# Astronomy

Second Semester

Weeks 8 – 9

# Monday (2/23)

- Test Review

- T: **(10) Science concepts. The student knows how astronomical tools collect and record information about celestial objects. The student is expected to:**
- **10A** investigate the use of black body radiation curves and emission, absorption, and continuous spectra in the identification and classification of celestial objects;
- O: I will be able to demonstrate my understanding of light
- D: by going over doppler and blueshift and then taking a test on light.
- A: doppler, blueshift, light, wavelength, frequency
- Y: What determines a shift in light?

# Tuesday / Wednesday (2/24 & 25)

- Shutdown Days

# Thursday (2/26)

- Test Review

- T: **(10) Science concepts. The student knows how astronomical tools collect and record information about celestial objects. The student is expected to:**
- **10A** investigate the use of black body radiation curves and emission, absorption, and continuous spectra in the identification and classification of celestial objects;
- O: I will be able to demonstrate my understanding of light
- D: by going over doppler and blueshift and then taking a test on light.
- A: doppler, blueshift, light, wavelength, frequency
- Y: What determines a shift in light?

# Launch

- “Don’t bunt. Aim out of the ballpark. Aim for the company of immortals.” —David Ogilvy

# Monday / Tuesday (3/2 & 3)

- Unit 7 Test (Light)

- T: **(10) Science concepts. The student knows how astronomical tools collect and record information about celestial objects. The student is expected to:**
- **10A** investigate the use of black body radiation curves and emission, absorption, and continuous spectra in the identification and classification of celestial objects;
- O: I will be able to demonstrate my understanding of light
- D: by going over doppler and blueshift and then taking a test on light.
- A: doppler, blueshift, light, wavelength, frequency
- Y: What determines a shift in light?

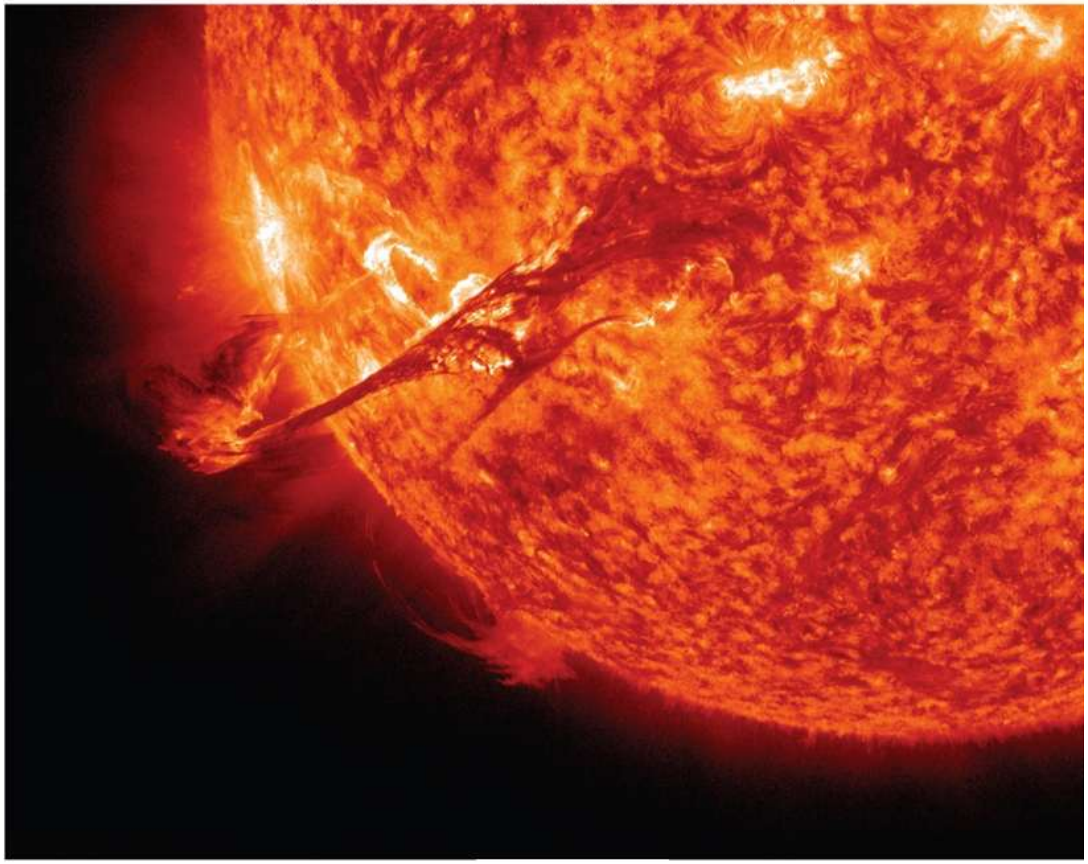
# Wednesday / Thursday (March 4 & 5)

- Begin Unit 8:  The Sun

- T: **(12) Science concepts. The student knows that our Sun serves as a model for stellar activity. The student is expected to:**
  - **12A** identify the approximate mass, size, motion, temperature, structure, and composition of the Sun;
- O: I will begin to learn about the sun
- D: by drawing a diagram, taking notes, and completing a close read.
- A: sun, photosphere, convection zone, radiative zone
- Y: How are the different layers of the sun arranged?

