

How do >40 keV ions originating from the Earth's bow shock propagate beyond distances of 0.2 AU upstream?

STEREO SWG, Pasadena, Feb. 2009

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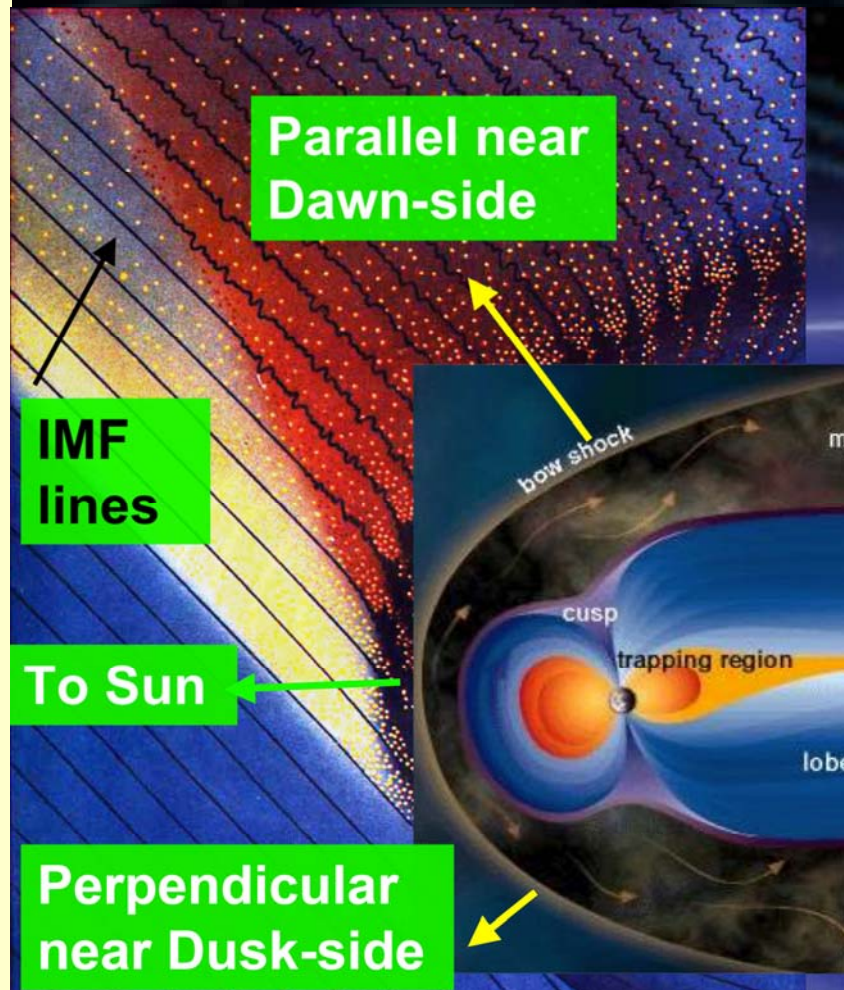
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Upstream Ion Events

- Observed since 1960's
 - Short duration ~ mins-hrs
 - Properties depend on location i.e., foreshock or far upstream
- Controversial origin
 - Fermi acc. at bow shock
 - Magnetospheric leakage
 - Cusp Acceleration
- This Talk focuses on:
 - Ion Composition
 - Energy Spectra
 - Simultaneous multi-spacecraft observations



Ion Composition & Spectra

Property	Bow-shock Acceleration	Leakage and escape from magnetosphere
Composition	Solar wind, e.g., C, Ne-S, Fe	Ionospheric ions - O ⁺ , N ⁺ + solar wind ions
Spectra	Exponential in E/Q; cut-off ~150 keV/e	Power-laws, extending up to ~2 MeV

→ Need composition measurements to distinguish solar wind species from magnetospheric ions

UPSTREAM EVENTS

>30 Re

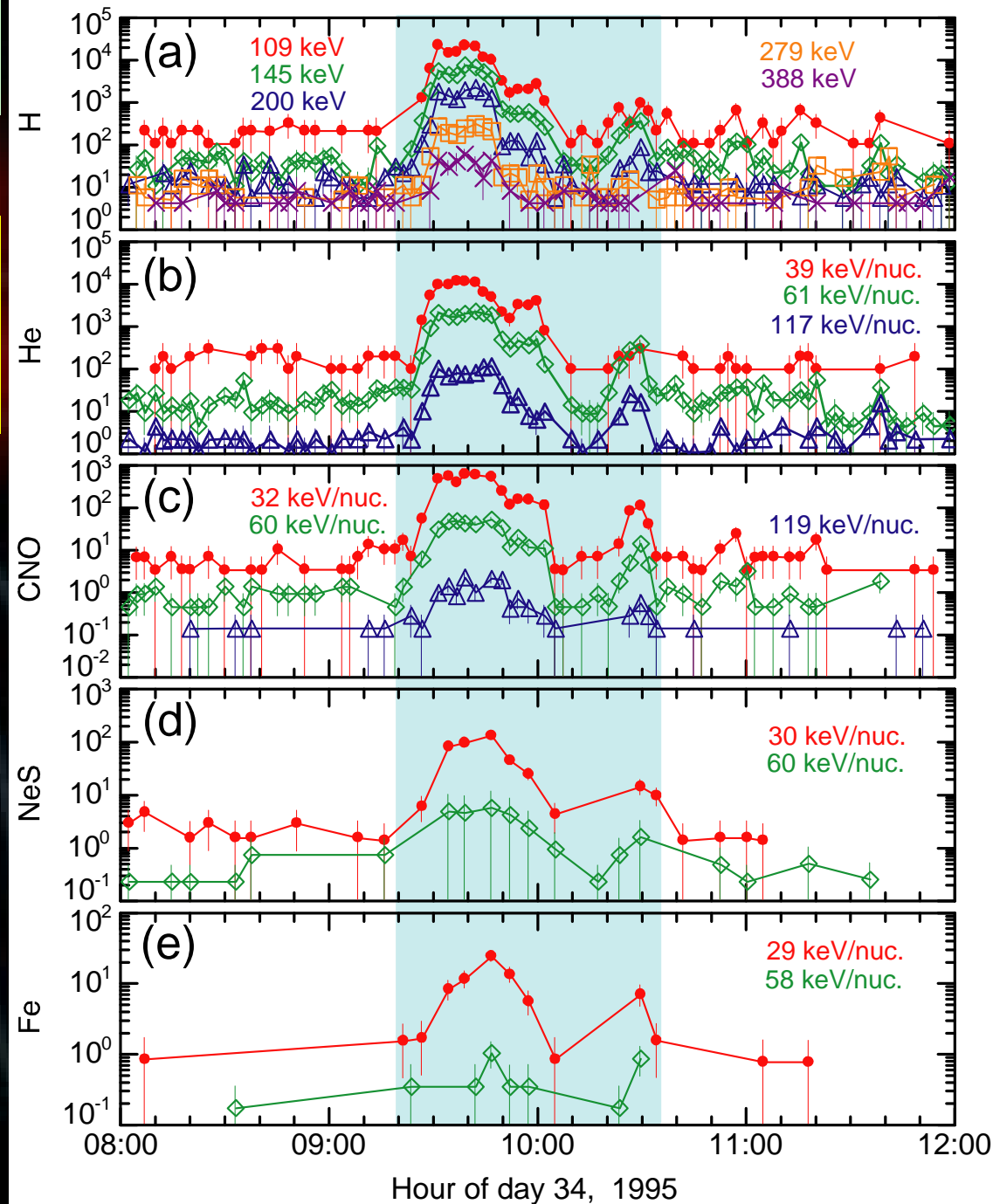
Wind/STEP Time-intensity profiles for 1 event

Abrupt intensity increases lasting an hour

Solar-wind species like Ne-S and Fe are present

Desai et al., 2000 JGR, vol.

