

The Energetic Particles in Shock- ICMEs Interaction Structures

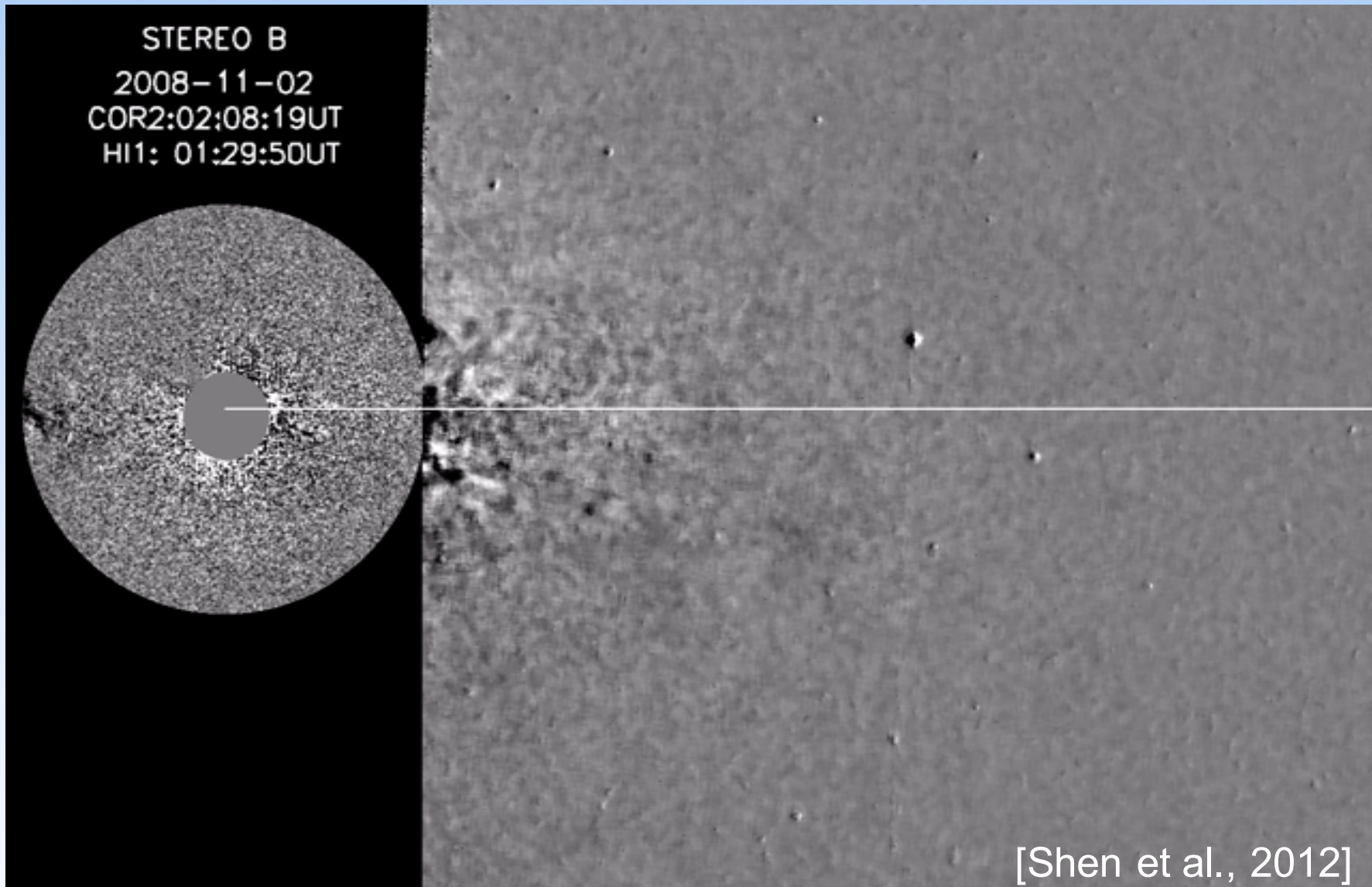
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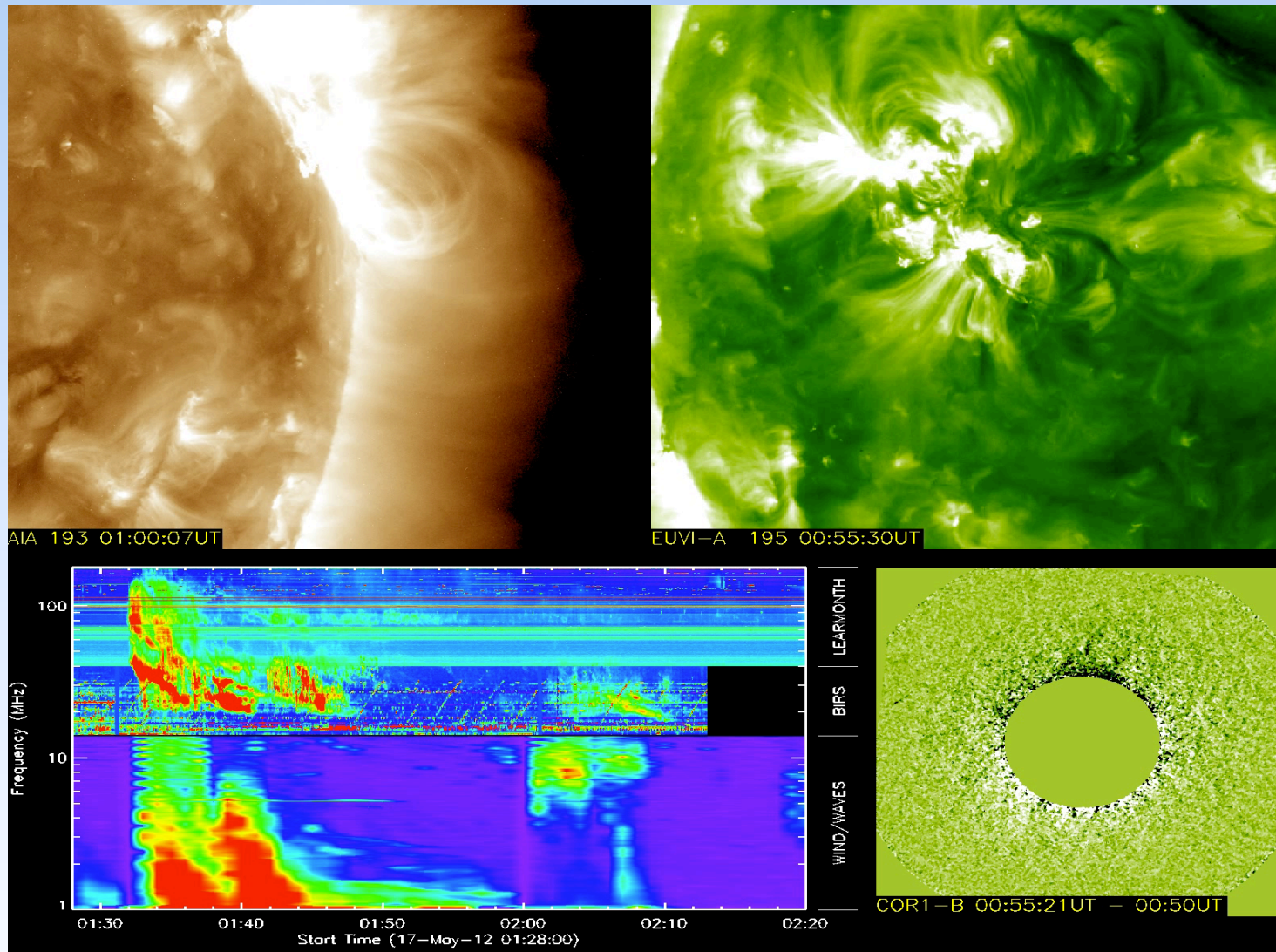
1. Introduction



Following CME may catch up and interacted with the preceding CME in interplanetary space

CME interaction may influence the SEP

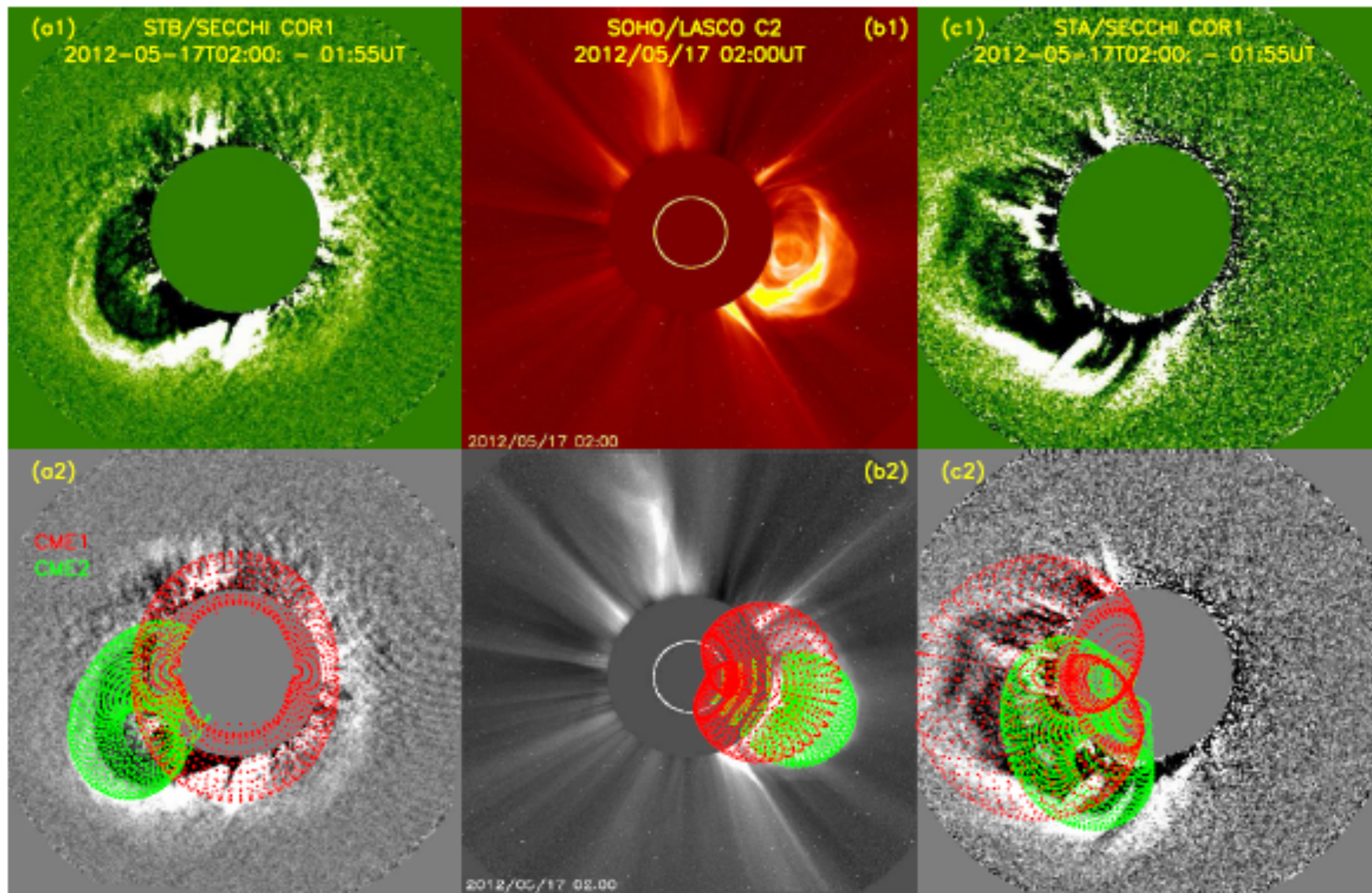
[e.g. Gopaslwamy et al., 2004; Li et al., 2012; Shen et al., 2013]



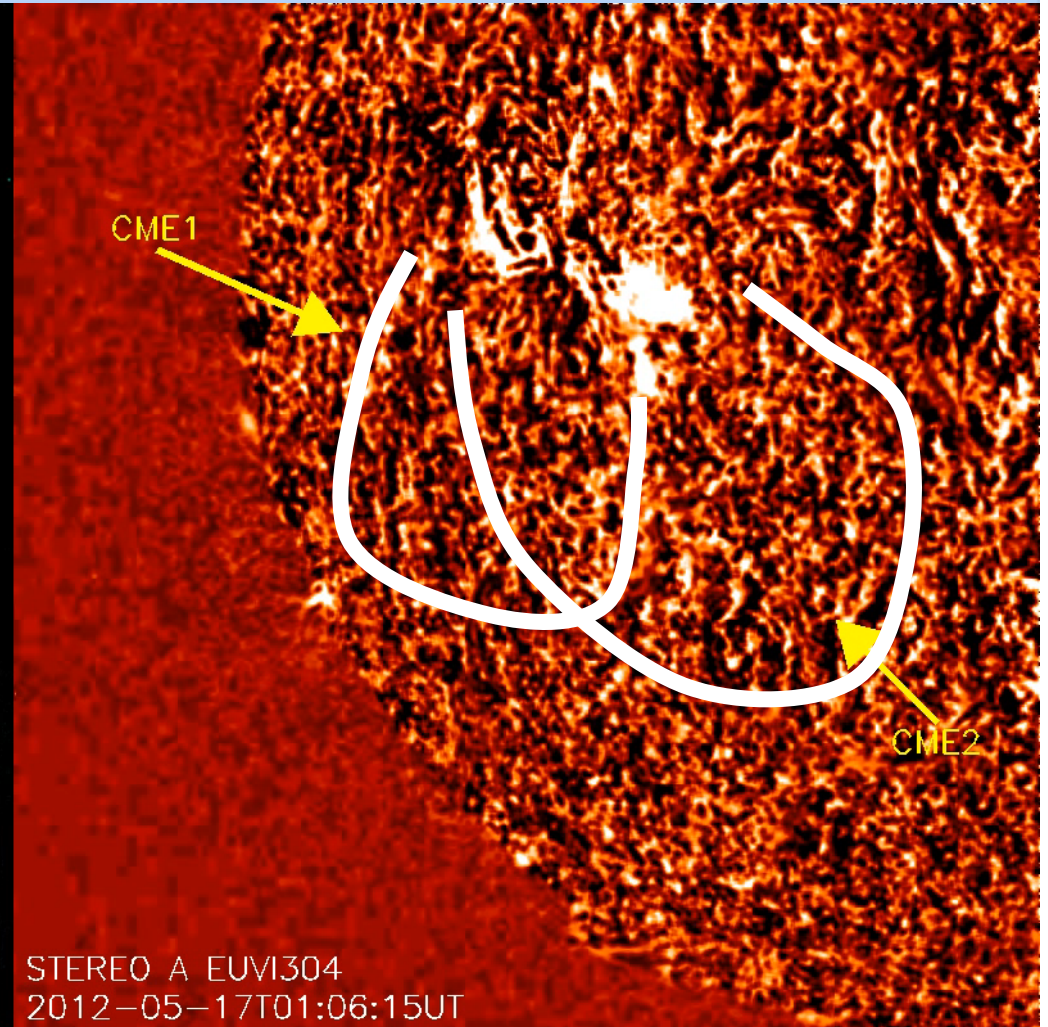
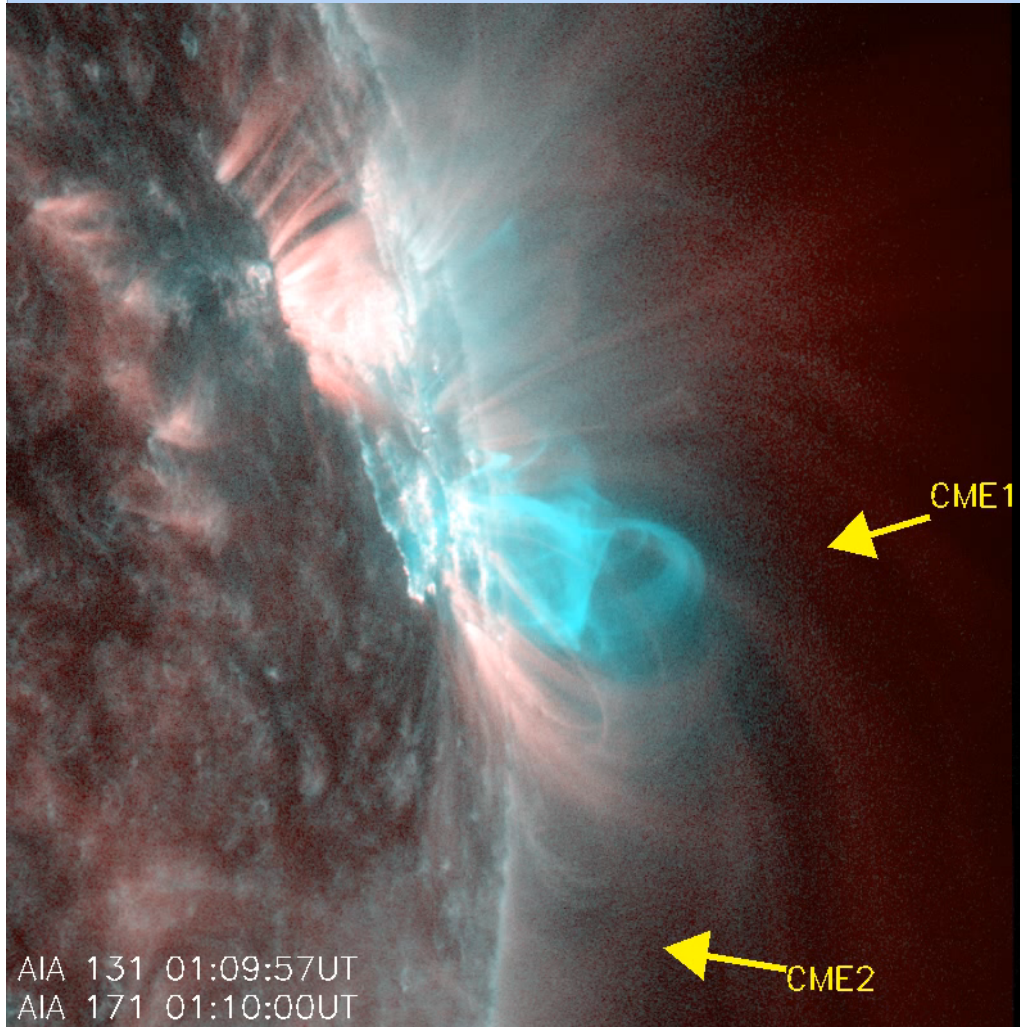
The first GLE event in solar cycle 24th:2012 05 17 event

