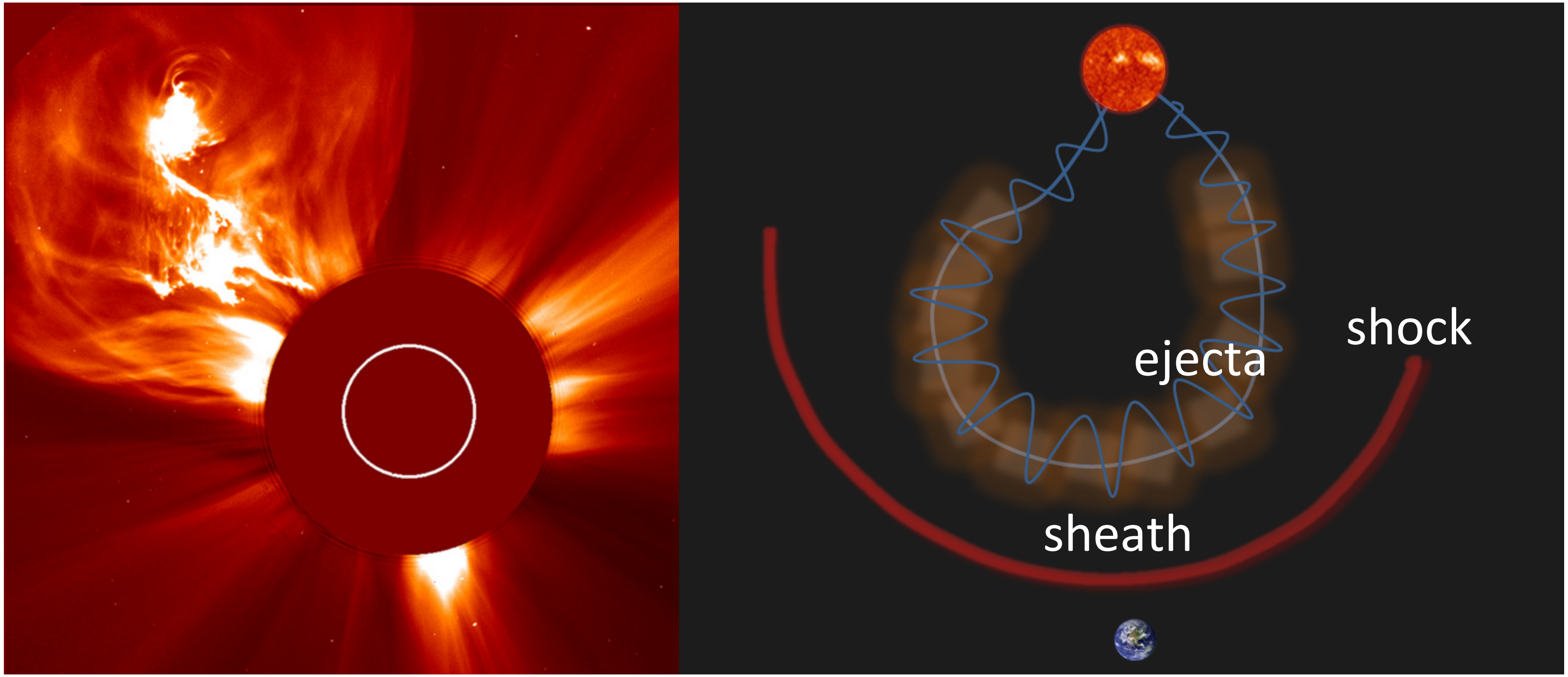
INTERNAL STRUCTURE OF INTERPLANETARY CORONAL MASS EJECTIONS AND RELATION TO REMOTE SENSING OBSERVATIONS

Emilia K.J Kilpua, A. Isavnin, A. Vourlidas, H. Koskinen, and L. Rodriguez,

Emilia Kilpua
University of Helsinki, Department of Physics, Finland
email: emilia.kilpua@helsinki.fi

UNIVERSITY OF HELSINKI
FACULTY OF SCIENCE



All CMEs have FRs? (e.g., Krall et al., 2006; Vourlidas et al., 2013)

in-situ reality

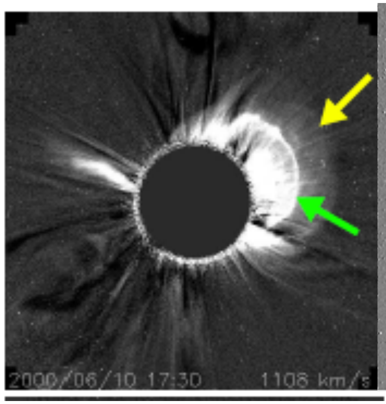
- range of signatures
- only about ~1/3 of ICMEs are FRs
- FR may occupy only a part of the ejecta
  (e.g., Gosling, 1990; Richardson and Cane, 2010, Kilpua et al, 2013)

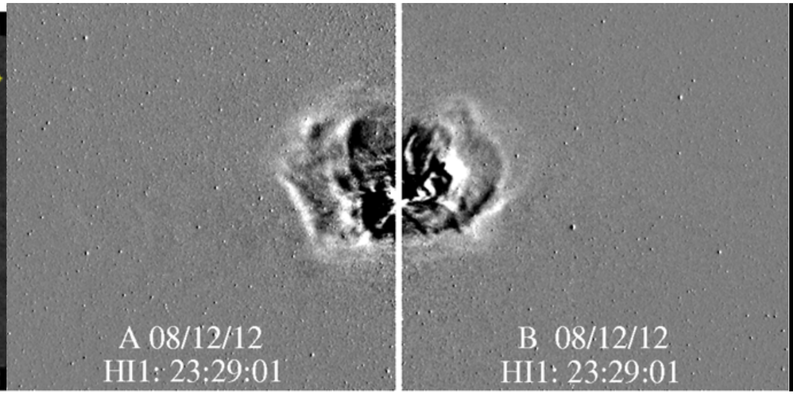
Motivation

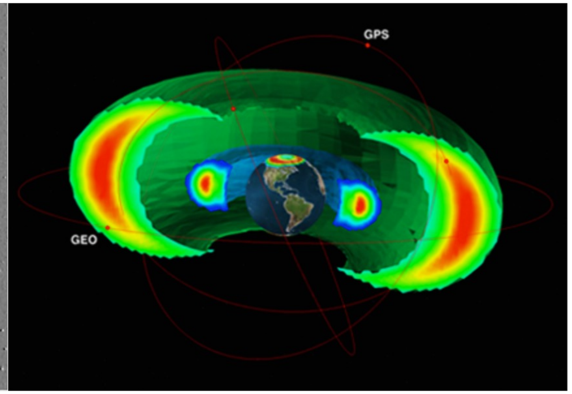
- Space weather forecasting
  - ICME substructures have different origin, properties and response of the near-Earth space environment
  - ring current vs. high-latitude currents (Huttunen et al., 2002; 2004)
  - key for Van Allen Belt response (Kilpua et al., 2015)

