The Solar Resource:

The Active Sun as a Source of Energy

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The Sun: A Source of Energy

Solar Structure
Solar Wind
Solar Cycle
Solar Activity
Sun Earth Connection
Solar Structure

- Core:
  \[ r < 0.3 \, R_S \]
- Radiative Zone:
  \[ 0.3 \, R_S < r < 0.7 \, R_S \]
- Convective Zone:
  \[ r > 0.7 \, R_S \]
- Photosphere:
  ‘Surface’ of the sun
- Corona:
  Solar Atmosphere

\[ R_S \sim 6.96 \times 10^8 \, \text{m} \sim 110 \times R_{\text{Earth}} \]
Core: Nuclear Fusion

$^1\text{H} + ^1\text{H} \rightarrow ^2\text{H} + e^+ + \nu_e$

$e^- + e^+ \rightarrow 2\ \gamma$

$^2\text{H} + ^1\text{H} \rightarrow ^3\text{He} + \gamma$

$^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + ^1\text{H} + ^1\text{H}$

Proton-Proton Chain

Overall Reaction:

$4^1\text{H} + 2e^- \rightarrow ^4\text{He} + 2\nu_e + 6\gamma$

$\Delta E = [4(1.007825u) - 4.002603u]\times[931\text{MeV/u}]$

$\Delta E = 26.7\ \text{MeV}$
The Radiative Zone is a region of highly ionized gas where the energy transport is primarily by photon diffusion where photons are absorbed and re-emitted.

At the base of the Convection Zone, lower efficiency of photon diffusion leads to thermal gradients where convection becomes the dominant mechanism for energy transport.
In the Photosphere the plasma becomes transparent to the optical spectrum, allowing for the escape of most of the electromagnetic energy reaching that layer. Hence, the Photosphere is the visible ‘surface’ of the sun.

Below the photosphere the plasma is so dense that we cannot see through it, but evidence of the convection zone are visible as ‘granules’.
Solar Spectrum, Variability, and Atmospheric Absorption

![Graph showing solar irradiance and variability across different wavelengths.](image)

TOTAL Irradiance = \( \int \) SPECTRAL Irradiance \( \sim 1366 \text{ Wm}^{-2} \)

 Courtesy of J. Lean, NRL
Solar Structure

The Solar Atmosphere:

- Photosphere
- Chromosphere
- Transition Zone
- Corona
- Heliosphere
Solar Wind

Density ~ 5-10 cm\(^{-3}\)
Speed ~ 450 km/s
Magnetic field ~ 6 nT

Temperature ~ \(10^5\) K
Sonic Mach ~ 10
Alfvén Mach ~ 4
At Solar Minimum the Sun’s magnetic field is very dipolar, and the solar wind carries the magnetic field radially outward, creating a neutral current sheet.
Solar Wind Propagation

McComas, D. J. et al., GRL, 1998
However, there are two additional effects, the rotation of the Sun, and the fact that the magnetic moment is not perfectly aligned with the rotation axis. These two effects create a spiral with ripples, or ‘ballerina skirt’ effect.
The Sun has an internally generated magnetic field that reverses about every 11 years (~22 years for magnetic cycle).

First noticed through the variation in the number of sunspots.

Later recognized by the level of energetic activity on the surface and its impact on the Earth.
Solar Cycle

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The Solar Cycle
Solar Activity

① Solar Flares

- Large release of energy:
  - Generate X-rays and sometimes even gamma rays
  - Magnetic loops colliding together
  - 10,000-100,000 km in size
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② Coronal Holes

• Release fast moving plasma continuously into space:
  – No magnetic confinement
  – Dark Areas in X-ray images
  – Large during solar minimum, smaller closer to solar max
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![Image of Sun with coronal hole](image_url)
Solar Activity

③ Coronal Mass Ejections

- Very large release of energy and energetic particles:
  - Generates X-rays
  - Releases very energetic ions
  - Larger than the Sun
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Source: High Altitude Observatory/Solar Maximum Mission Archives

HAO A-013
Solar Wind at Solar Minimum and Max

(White Light Eclipse Images from the High Altitude Observatory)
Solar Spectrum, Variability, and Atmospheric Absorption

TOTAL Irradiance = \int \text{SPECTRAL Irradiance} \approx 1366 \text{ Wm}^{-2}

Courtesy of J. Lean, NRL
Planetary Magnetic Fields

http://www.windows.ucar.edu
The Sun: A Source of Energy in Space

Solar Energy for Power: Earth orbit and robotic exploration

Solar Energy for Propulsion

M2P2: R. Winglee

Star Wars Episode II
Solar Image & Educational Resources

http://sohowww.nascom.nasa.gov/

http://stereo.jhuapl.edu/