STEREO observations of CIRs associated energetic heavy ions during the SEP events

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Low-energy SEPs – seed population for CIR acceleration

- Observations, which led to such suggestion: SEP-like corotating ion abundances at solar maximum (Richardson et al. 1993); CIR proton intensity increases after the SEP events (Sanderson et al. 1995, Torsti et al. 1999); the lack of correlation between CIR proton intensity and shock strength during periods of high solar activity (Desai et al. 1998, Kobayashi et al. 2000); overabundance of 3He in CIR events compared to the solar wind abundance (Mason et al. 2008).

- Limited theoretical studies: Kocharov et al. 2003 employed model of Giacalone et al. 2002 and show the SEPs can be reaccelerated in CIR without being shocks formed.

Why do we need more observations ?

• The idea - not yet investigated in detail: such mixed events are excluded from the analysis; no often that observations of CIR and SEP events coincide.

• Observations at solar minimum are especially important: CIR composition - unperturbed by SEPs very often; 'steady' CIR composition - attained, which is in turn ideally for study of the distortions by transients.

• The study of such cases may have an implication on the problem of acceleration mechanism in CIR events: this alternative source is attractive due to energies above CIR shock threshold.

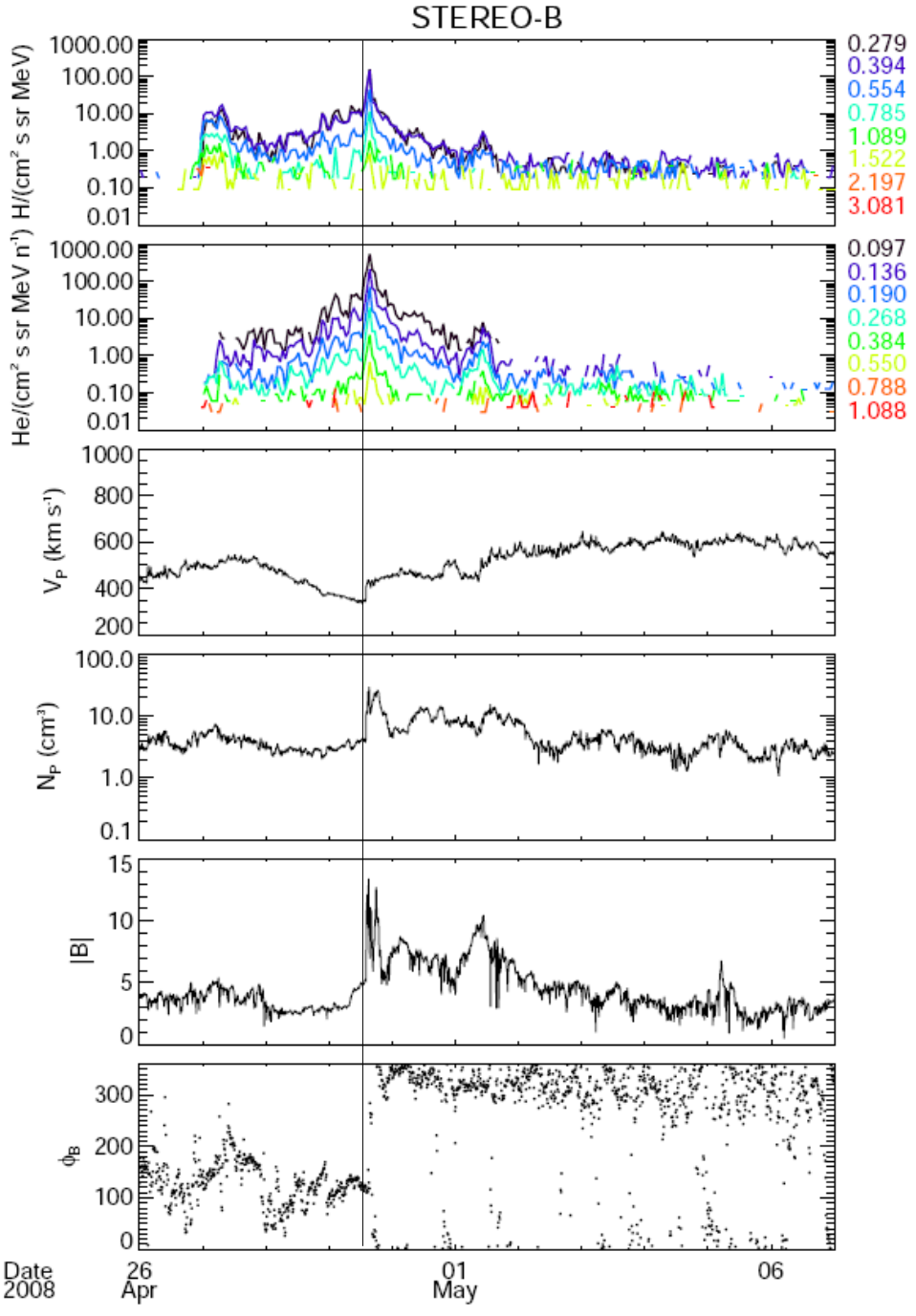
Scheme of the talk

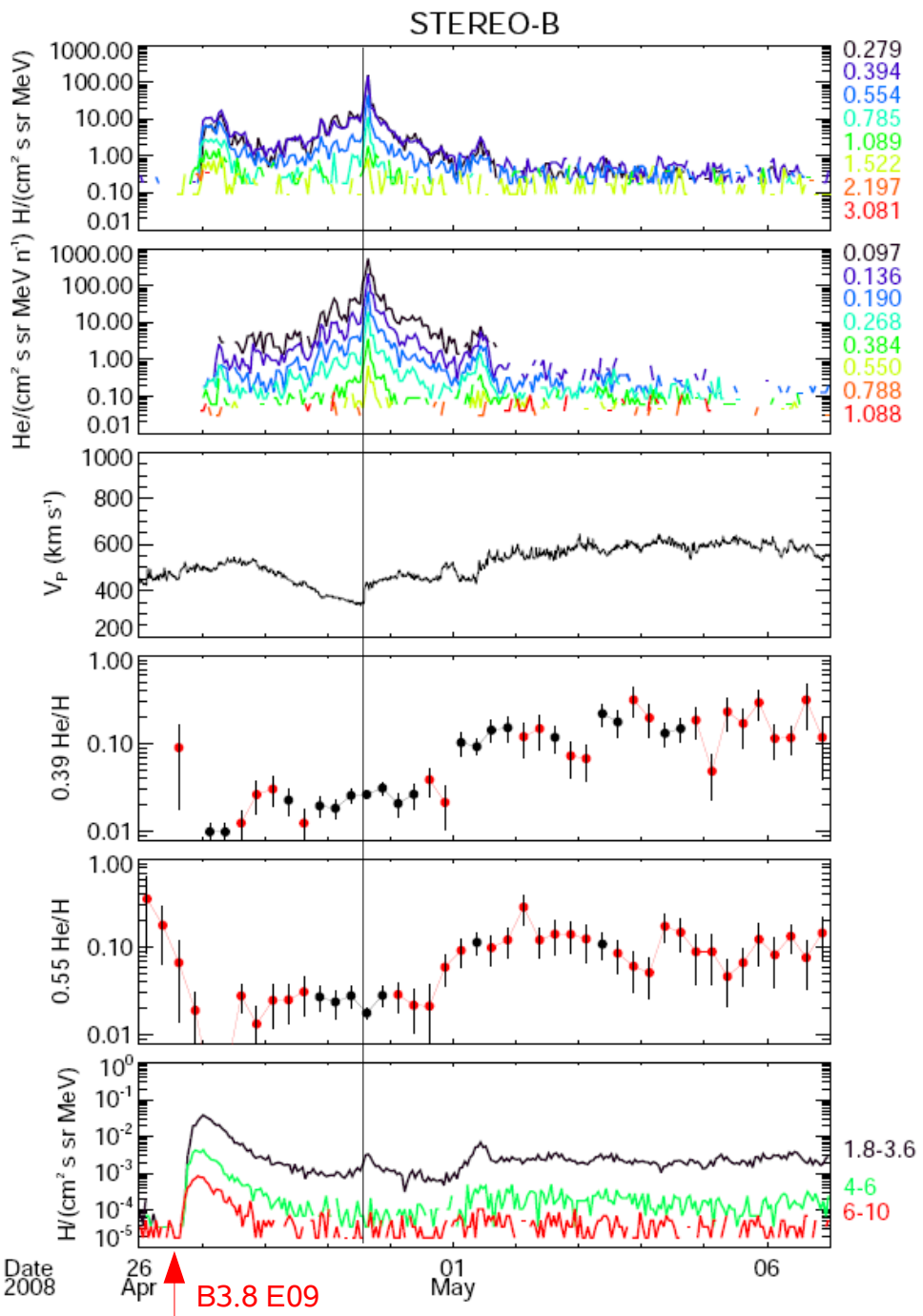
- May 18 and 24, 2007 CIR events – May 19 (SEP1) and 23 (SEP2), 2007 SEP events (Mewaldt et al. 2008)

- Examined: temporal variation of particle fluxes, elemental abundances and energy spectra

