

Credit: NASA

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University of Göttingen
Institute for Astrophysics

26 October 2015

ISEST Workshop, UNAM, Mexico City

Forecasting the Magnetic Field Configuration of CMEs

Outline

1. Magnetic field configuration of CMEs and their solar source regions
2. Observations and results from STEREO and the HELCATS Project
3. Challenges for improved space weather forecasts
4. Conclusions

Part 1

Magnetic Field Configuration of CMEs and Their Solar Source Regions

Why CME NRT modelling?



STEREO satellites provide 3D-view



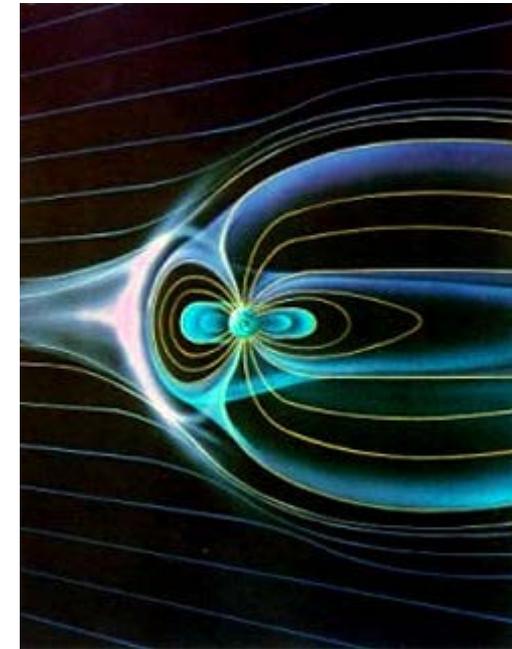
Which direction
does the CME go?
Will it miss?

ACE gives 15-30 mins
premonition time

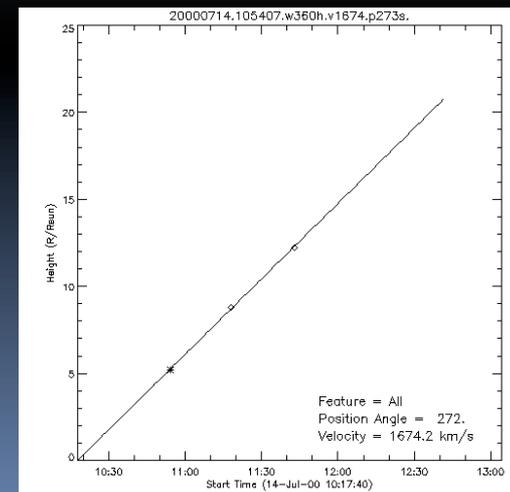
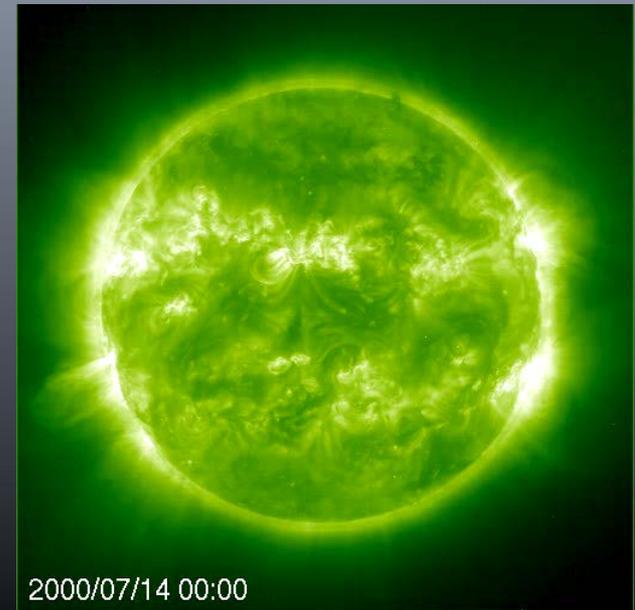
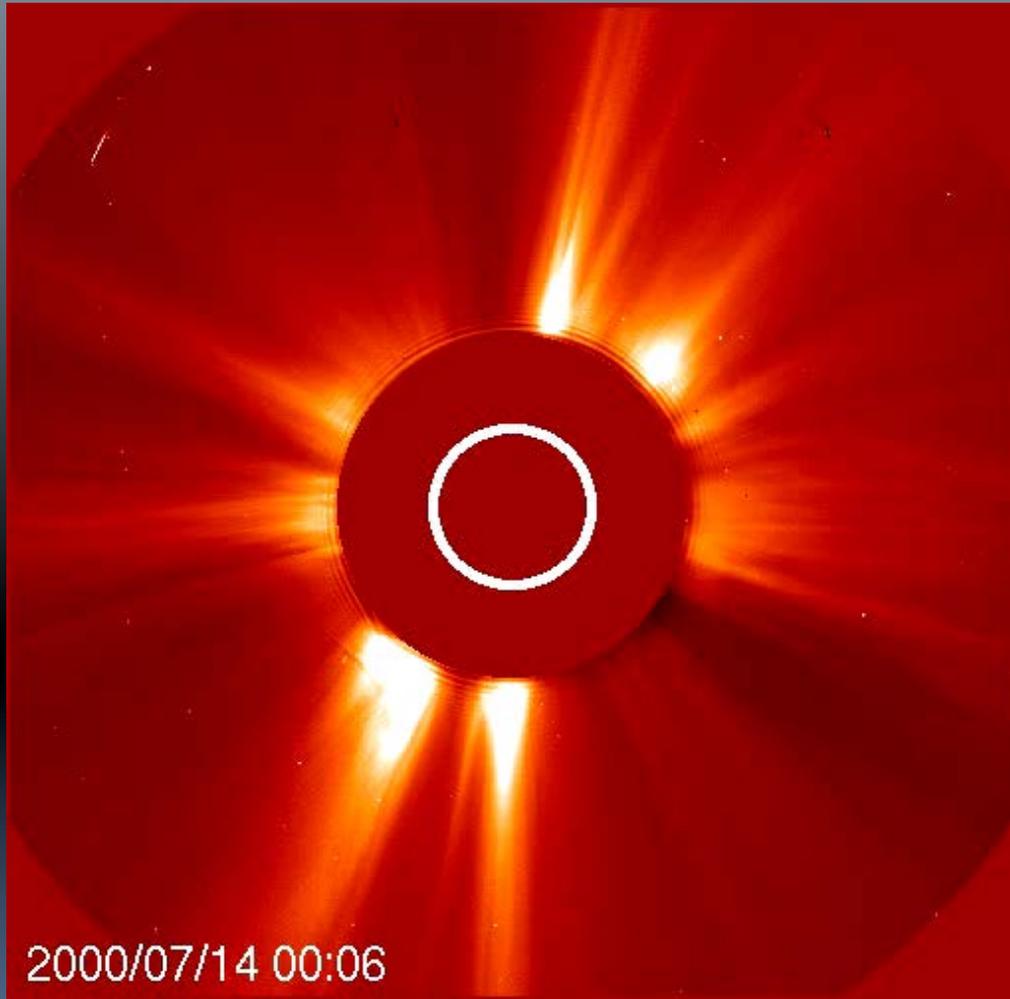


How fast is the
CME? When will it
arrive at Earth and

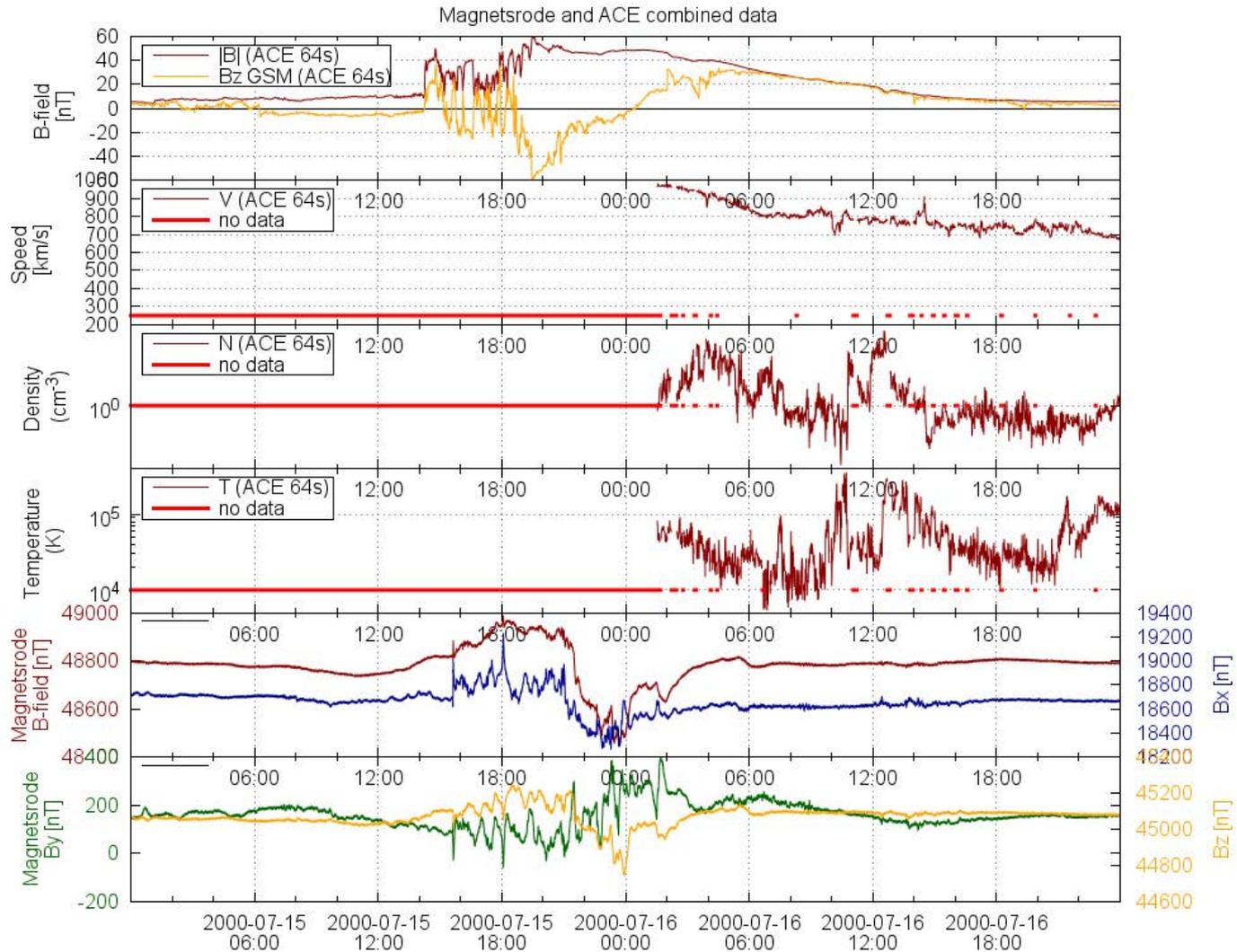
with which
-Bz ? ($\underline{E} = -\underline{v} \times \underline{B}$)



