Fifth Gait Technologies, The Next Step

Probabilistic Modeling of the Space Radiation Environment

Solar Energetic Particles (SEP), Solar Modulation and Space Radiation: New Opportunities in the AMS-02 ERA #2

Authors: Zachary Robinson, James H. Adams Jr., and Jonathan Fisher

Contacting Author: Zachary Robinson (zachary@5thgait.com)

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Fifth Gait Technologies

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Overview

- Why we need models for the space radiation environment
- Probabilistic Modeling Methodology
- Two new models:
  - Episode-Integrated Fluence Model
  - Peak Flux model

Why we need these models

- To determine the environment the mission will encounter
  - Reduce costly-overdesign
- Give the mission the best chance to succeed
  - Protect instruments and humans from radiation

The Probabilistic Method

The probability that no event with a flux $\geq \phi$ in T years:

$$F_T(M) = \sum_n \frac{(\mu T)^n}{n!} \exp(-\mu T)\,[P(M)]^n$$

Where $M = \log(\phi)$

This can be simplified to :

$$F_T(M) = exp\{-\mu T[1 - P(M)]\}$$

The Probabilistic Method

$$F_T(M) = exp\{-\mu T[1 - P(M)]\}$$

- No assumption has be made to elements or energy range.
- Need to find the cumulative distributions and episodes per year.

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Two Models

Both models:

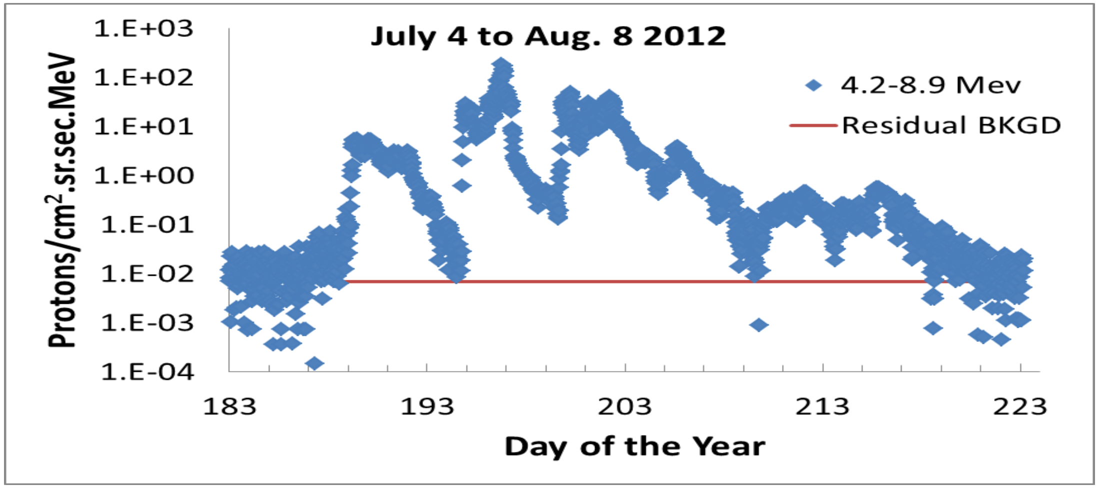
- Use a database where periods of elevated particle flux are identified by eye
- Allow the user to chose mission start date and duration.
- Confidence level that the user wishes to attain with their design.

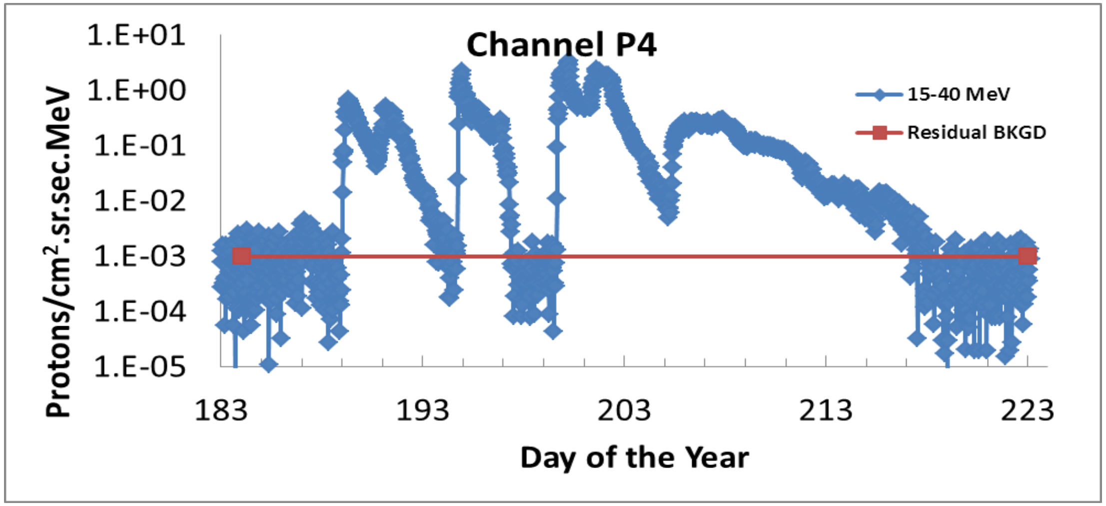
- Episode-Integrated Fluence Model (Robinson, 2015)
  - Missions ranging from a few weeks to several years
- Peak Flux Model
  - Missions ranging from 10's of minutes to several years

