STEREO/SEPT Observations during Solar Quiet Periods (March 2007-February 2008)

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STEREO SWG

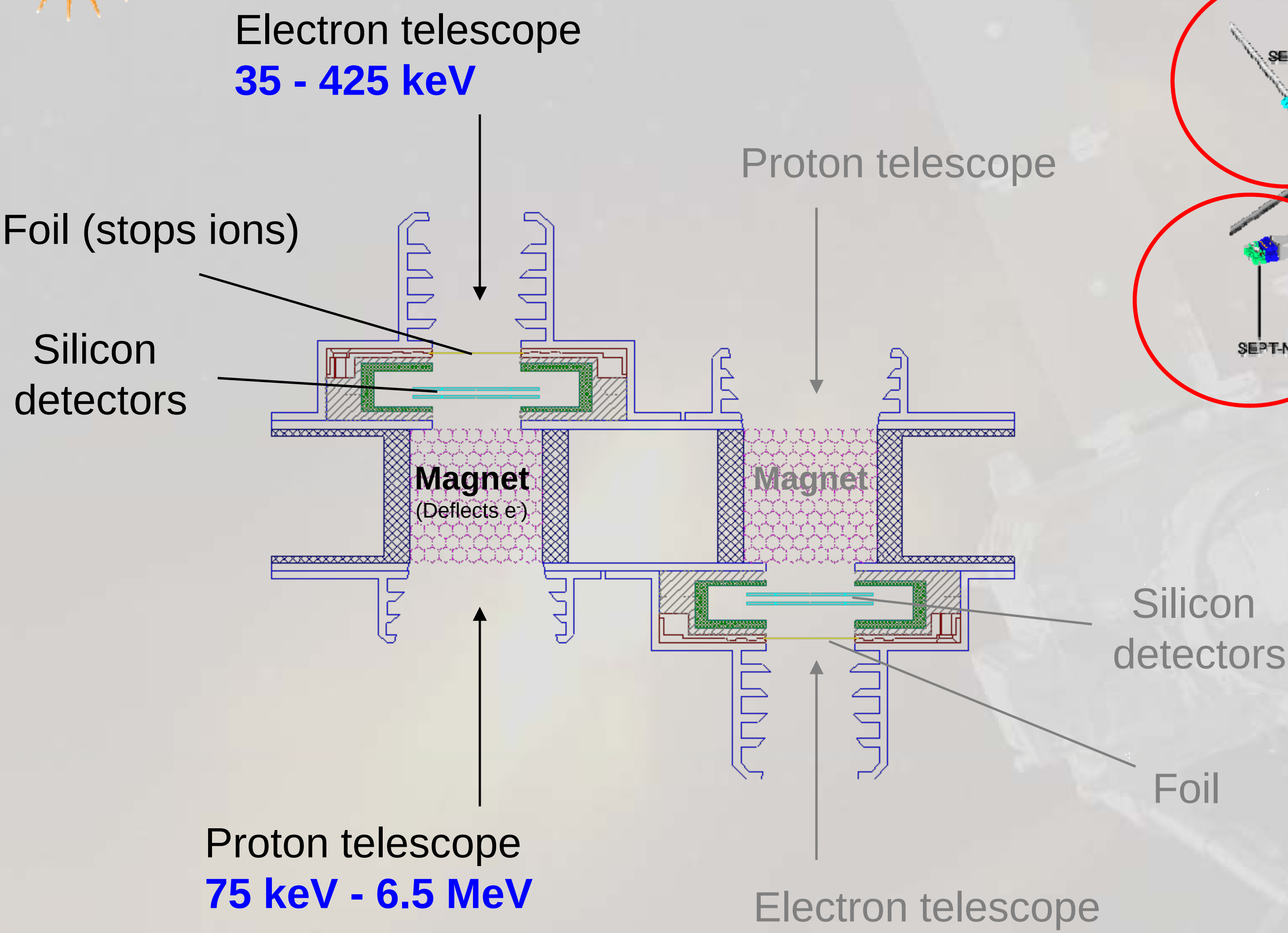
Pasadena, Feb 4, 2009

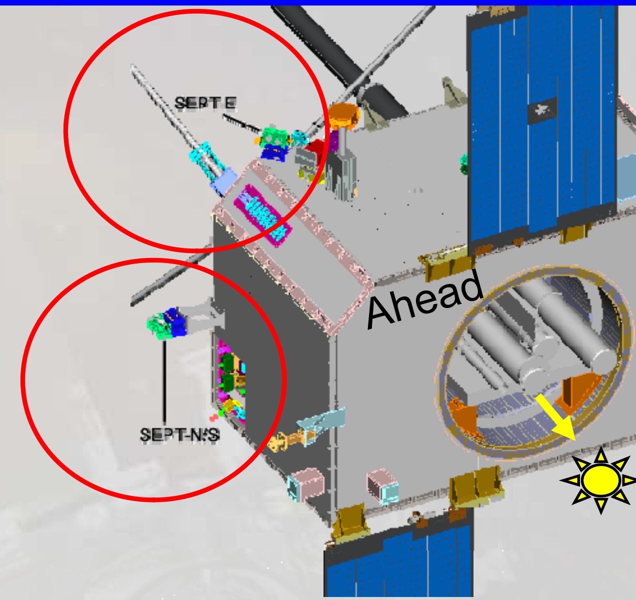
Outline

- STEREO-IMPACT/SEPT
- The period March 2007 – February 2008
- CIR-associated ion increases
  - Backmapping → Connecting remote and in-situ multi-spacecraft observations
  - Comparison of observations from different s/c
    - Spatial variations (radial, latitudinal)
    - Temporal variations – Possible sources:
      - CIR-ICME interaction
      - Coronal Hole evolution
  - General properties of the spectra
- Magnetospheric particles ("upstream" events)
  - Brief summary of observations

Papers submitted & under review: Klasen et al (AnGeo), Dresing et al (SolPhys), Gómez-Herrero et al, (JGR)

STEREO/SEPT (Solar Electron Proton Telescope)

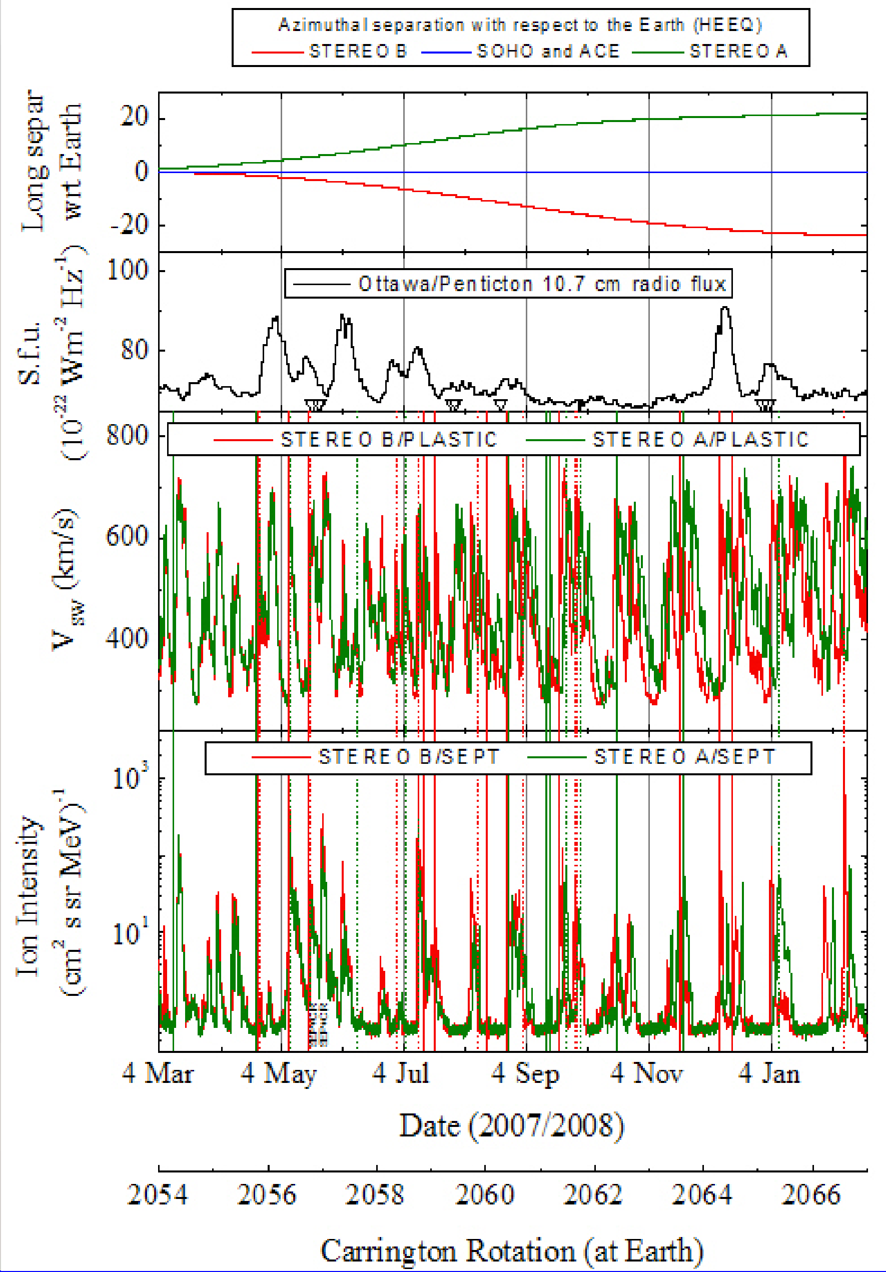




8 Telescopes per s/c: 2×North, 2×South, 2×Sun (along IMF), 2×Anti-Sun (along IMF)

Selected period: March 2007 – February 2008

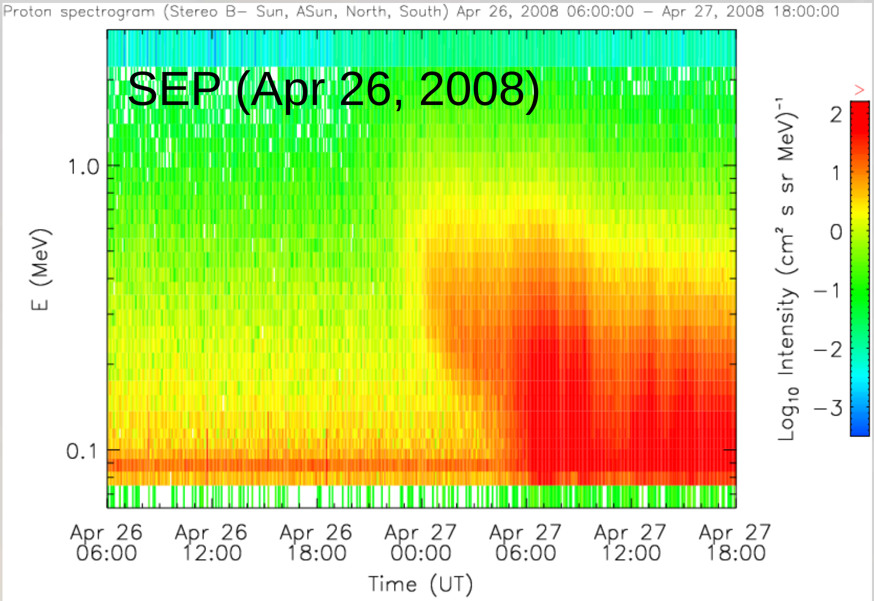
- Very low solar activity period
  - Few flares, CMEs and SEP events
  - → Suitable for CIR & upstream ions
- Spatial coverage:
  - Radial separation 0.03-0.13 AU
  - Latitudinal separation 0-5.7 deg
  - Longitudinal separation 1-46 deg
- IMPACT Instruments fully operational, PLASTIC data available
- Recurrent fast solar wind streams associated to coronal holes are clearly visible and show progressive delay
- Low energy ions (351-496 keV) show similar pattern (recurrence + delay)
- CIRs are the main source of ion increases < 10 MeV

