STEREO observations of the 7 Nov 2013 SEP event - an event inside a magnetic loop

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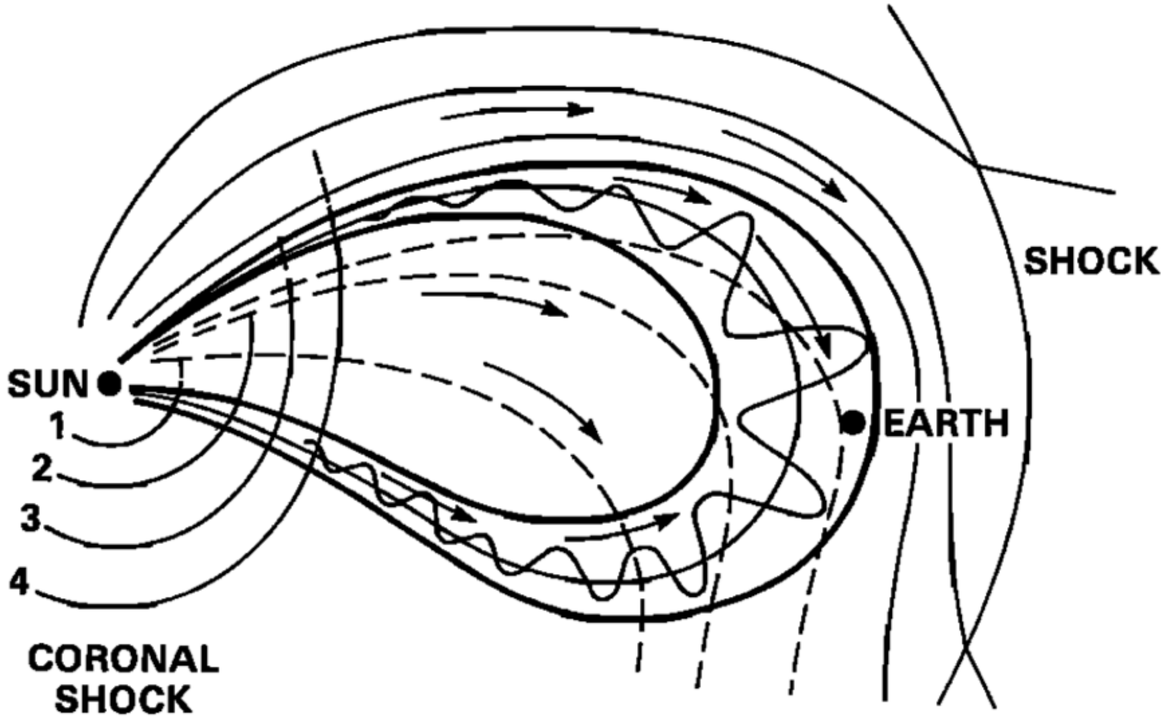
Motivation: SEP events inside magnetic clouds

- Magnetic clouds (MCs) are able to change the Parker magnetic field topology and therefore provide modified connections to the Sun (e.g. impulsive events from the east limb or far west limb: e.g. Richardson et al., 1991, Gómez-Herrero et al., 2006)



Richardson et al. 1991

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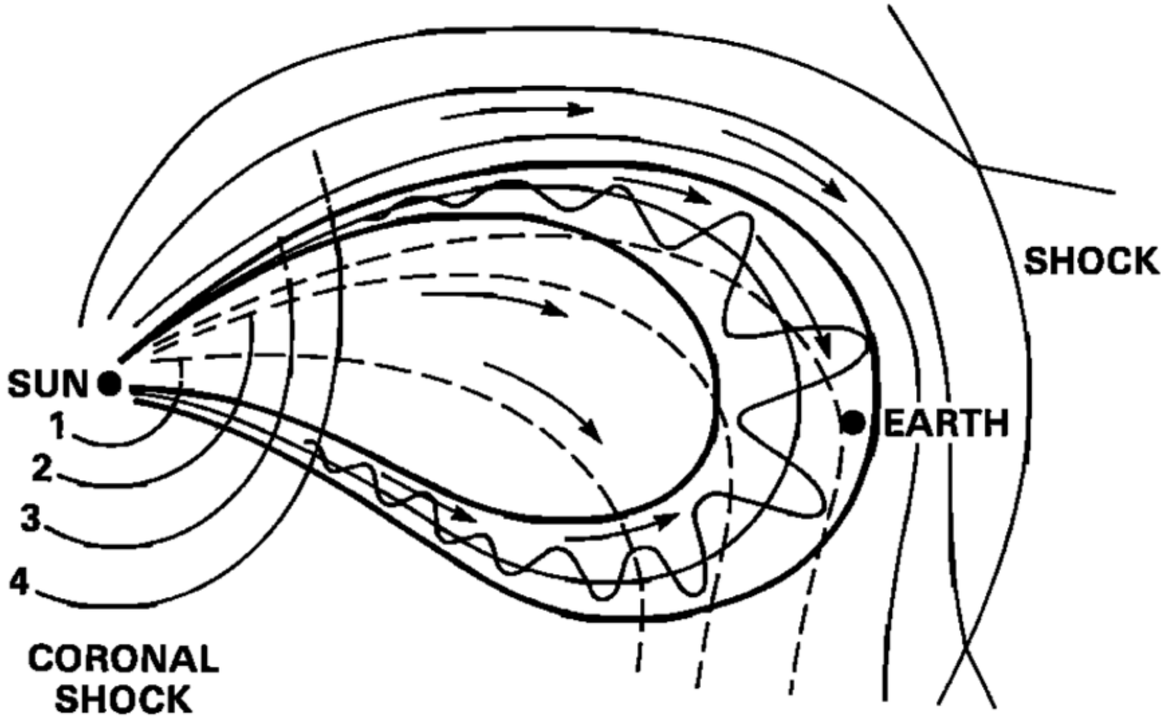
- SEP events inside MCs lend themselves to probe the magnetic field structure inside the MC (twist of magnetic field lines)
  e.g. Kahler et al., 2011a,b; Hu et al., 2015

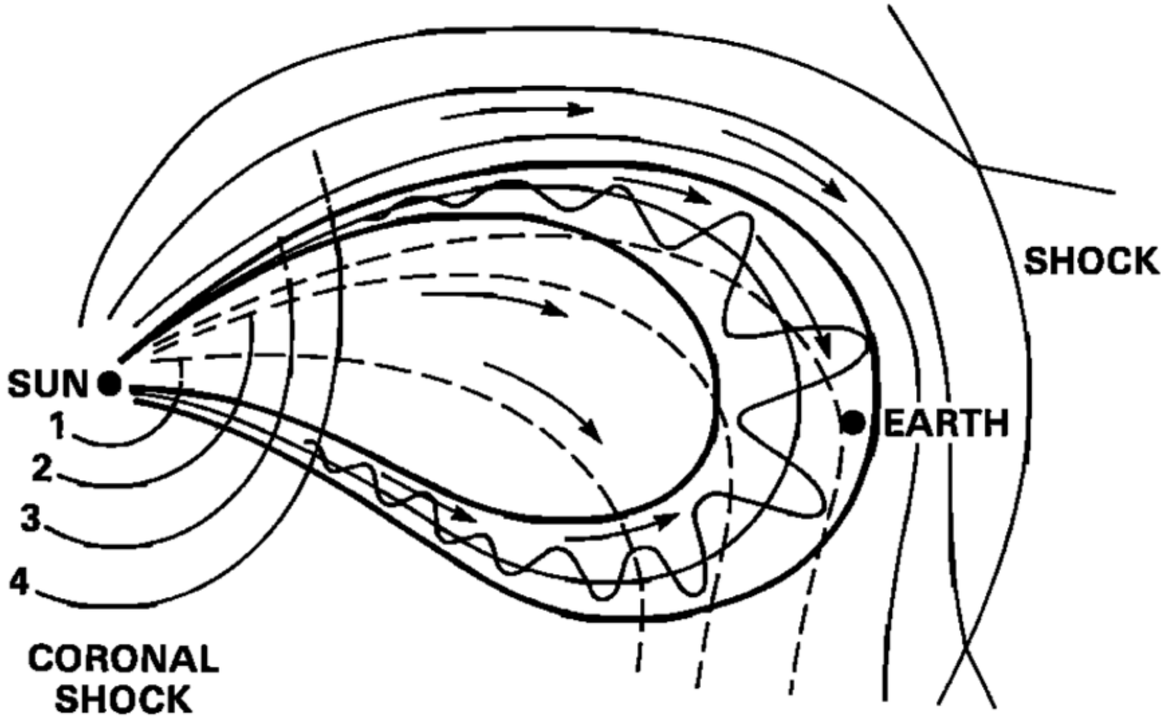


Richardson et al. 1991

Motivation: SEP events inside magnetic clouds

Structure of this talk:

1) Bi-directional SEP distribution in terms of the SEP injection
2) Twist of magnetic field lines inside the MC



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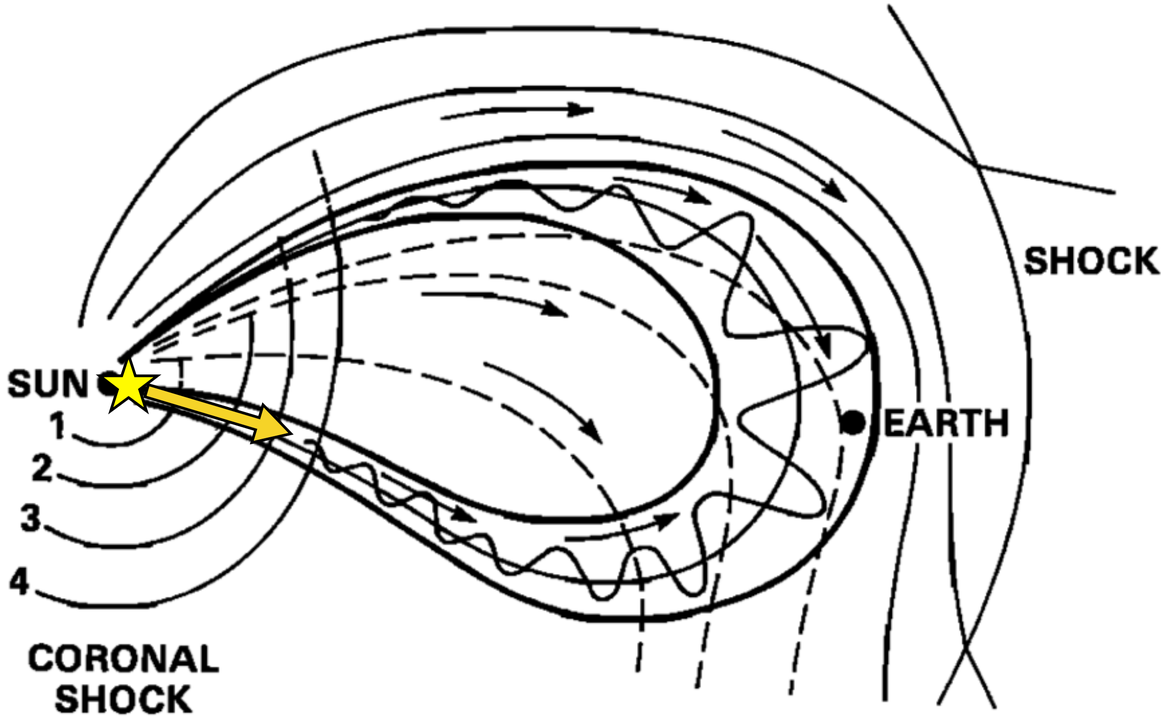
Injection of SEPs into a magnetic cloud

- A flare occurs directly below / inside the footpoint of one loop leg★



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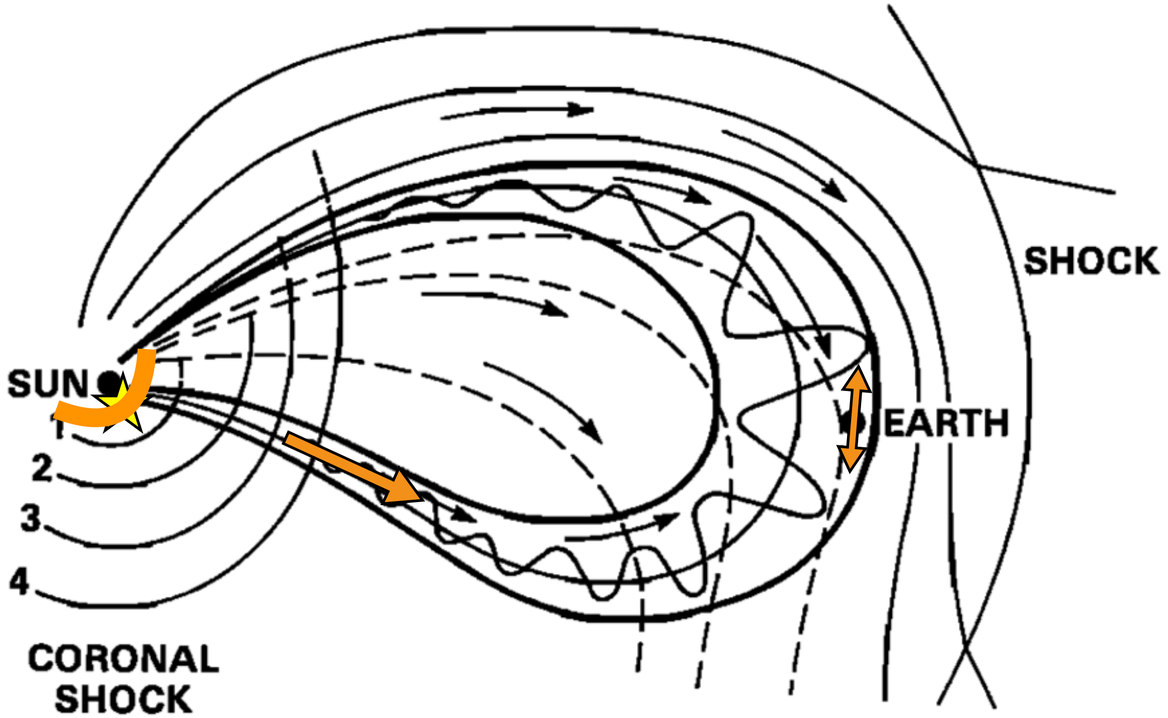
- A flare occurs directly below / inside the footpoint of one loop leg★
- A coronal shock (larger extent) intersects the loop leg