Sample CME: The July 14, 2000 event



Solar wind and ground-based magnetometer data

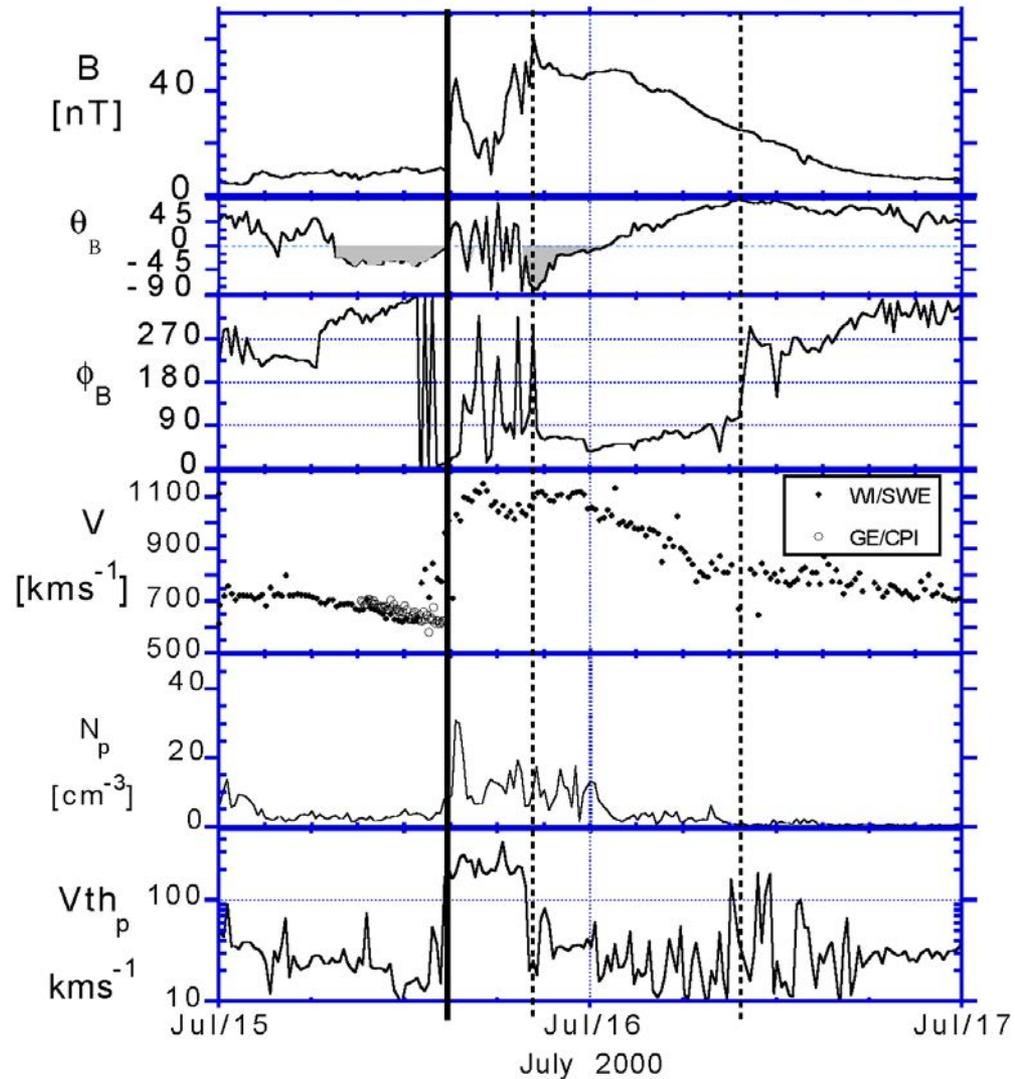


2014-09-09 16:35 CEST
2014-09-09 14:35 UTC

Kp: 8 9- 9 9- 8-

Credit: M.
Venzmer,
AFFECTS

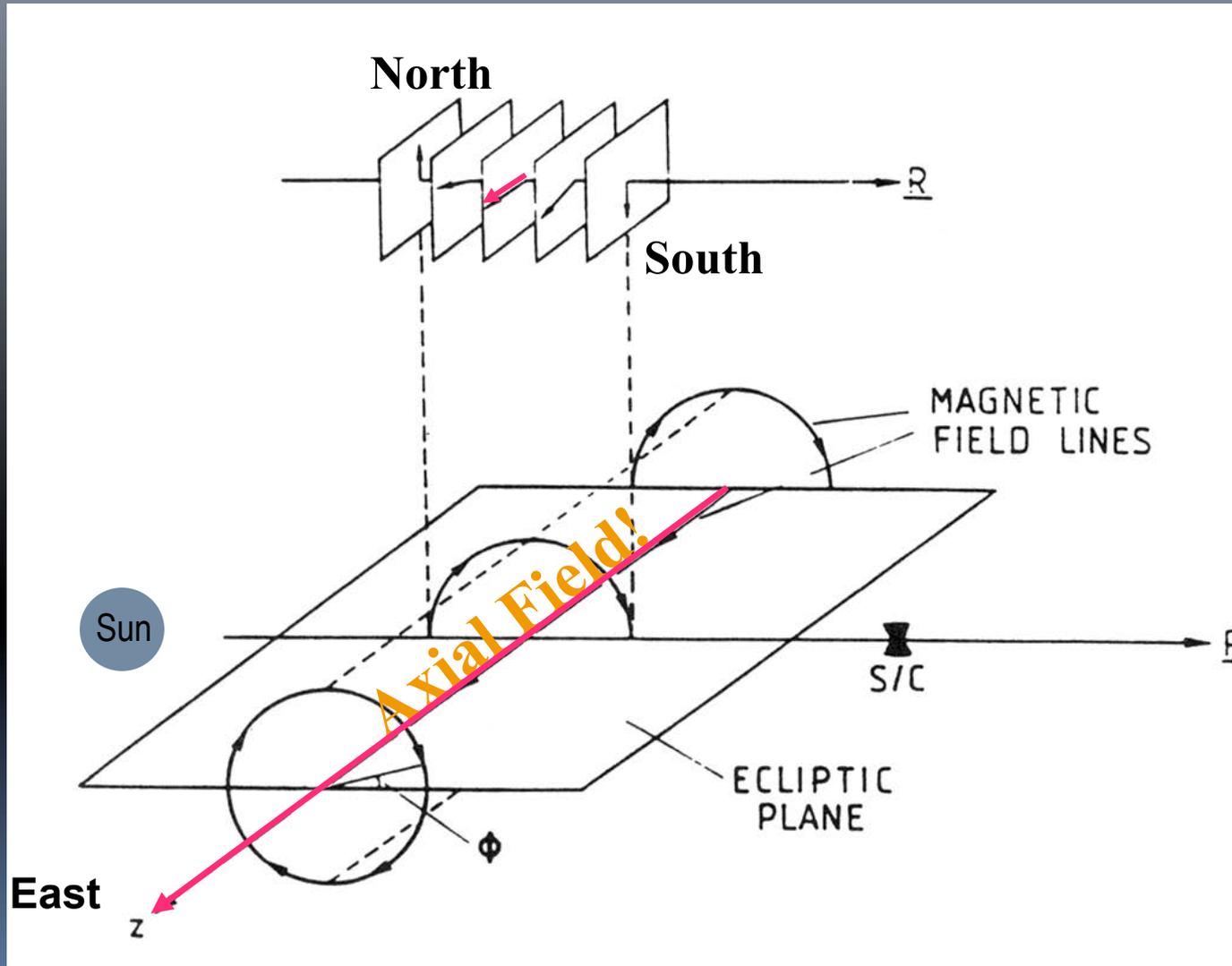
The solar wind data from Wind



S to N

E

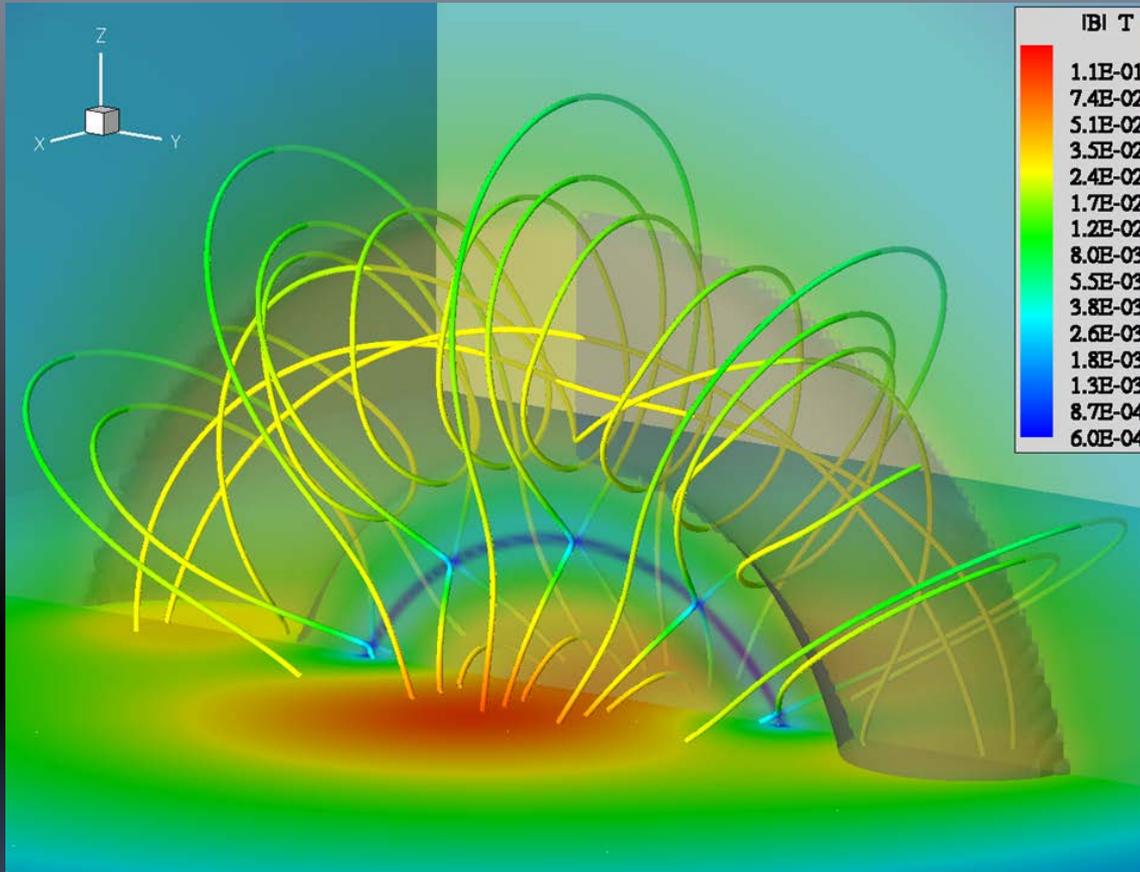
Explanation for the Magnetic Structure of a CME in the Solar Wind



In Principal,
the Cylinder can
be Arbitrarily
Inclined
with Respect
to the
Observer!

Helical Structure!

Sample References to Flux Rope Modeling



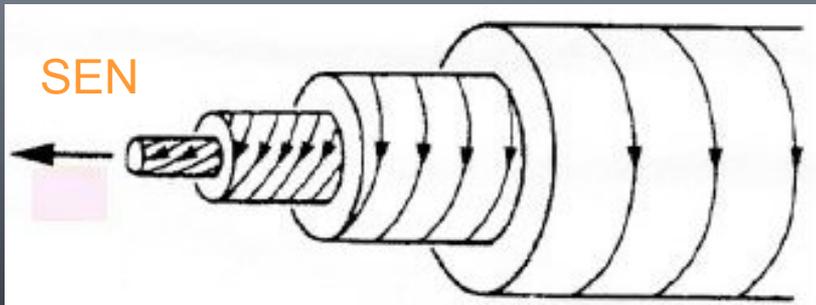
Credits: I. Roussev

- Marubashi
- Lepping
- Aulanier,
Demoulin
& Török
- Lugaz
- Roussev

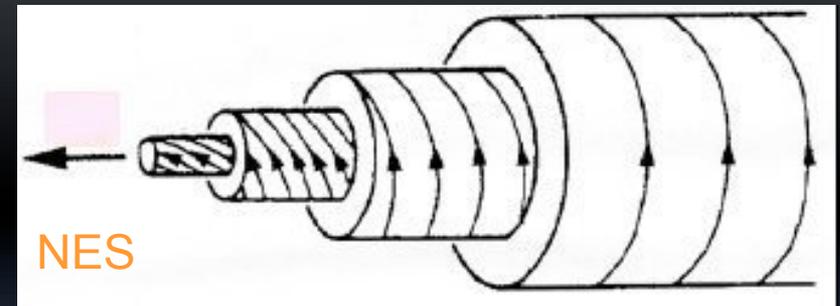
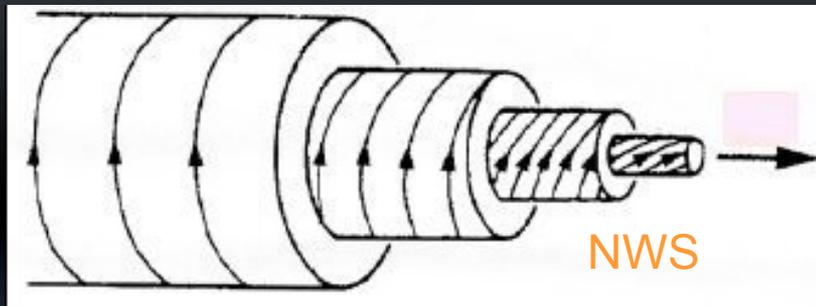
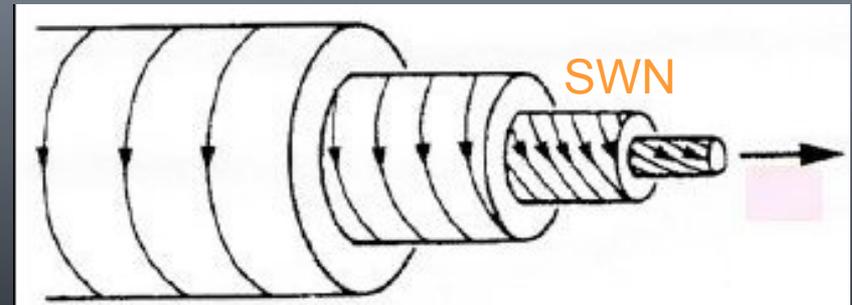
Importance of Lundquist Solutions

The four Different Types of Magnetic Flux Ropes

LH



RH

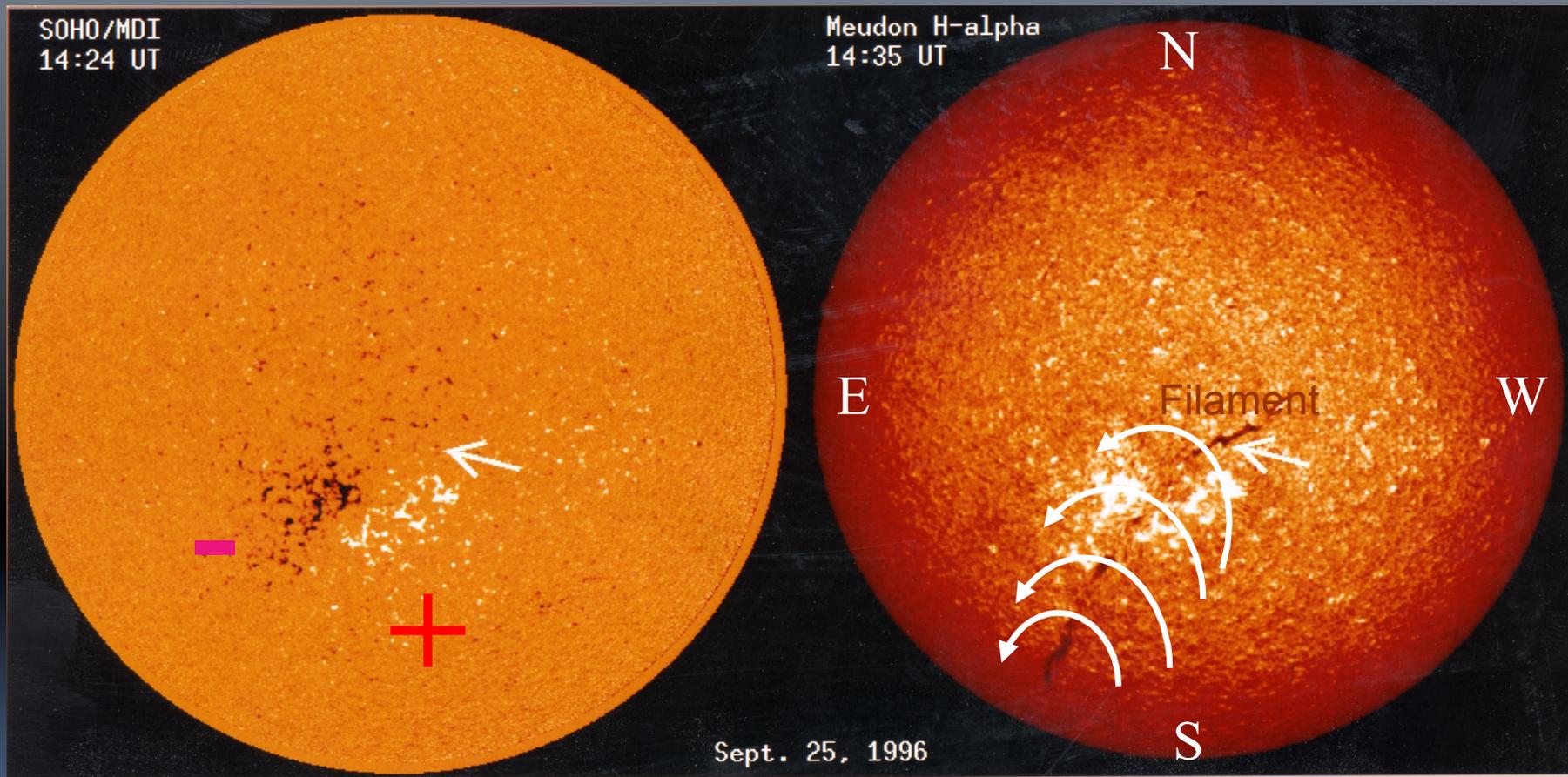


Based on Helios Observations in 1974-1981:

46 Unique Clouds, 23 LH, 23 RH

Bothmer & Schwenn, Ann. Geophys., 16, 1-24, 1998

The Structure of the Magnetic Field in Filaments above Opposite Polarity Regions

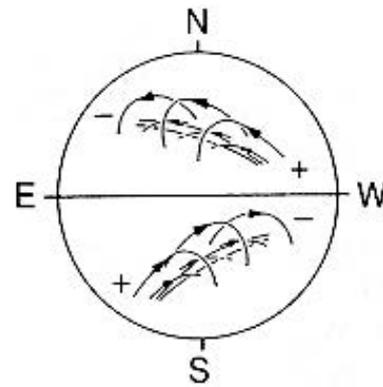
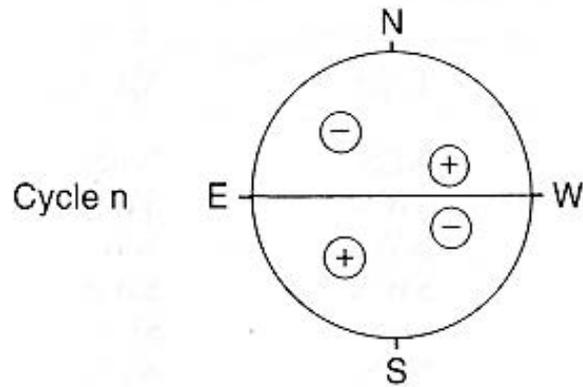


Scheme of the Dependence of CME Magnetic Cloud Configurations on the Solar Cycle

Magnetic polarity of sunspots

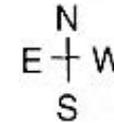
Structure of filaments

Flux rope type of magnetic clouds

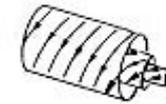


LH-helicity

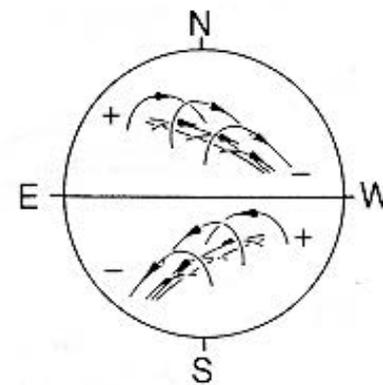
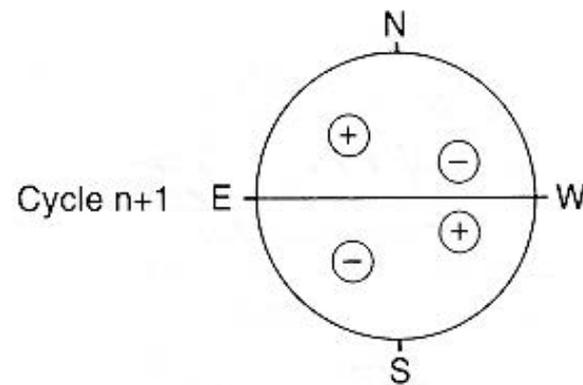
RH-helicity



SEN



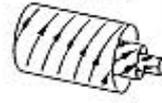
SWN



LH-helicity

RH-helicity

NWS



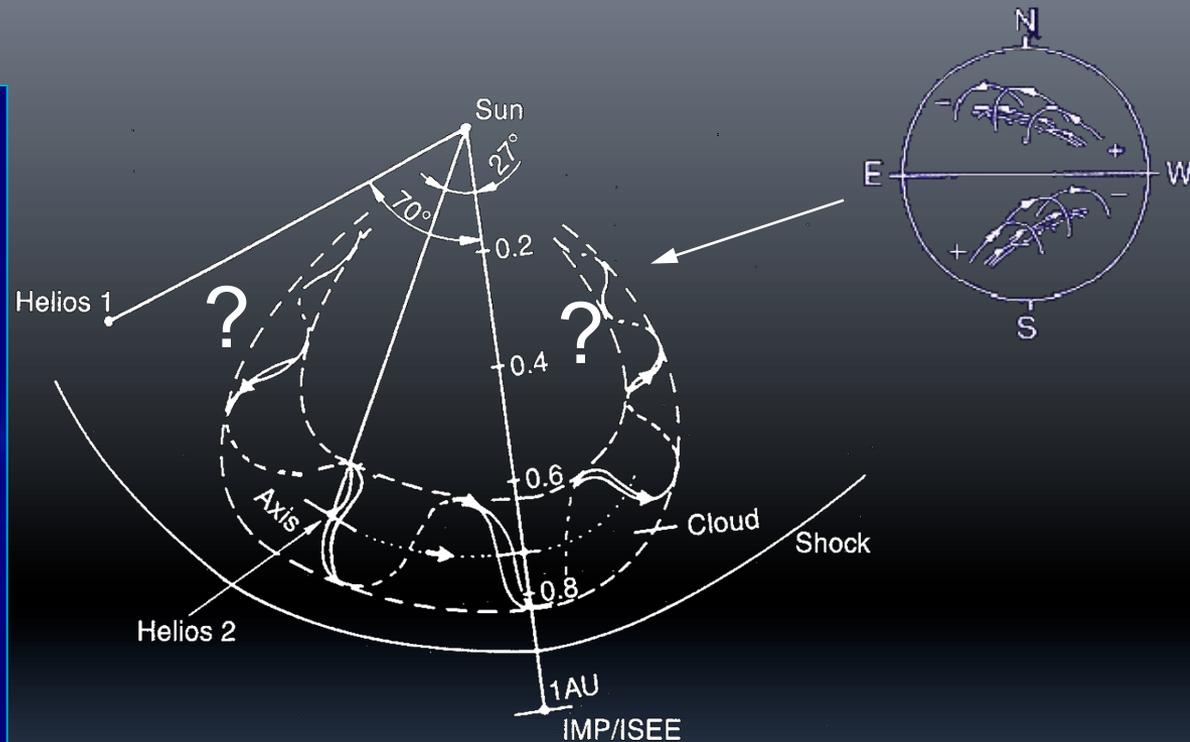
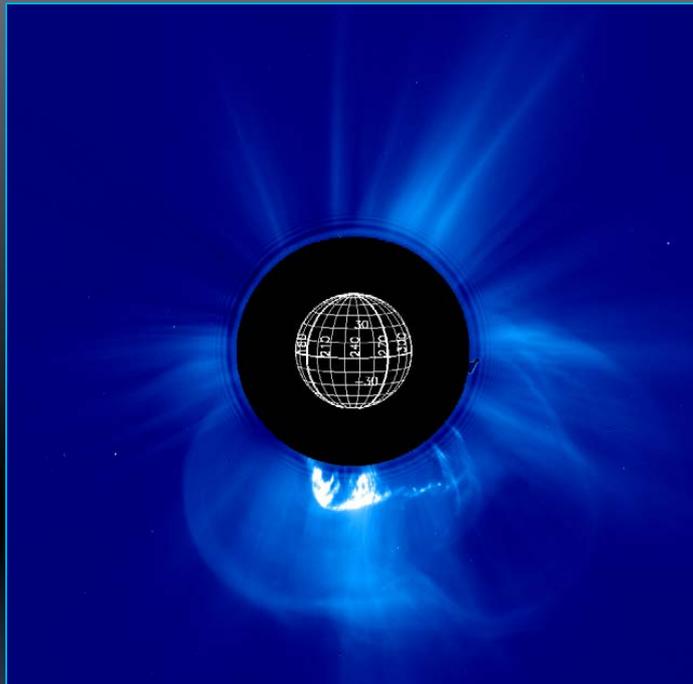
NES



