# Multi-Spacecraft Observations of SEPs: Applications for 3D Propagation Modelling

**B. Klecker**

**Max-Planck-Institut für extraterrestrische Physik, 85740 Garching, Germany**

**W. Dröge**

**University of Würzburg, Würzburg, Germany**

**Y.Y. Kartavykh, A. Kovaltsov**

**Ioffe Physical-Technical Institute, St. Petersburg, Russia**

**STEREO SWG #20**

**Meredith, NH**

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# OUTLINE

- **Part 1**

  **3D Propagation Model and First Results**

- **Part 2**

  **Future Applications to Observations with STEREO-A/B, SOHO, ACE, WIND**

Activity started as part of the ISSI Team # 118 on

*Transport of Energetic Particles in the Inner Heliosphere*

Team Members: M. Desai, **W. Dröge** (Lead), P. Evenson, B. Heber, T. Horbury, Y.Y. Kartavykh, B. Klecker, K.-L. Klein, S. Krucker, R. Schlickeiser, C. Smith

# THE 3D PROPAGATION MODEL

**Particle propagation in a 3D archimedian spiral magnetic field,**

**Including the effects of**

- **pitch angle scattering,**
- **focusing,**
- **diffusion perpendicular to B**
- **convection and adiabatic deceleration**

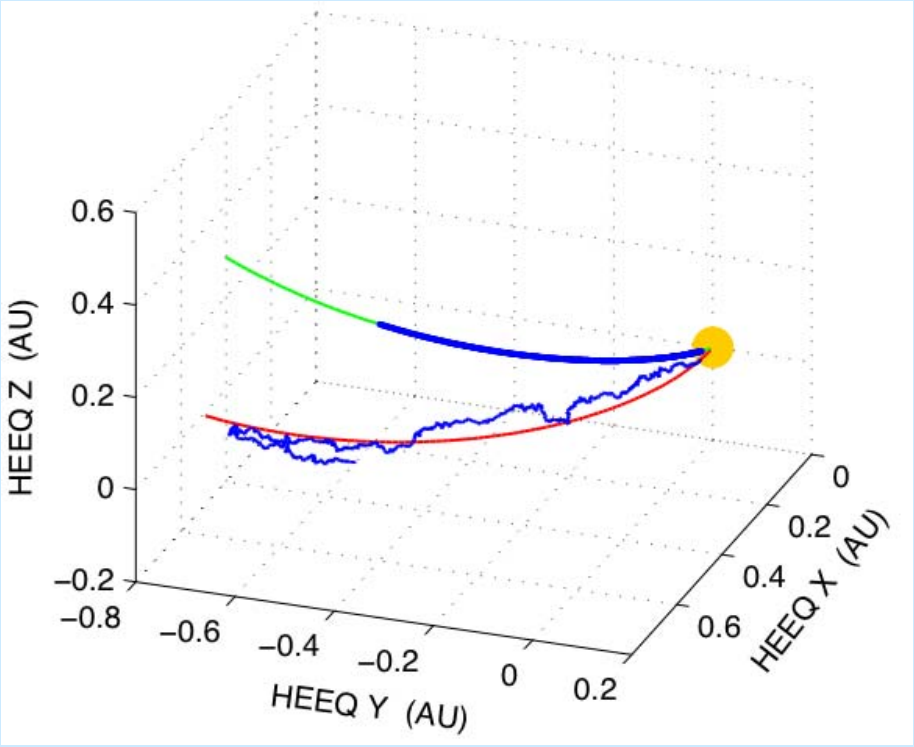
**Presently: model assumes impulsive injection at a localized source at the Sun**

**Numerical Method, solving stochastic differential equations**

(Paper “Anisotropic three-dimensional focused transport of solar energetic particles in the inner heliosphere“ by Dröge et al., ApJ, in refereeing process)

