Forecasting Solar Energetic Particle Events Using Changes in Electron Flux

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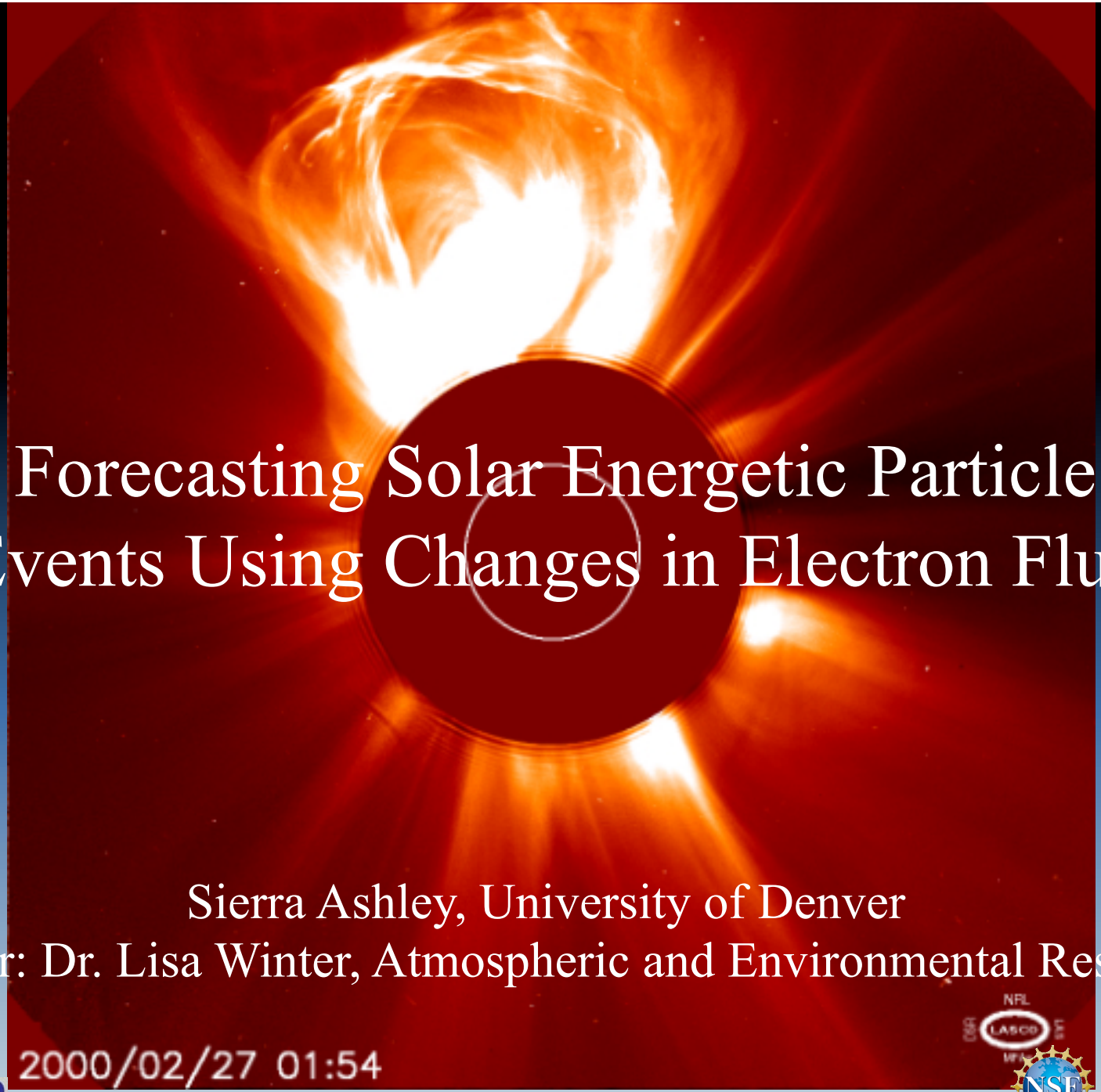


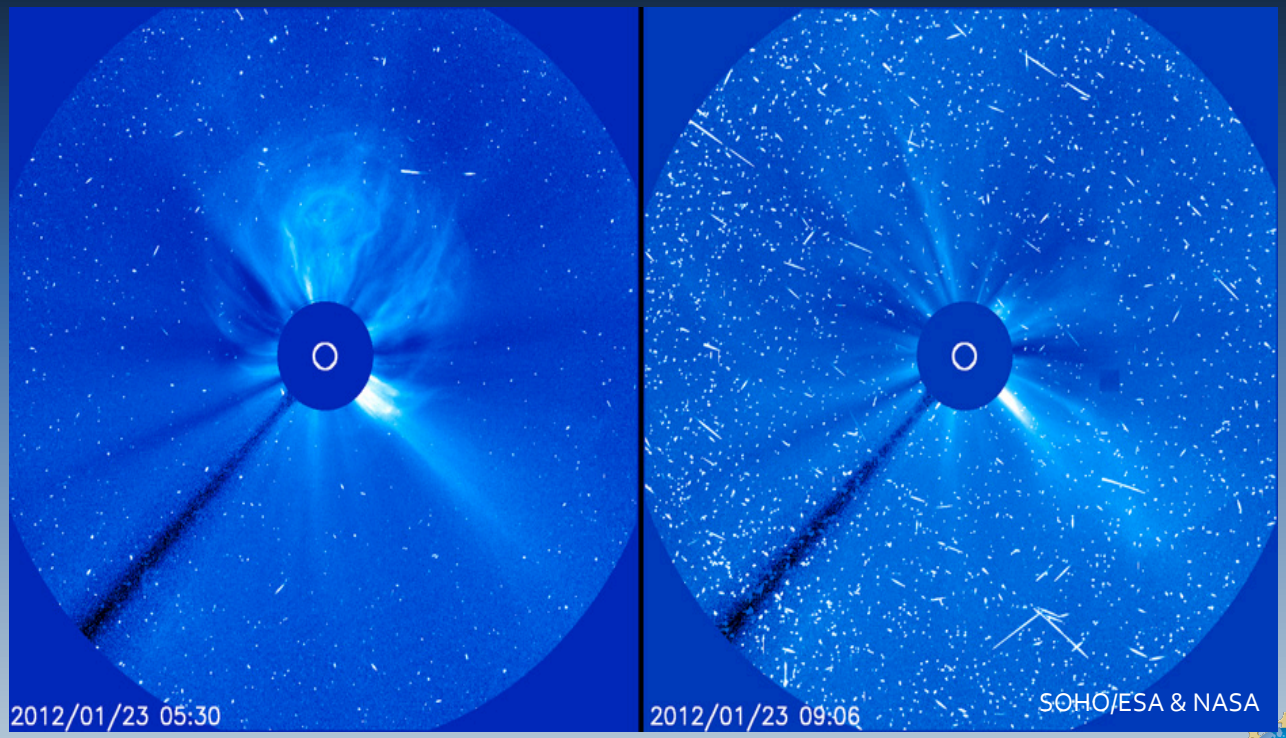
SOHO (NASA /ESA)