Data Base of SEP Episodes

- Episode-Integrated Fluence Proton Data Base
  - GME on IMP-8 and EPS on GOES
  - Normalized using isotropic periods of flux and Rodriguez et al. [2014]
  - Redistributed the GOES fluence in GME channels
- Peak Flux Data Bases
  - Proton
    - EPS on GOES
    - Normalized using periods of isotropic flux and Rodriguez et al. [2014]
  - Helium
    - Solar Energetic Particle Environment Modeling (SEPEM) system [Crosby et al., 2015]

Episode Identification





Images from Robinson, 2015

Cumulative Distributions

- Each channel was graphed as $1 - P(M)$
- Used three equations to fit each distribution
  - Power law
  - Log polynomial
  - Frechet distribution (following work of Xapsos et al. 1998)

$$N = N_{tot}\left(\frac{\phi^{-b} - \phi_{max}^{-b}}{\phi_{min}^{-b} - \phi_{max}^{-b}}\right)$$

Cumulative Distributions

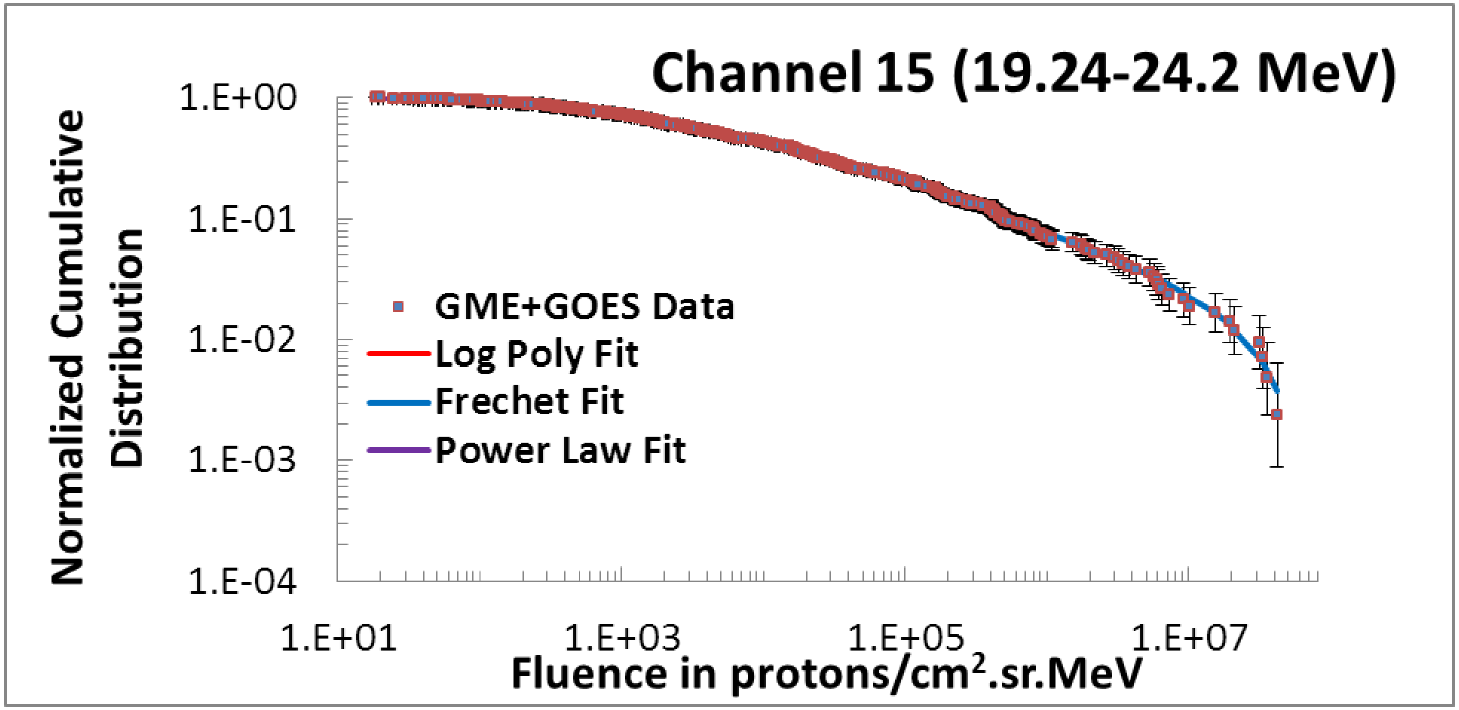


Image from
Robinson, 2015

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Episodes Per Year

Three different methods were used:

- Actual number of episodes per year (1974-2013)
- Sunspot Proxy (1953-1974, 2013-2019)
- 11-year solar cycle fit (2019 -2052)

