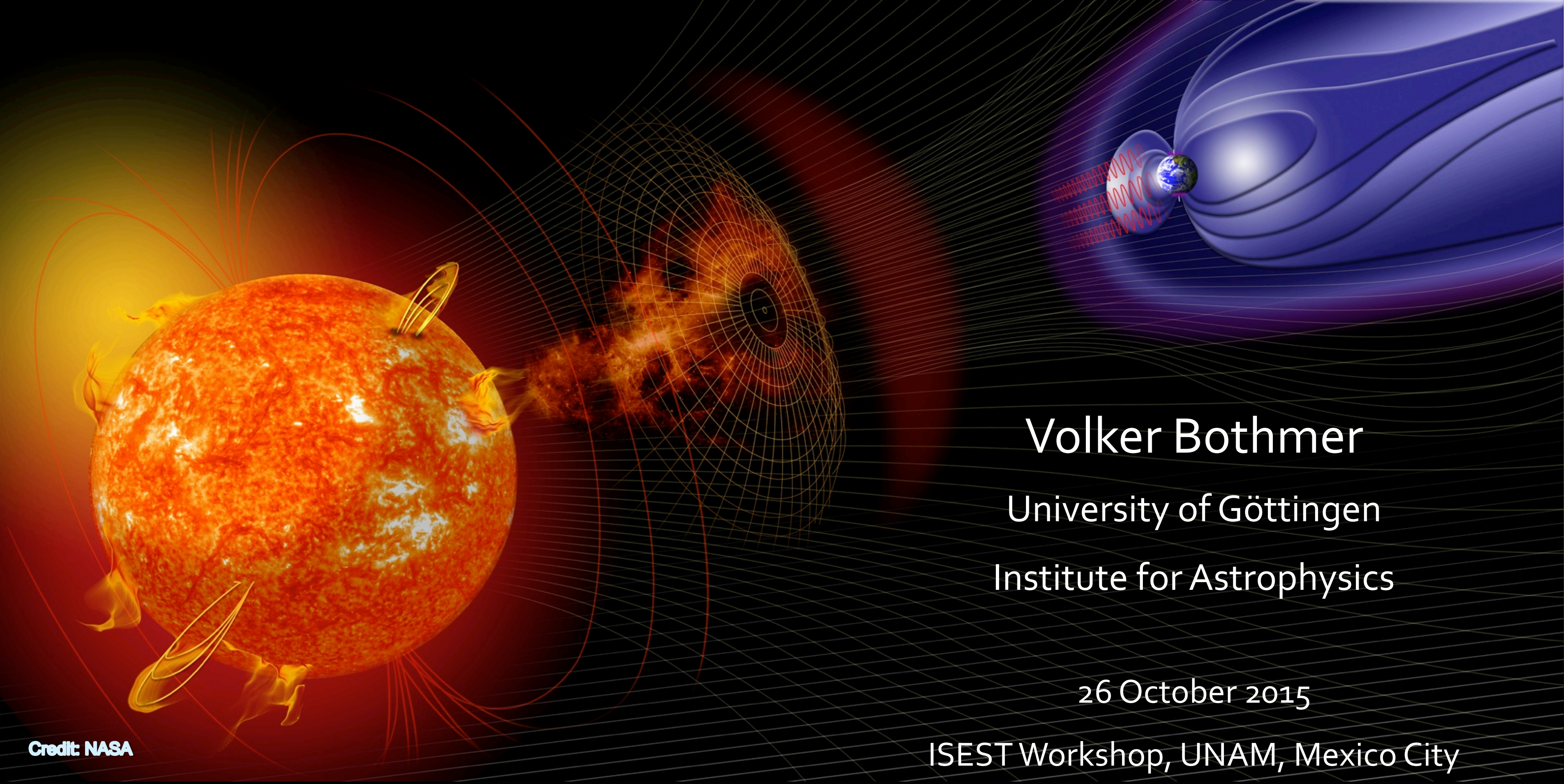


Volker Bothmer

University of Göttingen

Institute for Astrophysics

26 October 2015

ISEST Workshop, UNAM, Mexico City

Forecasting the Magnetic Field Configuration of CMEs

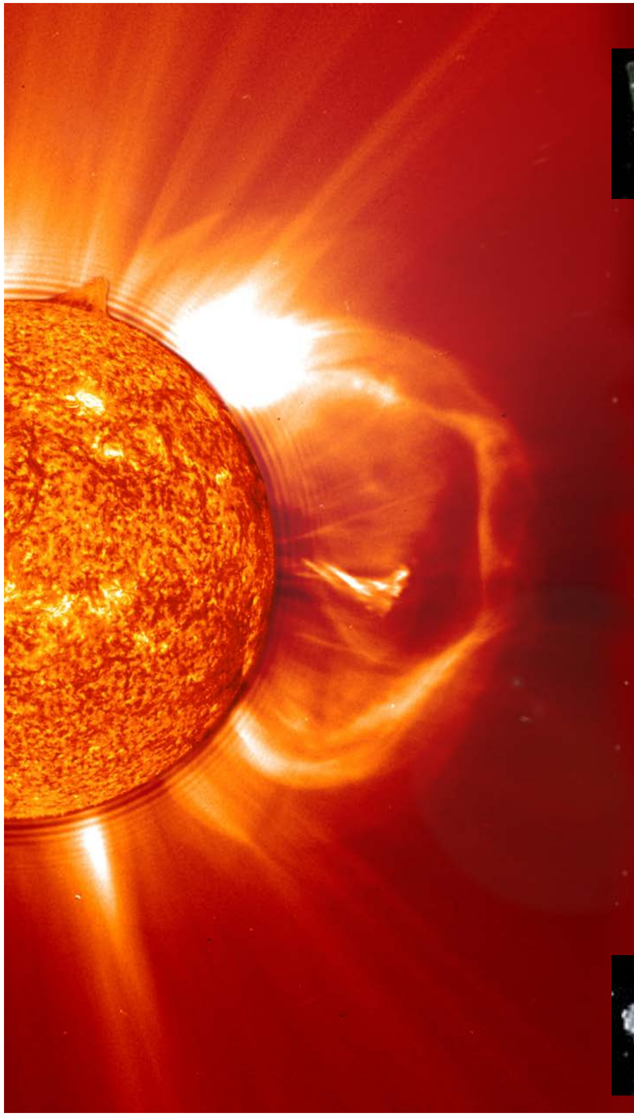
Outline

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

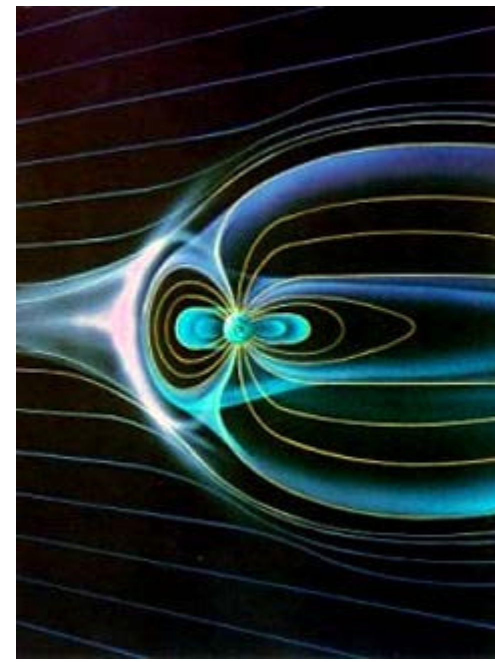
Why CME NRT modelling?



STEREO satellites provide 3D-view

ACE gives 15-30 mins premonition time

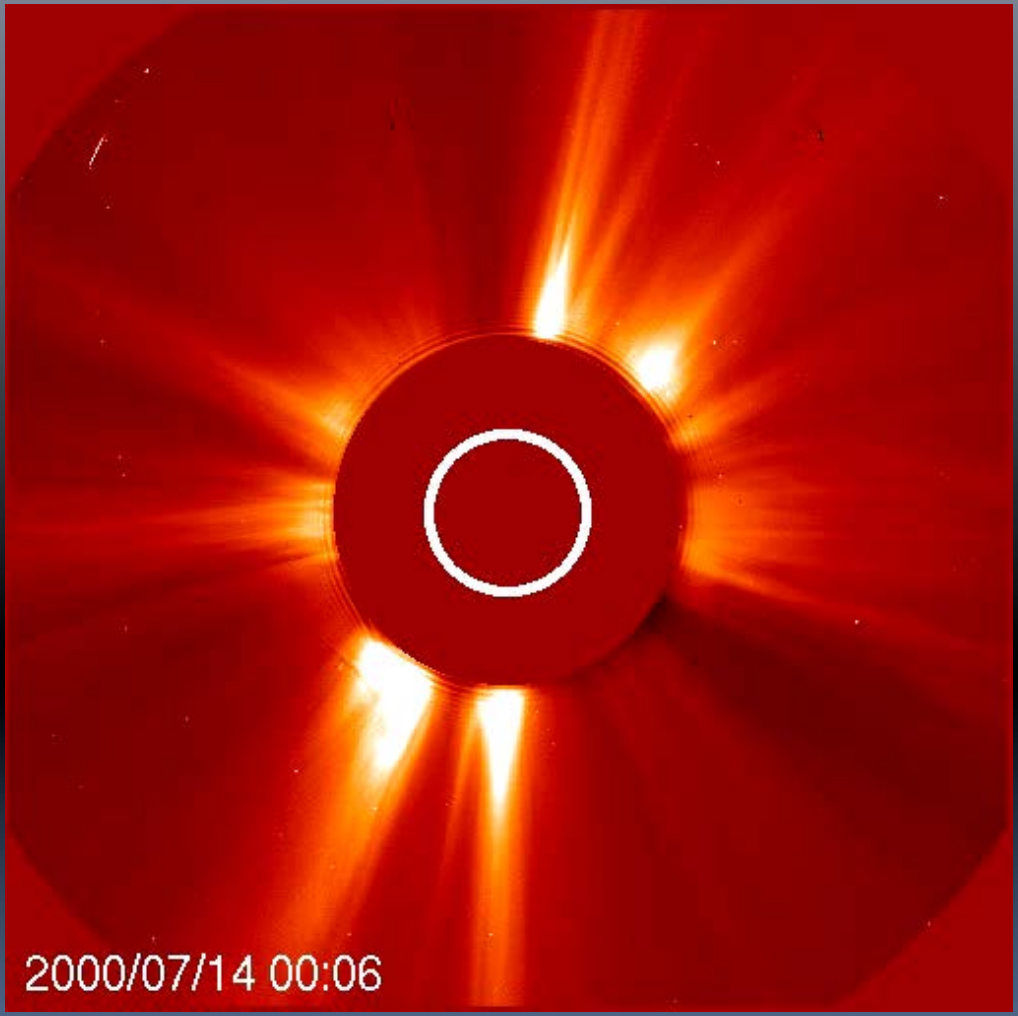
Which direction does the CME go? Will it miss?

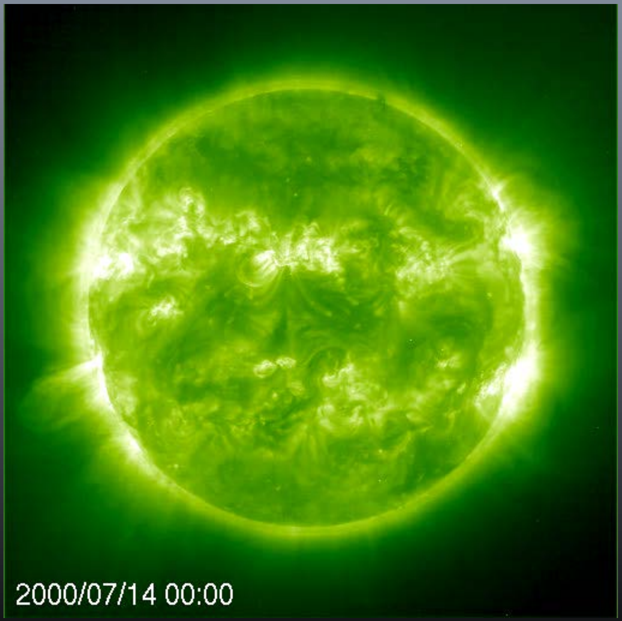


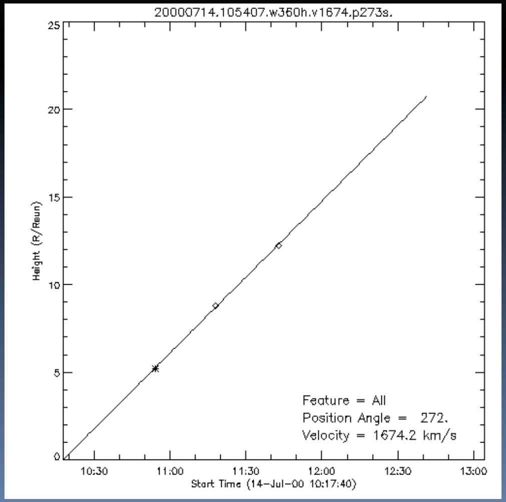
How fast is the CME? When will it arrive at Earth and with which -Bz ? ($\underline{E}=-\underline{v} \times \underline{B}$)

Images: NASA

Sample CME: The July 14, 2000 event

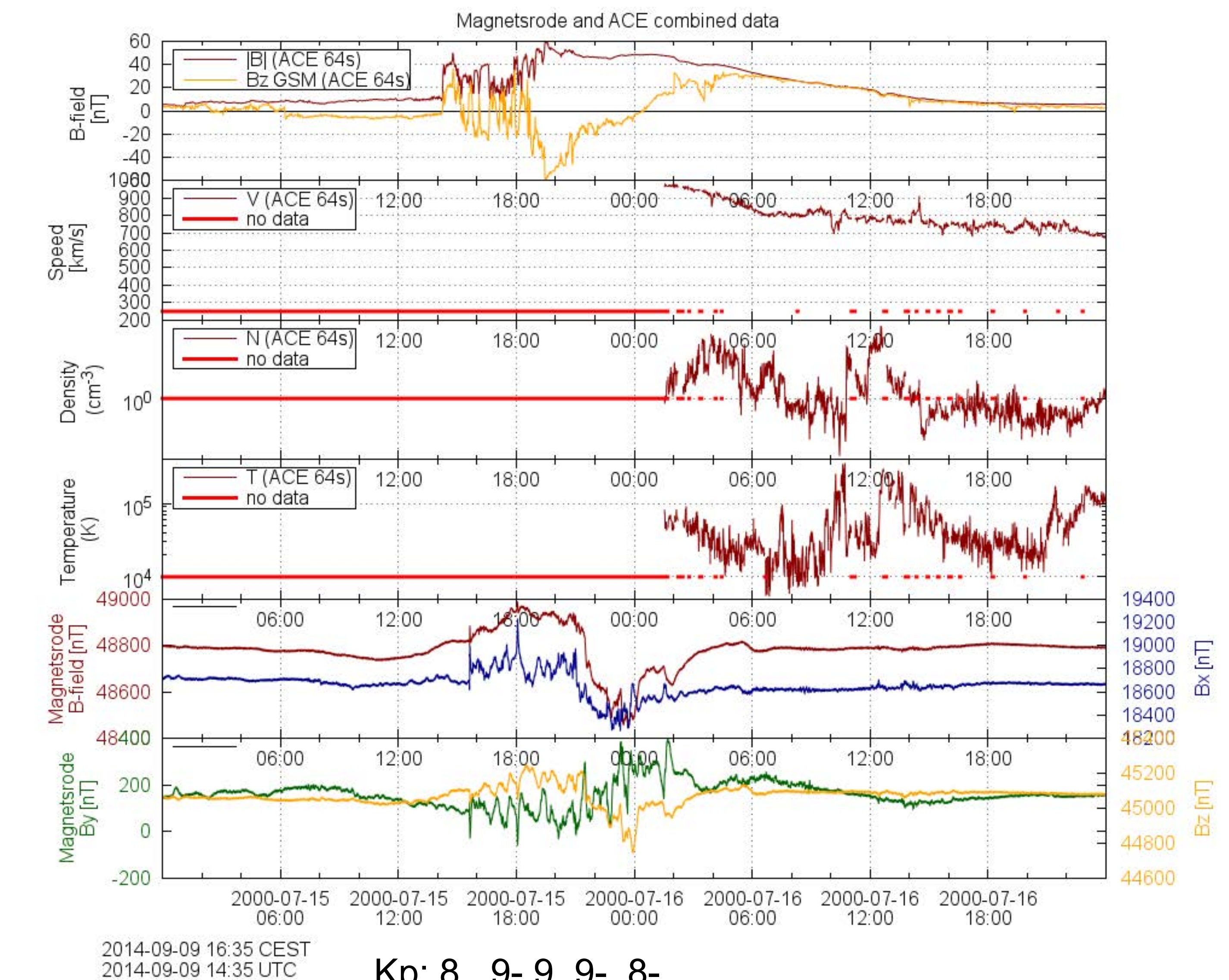






Credits: SOHO/LASCO CME catalogue

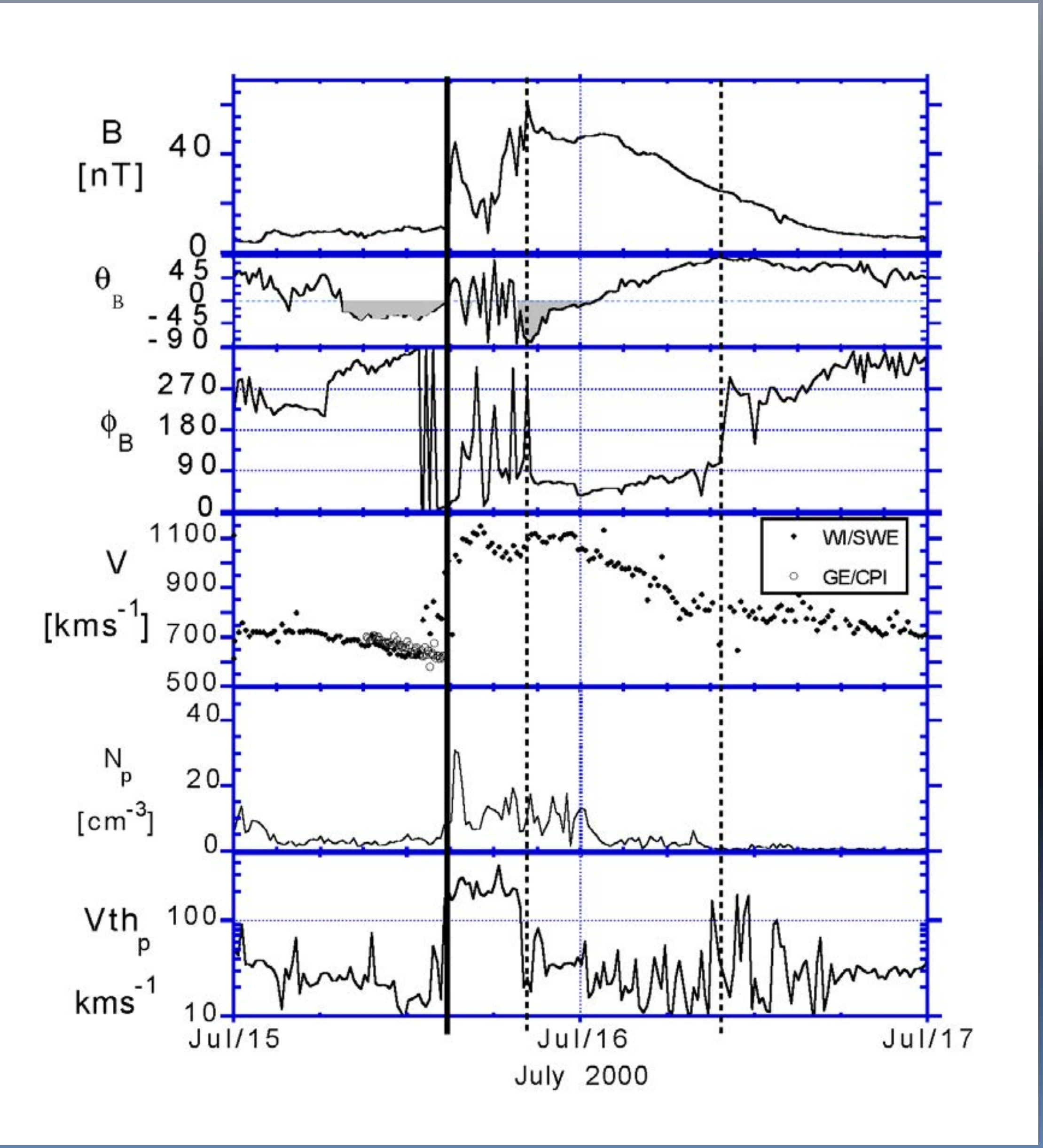
Solar wind and ground-based magnetometer data



