



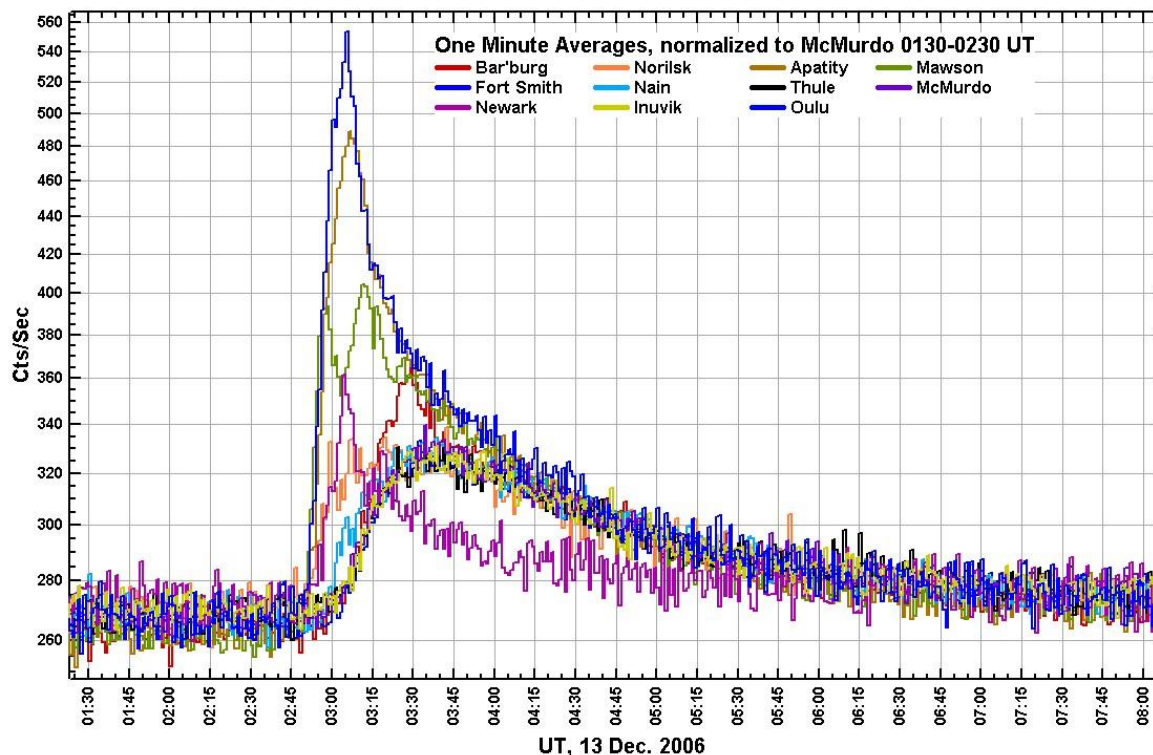
GLE and GLE-Wannabe Events in Solar Cycle 24

Christina M.S. Cohen (*Caltech*)
(J.G. Luhmann, R.A. Mewaldt, M.L. Mays,
H.M. Bain, Y. Li, C.O. Lee)

Ground Level Enhancements

- Historically
 - Increases in at least 2 separate ground-based monitors
- neutronm.bartol.udel.edu/~pyle/GLE_List.txt

Spaceship Earth Observations of the Solar Minimum GLE
Recorded December 13, 2006 by Neutron Monitors

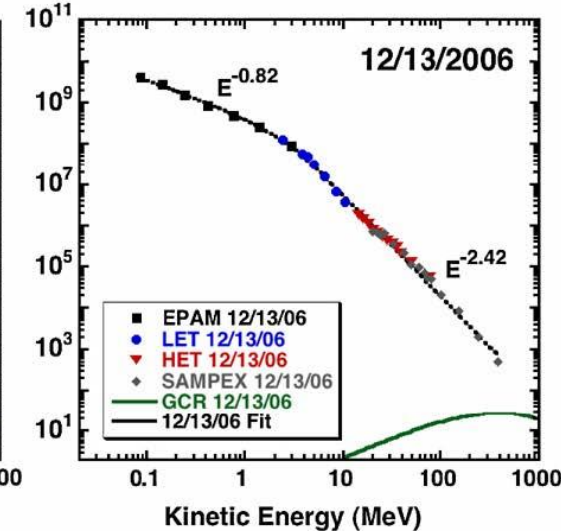
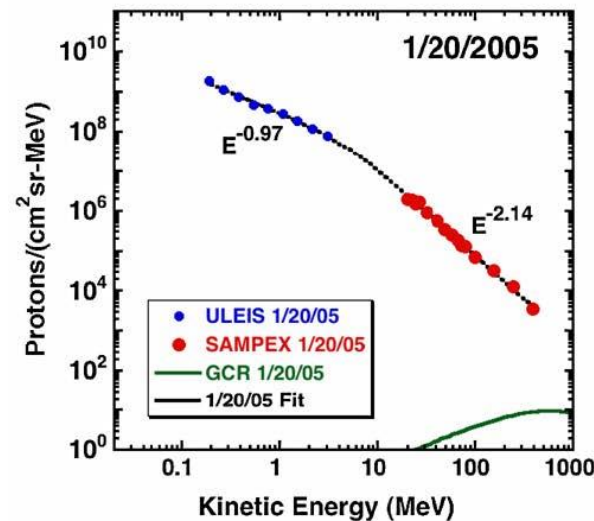
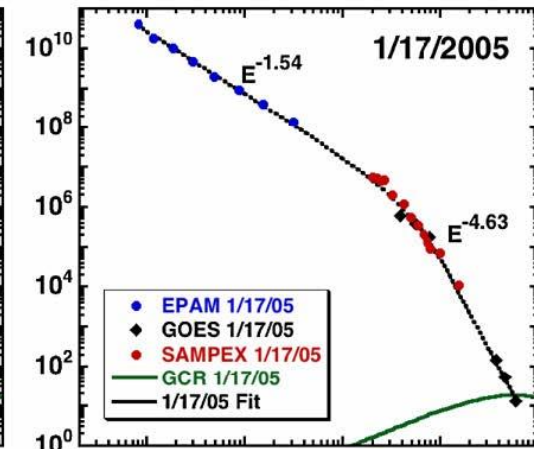
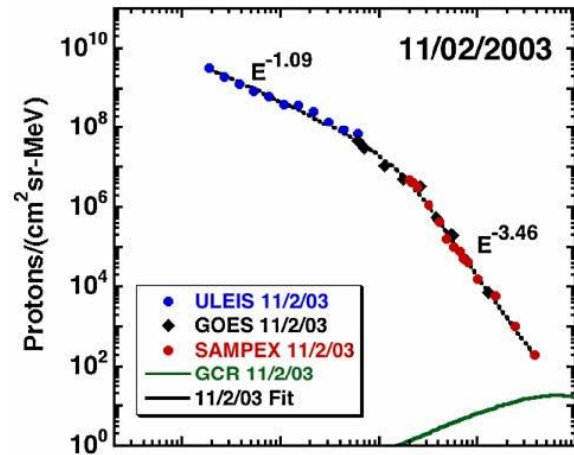


Ground Level Enhancements

- Historically
 - Increases in at least 2 separate ground-based monitors
 - neutronm.bartol.udel.edu/~pyle/GLE_List.txt
- Extreme type of SEP
 - Hard spectra
 - High fluences out to hundreds of MeV
 - Space weather hazard
 - Instrumentation
 - Astronauts
 - Polar flight passengers/crew

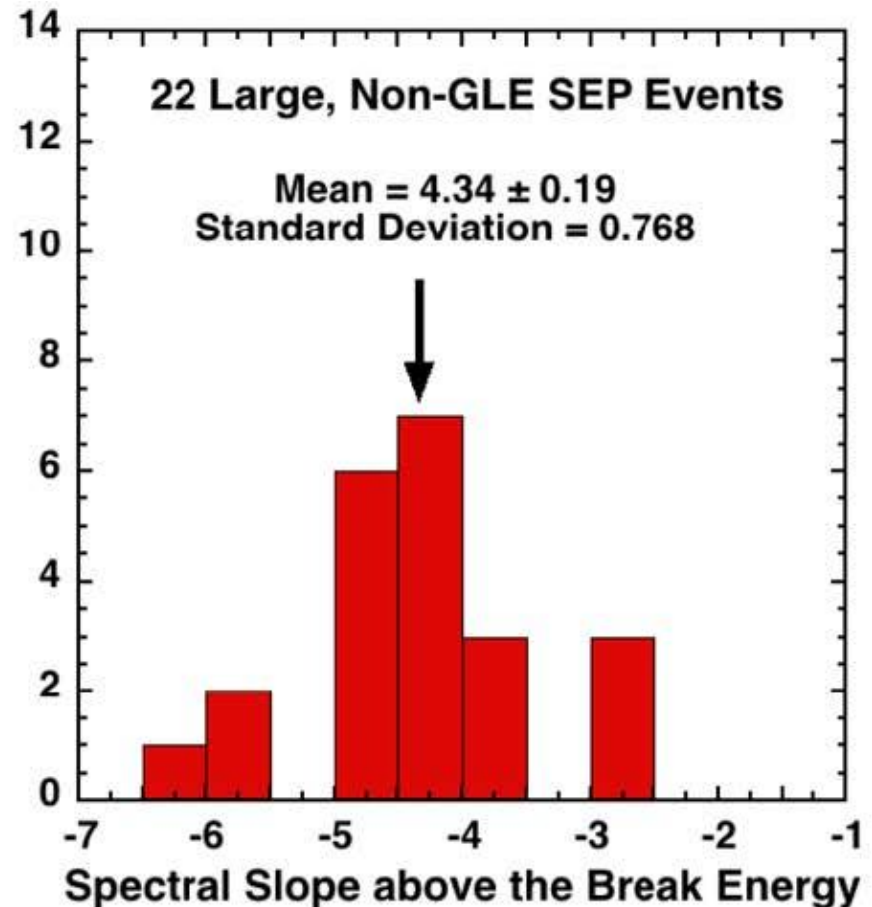
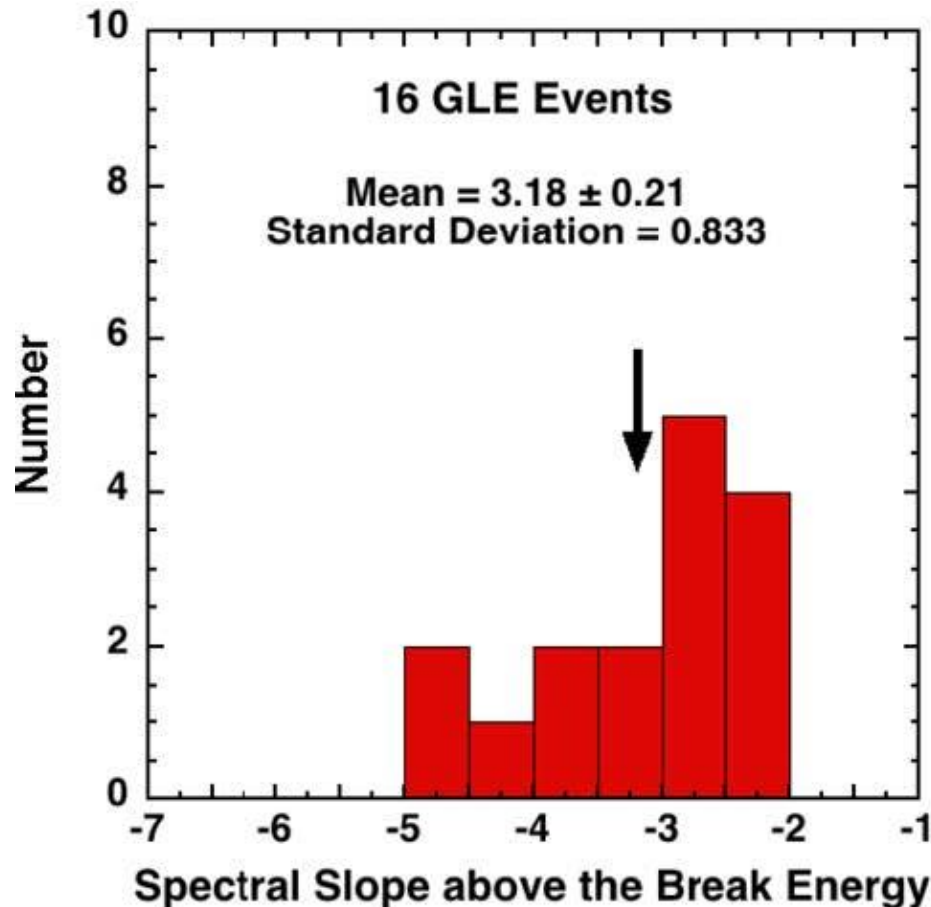
GLE Events

- Characteristics (vs large non-GLE SEP events)
 - Spectra are best characterized as double power-law



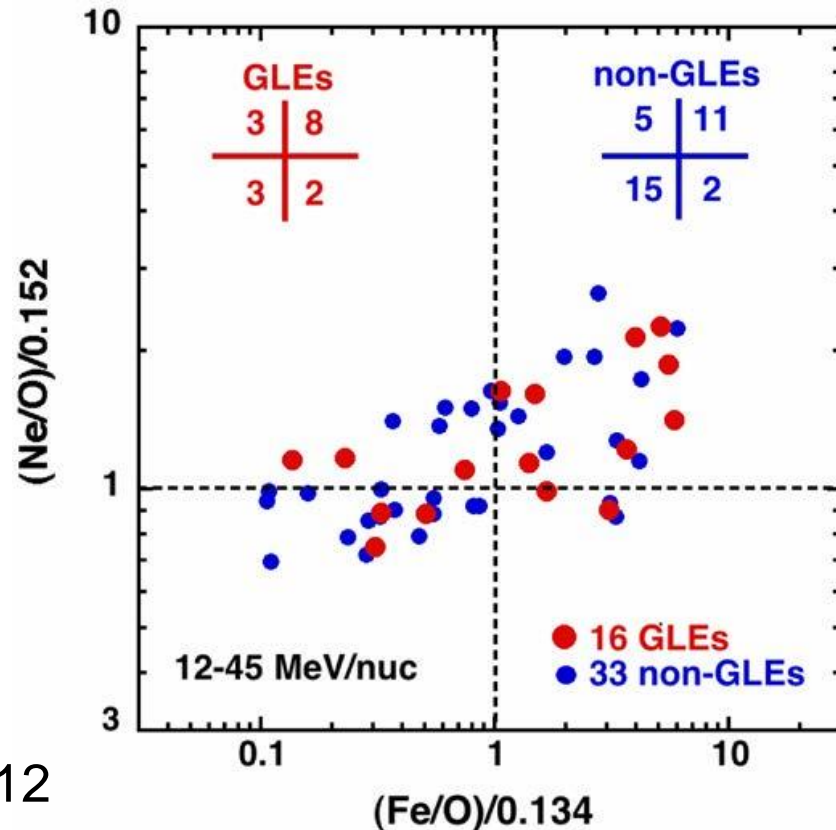
GLE Events

- Characteristics (vs large non-GLE SEP events)
 - Spectra are best characterized as double power-law
 - Spectra above break is harder



