

The Sun: A Star to Study in Our Backyard



for UAH REU

Friday, 3 June 2022

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Background Image: Joe Matus, NASA/MSFC, August 21, 2017

Outline

- A bit of history of USA astrophysics
- The Sun vs. a couple of stars
 - What is a Star?
 - What is the Sun like?
- Eclipses
- Solar Eruptions
- Jets in Coronal Holes



Astronomy /Astrophysics History in the United States

Maria Mitchell: Educating Future Scientists

- Discovered a comet in 1847 at age 29
- First woman elected to the American Academy of Arts and Sciences (1848)
- First woman elected to the American Association for the Advancement of Science (1850)
- First professor hired at new Vassar College (1865 – Poughkeepsie, New York)
- Co-founded the Association for the Advancement of Women (1873)



Maria Mitchell, Her Legacy: Her Students



Edward Pickering:
Advocate of women's
advanced study, Director
of Harvard Observatory
(1876)



Antonia Maury -- Became one of Edward Pickering's "computers"
1897: published a catalogue of stellar spectra -- first observatory publication credited to a woman.

Mary Watson Whitney -- Succeeded M. Mitchell as Chair of Astronomy Department, Director of Observatory, and Educator

Edward Pickering

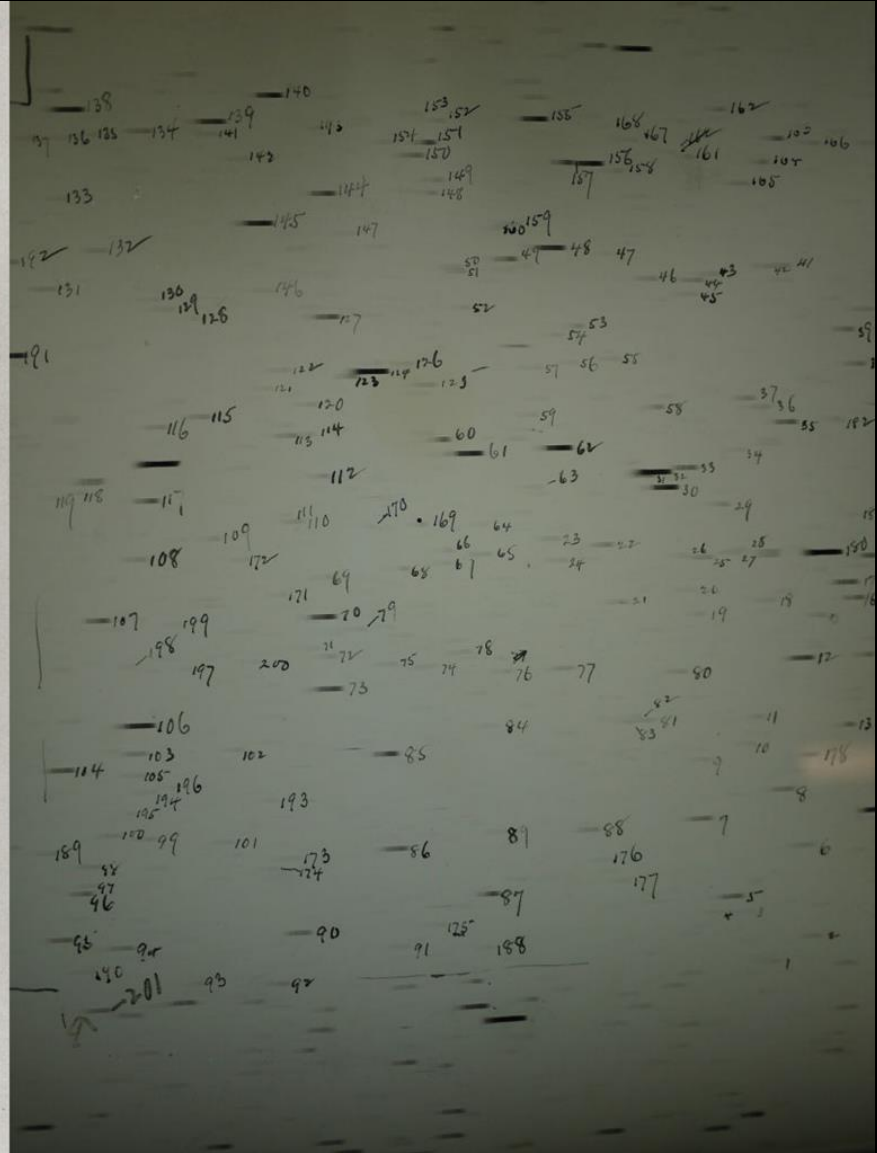
Not satisfied with the math skills of his male assistant,

hired his Scottish housekeeper Williamina Fleming

to help catalogue the spectra of 10,000 stars

Fleming hired 20 other female computers between 1885 and
1900.

Annie Cannon and Spectral Classifications



Edward Pickering and the “Computers” at Harvard Observatory



At Harvard College Observatory,
13 May, 1913

Image Credit: Licenced under Public Domain via Wikipedia
Commons - <http://commons.wikipedia.org>)



William Pickering and his “computers”
Antonia Maury on the far left with back to camera
Annie Cannon on far right

Harvard Computers

Williamina Fleming

Office Manager and classifier of stellar spectra

Antonia Maury

Improved classification system

Annie Jump Cannon

Classified spectra of southern stars and redesigned system, developed Harvard Classification System

Cecilia Payne-Gaposhkin

Determined the relationship between stellar classes and stellar temperature and determined that the Sun is mostly hydrogen

Henrietta Swan Leavitt

Intuited that all stars in Small Magellanic Cloud are approximately at the same distance from Earth, leading to her discovery of direct relationship between period and luminosity of Cepheid variables

Anna Winlock

Made the most complete catalog of stars near north and south (of her time), and calculated orbits and compiled data on asteroids

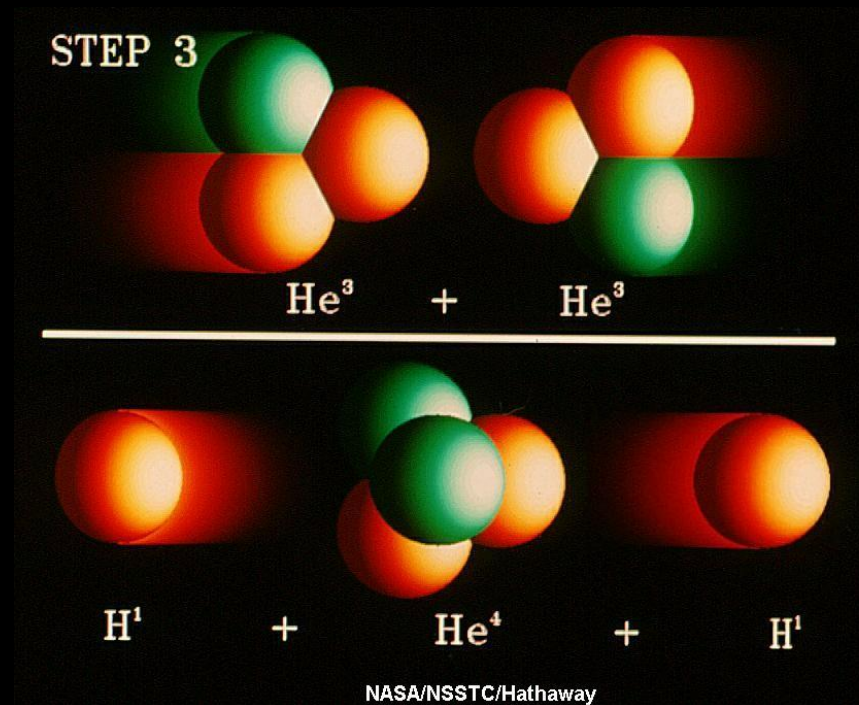
What is a Star?

What is a Star? -- Energy Production

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

For solar-type stars, this is the proton-proton chain

1. Two protons collide, form deuterium, a positron, and a neutrino.



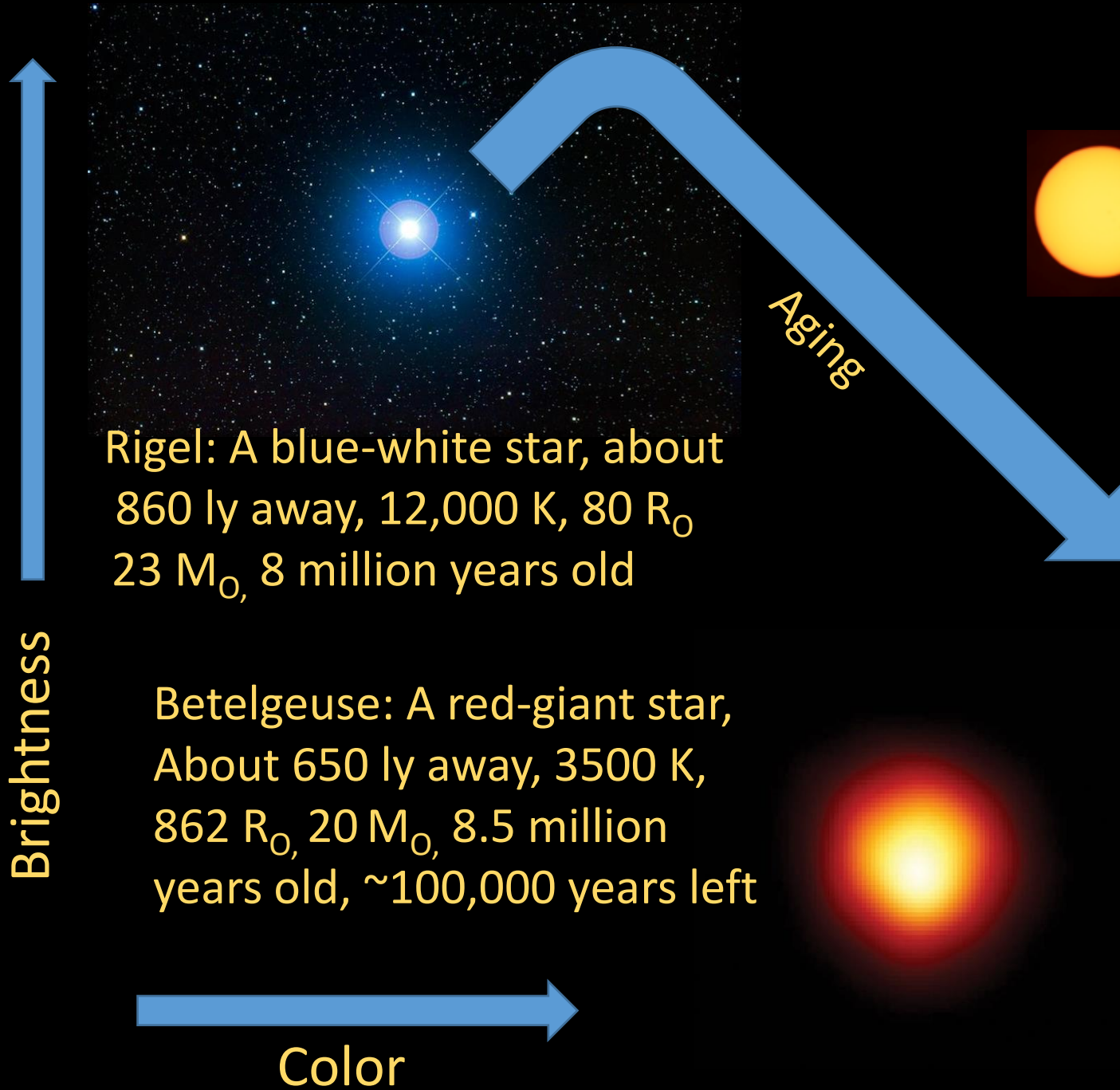
2. A proton collides with the deuterium, forming helium-3 and a gamma ray

