Modeling interplanetary coronal mass ejections observed by STEREO and Wind

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In collaboration with

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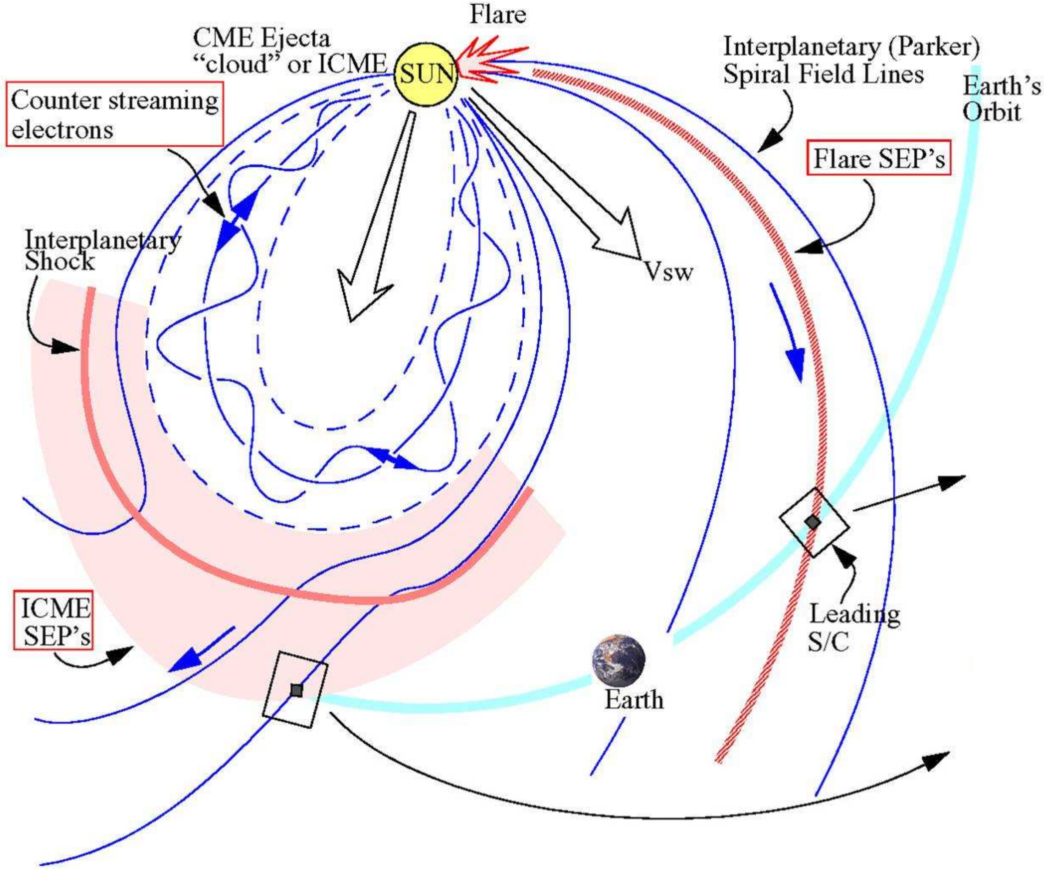
MCs /MFRs/ ICMEs

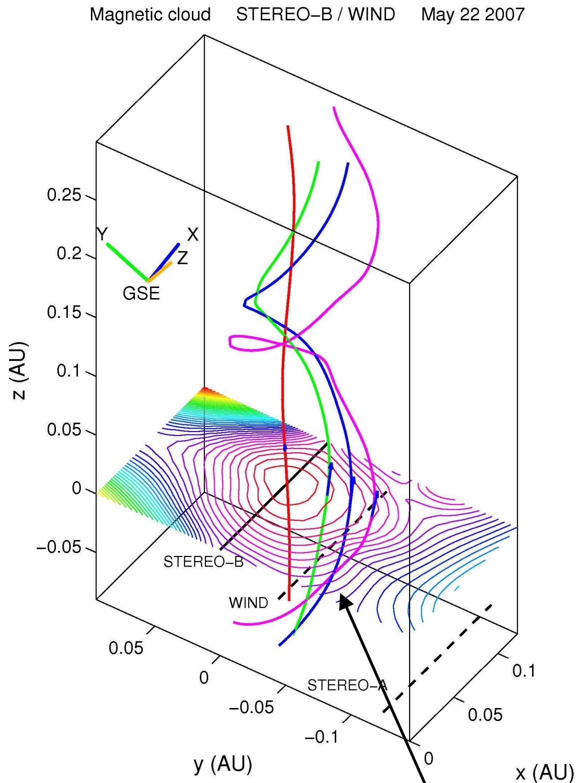
- Magnetic clouds – strong **B**, smoothly rotating **B**, low Tp
- Magnetic flux ropes – lack low Tp
- ICMEs – **B** rotation not clear

- we concentrate on **large scale** MCs and MFRs
- susceptible for modeling -> additional parameters

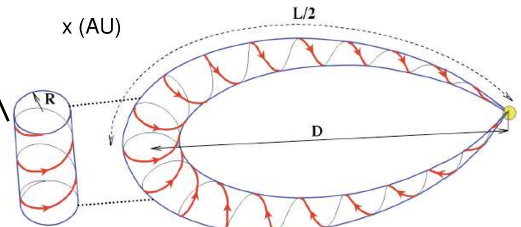


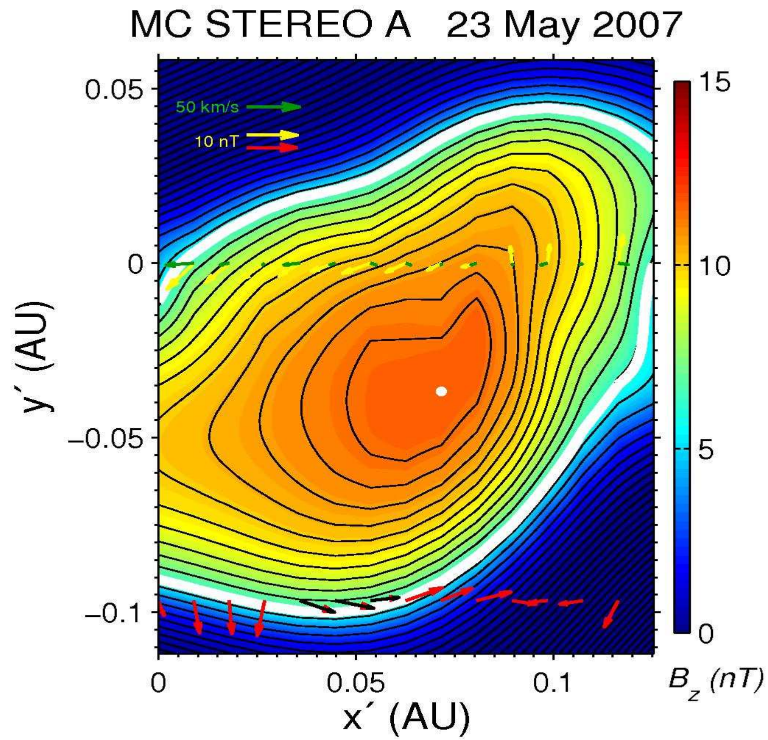
Work so far – May 2007

- Multi-spacecraft modeling
  2 events (22 + 23 May 2007) -> shape of the MC cross section
  see Kilpua et al. 2009, Sol. Phys.



