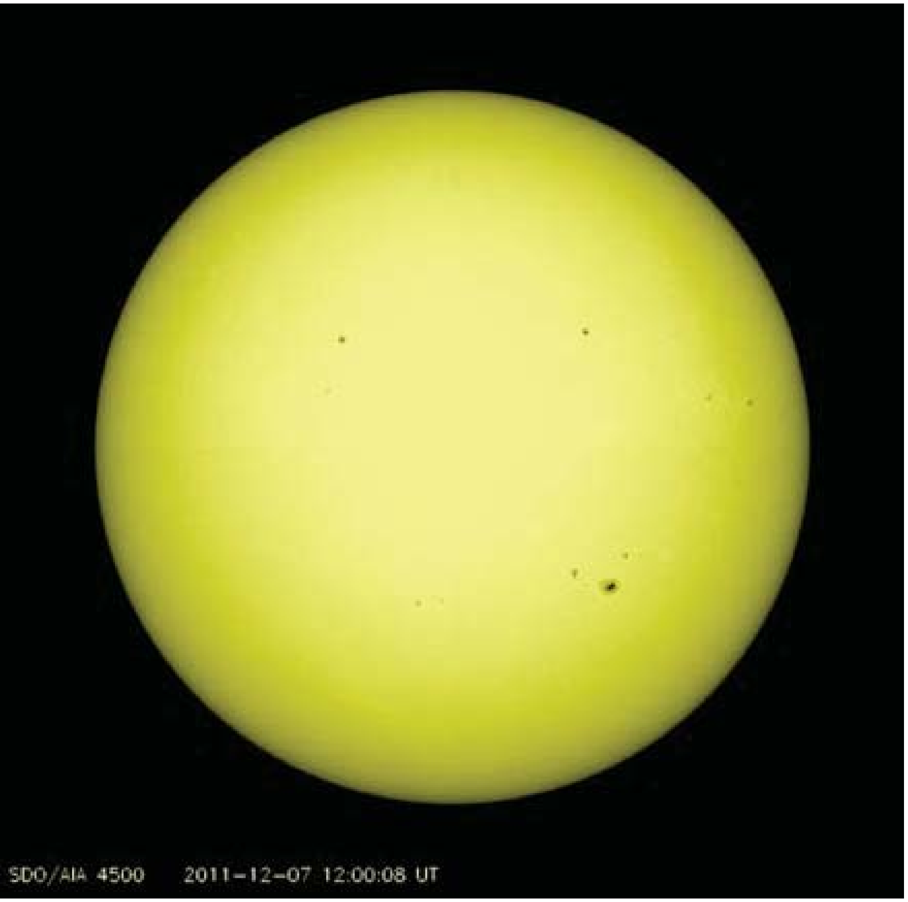


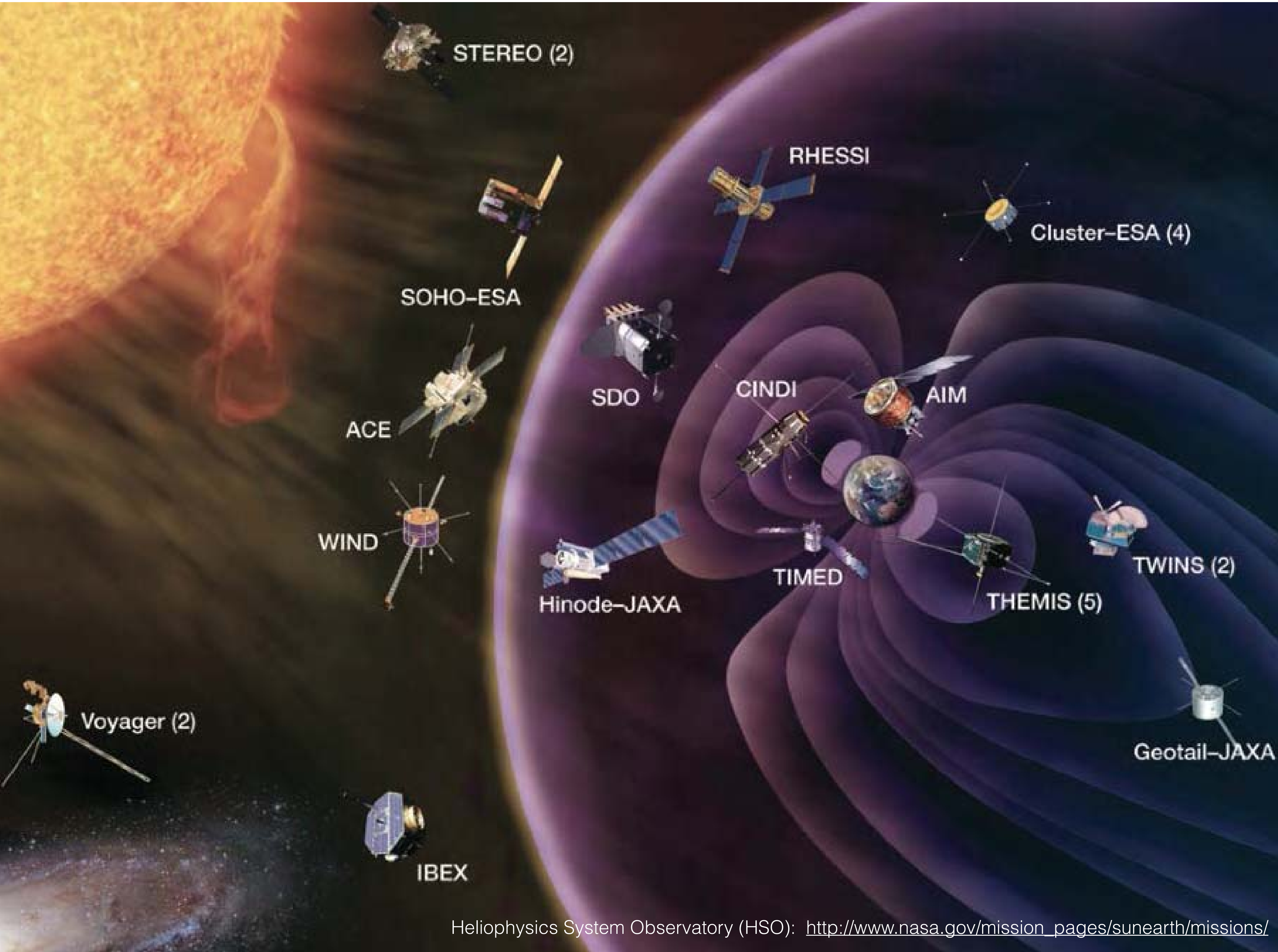
Solar Flares

Sabrina Savage (NASA/MSFC)

Heliophysics System Observatory (HSO)

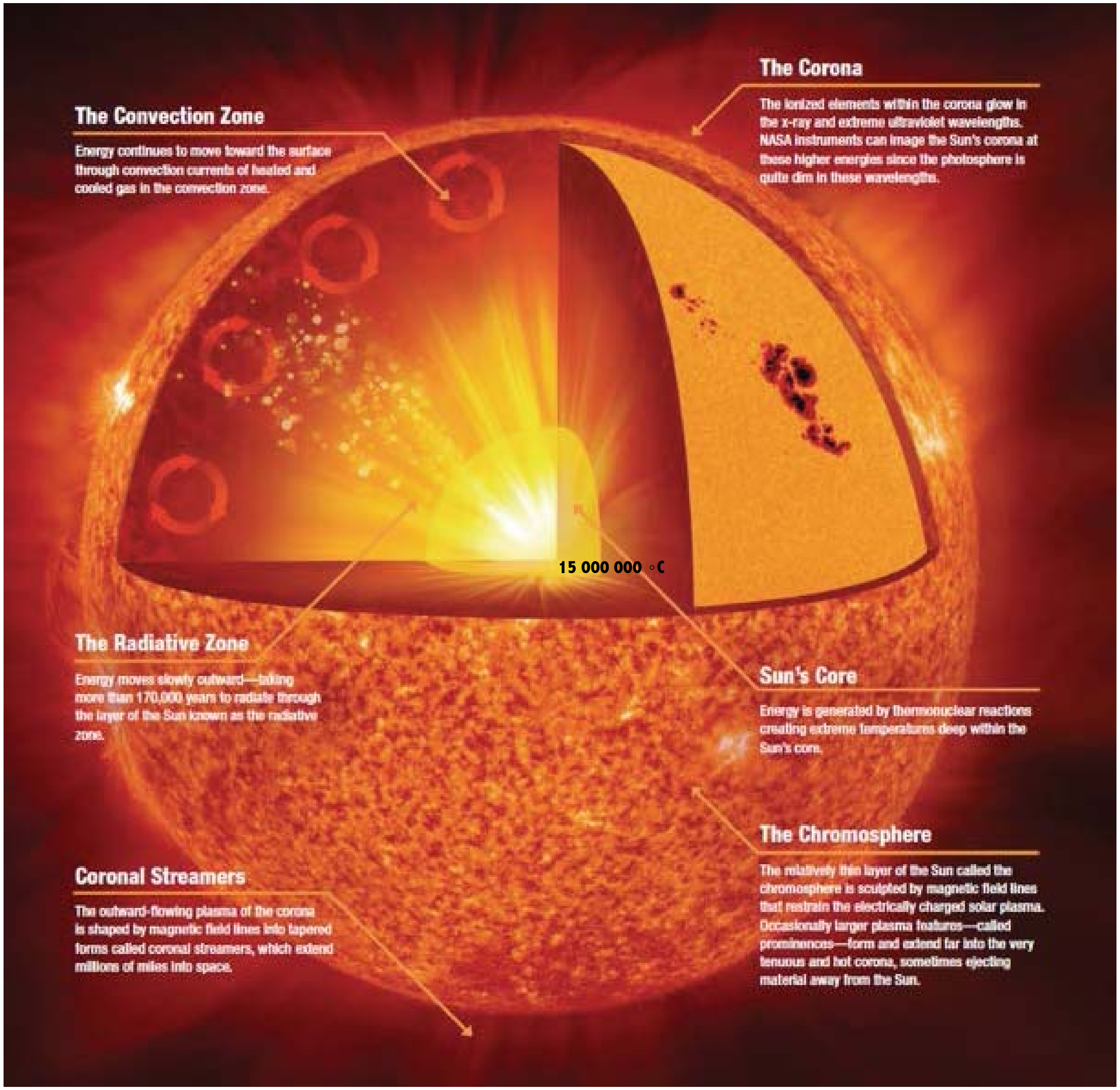
- Fleet of solar, heliospheric, geospace, and planetary satellites designed to work independently while enabling large-scale collaborative investigations.

http://www.nasa.gov/mission_pages/sunearth/missions/



Heliophysics System Observatory (HSO): http://www.nasa.gov/mission_pages/sunearth/missions/

The Sun in Layers



“Mysteries of the Sun”: NASA / Jenny Mottar

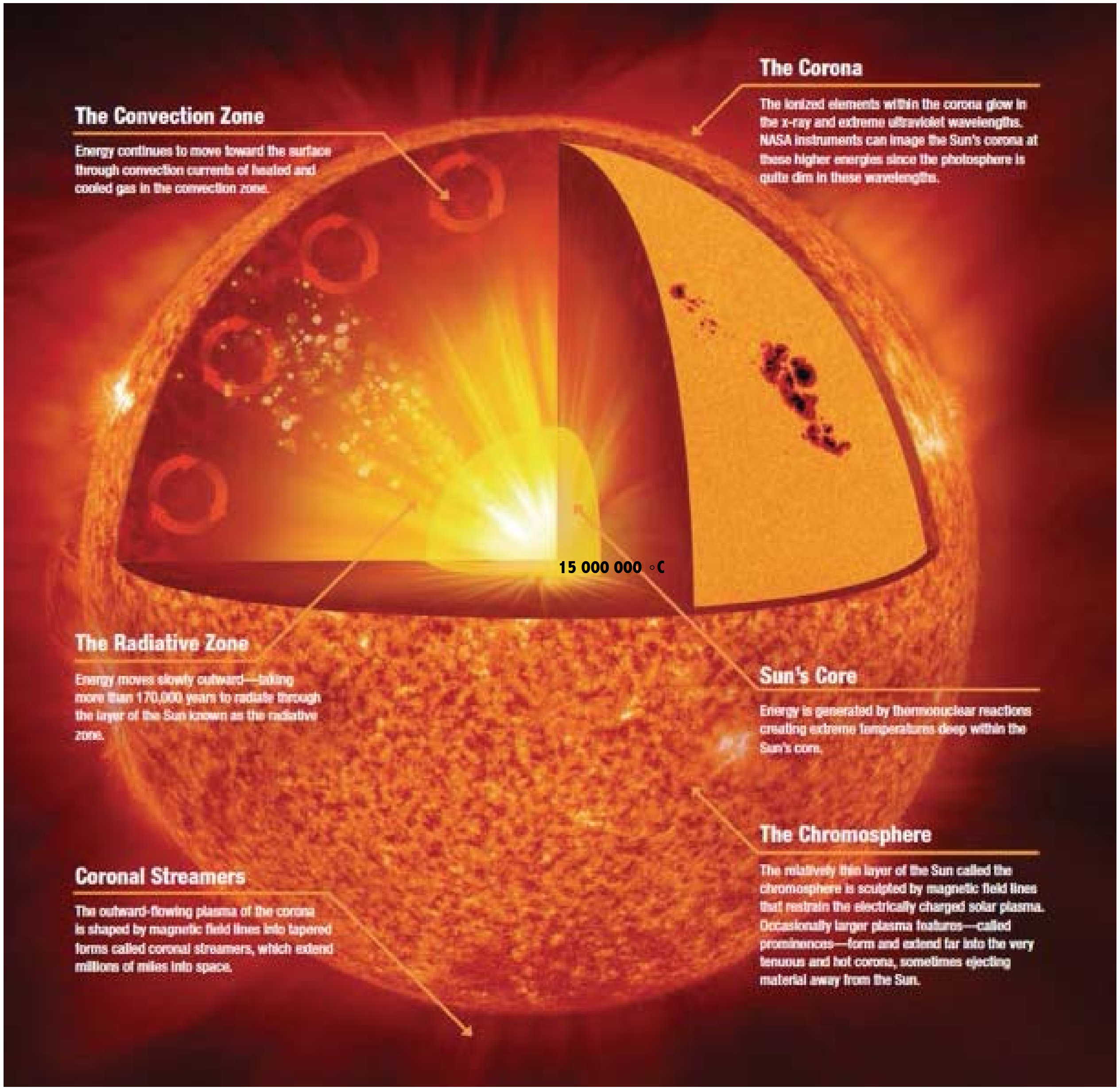
Converts 4 million tons of matter into energy every second.

Core is as dense as lead.

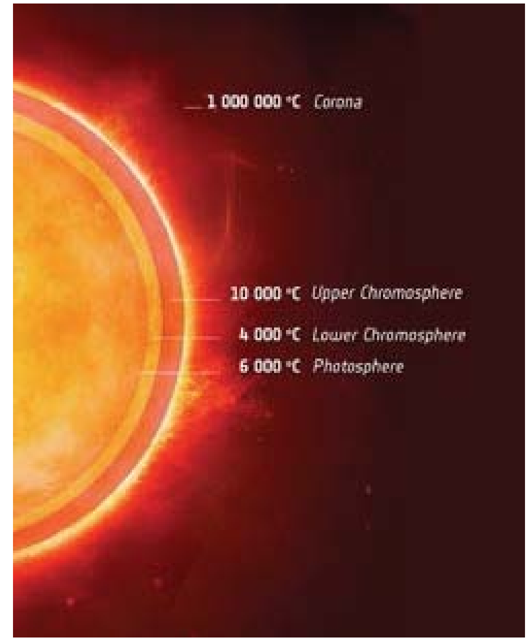
Interplay between magnetic pressure and gas (plasma) pressure.

Sun Facts: http://solarscience.msfc.nasa.gov/

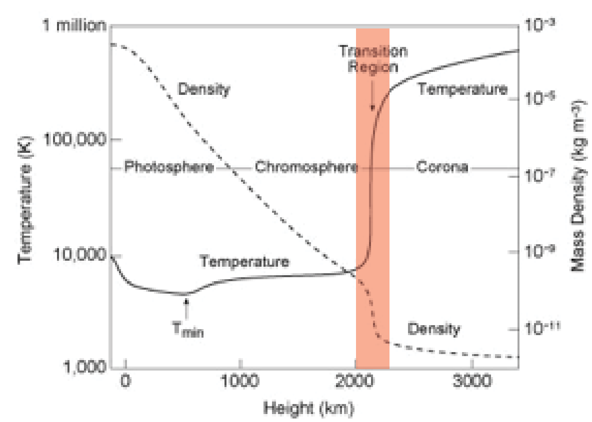
The Sun in Layers



"Mysteries of the Sun": NASA / Jenny Mottar



European Space Agency (ESA)

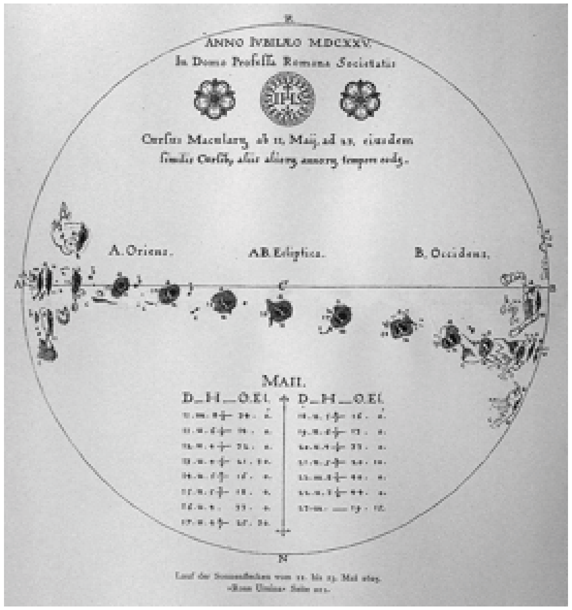


Smithsonian Astrophysical Observatory (SAO)

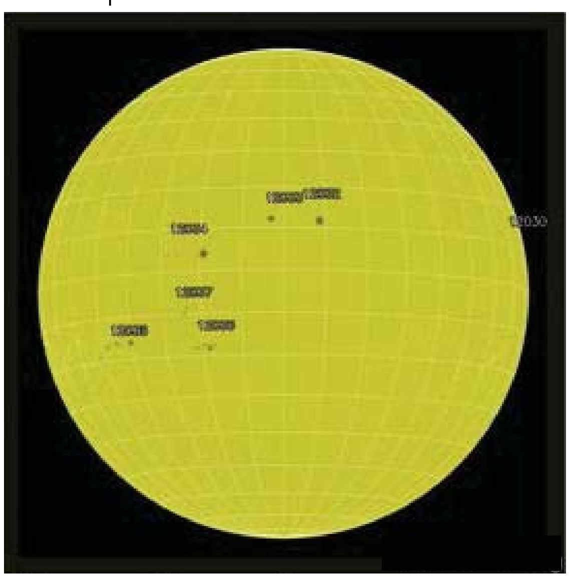
Sun Facts: http://solarscience.msfc.nasa.gov/

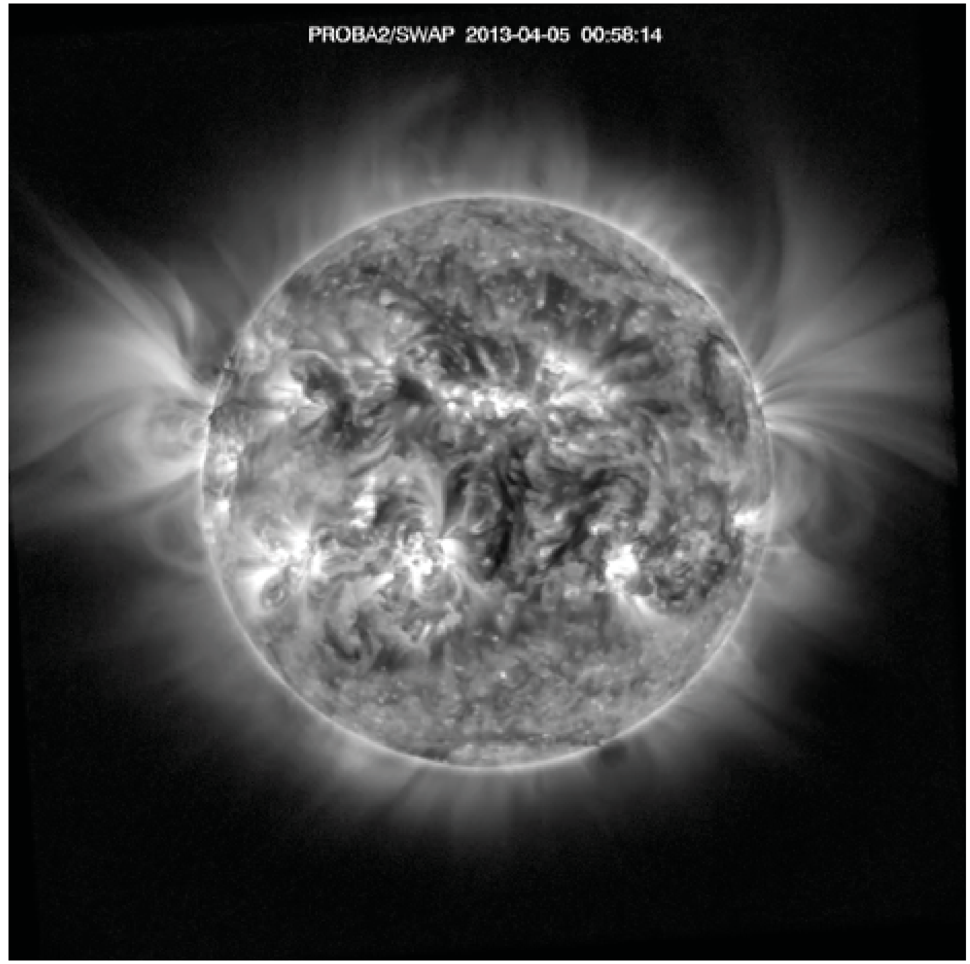
Sunspots & Active Regions

1625 May: Christoph Scheiner



2014 April 14: SDO HMI 6173 A





European Space Agency (ESA) / Royal Observatory Belgium (ROB)

