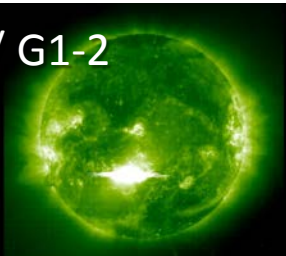


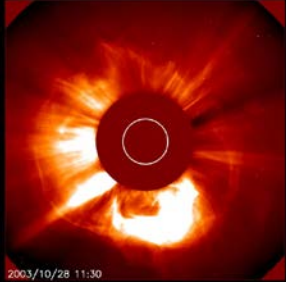
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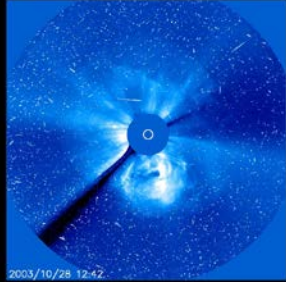
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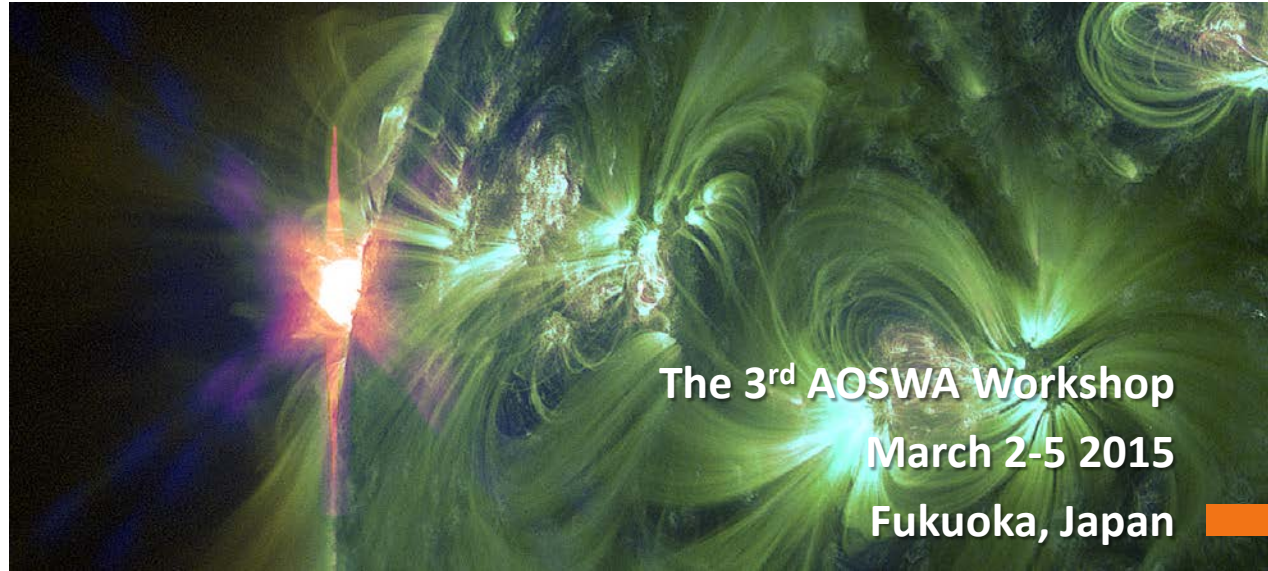
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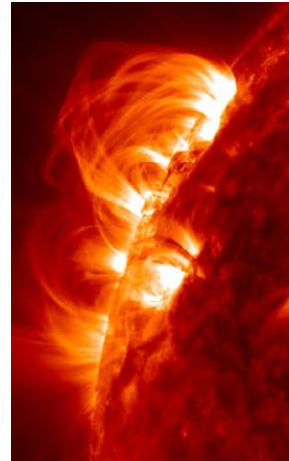


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Characteristics of Four SPE Classes according to onset timing and proton acceleration pattern



