Polar magnetic tornadoes - the structures that connect the Sun and the heliosphere

Olga Khabarova[1], Helmi Malova[2,3], Roman Kislov[1, 2], Lev Zelenyi[2], Vladimir Obridko[1], Alexander Kharshiladze[1], and Vladimir Kuznetsov[1]

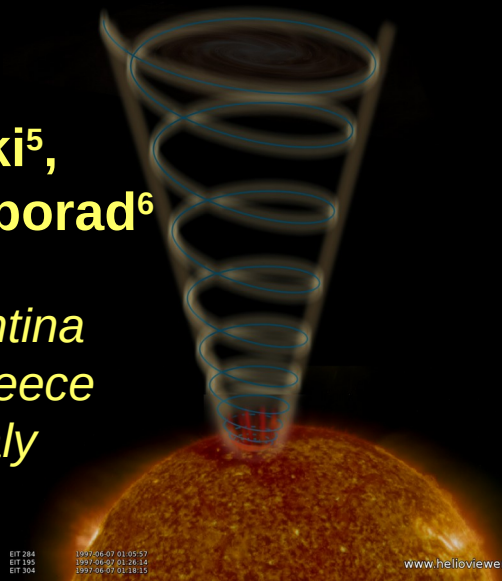
[1] Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation of the Russian Academy of Sciences (IZMIRAN), Moscow, Russia
[2] Space Research Institute (IKI RAS), Moscow, Russia
[3] Skobeltsyn Institute of Nuclear Physics, MSU, Moscow, Russia

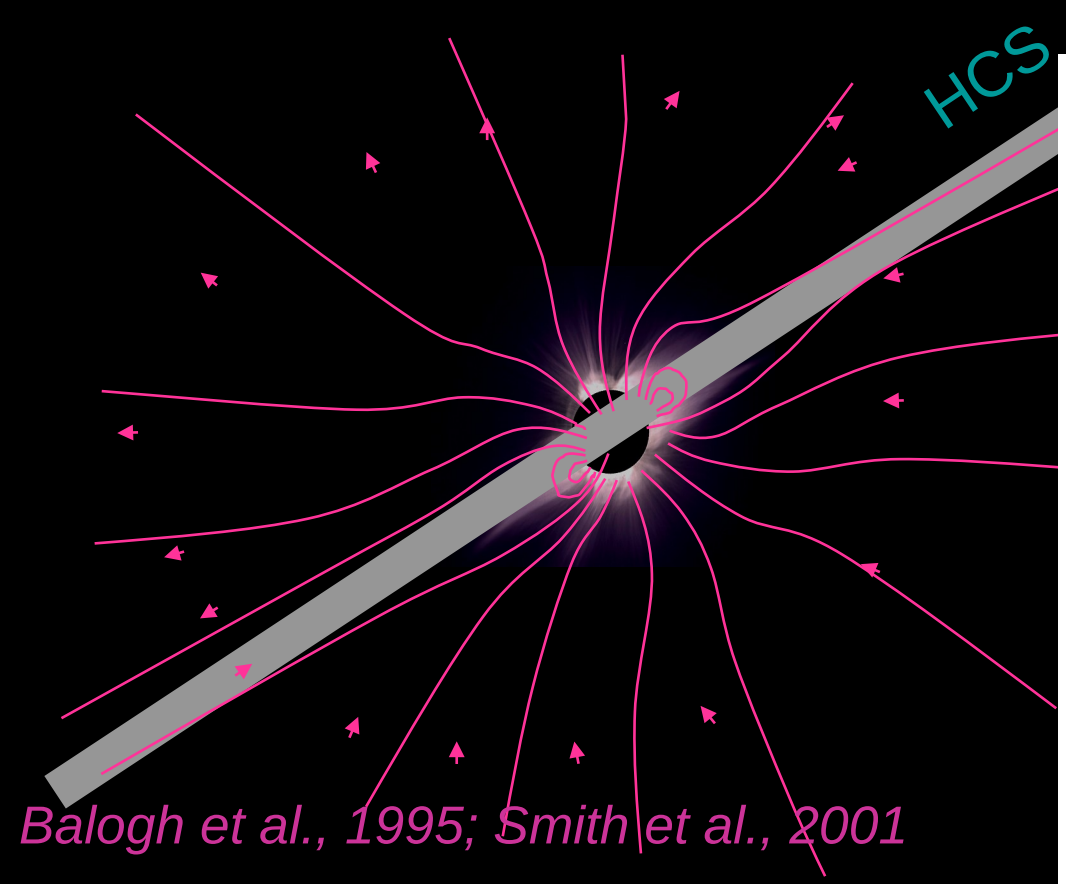
+

Hebe Cremades[4], Olga Malandraki[5], Luciano Merenda[4], Alessandro Bemporad[6]

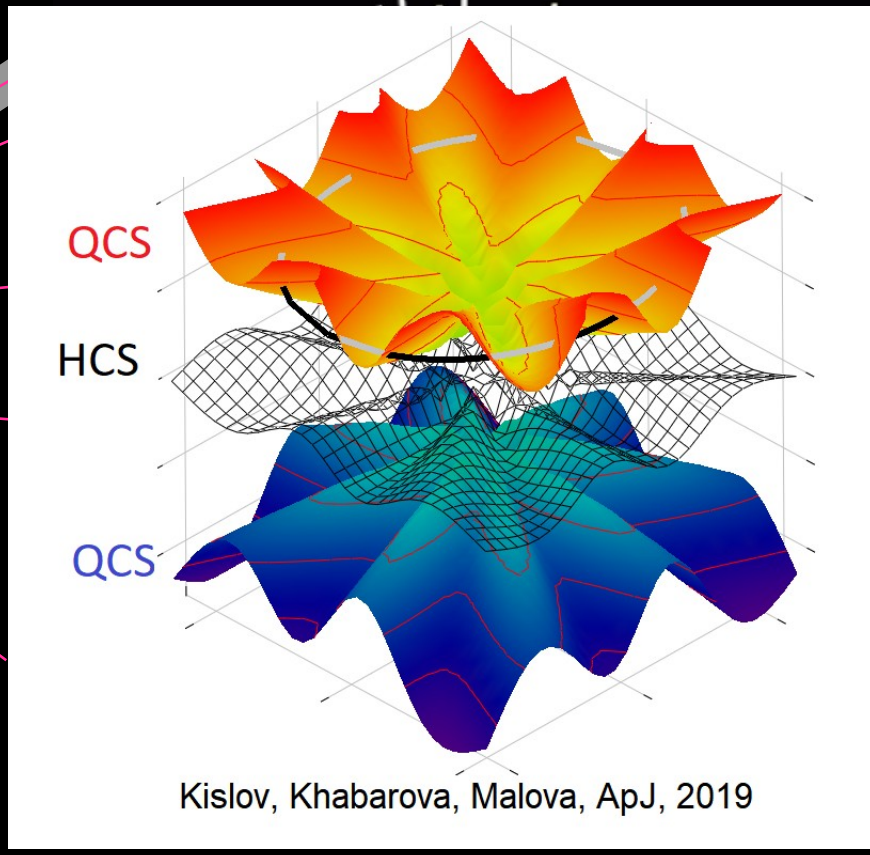
[4]UTN - FRM and CONICET, Mendoza, Argentina
[5] National Observatory of Athens, Athens, Greece
[6] INAF - Torino Astronomical Observatory, Italy

habarova@izmiran.ru



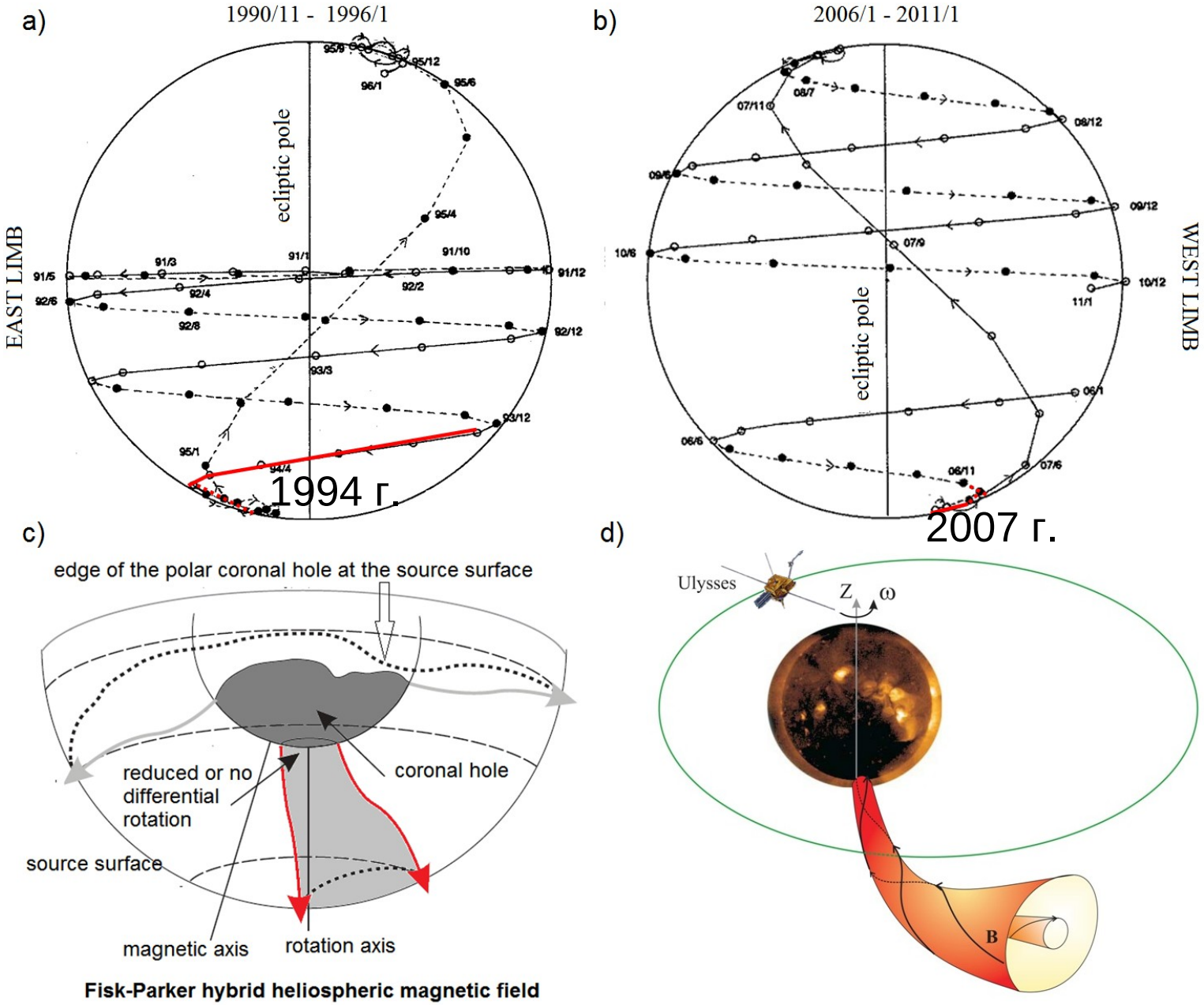


Balogh et al., 1995; Smith et al., 2001



Kislov, Khabarova, Malova, ApJ, 2019

The heliospheric current sheet and large-scale current sheets representing an extension of solar magnetic field neutral lines