Episodes Per Year

Sunspot Proxy

- Hathaway et al. (1994) predicted sunspot numbers
- Sunspot numbers compared to episodes per year
  - Exponential distribution with dead time correction factor (Robinson 2015)

$$N = (a\,n + b)\exp[-q(a\,n + b)]$$

Episodes Per Year

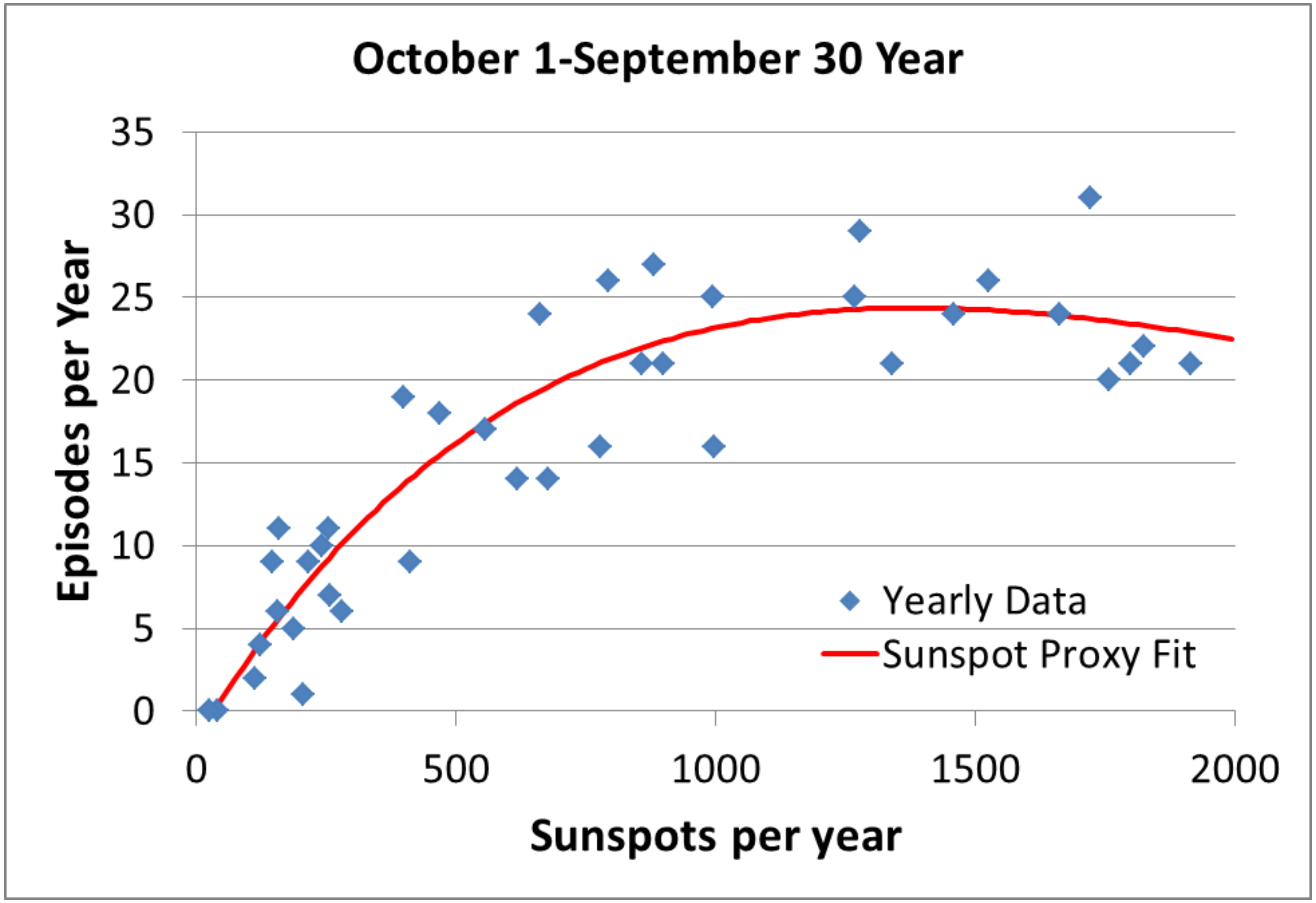

