Morphology of coronal hole and solar wind prediction based on SDO/AIA data from May 2010 to December 2014

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Introduction

- prepared list of solar wind disturbance (SWD) using the data from WIND and ACE satellites, recorded from May 2010 to December 2014, (the period when the data from SDO, SOHO and both STEREO satellites wes available);
- made a list of 219 SWD incorporated into an online catalogue for a general use; separeted solar wind signatures on: corotating interaction regions (CIRs), interplanetary coronal mass ejections (ICMEs) and complex signatures; we focused our attention on 152 CIRs (64% of all SW signatures) where stream interface (SI) was clearly recognisable;
- detailed analisys of *in situ* data (of the magnetic field B, flow speed v, proton dencity Np and thermal speed v_{th}) between the region in front and behind the SI;
- prepared list of CHs employing the data from SDO, measuring the longitude and latitude of CHs edges, calculated the dimensions of CHs
- as well as established correlation between SW parameters with CHs dimension and Dst index

The data set

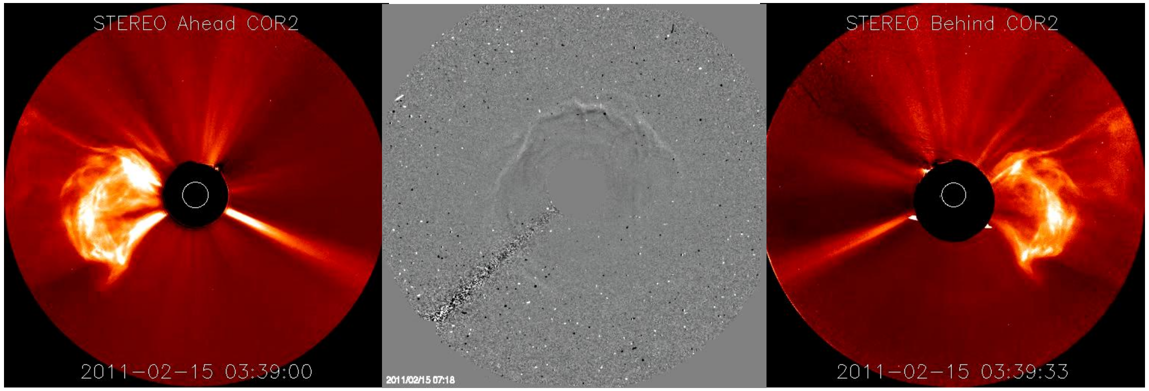
For SWD analysis at L1 point we used the WIND Magnetic Field Investigation (MFI) and Solar Wind Experiment (SWE) data, 1 minute resolution, GSE coordinates, accompained with ACE data.
http://wind.nasa.gov/mfi_swe_plot.php / http://www.srl.caltech.edu/ACE/ASC/level2/index.html

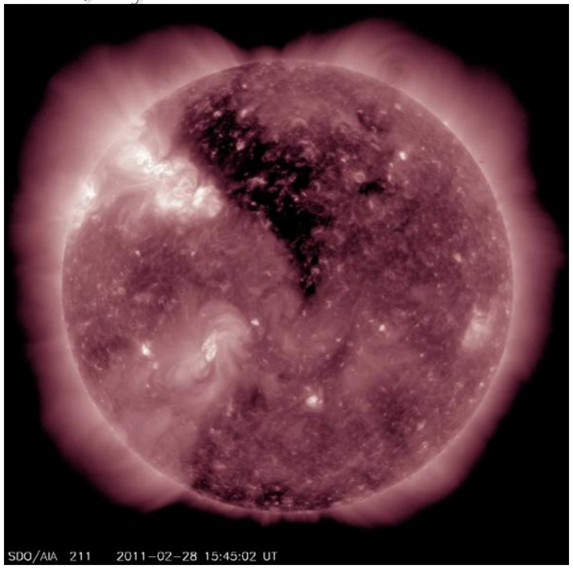
For the Recognition of the accompanied ICMEs we used data from *STEREO* satellites - *SECCHI-COR2* Outer Coronagraph and SECCHI-HI Heliospheric Imager http://stereo-ssc.nascom.nasa.gov/browse/ and SOHO satellite - LASCO C2 / C3 Coronagraphs http://lasco-www.nrl.navy.mil/daily_mpg/

For additional informationsof CH, we used the SDO Atmospheric Imaging Assembly (AIA) and Helioseismic Magnetic Imager (HMI) http://sdo.gsfc.nasa.gov/data/ , two wavelength channels 19.3 and 21.1nm

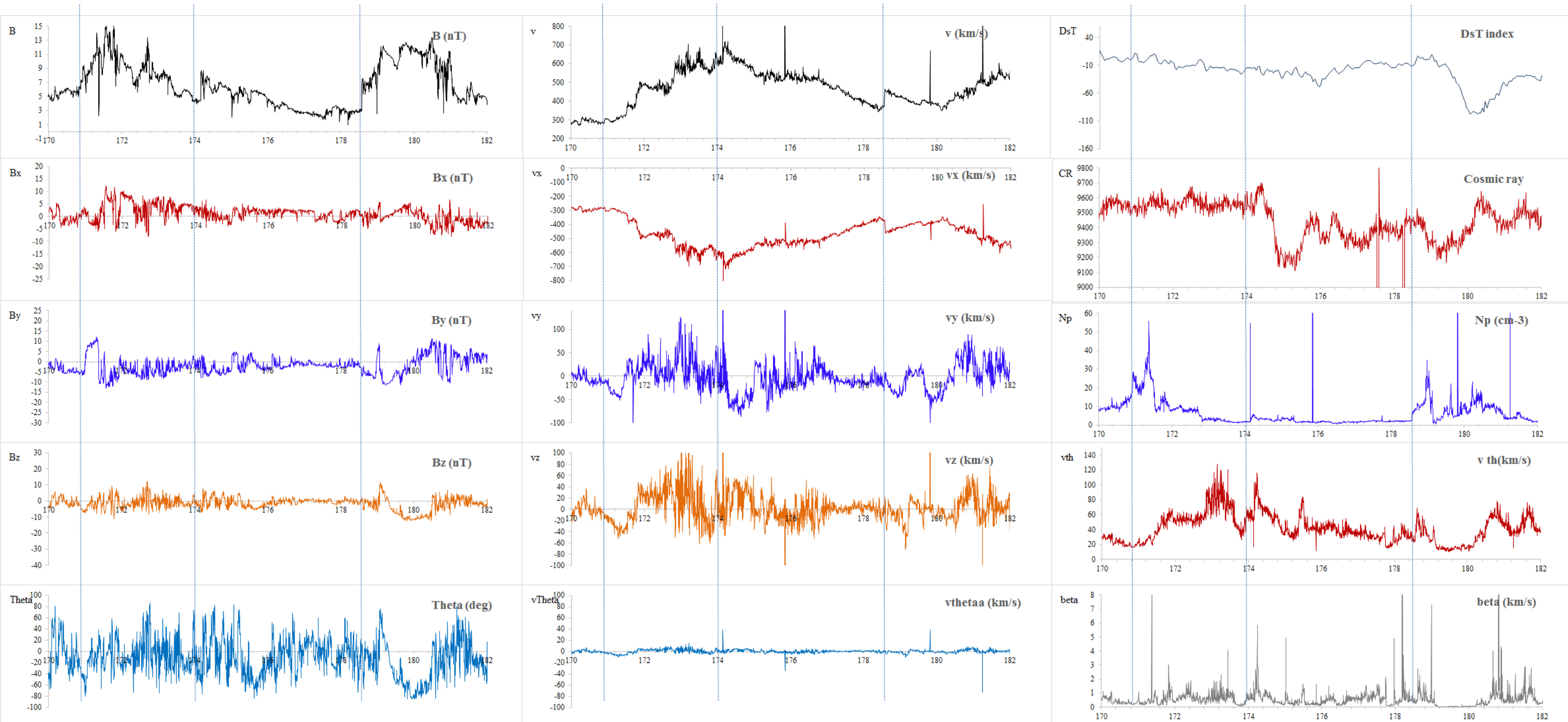
Accompained by Hourly Equatorial Dst Values - WDC for Geomagnetism, Kyoto

http://wdc.kugi.kyoto-u.ac.jp/dstdir/index.html





Solar wind disturbances – online catalog



- for period from **<u>May 2010 to December 2014</u>** - recognized 219 solar wind disturbances - online catalog for general use: https://zvjezdarnica.hr/pdf/ListSWDs.pdf
- The SW events were identified by adetailed inspection of the plasma and magnetic field structure Dumbović et al. (2012).
- separation of the disturbance in different types, regarding to its origin: ICMEs, HSSs and complex signatures - removed the ICME signatures

SWD counting – online catalog

List of Solar Wind Disturbance since January 2008 to August 2014

Compiled by Darije Maričić [(1)], Filip Šterc [(1)] and Mile Karlica[(2)],

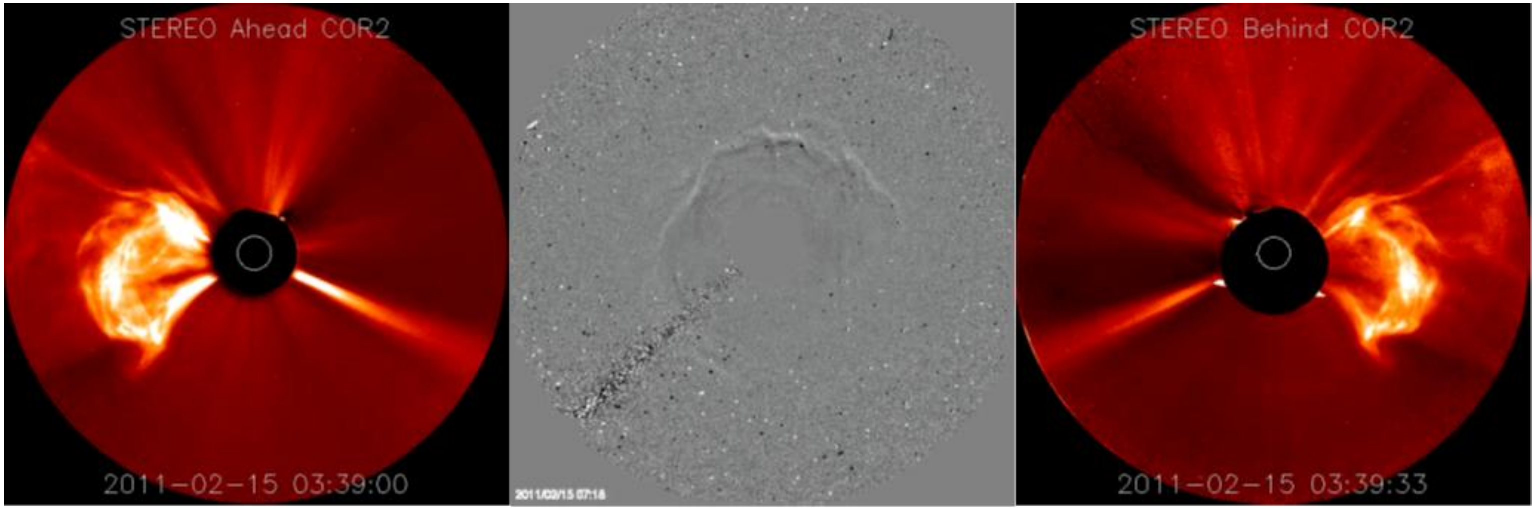
(1) Zagreb Astronomical Observatory, Croatia