- Understanding formation and evolution CMEs

- Link to the remote sensing observations

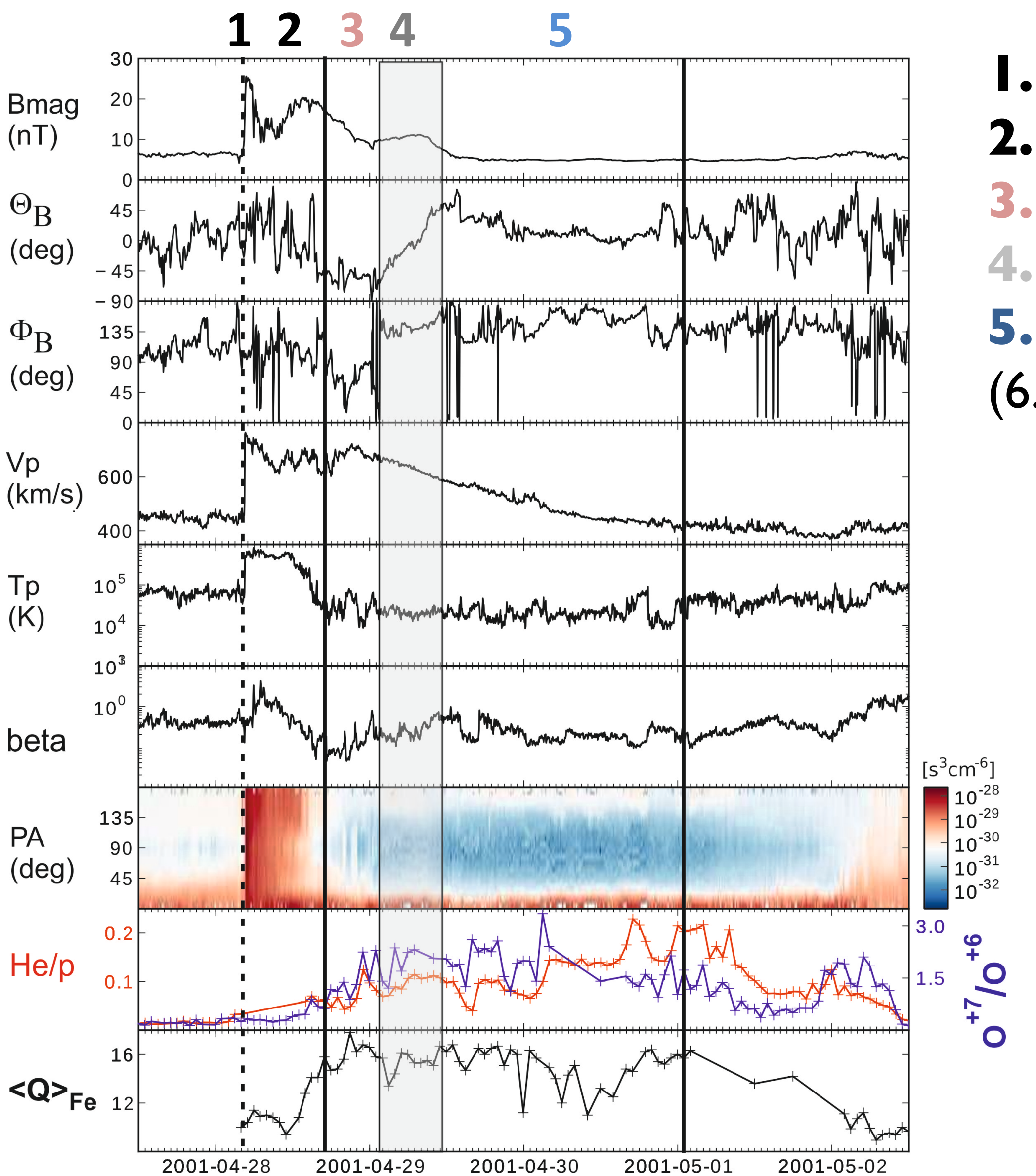






Kilpua et al., 2015 http://onlinelibrary.wiley.com/doi/10.1002/2015GL063542/full
Huttunen et al., 2002 http://adsabs.harvard.edu/abs/2002JGRA..107.1121H
Huttunen et al., 2004 http://adsabs.harvard.edu/abs/2004AnGeo..22.1729H

5-part interplanetary CME



1. shock

2. sheath (9.1 h)

3. front region (7.1 h)

4. flux rope (20.6 h)

5. back region (17.6 h)

(6. density blob)