Image from
Robinson, 2015

Episodes Per Year

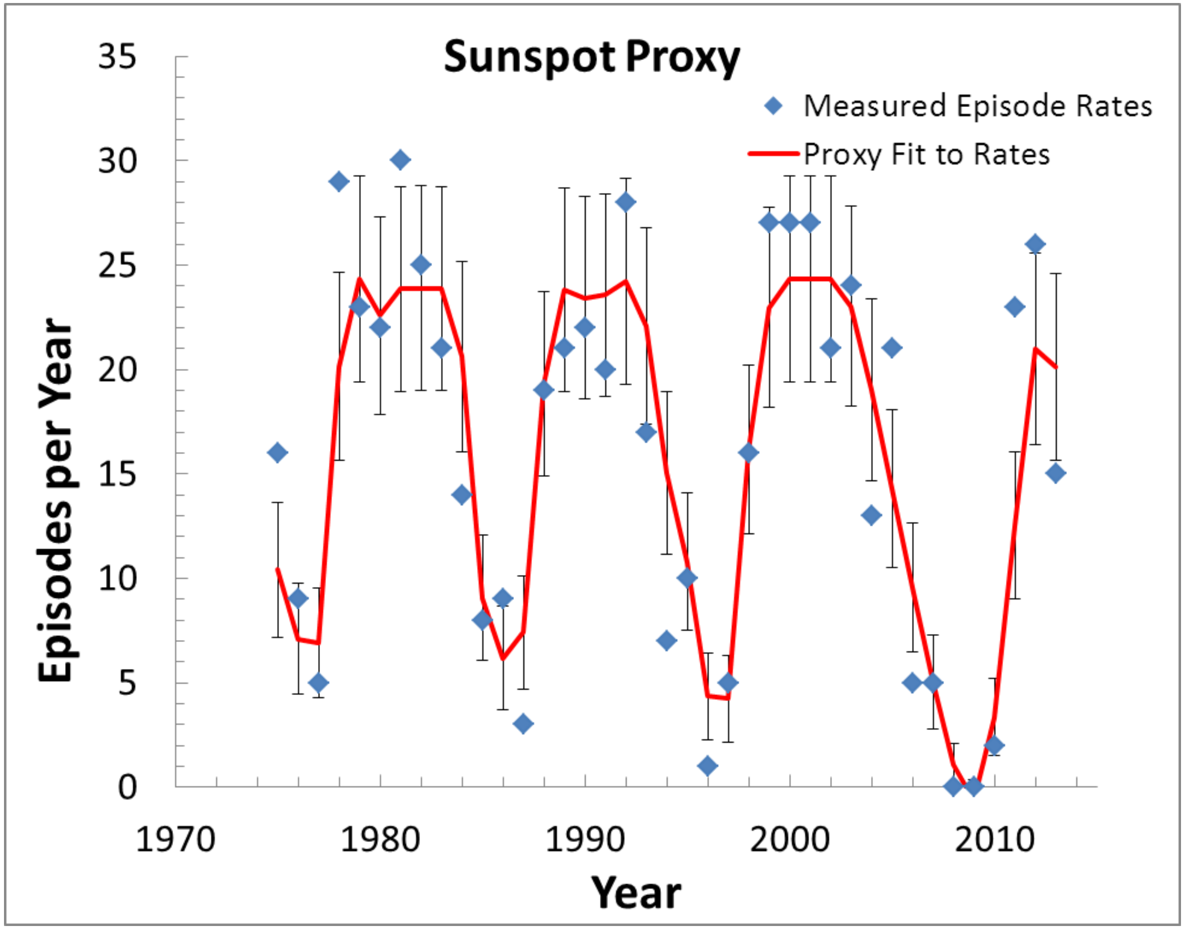

Image from
Robinson, 2015

Episodes Per Year

11-year solar cycle fit

- Fit an 11-year cycle to the database
- The set with the best Reduced Chi Squared was the year starting October 1 ending September 30 (Robinson 2015)

