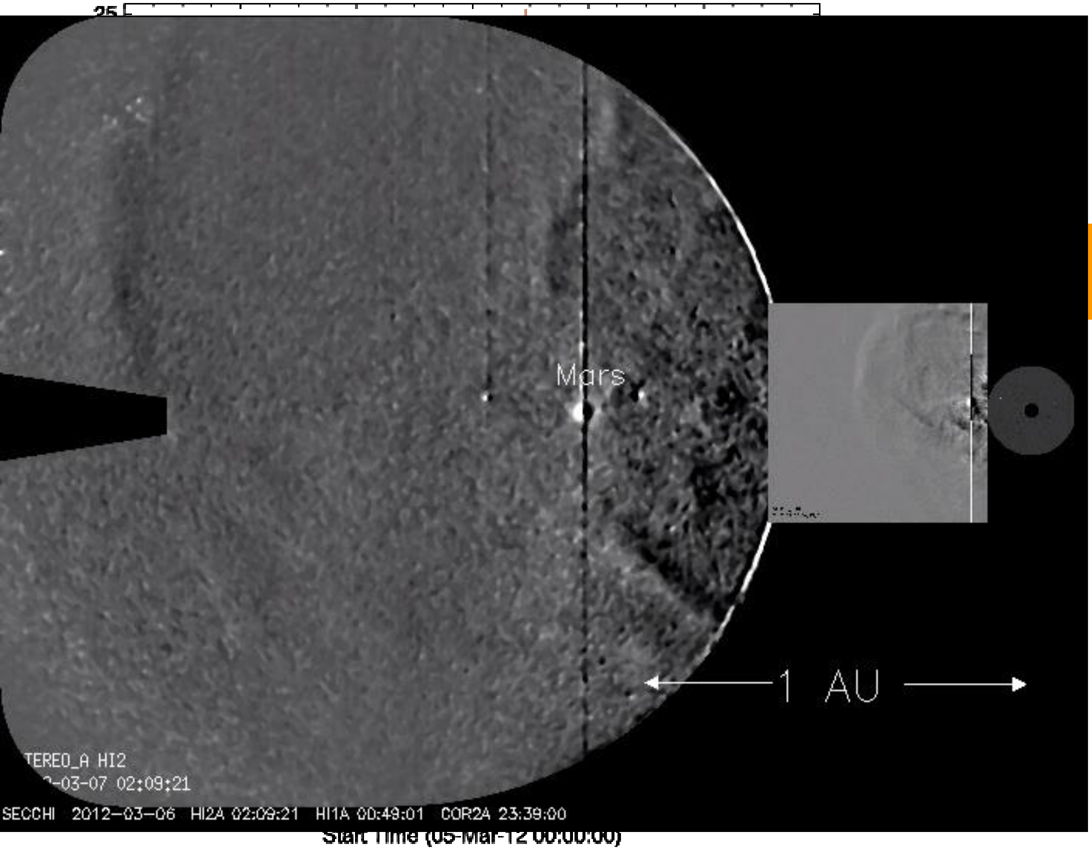
# 7-11 March 2012: a “busy” period in the geospace



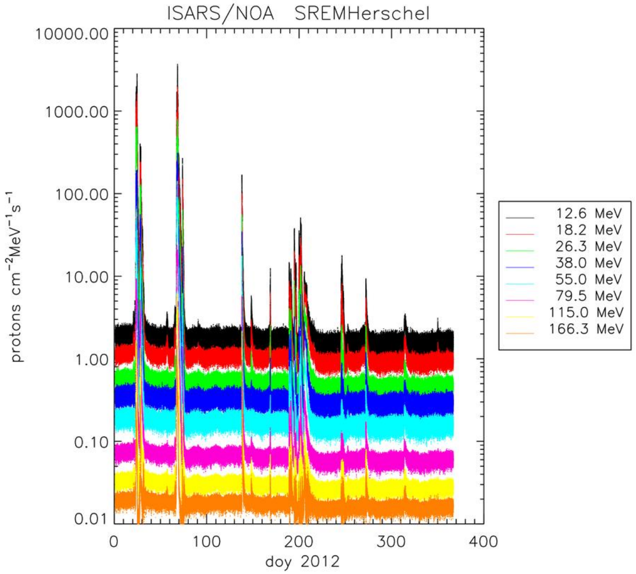

ICME

Geomagnetic storm

min Dst ~ -150 nT;

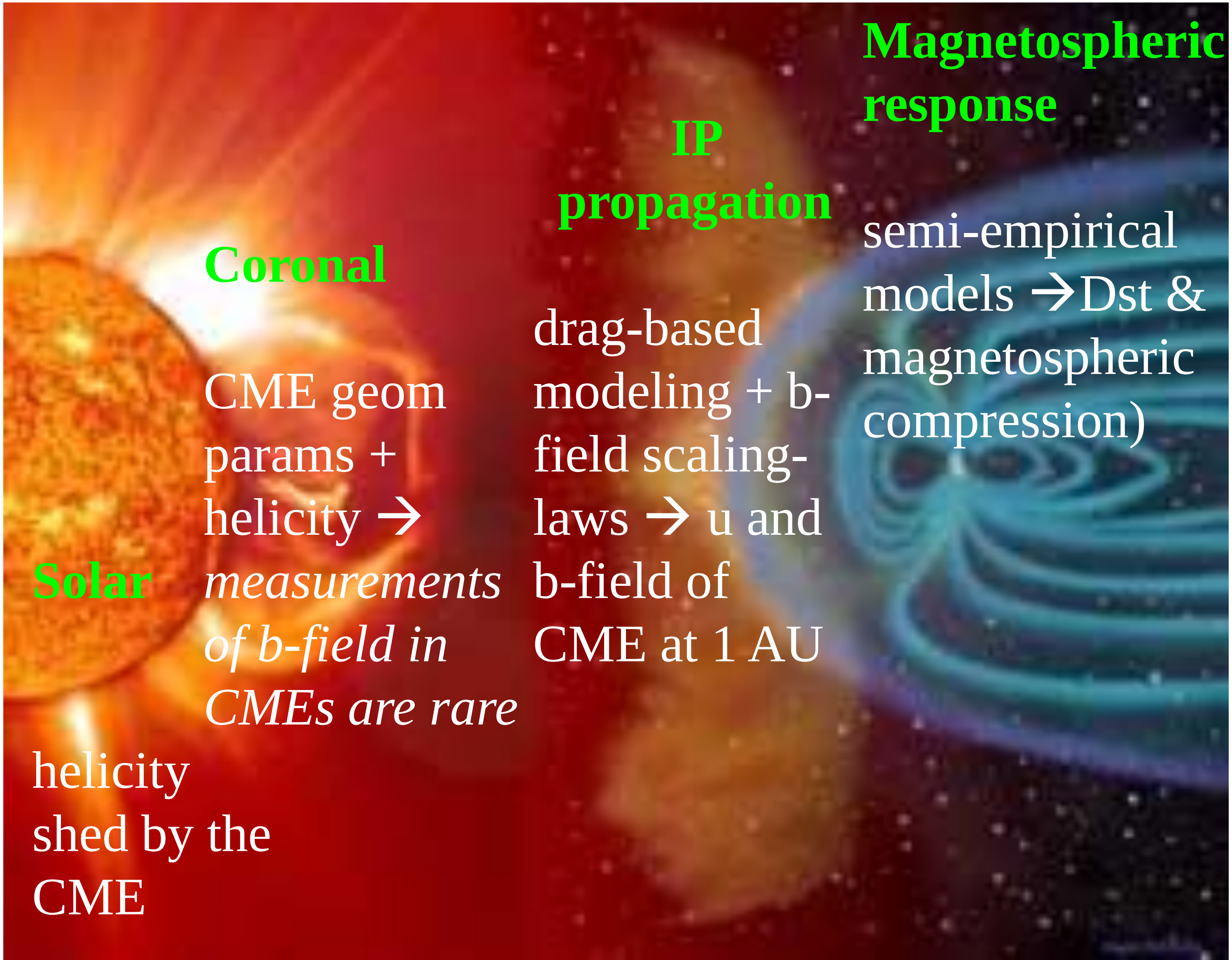
largest of cycle 24

Most intense proton event of 2012 ; shock & MIR reached V1 ~ 1 yr after (Gurnett et al. 2013; Liu et al. 2014)




Sanberg, Daglis, Anastasiadis

# Sun-Earth connections for a major geoeffective solar eruption



# Sun-to-Earth Analysis of a Major Geoeffective Solar Eruption within the Hellenic National Space Weather Research Network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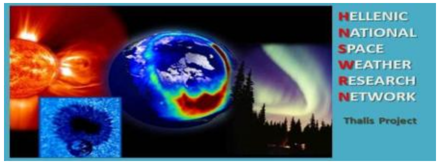
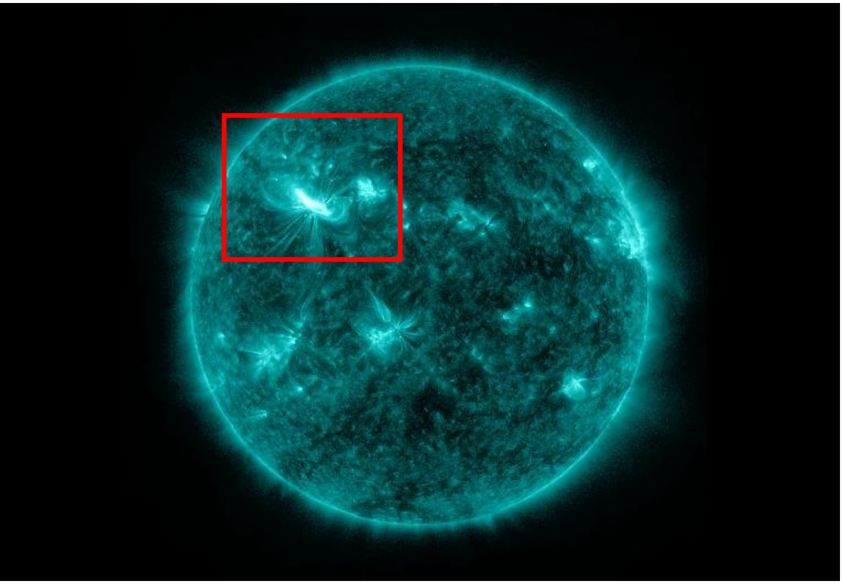
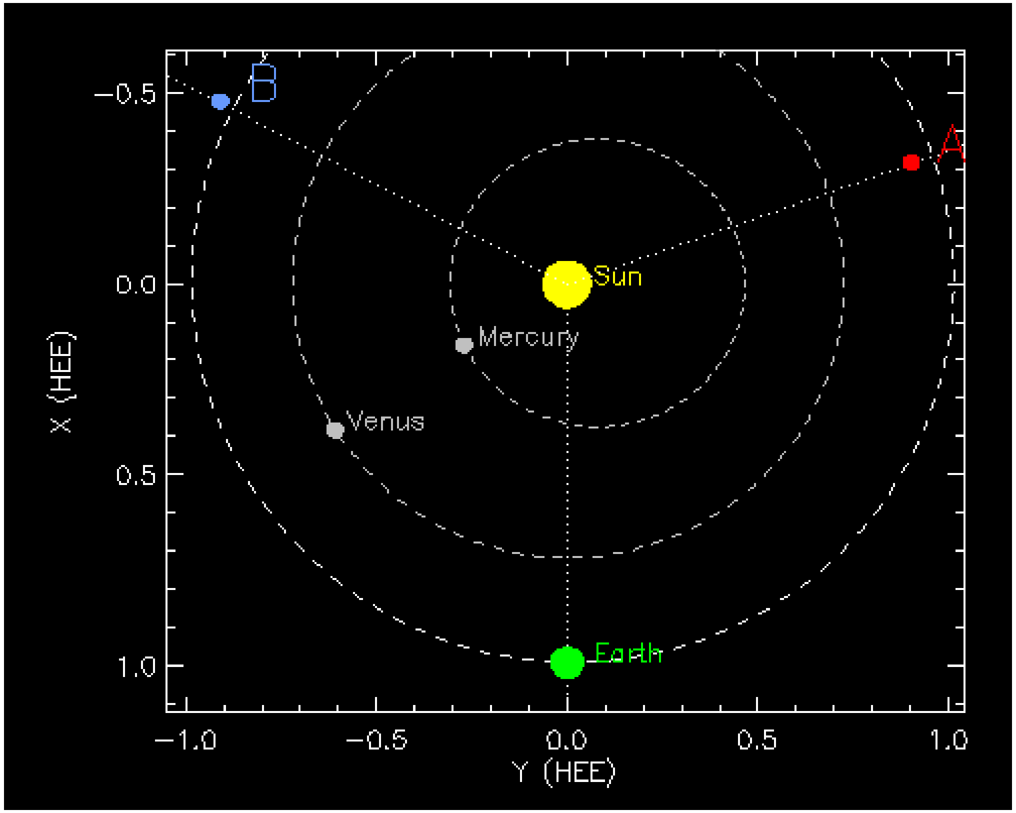


# Solar sources of the disturbances



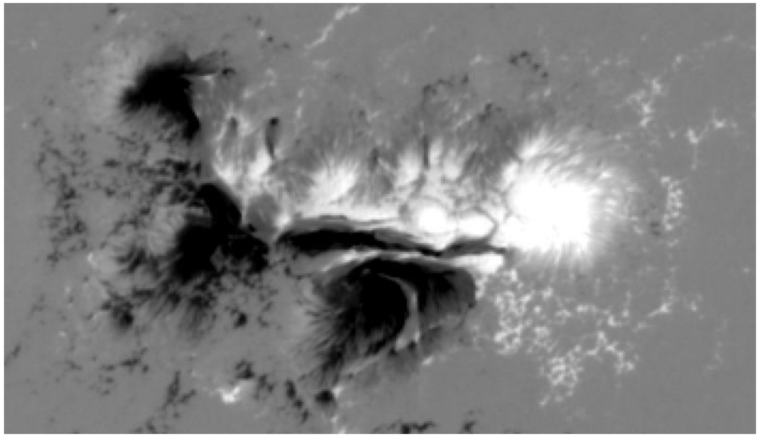
NOAA AR # 11429 (N18,E31)




Two eruptive X-class flares on early 7 March 2012 within 1 hours leading to 2 ultra-fast (>2000 km/s) CMEs (CME1 &CME2)

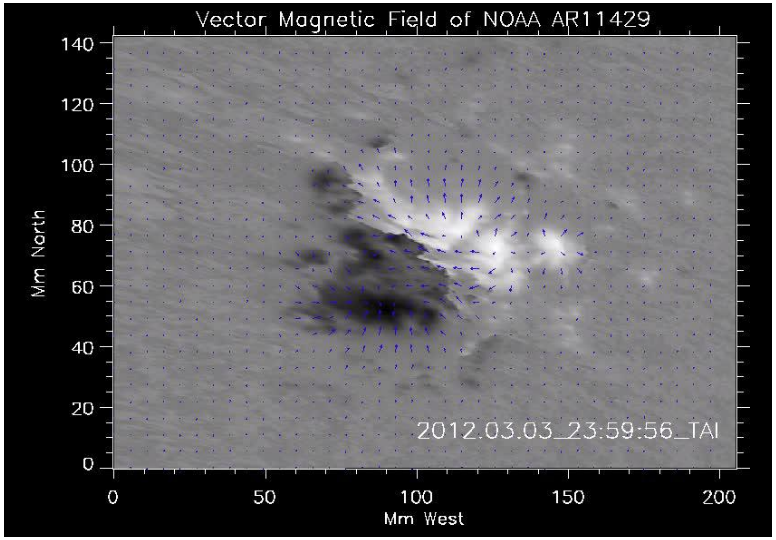
STB → 118 deg from Earth
STA → 109 deg from Earth