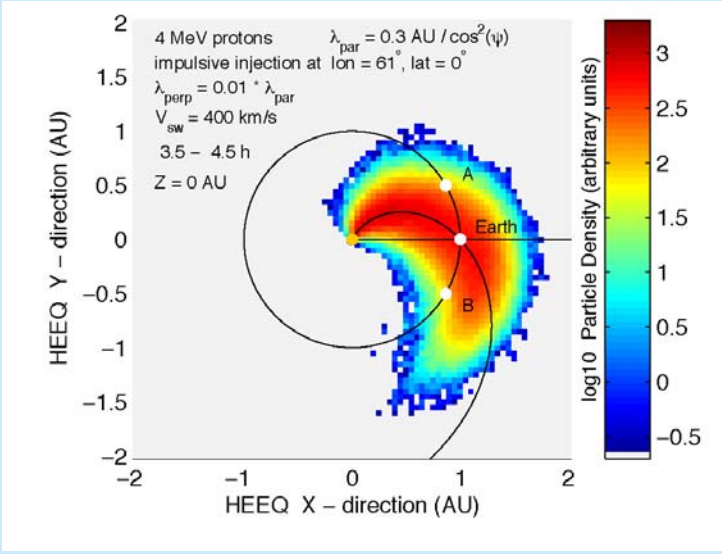
# THE 3D PROPAGATION MODEL

## Simulation for 4 MeV Protons




$\lambda_r = 0.3$ AU

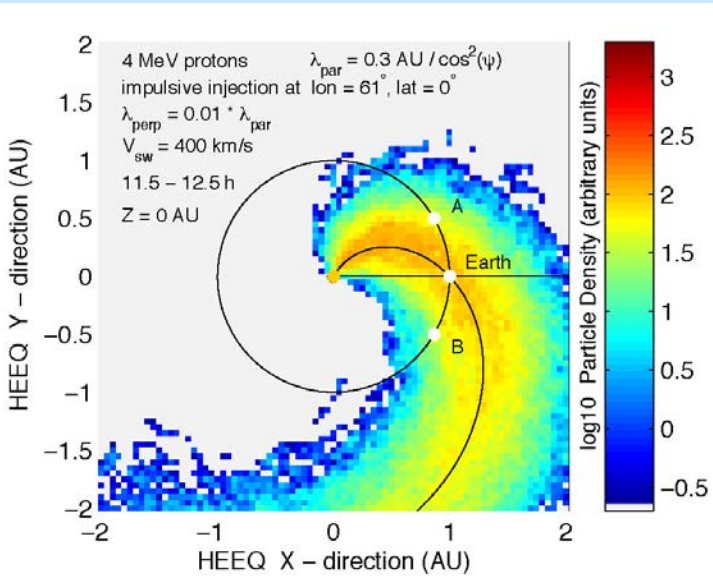
$\lambda_p = 0.01\lambda_{||}$




4h

Path of 4 MeV p with and without perpendicular diffusion

Dröge et al., 2009



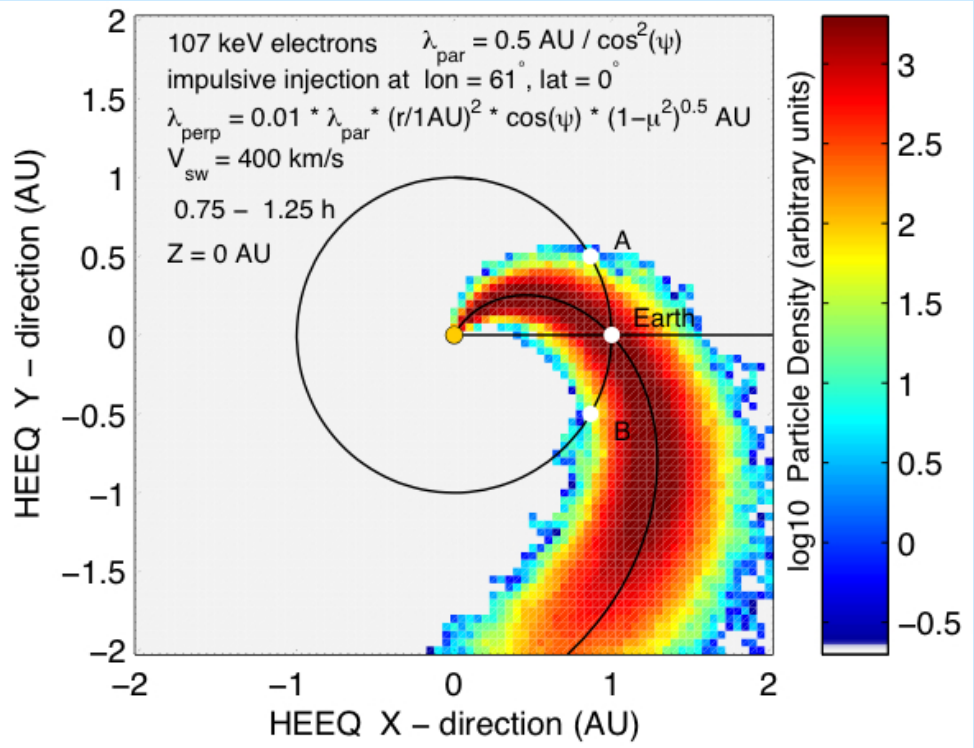

12h

# THE 3D PROPAGATION MODEL

**More realistic:**

**$\lambda_{perp}$ scales with gyroradius:**

$$\lambda_{\perp} = \alpha \cdot \lambda_{\parallel} \cdot \left(\frac{r}{1\mathrm{AU}}\right)^2 \cdot \cos\psi \cdot \sqrt{1-\mu^2} \quad \mathrm{AU}$$



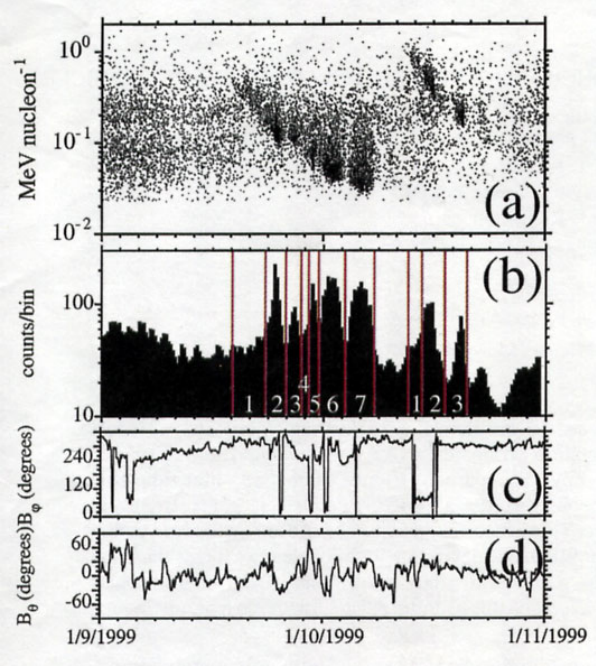

$$\lambda_{\parallel} = 0.5 \ \mathrm{AU}/\cos^2\psi$$

$$\alpha = 0.01$$

# THE 3D PROPAGATION MODEL

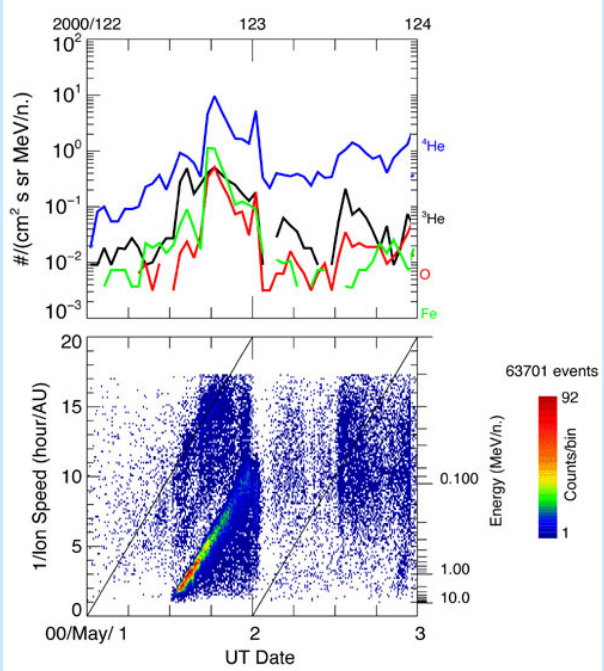
## Single Spacecraft Applications

### DROPOUTS




Mazur et al. (2000)

### CUTOFFS



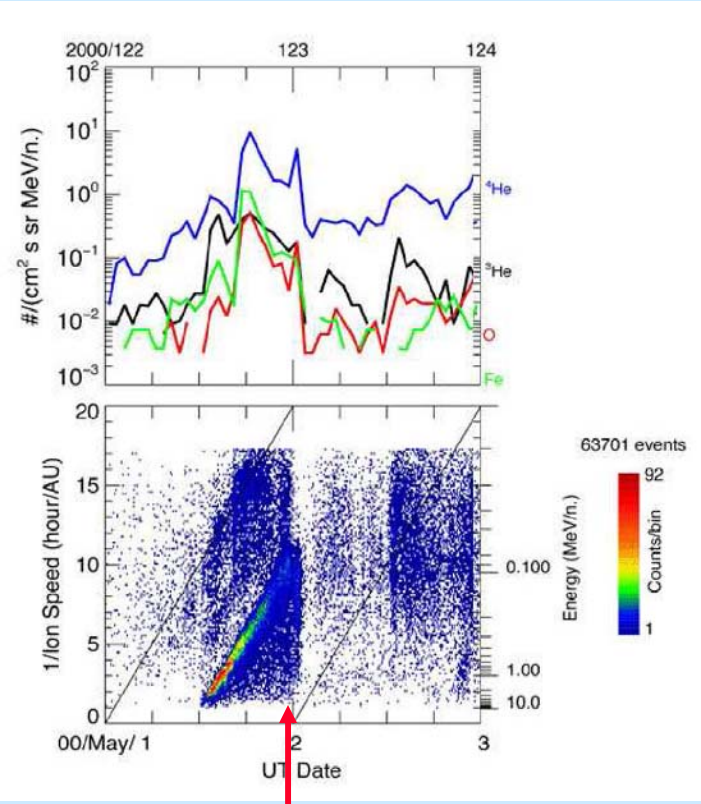

ACE ULEIS 1 May 2000

- **no velocity dispersion**
- **time variations correspond to large spatial gradients perpendicular to B, convected past the spacecraft**

