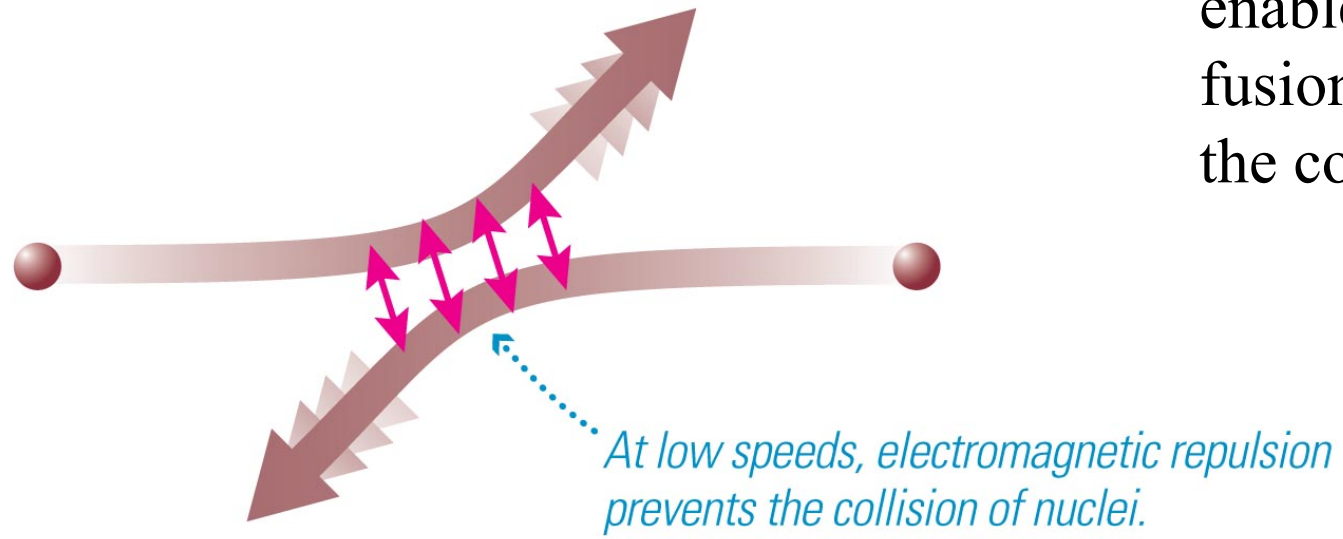
What I know today about the midterm

- Thursday, October 31st, 2-3:45 PM
  - Same time, same place
- Around 70-90 multiple choice / T-F questions
- Closed book and closed note
- No smartphones allowed
- Calculators of any kind are permitted, but the math can be readily done without them
- Equation Sheet Provided

