

SEPT/STEREO Observations of Upstream Particle Events: Almost Monoenergetic Ion Beams

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Upstream particle events ($E < 1$ MeV) stream from the Earth's magnetosphere towards the upstream region of the bow-shock (Asbridge et al. 1968)

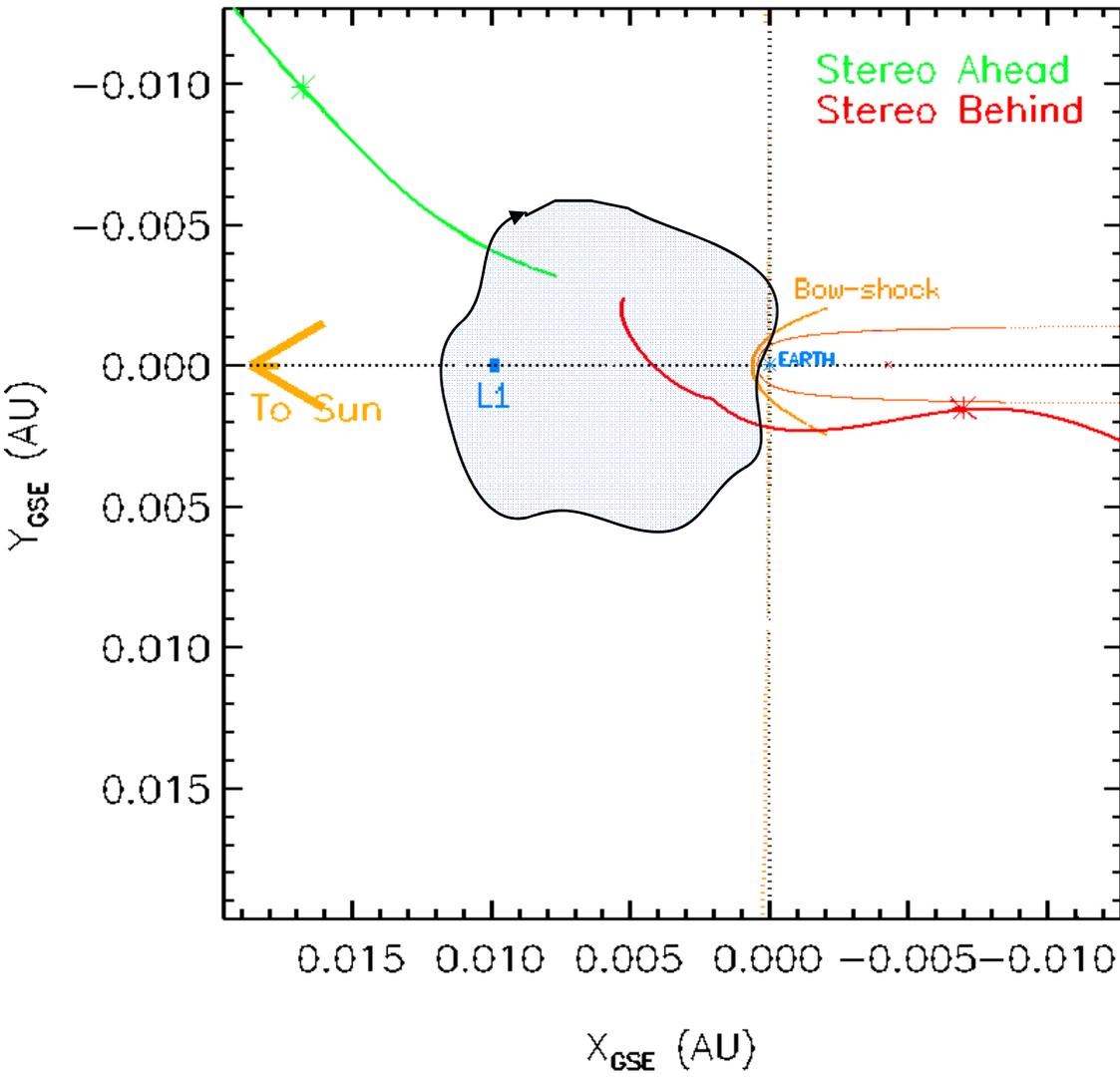
The origin was explained in two ways:

- acceleration at the bow-shock (e.g. Fermi or shock drift mechanisms)
- leakage of magnetospheric particles accelerated within the magnetosphere

All these mechanisms predict **power-law** energy spectra.

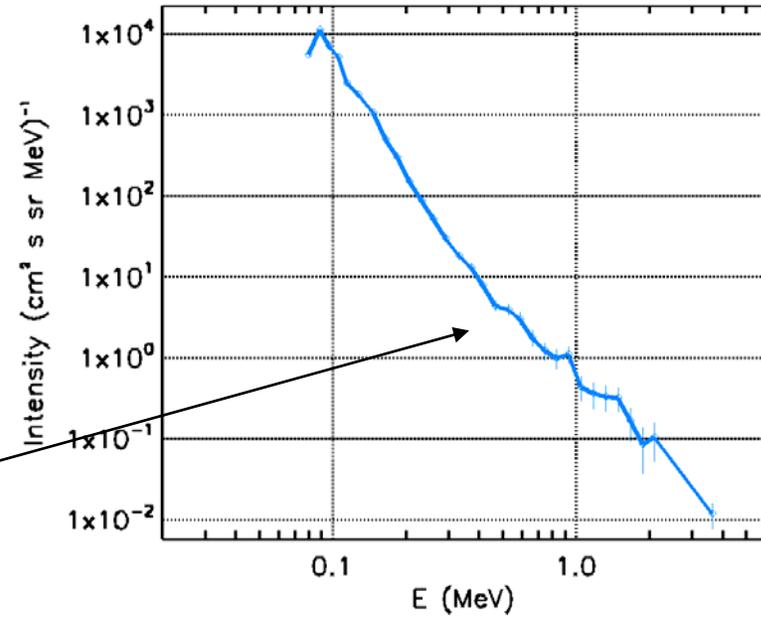
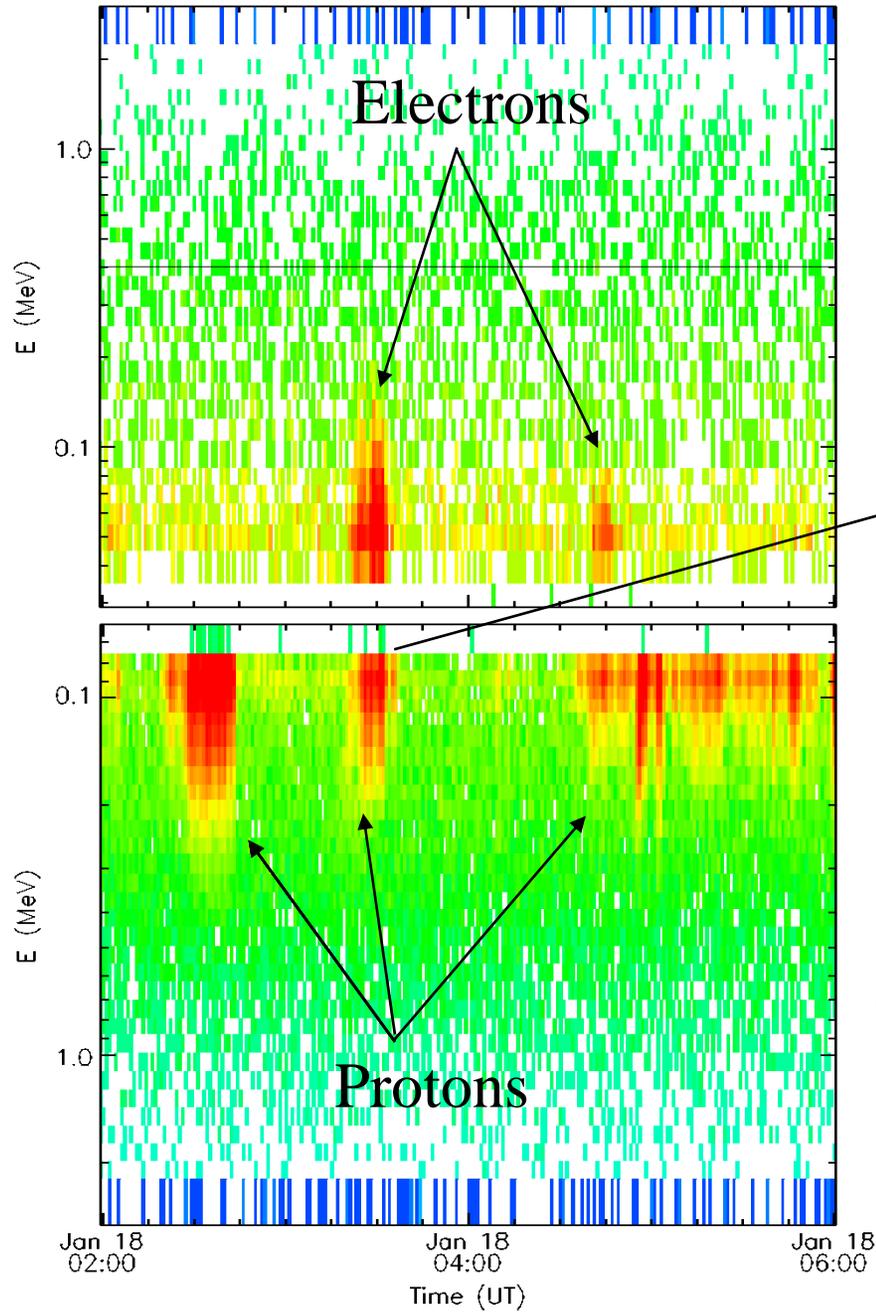
Indeed, such spectra were observed by different space missions during the last 40 years.