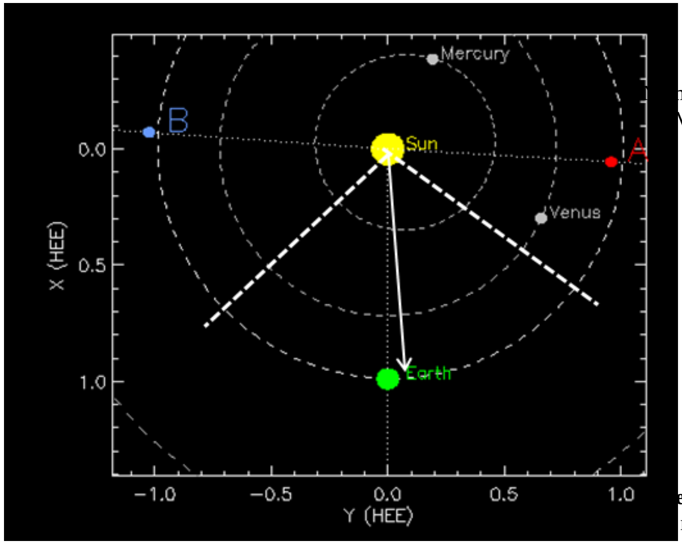
(2) Sapienza University of Rome, Italia,

No. (a)	Date of disturbnce (b) year	month	day	FD? (c)	DsT? (d)	MC? (e)	*Type of the SWD* (f)	onset B_{max} (g) (doy)	B_{max} (h) (nT)	onset v_{max} (i) (doy)	v_{max} (j) (kms^{-1})	onset Np_{max} (l) (doy)	Np_{max} (m) (cm^{-3})	onset vth_{max} (n) (doy)	Vth_{max} (o) (kms^{-1})	onset Dst (p) (doy)	onset Dst_{min} (q) (doy)	Dst_{min} (x) (nT)
	2008																	
1	2008	1	4	N	Y	N	*CIR*	5.28	17.90	5.30	657.60	4.93	47.70	5.33	90.20	4.92	5.42	-17
2	2008	1	12	N	Y	N	*CIR*	12.54	7.82	12.95	556.40	12.50	17.50	12.94	68.60	12.46	12.75	-27
3	2008	1	24	N	N	N	*CIR*	25.03	9.22	25.10	542.40	24.94	11.90	25.14	30.00	24.92	25.04	-5
4	2008	1	31	N	Y	N	*CIR*	31.69	14.56	31.79	597.30	31.62	36.20	31.76	78.00	31.38	32.04	-30
5	2008	2	9	N	Y	N	*CIR*	41.28	17.13	42.44	743.80	41.23	24.10	41.53	93.90	41.13	41.33	-14
6	2008	2	27	N	Y	N	*CIR*	58.70	10.15	58.70	772.60	58.68	29.70	61.18	91.90	58.58	58.83	-25
7	2008	3	7	N	Y	N	compelx distuprance	69.24	16.95	69.91	676.30	68.48	34.10	69.30	97.80	68.17	69.25	-89
8	2008	4	3	Y	Y	N	*CIR*	95.52	12.16	96.11	603.70	95.63	14.90	95.99	83.10	93.88	95.86	-33
9	2008	4	15	N	Y	N	*CIR*	107.46	12.76	107.87	618.50	107.42	22.00	107.51	69.60	107.25	107.92	-33
10	2008	4	22	N	Y	N	*CIR*	114.21	15.23	114.82	639.90	114.16	20.70	114.34	113.60	113.42	114.46	-40
11	2008	4	30	N	Y	N	*CIR*	121.75	10.16	121.98	515.00	121.73	28.90	121.79	69.70	121.67	121.88	-11
12	2008	5	19	Y	Y	N	*CIR*	141.61	9.42	142.44	581.00	140.34	33.30	142.04	66.40	139.04	142.21	-29
13	2008	5	28	N	Y	N	*CIR*	149.18	12.21	149.60	535.60	149.15	43.30	149.23	81.00	149.08	149.38	-11
14	2008	6	14	Y	Y	N	*CIR*	166.84	17.85	167.34	663.70	166.65	42.10	166.89	129.90	166.29	167.21	-41
15	2008	6	24	Y	Y	N	compelx distuprance	177.71	15.38	178.27	647.70	177.67	22.20	177.88	84.50	176.67	177.21	-29

https://zvjezdarnica.hr/pdf/ListSWDs.pdf

Recognition of ICME signature





Exclude back-side or lateral ICMEs

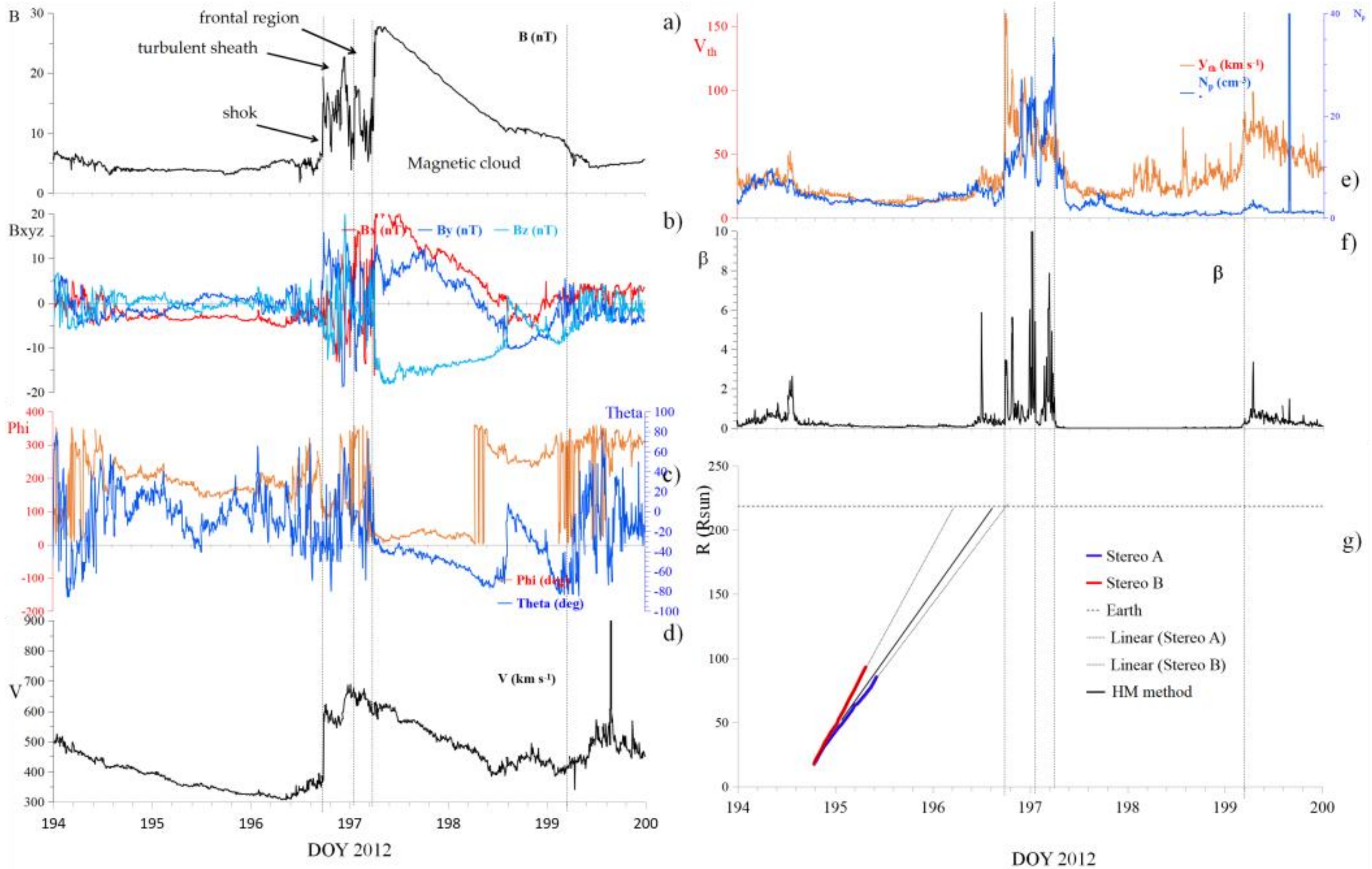
nber of ICMEs when compare COR2 ICME detections and
ND solar wind disturbance list covered period from May 2010 to December 2014

List	Number of ICMEs
ICME list	1594
SWD list	219
Beck side or lateral ICMEs	1131
Candidates for Earth-directed ICMEs	462
Confirmed Earth-impacted ICMEs with 67 *in situ* SW signatures	105
Single Earth-impacted ICMEs	33

e. Our method generated a list of 462 candidates for Earth-directed ICMEs, which
reduced to 105 confirmed Earth-impacted ICMEs.

