Origin of counter-streaming solar wind suprathermal electrons at solar minimum

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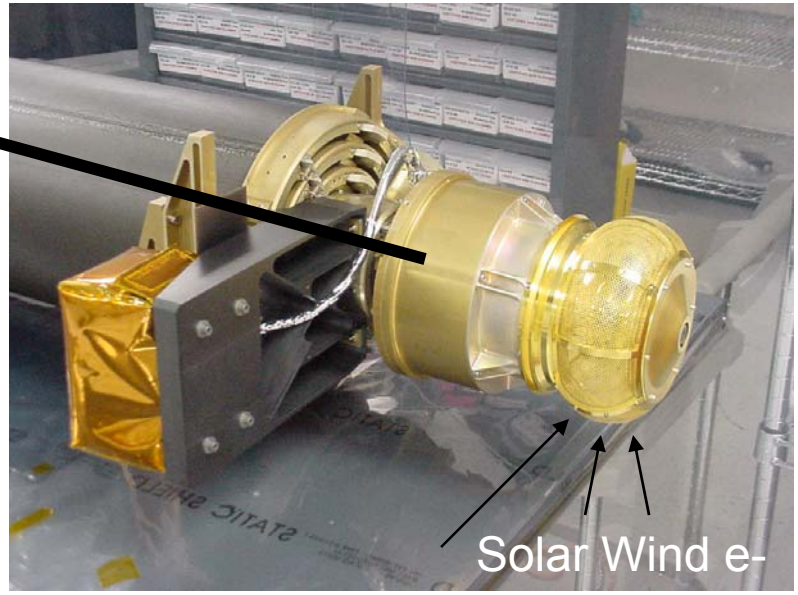
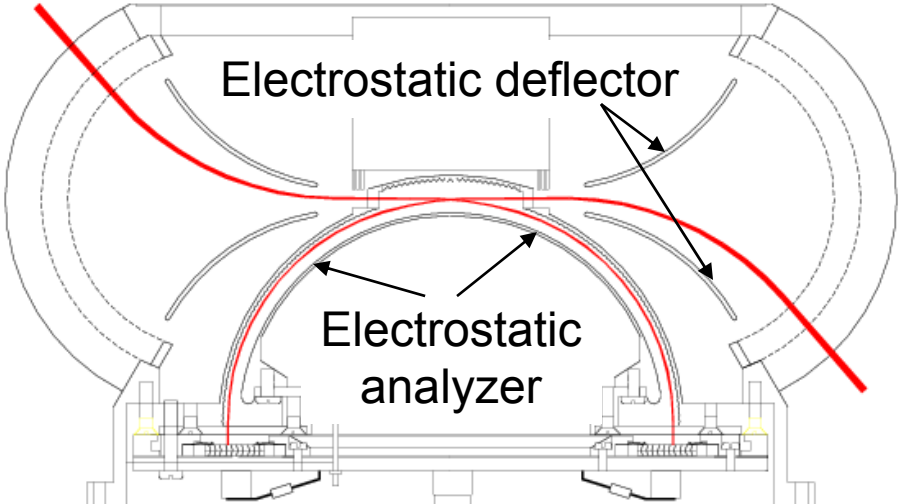
Outline

- Introduction to STEREO/SWEA
- Event illustration and method
- Relationship of counter-streaming suprathermal electrons (CSE) with:
  - Corotating interaction regions
  - CME / transients
  - Reconnection at the HCS
- Conclusions

Introduction

The STEREO Solar Wind Electron Analyzer (SWEA) instrument



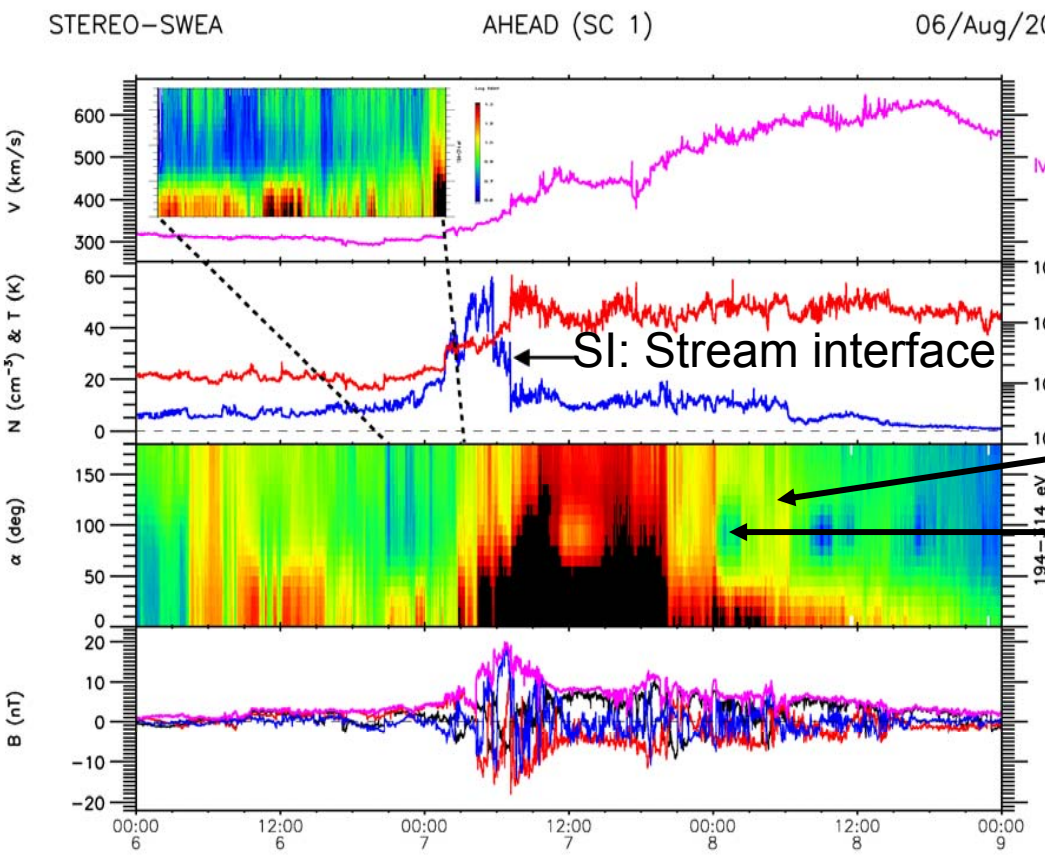


- **IMPACT/SWEA instruments identical on ST-A and B**
- **Inter-anode and inter-deflection calibrations**
- **Pitch angle distributions are well determined**
- **Checked between ST-A and B at short separations and with WIND/ACE**

