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UNIVERSITY OF GRAZ

Study of the interaction of a gradual ICME and an entraining high-speed stream

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Der Wissenschaftsfonds.

FFG Promoting Innovation.

Motivation

- Solar wind affects the CMEs propagation

(e.g., Manchester+ 2004[1], 2005[2]; Kay+ 2013[3],2015[4]; Kliem+ 2012[5]; Lavraud+ 2014[6])

- Few case studies that show the Sun-Earth chain of a CME-HSS interaction

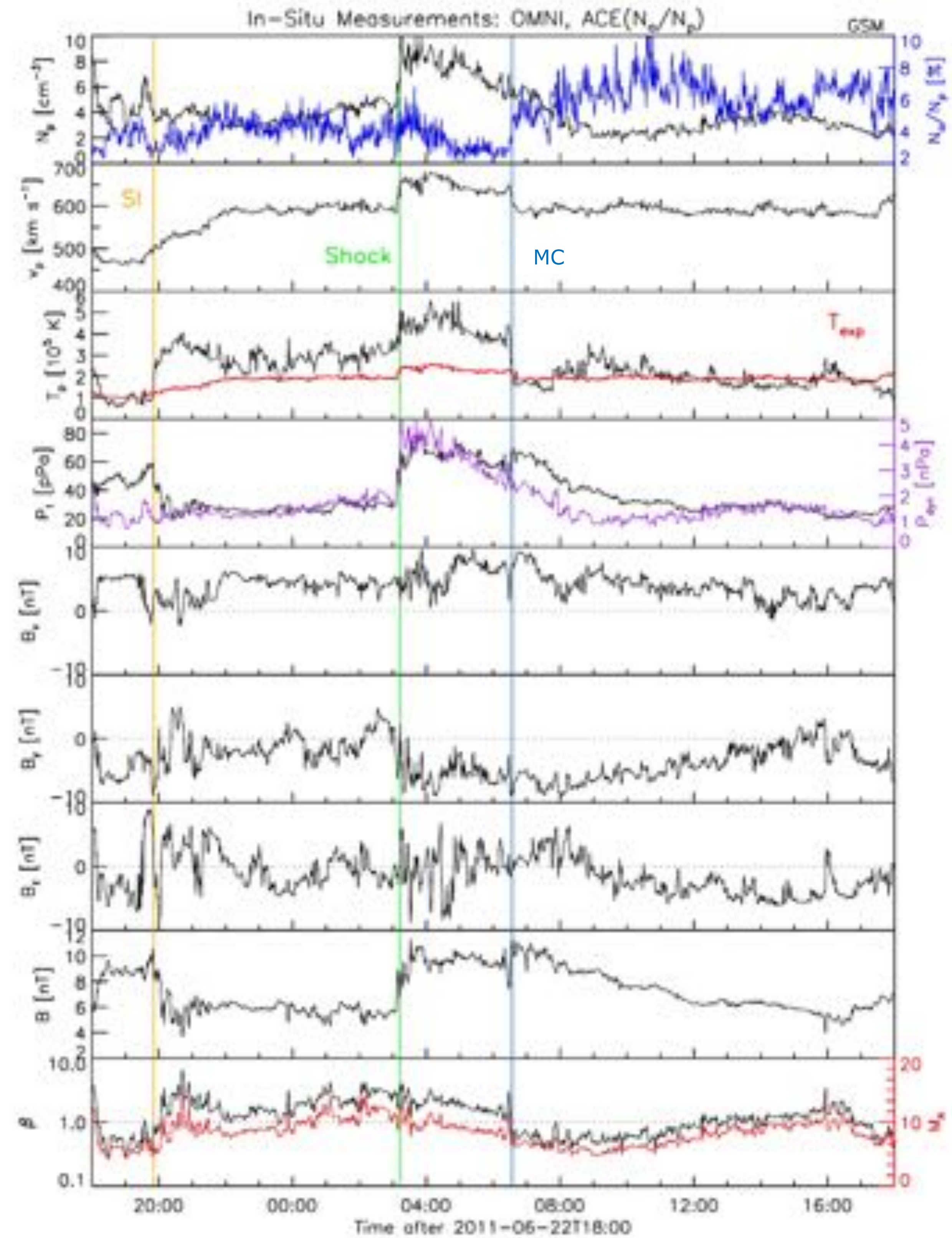
(e.g., Nieves-Chinchilla+ 2012[7]; Wang+ 2014[8]; Winslow+ 2016[9])

- Gain a better understanding of CME-HSS interactions processes, the resulting signatures as well as its geomagnetic effects

Solar wind in-situ measurements @ ~1au

- Interesting in-situ signatures

Find a suitable interpretation using modeling efforts and observations



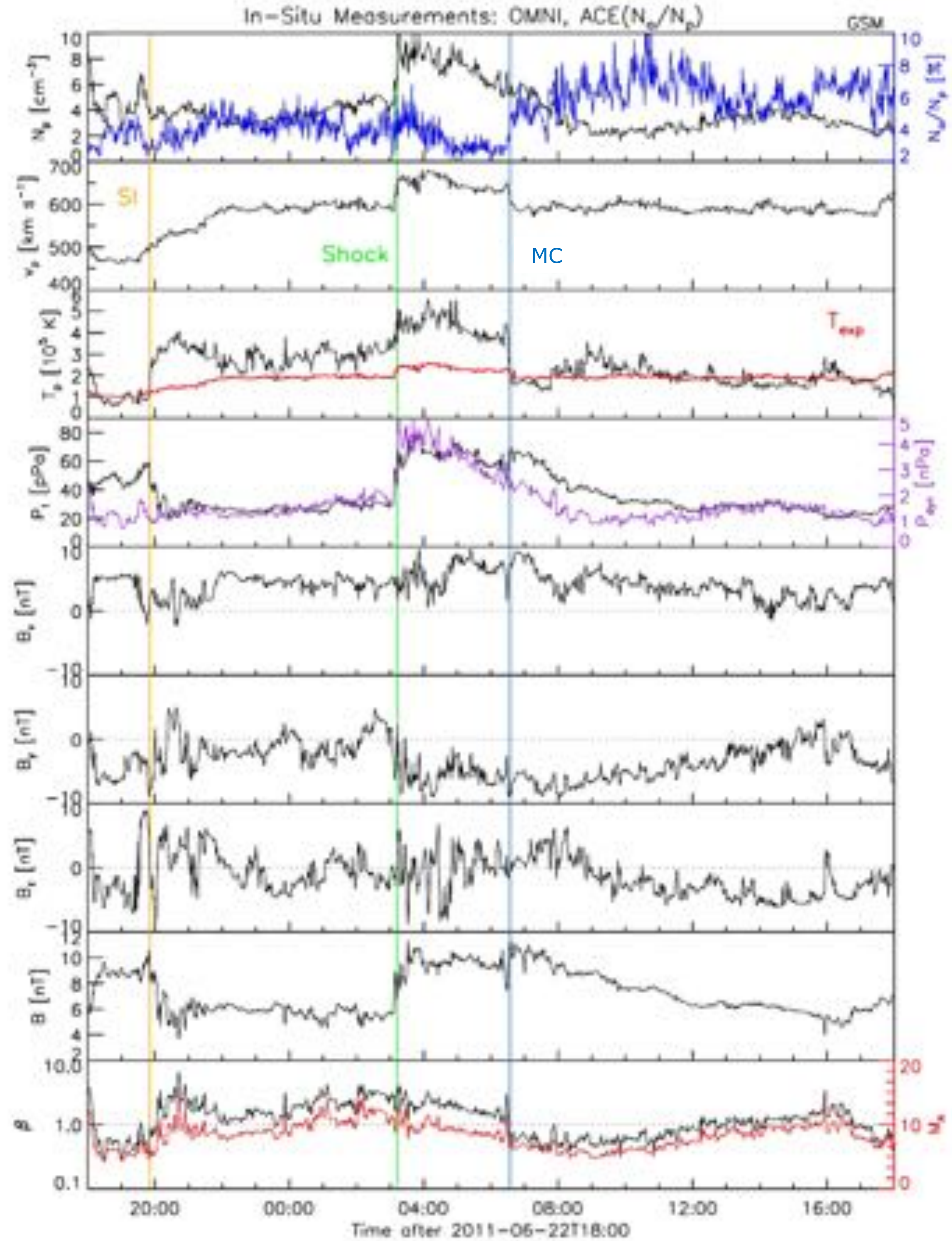
Solar wind in-situ measurements @ ~1au

- Interesting in-situ signatures

  Find a suitable interpretation using modeling efforts and observations

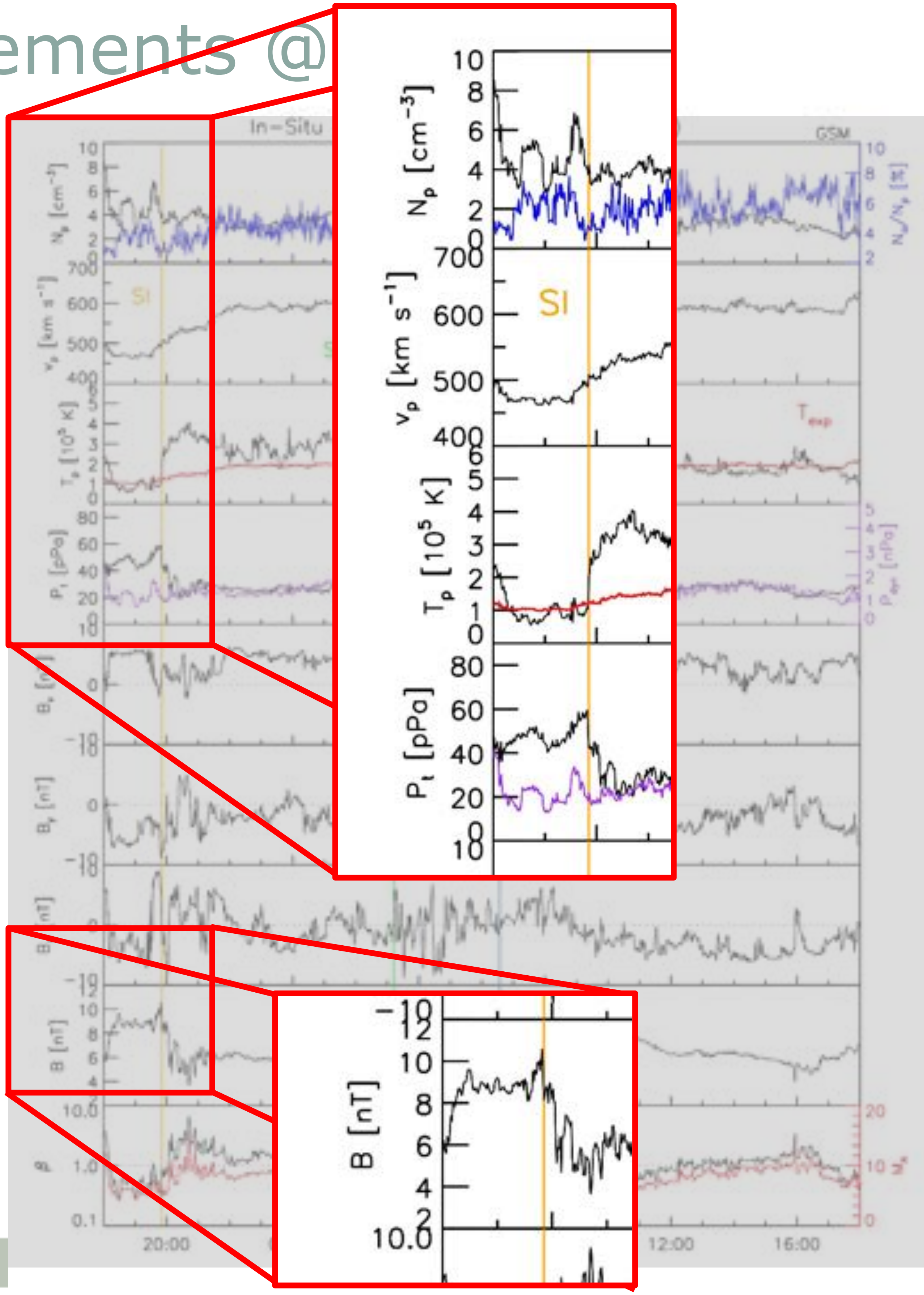
- 3 Signatures can be identified
  - SIR
  - Shock
  - Magnetic Structure/MC