GLE Events

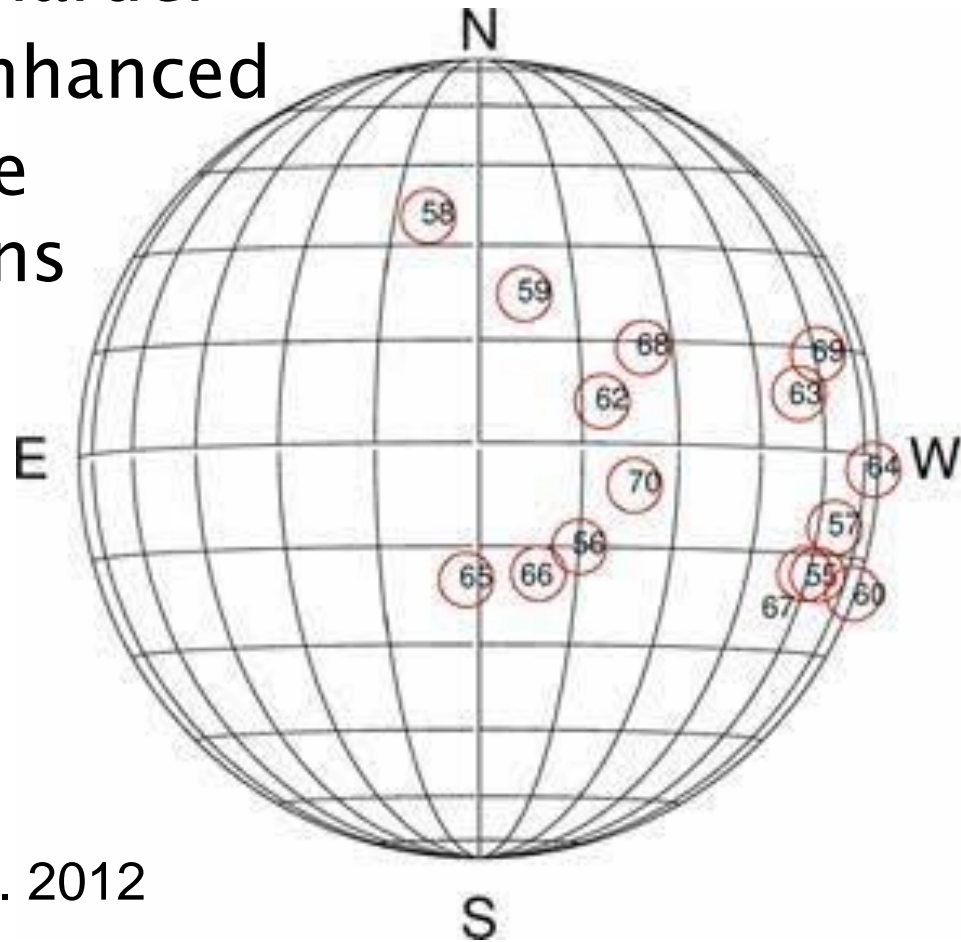
- Characteristics (vs large non-GLE SEP events)
 - Spectra are best characterized as double power-law
 - Spectra above break is harder
 - Fe/O and Ne/O often enhanced



Mewaldt, et al. 2012

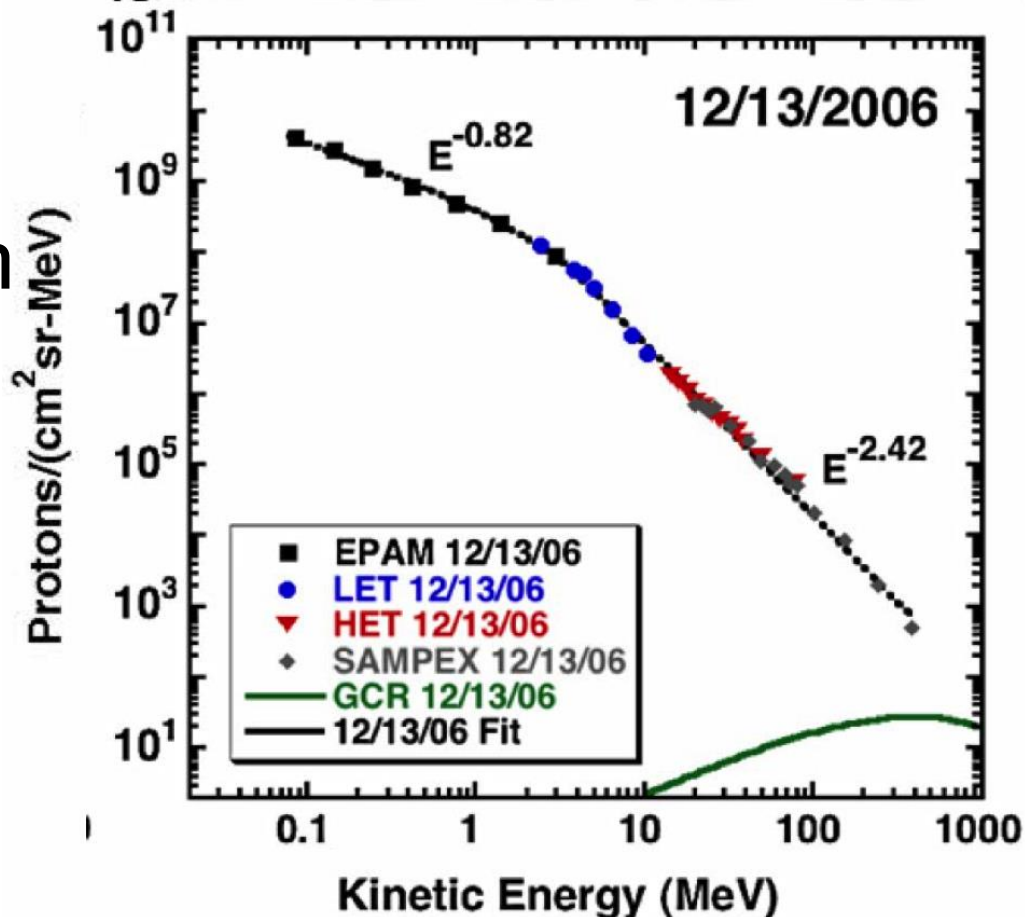
GLE Events

- Characteristics (vs large non-GLE SEP events)
 - Spectra are best characterized as double power-law
 - Spectra above break is harder
 - Fe/O and Ne/O often enhanced
 - Source regions are more likely to be active regions in the western solar hemisphere



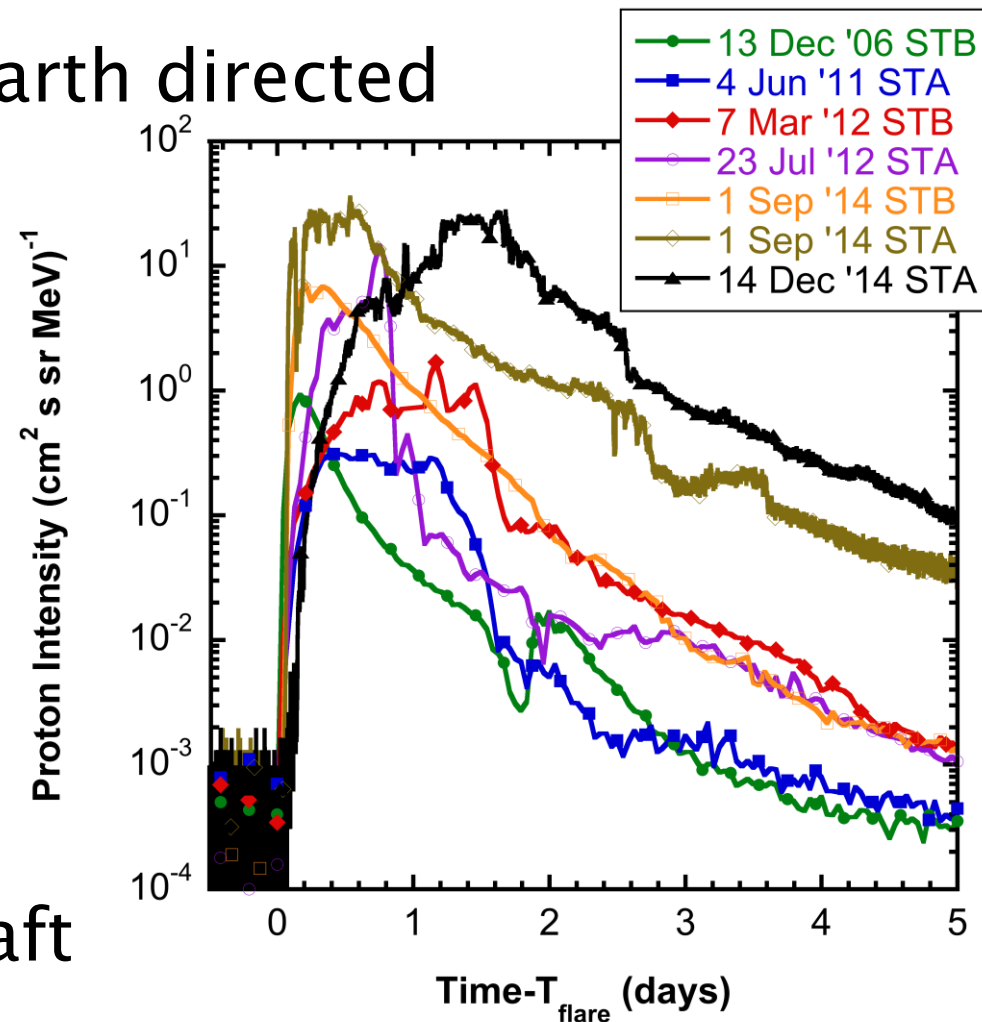
GLE-Wannabes

- GLE events are not preferentially directed towards Earth
 - But by definition non-Earth directed cannot be a GLE event
- Searched for GLE-Wannabe events with STEREO
 - Compared to 13 Dec 2006 event
 - Found 5 candidates



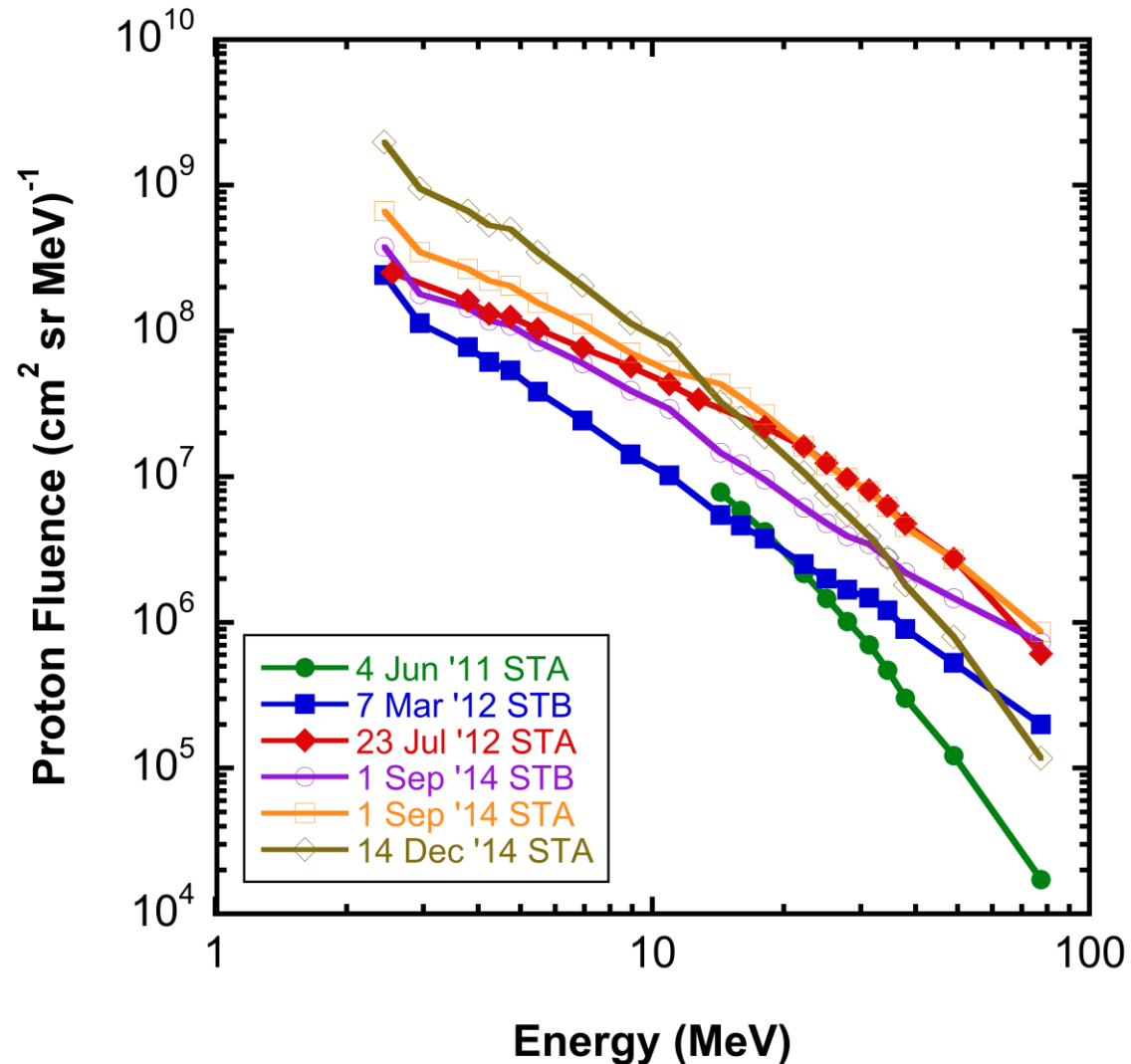
GLE-Wannabes

- GLE events are not preferentially directed towards Earth
 - But by definition non-Earth directed cannot be a GLE event
- Searched for GLE-Wannabe events with STEREO
 - Compared to 13 Dec 2006 event
 - Found 5 candidates
 - All source (except 1) were west of spacecraft



GLE-W Characteristics

- Fluence Spectra
 - LET+HET

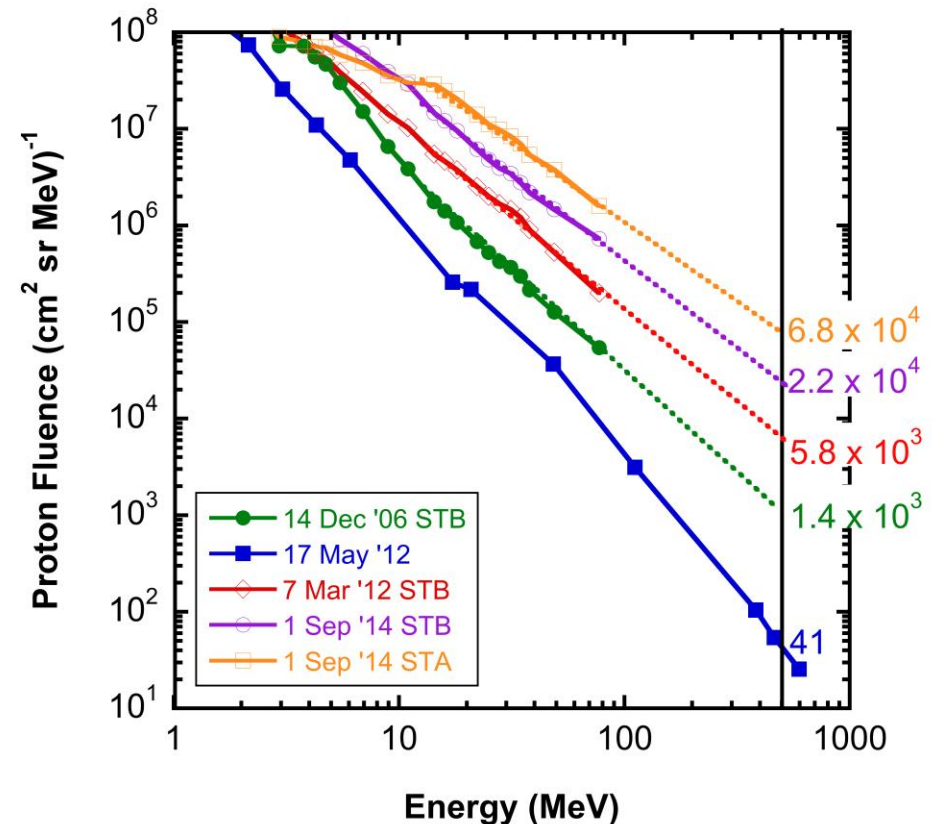
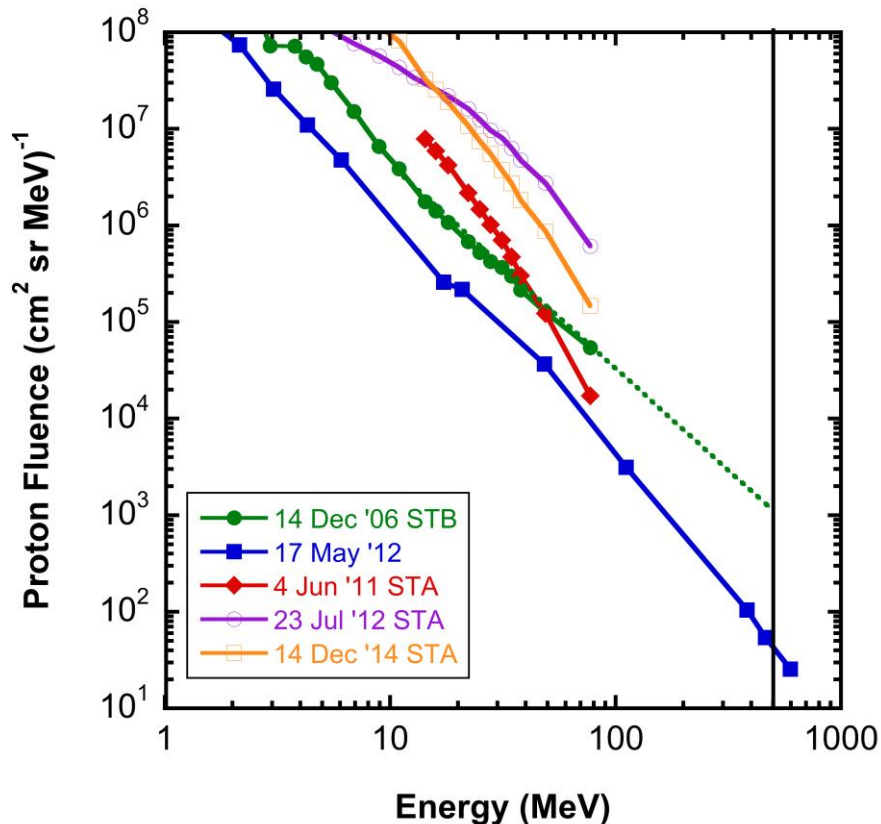