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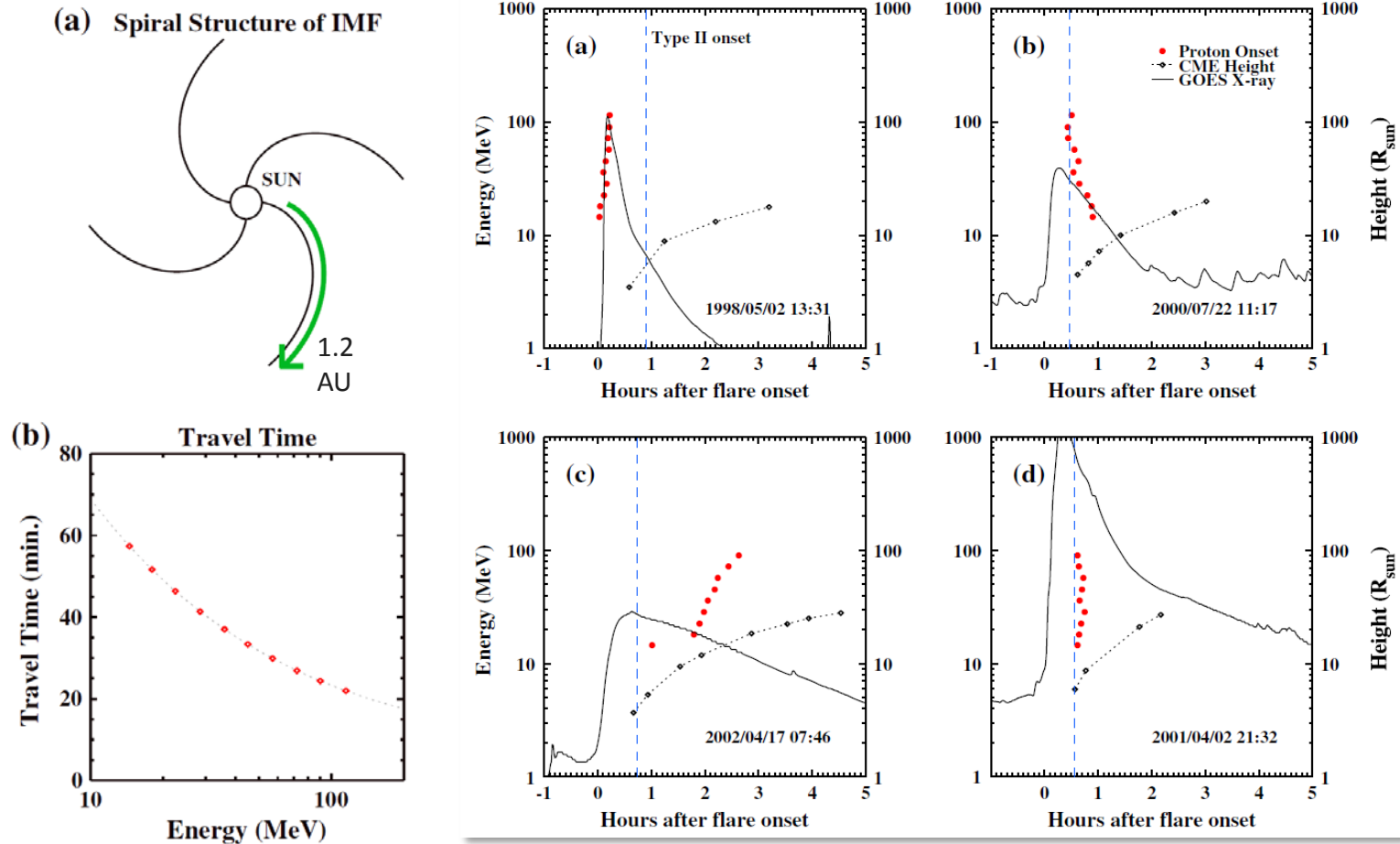
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◆ A refined classification of SPEs (Kim et al., 2015, JGR)

■ Data and methods

- 42 SPEs observed with SOHO/ERNE **multi-energy channel** detector from 1997 to 2012
- Velocity dispersion analysis: estimation of the SPE onset times **at the solar vicinity**
- Onset time comparison: SPEs, and associated flares, CMEs, and type II radio bursts.



