The Structure of Astronomy 100

The Easily Visible Sky

Tools of Astronomy

- Matter
- Energy
- Newton's Laws
- Gravity
- Light

Stars

Galaxies

Cosmology
The Sun: Our Star

The Sun is an ordinary star and shines the same way other stars of its type do.

The bright part normally seen is called the photosphere.

It is an almost perfect black body with a temperature of 5800 K.
What is the Sun made of

It is made of hot gas of electrons and nuclei (plasma).

There is no solid material in the sun! The gas is mostly hydrogen and helium, as is in the whole universe.
The Atmosphere of the Sun

Although the sun appears to have sharp edge, its surface actually has complicated structure.
The light we see originates from the thin photosphere.
Chromosphere

- 2000-3000 km thick
- Faint relative to the photosphere
- T ~ 10,000 K
Corona

- the outermost layer
- $T \sim 1$ million K
- made up of very diffuse (but extremely hot gas)
- coronal emission is dominated by X-rays
The heating of the corona

The corona is heated by energy from the sun's interior not as heat but as magnetic energy.
Granulation of the Photosphere

Each Granule is about the size of Texas and lasts for only 10-20 minutes before fading away!
Sunspots

Sunspots, about 1000 K cooler than the rest of the Sun's photosphere, appear as dark spots.

Sunspots come and go with time. Big sunspots can live for several weeks.
Solar Prominence

Composed of hot gas trapped in magnetic fields extending from one sunspot to another.
Solar Flare

A solar flare is a violet outburst that lasts in an hour or less; it occurs in an active region where oppositely directed magnetic fields meet and cancel each other.

It radiates X-ray, ultraviolet, and visible radiation, plus streams of high-energy protons and electrons.

A large flare can be a billion times more energetic than a large hydrogen bomb.
Solar Wind
Auroras: the Northern and Southern Lights

Dunedin, New Zealand
1 April 2001, 1:20
May 11, 2002

• Auroras seen as far south as New England
• Caused by a gust of solar wind
• These powerful gusts are guided by Earth’s magnetic field and can excite gases in the upper atmosphere, causing the air there to glow
November 24, 2001

• This was a Big One!
• Caused by two fast moving Coronal Mass Ejections
• Seen as far south as Texas and Arkansas, New Zealand and Australia also witnessed them.
The key point here is that nearly all “solar weather” is a result of changes in the magnetic fields that penetrate the Photosphere.
Due to change in magnetic field

Magnetic field lines

Measured by Zeeman effect
Why sunspot is colder

Magnetic fields trap gas.  

T ~ 5,800 K  
sunspots  
T ~ 4,500 K  

convection cells  

T ~ 5,800 K  

Magnetic fields of sunspots suppress convection and prevent surrounding plasma from sliding sideways into sunspot.
Differential Rotation of the Sun causes magnetic cycles

Rotation period: about a month

The middle rotates faster than the north or south.

Time-lapse (27 days) movie of x-ray emission from the Sun's corona. Source: Yohkoh Public Outreach Project.
Babcock Model
Bipolar sunspot pair
Leading spot is magnetic north

Leading spot is magnetic south
Solar activity peaks roughly each 11 years.
Structure of the Sun

- Radiative envelope
- Convective envelope
- Photosphere
- Chromosphere
- Core
- Corona
- Prominences
- Solar flare
- Sunspot
The Core is where all the action is.

- The core is the only place in the Sun where the temperature (10 million K) and density are high enough to support nuclear fusion
  (hydrogen bomb needs atomic bomb for ignition!)
- Every second, about 600 million tons of Hydrogen are fused into 596 million tons of helium.
- The remaining mass (4 million tons) is converted to energy in line with Einstein’s formula

\[ E = mc^2 \]
Nuclear Fusion in the Sun

- Hydrogen is constantly being transformed into helium in the Sun’s core.
\( \nu \) - neutrinos; \( \beta^+ \) - positrons; \( \gamma \) - gamma rays.
An aside about nuclear fusion
as a viable energy source

A few key points about the P-P Chain:

- It is a “clean” form of energy production.
  - Put 4 protons (Hydrogen) in and get one Helium and some energy back out.

- Given fuel (in the form of Hydrogen) it is a self-sustaining reaction.

- It requires *very* high temperatures (10^7 K)
The energy emitted by the Sun is produced

in a small region at the very center of the Sun.

uniformly throughout the entire Sun.

throughout the entire Sun but more in the center than at the surface.

from radioactive elements created in the Big Bang.
The bulk of the violent surface activity on the Sun is due to “seasonal” variations in the Sun’s _______.

- energy output
- radius
- electric fields
- magnetic fields
**Luminosity**

*Luminosity* is the **total** amount of power given off by a star.

- Since it’s a power, Luminosity is measured in Watts.

- For convenience, we often refer to the luminosity of a star in terms of the luminosity of the Sun.

  - Eg,
    - “That star has a luminosity of $22L_{\text{Sun}}$”
    - “That galaxy has a luminosity of $2 \times 10^{14}L_{\text{Sun}}$”
A Star’s brightness, depends on its distance from us.

- there are stars much more luminous than our sun in the sky, however, they are not nearly as bright because they are far away.

- Scientists will use apparent brightness and flux interchangeably.

A star’s apparent brightness = \( \frac{\text{luminosity}}{4\pi \text{(distance)}^2} \)
Eg., The Sun radiates an enormous amount of energy ($L_{\text{Sun}} = 4 \times 10^{26}$ Watts). Only about $10^{-9}$ of this actually hits the Earth. Yet, the power of sunlight that illuminates a patch of desert 100 km x 100 km is equal to the total power consumption of the US.