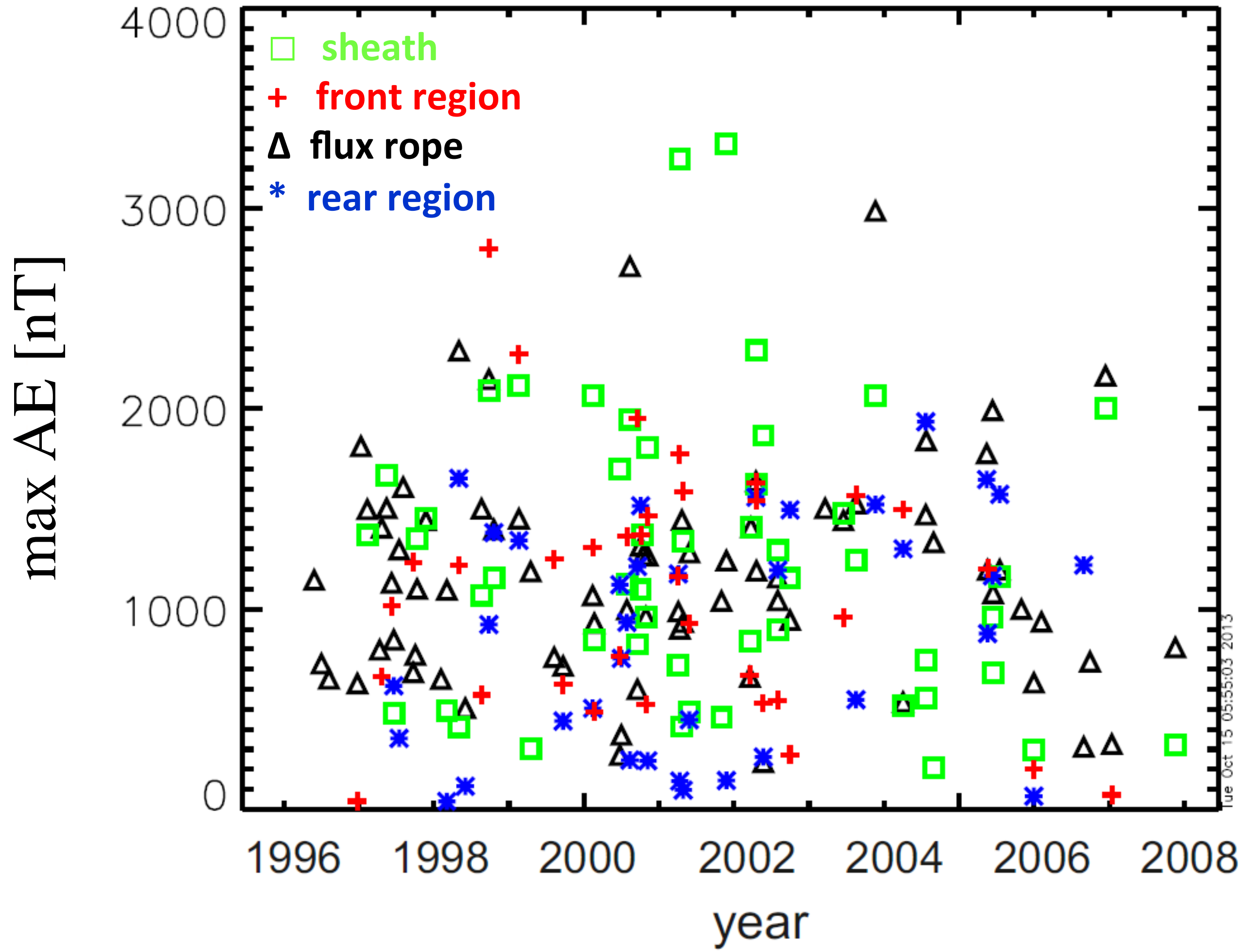
- 79 events analyzed (SC 23)
- R&C ICME list and Wind FR list

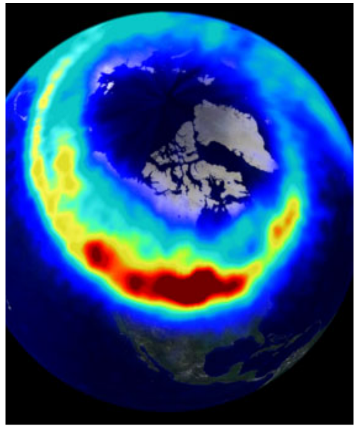
- FR and ejecta times coincide if front and rear regions last < 2 hours
- significant difference if > 6 hours

	leading edge	trailing edge	both edges
coincide	54%	46%	30%
significant difference	22%	38%	11%

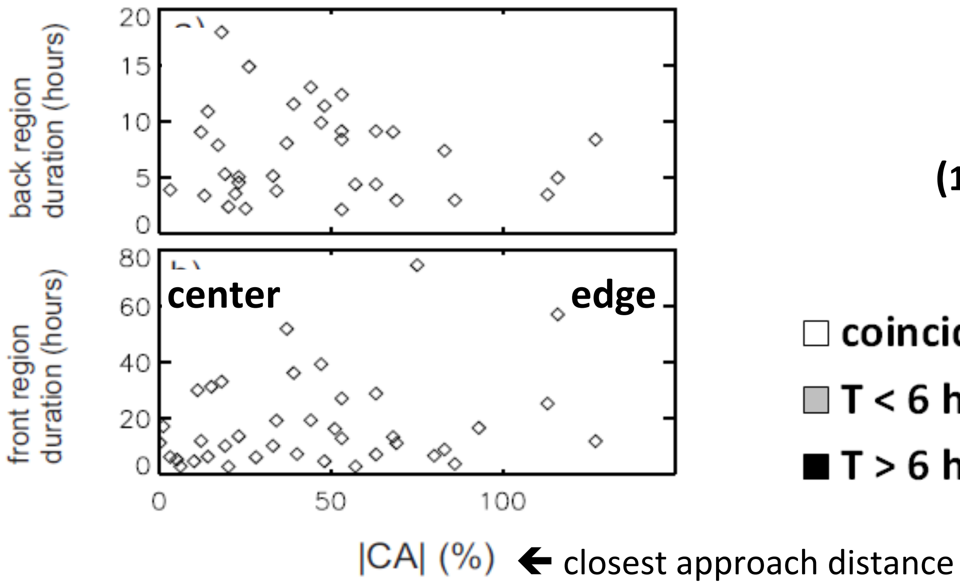
Kilpua et al., 2013, www.ann-geophys.net/31/1251/2013/