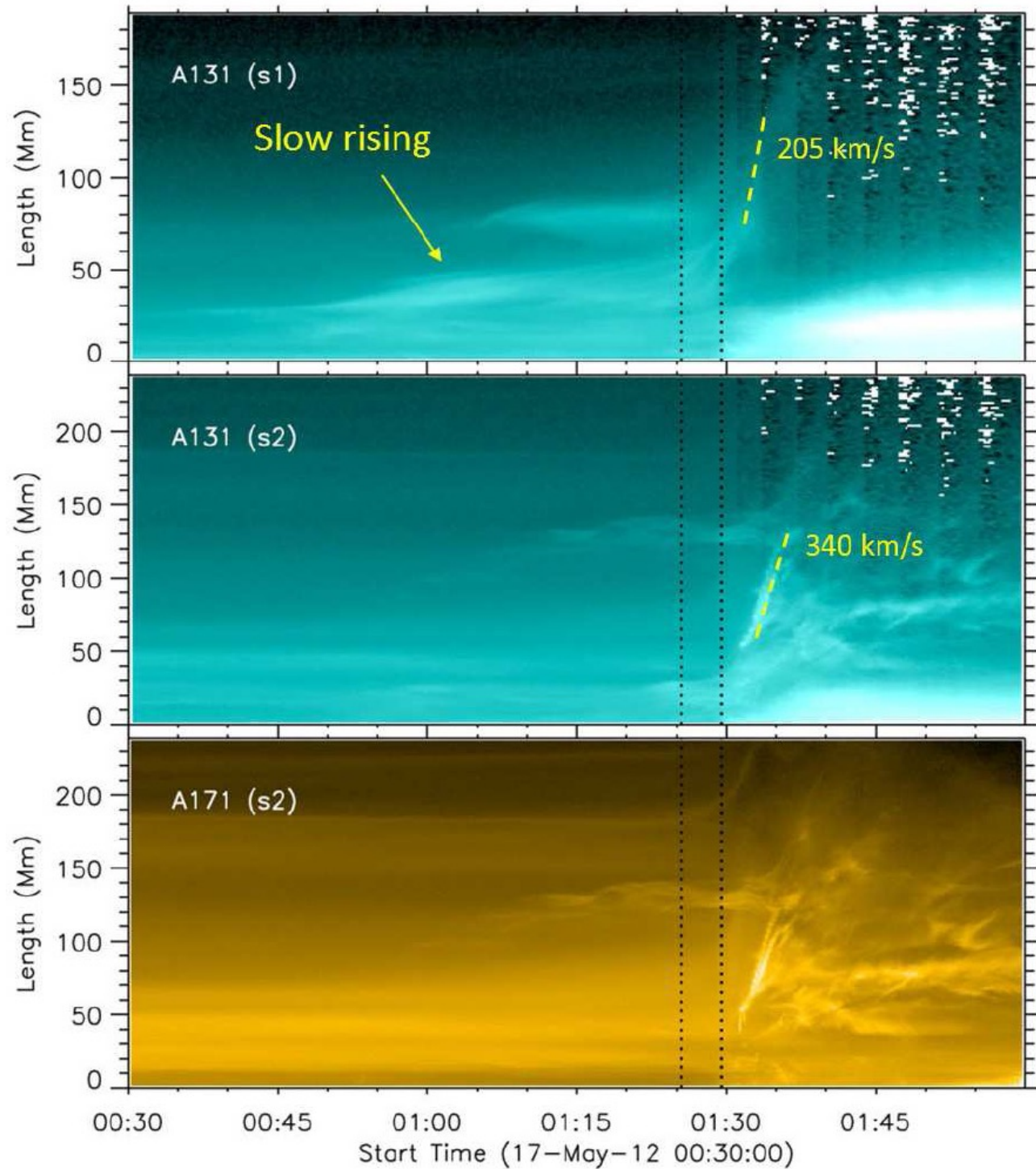
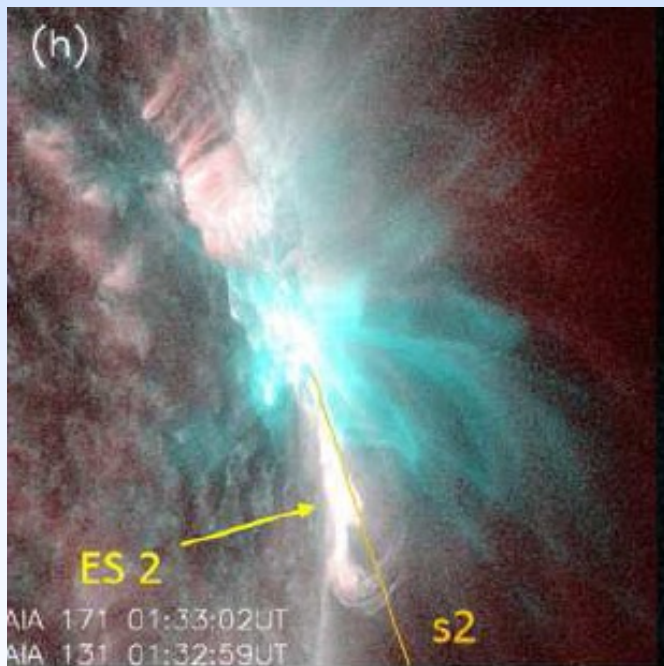
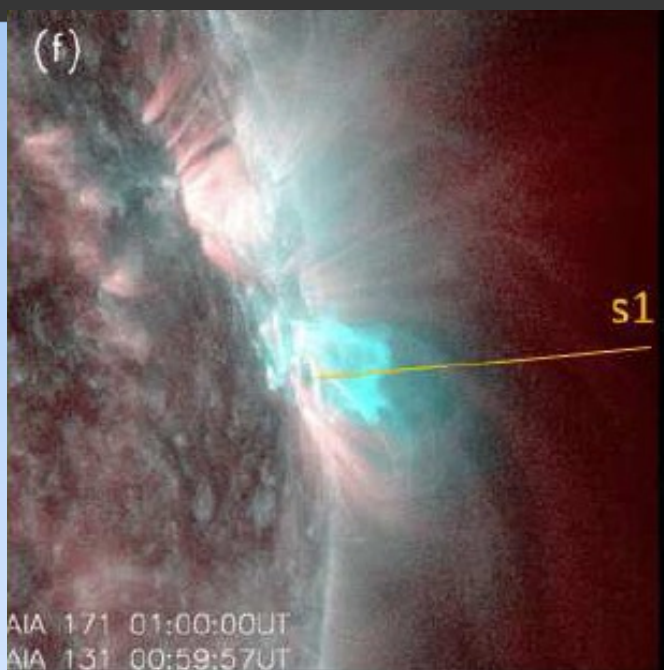
[Shen et al. 2013 APJ]

STEREO and SOHO observations

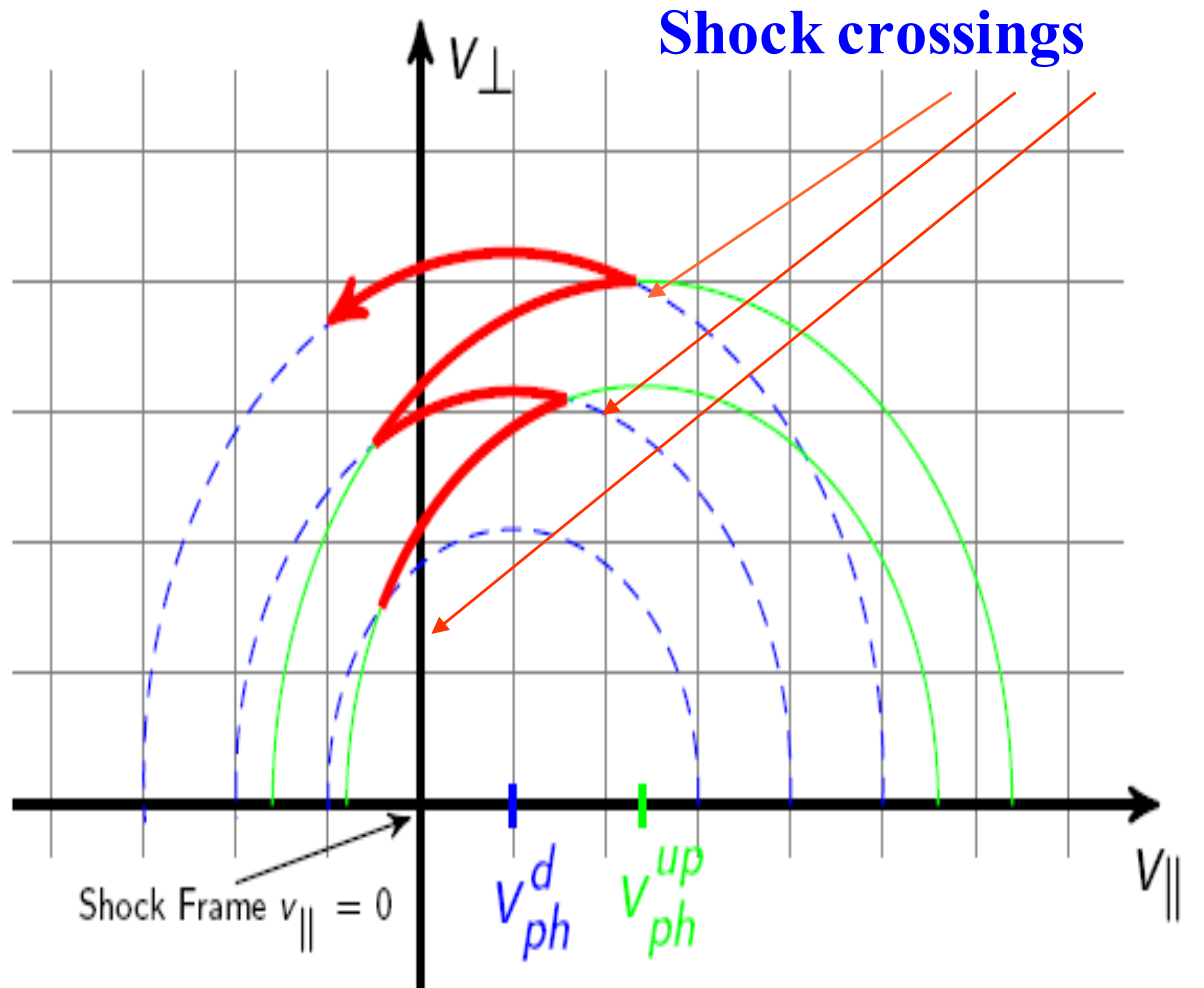


Two CMEs continuously erupted in 5 minutes



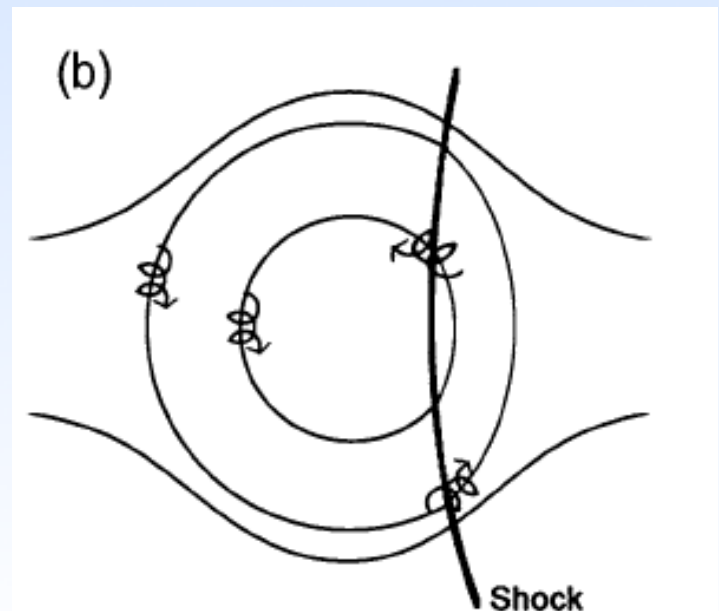


Why CMEs interaction important?

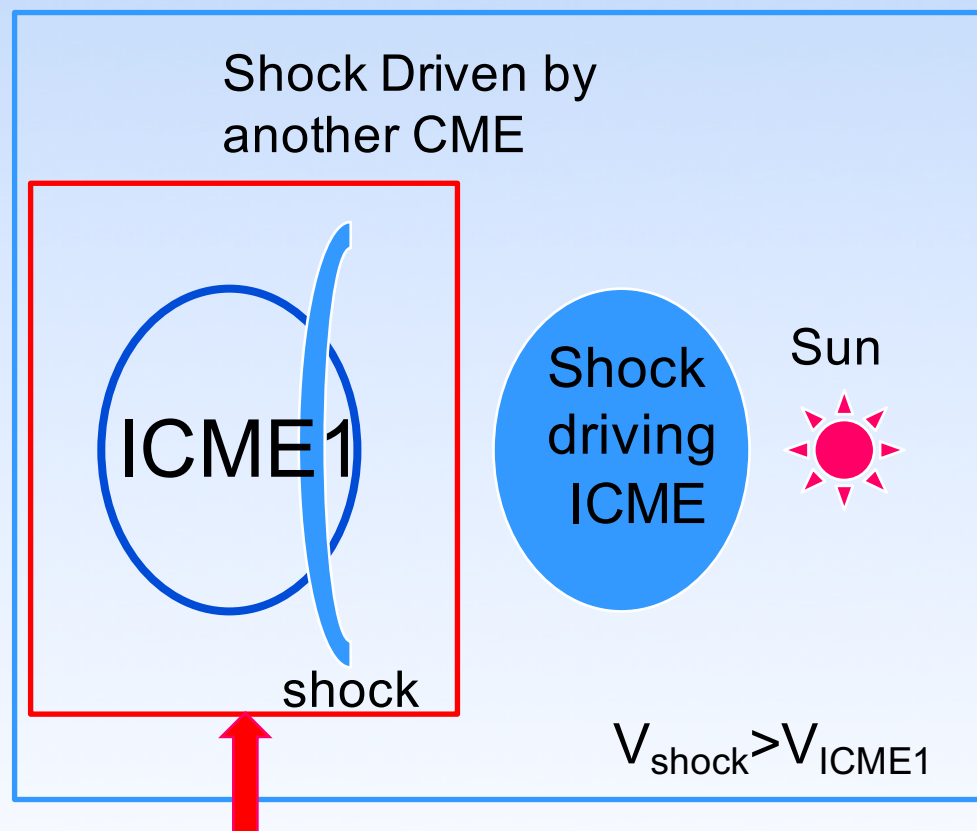
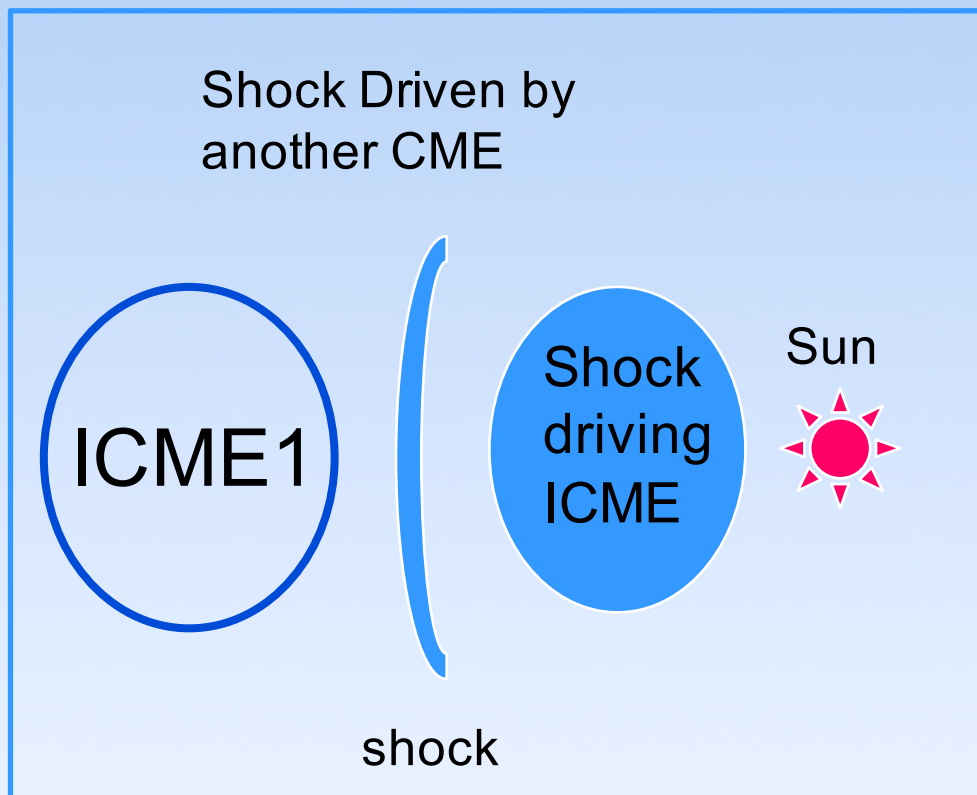


Sugiyama & Terasawa, 1999

- Increase seed population
- Enhanced turbulence level
- Another mechanism to make the particle back to shock



