1. The Sun
Sketch of the location of the solar system in the milky way
“Far out in the uncharted backwaters of the unfashionable end of the western spiral arm of the Galaxy lies a small unregarded yellow sun.

Orbiting this at a distance of roughly ninety-two million miles is an utterly insignificant little blue green planet whose ape-descended life forms are so amazingly primitive that they still think digital watches are a pretty neat idea.”
Daily view of the Sun
Structure of the Sun

Energy production in solar interior:

Three steps of p-p chain:

1) Deuteron production

\[ p + p \rightarrow D^2 + e^+ + \nu_e \]

2) He\(^3\) production

\[ D^2 + p \rightarrow He^3 + \gamma \]

3) He\(^4\) production

\[ He^3 + He^3 \rightarrow He^4 + 2p \]

\[ e^+ + e^- \rightarrow 2\gamma \]

\[ 4p \rightarrow He^4 + 6\gamma + 2\nu_e \]

\[ \Delta E = \Delta mc^2 = (4m_p - m_{He})c^2 = 0.007(4m_p)c^2 = 0.428 \cdot 10^{-11} J \]

\[ N = \frac{L_S}{\Delta E} = 10^{38} \]

\[ L_S = 3.854 \cdot 10^{26} Js^{-1} \]

\[ \Delta M (1s) = 5 \cdot 10^9 kg \]
### Basic facts about the Sun (1/2)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean distance from Earth</td>
<td>149.6 Million km ≈ 210 $R_E$</td>
</tr>
<tr>
<td>Length of solar radius</td>
<td>696,000 km ≈ 109 $R_E$</td>
</tr>
<tr>
<td>Mass</td>
<td>$1.989 \times 10^{30}$ kg ≈ 333,000 $M_E$</td>
</tr>
<tr>
<td>Volume</td>
<td>$1.412 \times 10^{27}$ m$^3$ (1.3 Mill. Earth)</td>
</tr>
<tr>
<td>Density in core</td>
<td>151,300 kg m$^{-3}$</td>
</tr>
<tr>
<td>Mean density</td>
<td>1409 kg m$^{-3}$</td>
</tr>
<tr>
<td>Pressure in core</td>
<td>$2.334 \times 10^{11}$ bar</td>
</tr>
<tr>
<td>„Surface“ pressure (photosphere)</td>
<td>0.0001 bar</td>
</tr>
<tr>
<td>„Surface“ temperature</td>
<td>5780 K</td>
</tr>
<tr>
<td>Age</td>
<td>ca. 4.55 Billion years</td>
</tr>
<tr>
<td>Lifetime</td>
<td>ca. 5 Billion years</td>
</tr>
<tr>
<td>Energy output</td>
<td>$3.9 \times 10^{23}$ kW</td>
</tr>
<tr>
<td>Basic facts about the Sun (2/2)</td>
<td></td>
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<tr>
<td>--------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Luminosity</strong></td>
<td>3.854 x 10^{26} J s^{-1}</td>
</tr>
<tr>
<td><strong>Solar “constant”</strong></td>
<td>1367 W/m²</td>
</tr>
<tr>
<td><strong>Chemical composition</strong></td>
<td>92.1% Hydrogen</td>
</tr>
<tr>
<td></td>
<td>7.8% Helium</td>
</tr>
<tr>
<td></td>
<td>0.1% other elements</td>
</tr>
<tr>
<td><strong>Escape velocity</strong></td>
<td>618 km/s (Earth: 11.15 km/s)</td>
</tr>
<tr>
<td><strong>Period of siderial rotation / w.r.t. Earth</strong></td>
<td>25.4 / 27.3 days</td>
</tr>
<tr>
<td>(Carrington, Bartels rotation systems)</td>
<td>25.7 (0°) – 30.8 (60°) days</td>
</tr>
<tr>
<td>! Differential rotation – the Sun rotates faster at the equator</td>
<td></td>
</tr>
<tr>
<td><strong>Time of rotation around galactic center</strong></td>
<td>2.4 x 10^{8} years</td>
</tr>
<tr>
<td><strong>Next star</strong></td>
<td>alpha-centauri</td>
</tr>
<tr>
<td><strong>Next galaxy</strong></td>
<td>Magellanic cloud</td>
</tr>
</tbody>
</table>
The visible variation of spots on the solar disk, the photosphere, reveals that the Sun is not a perfectly unchanging object.
Sunspots

- dark regions in photosphere = concentrations of magnetic flux
- cooler temperature \( (T \sim 4000 \text{ K}; \ T_{\text{Ph}} = 5780 \text{ K}) \)
- magnetic field strength \( \sim 0.2 - 0.4 \text{ T} \)
  \( (2000-4000 \text{ Gauß; } B_{\text{Earth}} \sim 50.000 \text{ nT} = 10^{-5} \text{ T}) \)
Large sunspots on the solar disk

March 30, 2001

Southpole

1 Solar Radius = $R_S = 696,000$ km

Approx. Size of Earth
1 $R_E = 6380$ km

Northpole

April 2, 2001

MDI HR Field of View (FoV)

1 Solar Rotation = $S_R = 25.4$ Days

From Earth: 27.3 days
Sunspots reveal solar rotation

2001/03/27 12:48 UT

SOHO/MDI

Galilei, ab 1609
Sunspot records

“Maunder Minimum”
Sunspot number


• "International Sunspot Number" from the Solar Influences Data Center in Belgium: http://sidc.oma.be/

Rudolph Wolf’s formula (1848):

$$R = k(10G + S)$$

**R**: sunspot number  
**G**: number of sunspot groups on solar disk  
**S**: total number of individual spots in all groups  
**K**: variable scaling factor (usually <1) that accounts for observing conditions and telescope type

*Monthly values since 1749*

The Boulder numbers are on average 25% higher than the "International Sunspot Number" because of data from different observatories.
Sunspot dynamics

Swedish 1 m Teleskop, La Palma, July 2002
However, sunspots do reveal only parts of the photospheric field structure, also information on coronal structure is missing – The Sun at visible and EUV wavelengths

The Sun imaged at different wavelengths on 9th November 2005 (Bothmer & Zhukov 2006)
The Sun is not a perfect black body

For a perfect black body the emission is a function of wavelength depending on temperature: Planck law of radiation: \[ k_\lambda = \frac{hc^2}{\lambda^5} \left( \frac{hc}{e^{\frac{hc}{kT}} - 1} \right) \]
Solar EM spectrum
Selected literature

- Aschwanden, M., Physics of the Solar Corona, Springer/Praxis, 2009