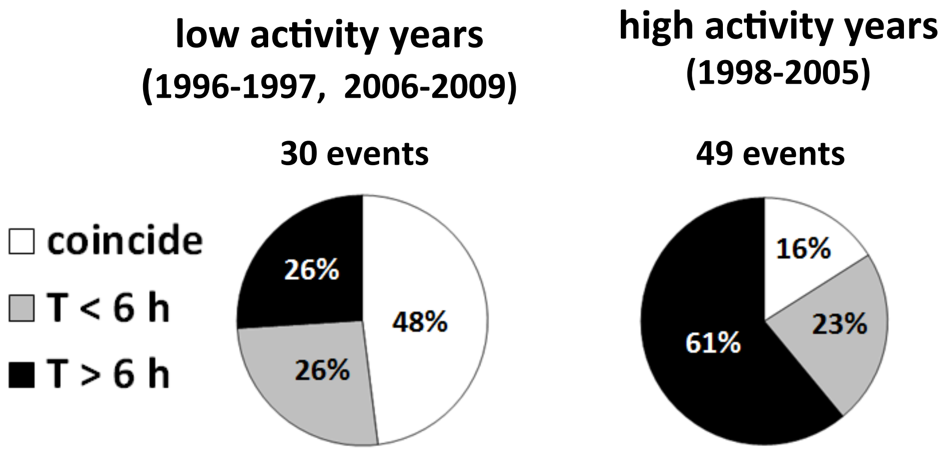
Geomagnetic response of different regions



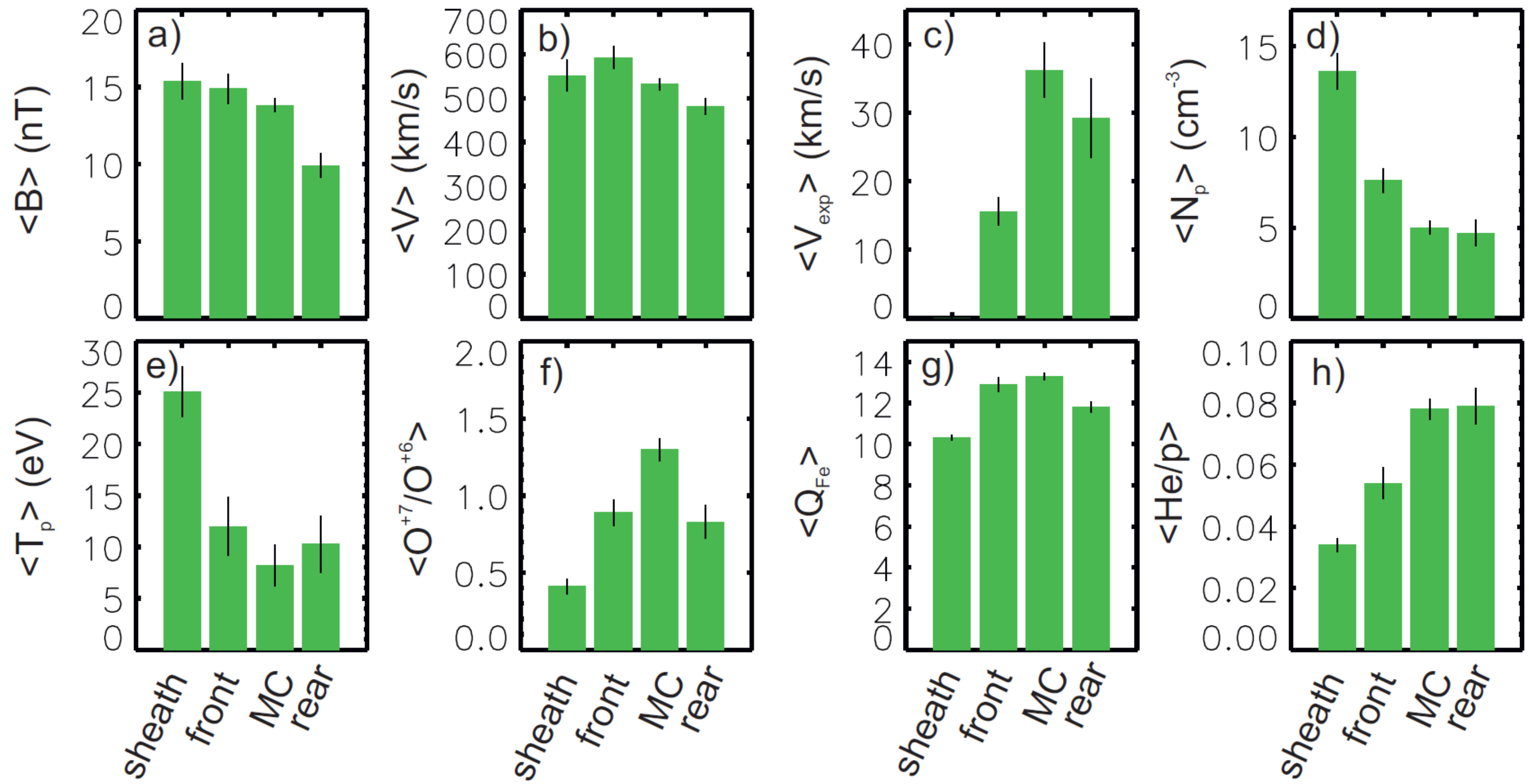


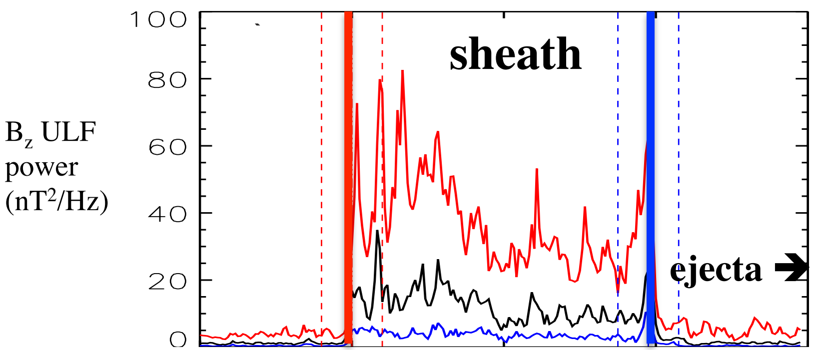
	LEADING EDGE		TRAILING EDGE	
	coincide	> 6 hours	coincide	> 6 hours
Events	43	17	36	30
V_{max} [km/s]	485	566	470	596
B_{max} [nT]	18.0	19.2	16.5	22.5
d_{FR} [AU]	0.21	0.25	0.21	0.20
$V_{exp} > 50$ km/s	13%	37%	11%	40%
V_{up} [km/s]	386	433	385	420
V_{down} [km/s]	425	448	432	464