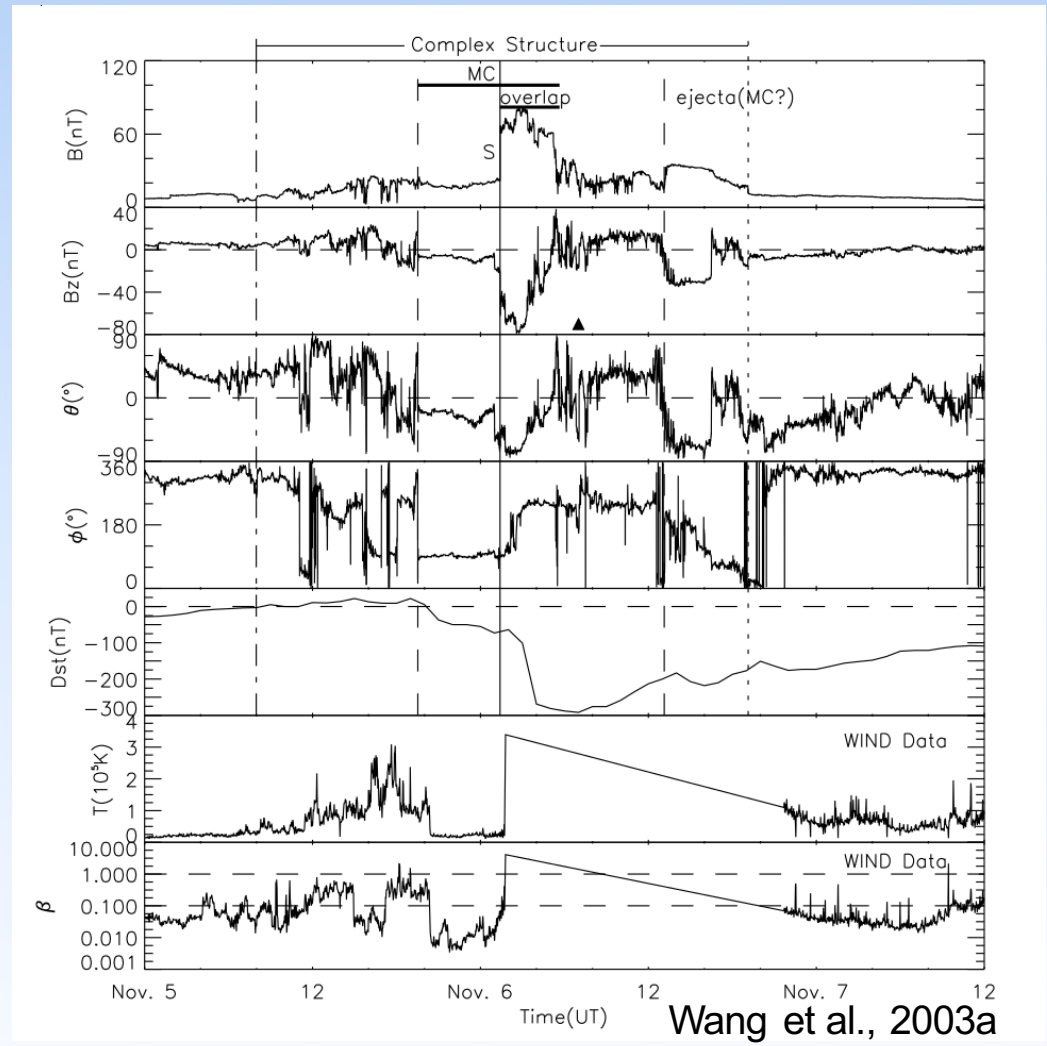
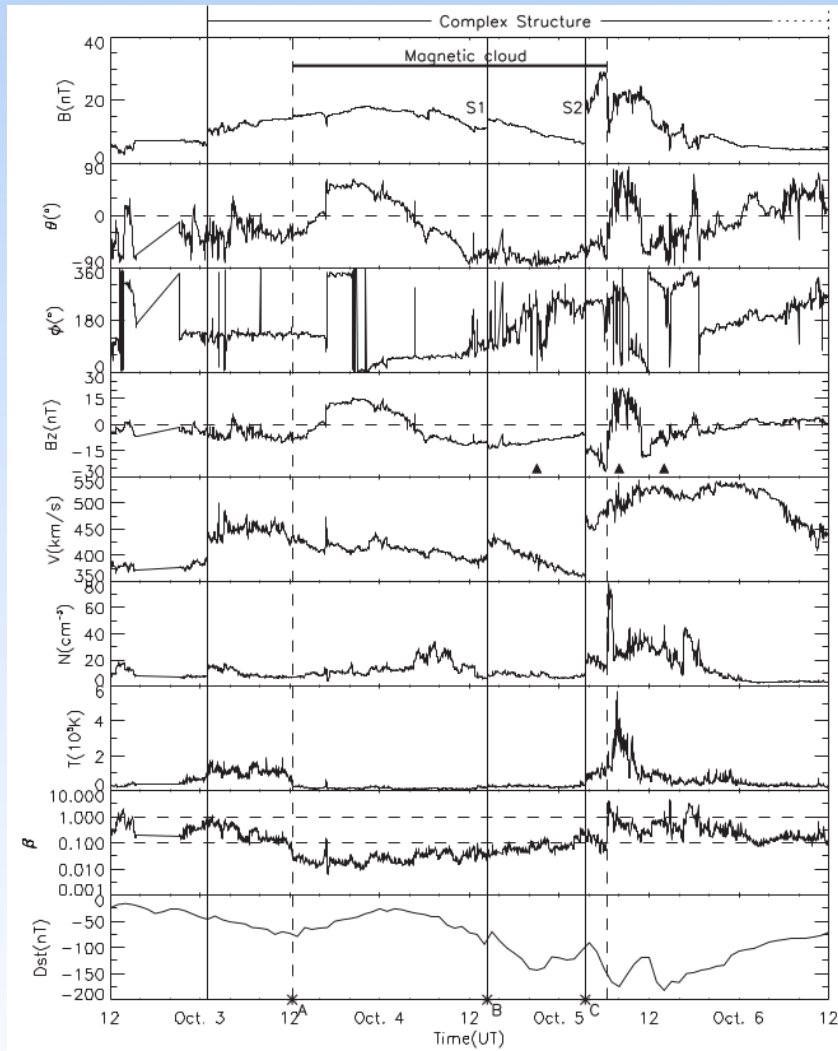
Shock-ICMEs (S-ICMEs) Structure



Inanov, 1982

Shock-ICME complex structure

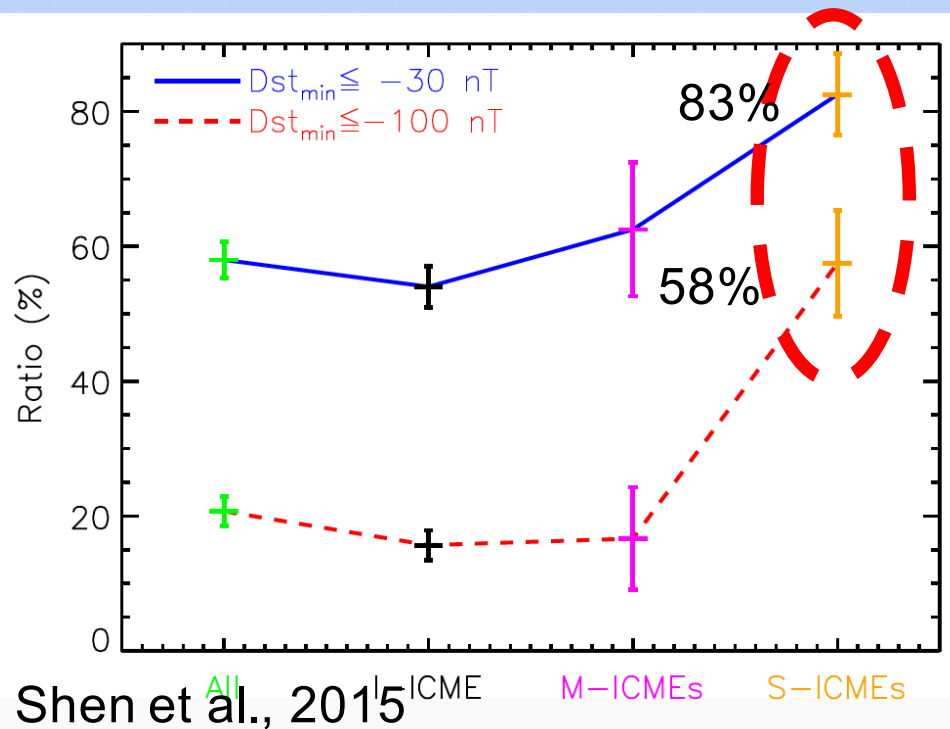
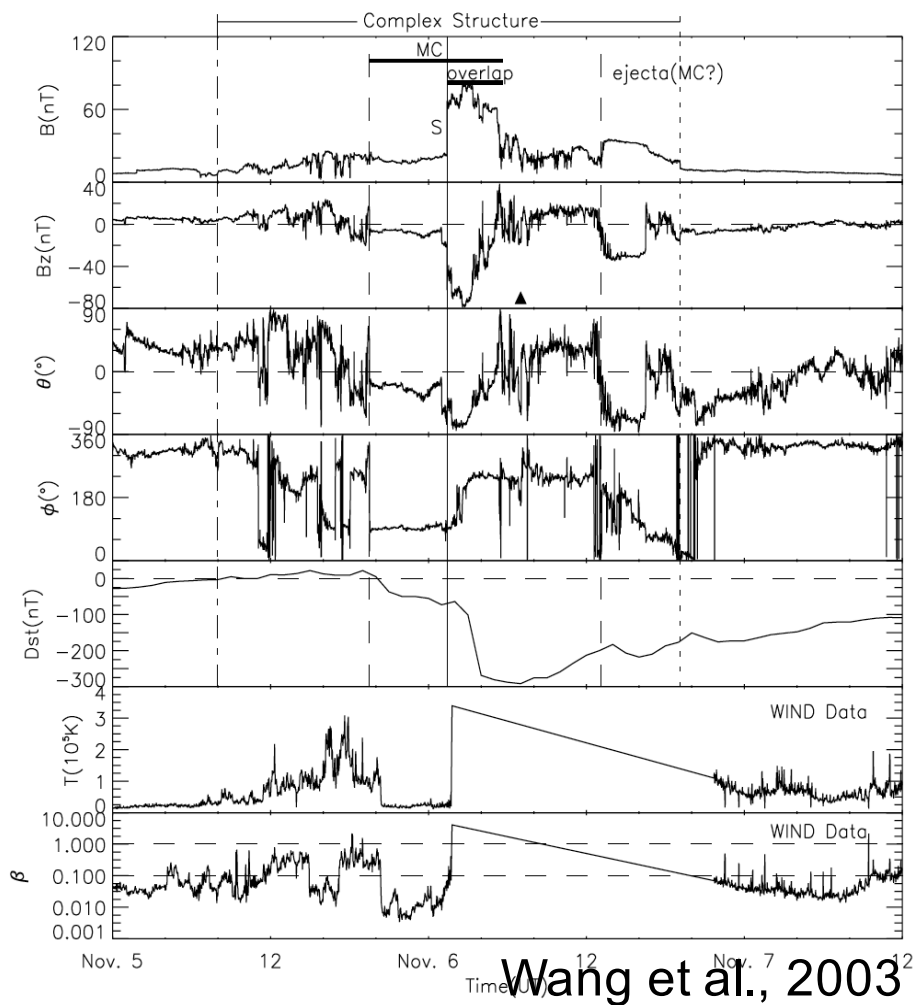
In situ observations of S-ICME structure



Wang et al., 2003a

S-ICMEs are important sources of geomagnetic storms

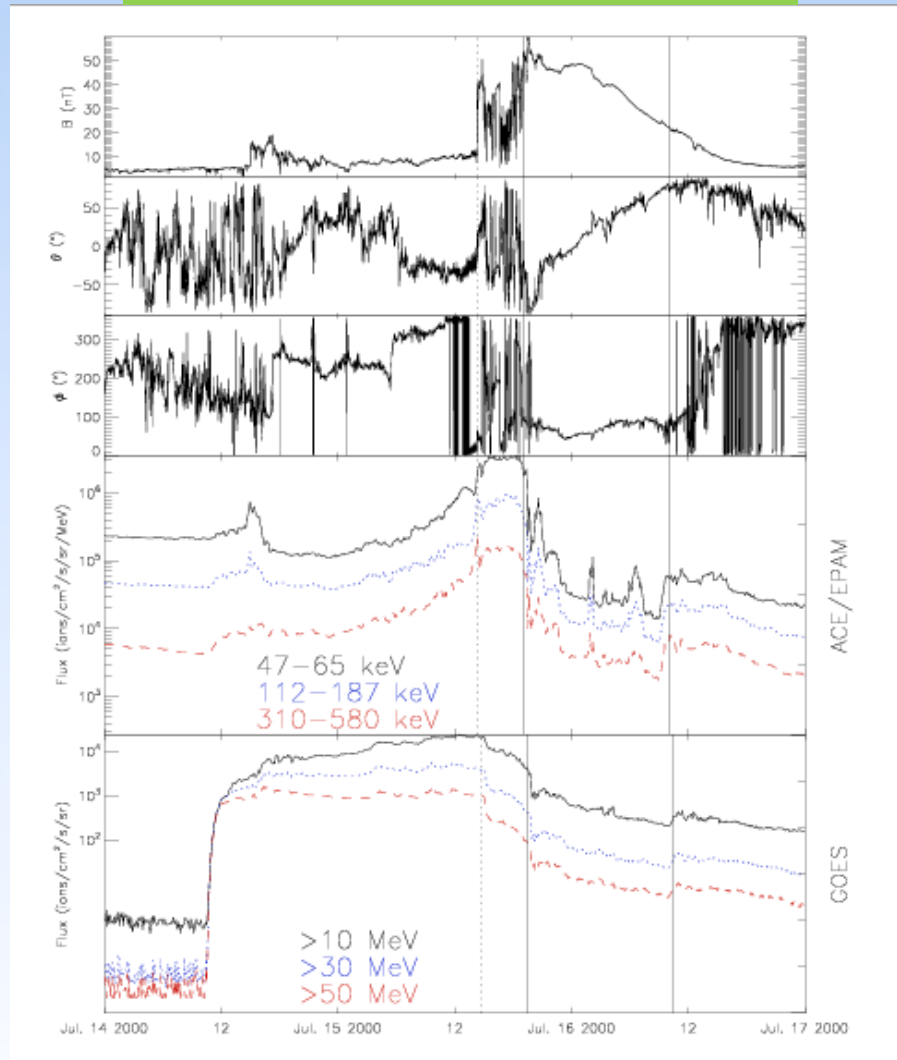
[e.g. Wang et al., 2003a,b; Lugaz et al., 2015; Shen et al., 2015]



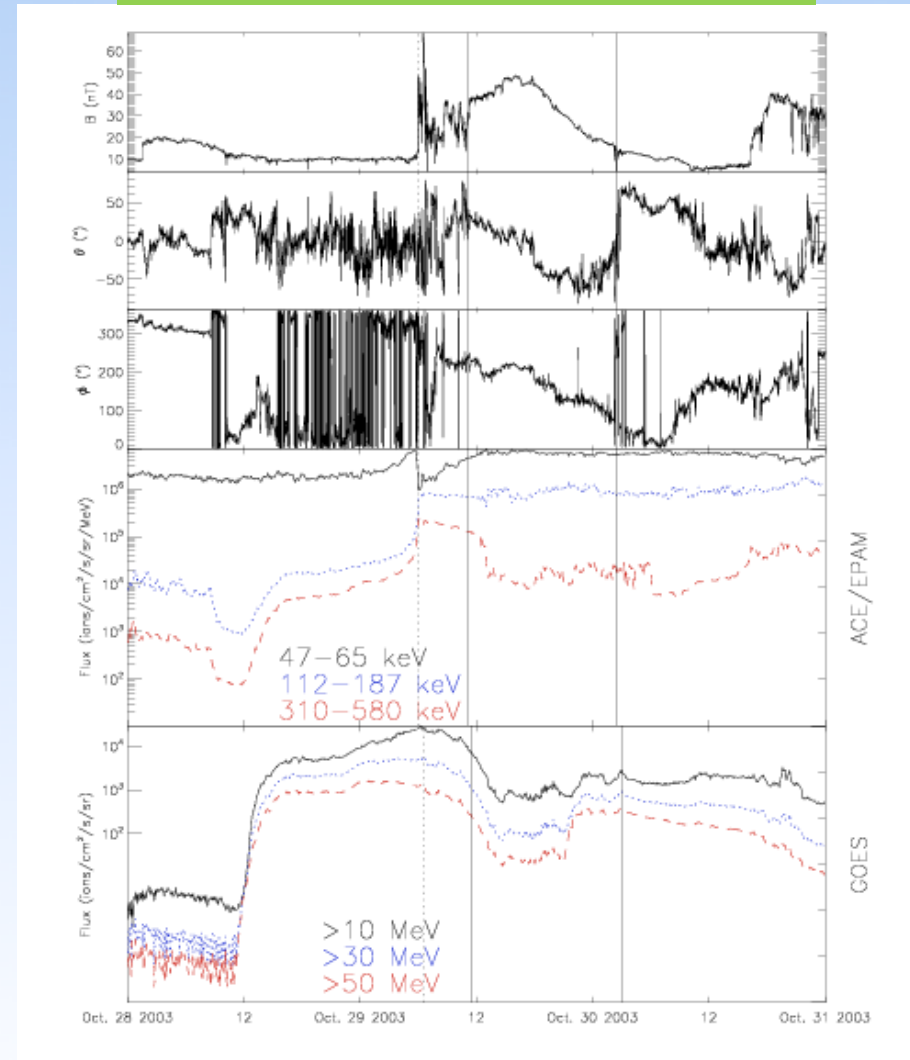
19 of 49 (~39%) S-ICMEs caused intense geomagnetic storms [Lugaz et al., 2015].