105 pp 61-78



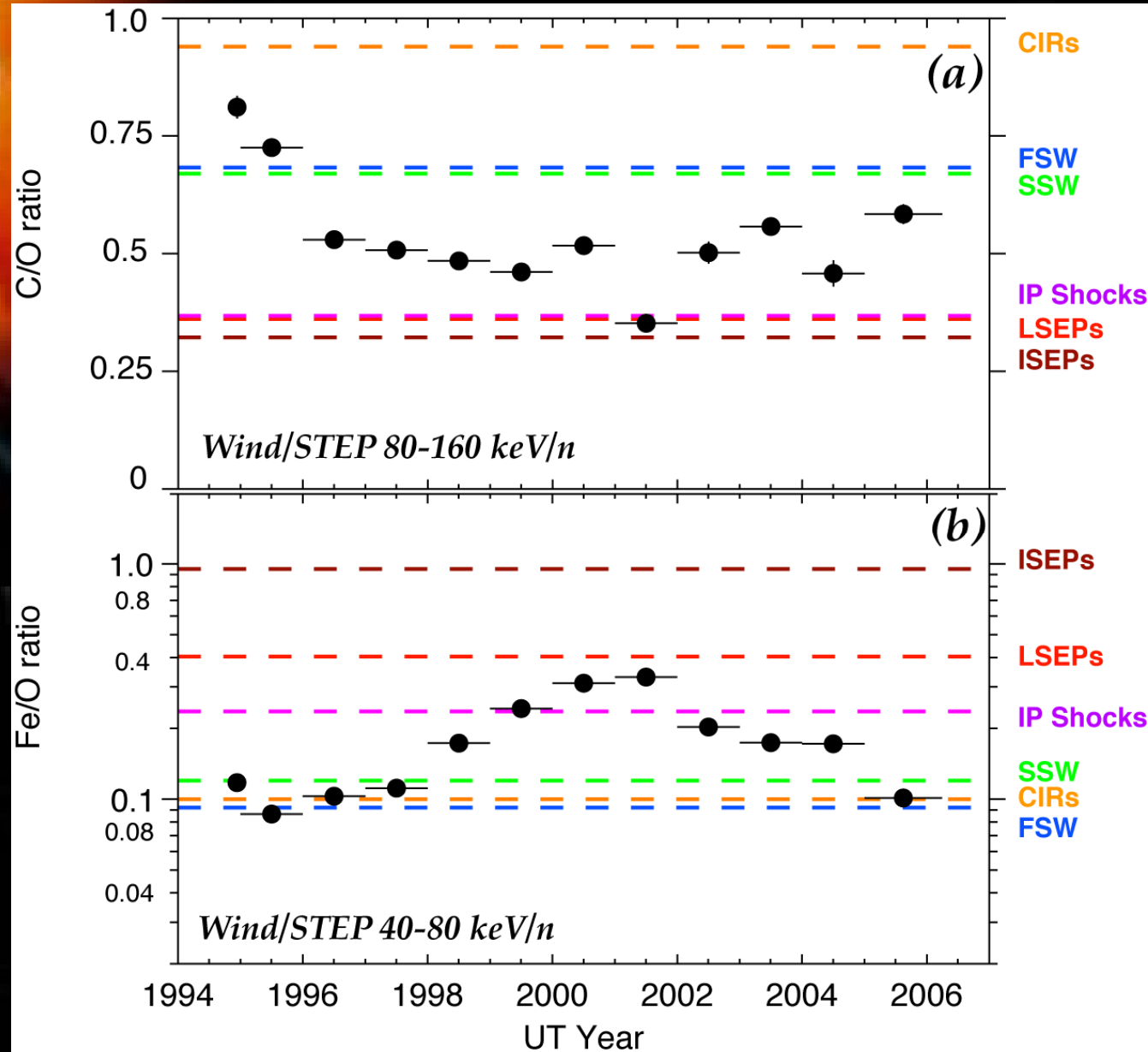
Composition of >3000 events

Composition of upstream ion events changes with solar cycle

SEP-like during solar maximum

CIR/SW-like during solar minimum

Desai et al. 2006; GRL, vol. 33, L181014, doi: 10.1029/2006GL027277



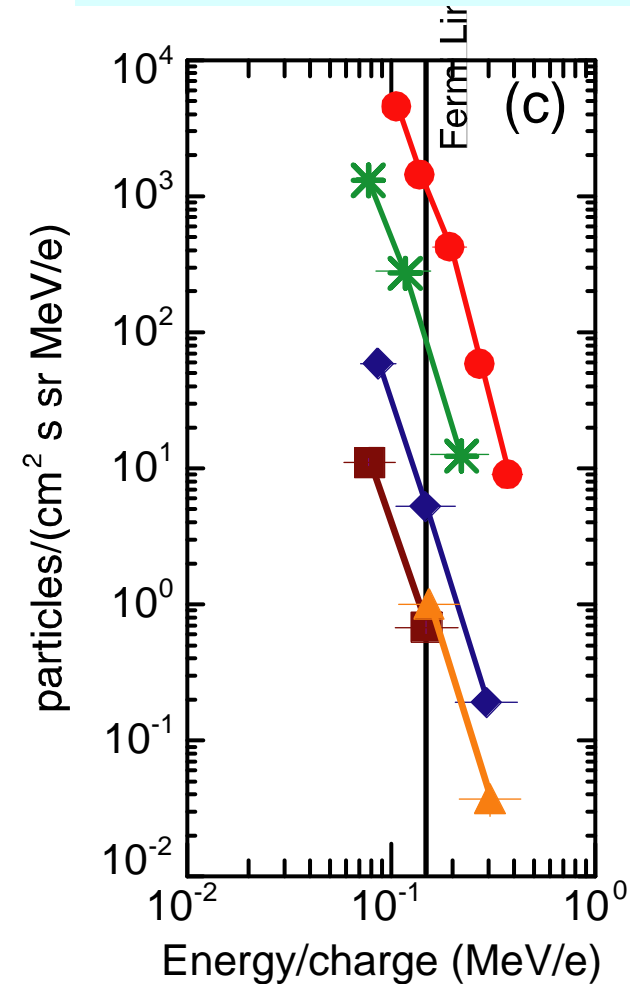
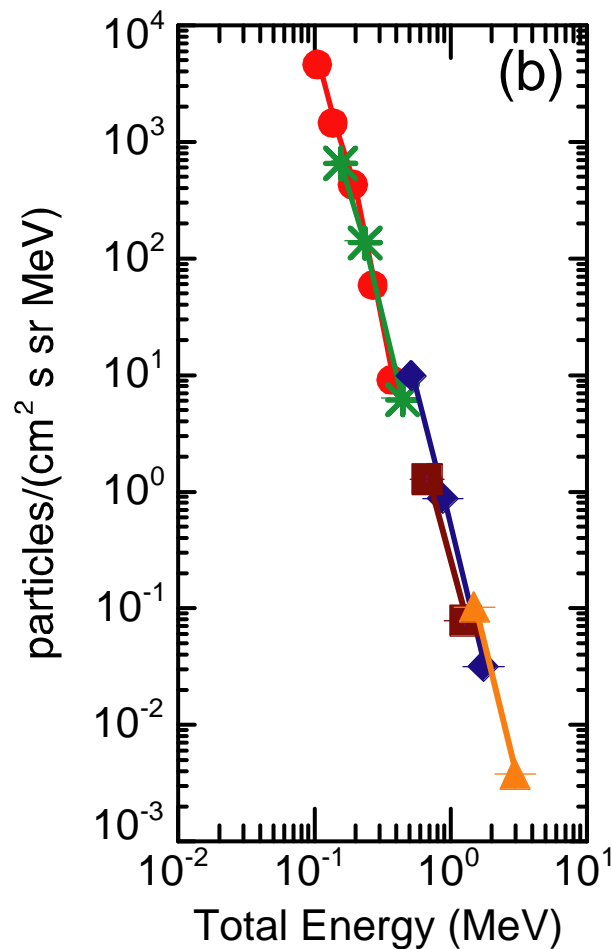
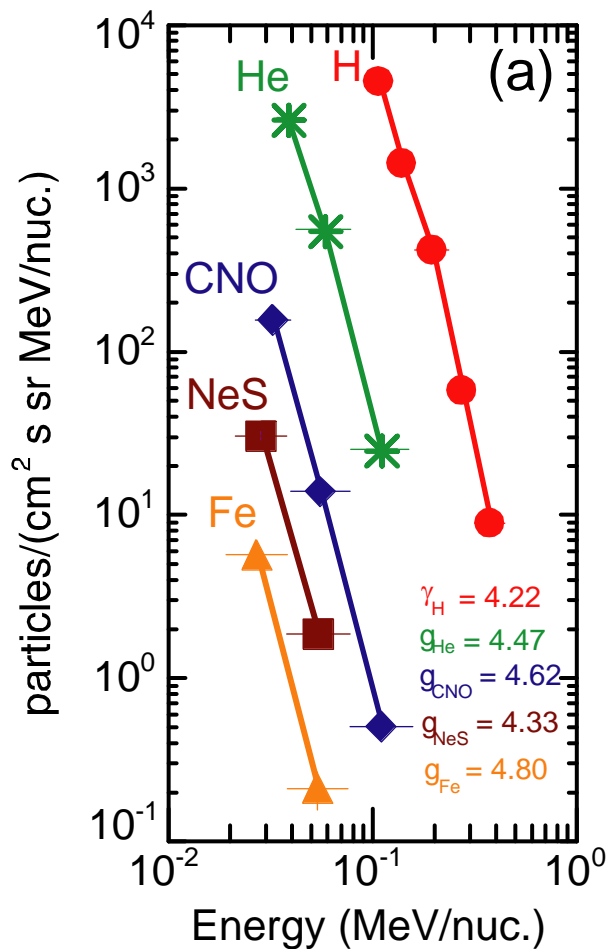
The Spectral Dilemma

Desai et al., 2000 JGR, vol.