Characteristics of different regions

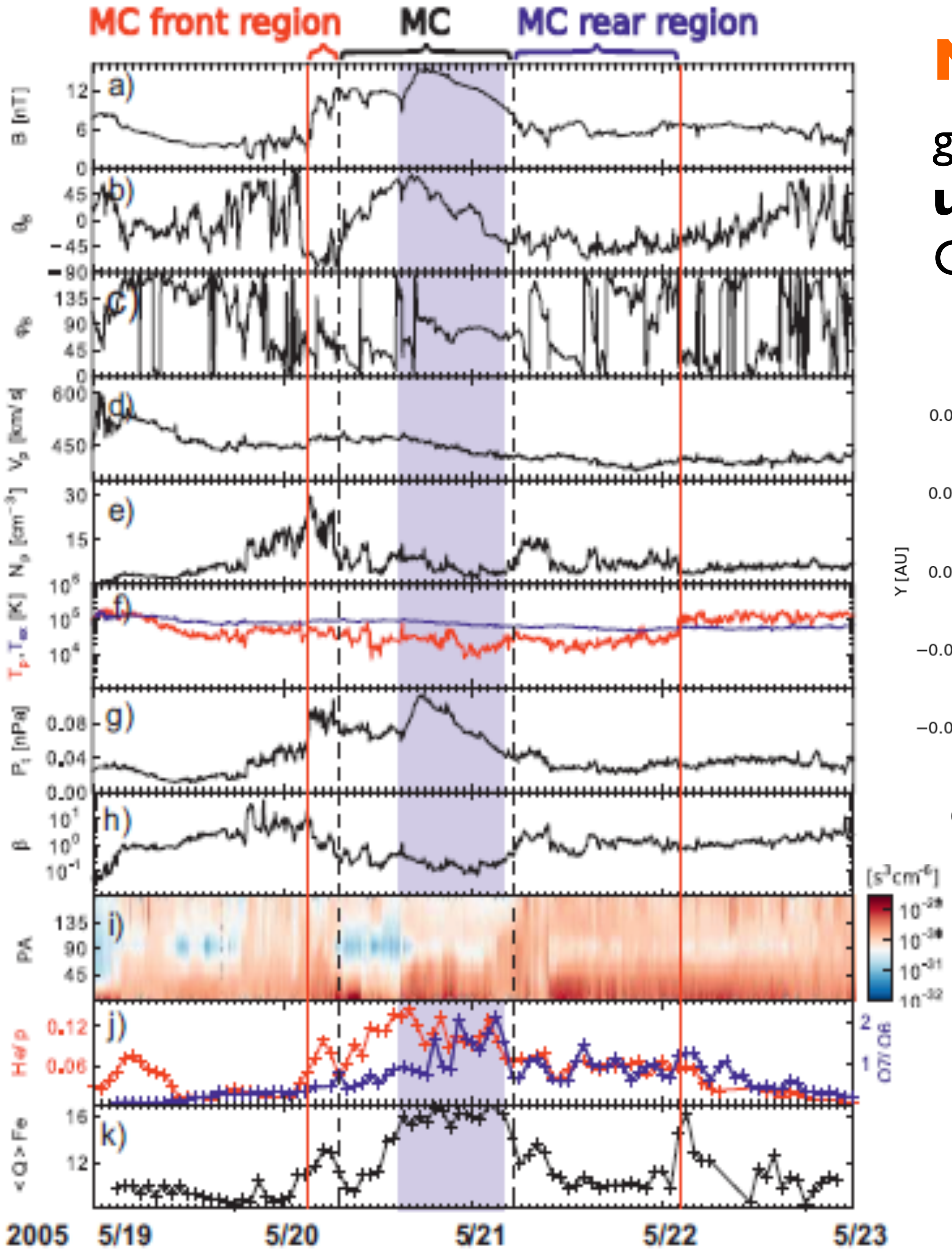




superposed epoch analysis (41 sheaths resampled to the same duration, population mean)

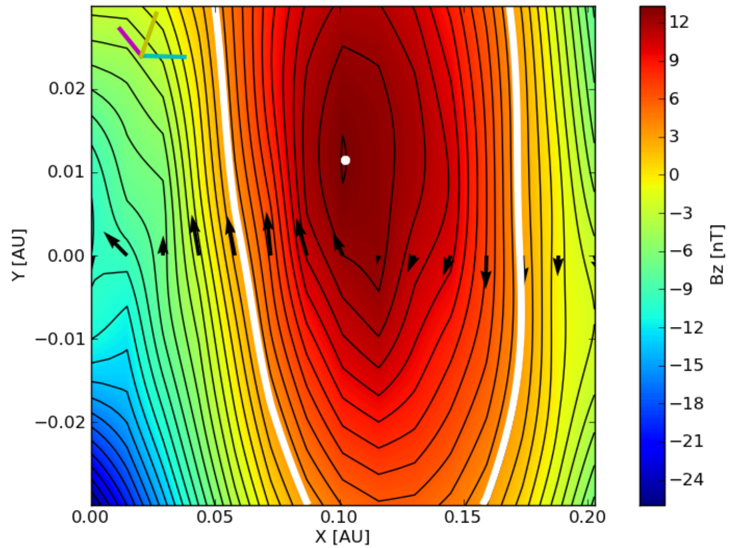
median, **upper quartile**, **lower quartile**

