On the Space Weather Response of Coronal Mass Ejections and Their Sheath Regions

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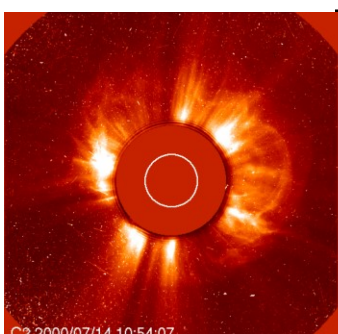
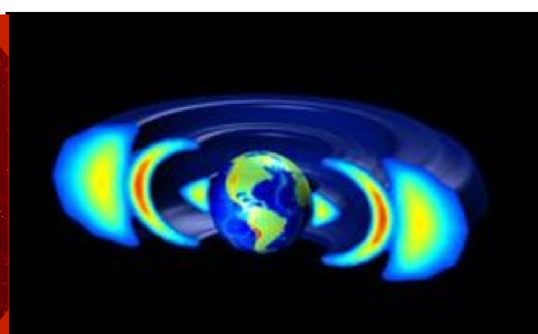
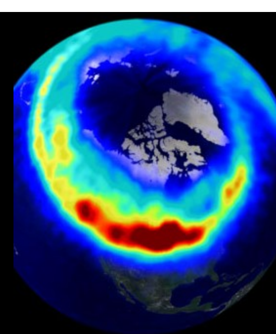
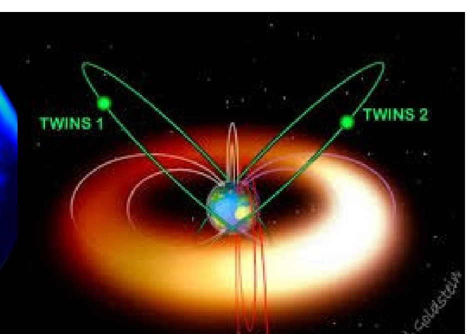
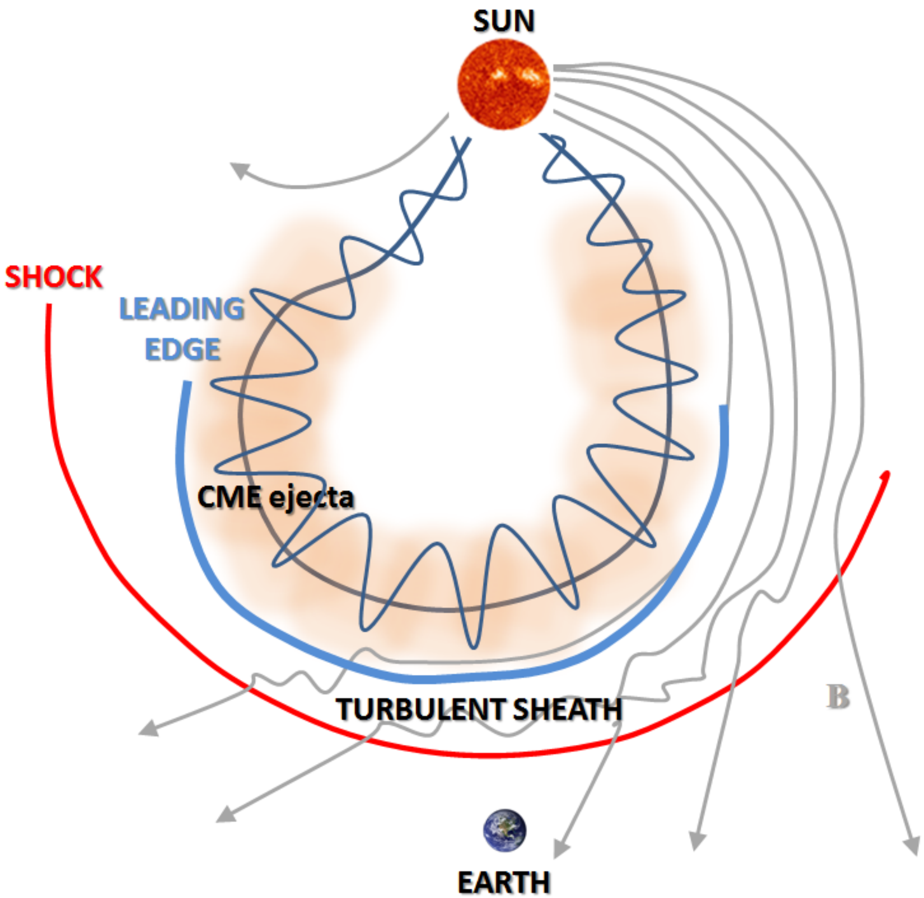
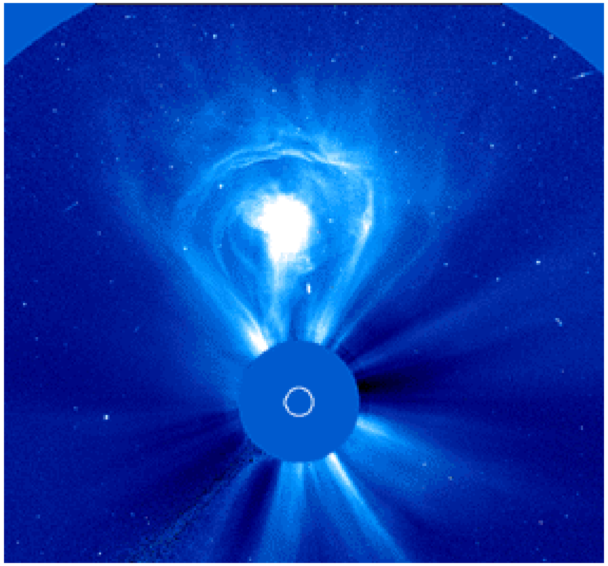
Outline

- CME structures
- Sheath regions
- Flux ropes
- Future challenges to predict geomagnetic response of coronal mass ejections (**long-term predictions**)



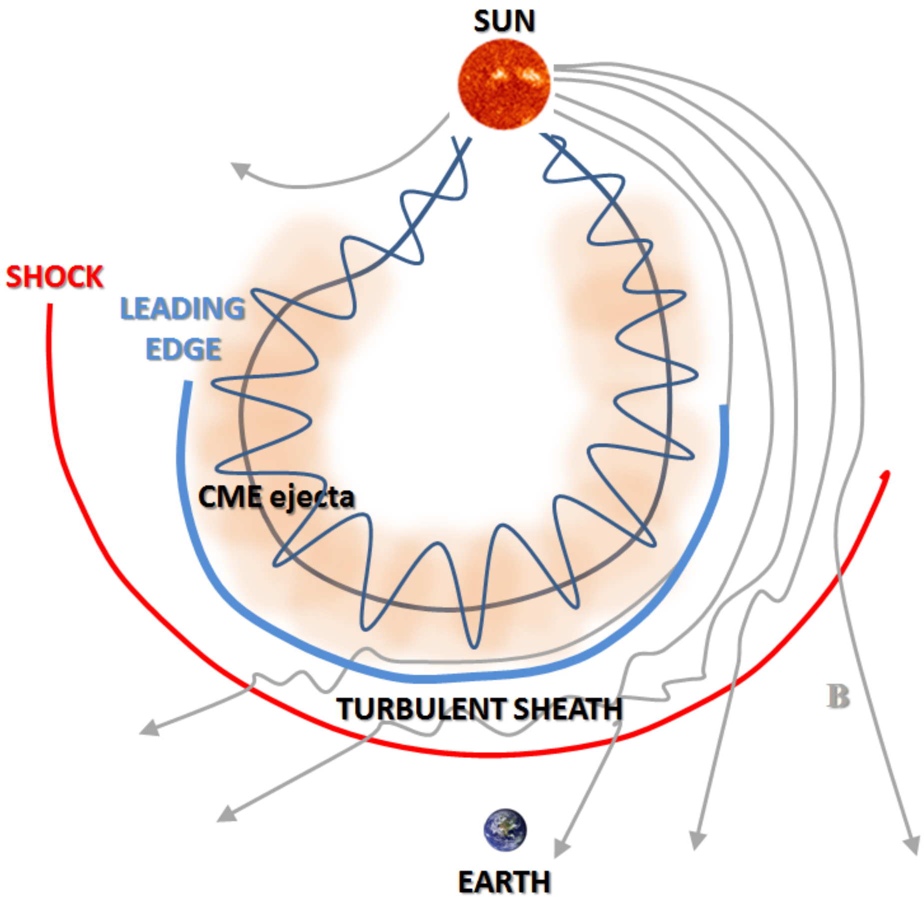




CMEs drive majority of intense space weather disturbances

A CME has two main geoeffective structures that have fundamentally different origin, distinct solar wind characteristics and different magnetospheric responses

