Coronal Mass Ejections and Geomagnetic Storms

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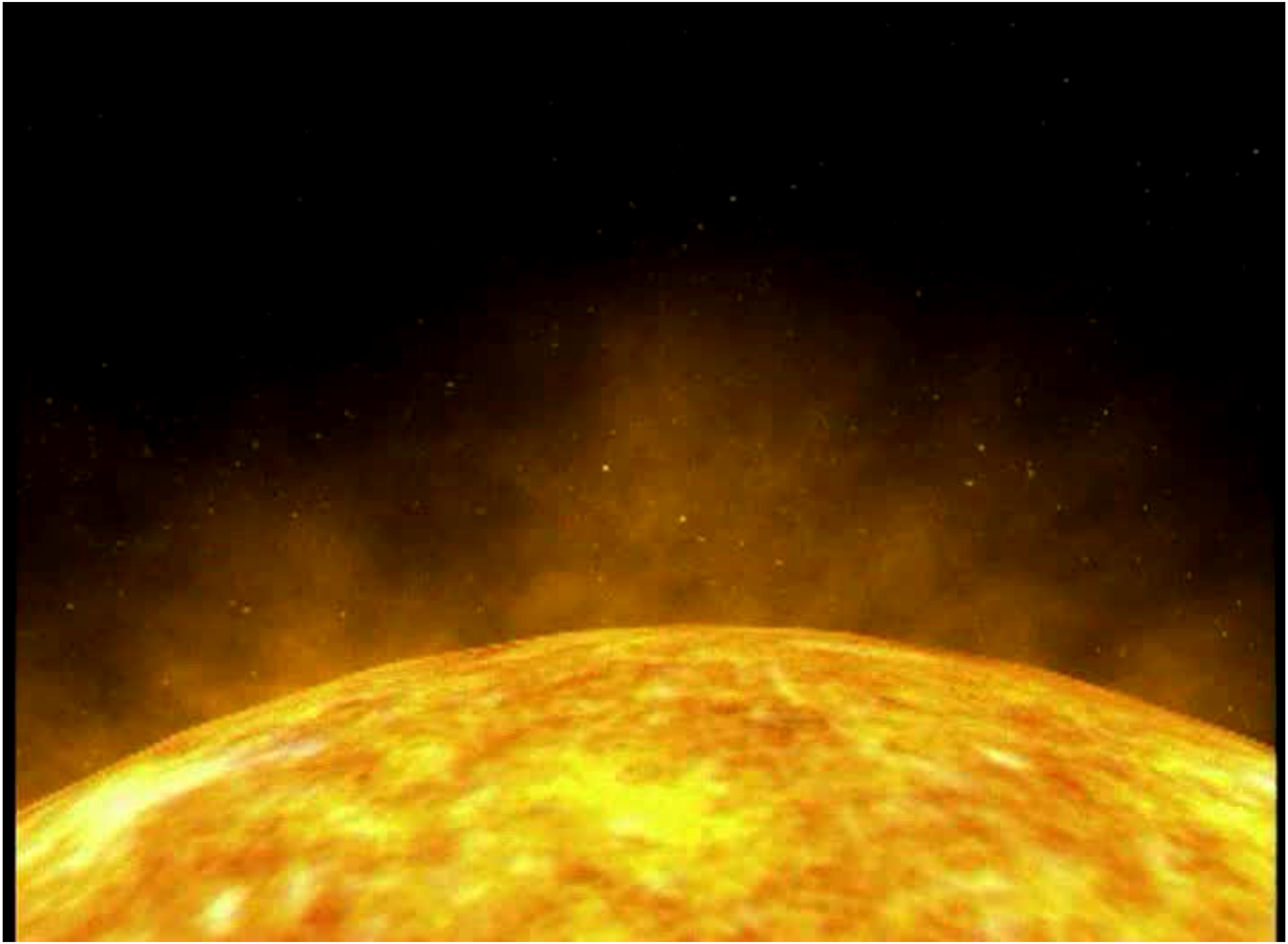
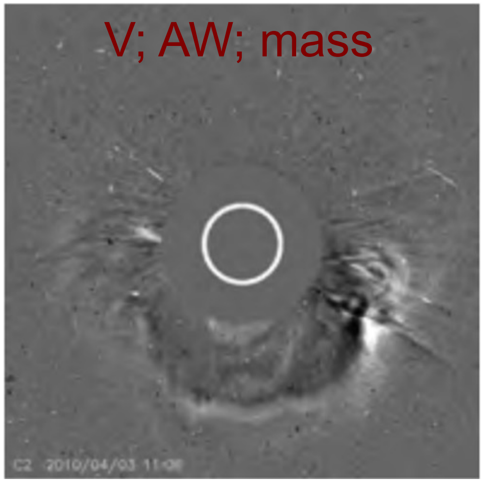
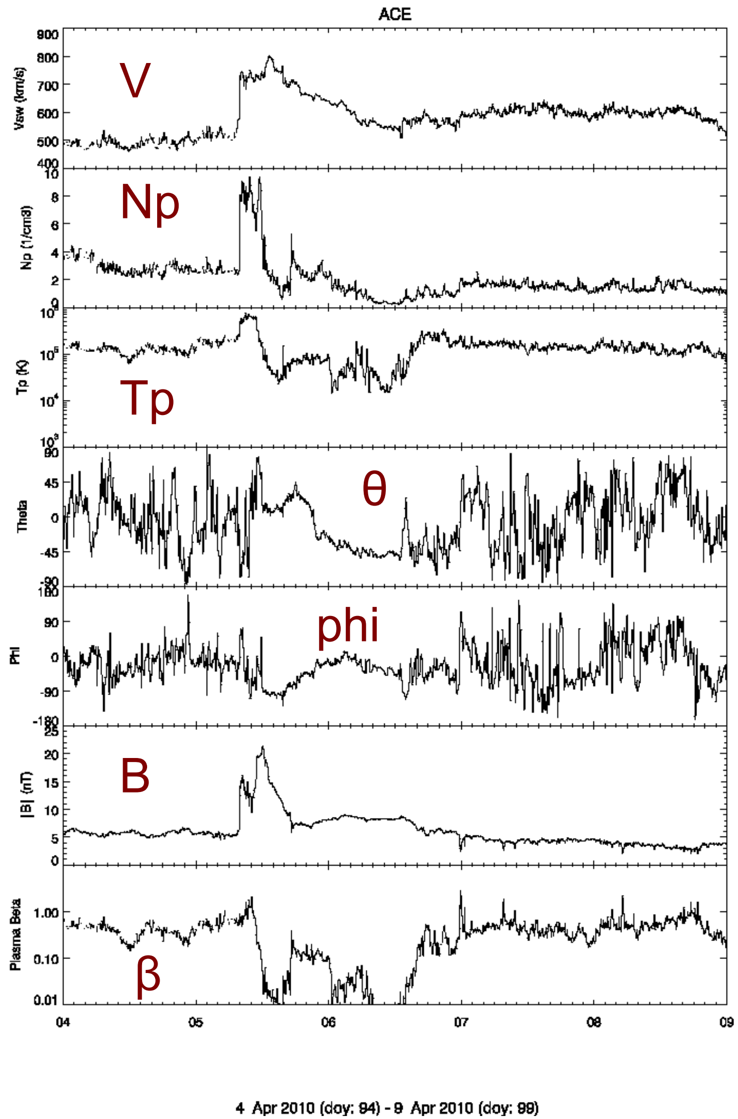
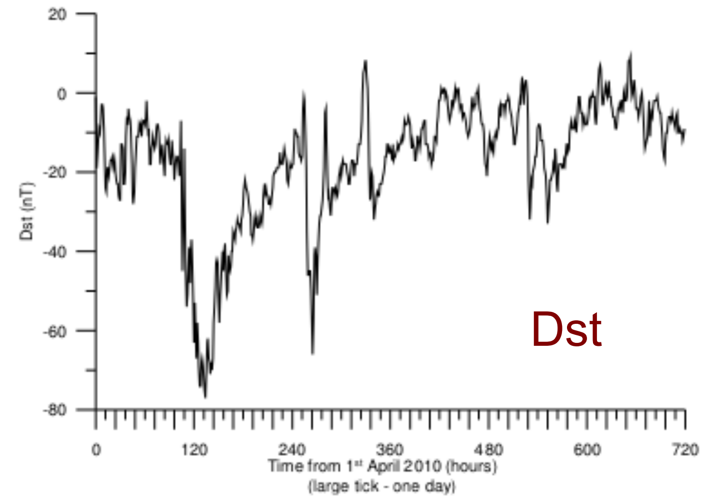


