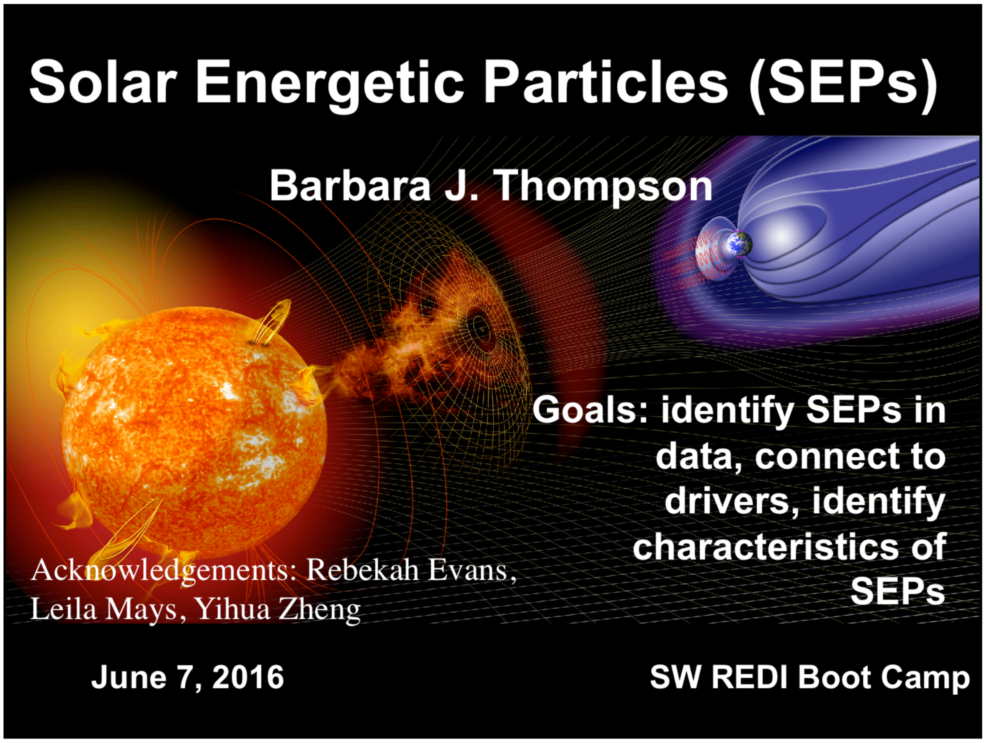


LOOK FOR AN SVS MOVIE!

SEPs: What are they?

Definition:

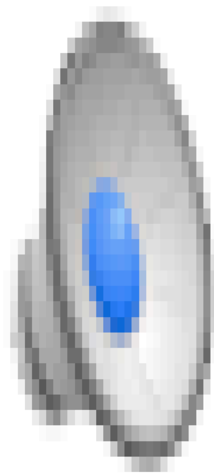
Energetic charged particles (such as electrons protons and other heavy ions) traveling much faster than ambient particles in the space plasma, at a fraction of the speed of light (relativistic!).

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

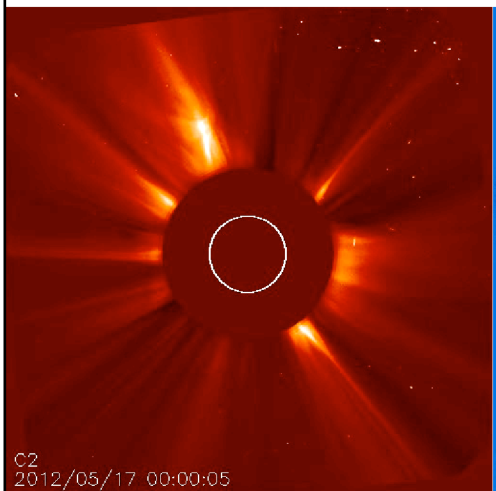
The term “SEP” usually refers to protons.

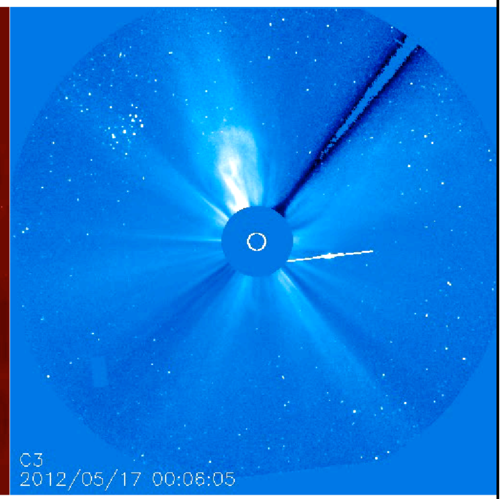
An SEP event is an enhancement in the radiation evironment.

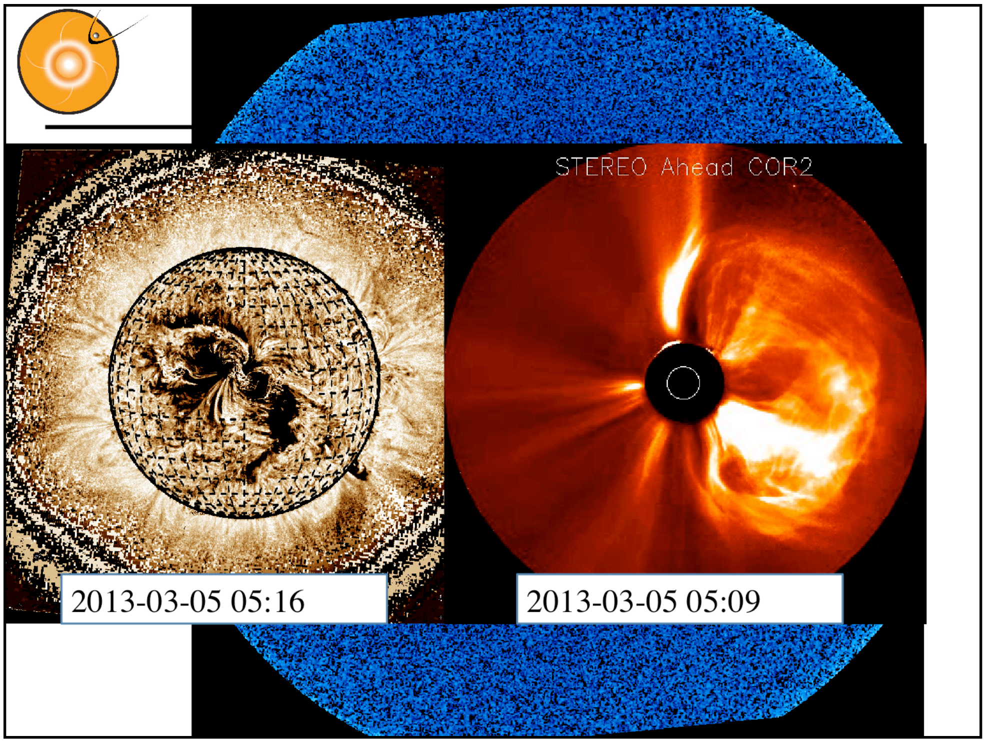
Summarize effects again.

