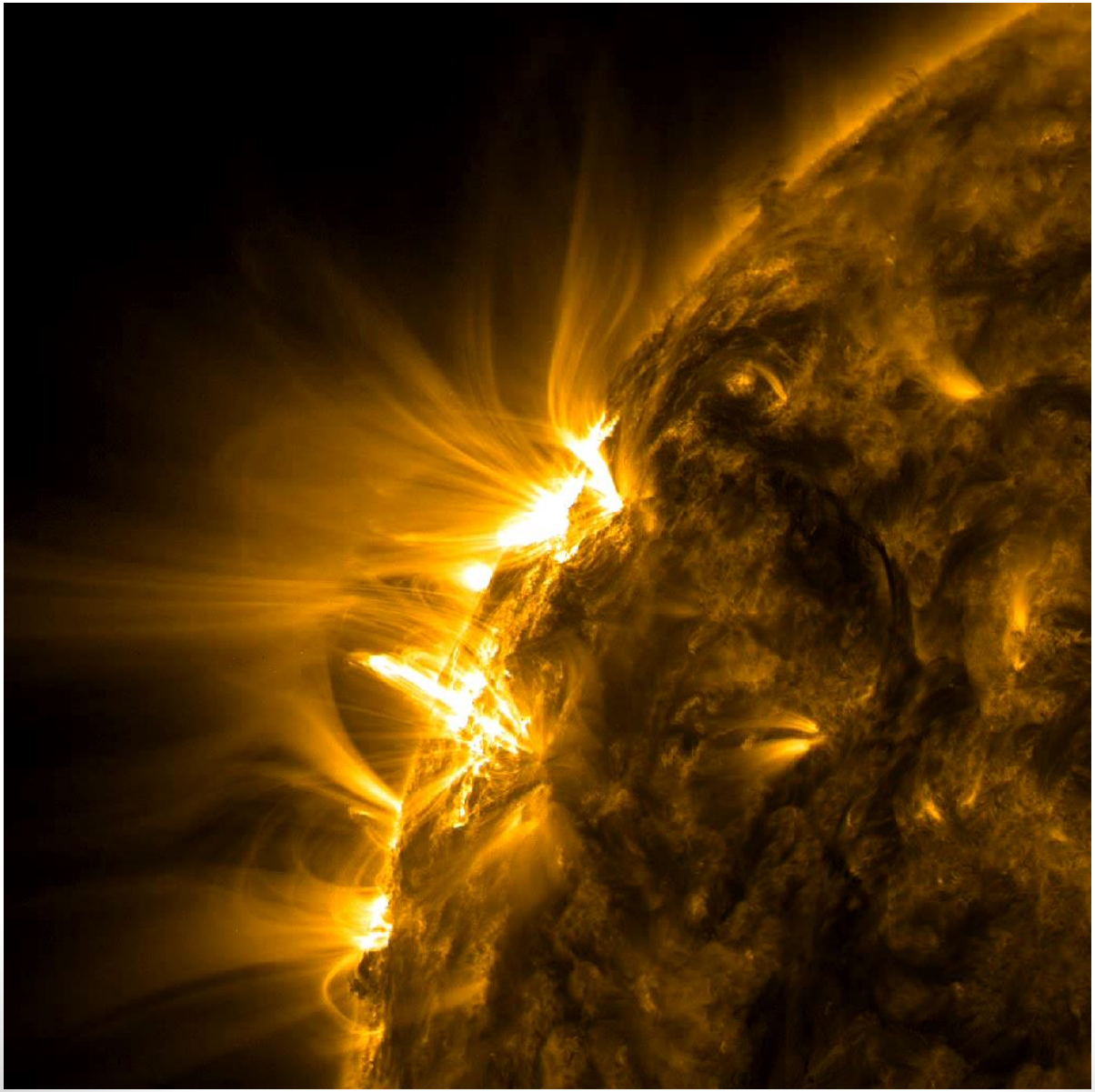
Imaging the heliosphere: The Heliospheric Imagers (HI) on board the STEREO spacecraft

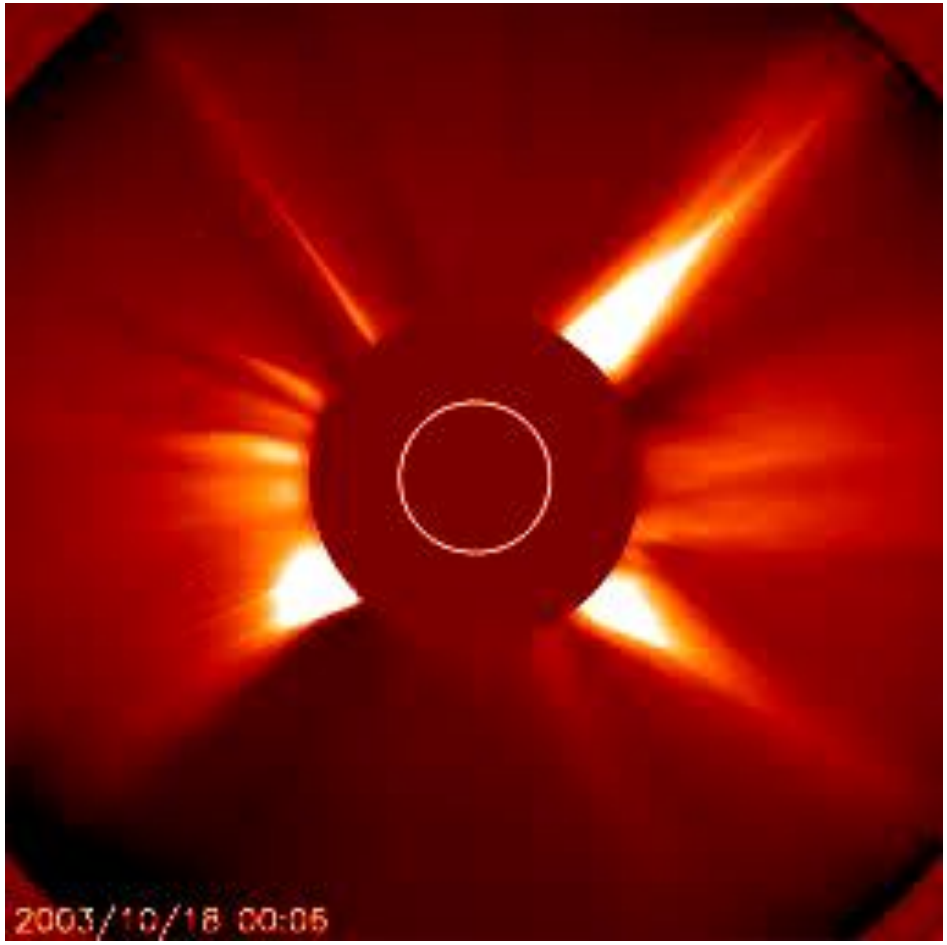
Richard Harrison & Jackie Davies

RAL Space

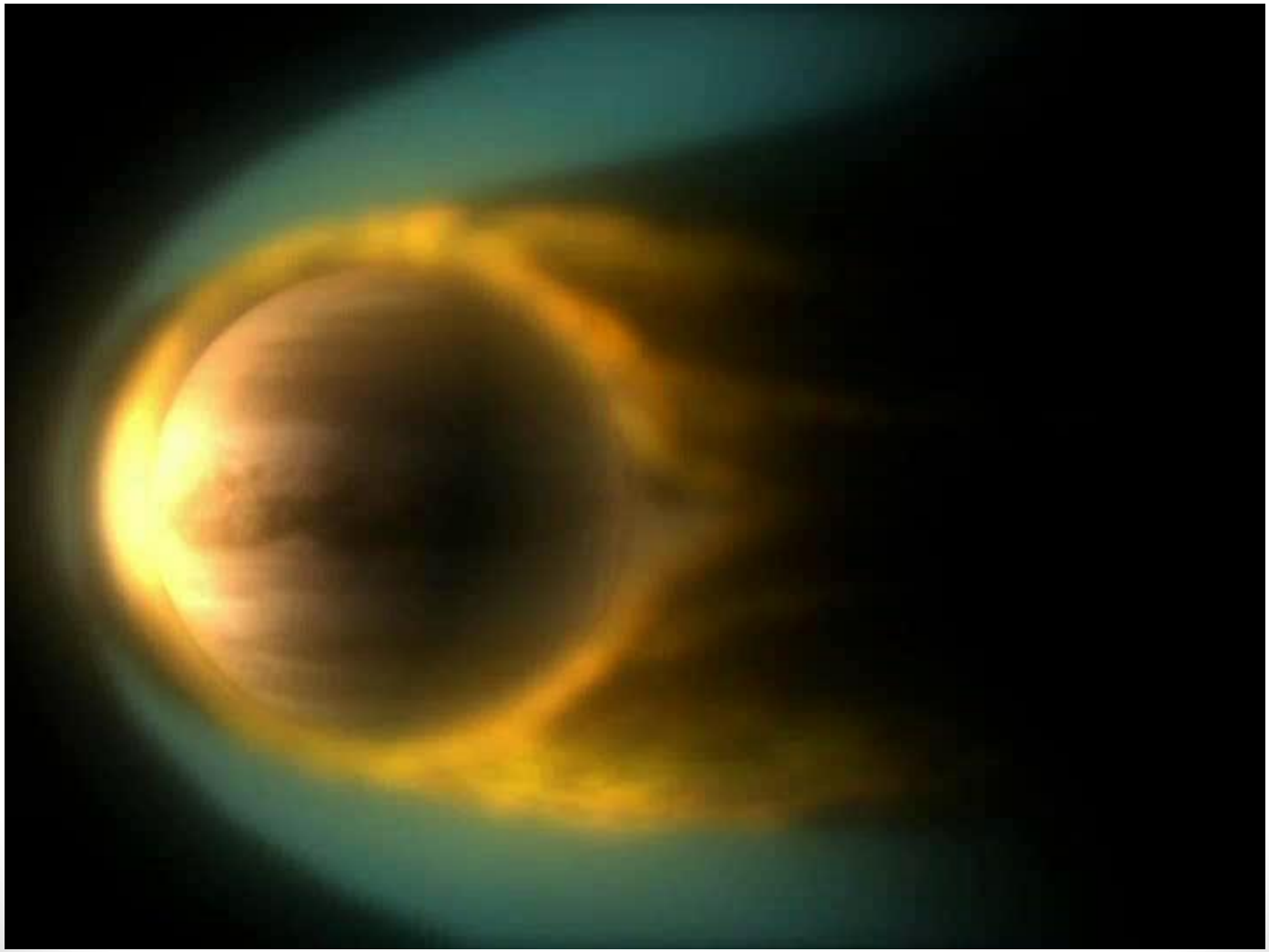
The ‘problem’



The ‘problem’



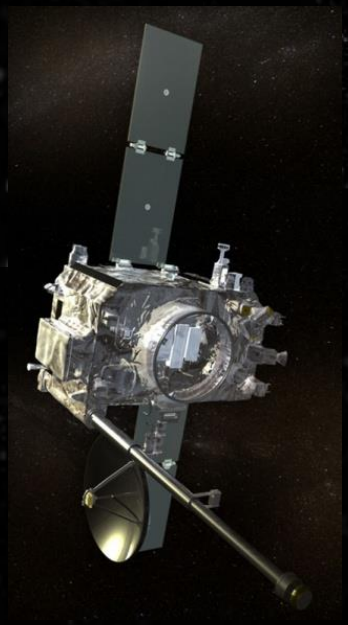
The ‘problem’

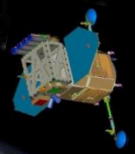


The international ‘fleet’

SOHO (ESA/NASA):
Launched 1995

STEREO-A (NASA):
Launched 2006





SDO (NASA):
Launched 2010

linode (JAXA):
aunched 2006

STEREO-B (NASA):
Launched 2006

STEREO
(*Solar Terrestial Relations Observatory*):
Mission remit

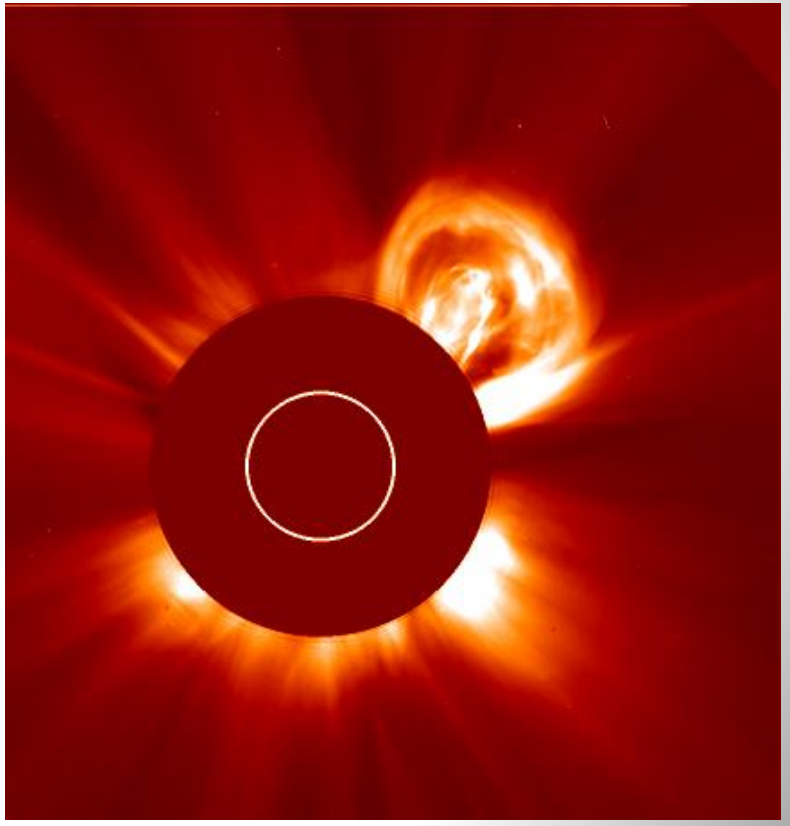
The STEREO mission was designed to study the launch and subsequent evolution of Coronal Mass Ejections (CMEs) as they propagate from the Sun to 1 AU and beyond, in particular those CMEs directed towards Earth.

What are CMEs?

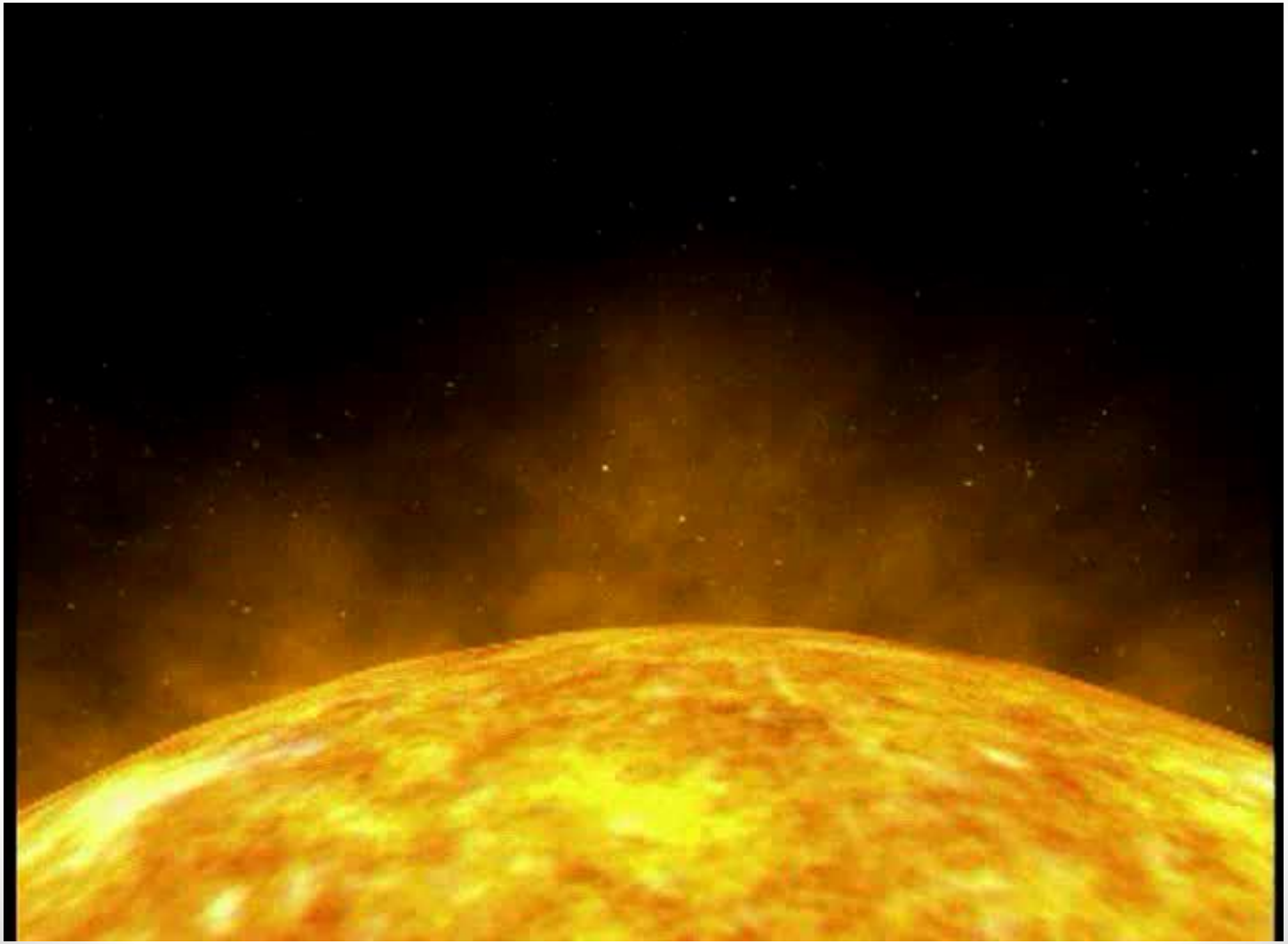
- CMEs are large-scale eruptions of solar material into the heliosphere

- Each can release 10^{12} to 10^{13} kg (1 to 10 billion tonnes) at speeds of 200 to over 2000 km s^{-1}

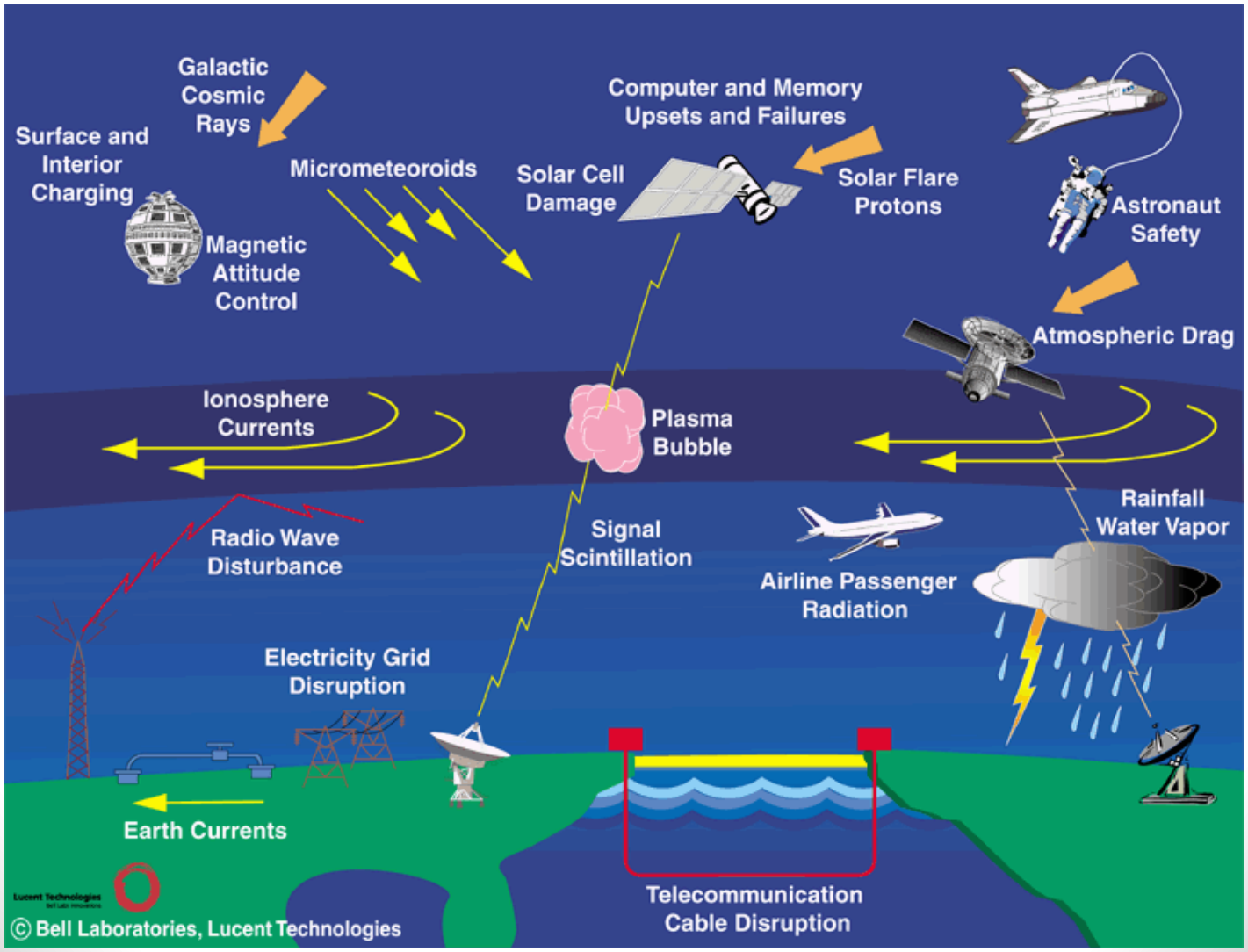
- CMEs are recognised as being the principal cause of detrimental 'space weather' effects on human systems



