Explosive Energy Release on the Sun and Beyond

1 o’clock Space Lecture

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Deities of the Sun

Ra
Egyptian god of the Sun

Helios
Ancient Greek Titan and Sun God

Huitzilopochtli
Aztec god of War and the Sun
The Sun

- Age – 4.6 billion years
- Size – 700,000 km radius (100x Earth radius)
- Distance – 150 million km
- Surface temp – 5500°C
- Core temp – 15 million °C
- Energy source – fusion of $\text{H} \rightarrow \text{He}$

Credit: NASA SDO
Structure of the Sun
Orion Nebula (1344 ly away)

Young Star Elias 2-27 (450 ly away)
(credit: Max Planck Institute for Astronomy)
Artist’s impression
(Credit: How it works)

HL Tau system
(Credit: ALMA, ESO)
Goldilocks Zone

Too hot...

Venus
0.72 AU
460 °C

Sun light and heat

Just right.

Earth
1 AU
14.6 °C

Too cold...

Pluto
39.5 AU
–238 °C
Future Goldilocks Zone

Future Sun

Earth
Mars
Jupiter
Saturn
Uranus
Neptune

Future ‘Habitable Zone’
Life of the Sun

• The life of a star is constant battle between gravity, and nuclear fusion in the core.
• The Sun’s life as a main sequence star is spent fusing H into He.
• In 5 bn years time, H runs out in the Sun’s core. It begins to contract, becoming hot enough to fuse He → C. This causes it to expand and become a red giant.
Death of the Sun

• Eventually, the Sun’s core will run out of He fuel. The Sun is not large enough to fuse heavier elements, so fusion stops.

• The Sun contracts, until the compressed atoms in the core resist any further collapse, creating a *white dwarf* star.

• As the core becomes a *white dwarf*, the outer layers of the Sun drift off into space, illuminated by radiation from the old core. This forms a *planetary nebula*.

• *White dwarfs* have no energy source, so slowly cool down over billions of years.
Worcester, England - 1128 AD

Portrait and sunspot diagram from Worcester Chronicles, 1128
Worcester, England - 1128 AD

Sunspot diagram from Worcester Chronicles, 1128

White light sunspot image, 1993
Europe, 1610 - 1801

- ‘Small planets closely orbiting the Sun’
  - Scheiner

- ‘Perhaps cloud-like structures in the solar atmosphere’
  - Galileo

- ‘Dense objects embedded in the Sun's luminous atmosphere’
  - Scheiner

- ‘Openings in the Sun's luminous atmosphere, allowing a view of the underlying, cooler surface of the Sun’
  - Herschel
Solar Cycle

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

AVERAGE DAILY SUNSPOT AREA (% OF VISIBLE HEMISPHERE)

http://solarscience.msfc.nasa.gov/

HATHAWAY NASA ARCS 2016-10
Sunspots
1859 – Carrington Event

- Richard Carrington – Part time astronomer, part time brewery owner
- September 1st 1859, observed two rapidly brightening areas of light in sunspot centre.
- Intense aurora followed the following night, all the way down to the tropics.
- Strengthen case for link between solar and geomagnetic activity
- First ever solar flare observation? Maybe not.

1705 - Stephen Gray noted ‘flash of lightning’ in sunspot.
1860 Eclipse – First CME observation

Comparison between G. Tempel’s CME sketch from 1860 (left), with modern SOHO satellite’s coronagraph imagery of a coronal mass ejection in July 2017
1908 – Sunspots are magnetic in nature

• George Hale observed Zeeman splitting in active regions, proving that sunspots are dominated by complex magnetic fields.
• Sunspot magnetic fields are over 1000 stronger than the Earth’s magnetic field.

More Sun historic info - https://www2.hao.ucar.edu/Education/SolarPhysicsHistoricalTimeline
Magnetic fields

Credit: mammothmemory
The Sun and the Electromagnetic Spectrum

X-ray  Ultraviolet  Visible light  Infrared

Increasing wavelength

gamma ray  ultraviolet  infrared  microwave  radio

Image credit: NASA
Frozen-in plasma
Magnetic Reconnection – the driver of energy release

Magnetic potential energy → Heating, particle acceleration and EM radiation
Solar Flares
Solar Flares

2017-09-06T11:00:30

2017-09-10T15:30:42
Magnetic reconnection models

Sweet-Parker reconnection (1957)
- Magnetic reconnection along an entire current sheet of oppositely orientated field lines.
- Energy release rate is far slower than that observed in flares.

Petschek reconnection (1964)
- Reconnection along a small fraction of the sheet, with a configuration sustained by slow shocks.
- It is unclear whether such a configuration can be sustained during a flare.
Magnetic reconnection models

Tearing mode / plasmoid instability

- If the sheet's length greatly exceeds its width, the current sheet collapses/reconnects in certain locations to produce plasmoids or 'magnetic islands'.
- These plasmoids continue to break down to progressively smaller scales in a turbulent cascade.

Which is happening?
Small-scale Reconnection – Solar Orbiter Campfires

ESA Solar Orbiter EUI – First light images
Coronal Mass Ejections (CMEs)
Arrival at Earth
Reconnection at Earth

Eastwood et al 2017
Solar System Aurora
Space Weather

Space Weather Impacts

AURORA (NORTHERN LIGHTS)

SATELLITES

COMMUNICATIONS

HUMAN SPACE EXPLORATION

AVIATION

ELECTRIC POWER

WEATHER.GOV/SPACE
Space Weather on other Stars
Exoplanets

Trappist-1 system. Credit: EarthSky
Black holes

Credit: NASA
Conclusion – Why we care about the Sun.

• The Sun acts as a window into astrophysical plasma processes. Studying these phenomena close-up provides an insight into the mechanics of much more elusive events.

• The Sun is volatile. Solar flares and coronal mass ejections cause space weather effects here on Earth. It is important we understand the physics behind these events.
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