3. Two He-3s collide to form He-4 plus two protons.

Basically, Hydrogen converts to Helium

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

What is a Star? -- Differences

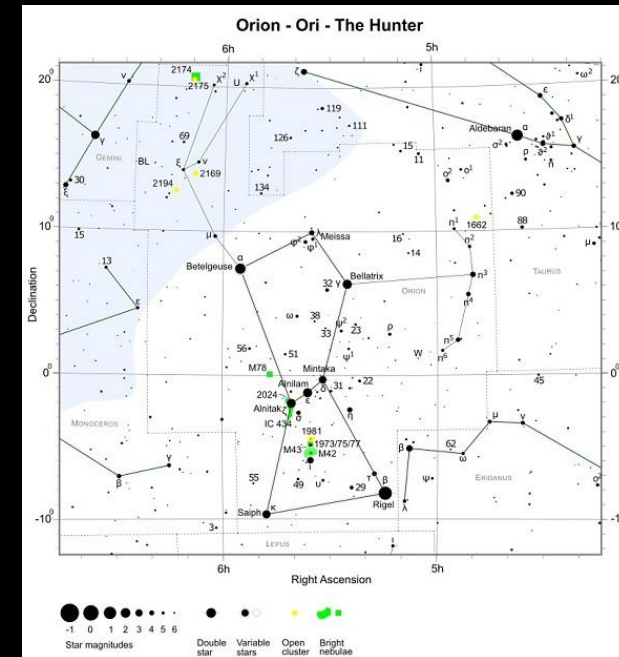


Rigel: A blue-white star, about 860 ly away, 12,000 K, 80 R_{\odot} , 23 M_{\odot} , 8 million years old

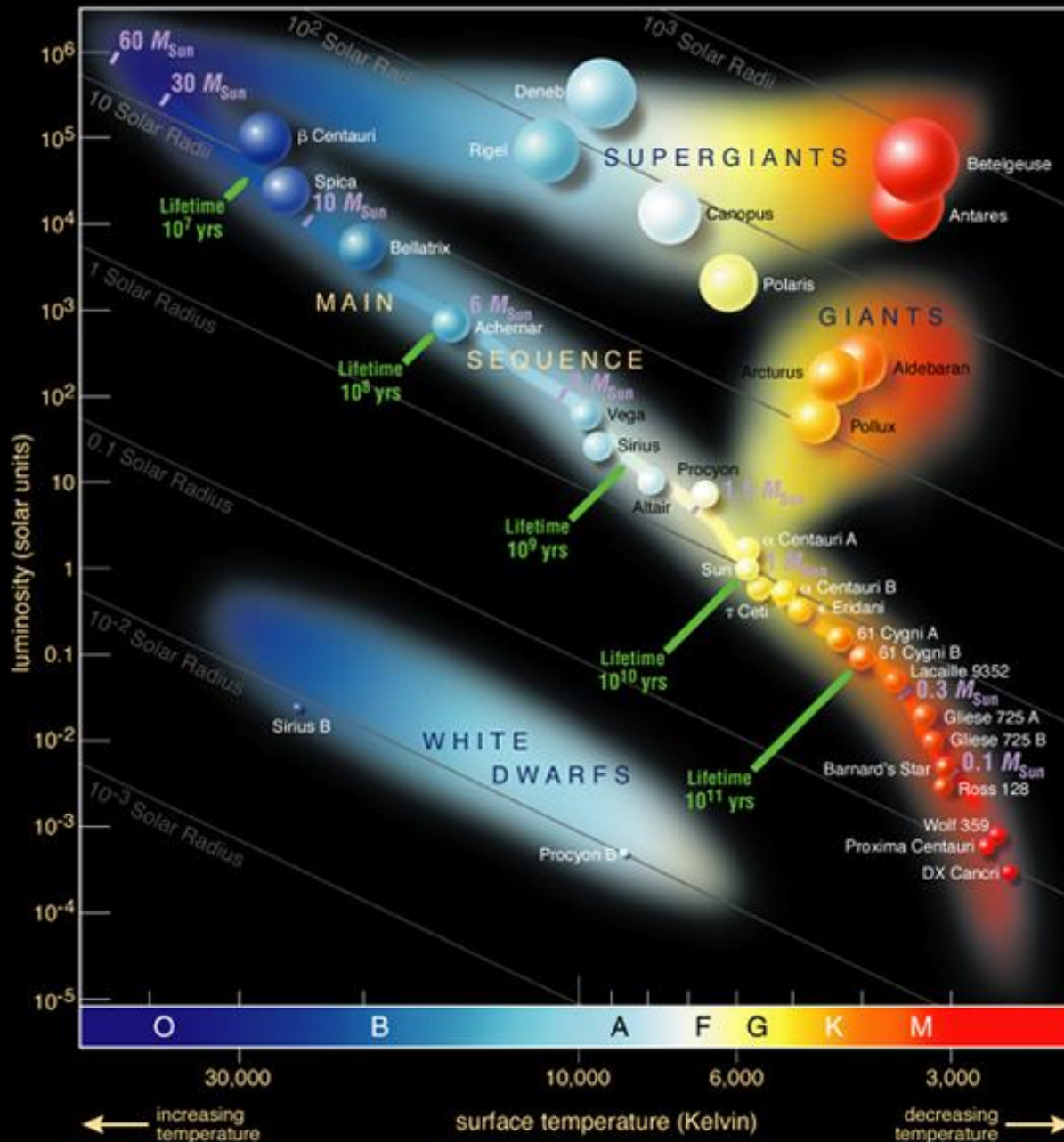
Betelgeuse: A red-giant star, About 650 ly away, 3500 K, 862 R_{\odot} , 20 M_{\odot} , 8.5 million years old, ~100,000 years left



Our Sun: A yellow star, ~8 lm away, 6000 K, ~700,000 km (432,000 mi, 2×10^{30} kg, 4.5 billion years old, ~5 billion yr left



Hertzsprung-Russell Diagram



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

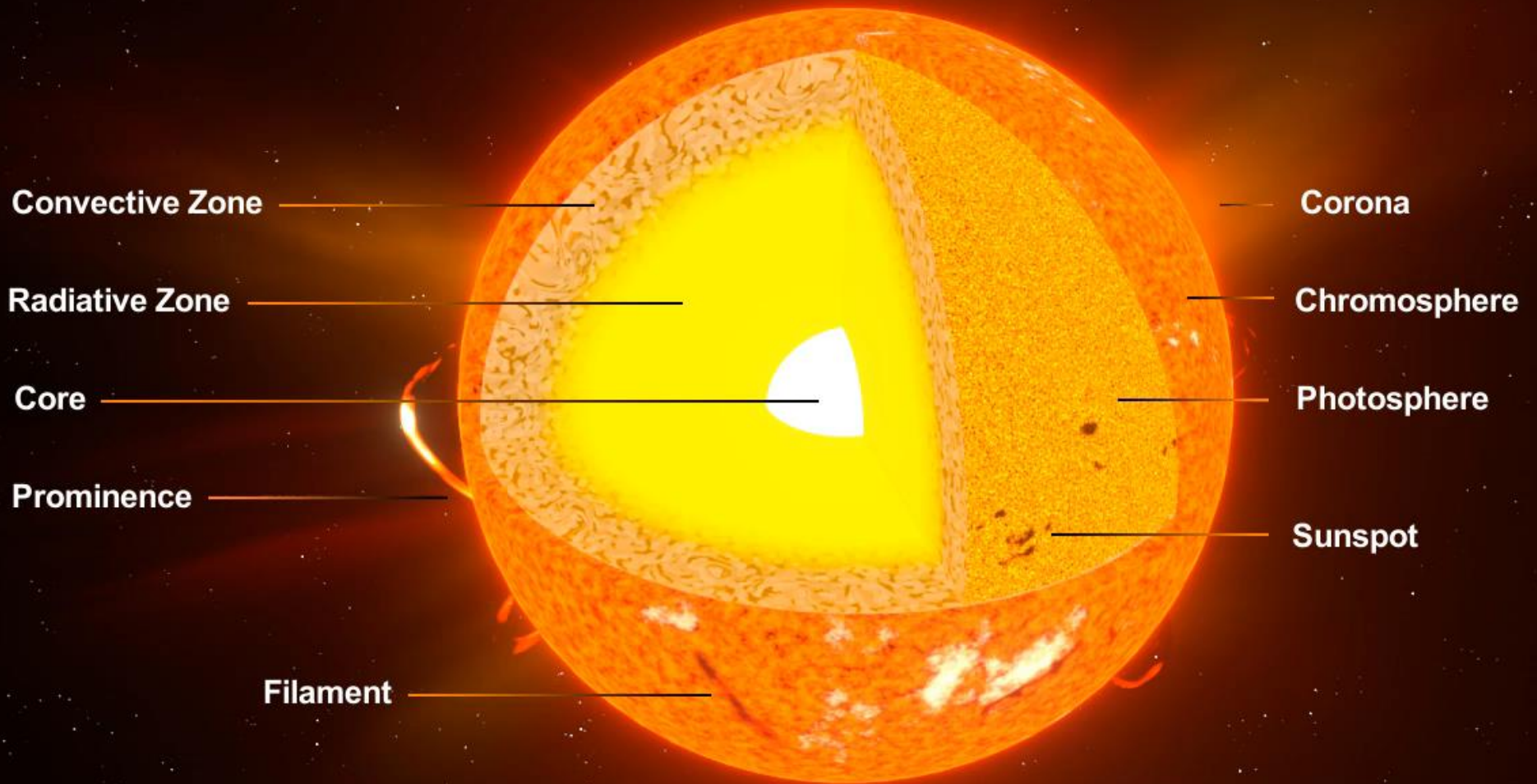
Sun is G2
 8.5 light minutes away

Betelgeuse is M2
 643 ly

Rigel is B8
 860 ly

What is the Sun like?

The Sun: Structure



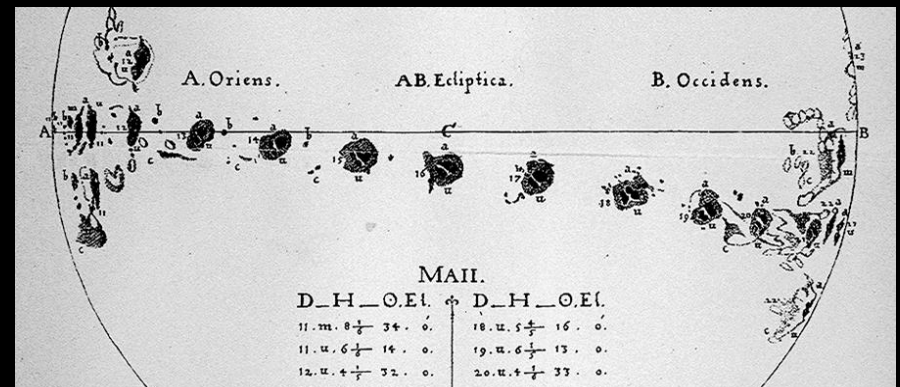
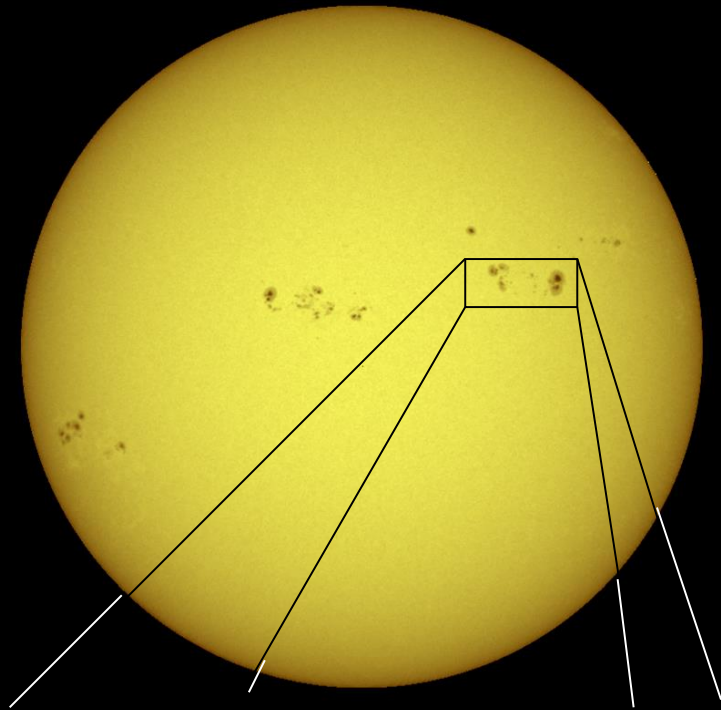
The Sun: Surface Features - Sunspots

Sunspots are regions that are cooler than their surroundings, produced by strong magnetic fields.