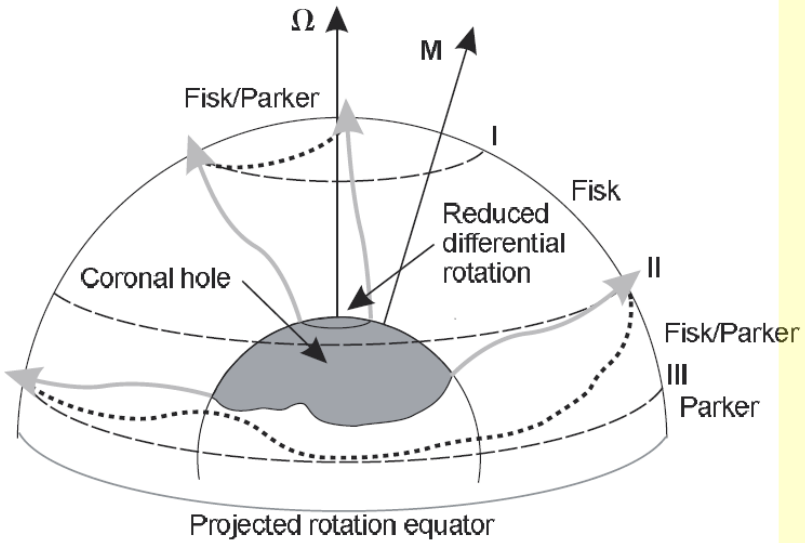


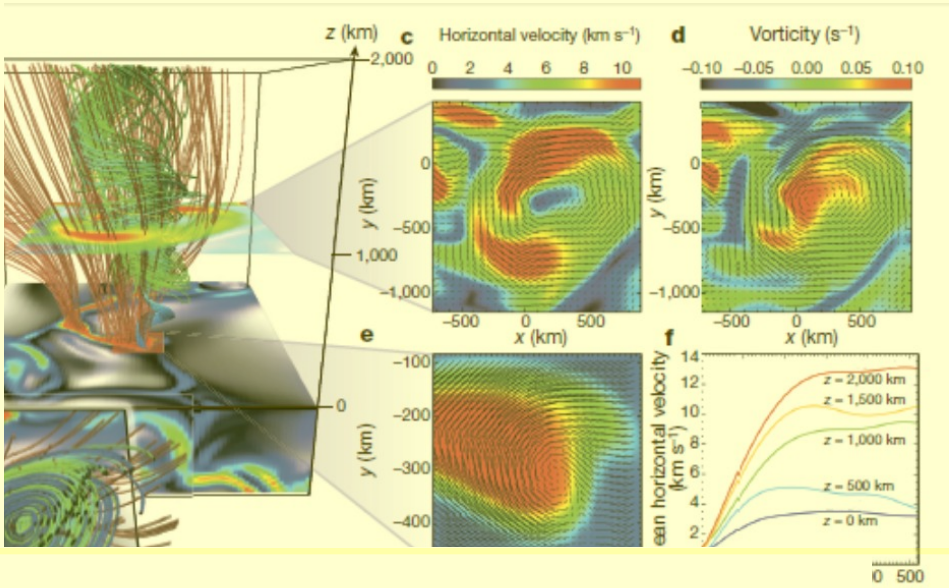
Khabarova et al. ApJ, 2017

THE ASTROPHYSICAL JOURNAL, 674:511–519, 2008 February 10

A FISK-PARKER HYBRID HELIOSPHERIC MAGNETIC FIELD WITH A SOLAR-CYCLE DEPENDENCE

R. A. BURGER, T. P. J. KRÜGER, M. HITGE, AND N. E. ENGELBRECHT
Unit for Space Physics, Potchefstroom Campus of the North-West University, Potchefstroom, 2520, South Africa; adri.burger@nwu.ac.za
Received 2007 September 18; accepted 2007 October 29





LETTER

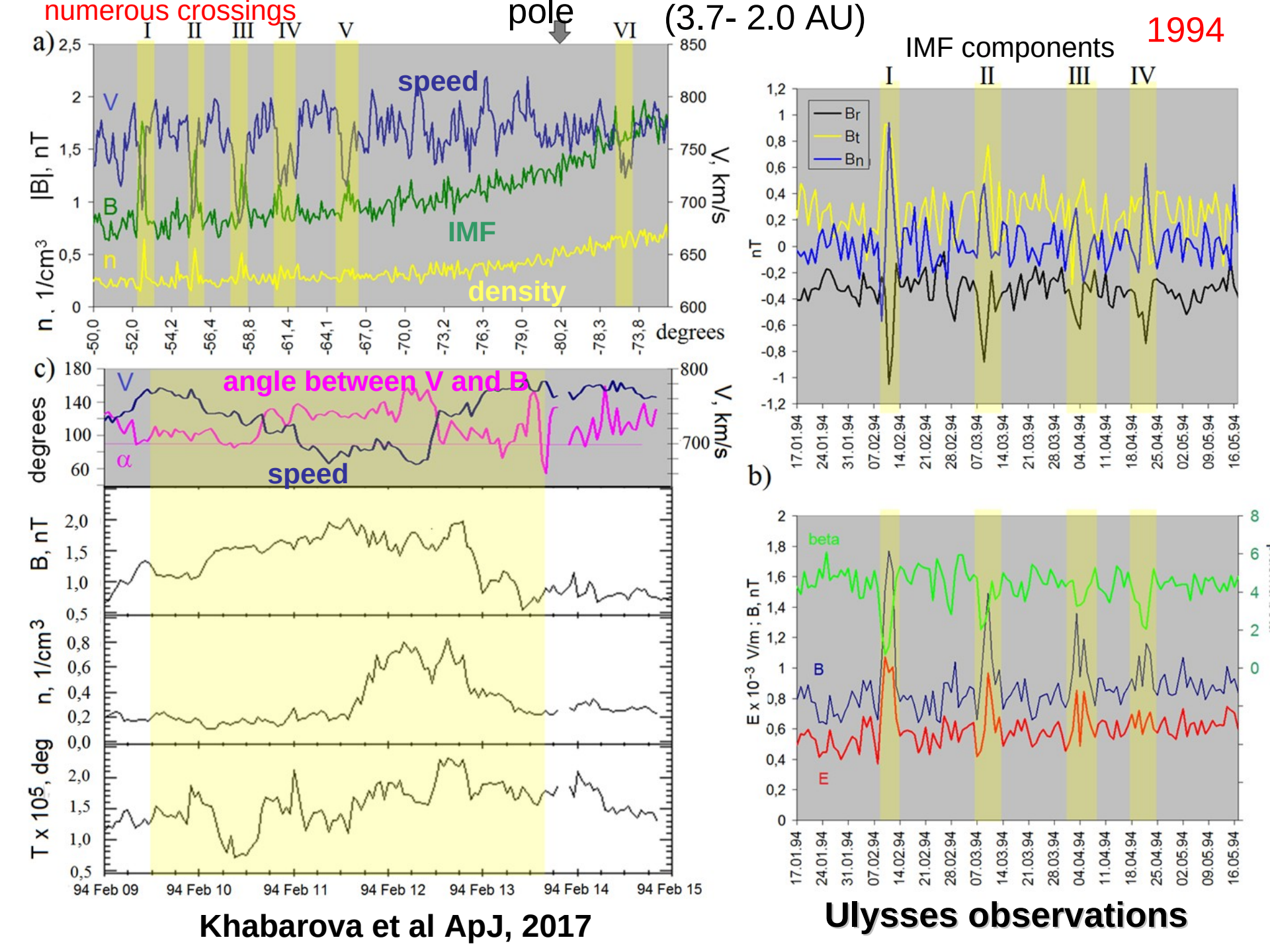
Nature 2012

doi:10.1038/nature11202

Magnetic tornadoes as energy channels into the solar corona

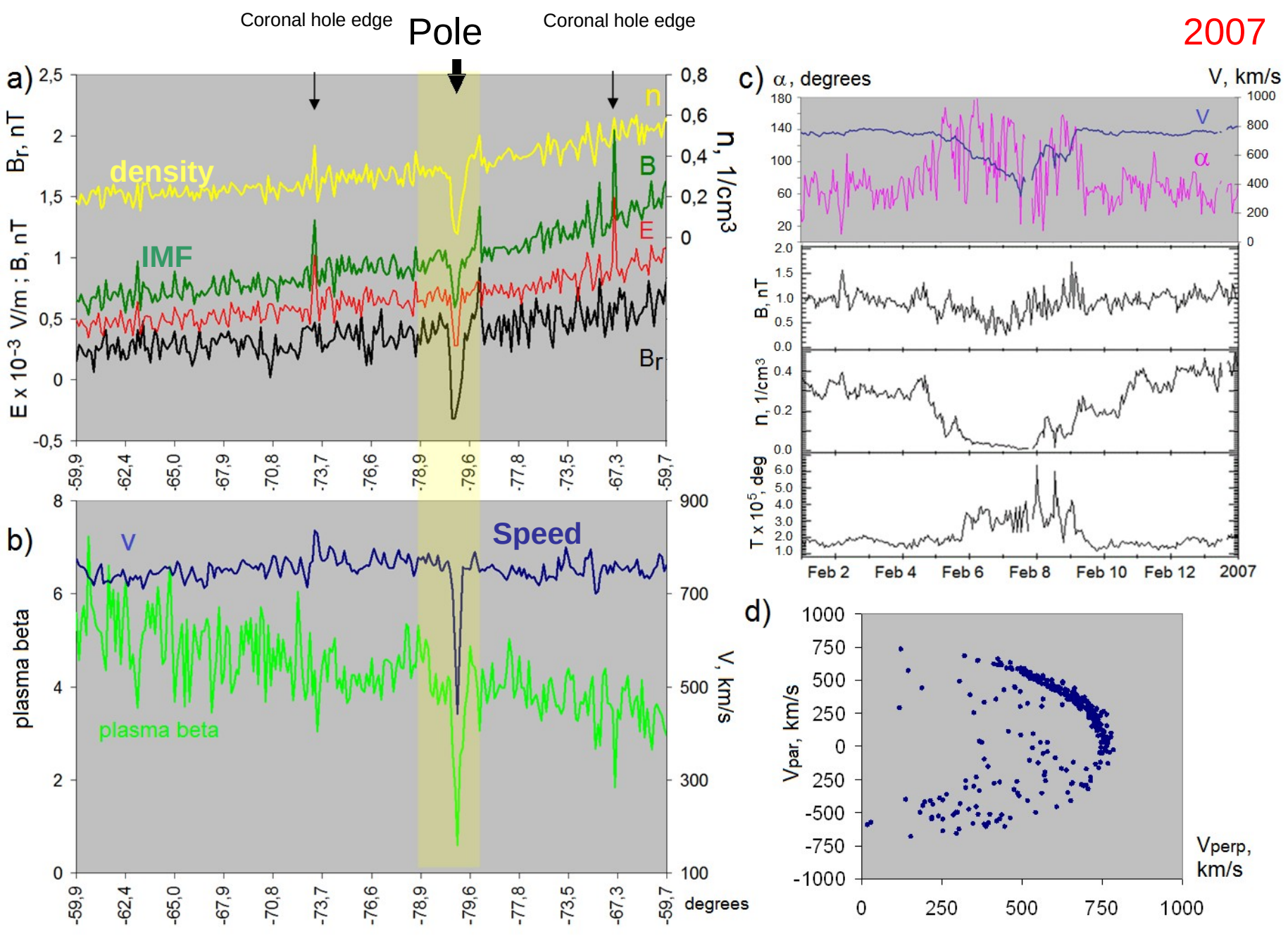
Sven Wedemeyer-Böhm[1,2], Eamon Scullion[1], Oskar Steiner[3], Luc Rouppe van der Voort[1], Jaime de la Cruz Rodriguez[4], Viktor Fedun[5] & Robert Erdélyi[5]

Small-scale magnetic tornadoes can occur at low latitudes

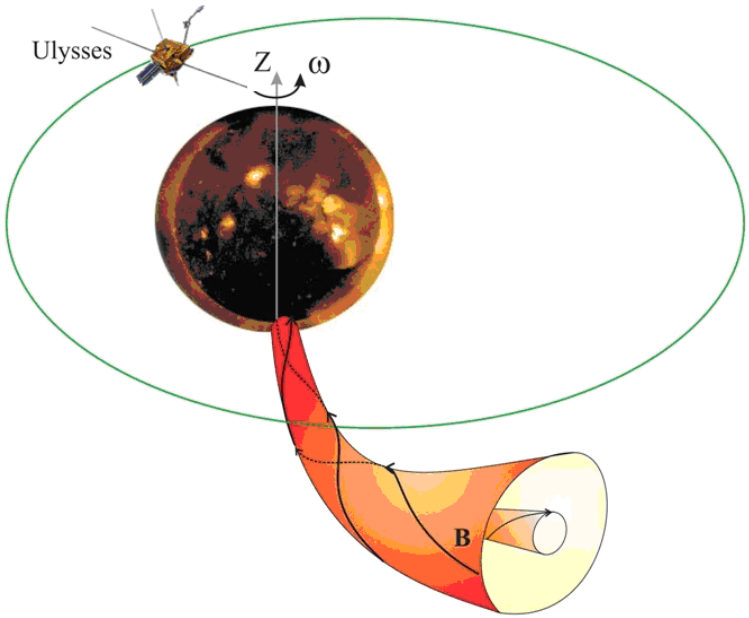


Khabarova et al ApJ, 2017

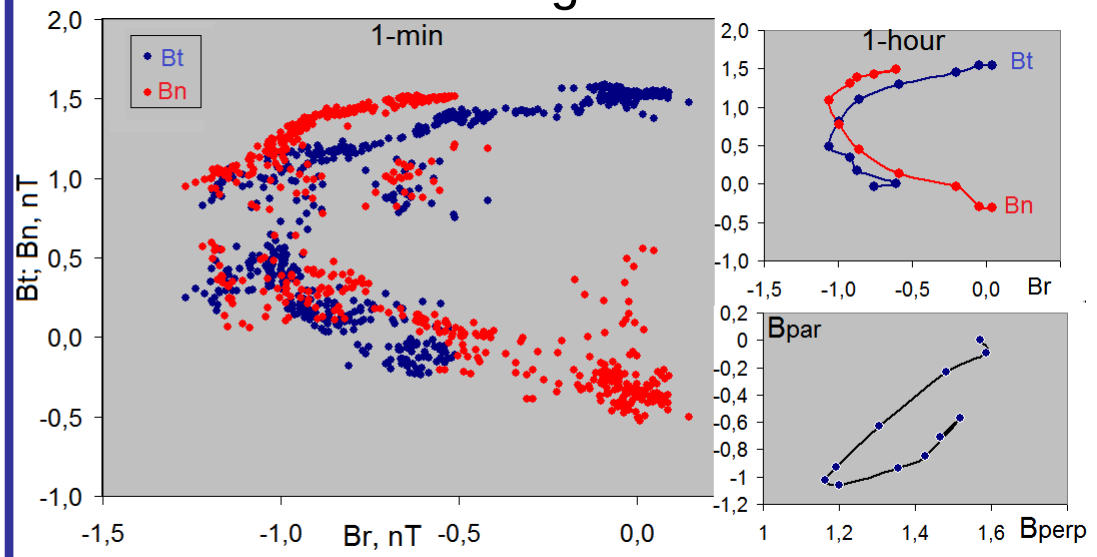
Ulysses observations



Large-scale high-latitude magnetic tornado bounded by a conic current sheet



Rotation of the magnetic field 1994



THE ASTROPHYSICAL JOURNAL, 836:108 (14pp), 2017 February 10

Khabarova et al.