  + HSS continues after MC



Solar wind in-situ measurements @

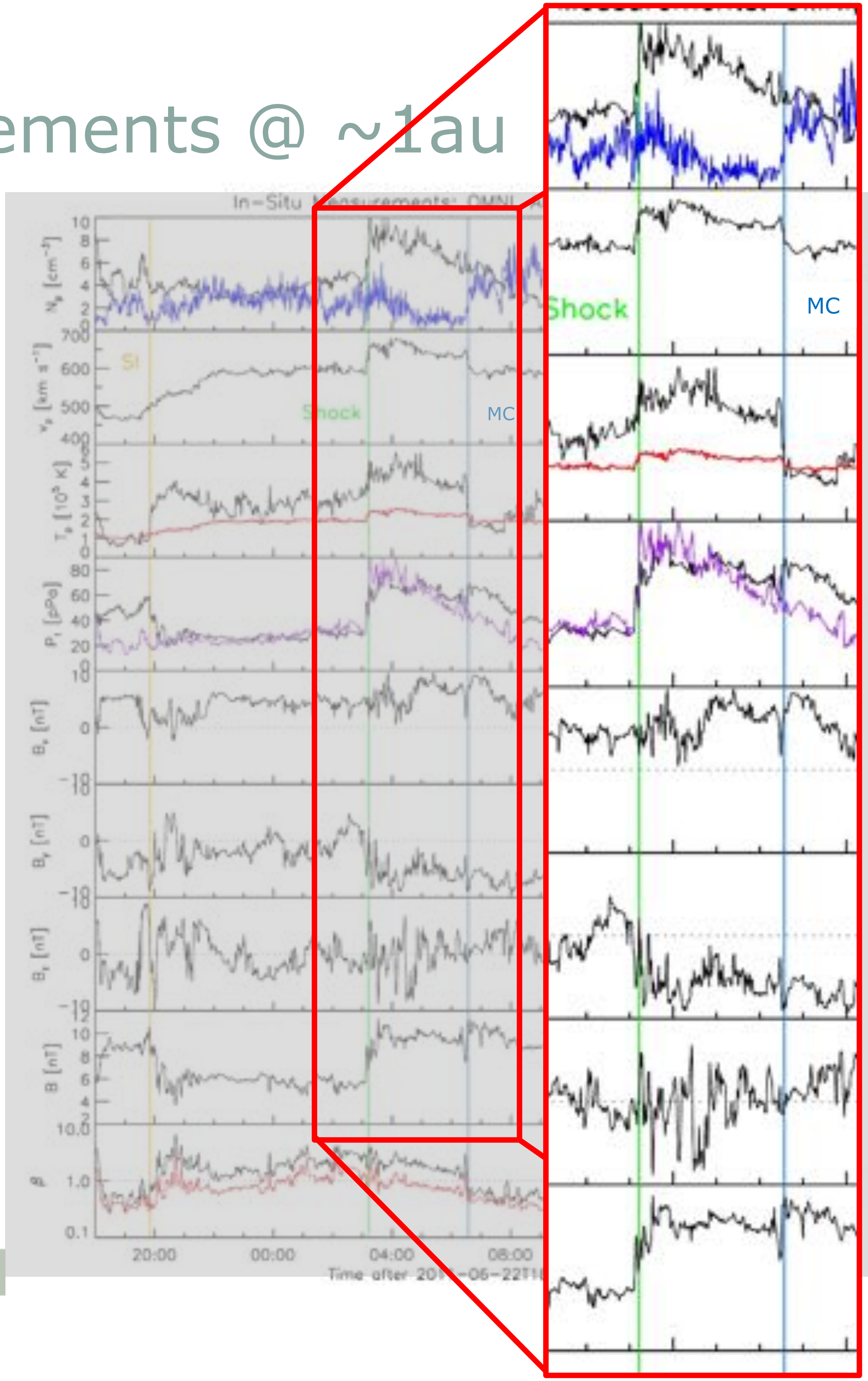
- Stream Interface (SI)
  - T_p increase, B, N_p & P_t drop



Solar wind in-situ measurements @ ~1au

- Stream Interface (SI)
  - T_p increase, B, N_p & P_t drop

- Moderate Shock Signature
  - Sharp rise in v_p, N_p, P_t, P_{dyn} & B
  - Density ratio ~2, B-ratio ~1.5
  - In the high speed part of the HSS
  - Most likely caused by the CME
  - Seems to be **not driven** ($v_{prior} = v_{CME}$)
  - **Short** standoff distance



Solar wind in-situ measure

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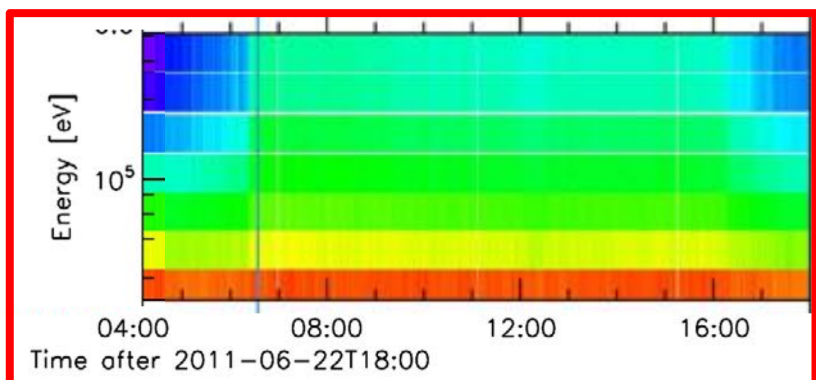
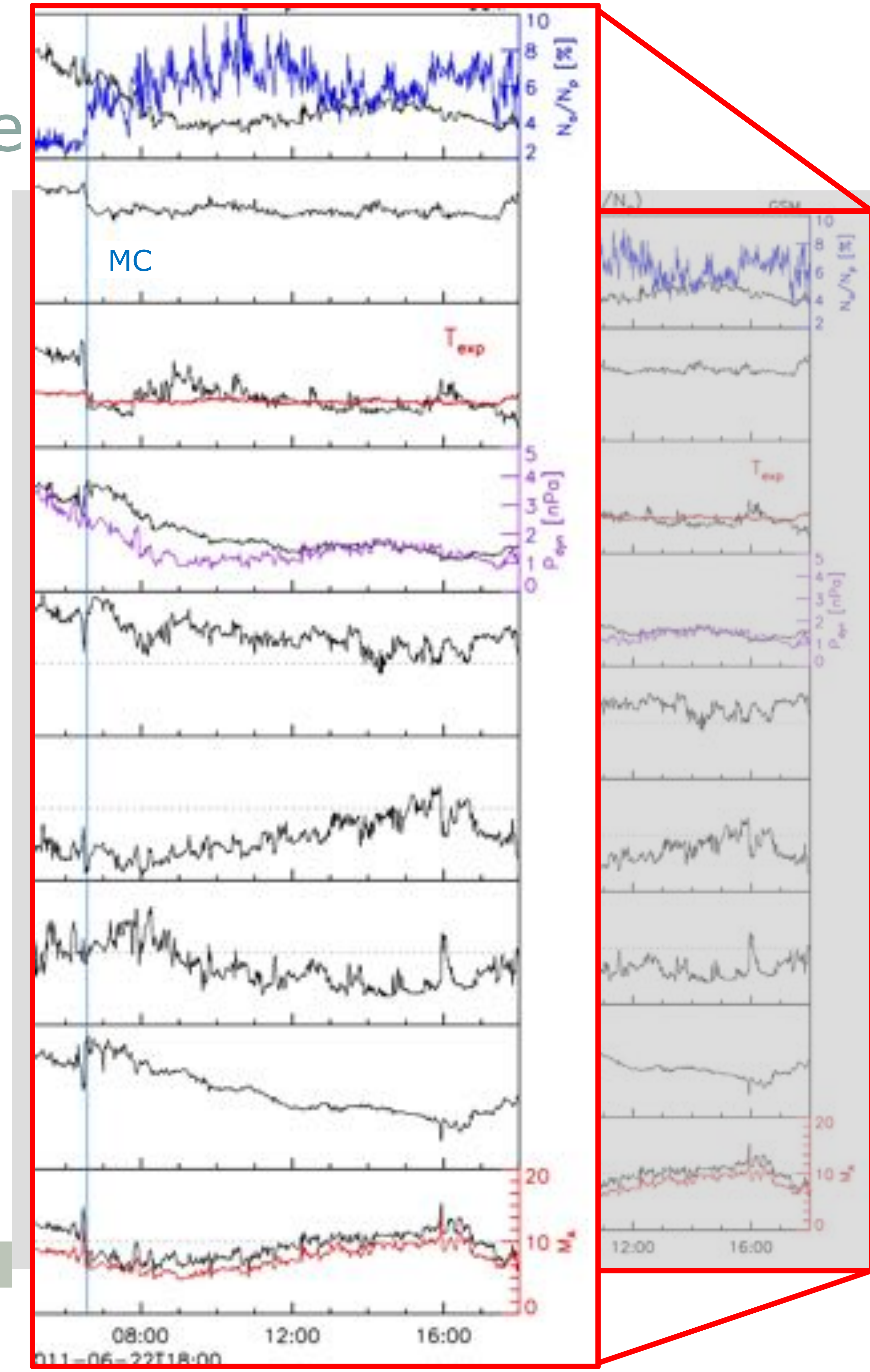
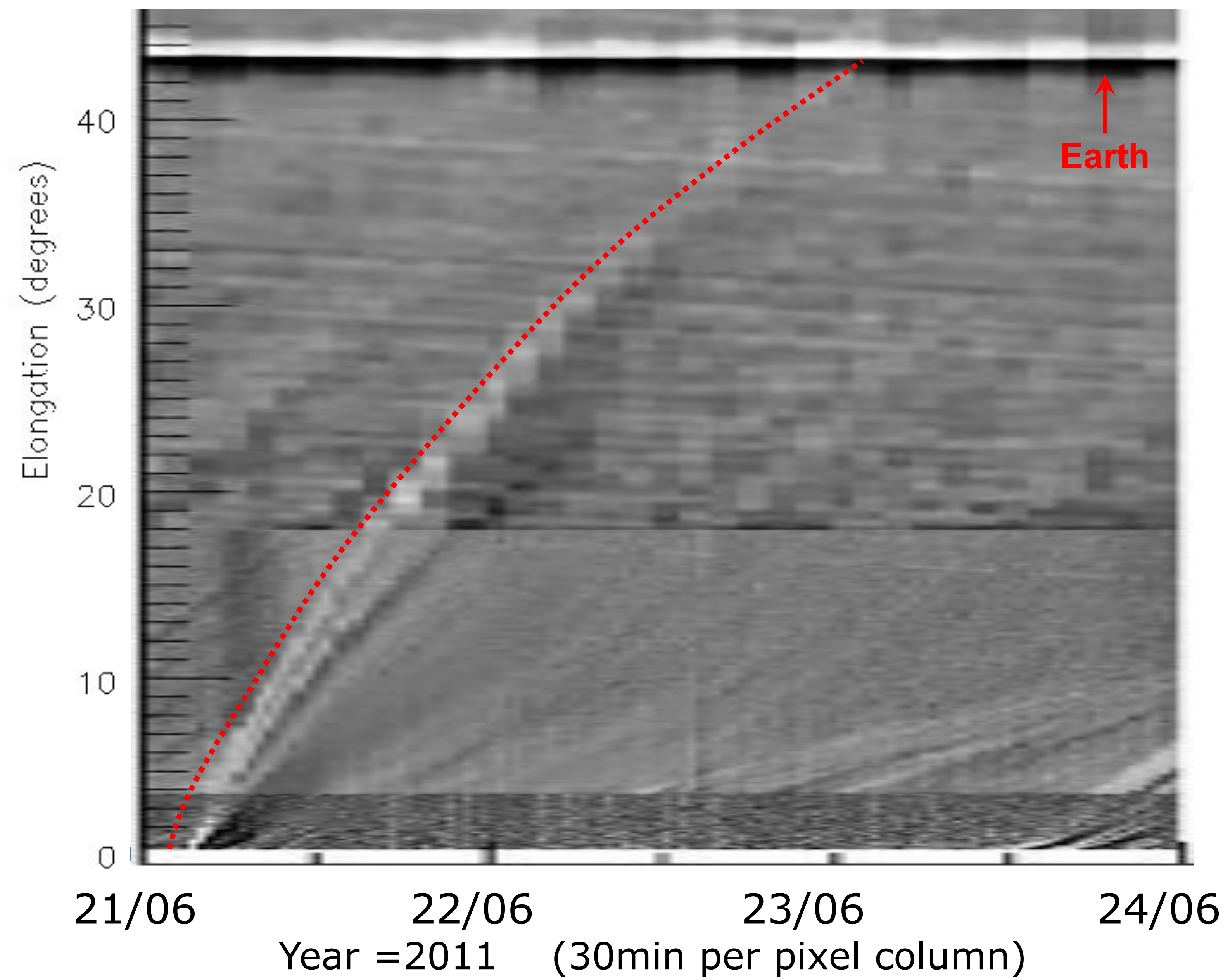
- MC Signature
  - low plasma beta, low alfvénic mach number, sharp Tp drop, increased α–particle ratio
  - Intensification of high energy e^- (~0.5MeV)