STEREO ORBIT (Feb 8, 2007 00:00:00 – Feb 9, 2007 00:00:00)



- In the past most of the upstream events were observed in the region between the Earth's bow-shock and the L1 point (ISEE-3, ACE, Wind, SOHO etc).

SEPT-A/AntiSun telescope (STEREO-A)

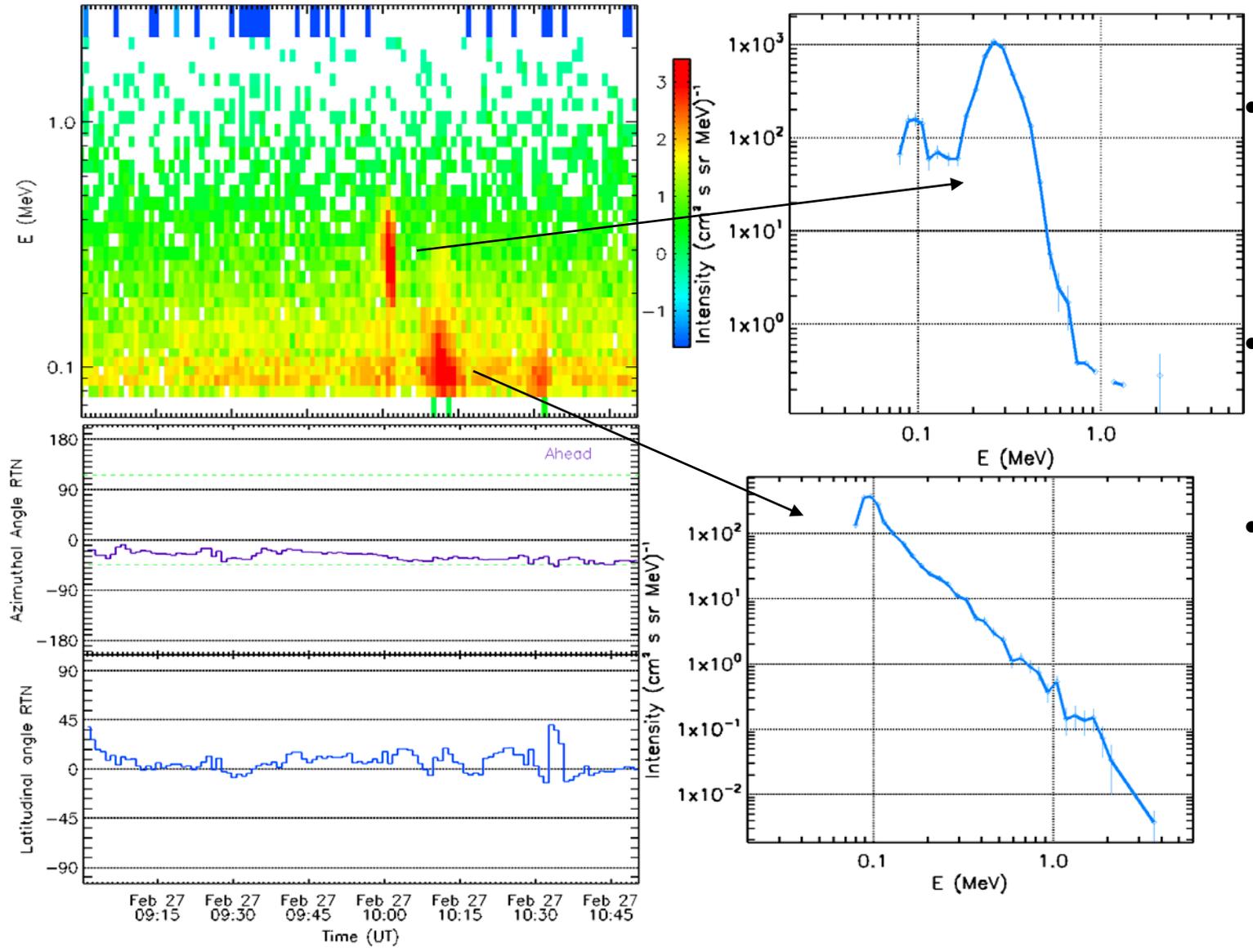


Energy spectrum of protons is a power-law.

A sequence of upstream proton & electron events. The first proton event was not accompanied by electrons.

”Almost Monoenergetic Ions” (AMI) Events

- about 10 years ago Lutsenko & Kudela (1999) reported detection of narrow lines ($E_{\text{FWHM}}/E_{\text{max}} \sim 0.15-0.30$) in the energy spectra (50-1000 keV) of upstream events using observations with the Interball-1 spacecraft. These ion events have been called ”Almost Monoenergetic Ions” (AMI) and were observed close upstream of the Earth's bow-shock and in the magnetosheath, only.
- these observation were not confirmed, before the launch of STEREO.
- using the Solar Electron Proton Telescope (SEPT) aboard STEREO-A&B we detected about 60 AMI events close to the bow-shock and to the magnetopause as well as far away from the Earth at distances up to 0.27 AU (6000 Re).