NOAA Active Regions: SolarMonitor.org

PROBA2 Science Center (ROB): http://proba2.sidc.be/

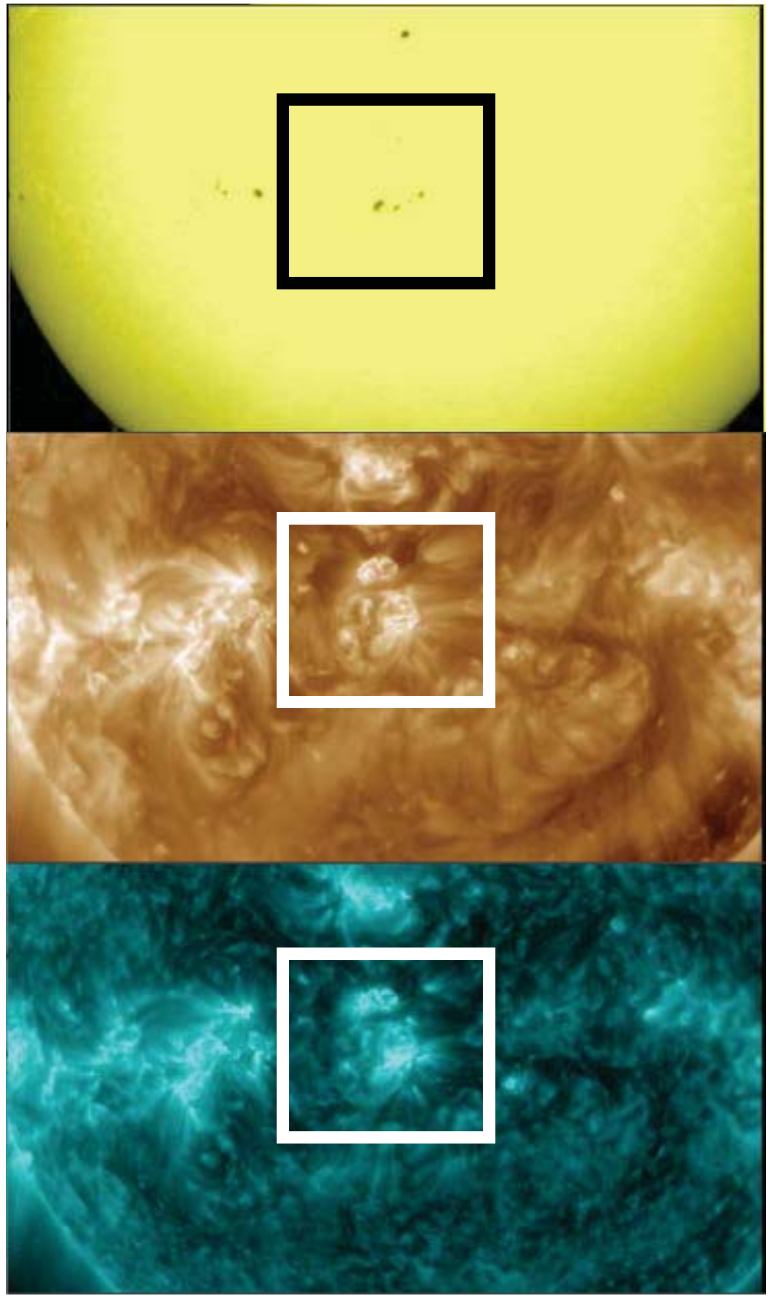
Sunspots & Active Regions

Formation

4500 A

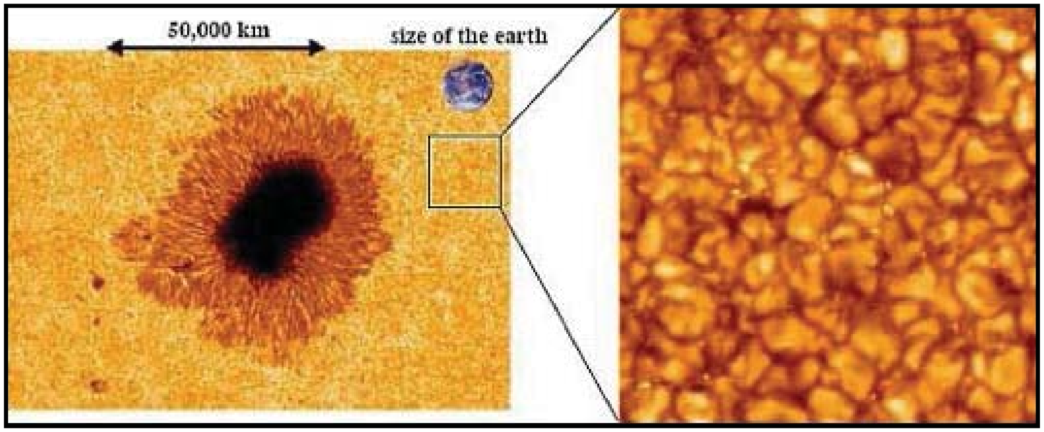
193 A

131 A

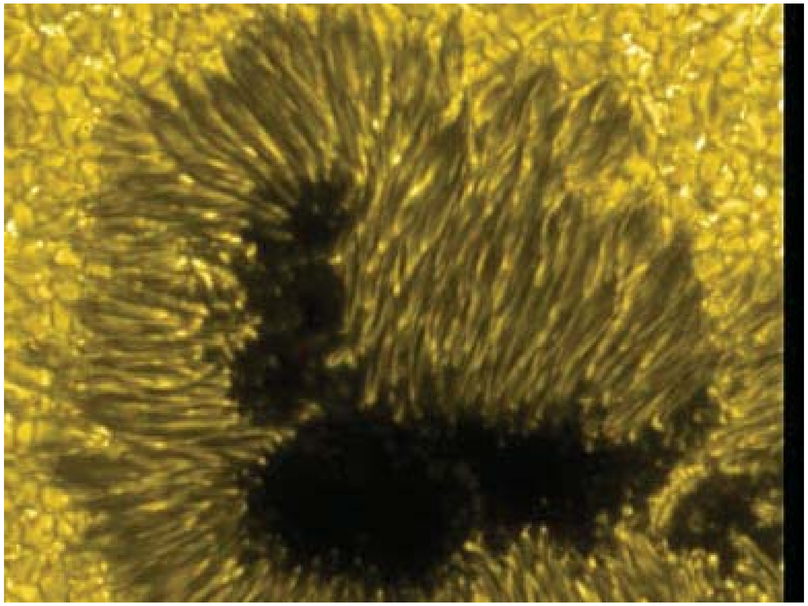


SDO / AIA
2014 Apr 13 - 15

Sunspots & Active Regions

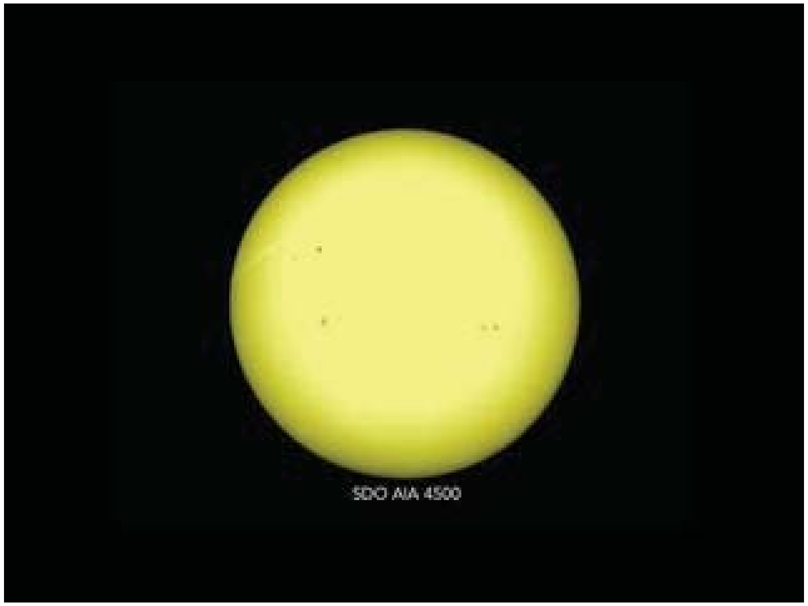


Hinode SOT: NASA / JAXA / NAOJ
Sunspot Magnetic fields ~ 3000-6000 times stronger than Earth's field. Magnetic pressure dominates gas pressure in spot, thus inhibiting convective flow of heat.



SOT (CN line 3883 A); 2007 May 2

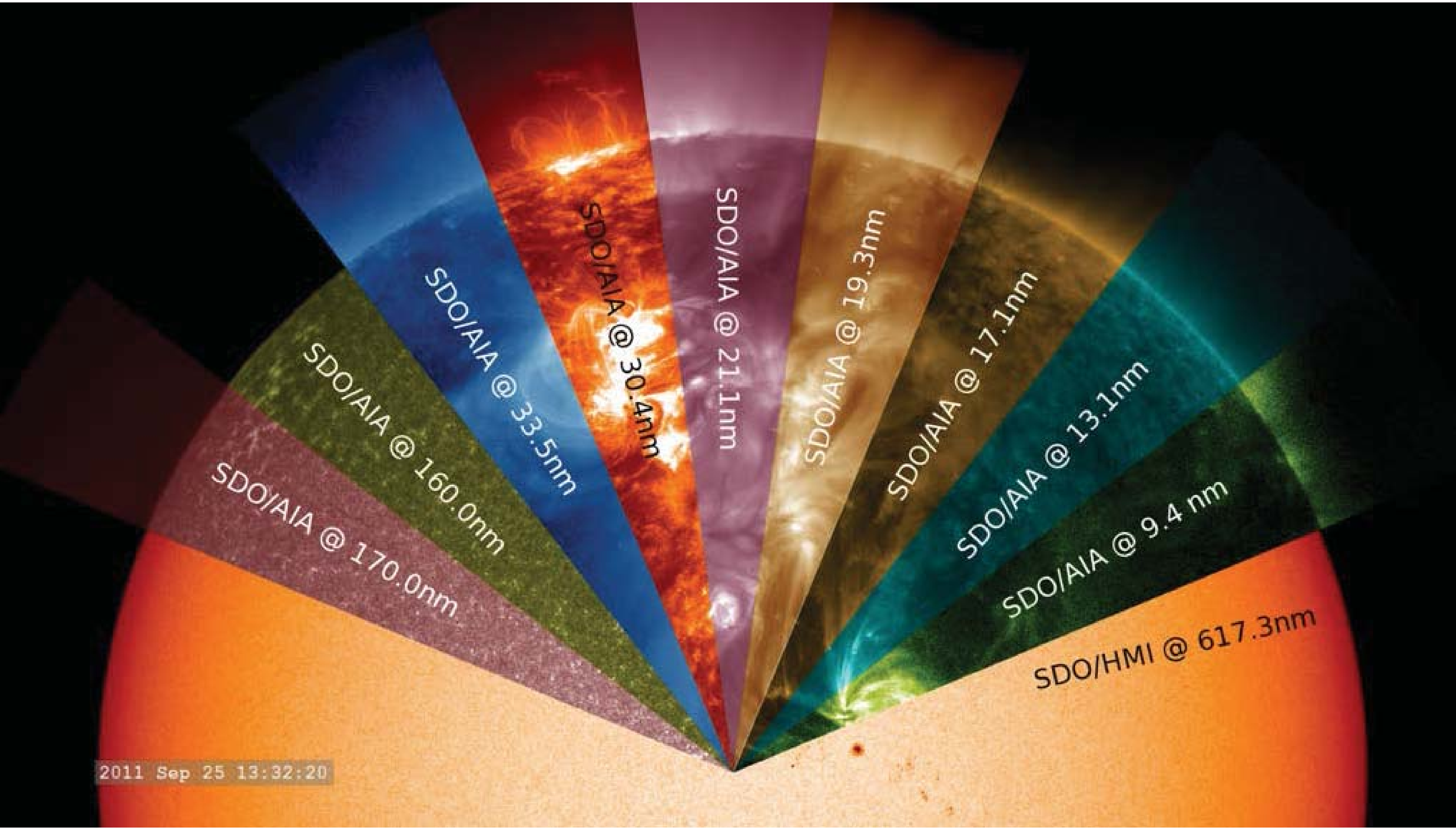
JHelioviewer *SDO* / AIA 2014 Apr 04



SOHO animation gallery

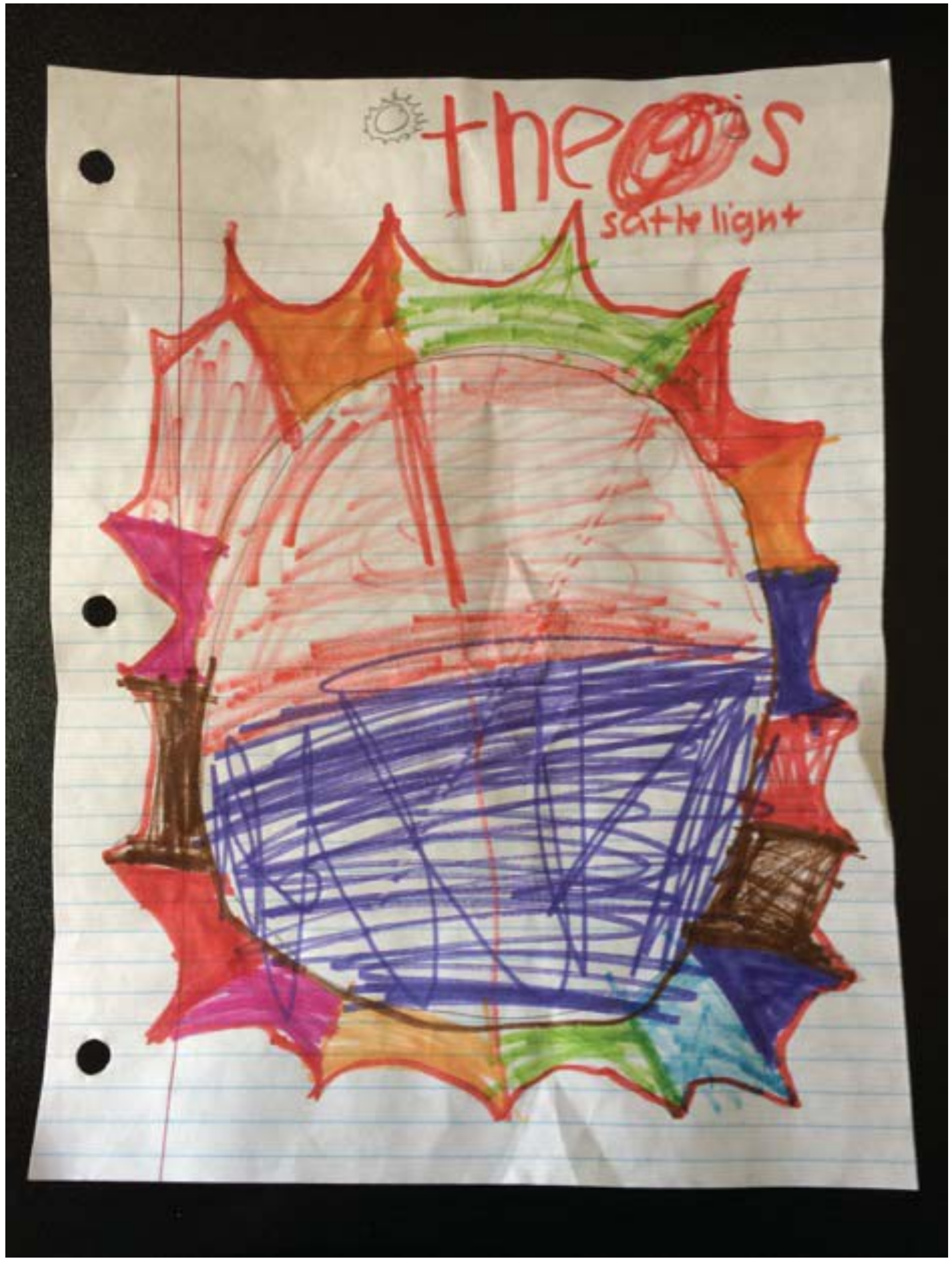
SOT Picture of the Day (POD): http://sot.lmsal.com/pod?cmd=view-gallery

Sunspots & Active Regions



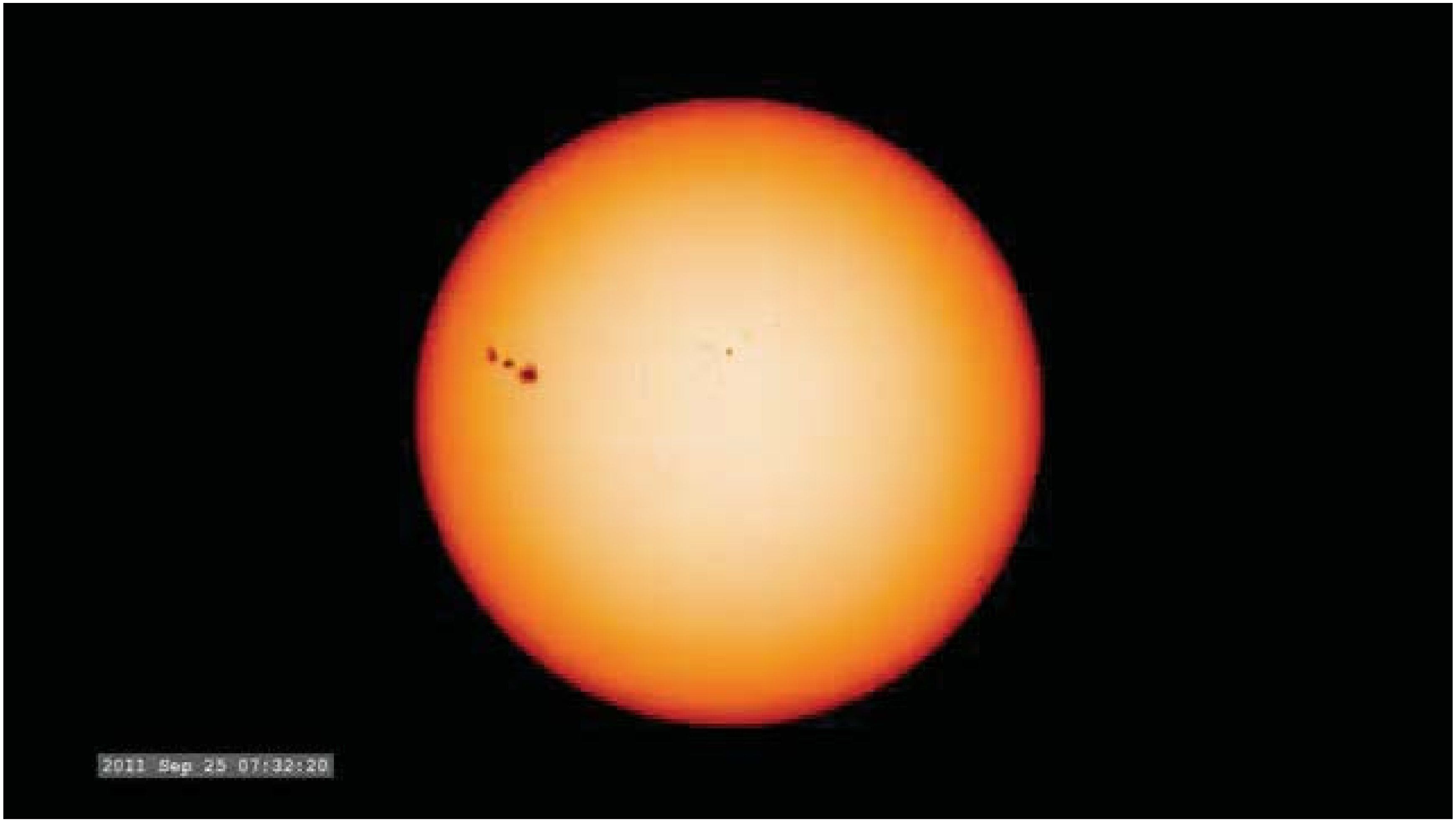
Solar Dynamics Observatory (GSFC) Jewel Box: http://svs.gsfc.nasa.gov/vis/a000000/a004100/a004117/

Sunspots & Active Regions



Courtesy of Milo Littenberg

Sunspots & Active Regions

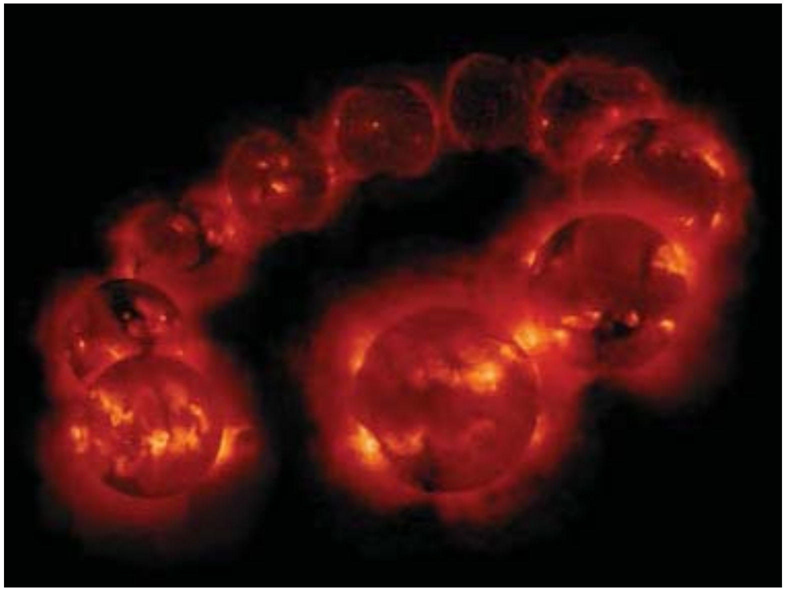


“SDO Jewel Box”

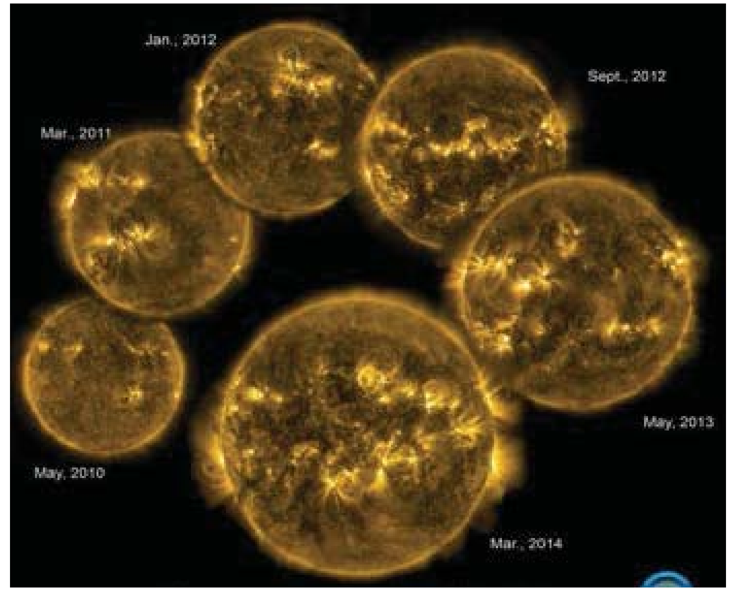
Solar features as seen with 10 different filters (i.e., plasma at different temperatures).