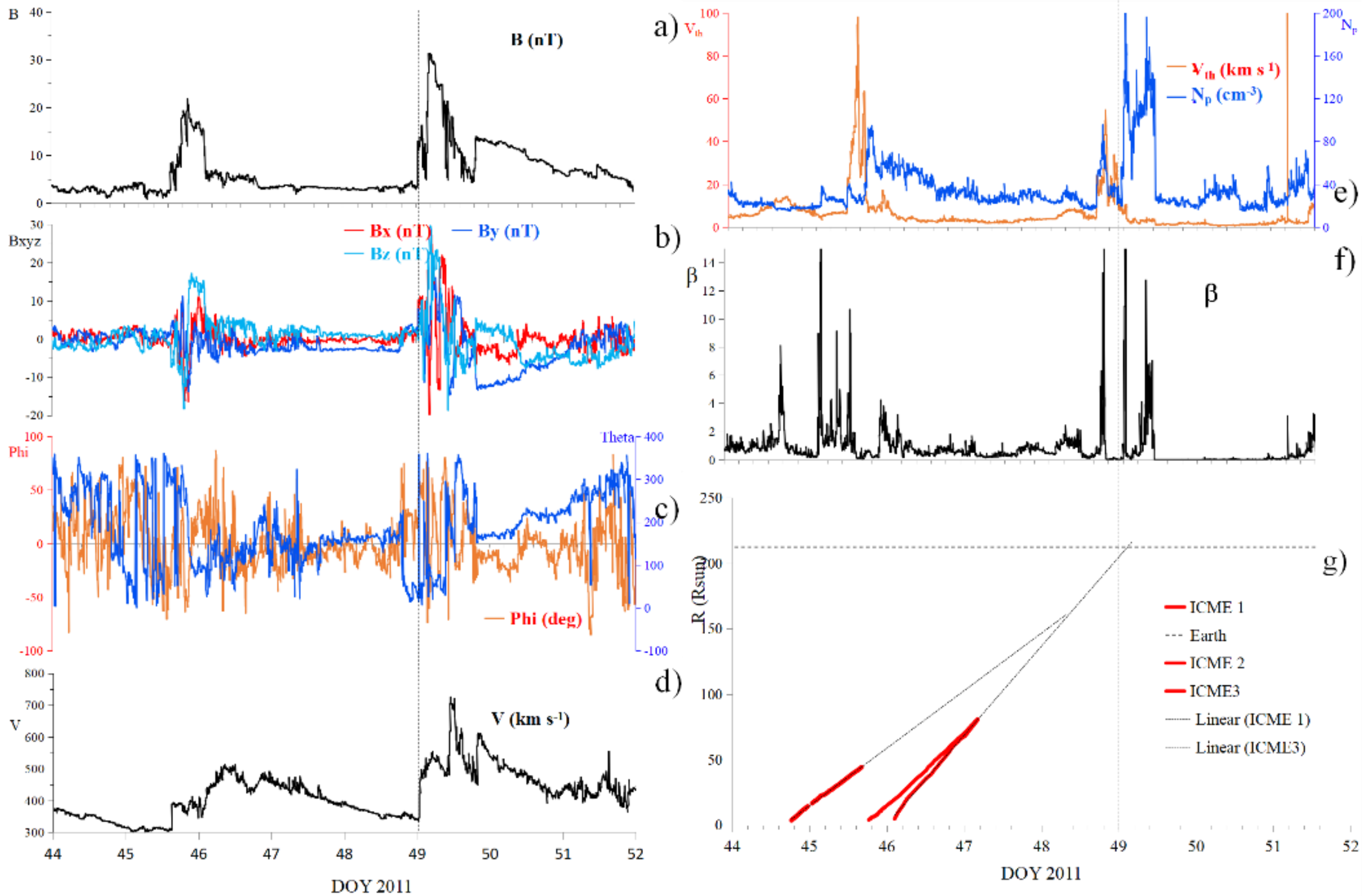
Kinematics of the ICMEs

- for 105 out of 462 ICME-s it was possible to connect with 67 corresponding solar wind disturbances
- from elogation-time, using HM approximation, wecalculated the direction and arrival time of ICME at Earth distance. method published in Maricic e*t al.* (2014)



the period (DOY = 194 - 200) from 12 to 18 July 2013

Interaction or single ICME

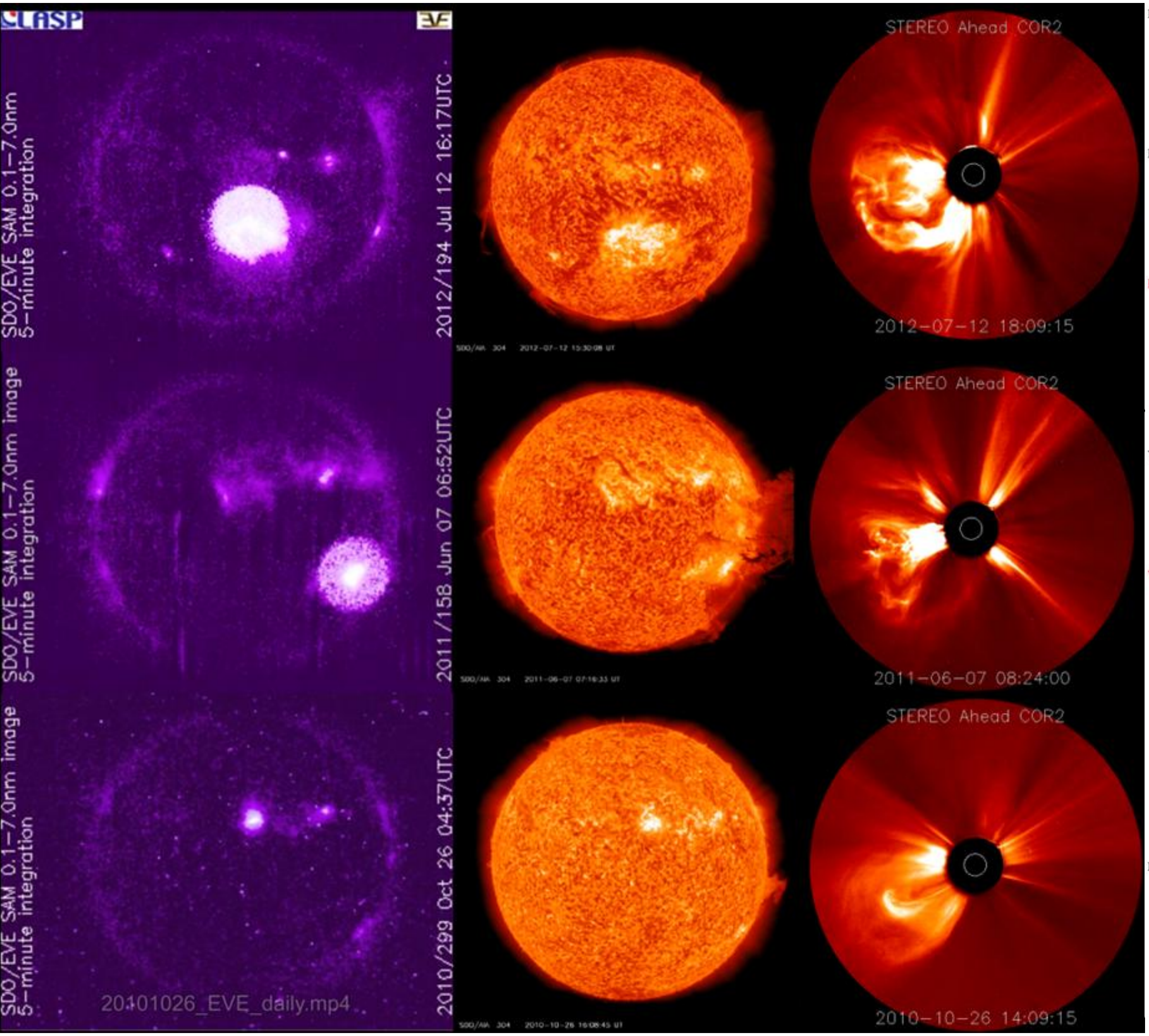


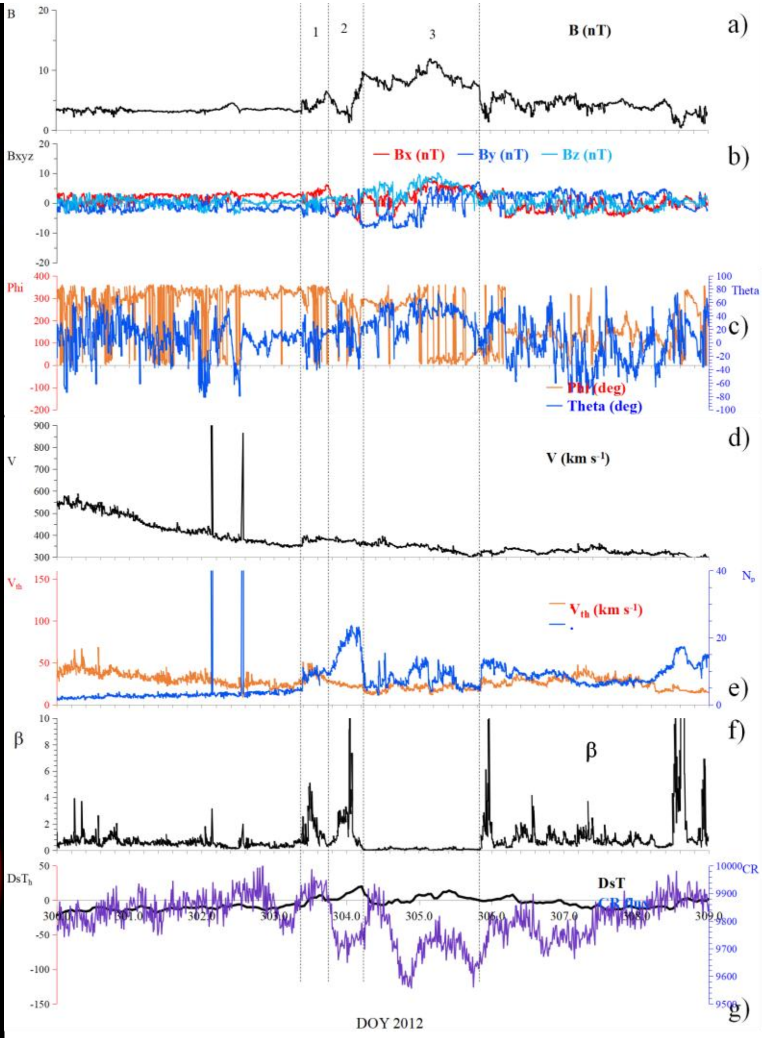
the period (DOY = 44 - 52) from 13 to 21 February 2011

- From total 105 ICMEs 67 caused solar wind disturbance.

- *39 of them caused by single arriving ICME* (~17% of all analysed SW disturbances) and 28 by ICMEs interaction (~12% of all SW disturbances).