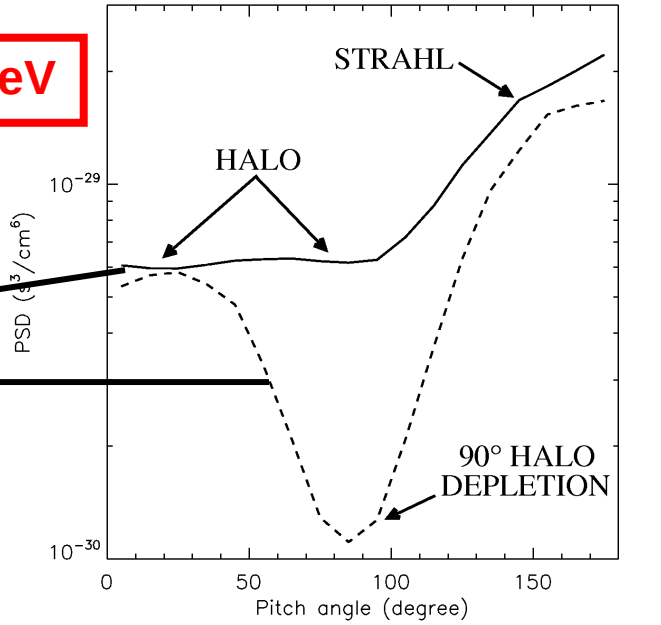
[*Sauvaud et al.*, 2008; *Luhmann et al.*, 2008]

Event illustration and method

Illustration of CSEs at CIRs (solar min.)



Sample PA distributions

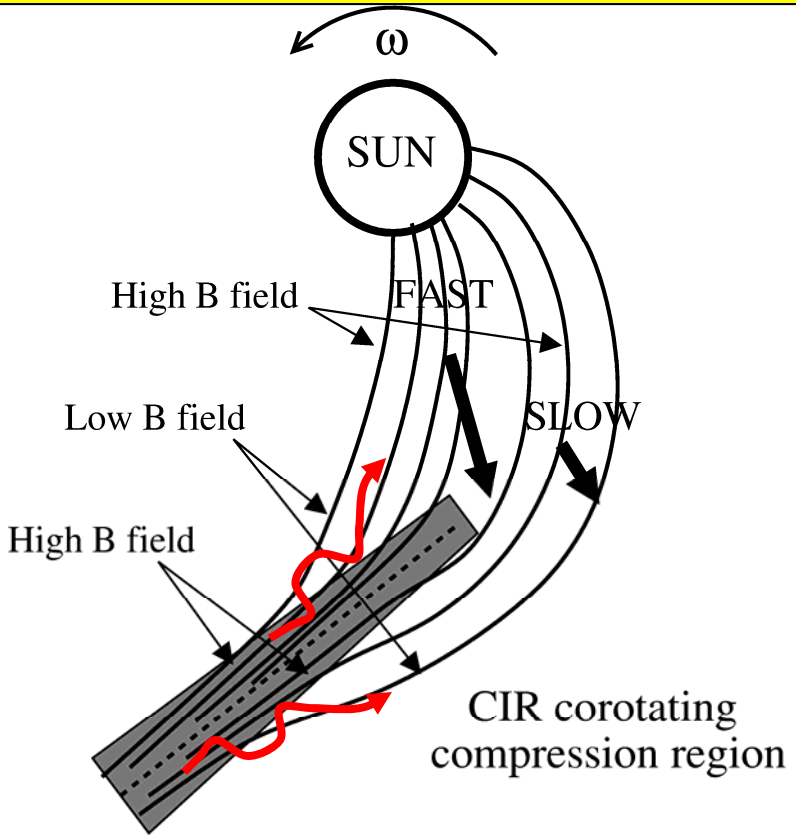


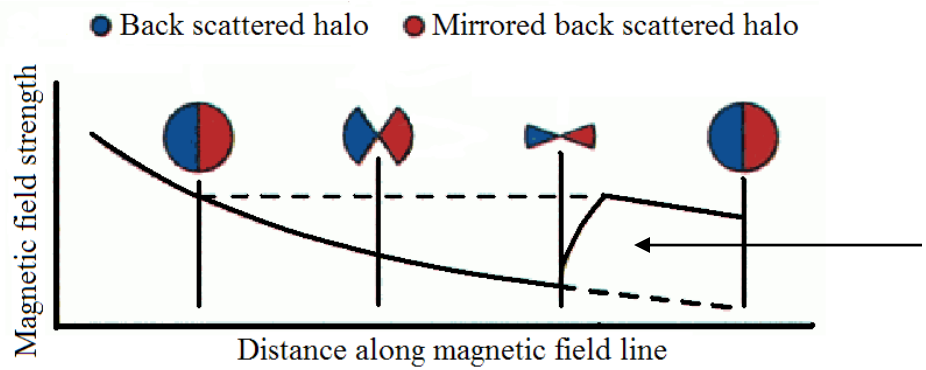
Analyzed all 2007 data:
- compared PSD of halo (lowest of 0° and 180°) with PSD at 90°
- CSE if 20% lower at 90°

→ **CSEs tend to appear:**
- Before and after SI/CIRs
- Not at the SI (max. in B)

CSEs and CIRs

Origin of CSEs around CIRs





Counter-streaming at CIRs may owe to combination of:

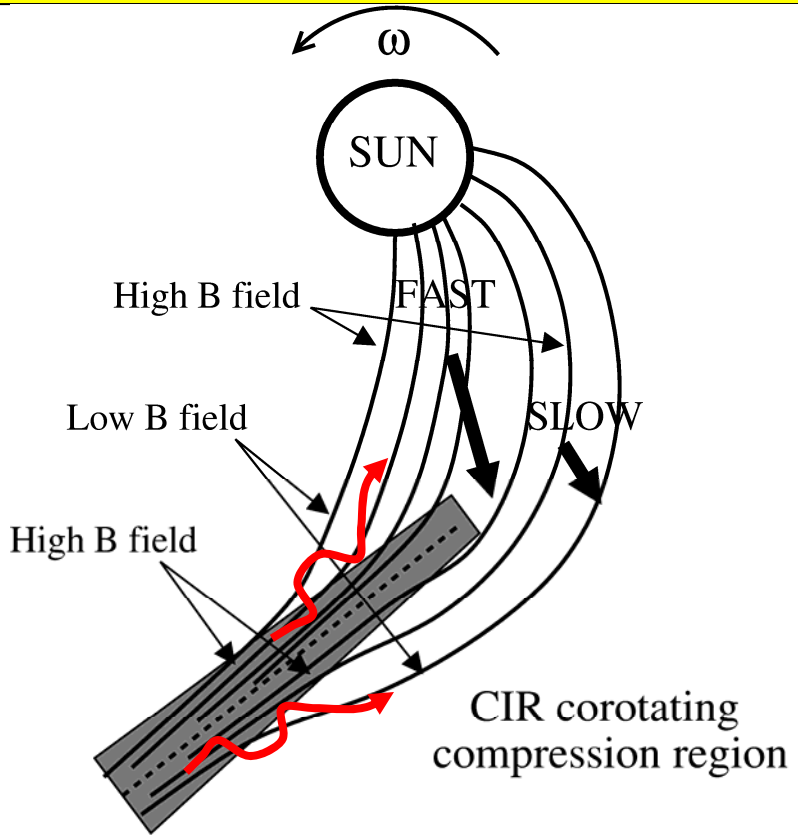
- shock acceleration,
- pitch-angle scattering,
- leakage and,
- 90° pitch angle depletion