No consideration of quadrupolar fields

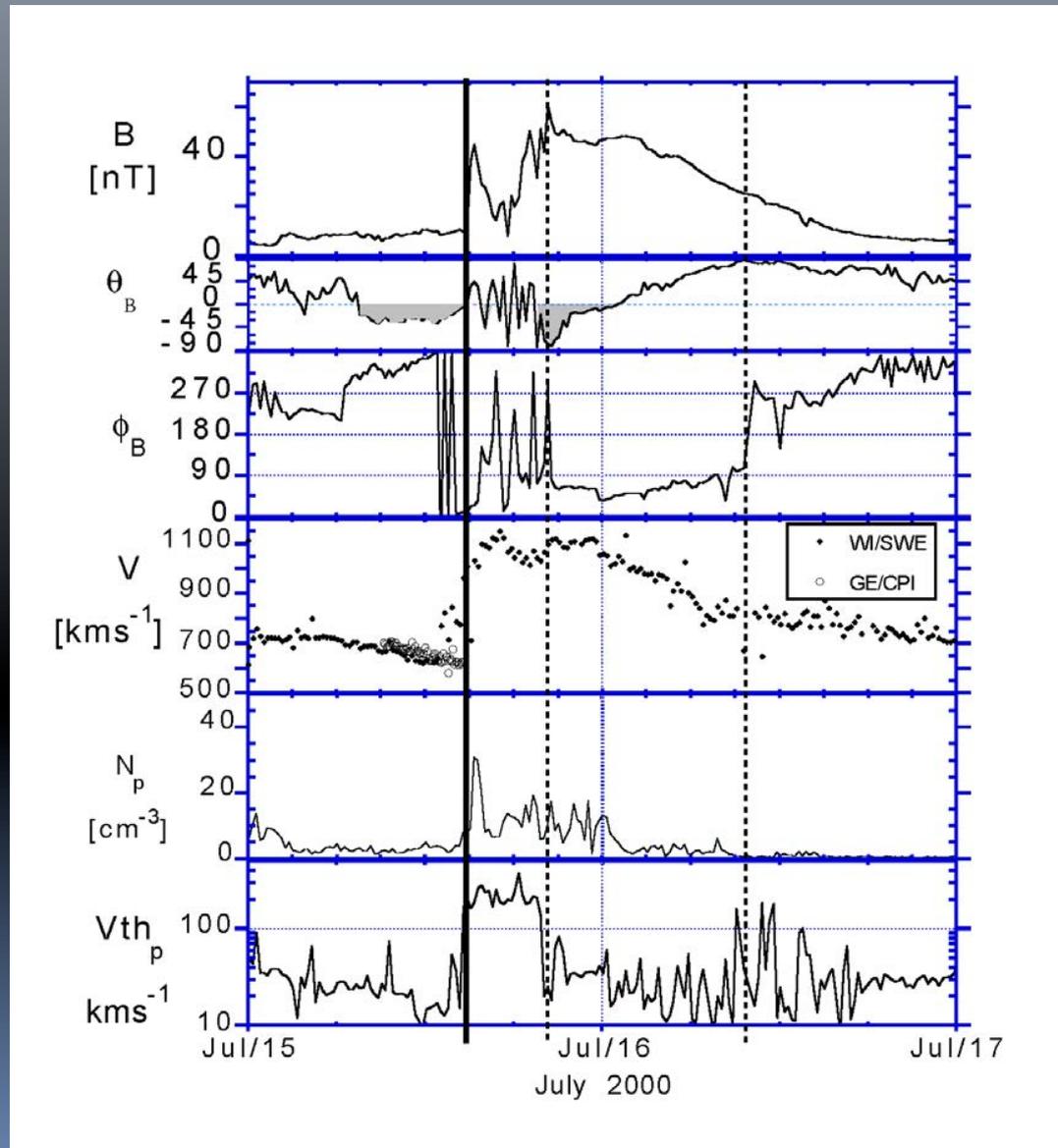
Bothmer & Schwenn, 1998

Sketch of the Possible Origin of Interplanetary Magnetic Flux Ropes

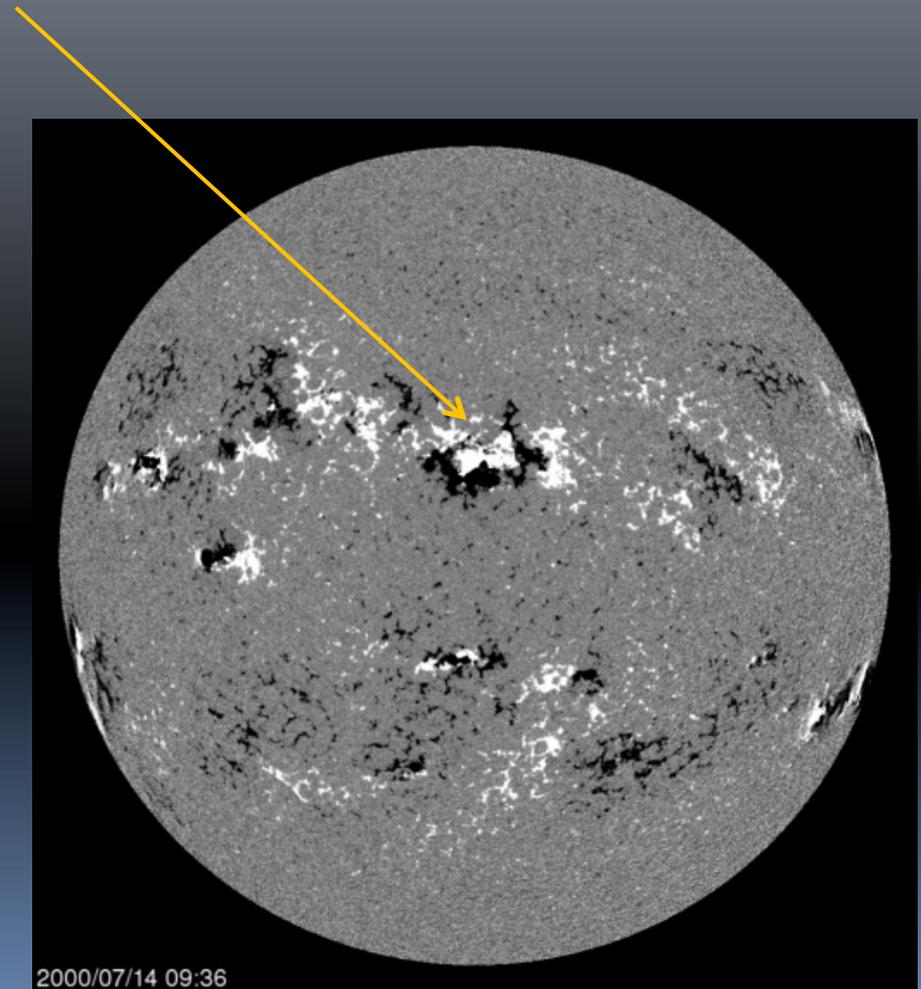
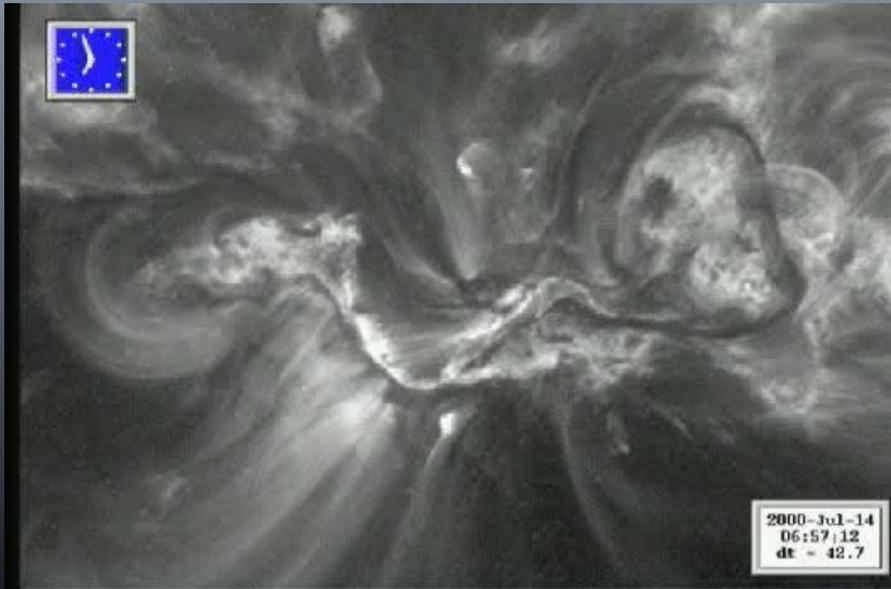


Only 1/3 of all ICMEs appear to be flux ropes (Gosling, 1993); 46% (Bothmer & Schwenn, 1996)

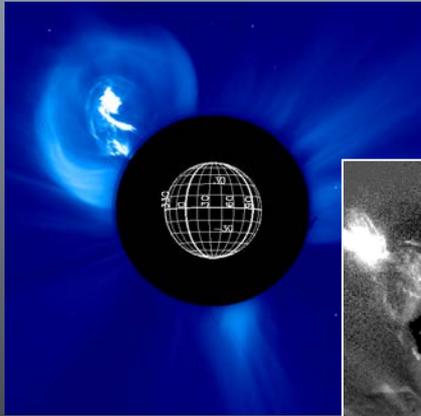
Let's come back to the origin of the July 2000 CME



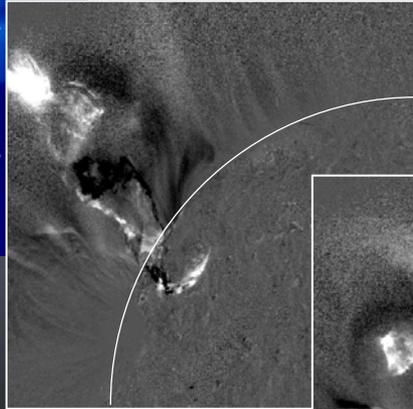
TRACE Observations and SOHO/MDI magnetogram



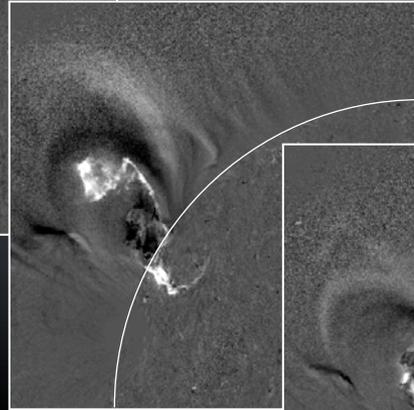
CMEs originate from bipolar photospheric fields regions



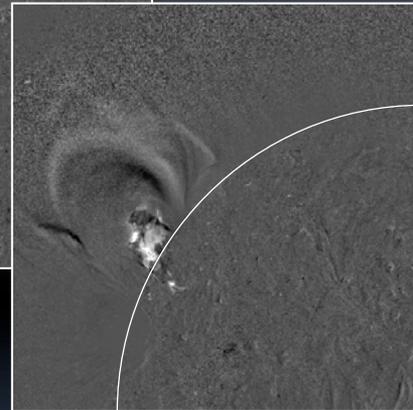
2002/01/04 10:06 UT



2002/01/04 9:36 UT



2002/01/04 9:24 UT

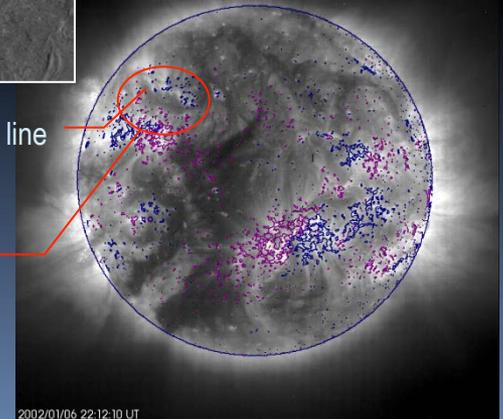


2002/01/04 9:12 UT

SOHO/EIT/LASCO/MDI

time ←

CMEs Origin

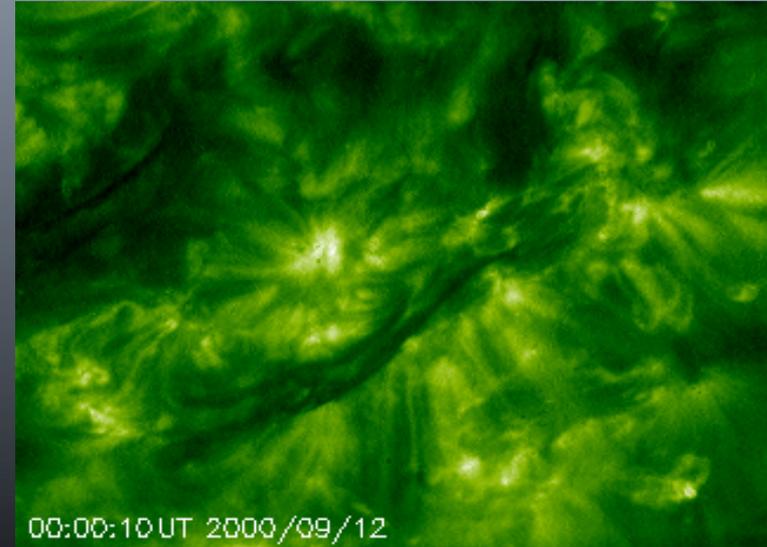
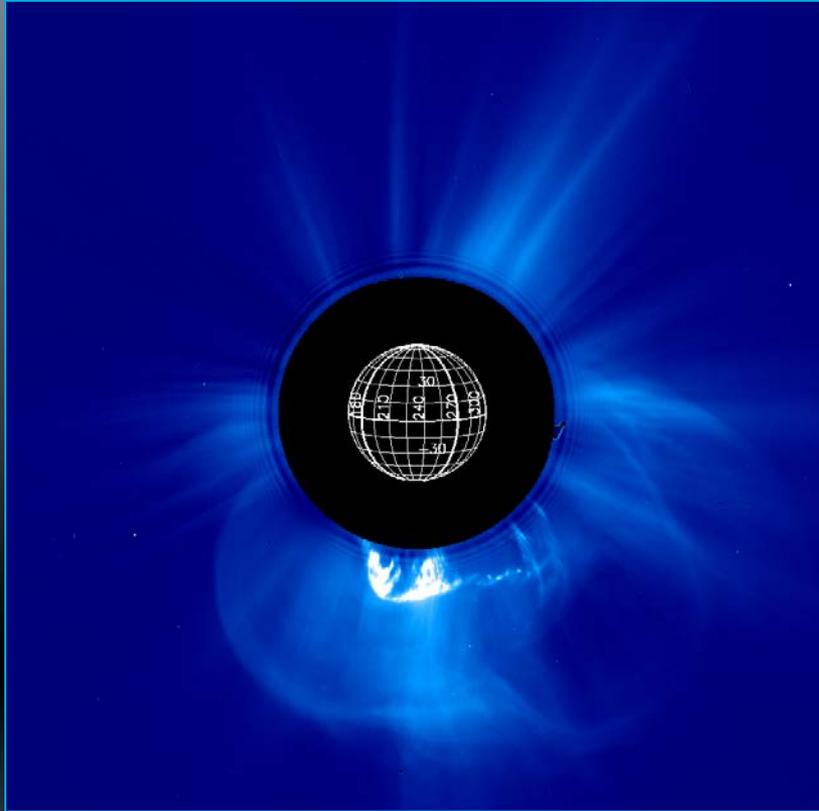


Neutral line

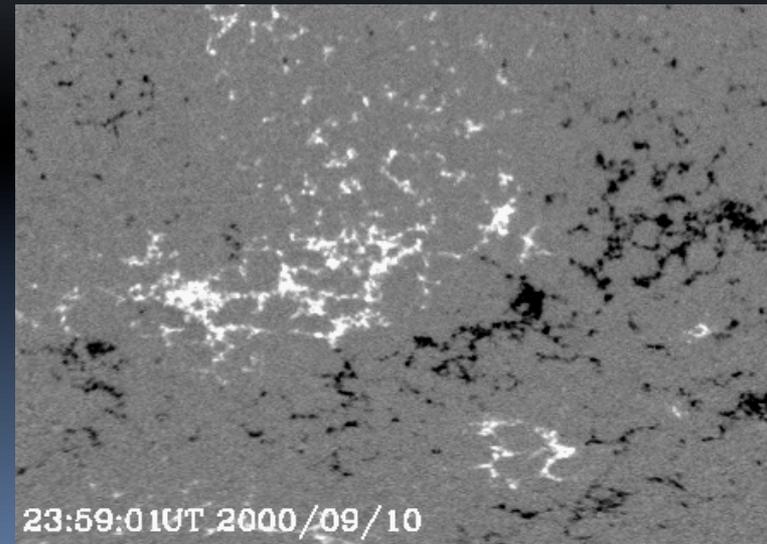
Opposite Polarities

2002/01/04 22:12:10 UT

Filament, Arcade and Variation of the Photospheric Magnetic Flux in the Source Region of a CME



EIT
195 Å



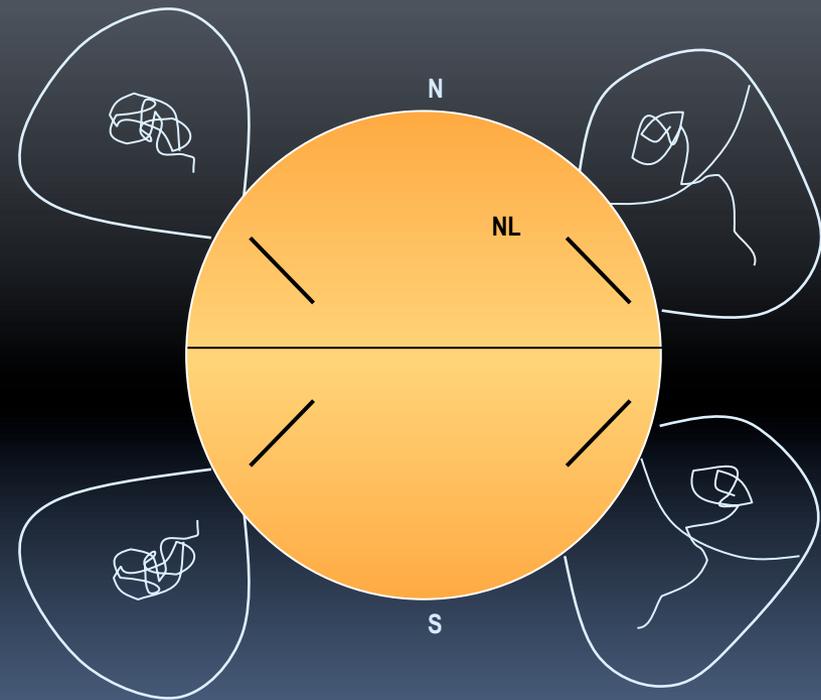
MDI

A detailed study was carried out to investigate the evolution of the photospheric flux in the source regions of CMEs (Tripathi, Bothmer, Cremades, *A&A*, 422, 307-322, 2004).