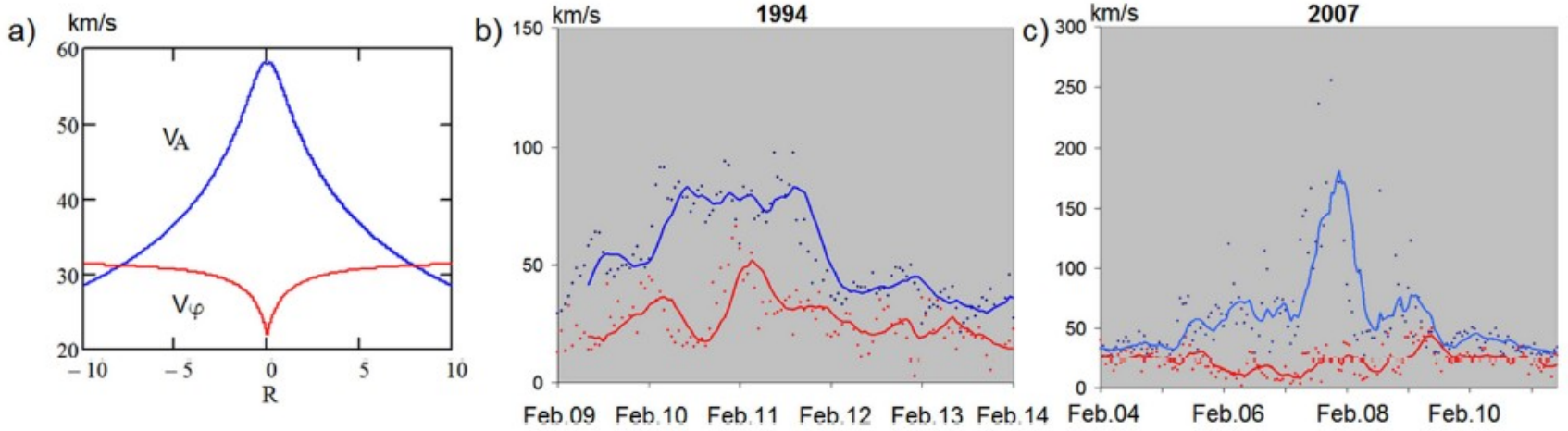


Figure 11. Alfvén (blue) and azimuthal (red) speeds inside and outside the CCS. (a) Modeling; (b), (c) *Ulysses* observations in 1994 and 2007, respectively.

Boundary of the tornado represents an azimuthal Alfven surface

Khabarova et al. ApJ, 2017

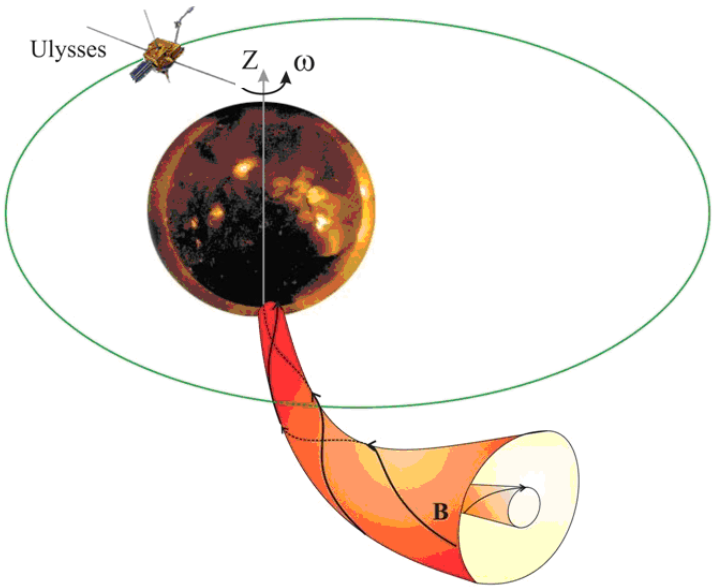
Polar tornado-like structure bounded by a conic/cylindrical current sheet in the polar heliosphere

- **D**rop of **V**

- Very low **plasma beta**

- Embedded current sheets

- Rotation of **B**

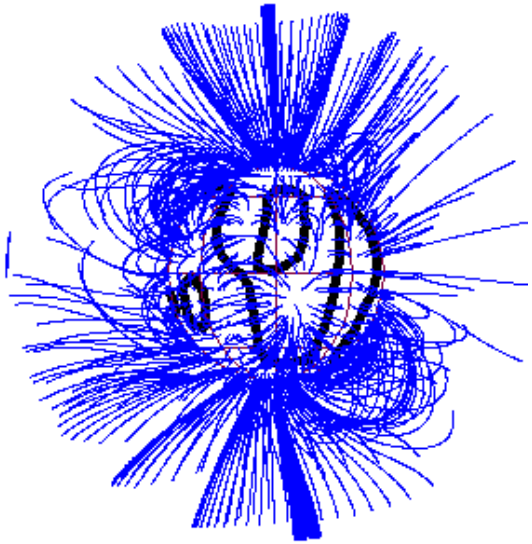


- Diameter at 2-3 AU is ~16 solar radii
- Occurs within the high-speed polar coronal hole
- Rotates with a period of ~30 days
- Solar minimum only