Outline

- Background
  - What are SEP events?
  - Why are they important?
  - GOES data
- Early methods and results
  - Determination of start times for increased proton and electron flux
- Revised methods
  - Use of peak proton and electron times
  - Time leading up to an SEP event
- Future Work
  - Analysis of more data

Solar Energetic Particle Events

- Associated with Coronal Mass Ejections
- High energy particles (protons, electrons, and other ions) ejected into space



Importance of Forecasting SEP Events

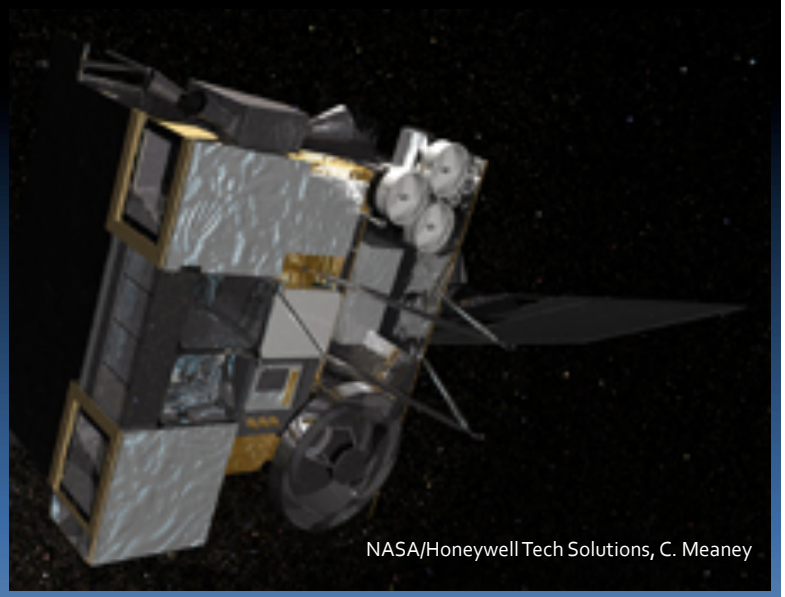
- SEP Events Can Cause:
  - ☞Radiation levels on transpolar flights become higher than normal
  - ☞Harm to astronauts
  - ☞Damage to satellites

- Predicting an event allows companies and governments to protect their investments and people in space and polar regions


Telesat Canada

Data Sources

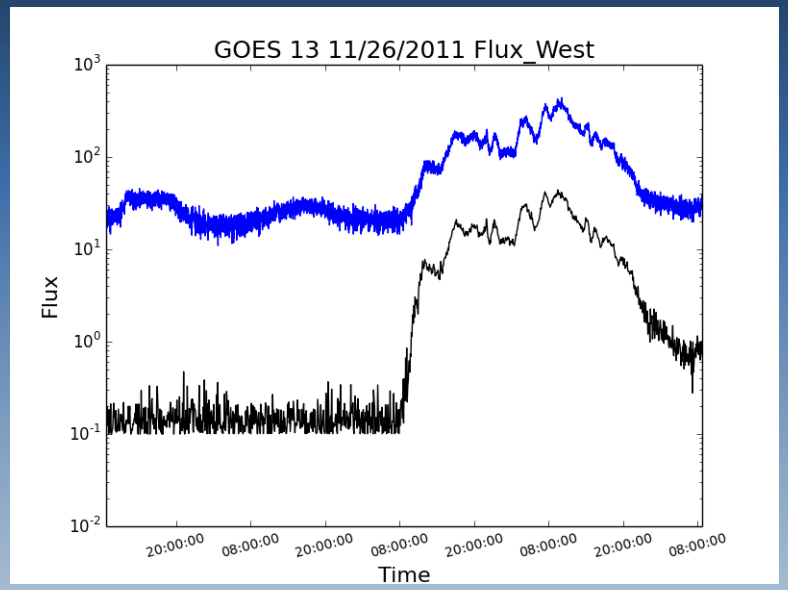
- Geostationary Operational Environmental Satellites

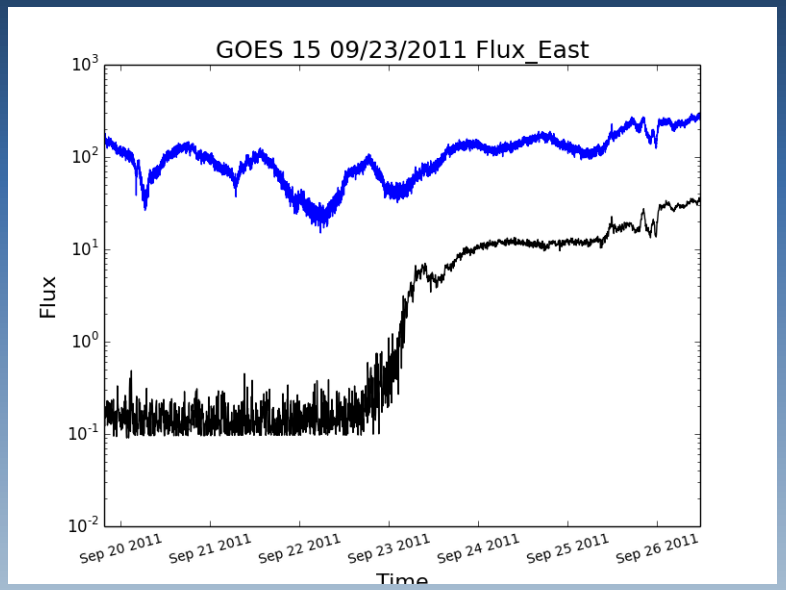


- GOES 13
  - ☞ Launched in May 2006
- GOES 15
  - ☞ Launched in March 2010
- Types of Data Analyzed
  - ☞ Proton data taken at 5 minute intervals
  - ☞ Electron data taken at 1 minute intervals