105, pp.61-78
Soft power-Laws

Single power-law in total energy

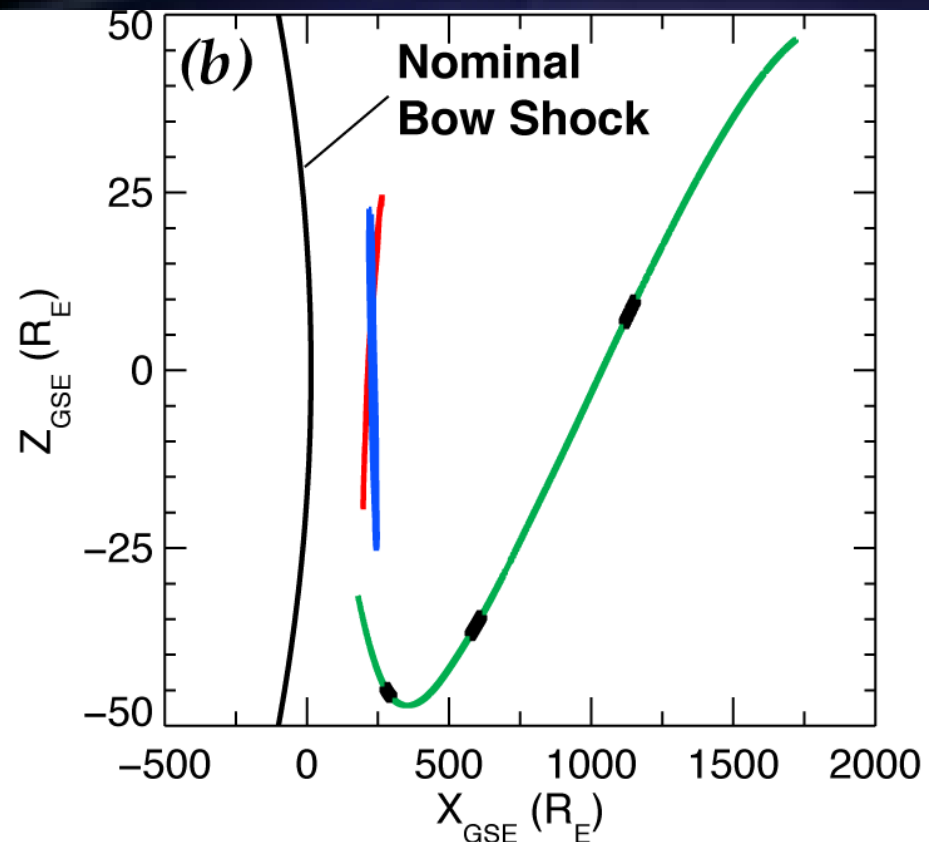
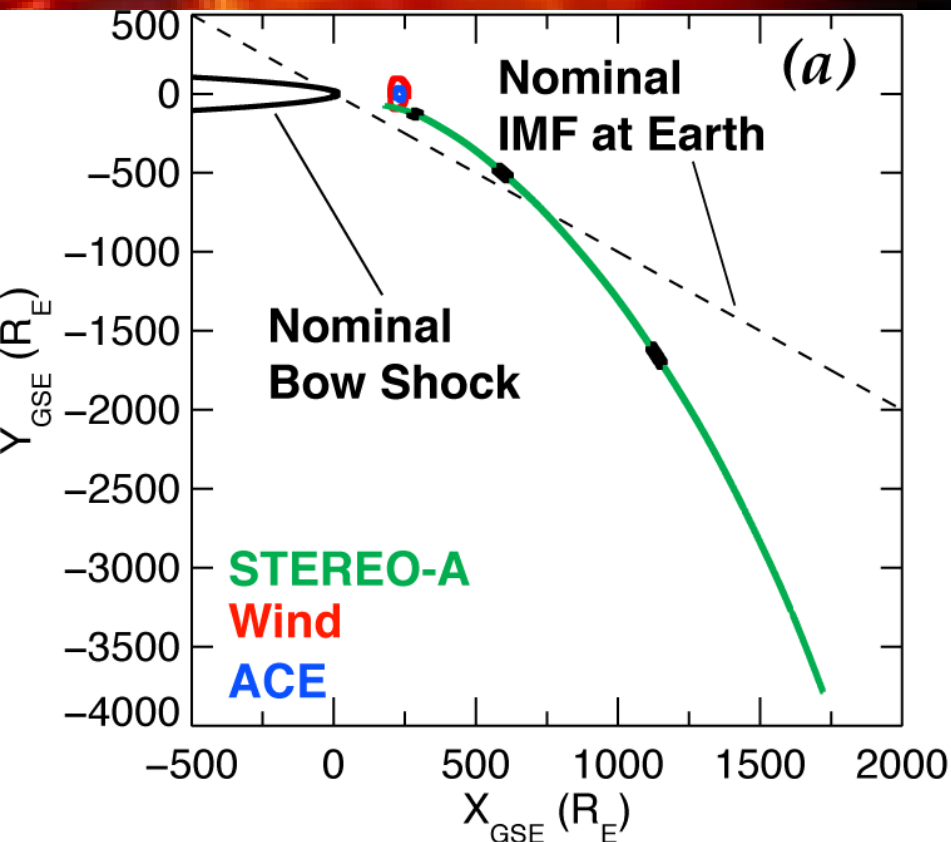
Extend above ~150 keV/q; Cut-off at ~300 keV/q

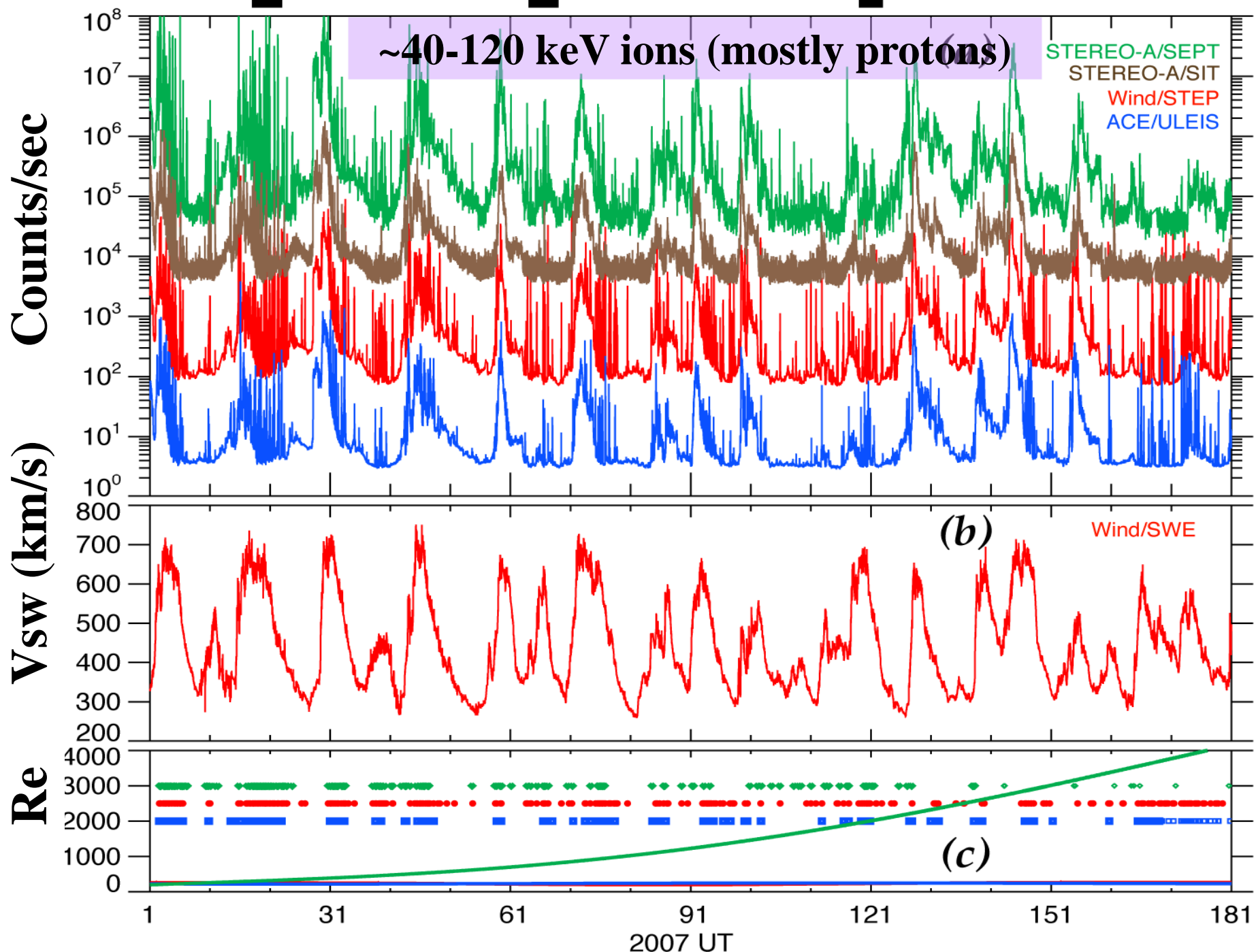


Composition & Spectra -- 1990's

- **Seed population comprises SW + interplanetary suprathermals and occasionally (<10% of events) singly-charged ionospheric ions**
- **Spectra behave as E^{-4} ; all species obey a single power-law upto ~2 MeV in total energy**
- ***Origin is external to magnetosphere***
- ***Acceleration site and mechanism --- still not clear***

Locations of ACE, Wind, and STEREO-A during 2007, 1 - 2007, 181





Event Selection and Data Analysis

- **Use ACE/ULEIS, Wind/STEP, STEREO-A/SEPT and STEREO-A/SIT measurements from 2007, day 1 - day 181.**
- **Identified upstream ion events (>40 keV) independently at each spacecraft**
 - 300 at Wind, 201 at ACE, and 181 at STEREO-A
- **Identified simultaneous events: Events that occurred within 2-hour intervals of ongoing events at Wind**
 - 90 simultaneous events at WIND/STEREO-A