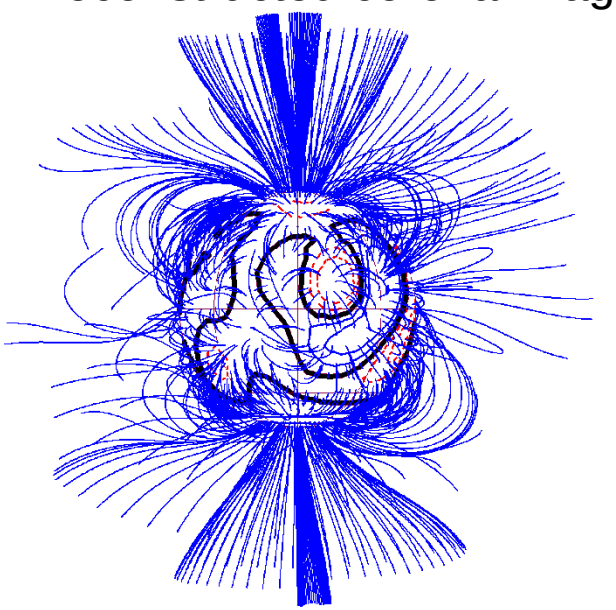
Solar minimum

reconstructed coronal magnetic field

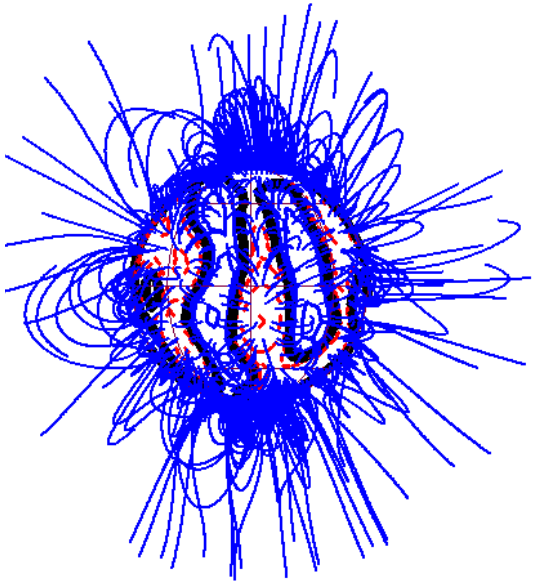
Solar maximum



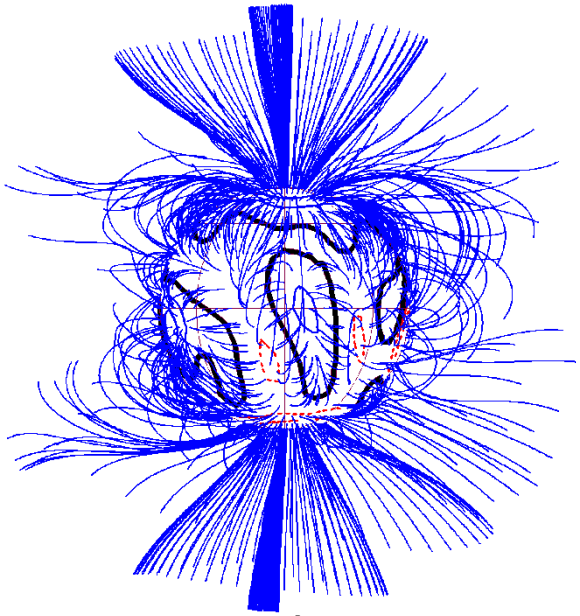
January 1994



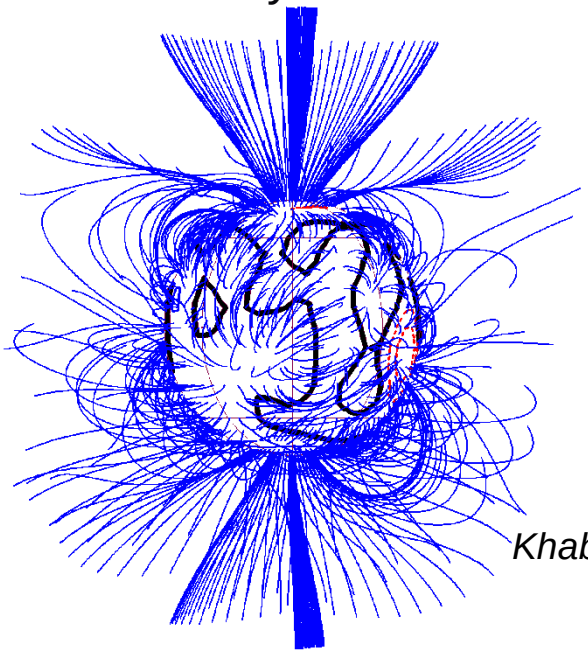
January 2006



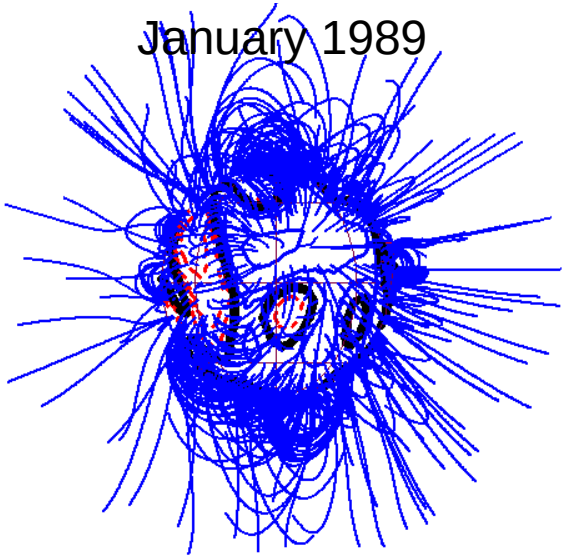
January 1989



September 1994



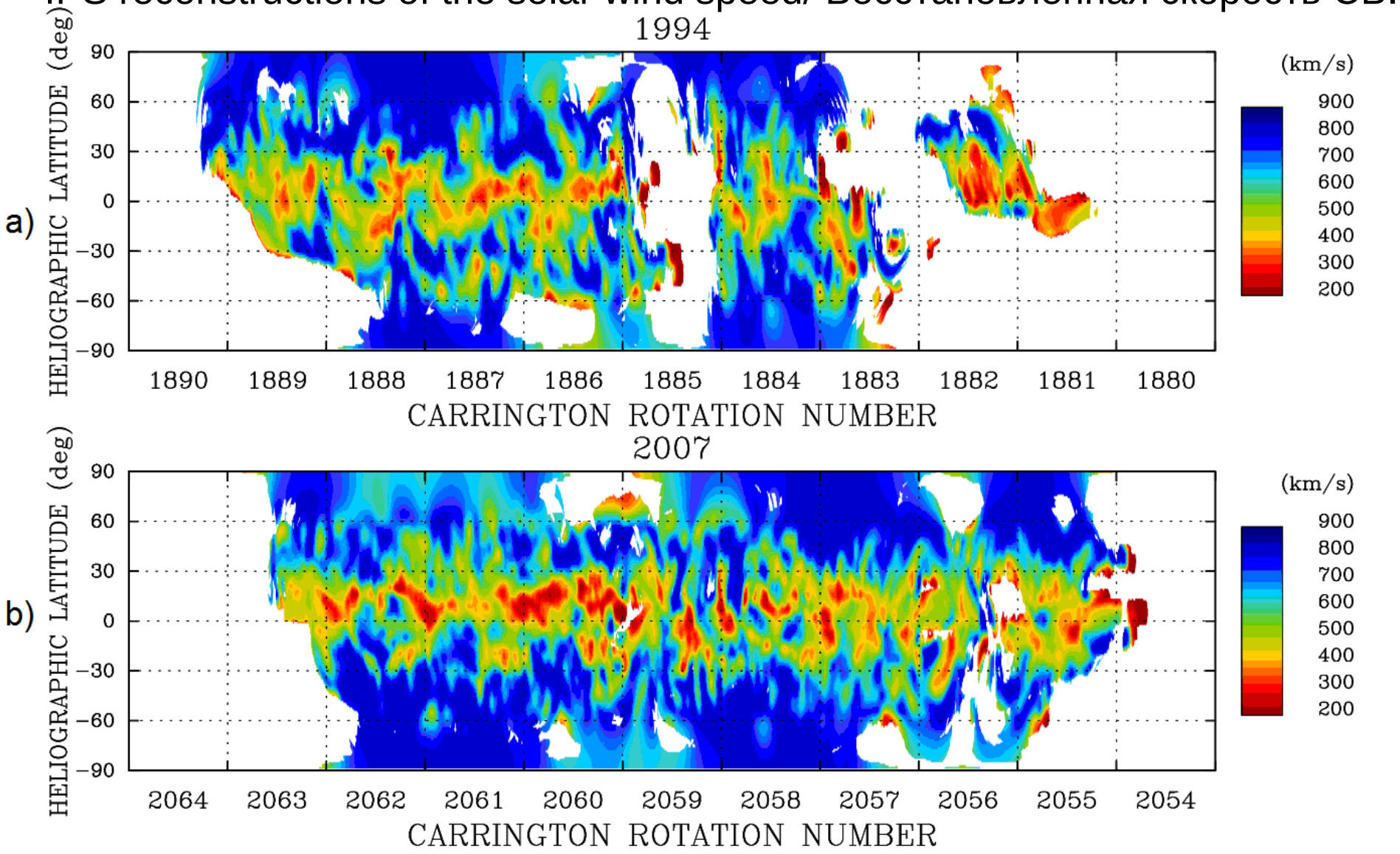
February 2007



Khabarova et al. ApJ, 2017

January 2000

IPS reconstructions of the solar wind speed/ Восстановленная скорость СВ.



Areas of the decreased speed observed at high latitudes via the IPS technique

Khabarova et al. ApJ, 2017

Tokumaru et al. 2017, SolPhys

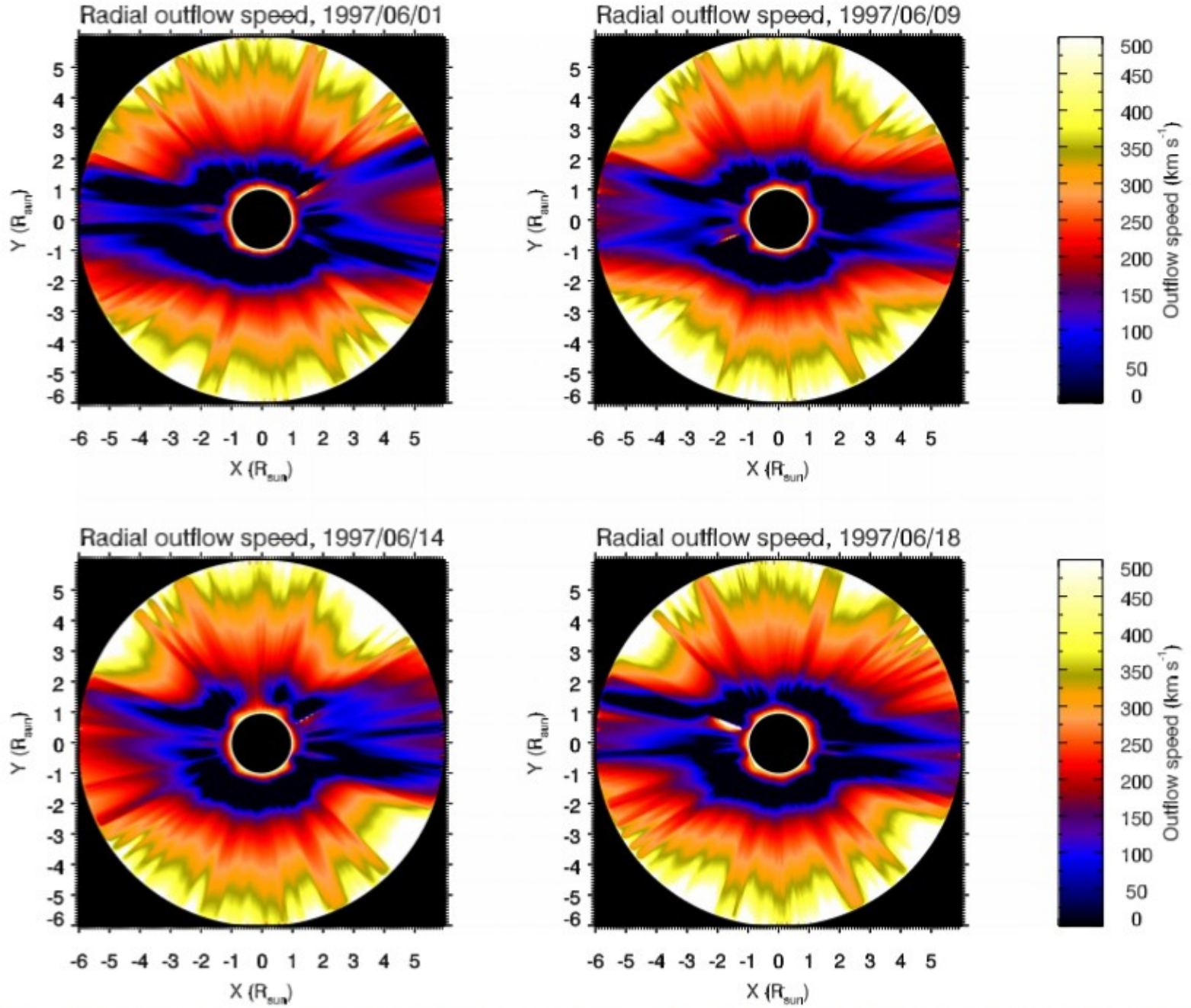


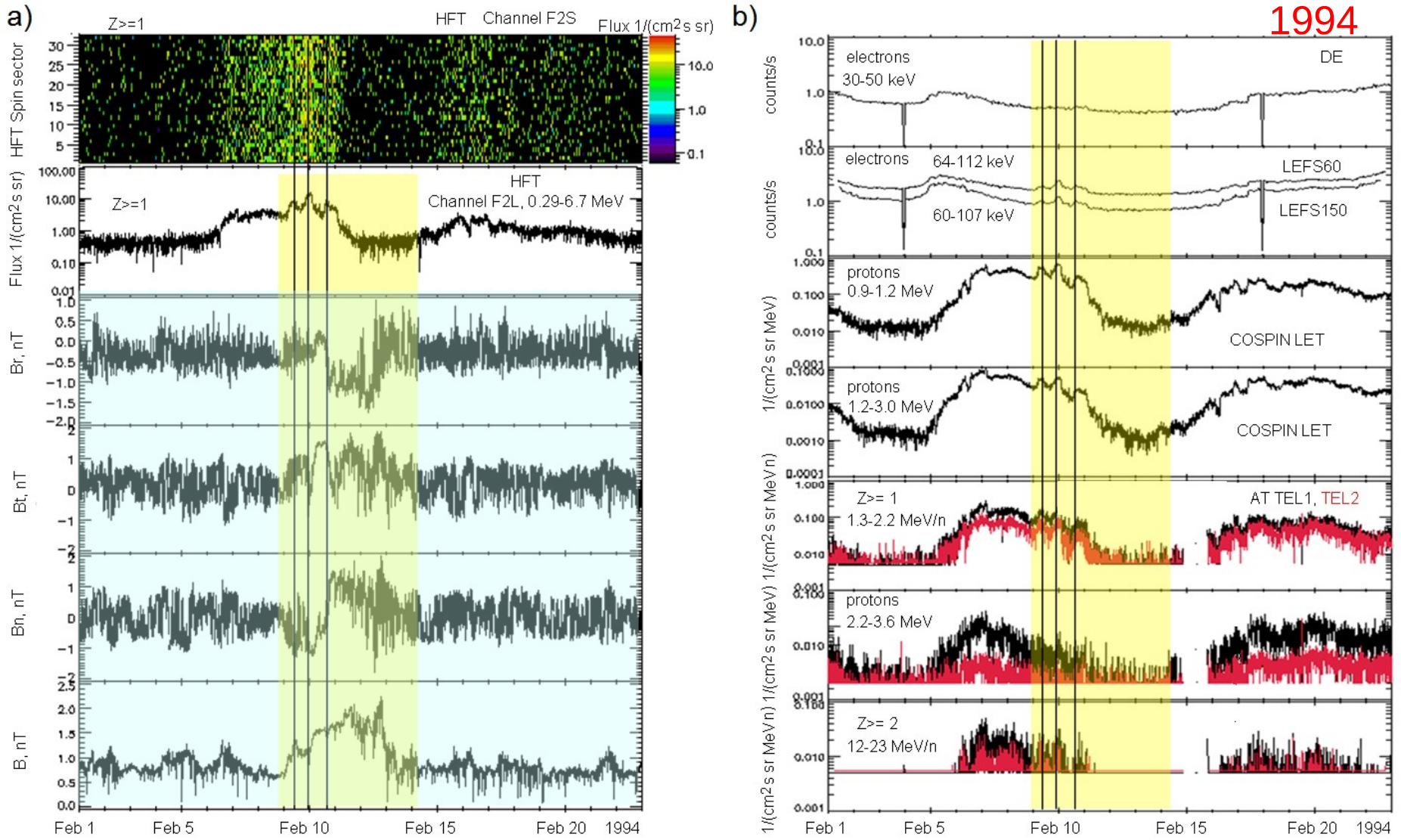
Figure 3. Sequence of radial outflow velocity images as derived from the ratio between VL and UV coronal emissions over four different days of 1997 June (

The existence of long-lived CCSs in the high-latitude solar wind could shed light on how energetic particles reach high latitudes

- There is a problem of the unusual presence of energetic particles of MeV energies at high heliolatitudes, which is still poorly understood (Smith et al. 2001; Sanderson et al. 2003; Lario et al. 2004; Sanderson 2004; Malandraki et al. 2009 etc.).

- Energetic particles of keV-MeV energies should propagate mainly along magnetic field lines, but if a source is an active region at low latitudes, it is not clear how they get to high latitudes. They are detected sometimes at high latitudes with a very short time delay with in-ecliptic observations that cannot correspond to particle diffusion across magnetic field lines.

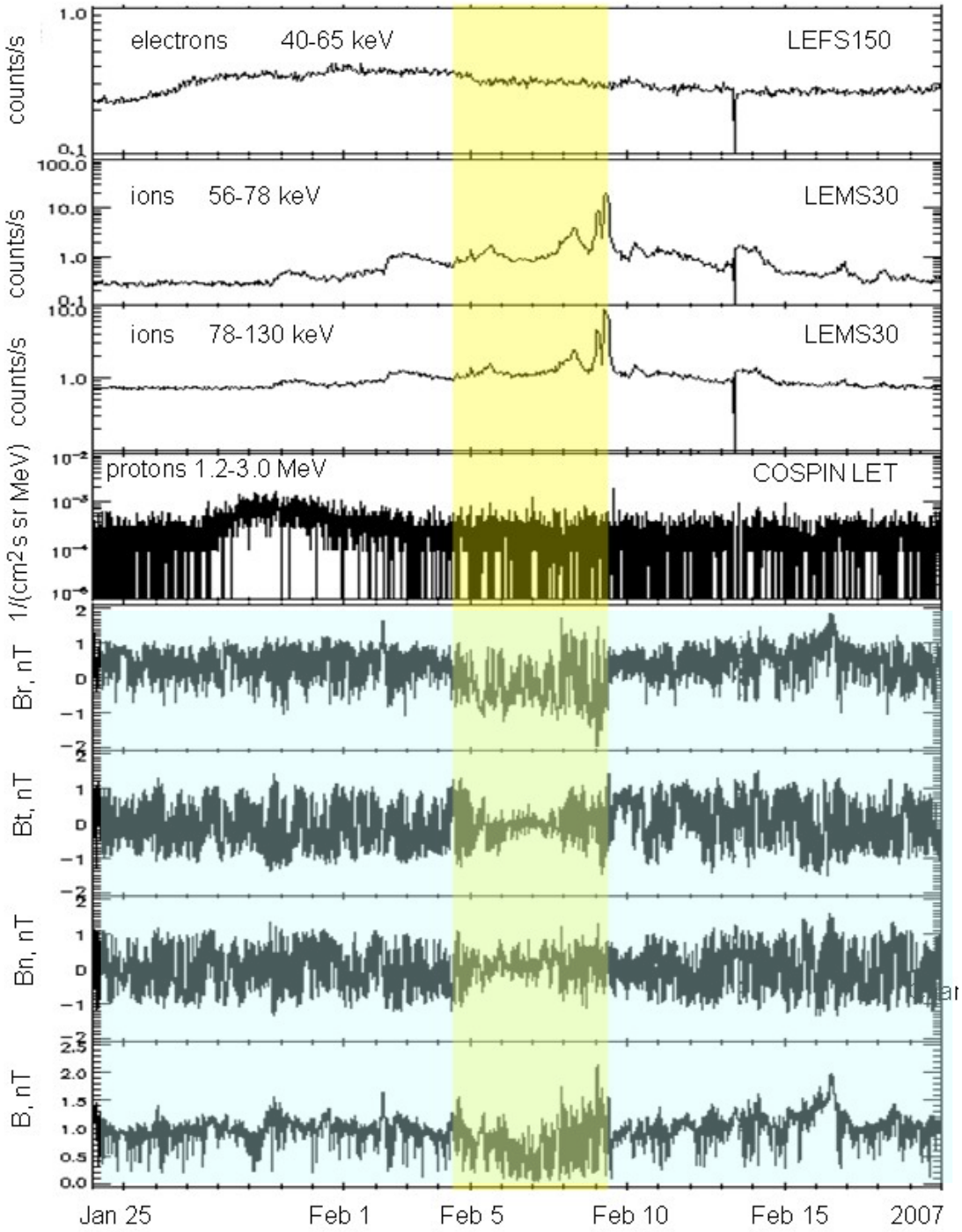
- Observations of keV–MeV energetic particles in polar regions in quiet times of solar minima are also puzzling.