-> Mirroring, bi-directional SEP distribution



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Injection of SEPs into a magnetic cloud

- A flare occurs directly below / inside the footpoint of one loop leg ★
- A coronal shock (larger extent) intersects the loop leg

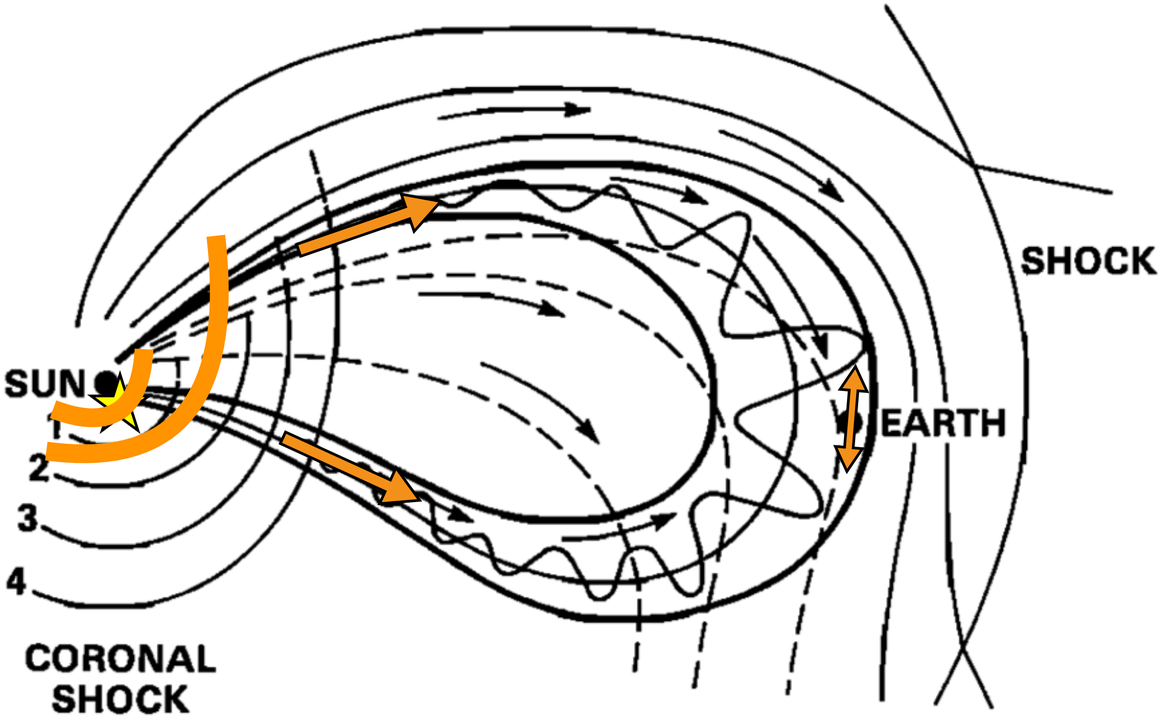
-> Mirroring, bi-directional SEP distribution

- Can a shock intersect both loop legs and inject particles into both legs?

  -> bi-directional SEP distribution

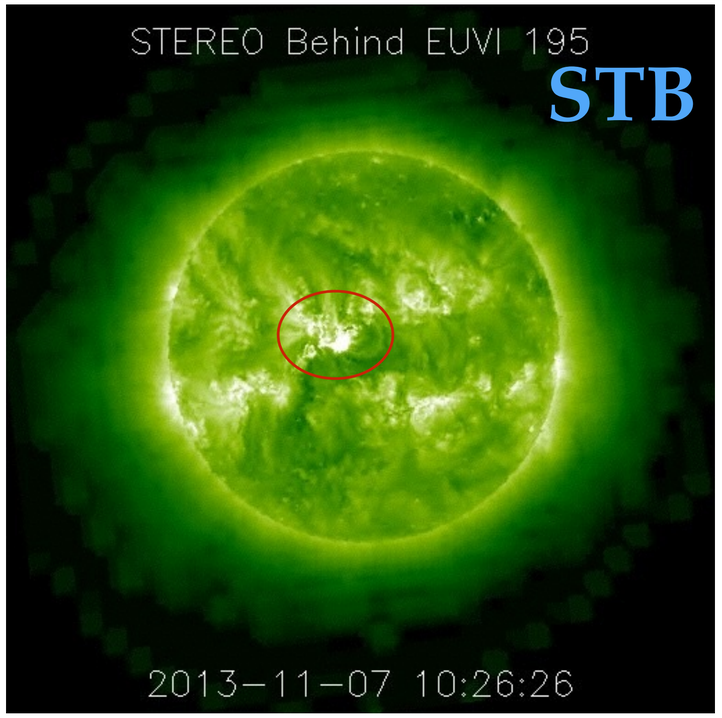
To our knowledge it could never be proven that an injection into **both** loop legs occurred

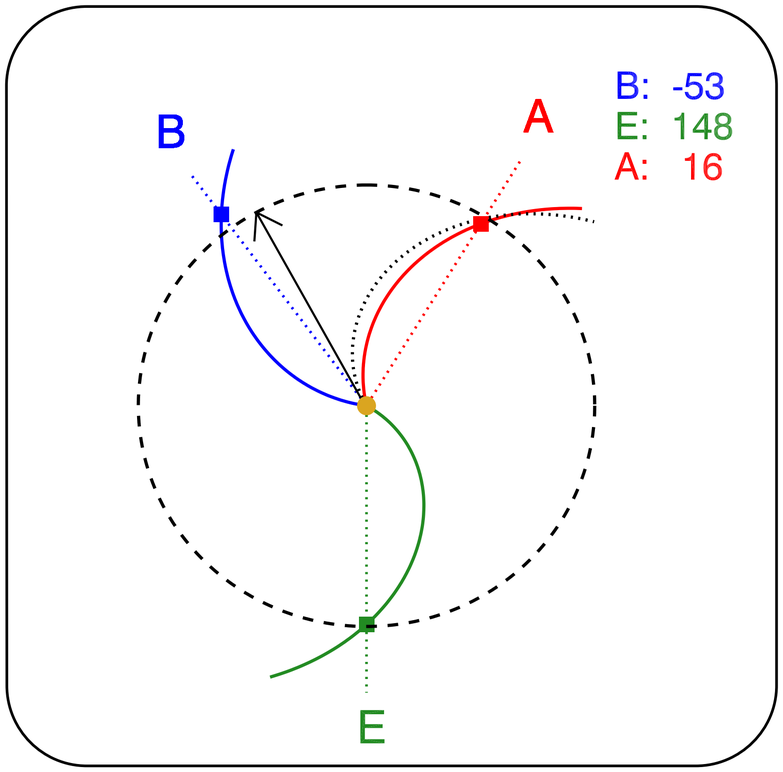
Problem: Similar signatures of mirroring and double injection

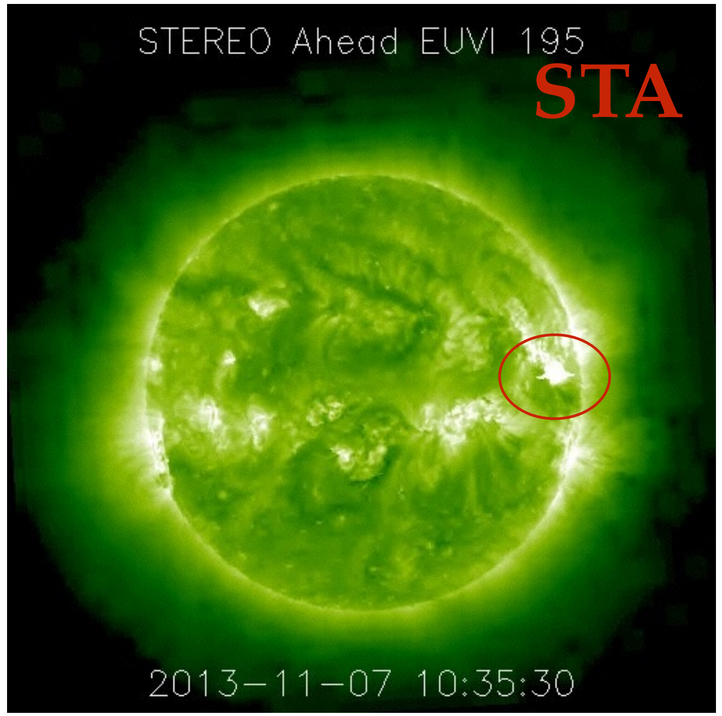


Richardson et al. 1991

The 7 Nov 2013 SEP event







The event is observed by STA and STB but not close to Earth

Flare at 10:15 UT

Flare Carr long: 37°

Electron observations at STA and STB

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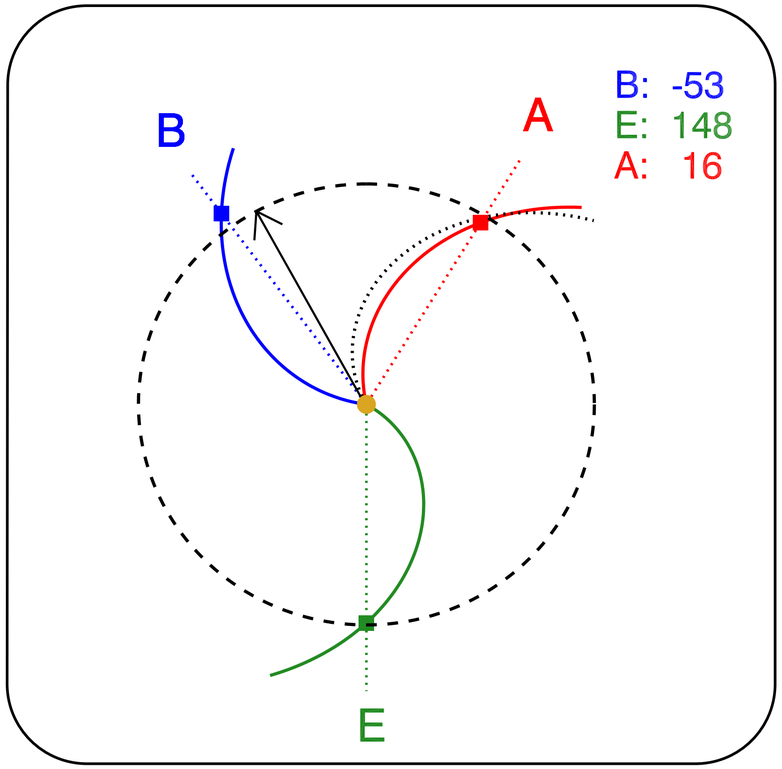
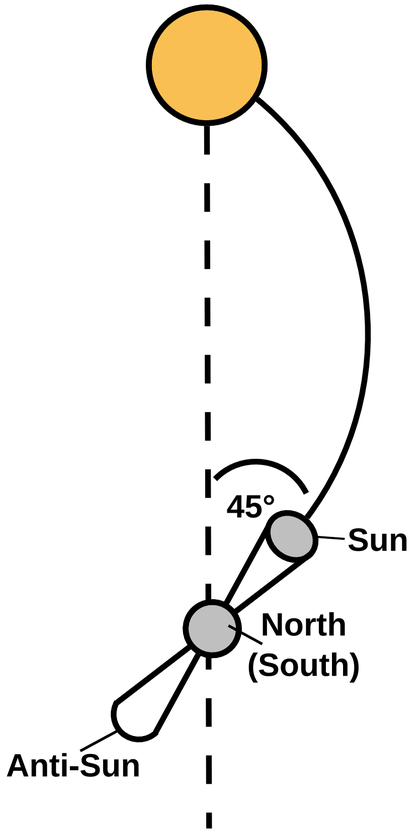
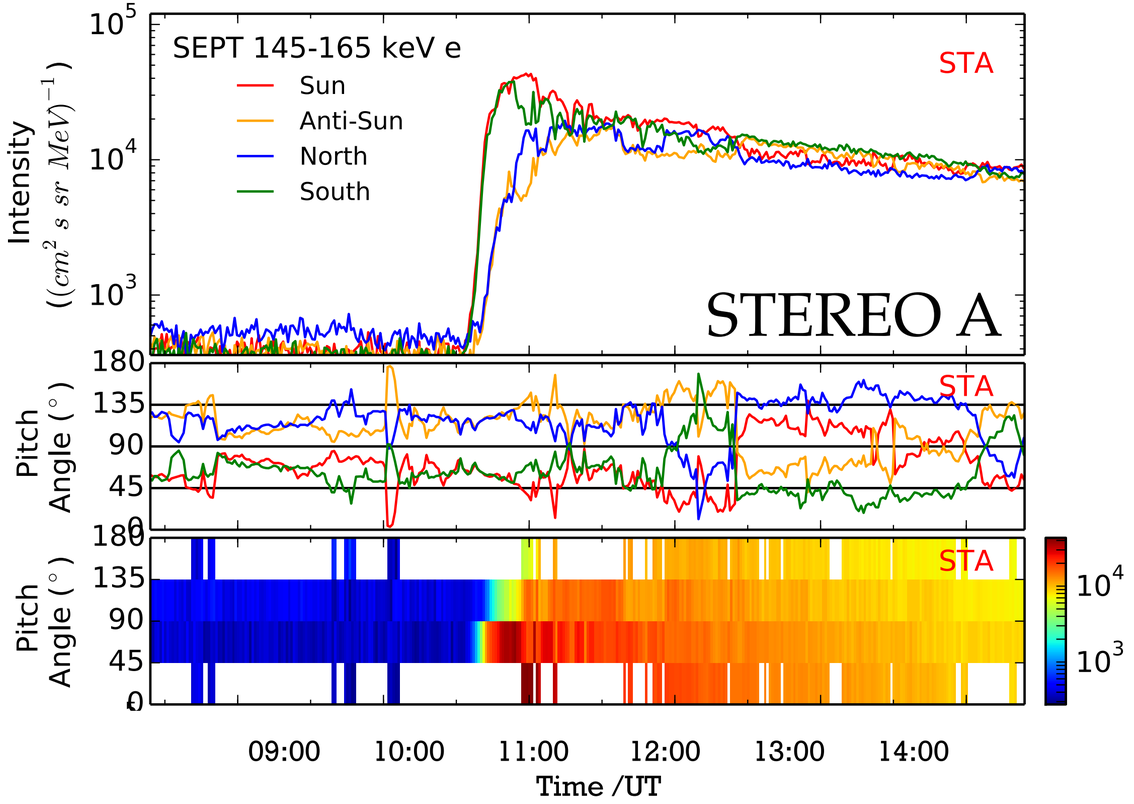