GLE-W Characteristics

- Fluence Spectra
 - LET+HET
 - Compared to GLEs of 17 May 2012 & 13 Dec 2006

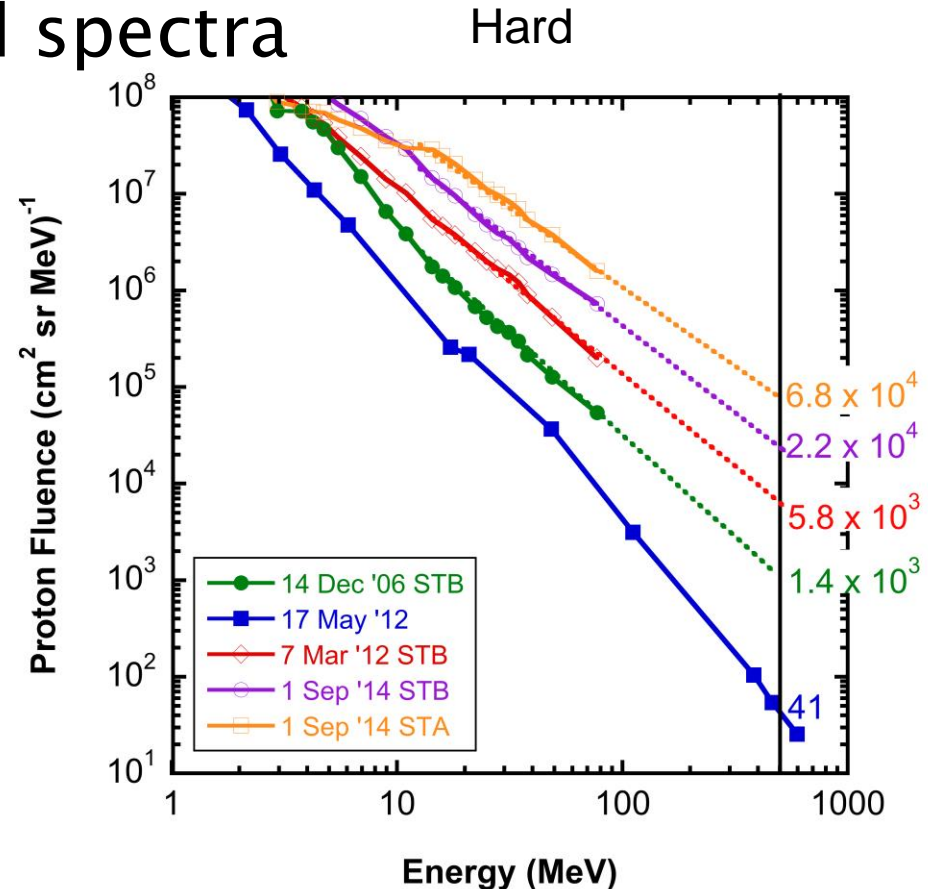
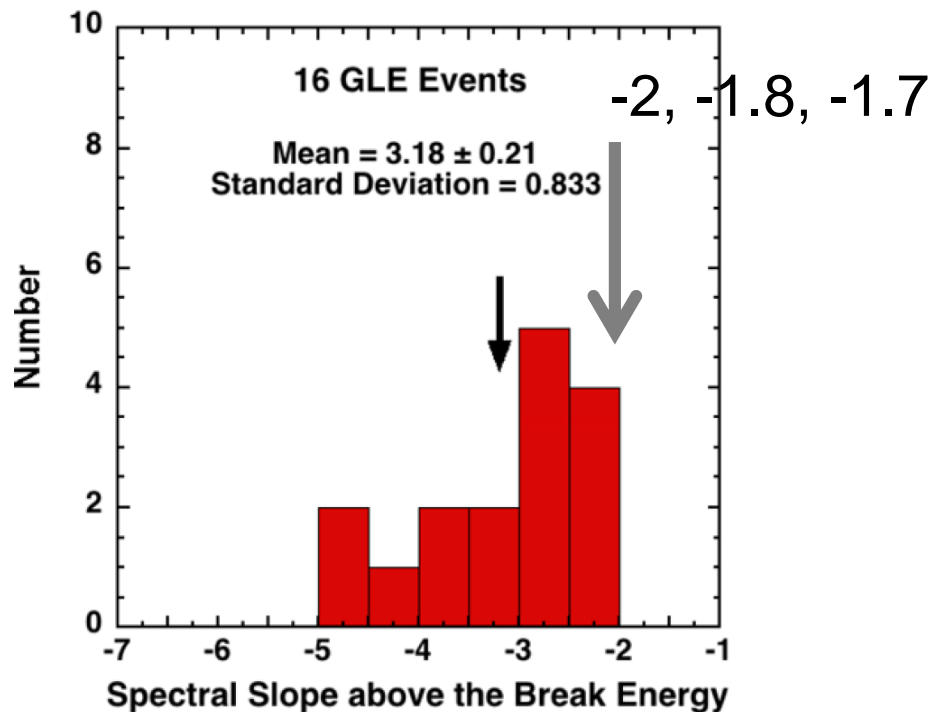
Soft

Hard



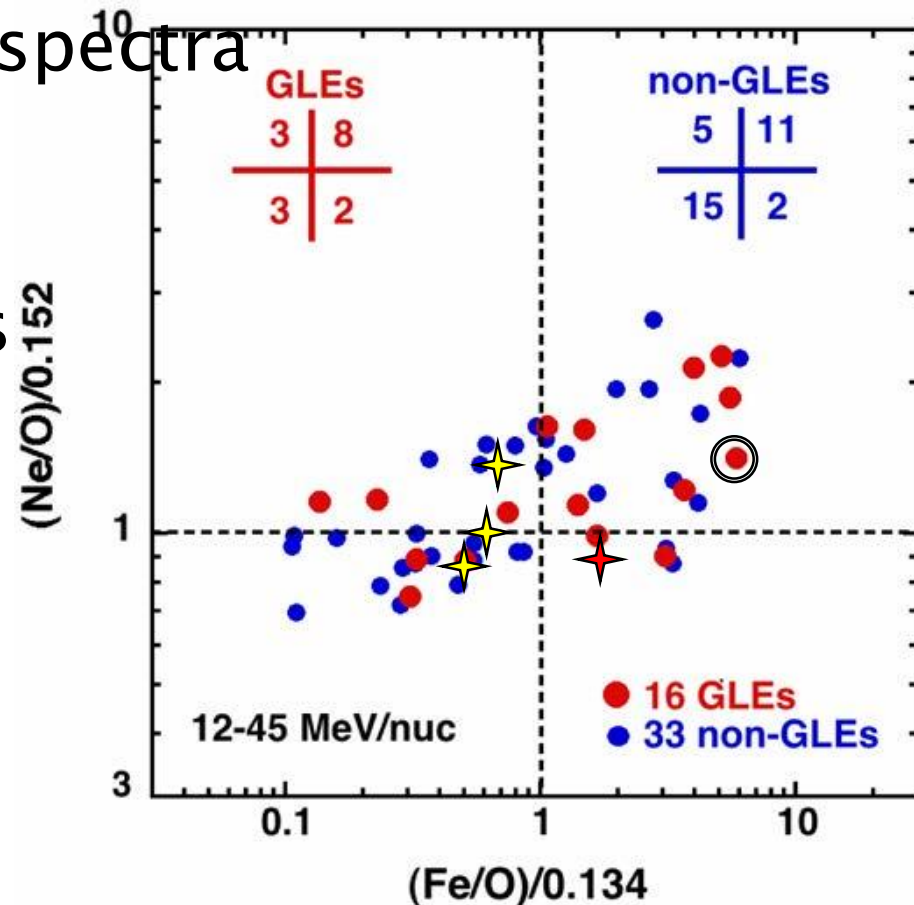
GLE-W Characteristics

- Fluence Spectra
 - LET+HET
 - Compared to GLEs of 17 May 2012 & 13 Dec 2006
 - Higher fluence and hard spectra
- similar to GLE events



GLE-W Characteristics

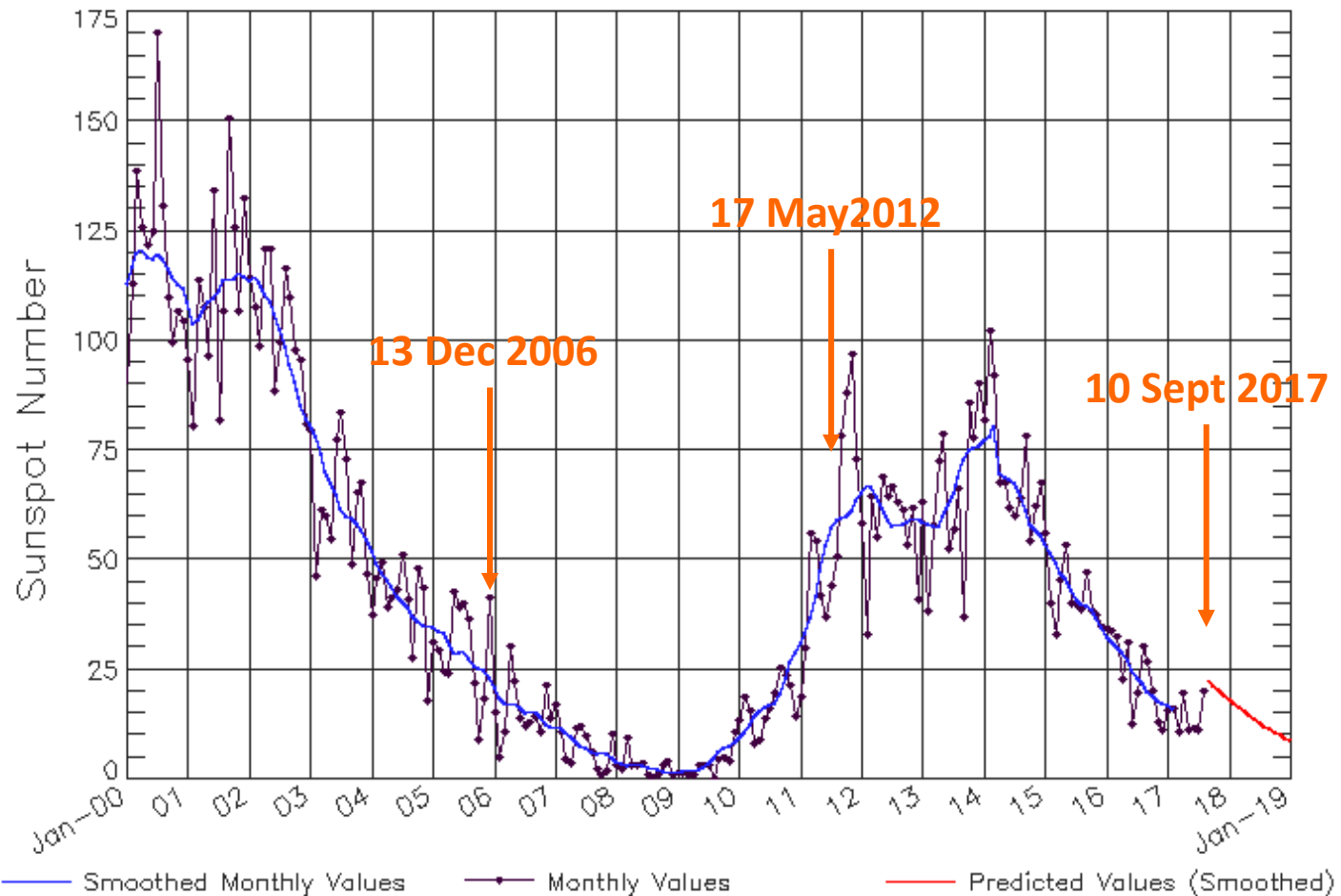
- Fluence Spectra
 - LET+HET
 - Compared to GLEs of 17 May 2012 & 13 Dec 2006
 - Higher fluence and hard spectra similar to GLE events
- Composition
 - Only 7 Mar 2012 shows Ne enhancement



