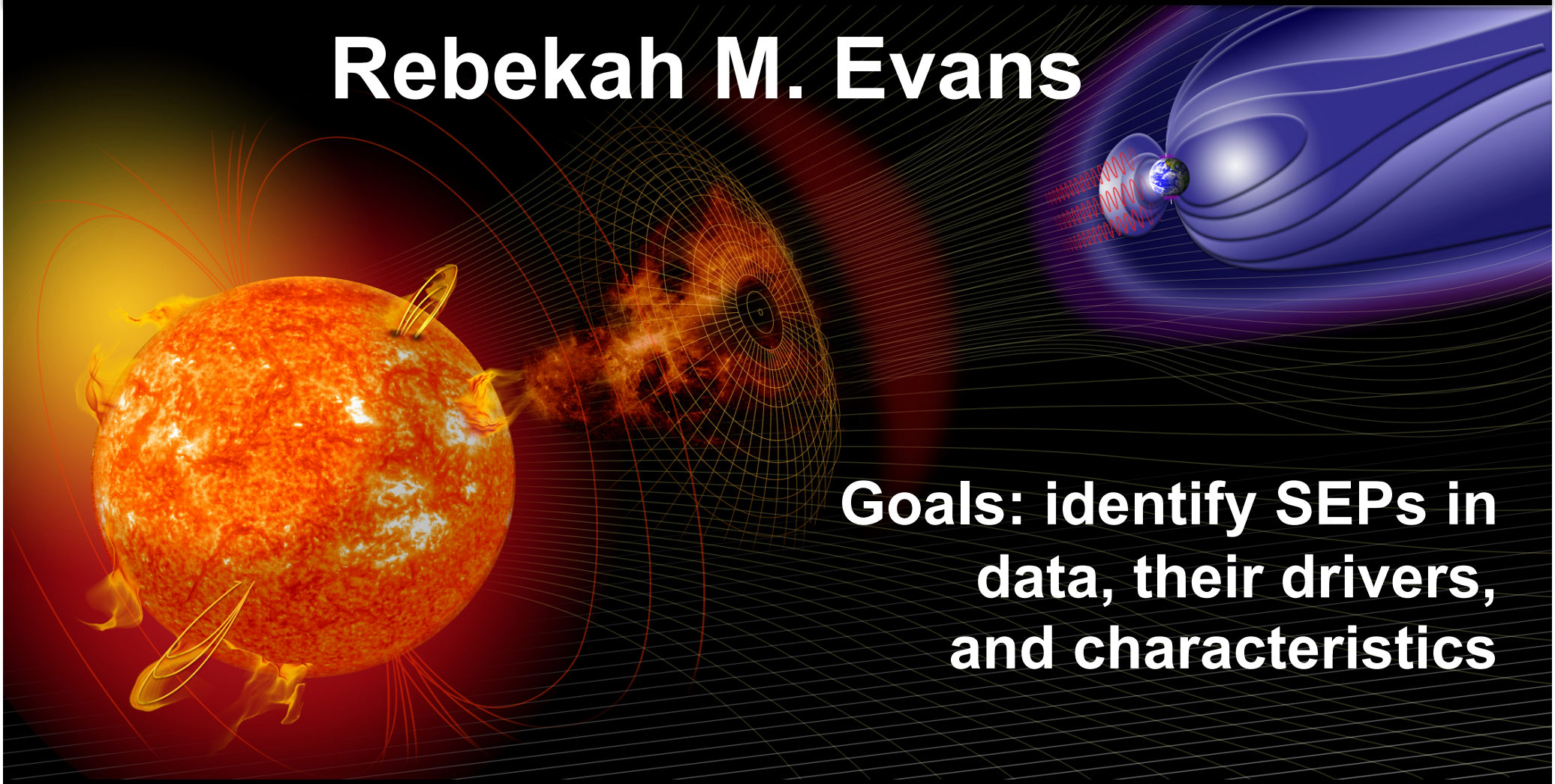
Solar Energetic Particles (SEPs)

Rebekah M. Evans



Goals: identify SEPs in data, their drivers, and characteristics

June 4, 2013

SW REDI Boot Camp

What are they?

Definition:

Energetic charged particles (such as electrons and protons) traveling much faster than ambient particles in the space plasma, at a % of the speed of light (relativistic!)

Elemental composition* (may vary event by event)

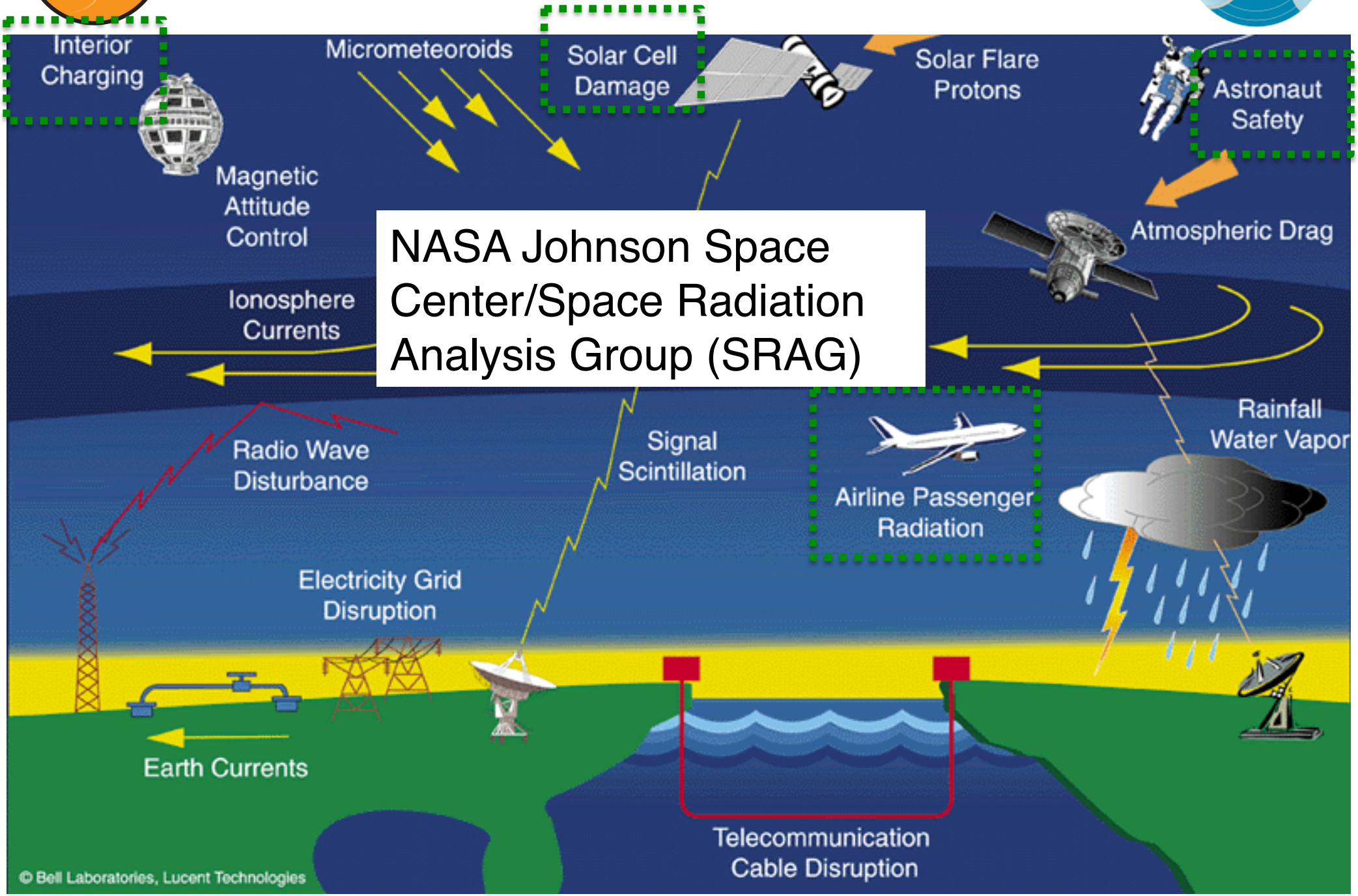
- 96.4% protons
- 3.5% alpha particles
- 0.1% heavier ions (not to be neglected!)

Energies: up to ~ GeV/nucleon

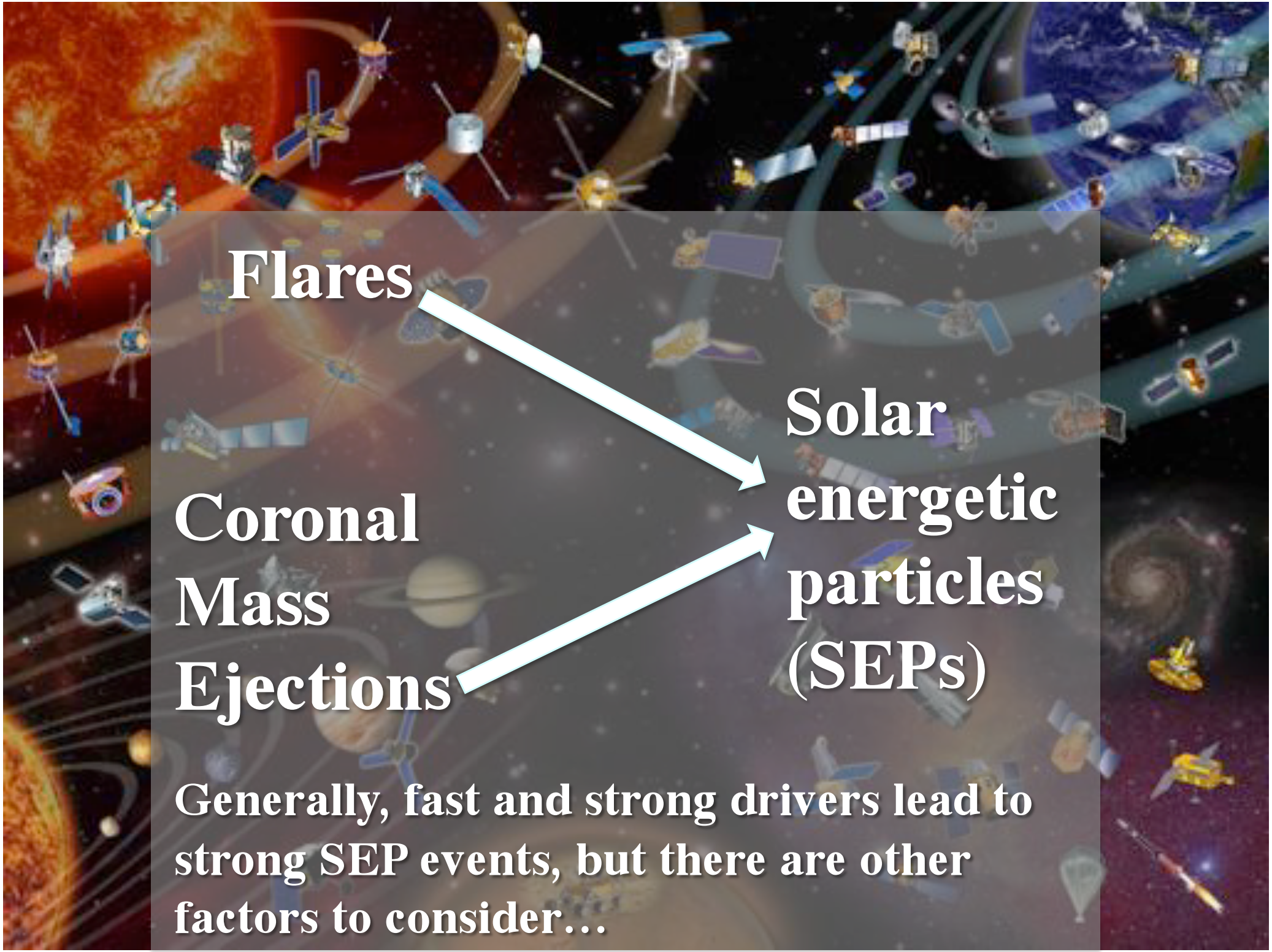
They can travel from the Sun to the Earth in one hour or less!