Energetic Particle intensity signatures in Isolated ICMEs

2000 July 14 Event
(Bastille Day event)

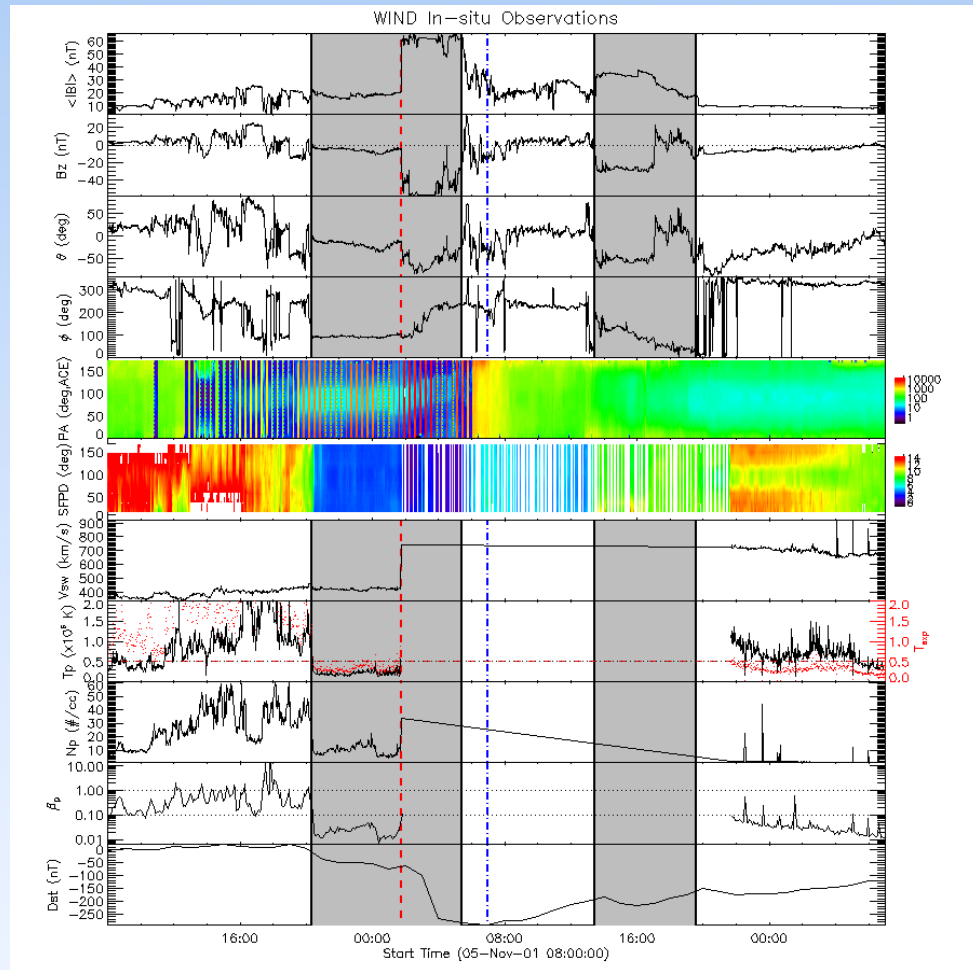


2003 October 28 Event
(Halloween event)

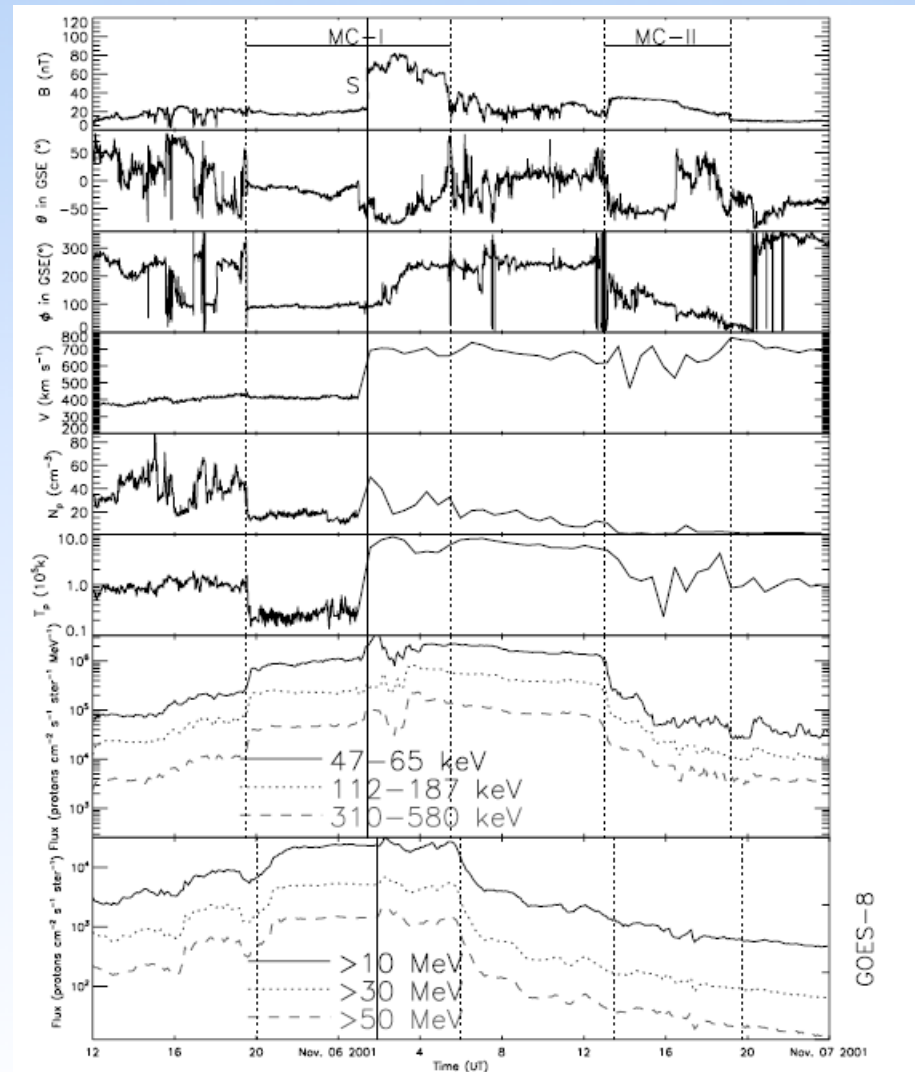


Intensity usually decreased in an isolated ICME [e.g. Cane,2000]

2. Energetic particles in S-ICMEs: Case Study



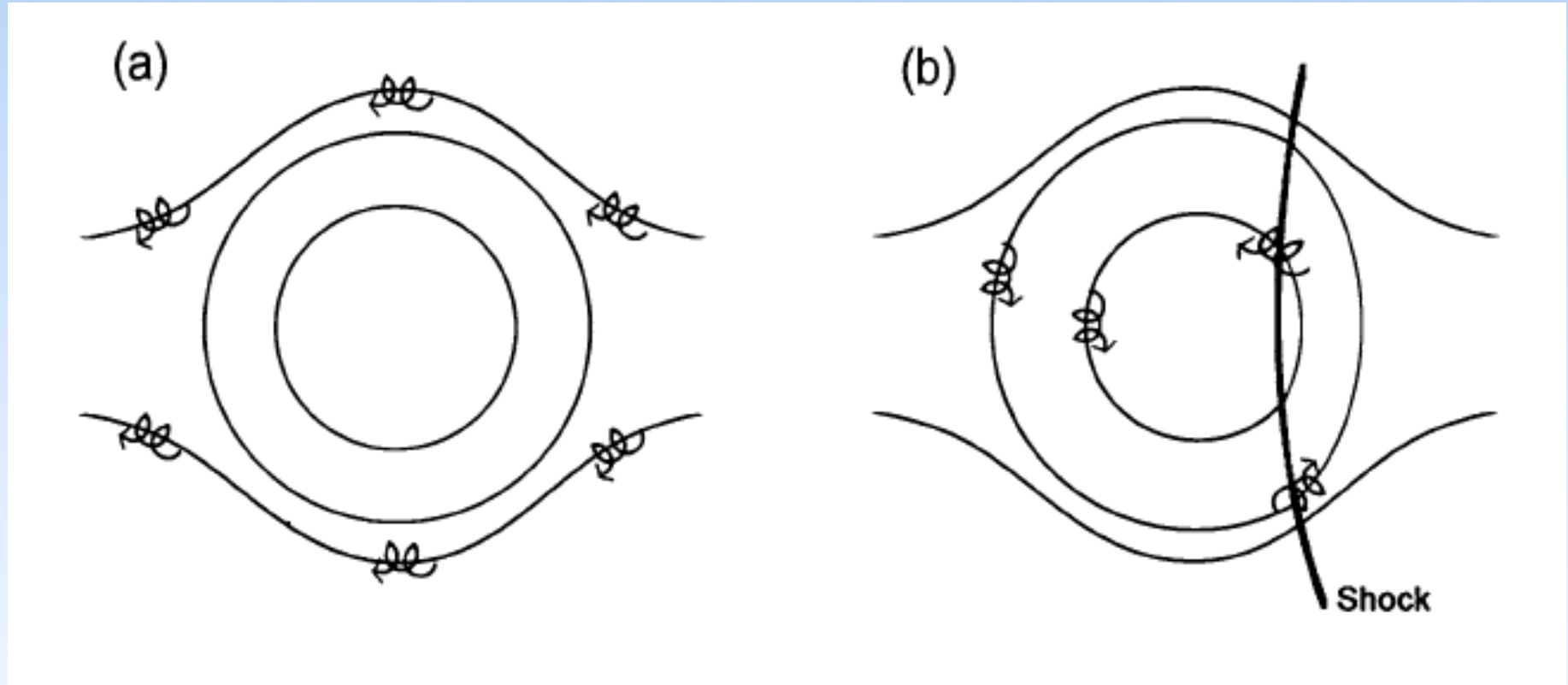
2001 November 5 event



The energetic particle intensity enhanced in this S-ICMEs event [Shen et al. 2008].

Possible explanation

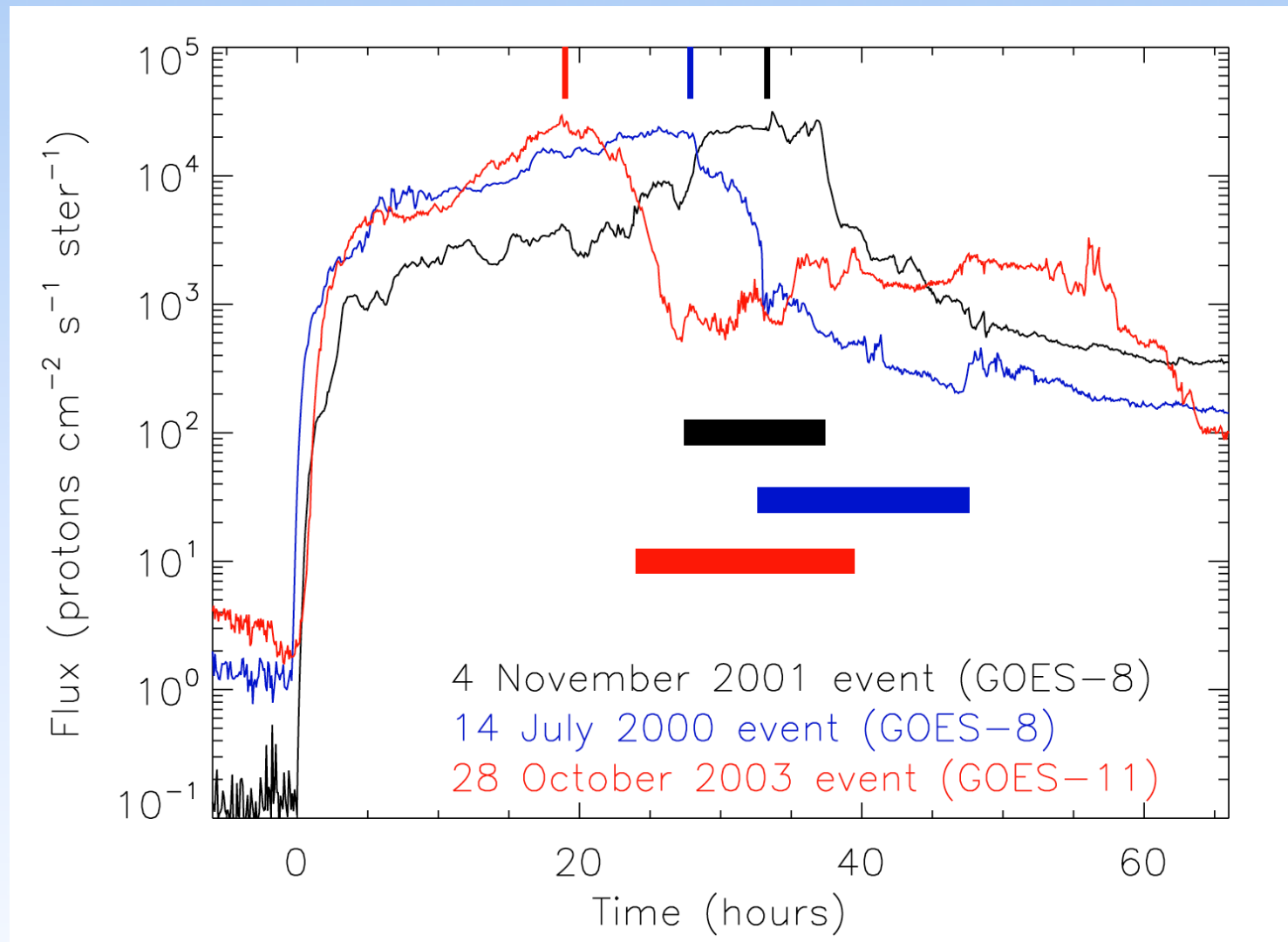
[Shen et al., 2008]



Normal Situation

Shock-ICME complex structure

Why is it important?



It is the main cause of the large SEP event in solar cycle 23rd!

Questions

1. Are all SEP intensity enhanced events Shock-ICMEs events?
2. Did the SEP intensity enhance in all the Shock-ICMEs events?

3. Catalogue of ICMEs recorded by WIND spacecraft Since 1996 at USTC

List of Interplanetary Coronal Mass Ejections (ICMEs)

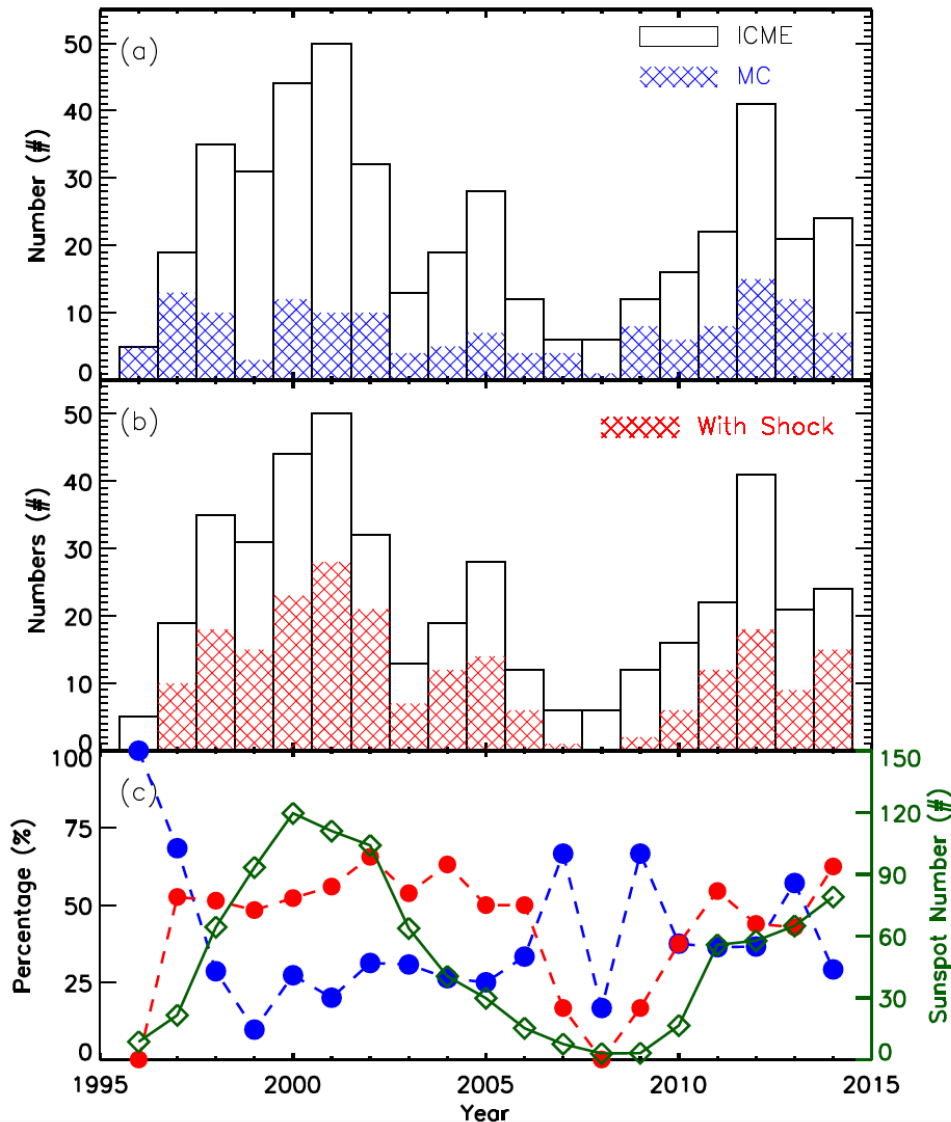
No	Shock Time	Start of the Ejecta	End of the Ejecta	MC	Mean Values in the Ejecta								Mean Values in the Sheath Region								Figures	Group Number	Type ²	Dst Peak Time	Dst _{min}	Group Figures
					B (nT)	B _s (nT)	Duration of Bs (hours)	v (km/s)	v _x B _s (mV/m)	T _p (10 ⁵ K)	N _p (cm ⁻³)	B (nT)	B _s (nT)	Duration of Bs (hours)	v (km/s)	v _x B _s (mV/m)	T _p (10 ⁵ K)	N _p (cm ⁻³)								
1	----	1996-05-27T14:44:15	1996-05-28T11:21:25	Y	9.20	4.70	11.70	380.10	1.88	0.25	8.78	-----	-----	-----	-----	-----	-----	-----	MAGSWE;EPF	1	I	1996-05-27T20:00:00	-33	MAGSWE;EPF		
2	----	1996-07-01T17:15:00	1996-07-02T10:16:29	Y	11.00	4.40	7.70	353.60	1.58	0.31	18.05	-----	-----	-----	-----	-----	-----	-----	MAGSWE;EPF	2	I	-----	-----	MAGSWE;EPF		
3	----	1996-08-07T11:42:00	1996-08-08T08:14:59	Y	6.50	2.80	17.20	345.60	0.96	0.30	8.55	-----	-----	-----	-----	-----	-----	-----	MAGSWE;EPF	3	I	-----	-----	MAGSWE;EPF		
4	----	1996-12-24T02:53:15	1996-12-24T13:41:15	Y	9.60	-0.00	0.00	377.40	-0.00	0.24	9.06	-----	-----	-----	-----	-----	-----	-----	MAGSWE;EPF	4	M	1996-12-25T13:00:00	-33	MAGSWE;EPF		
5	----	1996-12-24T16:23:15	1996-12-25T11:24:00	Y	11.00	5.10	6.10	331.70	1.62	0.32	11.75	-----	-----	-----	-----	-----	-----	-----	MAGSWE;EPF					MAGSWE;EPF		
6	1997-01-10T00:51:45	1997-01-10T04:41:15	1997-01-11T02:57:45	Y	14.70	7.60	15.70	437.40	3.44	0.26	19.44	8.80	4.50	1.80	440.60	1.99	0.87	13.22	MAGSWE;EPF	5	I	1997-01-10T10:00:00	-78	MAGSWE;EPF		
7	1997-02-09T12:49:30	1997-02-10T02:46:30	1997-02-10T18:40:30	Y	7.80	6.40	15.90	459.80	2.92	0.41	1.20	6.50	4.20	8.50	588.50	2.46	1.65	6.70	MAGSWE;EPF	6	I	1997-02-10T11:00:00	-68	MAGSWE;EPF		
8	----	1997-04-11T08:10:30	1997-04-11T14:55:30	Y	20.80	-0.00	0.00	462.90	-0.00	0.21	12.02	-----	-----	-----	-----	-----	-----	-----	MAGSWE;EPF	7	I	-----	-----	MAGSWE;EPF		
9	----	1997-04-11T08:10:30	1997-04-11T14:55:30	N	11.10	5.60	23.50	363.60	2.16	0.52	13.29	-----	-----	-----	-----	-----	-----	-----	MAGSWE;EPF	8	I	1997-04-11T14:55:30	-107	MAGSWE;EPF		

http://space.ustc.edu.cn/dreams/wind_icmes/

Time, Type, Parameters in the ejecta and sheath region, Related images, Geoeffectiveness

