(1+100/10) = 0.09 or 9%.

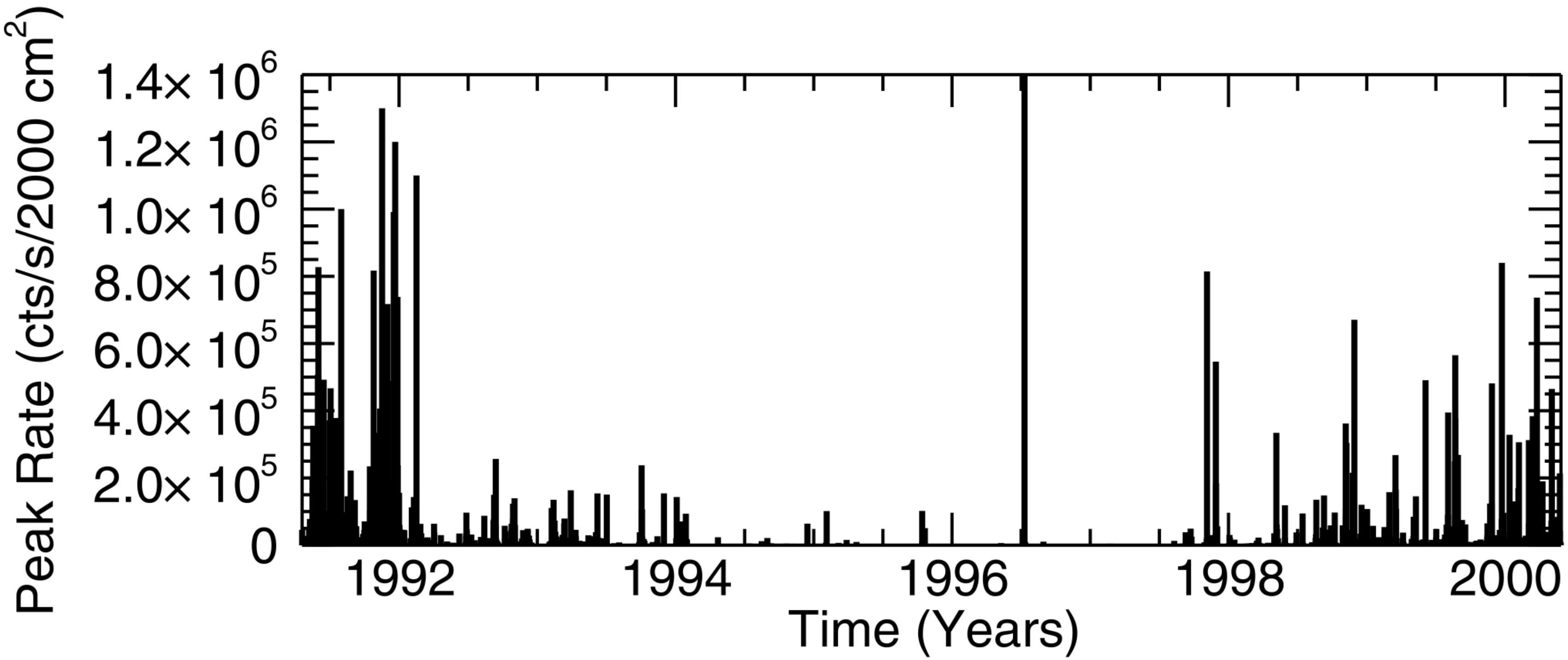
Assumptions

- Quasi-time-stationarity
- Poisson process (Independent events)
- Power-law distribution through at least the size of the Carrington event

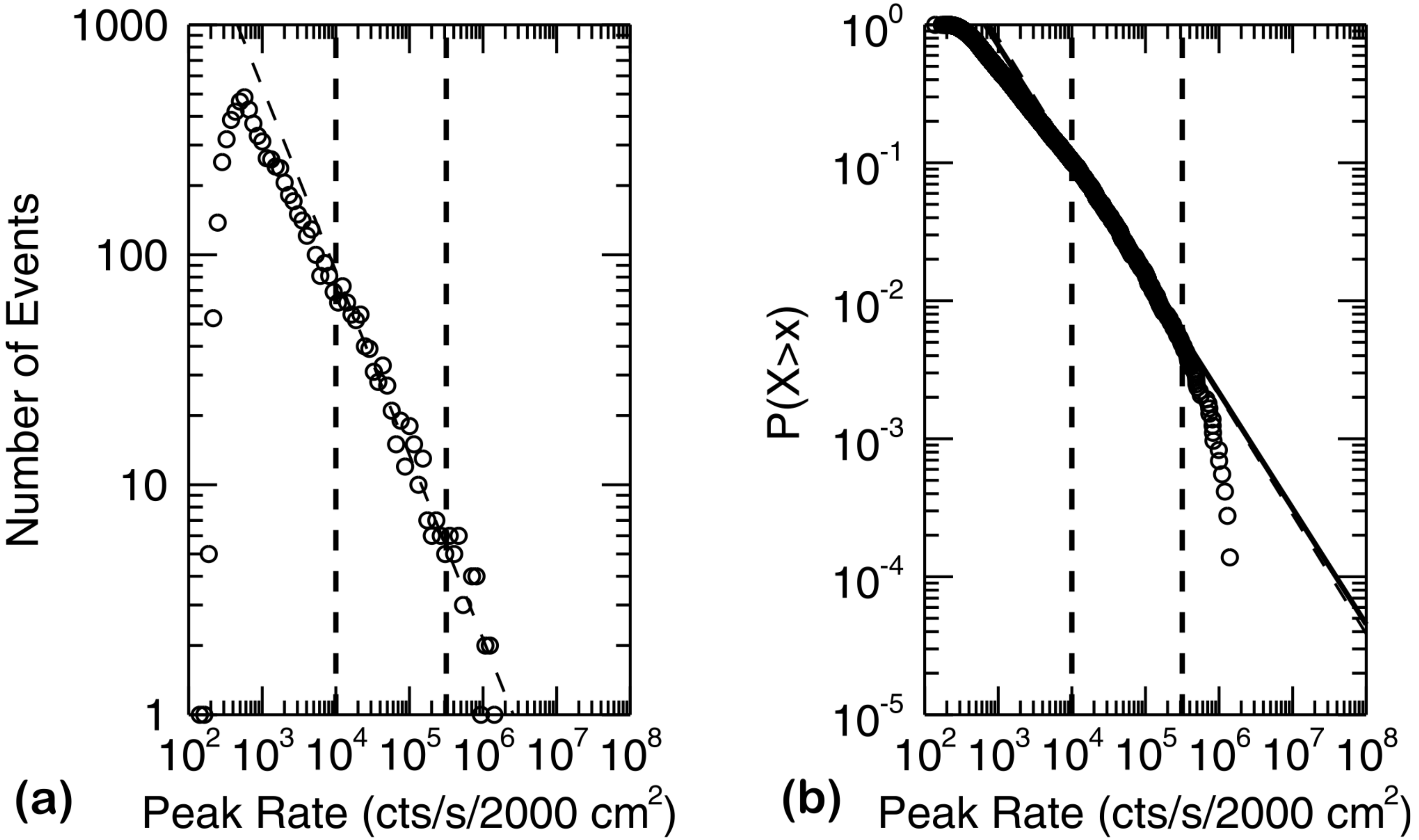
A representative selection of space weather datasets…

