Tracking the Corotating Density Structures in Heliospheric Imaging during 2007-2014

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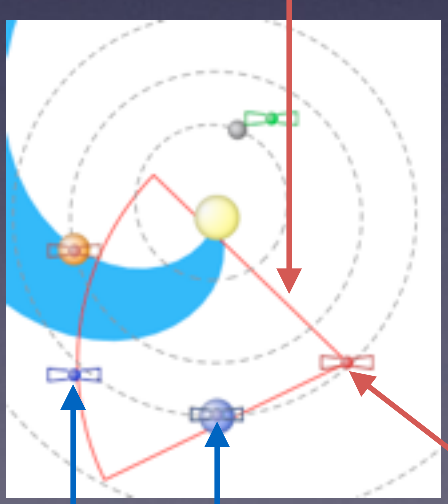
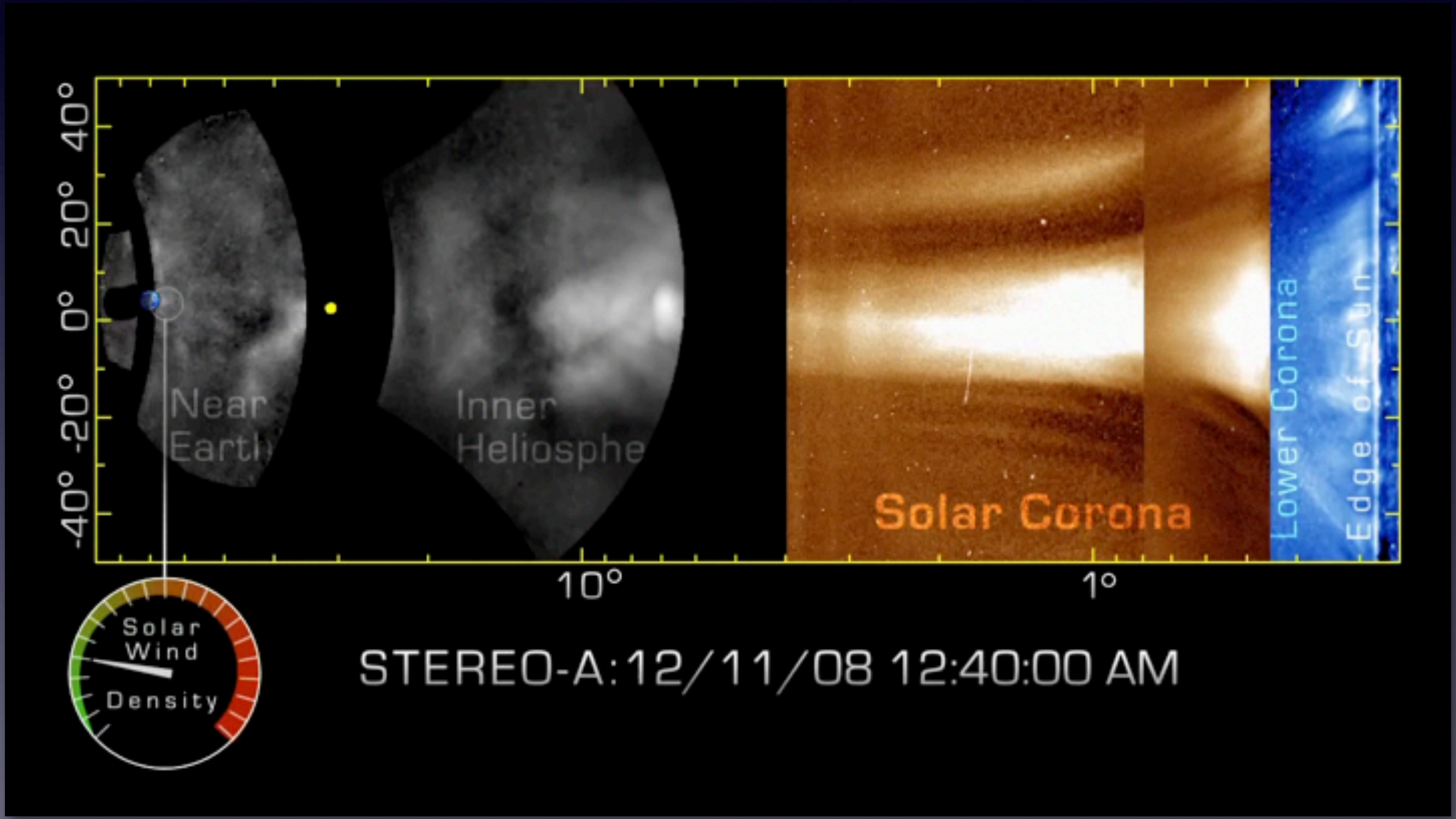
http://www.helcats-fp7.eu
https://arxiv.org/abs/1606.01127

Introduction: solar wind as seen by STEREO-A in white light

Field of view of ST-A cameras

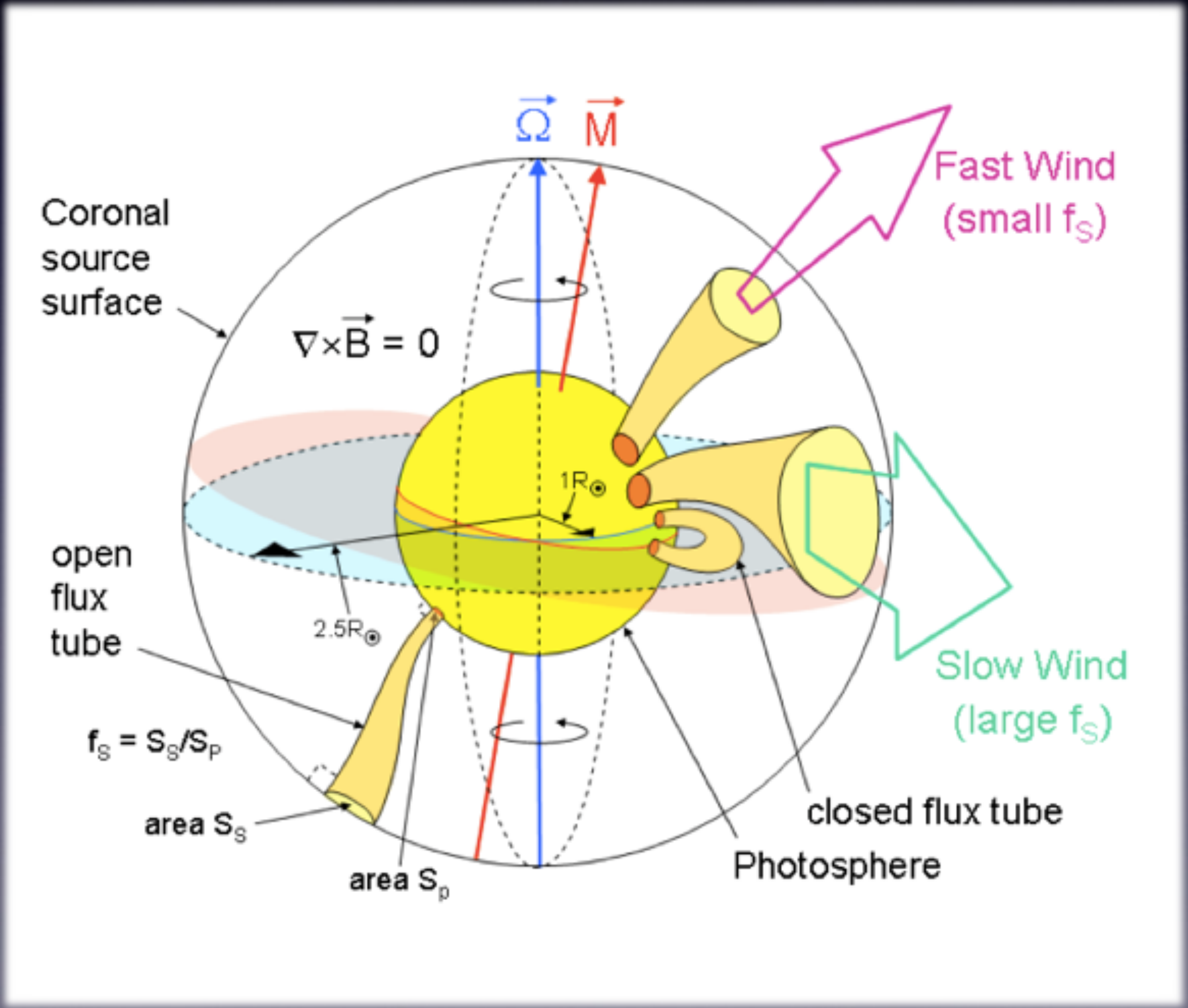


ST-B Earth (L1) ST-A

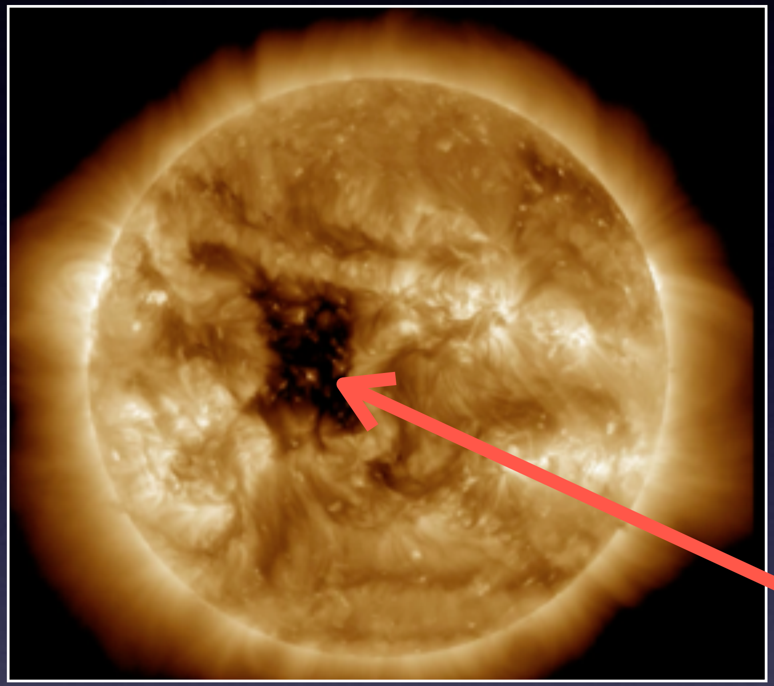


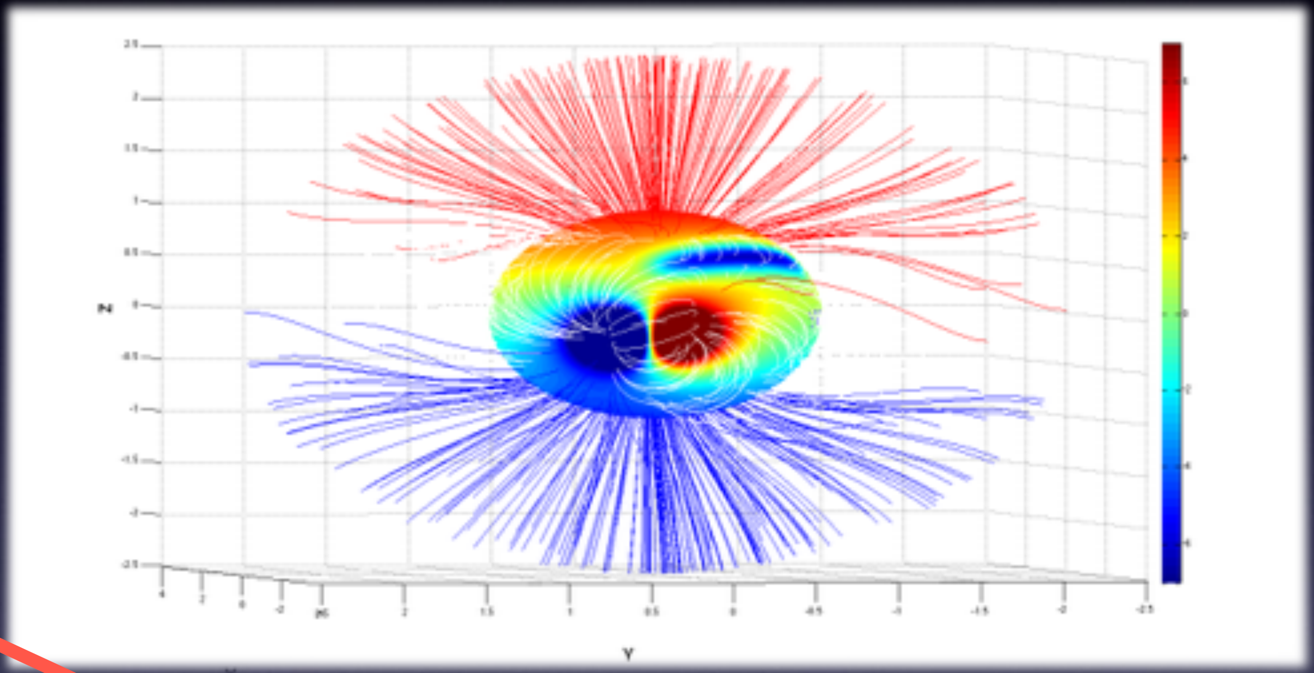
Kaiser et al. 2008; Eyles et al. 2009, Harrison et al. 2009

