The Sun: A Star to Study in Our Backyard

for Academy of the Sacred Heart
December 12, 2017

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

Outline

- A bit of history
- The Sun vs. a couple of stars
  - What is a Star?
  - What is the Sun like?
- The Parker Solar Probe

First Contact, August 21, 2017 Solar Eclipse

Image Credit: Mitzi Adams, NASA/MSFC, August 21, 2017
from Clarksville, Tennessee

History

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)
- Co-founded the Association for the Advancement of Women (1973)

Maria Mitchell: Her Legacy - Her Students


Mary Watson Whitney, 1847-1921, Professor of Astronomy at Vassar College, and first President of the Alumnae Association

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

Antonia Maury -- Became one of Edward Pickering's “computers” published in 1897 a catalogue of stellar spectra -- first observatory publication credited to a woman

Image Credit: Vassar College Special Collections Library

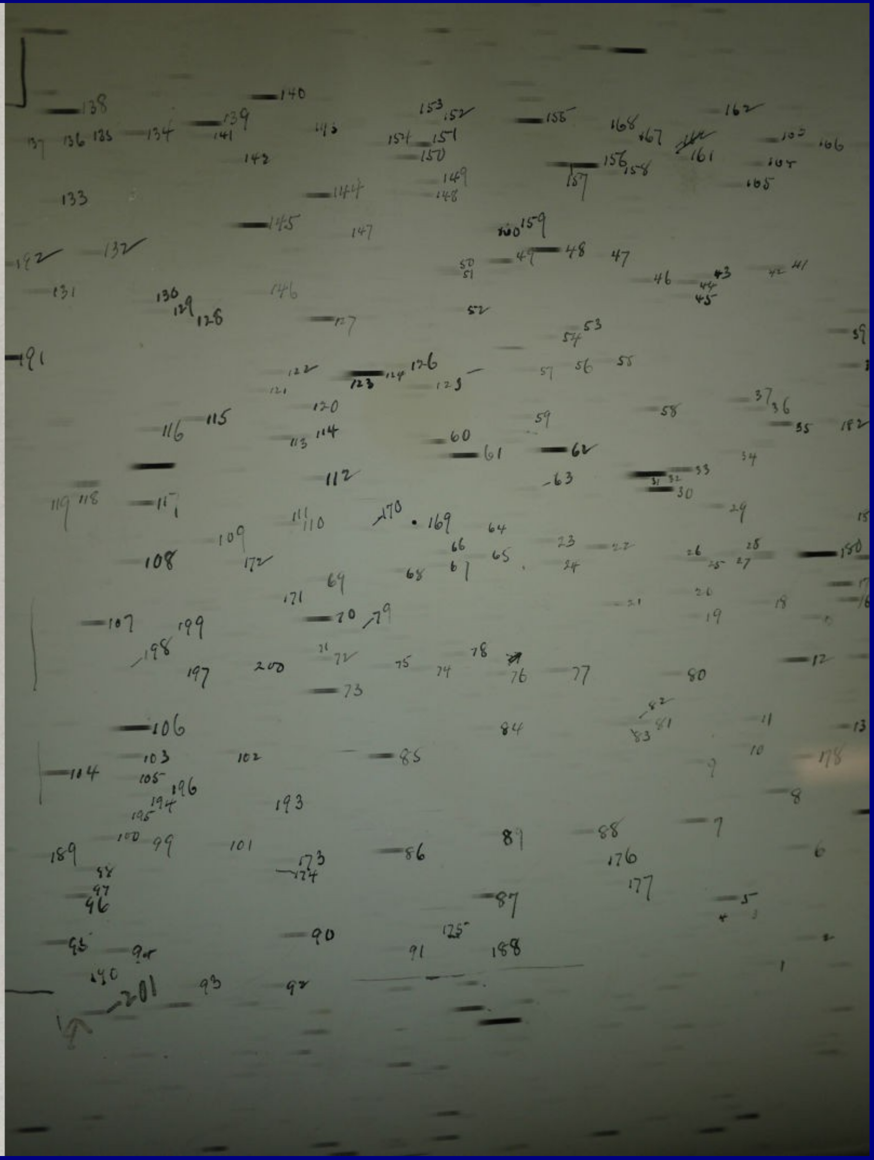
Edward Pickering and the “Computers” at Harvard Observatory

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

Image Credit: Vassar College Special Collections Library

Annie Cannon and Spectral Classifications



Annie Cannon (image from 1895) classified spectra of more than 425,000 stars

Image Credit: Harvard College Observatory

The Sun vs. a Couple of Stars

What is a Star?

- Energy Production
- Differences
- H-R Diagram

What is the Sun like?

- Structure
- Surface Features
- Magnetic Fields
- The Solar Cycle
- Solar Eruptions

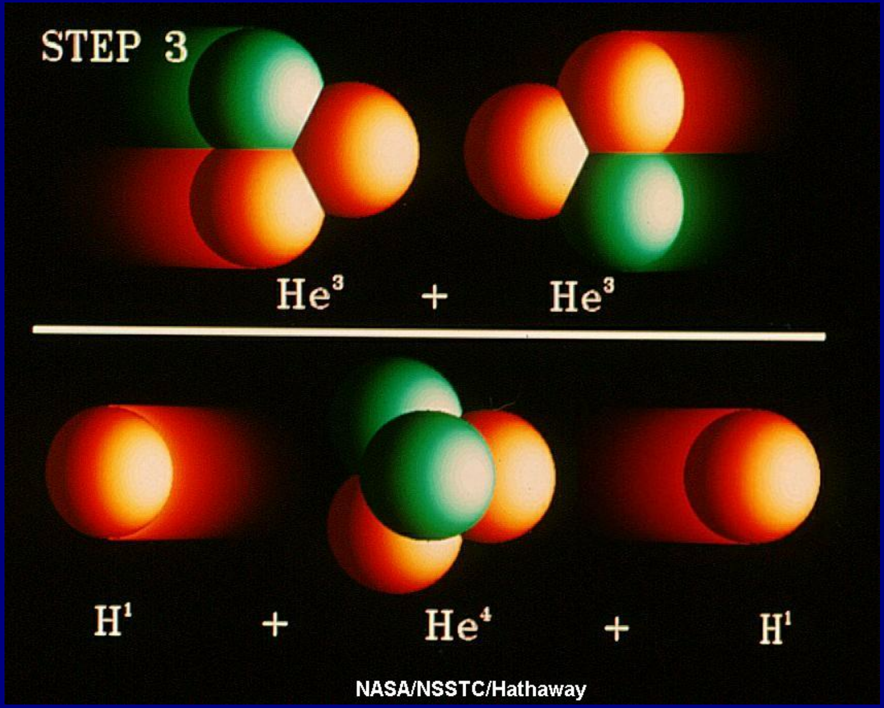
What is a Star?

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.



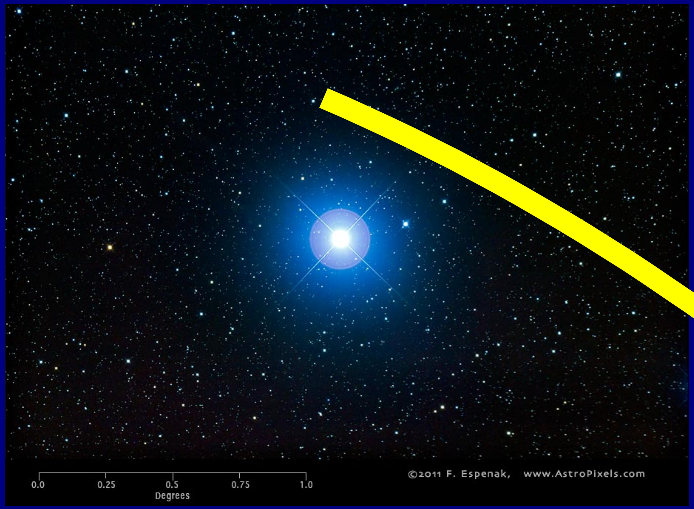
2. A proton collides with the deuterium, forming helium-3 and a gamma ray

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

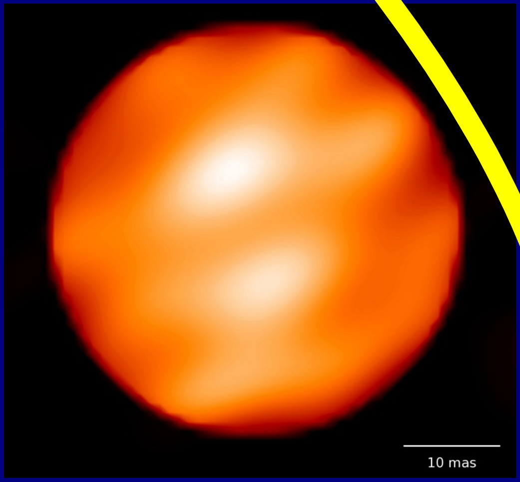


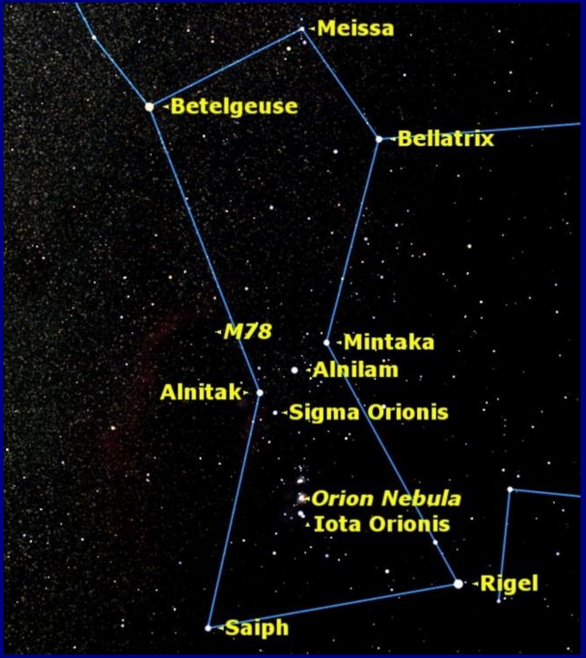
Rigel: A blue-white star, about 8600 ly away, 12,000 K, 80 $R_{\odot}$, 23 $M_{\odot}$, 8 million years old.

Aging

Our Sun: A yellow star, ~8 lm away, 6,000 K, ~700,000 km (432,000 mi), 2 x 10^{30} kg, 4.5 billion years old, ~ 5M yr left.

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 .