Kp: 8 9- 9 9- 8-

Credit: M. Venzmer, AFFECTS

The solar wind data from Wind

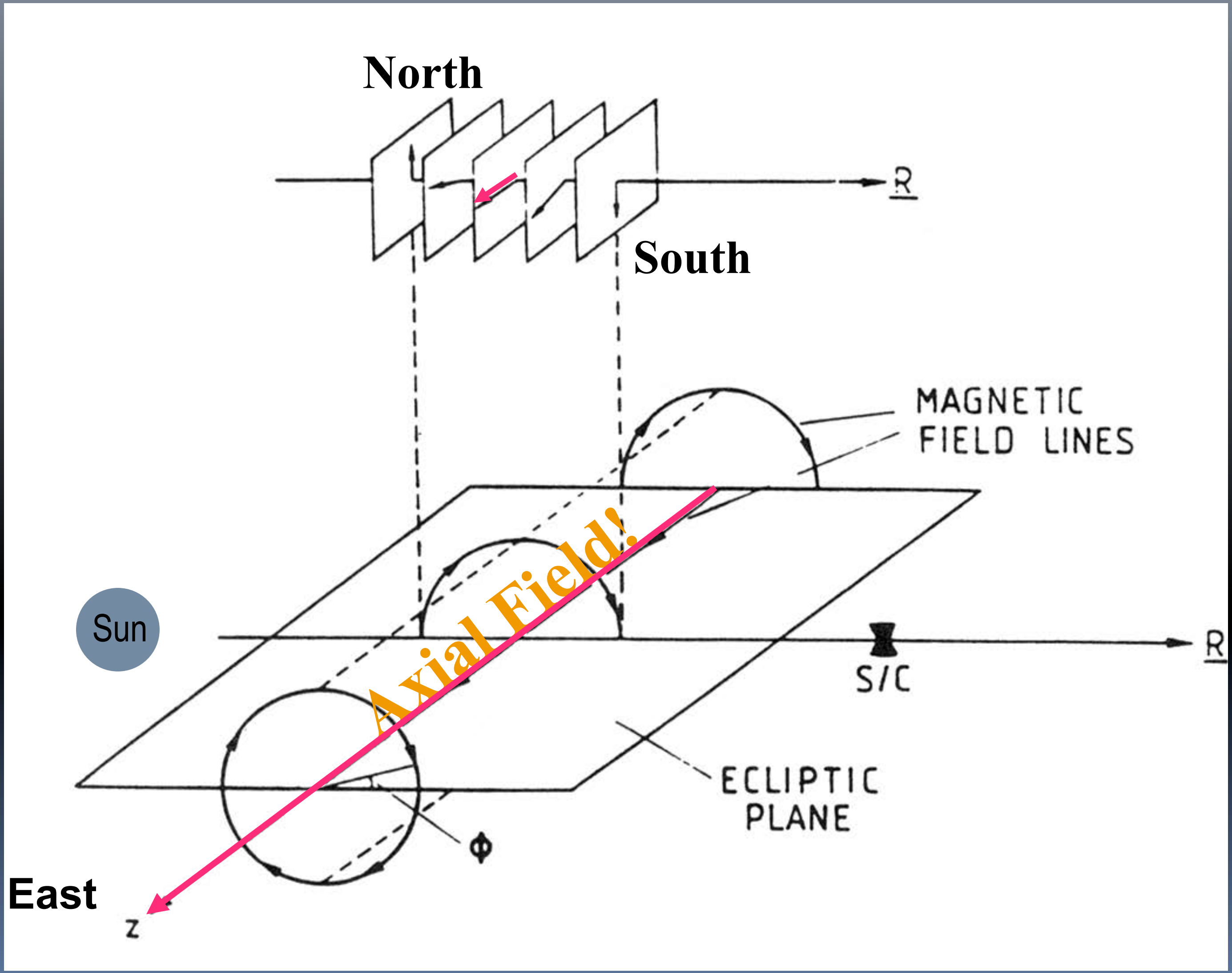


S to N

E

Credit: Bothmer & Daglis, 2006

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

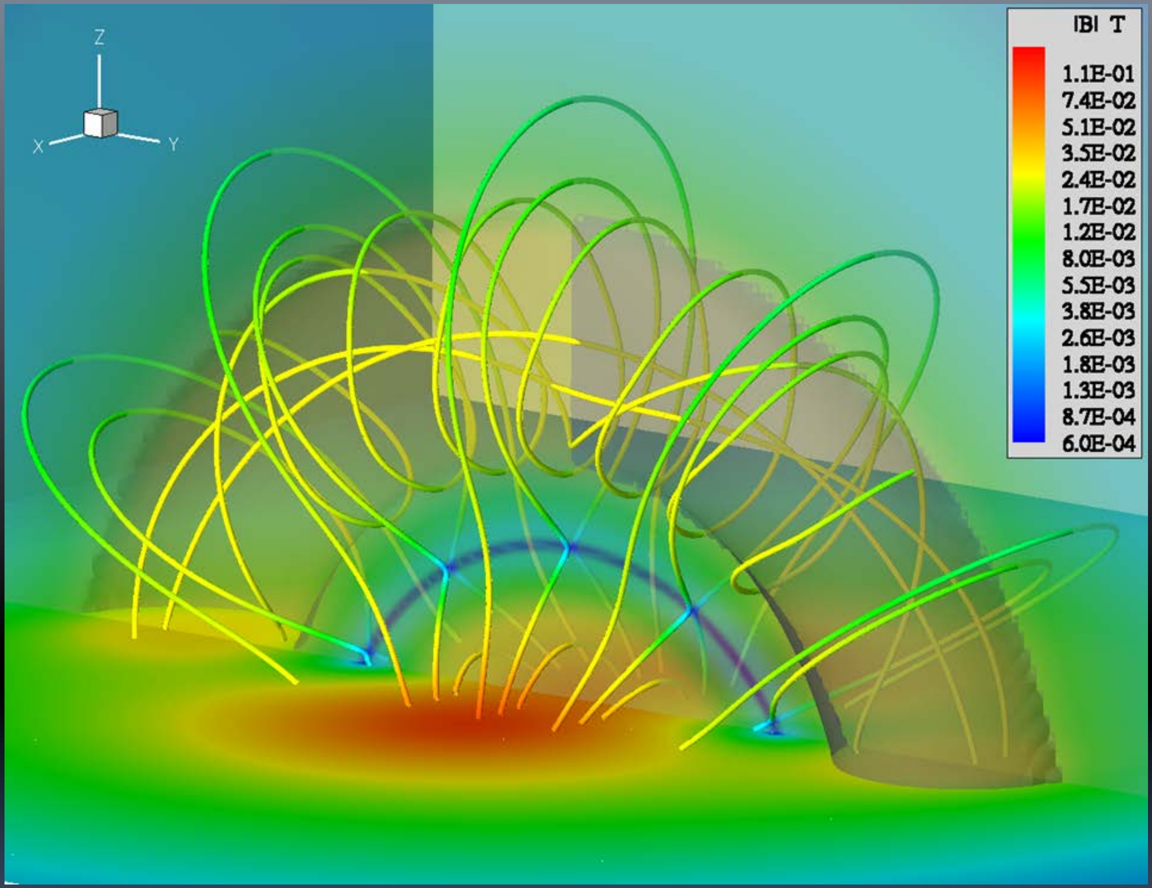


In Principal,
the Cylinder can
be Arbitrarily
Inclined
with Respect
to the
Observer!

Helical Structure!

Goldstein, 1983; Bothmer & Schwenn, Ann. Geophys., 16, 1-24, 1998

Sample References to Flux Rope Modeling

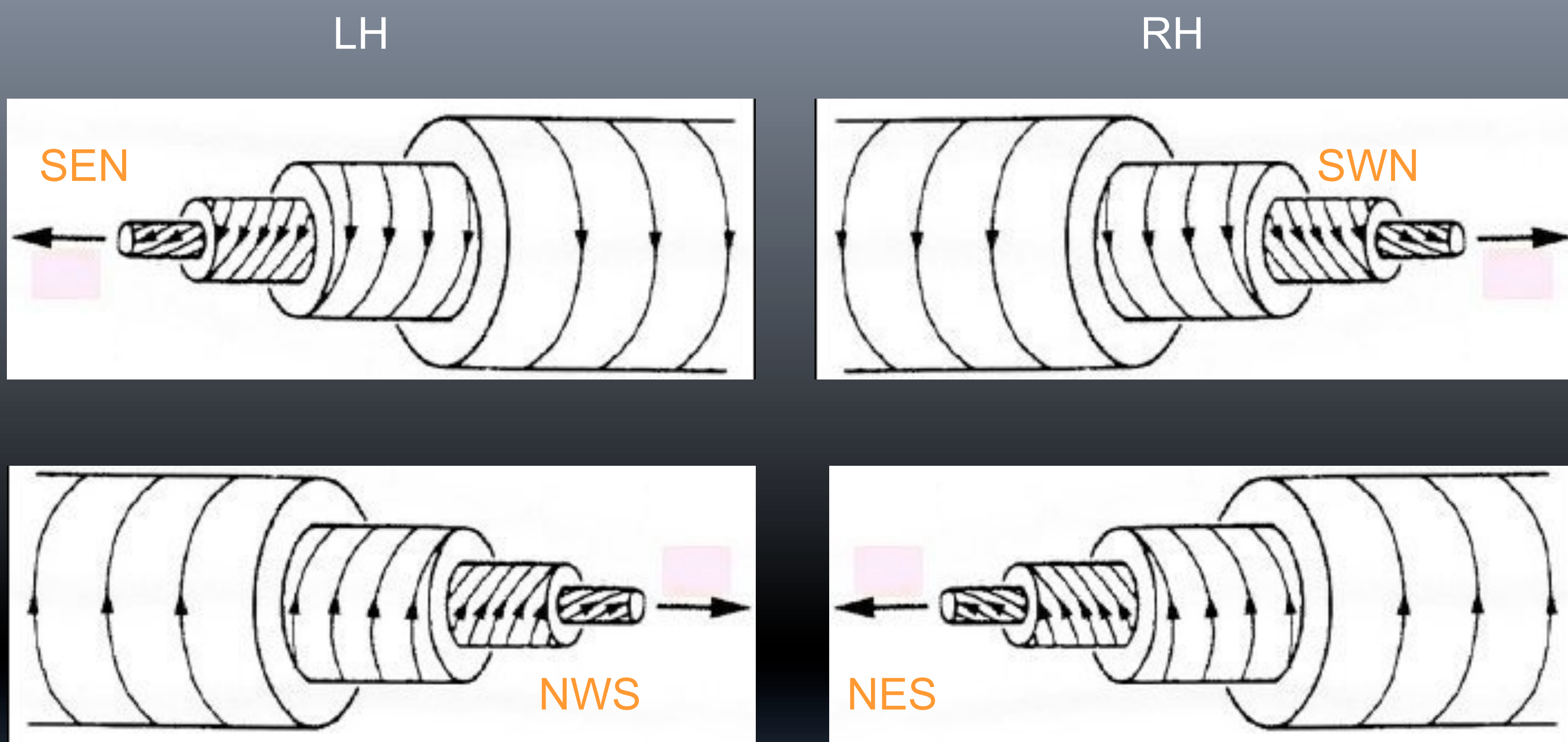


Credits: I. Roussev

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

Importance of Lundquist Solutions

The four Different Types of Magnetic Flux Ropes

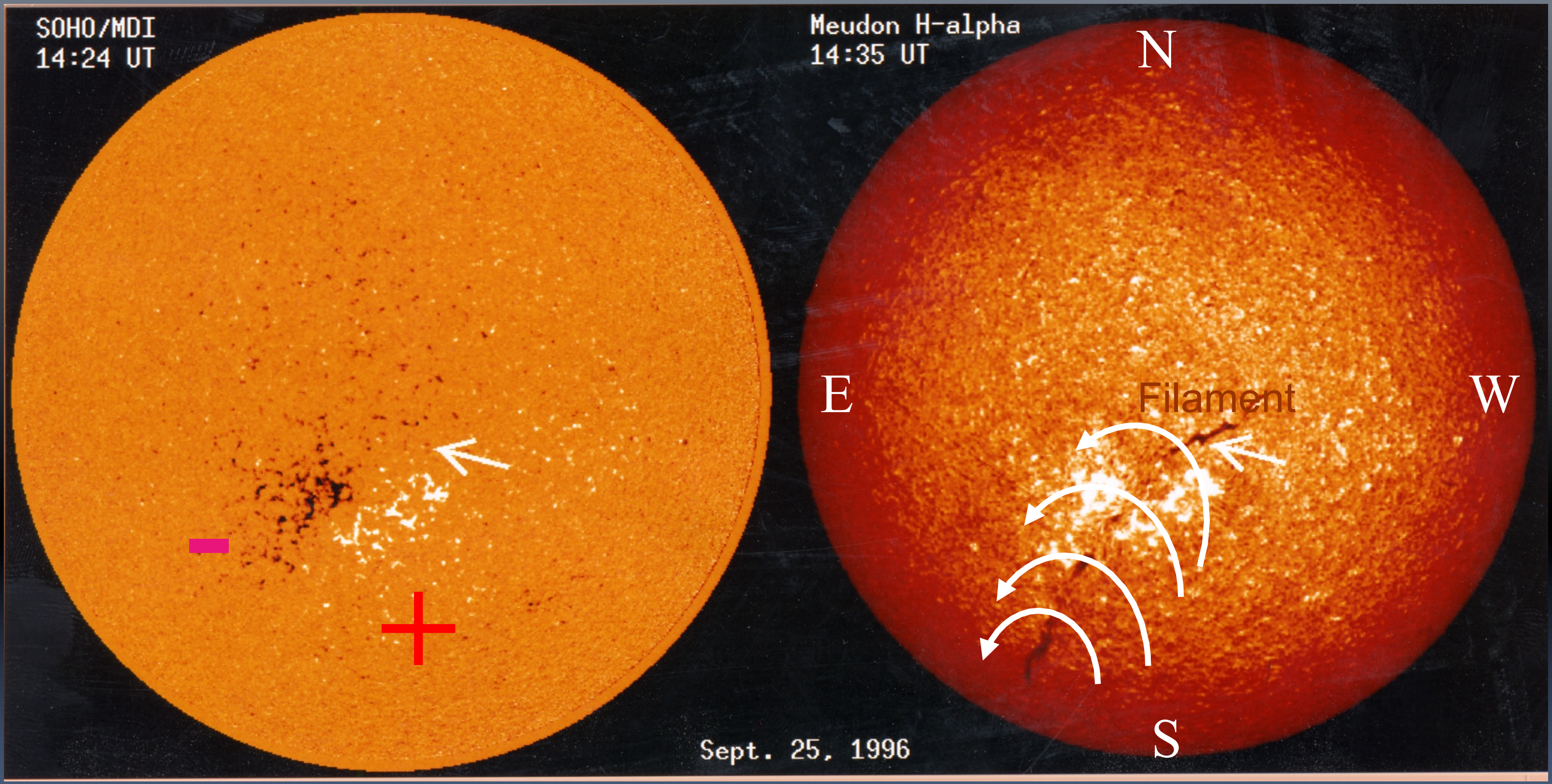


Based on Helios Observations in 1974-1981:

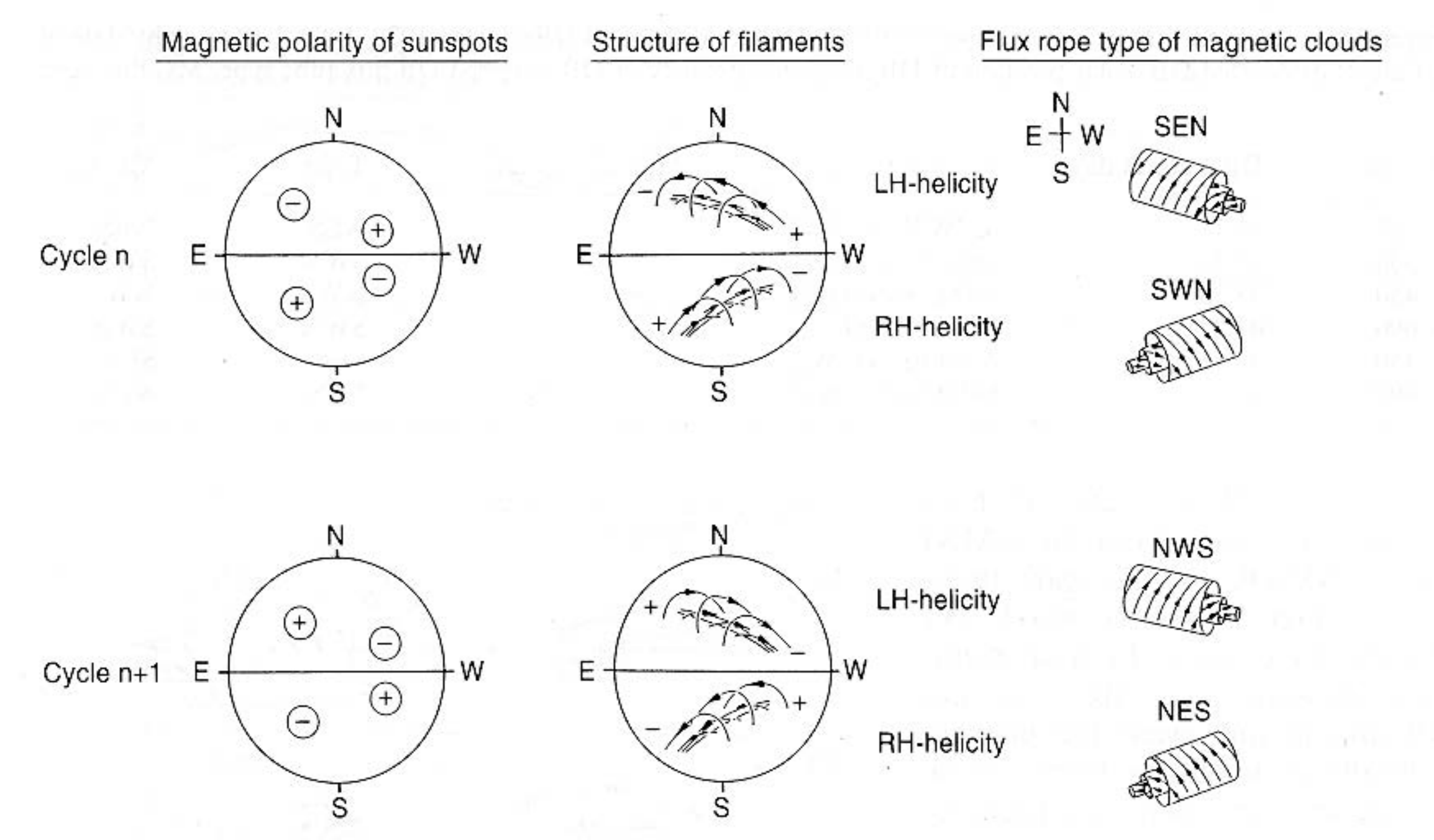
46 Unique Clouds, 23 LH, 23 RH

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

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



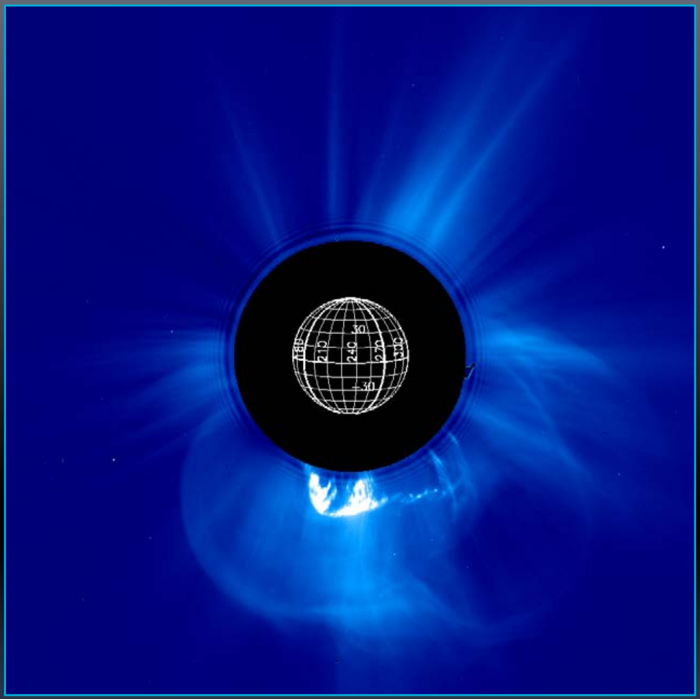
Scheme of the Dependence of CME Magnetic Cloud Configurations on the Solar Cycle