Numbers of ICMEs, MCs and Shocks Driven by ICMEs

[Chi et al., 2015, under review]

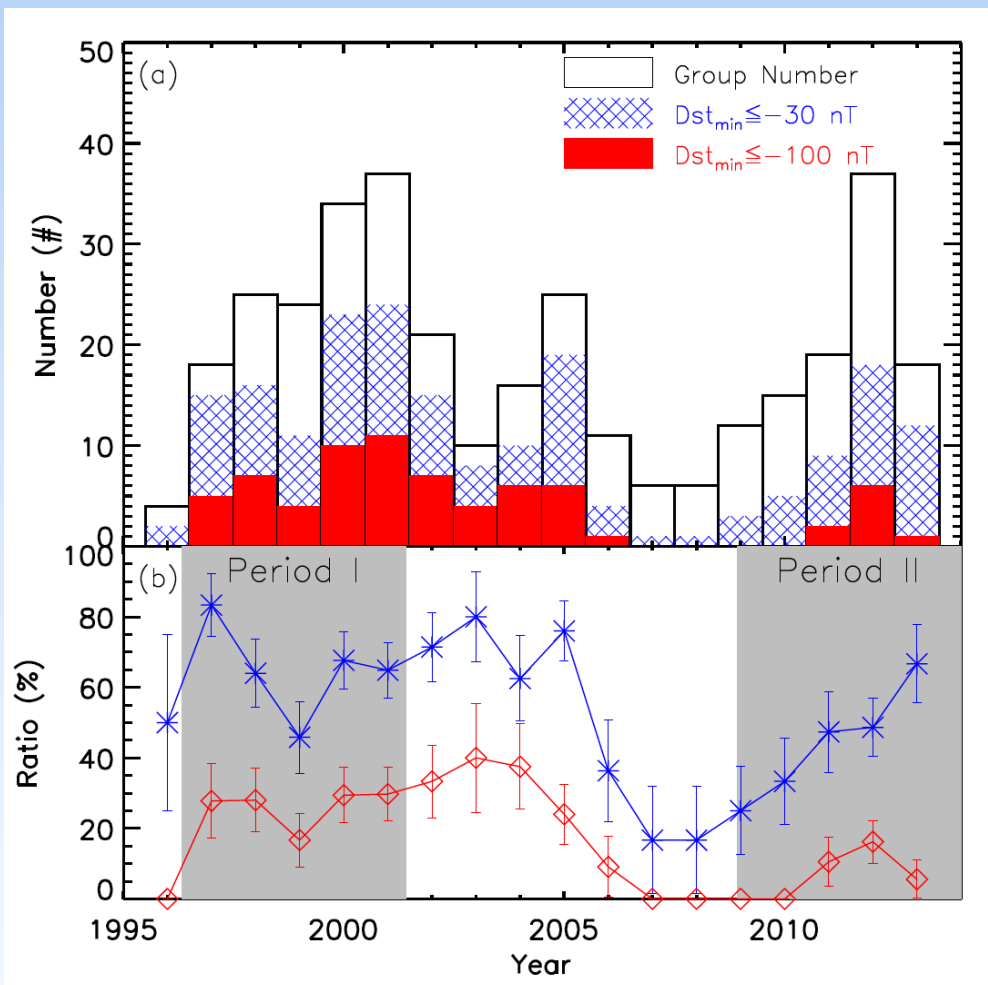


436 ICMEs from 1996 to 2014 in our catalogue

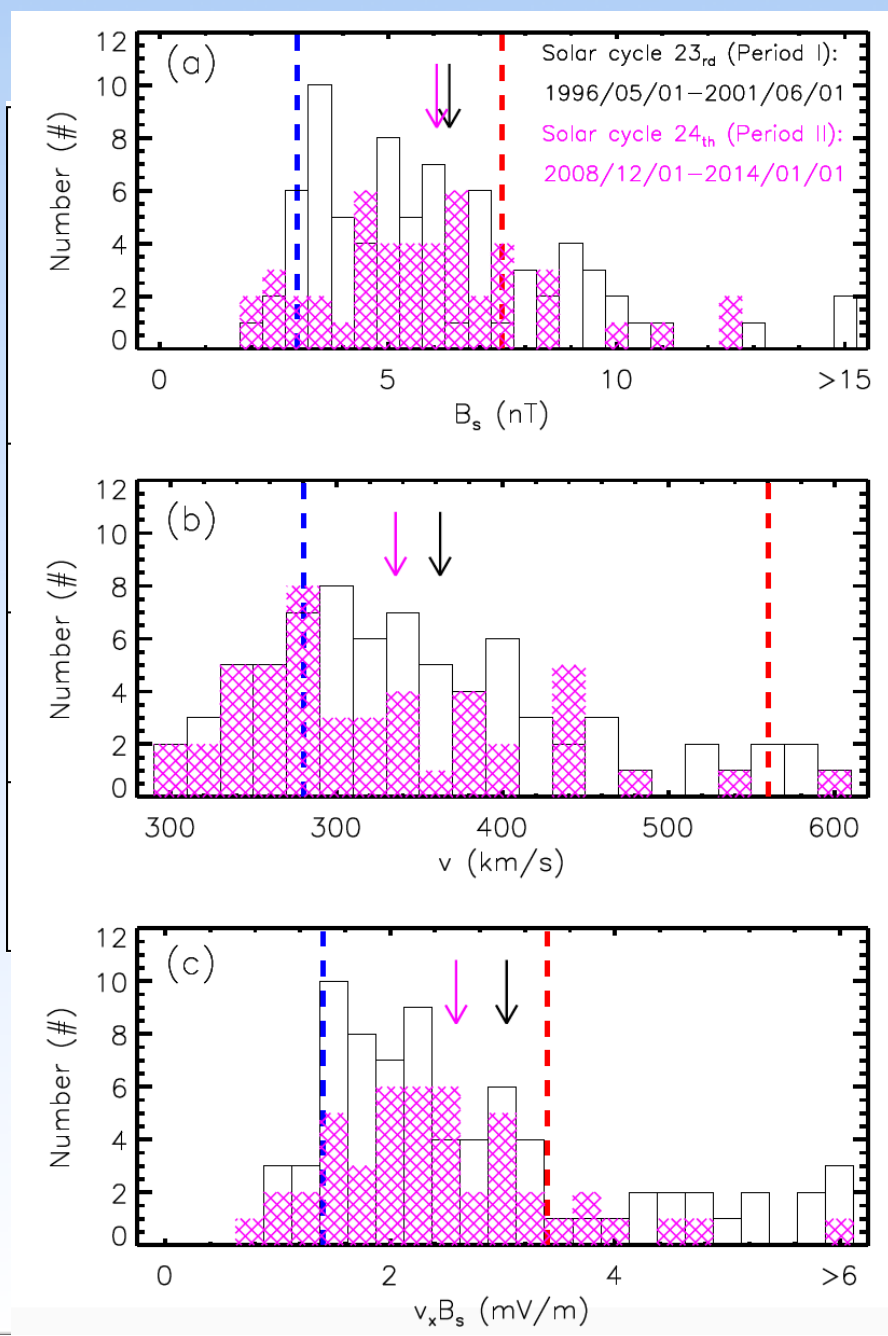
- ✓ ICME numbers are small in solar cycle 24
- ✓ MC numbers are similar between these two solar cycles
- ✓ Numbers of shocks driven by ICMEs are small in solar cycle 24

Geoeffectiveness of ICMEs

[Shen et al., 2015, under review]

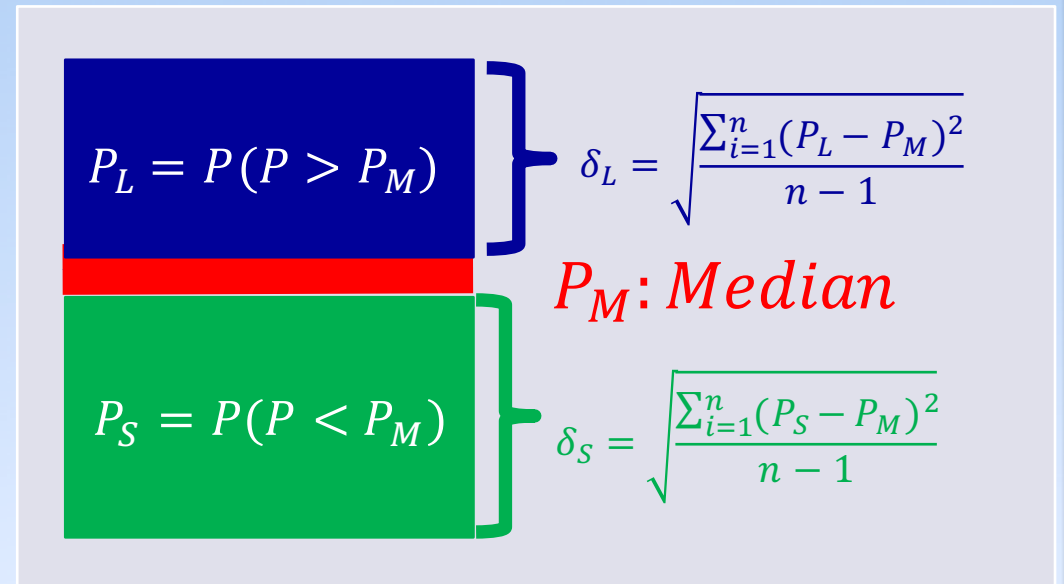
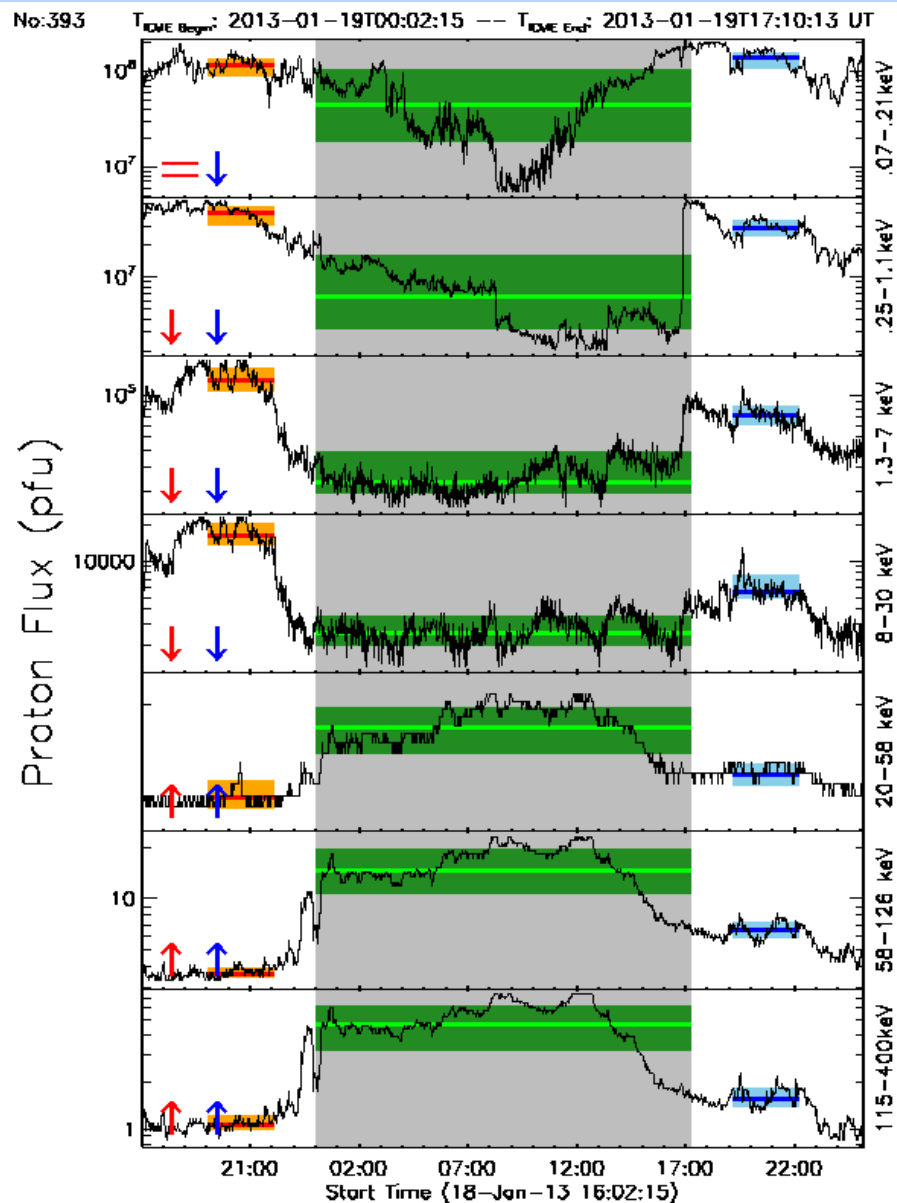