# Photospheric magnetic field & motions in SR



HMI Bz → complexity
(multiple & strong PILs)

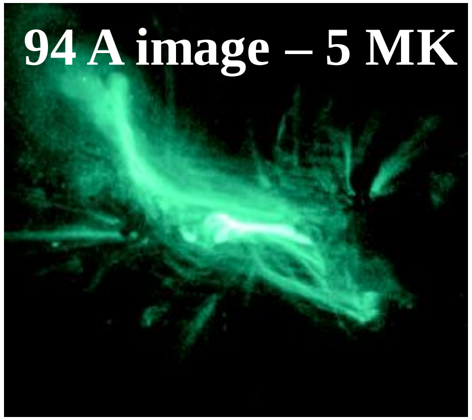
**Required elements for the build-up of magnetic energy and stresses and the formation of magnetic flux-ropes**

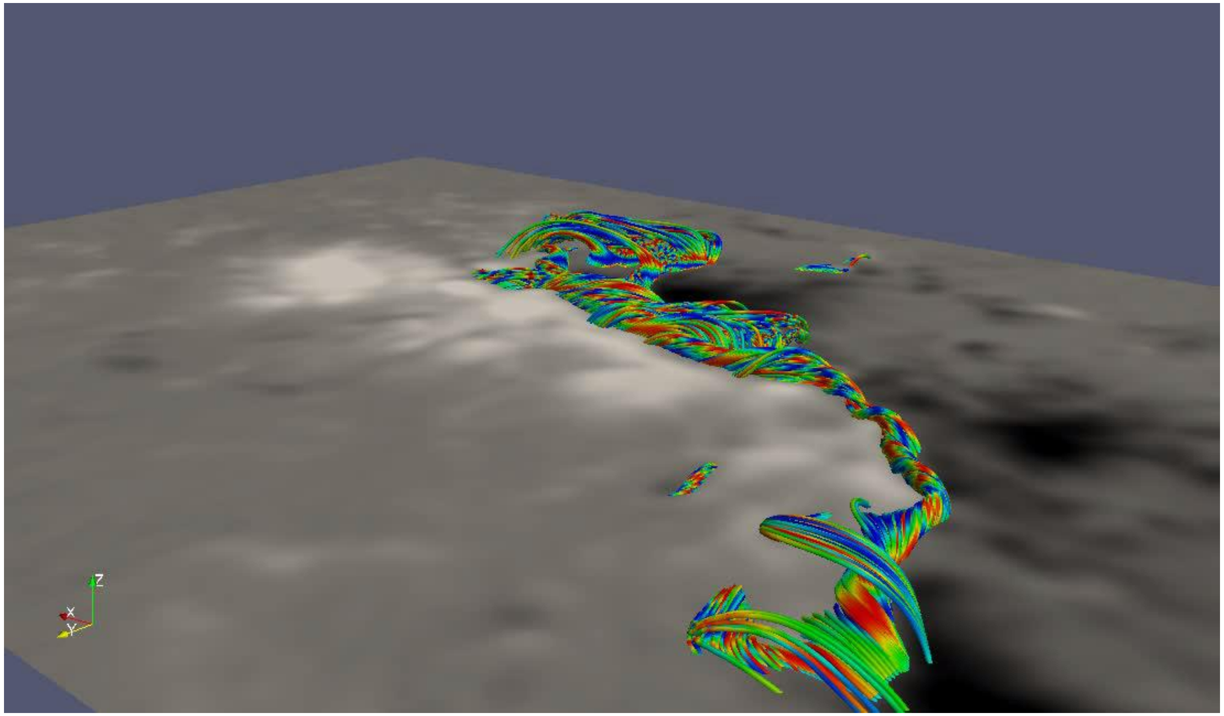


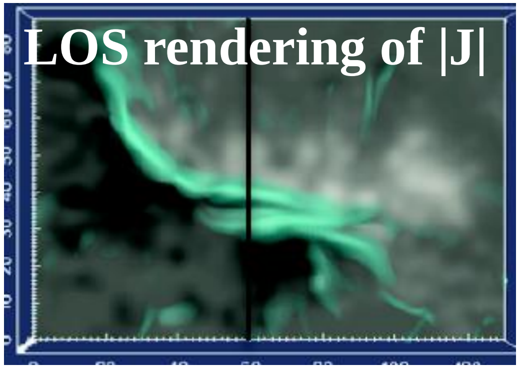

horizontal photospheric b-field ontop of Bz
→ shearing and rotating motions along and around the PIL

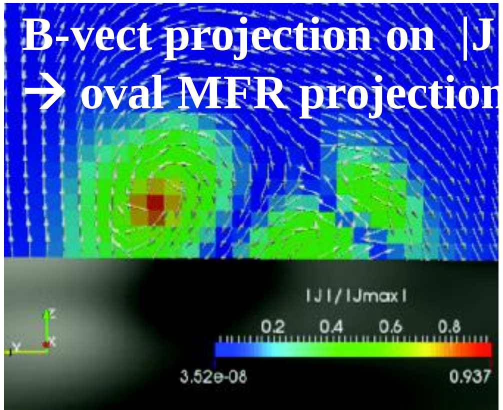
Chintzoglou

# NLFF B-field extrapolations show flux-rope structures




Chintzoglou, Patsourakos, Vourlidas, Zhang

# Example of coronagraphic observations of the WL CMEs and shock


**1st flare → CME1**

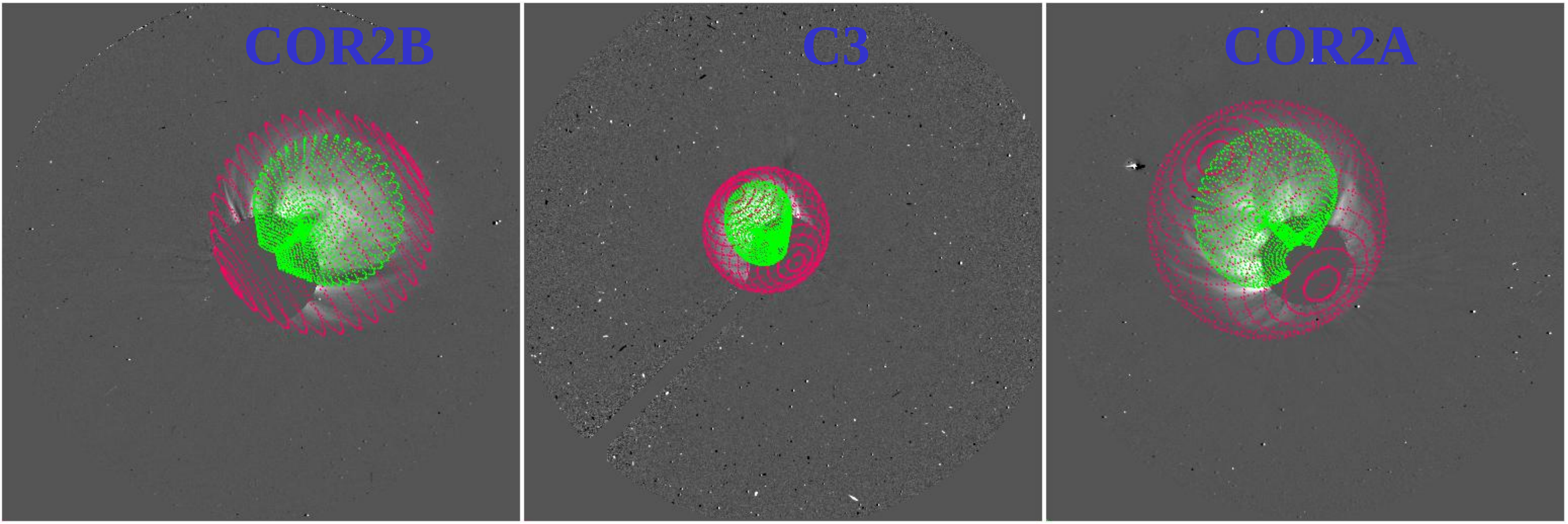
**Shock from CME1**

**2nd flare → CME2**

**corona too perturbed to see a WL shock from CME2**

**COR2A: FOV 2-15 Rs**

# CME1 & associated WL shock



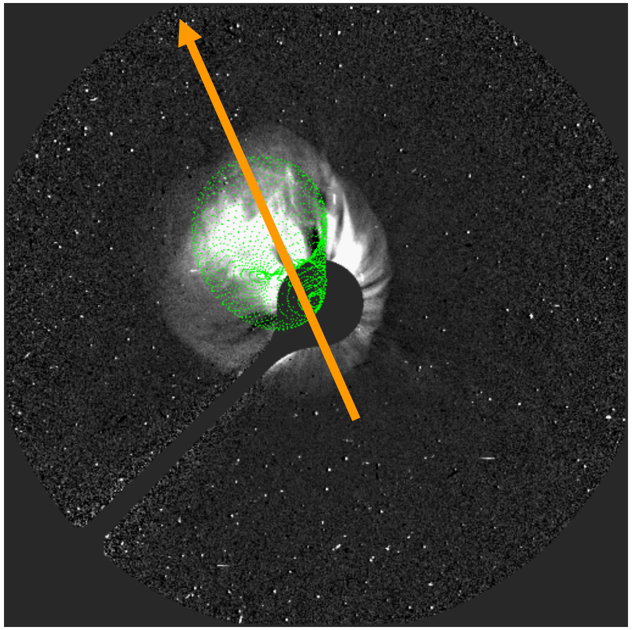

CME1 fitting w/GCS

WL shock fitting w/ oblate spheroid

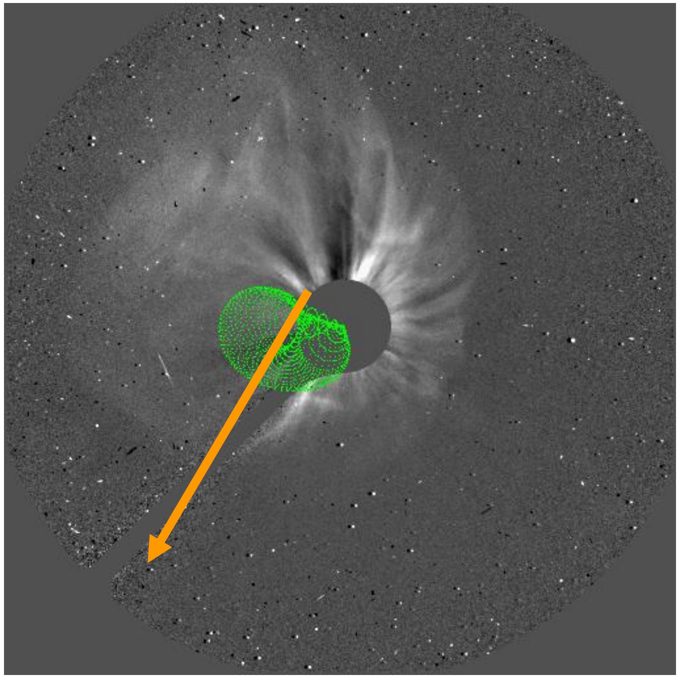
**Shock has an Earth-directed component**
**Not to be confused w/ Earth-directed CME!**

# Which CME is Earth-directed?

L1 views of the fitting for CME1 & CME2 (taken 1 hour apart)



CME1 → NE



**CME2** → SE
**heading towards Earth**

Patsourakos, Vourlidas

# Relating magnetic helicity & geometrical parameters w/ b-field in flux ropes

Dasso et al. 2003 derived a set of equations of the magnetic helicity of force-free (Lundquist 1950) and non force-free (Cid et al. 2002 & Hidalgo et al. 2002) flux ropes

$$\Delta H_m = \frac{4\pi B_0{}^2 L}{\alpha} \int_0^R J_1{}^2(\alpha R)\, dr$$

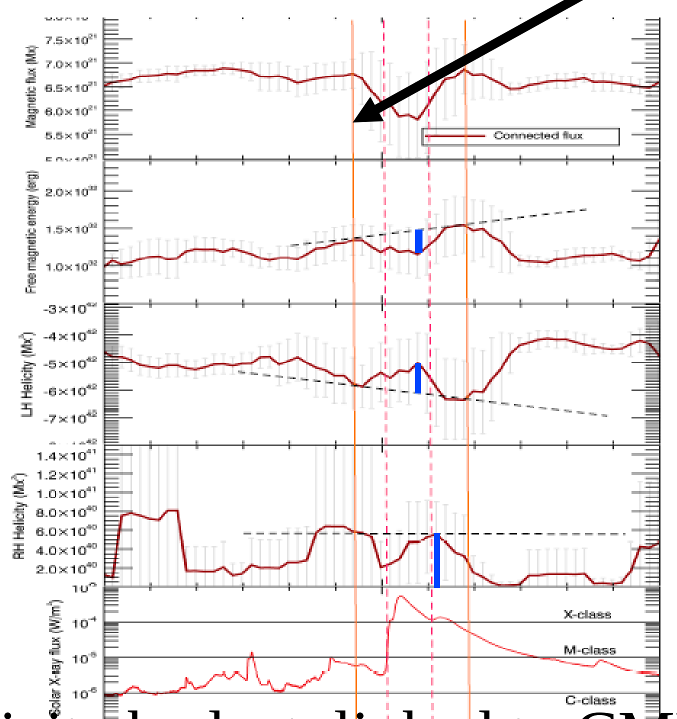
Lundquist force-free

$$\alpha R = 2.405$$ → purely poloidal field at FR edge

Patsourakos, Georgoulis

# Application to observations

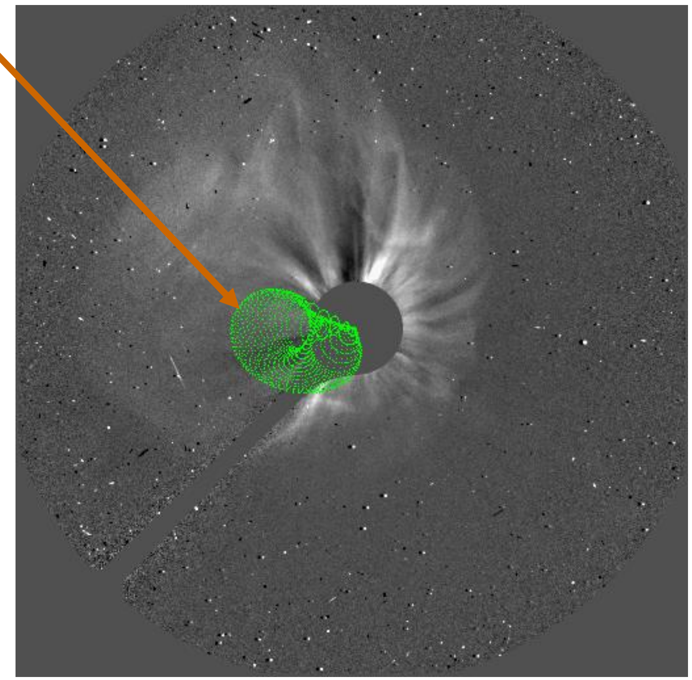
B=B(**Hm**, **R**, **L**, twist)




Helicity budget linked to CME2 from 3 methods (helicity injection, connectivity matrix, volume)

(*Georgoulis, Tziotziou, Moraitis, Nindos, Chintzoglou*)

helicity is conserved !