- Hard Solar X-ray data from BATSE
- CME speeds
- Dst
- > 30 MeV Proton Fluences
- (Others: Equatorward edge of the diffuse aurora, Auroral indices, Kp, etc.)

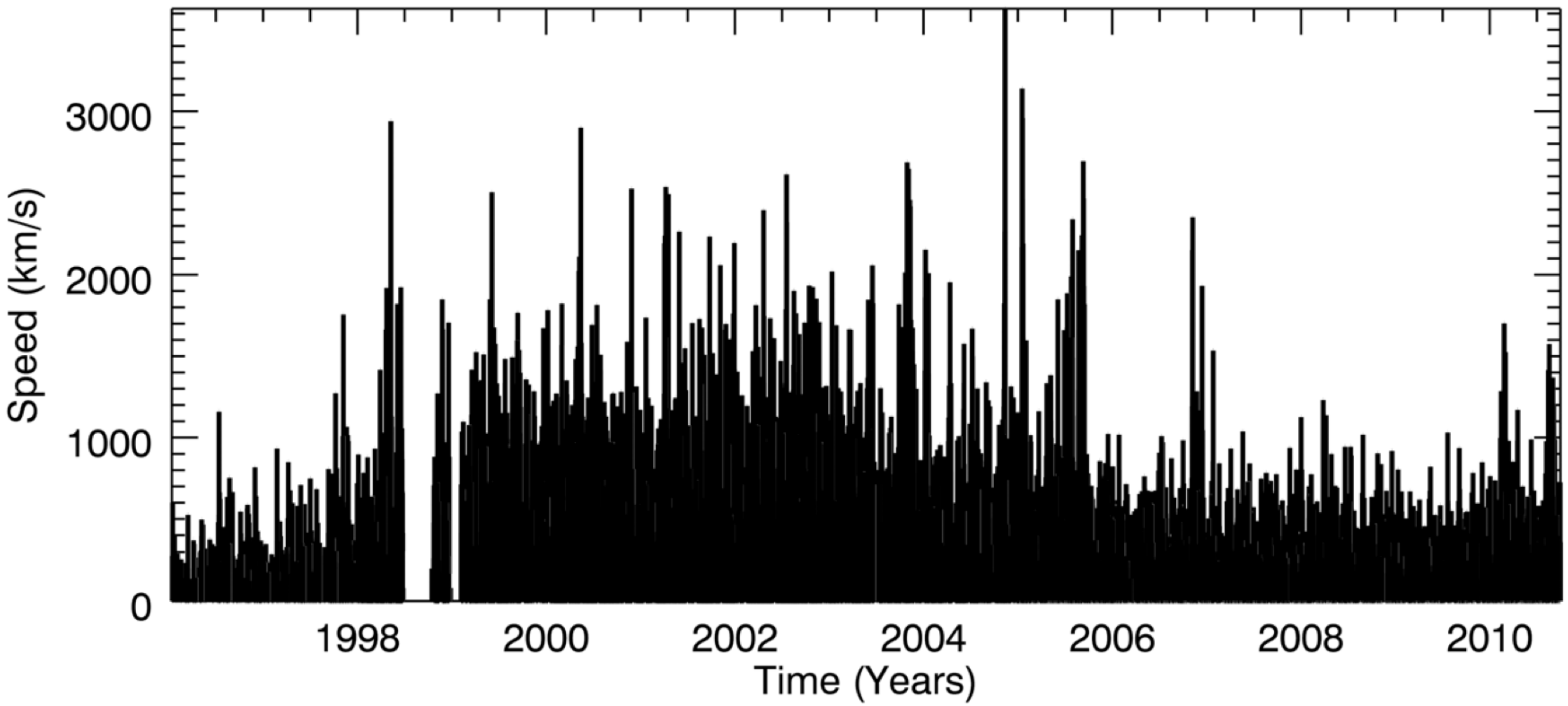
Hard X-Ray Data from BATSE



Hard X-Ray Data from BATSE

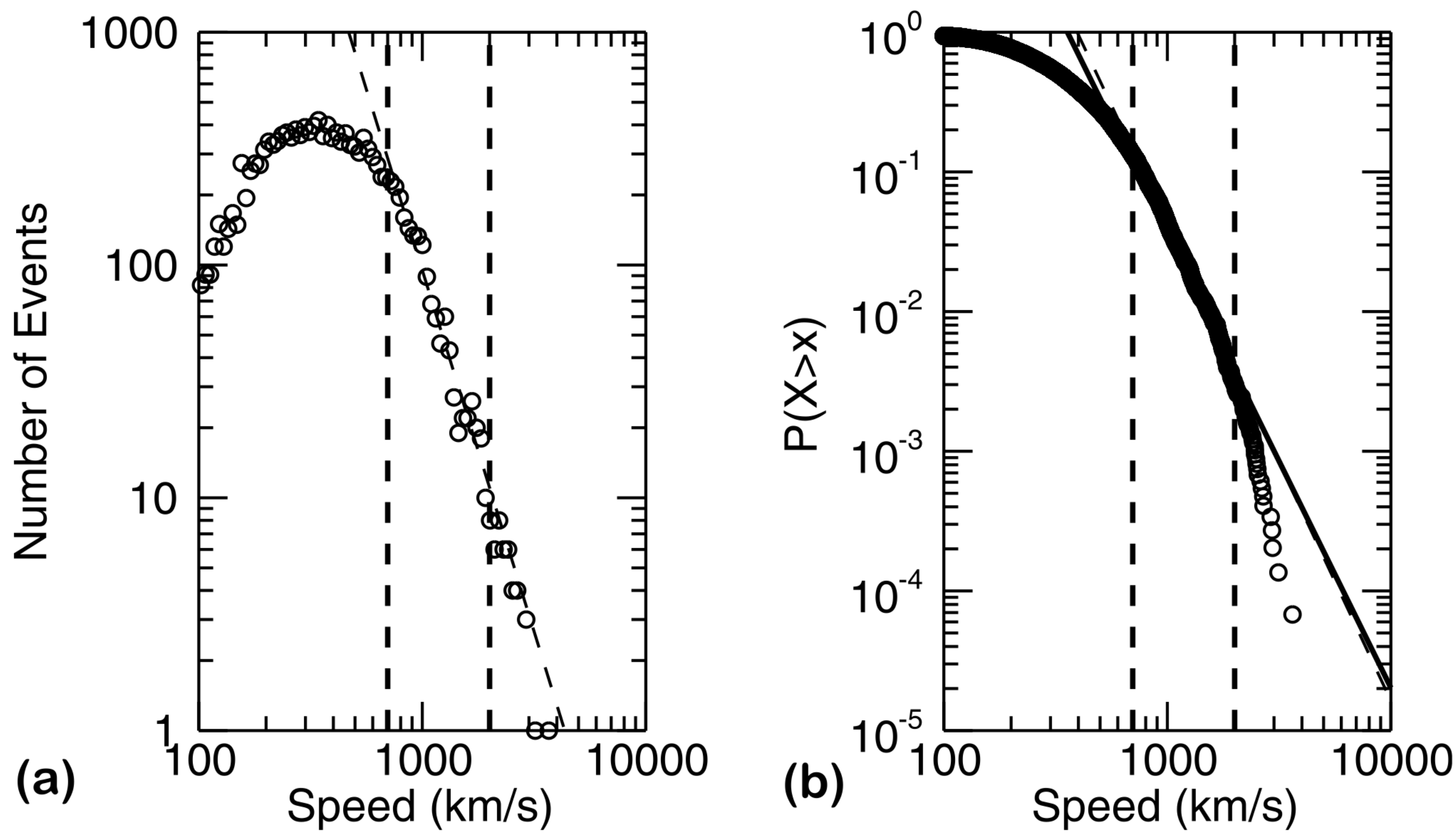