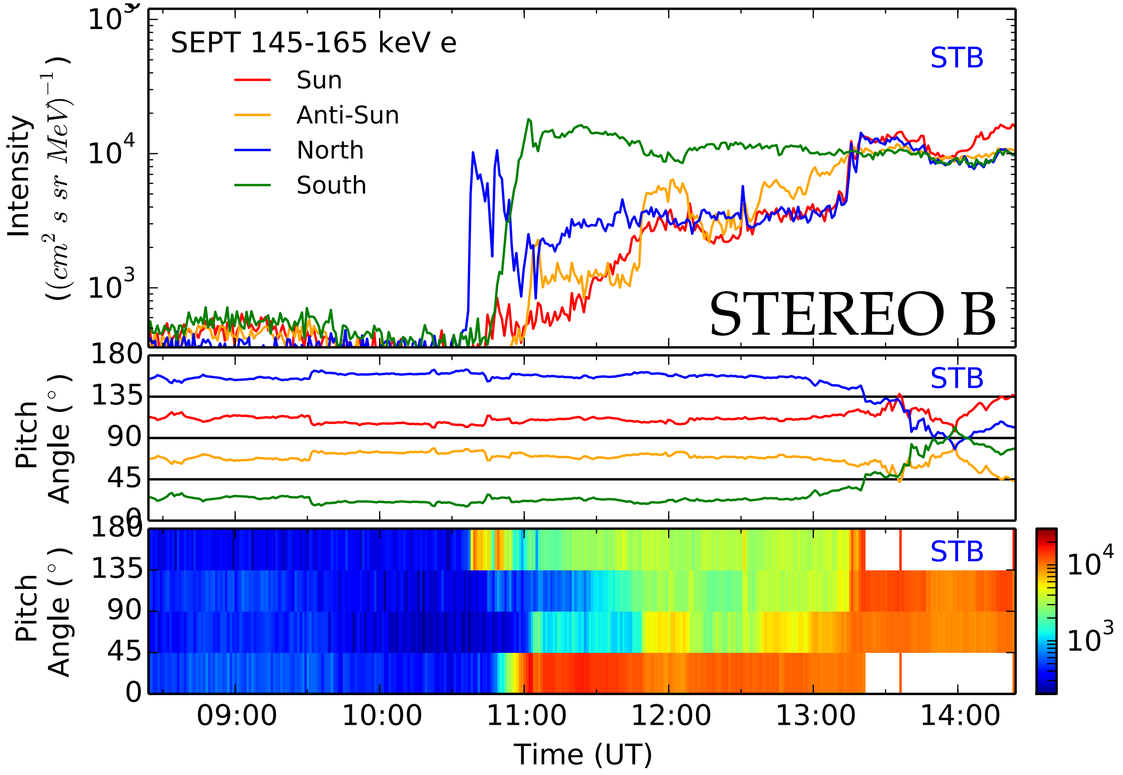
Viewing directions of STEREO/SEPT

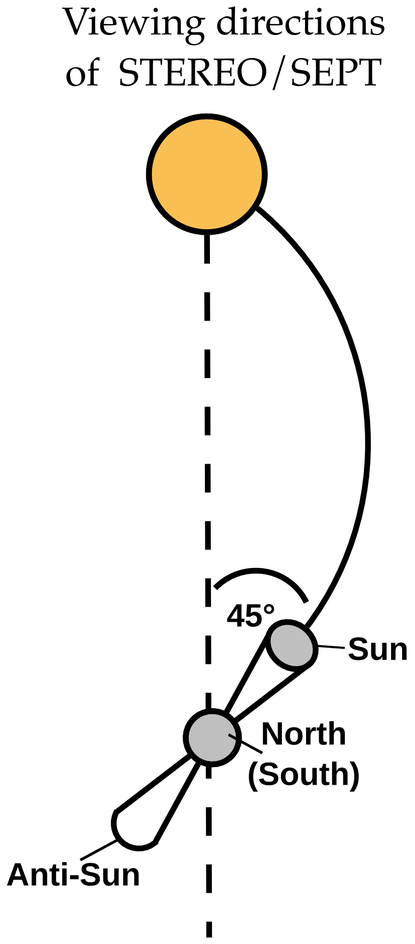


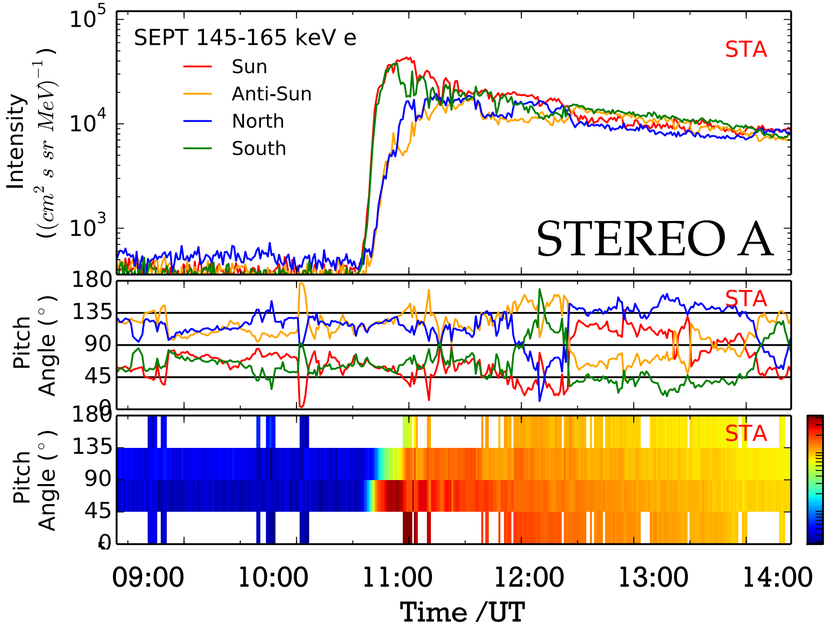


- Impulsive, anisotropic event, nothing special

Electron observations at STA and STB

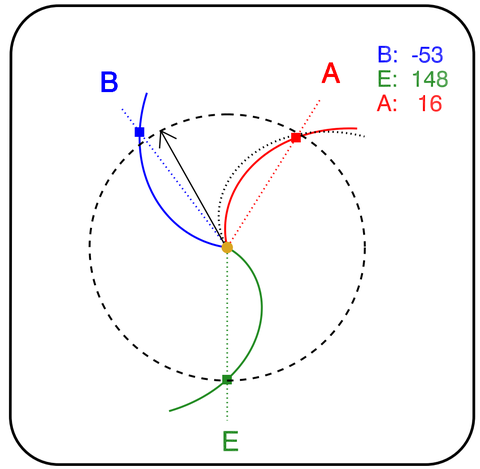






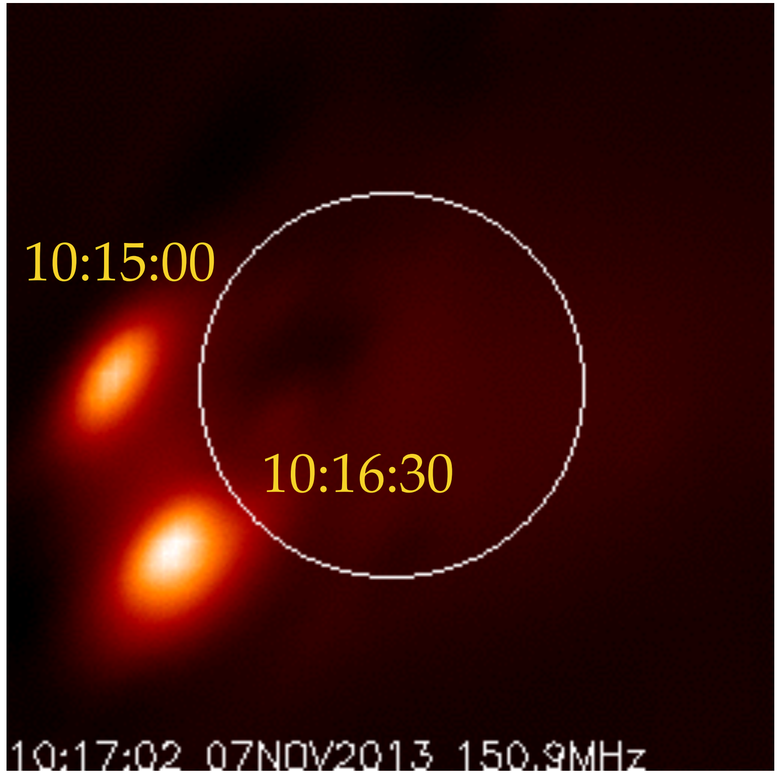
- Bi-directional distribution in north/south-direction
- **Later arriving beam (south) shows higher intensity!**
- **-> A double injection scenario is suggested!**

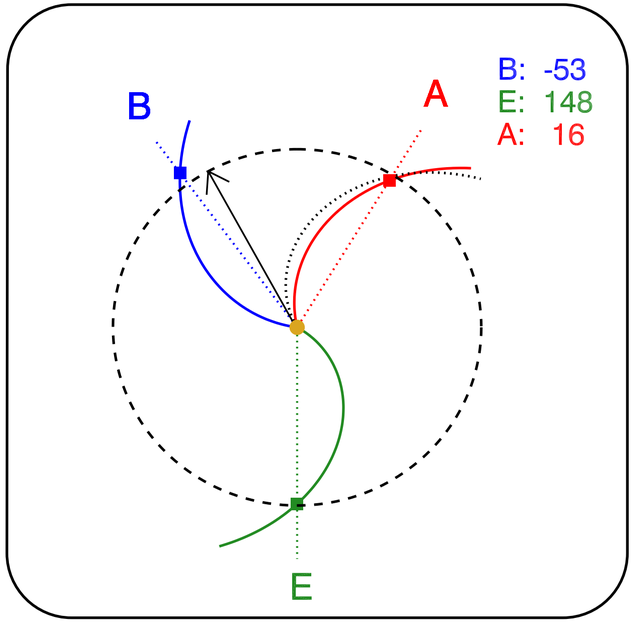
- Impulsive, anisotropic event, nothing special



SEP Injection: Radio signatures of TWO sources

NRH (ground based) station sees **two spatially separated radio sources** although the associated flare is behind the limb!