Tracing the CME propagation



STEREO-A (COR2, HI1, HI2) - jmaps, where we can see the CME propagating in Earth direction. The launch date we estimate to ***2011-06-21 02:00:00*** with an estimated impact around ***2011-06-23 04:00:00***

Associated Flare Event

- Gradual C7.7 Flare -
  21 June 2011 01:22 UT

- Active Region
  ~N17/W12 @ 01:22 UT

- LASCO HALO ICME
  - Also seen by both STEREOs

- Coronal Hole below the Active Region

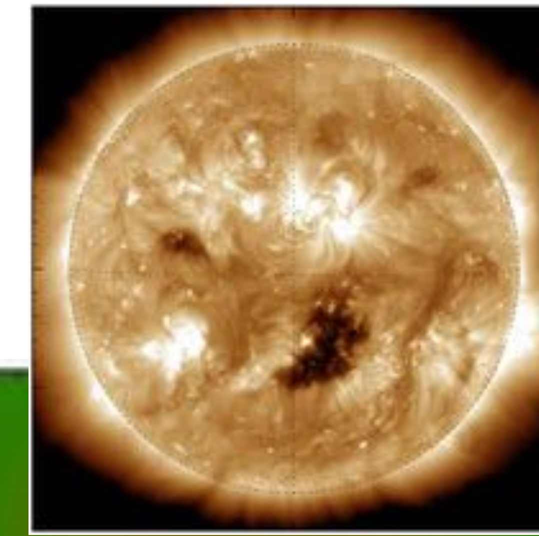
Composite Movie AIA/SDO
193Å, 211Å, 304Å by NASA

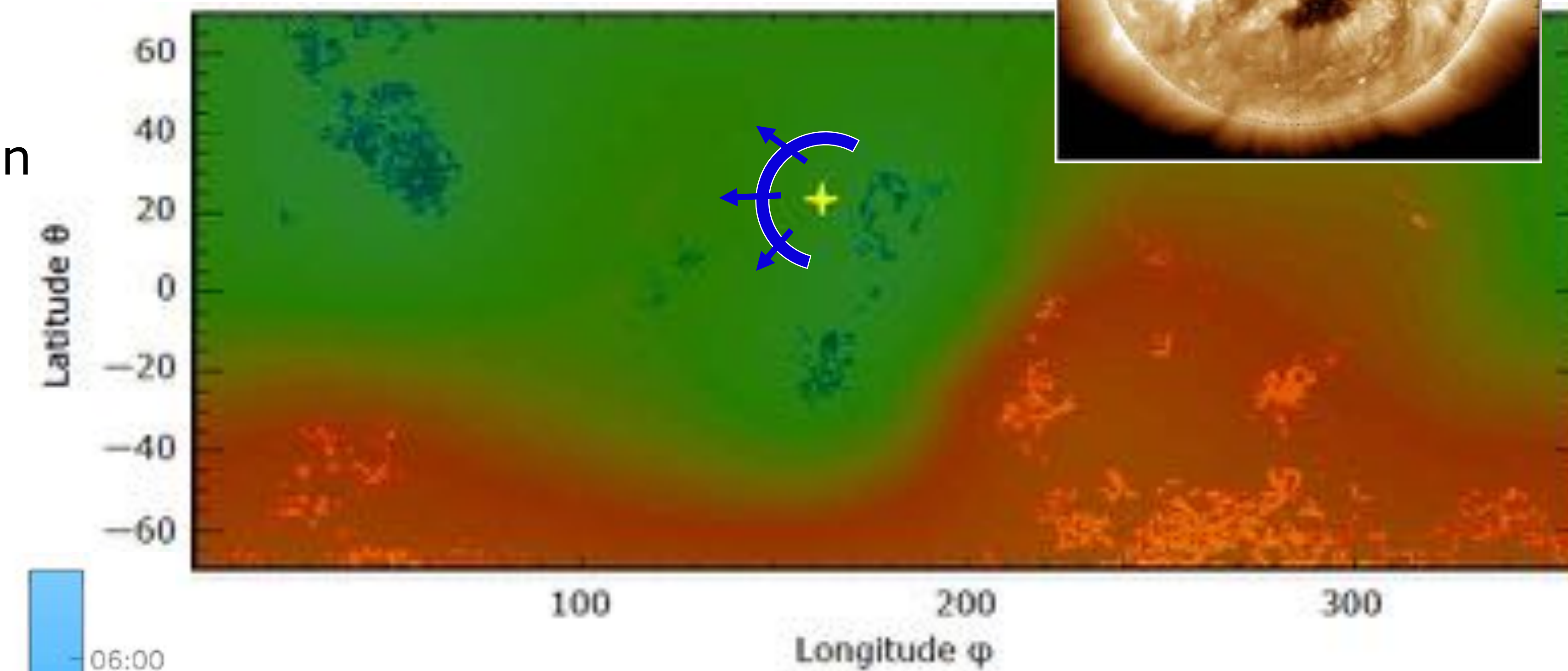
Low Coronal Signatures

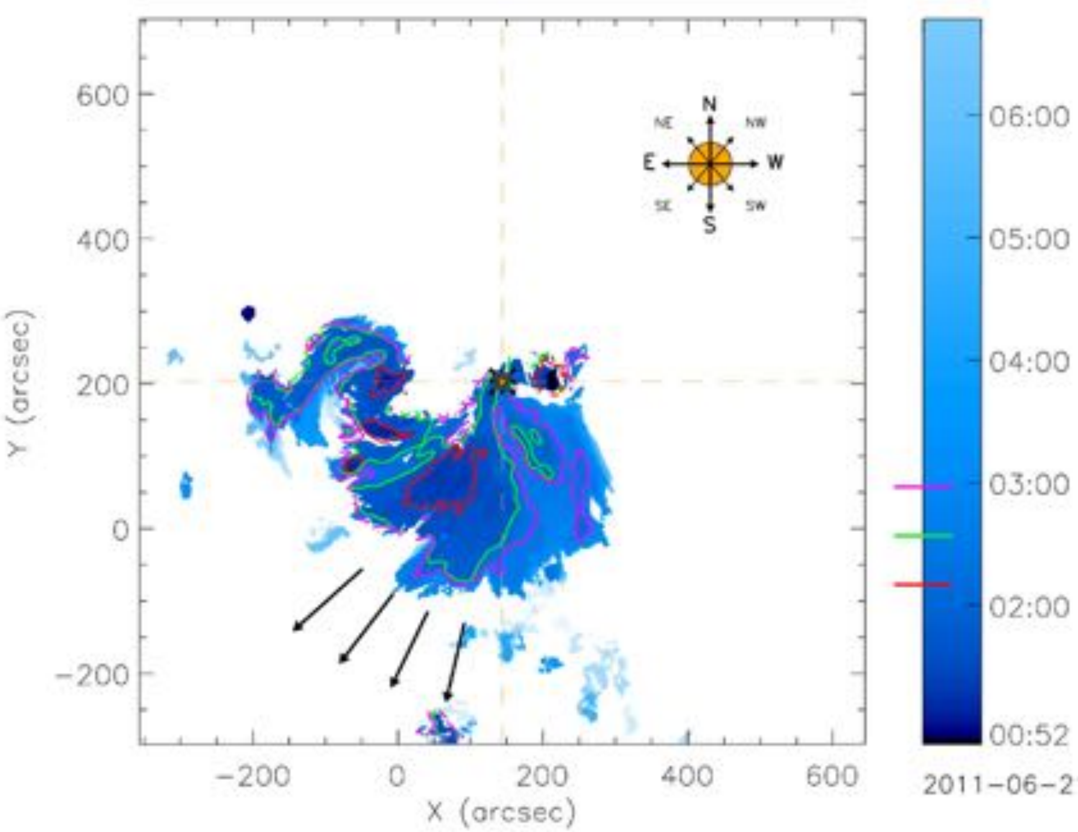
- NLFFF model (Tadesse et al. 2014[10])

- Deduce possible directions due to the *frozen-in* condition

Open field map at the photosphere with the magnetic field at 2.5Rs overlayed.







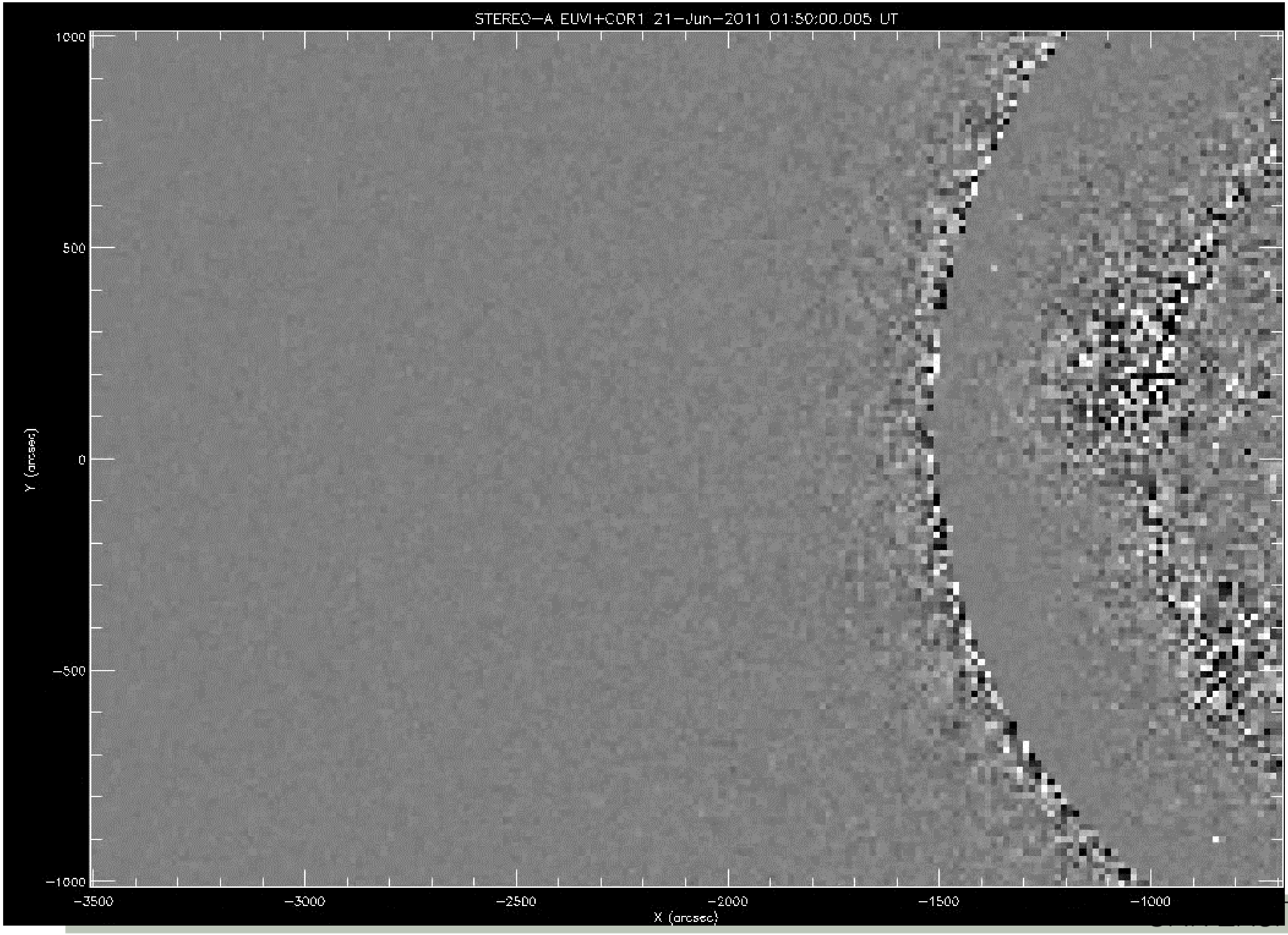
Evolution of the dimming, where each pixel is color-coded by the time of its first detection. Dark blue pixel are detected earlier than light blue pixels.