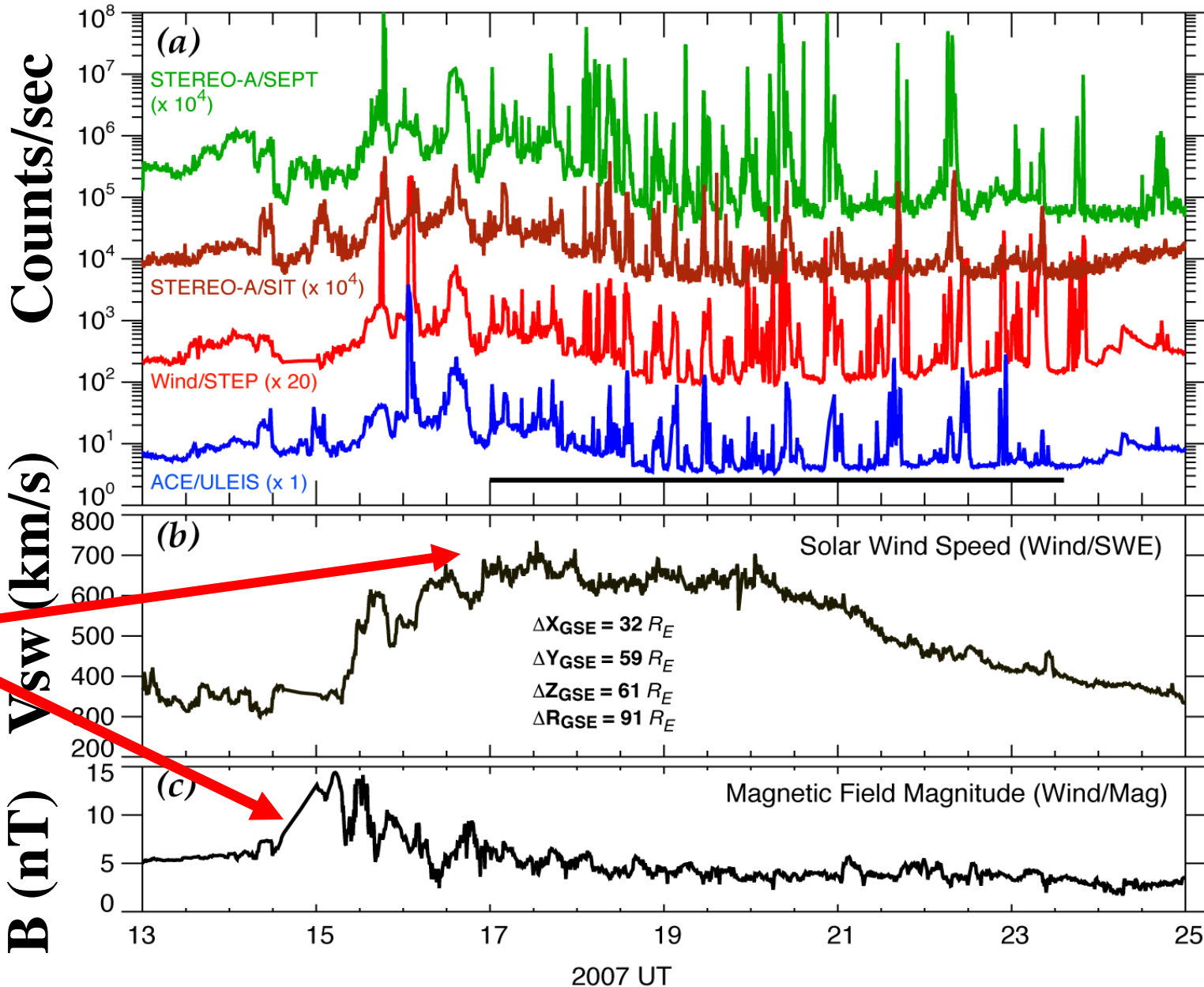
Series of upstream events

$\Delta X = 32 R_E$

$\Delta Y = 59 R_E$

$\Delta R = 91 R_E$

Occur in the high speed solar wind flow after the compression region passes Earth