Basic Scheme Explaining the 3D Structure of CMEs

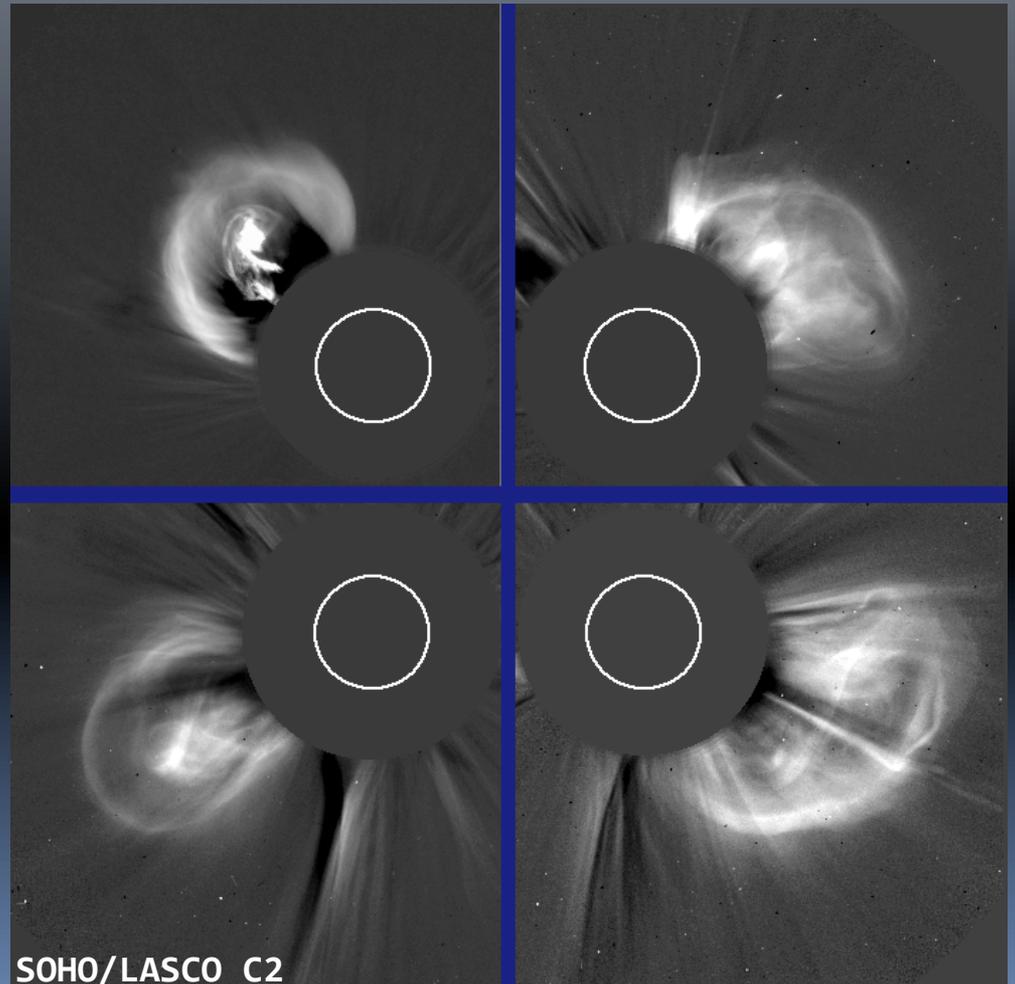
The WL coronagraph observations of CMEs can be modeled through large-scale magnetic flux ropes which properties depend on the magnetic source region characteristics.

Joy's & Hale's laws



Scheme is simplification !

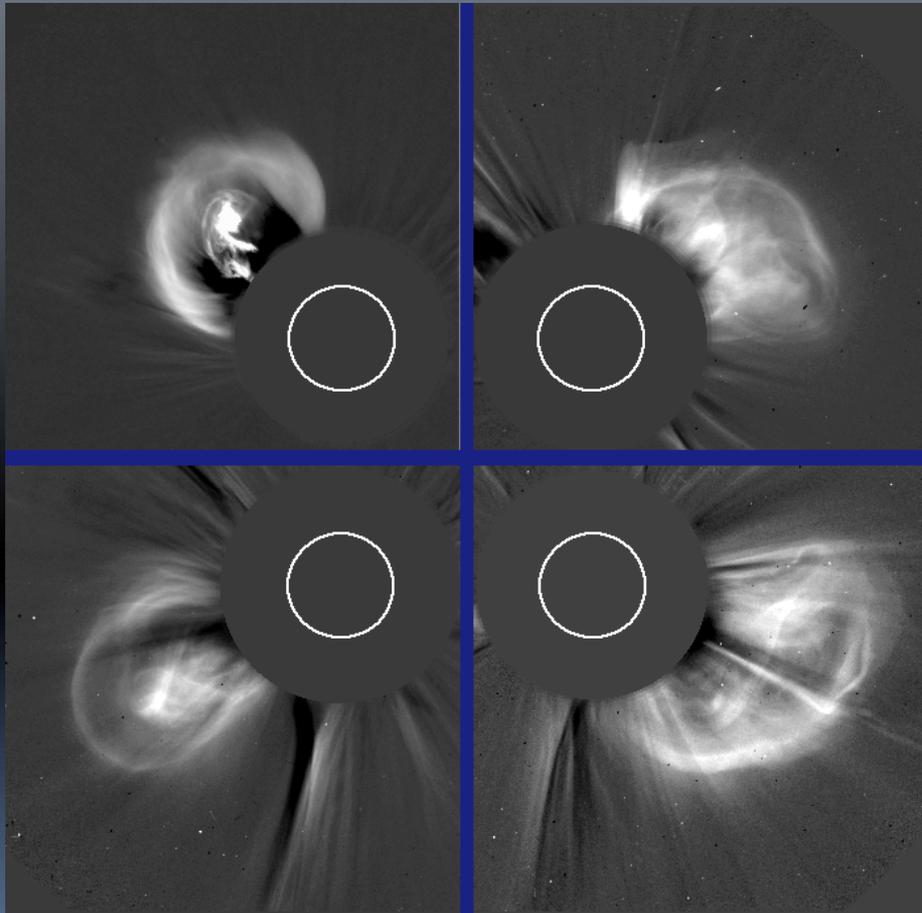
Cremades & Bothmer, A&A 2004



SOHO/LASCO C2

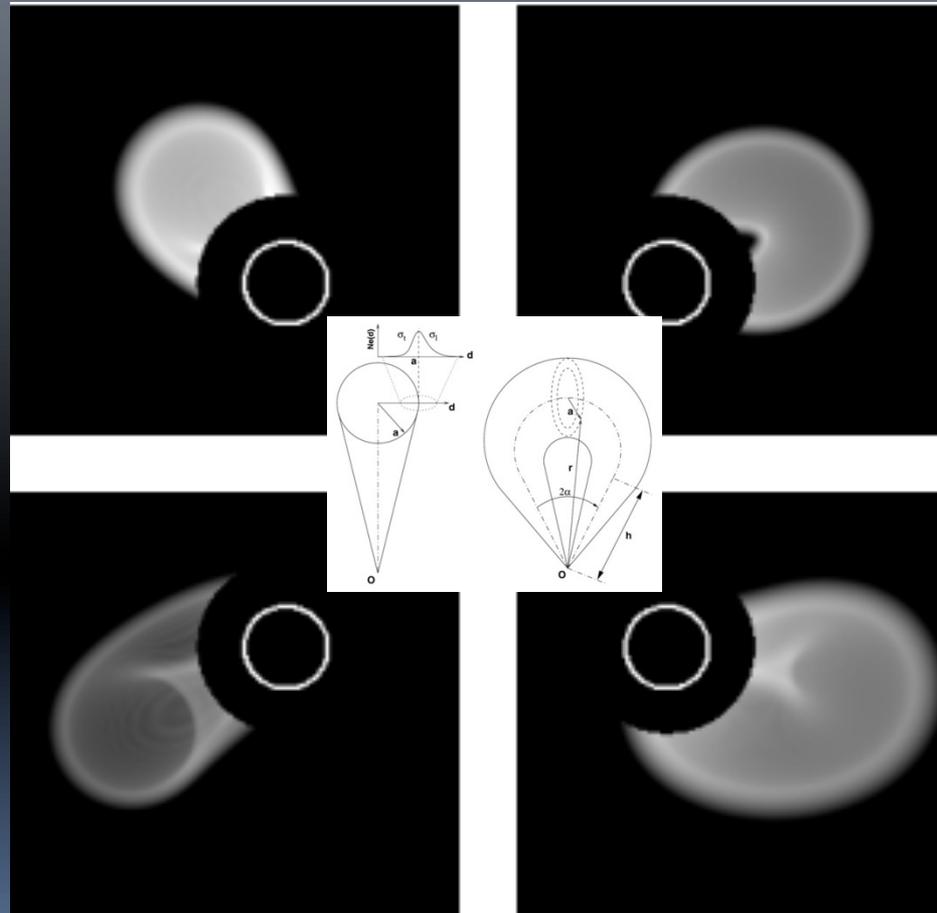
Modelling the Electron Density Distribution

LASCO Observations



Cremades & Bothmer, A&A 2004

Simulations (GCS-Modell, $\int n_e dV$)



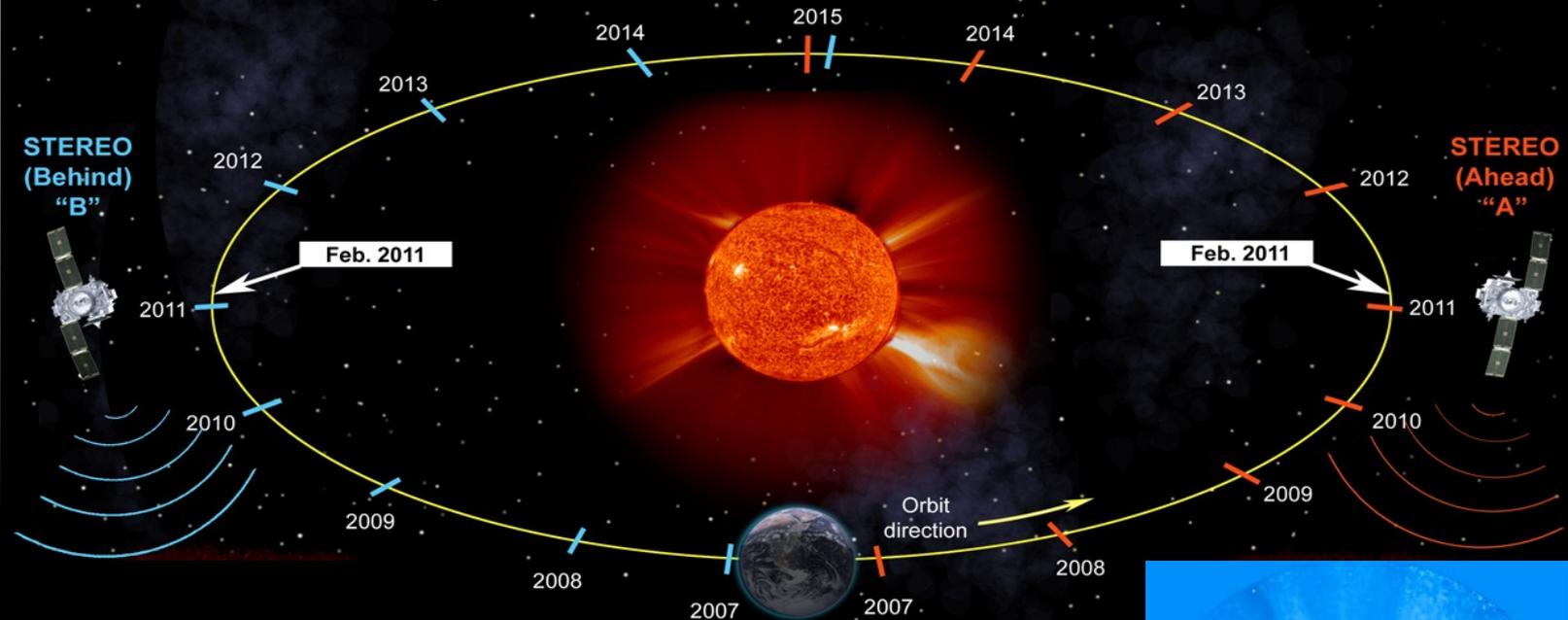
Howard, Thernissien and Vourlidis, ApJ 2006

Part 2

Observations and Results from STEREO and the HELCATS Project

Earth-Selfie from STEREO-A

NASA's STEREO Sees the Entire Sun



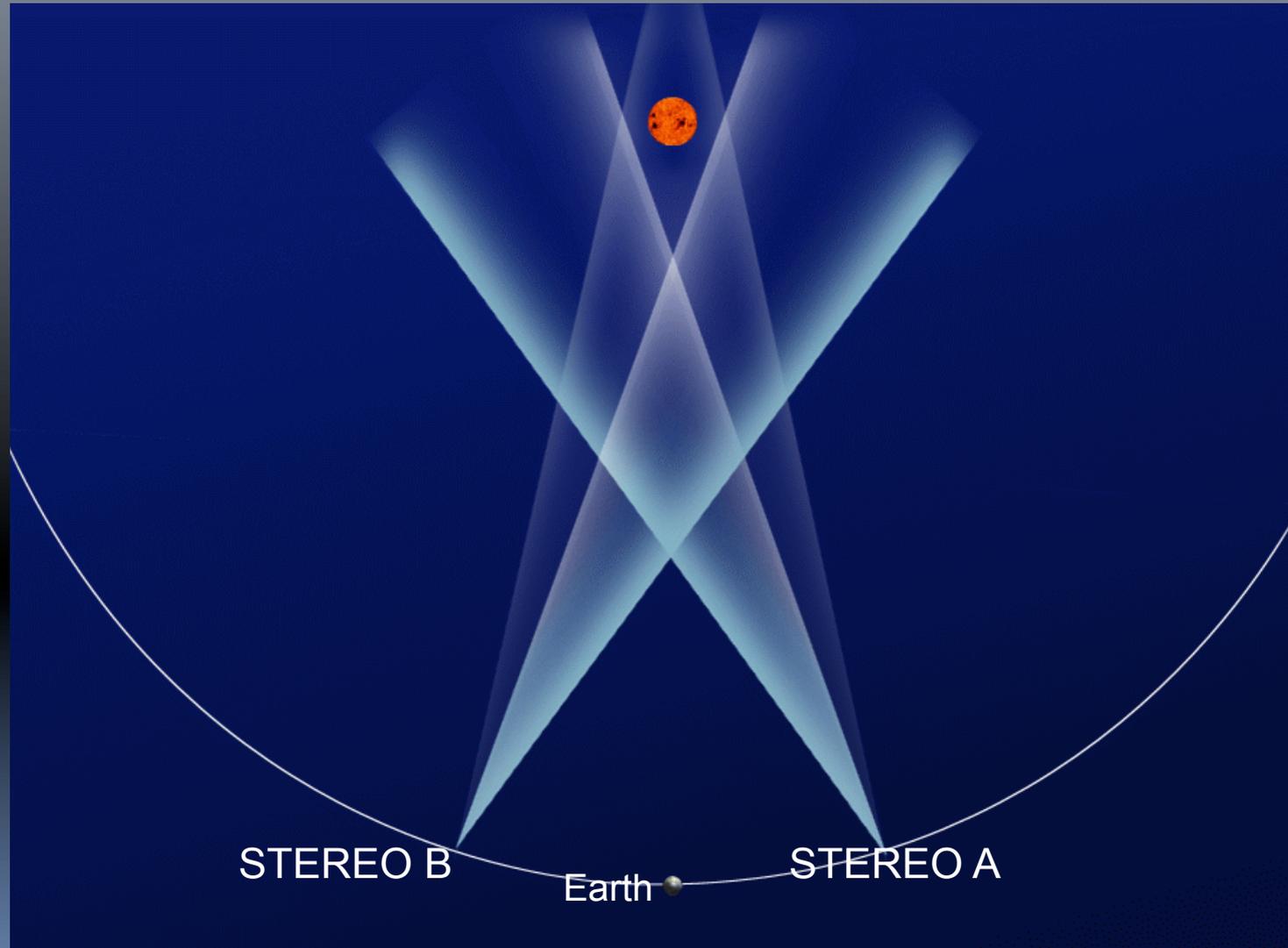
No image available

The two **STEREO** spacecraft reach 180 degrees separation and observe the *entire* Sun for the first time ever.