CME Speed



3000
2000
1000
0
Speed (km/s)
1998
2000
2002
2004
2006
2008
2010
Time (Years)

CME Speed



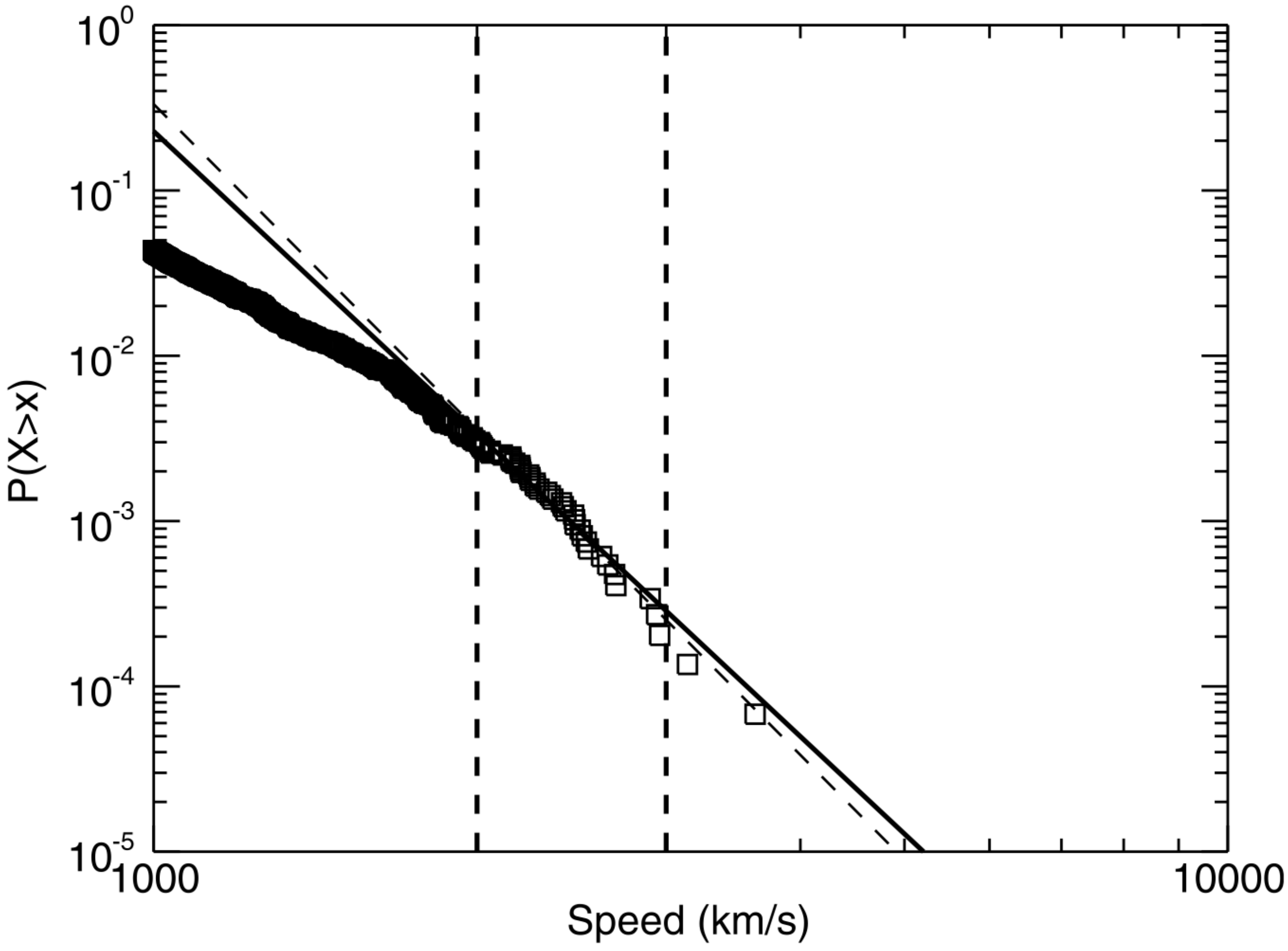
1000
100
10
1
100
1000
10000
Number of Events
Speed (km/s)
(a)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
100
1000
10000
P(X>x)
Speed (km/s)
(b)