# APPLICATION OF 3D PROPAGATION MODEL

## Single Spacecraft Observations

### I. Intensity-Time Profiles




ULEIS / ACE

Kartavykh, et al., 2007

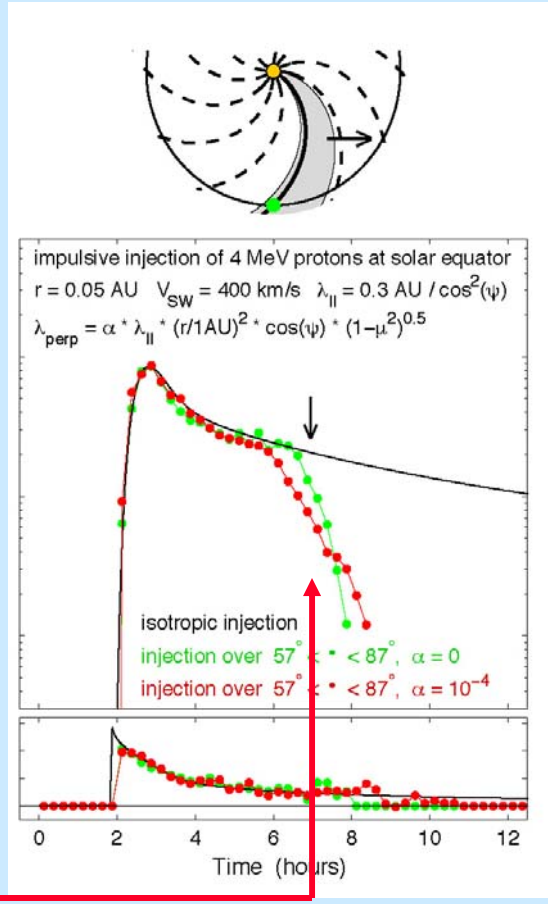
**Cutoff**

**No Perp Diffusion**

**Perp diffusion**

**With corotation**

Intensity



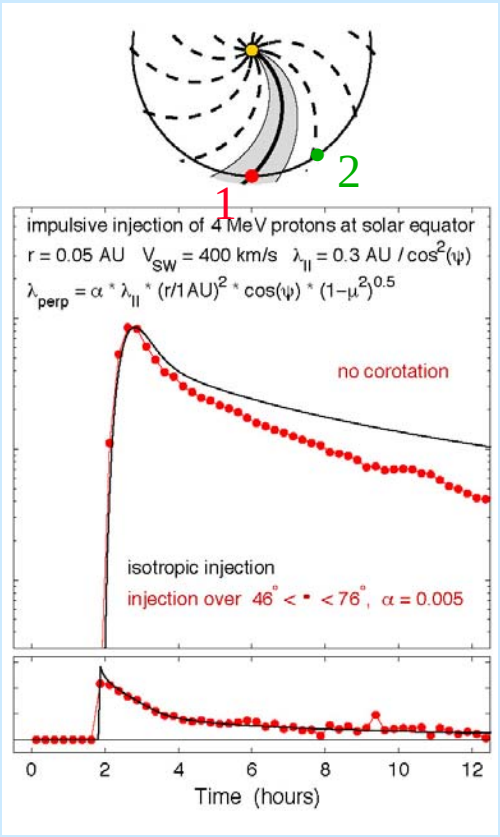

Dröge et al., 2009

upper limit for $\lambda_{perp} / \lambda_{||}$: $< 10^{-4}$ (at 1 AU)

# APPLICATION OF 3D PROPAGATION MODEL

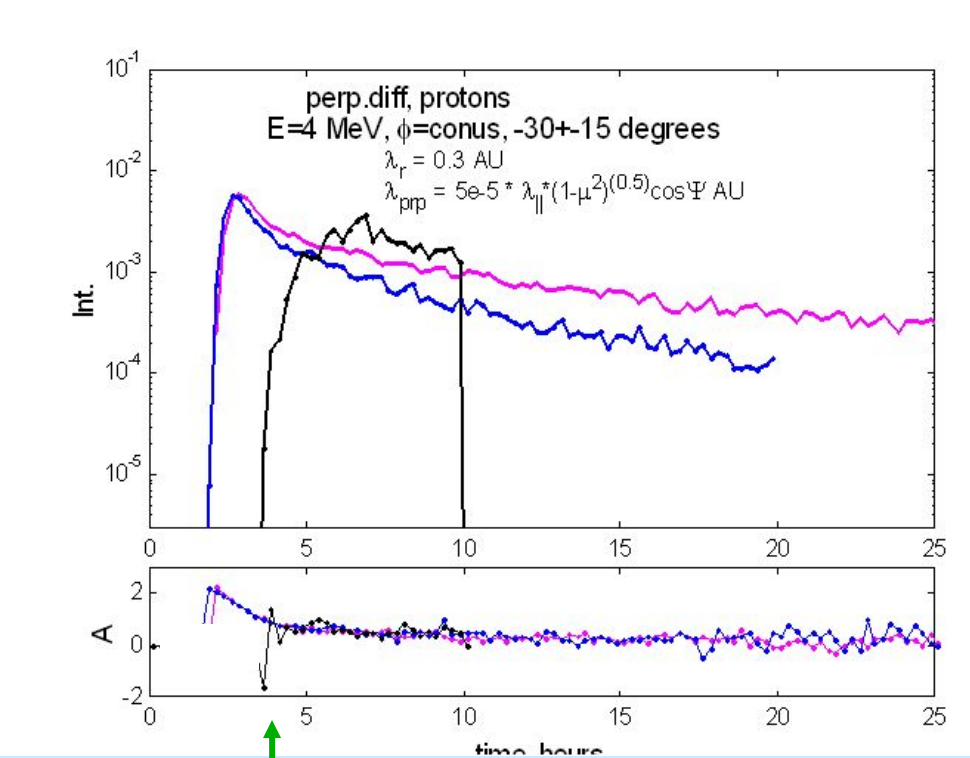
## Single Spacecraft Observations

## II. Anisotropies




Case 1: Large anisotropy

S/C inside flux tube filled with particles




Case 2: Small anisotropy

S/C entering flux tube filled with particles later

# APPLICATION OF 3D-PROPAGATION CODE TO OBSERVATIONS BY STEREO-A/B, ACE, WIND, SOHO

## II. Multi Spacecraft Observations

**(1) Use remote observations to obtain injection parameters at the Sun**

**Type II, III bursts, X-rays, CME- Radio - observations, ...**

**(2) In-situ Observations**

**Use Intensity-Time Profiles, Anisotropy-Time Profiles**

**as measured on several spacecraft separated in longitude, latitude, radial distance to infer**

- Injection characteristics at the Sun
- Propagation parameters in Interplanetary Space