◆ A refined classification of SPEs (Kim et al., 2015, JGR)

■ Main result

- SPE classification by two criteria of
 - SPE onset timing relative to flare peak time
 - Energy-dependent proton flux enhancement ($T_H - T_L$)

Table 2. Characteristics of Four SPE Groups

Group	Event #	Association	Acceleration		Energy Spectrum	
			Direction	$T_H - T_L$ (Average)	Dominant Energy Band	Enhancement
A	13 (31%)	Flare	Low → High	17 min	Low and Middle	$\sim 10^4$
B	13 (31%)	CME	High → Low	–26 min	High	$> 10^2$
C	9 (21%)	CME	Low → High	35 min	Low	$\sim 10^3$
D	7 (17%)	CME	Simultaneous	–1.8 min	Middle and High	$\sim 10^2$

- Group A
 - Proton flux increases during the flare X-ray intensity is increasing .
 - Flux enhancements starting from the lower energy
 - Large flux enhancements occur in a short time
- Groups B and C
 - Well coincident onsets with the first appearance of CMEs in LASCO FOV.
 - Relatively weak and slow flux enhancements
- Group D
 - Immediate flux enhancement in all energy channels within ~ 2 min.

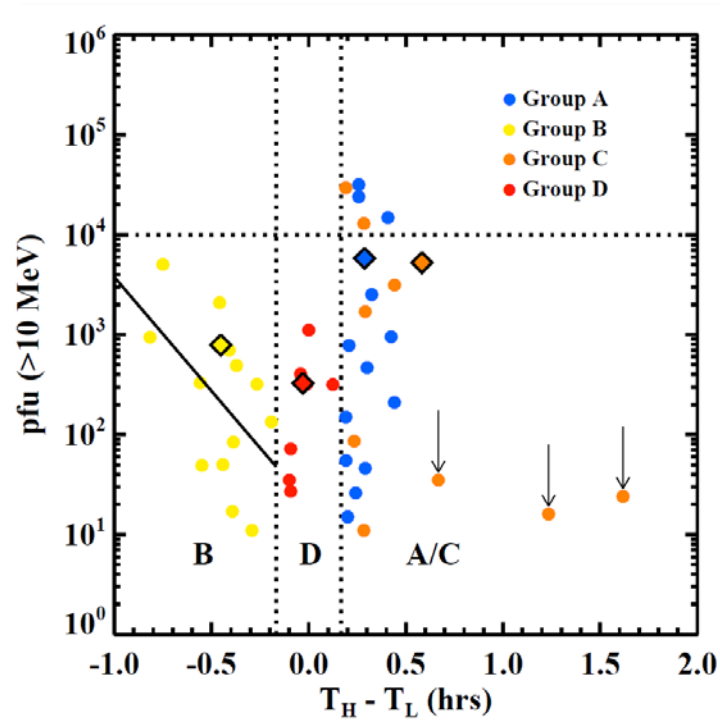
◆ Characteristics of four SPE classes

- Are there any typical characteristics of associated events and acceleration sites in each group?
 - SPE: proton flux and ($T_H - T_L$)
 - Flare: X-ray intensity and longitude
 - CME: angular width and speed
 - Acceleration Heights of SPE and type II radio burst

Characteristics		Group A	Group B	Group C	Group D	Total	CC with SPE
SPE	Proton Flux (pfu)	5824	788	5268	327	3230	...
	$T_H - T_L$ (hrs)	17	-27	35	-2	4	0.83
Flare	X-ray Int. (10^4)	2.11	1.61	2.37	3.77	2.29	-0.35
	Longitude (W)	53	36	35	62	45	-0.21
CME	Angular Width	274	350	274	337	308	-0.98
	Speed (km s^{-1})	1444	1573	1423	1855	1548	-0.84
Height (R_s)	SPE Onset	0.70	5.74	6.05	5.35	4.18	-0.56
	Type II Onset	3.85	2.95	4.28	5.73	3.98	-0.21