# The Sun, Our Star







- NASA/GSFC/SDO

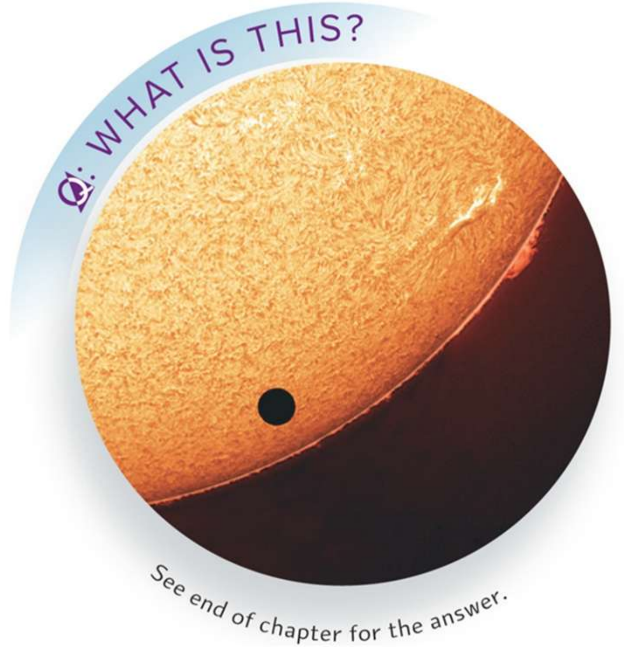
# The Sun

- The Sun is a star, a luminous ball of gas more than 100 times bigger than Earth.
- Although seemingly quiescent from a naked eye view, telescopic observations reveal a bevy of violent activity – fountains of incandescent gas and twisting magnetic fields.
- The Sun’s core is equally violent with a furnace of thermonuclear fire converting hydrogen into helium to the tune of an energy production equivalent to the detonation of 100 nuclear bombs.
- The force of gravity keeps the Sun in check – for now.

# Radius and Mass

- With a radius 100 × and a mass of 300,000 × that of Earth, the Sun must expend a large amount of energy to withstand its own self-gravity.

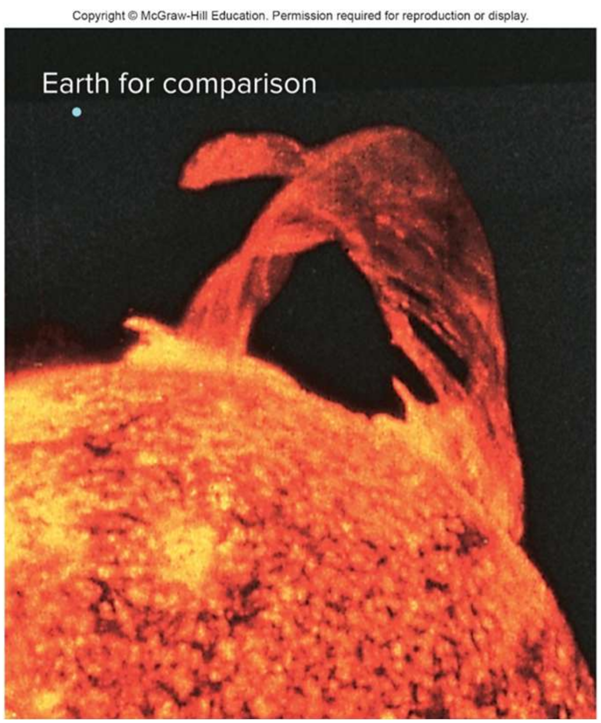







- © Stefan Seip/www.astromeeting.de

# Properties of the Sun




- The Sun's distance from Earth (about 150 million km or 1 AU) was once measured by triangulation, but is now done by radar.
- Once the distance is known, its diameter (about 1.4 million km) can be found from its angular size (about $\frac{1}{2}$ degree).

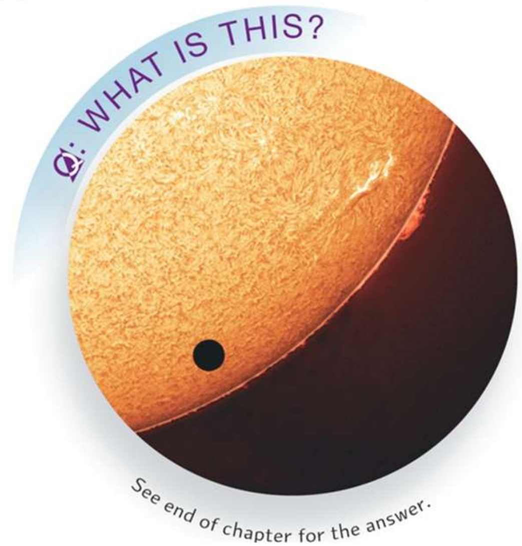


- NASA

# Mass and Temperature

- From the Sun's distance and Earth's orbital period, Kepler's modified third law gives the Sun's mass.
- From the mass and radius, the surface gravity of the Sun is found to be 30 × that of Earth.
- Next, the surface temperature (5780 K) is found from the Sun's color and the use of Wien's law for a blackbody.