Direct or flank





the period (DOY = 300 - 309) from 26 October to 4 November 2012

(13% of total ICME and ~2% whole SW, semple)
Stealth ICME; example 26 Oct 2010

Direct or flank

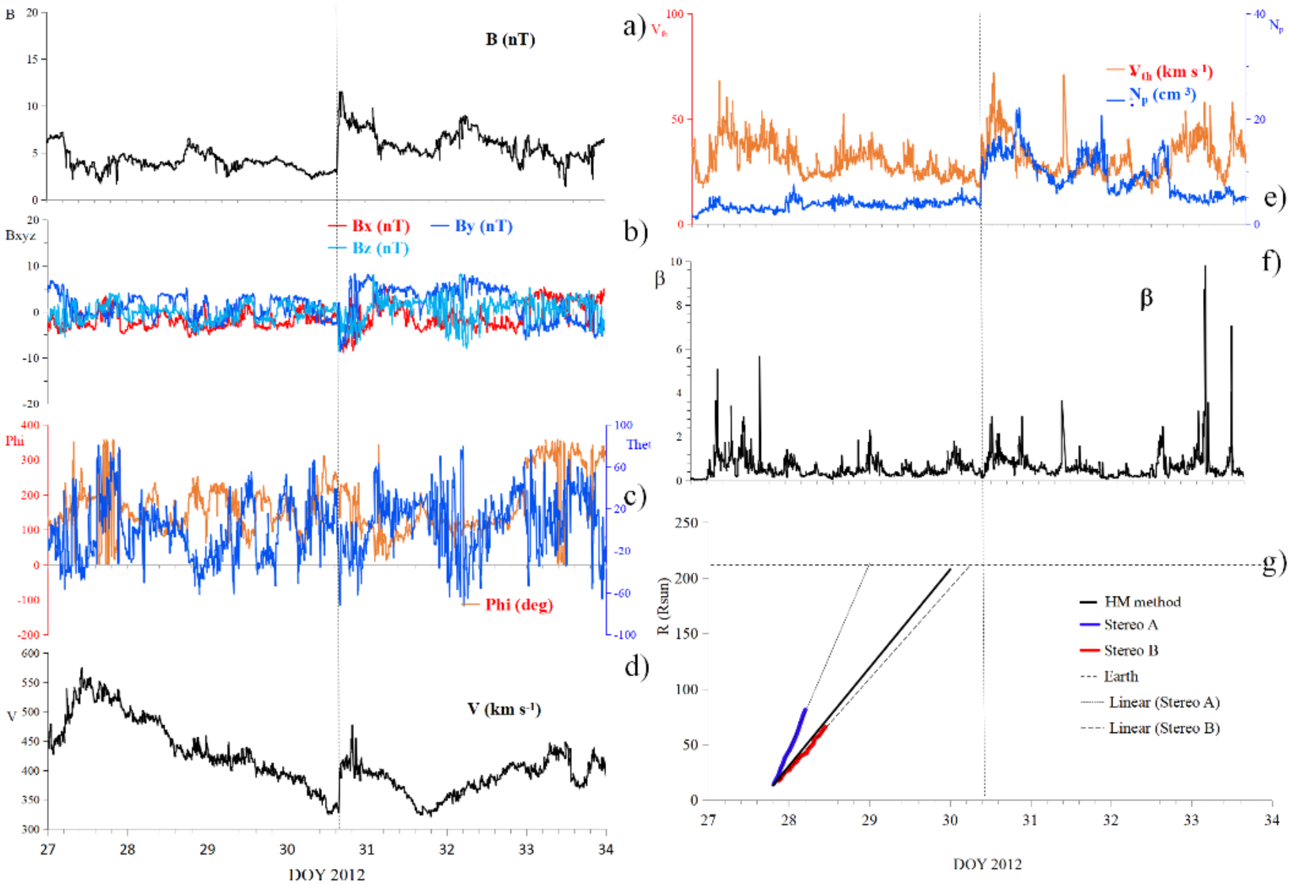
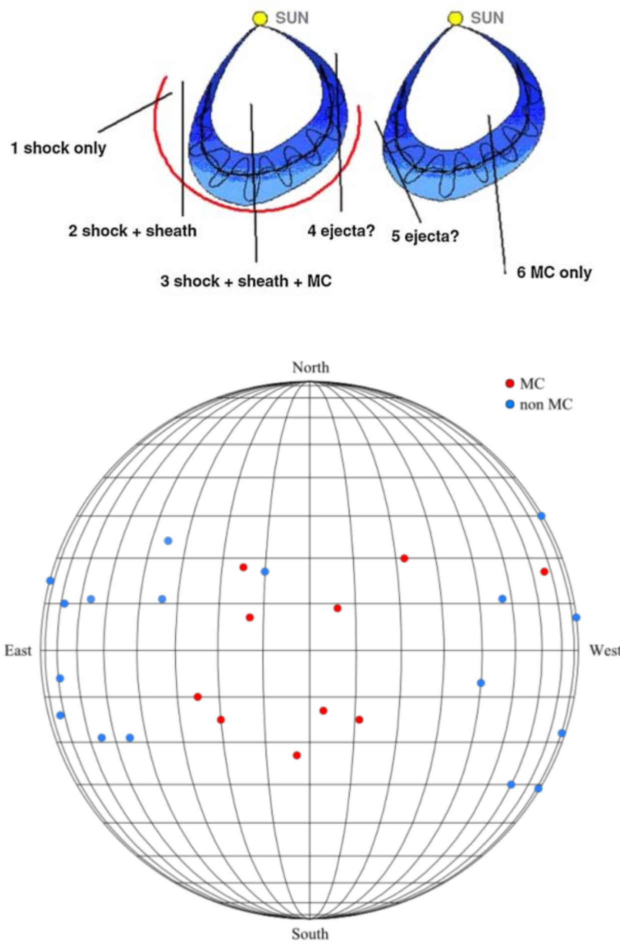
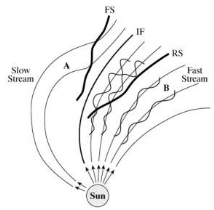


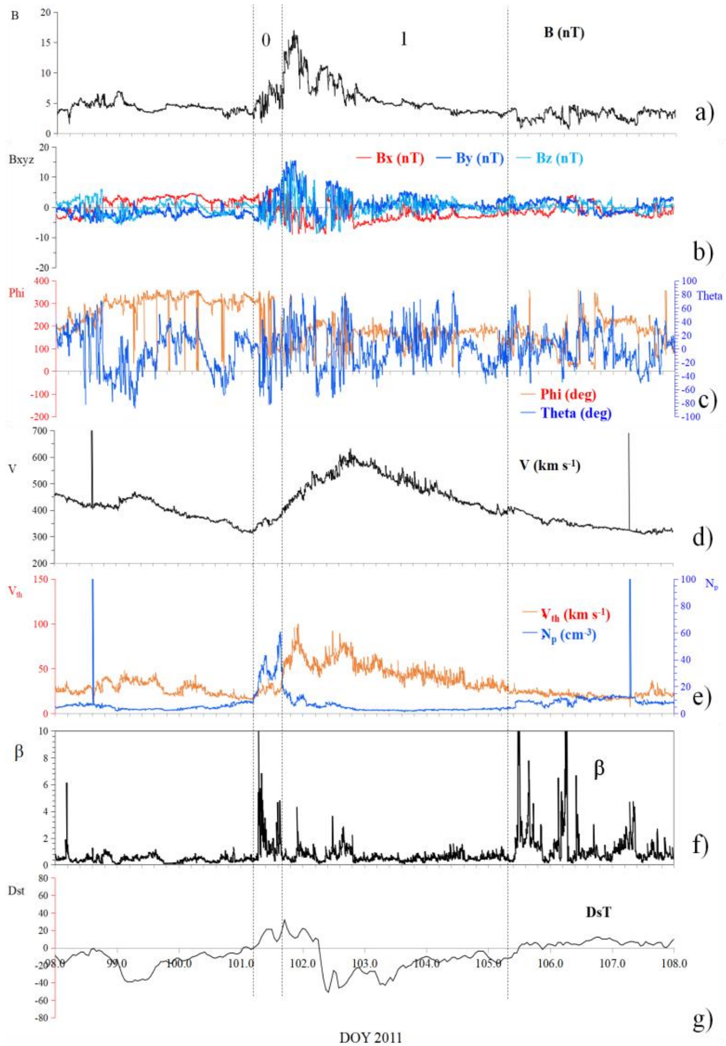
figure form Kim et al. (2013)

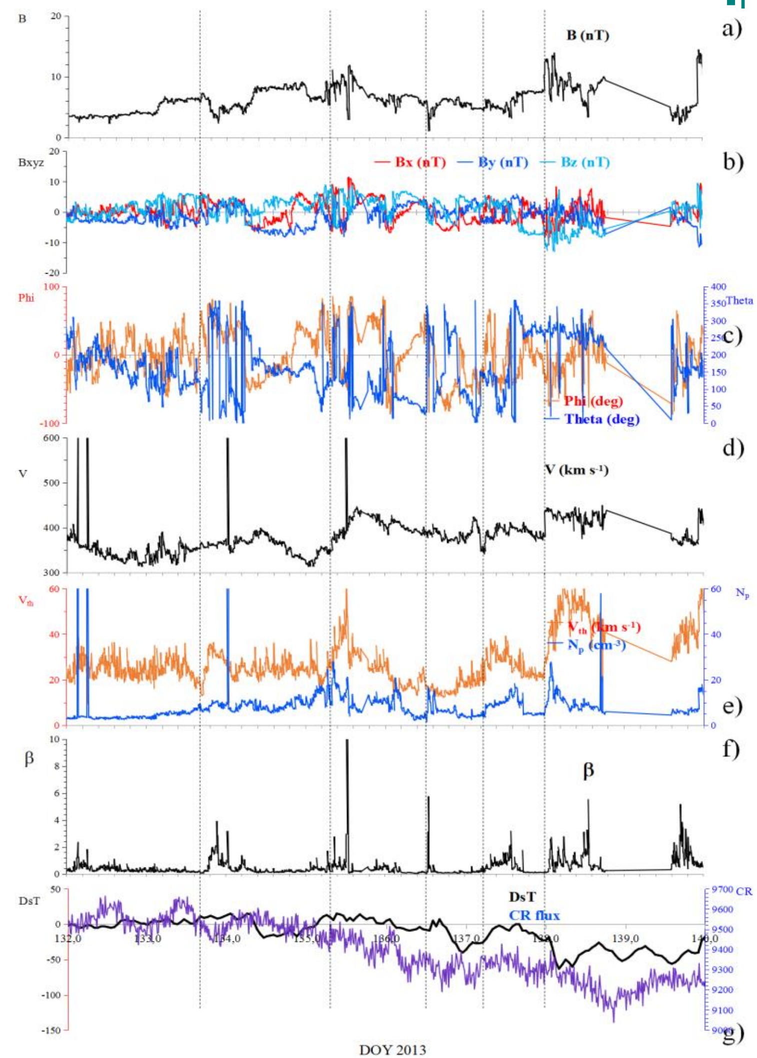


from 39 single ICMEs signatures: 18 direct and 21 flank;