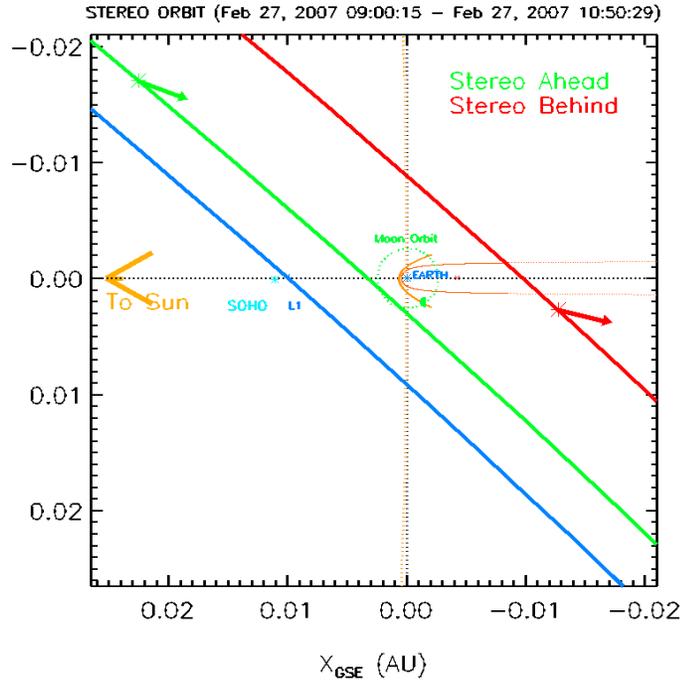
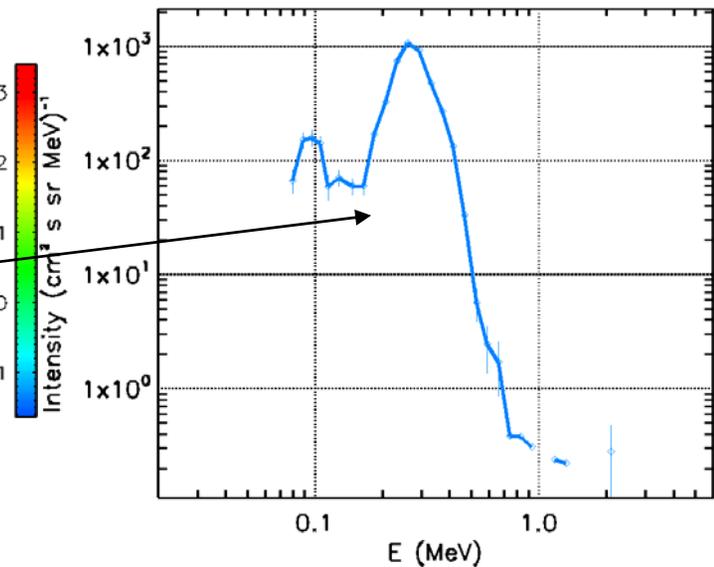
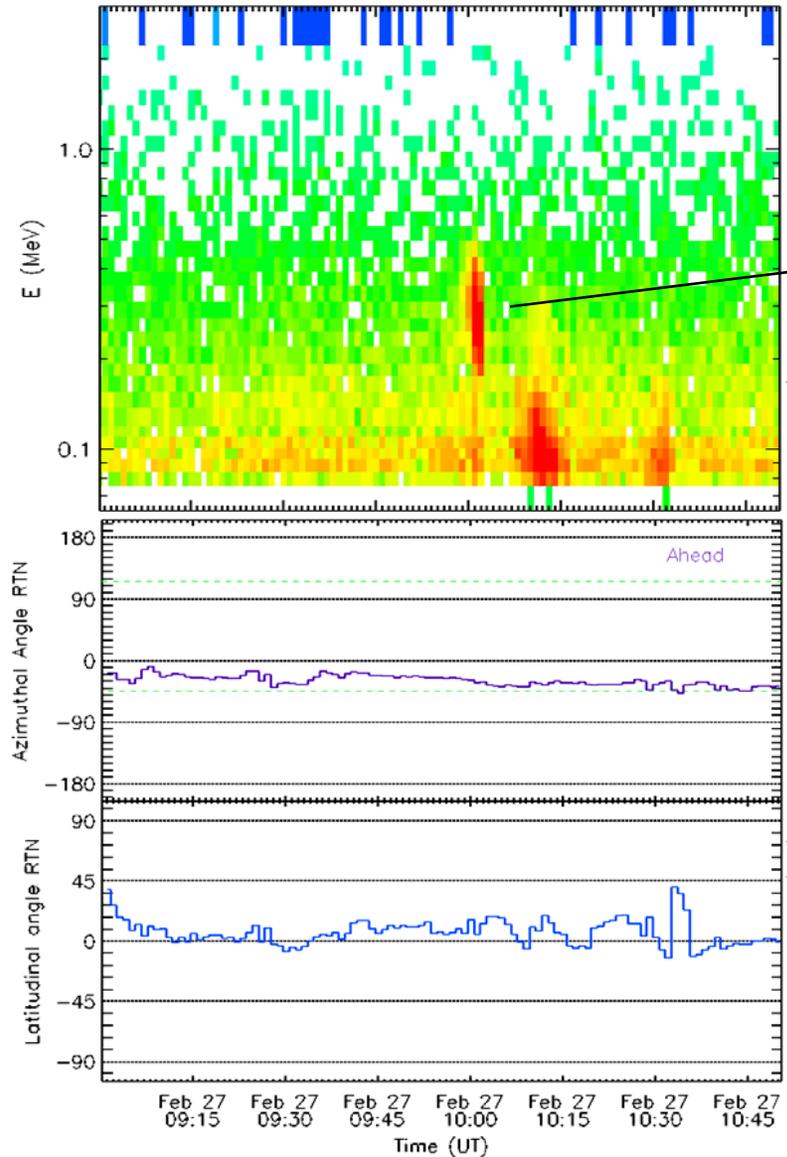