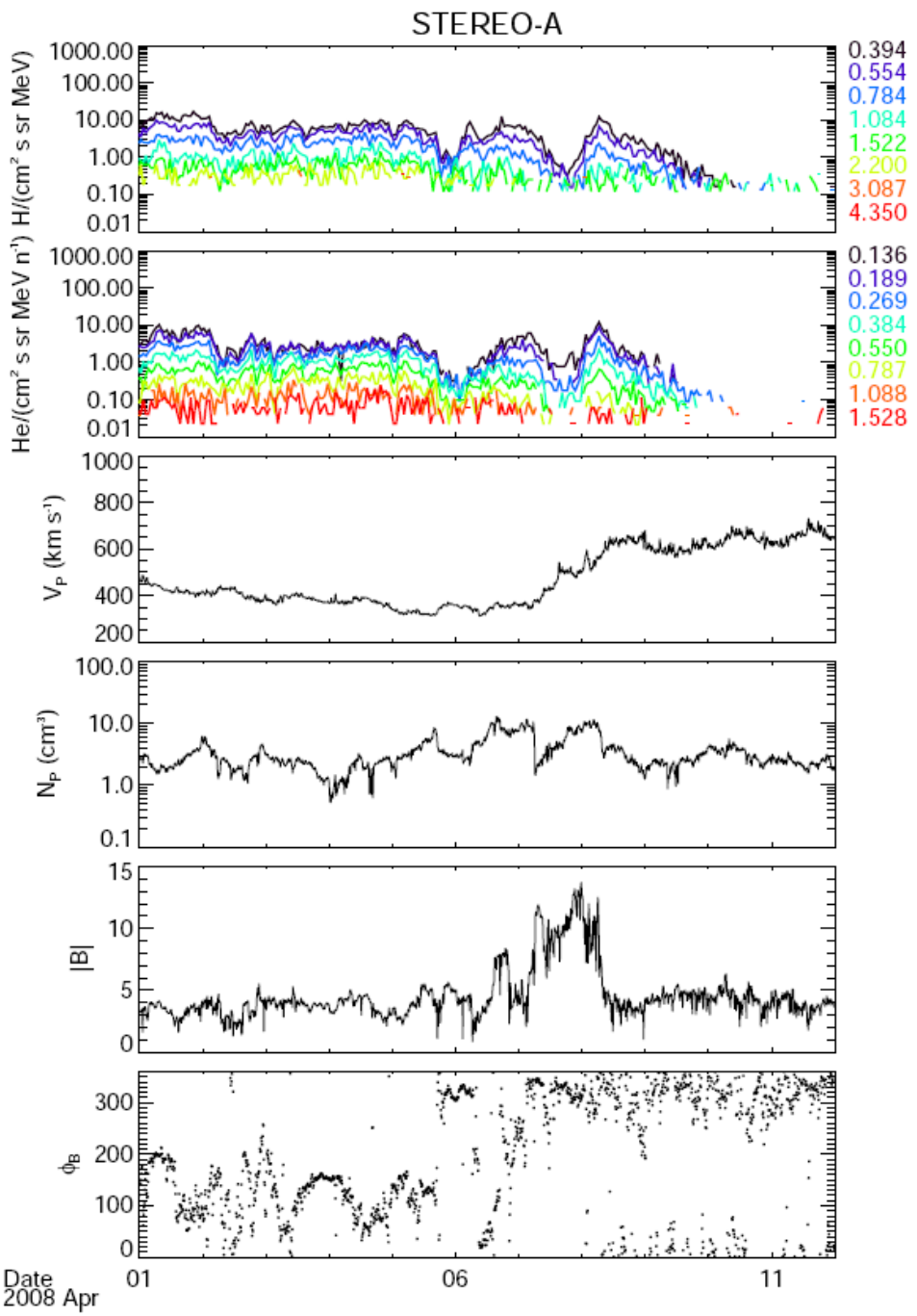
- STEREO-B April 26, 2008 SEP & STEREO-A April 05, 2008 SEP events

