GLE and GLE-Wannabe Events in Solar Cycle 24

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Ground Level Enhancements

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

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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

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  - 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
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- Compared to GLEs of 17 May 2012 & 13 Dec 2006
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

-2, -1.8, -1.7

16 GLE Events
Mean = 3.18 ± 0.21
Standard Deviation = 0.833

Proton Fluence (cm² sr MeV⁻¹)

Energy (MeV)
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

[Graph of ISES Solar Cycle Sunspot Number Progression]

- 13 Dec 2006
- 17 May 2012
- 10 Sept 2017
Latest GLE

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

- Broken power laws
  - $\gamma$ above break
    - H = -3.2
    - He = -3.5
    - O = -3.4
    - Fe = -3.6
Compared to Cycle 23

- Broken power laws
  - $\gamma$ 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
  - $\gamma$ 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
  - \( \gamma \) 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=0.20
- 1 Sep 2014 STB
  - Fe/O=0.10, Ne/O=0.15
- 1 Sep 2014 STA
  - Fe/O=0.07, Ne/O=0.13
- Of the STEREO events only some had hard spectra
- What is different?
Connection Modeling

- Used WSA-ENLIL+Cone model at CCMC
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
Connection Modeling

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

2011-06-05T02:00

SS -> None
Connection Modeling

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

2012-03-07T05:00

2014-09-01T18:00

Ecliptic Plane

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 > ~4-1600 x 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