CMEs Big gap $\leq$ 1 AU ICMEs gap $\leq$ 0.01 AU Geomagnetic storms

Zuccarello et al. 2013







From the Sun to the Earth the CMEs may:

- Deflect
- Rotate
- Get deformed

Manchester et al. 2014

Transfer of energy from ICME to magnetosphere:

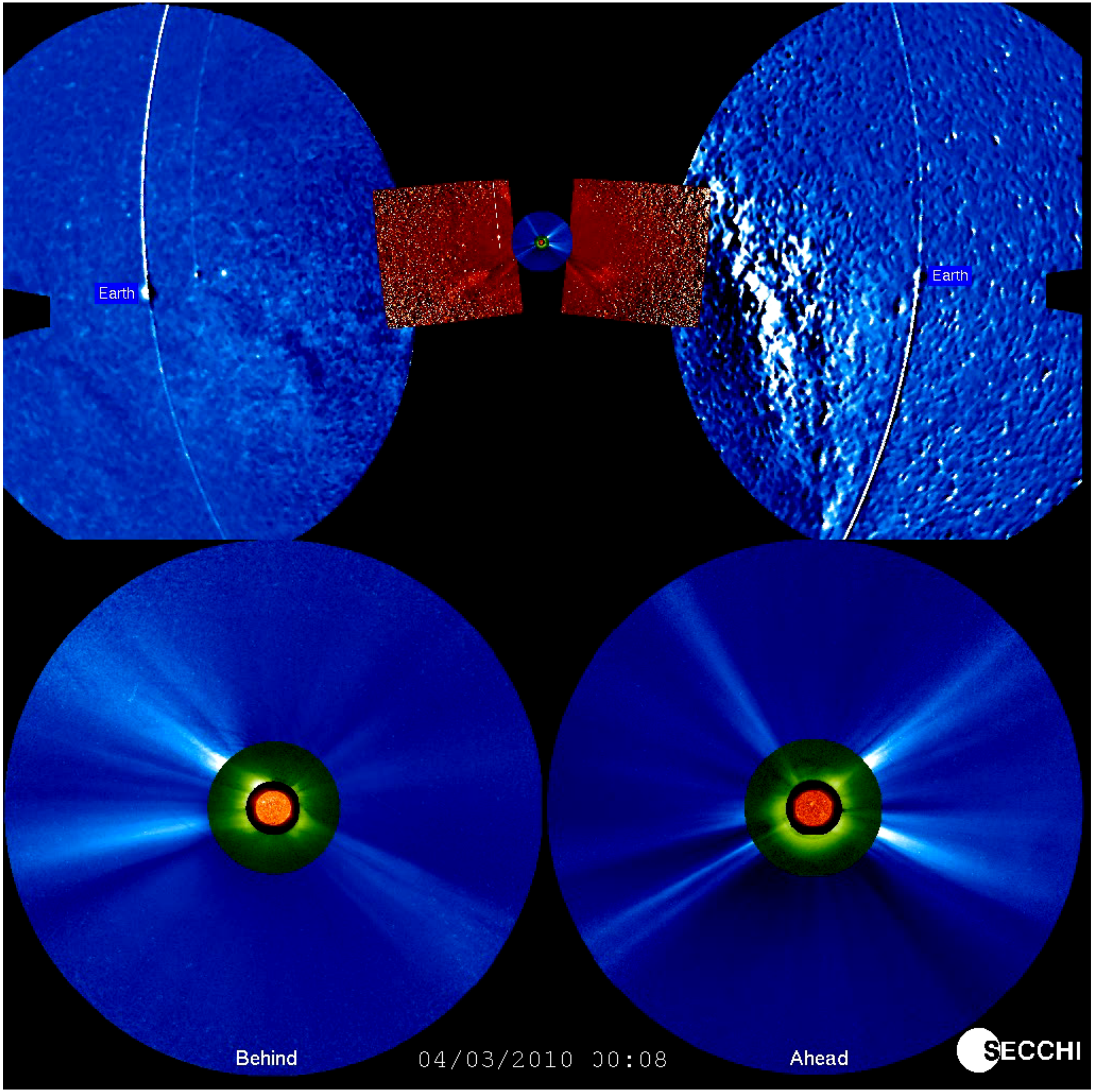
- Akasofu (1983) function:

$$\varepsilon = 10^7 V B^2 l_0^2 \sin^4(\theta/2) \ (J/s)$$

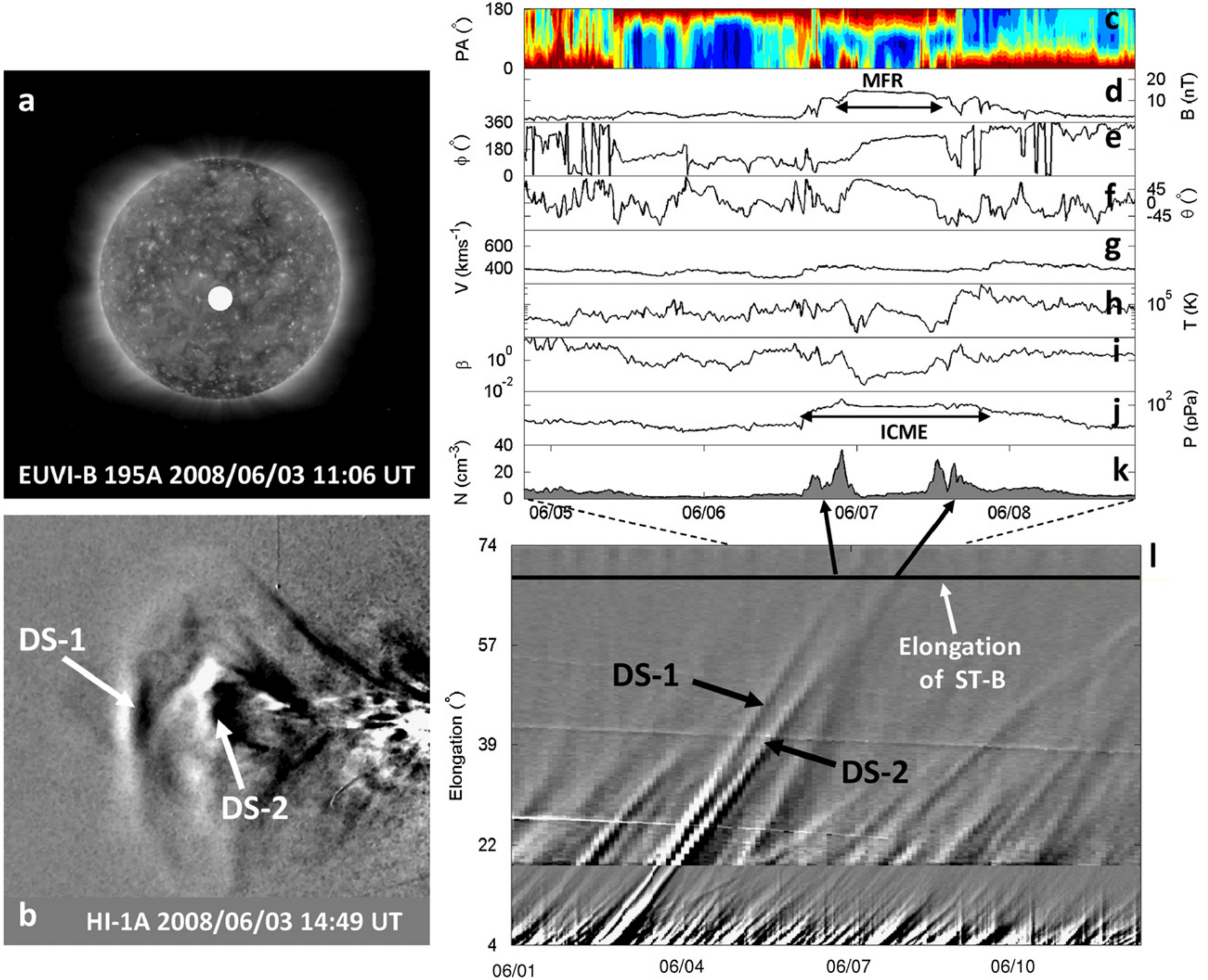
- Wang et al. 2014:

$$E_{IN} = 3.78 \times 10^7 n_{SW}^{0.24} V_{SW}^{1.47} B_T^{0.86} (\sin^{2.7}(\theta/2) + 0.25) \ [J/s]$$

Filling the gap?



Filling the gap?



Rouillard 2011

CME propagation

One needs to know:

1) the CME characteristics (area, mass, speed, direction of propagation, magnetic configuration..)

2) the properties of the medium through which CMEs propagate (density, speed, magnetic configuration)

3) the interaction between the CME and the medium (physical processes: deflection, rotation, deformation, reconnection, erosion – see e.g. Wang et al. 2004, Dasso et al. 2006, Lynch et al. 2009, Lugaz et al. 2011, Manchester et al. 2014)