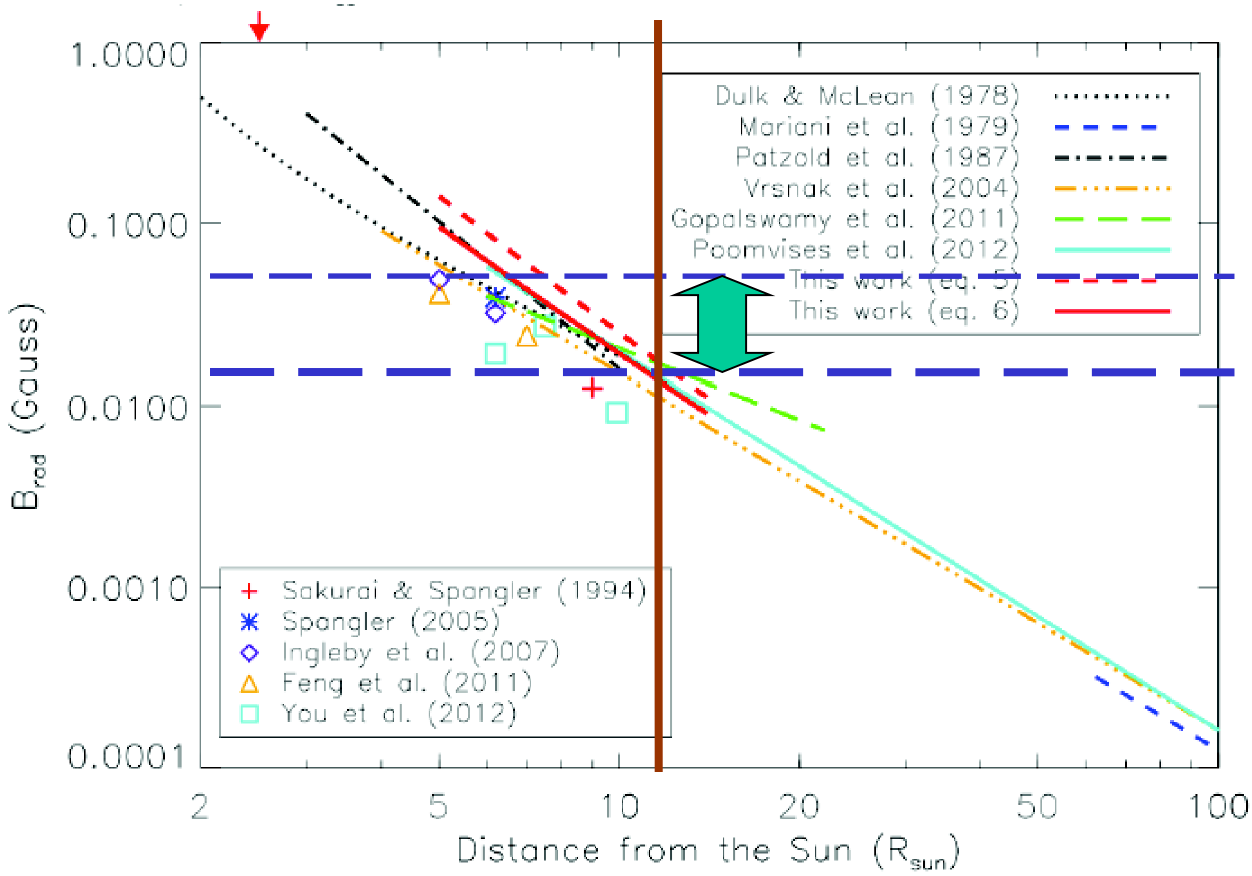


CME 3-ple SC fitting at 13 Rs

# Estimates of CME2 magnetic field @ 13 Rs

**CME b-field @ 13 Rs**

**median 0.035 Gauss; 1st & 3rd quartile 0.02 & 0.07 Gauss**



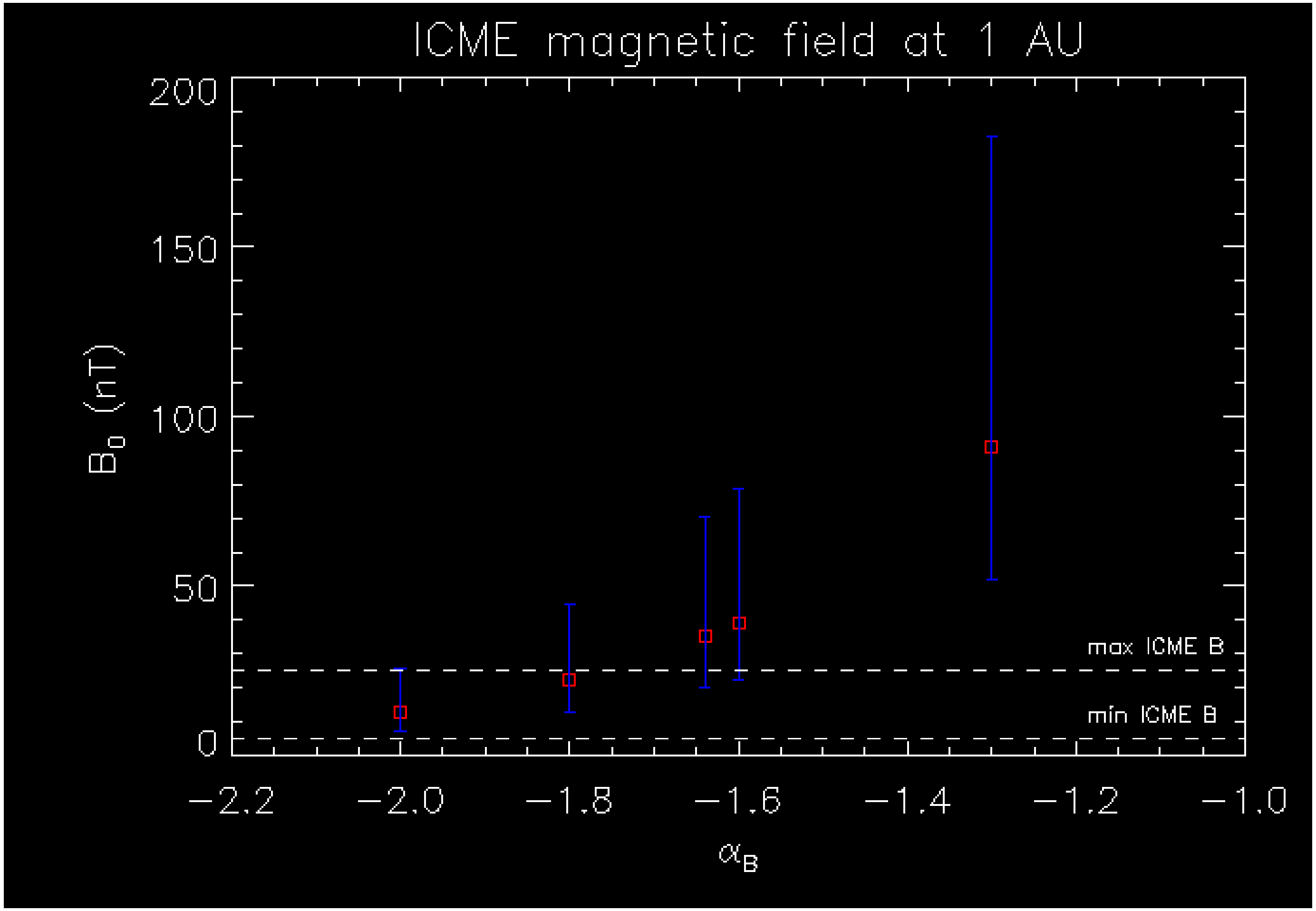

compilation from Mancuso & Gartzelli 2013

# Extrapolating CME2 b-field from 13 Rs to 1 AU

$$B_0(r) = B_*(r/r_*)^{\alpha_B}$$

$\alpha_B$ from Demoulin & Dasso 2009 compilation of of observations & models → [-2.0, -1.3]

# Comparing extrapolated CME2 b-field @ 1 AU w/ in-situ WIND observations of the corresponding ICME




**red → median B @ 13 Rs**

**blue → first (25%) and third (75%) quartiles @ 13 Rs**

# Extrapolate CME2 kinematics from 30 Rs to 1 AU

$$F_D = C_D M_{CME} \rho_w C_D A(v_{CME} - v_w)|v_{CME} - v_w|$$

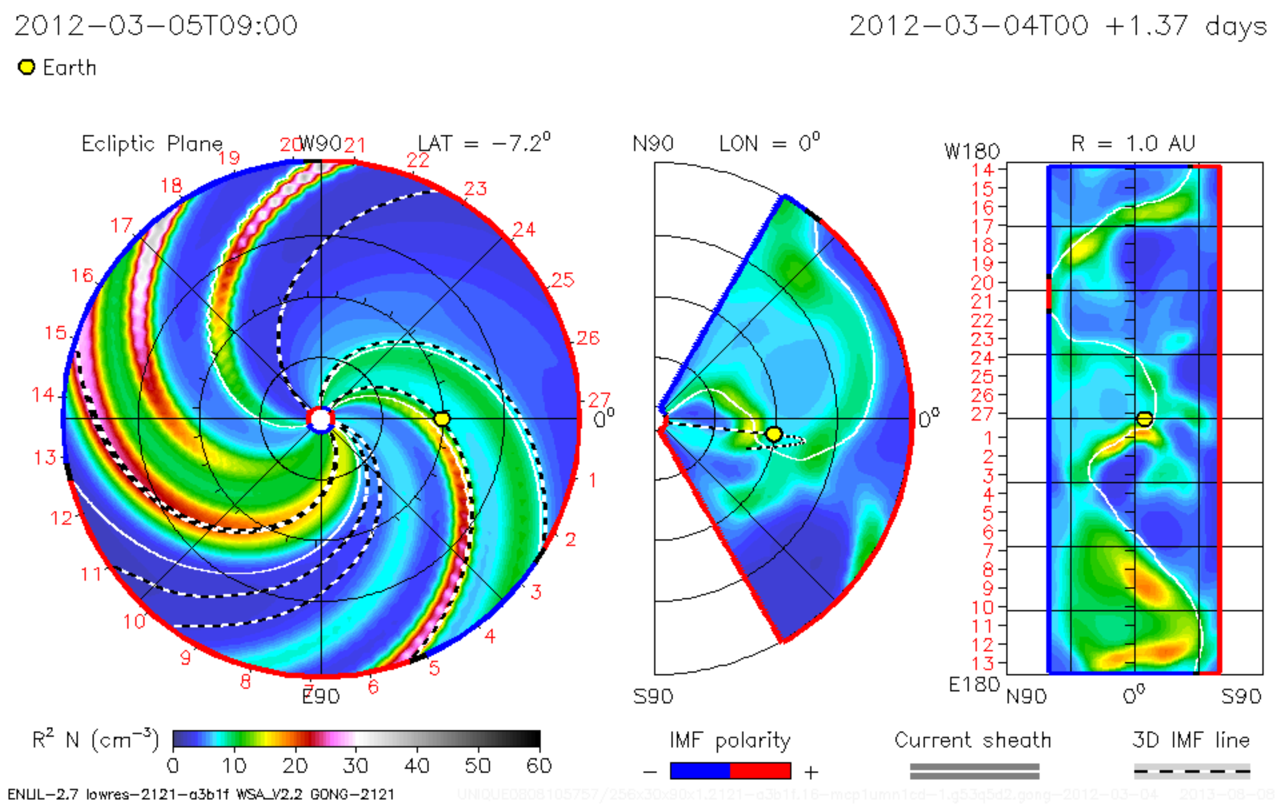
Apply the aerodynamic drag-force $F_D$ for > 30 Rs

$F_D$ depends on upstream solar wind ρ & u; MCME, A & u0 from CME2 WL observations

The CME **does not see upstream "quiet" swind**! shocked-plasma ahead of it ….

*Patsourakos, Podladchikova, Nindos, Vourlidas, Kouloumvakos*

# Estimate the upstream conditions for CME2 w/ ENLIL/CCMC simulations

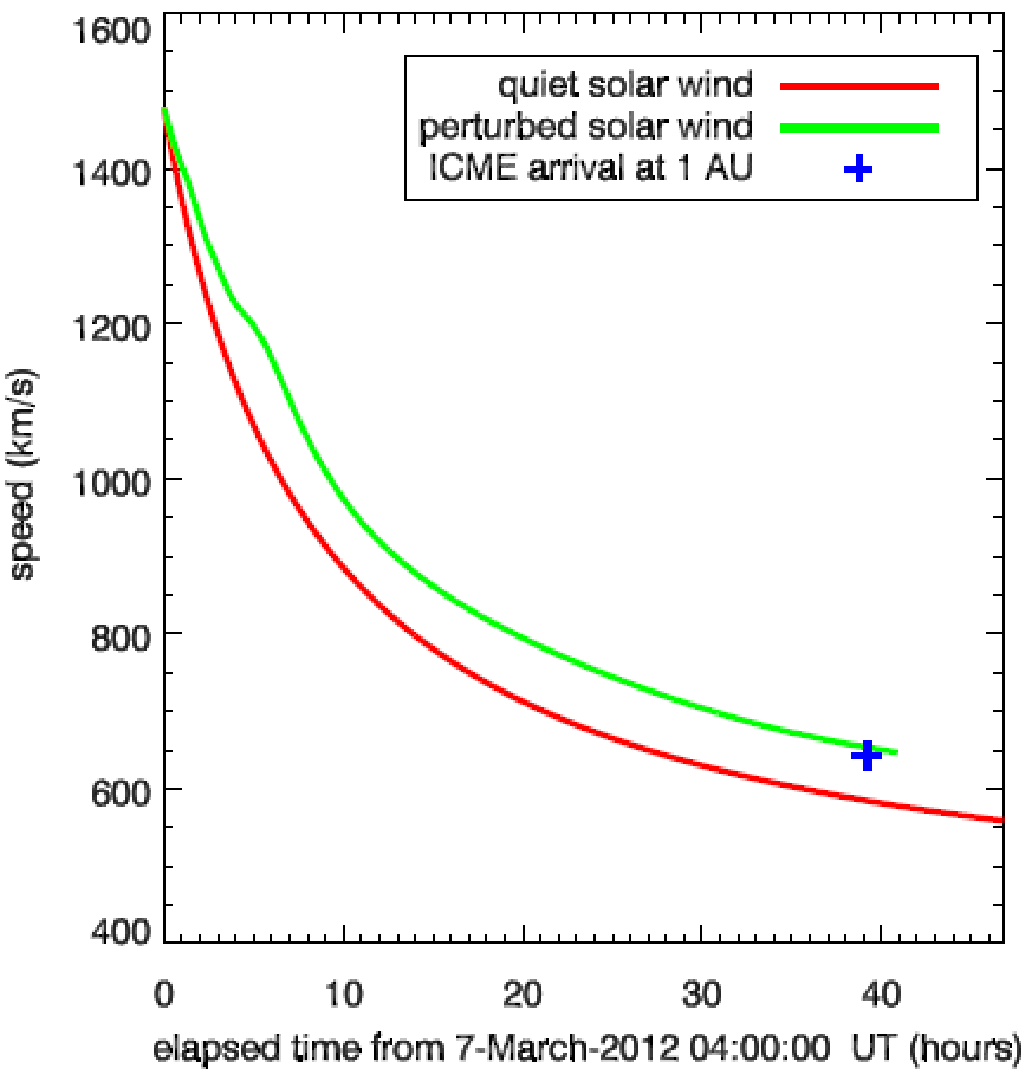



➢launch a hydrodynamic pressure pulse at 20 Rs **constrained** by the shock (associated with CME1) fittings (speed, angular extend, time …)