Möstl et al., 2009, JGR



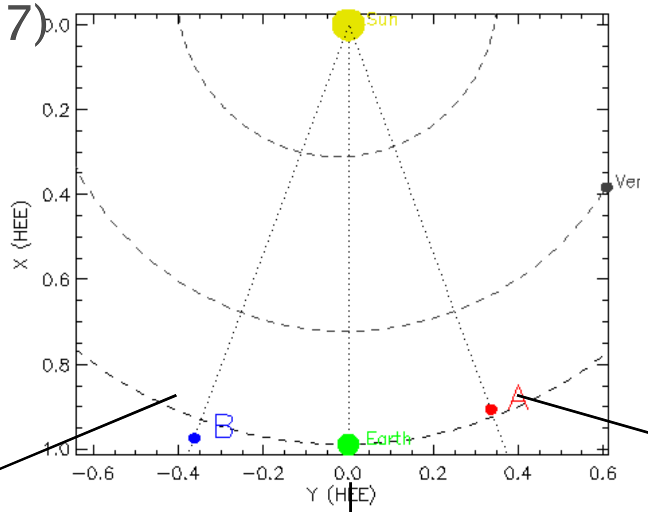


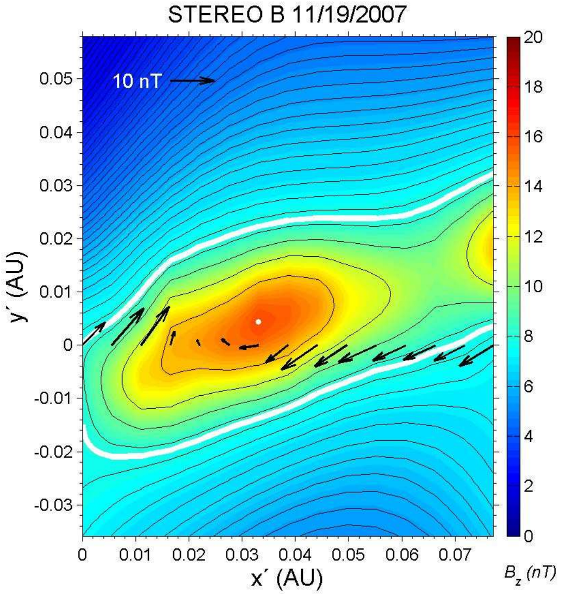
Möstl et al., 2009, Solar physics

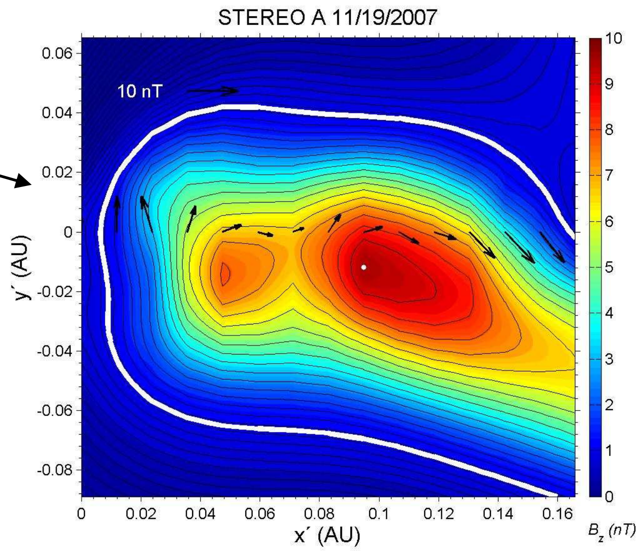
Sketch by Demoulin / Dasso

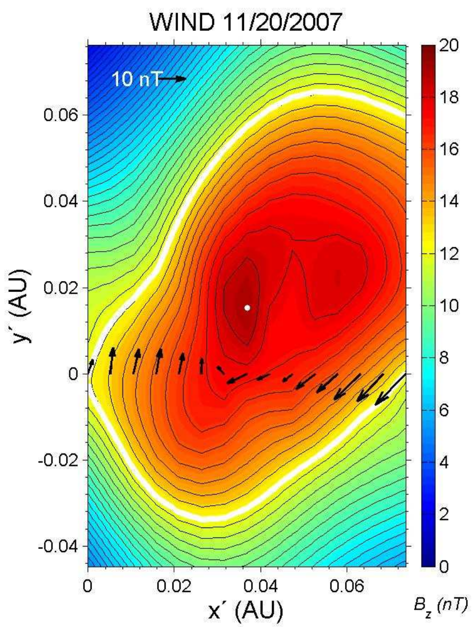
20 Nov 2007

- 1 event (20 Nov 2007) -> shape of the MC *along* the axis



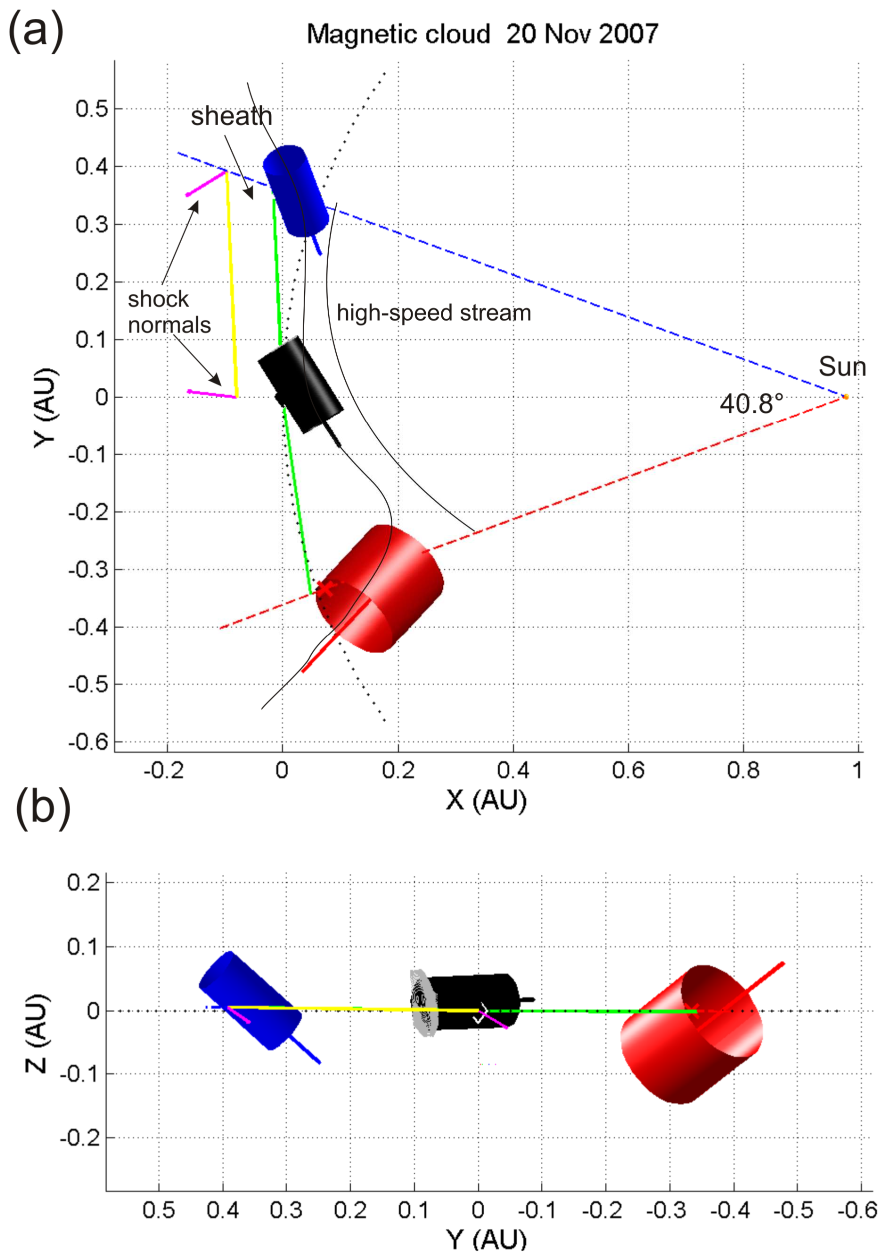




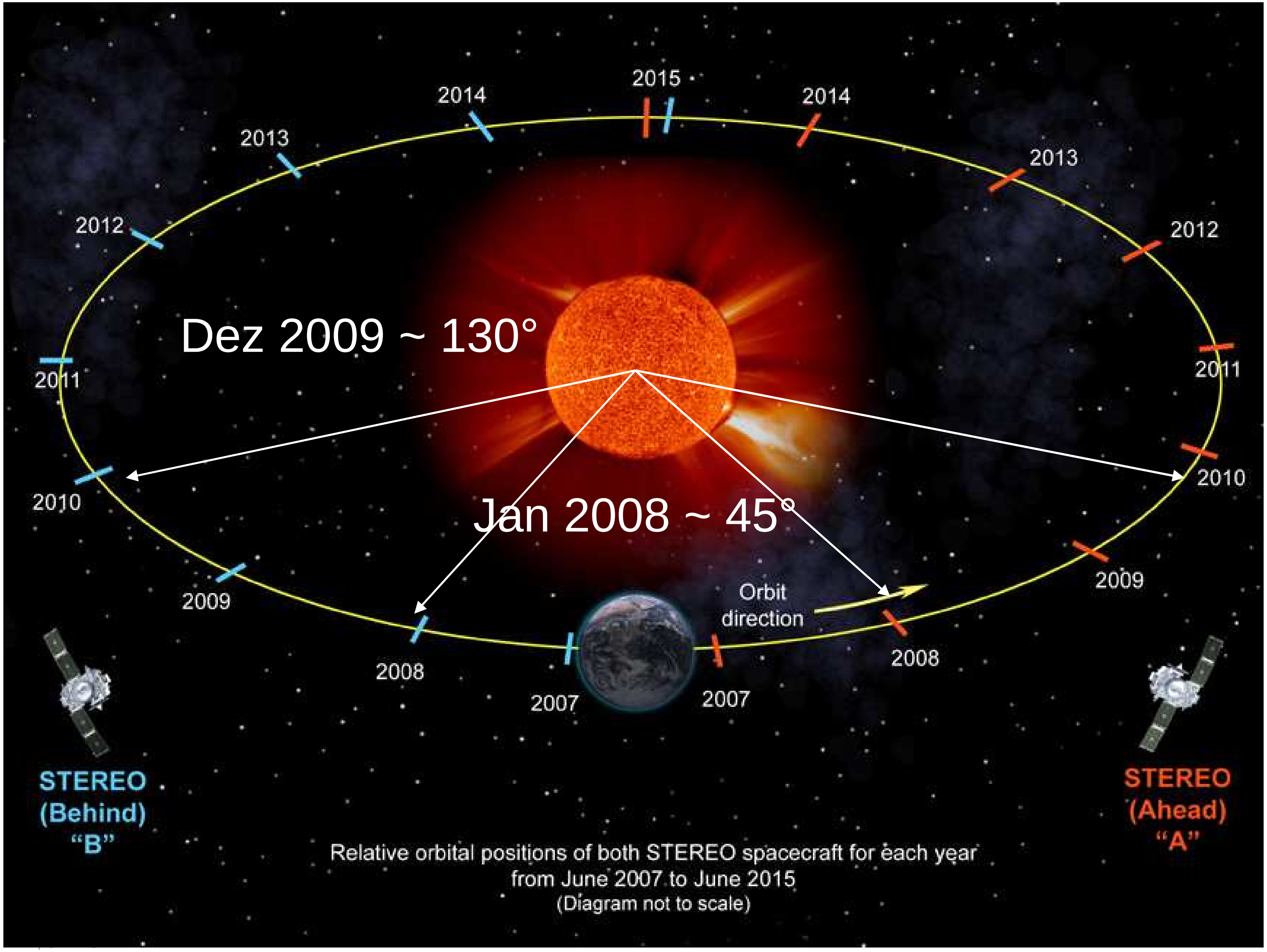


Farrugia et al. 2010
JASTP in preparation

20 Nov 2007


(a)
Magnetic cloud 20 Nov 2007
sheath
shock
normals
high-speed stream
Sun
40.8°
Y (AU)
X (AU)
(b)
Z (AU)
Y (AU)

STEREO 2008–2009



Aims & Data

Aims: Characterize parameters of MCs during
solar minimum + the early ascending phase of solar cycle 24

- STEREO (1 **Jan 2008 – 31 Oct 2009)**

IMPACT: magnetic field (1 min) Level 2

http://aten.igpp.ucla.edu/forms/stereo/level2_plasma_and_magnetic_field.html

PLASTIC: proton N, V, T (1 min) Level 2 Version 7

ftp://cdaweb.gsfc.nasa.gov/pub/istp/stereo/behind/l2/plastic/1dmax/1min/

- **WIND** MFI and SWE from NSSDC (**1 Jan 2008 – 31 Dec 2009**)

ftp://nssdcftp.gsfc.nasa.gov/spacecraft_data/wind/mag/1min_ascii/
ftp://nssdcftp.gsfc.nasa.gov/spacecraft_data/wind/plasma_swe/swe_kp_unspike/

Selection criteria:

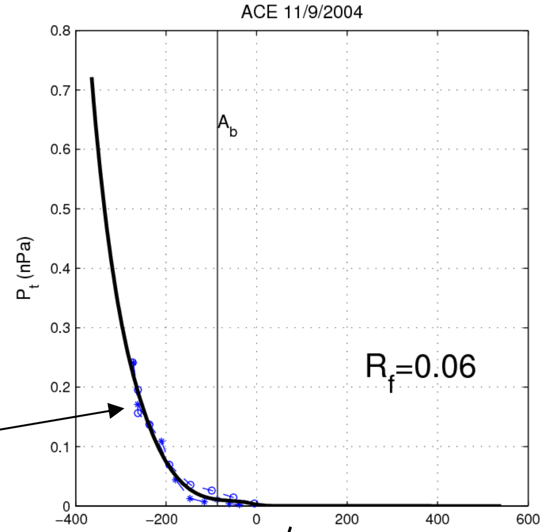
- Bmax > 6 nT ; duration >6 hours ; clear magnetic field rotation
- 18 MC/MFR events left out of ~50 ICMEs; 14 can be modeled completely