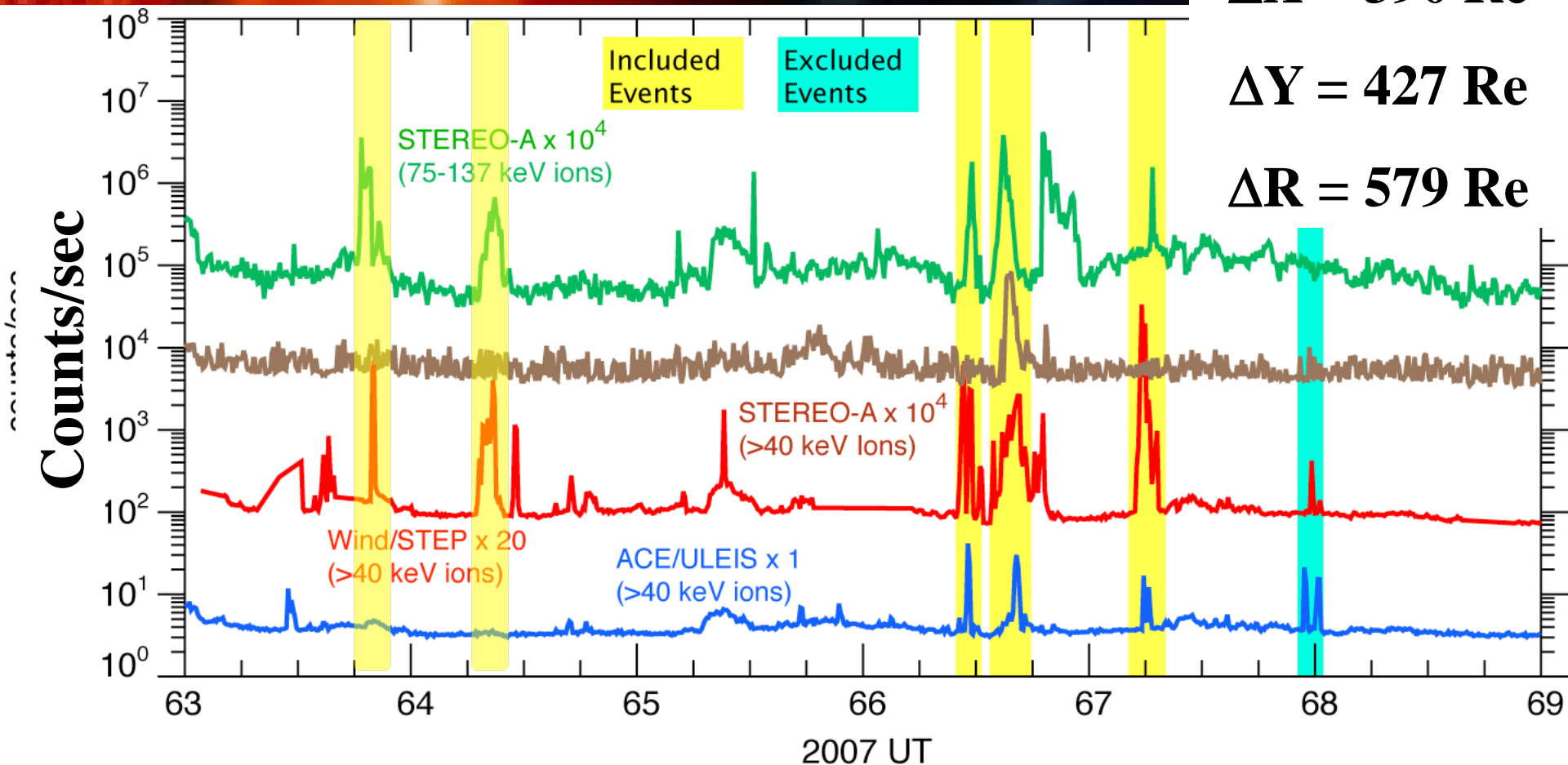


Simultaneous events at separation distance of $\sim 580 R_E$

$\Delta X = 390 R_E$

$\Delta Y = 427 R_E$

$\Delta R = 579 R_E$

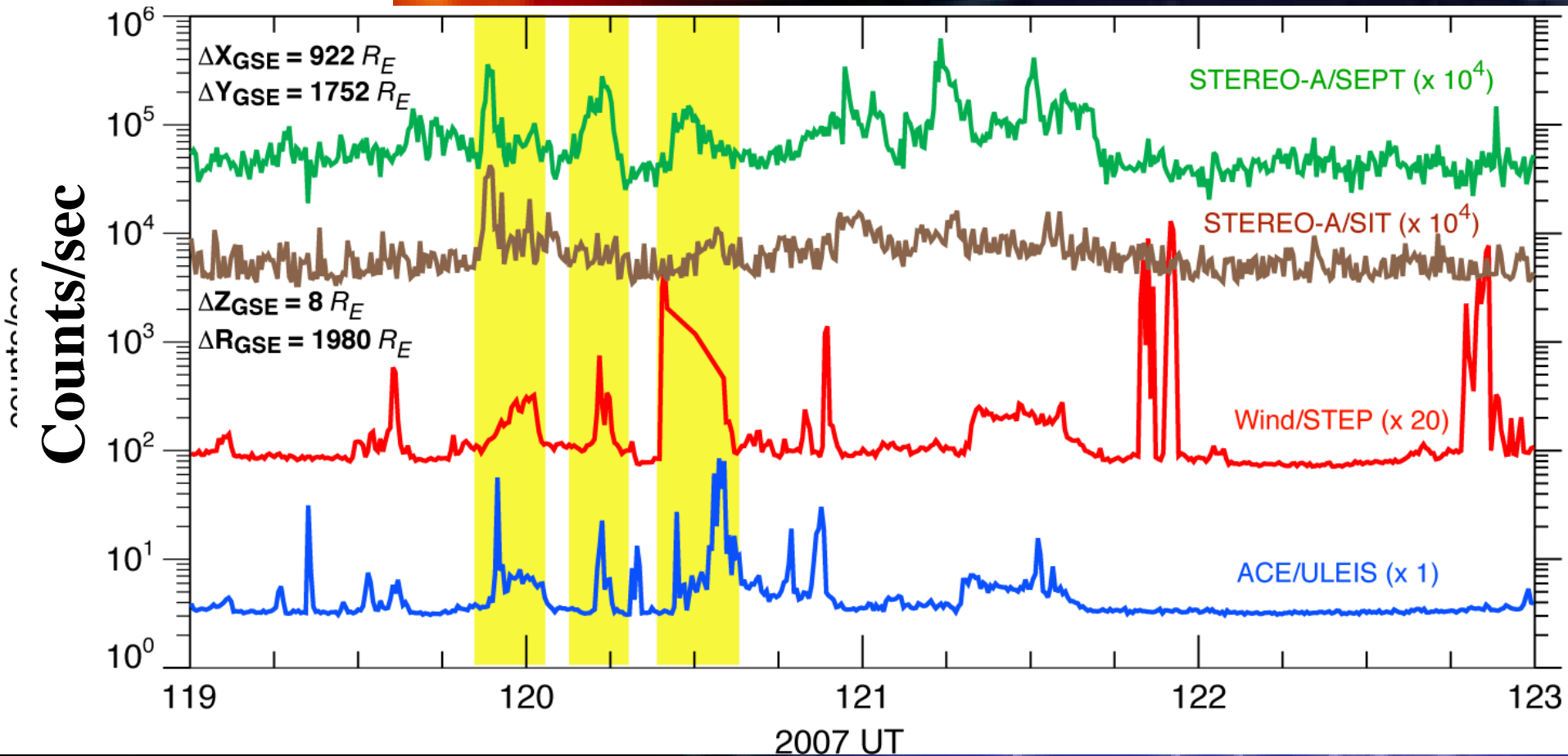


Simultaneous Events at separation distance of $\sim 2000 R_E$

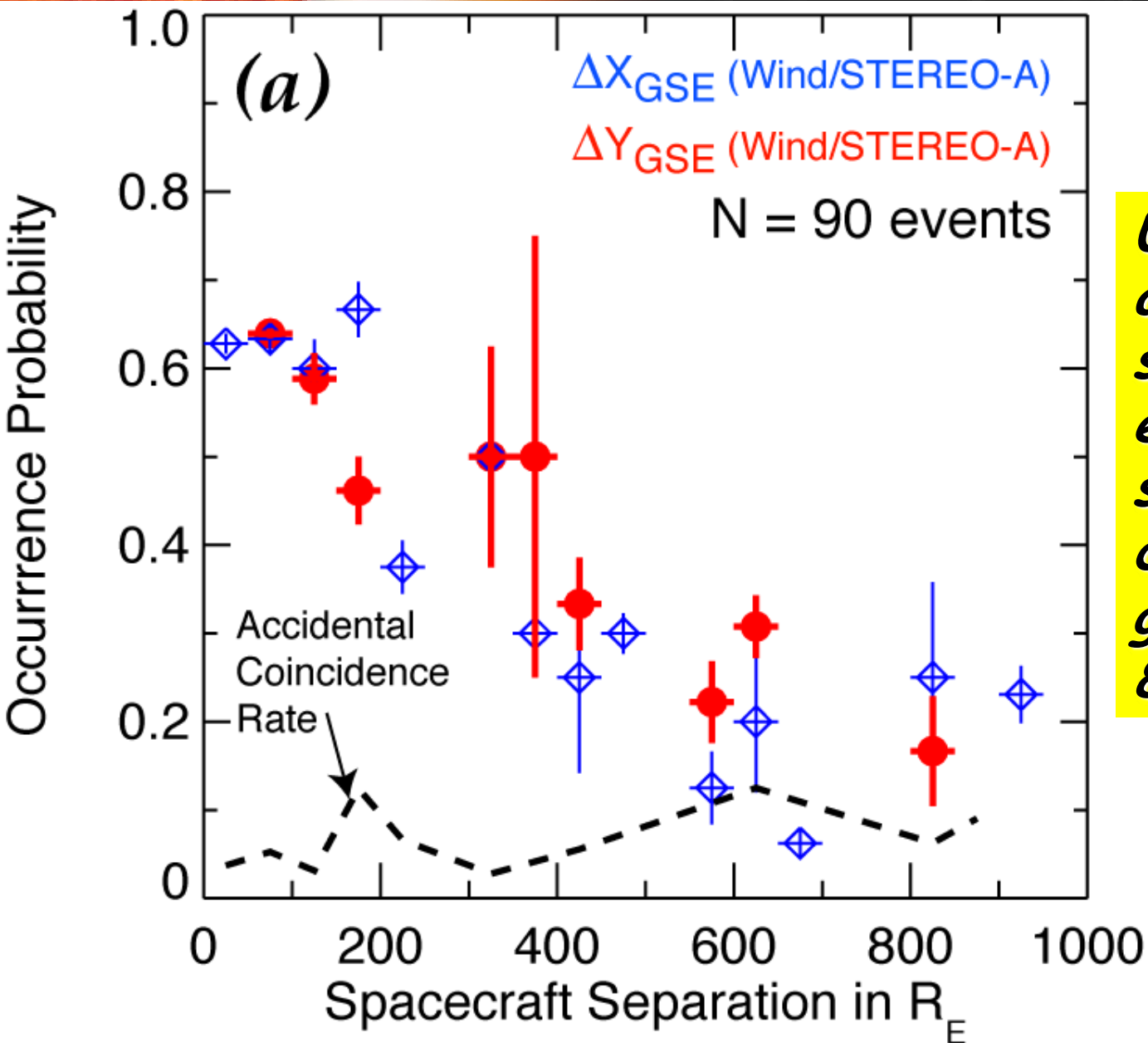
$\Delta X = 922 R_E$

$\Delta Y = 1752 R_E$

$\Delta R = 1980 R_E$



Occ. Prob. vs. S/C Separation



Upstream events are observed simultaneously even when the separation distance is greater than $800 R_E$



Results Summary

- STEREO-A observed upstream events even when it was separated from Earth by $\sim 1750 R_E$ in the radial and $\sim 3800 R_E$ in the lateral directions
- Occurrence probability of simultaneous upstream events at L1 and STEREO-A remained high ($\sim 20\text{-}30\%$) at large radial and lateral separation distances ($>500 R_E$);
 - Upstream events originate from a global source region and fill a large volume of interplanetary space upstream of Earth
- => Size of spatial structures >0.03 AU or more