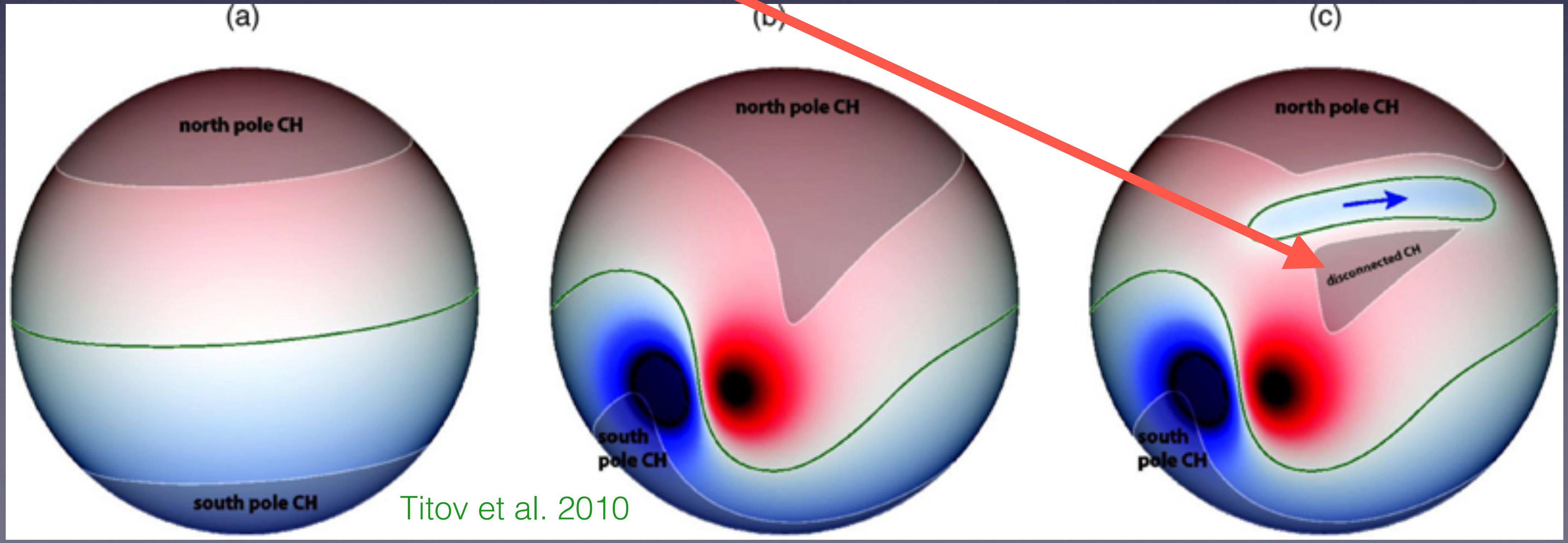
Sources of fast and slow solar wind



Low latitude coronal holes



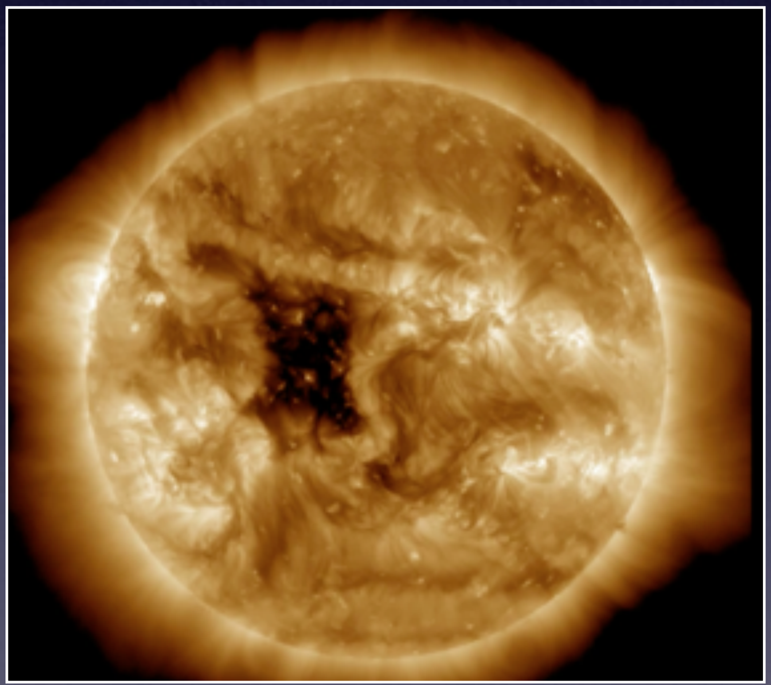


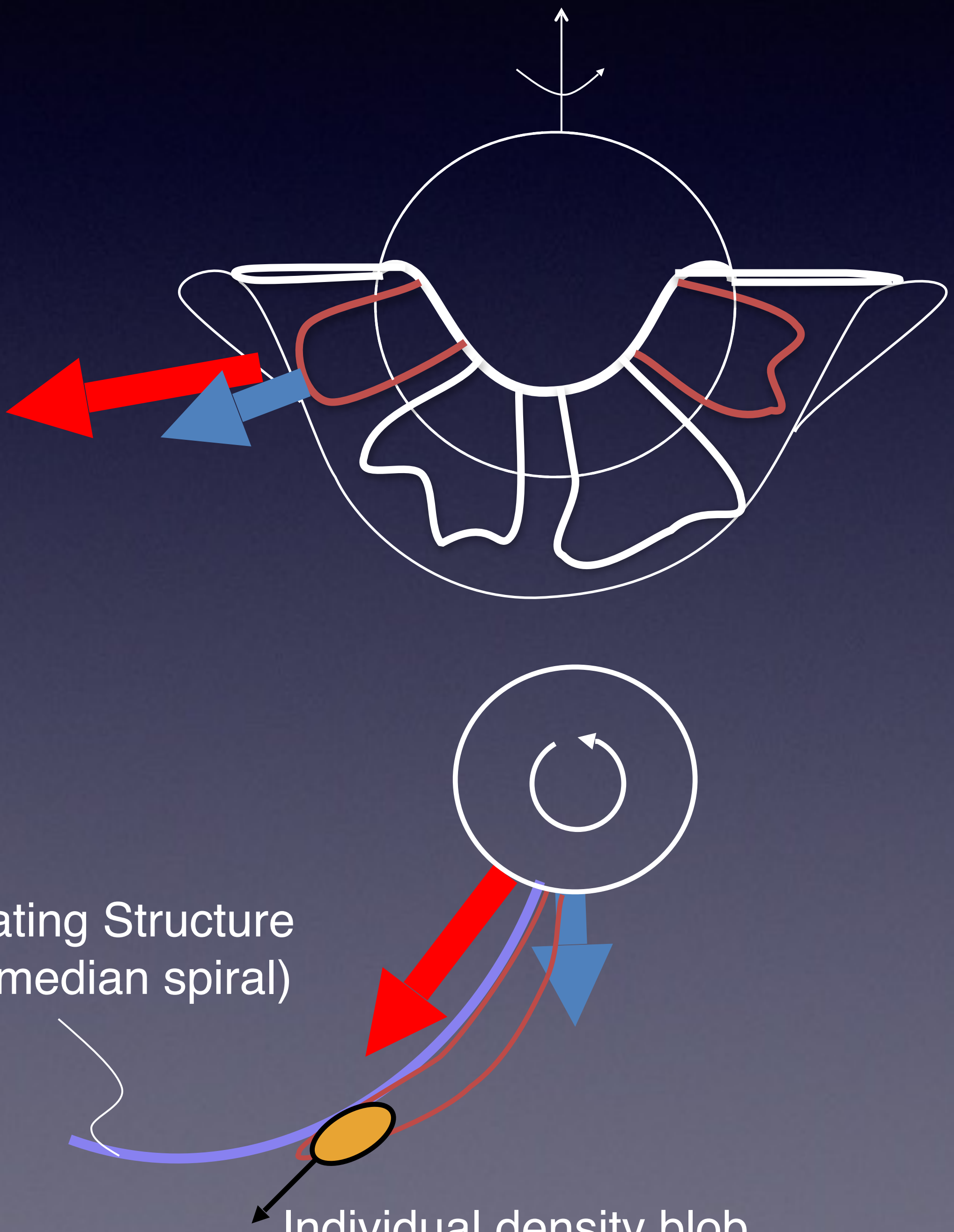


Corotating Density Structures (CDS)

Low attitude coronal hole -> fast wind source behind equatorial slow wind -> corotating density region

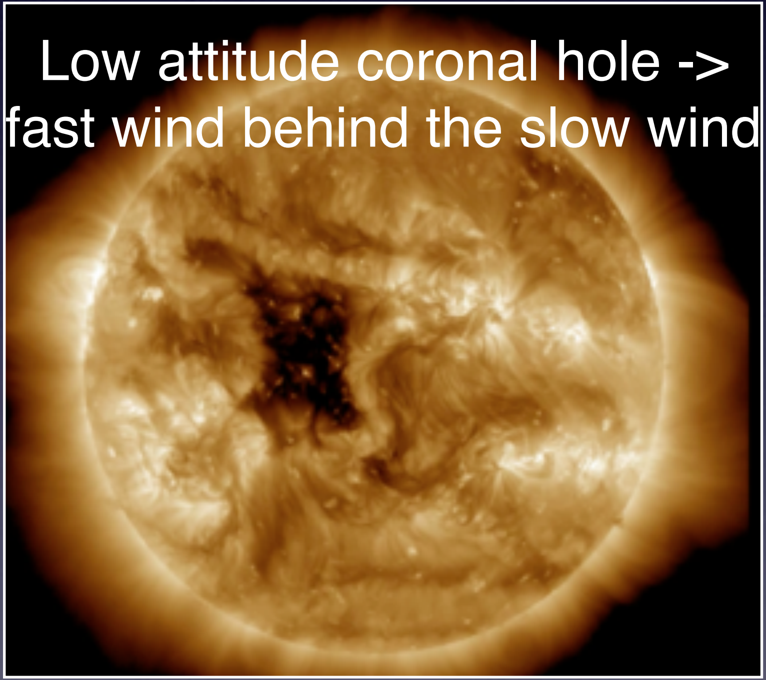
EUV image of the Sun
on 28 May 2013

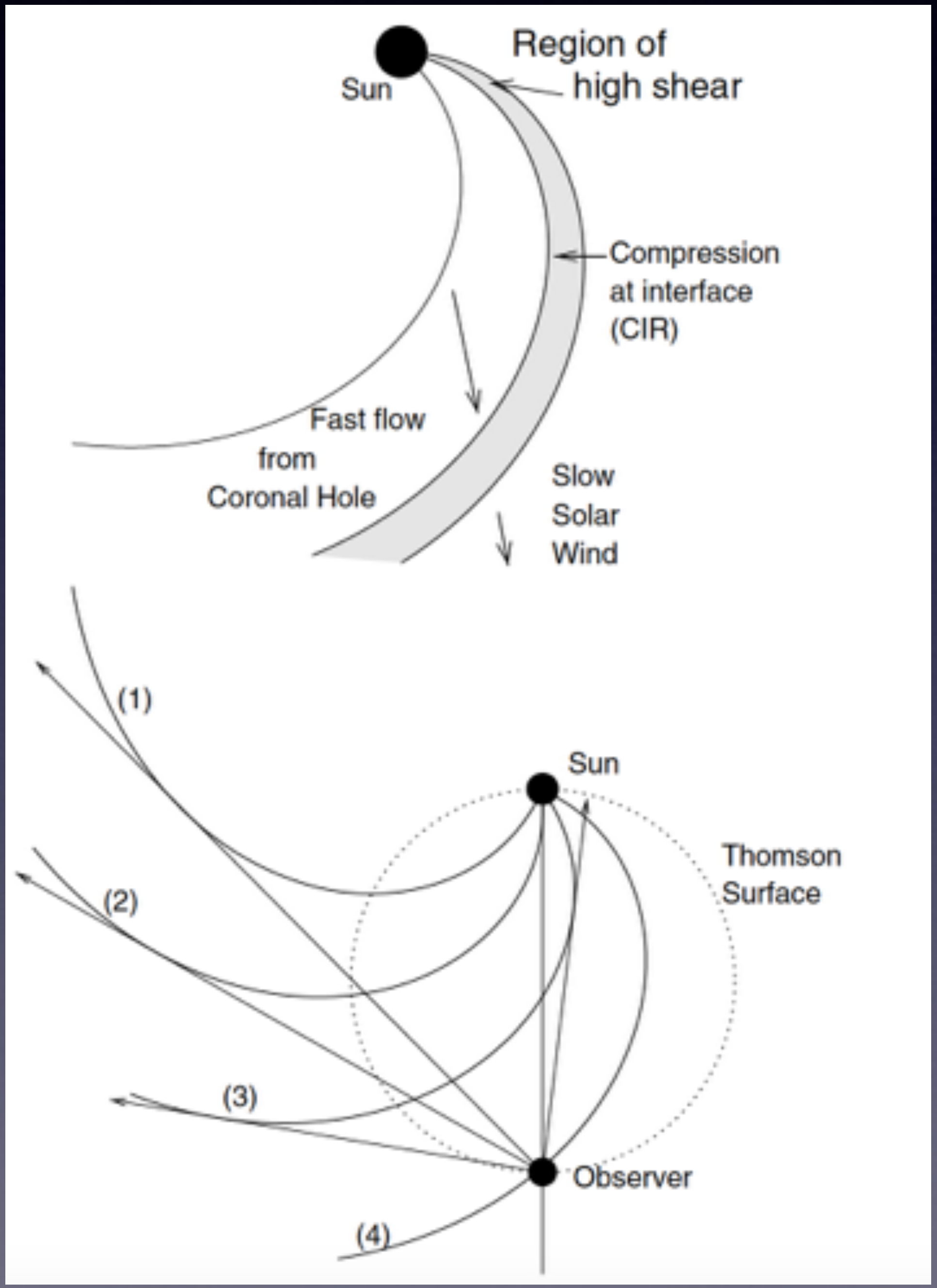




Observing CDSs

EUV image of the Sun
on 28 May 2013





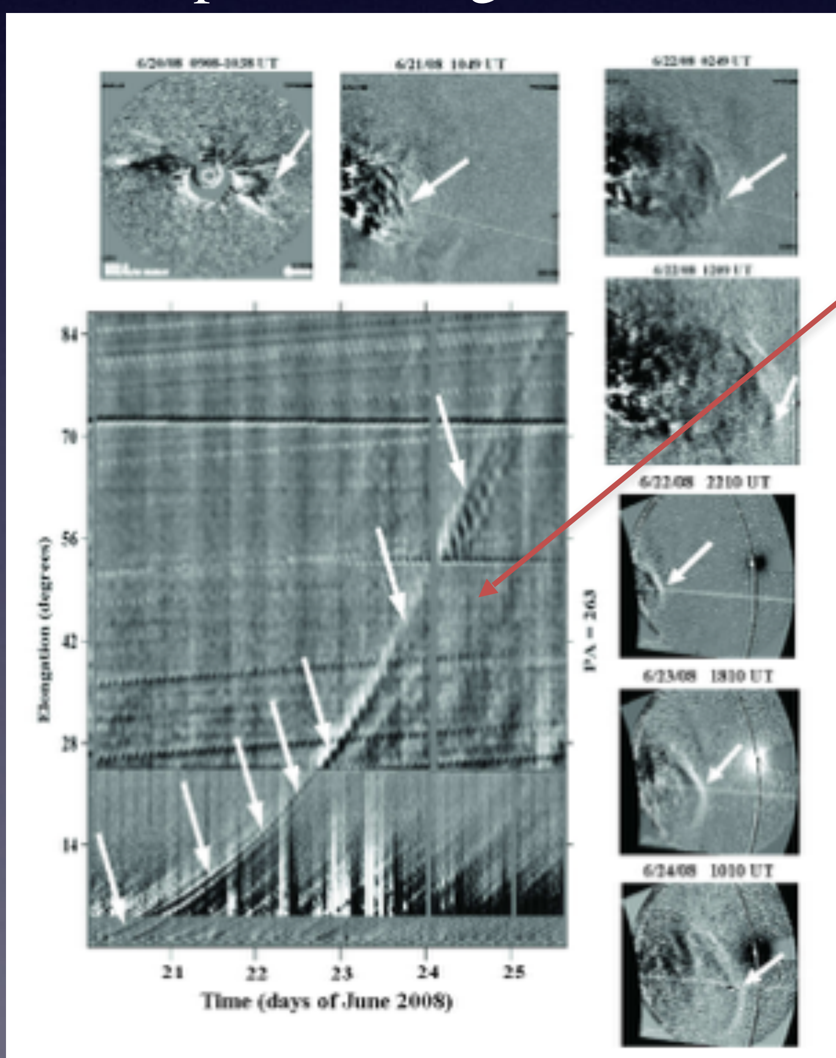
Tappin & Howard (2009)

J-maps and the fit of one density blob

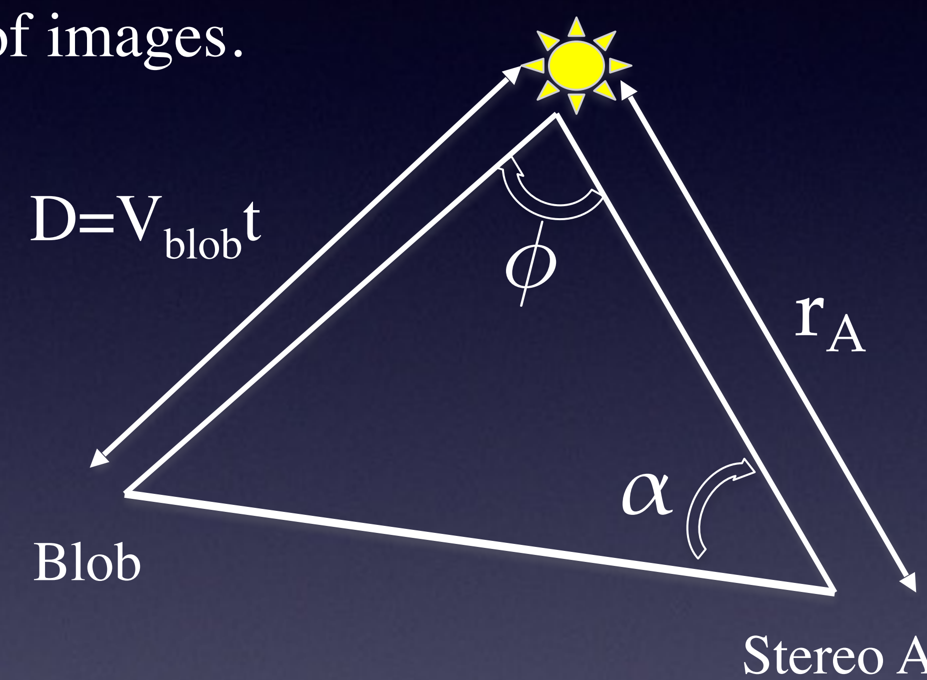
Sheeley et al. (1999), Davies et al. (2009)

Construct a J-map from running difference Heliospheric Images

In-ecliptic pixels band extracted from a time sequence of images.



Sheeley & Rouillard (2010)



Time-elongation profile with a constant speed seen from a satellite (Fixed phi approx.):

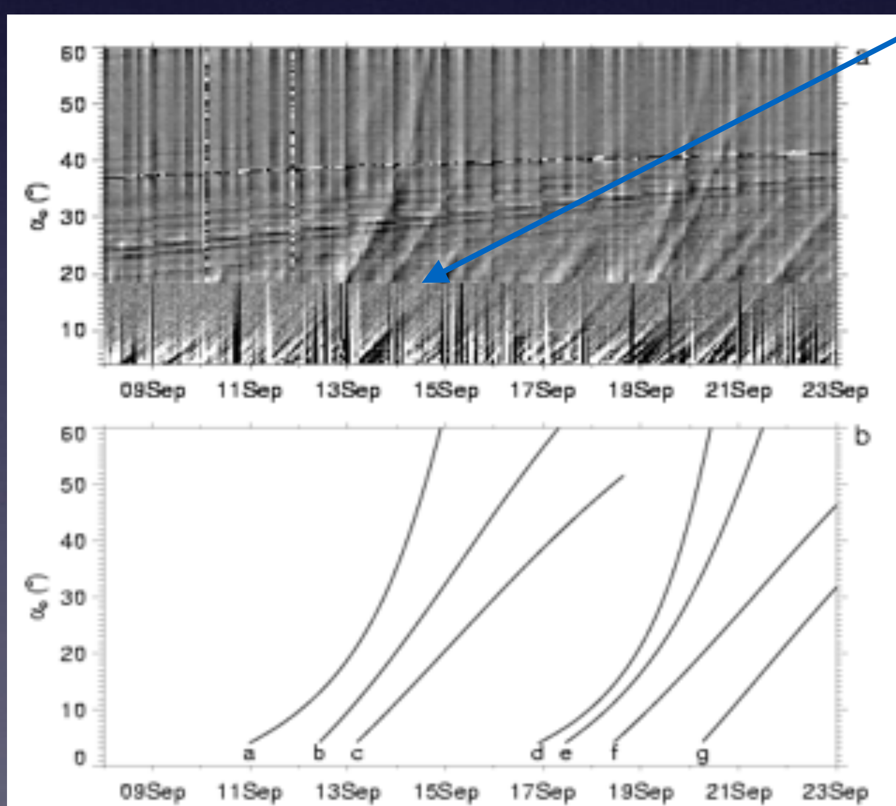
$$\alpha(t) = \arctan\left[\frac{V_b t \sin\phi}{r_A(t) - V_b t \cos\phi}\right]$$

Tracks are convergent in STEREO-A and divergent in STEREO-B.