Energetic particle flux enhancements (up to tens MeV) at the borders of the polar conic current sheet in 1994.

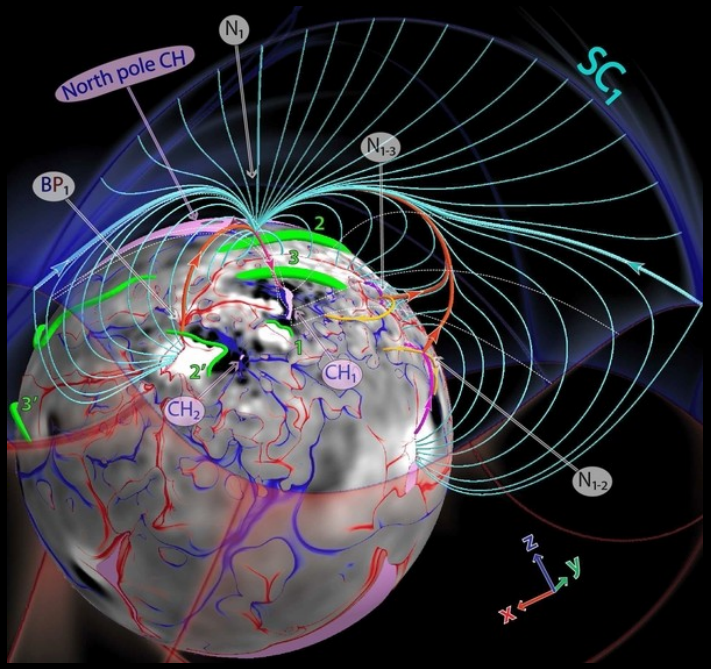
Khabarova et al. ApJ, 2017

2007

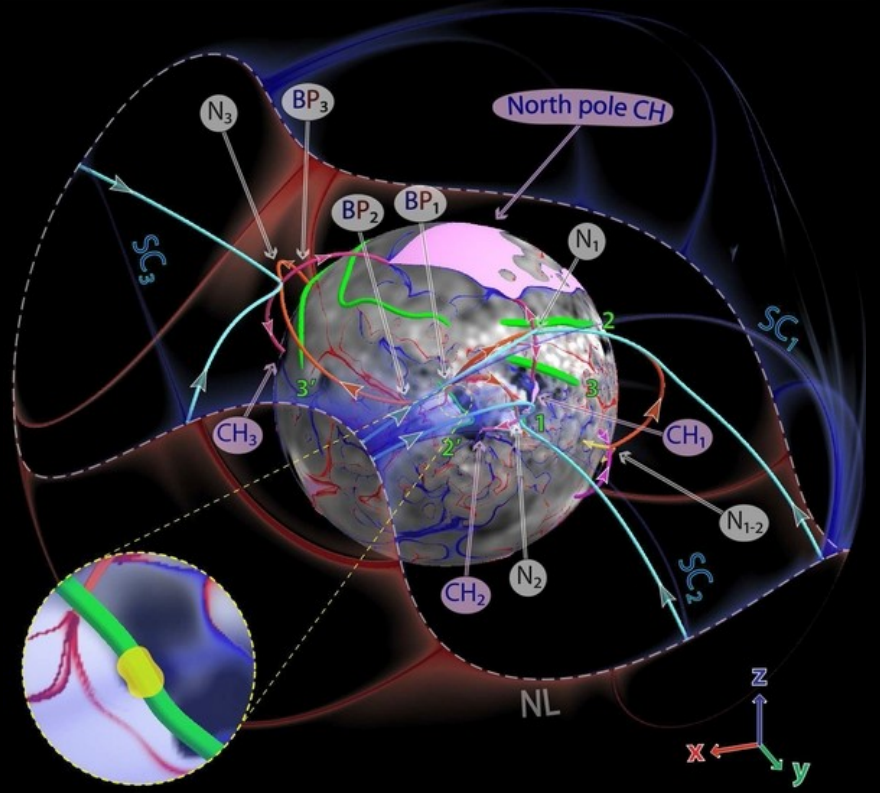


Energetic particle flux enhancements (up to several MeV) at the borders of the conic current sheet in 2007.