The term SEP usually refers to protons (even though “p” is particle)

Why do we care?

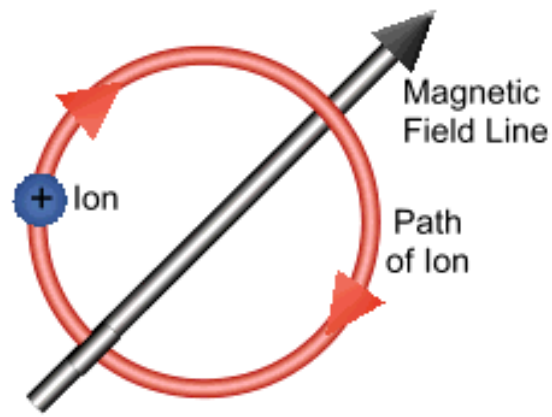


NASA Johnson Space Center/Space Radiation Analysis Group (SRAG)


Flares
Coronal Mass Ejections
Solar energetic particles (SEPs)
Generally, fast and strong drivers lead to strong SEP events, but there are other factors to consider…

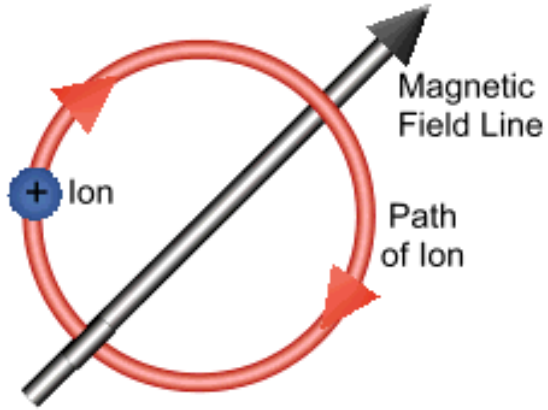
Magnetic fields guide SEPs

Charged particle motion* is confined by the magnetic field.



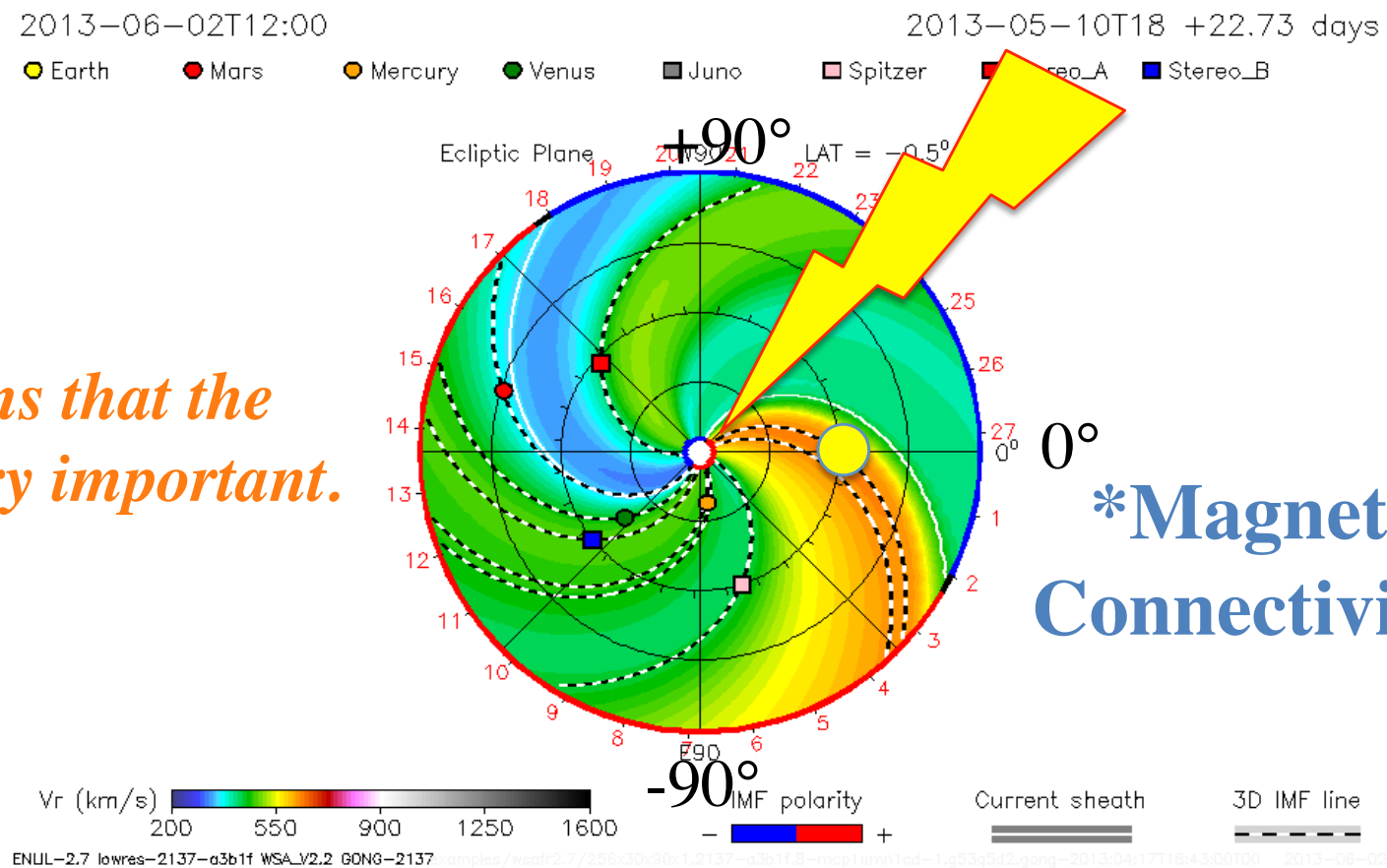
*in a substantially strong B

Magnetic fields guide SEPs



Charged particle motion* is confined by the magnetic field.

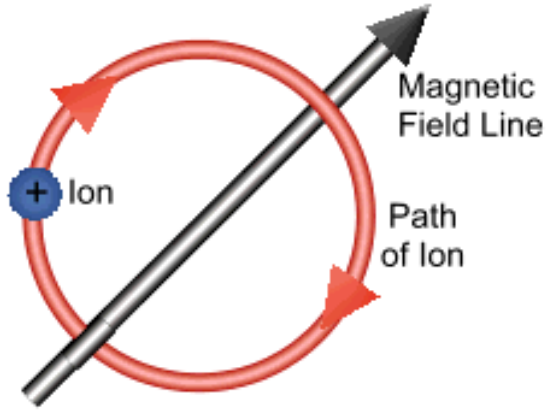
This means that the source is very important.



Magnetic Connectivity

*in a substantially strong B

Magnetic fields guide SEPs



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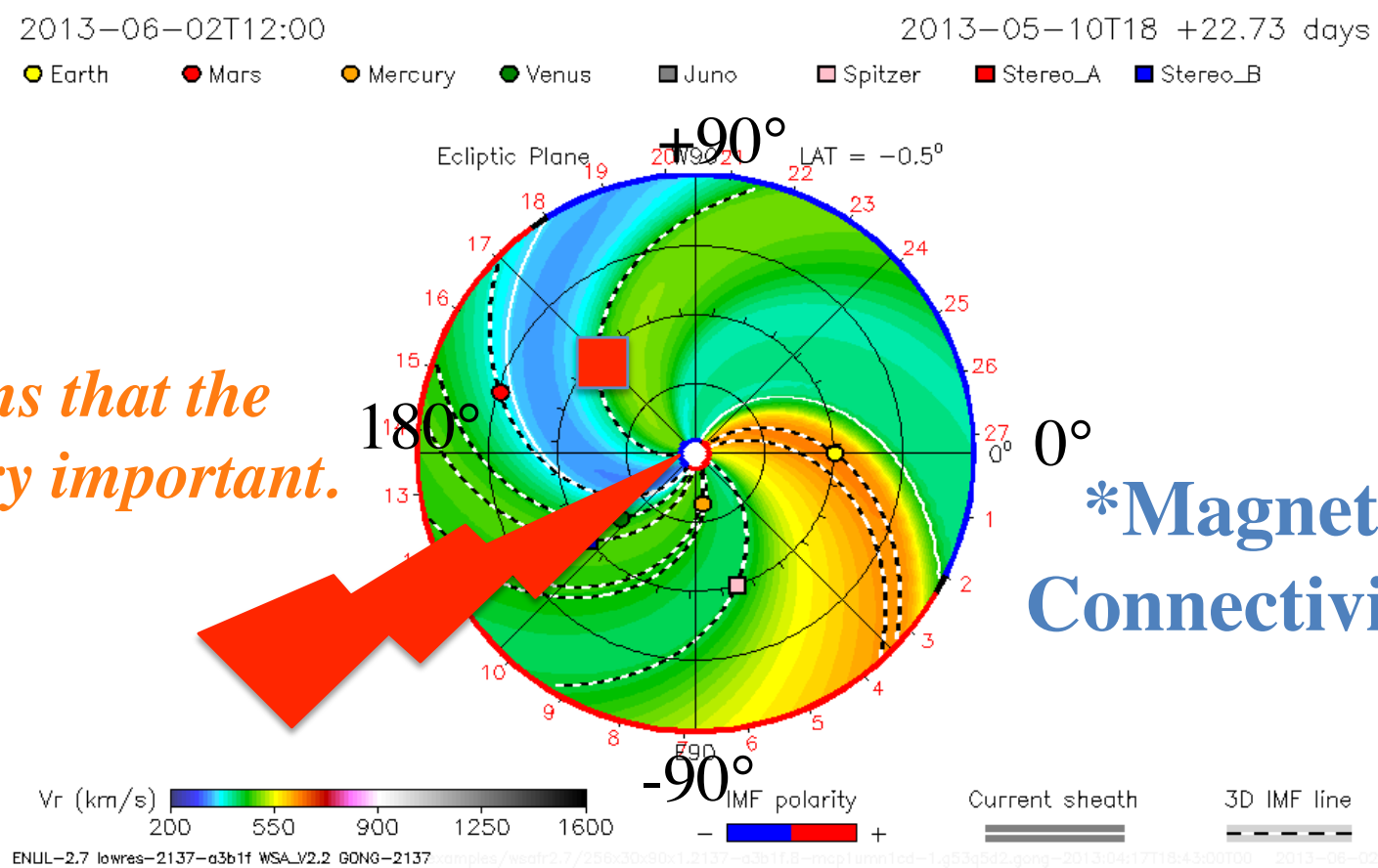

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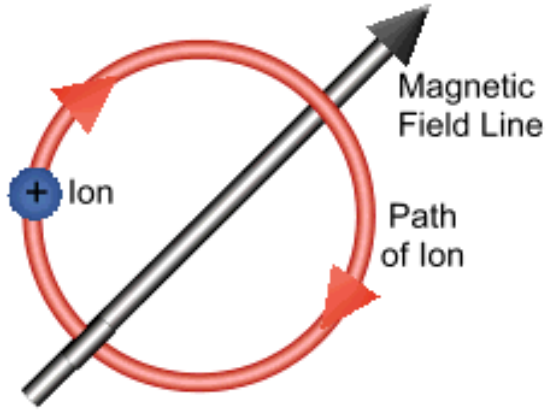

