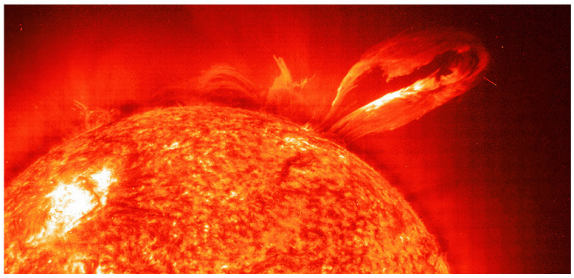
Chapter 14
Our Star

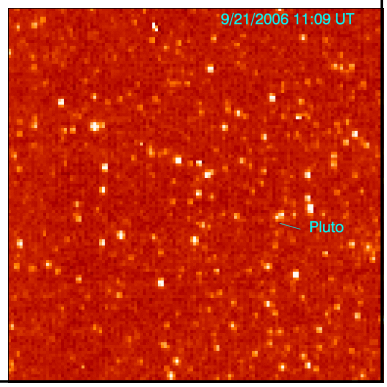


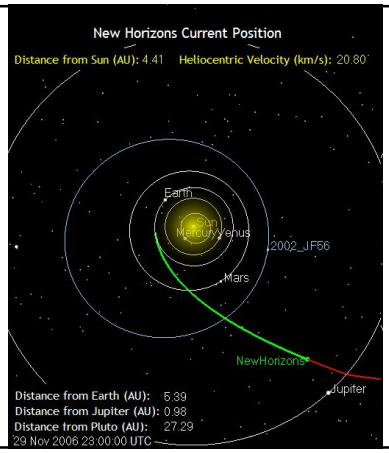
Agenda

- Announce:
  - Observations next Tue/Thurs—Time & Location
  - Remaining Quizzes now "Assigned" Online
  - Reminder: Project Presentations next week
- Trip to Pluto
- Muslims in space
- Review Ch. S4
- Ch. 14—Our Sun (last chapter)
- Extra Credit Presentations:
  - Katherine
  - Alissa…
- Evaluations
- Parallax lab

Visit to Pluto?

- New Horizons launched January, 2006
- Will fly by Pluto in 2015
- Cameras have spotted Pluto:





"The Determination of Prayer Times and Direction of the Qiblah in Space," by Dr. Zainol Abidin Abdul Rashid

A Muslim who wants to travel must study the techniques of determining prayer times and the direction of the Qibla ahead of travel in order to achieve complete worship. I will elaborate the method of determining prayer times and the Qiblah direction in space, primarily on the International Space Station (ISS). The ISS is more than 200 miles from the earth's surface and orbits the earth every ninety-two minutes, or roughly sixteen times a day. Do we have to worship eighty times a day (sixteen orbits a day multiplied by five prayer times?) This seems unlikely, since it is compulsory for a Muslim to pray five times a day according to an Earth day, as determined by Allah during the creation of Heaven and Earth - no matter where in space the Muslim is located.

As for the Qiblah, for Muslims there is only one the Kaaba, located in Mecca. A Qiblah that changes in references to a specific system is not in order! It must be remembered that Allah's creation is ordered.

A user-friendly, portable Muslims in Space calculator , could determine the direction of the Qiblah and prayer times on the ISS. Its essential feature would be the use of the Projected Earth and Qiblah Pole concepts. These are based on the interpretation of the holy house of angels in the sky above Mecca. The place is always rich with angels worshipping. As many as 70,000 angels circumambulate it every day.

That hot gasses emit emission lines

- tells us that different wavelengths of light carry different amounts of energy
- gives direct evidence that the orbits of electrons in atoms are quantized
- doesn't really tell us about atoms or electrons because we can't see them – we can only see the light

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- Particles from which all other particles are built
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- They would turn completely into matter or antimatter
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- They annihilate and release energy = mc^2
- They disappear but then reappear due to *pair production*

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- Four
- Eight
- None of the above

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The uncertainty principle says

- You can't know the position and momentum (motion) of a particle with complete precision
- You can't know the energy at a certain time of a particle with complete precision
- You could only know #1 or #2 with a very clever experiment
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One way to determine the position of an electron is to shine some light (a photon) on it

- Yes, but the energy of the photon will disturb the position of the electron
- If you use a low-energy photon (infrared, say) you could determine the position without disturbing the momentum much

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Two *fermions* (such as electrons, protons, neutrons)