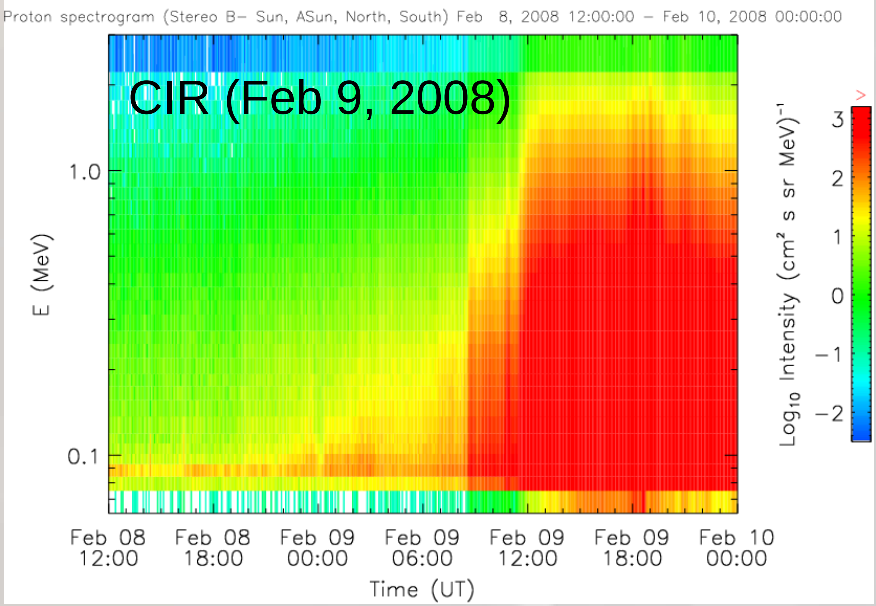


CIR shock list from MAG team: http://www-ssc.igpp.ucla.edu/forms/stereo/stereo_level_3.html

Typical observational characteristics of CIR-associated ion events

- No velocity dispersion
- Slow rise/decay (hours)
- Not correlated with solar activity (flares/CMEs)
- Correlated with fast SW streams
- Ions <10-20 MeV
- No relativistic (>500 keV) electrons
- Intensity maxima around CIR-shocks (if present at 1 AU)
- Positive radial gradient
- Azimuthal delay (co-rotation)



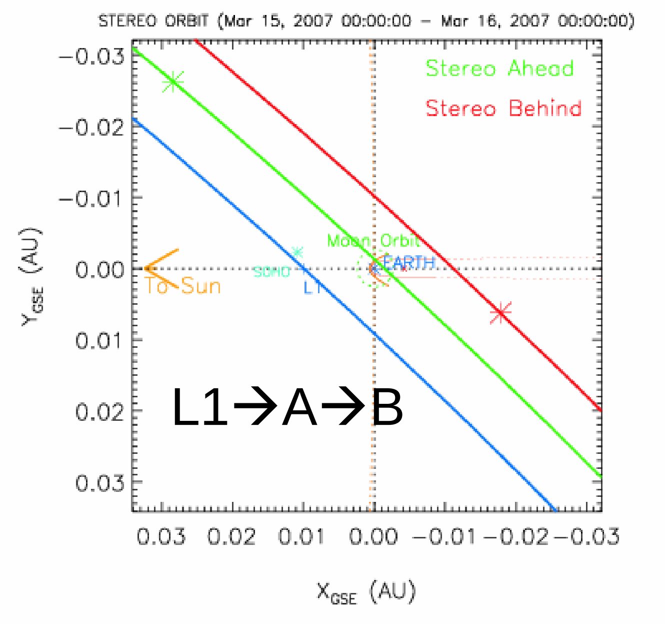


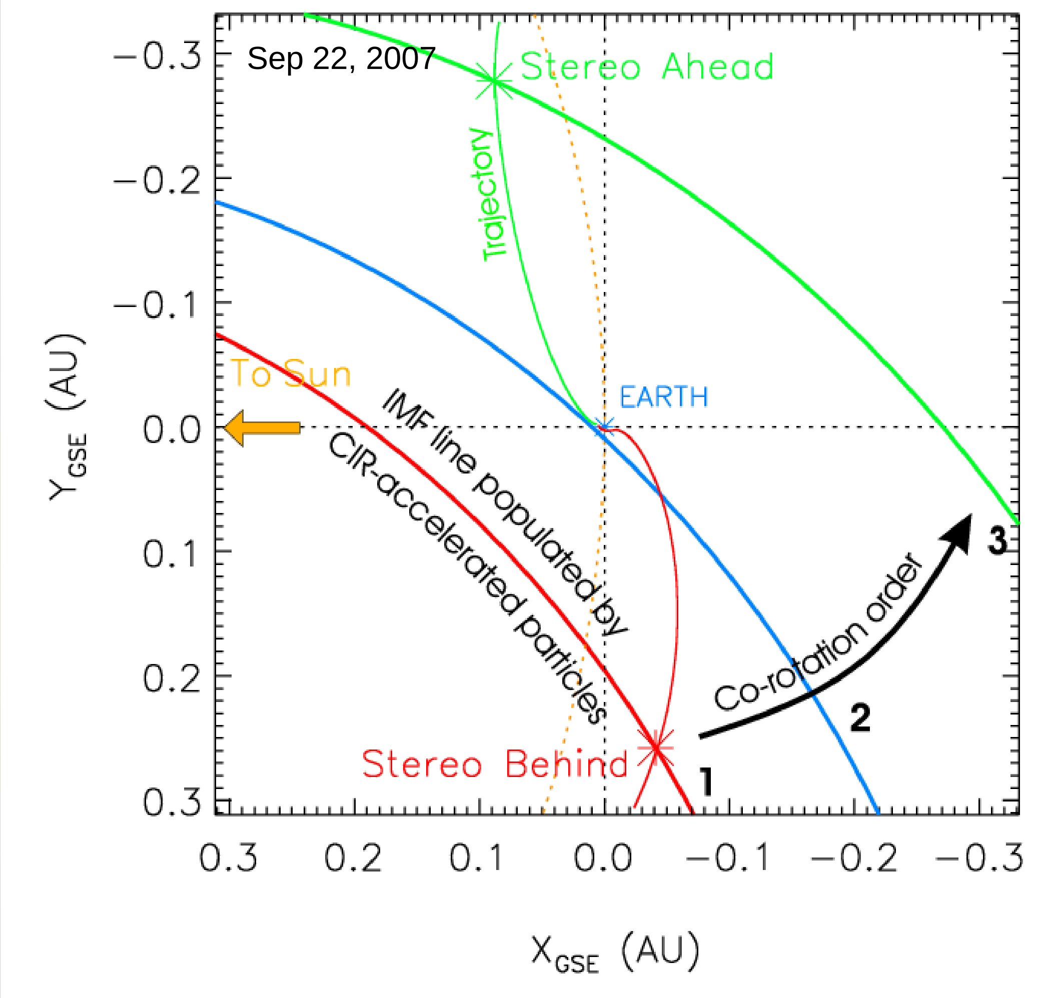
Co-rotation delay during CIR-associated particle increases

- Co-rotation time:

$$t_B - t_A = \frac{\phi_B - \phi_A}{\Omega^S_{SUN}} + \frac{r_B - r_A}{V_{SW}}$$

- Most of the time the sequence is B→L1→A
- For the early phase of the orbit, the western s/c can be earlier than the eastern s/c

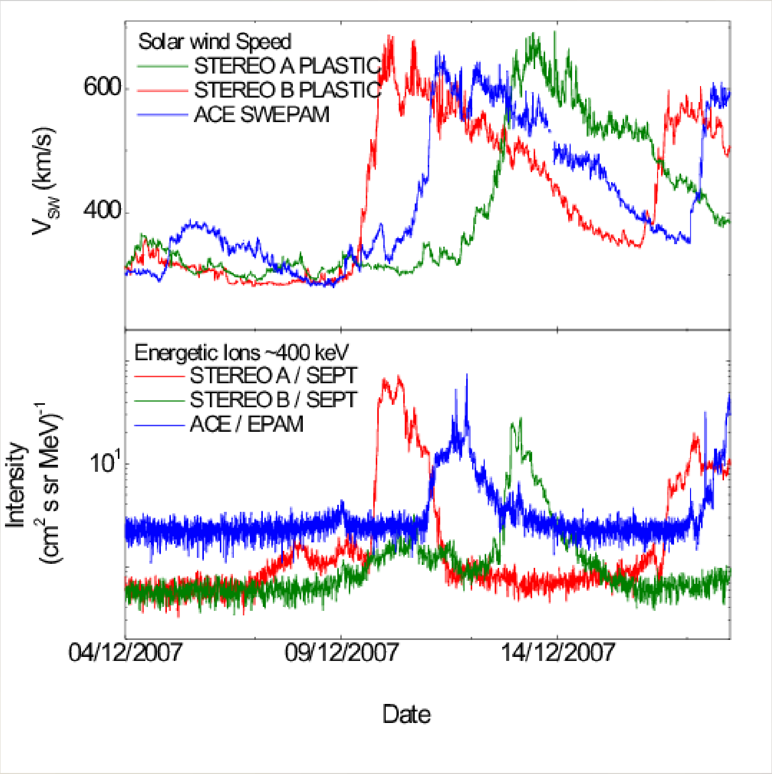


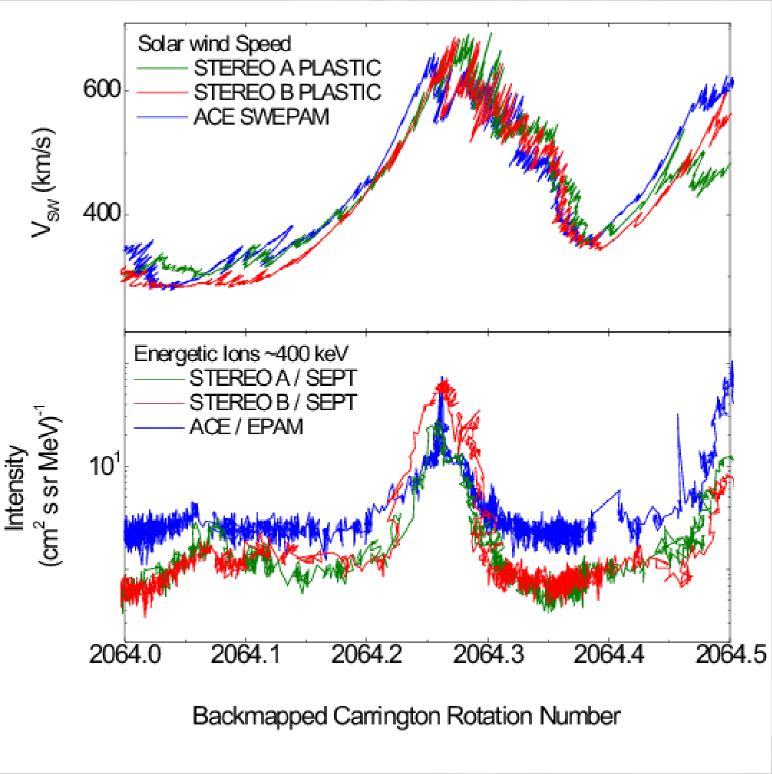


Ballistic Backmapping

- The progressive delay A-B is consistent with the corotating nature of the events. Overall reconstruction is possible using Ballistic backmapping:

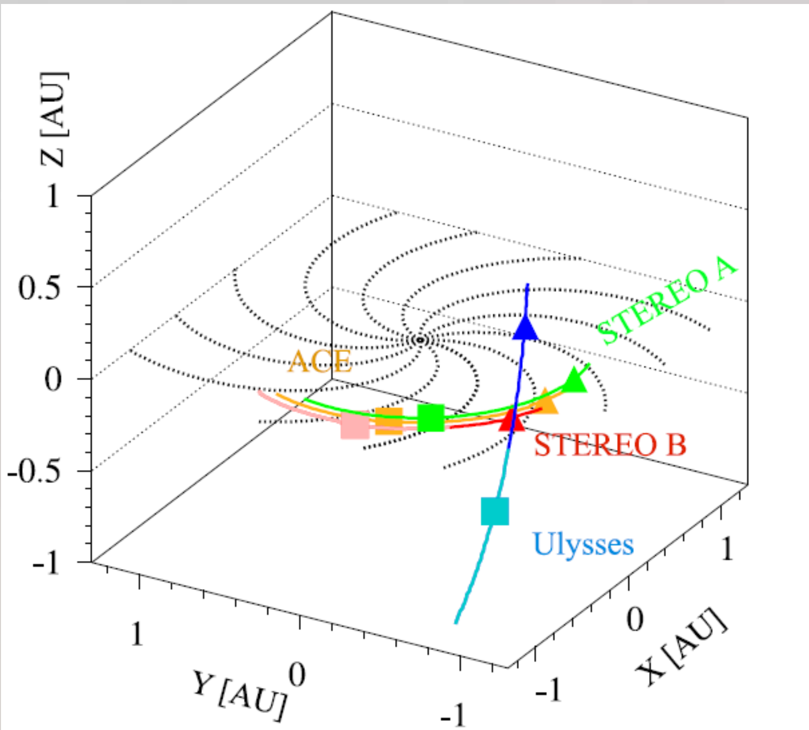
$$\Delta\phi = \frac{\Omega(r - r_0)}{V_{SW}}$$





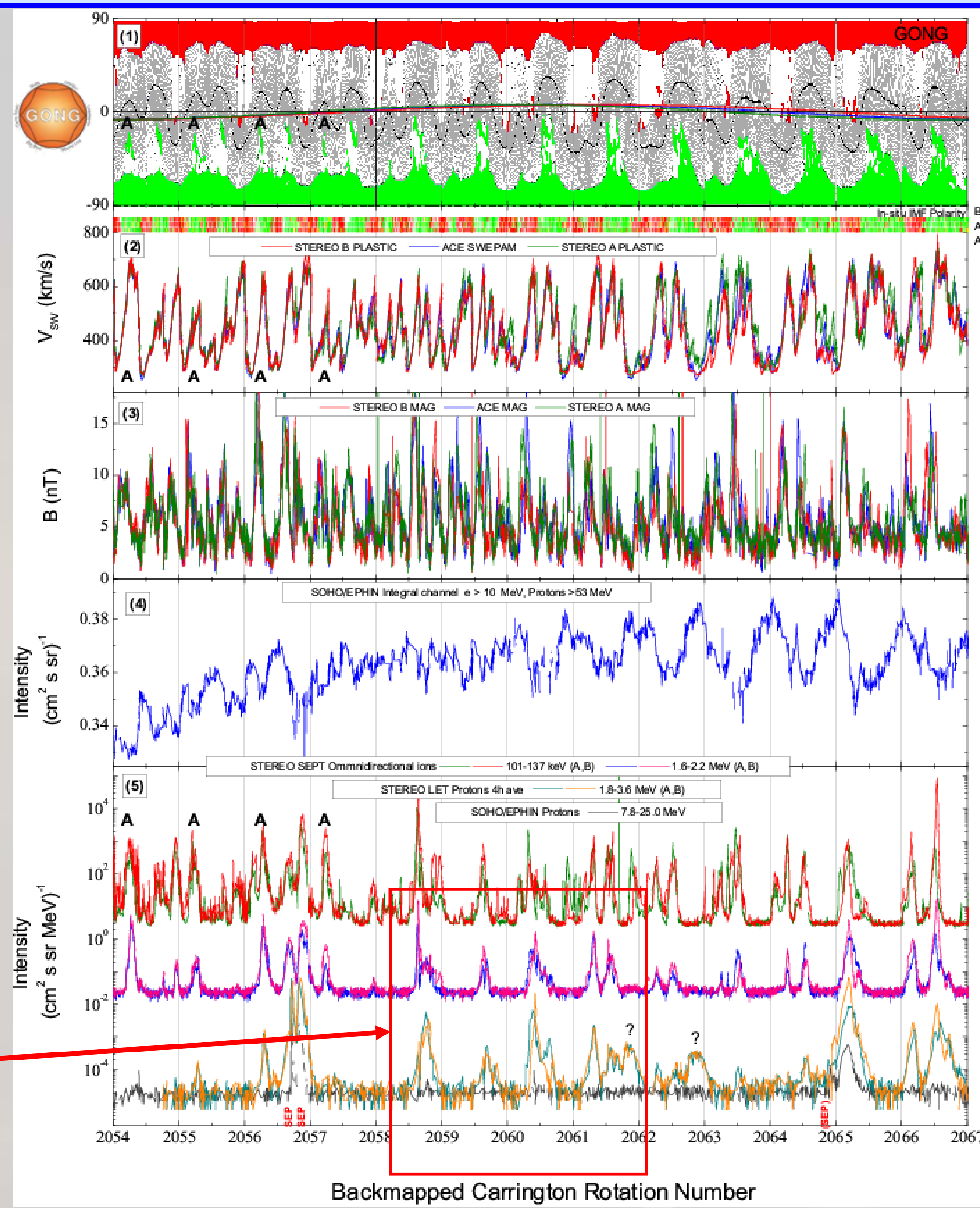
Overview of Backmapped in-situ data

- Backmapping allows direct comparison with PFSS coronal maps from GONG



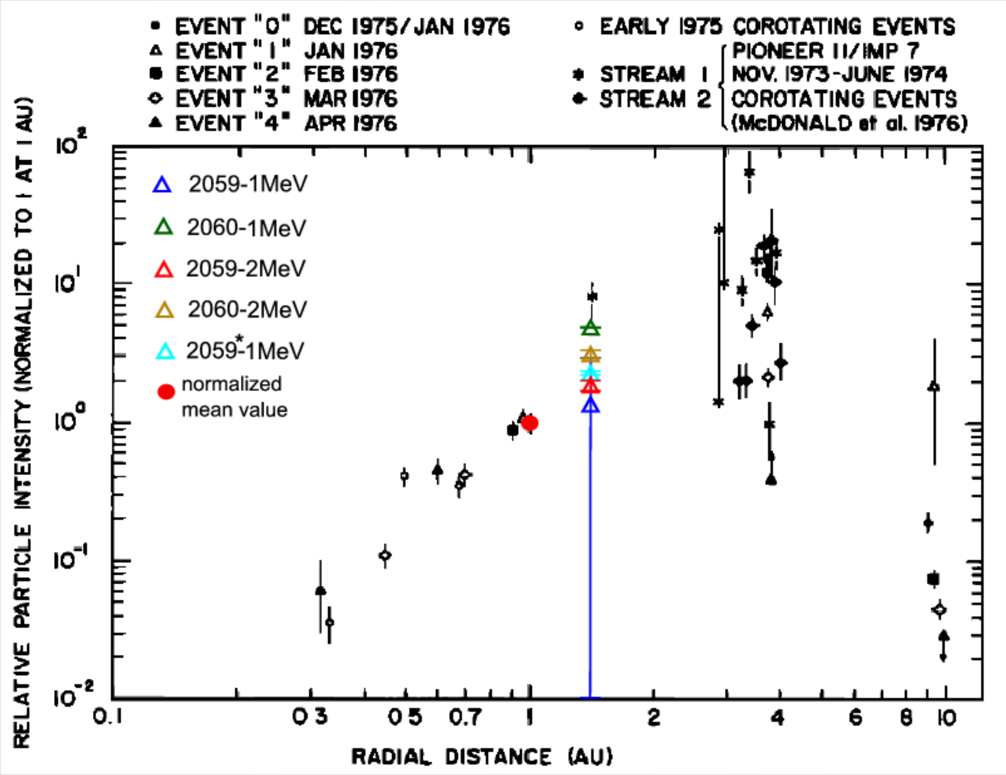
Ulysses crossing the ecliptic plane

(Dresing et al. Solphys, submitted)



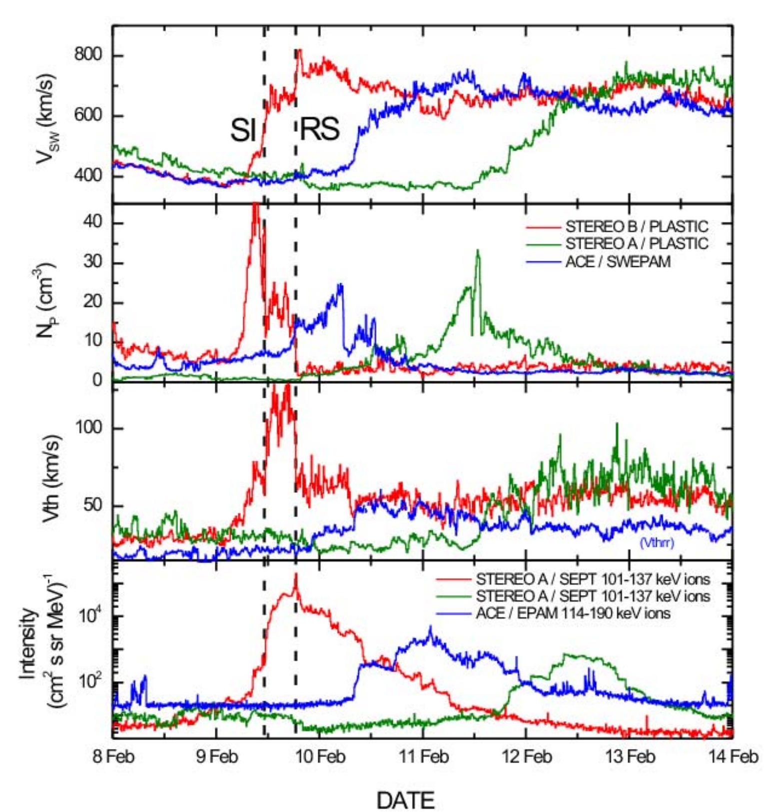
Radial Gradient

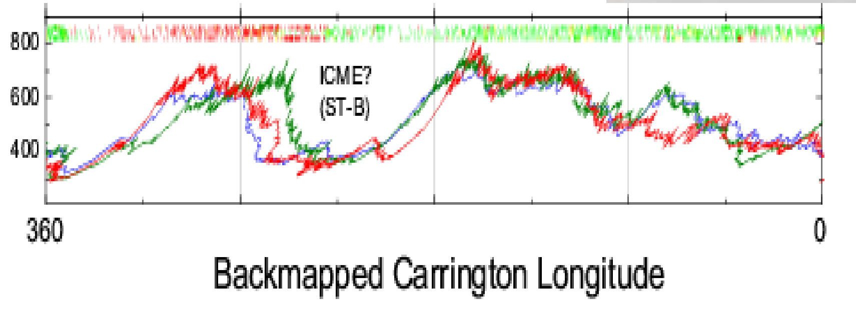
- Ratio between max intensities at 1.2-2.2 MeV (1h-avg) plotted vs radial separation
- Large dispersion, partly explained by latitudinal effects.
- Positive gradient comparable to the values found by van Hollebeke et al, 1978 (350 ± 150 %/AU inside 1 AU, dashed line)
- More detailed study using Ulysses data (two events during CR 2059, 2060)
- Remarkable exception: Feb 2008 event (CR 2066.59)