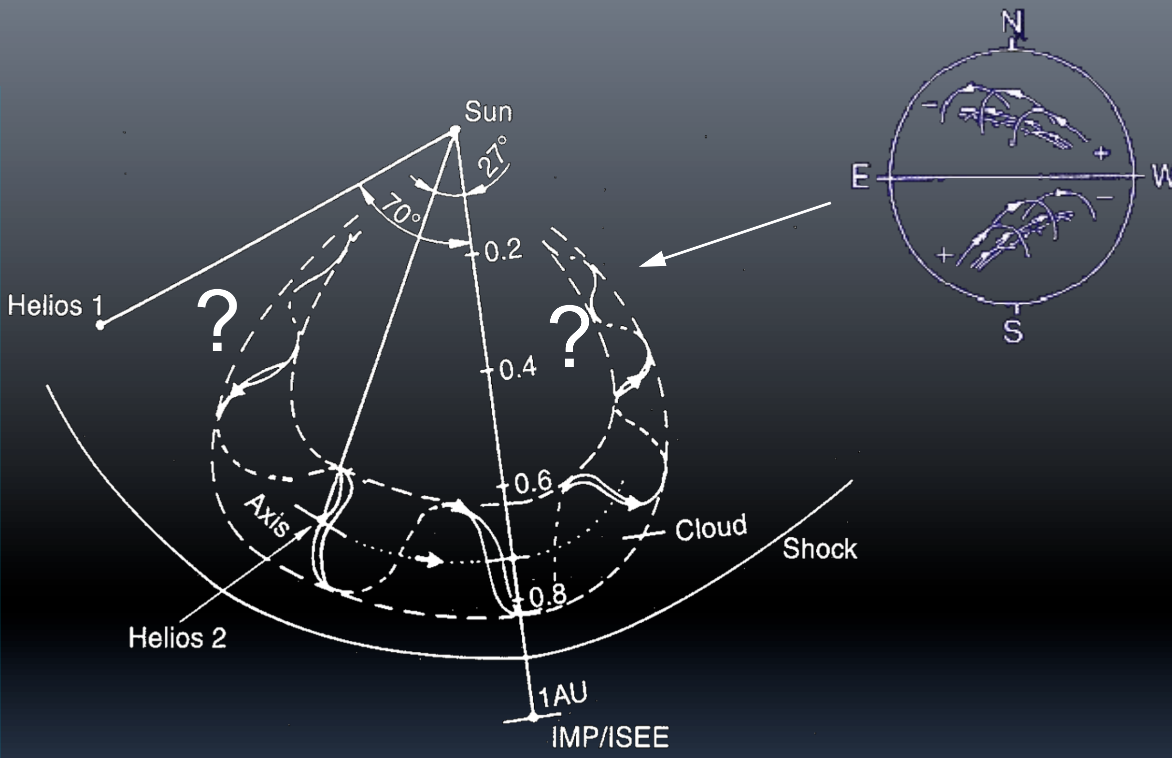


No consideration of quadrupolar fields

Bothmer & Schwenn, 1998

Sketch of the Possible Origin of Interplanetary Magnetic Flux Ropes

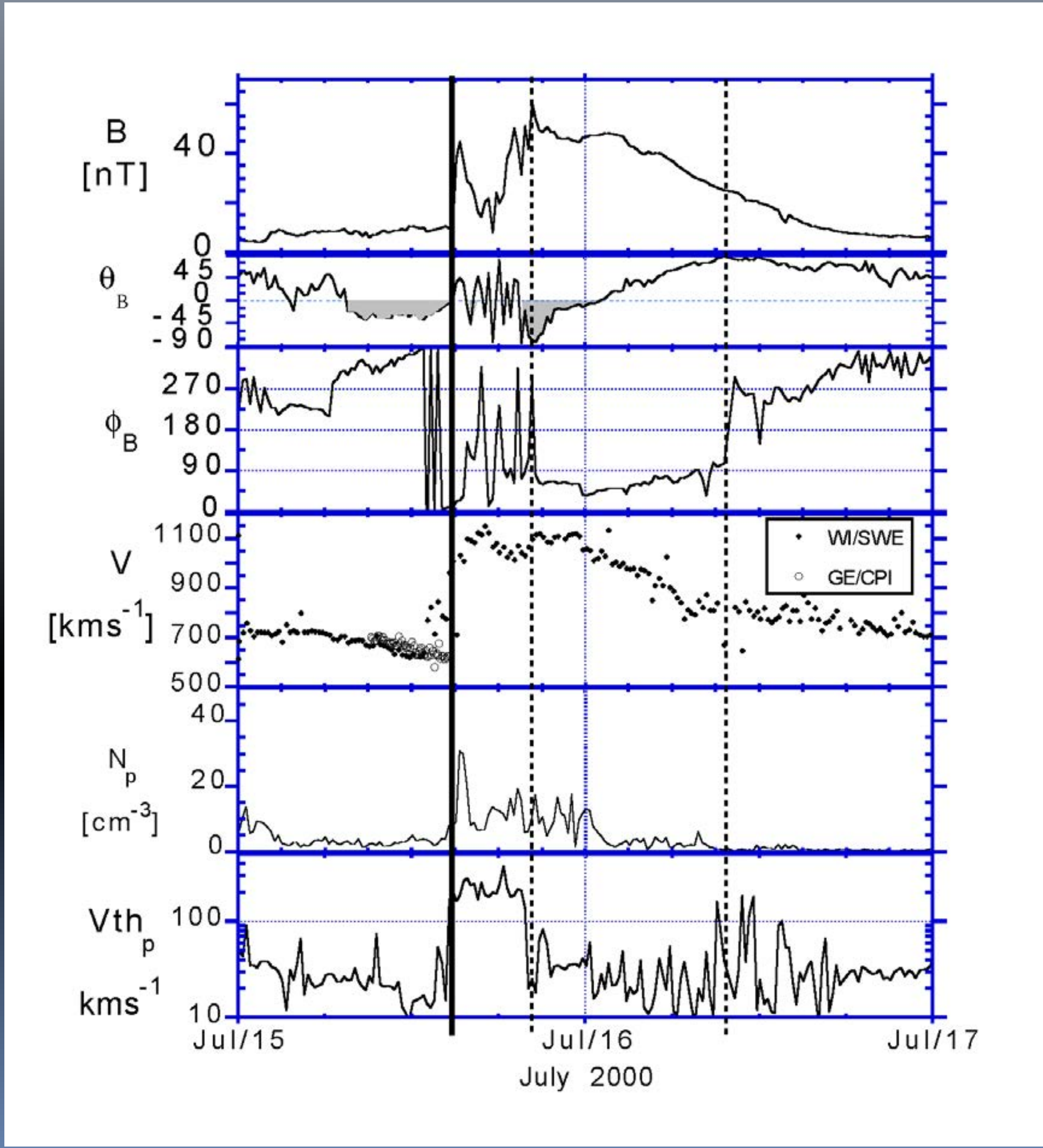




Only 1/3 of all ICMEs appear to be flux ropes (Gosling, 1993); 46% (Bothmer & Schwenn, 1996)

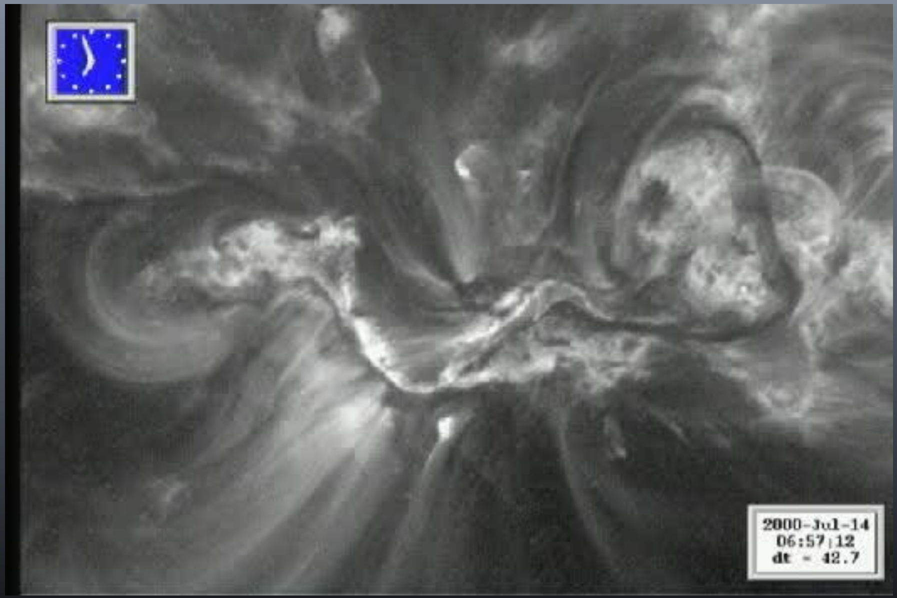
Adapted from Bothmer & Schwenn, Ann. Geophys., 16, 1-24, 1998

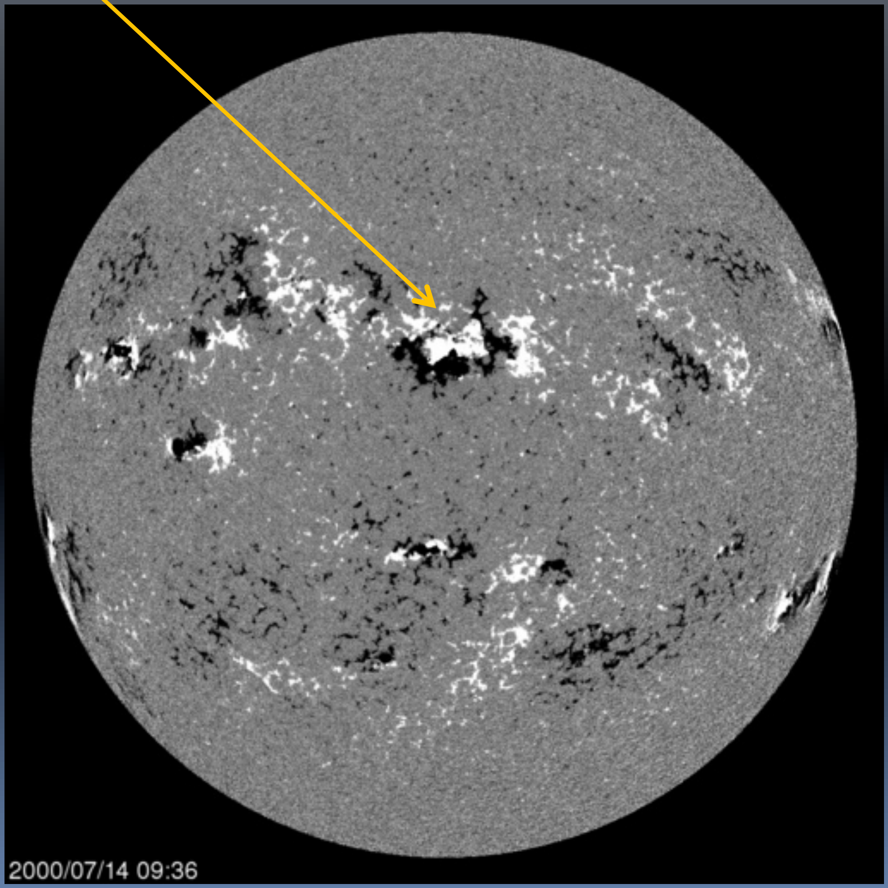
Let’s come back to the origin of the July 2000 CME



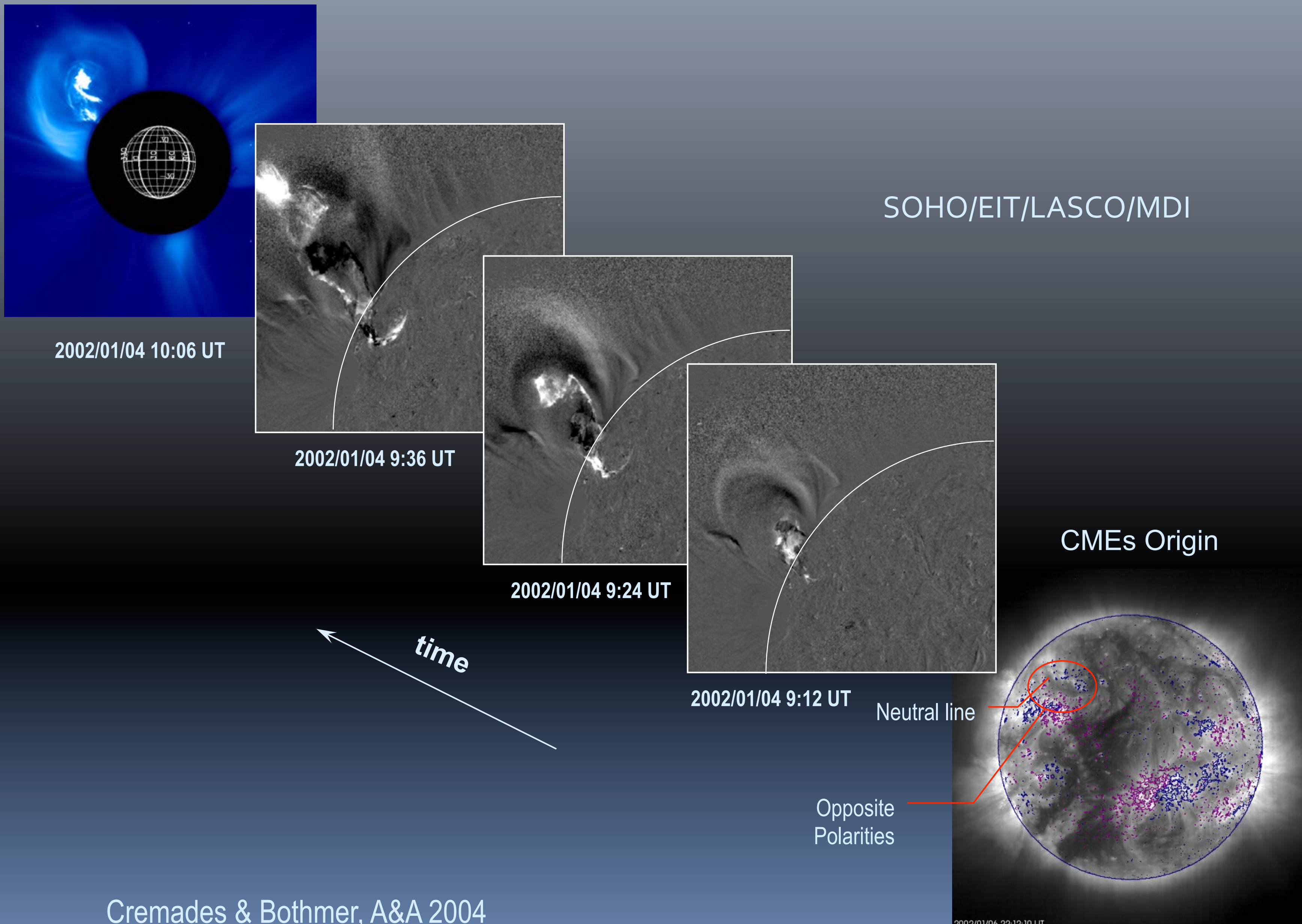
Credit: Bothmer & Daglis, 2006

TRACE Observations and SOHO/MDI magnetogram



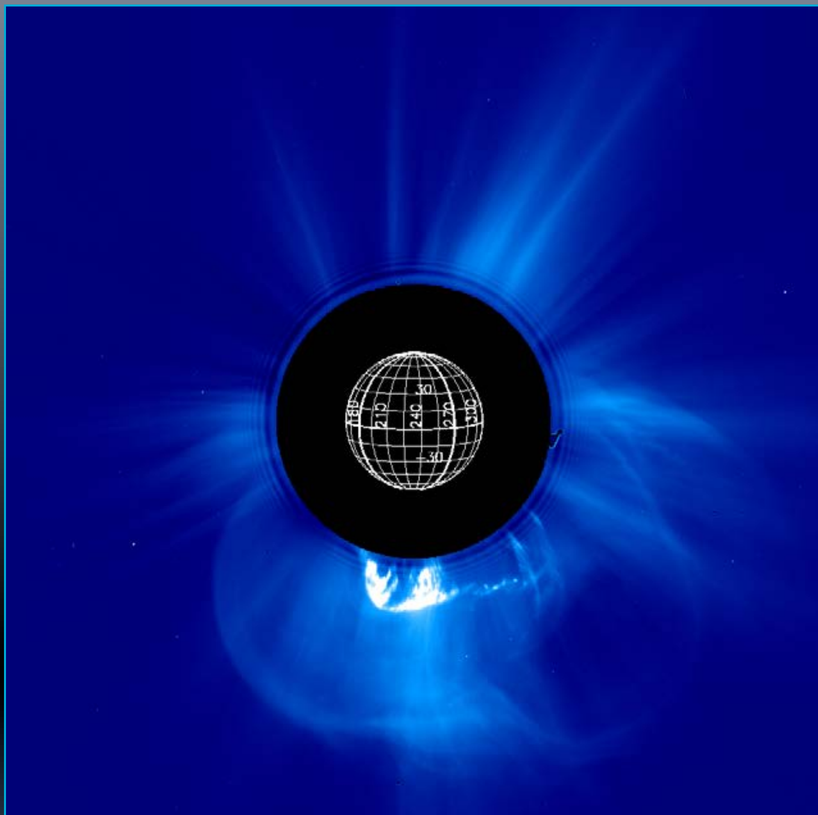


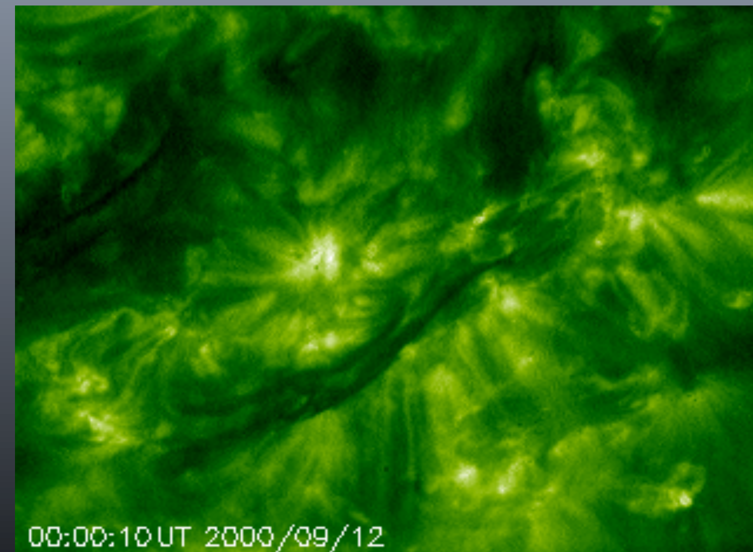
CMEs originate from bipolar photospheric fields regions



