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

Planet Nine?

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Presentation for Students of the Physics and Astronomy Department
UA-Tuscaloosa
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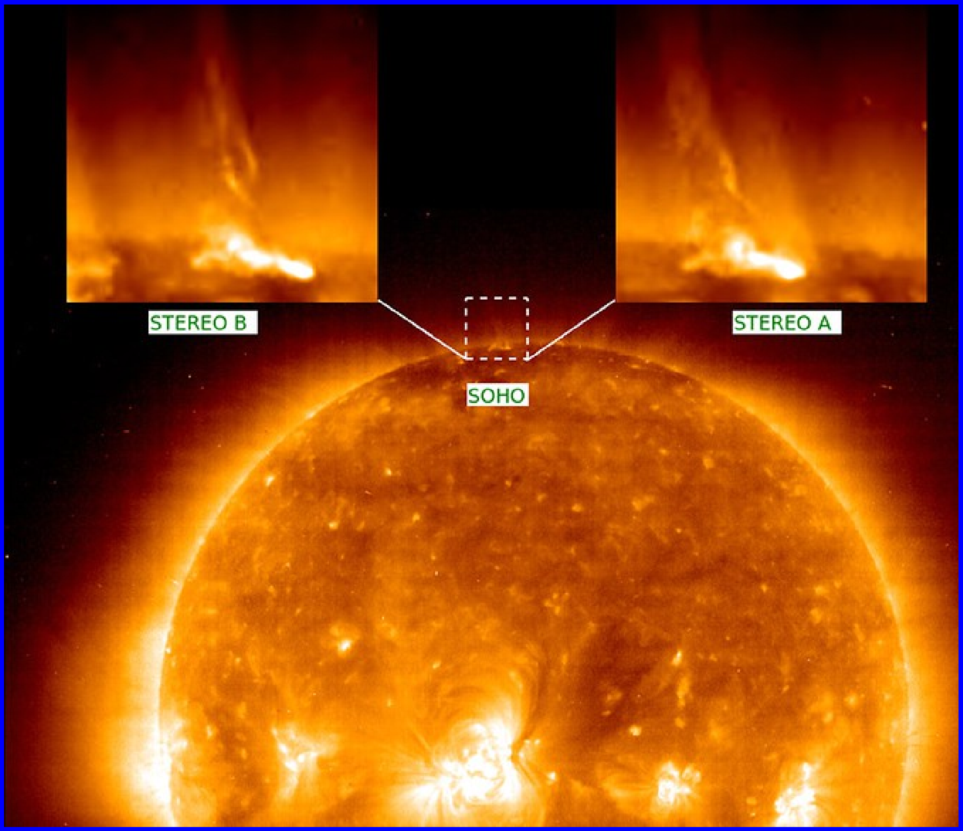
There is a star at the center of our solar system!



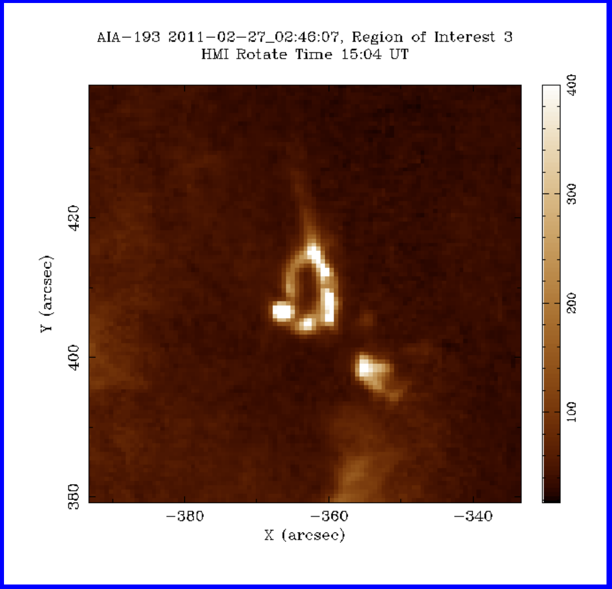
But what is a star?

How do stars work?

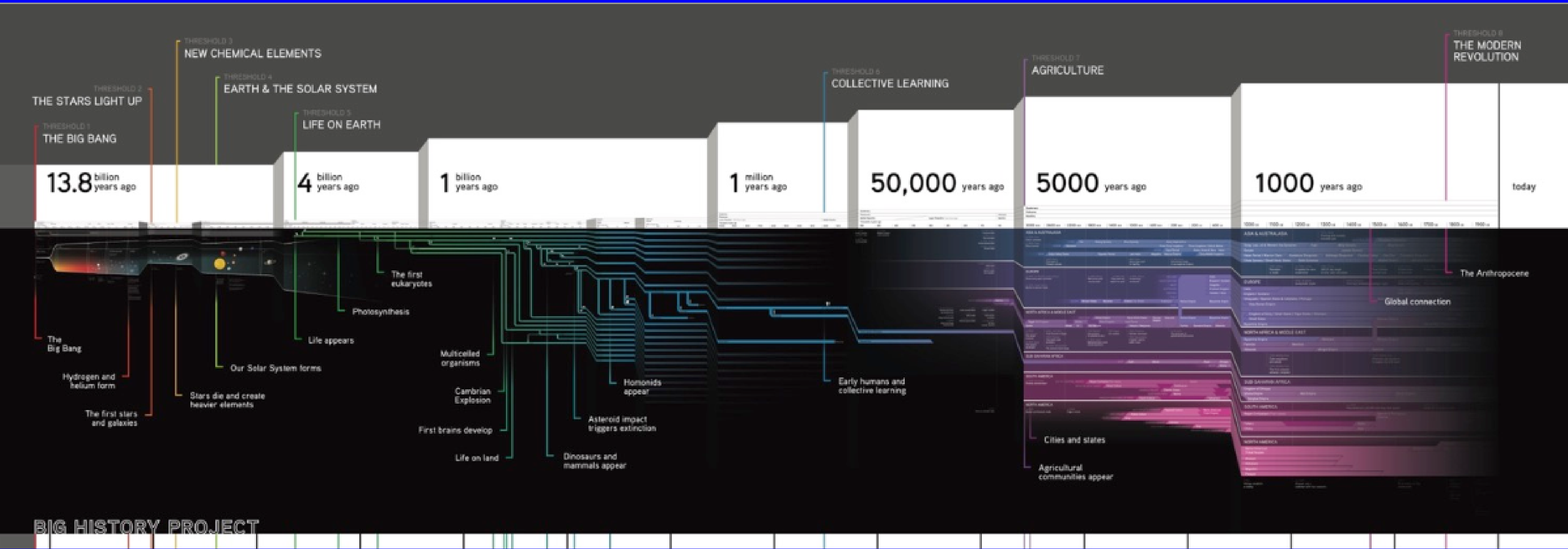
What are the characteristics of our Sun and how are these traits different from other stars?

How does the Sun compare to stars such as Betelgeuse and Rigel?

"Will the Sun end its life with a bang or a whimper?"



Putting it into Context
Astronomical Scales



Time, Distance Size

How big is a million, a billion, 13.8 billion ?

Count numbers, consider each number as one second.

Count to one million -- 11.6 days

Count to one billion -- Multiply 11.6 days by 1000 = 32 years

Count to 13.8 billion --> 439 years

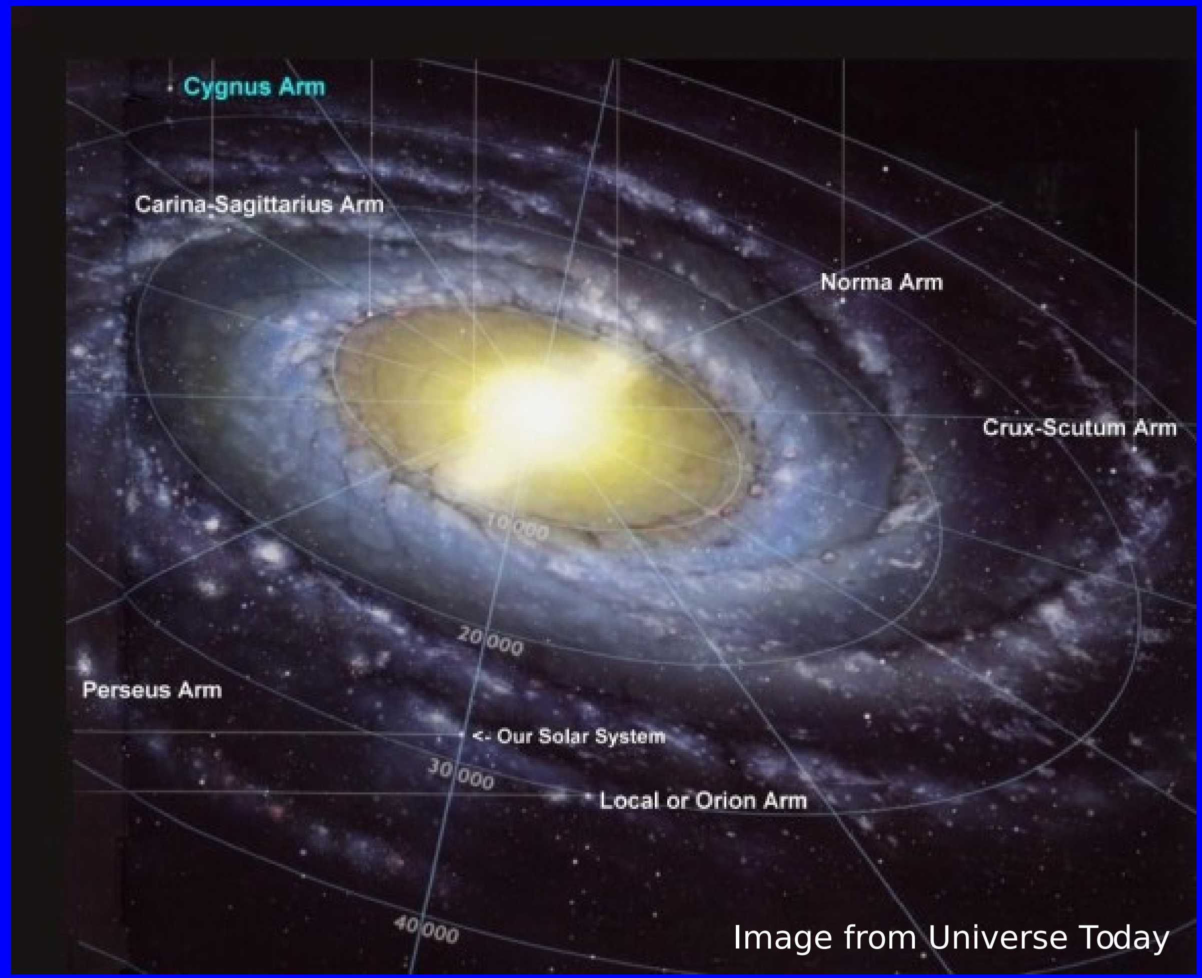
Perspective, continued...

The Sun is one of more than 100 billion stars in the Milky Way galaxy

There are over 30 galaxies in the local group with a diameter of ~10 million ly

The Sun is 25,000 light years from the galactic core

One galactic “year” takes about 250 million years.