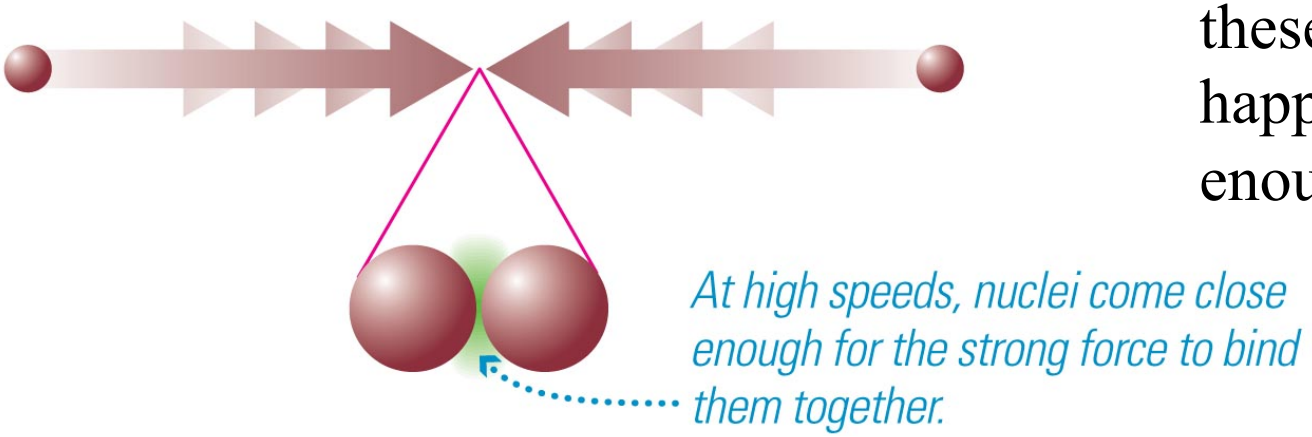
What I know today about your midterm

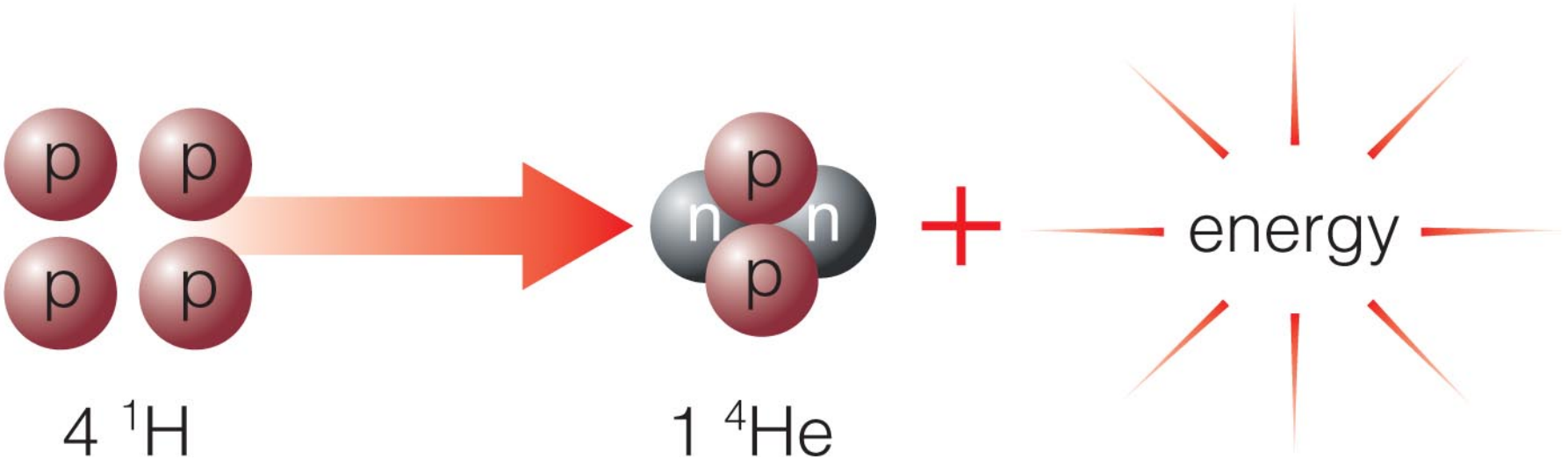
- Chris and Emily will proctor the Exam
- It is 30% of your quarter grade
- Review Sessions with Chris and Emily
  - Monday Night, 8 PM, locations are Thimann 1
  - Tuesday Night, 7:30 PM
- TA Discussion Sections and Office Hours will happen as planned
- Study Guide is being created
- Will get back to you on Scantrons….

High temperatures enable nuclear fusion to happen in the core.

