Coronal Mass Ejections: Space Weather Perspective

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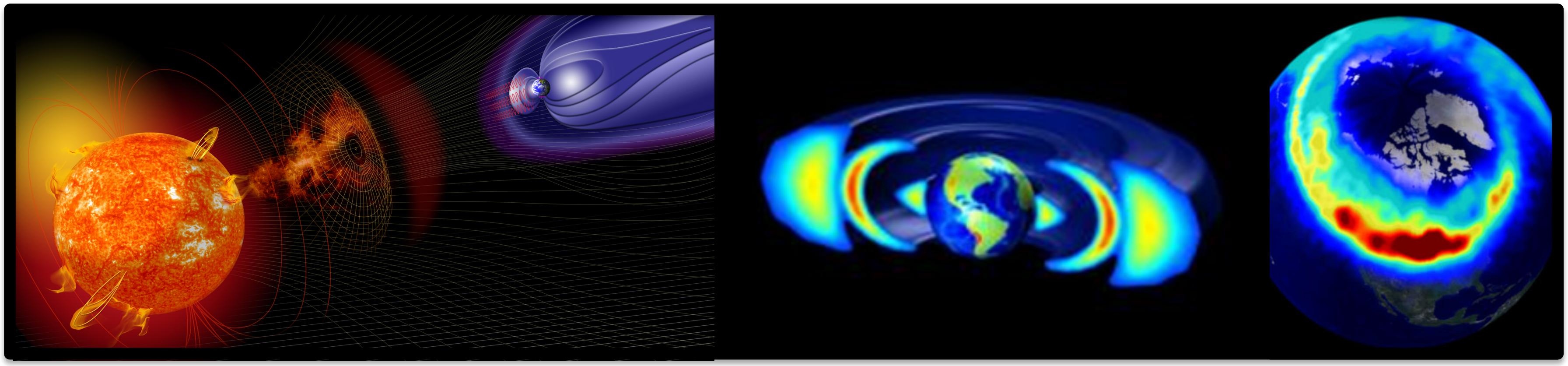
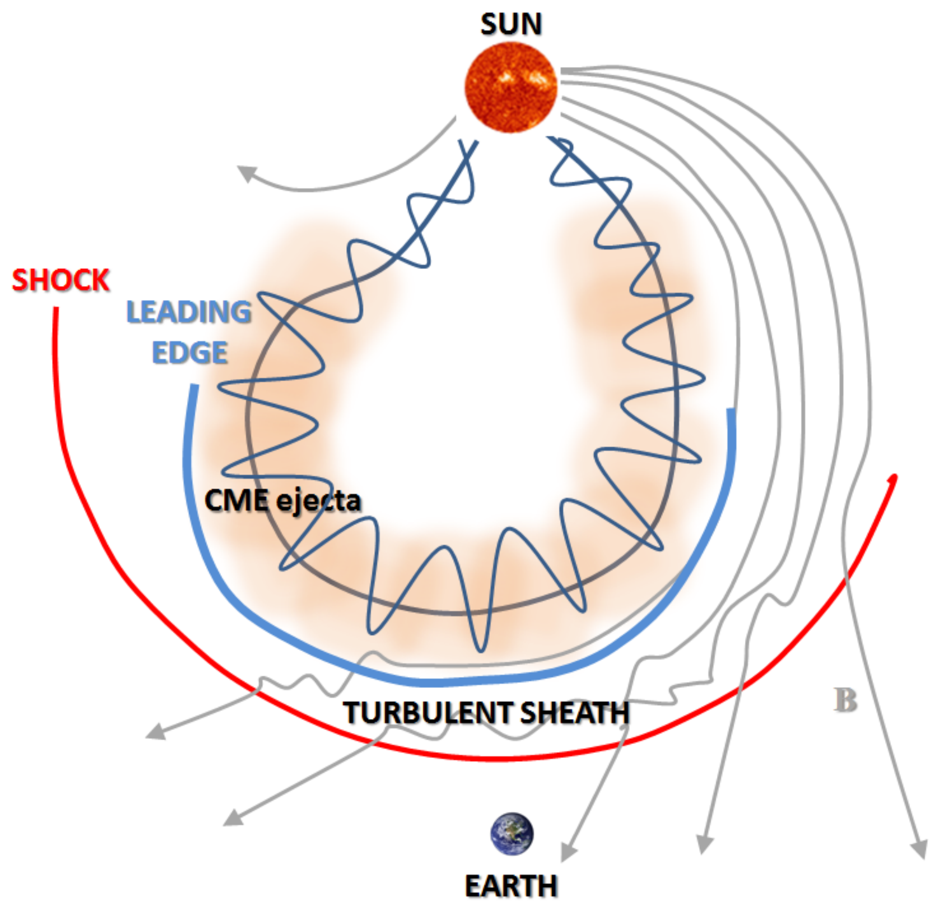
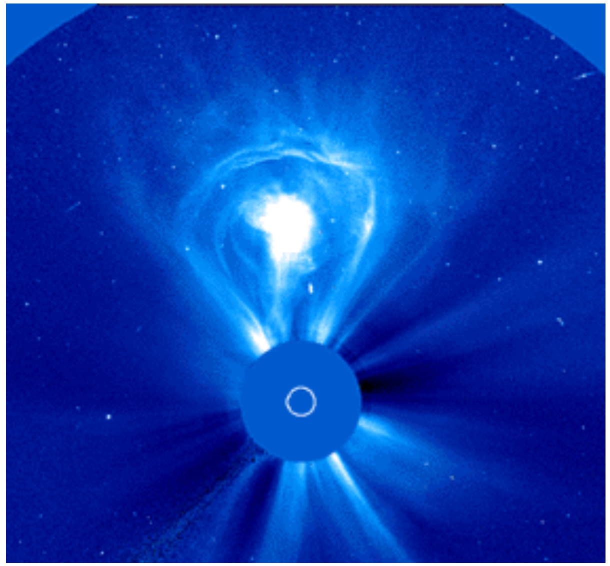
Outline

