

Flows, Gusts, and Blasts from the Sun:

the

Nature of the Beast

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ST13

for the

Alabama Power Grid Defense Conference

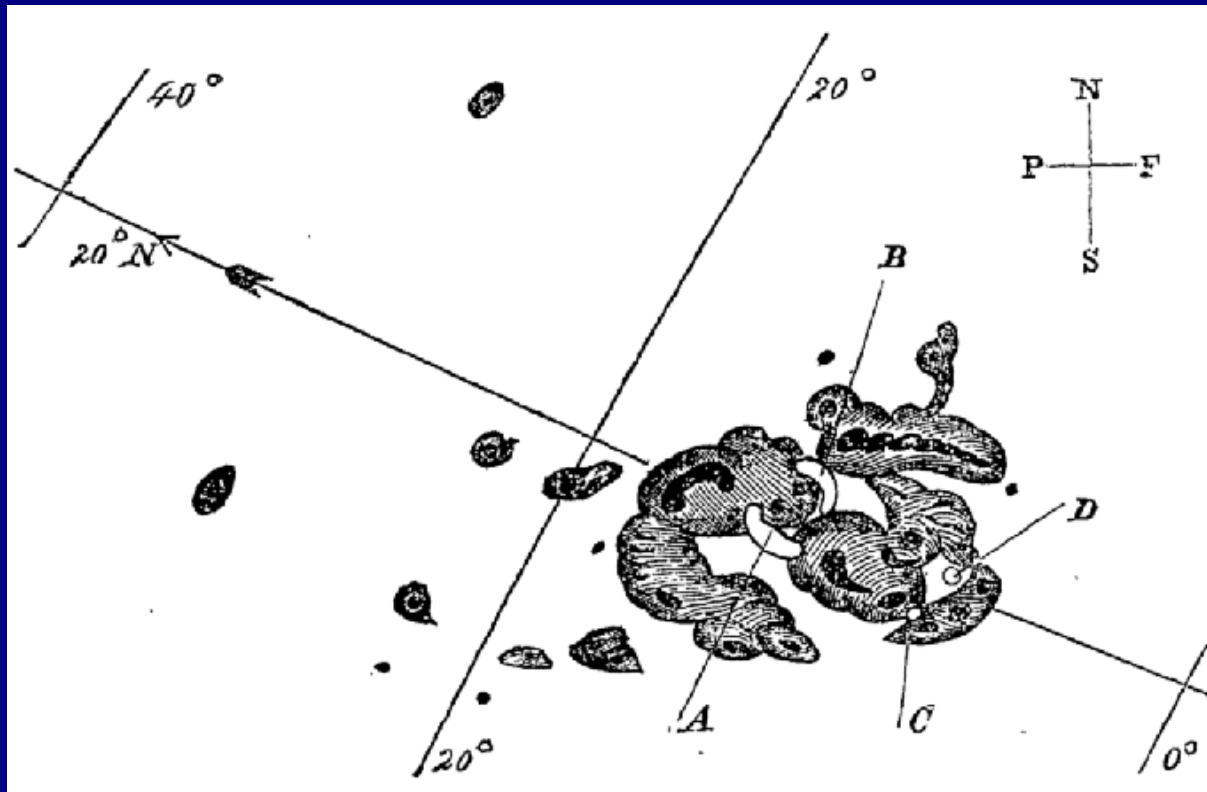
August 10, 2018

Flow of the Talk

- A Wee bit of History
- What is the Sun?
- Sunspots and the Solar Cycle
- Solar Eruptions

August 28 - September 2, 1859

The Carrington Event (and Richard Hodgson)

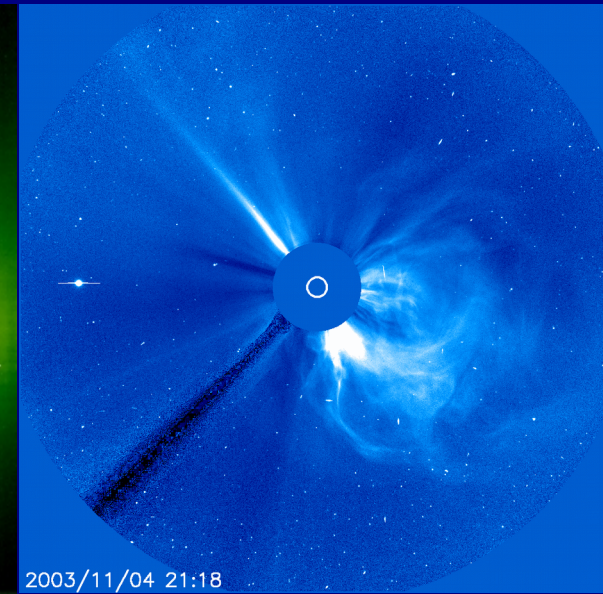
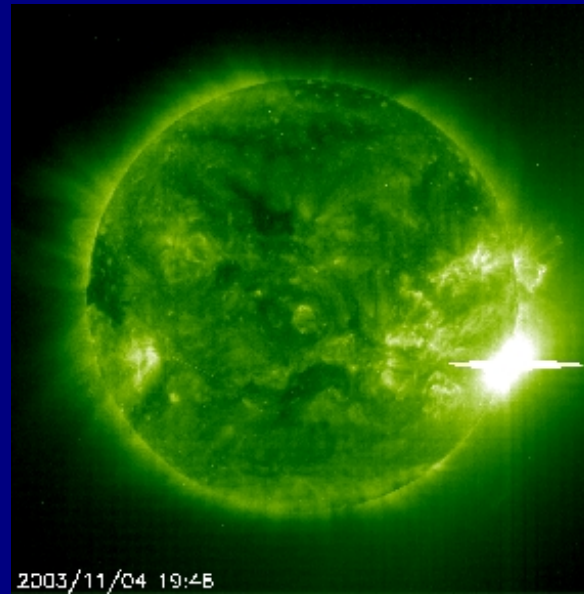
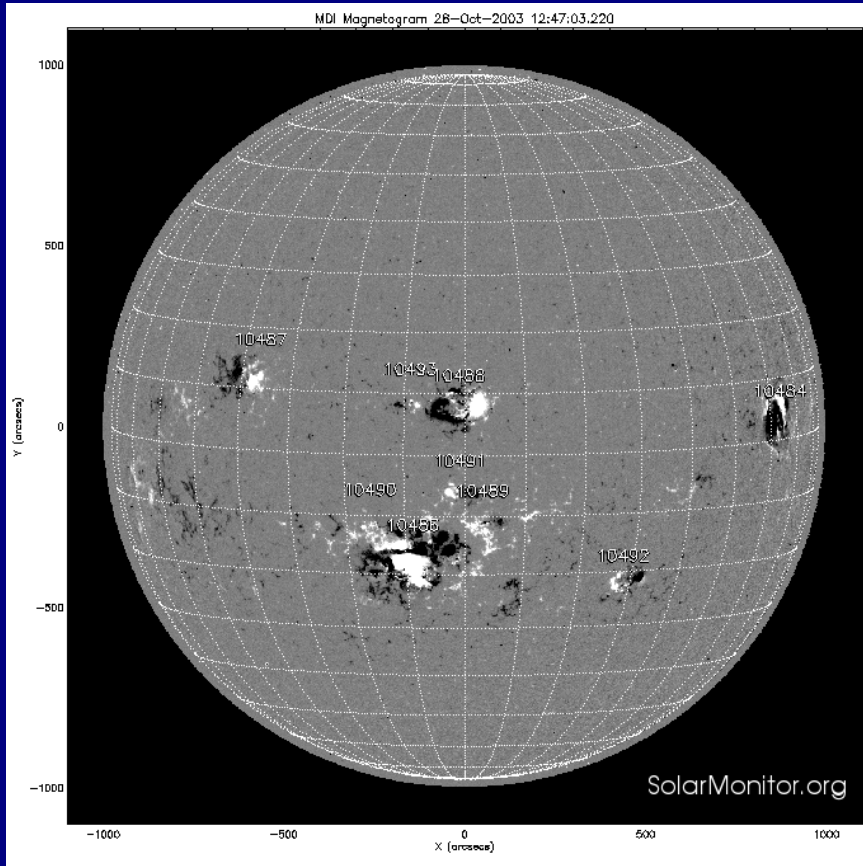


...Large print could no doubt have been easily read, for we can testify that the time on the face of a watch was easily legible...[Washington Daily National Intelligencer, September 3, 1859].

...The wire was then worked for about two hours without the usual batteries on the auroral current, working better than with the batteries connected. This is the first instance on record of more than a word or two having been transmitted with the auroral current...[Washington Daily National Intelligencer, Tuesday, September 6, 1859].

A brilliant display of Northern lights was witnessed from 8 o'clock to half-past 9 last night. The glare in the northern sky, previous to defining itself into the well-known features of the Aurora Borealis was sufficiently vivid to call out some of the fire companies.
[The Evening Star (Washington DC)]

Halloween Event: What if?



...The northern sky, for an extent of some forty five degrees, was luminous with a mass of red light, from whence shot up towards the zenith the usual streaks, at times vivid and beautiful...[New Orleans Daily Picayune, September 3, 1859].