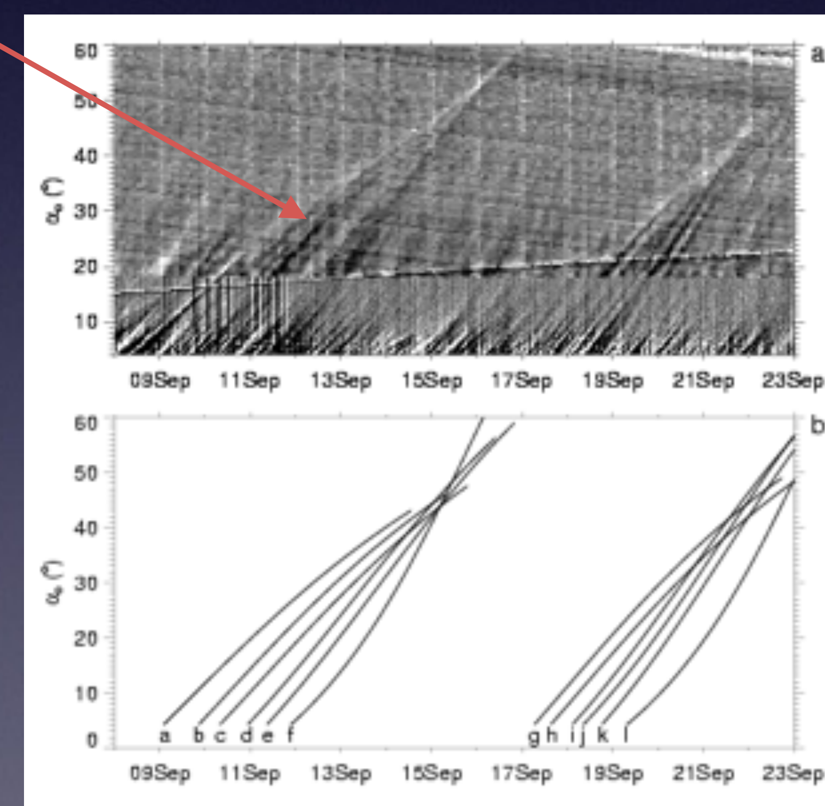
Patterns seen in HI of ST-A versus ST-A

$$\alpha(t) = \arctan\left[\frac{V_b t \sin\phi}{r_A(t) - V_b t \cos\phi}\right]$$

Stereo B

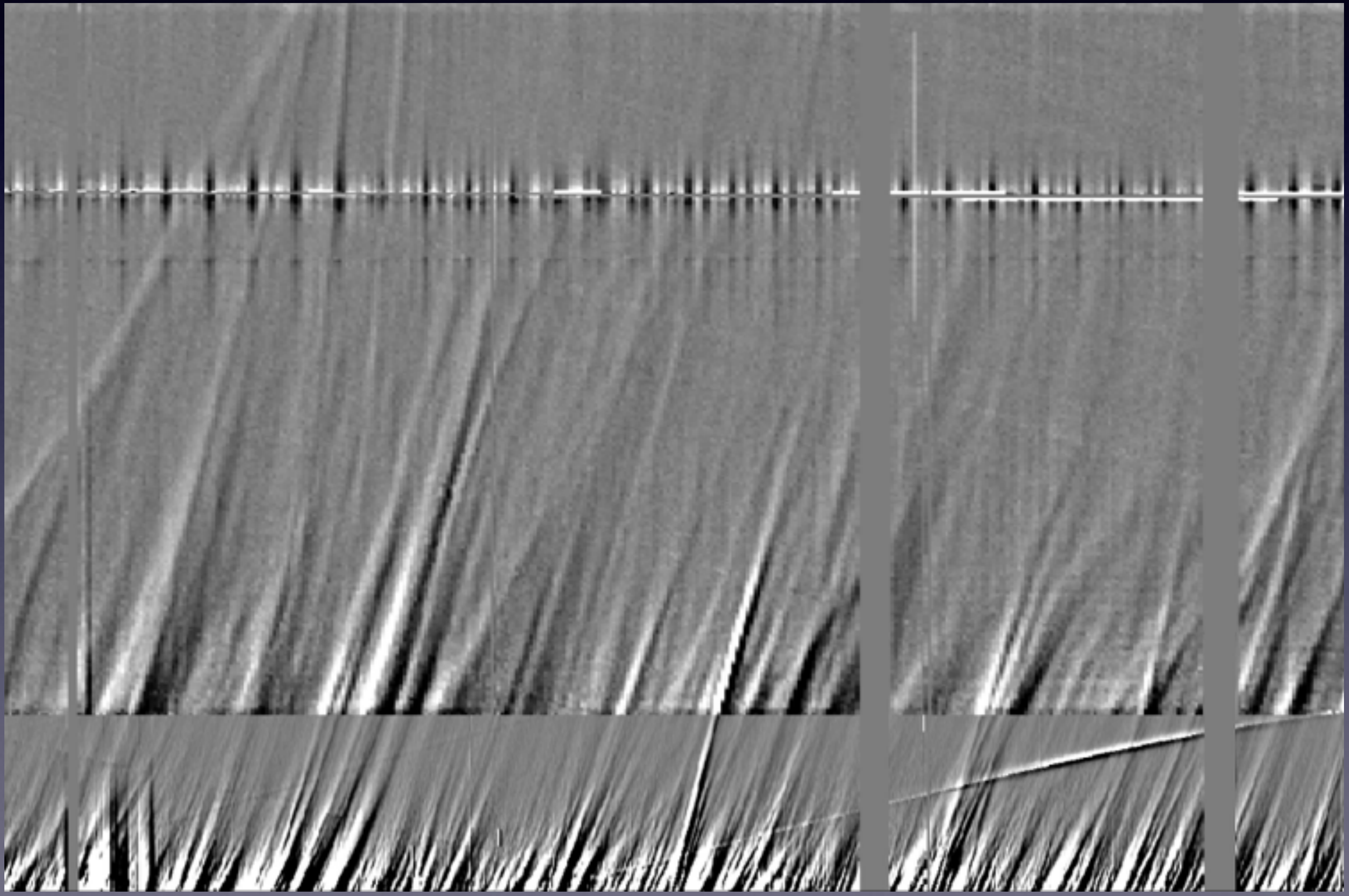


Stereo A

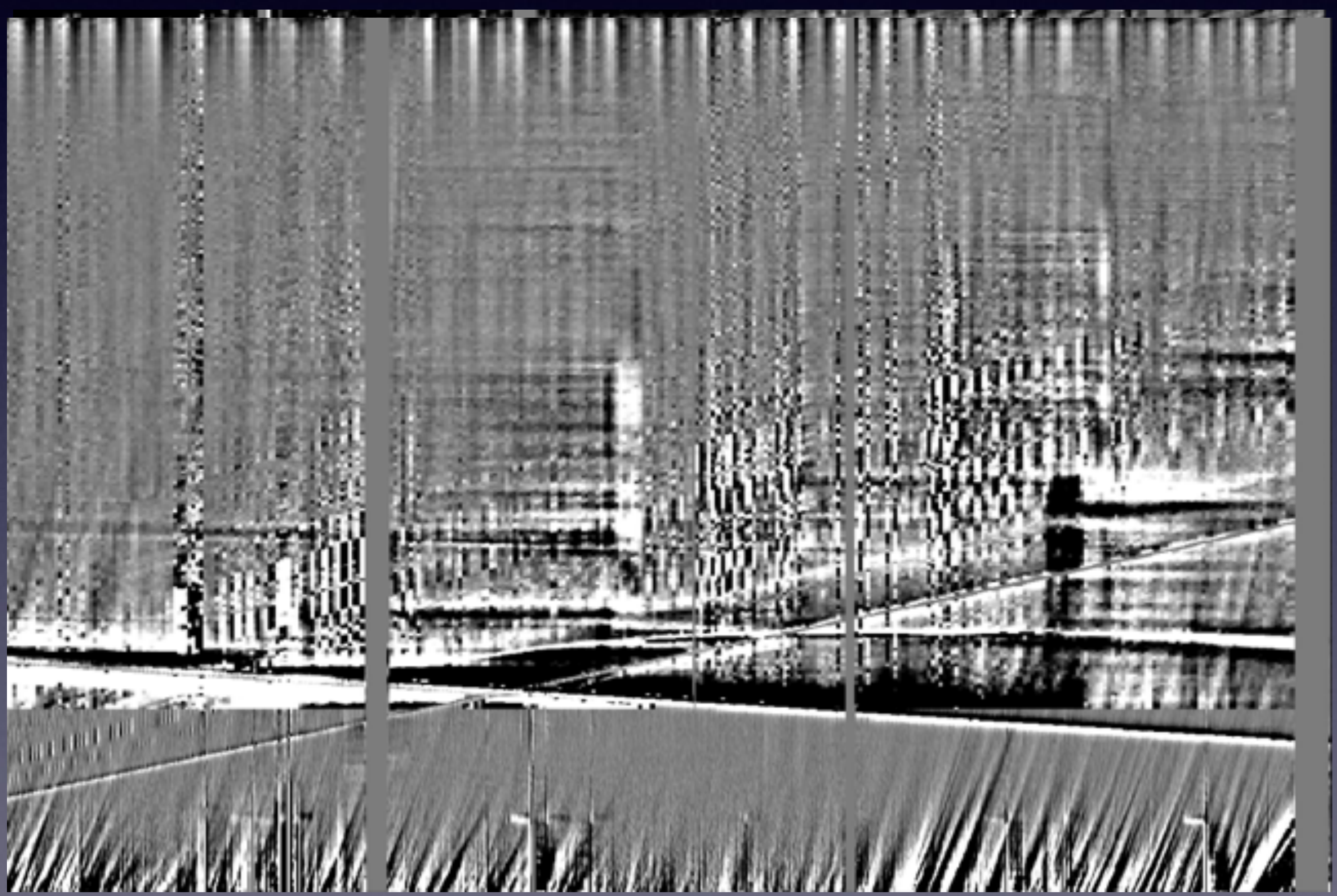


These traces mark are associated with the variability of plasma density along the CIR. Probably the compression of face-on blobs by high speed streams [Rouillard et al., 2008, 2010a,b; Sheeley et al. (2008)]

Stereo-A J-maps (examples)



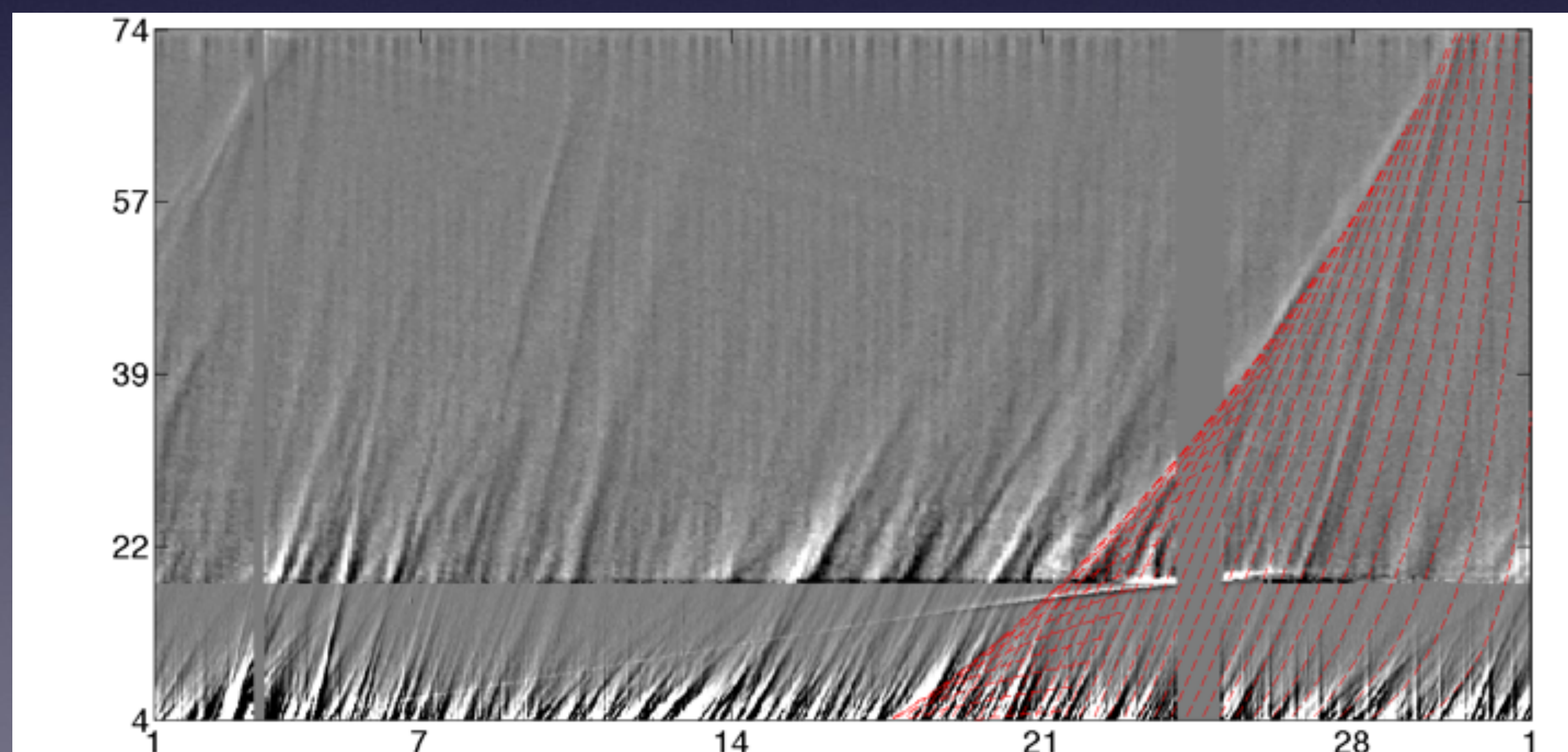
Stereo-B J-maps (examples)



More challenging to use then ST-A J-maps

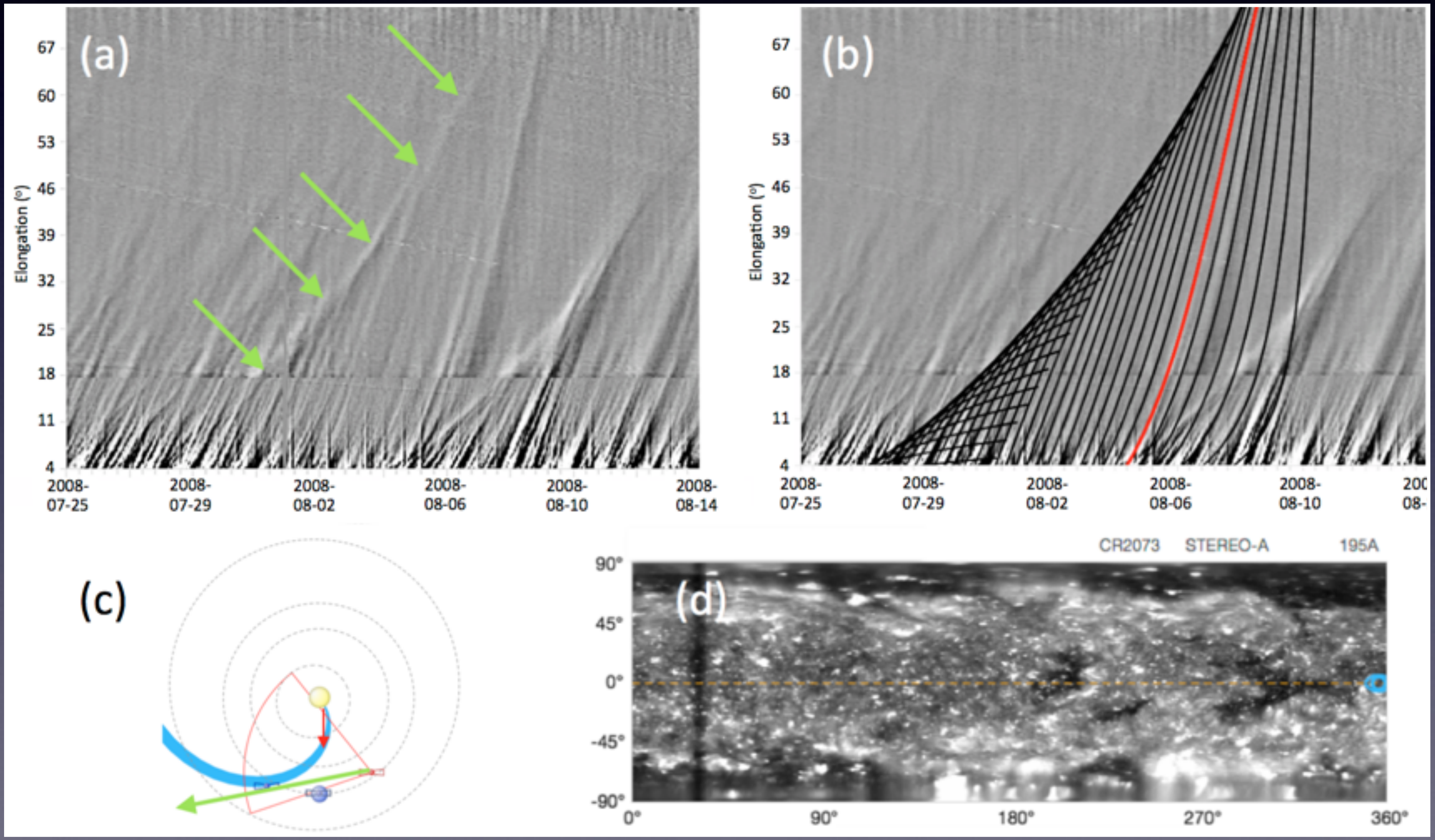
Fit of one CDS pattern in the ST-A J-map

- Clear pattern at the end of January 2008
- Identify one clearly seen blob and fit
- Assumptions : solar rotation rate of 25.38 days,
  fixed-phi fit, same speed for ALL blobs comprising the CDS,
  blobs released at 8 hours interval from the same location on the Sun.
- Reconstruct the other blob tracks and the envelope.