[*Gosling et al.*, 1993; 2001]

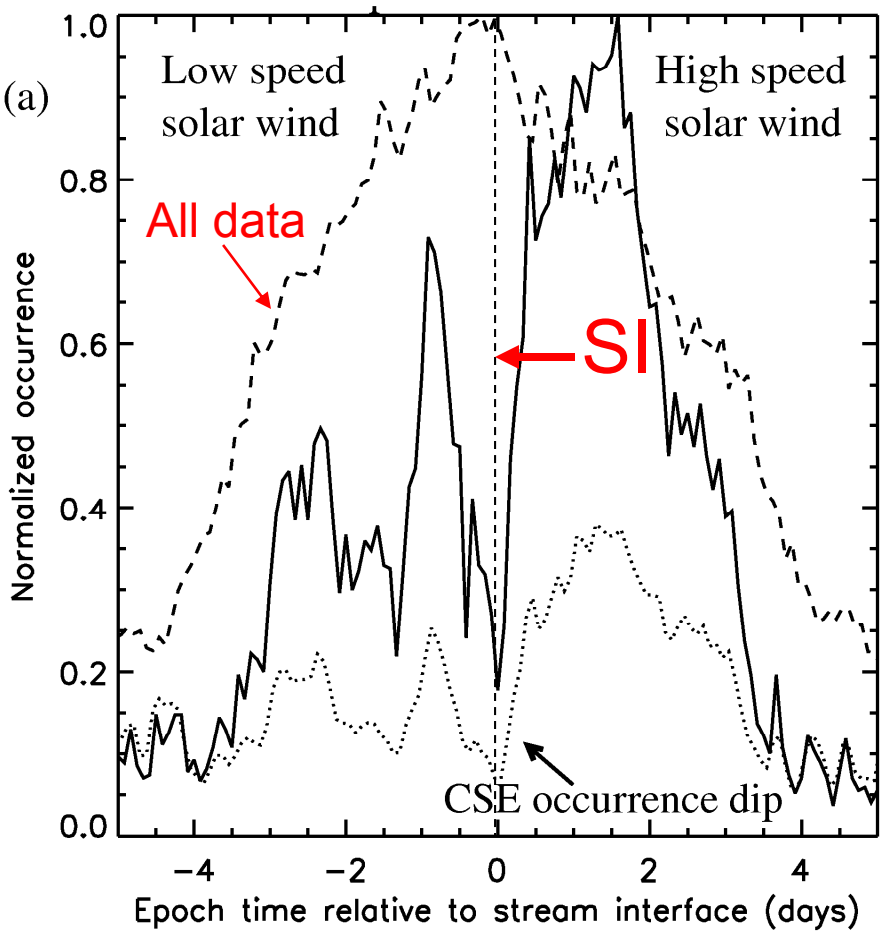
Statistical analyses yet to confirm this relationship

Non-monotonic B variation

Statistical relationship with CIRs



Superposed epoch analysis of CSE occurrence



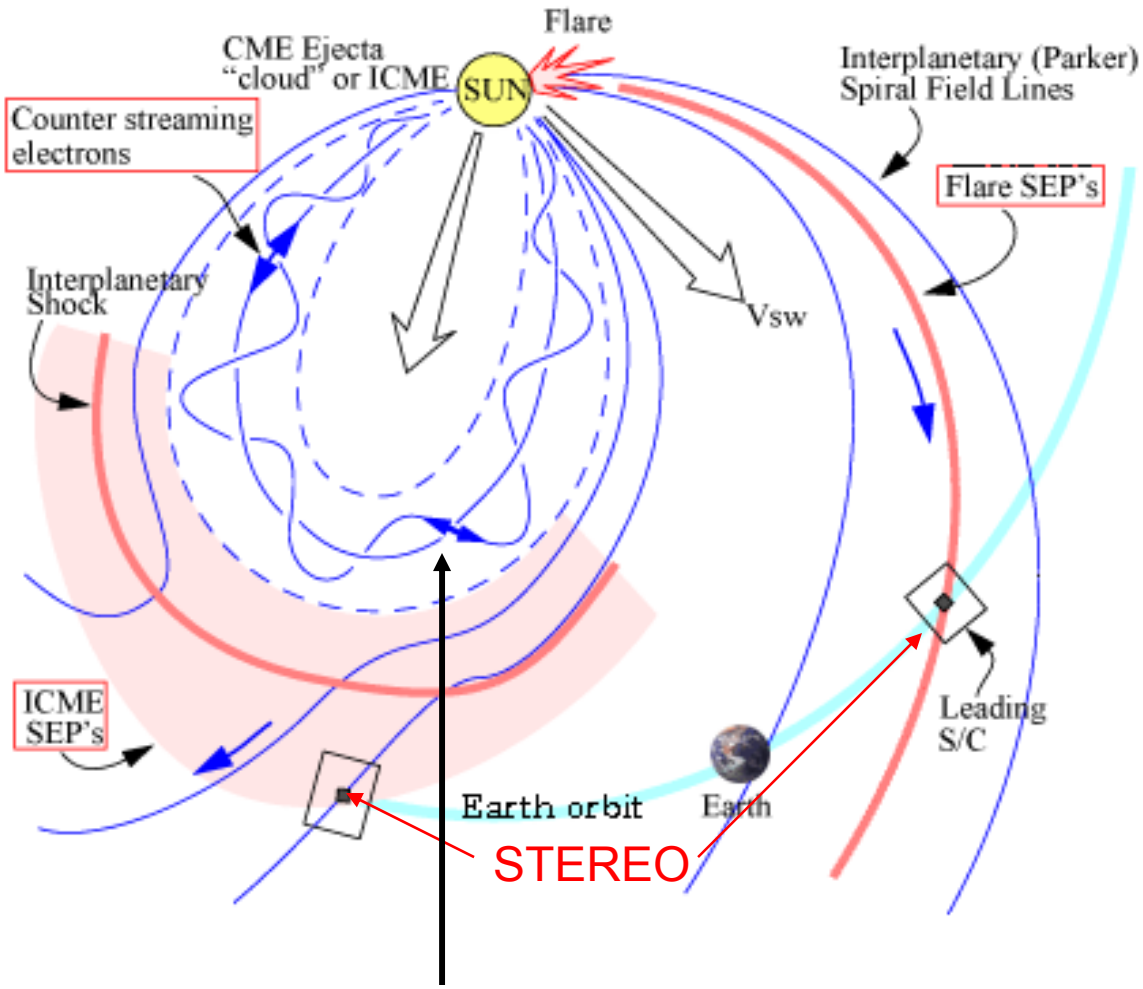
CSEs expected and observed:

- before and after stream interface (SI),
- but not much at SI, nor far from it

[*Lavraud et al.*, 2010]

CSEs and CME/transients

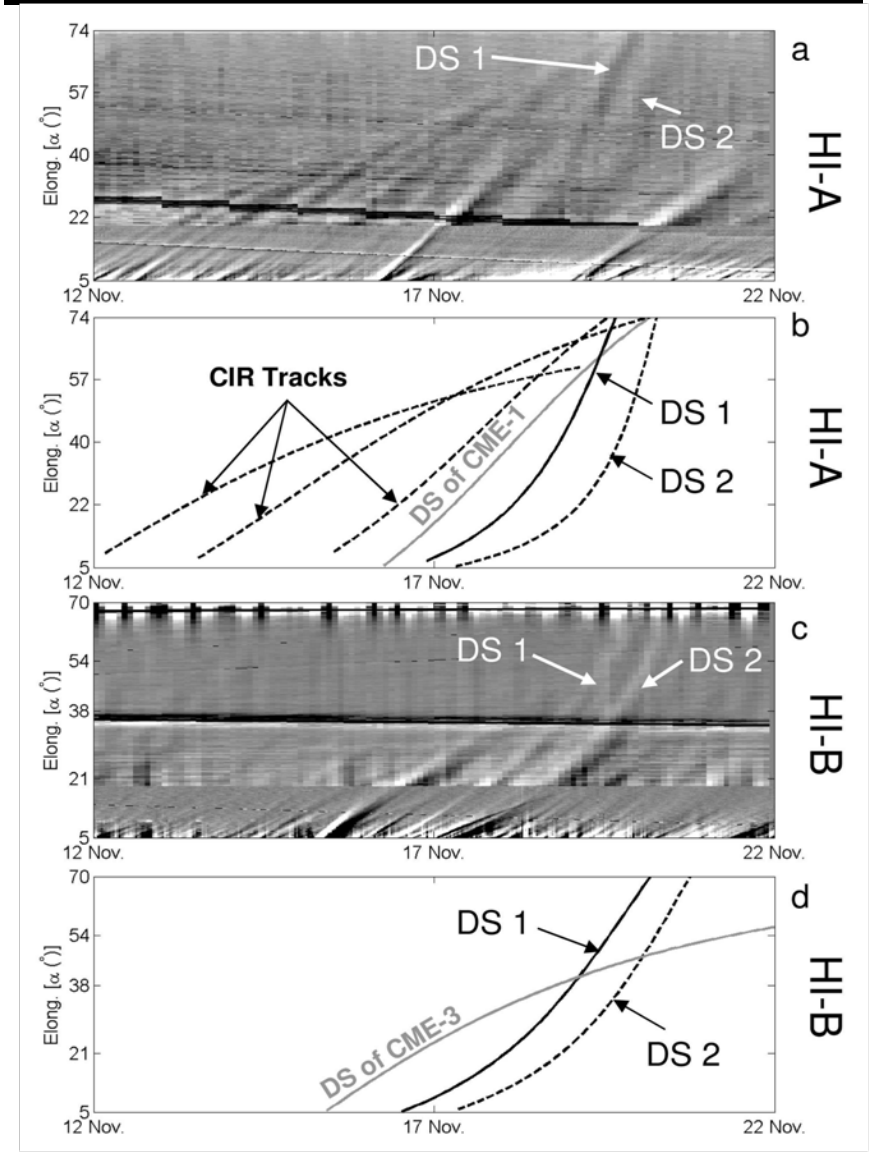
Origin of CSEs in CME/transients



Counter-streaming may owe to closed nature of CMEs (e.g., solar max) [*Gosling et al*., 1987]

Origin of transients at Solar minimum

J-maps from SECCHI-HI observations



DS = Density structure

- **HI difference images** highlight the passage of **density structures** in the field-of-view (FOV)

- The structures may be due to **blobs or compressions** associated with **CIRs and CMEs**

HI observations very often indicate complex signatures suggestive of transients embedded/entrained by CIRs

[e.g., *Rouillard et al*., 2008; 2009]

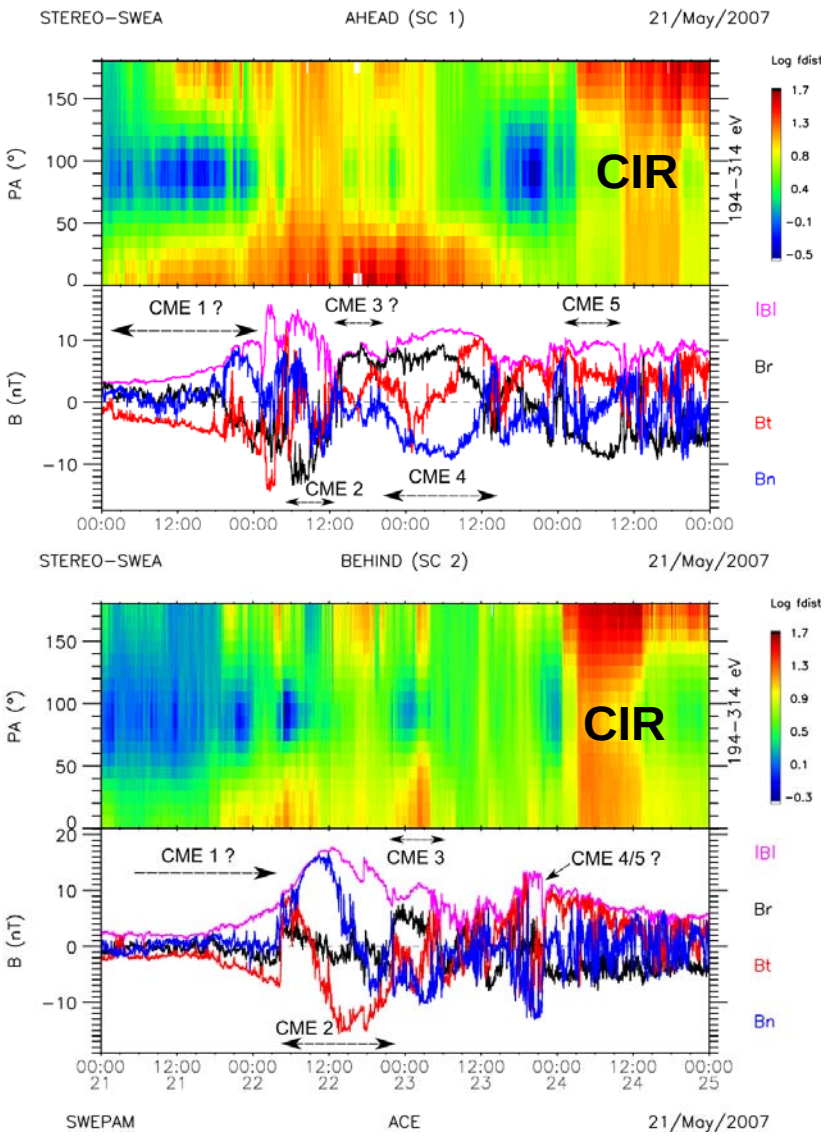
Relationship with transients/closed loops

CME-type structures:
- Counter-streaming electrons
- Enhanced B field
- Smooth B rotation
- Lower plasma β, etc.