Kilpua et al., 2013, http://adsabs.harvard.edu/abs/2013AnGeo..31.1559K



May 20-21, 2005

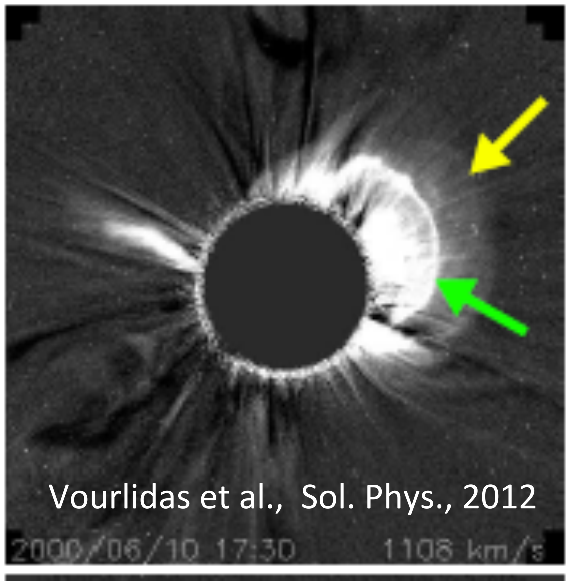
gray area:
unperturbed flux rope from Grad-Shafranov reconstruction



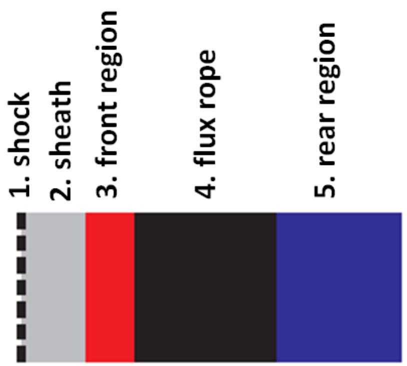
GS: produces the direction of the invariant FR axis and the reconstruction of the local cross-section. Assumes 2.5-D structures. Each helical equipotential line crossed twice, same Pt twice.

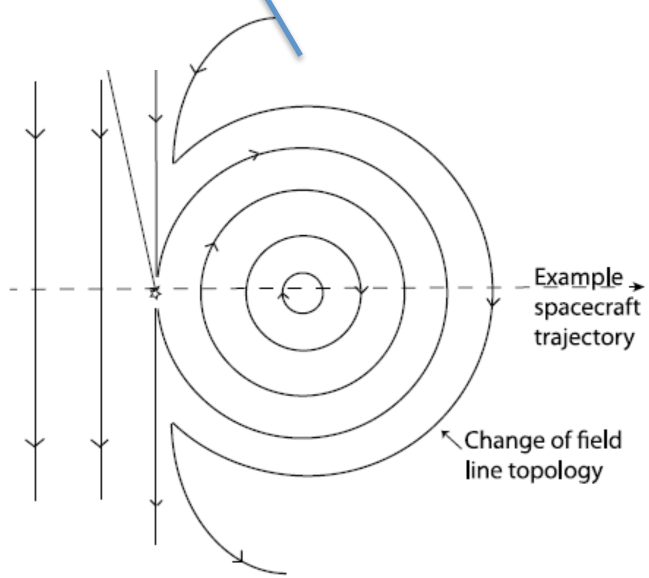
Kilpua et al., 2013, www.ann-geophys.net/31/1251/2013/

In-situ	Formation	Coronagraph
shock		shock
sheath	piled-up during travel from Sun to 1 AU	mainly further out
front region	perturbed front part of erupted FR, coronal arcades overlying erupting FR	bright rim, part of cavity
flux rope	**unperturbed** part of solar FR	cavity
rear region	perturbed end part of erupted FR, continuing outflows after FR	part of cavity, outflow?
blob	prominence material carried to ~1 AU	bright core