January 2008

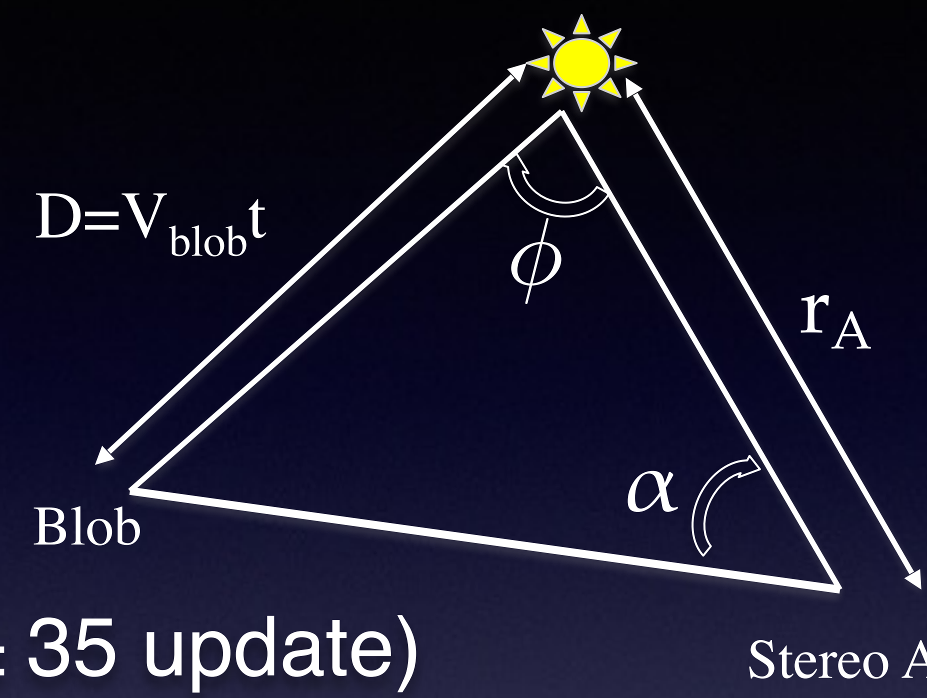
Stereo A , start on 2008-08-05. Vb=358 km/s, phi=34 deg.



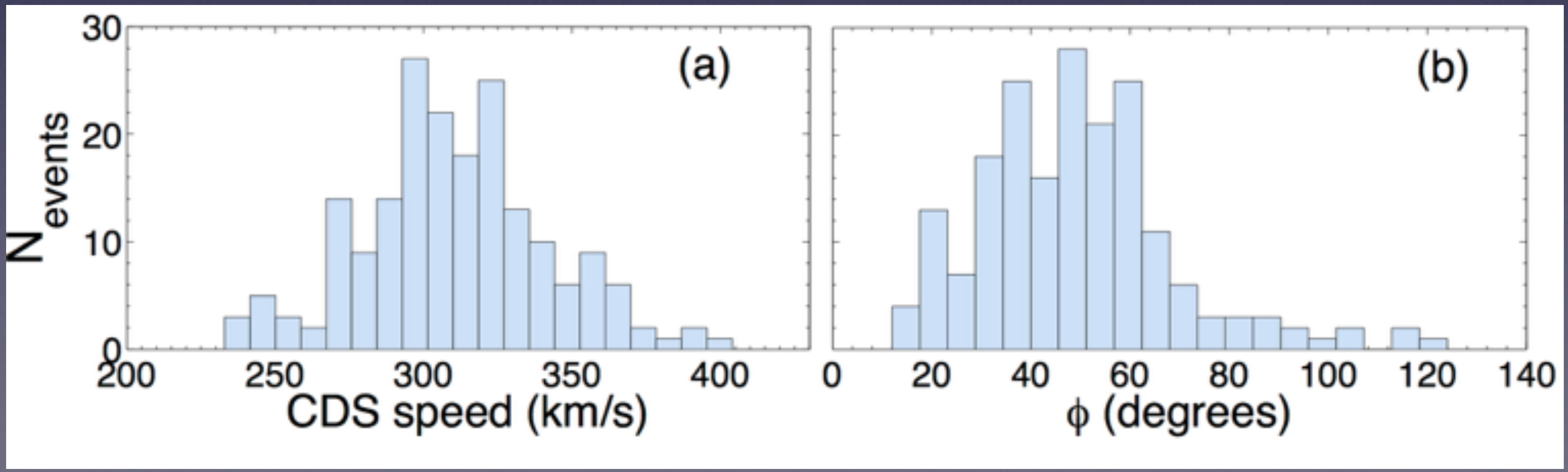
The catalogue

- Catalogue of 192 events in HI from STEREO-A running difference J-maps between 2007 and 2014.

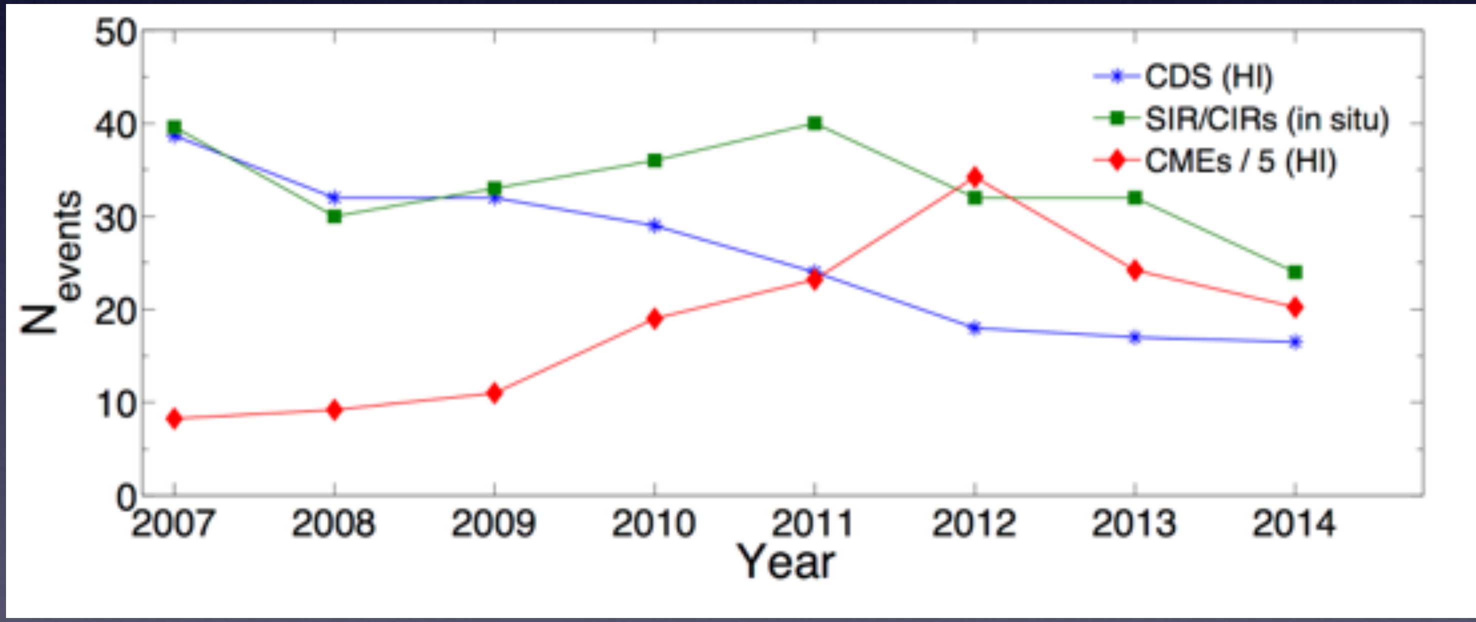
Speeds and longitude separations of CDSs



- Mean CDS speed: 310.7 ± 31 km/s (320 ± 35 update)
- Mean separation angle (phi): 49 ± 5 degrees



Events per year

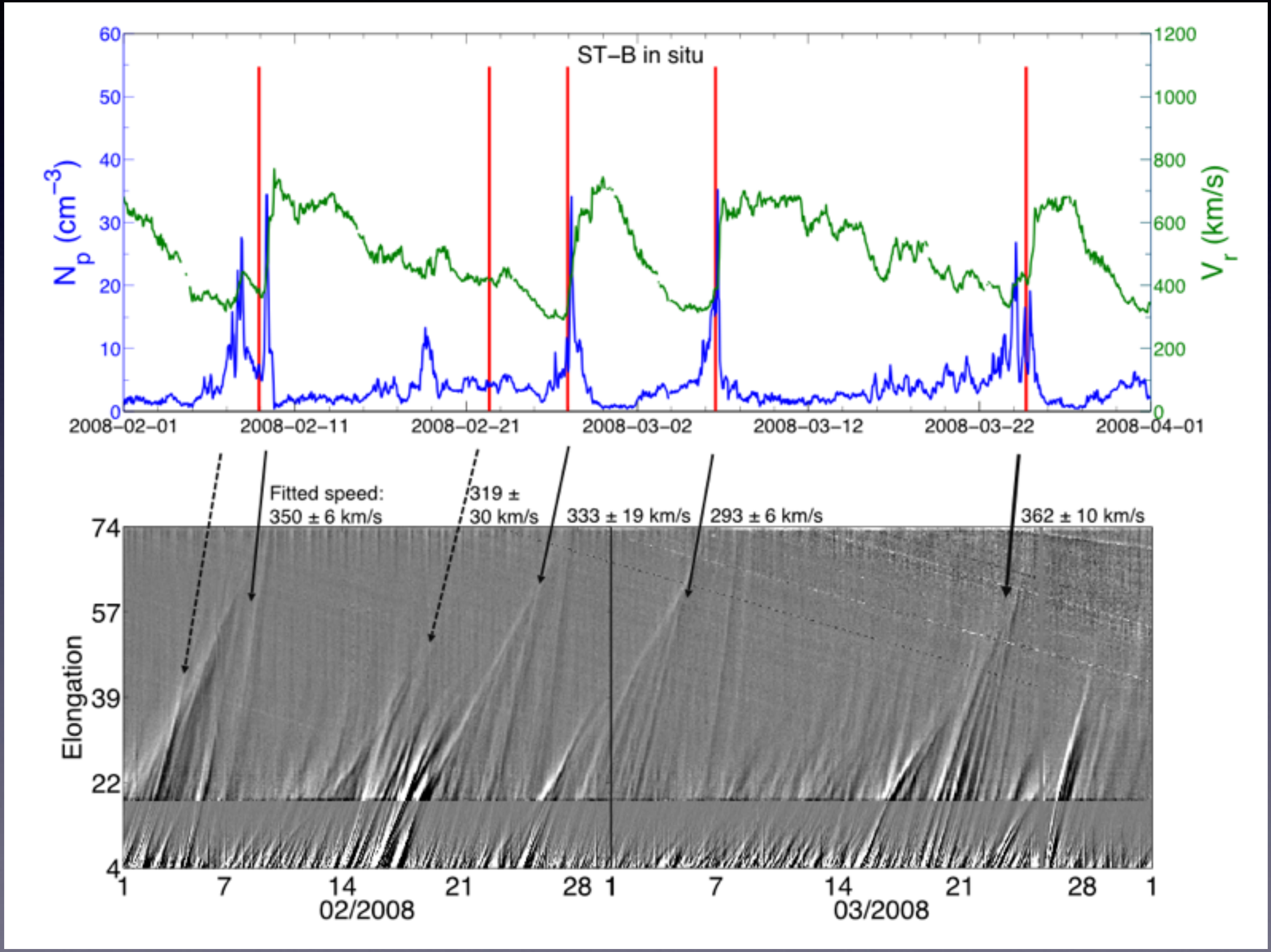


- CDSs: From 40/year on 2007 to 15/year on 2014
- In situ SIRs: 30-40/year
- CMEs: from 40 on 2007 to 200/year in 2012

Propagation to 1 AU

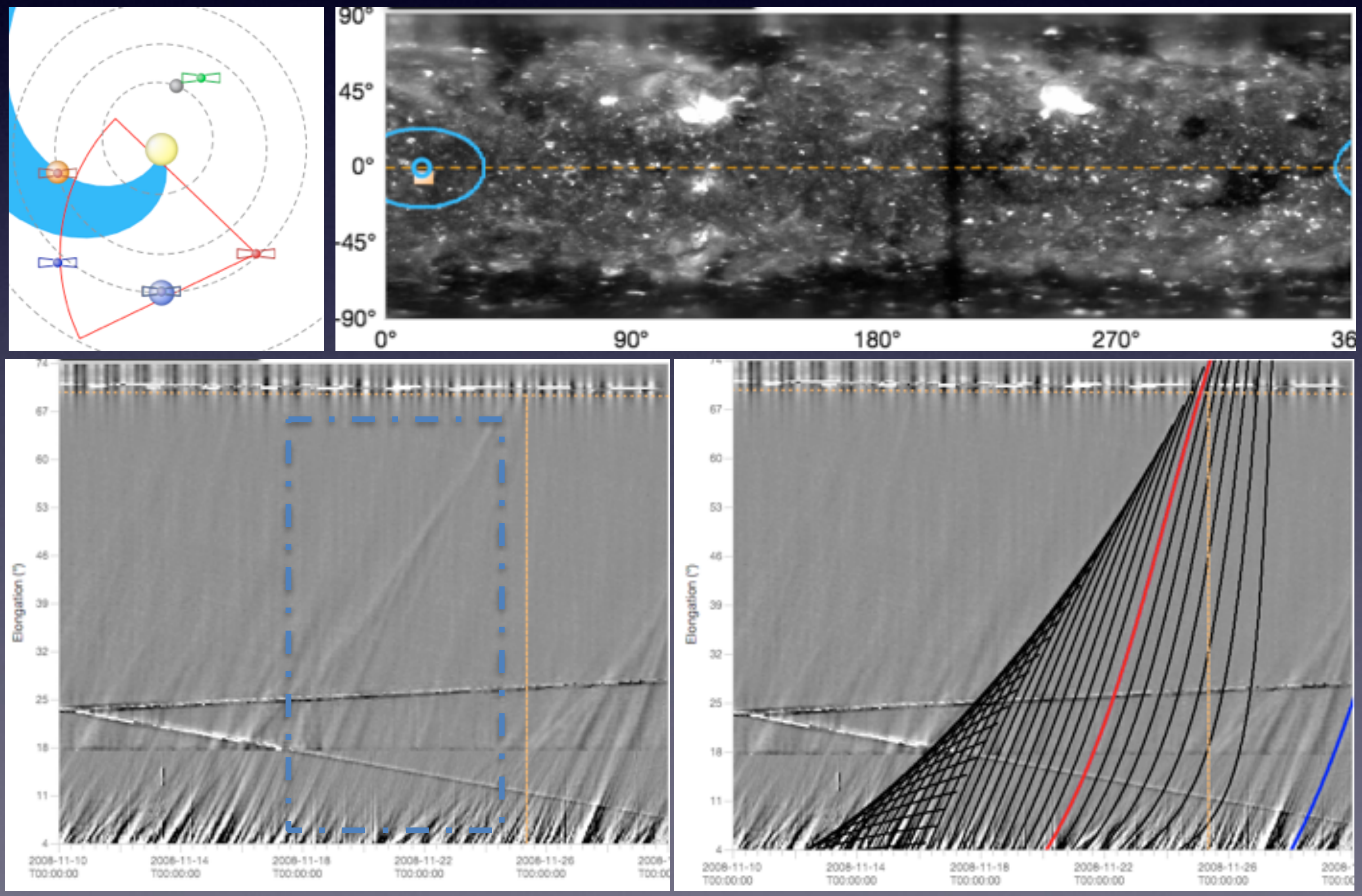
- Ballistic propagation (constant speed)
- For all 192 events from 2007 to 2014 (from solar minimum to solar maximum)
- Predicted impact time and the CDS speed compared with in situ observations at 1 AU (ST-A, ST-B, Ace, Wind)