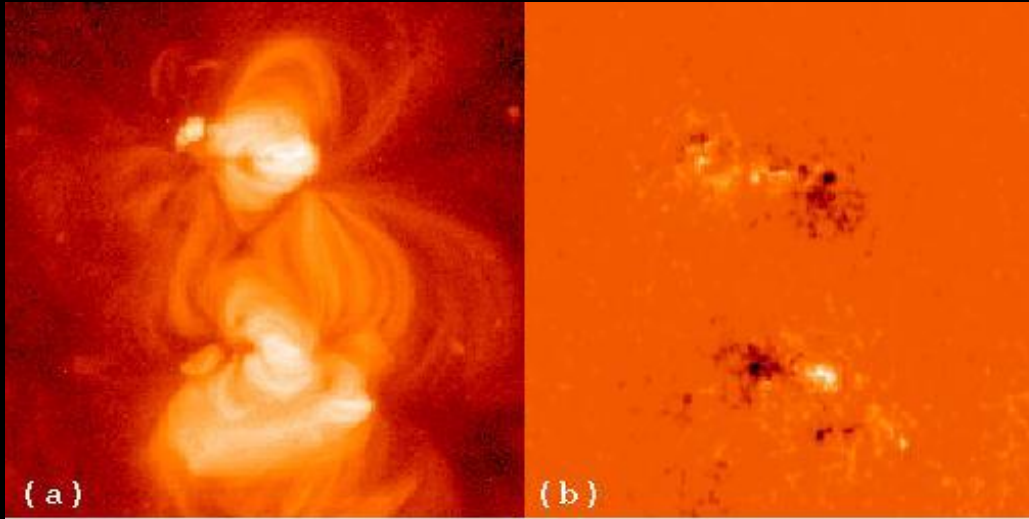
Sunspots have an Umbra surrounded by the lighter Penumbra.

Sunspots usually appear in groups, with lifetimes of days or weeks.

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

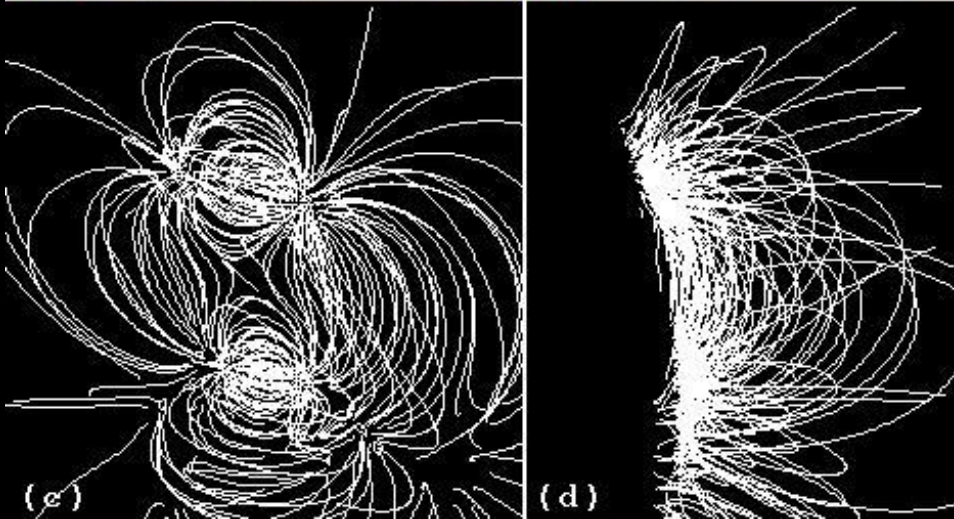


The Sun: Sunspot - Magnetic Fields



(a) Yohkoh Soft X-ray Telescope,
Corona
4 Jan, 1994 7:35 UT

(b) Line-of-Sight magnetic field
from Kitt Peak National Observatory
at 16:31 UT



(c), (d) Extrapolated Magnetic Field

The Sun: Sunspot Cycle Discovery

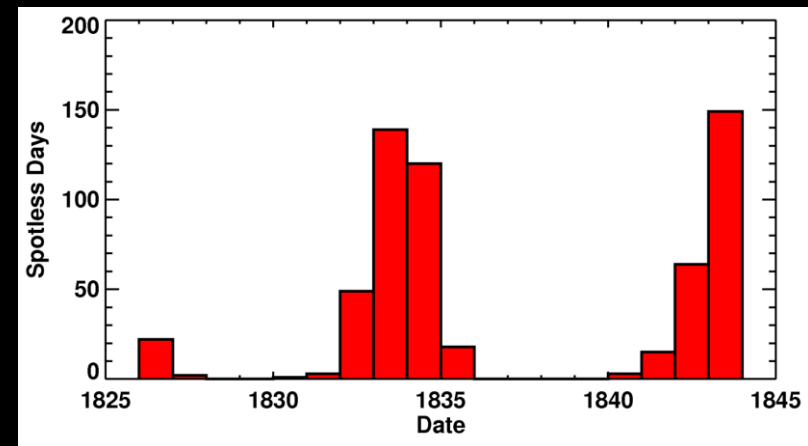
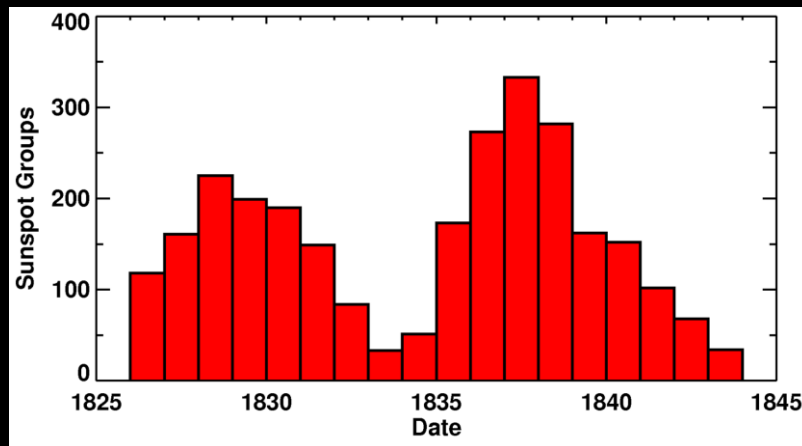
Sunspots observed > 230 years

1844 Heinrich Schwabe, amateur astronomer, Dessau, Germany

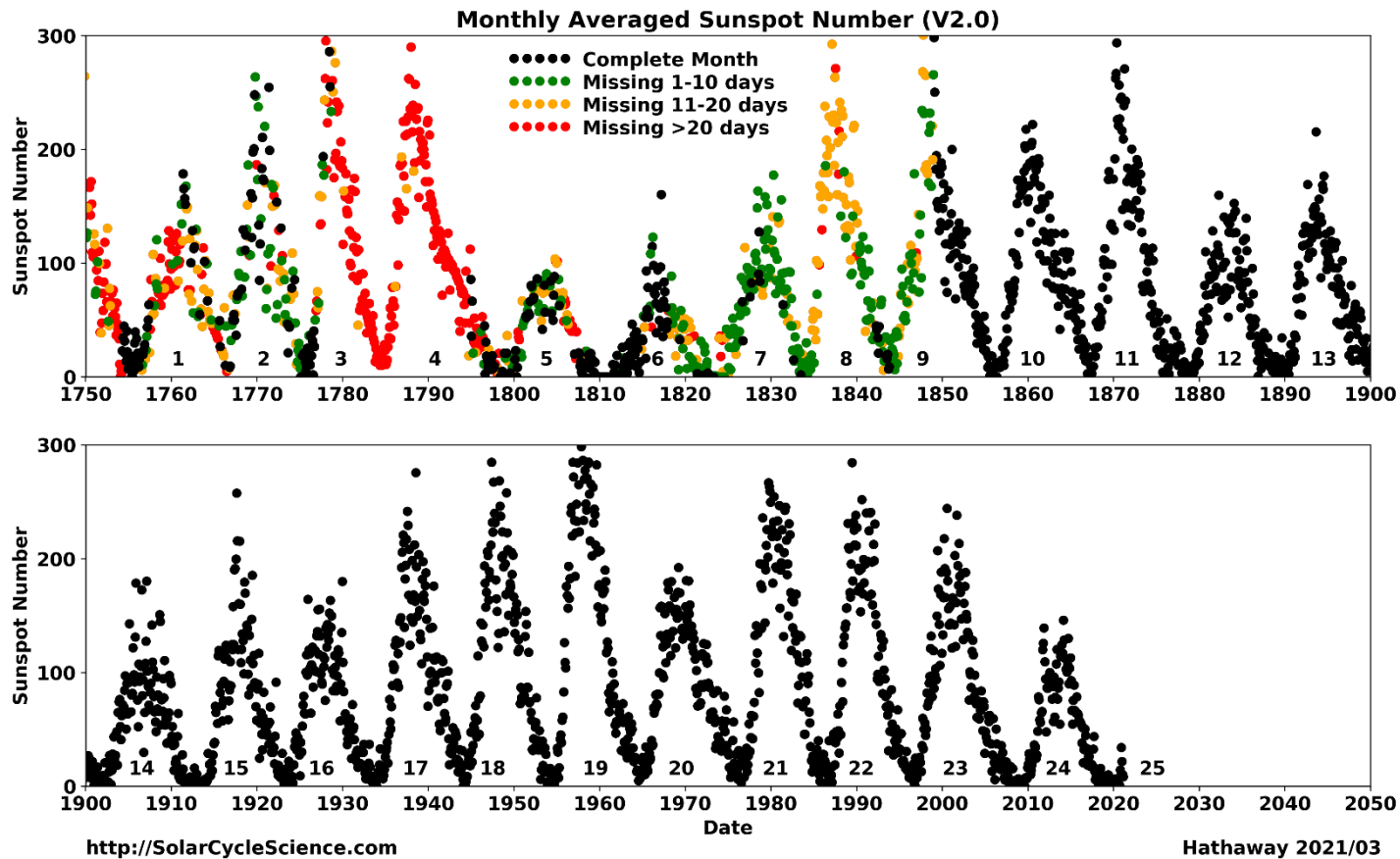
Cycle: increase and decrease over ~10-years

- number of sunspot groups and the
- number of days without sunspots

Schwabe's data for 1826 to 1843



The Sun: 24 Full Cycles Observed



- **Rudolf Wolf 1849 -- “Relative” Sunspot Number = 10 times number sunspot groups + total distinct spots**
- **Average cycle: ~11 years, -2, +3**
- **Average amplitude: ~100, with range from 50 to 200**
(Image used with permission of David Hathaway)