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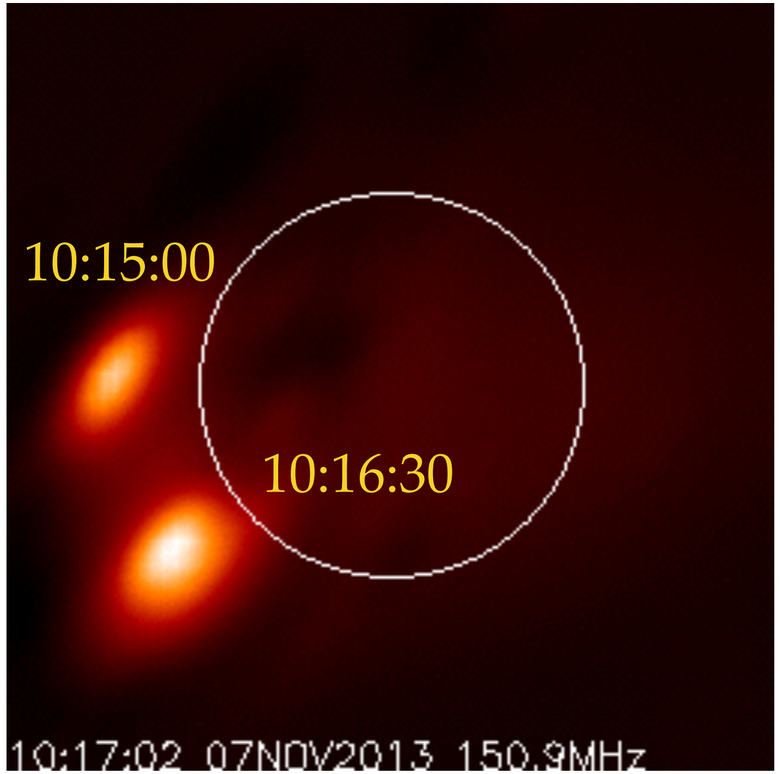
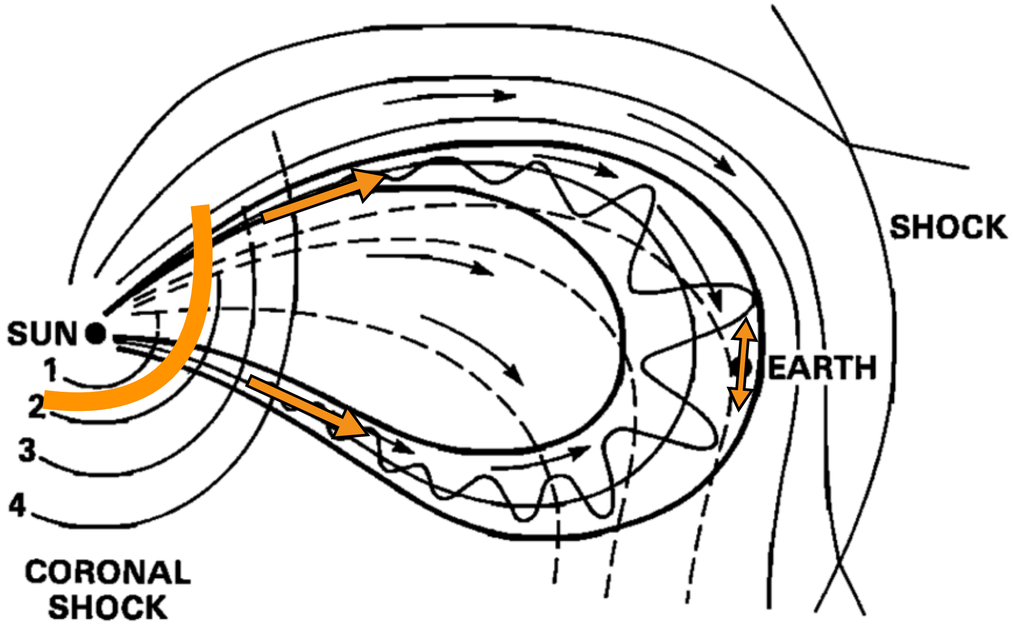
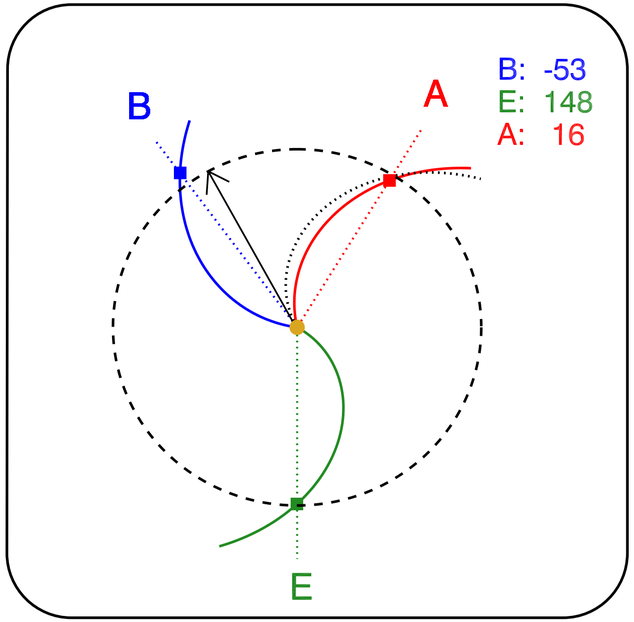
-> these distinct injections are likely associated to the two separated injections into the two MC loop legs

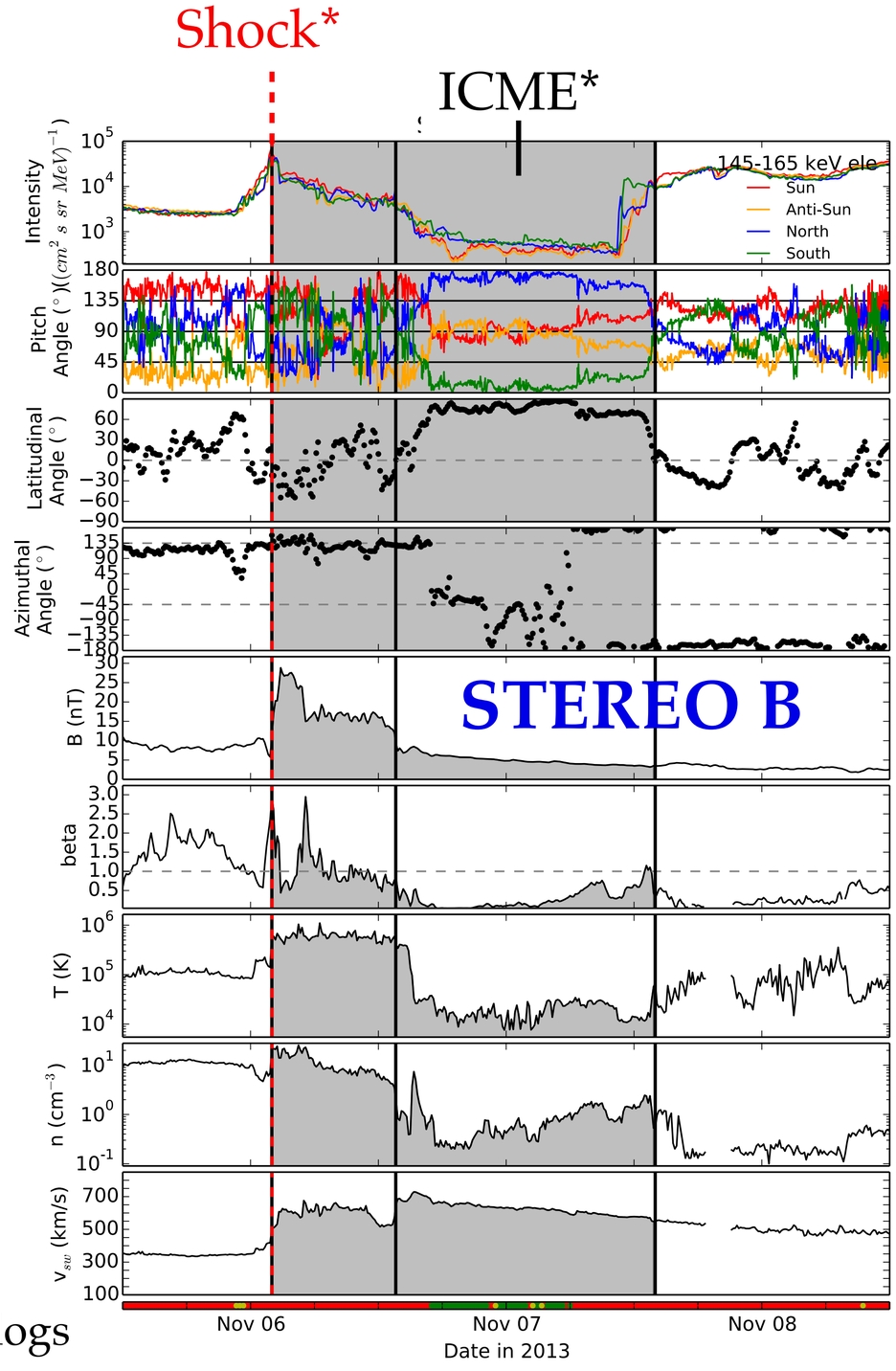




Richardson et al. 1991



Solar wind plasma and magnetic field observations



*Jian et al. SIR/ CME/shock catalogs

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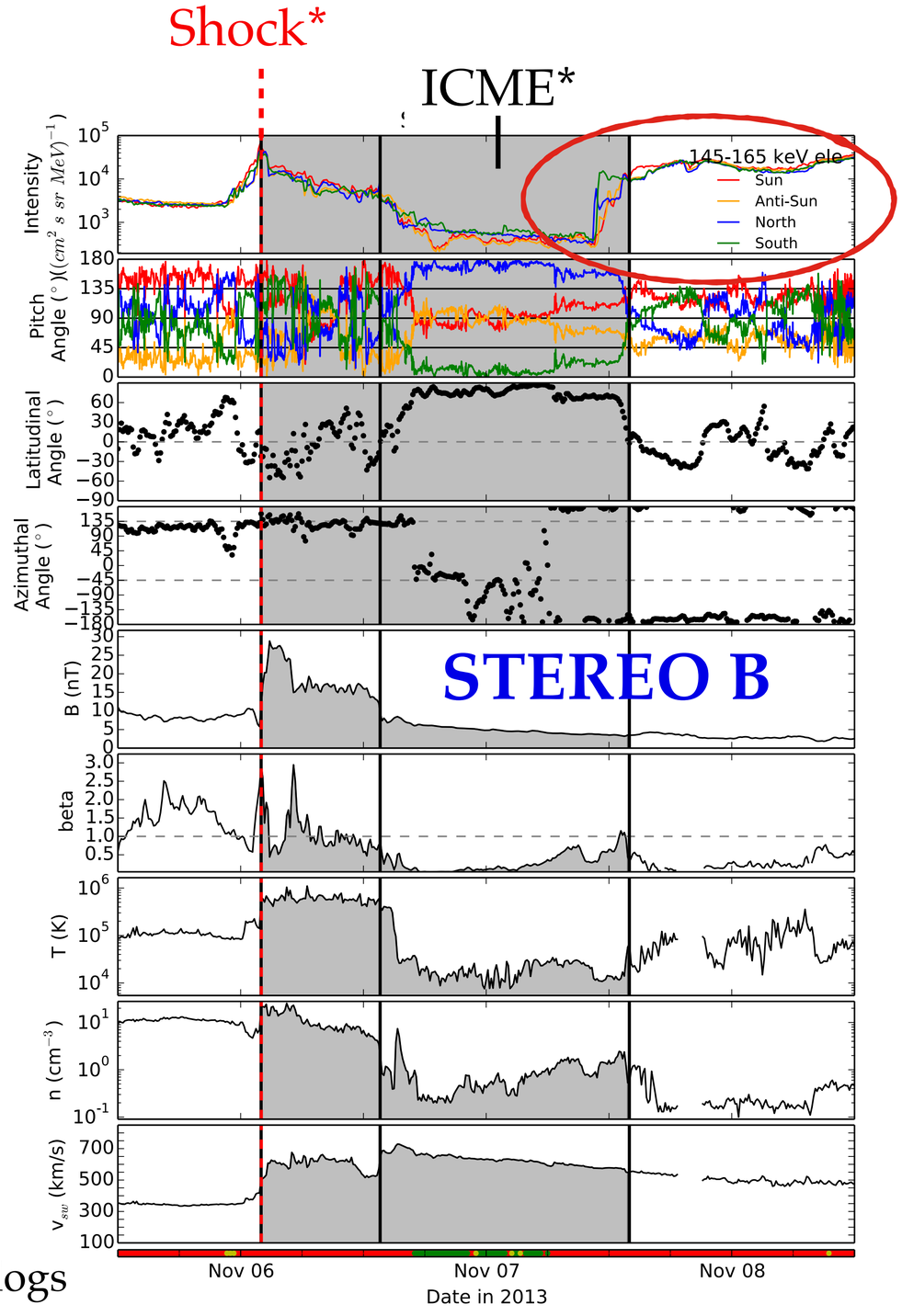