Different cases: fev-avril 2008



One event analysis : HI

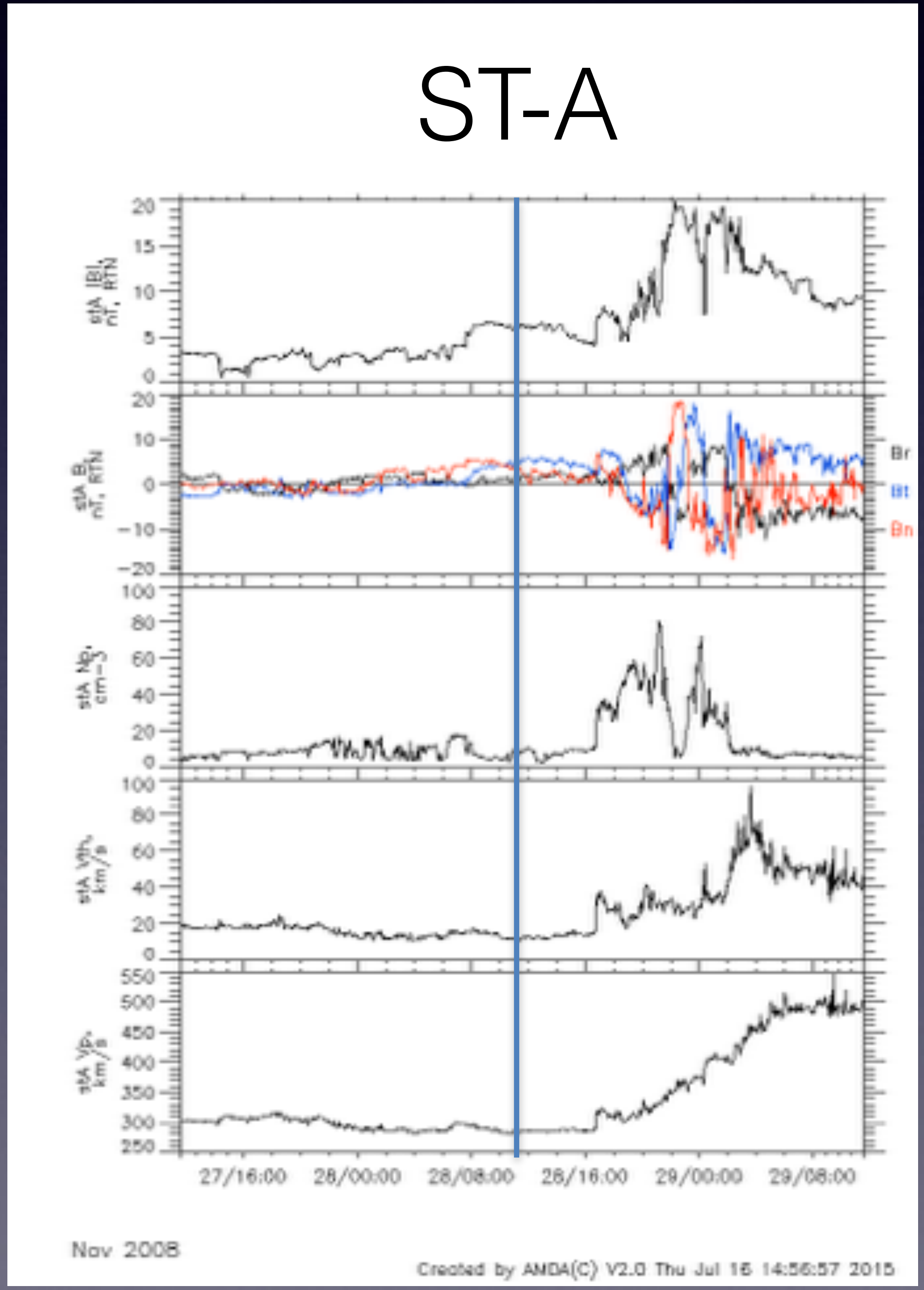
Stereo A , blob start on 2008-11-19. Vb=295 km/s, phi=38 deg.

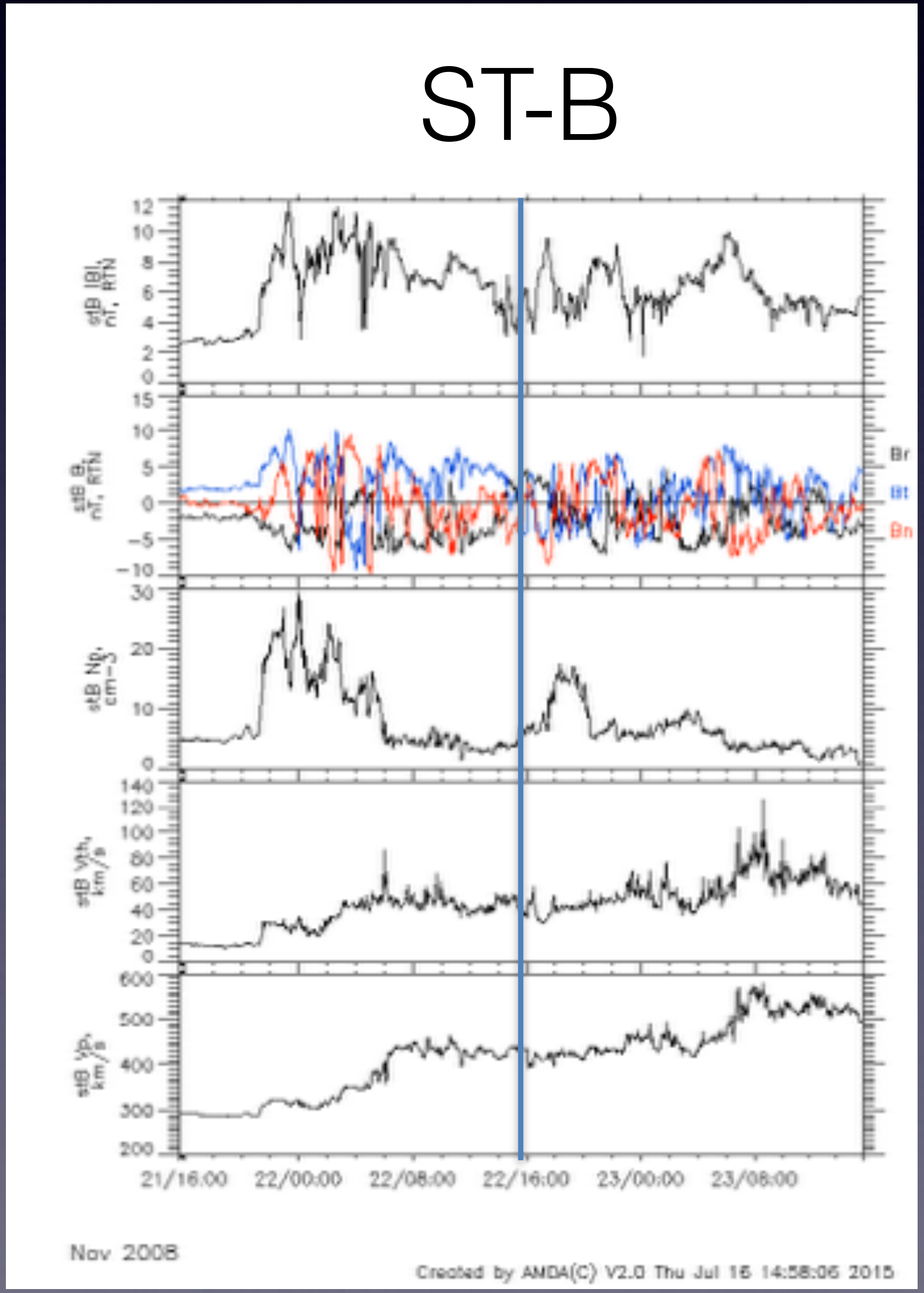


One event analysis : in situ (1)

Blob start on 2008-11-19. Vb=295 km/s, phi=38 deg.

In-situ data at ST-A (left) and ST-B (right) with predicted arrival time (blue line)

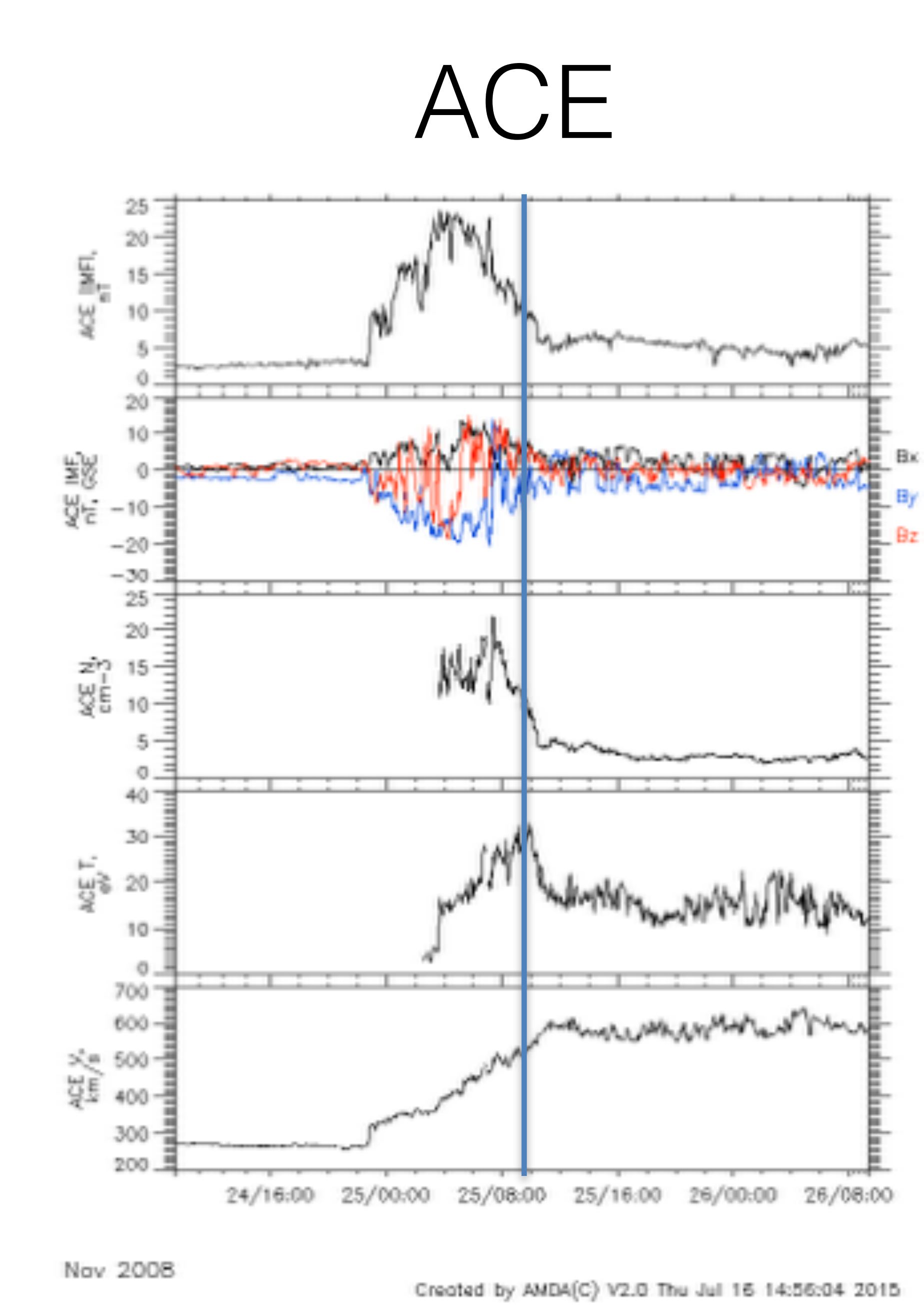


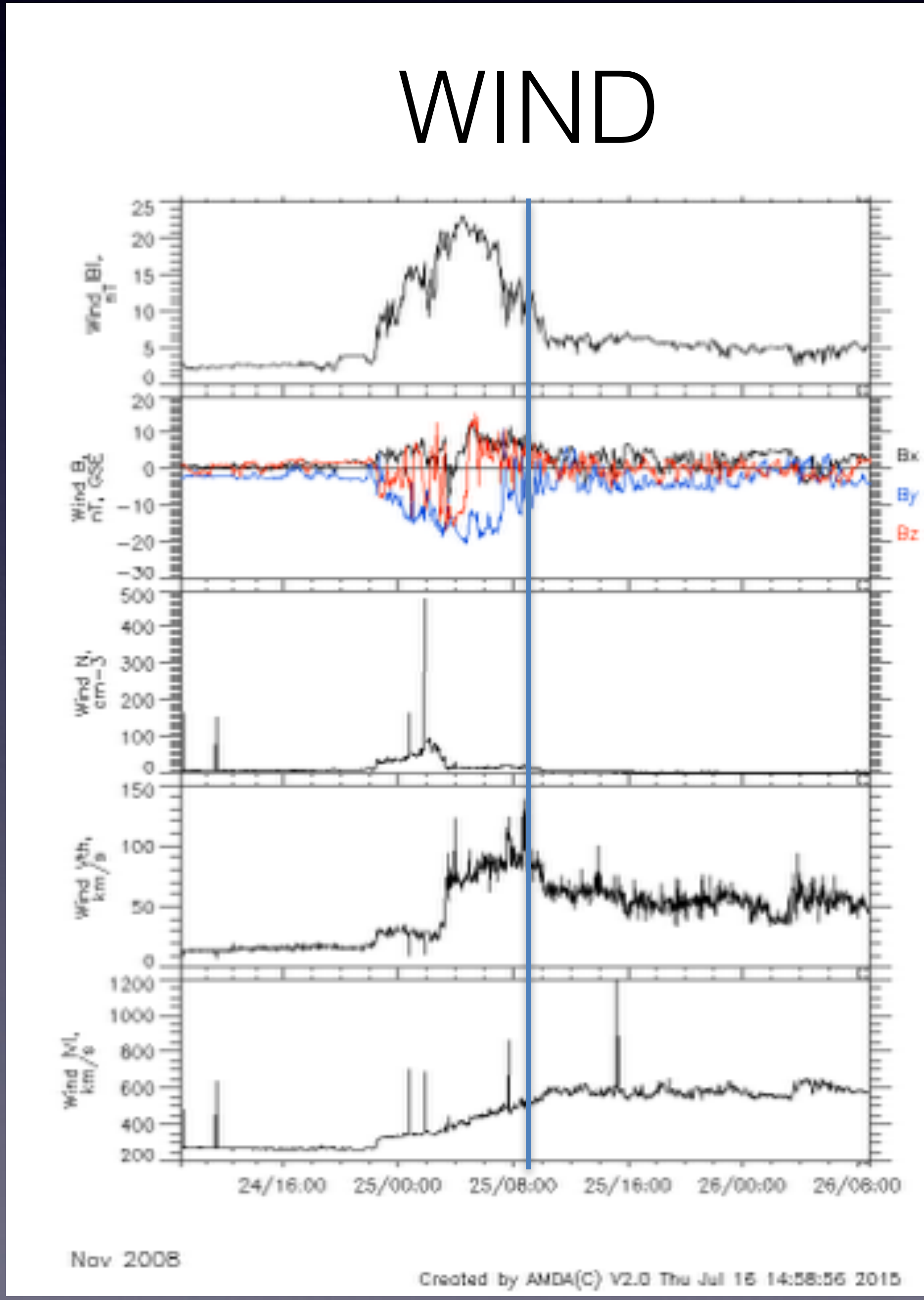


In advance at ST-A, late at ST-B

One event analysis : in situ (2)

In-situ data at ACE (left) and Wind (right) with predicted arrival time (blue line)