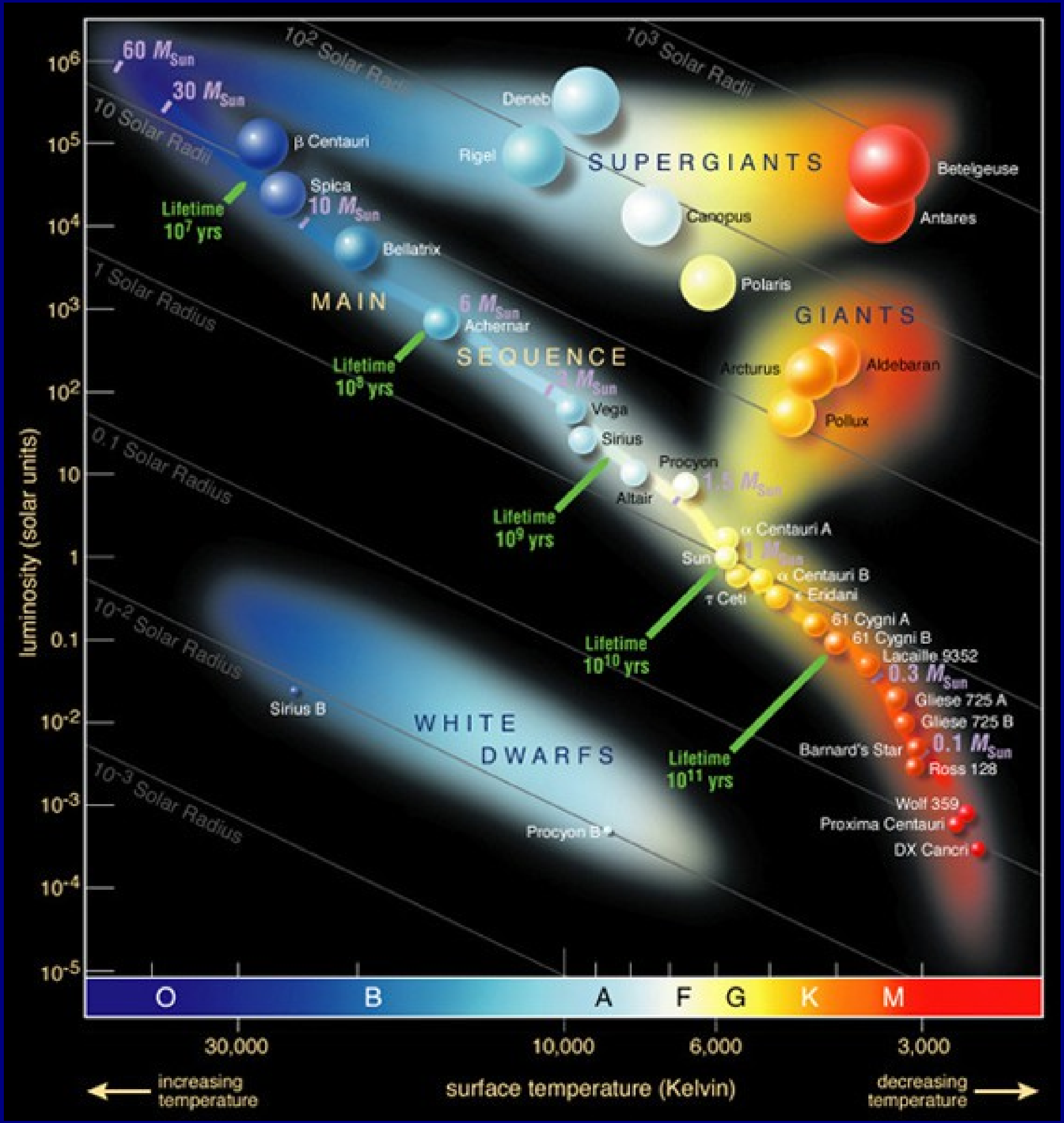




Brightness

Color

Hertzsprung-Russell Diagram



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

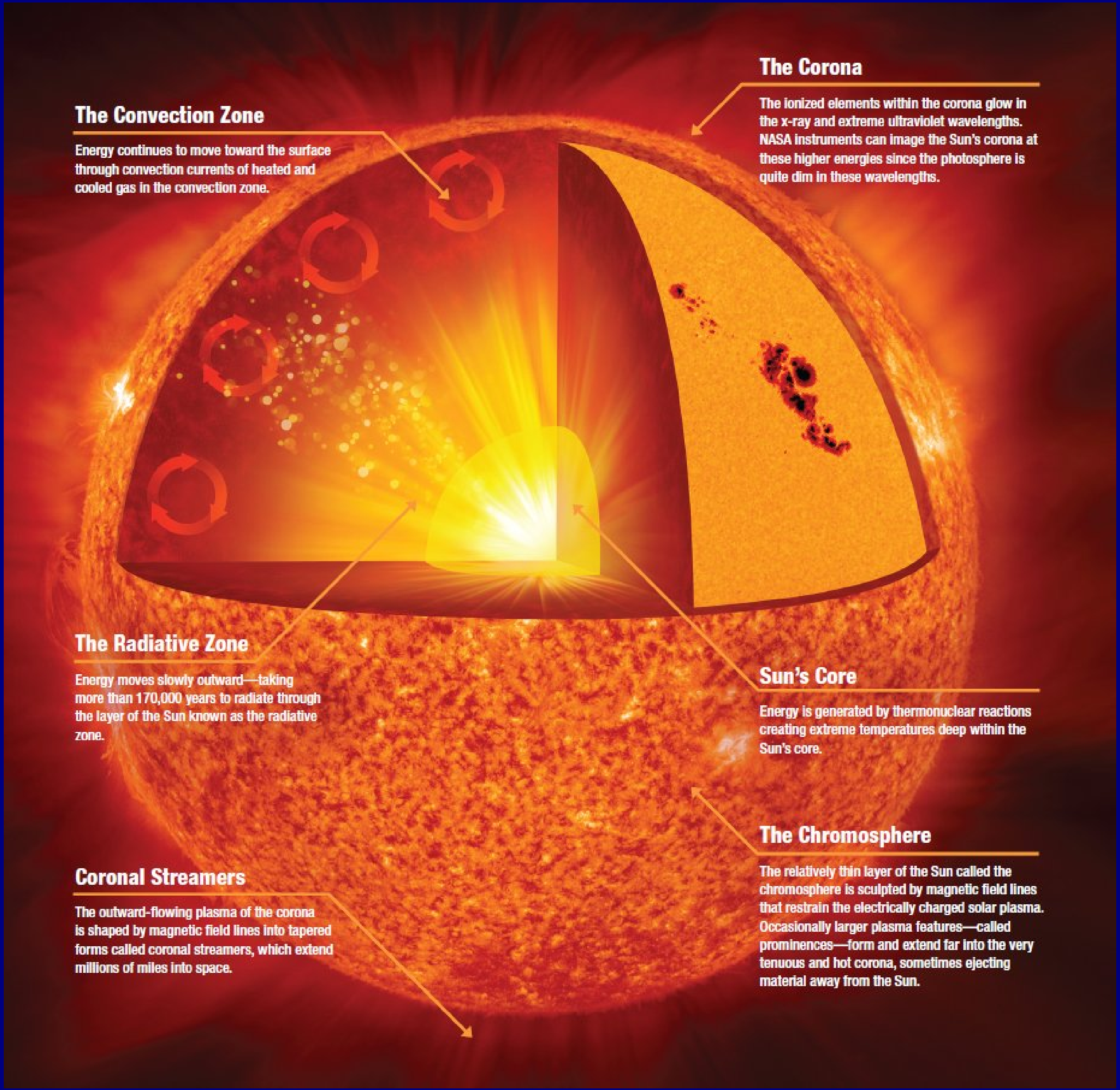
Sun is G2
8.5 light minutes away

Betelgeuse is M2
643 ly

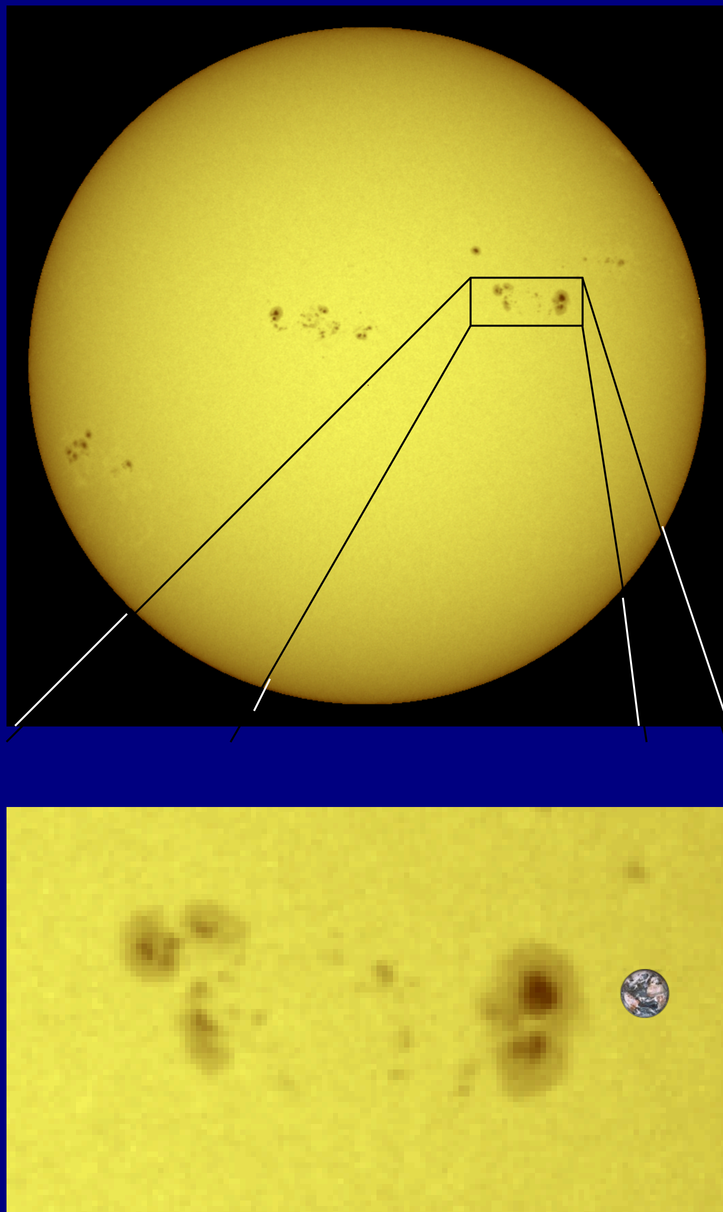
Rigel is B8
860 ly

What is the Sun like?

The Sun: Structure



The Sun: Surface Features - Sunspots



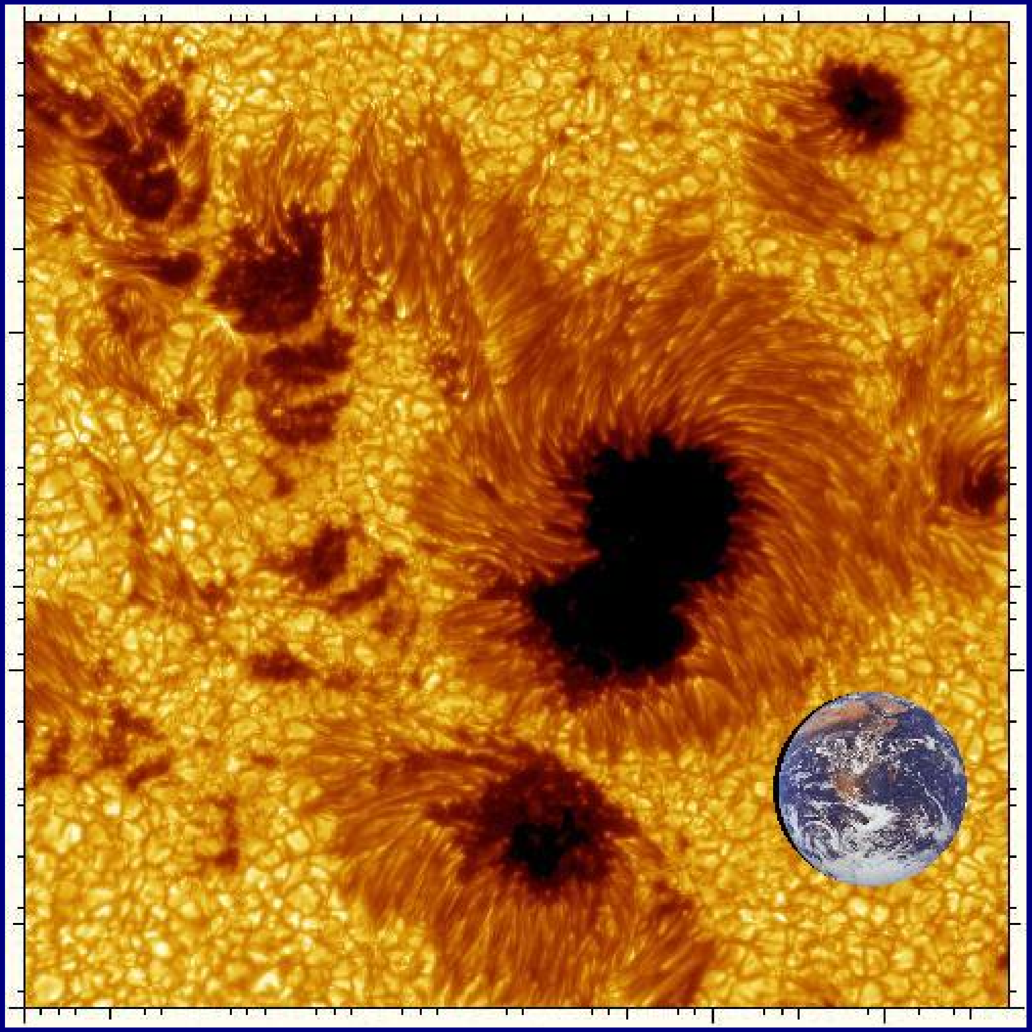
Sunspots are regions that are cooler than their surroundings, produced by strong magnetic fields.