Cremades & Bothmer, A&A 2004

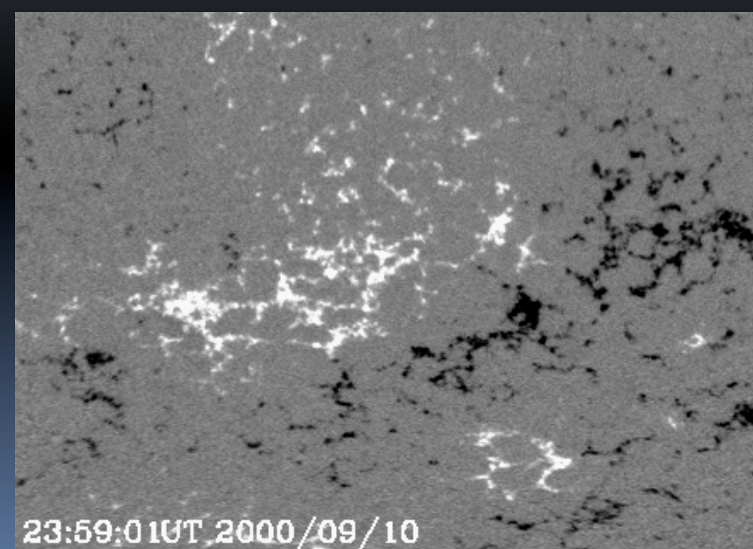
Filament, Arcade and Variation of the Photospheric Magnetic Flux in the Source Region of a CME





EIT

195 Å



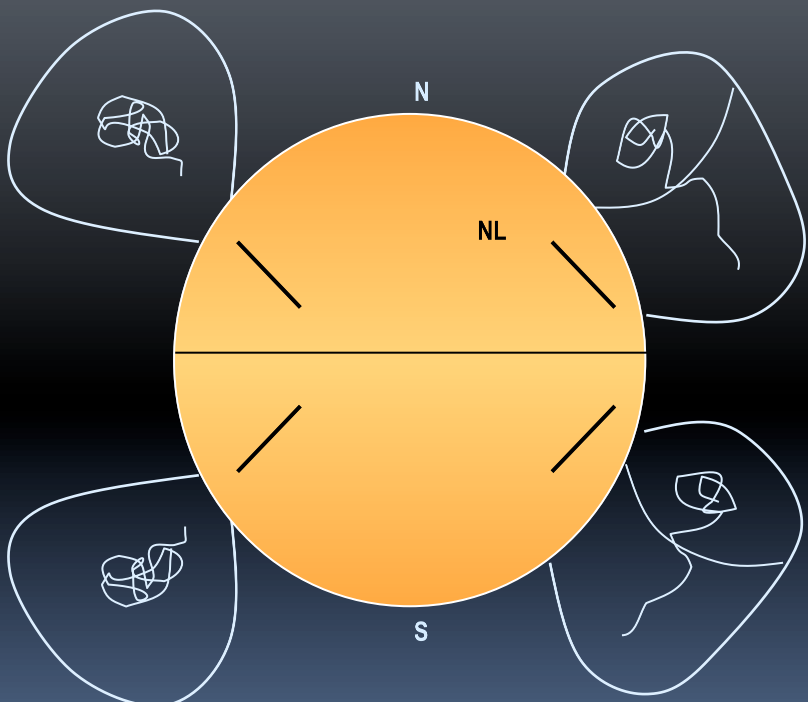
MDI

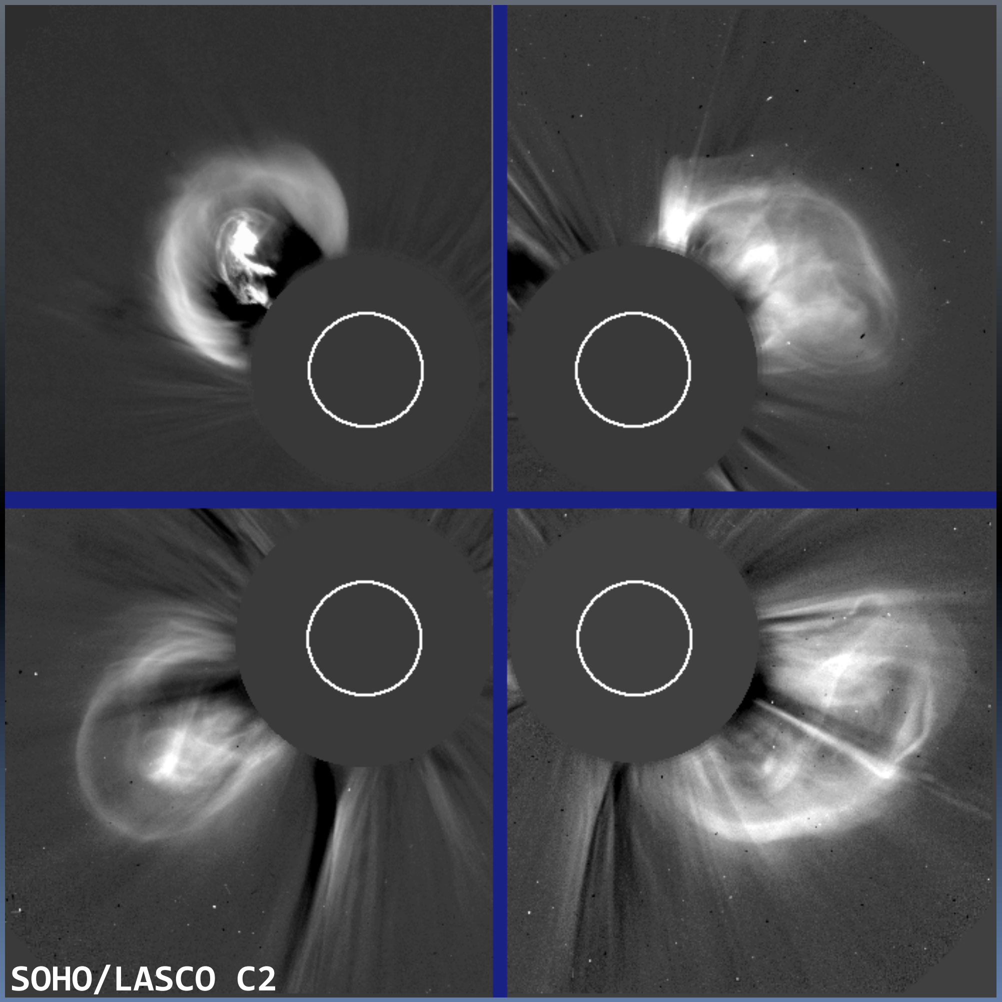
A detailed study was carried out to investigate the evolution of the photospheric flux in the source regions of CMEs (*Tripathi, Bothmer, Cremades, A&A, 422, 307-322, 2004)*.

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



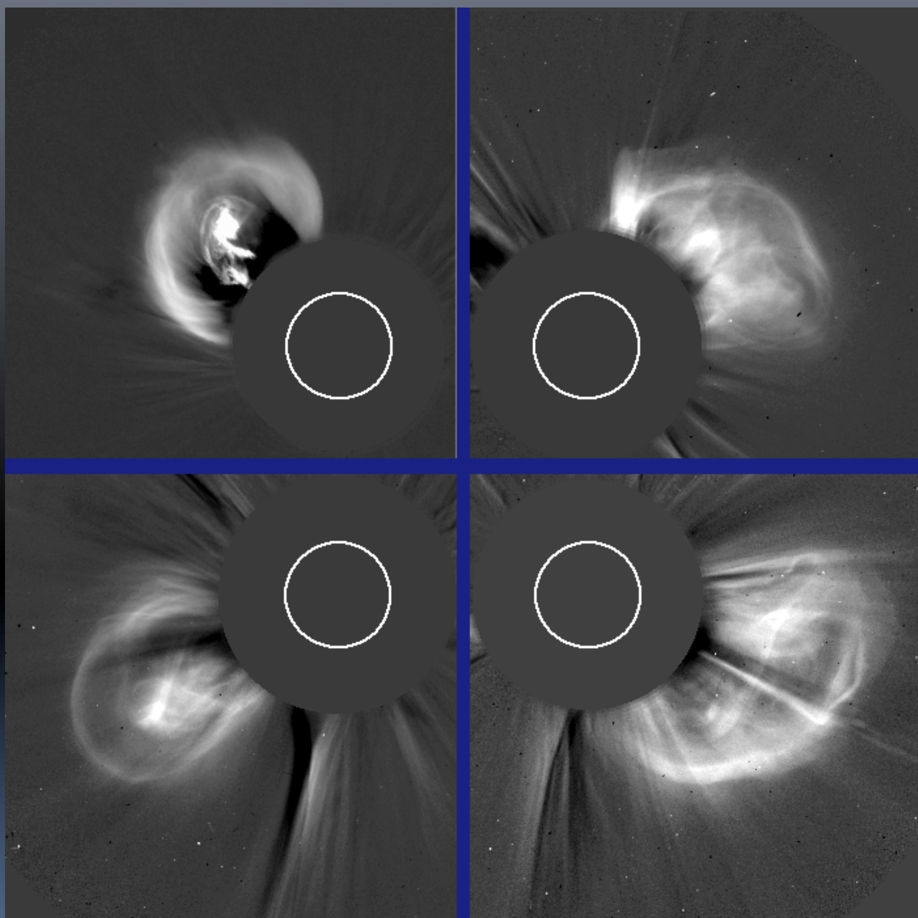


Scheme is simplification !

Cremades & Bothmer, A&A 2004

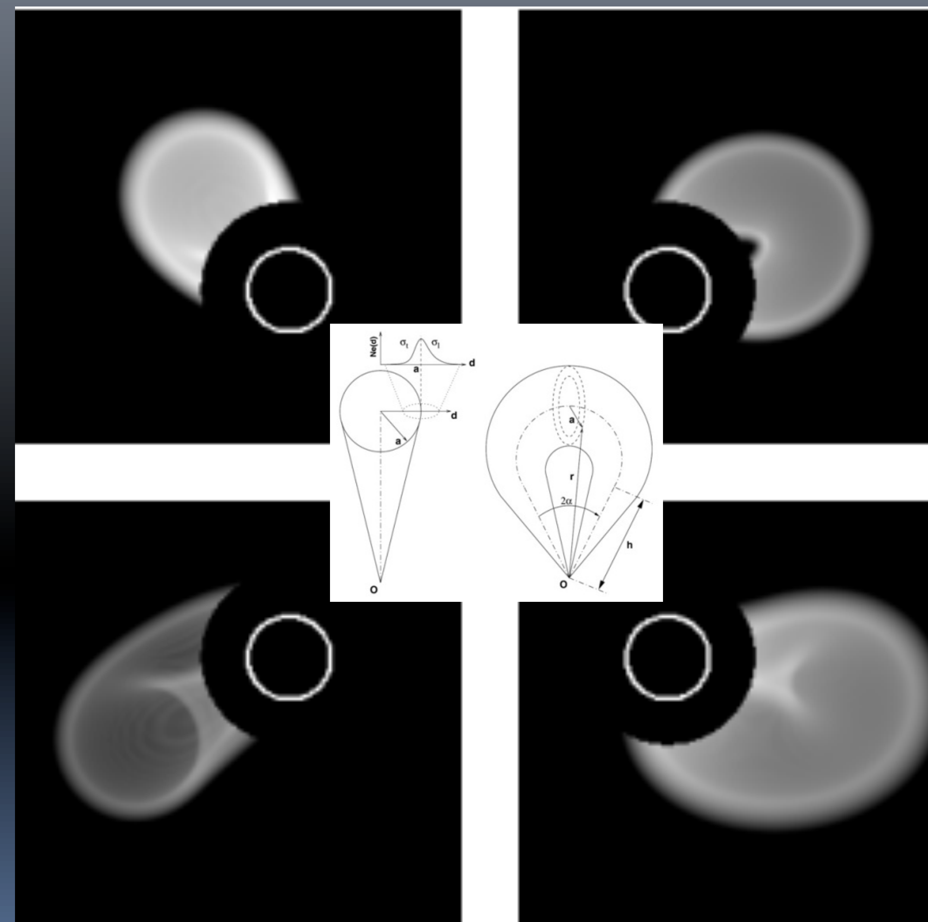
Modelling the Electron Density Distribution