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- Can't be in the same quantum state
- All of the above
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Quantum tunneling

- means that particles can be where they are not expected, but we can't be sure
- means that there is some probability that particles can travel into a region that they could not reach according to classical physics
- plays a key role in the nuclear reactions that power the sun
- All of the above
- All except #1

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Virtual particles

- come into and out of existence very fast
- come about due to the uncertainty principle
- allow some radiation to come from black holes
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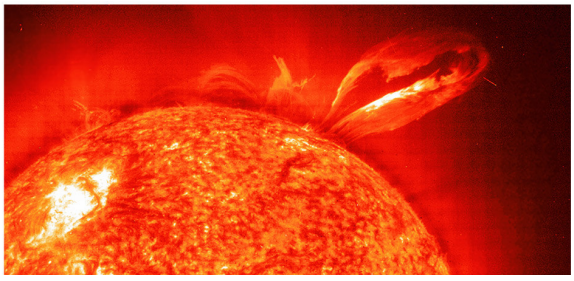
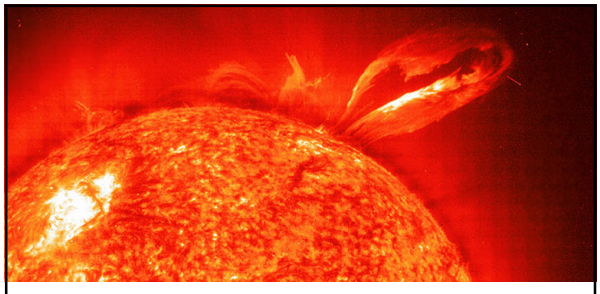
- **All of the above**
- All except #3

14.1 A Closer Look at the Sun

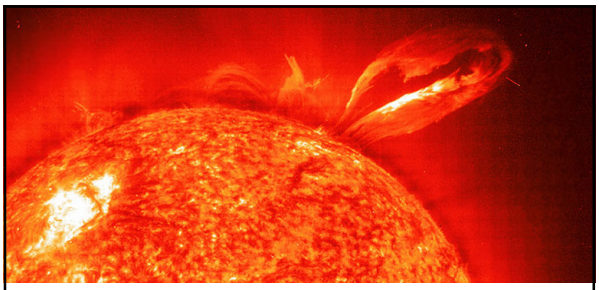
- Our goals for learning
- Why was the Sun's energy source a major mystery?
- Why does the Sun shine?
- What is the Sun's structure?

Why was the Sun's energy source a major mystery?



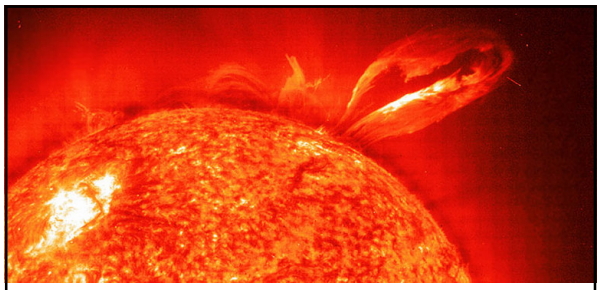


Is it on FIRE?



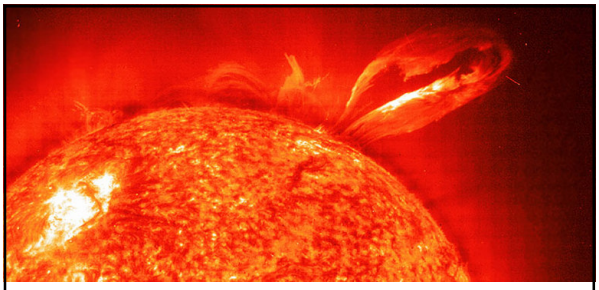
Is it on FIRE?

$$\frac{\text{Chemical Energy Content}}{\text{Luminosity}} \sim 10{,}000 \text{ years}$$

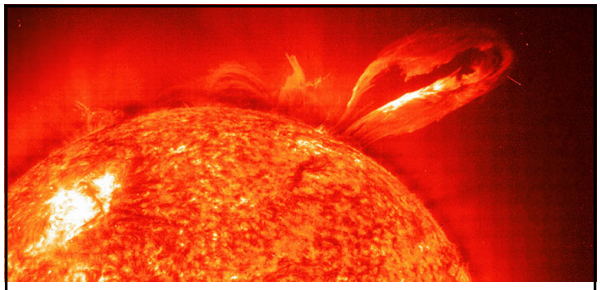


Is it on FIRE? … NO!