GS reconstruction

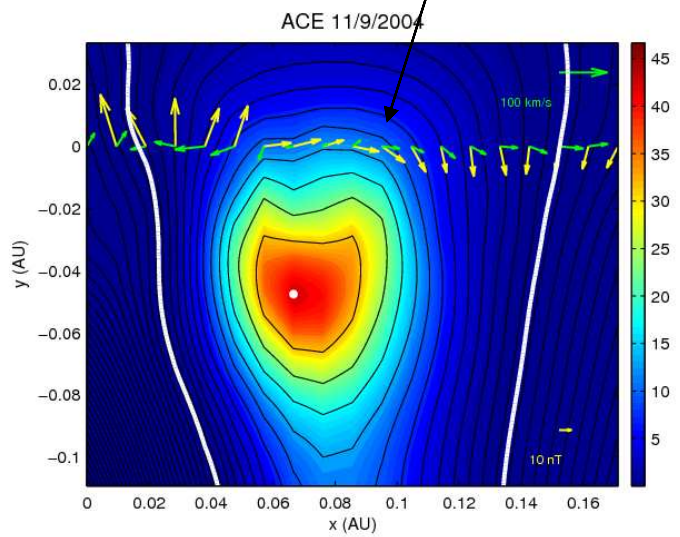
- Reconstruction by solving numerically the **Grad-Shafranov equation** (Hu and Sonnerup, 2002)
- 2 assumptions: **Invariant and time-independent**

$$\nabla p = \mathbf{j} \times \mathbf{B}, \quad \mu_0 \mathbf{j} = \nabla \times \mathbf{B}, \quad \nabla \cdot \mathbf{B} = 0.$$

$$\boxed{\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} = -\mu_0 \frac{d}{dA}\left(p + \frac{B_z^2}{2\mu_0}\right) = -\mu_0 \frac{dP_t}{dA}}$$



$$\Phi_t = \int \int B_z \, dx \, dy$$
$$\Phi_p = |A_m - A_b| L$$

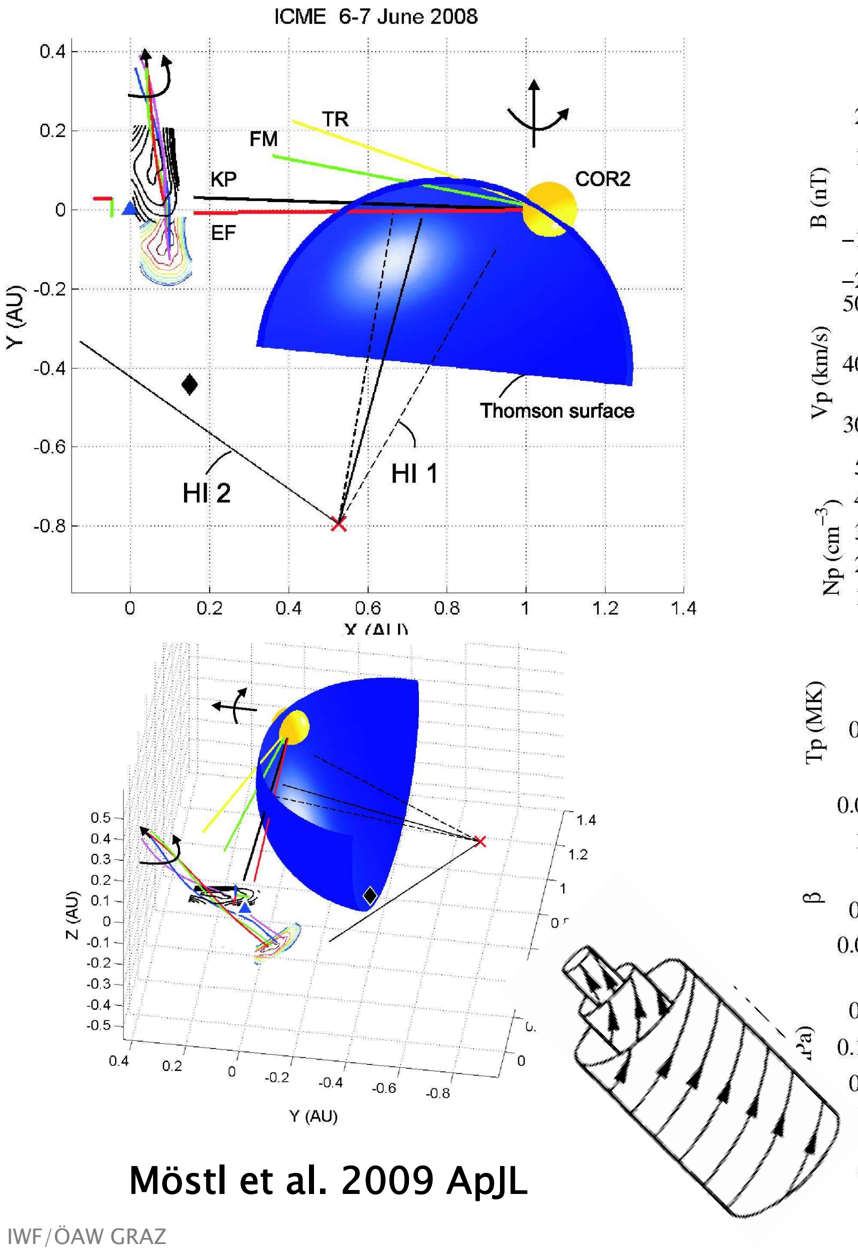


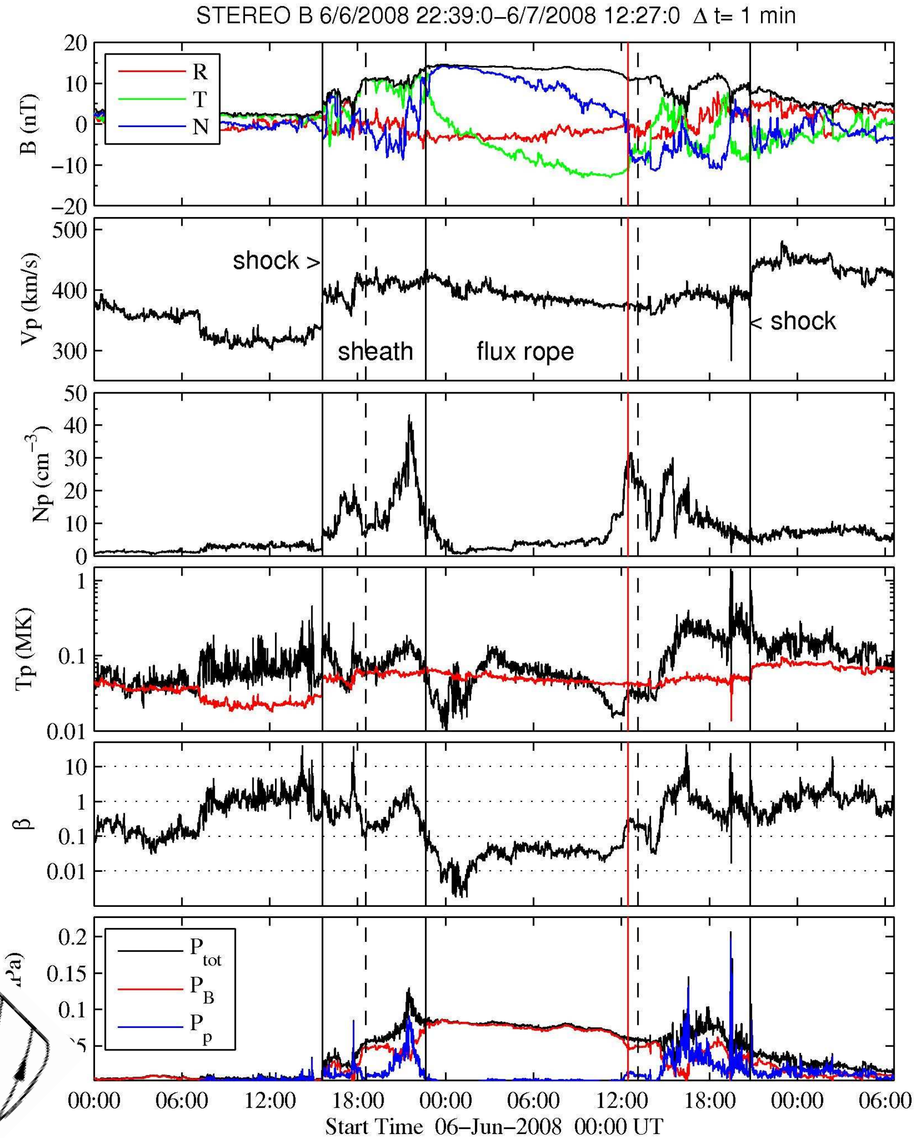
9 Nov 2004 MC

Additionally we get:

- orientations, axial fields, impact parameters
- magnetic fluxes, axial currents