Animation of an Earth-impacting CME



CME: potential Space Weather effects



STEREO: Launch

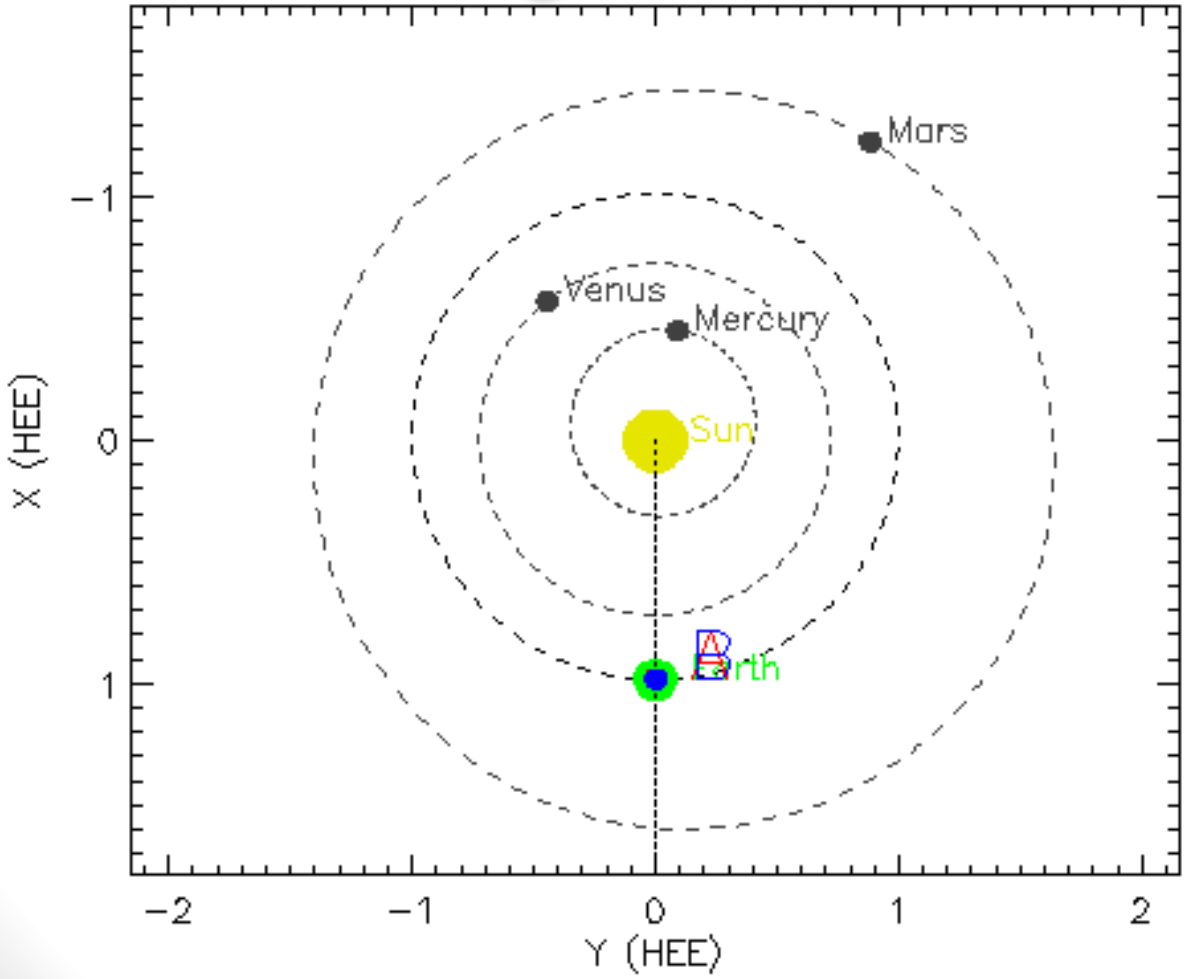
- The twin STEREO spacecraft were launched at 20:52 EDT on 25 Oct 2006, from Cape Canaveral Air Force Station on a Delta II rocket

- Lunar flybys propelled the spacecraft into near 1 AU ecliptic orbits - STEREO-A leading & STEREO-B lagging Earth in its orbit

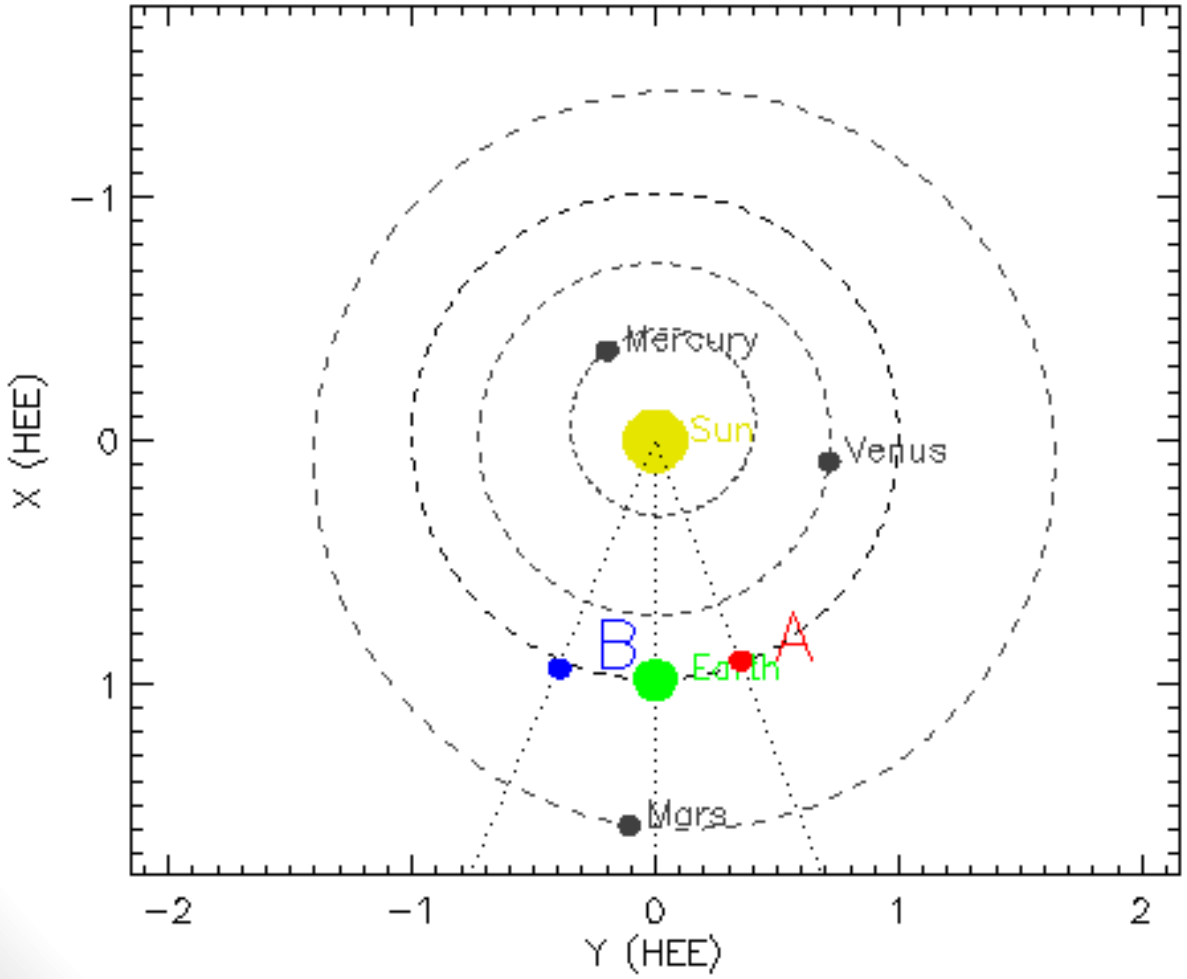
- Each spacecraft separates from Earth by 22.5° per year. Currently: STEREO-A is at 141° and STEREO-B 139°