→ evolve MHD to 2 AU

→ **deduce solar wind properties associated with region perturbed** by the shock

# Use of perturbed swind significantly impoves prediction of ICME arrival



# Empirical Dst-Sw relationships

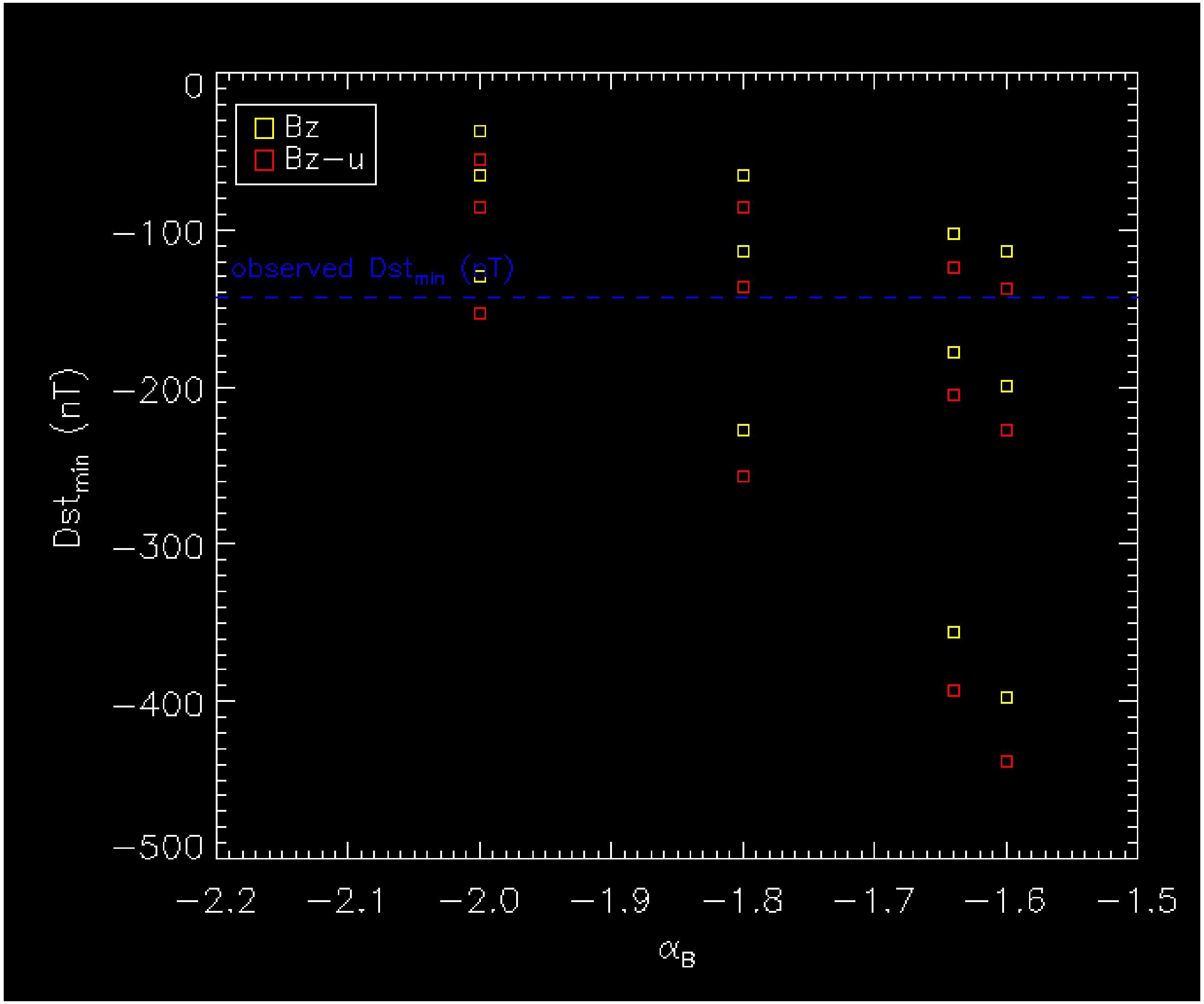
$$Dst_{\min} = 0.83 + 7.85 \times Bz_{\min},$$

Wu & Lepping 2005
135 MCs

$$Dst_{\min} = -16.48 - 12.89 \times (VB_s)_{\max}.$$

***Dst*min = f(*Bz*, *u*)** ***Bz,u from our modeling***

# Predicting the Dst of the associated m-storm

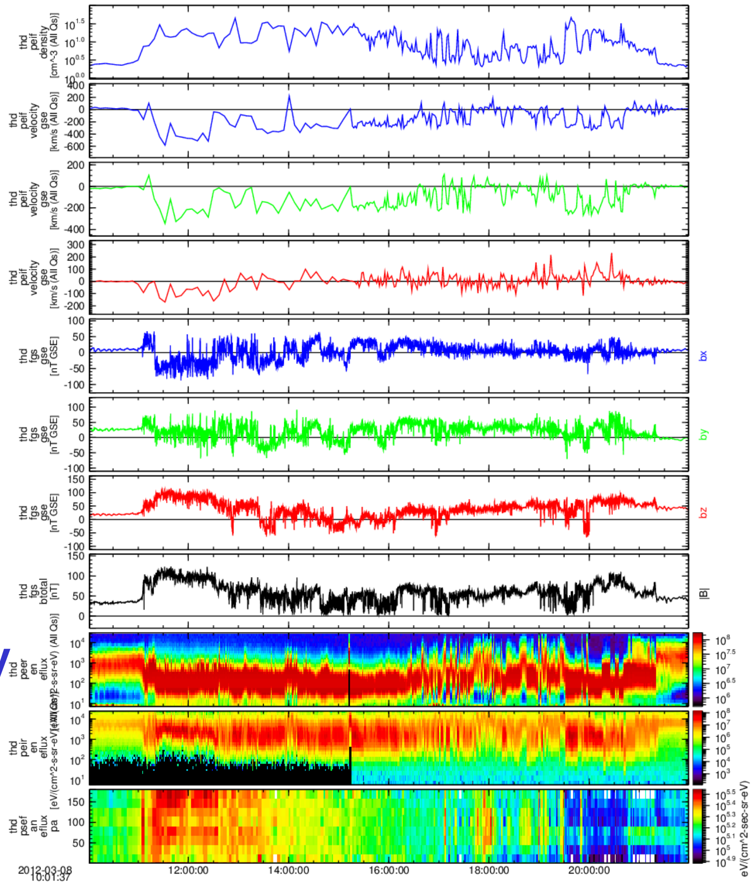


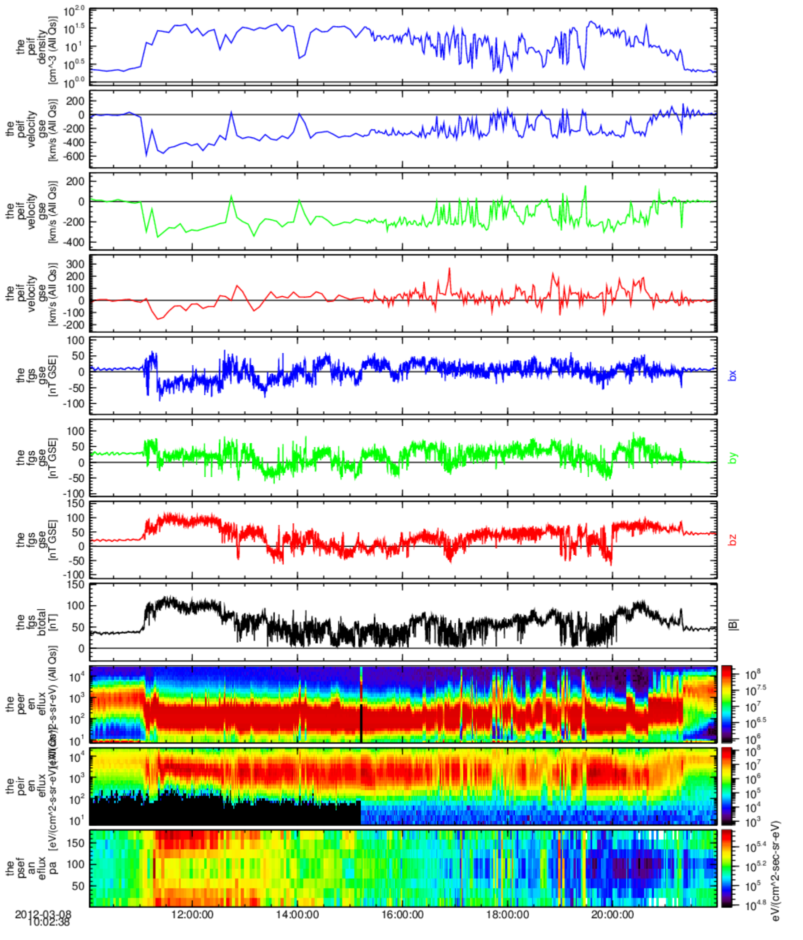

*power-law index of radial variation of  the b-field*

# Compression of the magnetosphere

**THEMIS D** | **THEMIS E**

Np
Vx
Vy
Vz
Bx
By
Bz
Btotal
e<30keV
i<30keV
PA_e>30keV



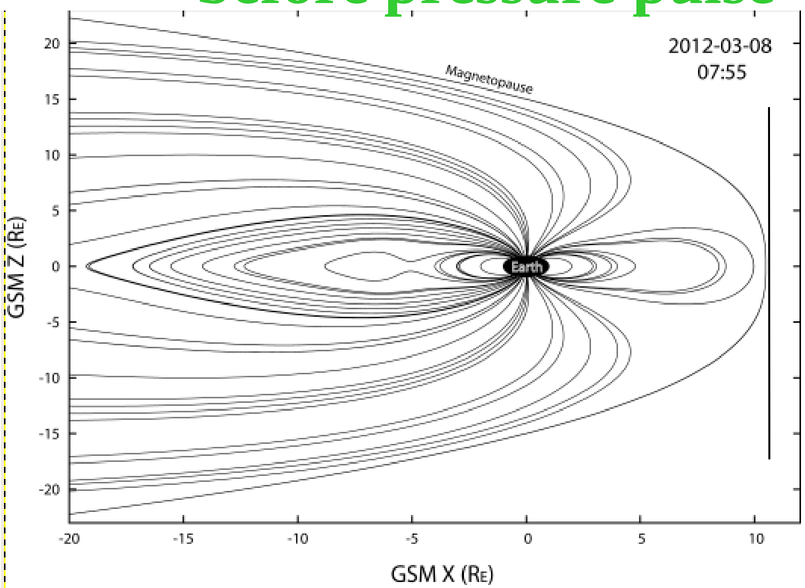




**Compression of the magnetosphere w/ THEMIS D,E moving to magnetosheath cold and dense plasma**

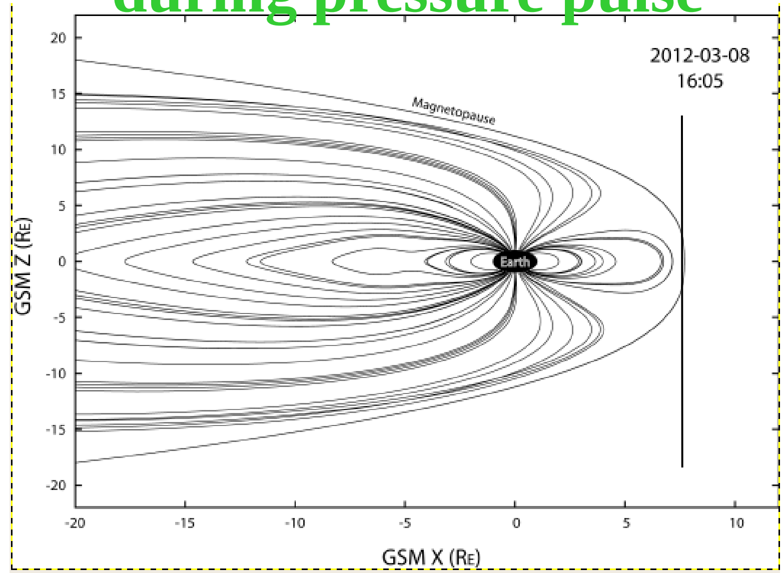
**Voyatzis, E. Sarris**

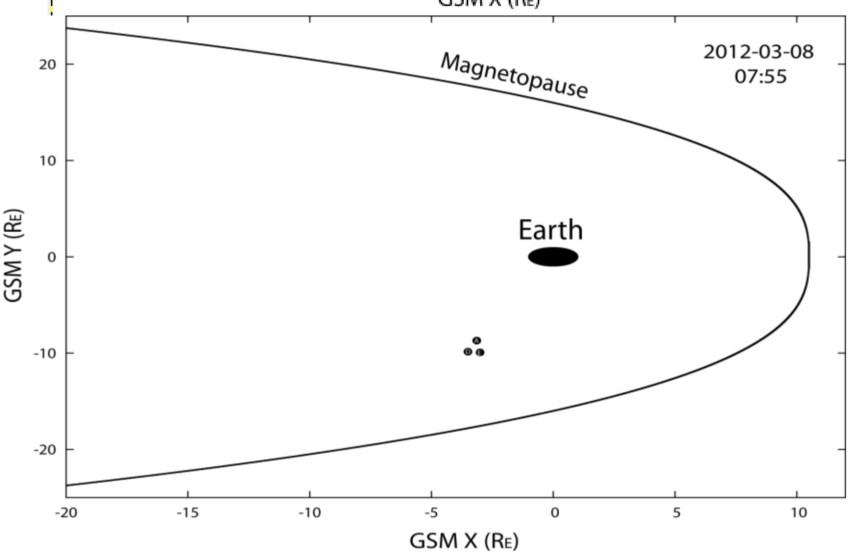
# Estimating magnetospheric compression from heliospheric/magnetospheric modeling