Initial Analysis

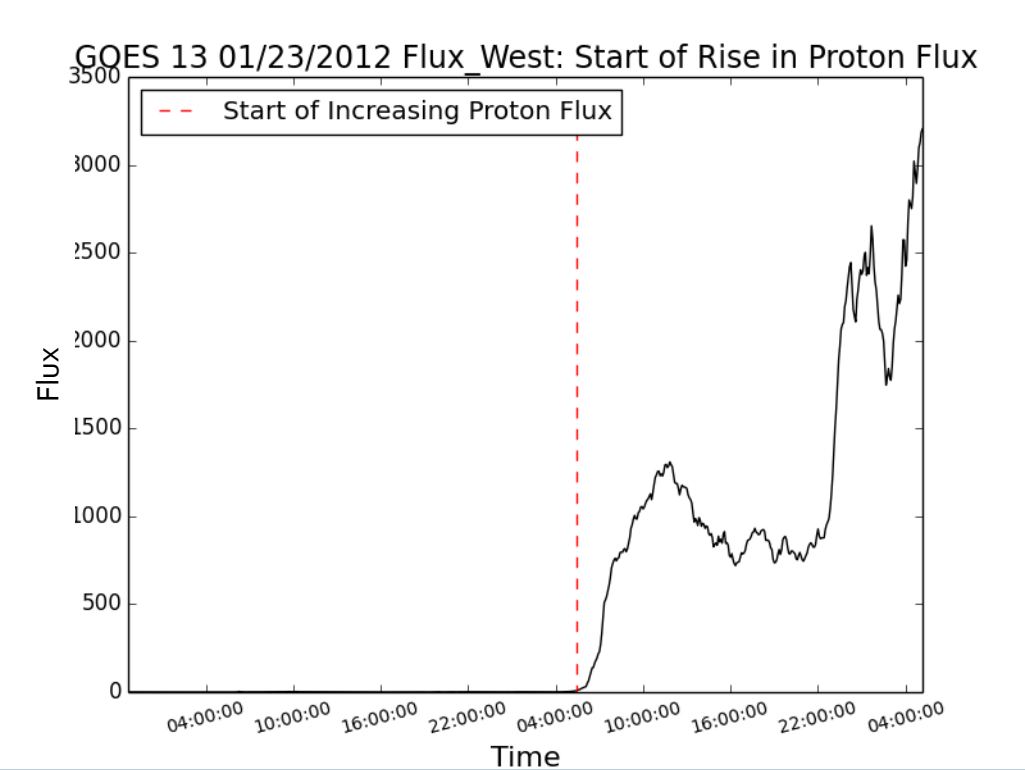
- Viewed 48 – 80 hour window of SEP events
- Protons (black line) with energy >10 MeV
- Electrons (blue line) with energy >2 MeV





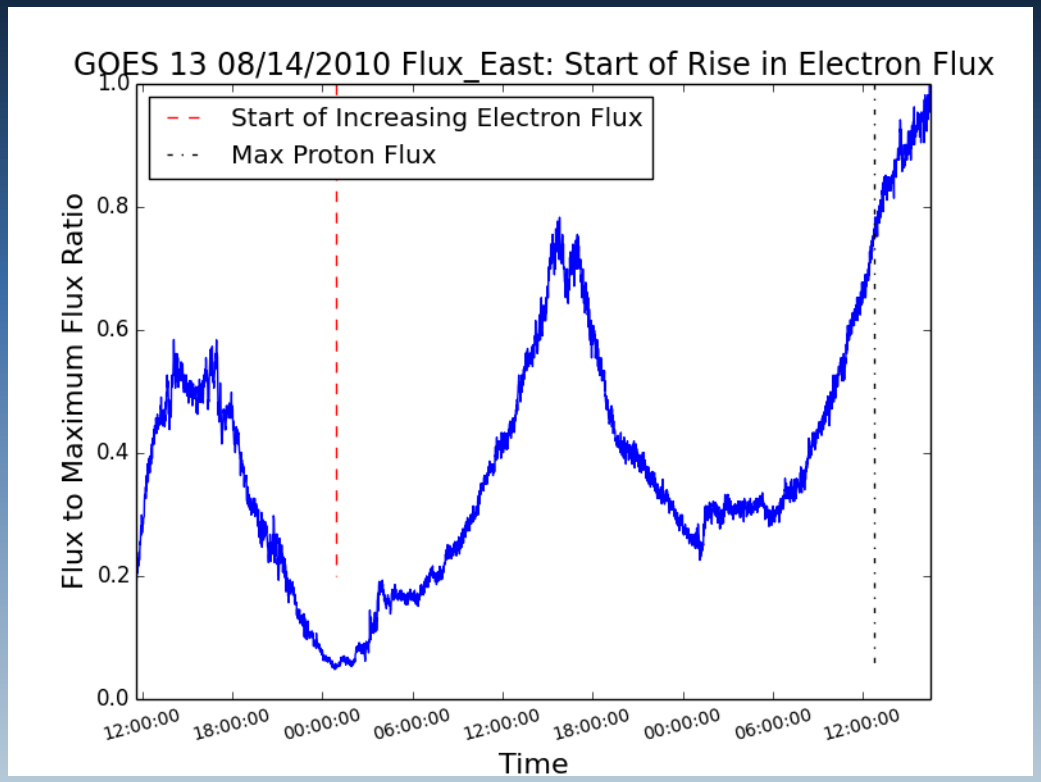
- Proton peak times determined by finding maximum flux over the time period
  - ☞ Times were confirmed with previous results (studied in Winter and Ledbetter, in prep)

- Start of SEP event determined by time that proton flux reached 10 proton flux units (pfu)



- Peak electron flux determined with the same method as peak proton flux

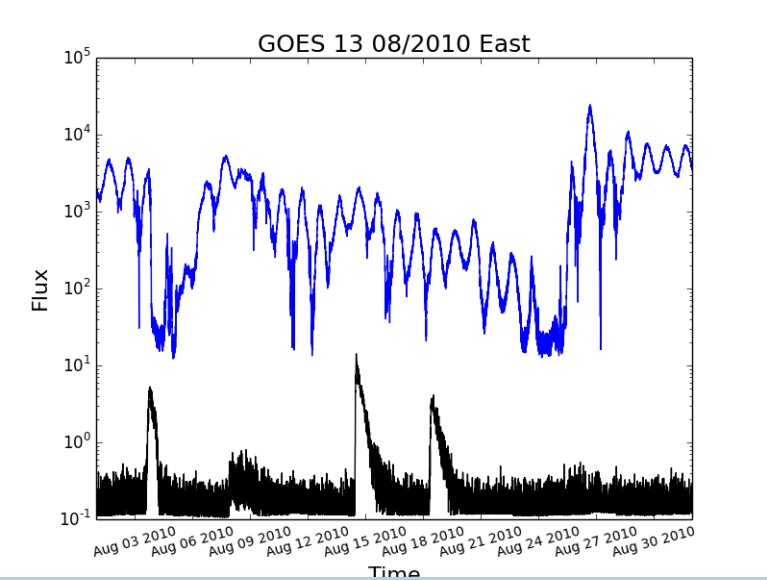
- Electron start time determined using a ratio of the maximum electron flux
  - Ratio based on what best fit the plot (there was an average ratio value of 0.16)