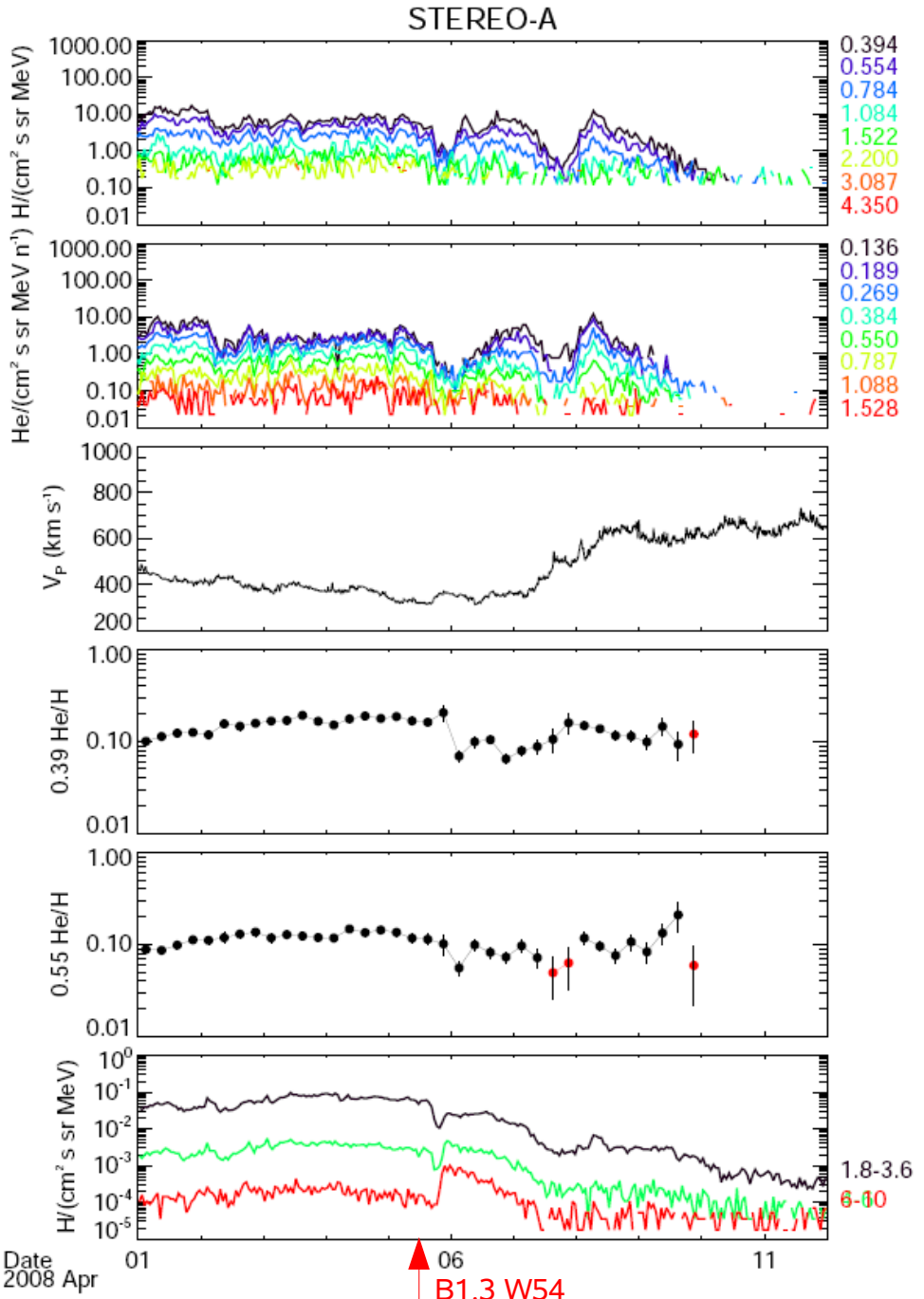
STEREO-B April 26, 2008 SEP event



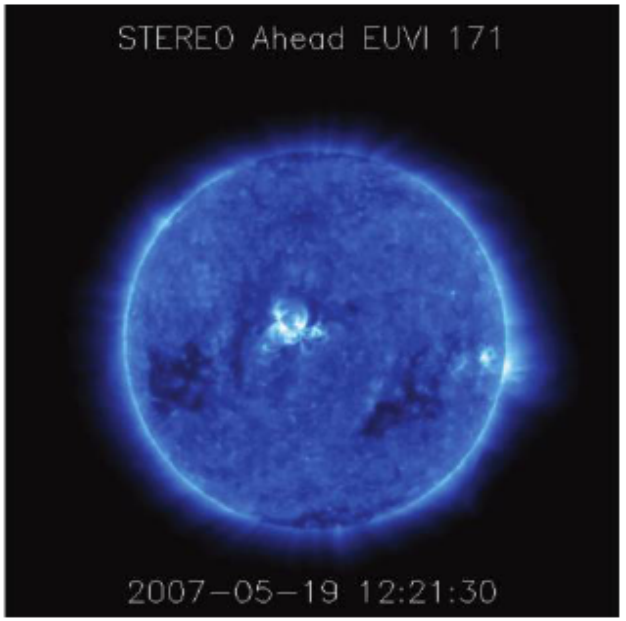


STEREO-A April 5, 2008 SEP event

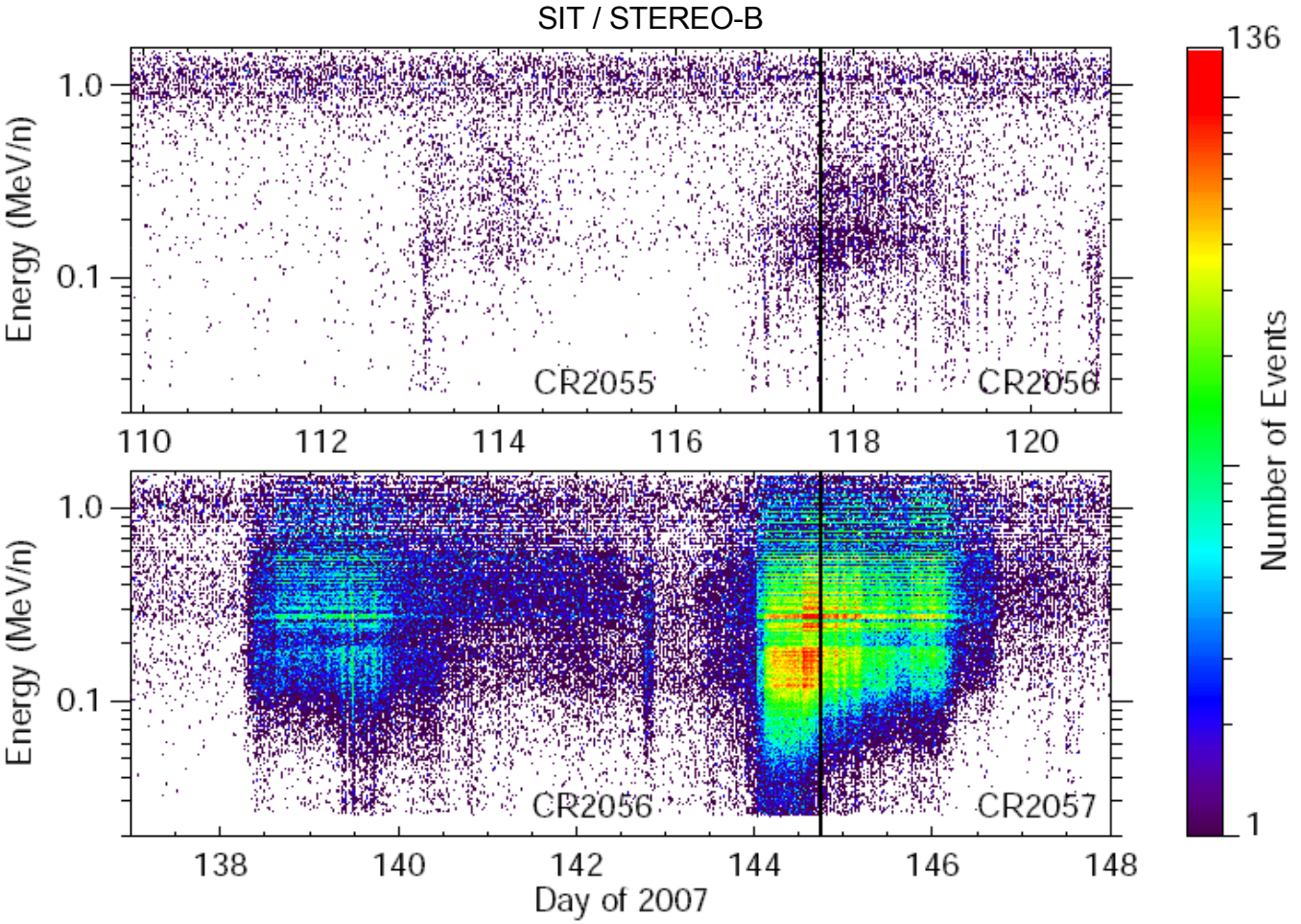




May 18 and 24, 2007 CIR events

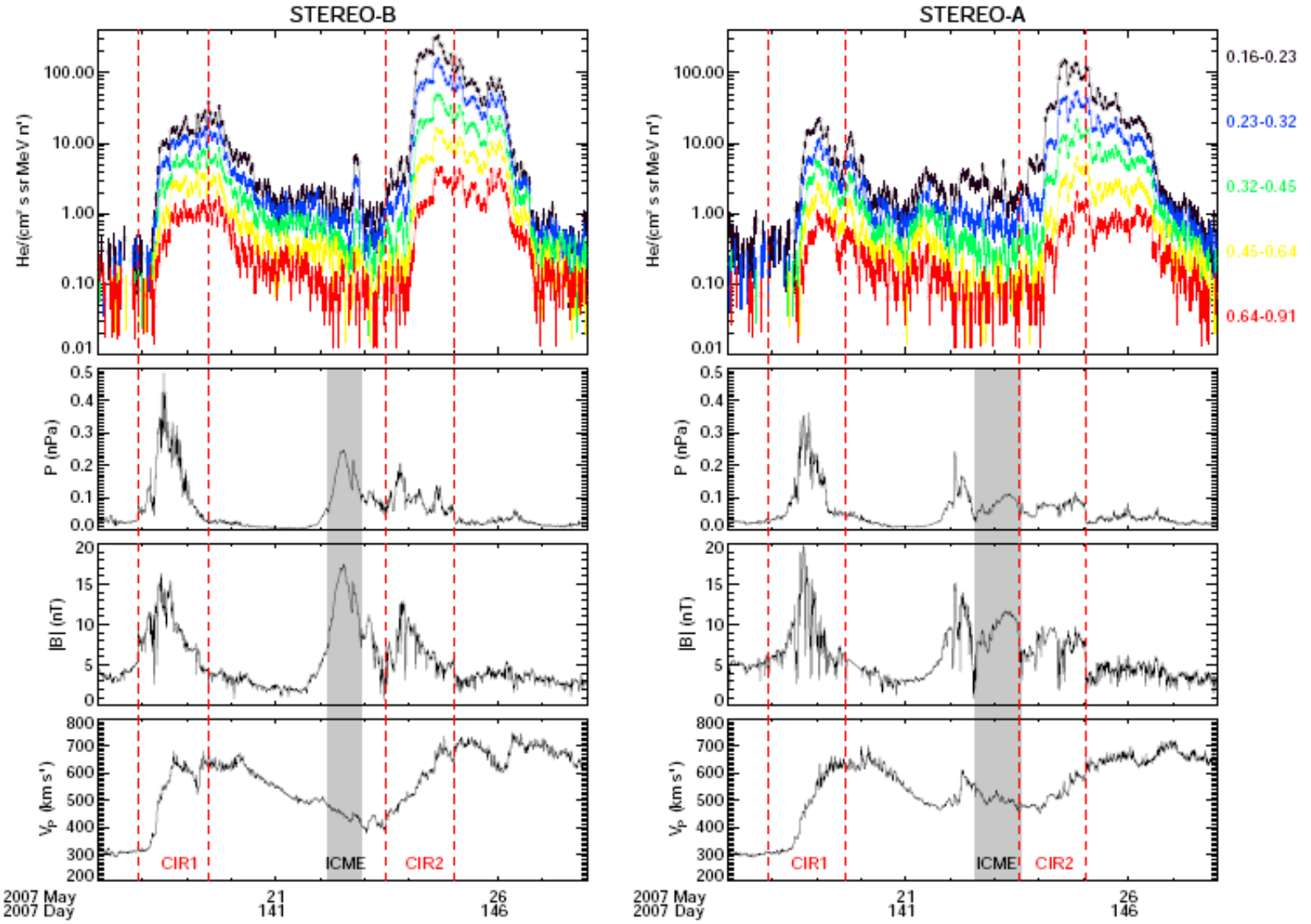


STEREO-A image of pre-eruption Sun on May 19 (day 139) (Li et al. 2008).



The enhancements with onsets on May 18 (day 138) and May 24 (day 144) do not have strong predecessors in previous three CRs.

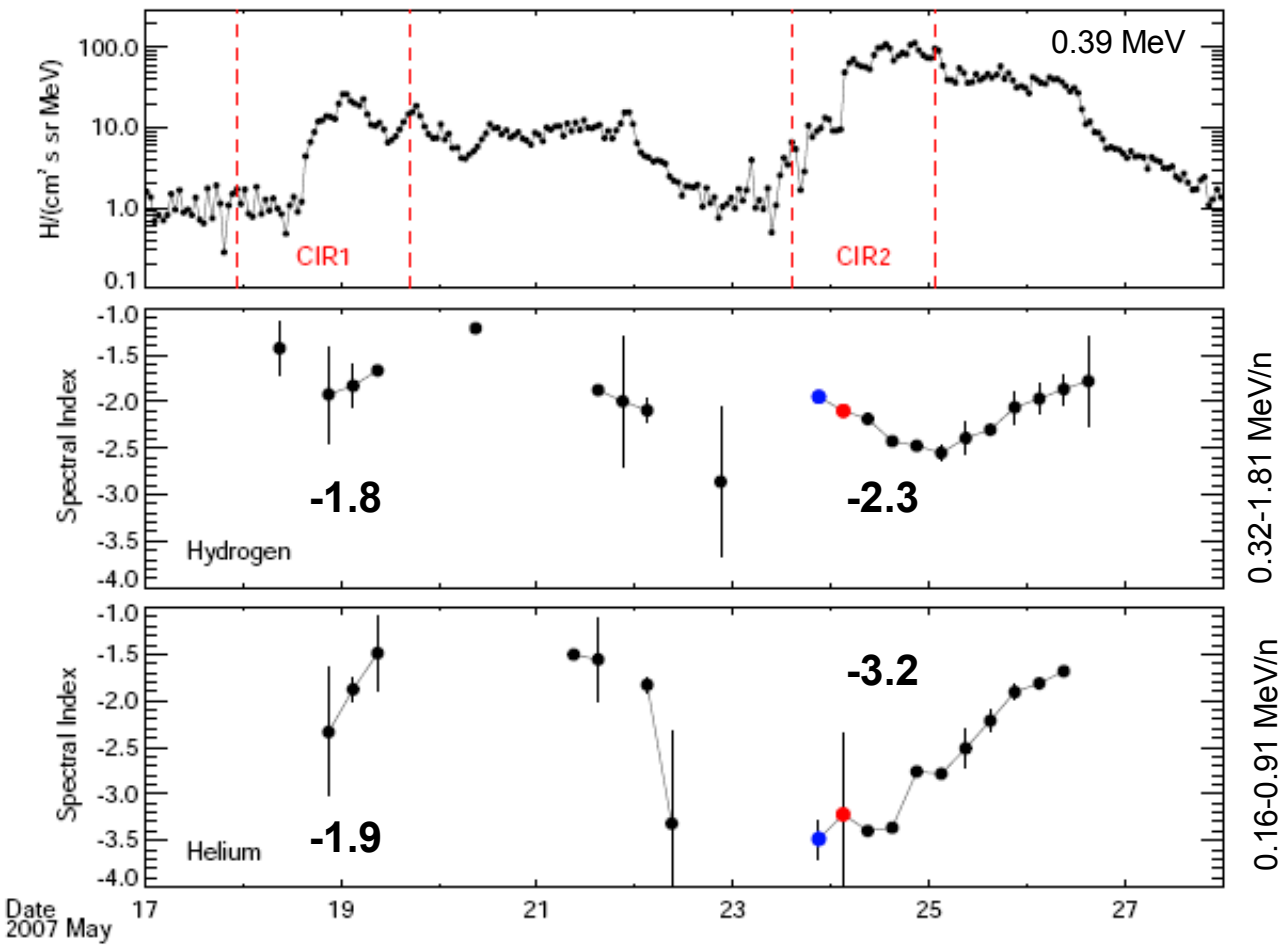
May 18 and 24, 2007 CIR events



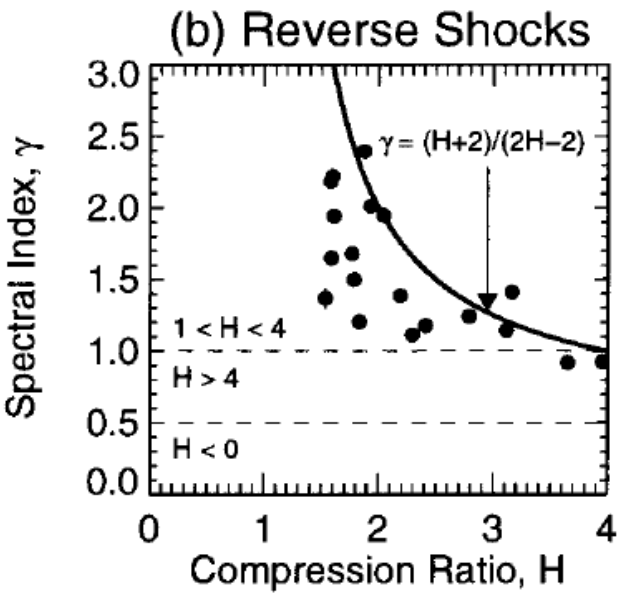
- (Δv, |B|, P) in CIR1 enhanced compared to values in CIR2
- Δv - related to shock strength (e.g. Kobayashi et al. 2000)