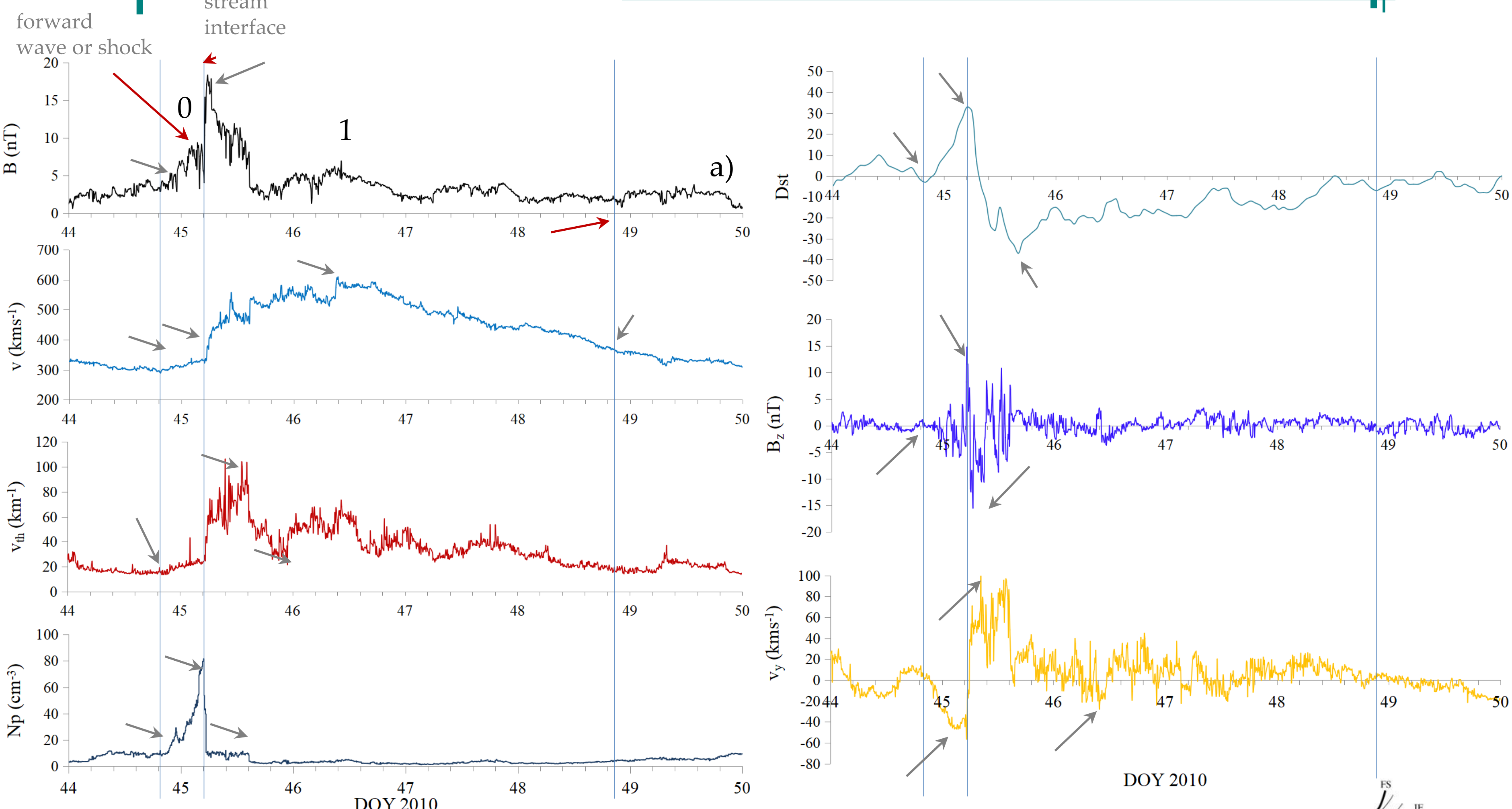
Complex disturbances





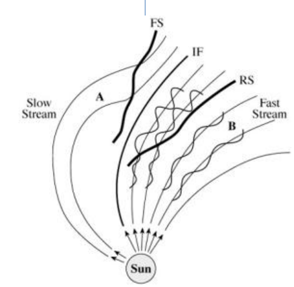
- for the analyzed period, from 219 SW disturbances 152 of them have been recognized as a HSSs
- 13 have complext structures – or interaction (6% of the SW semple) vs simple CIR 139 signatures (63% of the whole SW semple)

Measured parameters of HSS

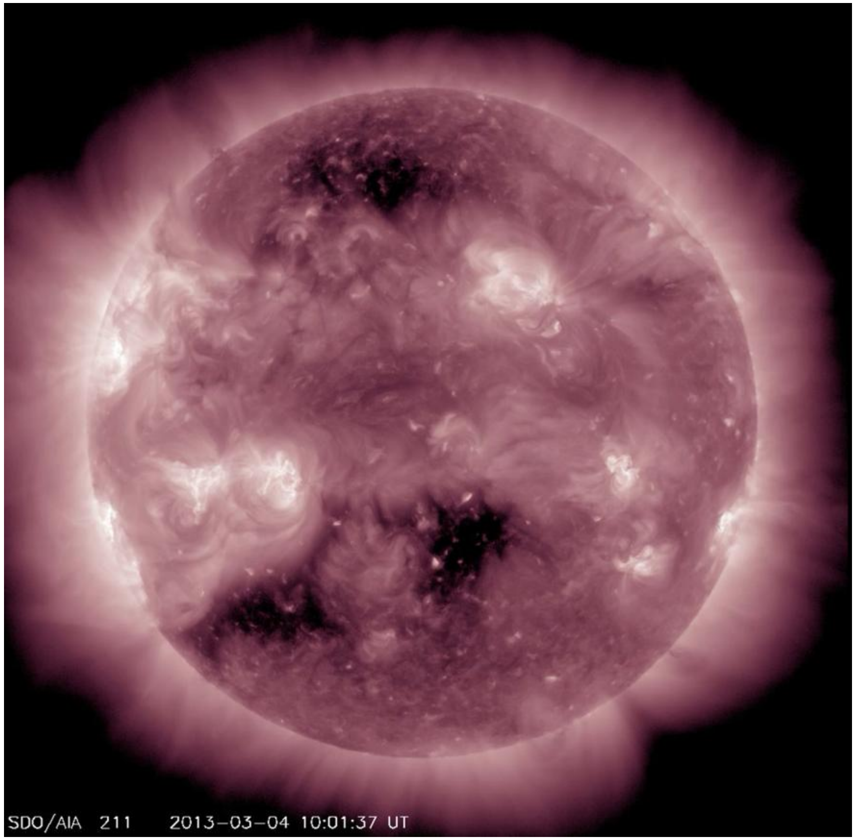


(a) magnetic field strength; (b)solar-wind speed; (c) proton thermal velocity; (d) proton density; (e) Dst index; (f) Bz component of magnetic field and (g) v_y solar-wind speed

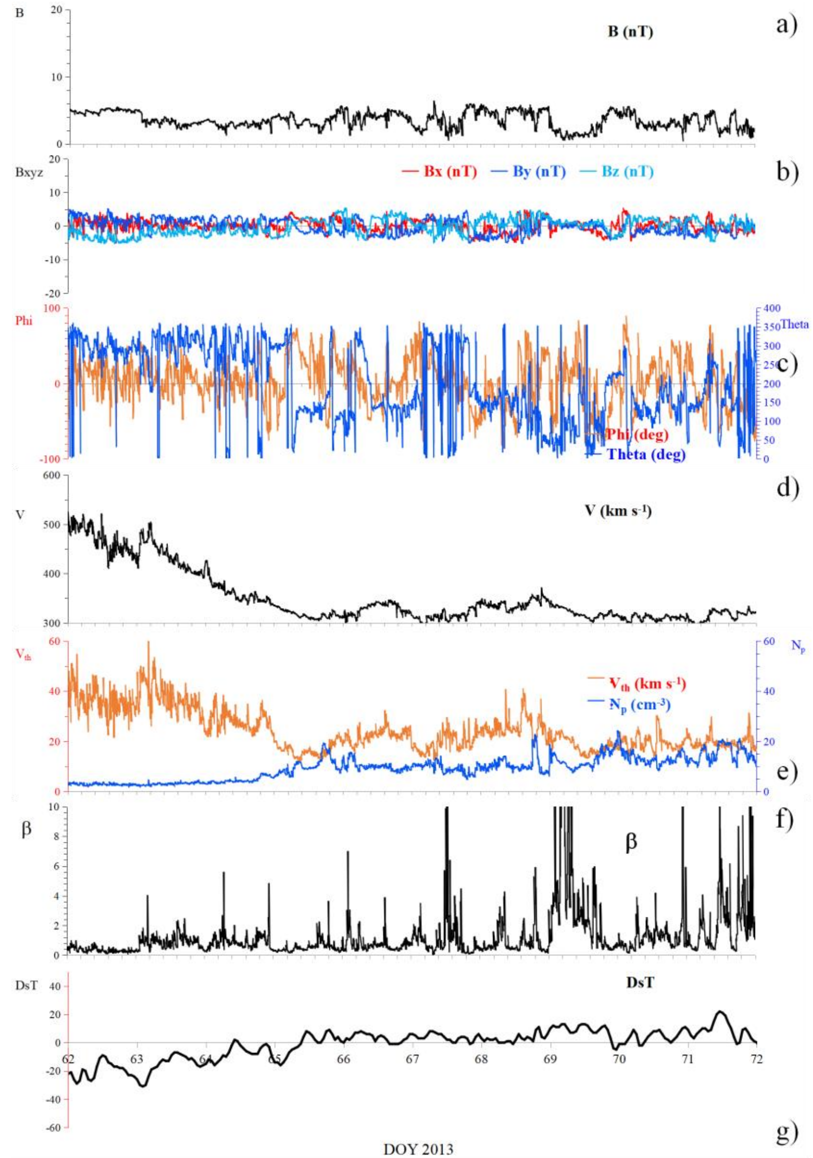
- for the analyzed period, from 219 SW disturbances 139 of them have been recognized as a CIR (69% of the whole SW disturbances semple)