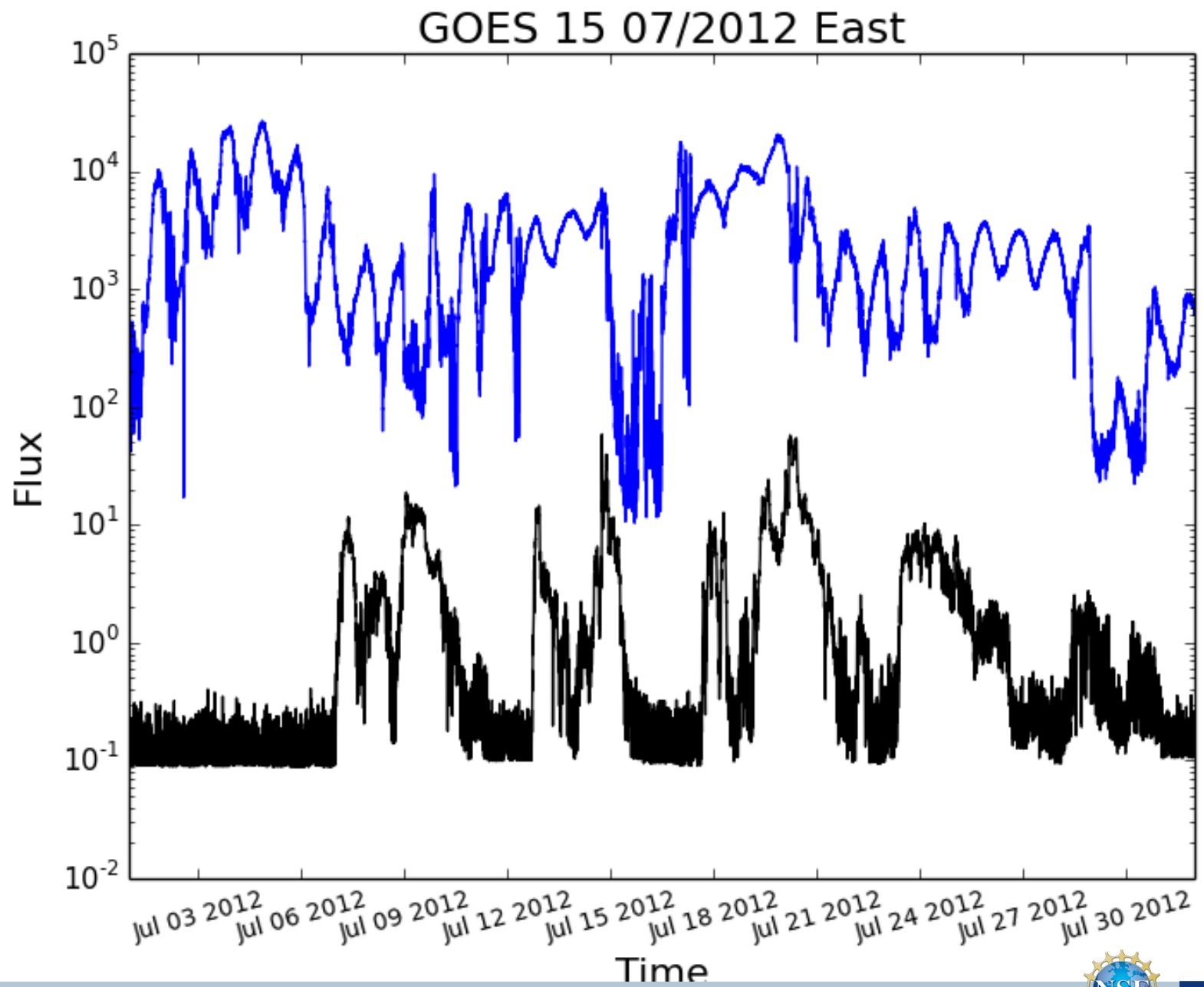


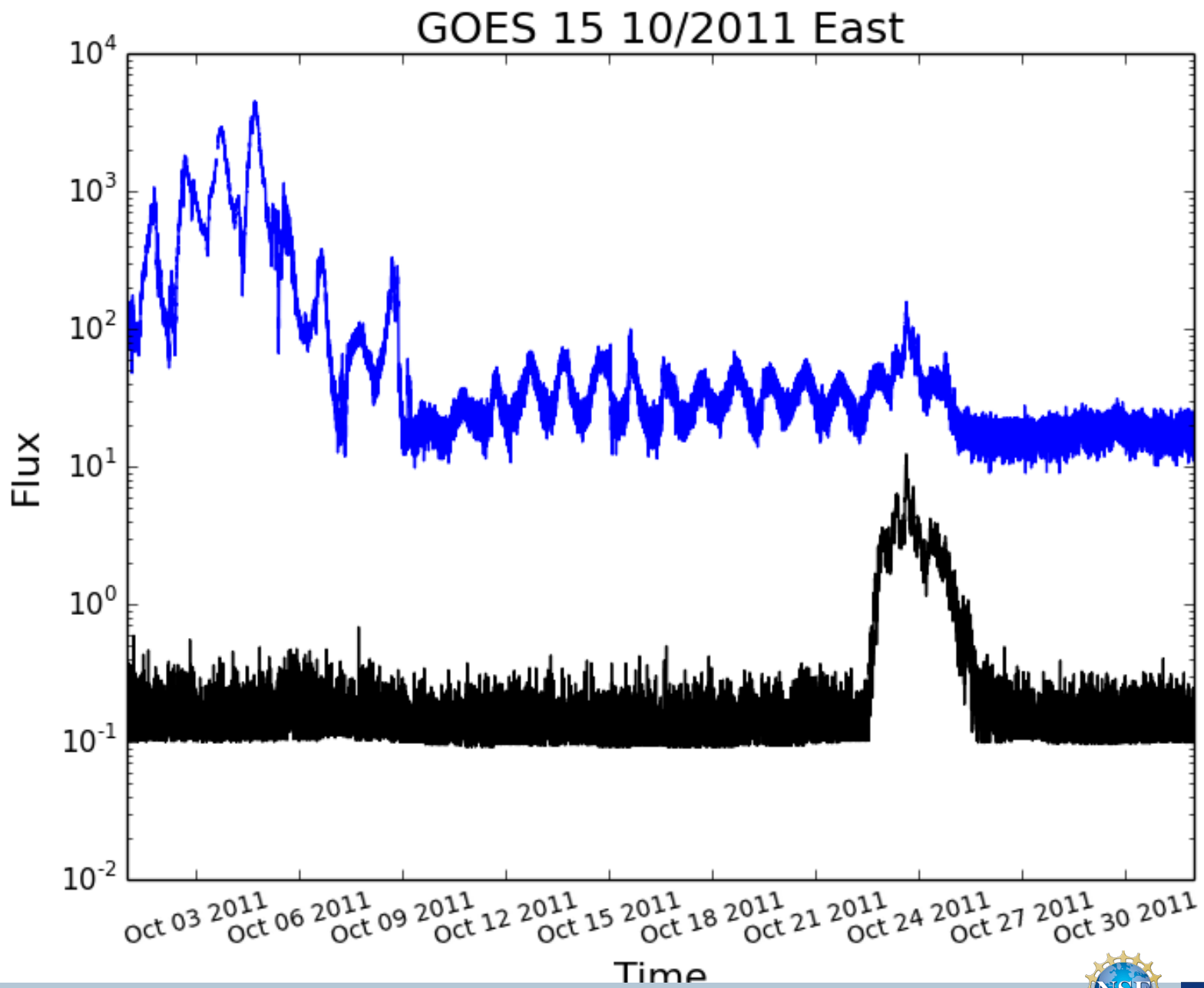
Month Long View of SEP Events

- Small windows limit view of electron activity
  - ☞ Disallowed determination of actual start time
  - ☞ Electron flux seemed to follow rise in proton flux

- Extension to month long plots