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Episodes Per Year

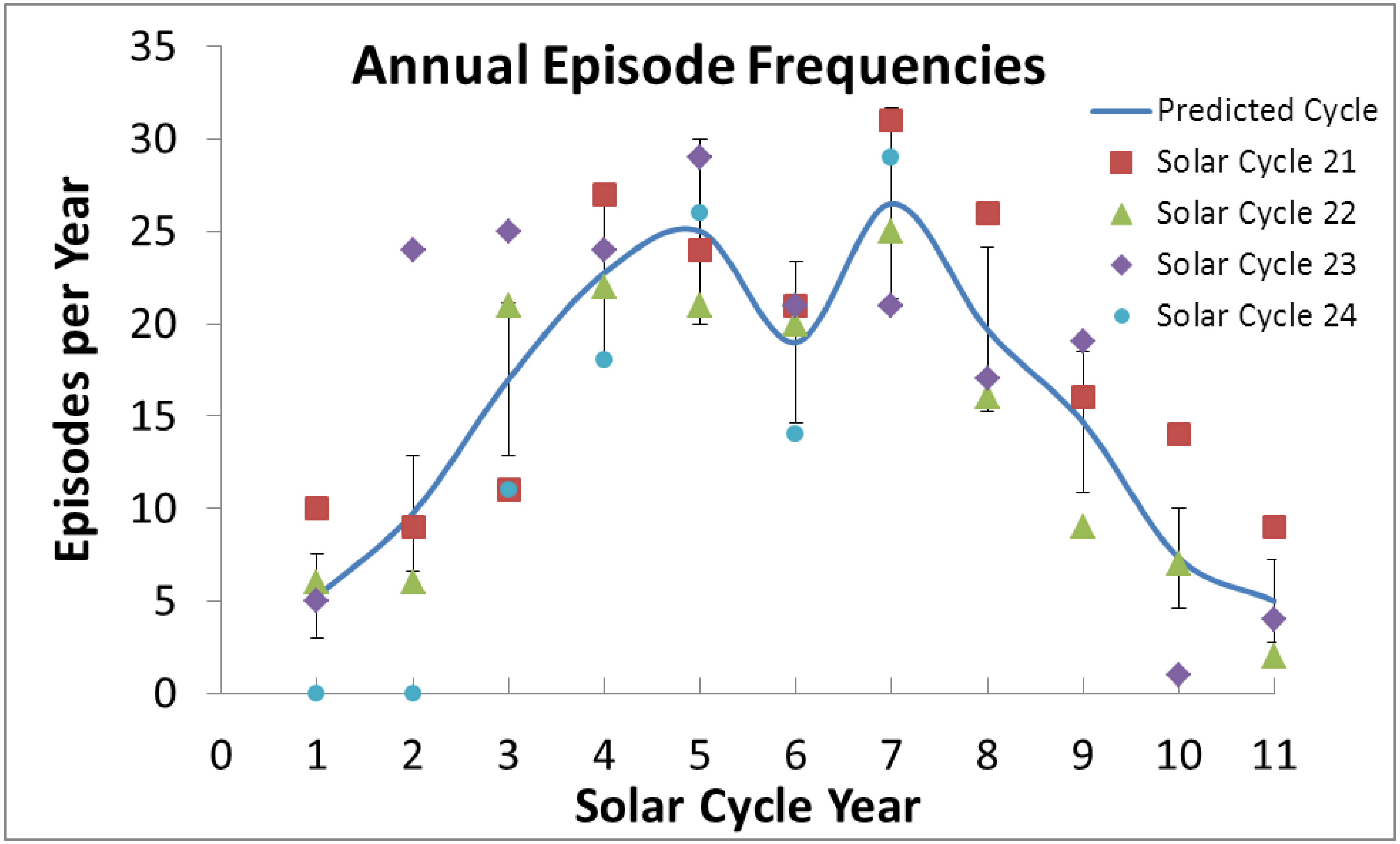
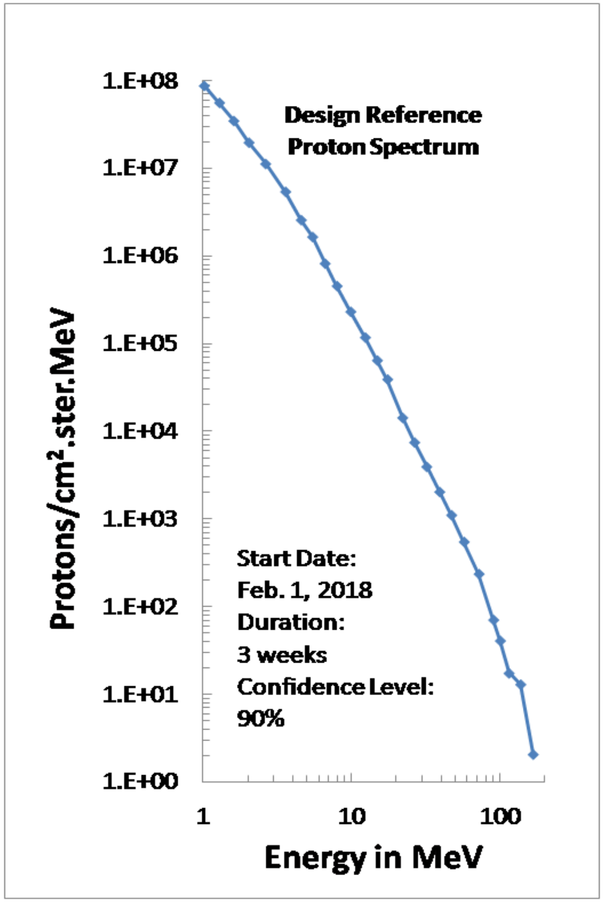
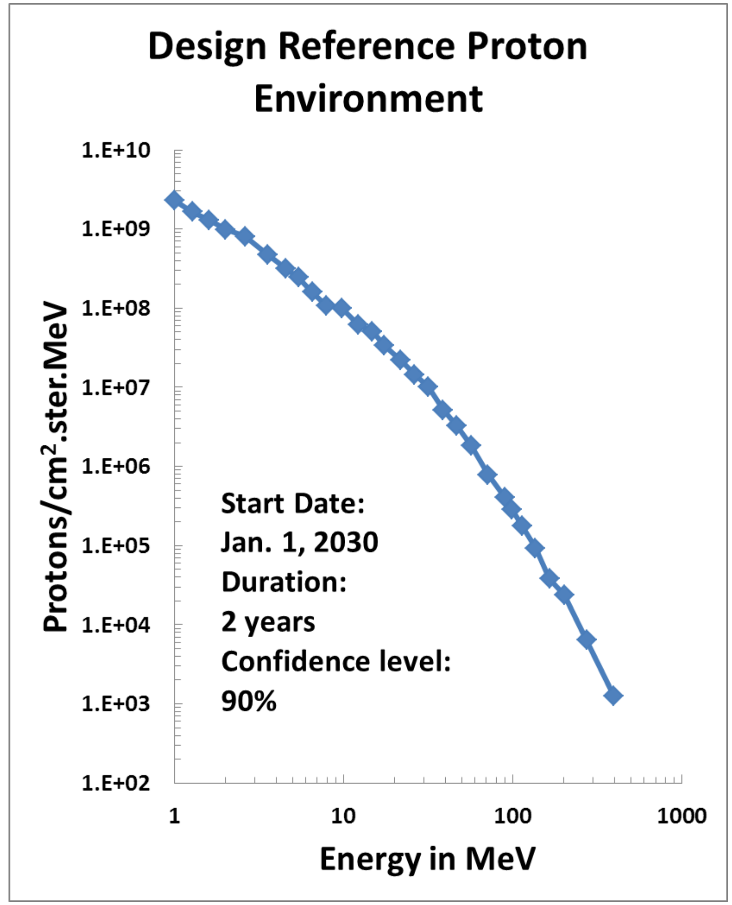