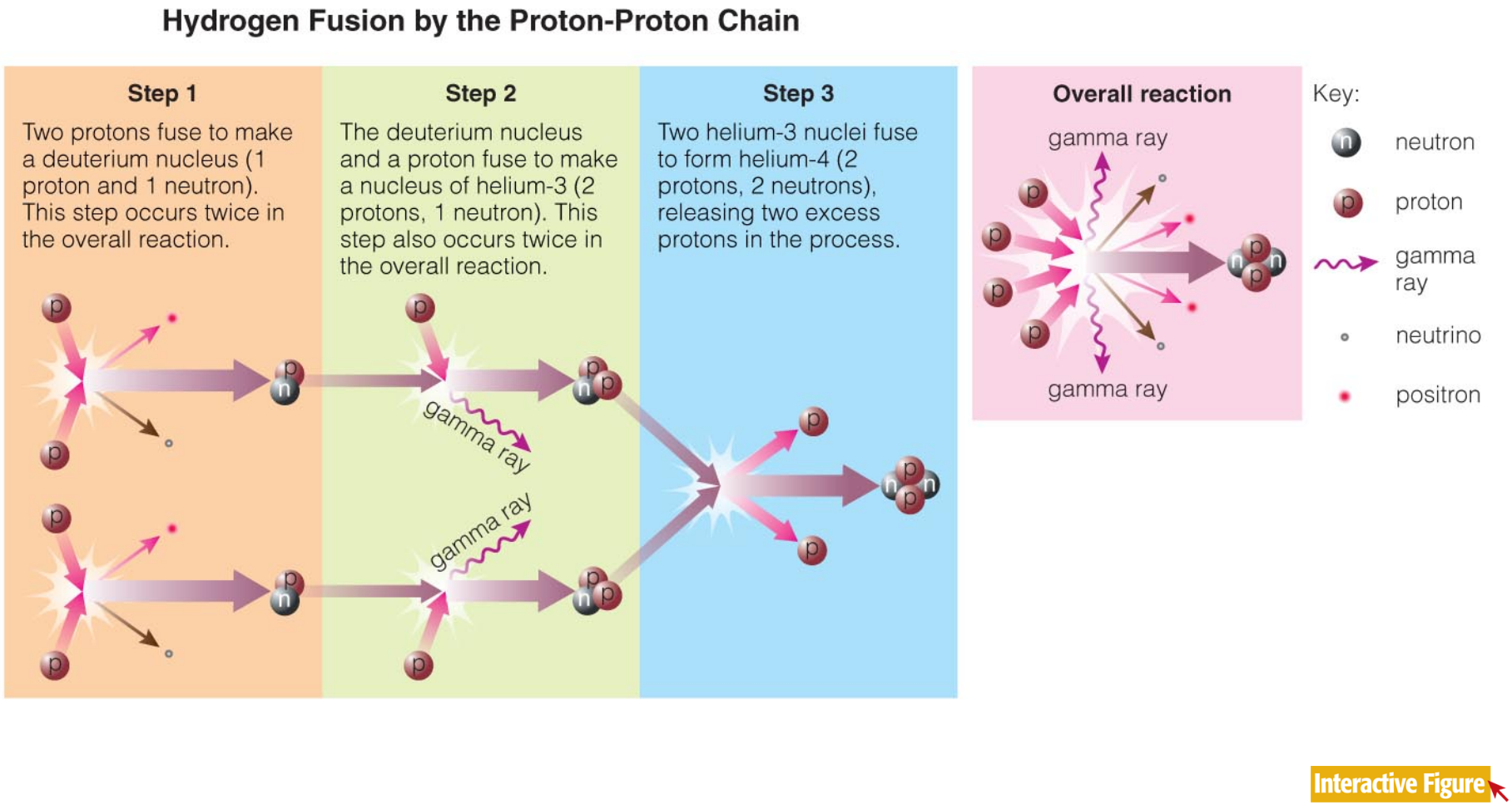


High density makes these collisions happen frequently enough

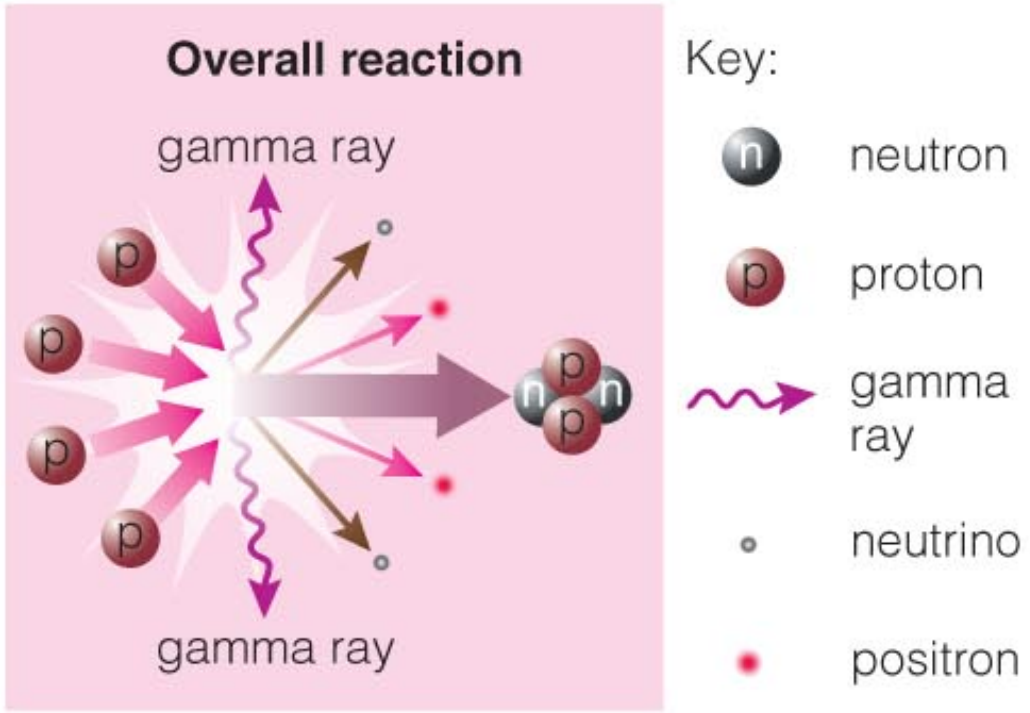




The Sun releases energy by fusing four hydrogen nuclei into one helium nucleus.



