Linking CMEs to Associated Solar Phenomena

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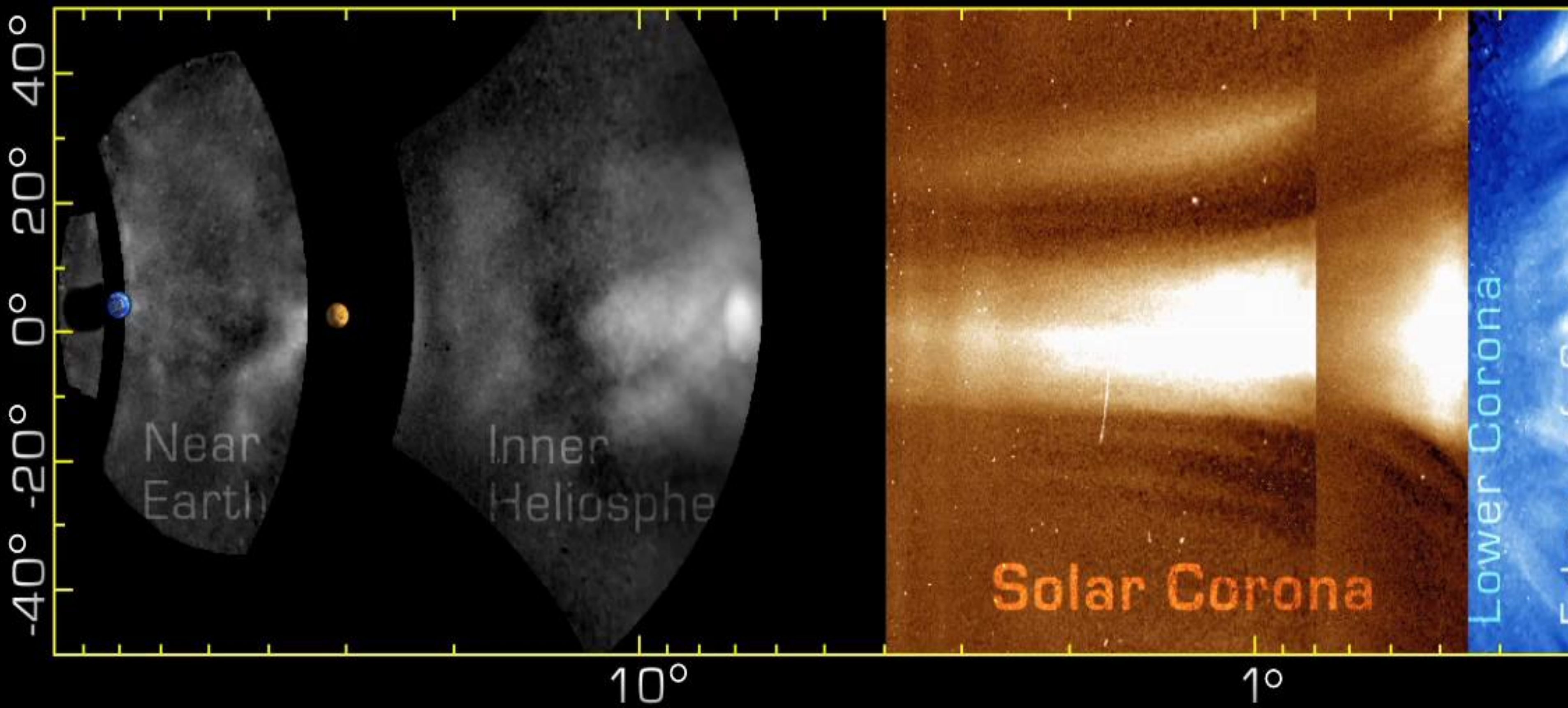
Göttingen Magnetischer Verein

- Trinity College Dublin was a site of Gottingen Magnetic Union (1836-1841).

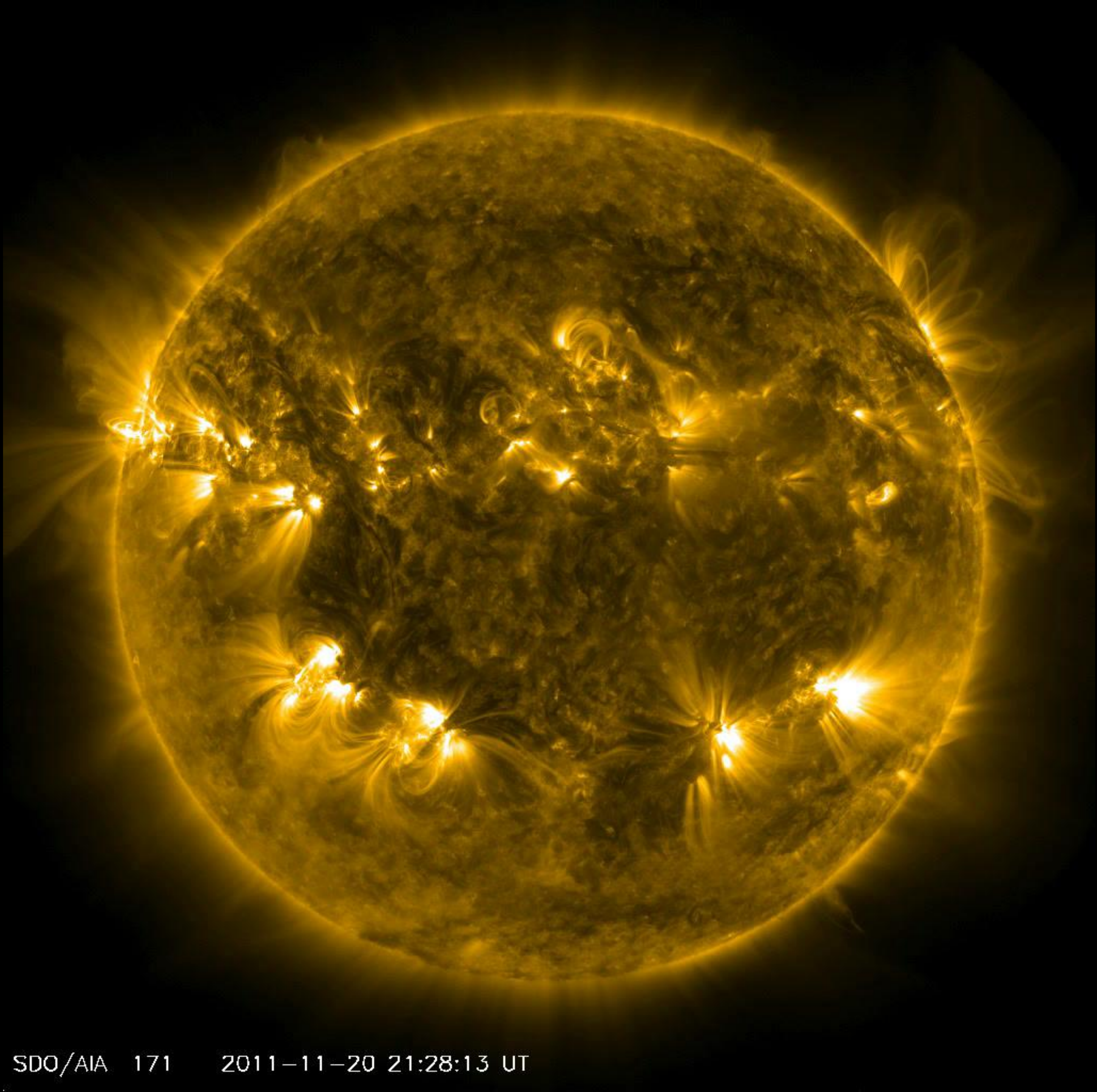
- Magnetic measurements up to every 5 mins.

- Led to magnetic crusades by Edward Sabine and Humphrey Lloyd.

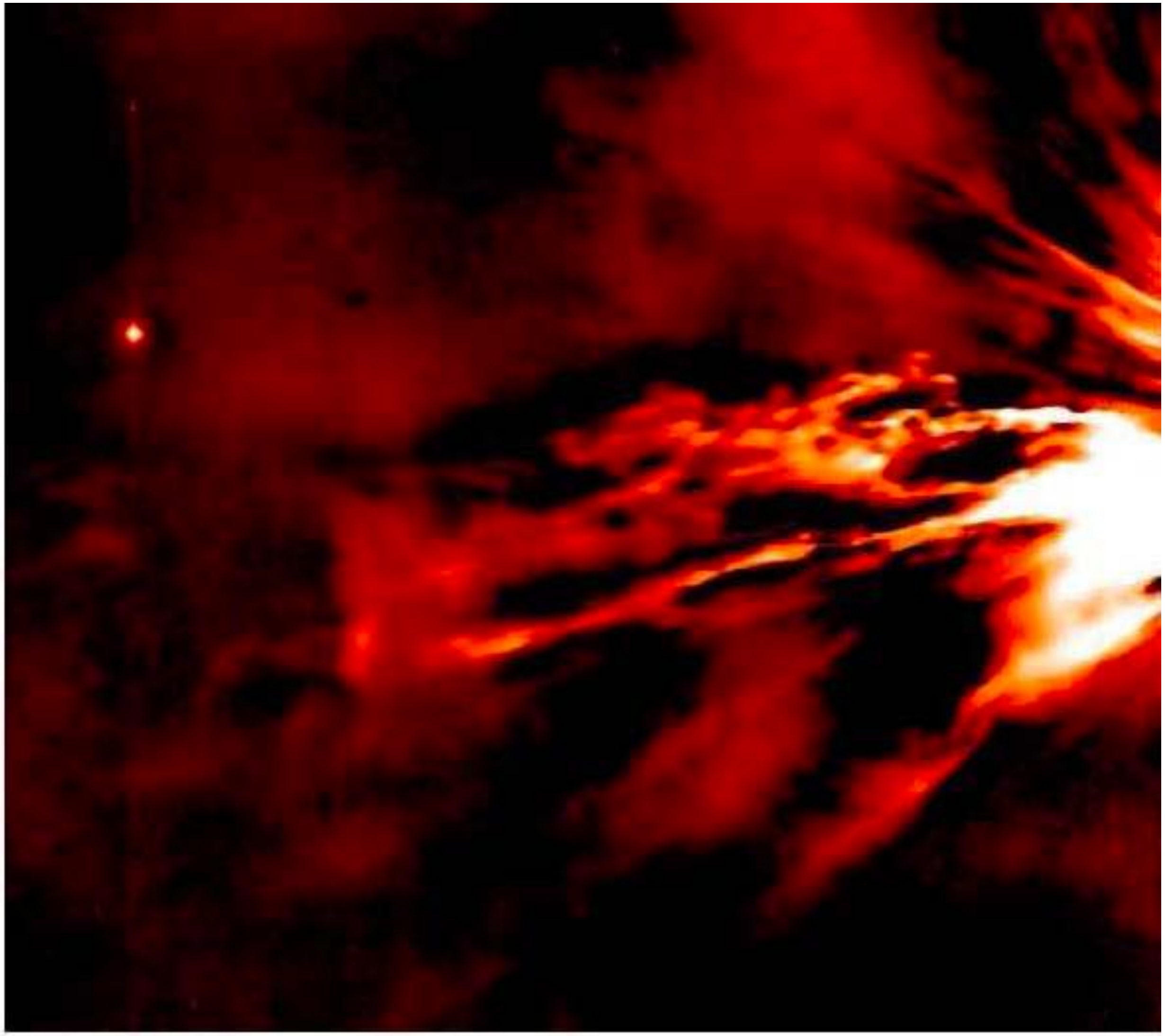
- Sabine (1852): Sunspot cycle identical to geomagnetic cycle.



STEREO-A:12/11/08 12:40:00 AM


SDO/AIA 171 2011-11-20 21:28:13 UT

The Problem: Linking ICMEs to CMEs to Flares to Active Regions



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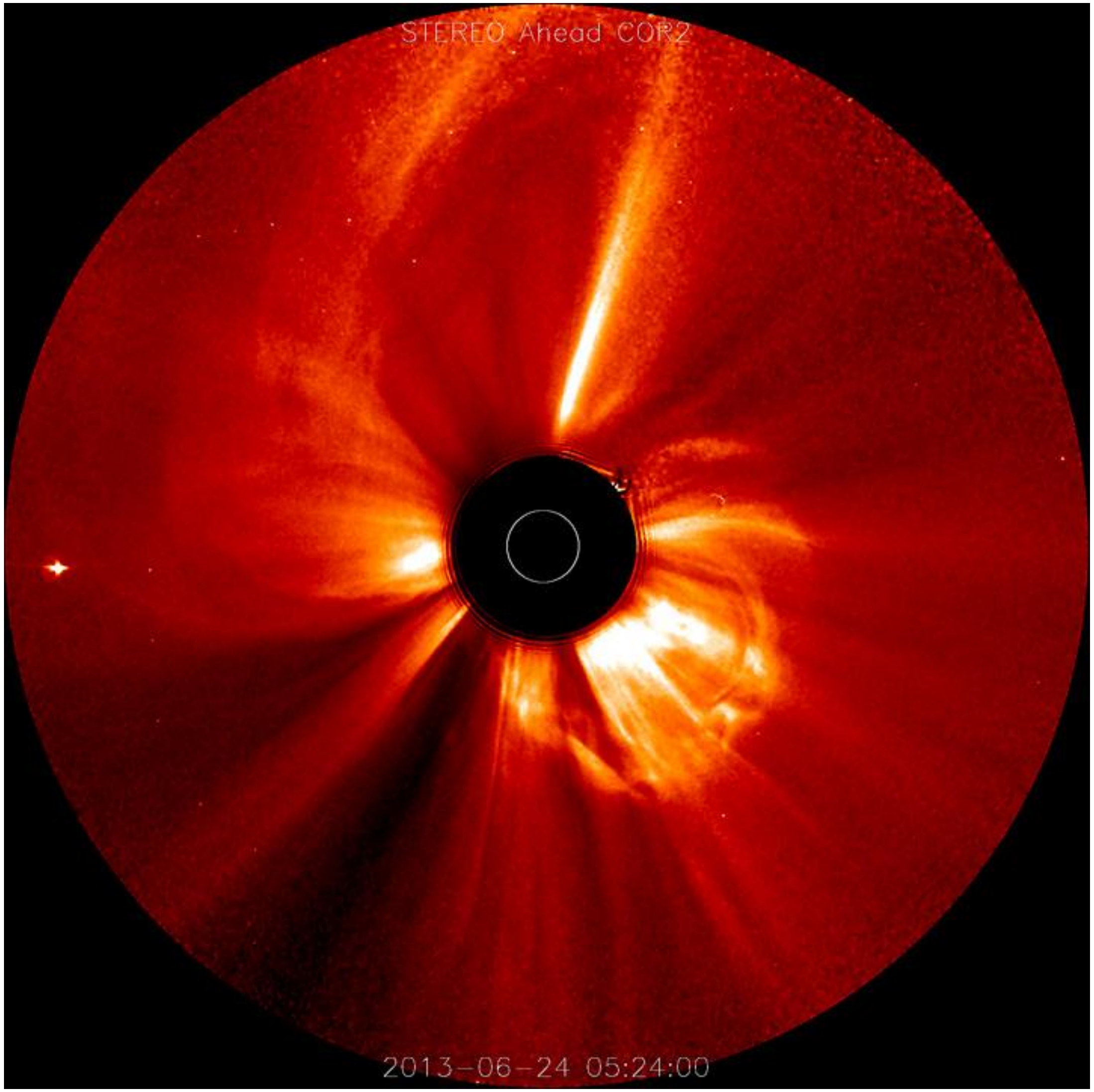

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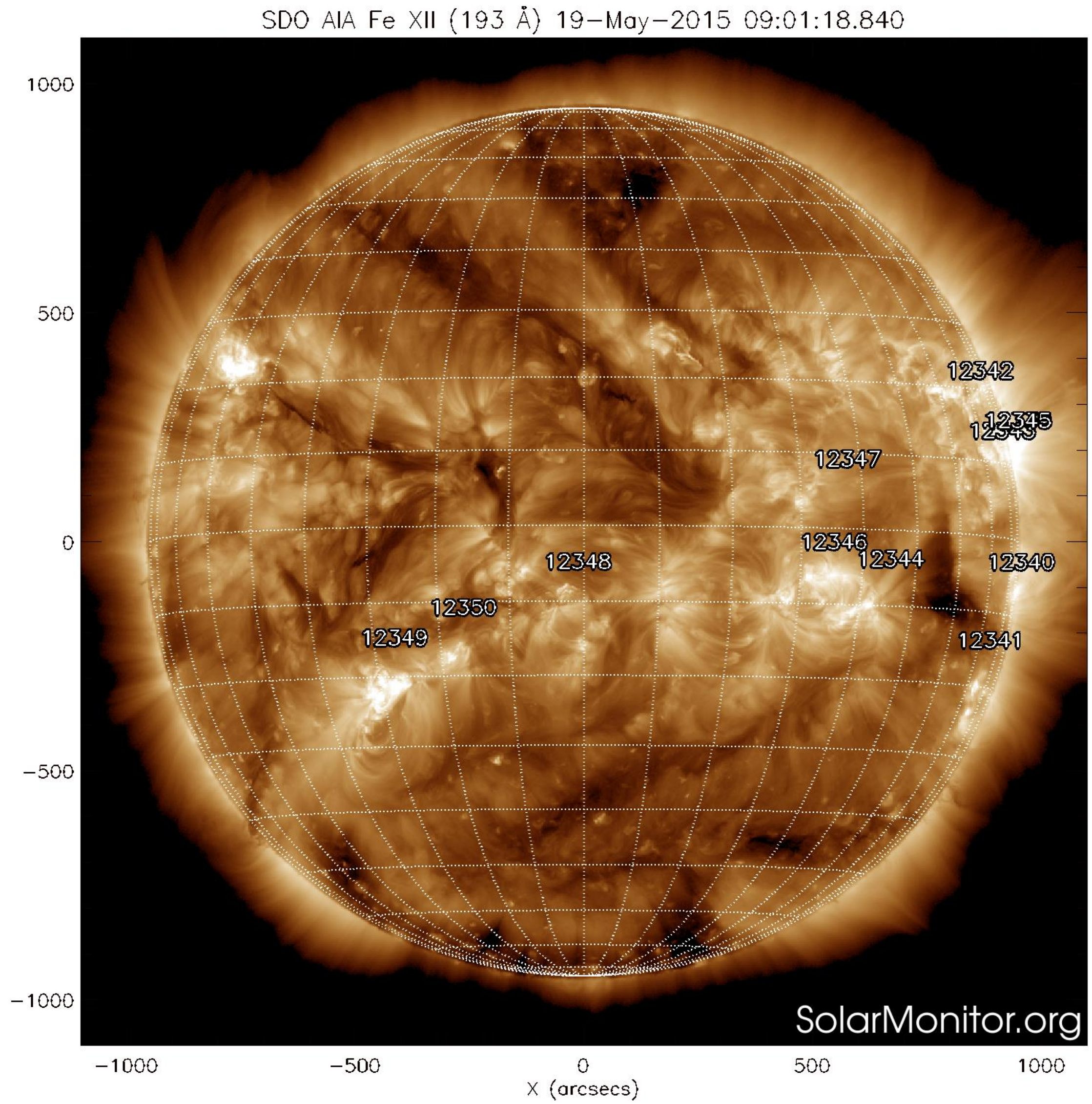