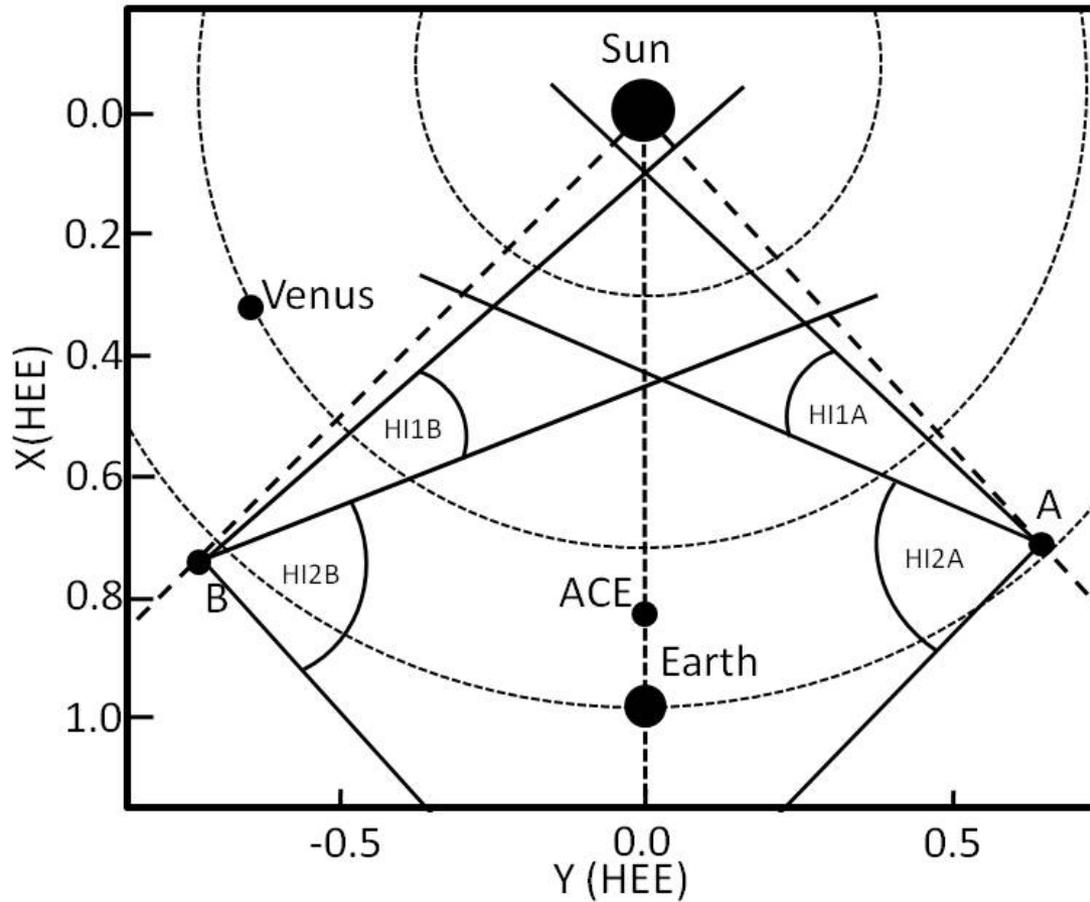
Drawing gives the relative orbital positions of both STEREO spacecraft for each year from June 2007 to June 2015. (Not to scale)



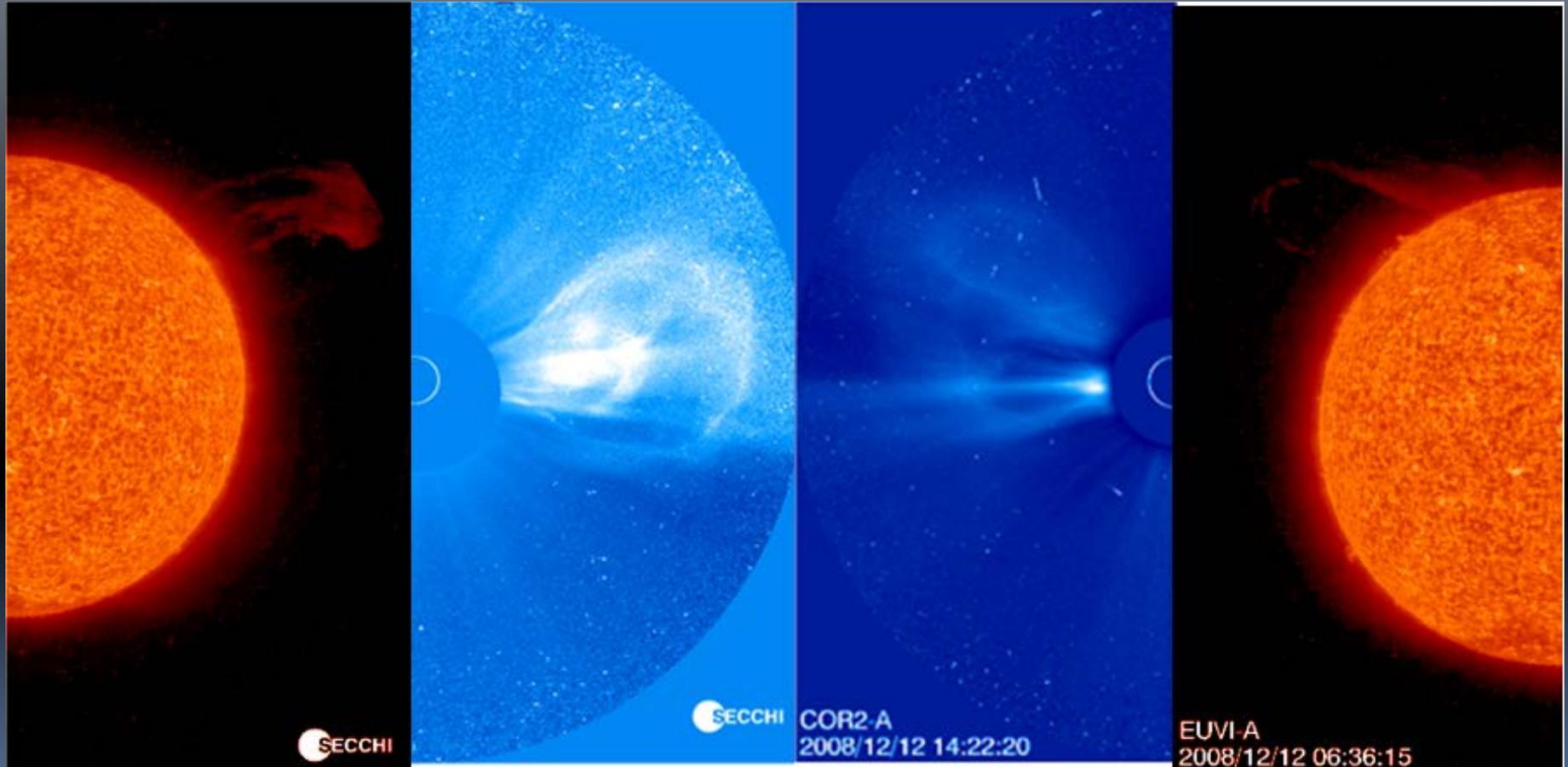
Stereoscopic Observations of the Sun-Earth System



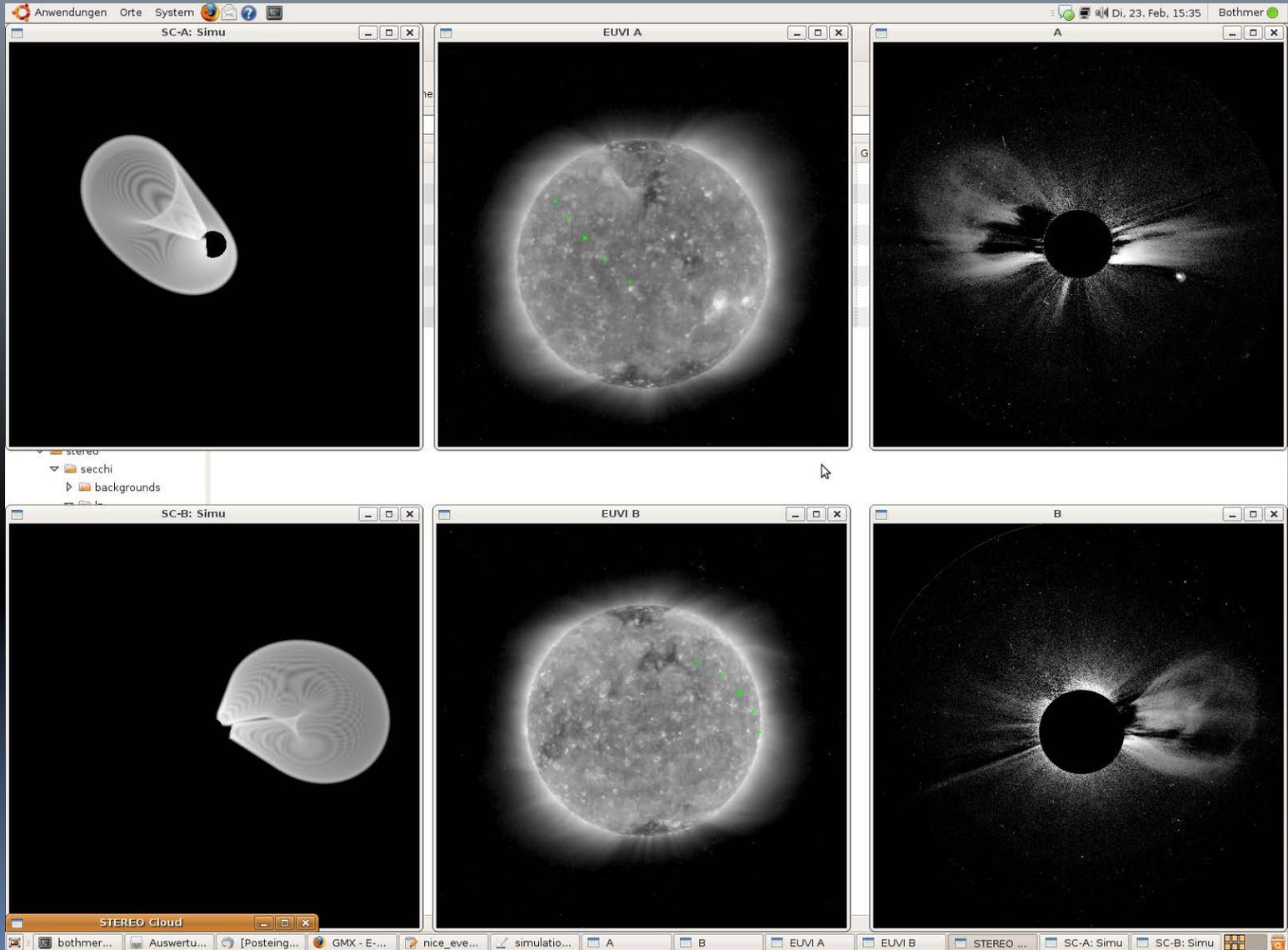
December 2008 – First CME Tracked All Away Along the Sun-Earth Line



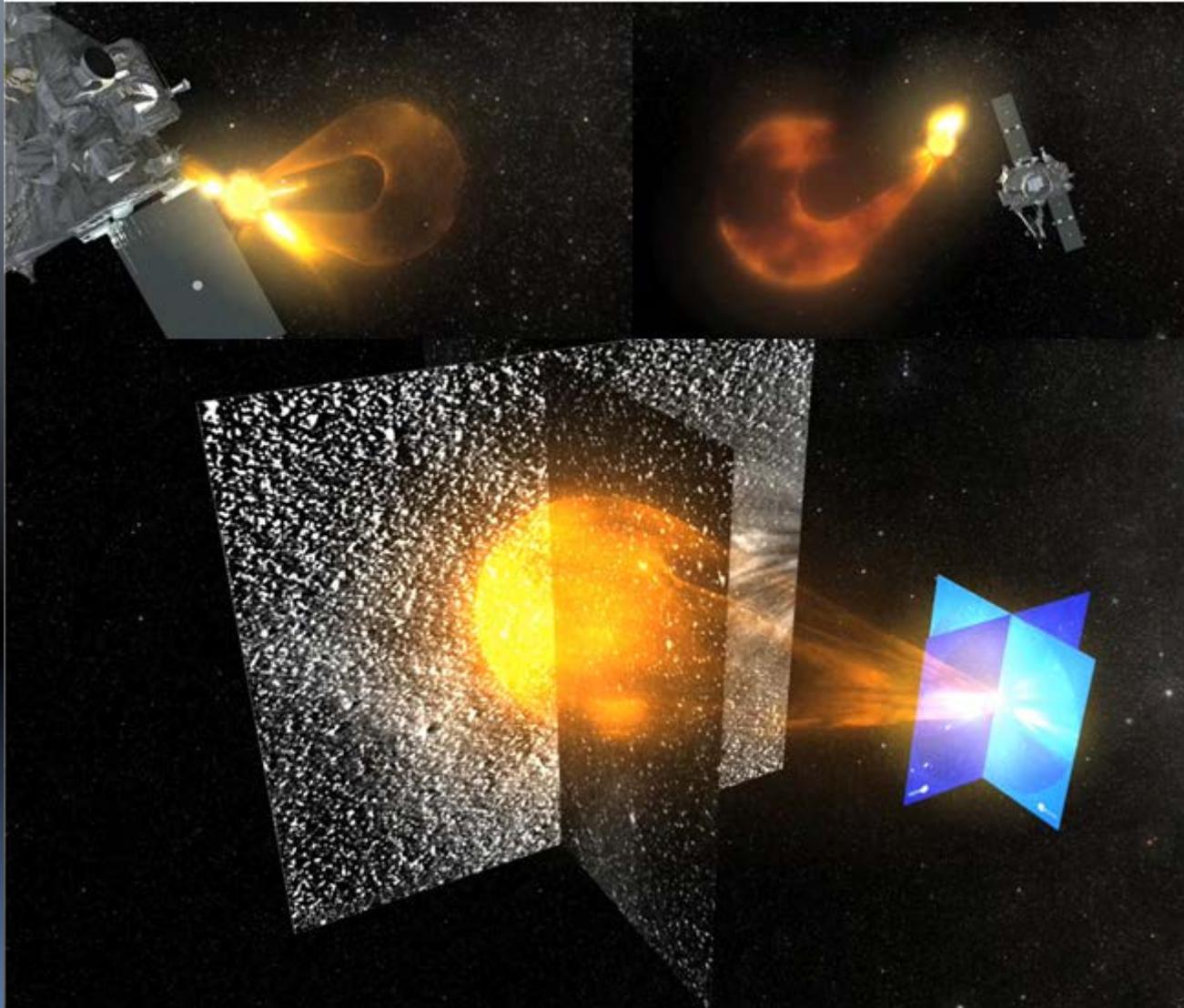
STEREO SECCHI/EUVI A, B 304 Å and COR 2 A, B Observations



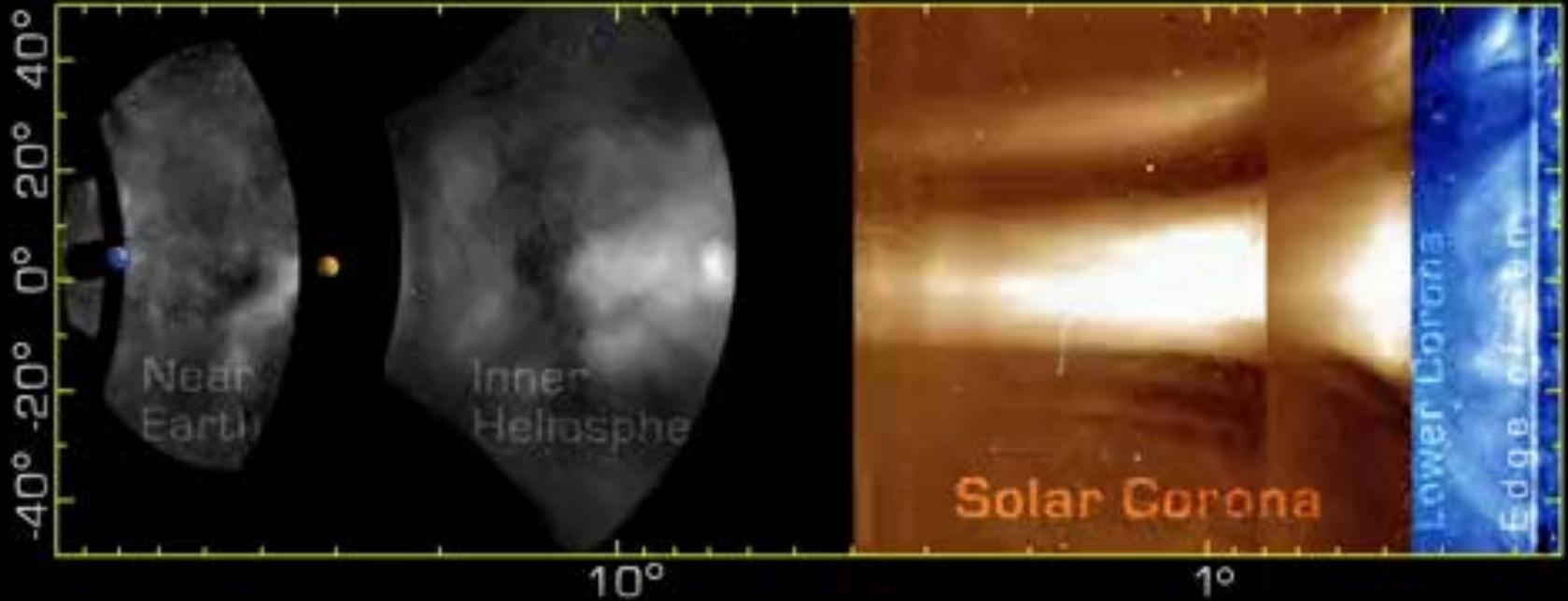
CME Modeling: Dec. 12, 2008



CMEs are large-scale magnetic flux ropes



CME tracked Sun to Earth



STEREO-A: 12/11/08 12:55:00 AM

Credit: NASA, deForest

The EU Project HELCATS



NEWS

LATEST FROM HELCATS

News and updates from the project

[2015-02-10: HELCATS release details of first open workshop](#)

[2014-12-10: HELCATS postdoc position advertised at IC](#)

[2014-10-01: HELCATS announcement press release](#)

[2014-06-10: Public web site launch](#)

[All news items...](#)

Events

VISIT HELCATS

The project will be represented at

[2015-05-19/22: The 1st HELCATS annual open workshop, UGOE](#)

[All Events...](#)

Who's Involved

MEET THE CONSORTIUM

[Consortium Institutes](#)

HELCASTS

THE SCIENCE OF TRACKING SOLAR STORMS



The advent of wide-angle imaging of the inner heliosphere has revolutionised the study of the solar wind and, in particular, transient solar wind structures such as Coronal Mass Ejections (CMEs) and Co-rotating Interaction Regions (CIRs).

CMEs comprise enormous plasma and magnetic field structures that are ejected from the Sun and propagate at what can be immense speeds through interplanetary space, while CIRs are characterised by extensive swathes of compressed plasma/ magnetic field that form along flow discontinuities of solar origin that permeate the inner heliosphere.

With Heliospheric Imaging came the unique ability to track the evolution of these features as they propagate through the inner heliosphere. Prior to the development of wide-angle imaging of the inner heliosphere, signatures of such solar wind transients could only be observed within a few solar radii of the Sun, and in the vicinity of a few near-Earth and interplanetary probes making in-situ measurements of the solar wind. Heliospheric Imaging has, for the first time, filled that vast and crucial observational gap.