(e.g., *Huttunen et al.*, 2002; http://adsabs.harvard.edu/abs/2002JGRA..107.1121H; Yermolaev et al., JGR 2013; Kilpua et al., 2015; http://adsabs.harvard.edu/abs/2015GeoRL..42.3076K)



Main CME substructures
(many studies do not separate)

- ejecta (often a flux rope)
  - smooth changes
  - erupted solar flux rope
- sheath region
  - turbulent, compressed
  - overlying coronal arcades
  - pile-up & expansion sheath

→ different ways to predict their properties

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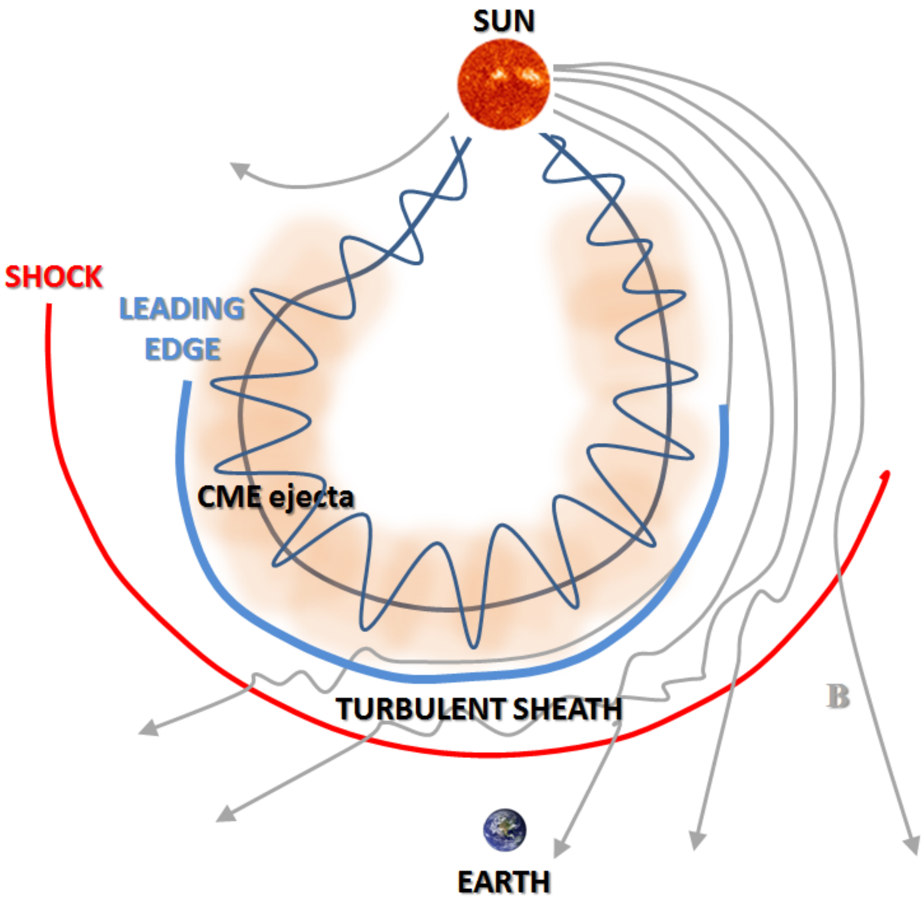
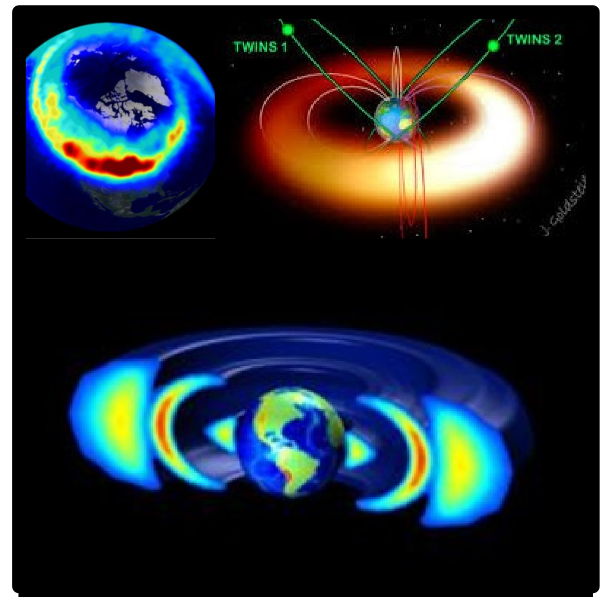


