Solar Flares
The Great American Solar Eclipse
August 21, 2017

What is a Solar Eclipse?
A solar eclipse happens when the Moon, as it orbits Earth, fully or partially blocks the light of the Sun, thus casting its shadow on Earth. Observers within the path of totality can expect to see something like the image below, whereas outside the path of totality will see the Sun partially eclipsed as a crescent Sun (with safe filters).

After the 2017 solar eclipse, the next total solar eclipse visible over the continental United States will be on April 8, 2024.

If the Sun is scaled to about 10 cm (3.9 in), Earth would be about 10 meters away (33 feet).

The predicted path of the August 21, 2017 solar eclipse
Duration of Greatest Eclipse: 2 min 40 sec (18:25 UT to 19:25 CDT or 1:25 p.m. CDT)
Location Greatest Eclipse: 36 deg 56 min N; 87 deg 40 min W (between Princeton and Hopkinsville, KY)
Path Width: approximately 115 km
Eclipse Predictions by Fred Espenak, GSFC, NASA-emeritus

Never look directly at the Sun unless you have filters that you know are safe.
For more information:
For more information about solar eclipses:
http://eclipse.gsfc.nasa.gov/solar.html
http://eclipsewise.com/solar
http://eclipse2017.org/

The NASA image above shows the Moon’s umbral shadow as seen from the International Space Station during the total solar eclipse on 29 March 2006.

Mitzi Adams • mitzi.adams@nasa.gov • 256-961-7626

www.nasa.gov
Heliophysics System Observatory (HSO)

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

The Sun in Layers

Converting 4 million tons of matter into energy every second.

Core is as dense as lead.

Interplay between magnetic pressure and gas (plasma) pressure.

“Mysteries of the Sun”: NASA / Jenny Mottar

Sun Facts: http://solarscience.msfc.nasa.gov/
The Sun in Layers

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

"Mysteries of the Sun": NASA / Jenny Mottar

European Space Agency (ESA)

Smithsonian Astrophysical Observatory (SAO)
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 Å

193 Å

131 Å

SDO / AIA
2014 Apr 13 - 15

JHelioviewer — Explore the Sun: http://jhelioviewer.org/
Sunspots & Active Regions

Hinode SOT: NASA / JAXA / NAOJ
Magnetic fields ~ 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

SOT (Ca H-line); 2006 Nov 20
Sunspots & Active Regions

Hinode / SOT: Disk crossing of AR 12192, the largest sunspot group to appear on the Sun in 25 years.
Sunspots & Active Regions

JHelioviewer SDO / AIA 2014 Apr 04

SOHO animation gallery

Sunspots & Active Regions

Solar Dynamics Observatory (GSFC) Jewel Box: http://svs.gsfc.nasa.gov/vis/a000000/a004100/a004117/
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 (9-14 years)

Yohkoh / SXT, ~ Full cycle

Hinode / XRT, ~ Half cycle

Hinode / EIS, ~ Half cycle

Hinode / XRT 2007 - 2012

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

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

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

1959 Carrington Event
Largest Geomagnetic storm recorded

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


Impacts of Space Weather

Impacts of Space Weather

SOHO Large Angle and Spectrometric Coronagraph Experiment (LASCO)

Image credit: NASA & L. Lanzerotti (NJIT)

Impacts of Space Weather

SOHO Large Angle and Spectrometric Coronagraph Experiment (LASCO)


Image credit: NASA
# Solar Flares (A Space-Based Tour)

<table>
<thead>
<tr>
<th>Skylab</th>
<th>Yohkoh / SXT</th>
<th>SOHO / EIT+LASCO</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Skylab" /></td>
<td><img src="image2" alt="Yohkoh/SXT" /></td>
<td><img src="image3" alt="SOHO/EIT+LASCO" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRACE</th>
<th>HINODE / SOT</th>
<th>HINODE / XRT</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4" alt="TRACE" /></td>
<td><img src="image5" alt="HINODE/SOT" /></td>
<td><img src="image6" alt="HINODE/XRT" /></td>
</tr>
</tbody>
</table>

Skylab SP-402 The Active Sun: [http://history.nasa.gov/SP-402/ch7.htm](http://history.nasa.gov/SP-402/ch7.htm)
Solar Flares (A Space-Based Tour)