MFR June 6 2008 STB

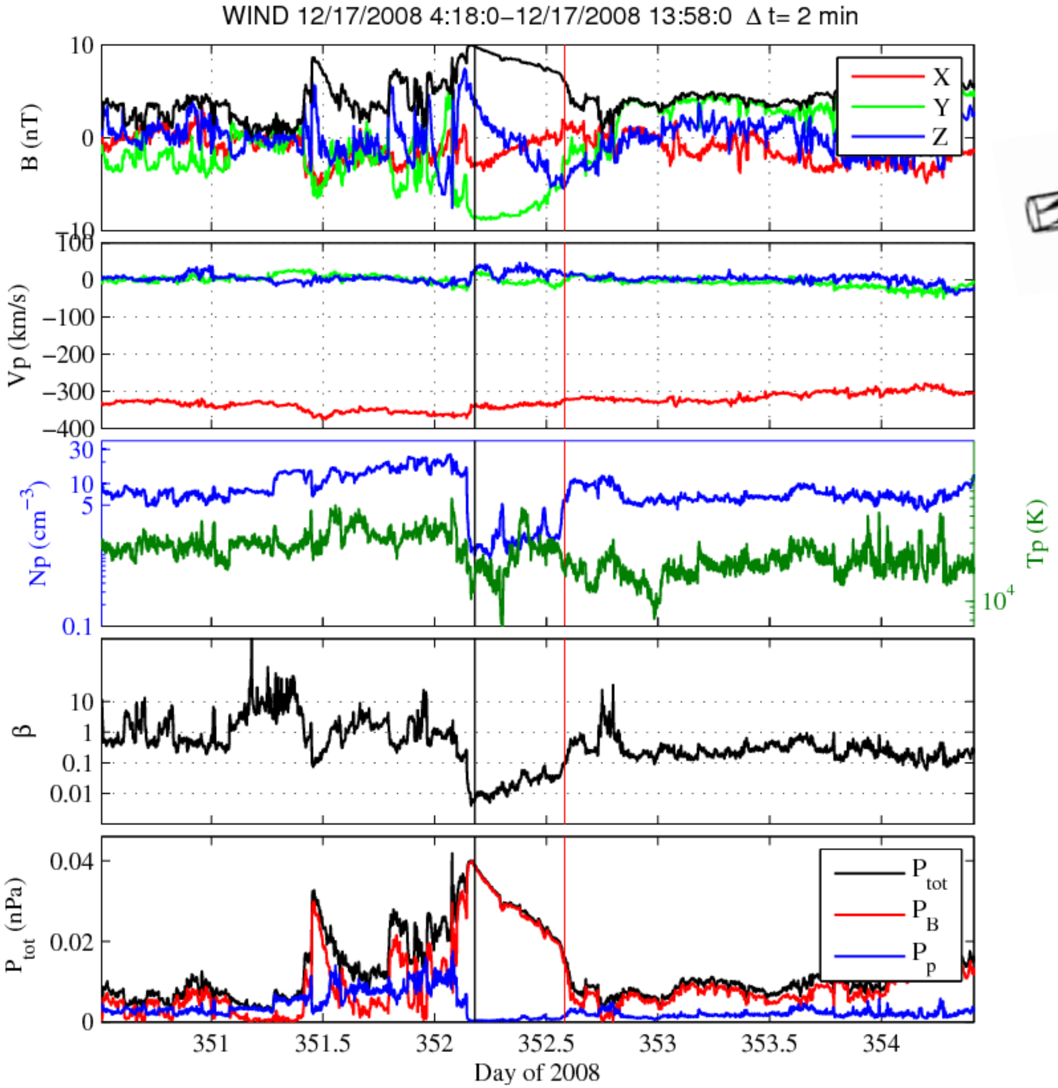


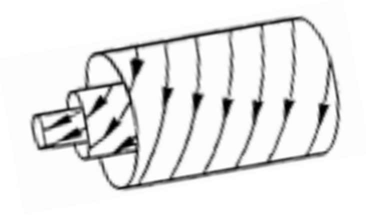


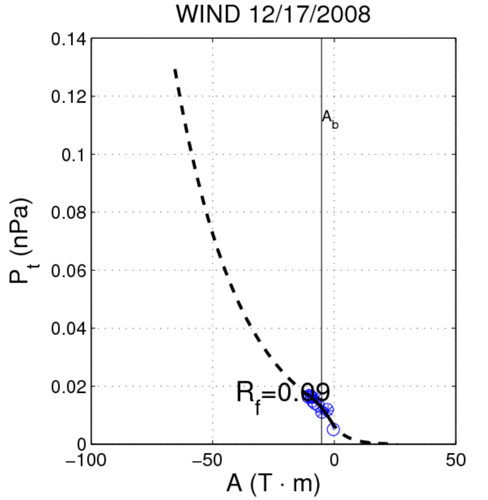
Möstl et al. 2009 ApJL

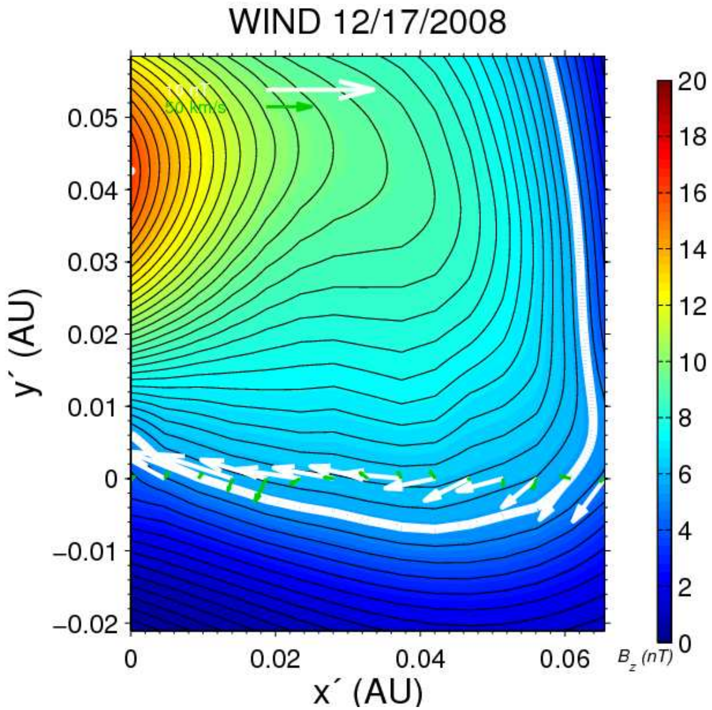
MC 17 Dec 2008 Wind

- Davies et al. GRL 2009 / Lui et al. ApJL 2010

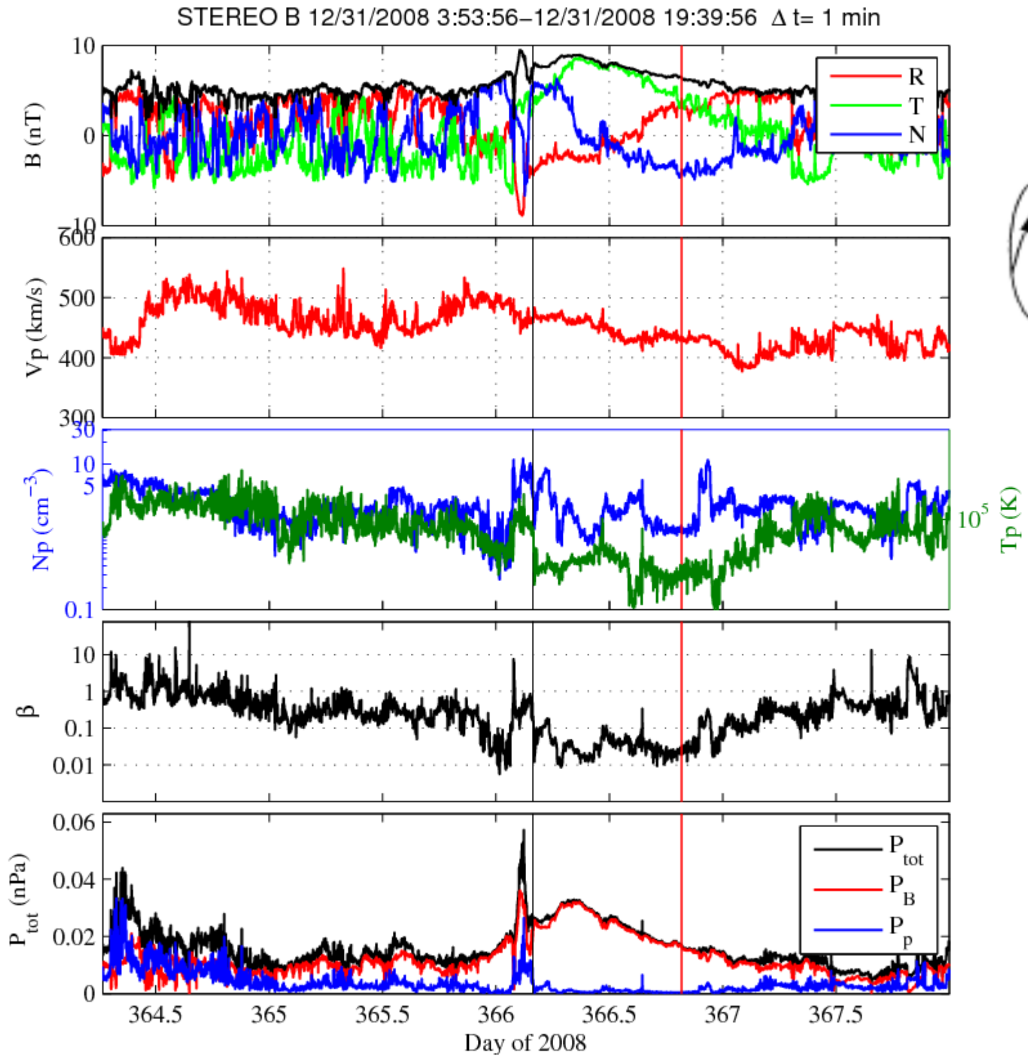


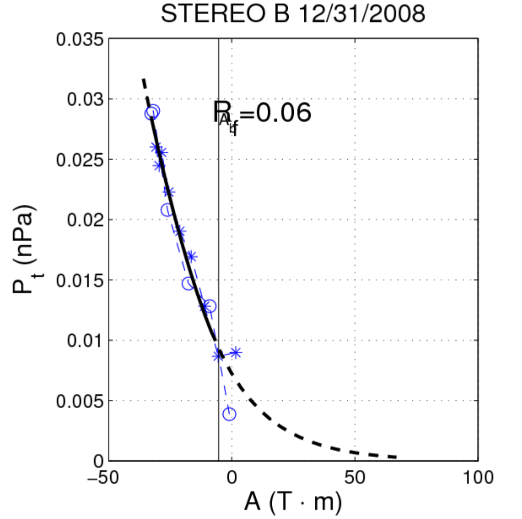


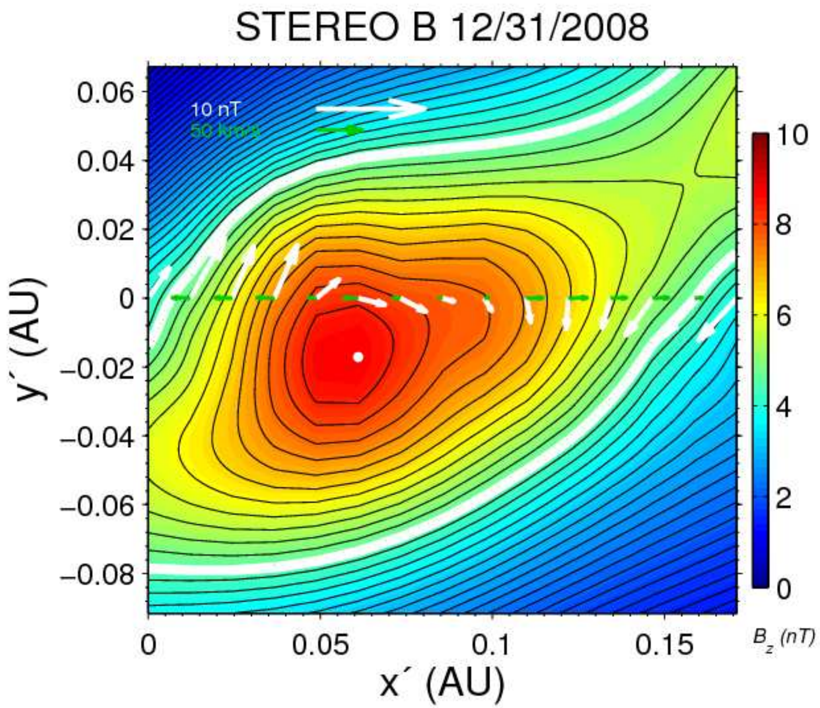




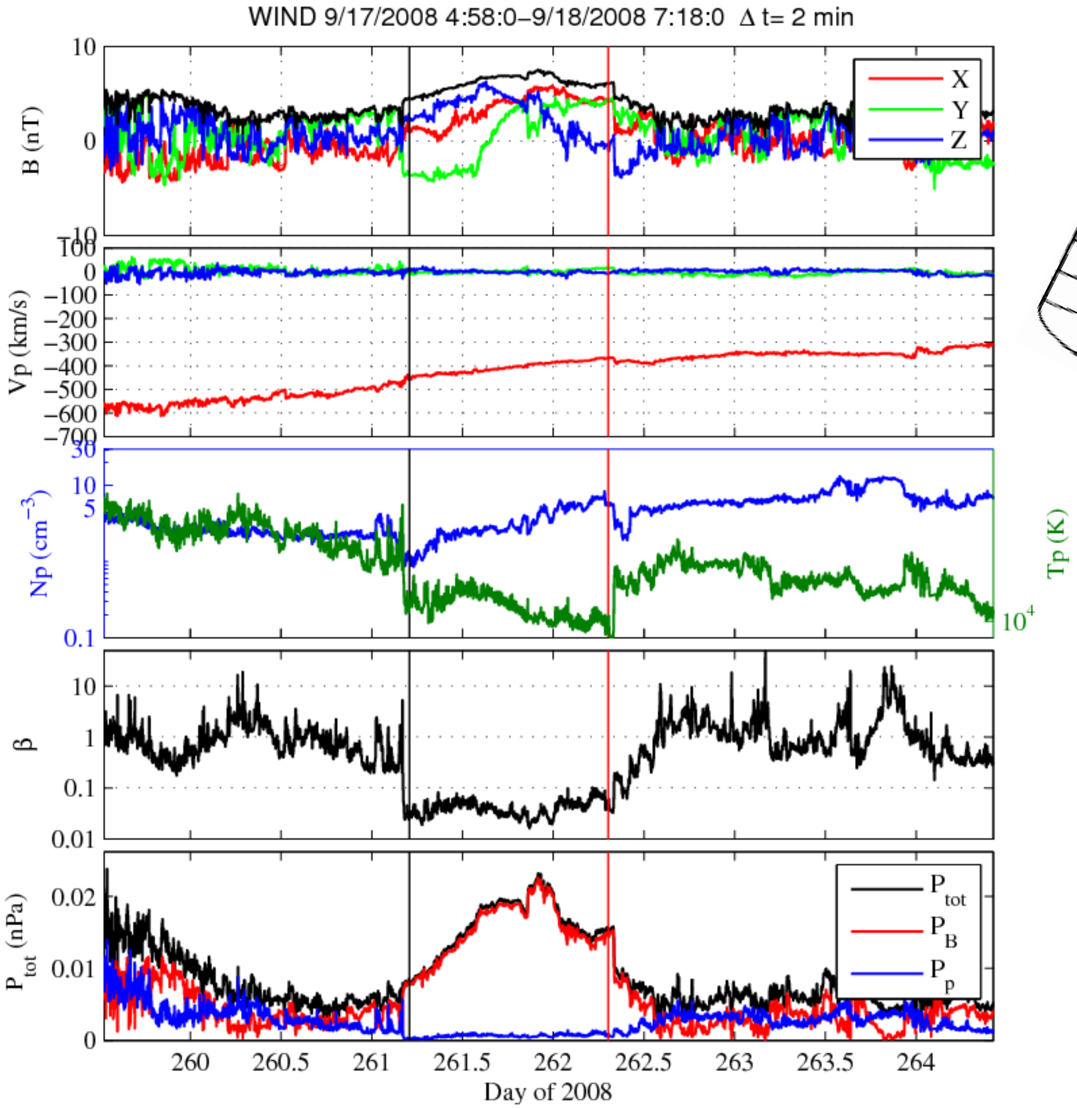
MC 31 Dec 2008 STB

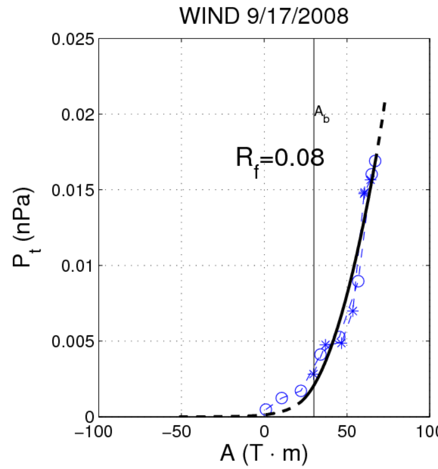


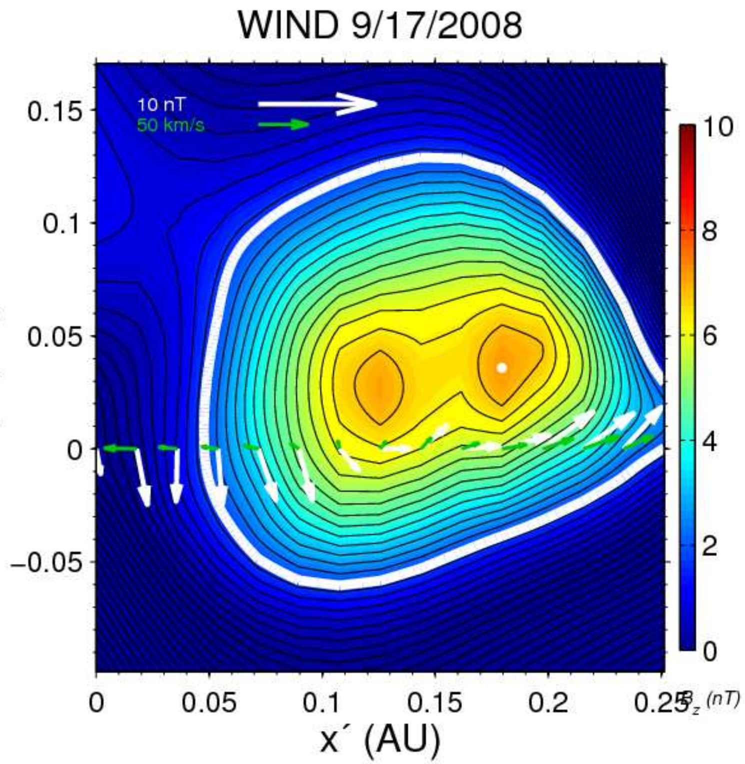




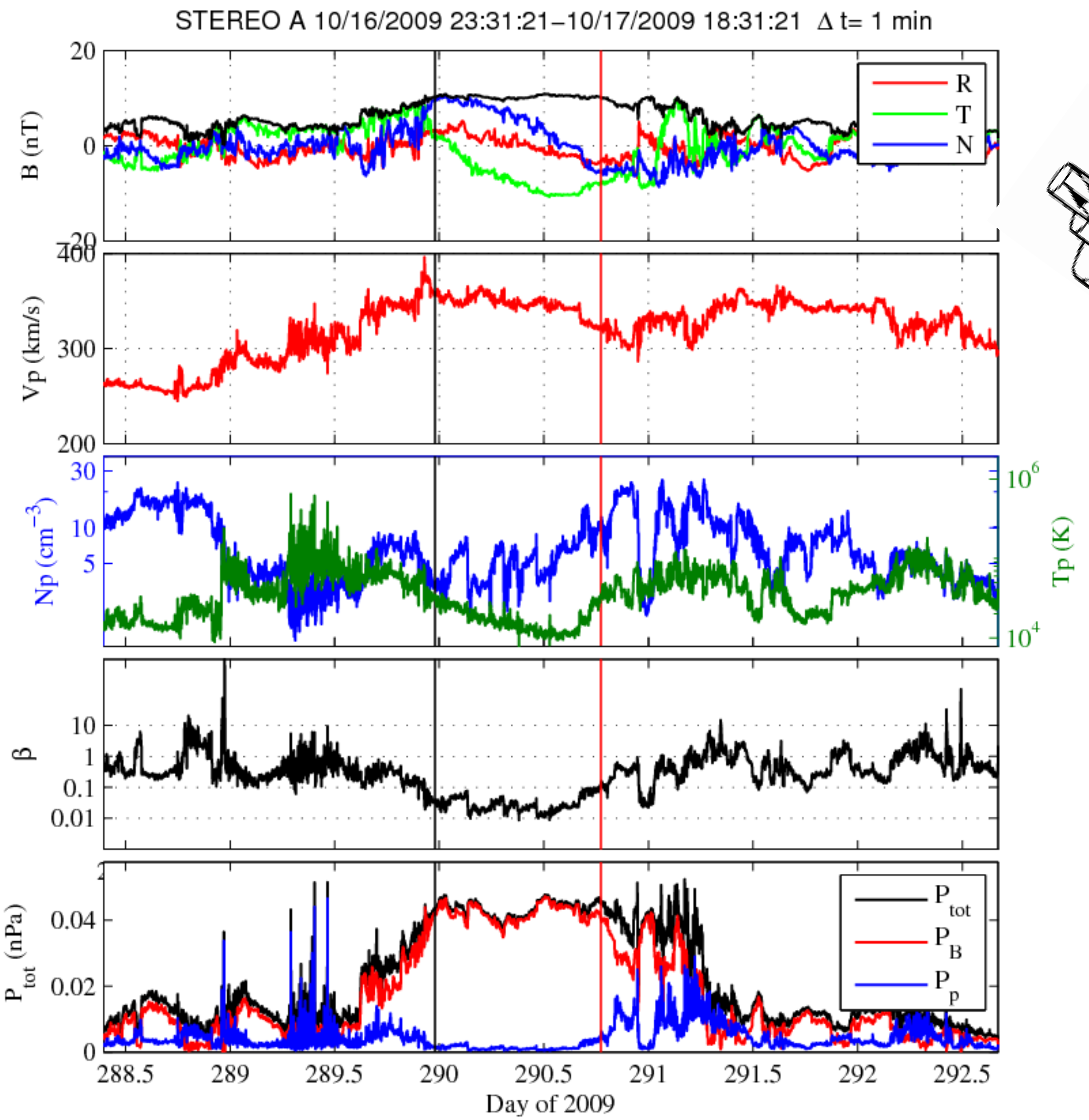