→ Acceleration strength of the CIR2 may not be > than that of the CIR1

May 18 and 24, 2007 CIR events



Protons out of ecliptic

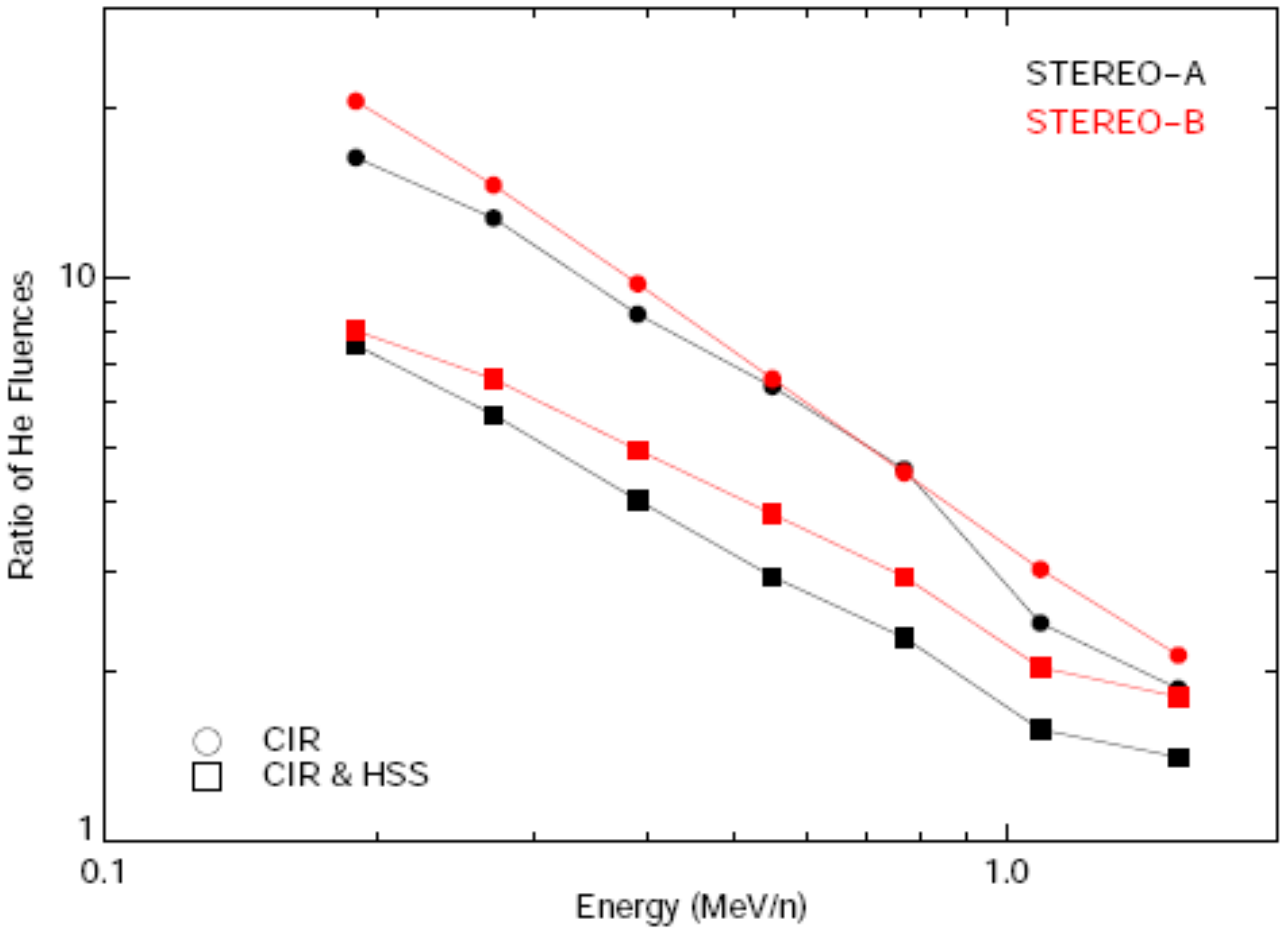


(Desai et al. 1999)

- The funct. relationship (a harder spectrum corresponding to stronger shock) is not clearly recognizable.

- H and He energy spectra inside CIR1 are much harder than inside CIR2 - In favour of previous assumption

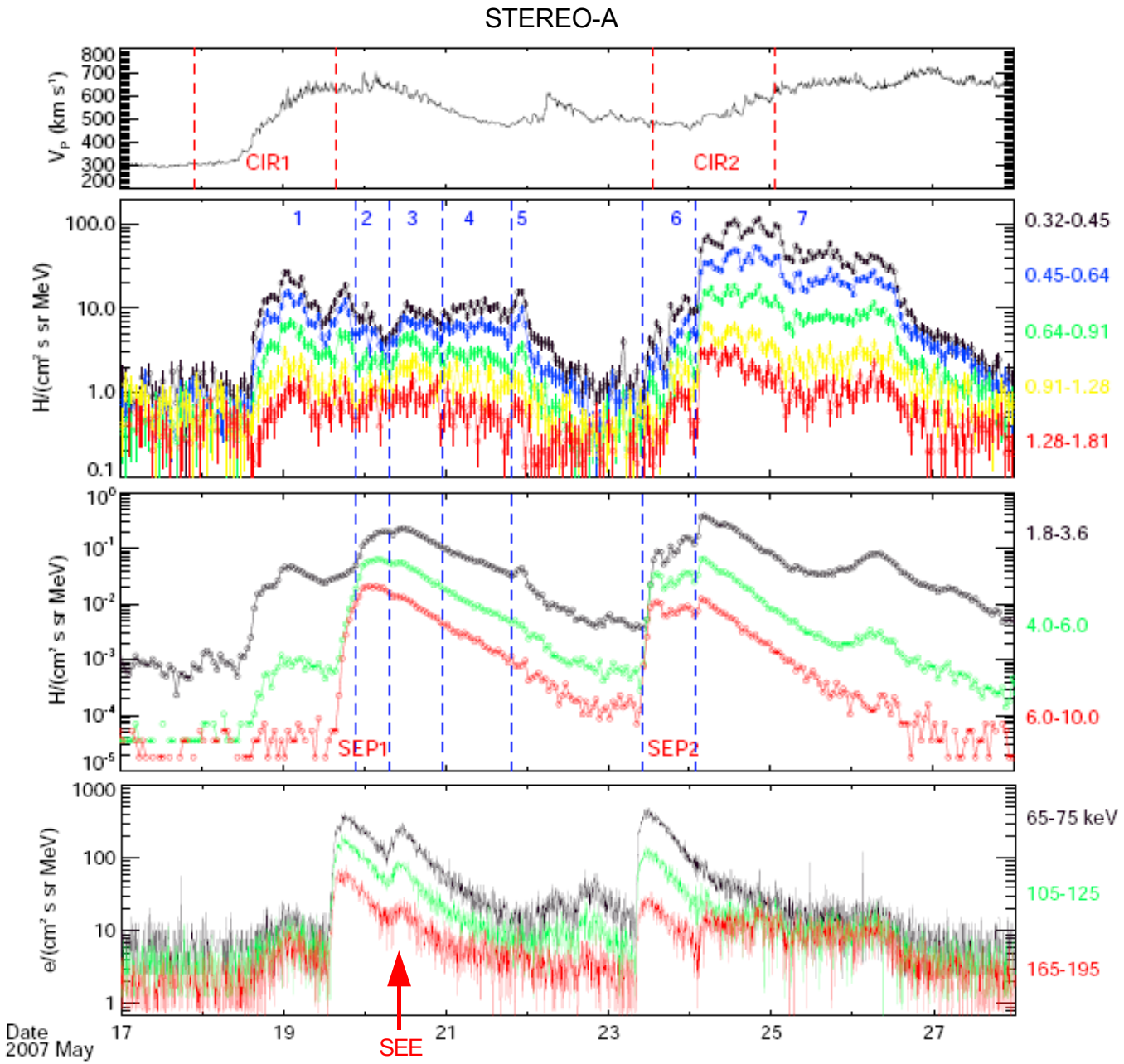
CIR2 : CIR1 Fluence



- He intensity in CIR2 exceeded that in CIR1: at lower energies the intensity difference is an order of magnitude
- < 1 MeV/n the relative intensity of He ions decreases with energy linearly in log-log scale

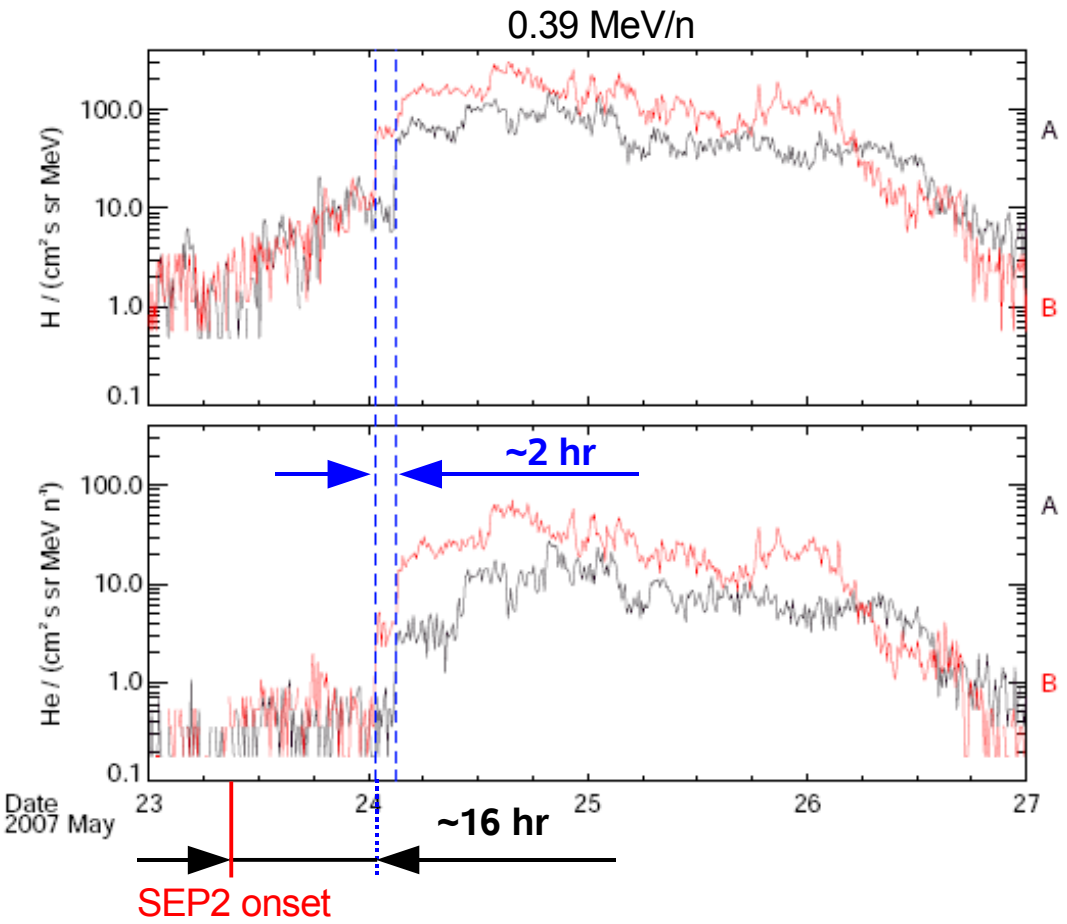
The intensity of particles accelerated at the CIR shocks is determined by the intensity of the seed particles and the shock strength (e.g. Scholer et al. 1980) → CIR2 accelerates particles out of seed population with higher intensities