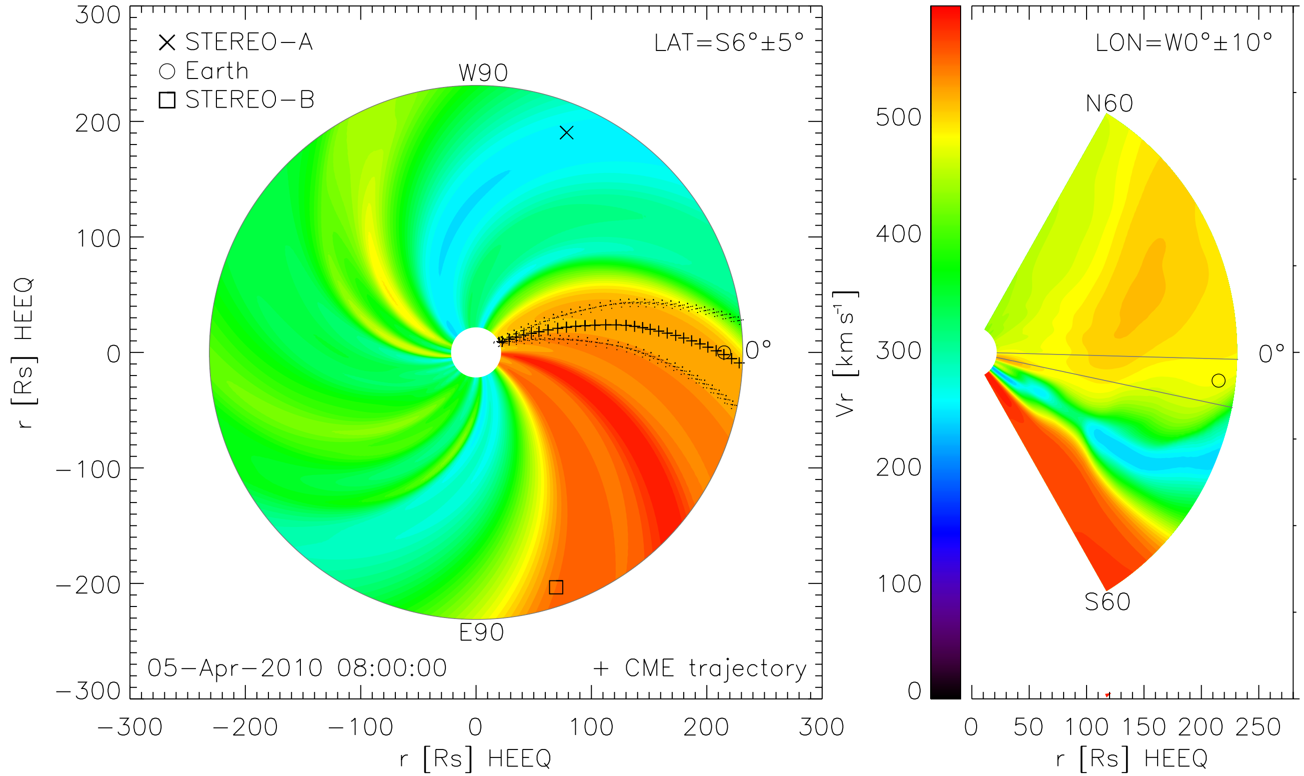
CME propagation

One can use:

- **Observations** – near Sun (SOHO, STEREO, PROBA2, SDO)
  – interplanetary space (STEREO/HI)
  – in situ (ACE, WIND, DISCOVR, SOHO, STEREO)

- **Models** − empirical: – drag based models (Cargill+ 1996, Vrsnak+ 2004-2014)
  – constant or cessation of acceleration before 1 AU (Gopalswamy et al. 2000, 2001)
  − MHD: ENLIL (Odstrcil 2003)
  EUHFORIA (Pomoell et al. 2017)

CME propagation



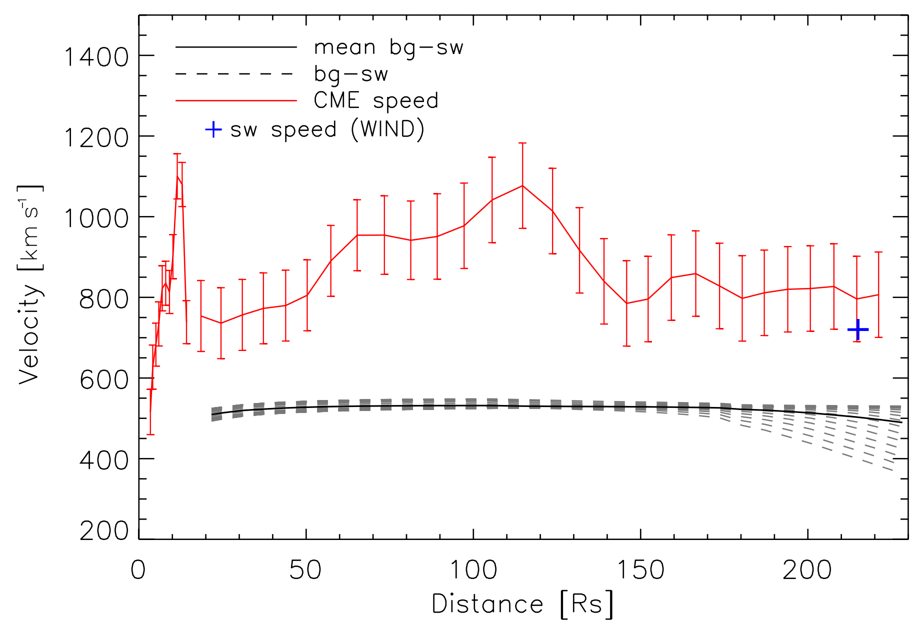
Solar wind background:

Wang-Sheeley-Arge + ENLIL

Forces acting on CME:

- the propelling Lorentz force -

- the drag force.