LASCO Observations



Cremades & Bothmer, A&A 2004

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

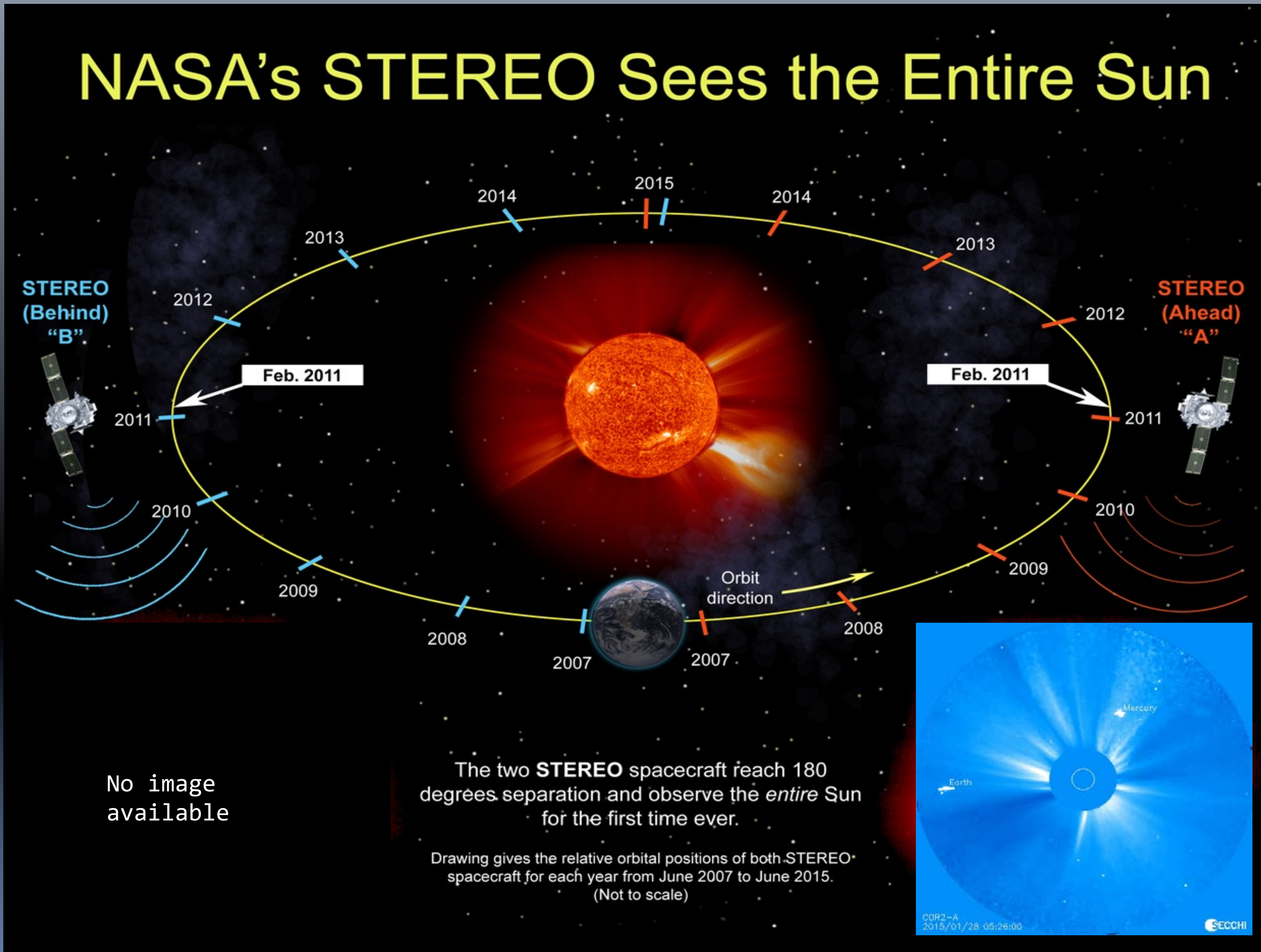


Howard, Thernissien and Vourlidas, ApJ 2006

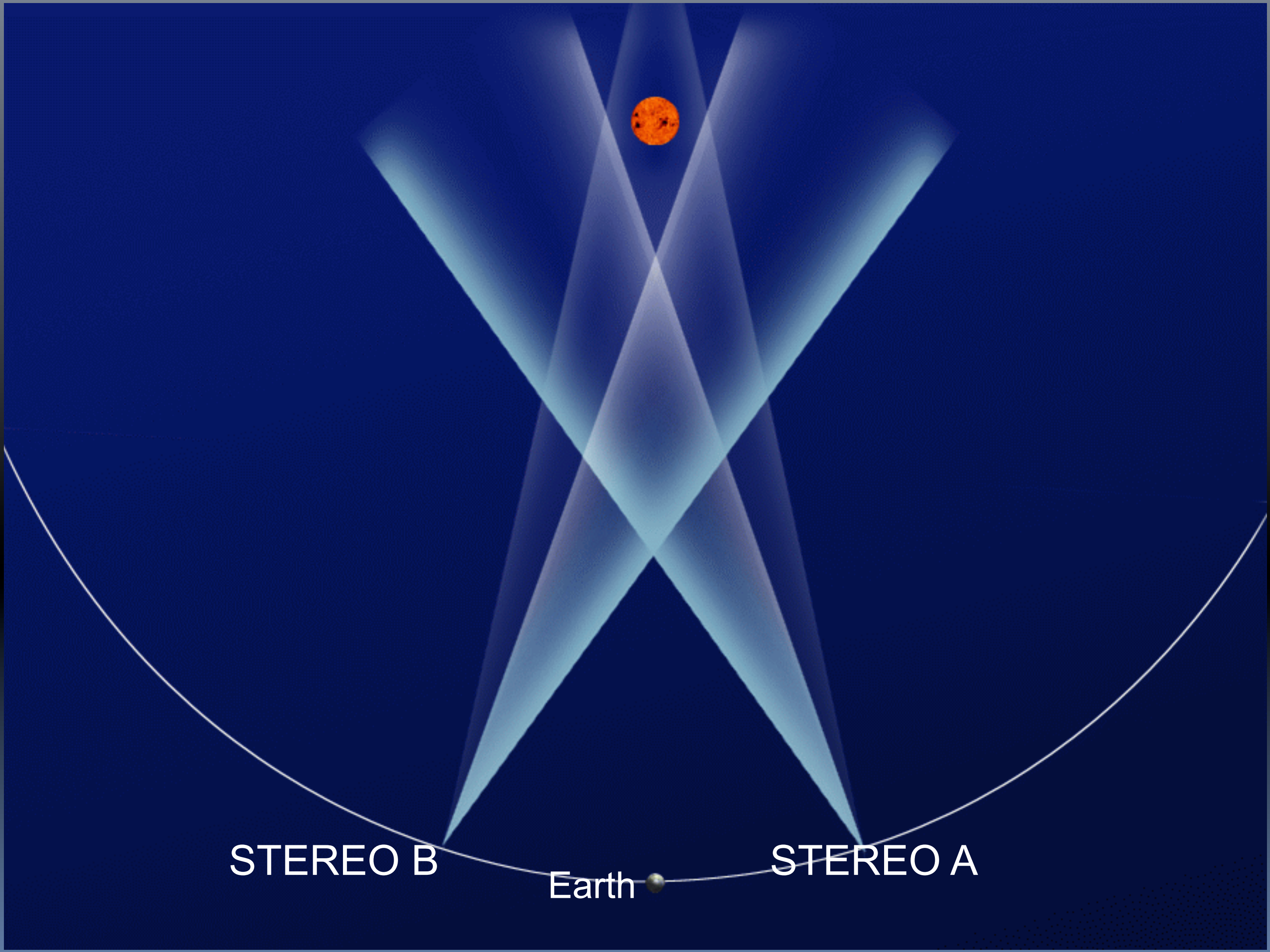
Part 2

Observations and Results from STEREO and the HELCATS Project

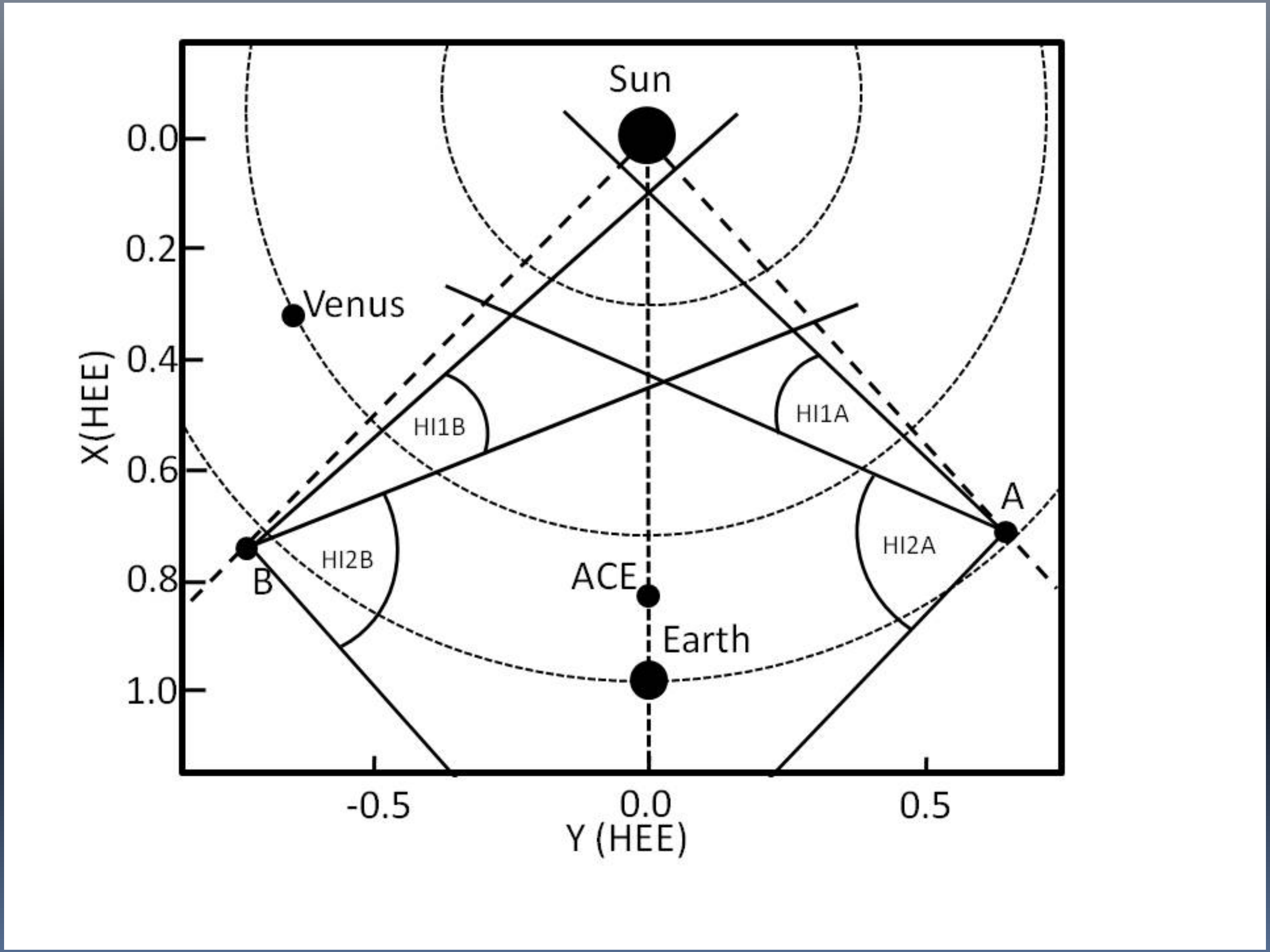
Earth-Selfie from STEREO-A



Stereoscopic Observations of the Sun-Earth System

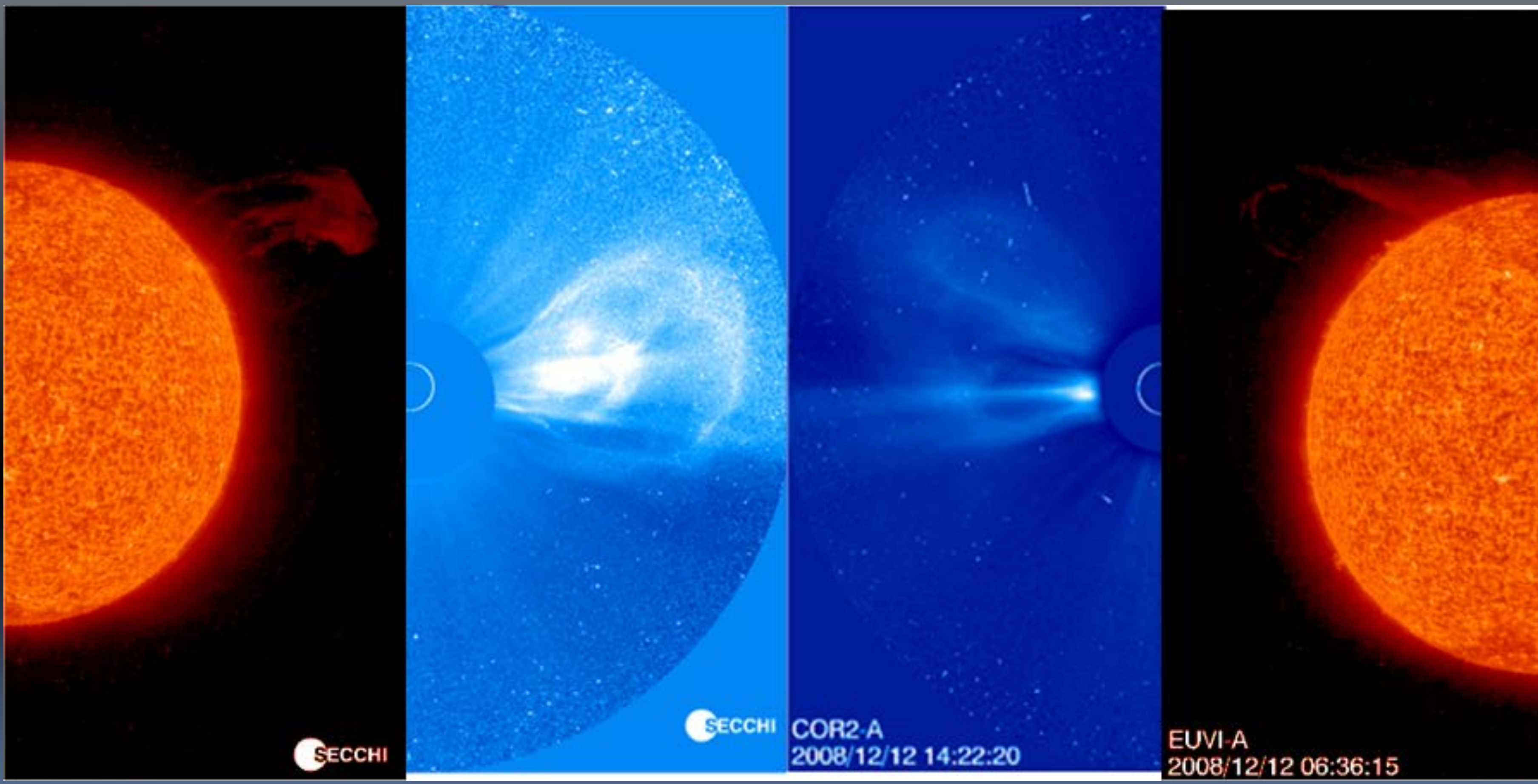


December 2008 – First CME Tracked All Away Along the Sun-Earth Line

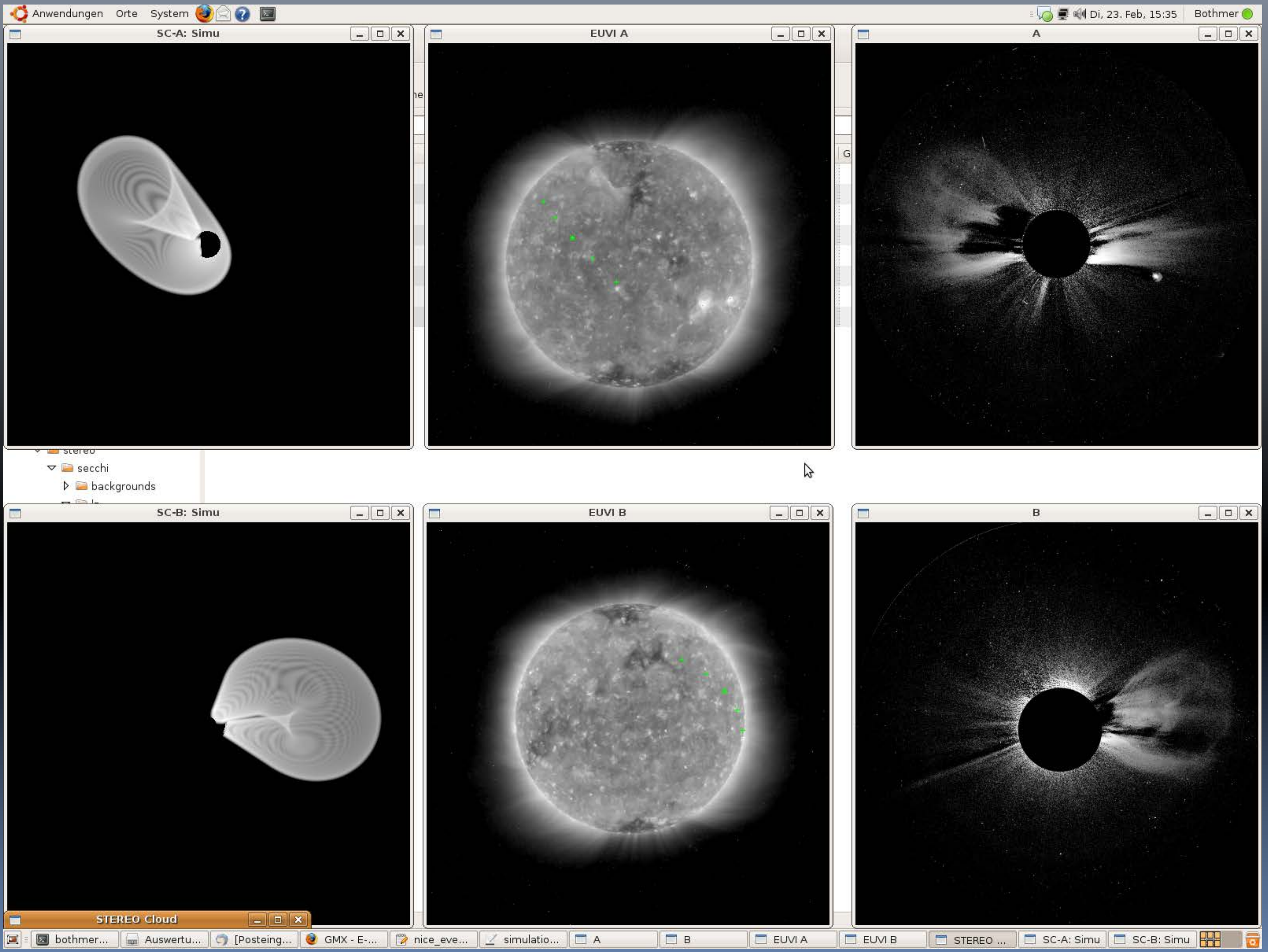


Davis et al., 2009

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

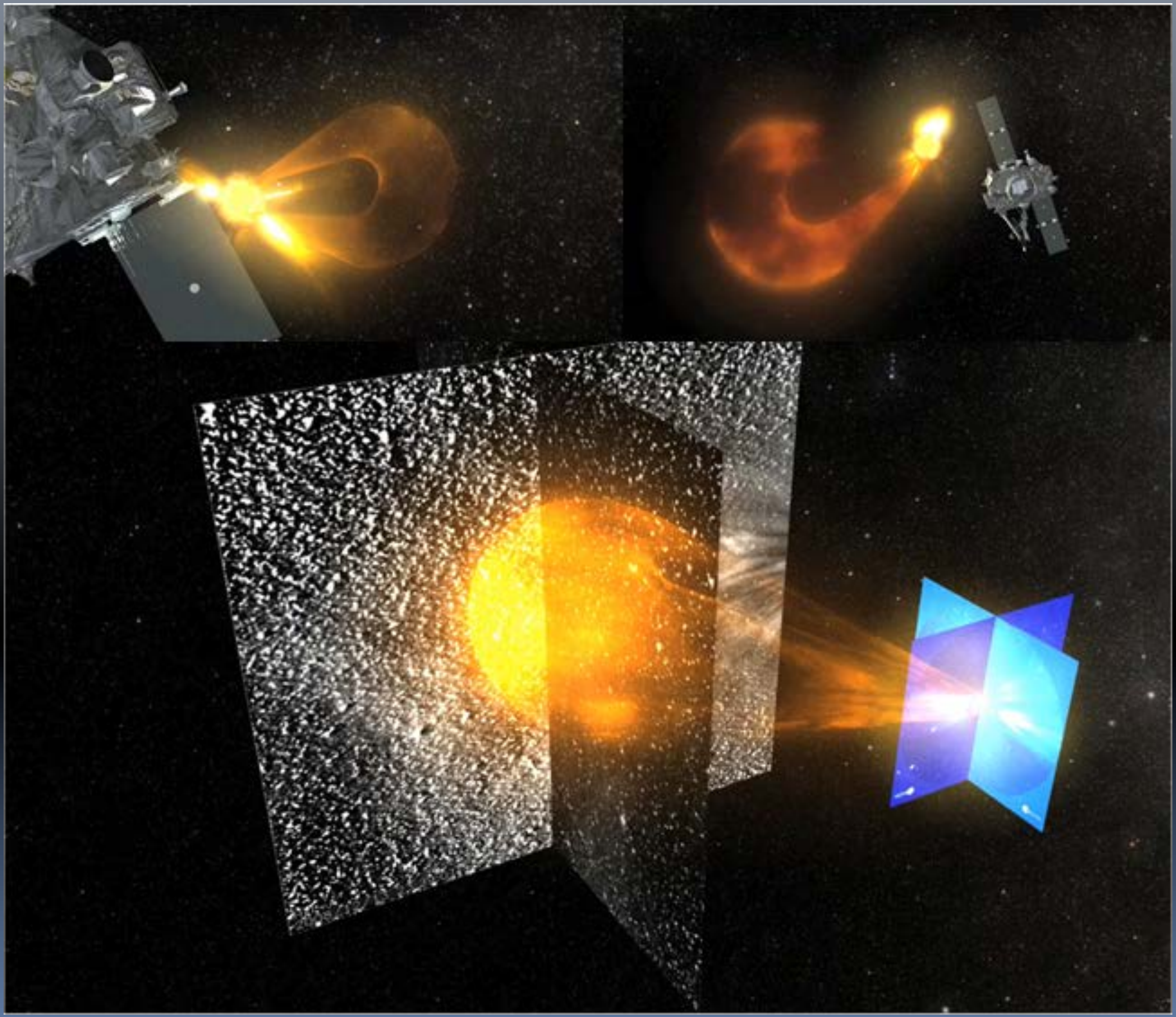


CME Modeling: Dec. 12, 2008



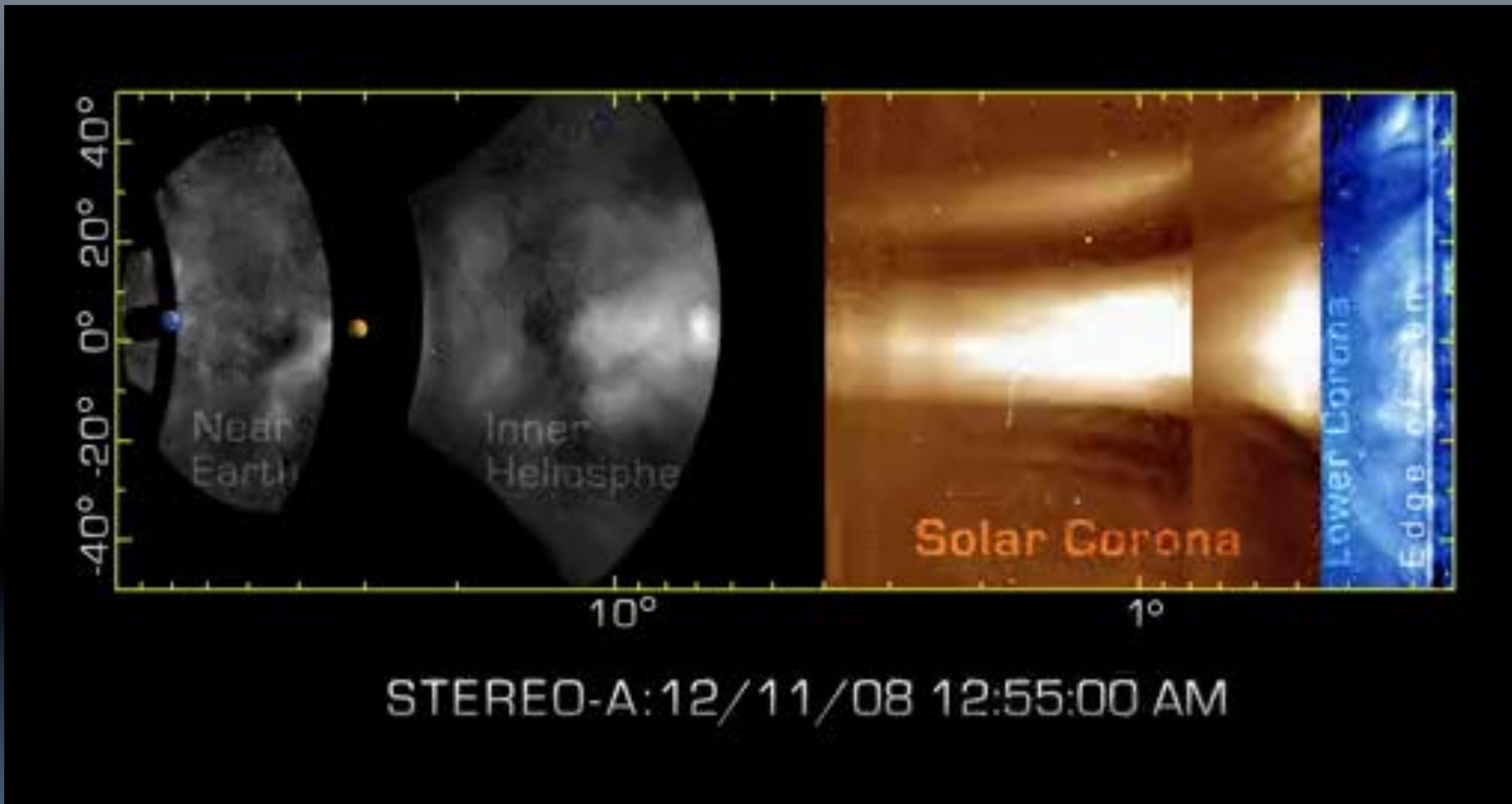
Credit: E. Bosman

CMEs are large-scale magnetic flux ropes



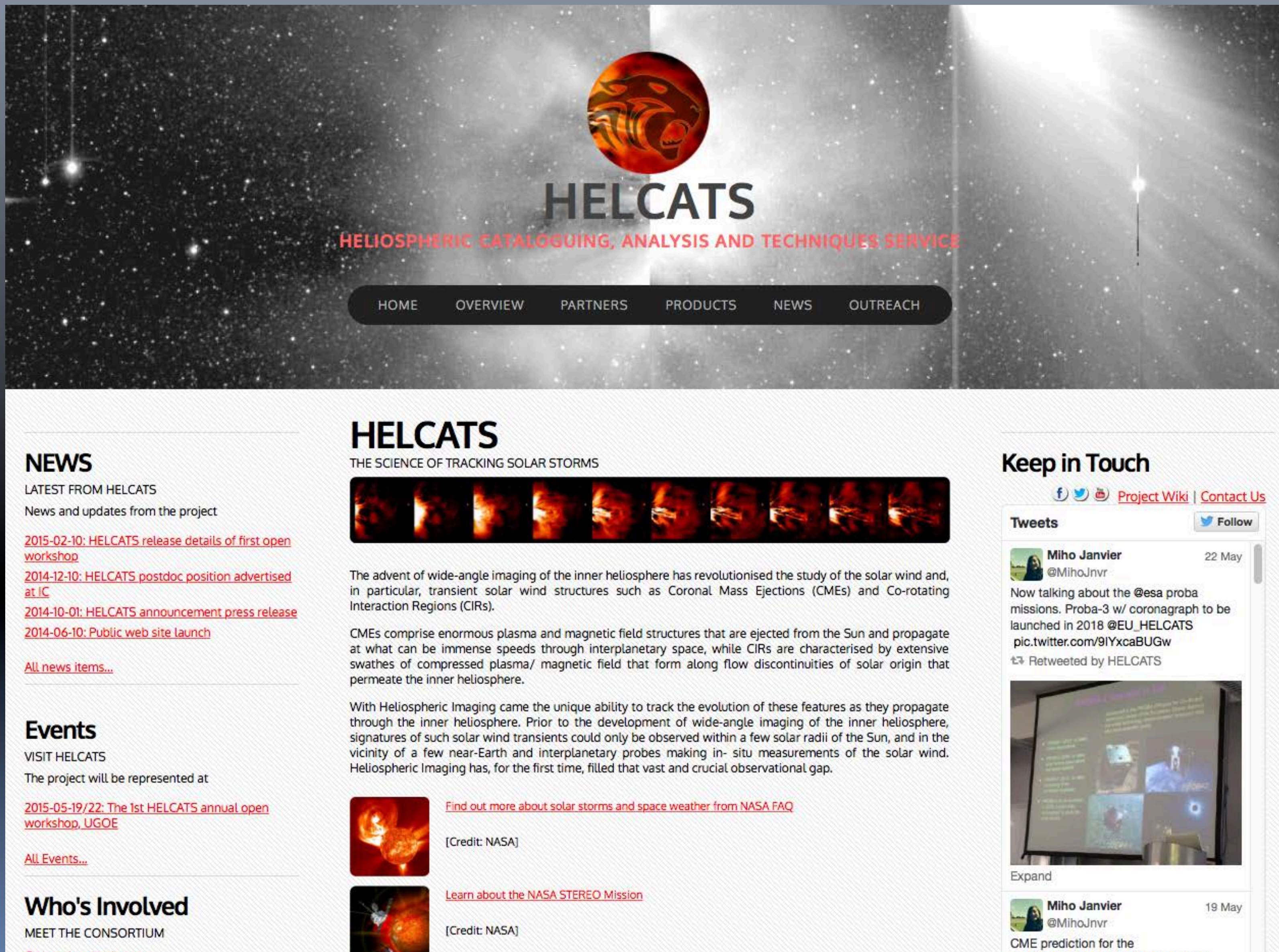