In situ observations confirm the recurrence of small- and large-scale transients in the slow wind ahead of CIRs

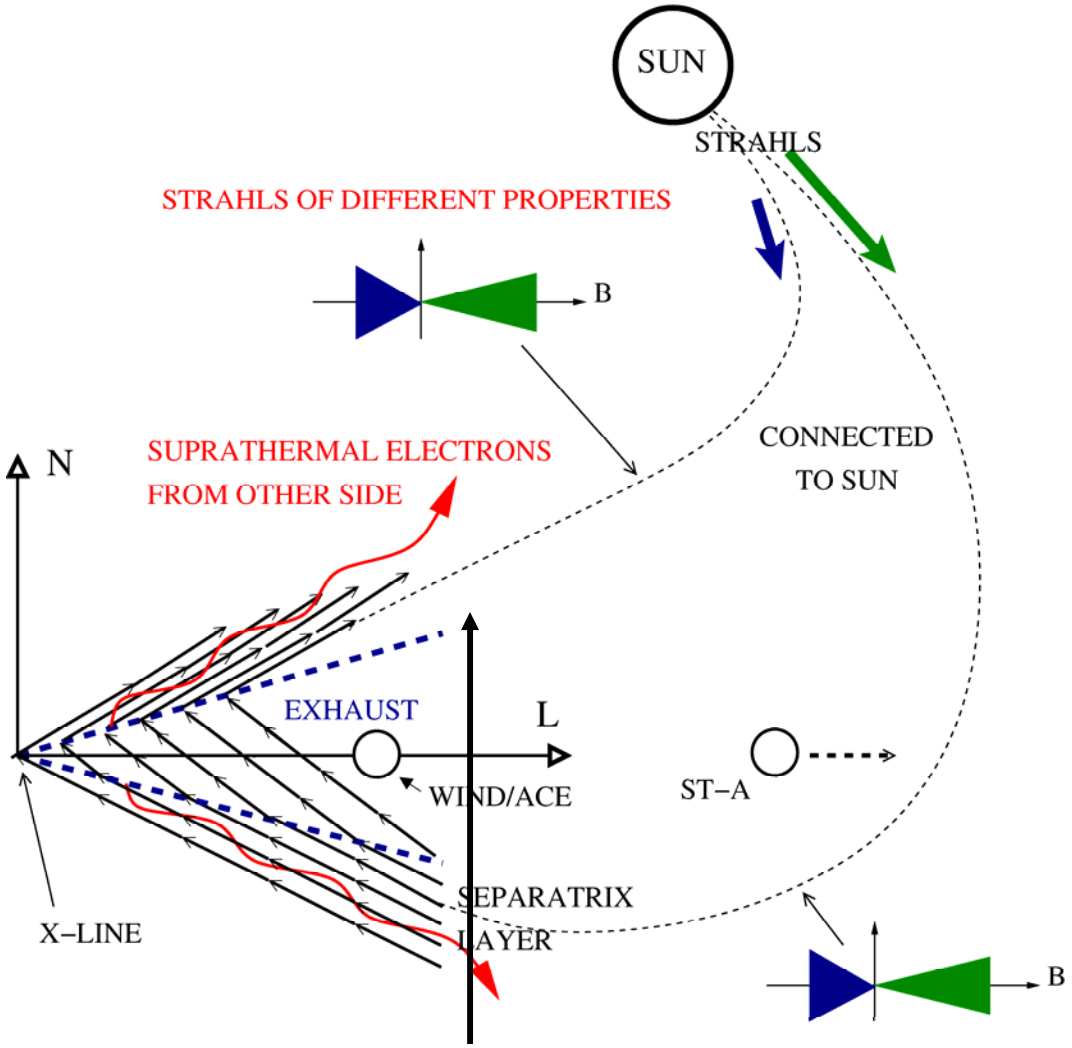
[e.g., *Rouillard et al*., 2008; 2009;
Kilpua et al., 2010;
Lavraud et al., 2010;
Chollet et al., 2010]

In situ electron PADs and B-field



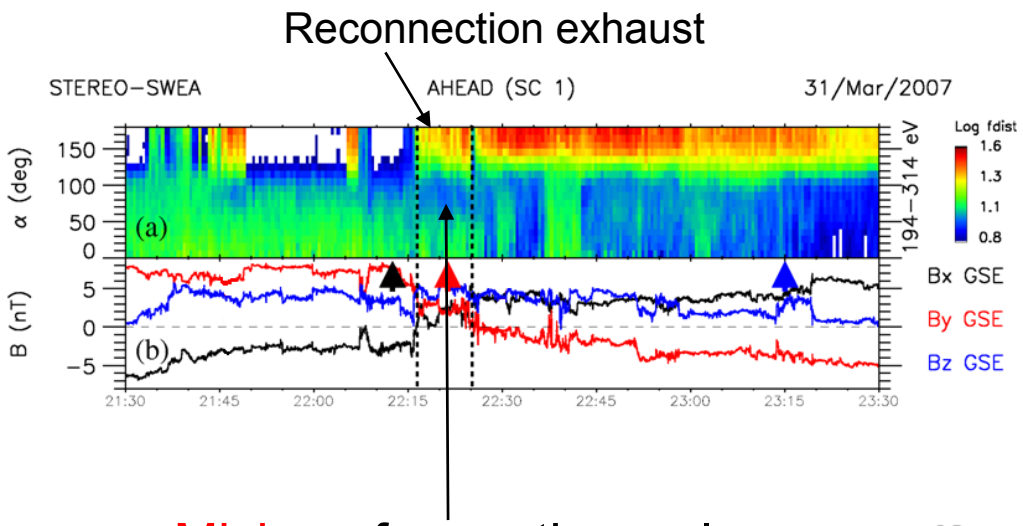
CSEs and reconnection at HCS

Origin of CSEs at the HCS



Counter-streaming may owe to <u>NEWLY</u> closed nature of loops after reconnection [*Gosling et al.*, 2006]