Space weather response

- auroral latitudes
- large-scale convection
- ring current
- Van Allen belts



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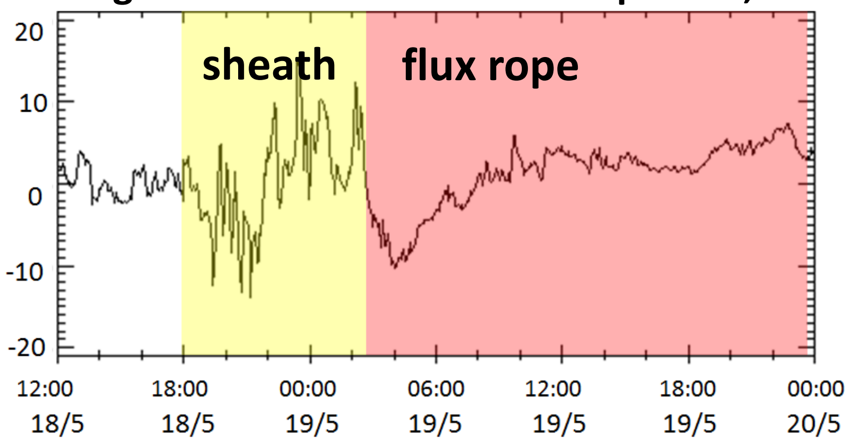
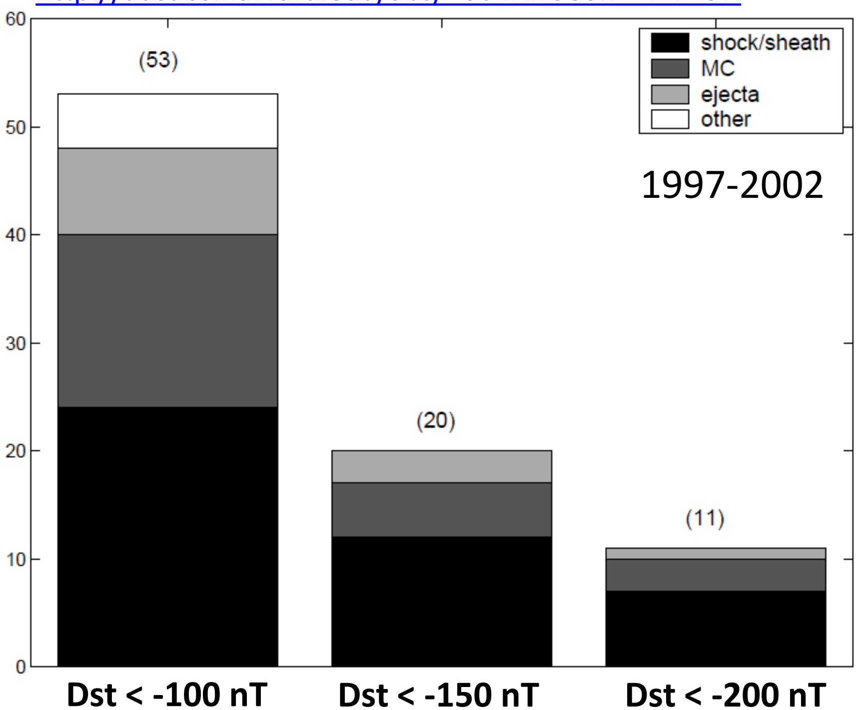
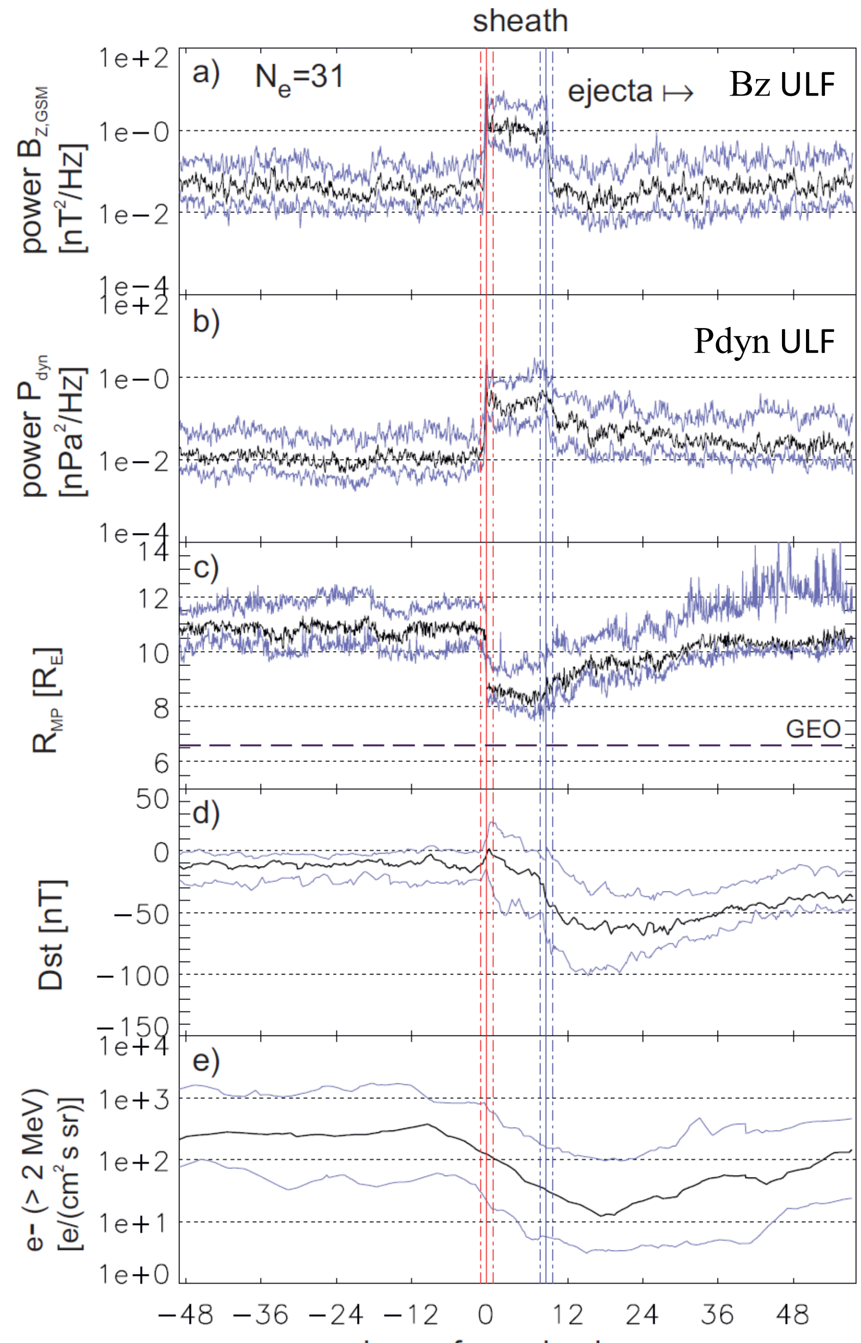
magnetic field north-south component, L1



Huttunen and Koskinen, 2004
http://adsabs.harvard.edu/abs/2004AnGeo..22.1729H





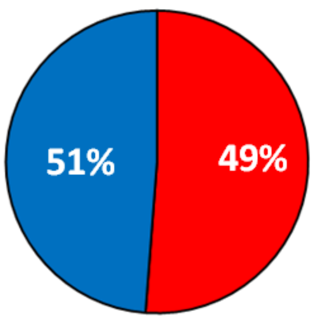
Hietala et al., GRL, 2014; Kilpua et al., 2015 http://adsabs.harvard.edu/abs/2015GeoRL..42.3076K)

A) low-inclined flux ropes

Bz:
South → North (SN)

Bz:
North → South (NS)

- dominant type changes with solar cycle (*Bothmer and Schwenn*, 1998; *Li et al.*, 2011)
- space weather predictions needs type for individual events



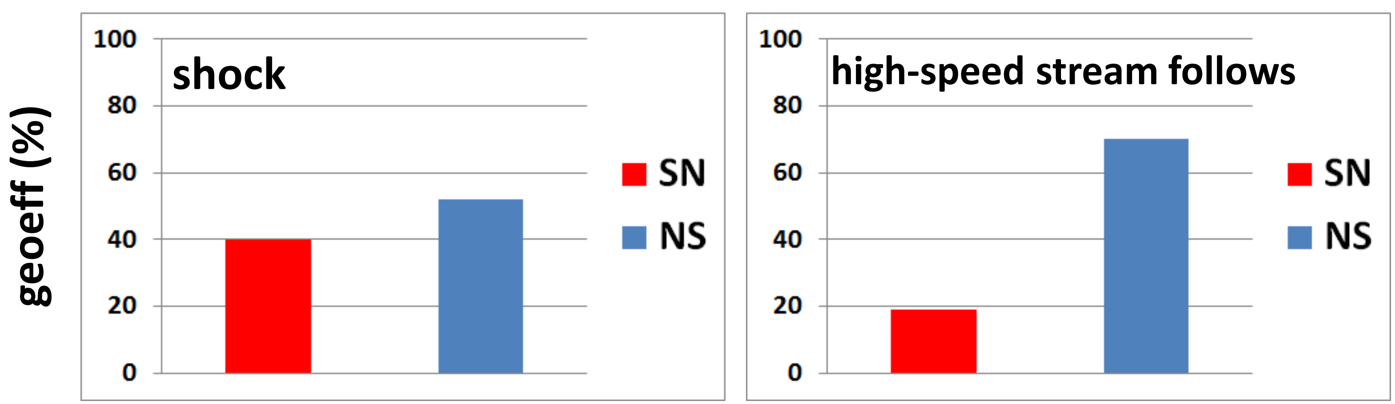
45 low-inclined FRs (1995-1999 & 2006-2010)

SN: mean Dst -74 nT

NS: mean Dst -79 nT

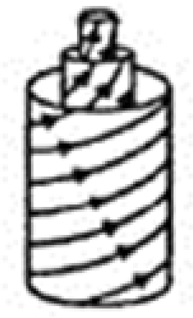
→ equally geoeffectivity!

Kilpua et al., 2012 http://adsabs.harvard.edu/abs/2012AnGeo..30.1037K

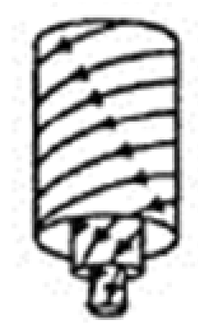


ambient solar wind modifies greatly the response!