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



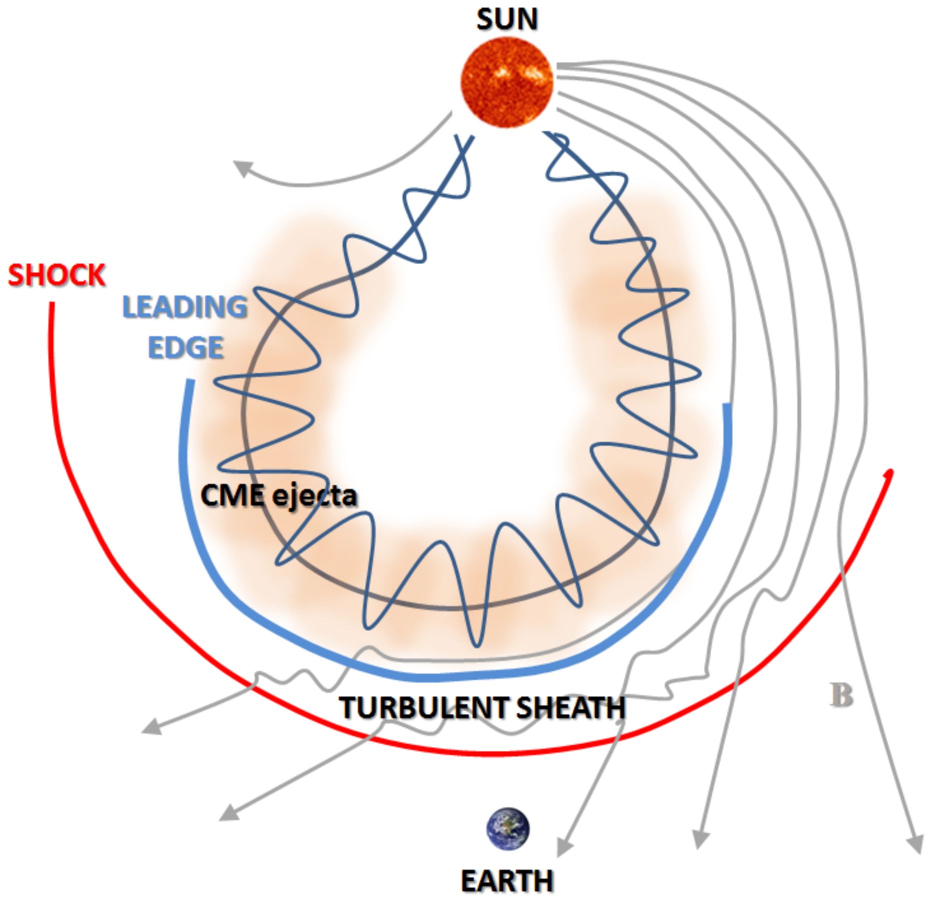




CMEs drive majority of intense space weather disturbances

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*](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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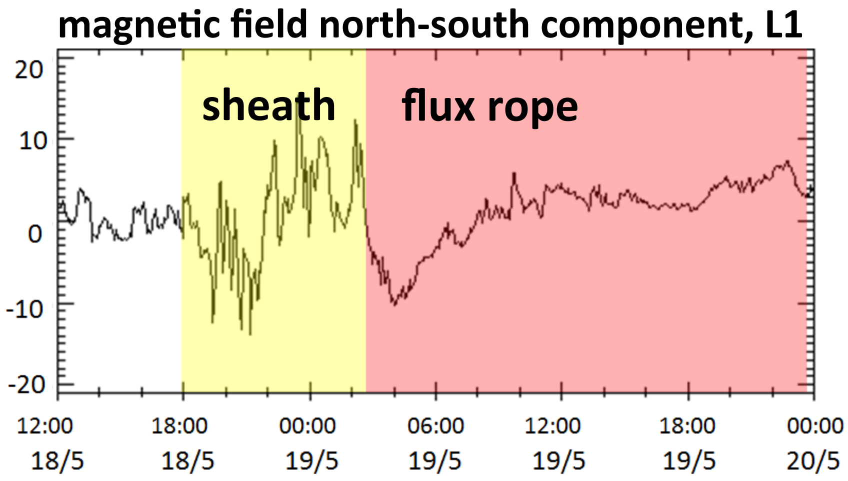
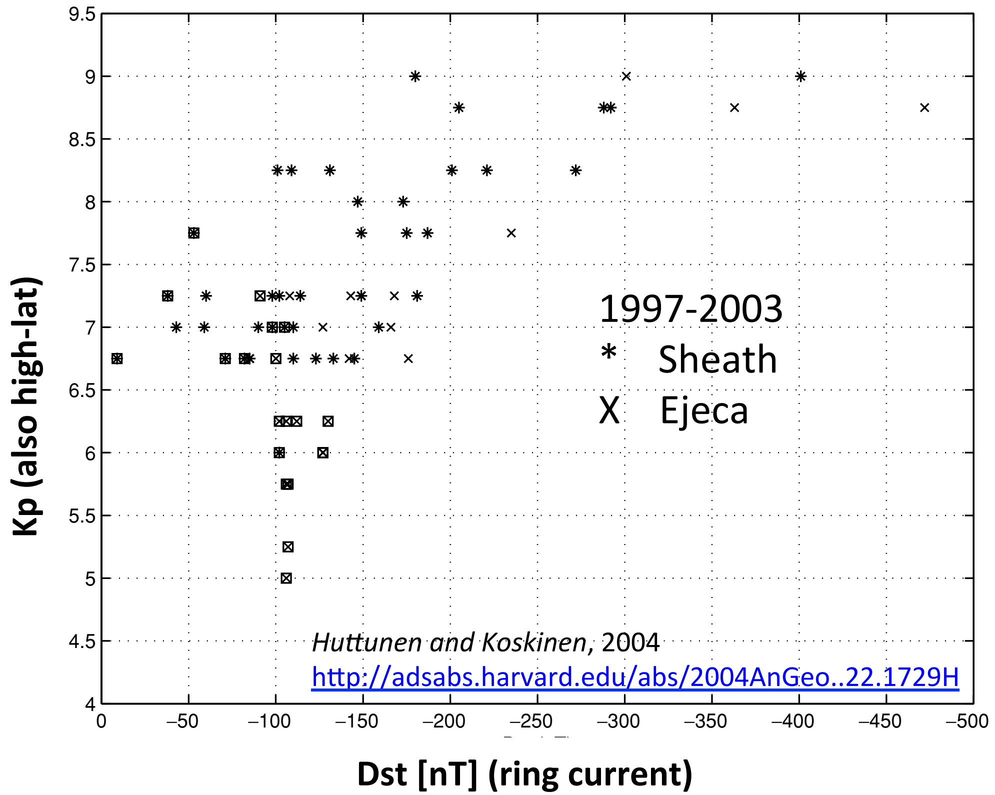
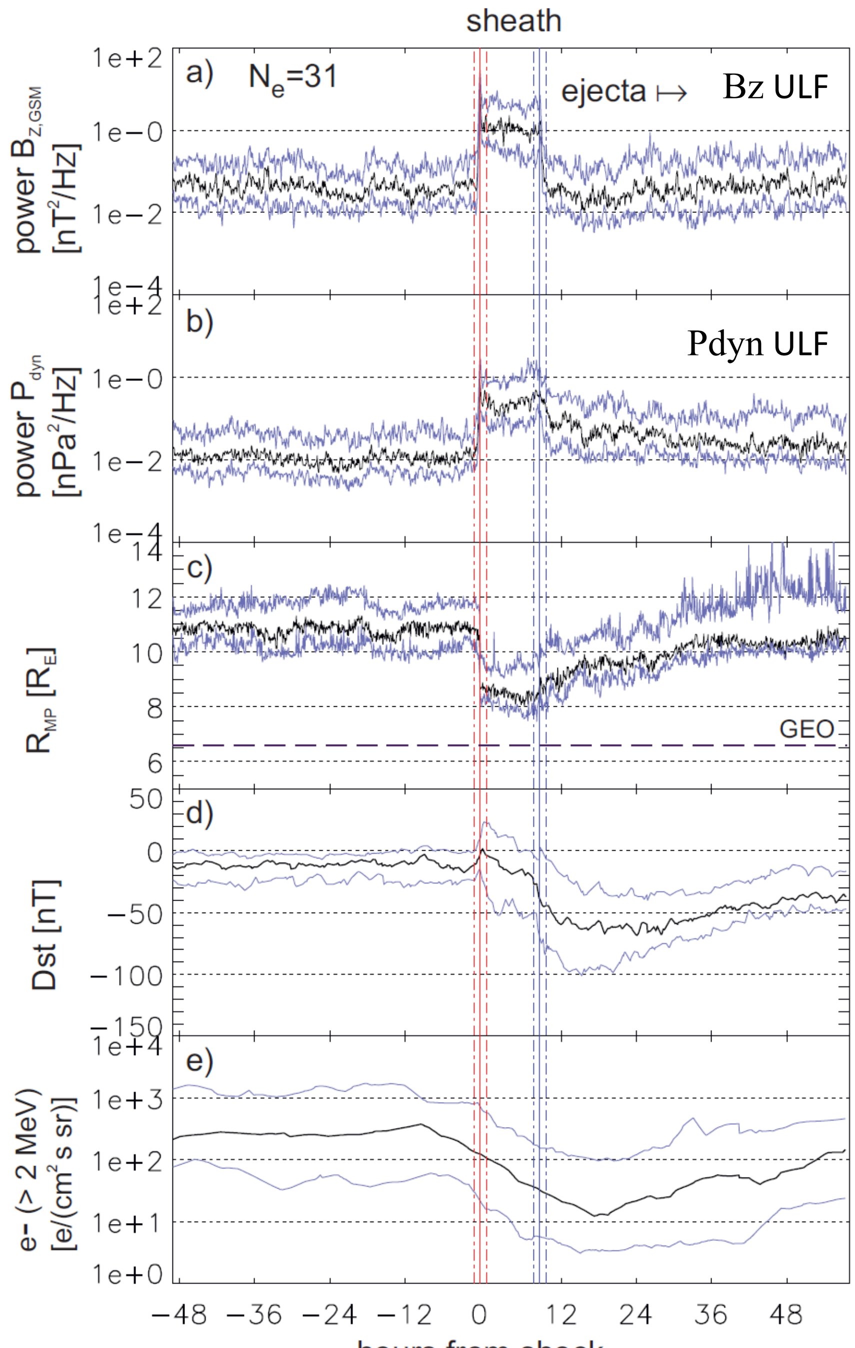