# APPLICATION OF 3D-PROPAGATION CODE TO OBSERVATIONS BY STEREO-A/B, ACE, WIND, SOHO

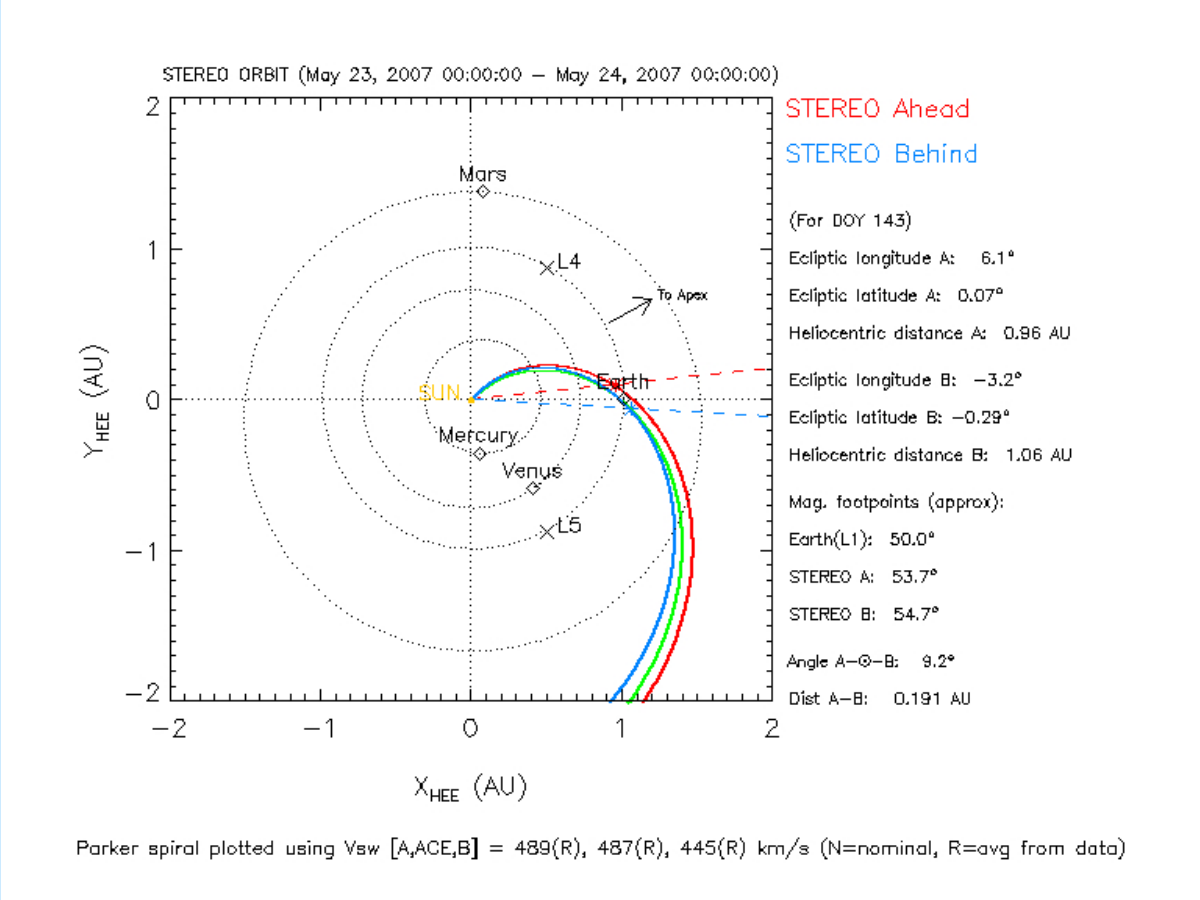
## Candidate Time Periods

I. May 2007

II. Nov 2008

III. May 2009

A - B Separation: 9.2°




(http://www2.physik.uni-kiel.de/stereo/browseplots/index.php)

# 2008 - Nov 3/4 Events

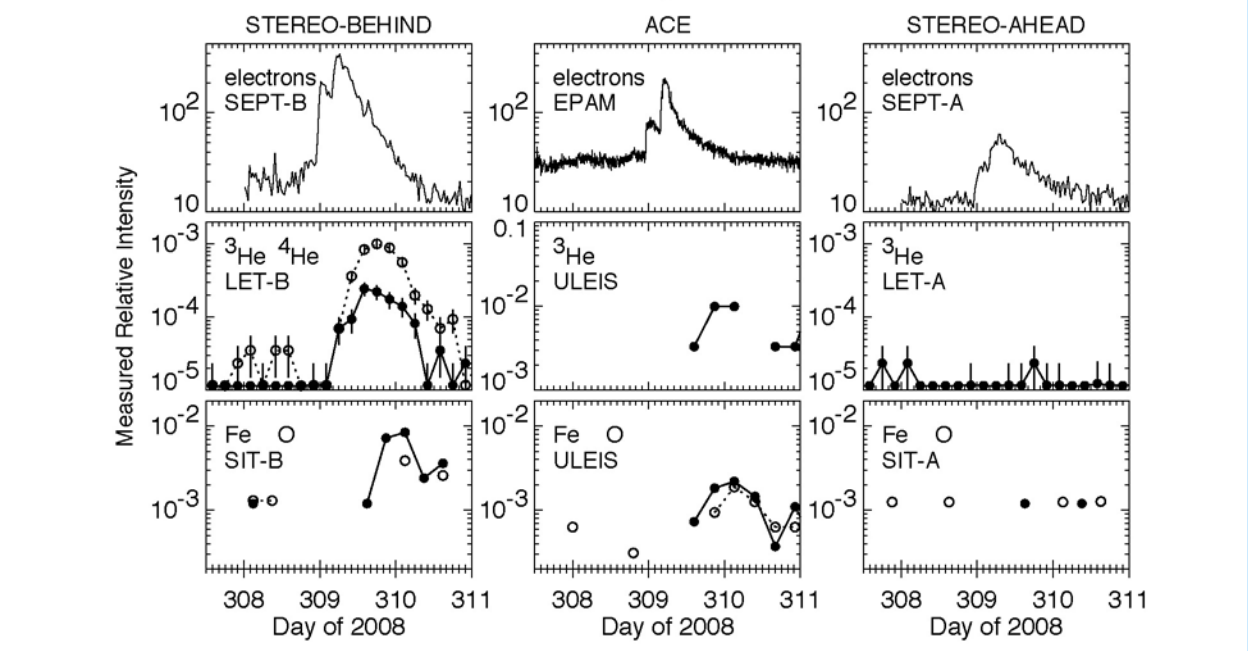
## In-Situ Observation with ACE and STEREO

### Candidate Time Periods

I. May 2007

II. Nov 2008

III. May 2009




Wiedenbeck et al., 2009

### (II) Nov 3/4 2008 Event

N35W38

C1 X-ray event

Type III burst

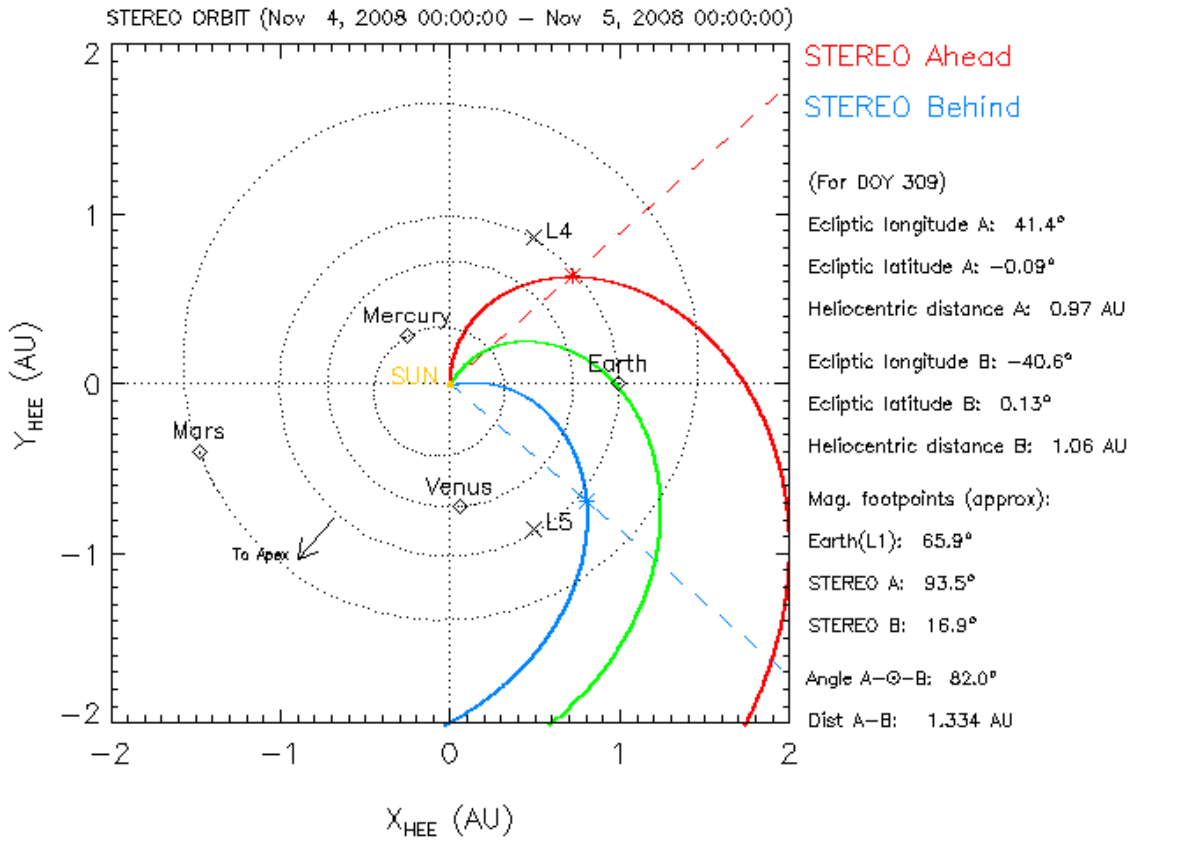
Small CME

(Wiedenbeck et al., ICRC 2009;