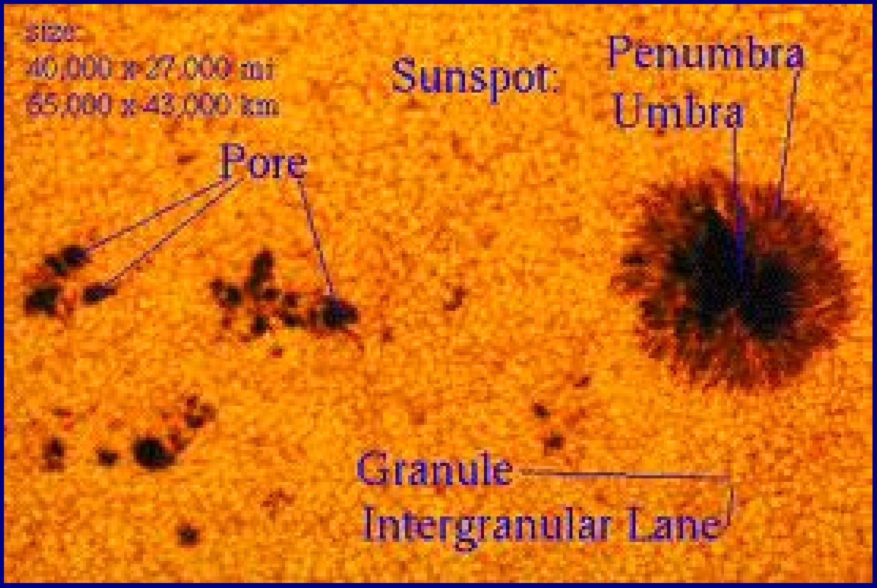
Sunspots have an Umbra surrounded by the lighter Penumbra.

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

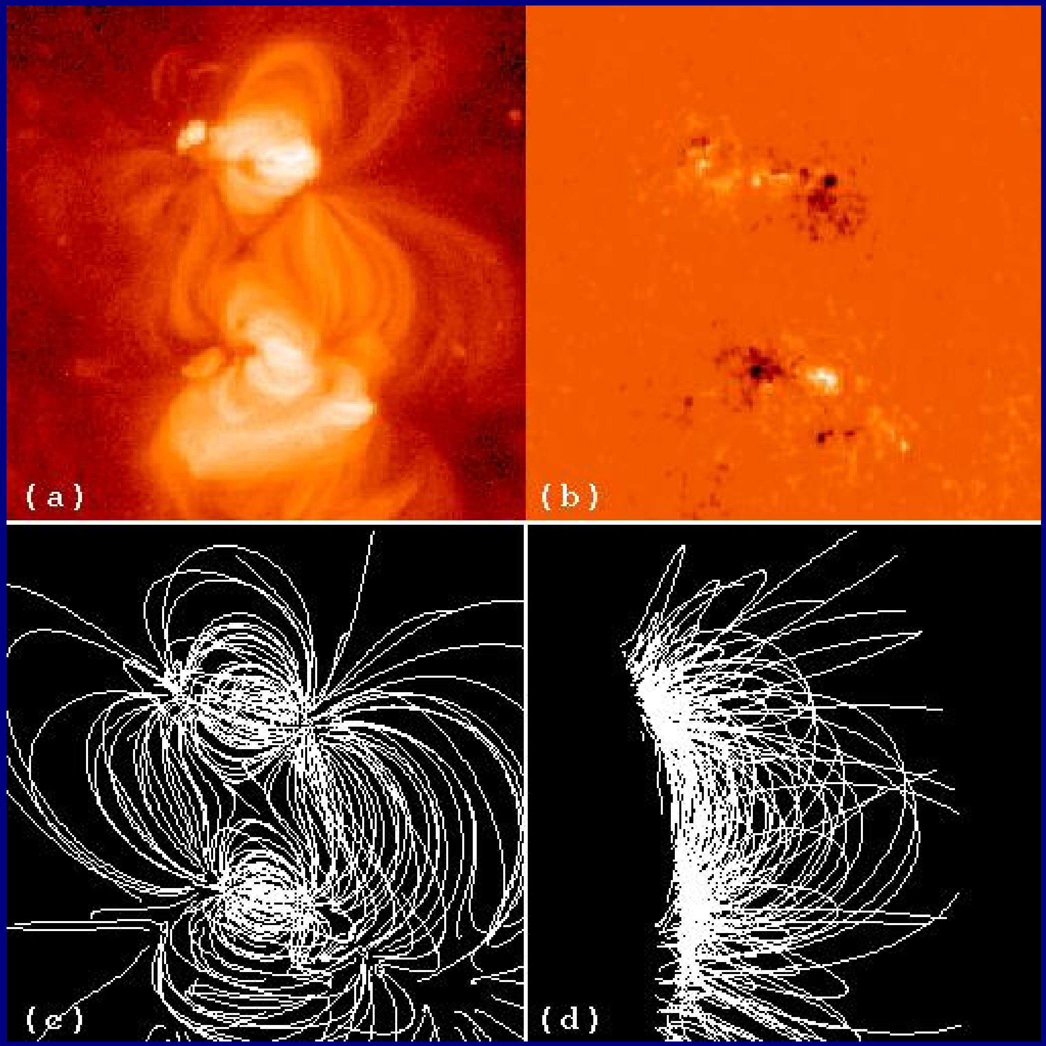
The earliest sunspot observations (c. 1609) indicated that the Sun rotates once in about 27 days.

The Sun: Sunspot Examples





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

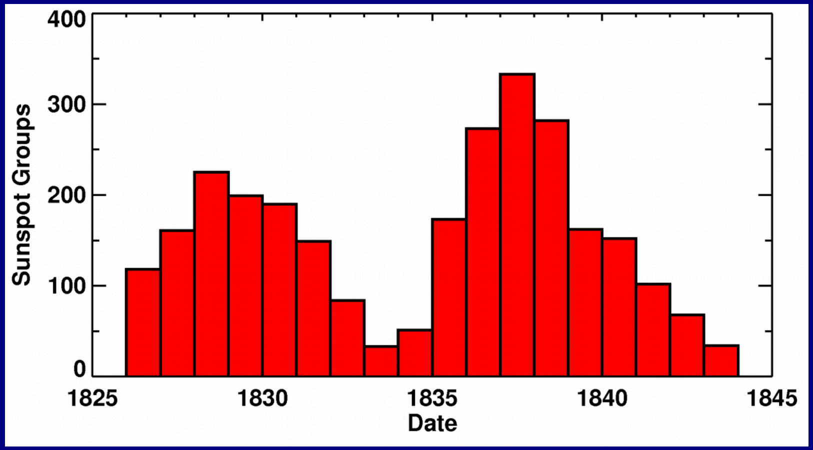
The Sun: The Solar Cycle

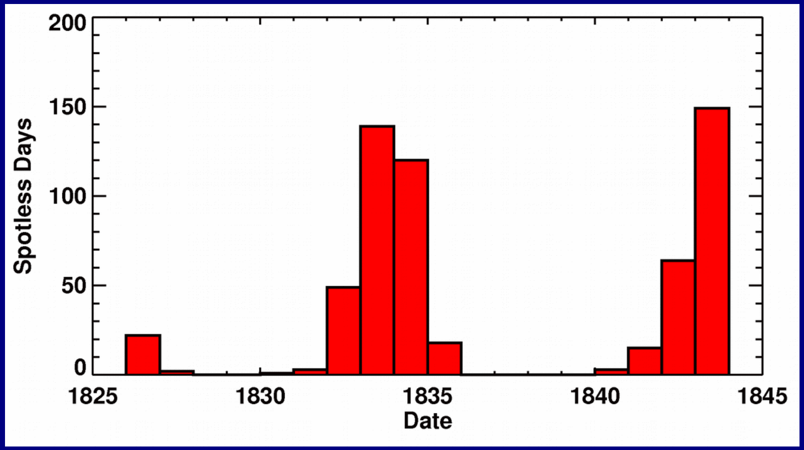
The Sun: Sunspot Cycle Discovery

Sunspots observed > 230 years
1844 Heinrich Schwabe, amateur astronomer, Dessau, Germany

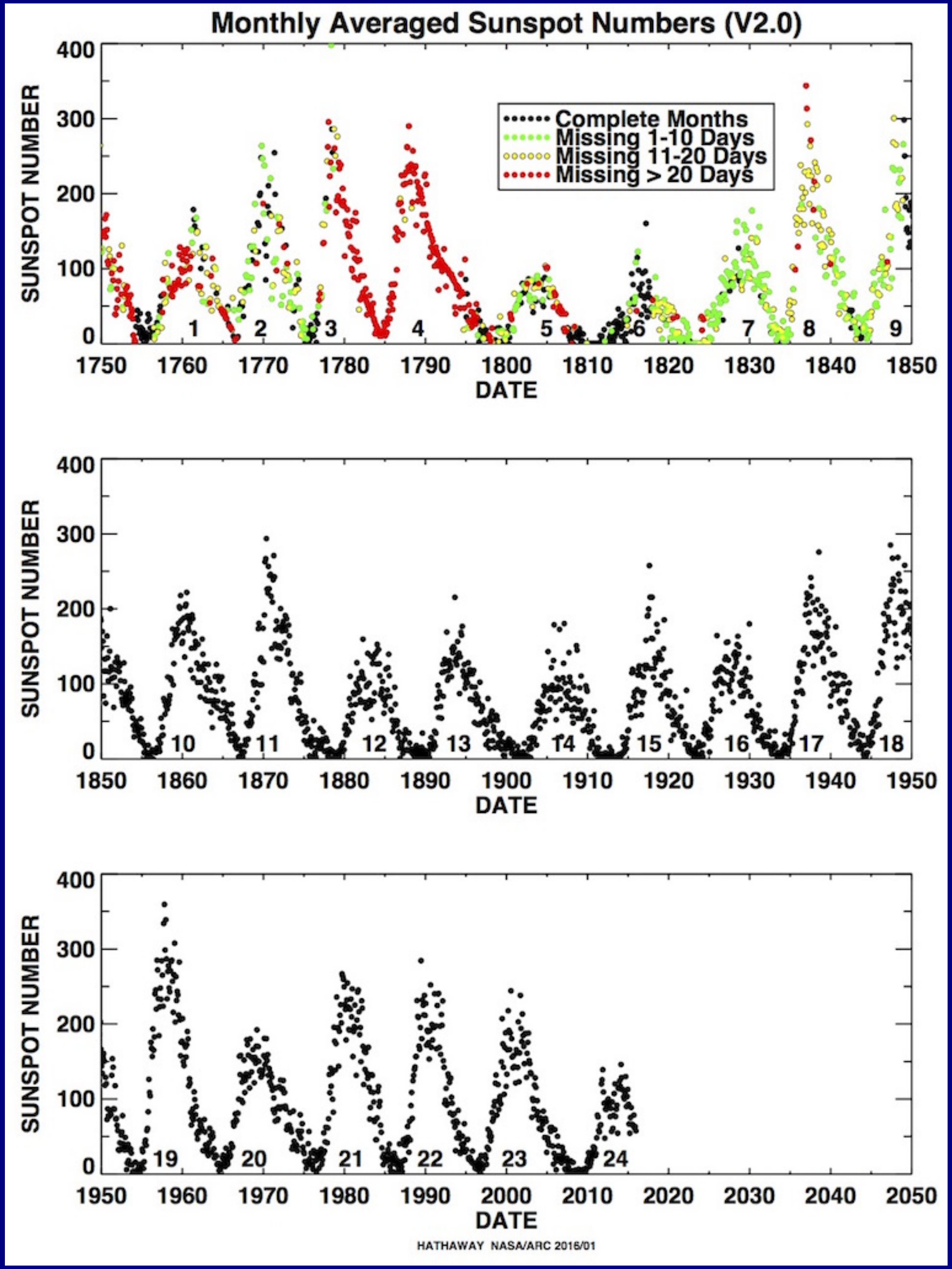
Cycle: increase and decrease over ~10-years
- number of sunspot groups and the
- number of days without sunspots