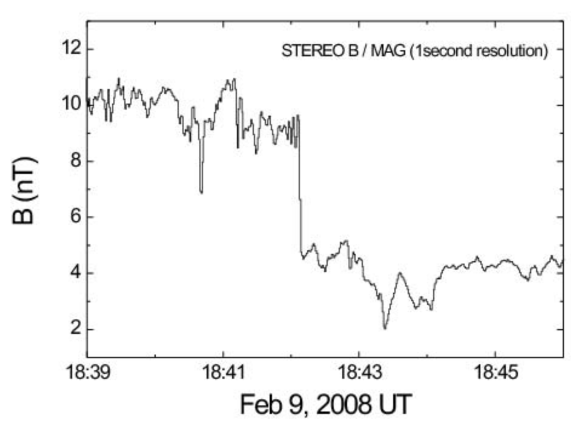


Radial Gradient - February 9-14, 2008 CIR

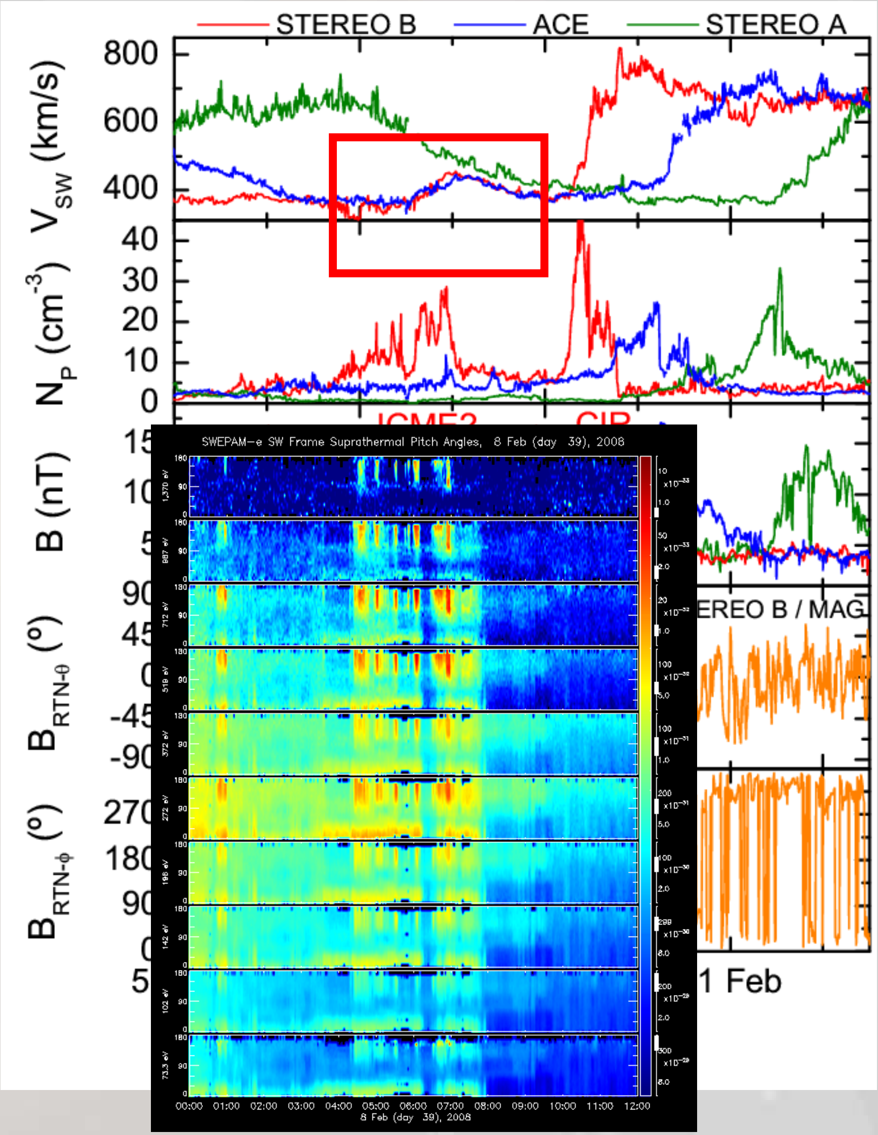
- Progressive decrease in the intensities ST-B→ACE→ST-A
- Maximum flux at STEREO B in coincidence with the reverse shock, already formed at 1 AU. The shock is not present for ACE and ST-A
- Small radial separation (0.03 AU) but intensity difference reaches factor 10
- Source coronal hole ~stable during the co-rotation
- Possible latitudinal effect ($\Delta\theta_{BA}$<3º) - STEREO-B enters in the stream >10º later





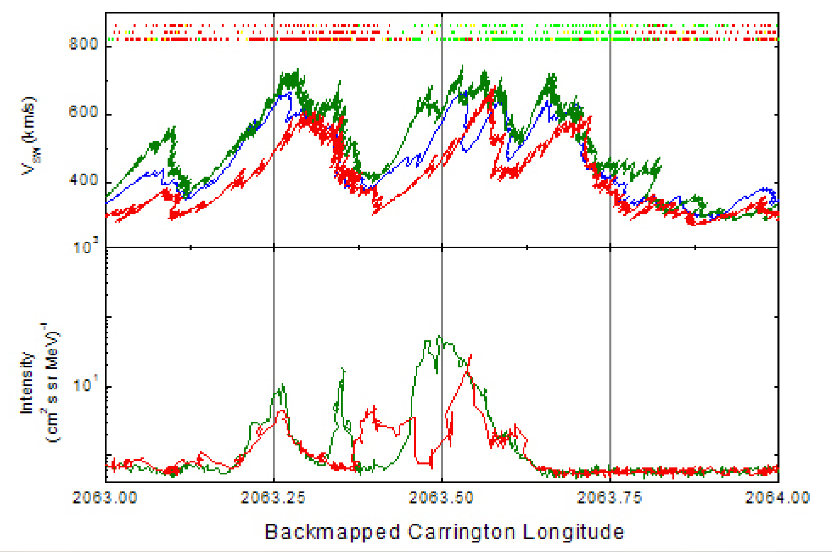


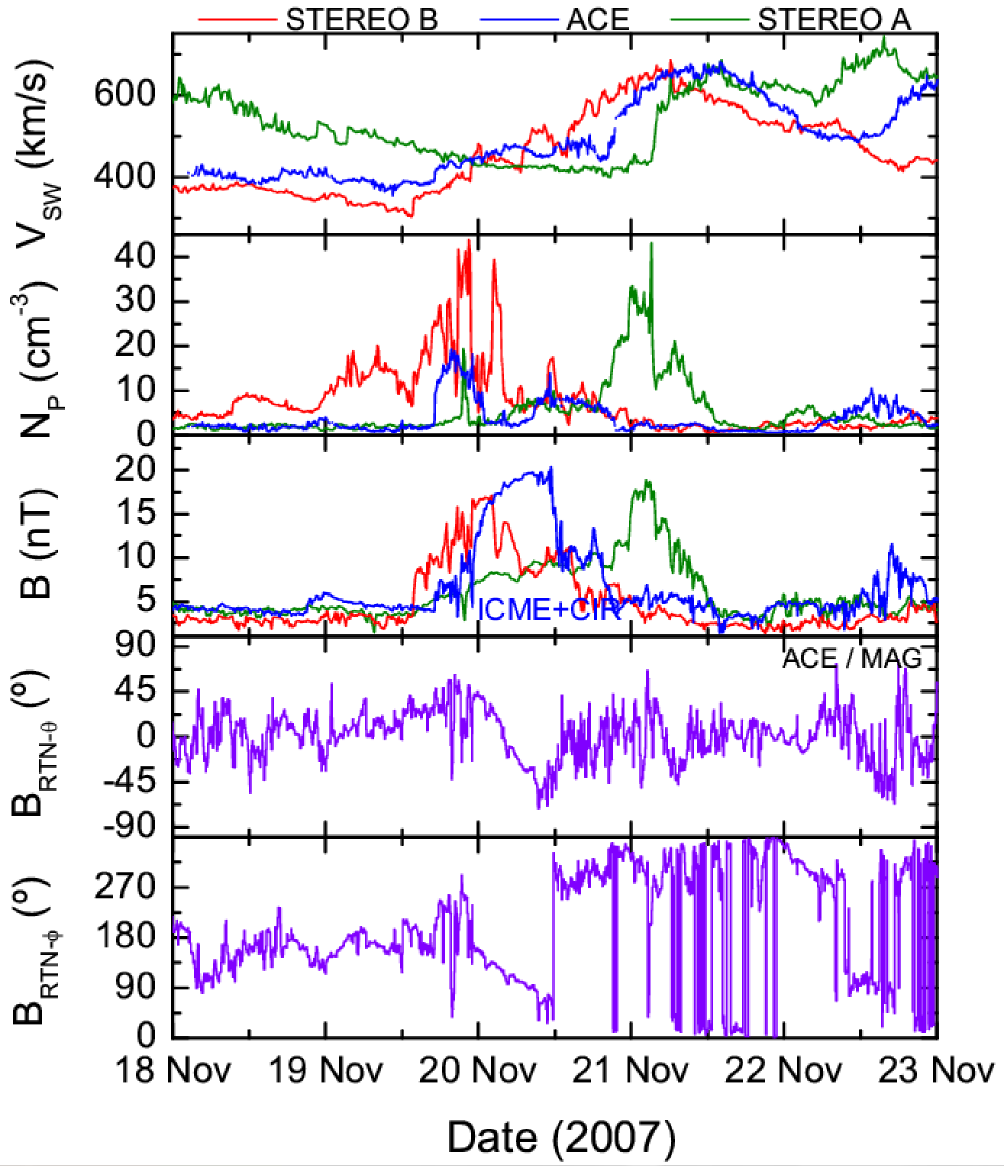
- The sudden disappearance of RS suggest additional causes
- Detailed examination of the solar wind data reveals possible IP ejecta moving radially before the CIR
  - BD Suprathermal electrons
  - ACE/ST-B coincident profile
  - Partial rotation of IMF, enhanced |B|
  - Candidate halo CME on Feb 4, 9:54, west from the coronal hole
- Additional compression when CIR overtakes ICME could explain the quick CIR evolution



Possible influence of transients: Nov 20-21, 2007 CIR

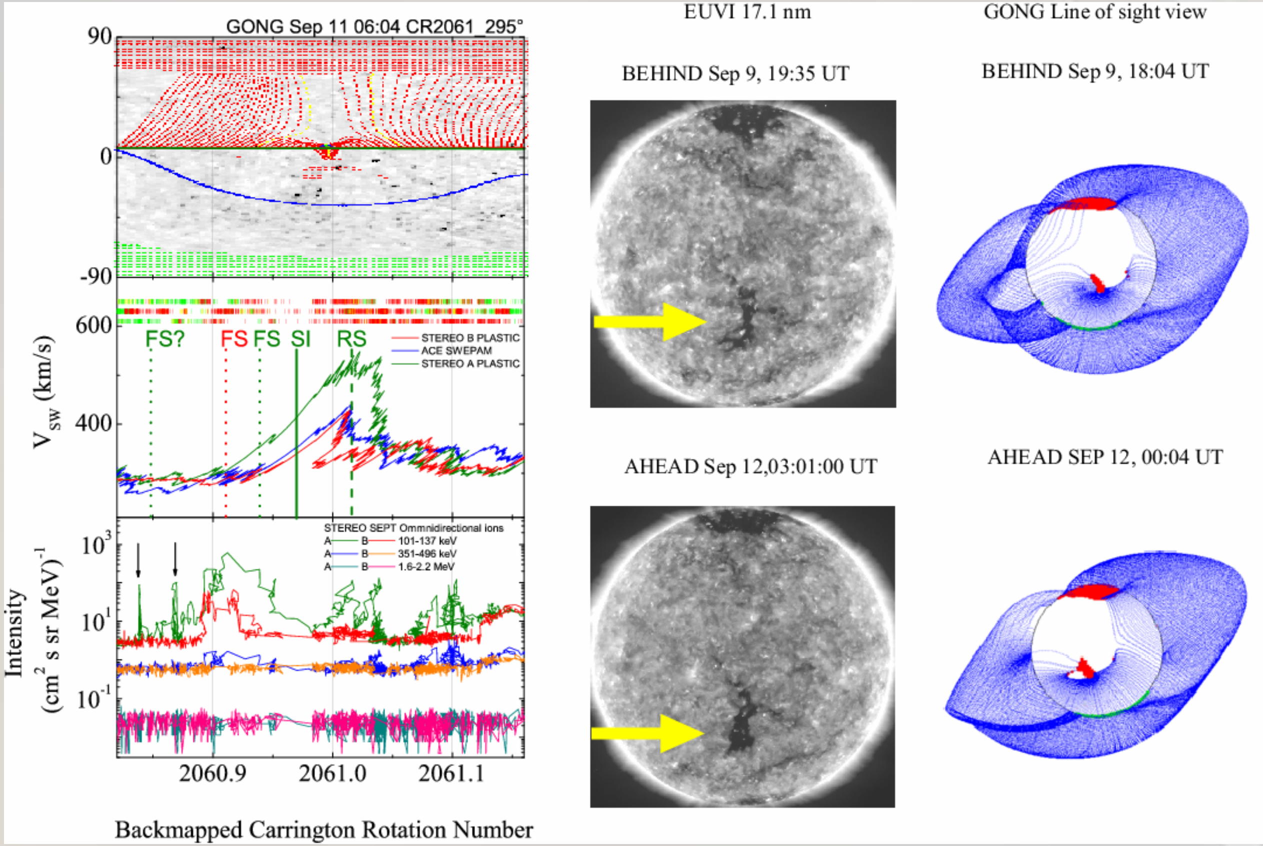
- Example of ICME just before a CIR. Clear magnetic cloud signatures observed by ACE (Nov 19-20)
- Possible origin: slow halo CME on Nov 15
- Backmapped profiles strongly affected, negative radial gradient (also affected by latitudinal effects)