Mason, et al., ApJ 2009)

# ORBIT CONFIGURATION OF STEREO-A/B and ACE

## for Day 309 (Nov 4) 2008




**Event:**

**N35W38**

**Separation**

**Footpoint - Flare**

| | ΔΦ |
|---|---|
| **STEREO-B** | **-2°** |
| **ACE** | **24°** |
| **STEREO-A** | **45°** |

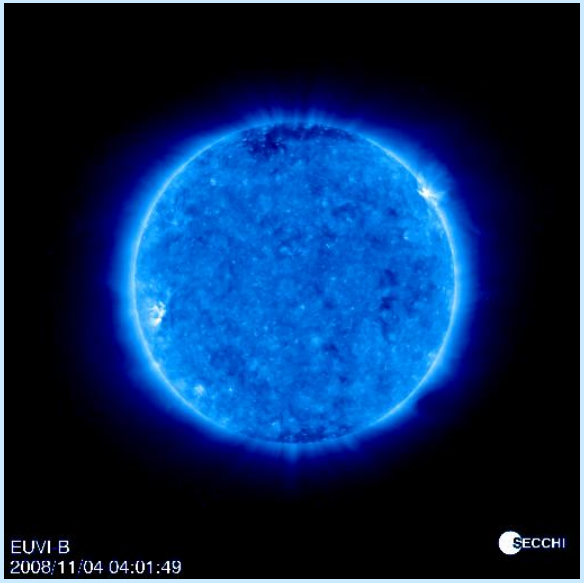
**A - B Separation: 82°**

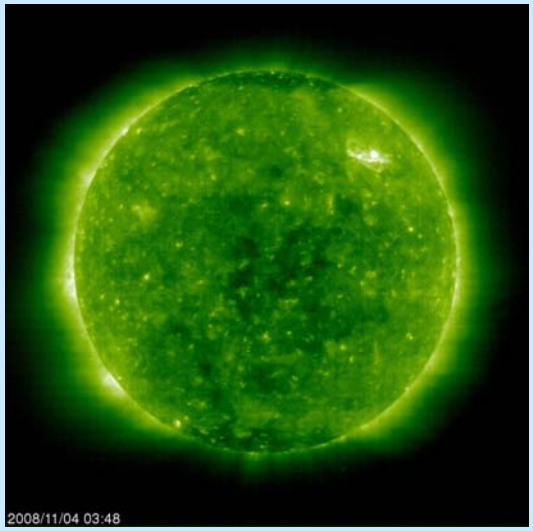
**Configuration of STEREO / ACE for Day 309 (Nov 4), 2008**
(http://www2.physik.uni-kiel.de/stereo/browseplots/index.php)