Schwabe's data for 1826 to 1843





The Sun: 23 Full Cycles Observed

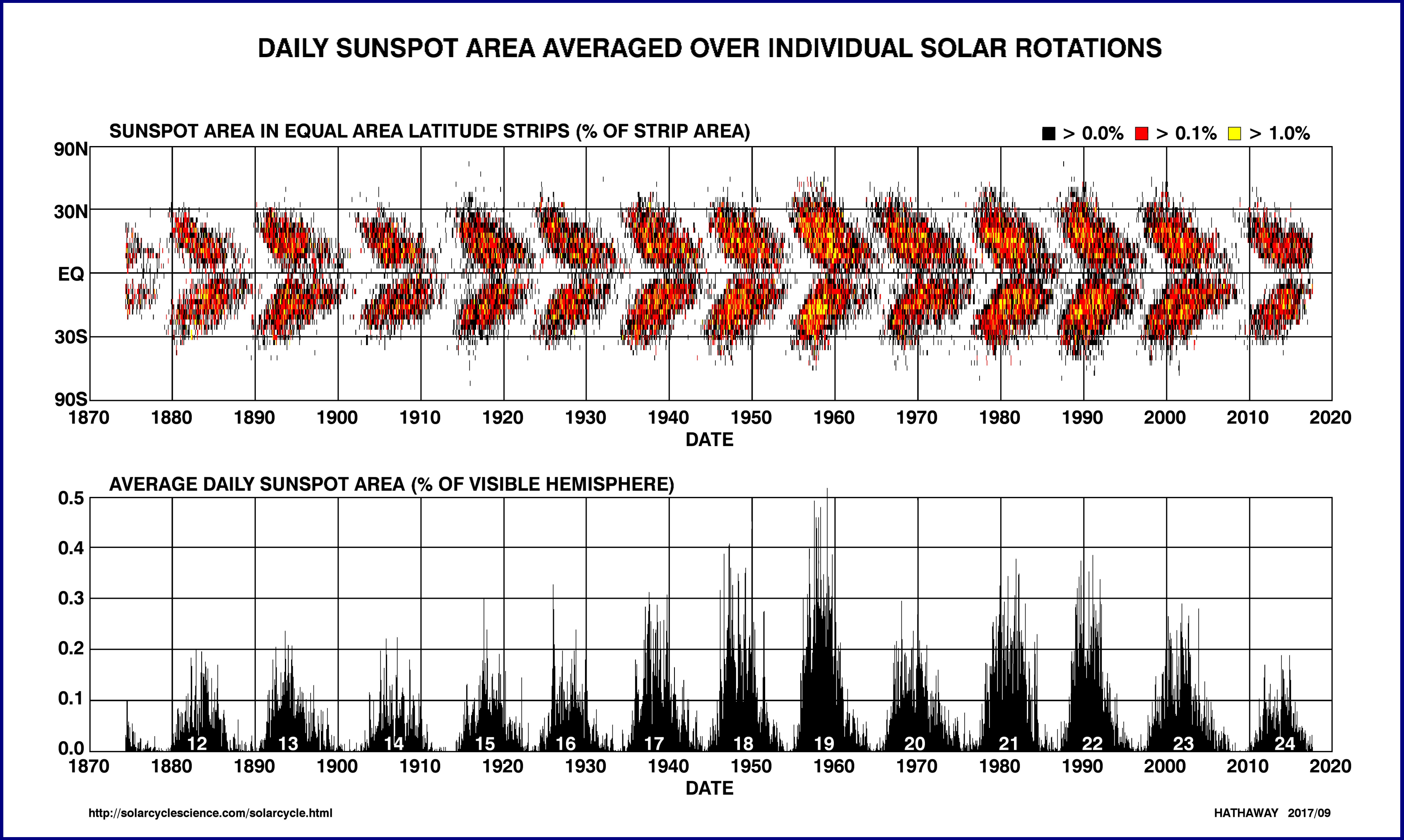


Rudolf Wolf 1849 -- "Relative" Sunspot Number = 10 times number sunspot groups + total distinct spots

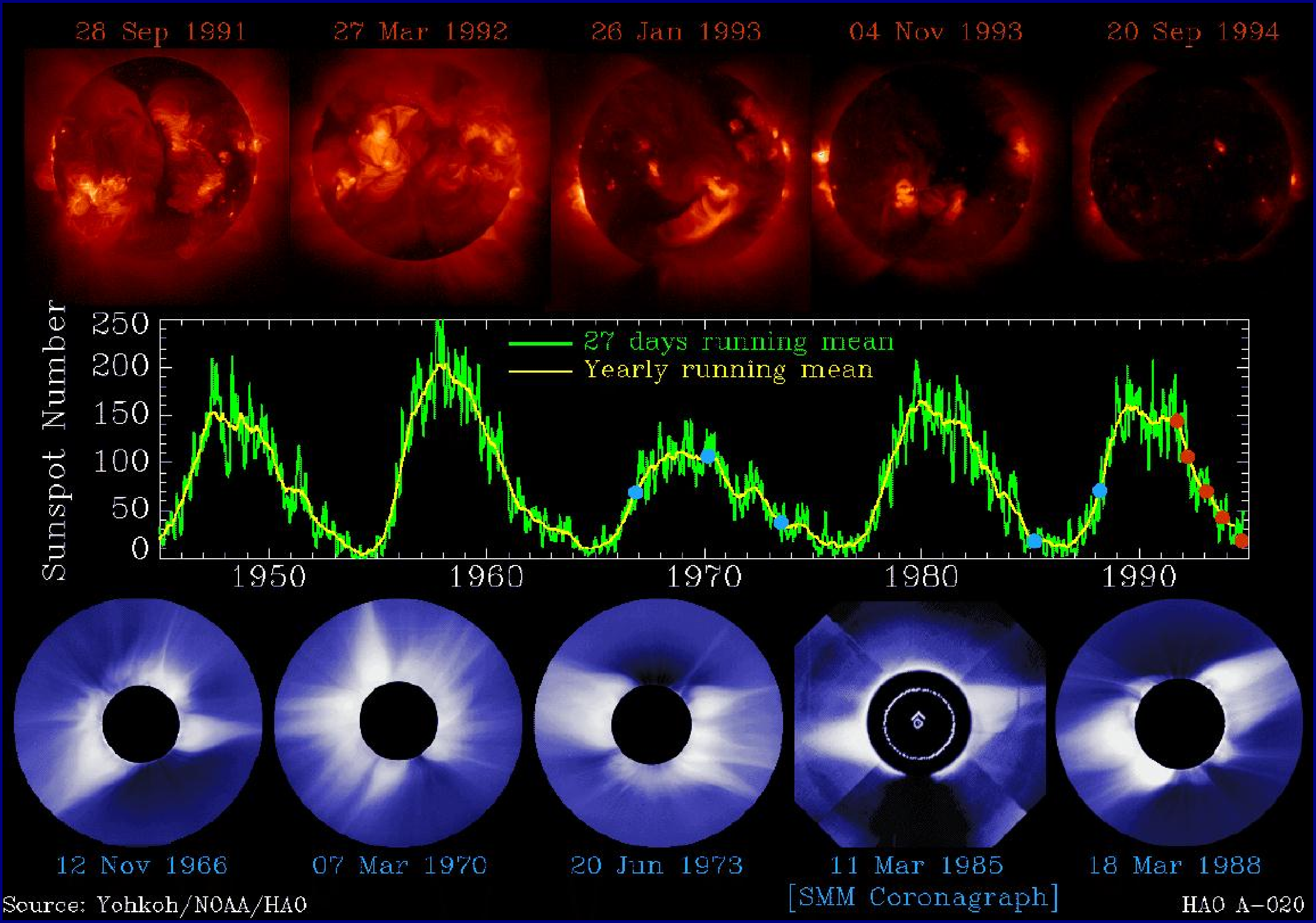
Average cycle: ~11 years, -2, +3

Average amplitude: ~100, with range from 50 to 200

The Sun: Sunspot Latitudes



The Corona and the Solar Cycle



The Corona "Now"
August 21, 2017

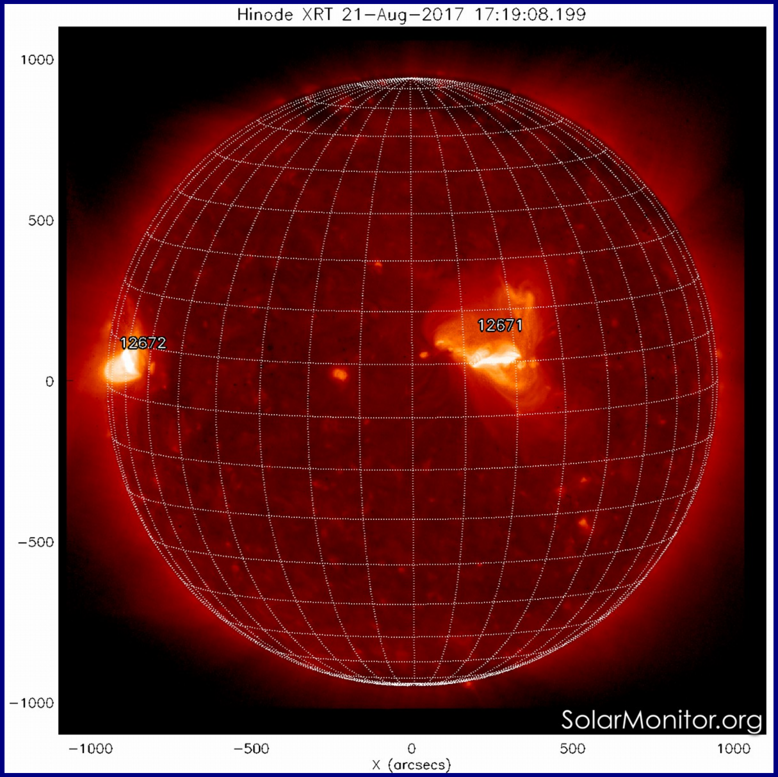
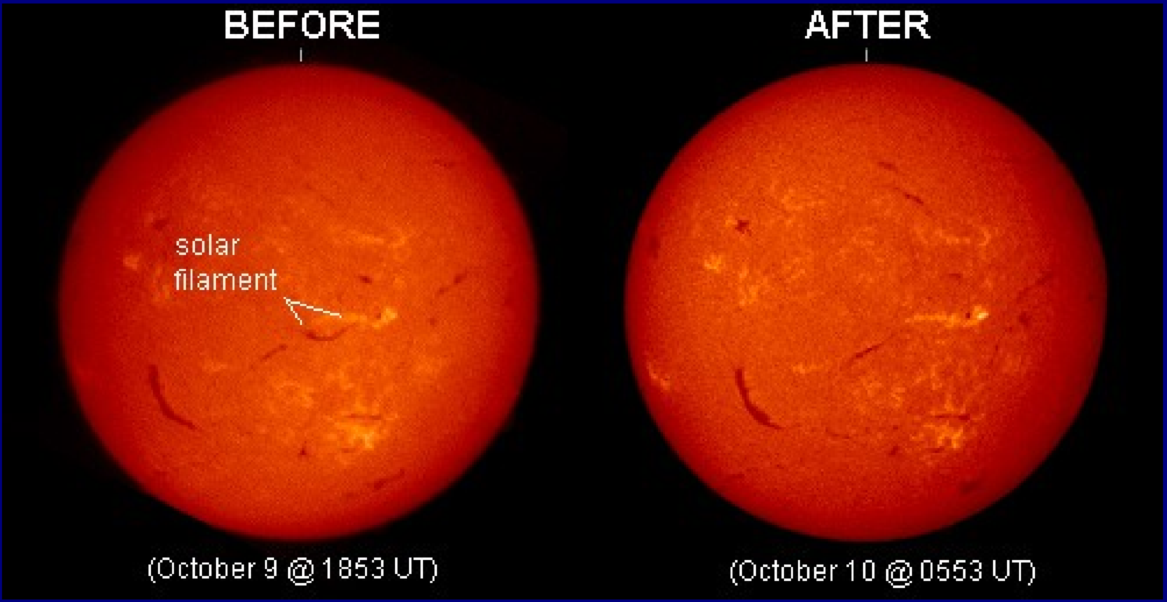