B) high-inclined flux ropes



Bz:
North (N)

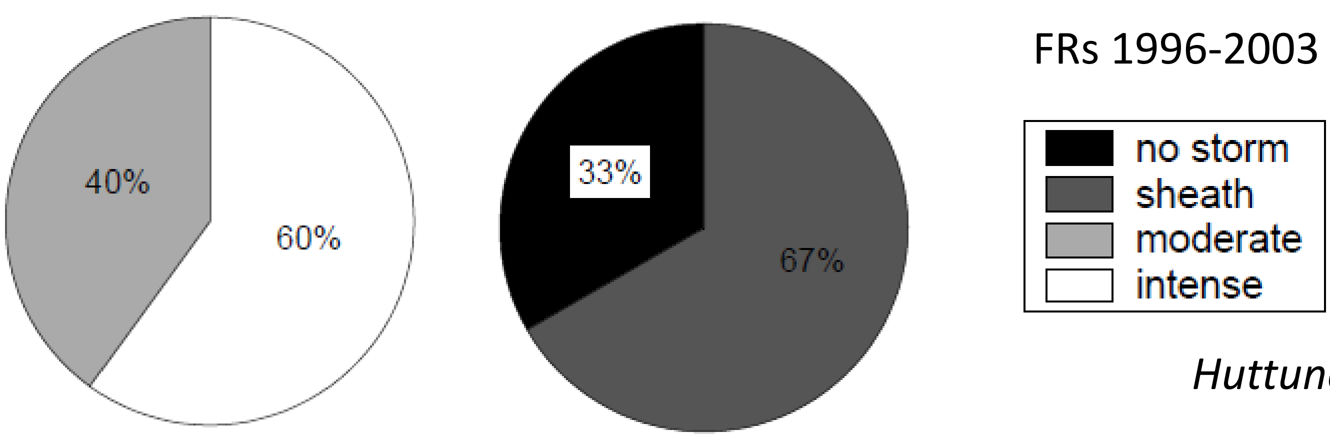


Bz:
South (S)

- N-type FRs not geoeffective, S-type FRs produce strong storms
  (*Huttunen et al*., 2005 http://adsabs.harvard.edu/abs/2005AnGeo..23..625H
  Kilpua et al., 2012)

S (15) **N (12)**

Sheath alone may drive a major storm!

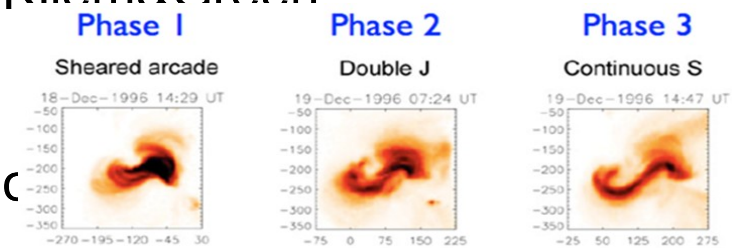


Huttunen et al., 2005

→ determination of the FR-type decisive!

There is yet no practical method to predict FR structure (nor sheath magnetic fields) in advance

- coronal magnetic fields cannot be observed directly
- Estimations based on erupting filament details, coronal arcades, and X-ray sigmoidal structures [e.g., Pevtsov et al., 1997; McAllister, 2001; Kliem&Green



Kliem&Green, 2014

ented use

tudies connecting solar and in

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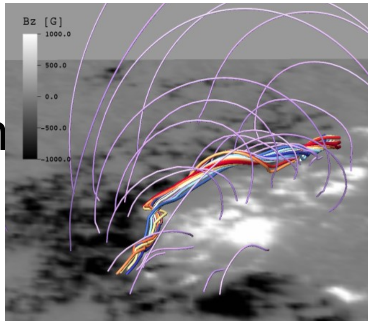
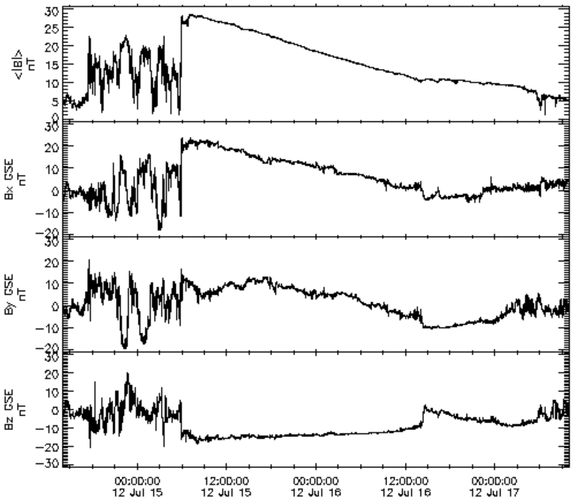
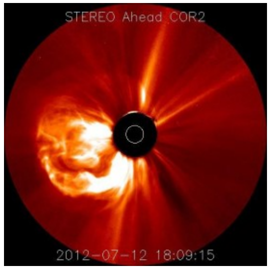
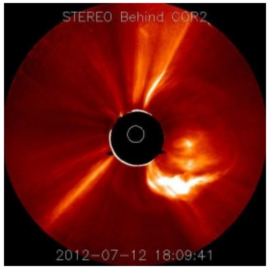
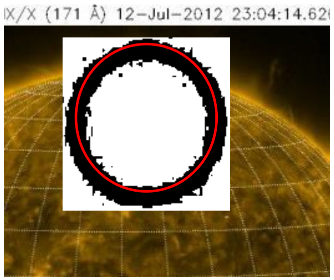
At UH we are working on this by combining both data-driven simulations and observations

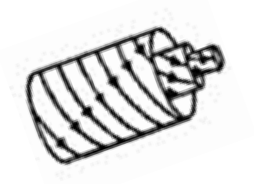










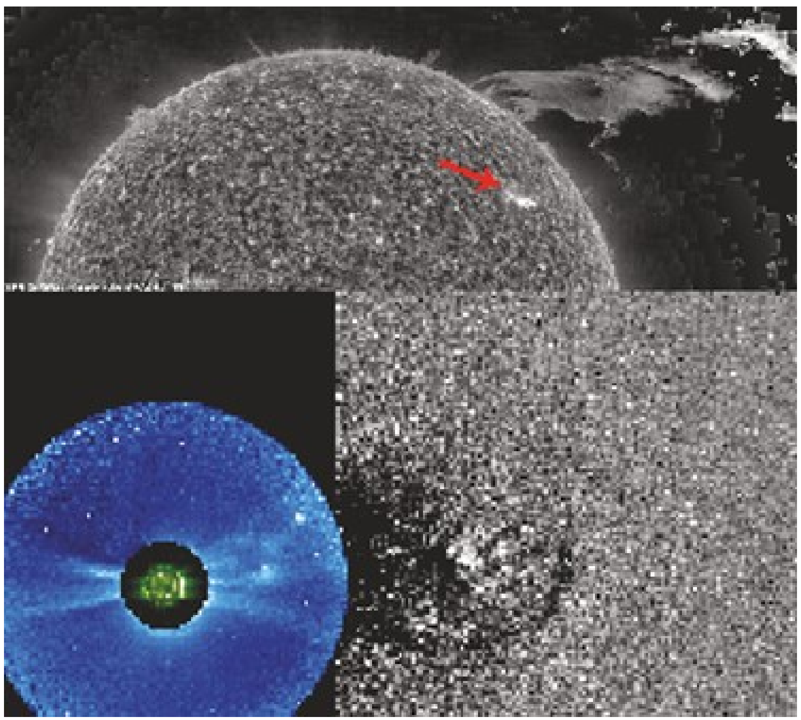


helicity, axial field direction and axis orientation

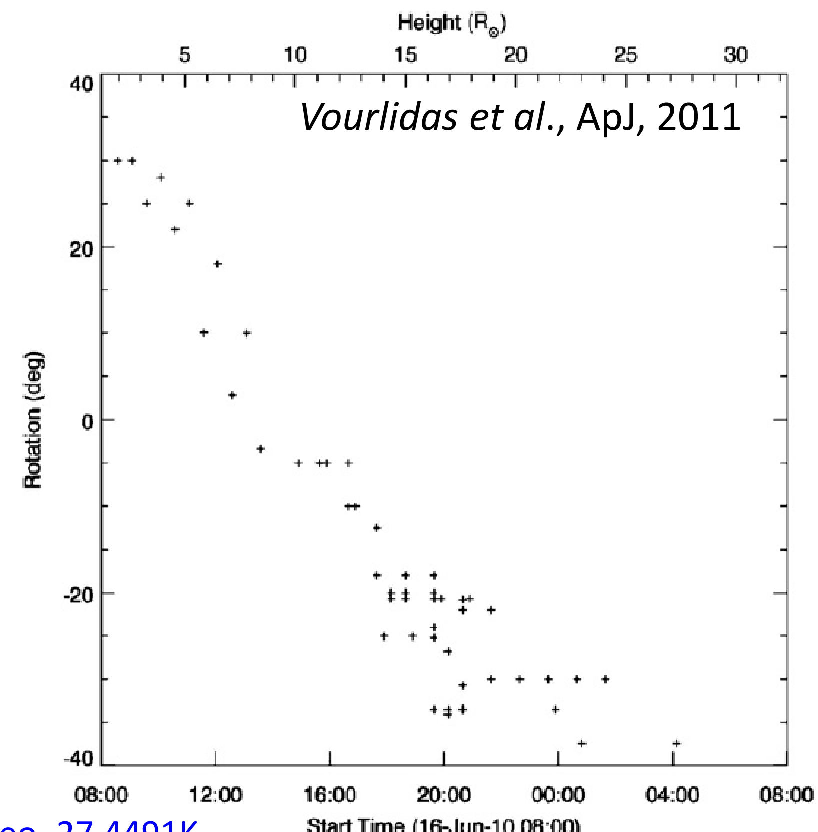
BUT!
Even if eruptive FR structure could be predicted it can change considerably during the travel from Sun to Earth

