Different Techniques for (and Some Success In) Measurement of Bs

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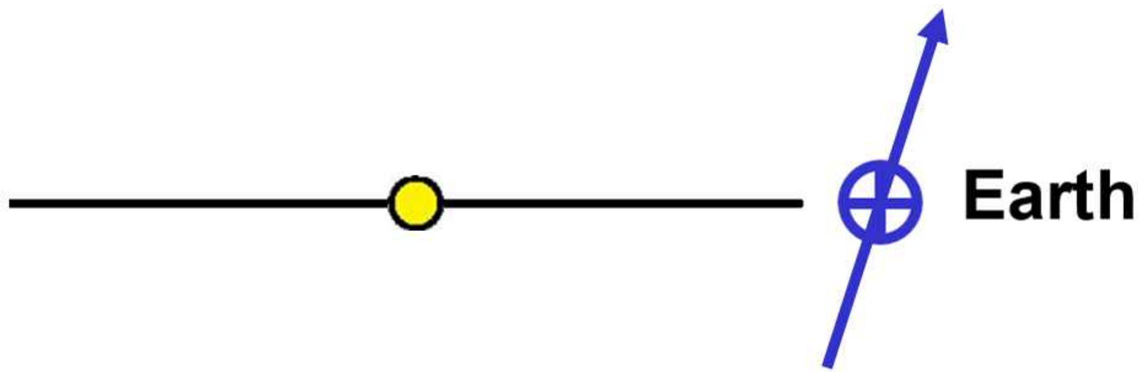
http://ips.ucsd.edu/ **http://smei.ucsd.edu/**

Different Techniques for Measurement of Bs

Introduction:



Bs: Definition

Geocentric Solar Magnetospheric (GSM) Bz:

The reasons to determine Bz

Concept studies: How we may be able to determine Bz

1) In CMEs.
2) In the background solar wind

Some successes in determining Bz

Different Techniques for Measurement of Bs

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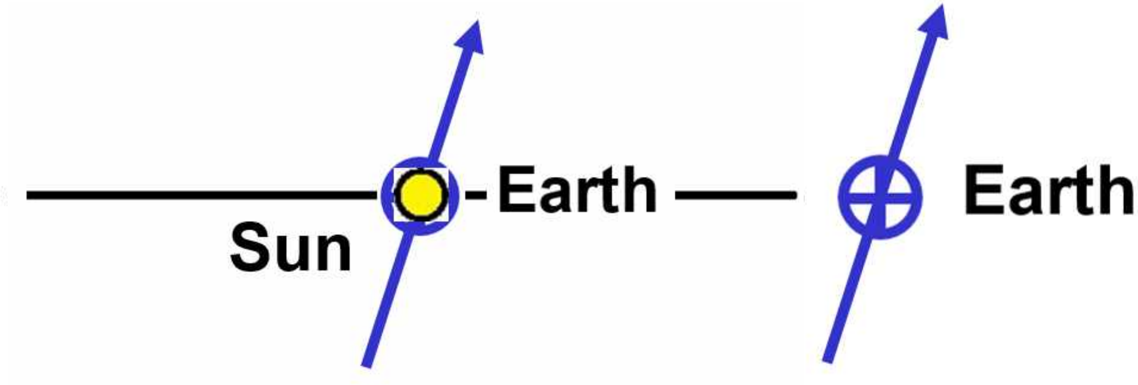

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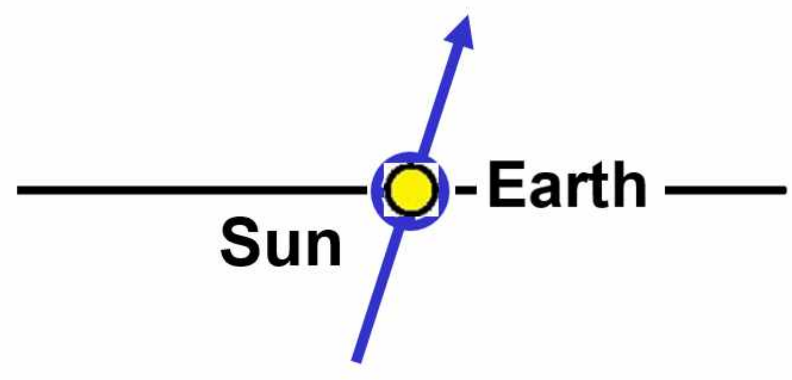

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Why Determine Bz?

Geomagnetic Substorm Activity

A brief (2-3 hour) disturbance in Earth's magnetosphere that releases energy from the tail of the magnetosphere causing particles to be injected into the high latitude ionosphere.

Geomagnetic Storm Activity

A series of substorms, or a strong or prolonged enhancement of the global magnetospheric electric field.

Both cause radio communication difficulties, particle precipitation into the ionosphere, aurora, satellite damage, ground-based currents, etc.,

A southward IMF is a common factor in the occurrence of both storms and substorms.

Different Techniques for Measurement of Bz

Generally the largest storms and substorms are associated with CMEs

Two factors in CMEs are important.

1) Southward Bz.

2) Dynamic pressure caused by high speed wind.

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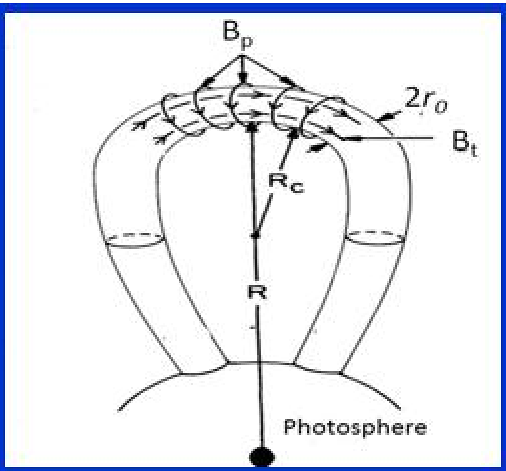
CMEs

Fm N. Gopalswamy

Motivation

- All CMEs reaching 1-AU seem to have flux rope structure (irrespective of observed MC or non-MC structure of ICMEs)



Mouschovias and Poland, 1978

Both geometrical and magnetic properties of a coronal flux rope can be obtained from eruption data (post-eruption arcade, LOS magnetogram, white-light CME) under the assumption of cylindrical force-free flux rope

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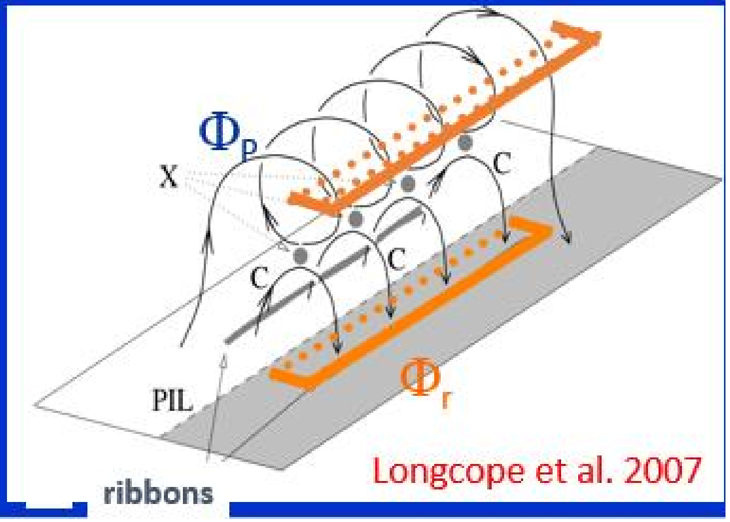
Fm N. Gopalswamy

CMEs

Background

- If CME flux ropes are formed during eruption, then the total reconnected (RC) flux (Φ_r) is same as the poloidal flux (Φ_p) of the resulting FR: $\Phi_r \approx \Phi_p$ (Longcope et al. 2007; Qiu et al. 2007; Hu et al. 2014; Gopalswamy et al. 2017)
- Φ_r can be computed using the photospheric B underlying cumulative ribbon area (Longcope et al. 2007; Qiu et al. 2007; Kazachenko et al. 2017)
- Φ_r can also be computed in a simpler way as half the flux underlying post eruption arcades (Gopalswamy et al. 2017)

- Coronal flux rope can be constructed using Φ_r and CME flux rope fit
- CME and flare properties closely related to Φ_r
- Coronal flux ropes can be tracked and compared with 1-au flux ropes



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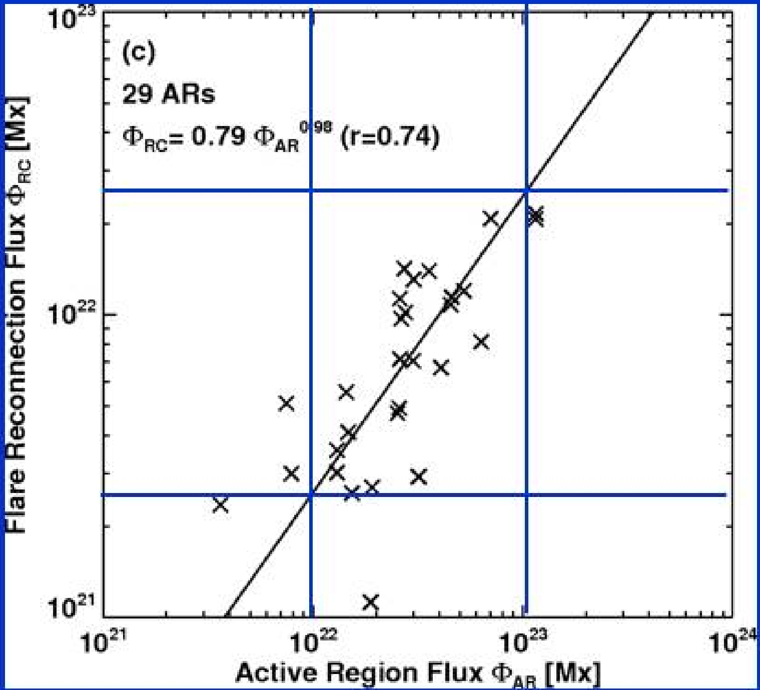
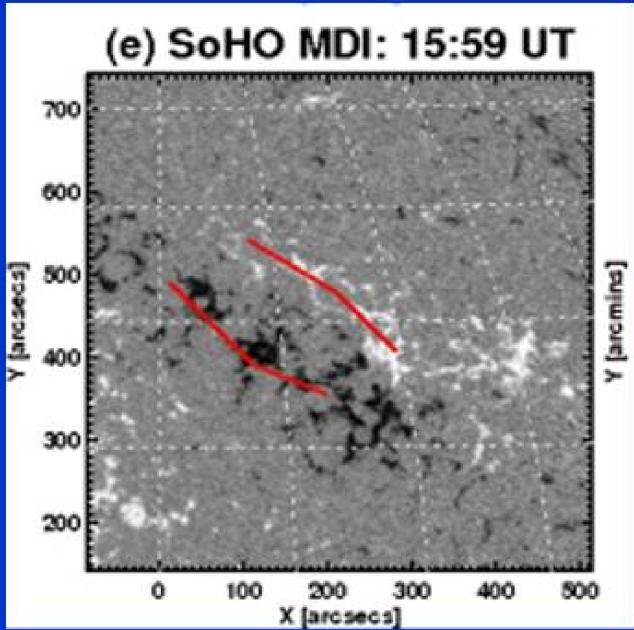
CMEs

AR Flux vs. RC Flux

About 28% of AR flux is reconnected in an eruption





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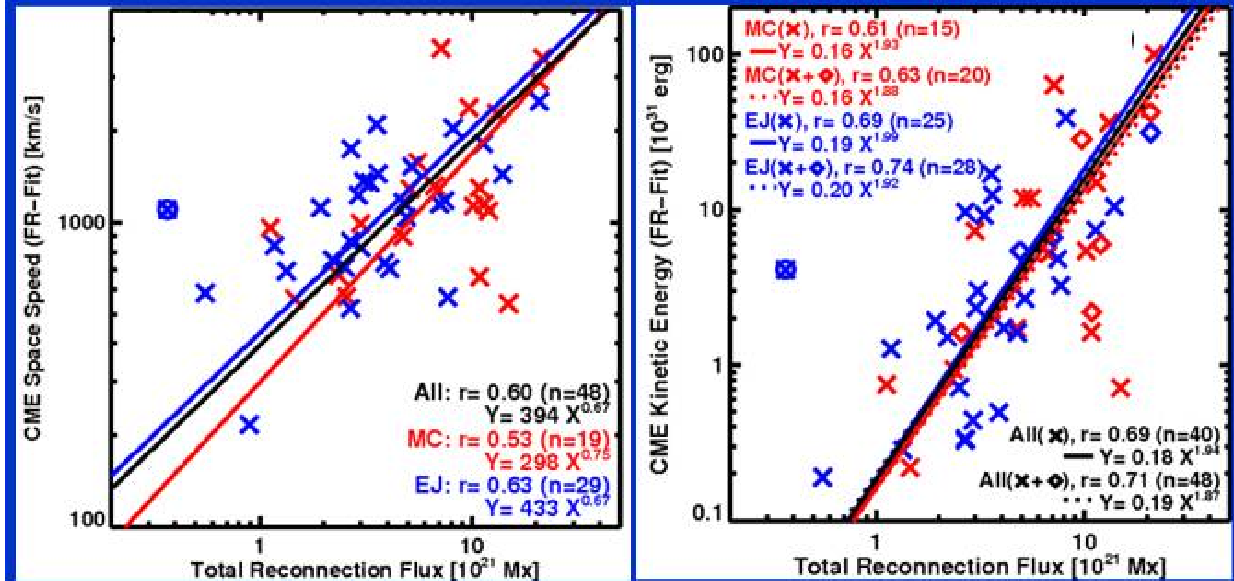
Fm N. Gopalswamy **CMEs**

CME Speed and Kinetic Energy



- Both speed and kinetic energy of the CMEs are well correlated with the RC Flux (r = 0.60, 0.69)
- The higher the RC Flux, the faster are the CMEs
- KE has the second highest correlation with RC flux (the highest was with soft X-ray flare fluence)
- True when the CMEs ended up as MCs or ejecta

One event (2000 October 2) was excluded from the correlations because the arcade was ill-defined.

Diamonds – no mass data, so 10^{16} g assumed

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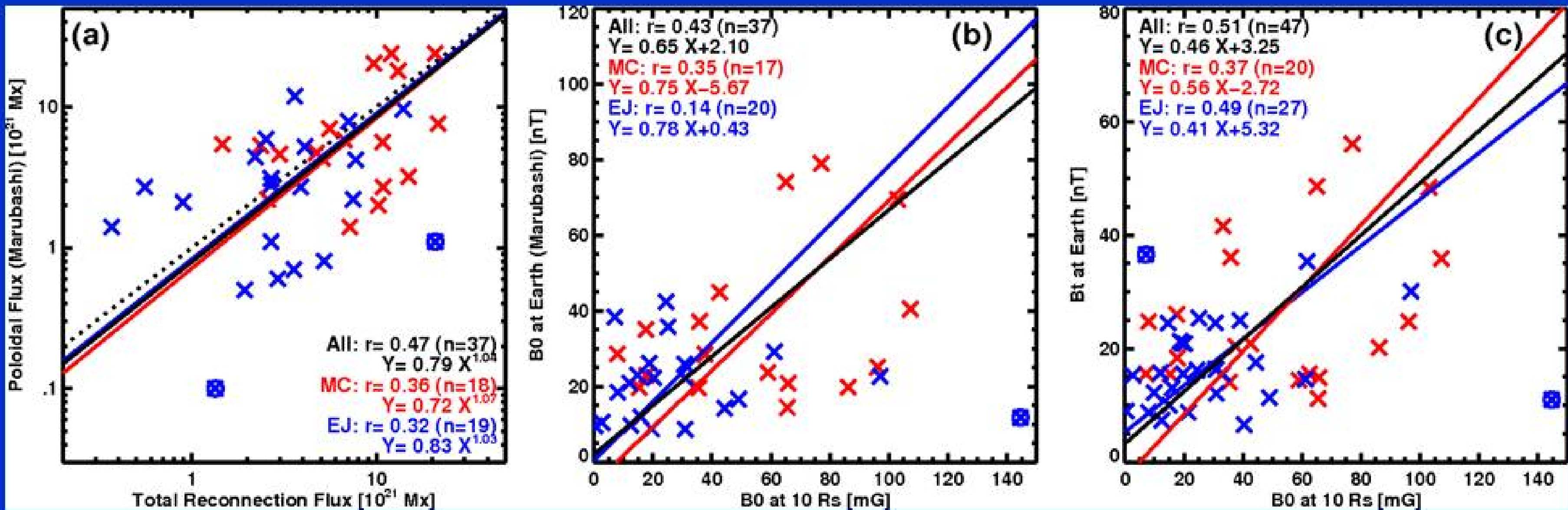
CMEs

FR Properties at 1 au and 10 Rs are Correlated



The relation between RC flux and ICME poloidal flux confirms previous results obtained just for MCs
The relation between the axial field at the Sun obtained from eruption data and that from flux rope fit agree quite well; the correlation is better when actual peak ICME field is used.

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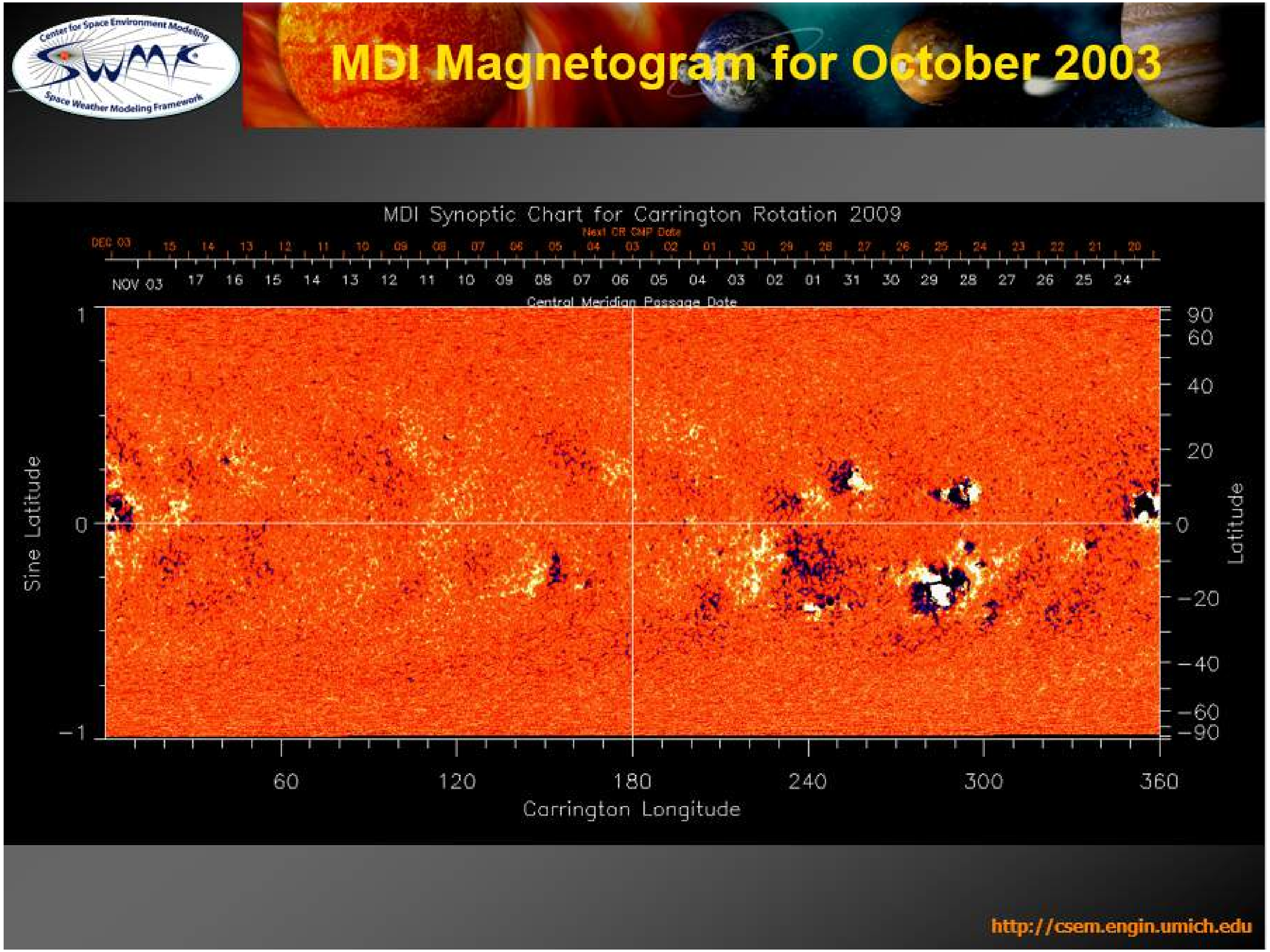
Fm Ward (Chip) Manchester **CMEs**



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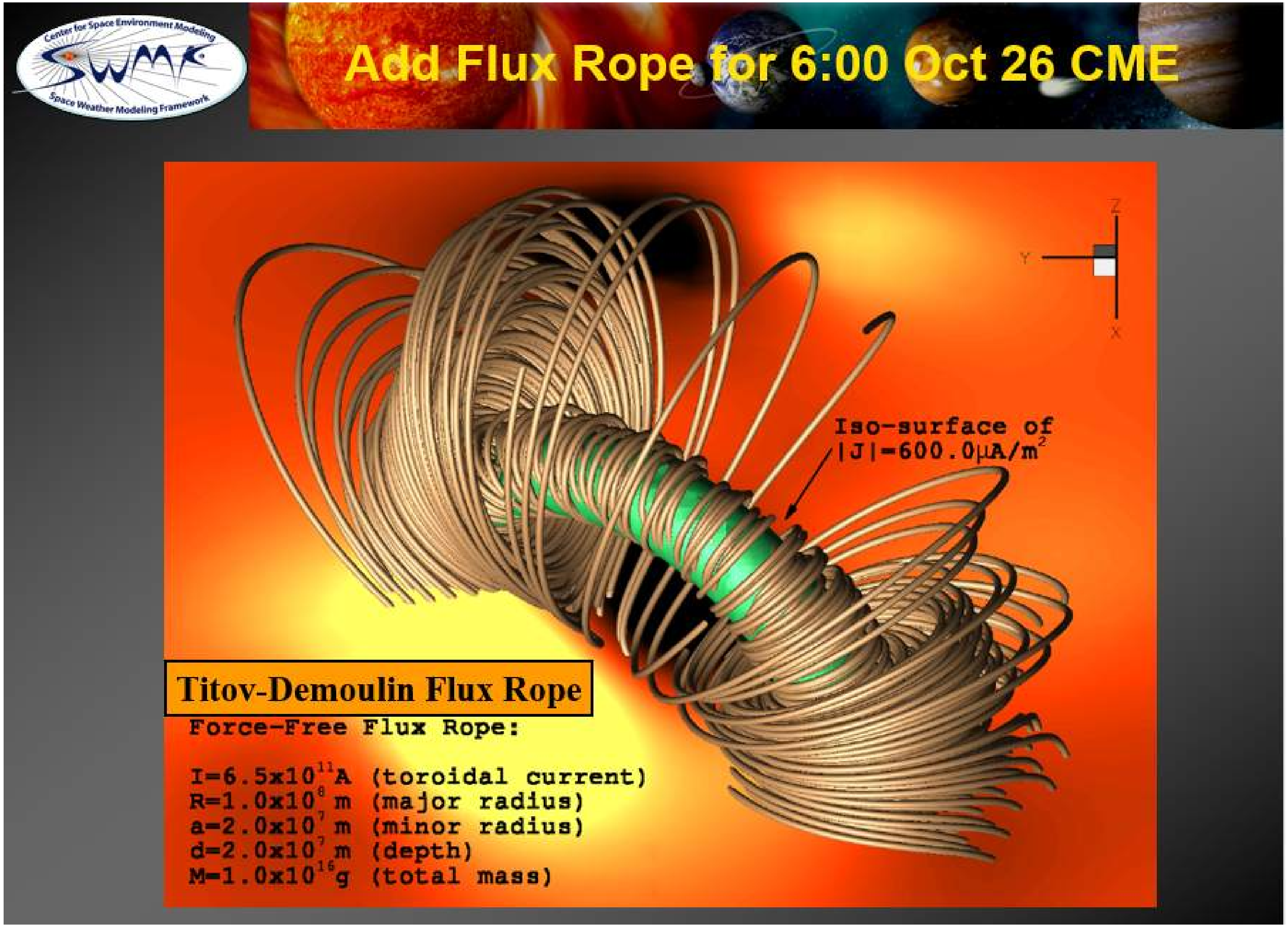

Different Techniques for Measurement of Bz

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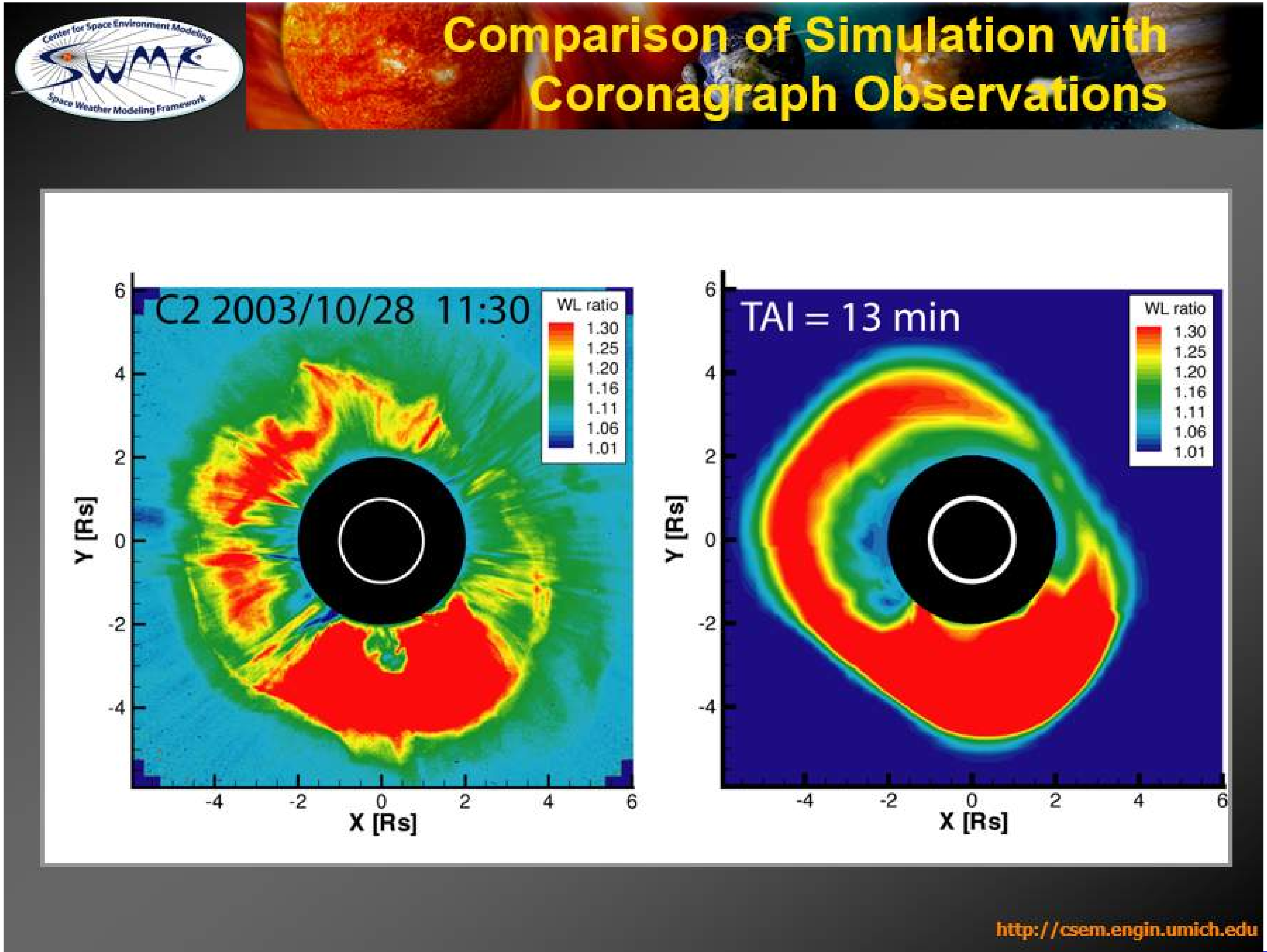