The **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.

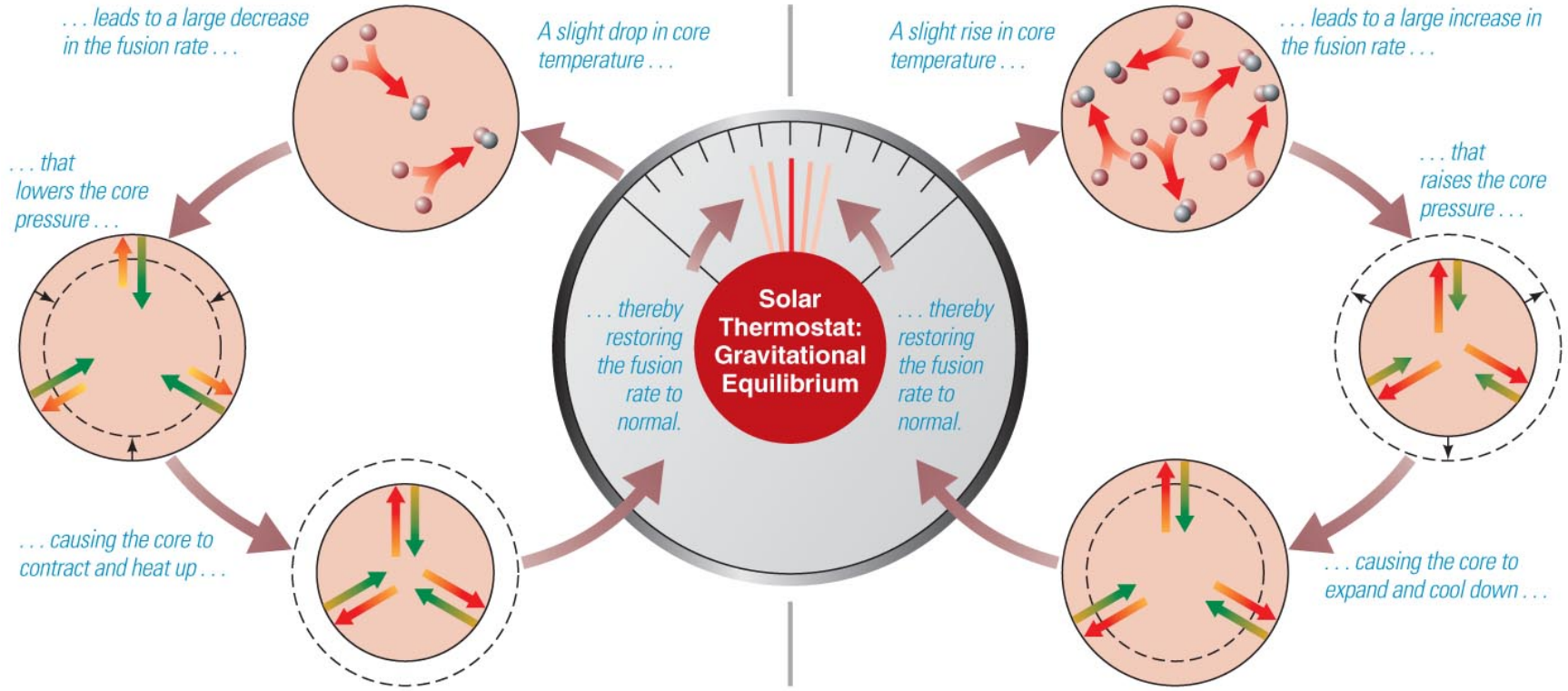
What conditions are required for nuclear fusion of hydrogen to occur?