  - ☞ Examine prolonged electron behavior before and during events
  - ☞ View entire SEP event



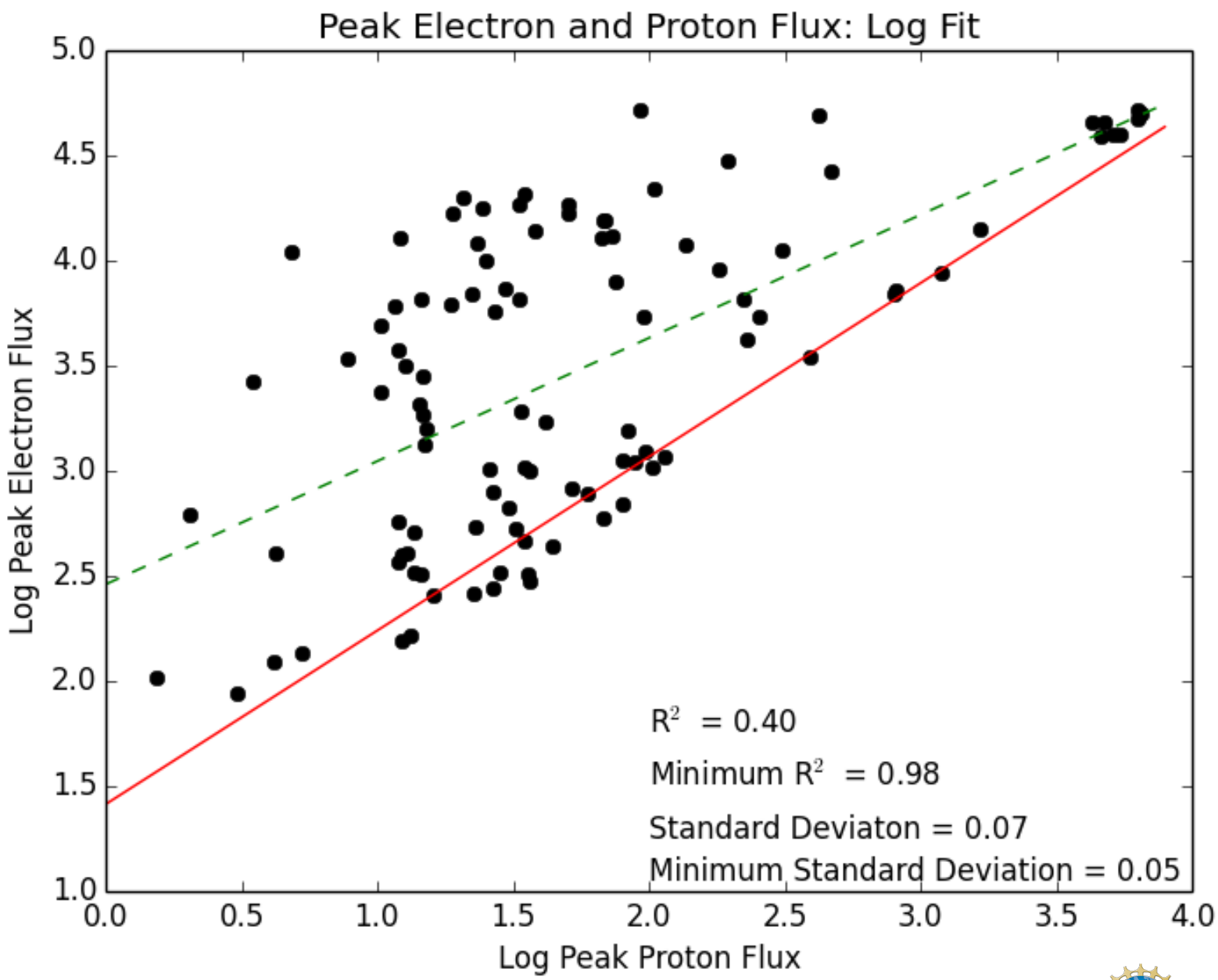

GOES 15 07/2012 East
Flux
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
Jul 03 2012
Jul 06 2012
Jul 09 2012
Jul 12 2012
Jul 15 2012
Jul 18 2012
Jul 21 2012
Jul 24 2012
Jul 27 2012
Jul 30 2012
Time