[Find out more about solar storms and space weather from NASA FAQ](#)

[Credit: NASA]



[Learn about the NASA STEREO Mission](#)

[Credit: NASA]

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 **Miho Janvier**
@MihoJnvr

22 May

Now talking about the @esa proba missions. Proba-3 w/ coronagraph to be launched in 2018 @EU_HELCASTS pic.twitter.com/9lYxcaBUGw

↳ Retweeted by HELCATS



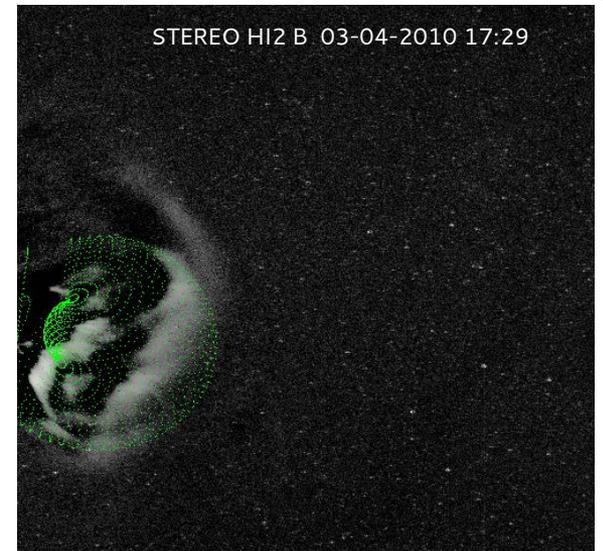
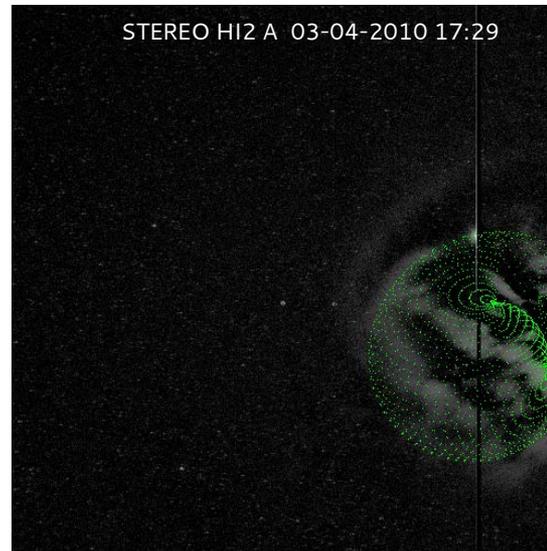
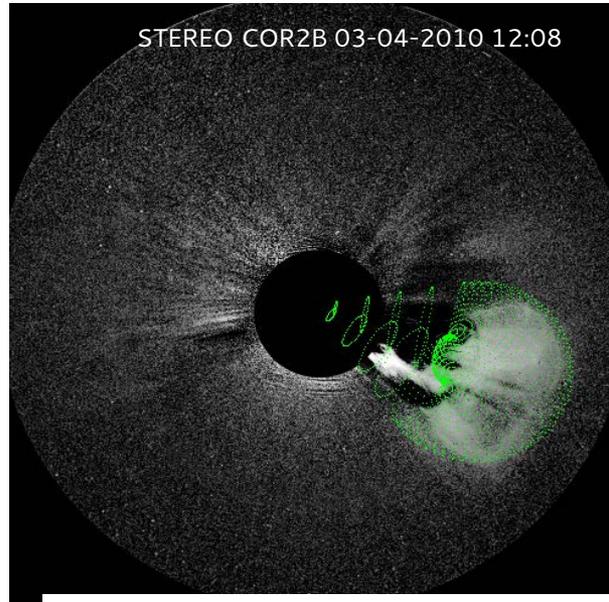
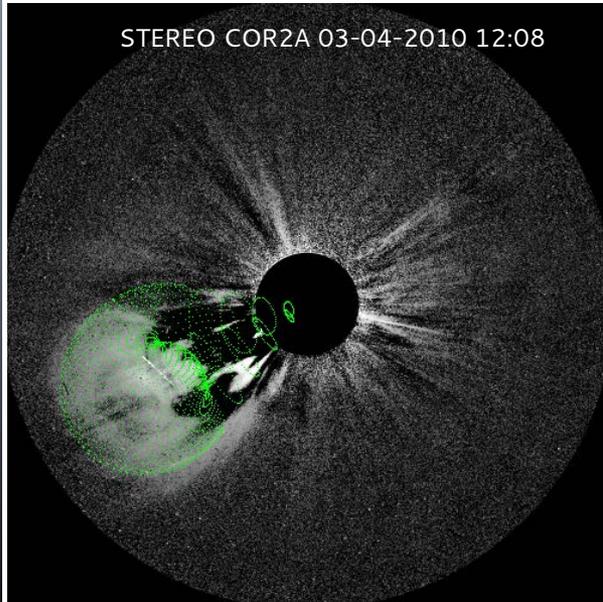
Expand

 **Miho Janvier**
@MihoJnvr

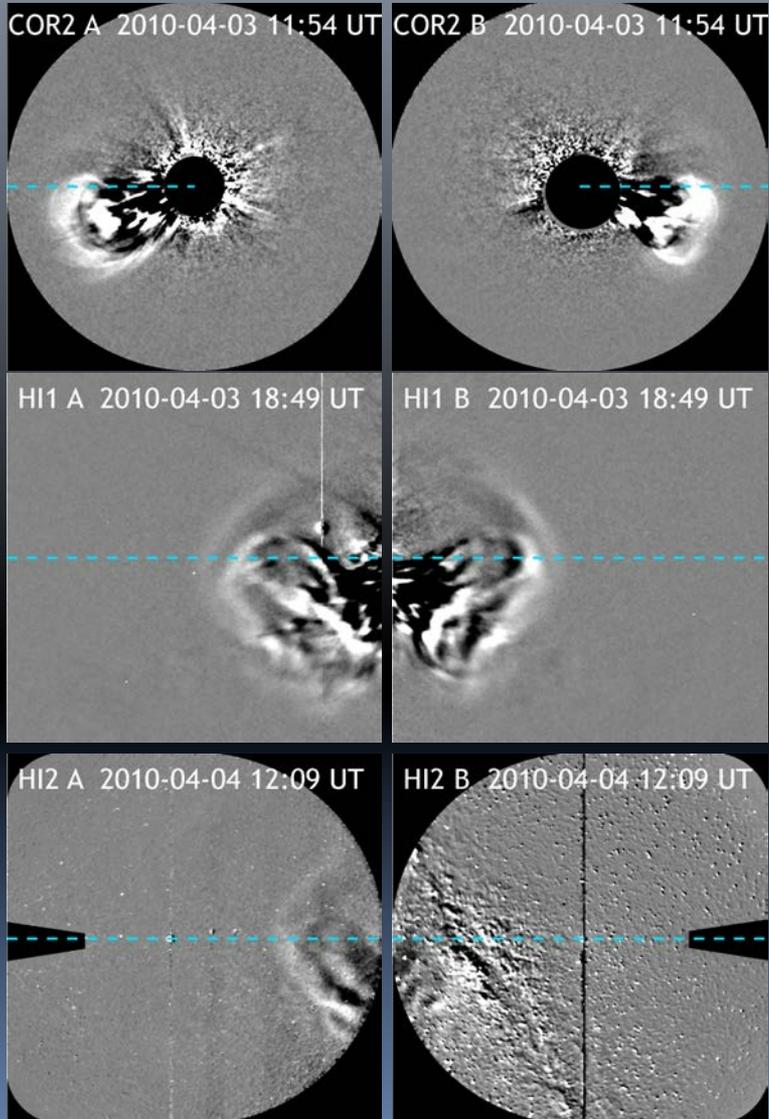
19 May

CME prediction for the @NASANewHorizons too by #ENLII

Stereoscopic Modeling in the Heliosphere



Research on CME Shock Stand-Off Distances



Volpes & Bothmer, Solar Phys.
DOI 10.1007/s11207-015-0775-z

An Application of the Stereoscopic Self-similar-Expansion Model to the Determination of CME-Driven Shock Parameters

	ACE	1st degree fit $\lambda = 10^\circ$	1st degree fit $\lambda = 90^\circ$
Standoff distance	19 R_\odot	30 R_\odot	26 R_\odot
Mach number	2.2	1.38	3.26
Compression ratio	2.84	0.75	2.82

	ACE	2nd degree fit $\lambda = 10^\circ$	2nd degree fit $\lambda = 90^\circ$
Standoff distance	19 R_\odot	29 R_\odot	26 R_\odot
Mach number	2.2	1.41	3.46
Compression ratio	2.84	0.78	2.91

Part 3

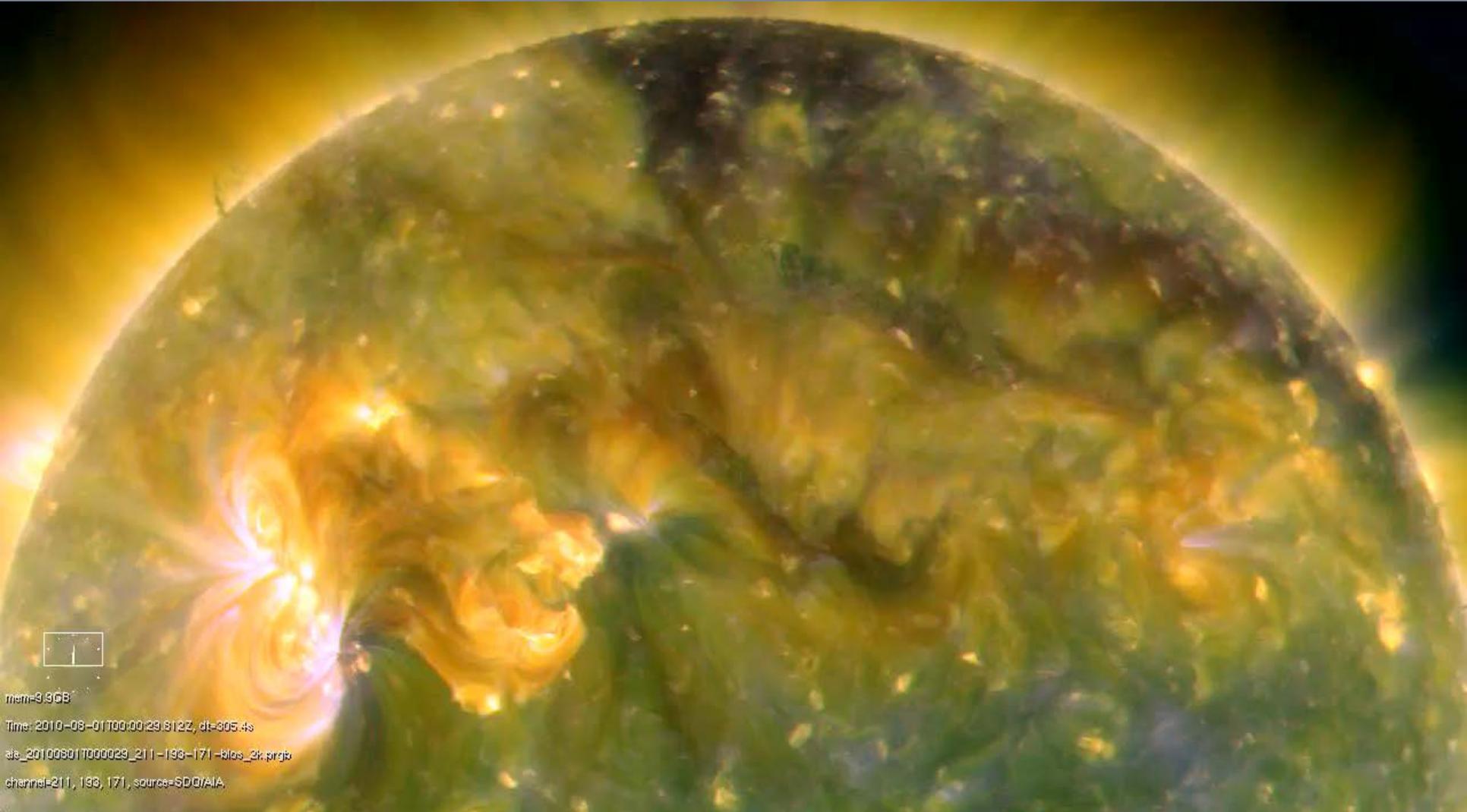
Challenges for improved space weather forecasts

Issues to be taken into account

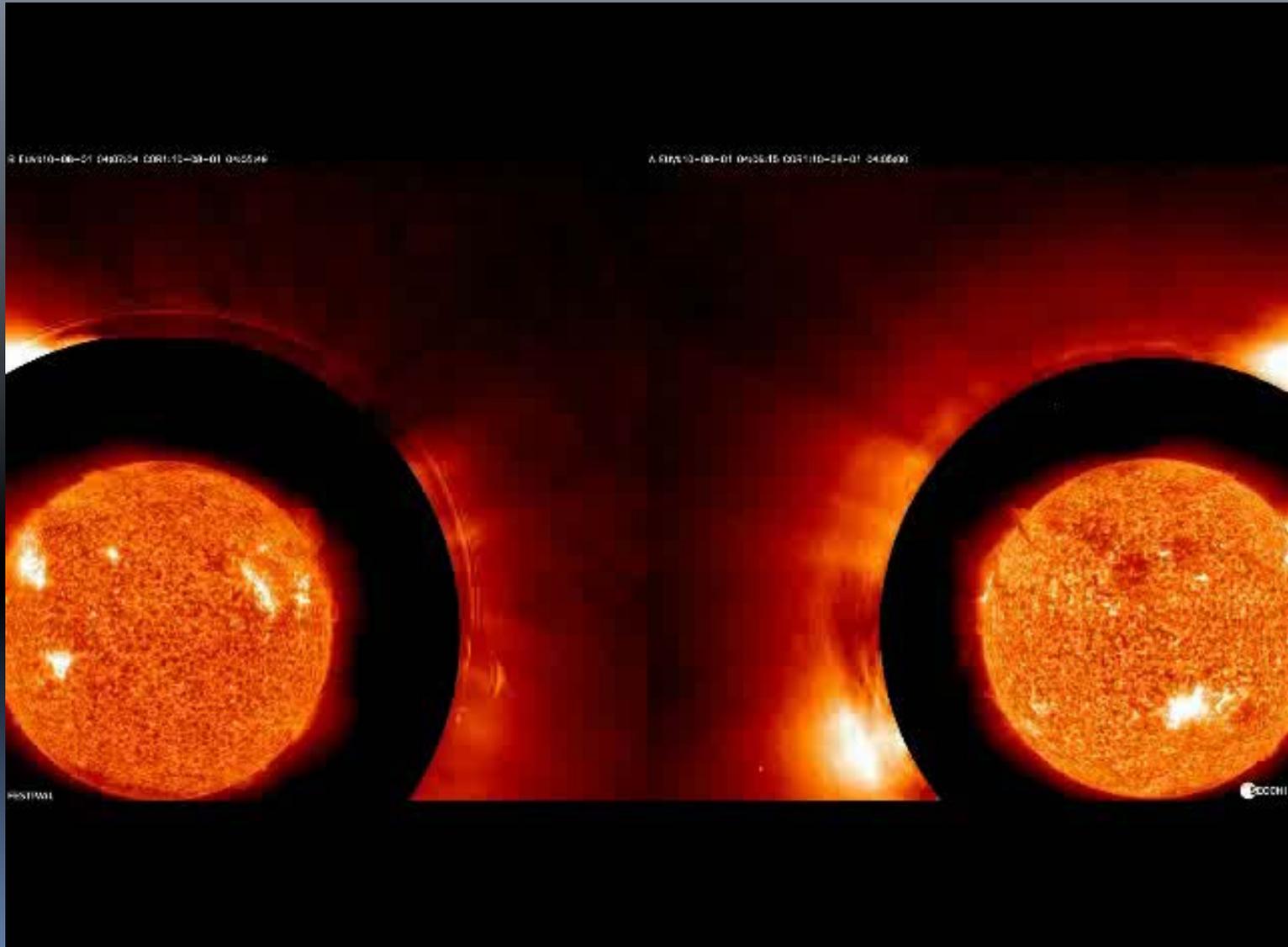
1. Multiple activity and complex energy release
2. Treatment of CME shock fronts and distortions
3. Lateral expansion of CMEs and subsequent B-Field expansion

STEREO/SECCHI: Direct Observation of a CME Sun to Earth in August 2010

Multiple Solar Activity: August 01, 2010, SDO/AIA

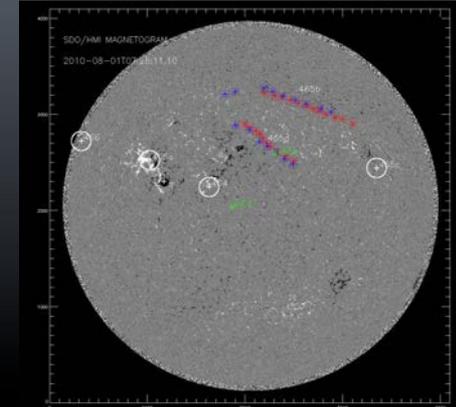
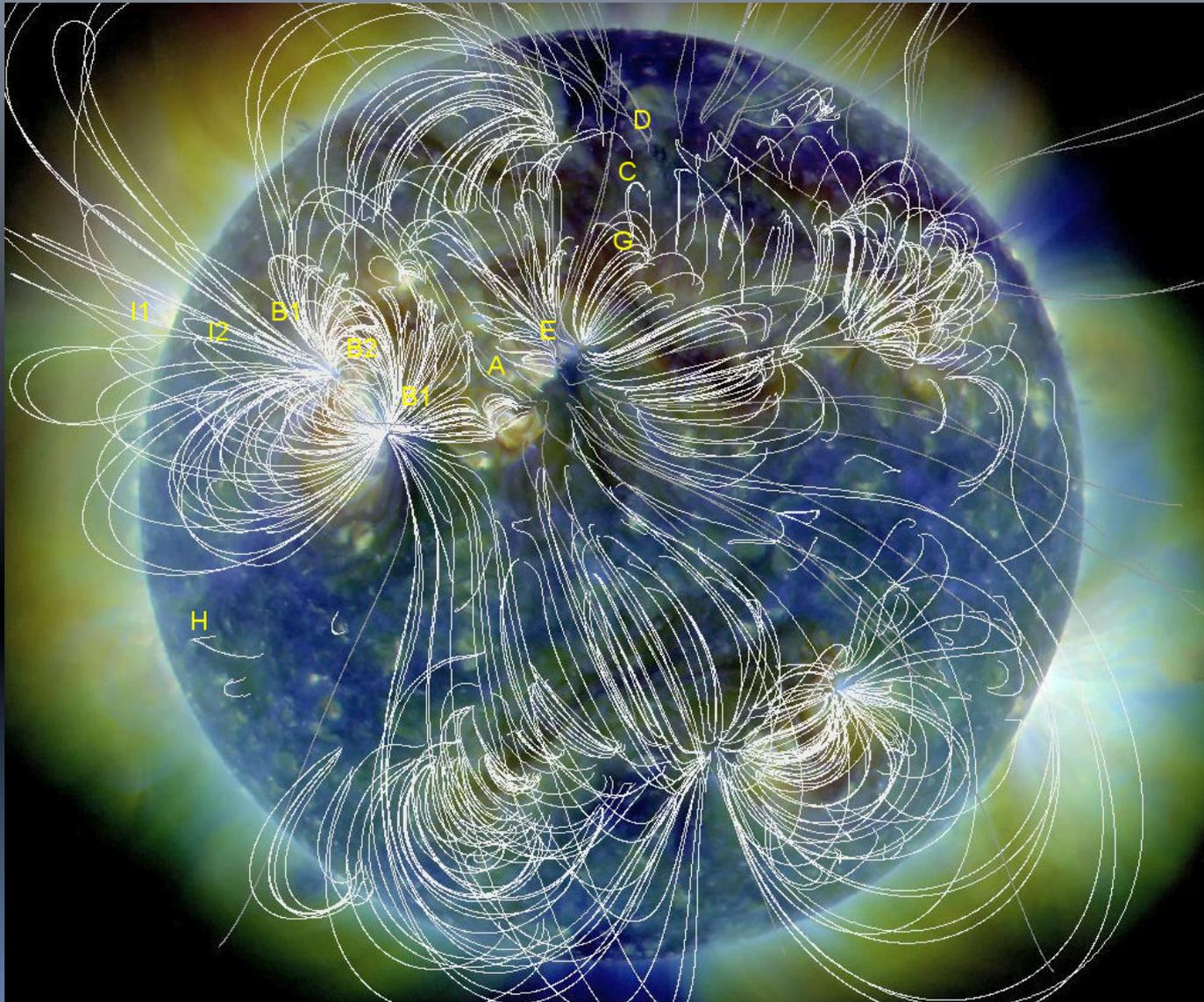