$$\frac{\text{Chemical Energy Content}}{\text{Luminosity}} \sim 10{,}000 \text{ years}$$

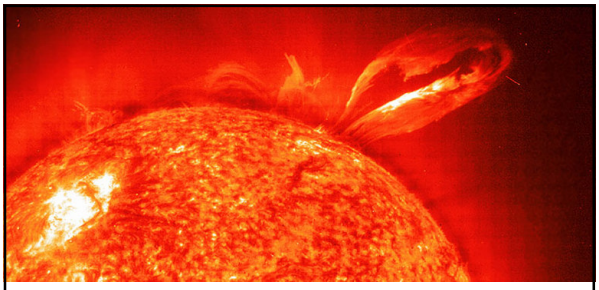


Is it CONTRACTING?



Is it CONTRACTING?

$$\frac{\text{Gravitational Potential Energy}}{\text{Luminosity}} \sim 25 \text{ million years}$$



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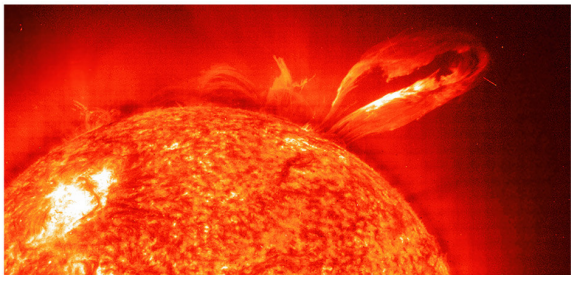
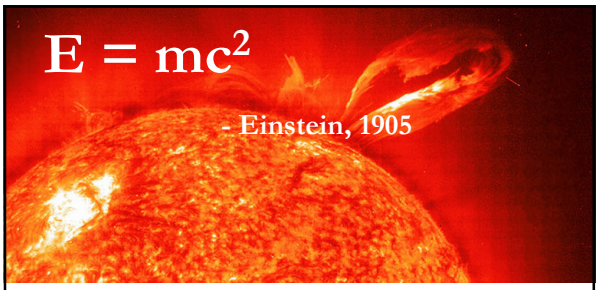
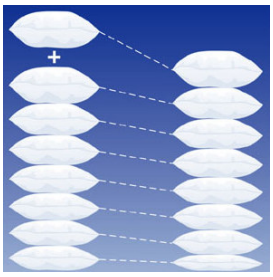
Why does the Sun shine?



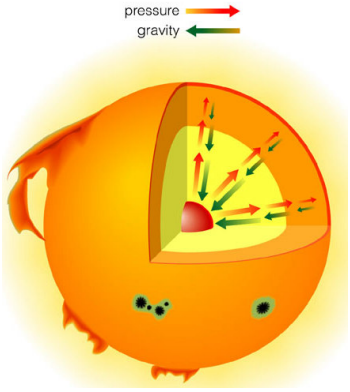


It can be powered by NUCLEAR ENERGY!

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

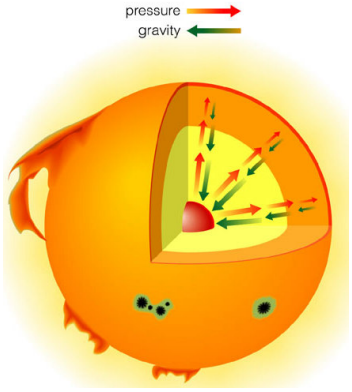


Weight of upper layers compresses lower layers



Gravitational equilibrium:

Energy provided by fusion maintains the pressure

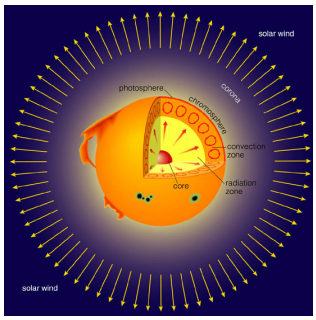


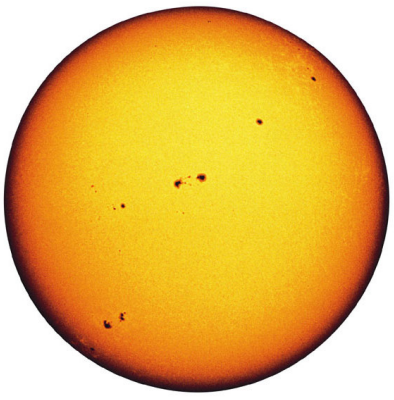
Gravitational contraction:

Provided energy that heated core as Sun was forming

Contraction stopped when fusion began

What is the Sun's structure?