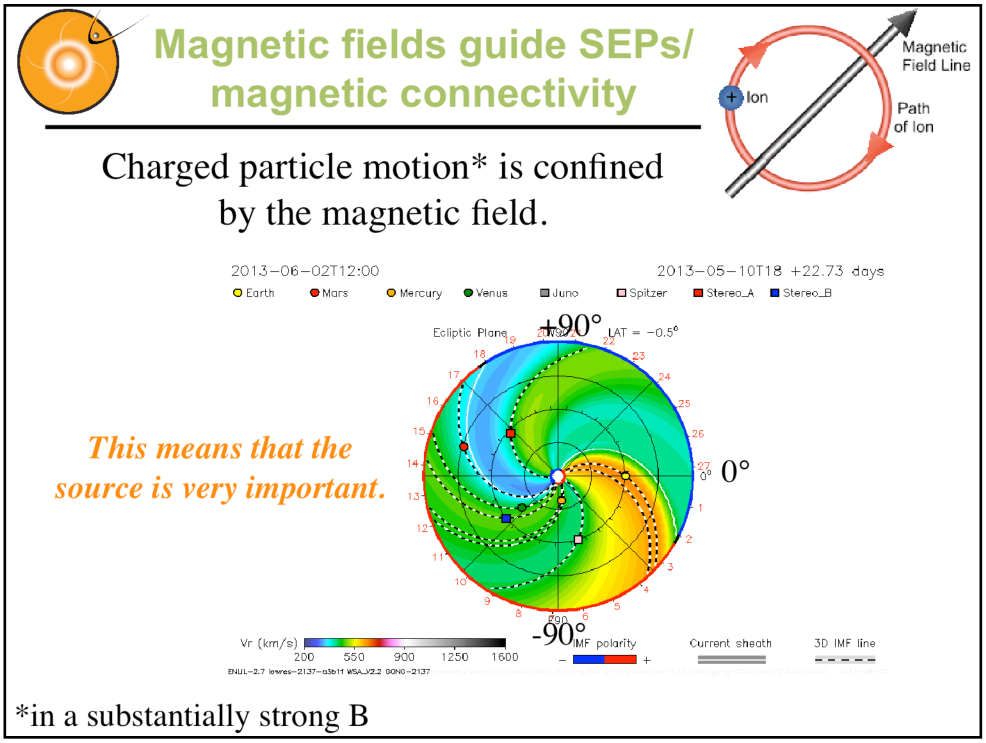


Let it snow[3]






STEREO Ahead COR2
2013-03-05 05:16
2013-03-05 05:09



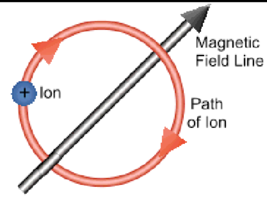
ENLIL

Charged particles, when the magnetic field is above some certain threshold, are tied to magnetic field lines. They will propagate along the magnetic field lines.

As we discussed earlier, because the Sun rotates, the interplanetary magnetic field takes a spiral shape in the equatorial plane. Use these lines to see where the soure regions can be for these spacecraft.

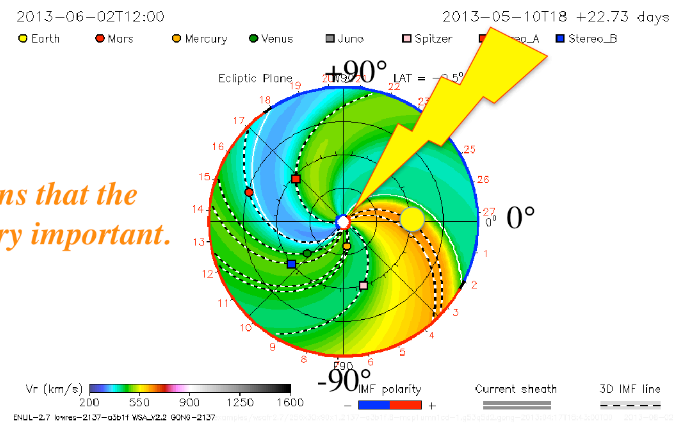
Just flares/source region connection

Magnetic fields guide SEPs/ magnetic connectivity



Charged particle motion* is confined by the magnetic field.

This means that the source is very important.



*in a substantially strong B

ENLIL

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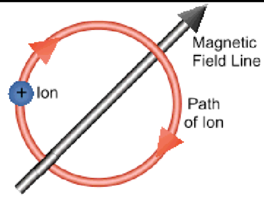
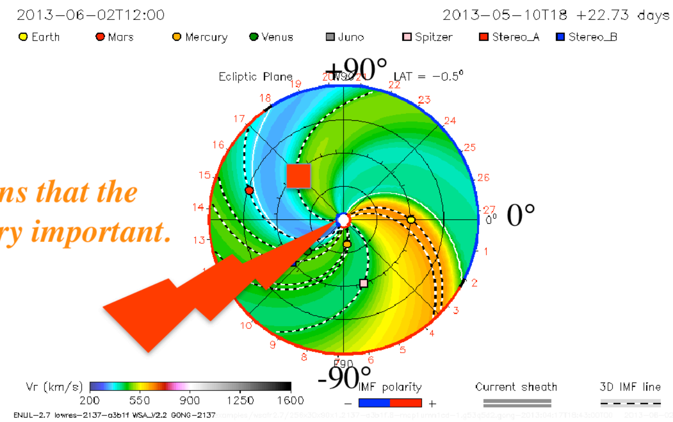
Just flares/source region connection

Magnetic fields guide SEPs



Best connected field line varies, if solar wind speed is faster then connection is closer



*in a substantially strong B

ENLIL

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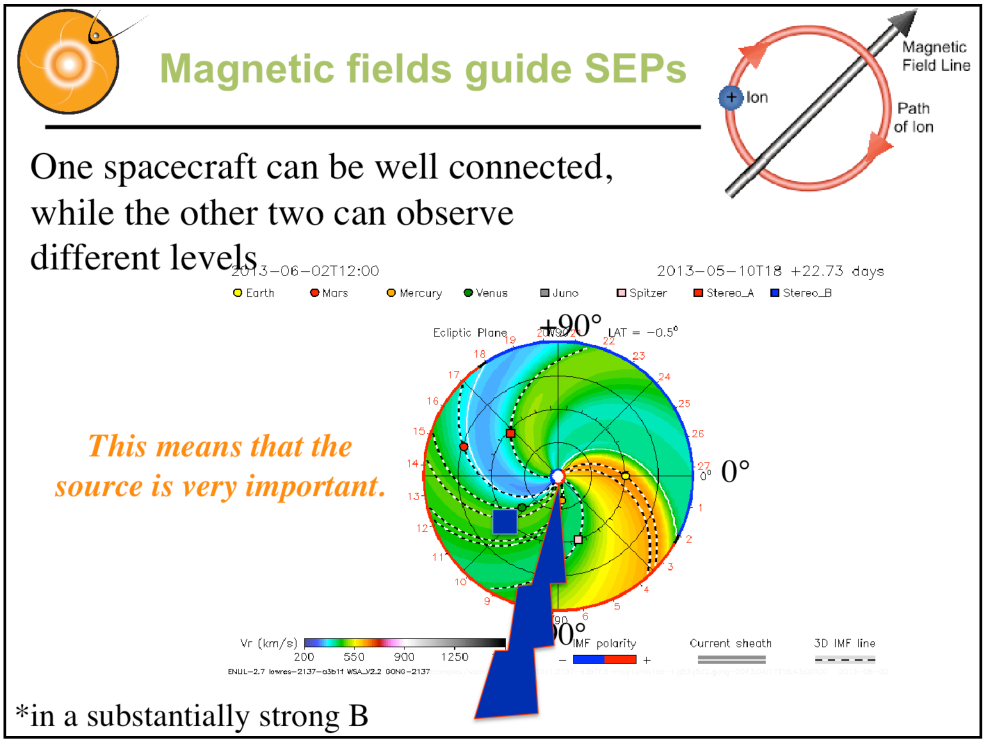
Just flares/source region connection