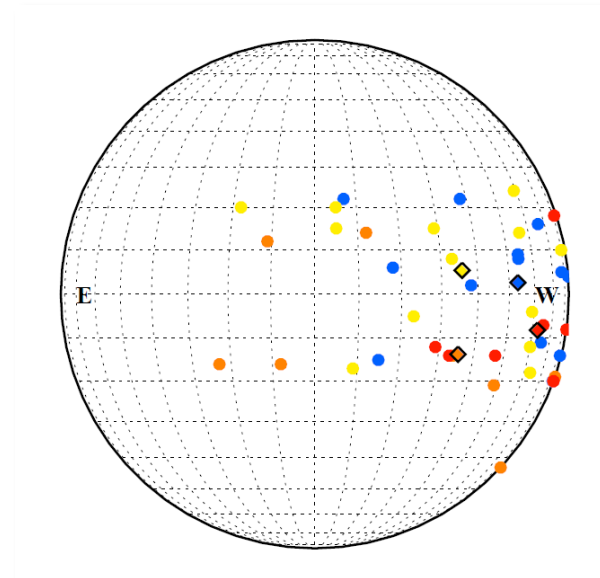
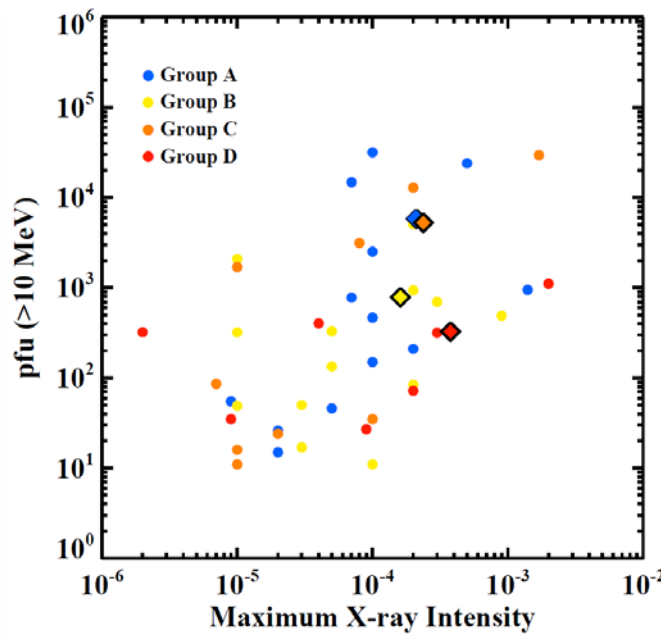
◆ SPE intensity and the onset time difference, $T_H - T_L$

- $T_H - T_L$: Onset time difference between the highest and the lowest energy channels
 - $T_H - T_L > 0$: Acceleration started first in the lower energy channel and later in higher energy
 - 5 strongest SPEs above 10^4 pfu have positive values and are classified into **groups A or C**.
 - Extended duration events: the exceptional 3 events of **group C** show very weak flux enhancements.



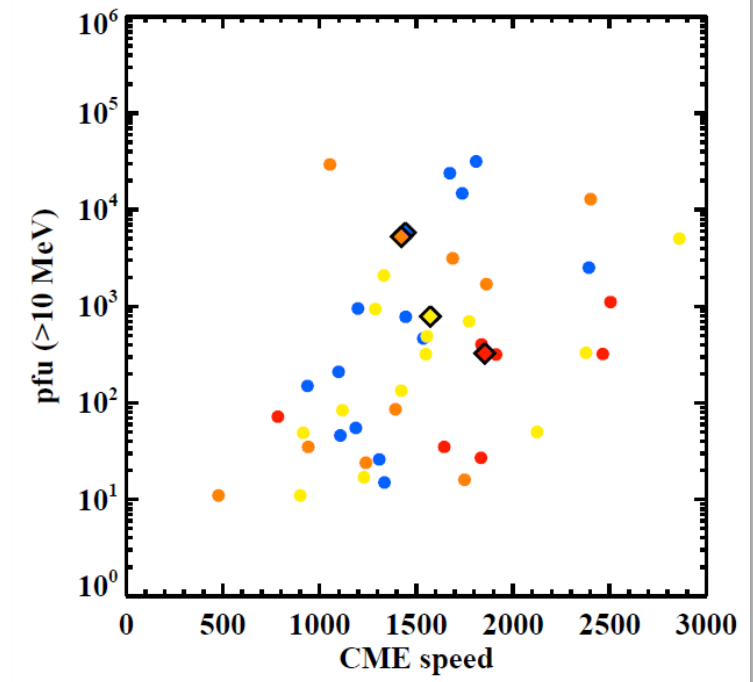
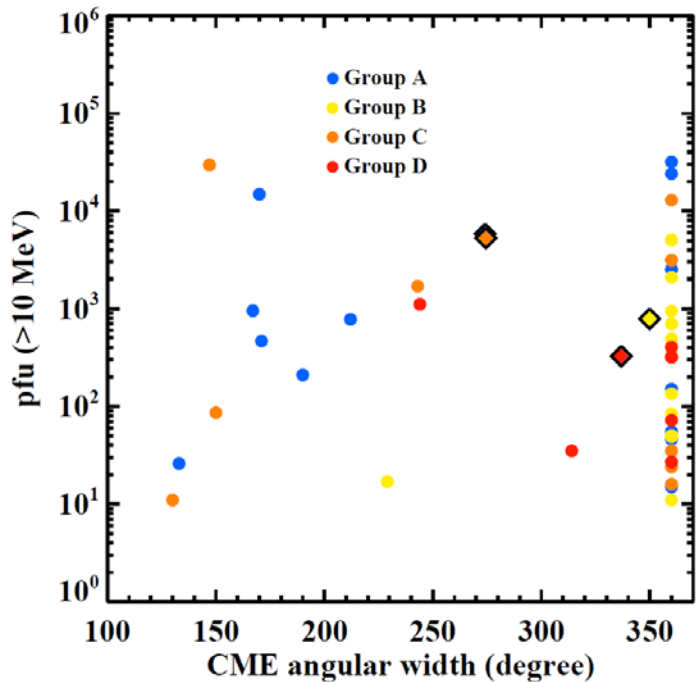
◆ Associated Flare