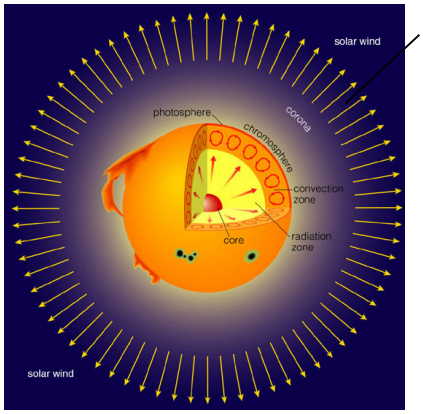




Radius:
6.9×10^8 m
(109 times Earth)

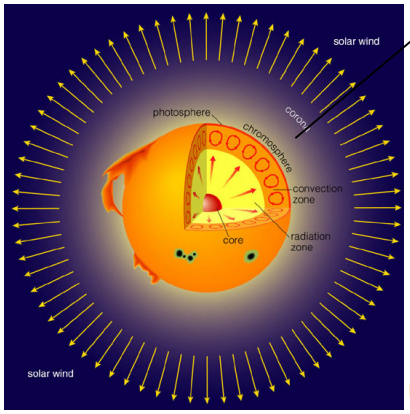
Mass:
2×10^{30} kg
(300,000 Earths)

Luminosity:
3.8×10^{26} watts



Solar wind:

A flow of charged particles from the surface of the Sun

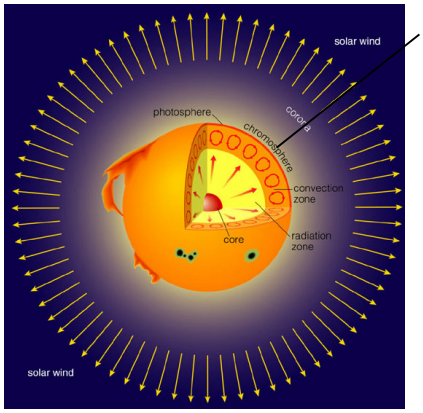


Corona:

Outermost layer of solar atmosphere

~1 million K

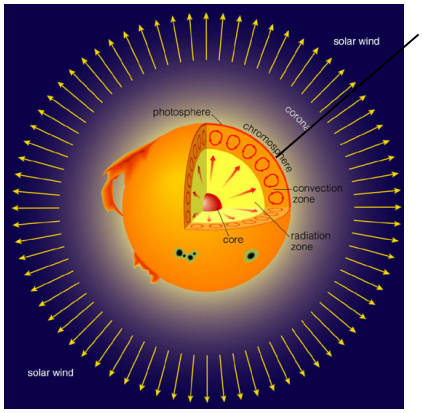
Interactive Figure



Chromosphere:

Middle layer of solar atmosphere

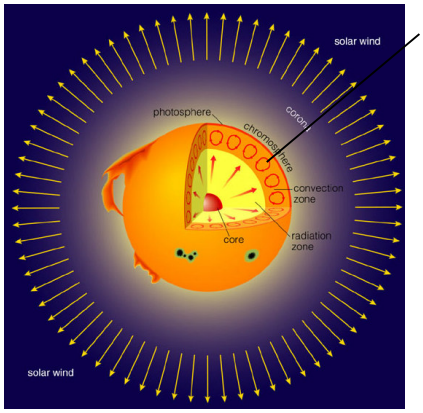
~ 10^4 - 10^5 K



Photosphere:

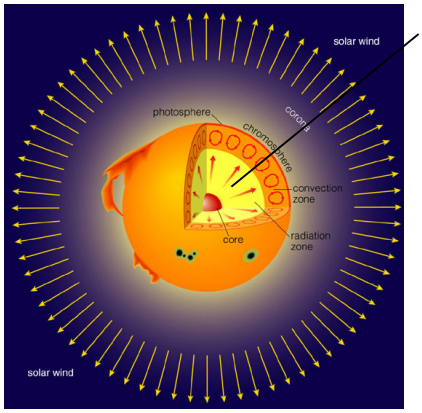
Visible surface of Sun

~ 6,000 K



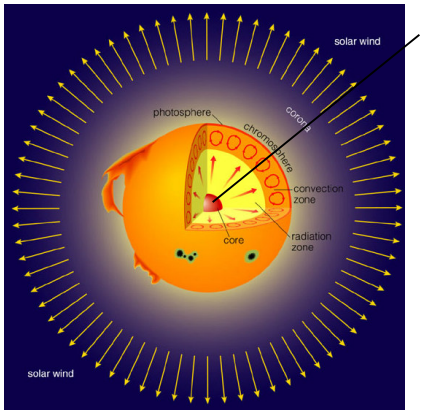
Convection Zone:

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.

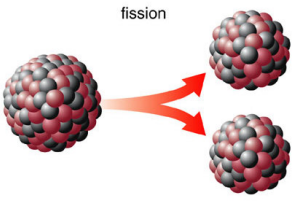
What have we learned?

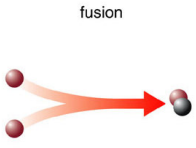
- What is the Sun's structure?
  - From inside out, the layers are:
    - Core
    - Radiation Zone
    - Convection Zone
    - Photosphere
    - Chromosphere
    - Corona

14.2 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?

How does nuclear fusion occur in the Sun?





Fission

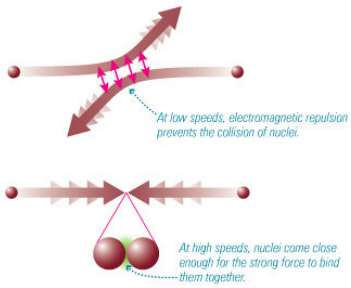
Big nucleus splits into smaller pieces

(Nuclear power plants)

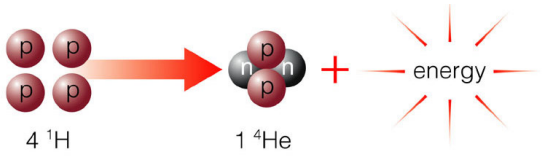
Fusion

Small nuclei stick together to make a bigger one

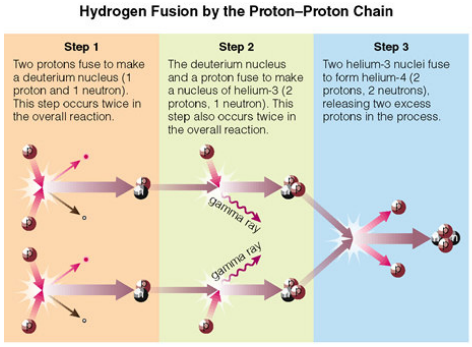
(Sun, stars)



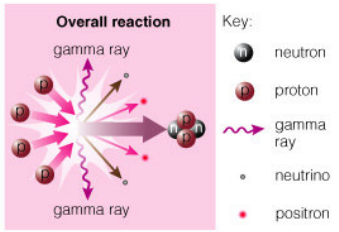
High temperature enables nuclear fusion to happen in the core



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



Proton-proton chain is how hydrogen fuses into helium in Sun



IN
4 protons

OUT
^{4}He nucleus
2 gamma rays
2 positrons
2 neutrinos

Total mass is 0.7% lower

Thought Question

What would happen inside the Sun if a slight rise in core temperature led to a rapid rise in fusion energy?

A. The core would expand and heat up slightly
B. The core would expand and cool
C. The Sun would blow up like a hydrogen bomb

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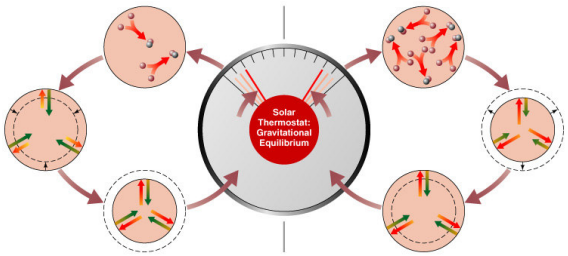
Solar thermostat keeps burning rate steady