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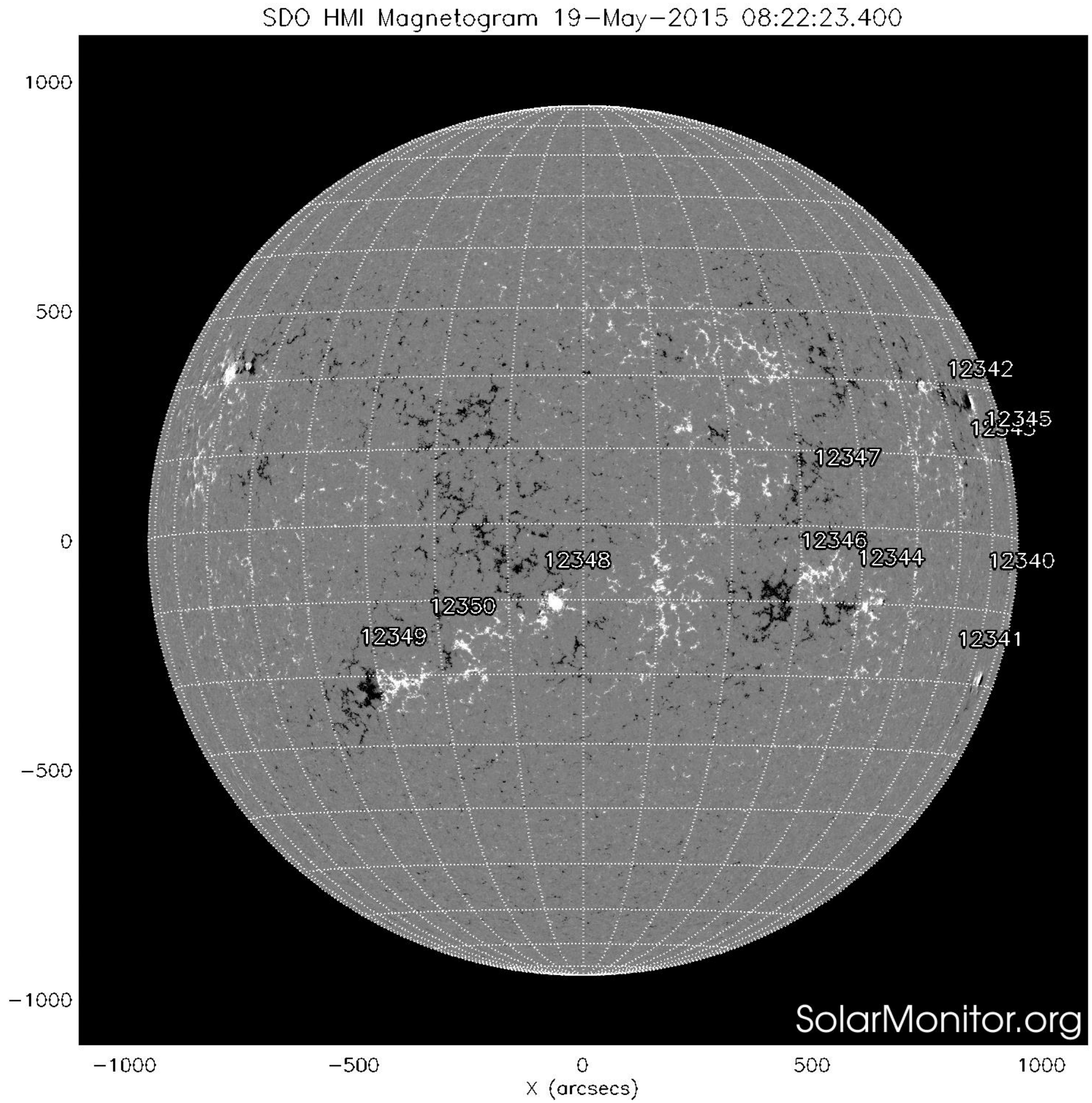

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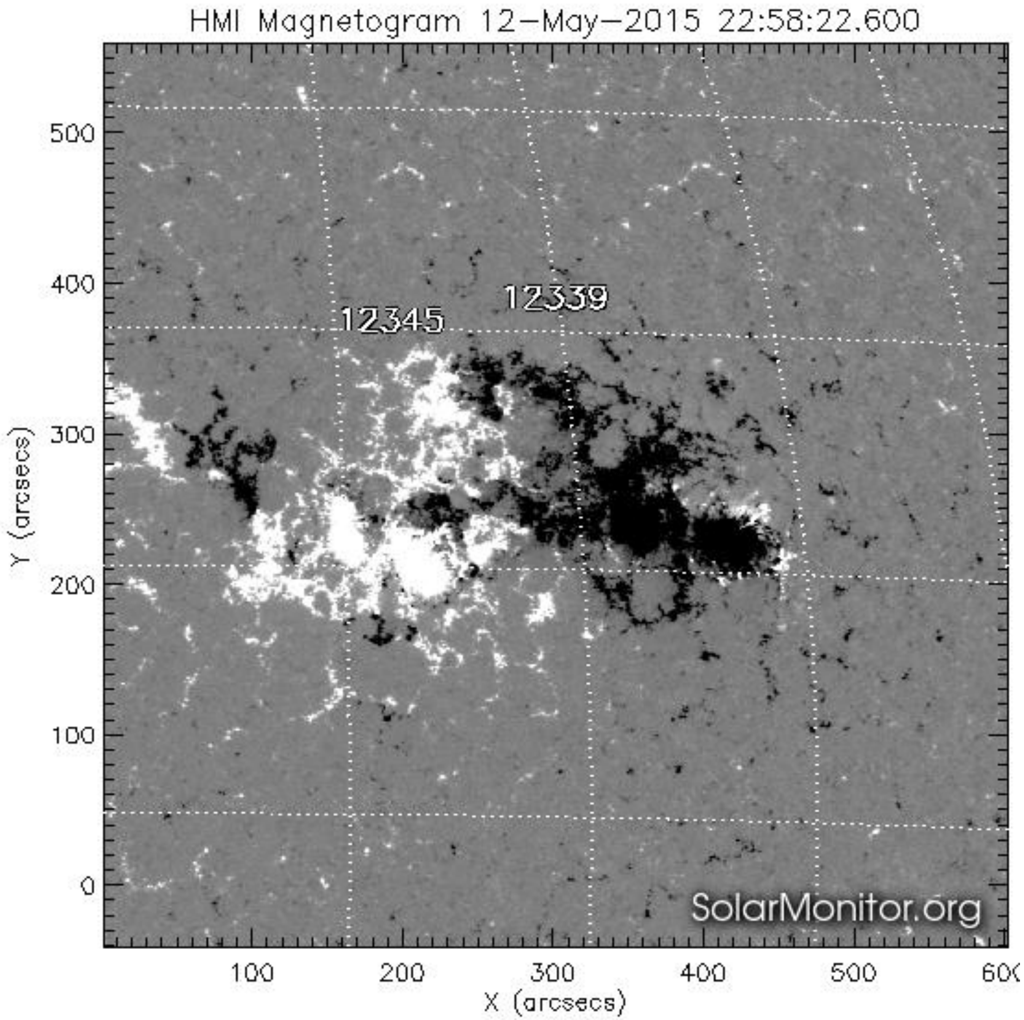

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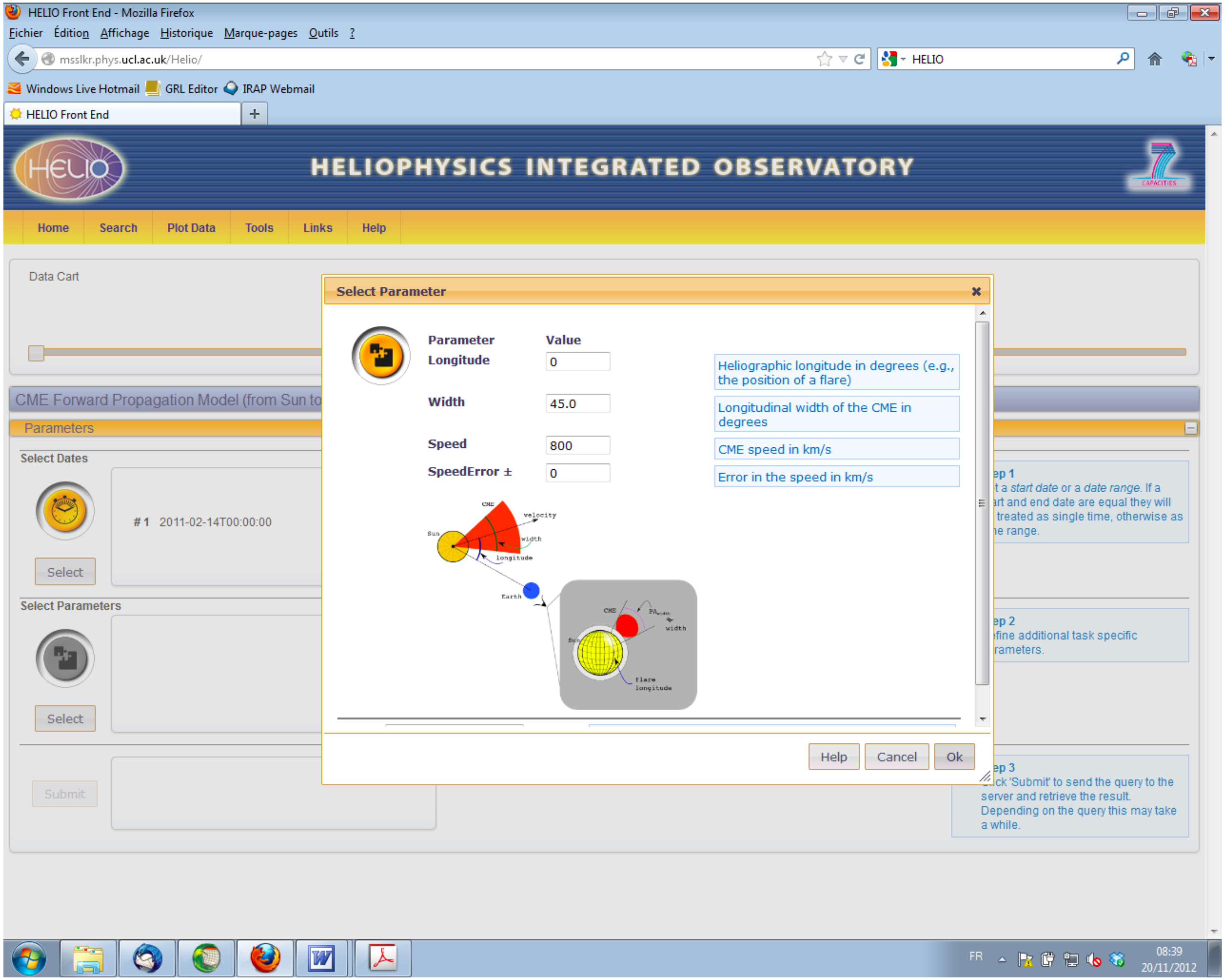
HELIO Propagation Model



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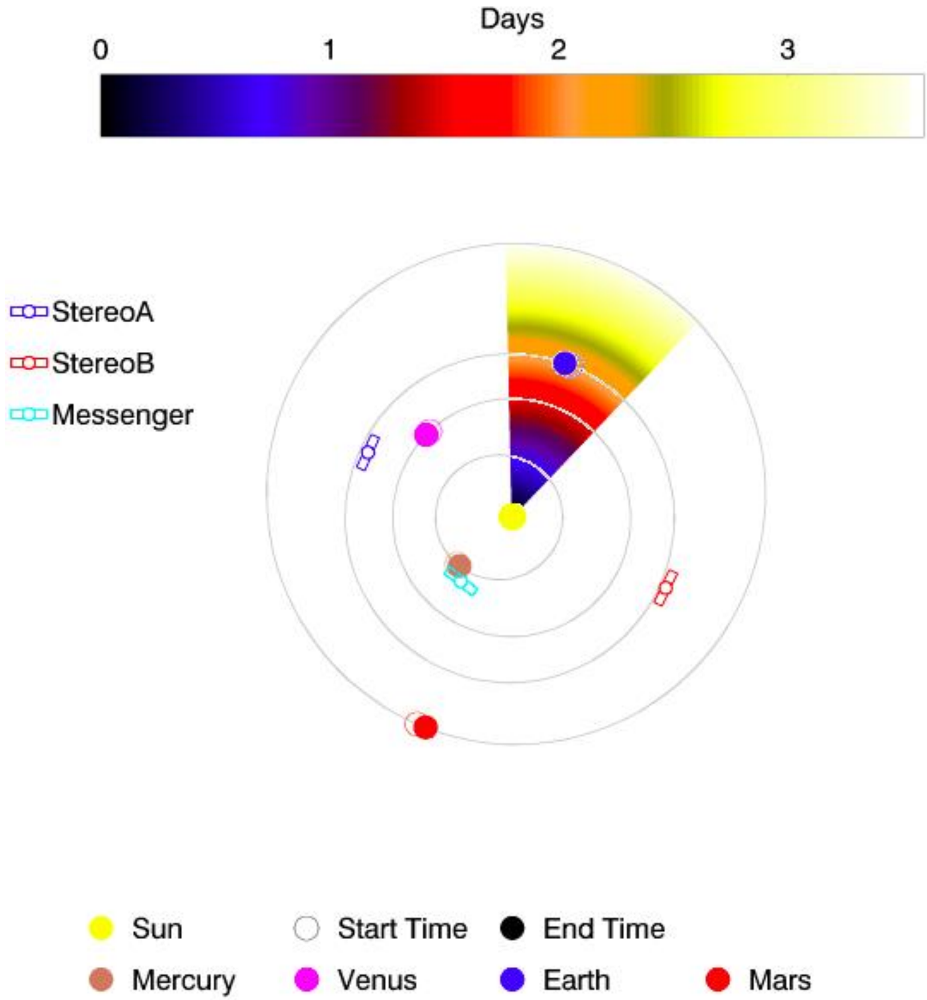
HELIO Propagation Model



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Ballistic Propagation Model

Input Property	Input Parameter
Initial time	τ_i
Initial distance	R_i
Final distance	R_f
Velocity range	$v \pm \Delta v$
Position angle	PA
Width	$(PA_N - PA_S) / 2$

- Search time window: $$t_f \pm \Delta t_f = t_i - \frac{R_i - R_f}{v \pm \Delta v}$$
- Search PA window: $\mathrm{PA} \pm \Delta\mathrm{PA}$

