Sun-Earth System Overview

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(thanks to Dr. Frank Eparvier for making most of the slides)
Why do We on Earth Care about the Sun?

The Sun directly or indirectly provides nearly all of the energy to the Earth system.

- Photons (light of all wavelengths)
- Plasmas (charged particles and magnetic fields)

Variability in the solar output drives variability in the Earth system.

- How the Earth system reacts to solar variability depends on the complicated, interconnected mechanisms involved in the Sun-Earth system.
The Sun Side of the Sun-Earth System

 Galactic Cosmic Rays

 Energetic Particles

 Interplanetary Magnetic Field

 Solar Wind

 Local Interstellar Medium

 Electromagnetic Radiation

 Galactic Cosmic Rays

 Atmosphere

 Magnetosphere

 Planet

 Heliosphere

The Earth Side of the Sun-Earth System
Statistics of the Sun

Radius = 696,000 km \approx 109 \ R_{\text{Earth}}

Volume \approx 1,300,000 \ V_{\text{Earth}}

Mass = 1.99 \times 10^{30} \ \text{kg} \approx 333,000 \ M_{\text{Earth}}

Composition:

<table>
<thead>
<tr>
<th>Element</th>
<th>by Number</th>
<th>by Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>92.1%</td>
<td>75%</td>
</tr>
<tr>
<td>Helium</td>
<td>7.8%</td>
<td>25%</td>
</tr>
<tr>
<td>Heavier Elements</td>
<td>&lt;0.1%</td>
<td>&lt;0.1%</td>
</tr>
</tbody>
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Much of this is in the form of ionized atoms = plasma
Energy Flow and Layers of the Sun

**Interior of Sun:**
**Core:** Where fusion occurs, ~15 million K

**Radiative Zone:** Energy carried outward slowly (~200,000 yrs) by photons through a very thick region of H & He, T~5 million K

**Convective Zone:** Energy carried outward via convection (hot plasma rises, reaches surface, radiatively cools, then sinks again), T~1 million K
Hydrogen Fusion in the Sun
“The Proton-Proton Chain”
Every second in the Sun's core, $600 \times 10^9$ kg H

$\rightarrow$

$596 \times 10^9$ kg He,

which is $0.7\%$ of

$4 \times 10^9$ kg to Energy:

$E=mc^2$
Energy Output of the Sun

Measure all photonic energy coming from the Sun at all wavelengths

Total Solar Irradiance = 1361 Watt/m² at 1 AU
Energy Flow and Layers of the Sun (2)

**Atmosphere of Sun:**

**Photosphere:** visible “surface” of Sun, point where gases go from being optically thick (opaque) to optically thin (transparent), T~5700 K

**Chromosphere:** “bottom” layer of atmosphere, visible as pink layer of hydrogen during total solar eclipses, T~10,000 K

**Transition Region:** narrow (~100-1000 km) layer between chromosphere and corona where temperatures rise rapidly T~10,000 K - 1 million K

**Corona:** “top” of solar atmosphere heated to extremes by complex (and not fully understood) magnetic means, T~ 2 million K

**Solar Wind:** extension of corona into interplanetary space, mostly protons and electrons streaming out on Sun’s magnetic field at speeds of ~400-1000 km/s, T~200,000 K at 1 AU
Differential Rotation of Sun

Core and Radiative Zone rotate rigidly. Outer layers of Sun rotate differentially.

- Core and radiative zone rotate rigidly.
- Outer layers rotate differentially.

25 days/rot.

35 days/rot.

Pole

Equator

25 days/rot.

35 days/rot.
Looking at the “Surface” of the Sun

Different wavelengths show us a different Sun.

Features that are dark at one wavelength are bright at other wavelengths.
Surface Features
Granules

Granules: Convection cells on photosphere, size ~ 1000 km (~ size of Texas)
Spicules

The Sun’s surface is in constant motion.

...unlike your typical cat.
**Sunspots**

Sunspots: Magnetically disturbed regions cooler than surrounding areas (~4000 - 5000 K) of photosphere (\(\therefore\) darker), usually come in pairs (N and S magnetic polarity), size \(~1500-50,000\) km, can last for months.
The magnetic nature of sunspots

Hale provided the first proof that sunspots are the seats of strong magnetic fields.
Prominences

Prominences & Filaments: Long-lasting (hours or days) condensations of gases held above the surface by erupting sections of magnetic field
Prominences (2)
**Flares**

**Flares:** short duration (minutes to hours) bursts of hot material out of surface, very bright at all wavelengths
Coronal Holes

Coronal Holes: areas of “open” magnetic field allowing plasma to stream out into solar wind
Coronal Mass Ejections

**CMEs**: large “blobs” of plasma (hot ionized gases enclosed in bubbles of magnetic field) that blow off the Sun and travel out through the solar system.
Solar Wind and IMF

Solar Wind: Charged particles streaming out from Sun

Interplanetary Magnetic Field (IMF): Solar magnetic field at distances of the planets

Solar wind flows out along “open” magnetic field lines.

IMF is twisted into “ballerina skirt” shape by solar rotation.
Photon Output of the Sun

The graph shows the solar irradiance and variability in the spectrum of the Sun. The y-axis represents the solar irradiance in units of mWm$^{-2}$nm$^{-1}$, while the x-axis represents the wavelength in nanometers (nm). The graph is divided into different regions: EUV (Extreme Ultraviolet), UV (Ultraviolet), VIS (Visible), and IR (Infrared). The spectral irradiance is indicated by the blue line, and the spectral variability is shown in red bars. The total variability is depicted by the red dashed line. The graph also shows the 11-year cycle ratio, indicating the variability during solar cycles.