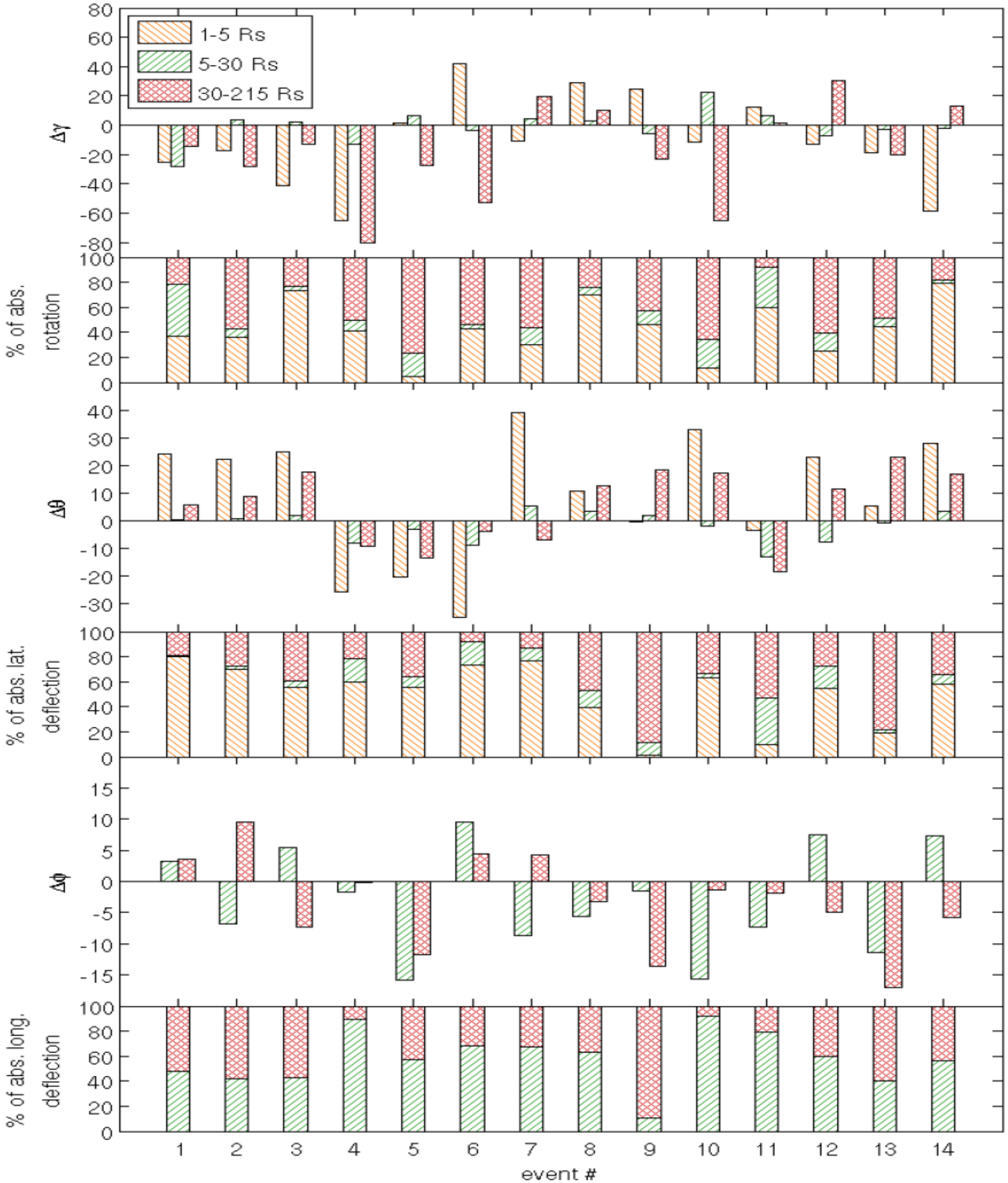
Deflection, rotation, deformation

(e.g. *Wang et al*., 2004, *Cremades et al*., 2005, *Yurchyshyn*, 2008; Möstl et al., 2015)



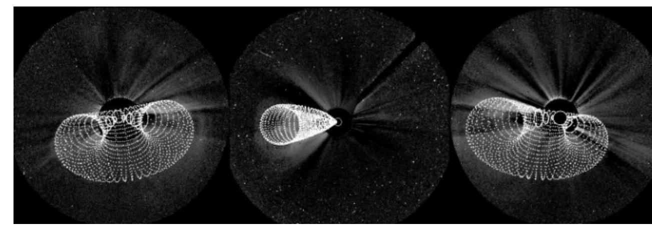
Kilpua et al., 2009 http://adsabs.harvard.edu/abs/2009AnGeo..27.4491K