Double MC? 17 Sep 2008 Wind

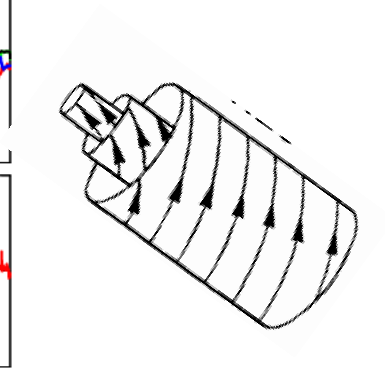


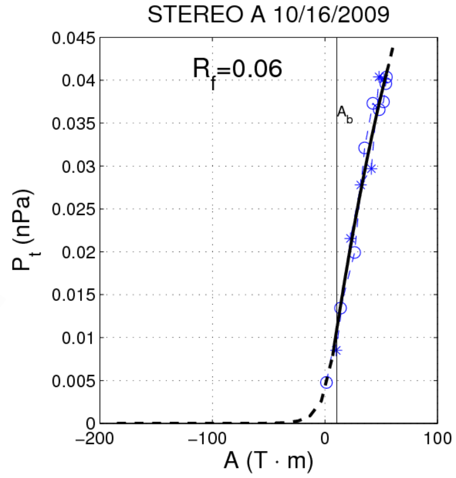


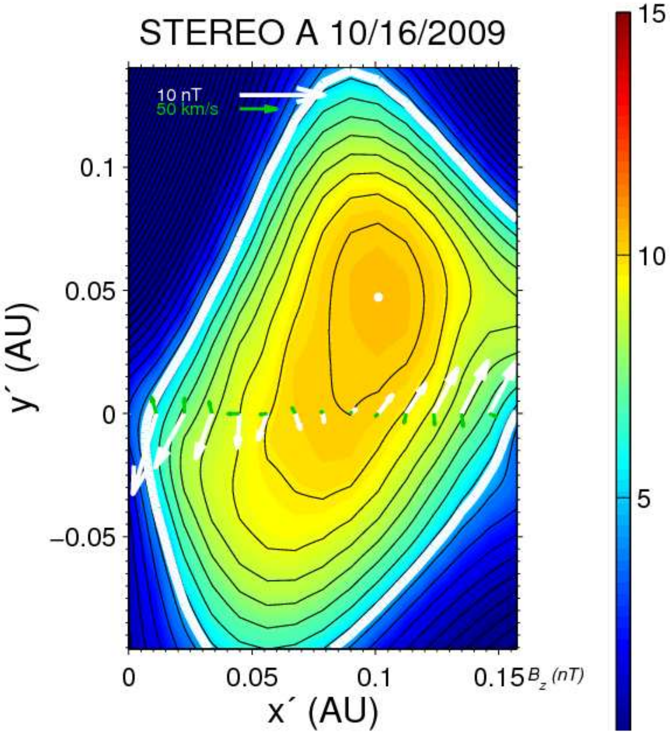


MC 16 Oct 2009 STA

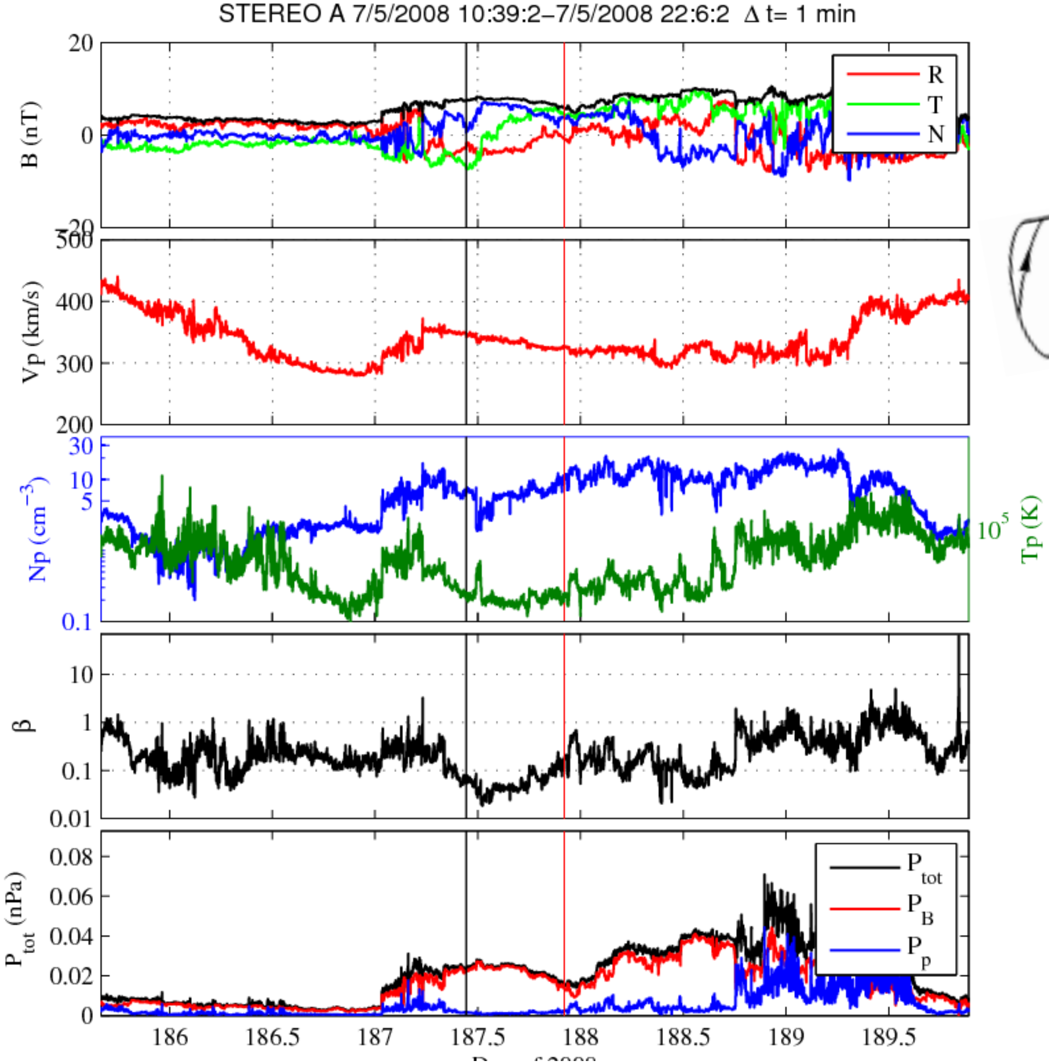


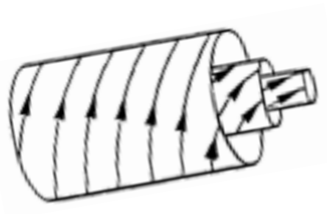


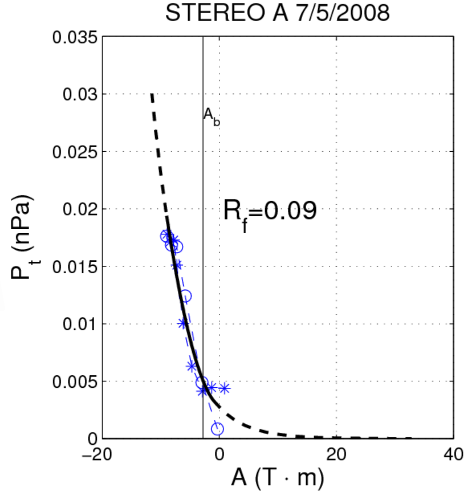


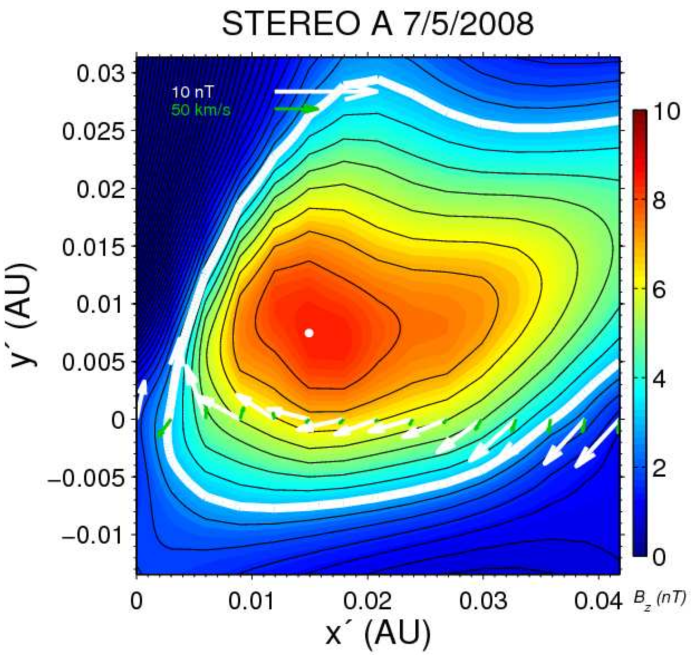


MC 5 July 2008 STA

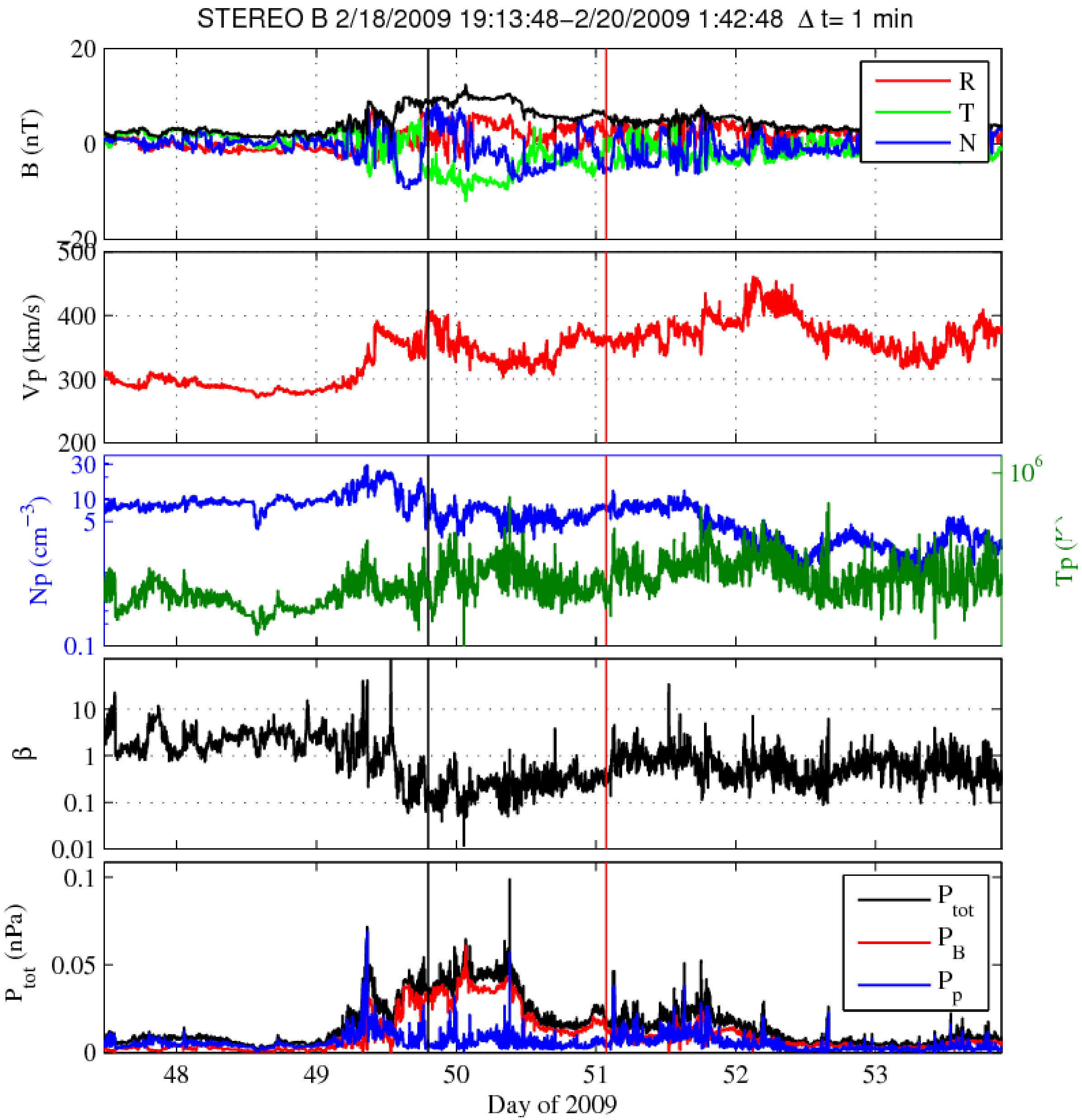


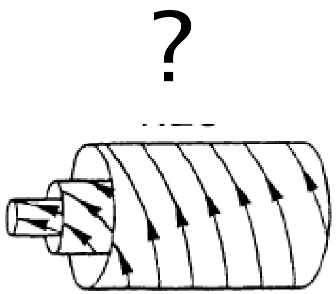






ICME Feb 18 2009

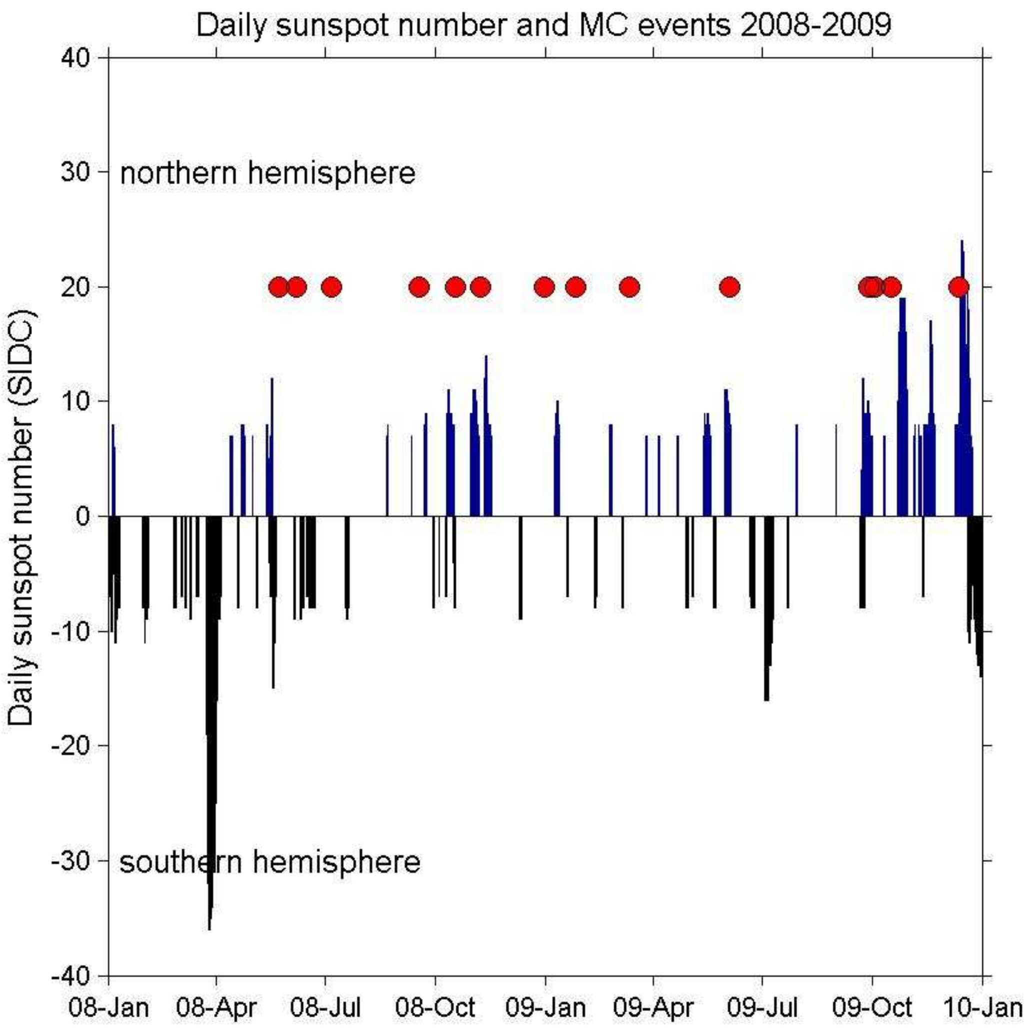


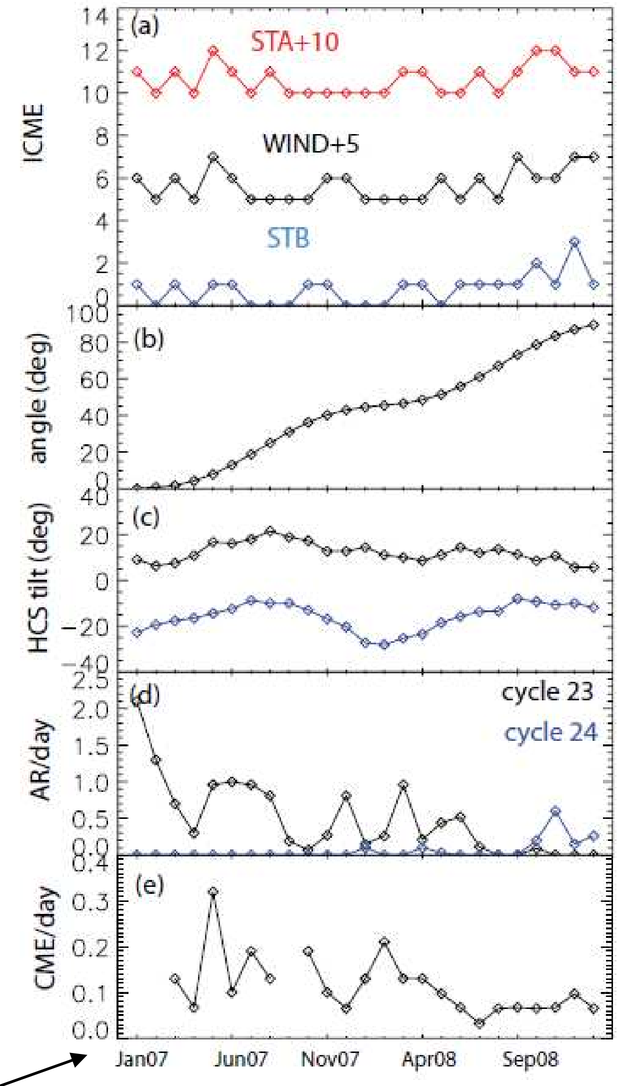


Table

nr.	s/c	MC start	dur.	V_{HT}	B_0	(θ,ϕ)	H	D	p	$\Phi_t;\Phi_p$	I_z	SW