Period I: 1 May 1996 to 1 June 2001
Period II: 1 December 2008 to 1 January 2014



4. Statistical Analysis of Particle Signature of ICMEs

Automatic Energetic Particle Signature Determination



$$P_{M,ICME} - \delta_{S,ICME} > P_{M,Back} + \delta_{L,Back}$$



$$P_{M,ICME} + \delta_{L,ICME} < P_{M,Back} - \delta_{S,Back}$$

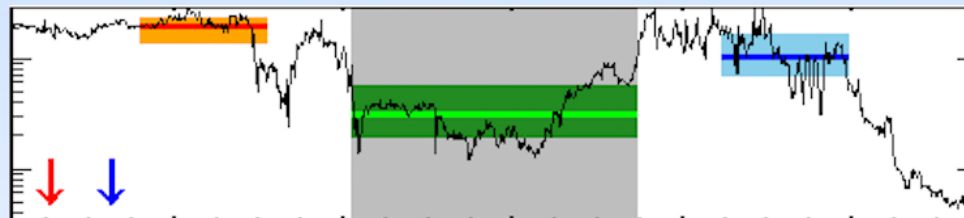


$$P_{M,ICME} + \delta_{L,ICME} > P_{M,Back} - \delta_{S,Back}$$

Increase	Decrease	Not Change	Other
↑↑	↓↓	Others	↑↓
↑=	↓=		↓↑

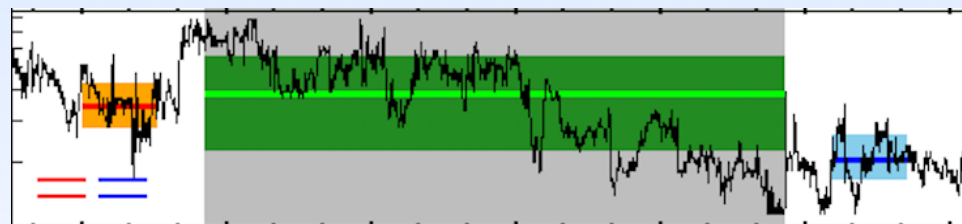


Increase

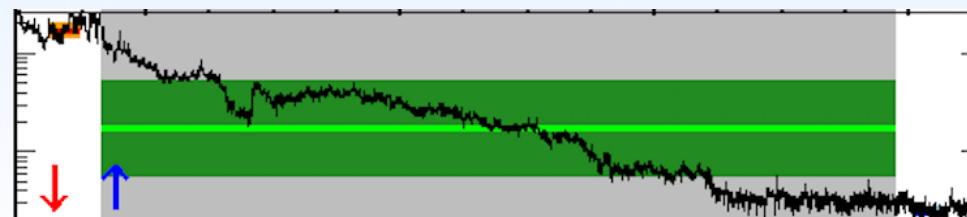


Decrease

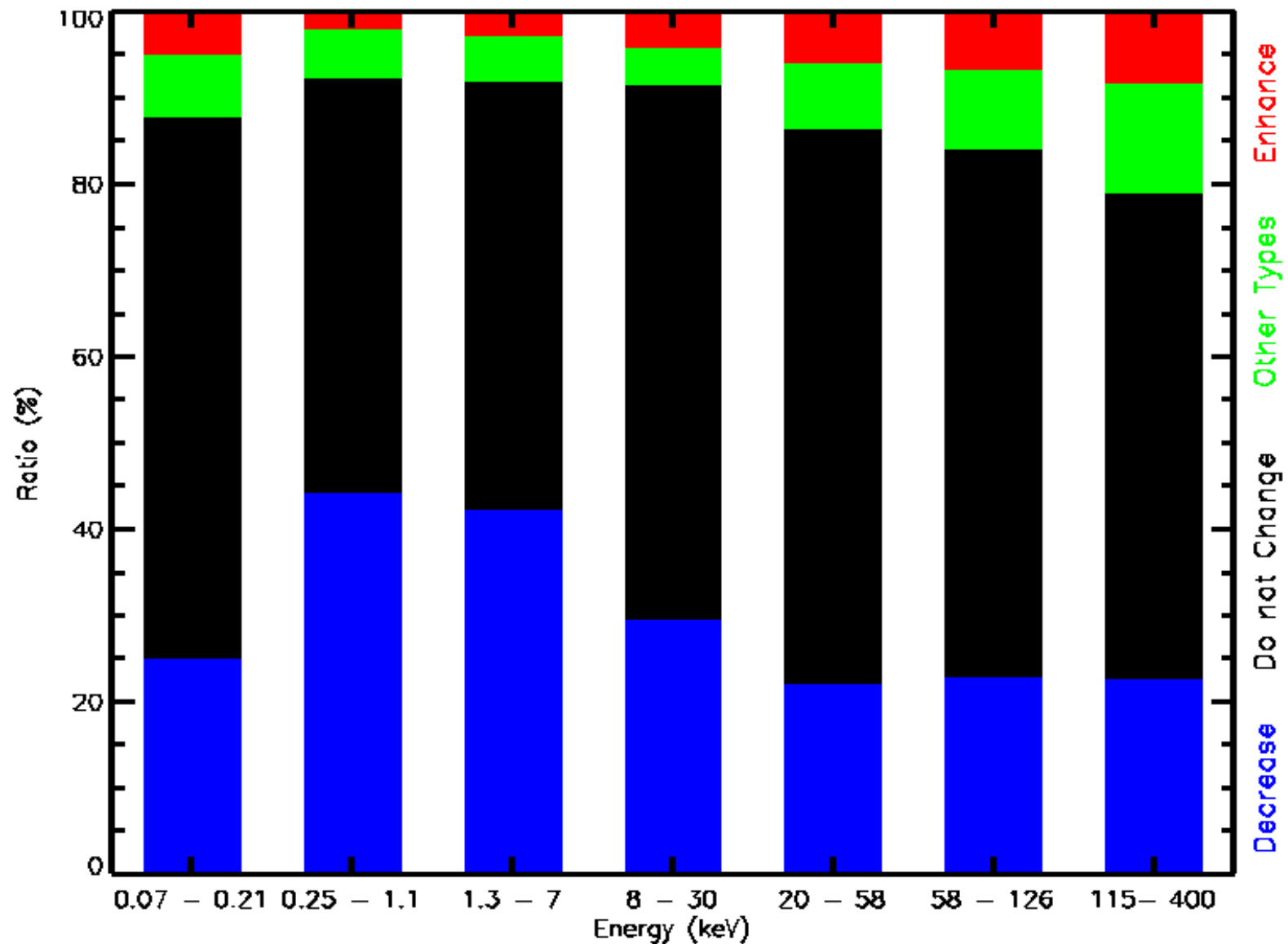
Not Change



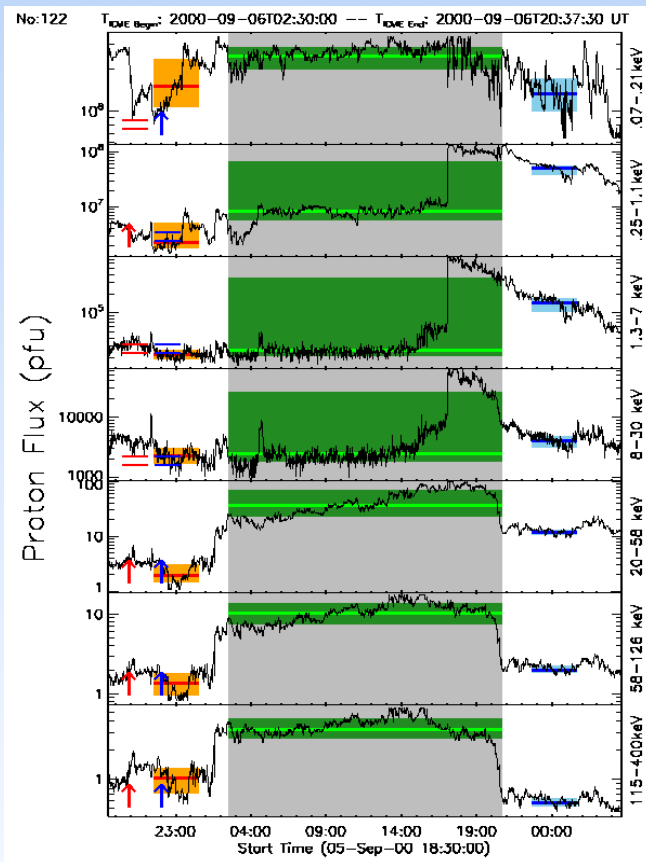
Other



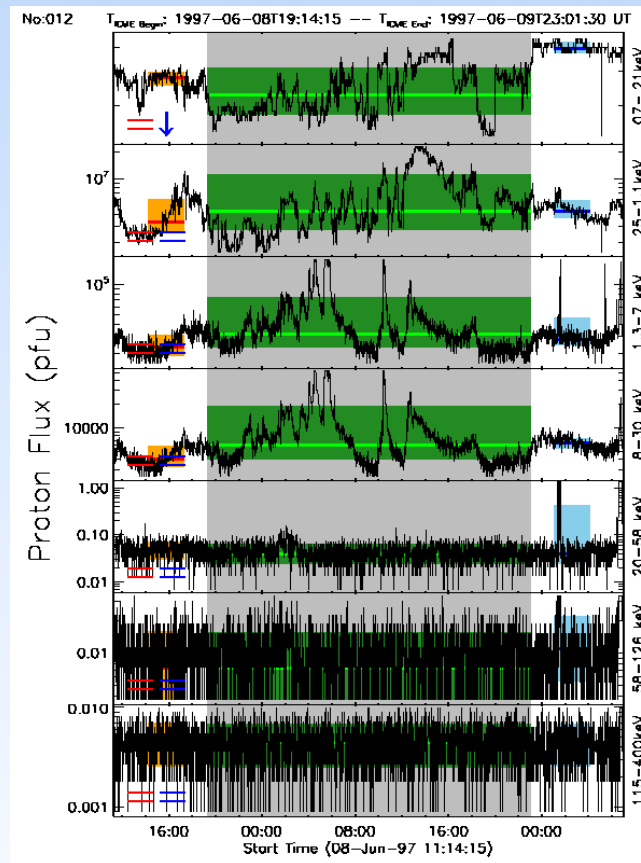
The automatic determination results based on the proton observations from WIND/3DP



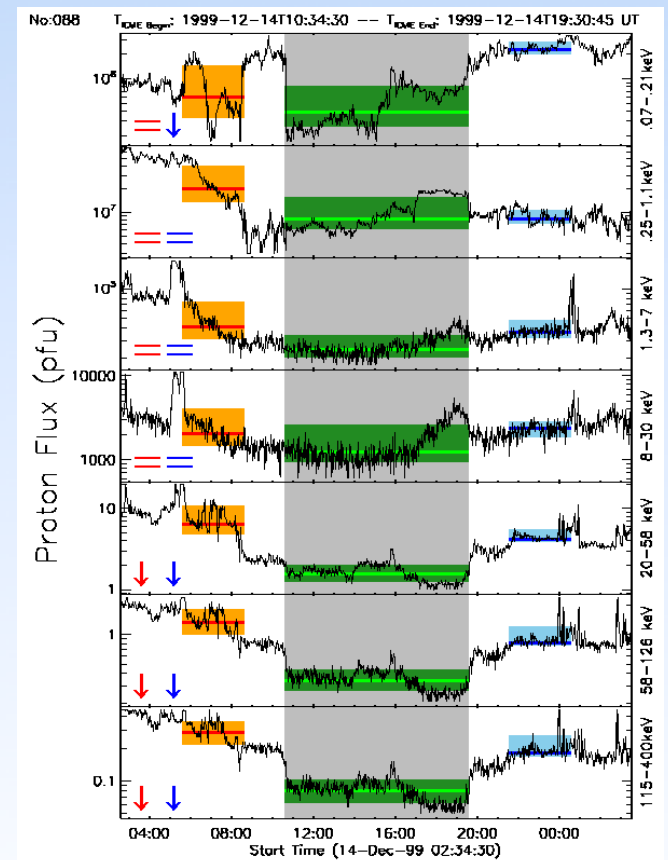
Definition: If the intensity increased (decreased) of an ICME in more than 3 (in 7) energy channels, we call it as the particle intensity increased (decreased) ICME event.



Increased event

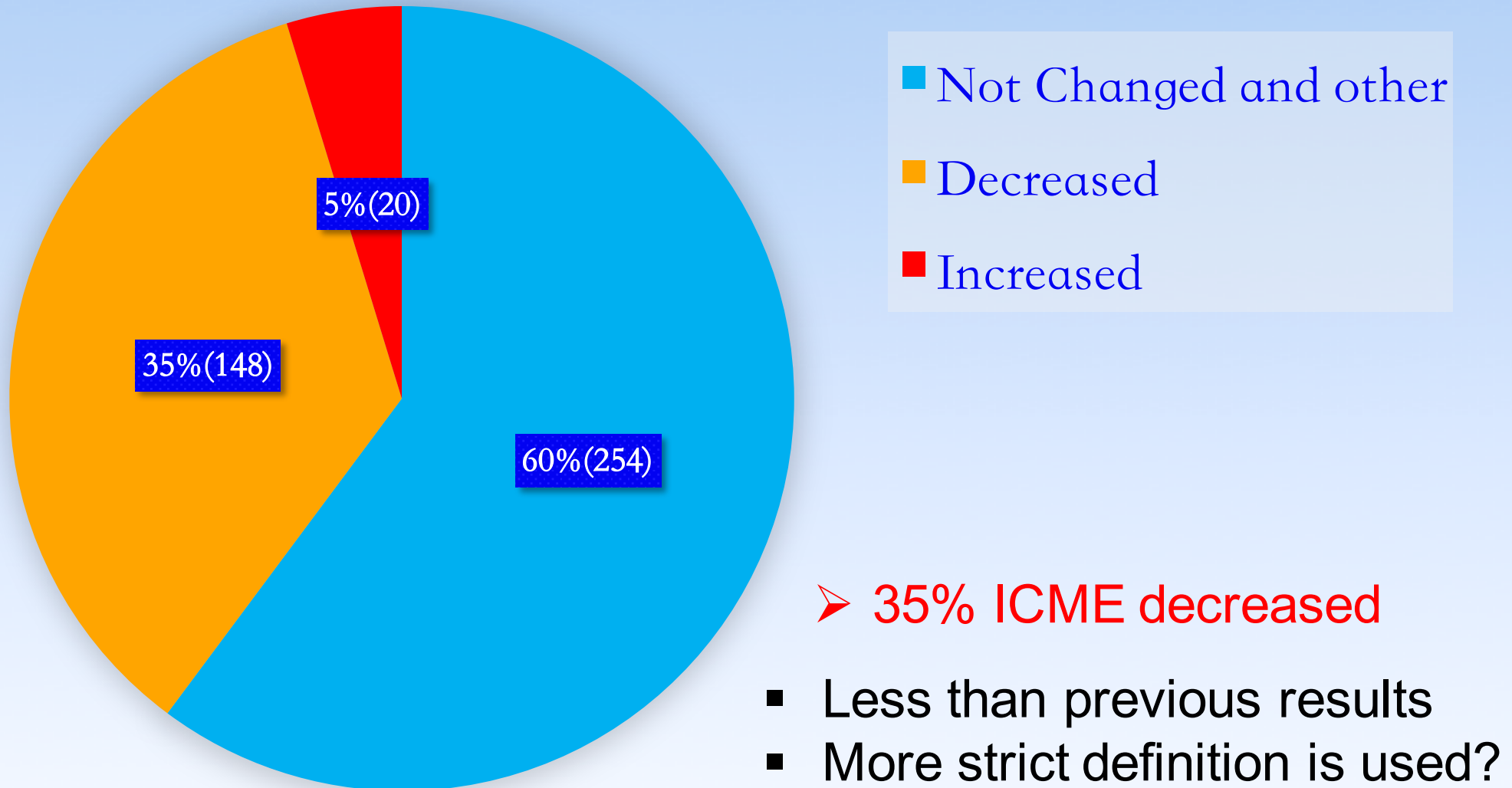


Not Changed



Decreased event

Statistical Results for All ICMEs

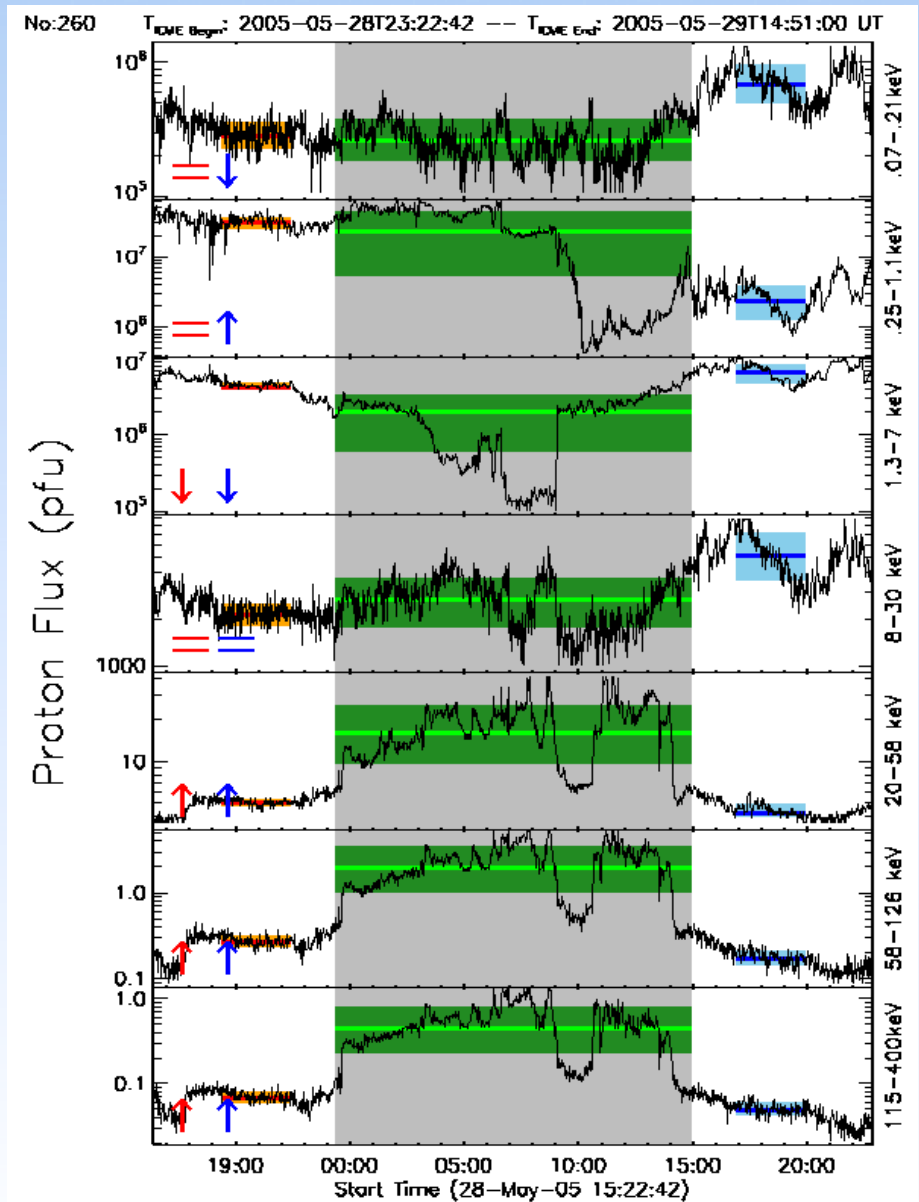
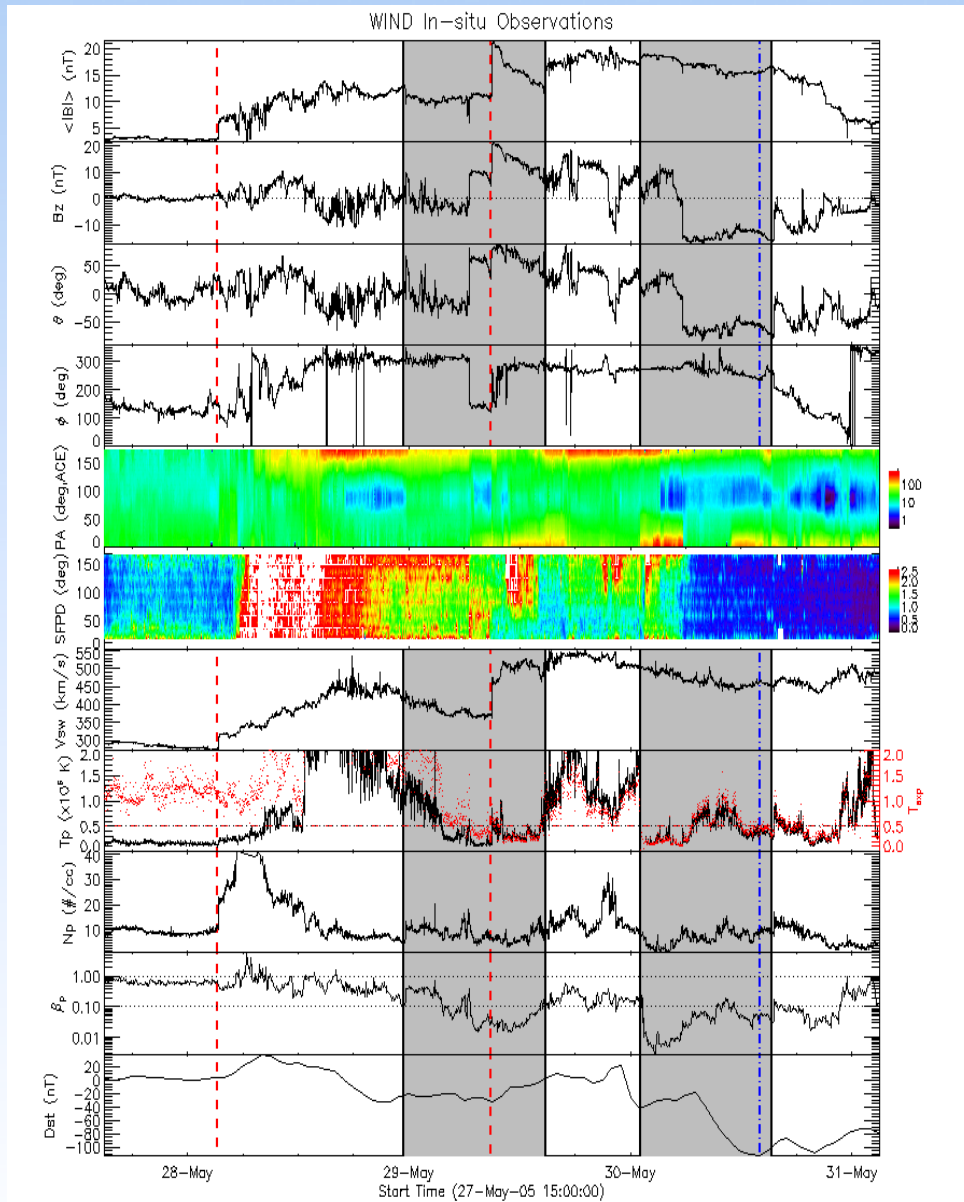