- Coronal dimmings represent the footpoints of the CME in the low corona

Reflect the initial propagation

- Using the method described in Dissauer et al. (2018)[11] the temporal evolution of the dimming is extracted.

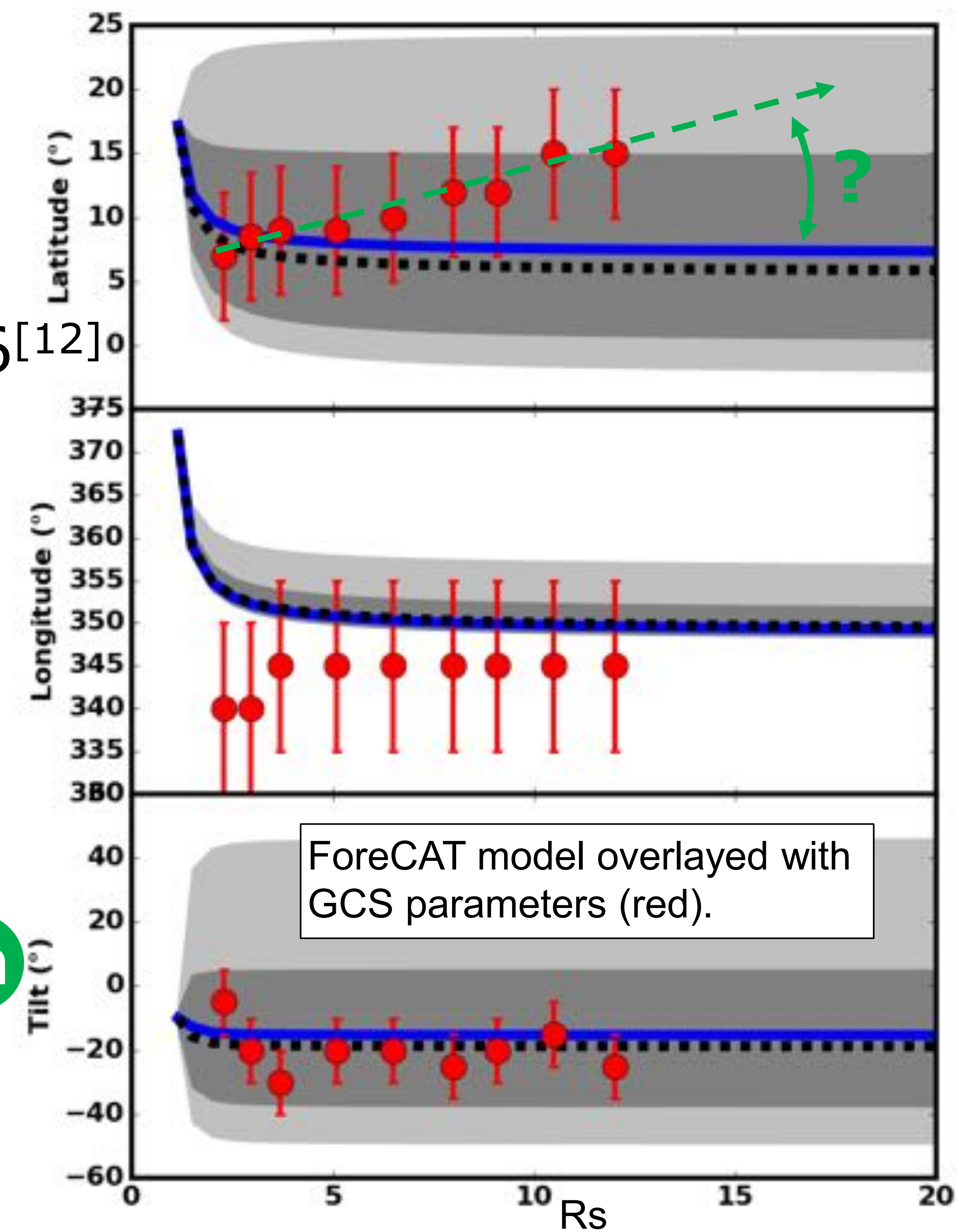
The CME - early propagation



Running difference composite movie of EUVI (195Å) and COR1 images taken by STEREO A

Further Modelling Efforts - ForeCAT & GCS

- ForeCAT model by Kay et al. 2015[4]
  - CME deflection based on static magnetic background forces
  - Initial values & propagation direction match observations



- GCS model by Thernisien et al. 2006[12]
  - 9 timesteps of the CME modelled
  - Tilt & Longitude are in good agreement
  - Deviation in the Latitude

From a dynamic CME – HSS interaction

Discussion & Summary

The results will be published;
Heinemann et al. in preparation

I. Reconstructed the CME launch from low coronal properties
   - *ejecta in south-eastern direction towards CH*

eg. Shown in the Coronal Dimming

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II. Investigated the CME-HSS interaction
- *Deflection/asymmetric propagation northward*
- *CME is embedded in the HSS* ⟶ *cannot expand unhindered*

(flux conserved expansion factor n_A=0.51±0.14, n_B=1.01±0.27, Dumbovic+ 2018[5])

Can be well observed in whitelight images, GCS reconstructions and ForeCAT model results

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III. Peculiarities in the in-situ data @ 1 au
   - *Seemingly non-driven shock*
   - *Short shock sheeth/standoff distance*

CME direction and s/c intersection in good agreement with models

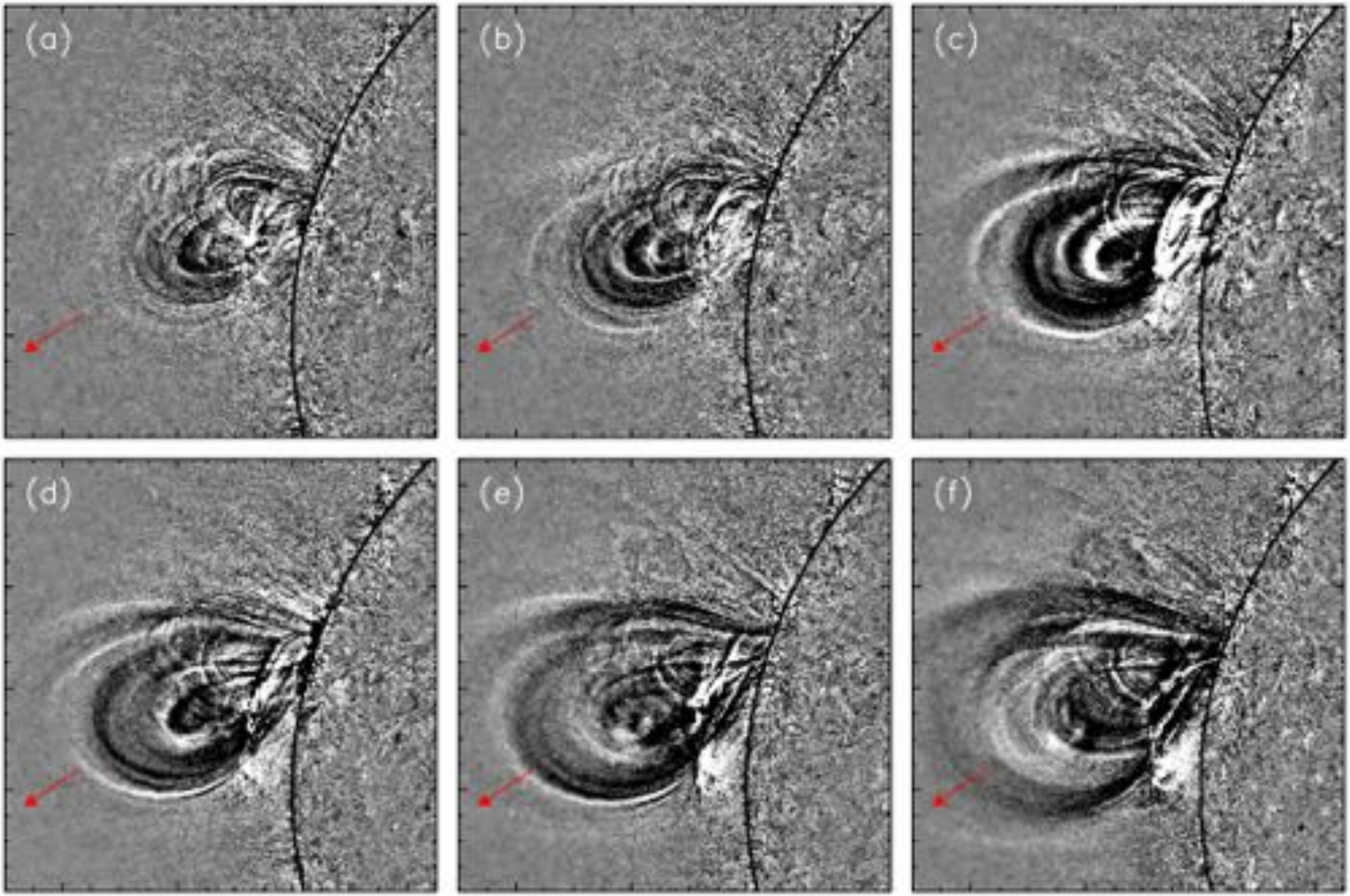
"Skimming s/c trajectory that misses the high speed part of the CME ⟶ *Shock is still being driven by the CME"*

Thank you for your attention !