Hinode / XRT:  http://xrt.cfa.harvard.edu

Hinode / XRT:  http://xrt.cfa.harvard.edu
Solar Flares (A Space-Based Tour)

Solar Flares (A Space-Based Tour)

Solar Dynamics Observatory (SDO): http://sdo.gsfc.nasa.gov/
Solar Flares (A Space-Based Tour)

**SDO / AIA + SOHO / LASCO**

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 Flares (A Space-Based Tour)

SDO / AIA + Hinode / EIS

Solar Flares (A Space-Based Tour)

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

SDO / AIA

Solar Dynamics Observatory (SDO): http://sdo.gsfc.nasa.gov/
Solar Flares (A Space-Based Tour)

Investigating Energy Release
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

Investigating Energy Release

Standard 2-D Flare Model

Investigating Energy Release

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

Yohkoh / SXT 1999 Jan 20

Downflowing Voids Above Arcade

Post-eruption Arcade (Saturated)

Solar Limb

TRACE

SOHO / LASCO

Hinode / XRT

Yohkoh / SXT
Investigating Energy Release

TRACE 193 A, X-flare, 2002 Apr 21

TRACE 193 A, X-flare, 2003 Nov 4
Investigating Energy Release

Hinode / XRT, 2008 Apr 9

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

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

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

Explanation for SADs & SADLs converging …

SDO / AIA, 2011 Oct 22

Bright thin loops retracting below voids.

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

SADs cooler than fan (and much less dense)
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:  
High-Altitude Propagating Pressure Imbalances?

What's the [X:]point?

-> High-Altitude Propagating Pressure Imbalances?
*Long-lived, highly extended* phenomena

SADs in the lower corona are typically observed well after reconnection has occurred.

In the extended corona, we are better able to observe the migrating reconnection sites.
Observing Magnetic Reconnection

Solar flares comparable to Magnetotail substorms

1. Magnetotail Substorm

2. Solar Flare

Note: Very different scales and plasma regimes.

Reeves et al. 2008
A Simplified 3-D Solar Flare Model

Strong potential analogy with magnetotail substorms

Savage et al. 2012
Observing Magnetic Reconnection

Substantial density drop following the dipolarization event!
Observing Magnetic Reconnection

Figure 4. Values of $V_x$ in the equatorial plane and in the $XZ$ plane located along the flow extraction points in Figure 2 ($Y = -7.5R_E$) at 05:00 ST are shown with divergent blue/red color table. A set of white field lines near the location of the BBF is plotted. The grey isosurfaces are drawn for values of $B_x = 0$ providing an illustration of the warping of the current sheet. The vector glyphs show plasma flow direction and are shaded with magnitude of the flow velocity.

that we see a depletion of the flux tube entropy in the region of the flow burst as seen by Birn et al. [2011] and reported in the LFM-RCM simulations of Pembroke et al. [2012]. Another important point evident from Figure 3 is that both plasma and field compression in front of the high-speed flow intensify as the structure moves closer to the Earth. Since the dipole field contribution is negligible (as is clear from the low $B_Z$ values earthward of the $B_Z$ peak), this is not a pileup process caused by breaking of the flow which can be important much closer to the Earth [Shiokawa et al., 1997]. Instead, the field and plasma appear to be piled up in front of the high-speed flow that compresses them as a piston.