...The French telegraph communications at Paris were greatly affected, and on interrupting the circuit of the conducting wire strong sparks were observed. The same thing occurred at the same time at all the telegraphic station in France...
[The Illustrated London News, September 24, 1859].

...There were strong currents of electricity observed on the wires, to which no batteries were attached, and some extraordinary electrical phenomena, difficulty of explanation, noticed...
[New Orleans Daily Picayune, Saturday, September 3, 1859].

NATIONAL SPACE WEATHER ACTION PLAN

October 2015

Space Weather Operations, Research, and Mitigation Task Force
Co-Chairs

Department of Commerce,
National Oceanic and Atmospheric Administration
Department of Homeland Security
Office of Science and Technology Policy

The National Space Weather Strategy (Strategy), released concurrently with this National Space Weather Action Plan (Action Plan), details national goals for leveraging existing policies and ongoing research and development efforts regarding space weather while promoting enhanced domestic and international coordination and cooperation across public and private sectors.

Source:

https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatheractionplan_20151028.pdf

Executive Order: Coordinating Efforts to Prepare the Nation for Space Weather Events

October 13, 2016

Issued in the final days of President Barack Obama's Presidency, the Executive Order called for (in brief):

1. Collaboration among agencies: Homeland Security, NASA, NSF
2. Cooperation between Secretaries of Defense, Interior, Commerce, Transportation, and Energy
3. The National Science and Technology Council (NSTC) shall establish a Space Weather Operations, Research, and Mitigation Subcommittee

Source:

<https://obamawhitehouse.archives.gov/the-press-office/2016/10/13/executive-order-coordinating-efforts-prepare-nation-space-weather-events>

Space Weather Research and Forecasting Act

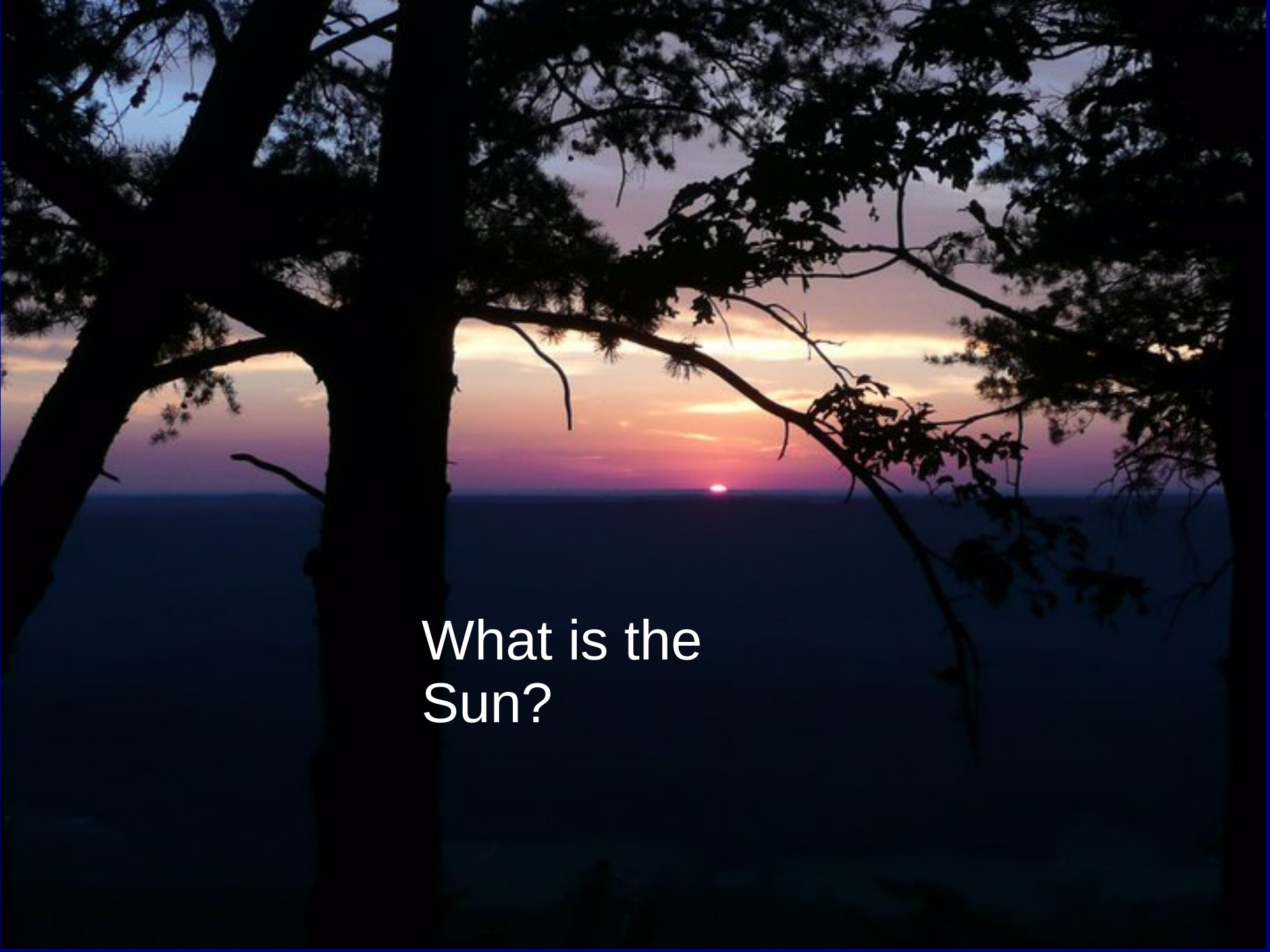
Passed Senate May 2, 2017

Now (Still) in the House
Excerpts:

An interagency working group shall leverage capabilities across participating Federal agencies, including -- National Oceanic and Atmospheric Administration (NOAA), NASA, NSF, DOD, Dept. of Interior, Dept. of Homeland Security, Department of Energy, Department of Transportation, including FAA and the Department of State

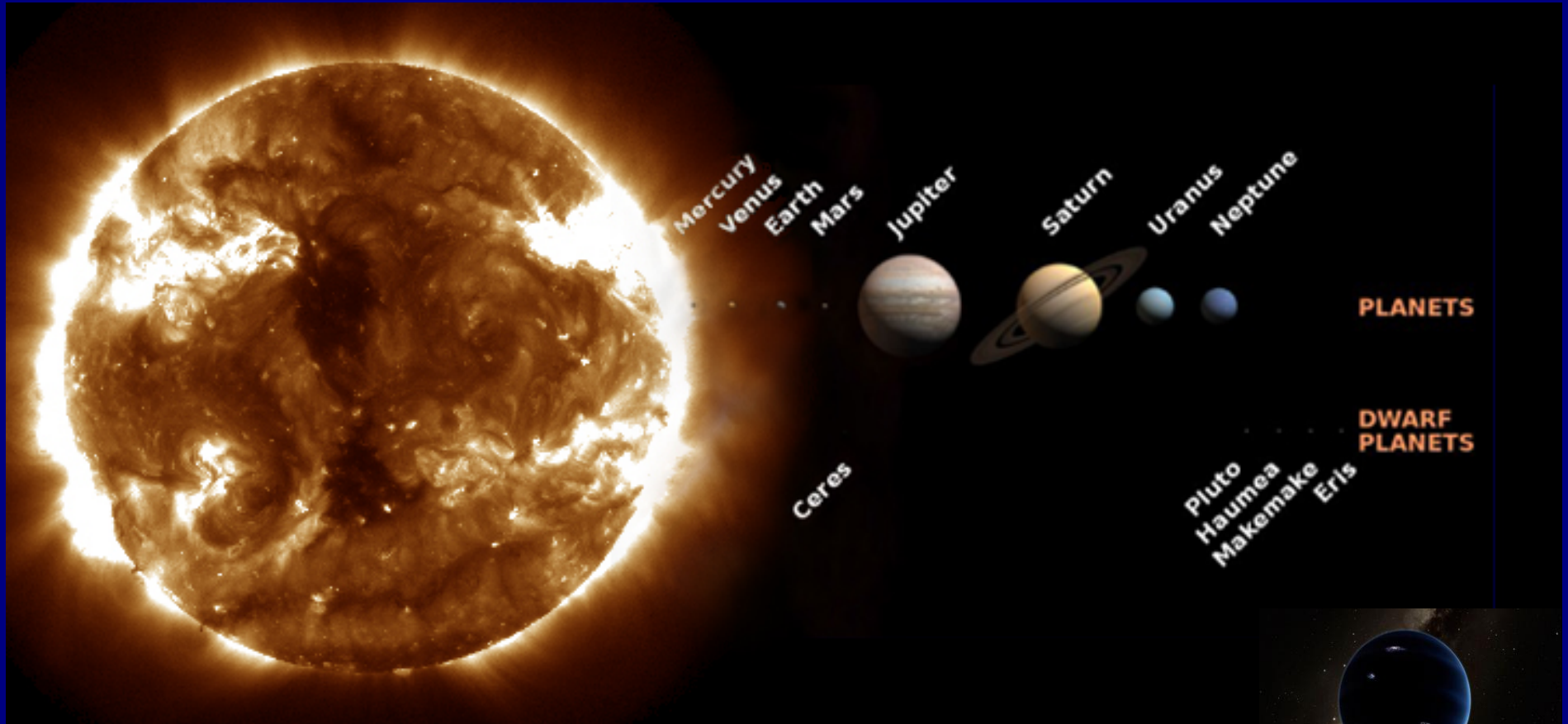
The Act includes Space Weather Metrics, a section describing the Protection of Critical Infrastructure, Protection of National Security Assets, and Ensuring the Safety of Civil Aviation.