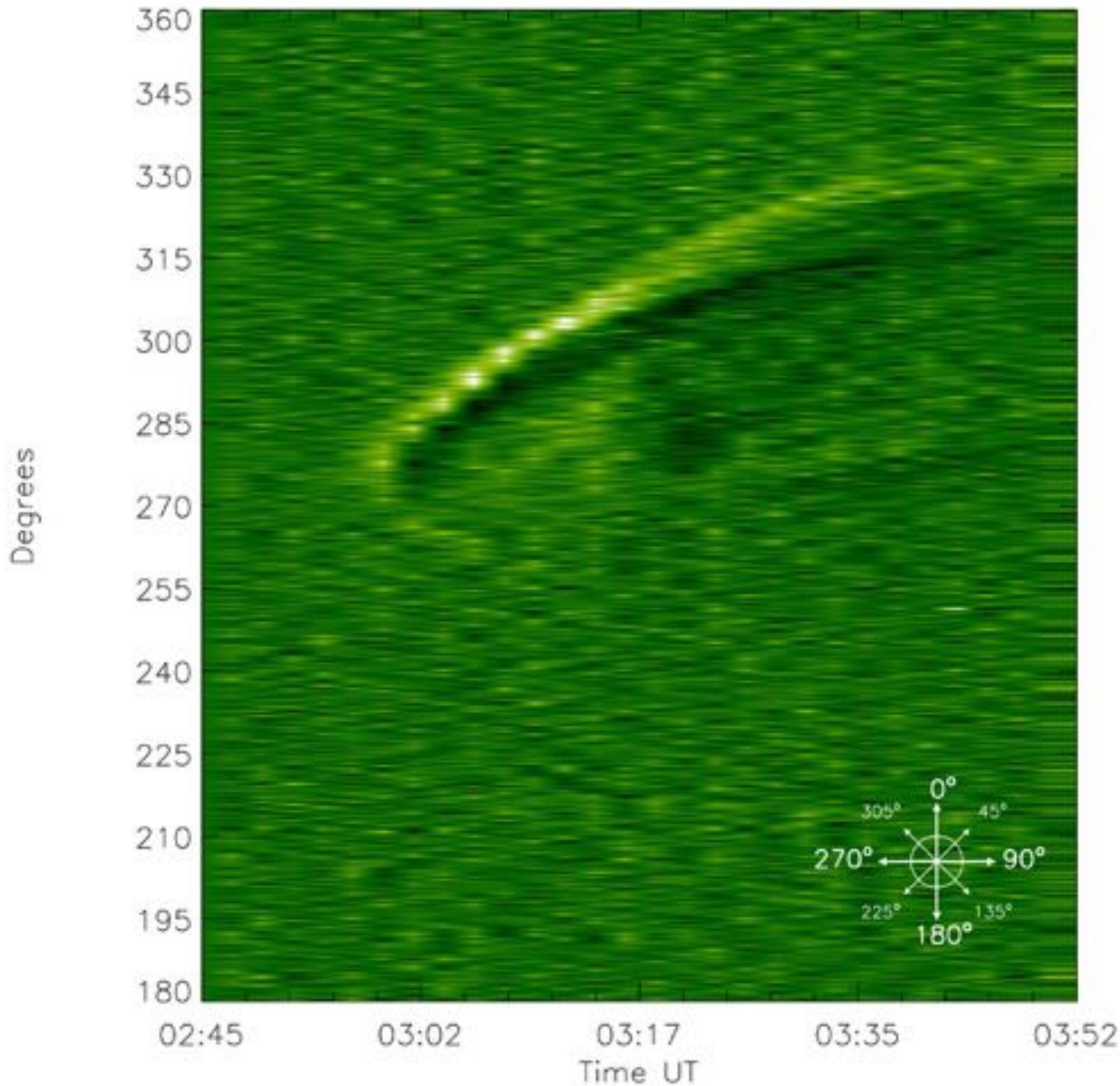
https://wirdou.files.wordpress.com/2014/12/heliocentric-geocentric.jpg

[1] Manchester, W. B., Gombosi, T. I., Roussev, I., et al. 2004, Journal of Geophysical Research (Space Physics), 109, A02107
[2] Manchester, IV, W. B., Gombosi, T. I., De Zeeuw, D. L., et al. 2005, ApJ, 622, 1225
[3] Kay, C., Opher, M., & Evans, R. M. 2013, ApJ, 775, 5
[4] Kay, C., Opher, M., & Evans, R. M. 2015, ApJ, 805, 168
[5] Kliem, B., Su, Y. N., van Ballegooijen, A. A., & DeLuca, E. E. 2013, ApJ, 779, 129
[6] Lavraud, B., Ruffenach, A., Rouillard, A. P., et al. 2014, Journal of Geophysical Research (Space Physics), 119, 26
[7] Nieves-Chinchilla, T., Colaninno, R., Vourlidas, A., et al. 2012, Journal of Geophysical Research (Space Physics), 117, A06106
[8] Wang, Y., Wang, B., Shen, C., Shen, F., & Lugaz, N. 2014, Journal of Geophysical Research (Space Physics), 119, 5117
[9] Winslow, R. M., Lugaz, N., Schwadron, N. A., et al. 2016, Journal of Geophysical Research (Space Physics), 121, 6092
[10] Tadesse, T., Wiegelmann, T., Gosain, S., MacNeice, P., & Pevtsov, A. A. 2014, A&A, 562, A105
[11] Dissauer, K., Veronig, A. M., Temmer, M., Podladchikova, T., & Vanninathan, K. 2018, ApJ, 855, 137
[12] Thernisien, A. F. R., Howard, R. A., & Vourlidas, A. 2006, ApJ, 652, 763
[13] Dumbovic, M., Heber, B., Vrsnak, B., Temmer, M., & Kirin, A. 2018, ApJ, 860, 71

CME Launch (EUVI/STA)