Proxima Centauri: α-Cen-A and α-Cen-B are at about 4.37 ly away,
Proxima is 4.24 ly away

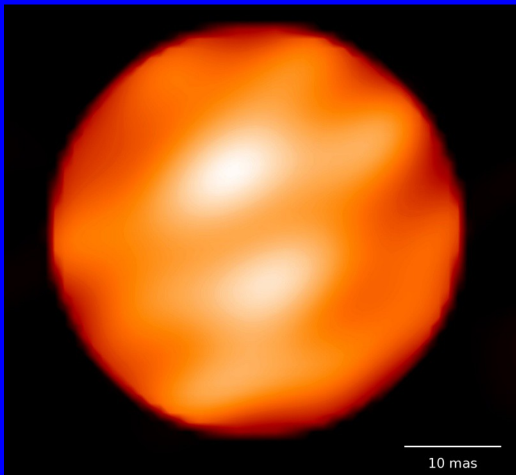
Imagine Sun to be grapefruit sized. With that scale, Alpha Centauri (the system) would be 4,000 kilometers or 2,500 miles away.

α-Cen-A is a G2, α-Cen-B is a K1, Proxima (α-Cen-C) is M6

What is a Star?

What is a Star?

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

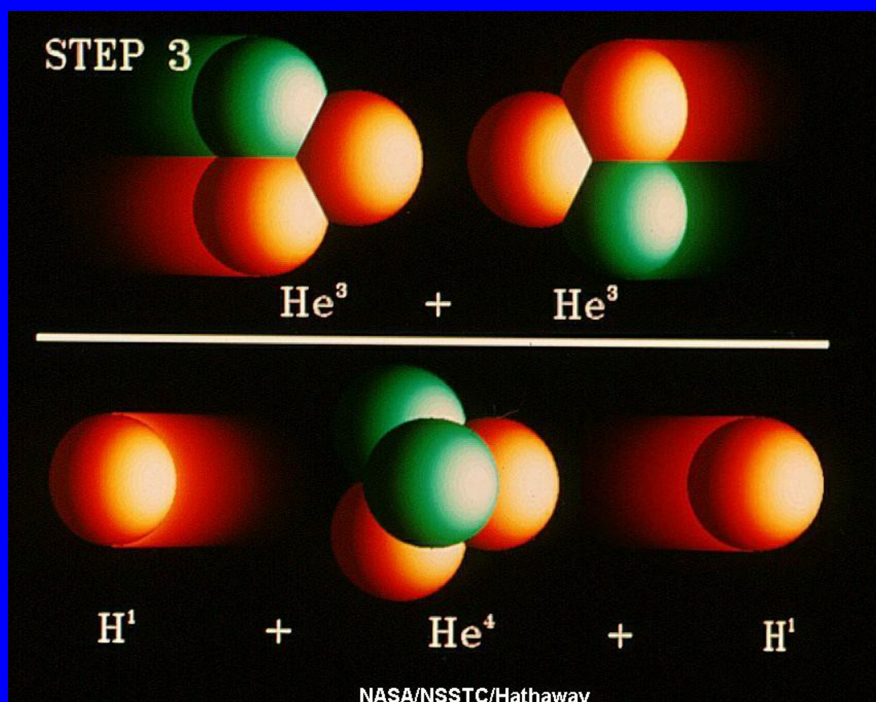


Betelgeuse: A red giant star, about 600 ly away, 3500 K, 1,180 $R_{\odot}$, 7.7 $M_{\odot}$.

Rigel: A blue-white star, about 770 ly away, 11,000 K, 80 $R_{\odot}$, 20 $M_{\odot}$.

Basically, hydrogen converts to Helium

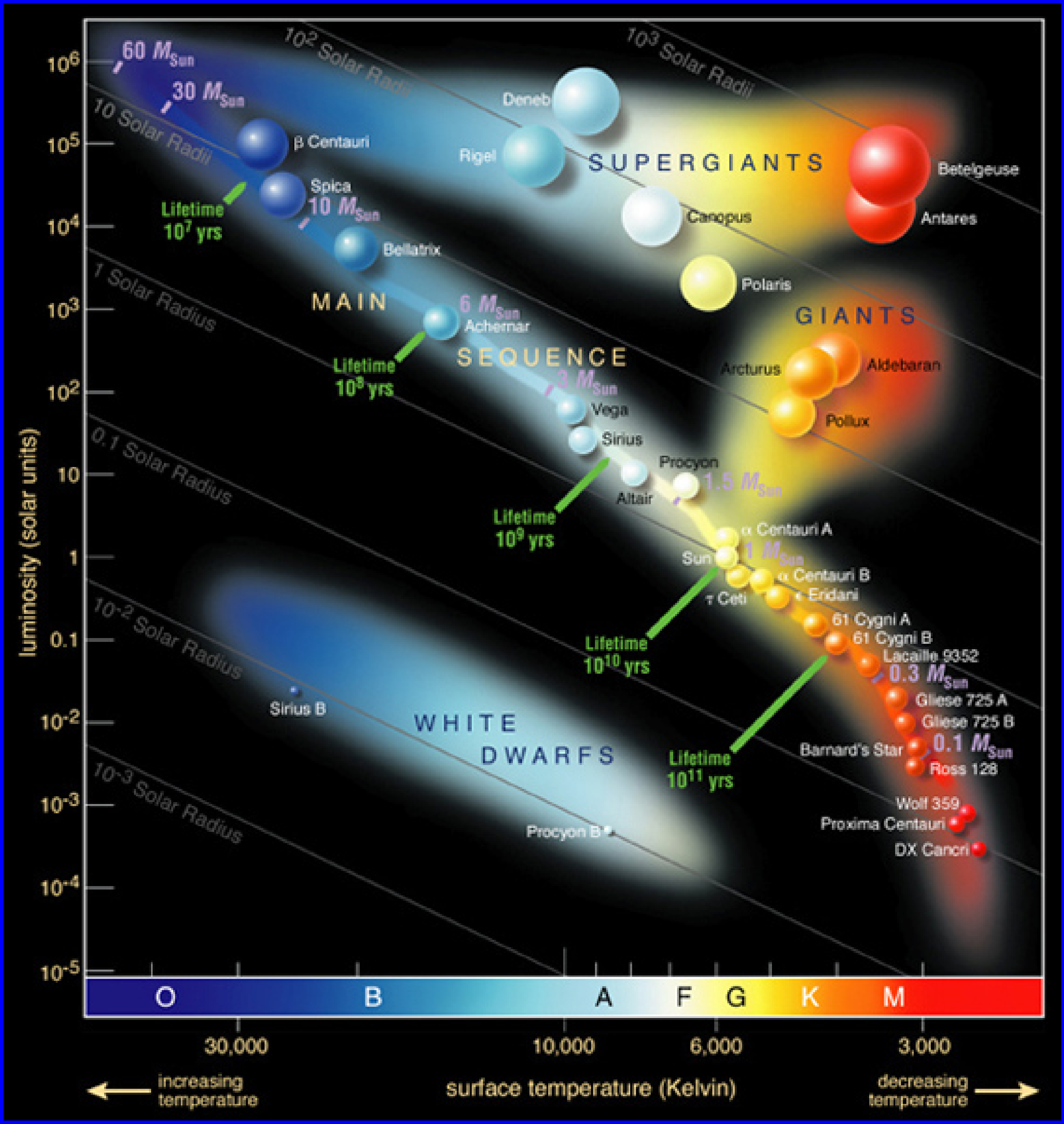
(High-mass stars, greater than about 2 solar masses use a different procedure, called the CNO cycle.)



For sun-type stars, there are three steps in the proton-proton chain:

1. Two protons collide, form deuterium, a positron, and neutrino.
2. A proton collides with the deuterium, forming helium-3 and a gamma ray
3. Two He-3s collide to form He-4 plus two protons.

Stellar Differences



α-Cen-A is G2,
α-Cen-B is K1,
Proxima (α-Cen-C) is M6,

the Sun is G2
8.5 light minutes away

Betelgeuse is M2
643 ly

Bellatrix is B2
250 ly

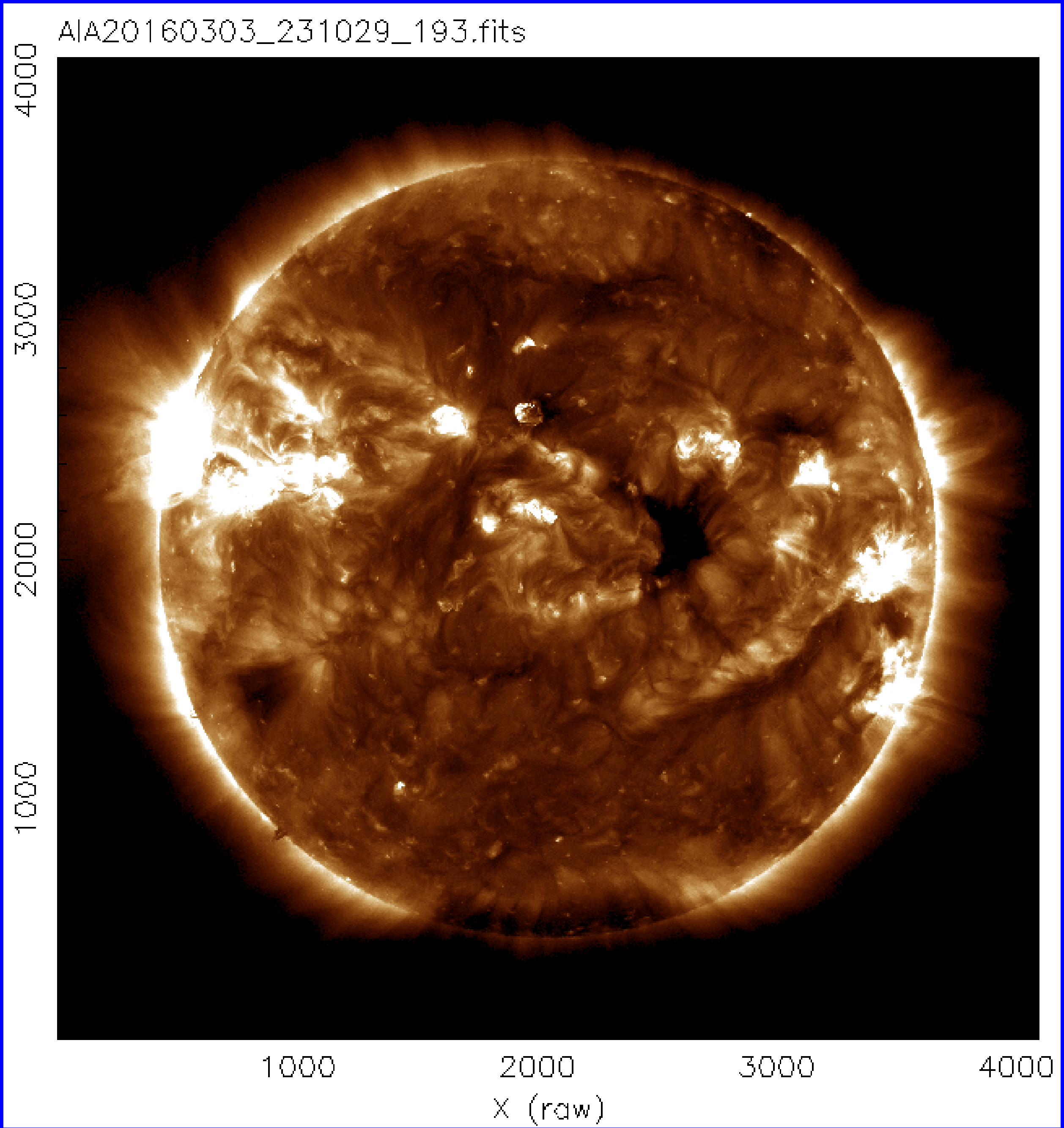
Rigel is B8
860 ly

Saiph is B0
650 ly

The Sun Itself

The Sun -- How Big? How Powerful?