Hietala et al., GRL, 2014; Kilpua et al., 2015 [http://adsabs.harvard.edu/abs/2015GeoRL..42.3076K)](http://adsabs.harvard.edu/abs/2015GeoRL..42.3076K)

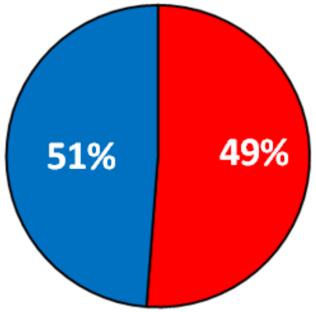
CME flux rope type decisive for space weather response

A) low-inclined flux ropes

Bz:
South → North (SN)

Bz:
North → South (NS)

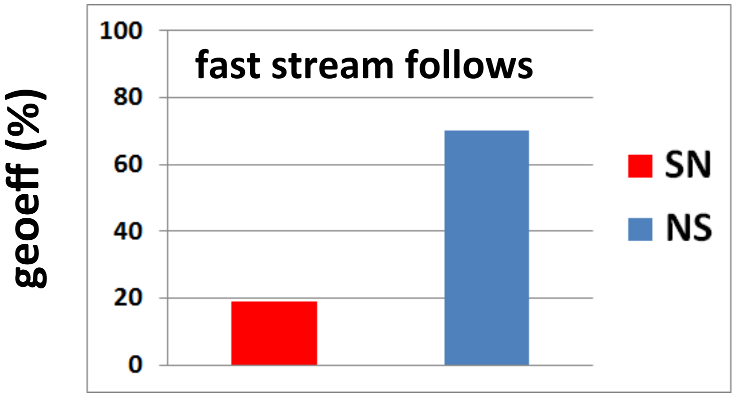
- dominant type changes with solar cycle (*Bothmer and Schwenn*, 1998; *Li et al.*, 2011)
- space weather predictions needs to know type for individual events
- both storm timing and storm magnitude (sequence important also!)



45 low-inclined flux ropes (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!

CME flux rope type decisive for space weather response

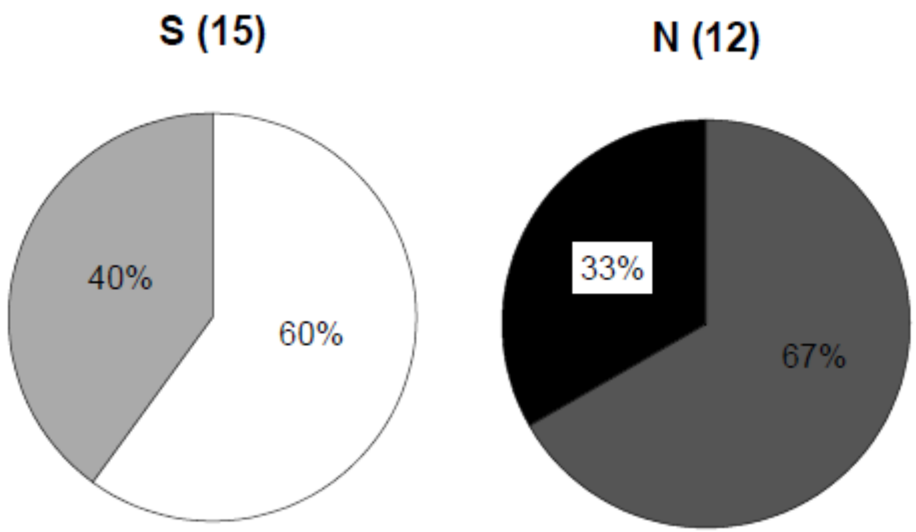
B) high-inclined flux ropes

Bz:
North (N)

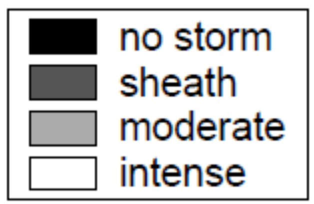
Bz:
South (S)

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

BUT sheath alone may drive a major storm even in a case of N-type flux rope!



flux ropes 1996-2003



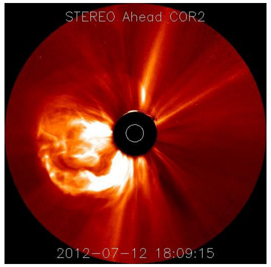
Huttunen et al., 2005

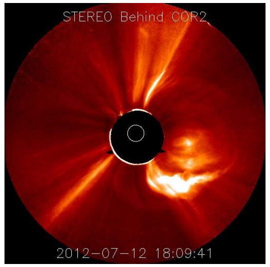
→ determination of the FR-type decisive!