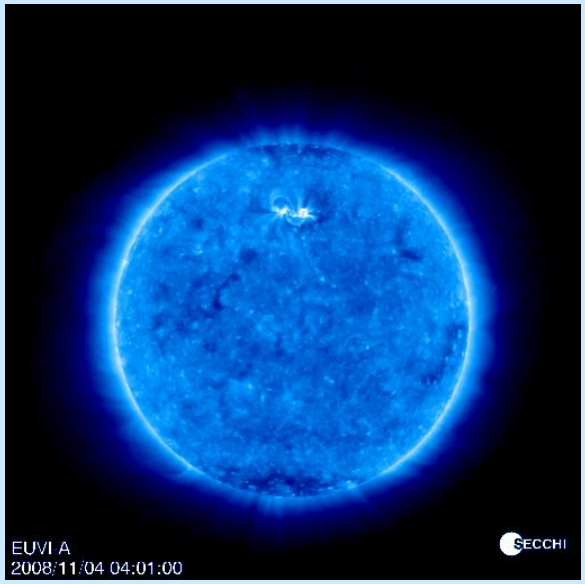
# 2008 - Nov 3/4 Events

## Remote Observation with SOHO and STEREO

**STEREO-B** **SOHO** **STEREO-A**



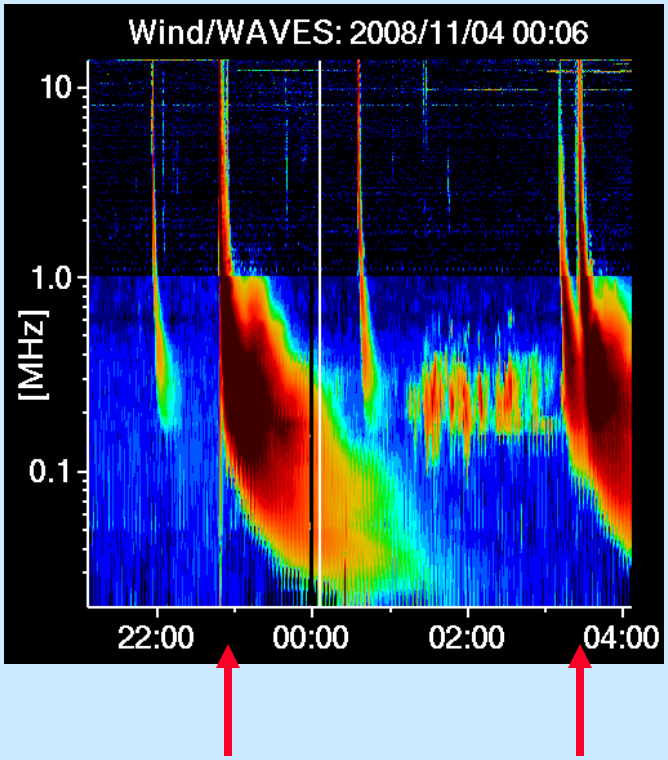

**Nov 4, 2008 Event**

**Active Region 11007**

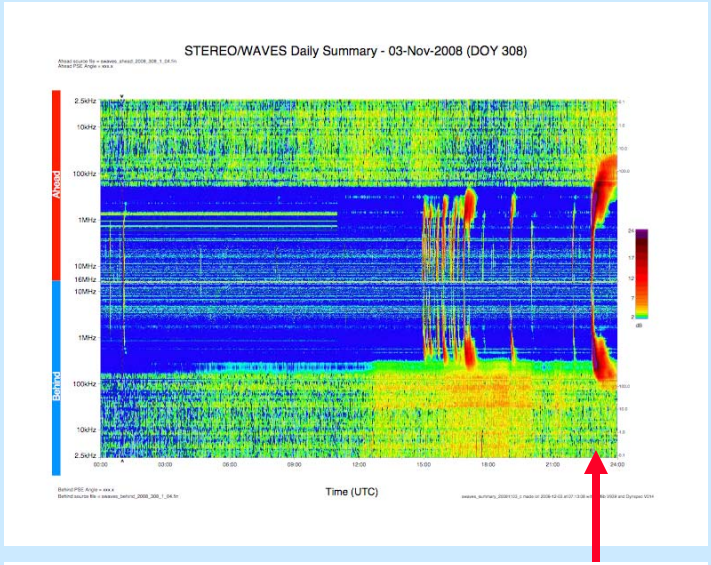
# 2008 - Nov 3/4 Events

## Remote Observation with STEREO and WIND

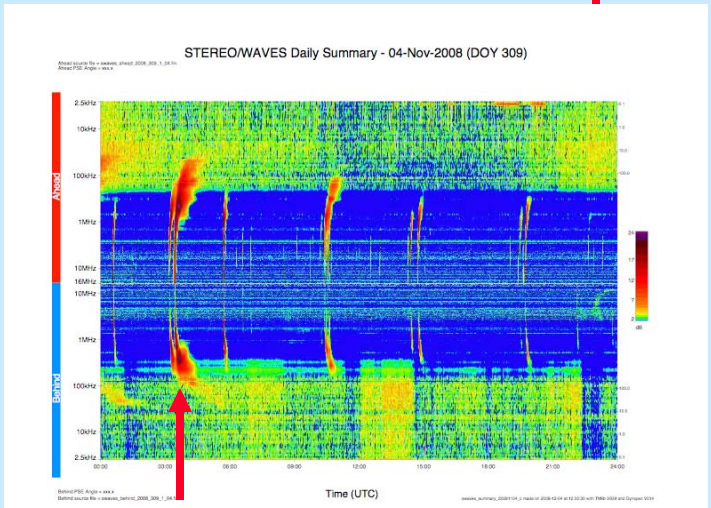
**WIND / WAVES**




**STEREO / WAVES**




**Nov 3**




**Nov 4**

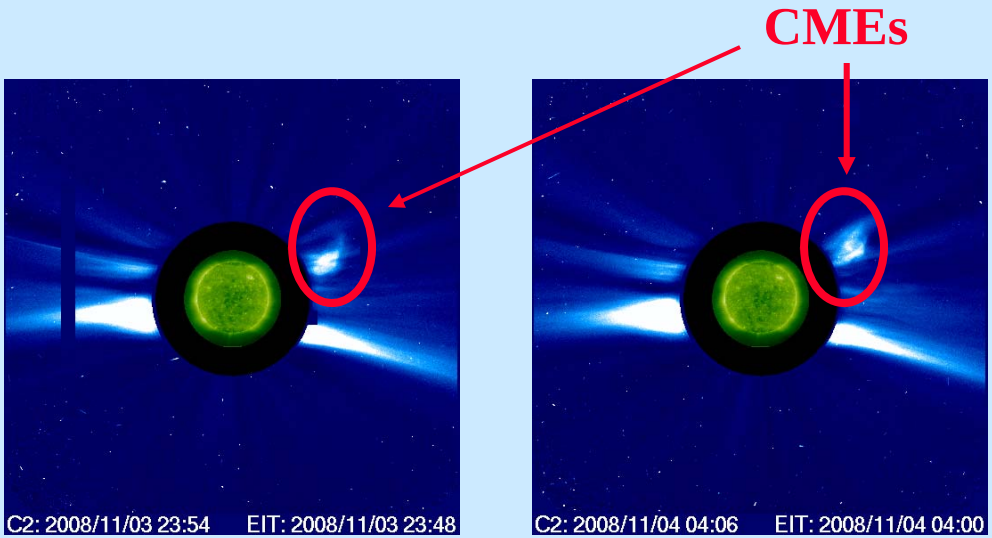