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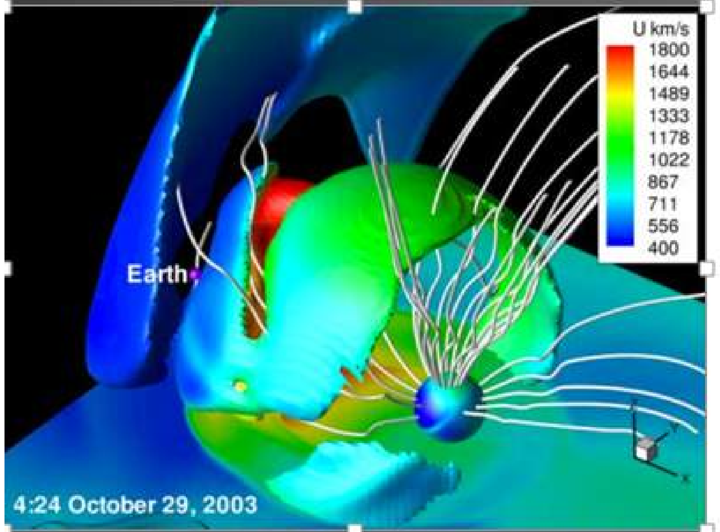
Fm Ward (Chip) Manchester **CMEs**

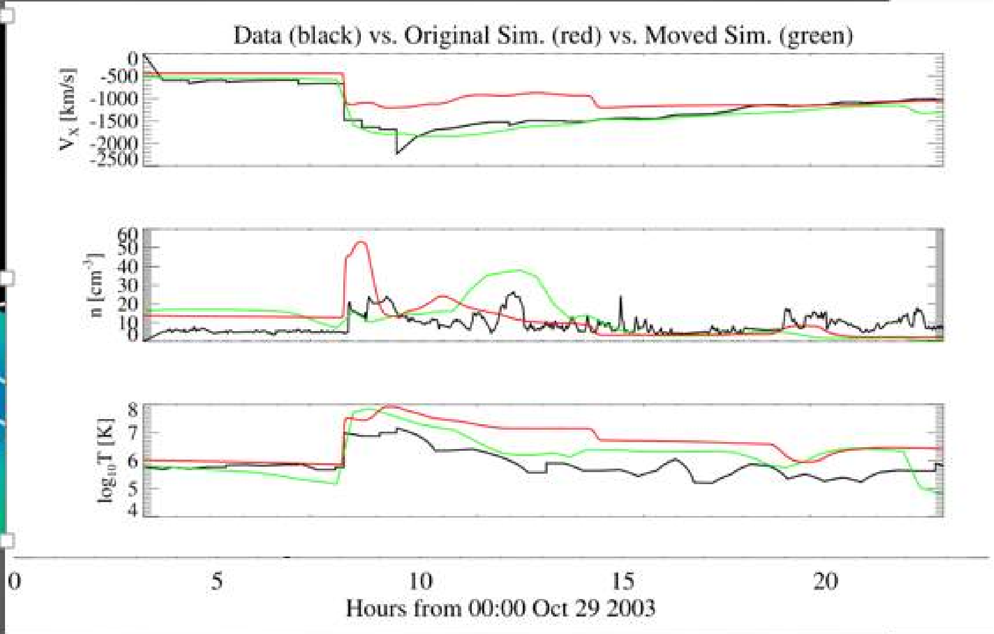
Center for Space Environment Modeling — SWMF Space Weather Modeling Framework

2003 Oct 28th CME Simulation

CME Simulation with the AWSoM Model:

- Titov-Demoulin flux rope erupts from active region 10486
- The simulation velocity is close but densities are too high.
- Arrival time shifted only 1.8 and 3.4 hours to match observations
- Green line shifted 9 degrees eastward





Toth et al. 2007
Manchester et al. 2008

http://csem.engin.umich.edu

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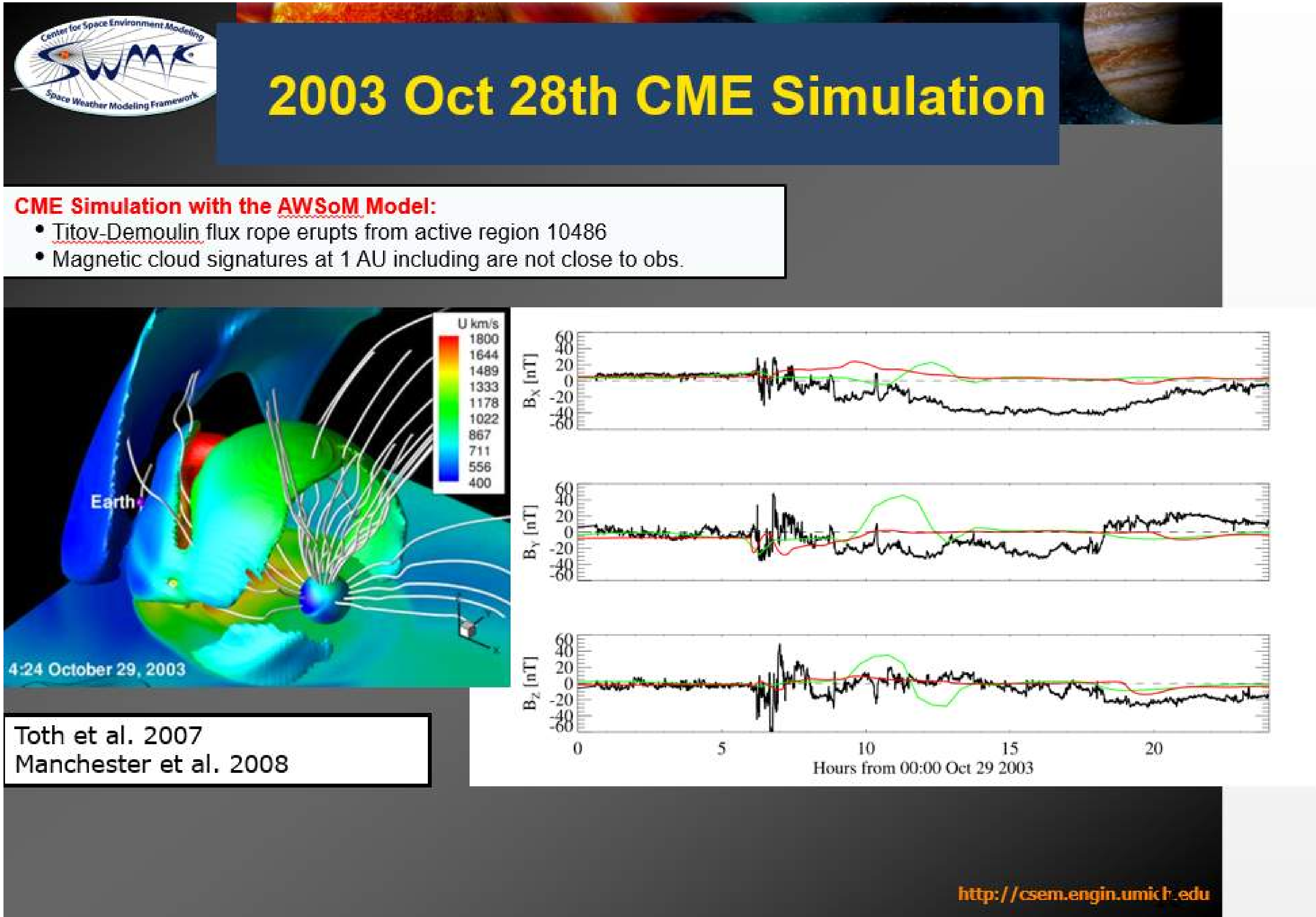

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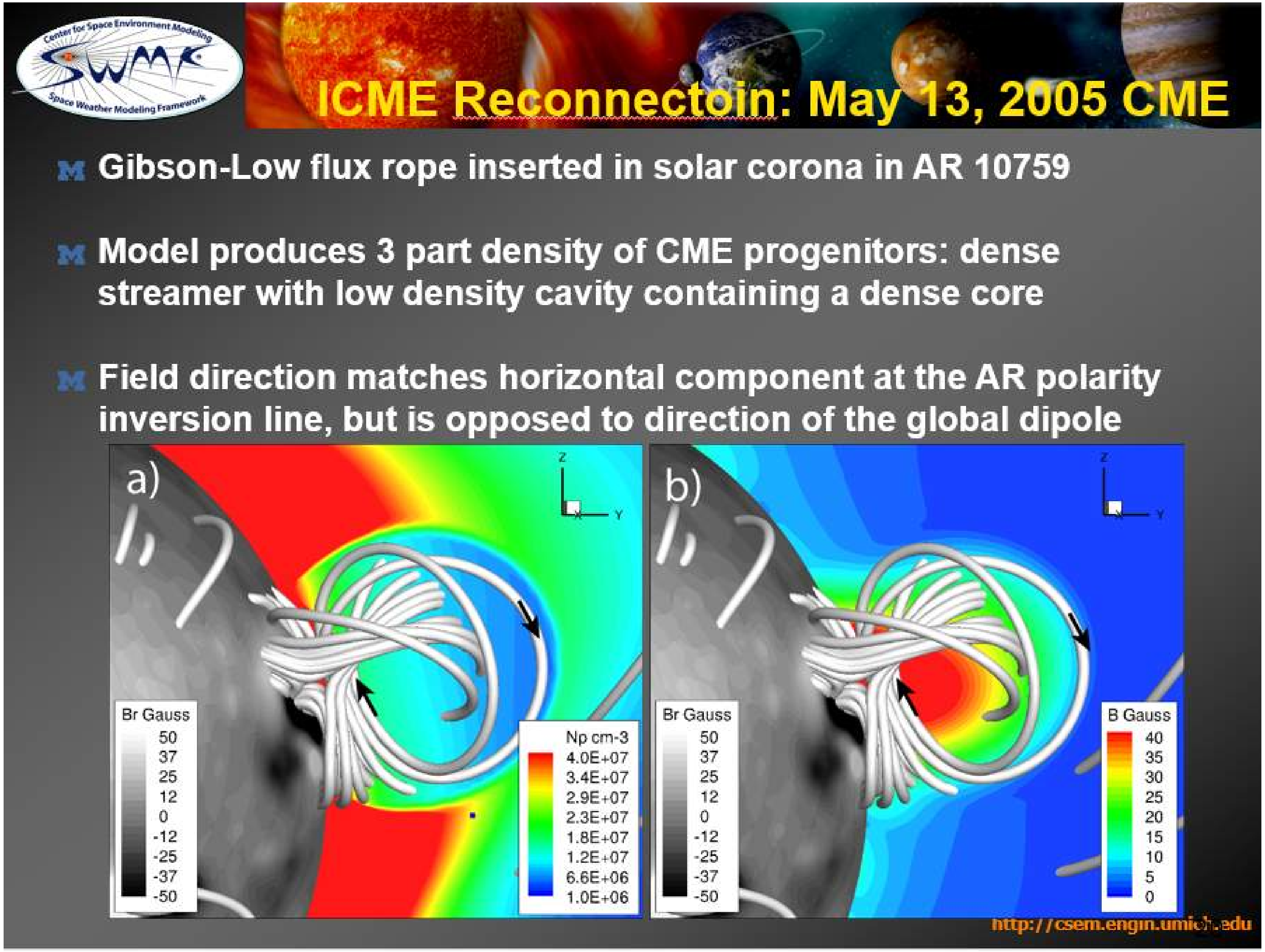

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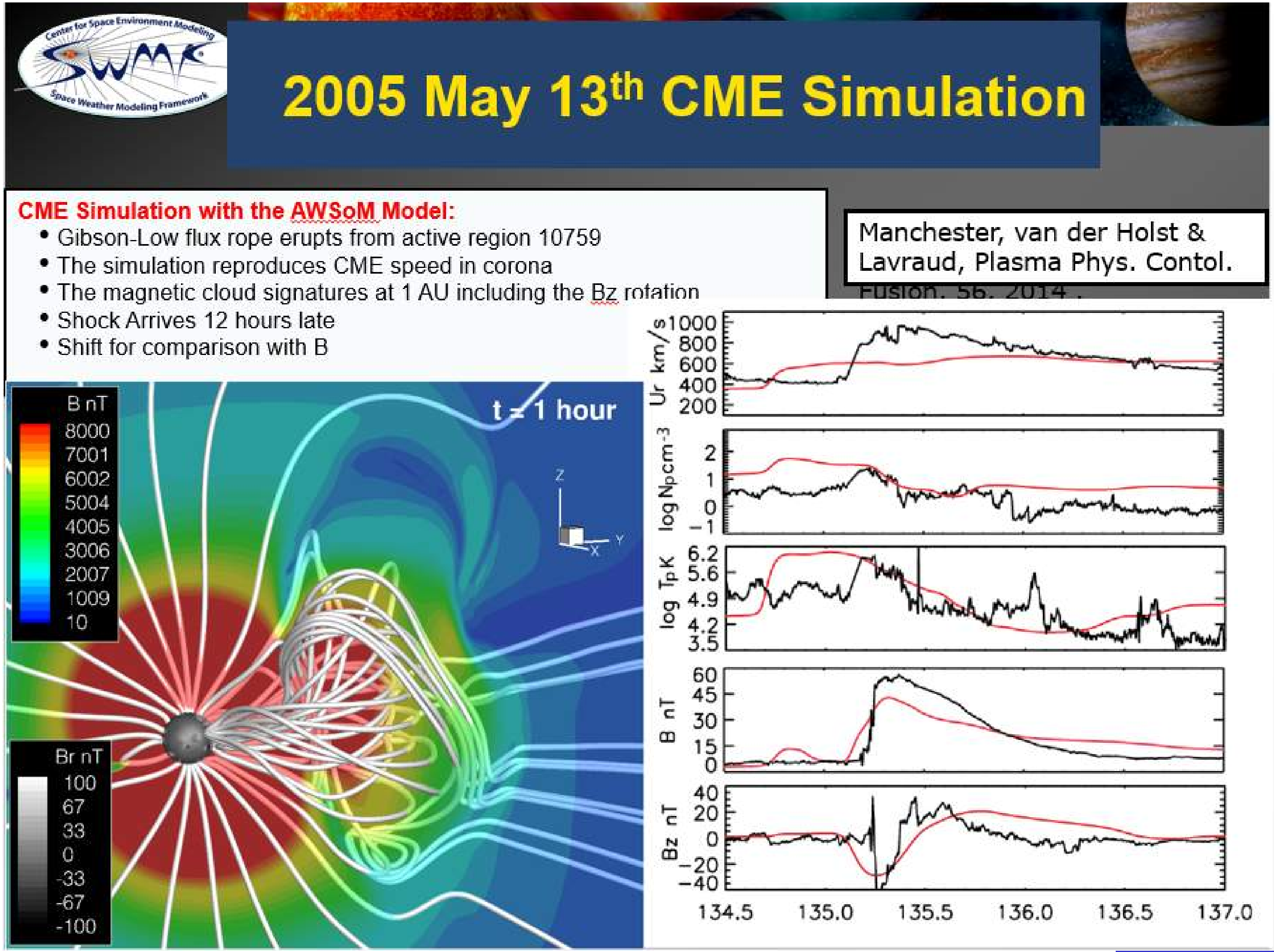

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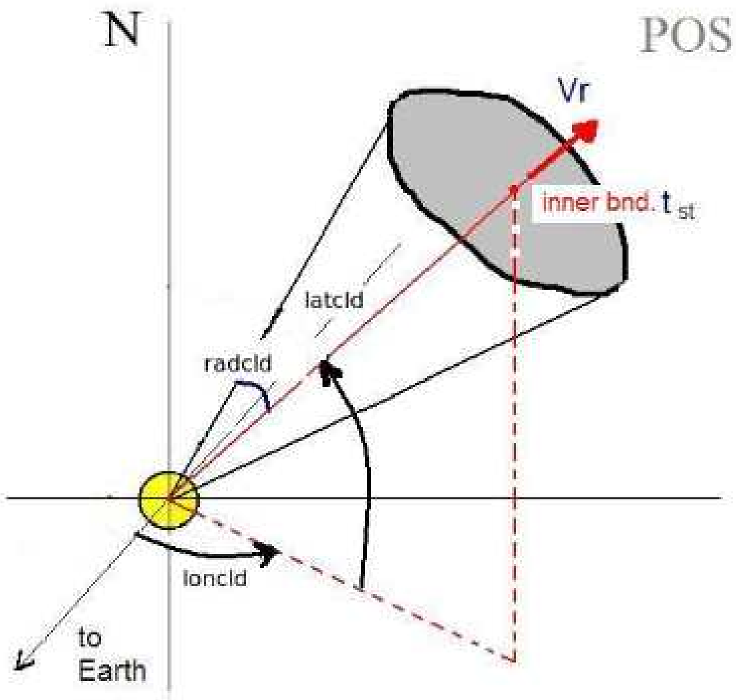
M. L. Mays & A. Taktakishvili

CMEs

Cone model parameters



Input to ENLIL cone model run

- time when cloud is at 21.5 Rs
- Latitude
- Longitude
- half-width
- Vr - radial velocity

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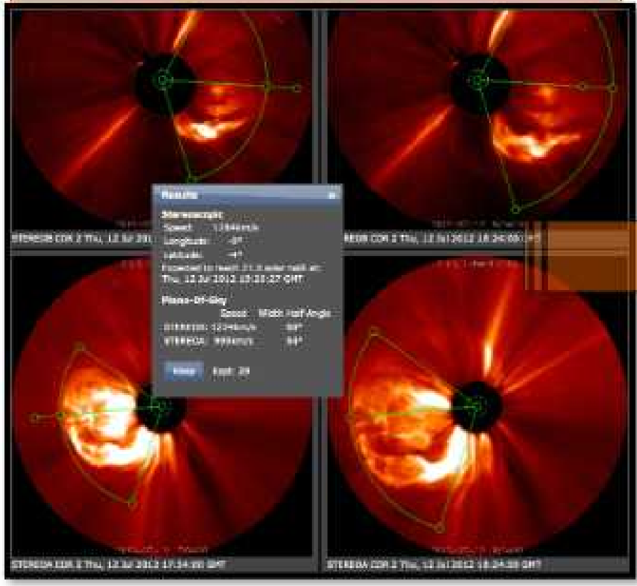
M. L. Mays & A. Taktakishvili

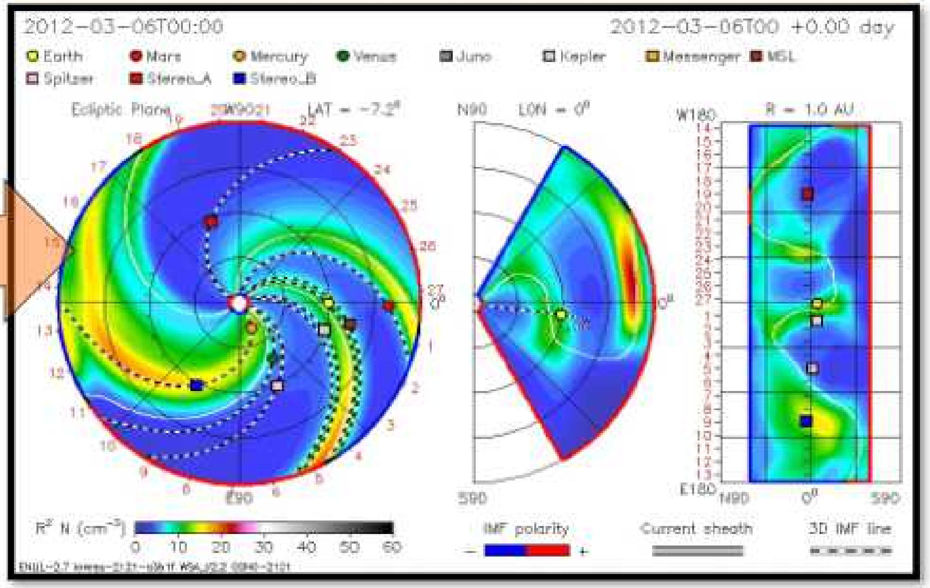
CMEs

WSA-ENLIL Cone Model

Parameters Defined with CCMC CME Triangulation Tool



CME Parameters: Input To WSA-ENLIL Cone Model



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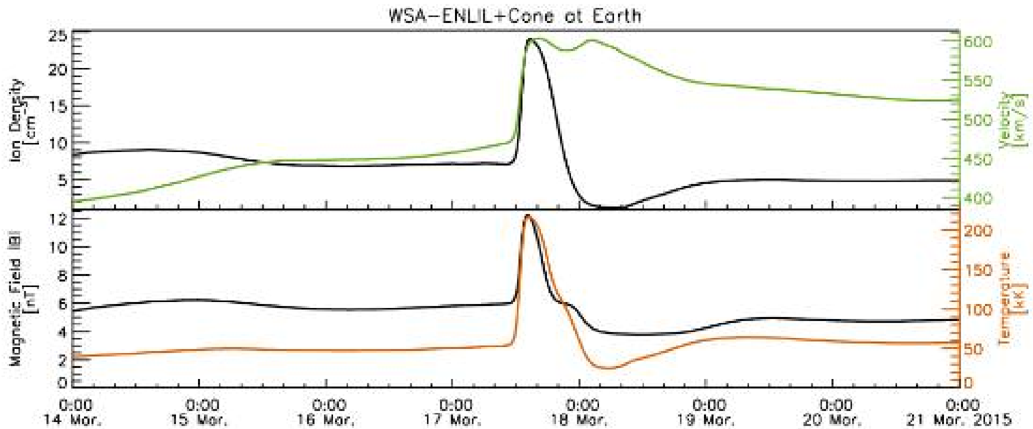
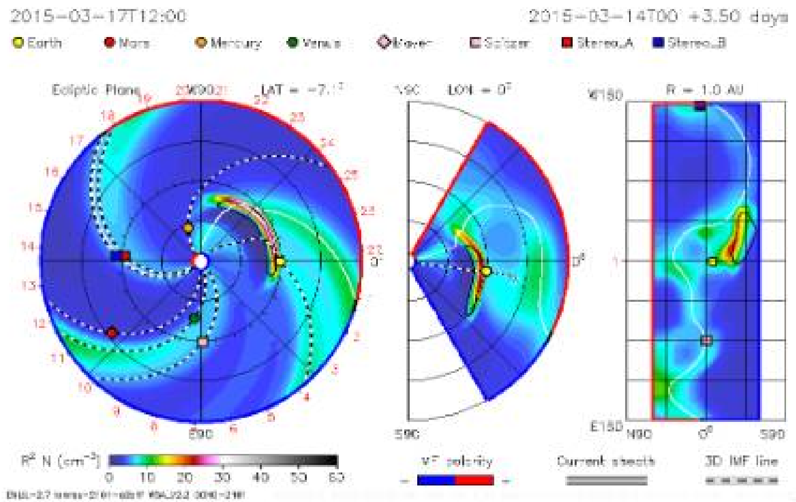
M. L. Mays & A. Taktakishvili **CMEs**

Determination of the CME Arrival Time – clear arrival



Timing and Field Amplitude sometimes good *(state of the art)*



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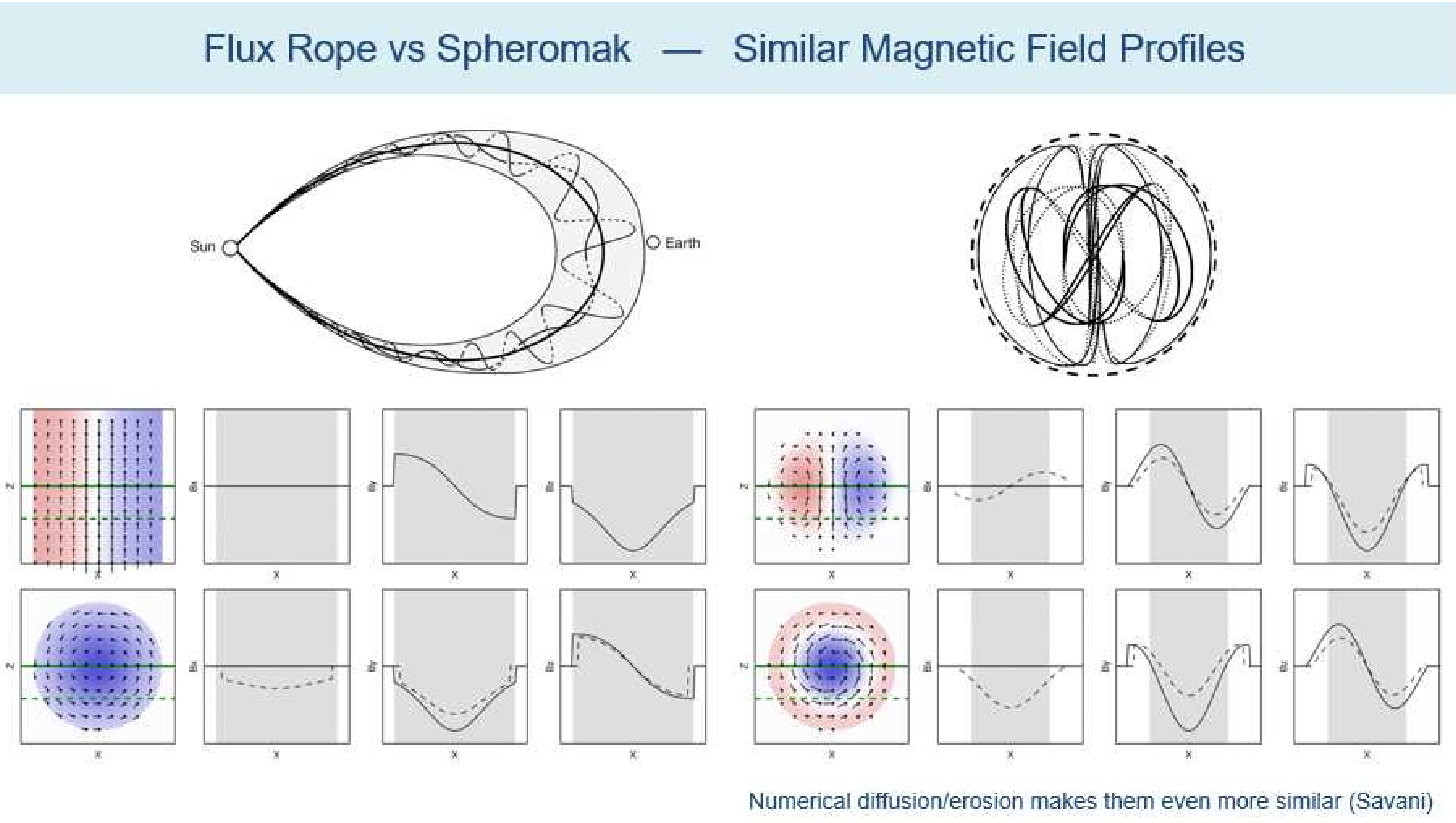
Different Techniques for Measurement of Bz