Solar Dynamics Observatory (GSFC) Jewel Box: http://svs.gsfc.nasa.gov/vis/a000000/a004100/a004117/

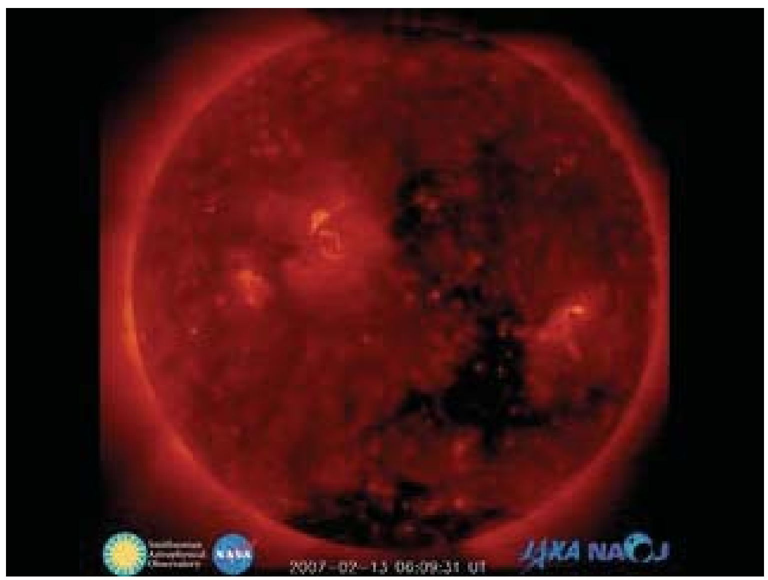
Solar Cycle



Yohkoh / SXT
1991 - 1999



SDO / AIA 171 A
2010 - 2014



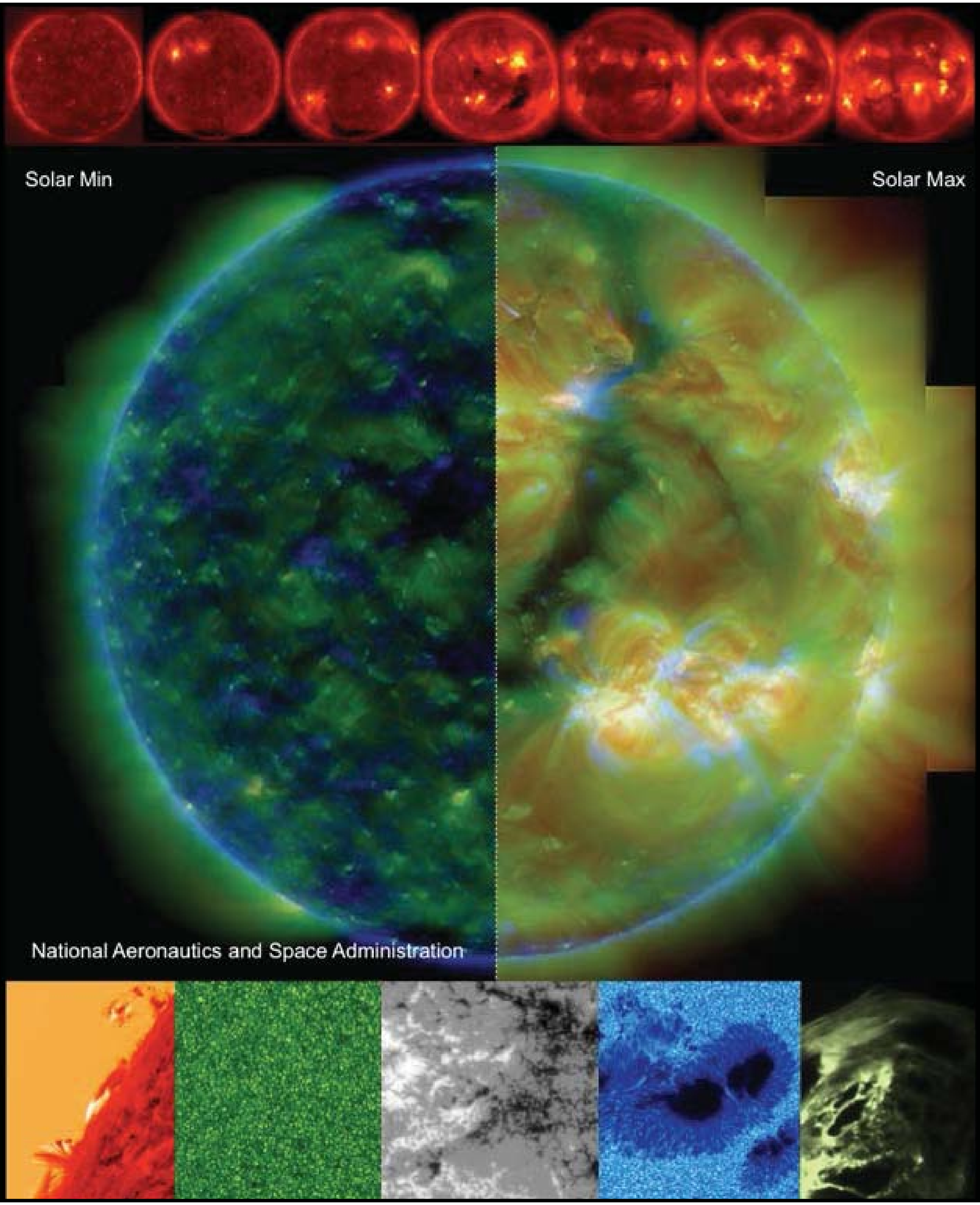
Hinode / XRT 2007 - 2012

9 - 14 year cycle

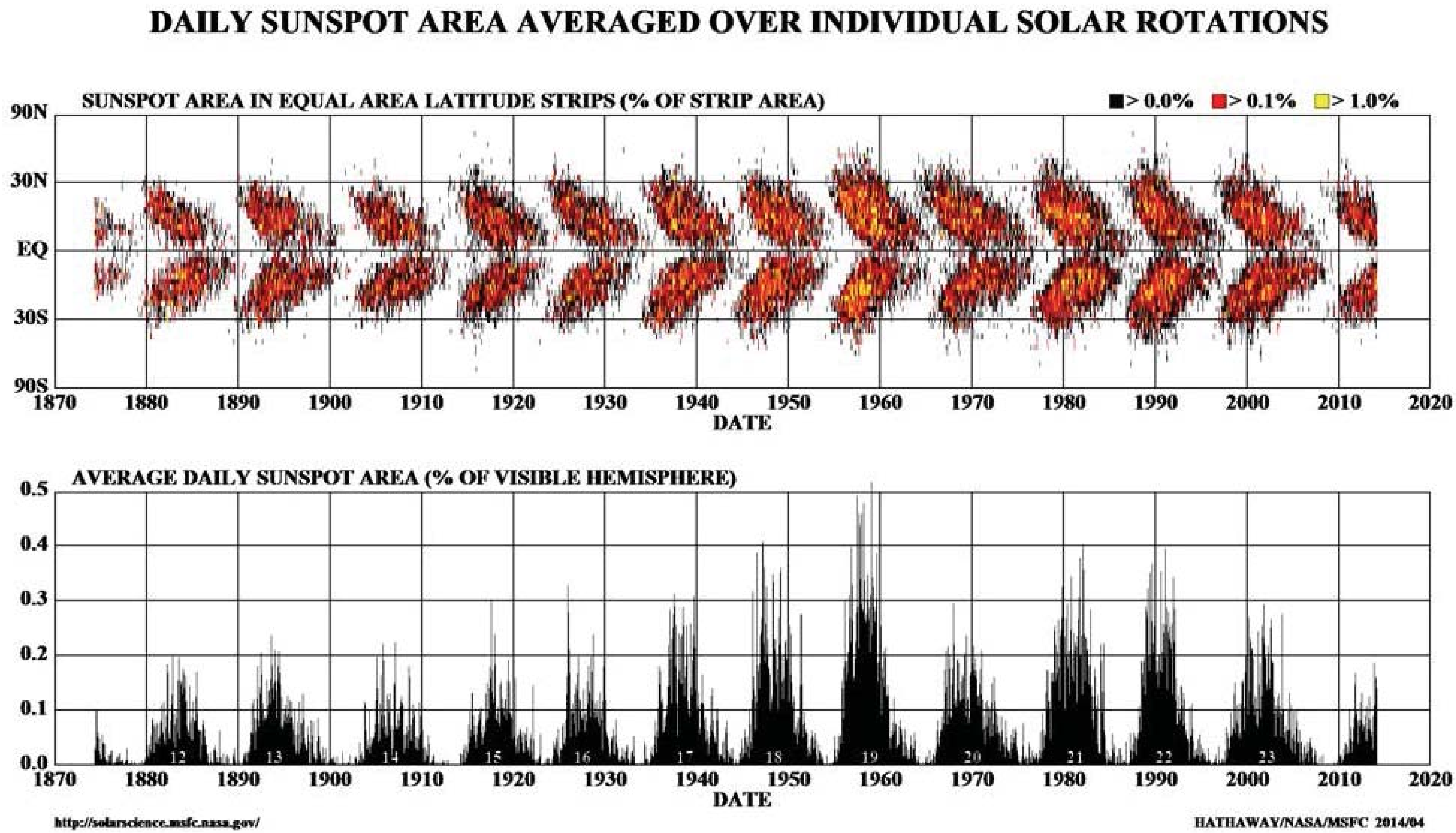
SXT: http://solar.physics.montana.edu/sxt/ XRT: http://xrt.cfa.harvard.edu/ SDO: http://sdo.gsfc.nasa.gov/

Hinode:

A Comprehensive Mission to Study the Variable Sun

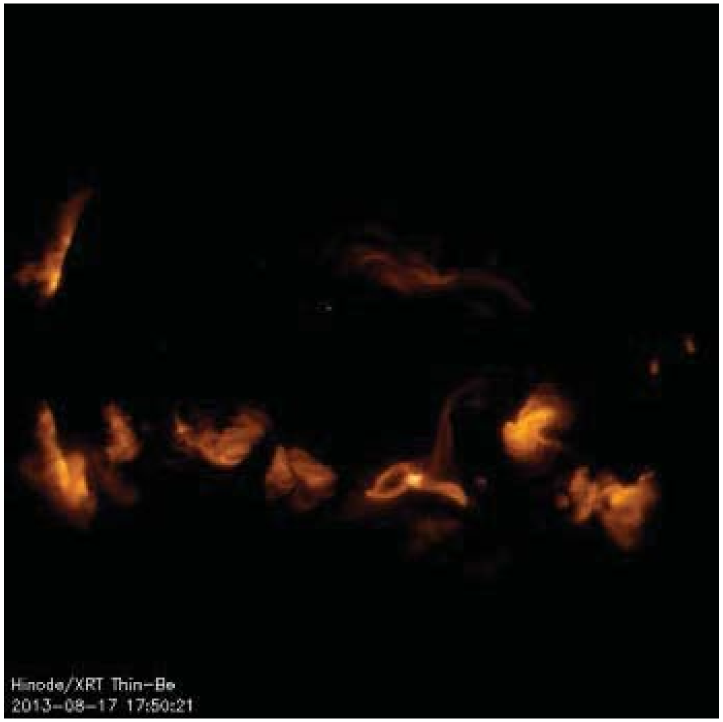


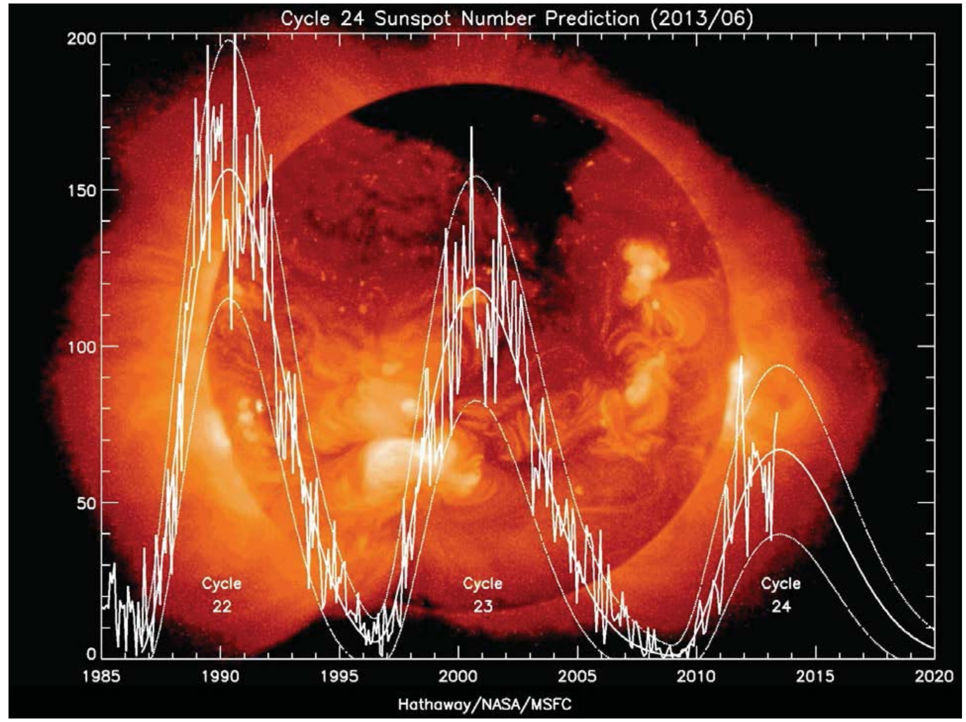
Solar Cycle



Data from the Royal Greenwich Observatory since 1874: http://solarscience.msfc.nasa.gov/SunspotCycle.shtml

Current Cycle

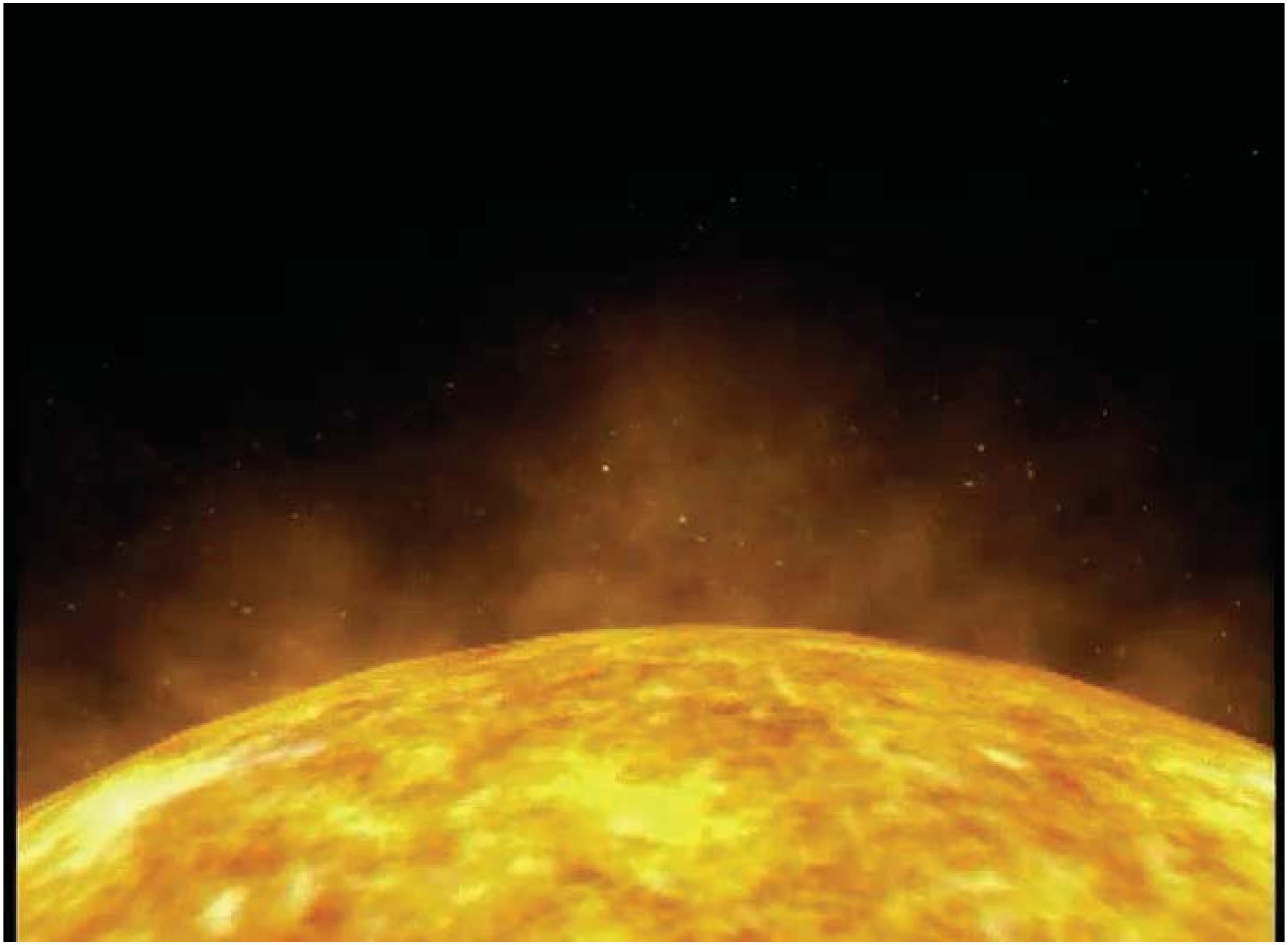




#24 — Smallest cycle in ~100 years
http://solarscience.msfc.nasa.gov/SunspotCycle.shtml

Hinode XRT Picture of the Week: http://xrt.cfa.harvard.edu/

Sun-Earth Interaction



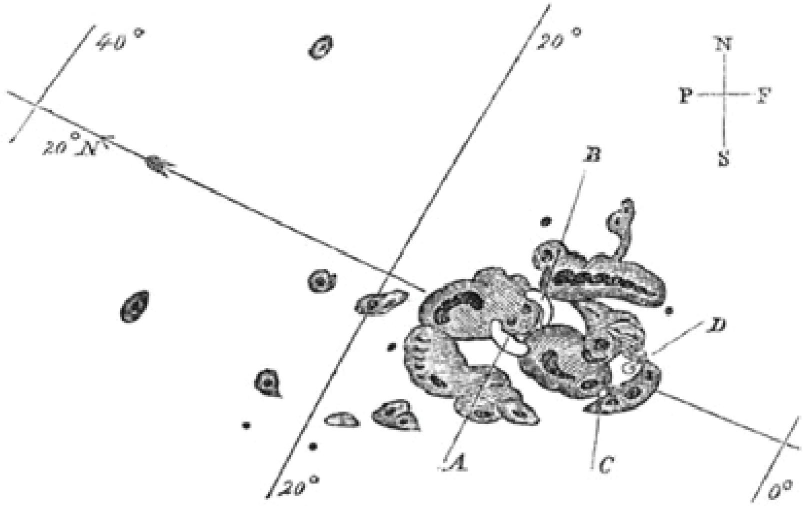
Solar storms cause the *Earth* to lose up to 100 tons of atmosphere into space.