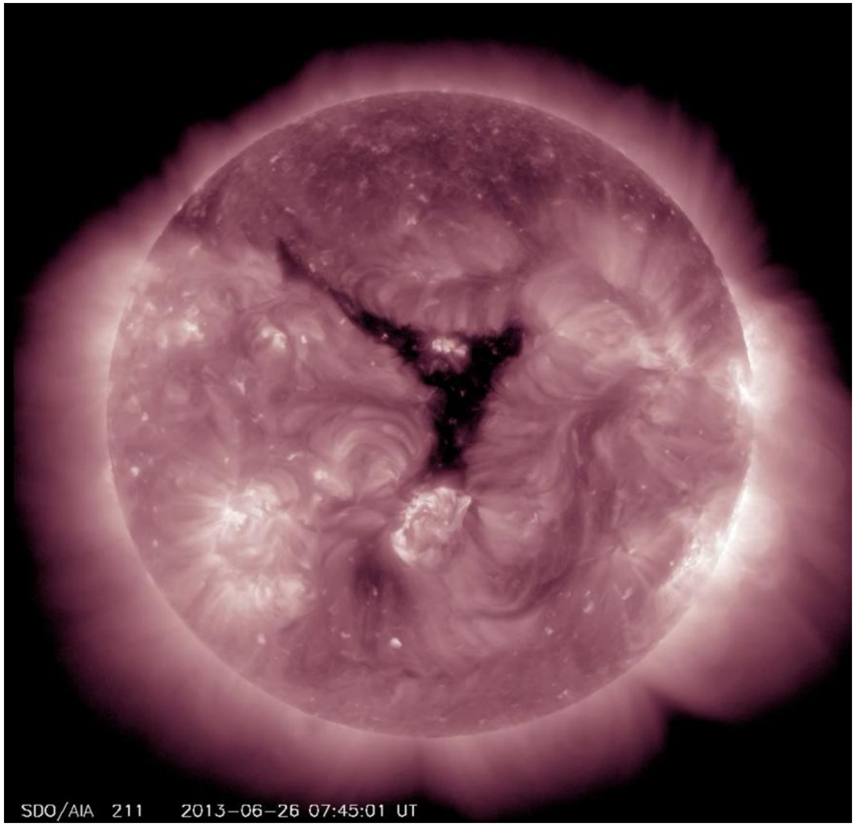
List of CHs and CHs with no *SWD*



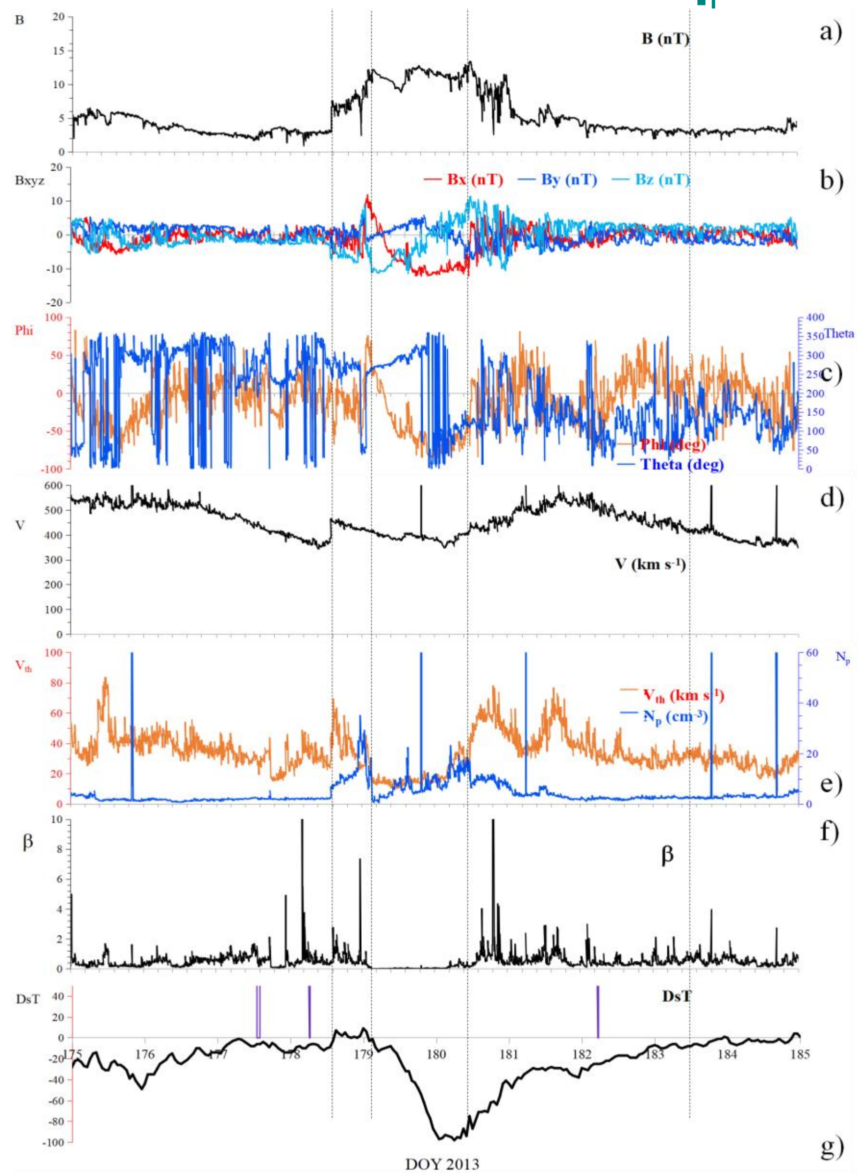
- from 156 CHs, 38 CH were without SWD signature (25% of whole CHs sample)



ICME and HSS interaction

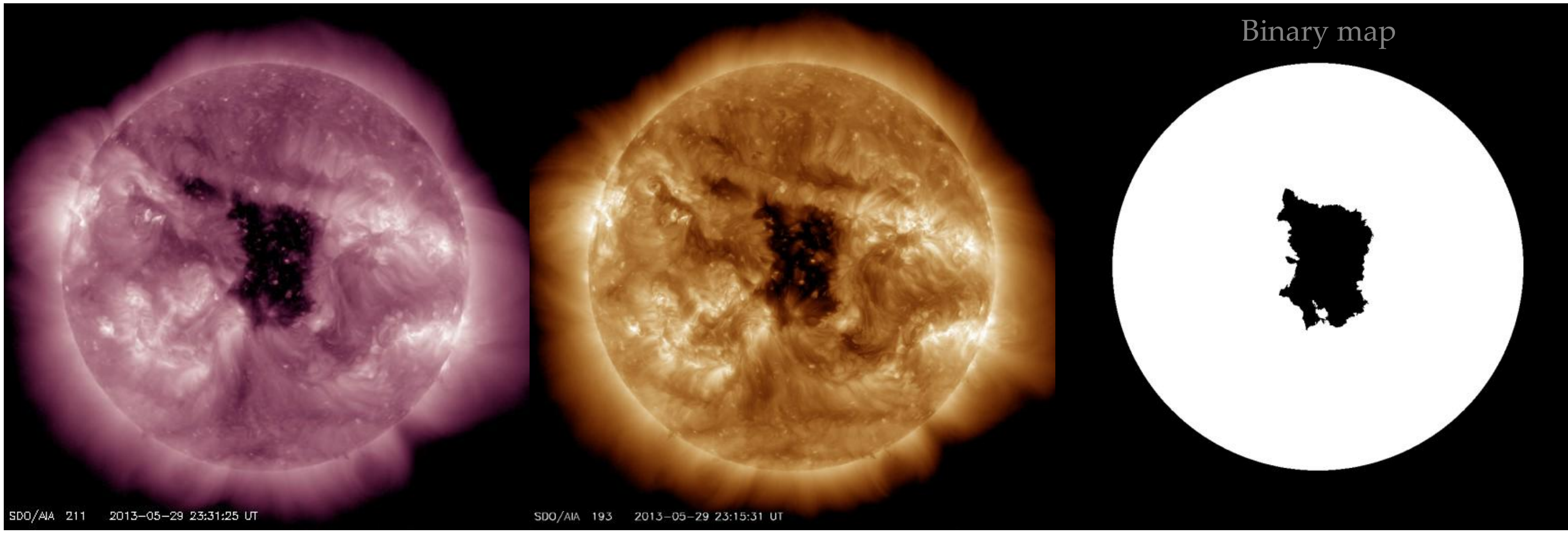


- from 219 SWD, 5 disturbances have been recognized as a posible ICME - HSS interaction



the period (DOY = 175 - 185) from 24 Jule to 4 July 2013

Measured parameters of CHs



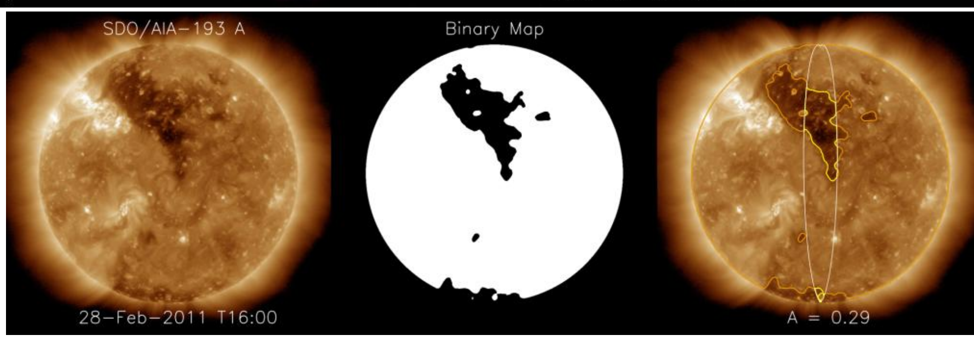
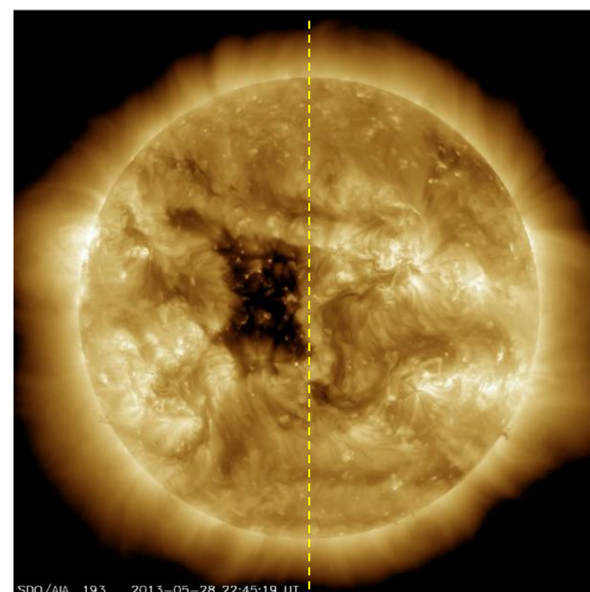


figure 1 form Rotter *et al.* (2015)