Coronal Hole evolution – Sept 2007 Event

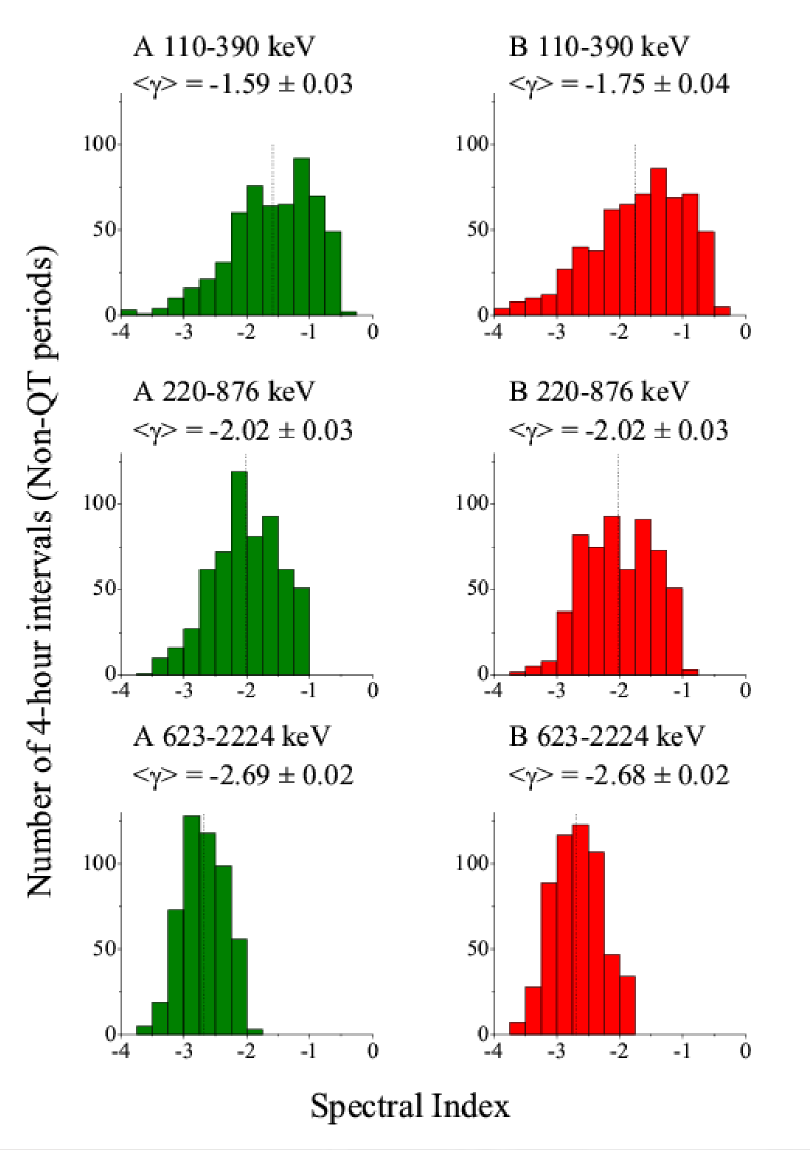
- Small low energy event associated with a weak and narrow stream originating in small near-equatorial CH.
- Negative radial gradient
- PFSS model and EUVI images show significant coronal hole evolution
- Latitudinal effect could also contribute (but $\Delta\theta_{BA}$ only 0.5º)



Black arrows:
Possible Far upstream
Events (0.3 AU!)

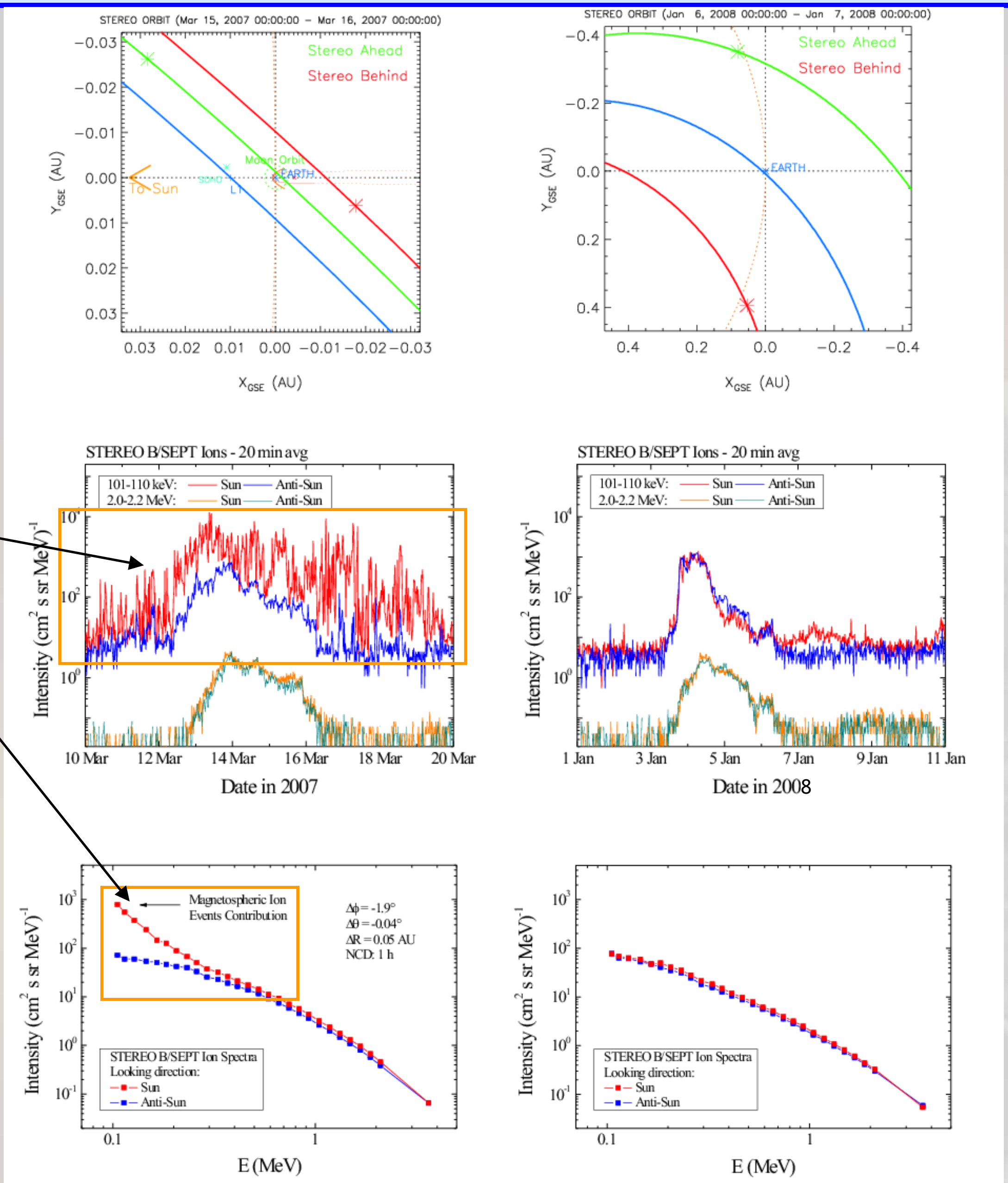
General properties of the ion spectrum during CIRs

- 4-h accumulated spectra during CIRs
- Factor 2 above background required
- Power law fits over three energy ranges
- Spectra steepens with energy
- Spectral indices comparable with the observations by Mason et al. (2008)
- Similar results for STEREO A and B, Wider range of variation at low energies
- Residual magnetospheric contribution at E<500 keV (steep spectrum)



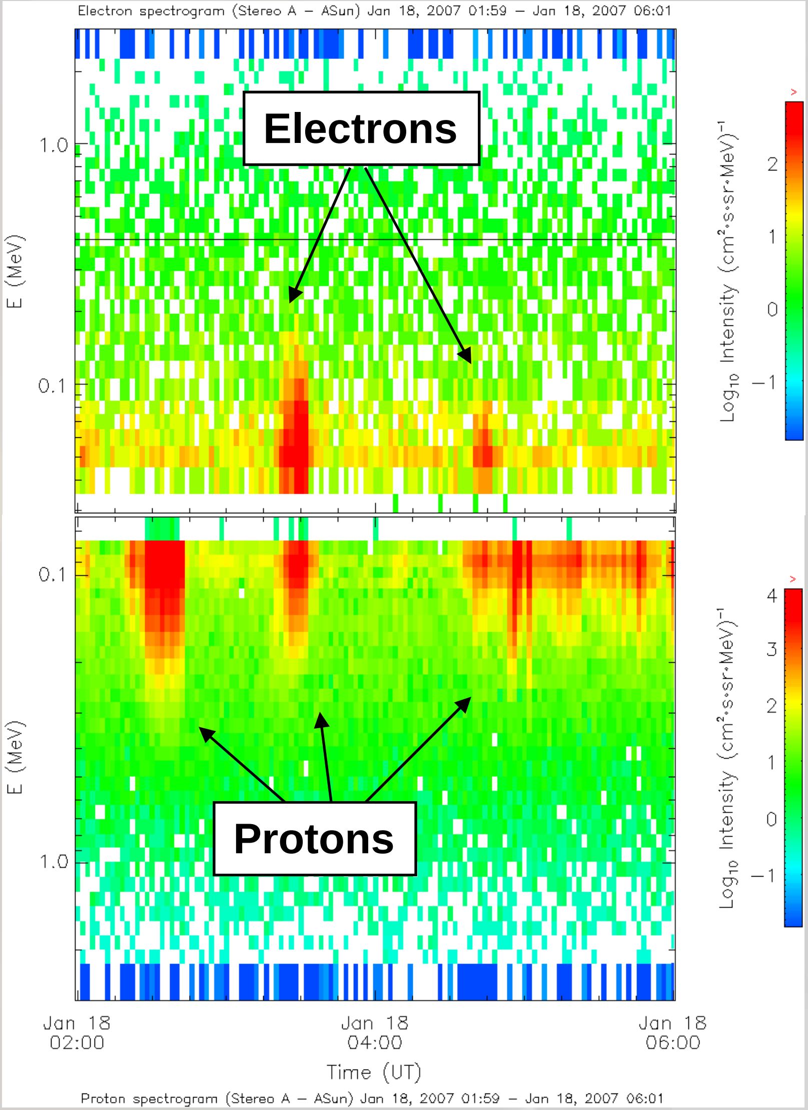
Magnetospheric contributions (“Upstream Events”)

Magnetospheric events



Magnetospheric Events

- Short duration (<2 hour, typically tens of minutes)
- Steep spectrum (typical γ ~ -4 to -5)
- No obvious differences in the typical spectra observed by STEREO B and STEREO A, despite the different connection areas
- Highly anisotropic
- Spiked time profile
- Protons and electrons are sometimes observed simultaneously
- Most of the events show no velocity dispersion