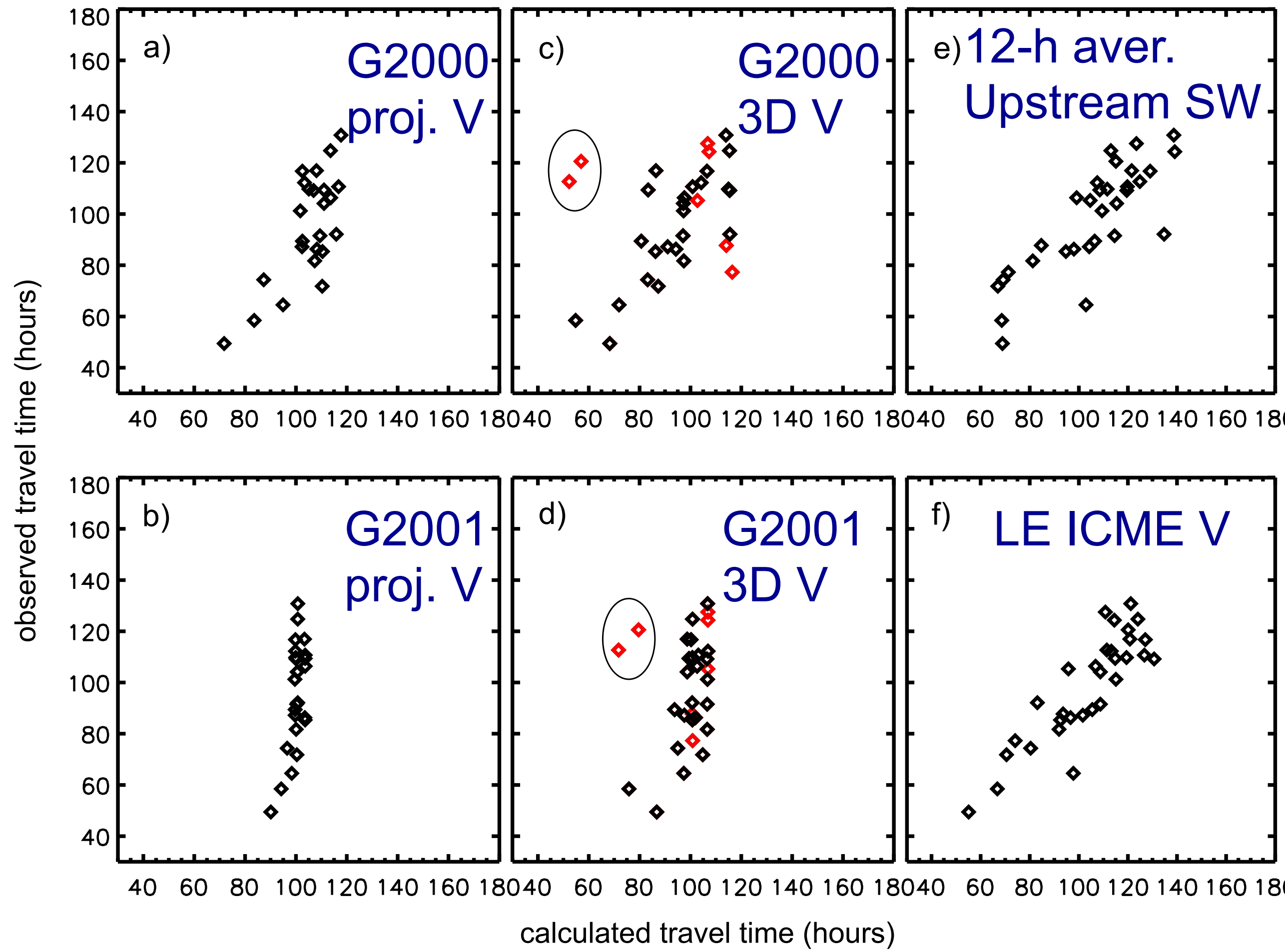


Temmer et al. 2011

CME propagation (2008 - 2010)

- **CME 3D speeds** give **slightly better predictions** than projected CME speeds

- **The observed CME transit times** from the Sun to 1 AU show a particularly **good correlation with the upstream solar-wind speed.**



Kilpua, Mierla et al. 2012

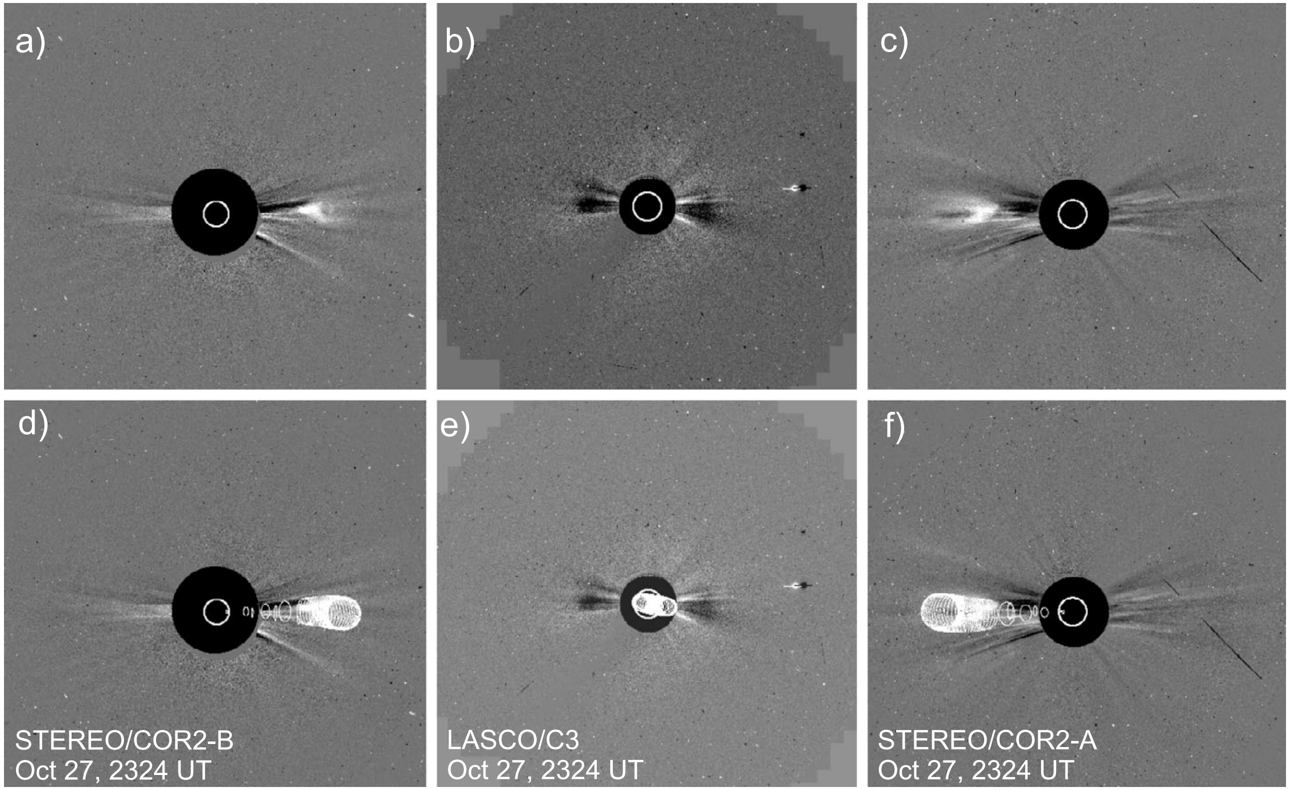
G2000 – Gopalswamy et al. 2000
G2001 – Gopalswamy et al. 2001