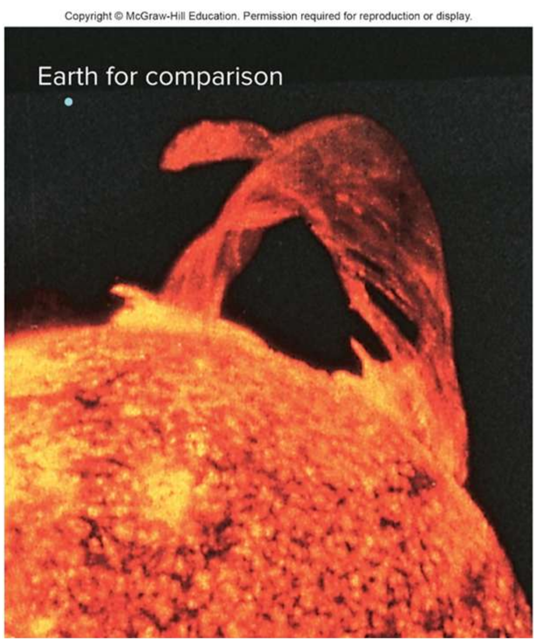







- Courtesy Stefan Seip/www.astromeeting.de

# Composition and Structure



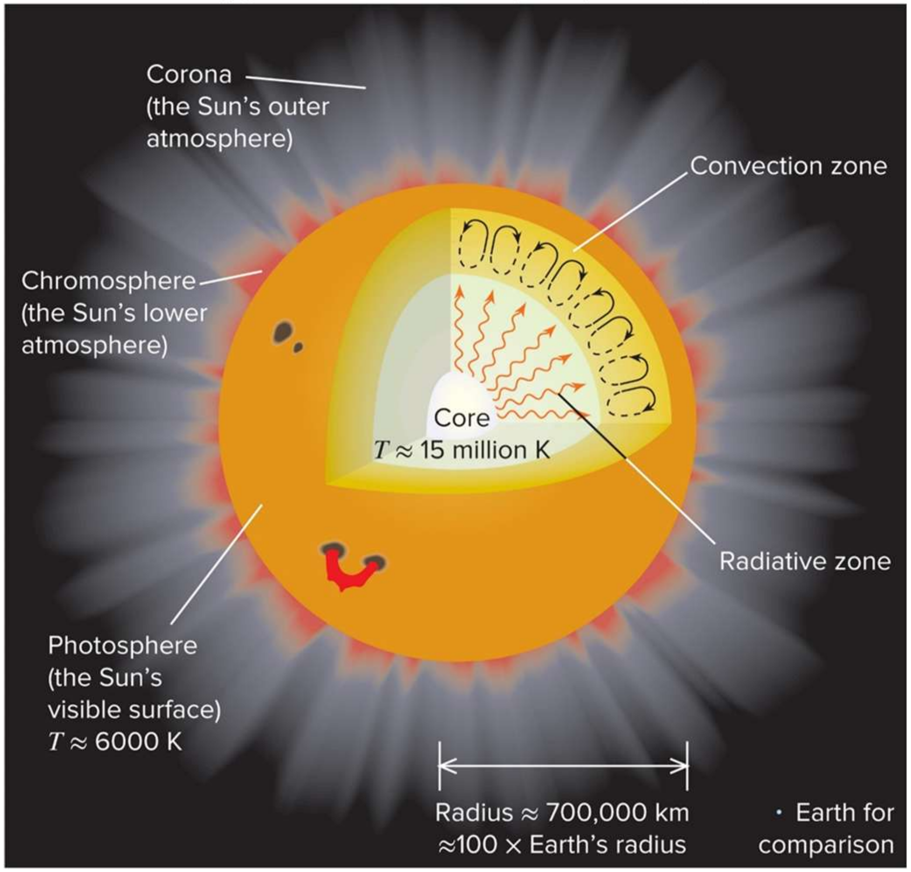

- Theoretical considerations then establish the Sun as gaseous throughout with a core temperature of 15 million K.
- From the amount of solar energy that reaches Earth $(4 \times 10^{26}$ watts), this energy must be replenished by fusion processes in its core.
- The Sun has plenty of hydrogen for fusion: its surface spectra shows hydrogen is 71% and 27% helium.



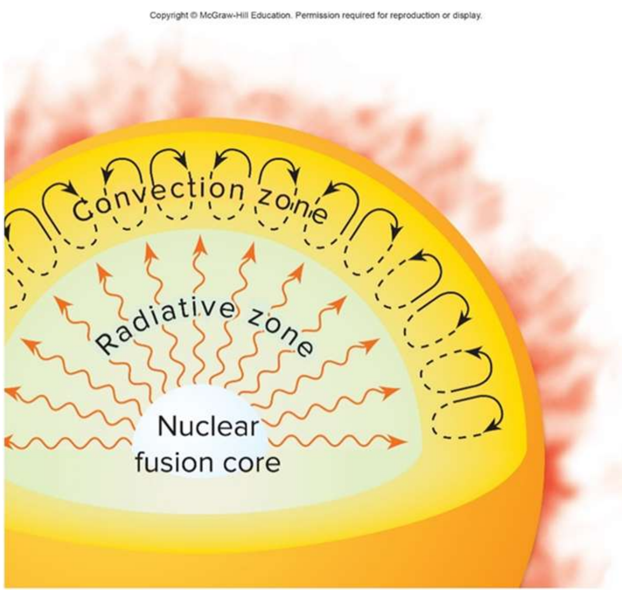
- NASA

# The Structure of the Sun



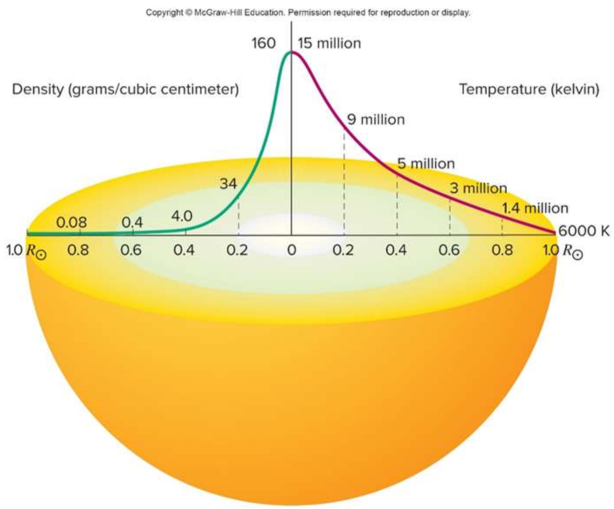


# The Solar Interior




- The low density upper layers of the Sun, where any photons created there can freely escape into space is called the ***photosphere.***
- The photosphere is the Sun's "surface."
- Layers below the photosphere are opaque, photons created there are readily absorbed by atoms located there, helping deeper layers retain heat.

# Temperature and Density Changes



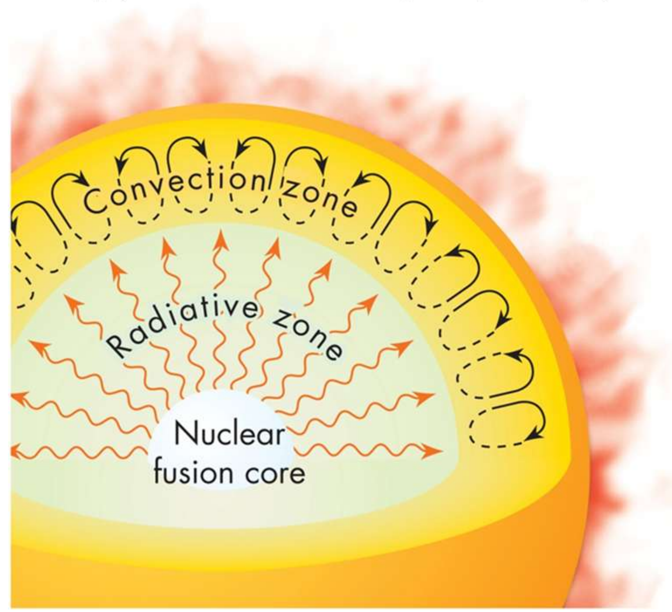

- Theoretical calculations show that the Sun’s surface temperature and density both increase as the core is approached.