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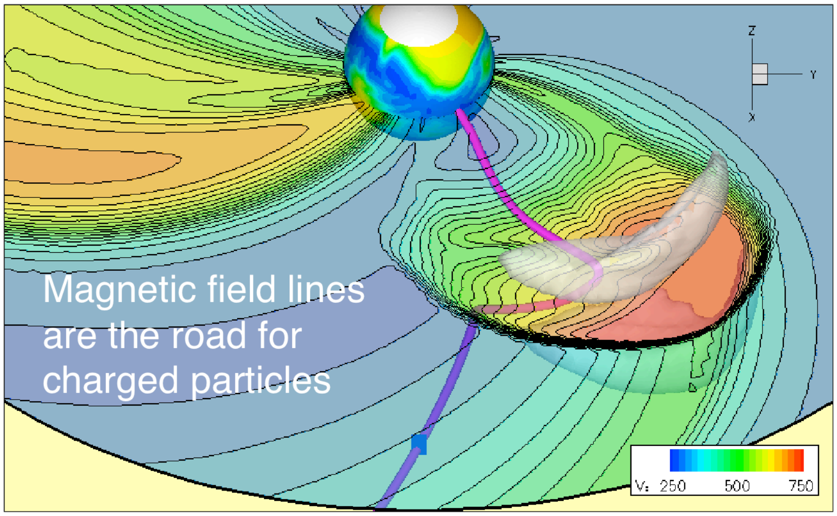
Just flares/source region connection

Wide Longitudinal Extent of SEP Events

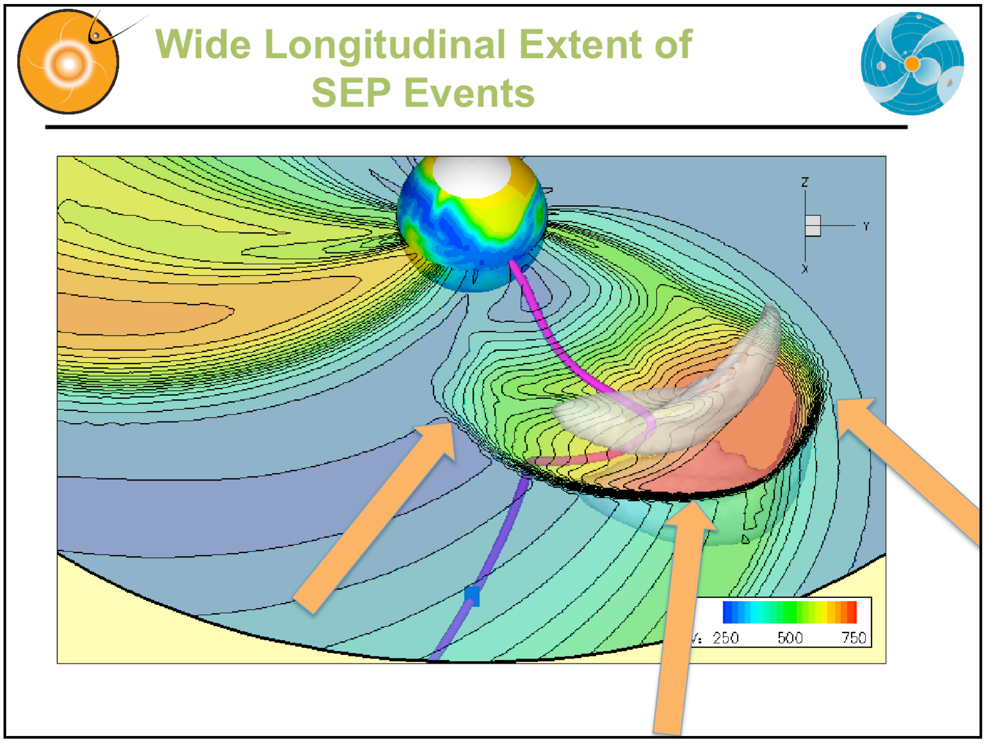


If particles do not easily cross from one magnetic field line to another, it may seem like all SEP events would then be very narrow in longitude.

However, a CME can play a role not only in accelerating the particles, but also in distributing them over a wide range of longitudes, as we can see here in this simulation.

Here is a simulation that shows us what that might look like.

So, remember, when there is a cme, it can widen the area of the SEPs.



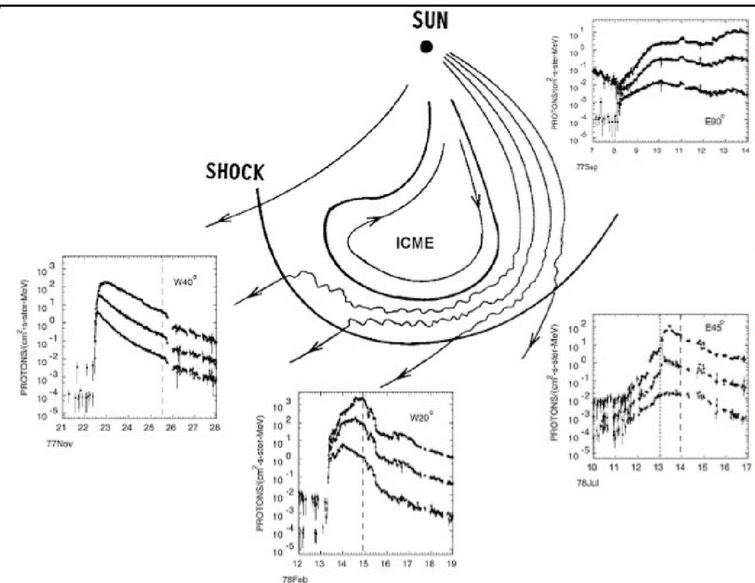
If particles do not easily cross from one magnetic field line to another, it may seem like all SEP events would then be very narrow in longitude.

However, a CME can play a role not only in accelerating the particles, but also in distributing them over a wide range of longitudes, as we can see here in this simulation. Sandro said how CMEs can be greater than 100 in width, so it is possible for the same SEP event to be seen at multiple locations.