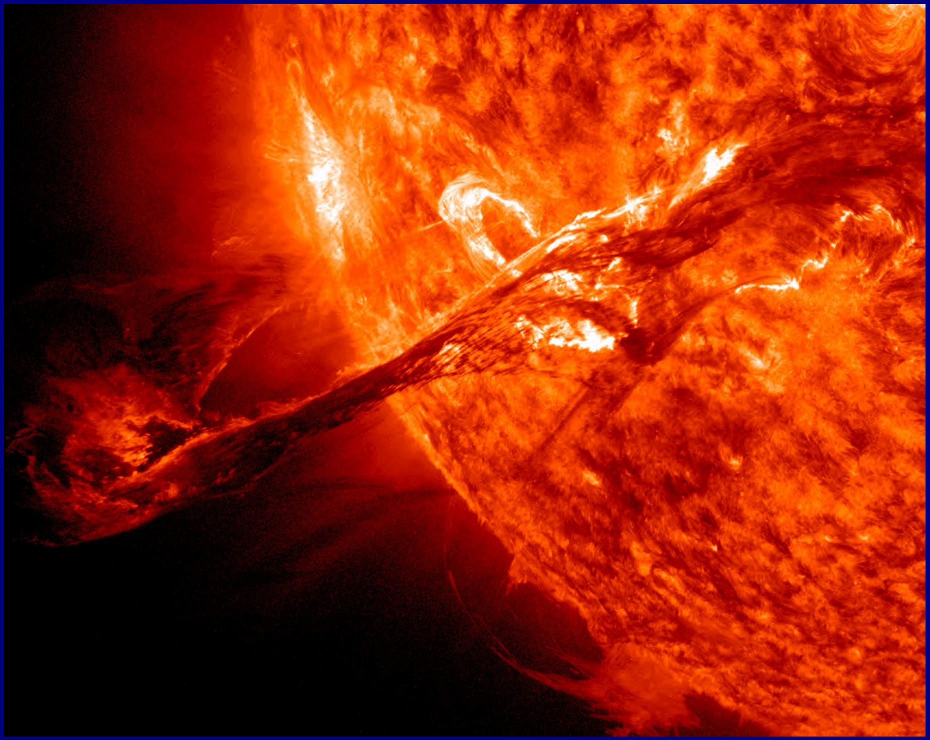
Image by Joe Matus, NASA/MSFC from Hopkinsville, KY

Solar Eruptions

Filament Eruptions

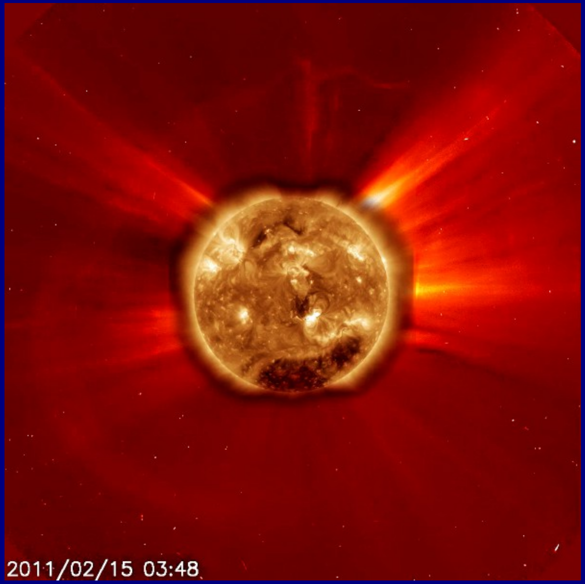


October 2000
Filament around AR 9182
C-7 flare triggered
Halo coronal-mass ejection (CME)
Image Credit: NOAA/SEC

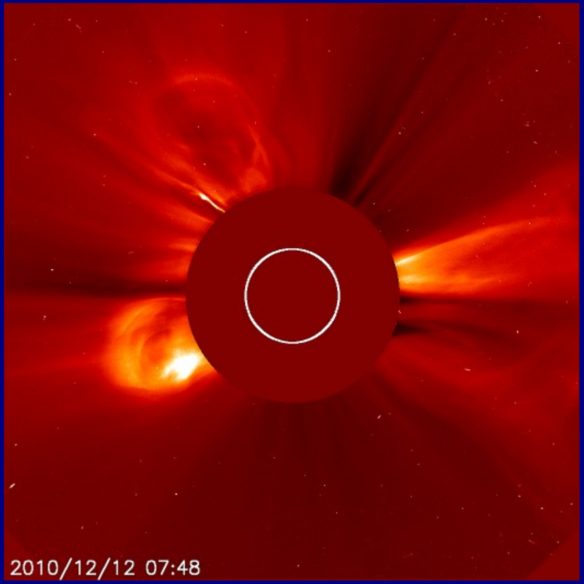


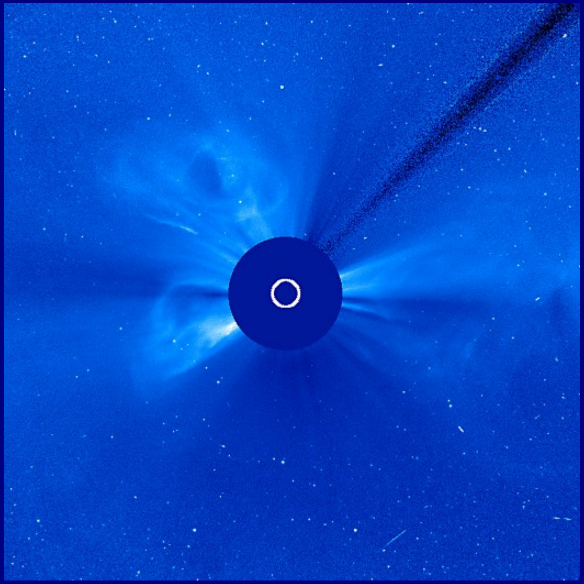
August 31, 2012
Filament eruption, CME
Plasma Speeds: > 900 mi/s
Normal Solar Wind Speed: ~250 mi/s
Image Credit: SDO/AIA in 304 Å.

More Solar Eruptions



SDO plus Soho C2
X2-flare and halo CME

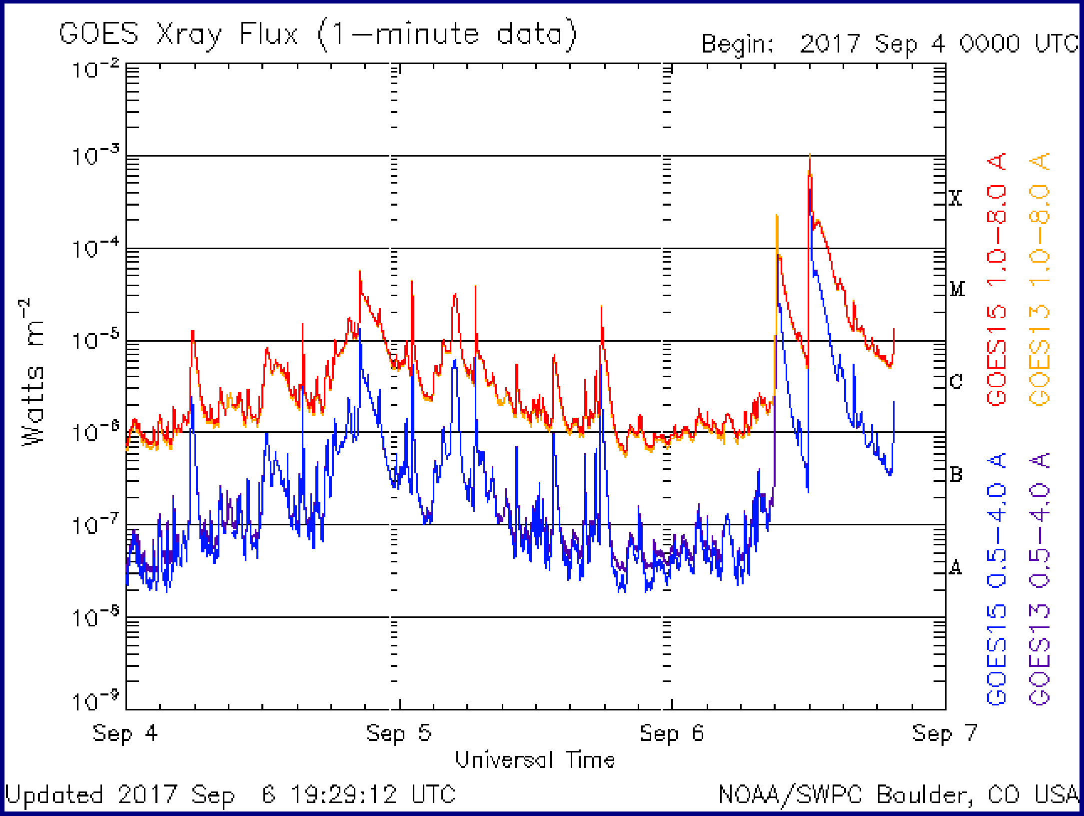




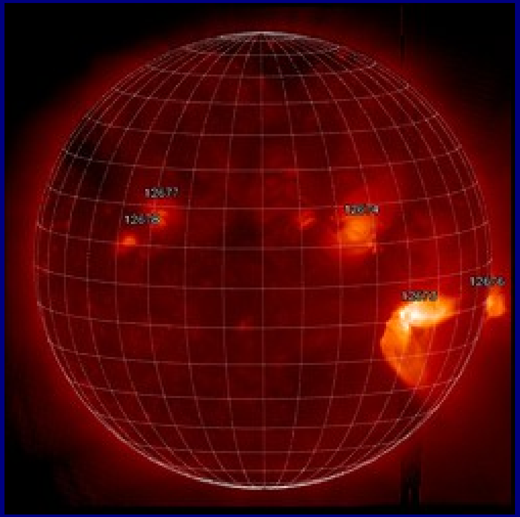
Three distinct CMEs
1. To right in both images, from a filament eruption,
2. From North Pole,
3. From far side of Sun.
All three eruptions happened within hours of each other.