Fm Dusan Odstrcil

CMEs



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Simulated CME Events

date (yyyy-mm-dd)	2010-04-03	2012-07-12	2013-07-09
time (hh:mm)	15:00	16:54	15:09
lat (deg)	-25	-13	2
lon (deg)	0	6	-10
rmajor (deg)	40	55	40
vcld (km/s)	812	830	500
tilt (deg)	330	280	315
bcav (nT)	2500	3000	2500
hcav (-1 | 1)	1	1	-1
ncld (2 | 3)	2	2	2
dcld (x/dfast)	1	1	1
tcld (x/tfast)	1	1	1
radcav (x/rmajor)	0.8	0.8	0.8
dcav (x/dfast)	1	1	1
tcav (x/tfast)	1	1	1

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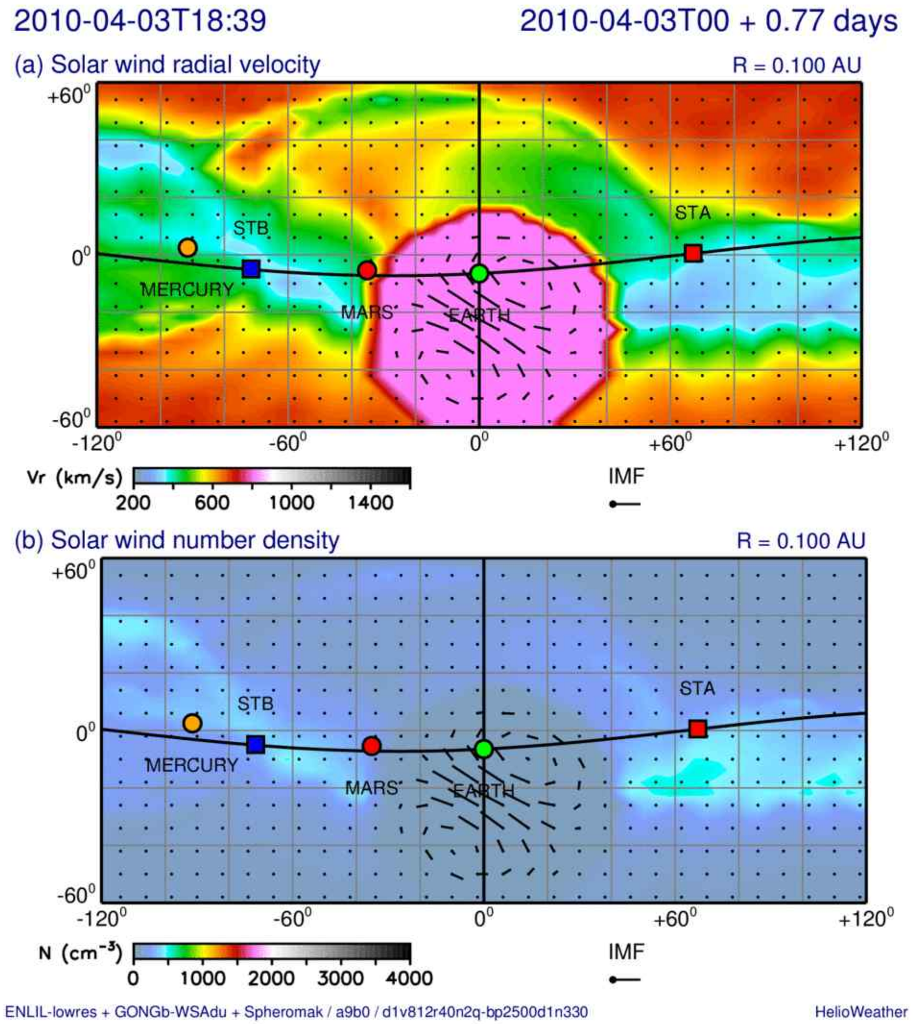
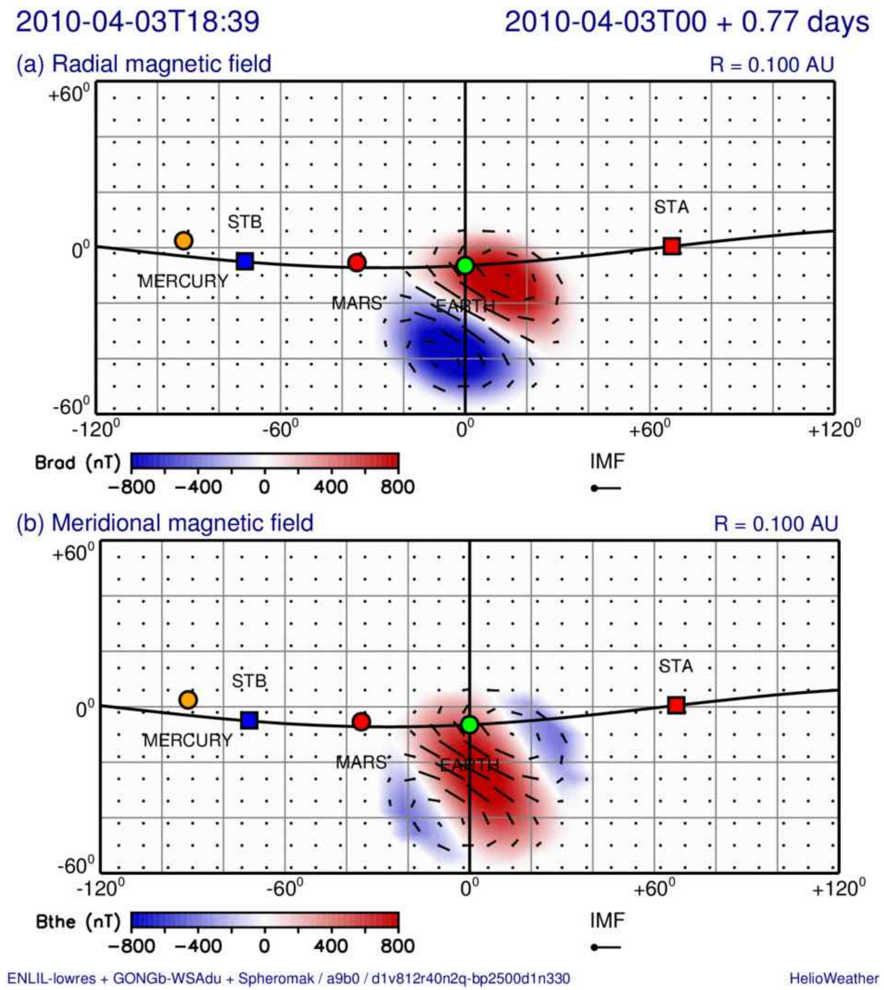
CMEs

CME Event 2010-04-03 — Boundary Conditions





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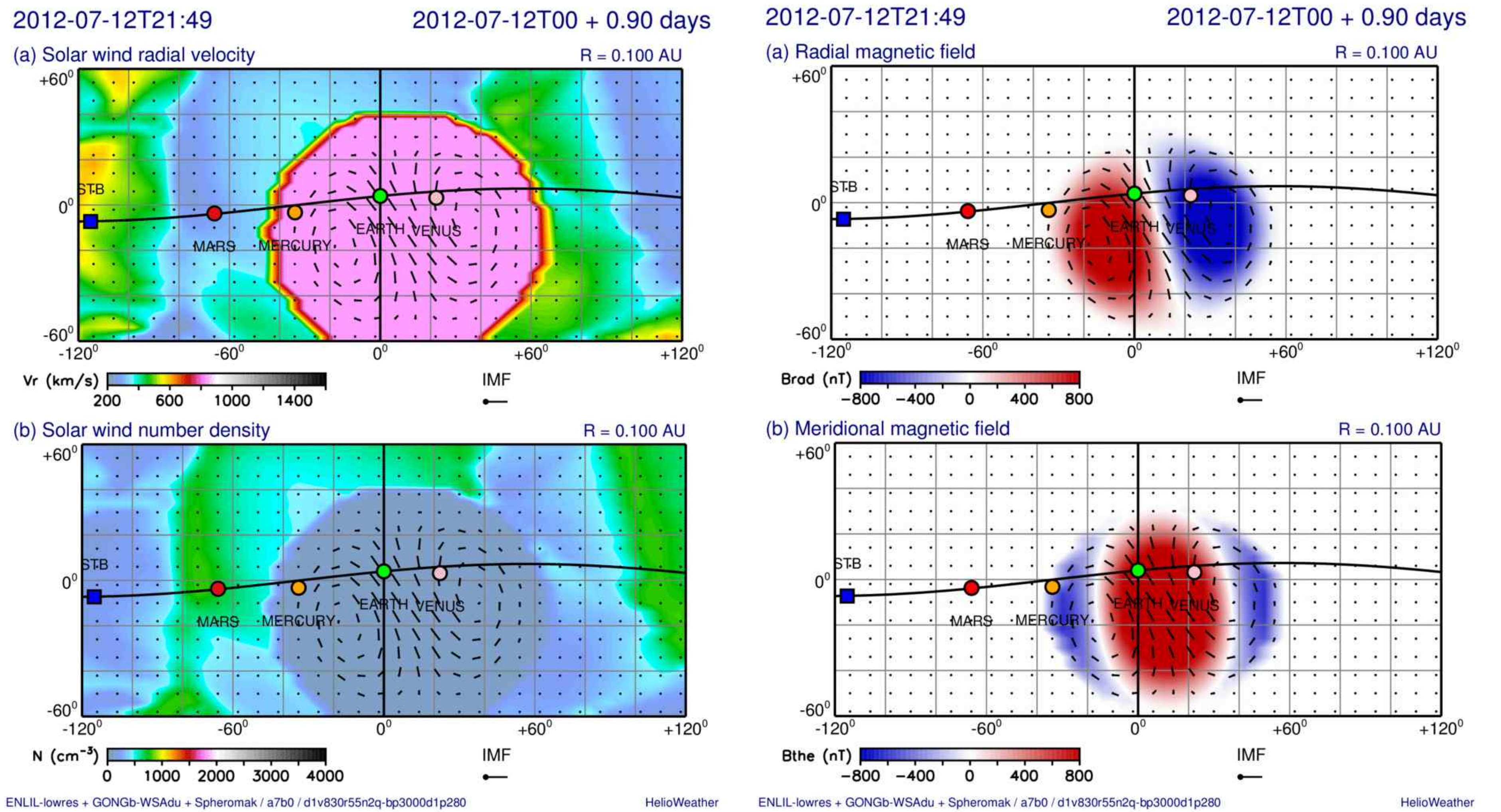
CME Event 2012-07-12 — Boundary Conditions



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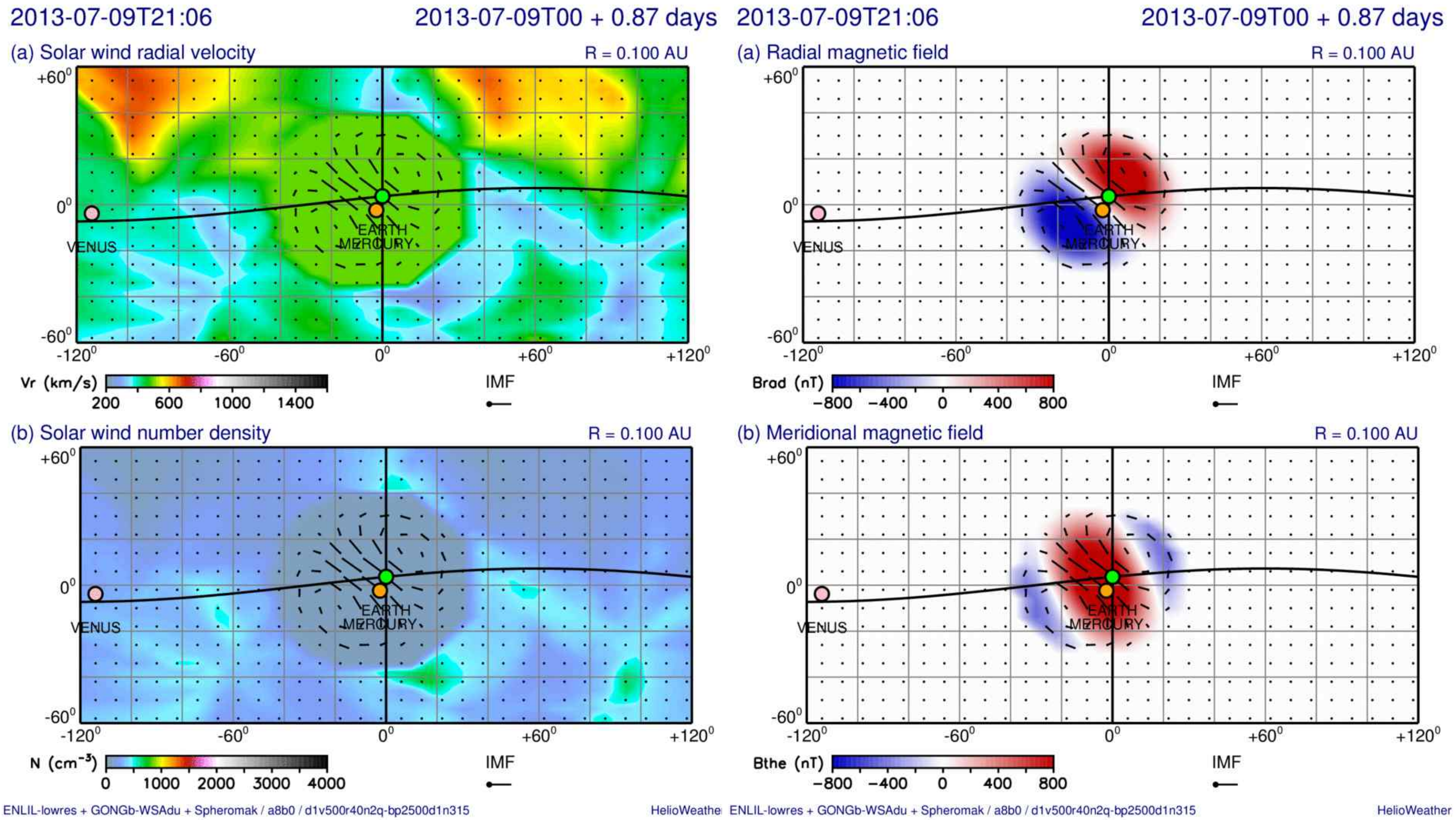
CME Event 2013-07-09 — Boundary Changes



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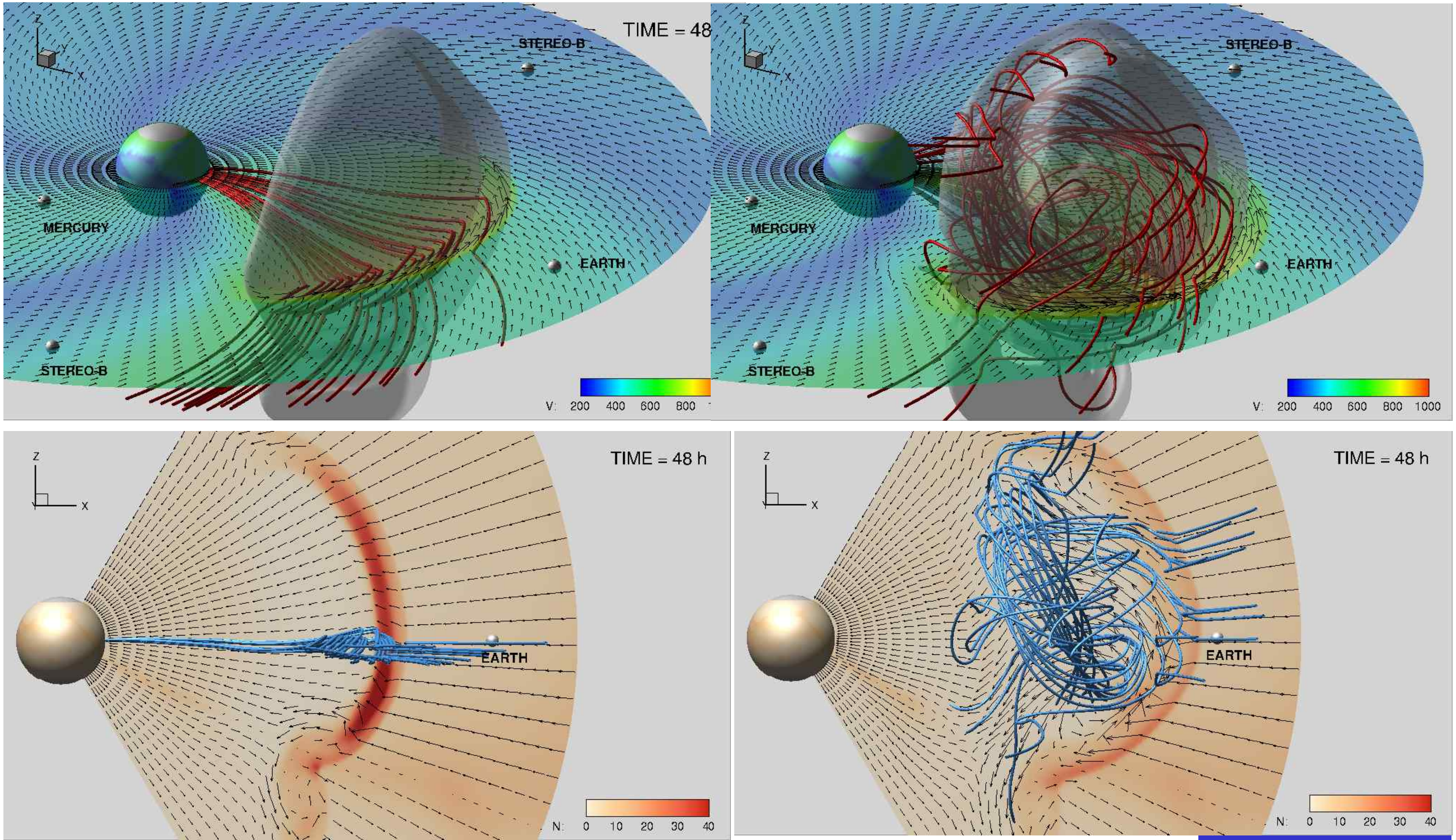
CMEs

2010-04-03 CME — “Cone” vs “Spheromak”



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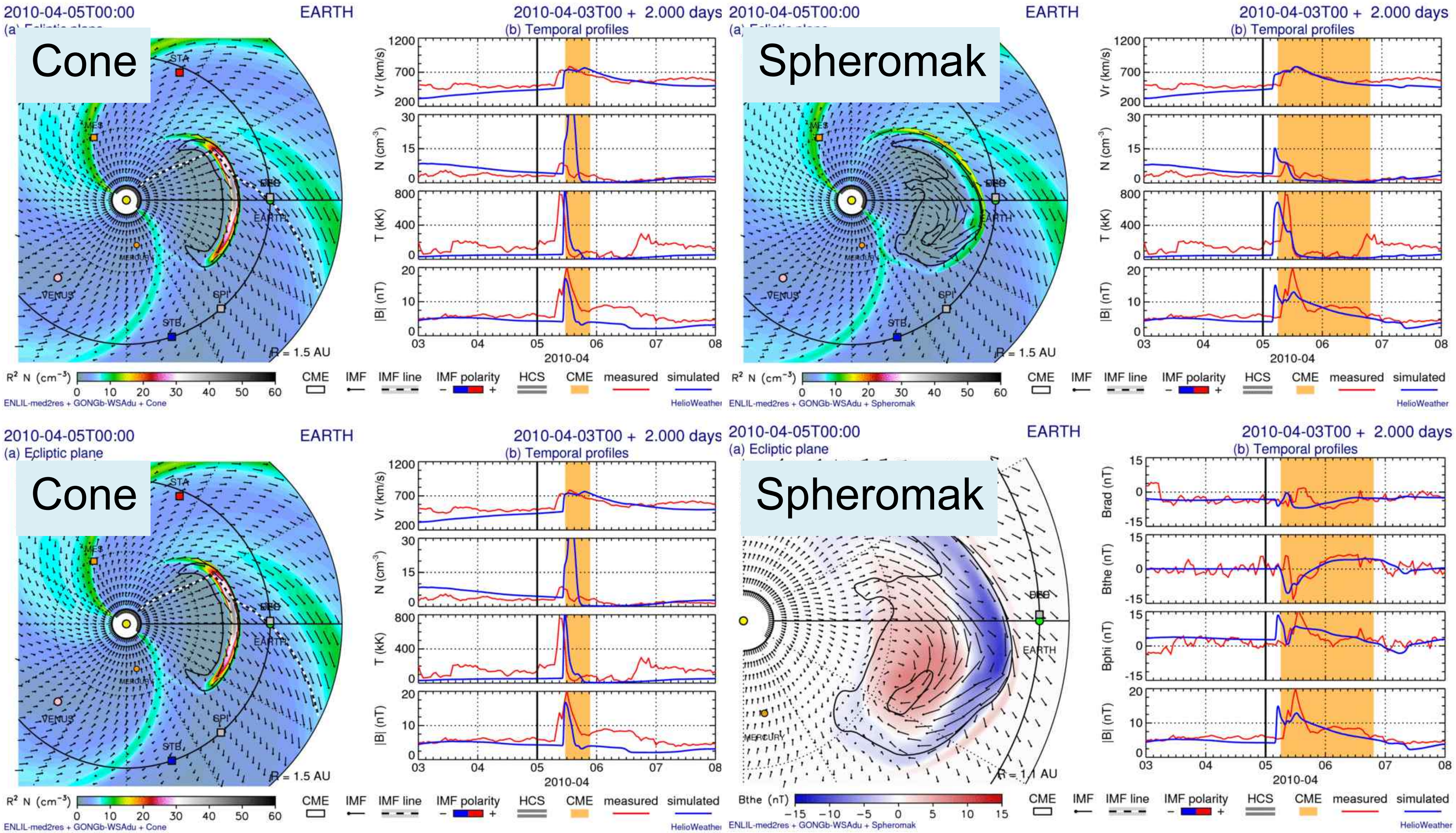
CMEs

2010-04-03 CME — “Cone” vs “Spheromak” density



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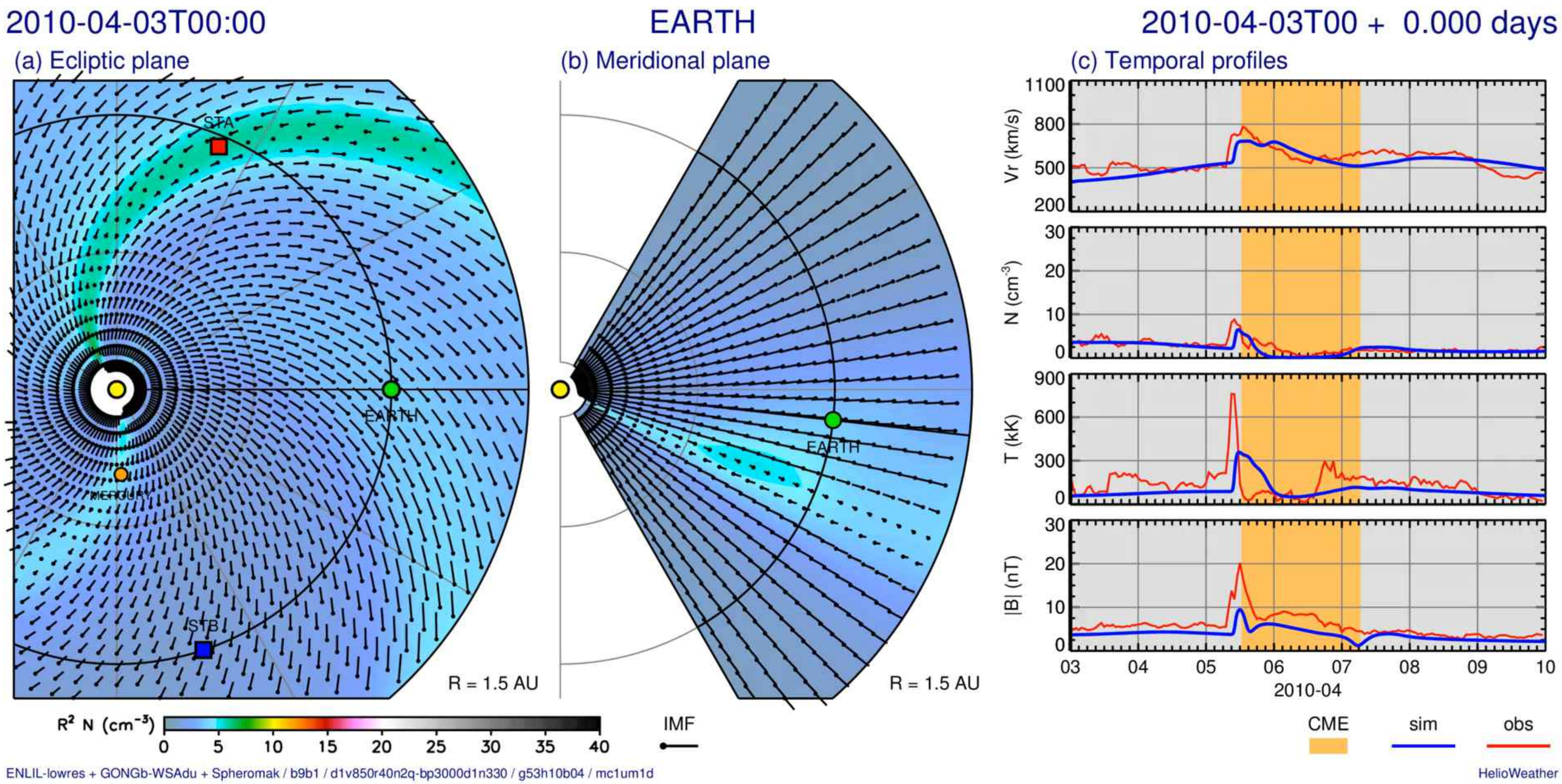
CMEs