Latest GLE

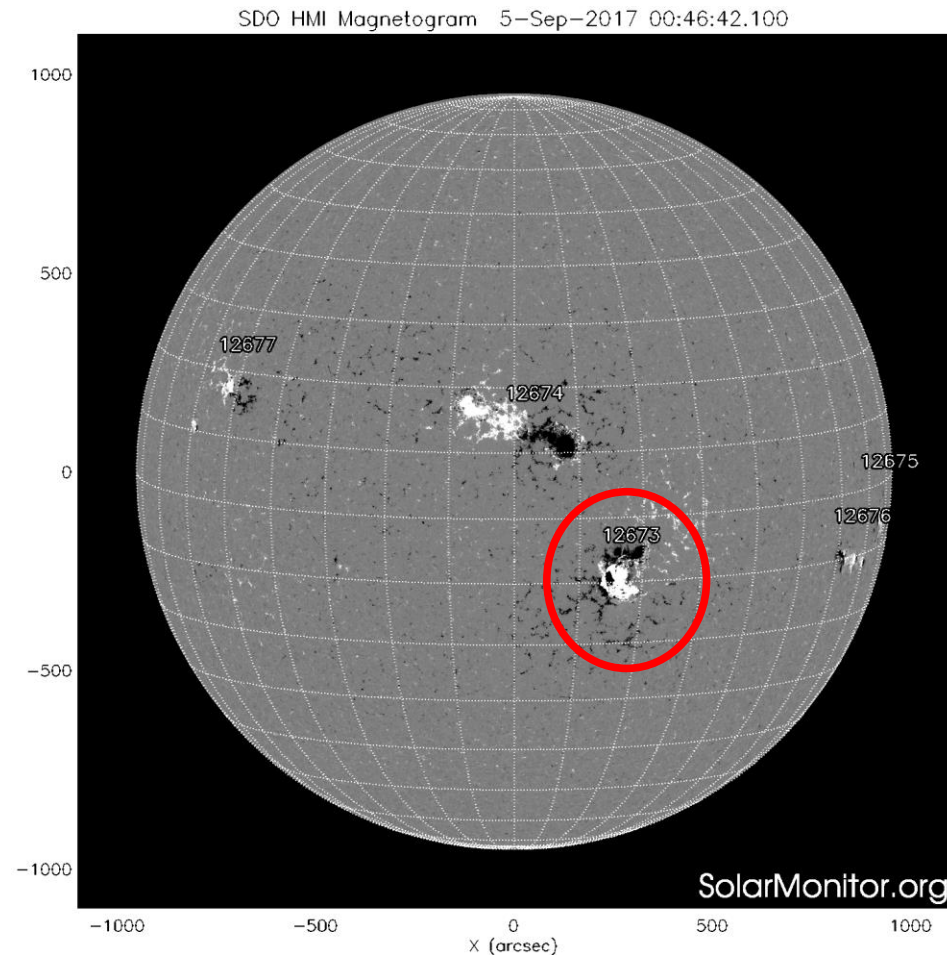
- Late in the cycle

ISES Solar Cycle Sunspot Number Progression
Observed data through Aug 2017



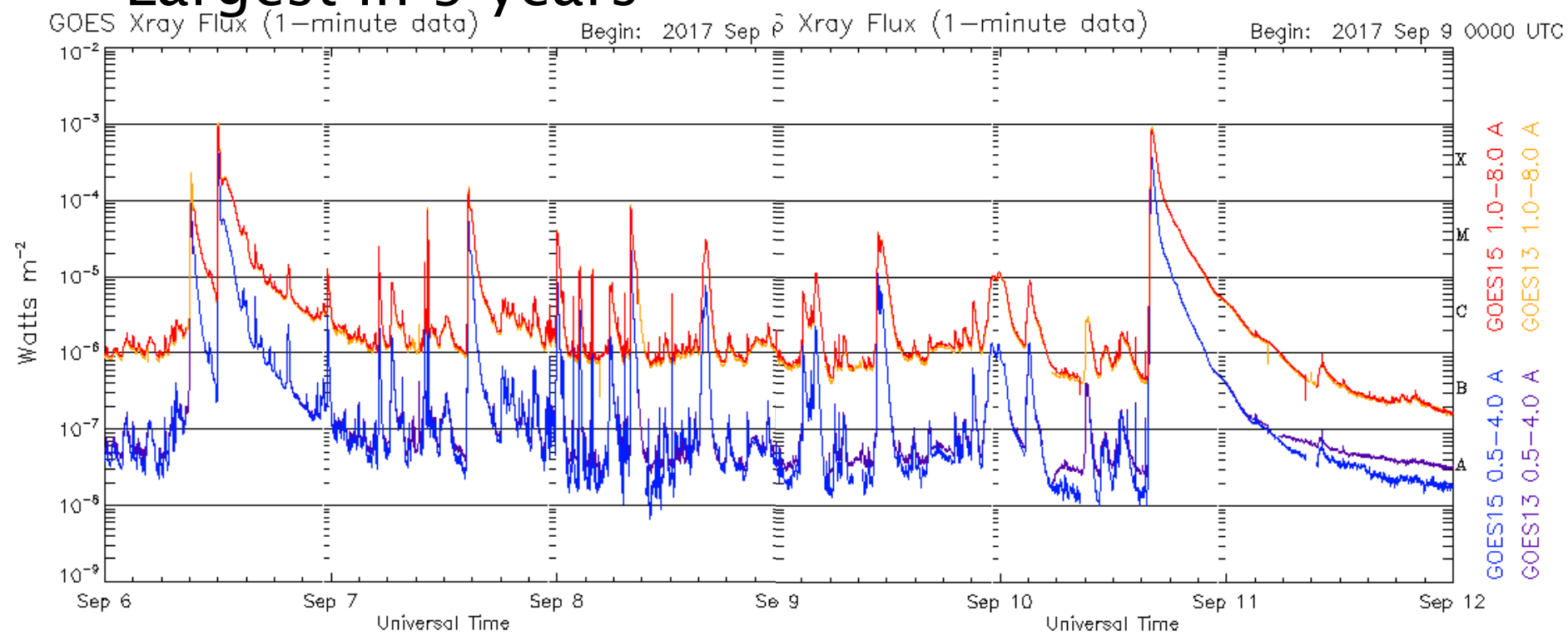
Latest GLE

- Late in the cycle
- Several large active regions



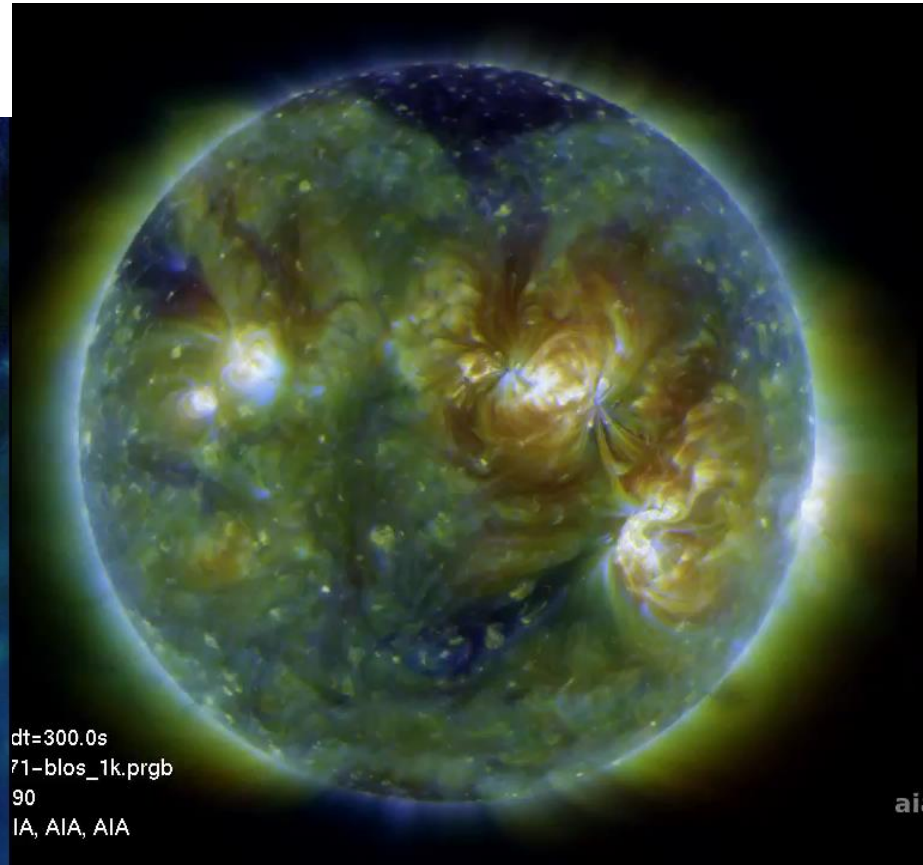
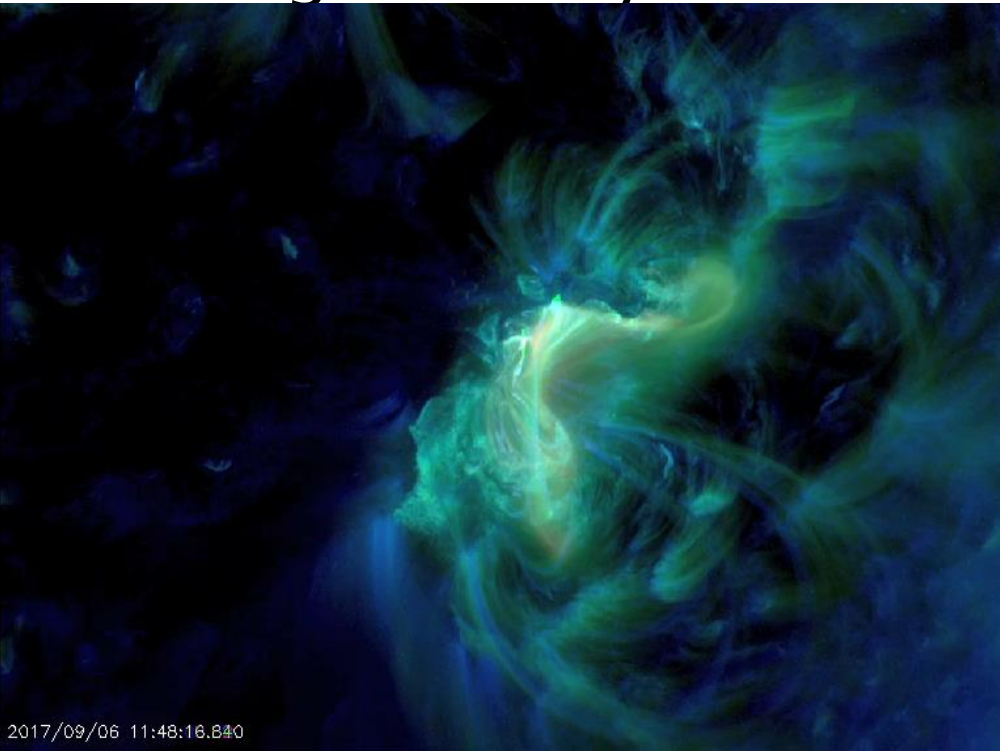
Latest GLE

- Late in the cycle
 - Several large active regions
 - 12673 $\beta\gamma\delta$ flaring
 - Largest in 9 years



Latest GLE

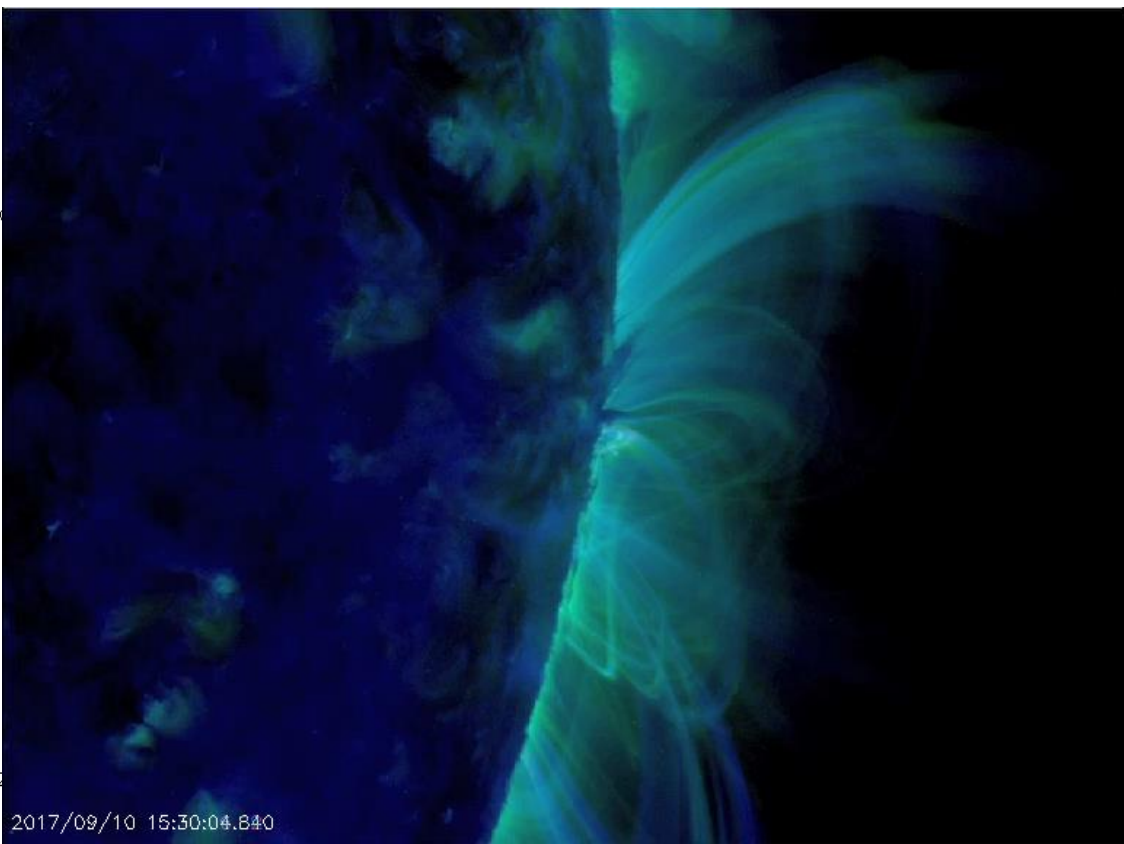
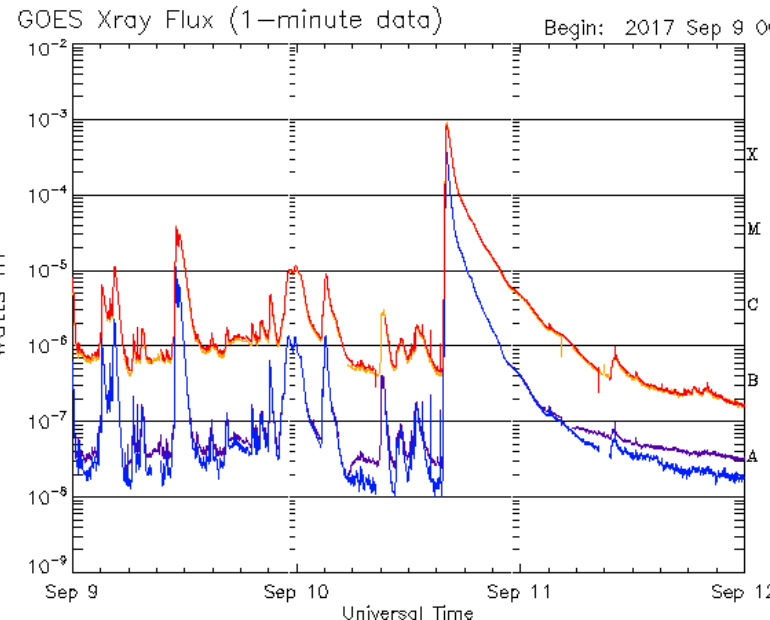
- Late in the cycle
 - Several large active regions
 - 12673 $\beta\gamma\delta$ flaring
 - Largest in 9 years



dt=300.0s
71-blos_1k.prgb
90
IA, AIA, AIA

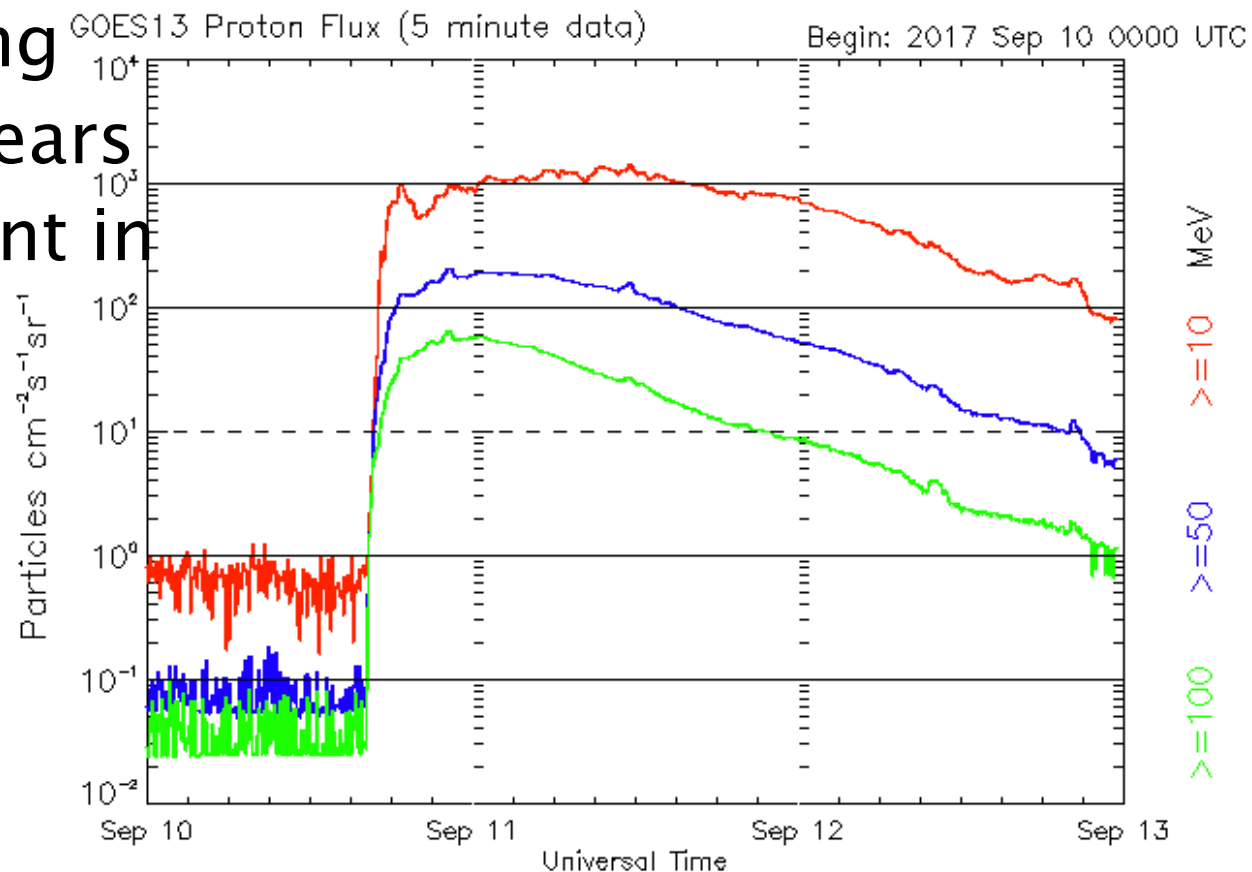
Latest GLE

- Late in the cycle
 - Several large active regions
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 - Largest in 9 years