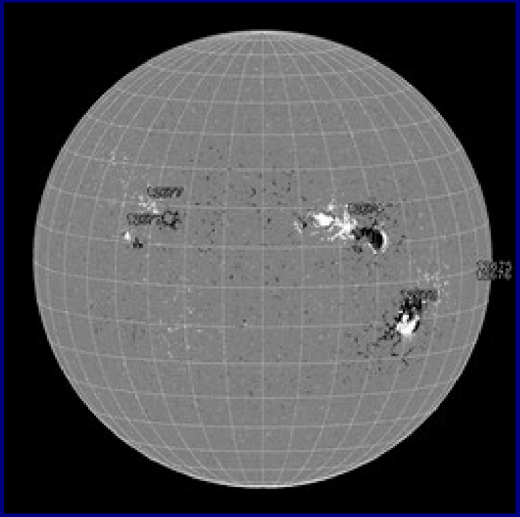
Image Credit:
SDO and
SOHO/LASCO

Solar Flare Classification



Sept. 6, 17:59UT
Hinode XRT
X9 flare





Sept. 6, 18:46 UT
SDO/HMI

Sun vs. Non-Solar-Type Stars Similarities

Sun	Other Stars
The Sun is on the main sequence	Other stars exist on the main sequence
The Sun produces spots on its surface	Other stars have spots
The Sun produces explosions of energy	Other stars flare
The Sun has a system of planets	Other stars have systems of planets - 2337 confirmed planets (Kepler)

Sun vs. Non-Solar-Type Stars Differences

Mass	High Mass Stars Live Short Lives
Temperature	High Mass -> High Temperature
Evolution	High Mass Stars End as Supernovae then Neutron Stars or Black Holes
Multiple Star Systems	Interactions Can Lead to Accretion and Lots of Flares

Parker Solar Probe

Parker Solar Probe: Approaching the Sun

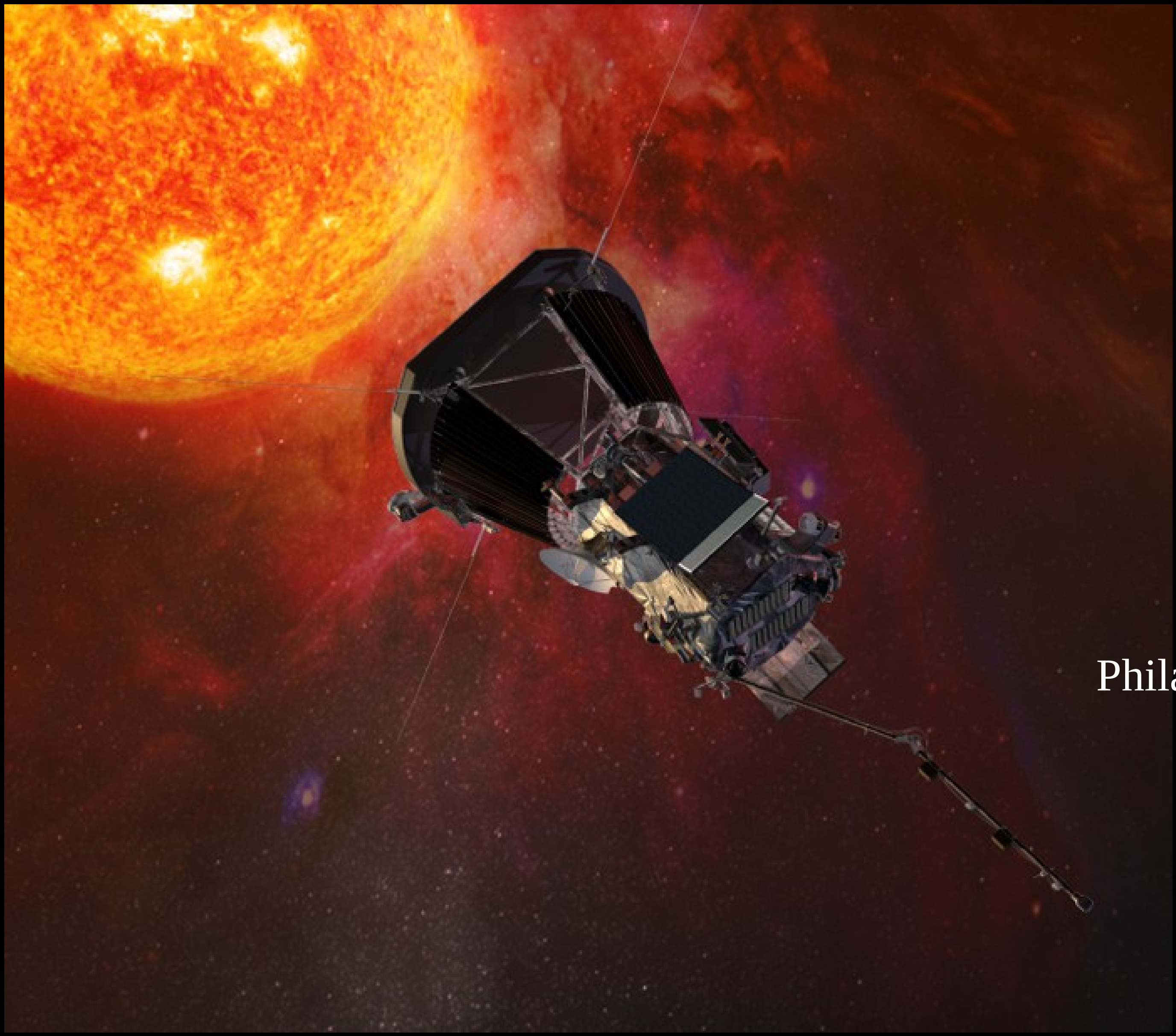


Image Credit: Johns Hopkins University Applied Physics Laboratory, Artist's Concept

Closest Approach:
3.83 million miles

Fastest Speed:
450,000 mph
Philadelphia to D.C. in one second

Parker Solar Probe: Science Objectives

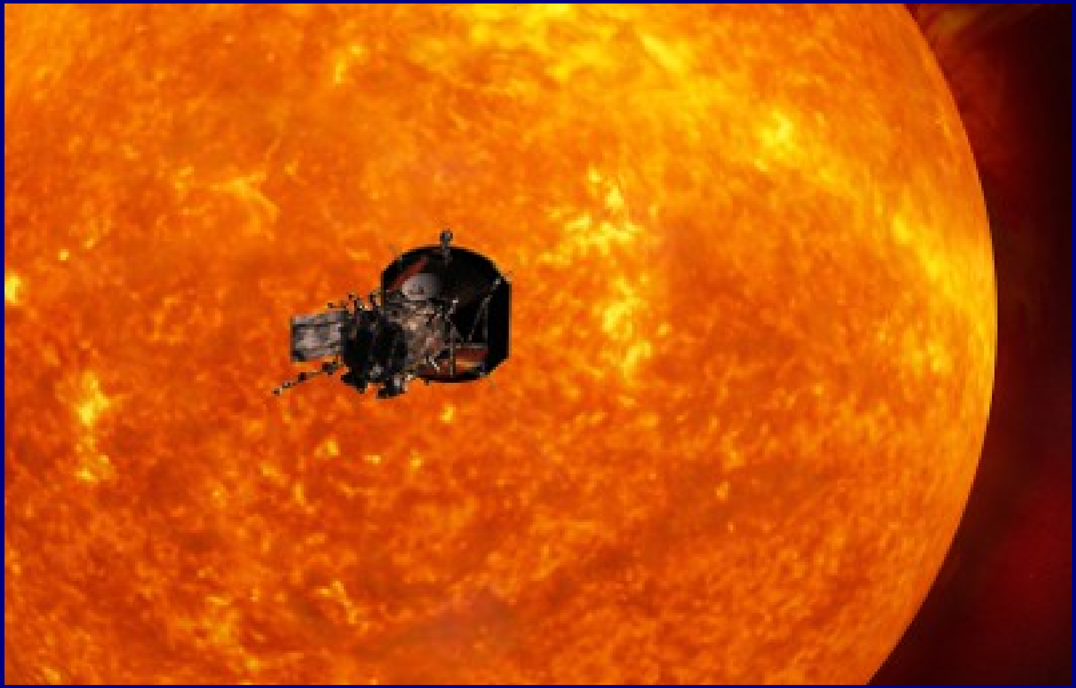


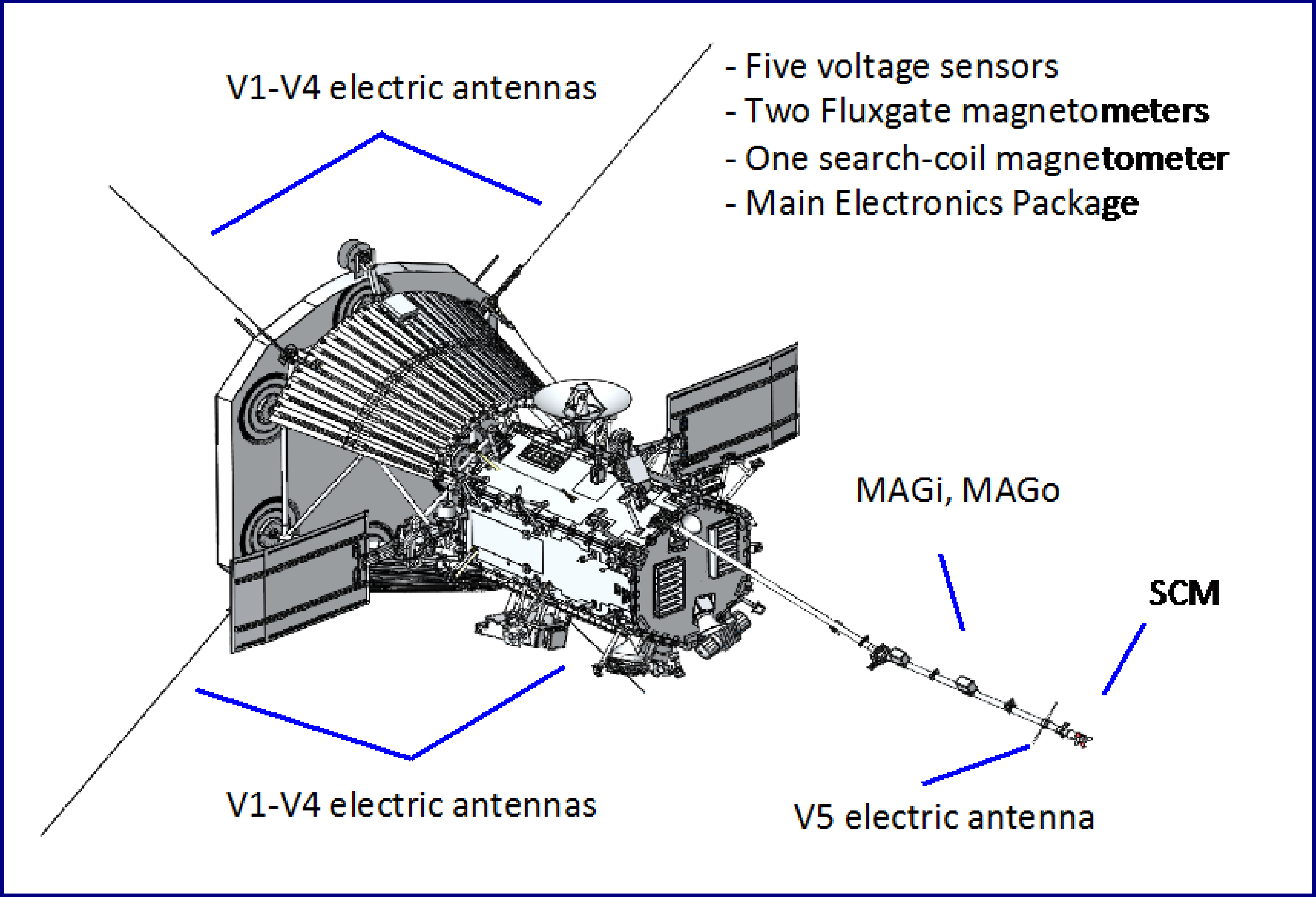
Image Credit: Johns Hopkins University Applied Physics Laboratory, Artist's Concept

- Trace flow of energy that heats and accelerates the corona and solar wind
- Determine structure and dynamics of plasma and magnetic fields at solar wind sources
- Explore mechanisms that accelerate and transport energetic particles

Parker Solar Probe: Investigations

Fields Experiment

Measurements of: electric and magnetic fields and waves, Poynting flux, absolute plasma density and electron temperature, spacecraft floating potential and density flucuations, and radio emissions.