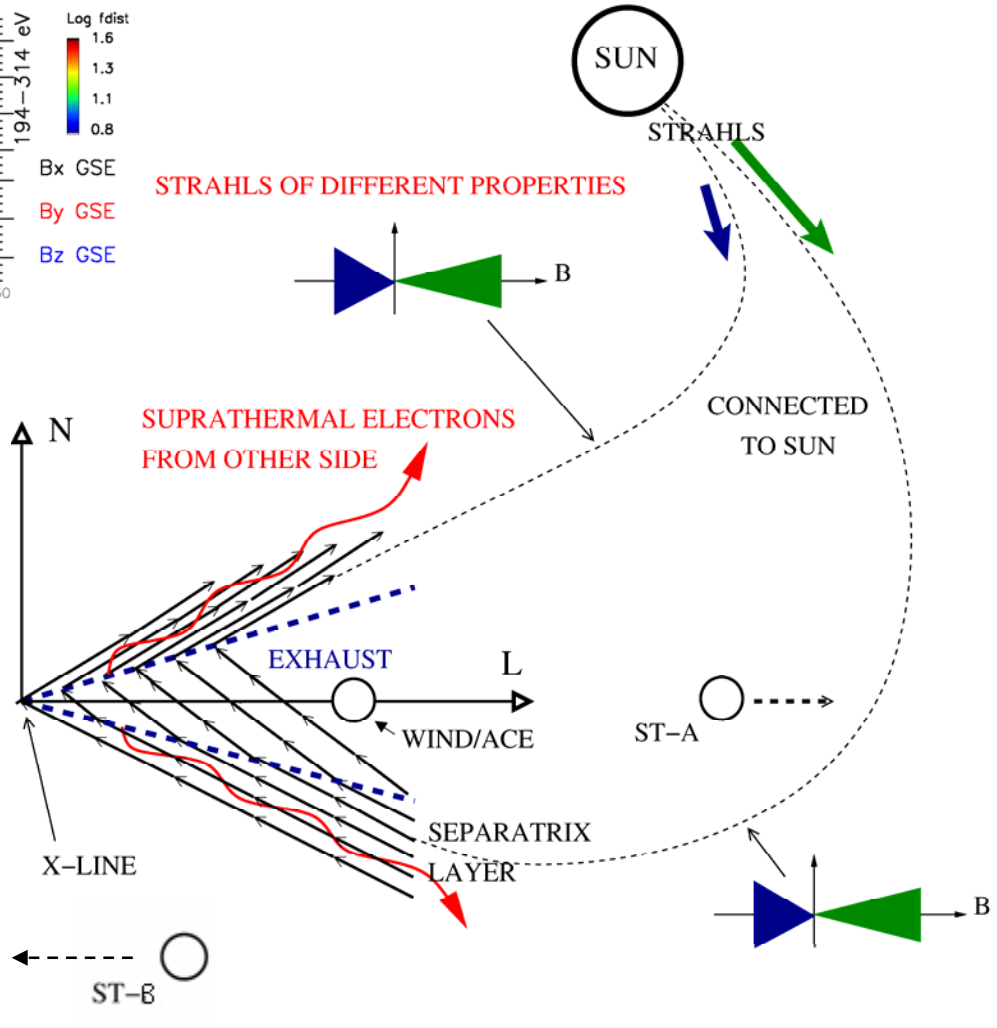
Origin of CSEs at the HCS



- Mixing of suprathermal electrons from both sides
  → Newly closed field lines

- Demonstration of electron separatrix layer existence

- Same exhaust observed by spacecraft 1800 R_E apart
  → Reconnection steady!?



[*Lavraud et al.*, 2009]

Conclusions

- CSEs occur 5-20% depending on definition criteria
  → Should occur more frequently:
  continuous pitch-angle scattering

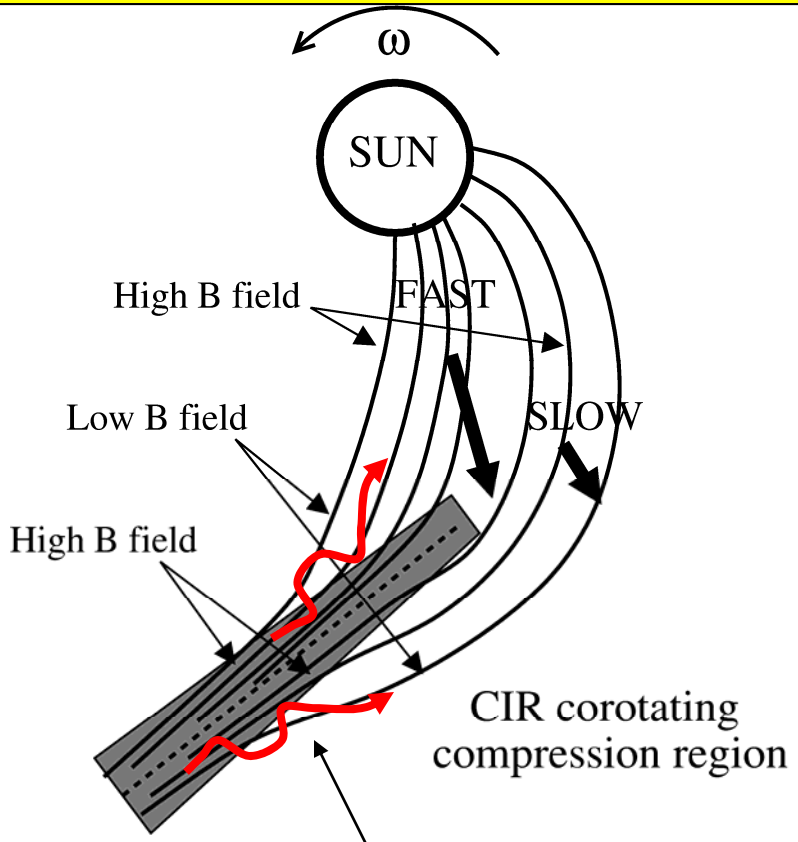
- CSEs are related to CIRs, i.e., the main locations of enhanced B and shock reflection that create CSEs
  → What about high helio. latitudes?

- CSEs from small-scale transients is also frequent in the slow wind prior to CIRs, only!
  → What is their occurrence and significance?