Orbital Configuration: 1st Jan 2007

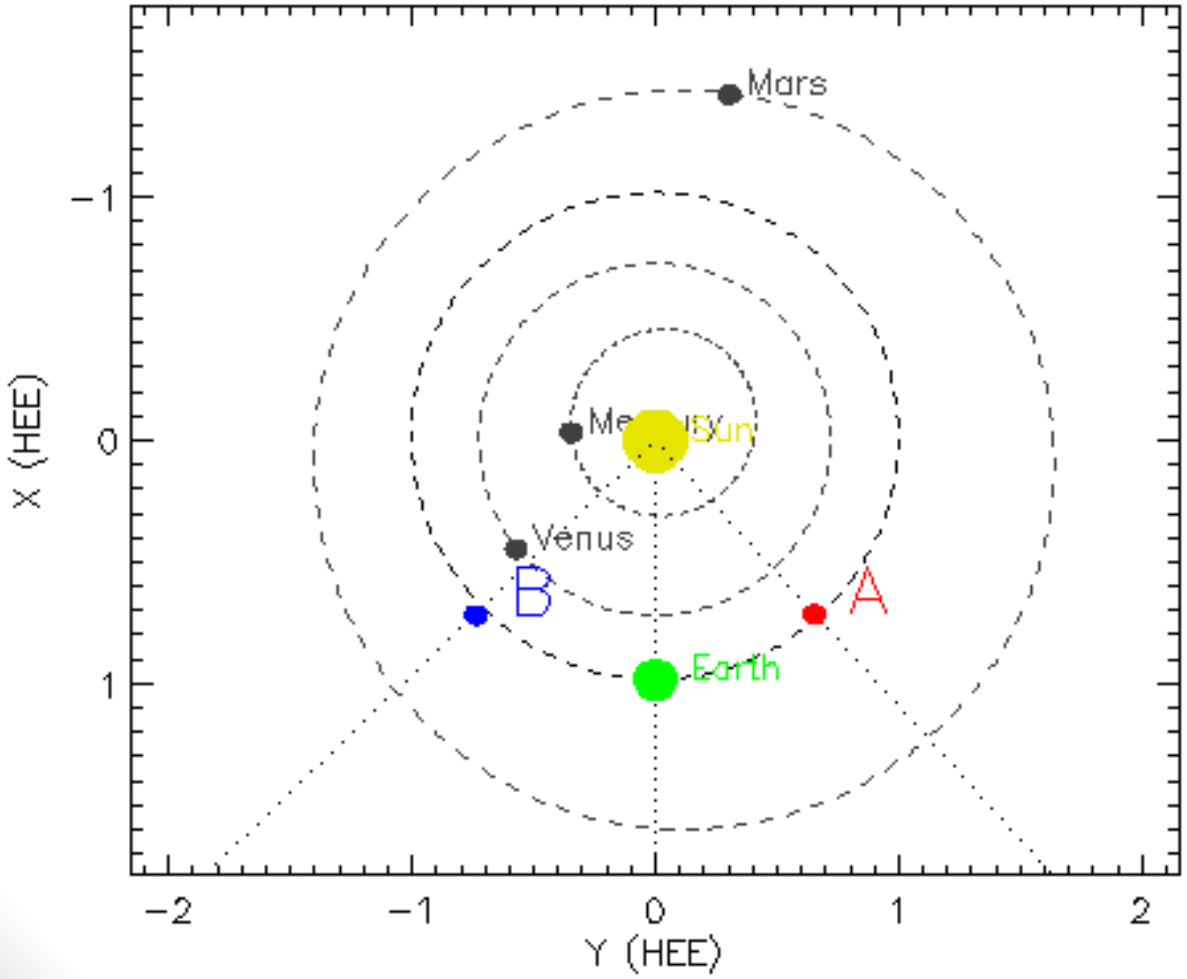
Ecliptic Plane



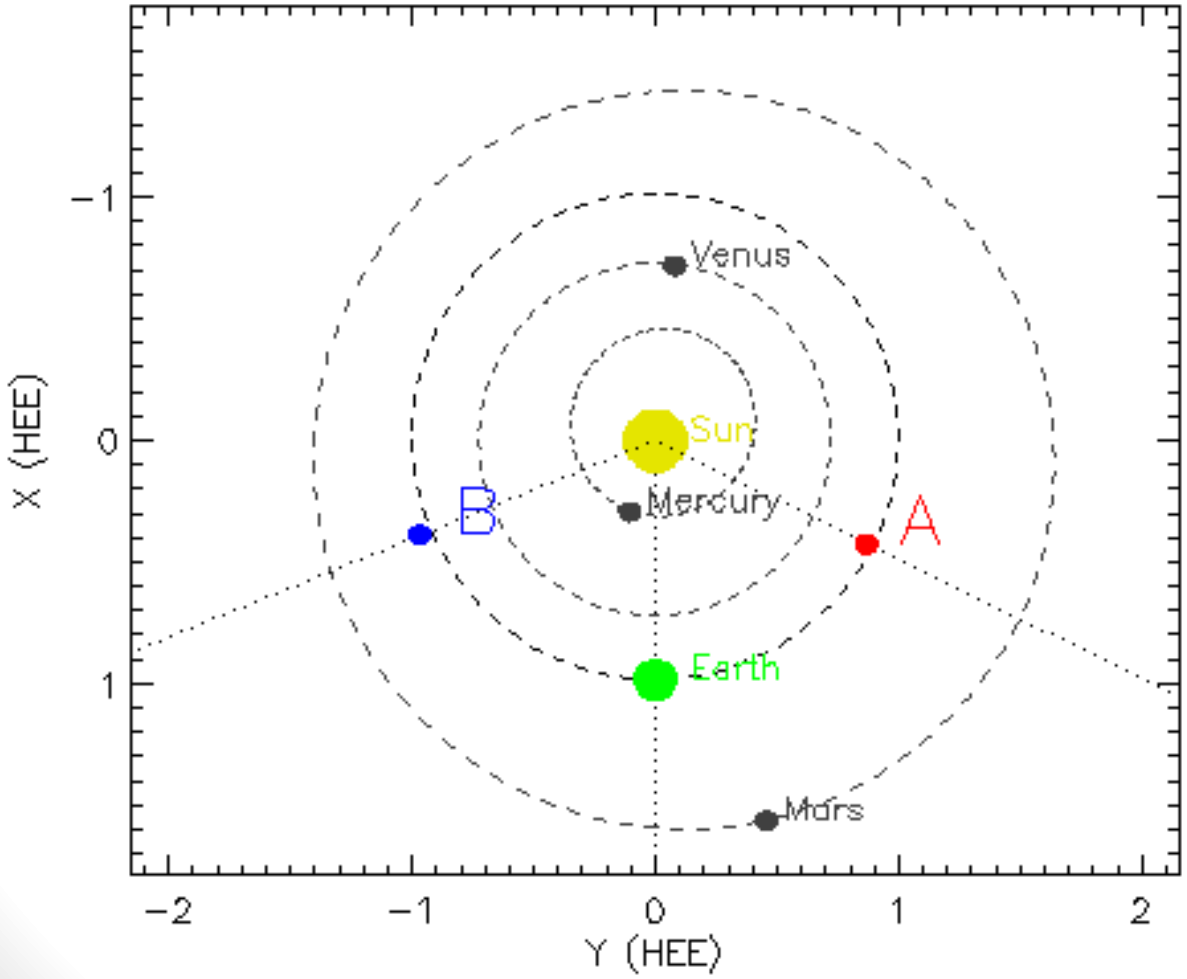
Orbital Configuration: 1st Jan 2008



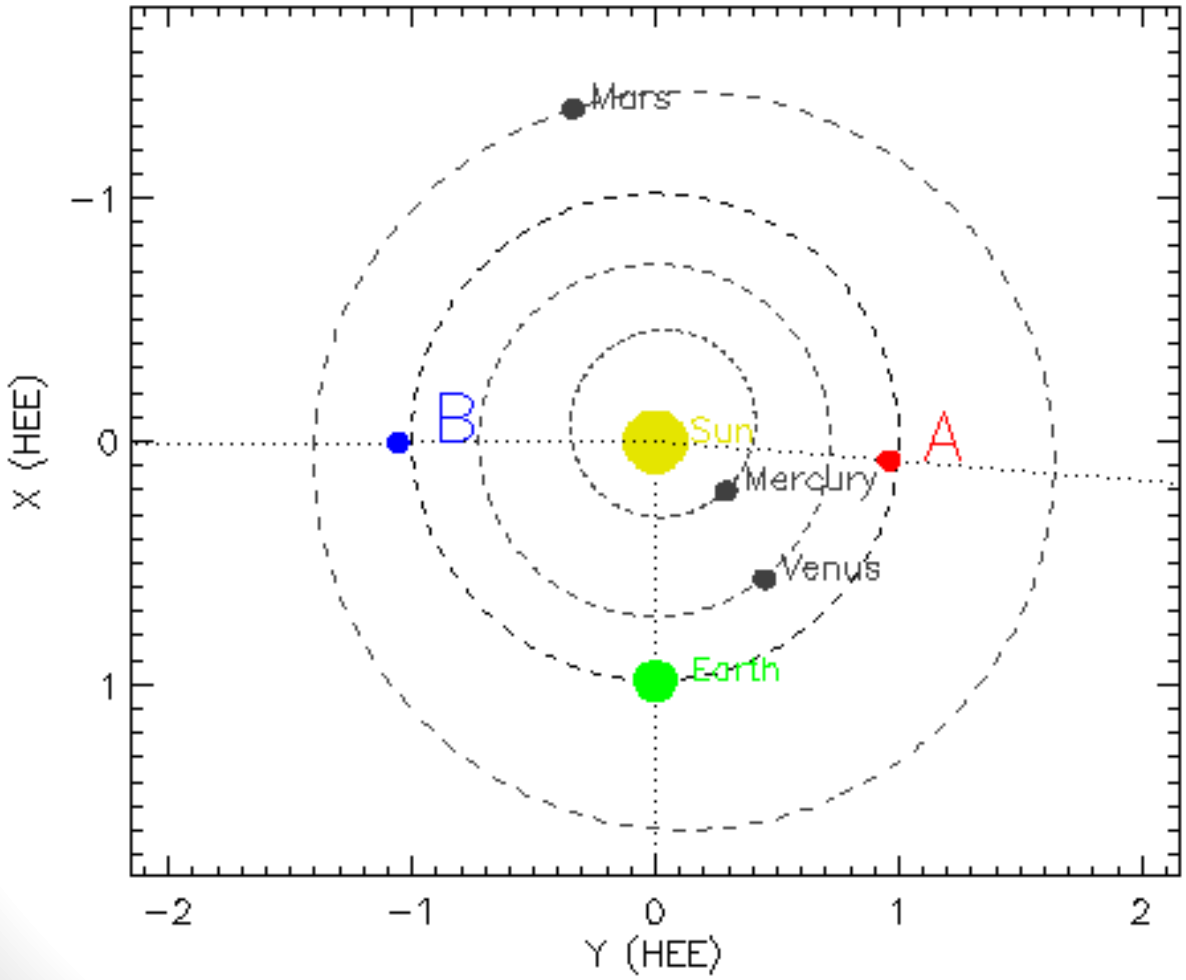
Orbital Configuration: 1st Jan 2009



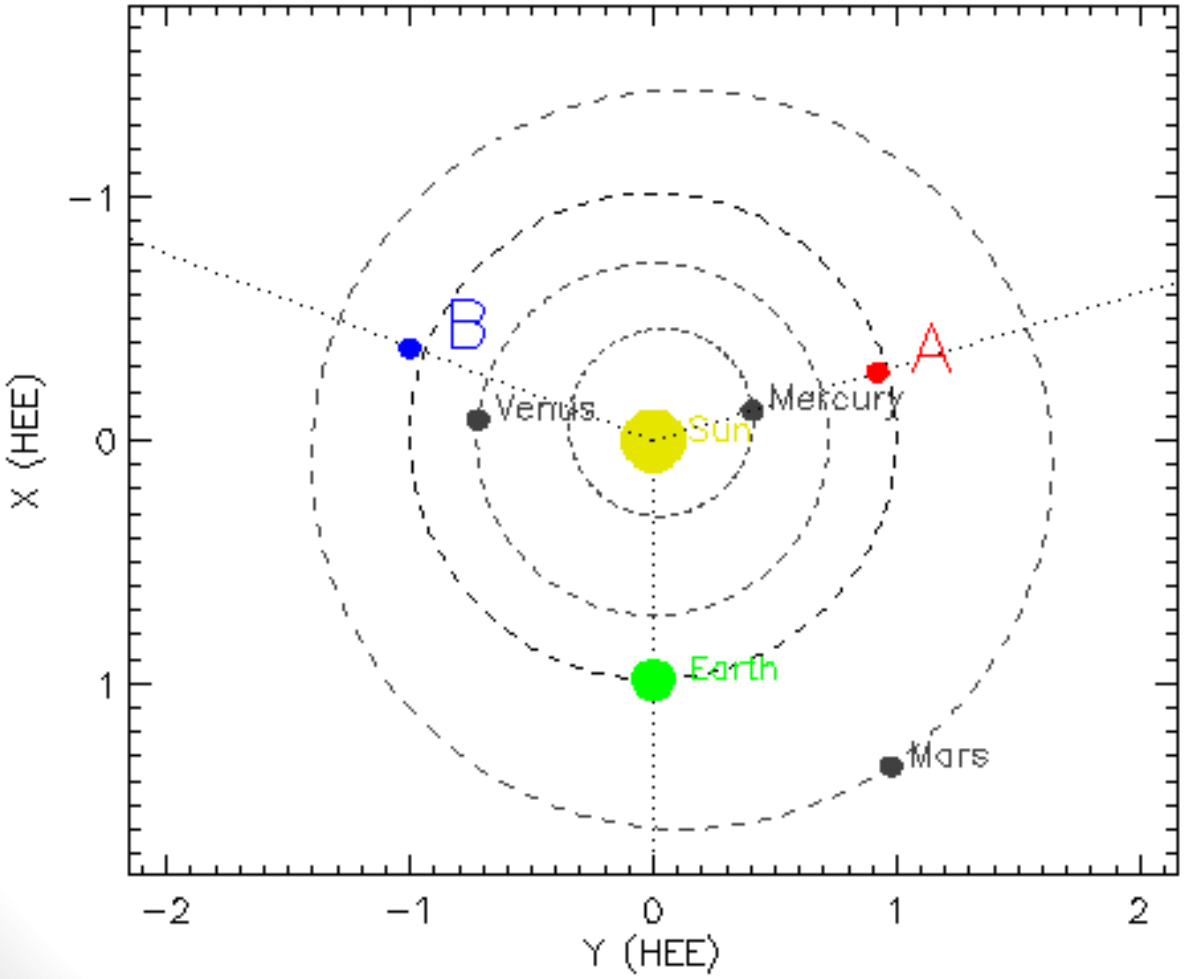
Orbital Configuration: 1st Jan 2010



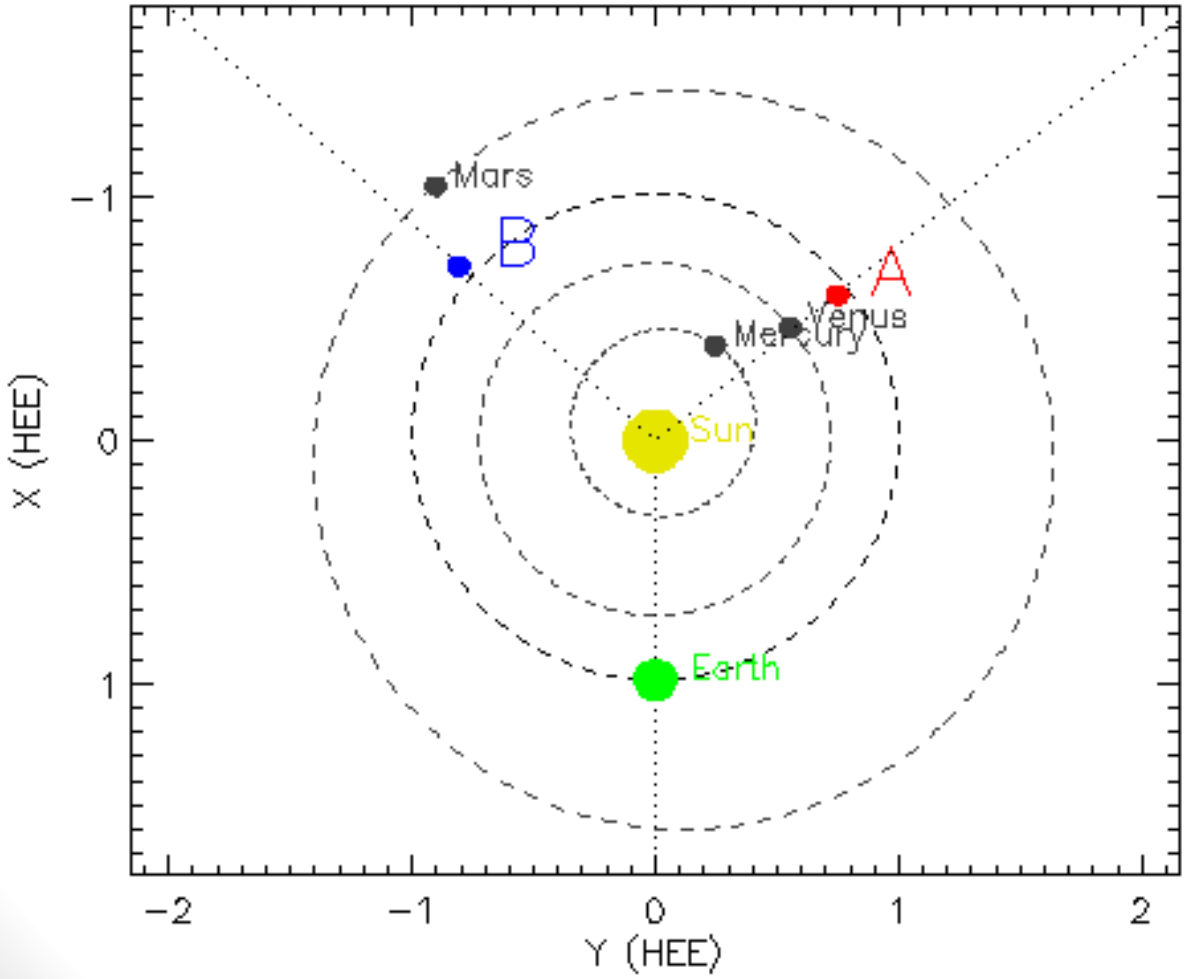
Orbital Configuration: 1st Jan 2011



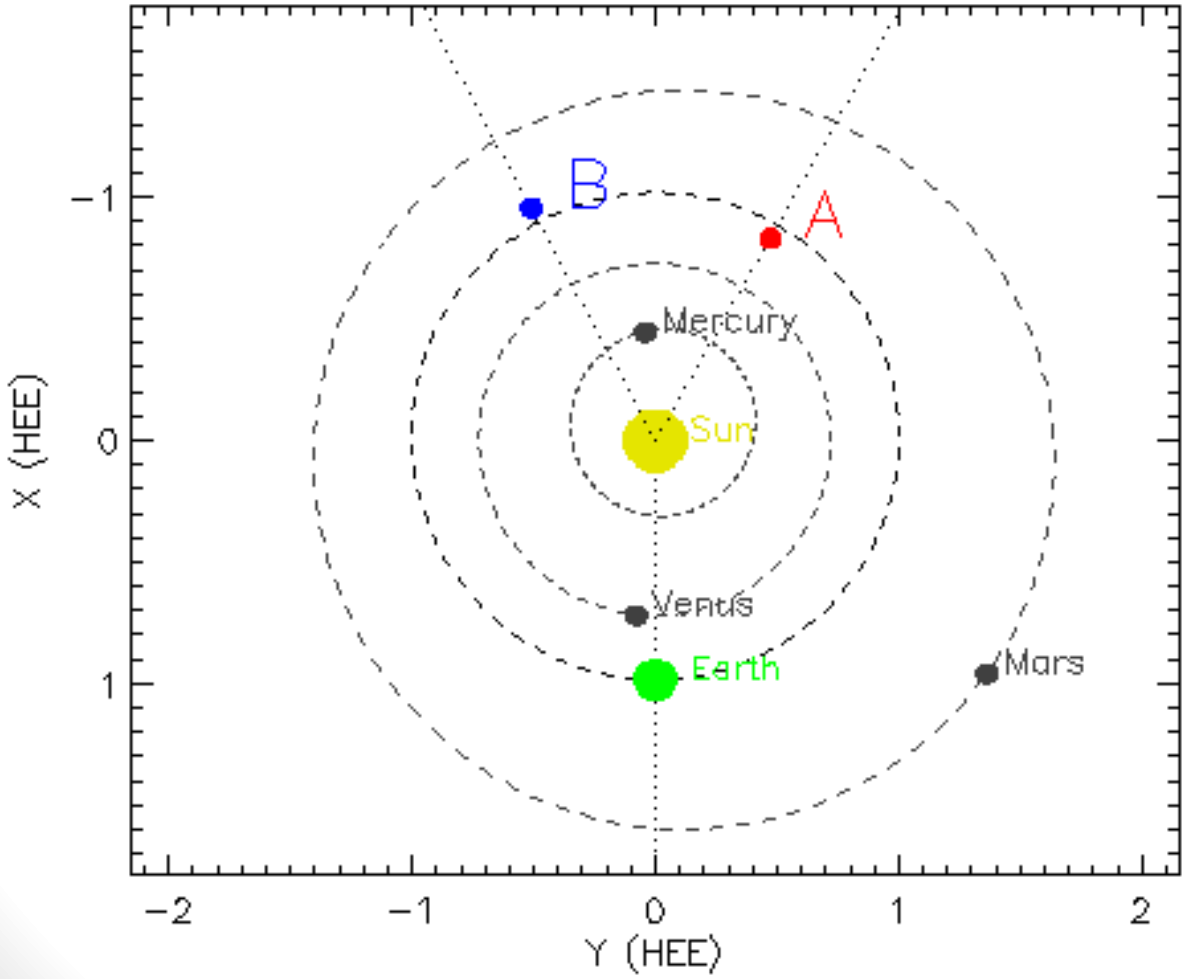
Orbital Configuration: 1st Jan 2012



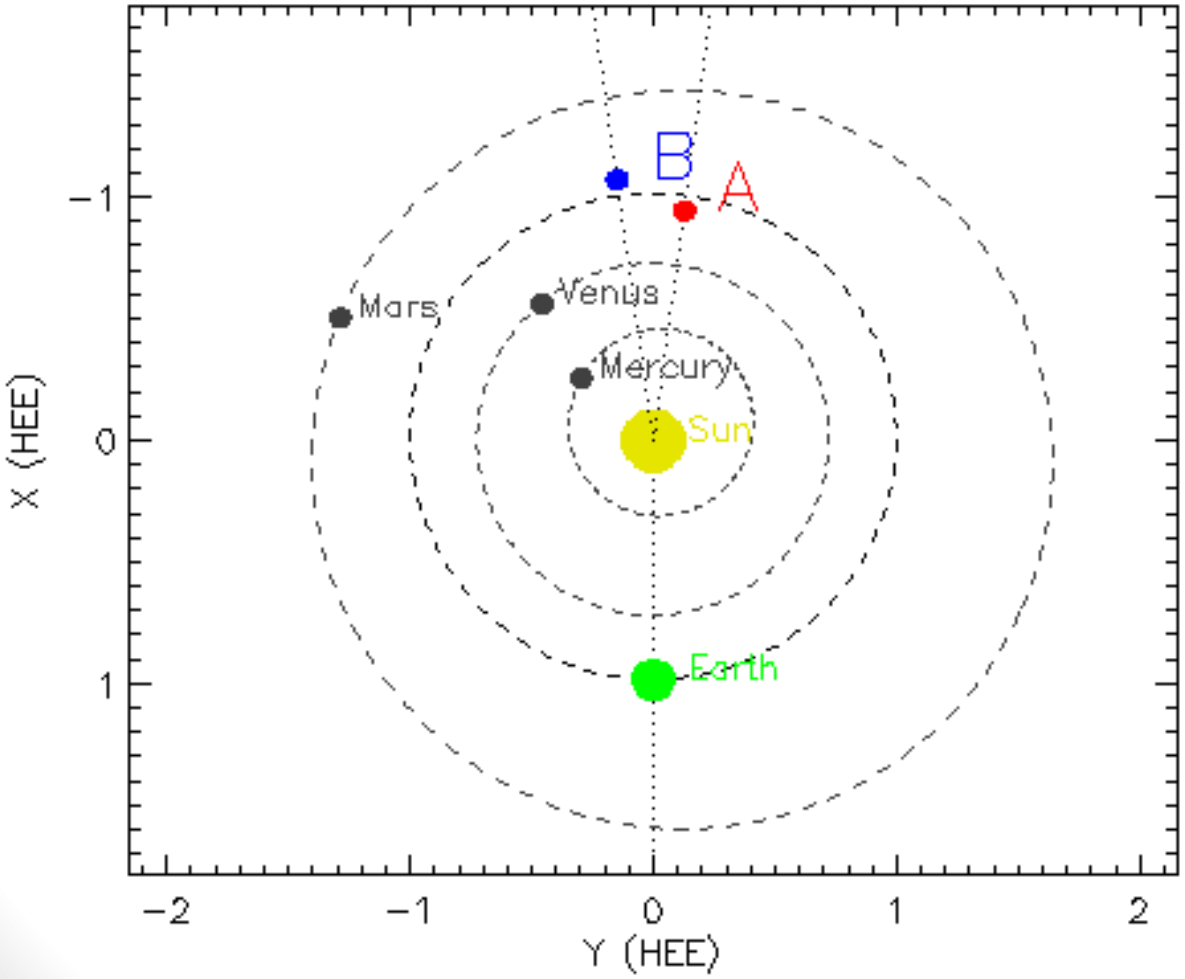
Orbital Configuration: 1st Jan 2013



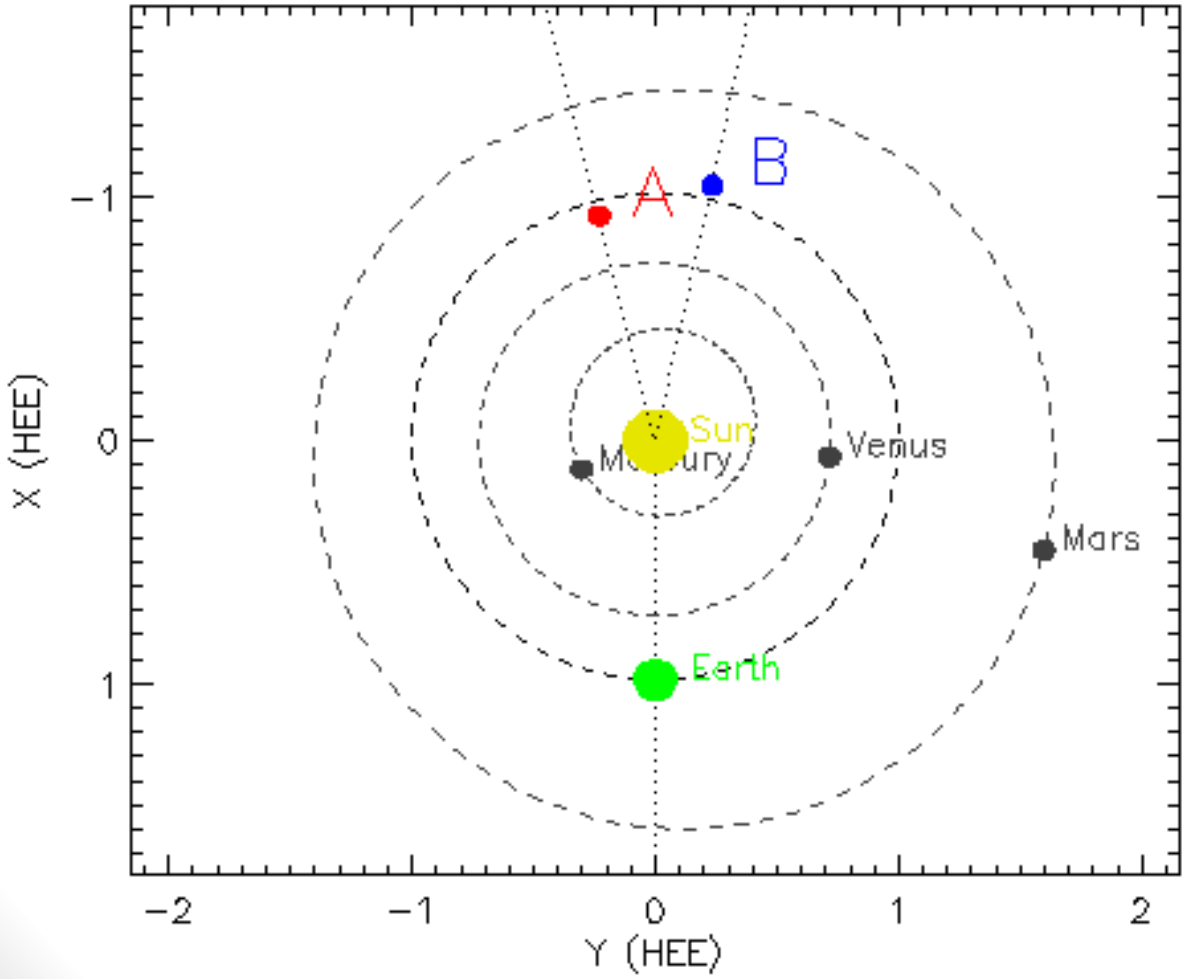
Orbital Configuration: 1st Jan 2014



Orbital Configuration: 1st Jan 2015



Orbital Configuration: 1st Jan 2016



STEREO Payload

The following four instrument packages are mounted on each near-identical STEREO spacecraft:

- **Sun-Earth Connection Coronal and Heliospheric Investigation (SECCHI):** suite of remote-sensing imaging instruments that, when combined, image from the solar disc out to 1 AU and beyond.
- **STEREO/WAVES (S/WAVES):** electric field instrument that enables the remote detection of solar radio bursts and in-situ observation of plasma waves.
- **In-situ Measurements of Particles And CME Transients (IMPACT):** in-situ measurements of thermal and suprathermal electrons, solar energetic particles (SEPs) and interplanetary magnetic field.
- **PLAsma and SupraThermal Ion Composition (PLASTIC):** in-situ measurements of thermal and suprathermal protons, alpha particles and heavy ions, including charge state.

STEREO/SECCHI

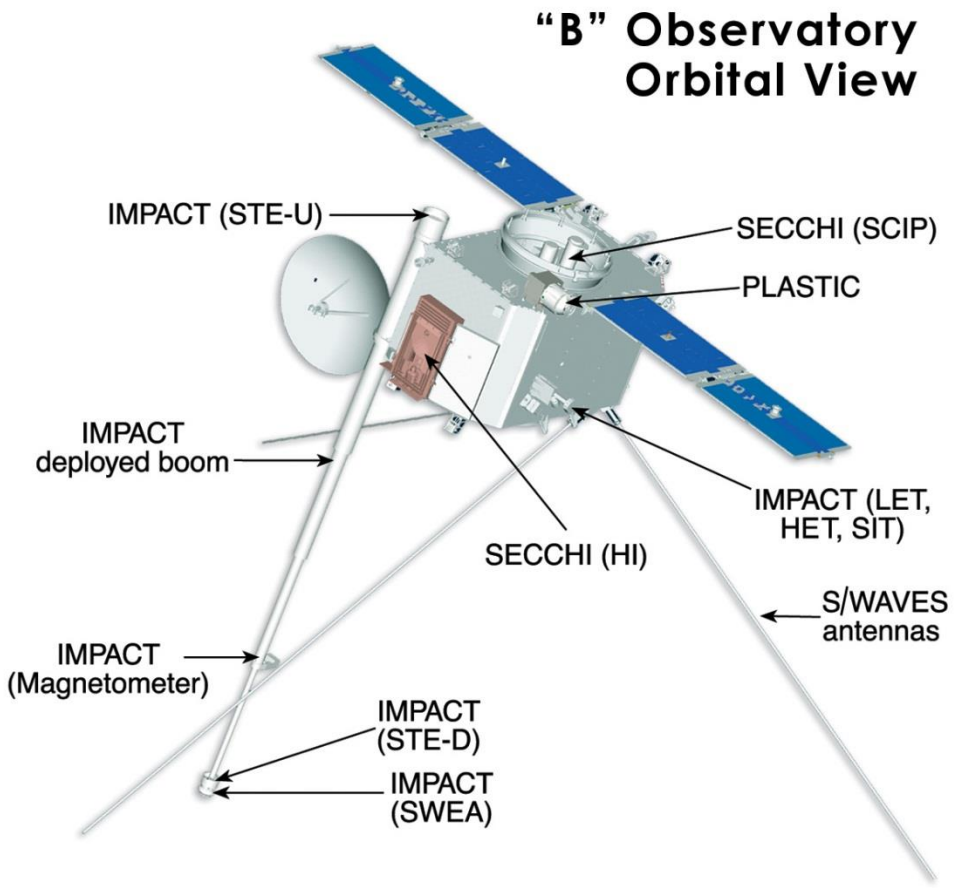
The SECCHI imaging package on each STEREO Spacecraft comprises:

- **Extreme Ultra Violet Imager (EUVI):** a full Sun instrument that images the chromosphere and corona in four emission lines: He II 304Å, Fe IX/X 171Å, Fe XII 195Å and Fe XV 284Å, out to 1.7 R_{Sun}.
  PI: Jim Lemen (Lockheed Martin)

- **Two white-light coronagraphs (COR1 and COR2):** that image the corona from 1.4 – 4 R_{Sun} P-O-S (COR1) and 2.5 – 15 R_{Sun} P-O-S (COR2).
  PI COR1: Joe Davila (NASA/Goddard Space Flight Centre)
  PI COR2: Denis Socker (Naval Research laboratory)

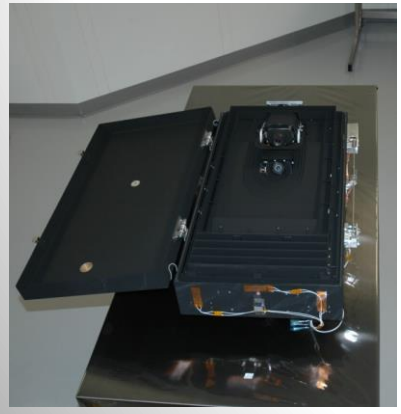
- **Heliospheric Imager (HI):** that consists of two CCD-based white-light imagers, HI-1 and HI-2, that, between them, image the outer corona/inner heliosphere from 4^{o} to 88^{o} elongation.
  PI: Richard Harrison (RAL Space)

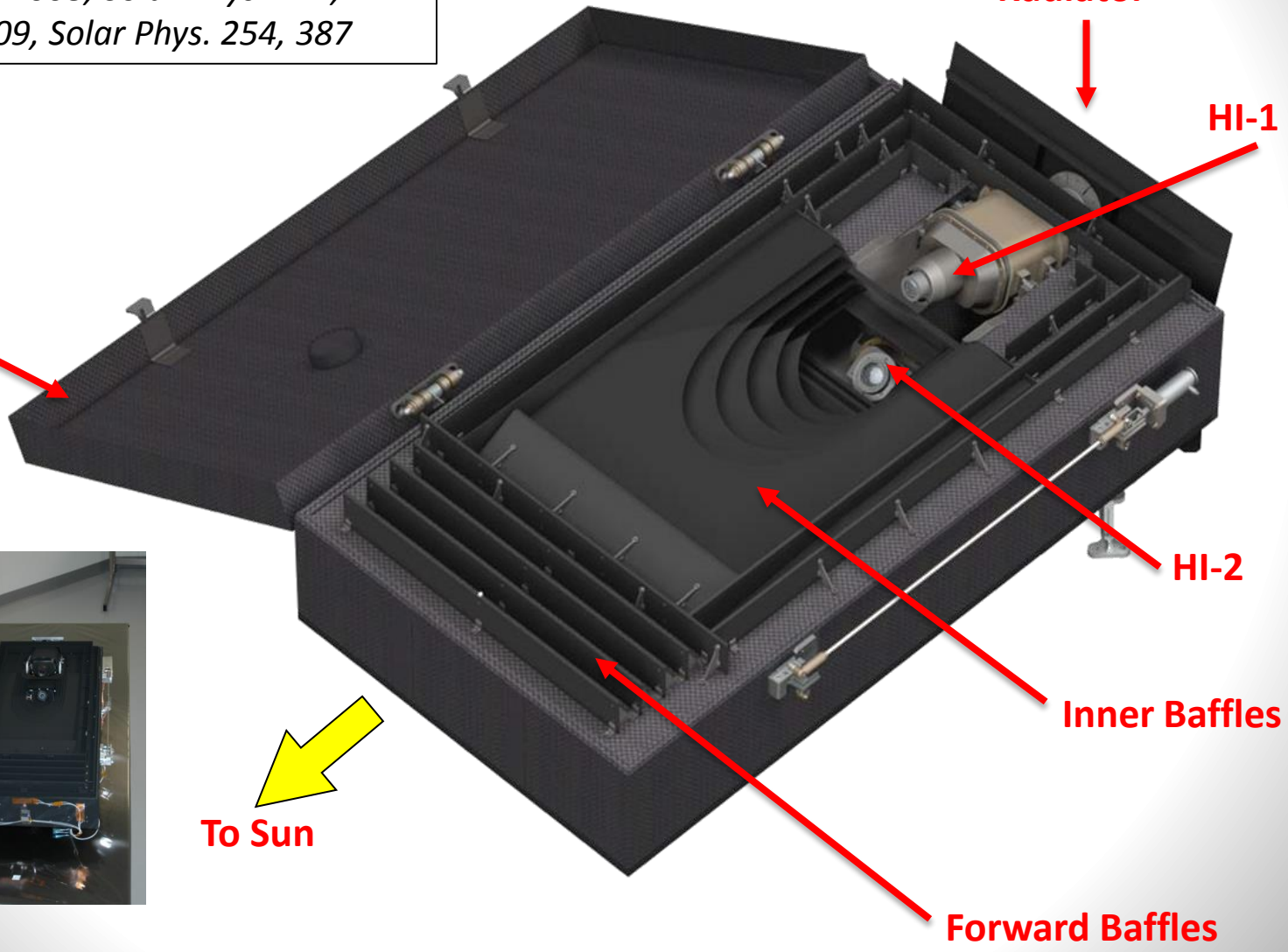
STEREO Payload



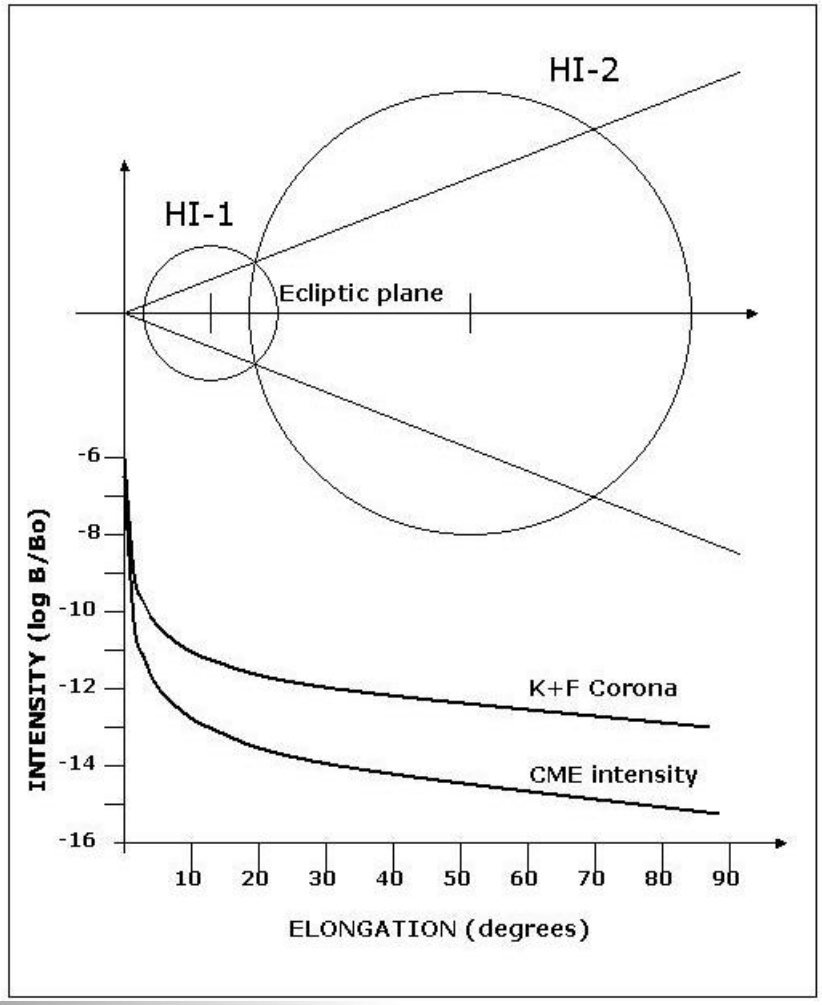
STEREO/HI

Harrison et al., 2008, Solar Phys. 247, 171
Eyles et al., 2009, Solar Phys. 254, 387





STEREO/HI



	HI-1	HI-2
Direction of Centre of FOV	**14 degrees**	**53.7 degrees**
Angular Field of View	**20 degrees**	**70 degrees**
Angular Range	**4-24 degrees**	**18.7-88.7 degrees**
Image Array (2x2 binning)	**1024x1024**	**1024x1024**
Image Pixel Size	**70 arcsec**	**4 arcmin**
Spectral Bandpass	**630-730 nm**	**400-1000 nm**
Nominal Image Cadence	**40 min**	**120 min**
Brightness Sensitivity (B_0 = solar disk)	**3×10^{-15} B_0**	**3×10^{-16} B_0**
Straylight Rejection	**3×10^{-13} B_0**	**10^{-14} B_0**

< 0.1 CME intensity at inner edge of FOV

~ magnitude 12; governed by anticipated CME intensity at outer edge

STEREO/HI

STEREO-A: HI door opened on 13 December 2006
STEREO-B: HI door opened on 11 January 2007

- HI detects light from a number of sources:

  Scatter from dust: F-corona;

  Thomson scatter from solar electrons: K-corona;

  Light from stars, planets, comets, asteroids, the Moon, UFOs or any other visual object in the field-of view.