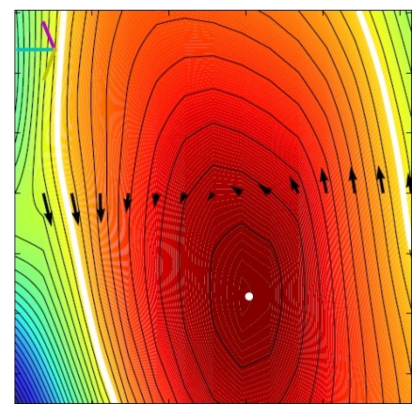


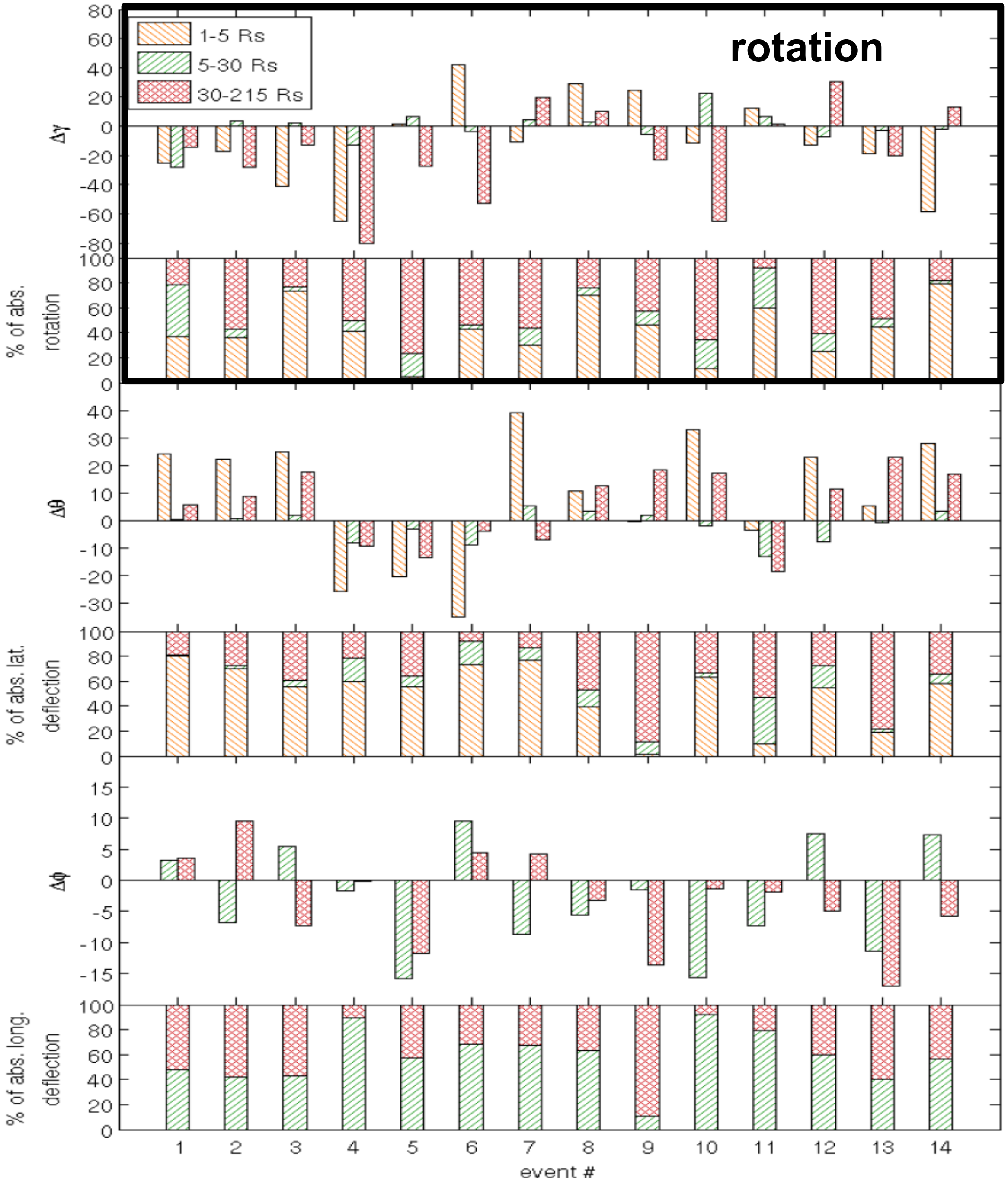


New tool to investigate FR 3-D geometrical evolution from Sun to Earth

Isavnin et al., Sol. Phys., 2013&2014







New tool to investigate FR geometrical evolution from Sun to Earth

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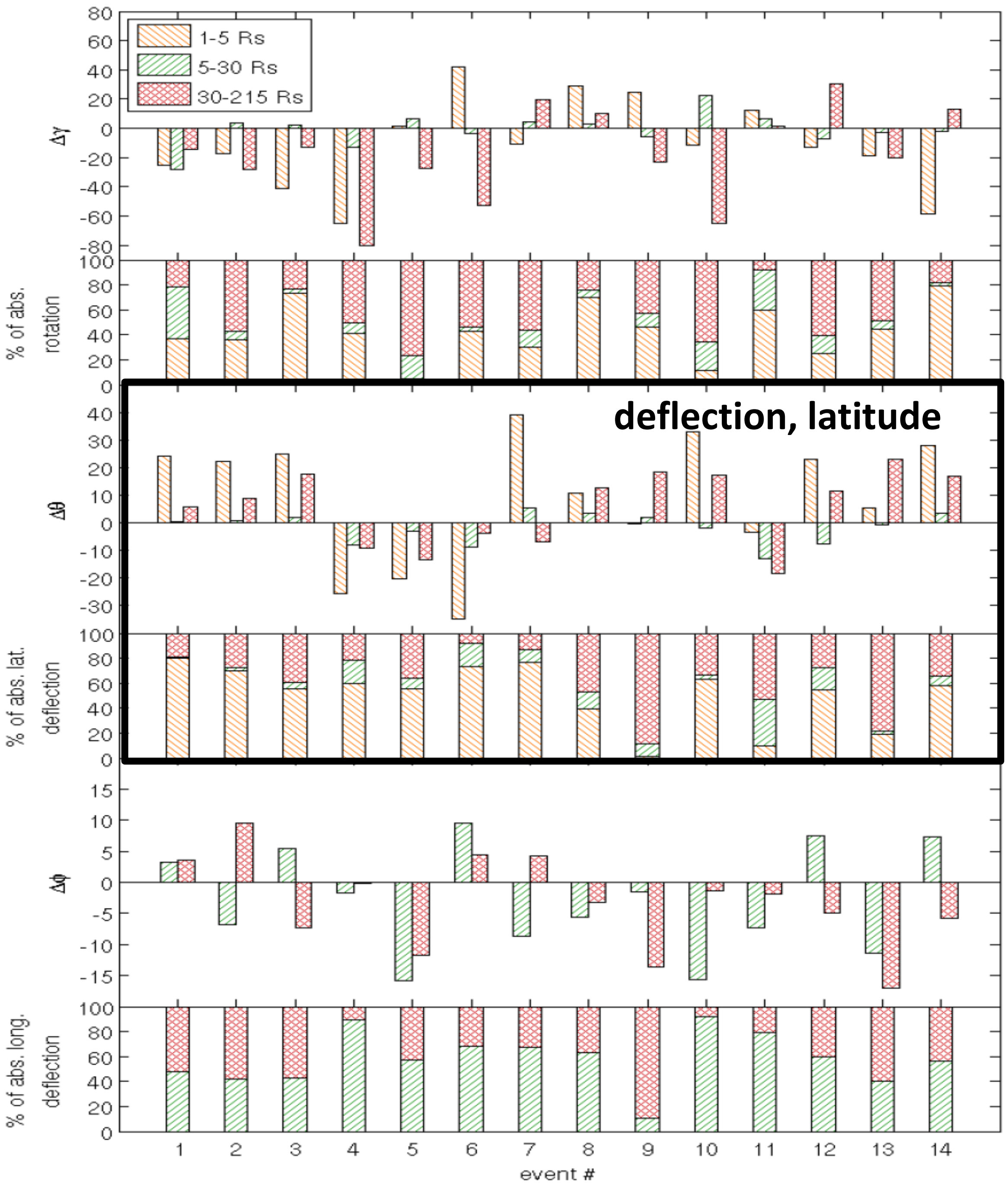

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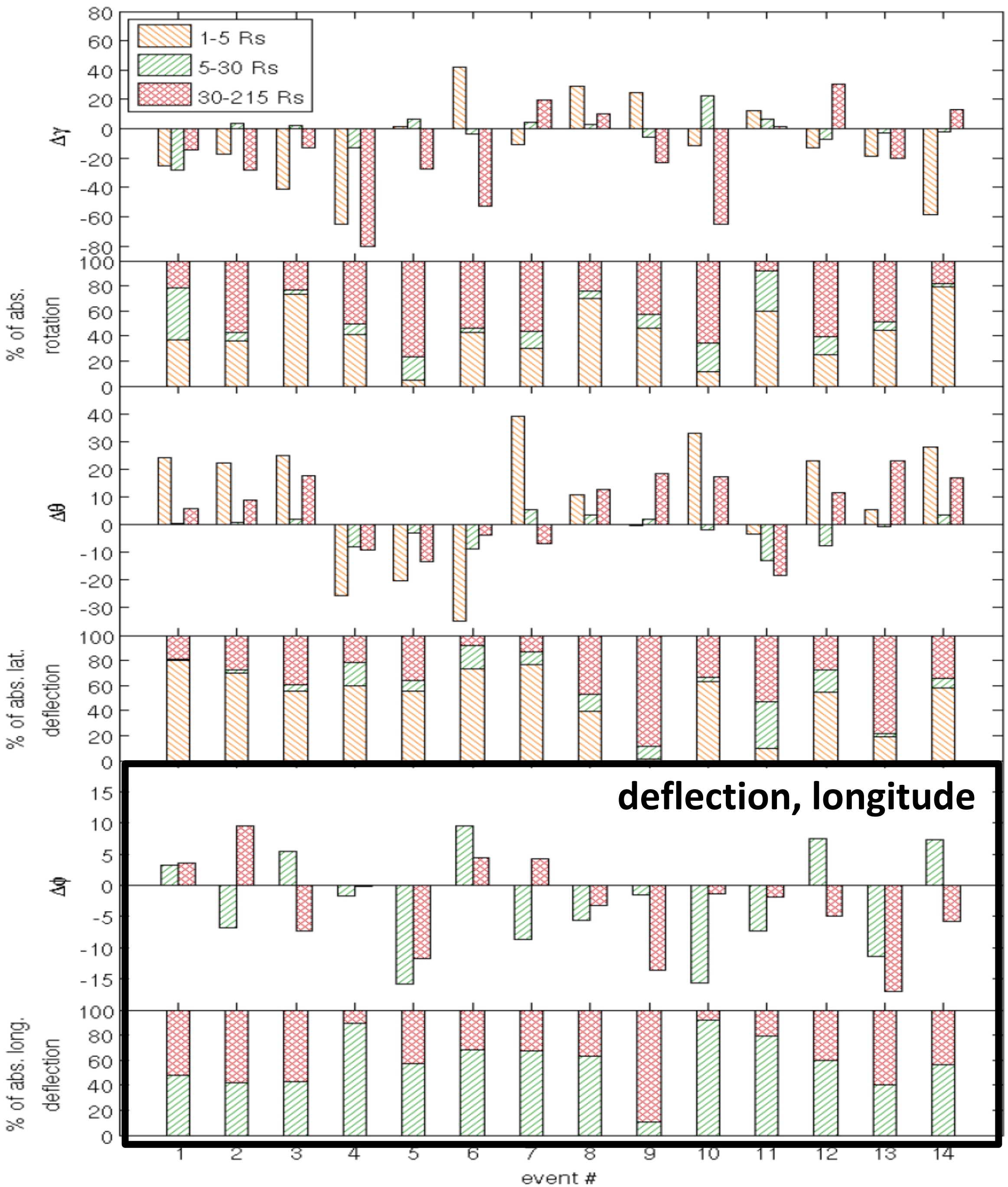