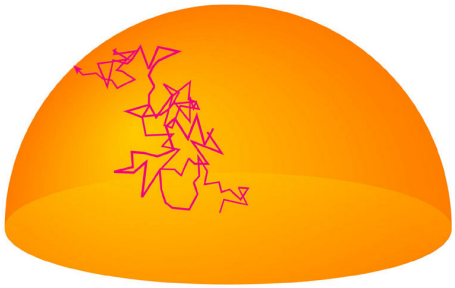
Solar Thermostat

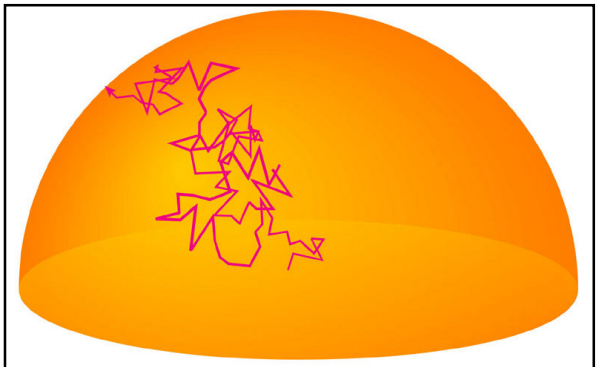


Decline in core temperature causes fusion rate to drop, so core contracts and heats up

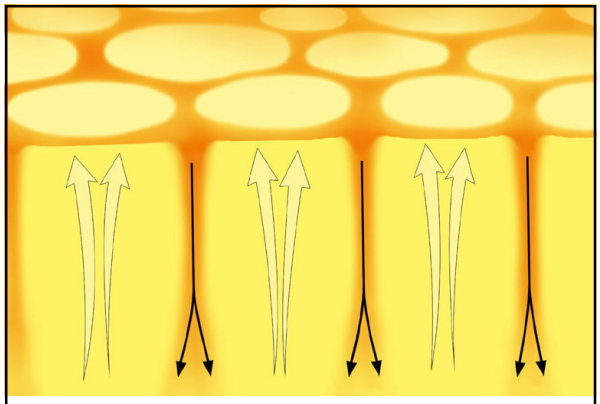
Rise in core temperature causes fusion rate to rise, so core expands and cools down

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

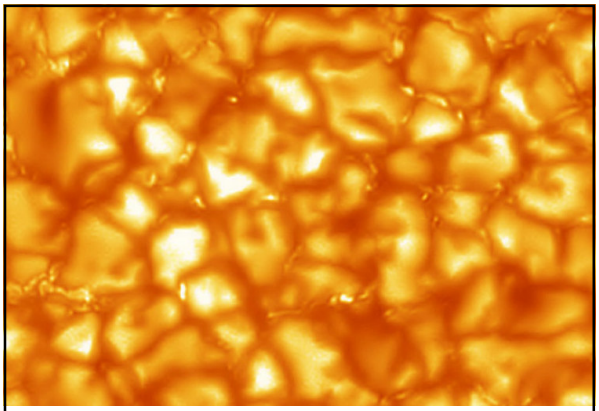




Energy gradually leaks out of radiation zone in form of randomly bouncing photons

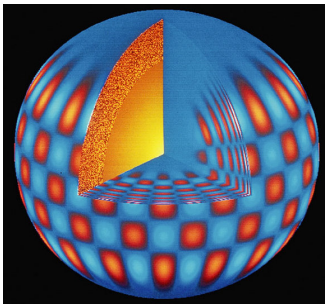


Convection (rising hot gas) takes energy to surface



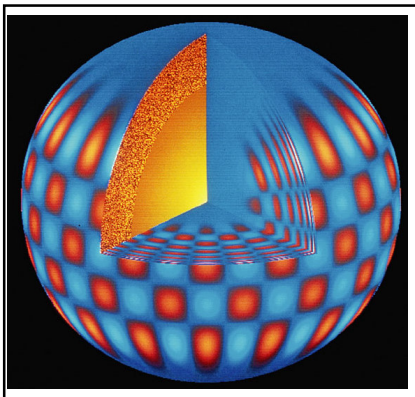
Bright blobs on photosphere are where hot gas is reaching surface

How we know what is happening inside the Sun?

