Astro 110-01 Lecture 16
The Sun
[Chapter 10 in the Essential Cosmic Perspective]
For problems with Mastering Astronomy

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She will need your login and password
Our goals for learning:

• Why does the Sun shine?
• What is the Sun’s structure?
Why does the Sun shine?

Sun as seen in He II 30.4 nm
Is it on FIRE?
Is it on FIRE?

Chemical Energy Content ~ 10,000 years
Luminosity (= $3.8 \times 10^{26}$ Watts)
Is it on FIRE? ... NO!

\[
\text{Chemical Energy Content} \quad \frac{\text{Luminosity}}{\sim 10,000 \text{ years}}
\]
Is it CONTRACTING?
Is it CONTRACTING?

Gravitational Potential Energy ~ 25 million years

Luminosity
Is it CONTRACTING? ... NO!

Gravitational Potential Energy

Luminosity

\[ \sim 25 \text{ million years} \]
It is powered by NUCLEAR ENERGY!

Nuclear Potential Energy (core) ~ 10 billion years
Luminosity

E = mc^2
—Einstein, 1905
Pressure and Gravity Balance within the Sun

- Sun’s internal pressure precisely balances gravity at every point within it keeping the Sun stable
  - Pressure must increase with depth
  - Pressure in core makes gas hot and dense enough to sustain nuclear fusion

- Energy released by fusion heats gas and maintains the pressure that keeps the Sun in balance against inward pull of gravity
Early Sun:

Sun was born some 4.5 billion years ago from a collapsing cloud of interstellar gas.

Gravitational contraction… provided energy that heated the core as the Sun was forming.

Contraction stopped when fusion began replacing the energy radiated into space.
Gravitational equilibrium:

Energy provided by fusion maintains the pressure

Both gravity and pressure decrease with distance from the core, but remain balanced
Pressure of an ideal gas

\[ P = N \ k \ T \]

- \( k \) = Boltzmann’s constant
- \( N \) = density
- \( T \) = temperature

Internal Temperature Profile of the Sun

Internal Pressure Profile of the Sun
What is the Sun’s structure?
Tools for exploring the Sun

- Observations in different parts of the spectrum:
  - X-rays → ultraviolet → visible → infrared
- Precise telescopes:
  - Angular size
- Newton’s version of Kepler’s 3rd law
  - Sun’s mass
- Motion of sunspots and Doppler shifts
  - Solar rotation

View of Sun in Different λs

Multi λ solar activity
**Radius:**
6.9 × 10^8 m  
(10^9 times Earth)

**Mass:**
2 × 10^{30} kg  
(300,000 Earths)

**Luminosity:**
3.8 × 10^{26} watts
Solar wind:
A flow of charged particles from the surface of the Sun
Corona: Outermost layer of solar atmosphere
~1 million K
Chromosphere: 
Middle layer of solar atmosphere
\[-10^4 - 10^5 \text{ K}\]
Photosphere:
Visible surface of Sun $\sim 6,000$ K

Convection zone:
Energy transported upward by rising hot gas

Cut-away section of the Sun
Radiation zone:
Energy transported upward by photons
Core:

Energy generated by nuclear fusion

~ 15 million K
What have we learned?

• Why does the Sun shine?
  — Chemical and gravitational energy sources could not explain how the Sun could sustain its luminosity for more than about 25 million years.
  
  — The Sun shines because gravitational equilibrium keeps its core hot and dense enough to release energy through nuclear fusion.
What is the Sun’s structure?

From inside out, the layers are:

- Core
- Radiation zone
- Convection zone
- Photosphere
- Chromosphere
- Corona
Nuclear Fusion in the Sun

Our goals for learning:

• How does nuclear fusion occur in the Sun?
• How does the energy from fusion get out of the Sun?
• How do we know what is happening inside the Sun?
Nuclear fission versus fusion

Fission
Big nucleus splits into smaller pieces
(Nuclear power plants)

Fusion
Small nuclei stick together to make a bigger one
(Sun, stars)
High temperatures enable nuclear fusion to happen in the core

At low speeds, electromagnetic repulsion prevents the collision of nuclei.

At high speeds, nuclei come close enough for the strong force to bind them together.
Sun releases energy by fusing four hydrogen nuclei into one helium nucleus.
Start with:
4 protons

End up with:
\(^4\text{He}\) nucleus
2 gamma rays
2 positrons
2 neutrinos

Total mass is 0.7% lower ≡ energy
\[ E = mc^2 \]