New tool to investigate FR geometrical evolution from Sun to Earth

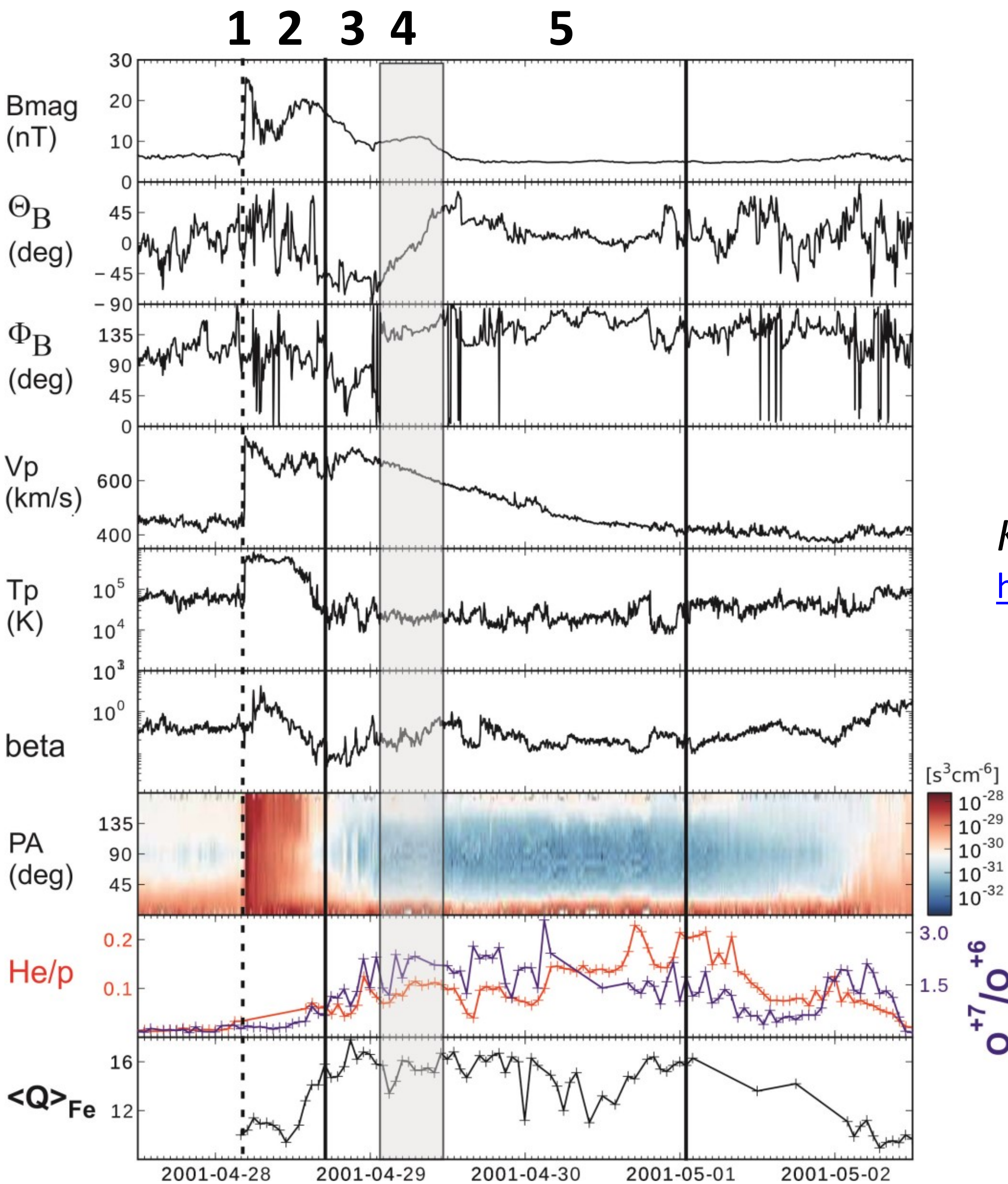
Isavnin et al., Sol. Phys., 2013&2014

→

- fastest changes occur within 1-30 R_S
- significant part of the evolution occurs > 30 R_S

Things are actually more complicated….

5(6)-part CME in-situ



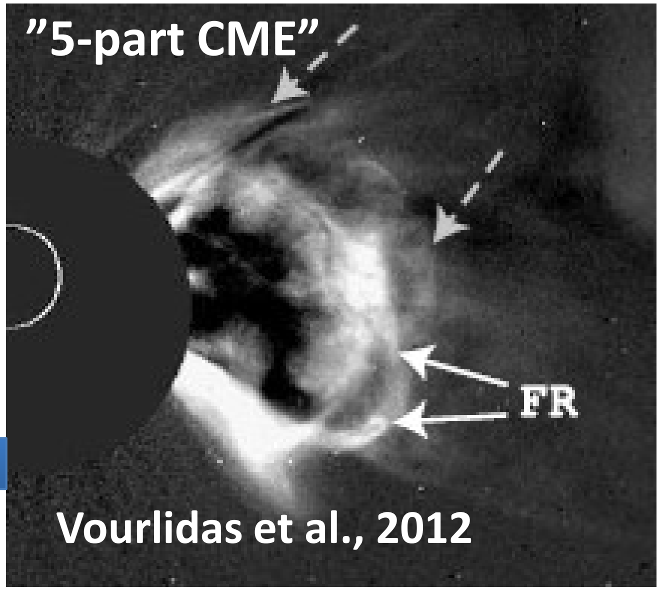
1. **shock**
2. **sheath**
3. **front region**
4. **flux rope (MC)**
5. **back region**

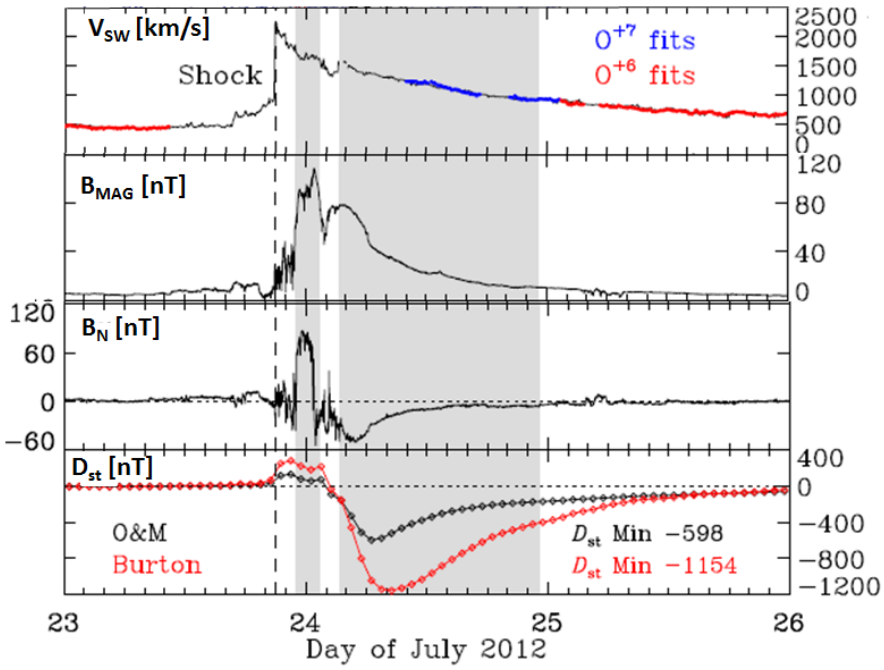
(6. density blob)