- the first event shows a monoenergetic line at 260 keV with FWHM=130 keV

- second and third events show “normal” power-law spectra

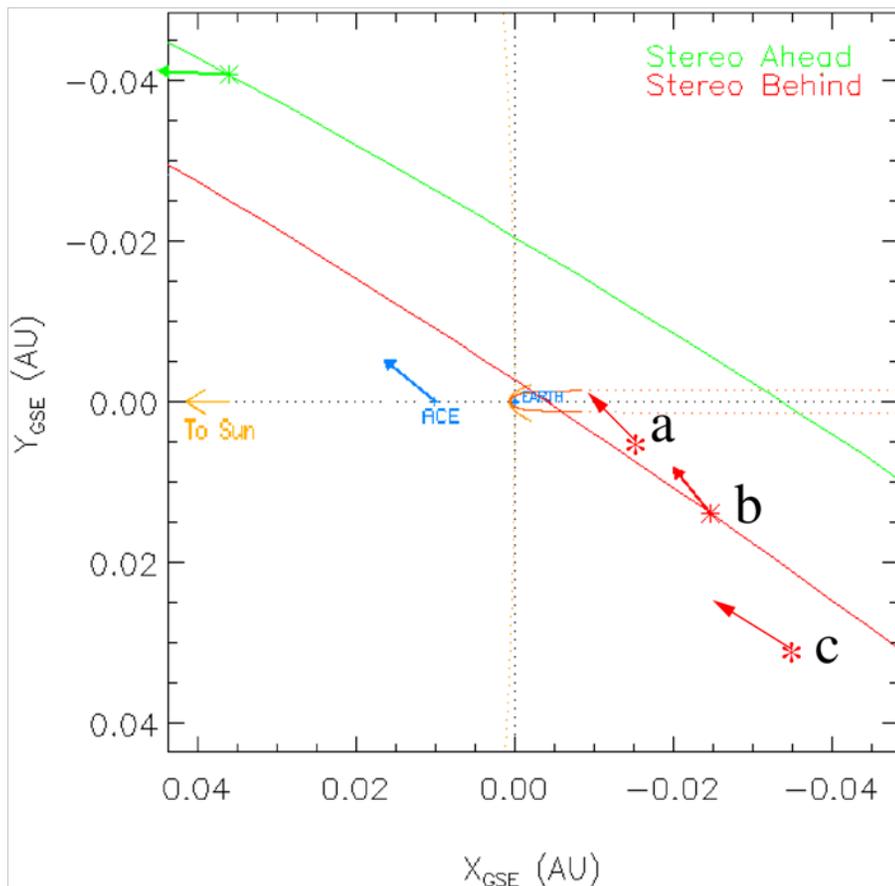
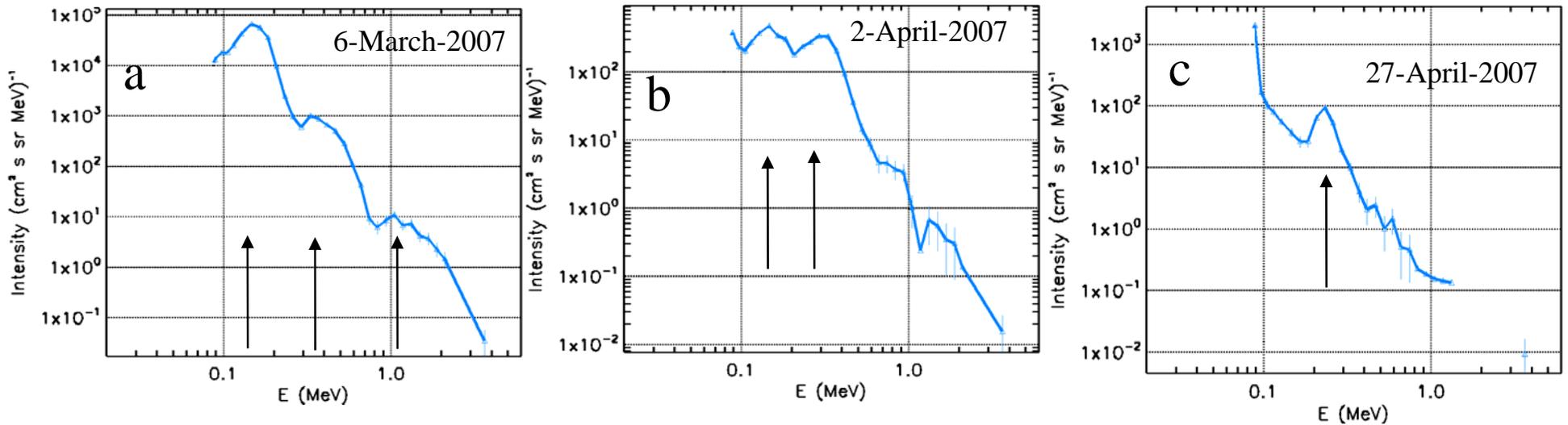
- no changes in IMF during and before the events

Almost Monoenergetic Event on 27-February-2007 (STEREO-A)



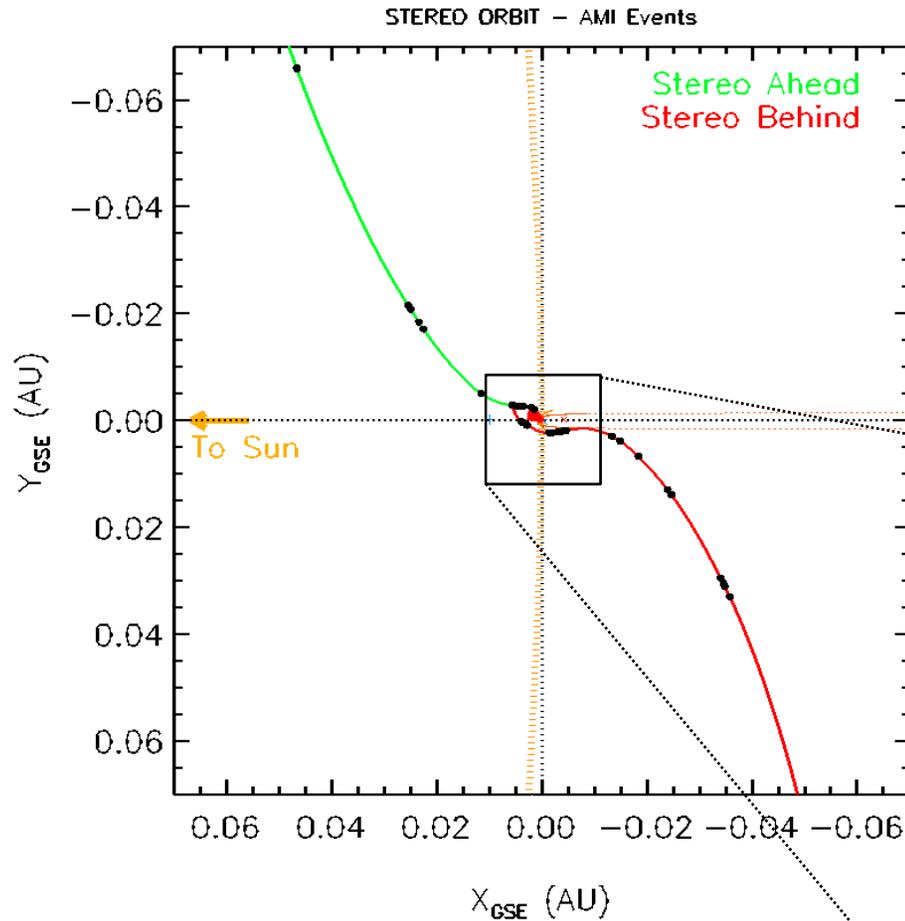
- STEREO-A: distance to Earth=0.028AU=659 Re
- the ecliptic IMF component (green arrow) is directed towards the magnetosphere
- the Parker spirals are drawn according to V_{sw} (ST-A&B, ACE)

Three, two & one line spectra (STEREO-B)