Probability of and Extreme ICME (based on speed)

- Assume *V*cme-crit ≥ 5,000 km/s
- Slope = -3.2
- Probability of observing such an event over the next decade:

  P(v>5,000 km/s) ~ 85%

CME Speed

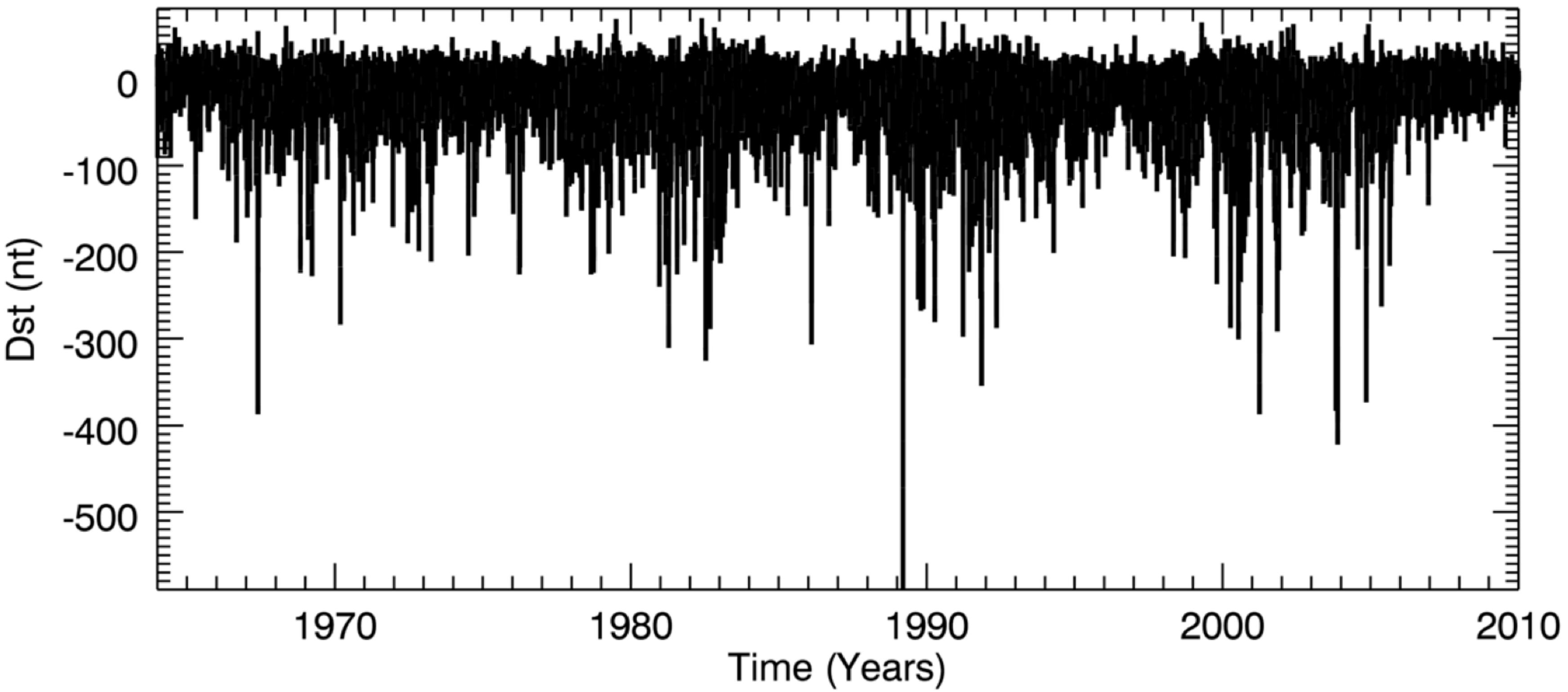


Probability of and Extreme ICME (based on speed)

- For CMEs > 2,000 km/s,
- Slope = -6.1
- Revised probability:

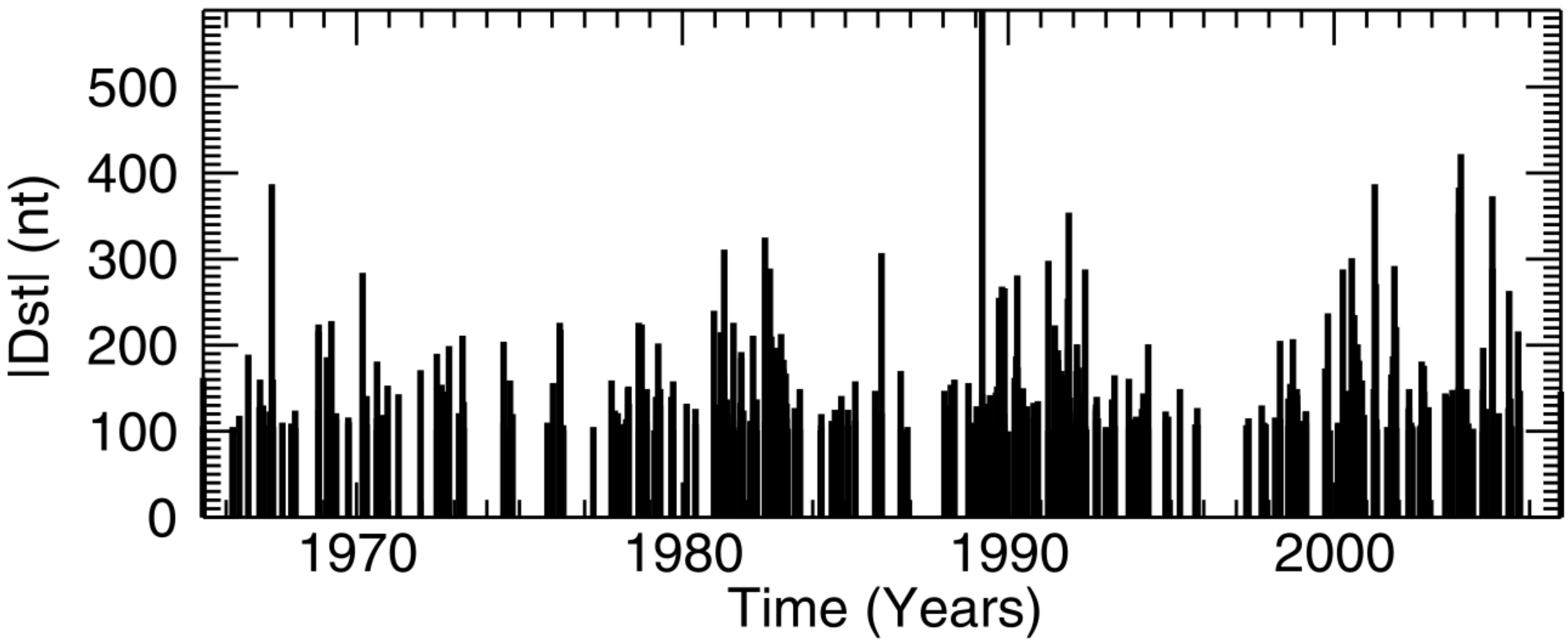
$$P\ (v \geq 5{,}000\ \text{km/s},\ \Delta t{=}10\ \text{yrs}) \sim 12\%$$