Density

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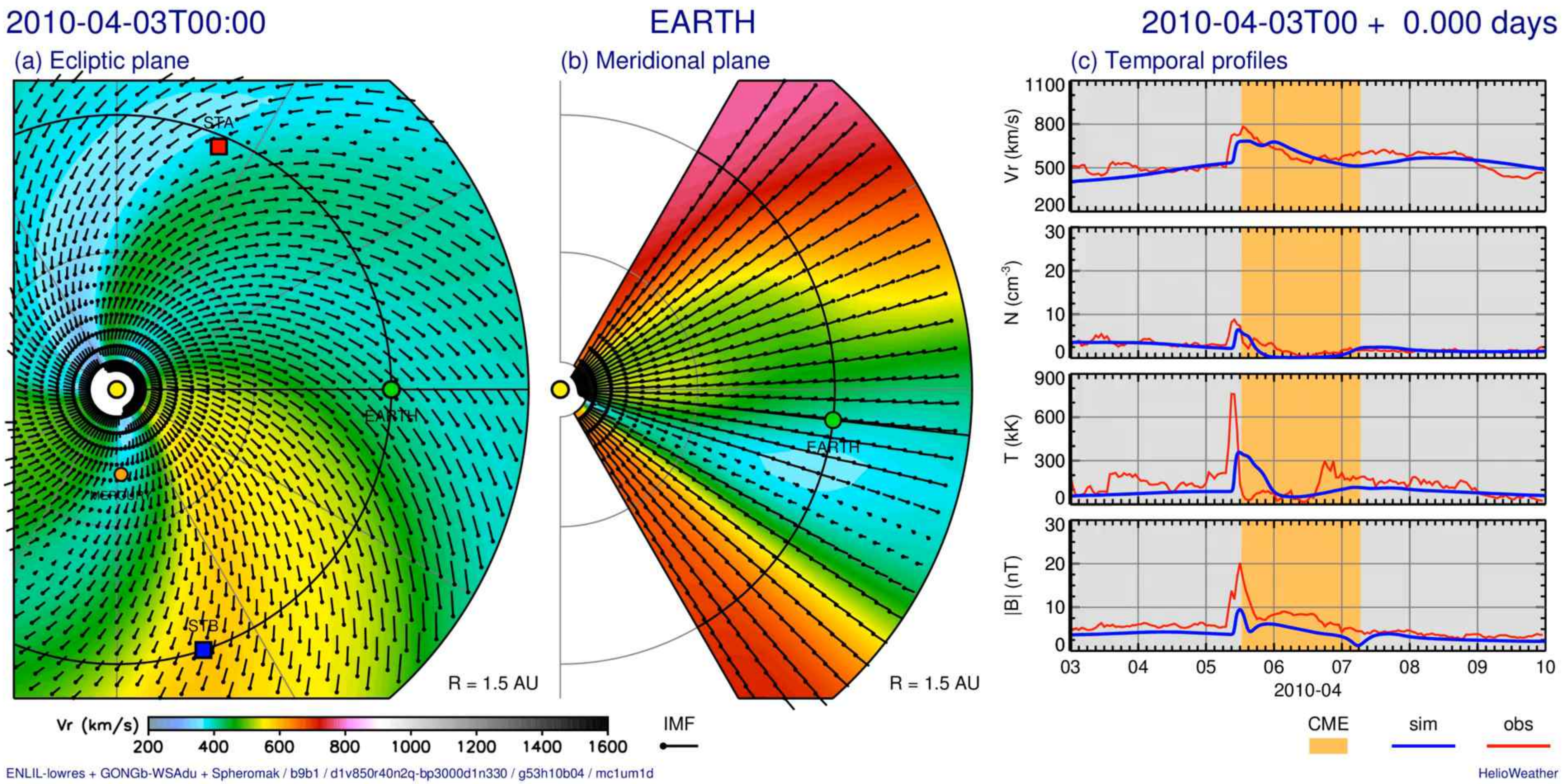

Velocity

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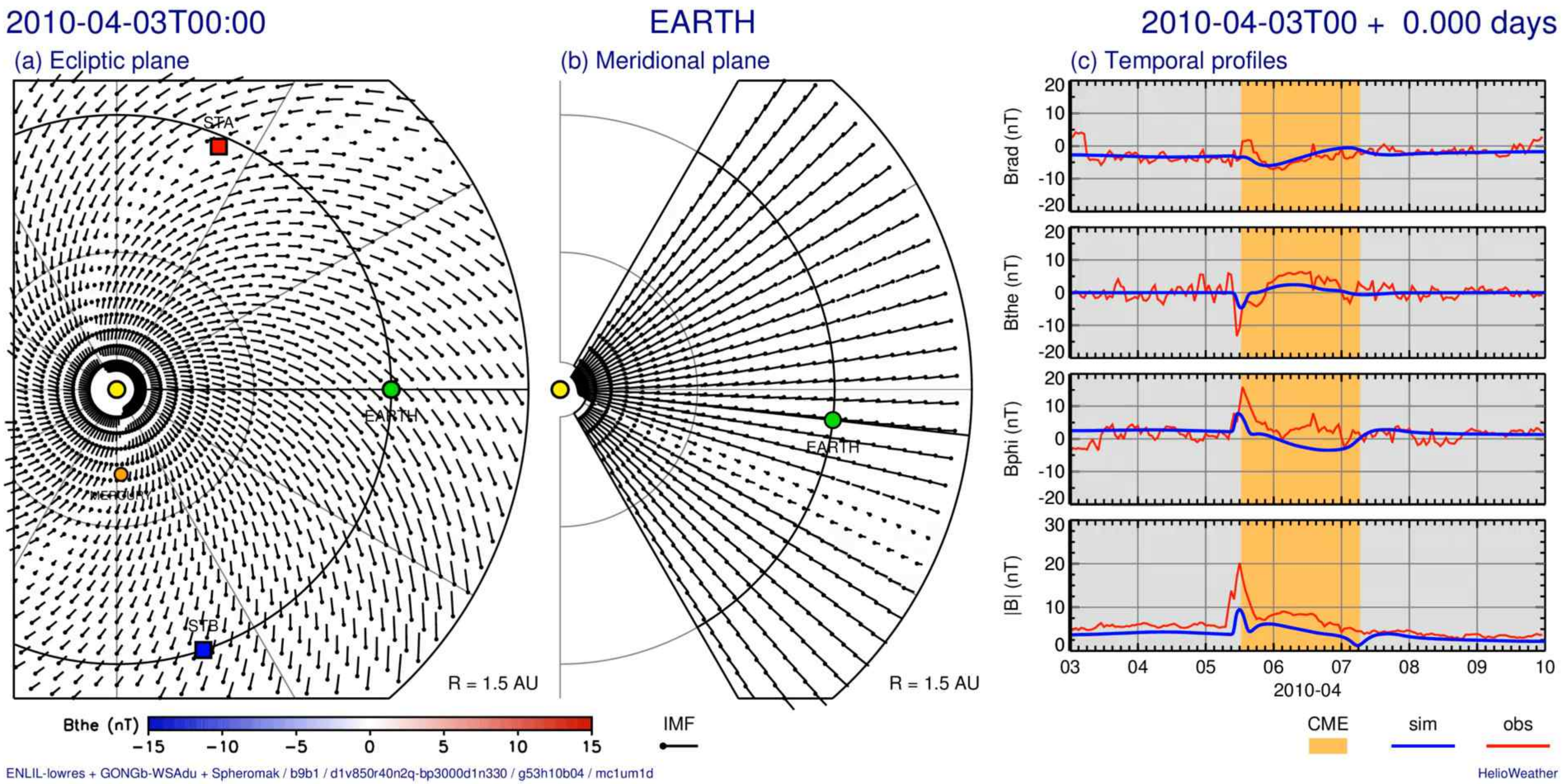
CMEs



Magnetic Field B_θ

Different Techniques for Measurement of Bz

Heliospheric Remote Sensing

IPS Heliospheric Analyses ISEE (STELab)

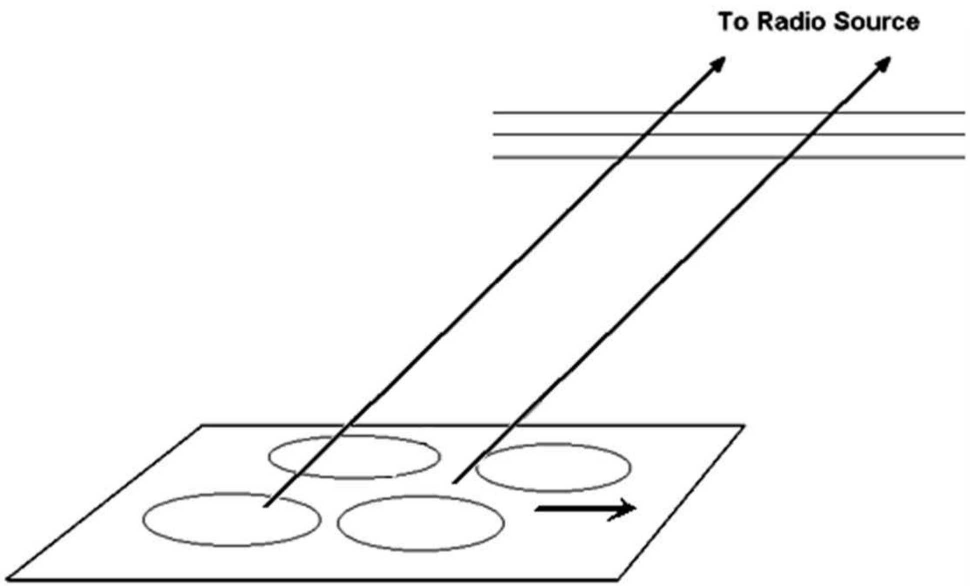
ISEE IPS array near Mt. Fuji

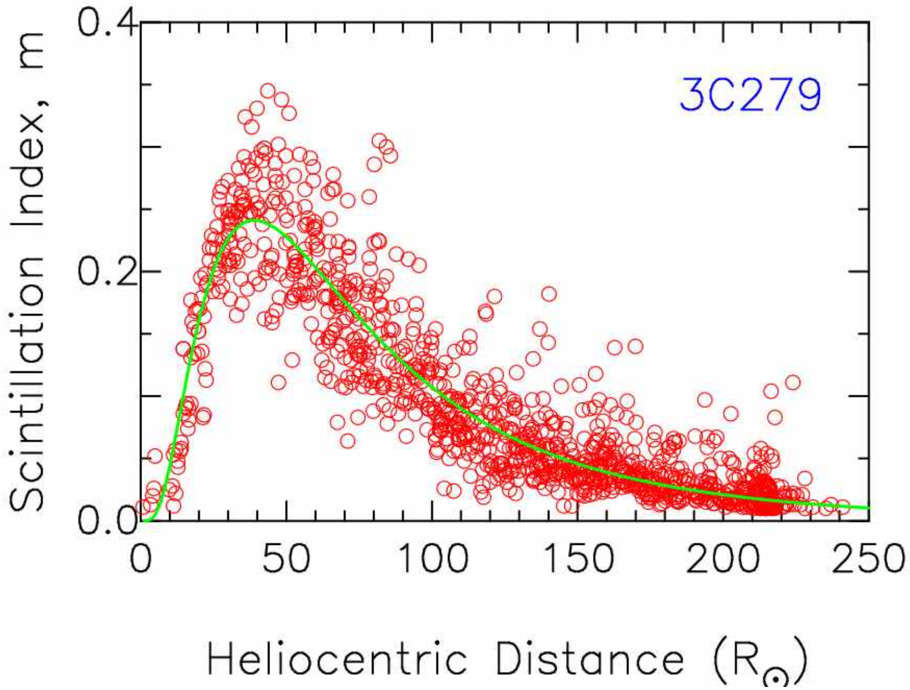
ISEE IPS array systems

Different Techniques for Measurement of Bz

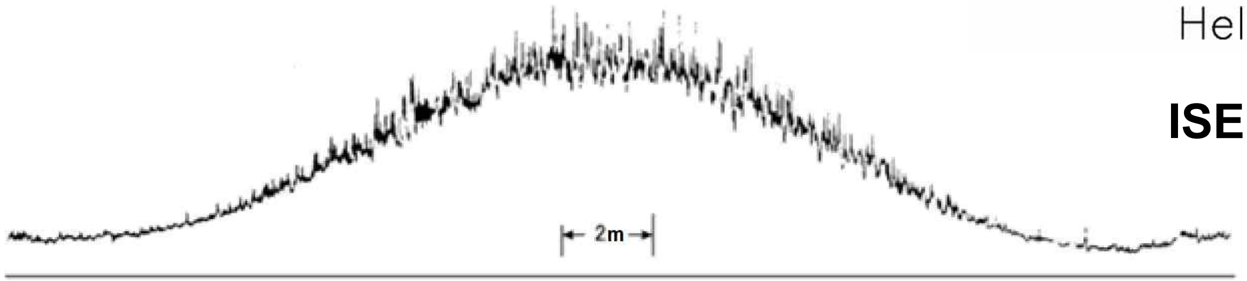
Heliospheric Remote Sensing

IPS Heliospheric Analyses ISEE (STELab)





IPS line-of-sight response



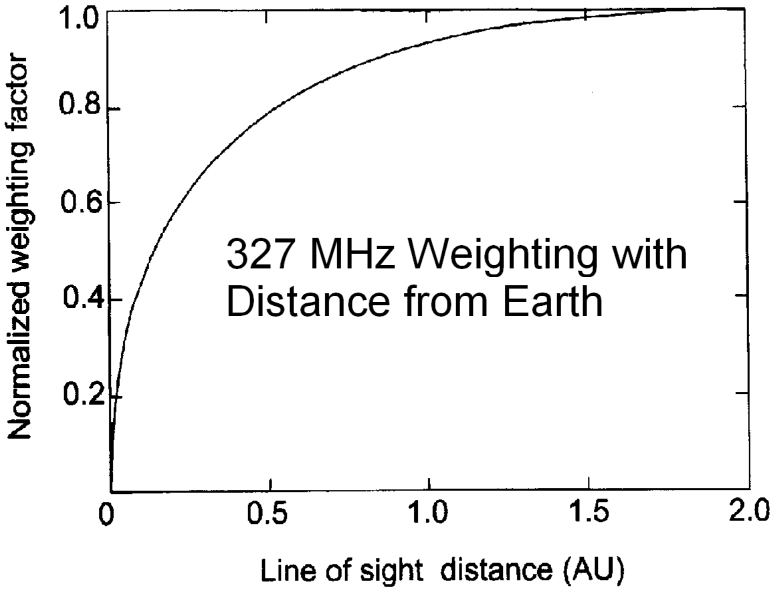
ISEE IPS array systems

Different Techniques for Measurement of Bz

Heliospheric Remote Sensing

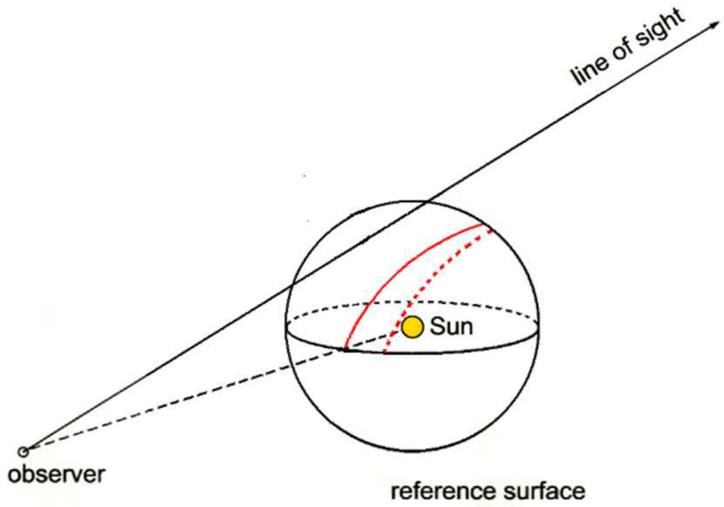
IPS line-of-sight response

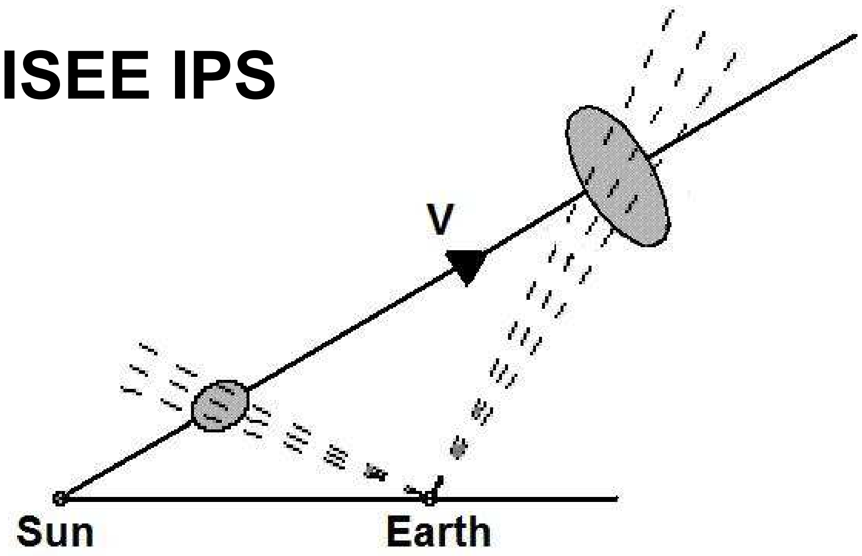
Jackson, B.V., *et al*., 2008, *Adv. in Geosciences,* 21, 339-360.



Heliospheric C.A.T. analyses: example line-of-sight distribution for each sky location to form the source surface of the 3D reconstruction.

ISEE IPS





Sample outward motion over time

Different Techniques for Measurement of Bz

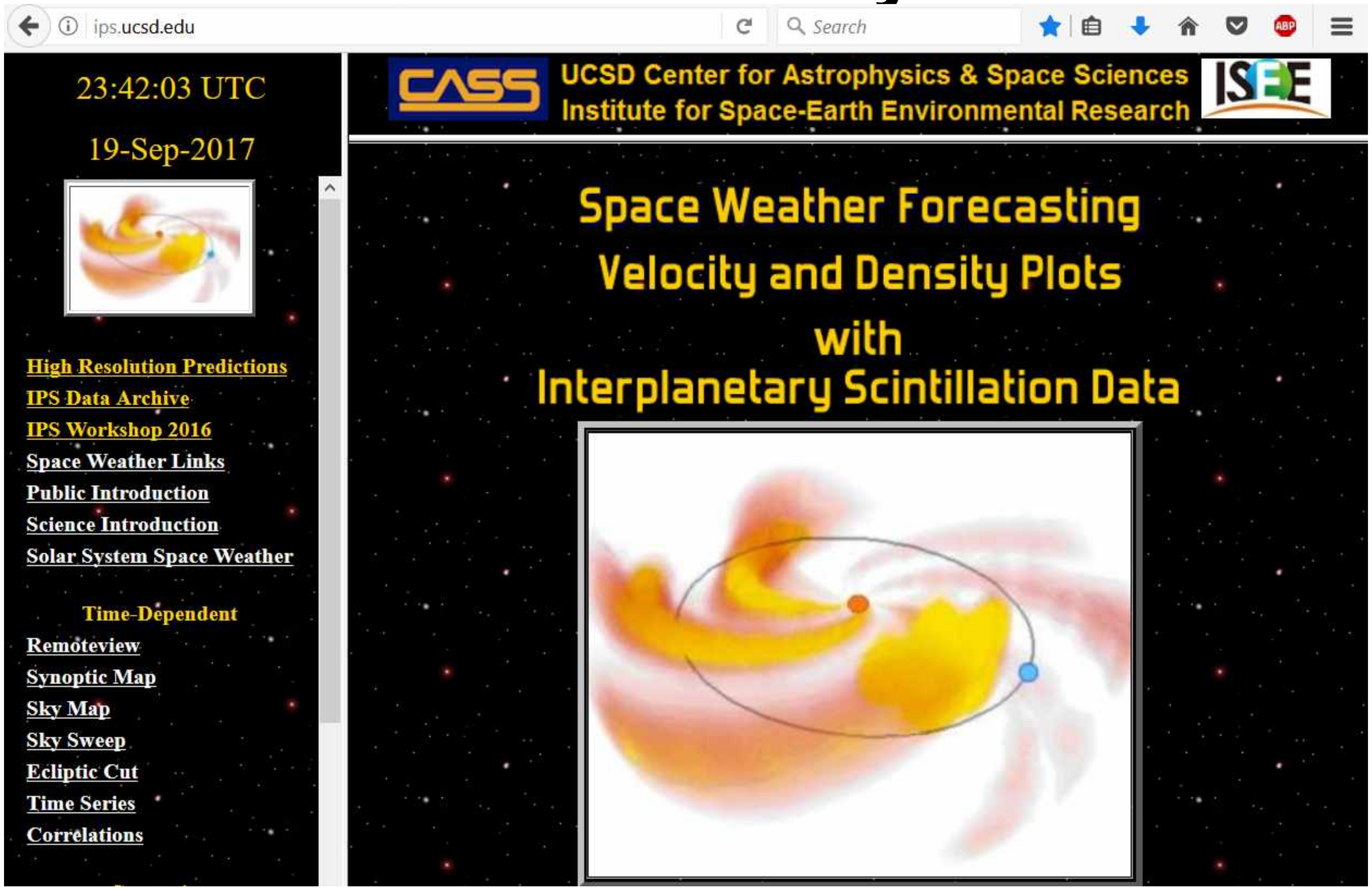
Heliospheric Remote Sensing

Jackson, B.V., *et al*., 2011, *Adv. in Geosciences,* 30, 93-115.

http://ips.ucsd.edu/ or http://ips.ucsd.edu/ips_workshop_2016/

UCSD Prediction Analyses

UCSD Web pages



Web analysis runs "automatically" using Linux on a P.C.

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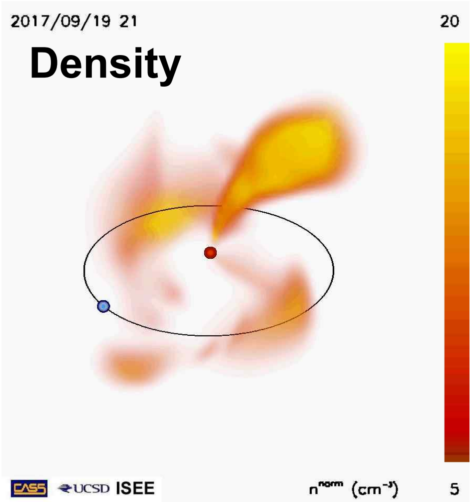
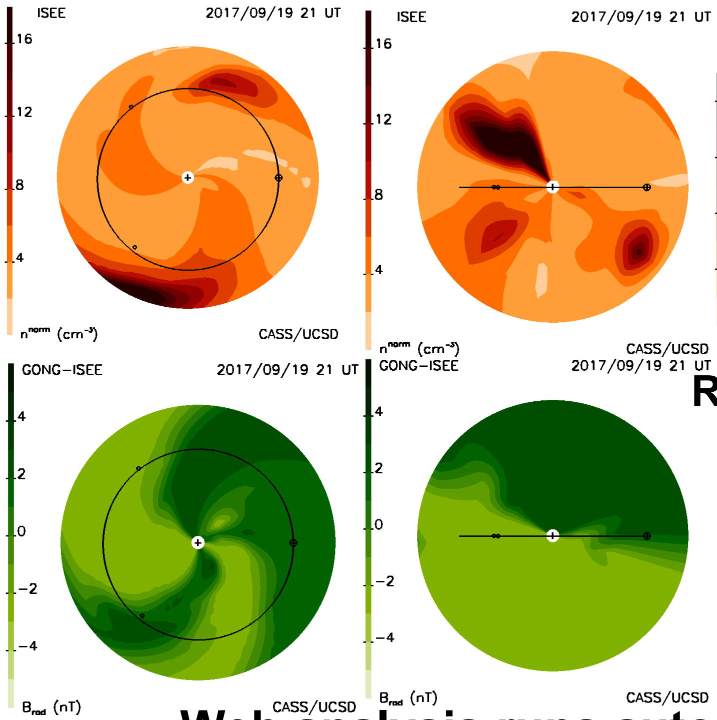
Heliospheric Remote Sensing



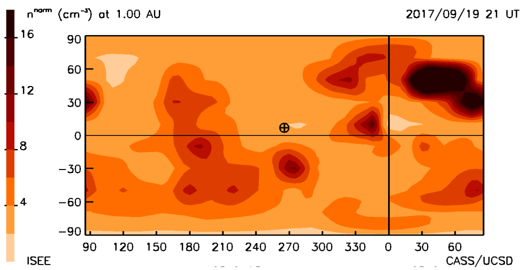
UCSD Prediction

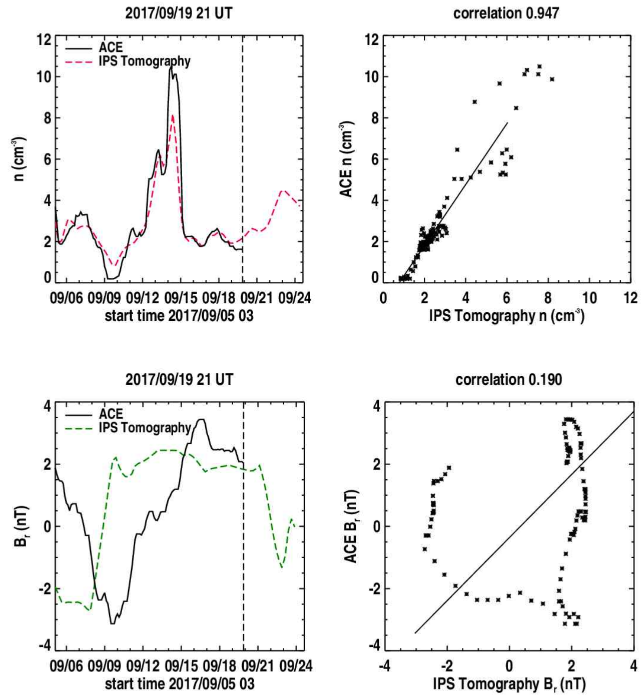
(http://ips.ucsd.edu/high_resolution_predictions)

Today's 21 UT Analysis from ISEE

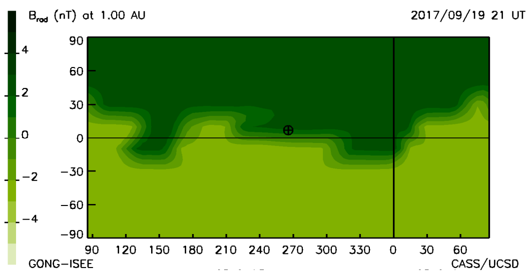


Density (n/cm³)





Radial Magnetic Field (nT)



Web analysis runs automatically using Linux on a P.C.