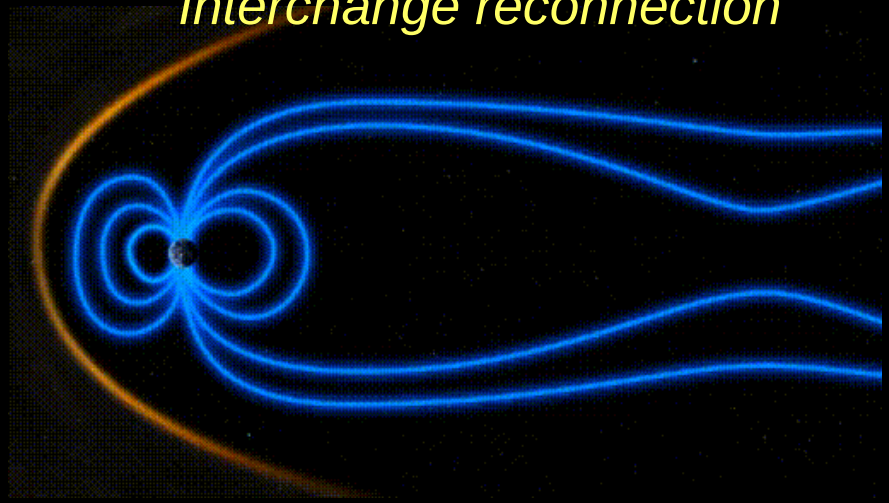
Khabarova et al. ApJ, 2017



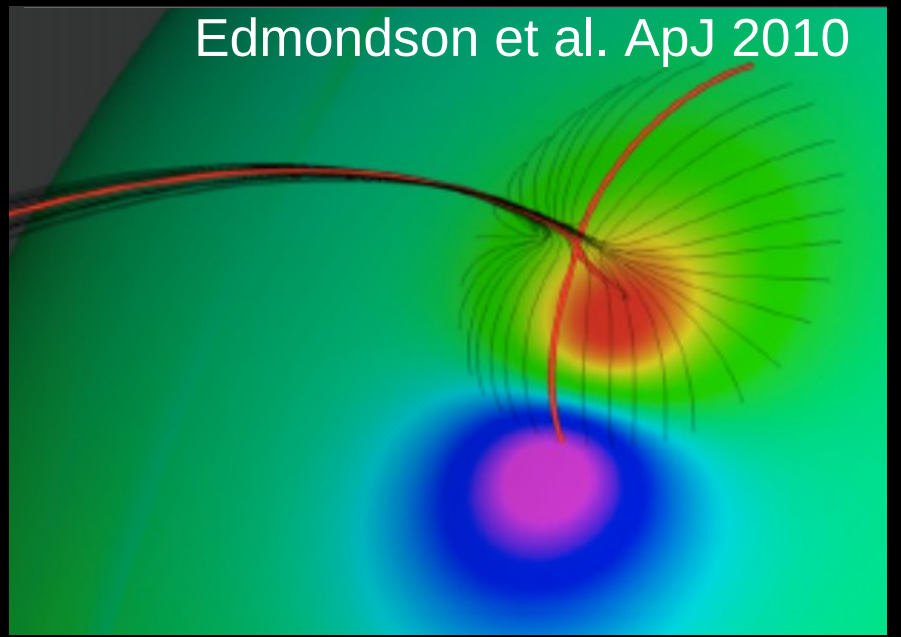
Titov et al. ApJ, 2012



Interchange reconnection

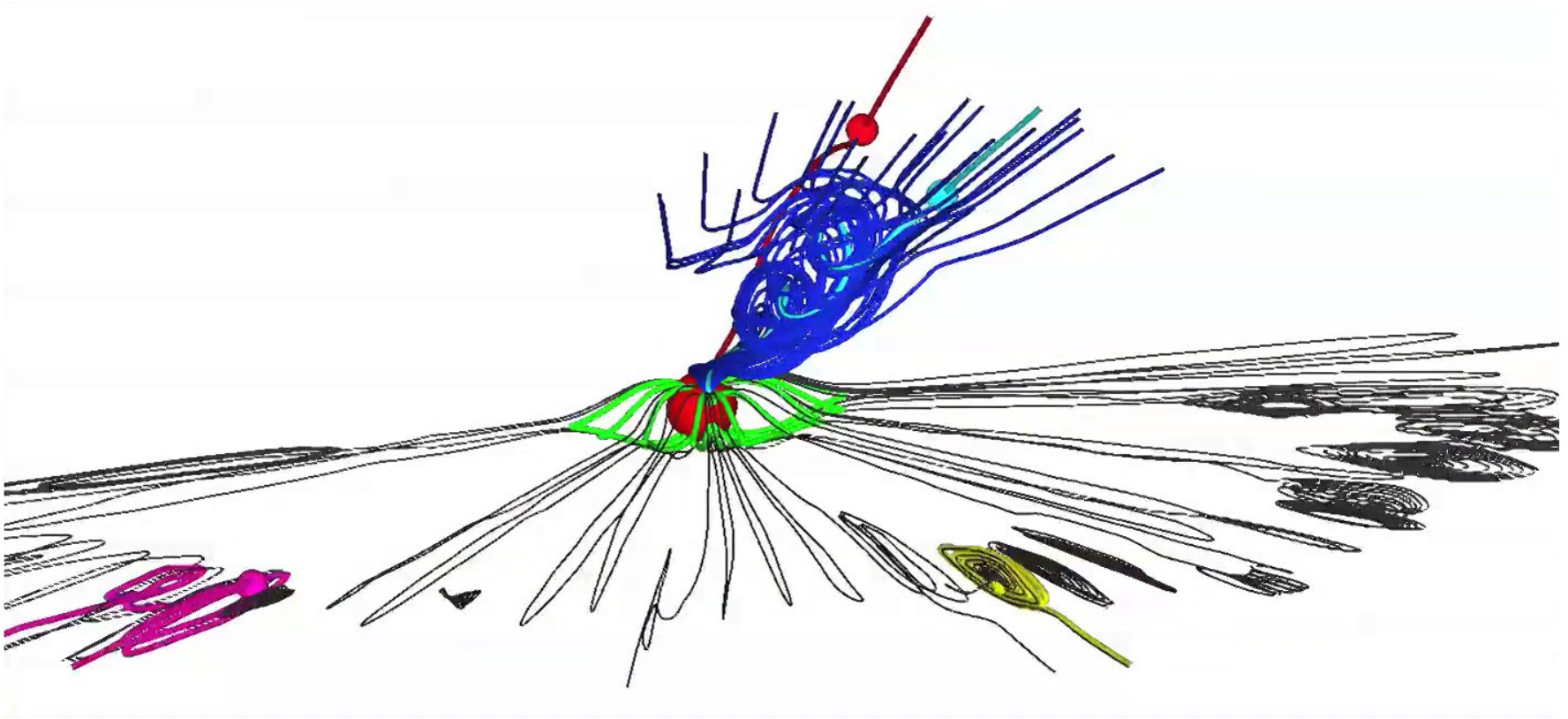


Edmondson et al. ApJ 2010



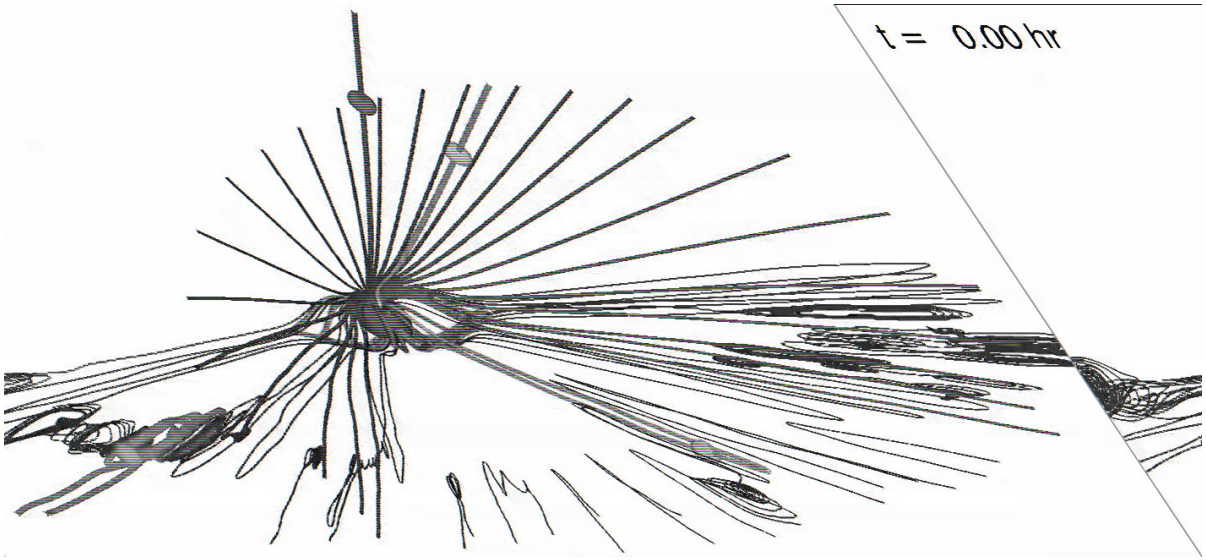
Interchange reconnection

The way to deliver energetic particles from low to high heliolatitudes



3-D modeling of formation of plasmoids/streamer blobs at the HCS at low heliolatitudes and torsional Alfvén waves at high heliolatitudes.

Higginson & Lynch, ApJ, 2018



3-D modeling of formation of plasmoids/streamer blobs at the HCS at low heliolatitudes and torsional Alfvén waves at high heliolatitudes.

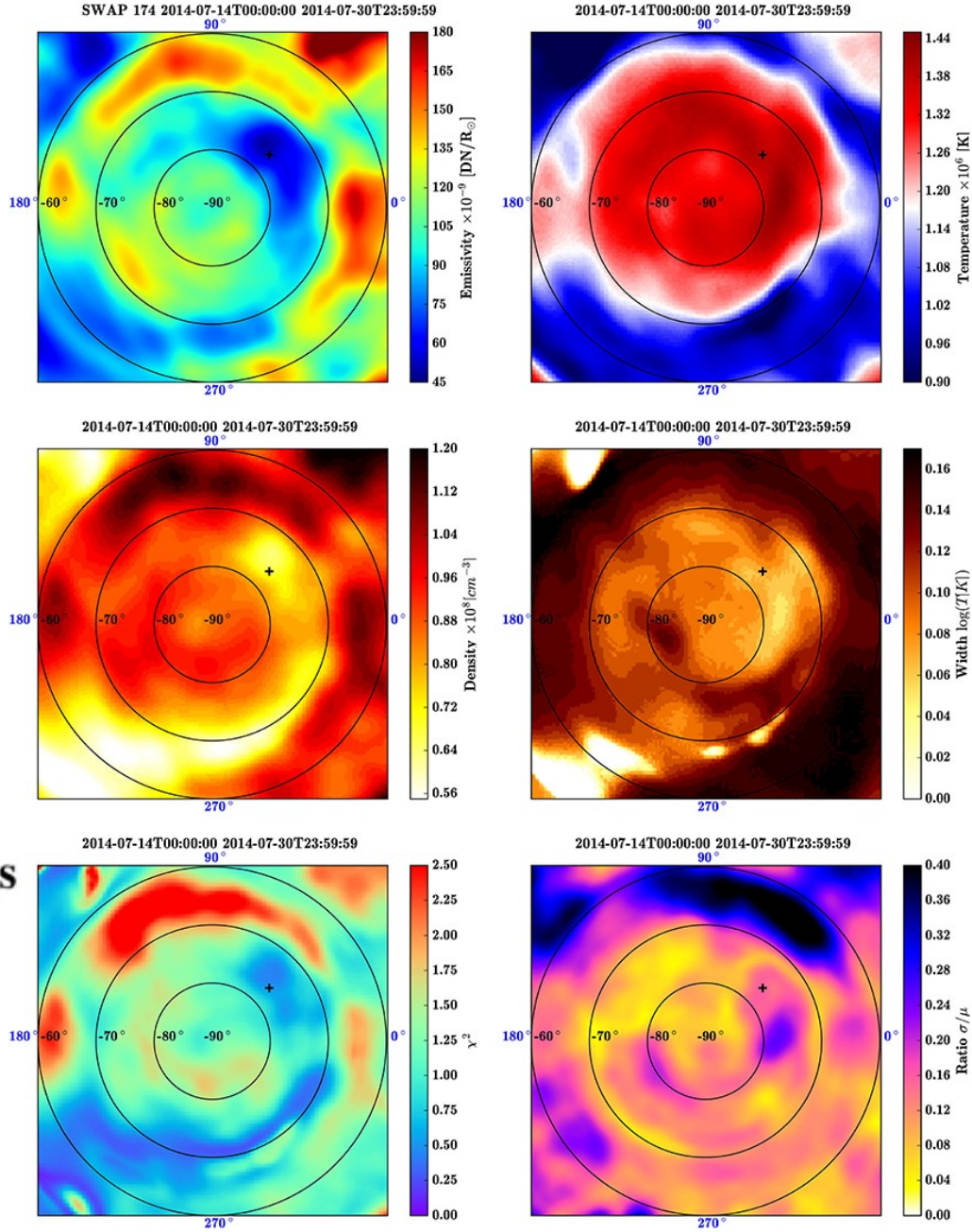
Higginson & Lynch, ApJ, 2018

Front. Astron. Space Sci., 03 May 2016 |
https://doi.org/10.3389/fspas.2016.00014

Lifecycle of a Large-Scale Polar Coronal Pseudostreamer/Cavity System

Chloé Guennou[1*], Laurel A. Rachmeler[2], Daniel B. Seaton[2,3,4] and Frédéric Auchère[5]

PROBA2/SWAP and
SDO/AIA EUV imagers



Astron. Astrophys. 361, 349–358 (2000)

On the origin of polar radio brightenings at short millimeter wavelengths

S. Pohjolainen[1,2,⋆]

Southern polar field reversal as revealed by a pseudostreamer

Laurel A Rachmeler, Royal Observatory of Belgium; **Chloé Guennou**, Instituto de Astrofísica de Canarias;
Daniel B Seaton, Royal Observatory of Belgium; **Frédéric Auchère**, Institut d'Astrophysique Spatiale (CNRS)

We tracked the formation, evolution, and disappearance of a pseudostreamer to determine when Solar Cycle 24 reversed polarity in the south.

The corona and heliosphere reversed polarity in February 2014.

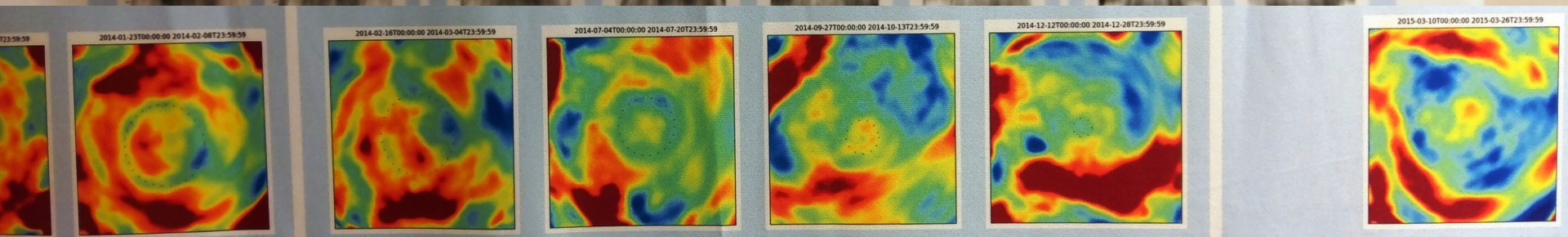
The photosphere reversed polarity in February 2015, one year later.

SWAP

SWAP is a solar EUV imager (17.4 nm) onboard ESA's PROBA2 satellite, which is in a sun-synchronous dawn-dusk orbit. SWAP has been observing the sun since 2010. Data and movies can be found at proba2.oma.be.

Tomography

We used tomography to determine the 3D EUV emissivity of the structure. We applied the TomograPy inversion code to SWAP observations using 17-day observation window for each reconstruction. AIA DEMT analysis on the pseudostreamer is in progress.



Tomographic inversion of the corona as seen by SWAP. The images of the emissivity of the south pole at a height of 1.05 Rsun are plotted in a Gnomonic projection (range of ±45 degrees). Red is high and blue is low emissivity. The approximate location of the neutral line is shown by the dotted circles.

polar coronal hole

K. Chandrashekhar et al.: Characteristics of polar coronal hole jets A&A, 2018

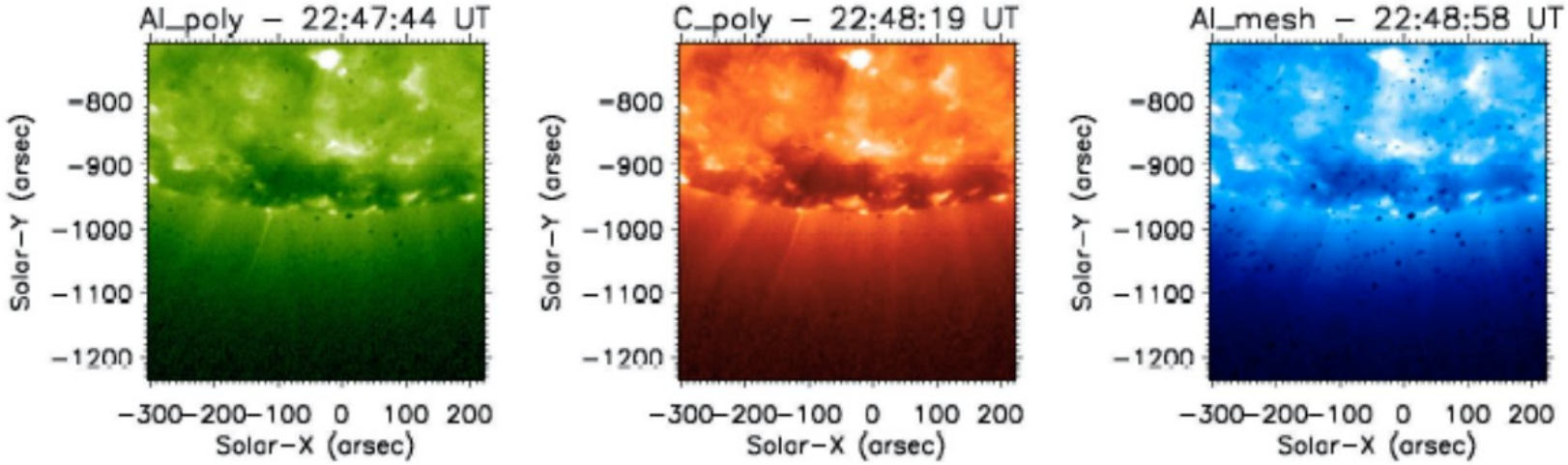


Fig. 2. Example of an XRT image sequence acquired on July 1, 2008 around 22:48 UT during polar-jet event 2 with the Al_poly (left), C_poly (middle), and Al_mesh (right) filters (see also the movie 2).

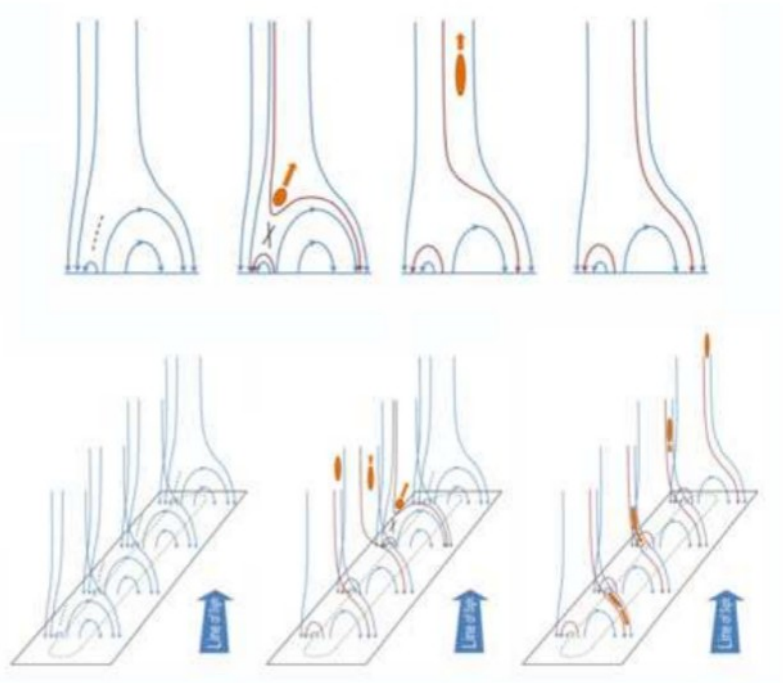


Fig. 11. Top: sequence of cartoons illustrating the occurrence of a single reconnection event in one of the pseudo-streamer-like arcades considered here (blue field lines) leading to a classical standard jet, see Figure 1 of Moore et al. (2010). The interchange reconnection occurs in the neutral current sheet (dashed line), leading to the formation of newly open and closed (red) field lines and to the ejection of a plasma packet along the open field lines.. Bottom: proposed interpretation of the observed jet observational properties. In particular, the drift is ascribed to many small-scale reconnections occur sequentially along a spine inclined with respect to the line of sight (see text).