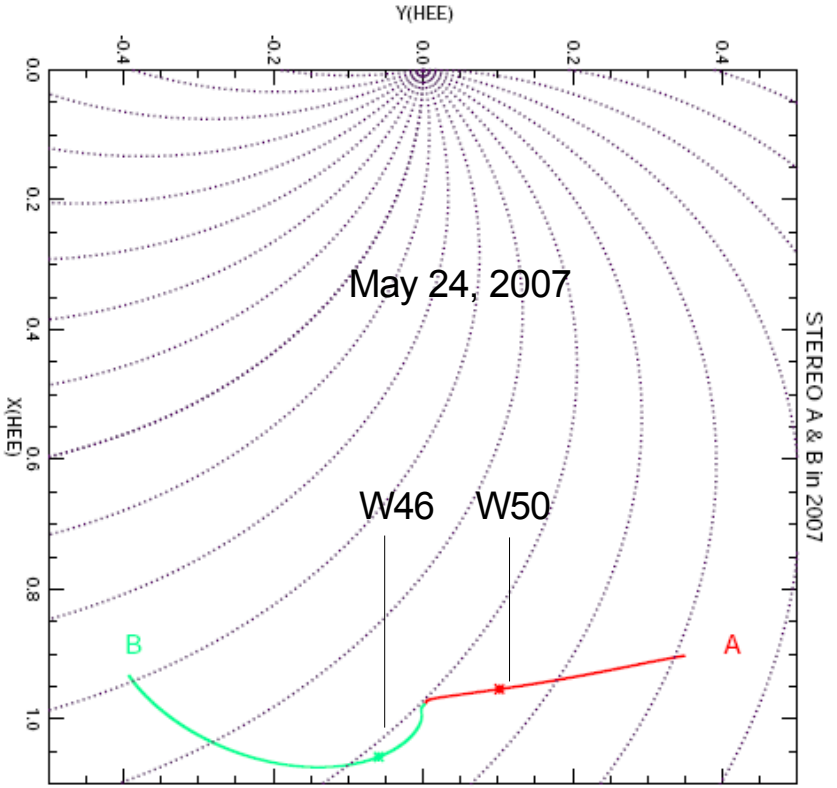
May 19 and 23, 2007 SEP events



- CIR1 event protons observed < 6 MeV in interval (1)
- low energy (SIT) protons show no clear response to the SEP1 event – period (2)
- additional rise of ion fluxes in interval (3) may be related to May 20 SEE event (Dröge et al. 2008)
- ion flux increases in the SIT energy channels within interval (6) were related to the SEP2 event; enhancement occurred inside the CIR2
- the SEP2 event decay (interval 7) is accompanied by low energy increase

May 24 event: SEP vs CIR enhancements



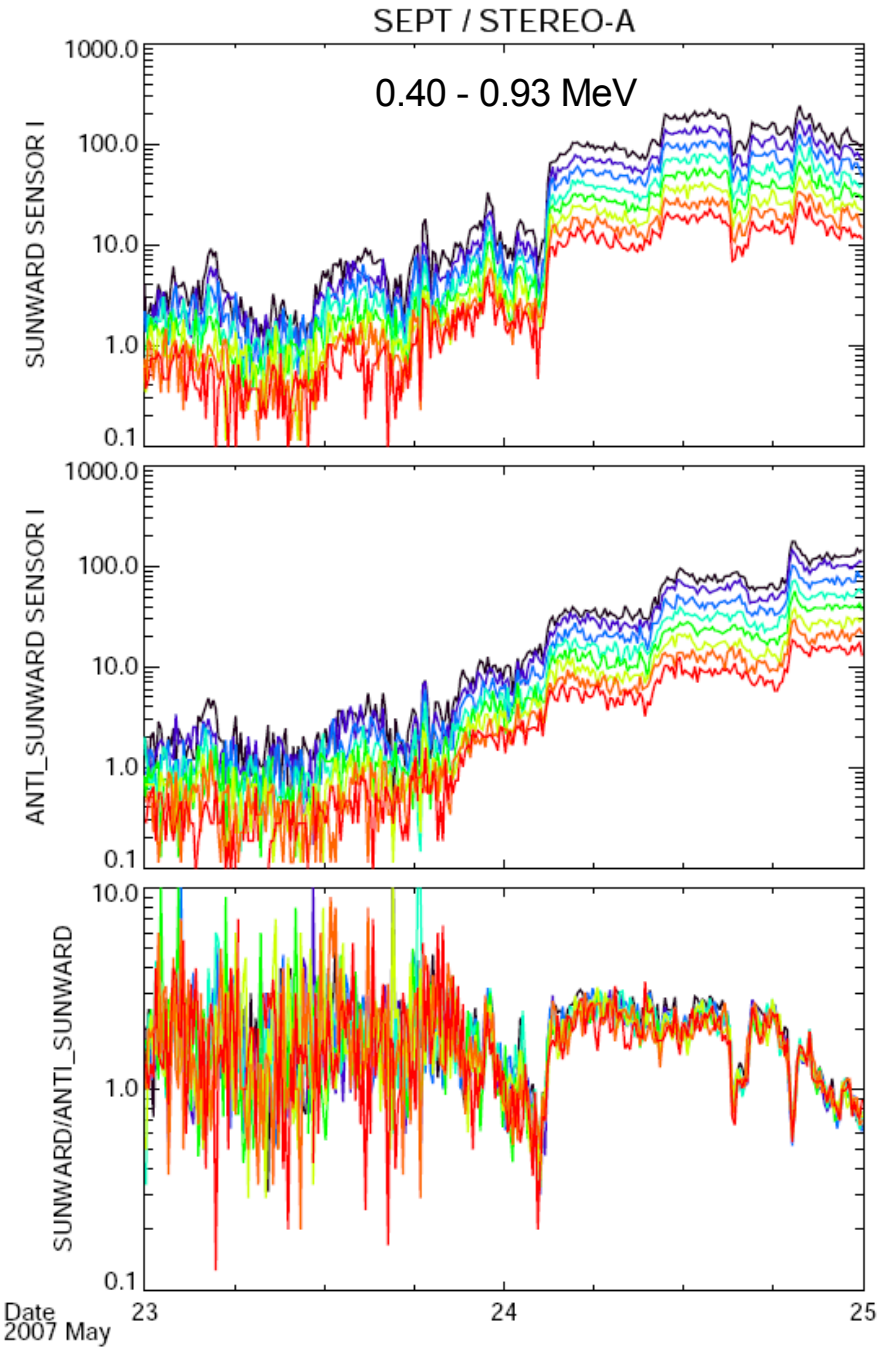


• CIR2 event onset appeared 16 hr after onset of the SEP2 event; the questions remains whether this enhancement may have not been related to the SEP2 event

• the increase on May 24 was observed first by STEREO-B and later by STEREO-A
• on May 24-25 ion fluxes observed by STEREO-B, located on 0.1 AU onward from A, are higher than the fluxes on STEREO-A

The enhancement with onset on May 24 below 1 MeV/n is a CIR event.

SEP vs CIR enhancements: Anisotropy

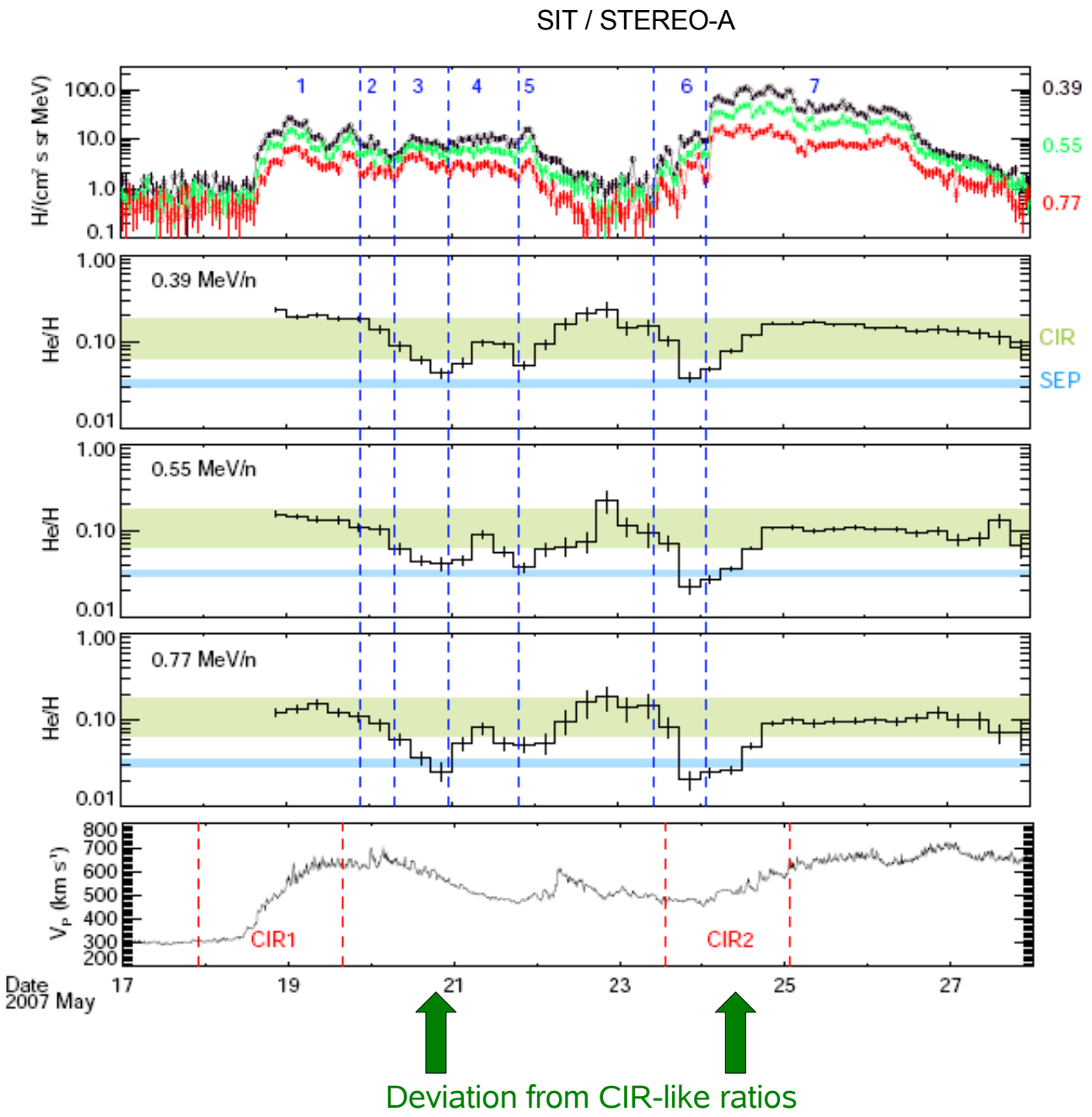


- the sign of the anisotropy changes at the onset of the May 24 enhancement

- the ratio changes in broad range during the SEP2 event onset but remains constant after the onset on May 24

- the sign of the anisotropy varies during the SEP2 event onset but after the onset on May 24 does not