Source: <https://www.govtrack.us/congress/bills/115/s141/text>

A photograph of a sunset or sunrise. The sun is a small, bright orange-red disk on the horizon, partially obscured by a dark, silhouetted tree trunk in the foreground. The sky is a gradient of colors, from deep blue at the top to a bright orange and yellow near the horizon. The foreground is dominated by the dark, intricate silhouettes of tree branches and leaves, creating a natural frame for the sun. The overall mood is serene and contemplative.

What is the
Sun?

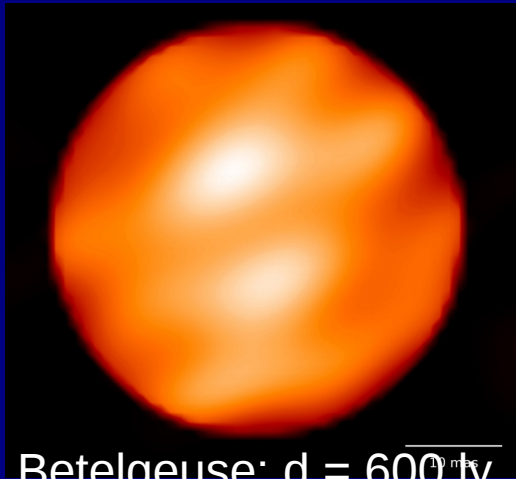
The Sun: A Star at the Center of our Solar System



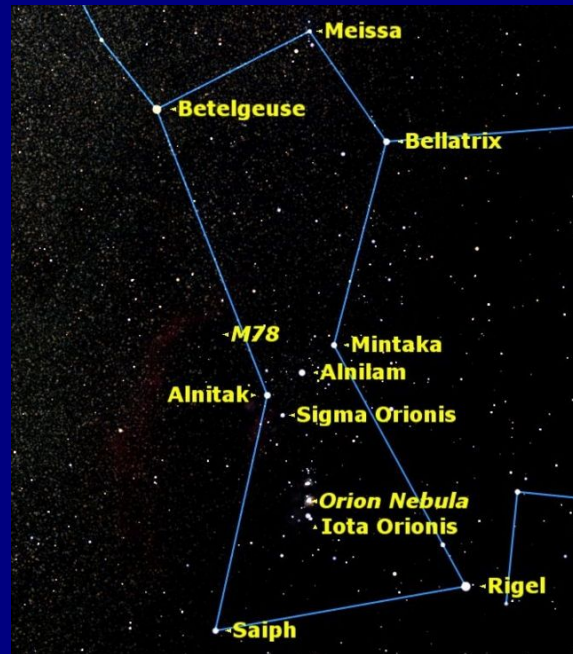
Planet
Nine?

What is a Star?

A star is an astrophysical body that produces its own light by thermonuclear reactions in its core.

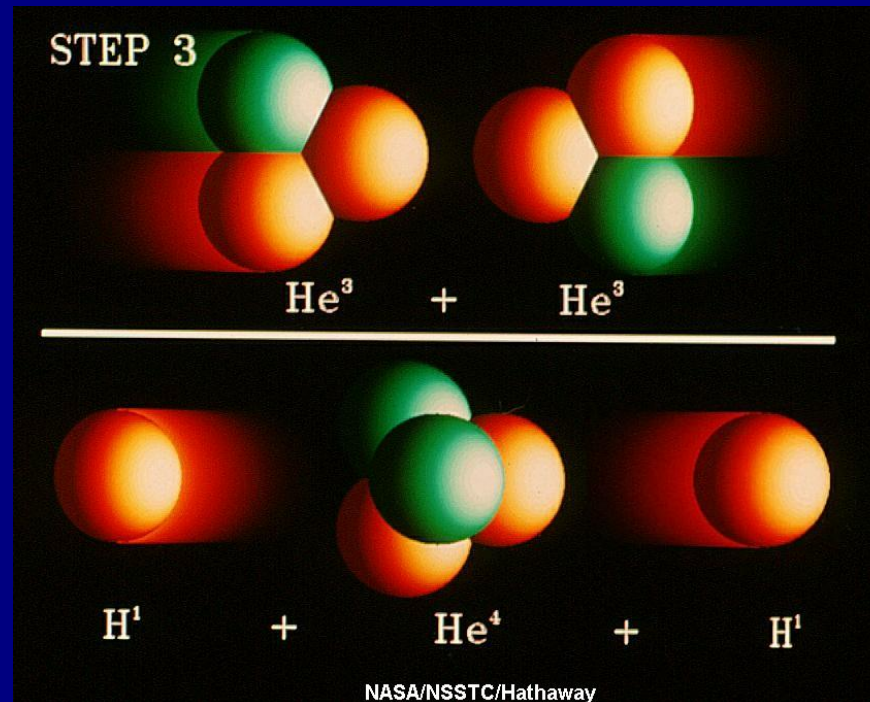


Betelgeuse: $d = 600 \text{ ly}$
 $T = 3500 \text{ K}$,
 $R = 1,180 R_{\odot}$,
 $M = 7.7 M_{\odot}$.



Rigel: $d = 770 \text{ ly}$,
 $T = 11,000 \text{ K}$,
 $R = 80 R_{\odot}$,
 $M = 20 M_{\odot}$.

Hydrogen + Hydrogen
 $\rightarrow$ Helium



For sun-type stars:

1. Two protons $\rightarrow$ deuterium, positron, neutrino
2. Proton + deuterium $\rightarrow$ helium-3 + gamma ray
3. Two He-3s $\rightarrow$ He-4 + two protons

Solar Structure

The Convection Zone

Energy continues to move toward the surface through convection currents of heated and cooled gas in the convection zone.

The Corona

The ionized elements within the corona glow in the x-ray and extreme ultraviolet wavelengths. NASA instruments can image the Sun's corona at these higher energies since the photosphere is quite dim in these wavelengths.

The Radiative Zone

Energy moves slowly outward—taking more than 170,000 years to radiate through the layer of the Sun known as the radiative zone.

Sun's Core

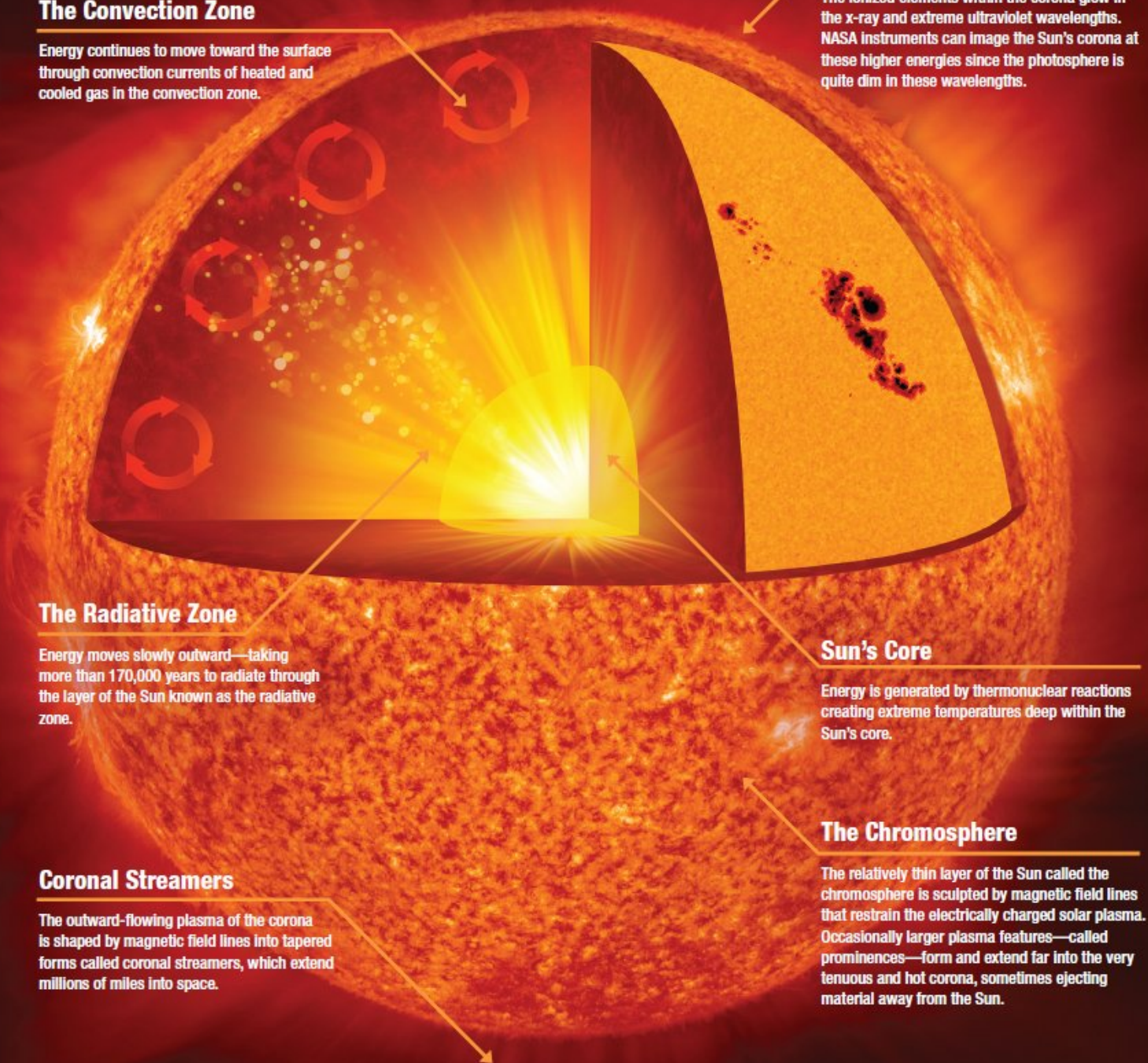
Energy is generated by thermonuclear reactions creating extreme temperatures deep within the Sun's core.