2008												
1	W	23-May 00:28	(10:08)	532	6.0	(38,32)	R	0.097	0.04	0.04;0.19	104	F
2	B	06-Jun 22:39	(13:48)	392	15.4	(51,278)	R	0.130	0.82	0.72;1.19	540	S
3	A	05-Jul 10:39	(11:27)	335	8.6	(28,168)	L	0.042	0.18	0.01;0.13	71	S
4	W	17-Sep 04:58	(02:20)	418	7.2	(63,48)	R	0.251	0.14	0.29;0.65	284	F
5	B	17-Oct 10:44	(17:38)	354	7.0	(-29,154)	R	0.093	0.00	0.05;0.20	141	SM
6	A	07-Nov 02:36	(21:17)	348	6.7	(4,31)	L	0.094	0.07	0.03;0.14	81	S
7	B	31-Dec 03:53	(15:46)	449	8.9	(2,91)	L	0.171	0.10	0.24;0.45	259	S
2009												
8	A	26-Jan 12:39	(13:41)	377	11.1	(11,288)	R	0.116	0.19	0.20;0.38	208	SM
9	W	12-Mar 02:18	(06:00)	349	10.5	(79,311)	R	0.051	0.09	0.04;0.15	66	FS
10	A	03-Jun 17:24	(22:54)	393	10.5	(12,219)	R	0.143	0.00	0.17;0.40	320	BS
11	B	28-Sep 04:10	(07:39)	332	6.4	(-49,163)	L	0.047	0.04	0.01;0.08	41	S
12	B	03-Oct 05:32	(12:20)	341	13.2	(-36,133)	L	0.084	0.04	0.06;0.20	126	S
13	A	16-Oct 23:31	(19:00)	348	10.5	(36,278)	R	0.157	0.30	0.46;0.75	362	S
14	W	12-Dec 21:58	(16:42)	275	7.7	(11,84)	R	0.110	0.06	0.03;0.09	101	S

MC occurence

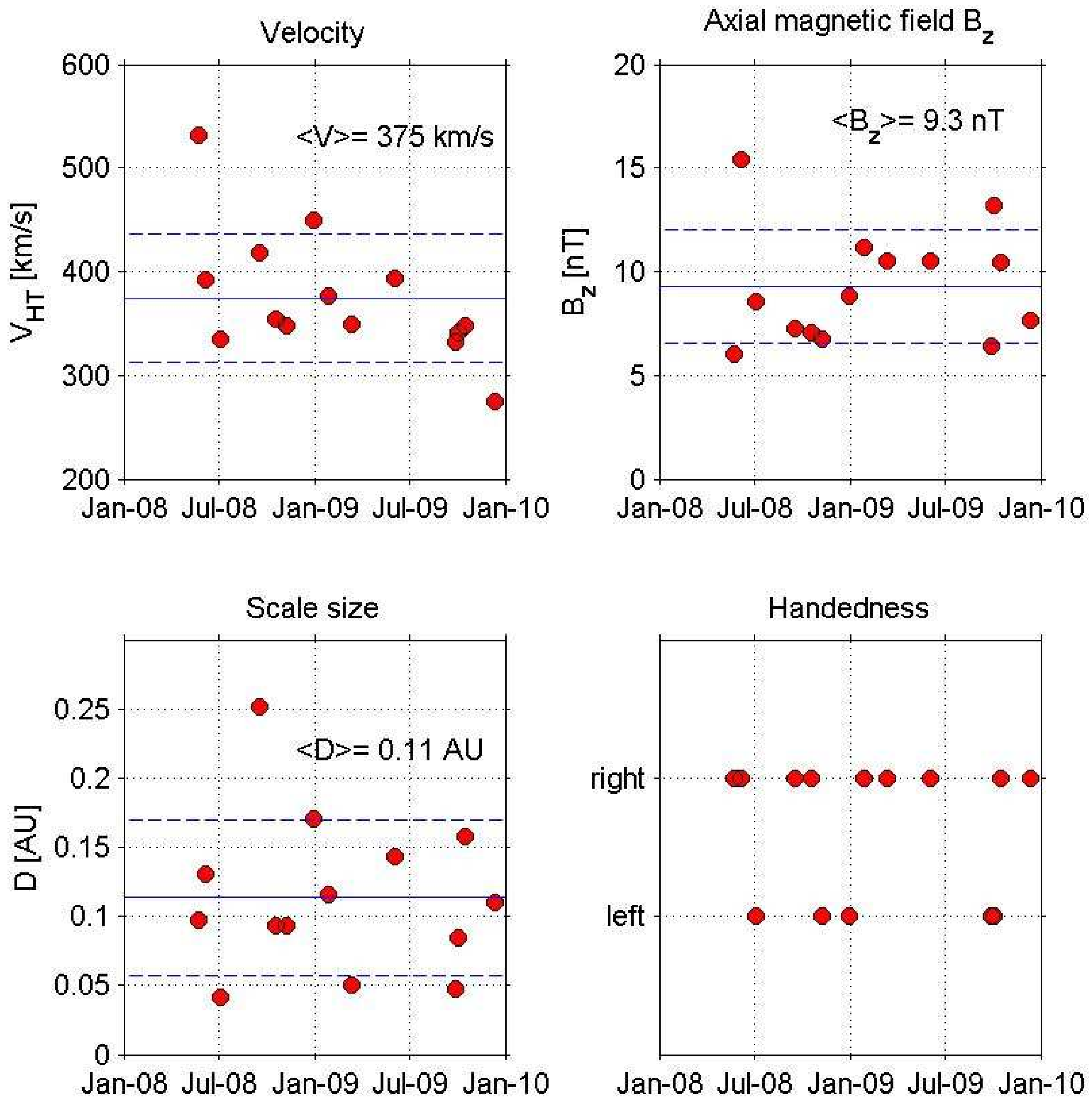




2008–2009

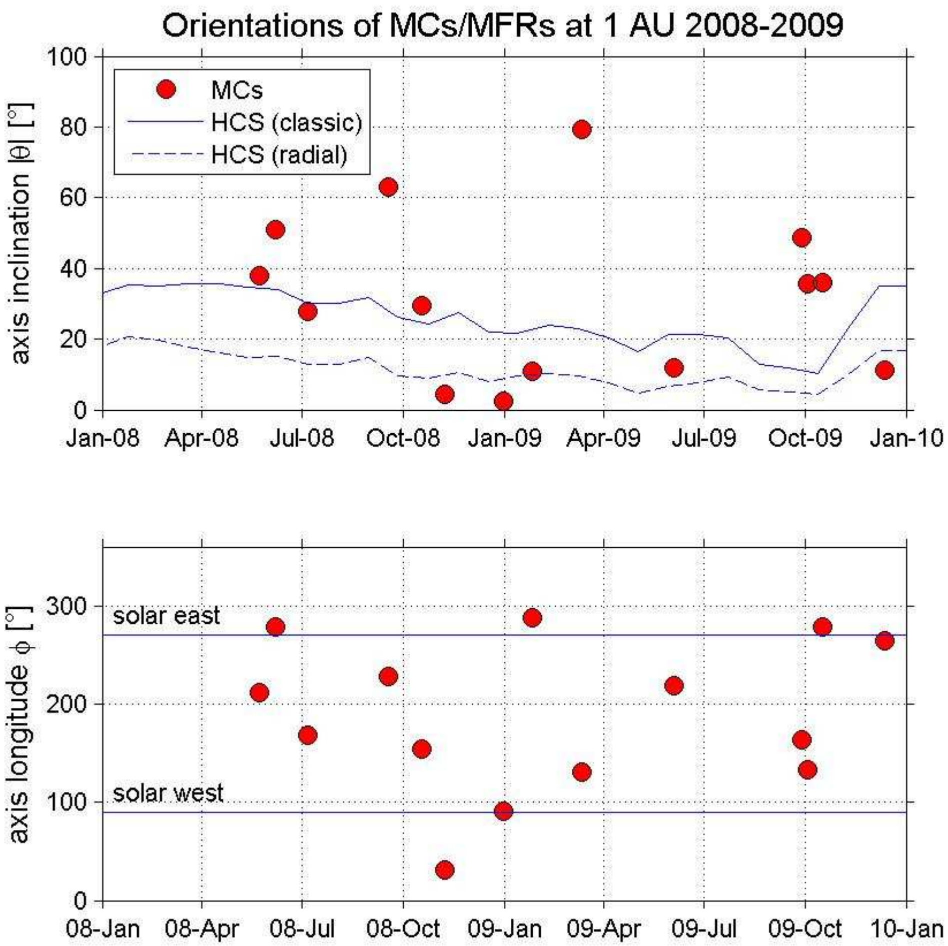
2007–2008: Kilpua et al. 2009 Ann. Geophys.