- The intensity of the F-corona far exceeds the intensity of the K-corona (which is what we are interested in), by a factor approaching 1000.

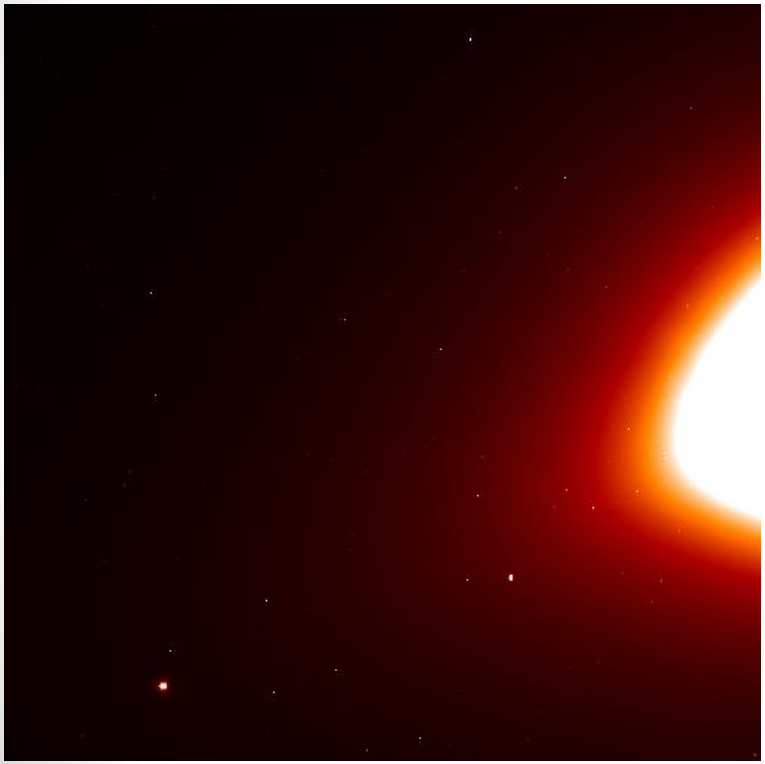
- As the F-corona is relatively stable over many days, its effect can be removed by:

  Subtracting a ‘background’ calculated over several days;

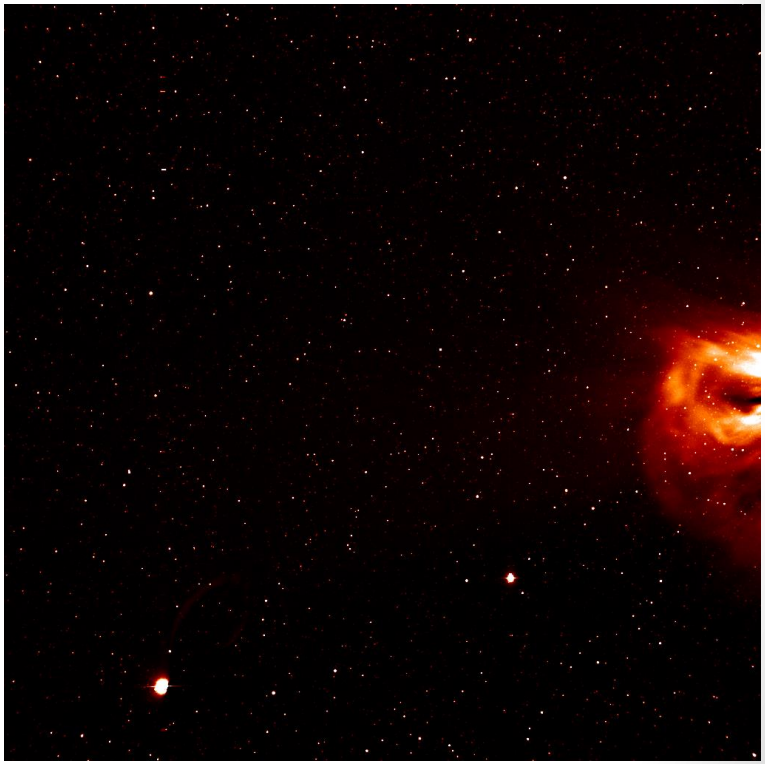
  Using a running difference technique.

STEREO/HI

Background-subtraction

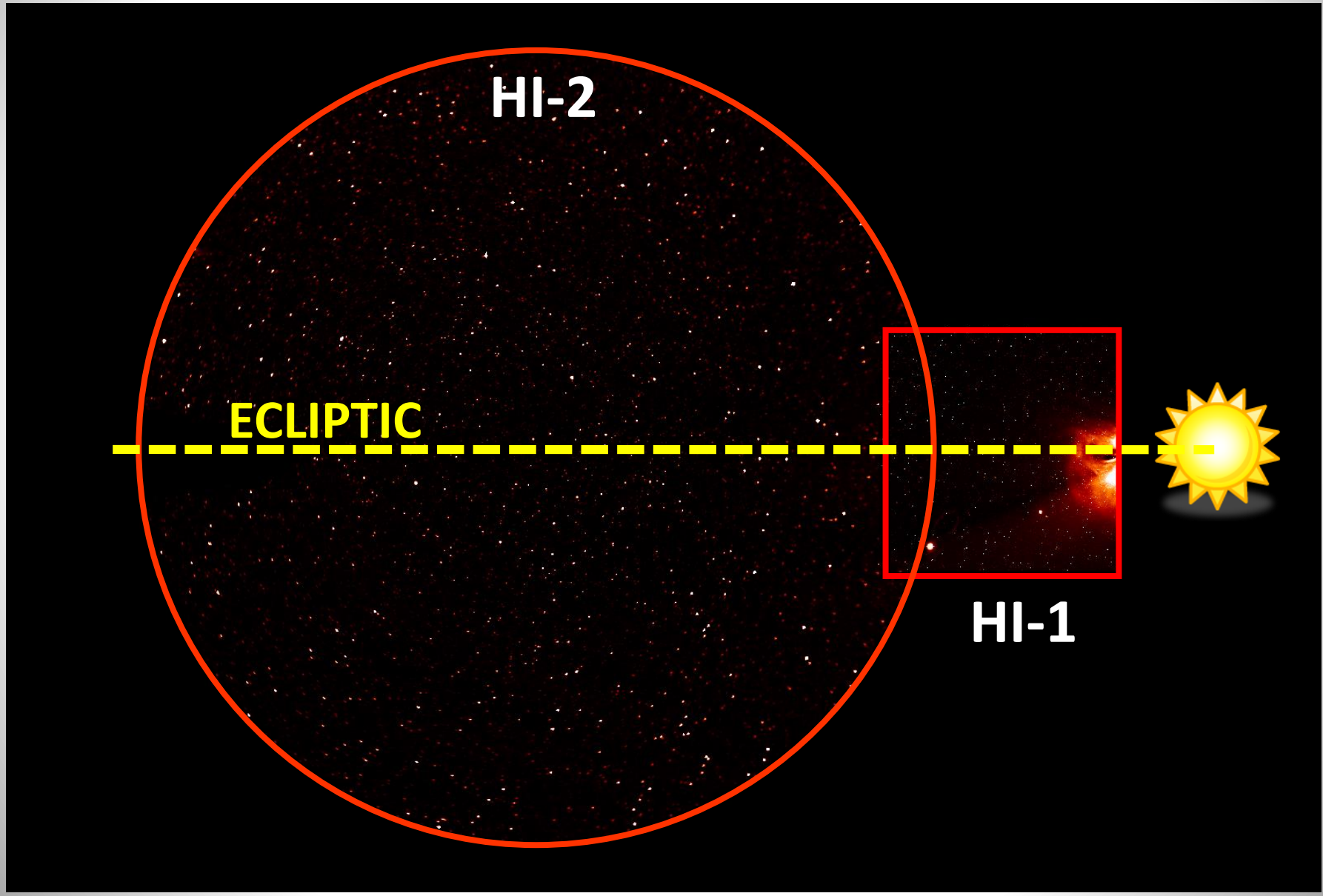


HI-1 image (STEREO-A) before background subtraction: mainly F-corona

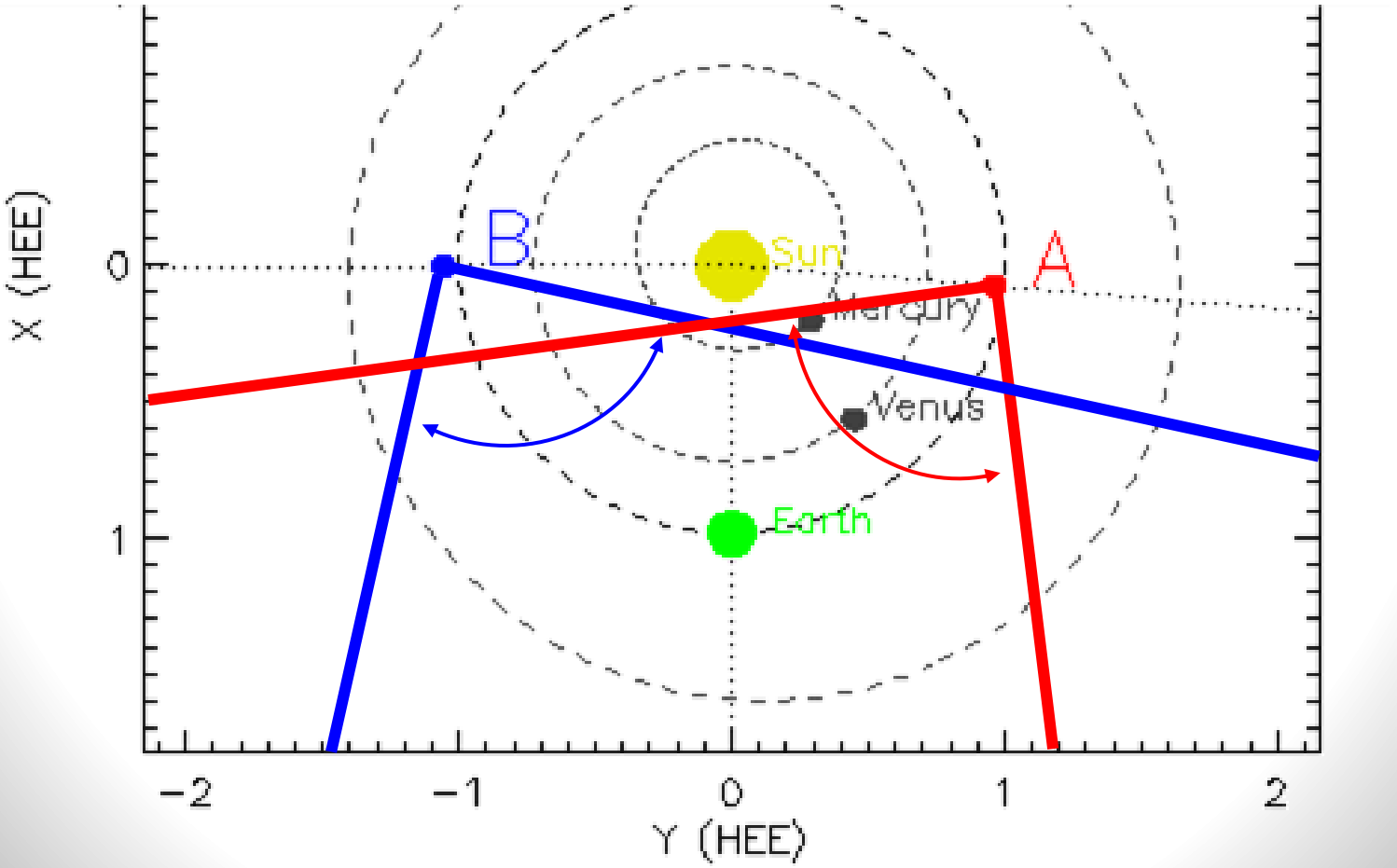


HI-1 image (STEREO-A) after background subtraction: mainly K-corona

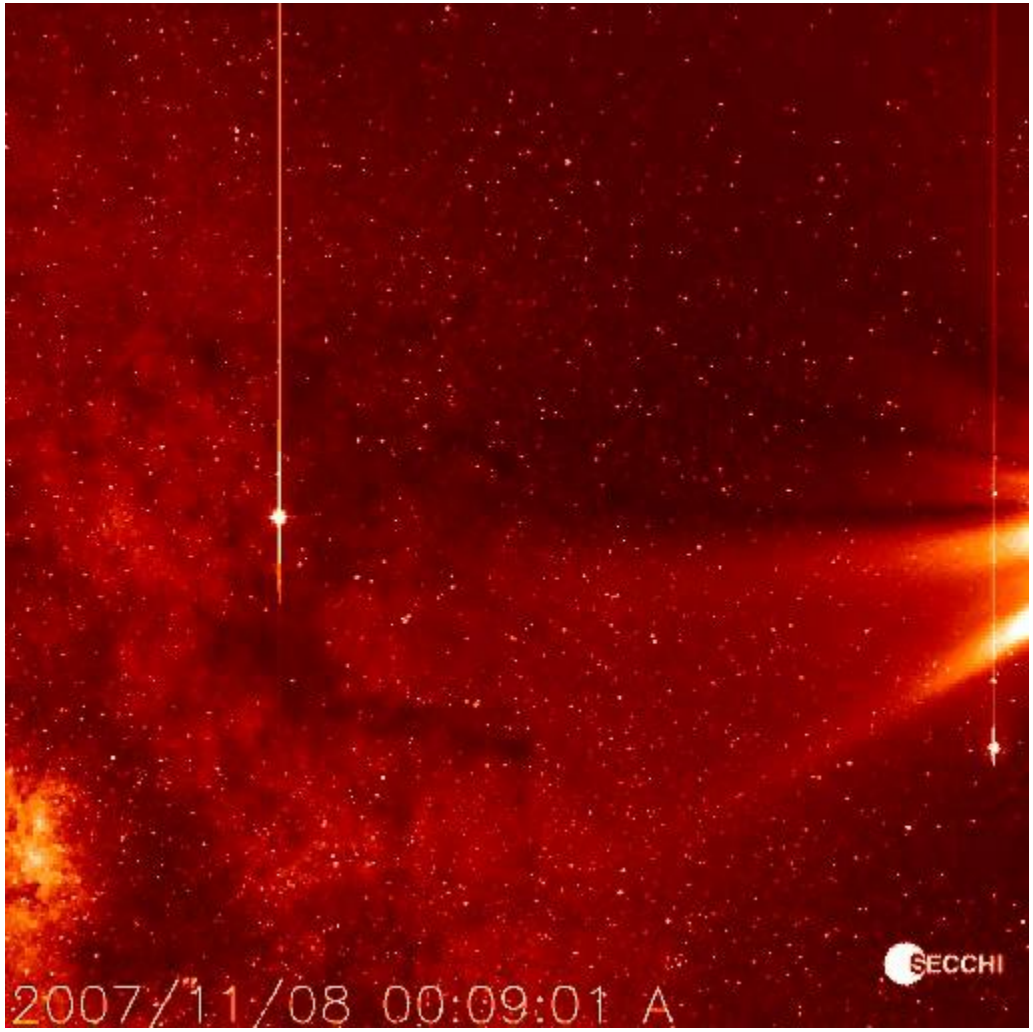
HI combined field of view



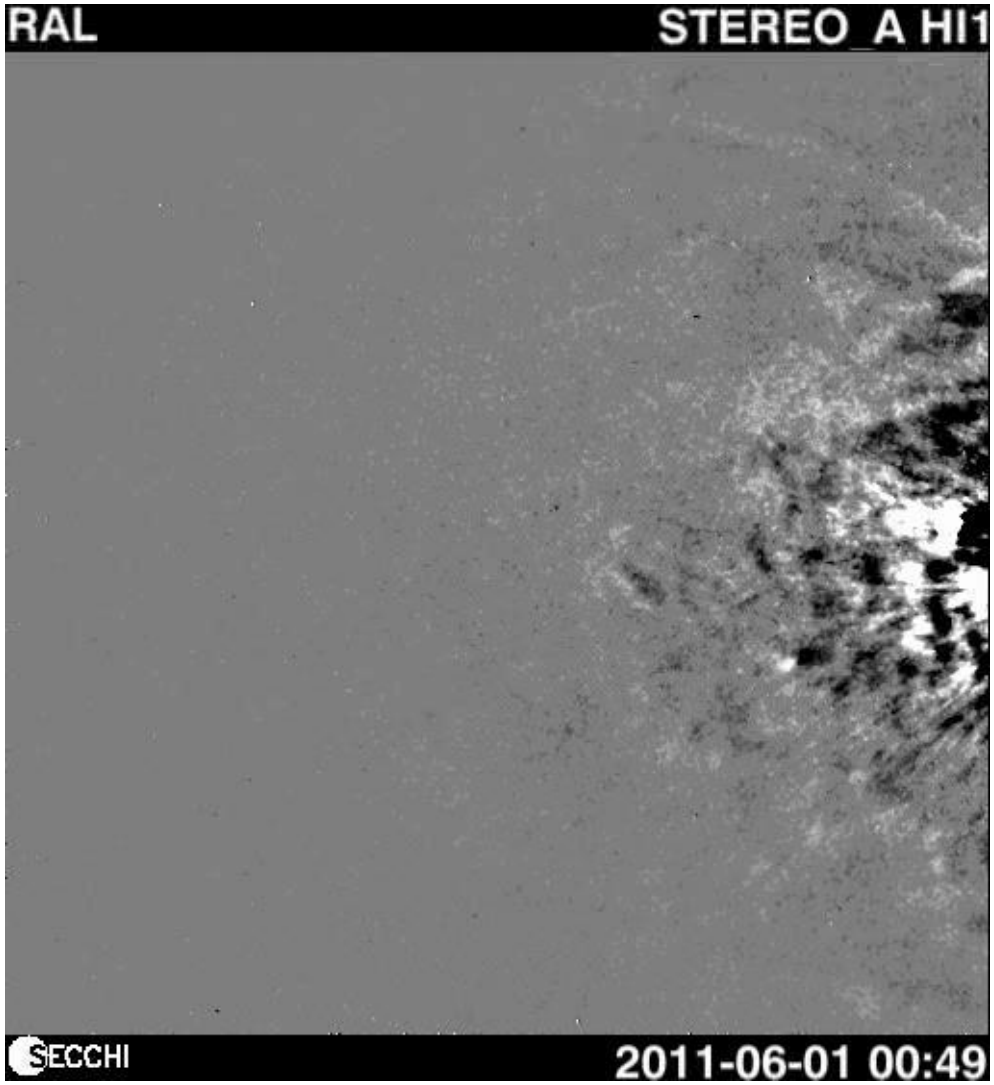
HI combined field of view in ecliptic plane (from above)