Image from
Robinson, 2015

Episode-Integrated Fluence Model



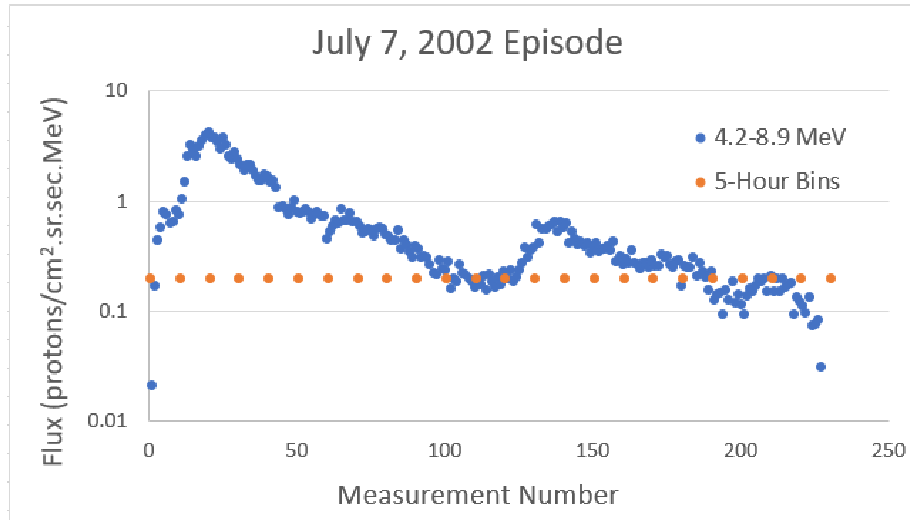


Images from Robinson, 2015

Peak Flux Model

Short Mission:

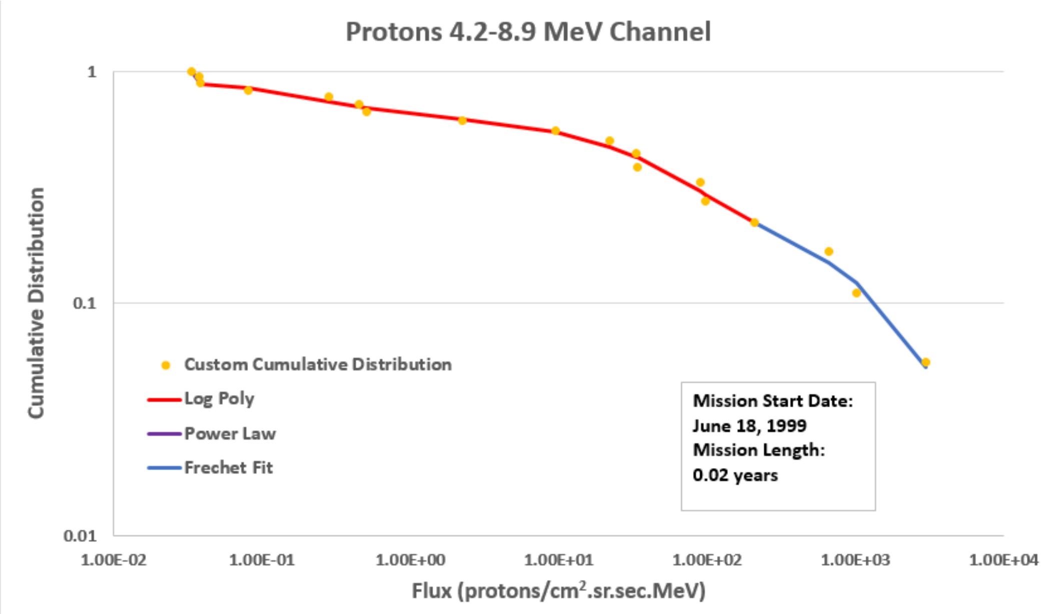
- Chronological list of flux measurements
  - Remove measurement at BKGD
- Mission length used to group data
  - Maximum flux taken to build a custom cumulative distribution
- Confidence Level used to determine if flux is above BKGD



