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

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Presentation for the
Wernher von Braun Planetarium of the
Von Braun Astronomical Society
January 23 and 30, 2016
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
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.

Perspective, continued...

Proxima Centauri: \(\alpha\)-Cen-A and \(\alpha\)-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.

\(\alpha\)-Cen-A is a G2, \(\alpha\)-Cen-B is a K1, Proxima (\(\alpha\)-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 $M_\odot$.

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 Itself
THE SUN

HOW BIG? HOW POWERFUL?

THE SUN CONTAINS MORE THAN 99.8% OF THE TOTAL MASS OF THE SOLAR SYSTEM.

38.6 BILLION BILLION MEGAWATTS OF POWER

AT THE CENTRE OF THE CORE: 150 TIMES THAT OF WATER

THE SUN'S DENSITY IS MORE THAN 137 TIMES THAT OF WATER

THE EARTH

1.3 MILLION EARTHS CAN FIT INSIDE THE SUN.

THE SUN

HYDROGEN

HELIUM

METALS

SOURCE: HTTP://NINEPLANETS.ORG  INFOGRAPHIC DESIGNED BY WAYNE DORRINGTON HTTP://WWW.WAYNEDORRINGTON.CO.UK
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.

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.

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.
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

(a) (b)

(c) (d)
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
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.
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
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.

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.

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

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 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

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

Never look directly at the Sun unless you have filters that you know are safe.
For more information:
http://eclipse.gsfc.nasa.gov/SEhelpr/safety.html
http://eclipse.gsfc.nasa.gov/solar.html
http://eclipsewise.com/solar
http://eclipse2017.org/

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.

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The CNO Cycle

\[ _6^1\text{C} + _1^1\text{H} \rightarrow _7^1\text{N} + \gamma \]

\[ _7^7\text{N} \rightarrow _6^6\text{C} + e^+ + \nu_e \]

\[ _6^6\text{C} + _1^1\text{H} \rightarrow _7^7\text{N} + \gamma \]

\[ _7^7\text{N} + _1^1\text{H} \rightarrow _8^8\text{O} + \gamma \]

\[ _8^8\text{O} \rightarrow _7^7\text{N} + e^+ + \nu_e \]

\[ _7^7\text{N} + _1^1\text{H} \rightarrow _6^6\text{C} + _4^4\text{He} \]
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.

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.