1.3 million Earths could fit inside the Sun

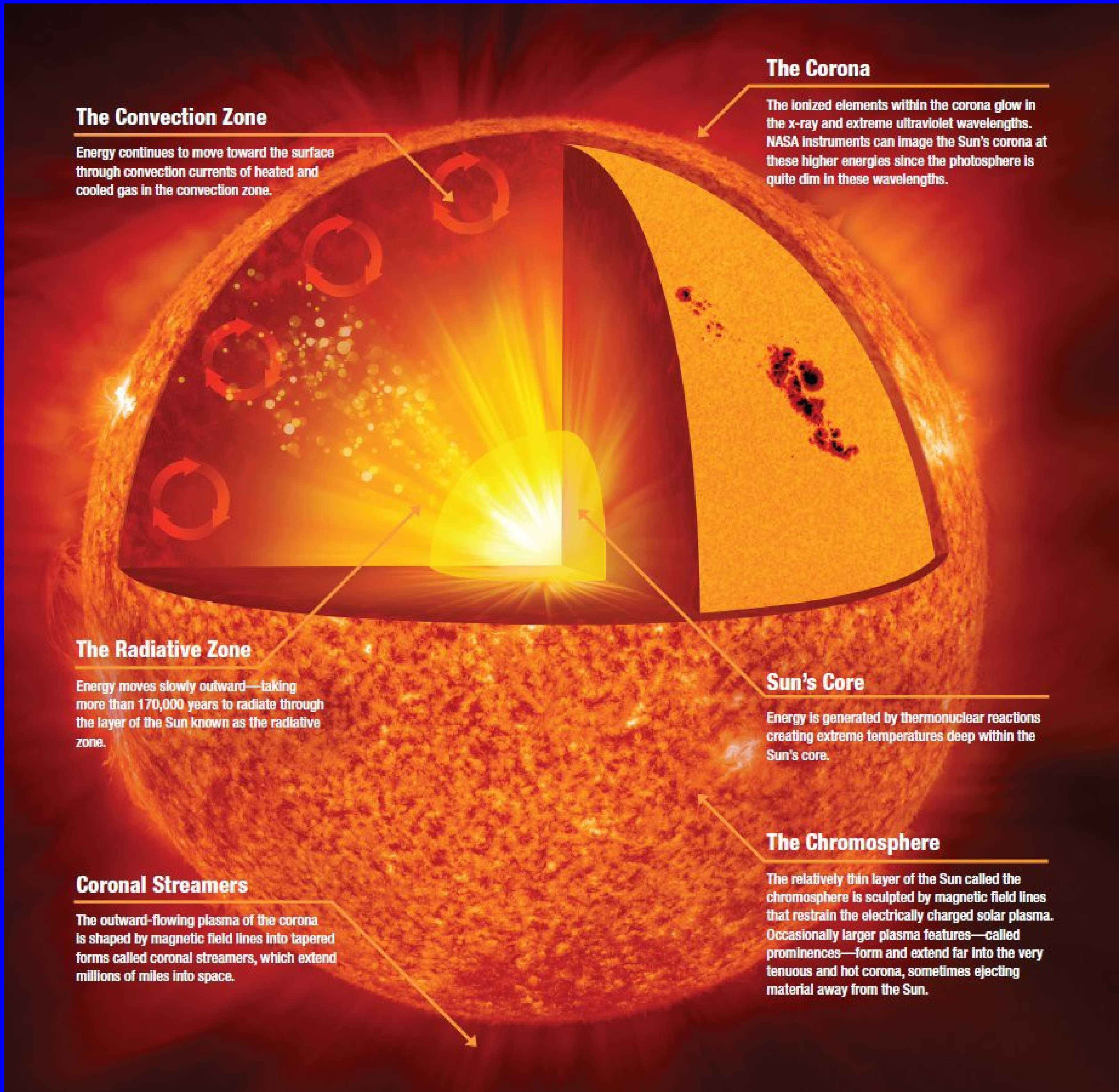


~ 630 million tons of H convert to He each second providing 1372 W/m^2 energy at Earth

Solar emission is ~ 4 x 10^{26} Watts
U.S. consumption is ~10^{13} Watts

Energy Examples

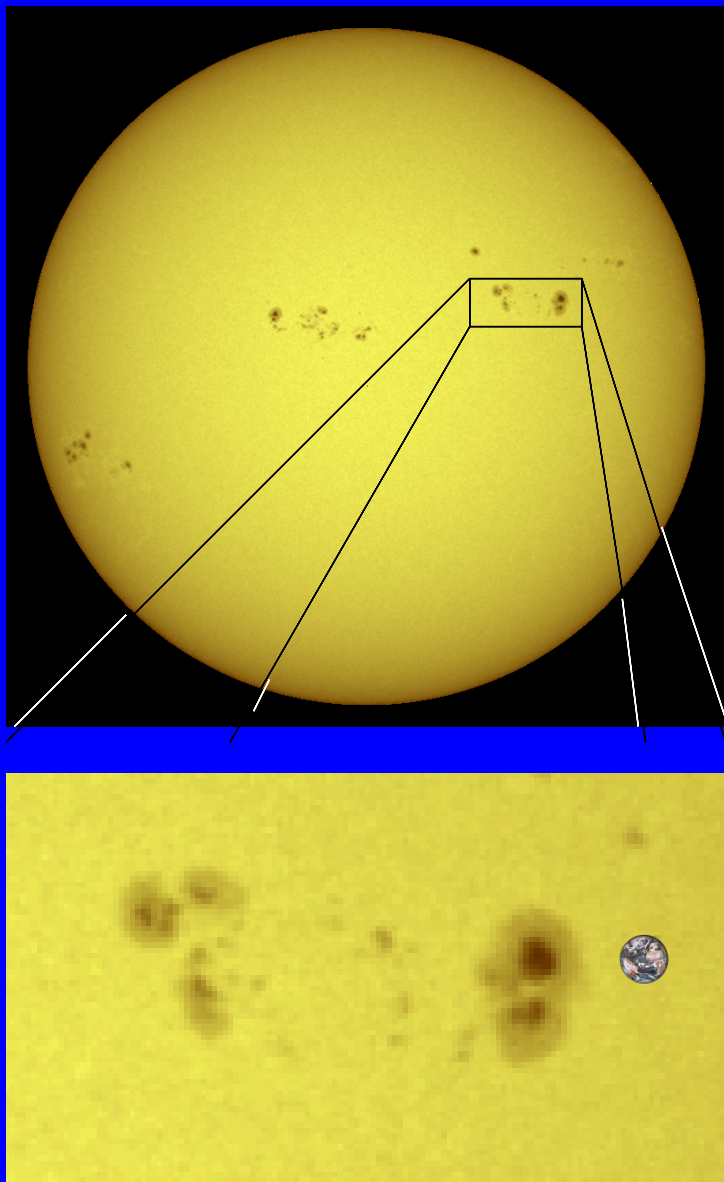
1 erg	= A snowflake hitting ground
8.4 x 10^6 J	= Human body uses/day
4.0 x 10^9 J	= 1 ton TNT
10^{25} J	= Solar Flare



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

Surface Features

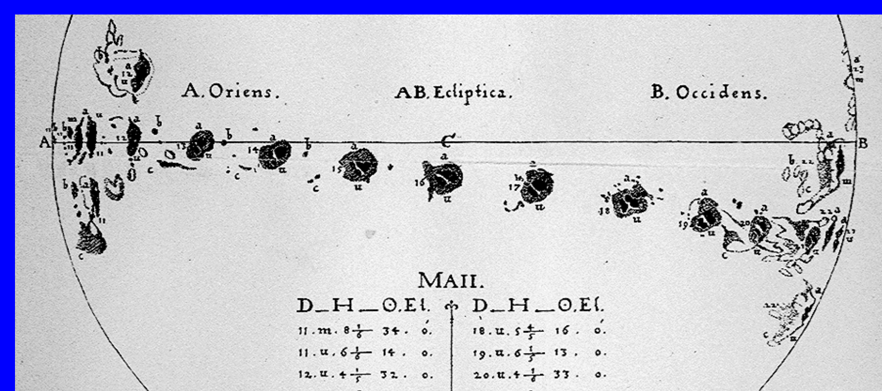
Sunspots



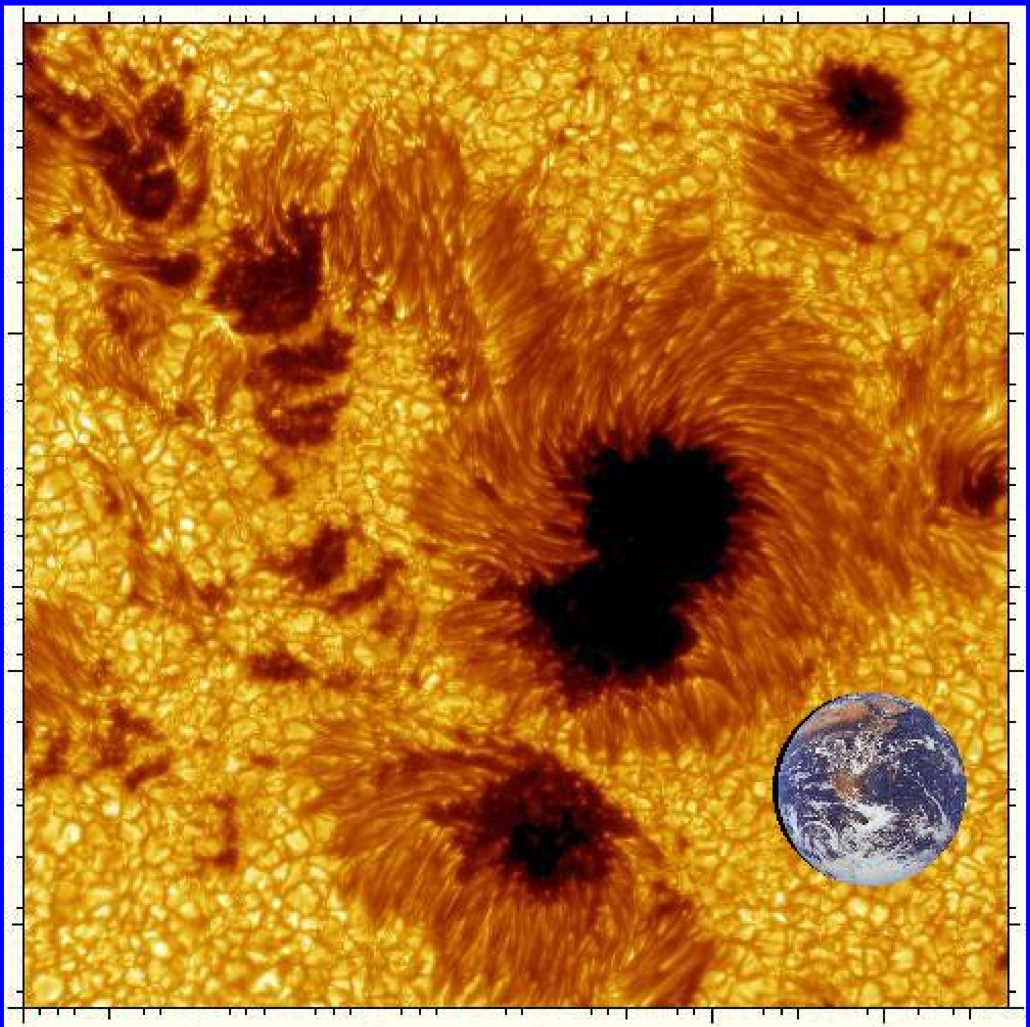
Sunspots are dark (and cooler) regions on the surface of the Sun. They have a darker inner region (the Umbra) surrounded by a lighter ring (the Penumbra).