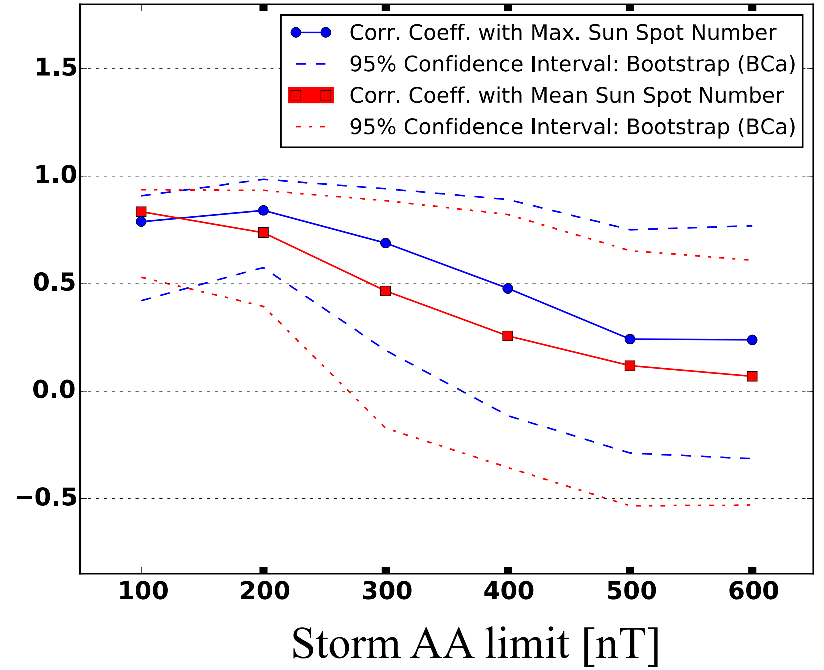
separated near the Sun or in IP space?

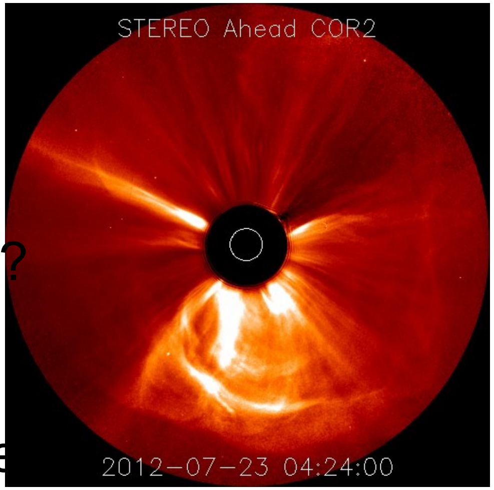
Kilpua et al., 2013
http://adsabs.harvard.edu/abs/2013AnGeo..31.1251K

?









Extreme storms

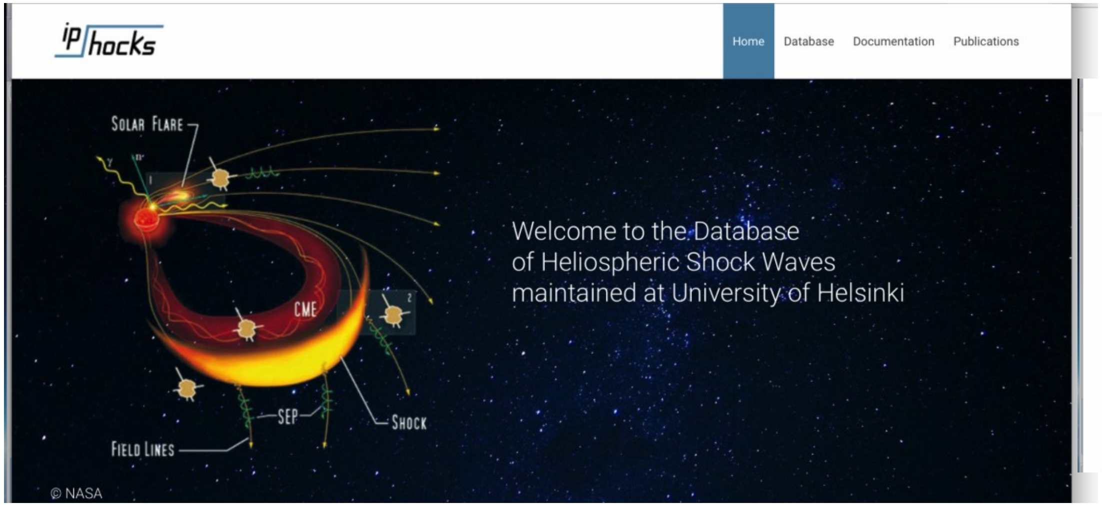
- produced by strong and super-fast interacting CMEs?
  (e.g., Liu et al., Nature Communications, 2014)

- They occurrence rate does not correlate with the size
  of the solar cycle.
  (Kilpua et al., 2015; http://adsabs.harvard.edu/abs/2015ApJ...806..272K).

(some) Future Challenges

- eruptive flux rope structure
- early flux rope evolution
- heliospheric flux rope evolution
- CME-CME interaction, interaction with ambient SW
- Predict the structure of the turbulent sheath region
- Bring solar, interplanetary and magnetospheric communities together to improve space weather predictions

ipshocks.fi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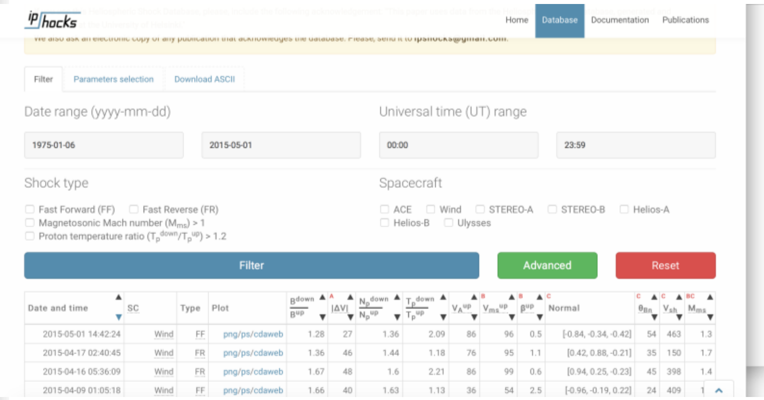
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2015-05-01
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00:00
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Shock type
Fast Forward (FF)
Fast Reverse (FR)
Magnetosonic Mach number (Mms) > 1
Proton temperature ratio (Tp down/Tp up) > 1.2
Spacecraft
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STEREO-B
Helios-A
Helios-B
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2015-05-01 14:42:24 | Wind | FF | png/ps/cdaweb | 1.28 | 27 | 1.36 | 2.09 | 86 | 96 | 0.5 | [-0.84, -0.34, -0.42] | 54 | 463 | 1.3
2015-04-17 02:40:45 | Wind | FR | png/ps/cdaweb | 1.36 | 46 | 1.44 | 1.18 | 76 | 95 | 1.1 | [0.42, 0.88, -0.21] | 35 | 150 | 1.7
2015-04-16 05:36:09 | Wind | FR | png/ps/cdaweb | 1.67 | 48 | 1.6 | 2.21 | 86 | 99 | 0.6 | [0.94, 0.25, -0.23] | 45 | 398 | 1.4
2015-04-09 01:05:18 | Wind | FF | png/ps/cdaweb | 1.66 | 40 | 1.63 | 1.13 | 36 | 54 | 2.5 | [-0.96, -0.19, 0.22] | 24 | 409


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