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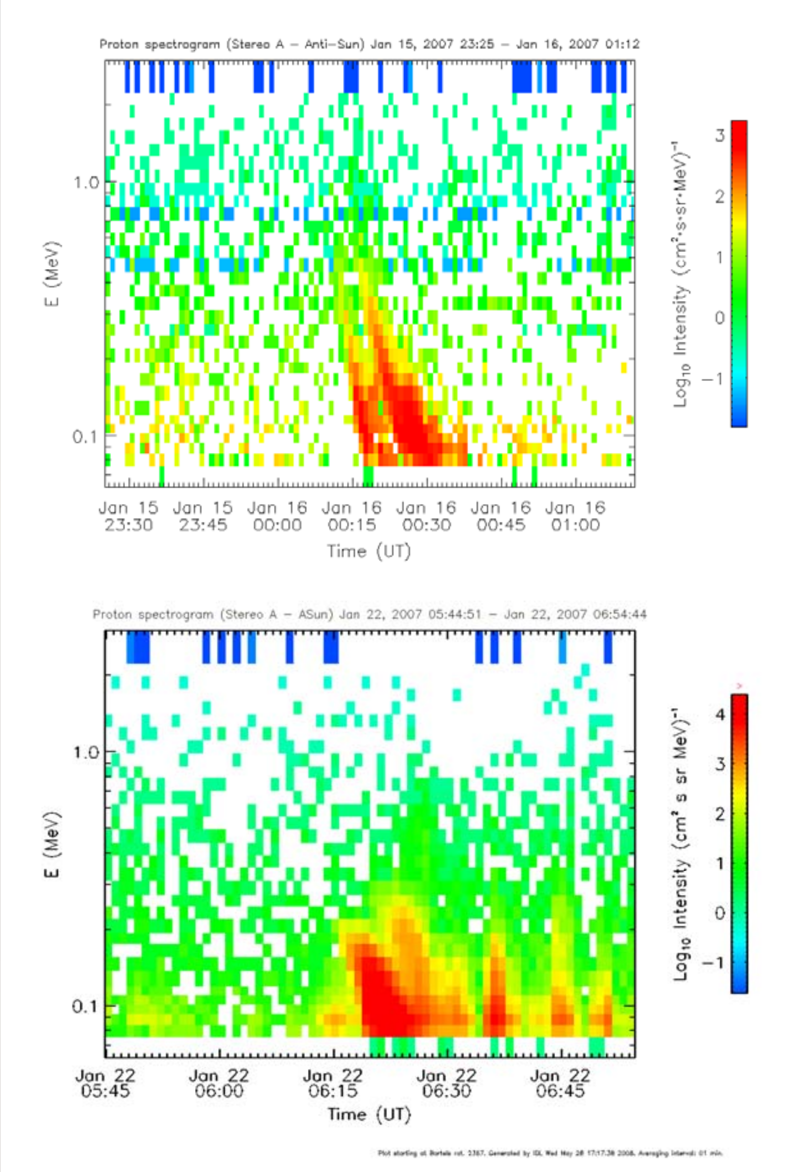
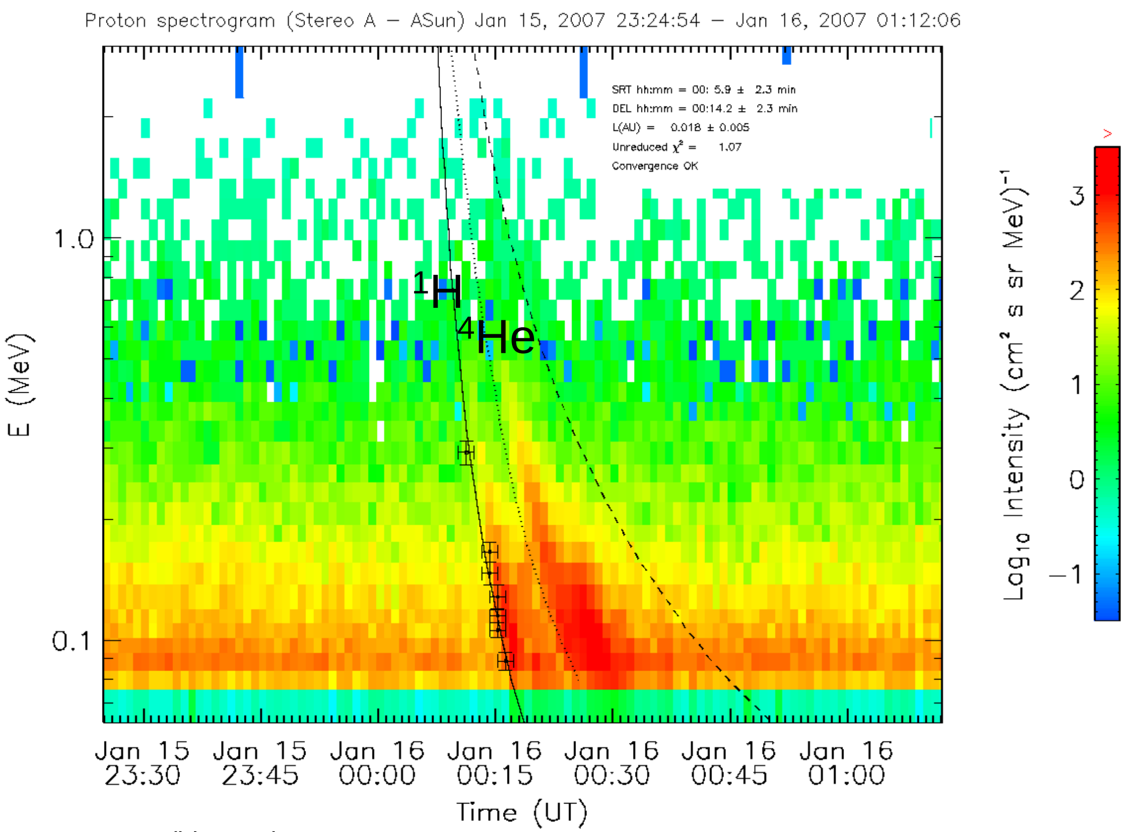
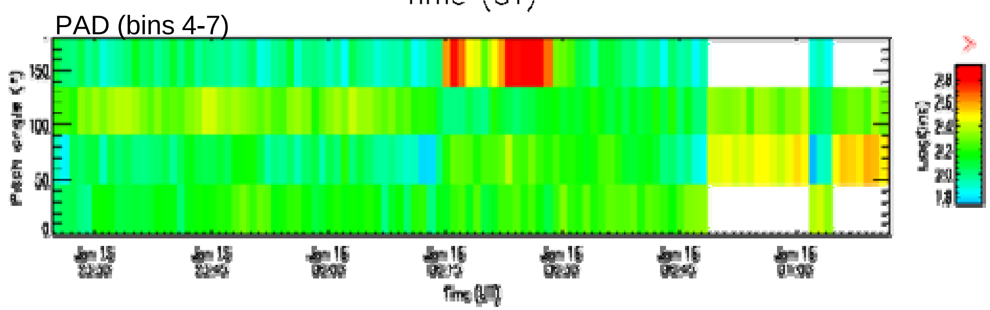
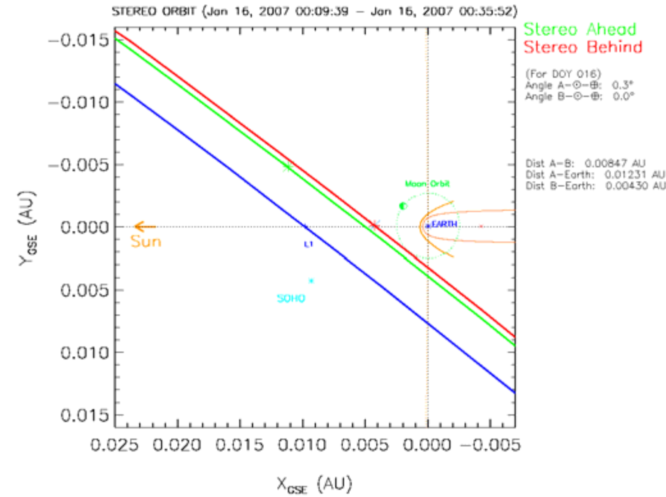
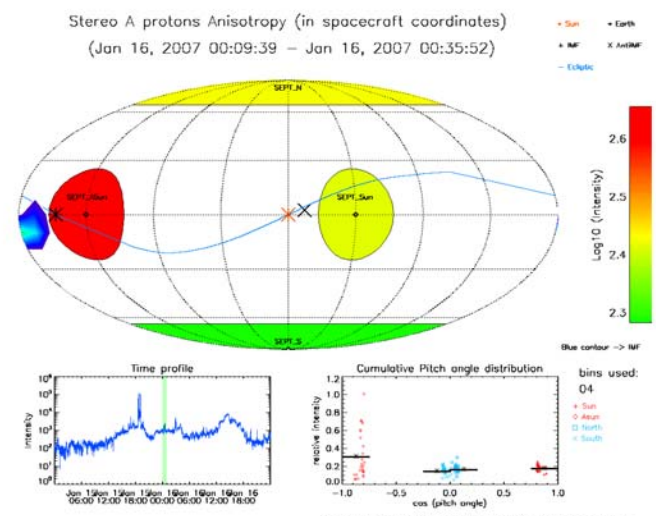