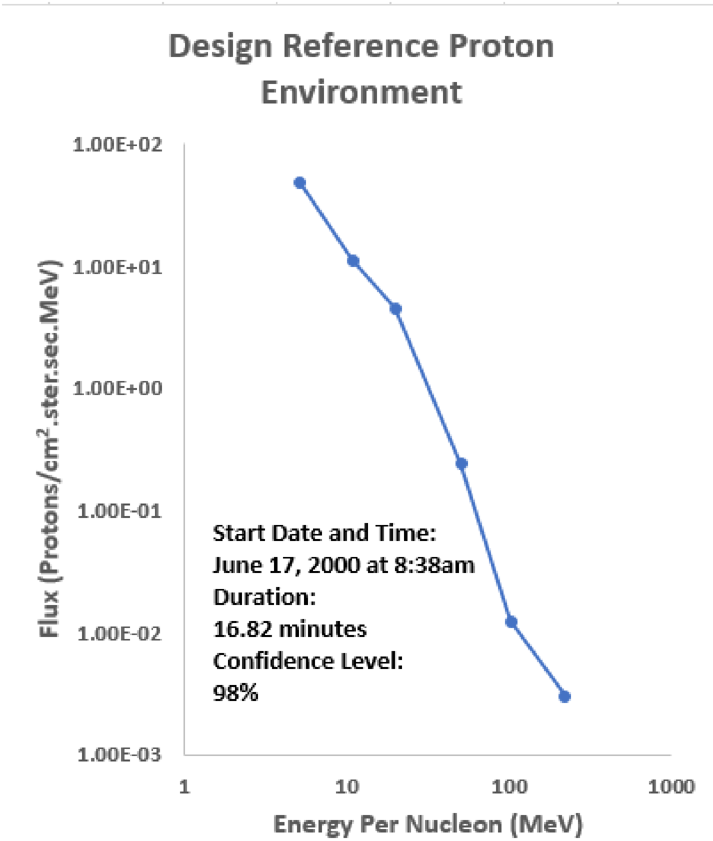
Peak Flux Model

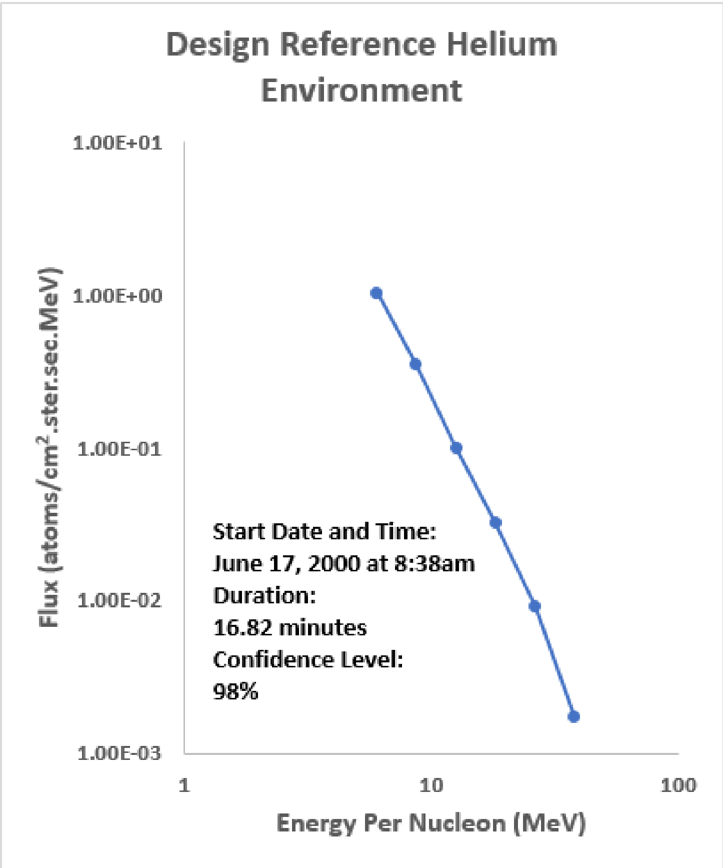
Short Mission:

- If under 1000 groups, use 3 fits [Robinson, 2015]:
  - Power Law
  - 6th Order Logarithmic Polynomial
  - Fréchet Distribution
- If over 1000 groups, use the custom distribution
- Linear interpolation used between values in distribution



Peak Flux Model





Future Work

- Update the Episode-Integrated Fluence Model
  - Include data from 2014-2016
  - Improve the normalization between the satellites
- Add the heavier ions to the Peak Flux Model
  - Build data bases for the most abundant elements
  - Use elemental ratios to scale distributions

References

- Robinson, Z. D. (2015). *New probabilistic model for episode integrated fluences of protons using episodes from 1973-2013*. University of Alabama in Huntsville.
- Xapsos, M. A., Summers, G. P., & Burke, E. A. (1998). Probability model for peak fluxes of solar proton events. *IEEE Transactions on Nuclear Science*, *45*(6 PART 1), 2948–2953. https://doi.org/10.1109/23.736551
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- Hathaway, D. H., Wilson, R. M., & Reichmann, E. J. (1994). The Shape of the Sunspot Cycles. *Solar Physics*, *151*, 177–190.

Extreme Value Theory

- Provides a way to study the extremes of a distribution in order to provide better predictions of the tails of a statistical distribution.
- Used in a wide range of fields (including radioactive emission and rainfall analysis)
  - Determining whether outlying observations should be used by astronomers. (Kotz and Nadarajah, 2000)
- This method used in the two models discussed today follows the work of Xapsos et al. (1998).