The Corona and the Solar Cycle

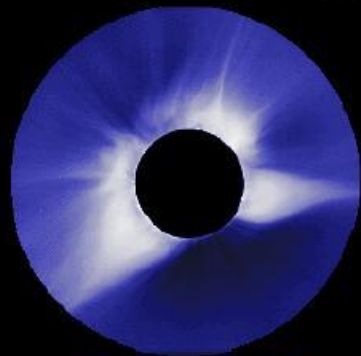
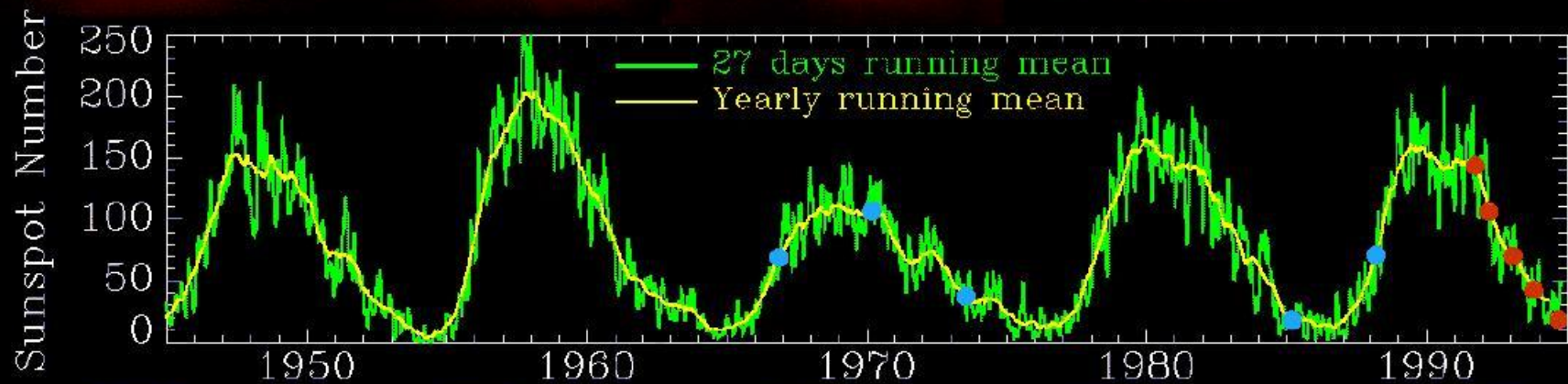
28 Sep 1991

27 Mar 1992

26 Jan 1993

04 Nov 1993

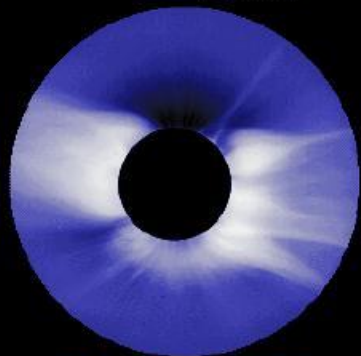
20 Sep 1994



12 Nov 1966



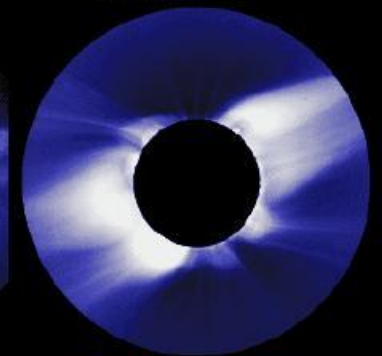
07 Mar 1970



20 Jun 1973



11 Mar 1985

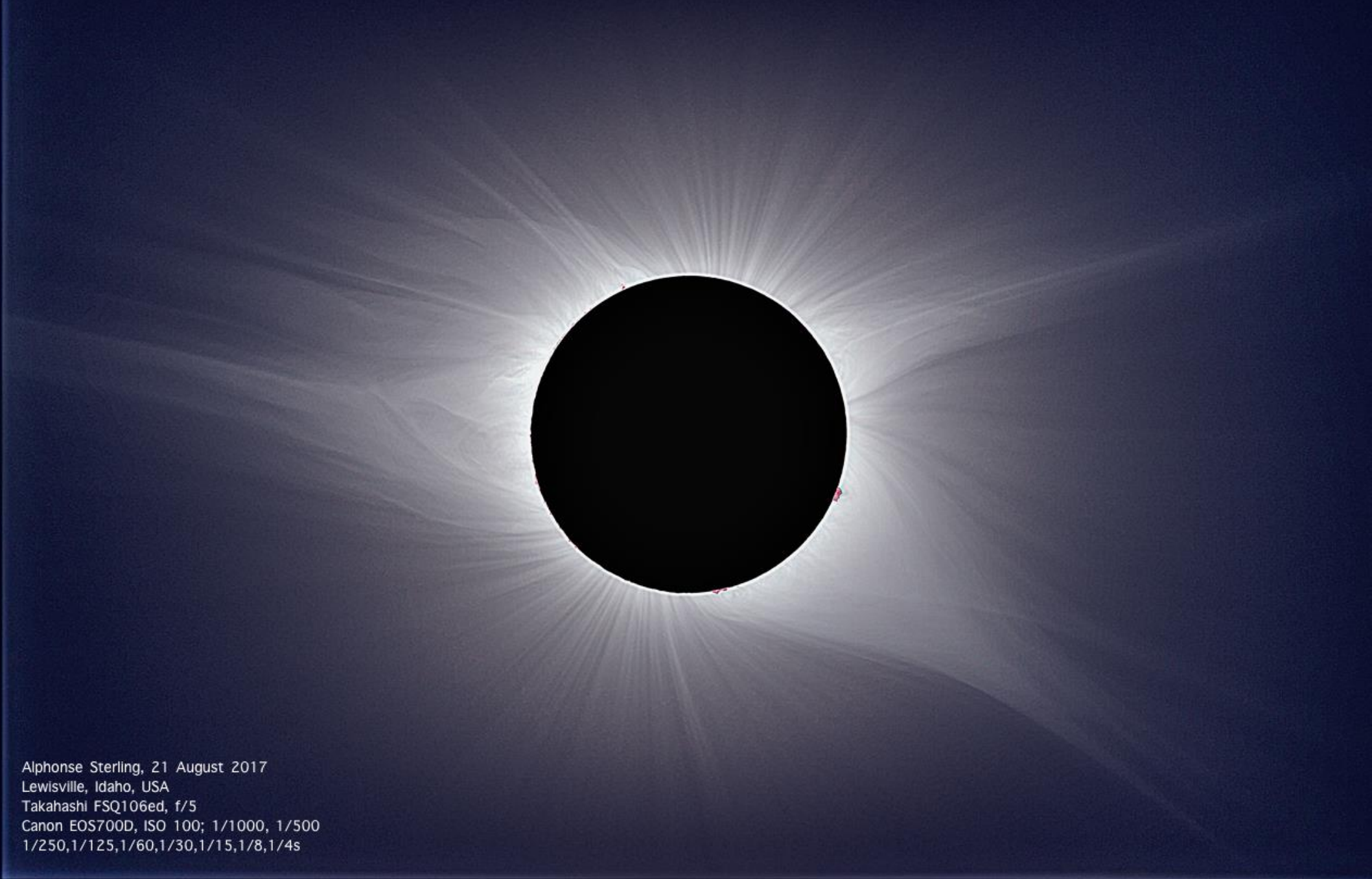


18 Mar 1988

Source: Yohkoh/NOAA/HAO

[SMM Coronagraph]

HAO A-020



Alphonse Sterling, 21 August 2017
Lewisville, Idaho, USA
Takahashi FSQ106ed, f/5
Canon EOS700D, ISO 100; 1/1000, 1/500
1/250, 1/125, 1/60, 1/30, 1/15, 1/8, 1/4s

Corona - The Sun's outermost atmosphere

The Corona August 21, 2017

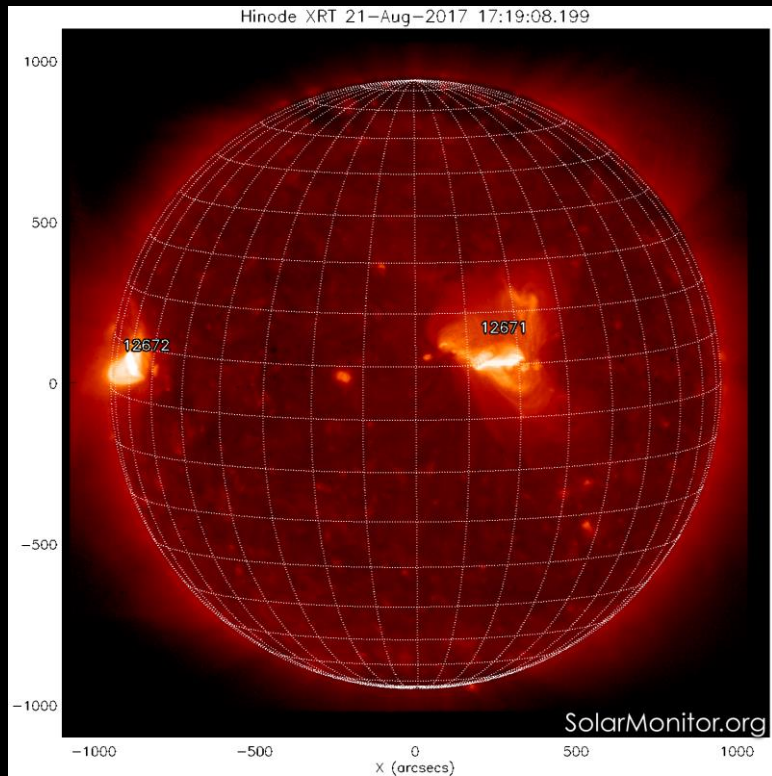


Image by Joe Matus, NASA/MSFC, taken from Hopkinsville, KY

Total Solar Eclipse August 21, 2017



Image Courtesy of Joe Matus, ST 24, NASA/MSFC

First Contact at APSU



Image: Mitzi Adams, NASA/MSFC

Totality at APSU



Totality at Hopkinsville, KY



Image from Dr. Jesse-Lee Dimech,
NASA NPP



Image from Joe Matus,
NASA/MSFC/ST24

Next "Big" U.S. Eclipses

Annular Solar Eclipse of 2023 Oct 14

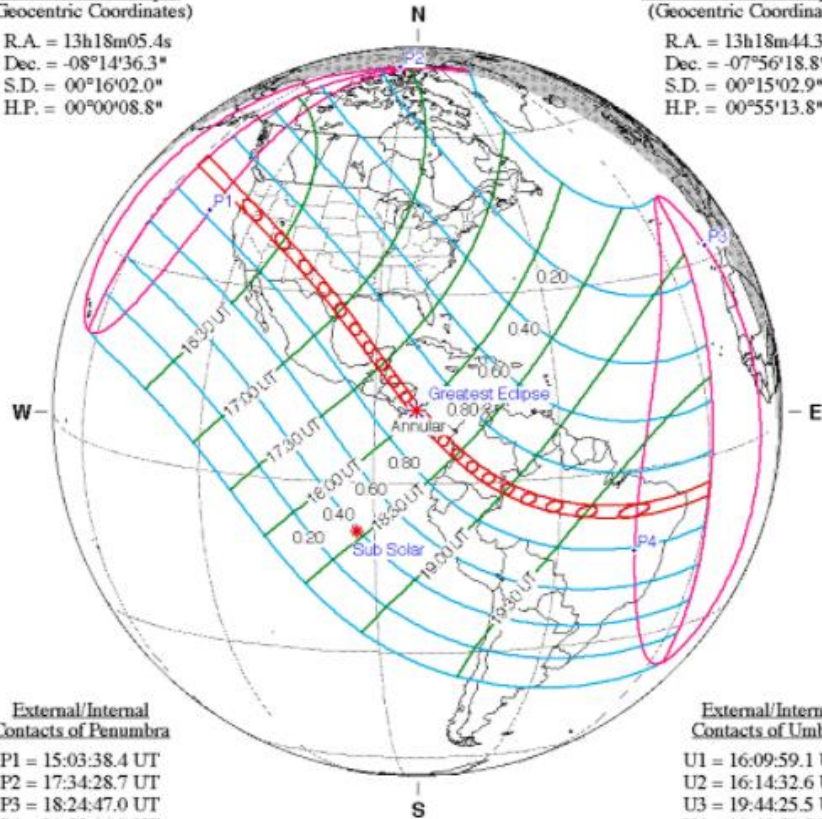
Geocentric Conjunction = 17:36:28.8 UT J.D. = 2460232.233667
 Greatest Eclipse = 17:59:21.0 UT J.D. = 2460232.249549
 Eclipse Magnitude = 0.9520 Gamma = 0.3752
 Saros Series = 134 Member = 44 of 71