Upstream Events with velocity dispersion





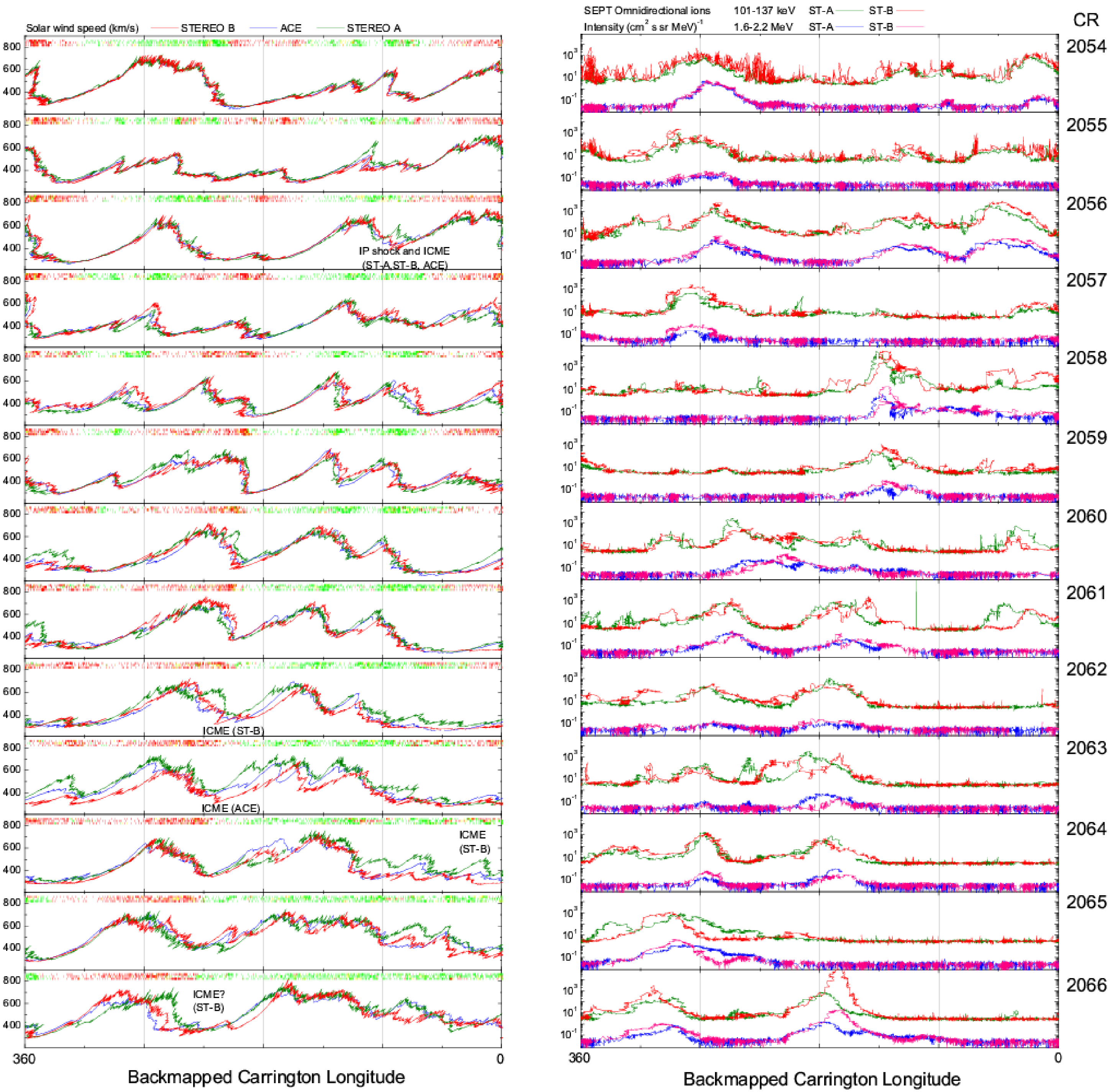




Conclusions

- The period March 2007-February 2008 is characterized by very low solar activity. CIRs are the dominant source of 70 keV-6.5 MeV ions
- Ballistic backmapping offers a rough explanation of the time delays for both, particles and solar wind data. It is also a valuable tool for the correlation of in-situ and remote observations
- The major sources of disagreement in the backmapped profiles are:
  - Latitudinal separation (important near the stream boundaries)
  - Coronal hole evolution
  - Evolution of the stream in the interplanetary medium
- The radial gradient between STEREO A and B can be appreciated over radial separations <0.15 AU. However the dispersion is very large. Latitudinal effects play an important role
- Observations suggest that ICME-CIR interactions can act as triggers of transient changes in the CIRs.
- The spectral slope varies from ~-1.5 at ~200 keV to ~-2.7 at ~1 MeV. STEREO A and B measure comparable spectral shapes, deviations are more important in the lower energy part of the spectrum.
- When the s/c are close to the Earth, magnetospheric ion bursts can contribute significantly to the lower energy part of the spectrum during CIRs. General characteristic of these events include
  - Short duration
  - High anisotropy
  - Steep spectrum
  - Spiked profile
  - No velocity dispersion (in most of the cases)

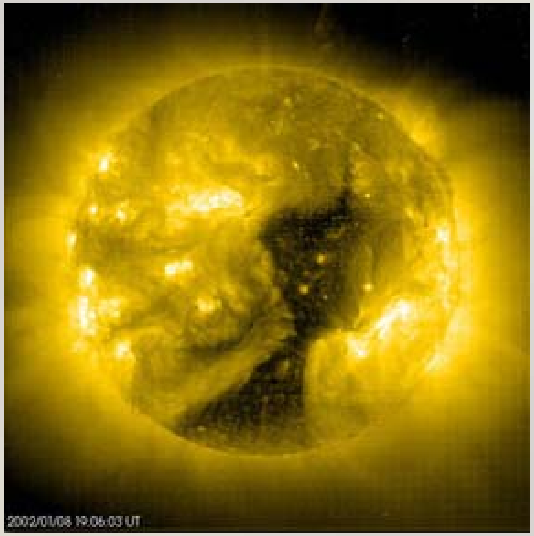
Additional slides

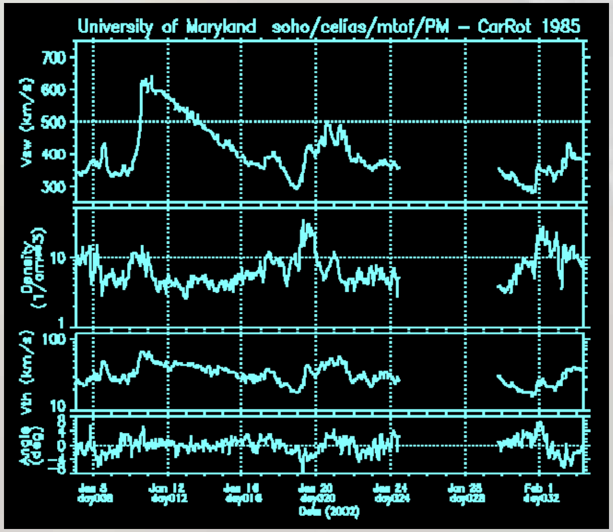

Solar wind speed (km/s)
STEREO B
ACE
STEREO A
800
600
400
IP shock and ICME
(ST-A,ST-B, ACE)
ICME (ST-B)
ICME (ACE)
ICME
(ST-B)
ICME?
(ST-B)
360
0
Backmapped Carrington Longitude
SEPT Omnidirectional ions
Intensity (cm^2 s sr MeV)^-1
101-137 keV
1.6-2.2 MeV
ST-A
ST-B
CR
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
360
0
Backmapped Carrington Longitude

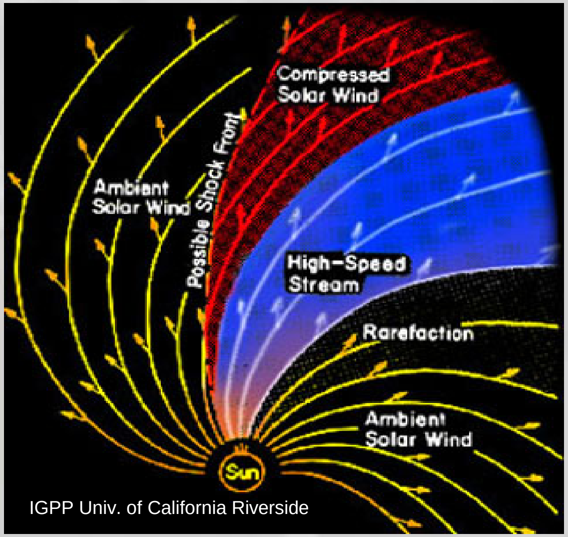
(Old slides)

Corotating Interaction Regions

- Coronal holes → High speed solar wind streams → Compression regions in the IP medium
- Radial evolution → eventually forward-reverse shock pairs bounding a co-rotating interaction region (CIR) are formed (typically beyond 2 AU)
- CIR-associated shocks → Particle acceleration (up to 10-20 Mev ions and hundreds of keV electrons)
- Stream Interface: sharp boundary separating fast and slow wind within a CIR, → characteristic in-situ signatures (density drop, temperature rise, flow shear, compositional differences…)

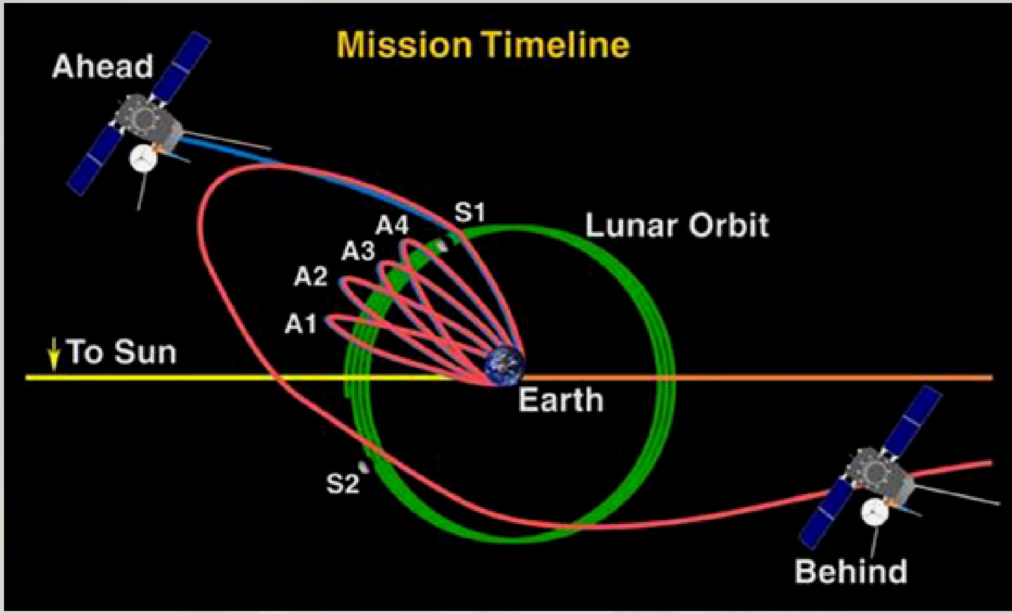


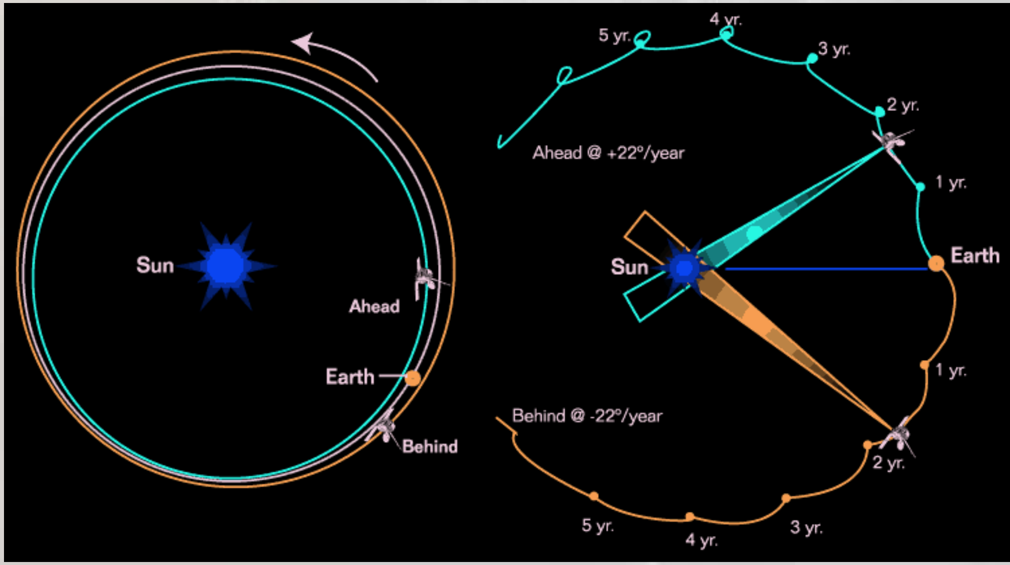




STEREO Orbit

- Launched on Oct 25, 2006
- SEPT B and A switched-on on Nov. 13 and 14, 2006
- Separation after lunar swingby S1 on Dec. 15, 2006
- SEPT-A doors opened on Dec. 14, 2006
- SEPT-B doors opened on Jan. 16, 2007
- Final orbit:
  - Near ecliptic, following Earth (0.95-1.09 AU)
  - Growing azimuthal separation 22°/year
  - Heliographic latitude from -7.3 to +7.3 degrees