## before pressure pulse



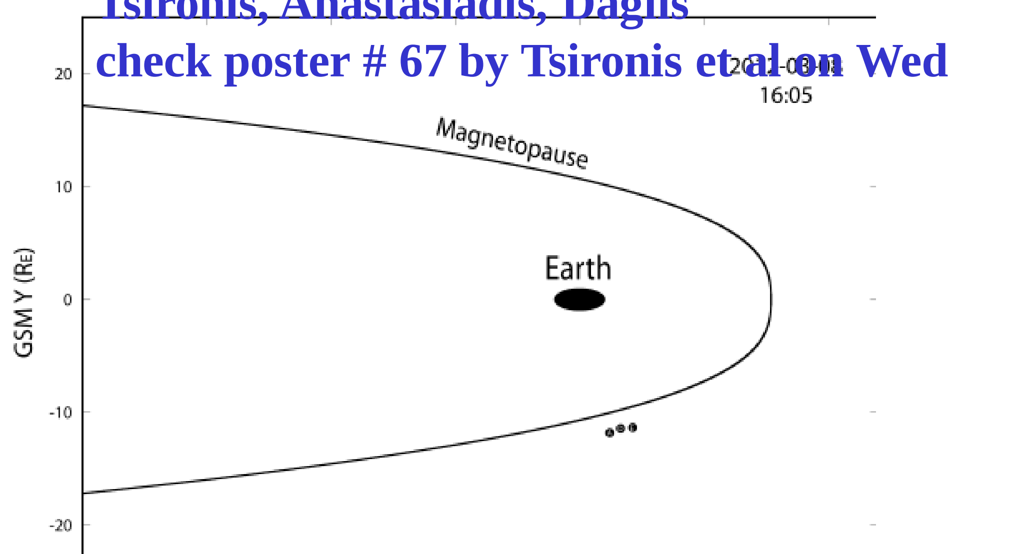

## during pressure pulse




**Tsironis, Anastasiadis, Daglis**

**check poster # 67 by Tsironis et al on Wed**



# What made CME2 so geoeffective?

- **Magnetic properties of source AR:** (strong PIL; helicity Em)

--- magnetic params at tail of corresponding distributions …

- **Non-radial propagation of CME in the low corona:** how a far-East event becoming Earth-directed

- **Preconditioning of IP medium by preceding shock:** shock ahead of CME2 led to a faster speed at 1 AU

- **Preconditioning of magnetosphere by previous events:** (e.g., Burlaga et al. 1987; Farrugia et al. 2006)

active period w/ another weaker geomagnetic strorm ~ 36 hours before

# Major Conclusions

- Sun-to-Earth analysis of a major (and challenge) solar eruption of major geoeffective impact

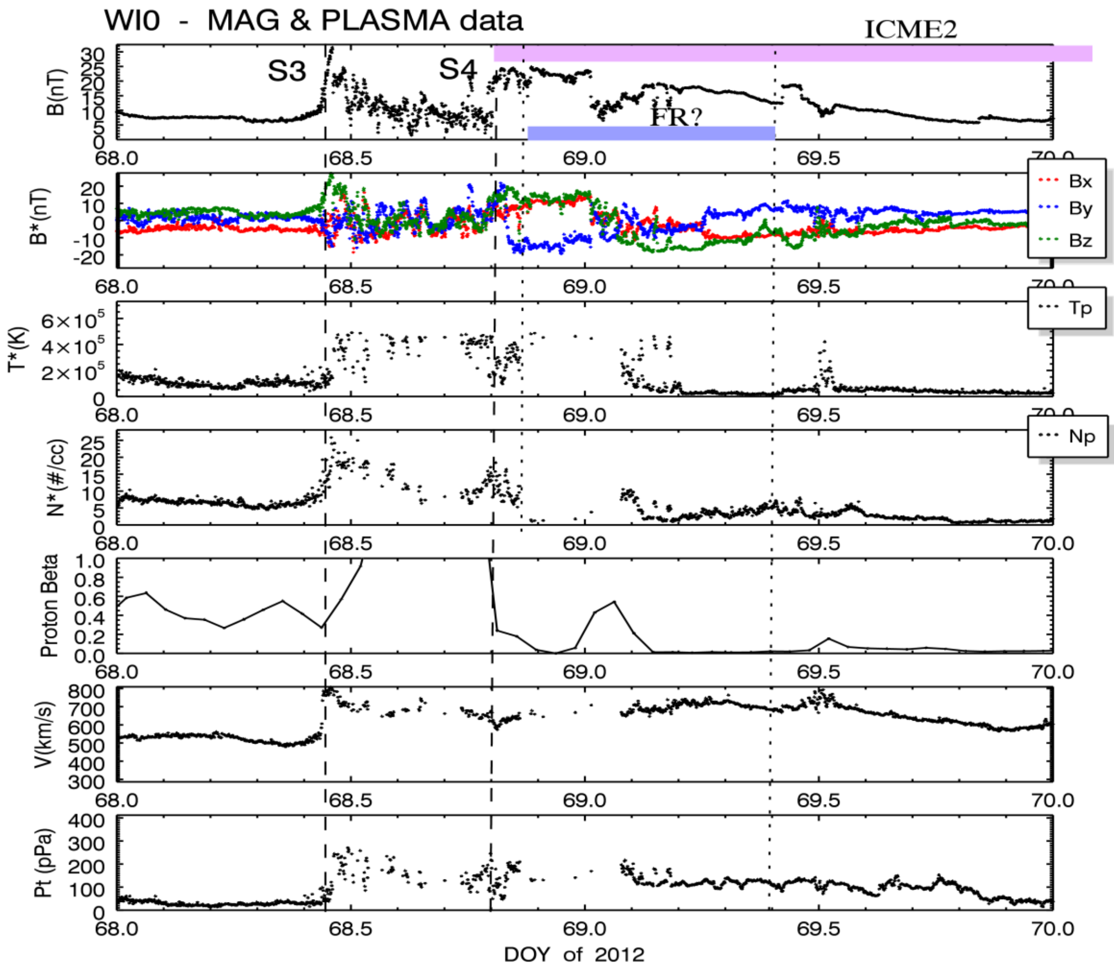
- The stressed magnetic seed structure was pressumably built-up during confined flaring events – small & big --- during the day(s) before the 7$^{th}$ in the complex and agitating source AR

- From the CME duo  the second was the  Earth-directed

- Shocks important aspect of CME propagation

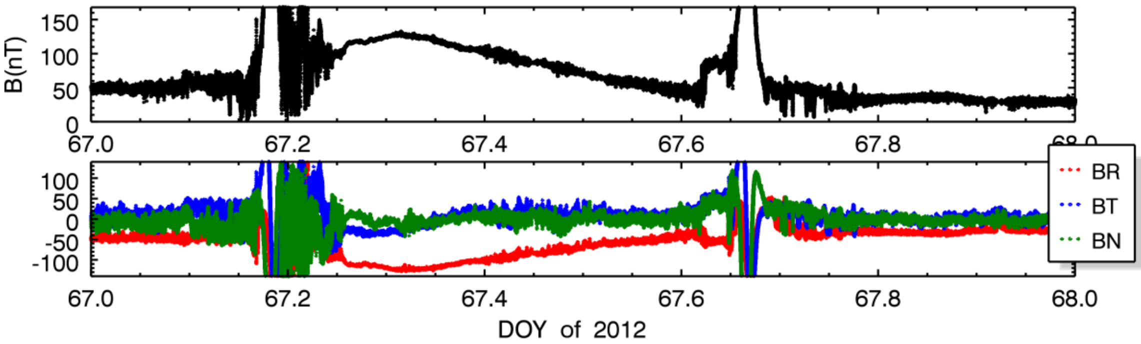
- First steps of building a framework that connects solar & coronal observations with geomagnetic impact --- needs validation with further events!