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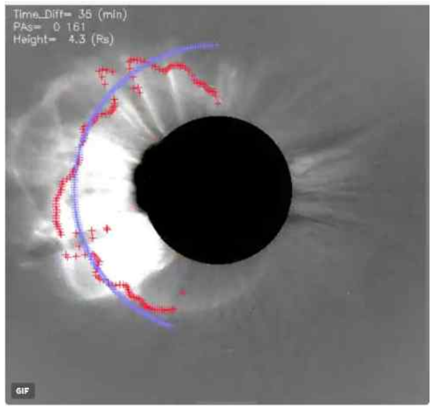
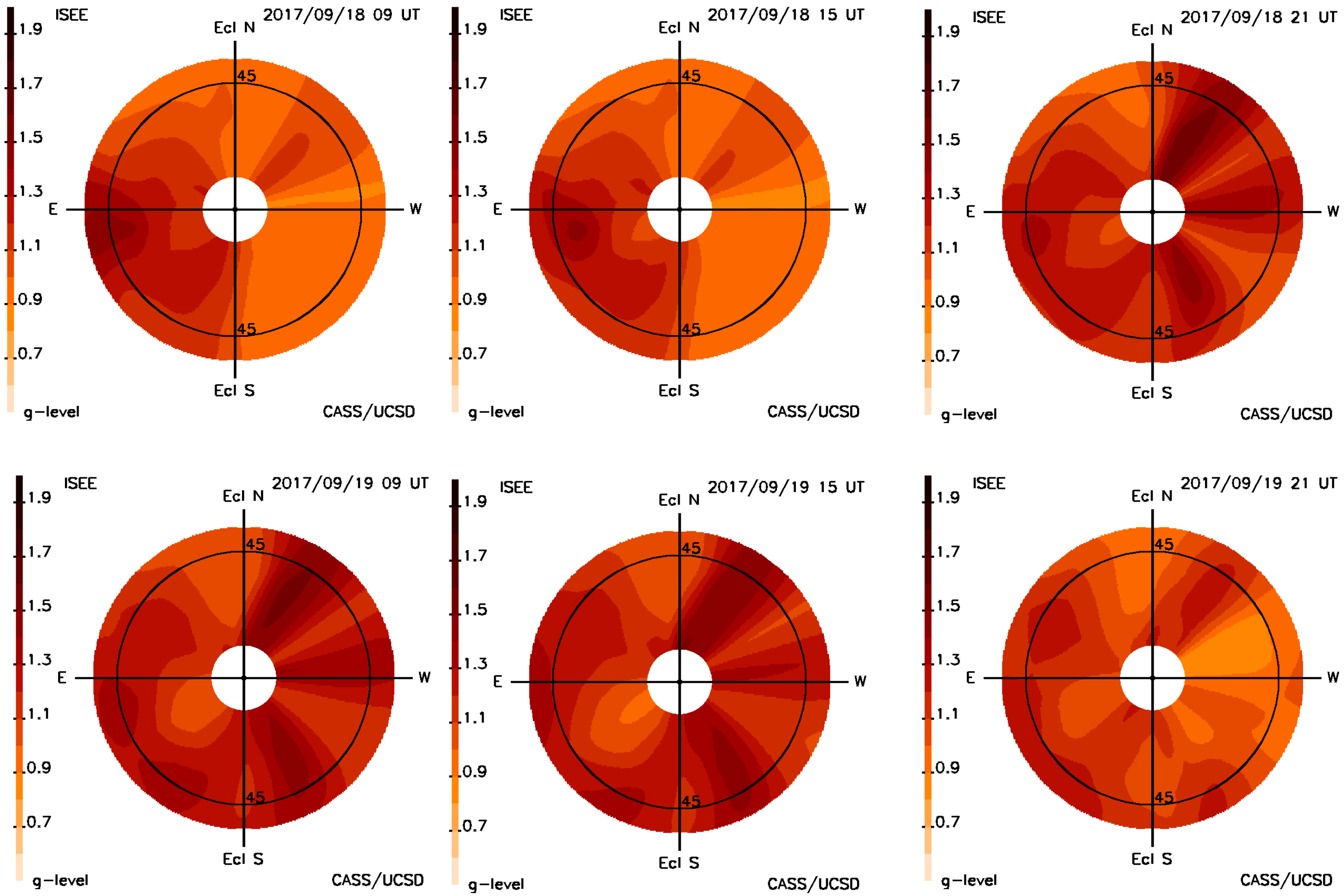
Heliospheric Remote Sensing

Backside halo CME sequence

2017/09/17 11:47 UT



11:47 AM - 17 Sep 2017



More Details

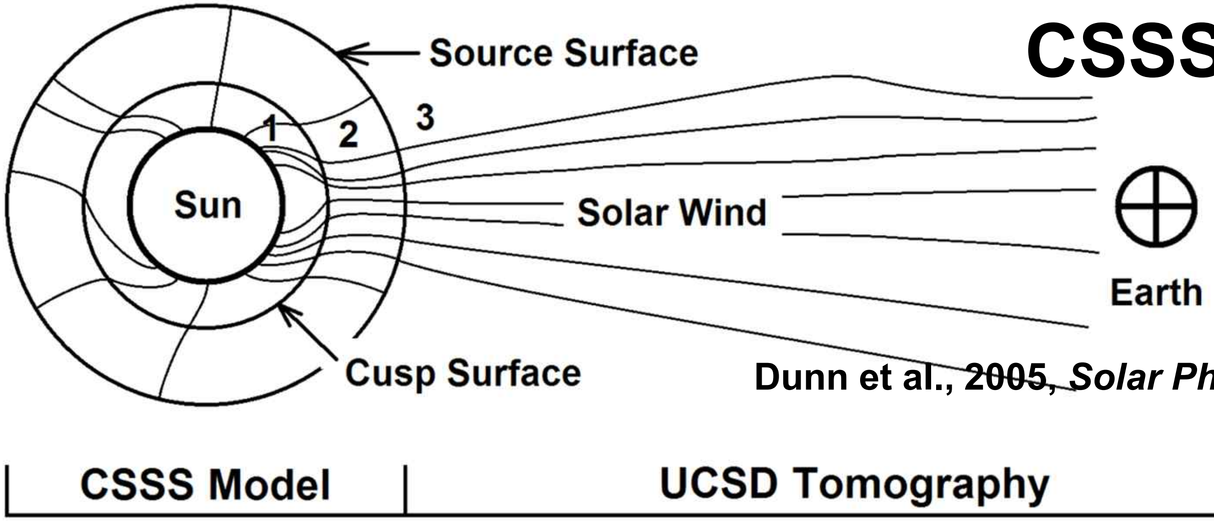
Magnetic Field

Different Techniques for Measurement of Bz

Heliospheric Remote Sensing

(Zhao, X. P. and Hoeksema, J. T., 1995, *J. Geophys. Res.*, 100 (A1), 19.)

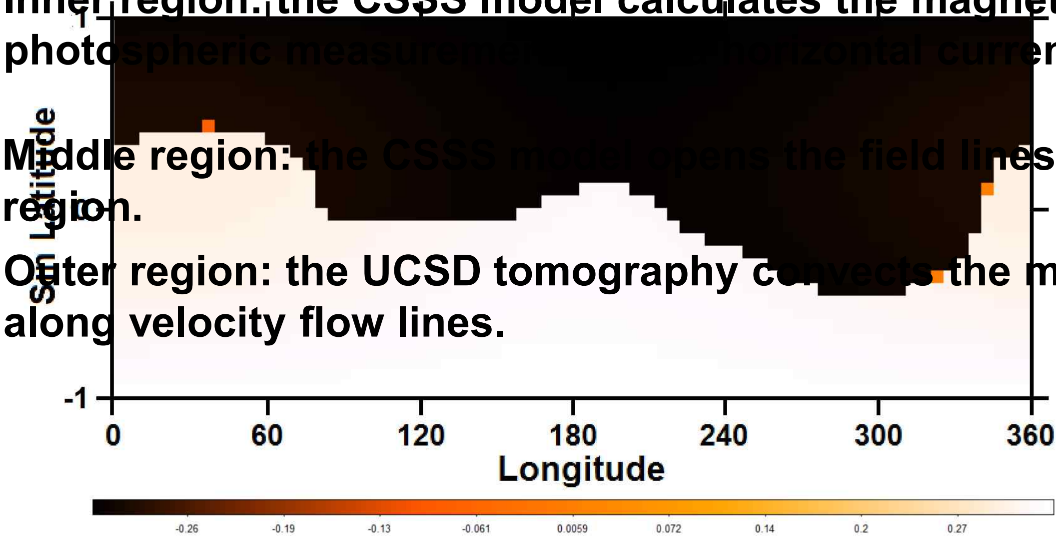
CSSS model



Dunn et al., 2005, *Solar Physics* 227: 339–353.

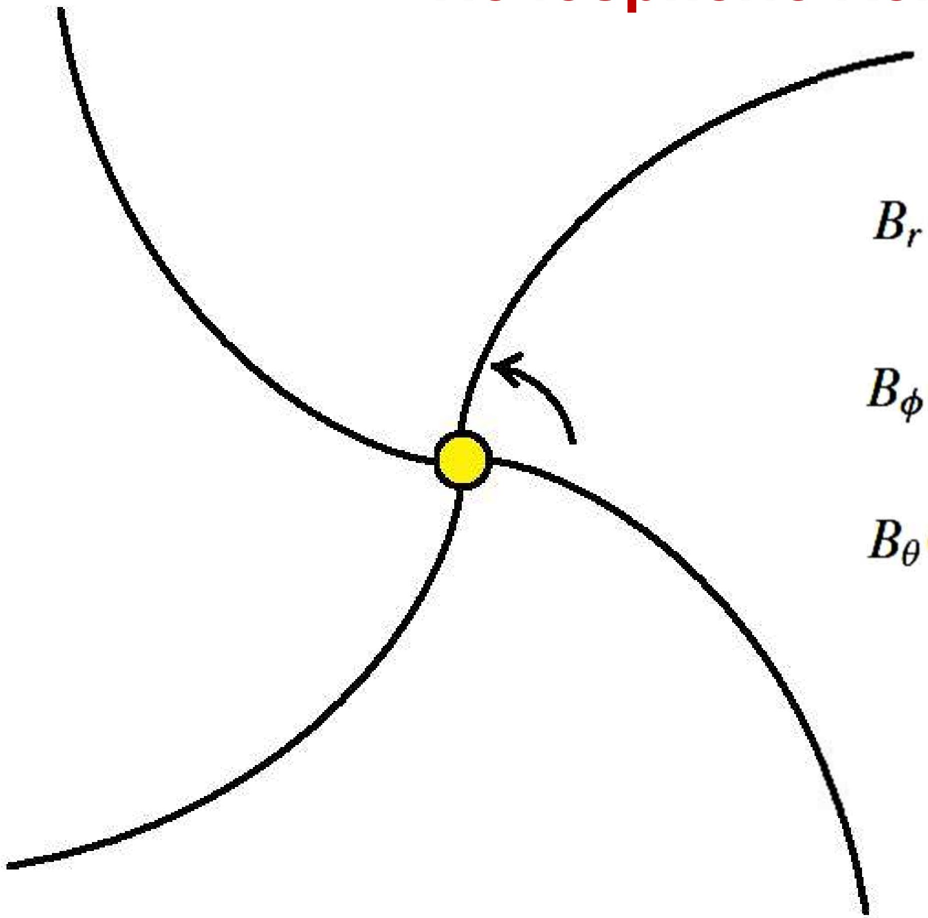
Source surface B_r field component sample

1. Inner region: the CSSS model calculates the magnetic field using photospheric measurements and a horizontal current model.
2. Middle region: the CSSS model opens the field lines. In the outer region.
3. Outer region: the UCSD tomography convects the magnetic field along velocity flow lines.



Different Techniques for Measurement of Bz

Heliospheric Remote Sensing



$$B_r(r, \phi, \theta) = B(r_0, \phi_0, \theta_0)\left(\frac{r_0}{r}\right)^2$$

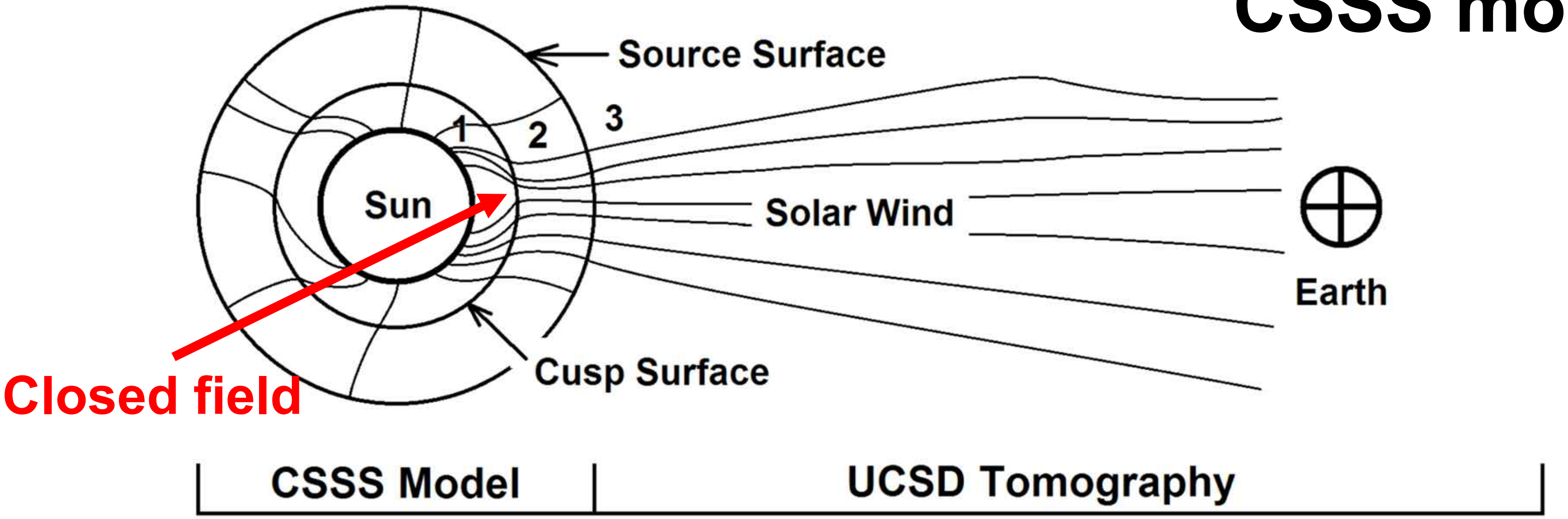
$$B_\phi(r, \phi, \theta) = -B(r)\left(\frac{\omega r_0 \sin(\theta)}{V}\right)\left(\frac{r_0}{r}\right)$$

$$B_\theta(r, \phi, \theta) = 0$$

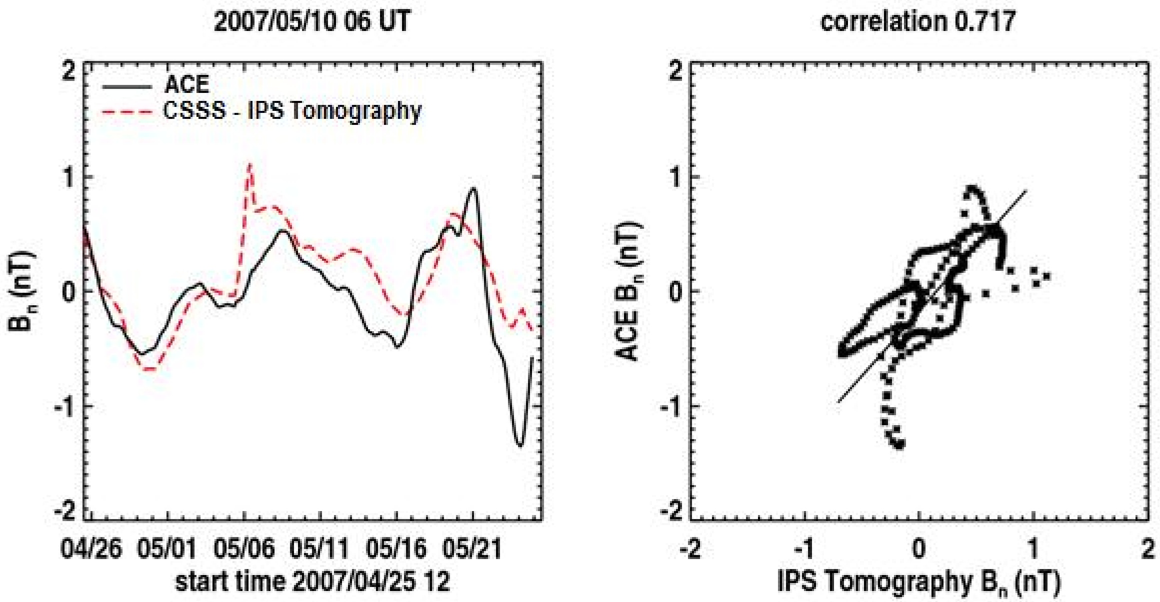
Different Techniques for Measurement of Bz

(Jackson, B.V., *et al.*, 2015, *ApJL,* 803:L1. 1- 5, doi:10.1088/2041-8205/803/1/L1.)

CSSS model



Extrapolated B_n closed field component for CR 2056

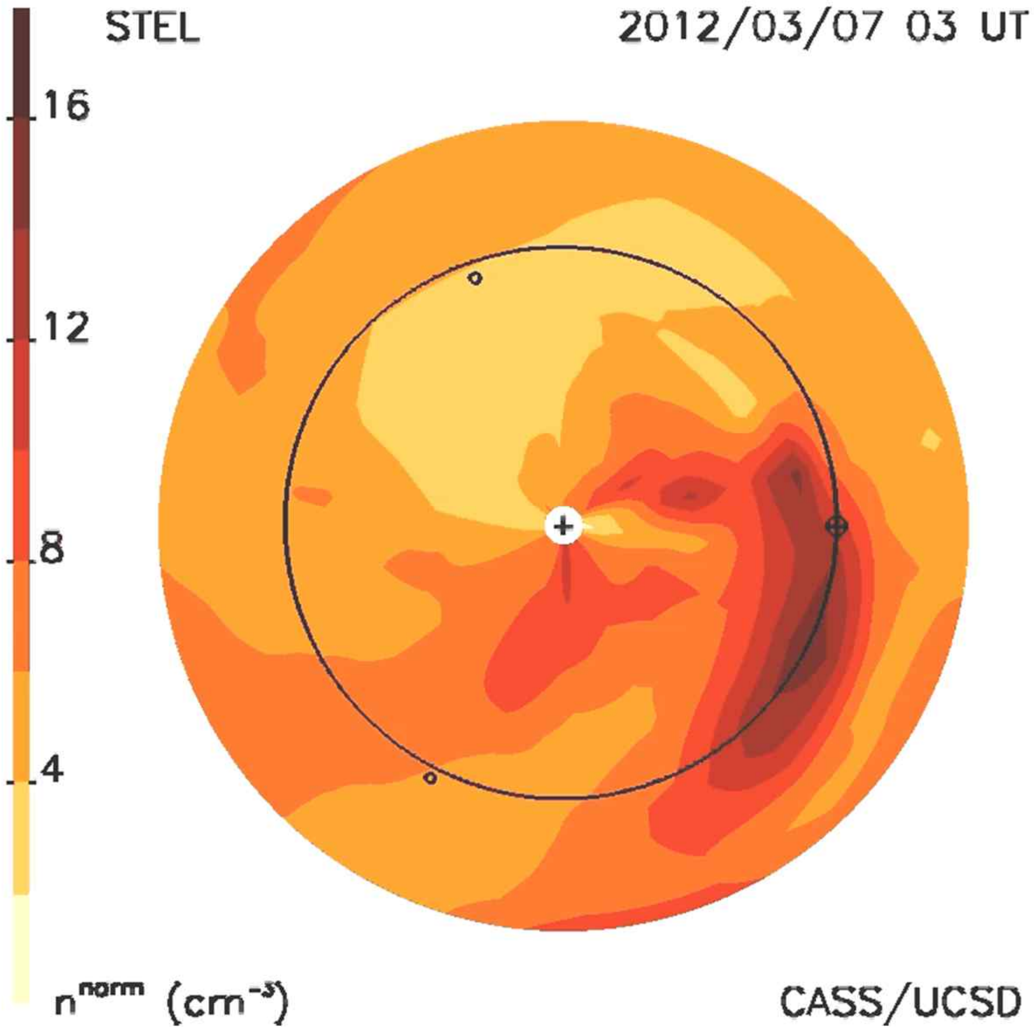


About $1/50^{th}$ of the static flux $r^{-1.34}$ fall-off

Different Techniques for Measurement of Bz

Heliospheric Remote Sensing

$$\Phi = \lambda^2 \int n_e \overline{B} \bullet \overline{ds}$$

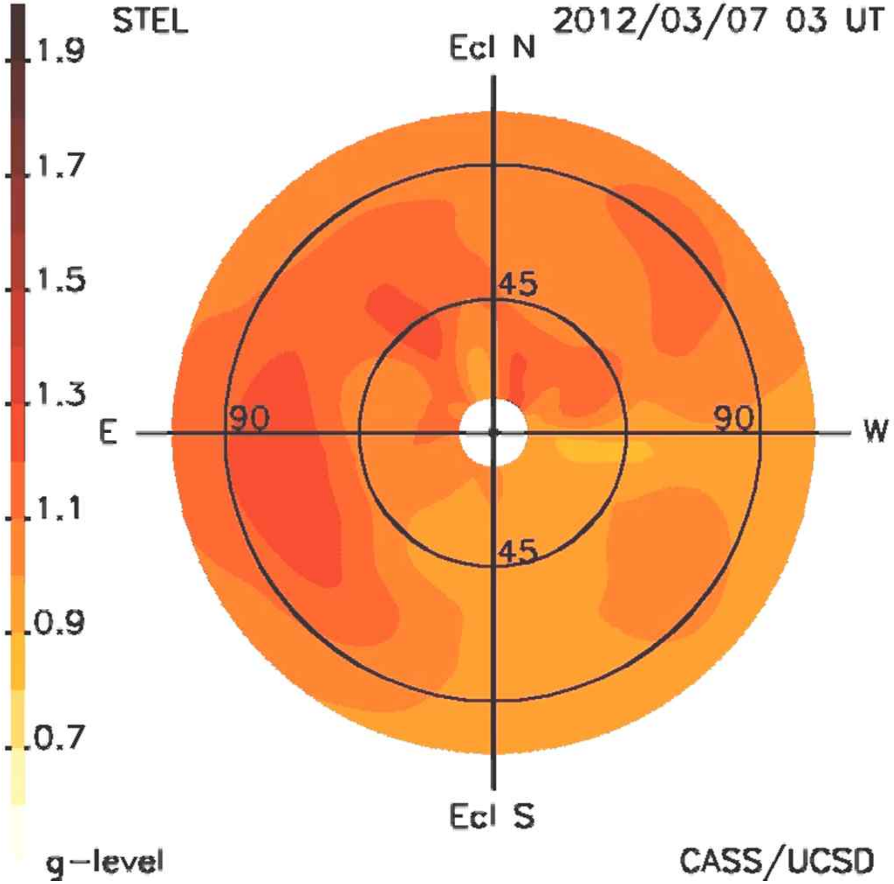


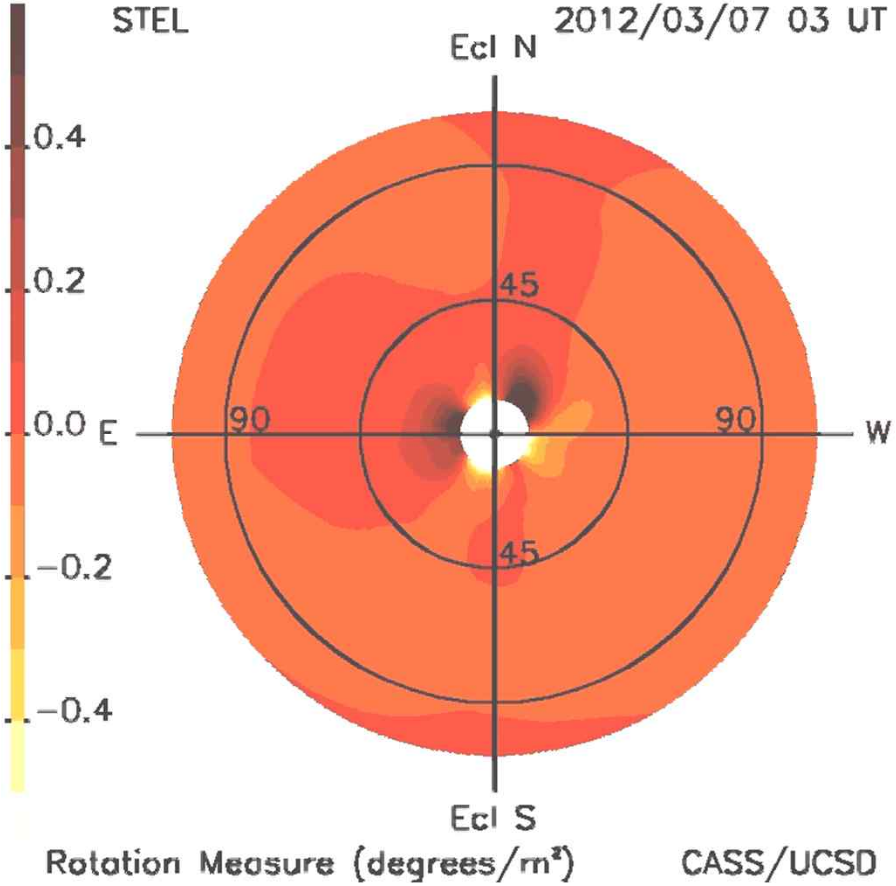
3-D reconstructions of Carrington rotation (CR) 2121 showing a CME of interest from 07 March 2012 launched around 01:00UT.

Different Techniques for Measurement of Bz

Heliospheric Remote Sensing

$$\Phi = \lambda^2 \int n_e \overline{B} \bullet \overline{ds}$$





The same period extracted from CR2121 comparing IPS *g*-level fisheye sky map (left) with that of reconstructed RM from ambient magnetic fields (right) perturbed by the CME.