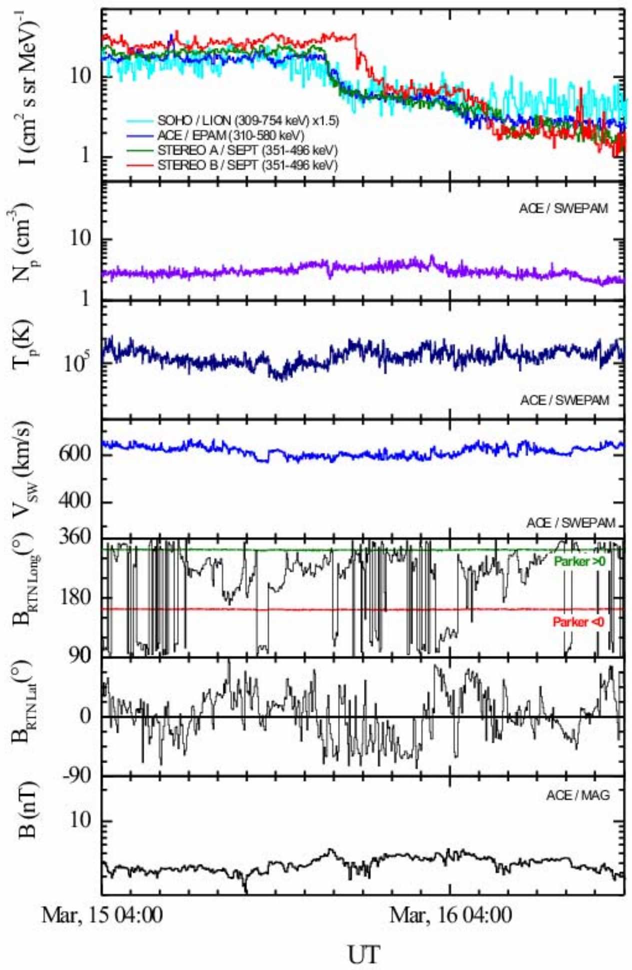


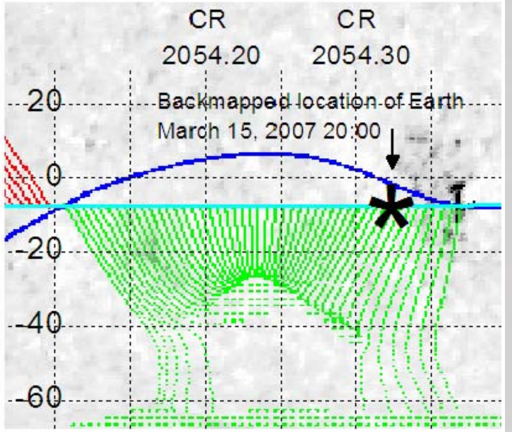


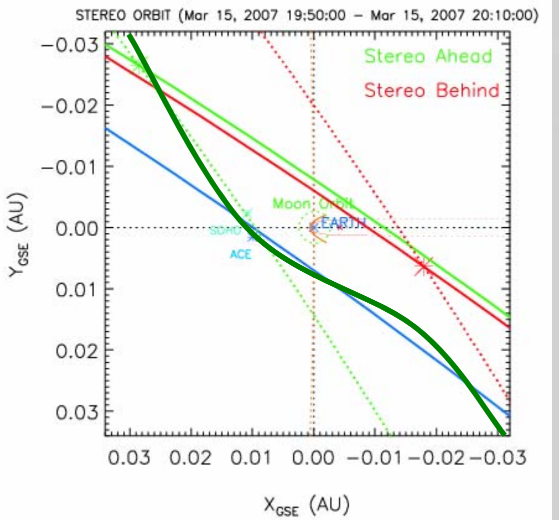
Small scale deviations from the ideal co-rotation

March 15-16, 2007 (decay phase of a CIR-associated ion increase)

- Delay pattern inconsistent with measured V_{SW}
- Inside the fast wind stream. Similar values for STEREO A, B, ACE
- Small latitudinal separation (0.05º)
- Deviations from Parker spiral over scales >0.02 AU offer a possible explanation



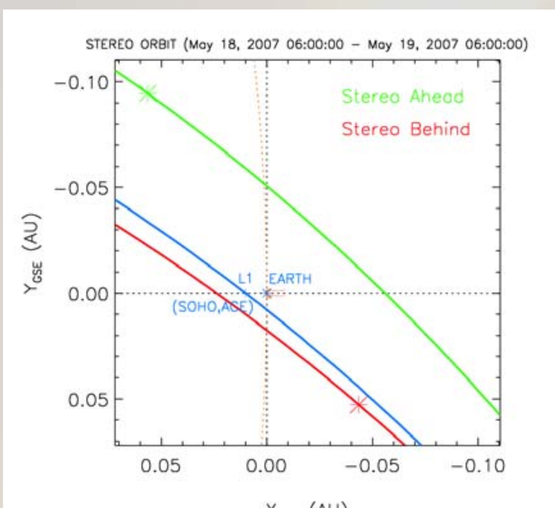


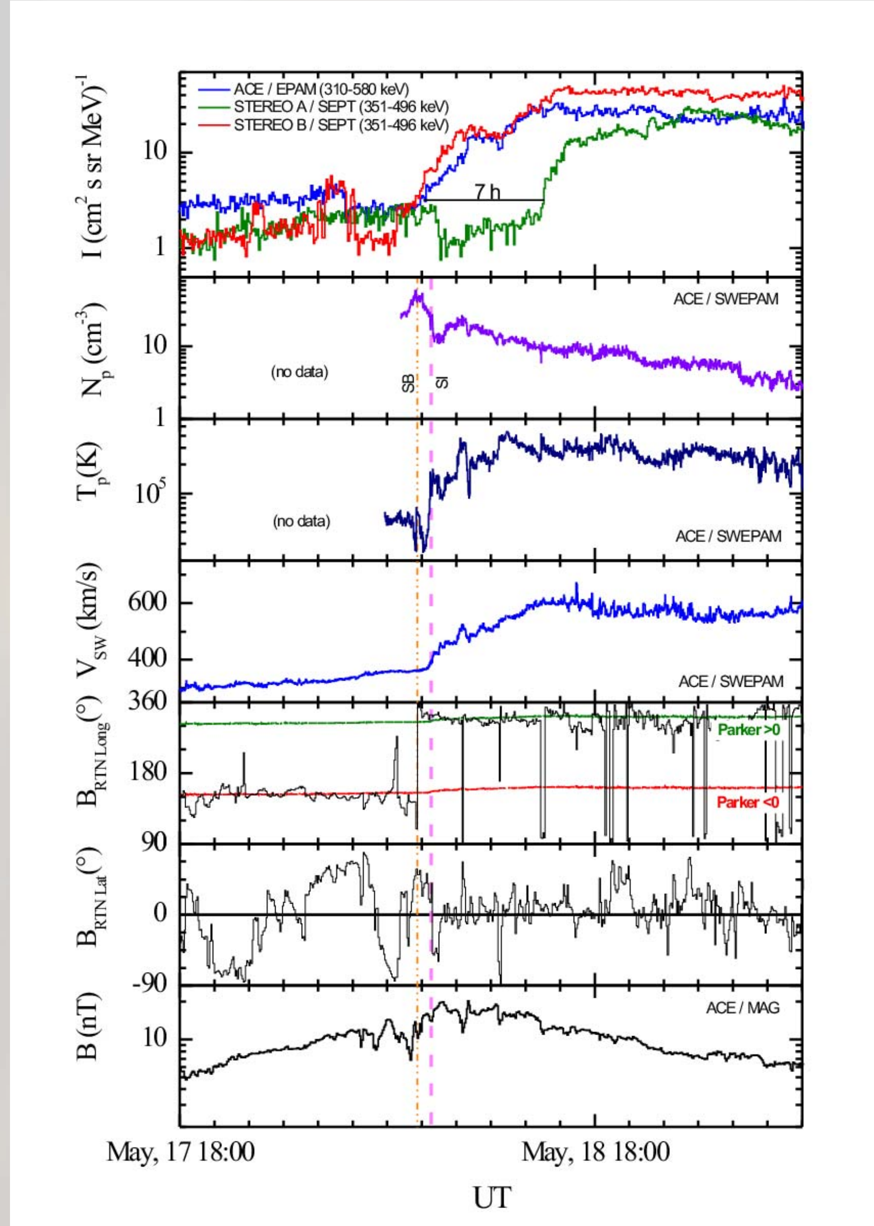


Small scale deviations from the ideal co-rotation

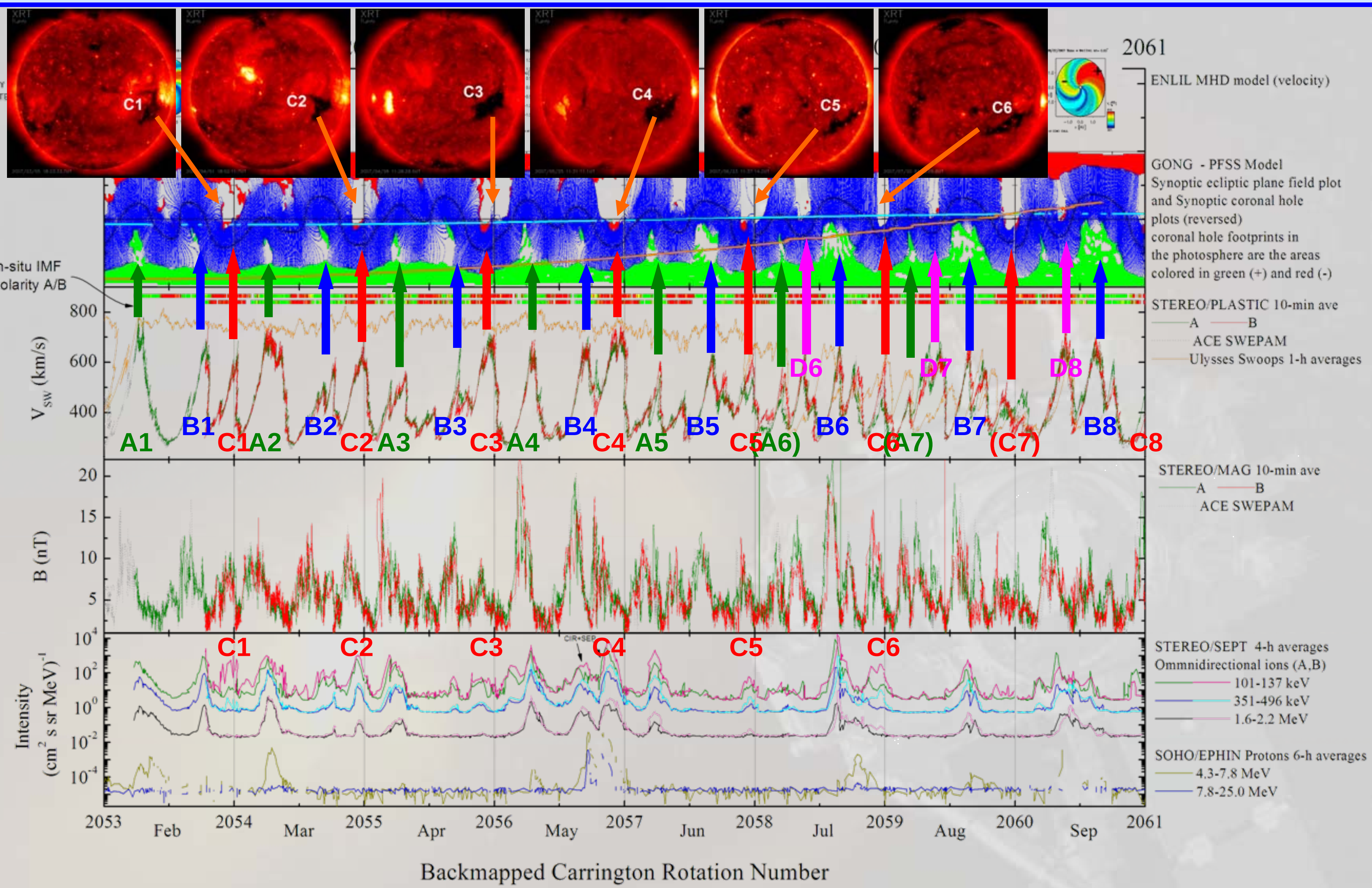
May 17-18, 2007, onset of a CIR-associated ion increase

- Near the stream interface
- latitudinal separation 1.4 º
- 7 h delay between A and B is consistent with 500-600 km/s solar wind
- Azimuthal IMF angle close to nominal values





Solar Wind and Energetic Particles (Feb-Sep 2007)



Acknowledgements
Global Oscillation Network Group (GONG) is managed by the National Solar Observatory, which is operated by AURA, Inc. under a cooperative agreement with the National Science Foundation. The data were acquired by instruments operated by the Big Bear Solar Observatory, High Altitude Observatory, Learmonth Solar Observatory, Udaipur Solar Observatory, Instituto de Astrofísica de Canarias, and Cerro Tololo Interamerican Observatory.
ENLIL MHD model by D. Odstrcil (Xie et al., JGR, vol 109, 2004) available thanks to The Community Coordinated Modeling Center (CCMC)

Coronal Hole Sequence CR 2053.0-2061.0