3.2. Superposed Epoch Analysis

Using Geotail observations between October 1993 and July 2001, Ohtani 2004 analyzed fast flow events in the magnetotail between $-5R_E$ and $-31R_E$ along the GSM $X$ axis and within $\pm 15R_E$ GSM $Y$. For fast earthward flows they defined the zero epoch time as the time when the $V_{\perp X}$ was below 200 km/s before it exceeded a value of 300 km/s. They also required the ion beta, $\beta_i$, to be greater than 0.5 in the 10 min prior to the zero epoch time in order to ensure that the spacecraft was located within the plasma sheet during the observed high-speed flow. This data set contains 818 earthward flow events. In order to construct a similar analysis of the LFM simulation results, we begin by extracting data from the $Z = 0R_E$ and $1R_E$ planes every 5 $R_E$ in $X$ between $-5$ and $-40R_E$ with a 1 $R_E$ spacing in $Y$ between $\pm 15R_E$. Since the simulation contains no dipole tilt, no $\beta_i$ check is required to ensure that the data are from the simulated plasma sheet. The relatively flat nature of the $B_x = 0$ isosurface in Figure 4 further supports this conclusion. The data are extracted from every dump file in the simulation interval from 04:30 to 06:00 ST. No attempt is made to correlate observations between points extracted from the LFM simulation. The SEA data set resulting from the LFM simulation contains 441 events in the $Z = 0$ plane and 185 events in the $Z = 1$ plane. As a side note we point out that while the simulation has no dipole tilt and purely southward IMF, the plasma sheet may not be completely symmetric about the equator due to, for instance, the development of kink-type modes [Korovinskiy et al., 2013]. Furthermore, the gradients in the Hall conductance arising from the day-night asymmetries present in the EUV conductance and more importantly the auroral oval produced by the empirical electron precipitation model will lead to breaking of dawn-dusk symmetry within the simulation.

Figure 5 shows a comparison between the SEA presented in Figure 3 of Ohtani 2004 and the results of the LFM simulation with Ohtani 2004 results in Figures 5a, 5d, and 5g and the LFM results in Figures 5b, 5c, 5e, 5f, 5h, and 5i. Figures 5a–5c contain the velocity data, Figures 5d–5f contain the magnetic field data, and Figures 5g–5i contain the density data. It is important to point out that unlike the velocity and magnetic field plots which share the same extent for the $Y$ axis, the Geotail data in Figure 5g have a much smaller $Y$ axis range than the LFM density data displayed in Figures 5h and 5i.

The Geotail data in Figure 5a show the perpendicular velocity rising rapidly in the minutes before the zero epoch time reaching a peak velocity of $\approx 300$ km/s after the zero epoch time and then returning within 5 min to velocity values seen before the BBF event. The parallel velocity is slightly larger than the perpendicular velocity before the event but only undergoes a very small increase during the BBF event. In the LFM data WILTBERGER ET AL. HIGH-RES MHD BBF SIMULATION 4562
Role of Marshall Space Flight Center
Role of Marshall Space Flight Center

We build and operate instruments and experiments in space!
Hi-C

Active Region 11520
July 11, 2012

22 publications for 5 minutes of data!

Science highlights:

Braided loops triggering energy release through magnetic reconnection (*Cirtain et al. 2013, Nature*)

Subflare triggers
Nanoflare heating
Loop sub-structure
Moss dynamics
Penumbral jets
Flows along filament threads
MHD waves
Sounding Rockets for Technology Development

CLASP sounding rocket launch
Role of Marshall Space Flight Center

Hi-C II rocket launch at White Sands Missile Range, New Mexico.
The Great American Solar Eclipse
August 21, 2017

What is a Solar Eclipse?
A solar eclipse happens when the Moon, as it orbits Earth, fully or partially blocks the light of the Sun, thus casting its shadow on Earth. Observers within the path of totality can expect to see something like the image below, whereas outside the path of totality will see the Sun partially eclipsed as a crescent Sun (with safe filters).

After the 2017 solar eclipse, the next total solar eclipse visible over the continental United States will be on April 8, 2024.

If the Sun is scaled to about 10 cm (3.9 in), Earth would be about 10 meters away (33 feet).

The predicted path of the August 21, 2017 solar eclipse
Duration of Greatest Eclipse: 2 min 40 sec
(18:25 UT=13:25 CDT or 1:25 p.m. CDT)
Location Greatest Eclipse:
36 deg 58 min N; 87 deg 40 min W
(between Princeton and Hopkinsville, KY)
Path Width: approximately 115 km
Eclipse Predictions by Fred Espenak, GSFC, NASA-emeritus

Never look directly at the Sun unless you have filters that you know are safe.
For more information:
For more information about solar eclipses:
http://eclipse.gsfc.nasa.gov/solar.html
http://eclipsewise.com/solar
http://eclipse2017.org/

The NASA image above shows the Moon’s umbral shadow as seen from the International Space Station during the total solar eclipse on 29 March 2006.

Mitzi Adams • mitzi.adams@nasa.gov • 256-961-7626

www.nasa.gov
Thanks!

National Aeronautics and Space Administration (NASA):  http://www.nasa.gov/