Sun at Greatest Eclipse
(Geocentric Coordinates)

R.A. = 13h18m05.4s
 Dec. = -08°14'36.3"
 S.D. = 00°16'02.0"
 H.P. = 00°00'08.8"

Moon at Greatest Eclipse
(Geocentric Coordinates)

R.A. = 13h18m44.3s
 Dec. = -07°56'18.8"
 S.D. = 00°15'02.9"
 H.P. = 00°55'13.8"



External/Internal
Contacts of Penumbra

P1 = 15:03:38.4 UT
 P2 = 17:34:28.7 UT
 P3 = 18:24:47.0 UT
 P4 = 20:55:06.9 UT

External/Internal
Contacts of Umbra

U1 = 16:09:59.1 UT
 U2 = 16:14:32.6 UT
 U3 = 19:44:25.5 UT
 U4 = 19:48:53.5 UT

Local Circumstances at Greatest Eclipse

Lat. = 11°21.7'N Sun Alt. = 67.9°
 Long. = 083°04.3'W Sun Azm. = 208.0°
 Path Width = 187.4 km Duration = 05m17.2s

Geocentric Libration
(Optical + Physical)

l = -3.80°
 b = -0.48°
 c = 20.45°

Brown Lun. No. = 1247

Ephemeris & Constants

Eph. = Newcomb/ILE
 ΔT = 80.7 s
 k1 = 0.2724880
 k2 = 0.2722810
 Δb = 0.0° Δl = 0.0°



F. Espenak, NASA's GSFC - Fri, Jul 2,

sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Total Solar Eclipse of 2024 Apr 08

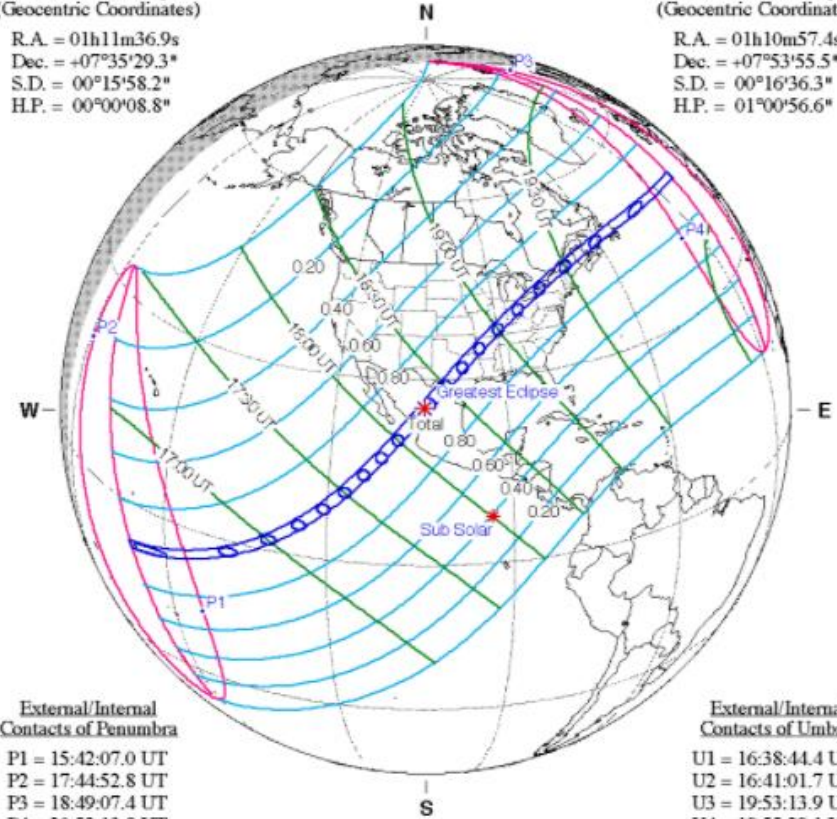
Geocentric Conjunction = 18:36:02.5 UT J.D. = 2460409.275029
 Greatest Eclipse = 18:17:13.1 UT J.D. = 2460409.261957
 Eclipse Magnitude = 1.0565 Gamma = 0.3432
 Saros Series = 139 Member = 30 of 71

Sun at Greatest Eclipse
(Geocentric Coordinates)

R.A. = 01h11m36.9s
 Dec. = +07°35'29.3"
 S.D. = 00°15'58.2"
 H.P. = 00°00'08.8"

Moon at Greatest Eclipse
(Geocentric Coordinates)

R.A. = 01h10m57.4s
 Dec. = +07°53'55.5"
 S.D. = 00°16'36.3"
 H.P. = 01°00'56.6"



External/Internal
Contacts of Penumbra

P1 = 15:42:07.0 UT
 P2 = 17:44:52.8 UT
 P3 = 18:49:07.4 UT
 P4 = 20:52:13.8 UT

External/Internal
Contacts of Umbra

U1 = 16:38:44.4 UT
 U2 = 16:41:01.7 UT
 U3 = 19:53:13.9 UT
 U4 = 19:55:29.1 UT

Local Circumstances at Greatest Eclipse

Lat. = 25°17.5'N Sun Alt. = 69.8°
 Long. = 104°07.2'W Sun Azm. = 149.4°
 Path Width = 197.5 km Duration = 04m28.1s

Geocentric Libration
(Optical + Physical)

l = 2.00°
 b = -0.46°
 c = -20.75°

Brown Lun. No. = 1253

Ephemeris & Constants

Eph. = Newcomb/ILE
 ΔT = 81.2 s
 k1 = 0.2724880
 k2 = 0.2722810
 Δb = 0.0° Δl = 0.0°