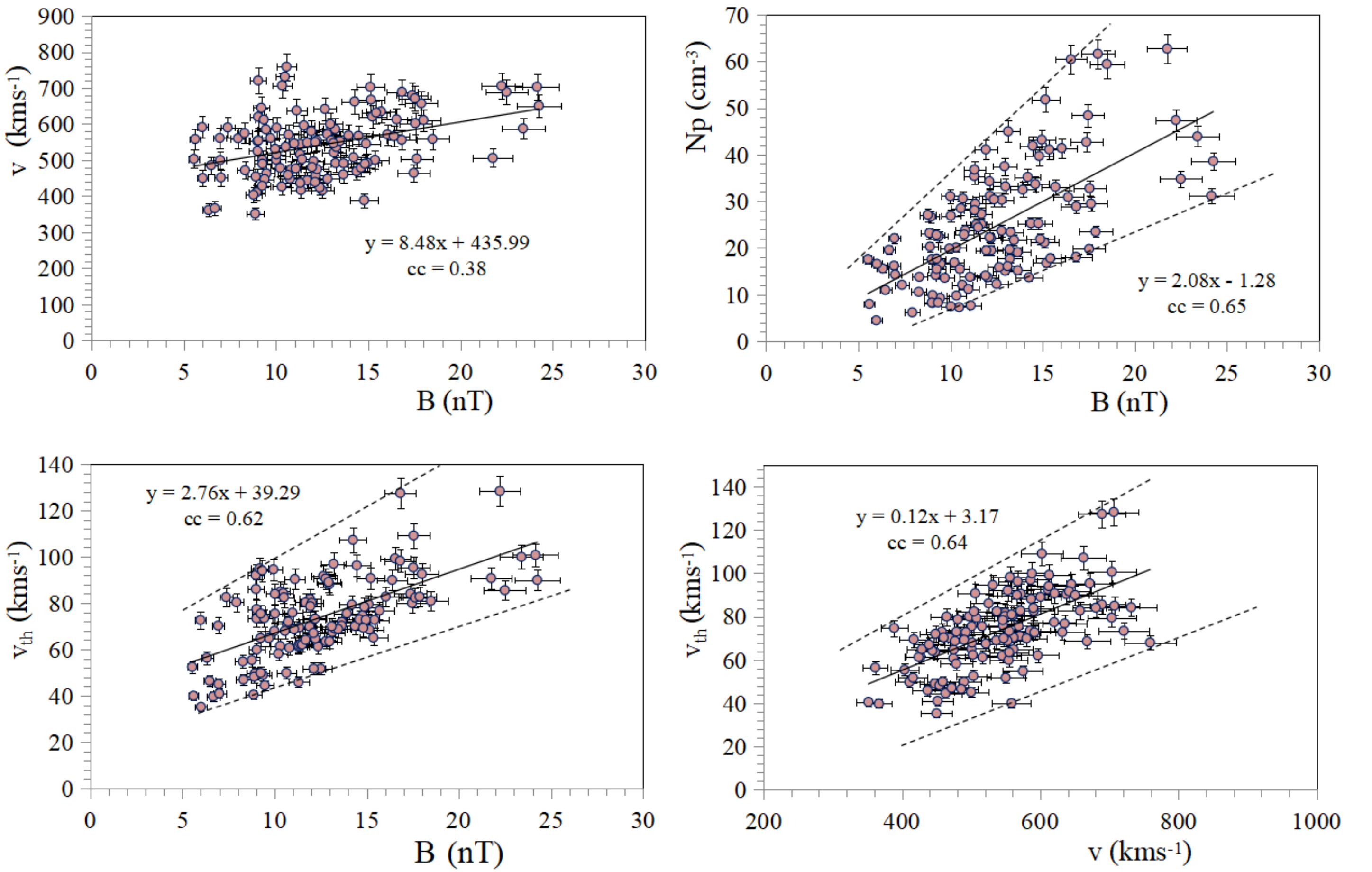


for the period from **May 2010 to December 2014** - 156 CHs were recognized

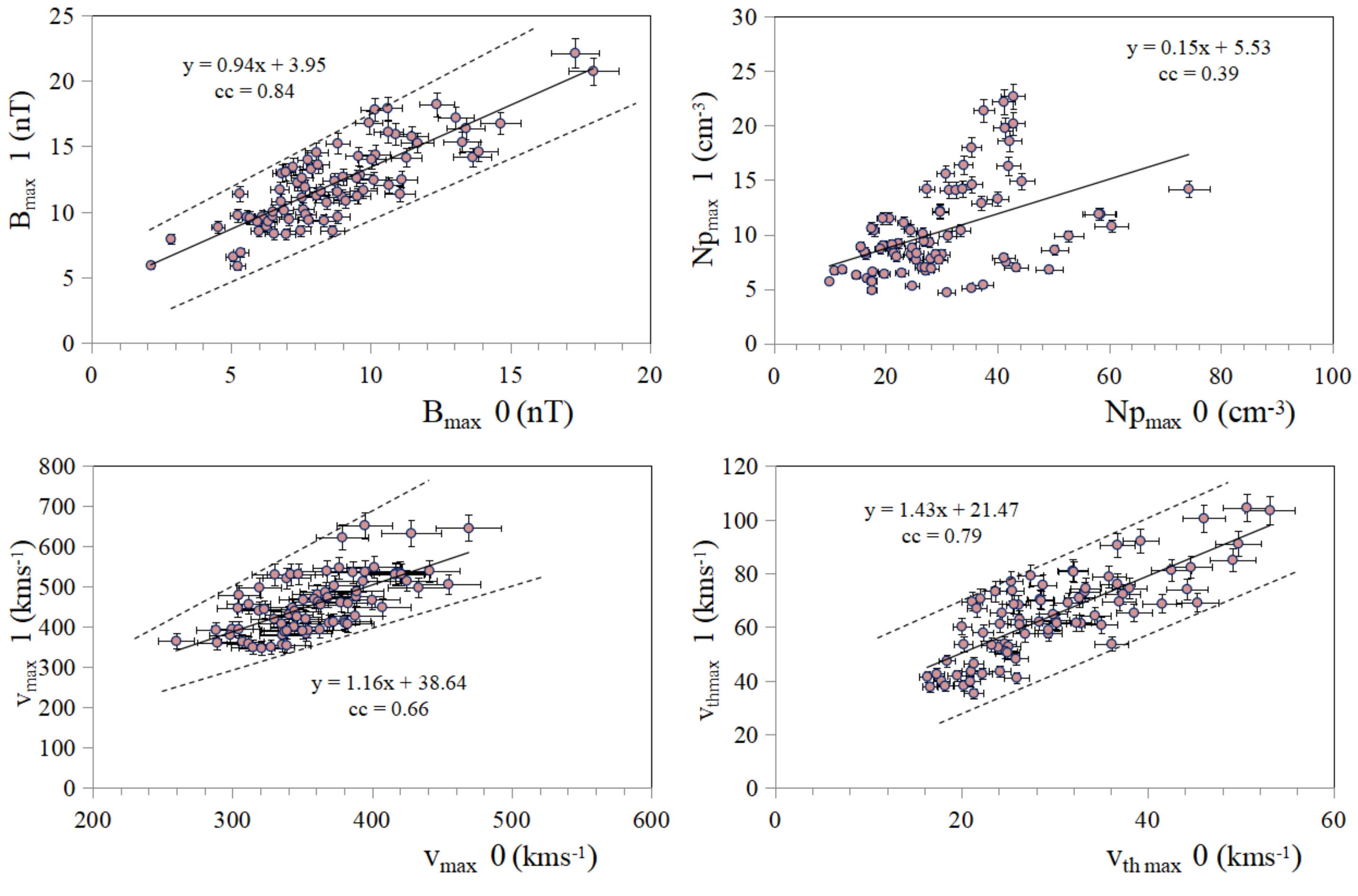
measured in SDO/AIA 19.3 and 22.1 nm data:

1. CH latidude - average width
2. CH longitude
3. onset of the CH on central solar meridian

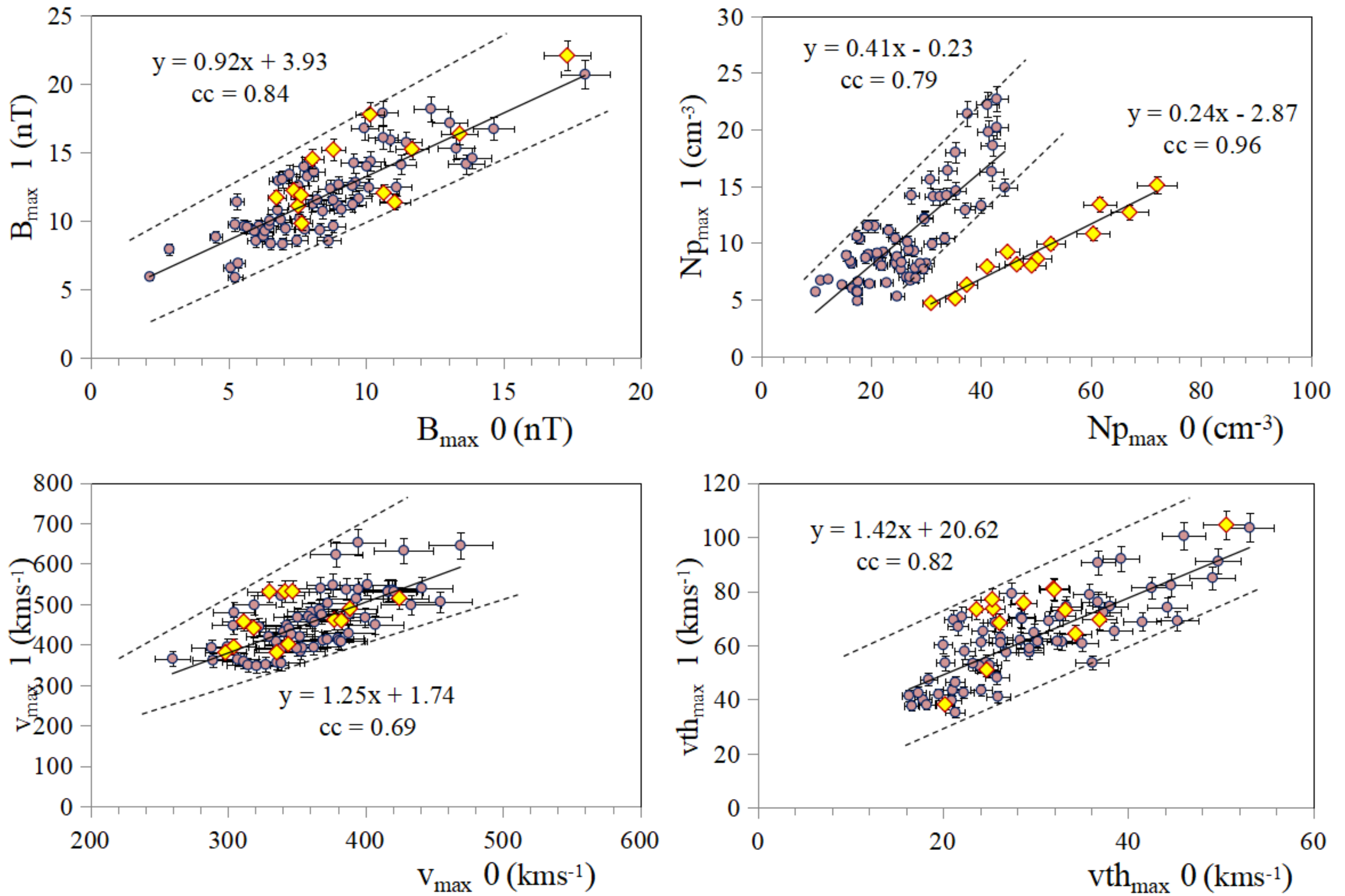
Results – SW parameters



Results – SW parameters

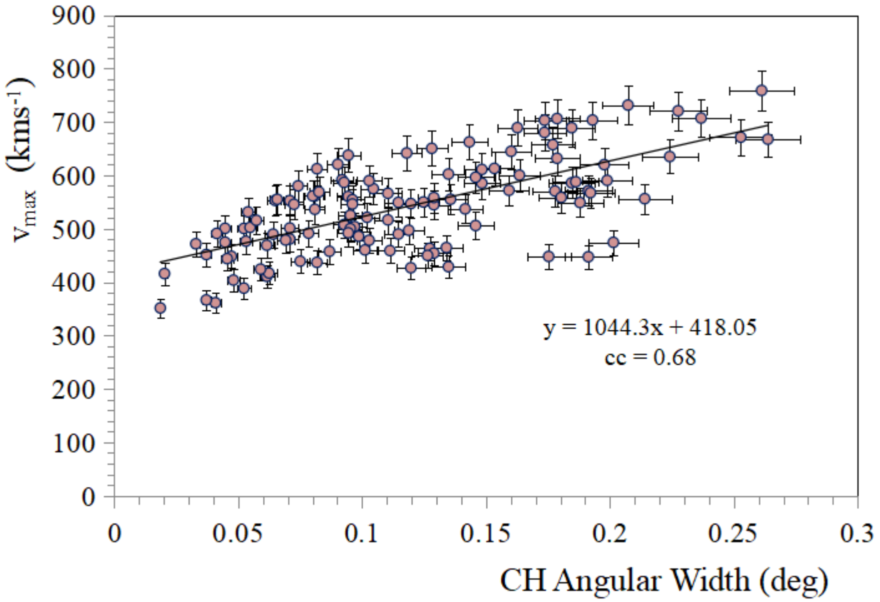


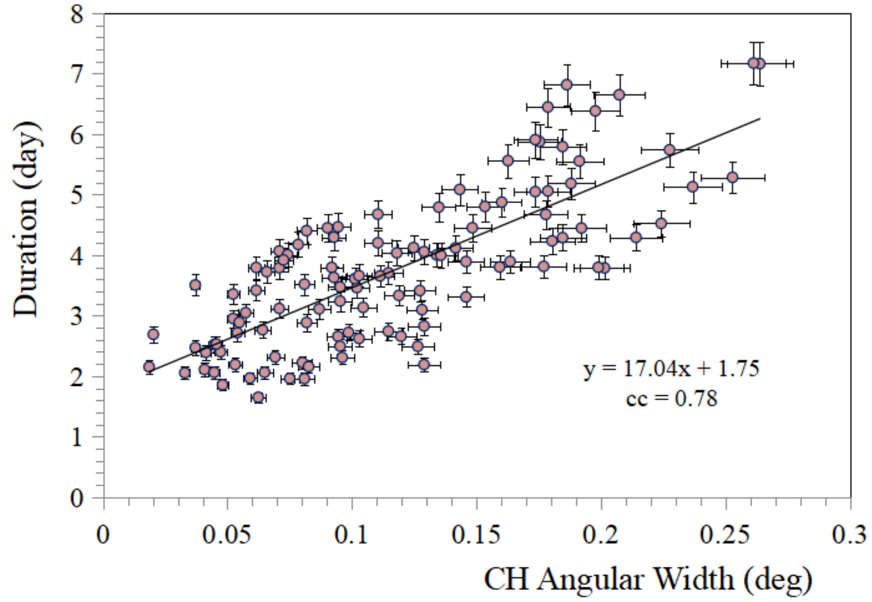
Results – SW parameters



- out of 139 CIRs only 17 have different Np correlation (12% of the whole CIRs sample)