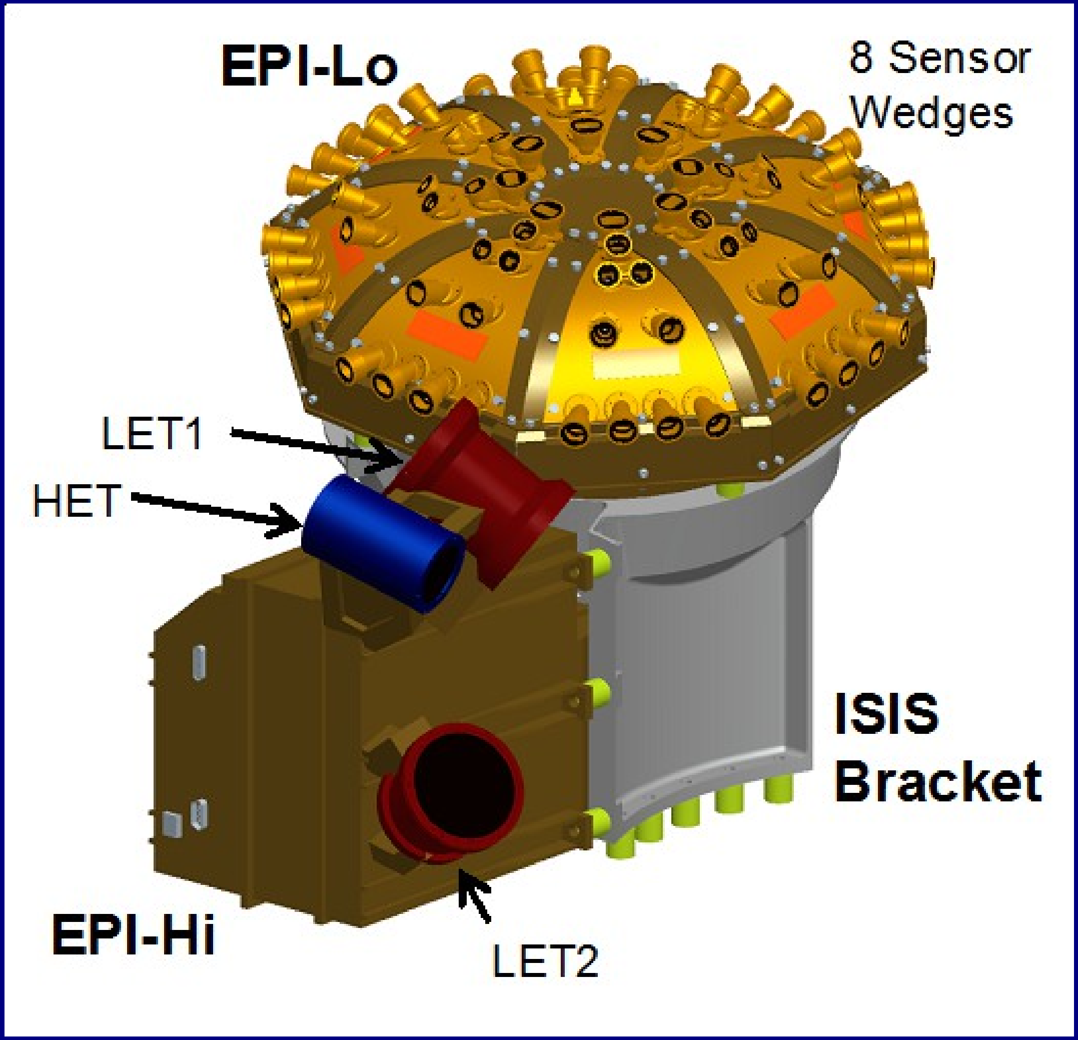


Parker Solar Probe: Investigations

Integrated Science Investigation of the Sun (ISIS)

Observations of: energetic electrons, protons, and heavy ions (10s of keV to 100 Mev)

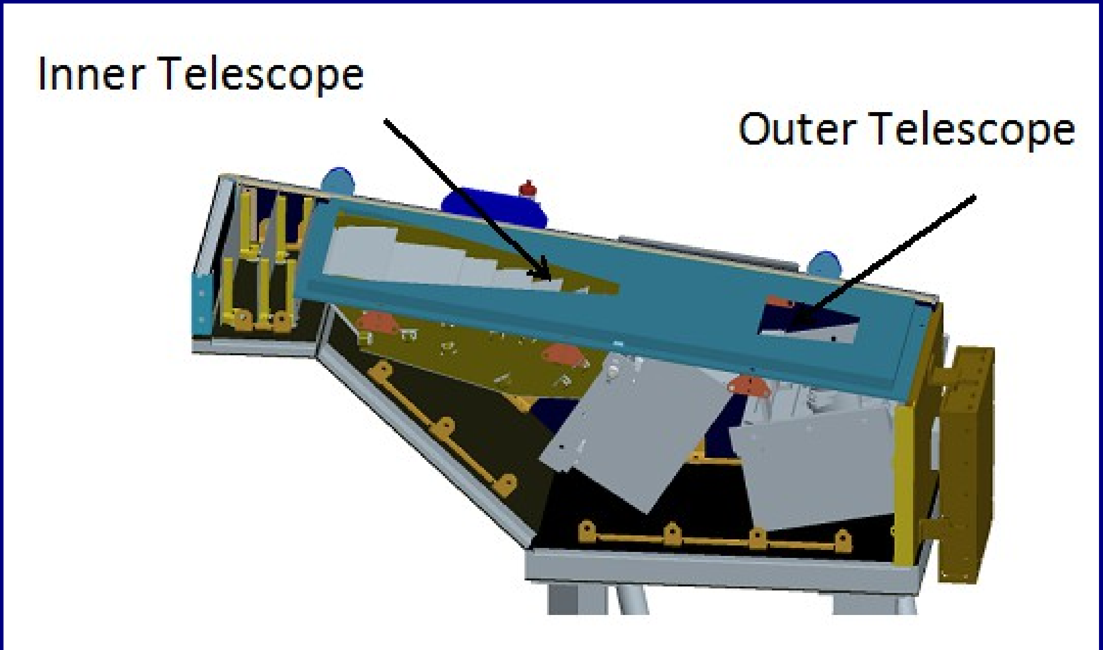
Correlates with : solar wind and coronal structures



Parker Solar Probe: Investigations

Wide-field Imager for Solar PRobe (WISPR)

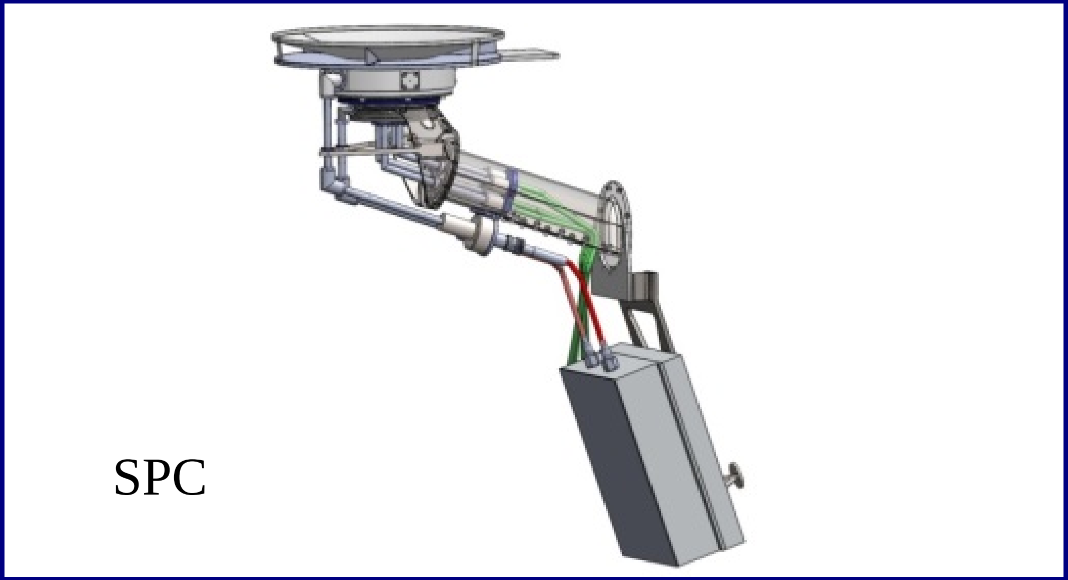
Images of: solar corona, inner heliosphere, solar wind, and shocks