# ICME observations @ L1

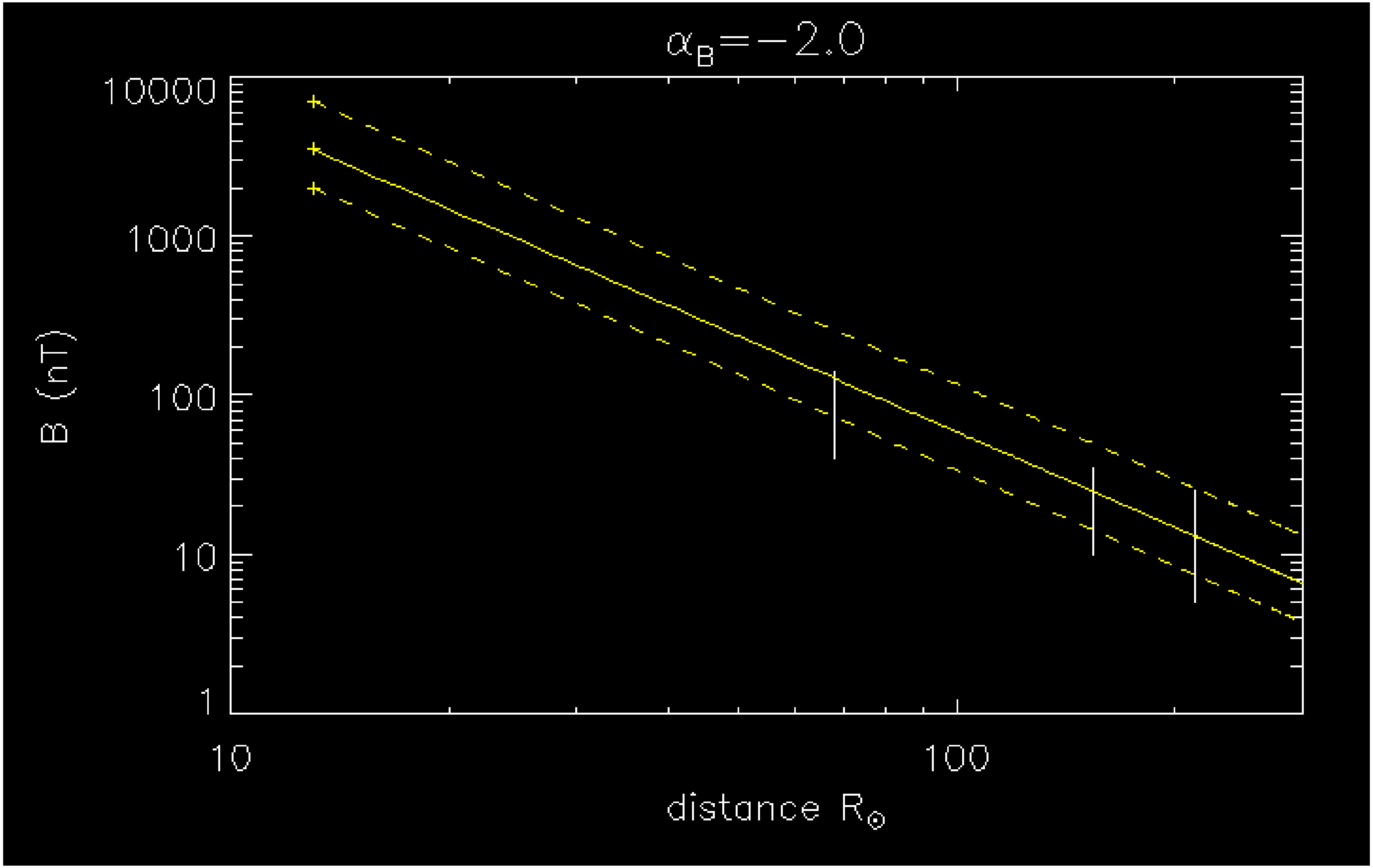



Nieves-Chinchilla

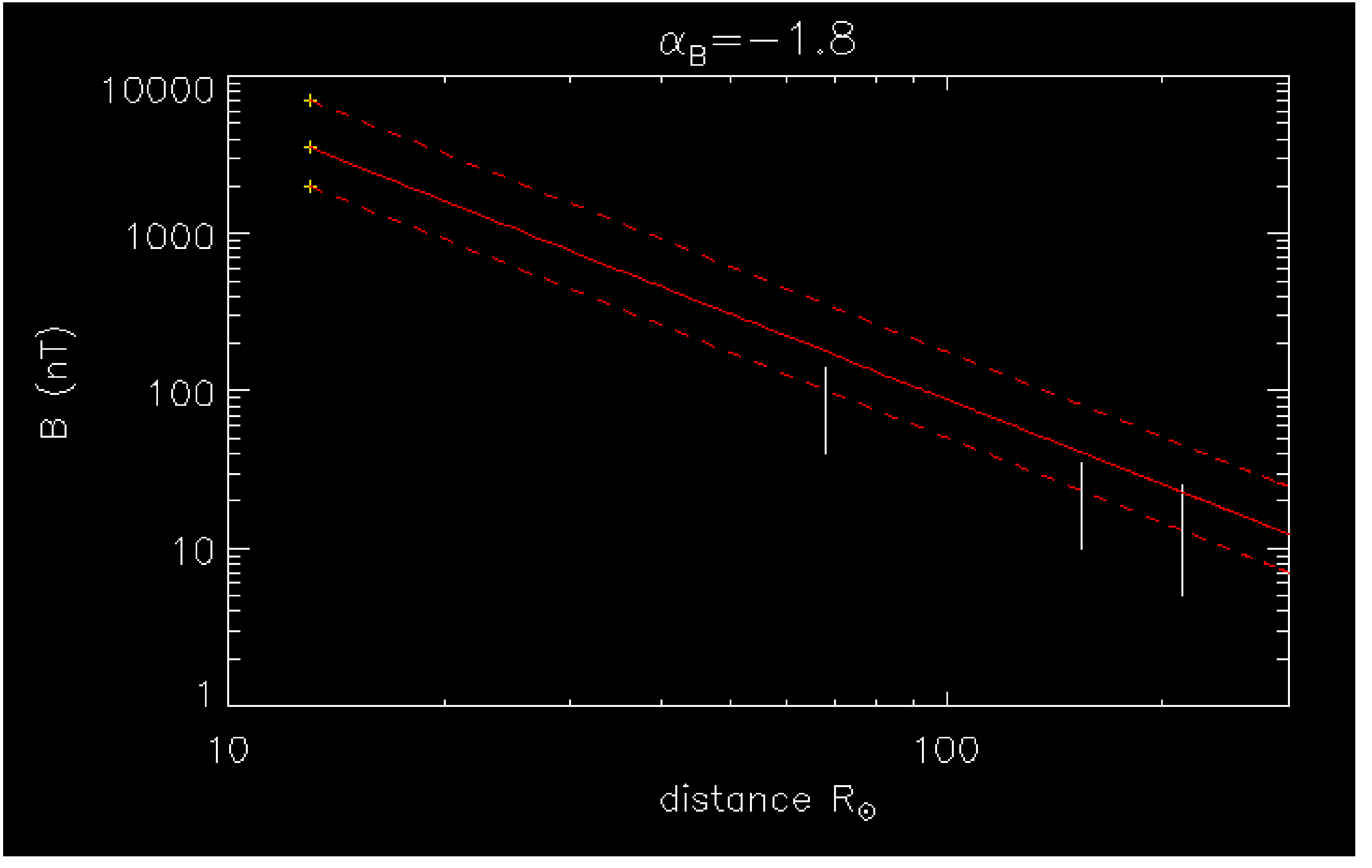
# Messenger Observations



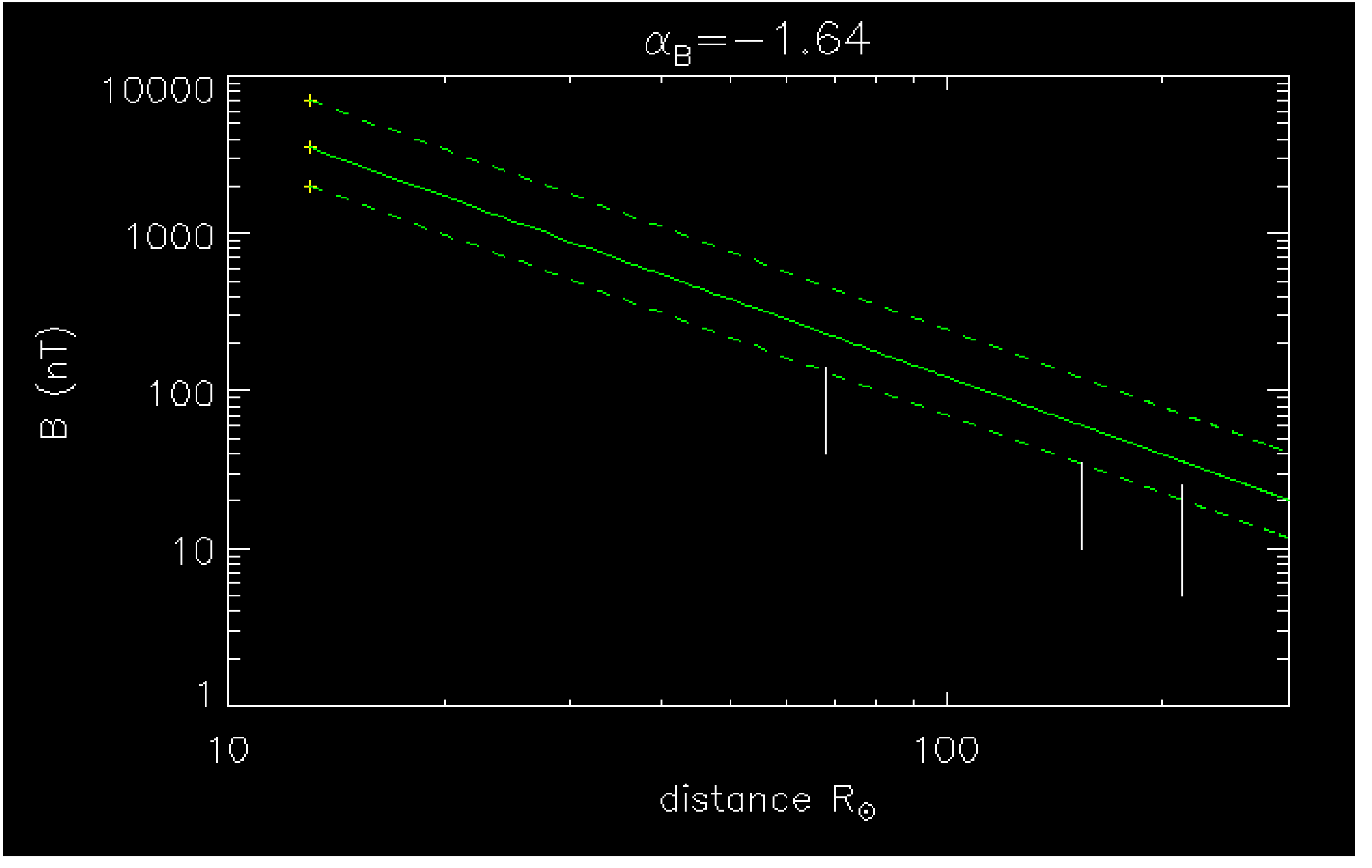
# Radial evolution of CME b-field



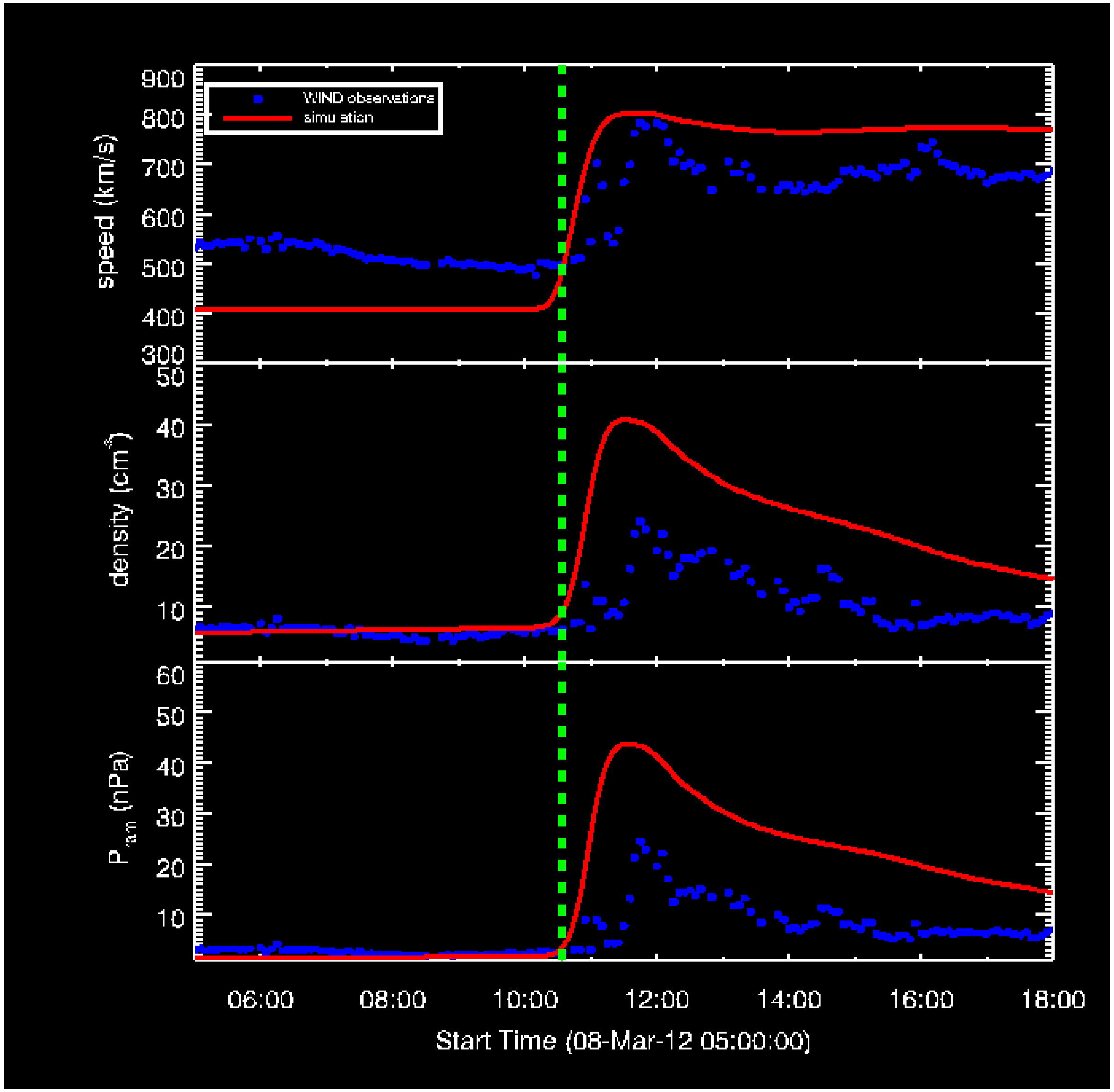
# Radial evolution of CME b-field



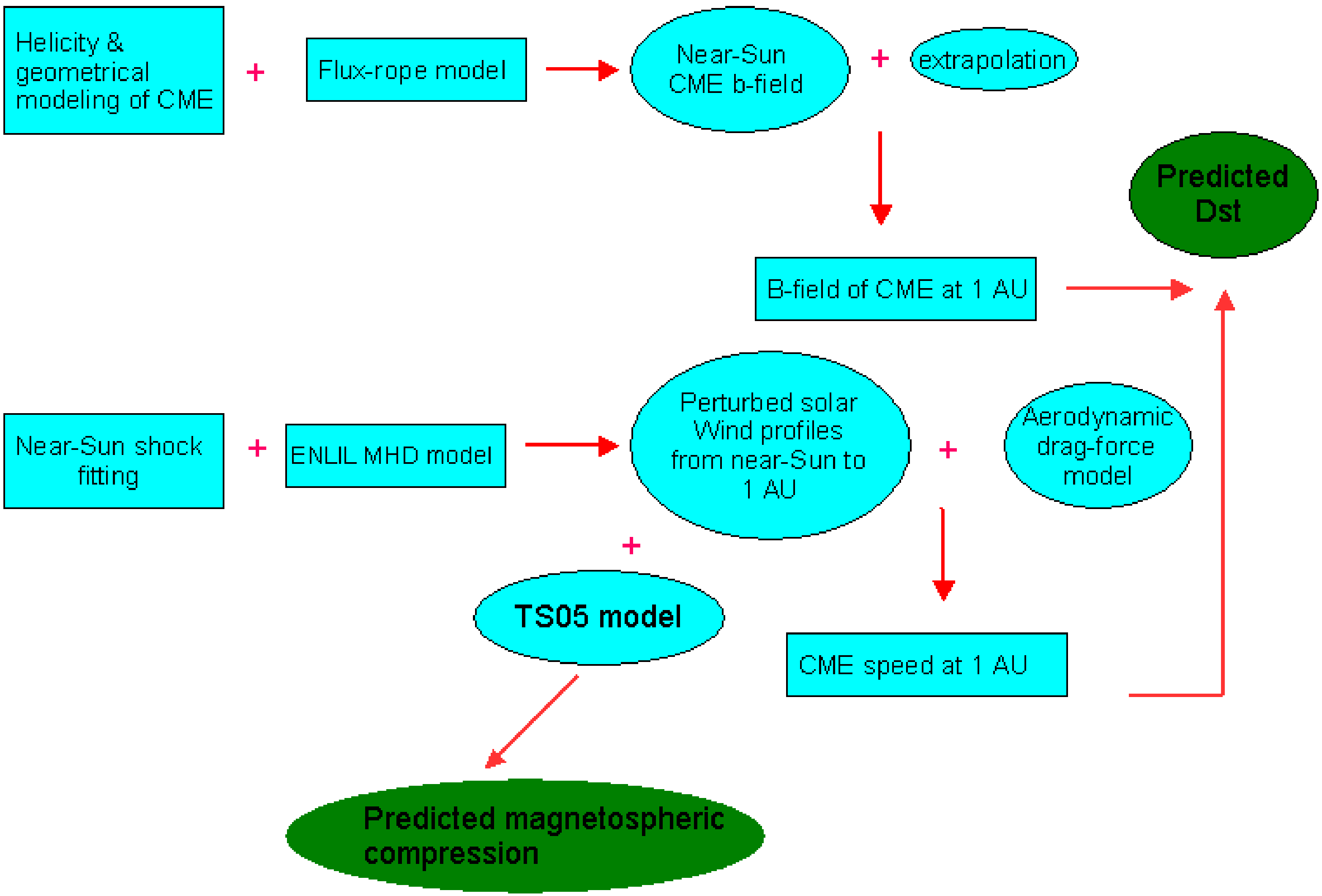
# Radial evolution of CME b-field



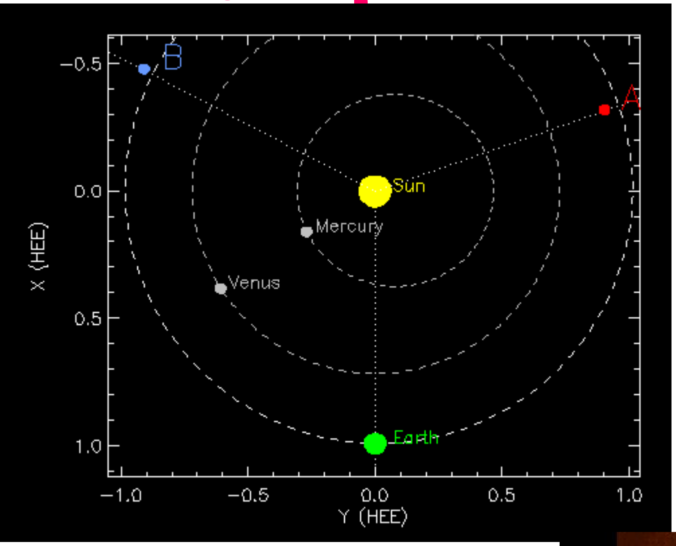
# Validation of the ENLIL simulation at 1 AU



# Flowchart


Helicity & geometrical modeling of CME
+
Flux-rope model
Near-Sun CME b-field
+
extrapolation
Predicted Dst
B-field of CME at 1 AU
Near-Sun shock fitting
+
ENLIL MHD model
Perturbed solar Wind profiles from near-Sun to 1 AU
+
Aerodynamic drag-force model
+
TS05 model
CME speed at 1 AU
Predicted magnetospheric compression

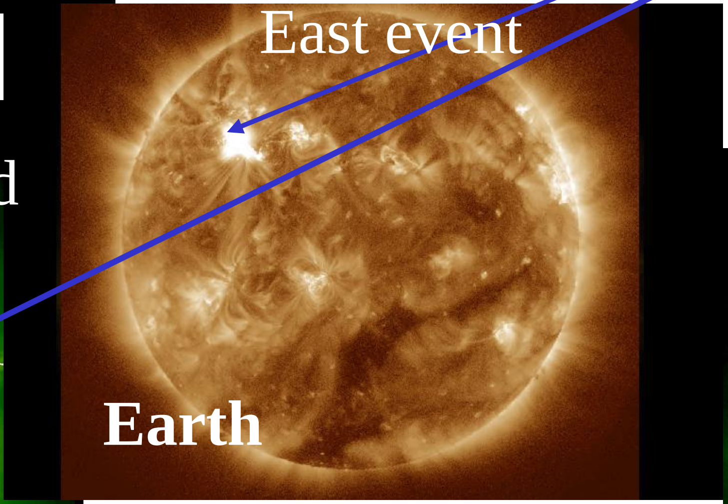
# Multiple view-point observing of the event