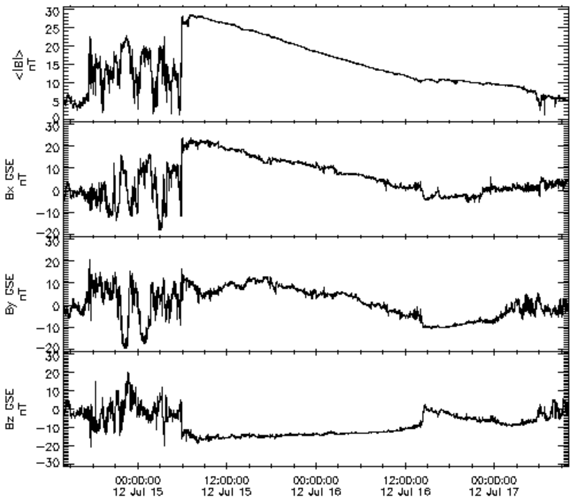
How to predict flux rope structure in advance?

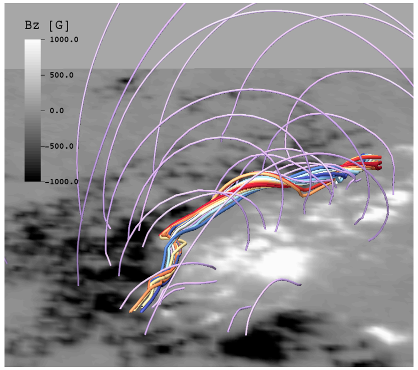
- indirect proxies from remote sensing observations based on erupting filament details, coronal arcades, and X-ray sigmoidal structures etc. [e.g., Pevtsov et al., 1997; McAllister, 2001; Kliem&Green, 2014]. However, **in fragmented use**
- no systematic statistical studies connecting solar and in-situ observations
- data driven simulations key as their determine flux rope structure self-consistently

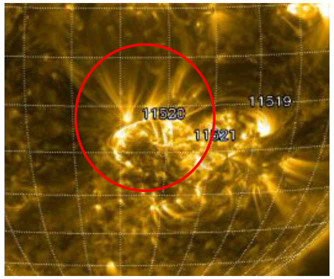
At UH we are working on this by **combining** both data-driven simulations and observations **+ in-situ validation**

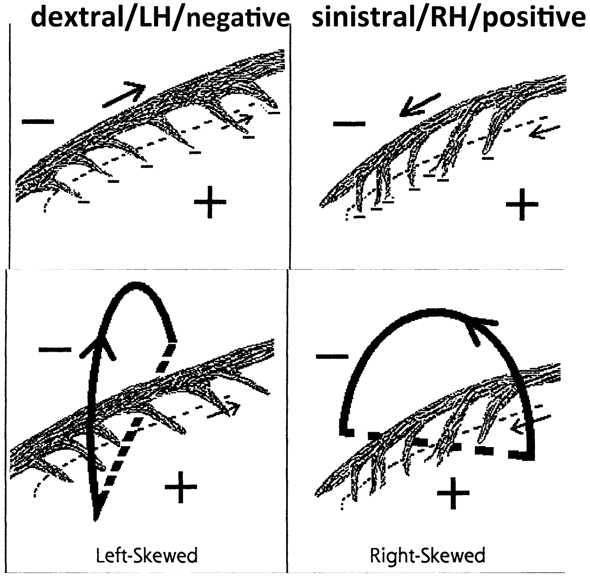


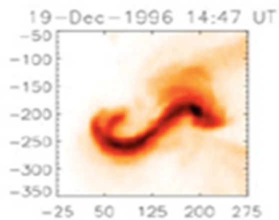












chirality, axial field direction, axis orientation, magnetic flux

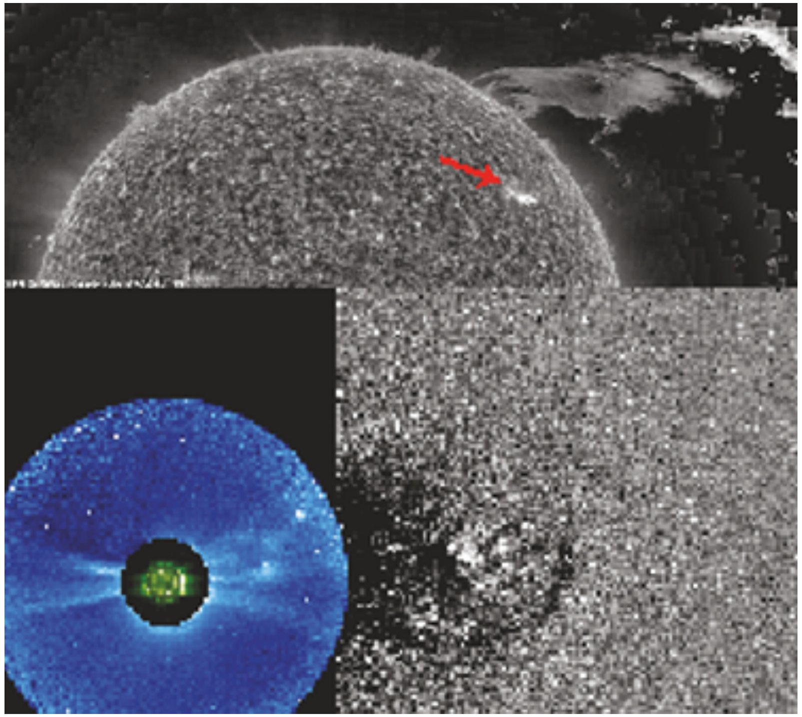
BUT!

Even if the eruptive flux rope structure could be predicted it can change considerably during the travel from Sun to Earth

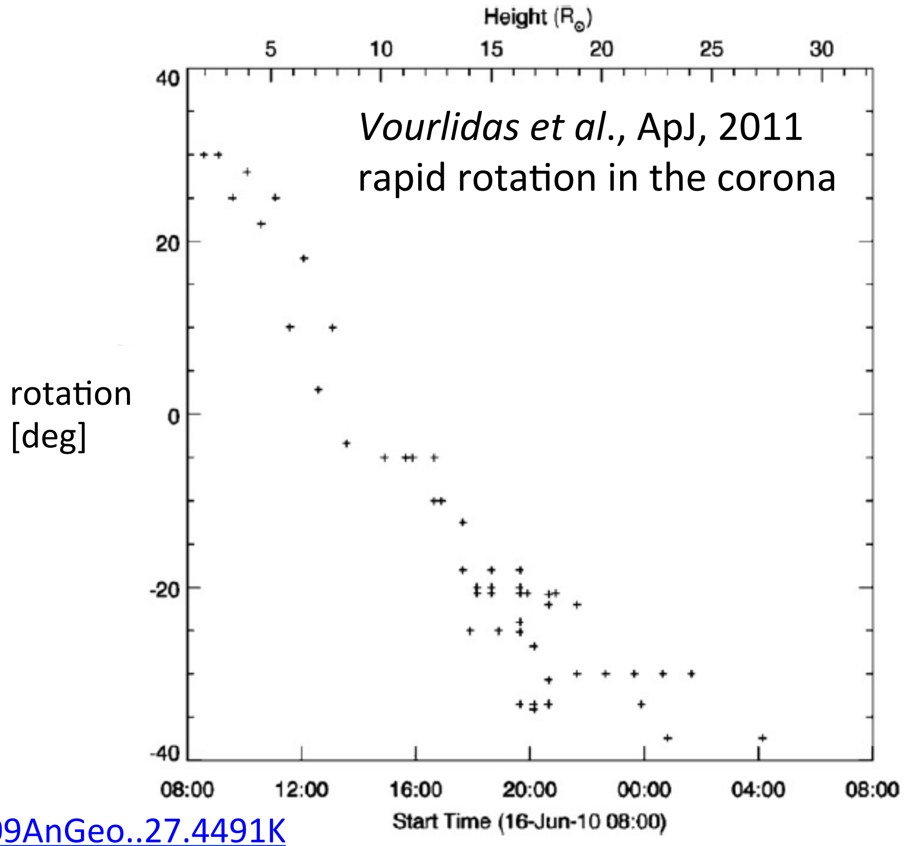
Deflection, rotation, deformation, erosion, …