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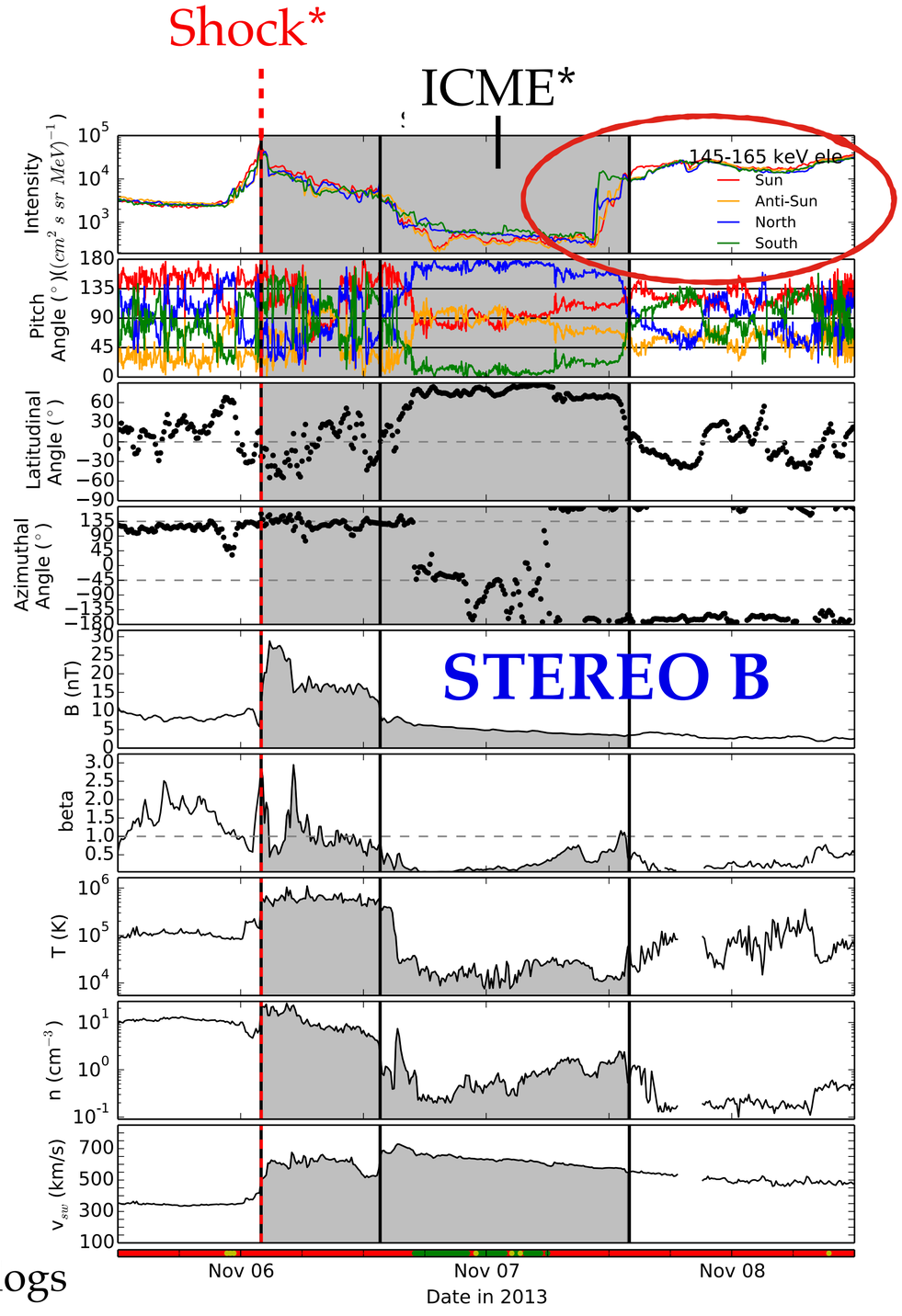
Solar wind plasma and magnetic field observations

Criteria for a magnetic cloud:

- ☑ Smooth rotation of the magnetic field
- ☑ Low proton temperature
- ☑ Bi-directional electron heat flux (not shown)
- ☐ Enhanced magnetic field
- ☑ very low plasma beta

- ▶ Magnetic-cloud like structure



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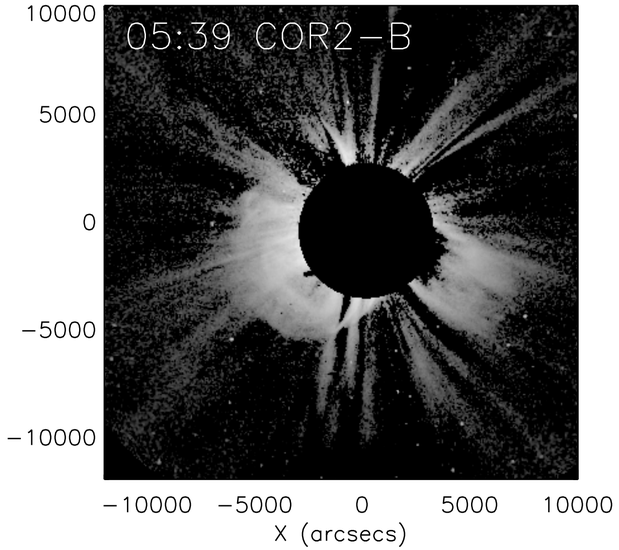
Graduated Cylindrical Shell (GCS) Model

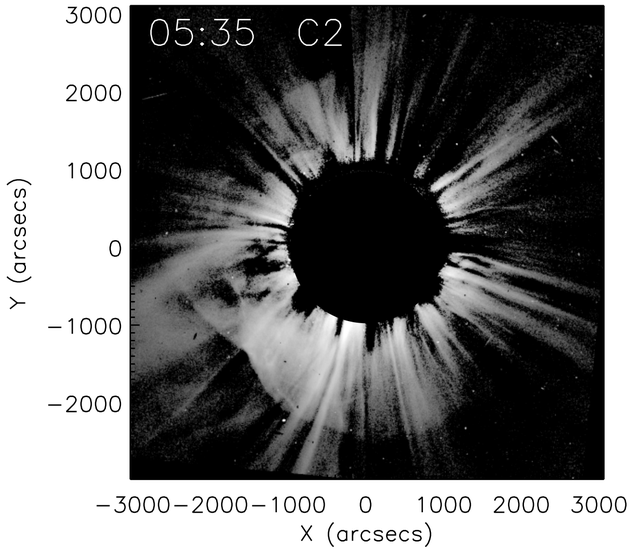
Reconstruction of the 3D morphology of the ICME close to the Sun

Graduated Cylindrical Shell (GCS, Thernisien et al. 2006) model applied to the white light coronagraph observations at STEREO and SOHO

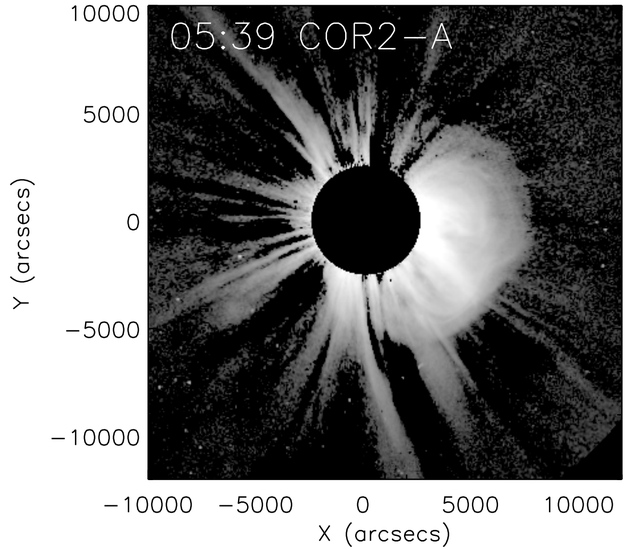
Result: high inclination of -85° (north/south directed)