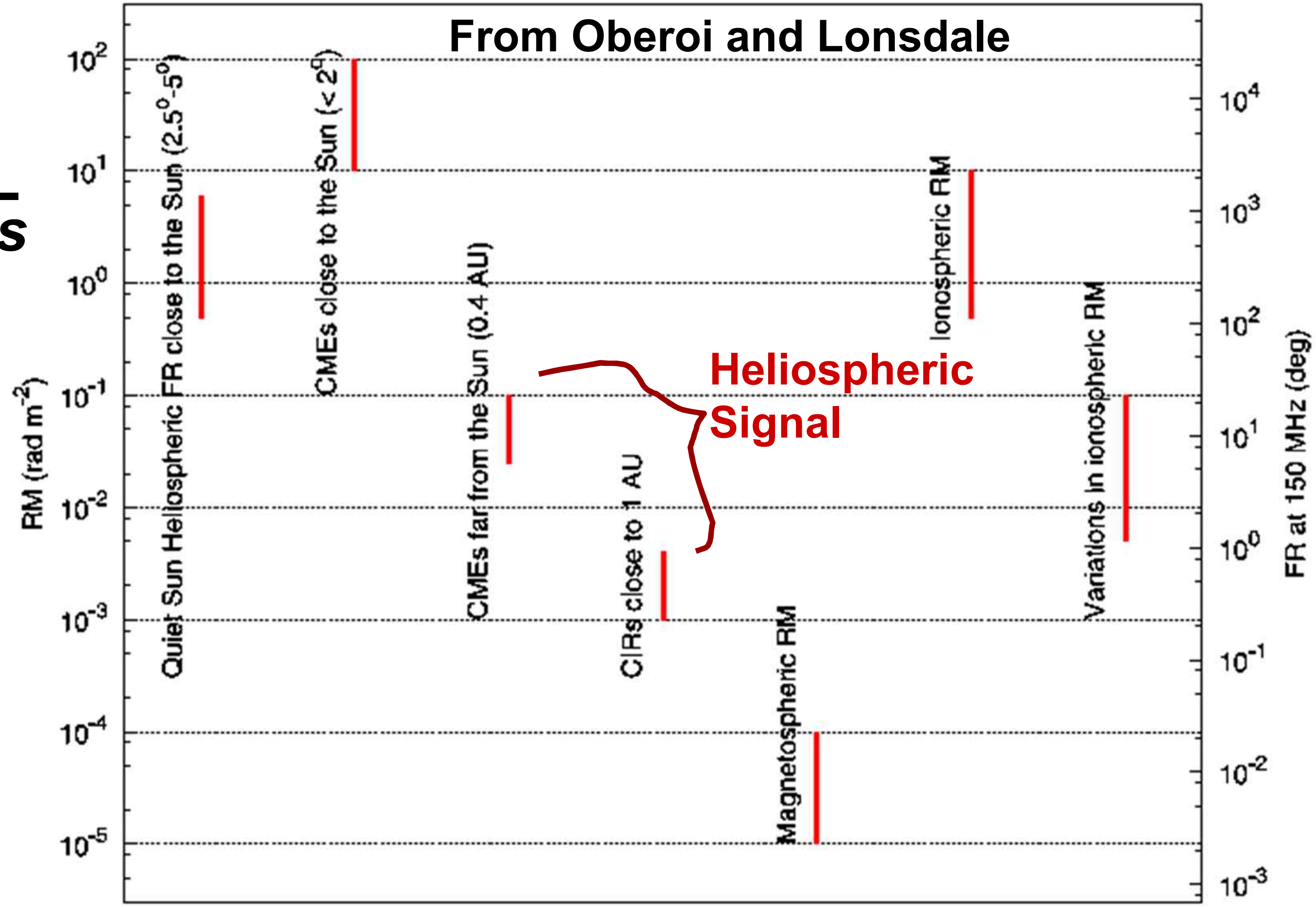
Different Techniques for Measurement of Bz

Heliospheric Remote Sensing

Oberoi and Lonsdale, 2012, *Radio Science,* 47, RS0K08, doi:10.1029/2012RS004992.

Faraday rotation signals at low frequency

$$\Phi = \lambda^2 \int n_e \overline{B} \cdot \overline{ds}$$



Different Techniques for Measurement of Bz

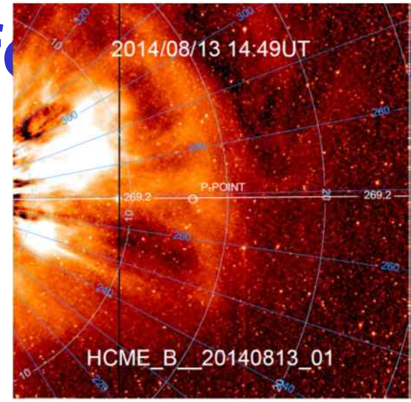
Heliospheric Remote Sensing

Fm Mario Bisi

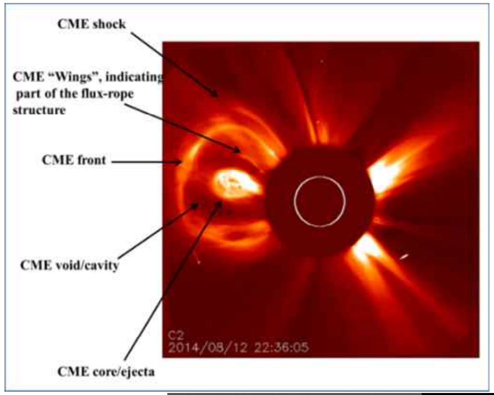
LOFAR

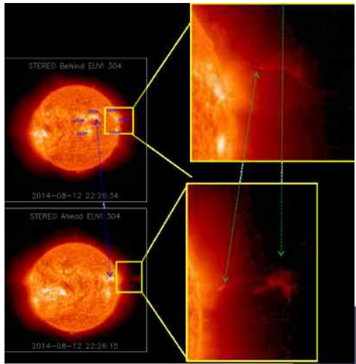
Different Techniques f… ment of Bz

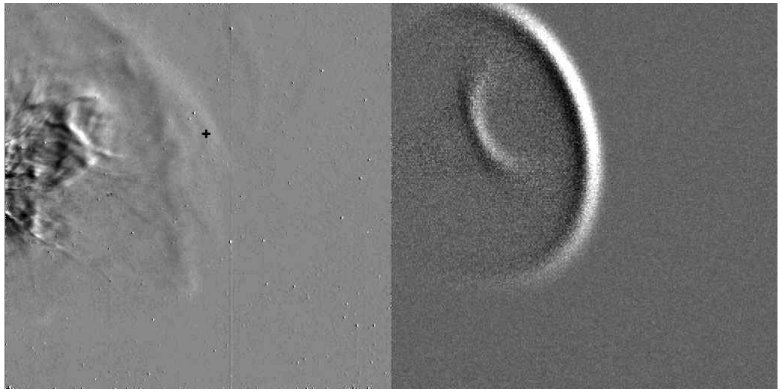
Fm Mario Bisi

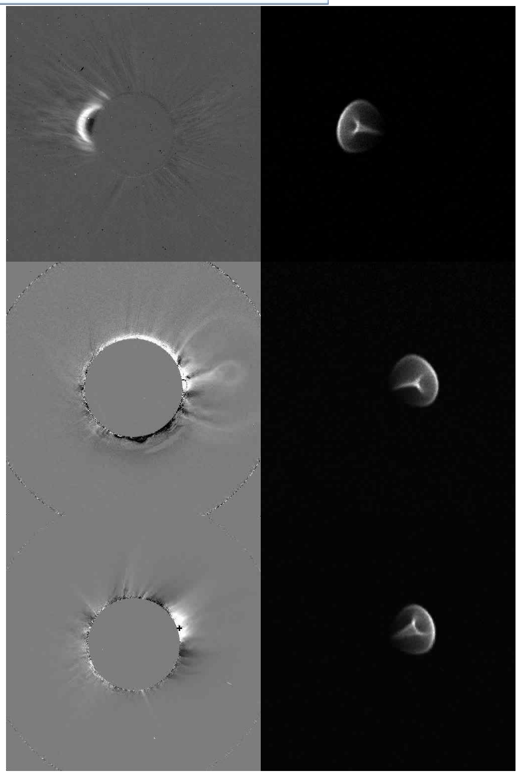


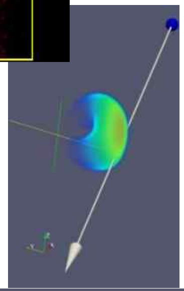
Heliospheric FR Observation

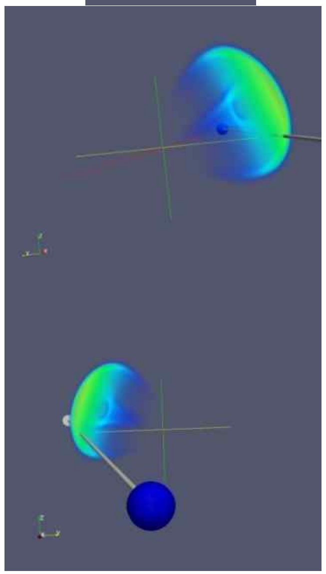


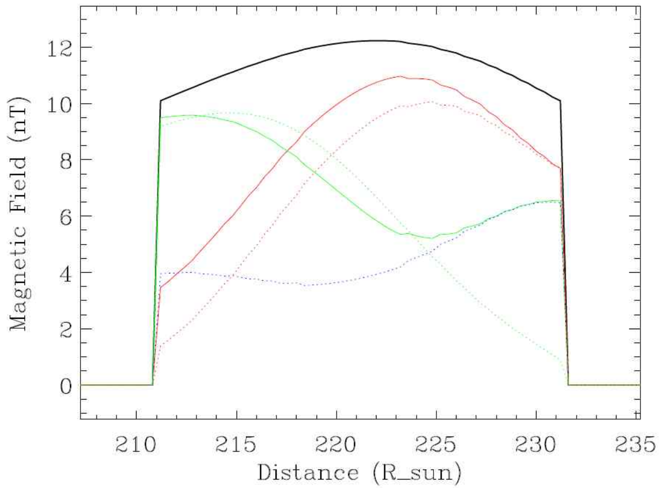












Different Techniques for Measurement of Bz

Heliospheric Remote Sensing

Fm Mario Bisi

Heliospheric FR Observations (3)

Time	Observed RM	Ion RM	Total RM
13:00	3.12722 ± 0.02	2.48140 ± 0.12264	0.64582 ± 0.12426
13:20	2.72809 ± 0.02	2.56207 ± 0.13366	0.16602 ± 0.13515
13:40	2.97102 ± 0.02	2.49809 ± 0.12492	0.47293 ± 0.10598
14:00	$3.06306 \pm$ —	2.48251 ± 0.14120	$0.58055 \pm$ —
14:20	$3.10321 \pm$ —	2.46633 ± 0.12987	$0.63688 \pm$ —
14:40	3.12737 ± 0.04	2.47916 ± 0.13886	0.64821 ± 0.14451
15:00	2.99077 ± 0.02	2.37482 ± 0.11960	0.61595 ± 0.12126

- Using simple dimensional-analysis calculations:

  RM = 0.002 x ne[cm^{-3}] x B[nT] x L[AU]° m^{-2}, where L is the contributing integration length along the LOS, we get a maximum expected RM value: RM = 0.002 x 669 x 150 x 0.25 = 50.2° m^{-2} (or 0.928 rad m^{-2}); perhaps high – but is very much in line with the LOFAR preliminary heliospheric RM values.

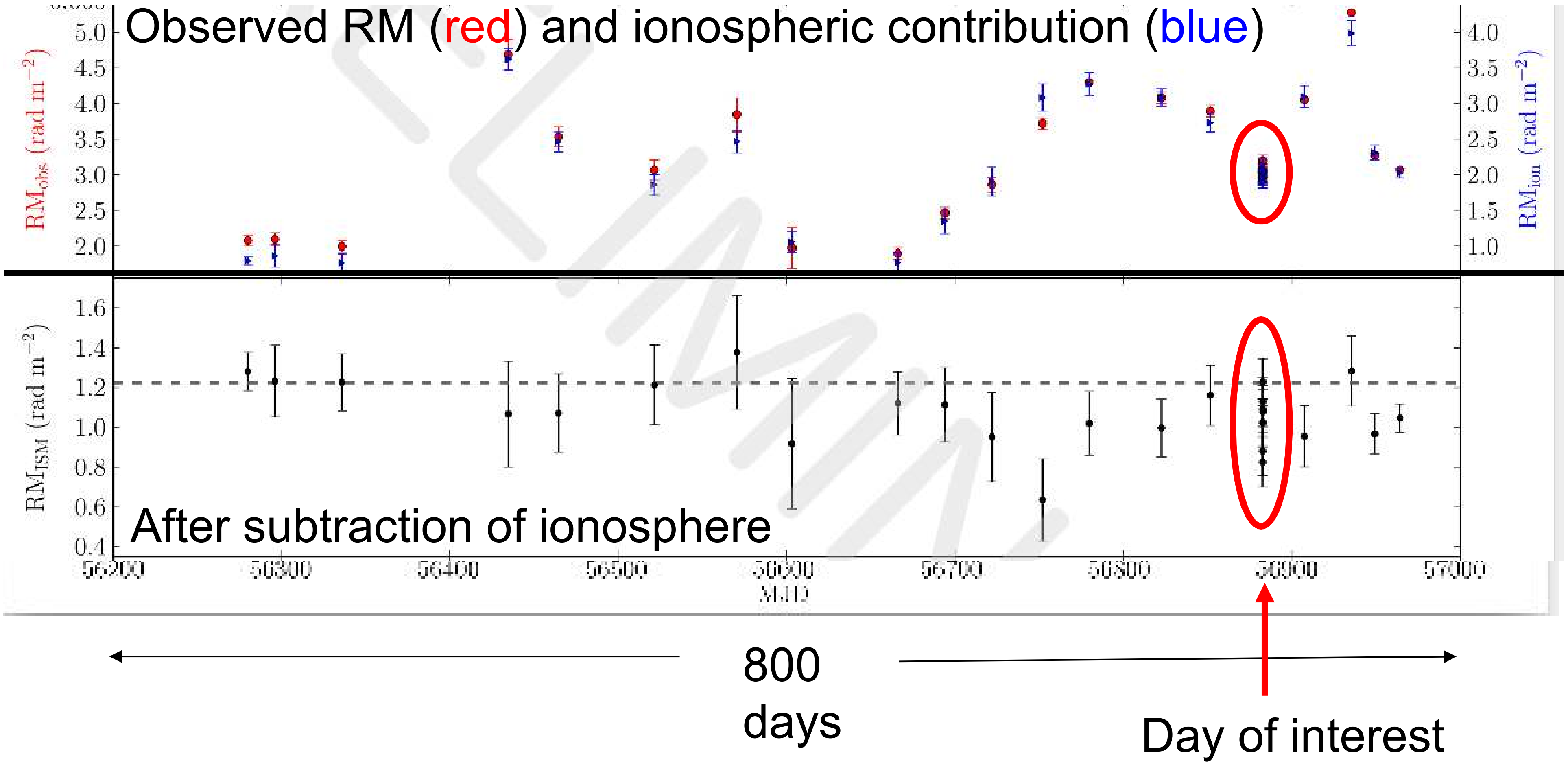
Different Techniques for Measurement of Bz

Heliospheric Remote Sensing

Interstellar Medium Variations

Fm Richard Fallows

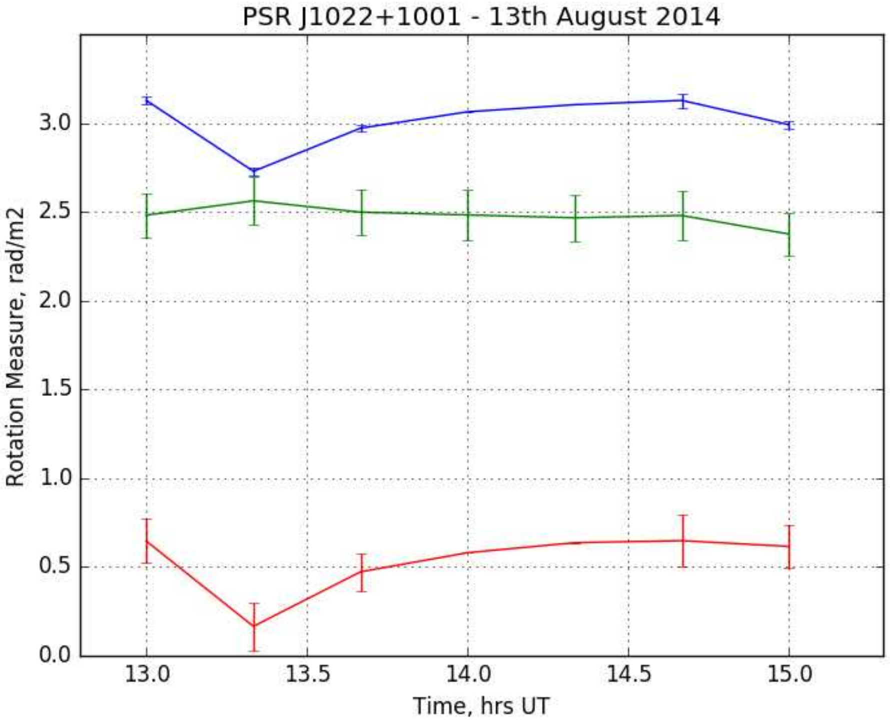
Plot courtesy Charlotte Sobey, CSIRO



Different Techniques for Measurement of Bz

Fm Richard Fallows **Heliospheric Remote Sensing**

RM Calculations – Current Estimates



Measured RM (ISM subtracted)

Calculated Ionospheric RM

RM difference

Modelling and number checking efforts underway indicate that the resulting difference in RM, assumed to be due to the heliosphere, is in the ballpark for that expected from the passage of this CME.

In the meantime

Choi *et al*., JGR, 122, 4921, doi: 10.1002/2016JA023836

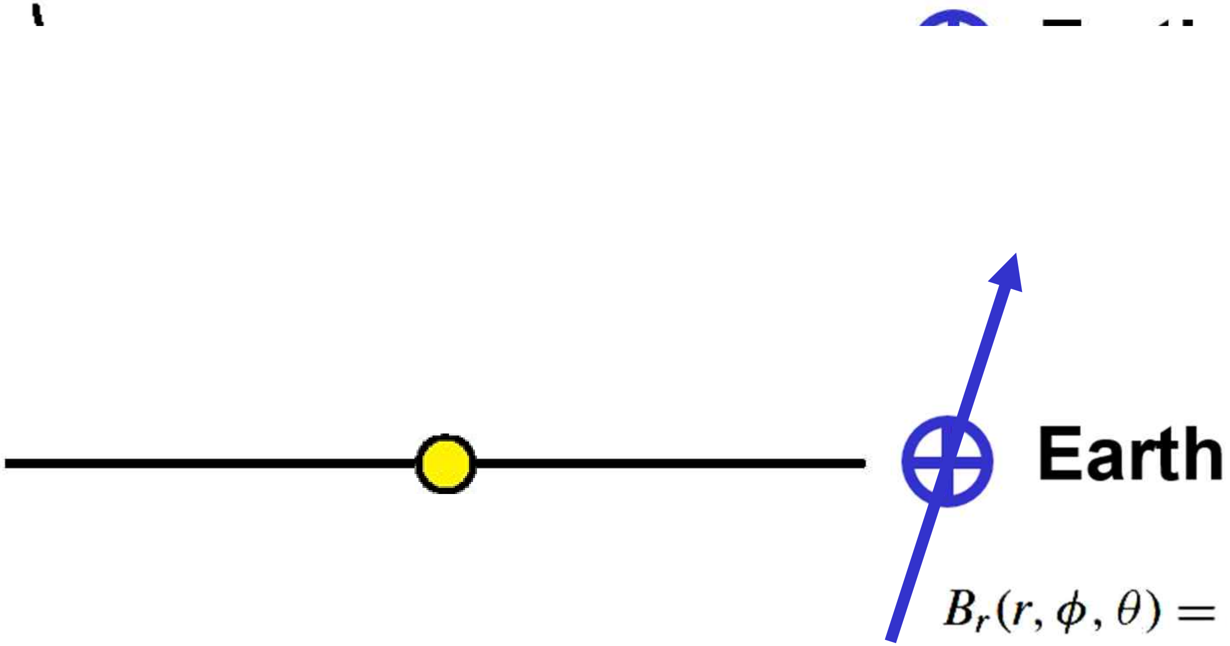
"**…**for substorms of weak to medium…even the weakly (in terms of either intensity or duration) southward IMF Bz should be considered significant…"

Magnetic Field
Russell - McPherron Effect
"Daily Implementation"

Different Techniques for Measurement of Bz

GSM coordinates

(Russell, C. T., and McPherron, R. L., 1973, *J. Geophys. Res.*, 78 (1), 92.)



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$$B_\phi(r,\phi,\theta) = -B(r)\left(\frac{\omega r_0\ \sin(\theta)}{V}\right)\left(\frac{r_0}{r}\right)$$

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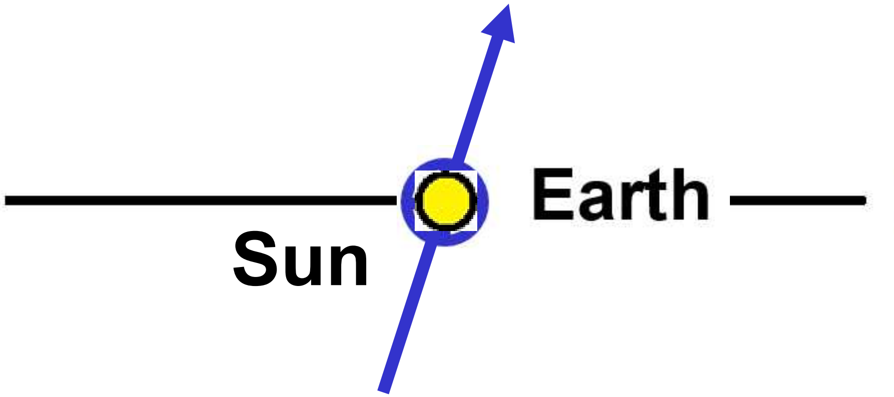
Different Techniques for Measurement of Bz

GSM coordinates

(Russell, C. T., and McPherron, R. L., 1973, *J. Geophys. Res.,* 78 (1), 92.)



$$B_r(r,\phi,\theta) = B(r_0,\phi_0,\theta_0)\left(\frac{r_0}{r}\right)^2$$

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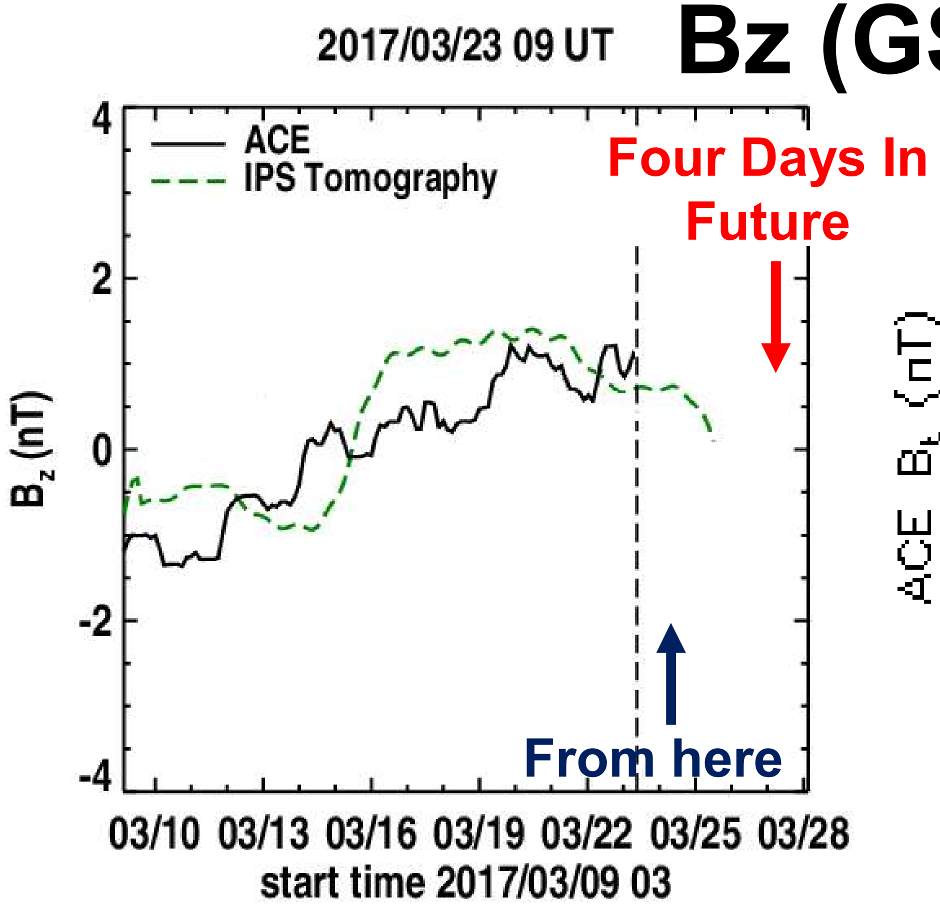
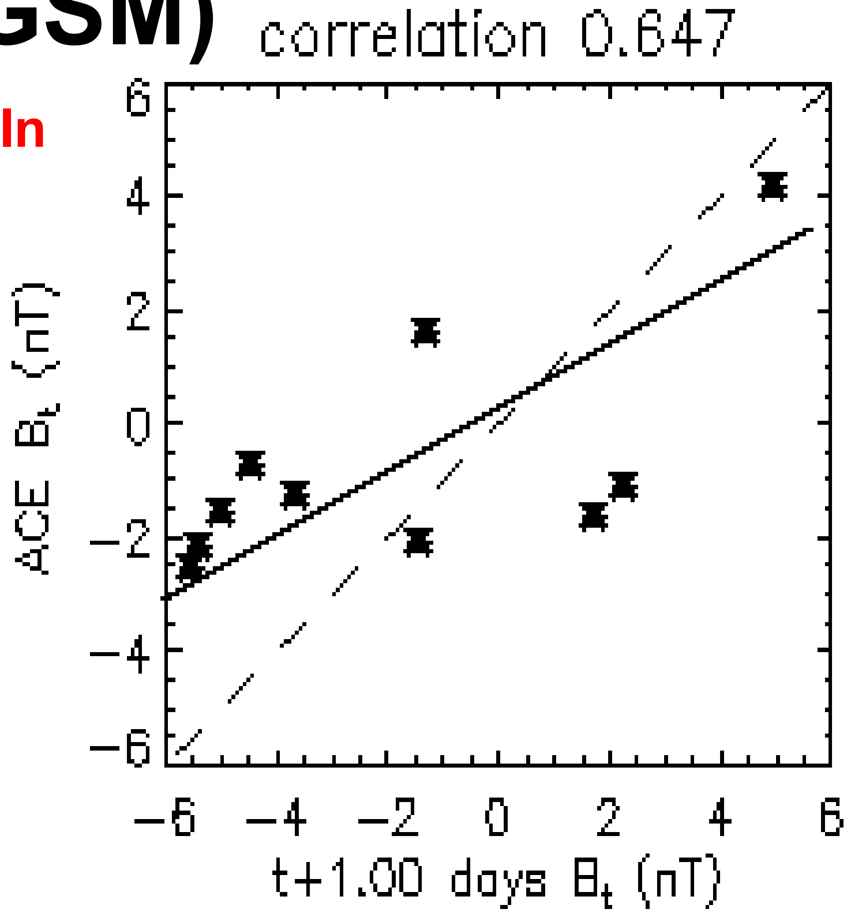
Different Techniques for Measurement of Bz

(see: http://ips.ucsd.edu/ips_workshop_2016)

UCSD Prediction Analyses
Last March Analyses from ISEE: Day -4

Bz (GSM)





Web analysis runs automatically using Linux on a P.C.