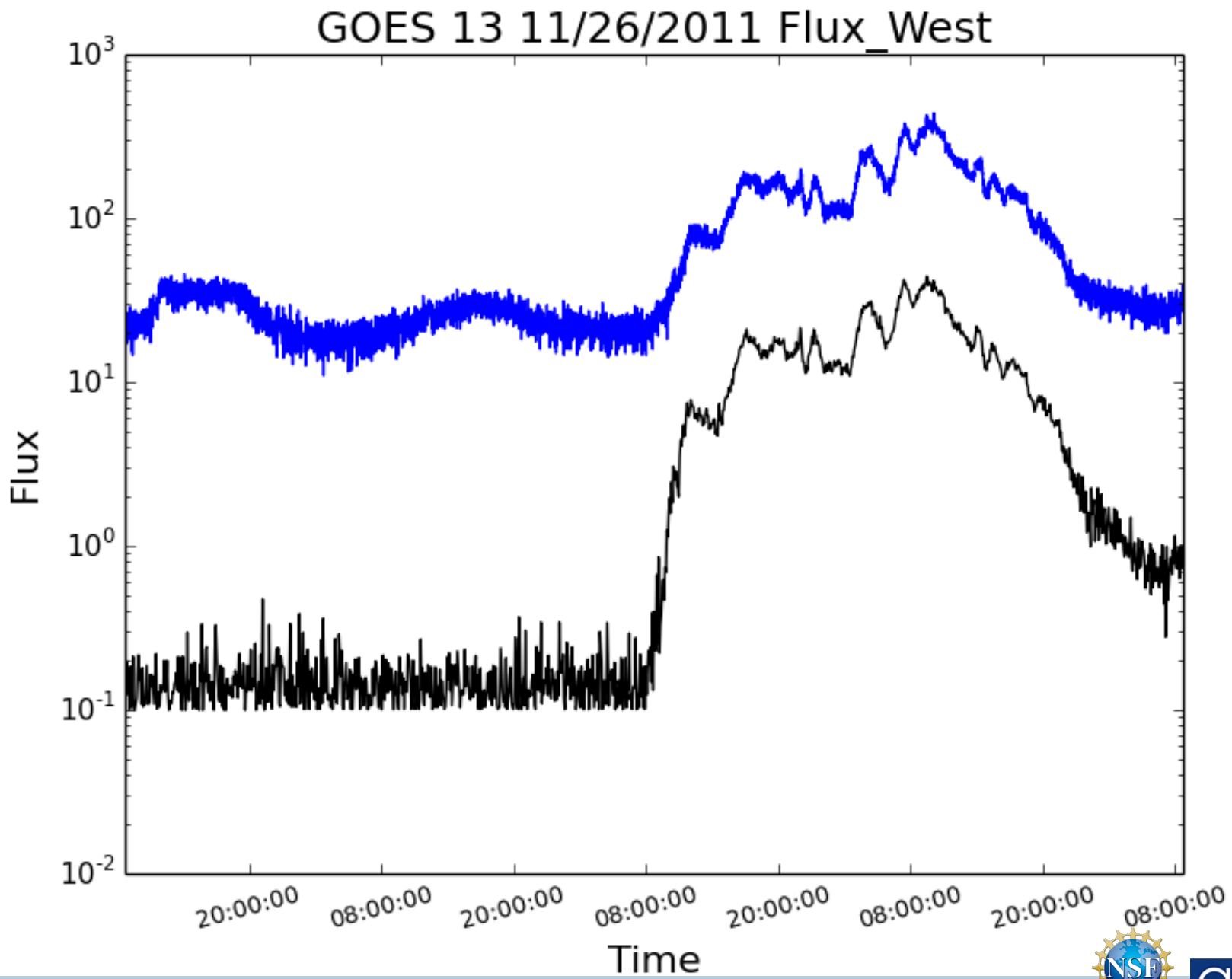

GOES 15 10/2011 East
Flux
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
Oct 03 2011
Oct 06 2011
Oct 09 2011
Oct 12 2011
Oct 15 2011
Oct 18 2011
Oct 21 2011
Oct 24 2011
Oct 27 2011
Oct 30 2011
Time

Use of Peak Times and Values

- From initial analysis
  - ☞ Electron start times not useful due to complex structure of electron profiles
  - ☞ Proton start times will provide next step analysis of lead-times
  - ☞ Peak proton and electron flux and times are useful in prediction

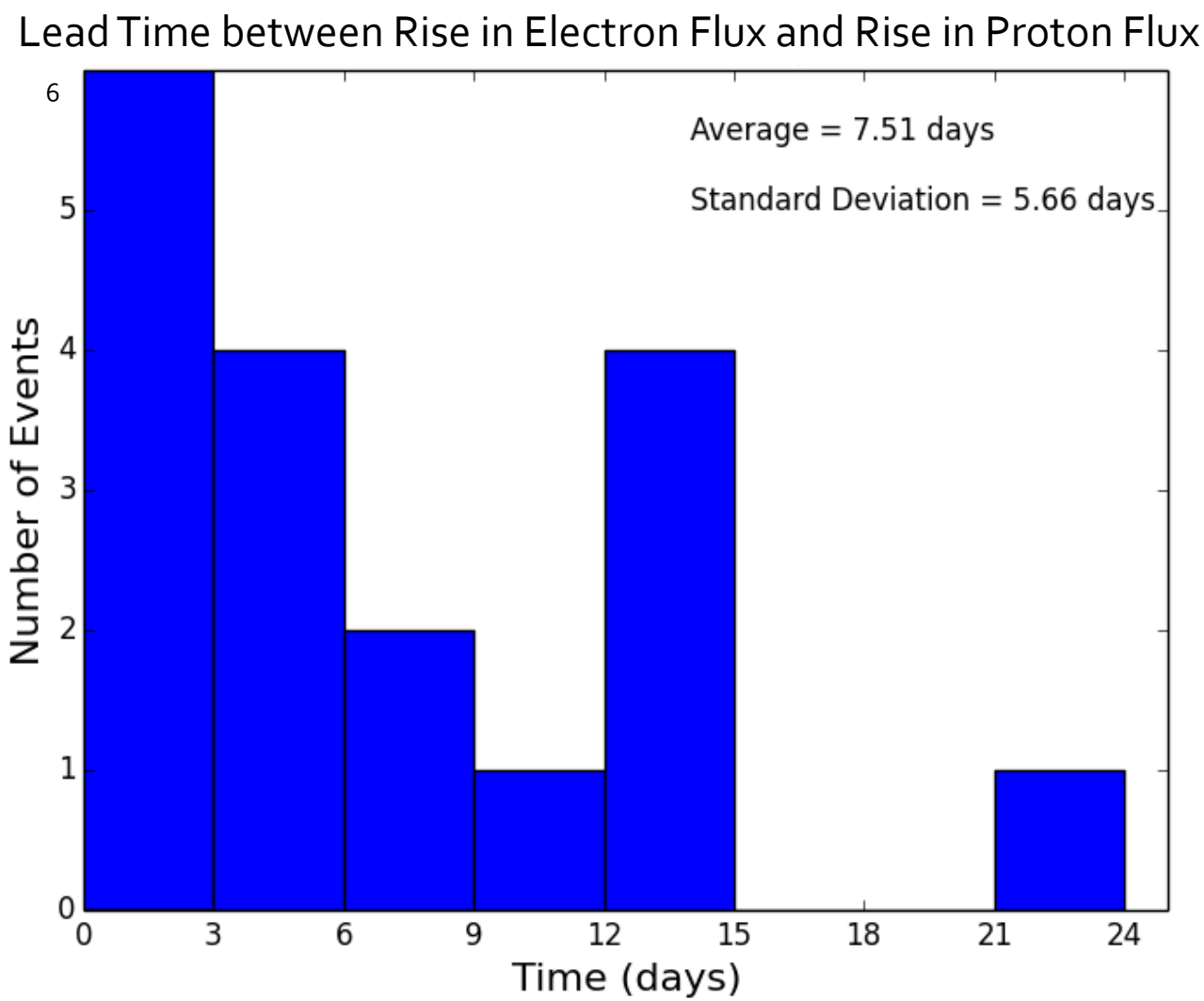
- Examination of data for correlation between peak electron and peak proton flux