- The density is similar to that found at sea level on Earth at the Sun’s surface and 100 × that of water at the core.

# The Radiative Zone

- Since the core is hotter than the surface, heat will flow outward from the Sun’s center.
- Near the Sun’s center, energy is moved outward by photon radiation – a region surrounding the core known as the ***radiative zone.***

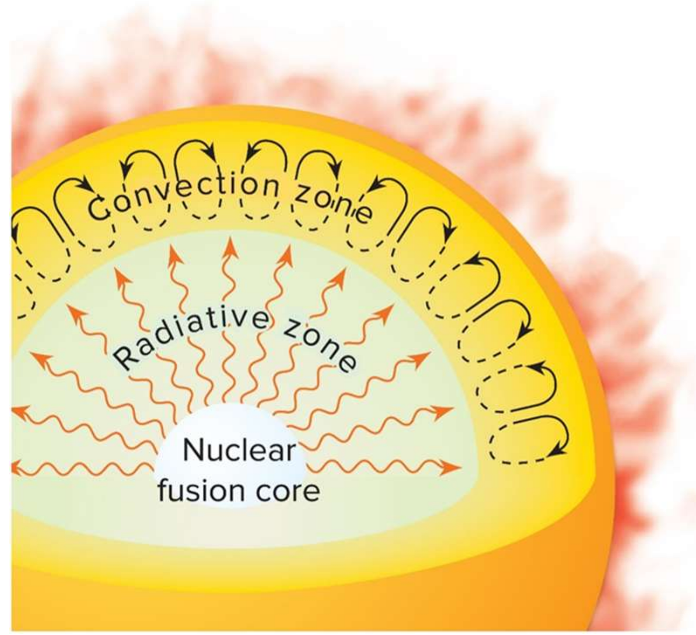




# Very Old Light

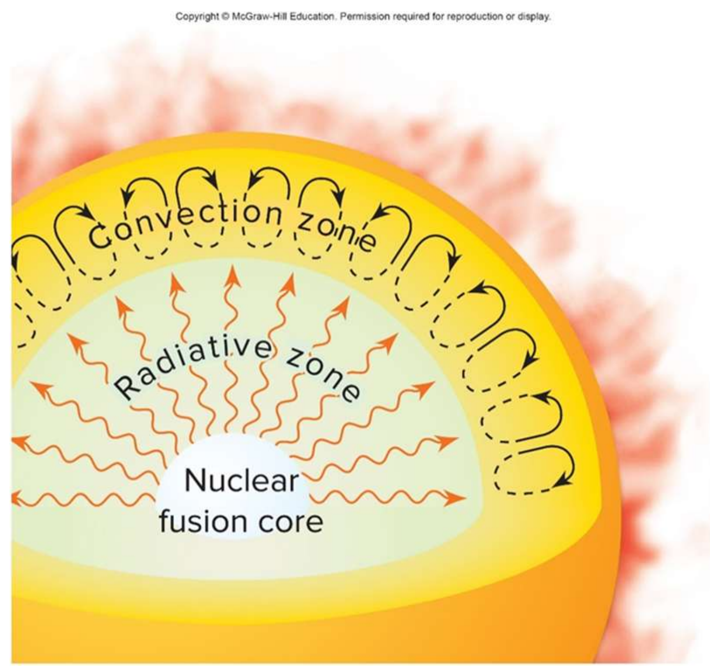
- Photons created in the Sun's interior do not travel very far before being reabsorbed – energy created in the Sun's center will take about 16 million years to eventually diffuse to the surface!





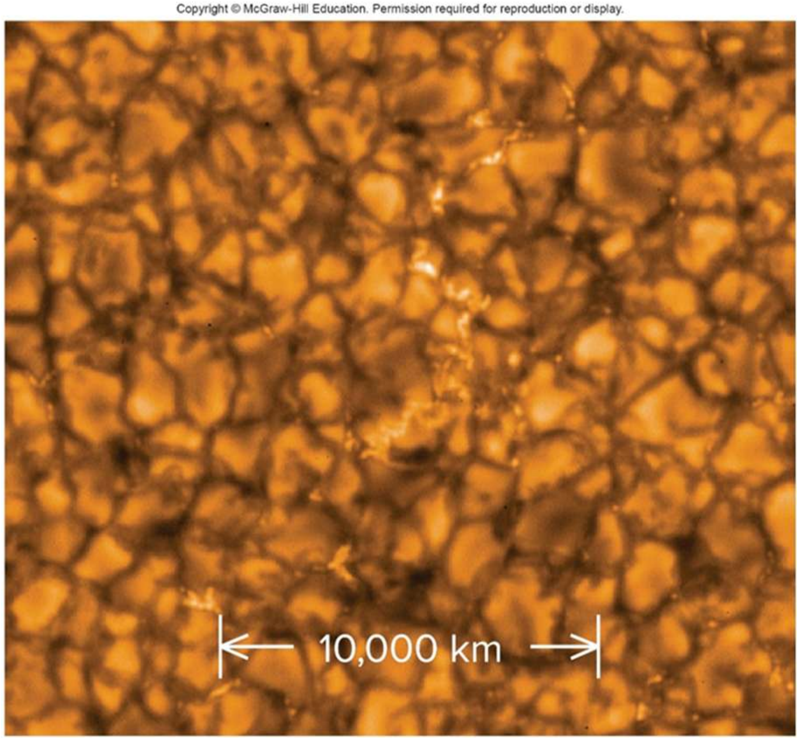
# The Convection Zone

- Above the radiative zone, energy is more efficiently transported by the rising and sinking of gas – this is the ***convection zone.***
- Heated material rises to the surface, cools, and sinks back down.



# Granulation





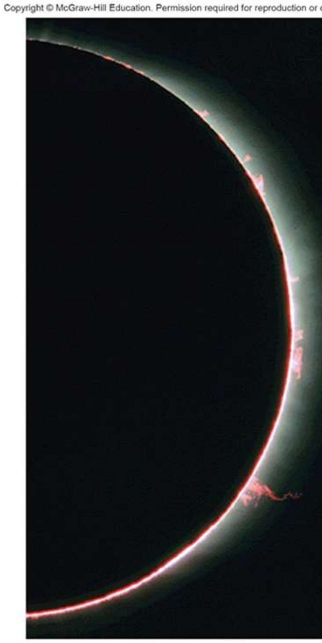

- Convection manifests itself in the photosphere as ***granulation,*** numerous bright regions surrounded by narrow dark zones.