Relative Ion Abundances - He/H



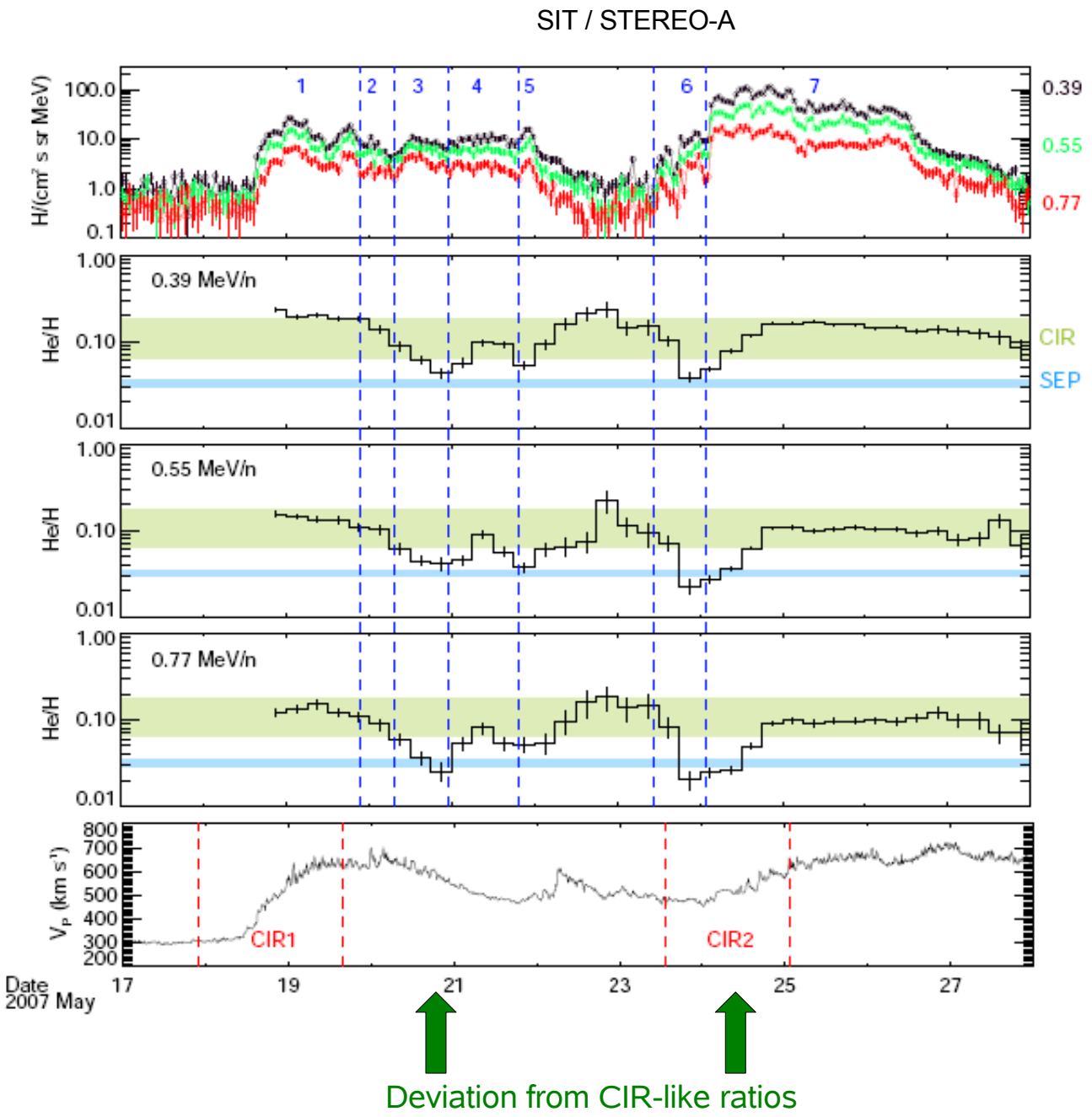
- CIR-like values inside the CIR1 and near the CIR2 trailing edge and in the fast solar wind - outside of the CIR2

- during the CIR1 and CIR2 events the ratio also deviated from CIR-like values an approaches to the SEP event ratio

- the first deviation occurs at the end of the interval (3) during the decay phase of the SEP1 and not around the SEP1 event intensity peak, the time period (2)

- the second deviation happens at the beginning of region (7) around the onset of CIR2 event

Relative Ion Abundances - He/H (2nd dev.)

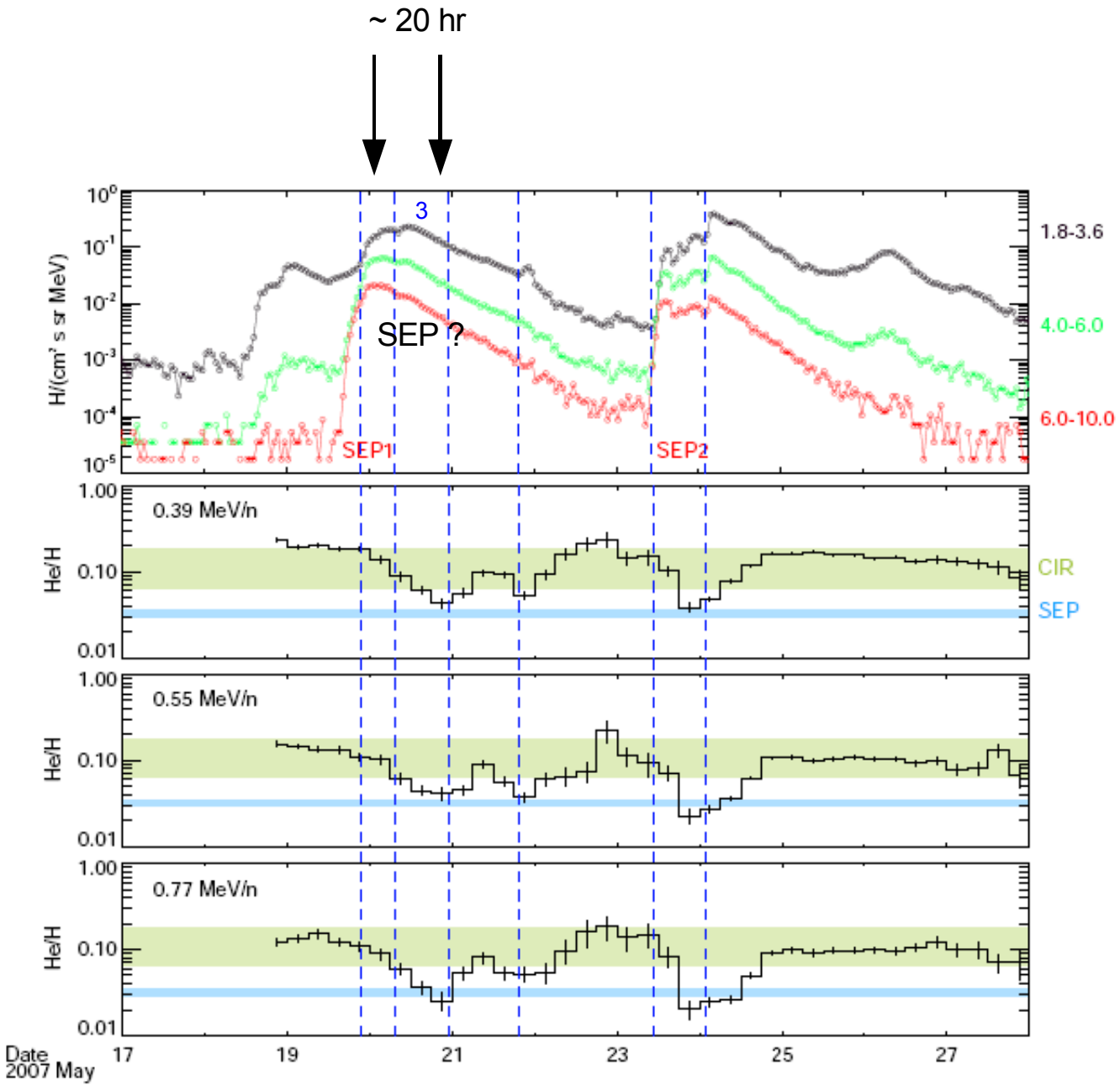


- < 1MeV/n the onset CIR2 ion intensities are about one order of magnitude higher than SEP2 event intensities

- by subtracting the preceding SEP intensities the SEP-like ratio will remain preserved

- an elemental abundance during the CIR2 event onset result from acceleration of the seed population with SEP-like composition. Such population could be provided by coincident SEP event.

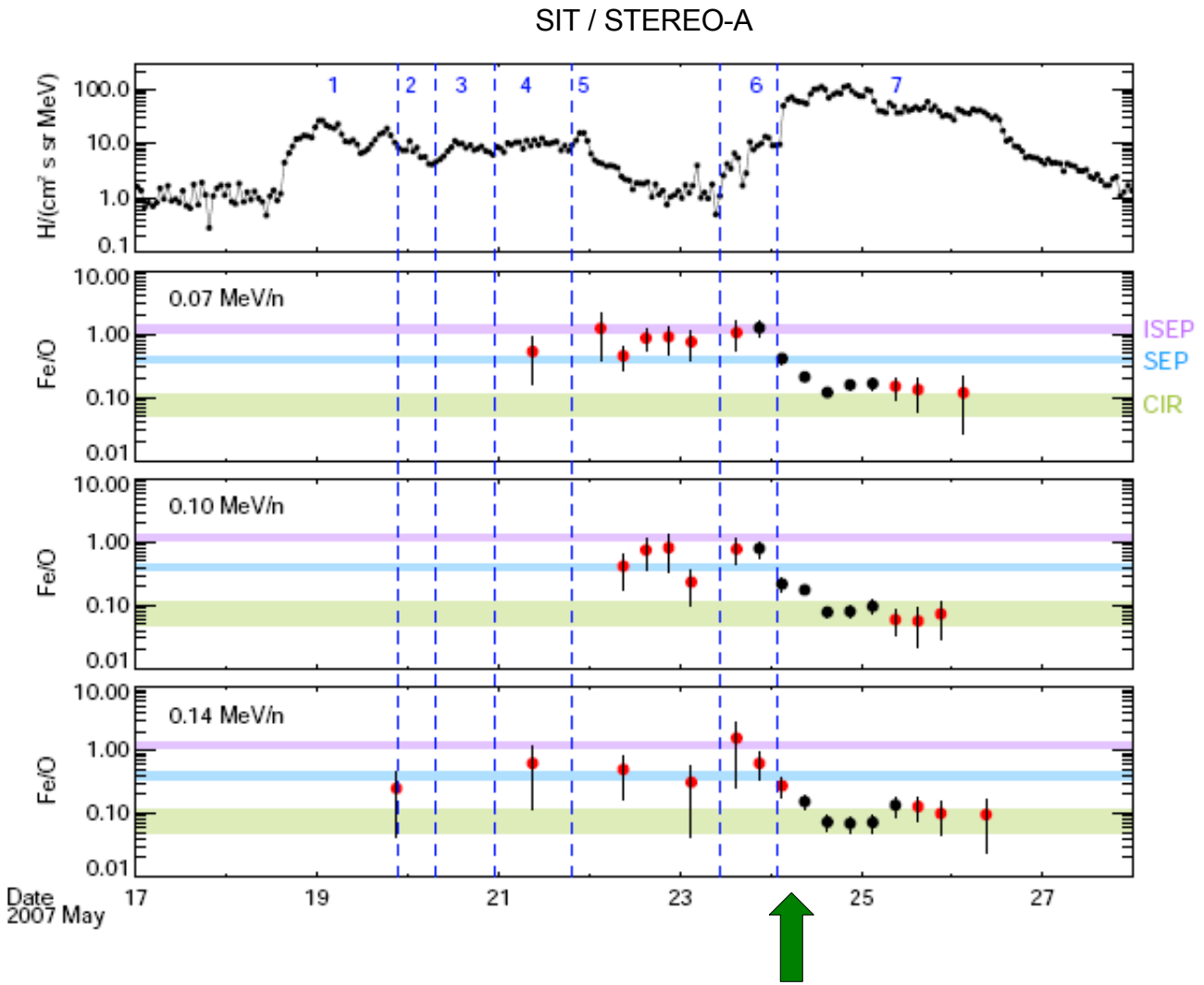
Relative Ion Abundances – He/H (1st dev.)