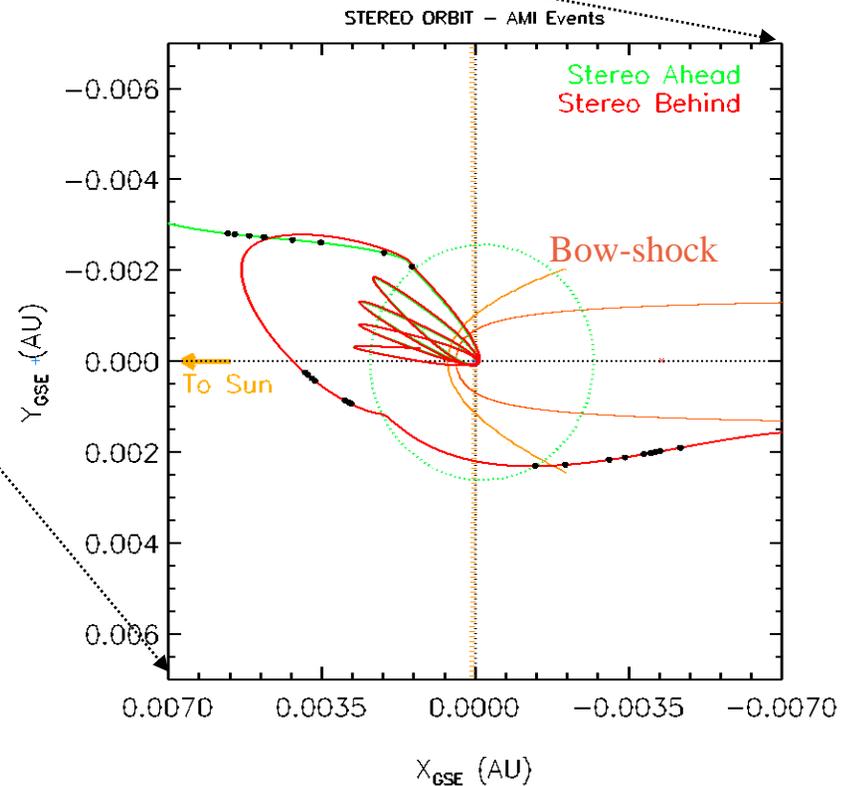


- AMI events far away from the Earth.
Distance to Earth: 351, 656 & 1150 Re
- the ecliptic IMF component (red arrow) is directed towards the magnetotail (a&b) or towards the bow-shock (c)

Spatial distribution of AMI events



- the AMI events (diamonds) were detected not only close to the bow-shock and close to the magnetopause, but also far away from the Earth up to distances of 0.27 AU (not in figure)



Main properties of AMI events

- AMI events show **one**, **two** or **three** narrow lines in the energy range from 120 to 1200 keV with a mean width ($E_{\text{FWHM}}/E_{\text{max}} = 0.40 \pm 0.02$)
- almost all events show a strong anisotropy streaming from the Earth direction
- the energy peak ratio is 1:2 by two lines, and 1:2:(5-6) by three lines
- AMIs were observed close to the bow-shock and close to the magnetopause as well as far away from the Earth (≤ 0.27 AU)
- mean duration time is 4 minutes
- only ~20% of 60 AMI events were associated with electron events
- normally the AMI events occur during high SW speed and when the B_z component of the IMF is negative

Possible sources of AMIs

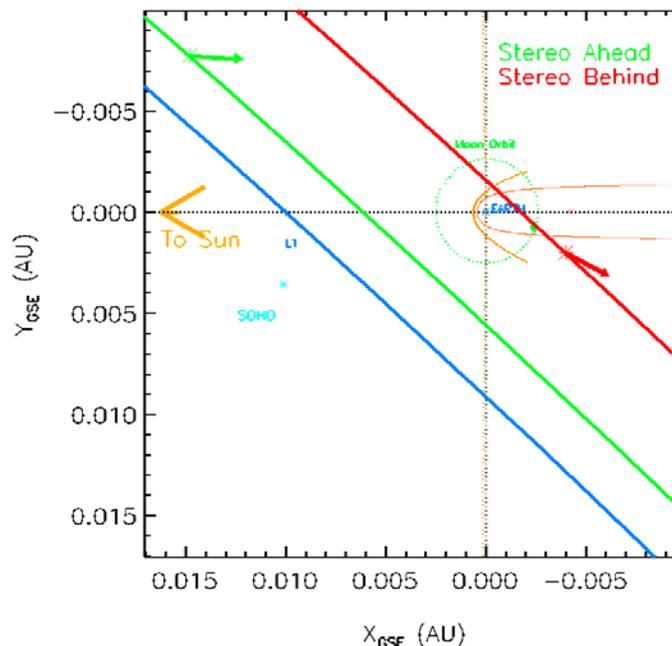
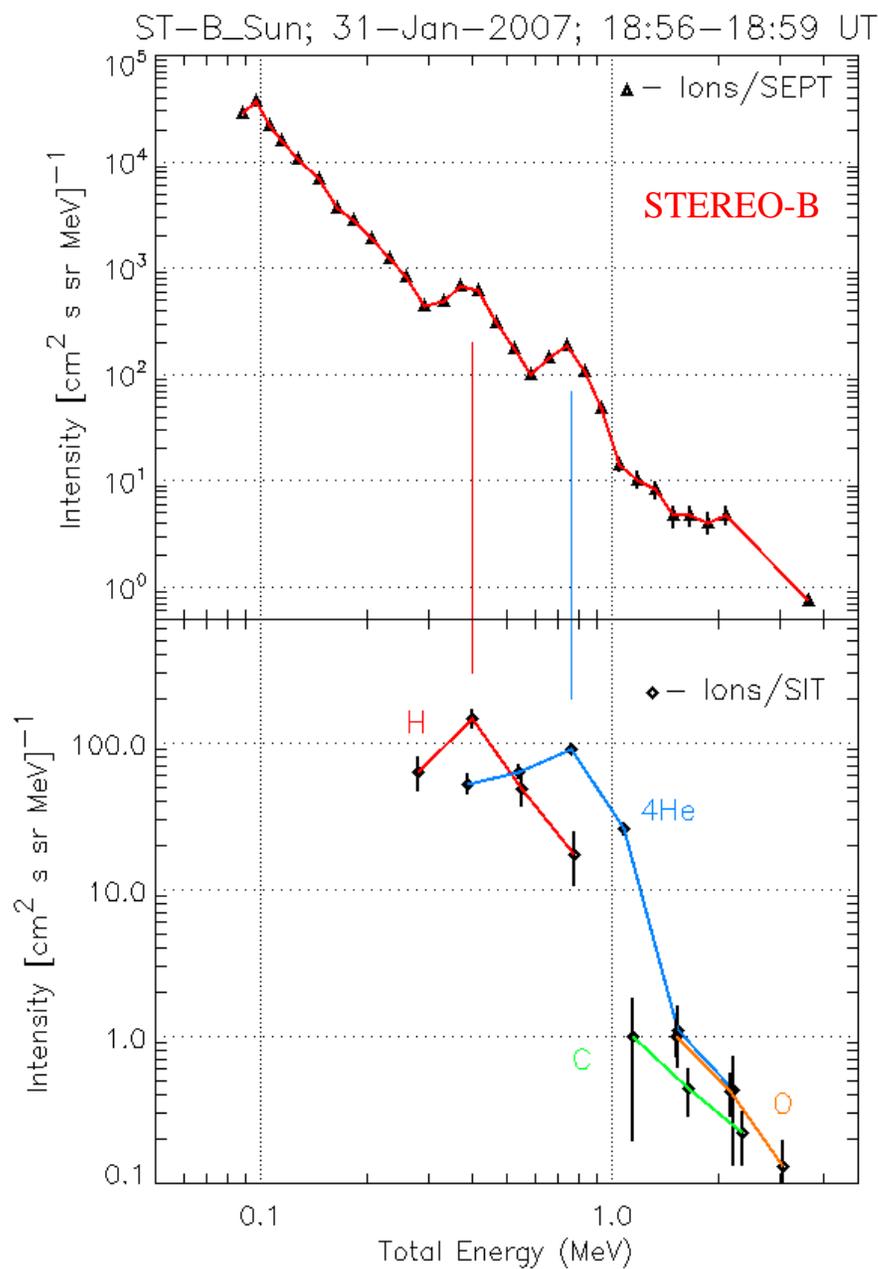
- A lot of AMI events were detected when **STEREO-B** was connected to the magnetopause, therefore it is plausible that the magnetopause is the best candidate for an AMI acceleration source
- the Earth's bow-shock and the CIR shocks cannot be excluded, because **STEREO-A** was also well connected to these structures
- We suggest like Lutsenko & Kudela (1999) that the narrow lines (AMI) may be explained as H^+ , He^{++} and $CNO^{+(5-6)}$ ion beams accelerated in an electrostatic field proportional to their charge Q , because the energy peak ratio in three line spectra is 1:2:(5-6), i.e.:

$$E_{ion} = Q \cdot F_{estat} \cdot d$$

where d is the size along the electrostatic field F_{estat}



Comparison of energy spectra obtained with the SEPT and SIT instruments



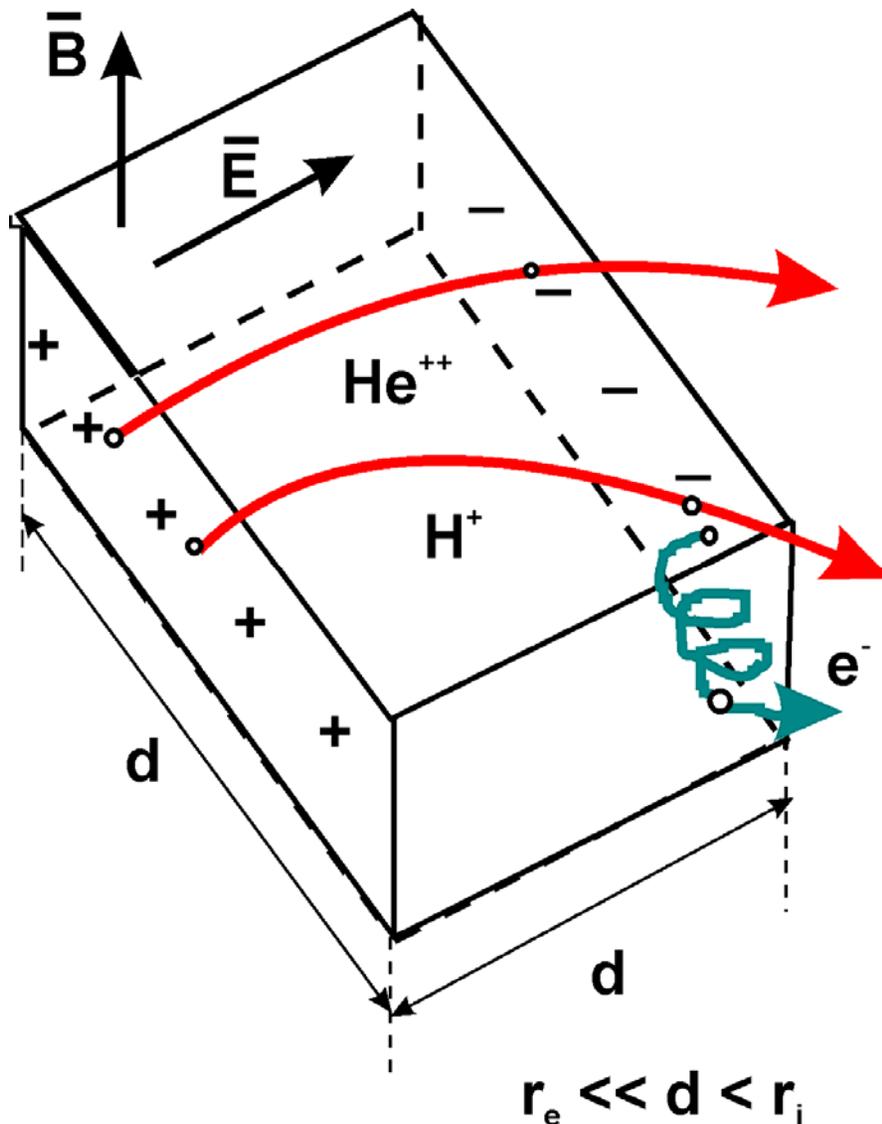
- two lines by SEPT
- two lines by SIT: first due to H^+ , second due to He^{++}
- energy peaks match each other very well
- in both spectra the peak ratio is 1:2
- these observations support the idea that AMI events are due to H^+ and He^{++} beams accelerated in an electrostatic field

Conclusions

- Using **SEPT/STEREO-A&B** we detected narrow energy lines (AMI) in the spectra of upstream events close to the Earth's bow-shock and along the STEREO trajectories up to distances of 0.27 AU from the Earth
- Multiline spectra show energy peak ratio of 1:2:(5-6)
- It is suggested that these lines occur due to acceleration of **protons**, **He⁺⁺** and **CNO⁺⁽⁵⁻⁶⁾** in a burst of strong electrostatic fields at the magnetopause or/and at the bow-shock/CIR shock

Lutsenko (2001) hypothesis on the AMI origin:

Acceleration must take place in a region with $\mathbf{E} \perp \mathbf{B}$ and dimensions d lower than ion and much greater than electron gyroradii. The potential drop ΔV must be of 50-150 keV