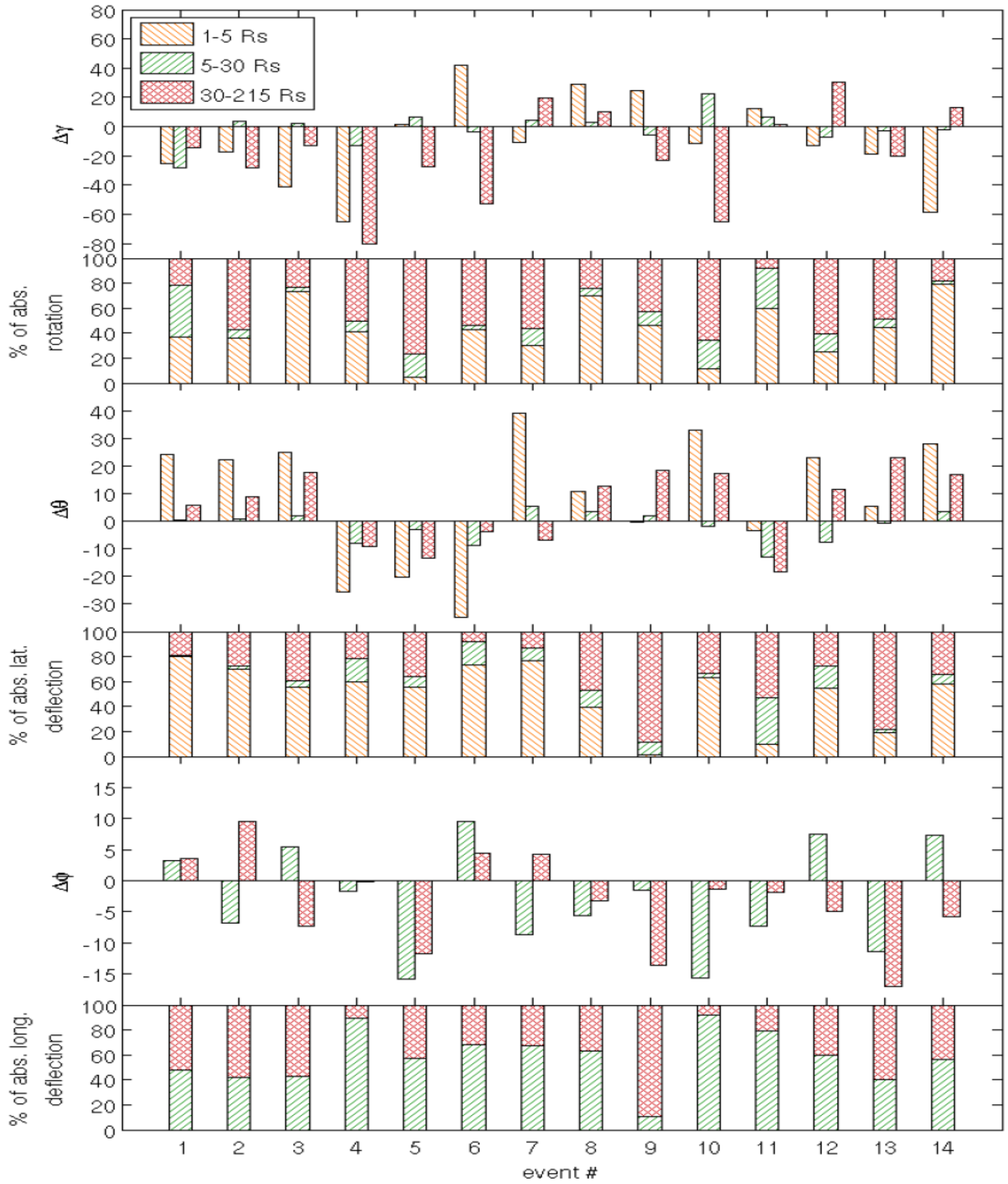
(e.g. *Wang et al.*, 2004, *Cremades et al.*, 2005, *Yurchyshyn*, 2008; Möstl et al., 2015)

- in the corona magnetic forces are important



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

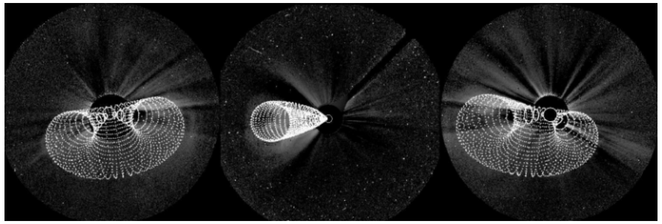




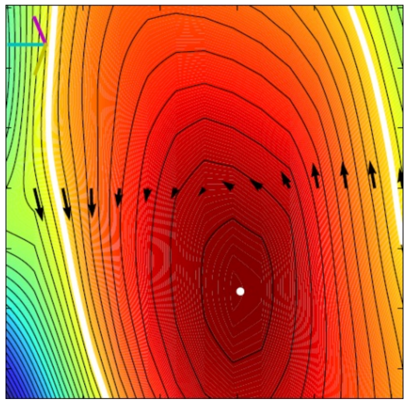
New tool to investigate flux rope 3-D geometrical evolution from Sun to Earth