A. a temperature of millions Kelvin
B. high density
C. the presence of uranium
D. all of the above
E. A and B

What conditions are required for nuclear fusion of hydrogen to occur?

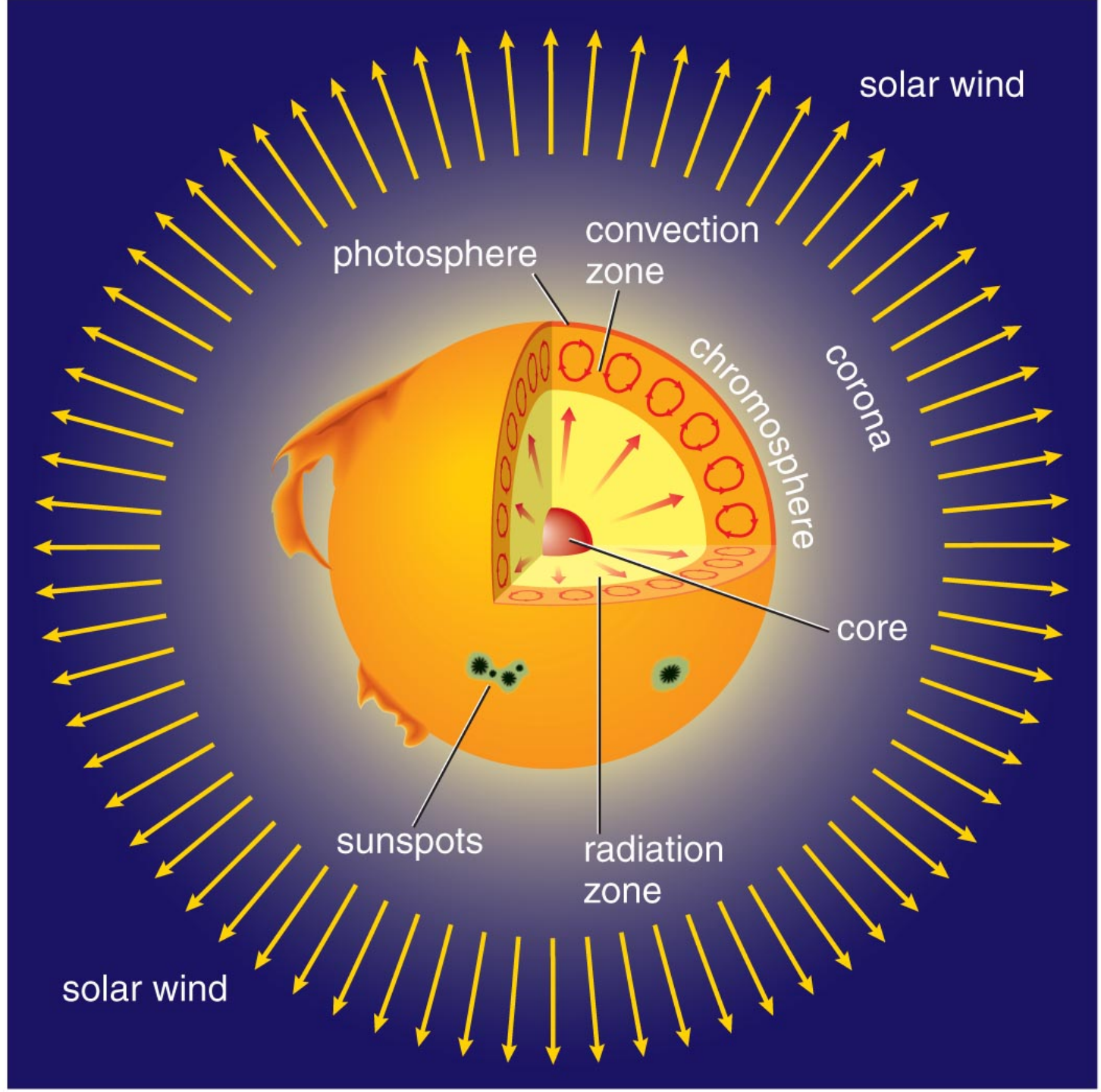
A. a temperature of millions Kelvin
B. high density
C. the presence of uranium
D. all of the above
E. A and B