CME propagation – deep minimum

- the wide-angle view point from STEREO is crucial to detect solar counterparts for weak ICMEs

- narrow CMEs (angular widths ≤ 20°) can arrive at Earth and an unstructured CME may result in a flux rope-type ICME.

- Ten out of 16 (63 %) of the associated CMEs were stealth CMEs.



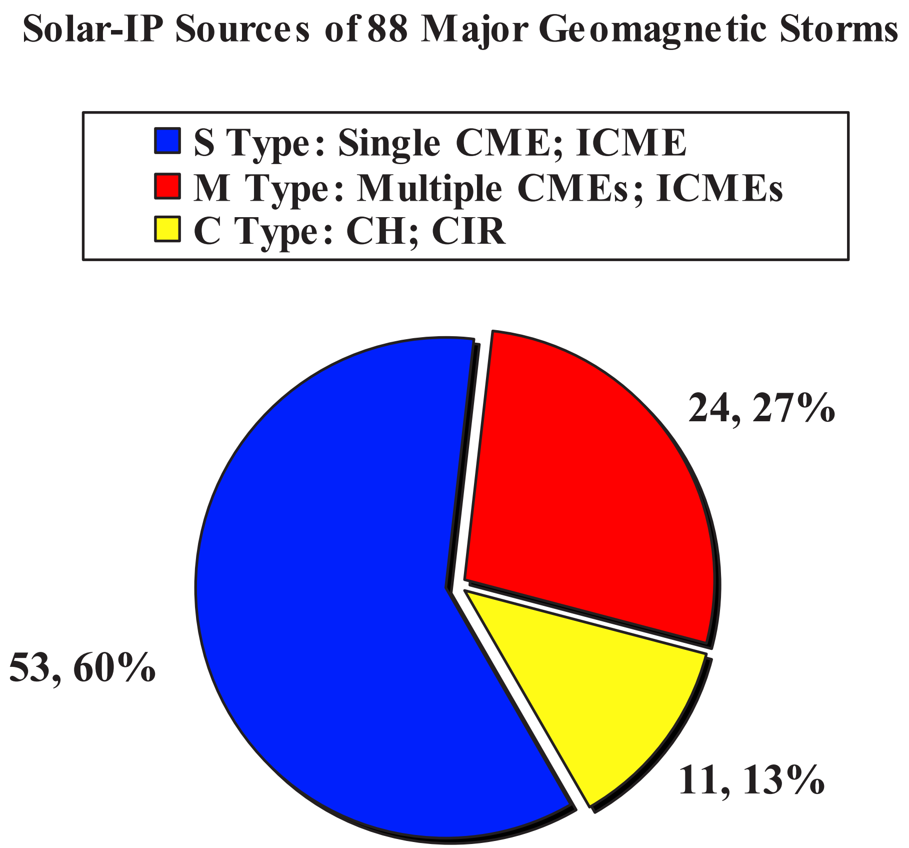
Kilpua, Mierla et al. 2014

Geomagnetic storms

- major storms are produced by **CMEs** (Goplaswamy et al. 2007, Zhang et al. 2007)

- Geomagnetic storms are highly correlated with **Bz, V•Bz,** CMEs **speeds** as well as with the **ram pressure** (Gonzalez et al. 1994, Srivastava and Venkatakrishnan, 2004, Gopalswamy et al. 2008, Echer et al. 2013).

- The major storms and superstorms meet the **GT criteria** (Echer et al. 2005, Gonzalez and Tsurutani 1987).