STEREO/SECCHI A, B EUVI, COR 1 – August 01, 2010

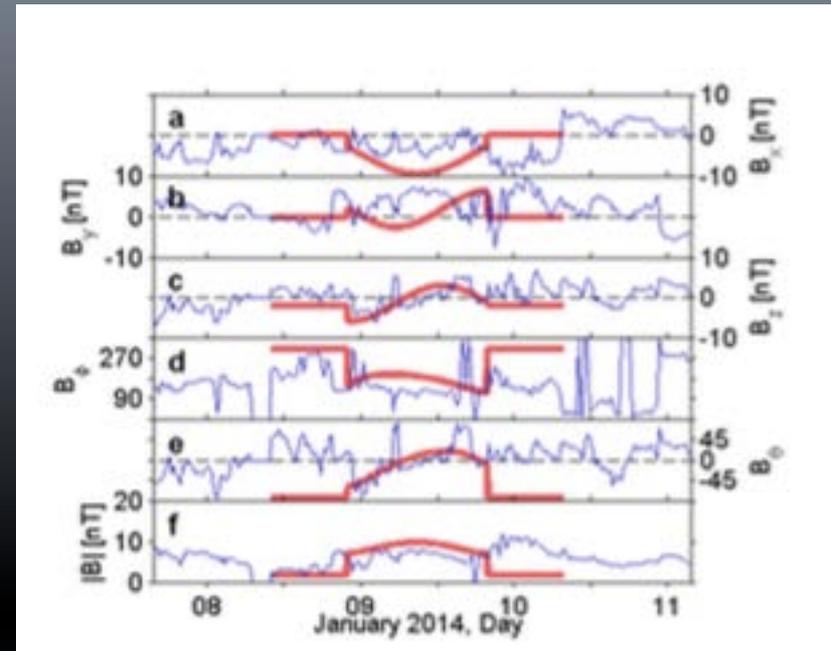
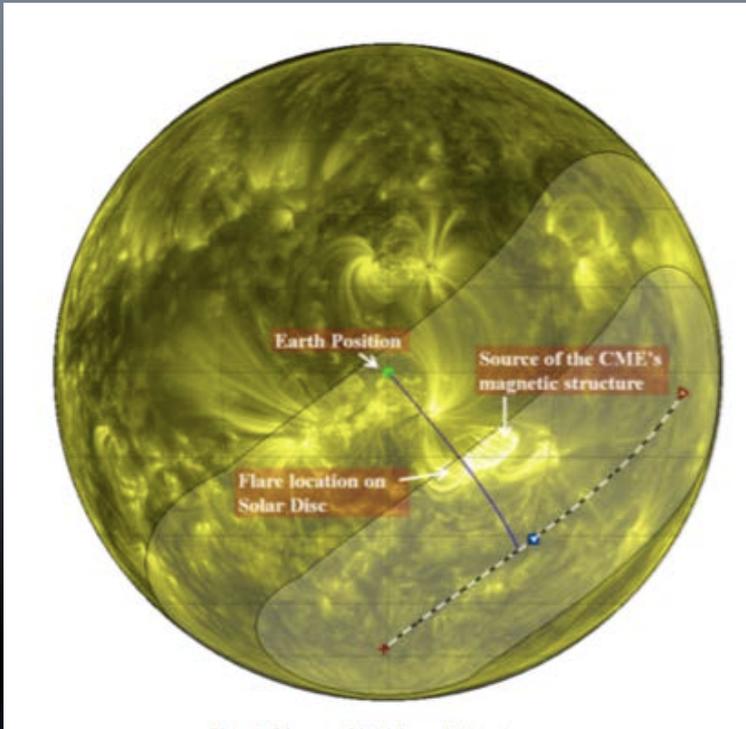


STEREO/SECCHI/HI1

Magnetic Field Structure on August 1 - SDO/HMI



New Study by N. Savani et al. 2015:



Predicting the magnetic vectors within coronal mass ejections arriving at Earth: 1. Initial Architecture

New Study by N. Savani et al. 2015

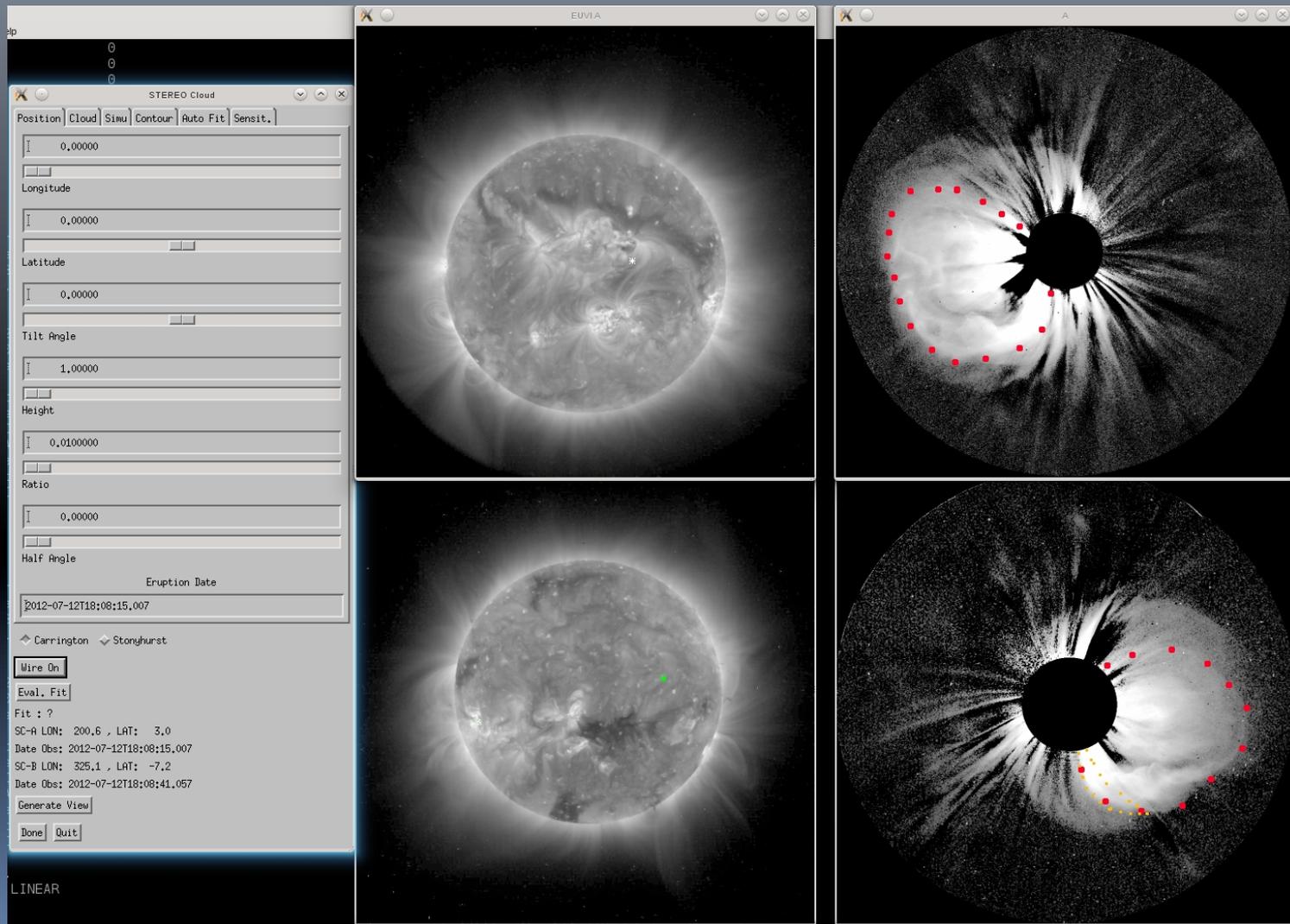
Eight events studied in detail - Conclusions:

“The example January 2014 event is severely deflected away from the Sun-Earth line and thus highlights the importance of including evolutionary estimates of CMEs from remote sensing when attempting to provide reliable forecasts.

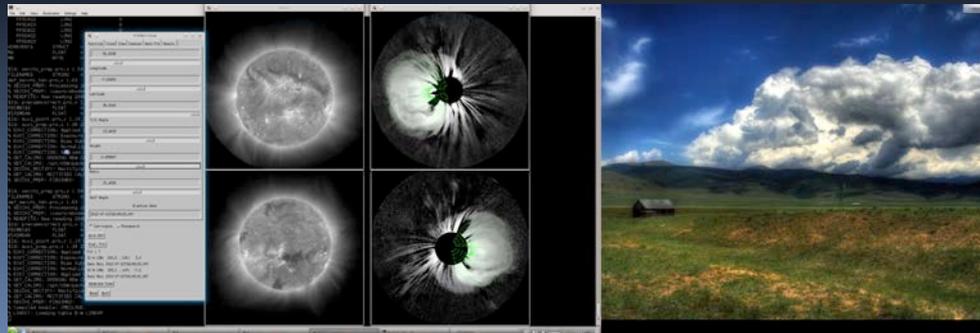
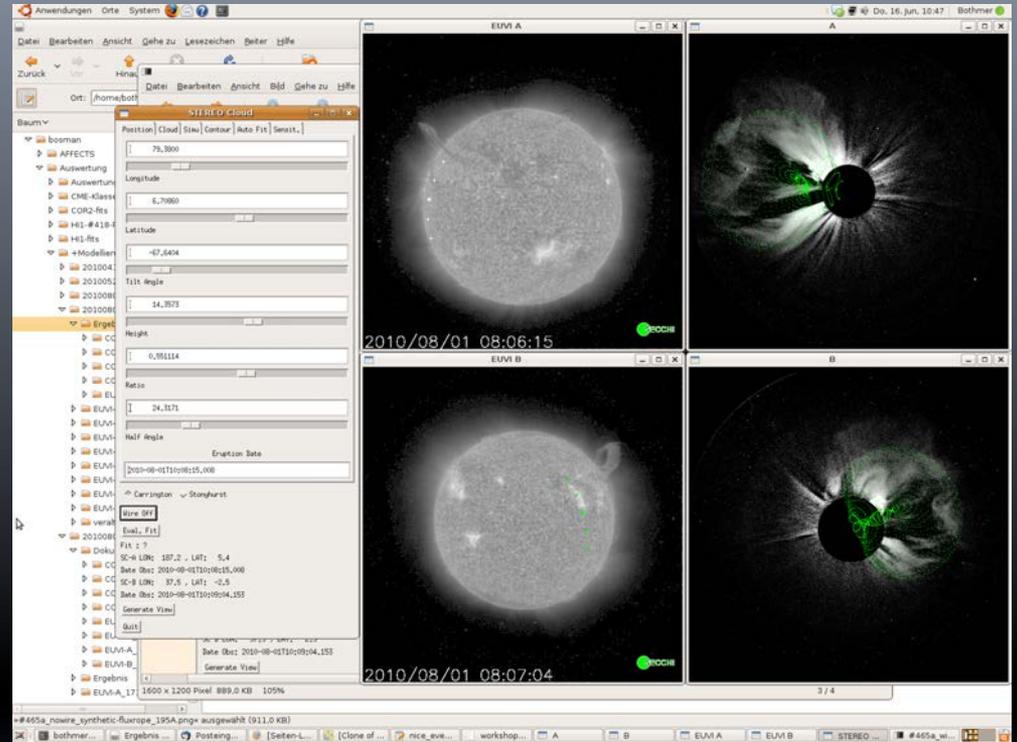
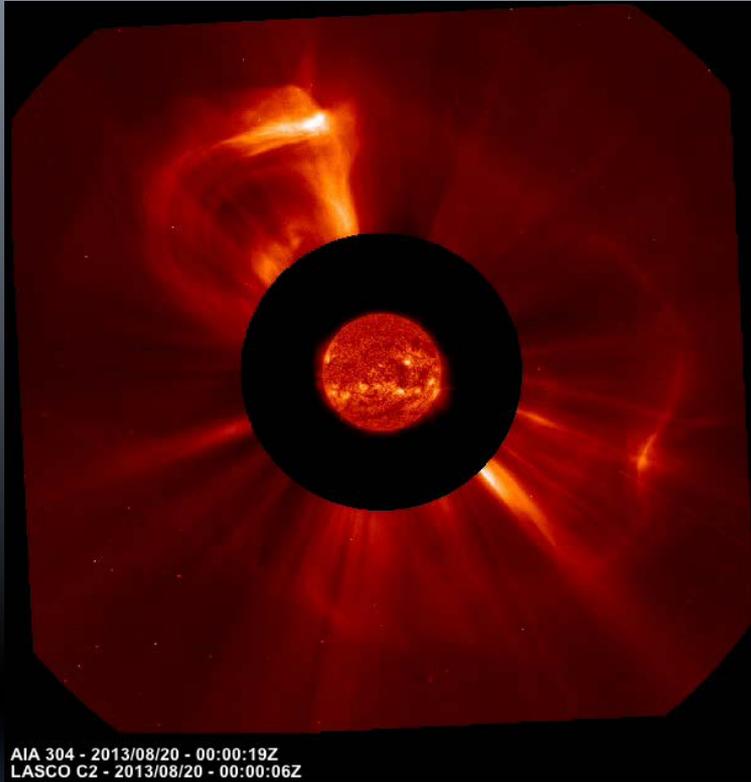
Also, to improve the reliability of the magnetic vector forecast, the initial topological structure determined by the Bothmer-Schwenn scheme must be adjusted for cases where the overlying field arcade clearly traverses two active regions.”

My comment: These events were of very weak field strength at 1 AU – not clear if all were real CME hits but could also be indeed due to quadrupolar structures.