Peak Electron and Proton Flux: Log Fit
Log Peak Electron Flux
Log Peak Proton Flux
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
R² = 0.40
Minimum R² = 0.98
Standard Deviaton = 0.07
Minimum Standard Deviation = 0.05


GOES 13 11/26/2011 Flux_West
Flux
Time
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
20:00:00
08:00:00
20:00:00
08:00:00
20:00:00
08:00:00
20:00:00
08:00:00

Using the Increase in Electron Flux to Predict Proton Peak Flux

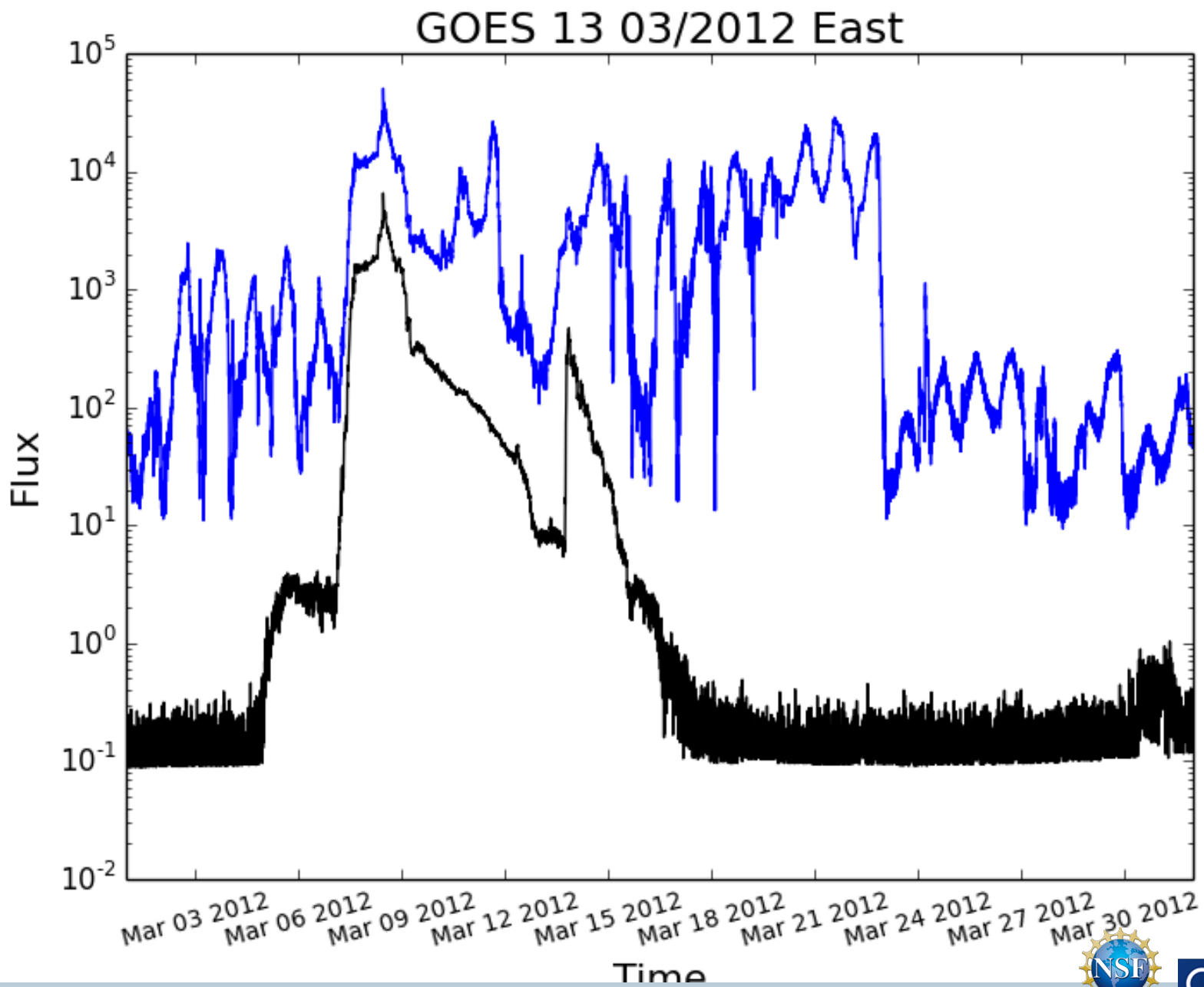
- To Test the possible use of the electron-proton peak flux correlation for forecasting proton peak flux
  - Used fit to the minimum electron peak flux vs. proton peak flux
  - Using value of peak proton flux and equation of the fit
  - Determined the time difference between electron flux level based on minimum fit and peak proton flux to find the "lead-time"