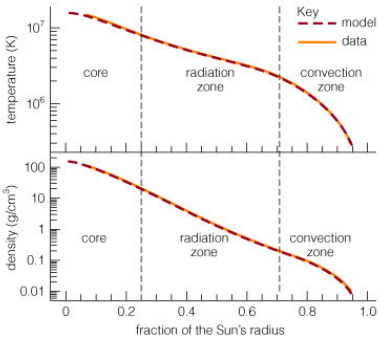


We learn about inside of Sun by …

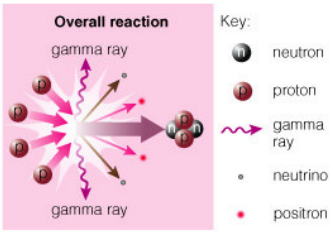
- Making mathematical models
- Observing solar vibrations
- Observing solar neutrinos



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

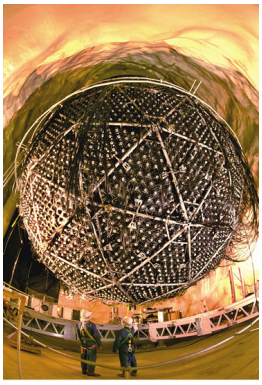


Neutrinos created during fusion fly directly through the Sun

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



Solar neutrino problem:

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

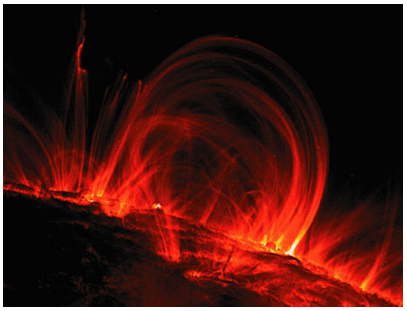
What have we learned?

- 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?

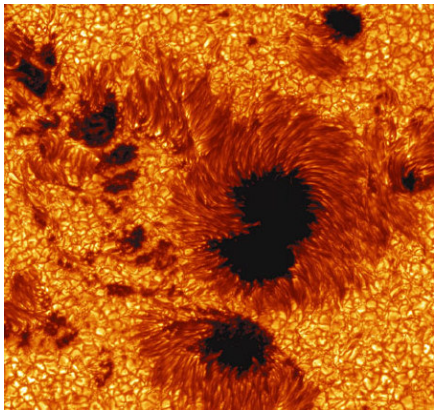
What causes solar activity?



Solar activity is like "weather"

- Sunspots
- Solar Flares
- Solar Prominences

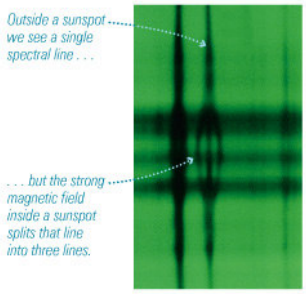
- All are related to magnetic fields



Sunspots

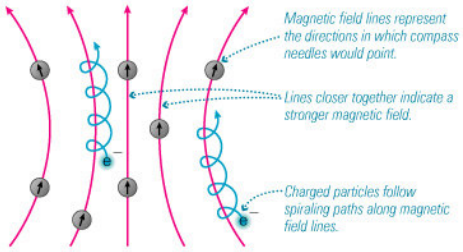
Are cooler than other parts of the Sun's surface (4000 K)