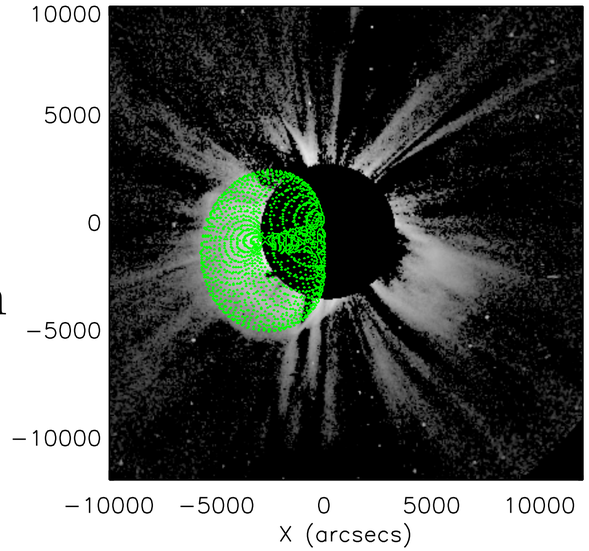
STEREO B / COR2

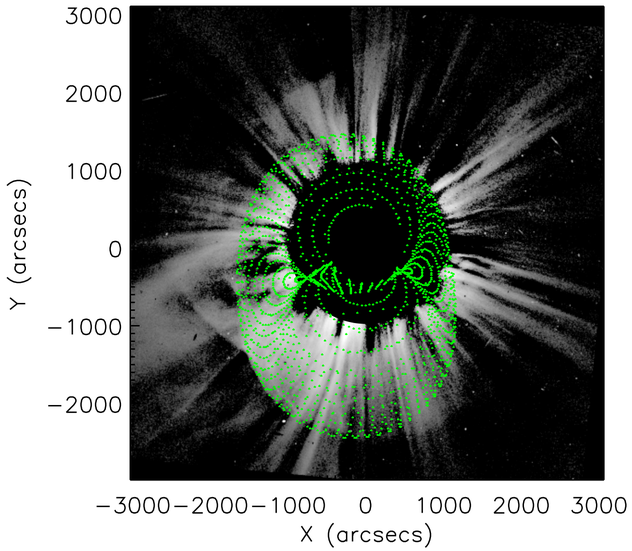


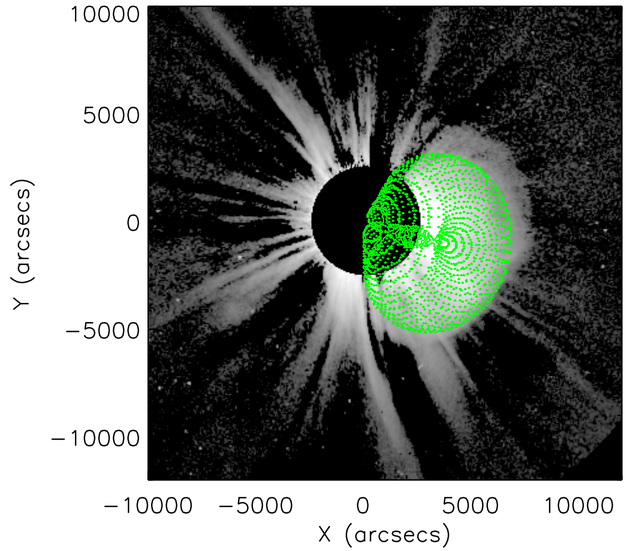
LASCO / C2



STEREO A / COR2

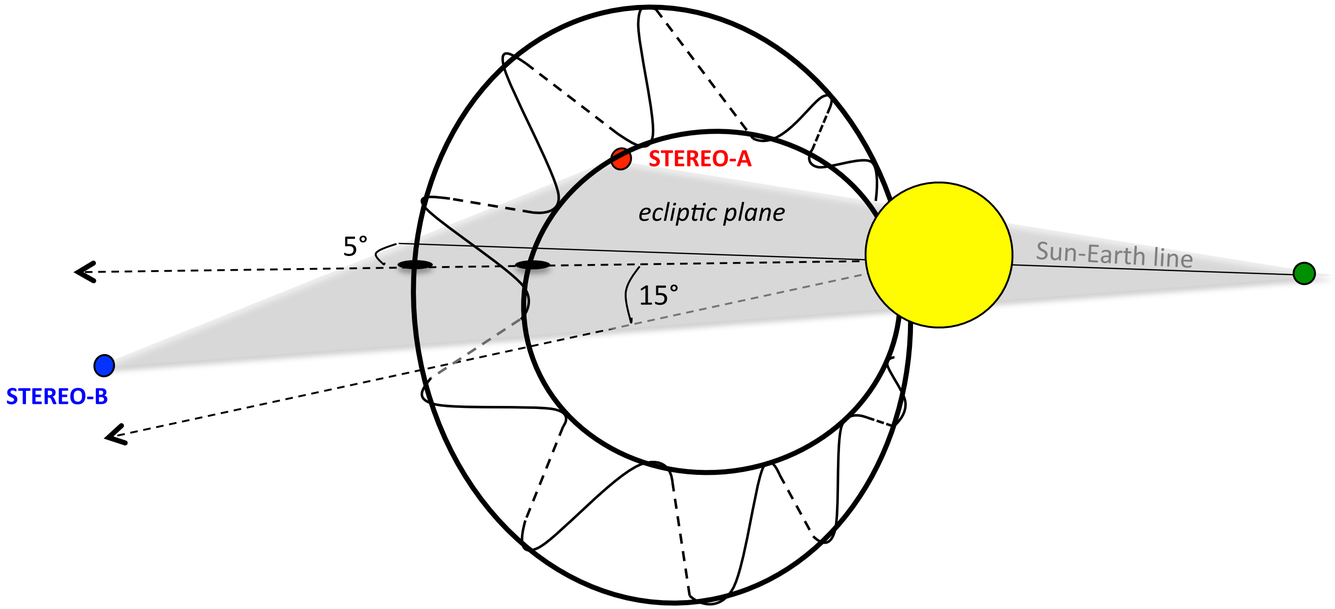


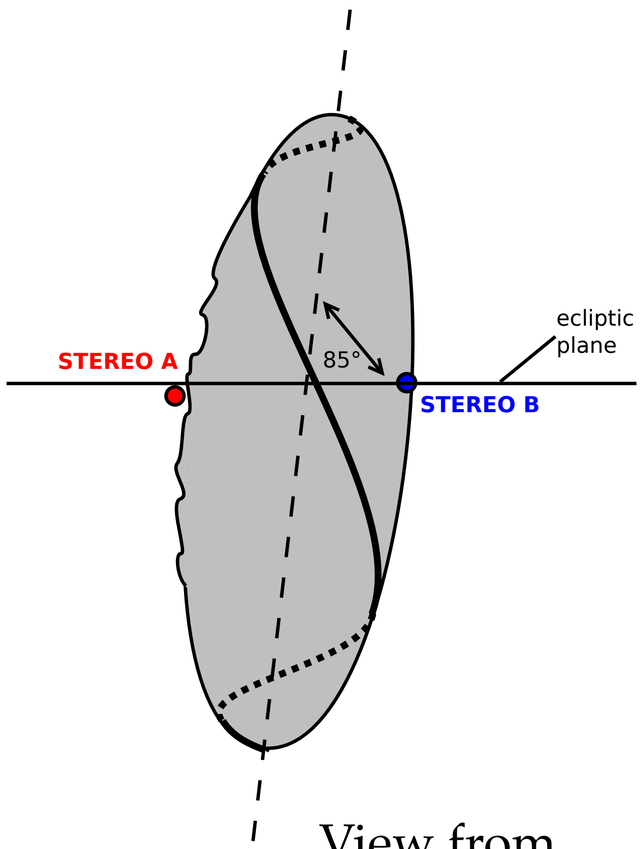




Orientation and dimension of the MC

- Graduated Cylindrical Shell (GCS, Thernisien et al. 2006) modelling results suggest that the MC is strongly inclined by -85° (north/south directed)
- CME propagates centrally between STA and STB
- CME is tilted towards south by 15°





View from outside 1AU towards the Sun

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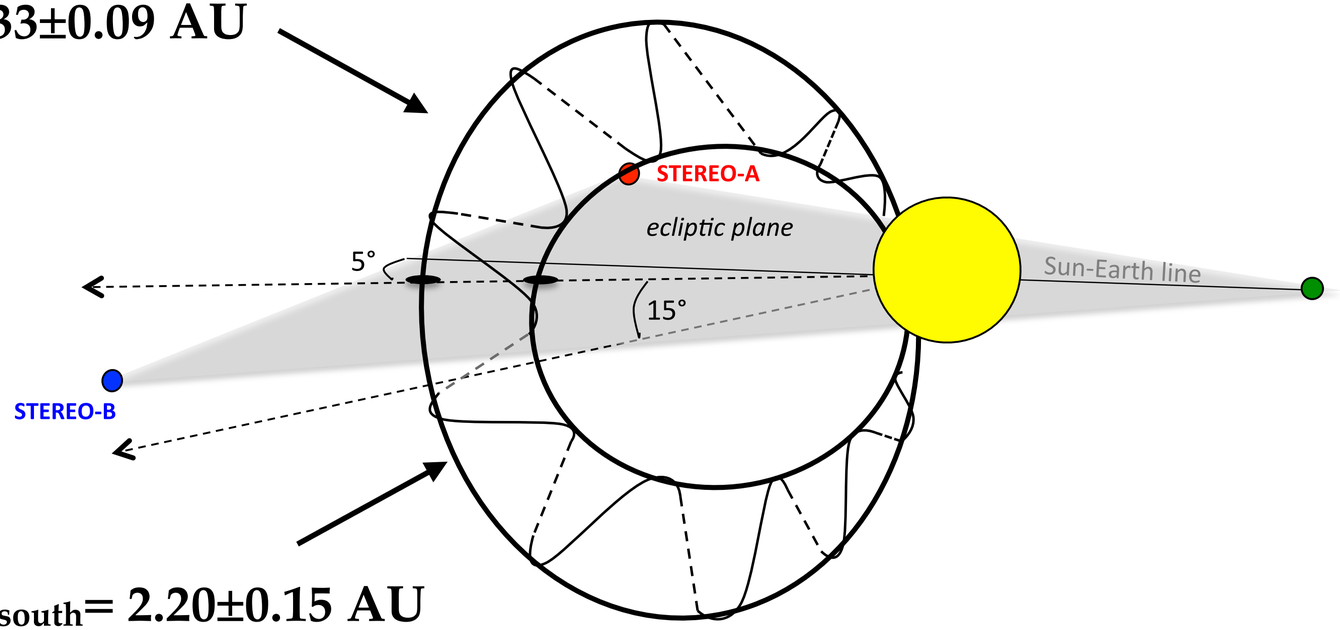
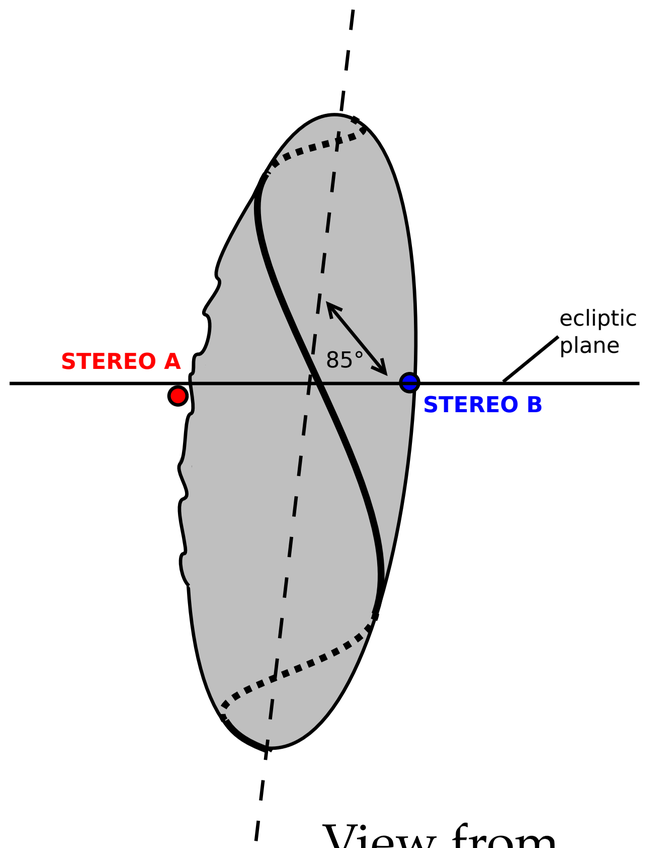
- Total loop length $\mathbf{L_{tot}=3.53\pm0.24\ AU}$

$\mathbf{L_{north}= 1.33\pm0.09\ AU}$



$\mathbf{L_{south}= 2.20\pm0.15\ AU}$



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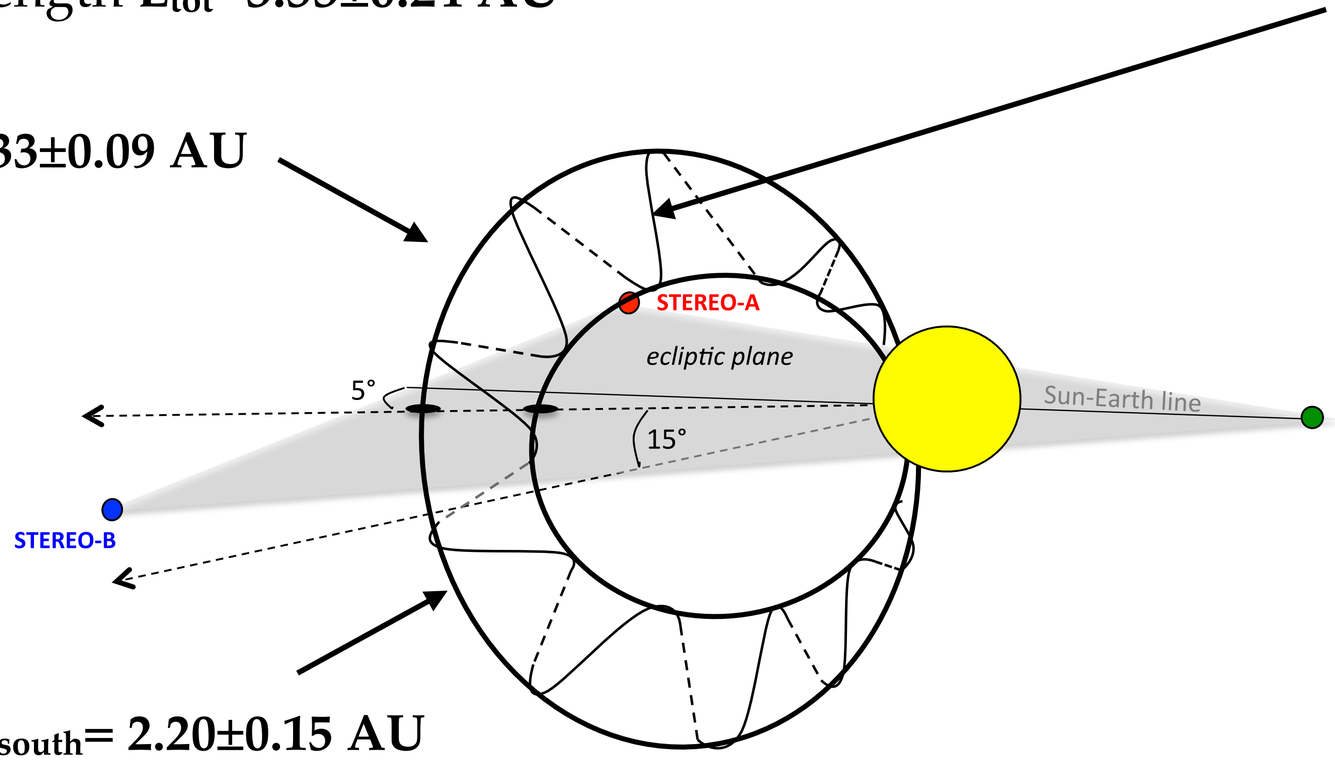
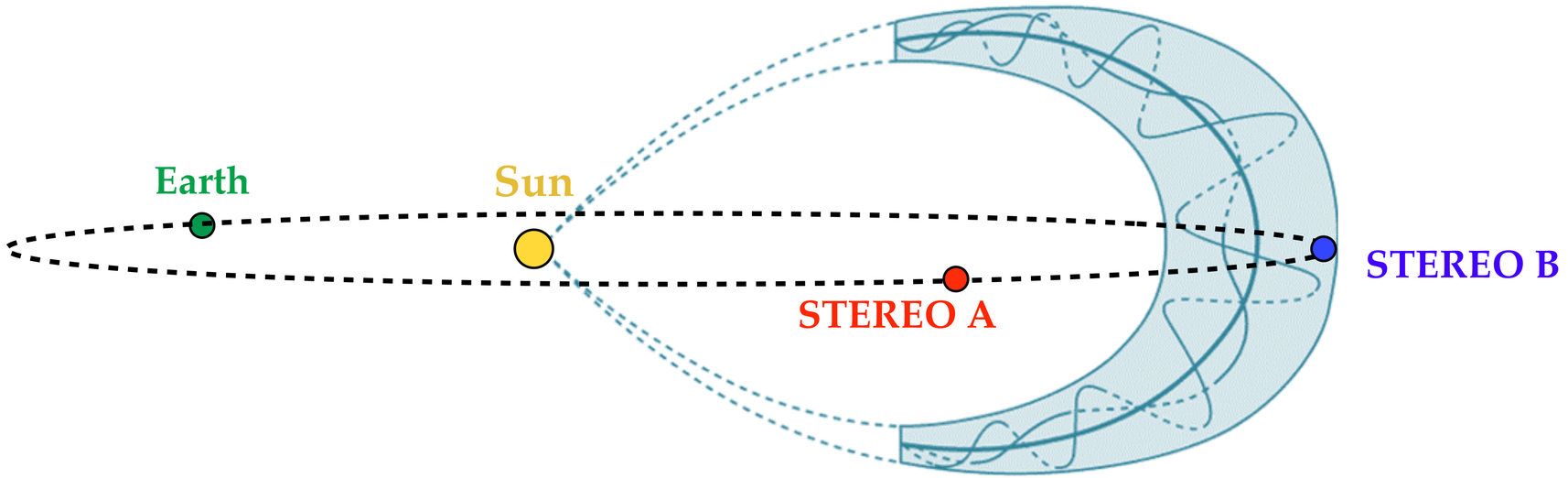


To probe the amount of **field line twist** inside the MC we determine the path lengths of the SEP electrons propagating through the structure

Lundquist model (Lundquist 1950) suggests strong field line twist.