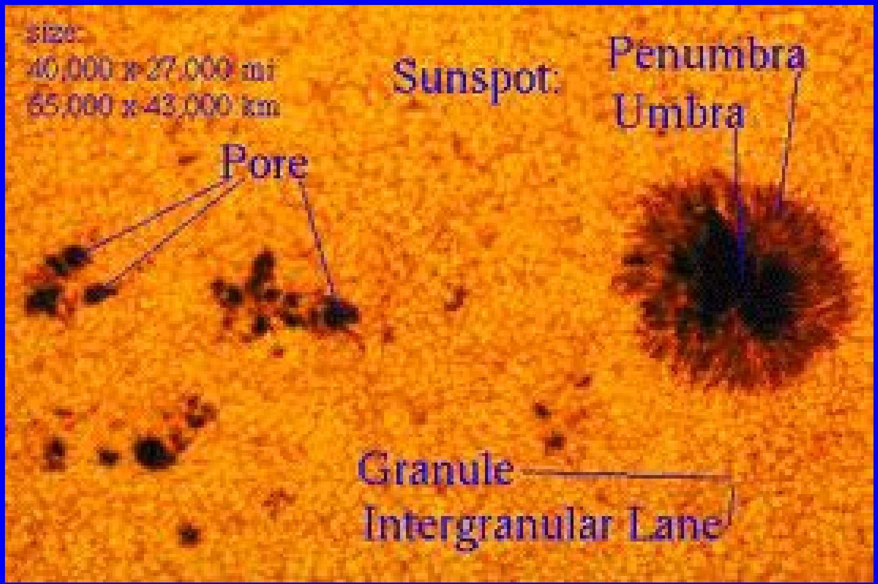
Sunspots usually appear in groups that form over hours or days and last for days or weeks.

The earliest sunspot observations (c. 1609) indicated that the Sun rotates once in about 27 days.



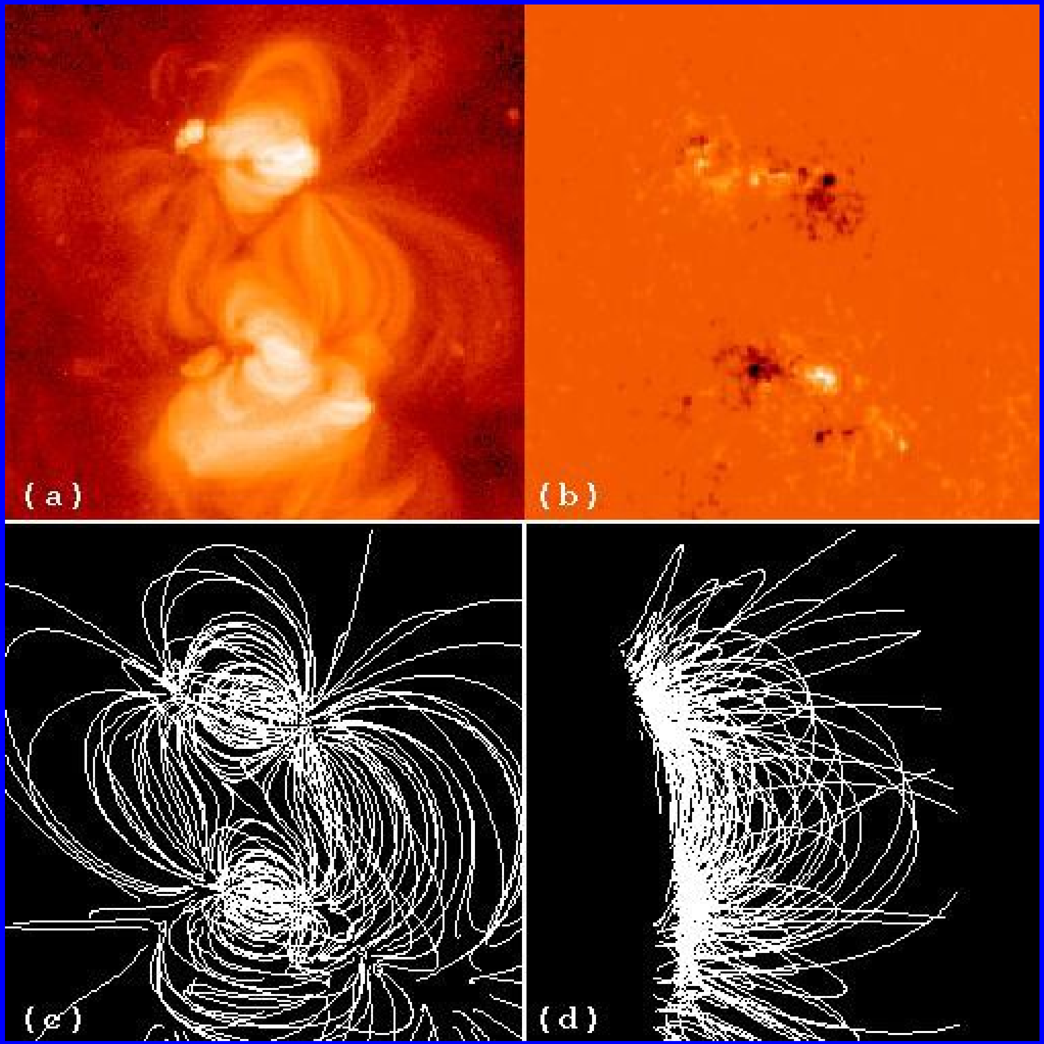
Sunspots
Examples





Magnetic Fields ABOVE the "Surface"