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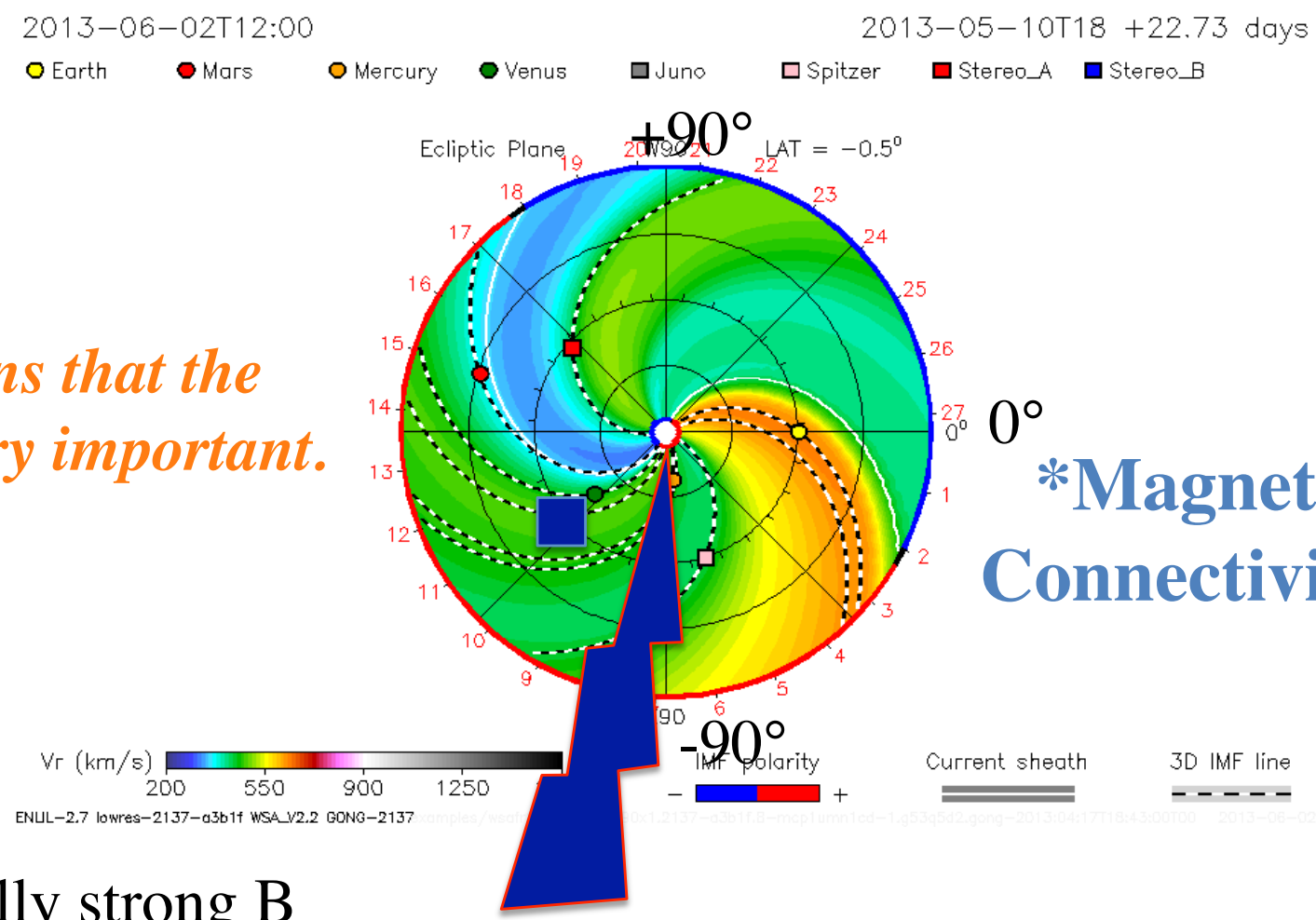
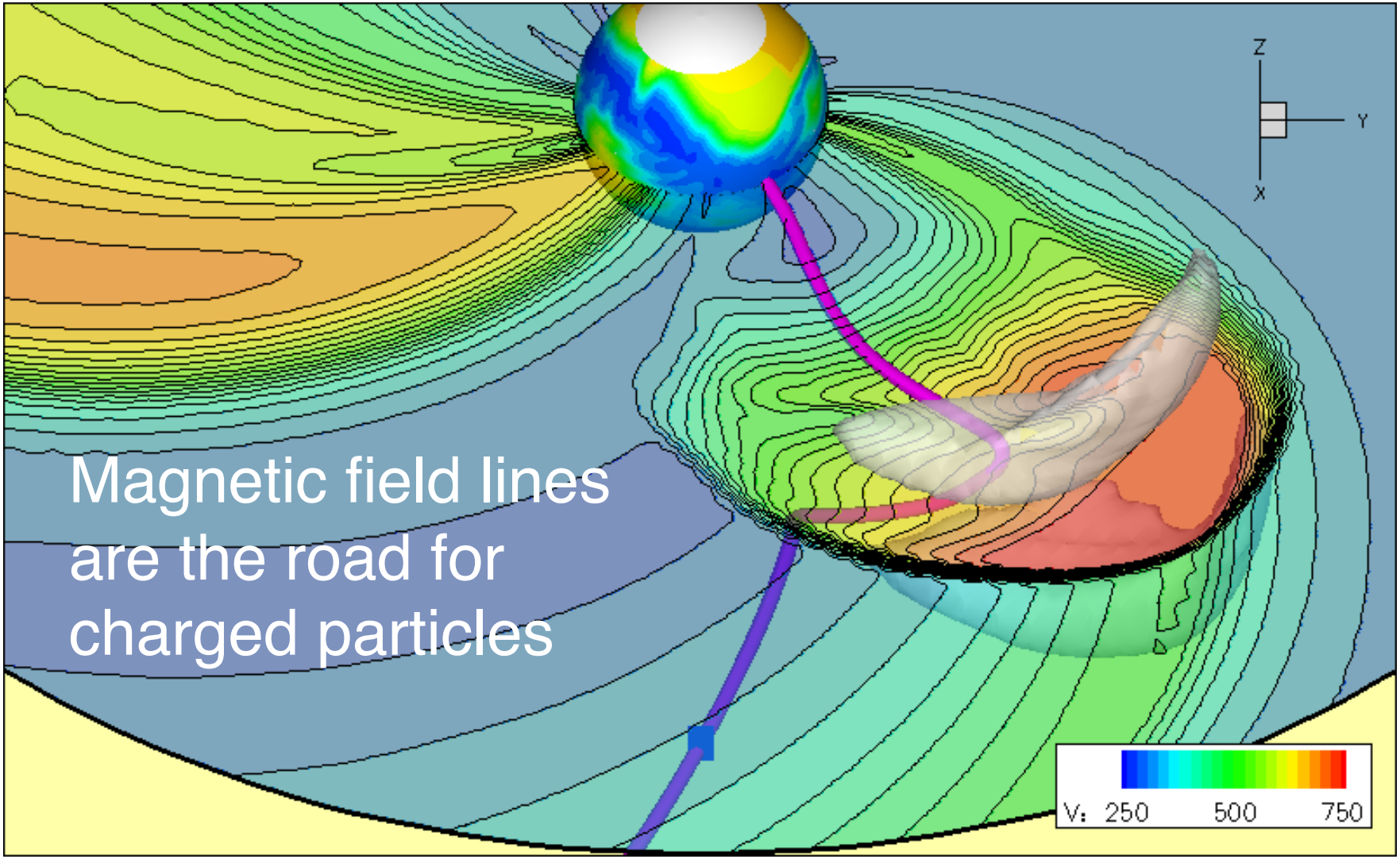


Magnetic Connectivity

*in a substantially strong B

CMEs Can Widen Longitudinal Extent of SEP Events



Magnetic Connectivity

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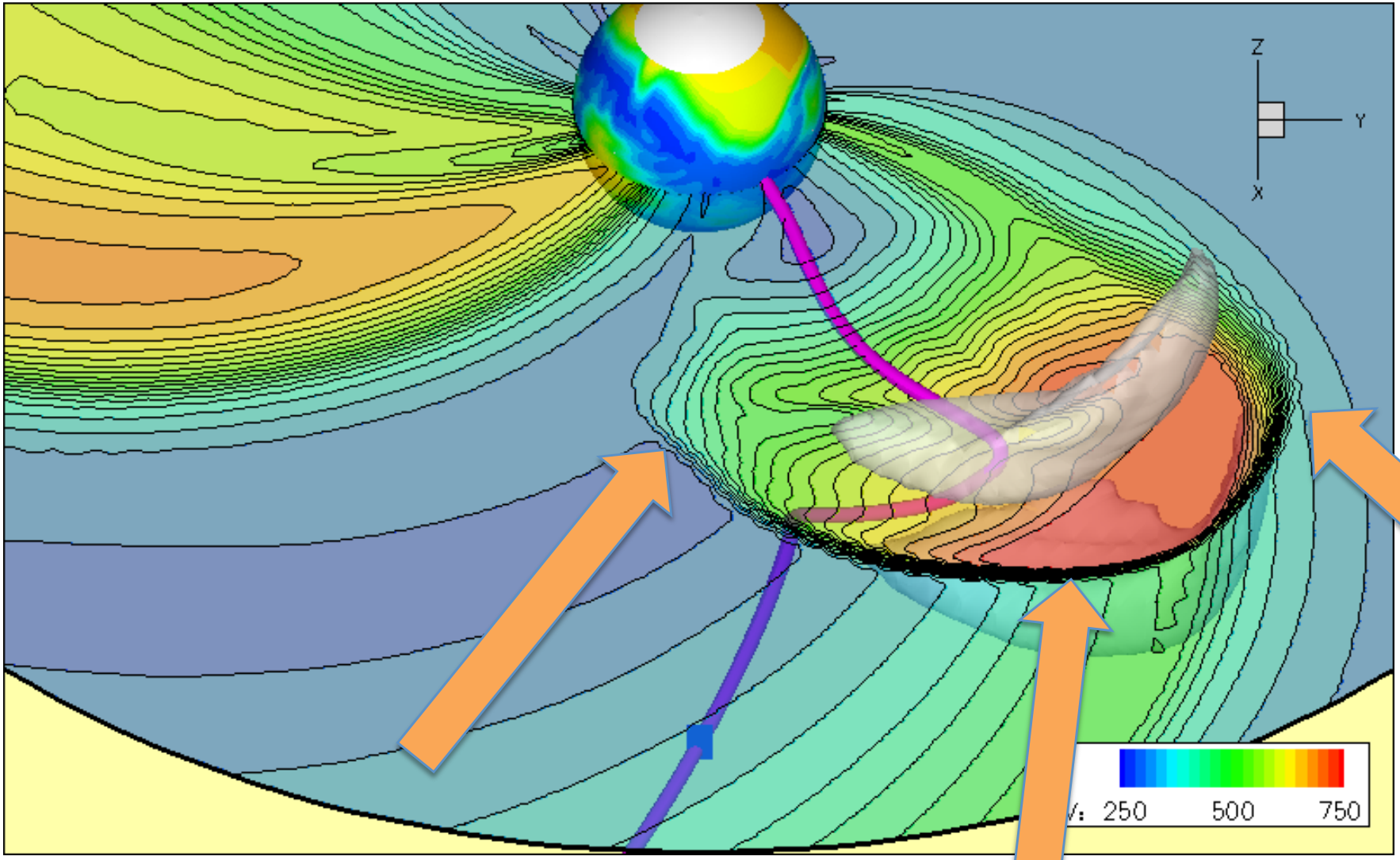


Magnetic Connectivity

How Do We Monitor SEP Levels?

Track the particle flux at different locations.
Units: pfu, pfu/MeV
(1 pfu = 1 particle flux unit= 1/cm^2/sec/sr)

- ***Heliosphere with STEREO In-situ Measurements of Particles and CME Transients (IMPACT)***
  - ***Differential energy band; example energy range: 13-100 MeV***
- ***Upstream of Earth with SOHO/COSTEP***
  - ***Differential energy bands; example energy range: 15.8-39.8 MeV***
- ***Geostationary Orbit with GOES***
  - ***Integral flux, example energy ranges: >10 MeV, >100 MeV***

How Do We Monitor SEP Levels?