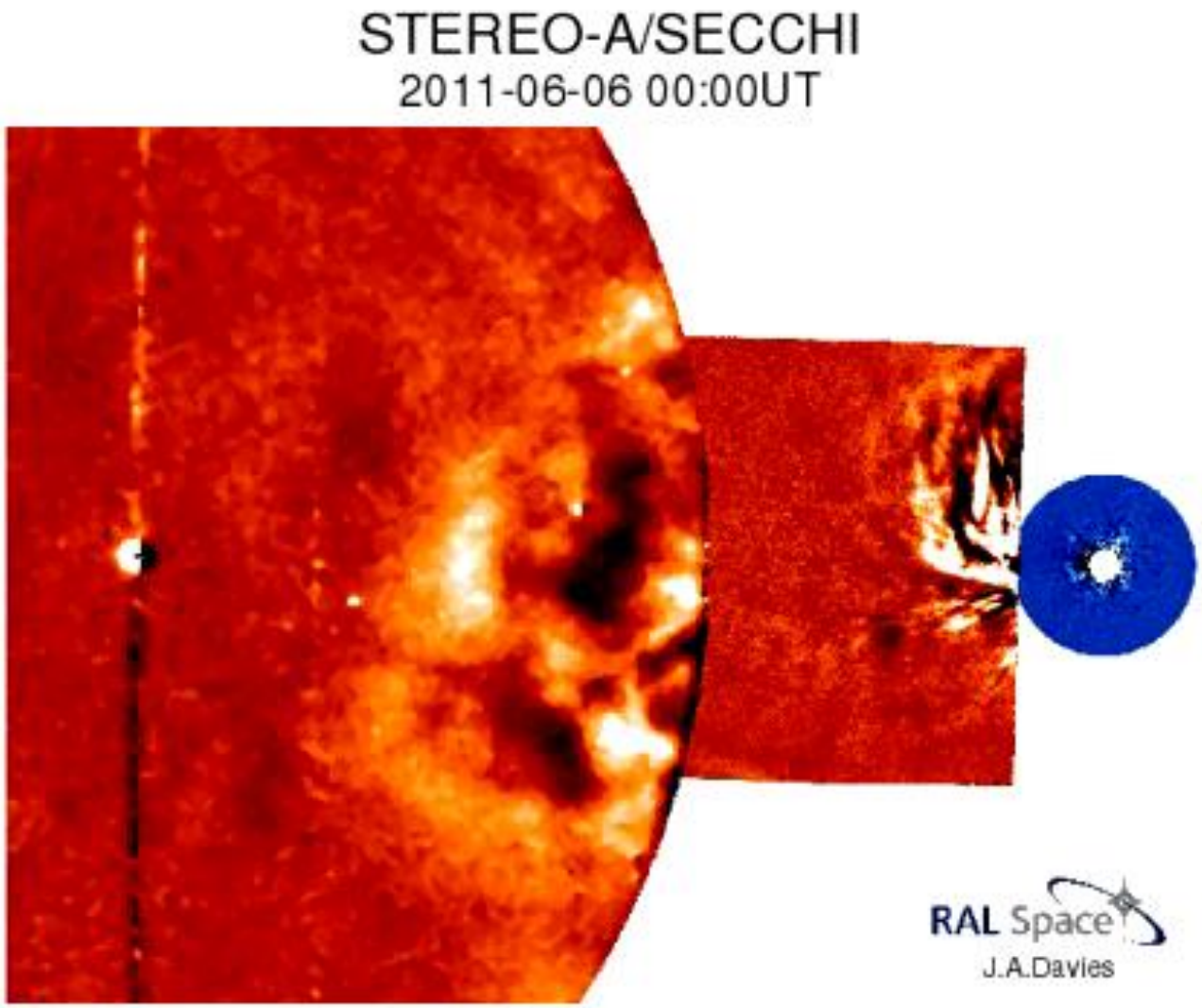
The quality of the data



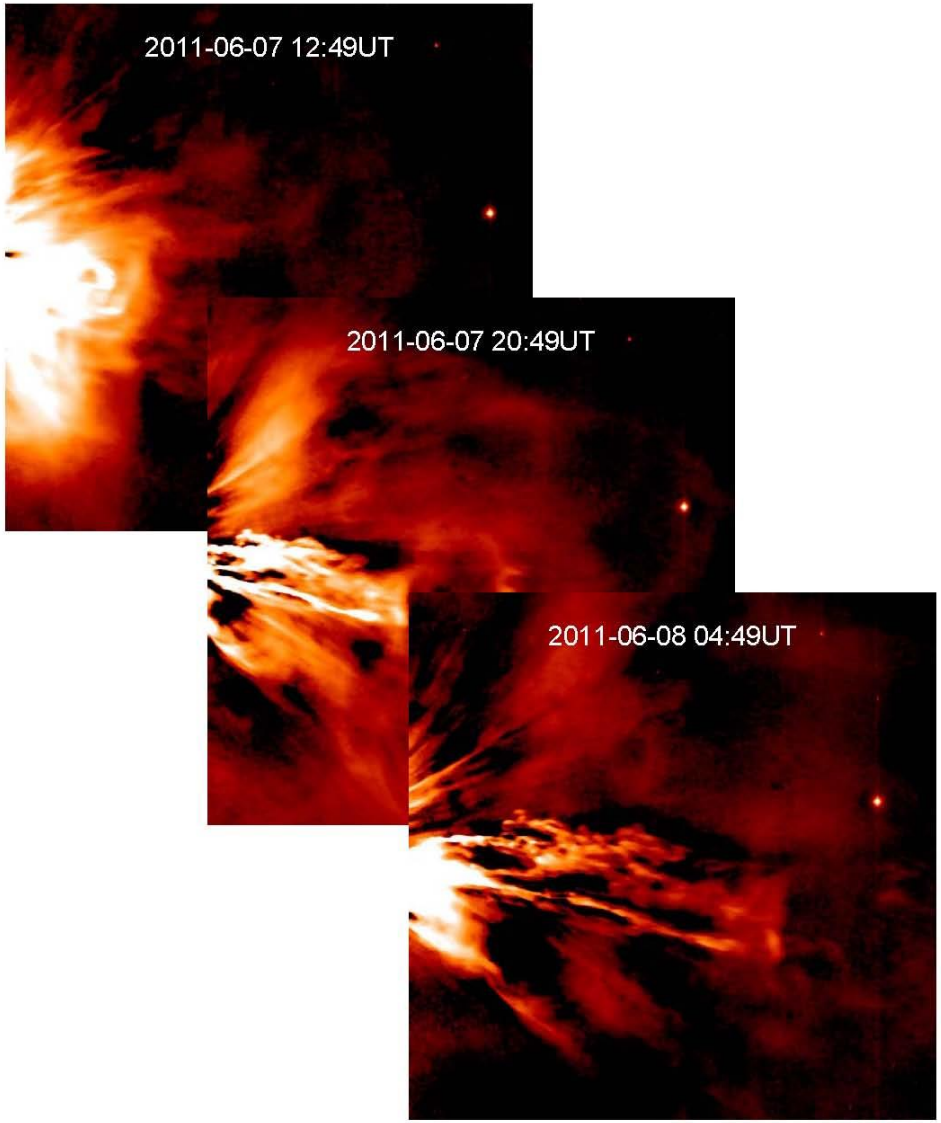
The complex inner heliosphere



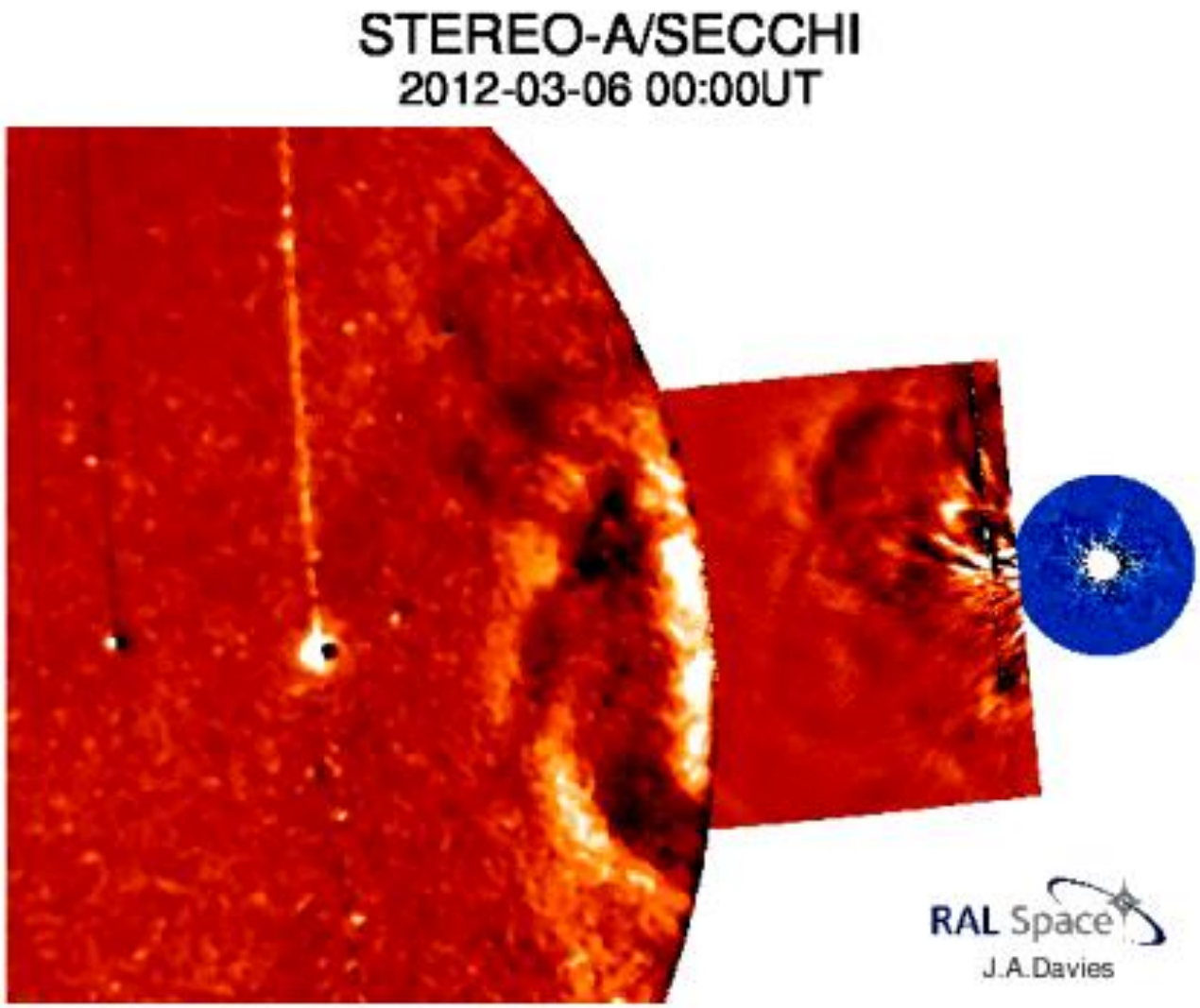
Coronal Mass Ejection



Coronal Mass Ejection

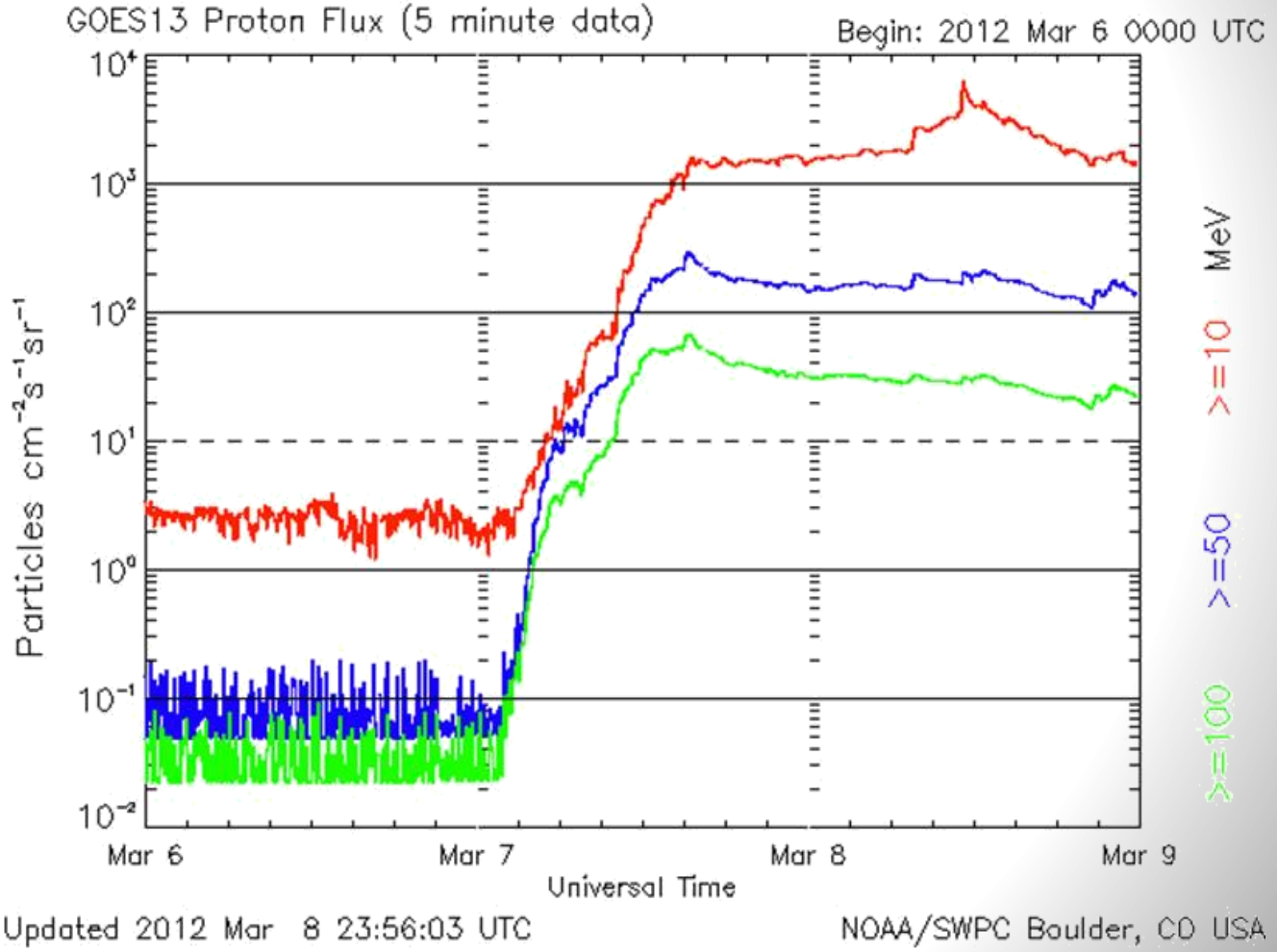


Earth-directed CME



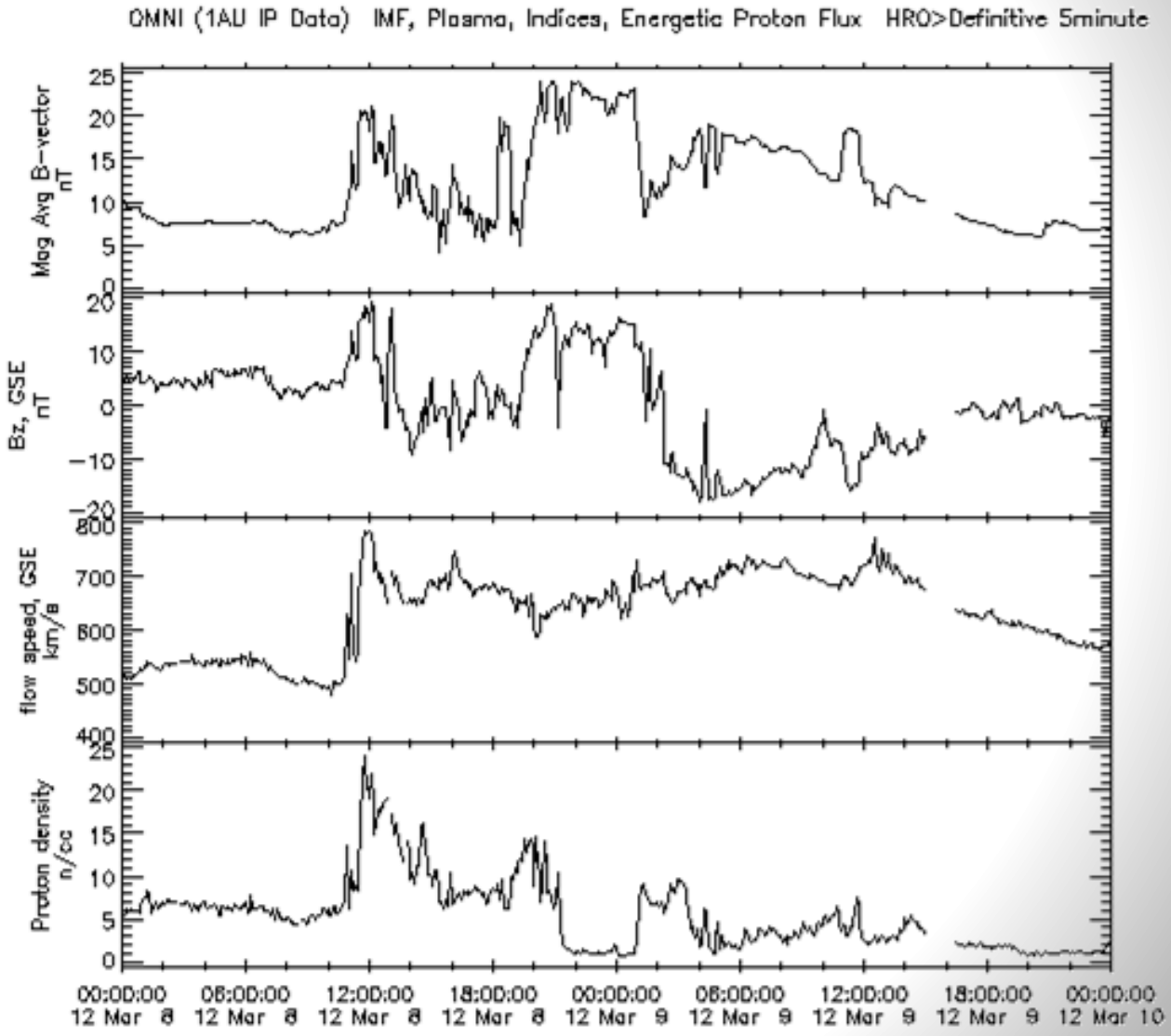
Earth-directed CME

100 MeV protons associated with the CME shock front start to arrive at Earth on 7th March (associated flare to east)



Earth-directed CME

CME arrival at the near-Earth (L1) Wind spacecraft on 8th March



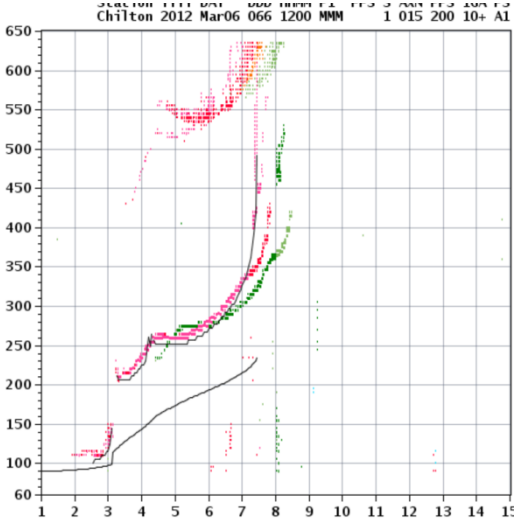
Earth-directed CME

Aurora viewed from Iceland on 8th March

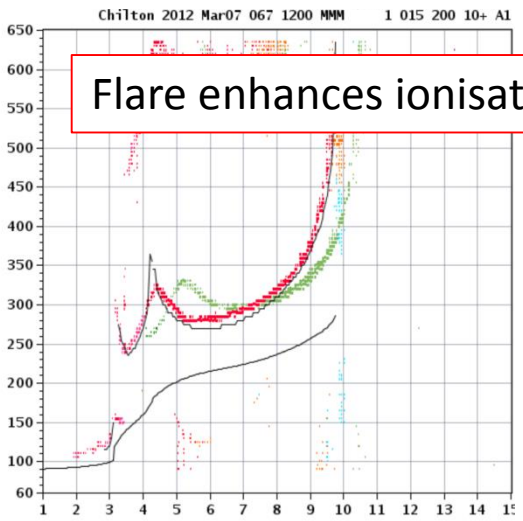
Earth-directed CME

Ionosphere above RAL: Chilton Ionosonde

Noon March 6 2012

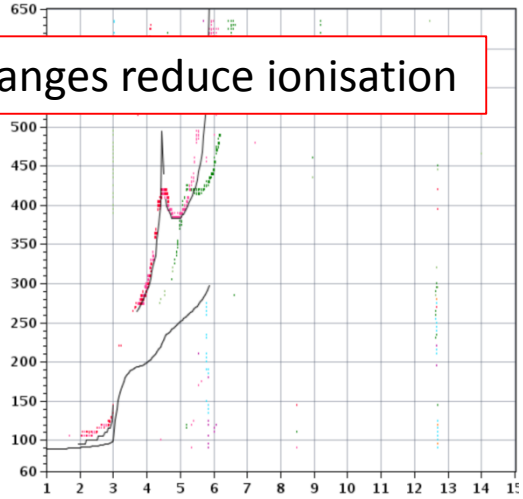


Noon March 7 2012



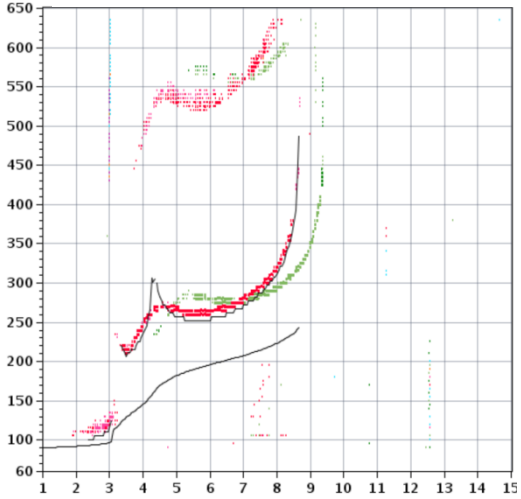
Flare enhances ionisation

Noon March 9 2012

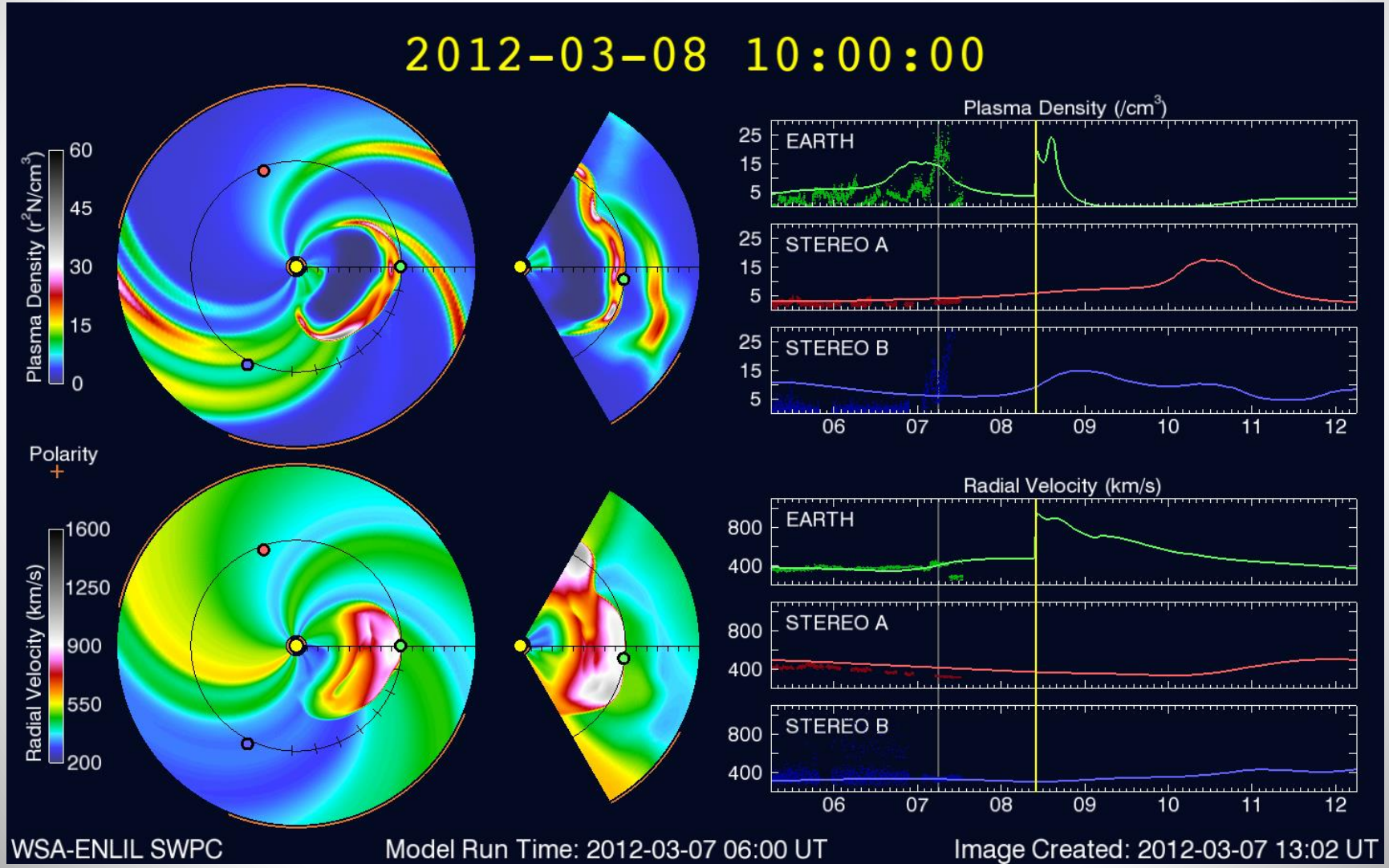


Composition changes reduce ionisation

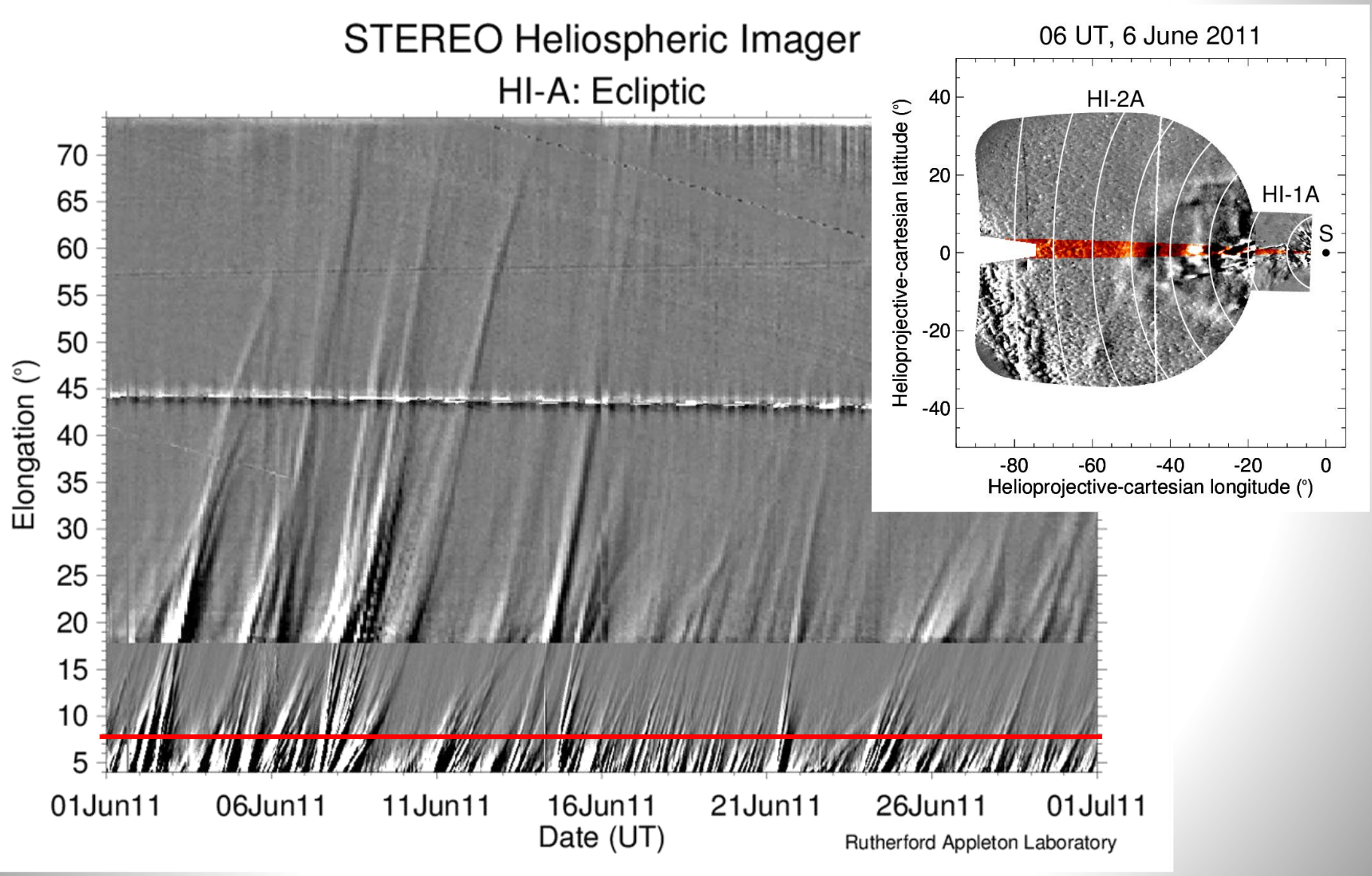
Noon March 10 2012



MHD model prediction (using ENLIL)