Latest GLE

- Late in the cycle
 - Several large active regions
 - 12673 $\beta\gamma\delta$ flaring
 - Largest in 9 years
 - Largest SEP event in ~ 3 years

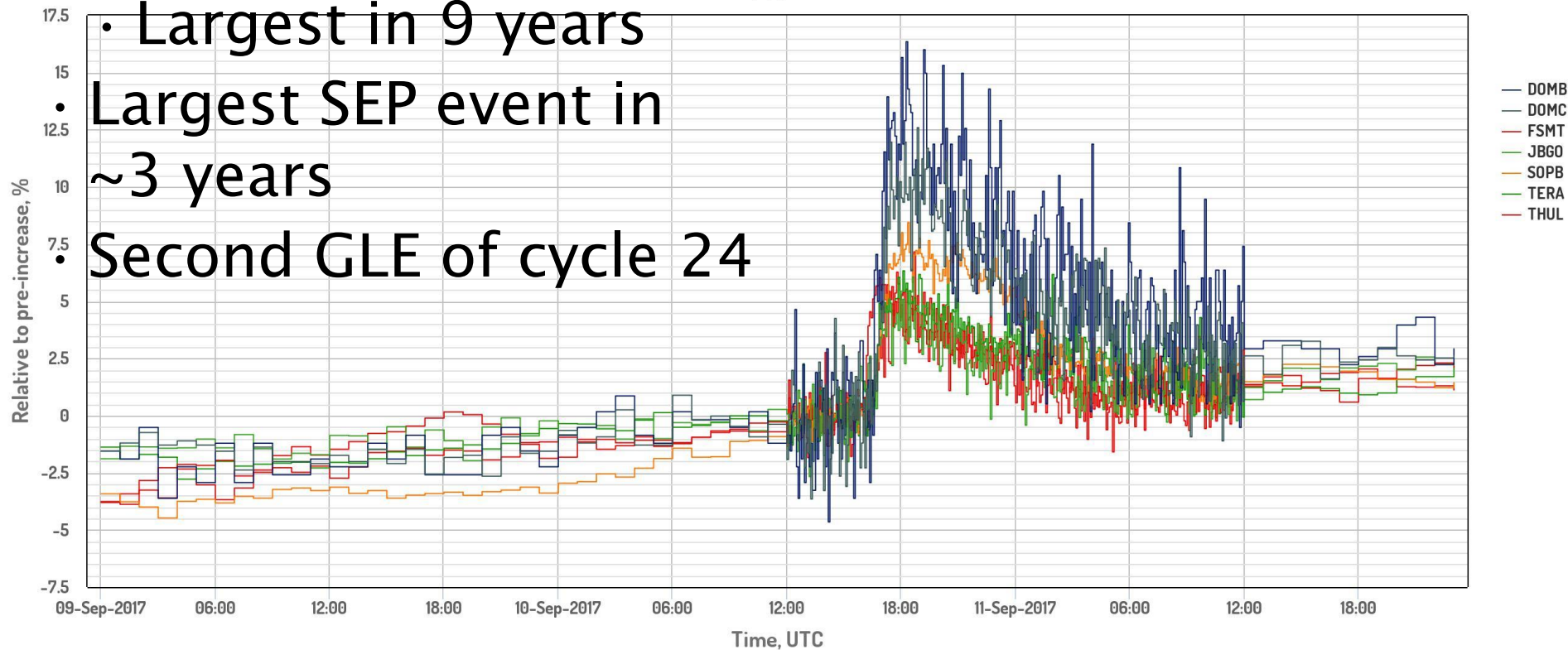


Latest GLE

- Late in the cycle
 - Several large active regions
 - 12673 $\beta\gamma\delta$ flaring
 - Largest in 9 years
 - Largest SEP event in ~3 years
 - Second GLE of cycle 24

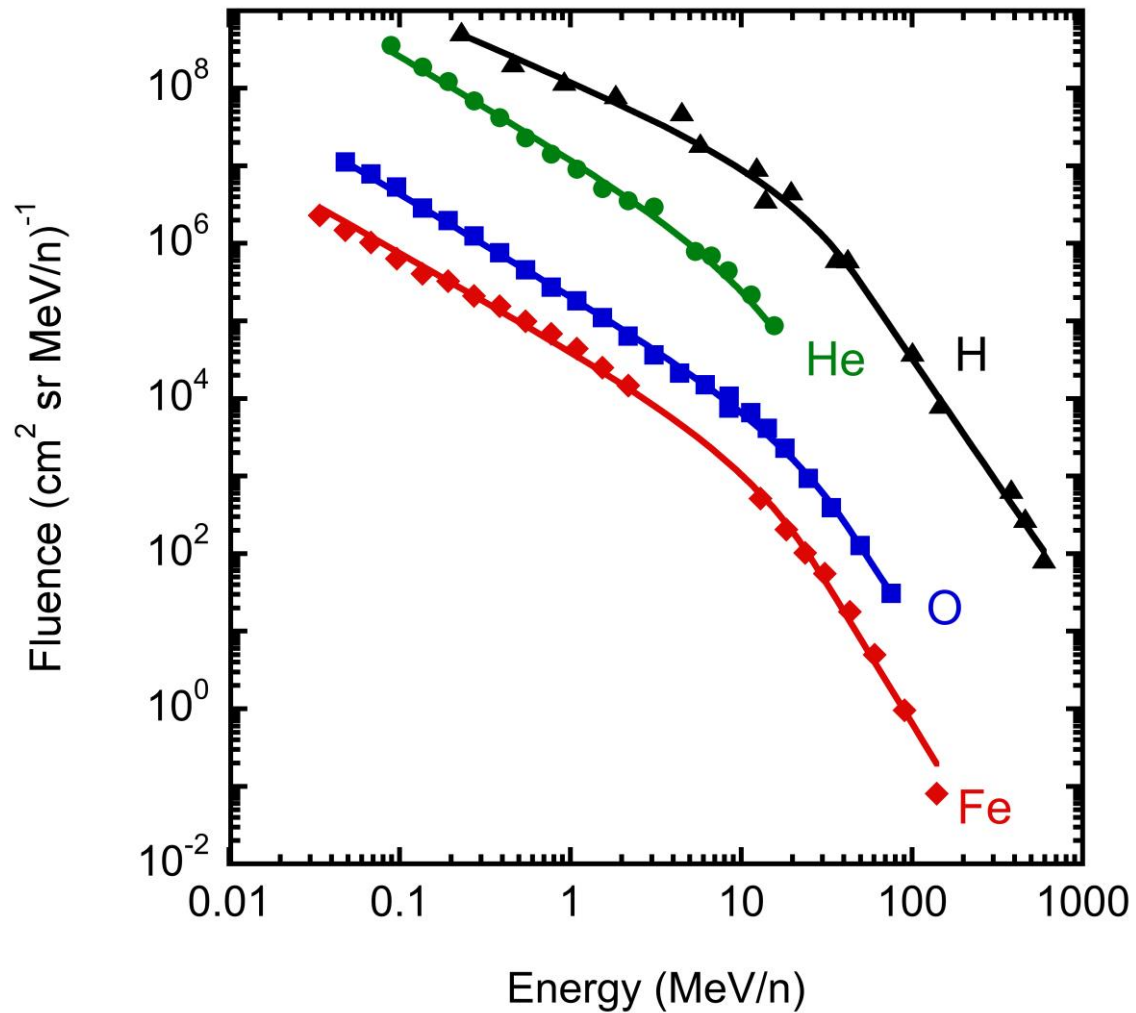
GLE #72

<https://gle oulu.fi>



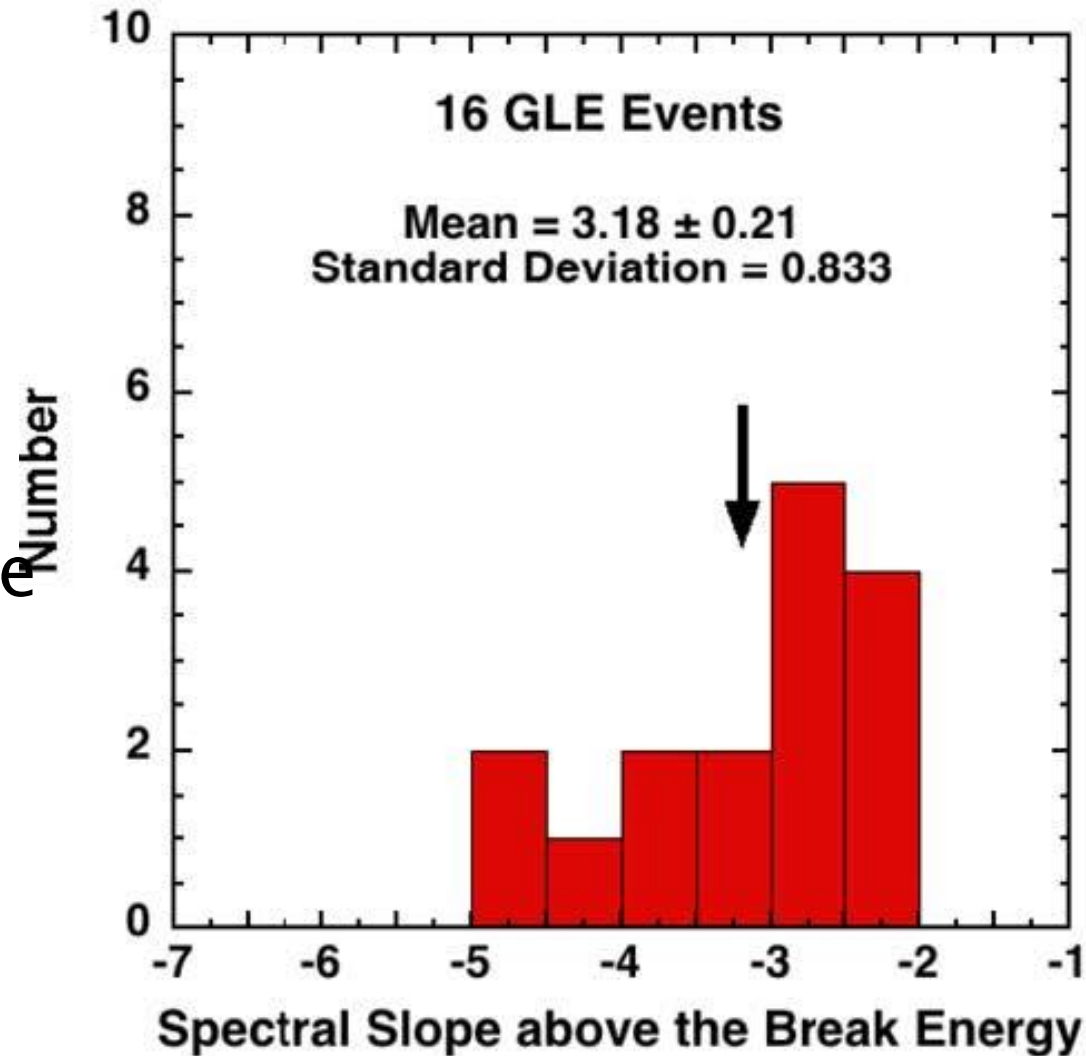
Event Spectra

- Broken power laws
 - γ above break
 - H = -3.2
 - He = -3.5
 - O = -3.4
 - Fe = -3.6



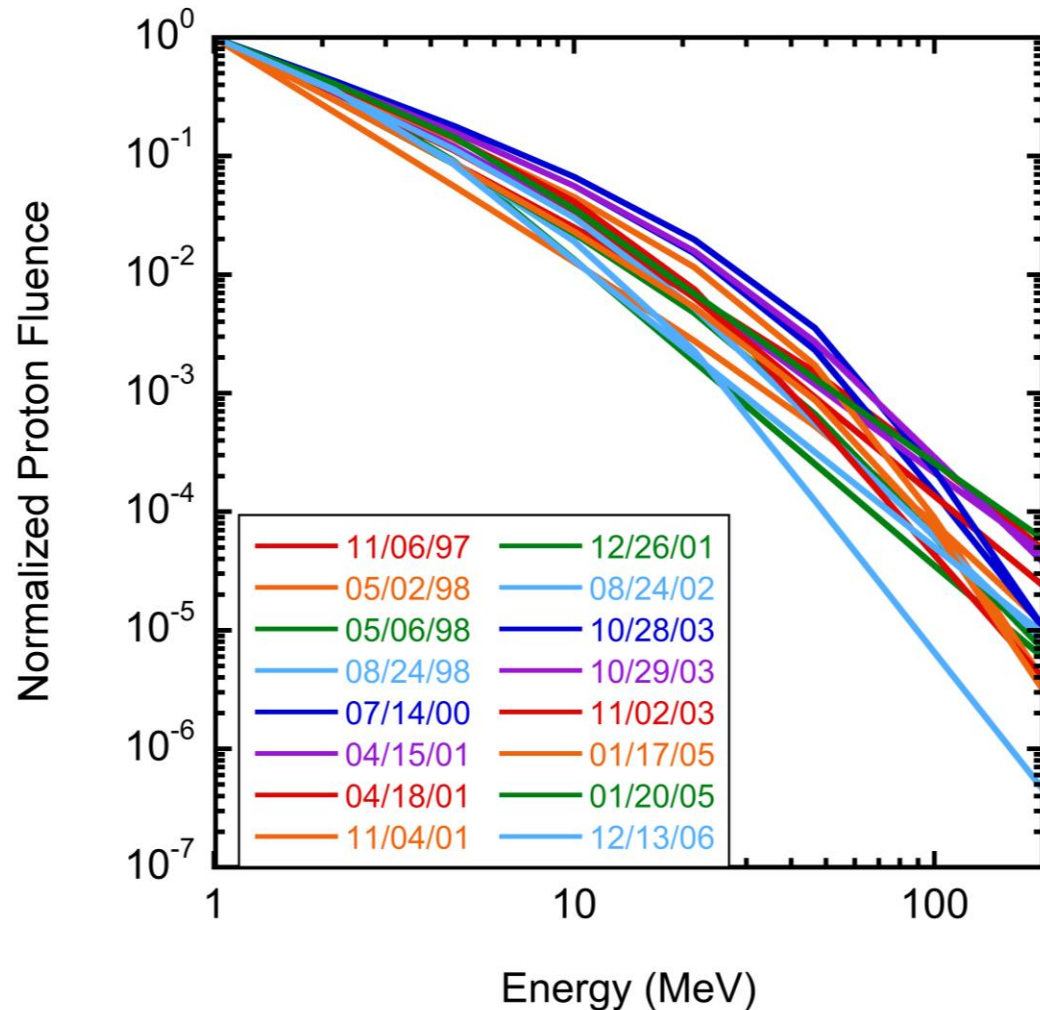
Compared to Cycle 23

- Broken power laws
 - γ above break
 - H = -3.2
 - He = -3.5
 - O = -3.4
 - Fe = -3.6
 - Close to GLE average