- Hinode JAXA/NASA/PPARC

# The Sun’s Atmosphere





- The extremely low-density gases that lie above the photosphere make up the Sun’s atmosphere.



- Courtesy of Jacques Guertin, Ph.D

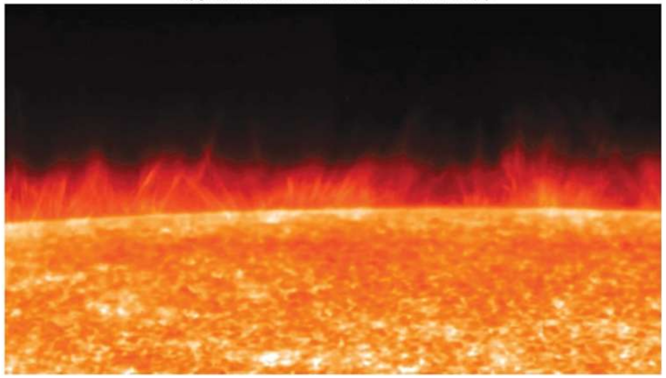
# Temperature Profile

- The density of the atmosphere decreases steadily with altitude and eventually merges with the near-vacuum of space.
- Immediately above the photosphere, the temperature of the atmosphere decreases but at higher altitudes, the temperature grows hotter, reaching temperatures of several million Kelvin.
- The reason for the increase in temperature is unknown, but speculation is that Sun’s magnetic field plays an important role.

# The Chromosphere

- The lower part of the atmosphere is referred to as the ***chromosphere.***
- The chromosphere appears as a thin red zone around the dark disk of a totally eclipsed Sun.
- The red is caused by the strong red emission line of hydrogen Ha.
- The chromosphere contains millions of thin columns called ***spicules,*** each a jet of hot gas.





- NASA/JAXA/Hinode

# The Corona



- Temperature in the corona eventually reaches about 1 million K (not much energy though due to low density).
- The corona, visible in a total solar eclipse, can be seen to reach altitudes of several solar radii.
- The corona is not uniform but has streamers and *coronal holes* dictated by the Sun's magnetic field.



- Courtesy of 1988 eclipse image/High Altitude Observatory (HAO)/University Corporation for Atmospheric Research (UCAR)/Boulder. Colorado, UCAR is sponsored by the National Science Foundation

# Friday (March 6)

- C-day

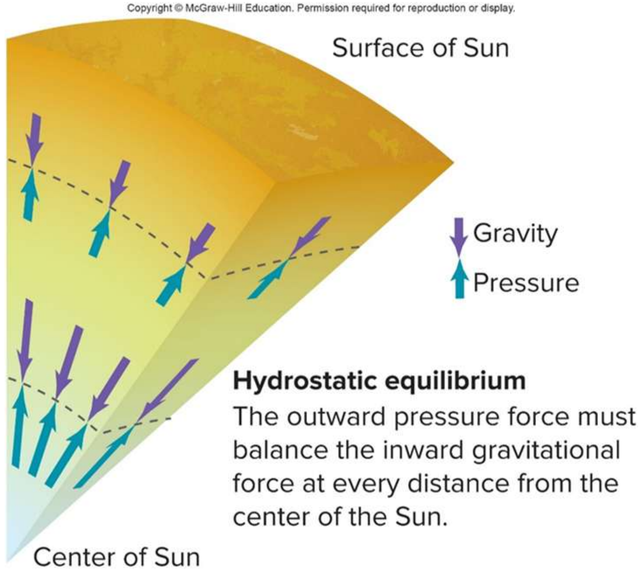
# Monday / Tuesday (March 9 & 10)

- T: **12B** distinguish between nuclear fusion and nuclear fission and identify the source of energy within the Sun as nuclear fusion of hydrogen to helium;
- O: I will be able to understand how the sun produces energy
- D: by taking notes, participating in class discussion, and completing a Discovery Ed and an Actively Learn
- A: fission, fusion, pressure, neutrinos
- Y: What reaction does the sun undergo to produce energy?

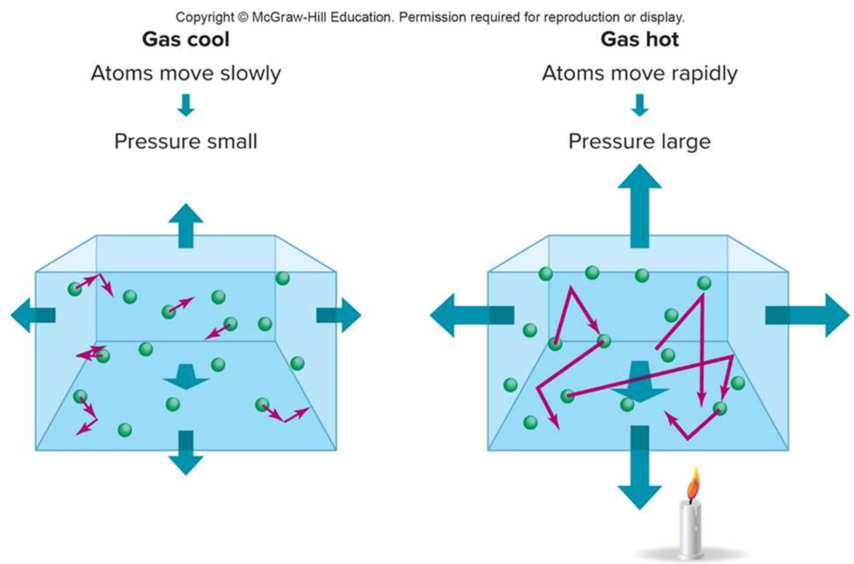
# How the Sun Works

- Structure of the Sun depends on a balance between its internal forces – specifically, a hydrostatic equilibrium between a force that prevents the Sun from collapsing and a force that holds it together.
- The inward (holding) force is the Sun's own gravity, while the outward (non-collapsing) force arises from the Sun's internal gas pressure.
- Without balance the Sun would rapidly change!