Yohkoh, 4 Jan, 1994



L-O-S magnetic field

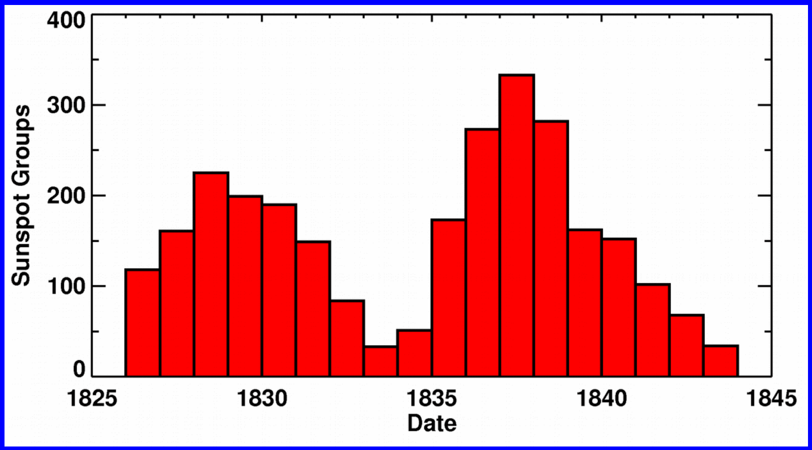
Extrapolated Magnetic Field

The Solar Cycle

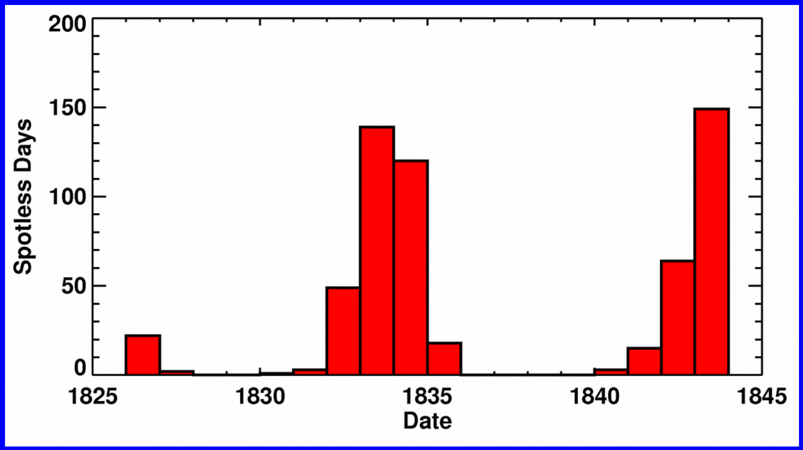
Sunspot Cycle Discovery

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

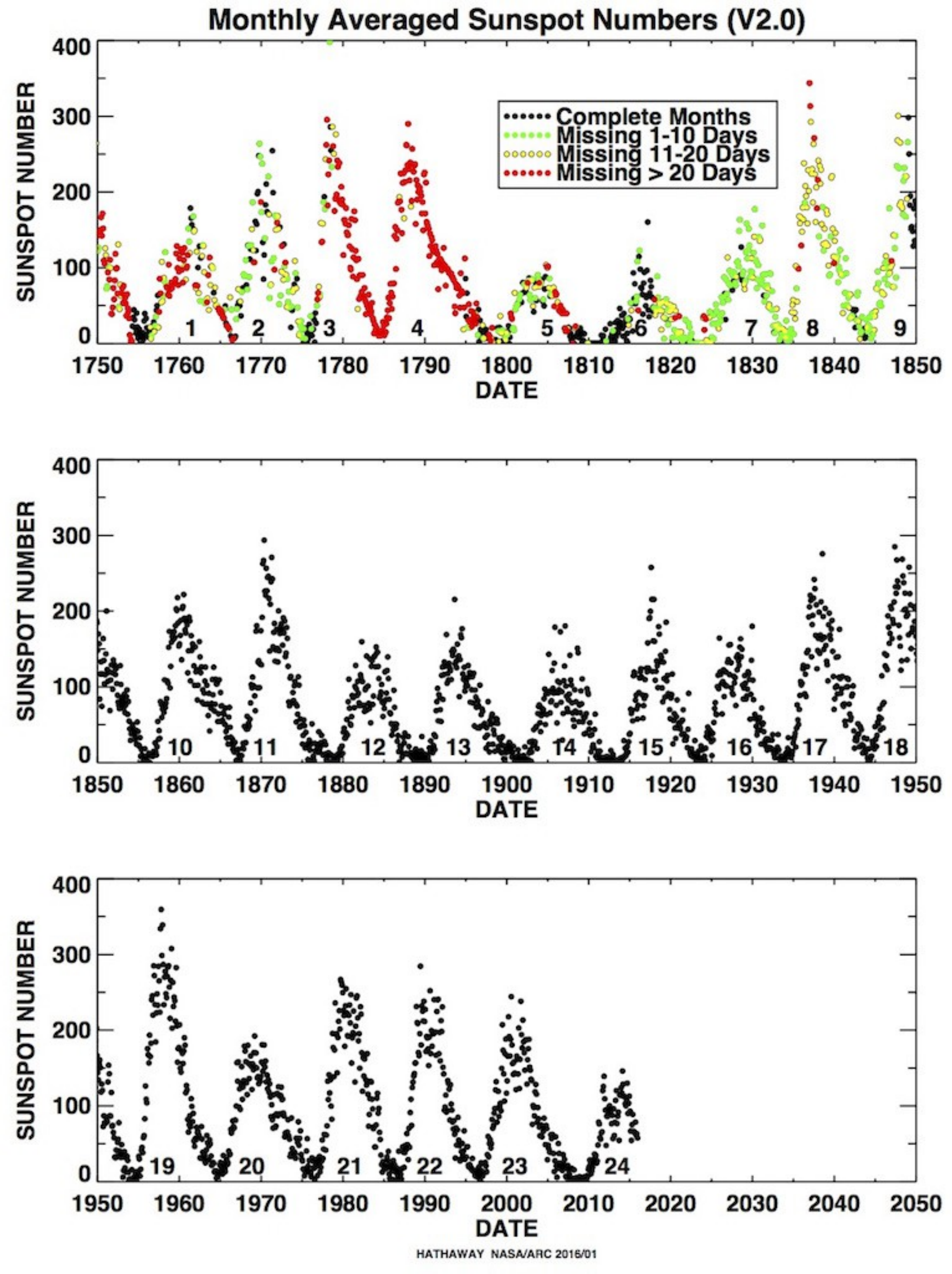


Number of Sunspot Groups per Year



Number of Spotless Days

23 Full Cycles



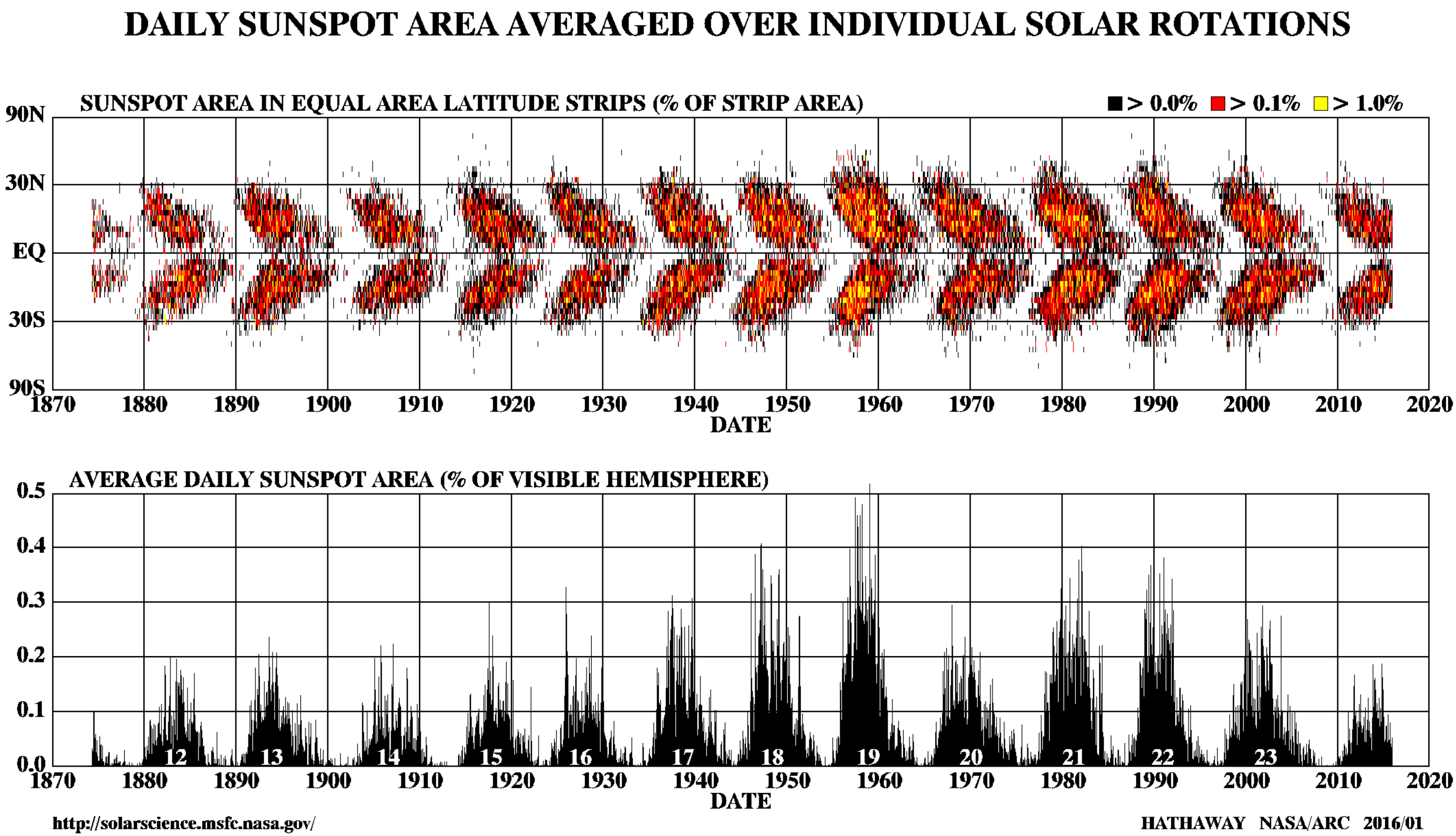
Shortly after Schawbe discovery Rudolf Wolf proposed using a “Relative” Sunspot Number count. While there were many days without observations prior to 1849, sunspots have been counted on every day since. To this day we continue to use Wolf’s Relative Sunspot Number and his cycle numbering.

The average cycle lasts about 11 years, but with a range from 9 to 14.

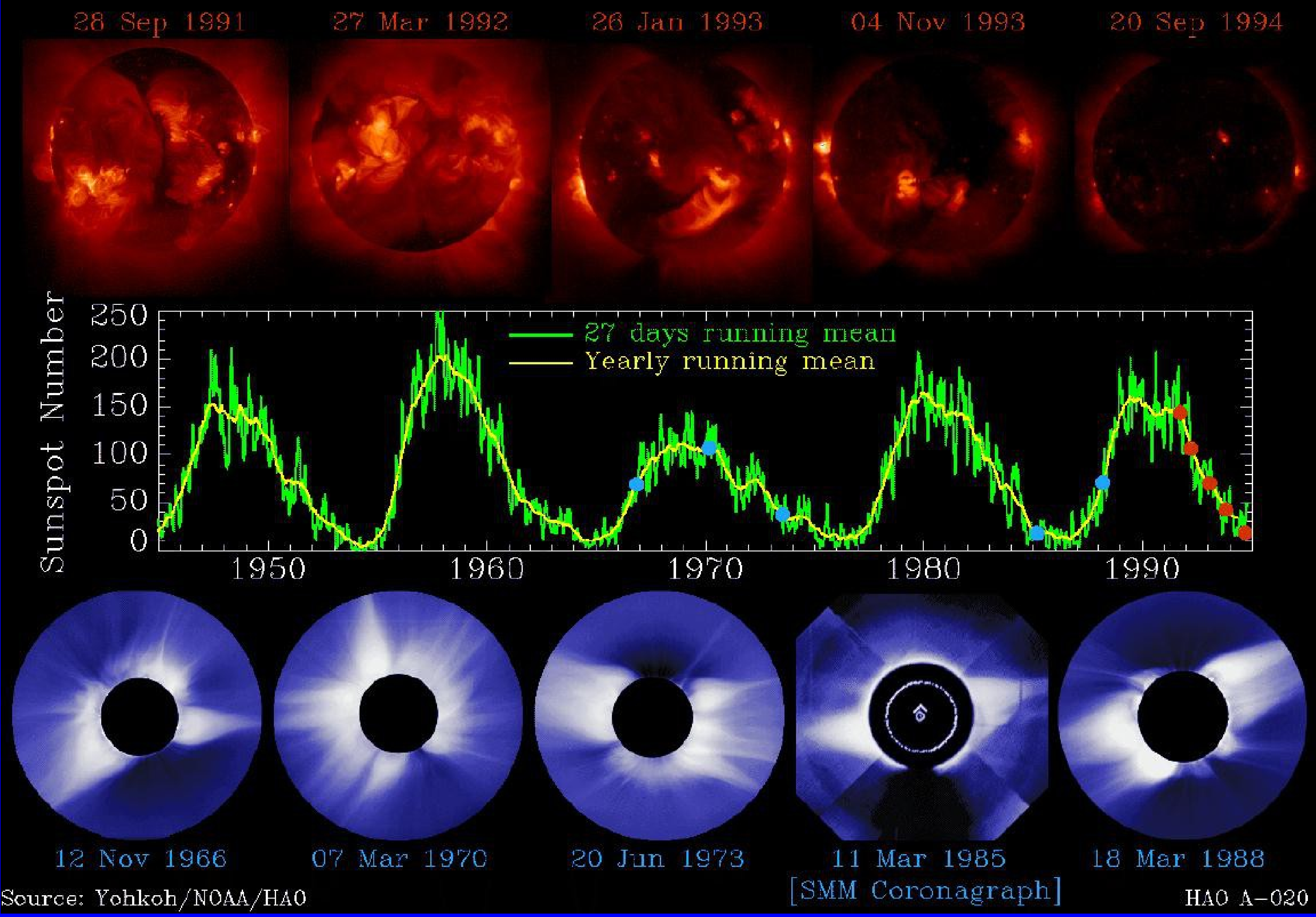
The average amplitude is about 100, but with a range from 50 to 200.

Sunspot Latitudes

Sunspots appear in two bands on either side of the equator. These bands drift toward the equator as the cycle progresses. Big cycles have wider bands that extend to higher latitudes. Cycles overlap by 2-3 years.