Coronal Streamers

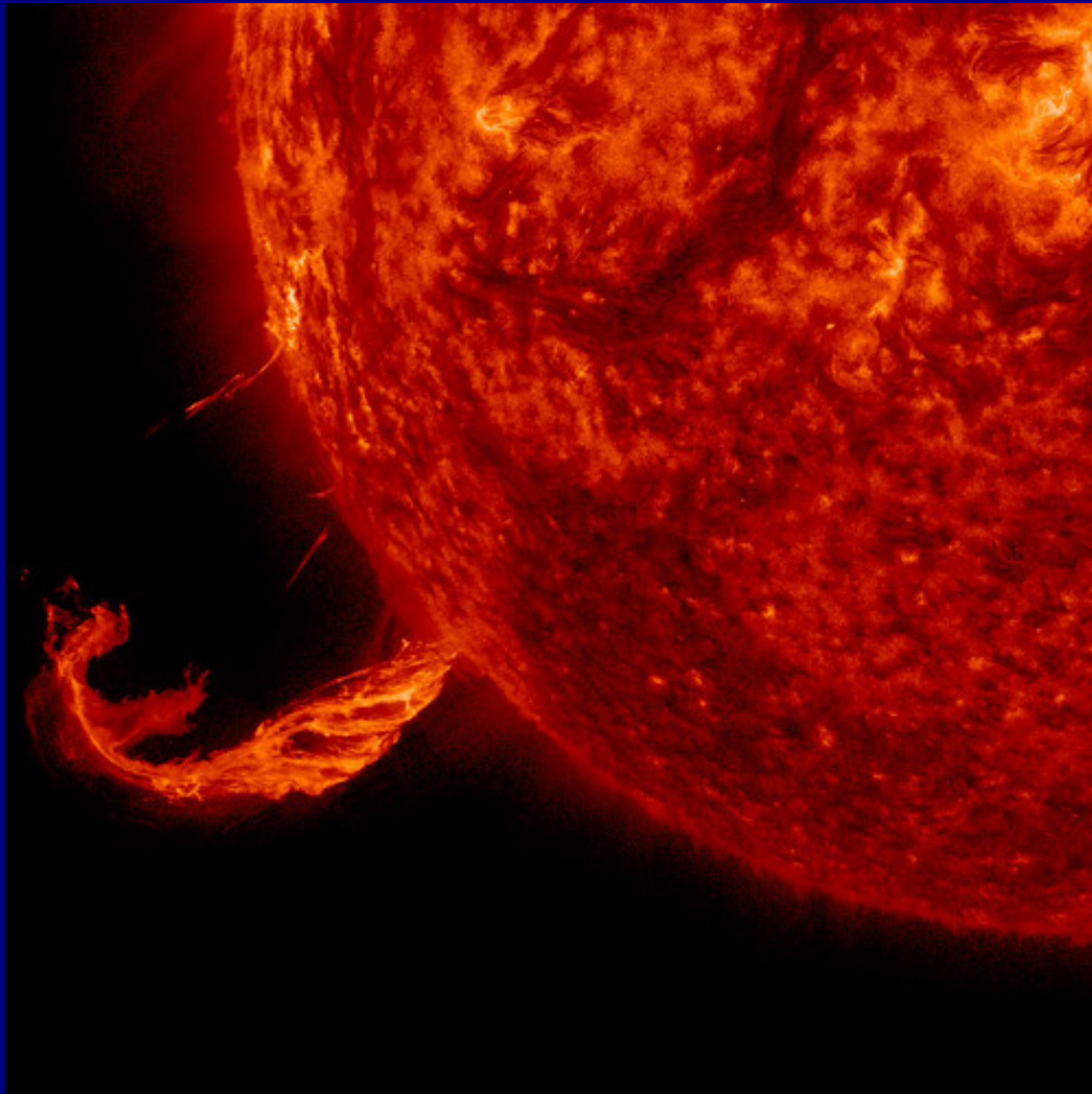
The outward-flowing plasma of the corona is shaped by magnetic field lines into tapered forms called coronal streamers, which extend millions of miles into space.

The Chromosphere

The relatively thin layer of the Sun called the chromosphere is sculpted by magnetic field lines that restrain the electrically charged solar plasma. Occasionally larger plasma features—called prominences—form and extend far into the very tenuous and hot corona, sometimes ejecting material away from the Sun.



The Sun -- How Big ? How Powerful ??



1.3 million Earths can fit
inside the Sun

The Sun contains more than
99.8% of the total mass of
the Solar System.

Pressure in the core is
approximately
250 billion billion atmospheres

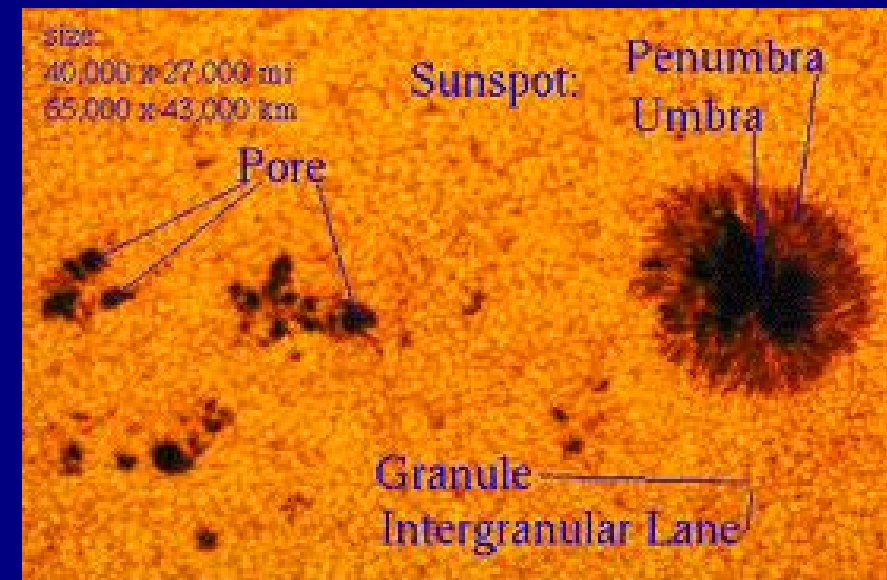
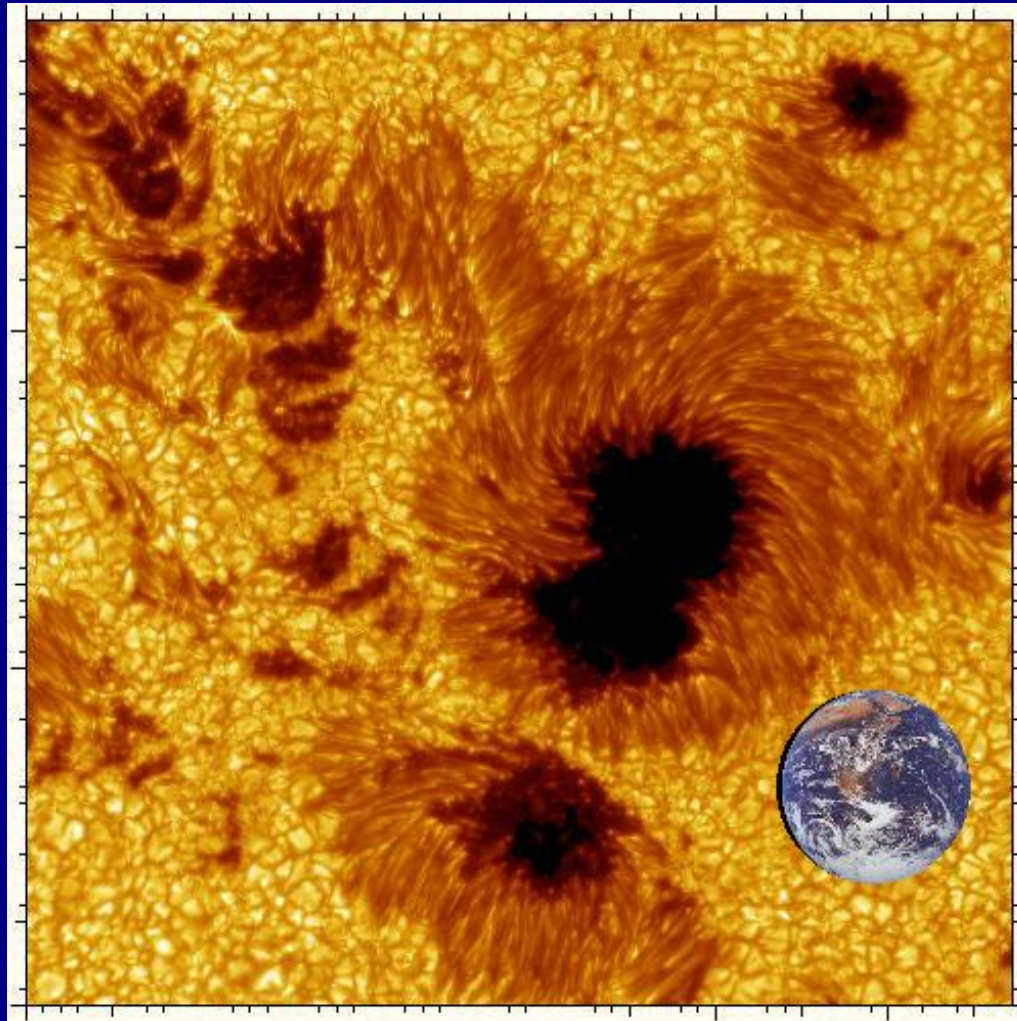
Energy conversion rate:
4.26 million metric tons/second,
this produces approximately
38,460 septillion Watts/second