Track the particle flux at different locations.
Flux units: pfu, pfu/MeV

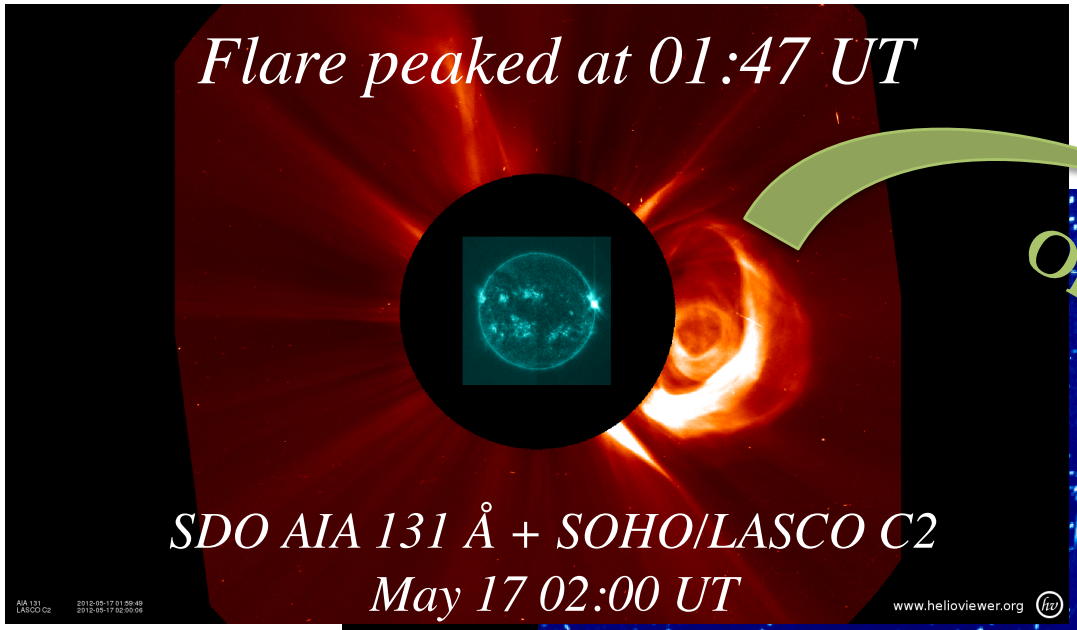
Another useful quantity:
Fluence = flux integrated over the entire event - dose
Important for biological effects (flights)

Event magnitudes:

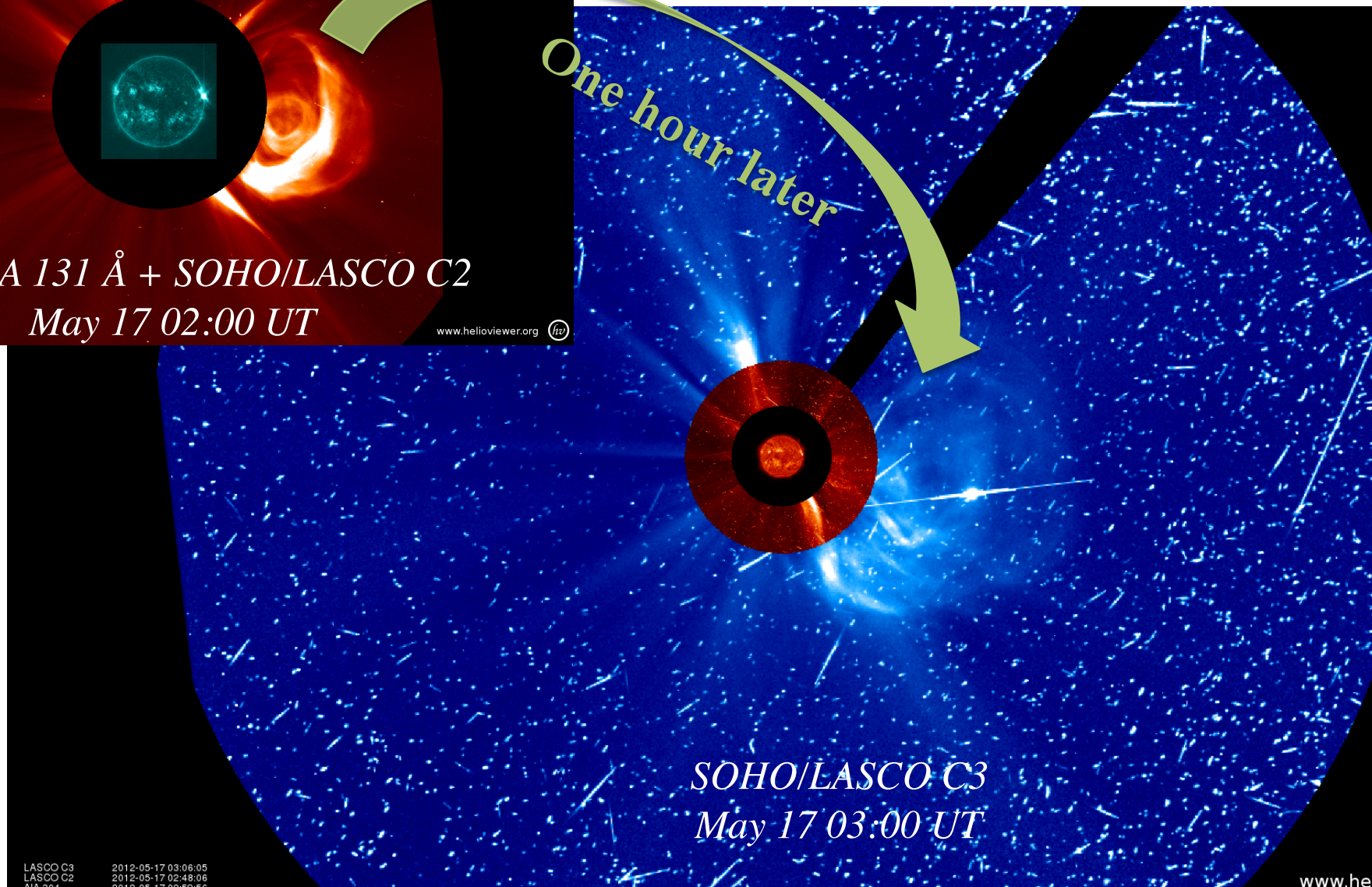
> 10 MeV/nucleon integral fluence: can exceed 10^9 cm^{-2}

> 10 MeV/nucleon peak flux: can exceed 10^5 $cm^{-2}s^{-1}$

Coronagraph acting as particle detector – SNOW!



One hour later



How do we define an SEP Event?

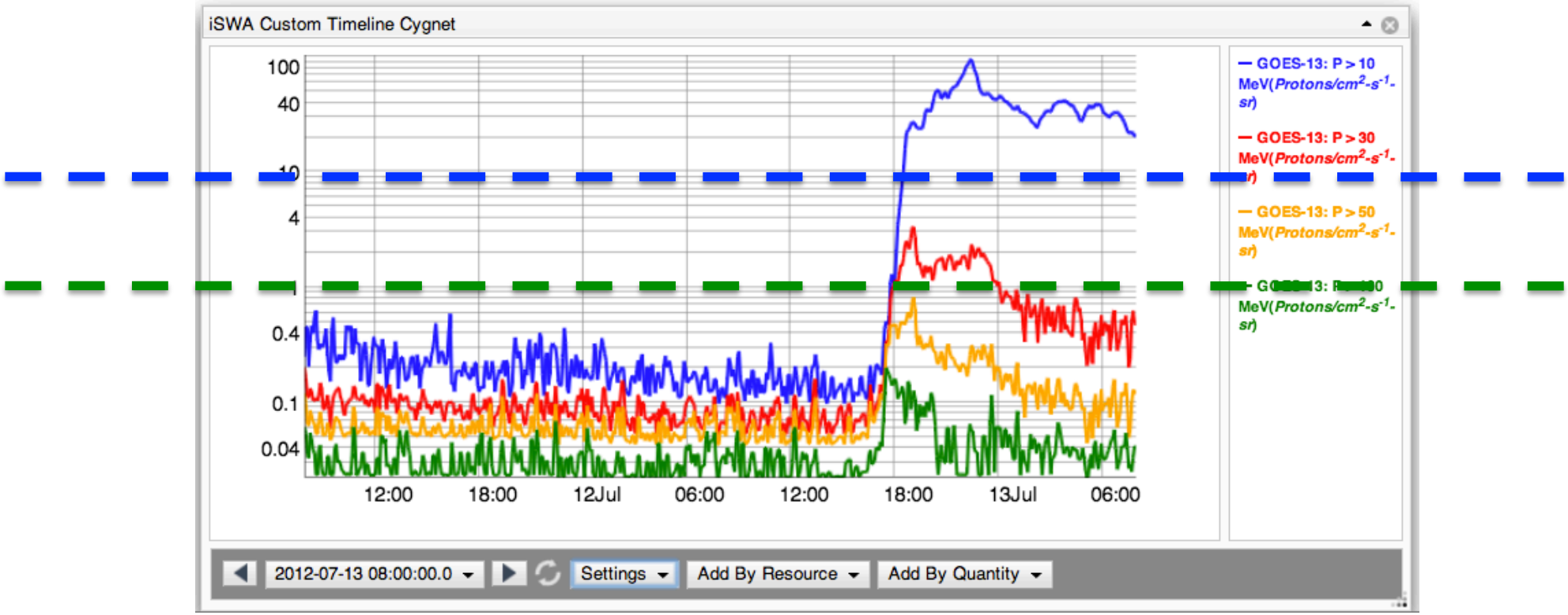
At the SWRC, SEP events are defined as:

GOES Proton E > 10 MeV channel > 10 pfu

GOES Proton E > 100 MeV channel > 1 pfu

SOHO Proton, >15.8 MeV channel > 0.1 pfu/MeV

STEREO Impact 13-100 MeV channel > 0.1 pfu/MeV



How Do We Quantify an SEP Event?

NOAA Space Weather Scale for Solar Radiation Storms

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Solar Radiation Storms			Flux level of >= 10 MeV particles (ions)*	Number of events when flux level was met (number of storm days**)
S 5	Extreme	**Biological:** unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Other systems:** complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	**Biological:** unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. **Other systems:** blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	**Biological:** radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. **Other systems:** degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	**Biological:** passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** **Satellite operations:** infrequent single-event upsets possible. **Other systems:** small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	**Biological:** none. **Satellite operations:** none. **Other systems:** minor impacts on HF radio in the polar regions.	10	50 per cycle

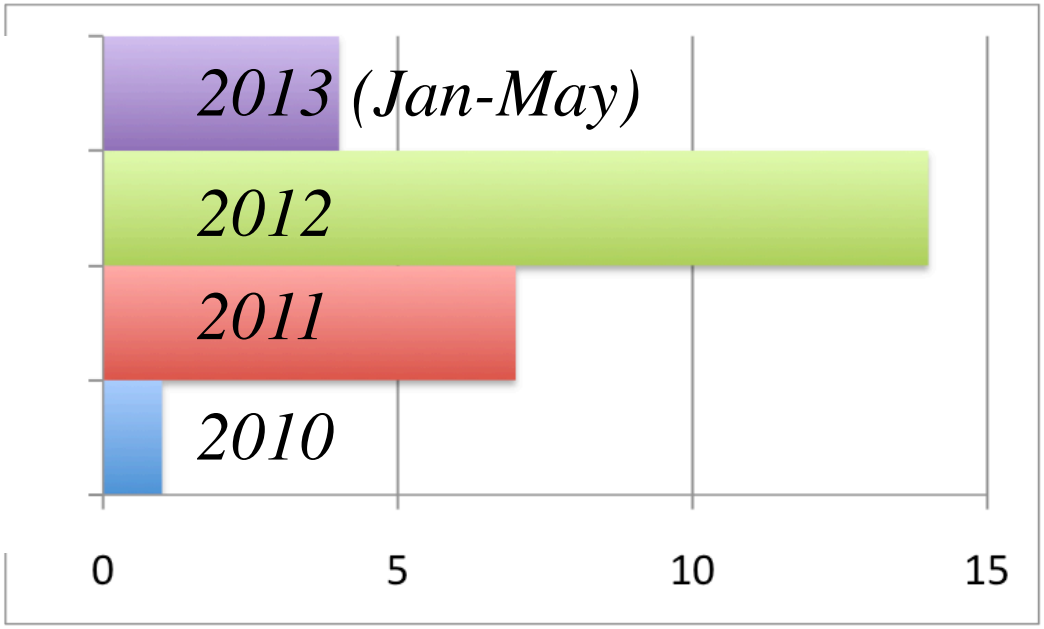
How Often Do SEP Events Occur?