Dst

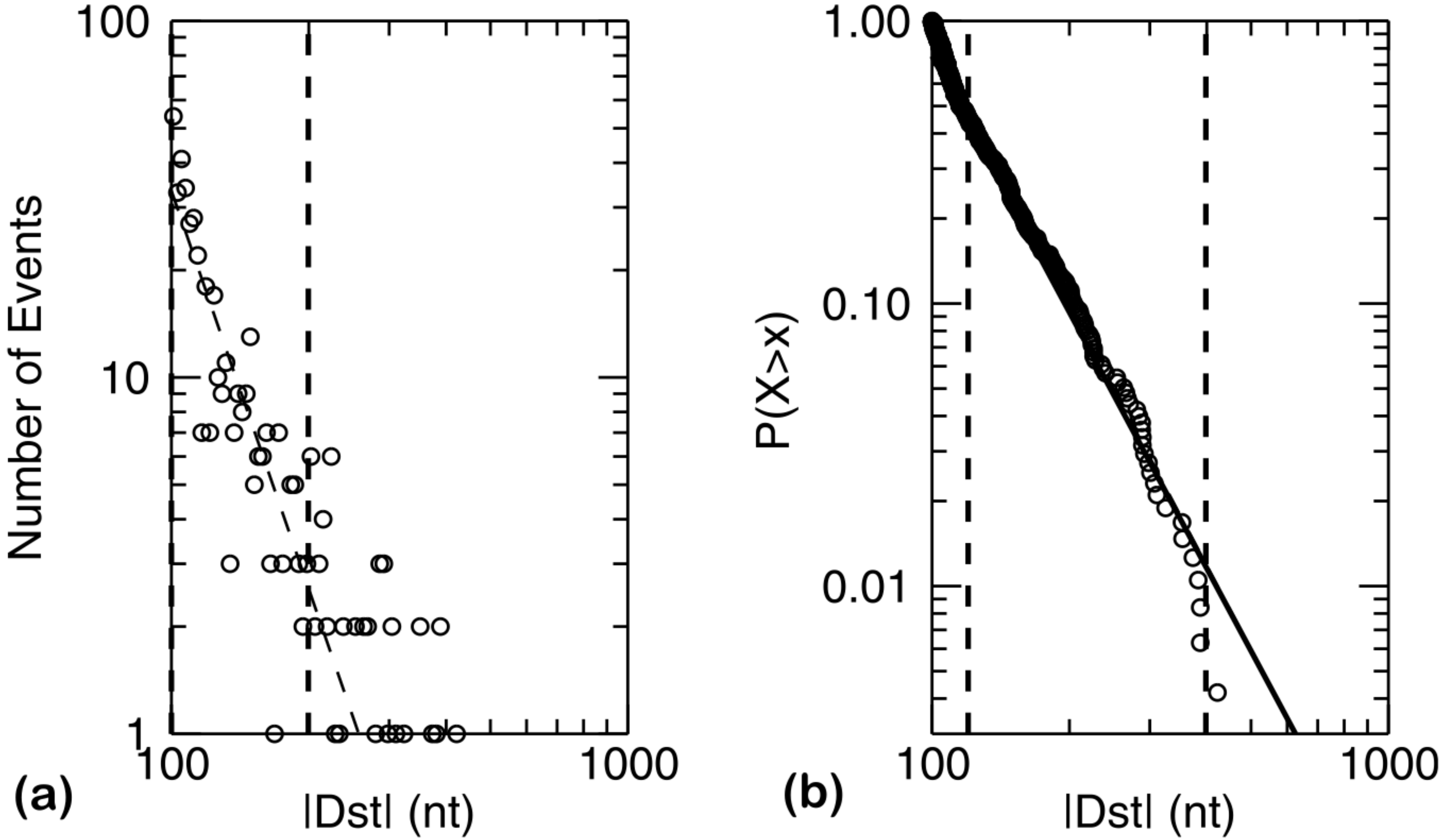


0
-100
-200
-300
-400
-500
Dst (nt)
1970
1980
1990
2000
2010
Time (Years)

Dst "Events" (Dst < -100 nT)



Dst Power Laws



Probability of and Extreme Geomagnetic Storm (based on Dst)