(Outburst304_big.mp4)

Sunspots and The Solar Cycle

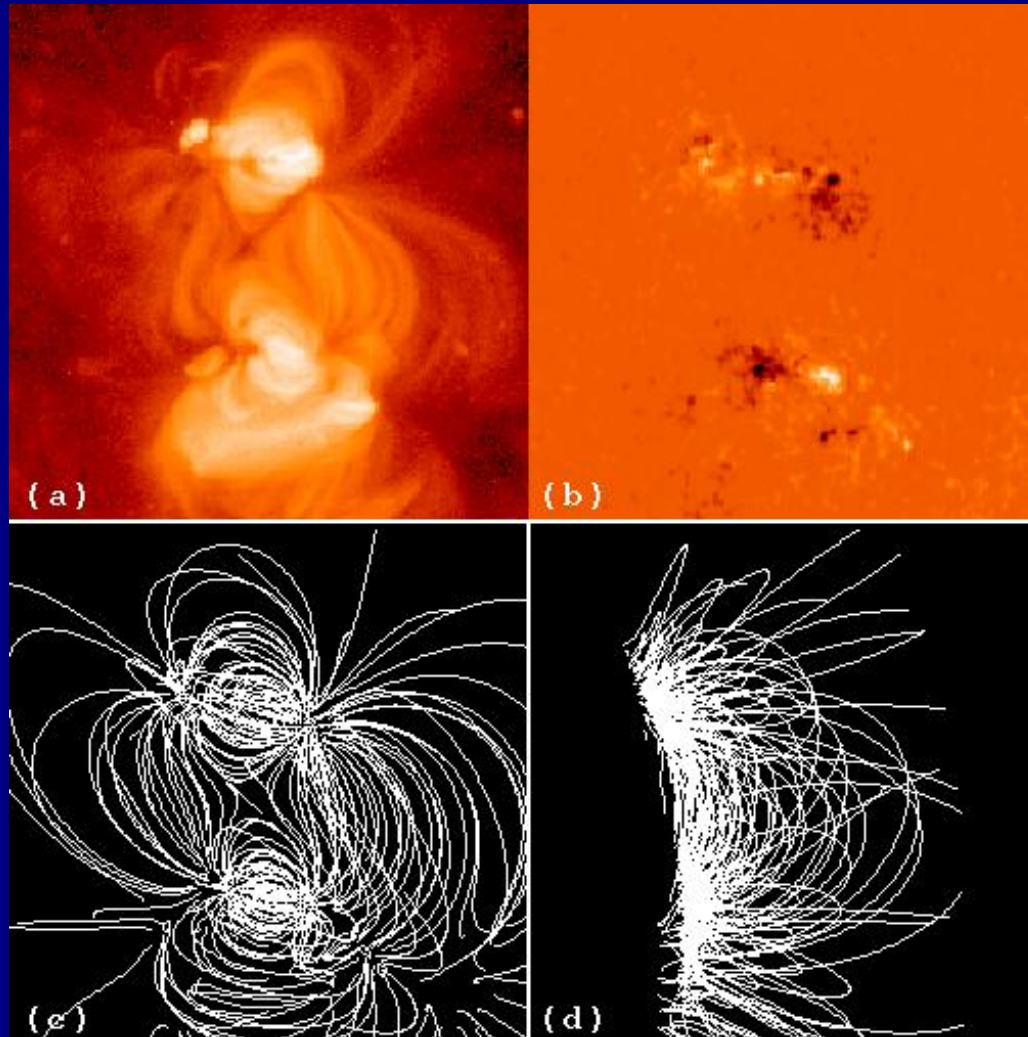
Sunspots

Examples



Magnetic Fields ABOVE the “Surface”

Yohkoh, 4 Jan, 1994



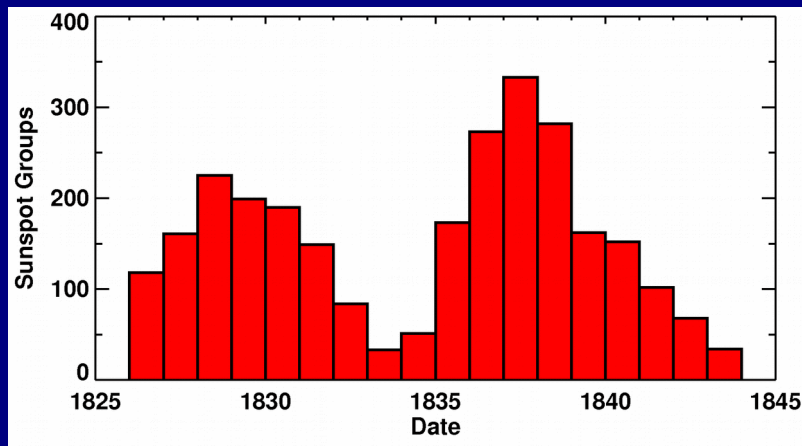
L-O-S magnetic field

Extrapolated Magnetic Field

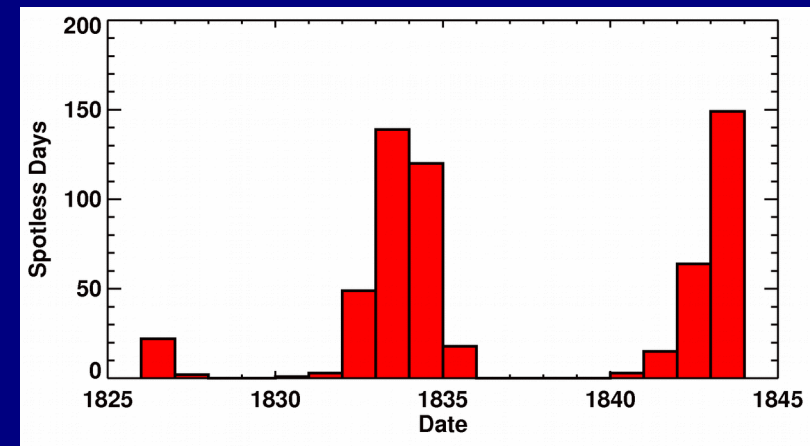
Sunspot Cycle Discovery

Astronomers had been observing sunspots for over 230 years before Heinrich Schwabe, an amateur astronomer in Dessau, Germany, discovered in 1844 that the number of sunspot groups and the number of days without sunspots increased and decreased in cycles of about 10-years.