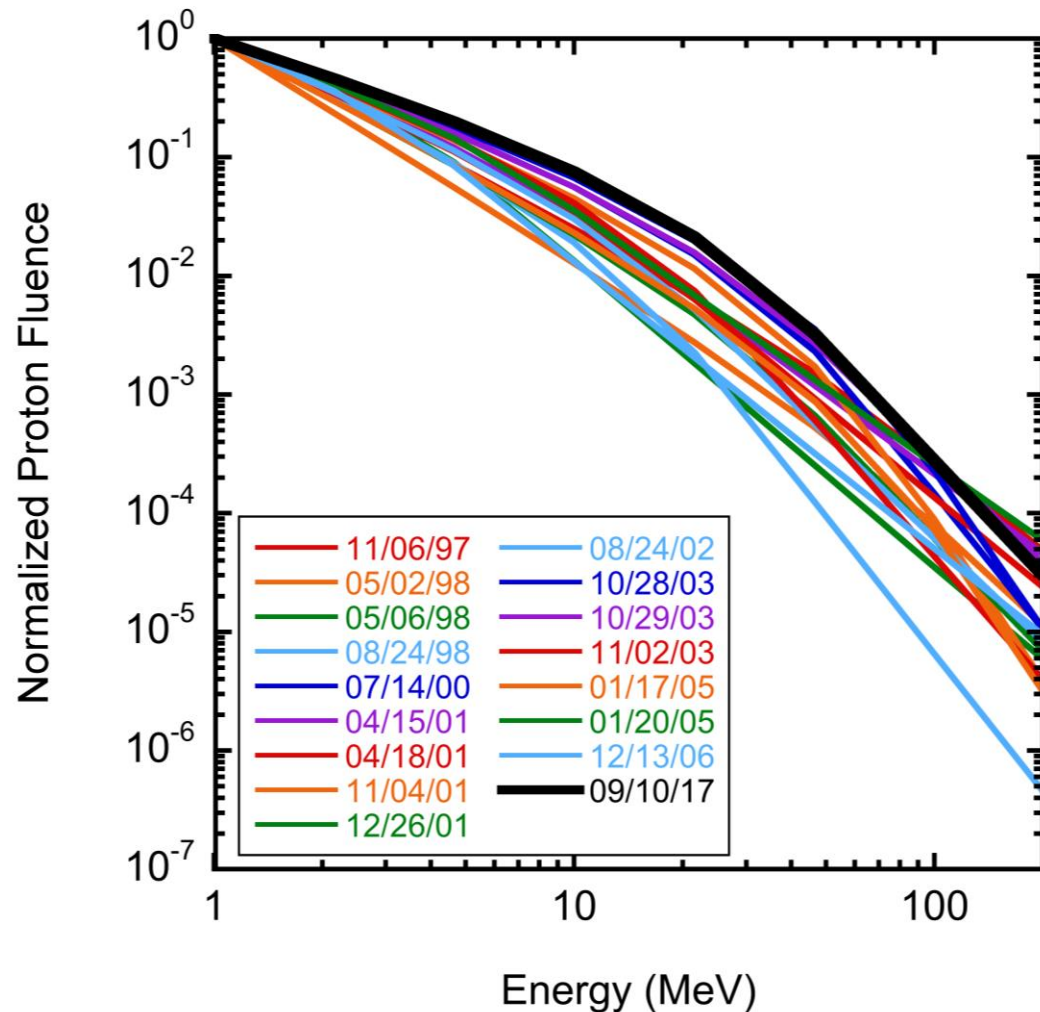
Compared to Cycle 23

- Broken power laws
 - γ above break
 - H = -3.2
 - He = -3.5
 - O = -3.4
 - Fe = -3.6
- Close to GLE average



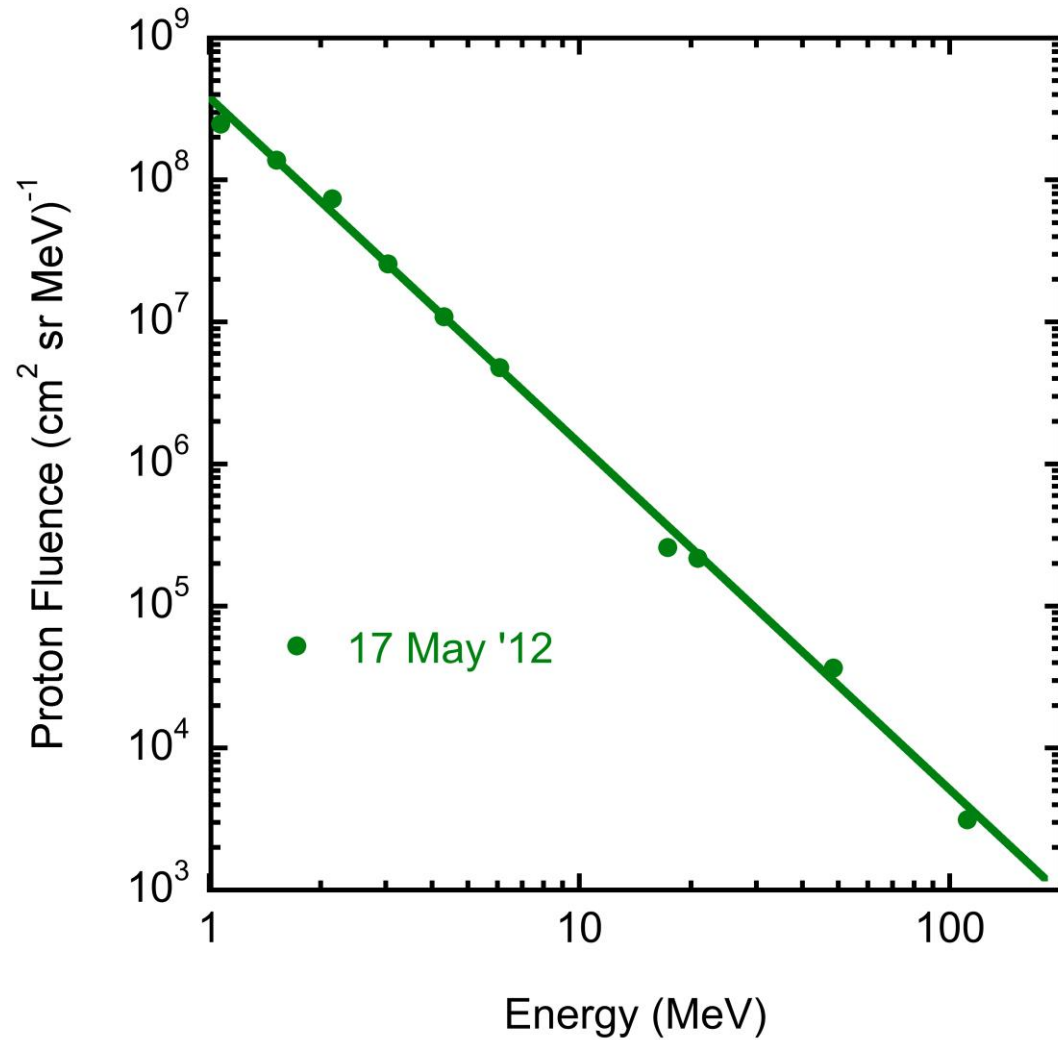
Compared to Cycle 23

- Broken power laws
 - γ above break
 - H = -3.2
 - He = -3.5
 - O = -3.4
 - Fe = -3.6
- Close to GLE average
 - Harder below break
 - Most similar to 28 Oct '03