- Flare intensity
 - Mean values of X-ray intensity is the strongest for **group D** and the weakest for **group B**.
→ It is hard to find any strong group dependence on the X-ray intensity.
- Flare location
 - **Groups A and D** have flaring sites close to the western limb.
 - Relatively short intervals between high and low energy channels, $T_H - T_L$
 - **Groups B and C** show wider distribution of flaring sites.
 - This tendency confirms that flare associated SPEs are relatively more connected from the foot-point of the interplanetary (IP) magnetic field line to the spacecraft.



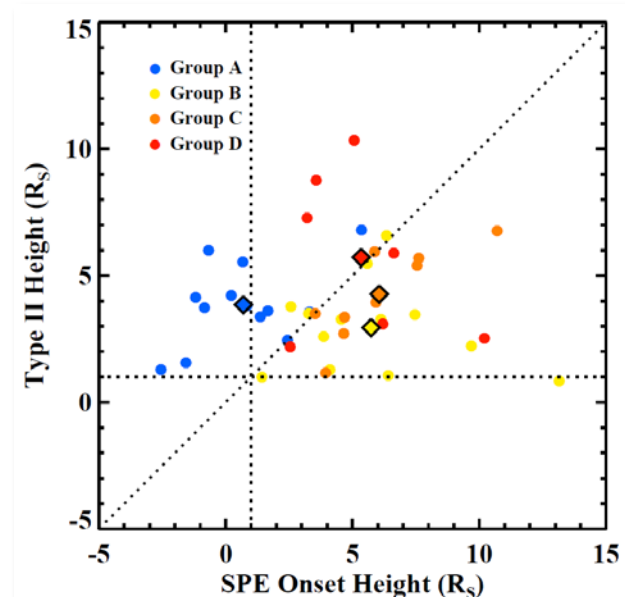
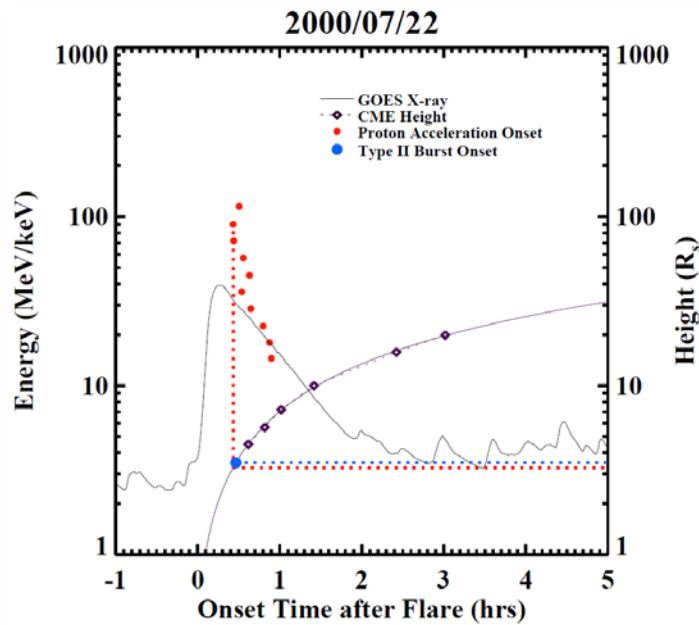
◆ Associated CME

- Angular width
 - Groups B and D: most of them are associated with full halo CMEs (mean=350° and 337°)
 - Groups A and C: mean=274°
 - Even the partial halo CMEs can accelerate protons under the certain conditions.
 - Or flare association? : acceleration pattern starts from the lower energy channel.
- Speed
 - Mean speed for group D is the fastest among all events with the value of 1855 km/s, however, the distribution seems to be roughly scattered.