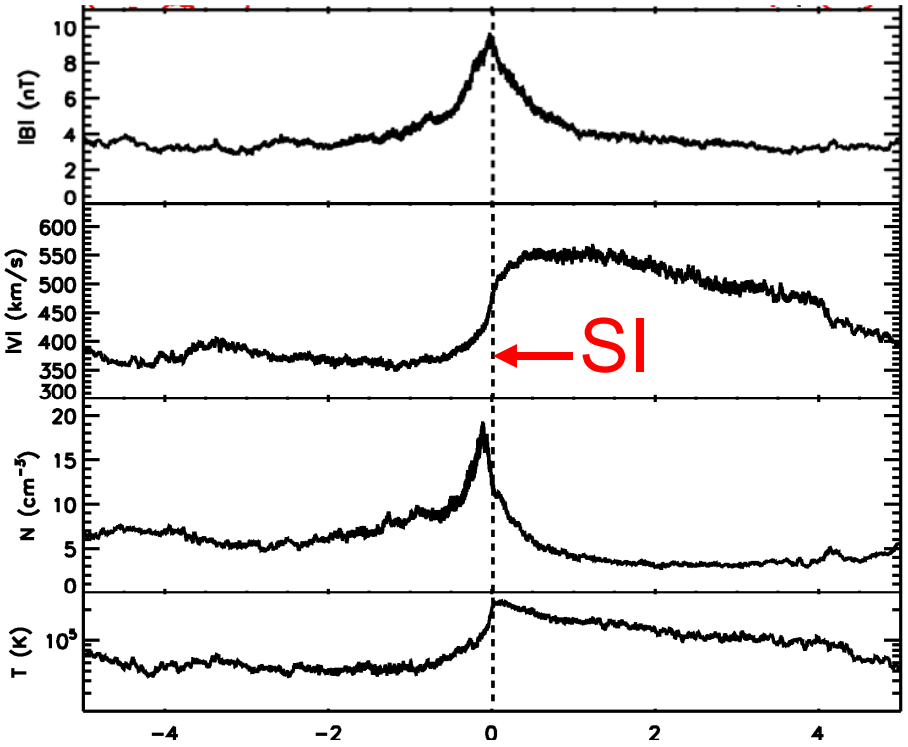
- CSEs observed in newly closed loops after magnetic reconnection, but only at the HCS
  → Minor significance!?

Additional slides

Statistical relationship with CIRs

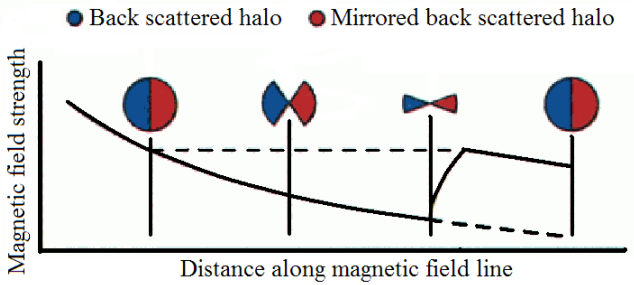


Superposed epoch analysis of SW parameters



Epoch time relative to stream interface (days)

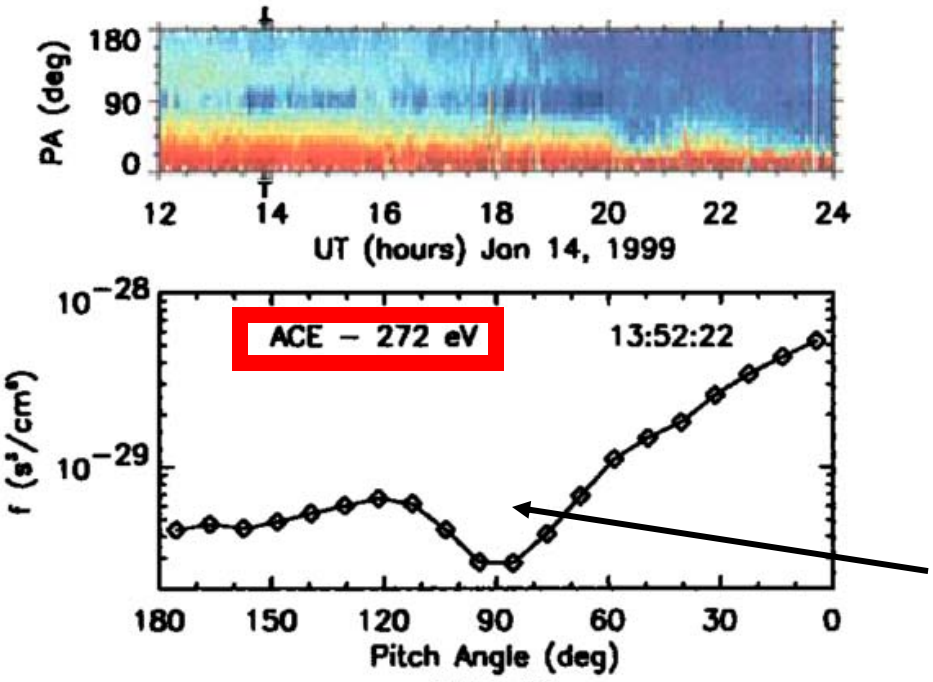
Structure favorable for both:
- acceleration and leakage
- 90° PA depletion from non-monotonic B-field



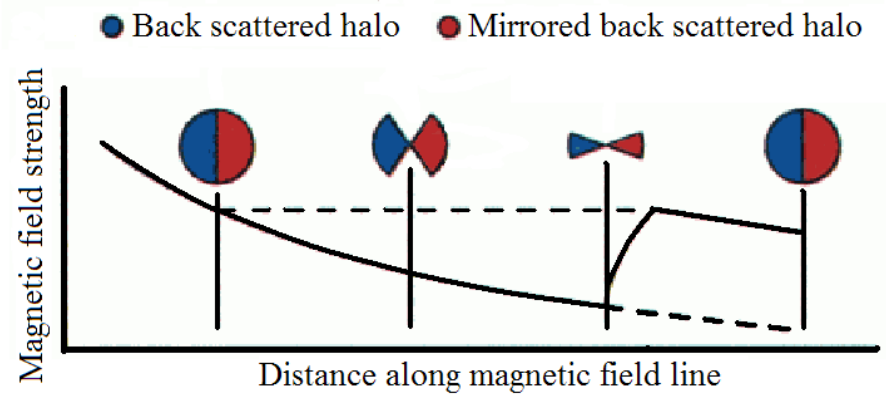
Additional notes

- CSEs are not limited to outside CIRs (unlike Gosling's idea), they can very well occur inside CIRs
- Fully developed shocks are not required to observe the heating responsible for enhanced PSDs in CIRs
- Some CSE from small-scale transients is also expected in the slow wind ahead of CIRs (only)

Origin of counter-streaming electrons (CSE)



- **Counter-streaming may owe to**
(1) closed CMEs (e.g., solar max) [*Gosling et al.*, 1987],
(2) shock acc. & leakage at CIRs [*Gosling et al.*, 1993],
(3) 90° pitch angle depletions [*Gosling et al.*, 2001]