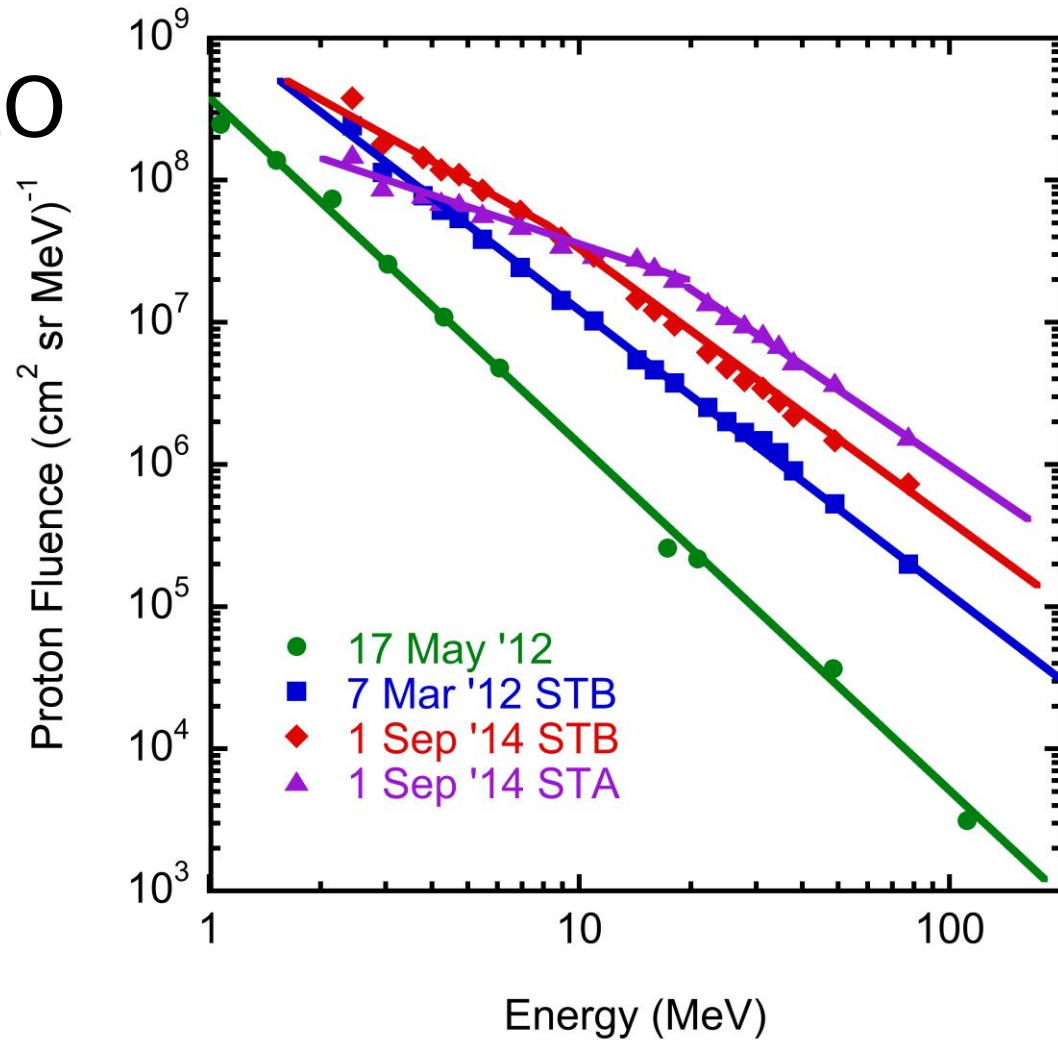
Compared to Cycle 24

• 17 May 2012



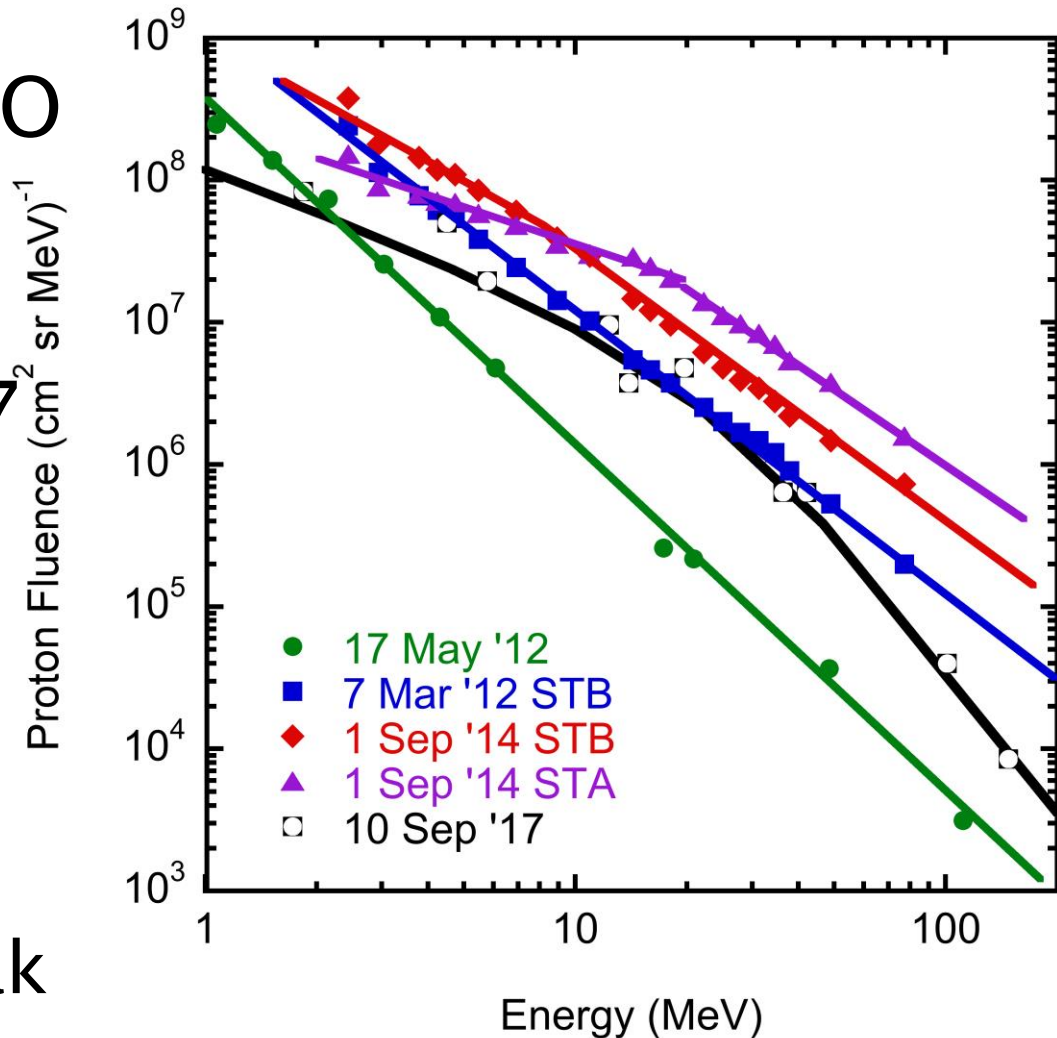
Compared to Cycle 24

- 17 May 2012
- GLE-Ws from STEREO
 - 7 March 2012
 - 1 September 2014



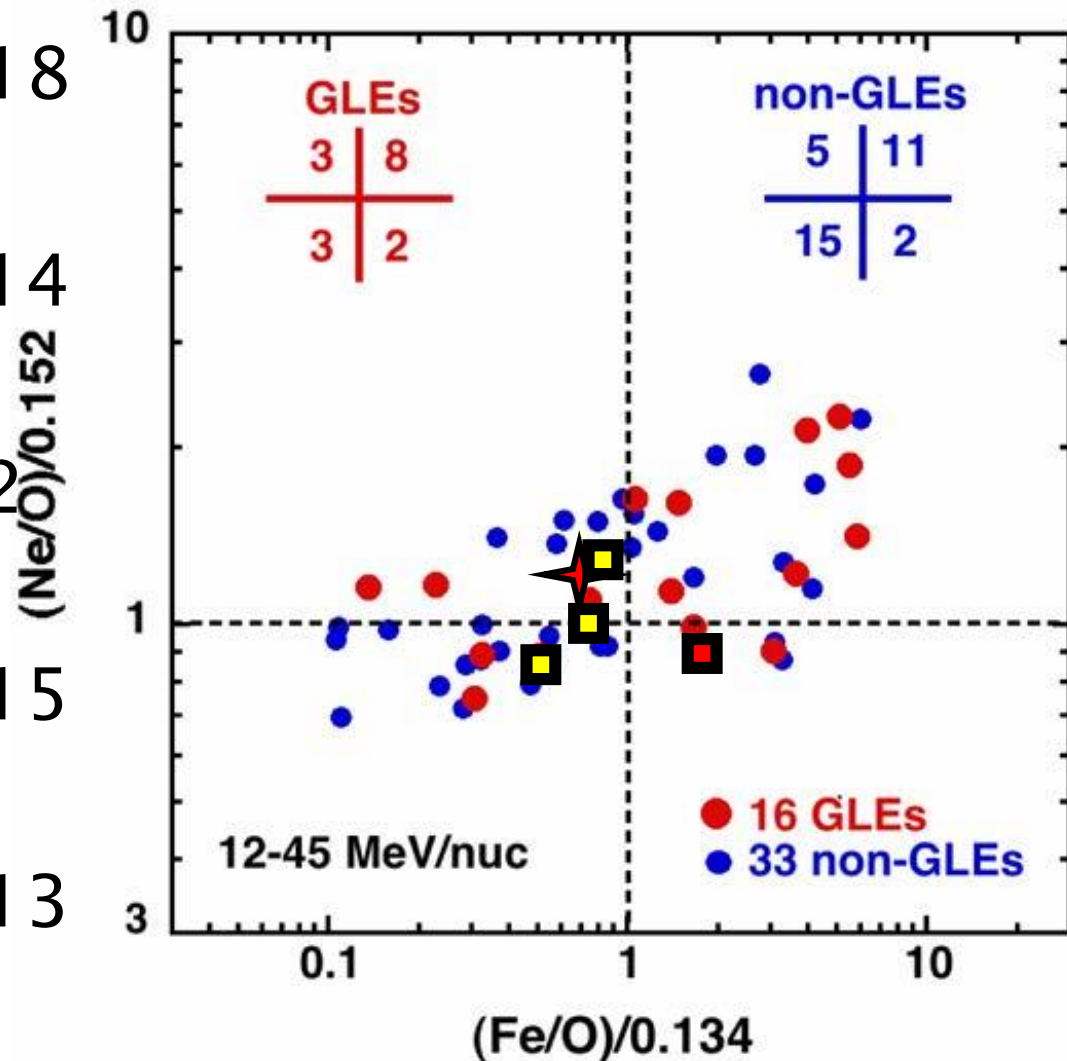
Compared to Cycle 24

- 17 May 2012
- GLE-Ws from STEREO
 - 7 March 2012
 - 1 September 2014
- 10 September 2017
 - Bigger than 17 May '12
 - Softer than others (except for possibly 1 Sept '14 STA)
 - Only one with a break ~20 MeV



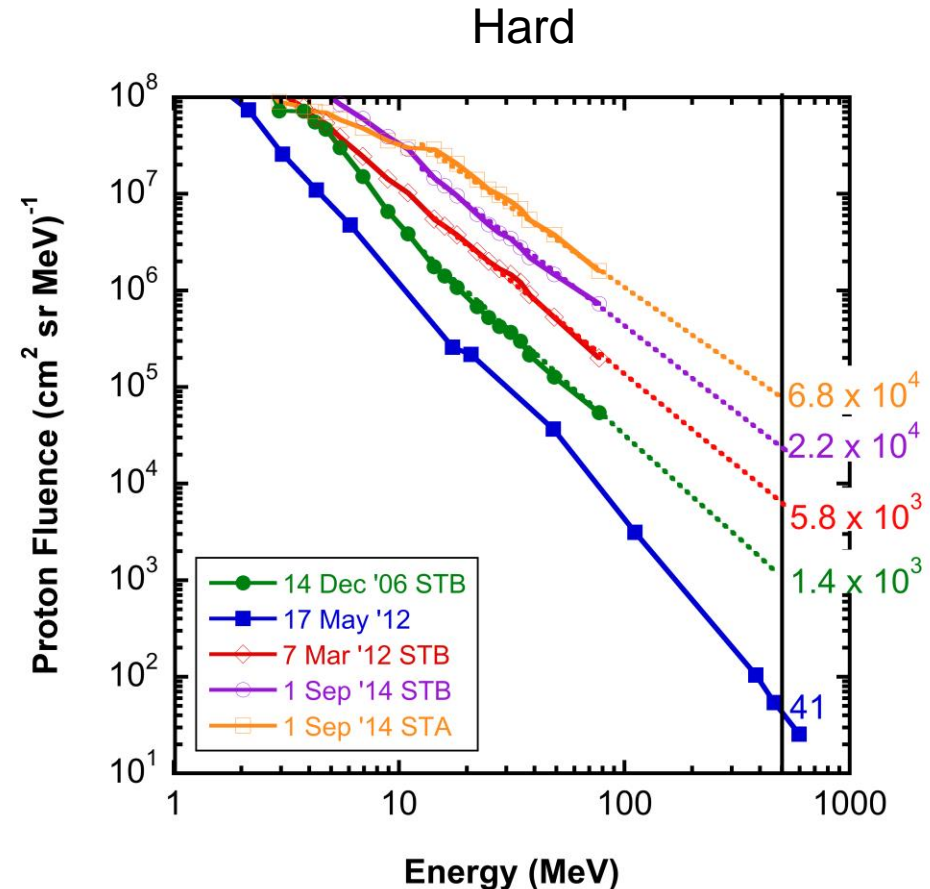
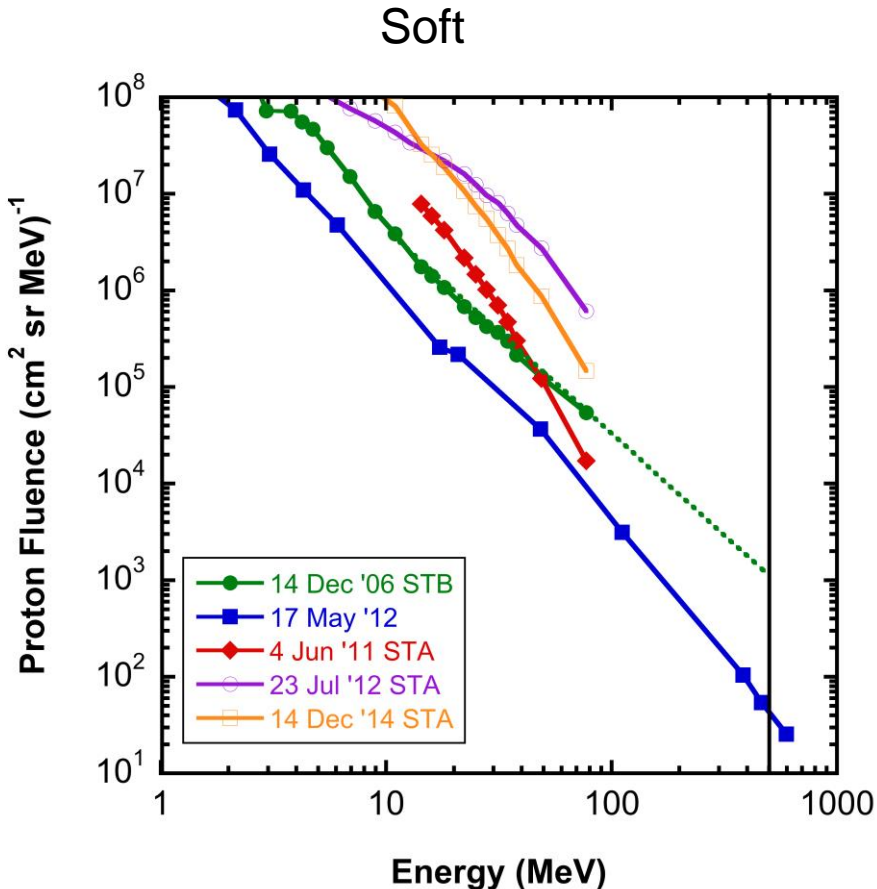
Composition

- 10 Sep 2017
 - Fe/O=0.10, Ne/O=0.18
- 17 May 2012
 - Fe/O=0.23, Ne/O=0.14
- 7 Mar 2012
 - Fe/O=0.11, Ne/O=0.2
- 1 Sep 2014 STB
 - Fe/O=0.10, Ne/O=0.15
- 1 Sep 2014 STA
 - Fe/O=0.07, Ne/O=0.13



The Making of a GLE-W

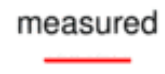
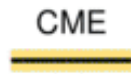
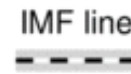
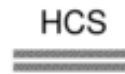
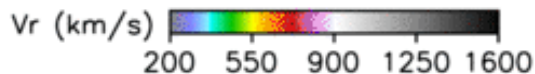
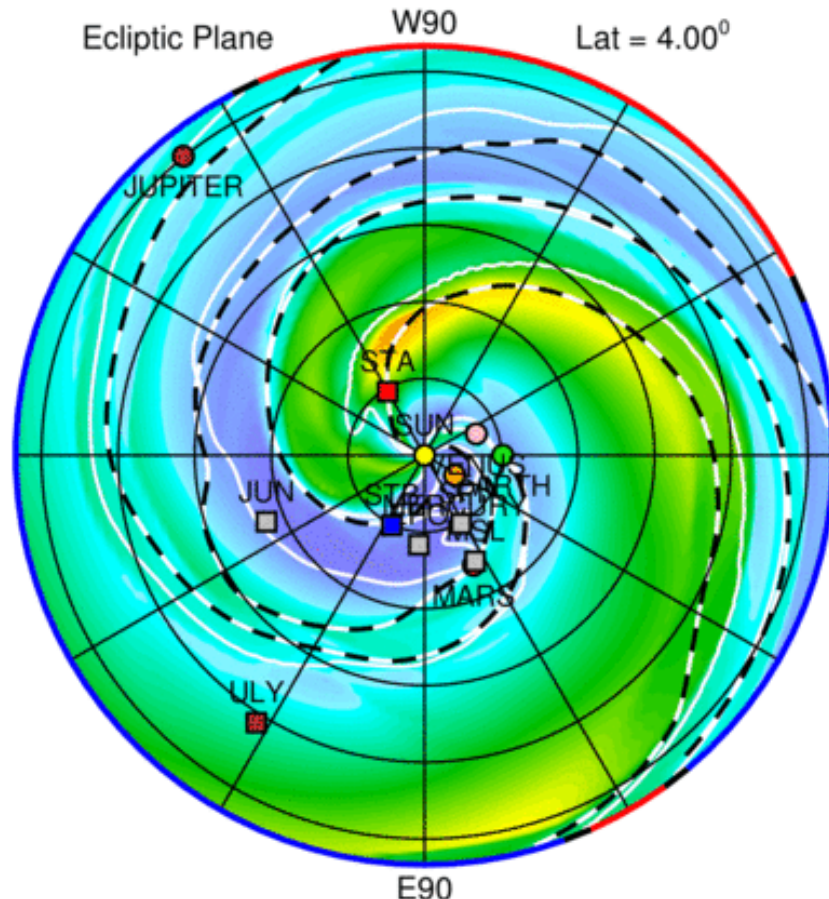
- Of the STEREO events only some had hard spectra
- What is different?



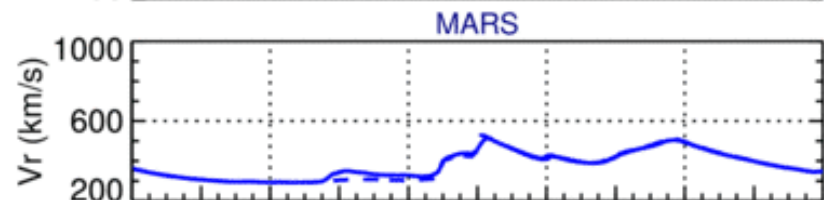
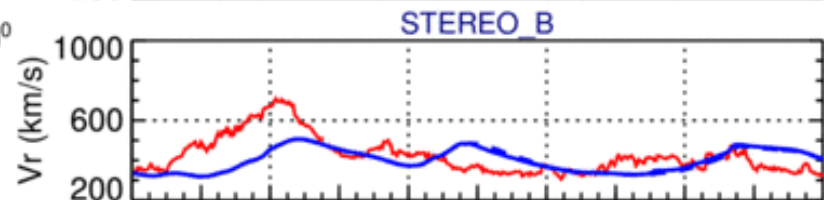
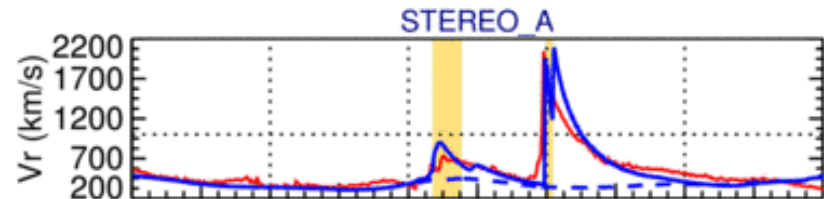
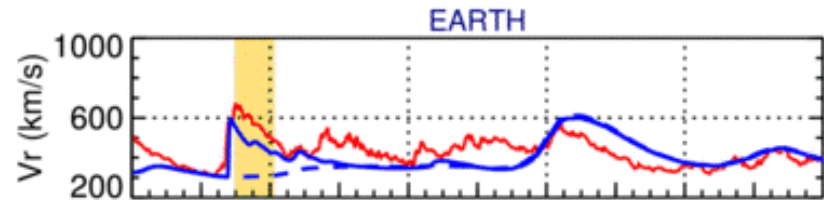
Connection Modeling

- Used WSA-ENLIL+Cone model at CCMC

2012-07-12T00:00



2012-07-12T00 + 0.00 days



12 16 20 24 28 01

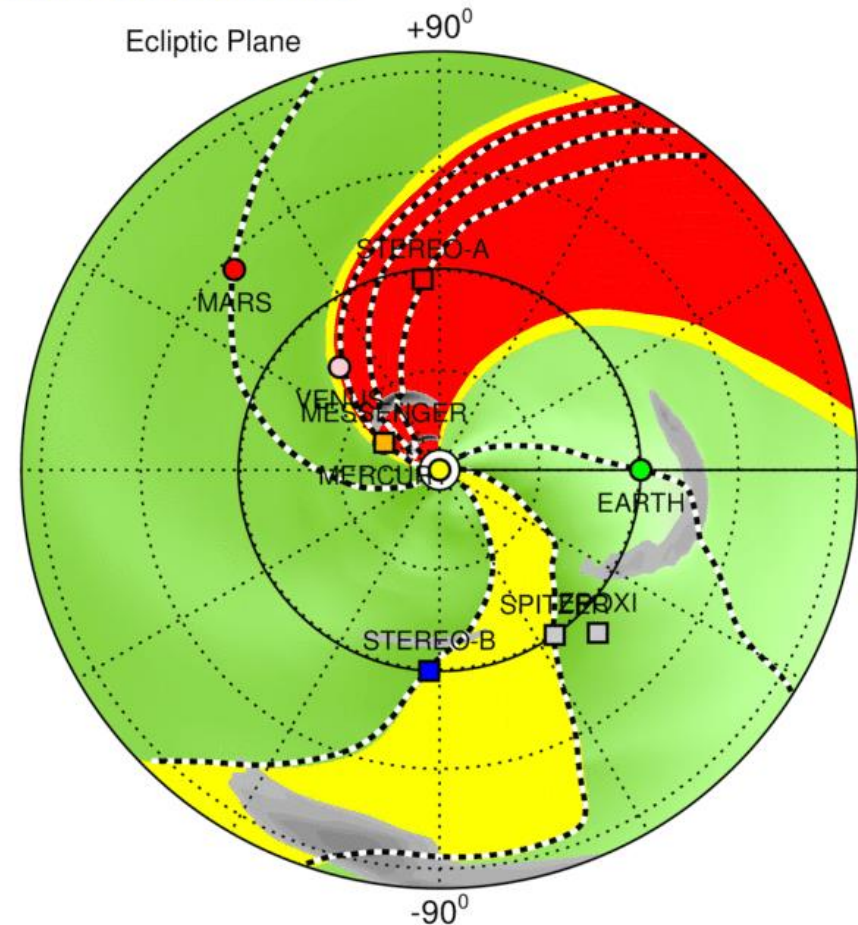
2012-07 / 2012-08

Connection Modeling

- Used WSA-ENLIL+Cone model at CCMC
- Identify regions connected to shock by speed increase