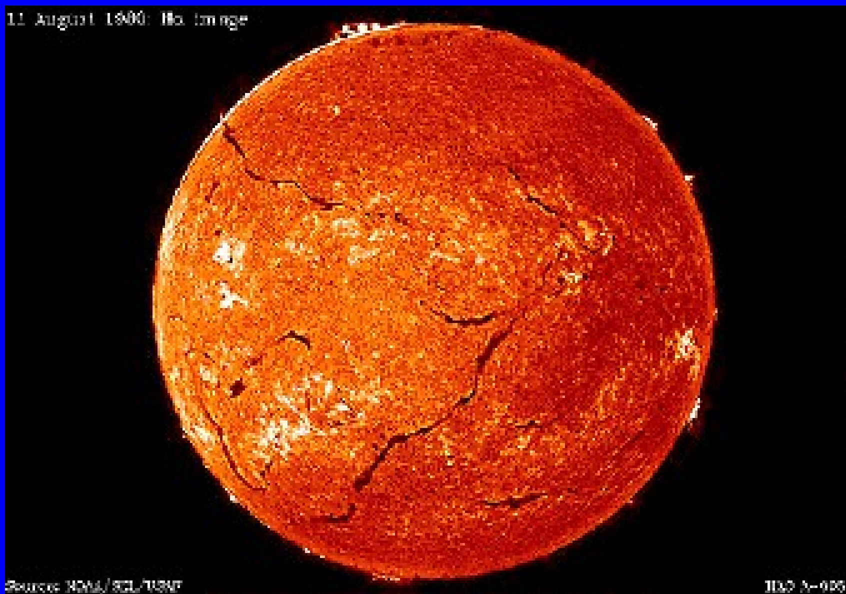


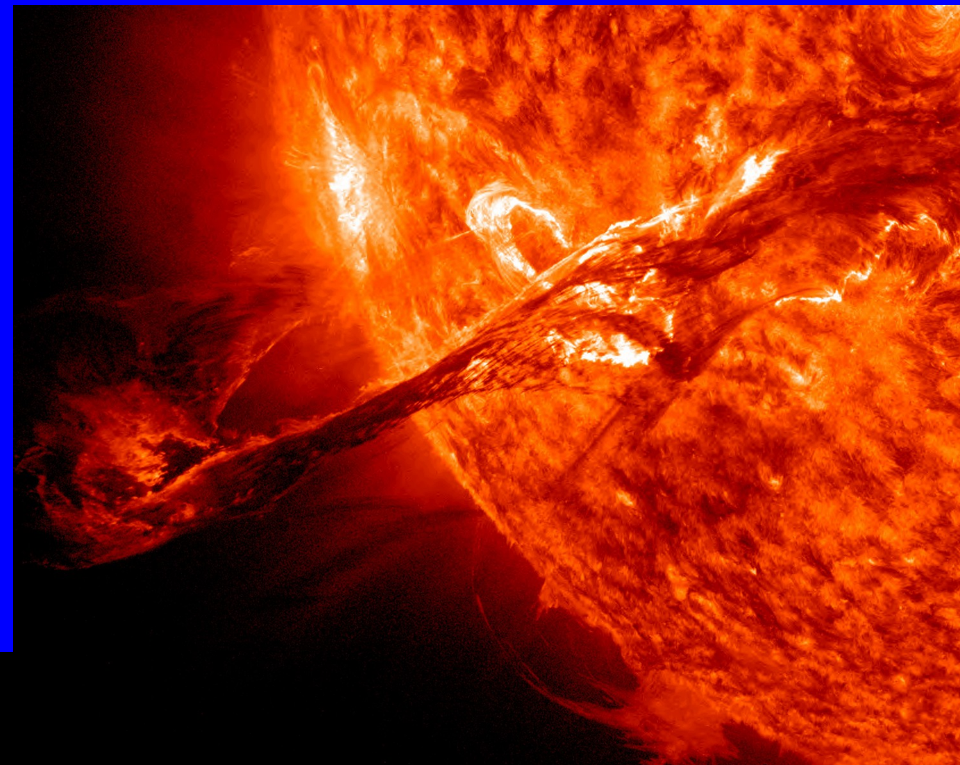
The Corona and the Solar Cycle



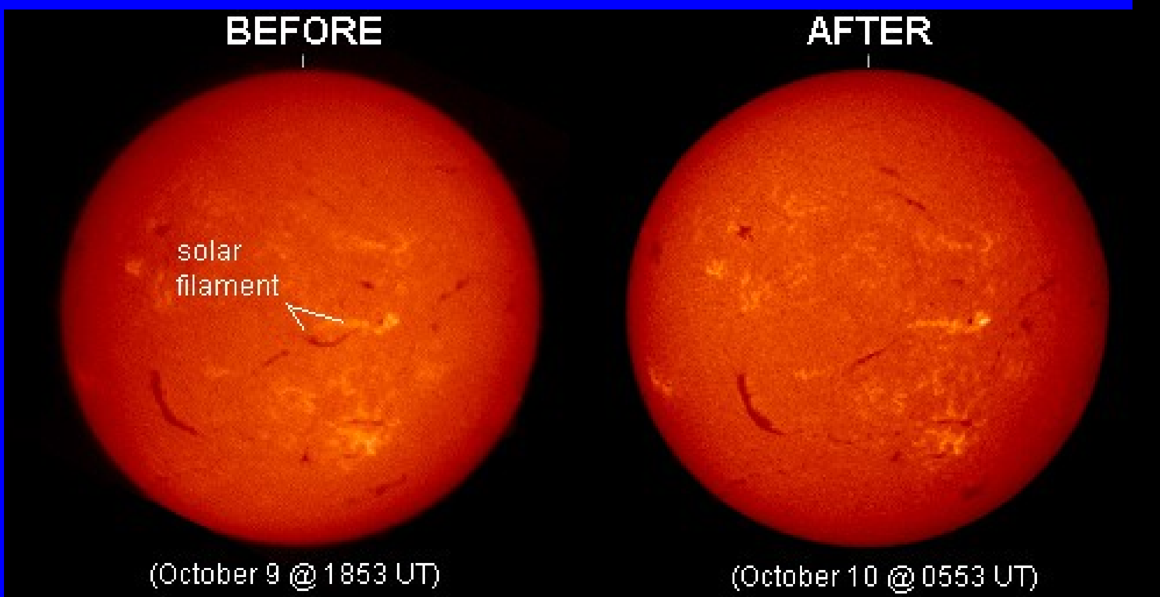
Solar Eruptions

Filament eruptions





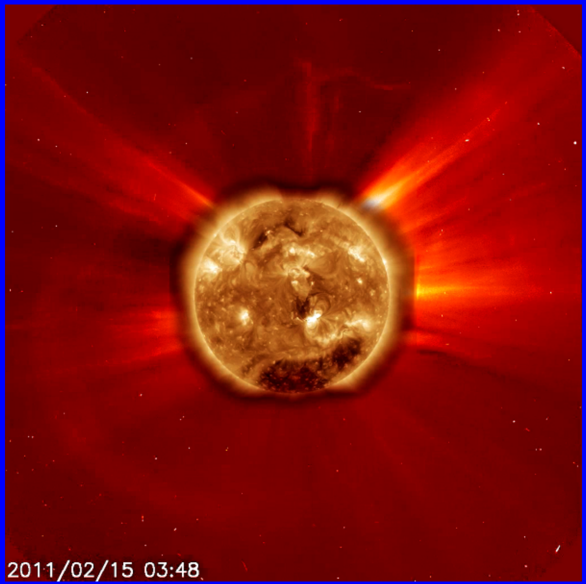
August 31, 2012, a filament erupted, triggering a CME. The plasma had speeds > 900 mi/s. This image is from SDO in 304 Å.



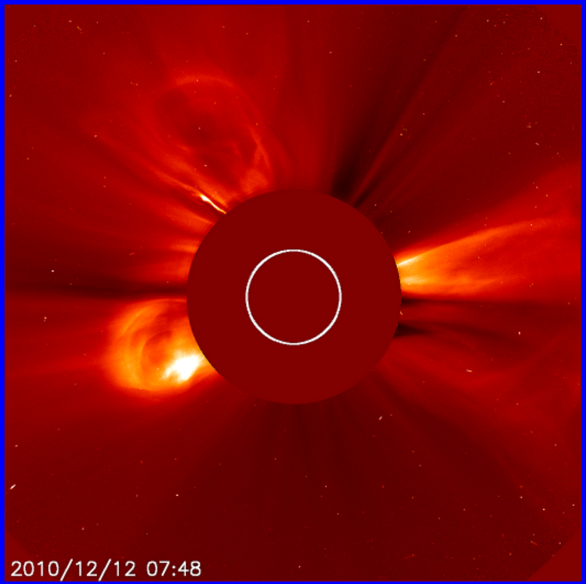
A filament around AR 9182 in October 2000. A C-7 flare was triggered, as well as a halo coronal-mass ejection (CME). Images from NOAA/SEC.

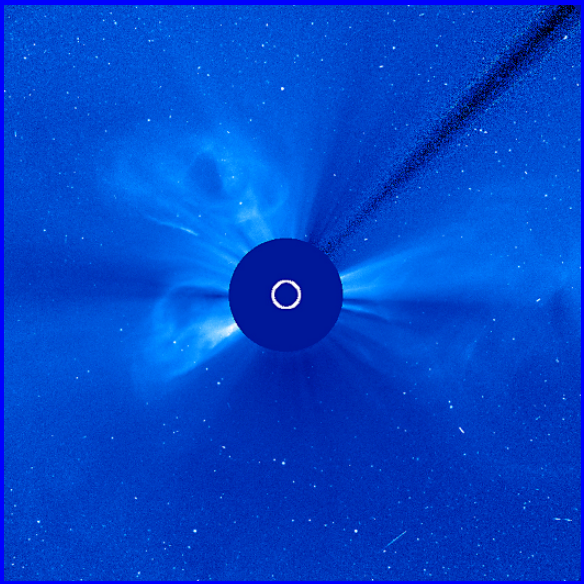
Other Types of Solar Eruptions

Solar Flares and Coronal Mass Ejections (CMEs)