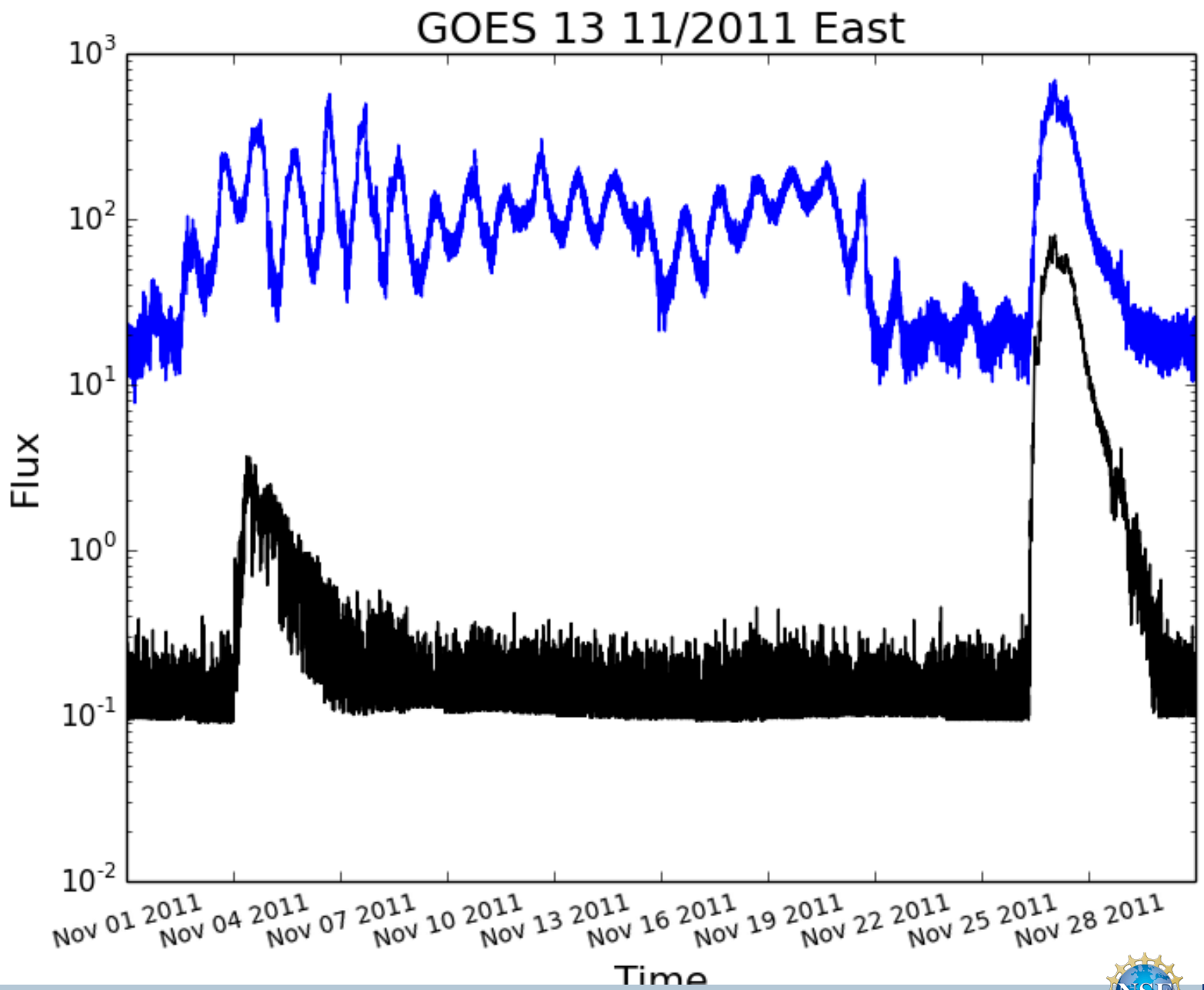


☞Minimum lead-time = 17 hours
☞Maximum lead-time = 22 days

Potential Problems for Forecasting with this Model

- 8 SEP events did not fit this model
  - 33% of our sample
  - Lower electron flux than expected based on the proton peak flux
  - Need to test for a larger sample of SEP events


GOES 13 03/2012 East
Flux
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
Mar 03 2012
Mar 06 2012
Mar 09 2012
Mar 12 2012
Mar 15 2012
Mar 18 2012
Mar 21 2012
Mar 24 2012
Mar 27 2012
Mar 30 2012
Time


GOES 13 11/2011 East
Flux
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
Nov 01 2011
Nov 04 2011
Nov 07 2011
Nov 10 2011
Nov 13 2011
Nov 16 2011
Nov 19 2011
Nov 22 2011
Nov 25 2011
Nov 28 2011
Time

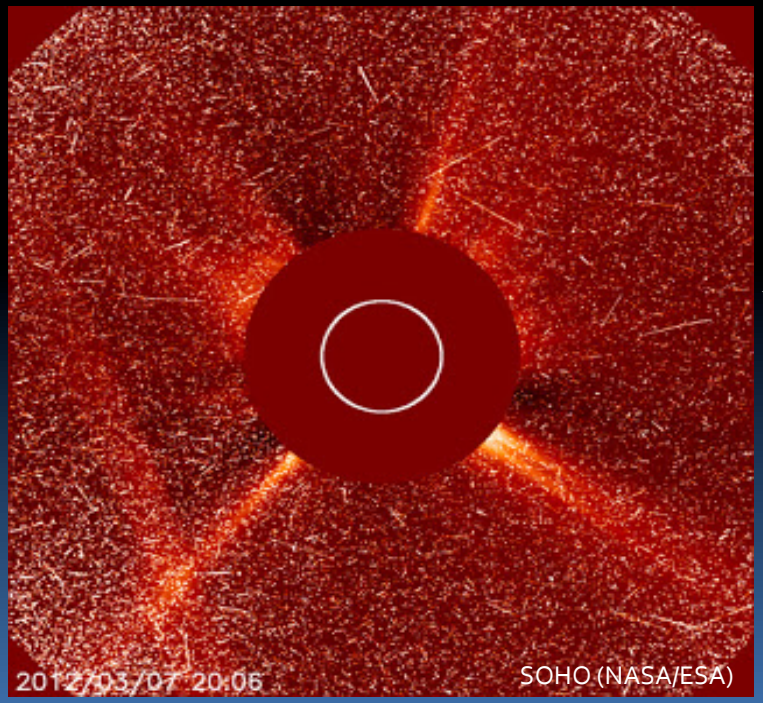
Conclusion

- **Correlation between peak electron and peak proton flux**

- **Technique used to find lead-time can be applied to forecast the peak of future SEP events**
  - ☞ **Accurate forecast can be used to warn people about possible risks to humans and satellites**

- **More work needs to be done**
  - ☞ **determine how to apply the technique for real-time forecasting**
  - ☞ **fully characterize the limitations, for instance 8 events did not have electron flux high enough to fit into this model**

Future Work



- **Determine whether the electron flux rises to these levels during times where there is no increase in proton flux**
- **Analyze data for the 123 radio bursts occurring during this time period (studied in Winter and Ledbetter, in prep).**

Acknowledgements

Mentor: Dr. Lisa Winter (AER)

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Lam, H.-L., D. H. Boteler, B. Burlton, and J. Evens (2010), Anik-E1 and E2 statellite failures of January 1994 revisited, Space Weather, 10, S100003, doi: 10.1029/2012SW000811