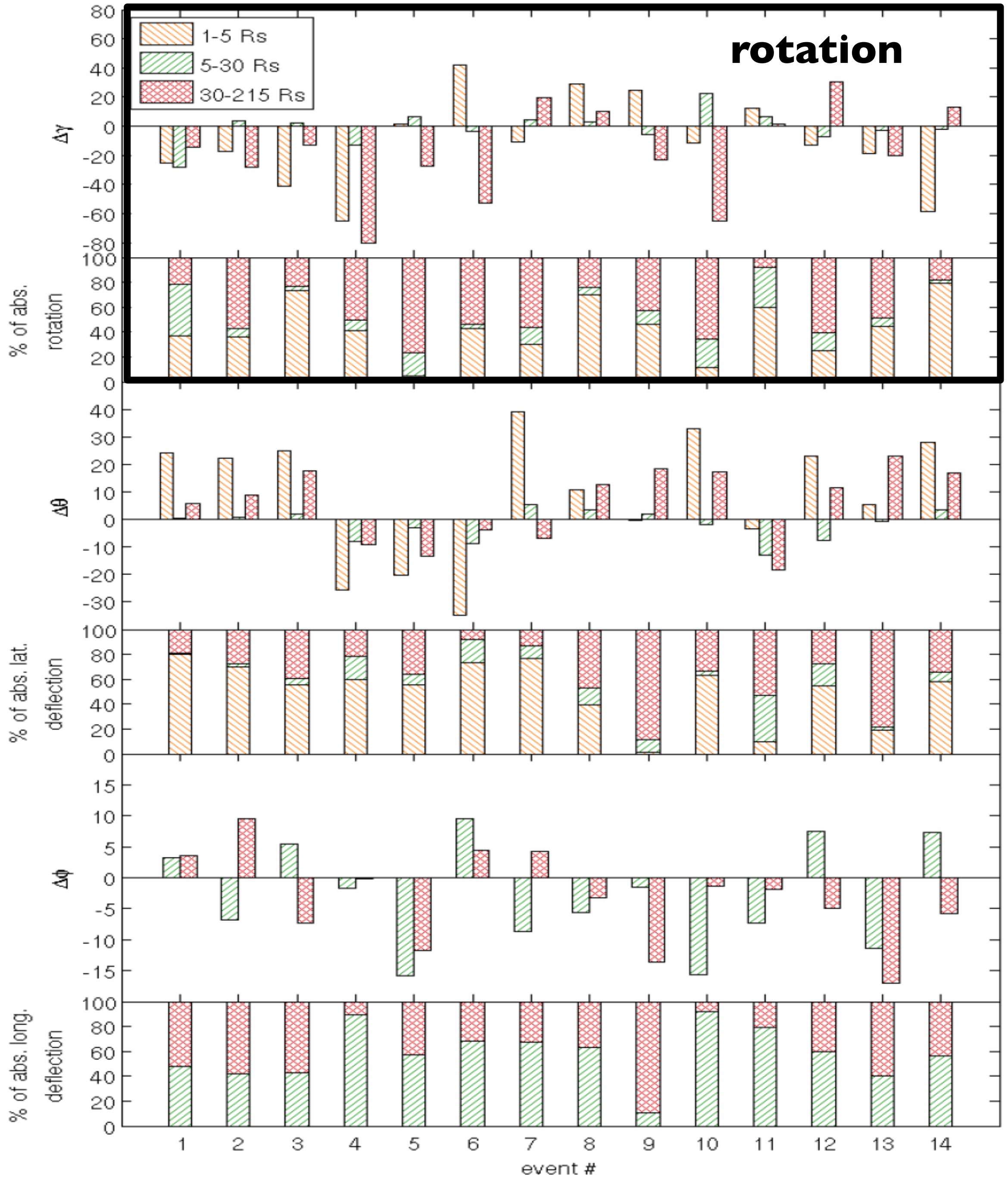
Isavnin et al., Sol. Phys., 2013&2014

white-light forward modelling



Grad-Shafranov reconstruction





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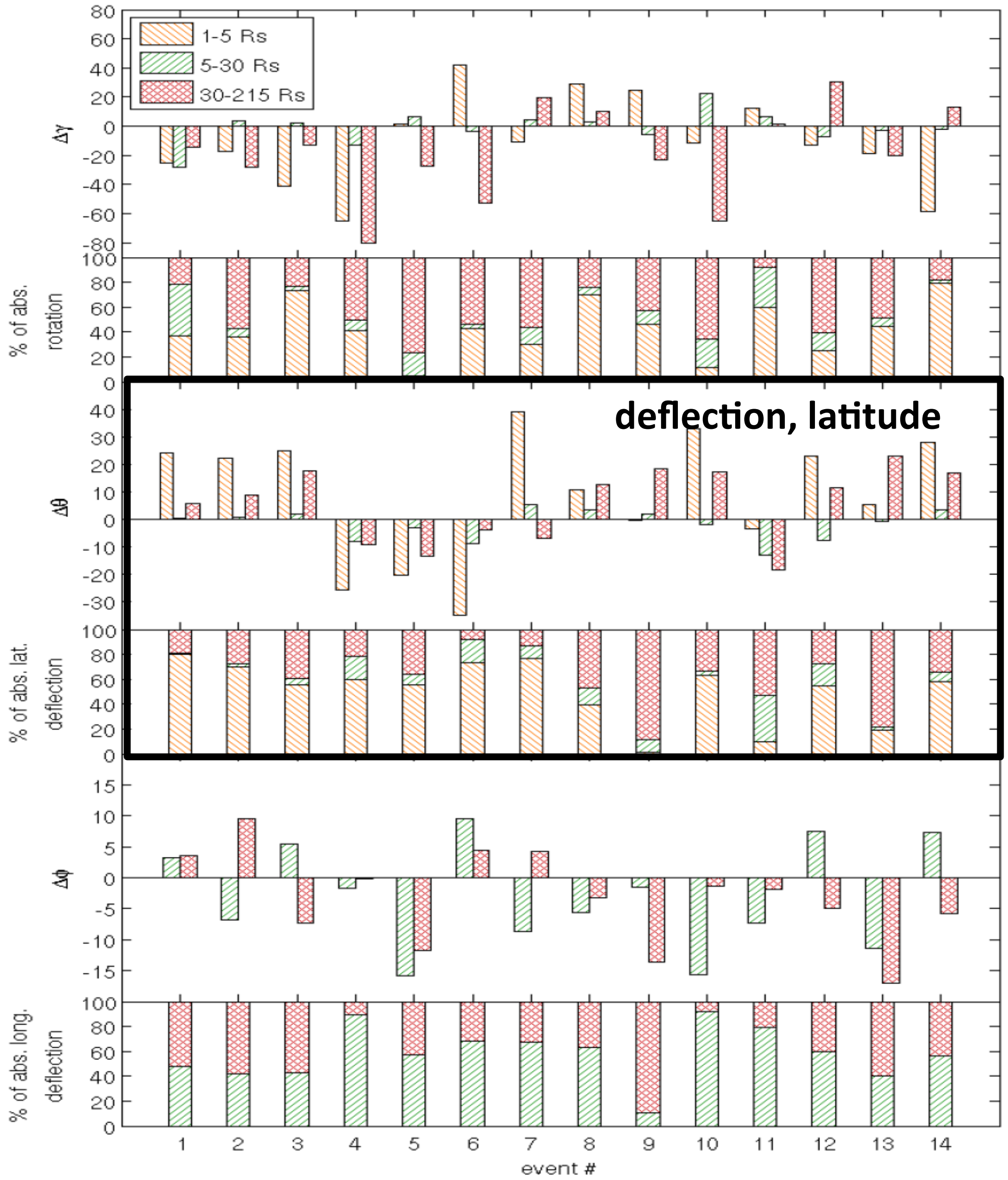