Different Techniques for Measurement of Bz

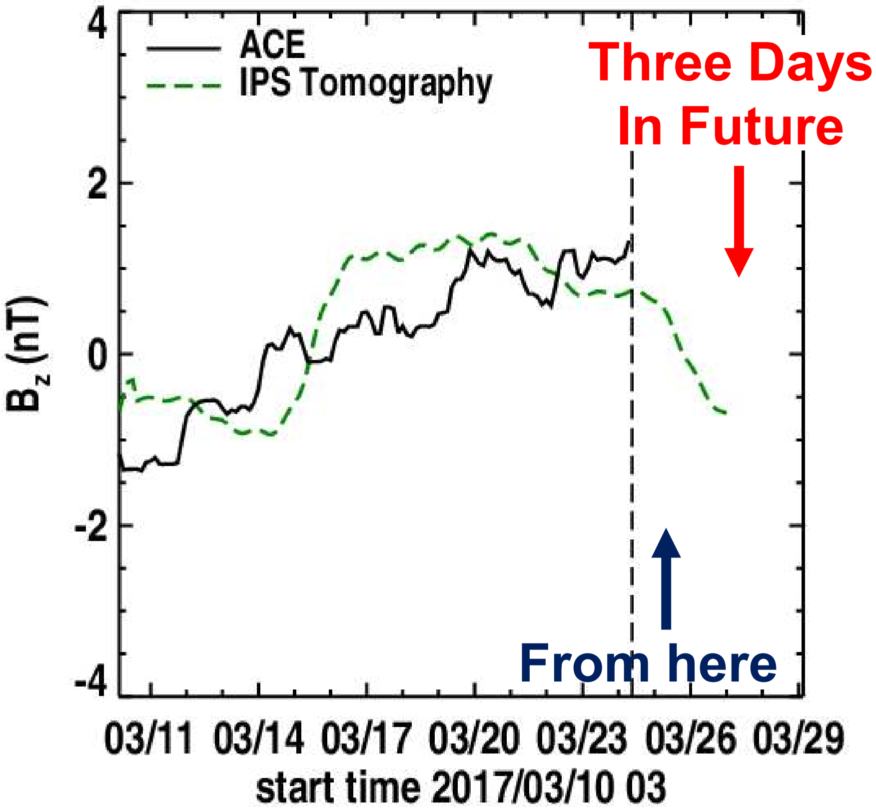
(see: http://ips.ucsd.edu/ips_workshop_2016)

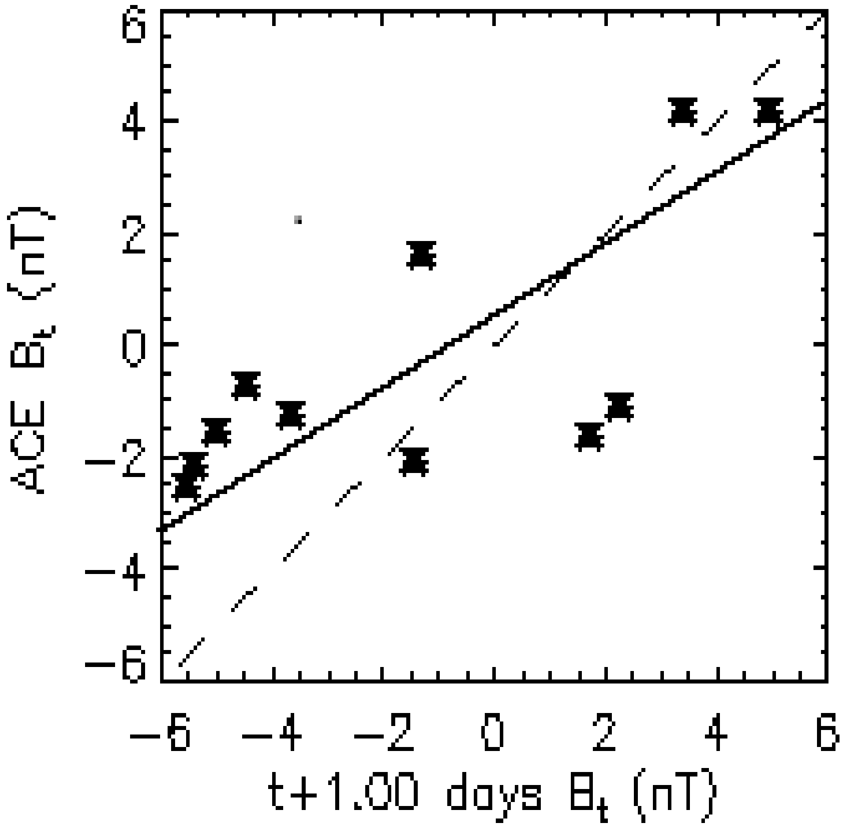
UCSD Prediction Analyses
Last March Analyses from ISEE: Day -3

2017/03/24 09 UT

Bz (GSM)

correlation 0.717





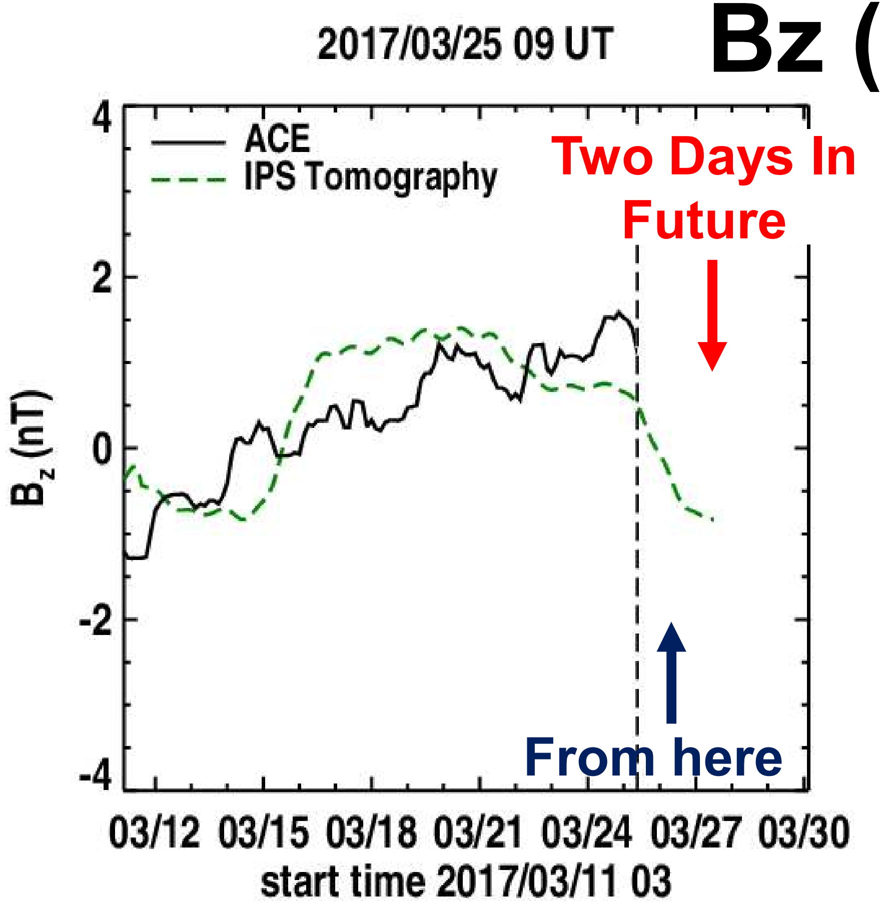
Web analysis runs automatically using Linux on a P.C.

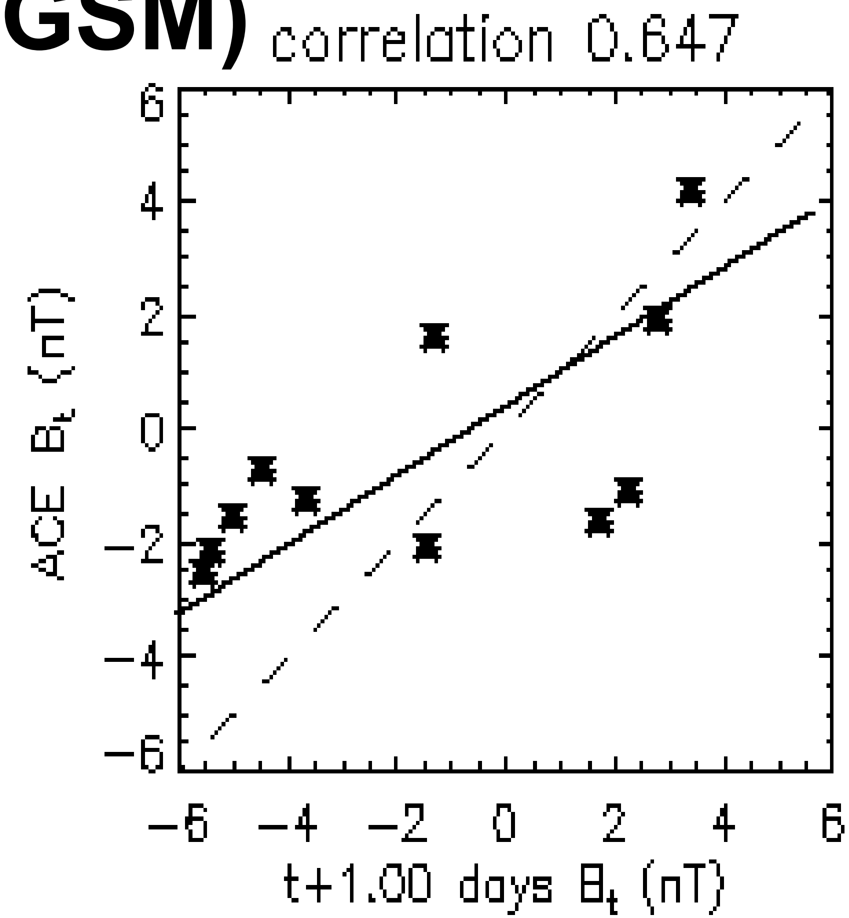
Different Techniques for Measurement of Bz

(see: http://ips.ucsd.edu/ips_workshop_2016)

UCSD Prediction Analyses
Last March Analyses from ISEE: Day -2

Bz (GSM)



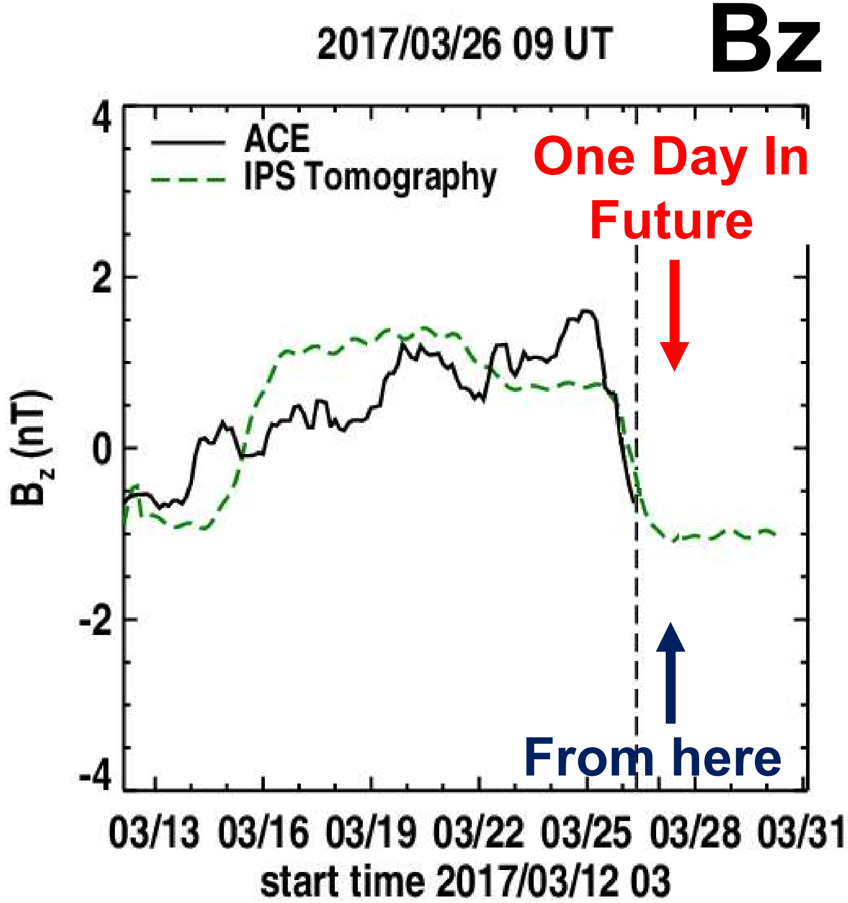


Web analysis runs automatically using Linux on a P.C.

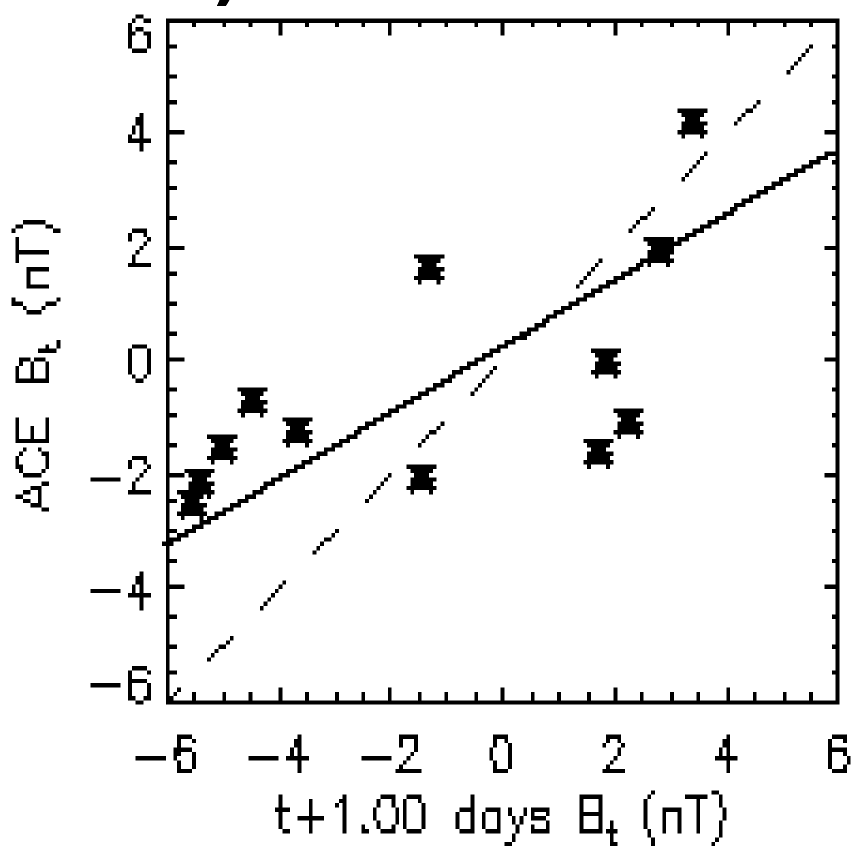
Different Techniques for Measurement of Bz

(see: http://ips.ucsd.edu/ips_workshop_2016)

UCSD Prediction Analyses
Last March Analyses from ISEE: Day -1



Bz (GSM)



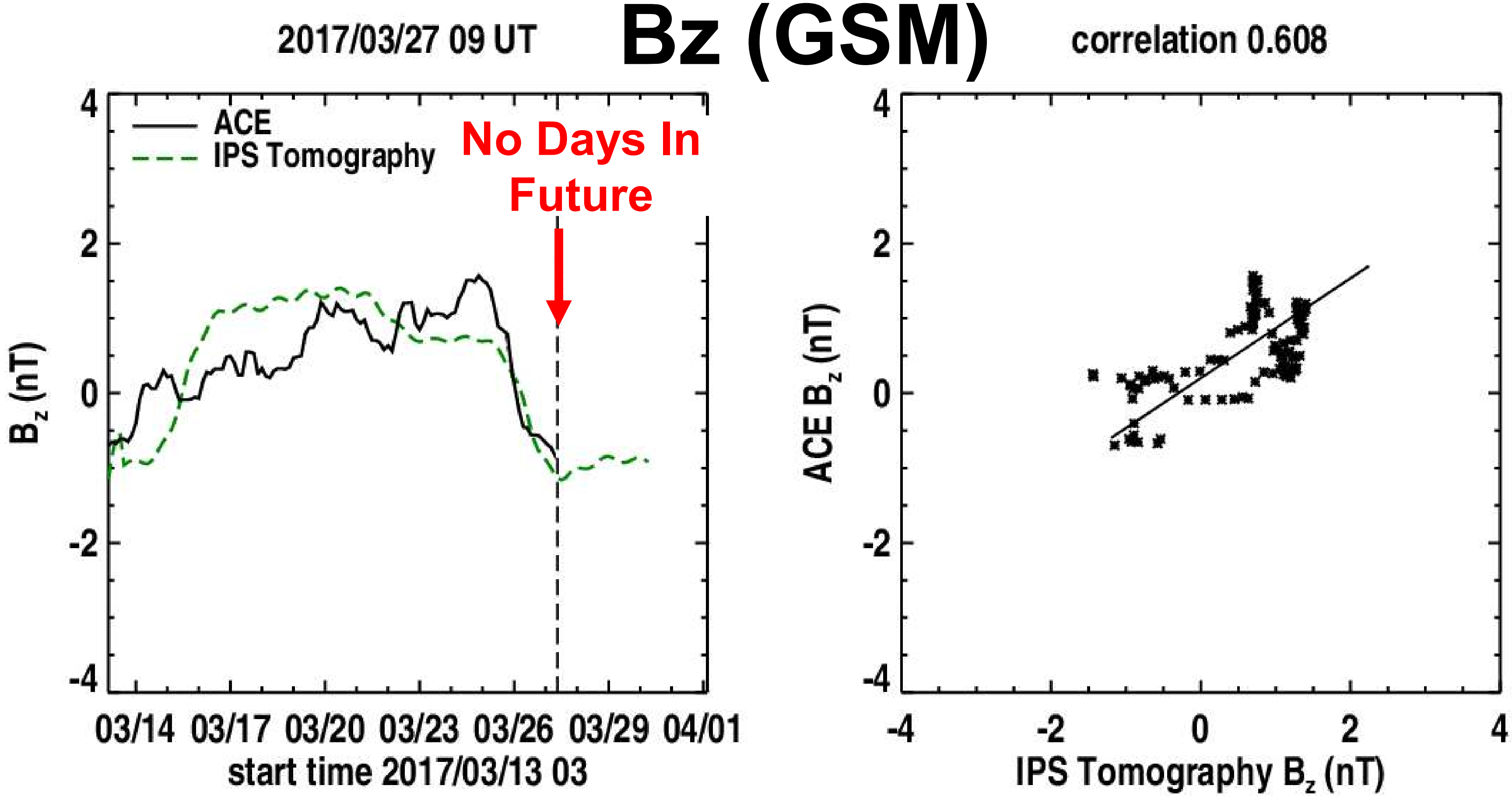
Web analysis runs automatically using Linux on a P.C.

Different Techniques for Measurement of Bz

(see: http://ips.ucsd.edu/ips_workshop_2016)

UCSD Prediction Analyses
Last March Analyses from ISEE: Day -1

Bz (GSM)



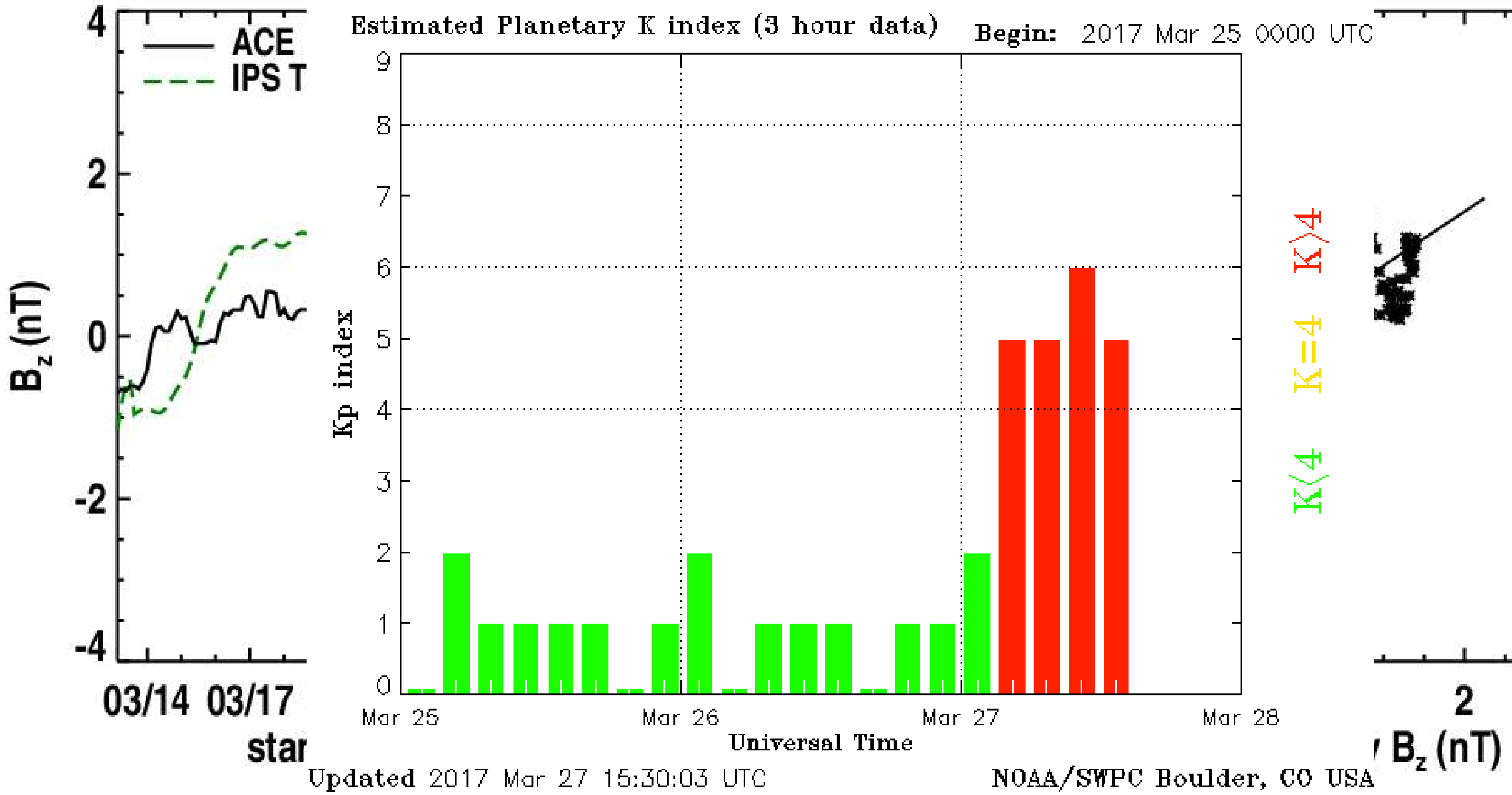
Web analysis runs automatically using Linux on a P.C.

Different Techniques for Measurement of Bz

(see: http://ips.ucsd.edu/ips_workshop_2016)

UCSD Predictions
Magnetic Field Analysis

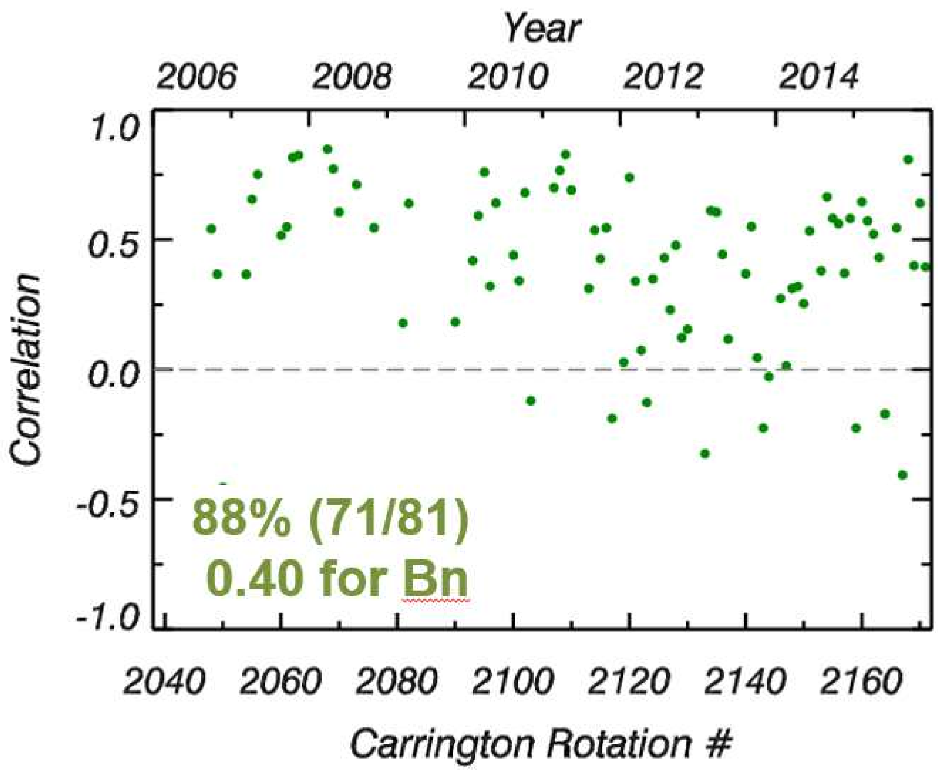
2017/03/27 09 UT **NOAA Kp** correlation 0.608



Web analysis runs automatically using Linux on a P.C.