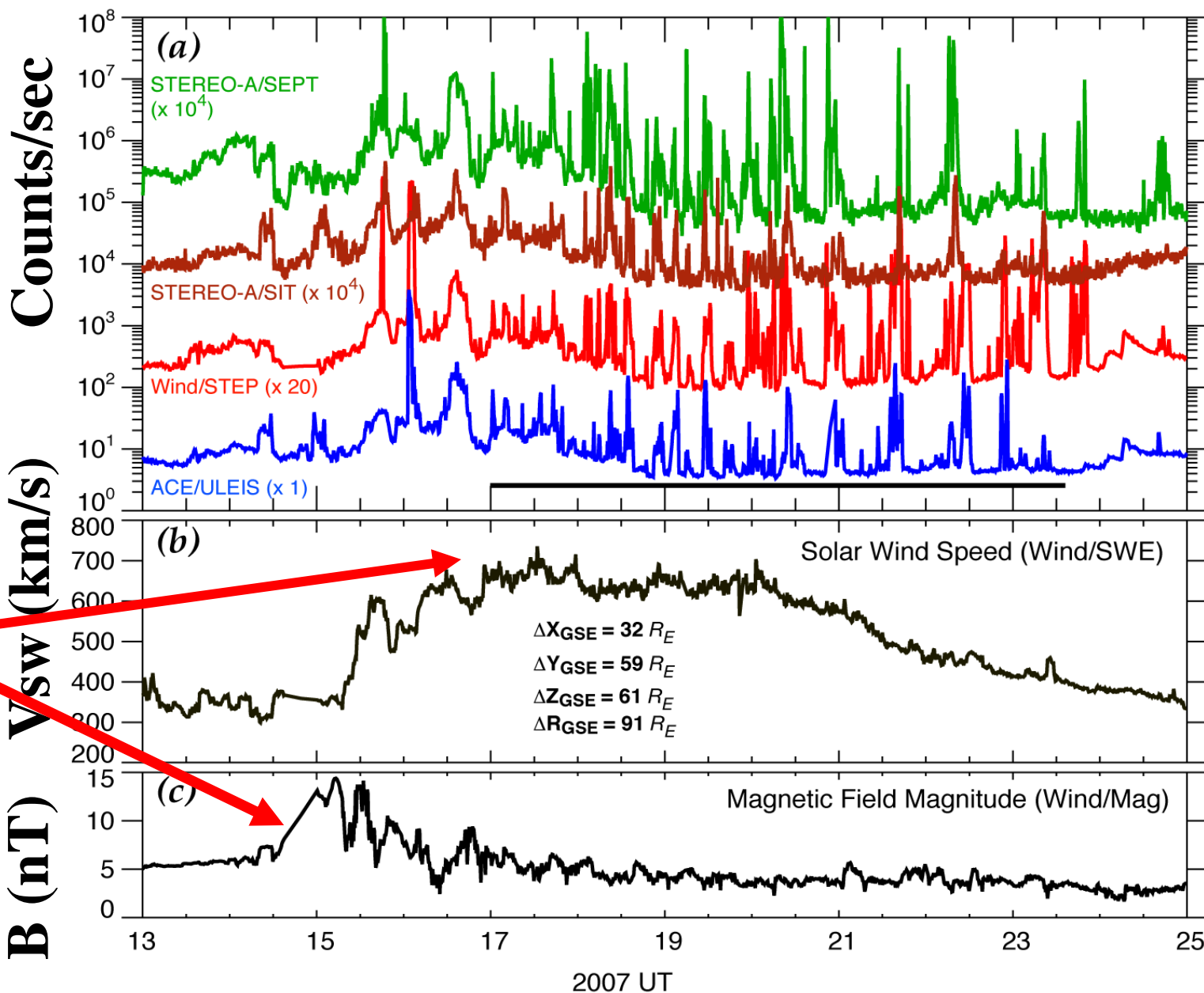
Upstream events & CIRs

$\Delta X = 32 R_E$

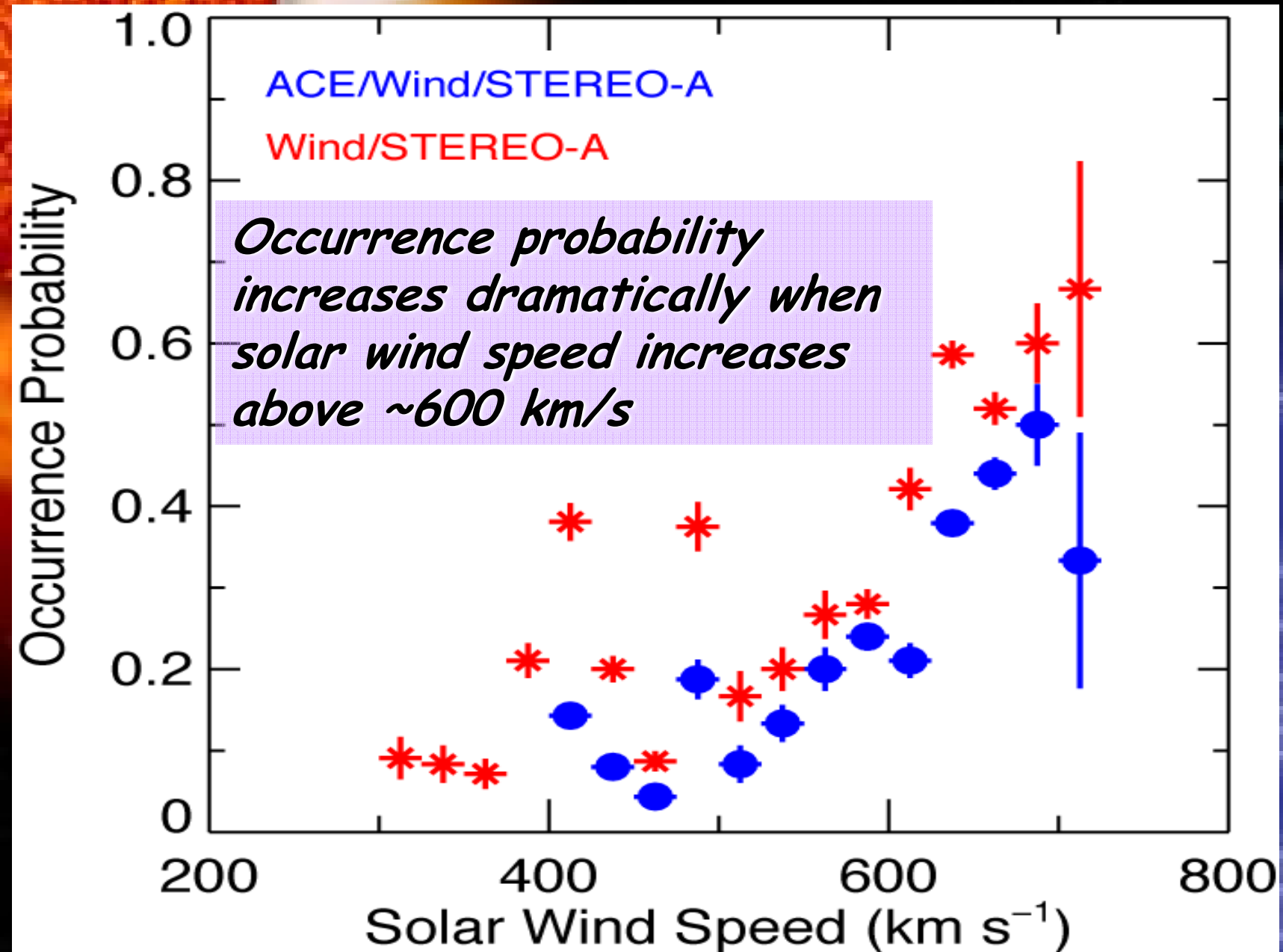
$\Delta Y = 59 R_E$

$\Delta R = 91 R_E$

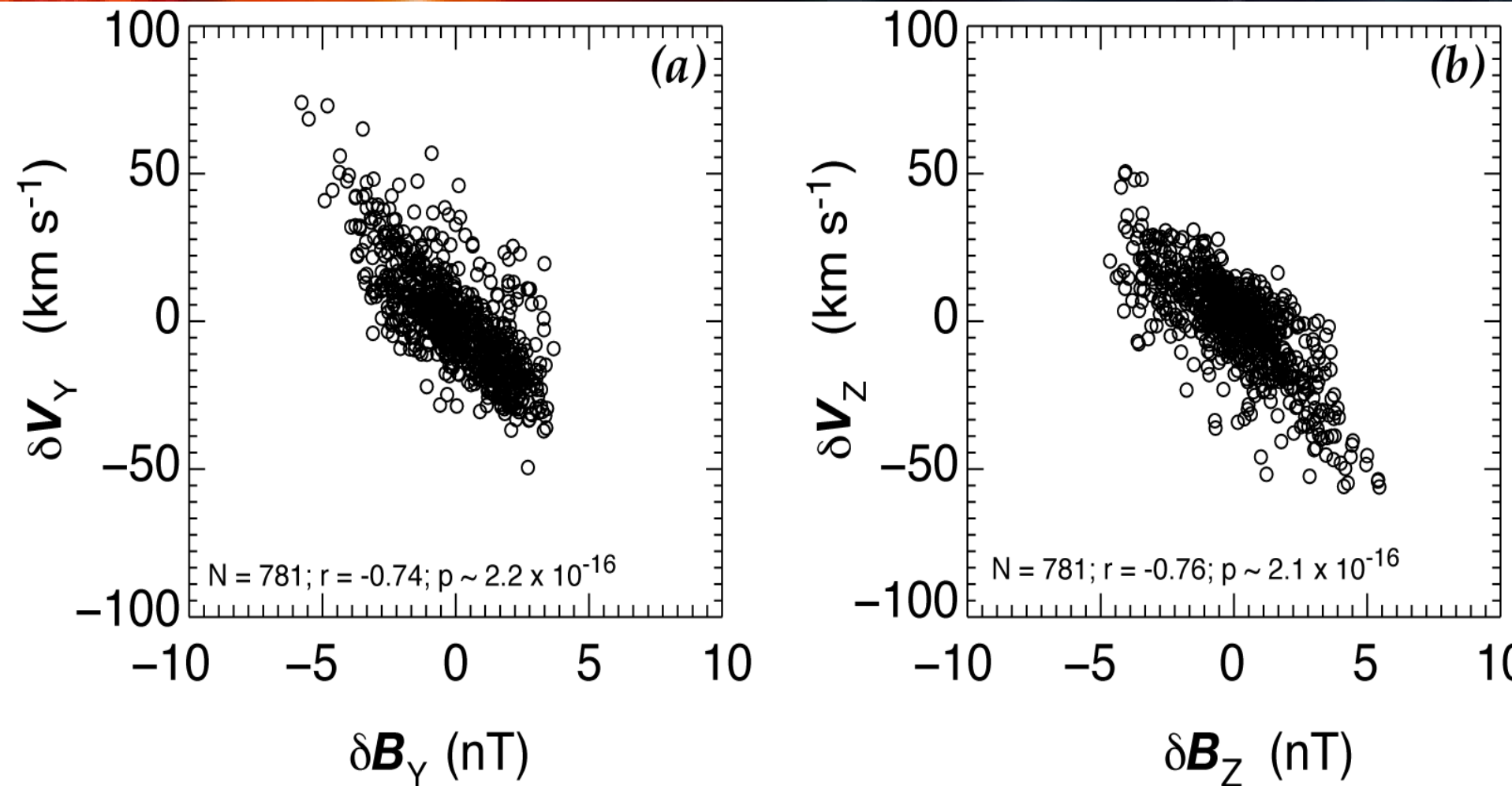
Occur in the high speed solar wind flow after the compression region passes Earth



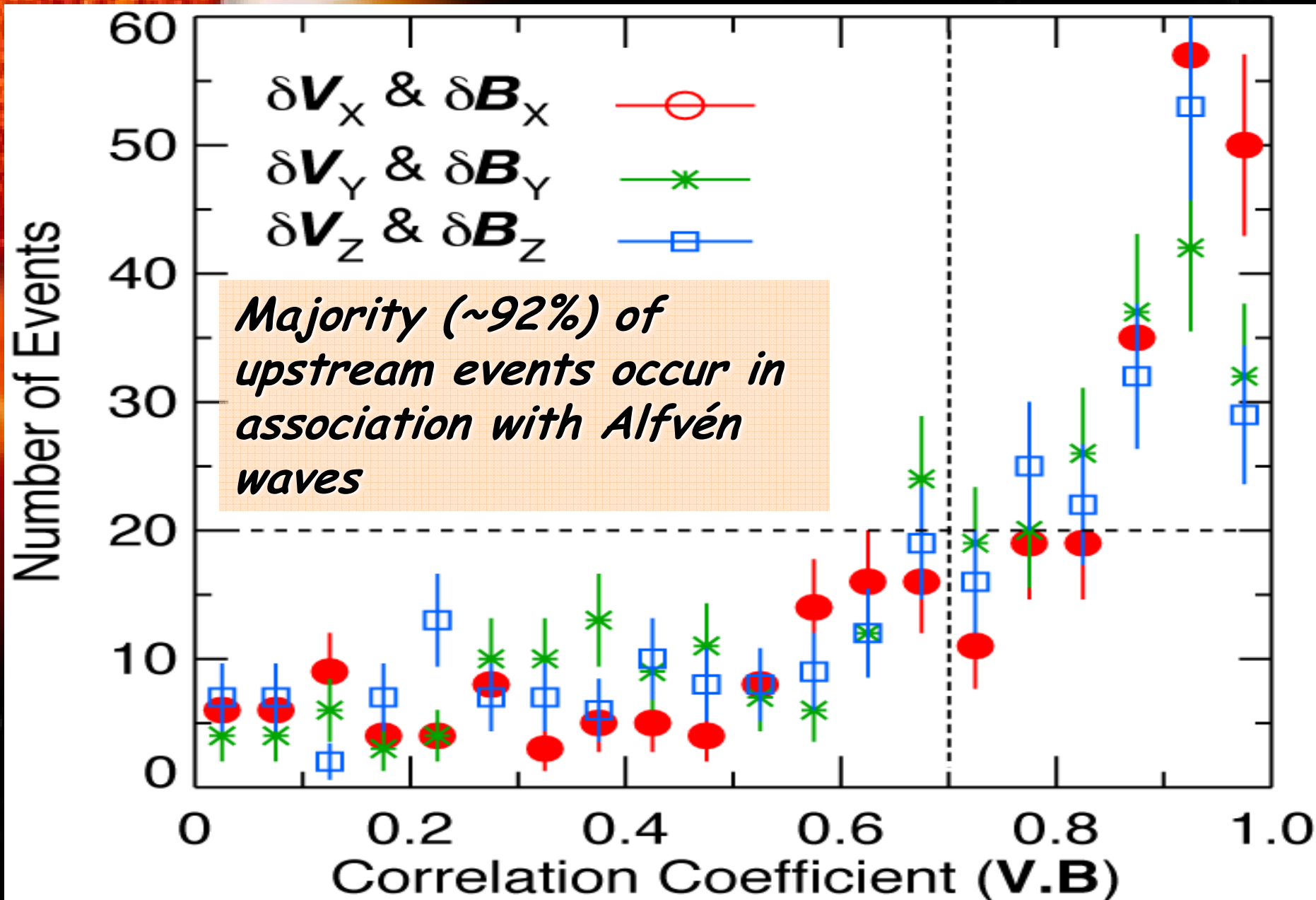
Occ. Prob. vs. V_{SW}



Events are correlated with the arrival of large amplitude anti-Sunward propagating Alfvén Waves