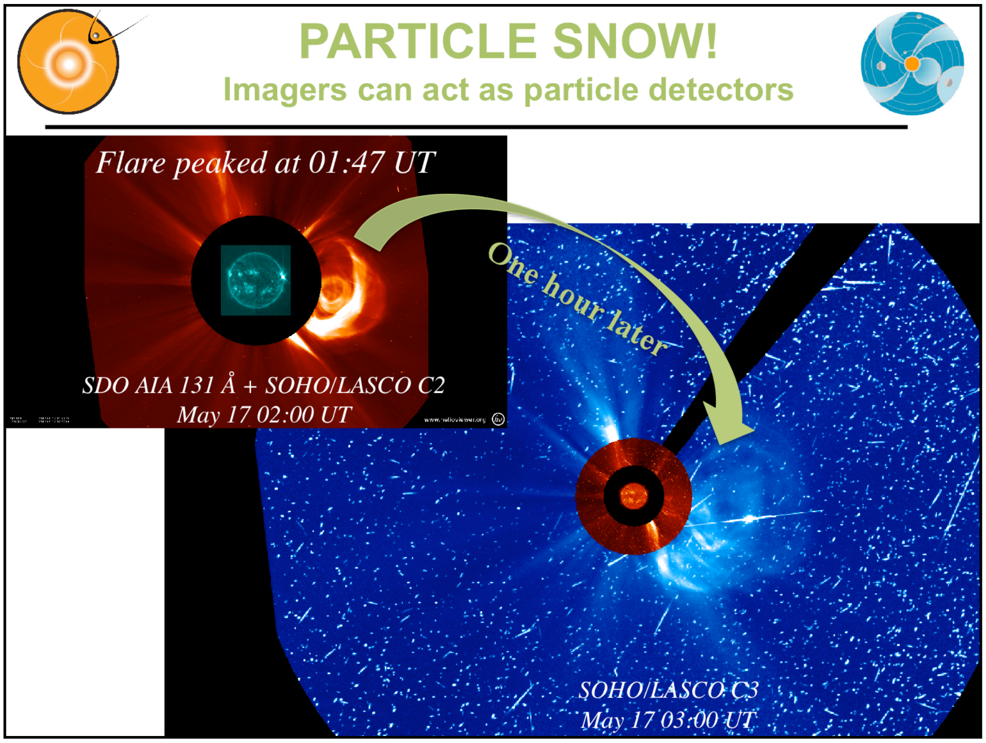
Here is a simulation that shows us what that might look like.

So, remember, when there is a cme, it can widen the area of the SEPs.

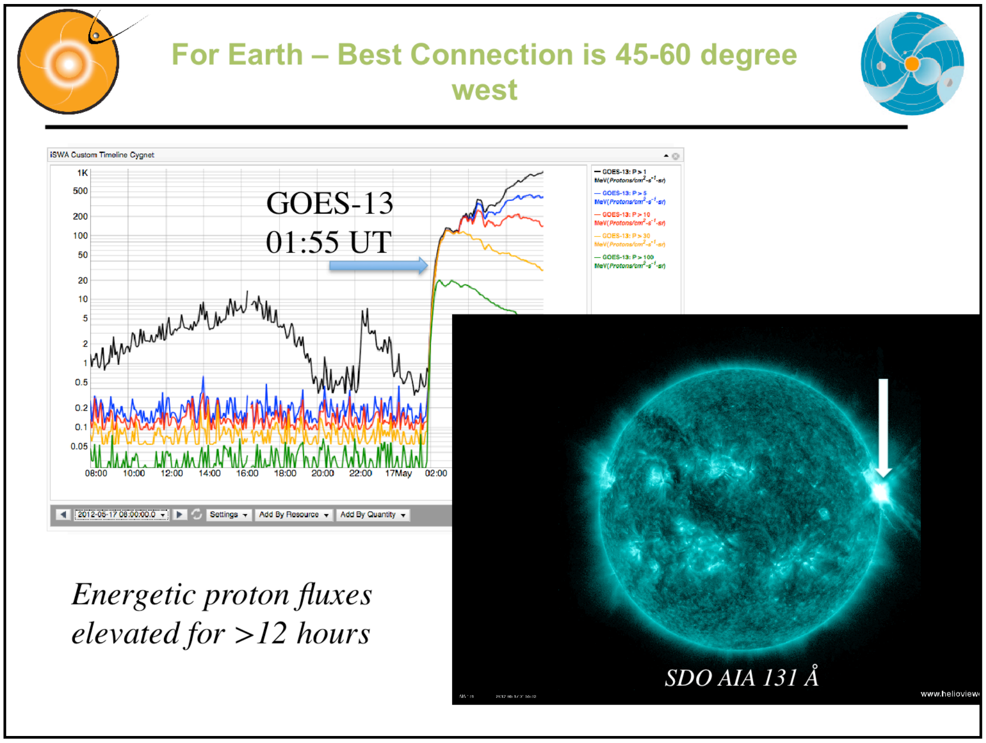
Recognizing profile shapes of SEP flux and associating it with the source/driver



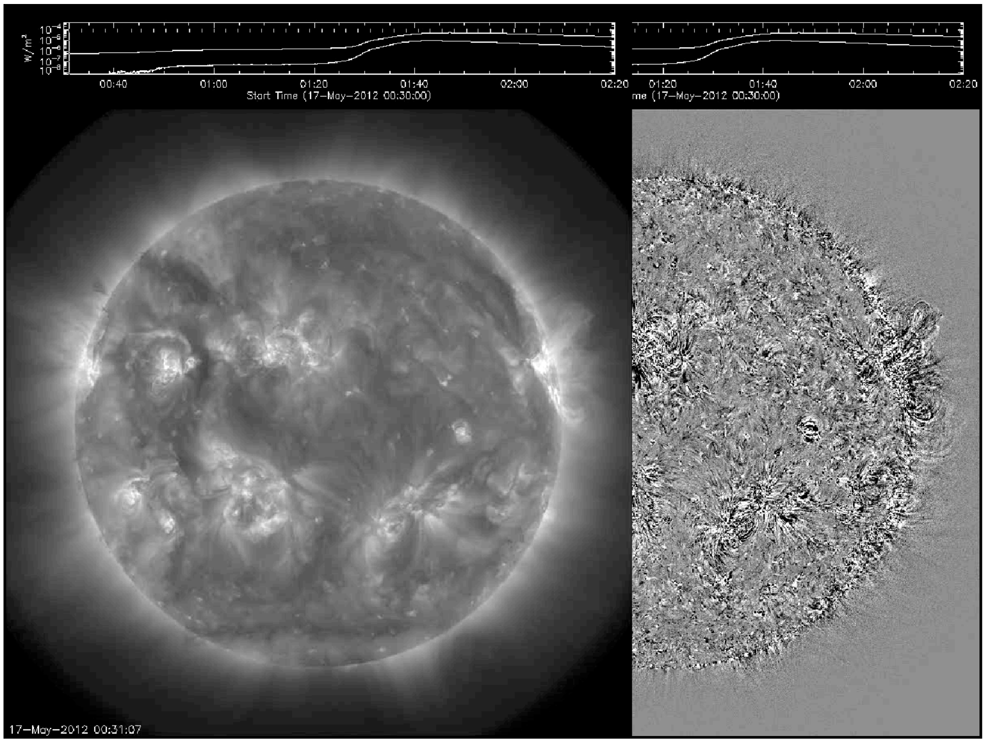
Lario & Cane, 2006



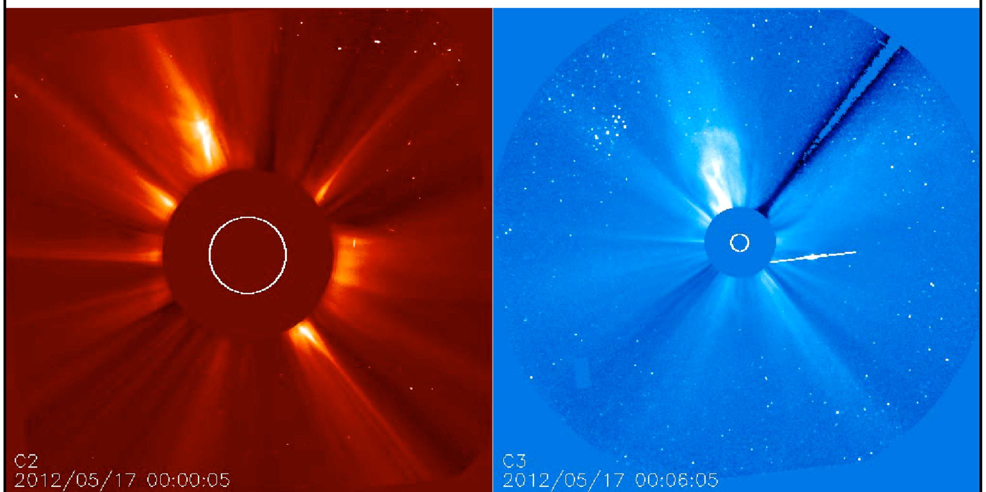
Another way that we "see" SEPs are in images, for example, coorngraphs. Here you can see the 'snow' of particles hitting the detector.