F. Espenak, NASA's GSFC - Fri, Jul 2,

sunearth.gsfc.nasa.gov/eclipse/eclipse.html

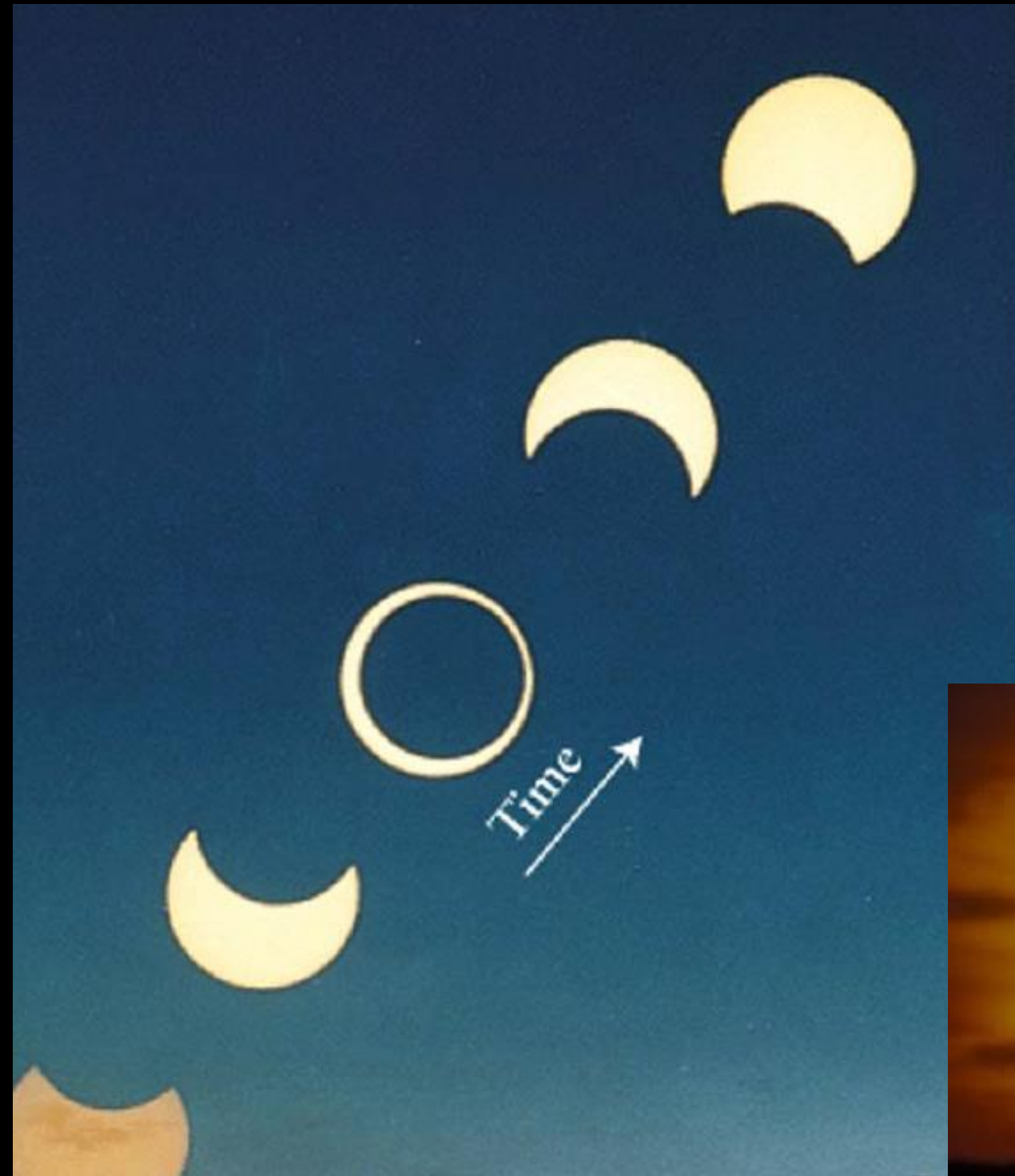


JUNE 10, 2021
ANNULAR SOLAR ECLIPSE

OCTOBER 14, 2023
ANNULAR SOLAR ECLIPSE

APRIL 8, 2024
TOTAL SOLAR ECLIPSE

Annular Eclipse





NO SOLAR ECLIPSE



NO LUNAR ECLIPSE

MOST MONTHS



SOLAR ECLIPSE



LUNAR ECLIPSE



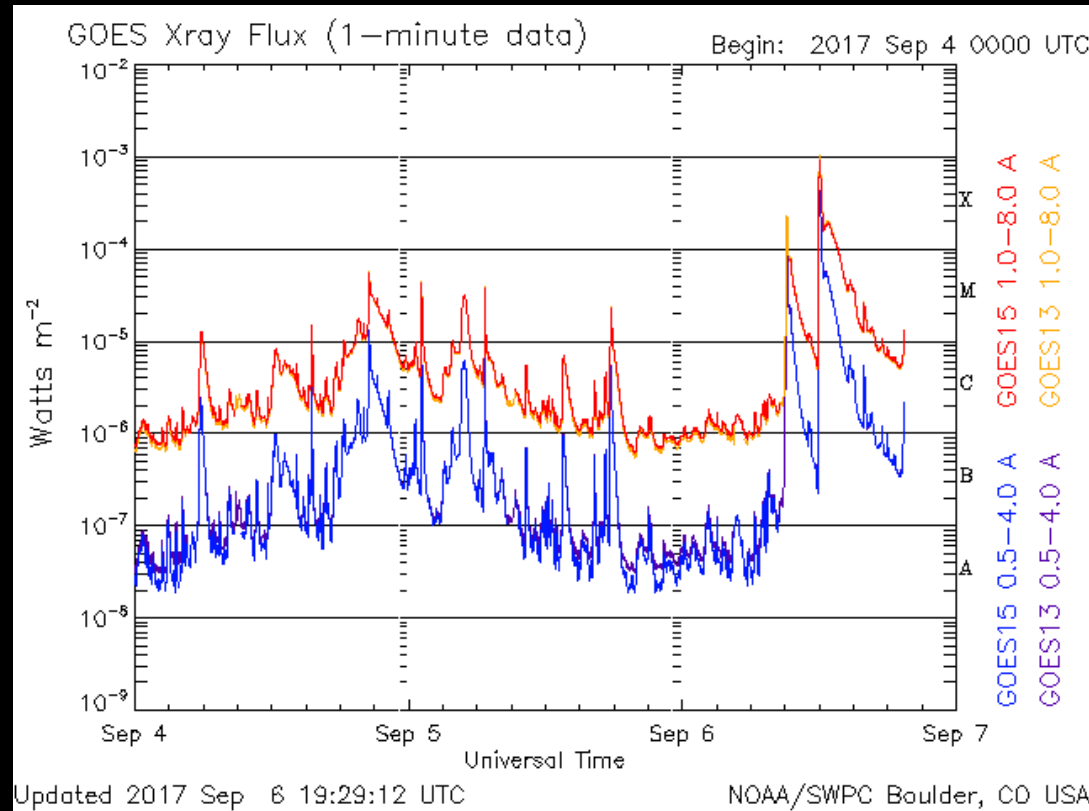
Solar Eruptions

Flares

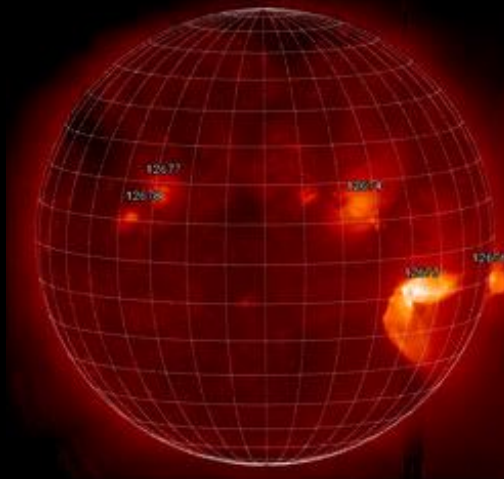
Coronal Mass Ejections

Jets

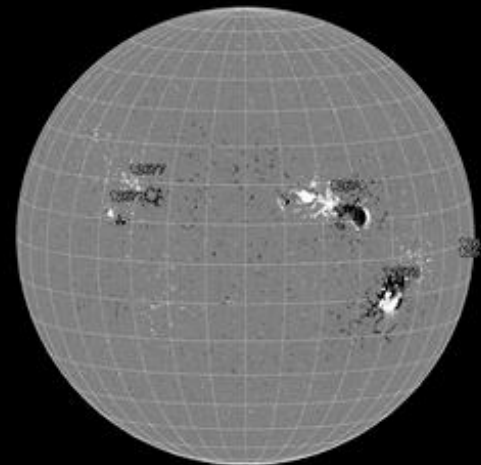
Solar Flare Classification



Sept. 6, 17:59 UT
Hinode X-Ray Telescope
(XRT) X9 flare



Sept. 6, 18:46 UT
SDO/Helioseismic
and Magnetic Imager
(HMI)



Jets in Coronal Holes

Coronal Jets

What is a Jet?

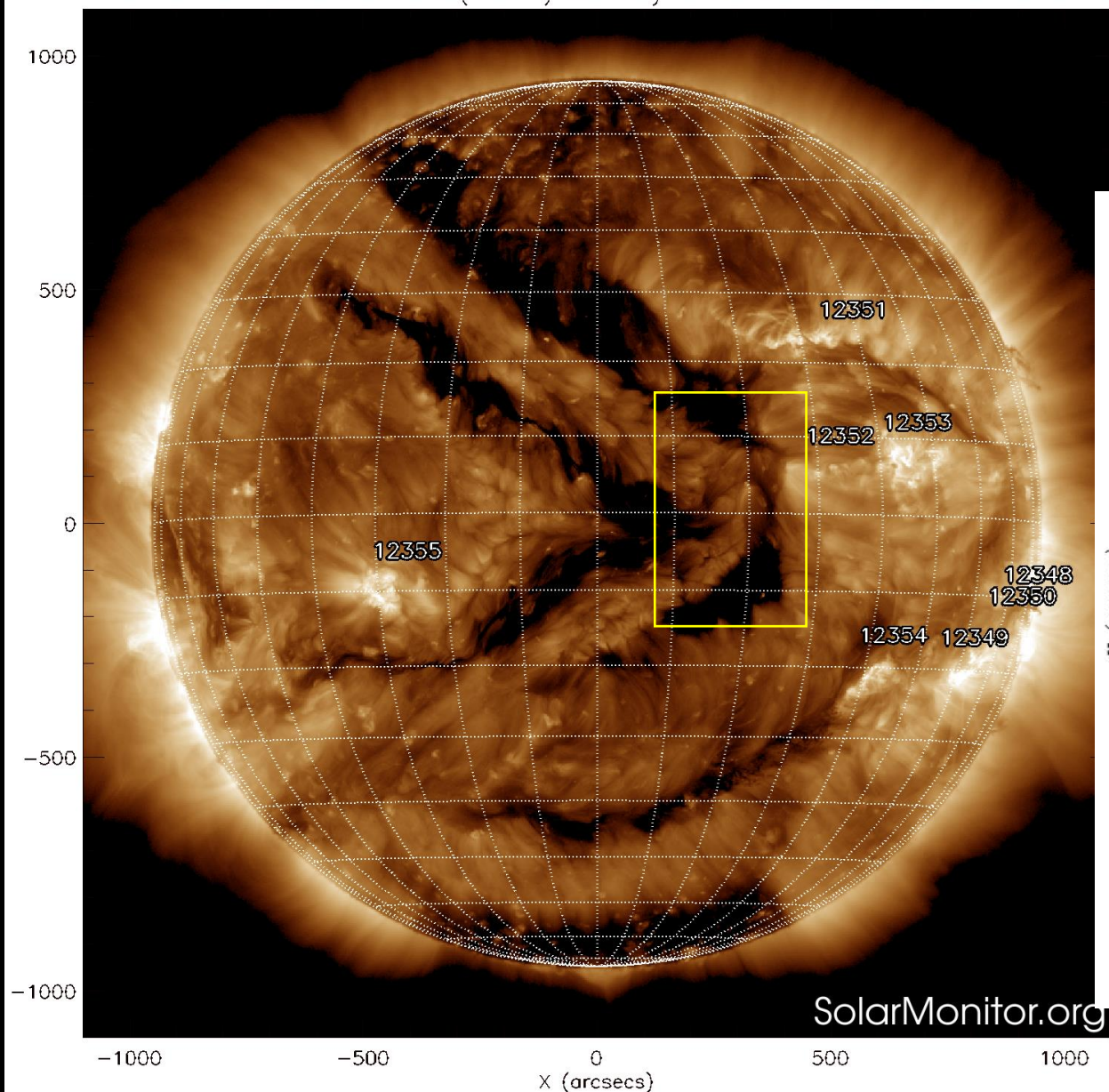


JET / noun – plural noun: jets

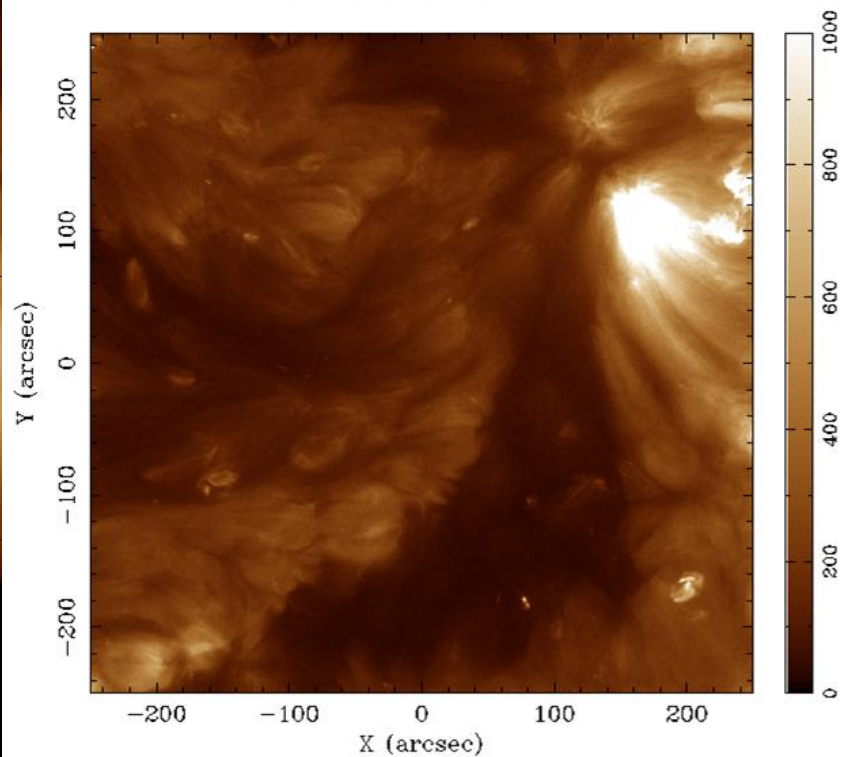
1. a rapid stream of liquid or gas forced out of a small opening. "a high-pressure shower with pulsating jets", a nozzle narrow opening for sending out a jet of liquid or gas. "Agnes turned up the gas jet"
2. an aircraft powered by one or more jet engines. "a private jet". "Astronauts fly T-38 jets."

Corona Holes in General (in EUV)