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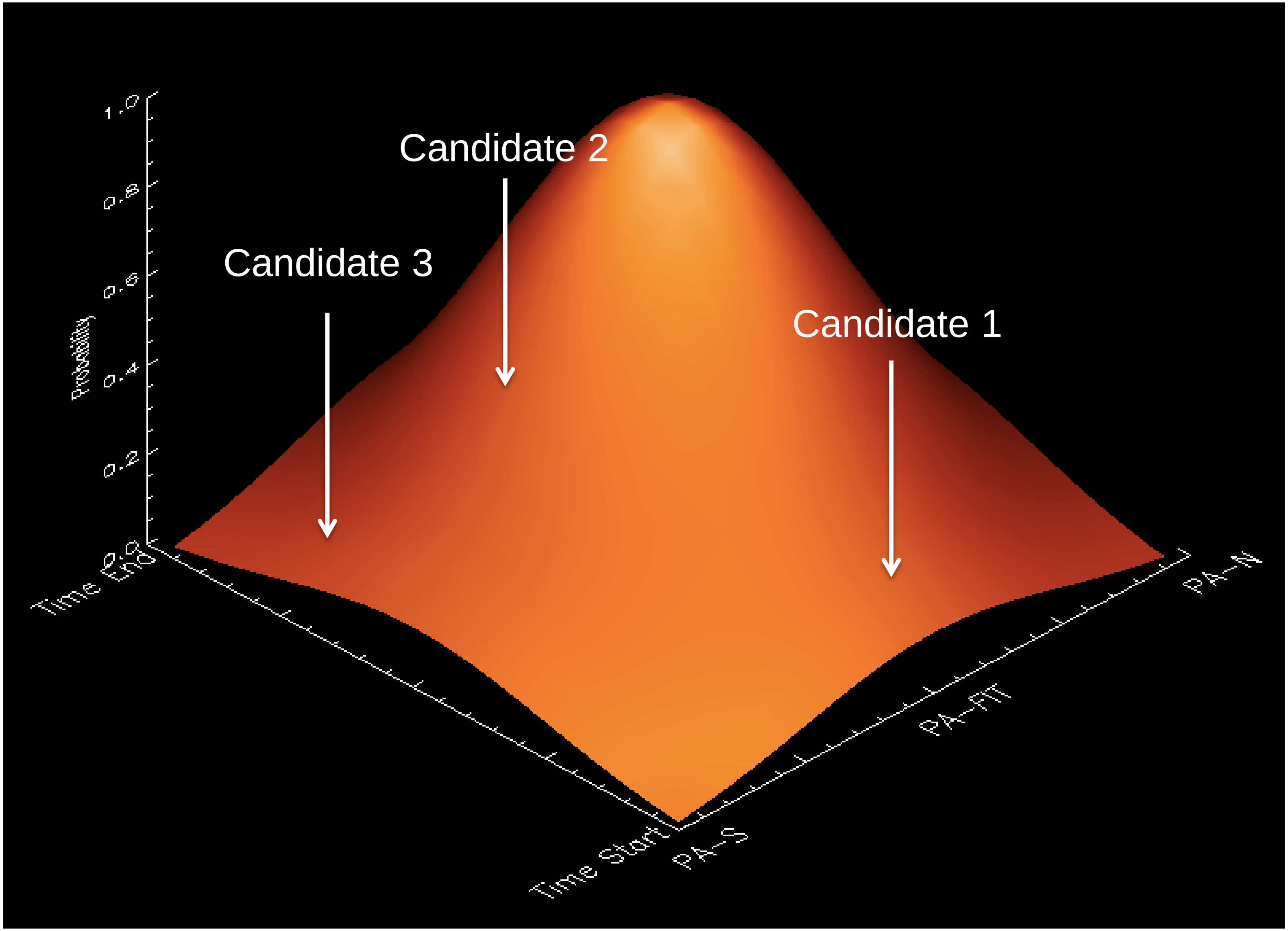
HI1 -> COR2

Input Property	Input Parameter
Initial time	τ_i
Initial distance	$12\ R_S$
Final distance	$2\ R_S$
Velocity range	200-600 km/s
Position angle	$\mathrm{PA}_{\mathrm{fit}}$
Width	$(PA_N - PA_S)\ /\ 2$

- Search time window: $$t_{COR2} \pm \Delta t_{COR2} = t_{HI1} - \frac{R_{HI1} - R_{COR2}}{v_{SW} \pm \Delta v_{SW}}$$
- Search PA window: $$\mathrm{PA}_{\mathrm{fit}} \pm \Delta \mathrm{P}$$

Candidate Probability Space



HELCATS HI CME List

WP2 Catalogue

Project Wiki | Contact Us

HELIOSPHERIC IMAGER CME CATALOGUE

The CME catalogue identified from the STEREO-HI instruments is shown below

This is version: TBD of the catalogue, released yyyy-mm-dd

Date range — From 2007-01-01 to 2010-01-01

PA mid: **0 to 360 degrees**

PA width: **15 to 180 degrees**

Show 10 entries

Search:

Show / hide columns

ID	Date [UTC]	SC	PA-N [deg]	PA-S [deg]	Quality	PA fit [deg]
HCME_A__20070419_01	2007-04-19 13:30	A	40	140	Good	105
HCME_A__20070502_01	2007-05-02 00:50	A	65	100	Fair	90
HCME_A__20070506_01	2007-05-06 06:50	A	85	120	Fair	100
HCME_A__20070509_01	2007-05-09 13:30	A	50	125	Fair	90
HCME_A__20070516_01	2007-05-16 01:30	A	30	120	Good	80
HCME_A__20070518_01	2007-05-18 00:10	A	95	115	Fair	110

Case Study

Low Coronal Event Catalogue

Catalogue of events occuring the low corona which were associated
with CMEs detected with the Heliospheric Imagers on board the STEREO spacecraft.

<1> No.	<2> Spacecraft (Stereo A/B)	<3> HI Date and Time (UT)	<4> HI PA North (degrees)	<5> HI PA South (degrees)	<6> COR2 Date and Time search window (UT)	<7> COR2 Cantidates Date and Time (UT)	<8> Flare Estimated Date and Time (UT)	<9> GOES Class	<10> NOAA Region (Location)	<11> Hale Class
29	A	29-Jul-2007 07:30	240	300						

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Case Study

- ***** HI2 Parameters *****
- HI2 Start Time :   29-Jul-2007 07:30:00.000
-
- ***** COR2 Search Parameters *****
- COR2 Start Time: 28-Jul-2007 18:37:46.668
- COR2 End Time :   29-Jul-2007 05:05:12.500
- Window (hours) :   10.457176
- COR2 PA-N   :   240.000
- COR2 PA-S   :   300.000
-
- ***** Flare Search Parameters *****
- Flare Start Time: 28-Jul-2007 17:25:22.918
- Flare End Time :   28-Jul-2007 18:01:34.793
- Window (mins)   :   36.197919

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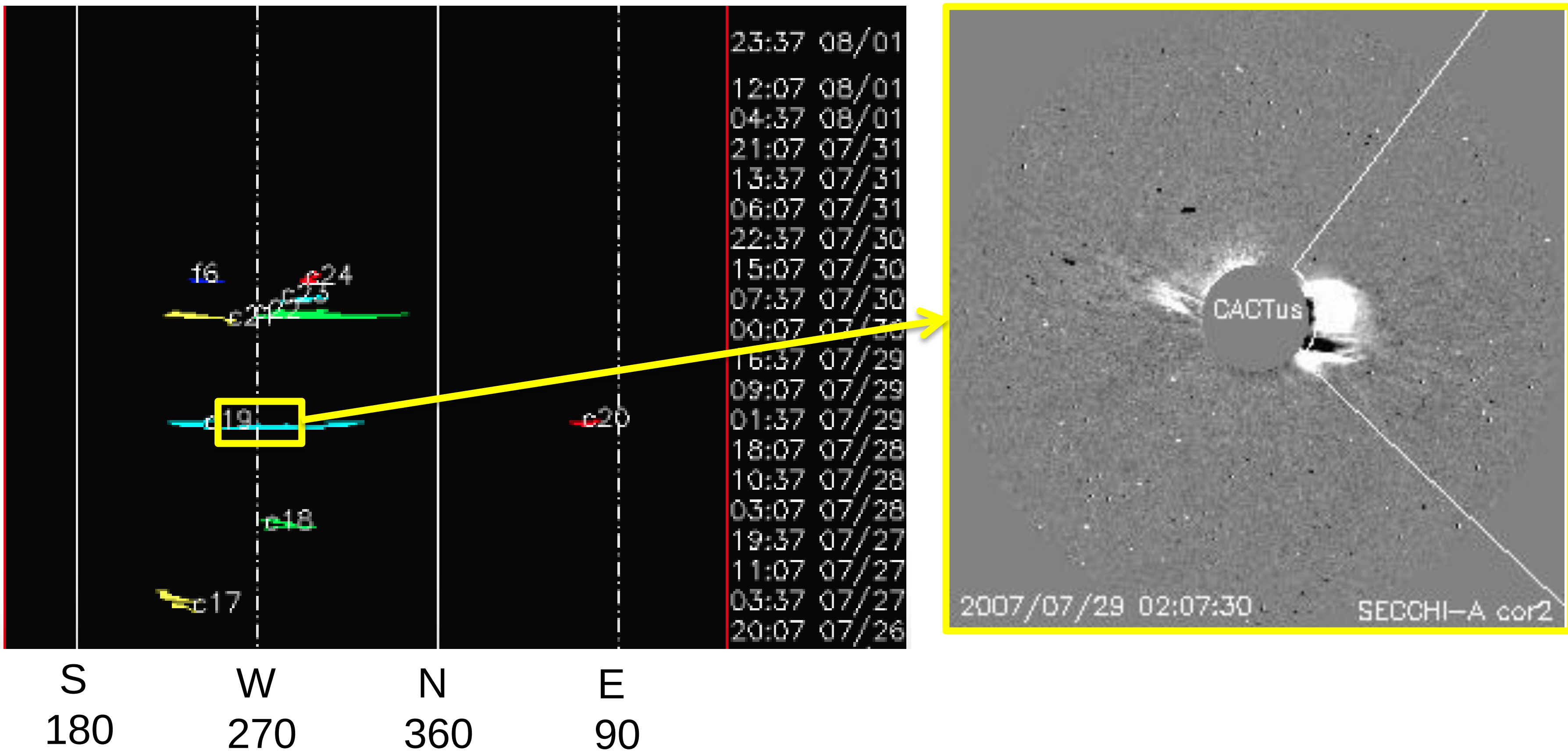
Case Study

Search Times: 28-Jul-2007 18:37
29-Jul-2007 05:05

Search PAs: 240-300



CME Candidate: 29-Jul-2007 01:37 | PA 275º | Width 96º | 625 km/s

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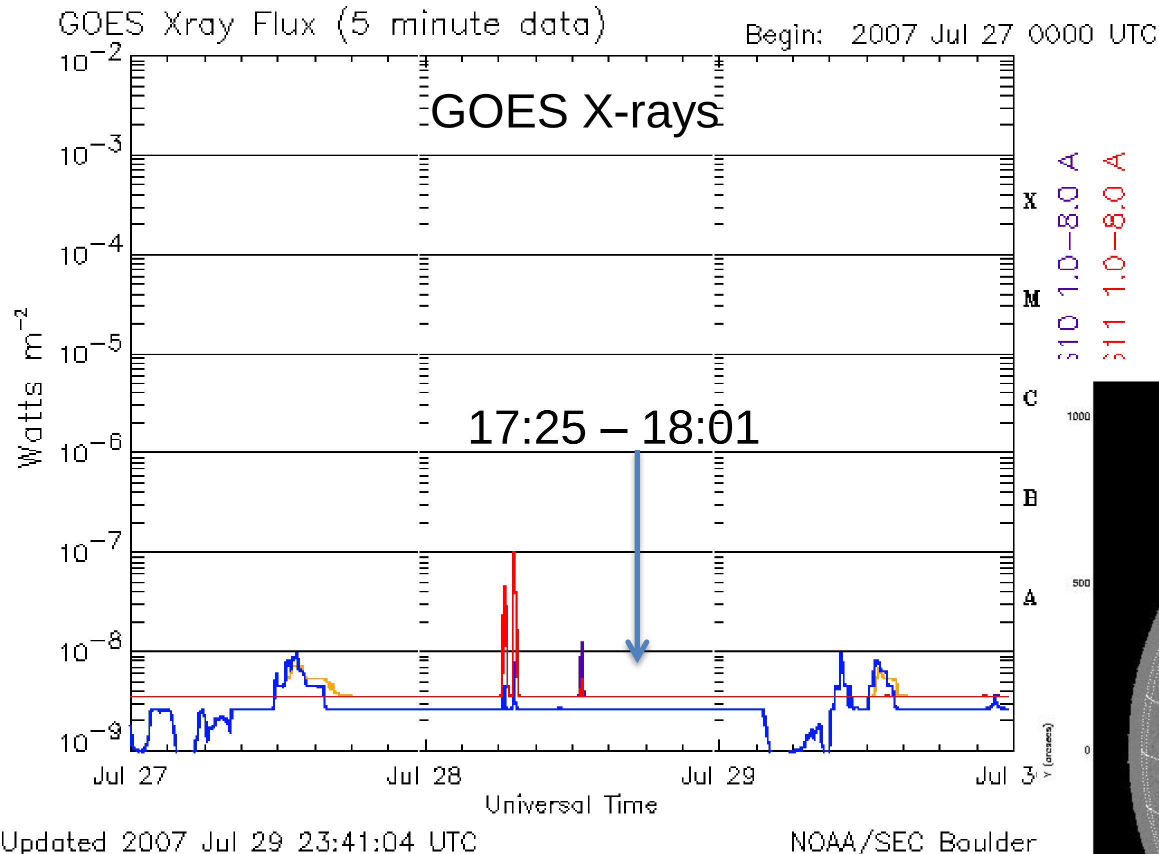
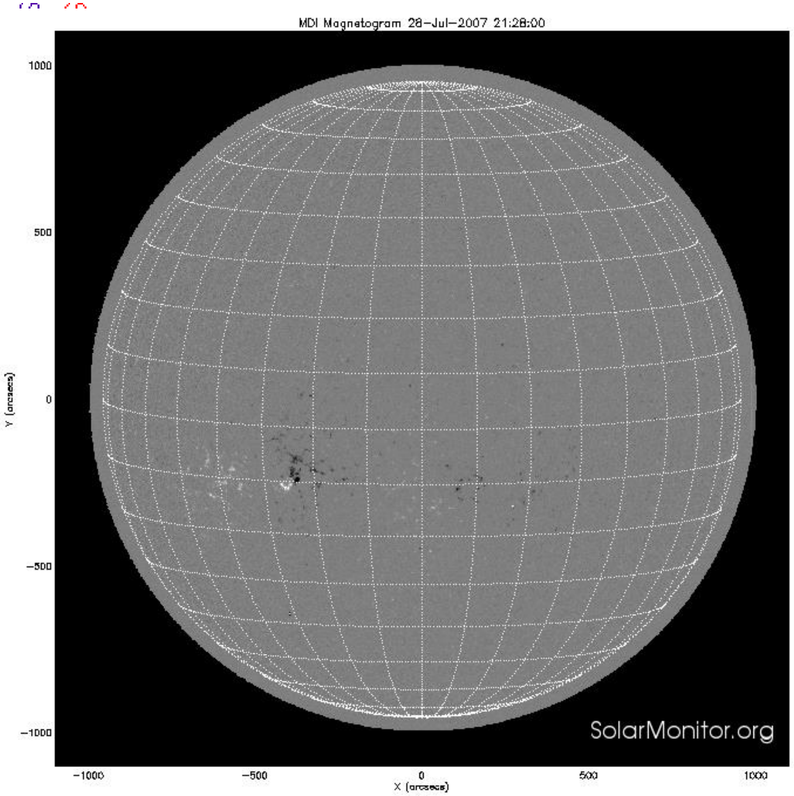
Case Study



Active Regions



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29	A	29-Jul-2007 07:30	240	300	28-Jul-2007 18:37 29-Jul-2007 05:05	29-Jul-2007 01:37	28-Jul-2007 17:25 28-Jul-2007 18:01	None	None	NA

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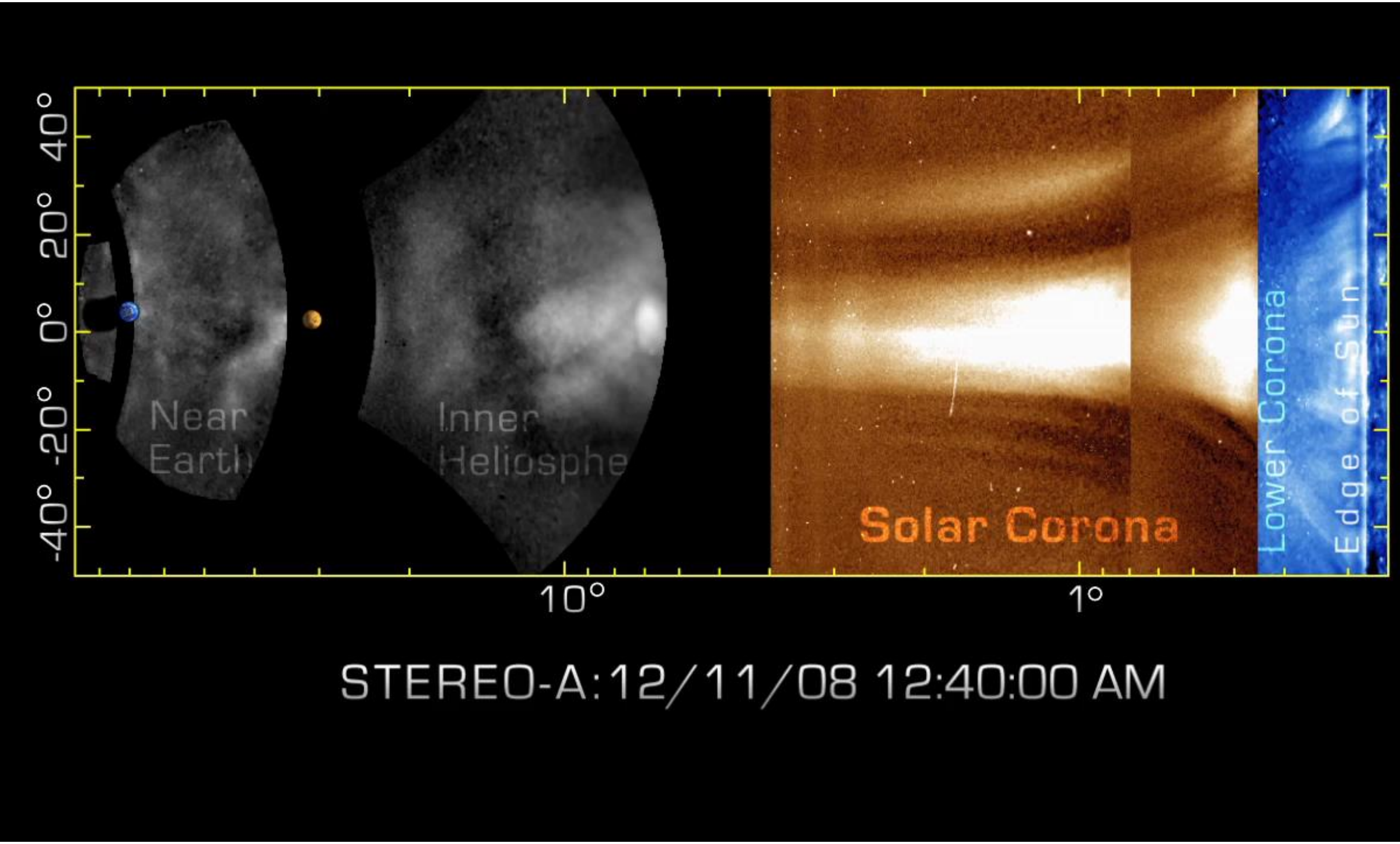
Position Angle Variation with Distance