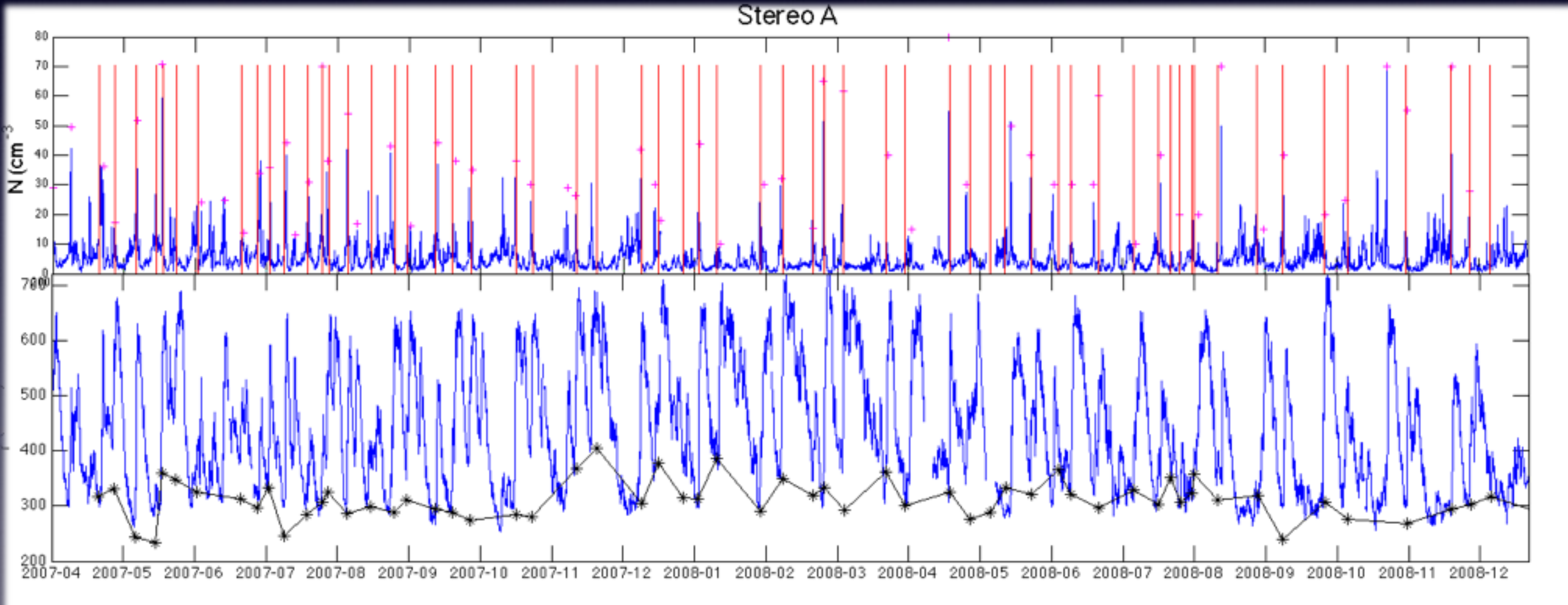


On the stream interface at ACE and Wind

Long-term analysis (2007-2014)

Global view (2007-2008)

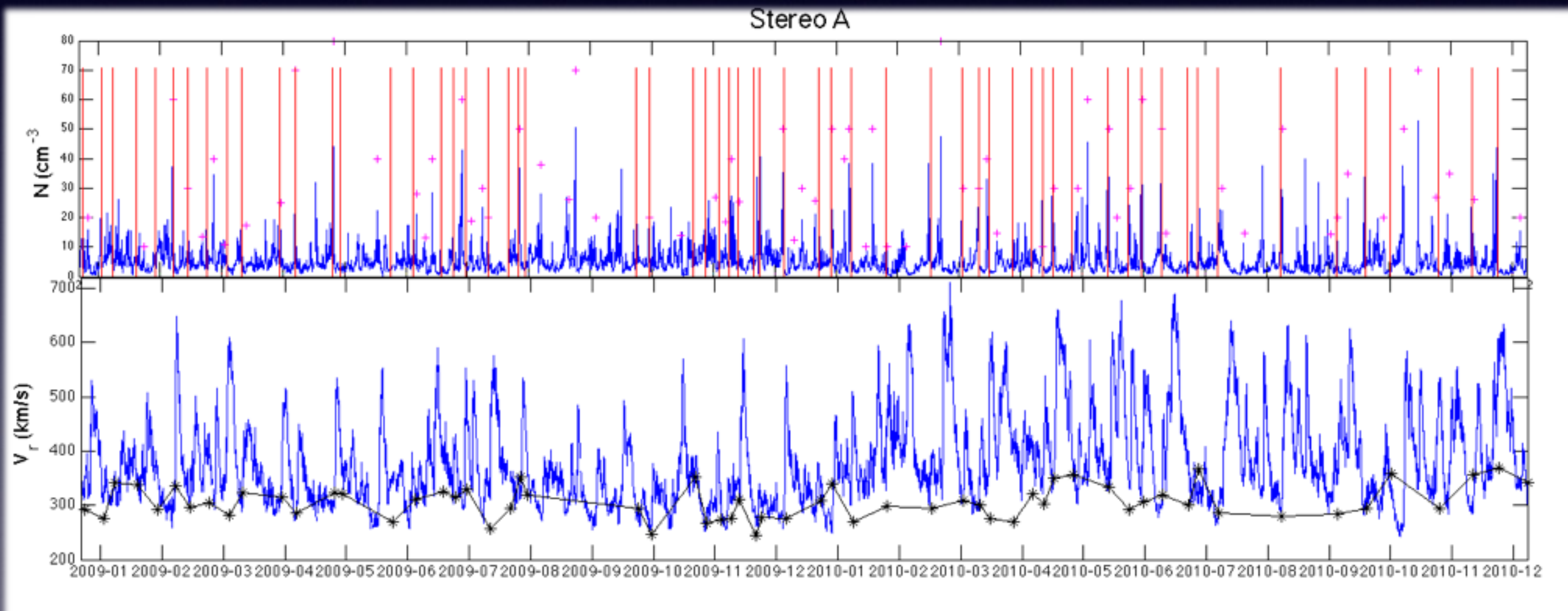
Solar wind density (upper panel) and speed (lower panel) at ST-A
Red vertical lines: predicted CDS arrival at ST-A. Black stars: predicted CDS speed



Almost all CDS counterparts to the in situ SIR/CIRs identified.
Speed follows the slow solar wind prior to the SI

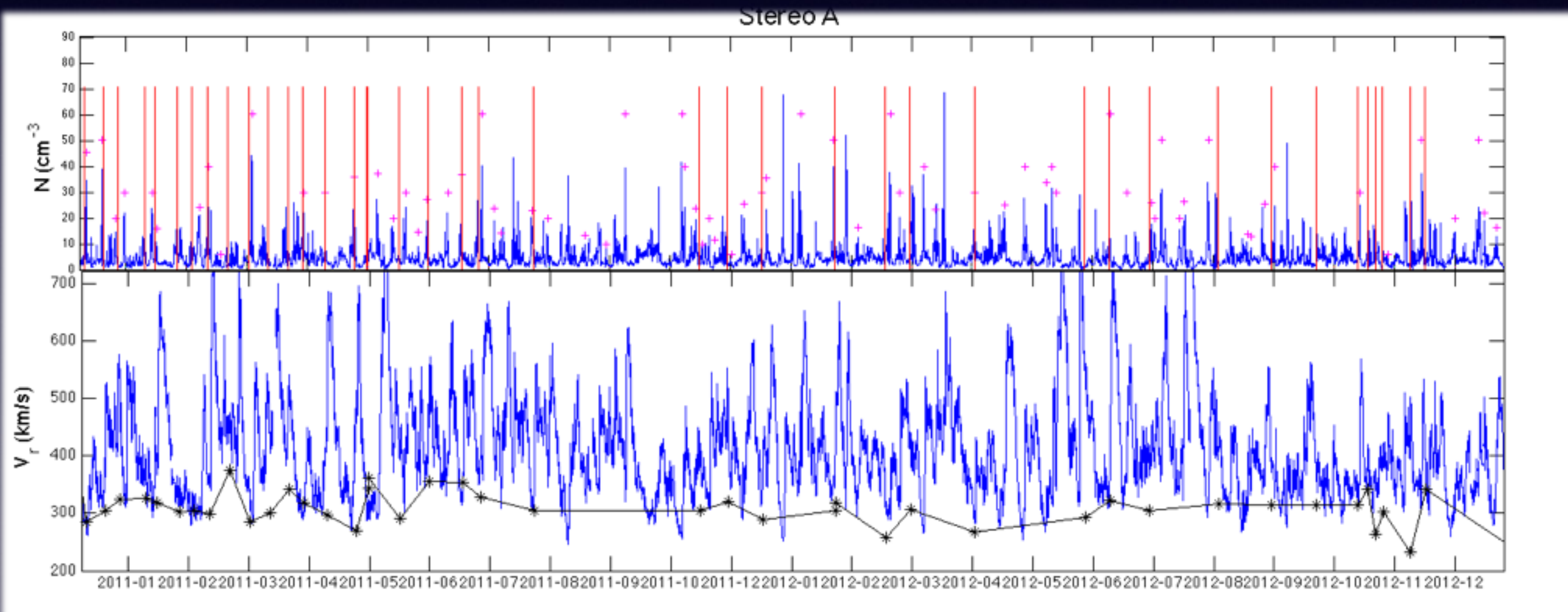
Global view (2009-2010)

Solar wind density (upper panel) and speed (lower panel) at ST-A
Red vertical lines: predicted CDS arrival at ST-A. Black stars: predicted CDS speed



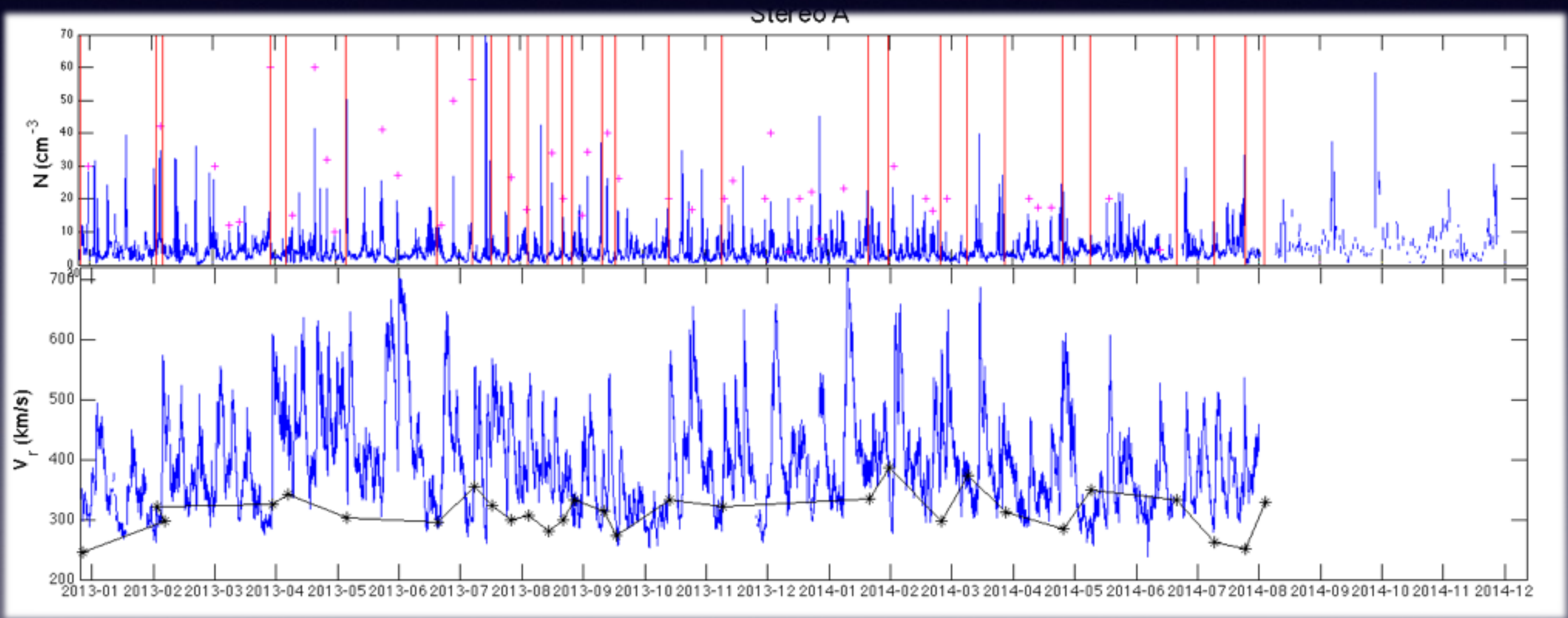
Global view (2011-2012)

Solar wind density (upper panel) and speed (lower panel) at ST-A
Red vertical lines: predicted CDS arrival at ST-A. Black stars: predicted CDS speed



Global view (2013-2014)

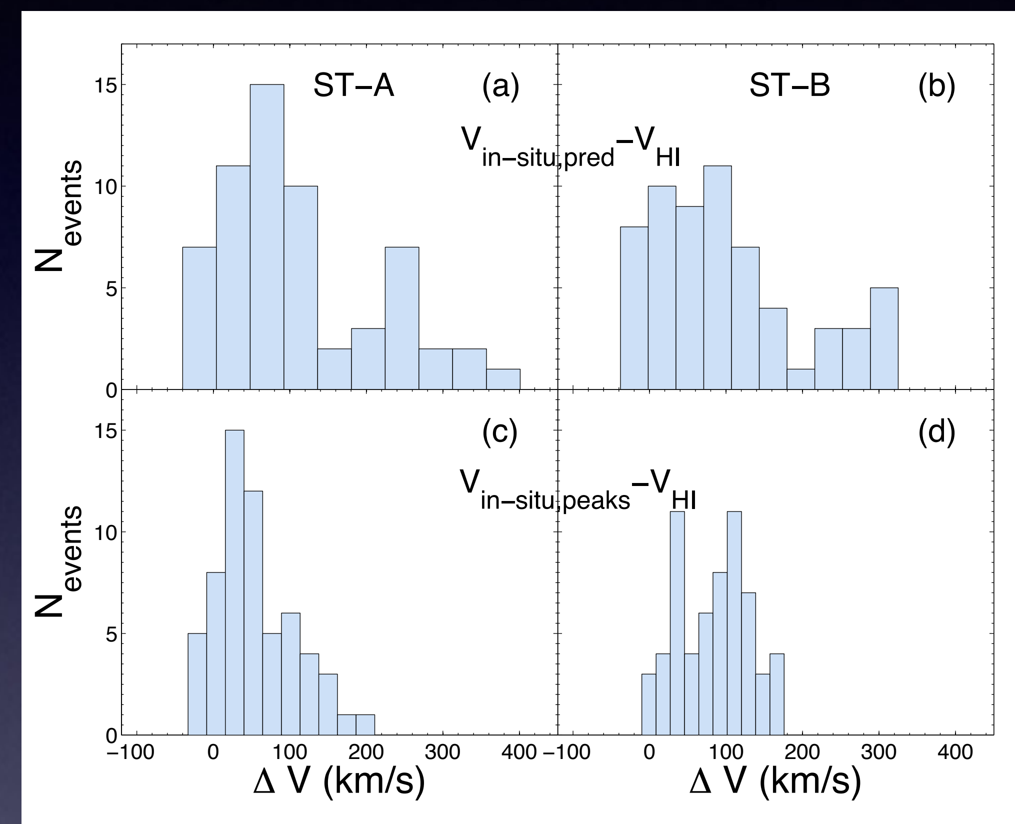
Solar wind density (upper panel) and speed (lower panel) at ST-A
Red vertical lines: predicted CDS arrival at ST-A. Black stars: predicted CDS speed



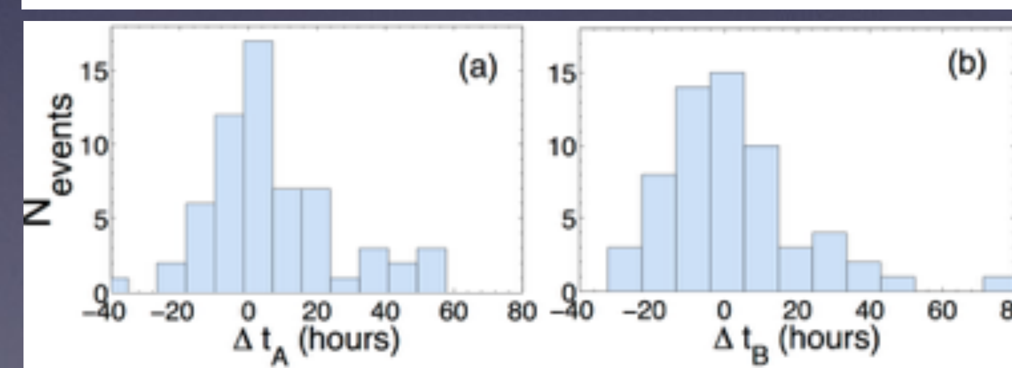
A number of CDS « missed » while SIR/CIRs seen in situ.