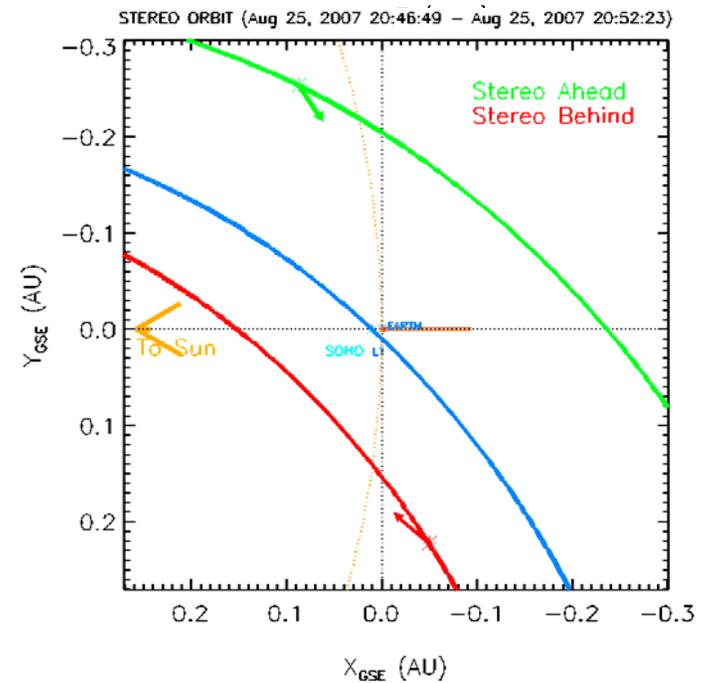
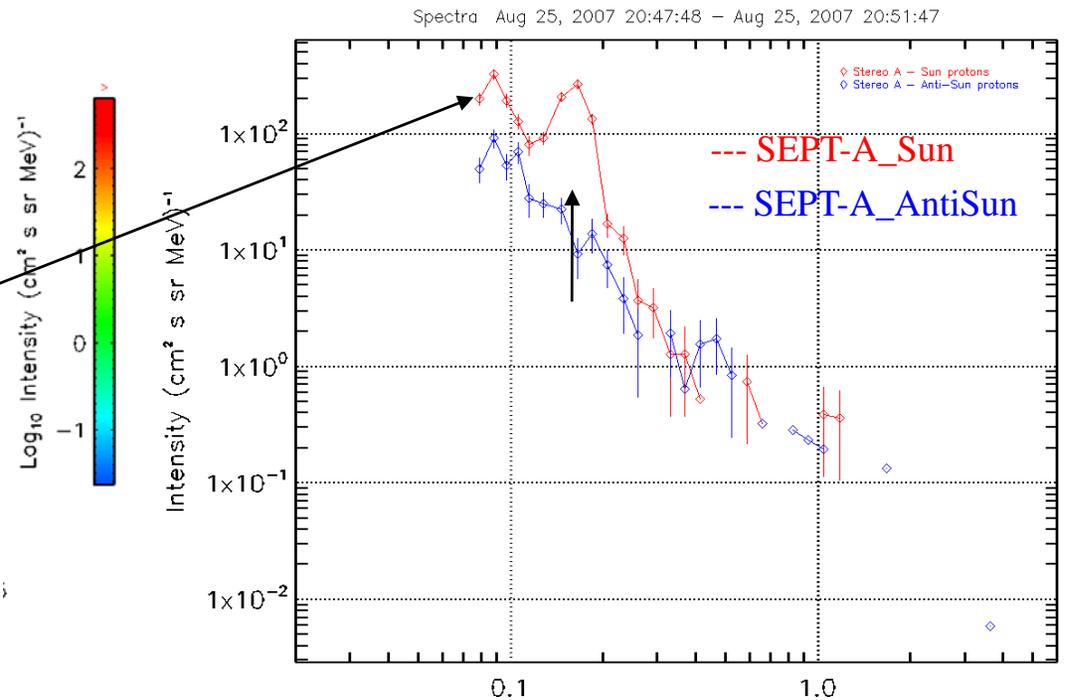
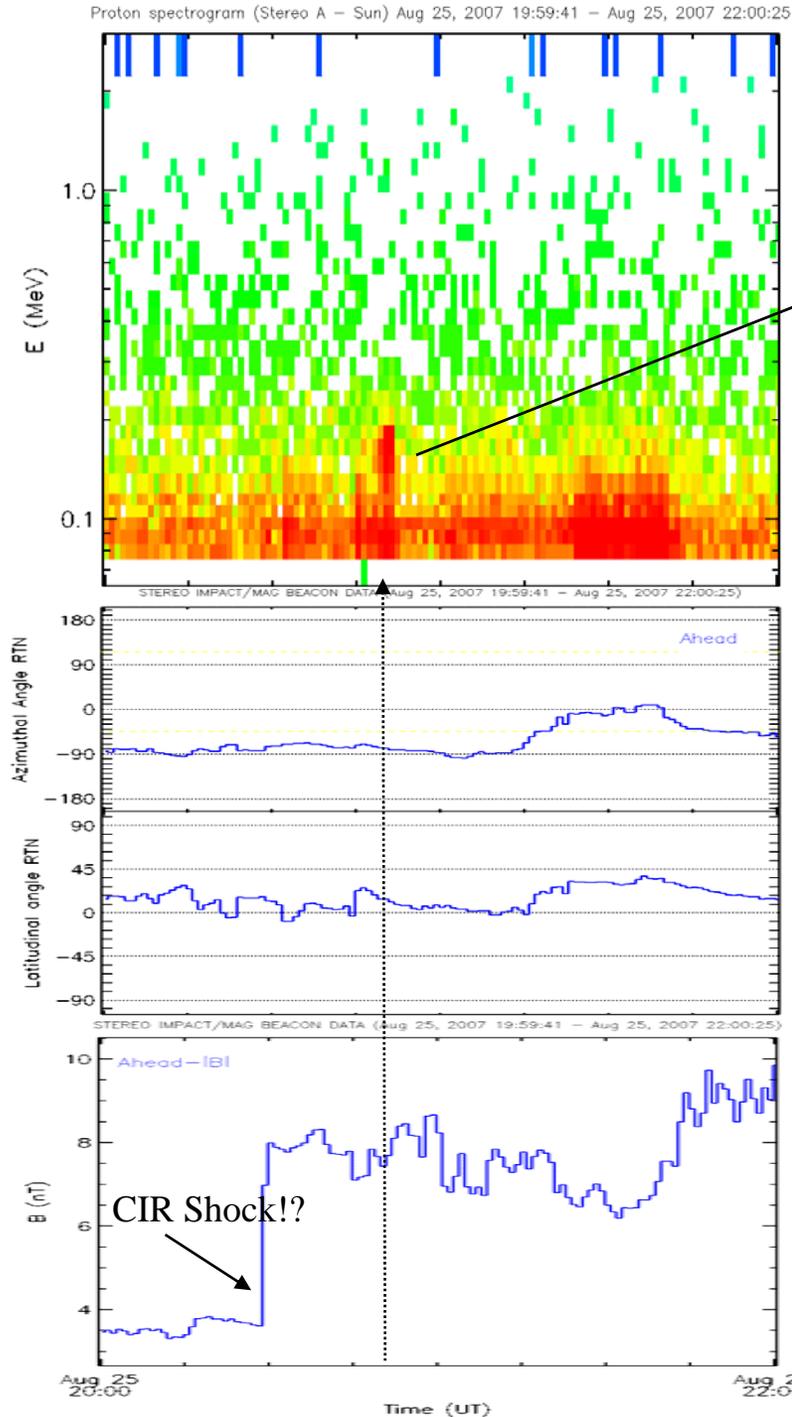
Acceleration of plasma ions in such a region must give 2 narrow lines in the spectrum with energy ratio of 1:2 (H^+ , He^{+2}) and a broader peak ($\text{C,N,O}^{+(5-6)}$) with energy 5-6 times that of H^+ . This indeed was observed. The intensity ratio, too, corresponds to the known solar wind composition.

Electrons cannot be accelerated (only swept out by $\mathbf{E} \times \mathbf{B}$ drift).

BUT, at STEREO we detected also AMI events associated with electrons.