New tool to investigate flux rope 3-D geometrical evolution from Sun to Earth

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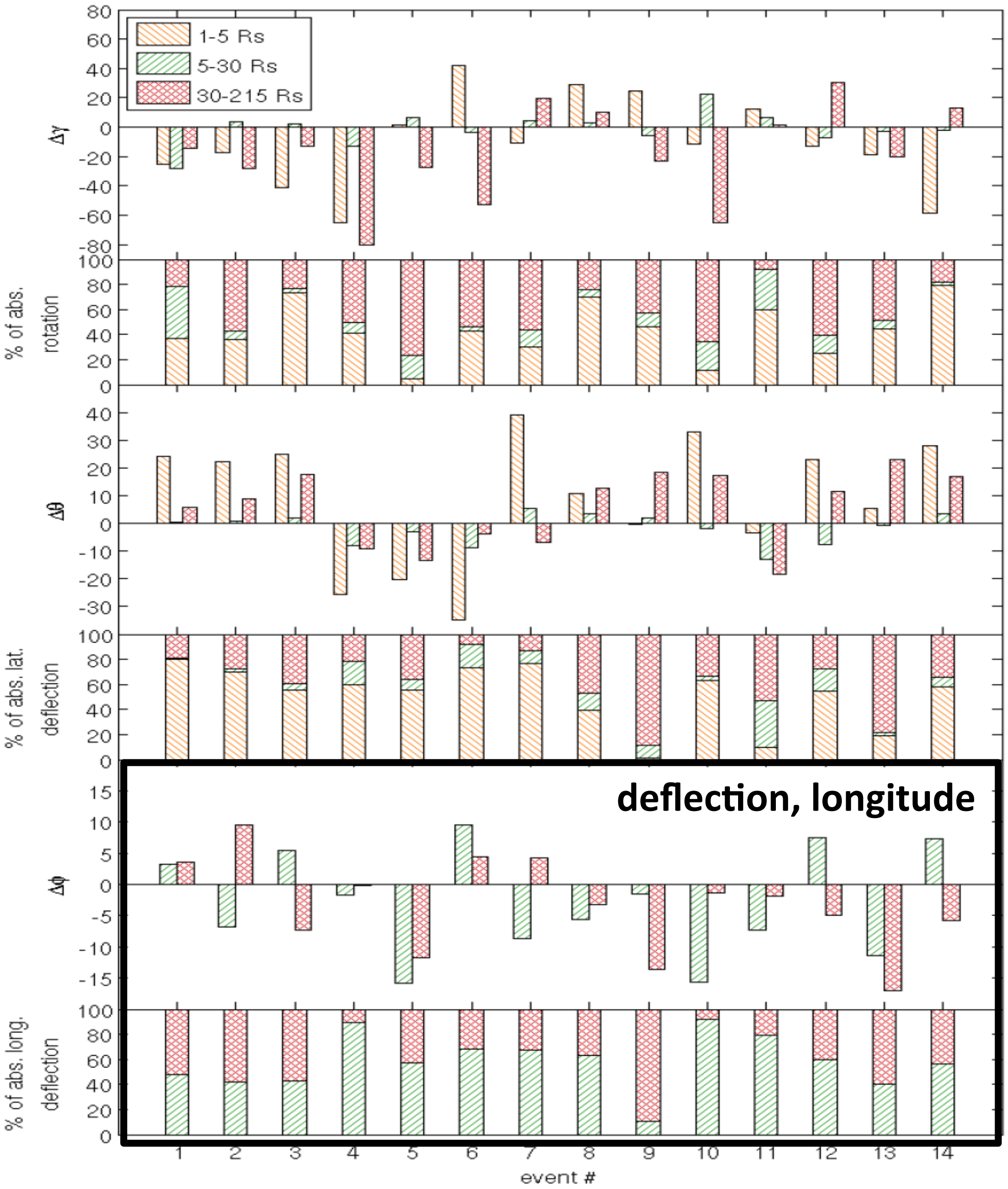


New tool to investigate flux rope 3-D geometrical evolution from Sun to Earth

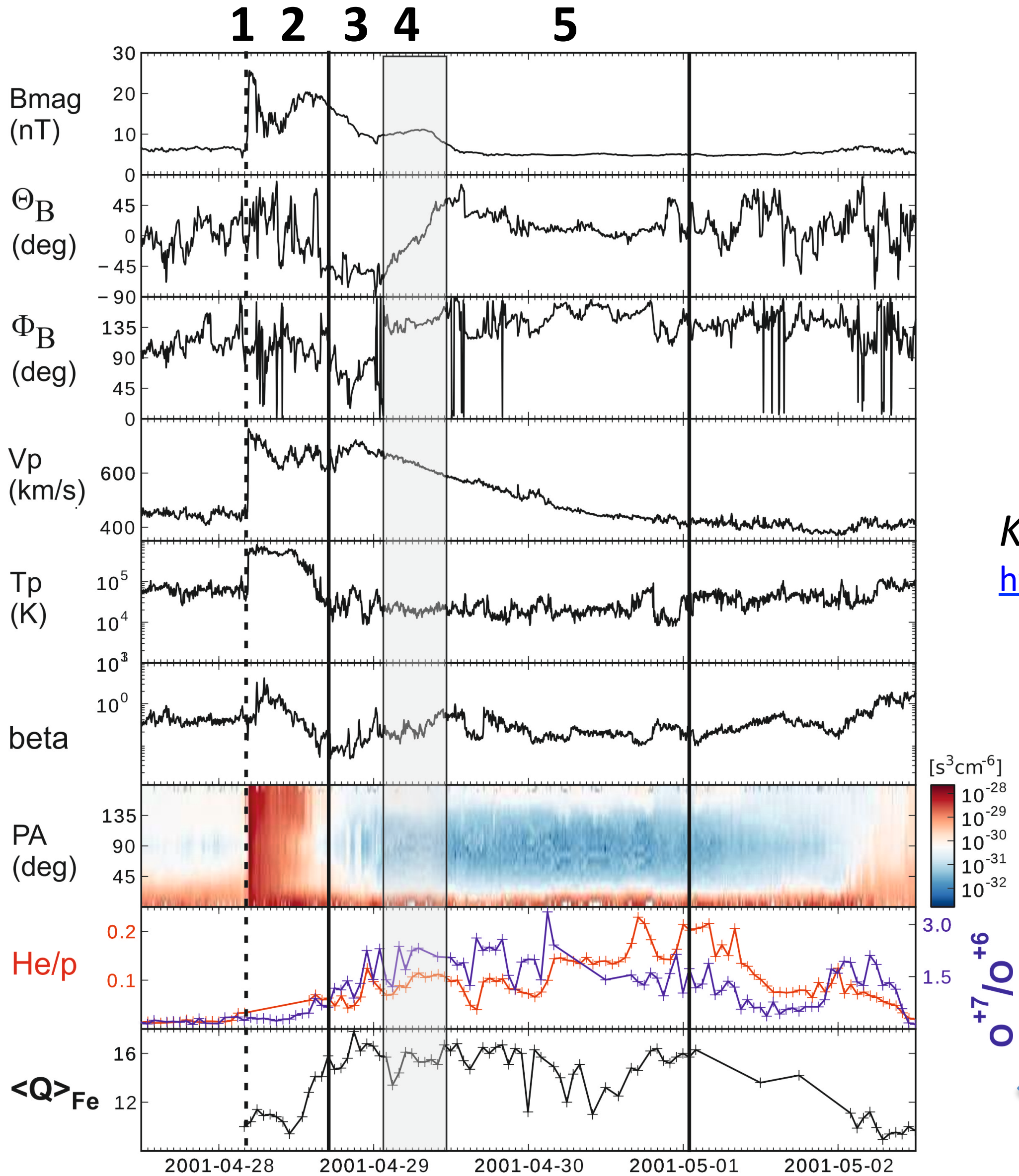
Isavnin et al., Sol. Phys., 2013&2014

→

- fastest changes occur within 1-30 R_S
- But significant evolution also in the inner heliosphere > 30 R_S

Things are actually more complicated….