- 20-200 km/s
- 200-400 km/s
- >400 km/s

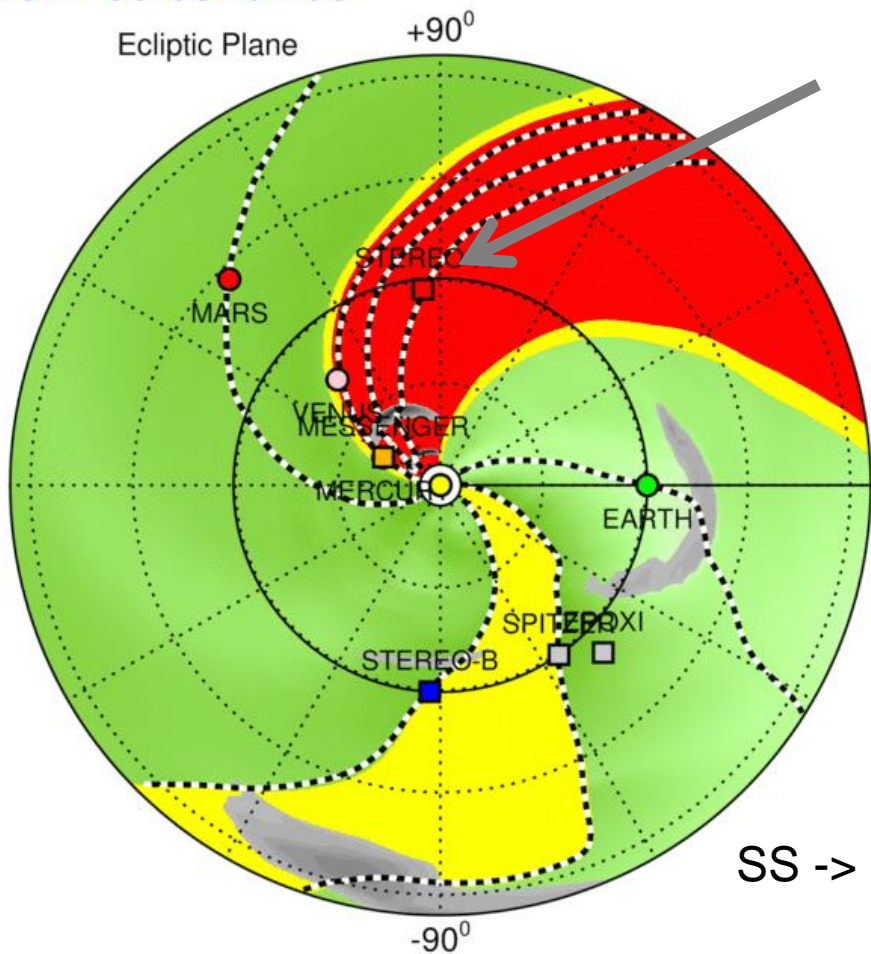
2011-06-05T02:00



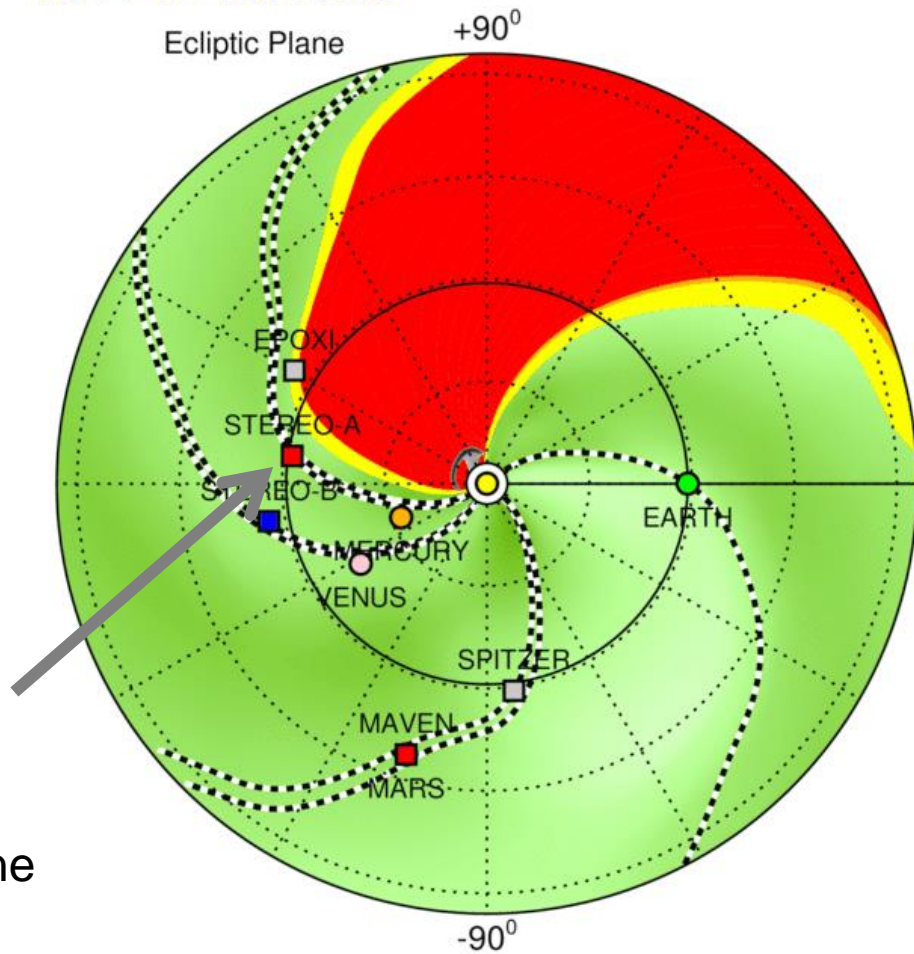
Connection Modeling

- Soft-spectra events vs hard-spectra events
- Prior CME connections

2011-06-05T02:00



2014-12-13T18:00

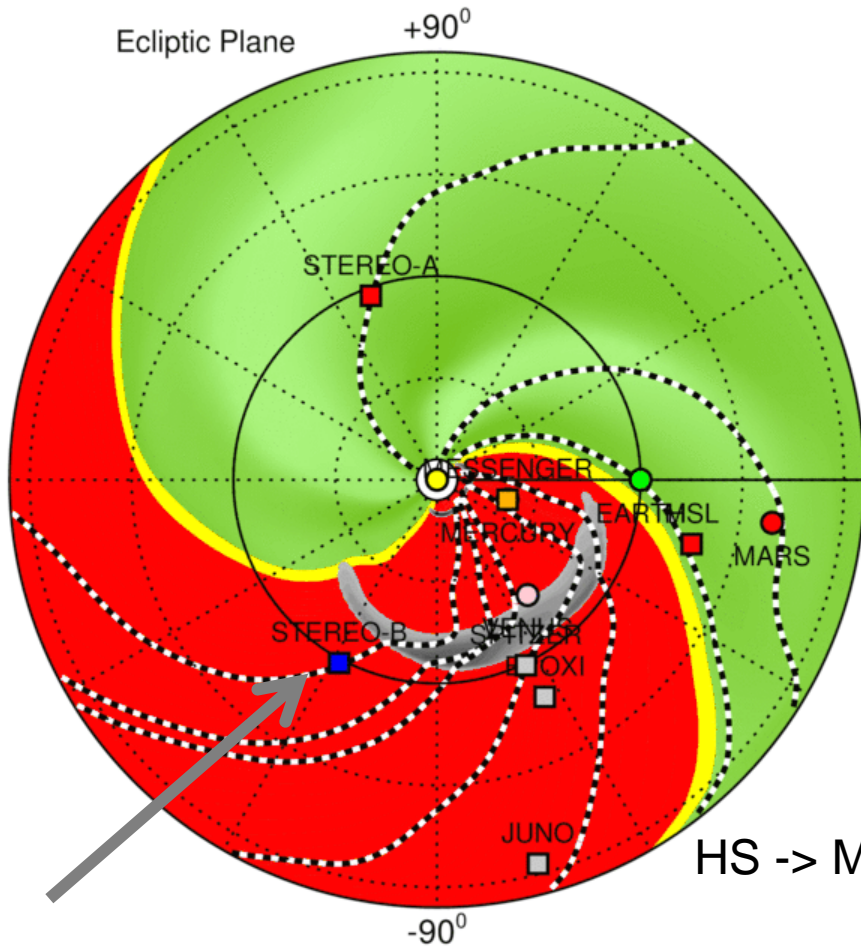


SS -> None

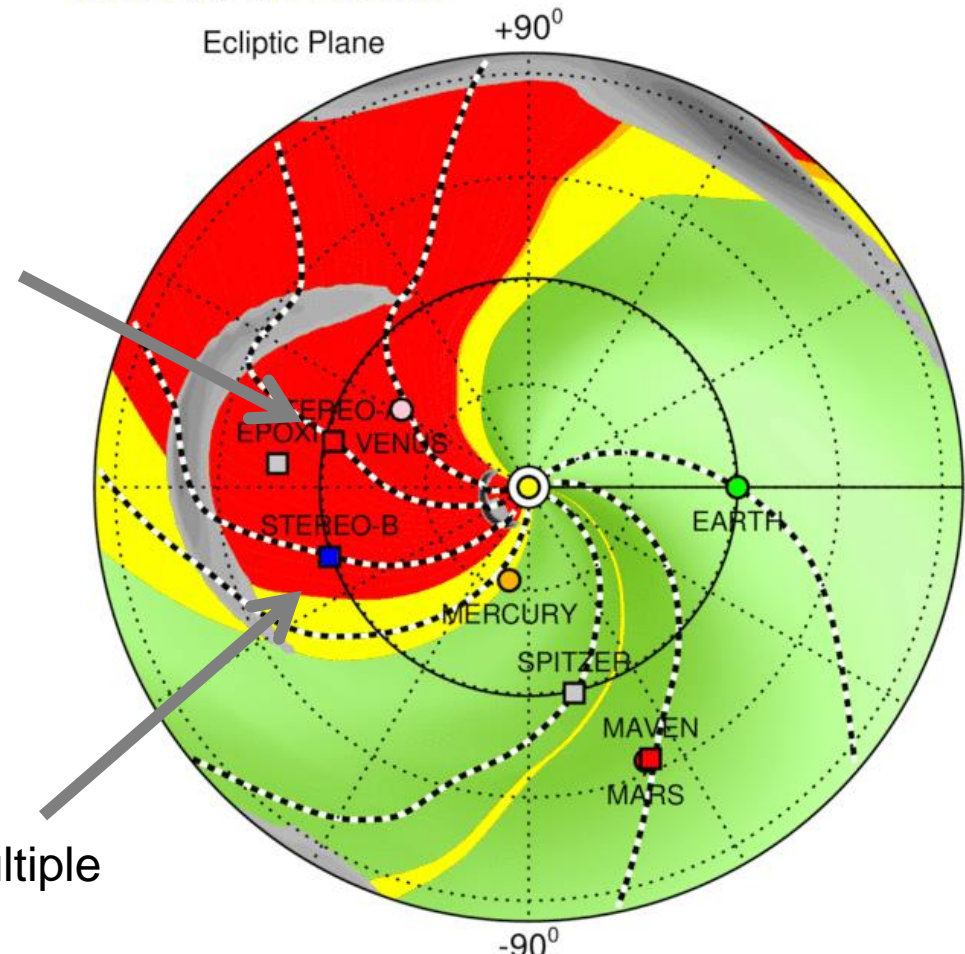
Connection Modeling

- Soft-spectra events vs hard-spectra events
 - Prior CME connections

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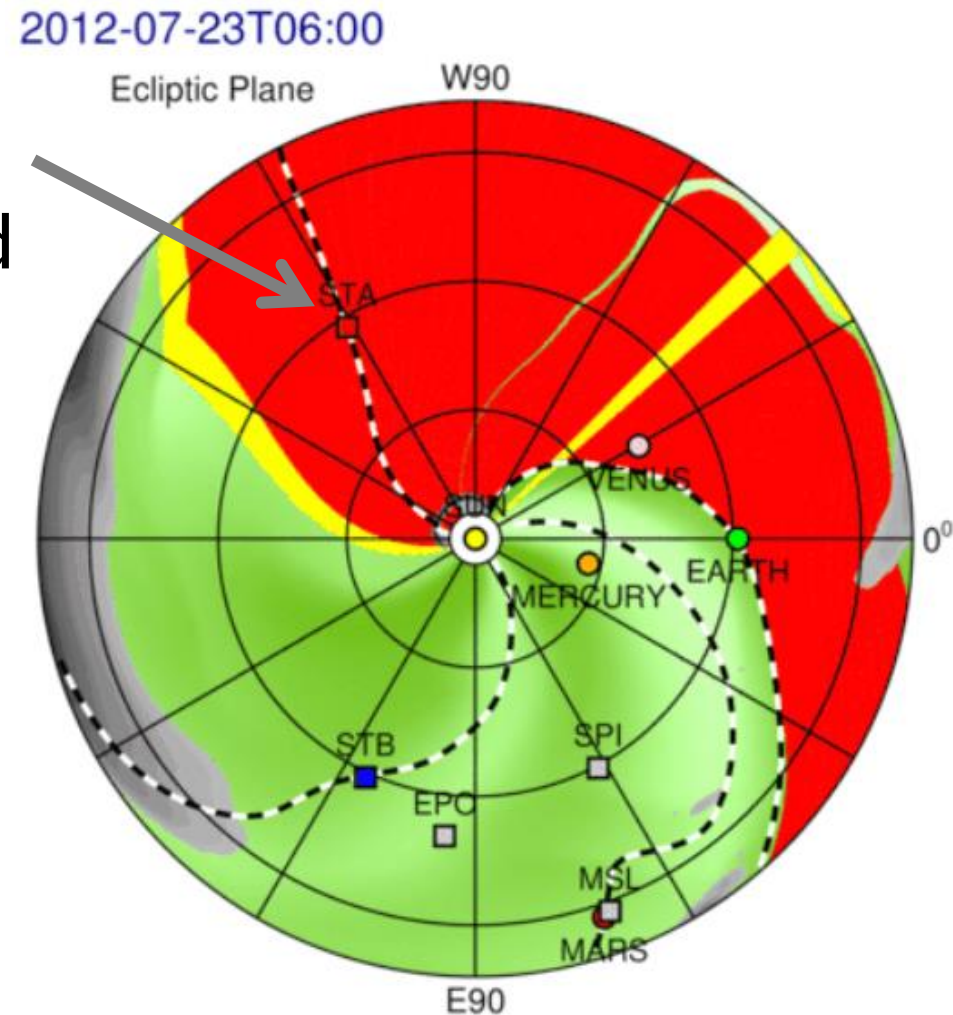
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HS -> Multiple

Connection Modeling

- Soft-spectra events vs hard-spectra events
 - Prior CME connections
 - SS events have no prior CMEs
 - HS events are connected to both event and prior CME
 - 23 July 2012 very complicated event less clear
- Haven't modeled cycle 24 GLEs yet



Summary

- Found GLE-W events in STEREO
 - 3 had hard spectra that extrapolated to 500 MeV were $> \sim 4-1600 \times$ 13 Dec 2006
 - Spectral indices similar to that of GLE events
 - No enhanced Fe, only 1 enhanced in Ne
- Sept 2017 GLE event
 - Average spectral index, but with break at ~ 20 MeV
 - Not enhanced in Fe but slightly in Ne
 - Bigger than 17 May 2012, but softer
- Cycle 24 GLE events are not enhanced in Fe
- Multi-CME connection may play a role in generating GLE events