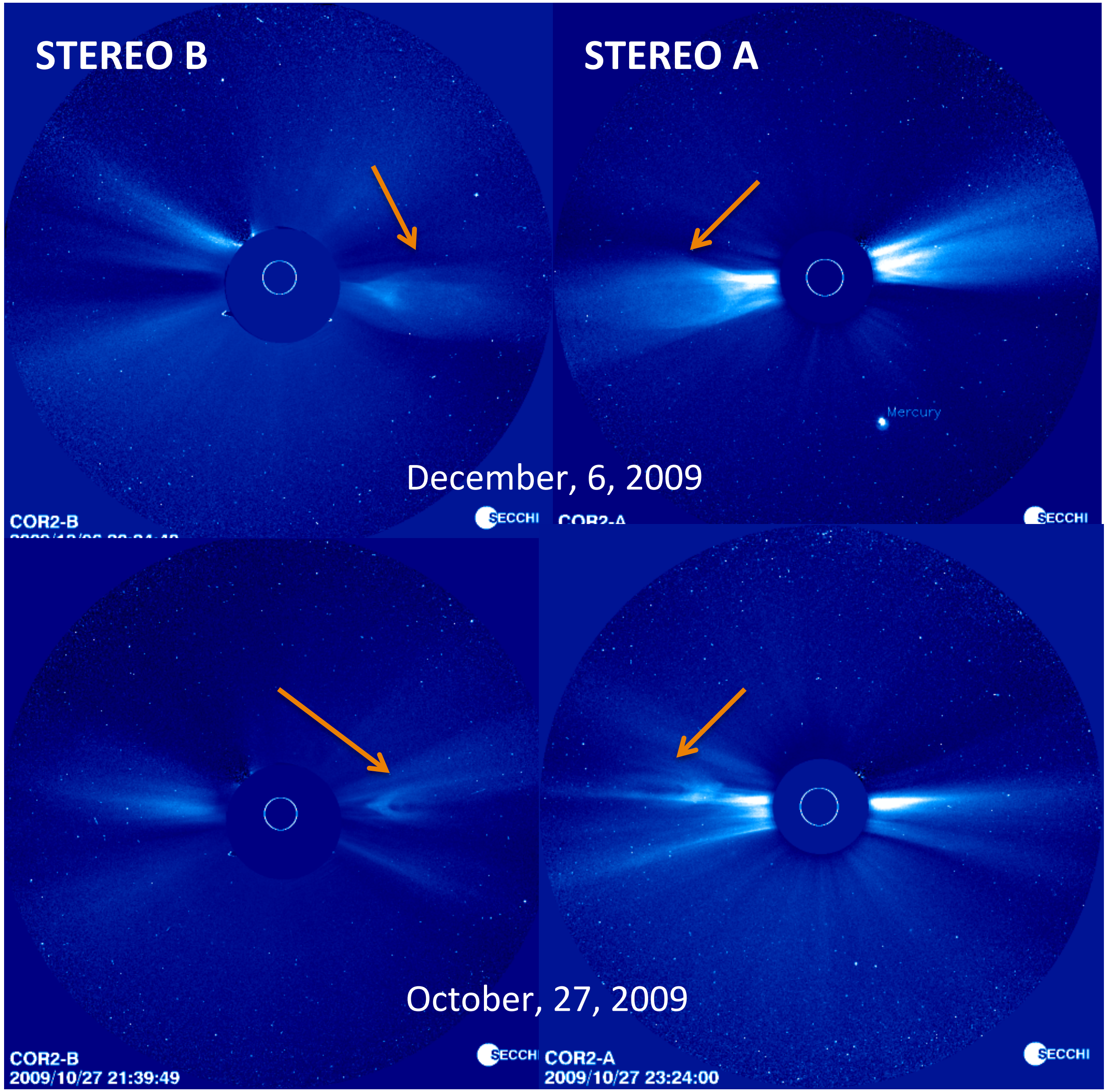
Vourlidas et al., Sol. Phys., 2012





Ruffenach,et al. JGR, 2013

Stealth CMEs not only in EUV, but also in white-light?

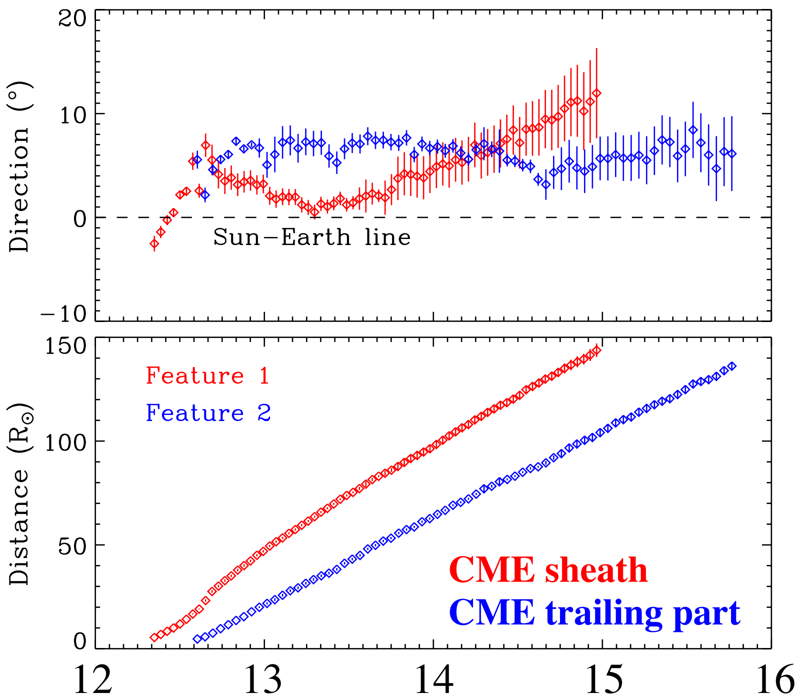


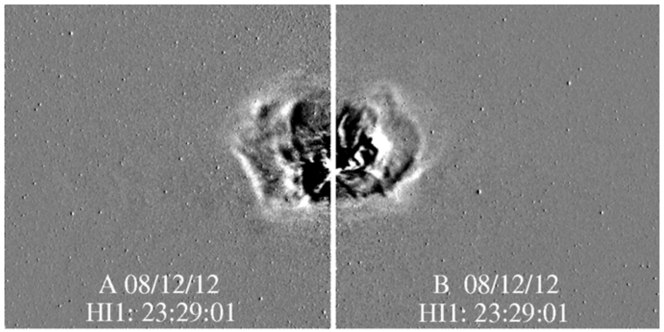
- Start very slowly!
  (long transit times)
- formed at higher heights

