The Sun and Space Weather

Mitzi Adams, M.S.
Solar Scientist
NASA/MSFC
ST 13

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What is the Sun?
The Sun: A Star at the Center of our Solar System
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 $M_{\odot}$.

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.

Basically, hydrogen converts to Helium.

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

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 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.

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.
Sunspots
Examples
Magnetic Fields ABOVE the “Surface”

Yohkoh, 4 Jan, 1994

L-O-S magnetic field

Extrapolated Magnetic Field
The Solar Cycle
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
 Shortly after Schawbe's discovery Rudolf Wolf proposed using a “Relative” Sunspot Number count. Prior to 1849, sunspots were not counted every day. We continue to use Wolf’s Relative Sunspot Number and his cycle numbering.

Average cycle: 11 years, with a range from 9 to 14.

Average amplitude: 100, with a range from 50 to 200.
Solar Eruptions
May 5, 2015, X2.7 flare

Flares

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 Holes as Seen in X rays and EUV

Coronal holes can last several solar rotations. As they rotate around they produce recurring storms at Earth every 27 days. Solar particles flow out easily and at high speeds. Solar particles flow out slowly - impeded by sun's magnetic field.
Jets in Coronal Holes

South Polar Jet: Hinode/P. Grigis
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)

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.
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]
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 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].

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].

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].

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].
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):


3. The National Science and Technology Council (NSTC) shall establish a Space Weather Operations, Research, and Mitigation Subcommittee

Has become Space Weather Strategy and Action Plan, released March, 2019
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.

See: https://www.govtrack.us/congress/bills/115/s141/text