Schwabe's data for 1826 to 1843



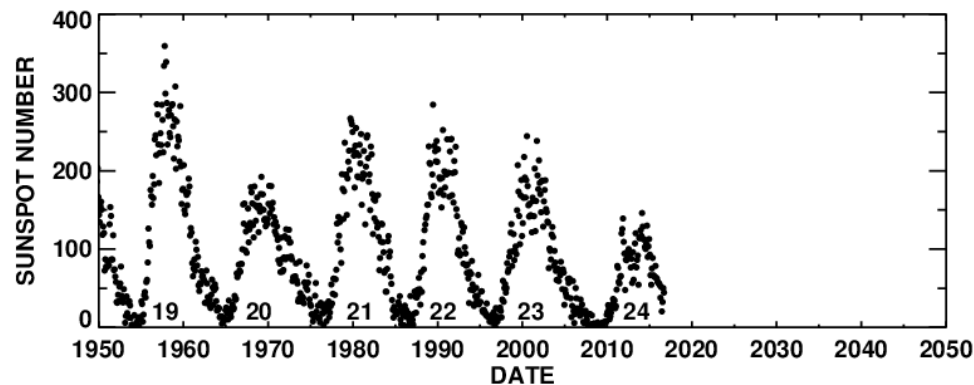
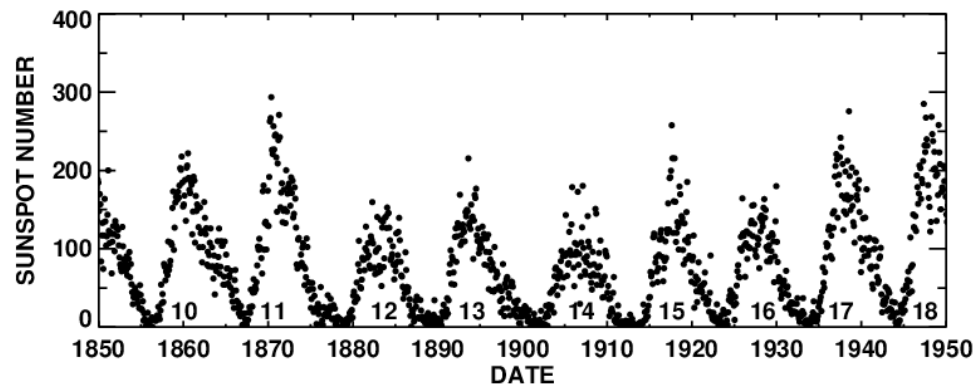
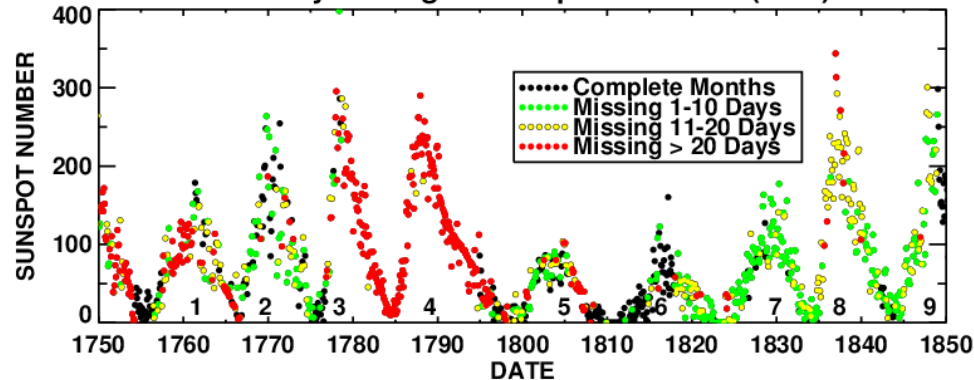
Number of Sunspot Groups per Year



Number of Spotless Days

23 Full Cycles

Monthly Averaged Sunspot Numbers (V2.0)



HATHAWAY SolarCycleScience.com 2018/06

- Rudolf Wolf --> “Relative” Sunspot Number
 $R = k(10g + s)$: g =groups, s =spots,
 k =location/observer scaling factor

- Prior to 1849 -- many days with no observations; after continuous

- Wolf’s Relative Sunspot Number and cycle numbering still used today

- Average cycle: ~ 11 years, with range of 9 to 14

- Average amplitude: ~ 100, with range of 50 to 200

Image Used with Permission from Dr. David Hathaway,
retired NASA solar scientist.

Solar Eruptions

Flares

May 5, 2015, X2.7 flare

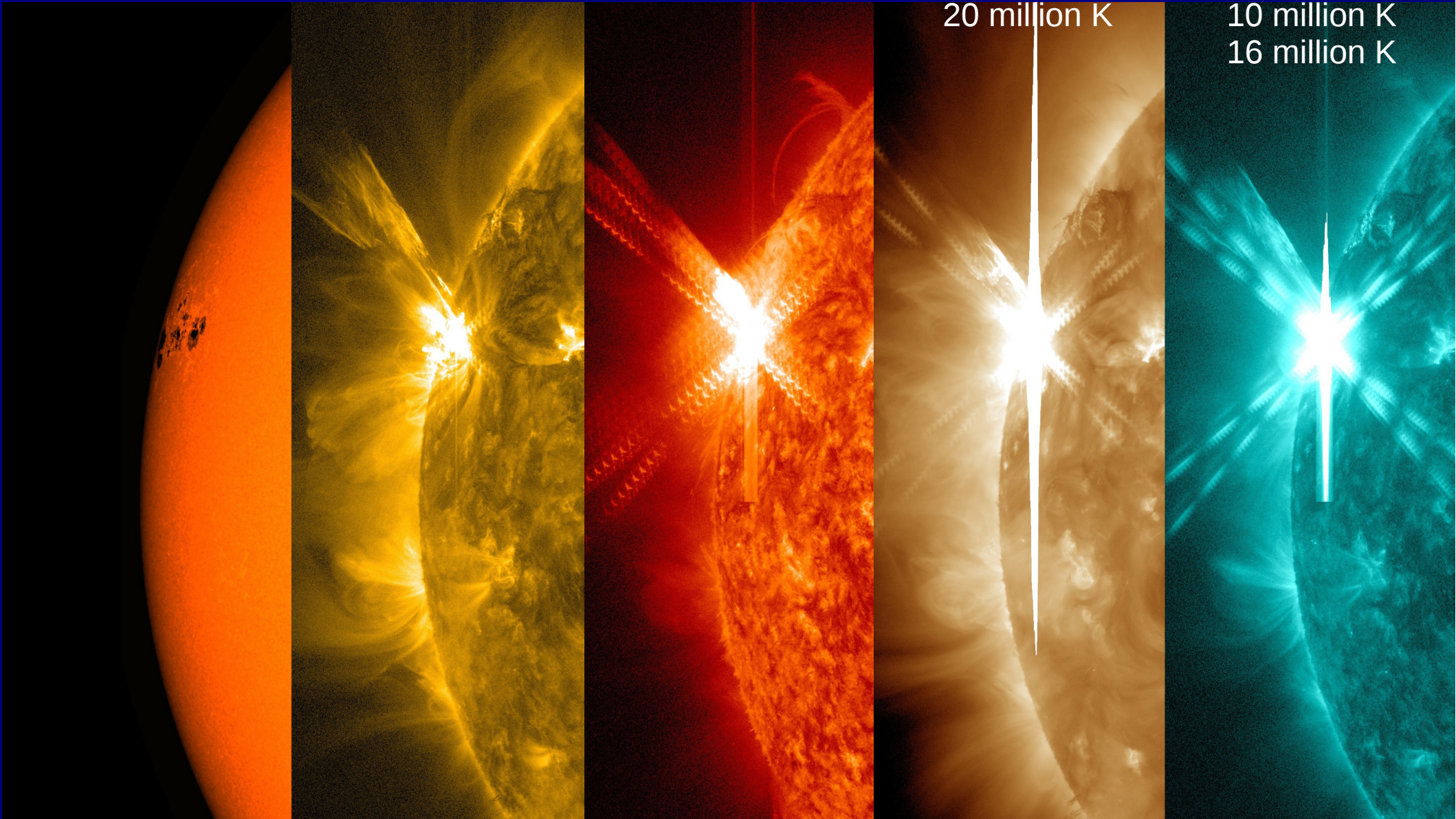
White Light
~5000 K
(10,000 F)