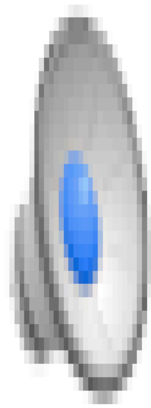


Not only were the >10 Mev channel elevated well above our threshold, but the >50 and >100 channels as well, which tell us that this event was very efficient at accelerating the highest energy particles.



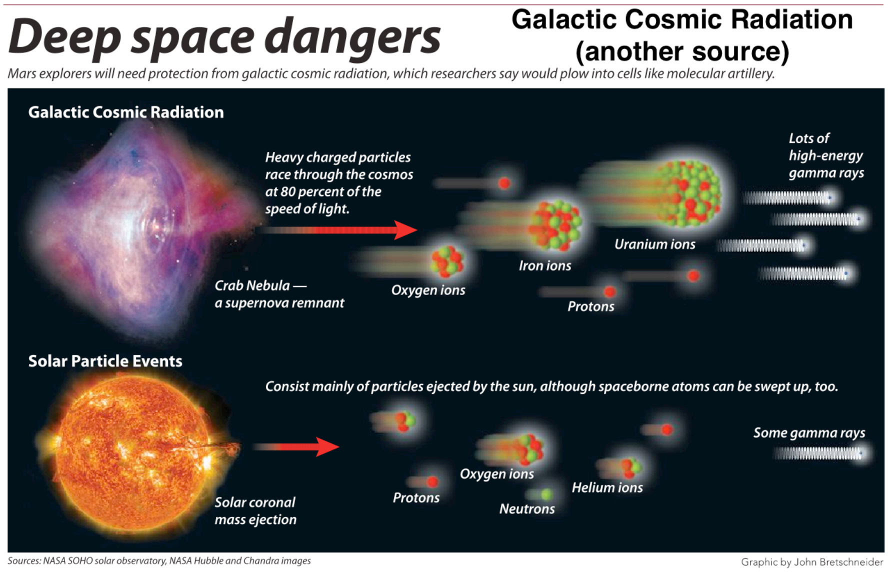
Credit: Nariaki Nitta, LMSAL

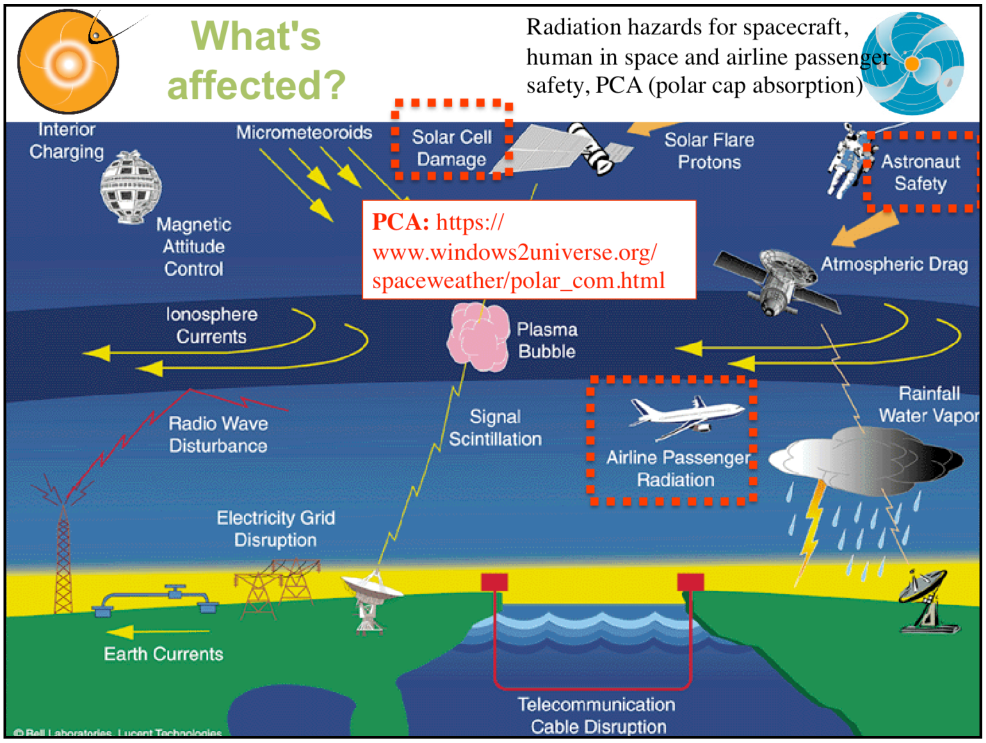

C2
2012/05/17 00:00:05
C3
2012/05/17 00:06:05



SEPs – important source of space radiation: hard to predict

Galactic Cosmic Radiation (another source)





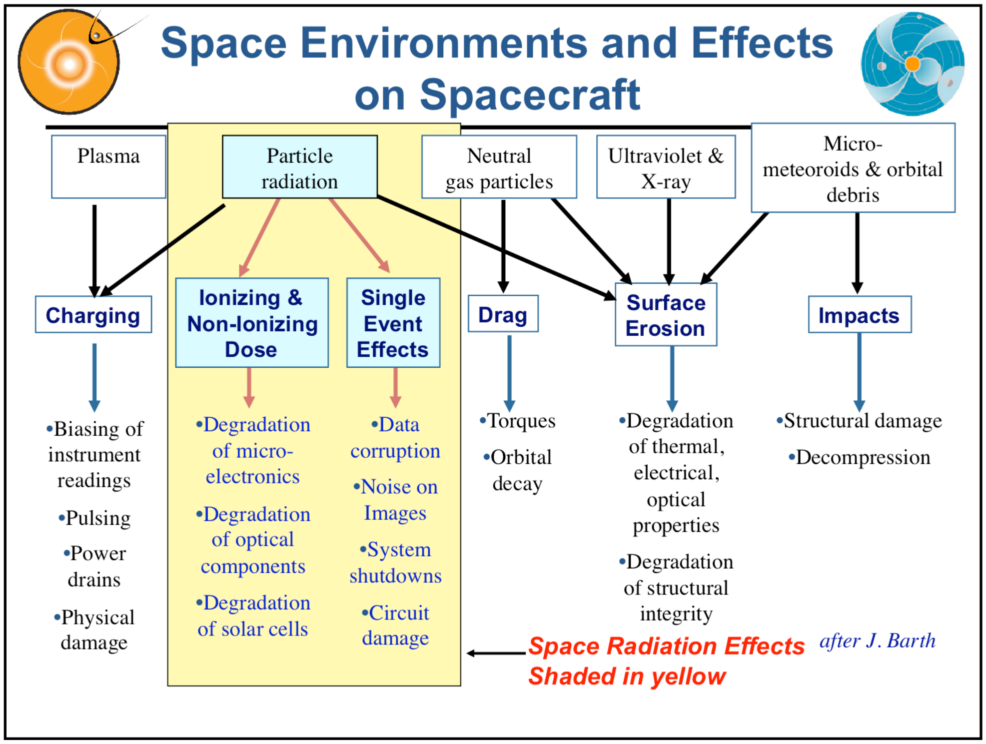
An SEP event is an enhancement in the radiation environment.