Extreme Value Theory

- Maximize entropy

$$S = -\int_0^{M_{max}} p(M)\ln[p(M)]\,dM$$

Where $M = \log(\phi)$

- Conditions:

$\int_0^{M_{max}} p(M)dM = 1$

$\int_0^{M_{max}} Mp(M)dM = \omega$

$M_{min} = 0$

M_{max} is finite

Extreme Value Theory

- Using Lagrange multipliers

$$p(M) = \frac{\lambda}{1 - \exp(-\lambda M_{\max})} \exp(-\lambda M)$$

- Integrate from 0 to M:

$$P(M) = \frac{1 - \exp(-\lambda M)}{1 - \exp(-\lambda M_{\max})}$$

Extreme Value Theory

- The probability that n events won't have a flux $\geq \phi$:

$$[P(M)]^n$$

- Using Poisson's equation:

$$\frac{\left[e^{(-\mu T)}(\mu T)^n\right]}{n!}$$

Cumulative Distributions

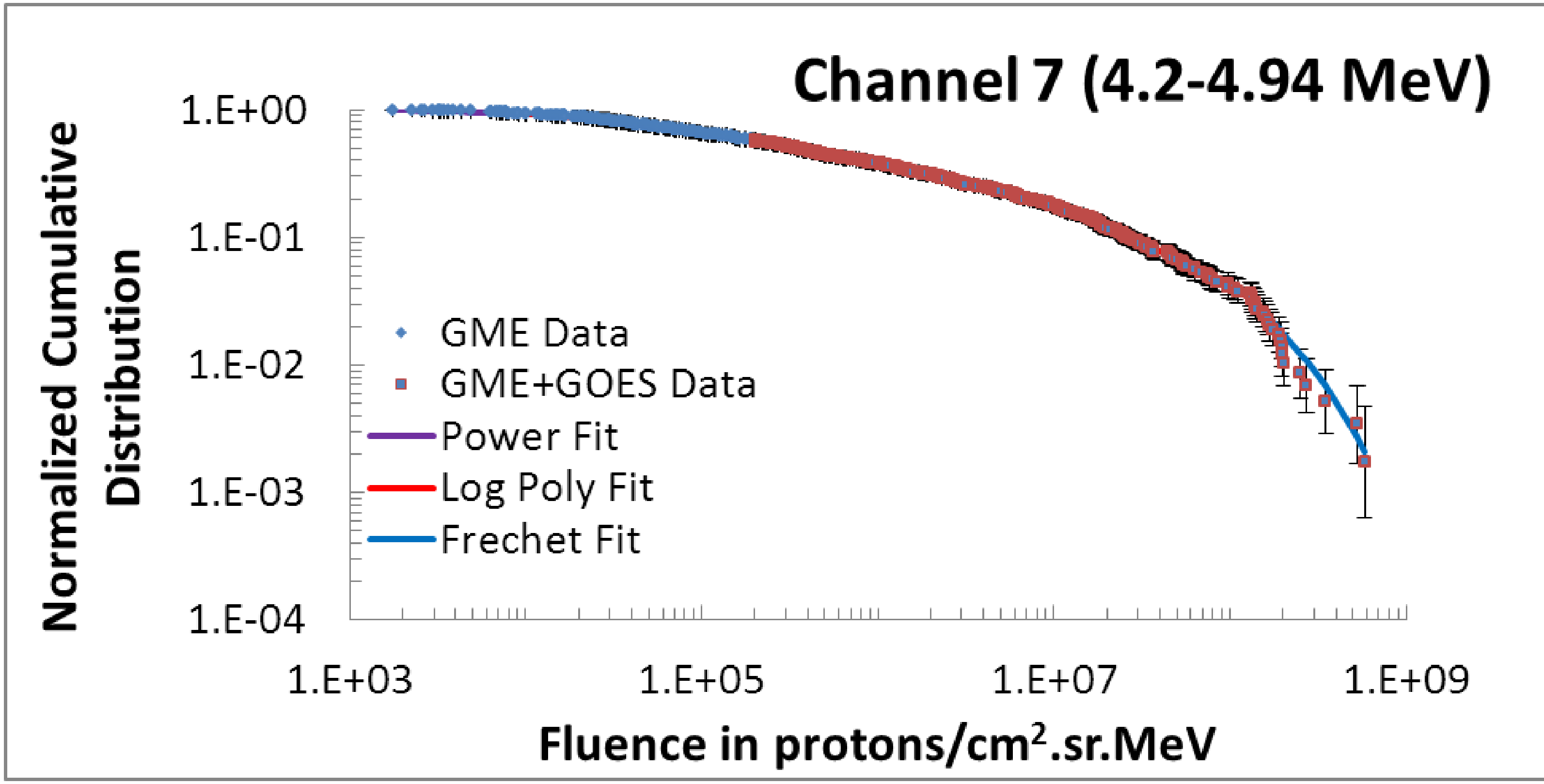

Image from
Robinson, 2015