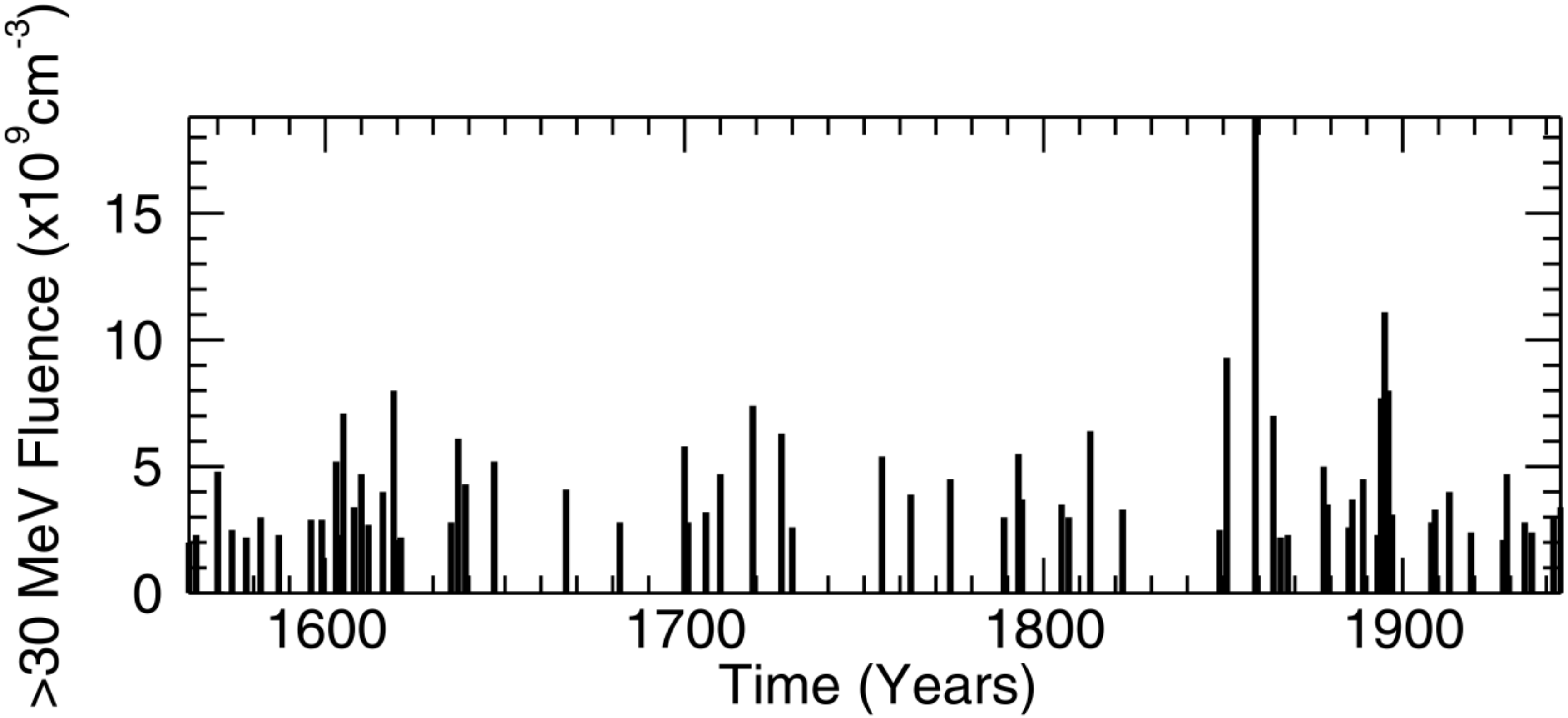
- For Dst < -850 nT:

$$P(Dst \leq -850\ nT, \Delta t{=}10\ yrs) \sim 12\%$$

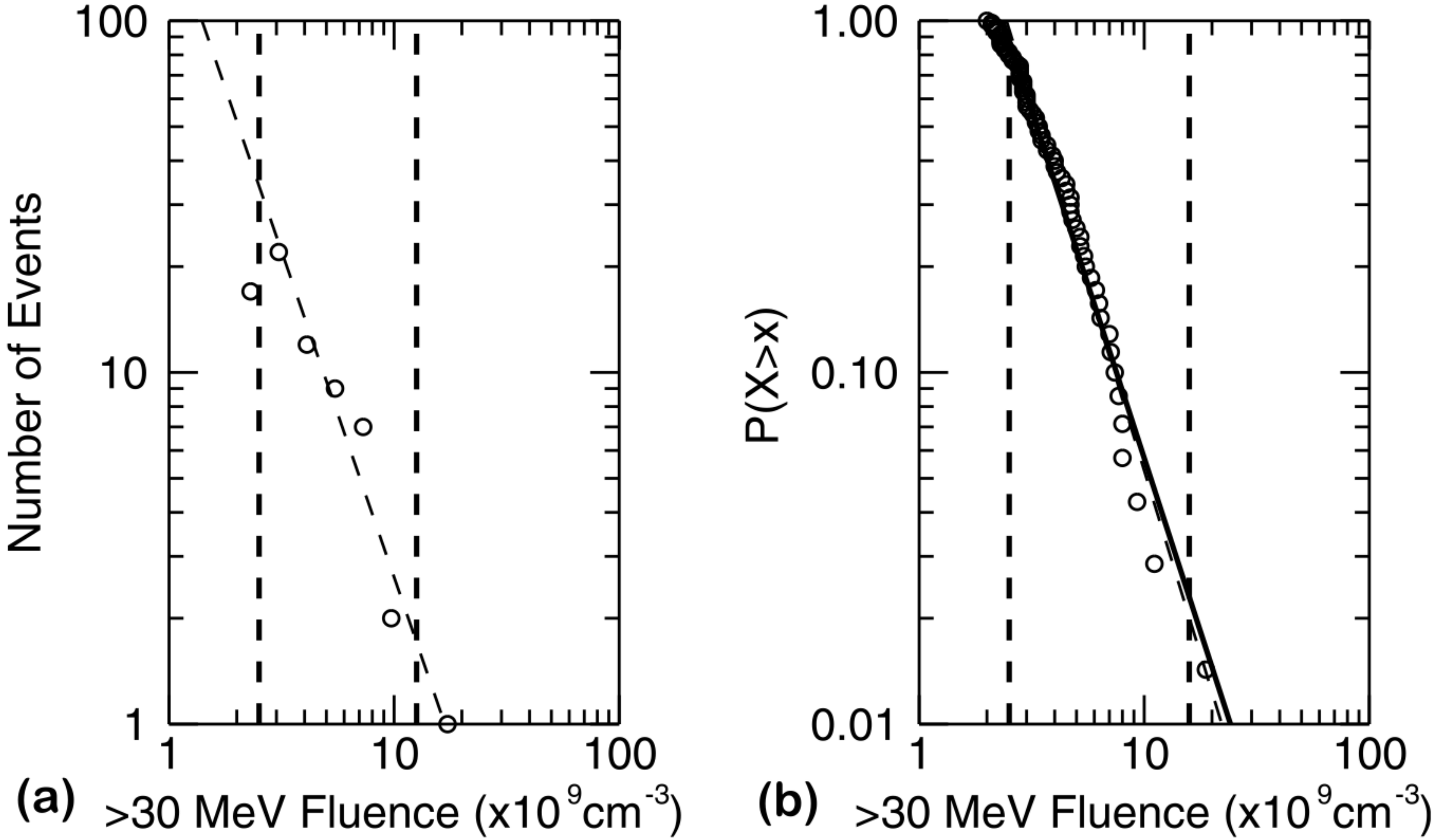
- For Dst < -1700 nT:

$$P(Dst \leq -1700\ nT, \Delta t{=}10\ yrs) \sim 1.5\%$$

>30 MeV Fluences



>30 MeV Fluences



Probability of an Extreme SPE (based on >30 MeV Proton Fluences)