- observed delay could be a result of enhanced scattering in SEP1 event, reported by Dröge et al. 2008, or due to contribution from adjacent SEP event

- SEP-like He/H ratio at interval (3) could be due to contamination by SEPs

Relative Ion Abundances - Fe/O

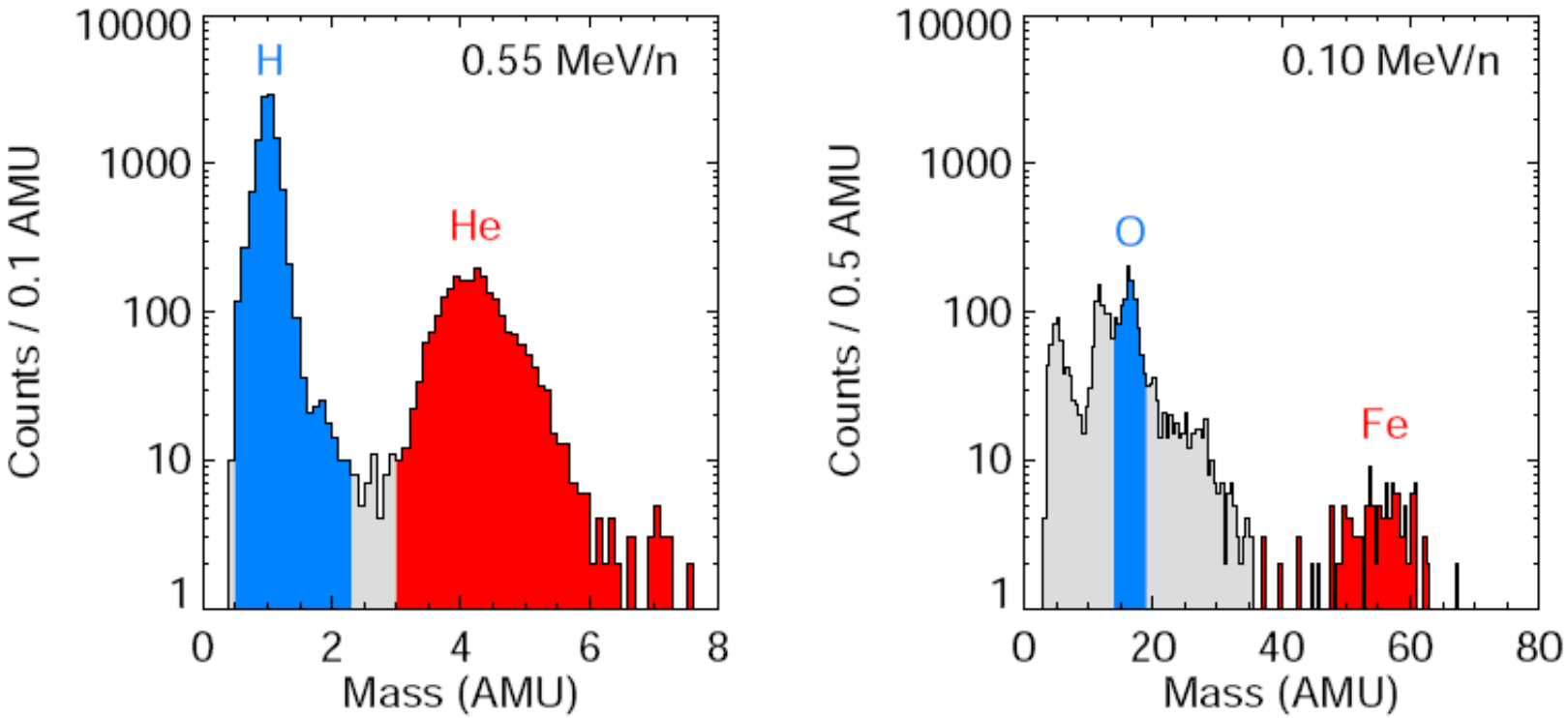


Deviation from CIR-like ratios

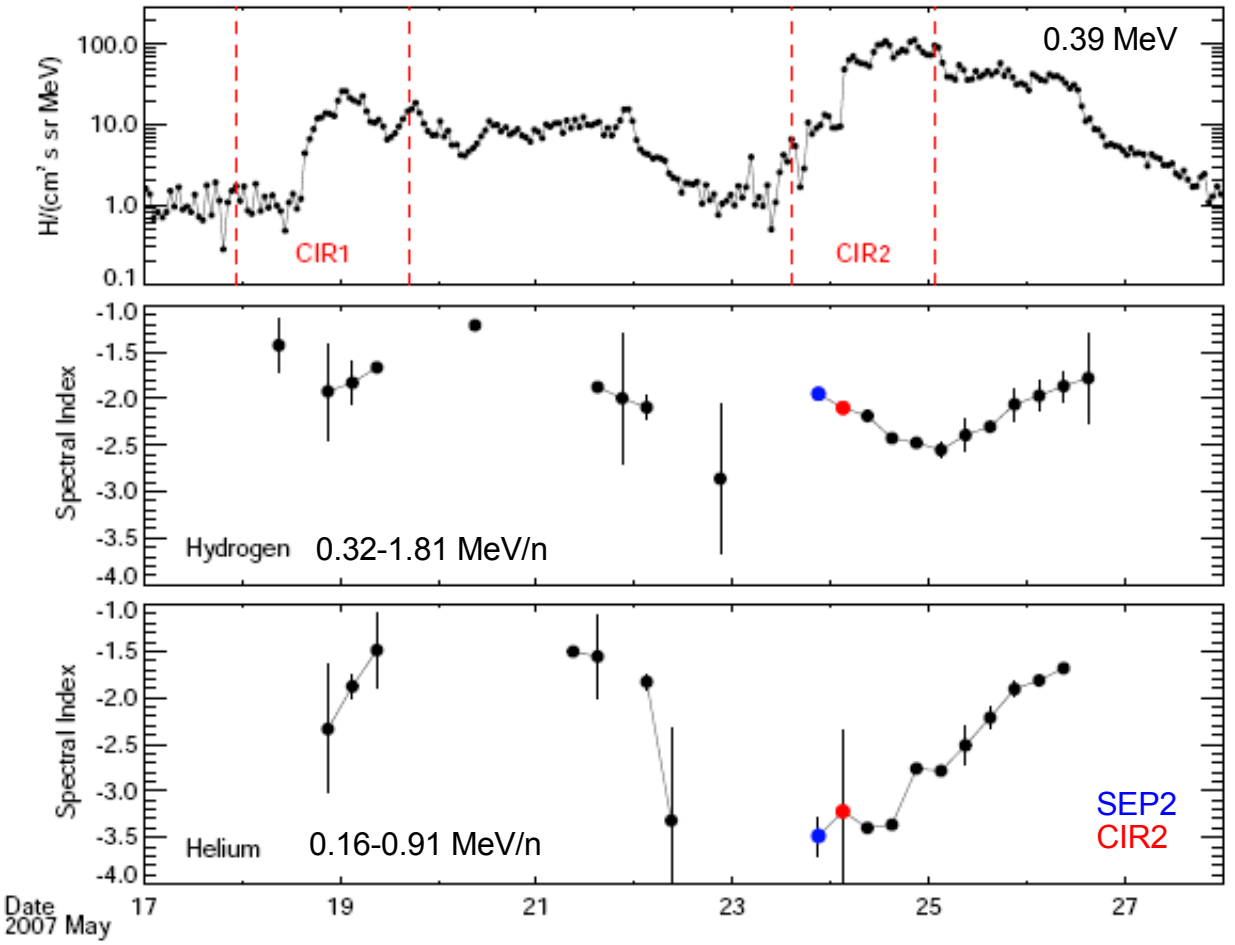
SEP-like ratios:

- on May 22-23 at times of the ICME transit – possibly due to presence of impulsive flare particles inside the ICME (enhanced He abundance also observed
- period (6) – during the SEP2 event
- around the onset of CIR2 event