**Onset times on** **Nov 3, 22:45**

**Nov 4, 03:24**

# 2008 - Nov 3/4 Events

## Remote Observation with SOHO

**SOHO / EIT**




| | |
|---|---|
| Nov 3 23:30 | Nov 4 03:54 |
| Speed: ~ 370 km/s | ~ 732 km/s |
| Width: ~ 46° | ~ 66° |

# 2008 - Nov 3/4 Events

## In-Situ Observation with ACE and STEREO

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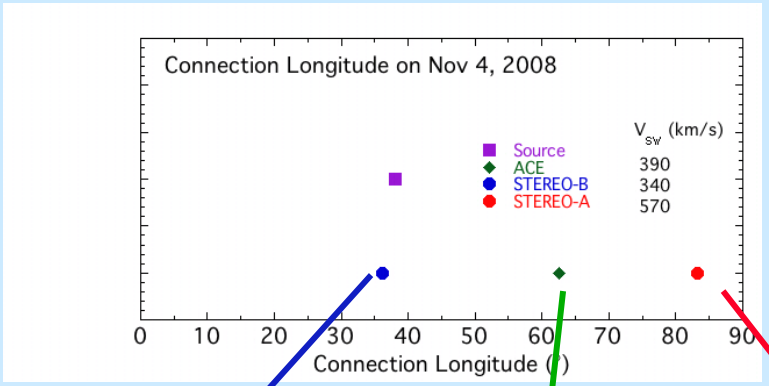
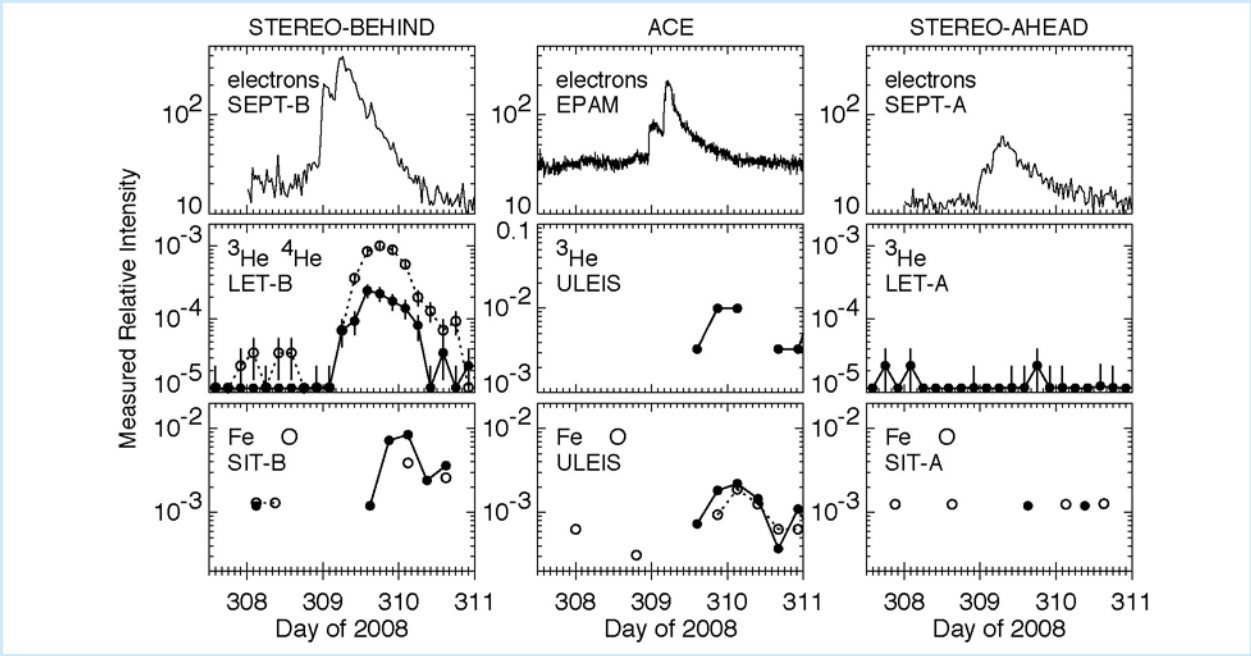
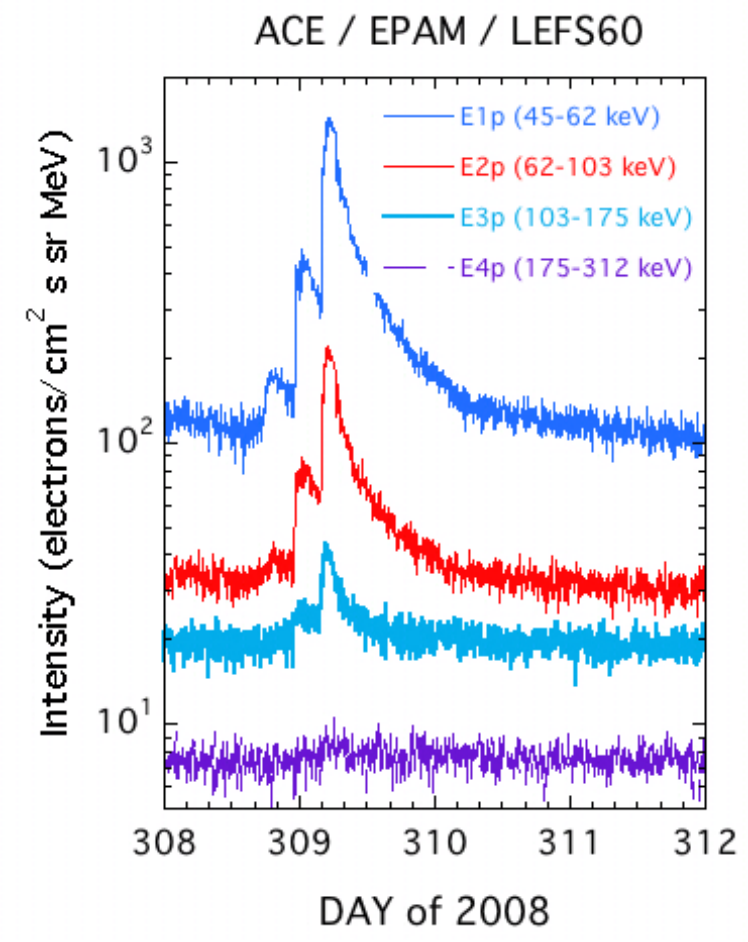