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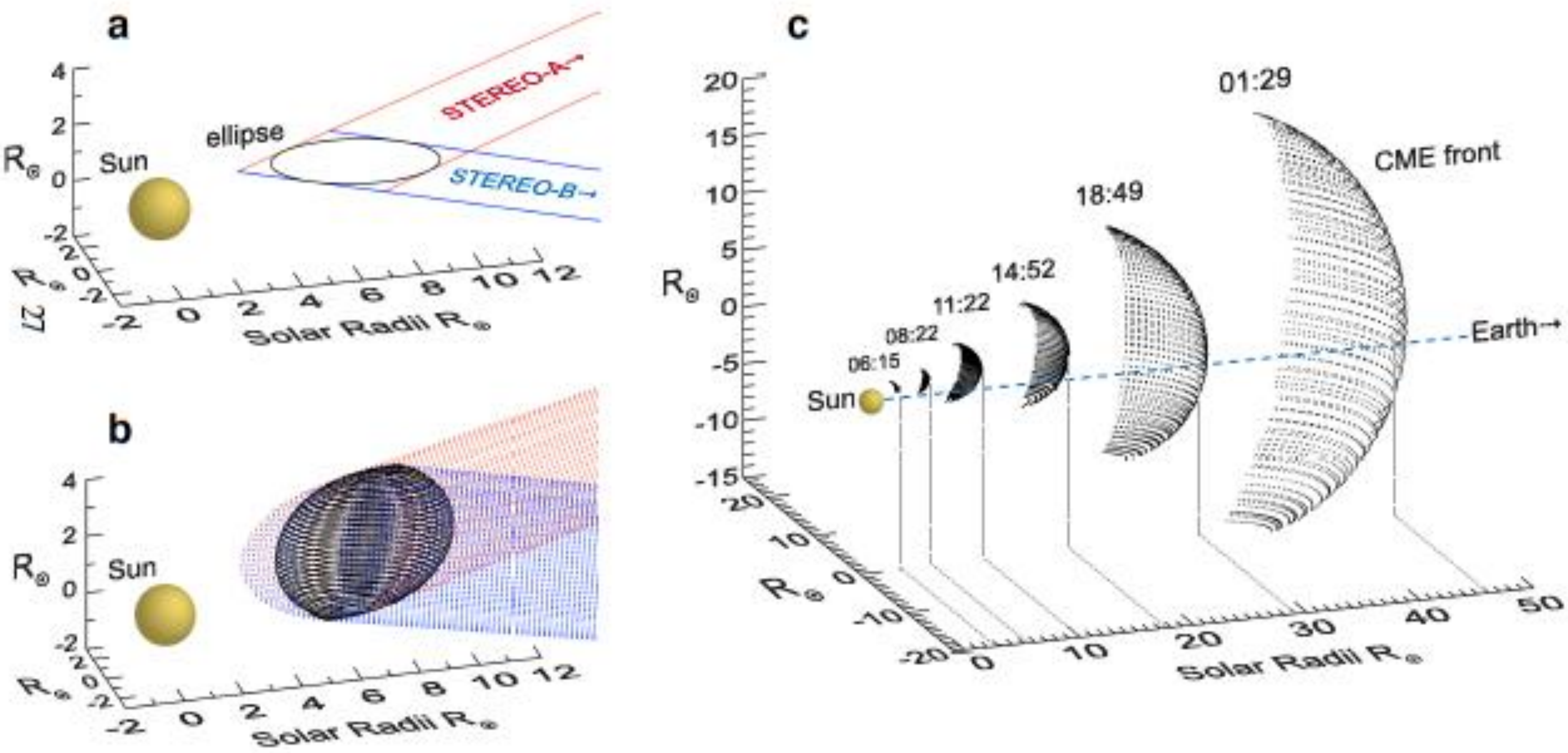
CME Deflection



Byrne et al. (2010)

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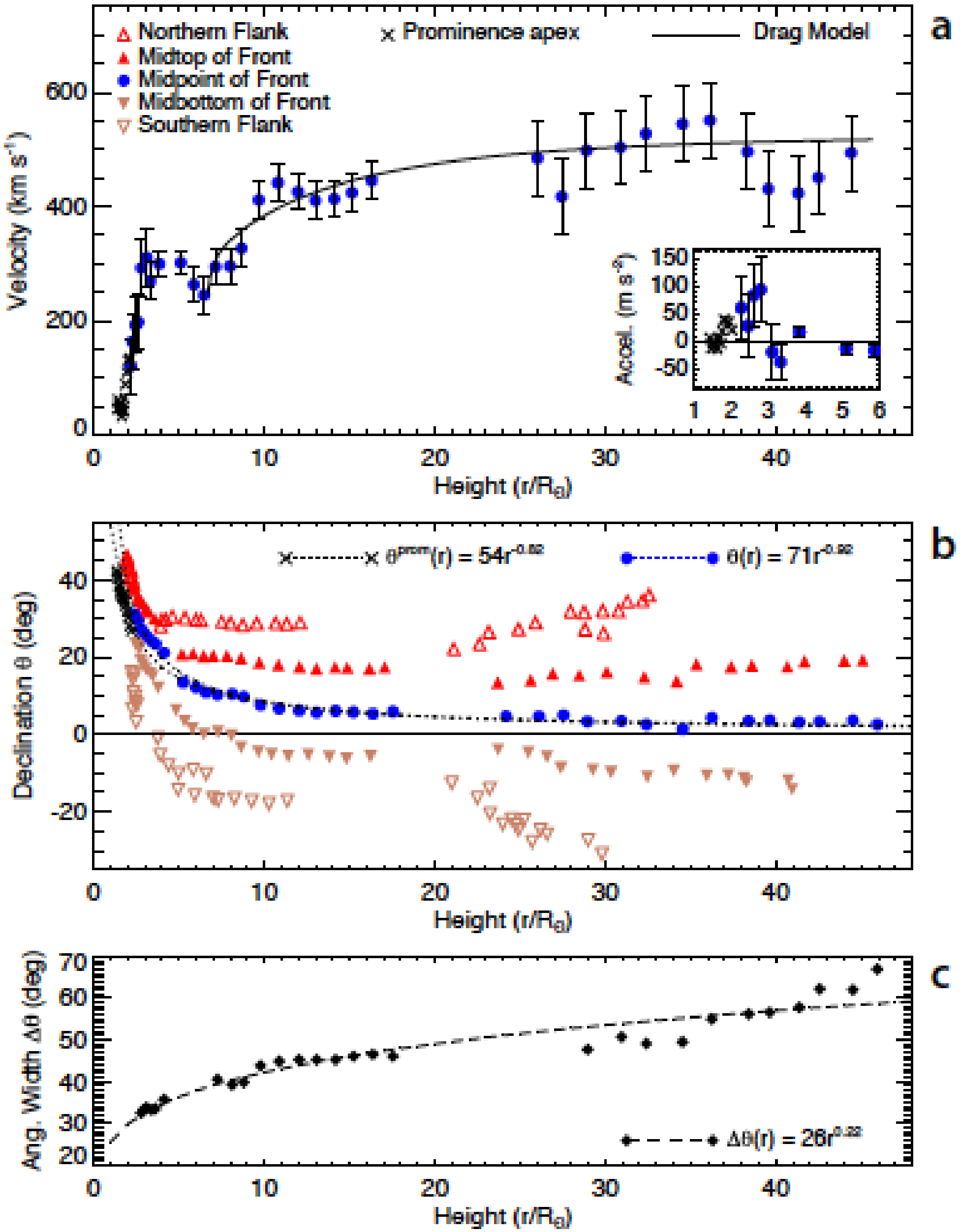
Velocity

Declination

Width



Byrne et al. (2010)

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Improved Inverse Tracking

- Use variable velocity profile

$$t_f = t_i - \int_{R_i}^{R_f} \frac{1}{v(R)} dR$$

- Drag-based propagation model to obtain *v(R)*

- SOTERIA Drag-Based Model
  http://oh.geof.unizg.hr/DBM/dbm.php

- E.g Vršnak et al. (2010)

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Modelling of CME Motion

- Simple model for CME propagation in heliosphere

$$r \frac{dv}{dt} = - \frac{1}{2} r \mathrm{D} v^{2} A C_{D}$$

- Numerical integration gives *v(r).*

- Vršnak et al. (2002), Reiner et al. (2003), Tappin (2006).

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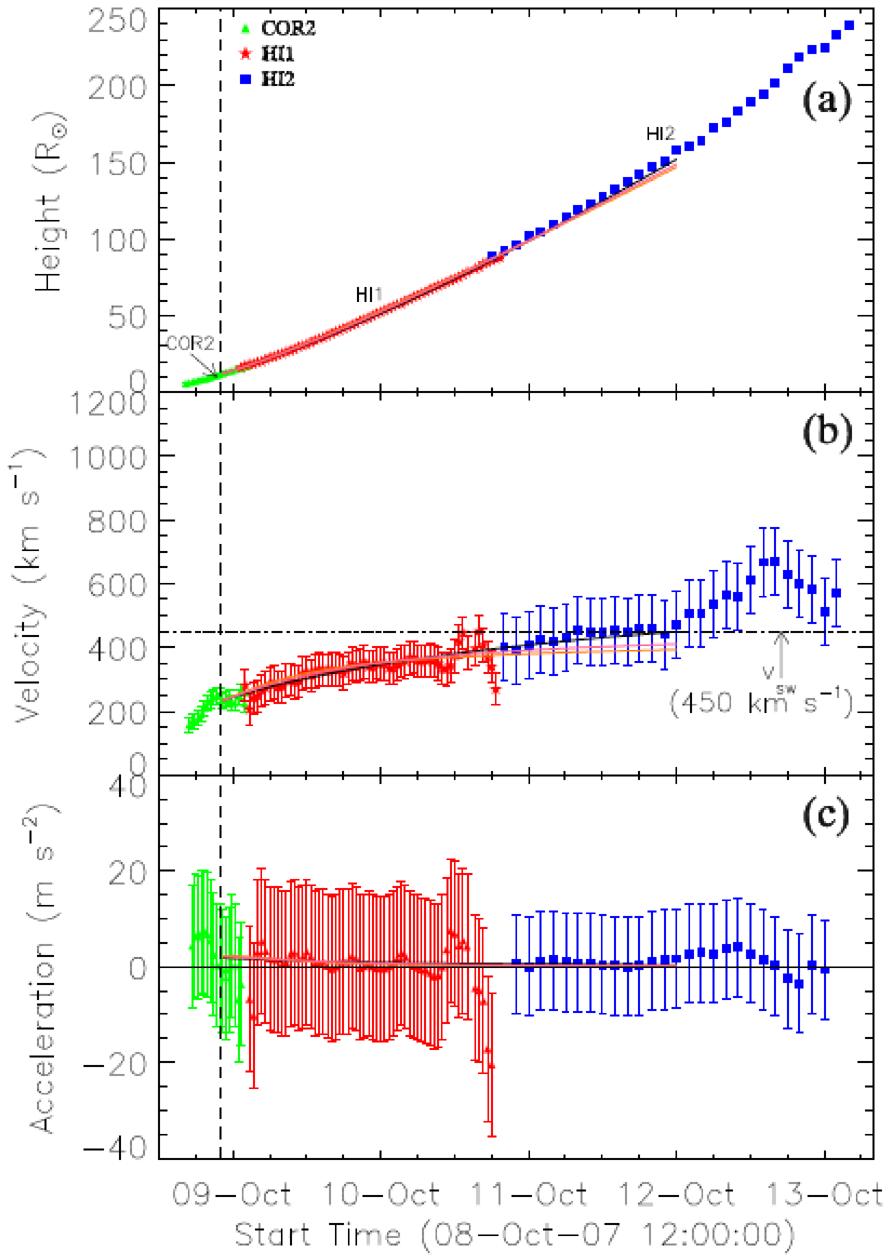
Slow CME



Maloney & Gallagher (2010)

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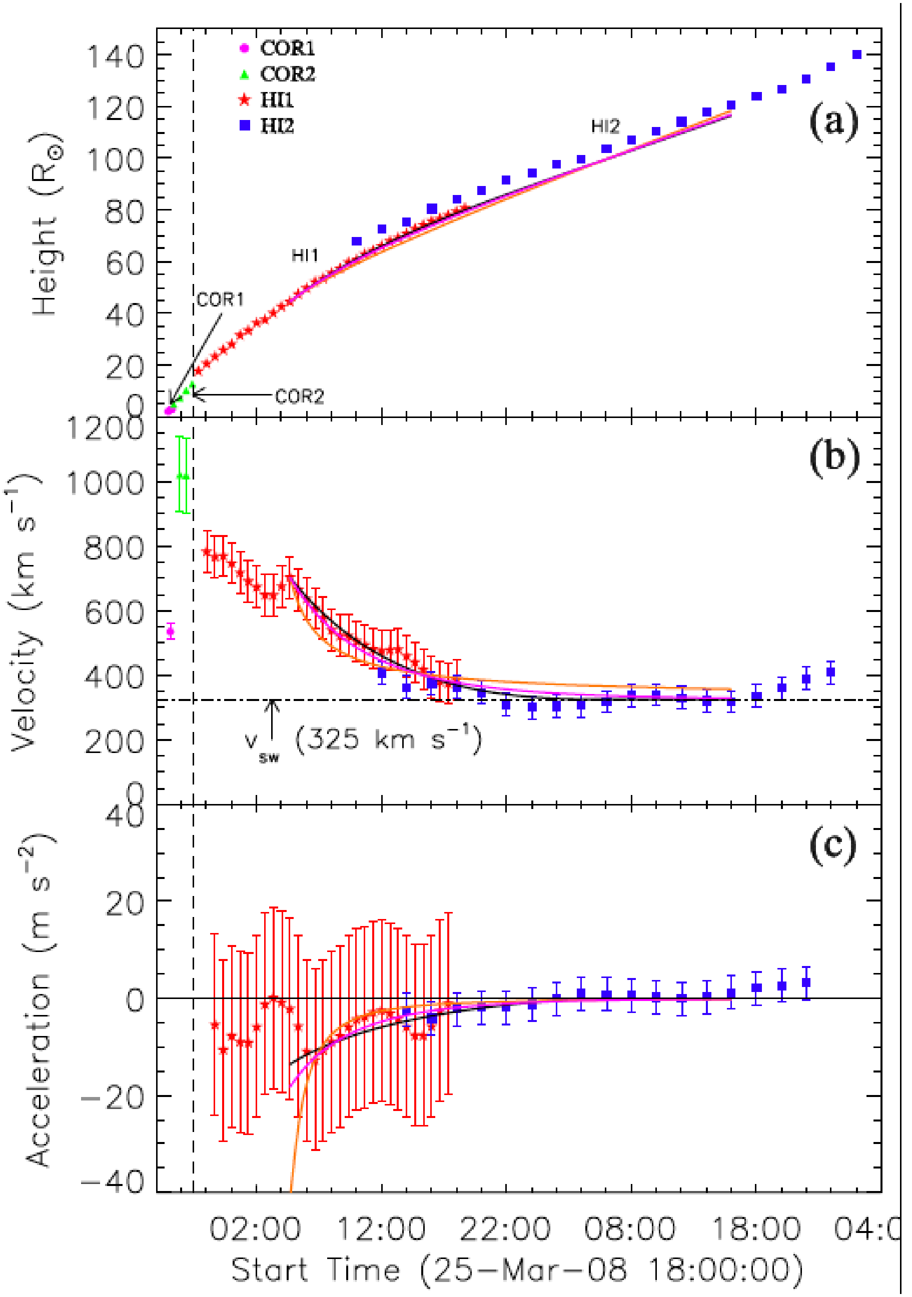
Fast CME



Maloney & Gallagher (2010)