Aurora mostly caused by ionospheric particles disrupted by currents induced from the coronal mass ejection — not the solar wind directly.

Aurora can generate up to 100 trillion watts of power.

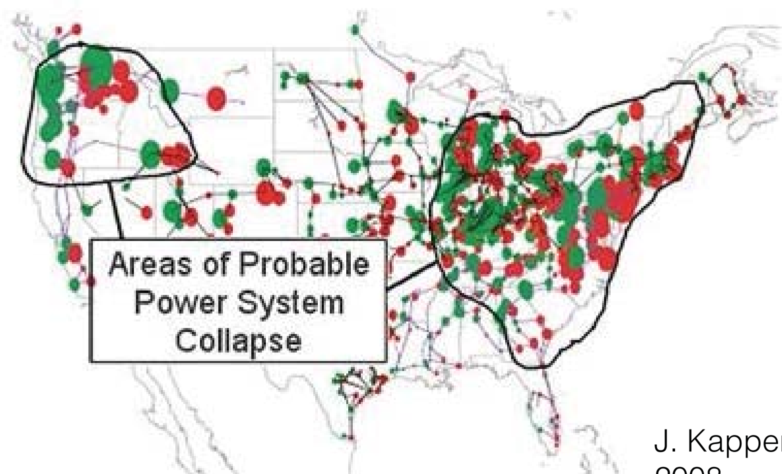
SOHO animation gallery: http://soho.nascom.nasa.gov/bestofsoho/Movies/animations.html

Impacts of Space Weather

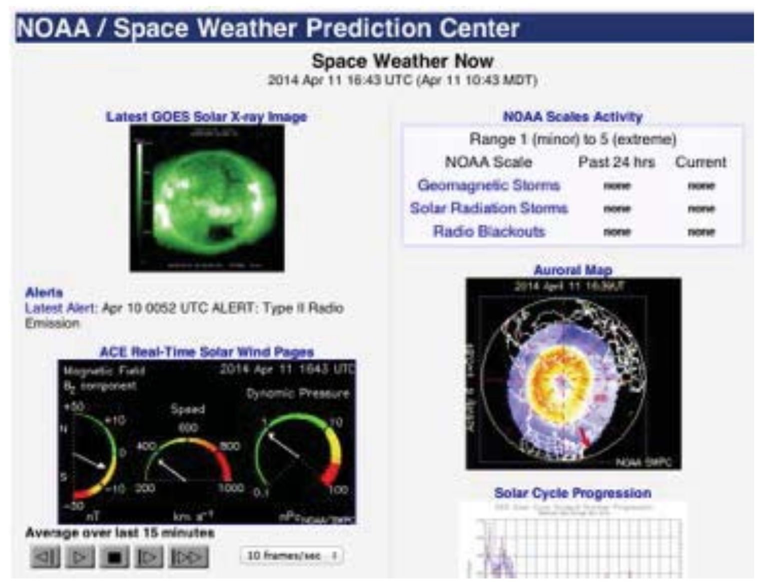


1859 Carrington Event
Largest Geomagnetic storm recorded

M. A. Shea, Geophysics Directorate, Phillips Laboratory
1989 Superstorm Blackout, $6 Billion loss to economy



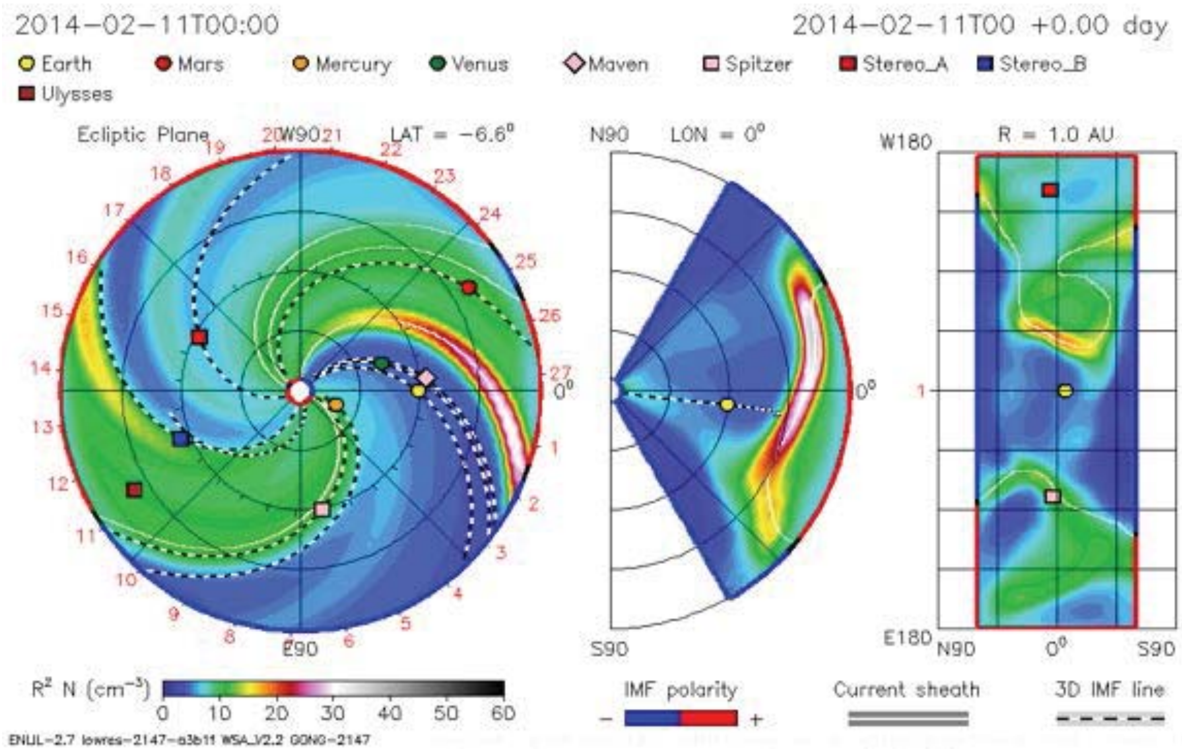
J. Kappenman
2008

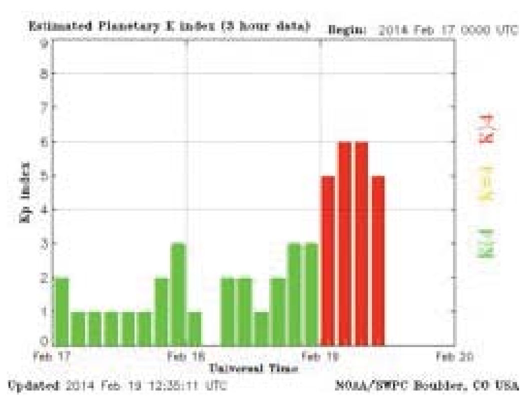


http://www.swpc.noaa.gov/SWN/

National Academy of Sciences Report Summary: http://event.arc.nasa.gov/swsw/pdf/Kappenman_AMES_Oct16.pdf

Impacts of Space Weather



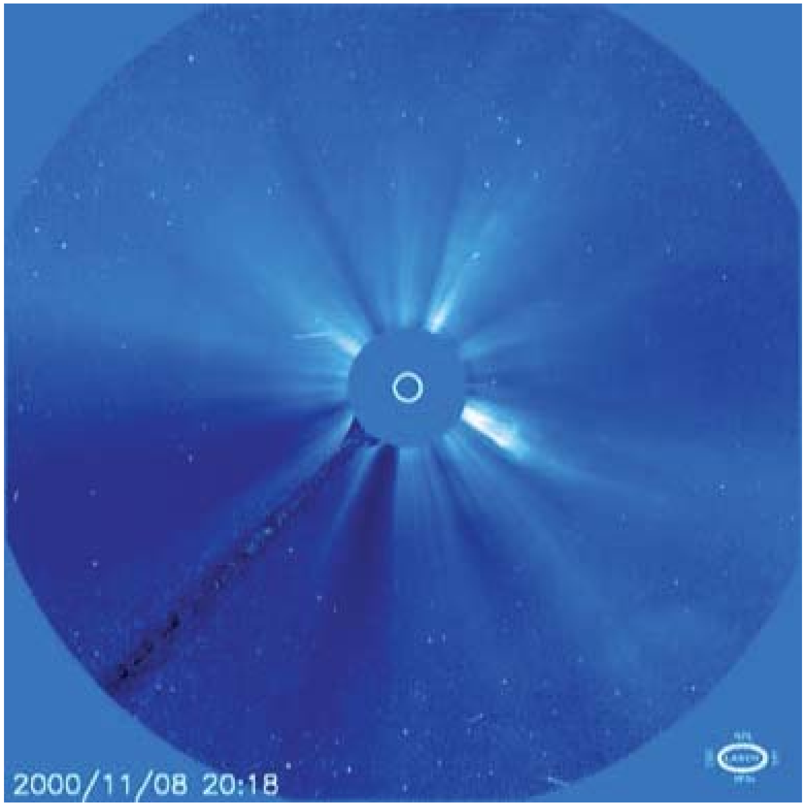


NOAA / SWPC

http://www.spaceweather.com

NASA SWRC: http://swrc.gsfc.nasa.gov/main/cmemodels , The Sun Today: http://www.thesuntoday.org/space-weather/

Impacts of Space Weather



SOHO Large Angle and Spectrometric Coronagraph Experiment (LASCO)

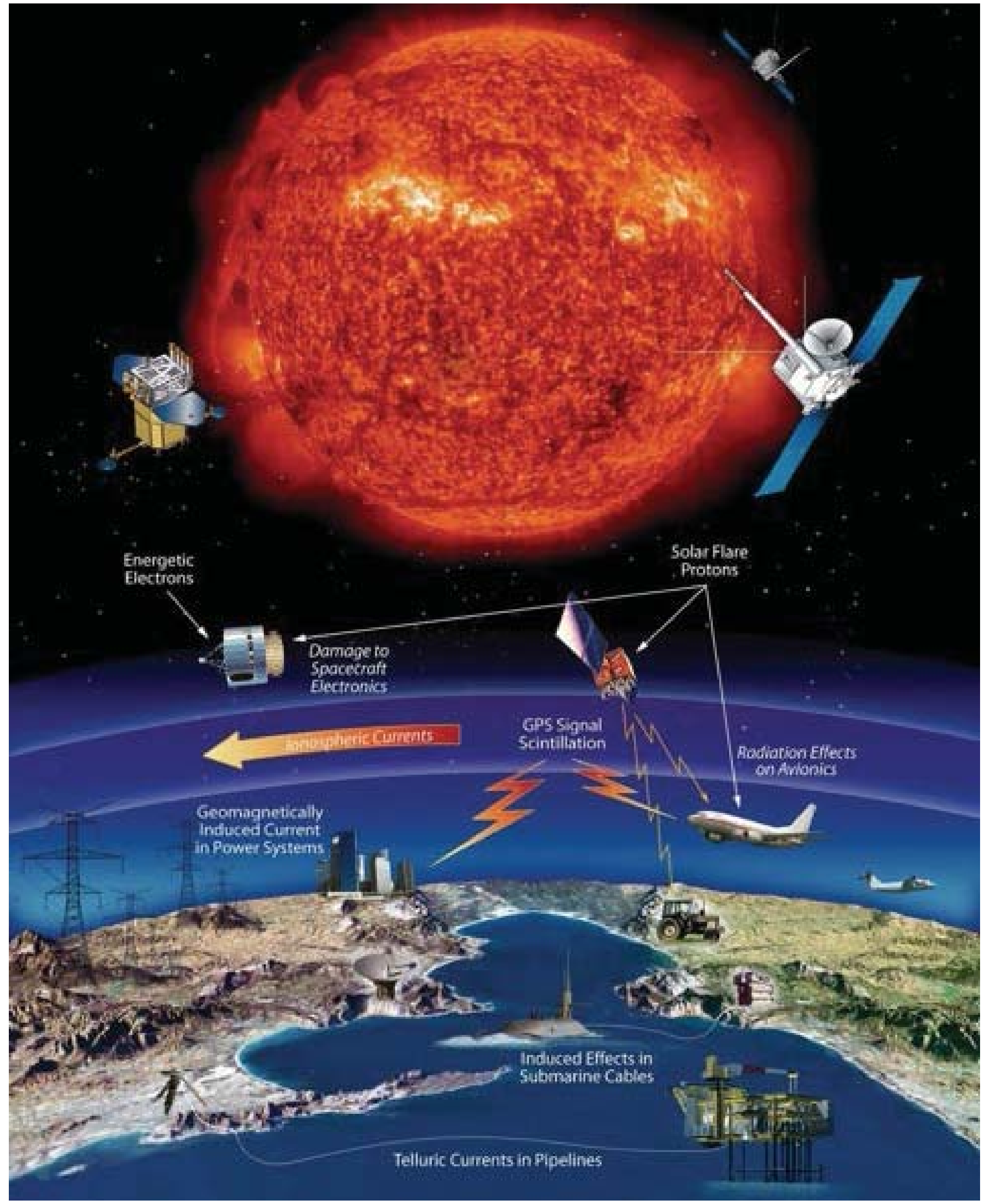
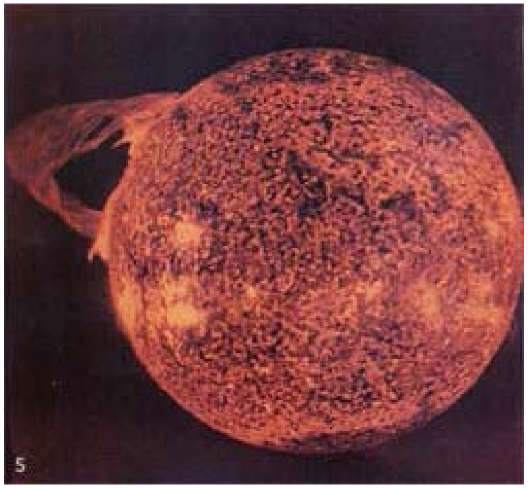


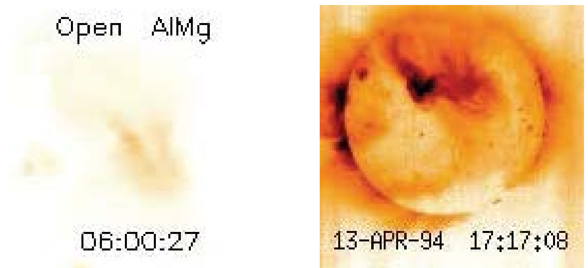
Image credit: NASA & L. Lanzerotti (NJIT)

LASCO: http://lasco-www.nrl.navy.mil/

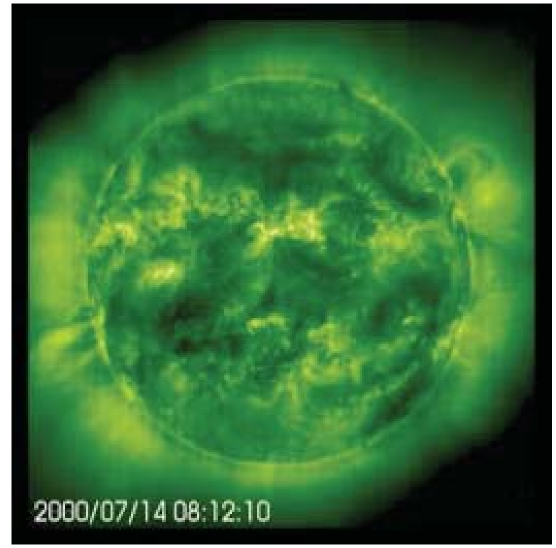
Solar Flares (A Space-Based Tour)