5(6)-part CME in-situ

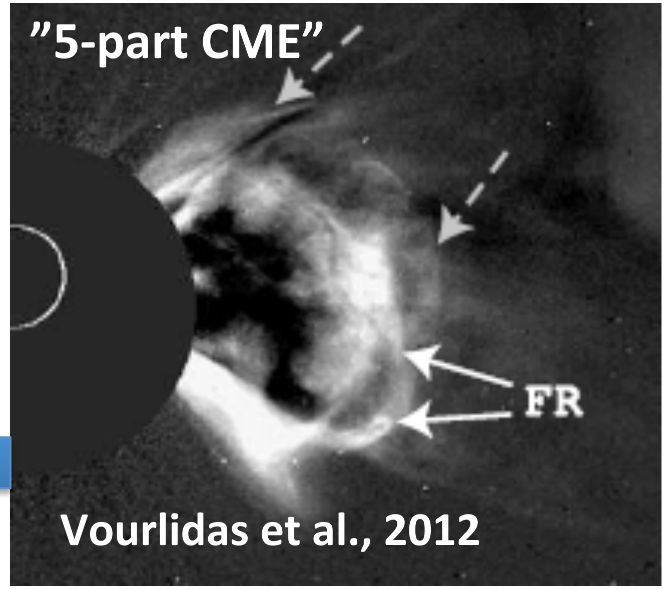


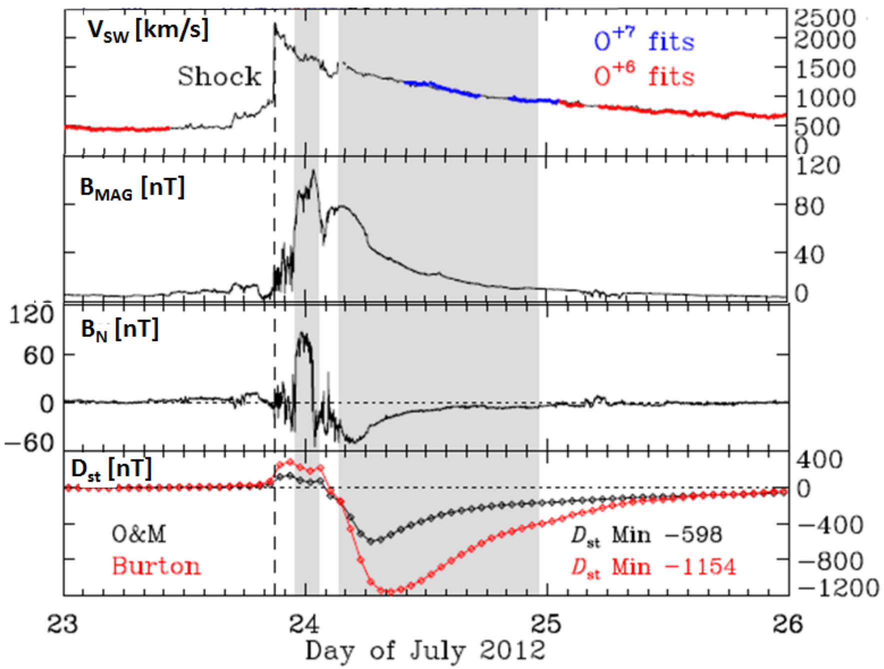
1. shock
2. sheath
3. front region
4. flux rope (MC)
5. back region
(6. density blob)

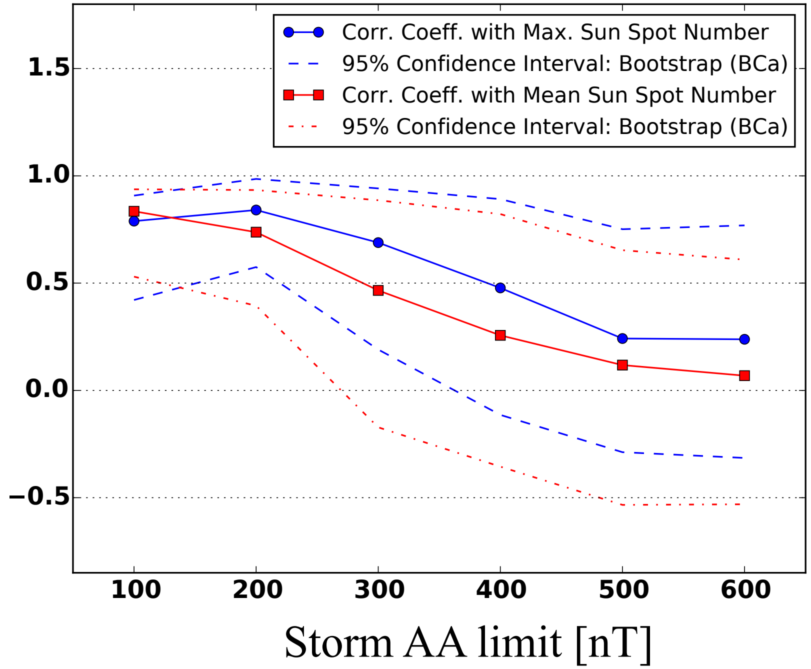
separated near the Sun or in IP space?

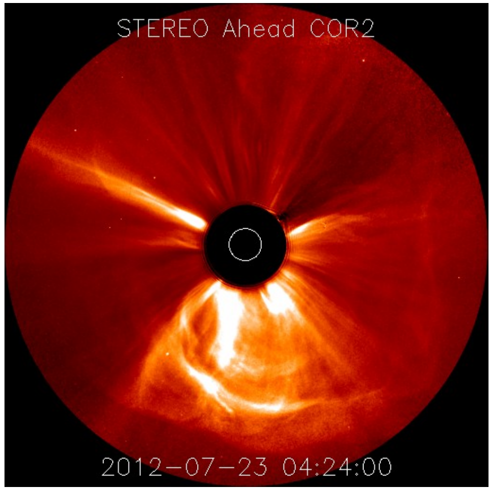
Kilpua et al., 2013
http://adsabs.harvard.edu/abs/2013AnGeo..31.1251K

?









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 most dramatic, may change significantly the ability to drive magnetospheric storm

- heliospheric flux rope evolution also matters

- CME-CME interaction, interaction with ambient SW

- Predict the structure of turbulent CME sheath region (interlinked to the flux rope evolution)

- Bring solar, interplanetary and magnetospheric communities as well as observational and simulation communities together to improve space weather predictions

EGU 2016 Session:

ST1.7

Insights for Early Predictions of Magnetic and Dynamic Properties of Interplanetary Coronal Mass Ejections using Observations, Theory and Modeling

Convener: Emilia Kilpua

Co-Conveners: N. P. Savani, Spiros Patsourakos ipshocks.fi