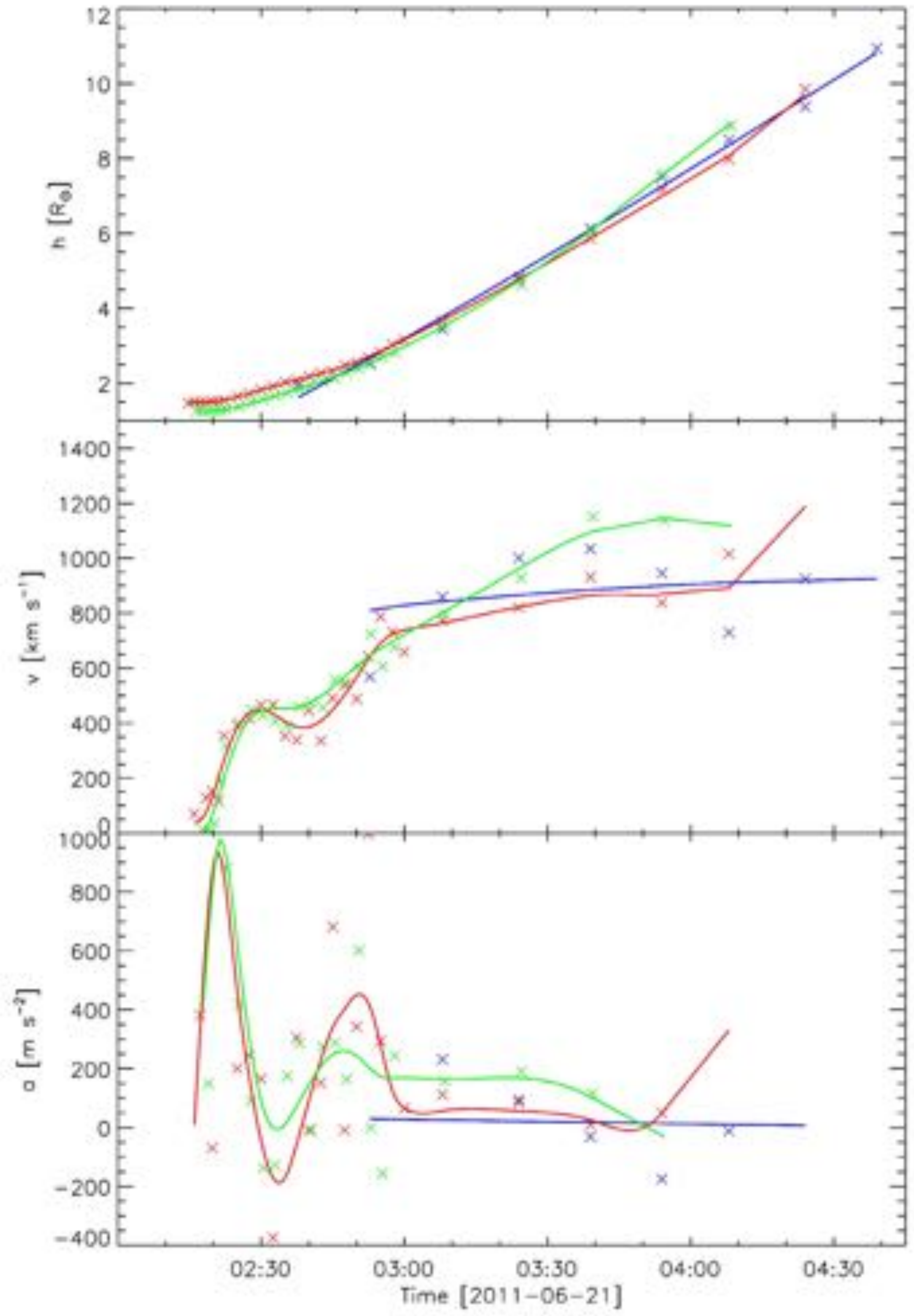


Circular Stack @ 2.9Rs

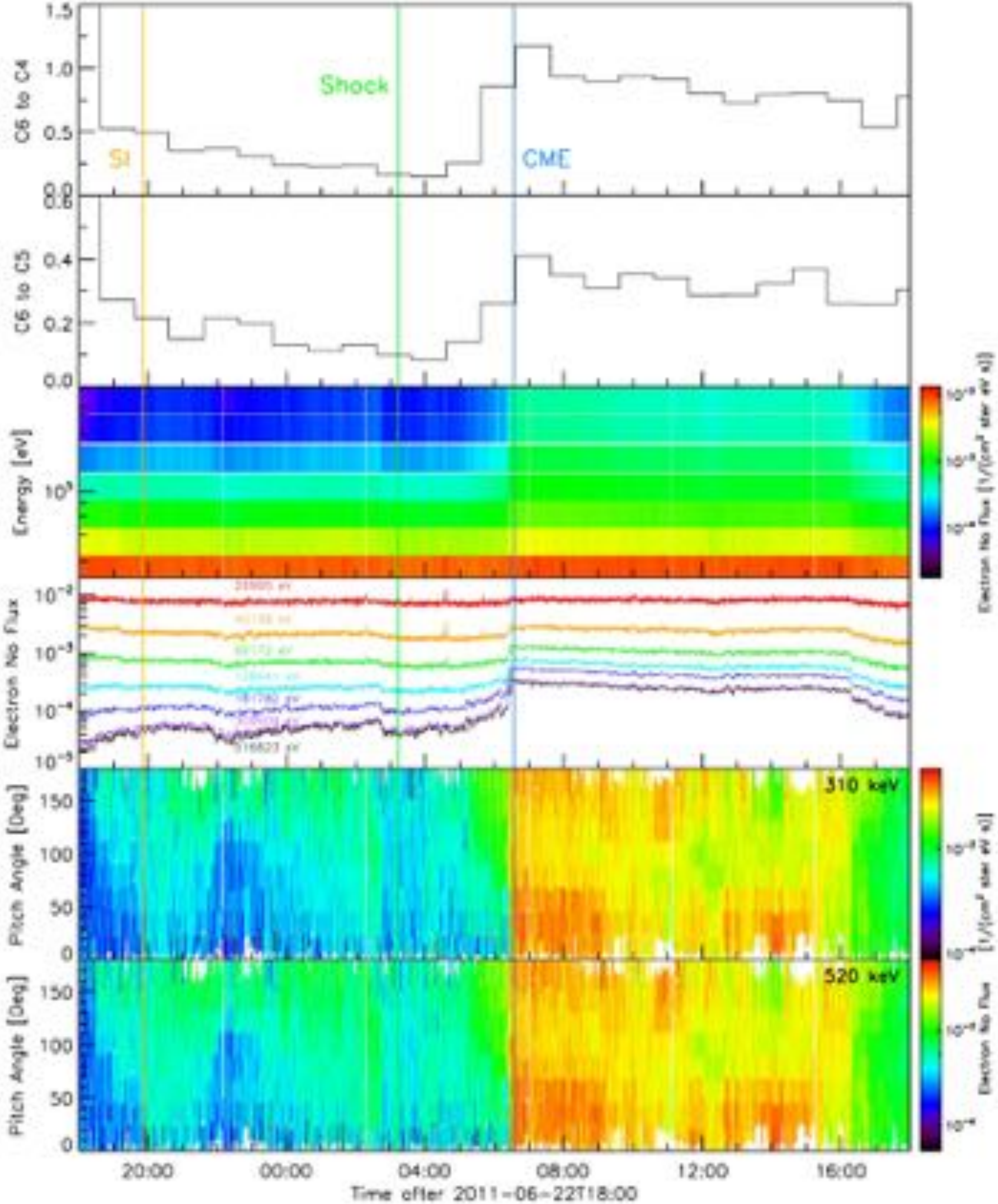


CME KINEMATICS

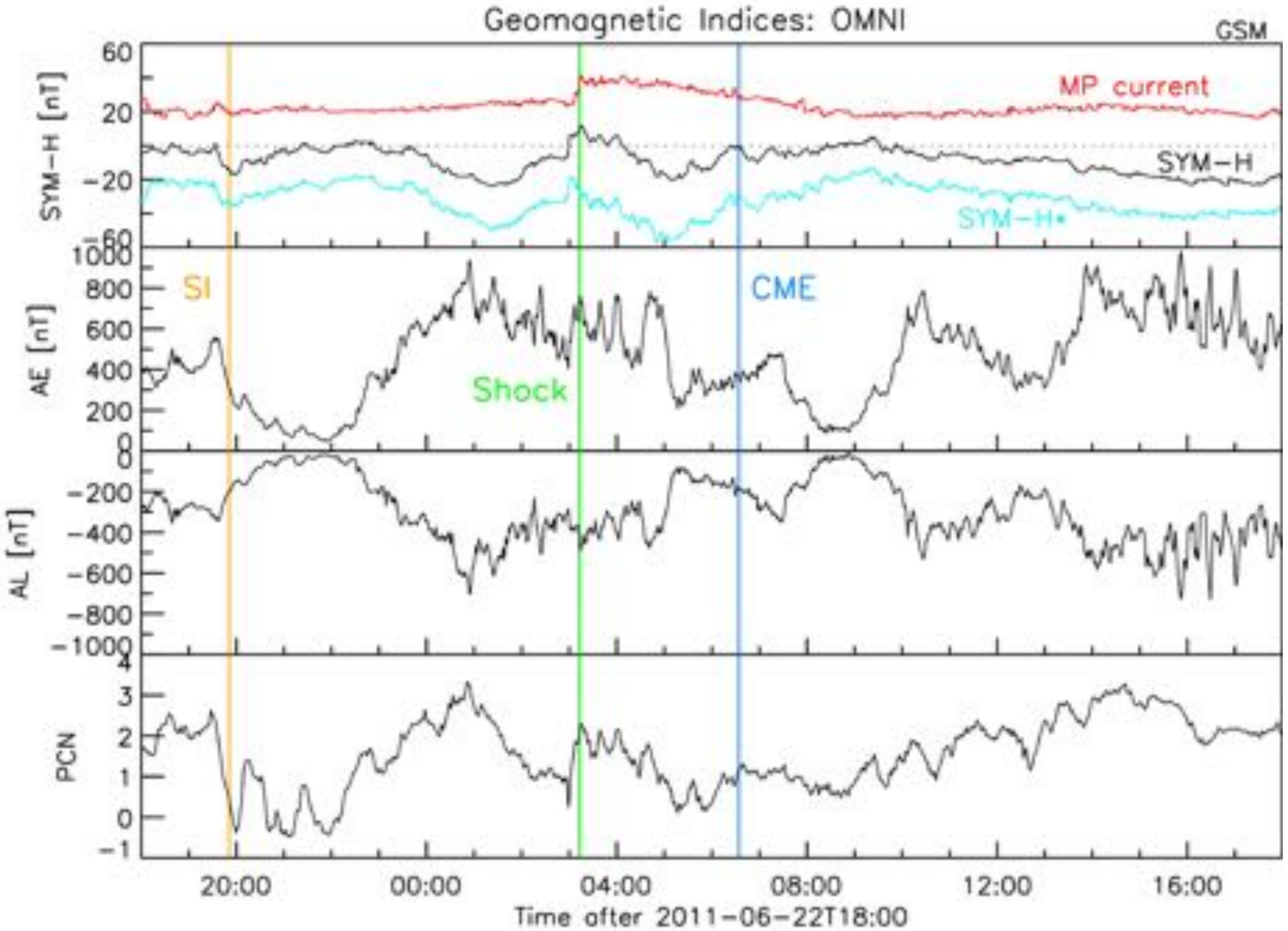
- Measured in Earth direction
  - GCS model
  - STEREO-A
  - STEREO-B

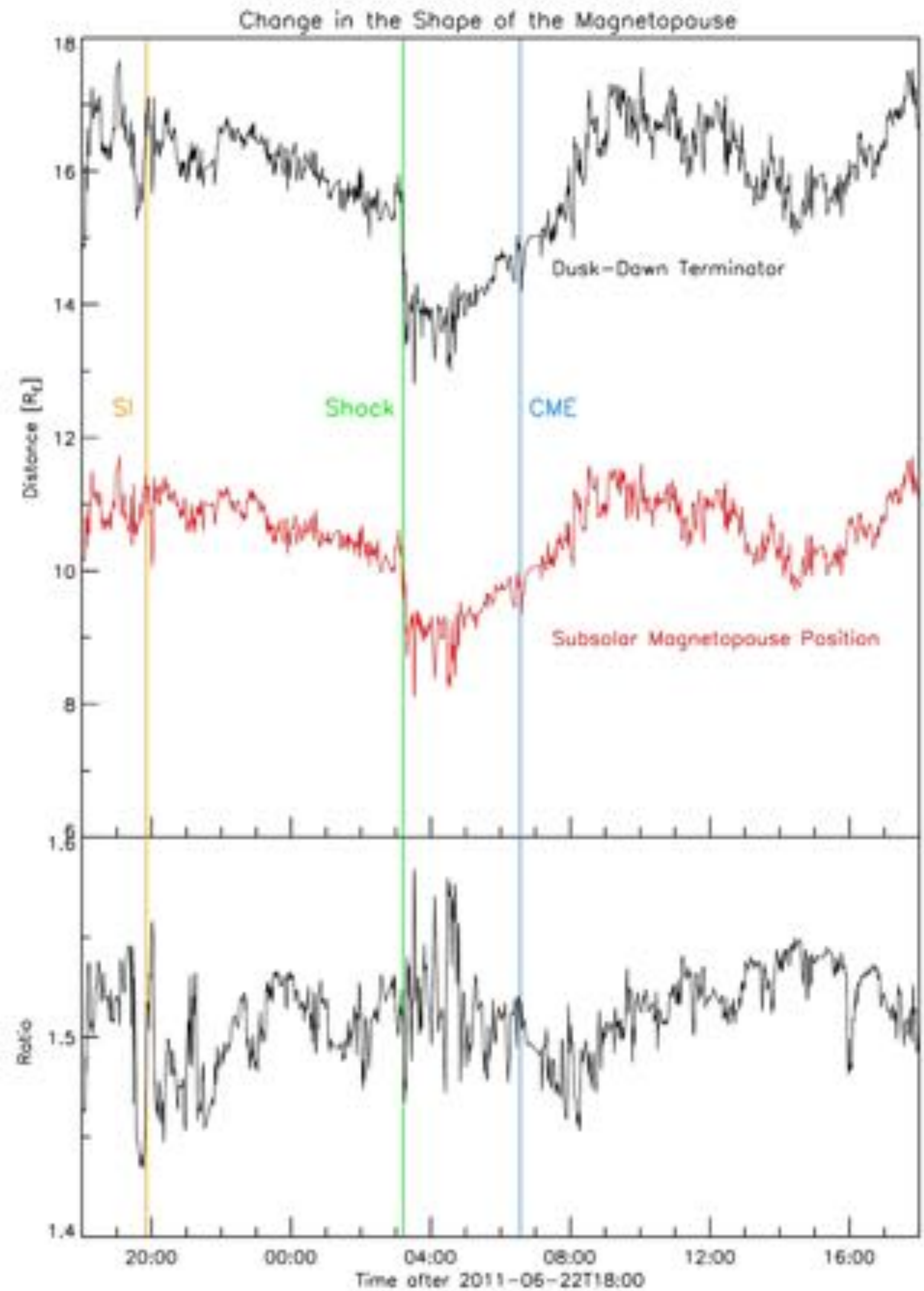


Additional In-situ data



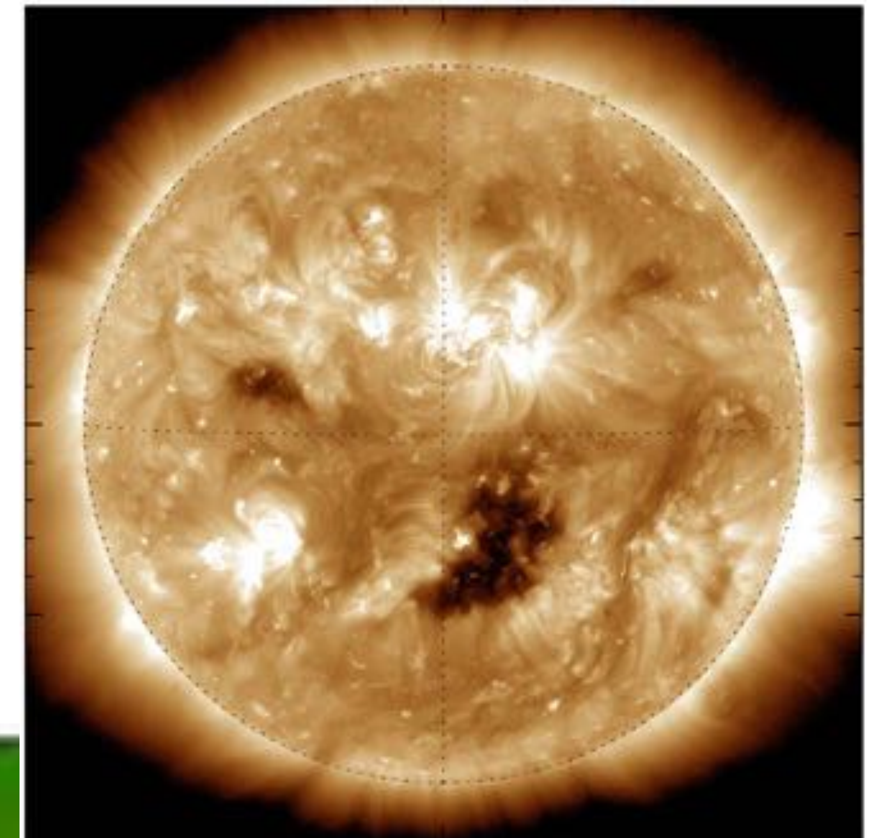
Geomagnetic Effects



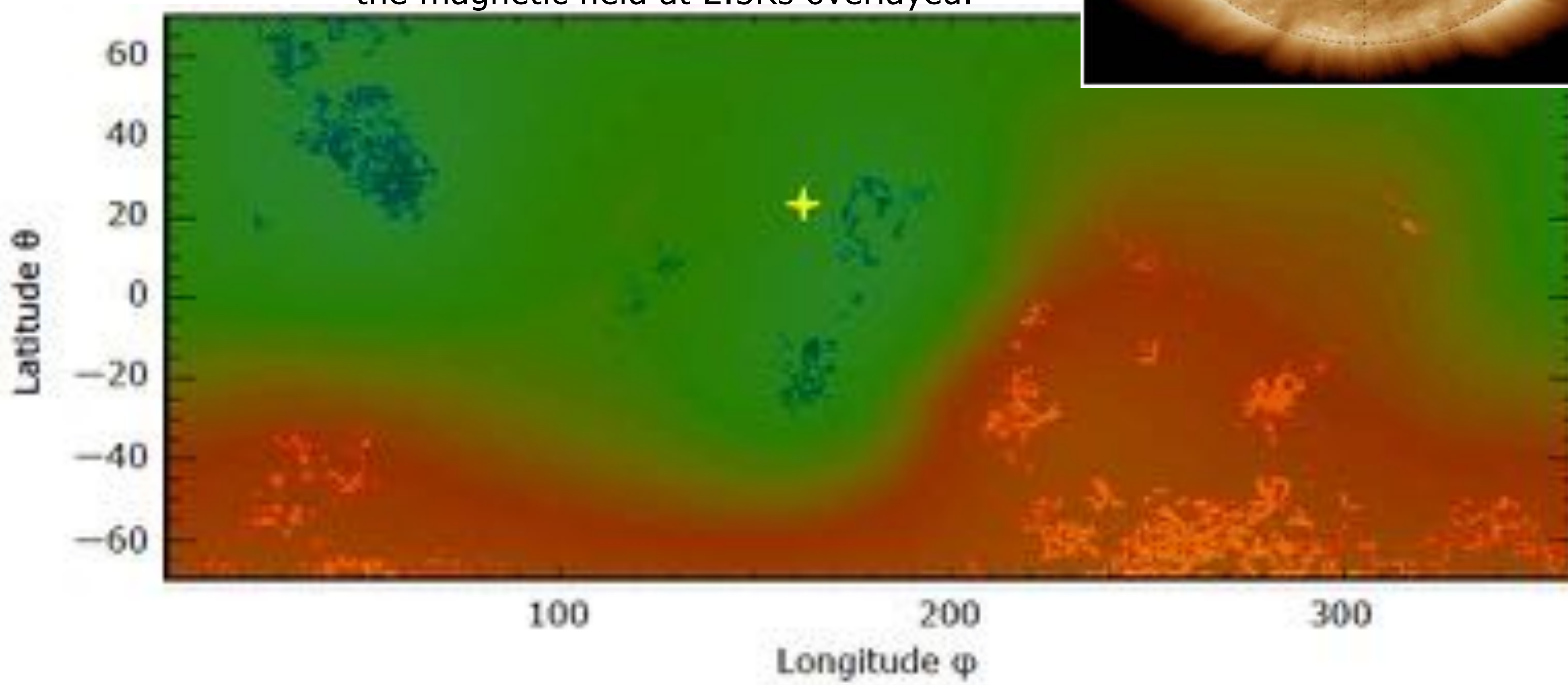


Surface Configuration – The magnetic field

- NLFFF model (Tadesse et al. 2014[1])
  - To deduce possible propagation and expansion directions due to the *frozen-in* condition



Open field map at the photosphere with the magnetic field at 2.5Rs overlayed.