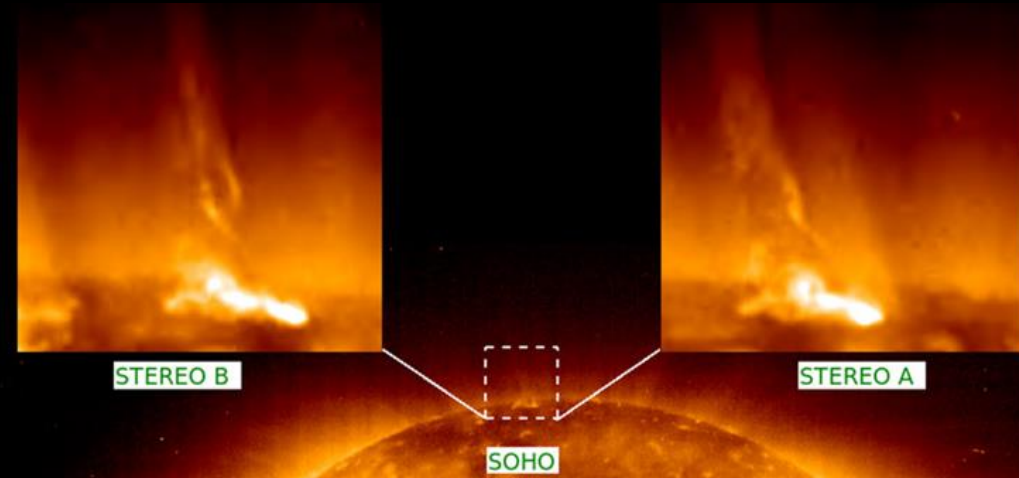
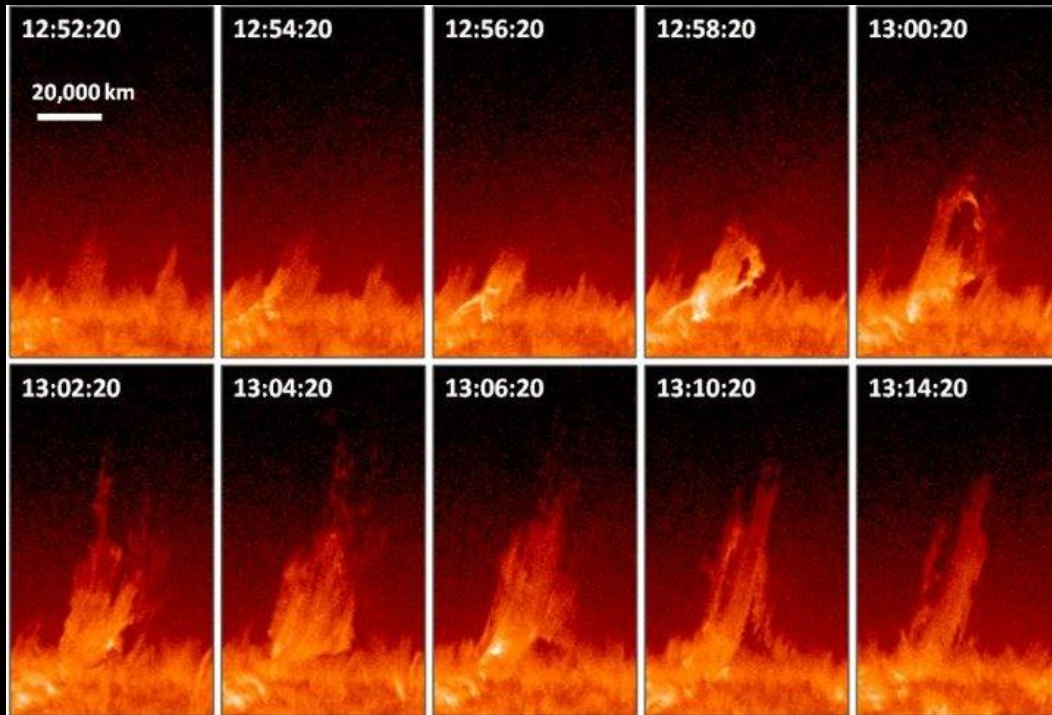
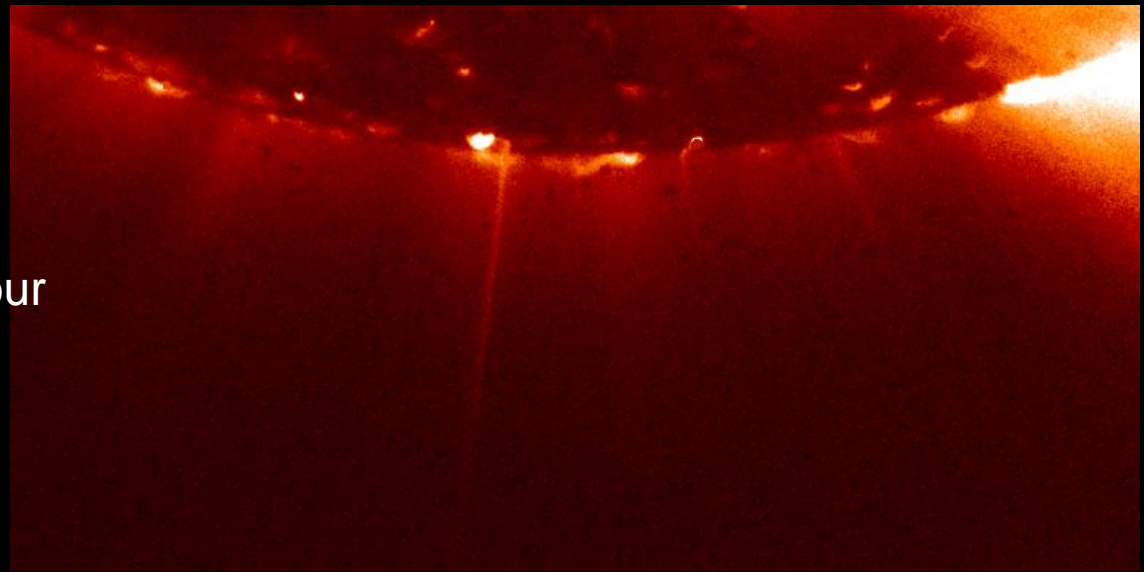
SDO AIA Fe XII (193 Å) 25-May-2015 23:30:42.840



AIA-193 2015-05-24_19:11:18 Coronal Hole
Rotate Time 19:00 UT



Solar jets 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.

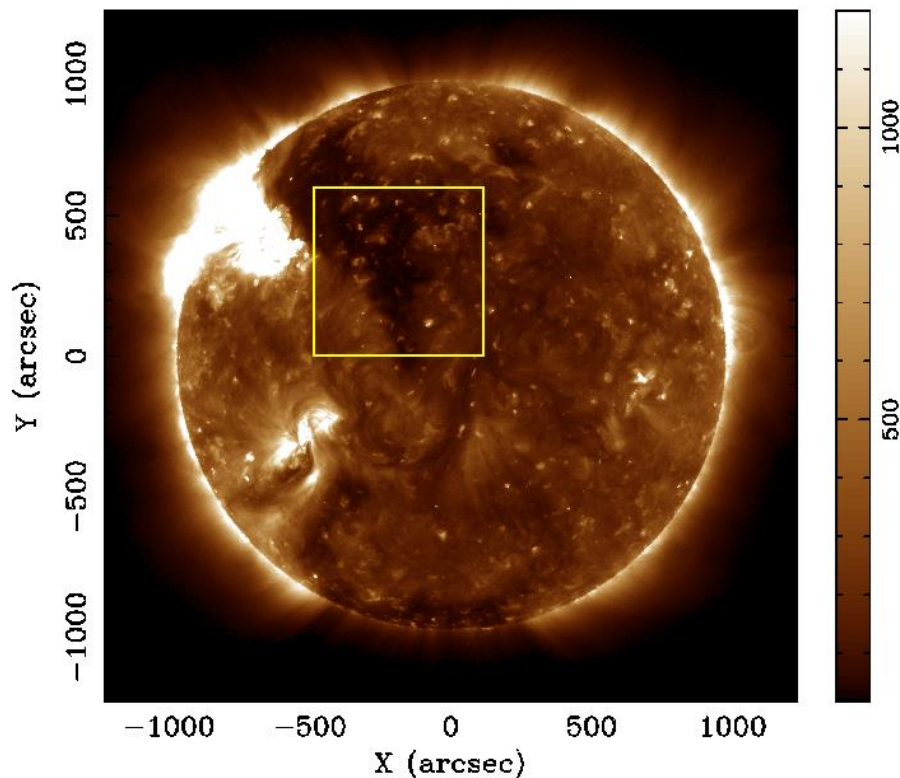
From: The Cool Component and the Dichotomy, Lateral Expansion, and Axial Rotation of Solar X-Ray Jets, R.L. Moore, *et al.*, *ApJ*, 768:134 2013 June 1

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

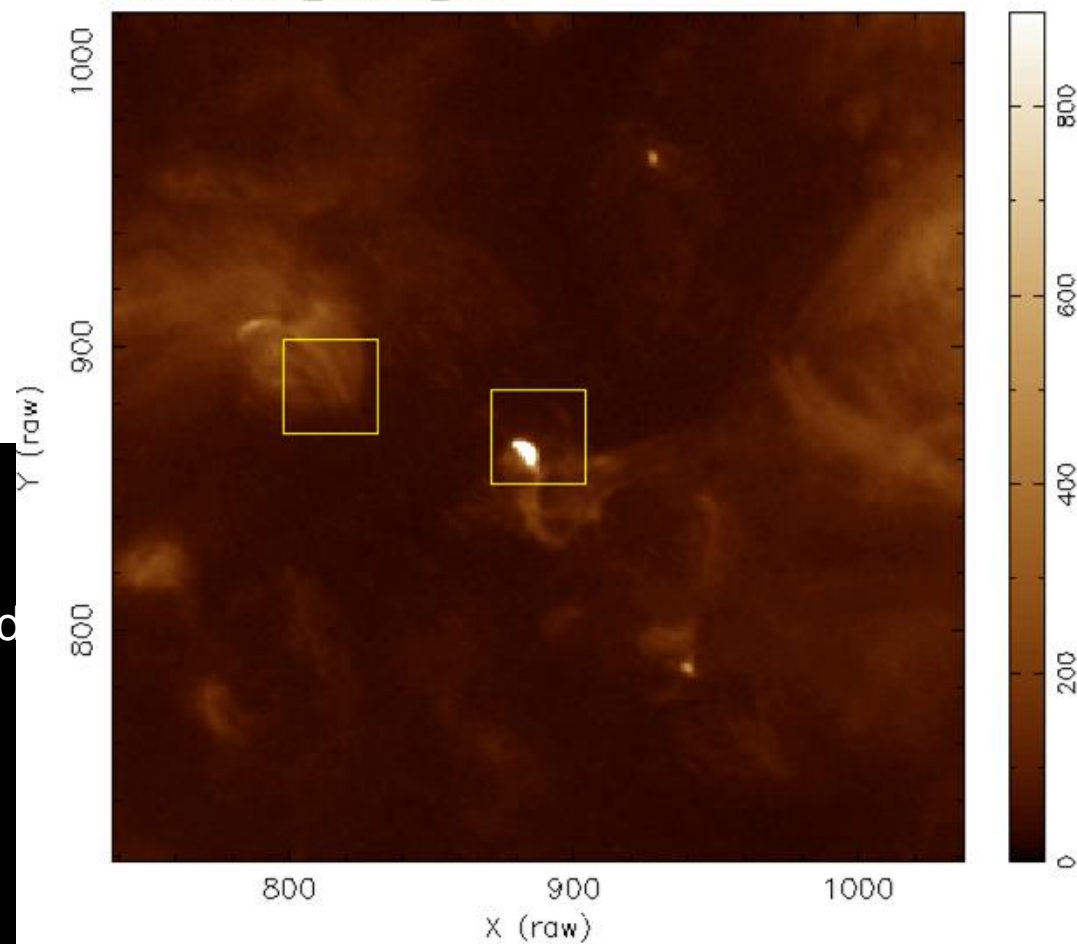
Jets in Coronal Holes

AIA-193 Full-Disk Image, 27-Feb-2011, 15:04:19 UT



This jet has a component with speeds > 200 km/s (1 min).
In 304 \AA , speeds are ~ 80 km/s (4 min.)