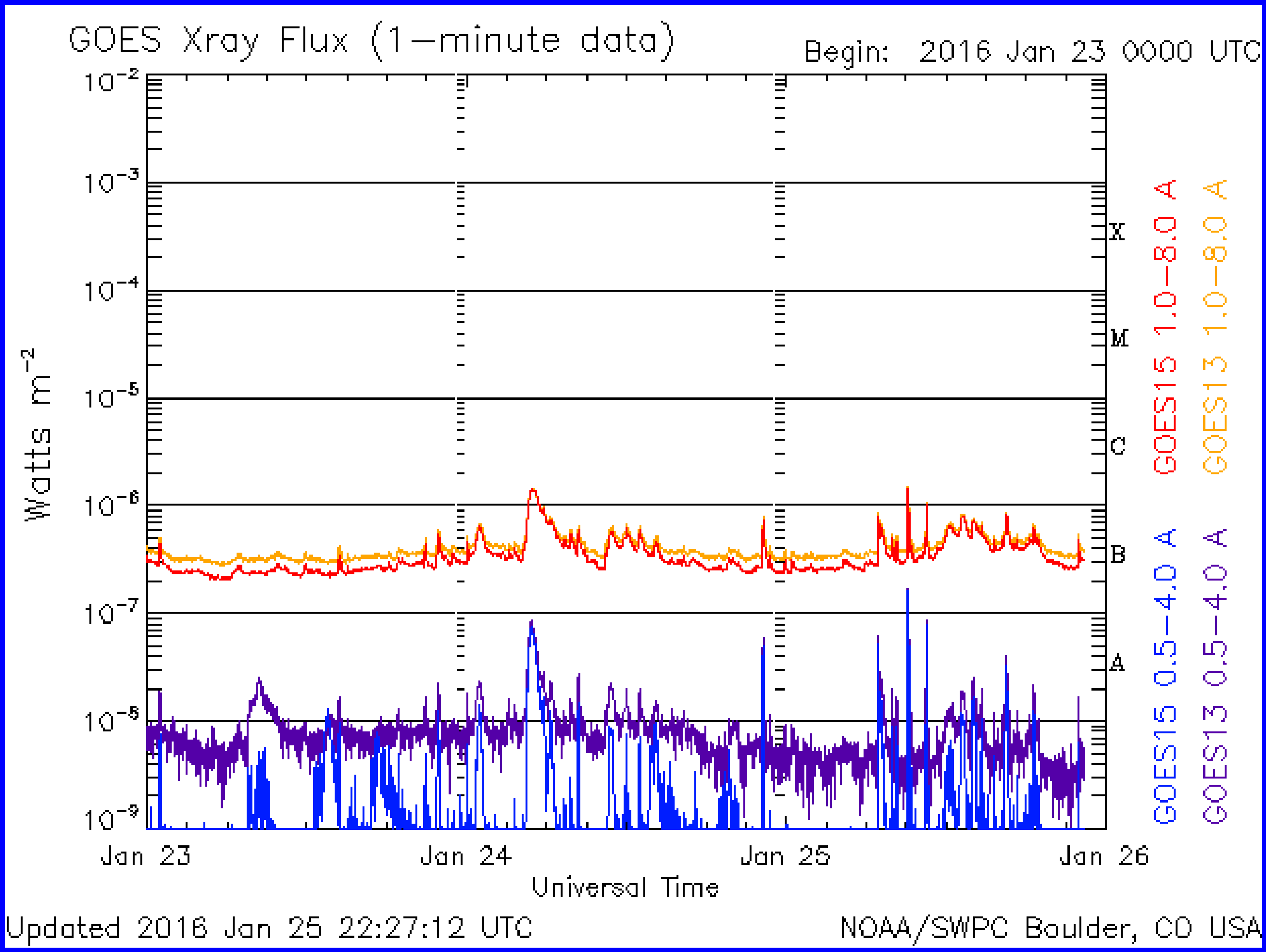
This combo of SDO and Soho C2 shows X2-flare and CME





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.

How to Classify a Solar Flare



What are the characteristics of our Sun?

How is the Sun Different from Other stars?

Solar Characteristics

- The Sun is on the main sequence
- The Sun produces spots on its surface
- The Sun produces explosions of energy
- The Sun has a system of planets

Stellar Characteristics

- Other stars are on the main sequence
- Other stars have spots
- Other stars flare
- Other stars have systems of planets - 2740 confirmed planets (Kepler)

Major Differences

Mass:	High mass stars burn out quickly
Temperature:	Higher mass implies higher temperature
Multiple star system:	Interactions can lead to accretion and lots of flares

Summary

Our Sun is a single star with a system of planets

The Sun is a stable star, currently happily converting hydrogen to helium

The Sun will remain on the Main Sequence of ~ 4.5 billion years more

The Sun is an active star, which produces spots, flares, and coronal mass ejections

Will the Sun end its life with a bang or a whimper?

The Great American Solar Eclipse

August 21, 2017

National Aeronautics and Space Administration

The Earth/Sun sizes and distances in this illustration are not to scale. Scaling to the size of the Sun here (about 10 cm), Earth would be about 10 meters (30 feet) away and six times smaller than drawn.

The next total LUNAR eclipse will be on **27 September, 2015.**

Umbral eclipse begins: 8:07 p.m. CDT

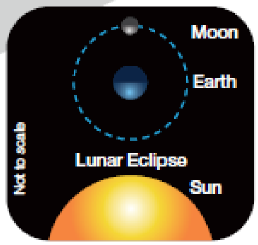
Greatest eclipse: 9:47 p.m CDT

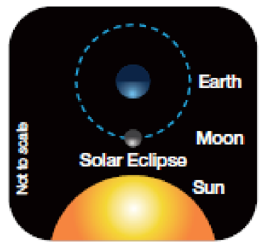
Umbral eclipse ends: 11:27 p.m. CDT

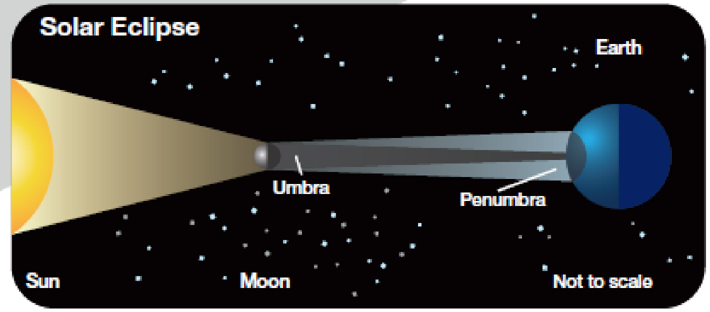
What is a Solar Eclipse?

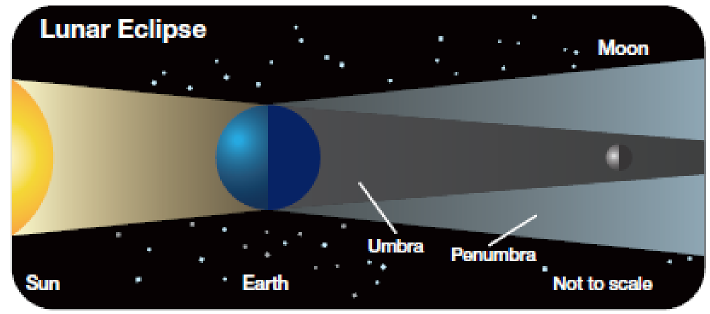
A solar eclipse happens when the Moon, as it orbits Earth, fully or partially blocks the light of the Sun, thus casting its shadow on Earth.

In contrast, a **lunar eclipse** occurs when Earth is between the Moon and the Sun, Earth blocks the light of the Sun, and the Moon is fully or partially engulfed by Earth's shadow.









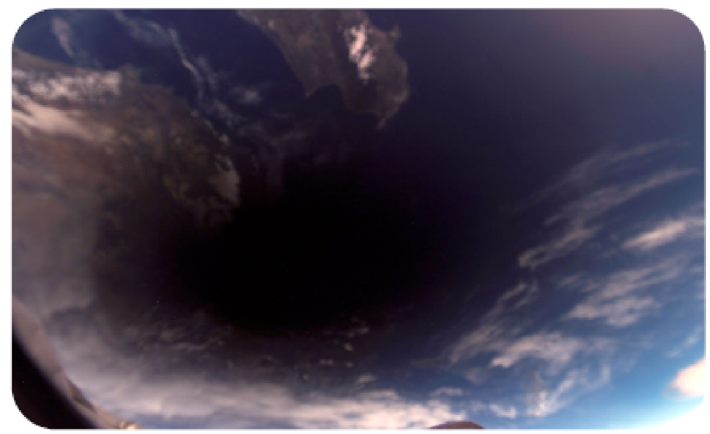
The predicted path of the August 21, 2017 solar eclipse

Duration of Greatest Eclipse (18:25 UT=13:25 CDT or 1:25 p.m. CDT): **2 min 40 sec**

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



http://mail.colonial.net/~hkaiter/index.html

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.

Never look directly at the Sun unless you have filters that you know are safe.

For more information: http://eclipse/gsfc.nasa.gov/SEhelp/safety.html

For more information about solar eclipses: http://eclipse.gsfc.nasa.gov/solar.html
http://eclipsewise.com/solar
http://eclipse2017.org/

www.nasa.gov

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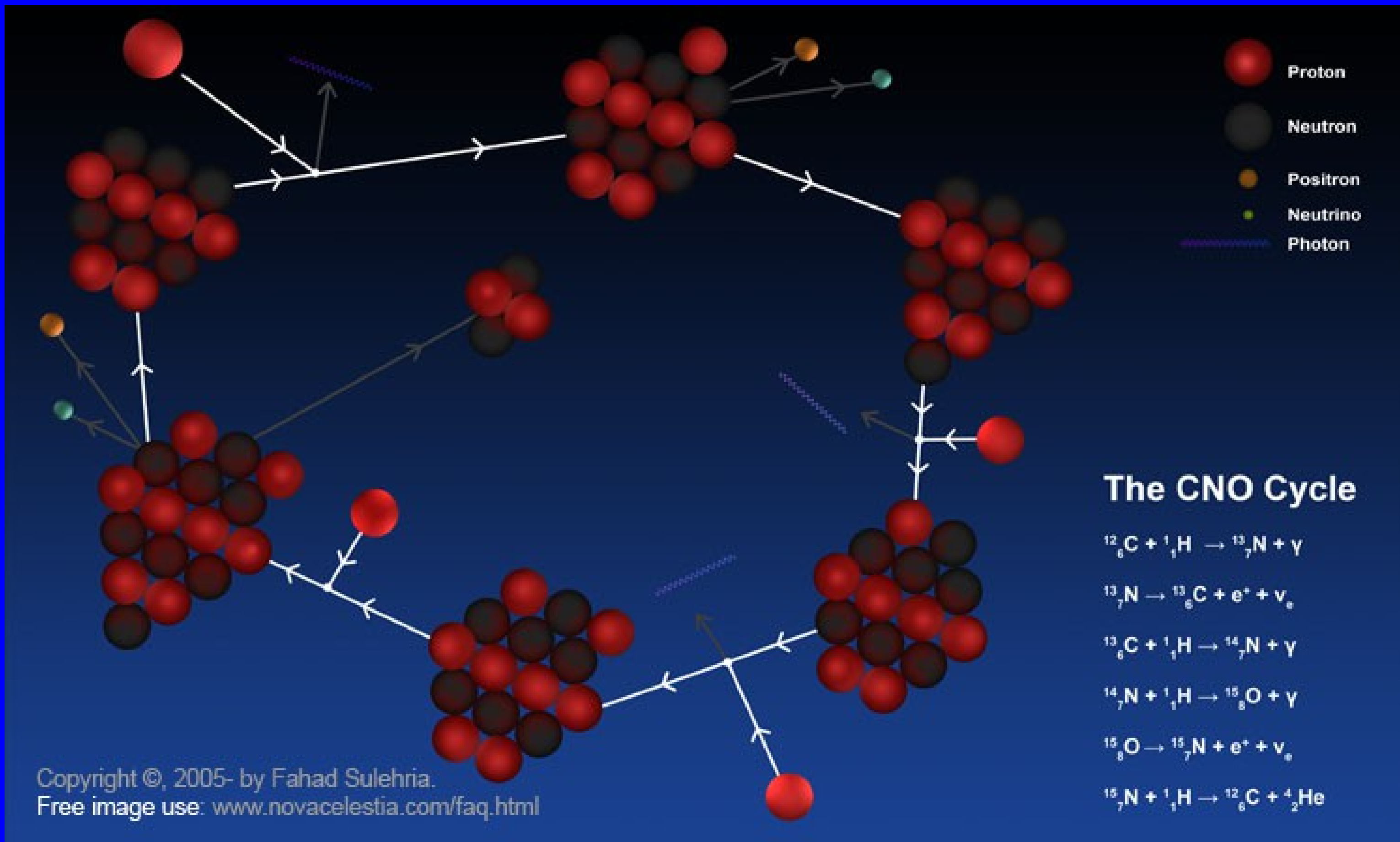