171 Å
Fe IX
63,000 K

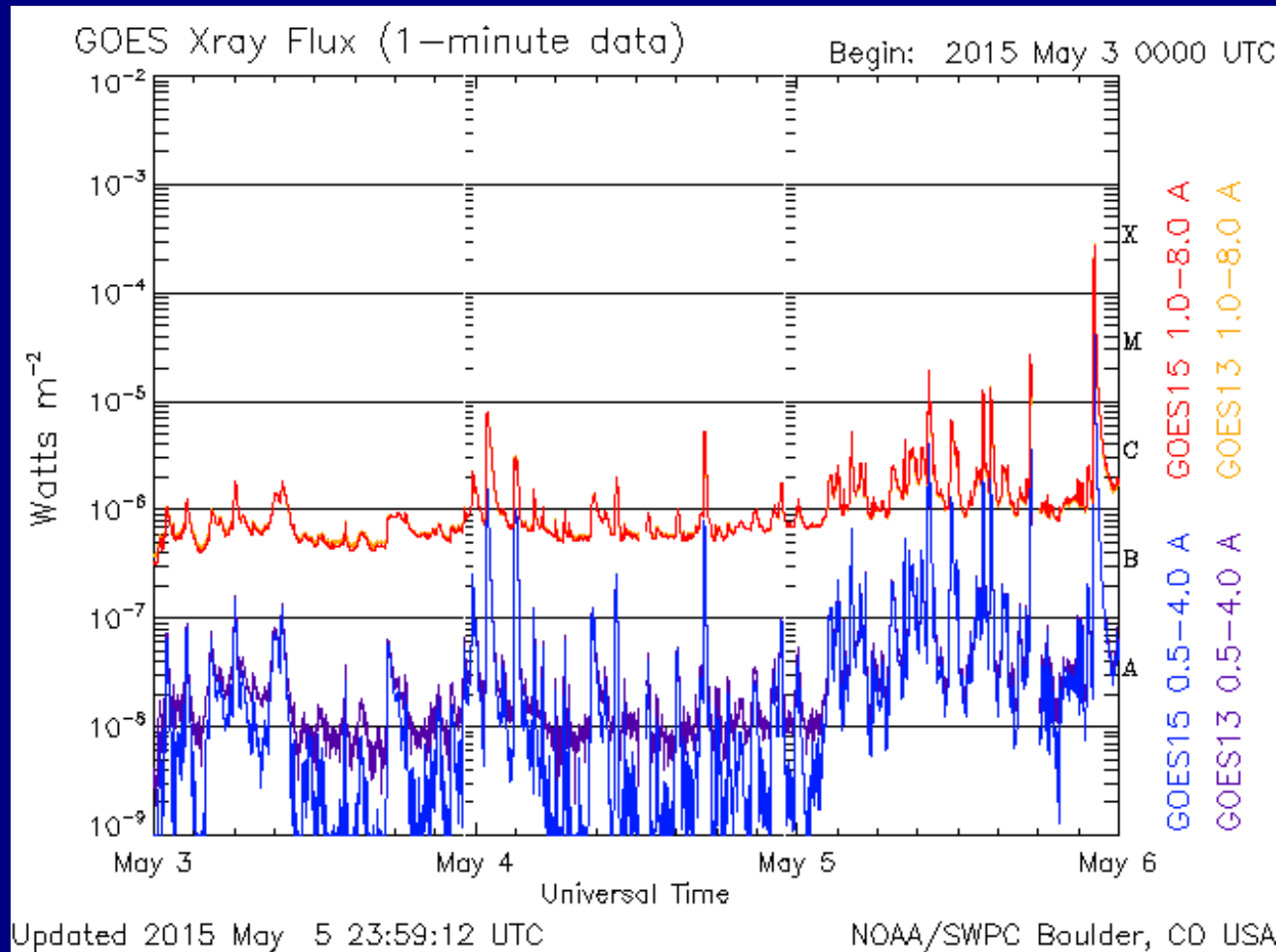
304 Å
He II
50,000 K

193 Å
Fe XII, XXIV
1.2 million K,
20 million K

131 Å
Fe VIII, XX, XXIII
40,000 K,
10 million K
16 million K

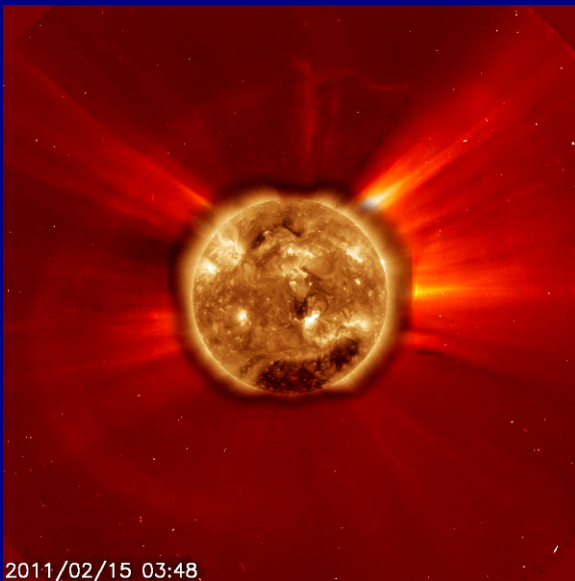


How to Classify a Solar Flare

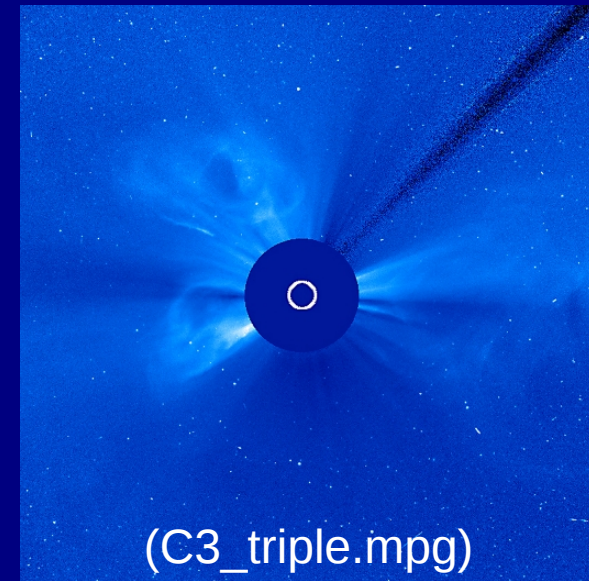
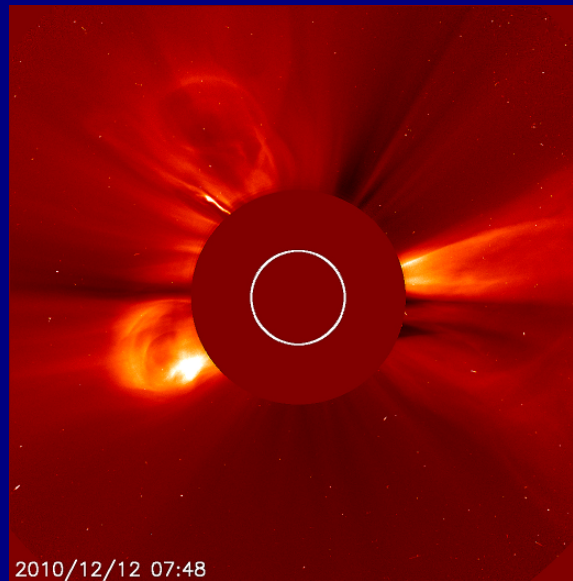


Hiroshima Bomb ~ 15 kiloton TNT
A flare ~ 1 billion megaton TNT

Coronal Mass Ejections (CMEs)

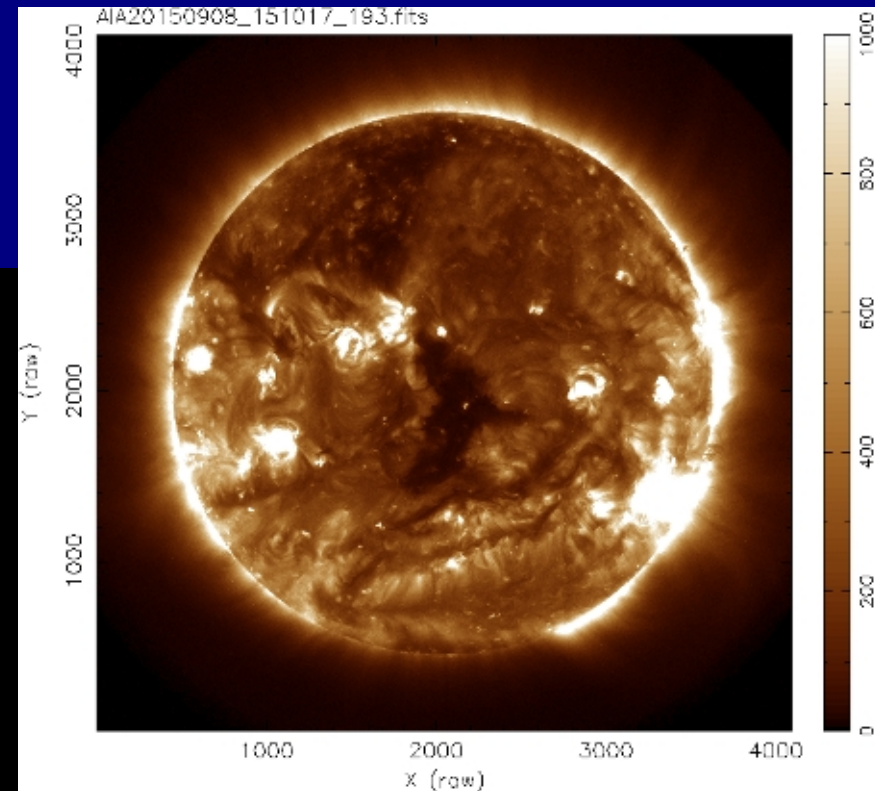
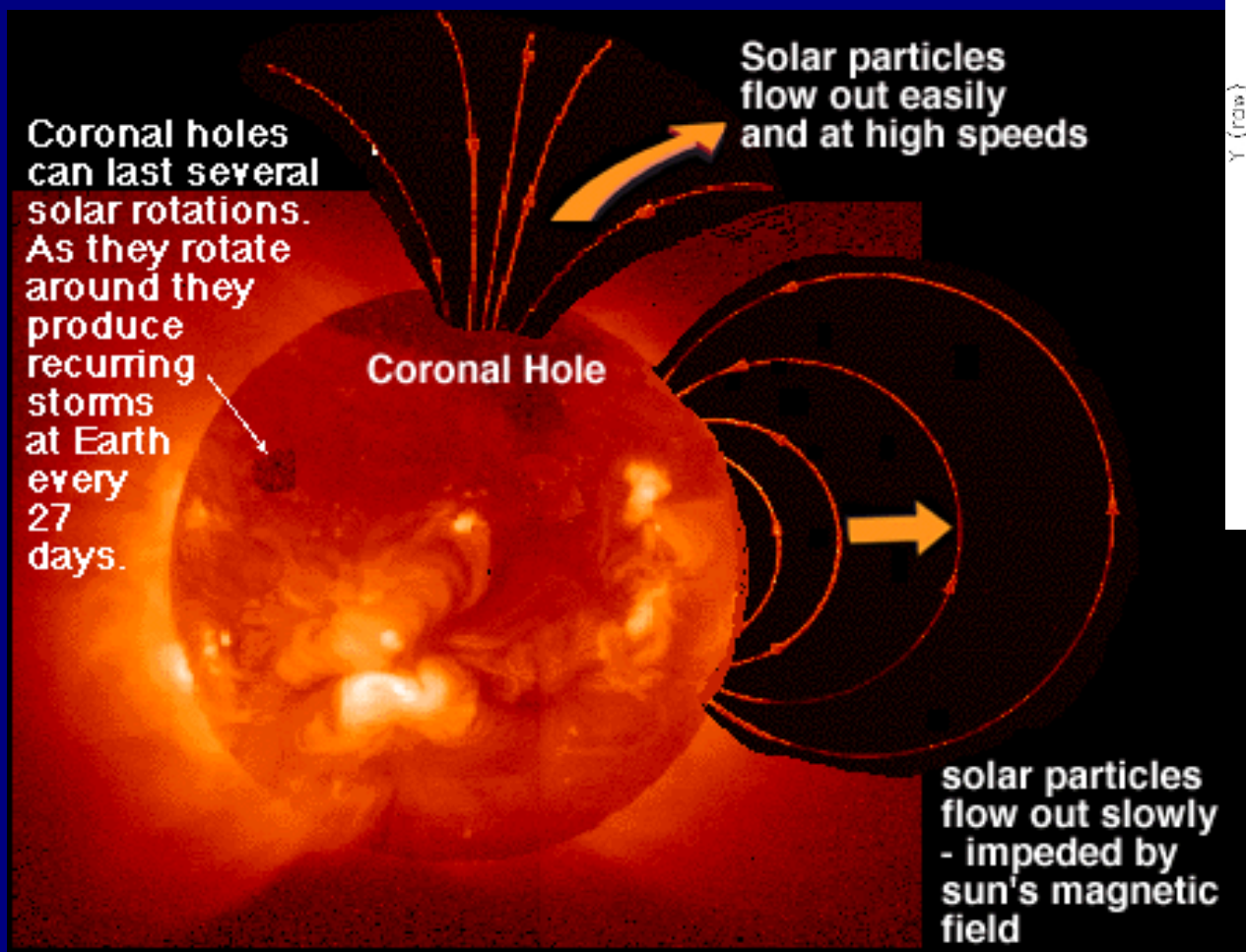