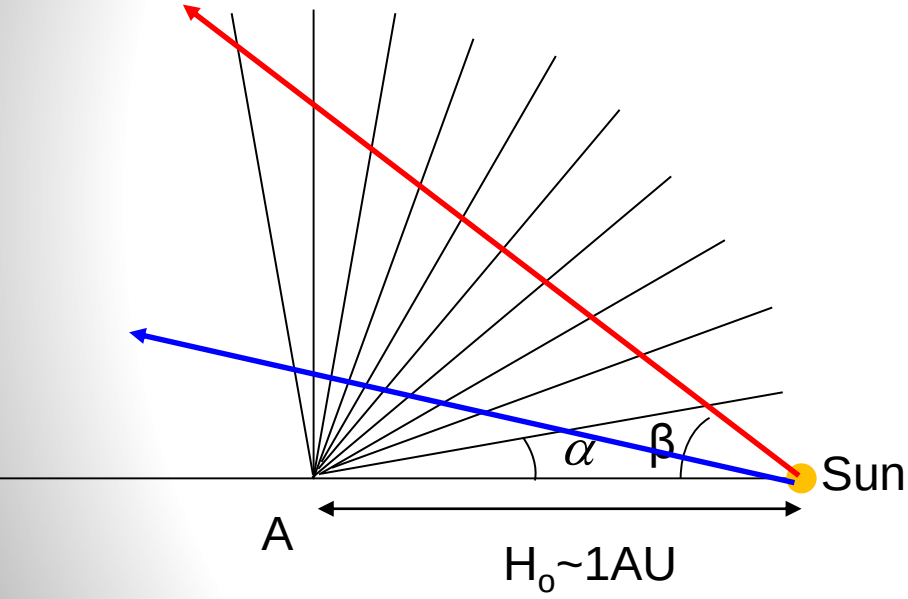


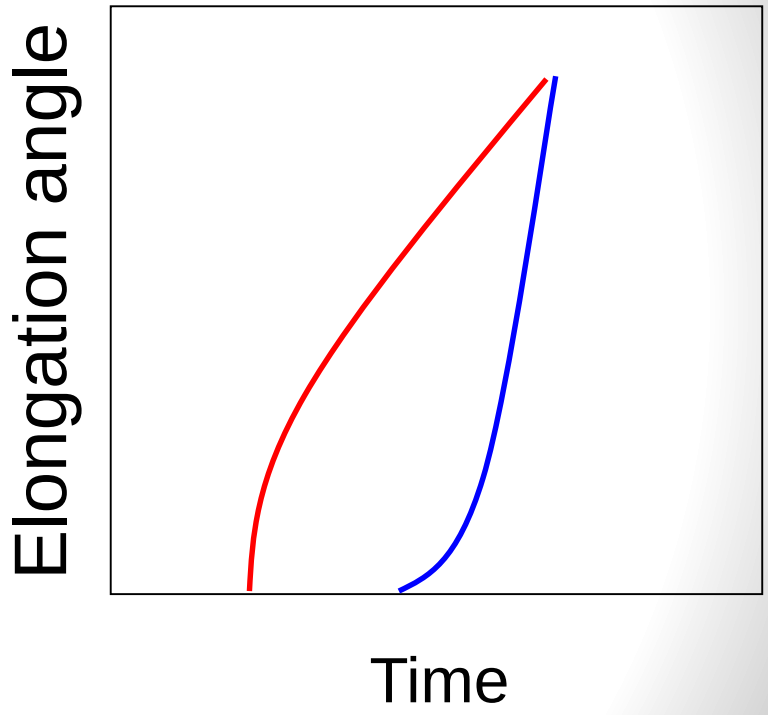
CME* geometrical modelling



CME* geometrical modelling

Apparent Acceleration at large elongations



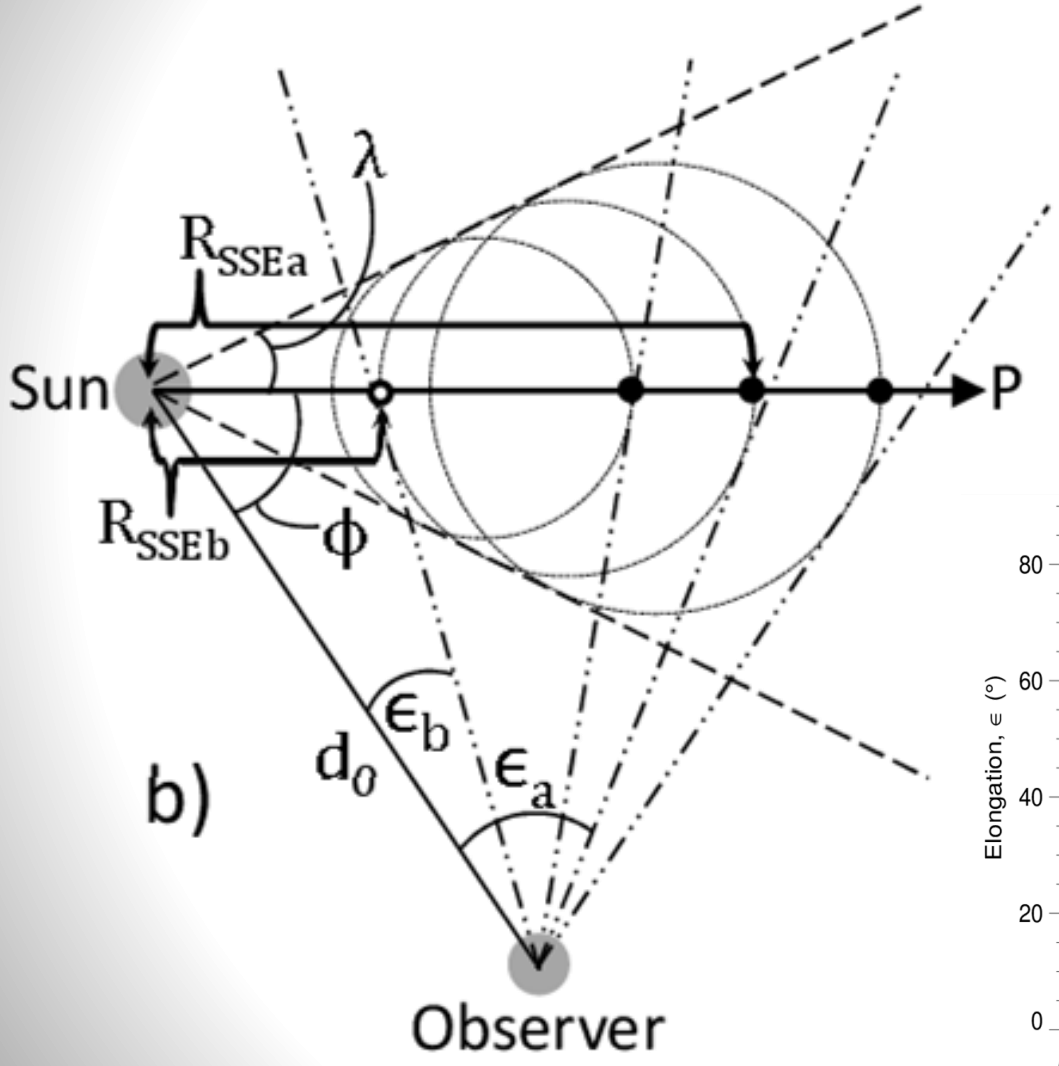


Assuming the CME propagates radially at a constant speed;

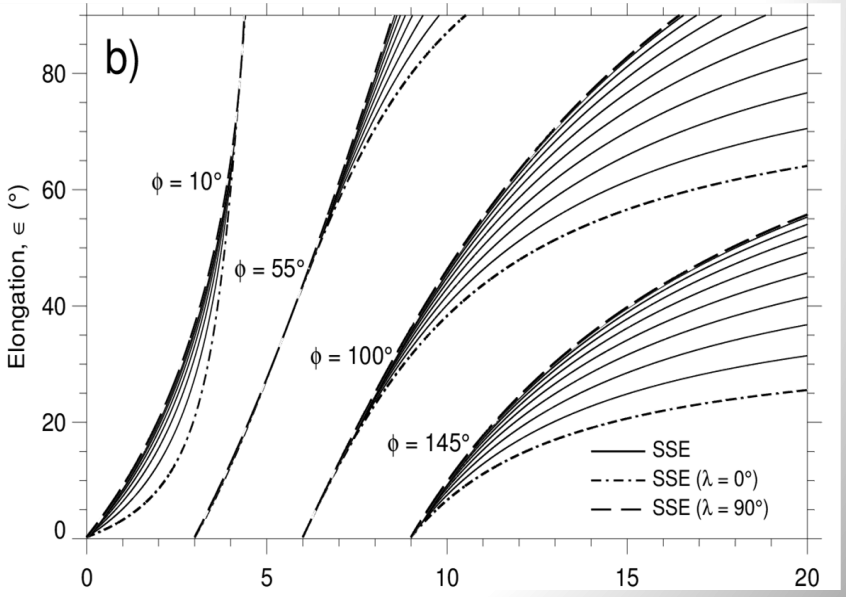
$$\alpha(t) = \arctan\left[\frac{vt\sin(\beta)}{H_o - vt\cos(\beta)}\right]$$

(Sheeley et al., JGR,1999)

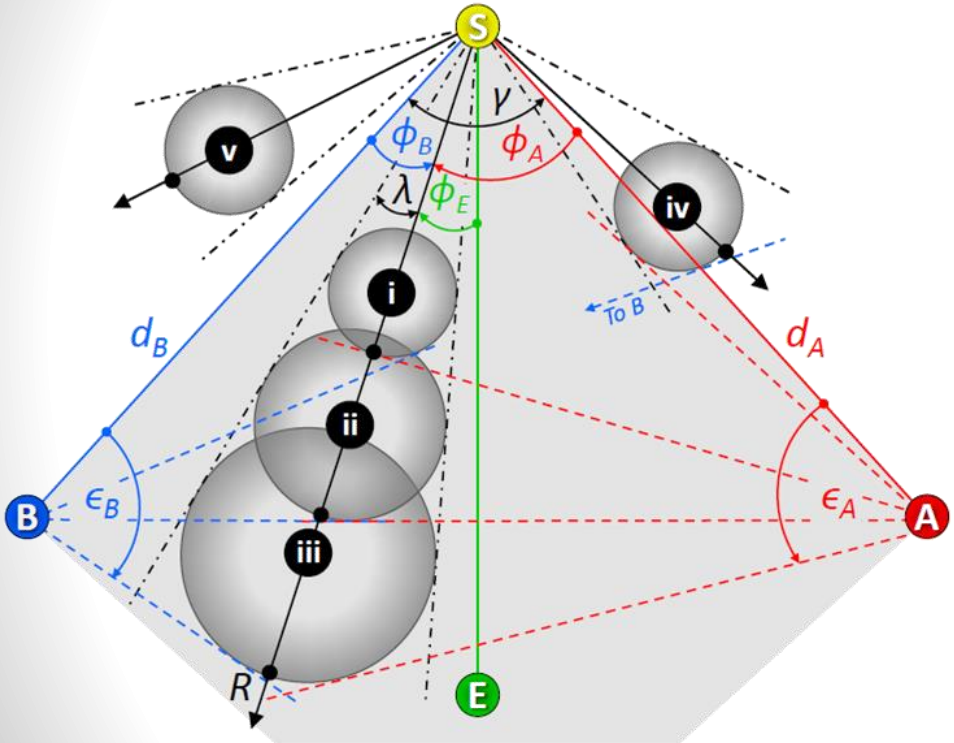
CME* geometrical modelling

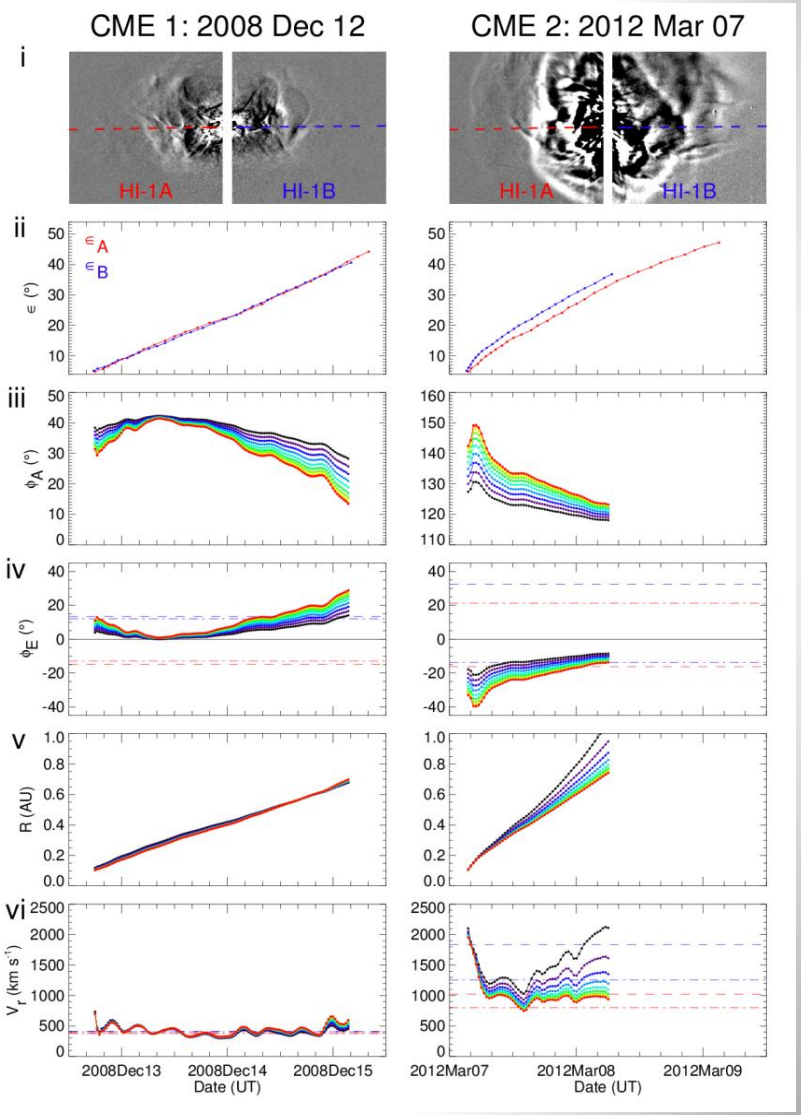


Davies et al., 2009, GRL 36, L02102
Davies et al., 2012, ApJ 750, 23



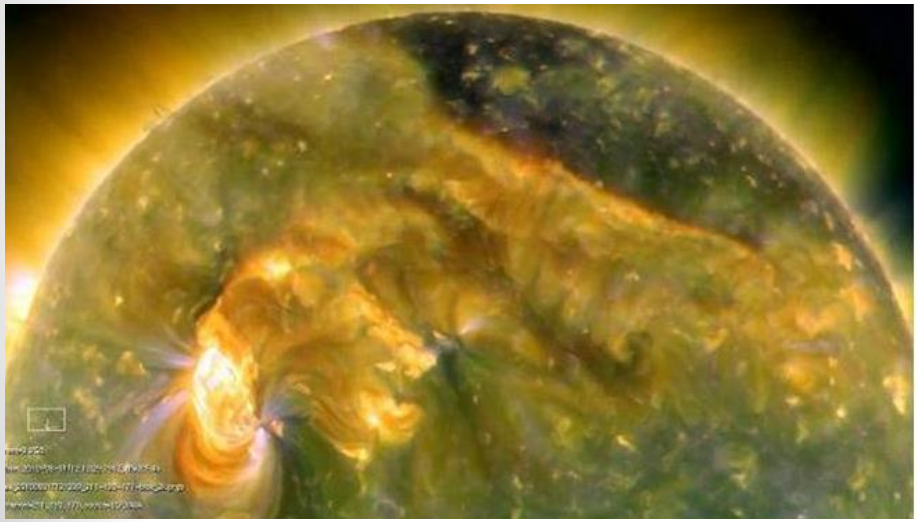
CME* geometrical modelling

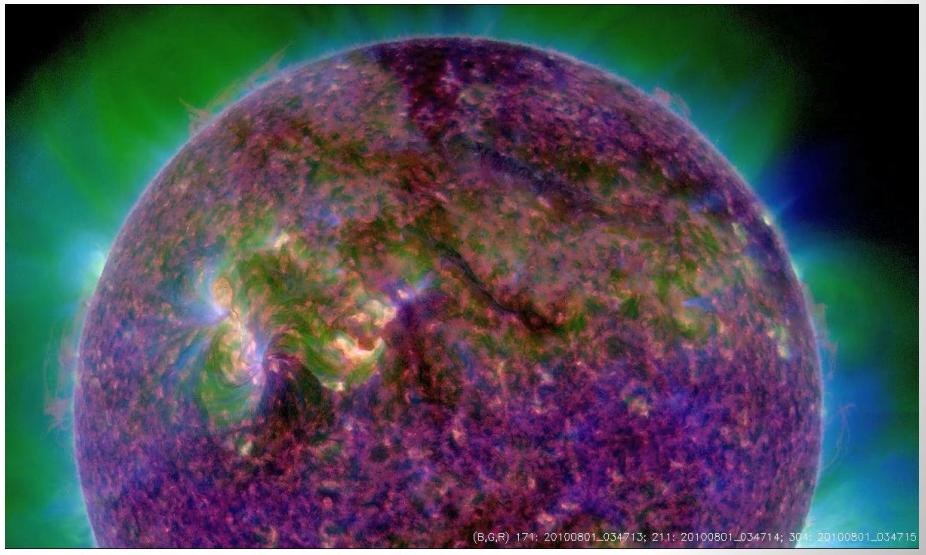




Davies et al., 2013, ApJ in press

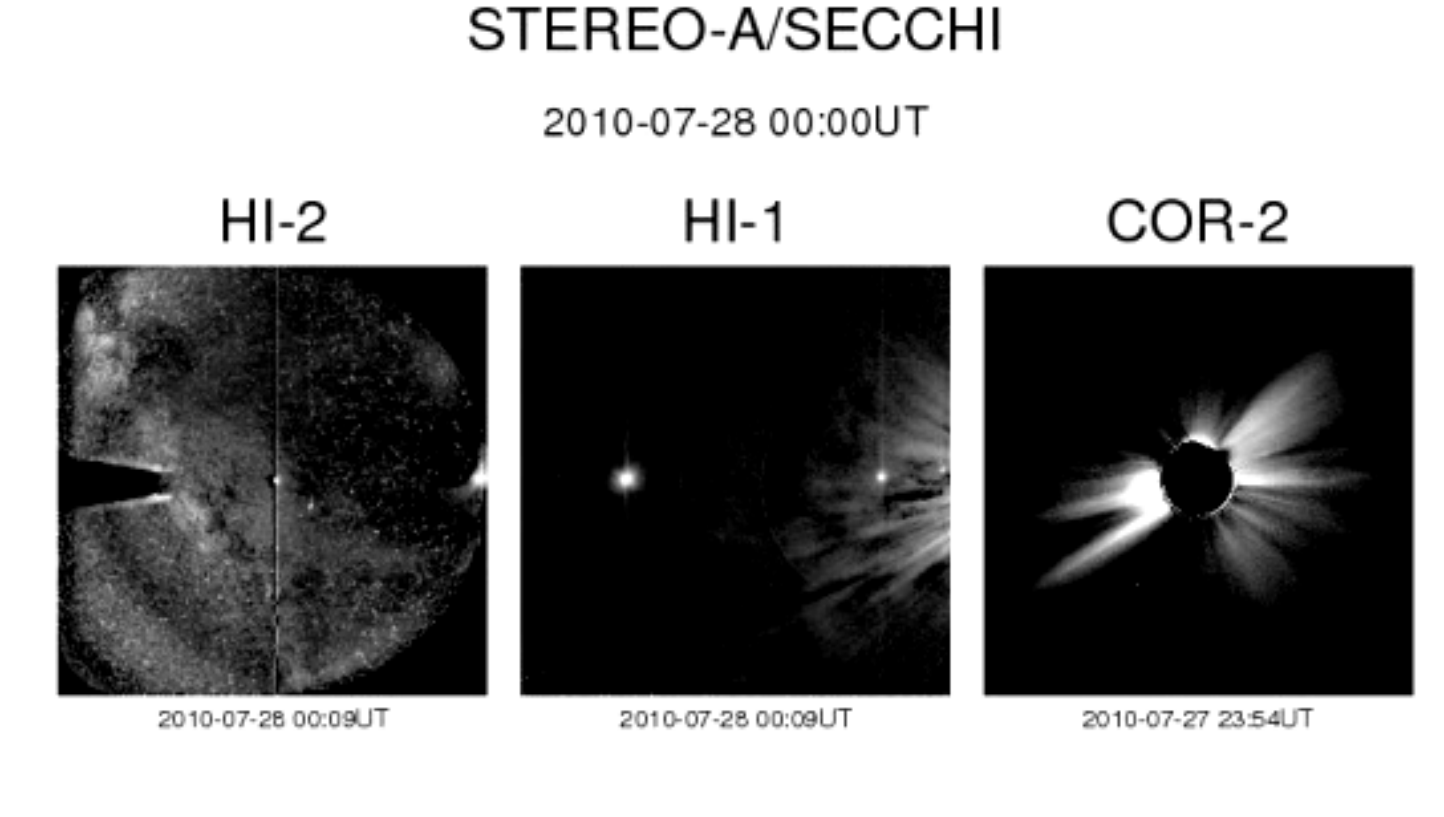
Sequence of Earth-directed CMEs (August 2010)