SEP event detections in the near-Earth environment

(GOES 13, Proton E > 10 MeV channel)

2007-2009: Zero Events - Solar Minimum

Total Events (Earth)



Since March 2011

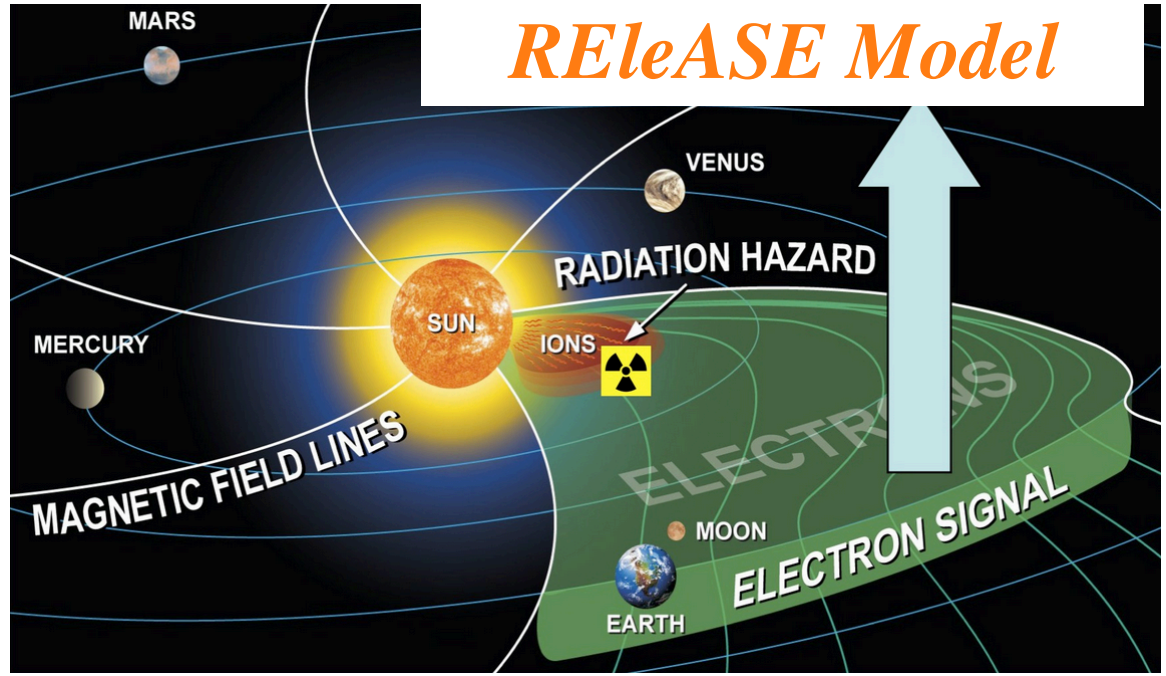
STEREO A: 16

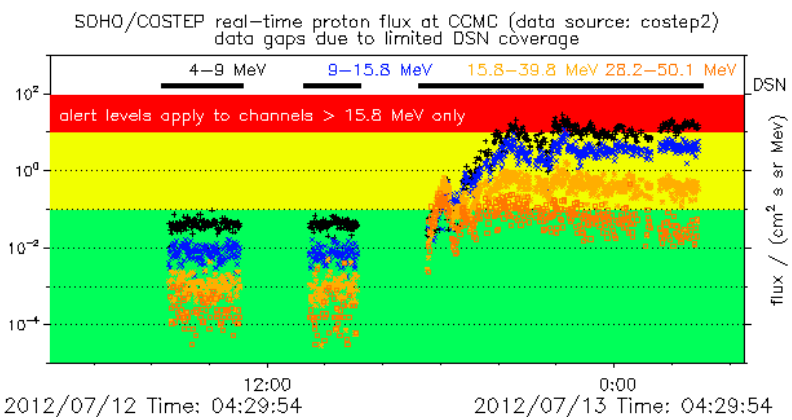
STEREO B: 11

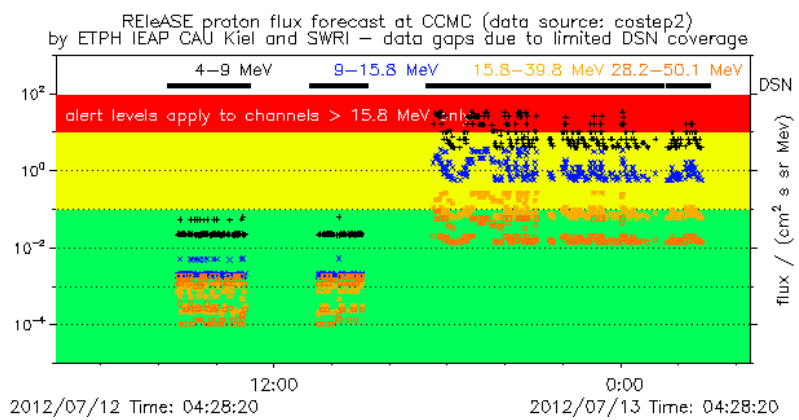
Can we forecast SEP events?

Uses detection of high energy *electrons* to predict arrival of high energy *protons*

Data source: SOHO/ COSTEP



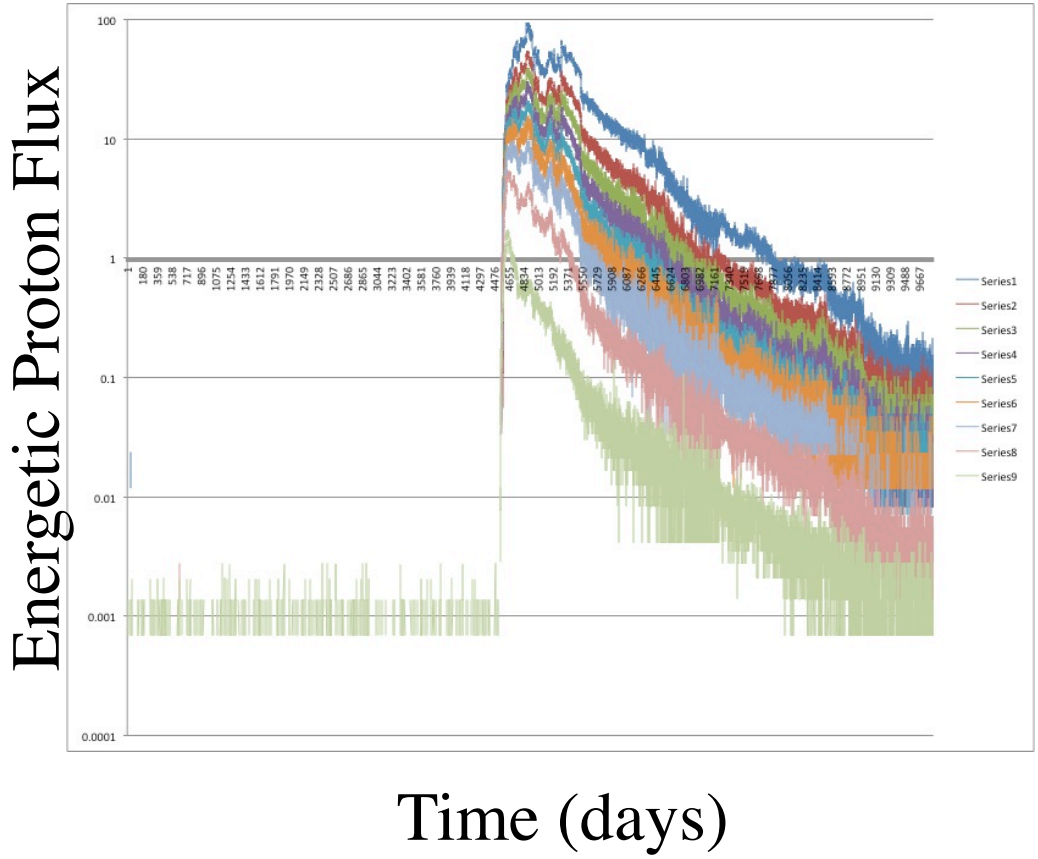




Recognizing profile shapes of SEP flux and associations with the driver(s)

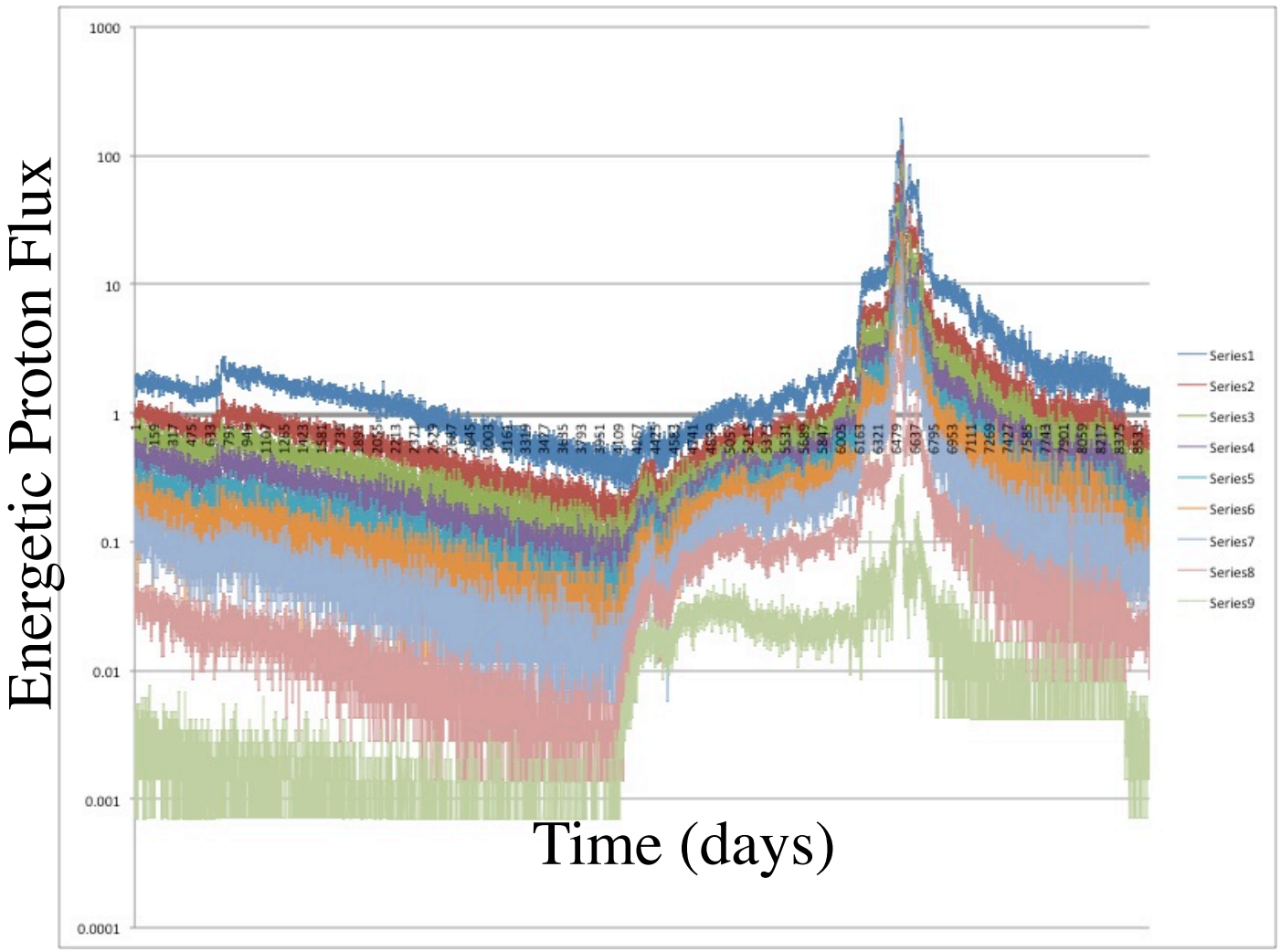
Impulsive SEP event

The peak at the beginning due to flare, fall off – indicates how well connected you are to the source (timing)