Statistical comparison

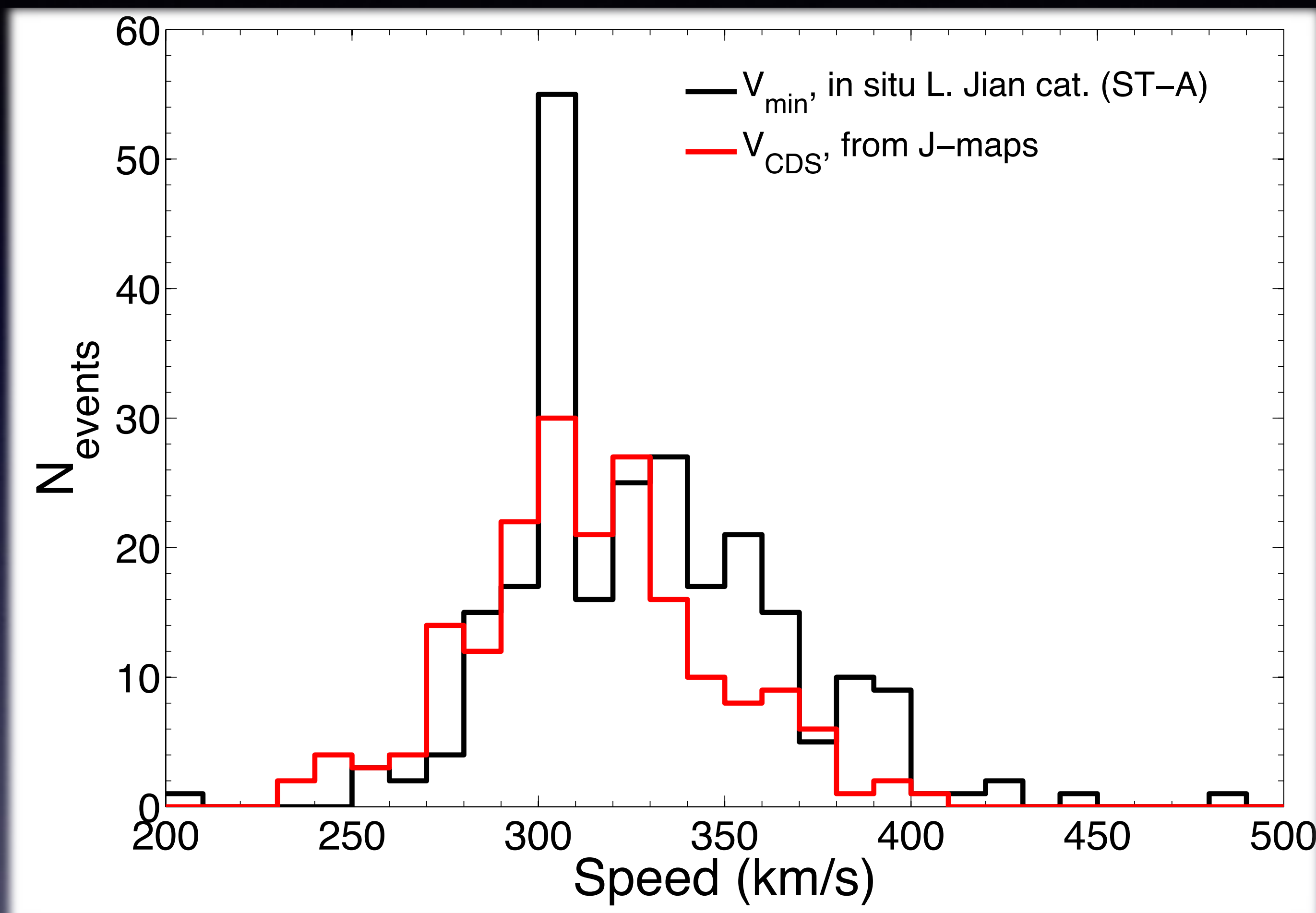
- Speeds : mean predicted CDS = 310 kms. When measured in situ at predicted arrival times = broad distribution with mean 410 km/s. When closest density peak times in situ are considered narrower distribution around 385 km/s.

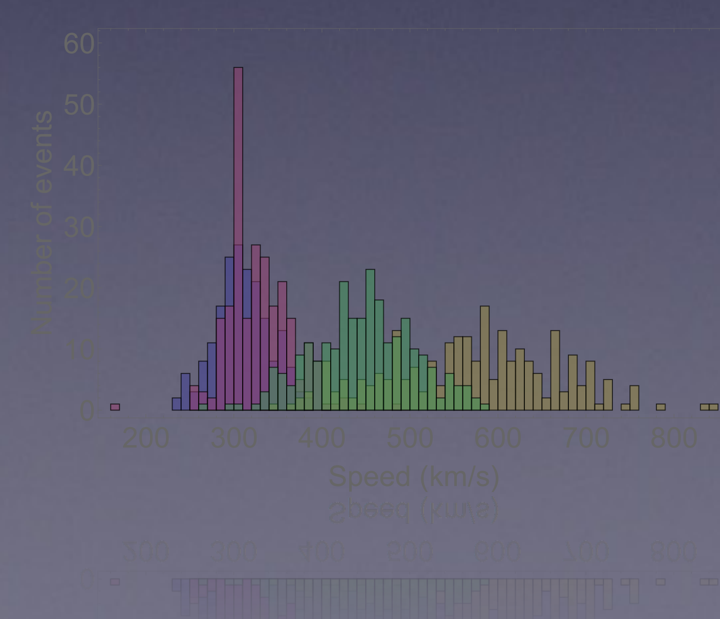


- Time delay between predicted and the closest density peaks. Most probable 9 (ST-A) and 11 (ST-B) hours error.



Comparison to Lan Jian's catalogue

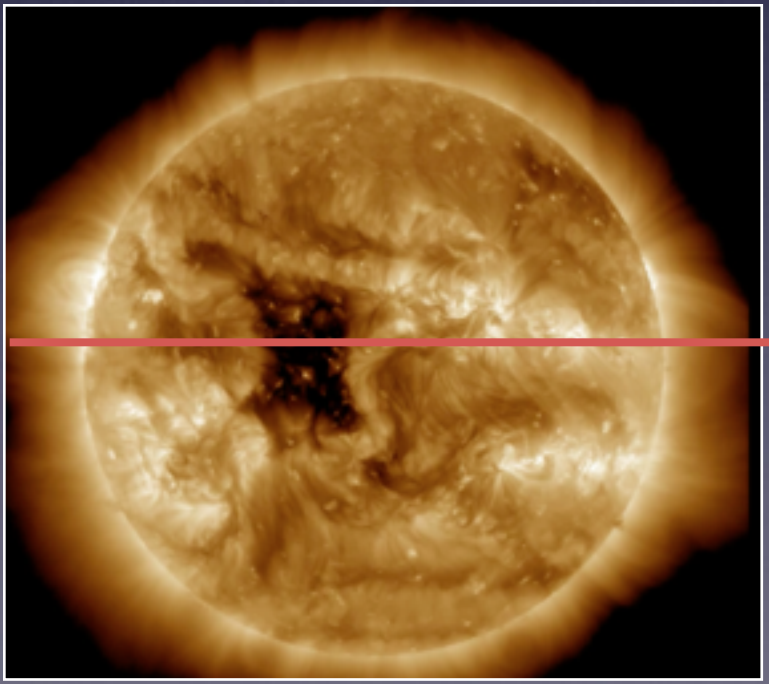




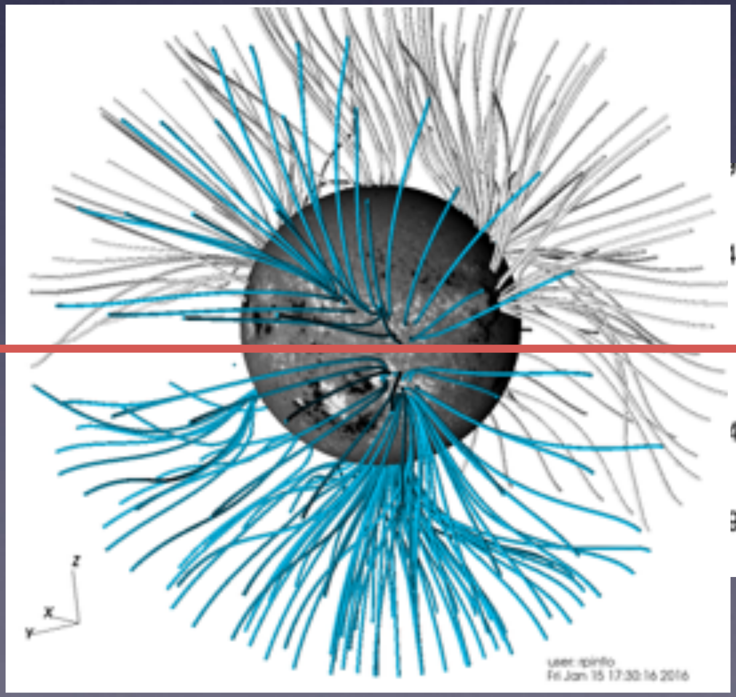
Nature of the CDSs

- PFSS extrapolation and construction of the field model.
  For every Carrington rotation between 2007 and 2014
- Over plot the back traced anchor point for each CDS catalogued.

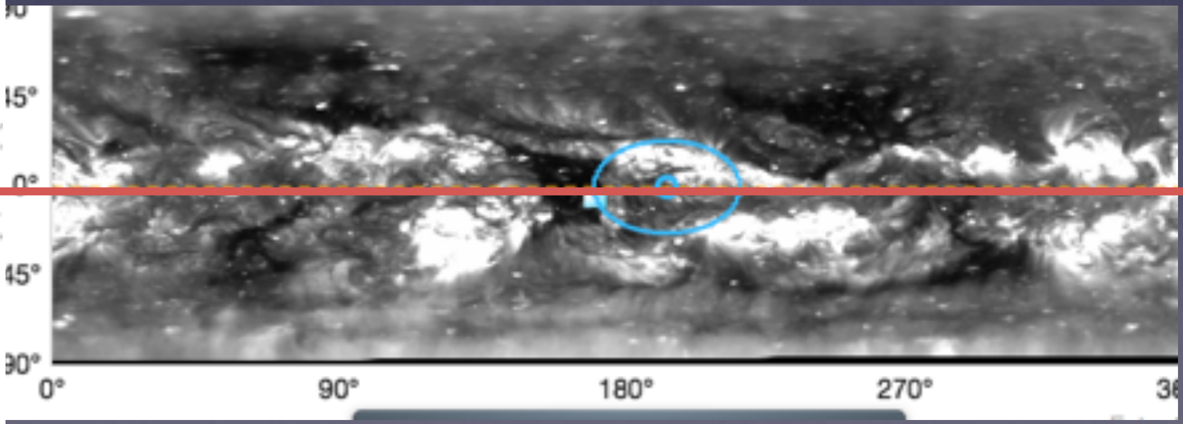
EUV



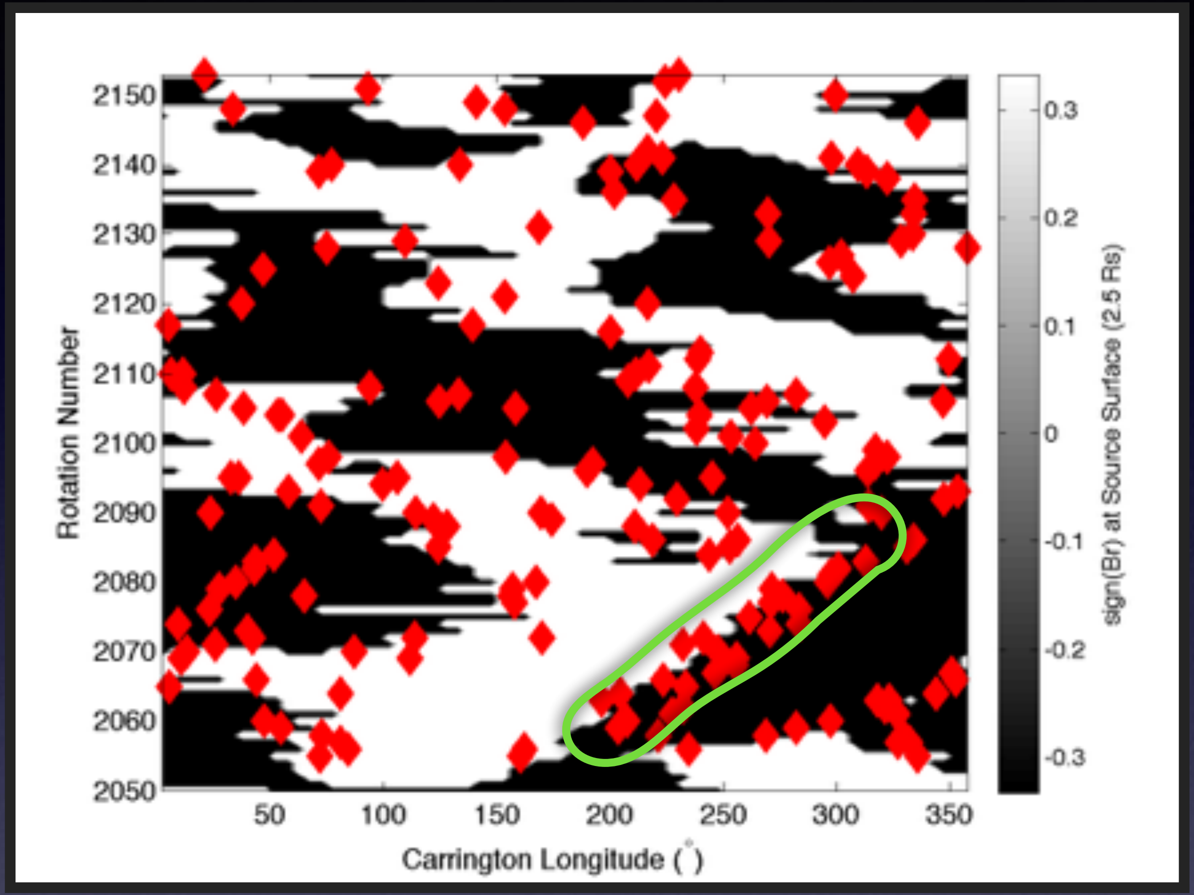
PFSS



Carrington map in EUV
+ Anchor point

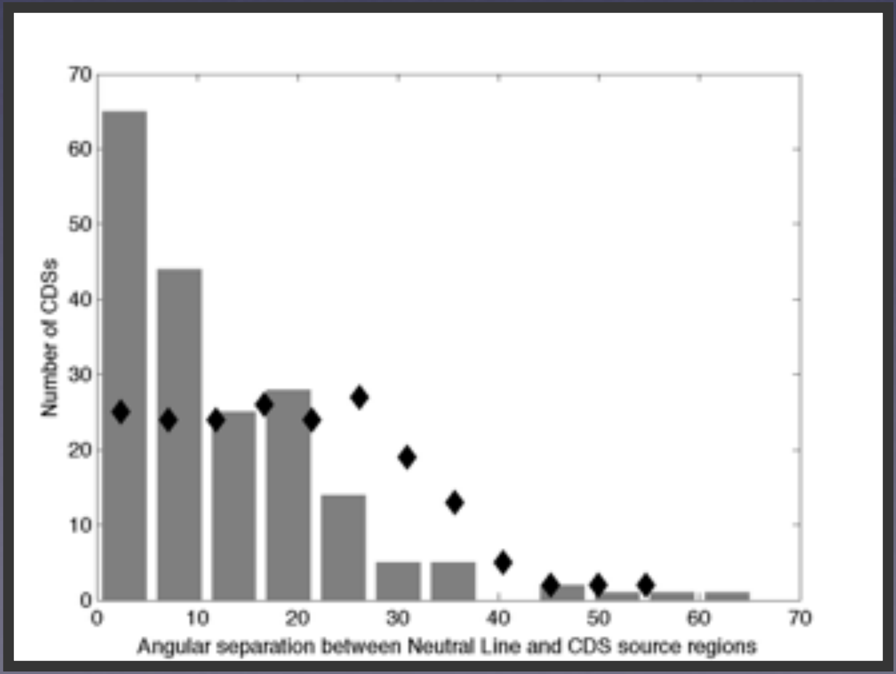


Relationship to the HCS and magnetic sectors



Stack plot:
Carr. longitude vs date (in Carr Rotation Numbers unit)
Red diamonds: back traced anchor point of the catalogued CDSs.
Minimim Period (Rotations < 2100): Association with the polarity inversion of the magnetic field (Neutral Line). Sectoring of a large part of events.

Angular separation between the anchor point and the HCS at the Source Surface. Excess of events with <10 degrees separation as compared to a random distribution.



Conclusions

- Catalogue of 192 CDSs from 2007 to 2014 in ST-A J-maps realized. Propagation to 1 AU and back to the Sun done for each event. Arrival times at different probes (ST-A, ST-B, Ace, Wind…). Available on the HELCATS website and interactively using Propagation Tool.
- Mean predicted CDS speed is 310.7 ± 31 km/s. HI identification seems to track the slow solar wind prior to the stream interface at 1 AU.
- Nature of the CDSs: link with the Heliospheric Current Sheet seen from the back traced anchor points at the Sun surface. Eventually evolving into SIR/CIRs at ~1 AU.
- Space weather implications. At solar minimum: all events identifiable. Solar maximum: CME activity and less stable Coronal Holes prevent largely to track all events. Implications for the possible future missions to L3 or L4.