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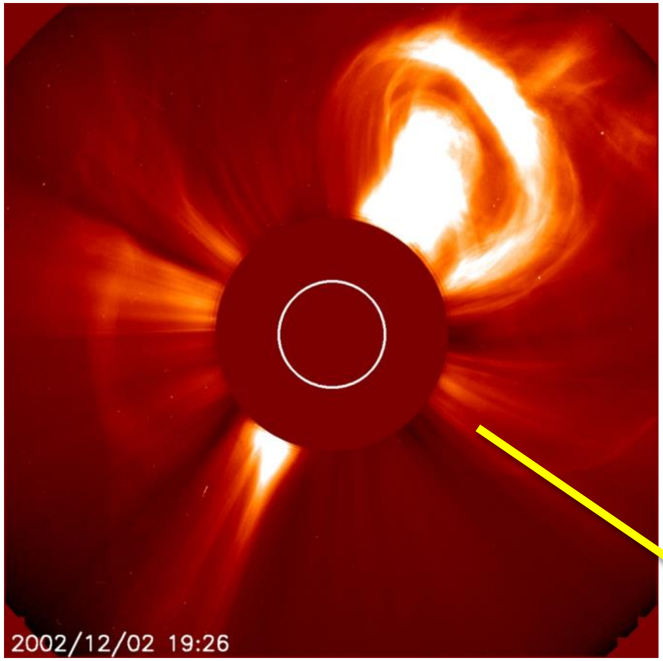
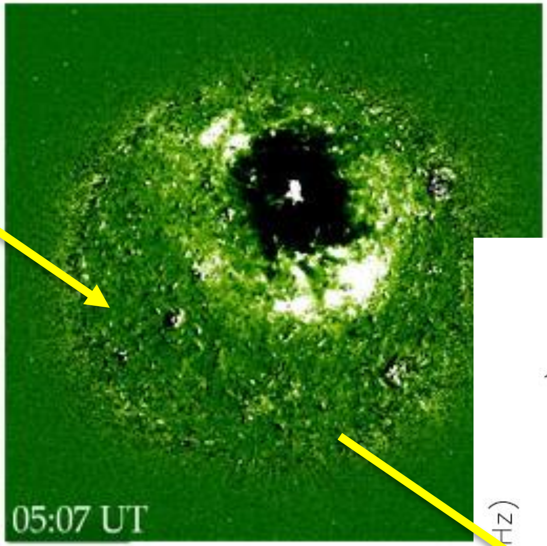
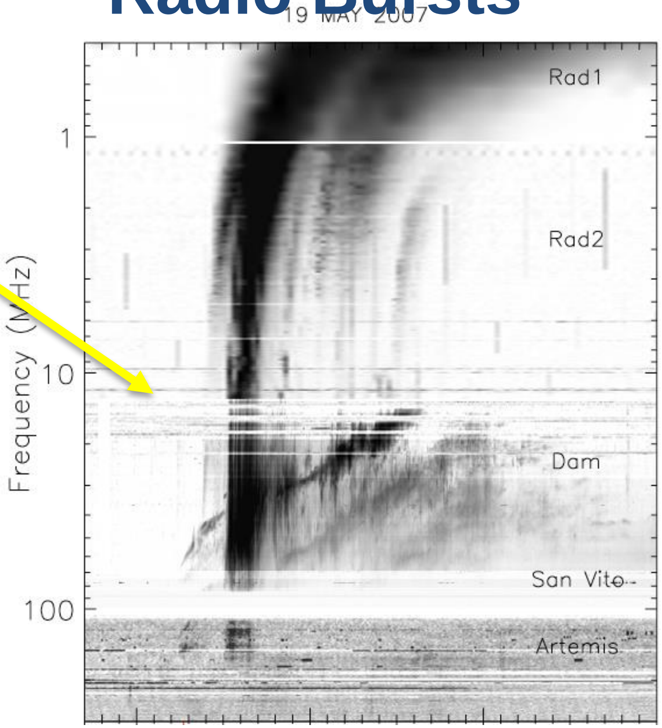
Coronal Mass Ejections



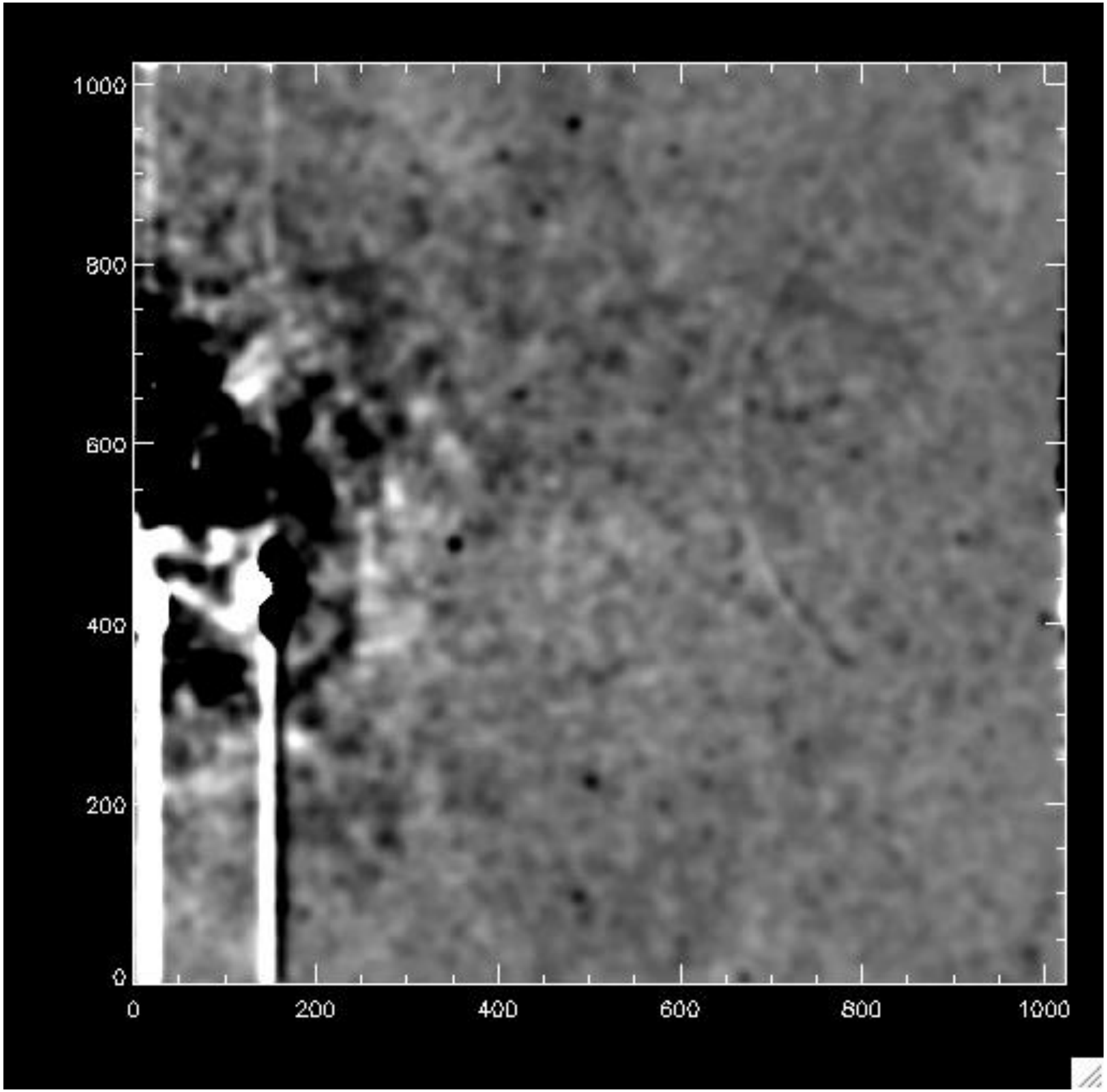
Coronal Waves



Radio Bursts



How are these related?
How are shocks formed?



Maloney & Gallagher (2011)

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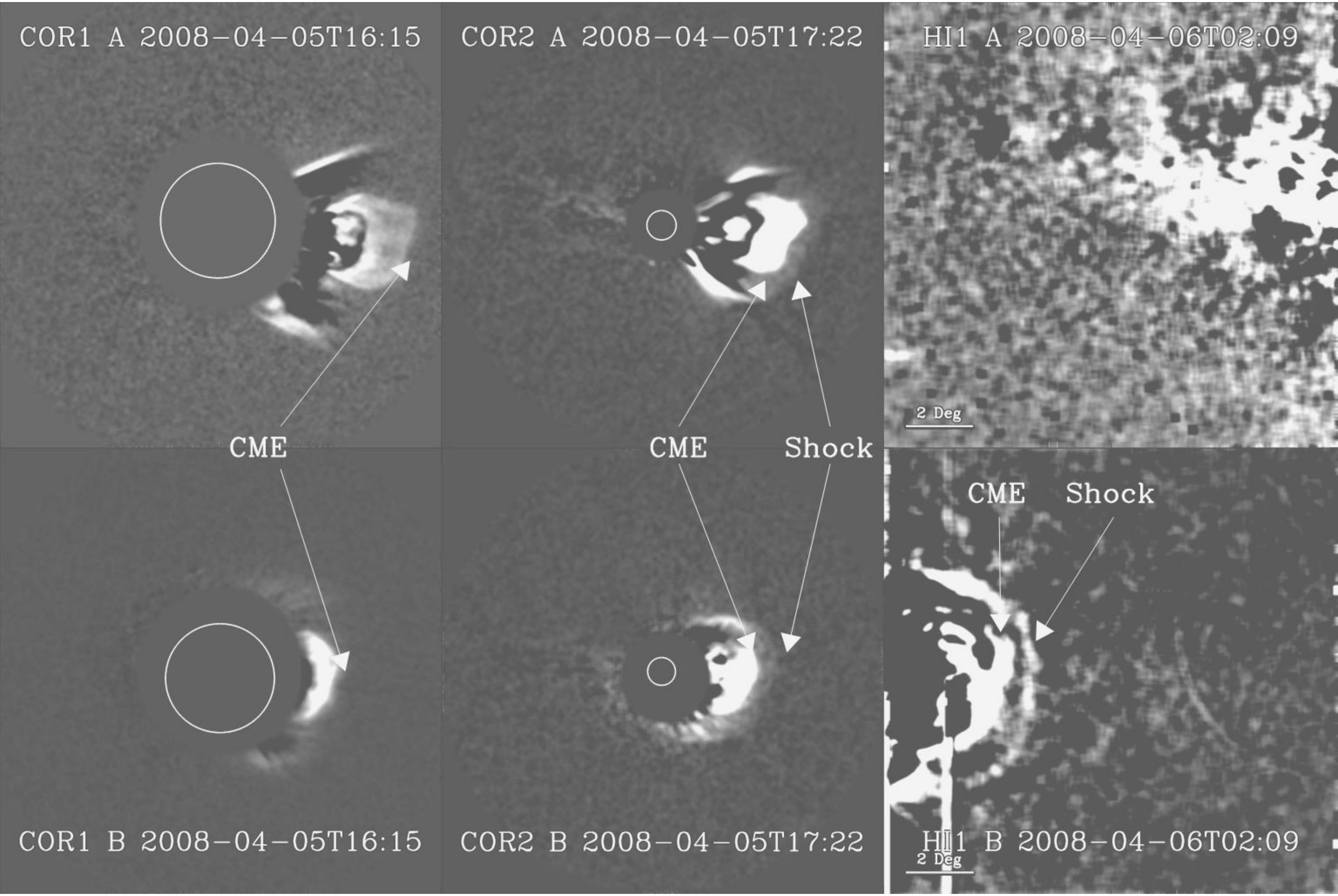

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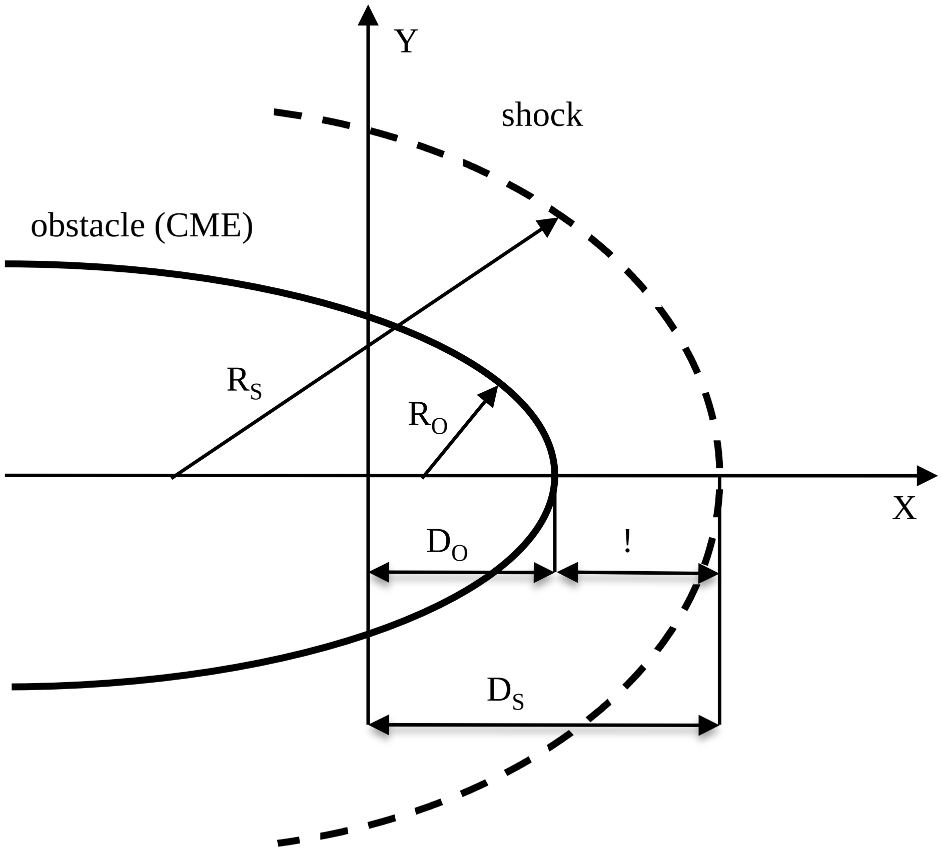
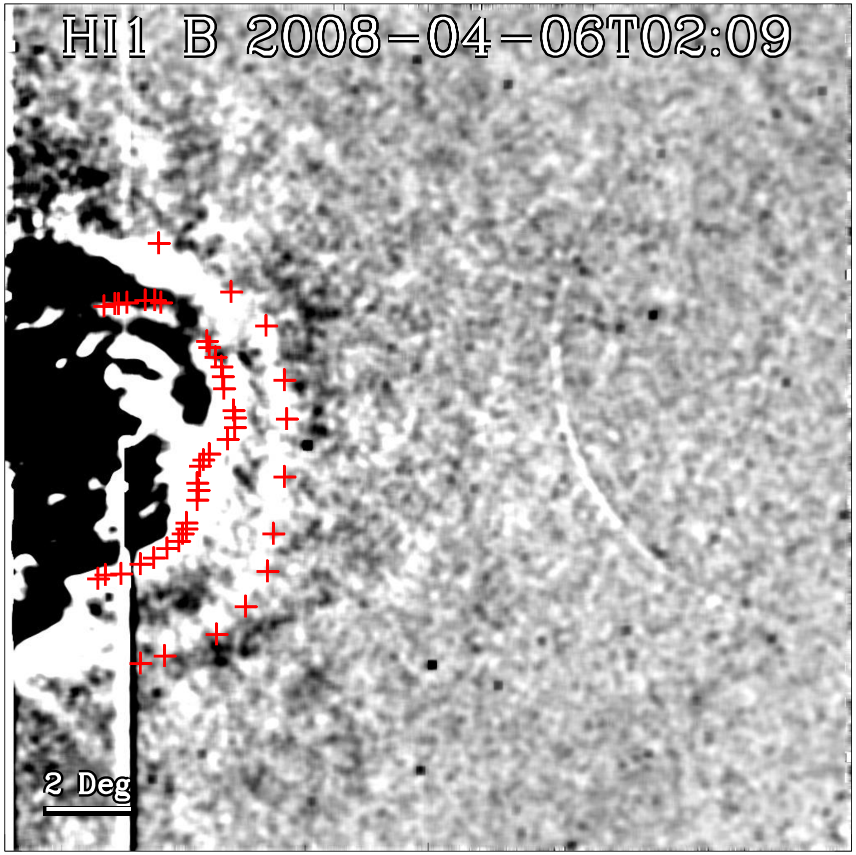
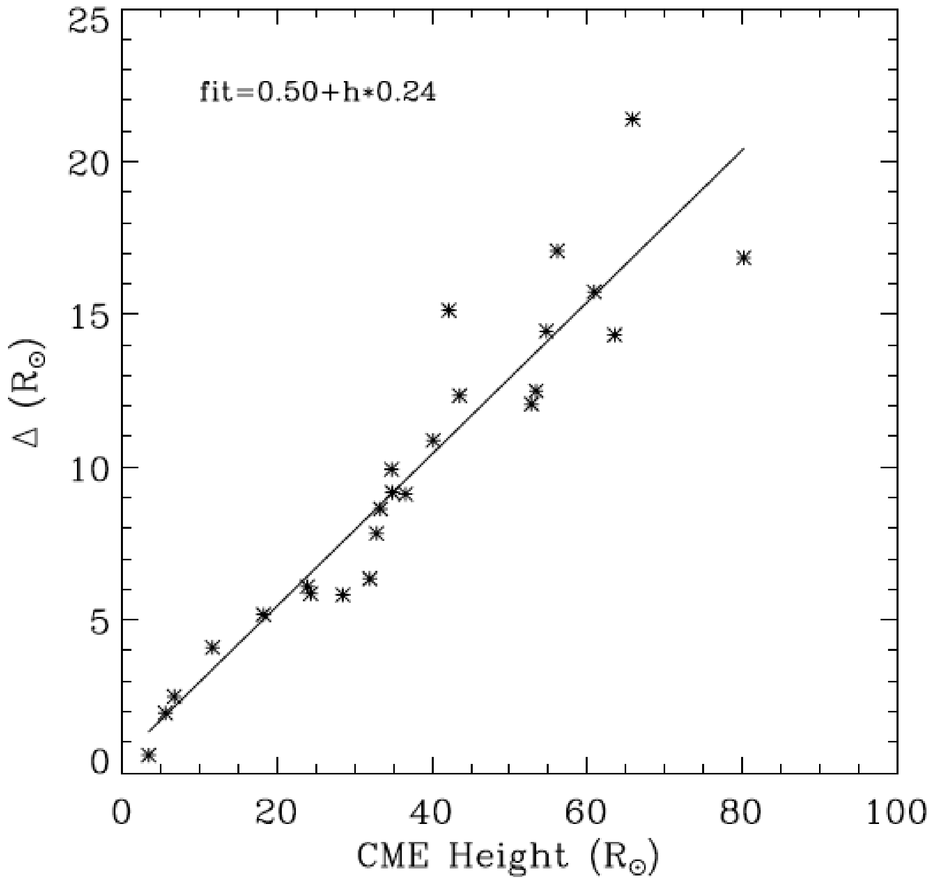
CME and Shock-Front Positions





CME-Driven Shock Properties



Shock standoff distance (Δ) varies linearly with height.

Linear extrapolation gives Δ ~ 40 R_{sun} at Earth.

Can give improved estimate of shock arrival time at Earth.