Gradual SEP event

Slow rise, then peak when the ICME passes the spacecraft



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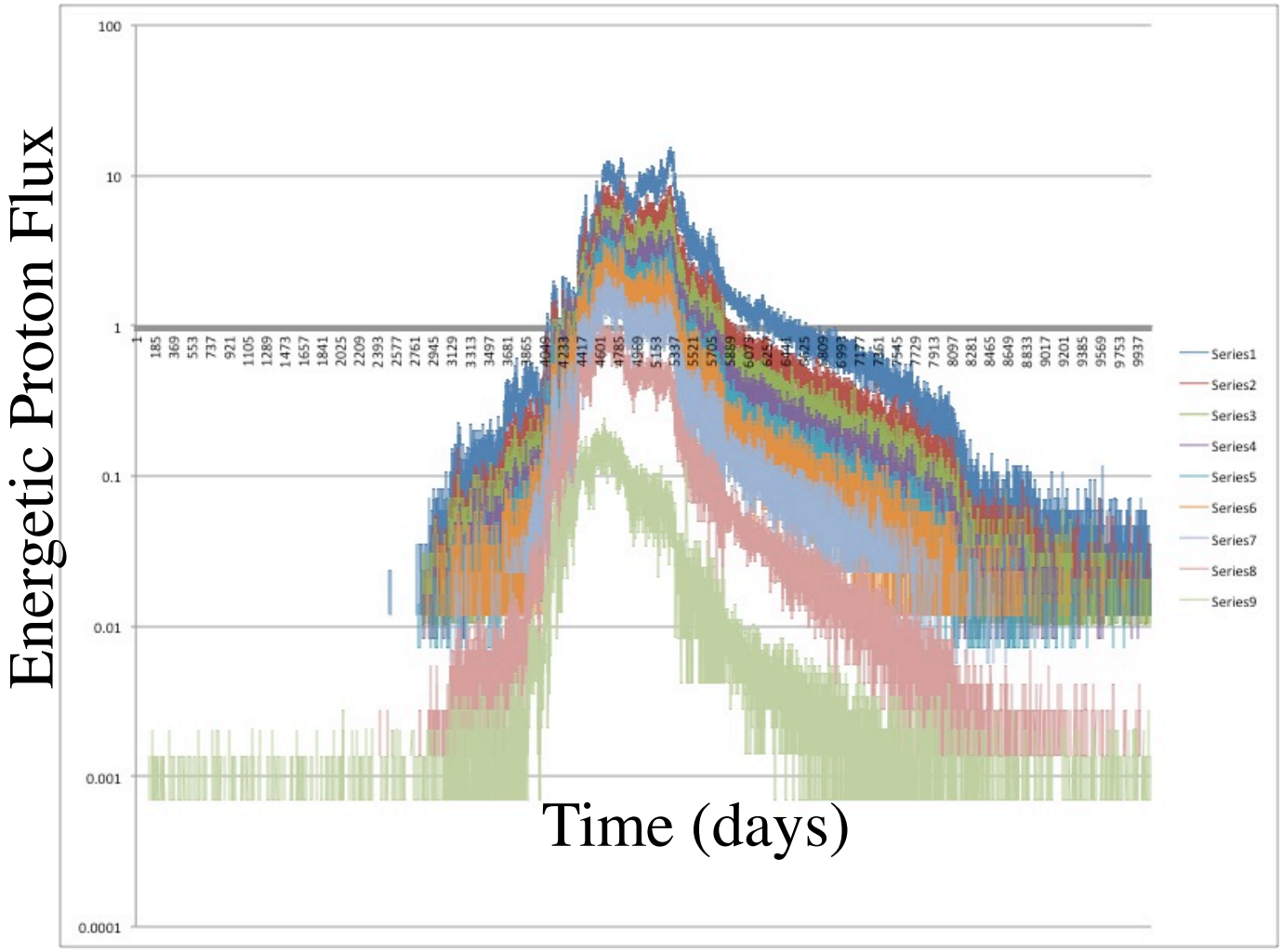
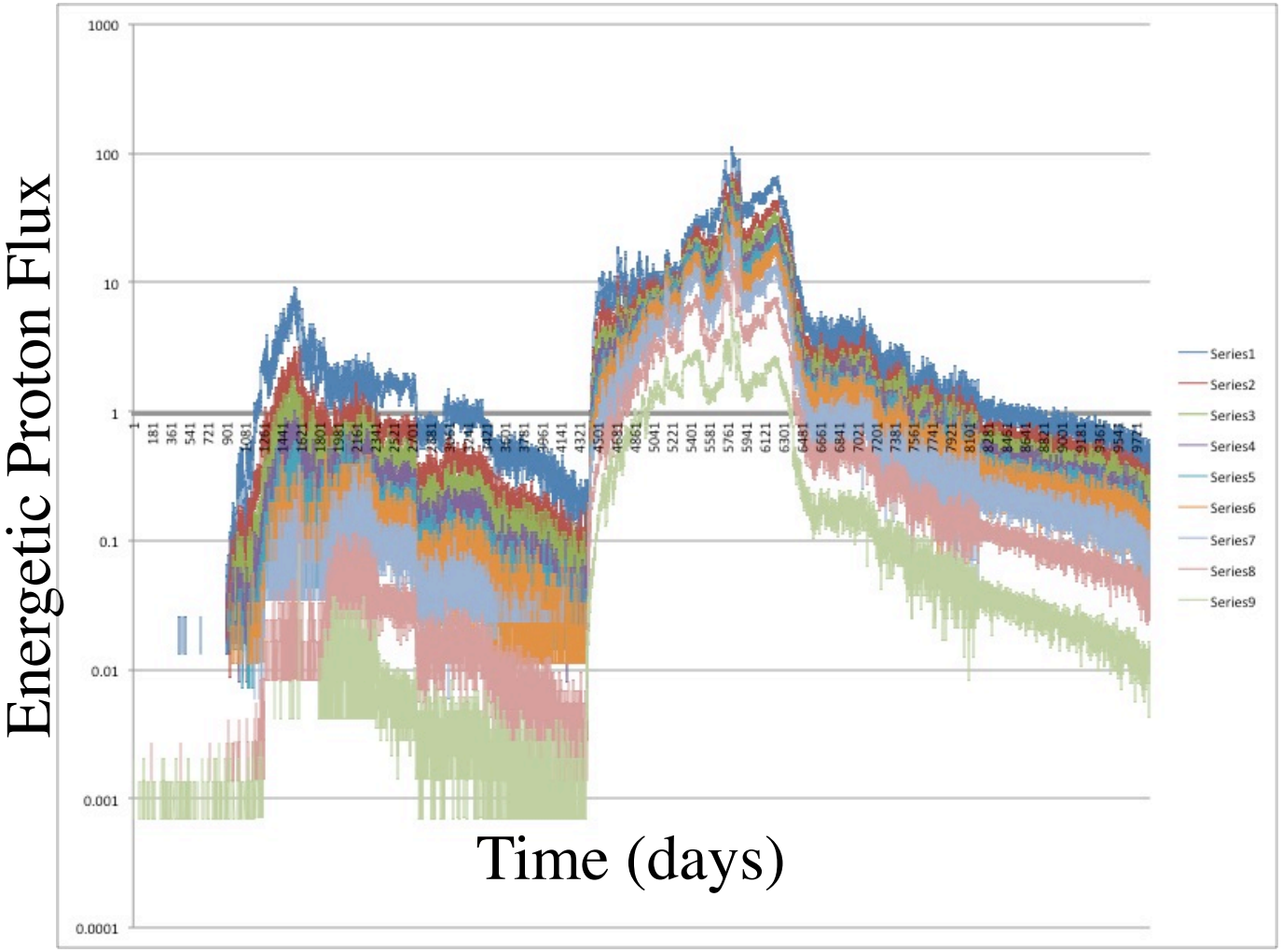
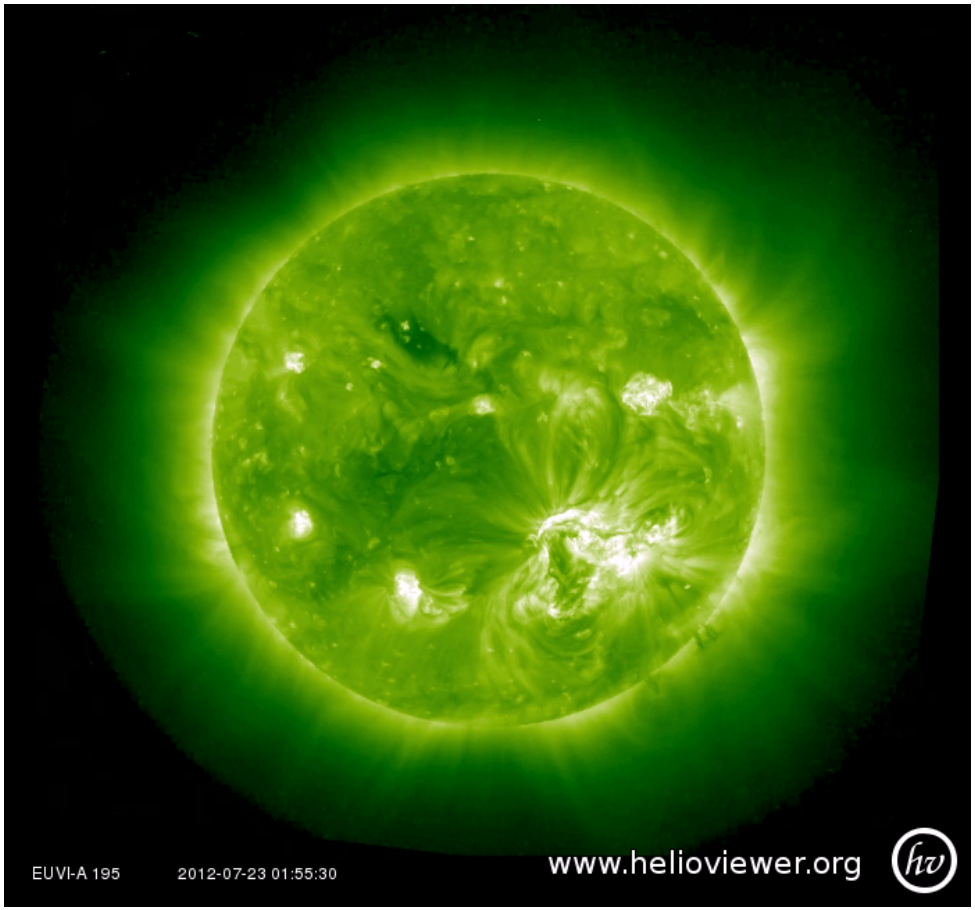