See also Karpen et al. ApJ, 2017; Tian et al. ApJ, 2017

Nisticò et al.: N-S asymmetry of polar jet deflection A&A, 2015

polar coronal hole jets

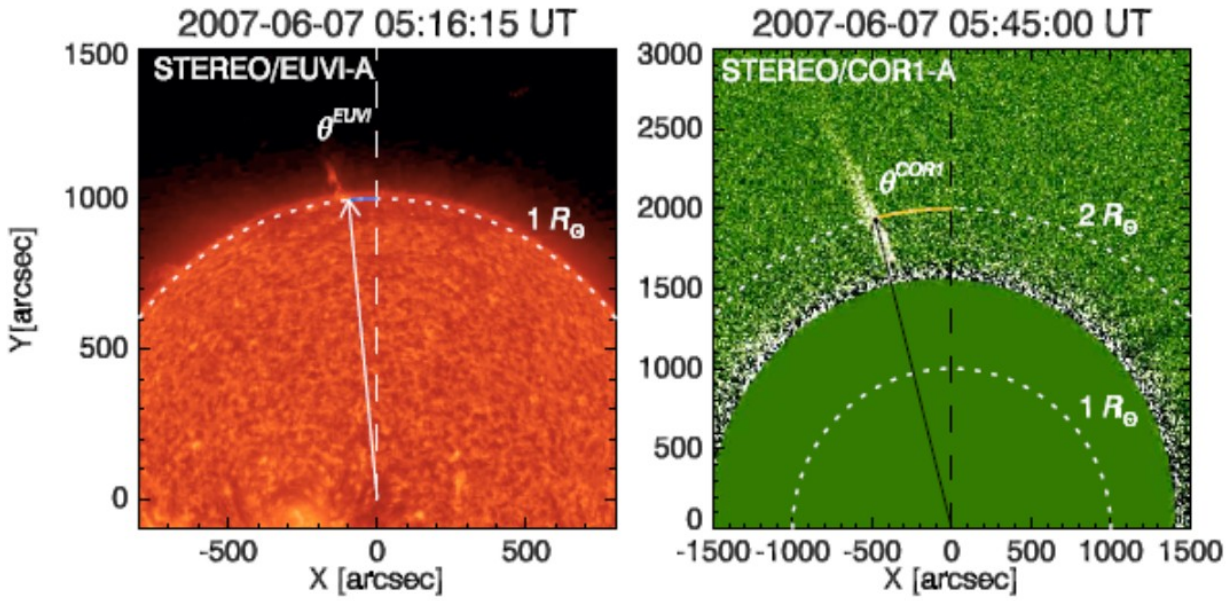
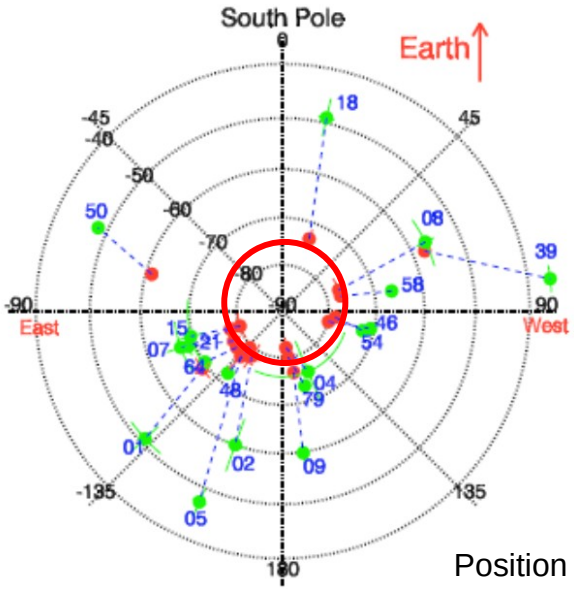


Fig. 1. Image of the Sun at 304 Å (left) from EUVI and from COR1 in white light (right). PAs are from the north solar axis in the counterclockwise direction (see the reference frame overlapped on the images) at 1 $R_\odot$ in the EUVI FOV and at 2 $R_\odot$ in the COR1 FOV.



Rotating root of a conic current sheet serves as a foot-circle for reconnection-driven polar jets inside polar coronal holes. This phenomenon naturally explains the occurrence of energetic particles of keV-MeV energies observed by Ulysses at edges of CCSs in the solar wind.

Position of jets at 1 $R_\odot$ are in red, at 2 $R_\odot$ in green, respectively

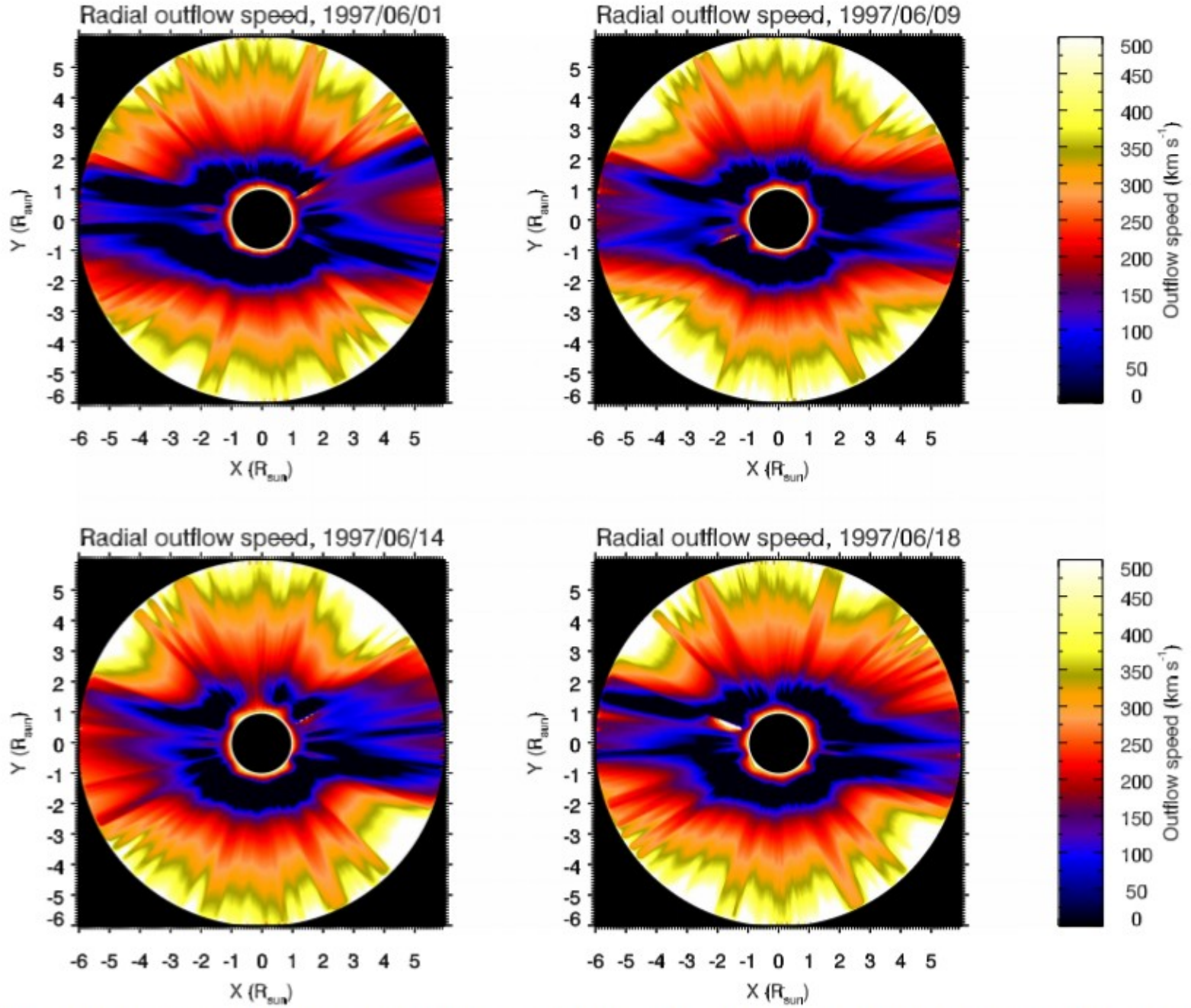
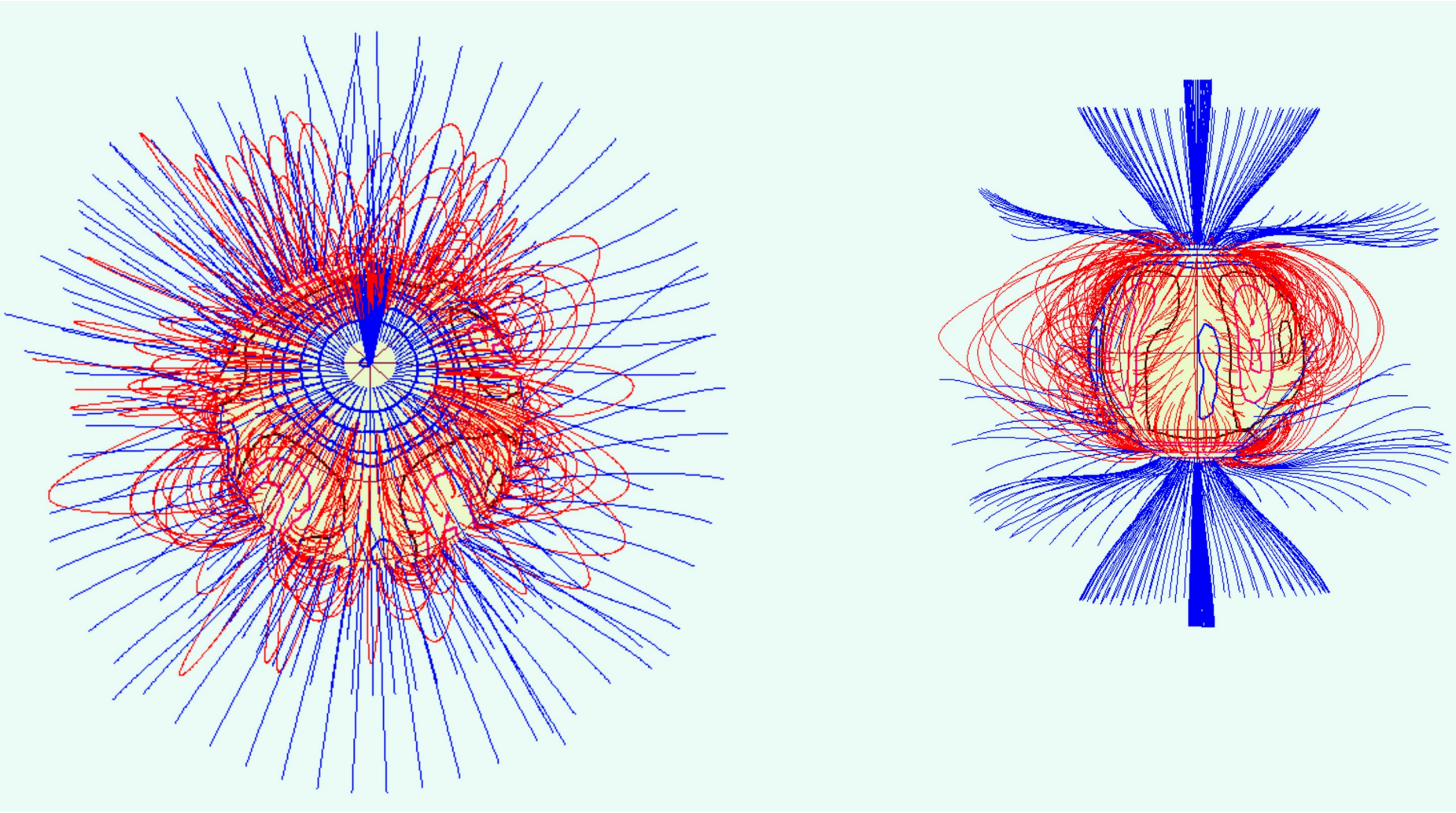
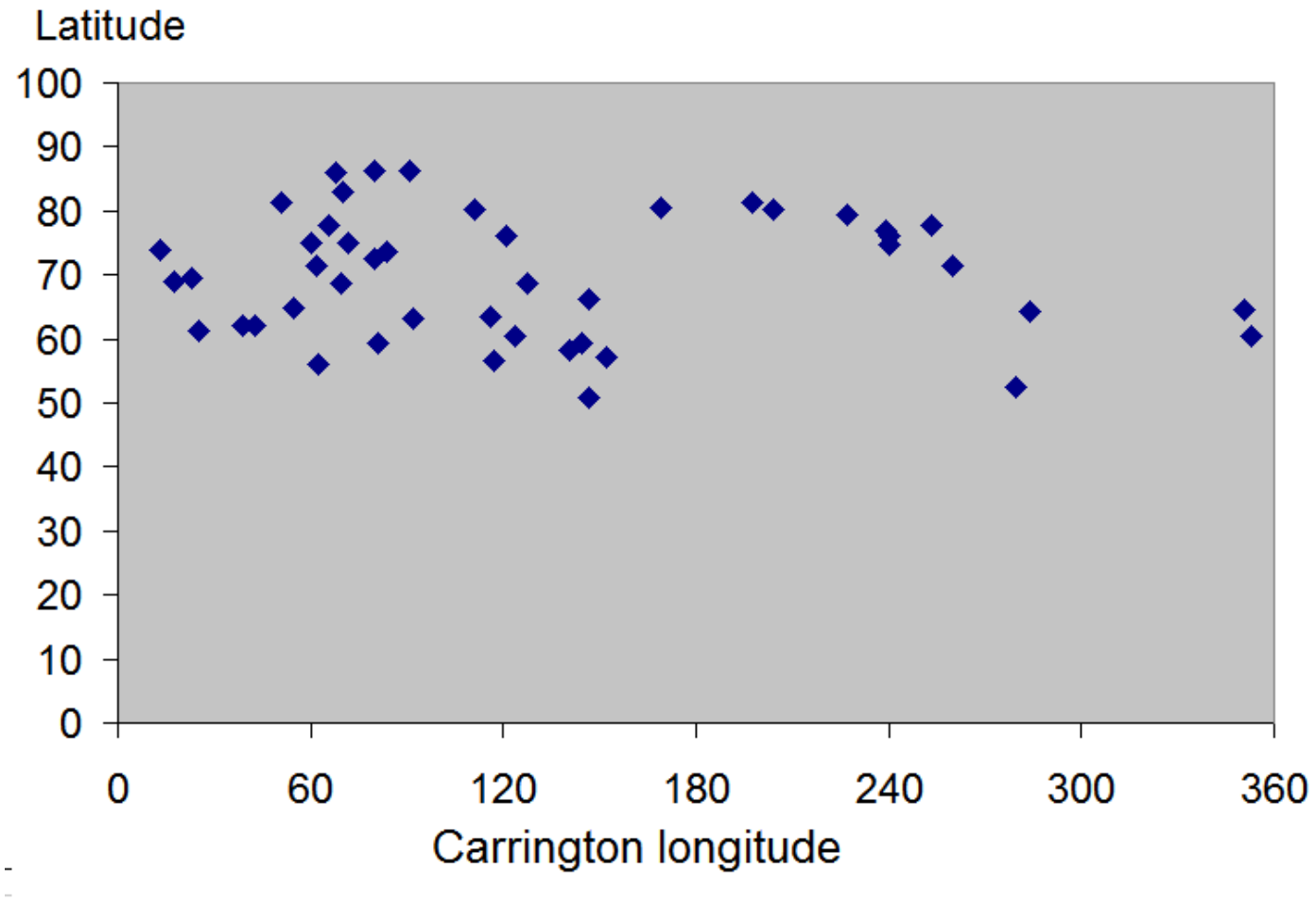