Proton
Neutron
Positron
Neutrino
Photon
The CNO Cycle
$^{12}_{6}C + ^{1}_{1}H \rightarrow ^{13}_{7}N + \gamma$
$^{13}_{7}N \rightarrow ^{13}_{6}C + e^{+} + \nu_{e}$
$^{13}_{6}C + ^{1}_{1}H \rightarrow ^{14}_{7}N + \gamma$
$^{14}_{7}N + ^{1}_{1}H \rightarrow ^{15}_{8}O + \gamma$
$^{15}_{8}O \rightarrow ^{15}_{7}N + e^{+} + \nu_{e}$
$^{15}_{7}N + ^{1}_{1}H \rightarrow ^{12}_{6}C + ^{4}_{2}He$
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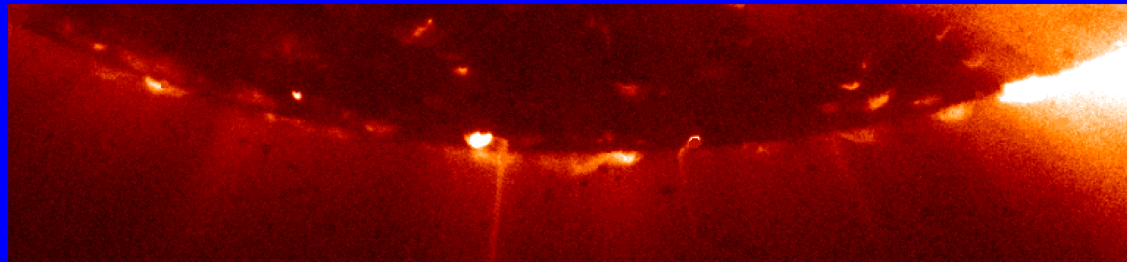
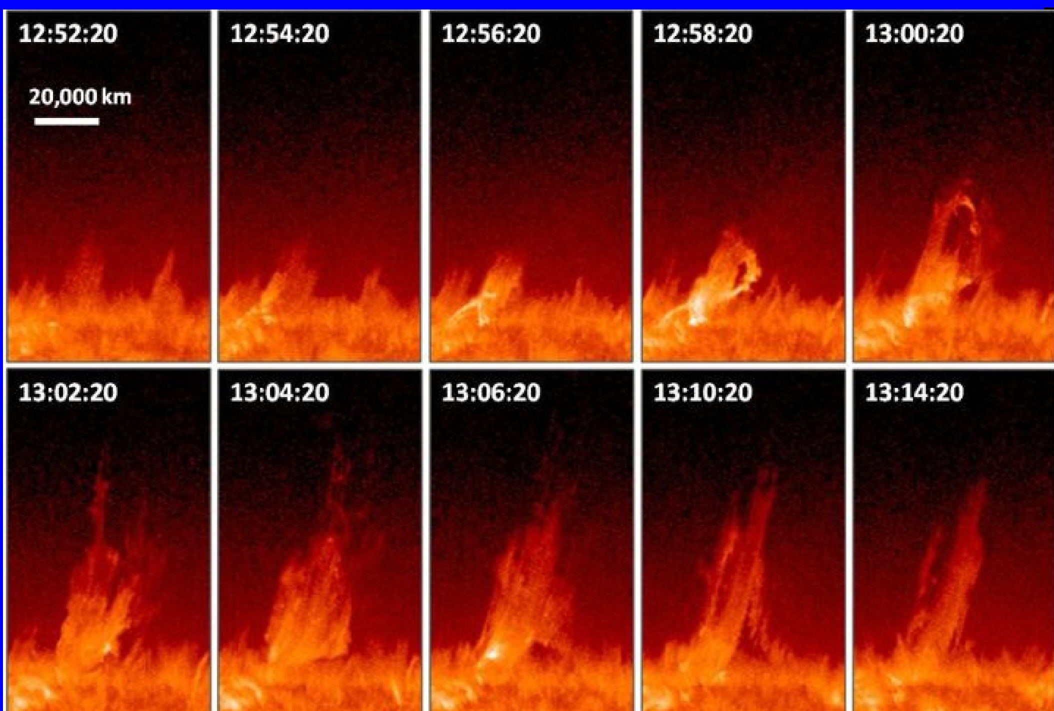


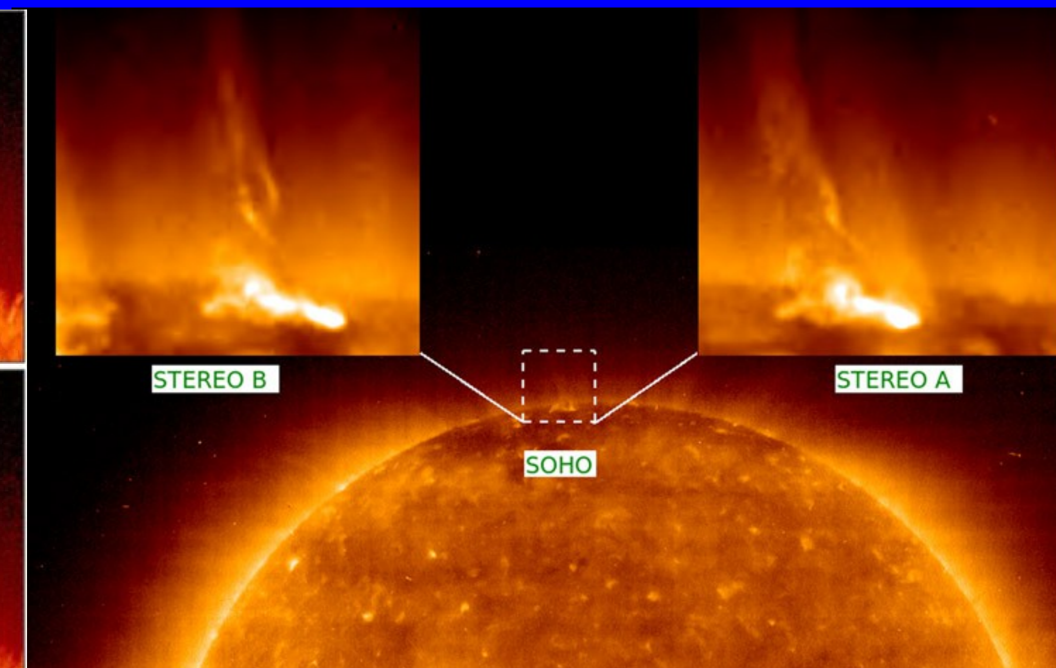
South Polar Jet: Hinode/P. Grigis

Solar jets are not as fast as astrophysical jets, but they can eject a million tons of matter at a speed of a million miles per hour (~45,000 km/s) in just a few minutes.



Above is an example of a “blowout” jet, from a northern polar coronal hole on 2010 October 2. The images are from SDO's AIA in 304 Å.

From: The Cool Component and the Dichotomy, Lateral Expansion, and Axial Rotation of Solar X-Ray Jets, R.L. Moore, *et al.*, **ApJ,** 768:134 2013 June 1

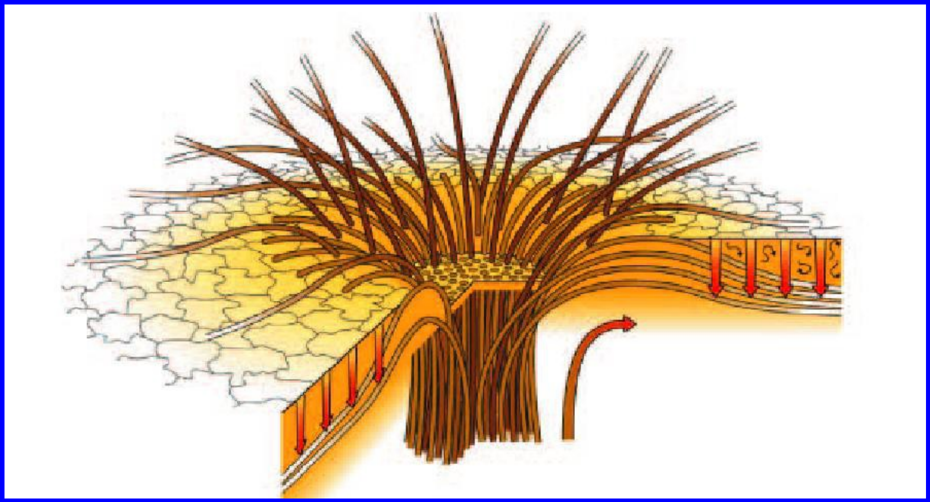


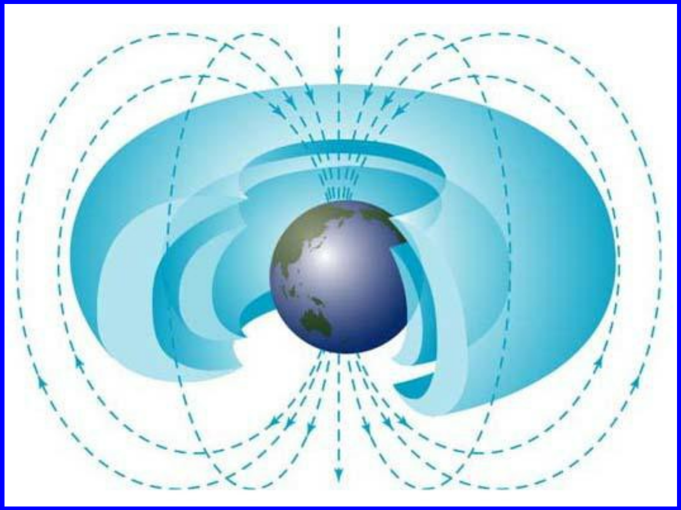
STEREO Stereoscopic Observations Constraining the Initiation of Polar Coronal Jets
S. Patsourakos, E.Pariat, A. Vourlidas, S. K. Antiochos, J. P. Wuesler
The Astrophysical Journal Letters; June 10 2008
http://arxiv.org/abs/0804.4862

A Model for Solar Jets
E. Pariat, S.K. Antiochos, C.R. DeVore

Sunspot Structure and Magnetic Field

Sunspots are regions where intense magnetic fields break through the surface of the Sun. The magnetic field strengths are typically about 6000 times stronger than the Earth's magnetic field.





Magnetic fields and the ionized gases within the Sun are intimately tied together. Where magnetic pressure dominates – the gas follows the magnetic field. Where gas pressure dominates – the magnetic field follows the gas. In sunspots the magnetic pressure dominates – this inhibits the convective transport of heat and makes sunspots cooler.