Multiple SEP event

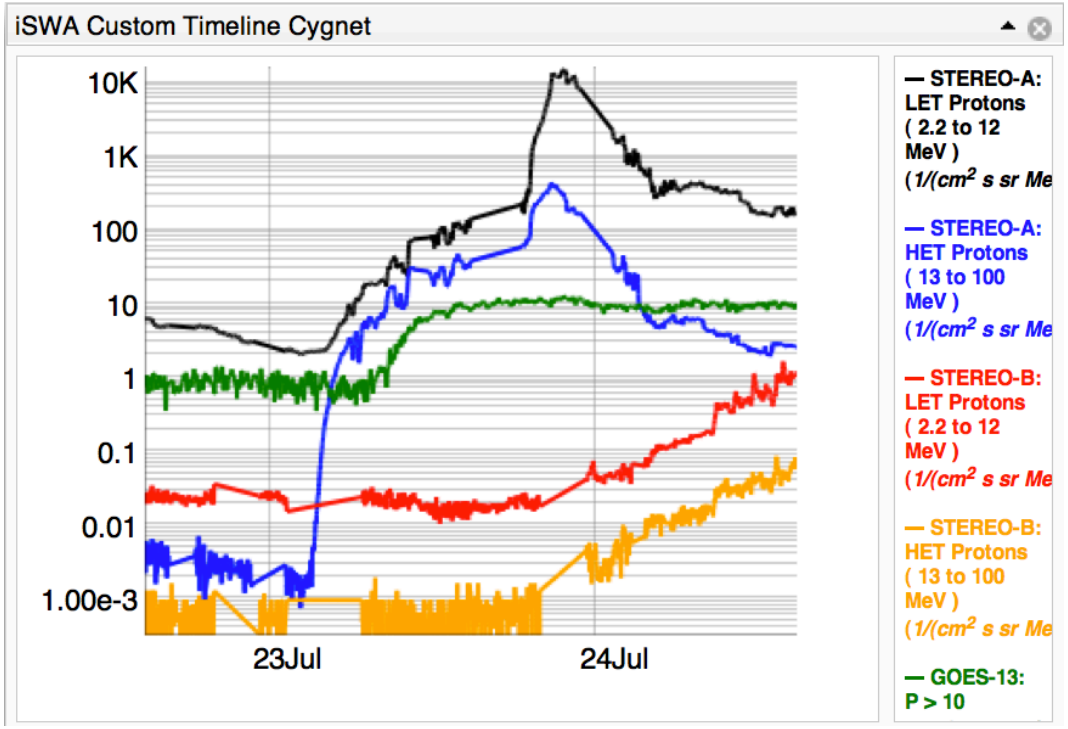
Another event occurs before the first ends



July 23, 2012

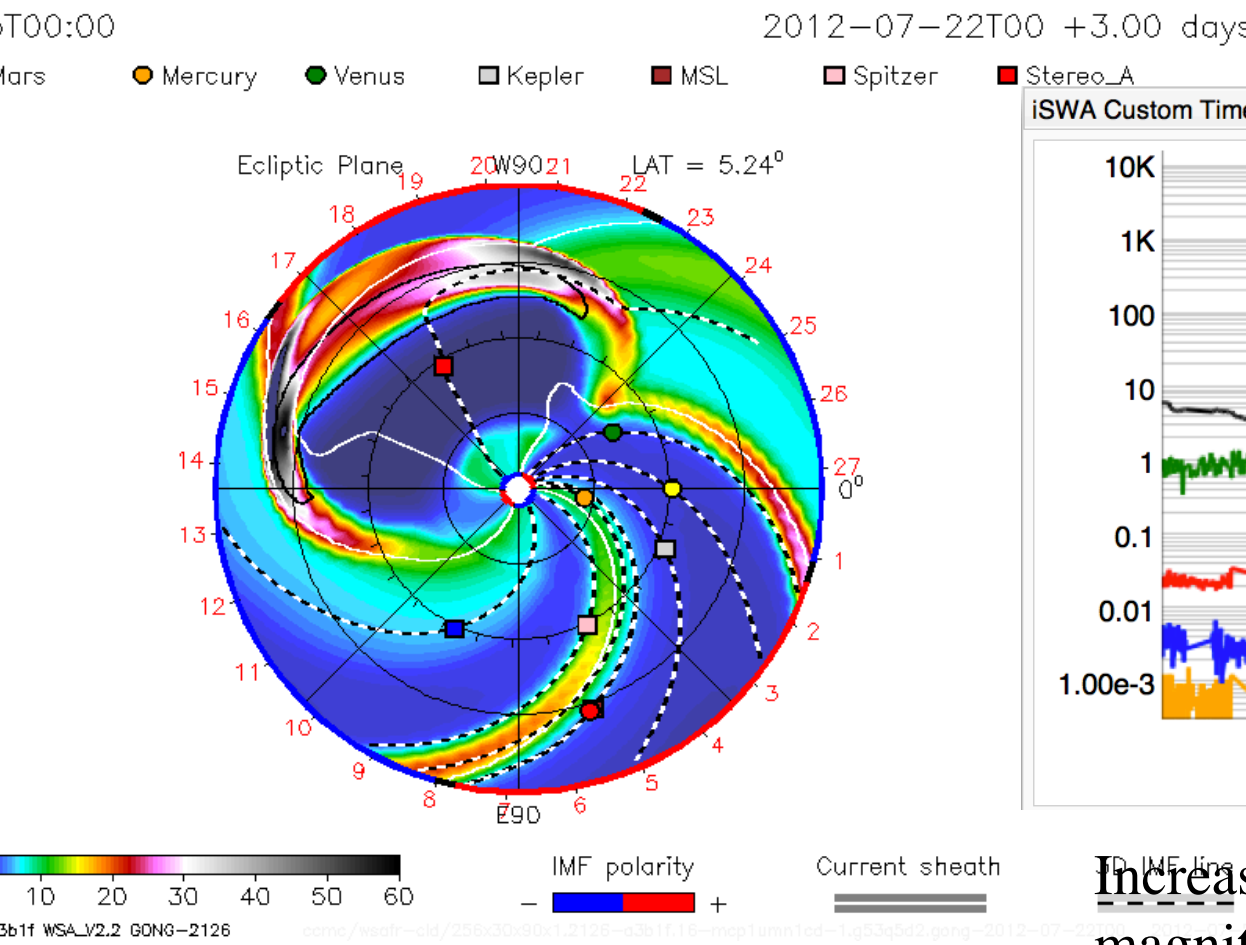


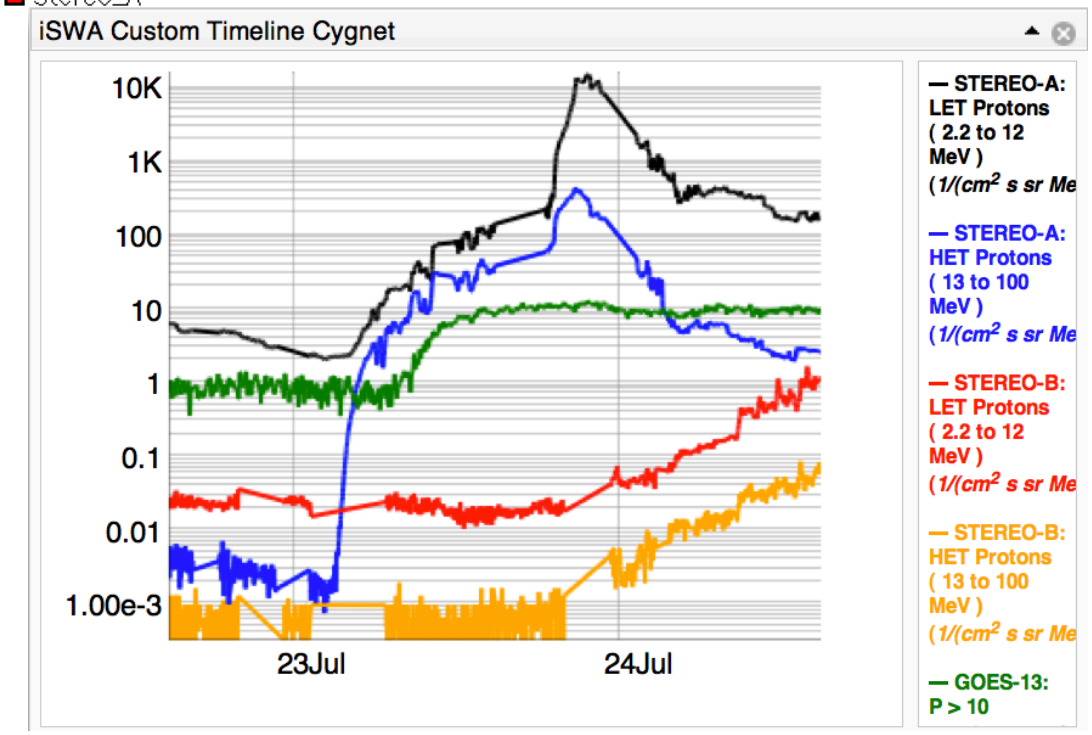
July 23 flare as seen in STEREO A EUVI 195



Increase of more than 5 orders of magnitude at STEREO A
SEP event also detected by GOES, and later enhancement seen at STEREO B (possibly due to IPS)