Figure 3. Sequence of radial outflow velocity images as derived from the ratio between VL and UV coronal emissions over four different days of 1997 June (

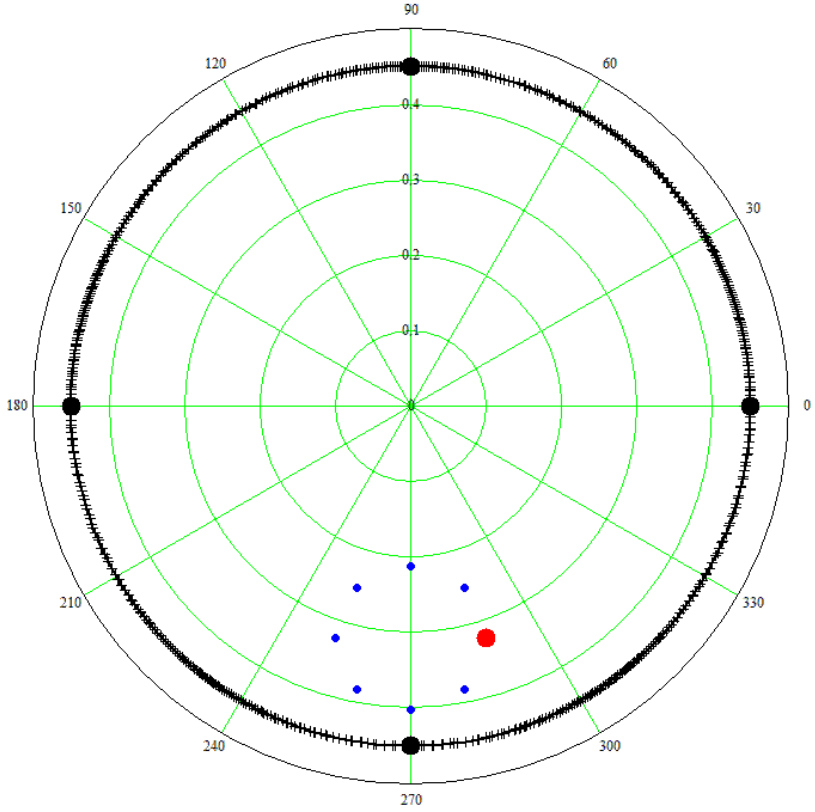


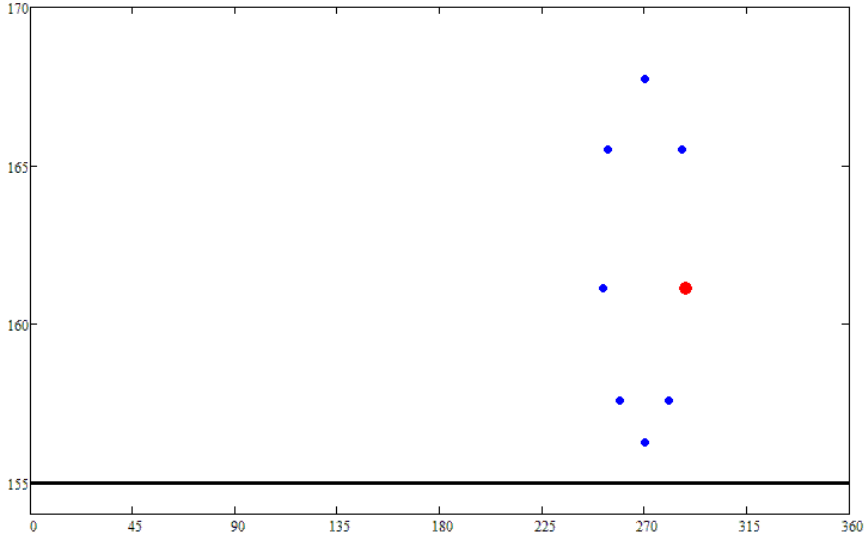
Reconstruction of the magnetic field lines in the corona (12 June 1997)

Location of reconnection-driven polar jets
inside the North coronal hole in June 1997

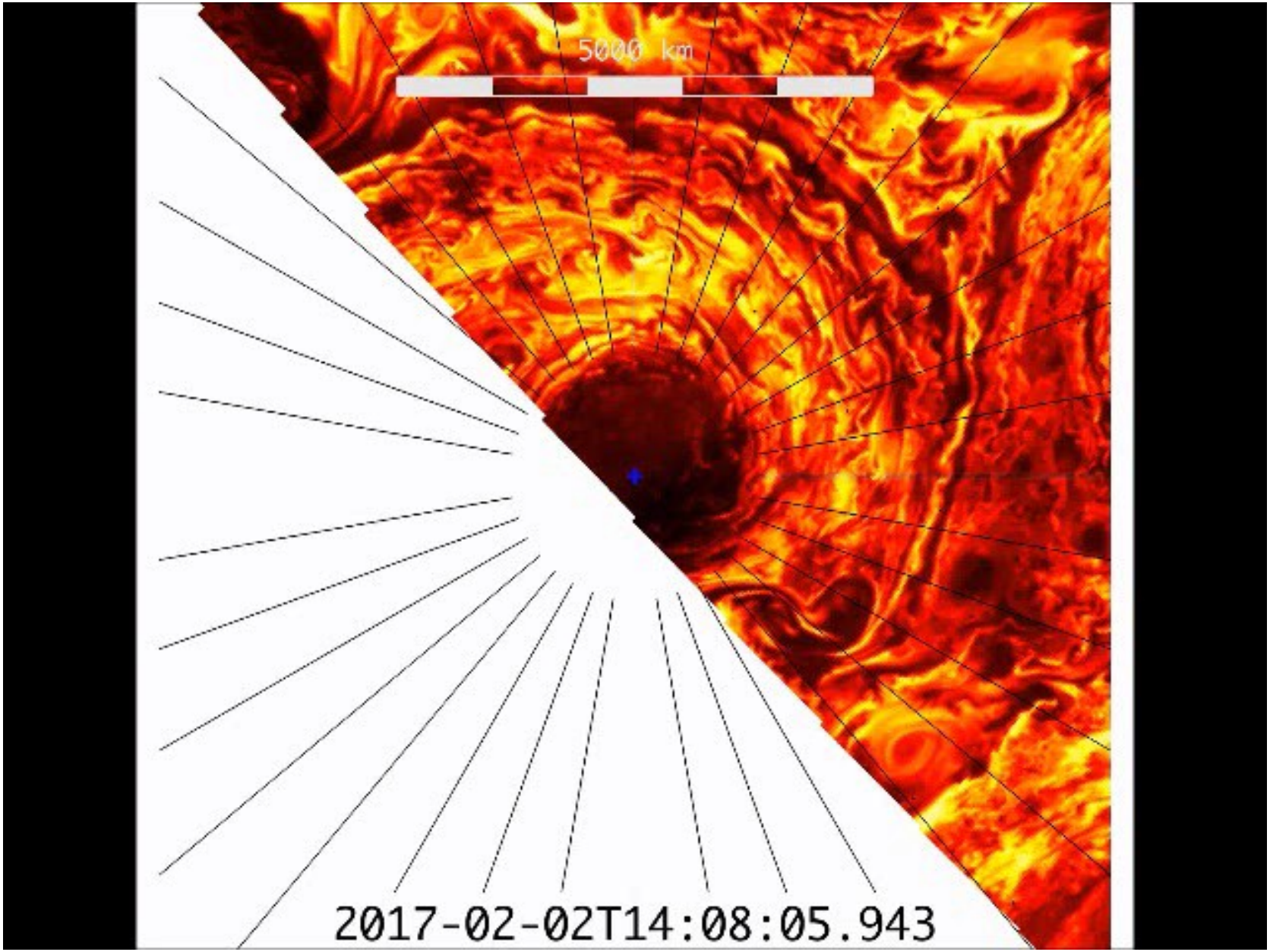


Location of polar jets is identified by Hebe Cremades and Luciano Merenda


90
120
60
150
30
0.4
0.3
0.2
0.1
180
0
210
330
240
300
270


170
165
160
155
0
45
90
135
180
225
270
315
360

Similarities with Jupiter



Juno observations

CONCLUSIONS

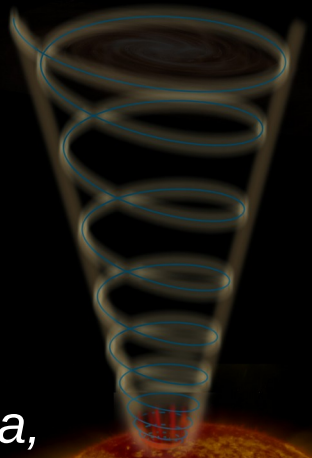
- Polar multi-structural magnetic tornados exist!

- Those boundaries represent conic current sheets (CCSs) that may be observed at the Sun as neutral lines rooting magnetic reconnection driven polar jets.

- CCSs rotate faster than the surrounding coronal hole.

- In the corona, CCSs are seen as cones of magnetic field lines. The speed and the plasma beta decrease inside CCSs,.

- CCSs represent (i) sources of local particle acceleration via magnetic reconnection in the solar wind, and (ii) magnetic channels for energetic particles accelerated at the Sun.



- Khabarova, Malova, Kislov, Zelenyi, Obridko, Kharshiladze, Tokumaru, Sokół, Grzedzielski, Fujiki,
High-latitude conic current sheets in the solar wind,
The Astrophysical Journal, 836, 108, 1, 2017

- Khabarova, Cremades, Malandraki, Kislov, Malova, Obridko, Bemporad, Zelenyi, Kuznetsov, Kharshiladze,
2021, in preparation