STEREO/SECCHI Consortium

CME tracked Sun to Earth

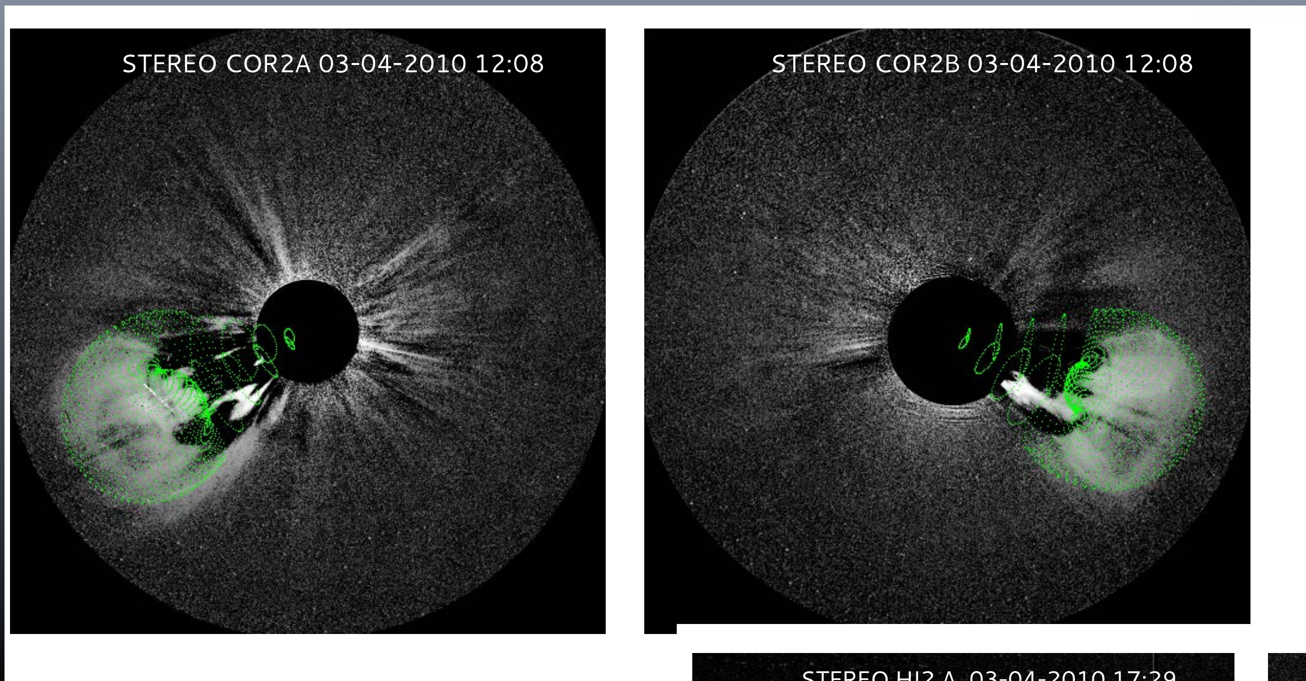


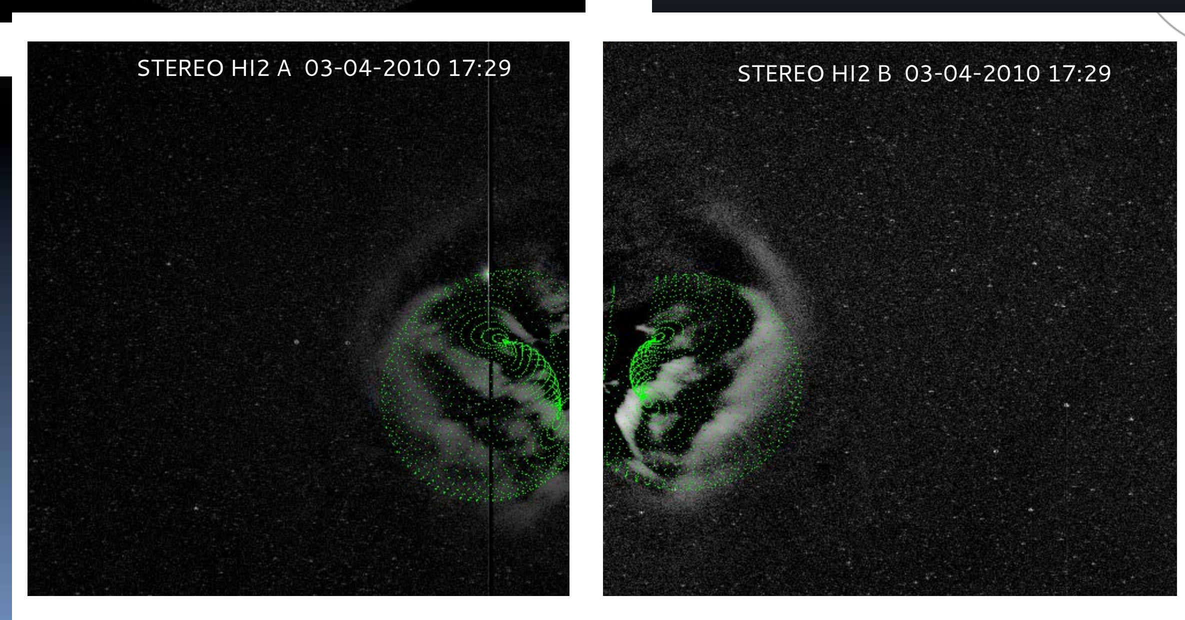
Credit: NASA, deForest

The EU Project HELCATS



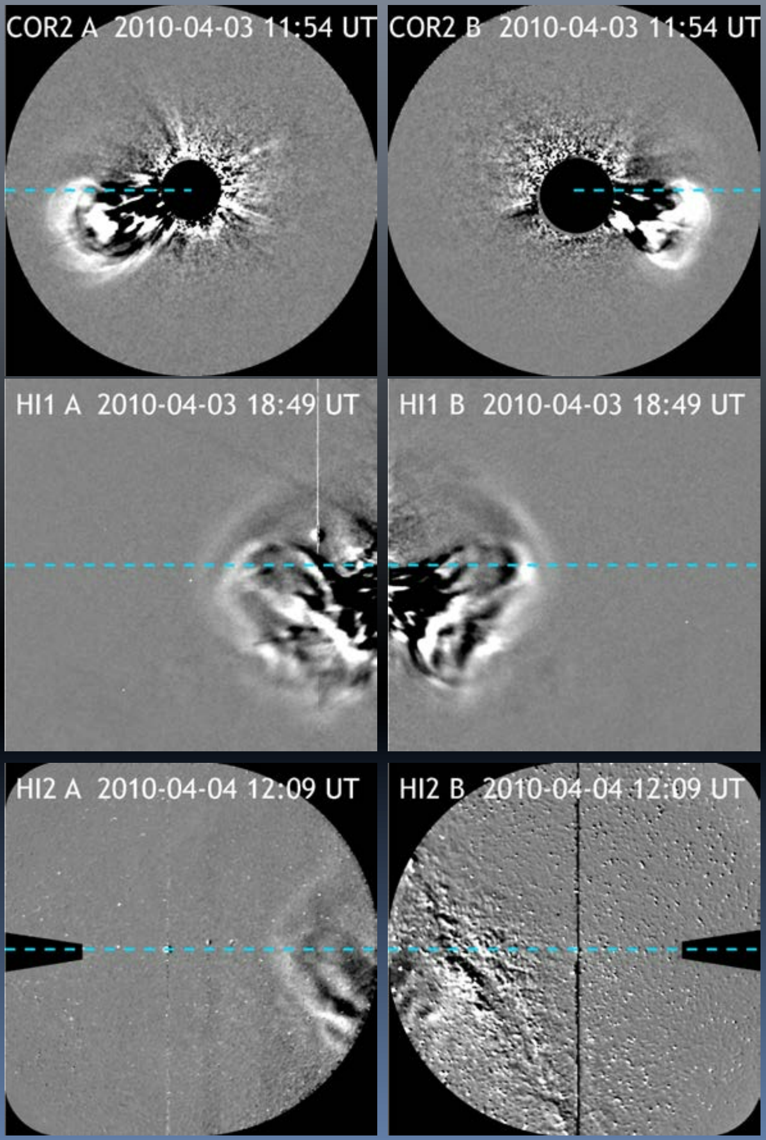
Stereoscopic Modeling in the Heliosphere





Volpes and Bothmer, 2015

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 $\lambda = 10°$	1st degree fit $\lambda = 90°$
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 $\lambda = 10°$	2nd degree fit $\lambda = 90°$
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

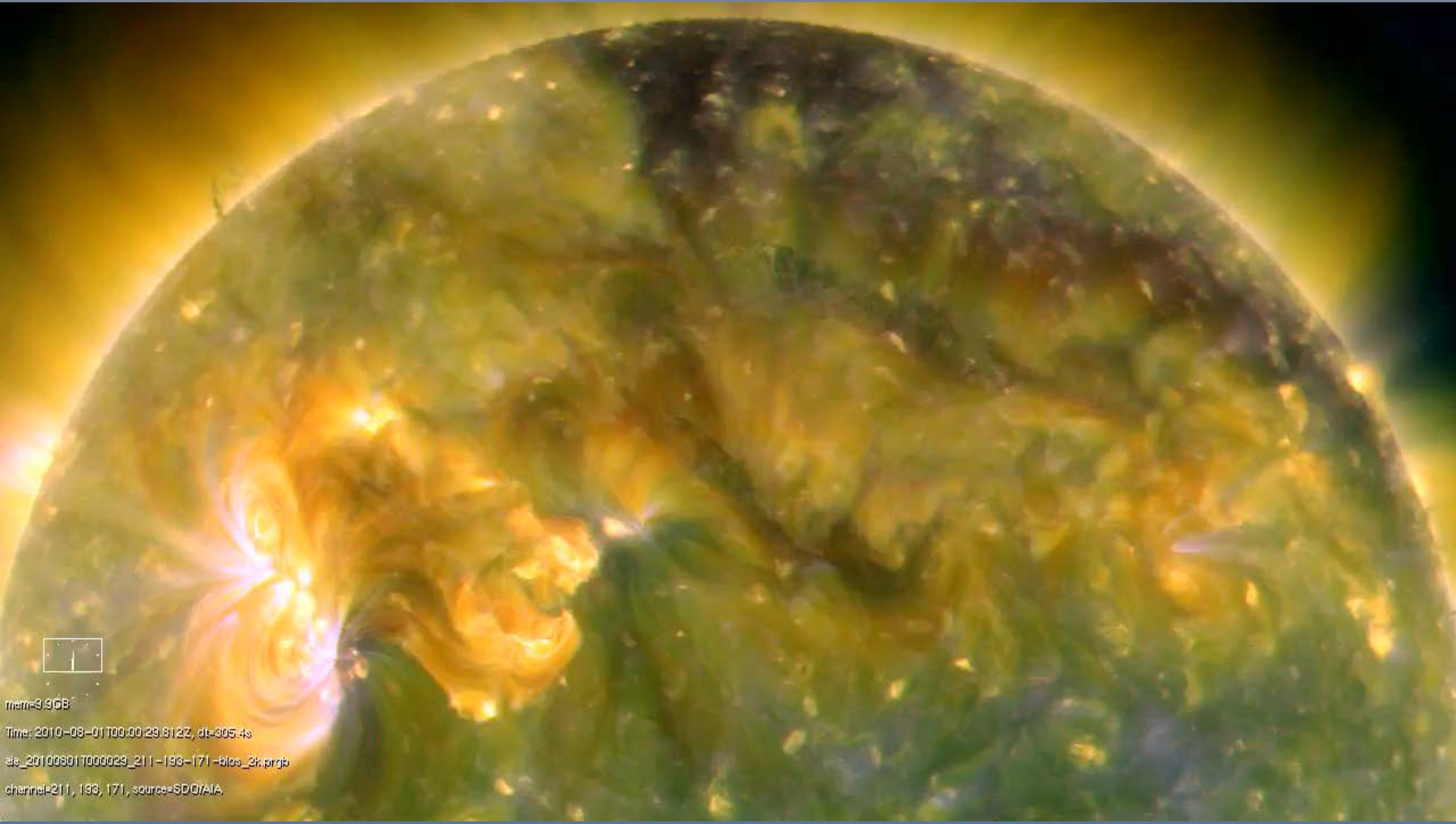
Challenges for improved space weather forecasts

Issues to be taken into account

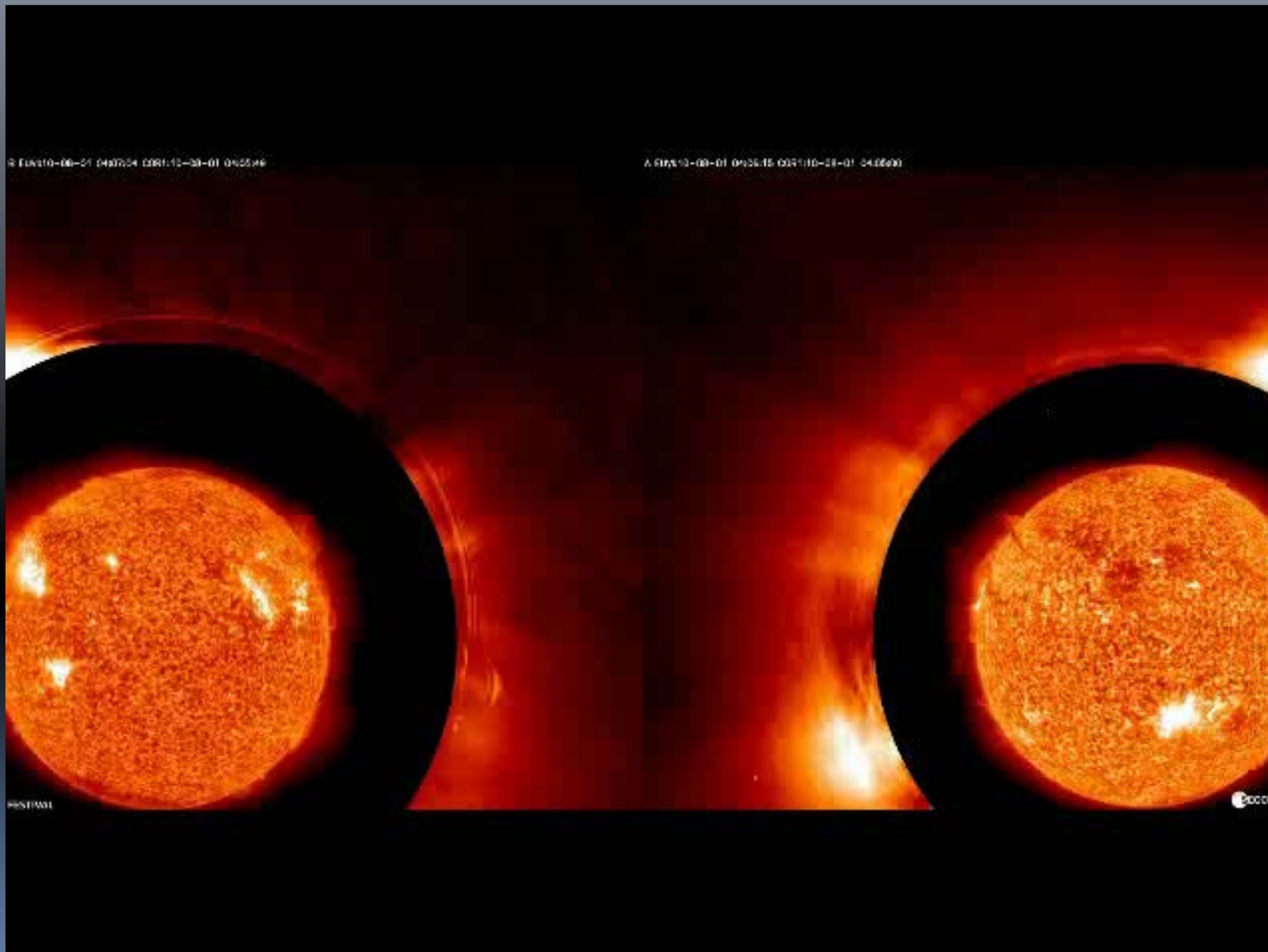
1. Multiple activity and complex energy release
2. Treatment of CME shock fronts and distortions
3. Lateral expansion of CMEs and subsequent B-Field expansion