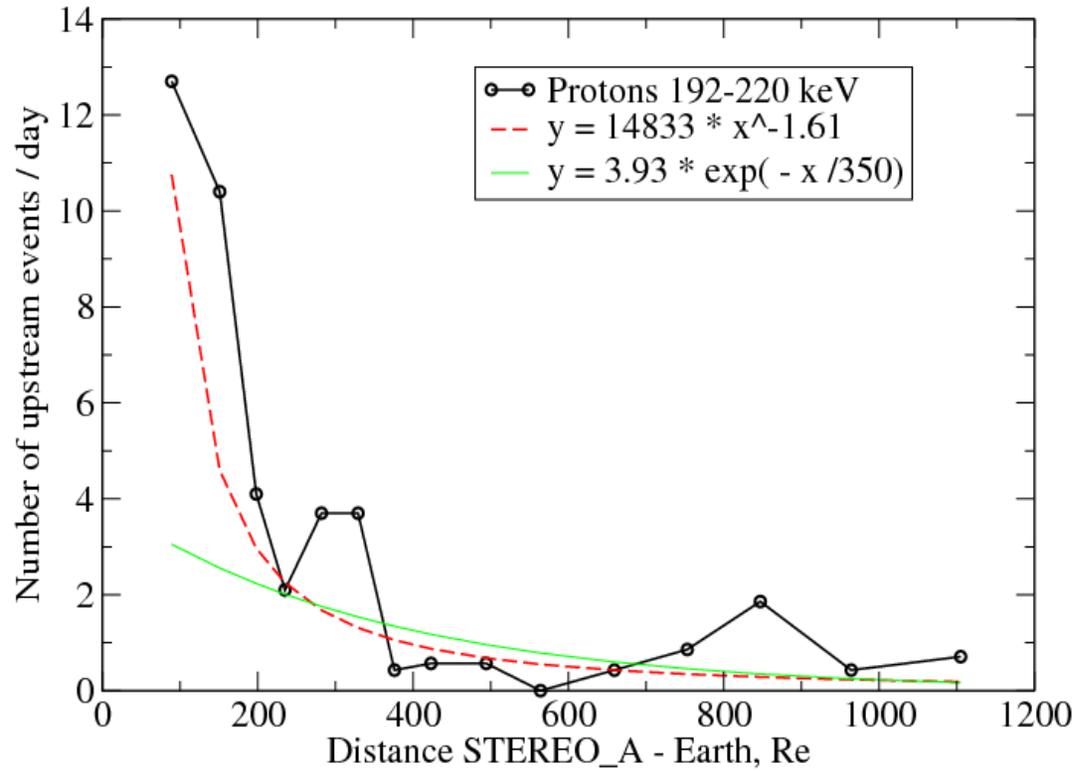
AMI event streaming from the Sun direction!

Is it accelerated at the Sun or by the CIR shock?



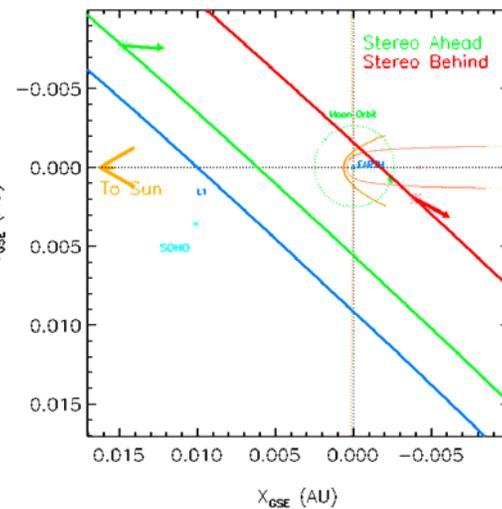
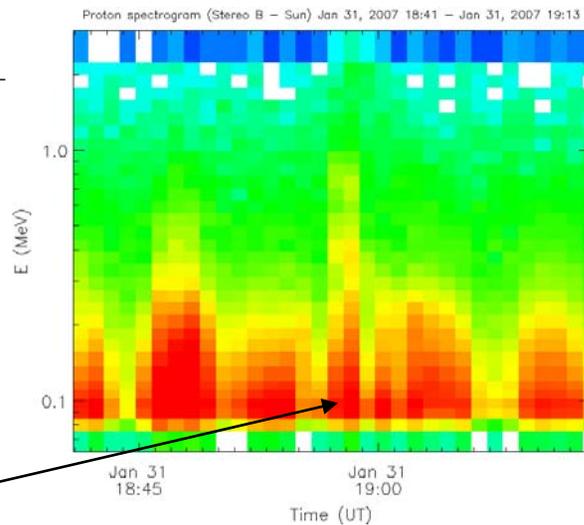
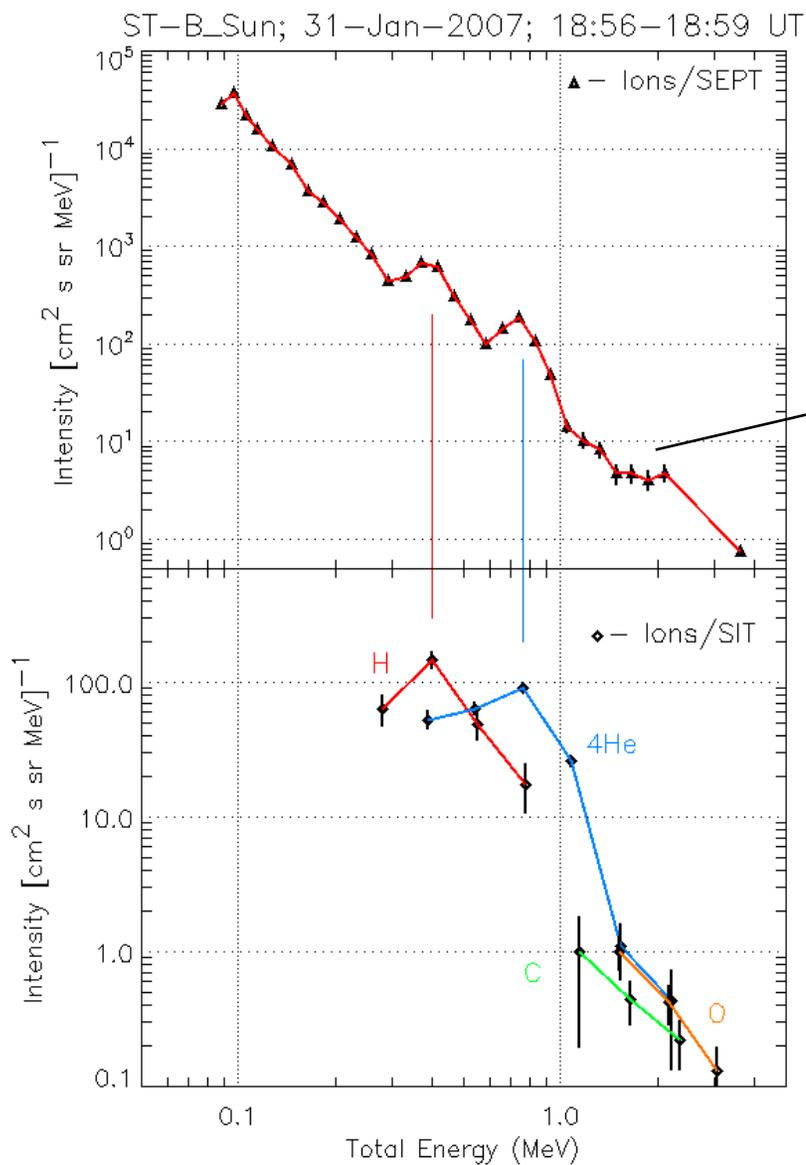
The End

Upstream proton events vs. distance from the Earth



Comparison of energy spectra obtained with the SEPT and the SIT instruments

STEREO-B



Stereo-B, dist. to Earth=0.054 AU=126 Re