# Pressure in the Sun




- ***Pressure*** in a gas comes from atomic collisions.
- The amount of pressure is in direct proportion to the speed of the atoms and their density and is expressed in the ***perfect*** or ***ideal gas law.***

# Powering the Sun

- Given that the Sun loses energy as sunshine, an internal energy source must be present to maintain hydrostatic equilibrium.
- If the Sun were made of pure coal, the Sun would last only a few thousand years.
- If the Sun were not in equilibrium, but creating light energy from gravitational energy (the Sun is collapsing), the Sun could last 10 million years.
- These and many other chemical-based sources of energy are not adequate to account for the Sun's several billion year age.

# E = mc Squared

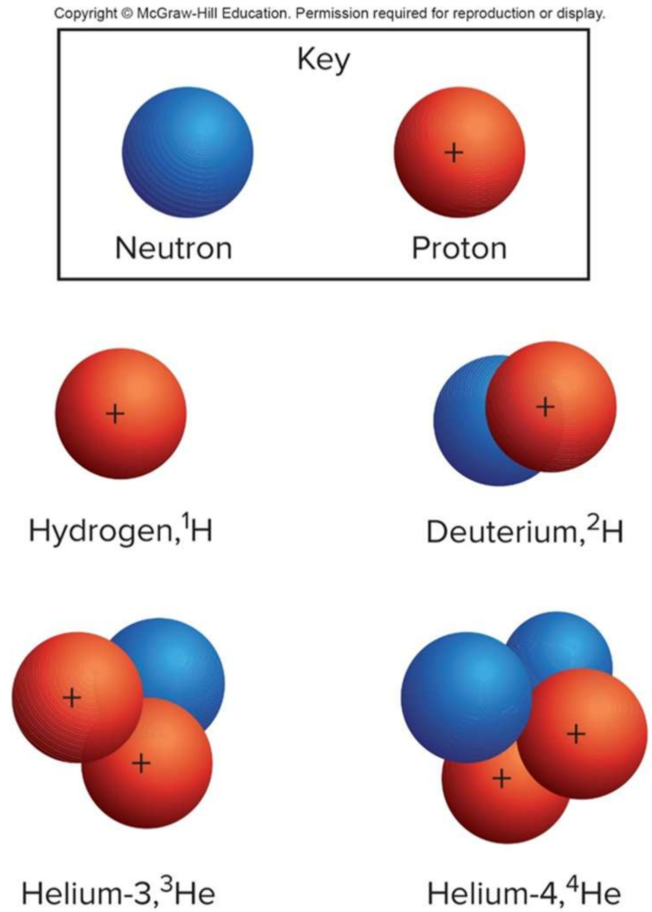
- Mass-energy is the key
- In 1905, Einstein showed that energy and mass were equivalent through his famous $E = mc^2$ equation.
- 1 gram of mass is equivalent to the energy of a small nuclear weapon.
- The trick is finding a process to convert mass into other forms of energy.

# Nuclear Fusion

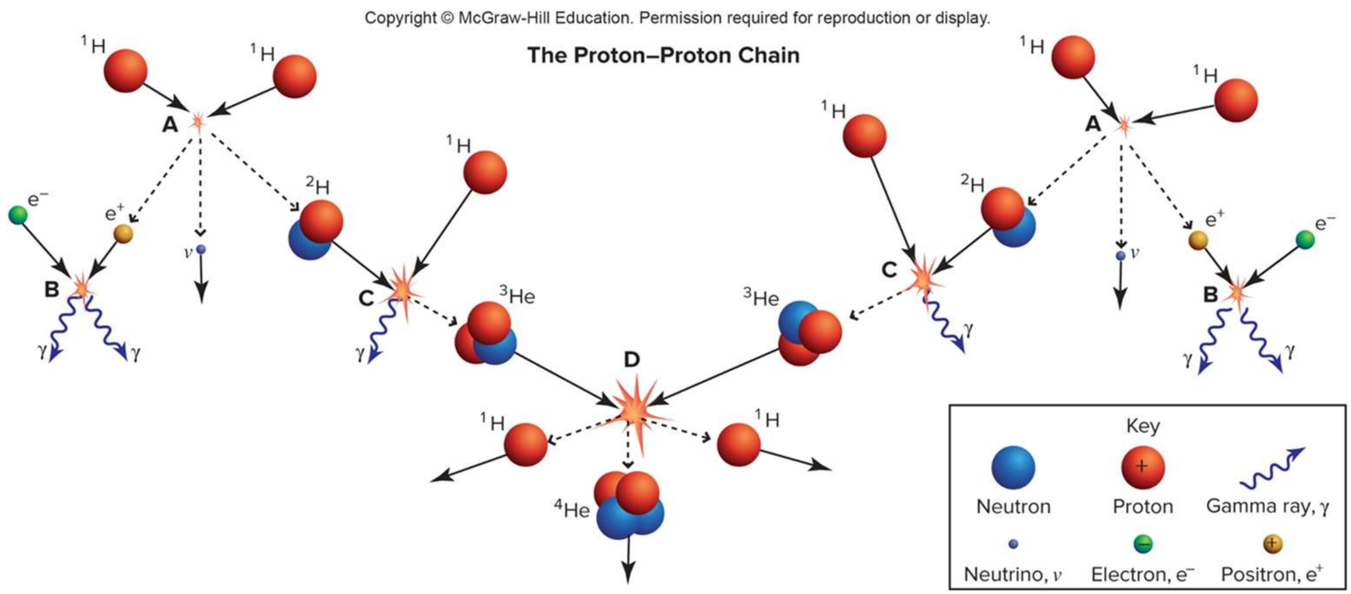
- A detailed process for mass conversion in the Sun called ***nuclear fusion*** was found:
- Sun's core temperature is high enough to force positively charged protons close enough together to bind them together via the ***nuclear*** or ***strong force.***
- The net effect is that four protons are converted into a helium nucleus (plus other particles and energy) in a three-step process called the ***proton-proton chain.***

# Isotopes

- In the proton-proton cycle, isotopes are intermediate steps between protons and their ultimate fusion into $^4He$.