➤ 35% ICME decreased

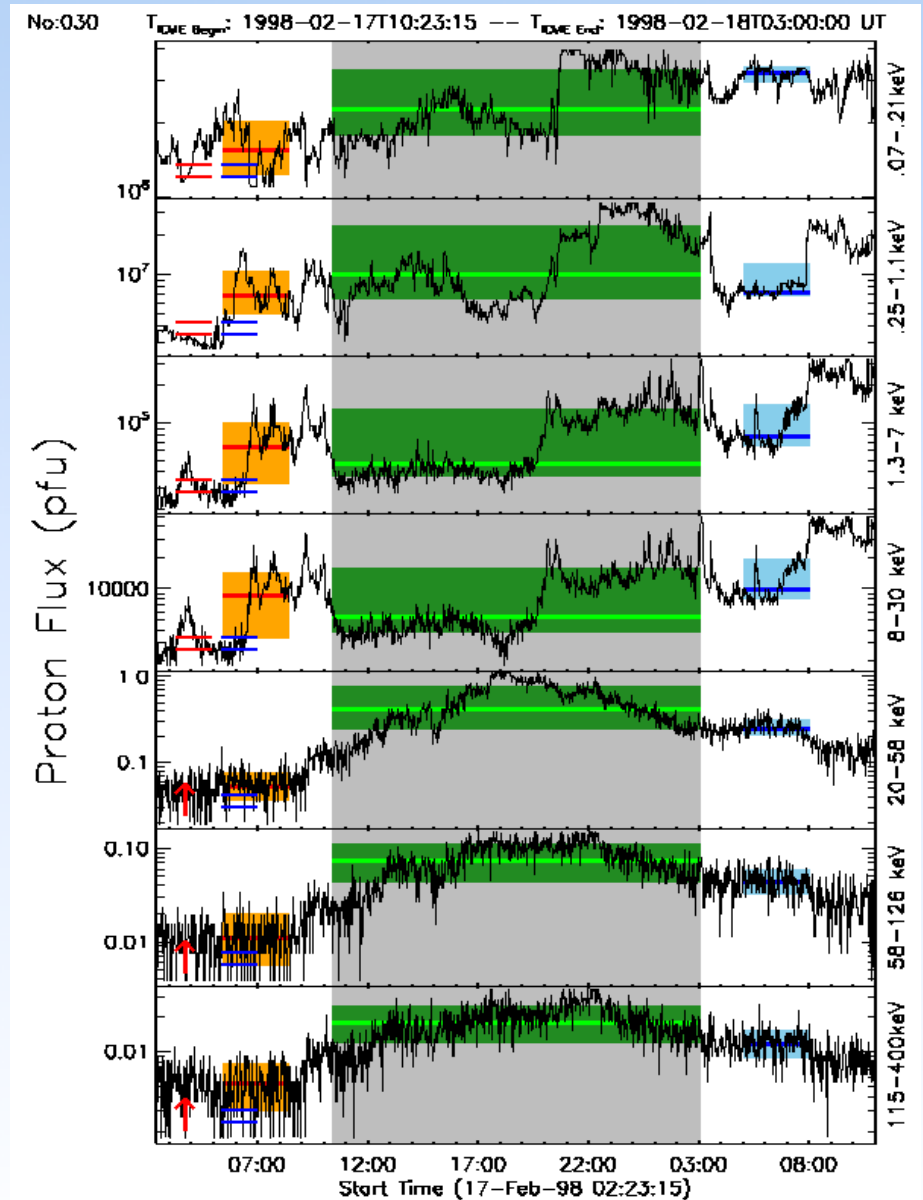
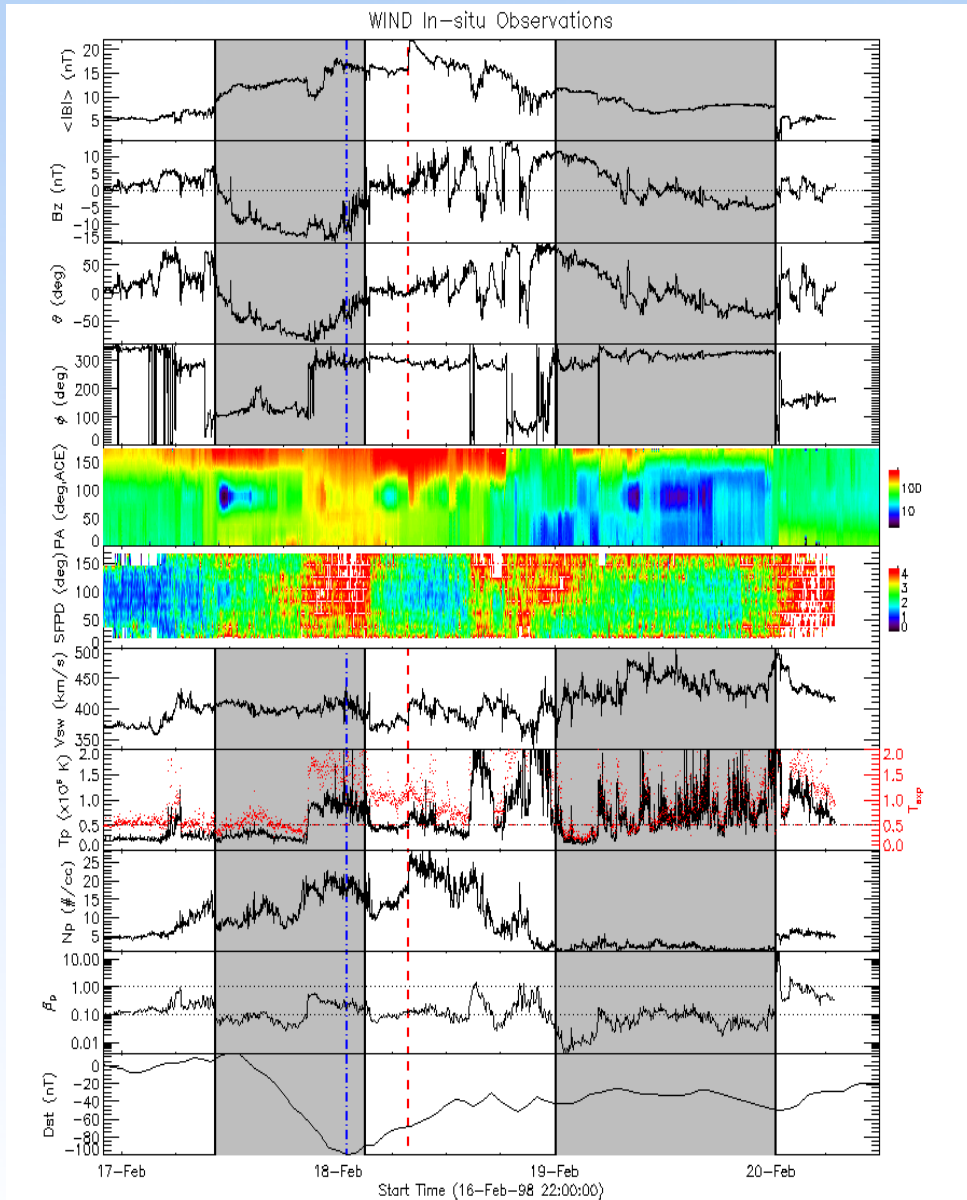
- Less than previous results
- More strict definition is used?

436 (events) – (14 bad data events) ➤ Only About 5% ICME increased
= 422 ICME events

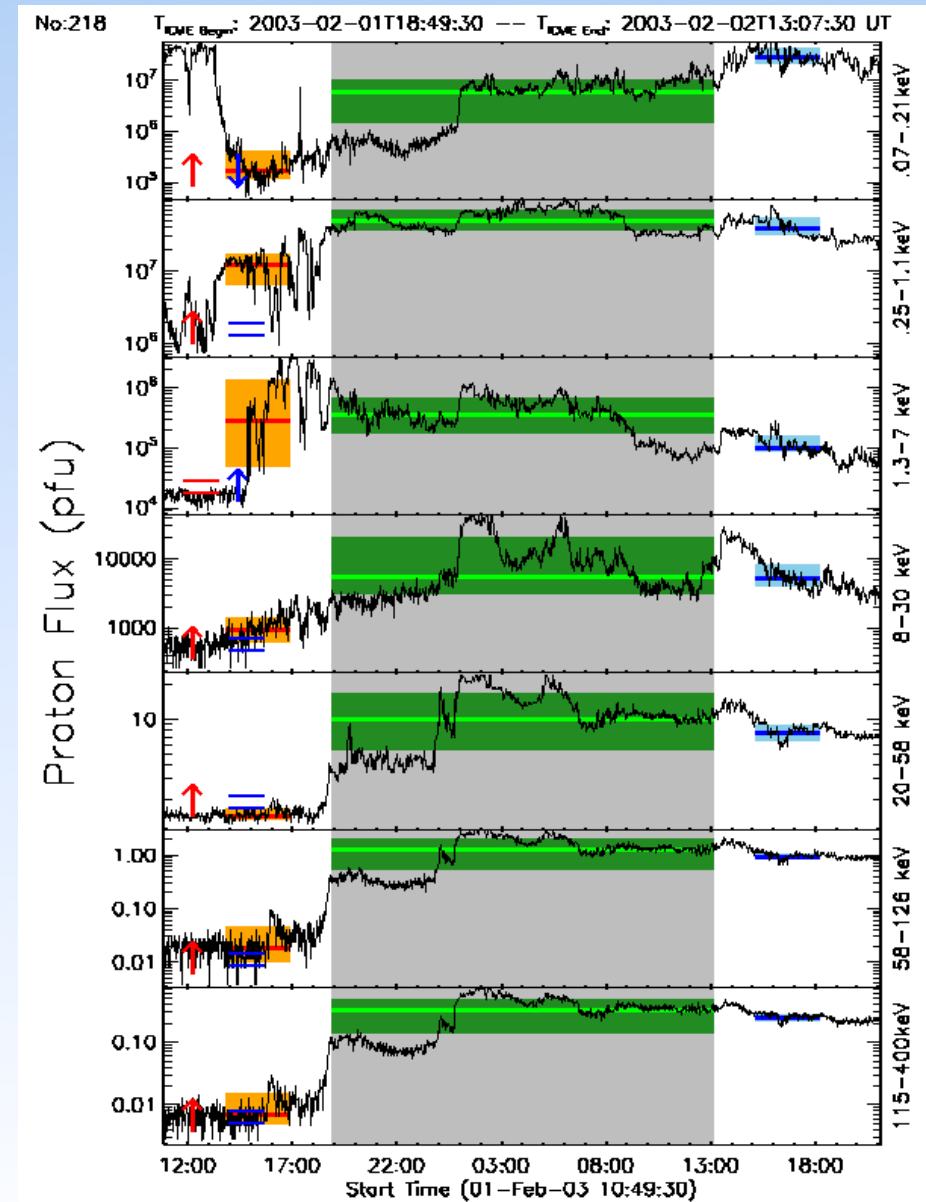
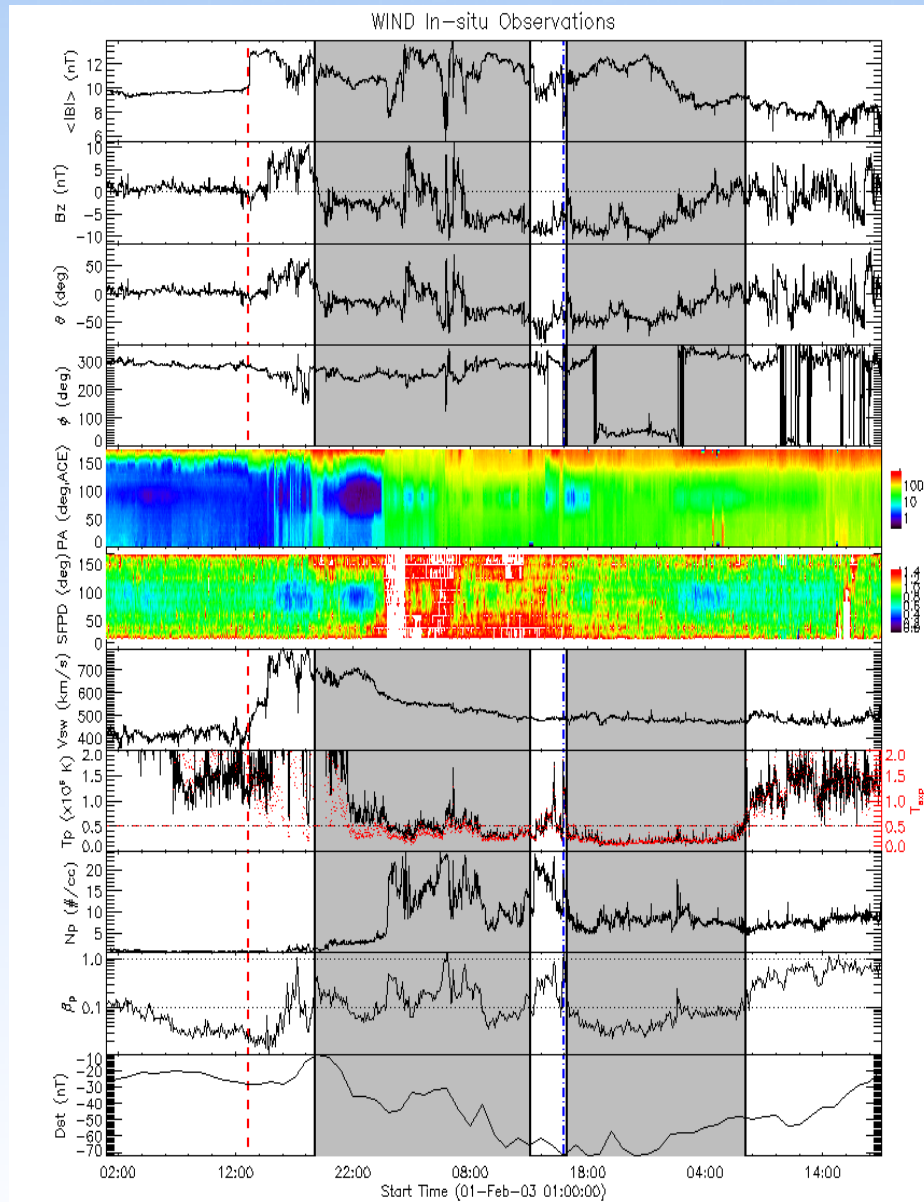
Increase in an S-ICMEs event



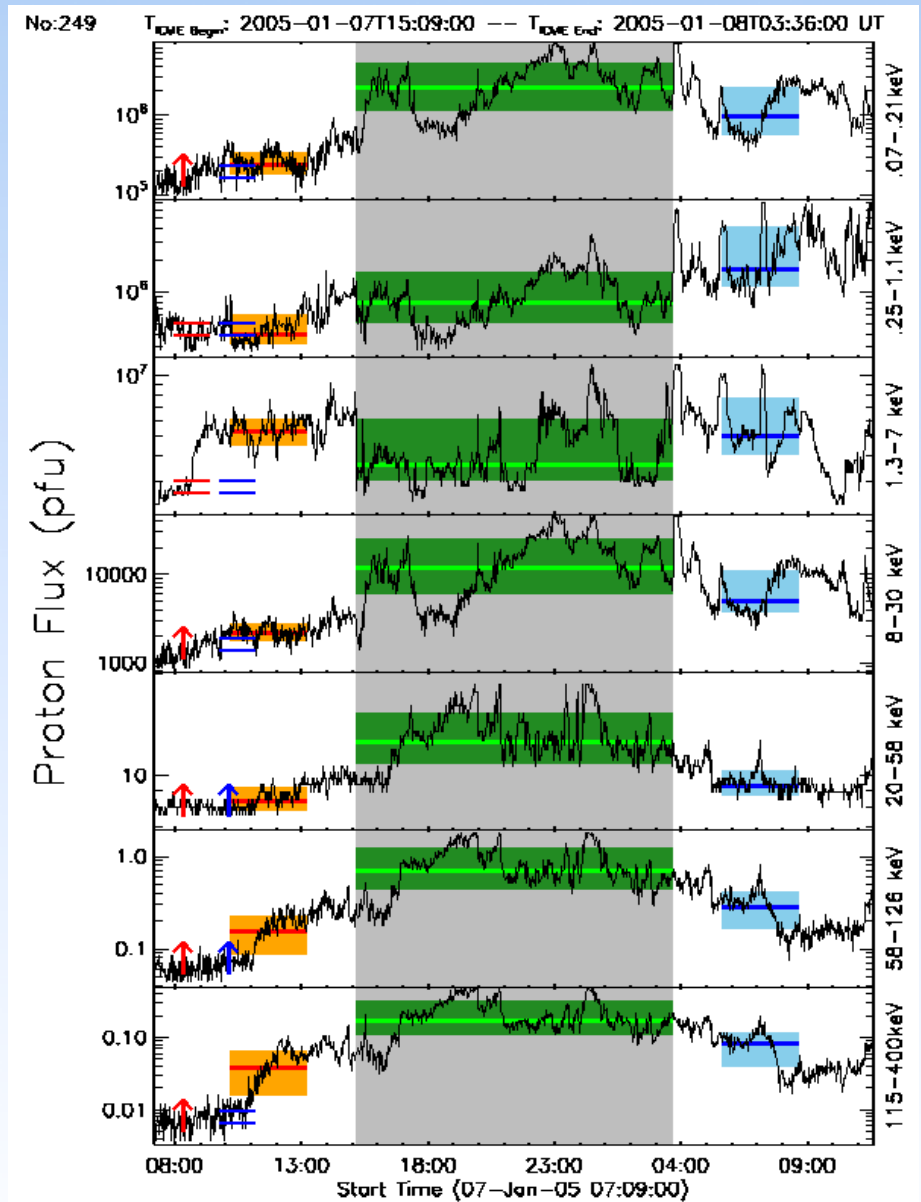
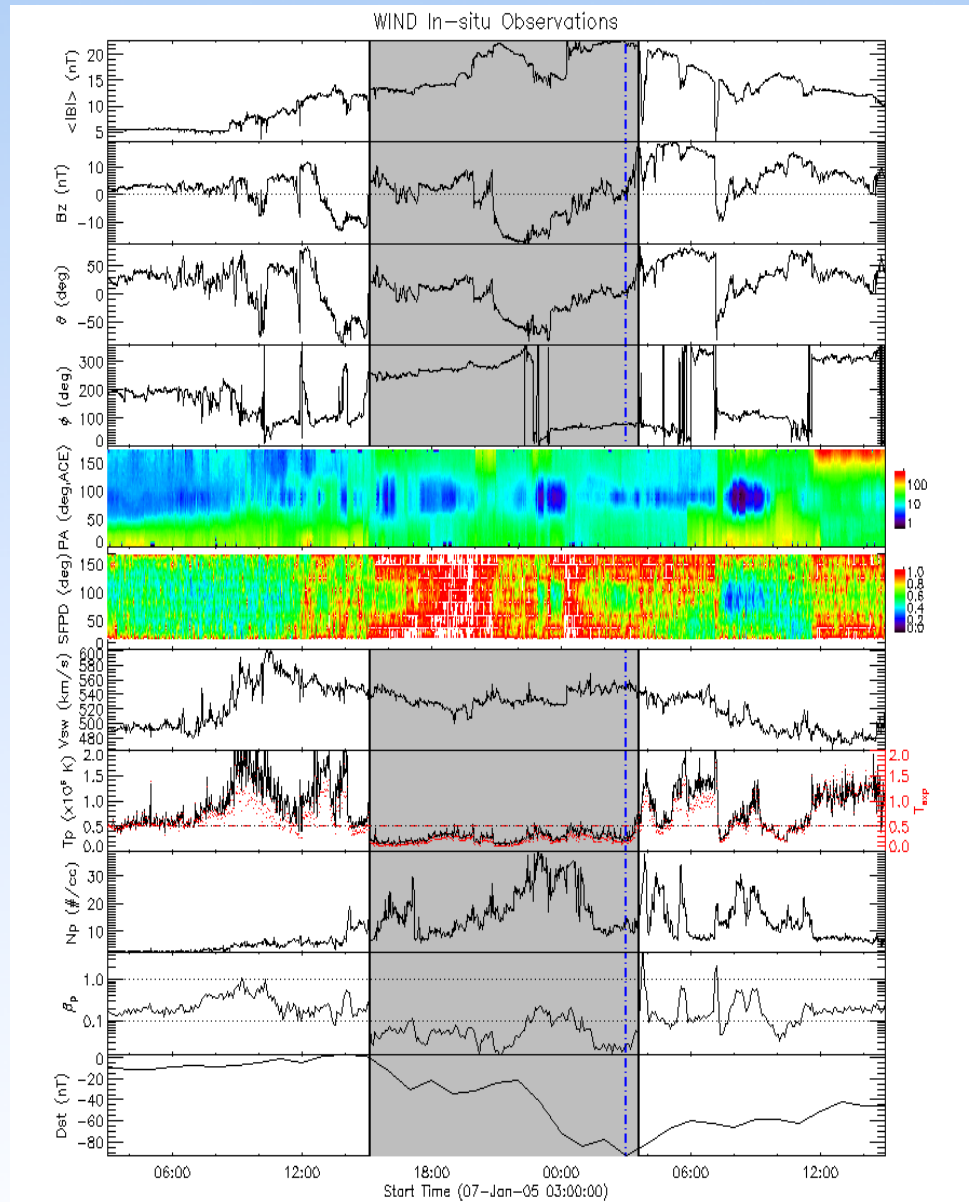
Increase in an ICMEs with behind Shock event