Different Techniques for Measurement of Bz

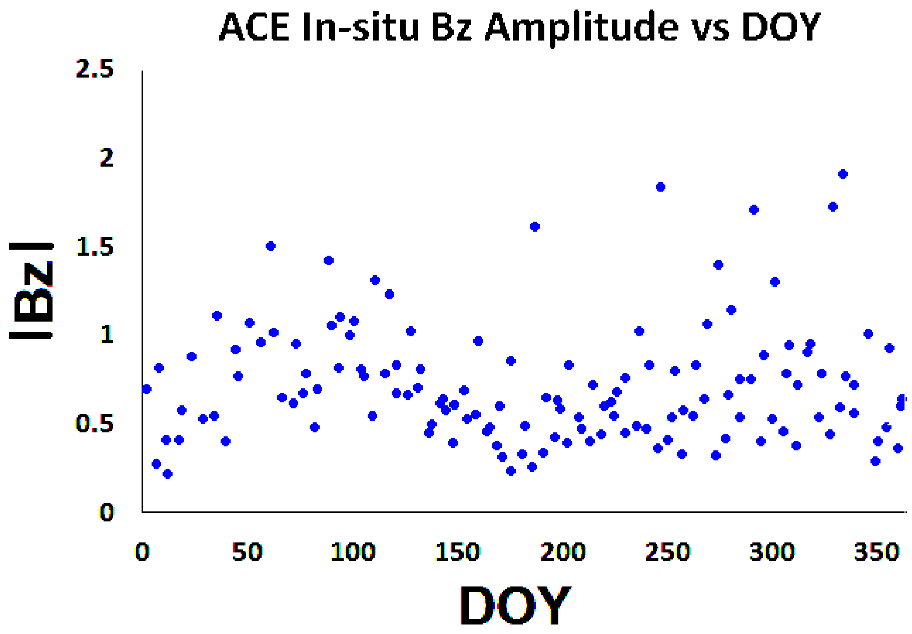
ACE and IPS-derived Bz Pearson's R Correlation per Carrington Rotation in GSM Coordinates over Ten Years

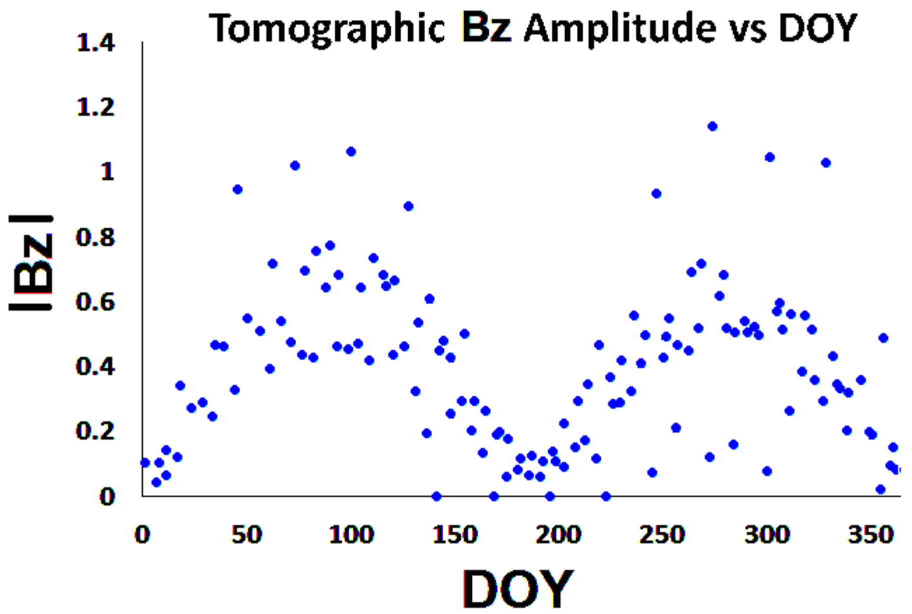


(CRs of Bz excursion < 0.25 nT are removed)

Positive Correlations (over 10 years)

Different Techniques for Measurement of Bz





(Russell, C. T., and McPherron, R. L., 1973, *J. Geophys. Res.*, 78 (1), 92.)

10 years of ACE data

Bz Amplitude in GSM coordinates

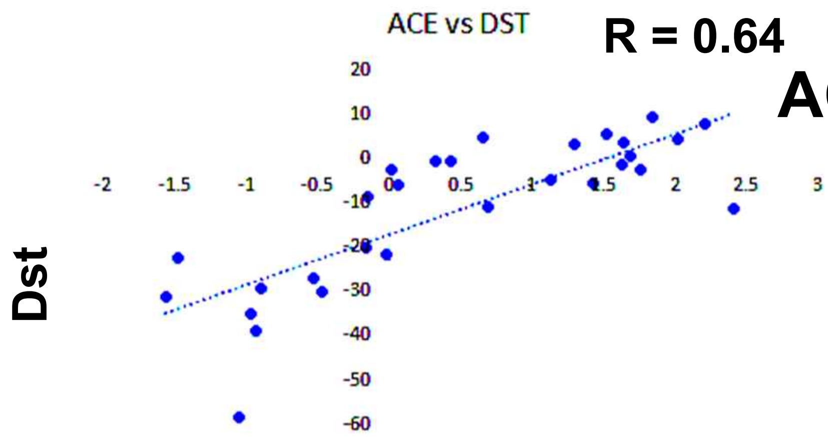
10 years of GONG data – IPS extrapolation

Different Techniques for Measurement of Bz

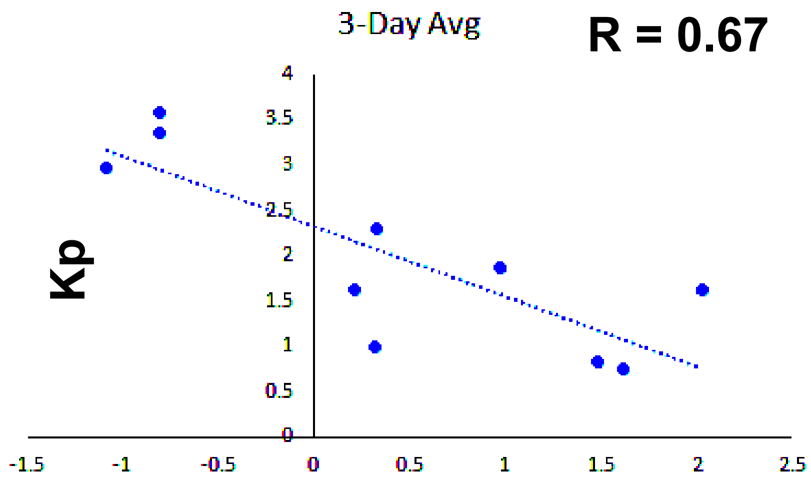
UCSD Prediction Analyses - 2016 Study

Dst vs GSM Bz (CR 2074) Kp vs GSM Bz

ACE

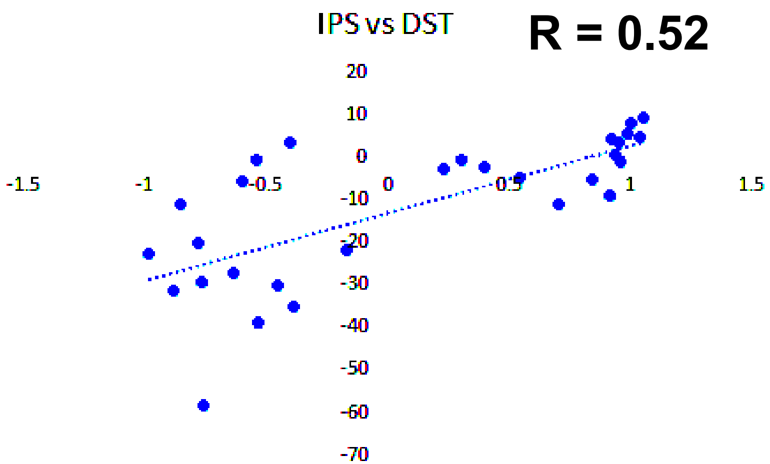


ACE Bz

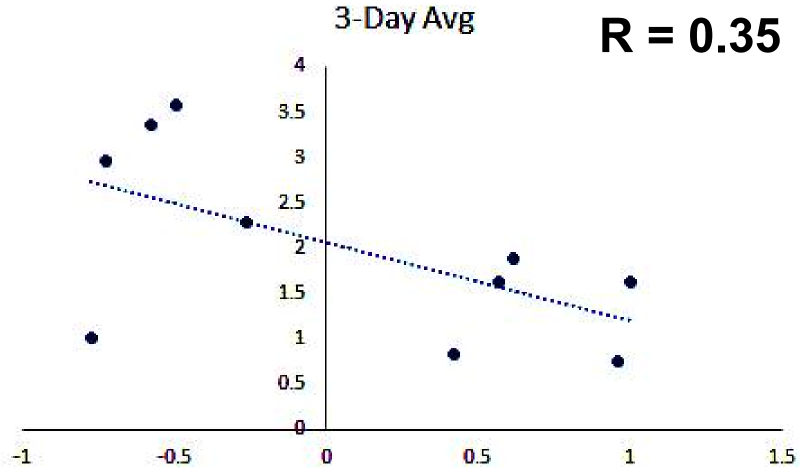


ACE Bz

IPS



IPS-derived Bz



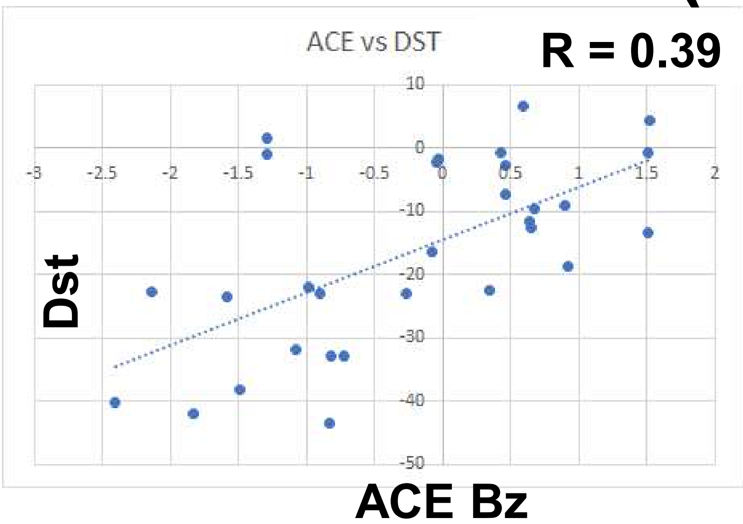
IPS-derived Bz

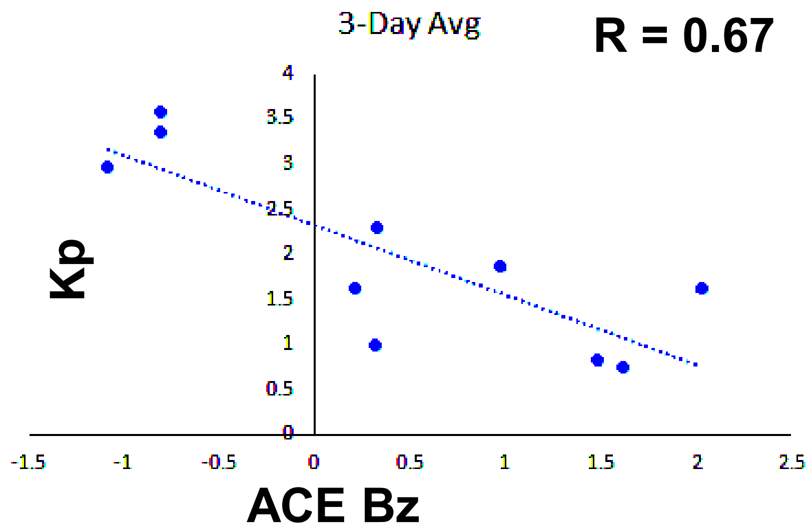
Different Techniques for Measurement of Bz

UCSD Prediction Analyses - 2016 Study

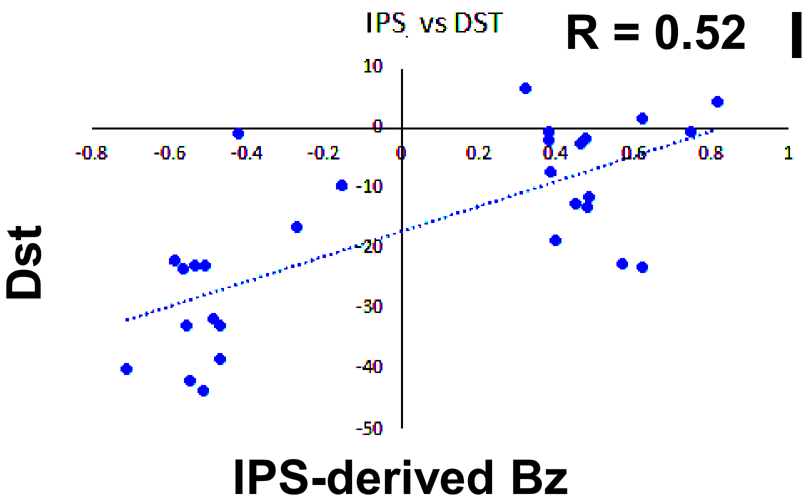
Dst vs GSM Bz (CR 2083) Kp vs GSM Bz

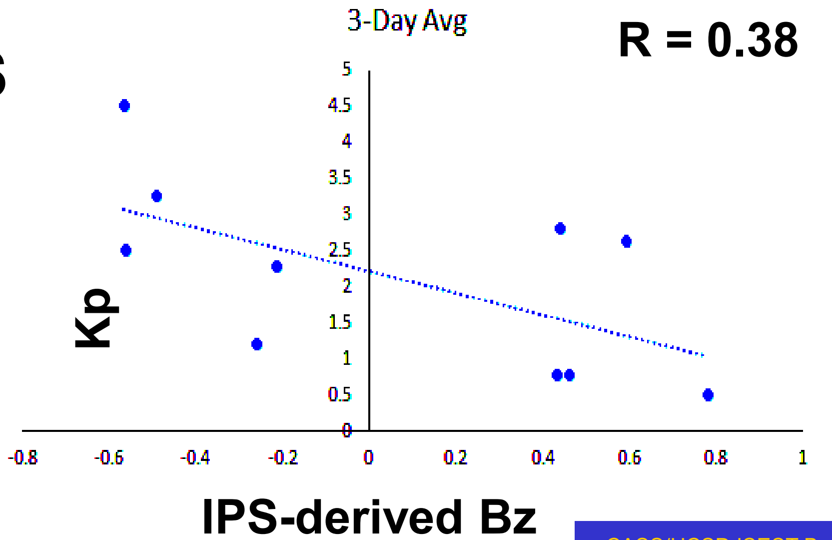
ACE





IPS

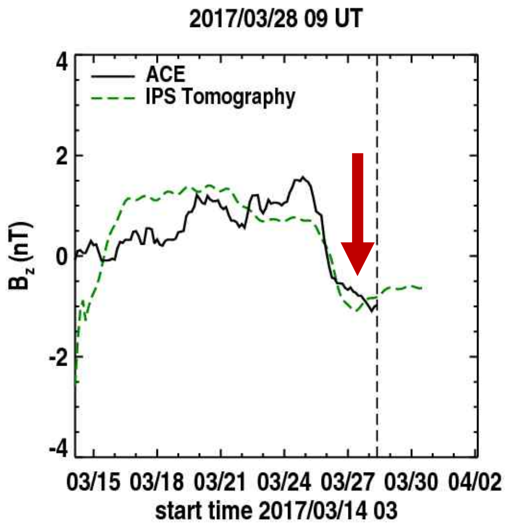


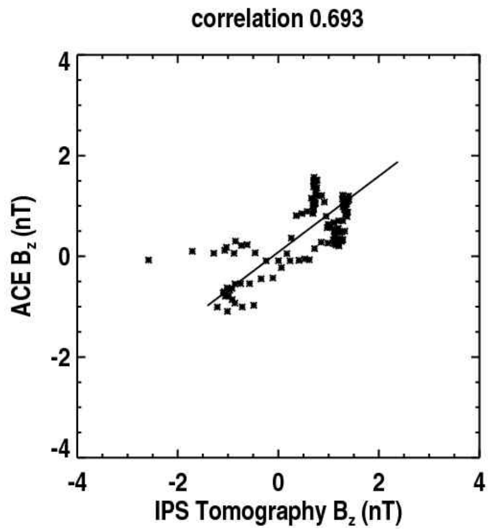


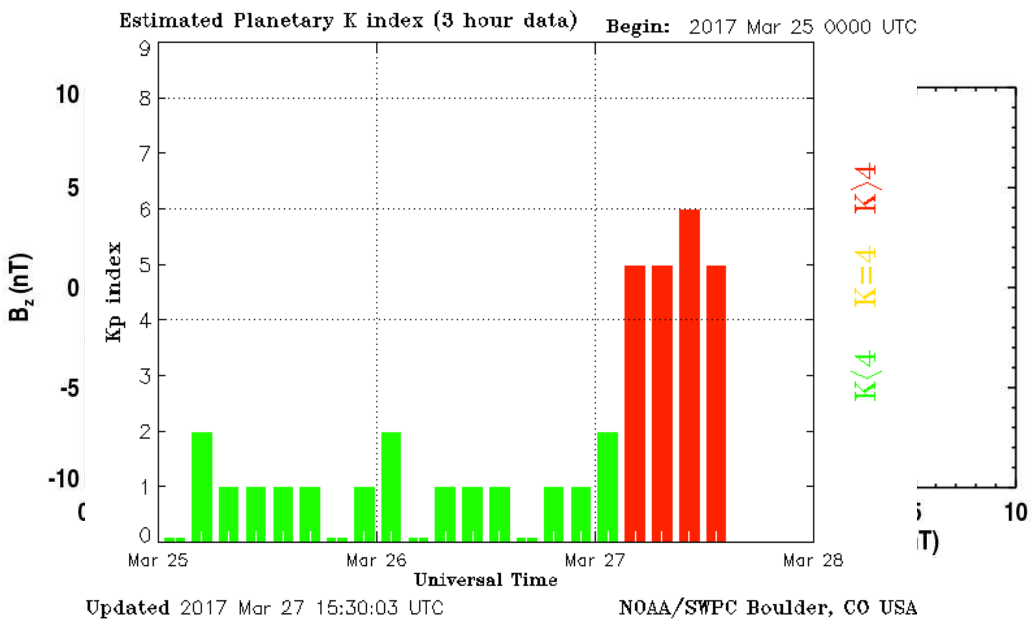
Different Techniques for Measurement of Bz

“Can’t possibly be right” - a good NOAA colleague

GSM Bz







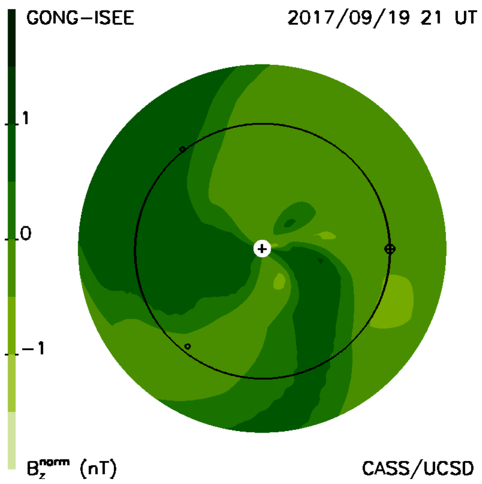
Largest min -Bz

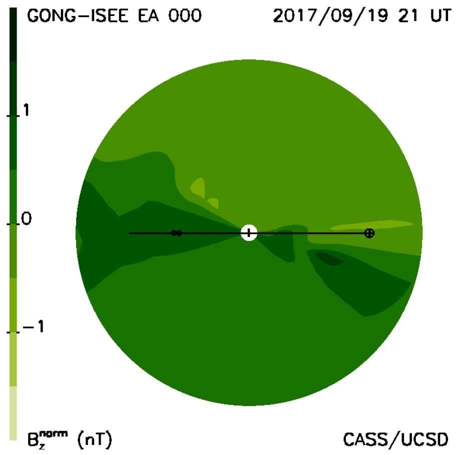
-17nT 09 UT 03/27

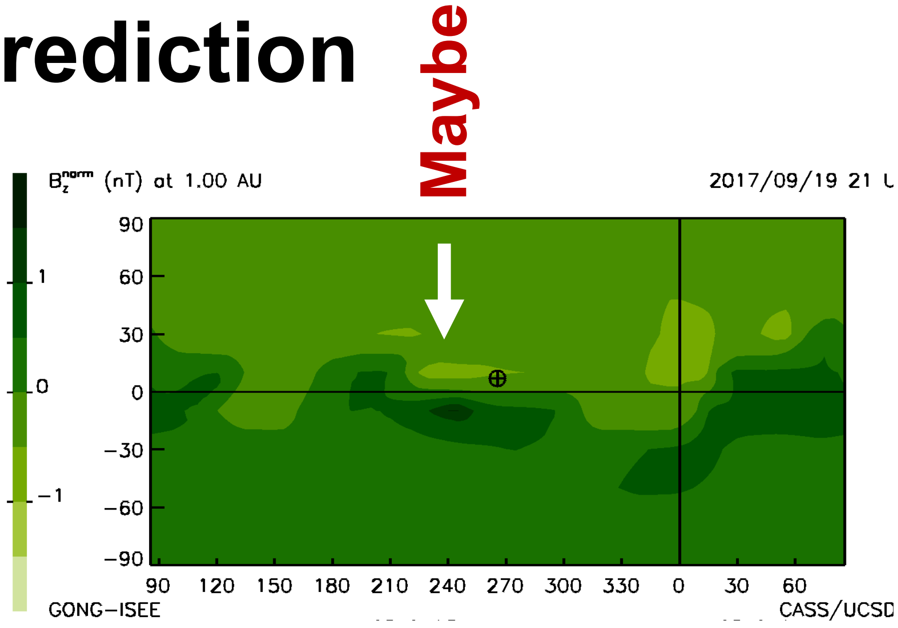
(Perhaps)

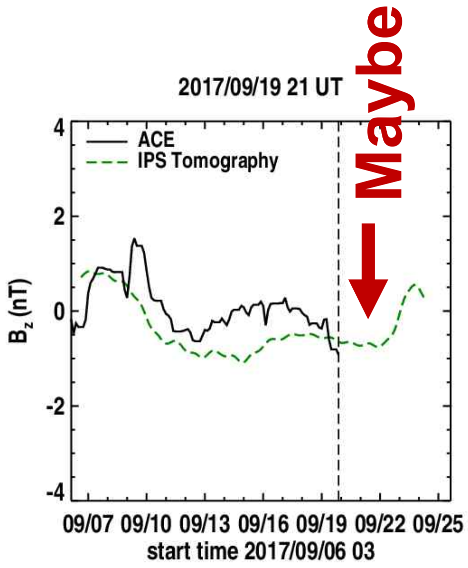
Different Techniques for Measurement of Bz

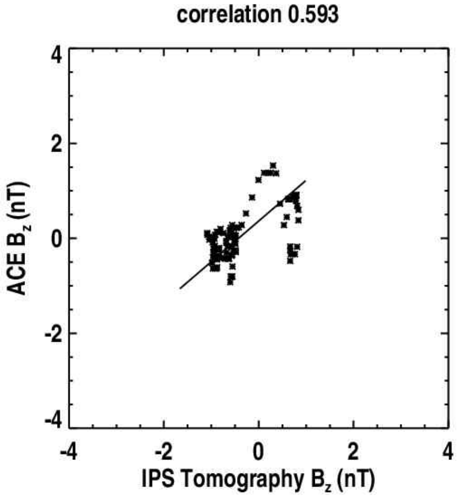
GSM Bz UCSD current prediction

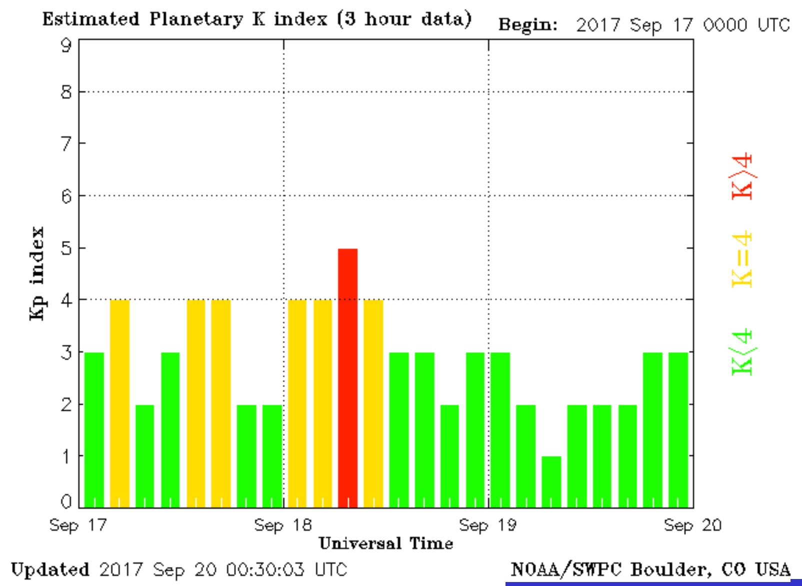








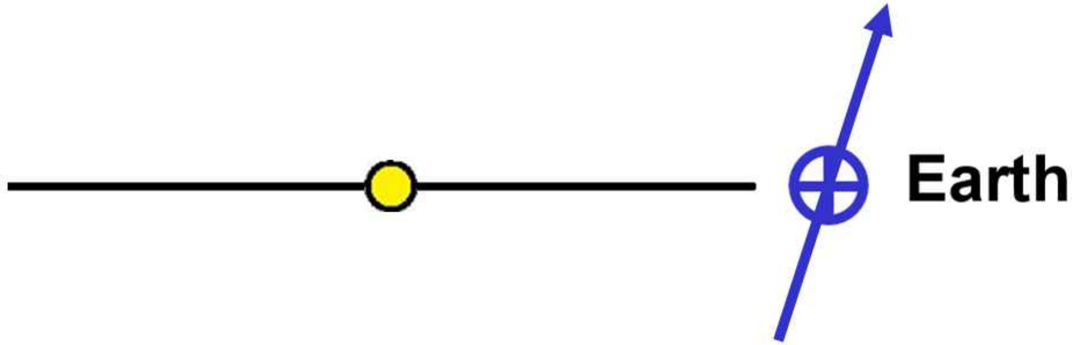




CASS/UCSD ISEST Bz 2017

Different Techniques for Measurement of Bz

Conclusions:



Geocentric Solar Magnetospheric (GSM) Bz:

The reasons to determine Bz

Concept studies: How we may be able to determine Bz

1) **In CMEs.**
2) **In the background solar wind**

Now there are some successes in determining Bz