Skylab

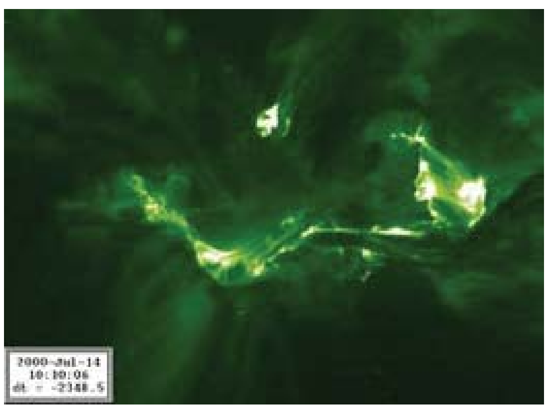


Yohkoh / SXT

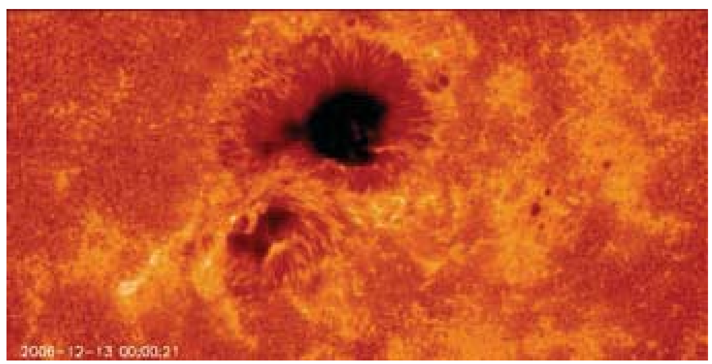


SOHO / EIT+LASCO

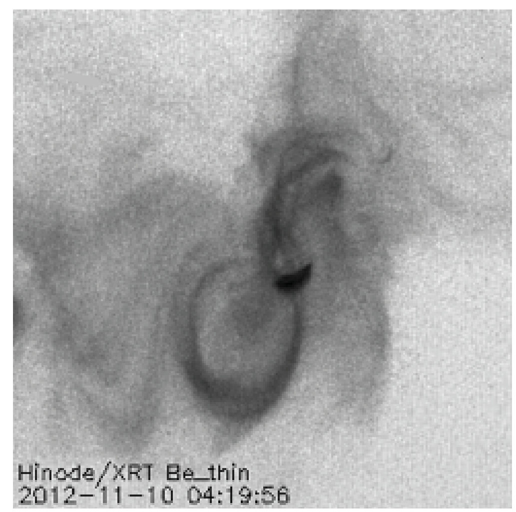
TRACE



HINODE / SOT

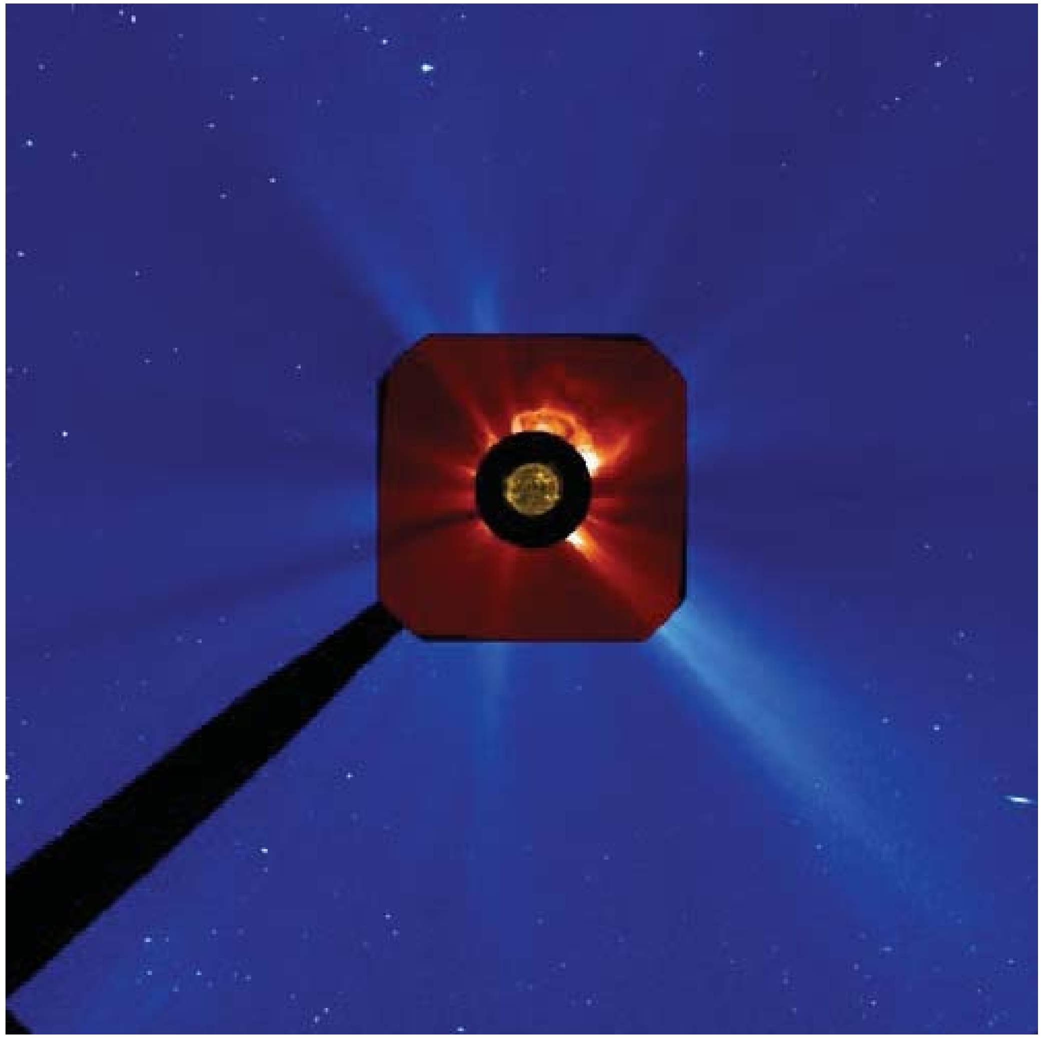


HINODE / XRT



Skylab SP-402 The Active Sun: http://history.nasa.gov/SP-402/ch7.htm

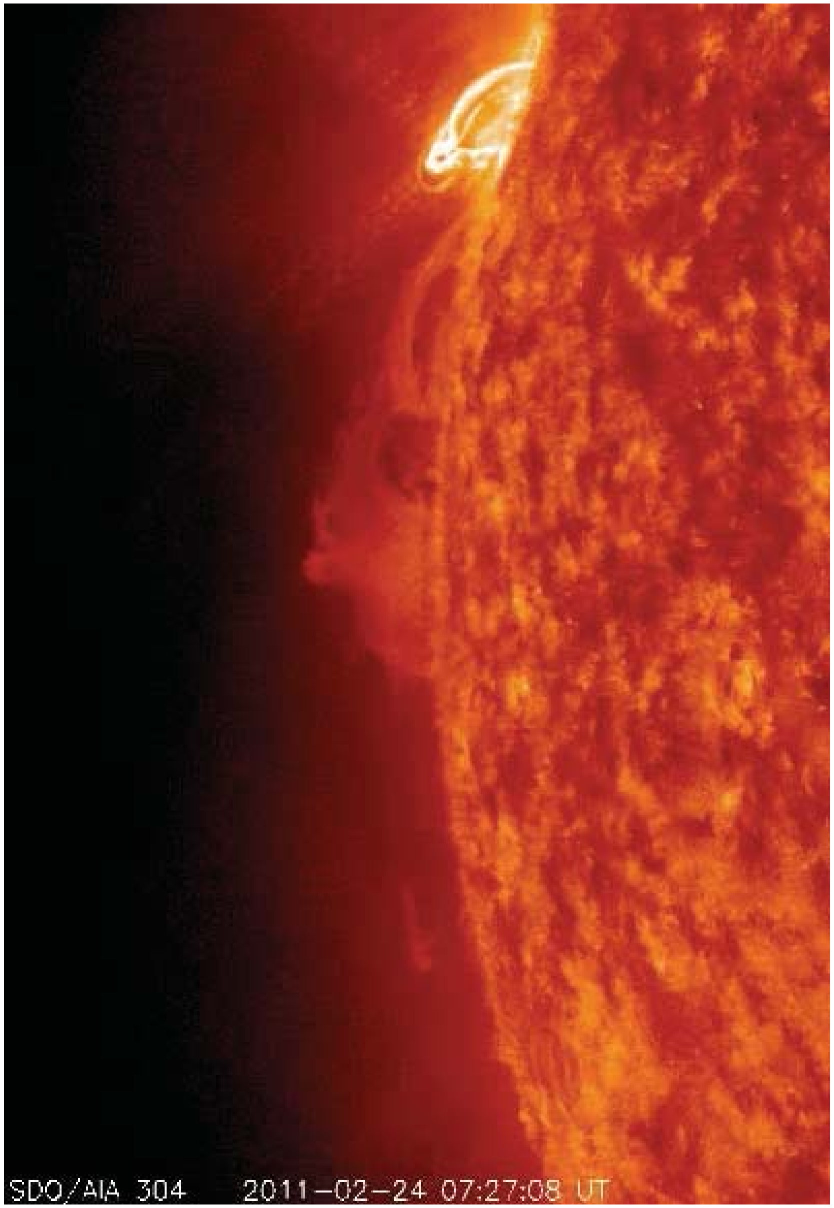
Solar Flares (A Space-Based Tour)

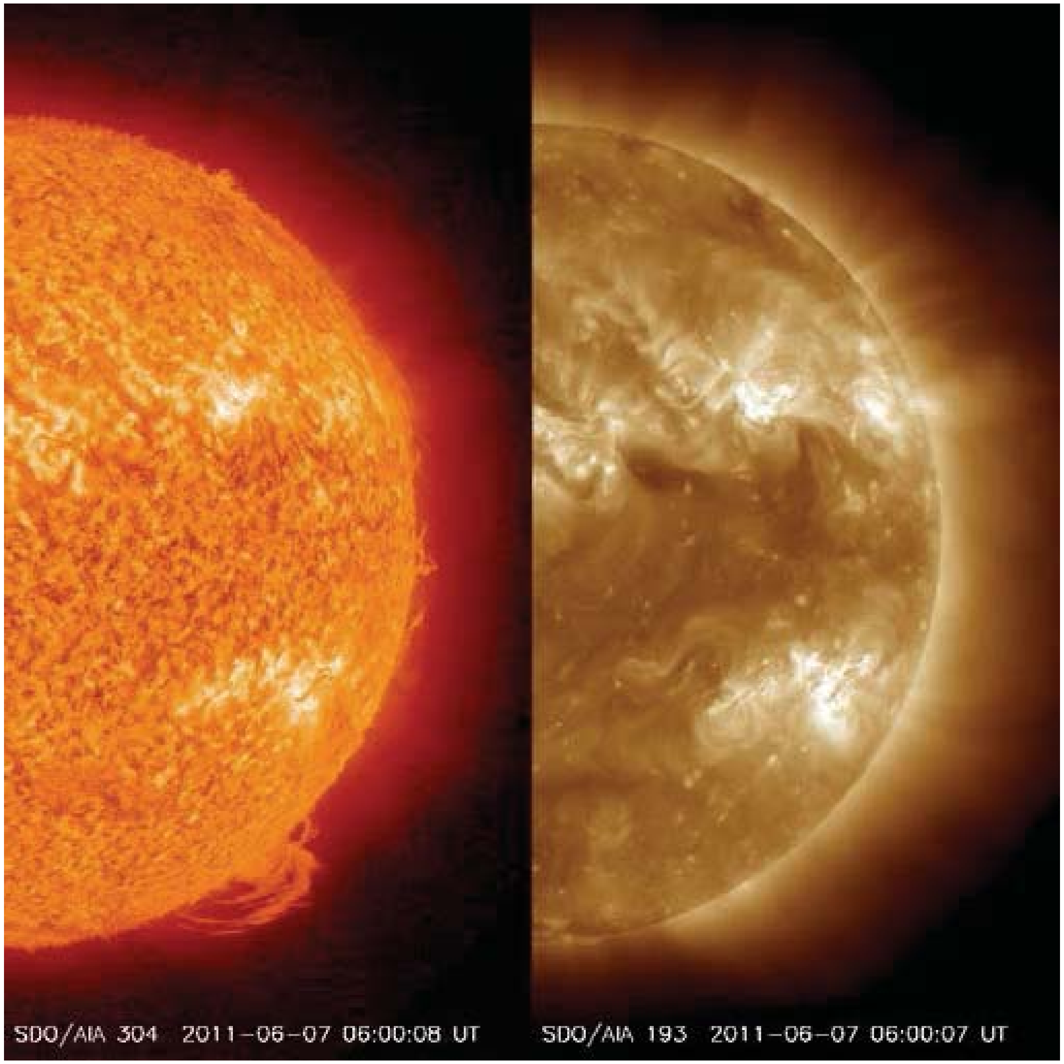


SDO / AIA + *SOHO* / LASCO

Solar Dynamics Observatory (SDO): http://sdo.gsfc.nasa.gov/ ; LASCO: http://lasco-www.nrl.navy.mil/

Solar Flares (A Space-Based Tour)

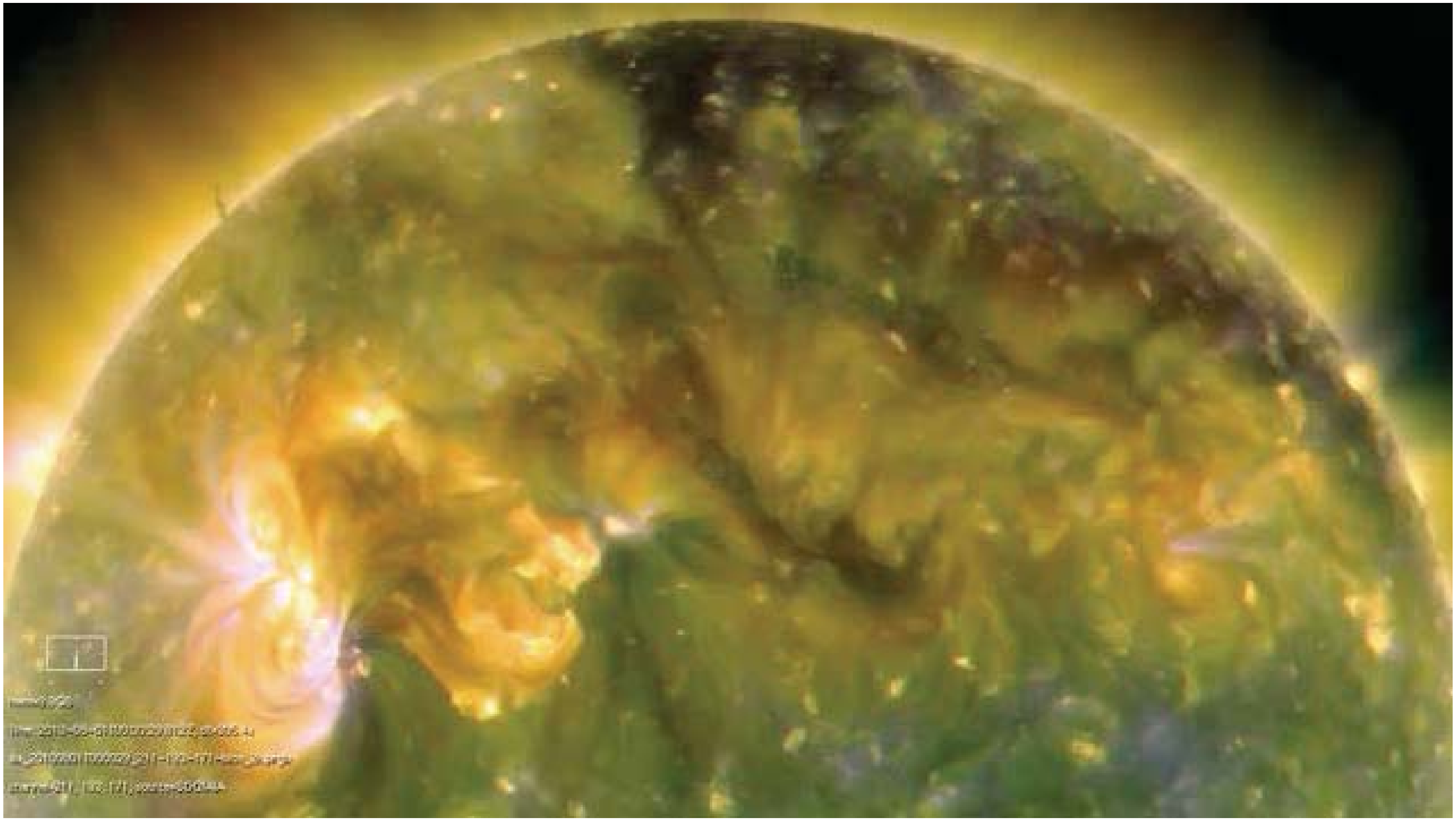




SDO / AIA

Solar Dynamics Observatory (SDO): http://sdo.gsfc.nasa.gov/

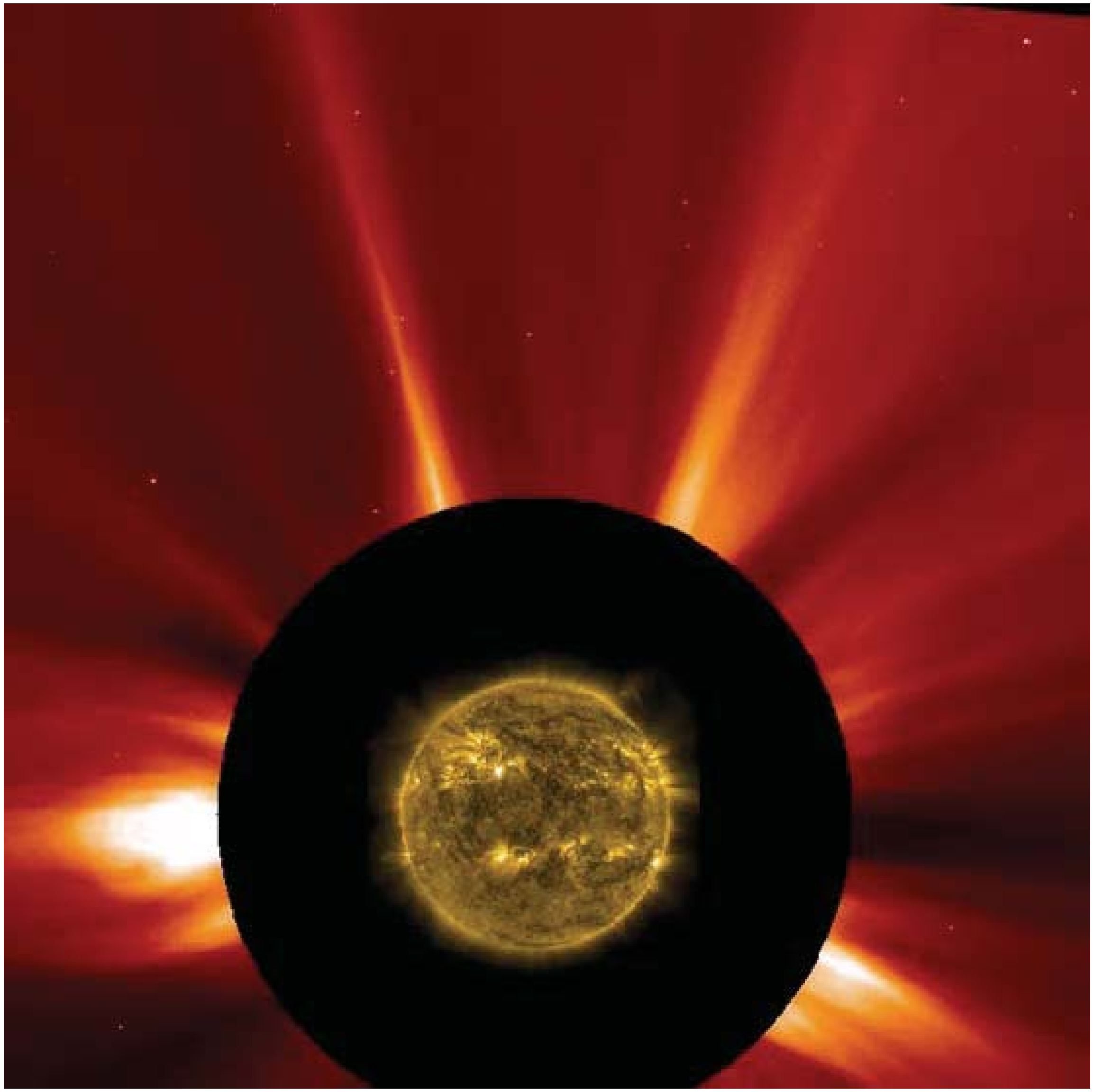
Solar Flares (A Space-Based Tour)



SDO / AIA

Solar Dynamics Observatory (SDO): http://sdo.gsfc.nasa.gov/

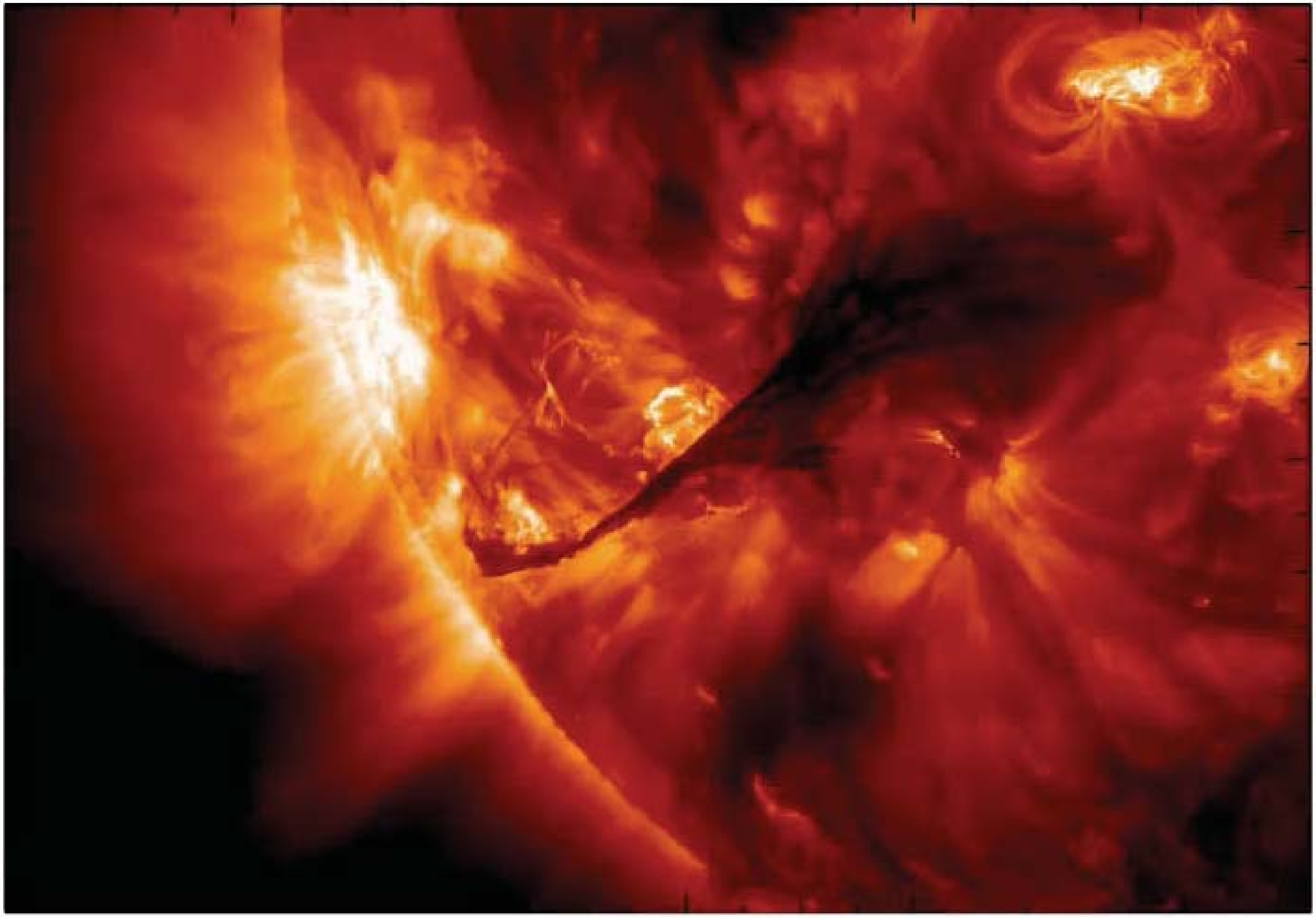
Solar Flares (A Space-Based Tour)



SDO / AIA + *SOHO* / LASCO

Solar Dynamics Observatory (SDO): http://sdo.gsfc.nasa.gov/ ; LASCO: http://lasco-www.nrl.navy.mil/

Solar Flares (A Space-Based Tour)

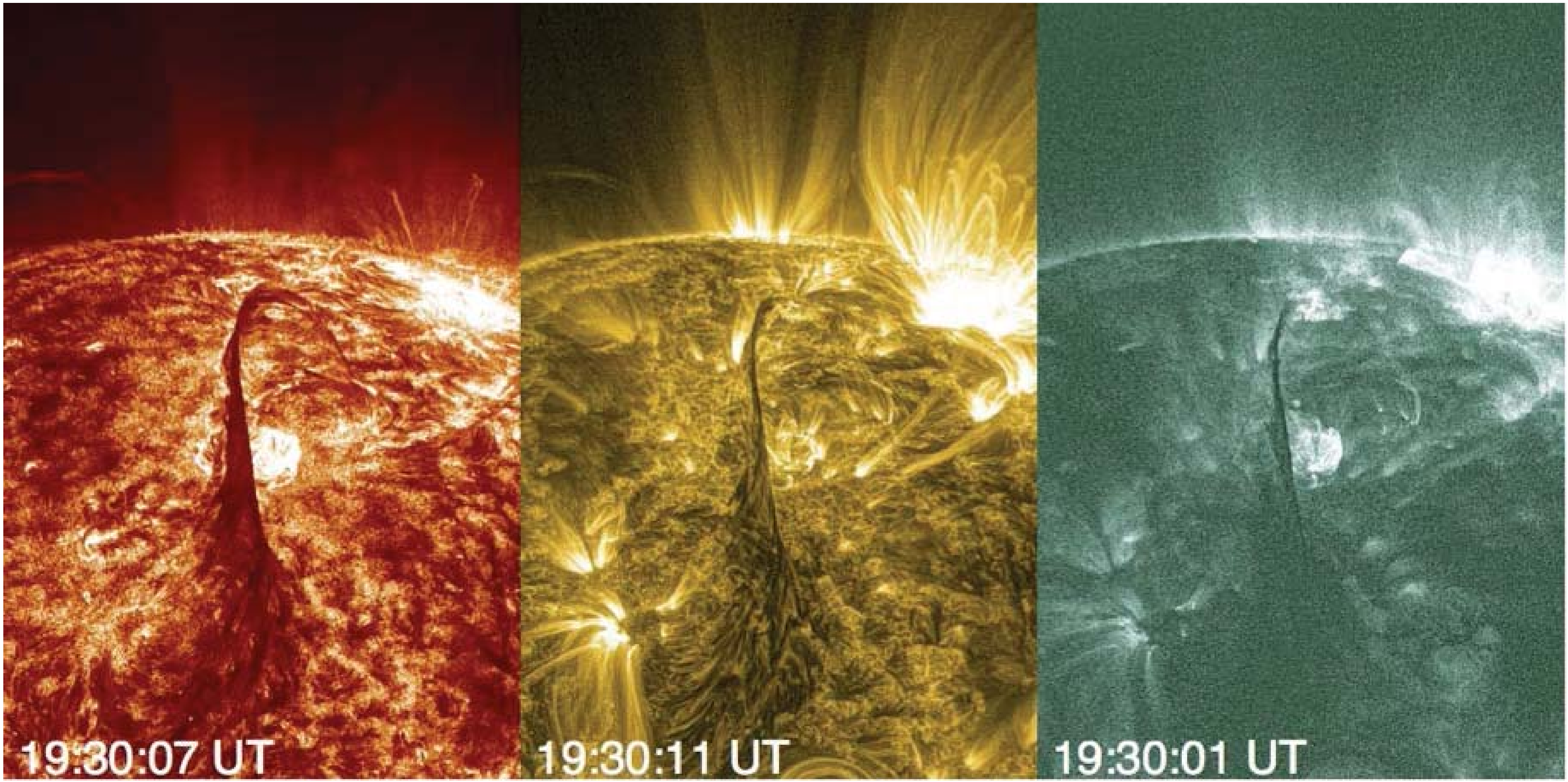


SDO / AIA + *Hinode* / EIS

Solar Dynamics Observatory (SDO): http://sdo.gsfc.nasa.gov/ ; EIS: http://solarb.mssl.ucl.ac.uk/SolarB/Solar-B.jsp

Solar Flares (A Space-Based Tour)

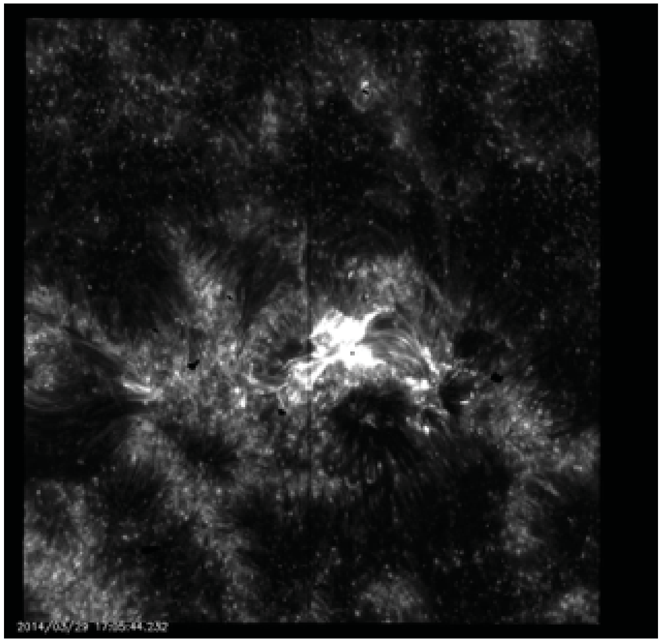
Same flare as previous slide but in 3 different AIA channels and enhanced for contrast.