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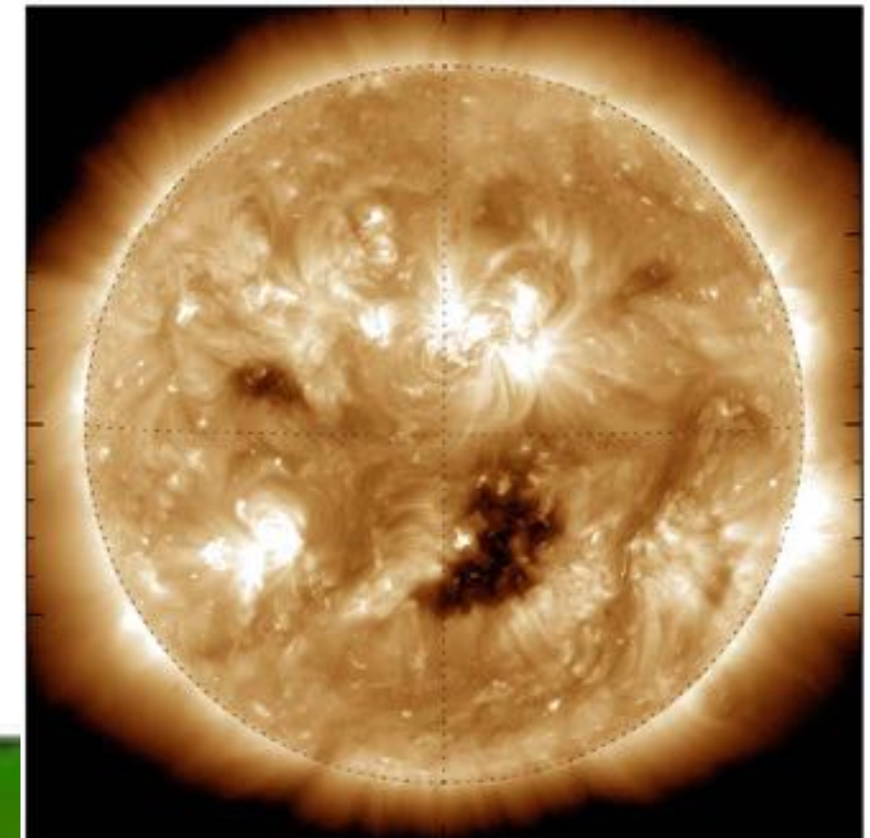

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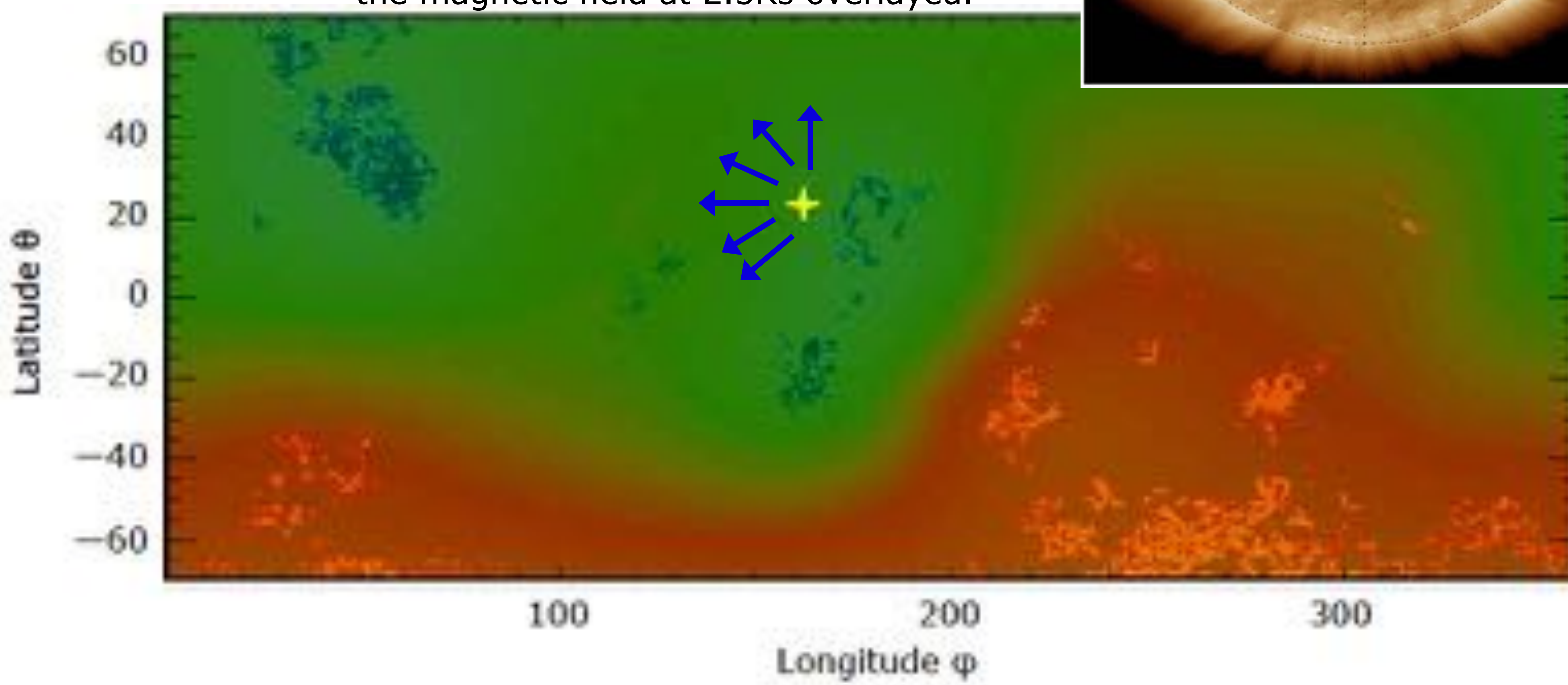
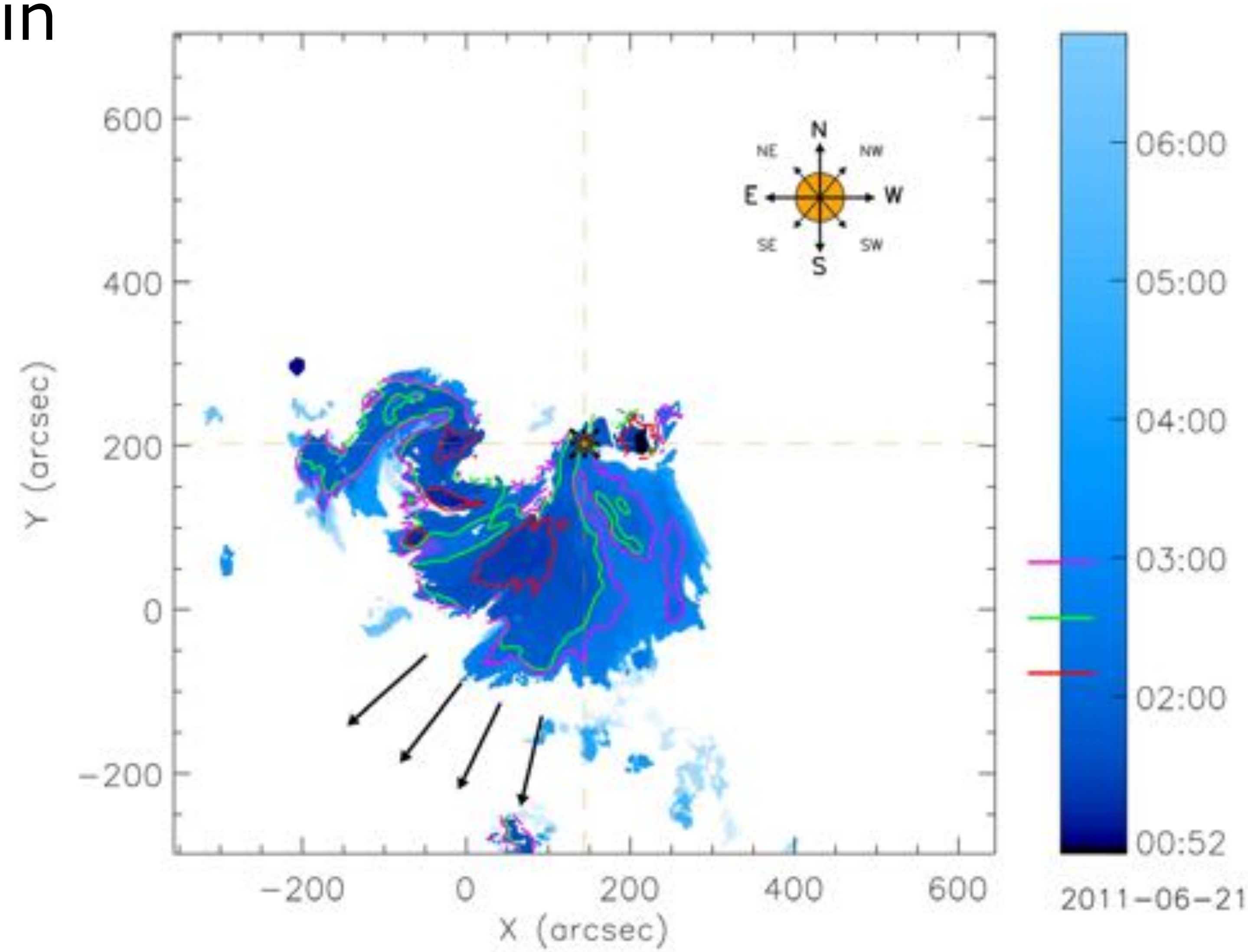


CME Surface Signature – Coronal Dimming

- Coronal dimmings represent the footpoints of the CME in the low corona.

Reflect the initial propagation

- Using the method described in Dissauer et al. (2018)[2] the temporal evolution of the dimming is extracted.



Evolution of the dimming, where each pixel is color-coded by the time of its first detection. Dark blue pixel are detected earlier than light blue pixels. The three contours represent the dimming at 02:10 UT(red), 02:34 UT (green), and 02:58 UT (magenta), respectively.