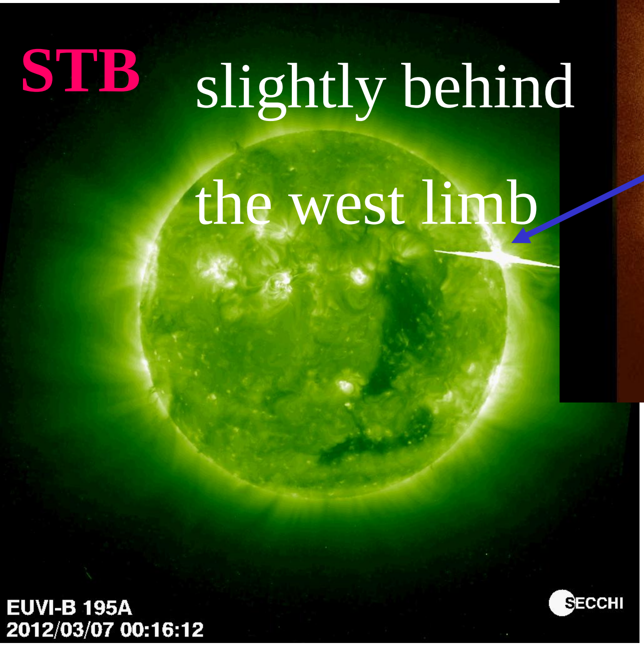


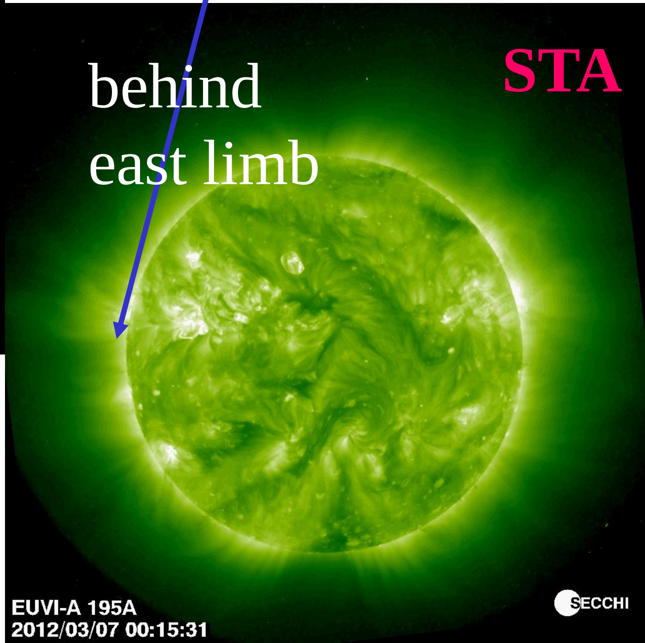

STB → 118 deg from Earth

STA → 109 deg from Earth

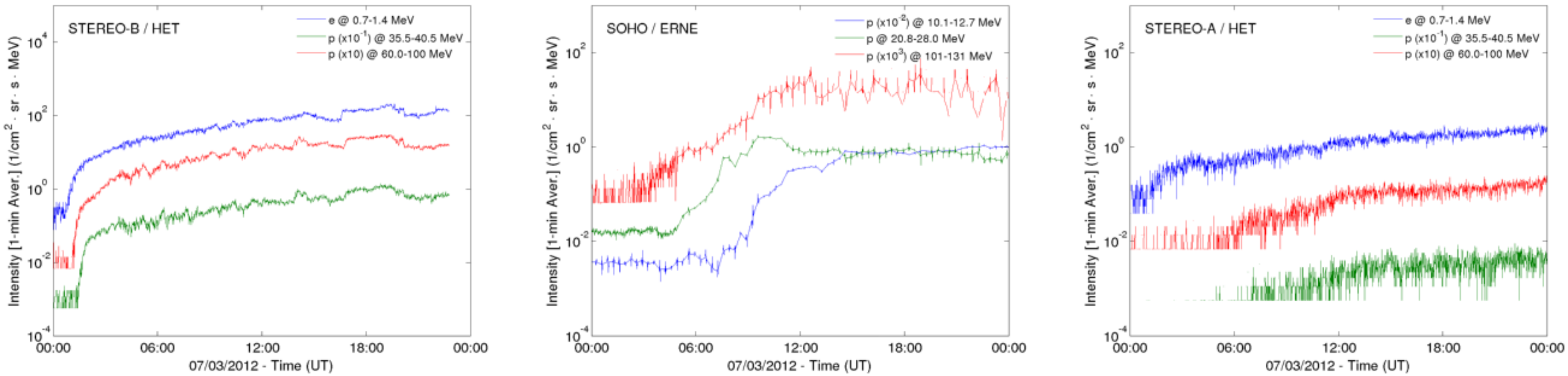
source region



# SEPs during 7 March 2012

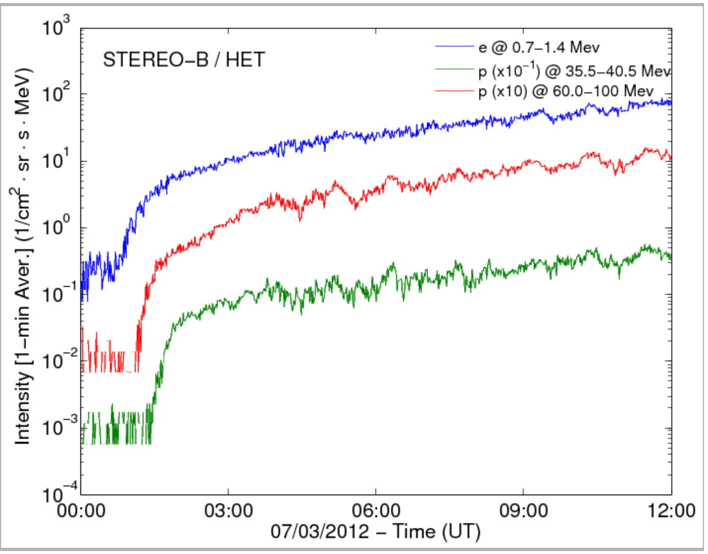


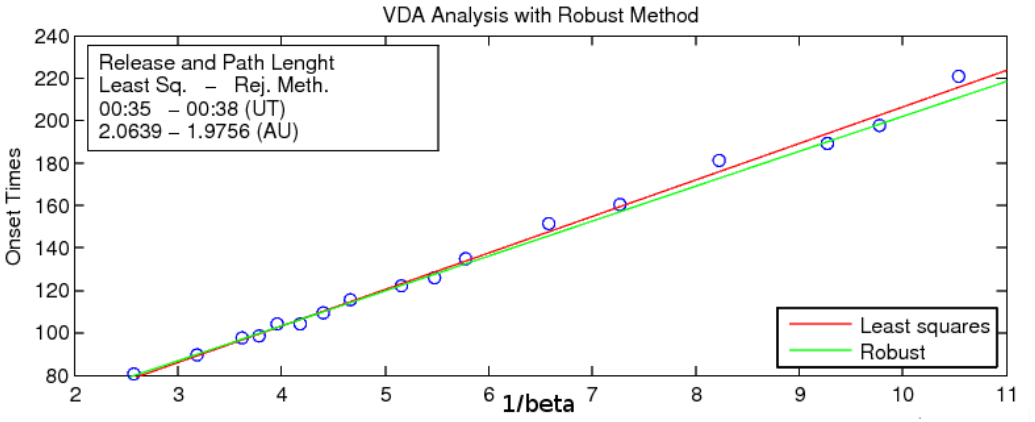

- ❑ prompt particle rise at STB
- ❑ gradual & delayed rise at L1
- ❑ weak enhancement at STA

**Kouloumvakos**

# Determining SEP release times with VDA

## STEREO B




release time @ Sun-STB field-line: 00:35 +- 1 min

→**the first event is responsible for the particles seen in STB (second event peaks after 01:00)**

## Kouloumvakos

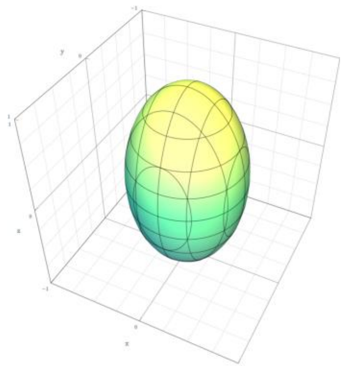
# Example of coronagraphic observations of the WL CMEs and shock

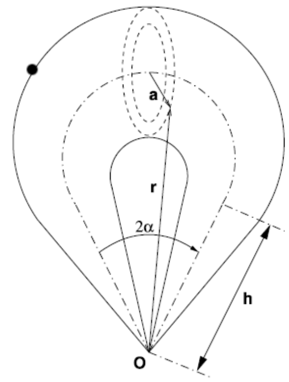

**COR2A: FOV 2-15 Rs**

# Example of 3-ple SC WL shock & CME fitting

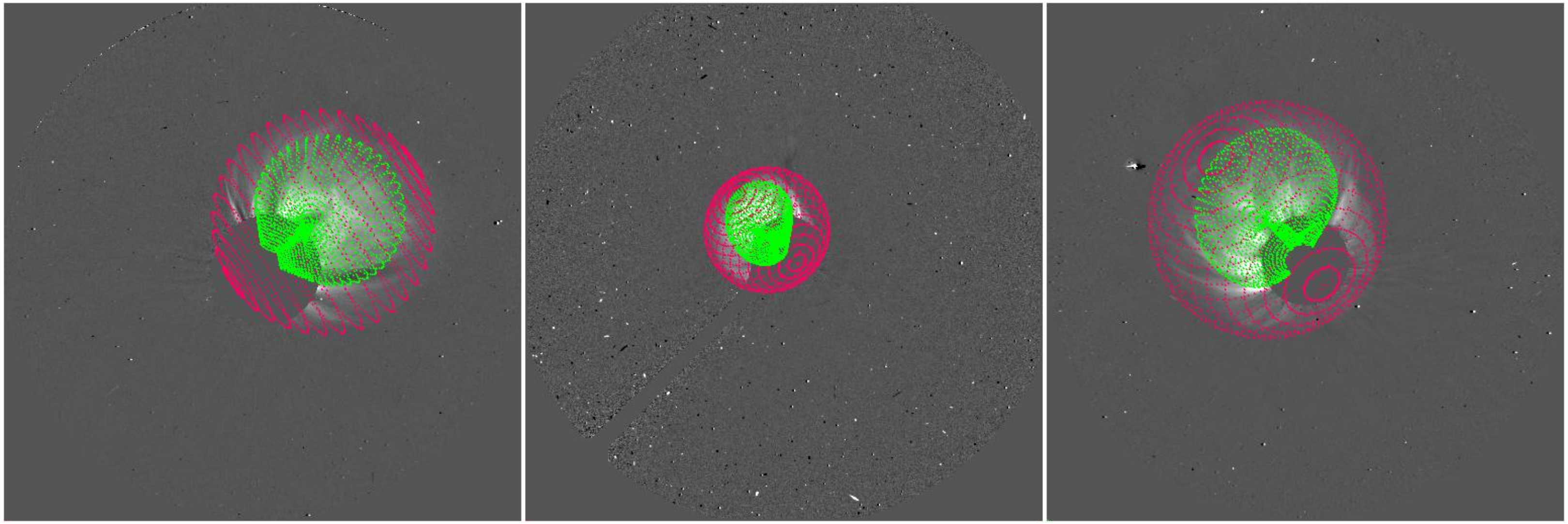
*Shock* → *spheroid (ellipse with revolution) model* (h,d,s)

*CME* → *Graduated Cylindrical Shell (GCS) model (= 2 conical legs + tubular section) Thernisien et al. 2006*