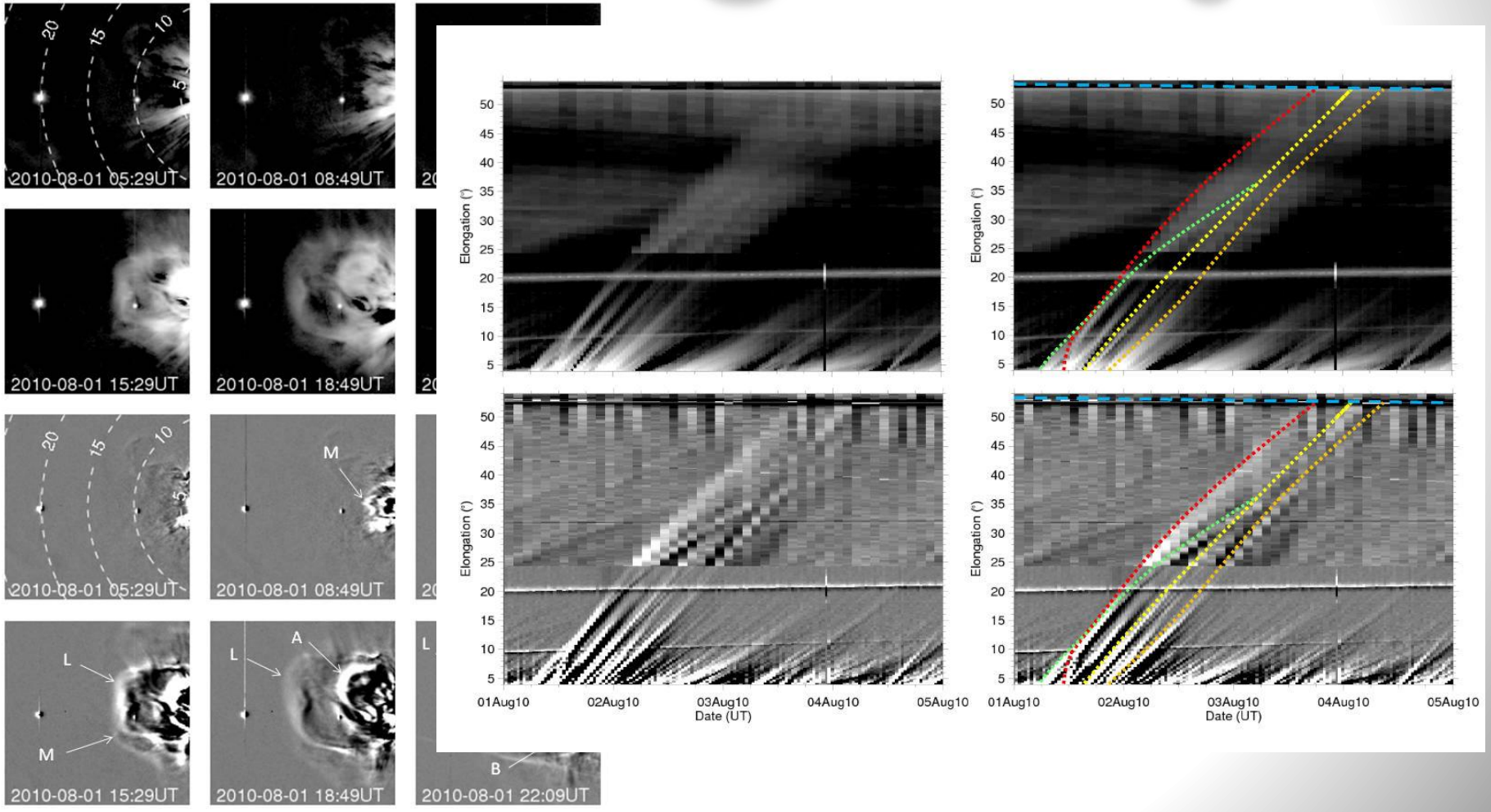


Harrison et al., 2012, ApJ 750, 45

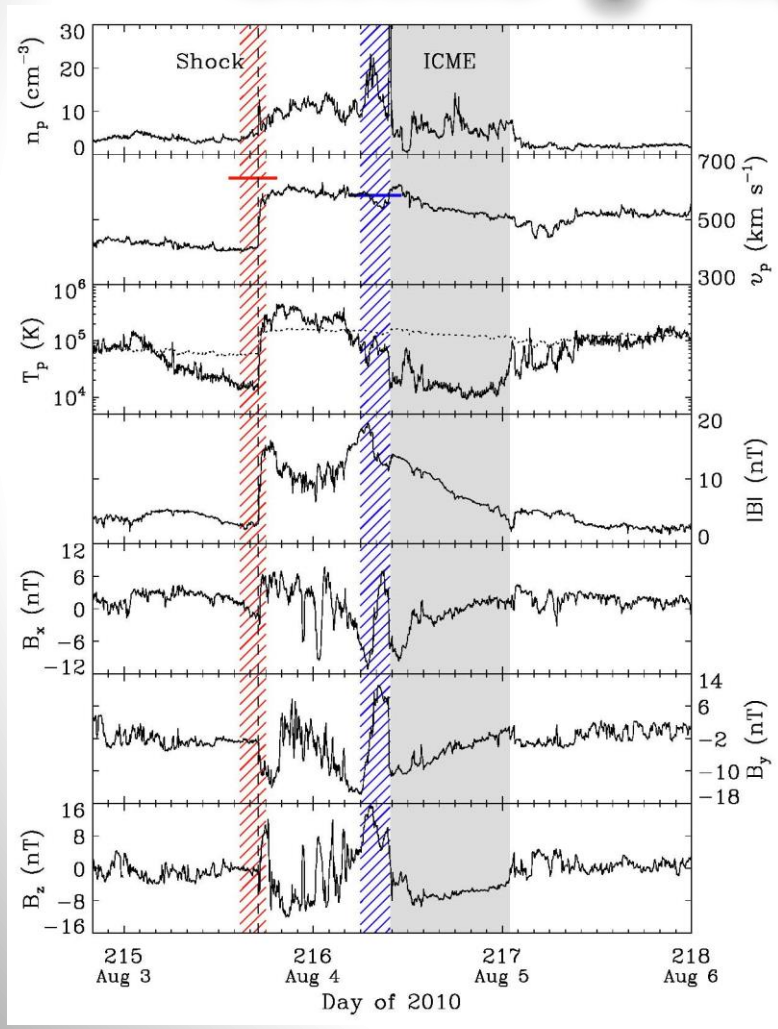
Sequence of Earth-directed CMEs (August 2010)



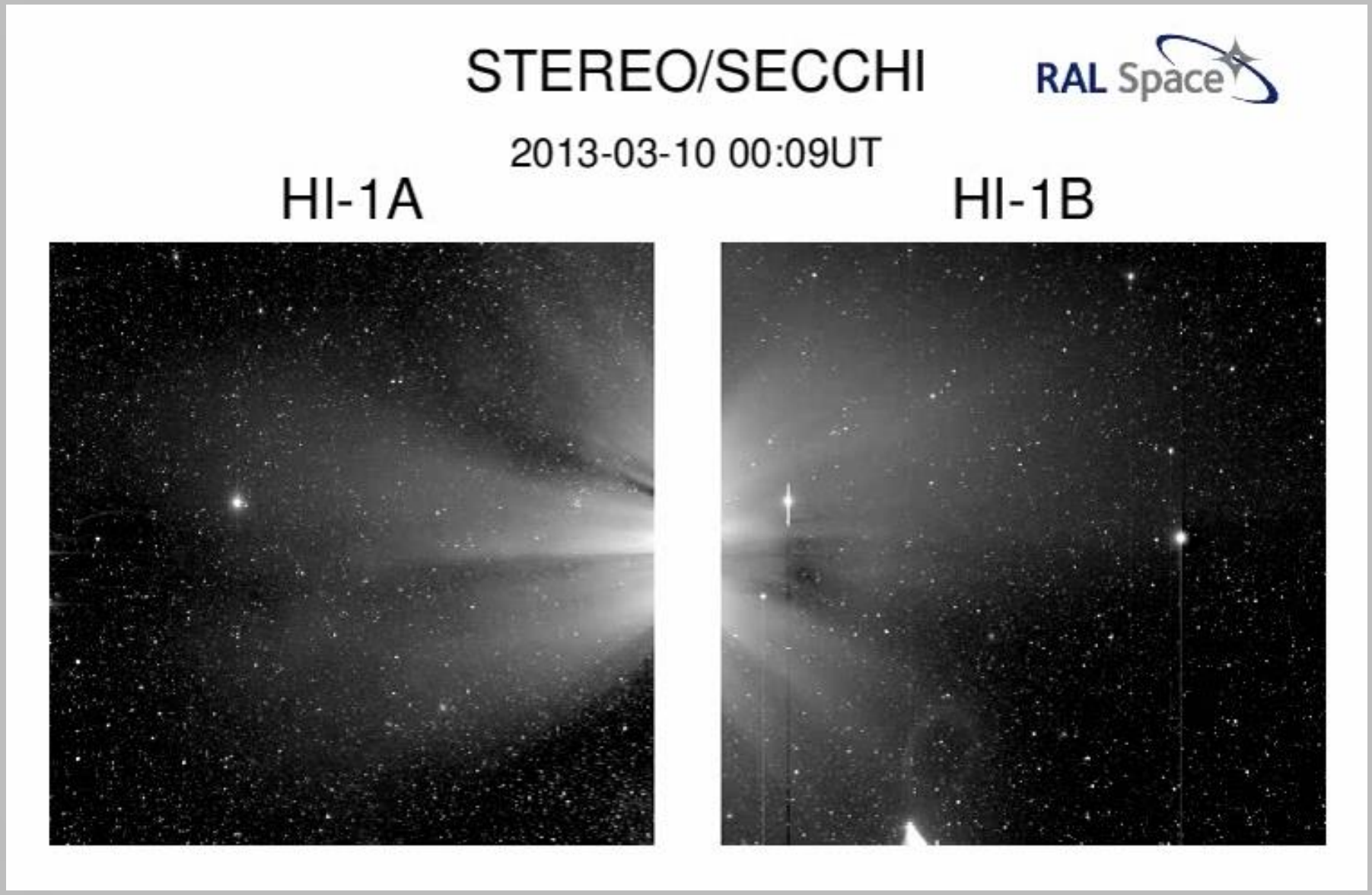
Sequence of Earth-directed CMEs (August 2010)



Sequence of Earth-directed CMEs (August 2010)



St. Patricks's day storm & Comet PanSTARRS

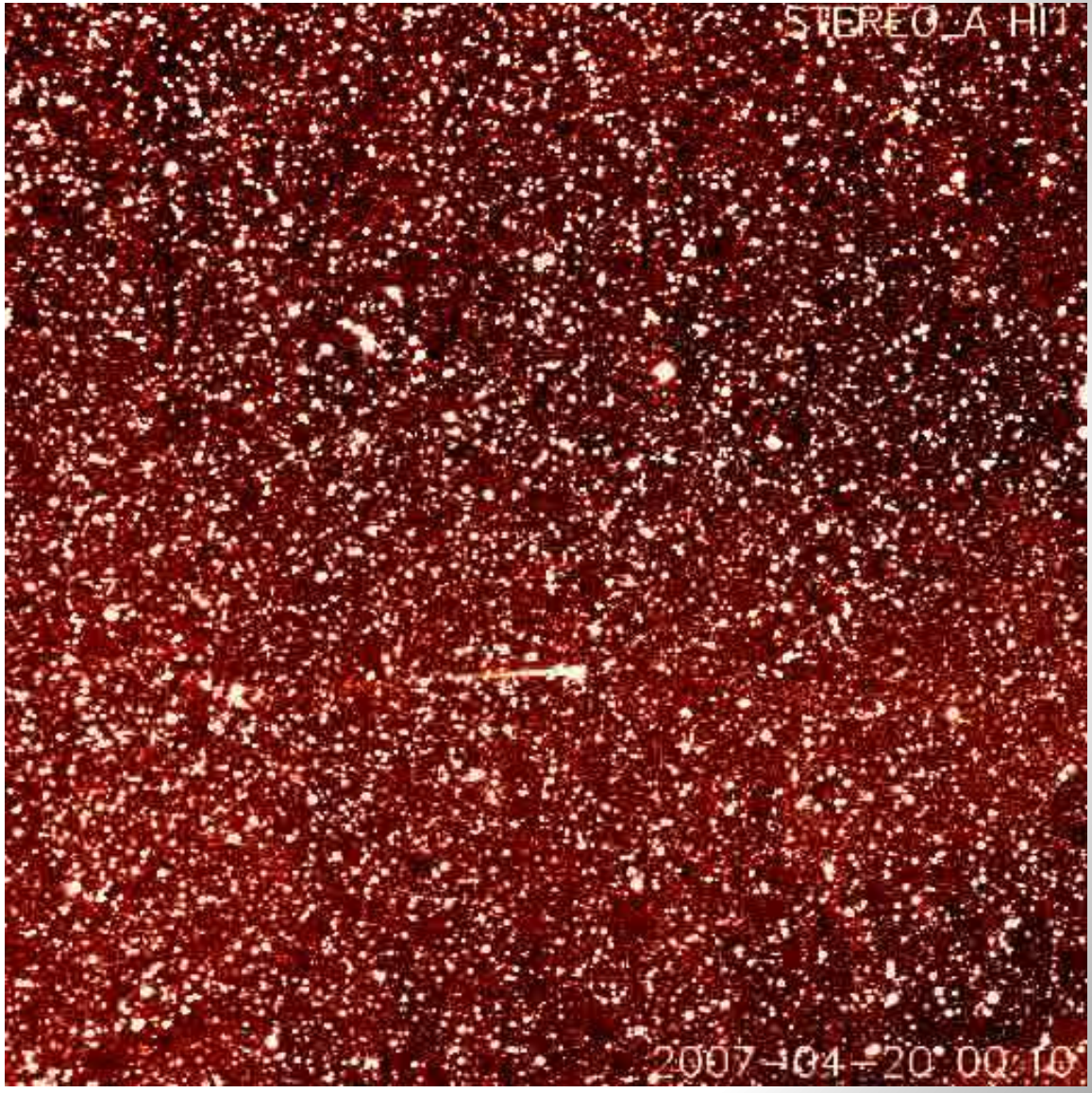


Comet Encke: tail disconnection event

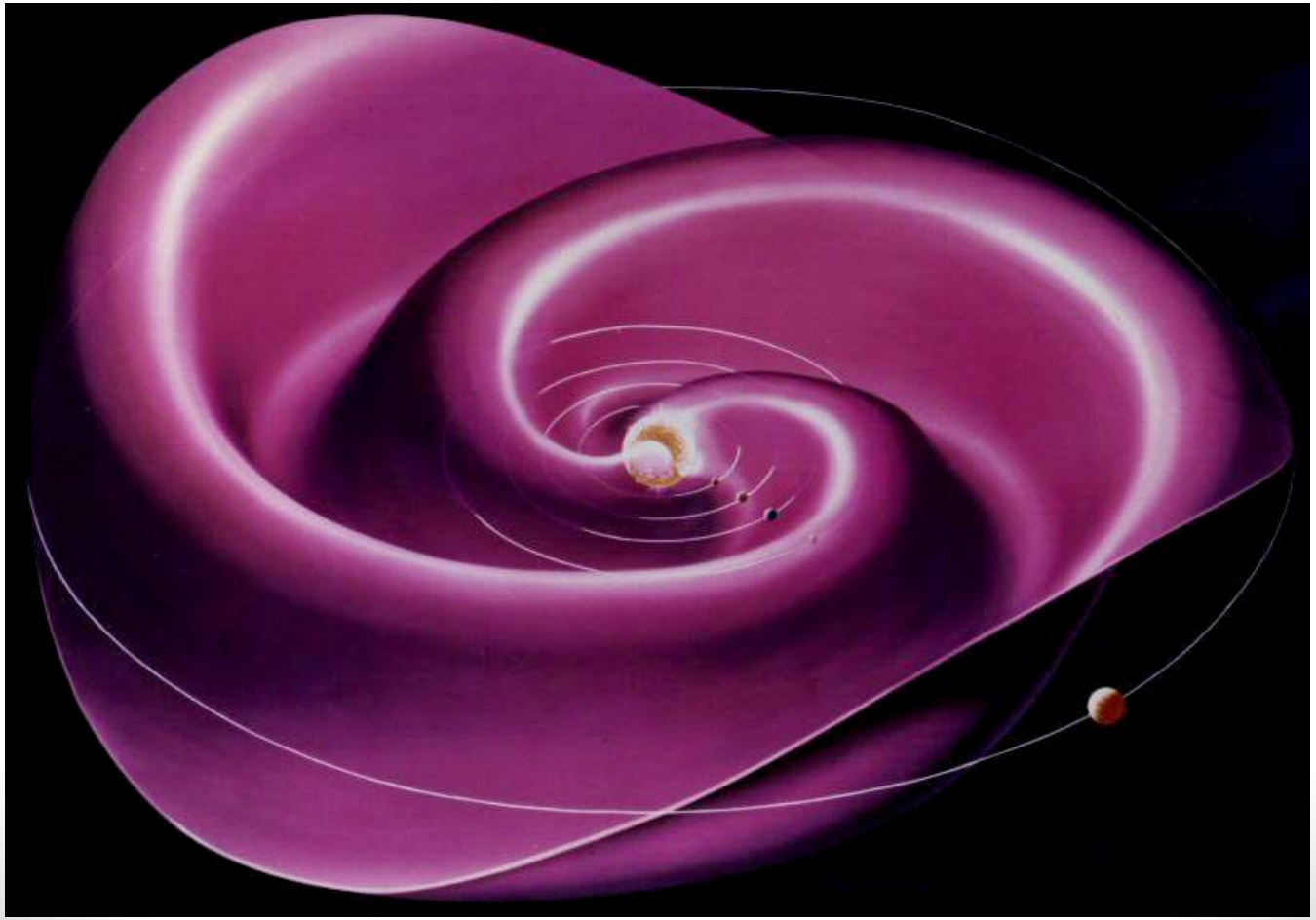
Period: 3.3 years

Perihelion distance: 0.338 AU

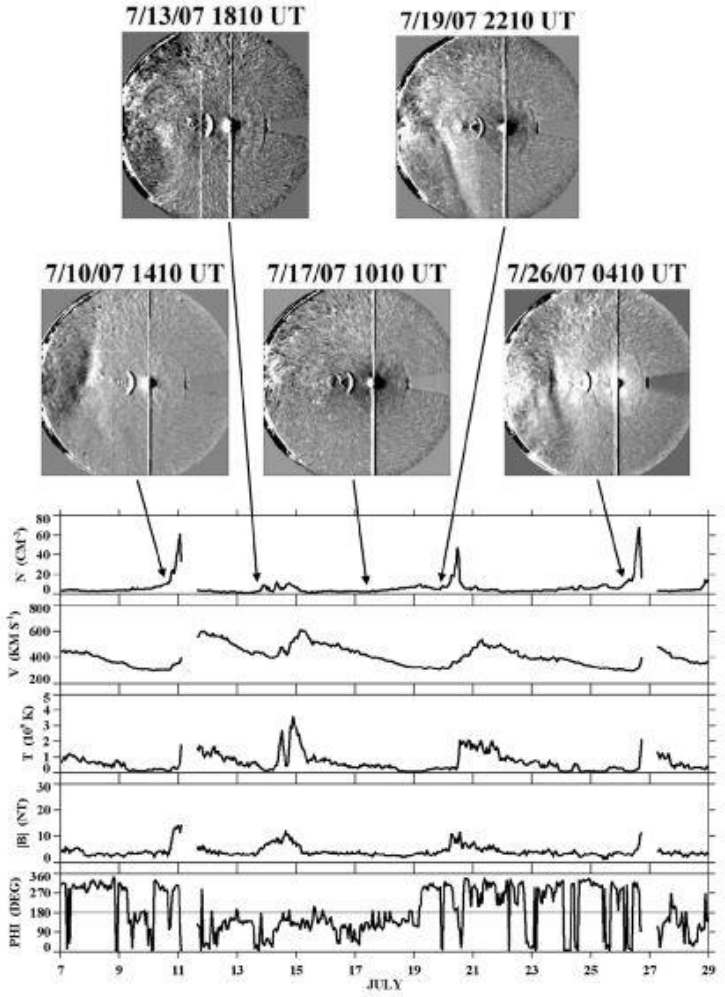
20th April 2007: tail 'disconnection' event



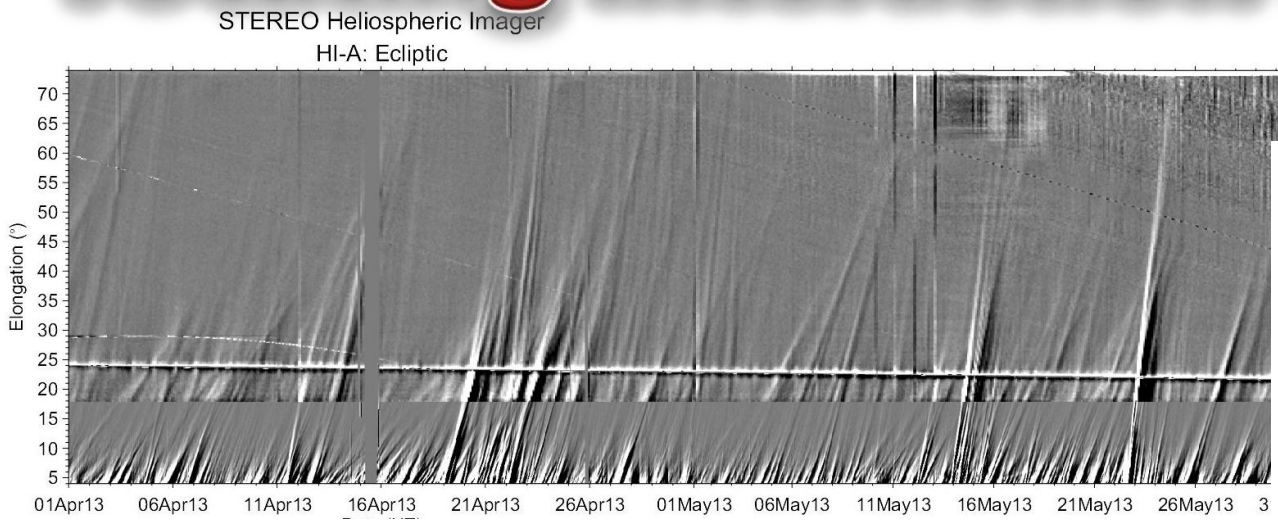
Remote sensing the co-rotating interaction regions