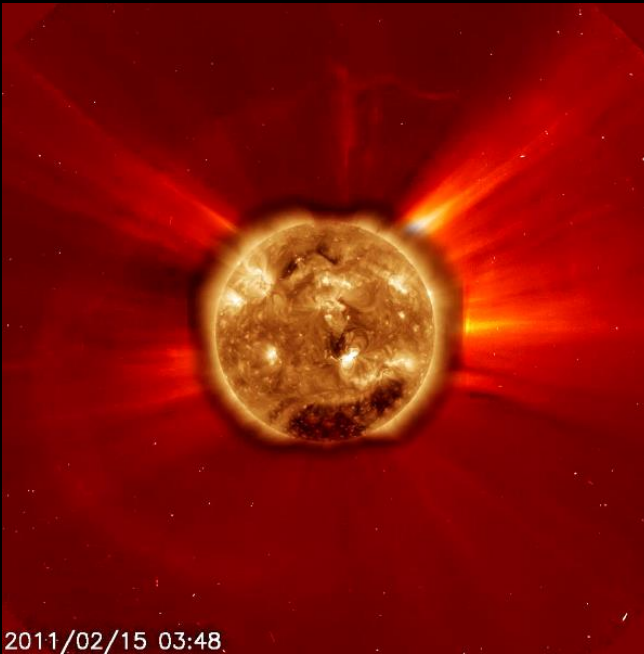
2011-02-27_130519_r.fits



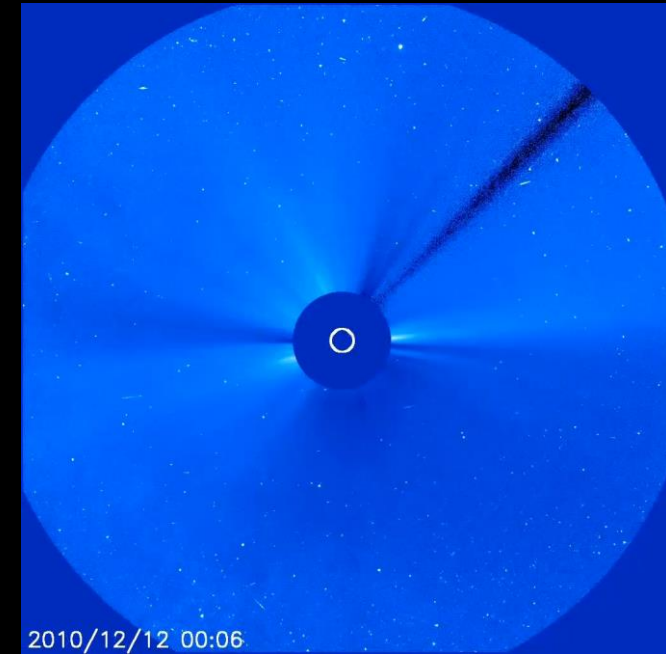
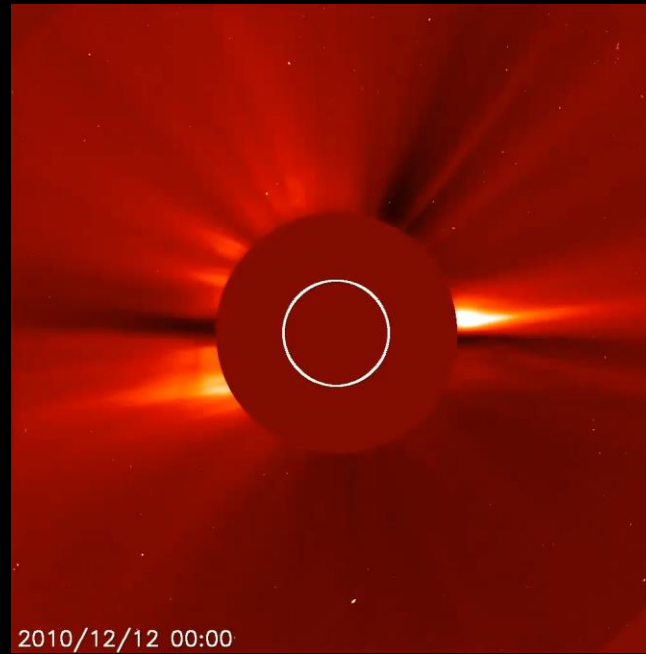
Coronal Mass Ejections have typical speeds of about 300 km/s, but can range from 100 - 3000 km/s

Solar Eruptions

Coronal Mass Ejections



SDO plus SOHO C2
X2-flare and halo CME



Three distinct CMEs

1. To right in both images, from a filament eruption,
2. From North Pole,
3. From far side of Sun.

All three eruptions happened within hours of each other.

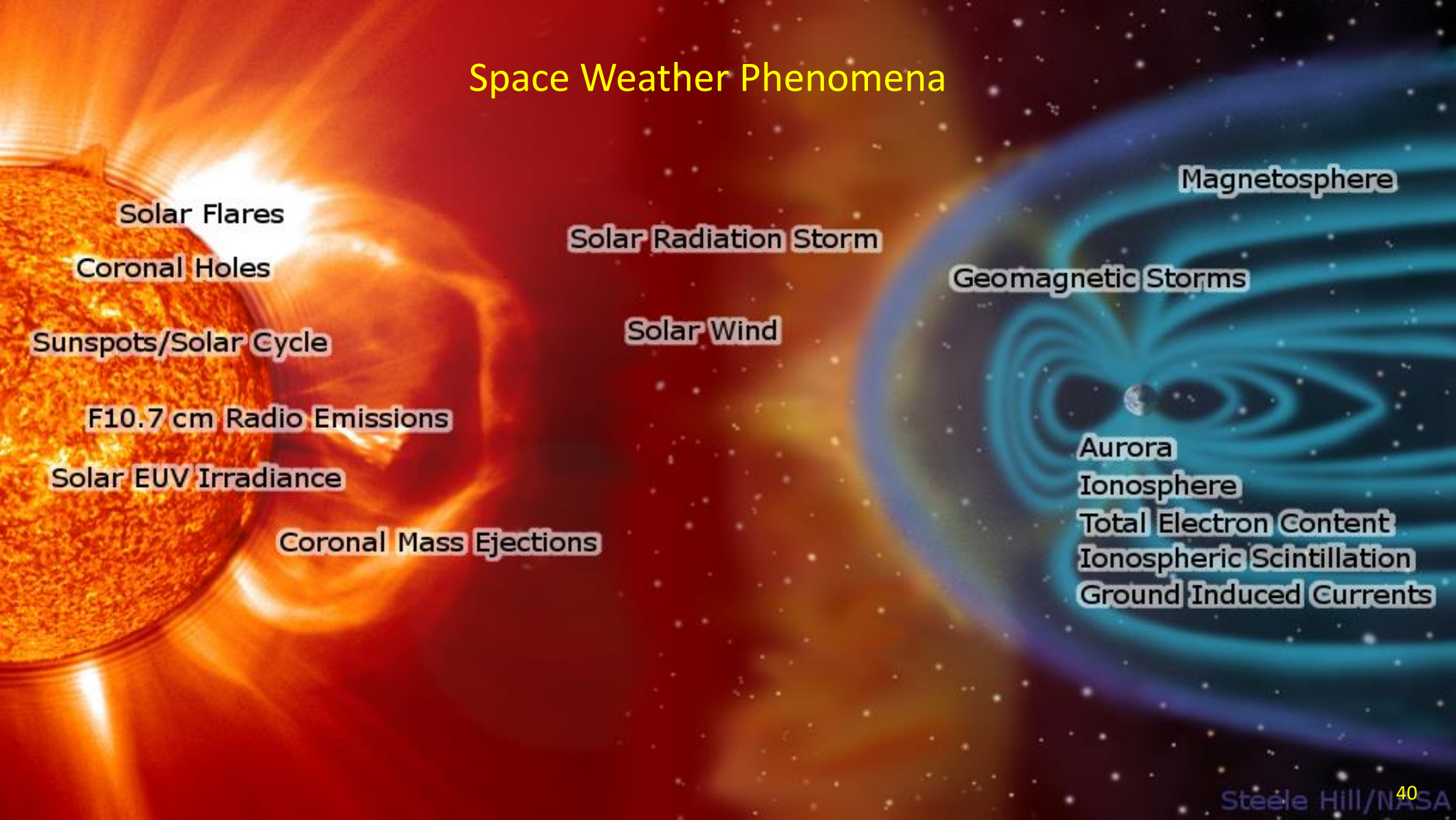
Space Weather

Definition:

Space Weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space-based and ground-based technological systems, as well as endangering life or health. Just like weather on Earth, Space Weather has its seasons, with solar activity rising and falling over an approximate 11-year solar cycle.

Reference: NOAA/NWS Space Weather Prediction Center

Space Weather Phenomena



Solar Flares
Coronal Holes
Sunspots/Solar Cycle
F10.7 cm Radio Emissions
Solar EUV Irradiance
Coronal Mass Ejections

Solar Radiation Storm
Solar Wind

Magnetosphere
Geomagnetic Storms
Aurora
Ionosphere
Total Electron Content
Ionospheric Scintillation
Ground Induced Currents

Aurorae: Benign Space Weather Effects



GEOMAGNETIC STORMS

Reference: NOAA/NWS Space Weather Prediction Center

Energetic
Electrons

Solar Flare
Protons

Damage to
Spacecraft
Electronics

Ionospheric
Currents

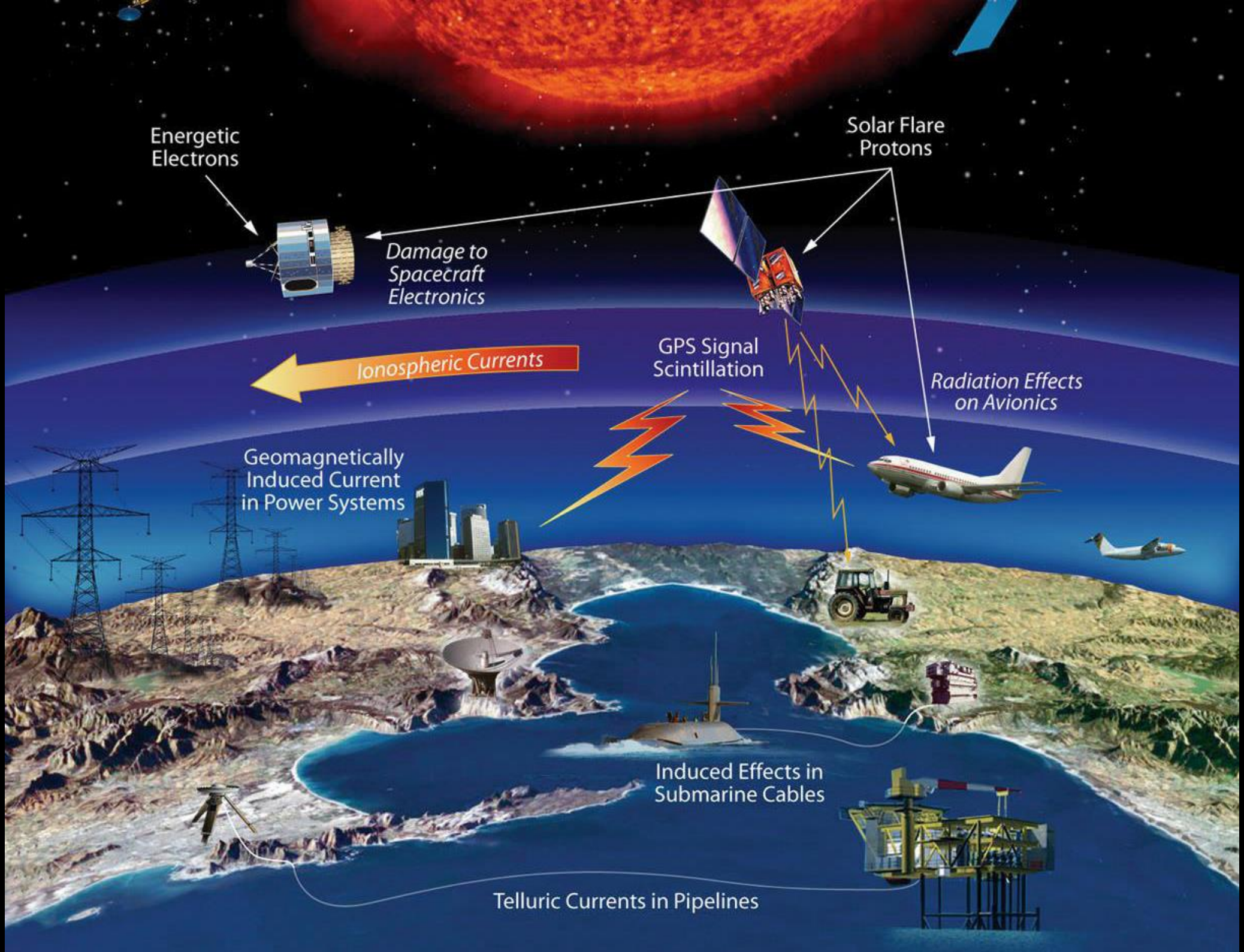
GPS Signal
Scintillation

Radiation Effects
on Avionics

Geomagnetically
Induced Current
in Power Systems

Induced Effects in
Submarine Cables

Telluric Currents in Pipelines



Summary

Our Sun is a single star with a system of planets

The Sun is a stable star, 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

Jets of all sizes occur on the Sun.

The mechanism for producing the jets seems to be similar at all scales.

Because chromospheric jets can trigger flares and CMEs, which can affect Earth, it is important to understand all jets.

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