Complements

- Superposed epoch analysis
- Conlon et al. 15 (spacecraft motion effect)
- input from IPS observations
- 1D MHD simulations

Superposed epoch analysis

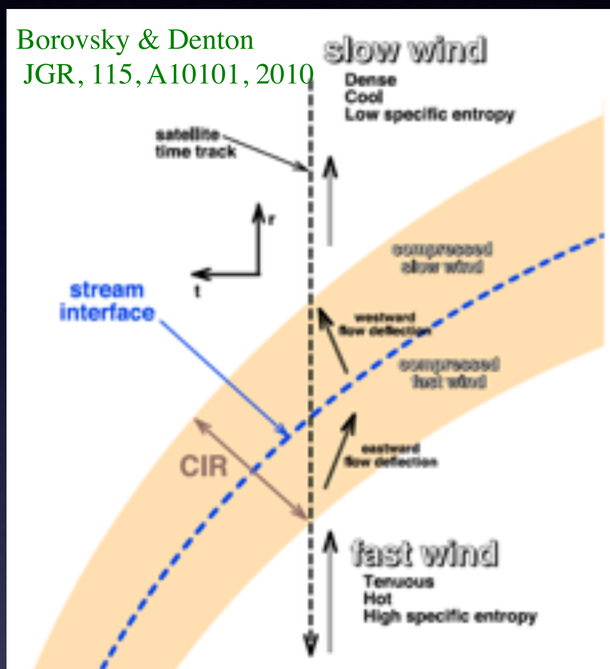
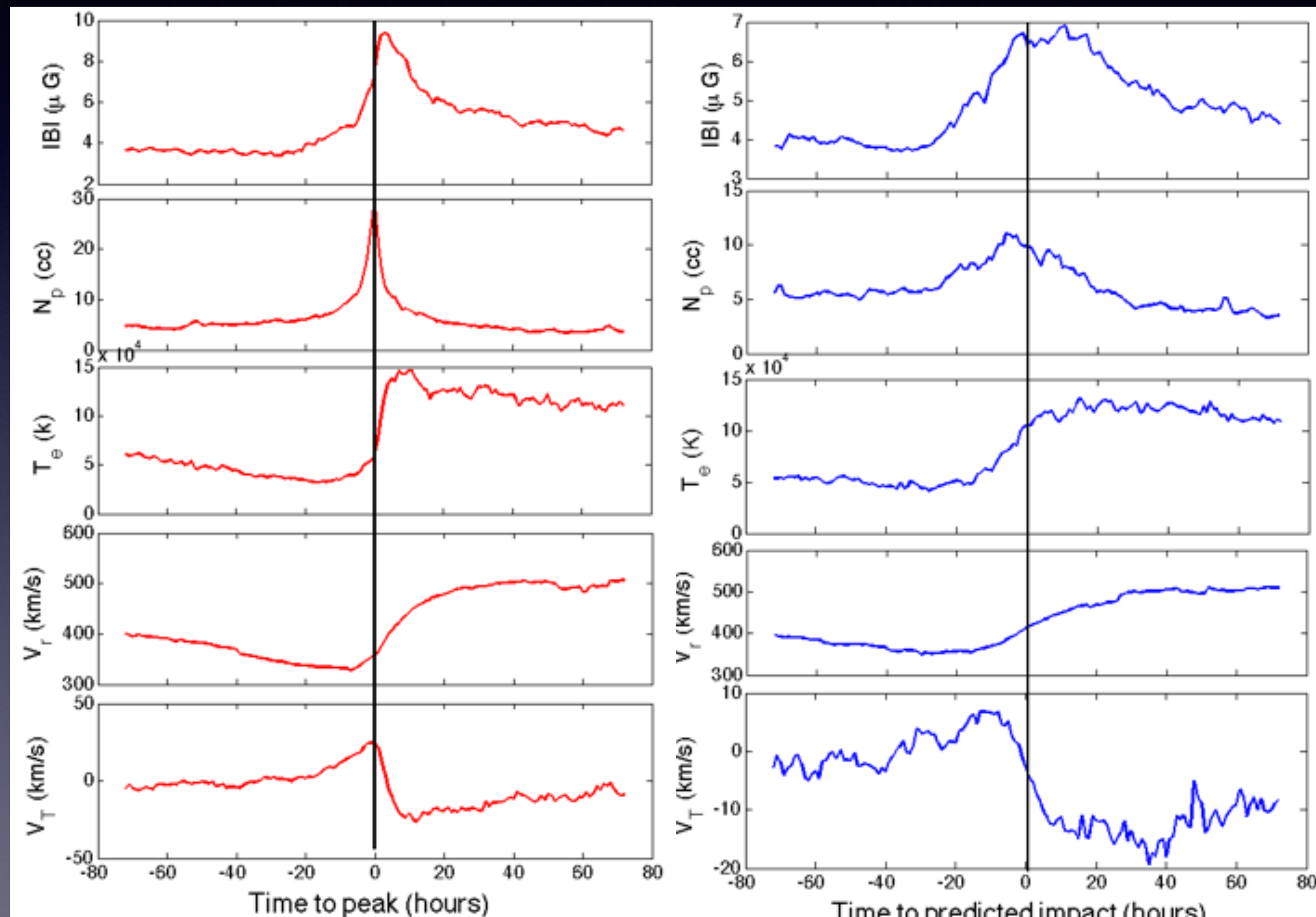


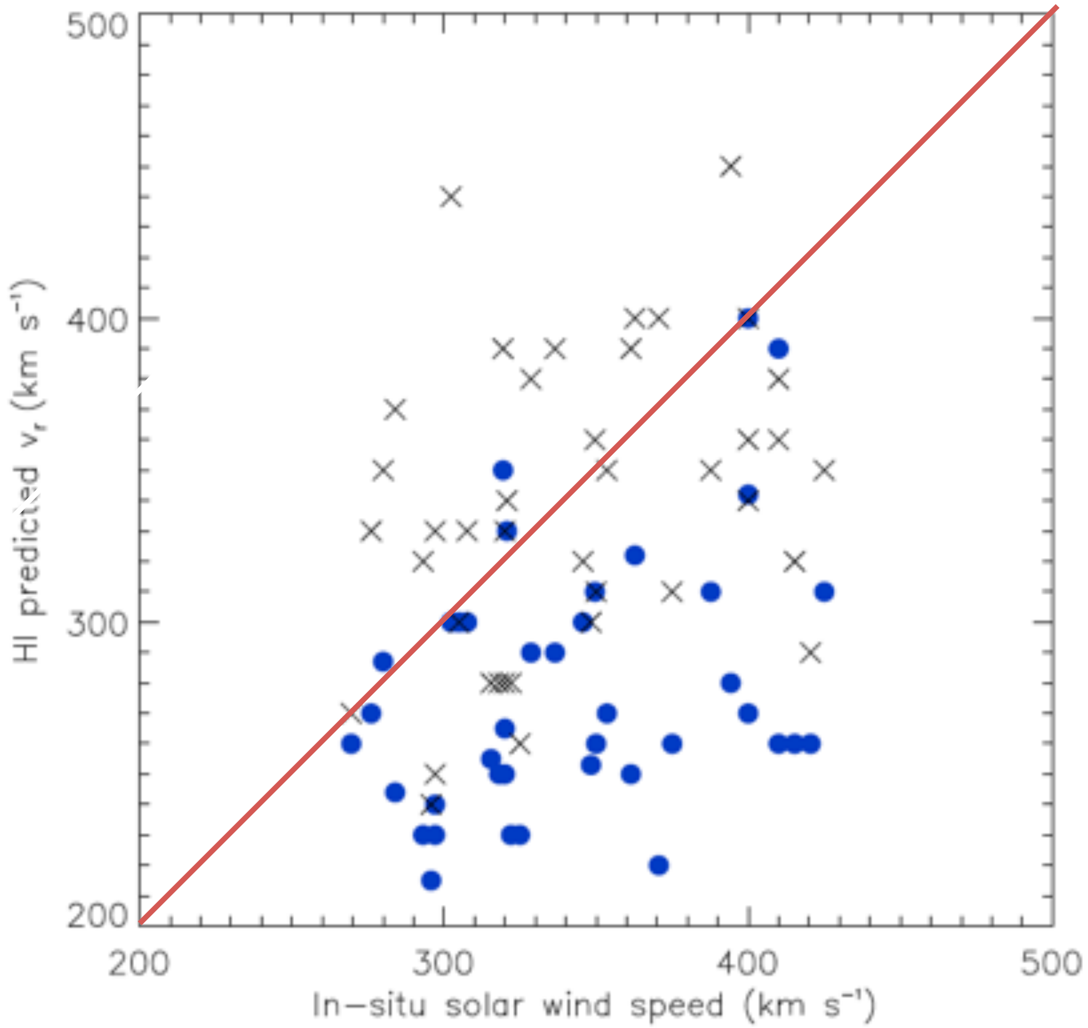
Figure 5. A sketch of a CIR in the vicinity of 1 AU. Standard view in the reference frame of the Sun in RTN coordinates. The reference frame emphasizes the westward-eastward flow deflection (arrows) in the CIR (brown shading).



- Red curves: based on the closest density peaks
- Blue curves: based on the predicted CDS arrival times. Smoothed cause of the arrival time prediction uncertainty.
- Can do better…
- … in progress

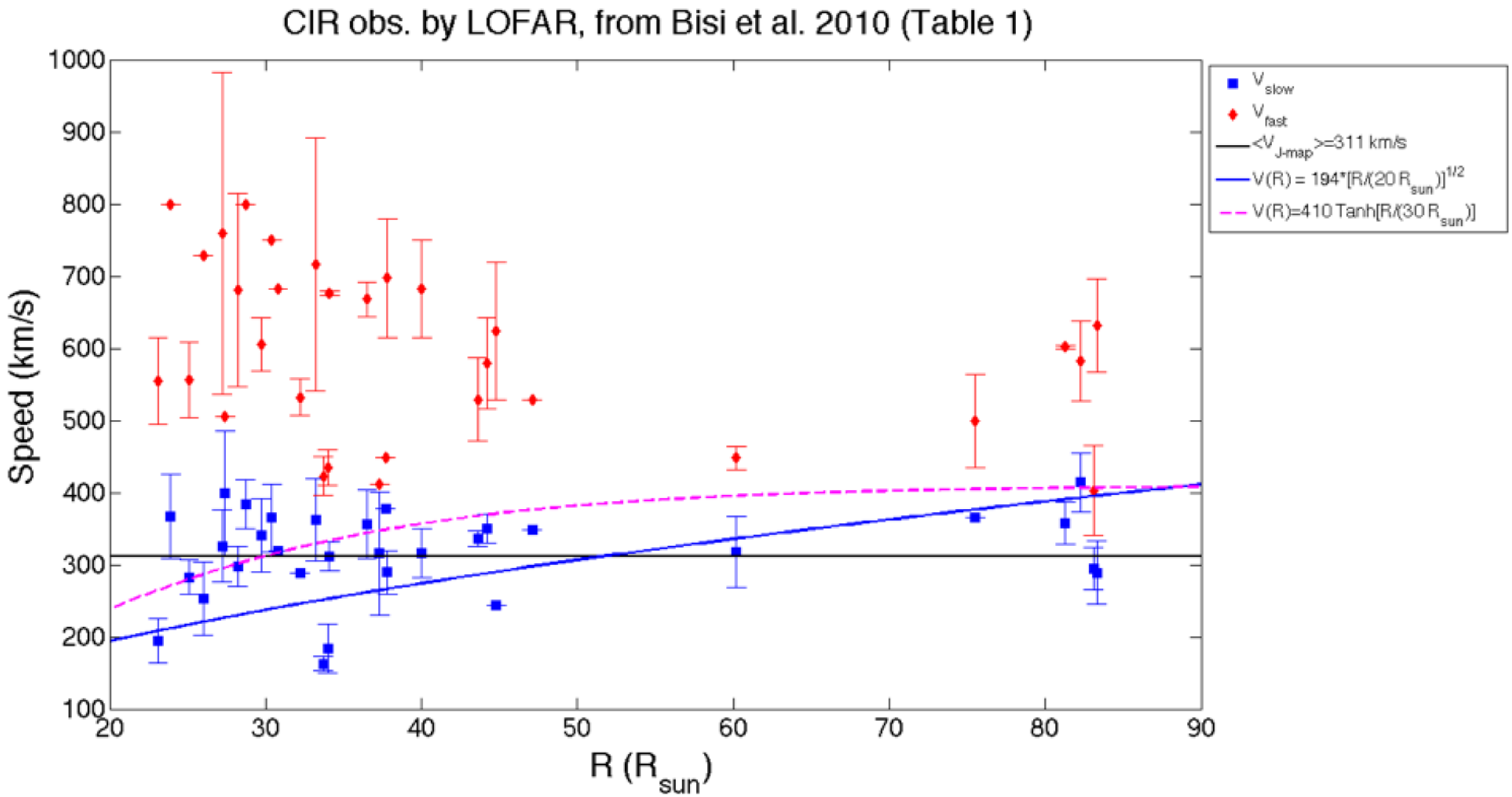
Conlon et al. 15

Figure 6 The CIR speed as measured by HI *versus* the speed associated with the enhancement in density as measured *in-situ* by ACE. The blue points show those speeds as estimated from HI without incorporating spacecraft motion and the black crosses including spacecraft motion. A general increase in propagation speed estimated from HI can be seen when incorporating spacecraft motion.



Include all spacecraft motions into the fitting procedure may increase the fitted speed by ~30-40 km/s

Input from IPS radio measurements



C.Tao 1D MHD simulations of the solar wind

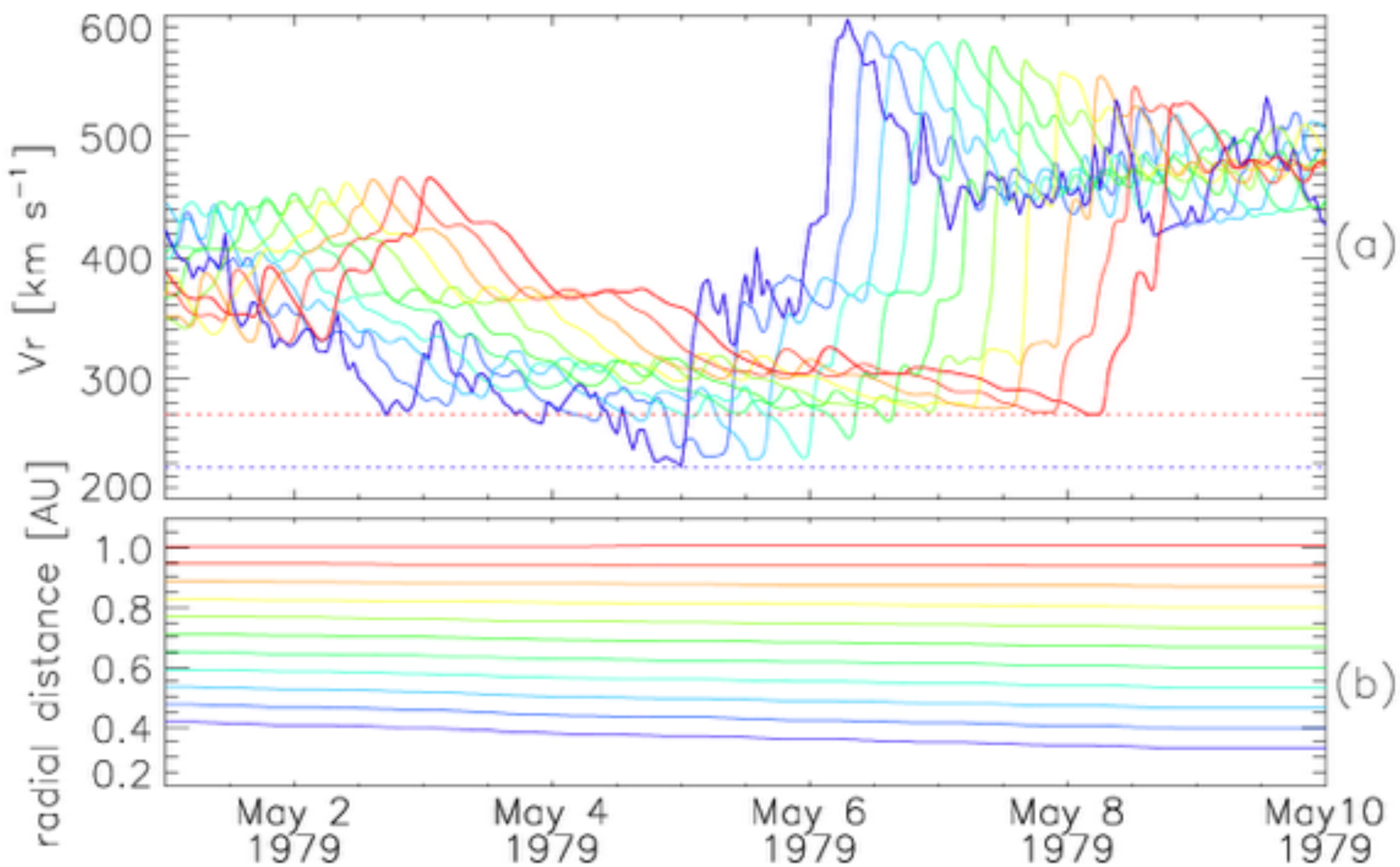


Figure S1. The radial velocity of the solar wind measured by HELIOS 1 between 1 and 10 May 1979 is shown by the blue solid line in the upper panel (a). The radial velocity outputs of the 1D MHD propagation model are presented for different heliocentric distances with the rest of the colored solid lines in panel (a). The lower panel (b) shows the heliocentric distances of the radial velocity shown by corresponding colors. Dashed lines in (a) show the minimum velocity of HELIOS 1 observation (blue) and that of model output at 1 AU (red).

Sanchez-Diaz et al. 16

Compressed blobs inside the interaction region (SI) may accelerate while traveling from 0.3 to 1 AU