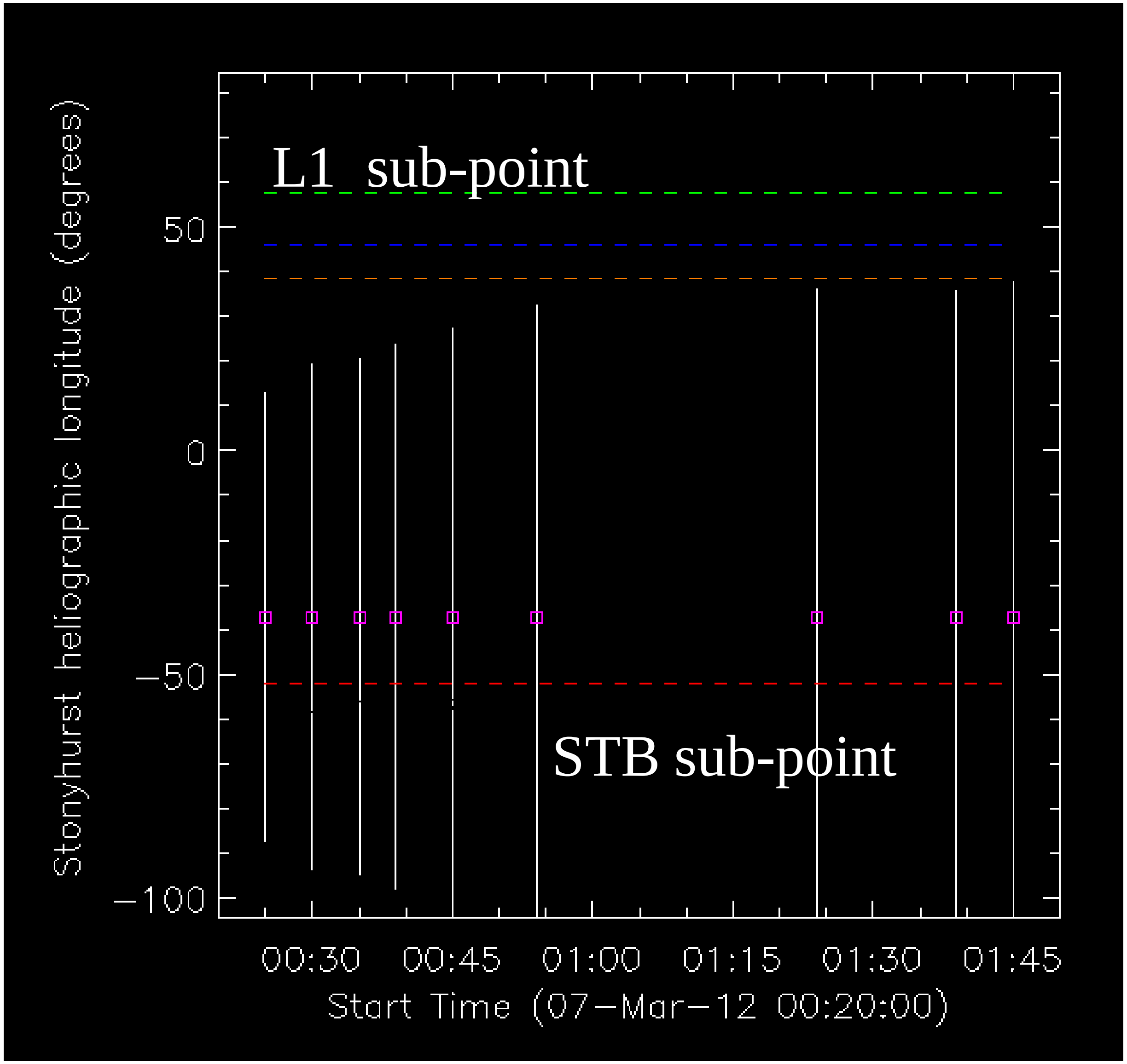





**COR2B** **C3** **COR2A**



# Evolution of WL shock longitudinal extend

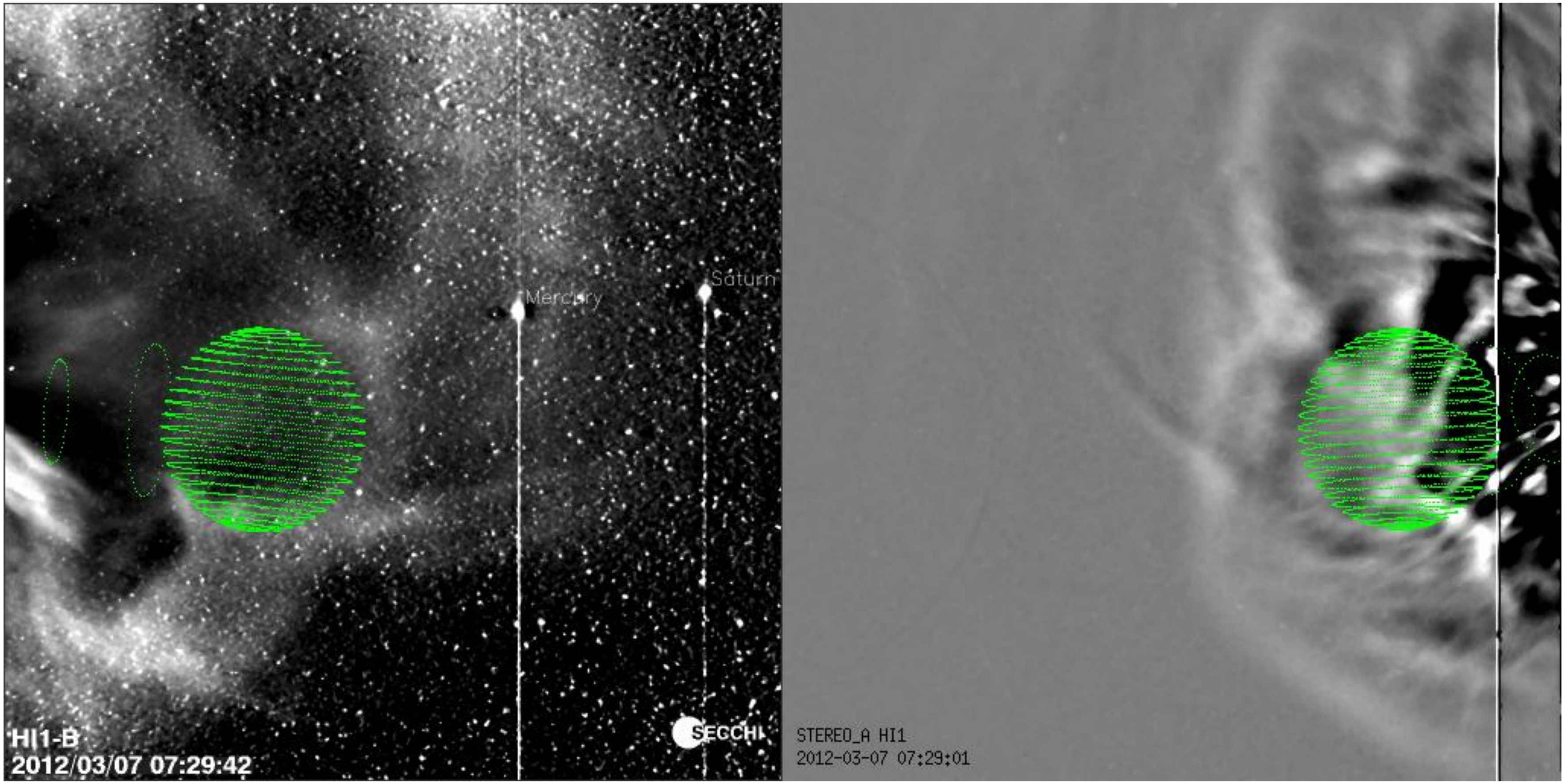



Immediate contact w/ Sun-STB b-field line

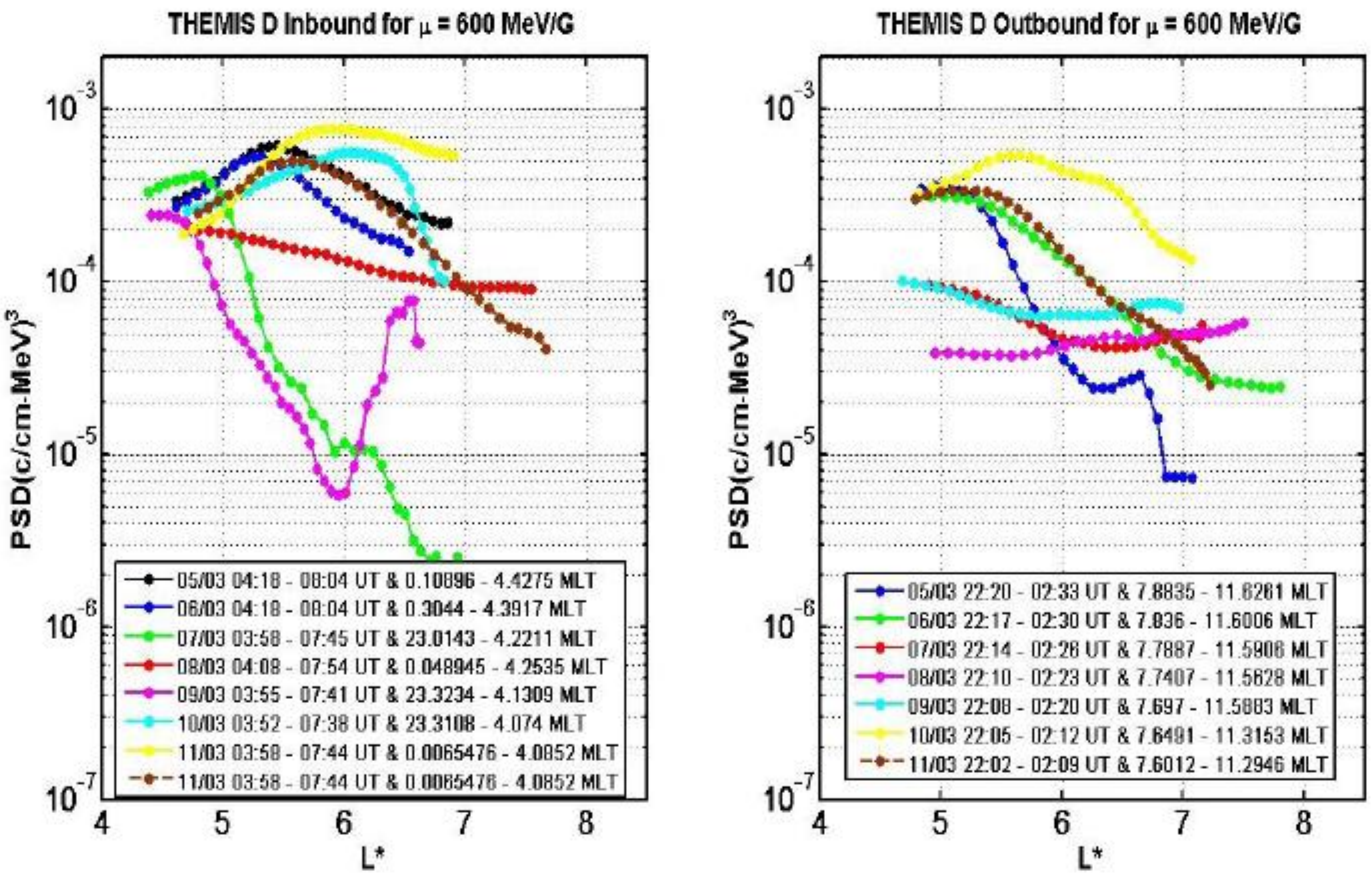
Not contact w/ Sun-L1 b-line line →

consistent w/ delayed particles at L1

# Sample HI1 CME2 fitting

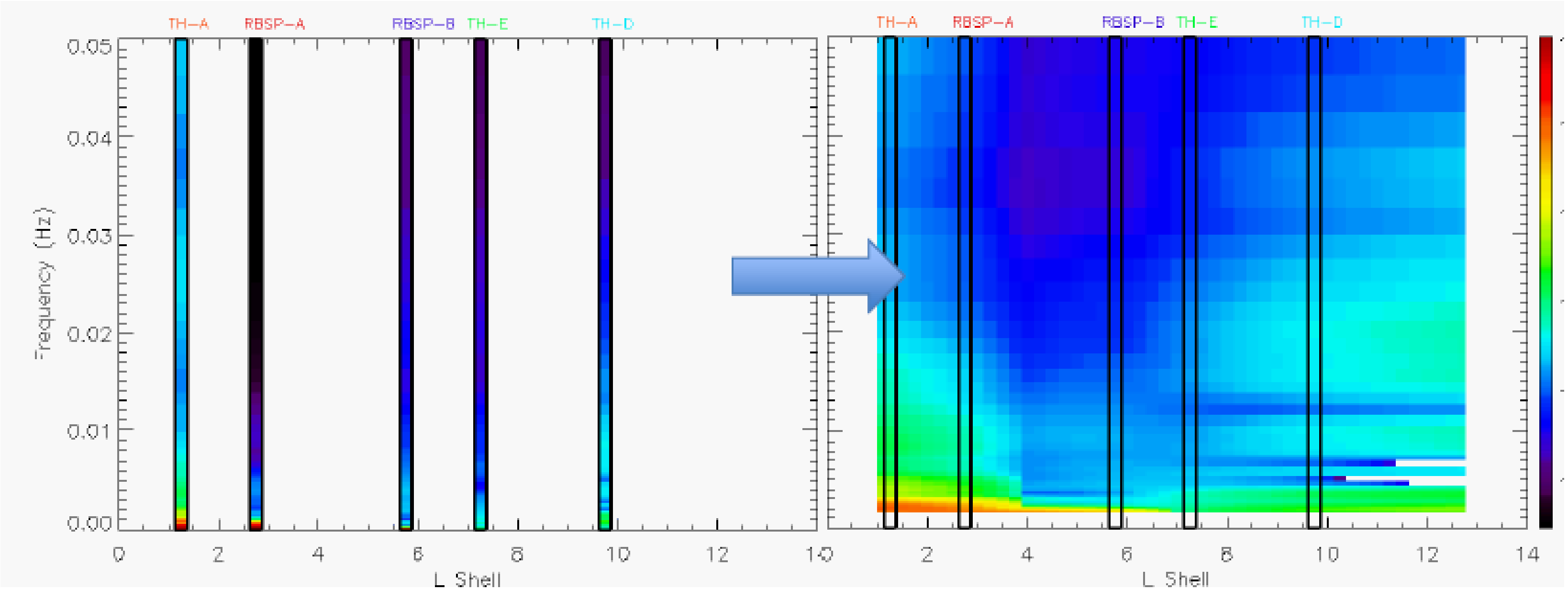


# Electron dropout




Katsavrias & Daglis

# ULF wave enhancement



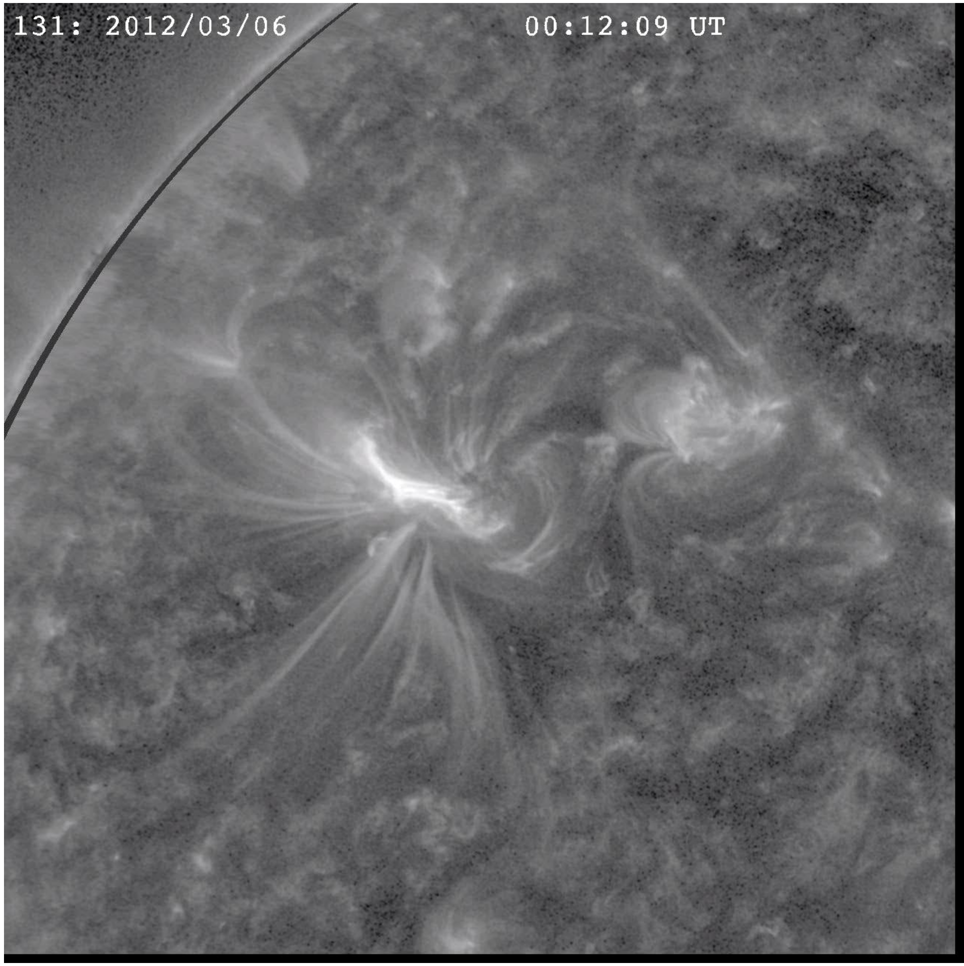

T. Sarris

# Coronal activities leading to the 7 March events

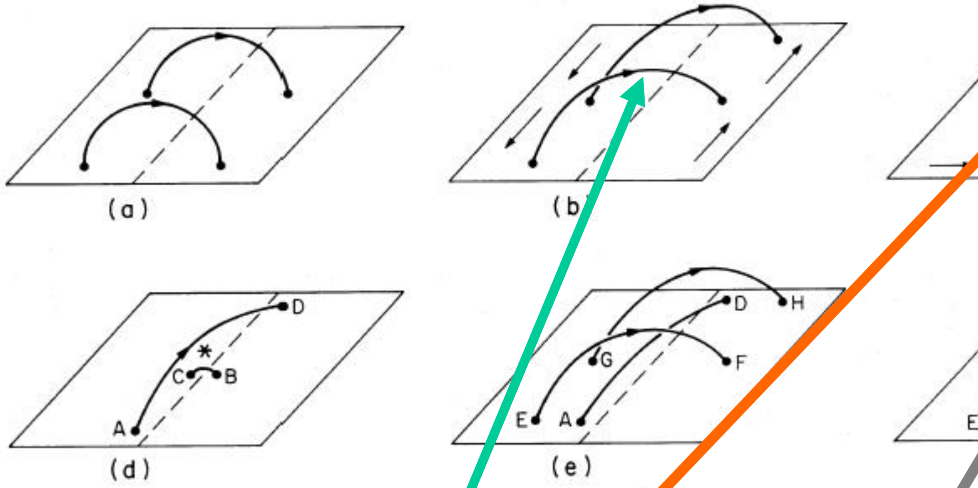
Transient activities (including an M-class flare) around the PIL during the 6$^{th}$ leading to flux-rope like features

NOT resulting into an impulsive CME

AIA 131 A movie



# Basic scenario of magnetic flux-rope formation




**MHD simulations**

Archontis et al. 2012,2013
Archontis & Torok 2013
Aulanier et al. 2010, 2012
Fan 2012
Karpen, Antiochos, DeVore, 2012
Leake et al. 2013,2014
Mikic et al. 2013
Roussev et al. 2012
Schrijver et al. 2011
Zuccarello, Meliani, Poedts, 2012

s,

**boundary motions** (shearing, twisting, conv

**reconnections** at photospheric (photospheric flux cancellation) lvl & above

formation of **stressed (coiled) field lines** + **plasma heating** to flare temps

process occurring whether there is a CME or not & *during "major" flaring or AR "flickering"*

**found in MHD simulations irrespectively** of the route to reconnection