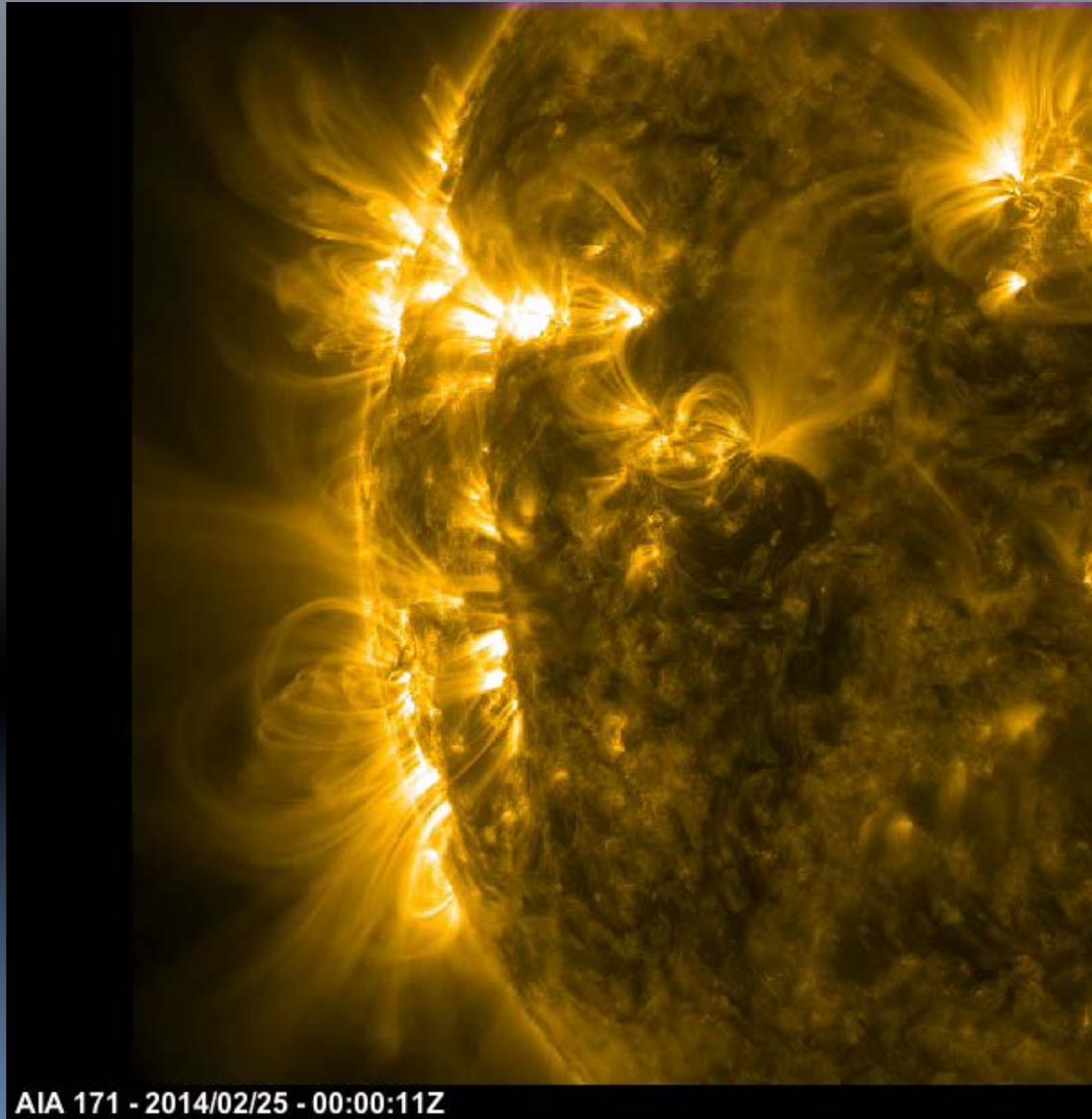
Shock fronts ahead of CMEs



Distortion of CME fronts

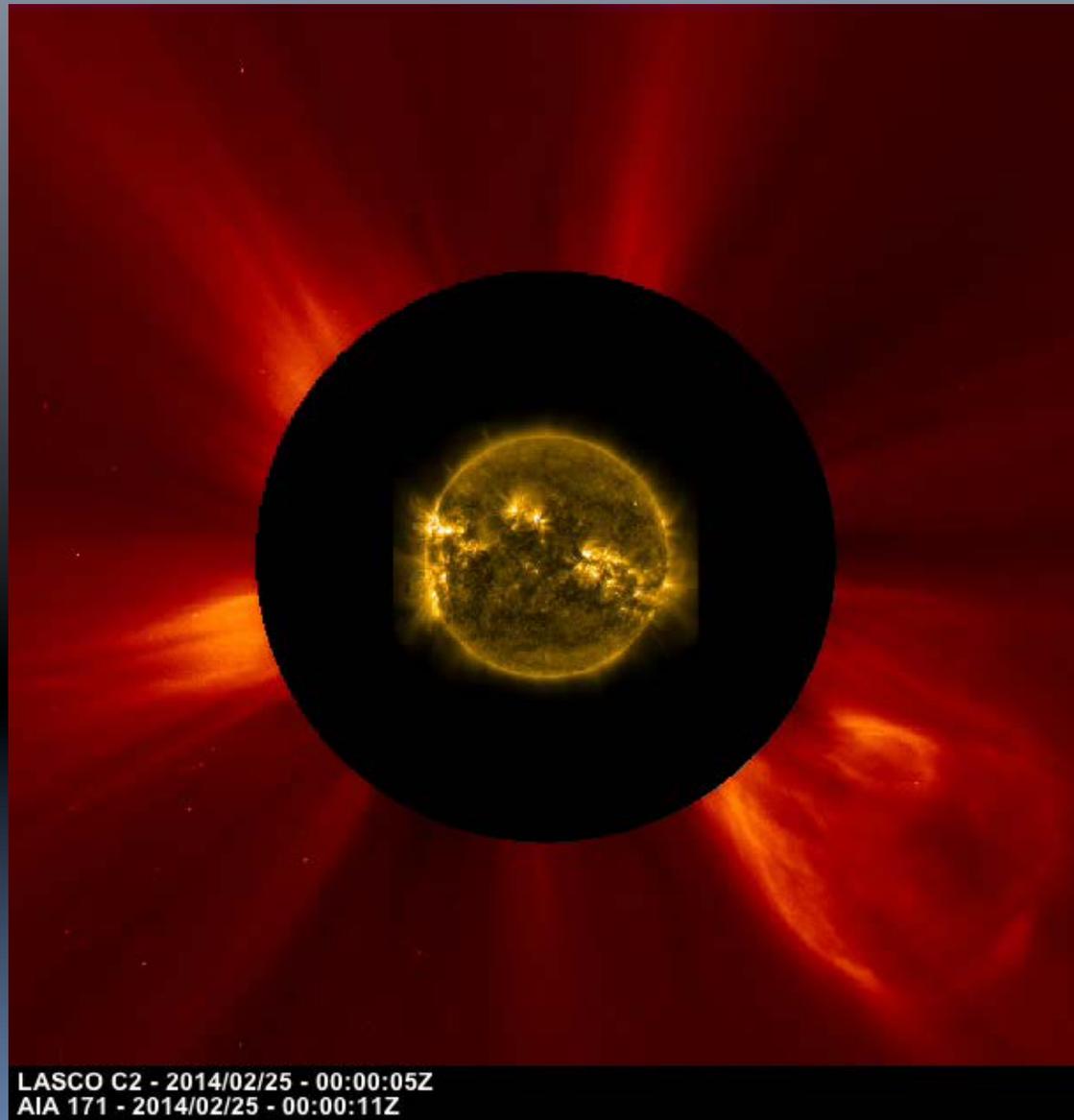


A typical solar storm onset: Flare and CME



Credit: SDO/AIA

Near-Sun rapid CME-Evolution



Credit: SDO, SOHO

The associate low coronal wave: Lateral Expansion

2014-02-25 00:34:01 (21.1 nm, dimming 2960, seq 1)
intensity 0.0 * 10⁶

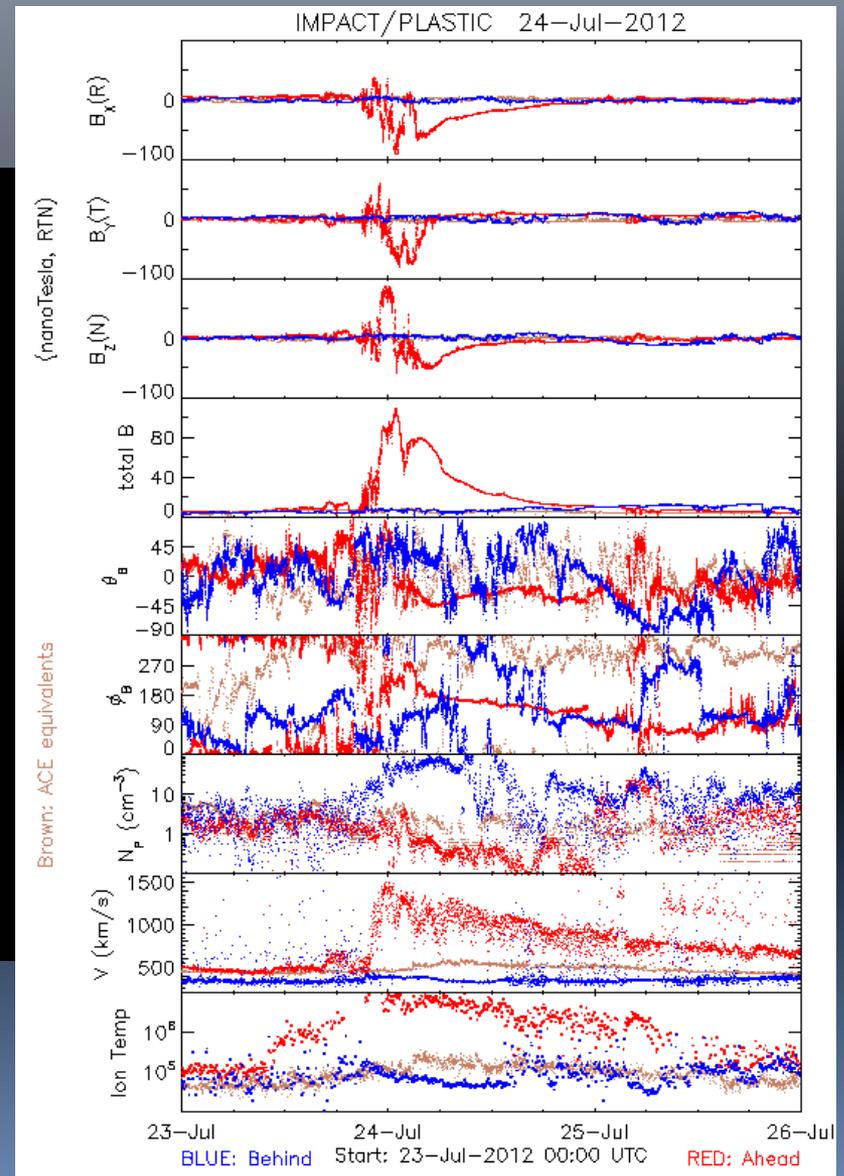


Credit: SDO/AIA, SIDC, STAFF

The July 24, 2012 CME – High-Intense Magnetic Field – STEREO observations



About 50 such CME events observed with SOHO/LASCO in cycle 23



UGOE AFFECTS DDC

Created by Adam Pluta

Institute for Astrophysik Goettingen

ACE SOHO ICECREAM DRAG KP SR-Flux Sunspots



ACE Parameters at L1_sun

CME_Speed[km/s]	1343
Arrival Date	30122000
Arrival Time [UT]	15:00
Calculate Launchtime	
Launch Date	29.12.2000
Launch Time [UT]	0
Avg Travelspeed	0

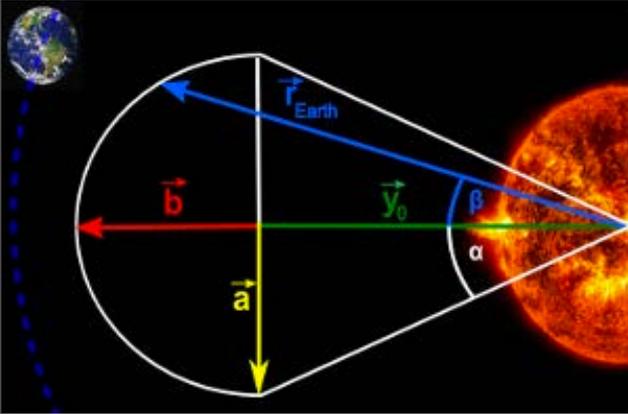
Test



Credit: A. Pluta, AFFECTS, HELCATS

DDC Forecast: Arrival Time 17 March 07 UT, L1 Speed $V=600-730$ km/s

ACE SOHO **ICECREAM** DRAG KP SR-Flux Sunspots



Parameters at R1_sun

V_APEX

Sourceregion Longitude

Sourceregion Latitude

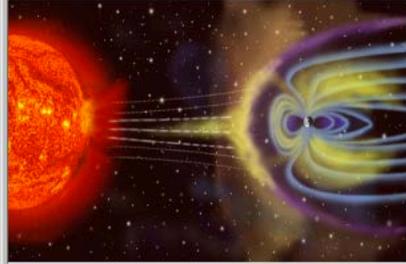
Half-Angle CME [DEG]

a

b

y_0

ACE SOHO ICECREAM DRAG KP **SR-Flux** Sunspots



Parameters at L1

Sourceregion Longitude

Sourceregion Latitude

Start Date

Start Time [UT]

Solar Cycle

Scale Factor

X-offset [Pixel]

SR-Flux

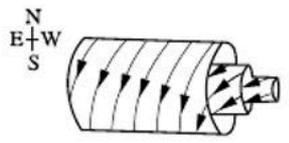
Mag. Equator

For SourceRegion Long

Diff.Mag. Equator [deg]

Magnetic Cloud Orientation

SEN **Left-handed**



ACE SOHO ICECREAM DRAG **KP** SR-Flux Sunspots



Velocity

KP negativ -Bz

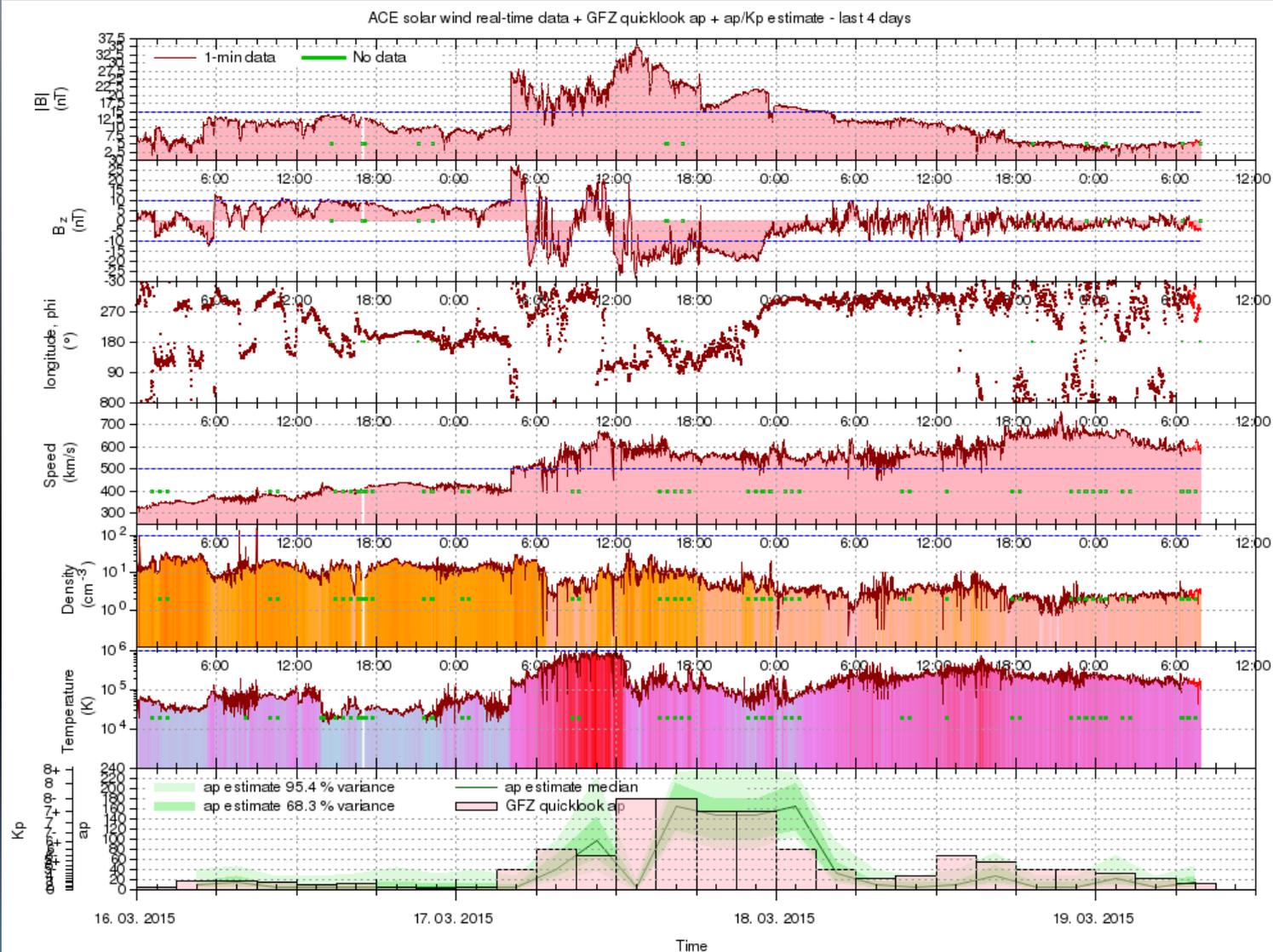
KP positiv +Bz

KP strongest

NOAA G-SCALE

Kp=9 : G5 (extreme)
 Kp=8 : G4 (severe)
 Kp=7 : G3 (strong)
 Kp=6 : G2 (moderate)
 Kp=5 : G1 (minor)

March 2015 CME



2015-03-19 08:55 CEST
2015-03-19 07:55 UTC

Credit: M.
Venzmer,
AFFECTS



AFFECTS

- **Advanced Forecast For Ensuring Communications Through Space** - is a space research project under the 7th Framework Programme of the European Union.

AFFECTS will provide advanced early space weather warning to protect communication systems.



The latest **Space Weather Reports** can be found at [WEATHER](#).

Please note that we only update that page in case of a major event!



You can now subscribe to our new feed "AFFECTS space weather reports and storm warnings" to keep informed about severe space weather conditions. Subscribe here: http://www.affects-fp7.eu/space-weather-reports/rss_sw-reports.xml

PLEASE NOTE: When using SAFARI the rss feed might be displayed in your MAIL account. Additionally, it does not work with GOOGLE CHROME.

THE FOLLOWING INSTITUTIONS ARE INVOLVED IN AFFECTS:

Ben. No.	Country	Institution	Short Name	Scientific Contact
1	Germany	Georg-August-University Göttingen	UGOE	Dr. Volker Bothmer, project coordinator
2	Belgium	Royal Observatory of Belgium	ROB	Dr. Ronald Van der Linden, Dr. Cis Verbeeck
3	Ukraine	Space Research Institute	SRI NASU-NSAU	Dr. Aleksei Parnowski
4	Germany	Fraunhofer IPM	FHG	Dr. Raimund Brunner
5	Norway	University of Tromsø	UoT	Prof. Chris Hall
6	Germany	German Aerospace Center	DLR	Dr. Norbert Jakowski, Dr. Jens Berdermann
7	Germany	Asbrium GmbH	ASTRIUM ST	Wilfried Pfeffer
8	U.S.A.	Space Weather Prediction Center of NOAA	NOAA-SWPC	Dr. Rodney Viereck
9	Germany	Planetarium Hamburg	Planetarium HH	Thomas W. Kraupe

For more information about the AFFECTS project partners please look at [Project -> Partners](#)

LATEST NEWS

13/01/2015: The update of the **AFFECTS iOS App** is now available on the App store.

07/01/2015: The **AFFECTS iOS App** upgrade is currently being tested. The upgrade will resolve also issues with website access of STEREO images and general functionality of push alerts.

18/12/2014: The **AFFECTS Website** has been upgraded to accomplish the new NOAA SWPC website structure. The **AFFECTS iOS App** has been upgraded as well and will soon be available through the App store. Due to the holiday season it will be released in January.

26/11/2014: The new version of the **AFFECTS Android App** is now online available under -> [SERVICES](#).

14/11/2014: The **AFFECTS Print Brochure** and **Interactive Service Guide** are now online available at -> [SERVICES](#) - click on [Services](#) - and at -> [PR](#). For hardcopy requests please contact the AFFECTS coordinator.

13/11/2014: Latest space weather news about solar storms caused by the **reappearing sunspot group 2192** can be found under "Weather".

10/07/14: The **AFFECTS iOS Space Weather App** is now available on the [App Store](#).

11/02/14: The next **AFFECTS General Meeting incl. Steering Committee Meeting** takes place in Brussels from February 17-19, 2014. Further information can be found at -> [PROJECT](#) -> [MEETINGS](#) -> [3rd GM](#).

10/02/14: Recently, we created a **YouTube channel** showing our AFFECTS preproject trailer. The channel can be

AFFECTS Website

[http://
www.affects
-fp7.eu/
weather](http://www.affects-fp7.eu/weather)

Conclusions

1. The magnetic field configuration of CMEs can be predicted from solar magnetograms based on the B&S scheme
2. Complexity of magnetic field structure arises from different sources: SR photospheric field complexity, lateral expansion, deflection (e.g., January 2014 CME), non force-free evolution
3. I think we often luckily miss CME cores – likelihood of a Carrington event may even be independent of threshold estimates
4. However, all of this is not too different from problems of terrestrial weather forecasts and natural hazard occurrences
5. These aspects are challenges for upcoming projects and offer bright perspectives for collaborative research