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

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

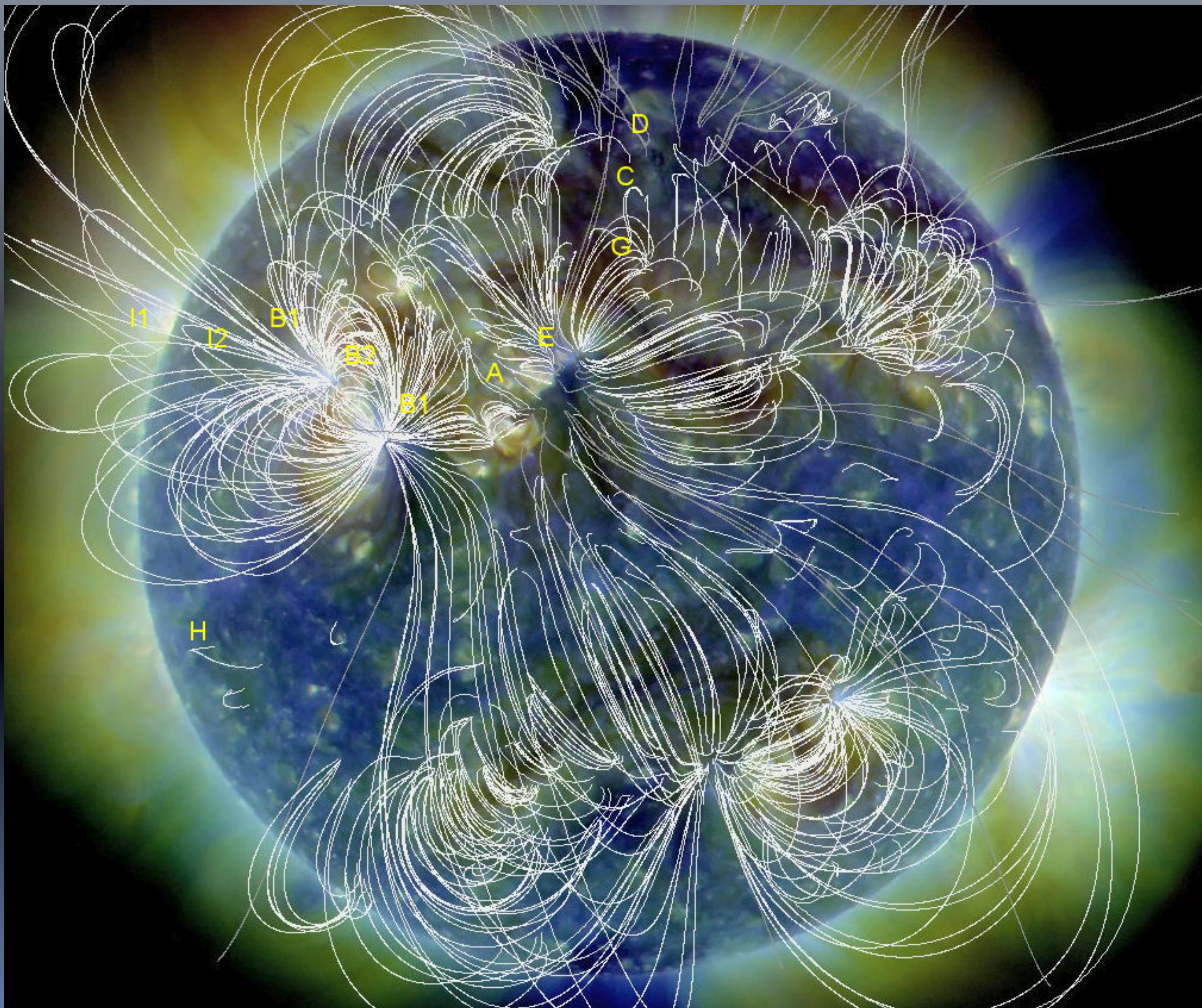


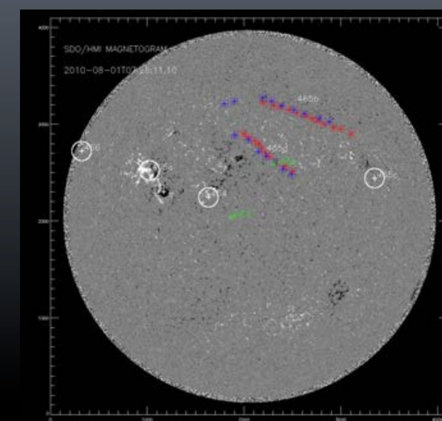
STEREO/SECCHI A, B EUVI, COR 1 – August 01, 2010



STEREO/SECCHI/HI1

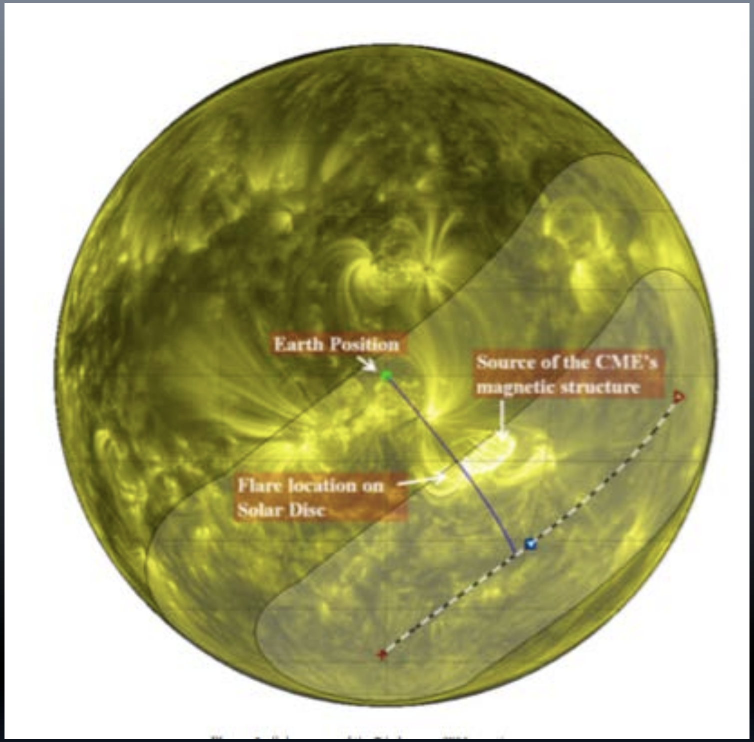
Magnetic Field Structure on August 1 - SDO/HMI

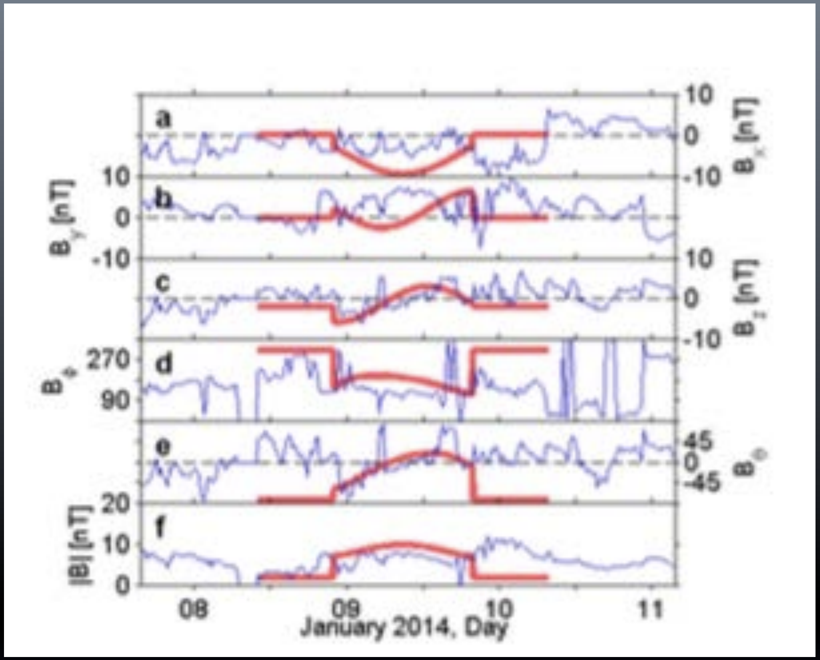




Schrijver and Title 2010

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

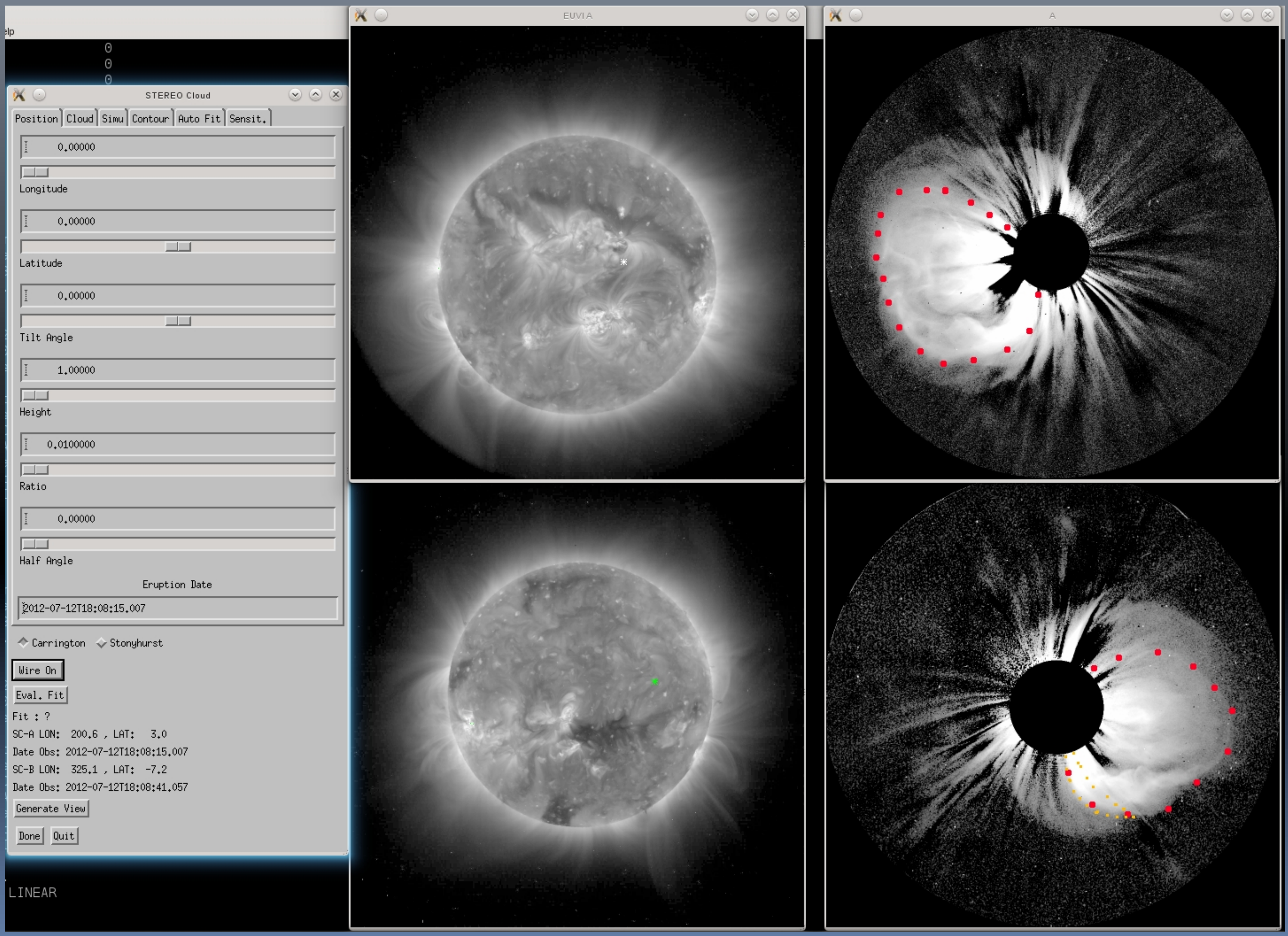
Eight events studied in detail - Conclusions:

“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.

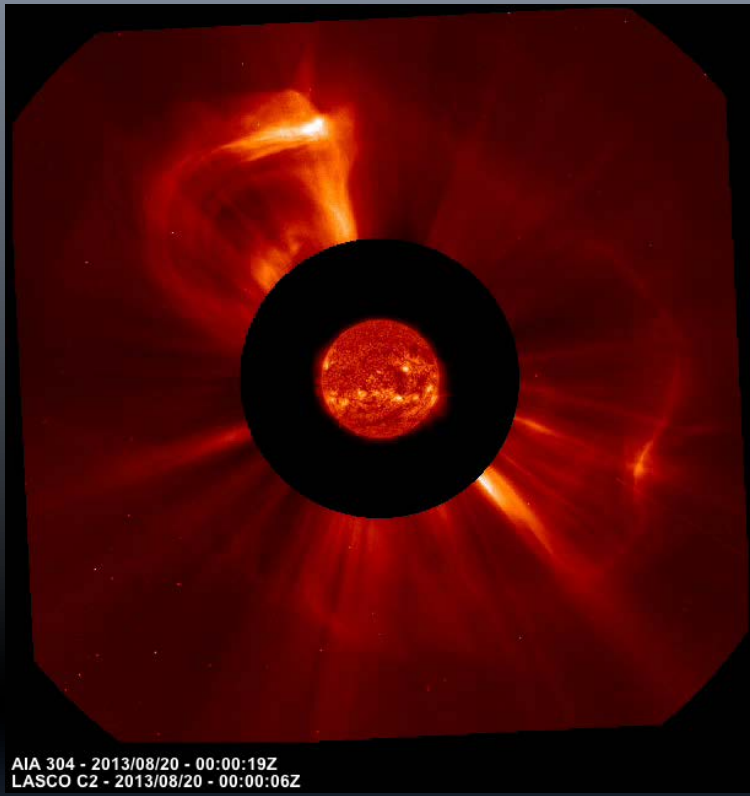
Also, to improve the reliability of the magnetic vector forecast, the initial topological struc- ture determined by the Bothmer-Schwenn scheme must be adjusted for cases where the overlying field arcade clearly traverses two active regions.”

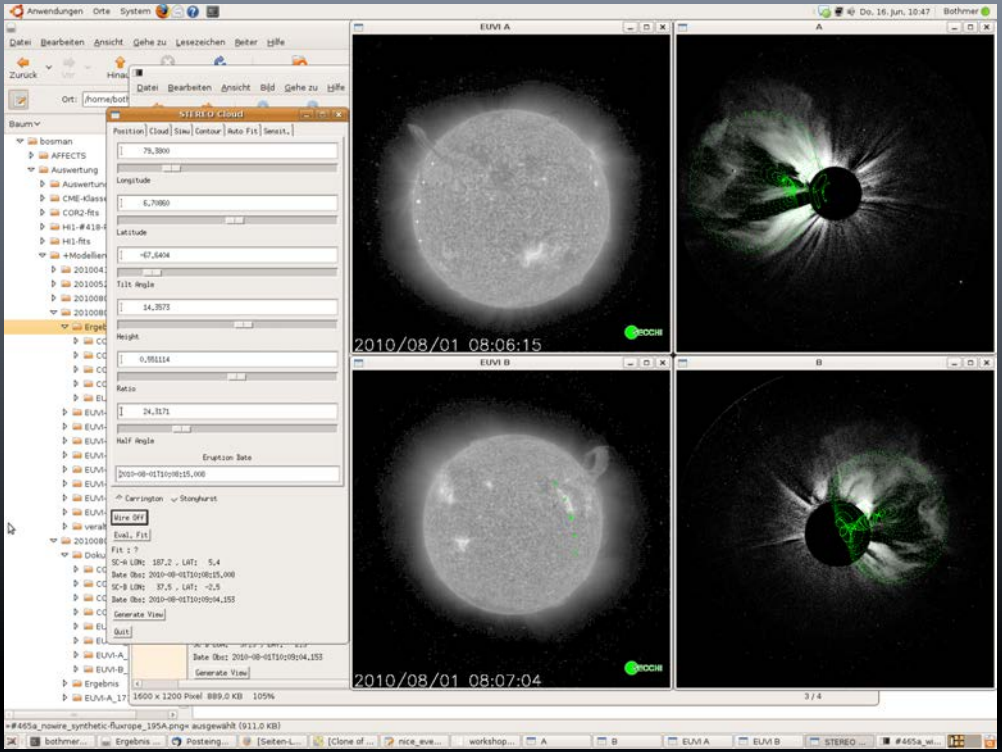
My comment: These events were of very weak field strength at 1 AU – not clear if all were real CME hits but could also be indeed due to quadrupolar structures.