This combo of SDO and
Soho C2 shows X2-flare
and CME
(X2_C2_combo_best.mpg)



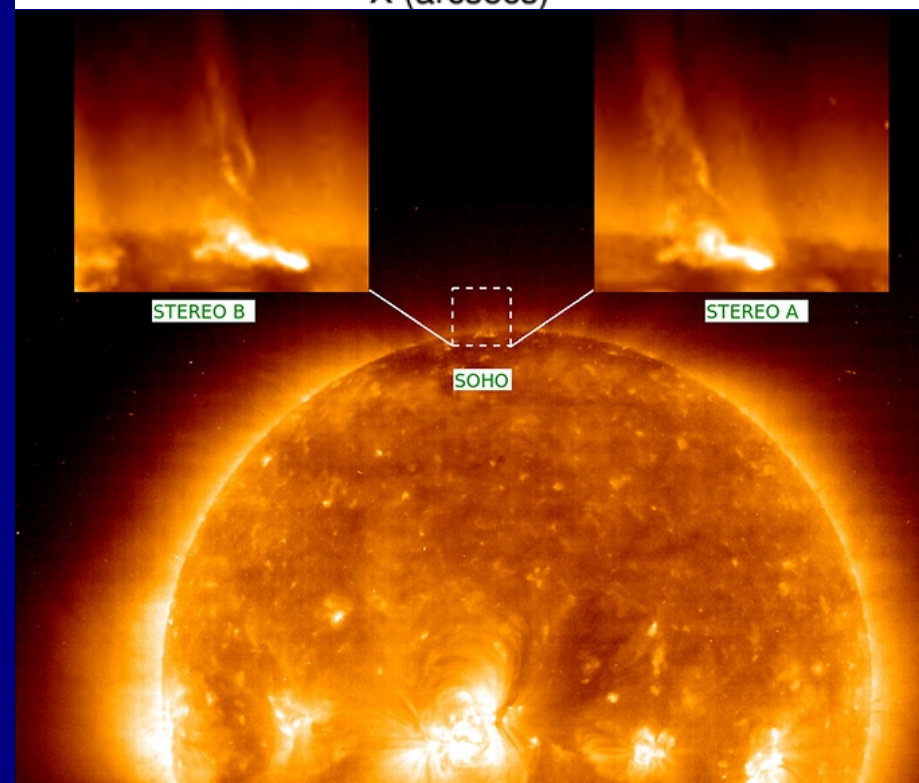
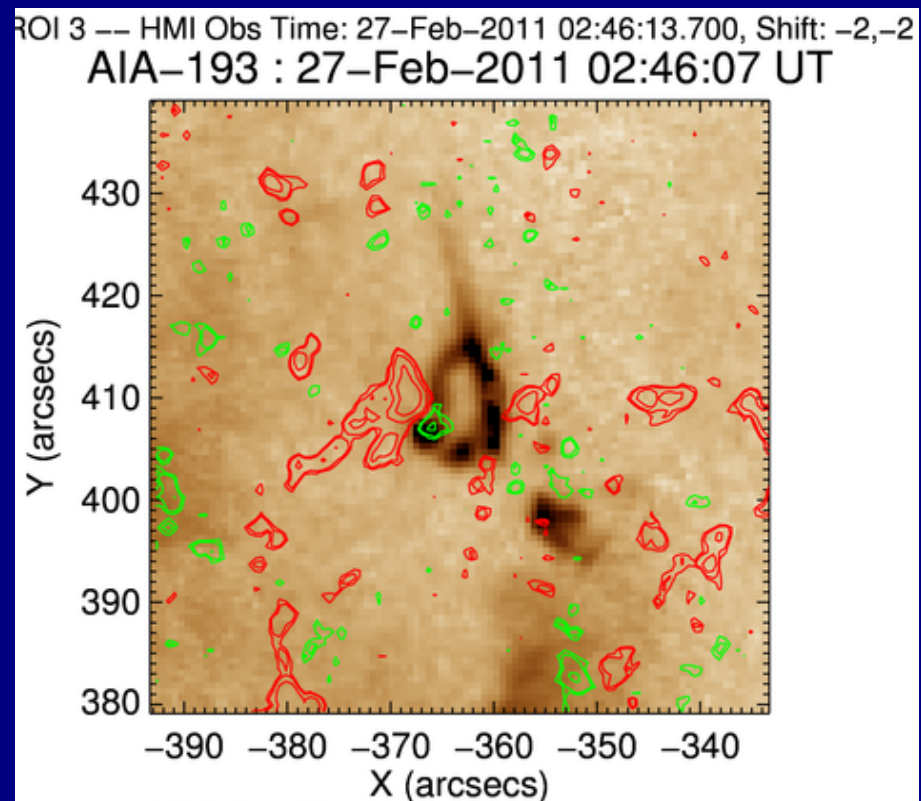
Three distinct CMEs: First (to right) was from a filament eruption, second from north pole, third from far side of Sun. All three eruptions happened within hours of each other.

Solar Wind: Coronal Holes as Seen in X rays and EUV

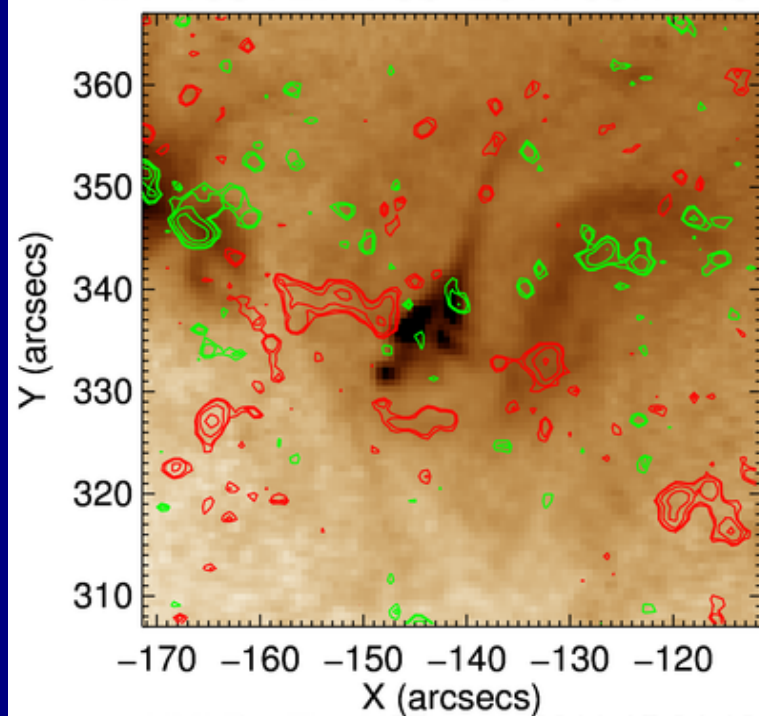


Jets in Coronal Holes

South Polar Jet: Hinode/P. Grigis



ROI 4 -- HMI Obs Time: 27-Feb-2011 03:41:43.700, Shift: -2,-2
AIA-193 : 27-Feb-2011 03:41:43 UT



Summary

- The Sun is a Star
- The Sun has Cycles of Activity
- The Sun Produces Explosive Events: Jets, Flares, Coronal-Mass Ejections
- There is a Plan for Governmental Support for Research and Forecasting and Collaboration Between Agencies