Further Modelling Efforts - ForeCAT & GCS

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  - Initial values & propagation direction match observations
- GCS model by Thernisien et al. 2006[4]
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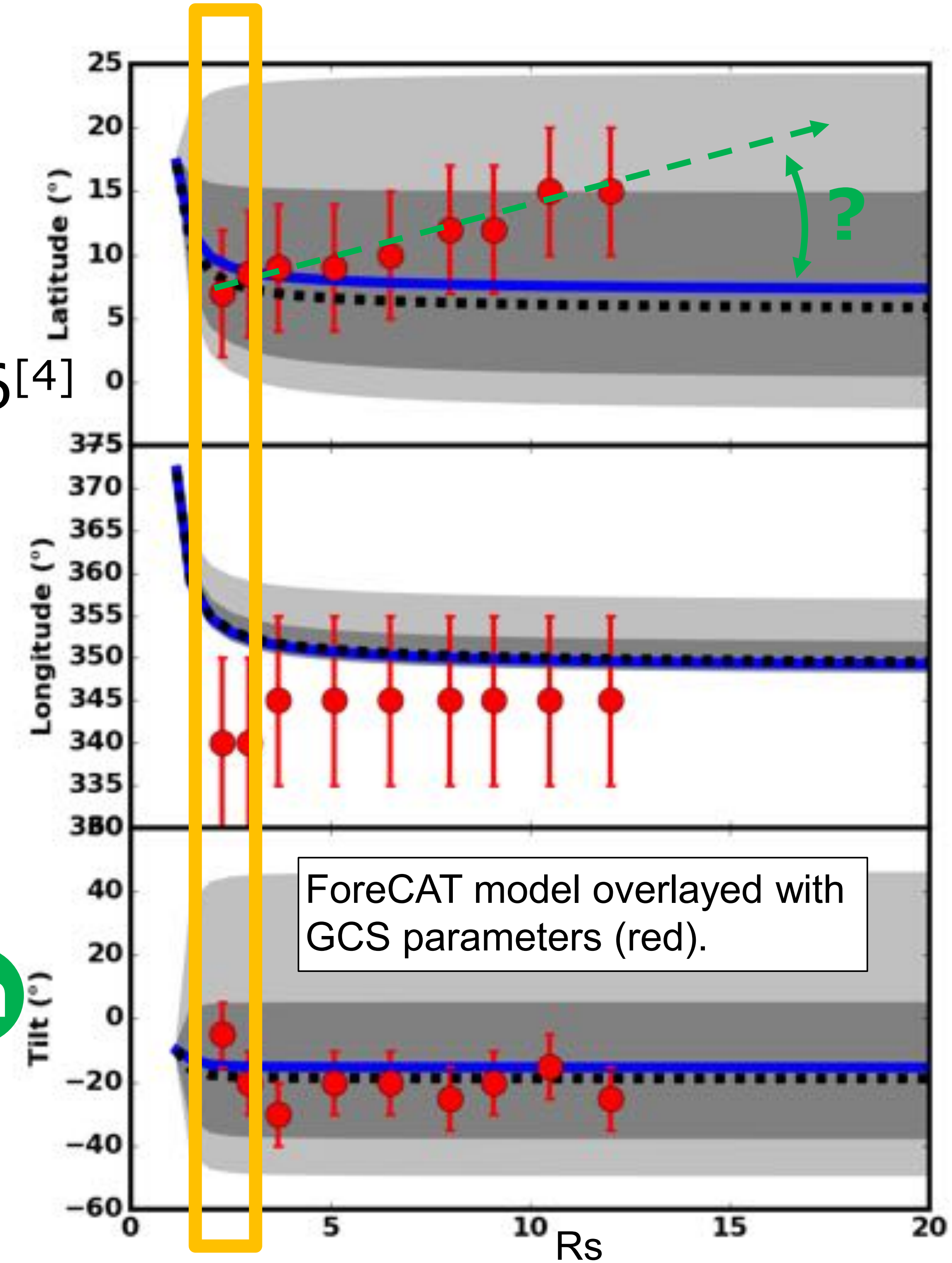
From a dynamic CME – HSS interaction



Whats the story?

- Gradual C7.7 Flare → *ejecta in north-eastern direction towards CH*

- CME interacts with the open field @2.5-3 Rs
  → *Deflected northwards/ asymmetrically propagates*

- HSS wraps around the CME (CME in-situ signature in the high speed part of the HSS)
  → *CME cannot expand properly* *(expansion factor n_A=0.51±0.14, n_B=1.01±0.27, Dumbovic+ 2018[5])*

- s/c trajectory does not pass through CME apex
  → *Shock is still being driven by the CME, but not from the part measured in-situ*

CME direction and s/c intersection in good agreement with models

Remote Sensing Observations – EUV/Whitelight

- Comparison to direct observations

Running difference composite movie of EUVI (195Å) and COR1 images taken by STEREO A

EUVI

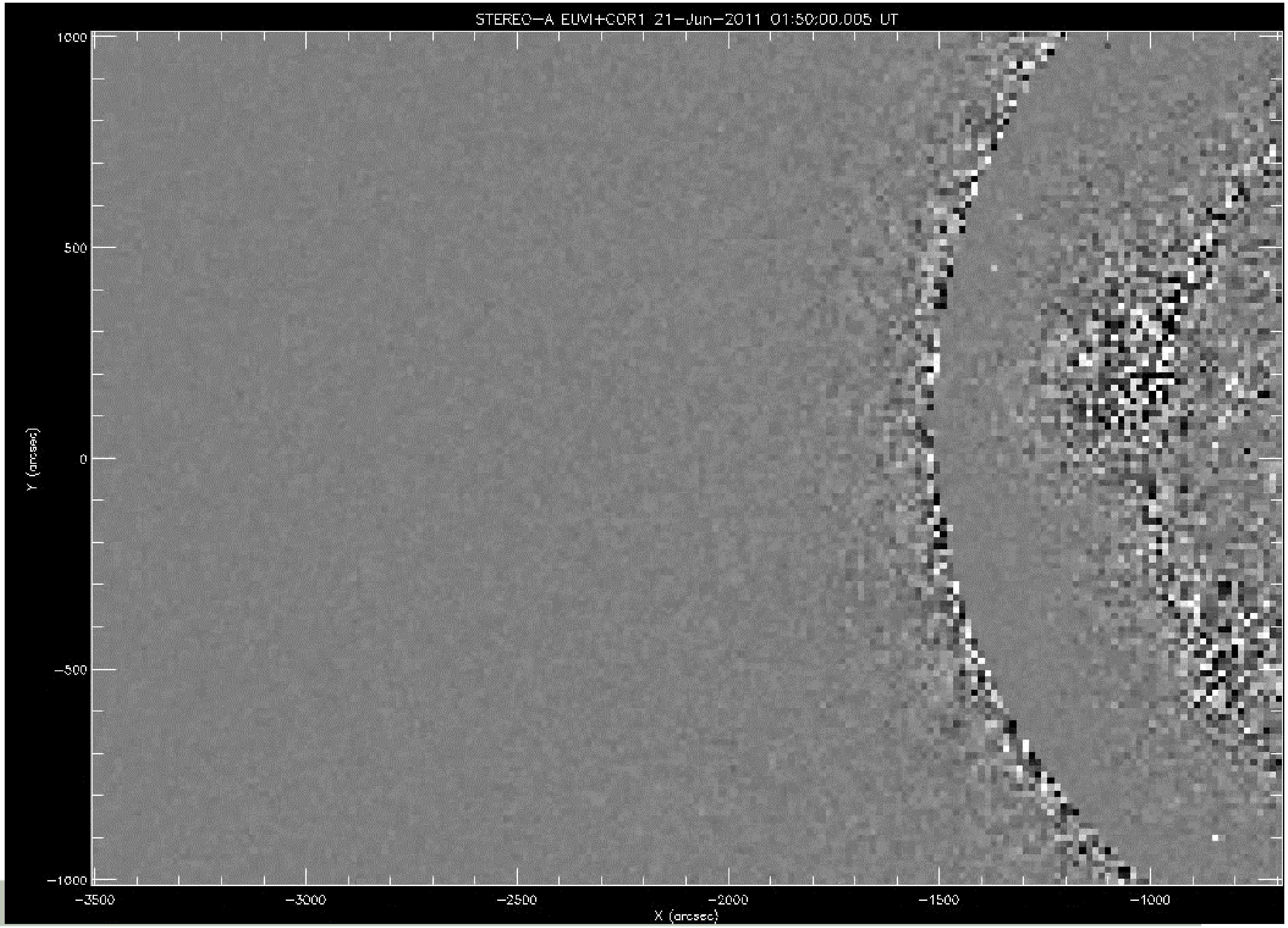
Clear southward motion in the lower corona

As predicted from the Coronal Dimming

COR1

Deflection/Asymmetric expansion northwards

As expected from the NLFFF model



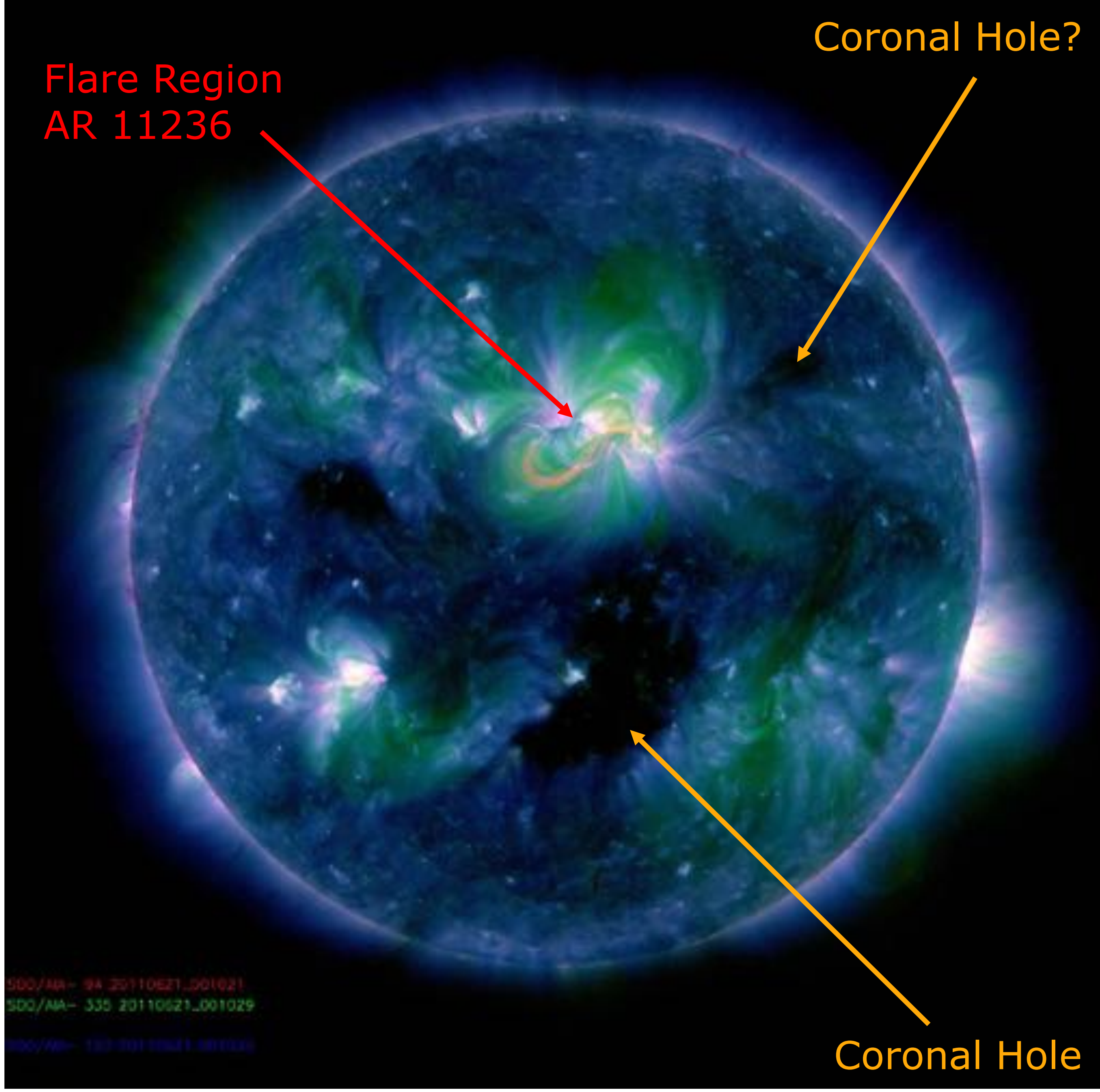
The Event

- Gradual C7.7 Flare -
  21 June 2011 01:22 UT

- Active Region
  ~N17/W12 @ 01:22 UT

- LASCO HALO ICME
  - Also seen by both STEREOs

- CME in-situ signature at 1 au
  in the high speed part of the HSS



Composite image AIA/SDO 94Å, 193Å, 335Å by NASA

Indicates a CME – HSS interaction