Summarize effects again.

For this effect and the biological/ human radiation risk hazard, we partner with the Space Rad Analysis Group NASA JSC.

Definition:

Energetic charged particles charged particles such as energetic electrons that are traveling much faster than ambient electrons in the space plasma and have the potential for causing ionizing radiation damage to spacecraft and


Space Environments and Effects on Spacecraft
Plasma
Particle radiation
Neutral gas particles
Ultraviolet & X-ray
Micro-meteoroids & orbital debris
Charging
Ionizing & Non-Ionizing Dose
Single Event Effects
Drag
Surface Erosion
Impacts
•Biasing of instrument readings
•Pulsing
•Power drains
•Physical damage
•Degradation of micro-electronics
•Degradation of optical components
•Degradation of solar cells
•Data corruption
•Noise on Images
•System shutdowns
•Circuit damage
•Torques
•Orbital decay
•Degradation of thermal, electrical, optical properties
•Degradation of structural integrity
•Structural damage
•Decompression
Space Radiation Effects Shaded in yellow
after J. Barth

How Do We Monitor SEP Levels?

(1 pfu = 1 particle flux unit= 1/ cm^2/sec/sr)

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

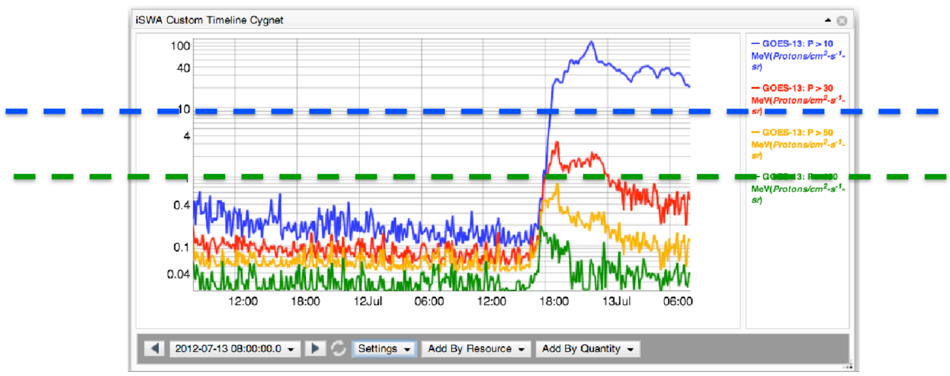
- *Heliosphere with STEREO In-situ Measurements of Particles and CME Transients (IMPACT)*
  - *Differential energy band; Units measured, some energy ranges are:*
- *Upstream of Earth with ACE, SOHO/COSTEP*
  - *Units measured, some energy ranges are:*
- *Geostationary Orbit with GOES*
  - *Integral flux, Units measured, some energy ranges are: pfu particle flux unit*
  - *Inside the Earth's magnetosphere (usually)*

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

Converting between the two is important to know in order to quantify the relative strengths.

How do we define an SEP Event?

SWRC: SEP event detections are defined as:
GOES Proton E > 10 MeV channel > 10 pfu
GOES Proton E > 100 MeV channel > 1 pfu



Here is an example of an event where the 10 MeV limit was met, but not the 100 MeV.

SOHO: > 15.8 MeV proton channels 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

Fluence is also important

Human Safety in Space

- GCR
- **SEP**

Johnson Space Center/Space Radiation Analysis Group (SRAG)

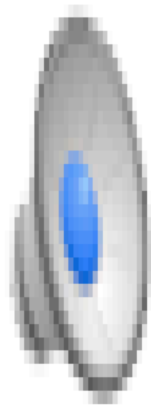
Limit: the > 100 MeV flux exceeding 1pfu

(1 pfu = 1 particle flux unit= 1/cm^2/sec/sr)

- All clear (EVA –extravehicular activity)

24

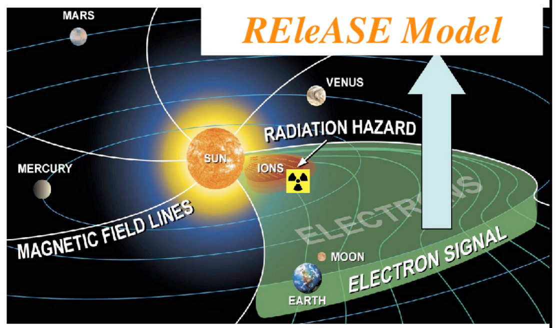
Can we predict SEP events?

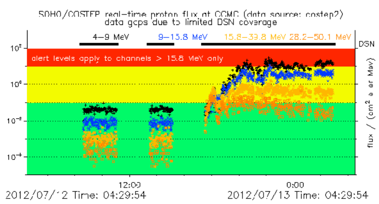


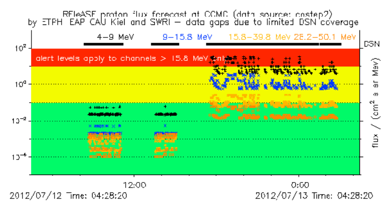
Can we predict SEP events?

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

Data source: SOHO COSTEP



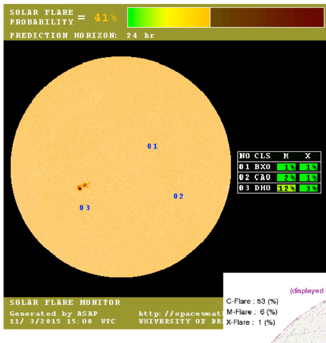




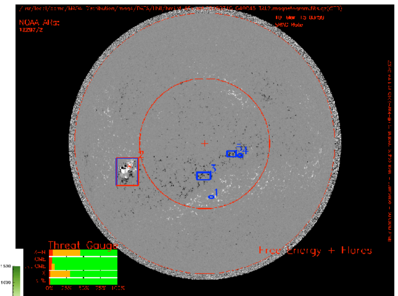
http://iswa.gsfc.nasa.gov/wiki/index.php/SOHO/Costep_Proton_Flux_-_Forecast

SEP prediction (active region)