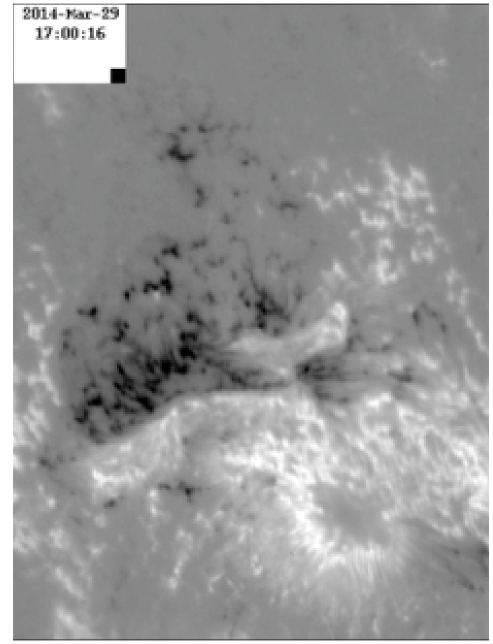
SDO / AIA

Solar Flares (A Space-Based Tour)

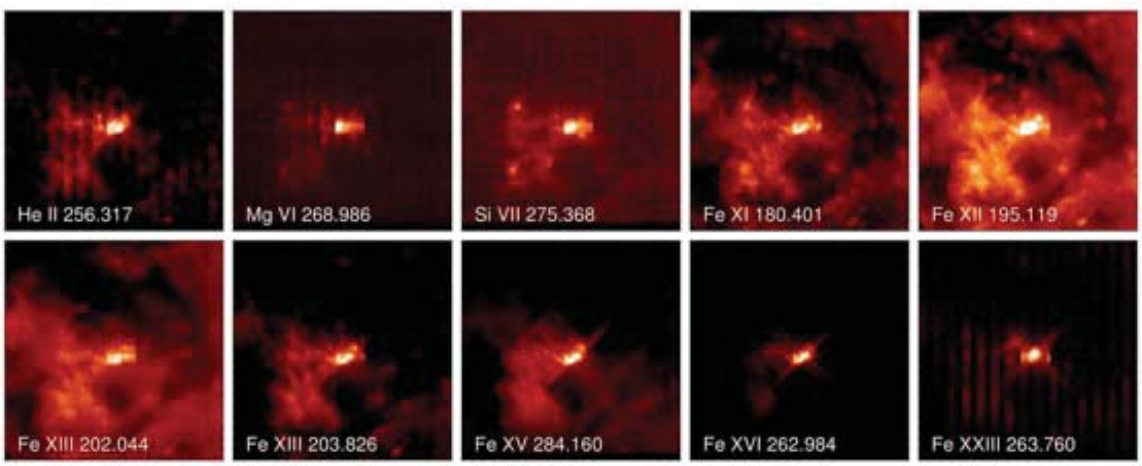
IRIS



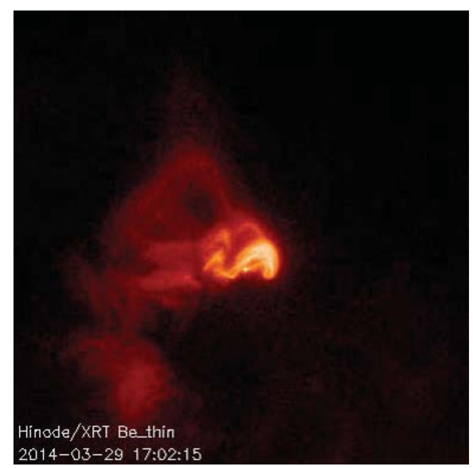
Hinode / SOT [Magnetogram]



Hinode / EIS



Hinode / XRT

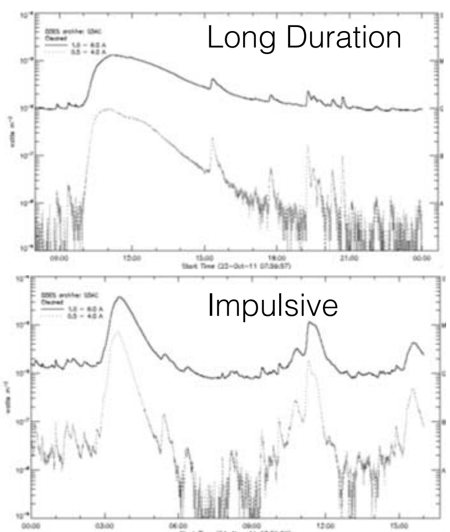


Interface Region Imaging Spectrograph (IRIS): http://iris.gsfc.nasa.gov/ ; Hinode: http://hinode.msfc.nasa.gov/

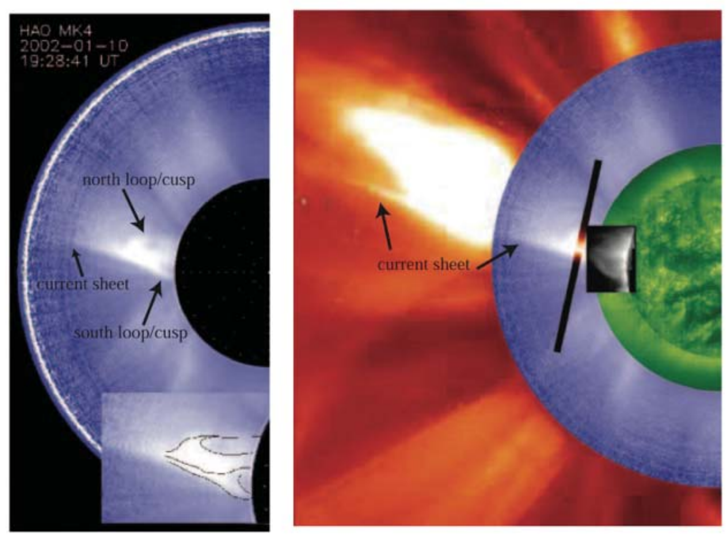
Investigating Energy Release

Focus on Long Duration Events

- Energy released for many hours
- Associated with Coronal Mass Ejections (CMEs)
- Development of current sheets and supra-arcade fans



Example GOES lightcurves



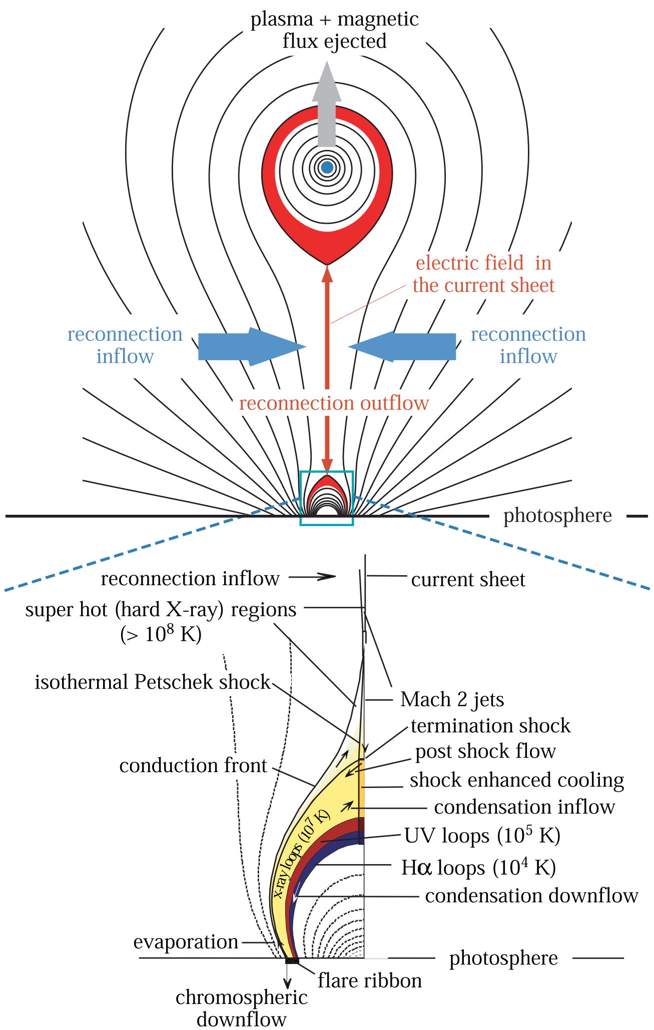
Ko et al. 2003

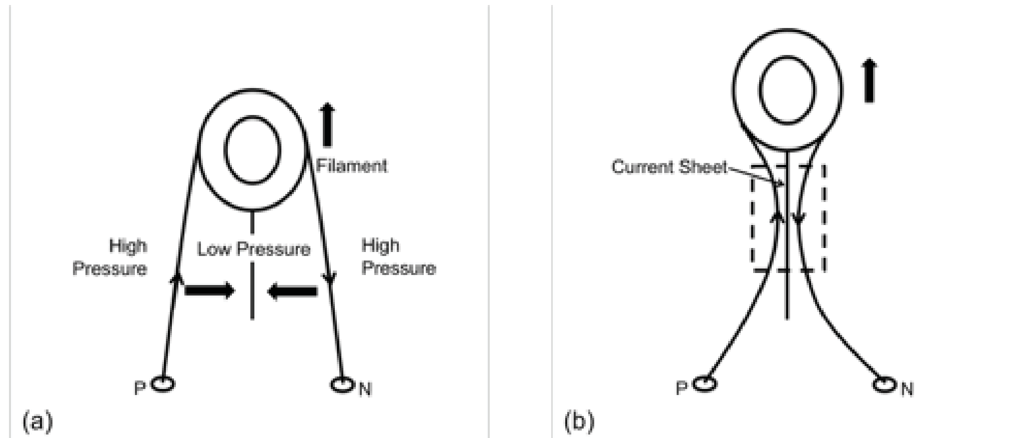
Savage & McKenzie 2011

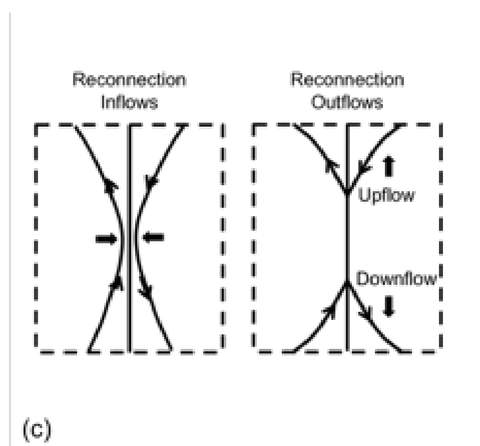
Geostationary Satellite Server (GOES) X-ray lightcurves: http://solarmonitor.org/goes_pop.php?date=20140410&type=xray

Investigating Energy Release

Standard **2-D** Flare Model







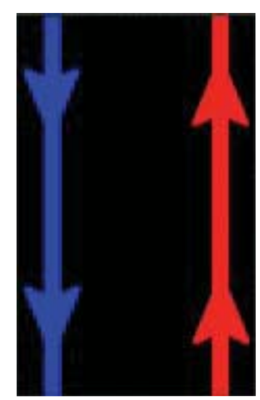


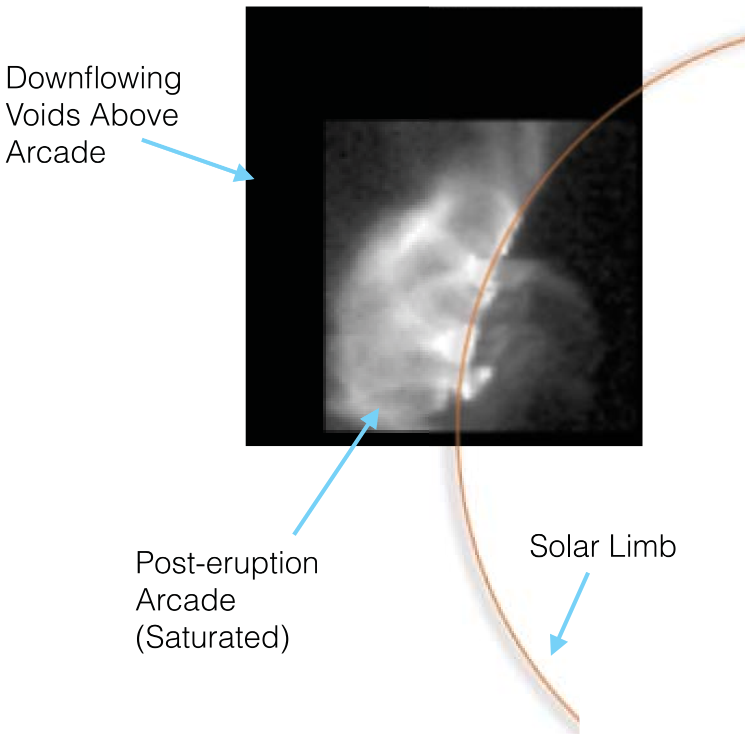
Image Credit: ESA

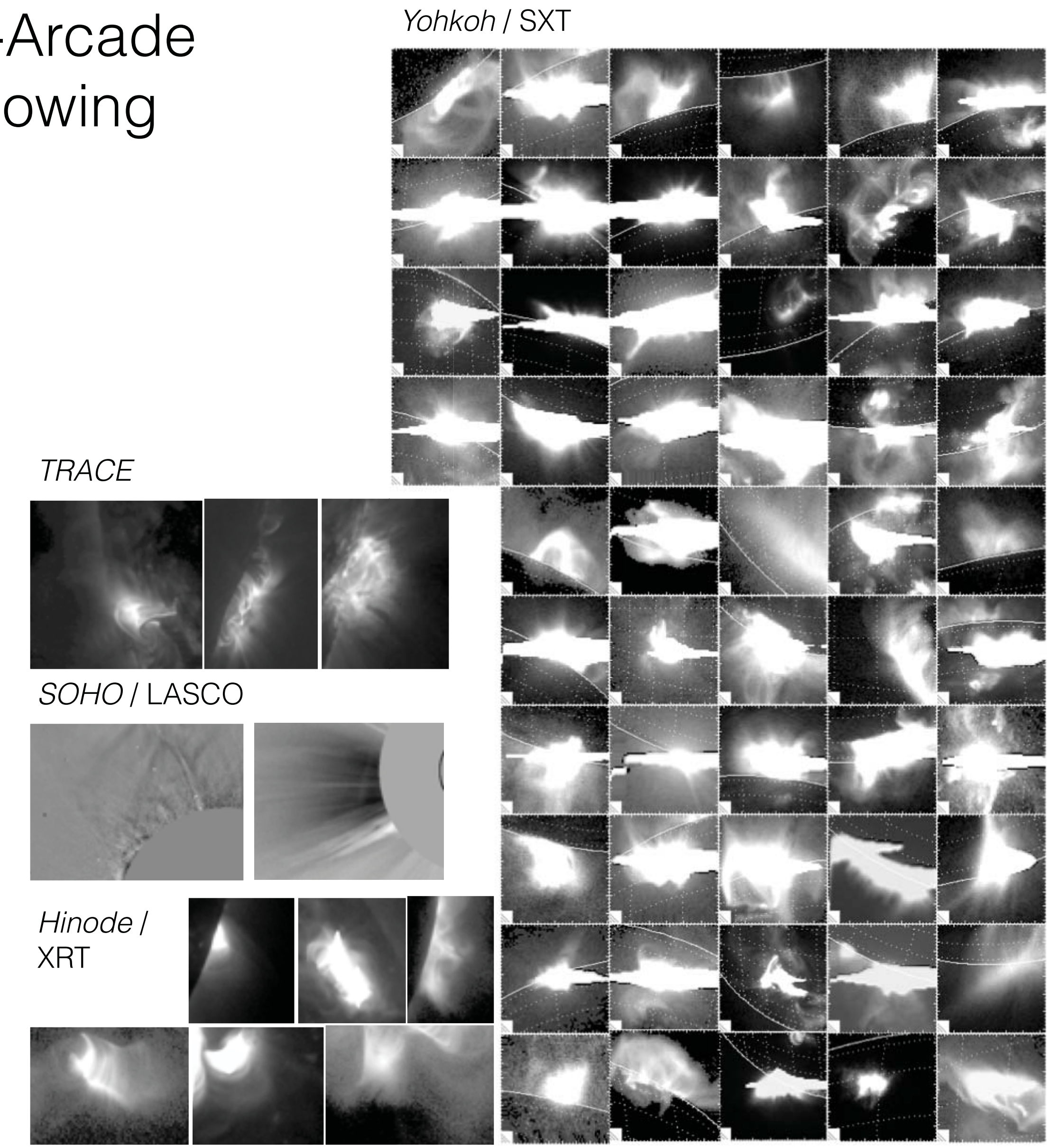
Updated CSHKP model: Forbes & Acton 1996; Lin & Forbes 2000; Ko et al. 2003

Investigating Energy Release

Early observations of Supra-Arcade Downflows (SADs) & Downflowing Loops (SADLs)