Kahler et al. 2011a,b find extremely low twist.

Electron propagation path length



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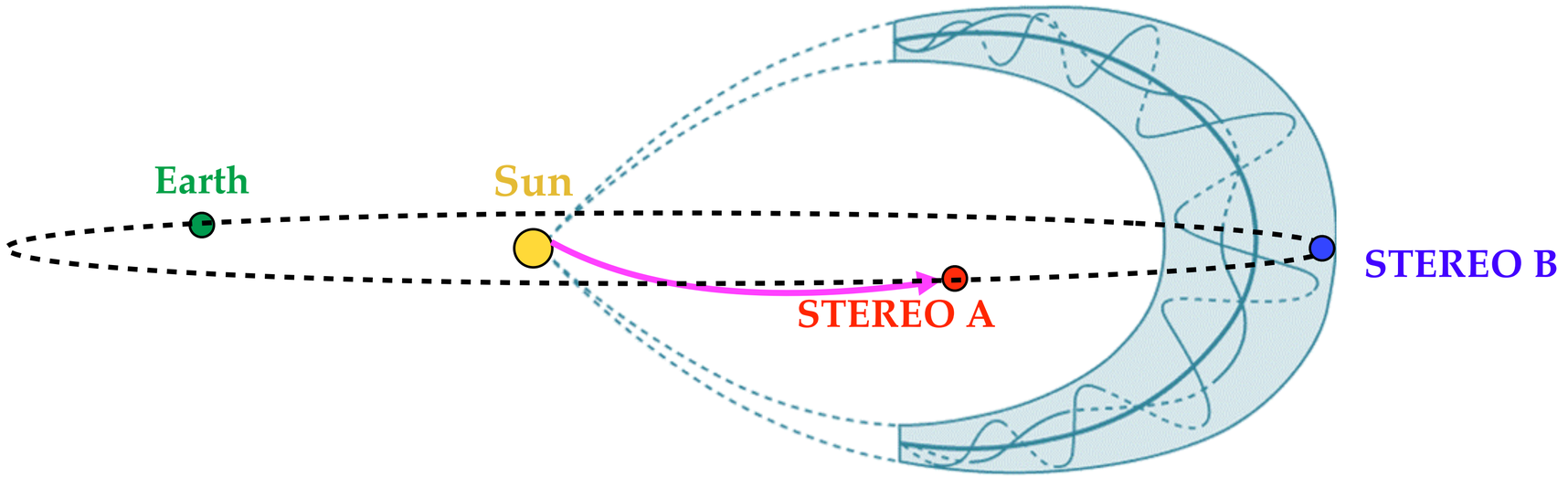

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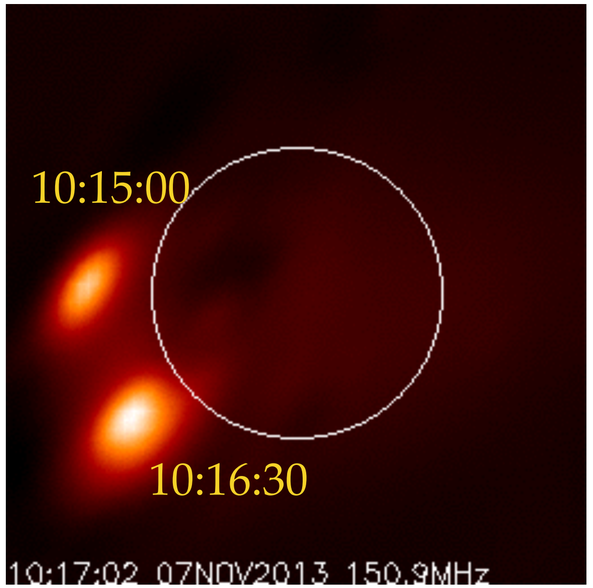
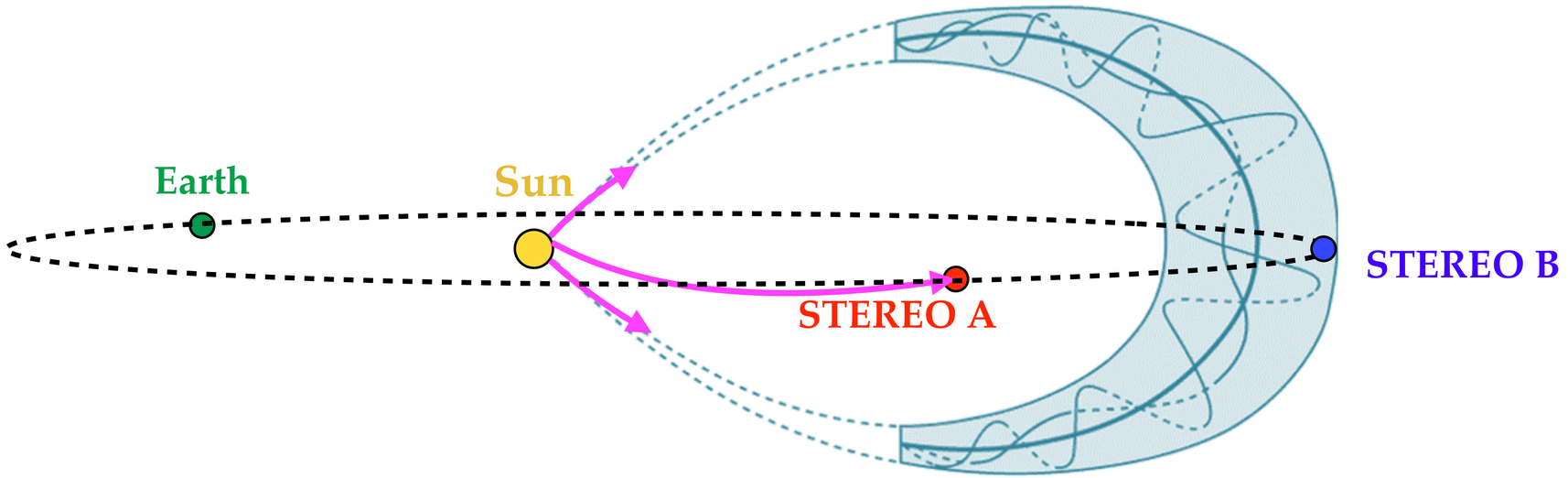


155 keV electrons



Dresing et al., University of Kiel, Germany

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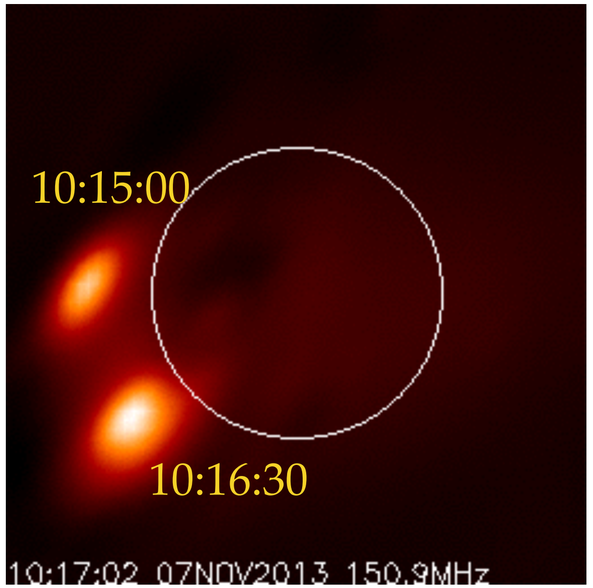

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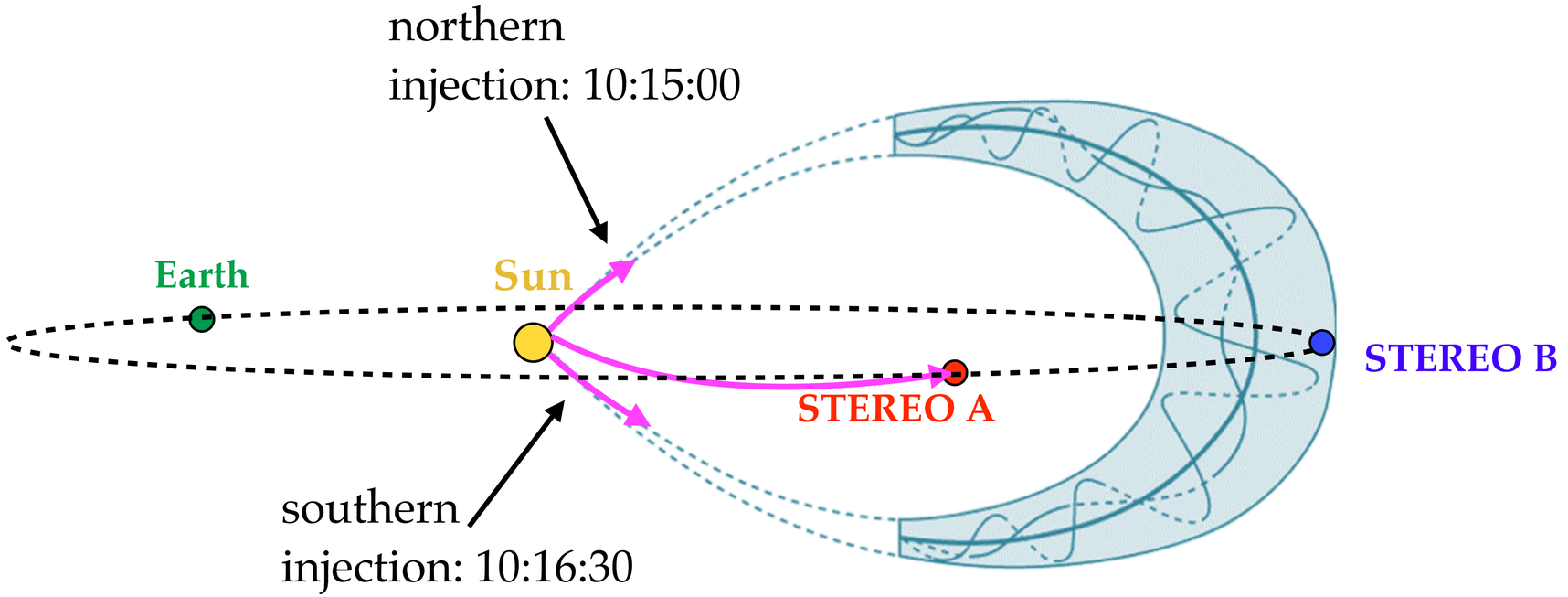

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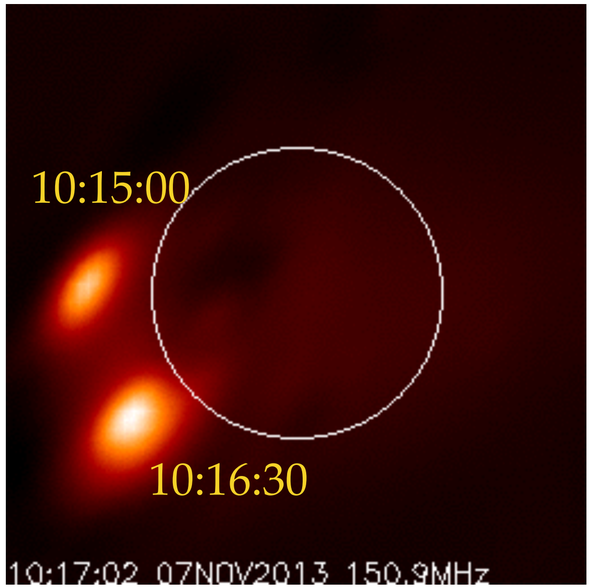

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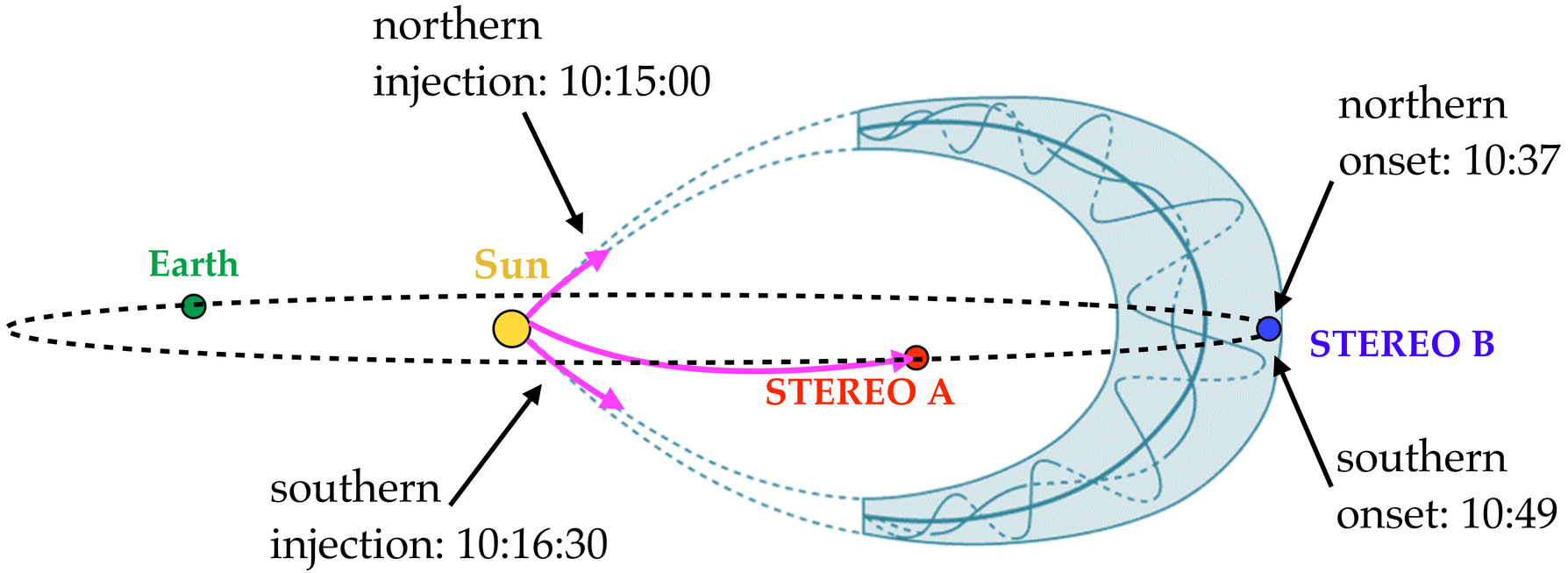