Solar Thermostat



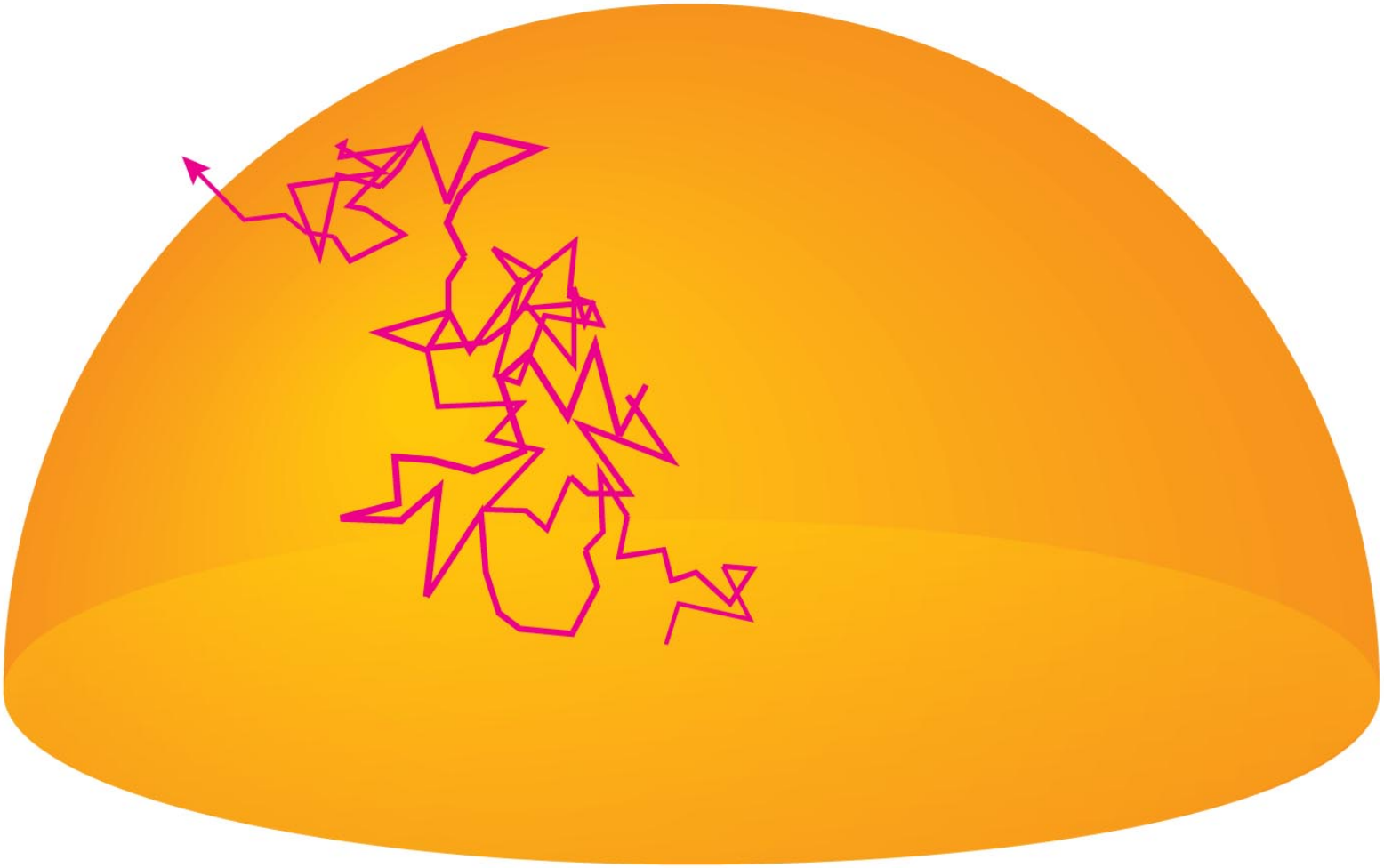
Decline in core temperature causes fusion rate to drop, so core contracts and heats up.