Upstream events & Alfvén Waves



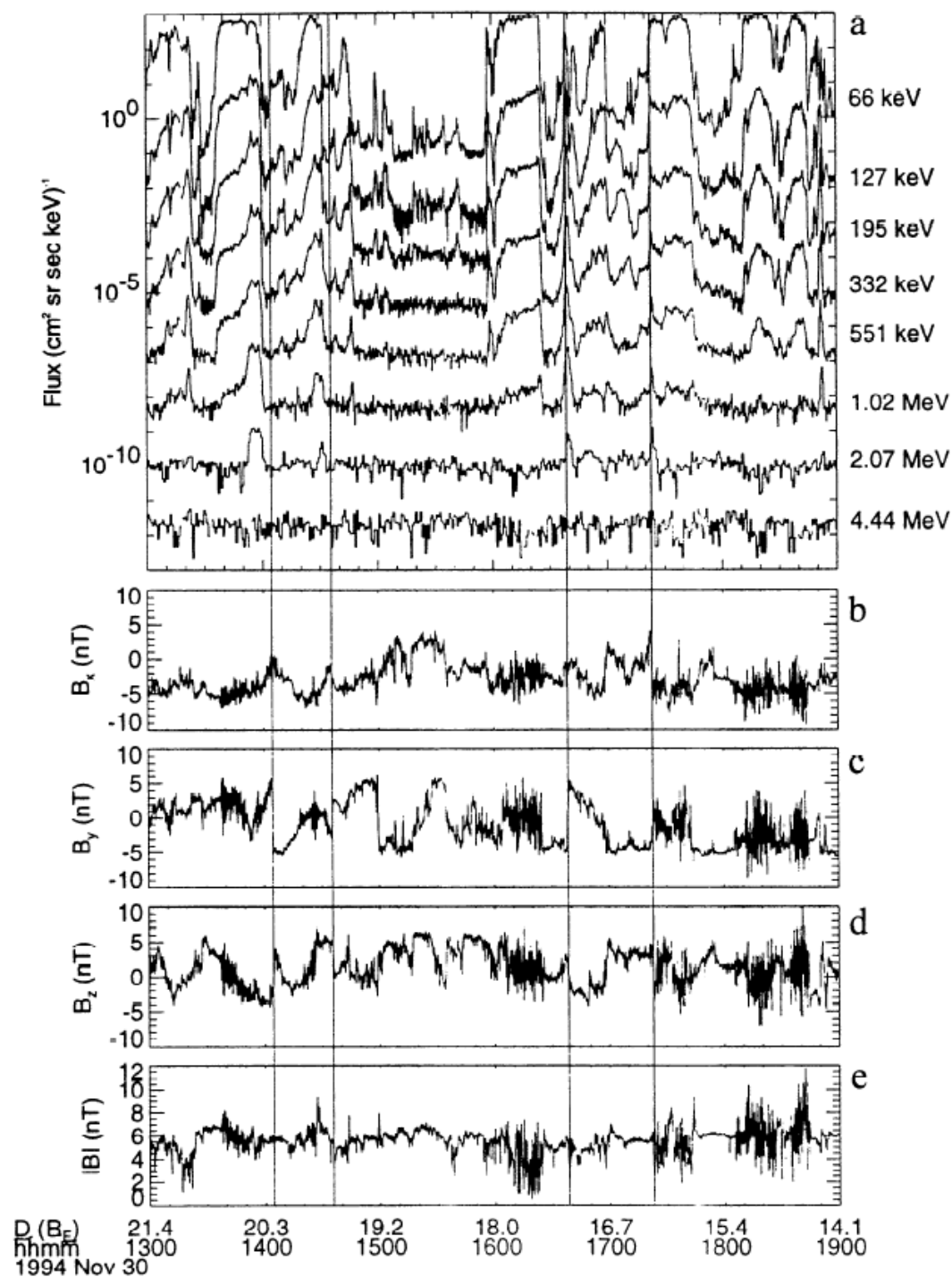
Possible Scenarios

- **Compression regions energize the magnetosphere and Alfvén waves provide easy access to ions accelerated inside the magnetosphere**
- **Compression regions initiate a bow shock acceleration process, and the Alfvén waves facilitate their transport out to STEREO-A**
- **Compression regions play a minor role; Alfvén waves themselves play a dominant role in accelerating the particles as well as in acting as channels transport to large distances upstream**

Freeman & Parks (2000)

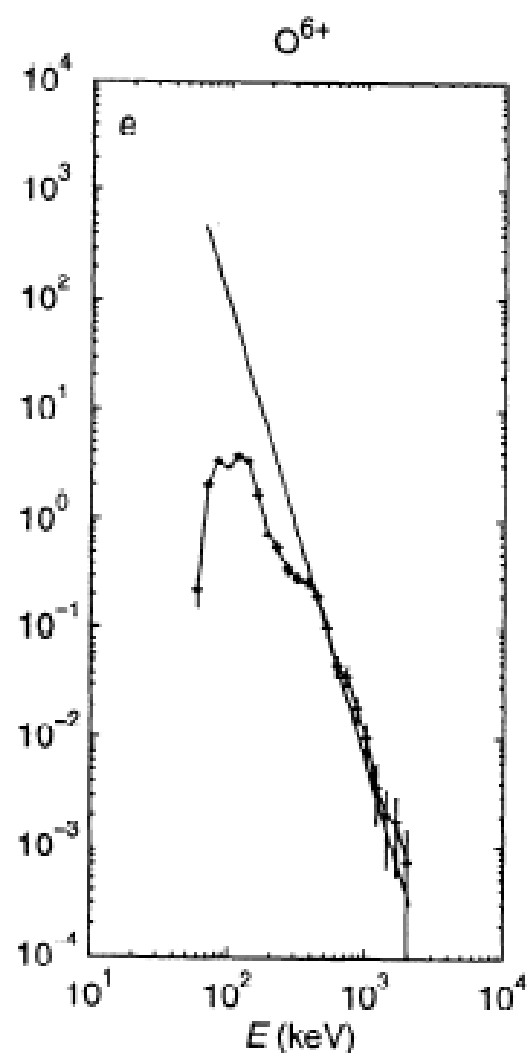
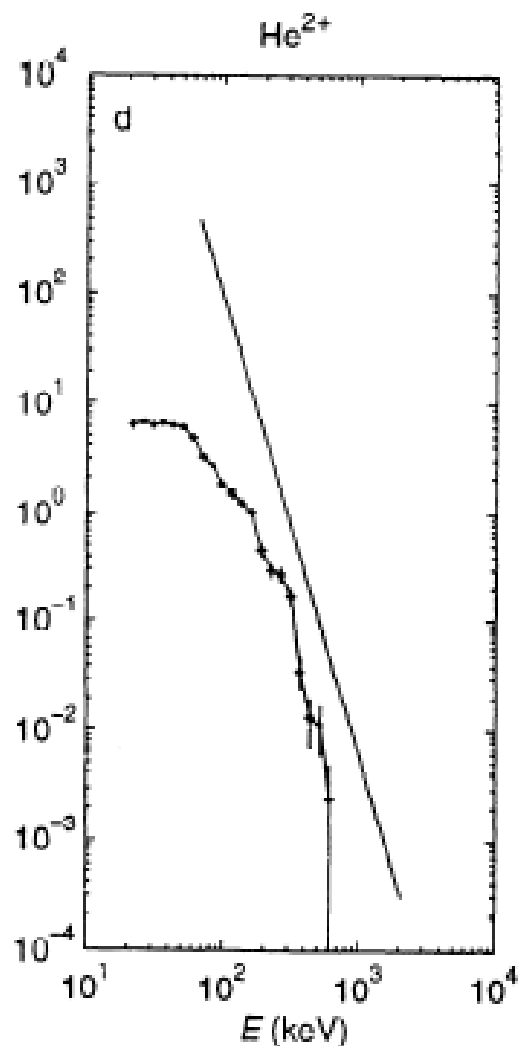
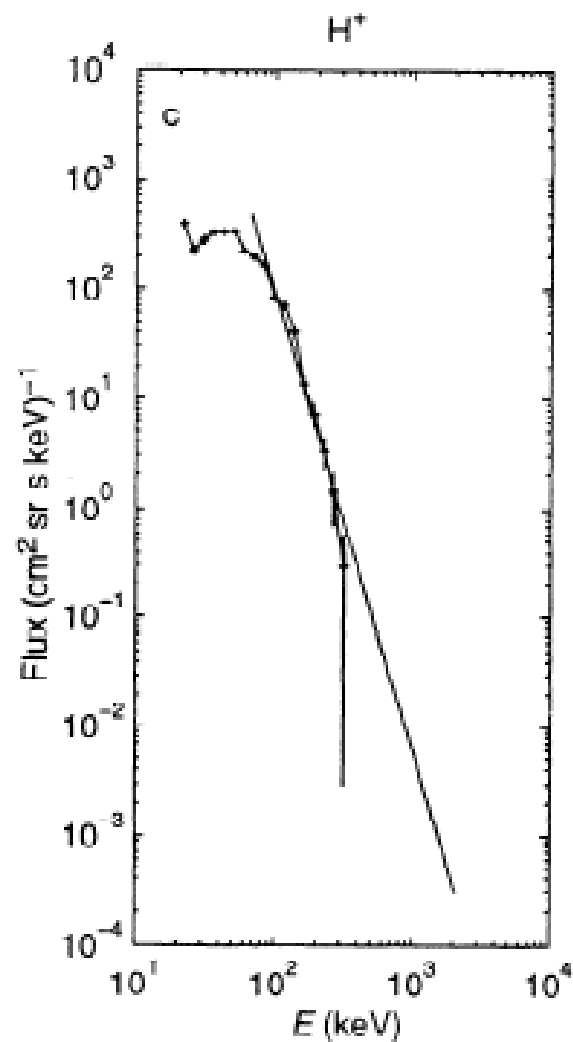
Upstream ions are accelerated by reflection between two converging magnetic mirrors: (1) large IMF rotations and (2) the Earth's bow shock

Our results show that these "IMF rotations" are large amplitude Alfvén waves that are embedded in high-speed solar wind streams



All species are accelerated up to a maximum E/Q of ~ 300 keV/ q

Freeman & Parks (2000)