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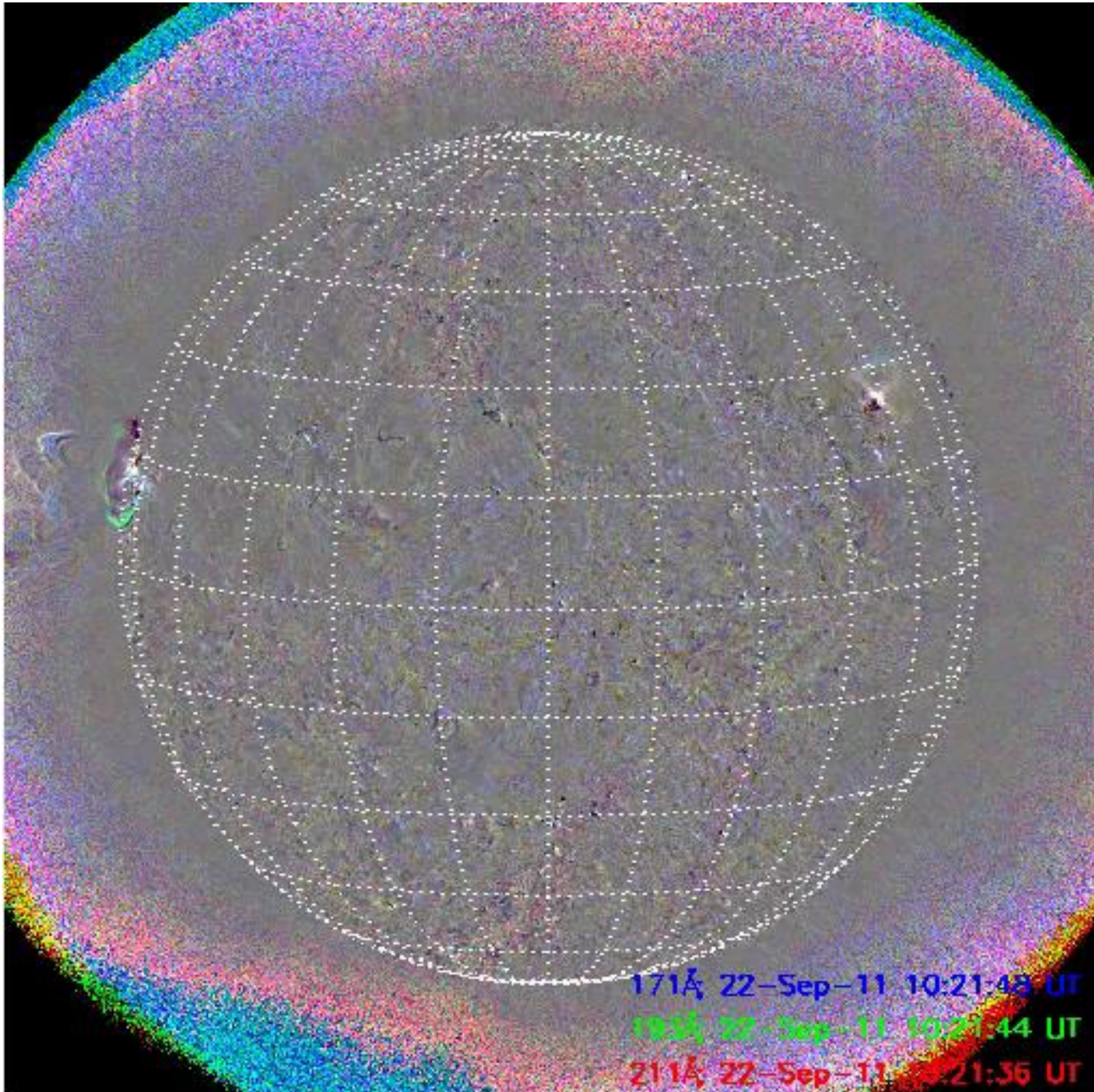

CME and EUV Wave

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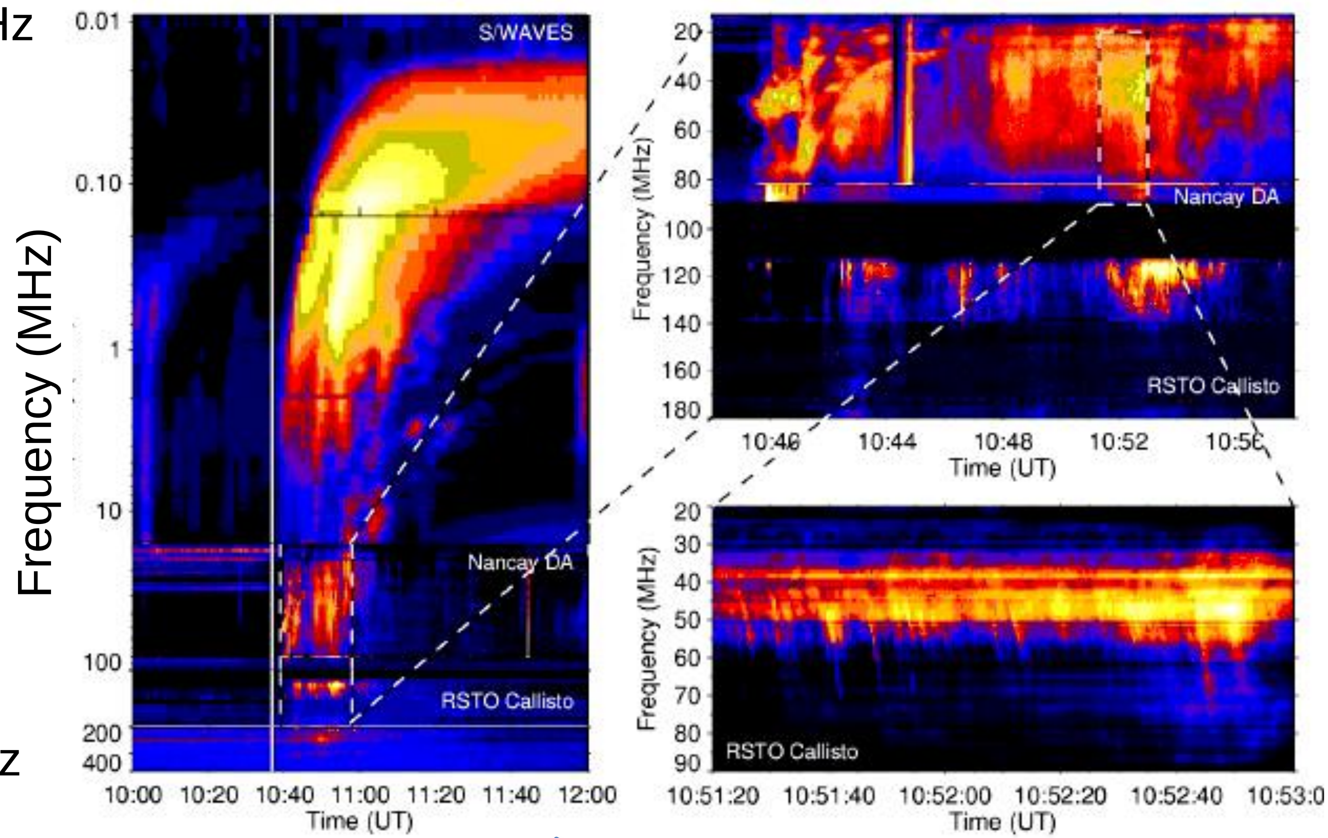
Birr, STEREO and Nancay Radio Spectra

0.01 MHz

400 MHz

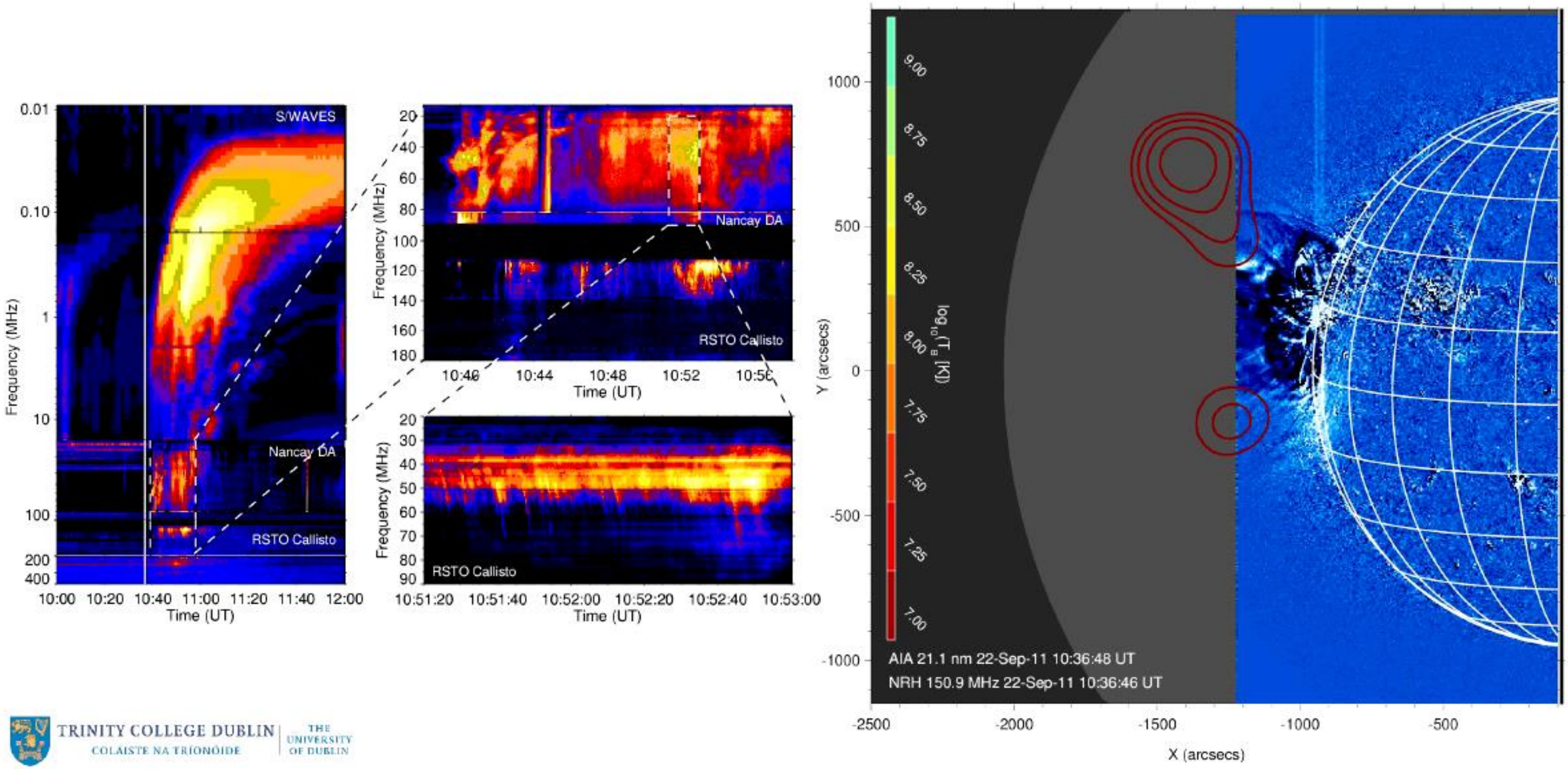


~2 hours

<2 minutes

Carley et al. (2013)

Radio Spectra & Images and EUV Wave



TRINITY COLLEGE DUBLIN COLÁISTE NA TRÍONÓIDE THE UNIVERSITY OF DUBLIN

Carley et al. (2013)

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How do we find shock heights?

Frequency(t)

↓ $n_e(f)$

Density(t)

↓ $h(n_e)$

Height(t)

Plasma frequency:

$$f_p[Hz] \approx 9000\sqrt{n_e[cm^{-3}]}$$

Example model:

$$n_e(h) = n_0 e^{-h/H}$$

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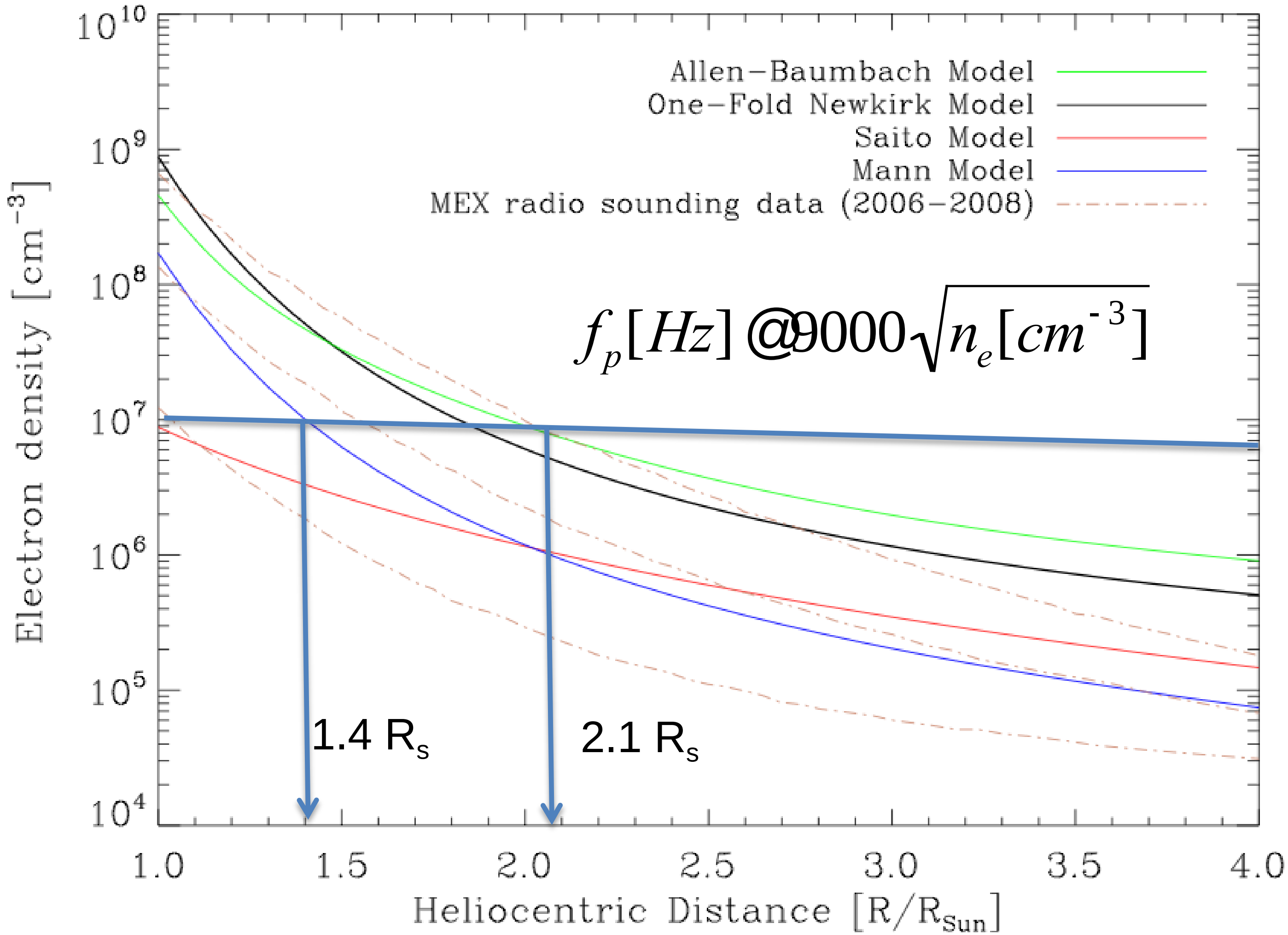
Type II Height Problem



=> Given frequency gives single density but ***model dependent*** heights!