- Fluence > 18.8×10^9 cm^{-1}
- Slope = -2.0

$$P(> 18.8 \times 10^9 \text{ cm}^{-1}, \Delta t = 10 \text{ yrs}) \sim 3\%$$

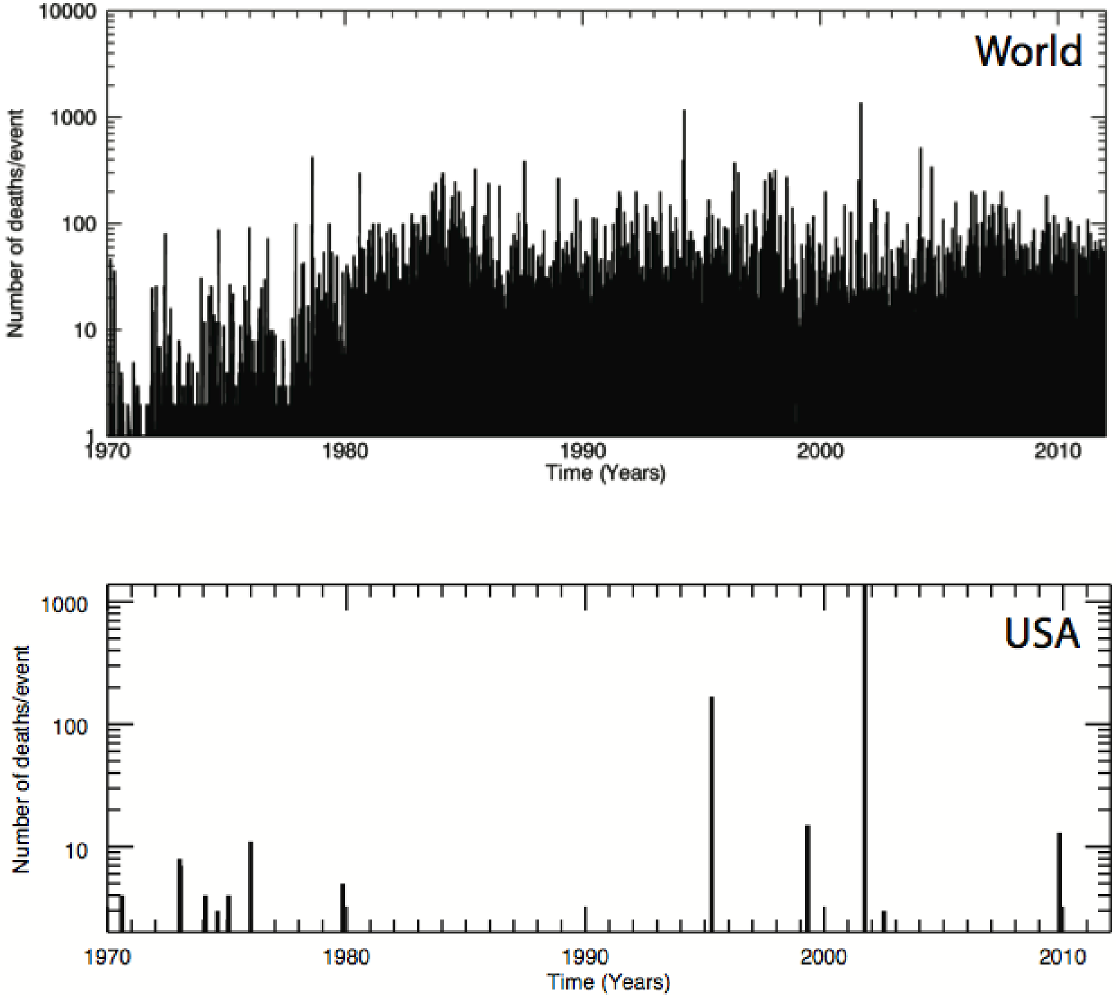
Summary

- Probability of occurrence of a Carrington-like (or worse) event is sensitive to the definition of event
- There are a number of assumptions that may or may not hold:
  - Time stationarity
  - Poisson process
  - Power-law distribution
- Major issue that remains to be addressed is the uncertainty associated with the predictions