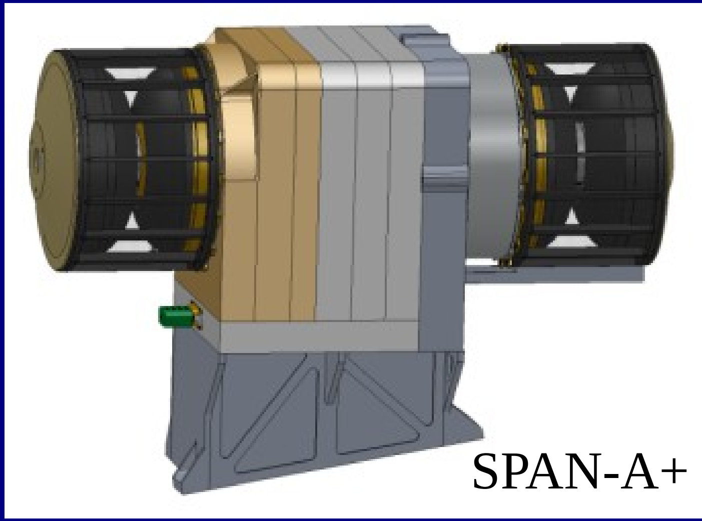


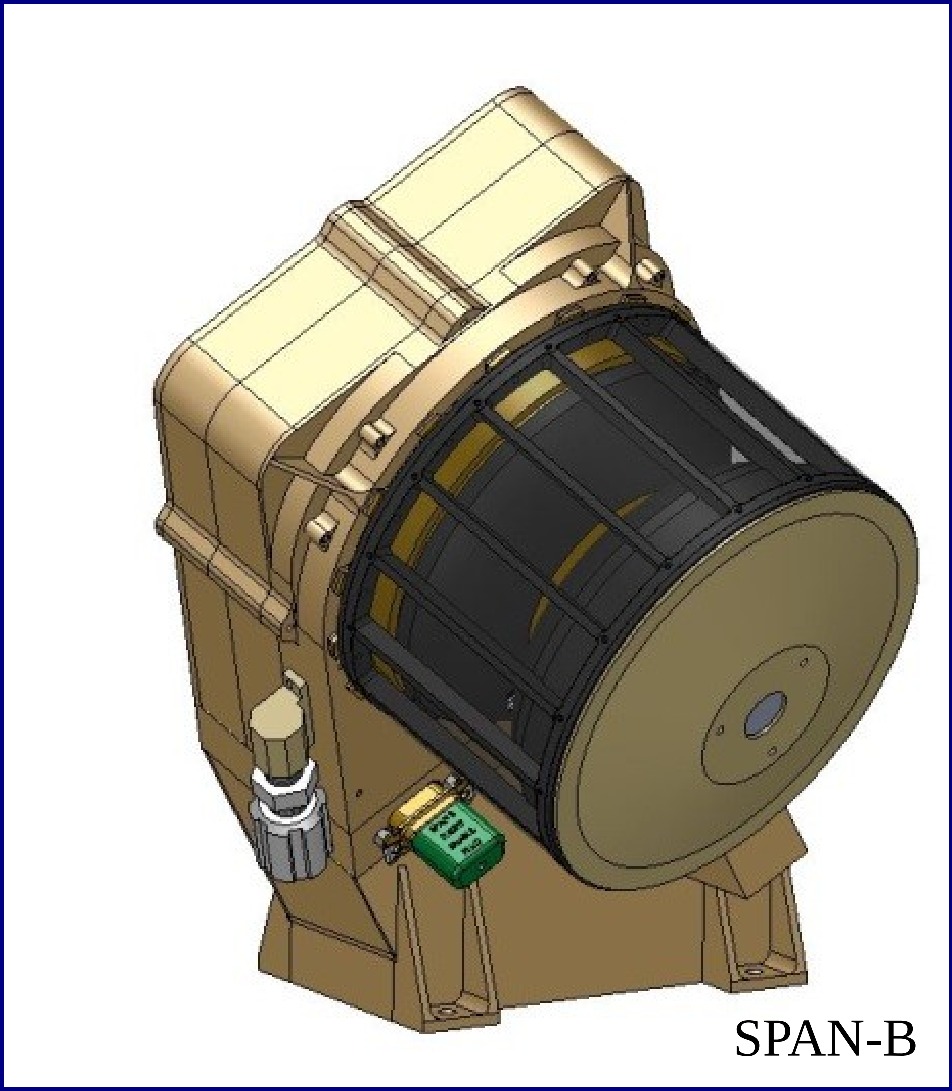
Parker Solar Probe: Investigations

Solar Wind Electrons Alphas and Protons (SWEAP)

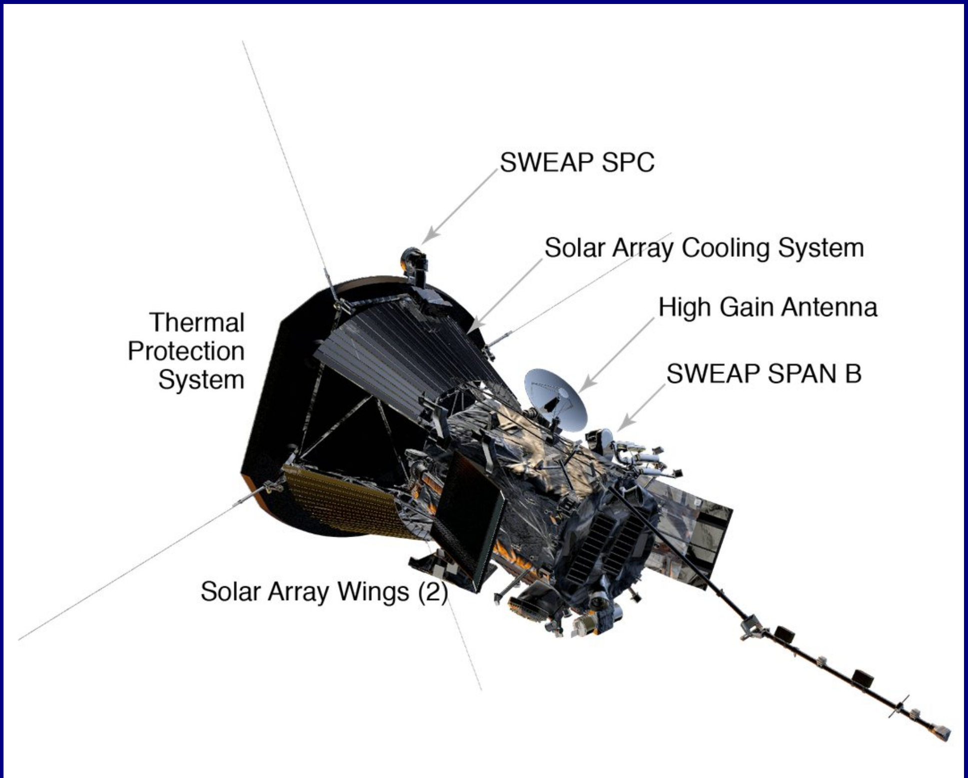
Counts: electrons, protons, helium ions
Measures: velocity, density, and temperature

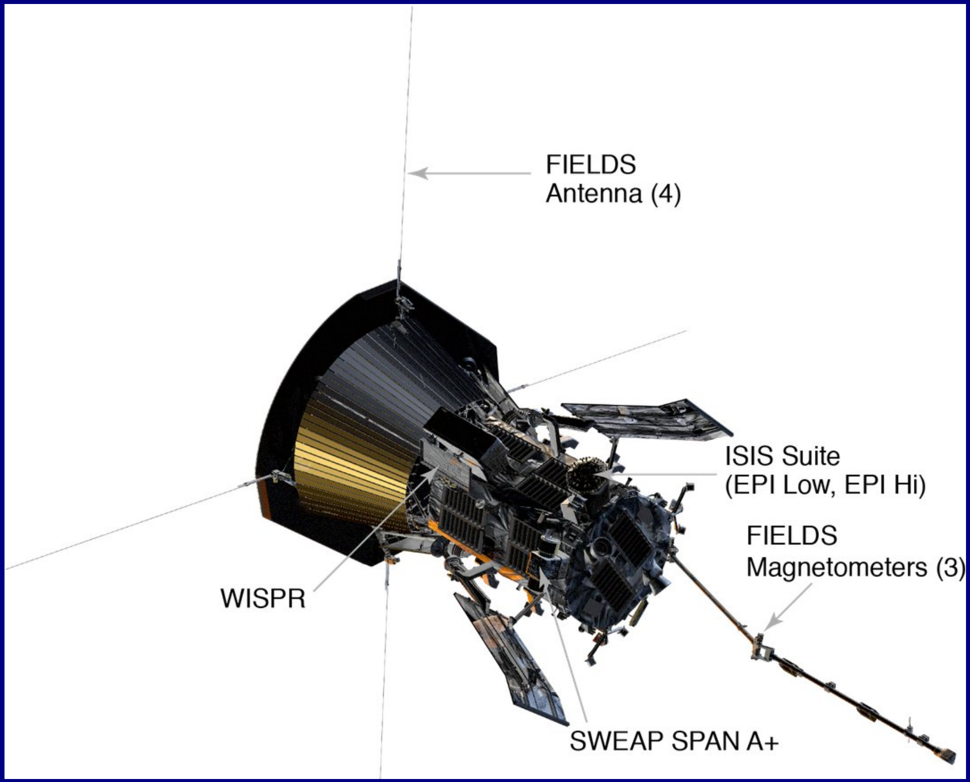






Parker Solar Probe: Spacecraft





Mass: 685 kg

S/C height: 3 m

TPS max diameter: 2.3 m

S/C bus diameter: 1 m

Actively cooled solar arrays

388 W at encounter

Solar array area: 1.55 m^2

Radiator area under TPS: 4 m^2

Wheels for attitude control

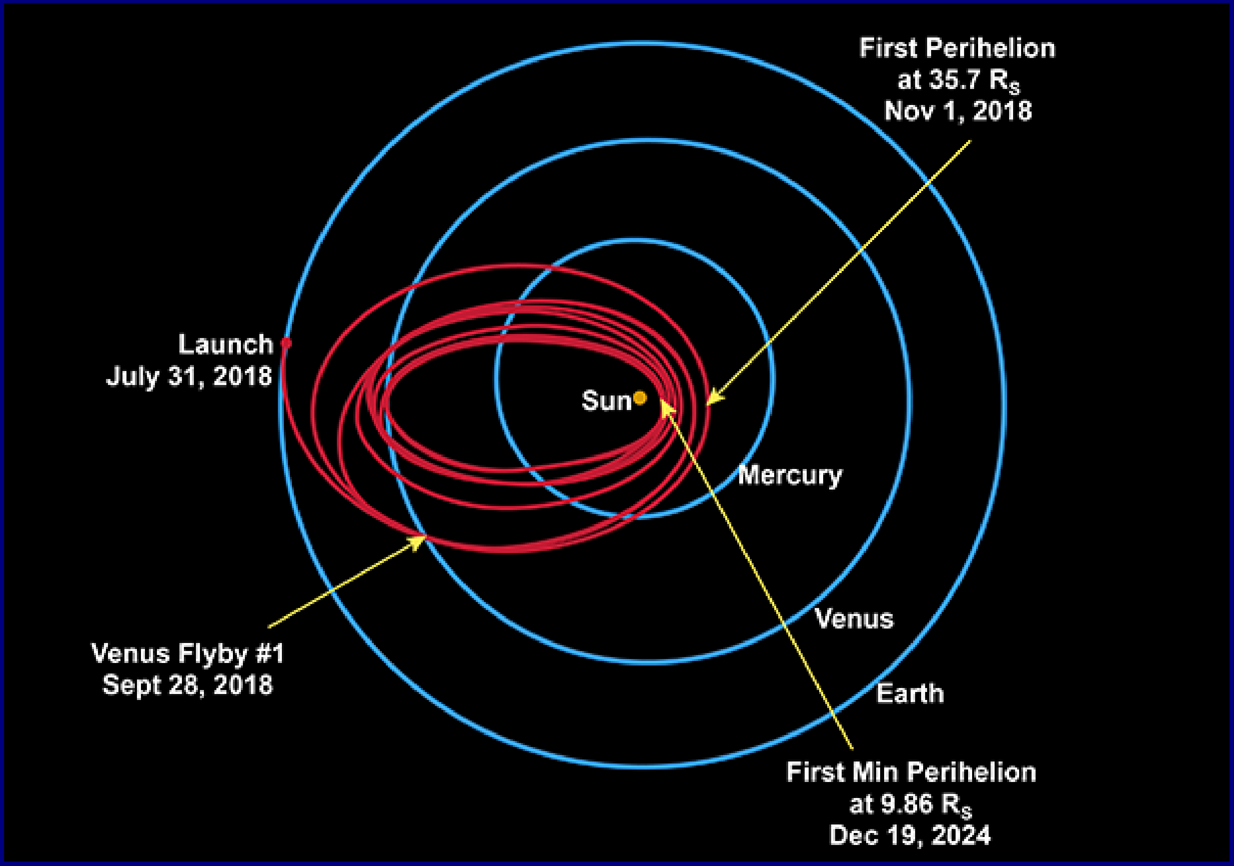
Science downlink rate: 167 kb/s at 1AU

Parker Solar Probe: Launch

Launch Window: July 31 - August 19, 2018

Delta IV-Heavy with Upper Stage
Image Credit: ULA

Parker Solar Probe: Trajectory



24 Orbits

7 Venus Gravity Assists

Temps at Closest Approach:
1400° C at shield
~25° C behind shield

First Close Approach
December 19, 2024

Last Close Approach
June 14, 2025