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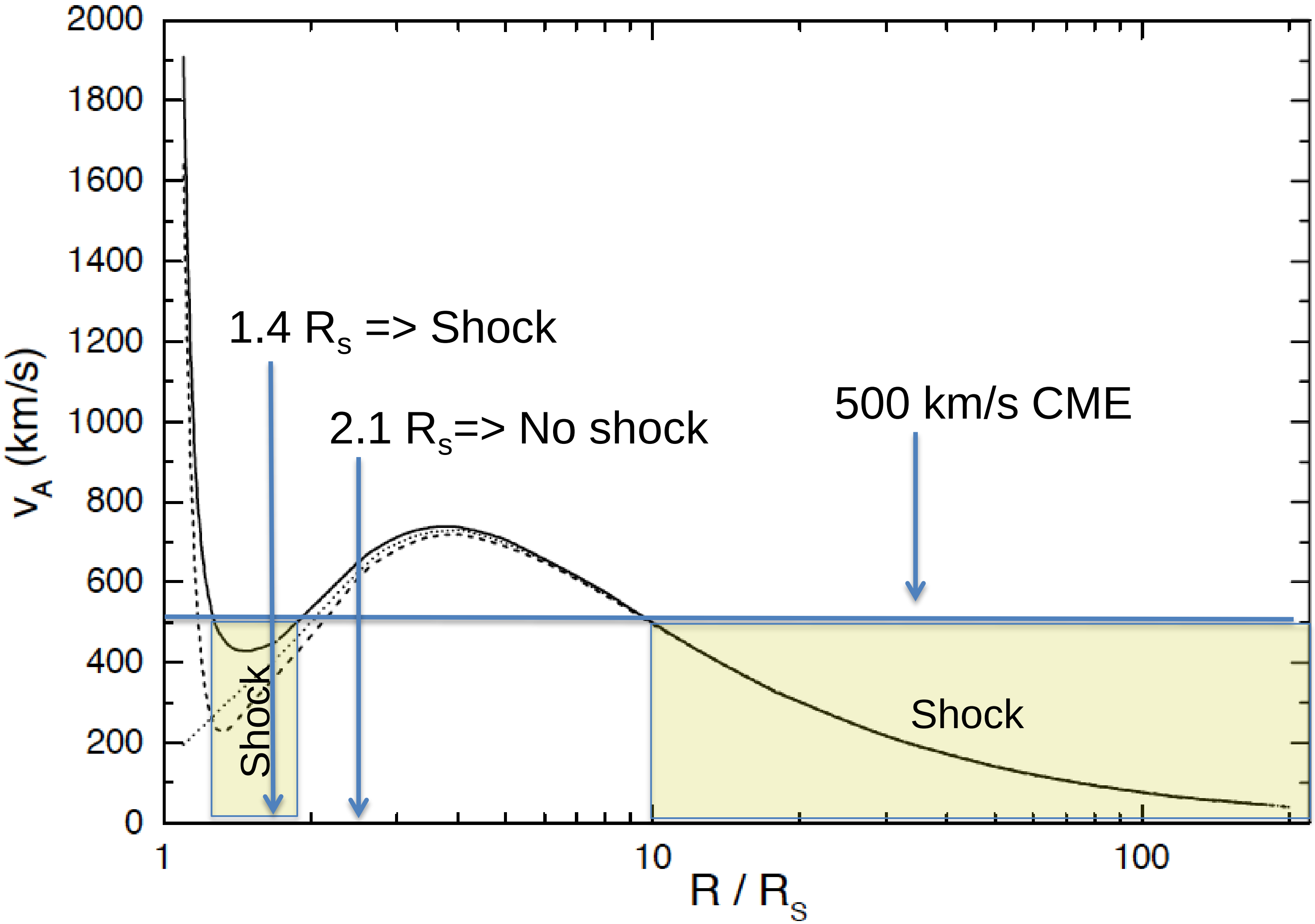
Shock Height Problem



Solution: Data-constrained Alfven Maps

Potential magnetic field model (PFSS)

$$v_{Alfven}(x,y) = \frac{B(x,y)}{\sqrt{m_p n_e(x,y)}}$$

Electron density maps (SDO/AIA and SOHO/LASCO)

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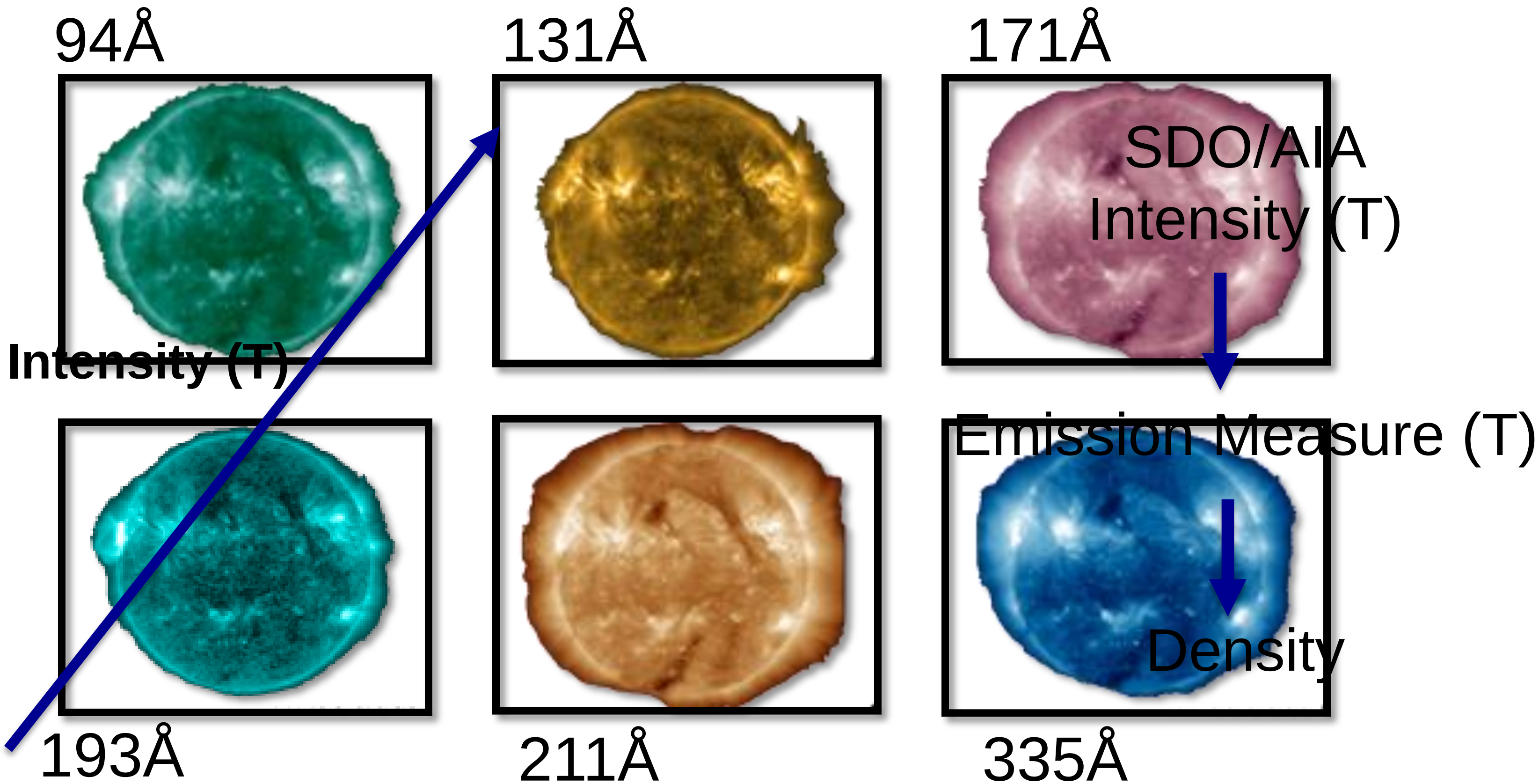
Densities in low corona (<1.3 R_S)



Aschwanden et al. (2011)

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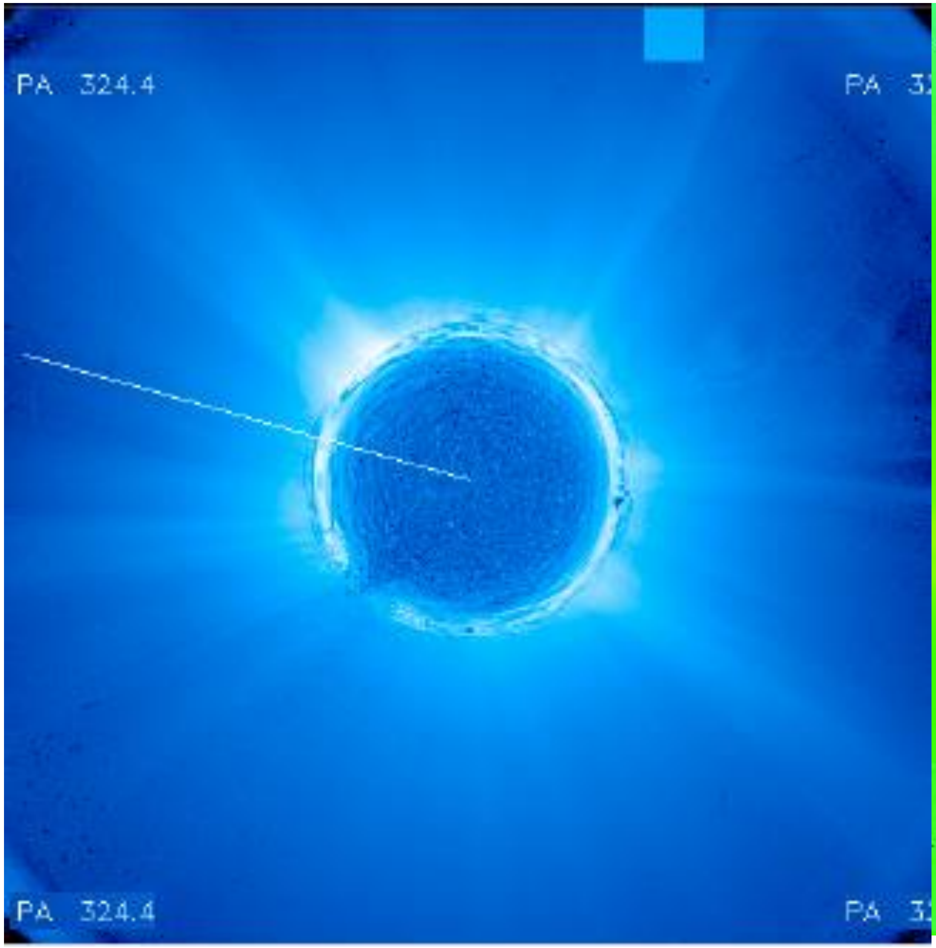
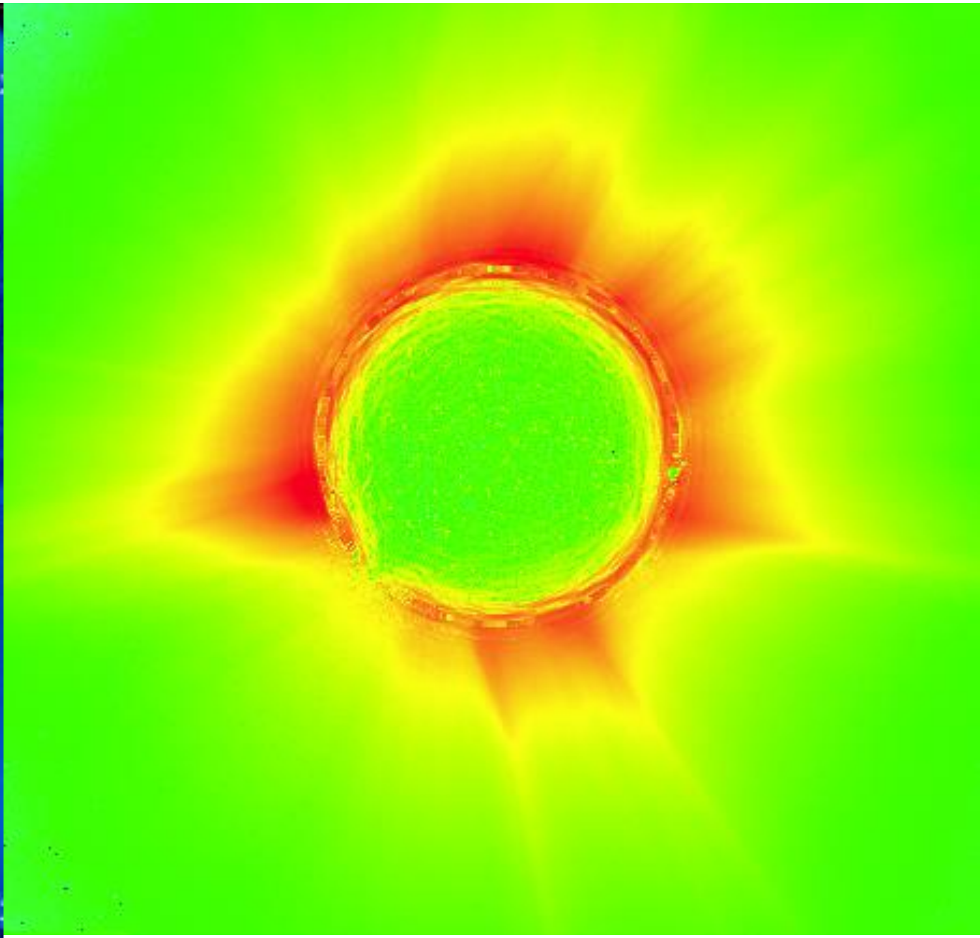
Densities in high corona (>2.5 R_S)

SOHO/LASCO Intensity → **Electron Density**





$$Brightness \propto \int_{LOS} n_e(r) G(r,s)\, ds$$

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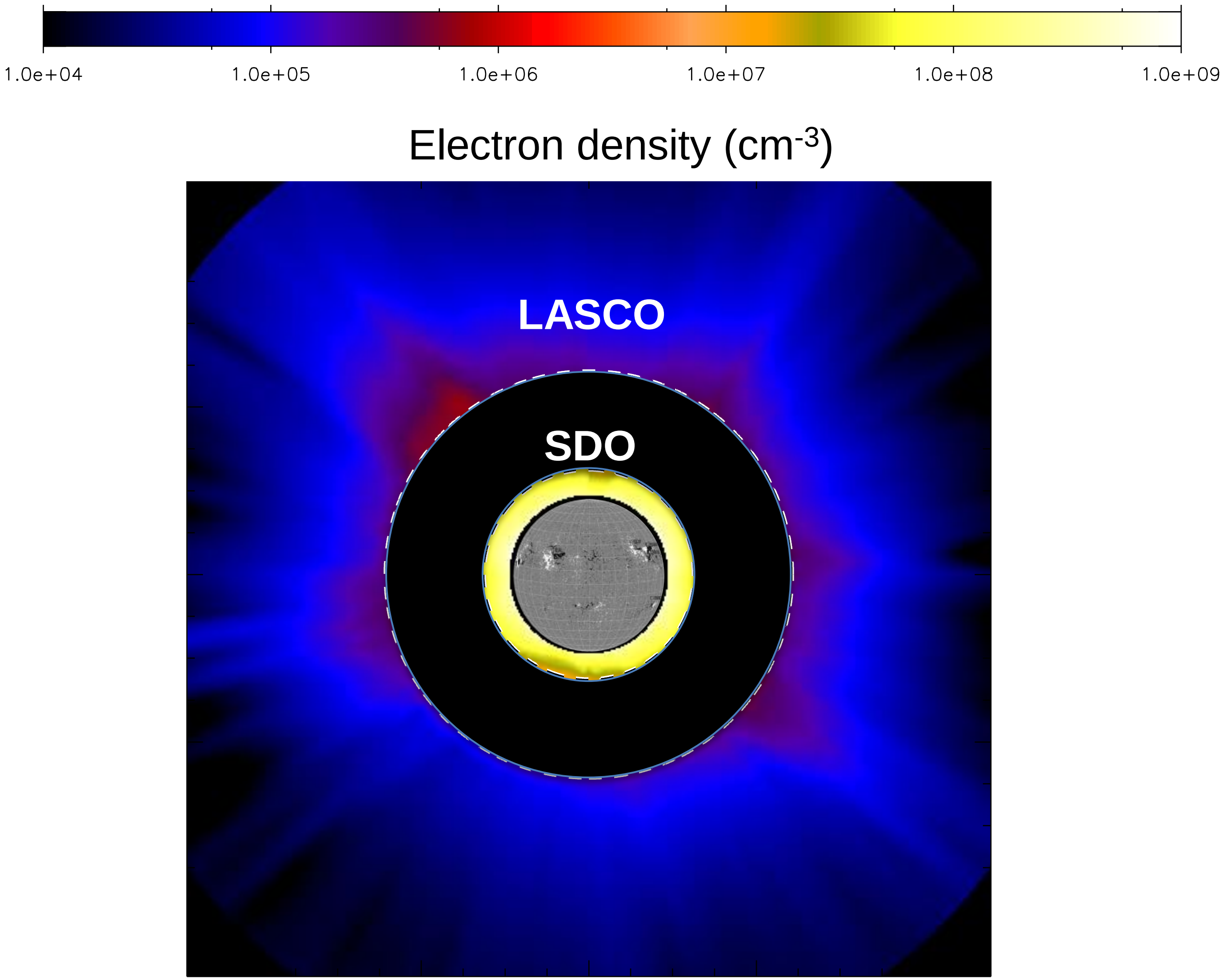
Electron Density Map



Two-component Density Model

- Spherically symmetric corona in hydrostatic equilibrium:

$$n_{ss}(r) = n_{ss}(r = 1\ R_\odot) \exp\left[-\frac{\mu m_p G M_\odot}{k T R_\odot}\left(\frac{r_0}{r} - 1\right)\right]$$

- At $r < r_0$, reduces to plane parallel solution

$$n_{pp}(r) = n_{pp}(r = 1\ R_\odot) \exp\left[-\frac{r}{H}\right]$$

- Combine spherically symmetric and plane parallel

$$n(r) = n_{pp}(r) + n_{ss}(r)$$

Zucca et al. (2014)