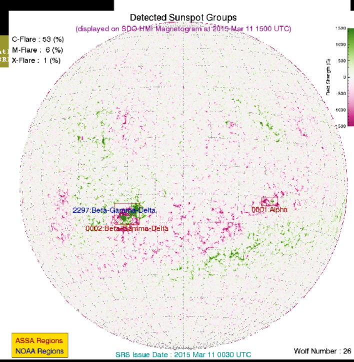
x2.2 flare on March 11, 2015



ASAP

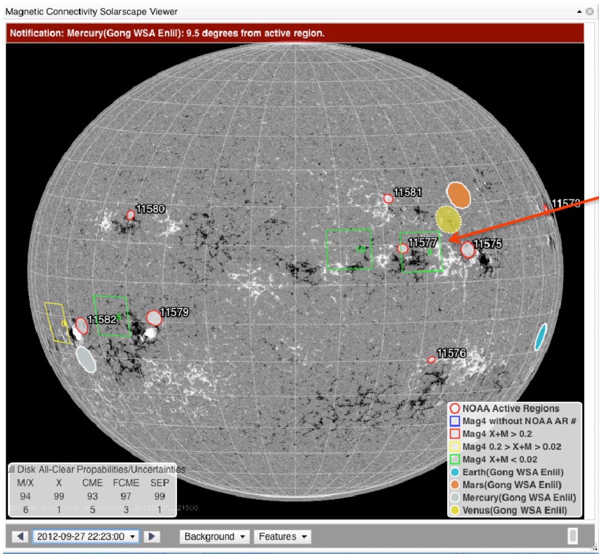


MAG4



ASSA

Solarscape/magnetic connectivity

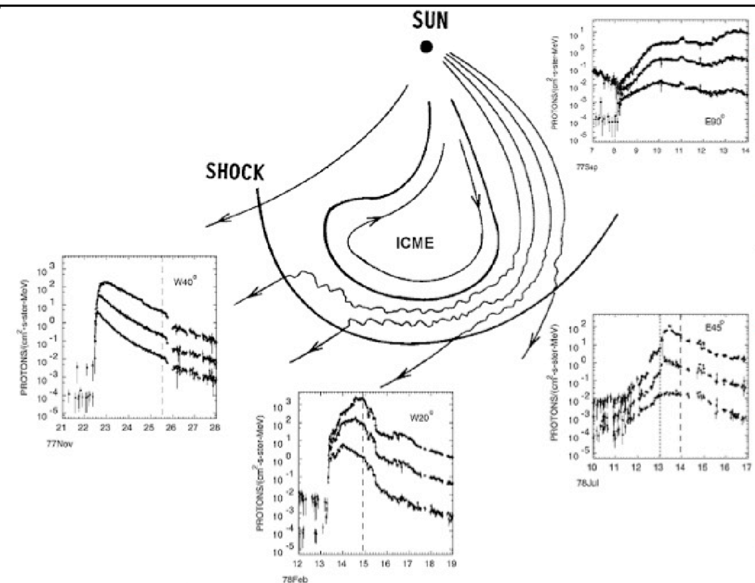


C3.7 class flare
AR 11577

20120927_2336 2012/09/27 23:36:00 00:34:00 23:57:00 C3.7 N09W32 (1577)
LDE longduration event N09W32

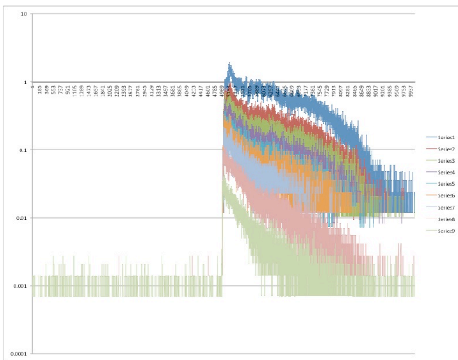
Earth-directed. Hemispheric wave, asymmetric halo

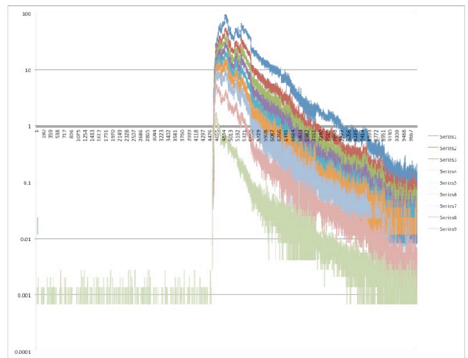
Recognizing profile shapes of SEP flux and associating it with the source/driver



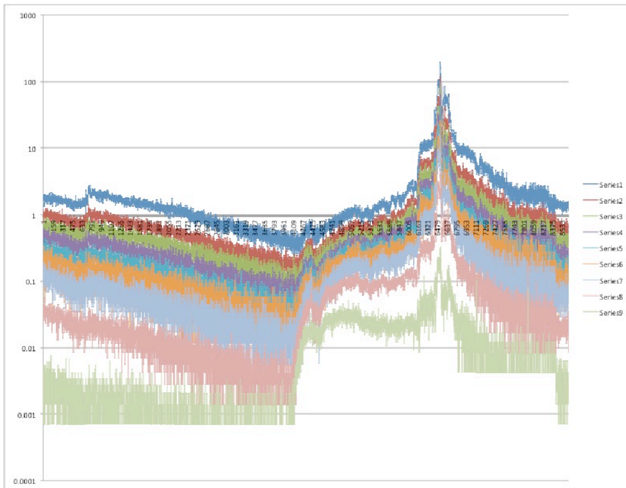
Lario & Cane, 2006

Impulsive: The "peak at the beginning, rapid fall off" – indicates how well connected you are to the source

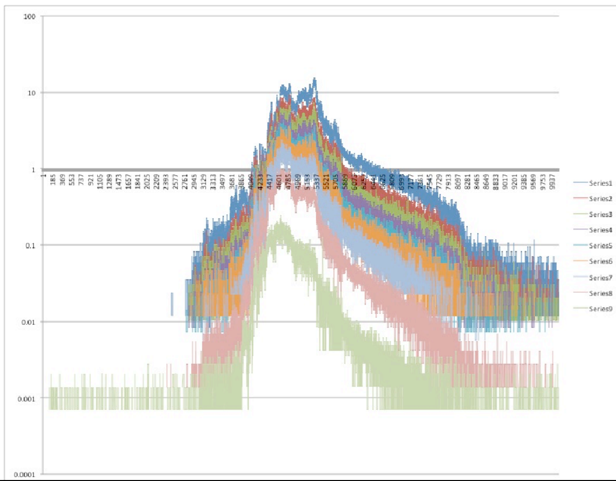




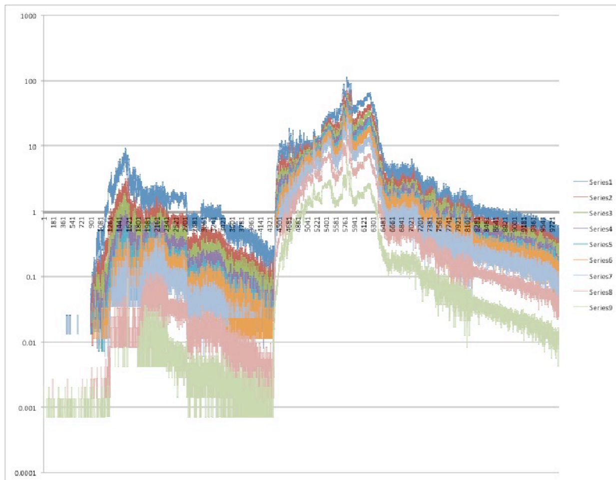
Gradual: The “slow rise after eruption, then peak when the ICME passes the spacecraft”



The "slow rise then peak, (slow rise can let you
know that you are not well connected
ICME doesn't hit spacecraft so falls off"