◆ Acceleration Heights

- H_p and H_e
 - Heights of CME front edge at the onset times of proton acceleration (H_p) and type II burst (H_e) based on the extrapolation of LASCO observation.
 - Only for **group A**
 - H_p is lower than 1 R_s and $H_p < H_e$.
 - $H_p < 1 \rightarrow$ the event might have no relation with CME.
 - The other events in **groups B, C, and D**
 - H_e is increasing according to the groups, however H_p is not.
 - SPEs in groups B and C are located beneath the line.
- Proton acceleration follows after the electron acceleration.



◆ Typical Characteristics of Groups

■ Group A

- Strong SPE flux in spite of weak X-ray intensity.
- Its CME properties of speed and angular width are also weaker than average values.
- It is clear that those events are associated with flares since their low acceleration height and western biased longitudes.

■ Group B

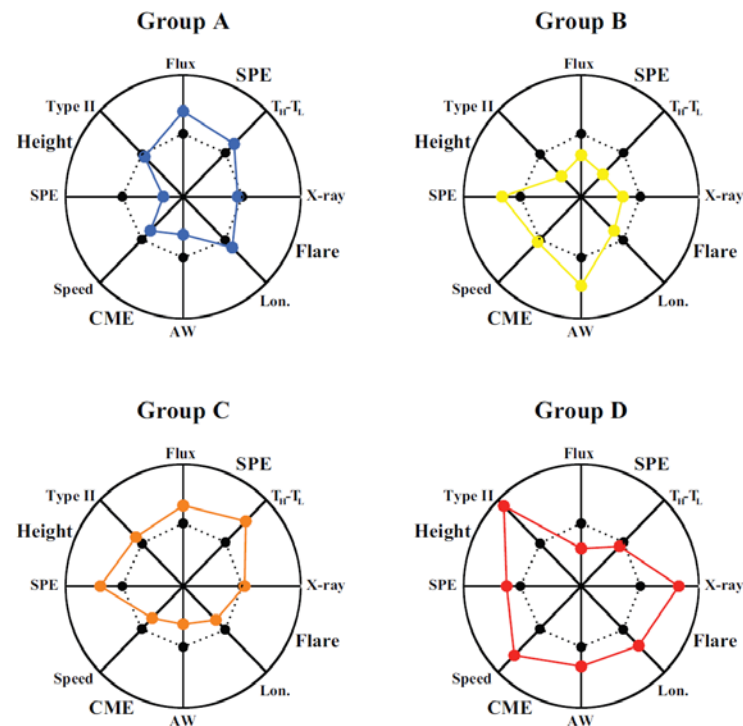
- CME biased properties - weak flare and SPE intensities, but wide angular width and fast speed with higher proton acceleration site and wider longitude of flaring site.

■ Group C

- Strong SPE intensity in spite of weak flare and CME.

■ Group D

- Association with very strong flares and CMEs.
- Acceleration sites of proton and electron are relatively higher.
- However the proton intensity is very weak.





◆ Summary

- If the proton acceleration starts from a lower energy (Group A and C),
 - A SPE has a higher chance to be a strong event (> 5000 pfu) even if the associated flare and CME are not so strong.
 - Group A: acceleration sites are very low (~ 1 Rs) and close to the western limb.
 - Group C: relatively higher (mean= 6.05 Rs) and wider acceleration sites.
- When the proton acceleration starts from the higher energy (Group B),
 - A SPE tends to be a relatively weak event (< 1000 pfu), in spite of its associated CME is relatively stronger than previous group.
- SPEs with simultaneous acceleration in whole energy range within 10 minutes (Group D)
 - Acceleration heights are very close to the locations of type II radio bursts.
 - Weakest proton flux (mean= 327 pfu) in spite of strong related eruptions.