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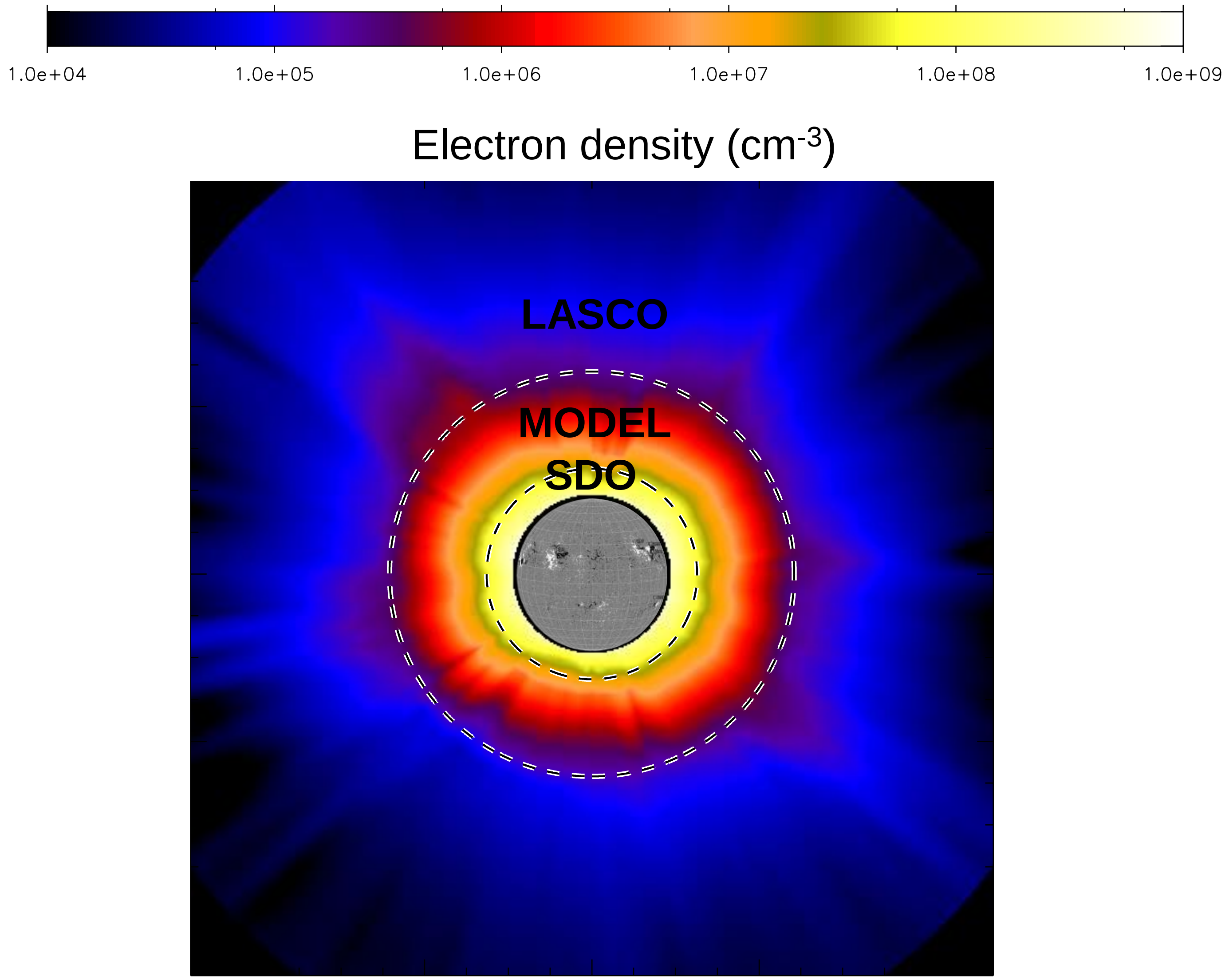
Electron Density Map



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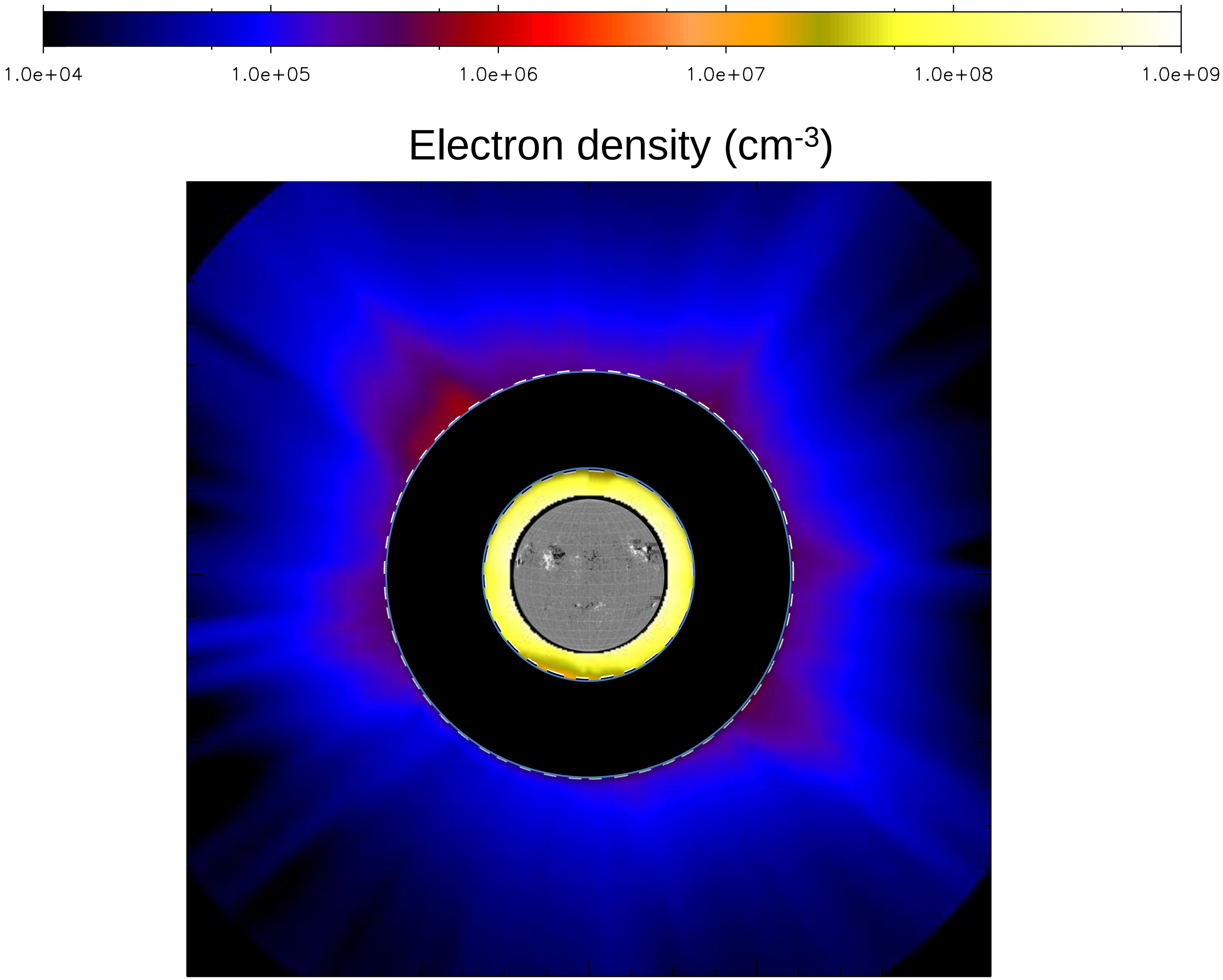
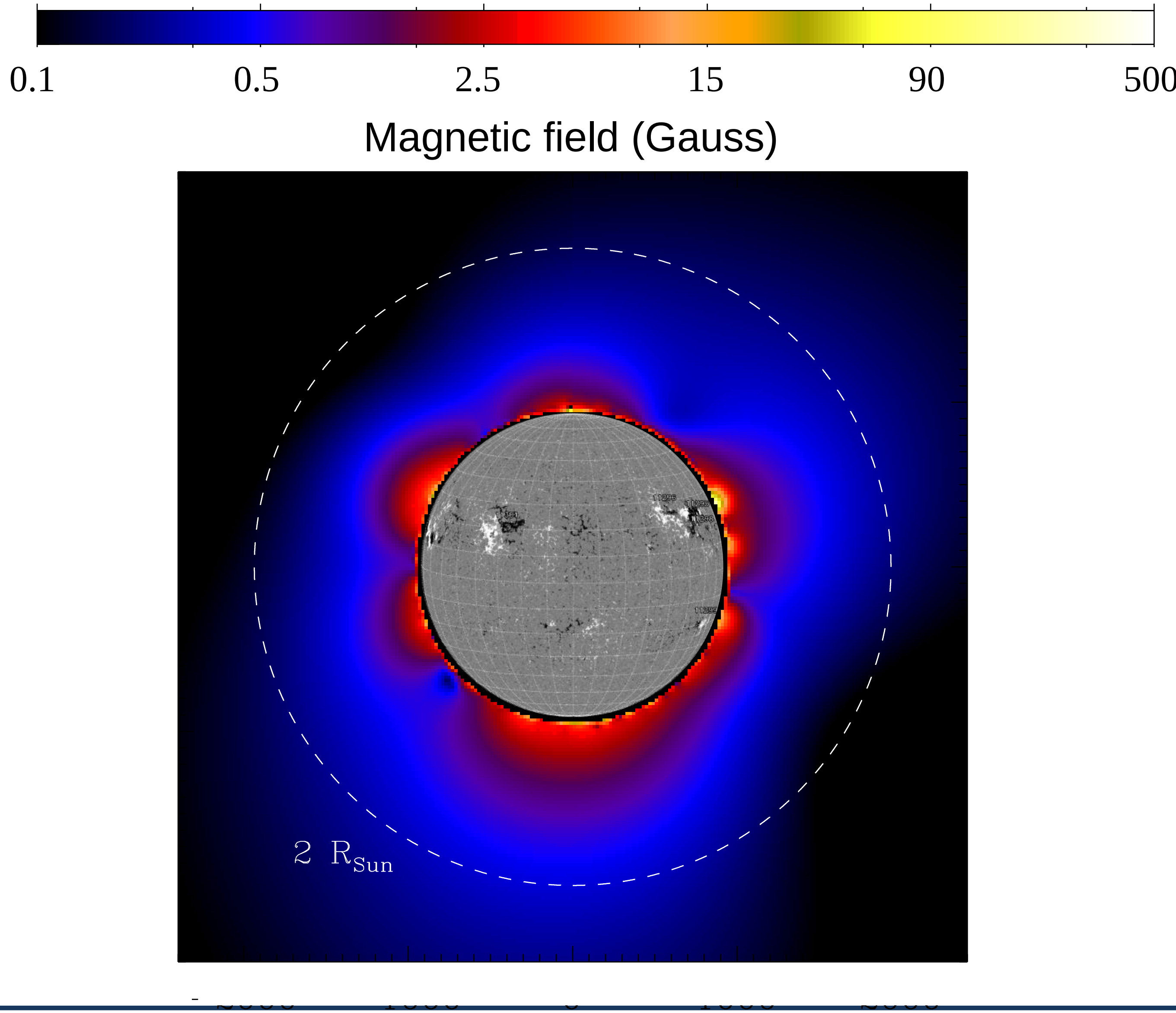
Electron Density Map



Magnetic Field Extrapolations



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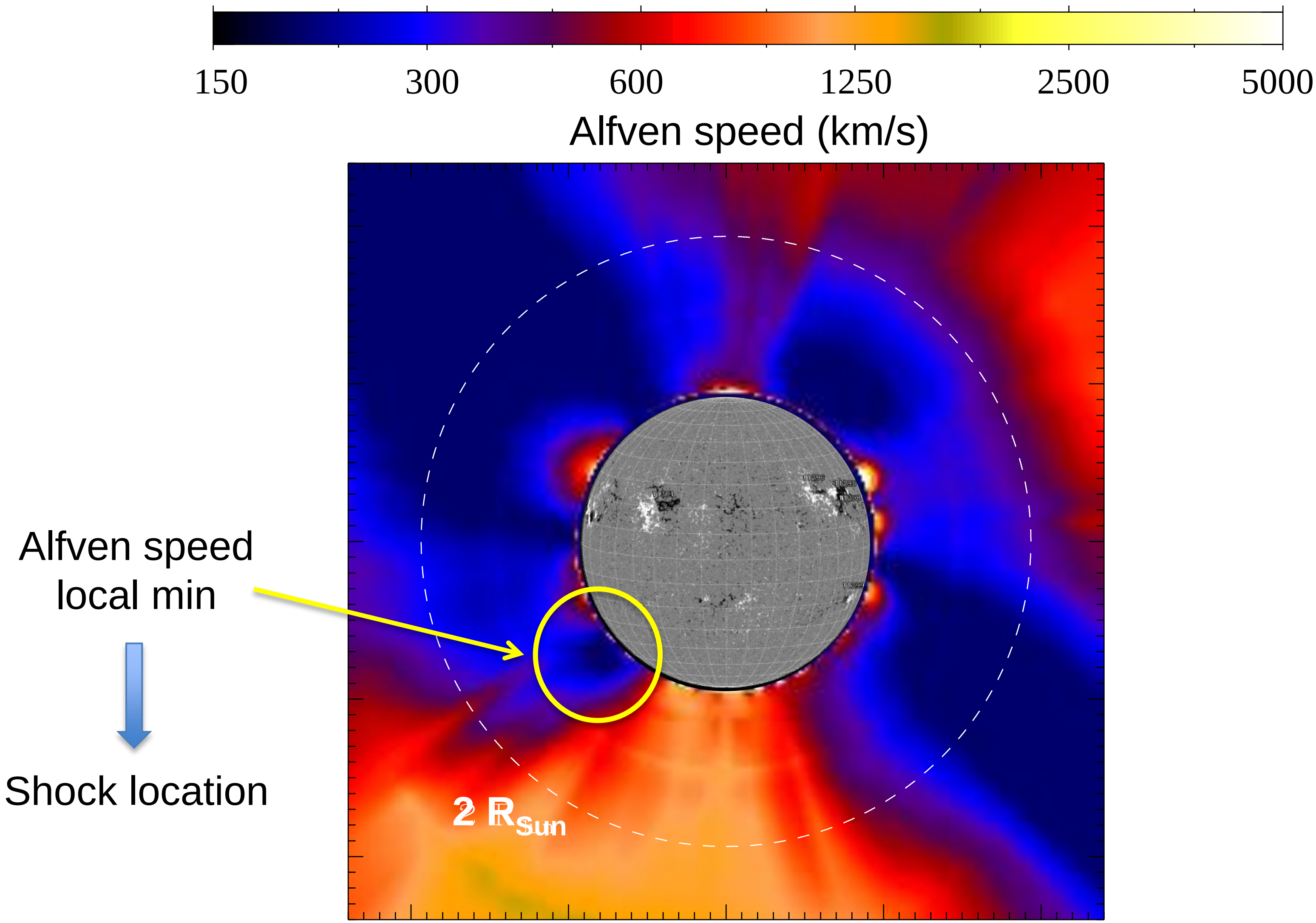
Alfvén Speed Map



Zucca et al. (2014)

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Conclusions

- Linking heliospheric to coronagraph features
  - Ballistic model works well
- Linking coronagraph to low corona and surface
  - Challenging - deflection important
  - Activity in EUV images key
- Linking CMEs to IP and coronal Type II bursts
  - Difficult without radio images
  - Density and Alfven maps key

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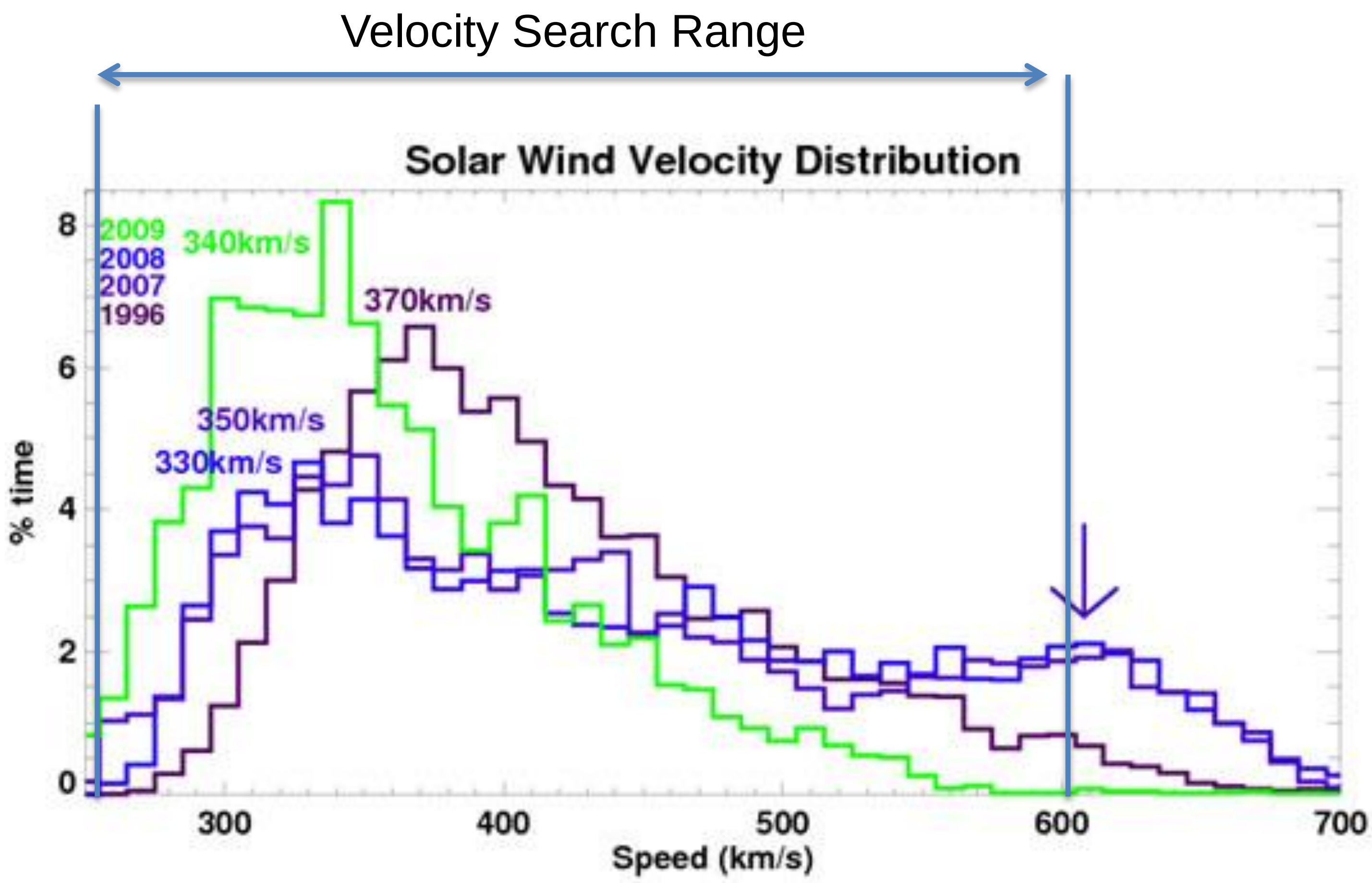
Solar Wind Velocity Distribution



De Toma (2009)

CME Velocity Distribution