Are regions with strong magnetic fields

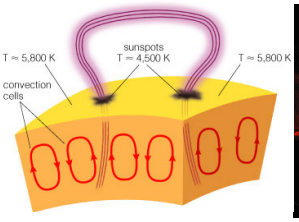


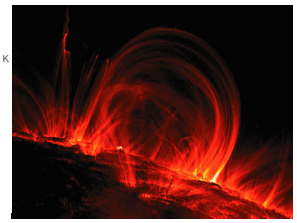
Zeeman Effect

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

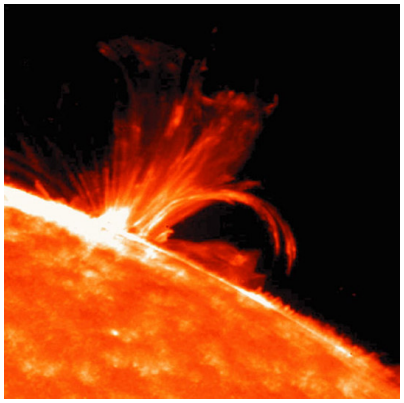


Charged particles spiral along magnetic field lines

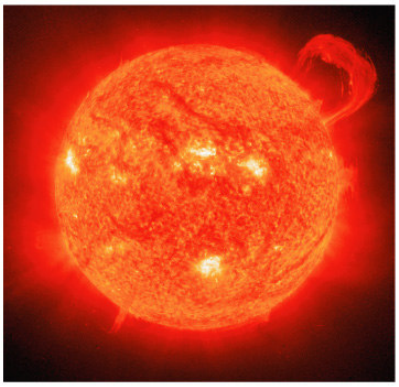




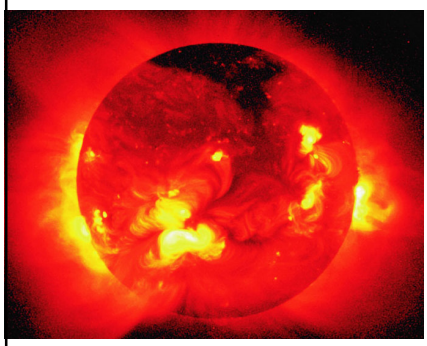
Loops of bright gas often connect sunspot pairs



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

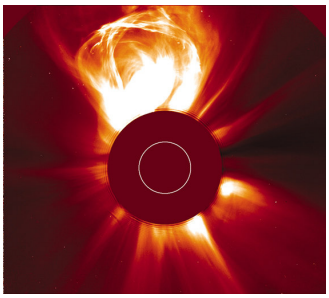


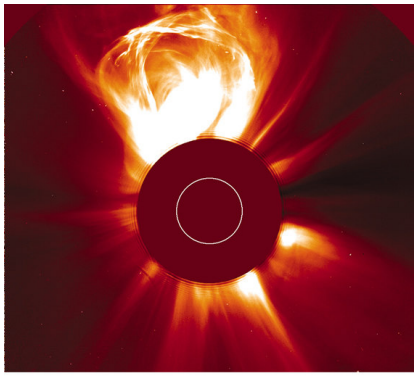
Magnetic activity also causes ***solar prominences*** that erupt high above the Sun's surface



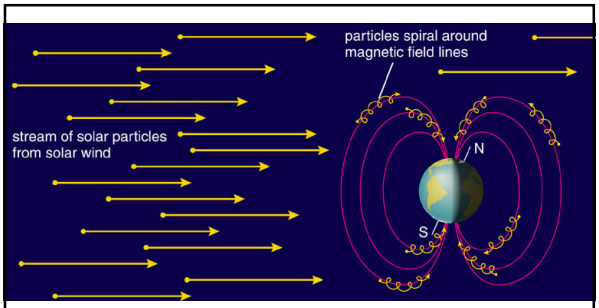
Corona appears bright in X-ray photos in places where magnetic fields trap hot gas

How does solar activity affect humans?



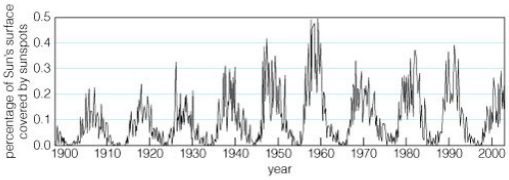


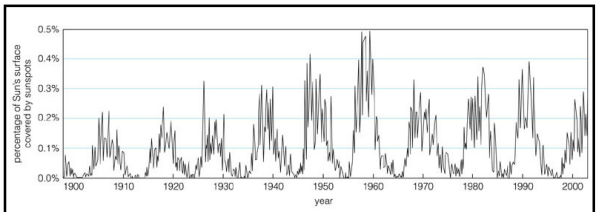
Coronal mass ejections send bursts of energetic charged particles out through the solar system



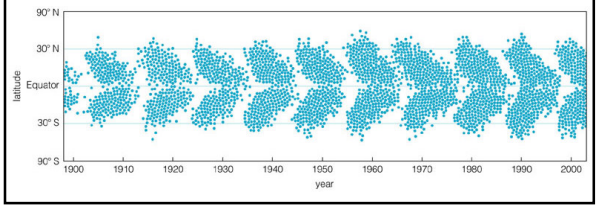
Charged particles streaming from Sun can disrupt electrical power grids and can disable communications satellites

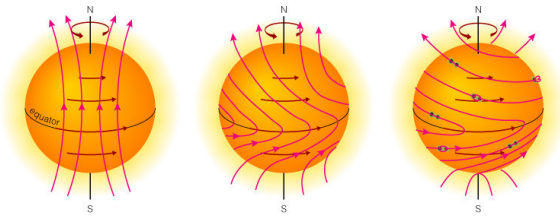
How does solar activity vary with time?





Number of sunspots rises and falls in 11-year cycle





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