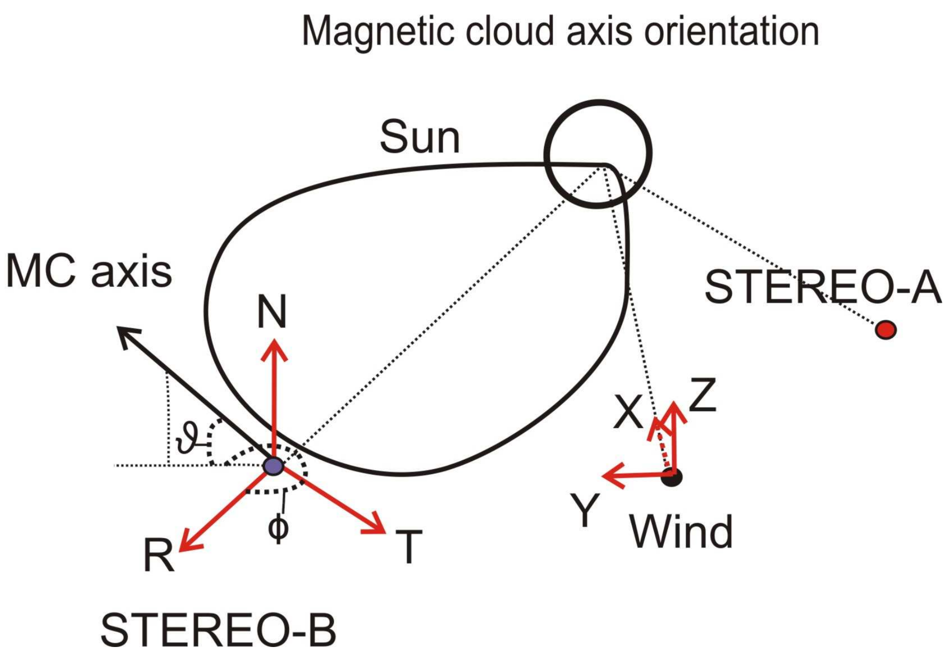
Average values



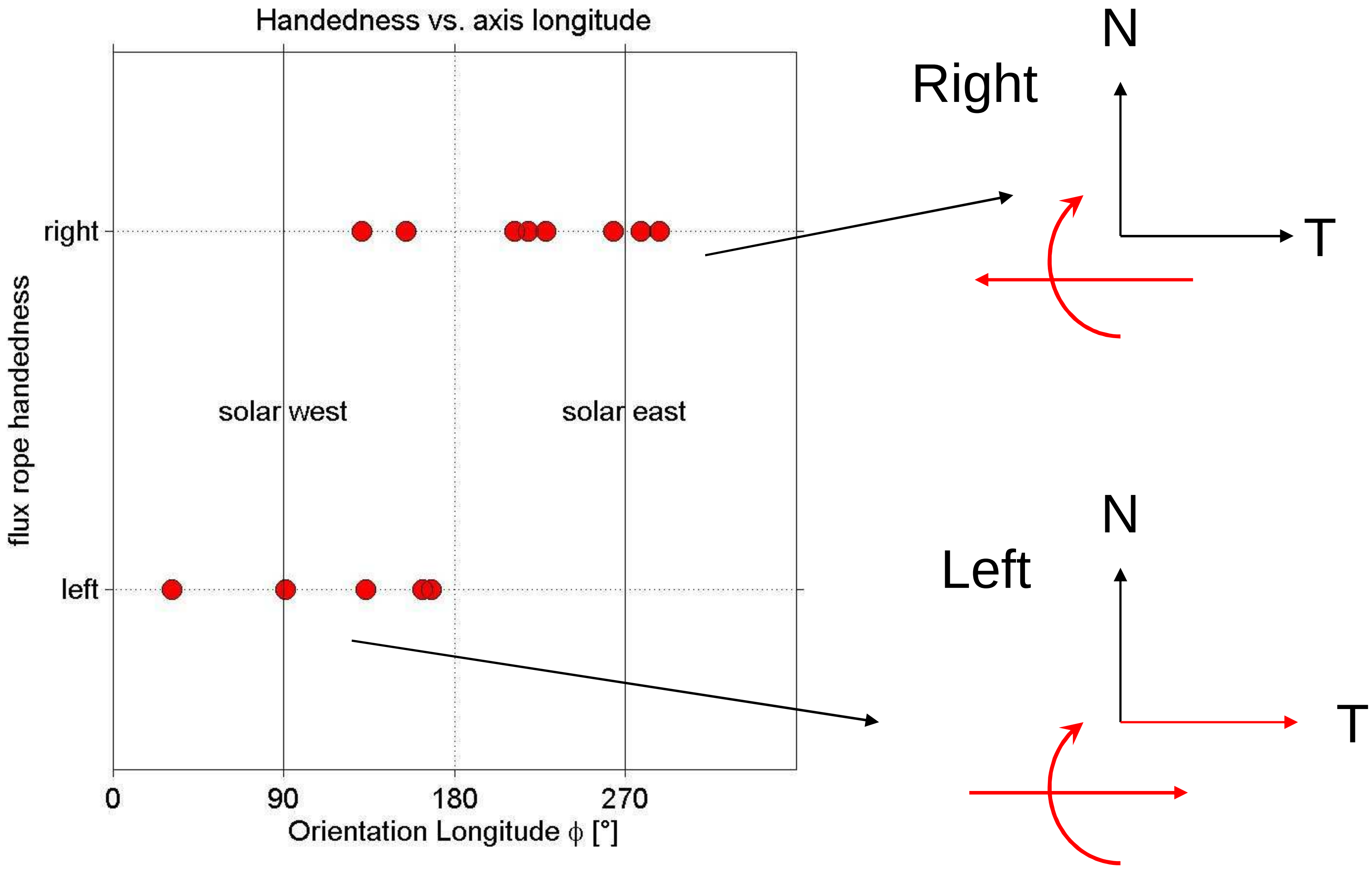
Axis orientations

- Difference GS/MV: 10° on average

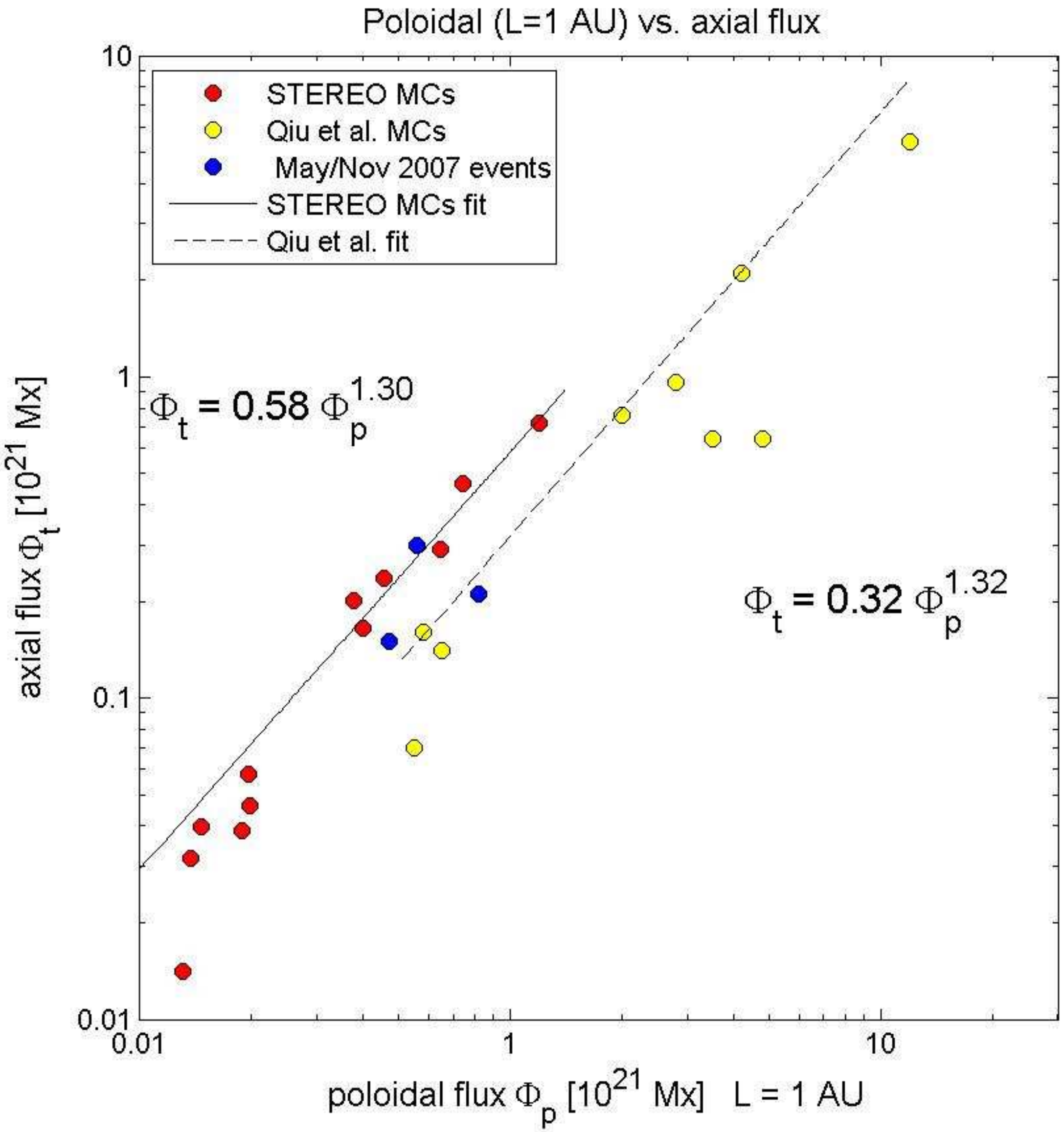


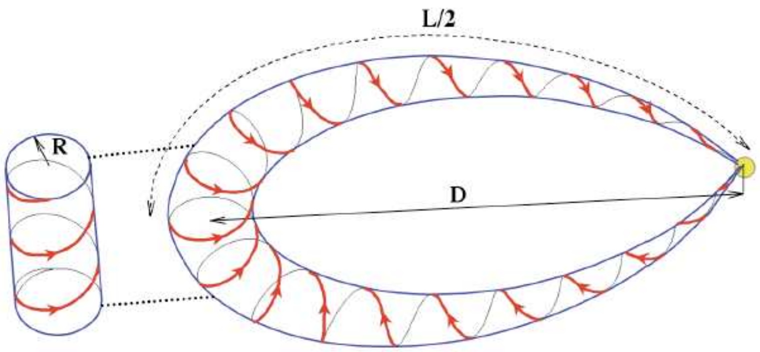


Handedness and axis longitude



Magnetic fluxes





Conclusions

- We modeled MCs/MFRs at 1 AU in 2008 and 2009
- 14 events (preliminary)
- **Occurence rate of MCs** quite constant
- **Only ~1/3 of ICMEs** can be modeled
  (only for these the field rotations are smooth and clear enough)
- Almost all embedded in slow solar wind < 500 km/s
- No obvious correlation between orientation and the HCS tilt
- Very slow **velocities** (300 km/s) at the end of 2009
- **Magnetic fluxes** overlap with those connected to C / M class flares

- Results probably useful for evolution of the solar global field and especially for **comparisons with CME directions, orientations as inferred from STEREO/SECCHI**
  (fitting with Sheeley method, kinematics, arrival times…)
- thanks!