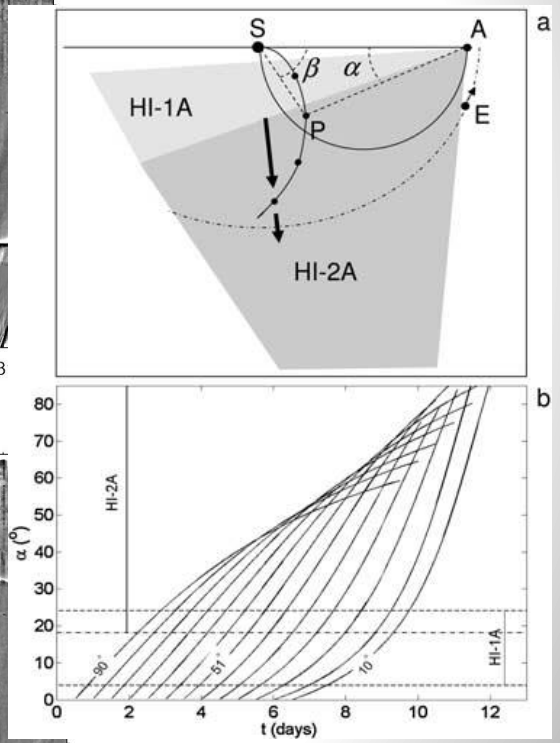


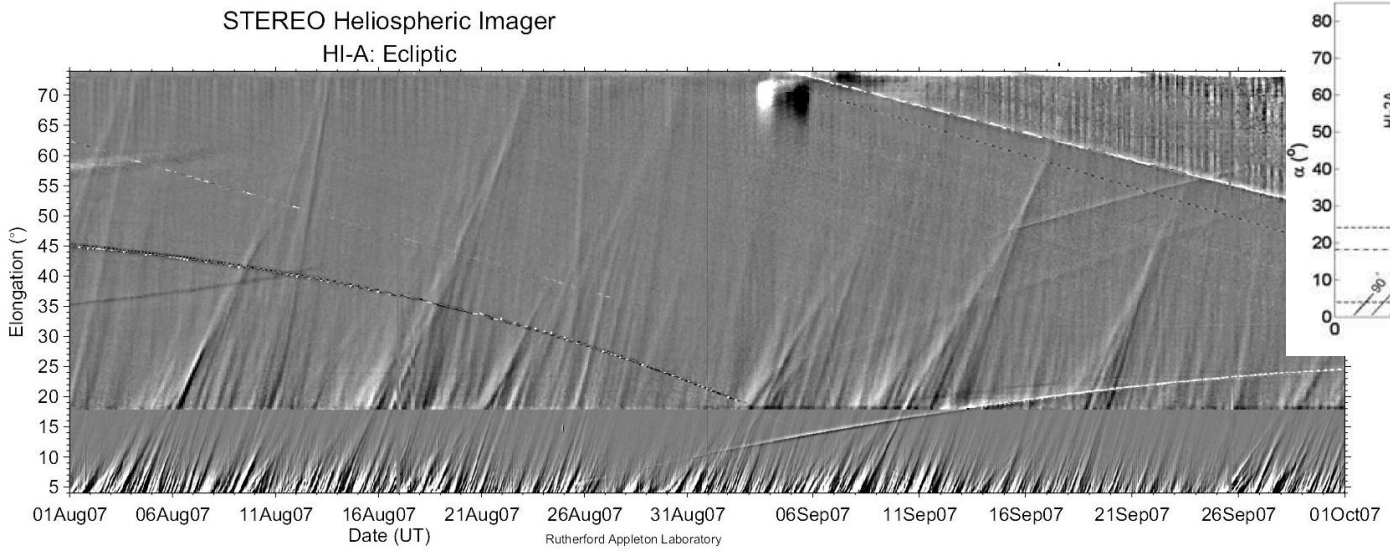
Remote sensing the co-rotating interaction regions



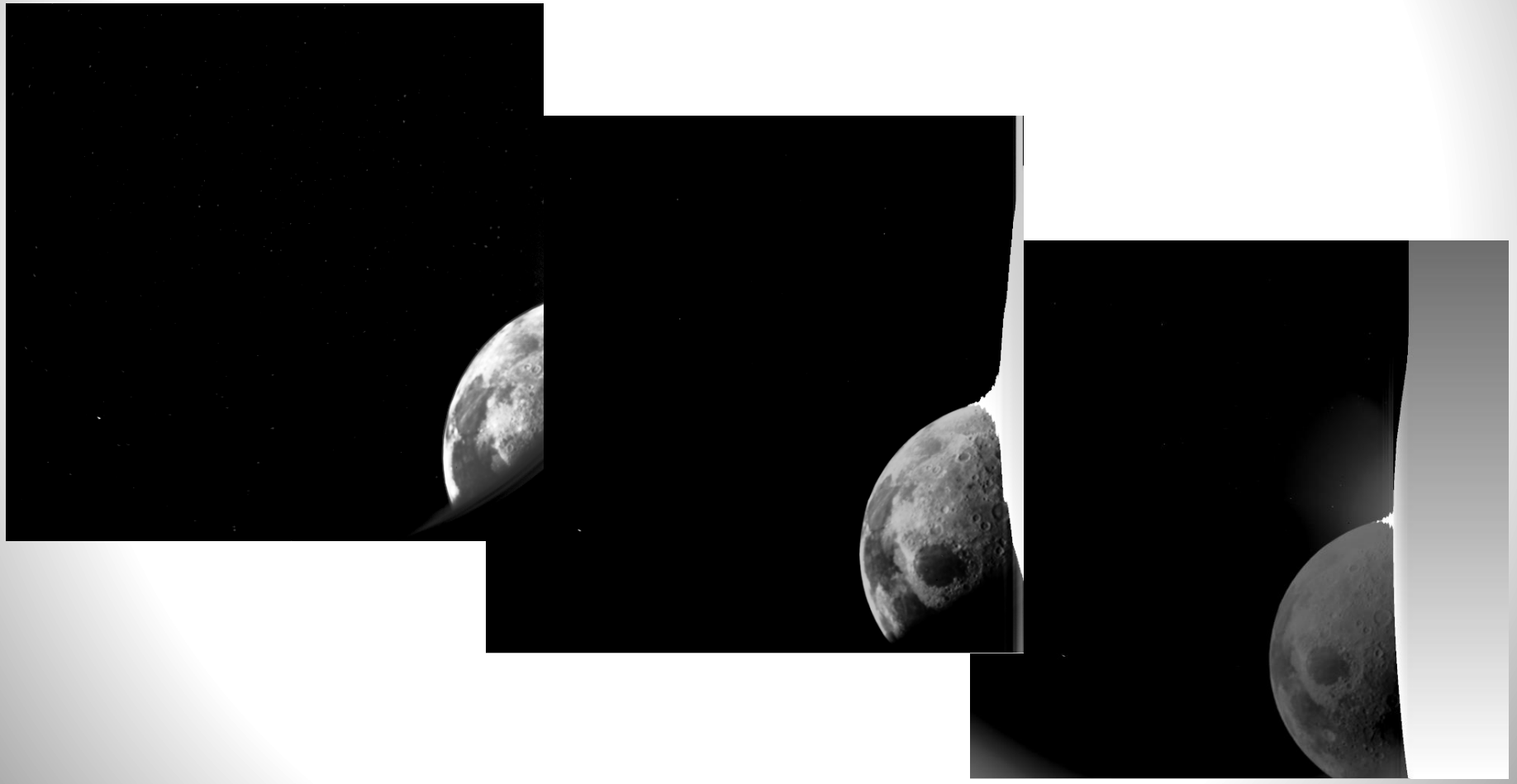
Remote sensing the co-rotating interaction regions



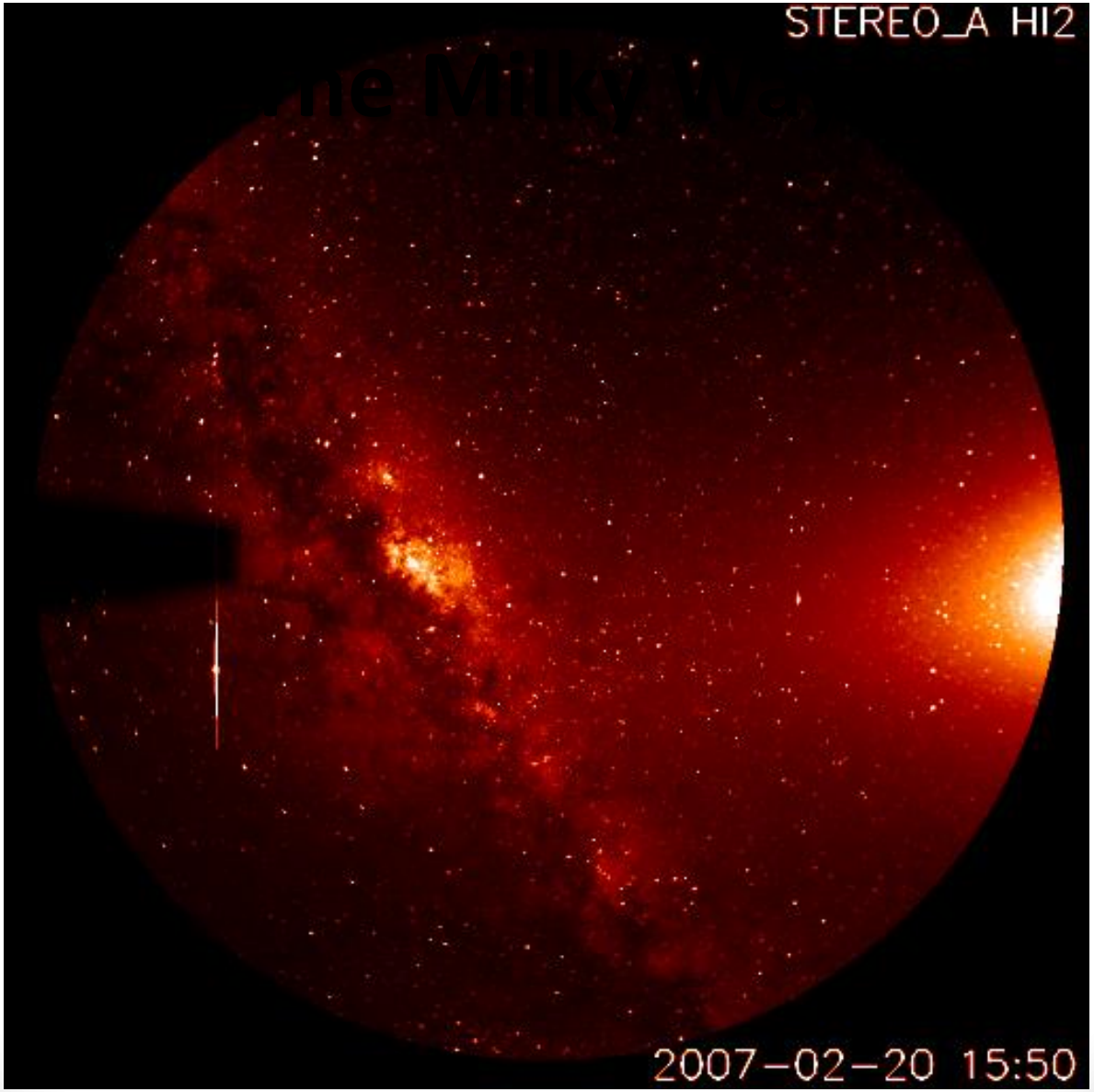




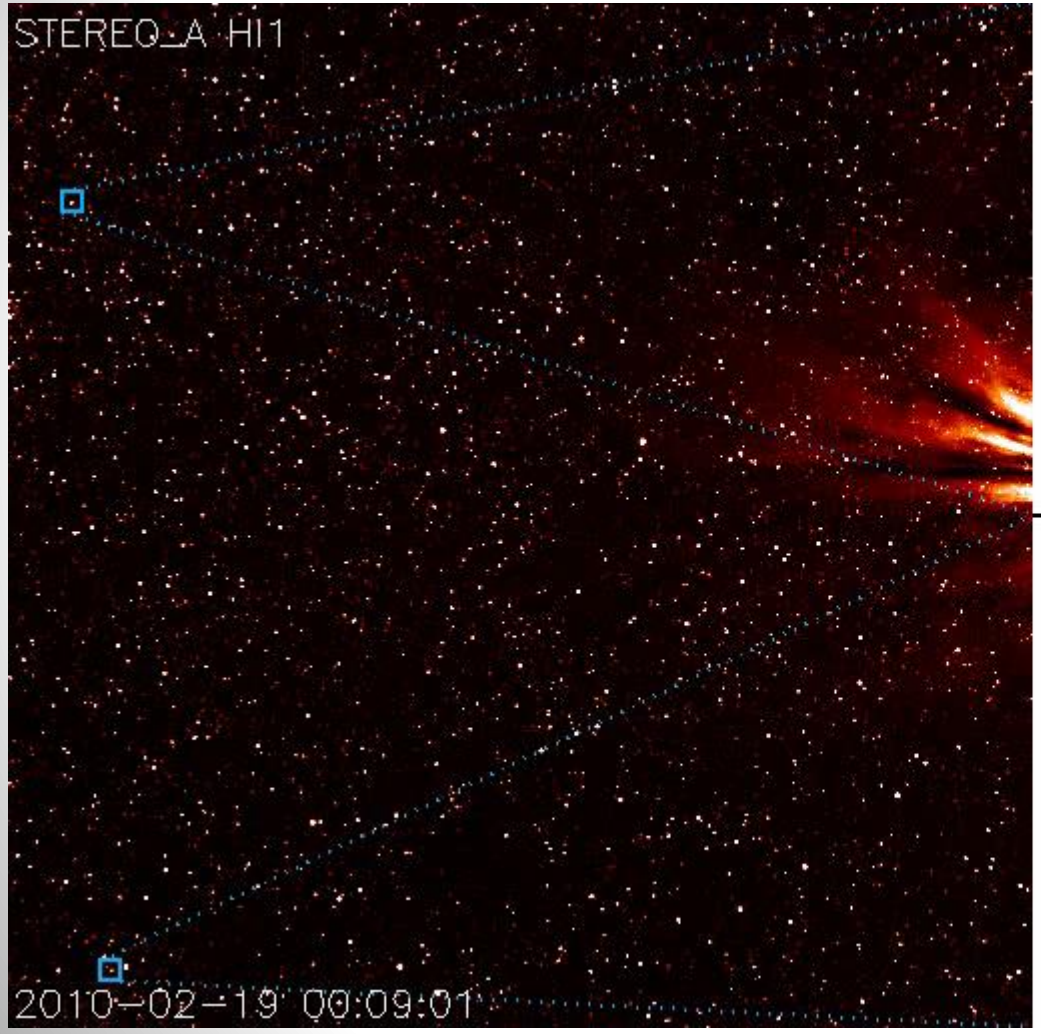
Dark side of the Moon, imaged during lunar swingby, by STEREO-B

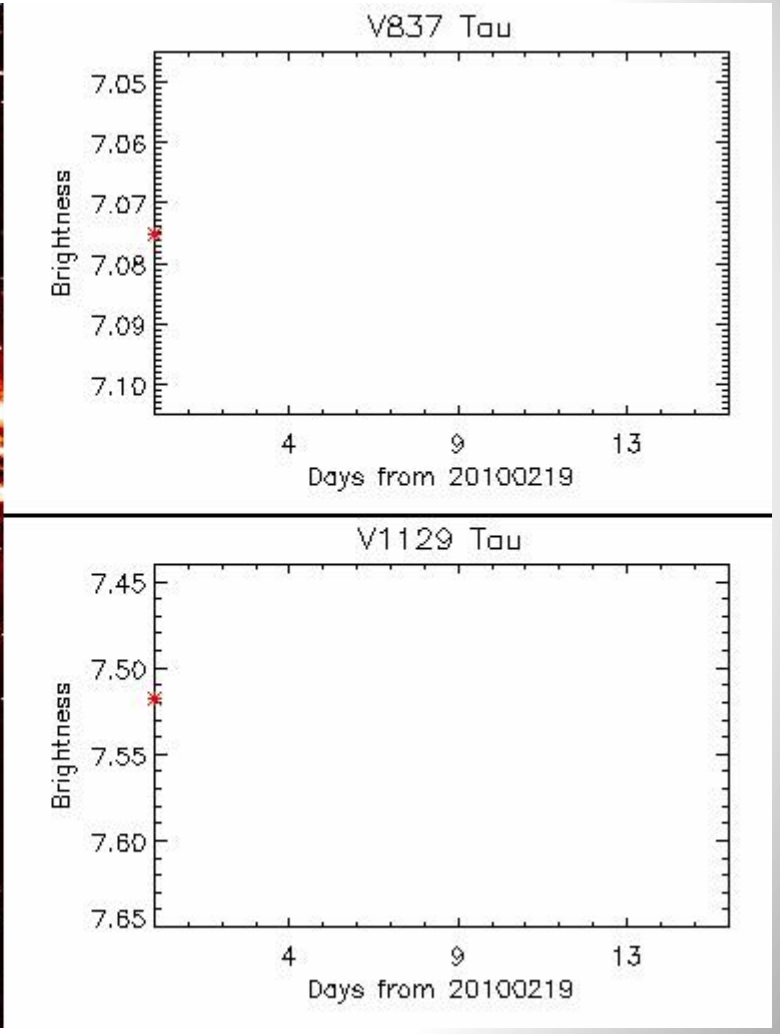


The Milky Way

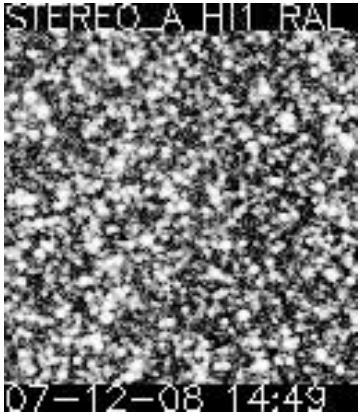


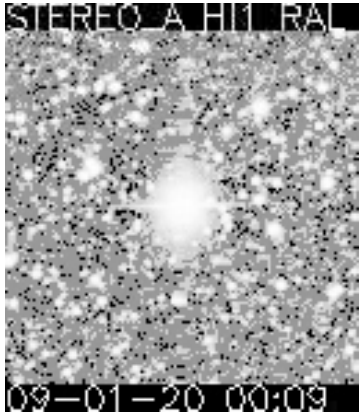
In Search for (variable) stars
(and potentially exoplanets)

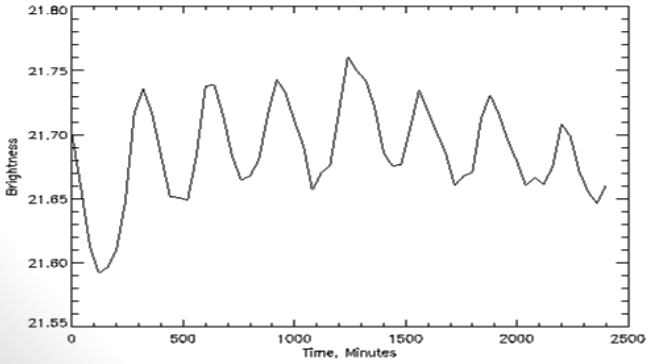




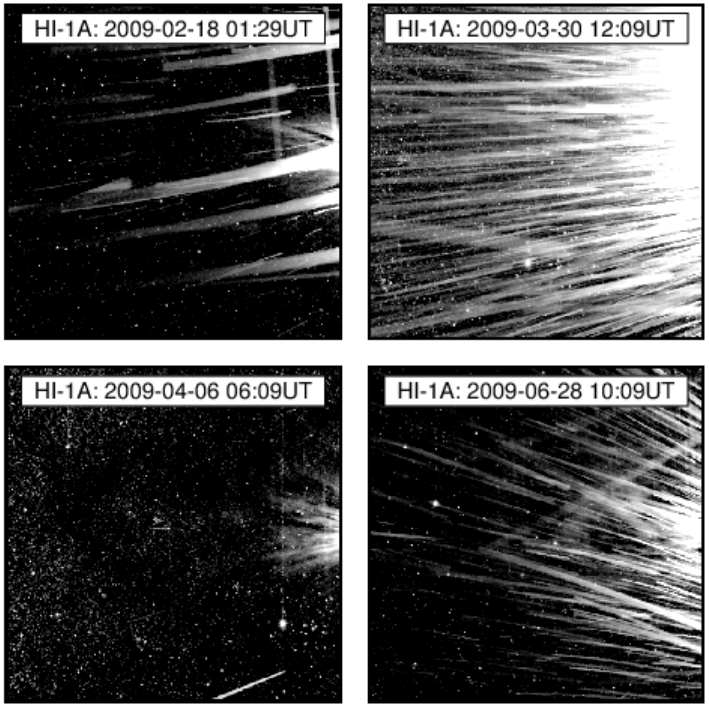
Asteroids & Mercury's sodium tail

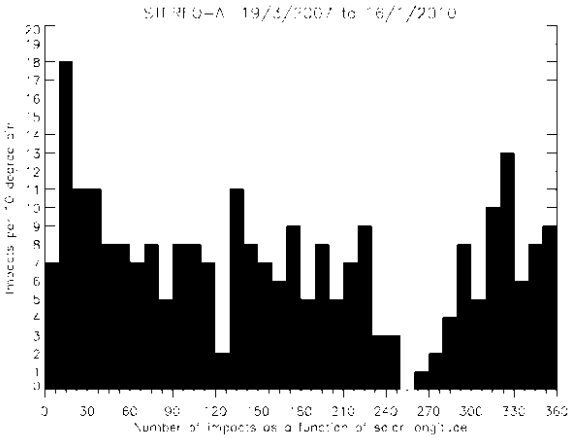


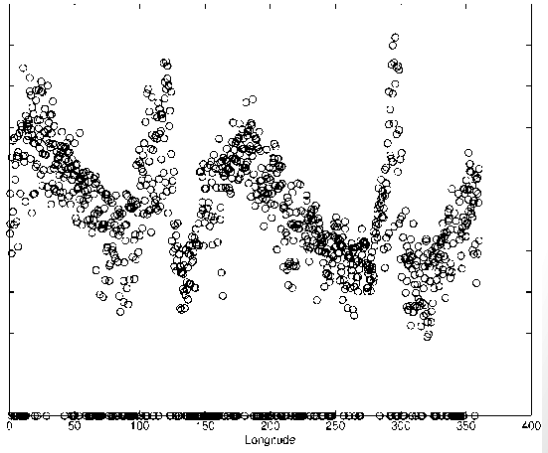


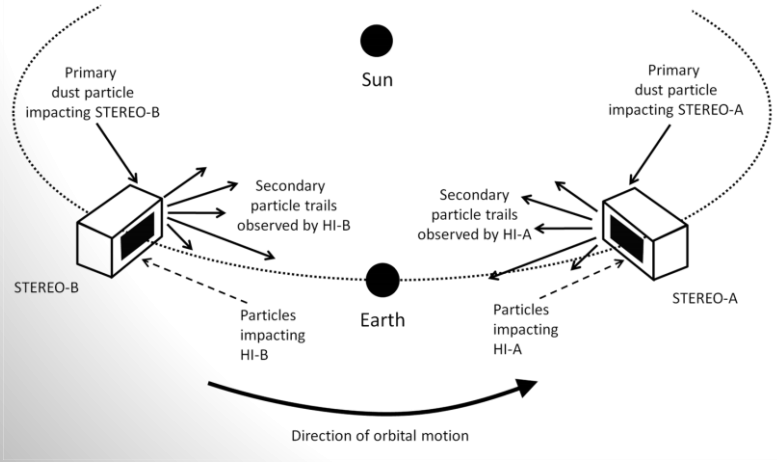


Dust detection using HI (Davis et al. 2011)









Accessing STEREO information

Accessing STEREO information

General STEREO website: http://stereo.gsfc/nasa.gov/

STEREO Science Centre: http://stereo-ssc.nascom.nasa.gov/

Accessing HI information

HI information: http://www.stereo.rl.ac.uk/ - includes publications, general information, data, gallery etc…

HI movies: http://www.ukssdc.ac.uk/solar/stereo/movies/MOVIES/

STEREO HI people:

Principal Investigator – Richard Harrison
Project Scientist – Jackie Davies
Instrument Manager – Chris Eyles
Data/Software Manager – Steve Crothers
UKSSDC Manager – Matthew Wild

www.solarstormwatch.com

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Photo by NASA

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Watch our solar scientists explain why your contributions are vital, and find out what they're doing with your results behind the scenes.

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MISSION BRIEFING

Explore our interactive mission briefing to get up to speed with solar science, zoom in on the STEREO spacecraft and meet our science team.

VISIT MISSION BRIEFING

Featured member

Jo Echo Syan

Member since: February 2009

The cool thing is, I am welcome, allowed to ponder, be amazed and explore not only a subject previously inaccessible to me, but it has also enabled me to respond and take a new approach to my work as an Artist.

Achievements

Accessing STEREO information

HI data is accessible from the UKSSDC (you need to be a registered user):

http://www.ukssdc.rl.ac.uk/solar/stereo/data.html