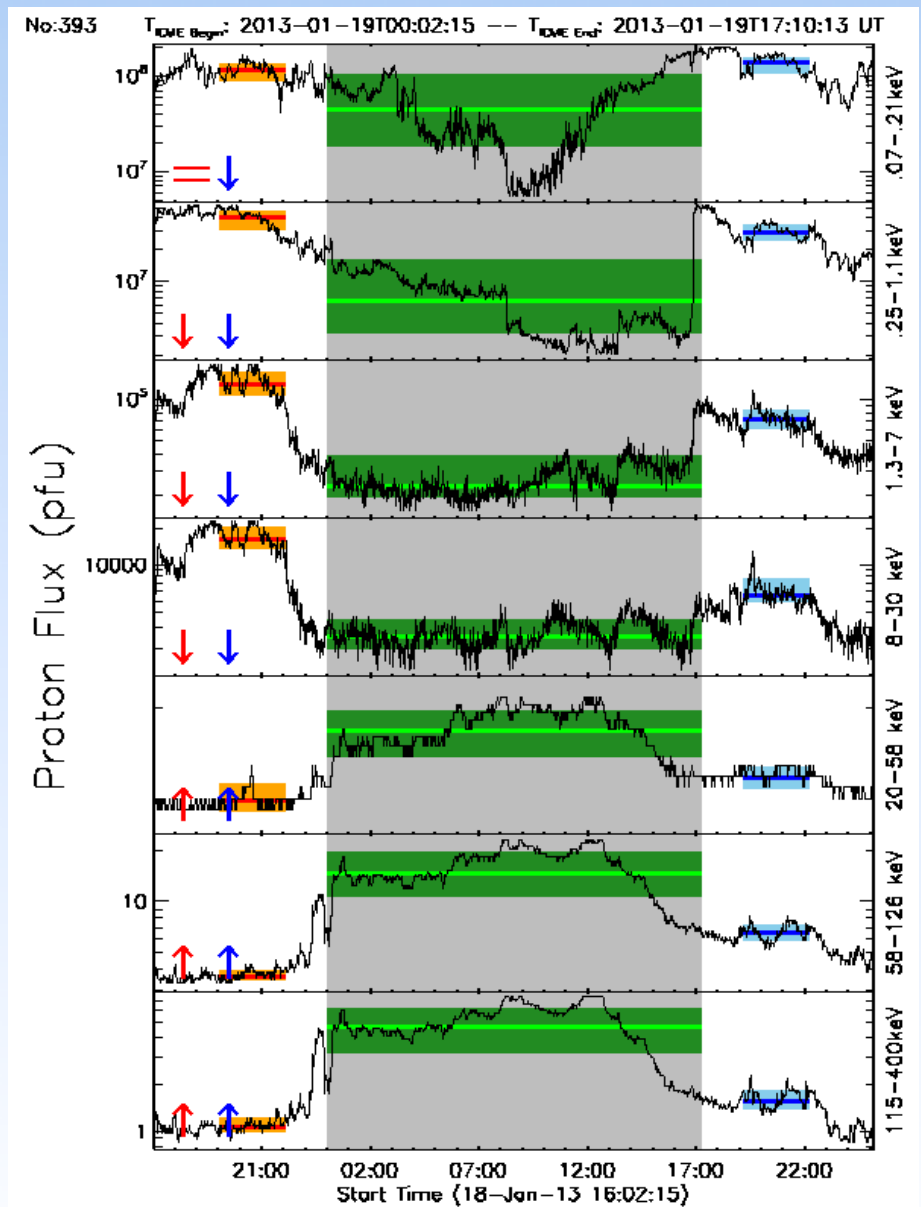
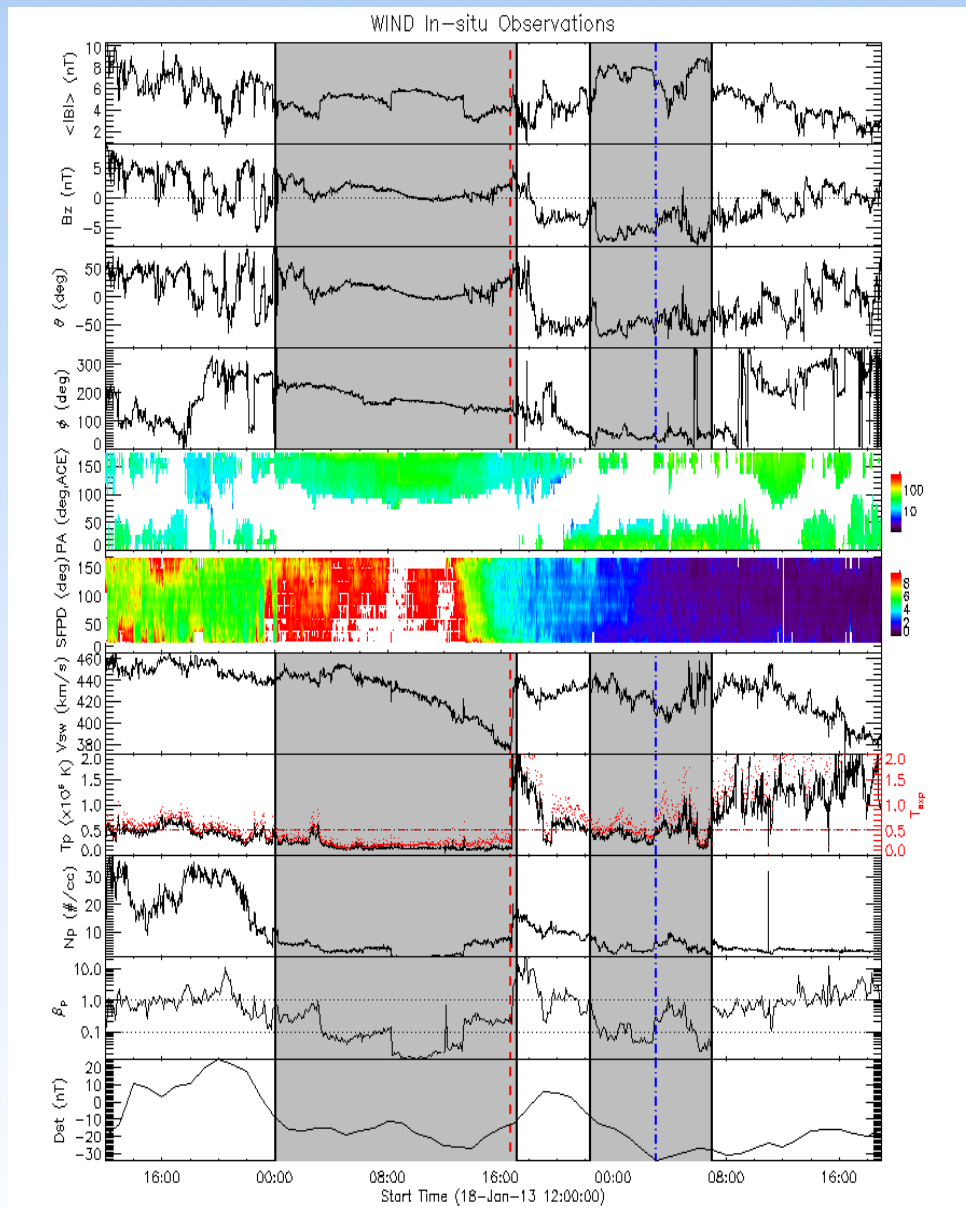
Increase in a Multiple-ICMEs (M-ICMEs) event



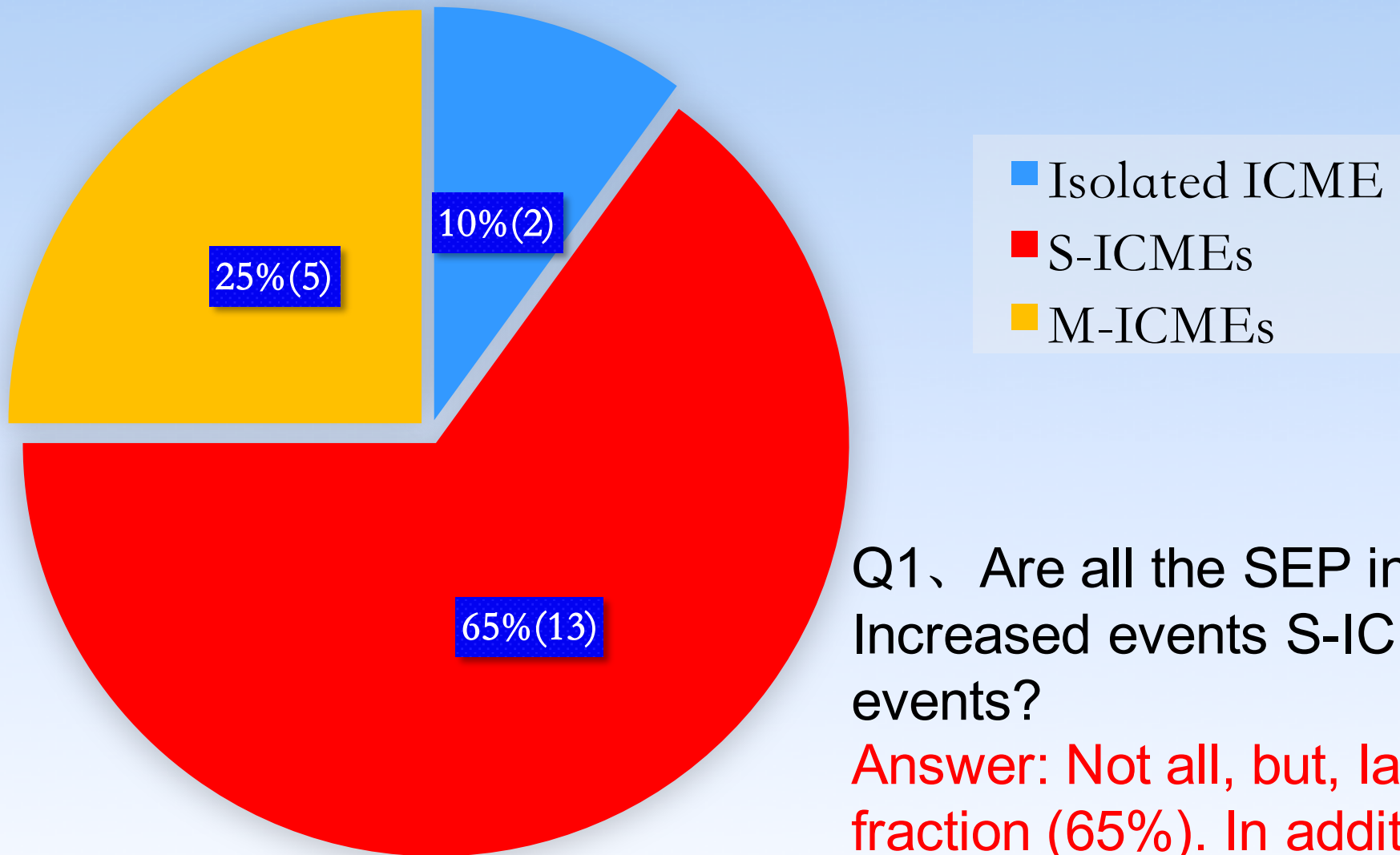
Increase in an Isolated-ICME event



Decrease or Increase?



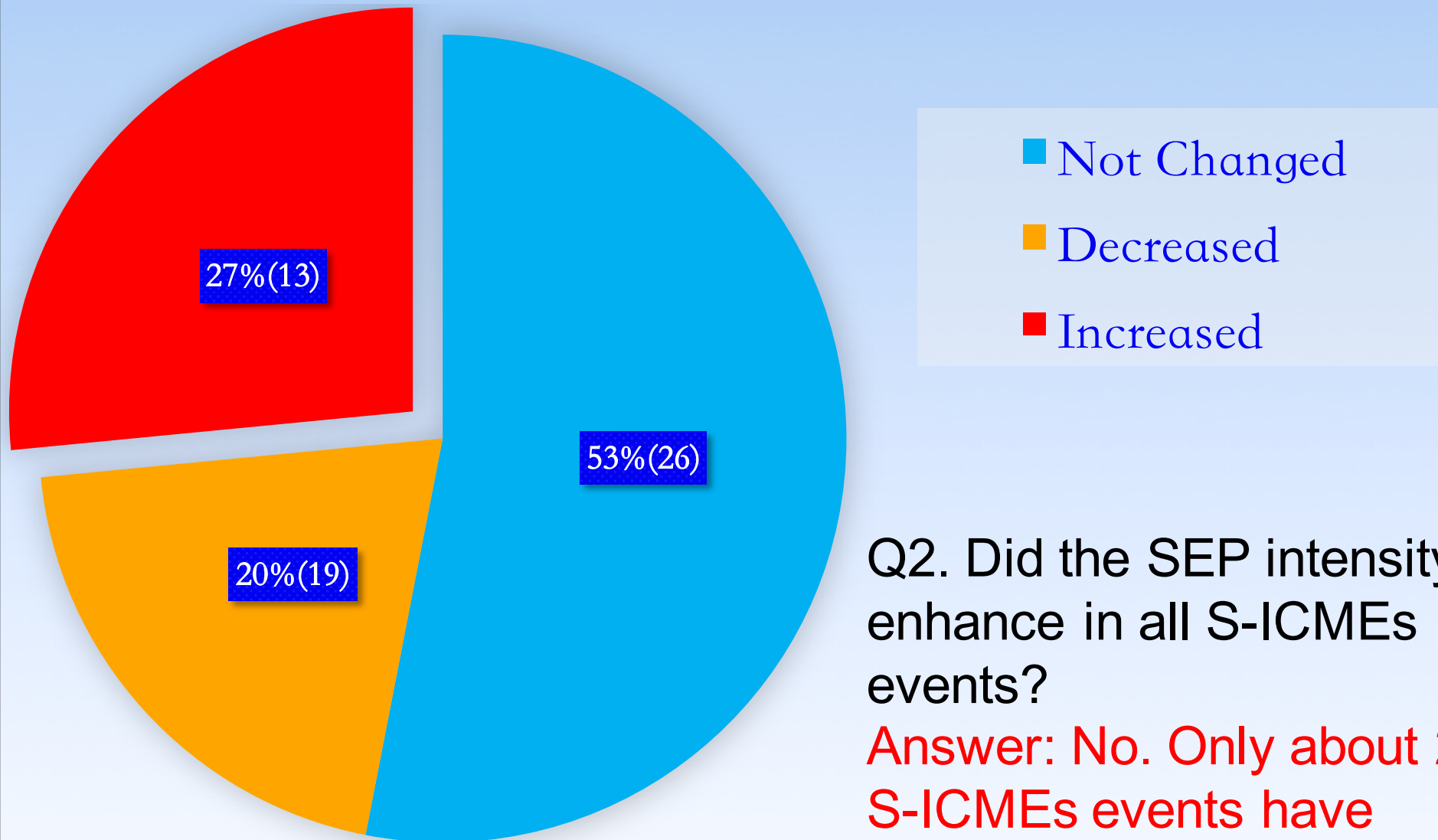
Type of Enhanced events



Q1、 Are all the SEP intensity Increased events S-ICMEs events?

Answer: Not all, but, large fraction (65%). In addition, other 25% were caused by Multiple-ICMEs event.

S-ICMEs events



Q2. Did the SEP intensity enhance in all S-ICMEs events?

Answer: No. Only about 27% S-ICMEs events have enhanced SEP intensity signature.

Why?

Possible influence parameters:

- Magnetic topology?
Structure of ICME?...
- Shock parameters?
Speed, Mach Number, Compression ratio...
- Background parameters?
Seed particle? Turbulence?...
- Any Others?

Detailed study of this issue may help understand the physics of the shock acceleration!

5. Conclusions

- ✓ S-ICMEs are the main causes of the enhancement of energetic particle intensity in ICMEs.
- 65% particle intensity increased ICMEs are S-ICMEs
- Shock inside the ICME is an important factor!
- ✓ Only about 27% S-ICMEs caused enhanced SEP intensity.
- **Why?** More works including the data analysis and theoretical analysis are needed!

Thanks!