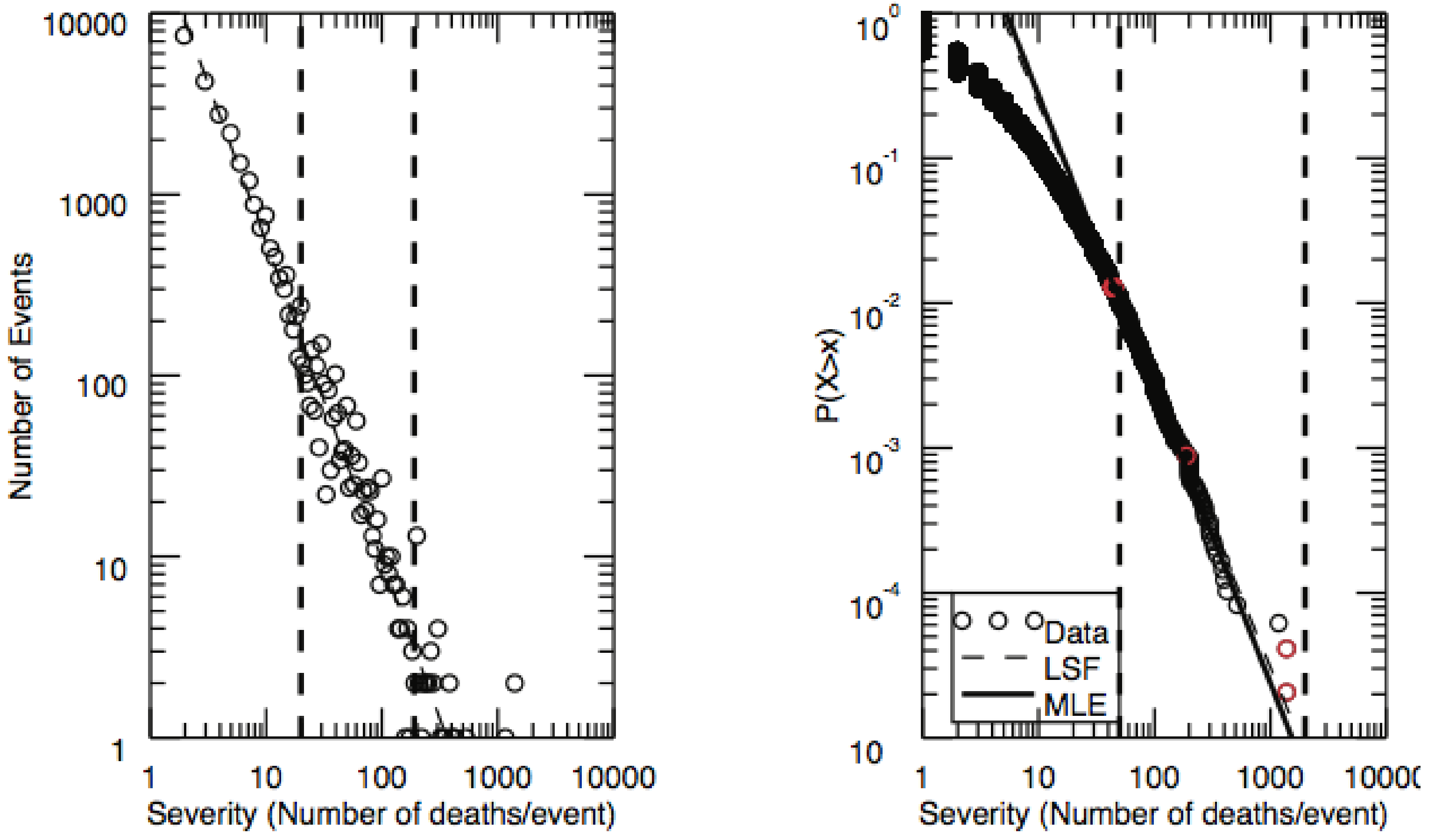
Future work

- How to assess the uncertainties?
  - Jeff Love's work (next talk)
  - Maximum likelihood methods
  - Multiple models of the distribution's tail - Robustness
  - Estimates of parameter and model uncertainty
- Assessing the temporal variability in extreme event probabilities
- Look at other measures of extreme event behavior (GICs, Eq. edge of diffuse aurora, etc.)
- Couple probabilistic forecasts with event-based physical/empirical models

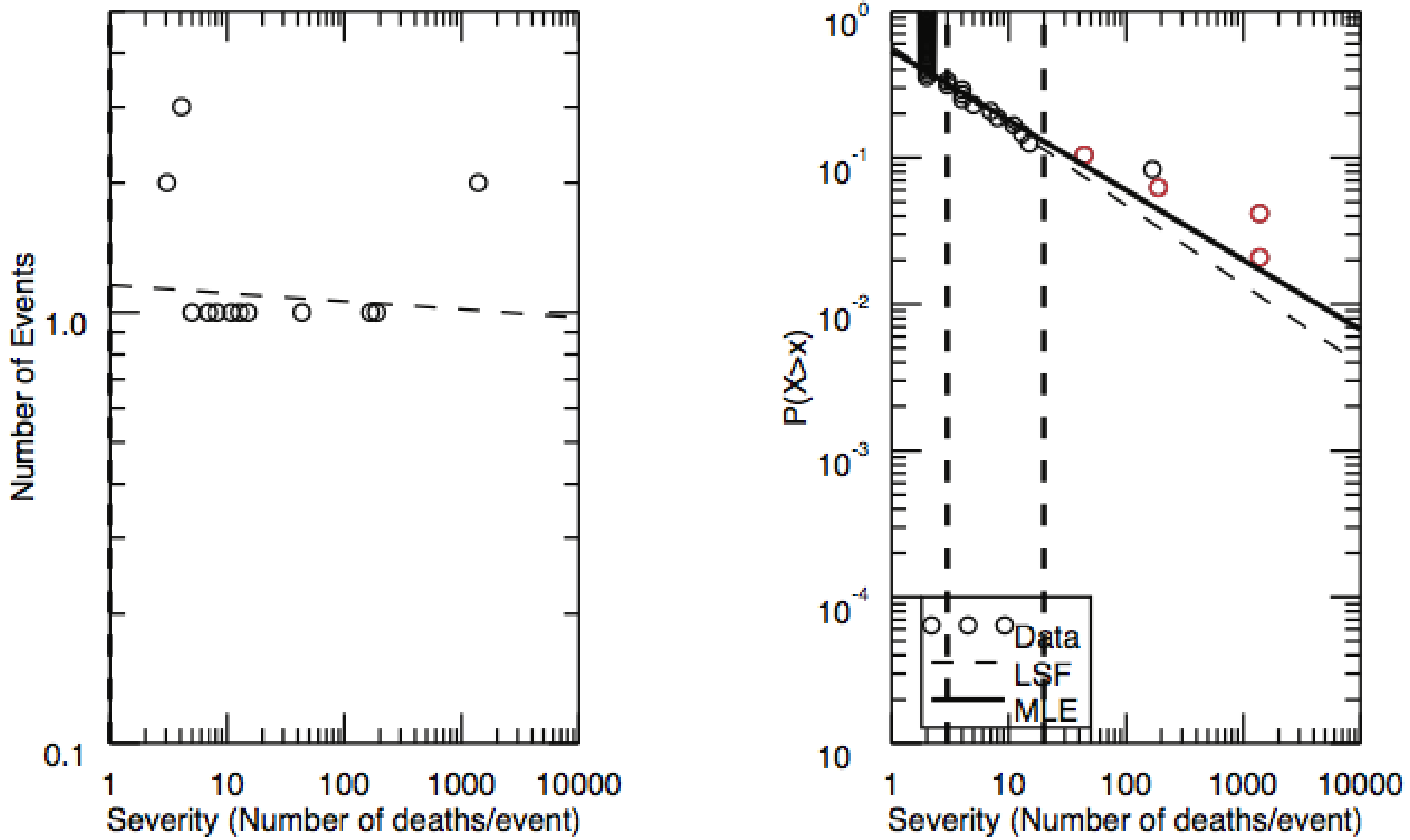
Terrorist Attacks



Terrorist Attacks: World



Terrorist Attacks: USA



Terrorist Attacks: Evolution of Probability over last 40 years