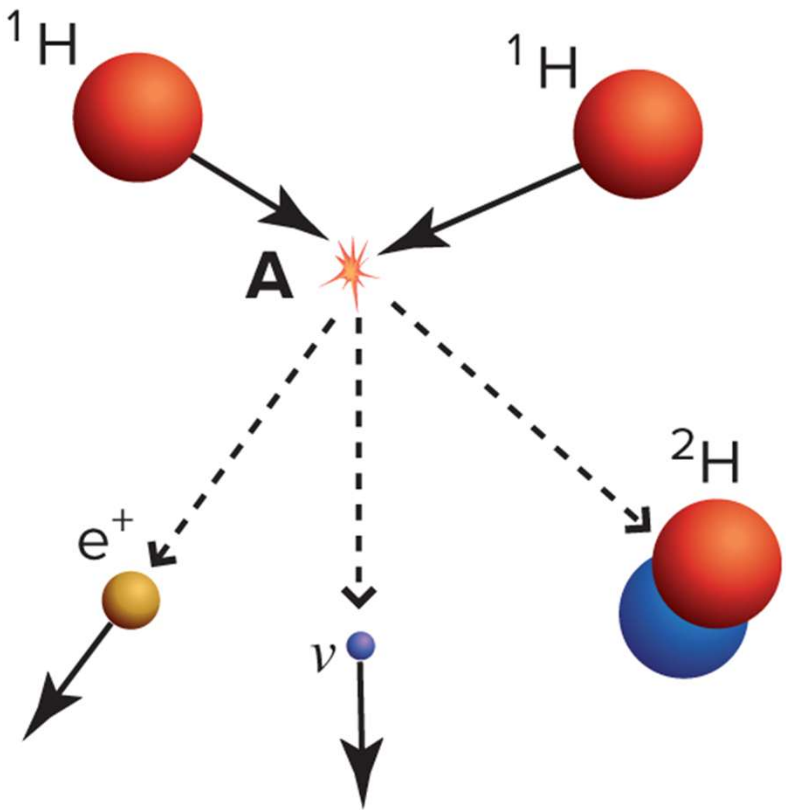


# The Proton-Proton Chain



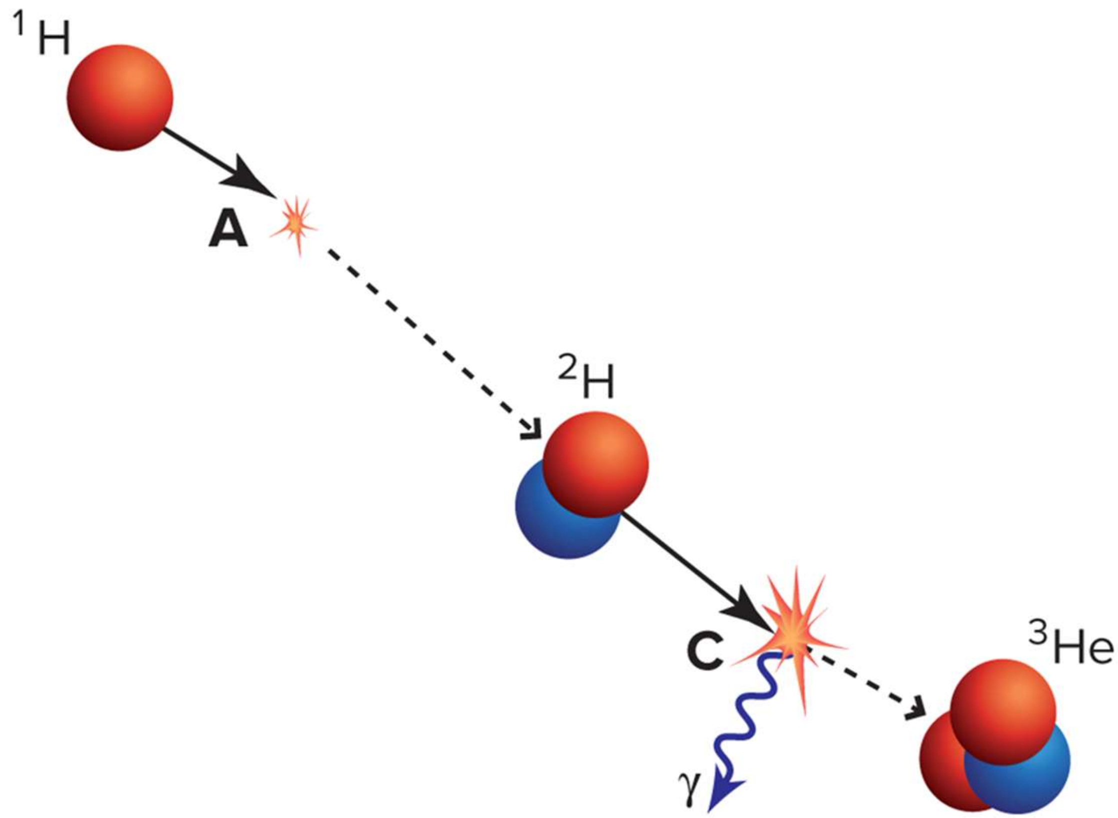
# The Proton-Proton Chain: Step 1





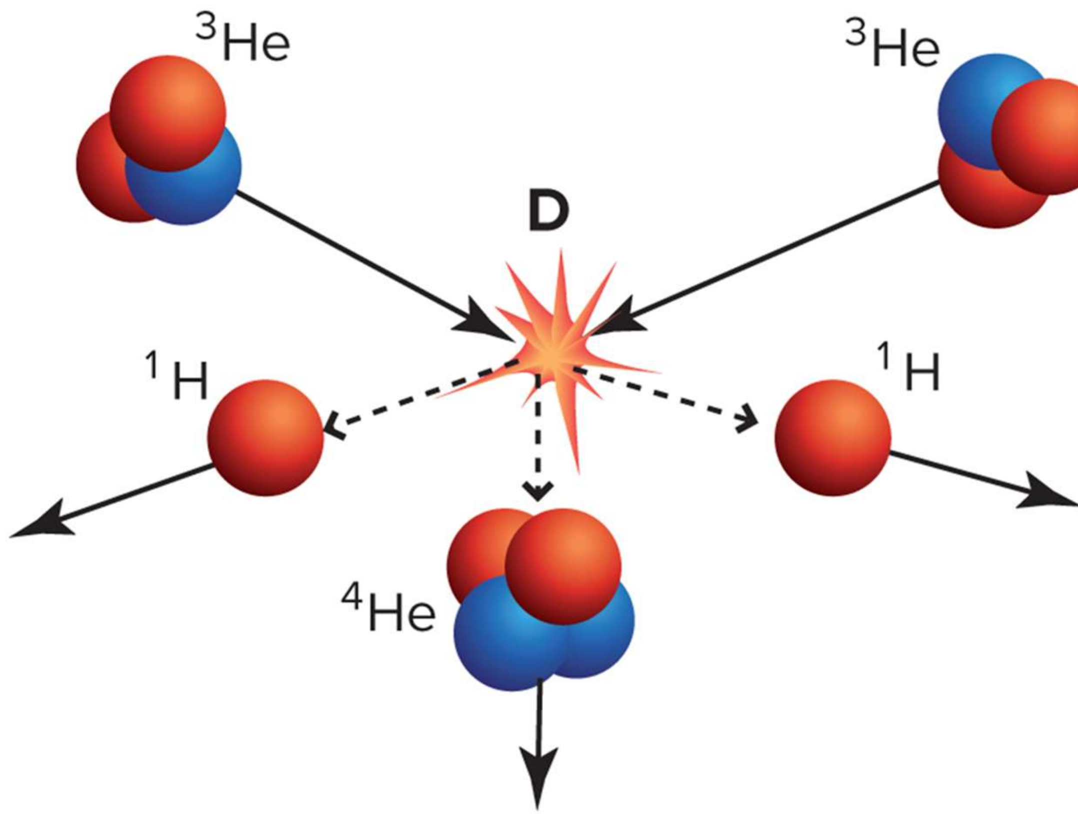
# The Proton-Proton Chain: Step 2





# The Proton-Proton Chain: Step 3

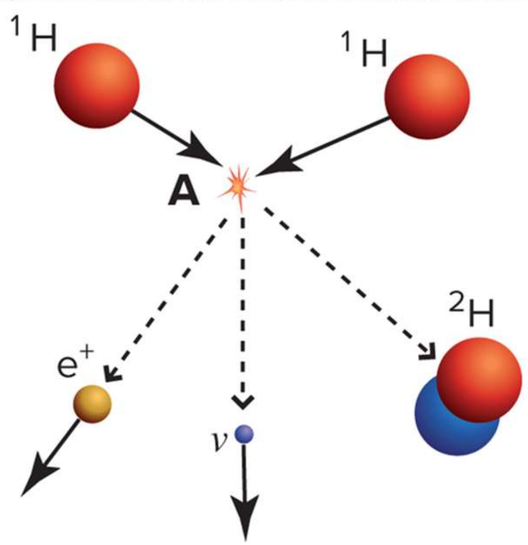




# Solar Neutrinos

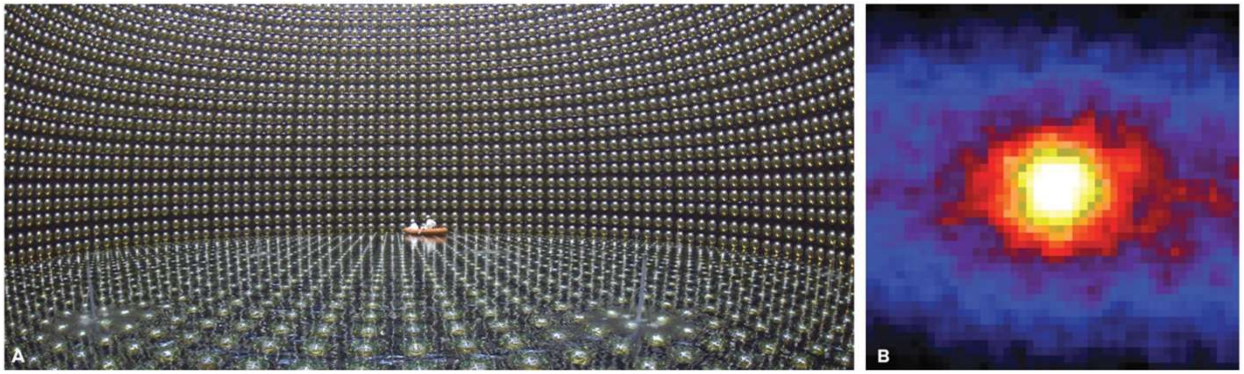
- The nuclear fusion process in the Sun's core creates neutrinos.
- ***Neutrinos*** lack electric charge, have a very small mass, escape the Sun's interior relatively unaffected, and shower Earth (about 1 trillion pass through a human per second).
- Infrequently, a neutrino interacts with matter and can be detected.





# Difficult to Detect






- A neutrino's low reactivity with other forms of matter requires special detection arrangements.
- Detectors buried deep in the ground to prevent spurious signals as those produced by ***cosmic rays*** (high energy particles, like protons and electrons, with their source beyond the Solar System).
- Large tanks of water and special light detectors.



- A: © kamioka Observatory, ICRR (Institute of Cosmic Ray Research), The University of Tokyo; b:Super-kamaikande Collaboration (courtesy of R.Svoboda)

# The Neutrino Crisis

- Detected neutrinos are about three times less than predicted – possible reasons:
- Model of solar interior could be wrong.
- Neutrinos have properties that are not well understood.
- Fusion reactions in the sun only produce electron neutrinos, but there are two other types: muon neutrinos and tau neutrinos.
- Subsequent observations with new detectors found all three types of neutrinos. Is our understanding of solar fusion wrong?
- No! It turns out that neutrinos can morph between types, if they have mass. Electron neutrinos from the sun become the other two types on their way to Earth.

# Solar Seismology

- Solar seismology is the study of the Sun's interior by analyzing wave motions on the Sun's surface and atmosphere.
- The wave motion can be detected by the Doppler shift of the moving material.
- The detected wave motion gives temperature and density profiles deep in the Sun's interior.
- These profiles are independent confirmation of current solar models.
- Determined the helium fraction in the core—implies the sun is about halfway through its H.
- Helped solve neutrino problem.