Yohkoh / SXT 1999 Jan 20

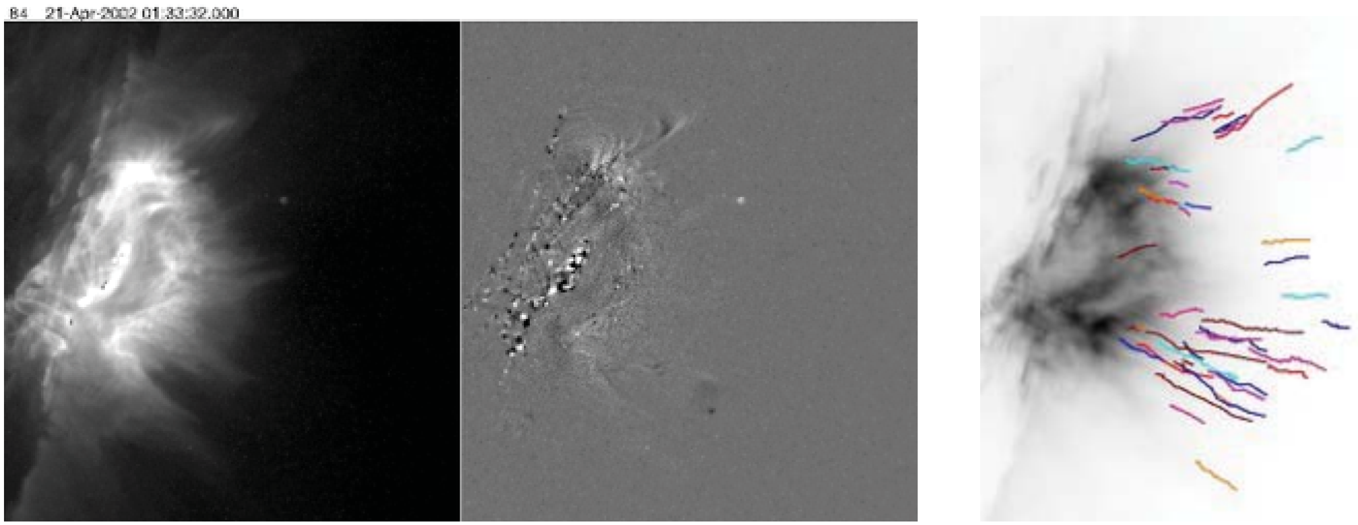




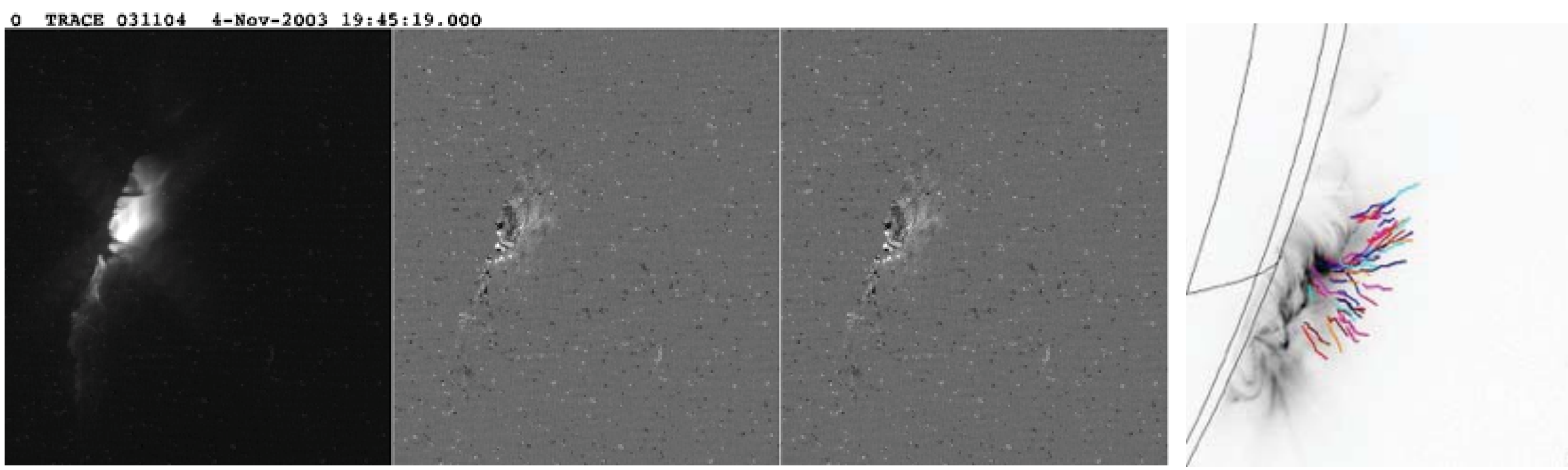
McKenzie & Hudson 1999; Khan et al. 2007; Savage & McKenzie 2011

Investigating Energy Release

TRACE 193 A, X-flare, 2002 Apr 21



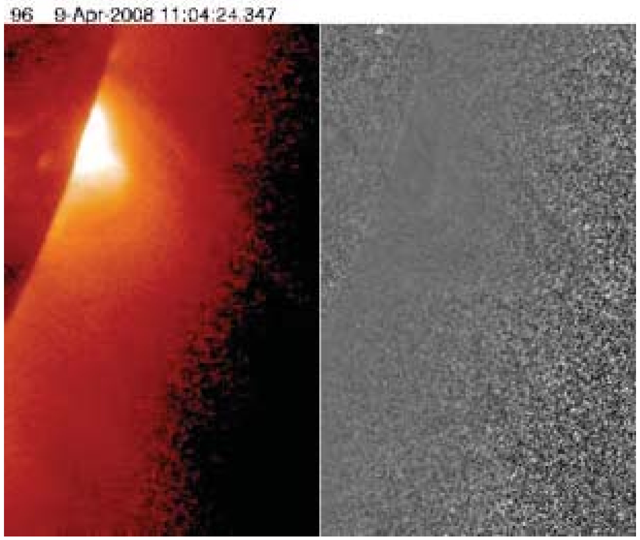
TRACE 193 A, X-flare, 2003 Nov 4

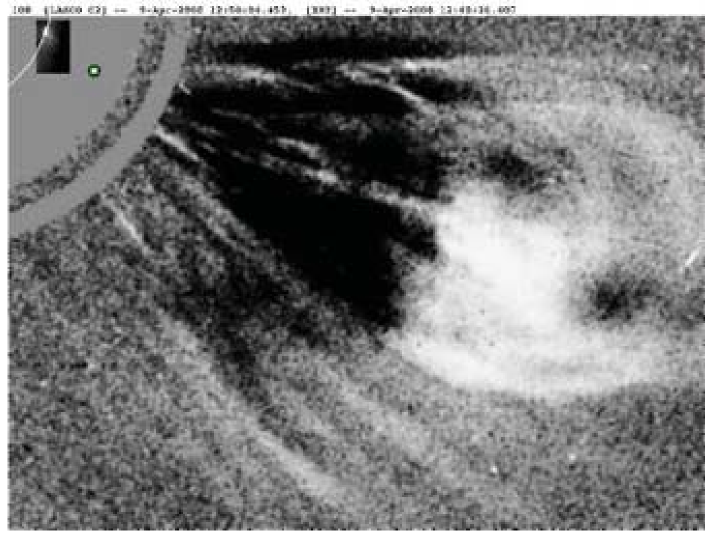


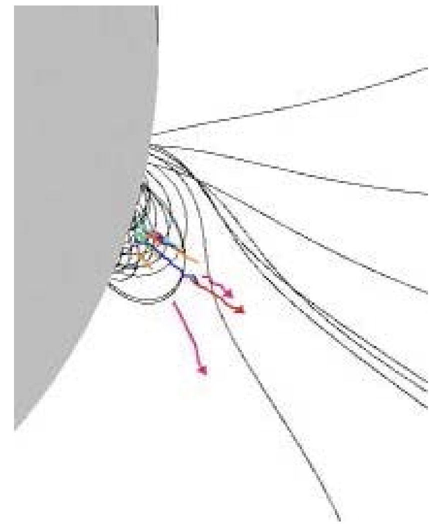
McKenzie & Savage 2009

Investigating Energy Release

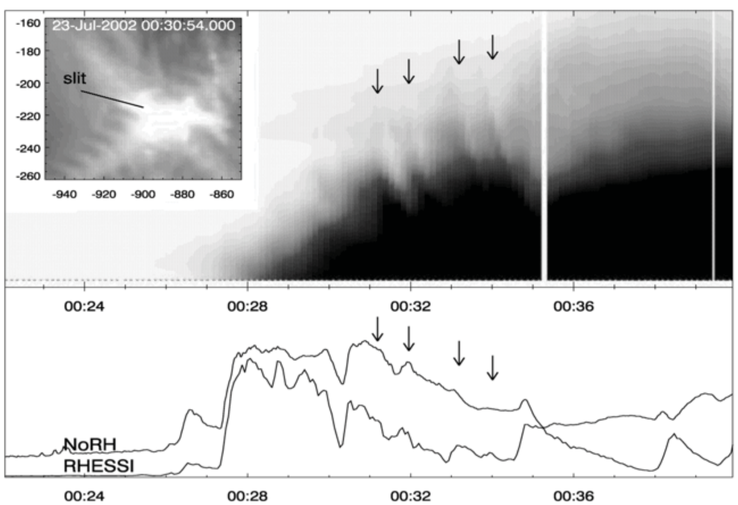
Hinode / XRT, 2008 Apr 9



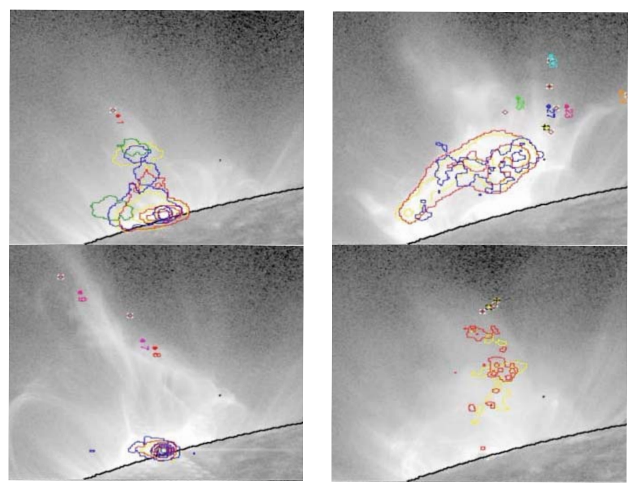




TRACE + *RHESSI* + NoRH radio (lightcurve), 2002 Jul 23



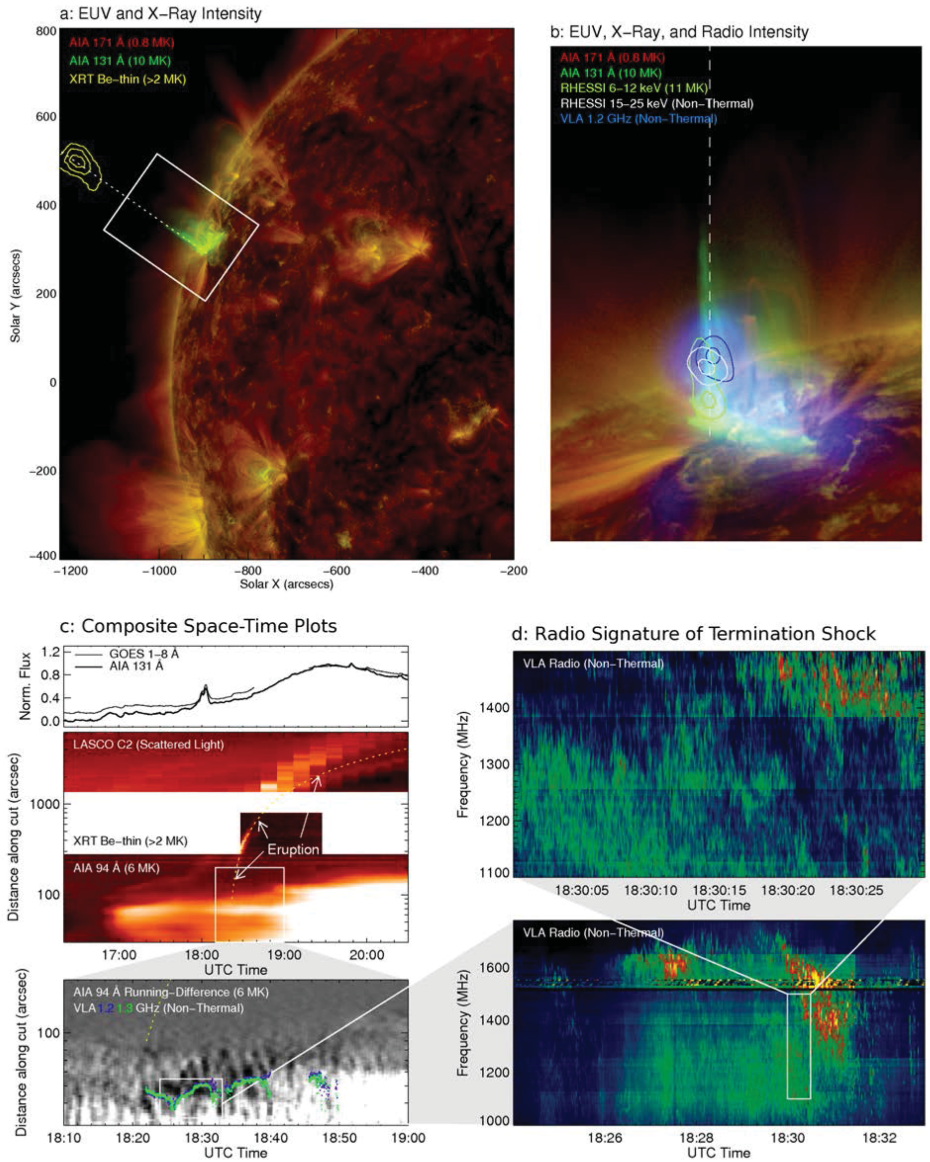
SDO / AIA + *RHESSI* (contours), 2010 Nov 3



And now RADIO!…

Savage et al. 2012; Savage et al. 2010; Asai et al. 2004; Yokoyama & Shibata 1999

Investigating Energy Release



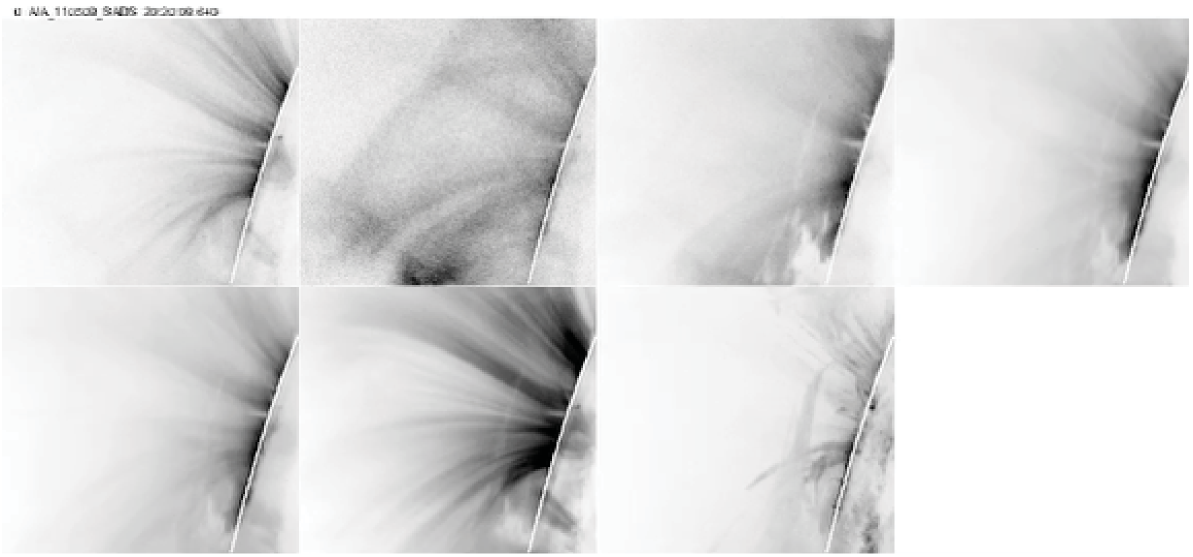
Jansky Very Large Array (VLA) observations:

D) Possible termination shocks at the arcade looptops.

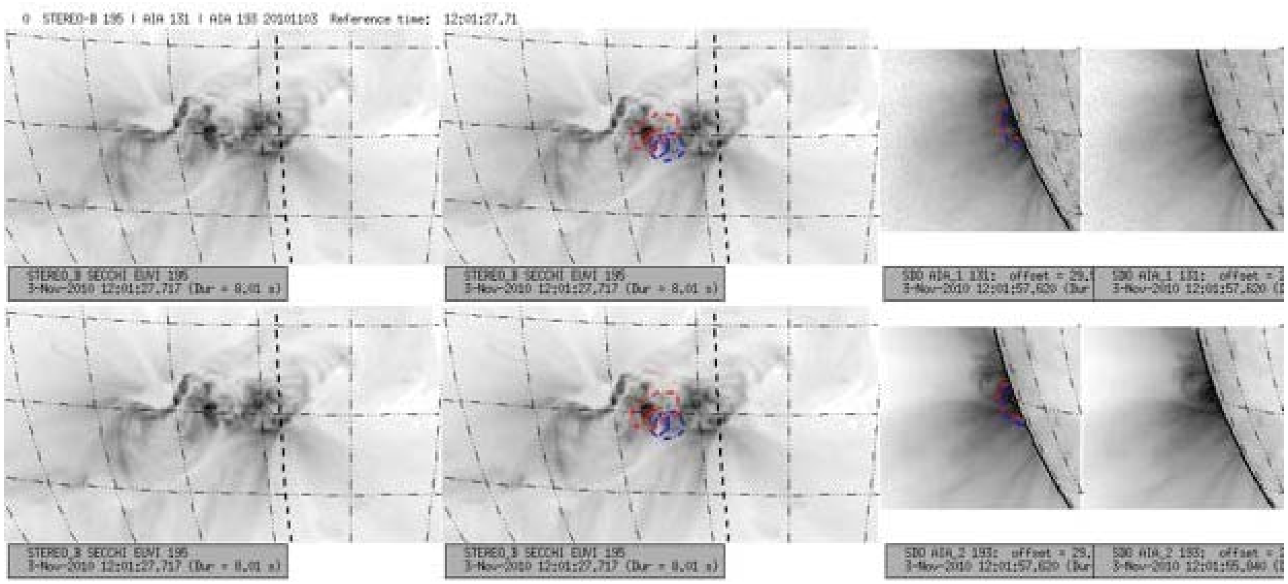
Savage et al. 2012; Savage et al. 2010; Asai et al. 2004; Yokoyama & Shibata 1999

Investigating Energy Release

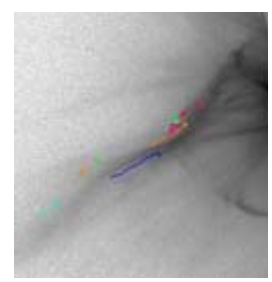
SDO / AIA, 2011 May 9



SDO / AIA + *STEREO* / SECCHI, 2010 Nov 3



Inflows
Composite



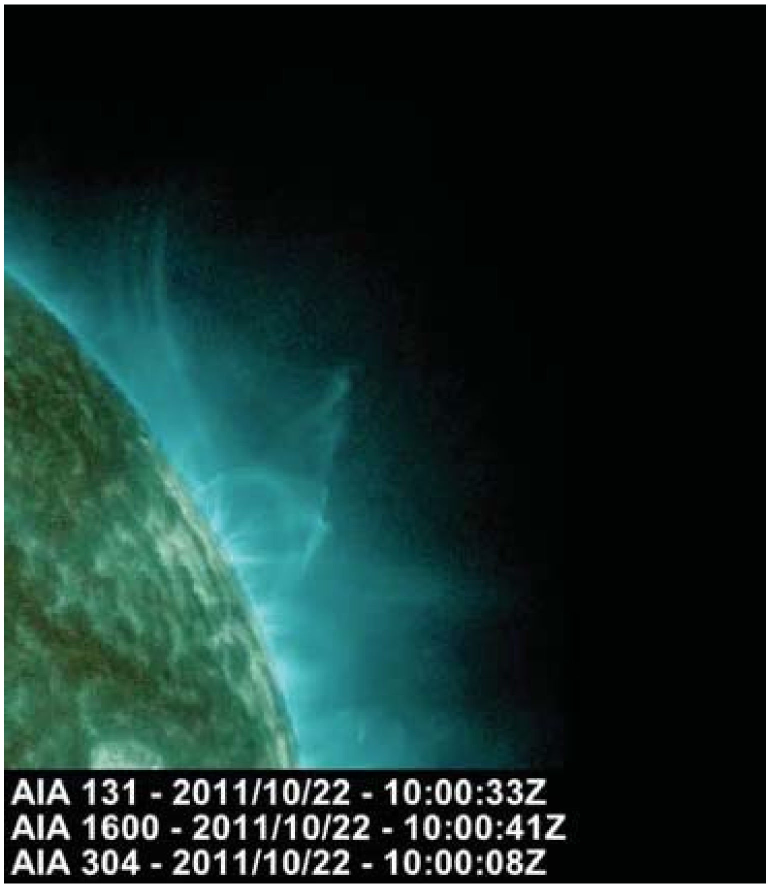
Outflows
131 A

Savage et al. 2012

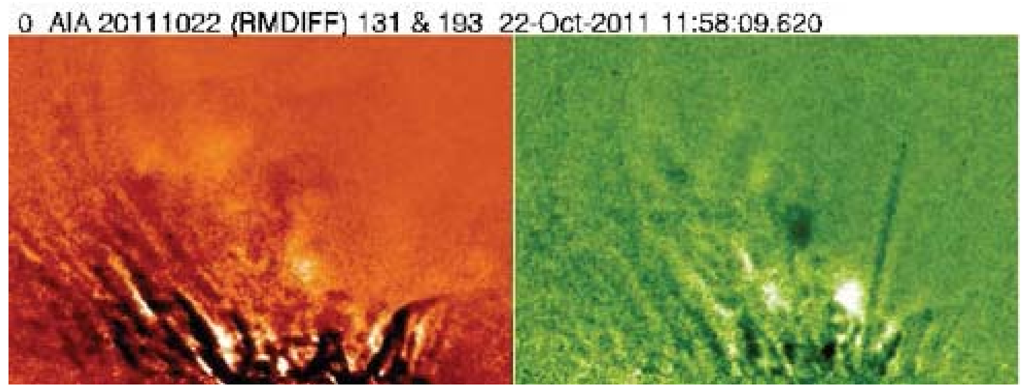
Investigating Energy Release

Explanation for SADs & SADLs converging …

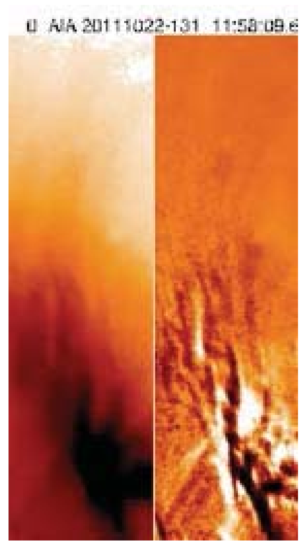
SDO / AIA, 2011 Oct 22

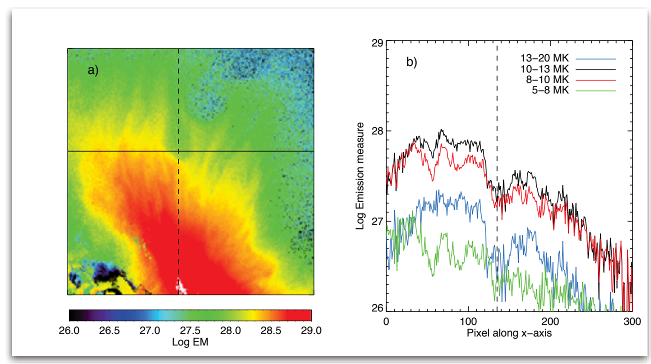


Movie Credit: D. E. McKenzie, Mont. State Univ



Bright thin loops retracting below voids.