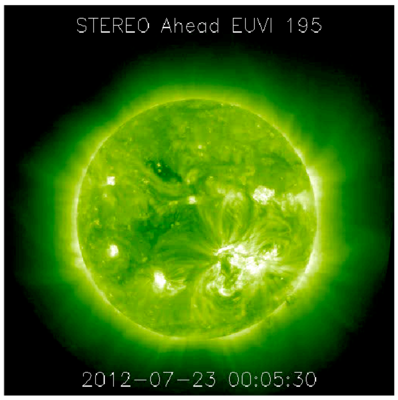


Multiple events can compound impact

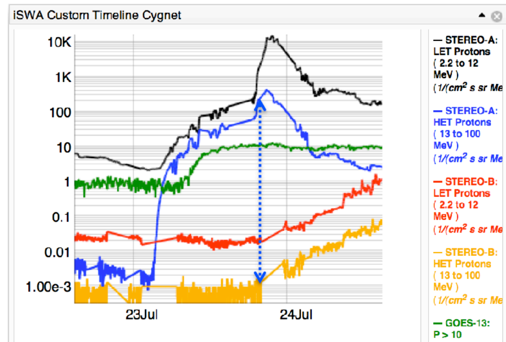


July 23, 2012

It reaches one spacecraft, then later another…

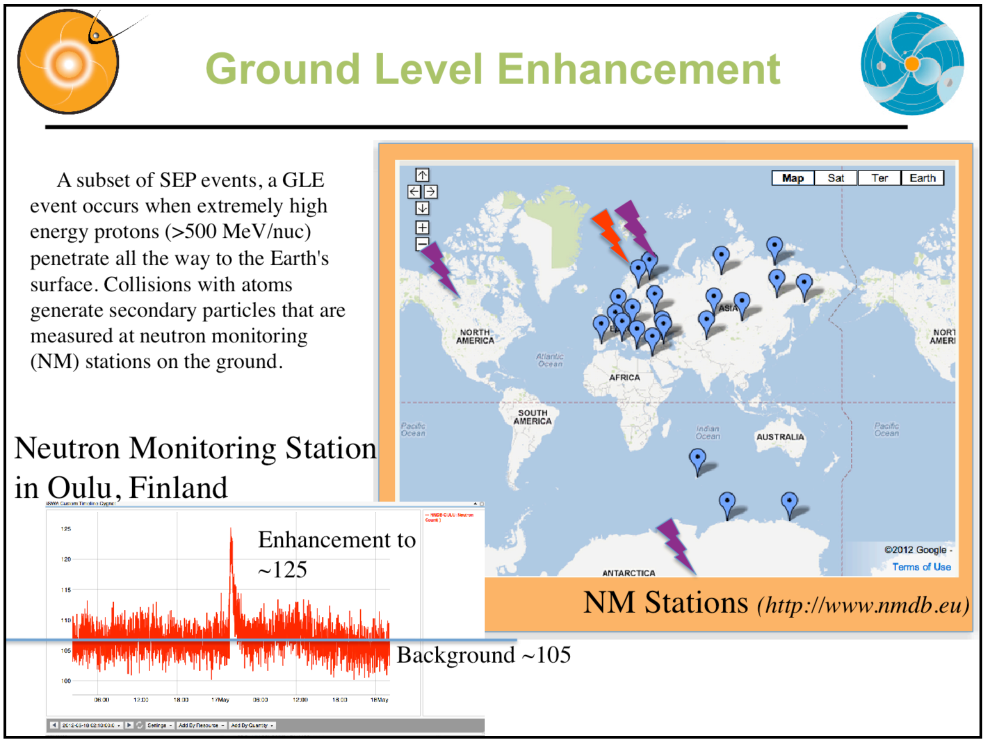


July 23 flare as seen in STEREO A EUVI 195



Increase of more than 5 orders of magnitude at STEREO A
SEP event also detected by GOES, and later enhancement seen at STEREO B

On July 23rd it really put on a show.



The most extreme events…

This suspicious was confirmed by the detection of neutron enhancement at 4 stations. Those neutrons are reaction particles from relativistic protons

Add arrows to mark stations that observed May 17 GLE – what WAS THE TIME????

Save discussion of GLE events in SC 23 and characteristics of GLEs until 2^{nd} half of talk. First half should only be observations!

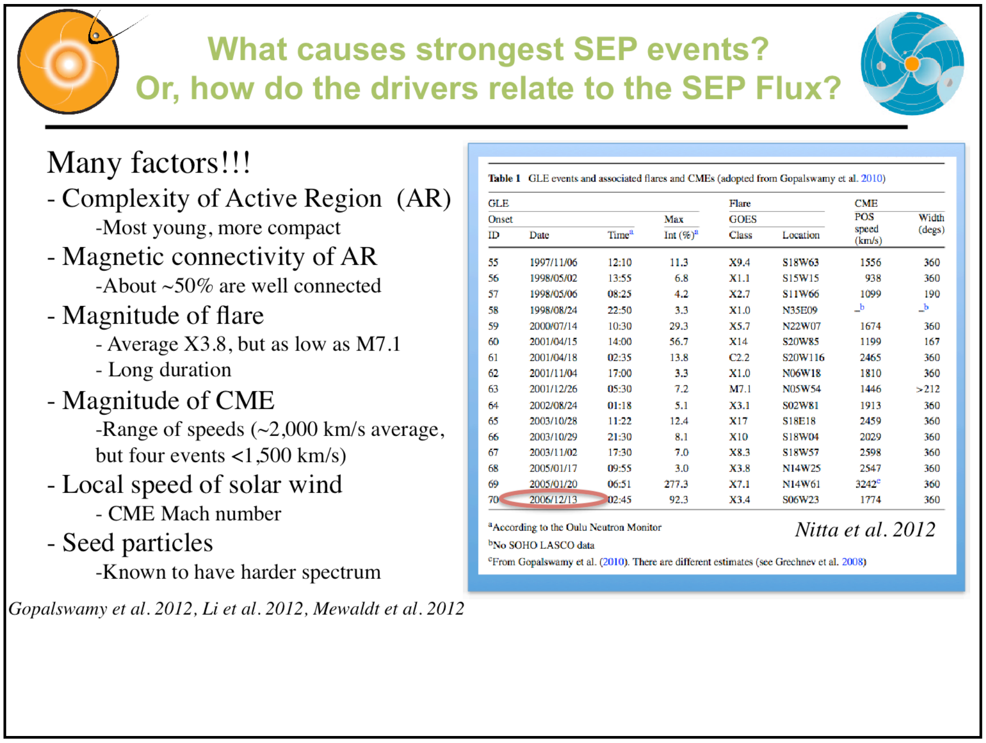


Table 1 GLE events and associated flares and CMEs (adopted from Gopalswamy et al. 2010)

GLE Onset ID	Date	Time[a]	Max Int (%)[a]	Flare GOES Class	Flare Location	CME POS speed (km/s)	CME 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)

Like I said, these events prompt more questions and more questions, so we want to look at all of the extreme events (GLE) and see if any characteristics of the solar part of the storm can tell us about what is happening. And the answer is that while there are trends, it's not true that strong flare cause GLEs, as you saw only M5 cause the May event, it's not the fastest and biggest CMEs.

Again I want to emphasize that these are all just speculations because most of the interesting stuff is happening in a region that is not well covered by coronagraphs.

End with: And so we are motivated to model the acceleration of particles by CME driven shocks in the low corona…

Comparing to previous AR1476 flares: Longer duration, but similar magnitude

March 7th event: flare and CME weaker, SEPs at Earth 20x weaker

Solar Cycle 23 GLE events: no CME in previous 24 hours (to generate seed particles)

What was special about this flare and CME to generate a GLE?

Timing: CME erupted during rise time of flare

Connectivity: AR well connected to Earth

CME speed 1,500 km/s sufficient to drive shock in low corona (Evans et al. 2008)

Must have been very wide CME (to impact STEREO A and Earth)

As is common, they were not geoeffective (Kp max =4)

Possible Type II radio burst indicates CME driven shock

Exceptions to every rule!
September 28, 2012 – whole heliosphere event – C3.7 flare

20120927_2336 2012/09/27 23:36:00 00:34:00 23:57:00 C3.7 N09W32 (1577)
LDE longduration event N09W32

Earth-directed. Hemispheric wave, asymmetric halo

SEP Layout

http://bit.ly/alert_SEP_layout