July 23, 2012





July 23 CME as modeled with WSA-ENLIL + cone

Increase of more than 5 orders of magnitude at STEREO A
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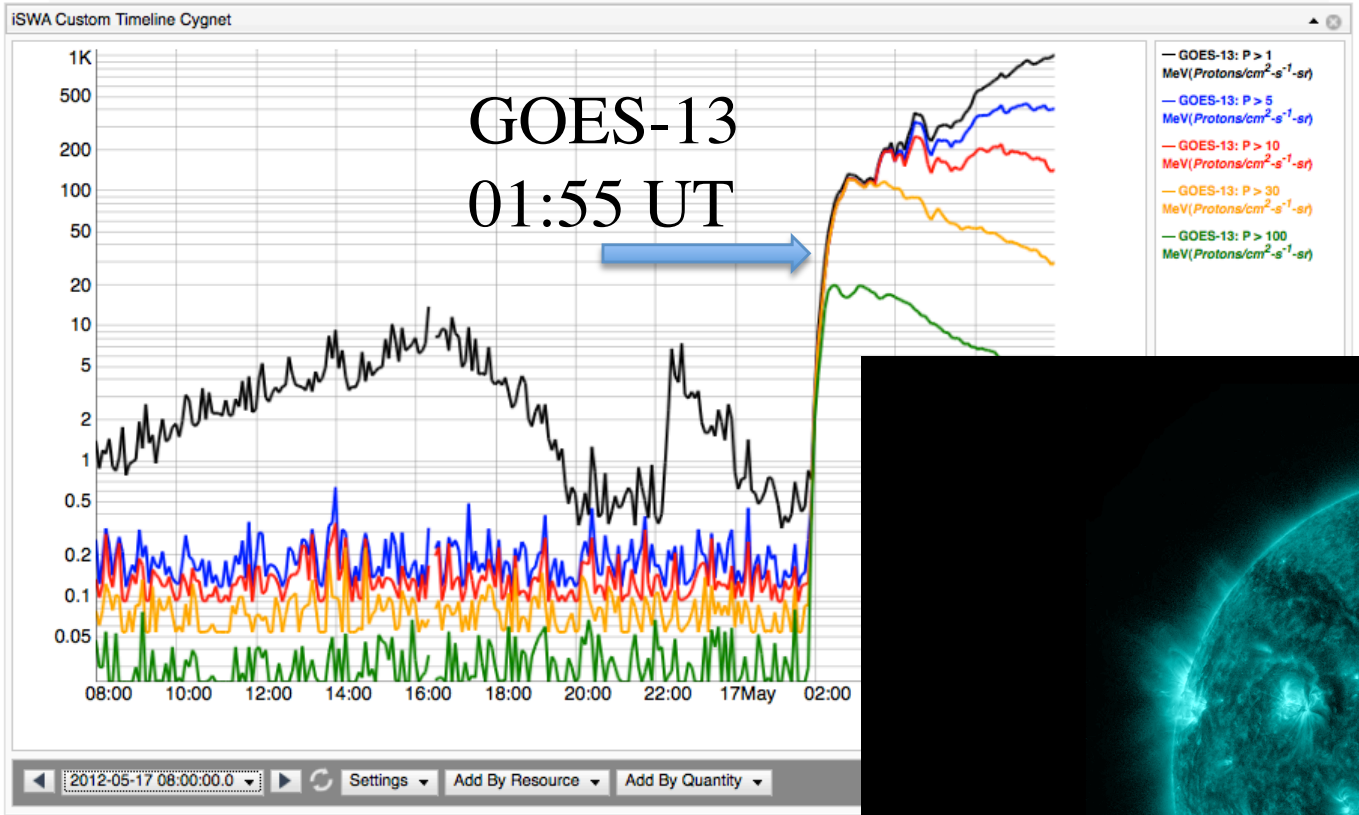
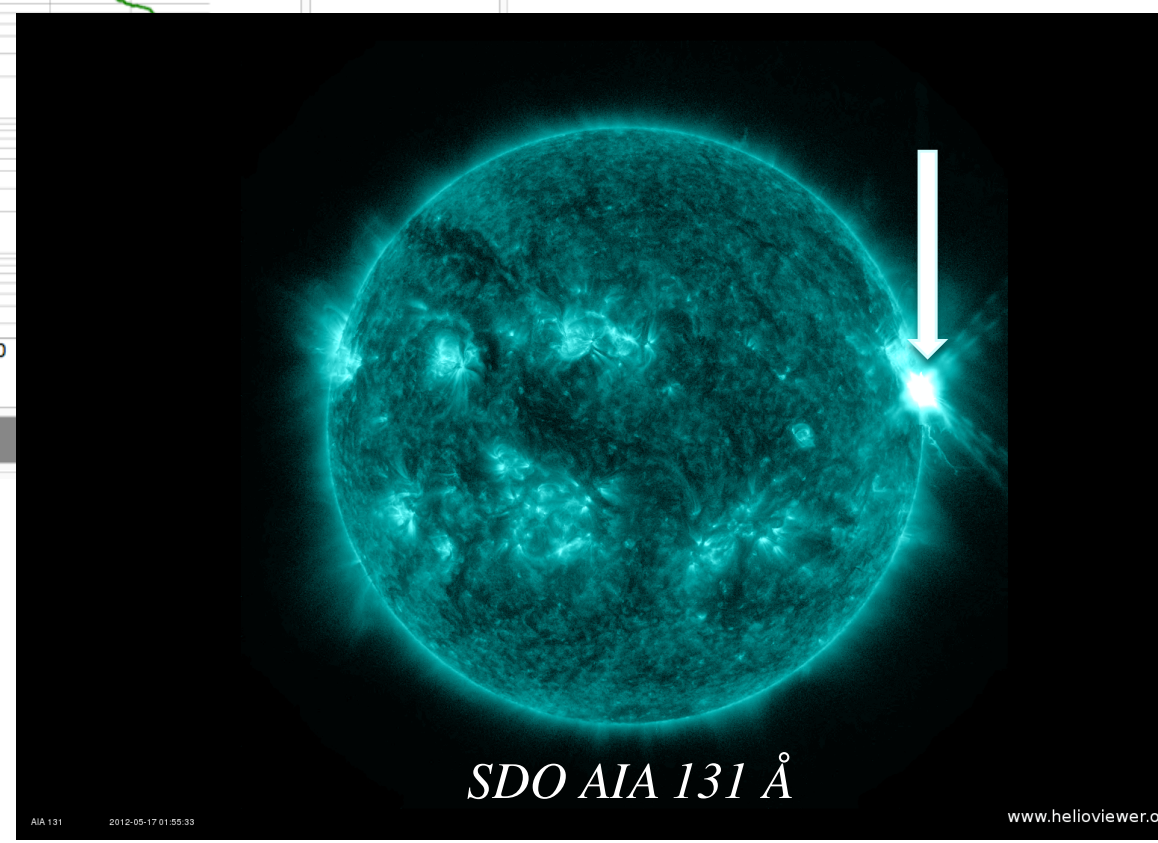
For Earth – Best Connection is Western Limb





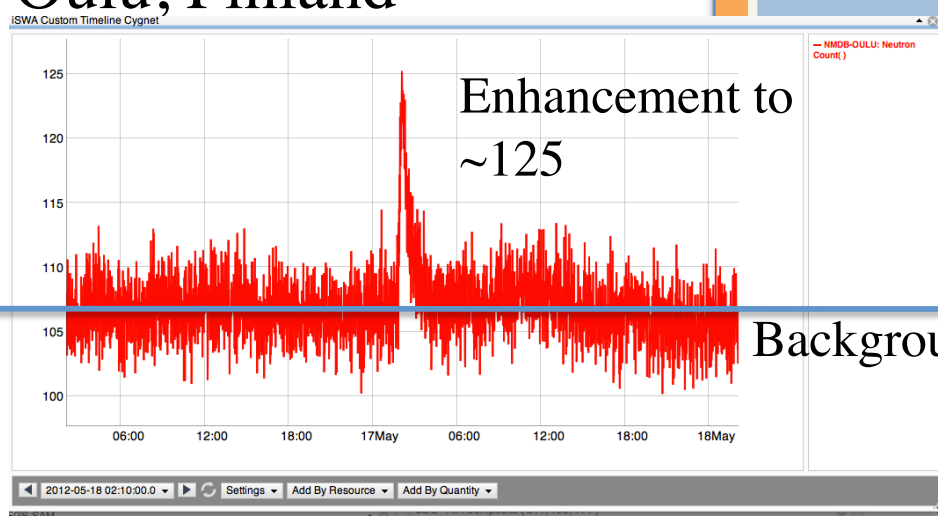
Energetic proton fluxes elevated for >12 hours

Ground Level Enhancement

A subset of SEP events, a GLE event occurs when extremely high energy protons (>500 MeV/nuc) penetrate the Earth's atmosphere. Collisions with atoms generate secondary particles that are measured at neutron monitoring (NM) stations on the ground.

NM Stations *(http://www.nmdb.eu)*

Neutron Monitoring Station in Oulu, Finland



Enhancement to ~125

Background ~105

What causes strong SEP events?

Complexity of AR

-Most young, more compact

- Magnetic connectivity of AR

-About ~50% are well connected

- Magnitude of flare

- Average X3.8, but as low as M7.1

- Long duration

- Magnitude of CME

-Range of speeds (~2,000 km/s average, but four events <1,500 km/s)

- Seed particles

-Known to have harder spectrum

Table 1 GLE events and associated flares and CMEs (adopted from Gopalswamy et al. 2010)

GLE Onset ID	Date	Time[a]	Max Int (%)[a]	Flare GOES Class	Location	CME POS speed (km/s)	Width (degs)
55	1997/11/06	12:10	11.3	X9.4	S18W63	1556	360
56	1998/05/02	13:55	6.8	X1.1	S15W15	938	360
57	1998/05/06	08:25	4.2	X2.7	S11W66	1099	190
58	1998/08/24	22:50	3.3	X1.0	N35E09	–[b]	–[b]
59	2000/07/14	10:30	29.3	X5.7	N22W07	1674	360
60	2001/04/15	14:00	56.7	X14	S20W85	1199	167
61	2001/04/18	02:35	13.8	C2.2	S20W116	2465	360
62	2001/11/04	17:00	3.3	X1.0	N06W18	1810	360
63	2001/12/26	05:30	7.2	M7.1	N05W54	1446	>212
64	2002/08/24	01:18	5.1	X3.1	S02W81	1913	360
65	2003/10/28	11:22	12.4	X17	S18E18	2459	360
66	2003/10/29	21:30	8.1	X10	S18W04	2029	360
67	2003/11/02	17:30	7.0	X8.3	S18W57	2598	360
68	2005/01/17	09:55	3.0	X3.8	N14W25	2547	360
69	2005/01/20	06:51	277.3	X7.1	N14W61	3242[c]	360
70	2006/12/13	02:45	92.3	X3.4	S06W23	1774	360

[a]According to the Oulu Neutron Monitor

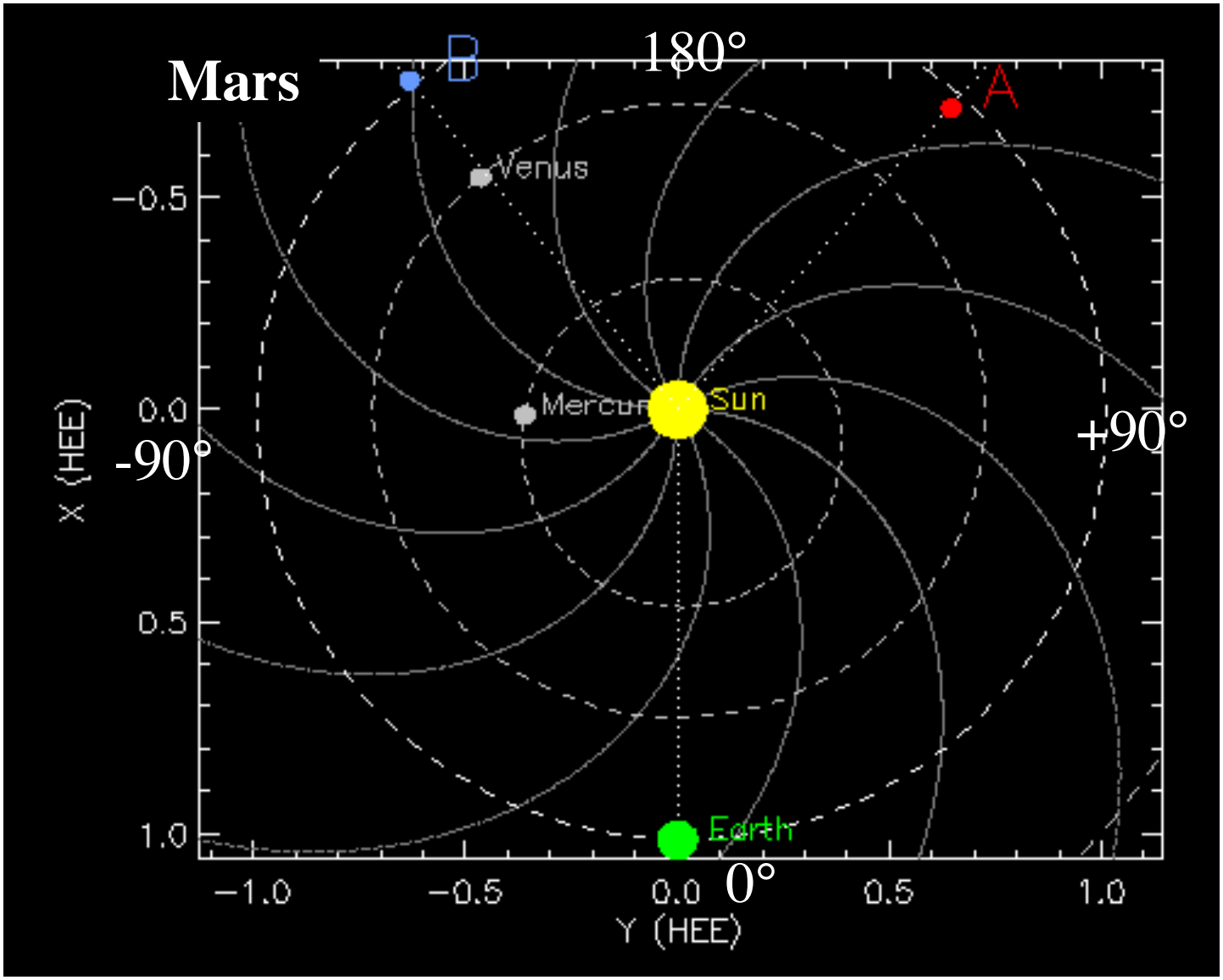
[b]No SOHO LASCO data

[c]From Gopalswamy et al. (2010). There are different estimates (see Grechnev et al. 2008)

Nitta et al. 2012

Gopalswamy et al. 2012, Li et al. 2012, Mewaldt et al. 2012

Where are NASA assets now?



Summary

- SEP events are associated with flares and CMEs
- Charged particles travel along magnetic field lines, and so magnetic connectivity is important
- Monitor energetic protons in the magnetosphere, upstream of the Earth, and in the heliosphere
- An event occurs when the flux increases by ~2 orders of magnitude above background levels
- Can last days
- Space weather effects include biological, spacecraft damage