SADs cooler than fan (and much less dense)

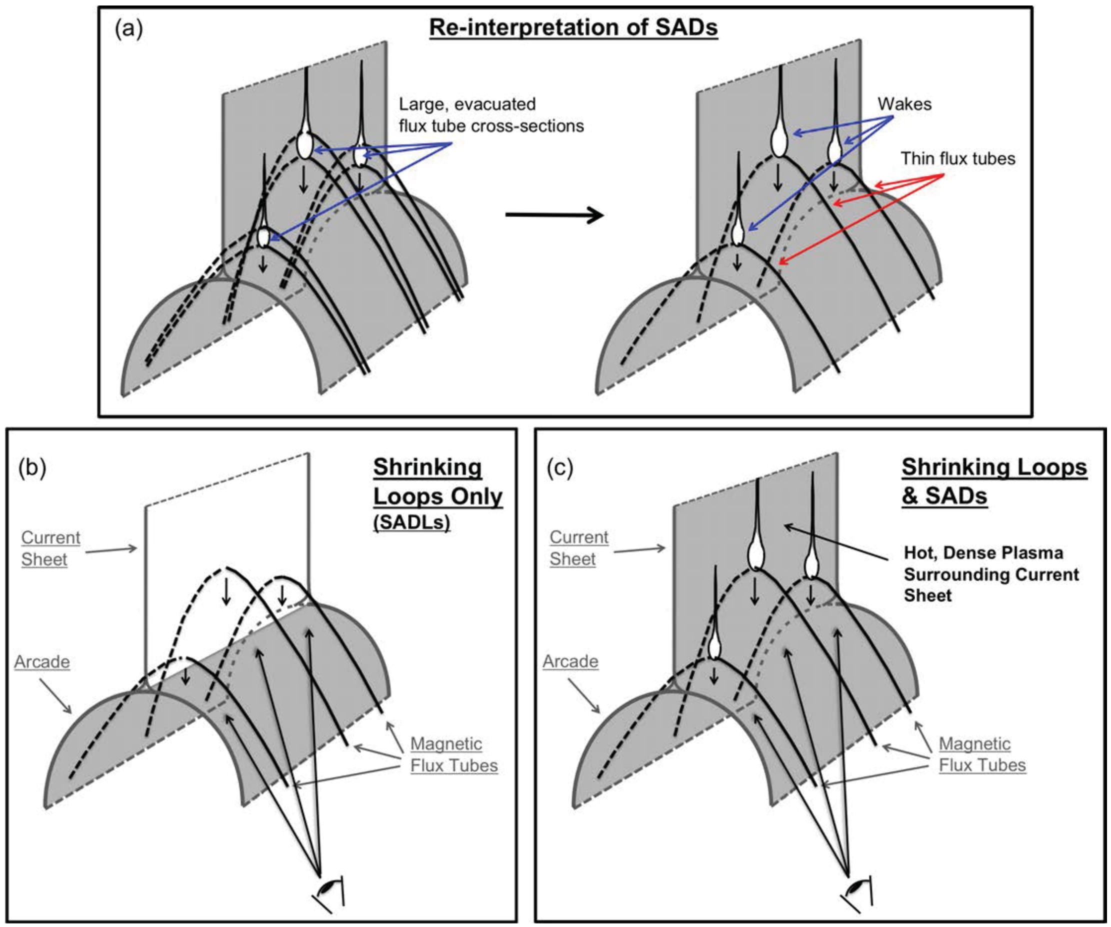
Savage, McKenzie, Reeves 2012

Investigating Energy Release

Explanation for SADs & SADLs converging …

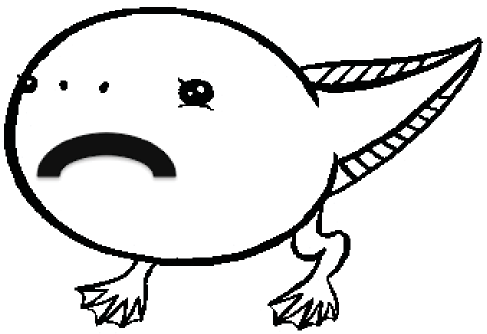
—> Loops outflows of patchy, bursty magnetic reconnection?!

—> Voids rarefaction regions behind retracting loops?



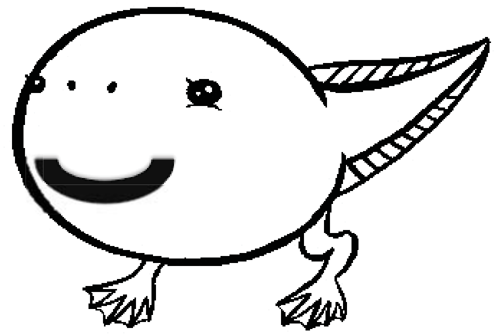
Savage, McKenzie, Reeves 2012 ; RHESSI nugget #168: http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/Supra-Arcade_Downflows

Sadpoles



?

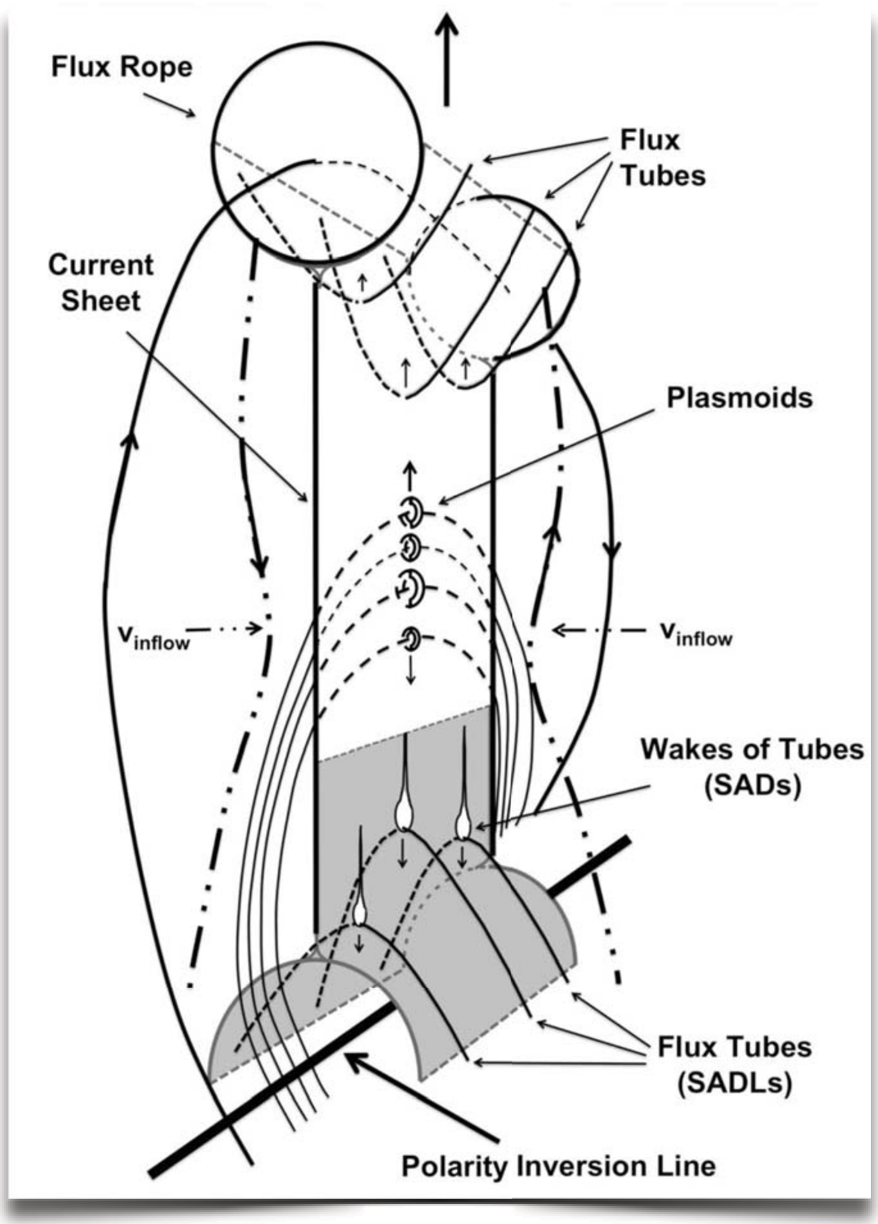
Happis



HAPPIs: High-Altitude Propagating Pressure Imbalances?

No references…. yet…

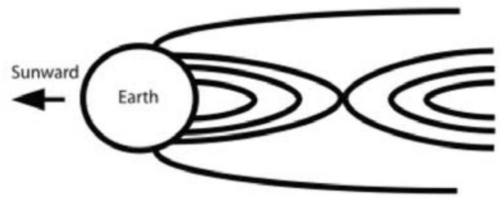
A Simplified **3-D** Solar Flare Model



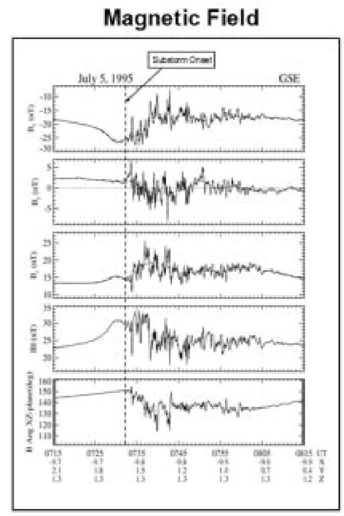
Savage et al. 2012

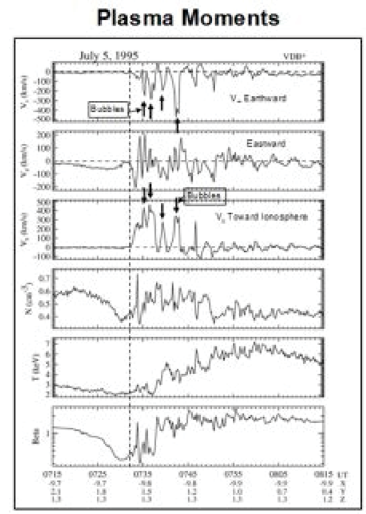
Observing Magnetic Reconnection

Solar flares comparable to Magnetotail substorms



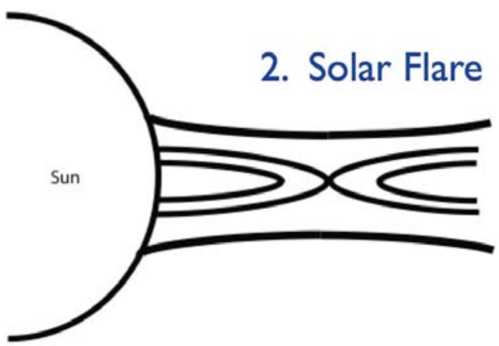
1. Magnetotail Substorm

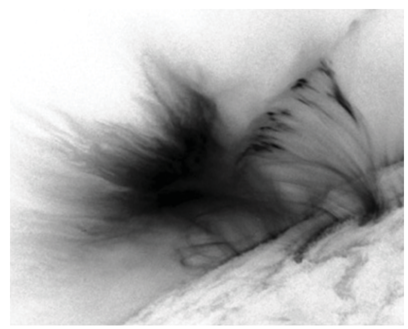




Magnetotail:

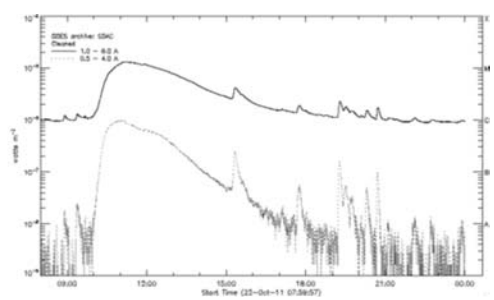
In Situ Measurements

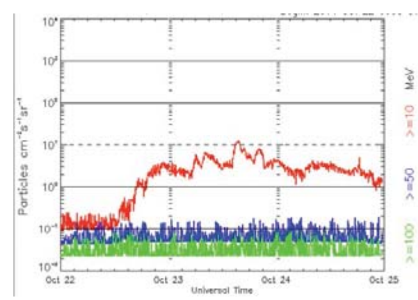




Solar:

Global Context

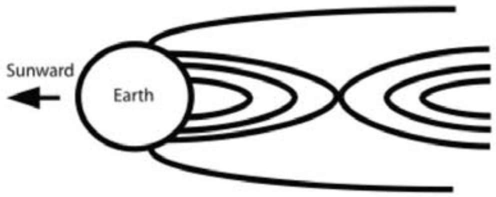




Note: Very different scales and plasma regimes. **BUT COMPARABLE ALFVEN SPEEDS!**

Reeves et al. 2008

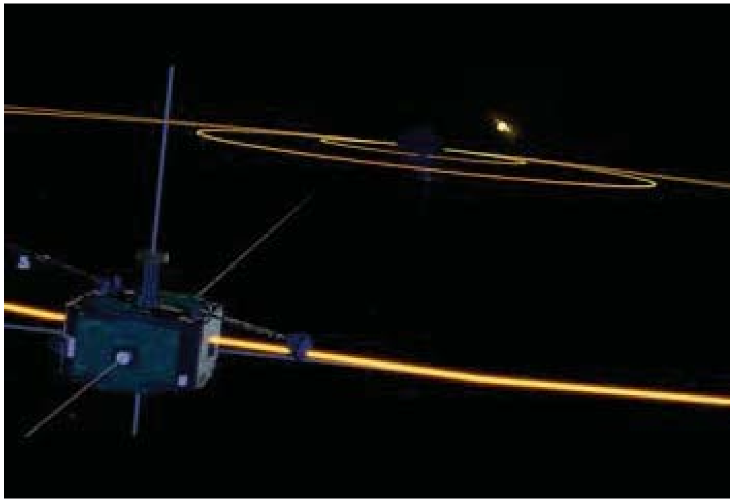
Observing Magnetic Reconnection

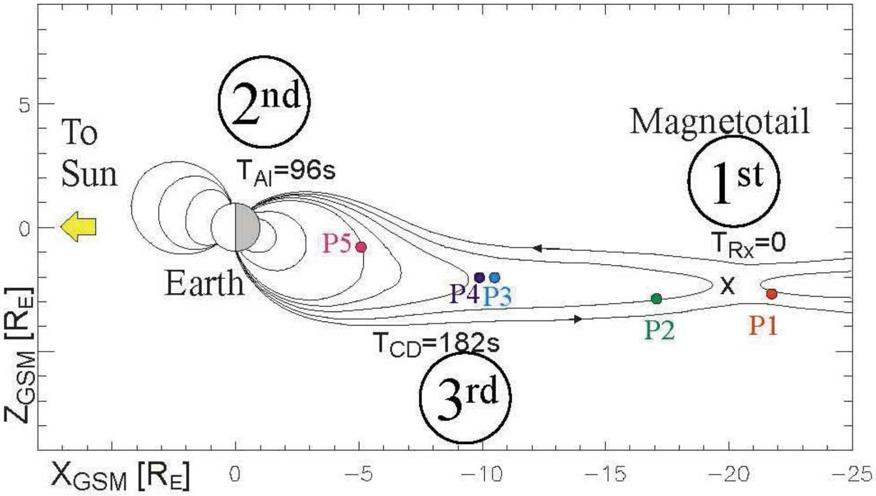


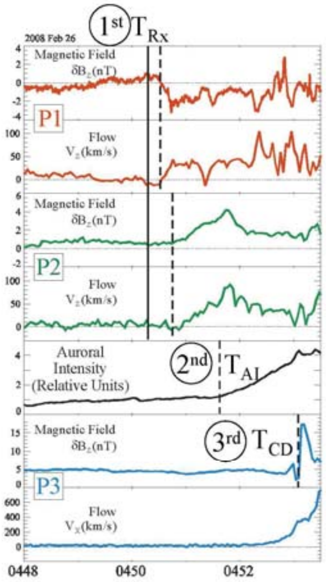
I. Magnetotail Substorm

THEMIS:

Constellation of satellites
Measure B, E, density, etc.

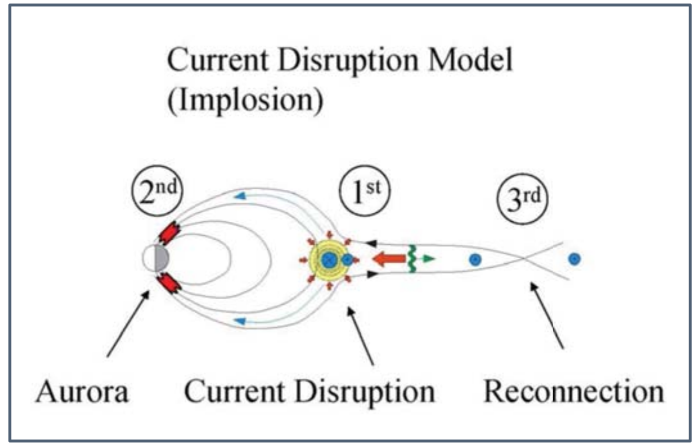


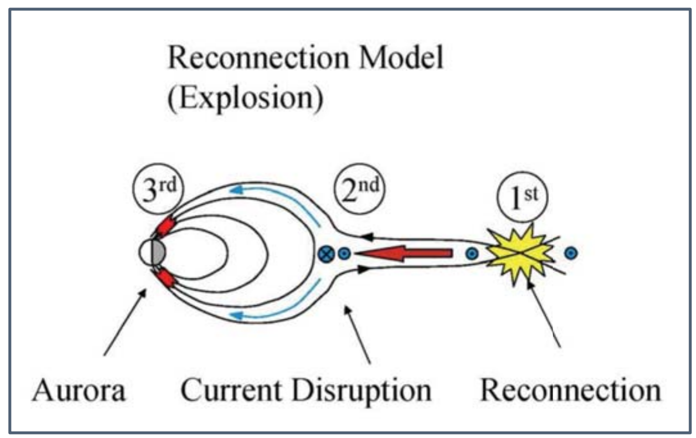




Observing Magnetic Reconnection

1. Magnetotail Substorm

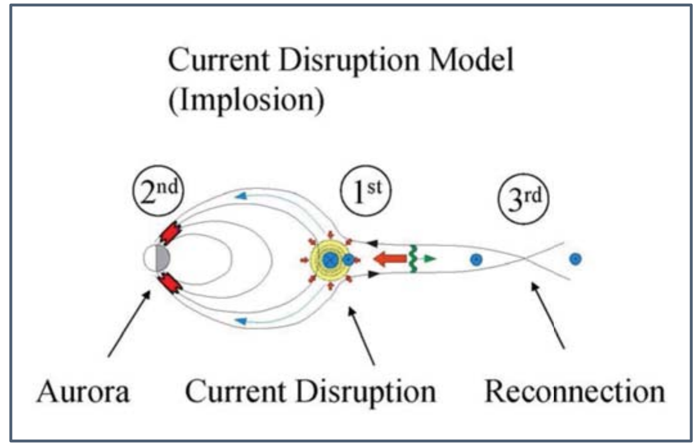


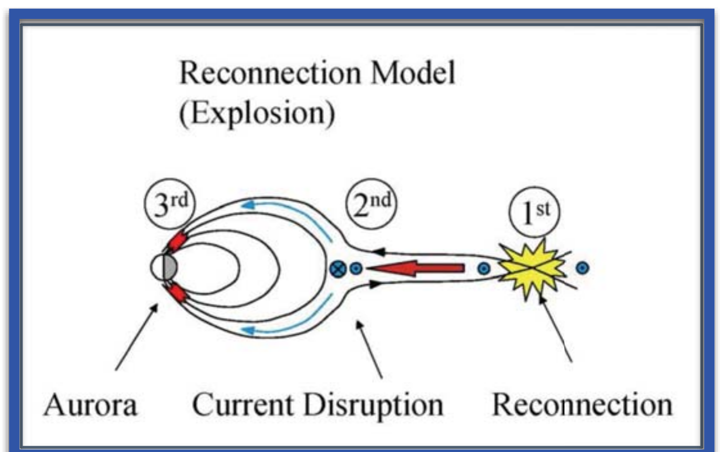


Angelopoulos et al. 2008

Observing Magnetic Reconnection

1. Magnetotail Substorm





Akin to Solar Flares!!

Angelopoulos et al. 2008

SDO 2nd Year Highlights

Goddard Multimedia: http://svs.gsfc.nasa.gov/vis/a010000/a010900/a010966/index.html