Results – SW vs CH parameters

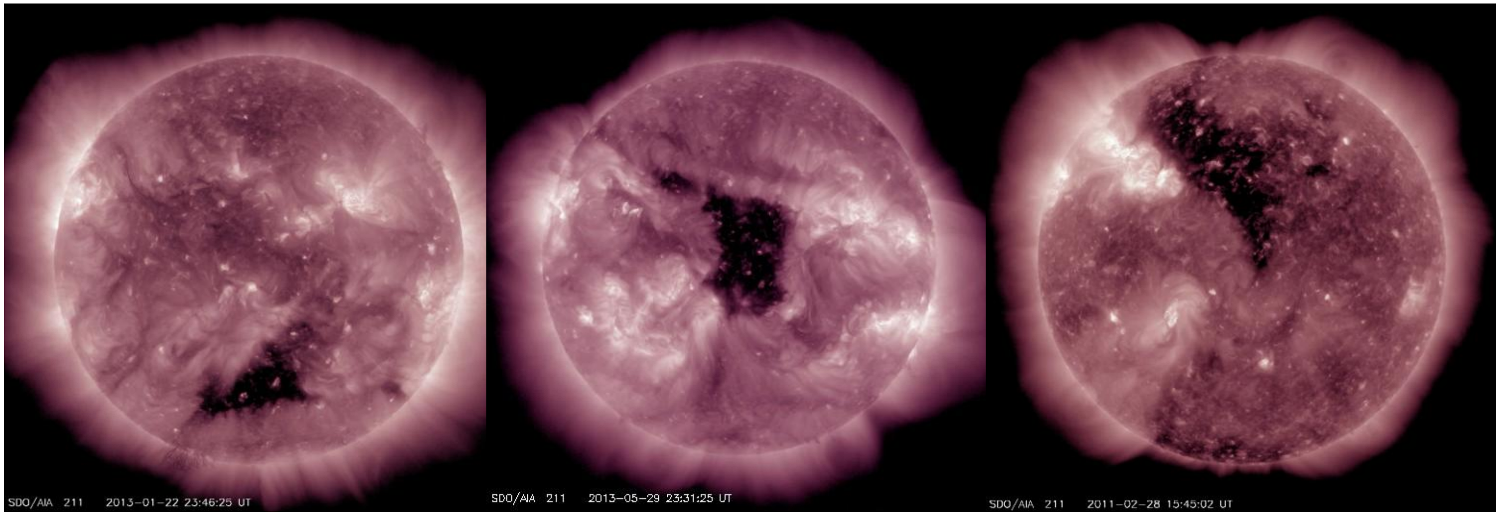


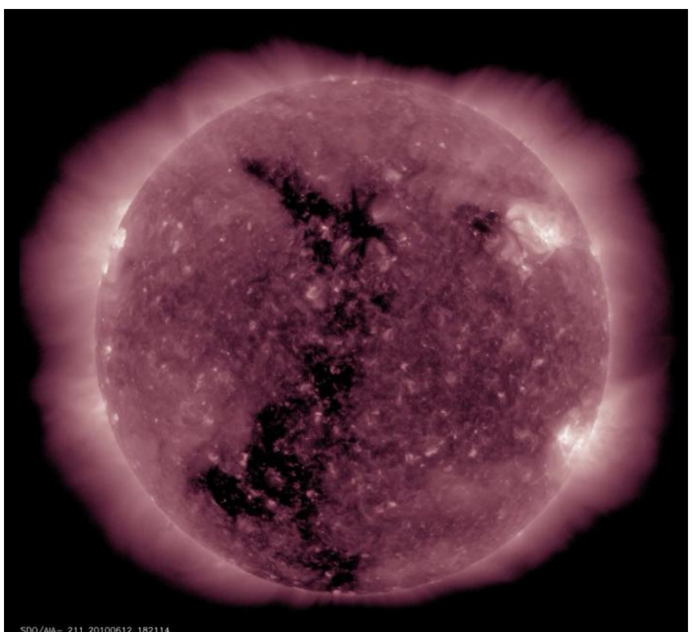


Number of CHs when compare SDO/AIA detections and *WIND* solar wind disturbance list covered period from May 2010 to December 2014

List	Number of CHs
CH list	156
SWD list	219
number of CIRs signatures	152
joined CH - SWD	118 (75% of whole CHs semple)
CH withouth SWD	38 (25% of whole CHs semple)
CIR interaction	5 (4 % of whole CHs semple)

Results – SW vs CH parameters



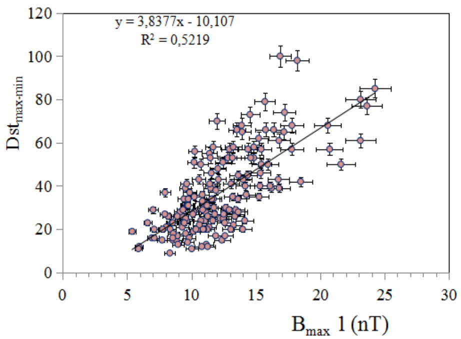


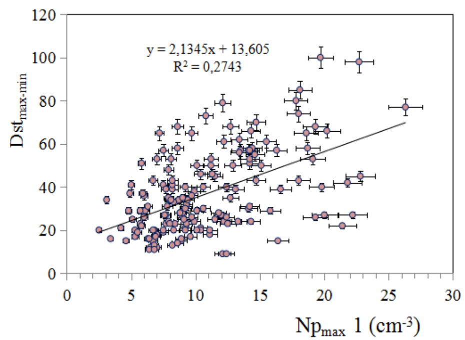
The solar wind speed arrival time

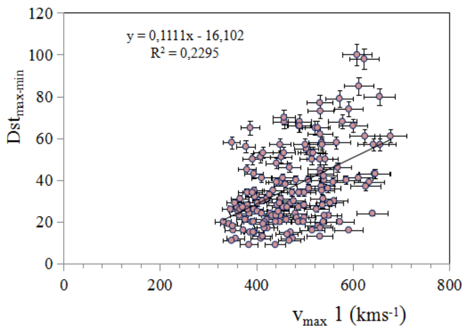
For whole CHs semple	3.18 ± 0.5 days
only equator CHs	3.05 ± 0.5 days
only south CHs	3.35 ± 0.5 days
only nord CHs	3.44 ± 0.5 days

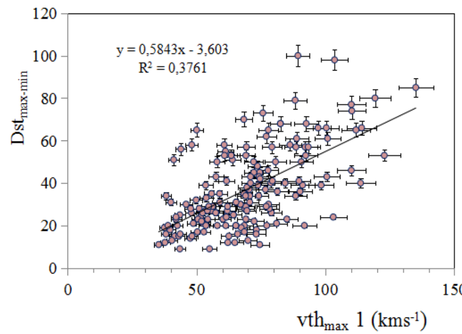
estimated values in Rotter *et al.* (2015)
4.02 ± 0.5 days

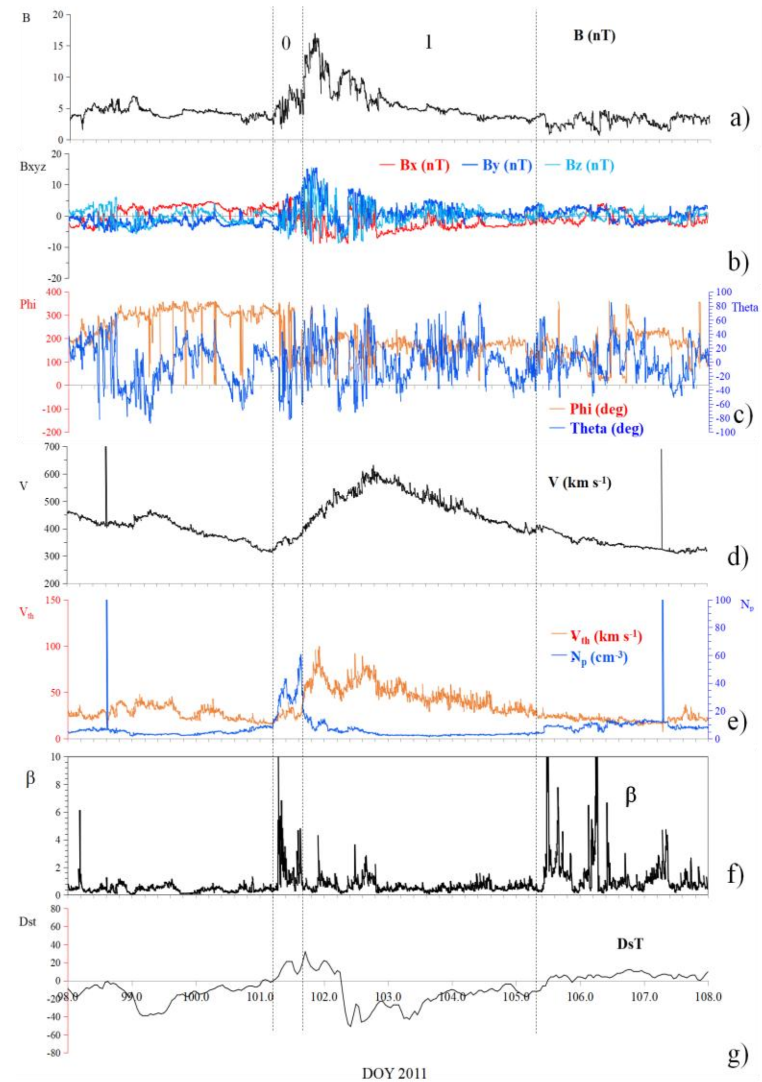
Dst - results











- the main decrease of Dst index occurs in region in front of SI;
- while the main increase of Dst index occurs between forward wave or shock and SI
- correlation of the Dst decrease (min - max) is higher for region 1 (between SI and reverse wave)

Conclusions

from the analysis of SW disturbances ⇒ we foud 219 solar wind disturbances from May 2010 to the December 2014 (4.5 years period).

removing ICMEs signatures ⇒ from elogation-time, using HM approximation, we calculated the direction and arrival time of ICME at Earth distance. 105 CMEs can be connected with 67 corresponding SW disturbance.

clasification of SW signatures ⇒ corotating interaction regions (CIRs) ~ 61 %, interplanetary coronal mass ejections (ICMEs) ~ 24 %, interactions and complex signatures ~ 15 %;

from analysis of the SW parameters ⇒

- correlation coeff. of magnetic field *B*, proton thermal speed v_{th} and flow speed *V* between the region in front and behind the SI are: cc = 0.83, 0.78 and 0.6, respectively
- correlation of proton density *Np* in front and behind the SI indicated two different families of CIRs with correlation coefficients cc = 0.83 and 0.96
- we found high correlation between CH angular width with flow speed and duration od SW disturbance (cc = 0.68 and 0.78 respectivelly)

in future ⇒ estimate and analyze coronal hole (in more then two wavelengths) as a place of origin of the CIRs, using the data from SDO Atmospheric Imaging Assembly (AIA) and Helioseismic Magnetic Imager (HMI)