# Chapter 14
# Our Star



## 14.1 A Closer Look at the Sun

Our goals for learning:

- Why was the Sun's energy source a major mystery?
- Why does the Sun shine?
- What is the Sun's structure?



# $E = mc^2$

**- Einstein, 1905**

***It can be powered by NUCLEAR ENERGY!***

$$\frac{\text{Nuclear Potential Energy (core)}}{\text{Luminosity}} \sim 10 \text{ billion years}$$

***Gravitational equilibrium:***

Energy provided by fusion maintains the pressure



***Gravitational contraction:***

Provided the energy that heated the core as Sun was forming

Contraction stopped when fusion began



***Radius:***

$6.9 \times 10^8$ m

(109 times Earth)

***Mass:***

$2 \times 10^{30}$ kg

(300,000 Earths)

***Luminosity:***

$3.8 \times 10^{26}$ 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

~ $10^4$ - $10^5$ K

***Photosphere:***

Visible surface of Sun

~ 6,000 K

***Convection Zone:***

Energy transported upward by rising hot gas

***Radiation Zone:***

Energy transported upward by photons

***Core:***

Energy generated by nuclear fusion

~ 15 million K



## What have we learned?

- Why was the Sun's energy source a major mystery?
  - Chemical and gravitational energy sources could not explain how the Sun could sustain its luminosity for more than about 25 million years
- Why does the Sun shine?
  - The Sun shines because **gravitational equilibrium** keeps its core hot and dense enough to release energy through nuclear fusion.



## What have we learned?

- What is the Sun's structure?
  - From inside out, the layers are:
    - Core
    - Radiation Zone
    - Convection Zone
    - Photosphere
    - Chromosphere
    - Corona

# 14.2 The Cosmic Crucible

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?



***Fission***

Big nucleus splits into smaller pieces

(Nuclear power plants)

***Fusion***

Small nuclei stick together to make a bigger one

(Sun, stars)

High temperature enables nuclear fusion to happen in the core

Sun releases energy by fusing four hydrogen nuclei into one helium nucleus



***IN***

4 protons

***OUT***

$^4$He nucleus
2 gamma rays
2 positrons
2 neutrinos

***Total mass is 0.7% lower***

## How does the energy from fusion get out of the Sun?

Energy gradually leaks out of radiation zone in form of randomly bouncing photons



## *We learn about inside of Sun by …*

- Making mathematical models
- Observing solar vibrations
- Observing solar neutrinos



Patterns of vibration on surface tell us about what Sun is like inside

Data on solar vibrations agree very well with mathematical models of solar interior

Neutrinos created during fusion fly directly through the Sun

Observations of these solar neutrinos can tell us what's happening in core

***Solar neutrino problem:***

Early searches for solar neutrinos failed to find the predicted number

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Early searches for solar neutrinos failed to find the predicted number

More recent observations find the right number of neutrinos, but some have changed form



## What have we learned?

- How does nuclear fusion occur in the Sun?
  - The core's extreme temperature and density are just right for nuclear fusion of hydrogen to helium through the proton-proton chain
  - Gravitational equilibrium acts as a thermostat to regulate the core temperature because fusion rate is very sensitive to temperature



## What have we learned?

- How does the energy from fusion get out of the Sun?
  - Randomly bouncing photons carry it through the radiation zone
  - Rising of hot plasma carries energy through the convection zone to photosphere
- How do we know what is happening inside the Sun?
  - Mathematical models agree with observations of solar vibrations and solar neutrinos

## 14.3 The Sun-Earth Connection

Our goals for learning:

- What causes solar activity?
- How does solar activity affect humans?
- How does solar activity vary with time?



## *Solar activity is like "weather"*

- Sunspots
- Solar Flares
- Solar Prominences

All are related to magnetic fields



***Sunspots***

Are cooler than other parts of the Sun's surface (4000 K)

Are regions with strong magnetic fields

***Zeeman Effect***

We can measure magnetic fields in sunspots by observing the splitting of spectral lines

Magnetic activity causes ***solar flares*** that send bursts of X-rays and charged particles into space

Magnetic activity also causes ***solar prominences*** that erupt high above the Sun's surface



***Coronal mass ejections*** send bursts of energetic charged particles out through the solar system

Charged particles streaming from Sun can disrupt electrical power grids and can disable communications satellites

Sunspot cycle has something to do with winding and twisting of Sun's magnetic field



## What have we learned?

- What causes solar activity?
  - Stretching and twisting of magnetic field lines near the Sun's surface causes solar activity
- How does solar activity affect humans?
  - Bursts of charged particles from the Sun can disrupt communications, satellites, and electrical power generation
- How does solar activity vary with time?
  - Activity rises and falls with an 11-year period