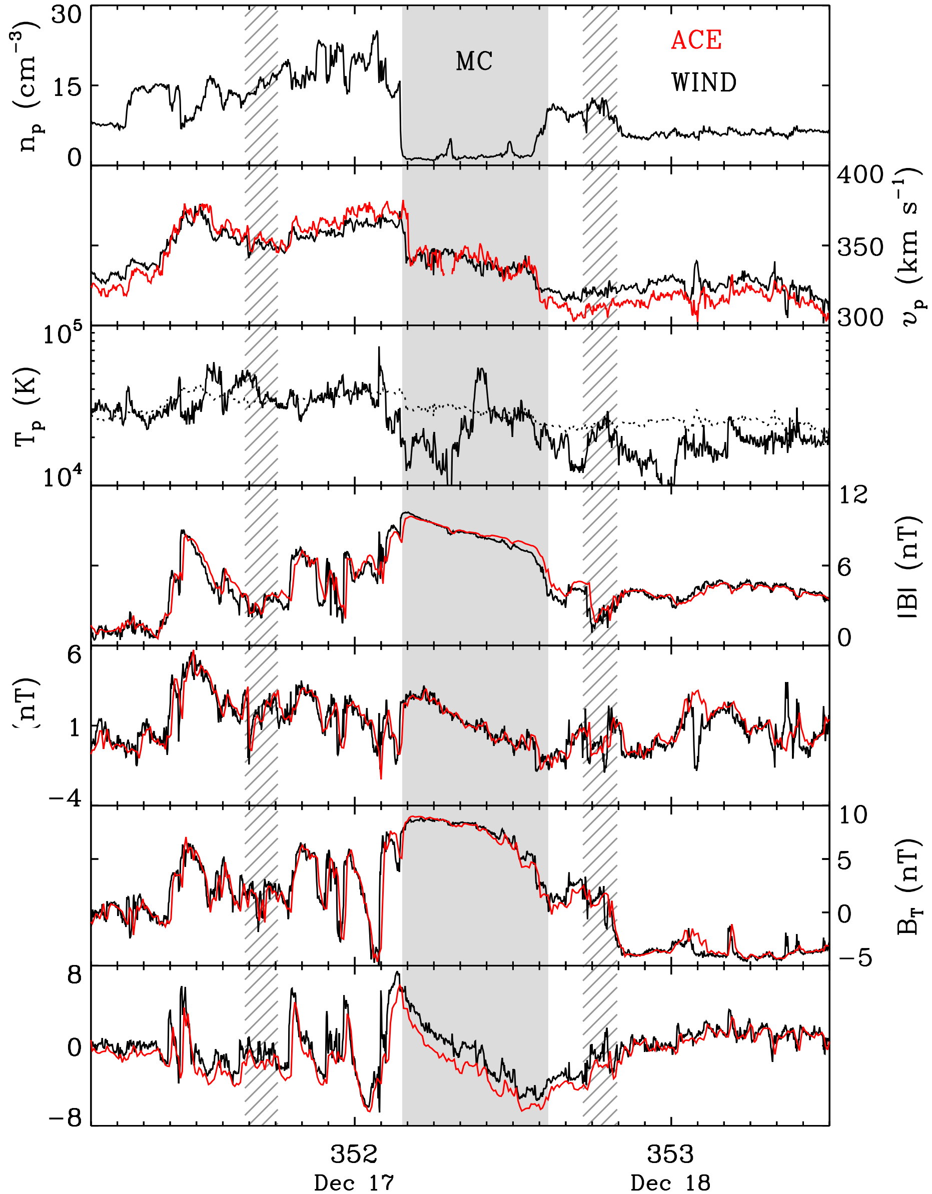
➔ no bright rim

(concave bottom part difficult to detect)

Kilpua et al., Sol. Phys. 2014, http://link.springer.com/article/10.1007%2Fs11207-014-0552-4





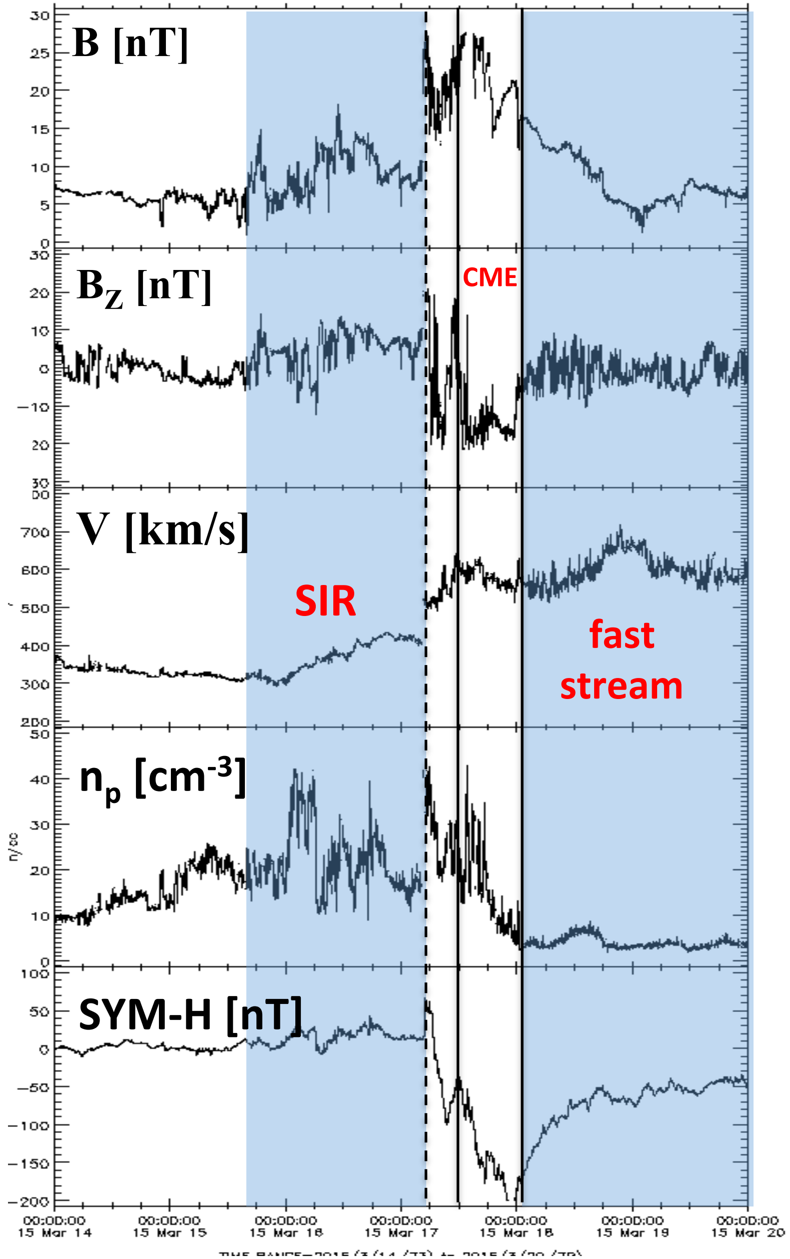


Liu et al., The Astrophysical Journal, 722:1762–1777, 2010

Storm on March 17-18, 2015

- CME on March 15 impact with a dense and slow solar wind ahead (part of the stream interaction region)
- compression by the trailing fast wind (no expansion)

➔ high density throughout the event



event analyzed in:
Kataoka et al., 2015, submitted to GRL

Discussion and Conclusions

- ICME and FR boundaries coincide only in 30% of studied events (mismatch larger and more frequent at the rear boundary)
- Events with large mismatch are stronger, faster, experience stronger expansion and occur mostly during high solar activity (more CME-CME interaction, more AR related impulsive events?)
- Sheath, flux rope, front and rear regions have different characteristics. All drive significant magnetospheric activity
- In particular, different compositional signatures suggest that different regions may have at least partly formed already close to the Sun
- Challenge to relate to the white observations
- At solar minimum at least many stealth CMEs also in white-light (no bright rim, faint concave bottom part)