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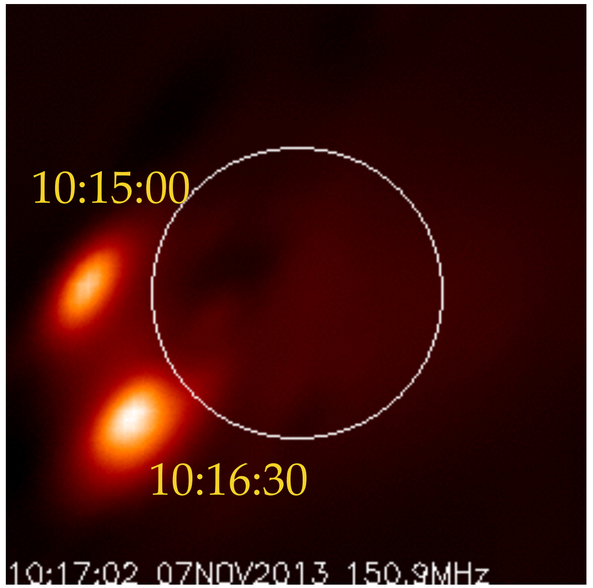

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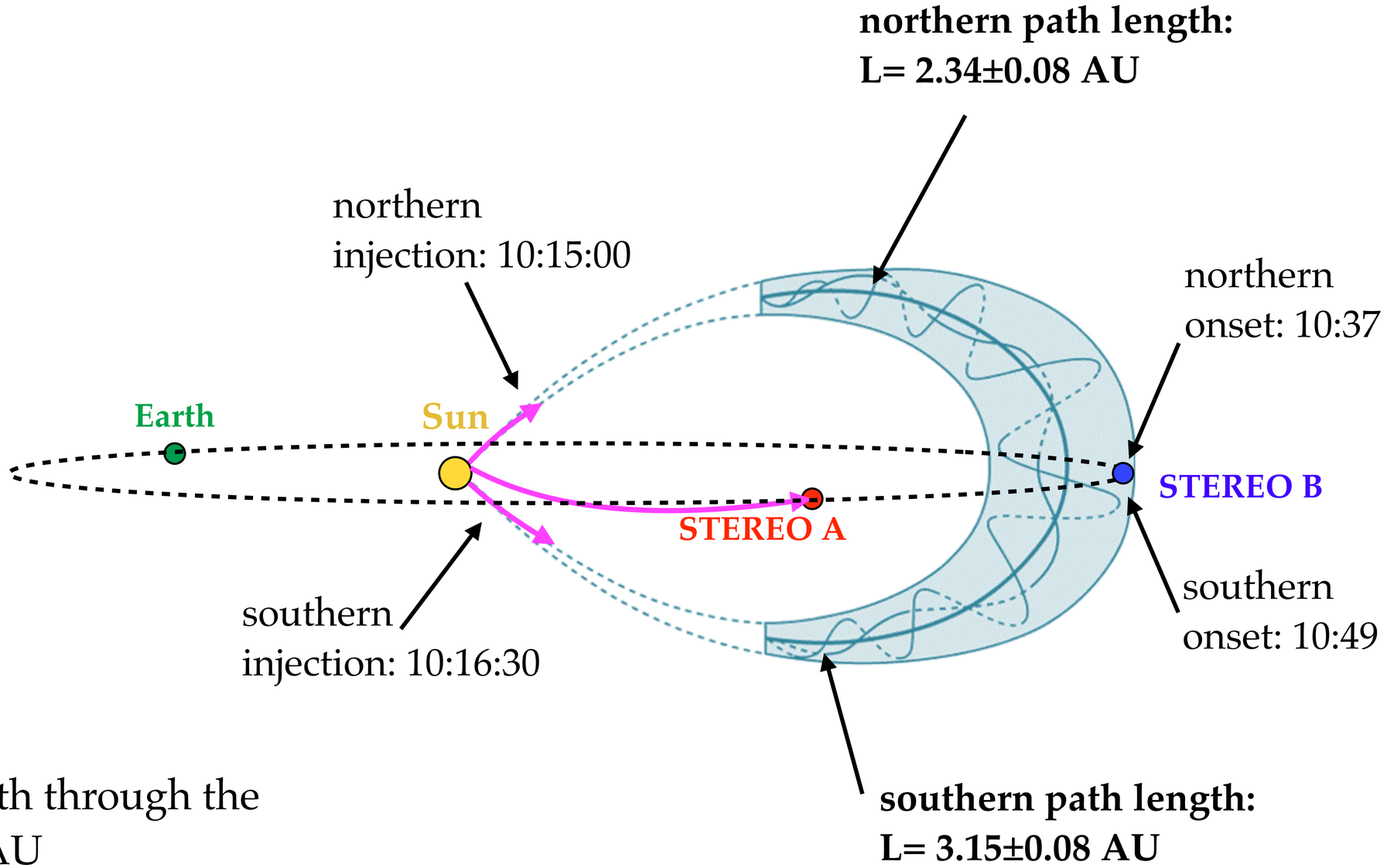
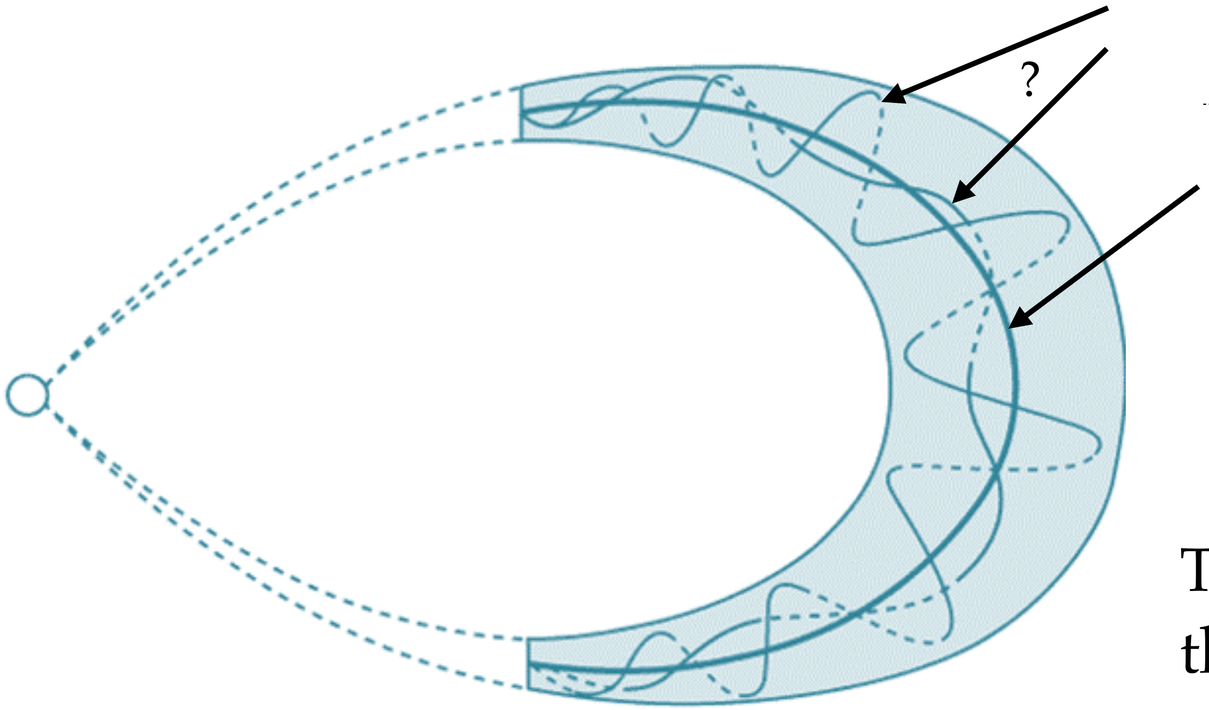


Total electron path length through the flux rope: L=5.49±0.16 AU

Dresing et al., University of Kiel, Germany

How strong is the magnetic field line twist inside the MC?



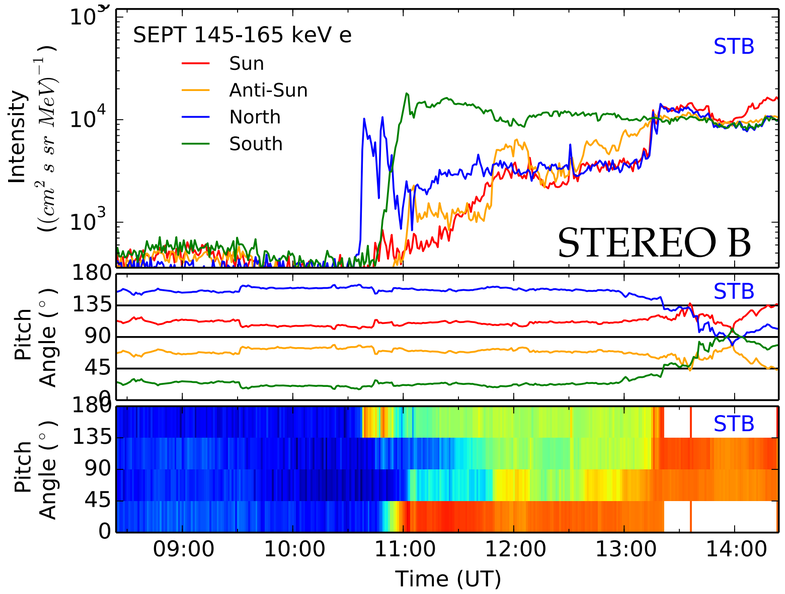
	L total / AU	L north / AU	L south /AU
155keV electron path length	5.49±0.16	2.34±0.08	3.15±0.08
MC length (GCS model)	3.53±0.24	1.33±0.09	2.20±0.15

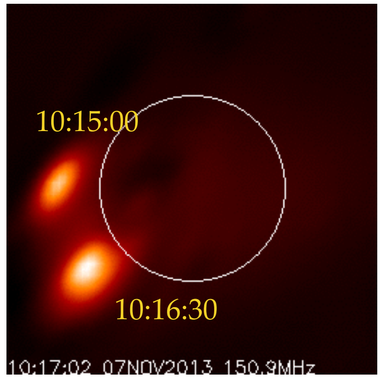
The electron path length is around 50% longer than the estimated dimension of the MC

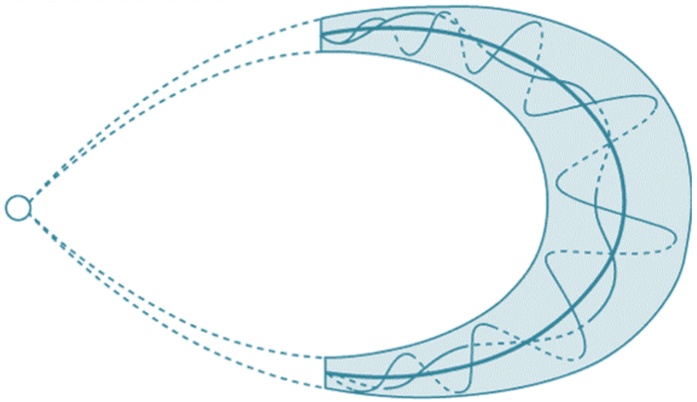
-> moderate field line twist inside MC although at the very outer edge of the MC

Summary

- SEP event on 7 Nov 2013 observed by both STEREO spacecraft
- STB inside north/south oriented magnetic structure in which the SEPs are injected -> bi-directional distribution
- Relative timing and peak intensities in the NORTH and SOUTH sectors at STB suggest that **an injection into both loop legs happened**
- NRH radio observations of two separate sources seem to confirm that scenario







- Electron path lengths inside MC in comparison to estimated length of the MC itself (50% longer) reveals a moderate amount of field line twist inside the MC