SIT / STEREO-A mass histograms, May 24 2007

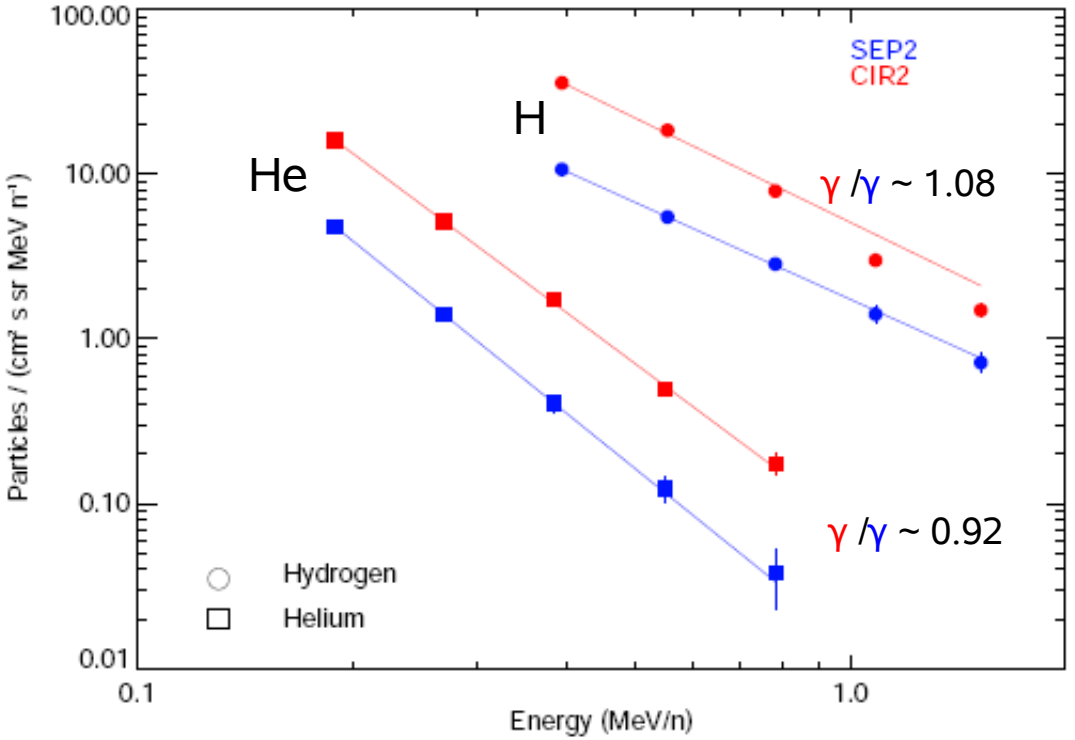


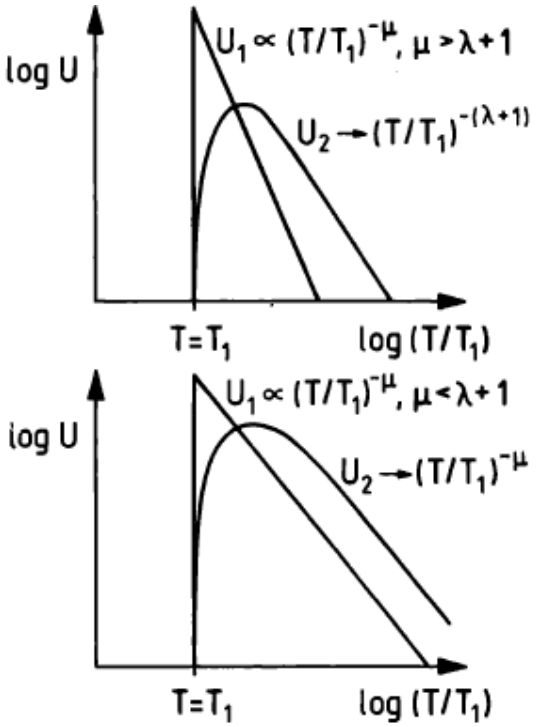
Energy Spectra



- SEP2 and onset CIR2 event spectral indices showed a little change, even though related fluxes change suddenly and in one order of magnitude

Energy Spectra





softer initial spectrum

shock/injected < 1

flatter initial spectrum

shock/injected = 1

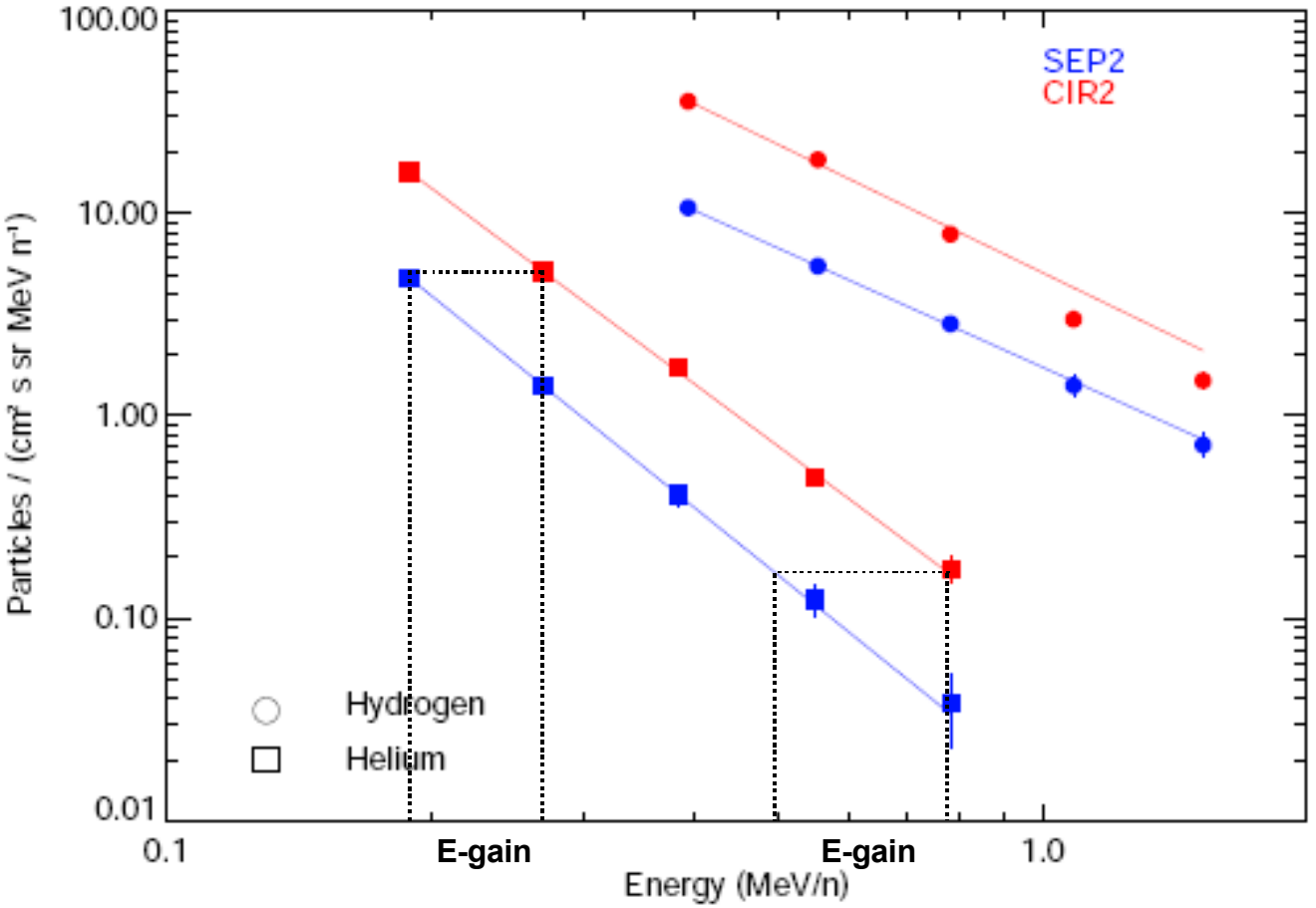
(Axford 1980)

- power law shapes < 1 MeV/n and change of the corotating spectrum around the 1 MeV/n-consistent with previous observations

- similarity between corotating and preceding SEP event spectra supports the conclusion - CIR2 re-accelerated ambient solar particles

If injected spectrum is flatter than the 'shock' spectrum, the spectra will be identical (Axford 1980).

Energy Spectra



• At 0.4-0.9 MeV/n H ions gain a factor of ~ 1.7 and at 0.2-0.5 MeV/n He ions gain a factor of ~ 1.5

• The values are somewhat lower than Tan et al. 1989 factor of 2 for IP shock accelerated SEPs

Summary

We investigated particle events at energies from 0.1 to 1 MeV/n, associated with 2 closely spaced compression regions, CIR1 and CIR2, which immediately precede and follow 2 weak SEP event onsets.

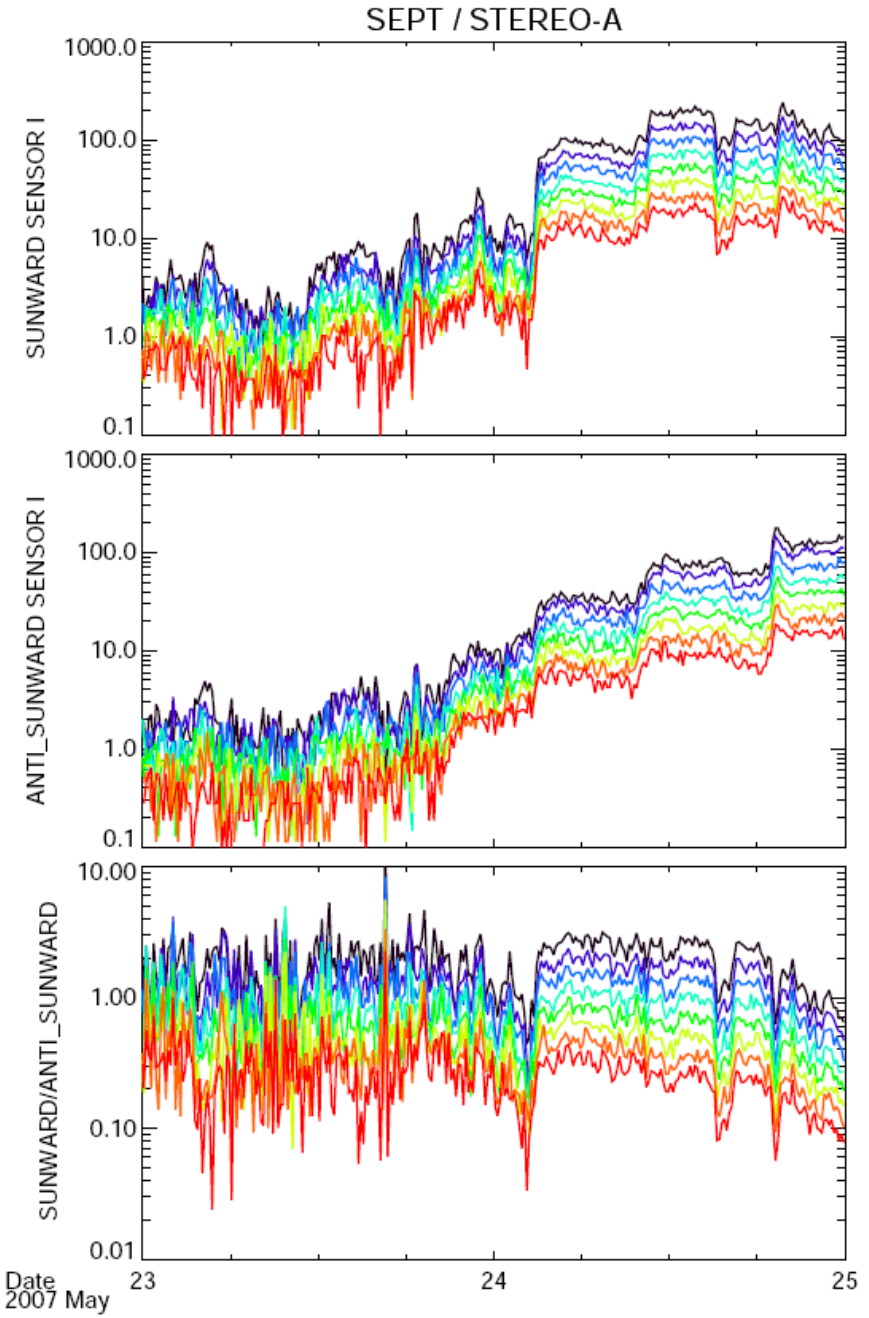
- We suggest a higher ion fluxes of the CIR2 could be due to additional source population.

- The relative abundances of H, He, O and Fe inside CIR2 and He/H ratio in HSS of CIR1 are very close to the SEP abundances.

- The similarity in elemental abundances and in spectral slopes suggests that the CIR2 contains as seed population ions from the preceding SEP event.

- The elemental abundances late in the CIR1 event can be explained by an SEP contamination.

Supplement


SEPT / STEREO-A
SUNWARD SENSOR I
1000.0
100.0
10.0
1.0
0.1
ANTI_SUNWARD SENSOR I
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SUNWARD/ANTI_SUNWARD
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0.10
0.01
Date
2007 May
23
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