Zhang et al. 2007

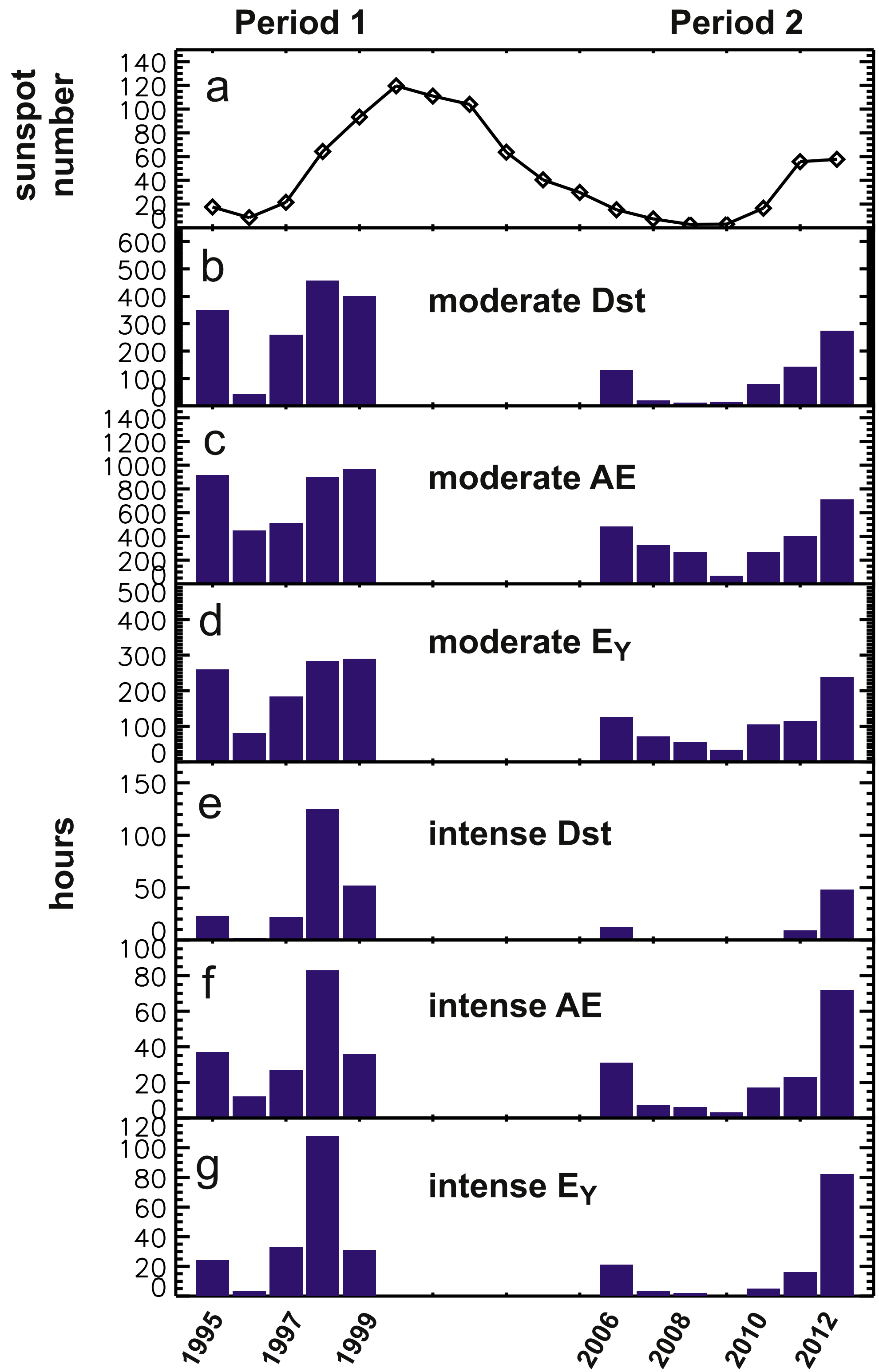
(GT criteria: a necessary IP condition for an intense geomagnetic storm to occur is the presence of an intense m.f. (Bs > 10 nT) for long durations (t > 3 h) of time.)

Geomagnetic storms

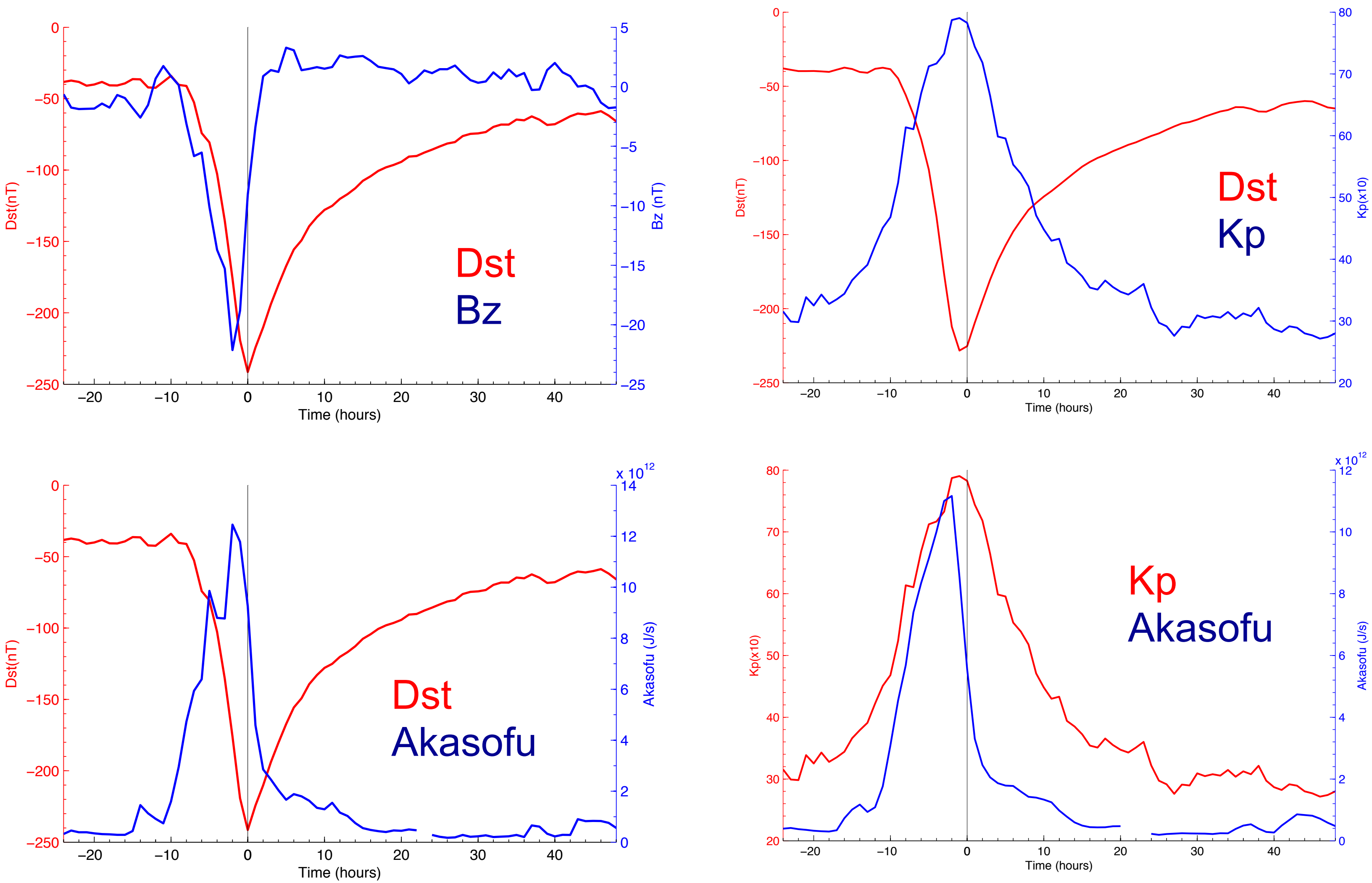
- Period1: 1995-1999
- Period2: 2006-2012