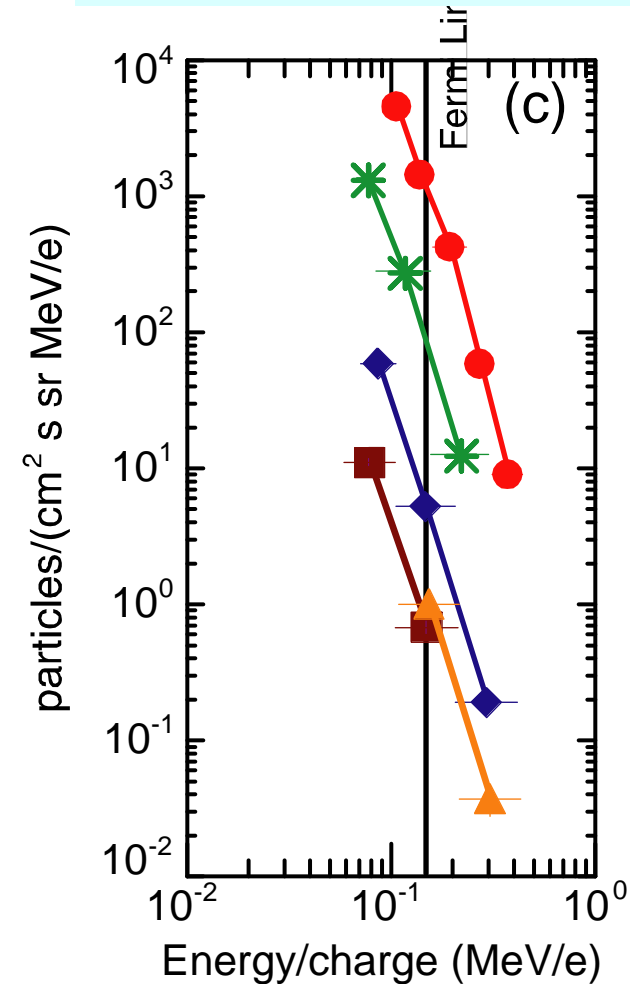
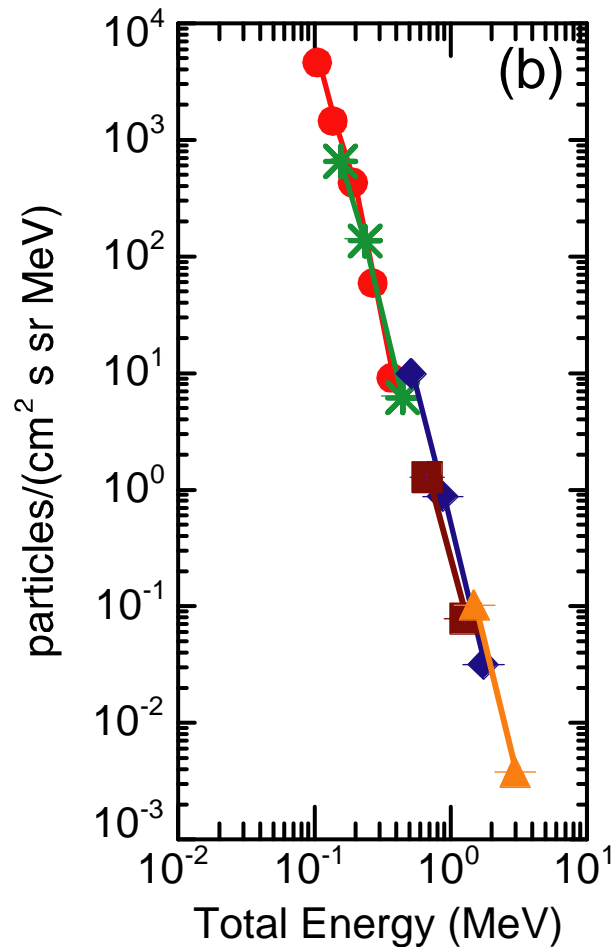
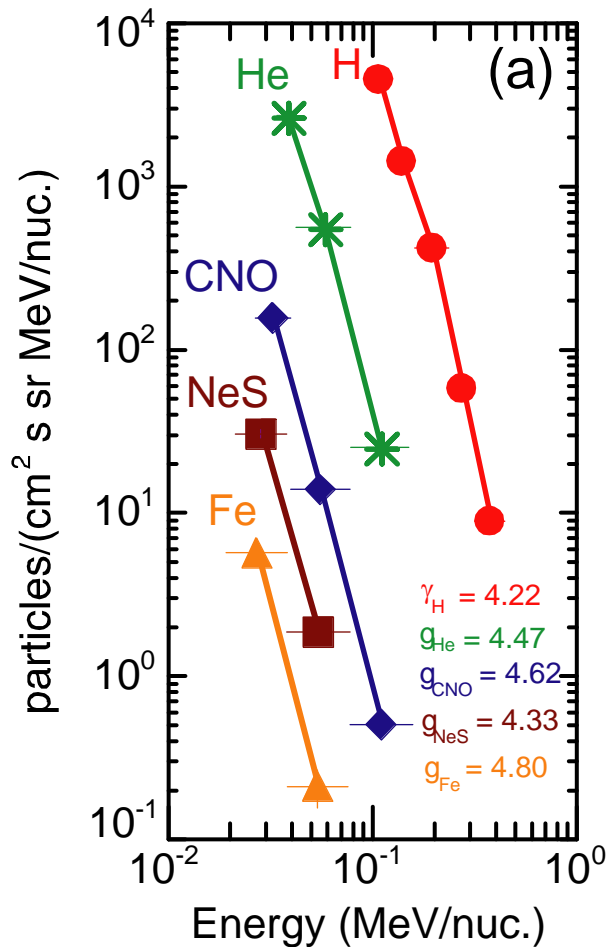
A possible solution?

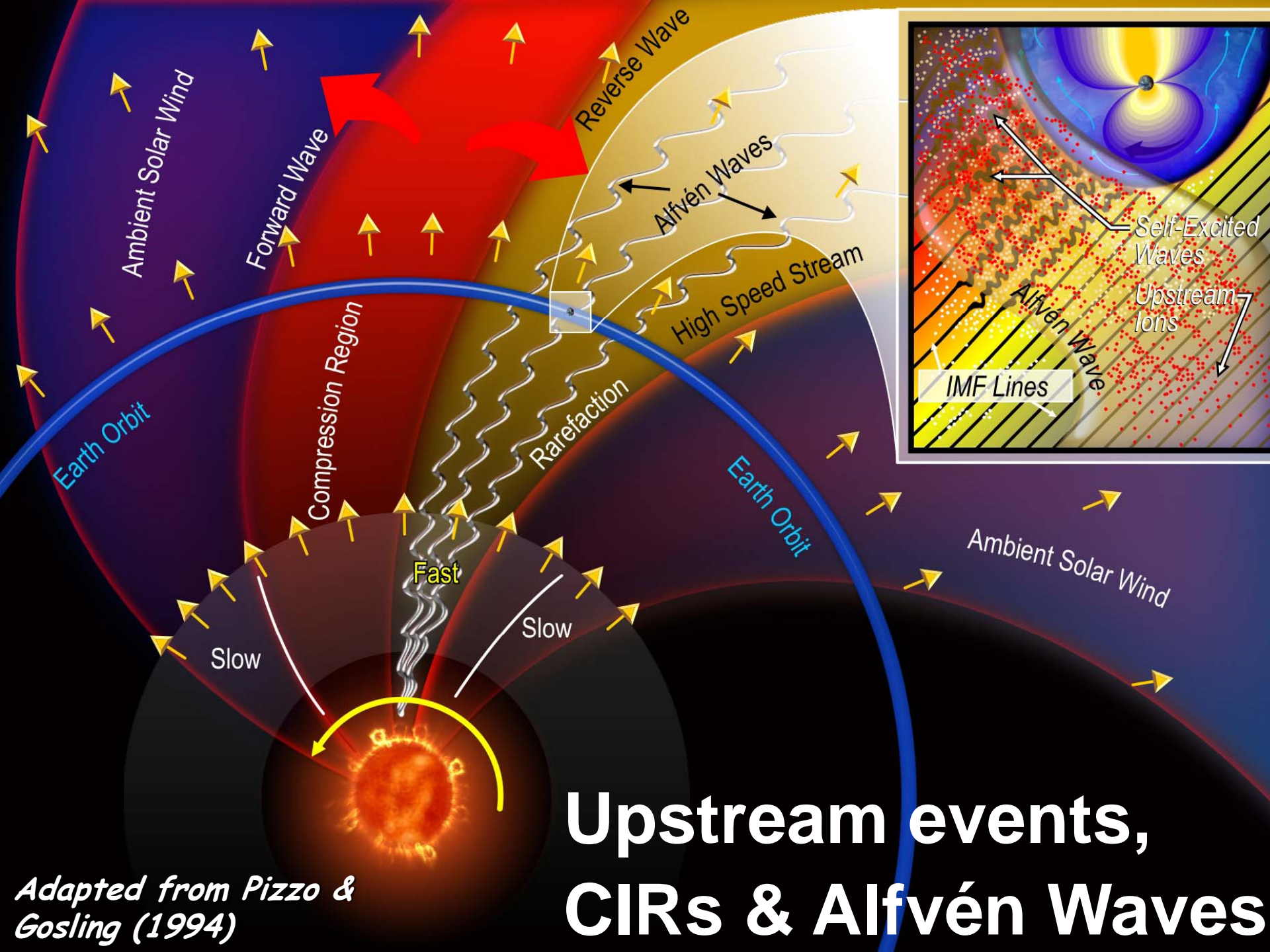
Desai et al., 2000 JGR, vol.

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Soft power-Laws

Single power-law in total energy

Extend above ~150 keV/q; Cut-off at ~300 keV/q





Upstream events, CIRs & Alfvén Waves

Adapted from Pizzo & Gosling (1994)

Conclusions

- **Composition & Spectra**
 - Seed population comprises suprathermals and occasionally singly-charged ionospheric ions
 - Spectral indices of E^{-4} ; all species obey a single power-law in total energy and cutoff at ~ 300 keV/q
- **Spatial Distributions**
 - Imply global source region probably as large as the size of the Earth's bow shock
 - Ions propagate inside large amplitude Alfvén waves of the order of 0.03 AU or more that are embedded in high-speed solar wind streams
- **Alfvén waves and the Earth's bow shock act as converging magnetic mirrors and accelerate SW suprathermals via the first-order Fermi process**