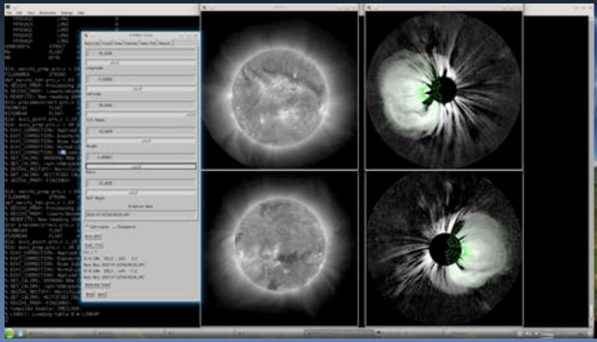
Shock fronts ahead of CMEs



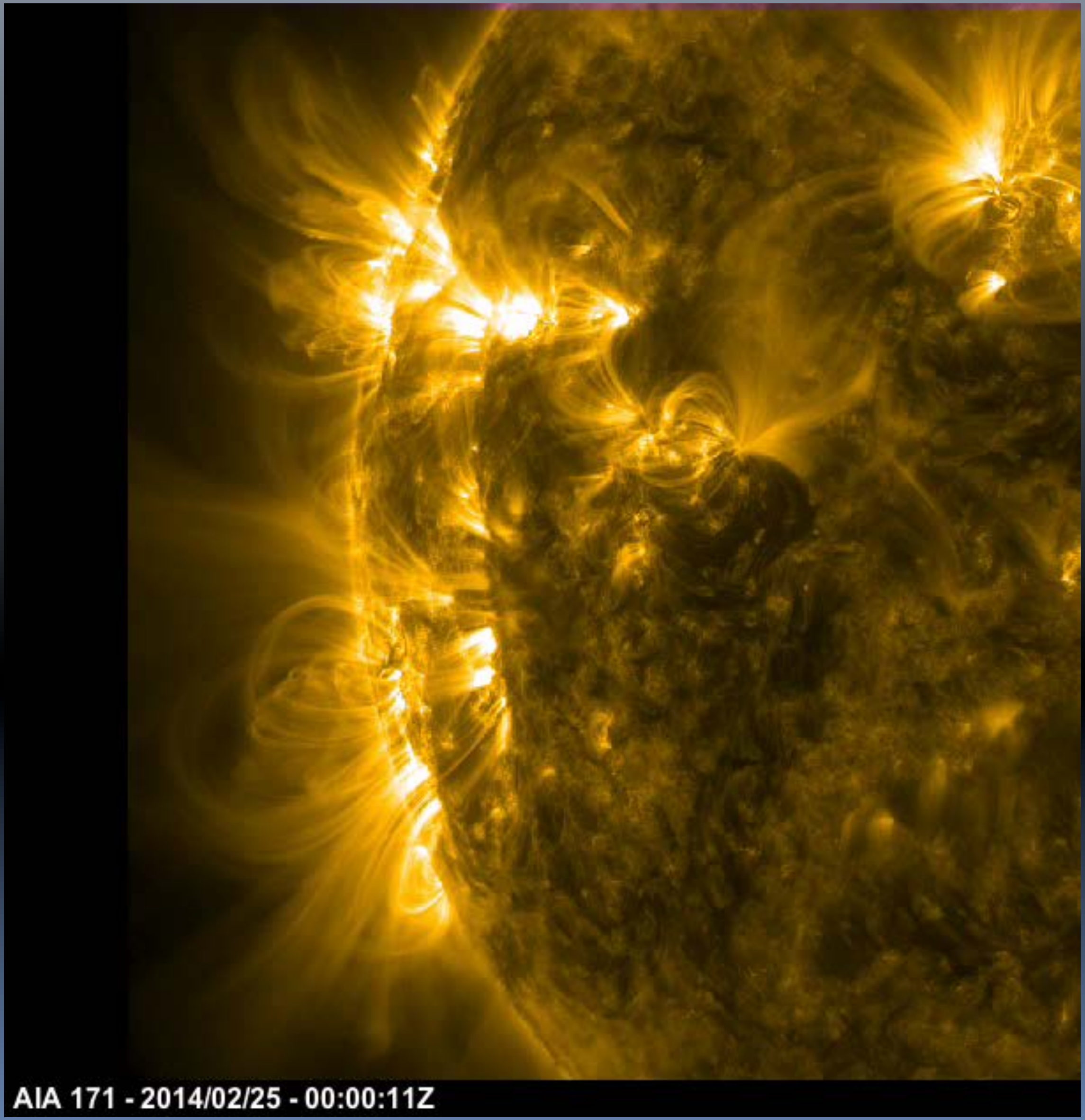
Distortion of CME fronts





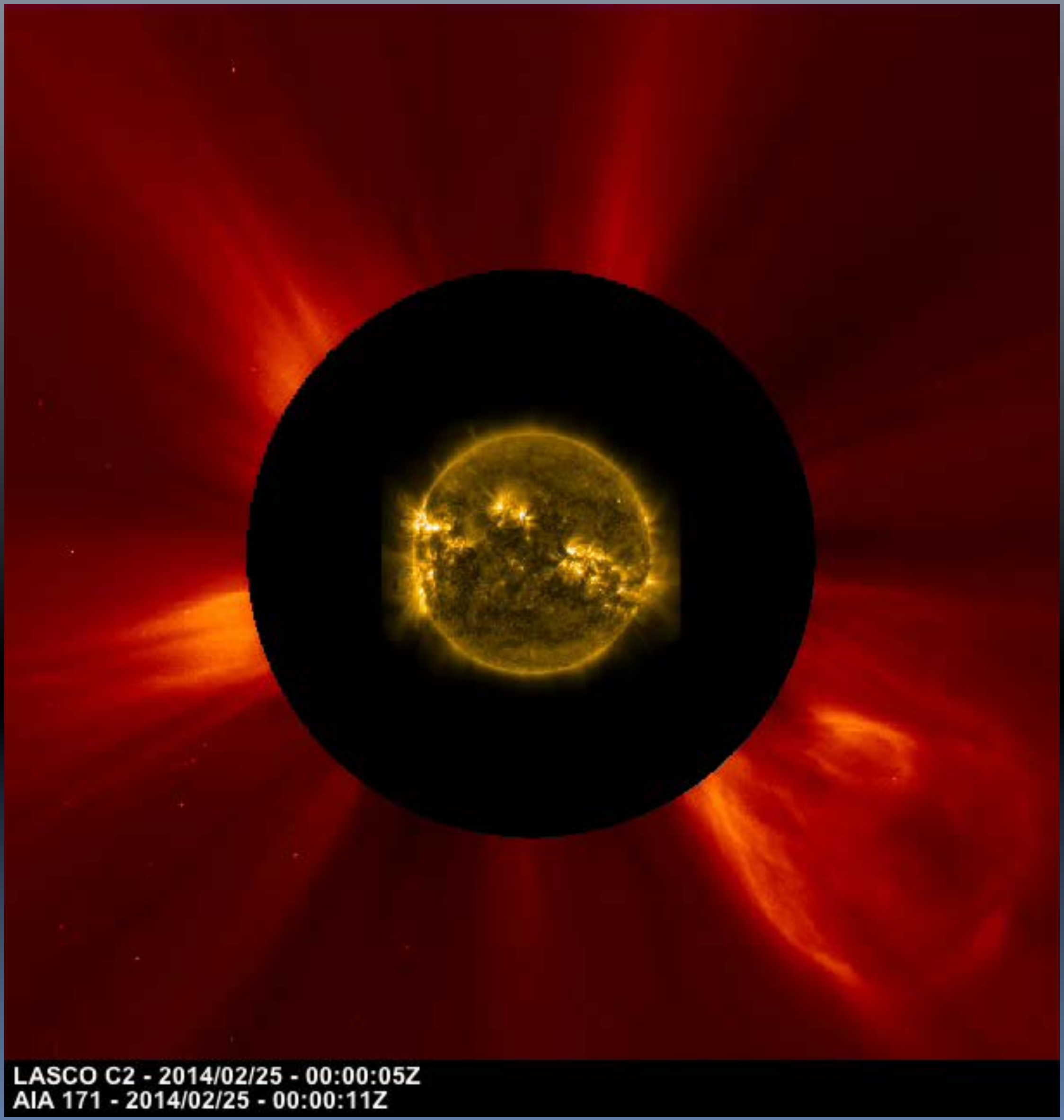


A typical solar storm onset: Flare and CME



Credit: SDO/AIA

Near-Sun rapid CME-Evolution



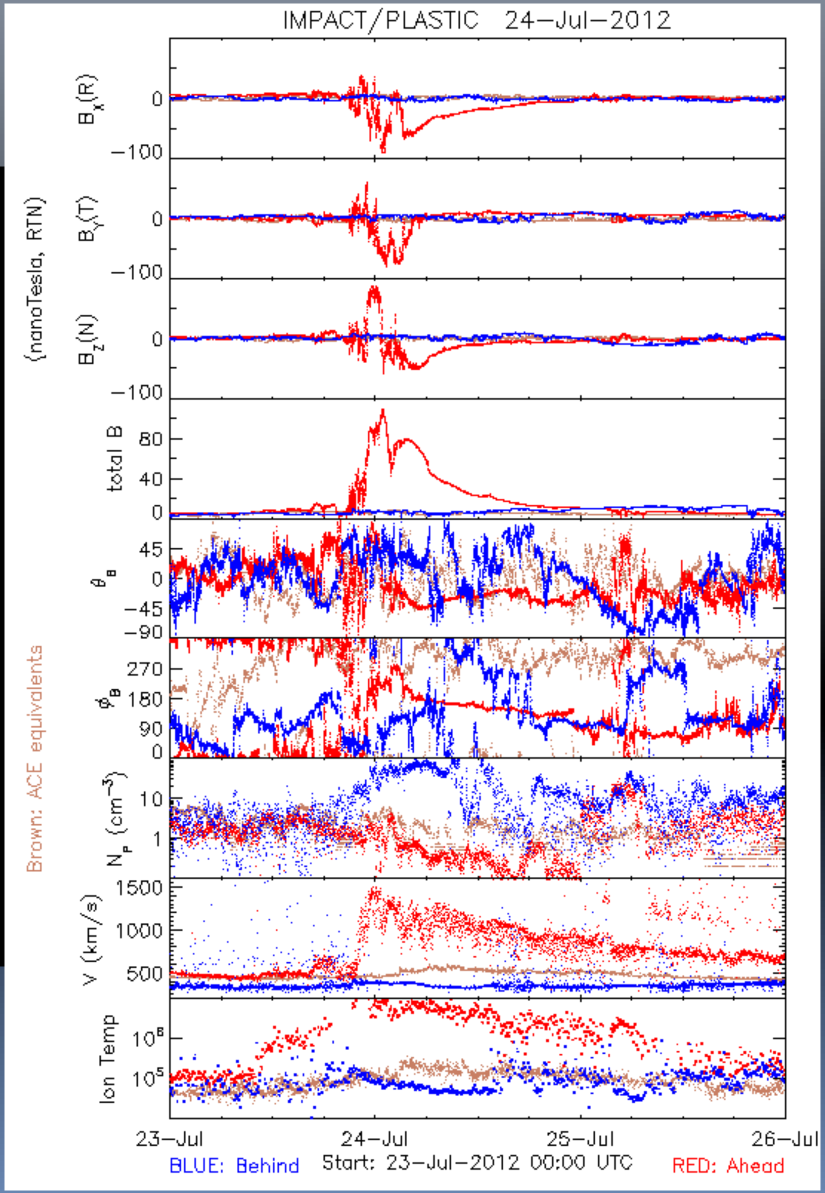
Credit: SDO, SOHO

The associate low coronal wave: Lateral Expansion

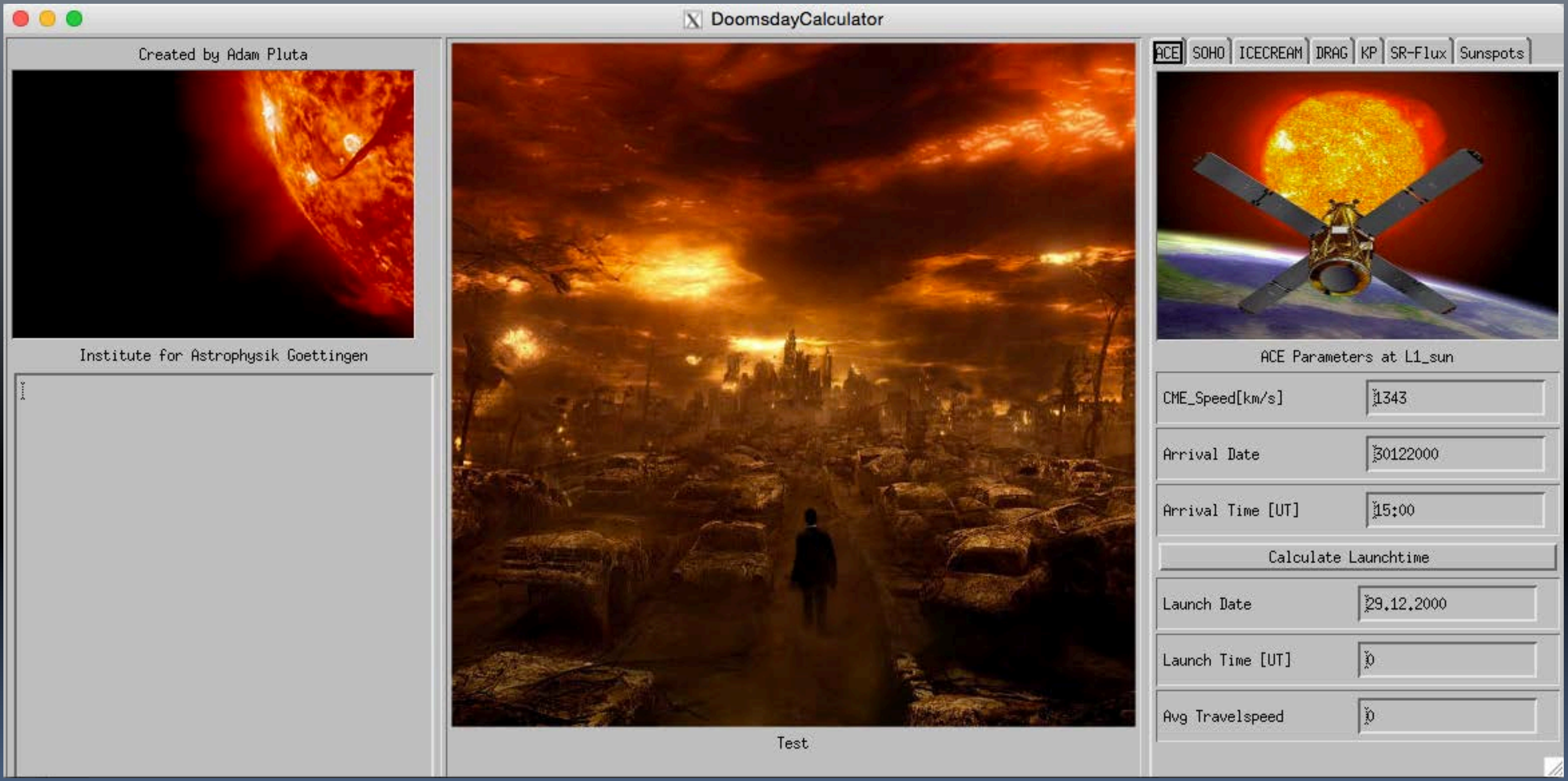
Credit: SDO/AIA, SIDC, STAFF

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

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

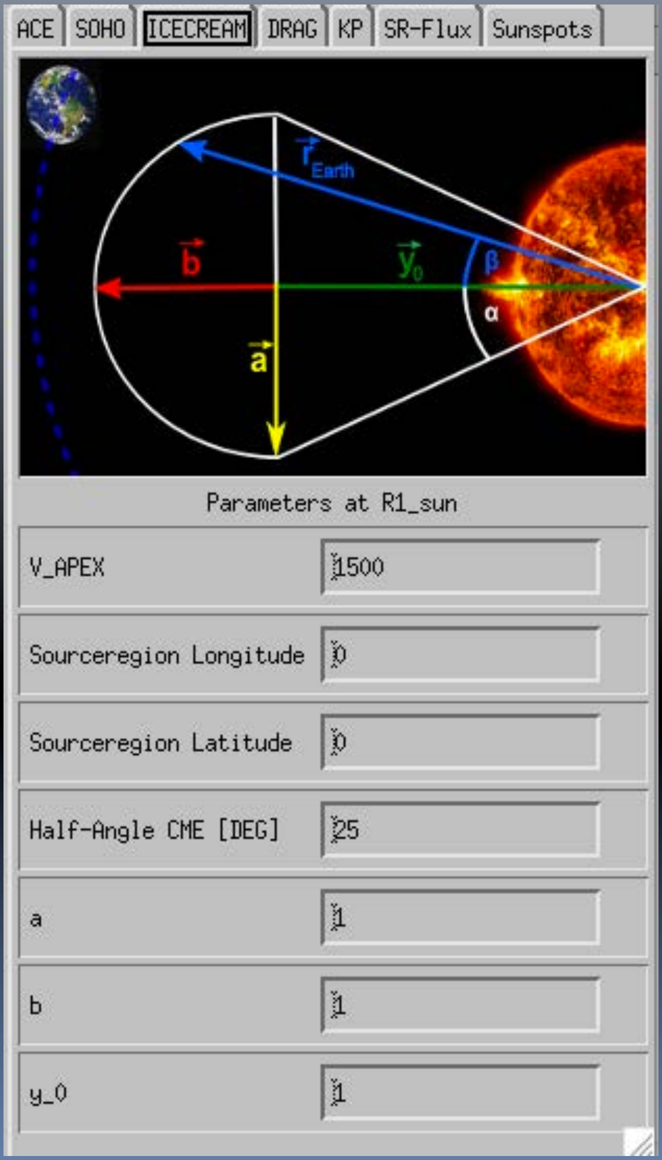


UGOE AFFECTS DDC



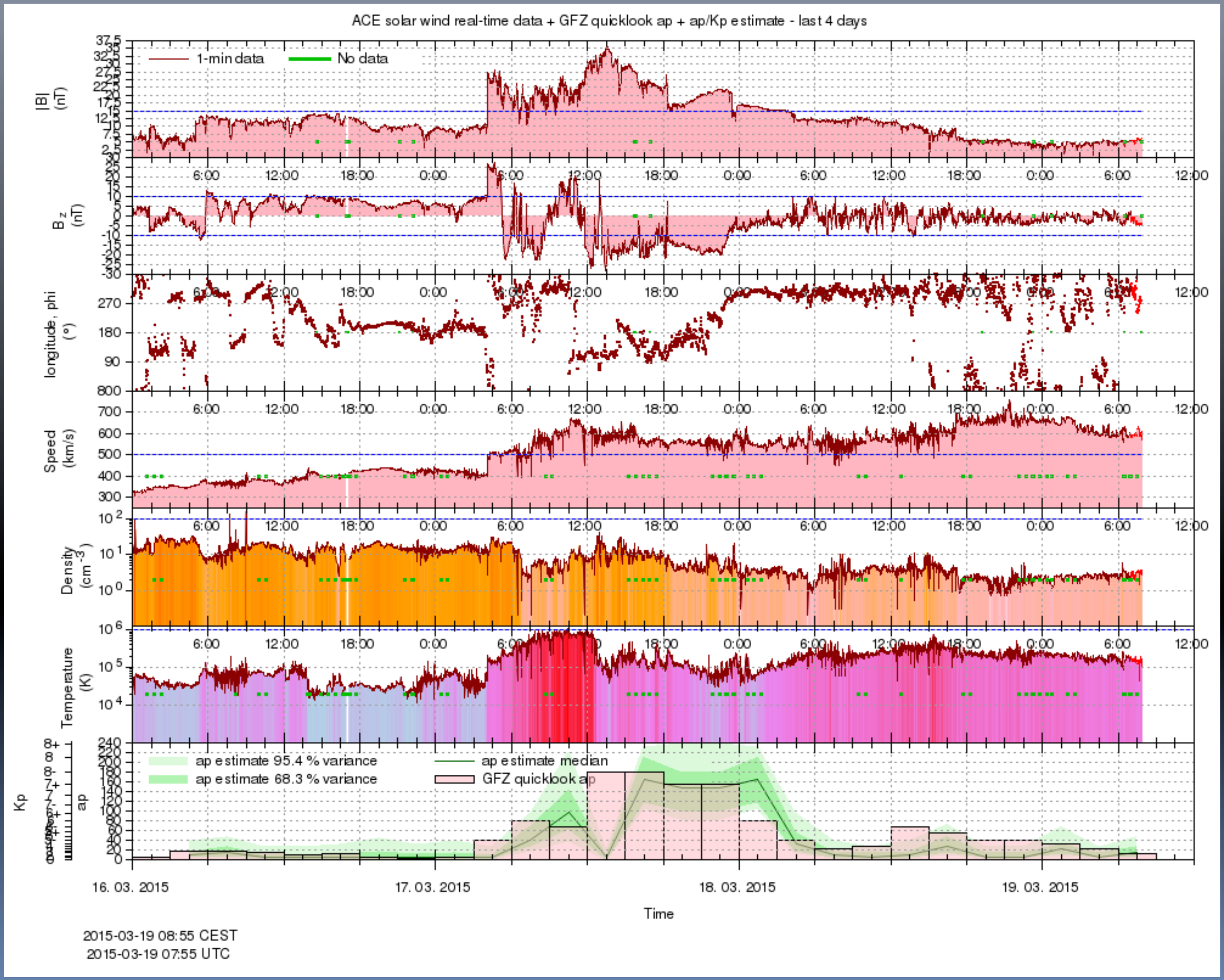
Credit: A. Pluta, AFFECTS, HELCATS

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

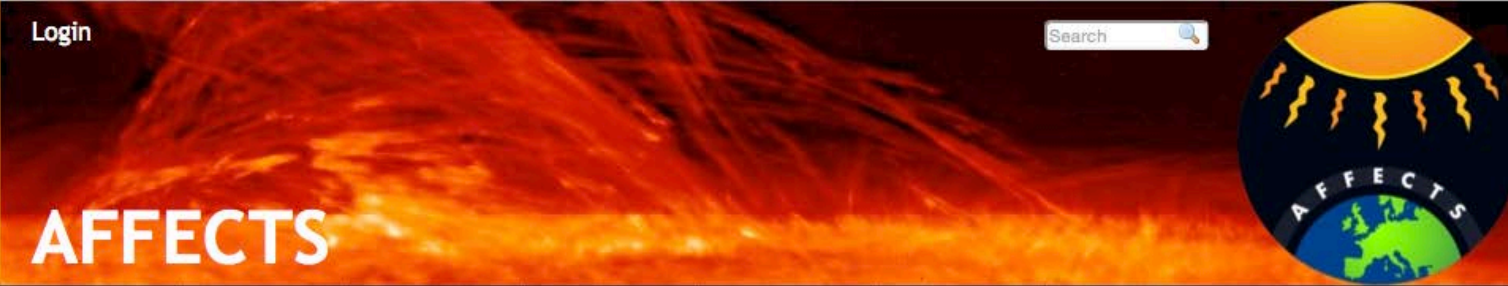


Credit: A. Pluta, AFFECTS, HELCATS

March 2015 CME



Credit: M. Venzmer, AFFECTS



AFFECTS Website

http://www.affects-fp7.eu/weather

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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 Aeropace Center	DLR	Dr. Norbert Jakowski, Dr. Jens Berdermann
7	Germany	Astrium 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 preoject trailer. The channel can be

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 – likeliness 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