- the **weak southward IMF** and the lack of strong ICMEs led to **weak Dst activity** in Period2.
- **Low solar wind densities** may have further weakened the ring current response and the solar wind–magnetosphere coupling efficiency.
- **No difference in solar wind speed** between the 2 periods

Kilpua et al. 2014



Energy transfer - Coupling functions



CMEs in SC23, Dst < -150 nT

$r(Bz, Dst)_{-2} = 0.76$

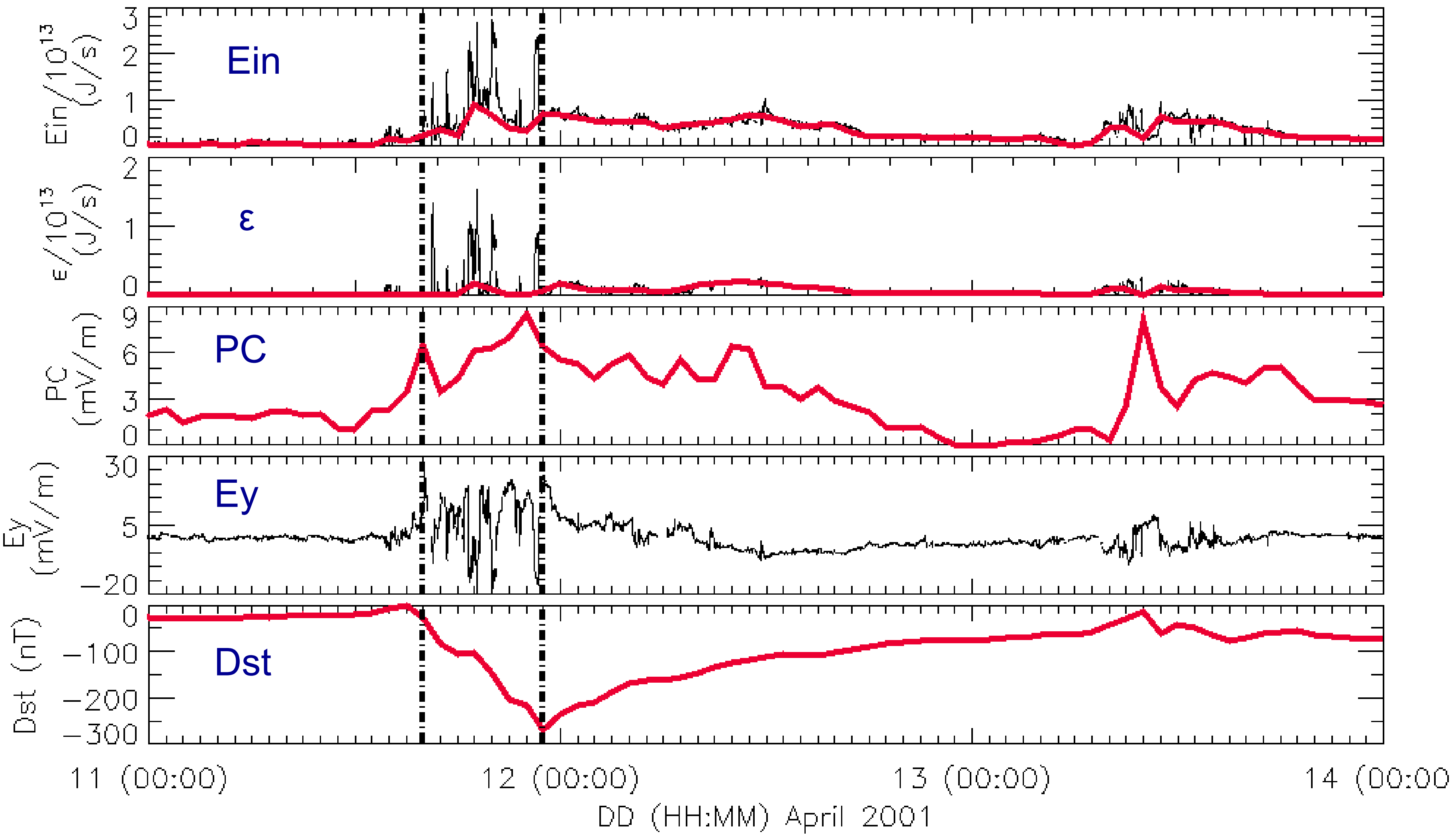
$r(Bs \cdot V, Dst)_{-2} = -0.74$

$r(V, Dst)_{-3} = -0.29$

$r(\rho, Dst)_{-1} = -0.13$

Oprea, Mierla et al. 2013

Energy transfer - Coupling functions



Geomagnetic storm on April 11, 2001

Besliu-Ionescu, Mierla and Maris, 2016

Summary

Still needed:

To understand the CME propagation into IP space:

- To improve the background solar wind
- To understand the interaction between the CMEs and SW
- To improve the forecast of the CME arrival at the spacecraft and the forecast of Bz

To understand the coupling between ICME and magnetosphere

Other recent studies not shown in this talk

CME propagation:

- Using STEREO/HI and/or drag approaches: Vrsnak+ 2010, 2013, Maloney+ 2010, Moestl+ 2014, Colaninno+ 2013, Mishra+ 2013, Lugaz+ 2013, Hess+ 2014, Wang+ 2014, Temmer+ 2015, Zic+ 2015, Shi+ 2015, Zhao+ 2016, Rollett+ 2016, etc.
- MHD: Lugaz+ 2011, Vrsnak+ 2014, Isavnin+ 2014, Webb+ 2014, Manchester+ 2014, Shen+ 2014, Pizzo+ 2015, Wang+ 2016, etc.

Geomagnetic storms:

- extreme geomagnetic storms: Cid+ 2014, 2015, etc.
- SC23 storms: Andriyas+ 2017, Hema+ 2017, etc.
- SC24 storms: Kataoka+ 2015, Wu+ 2016, Bisht+ 2017, Selvakumaran+ 2016, etc.
- prediction: Kataoka+ 2016, Kubicka+ 2016, etc.