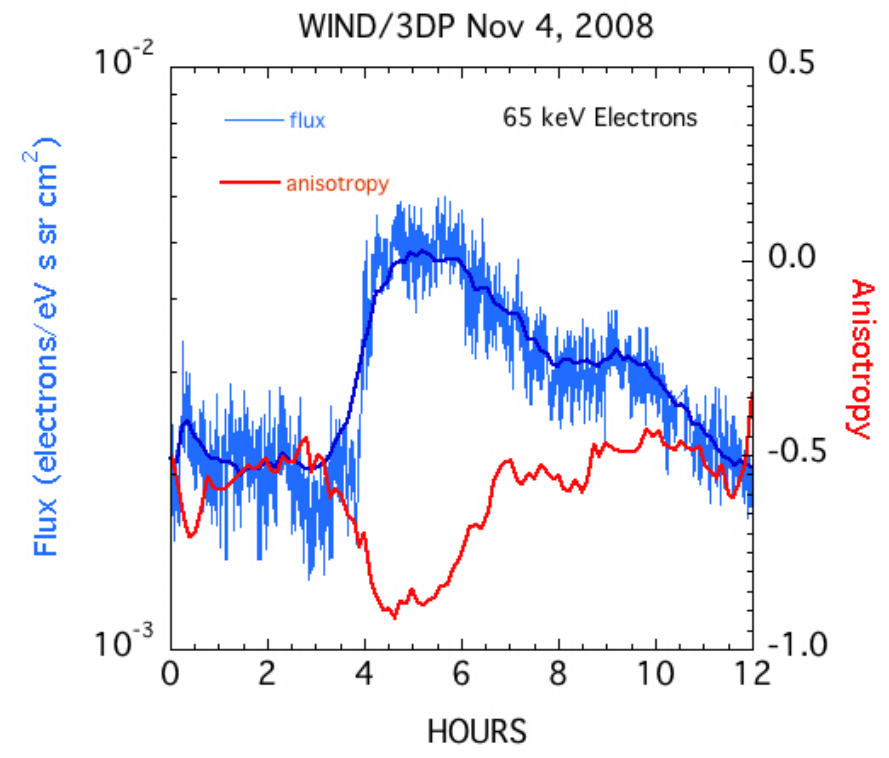
# 2008 - Nov 3/4 Events

## In-Situ Observation with ACE, WIND and STEREO

**ACE / EPAM**




**WIND / 3DP**

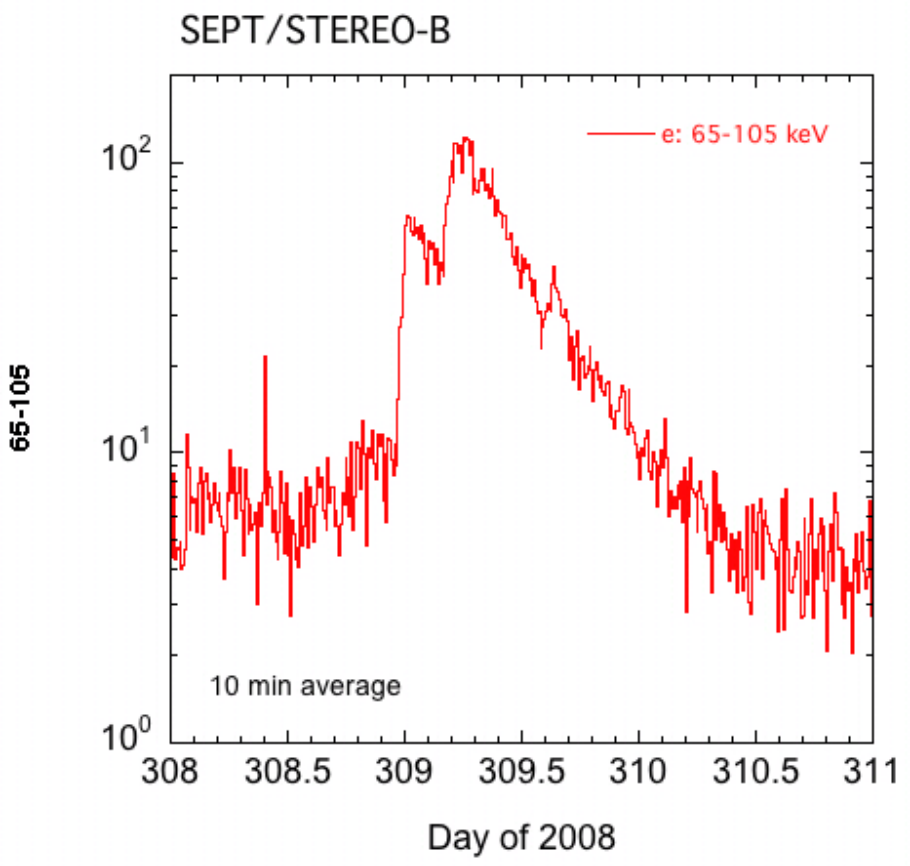



**Type III bursts on Nov 4: 03:24**

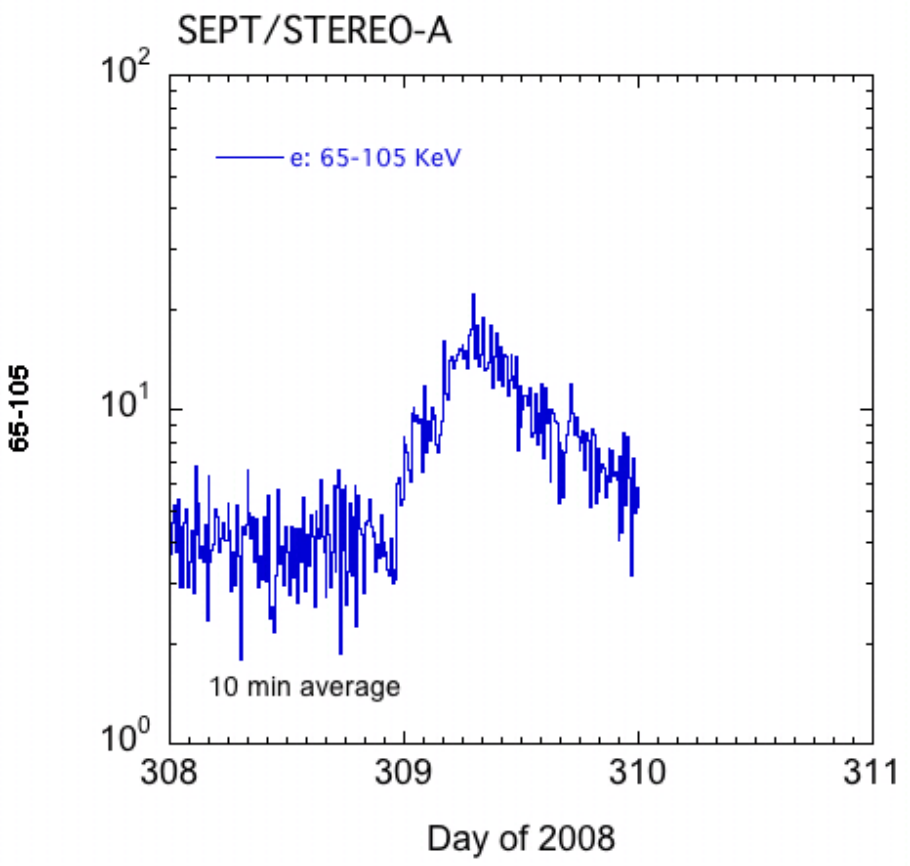
# 2008 - Nov 3/4 Events

## In-Situ Observation with ACE, WIND and STEREO

**STEREO / SEPT**

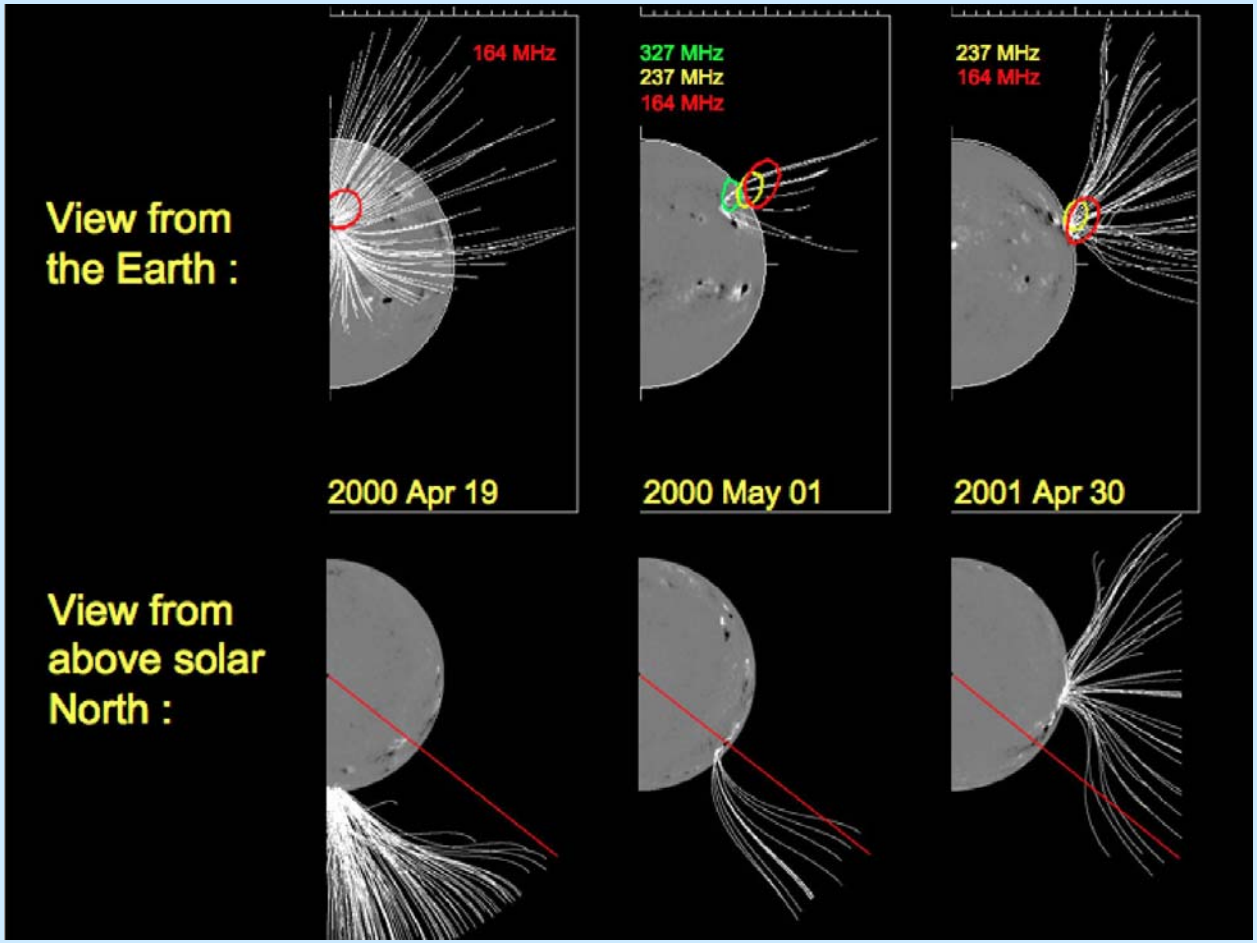



**STEREO / SEPT**



# POSSIBLE COMPLICATIONS

## Flare Longitude is not Necessarily Injection Longitude




**Intensity contours of 50%$_{max}$ type III bursts**

**Magnetogram**

**Open field line maps computed with PFSS model**

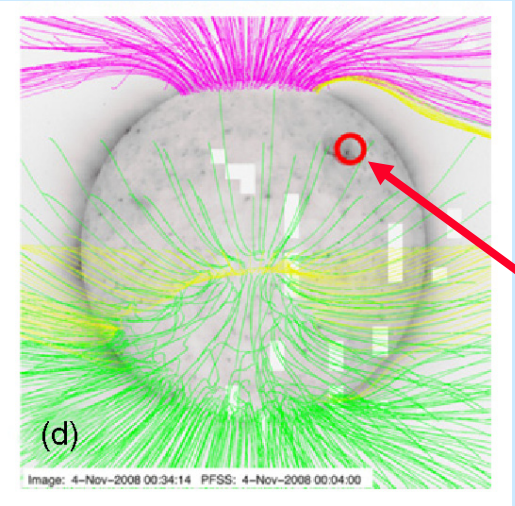
Klein, et al., 2008

**Fast access to open field lines at large $\Delta\Phi$ due to non-radial flux tubes**

# 2008 - Nov 3/4 Events

## Event Summary

- ~40 - 300 keV electrons observed over large range of solar longitudes
- intensity (two injections)- and anisotropy-time profiles are providing constraints on pitch angle scattering, perpendicular diffusion, and location of injection




- PFSS model does not show open field lines that connect to near-equator region
- Possible resolution of this puzzle: dynamical changes in magnetic field configuration by CME

**Mason, et al., 2009**

Open field line maps from photosphere to 2.5 $R_S$ surface from PFSS model .

Yellow: open field lines that connect to the ecliptic

# SUMMARY

**May 2007 Events**

Good candidates for single spacecraft analysis of intensity and anisotropy

**Nov 2008 Events**

Multispacecraft analysis could be promising, Ion intensity too small

**May 2009 Events**

Good statistics for ions and electrons, intensity and anisotropy measurements are available

Events observed at large longitudinal separation: non-radial flux tubes close to the Sun may be important