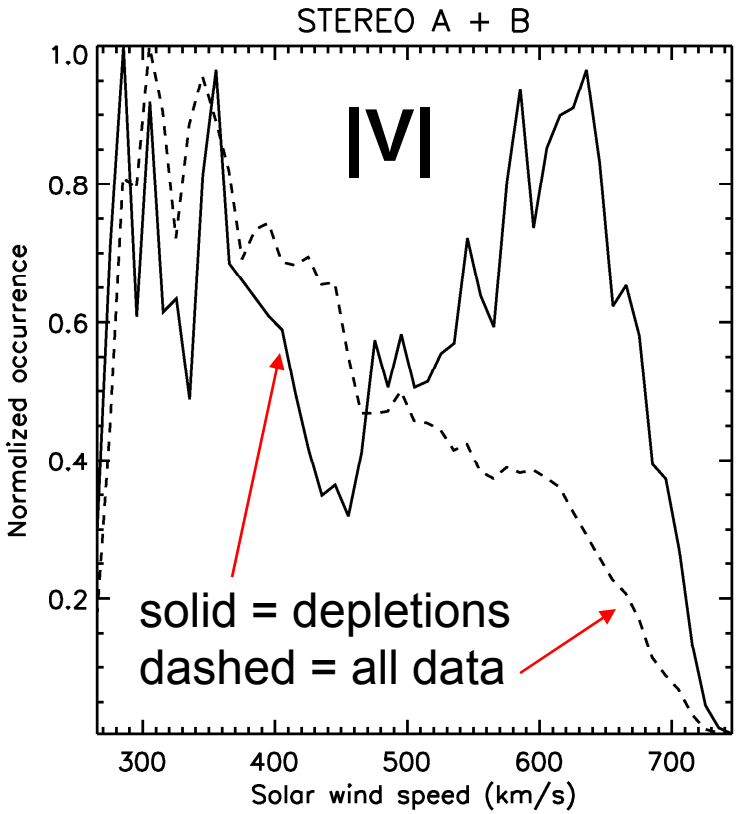


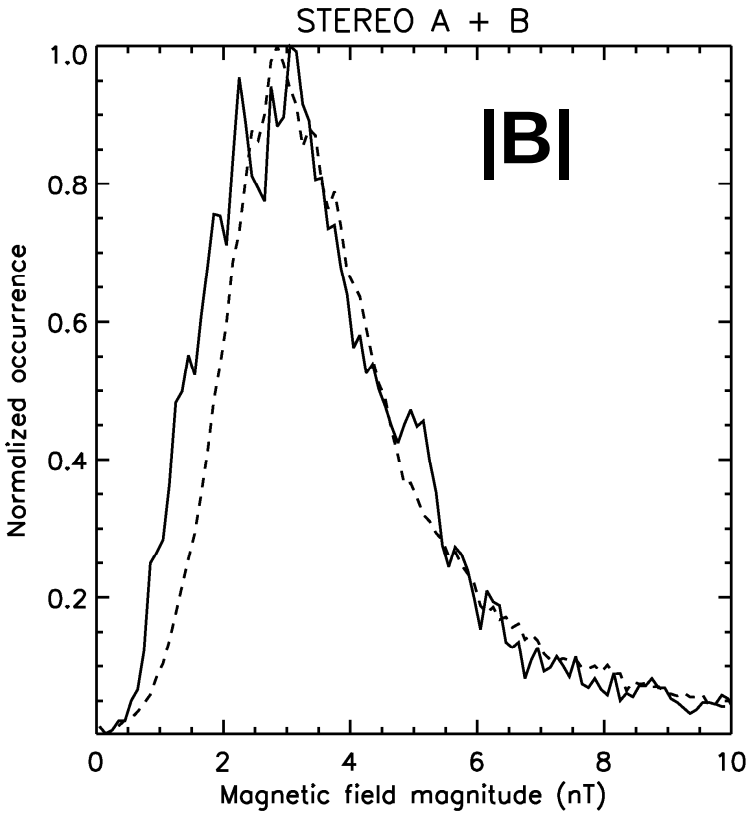
Statistical analyses yet to confirm CSEs relationship with such structures at solar minimum, i.e., CIRs and closed loops

Magnetic field and velocity dependencies

Normalized occurrence distributions during CSE

Occurrence f = ~15% for 20% PSD decrease at 90°

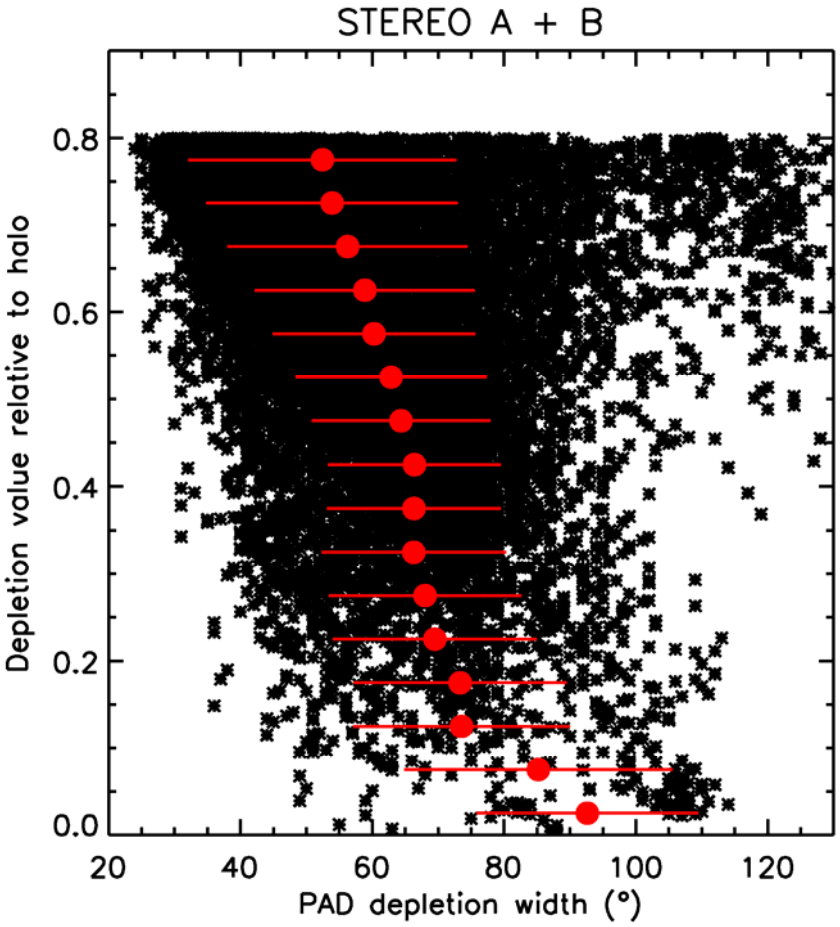




→ |V| higher than average during counter-streaming

→ |B| slightly lower than average during counter-streaming

Depletion magnitude versus depletion width



→ **Larger depletion magnitudes = wider depletions**

→ **Depletions never totally devoid of plasma:**
continuous pitch-angle scattering