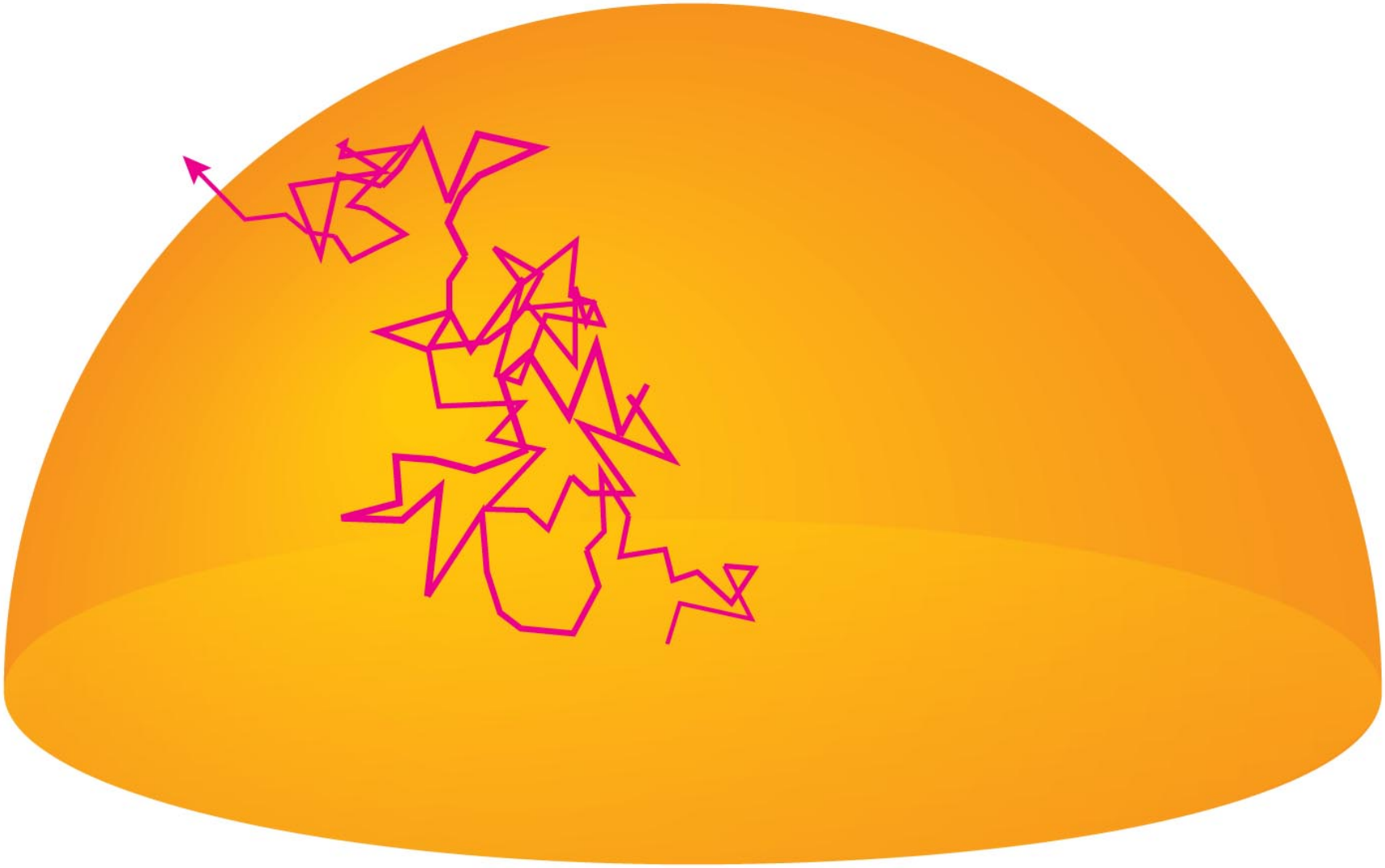
Rise in core temperature causes fusion rate to rise, so core expands and cools down.



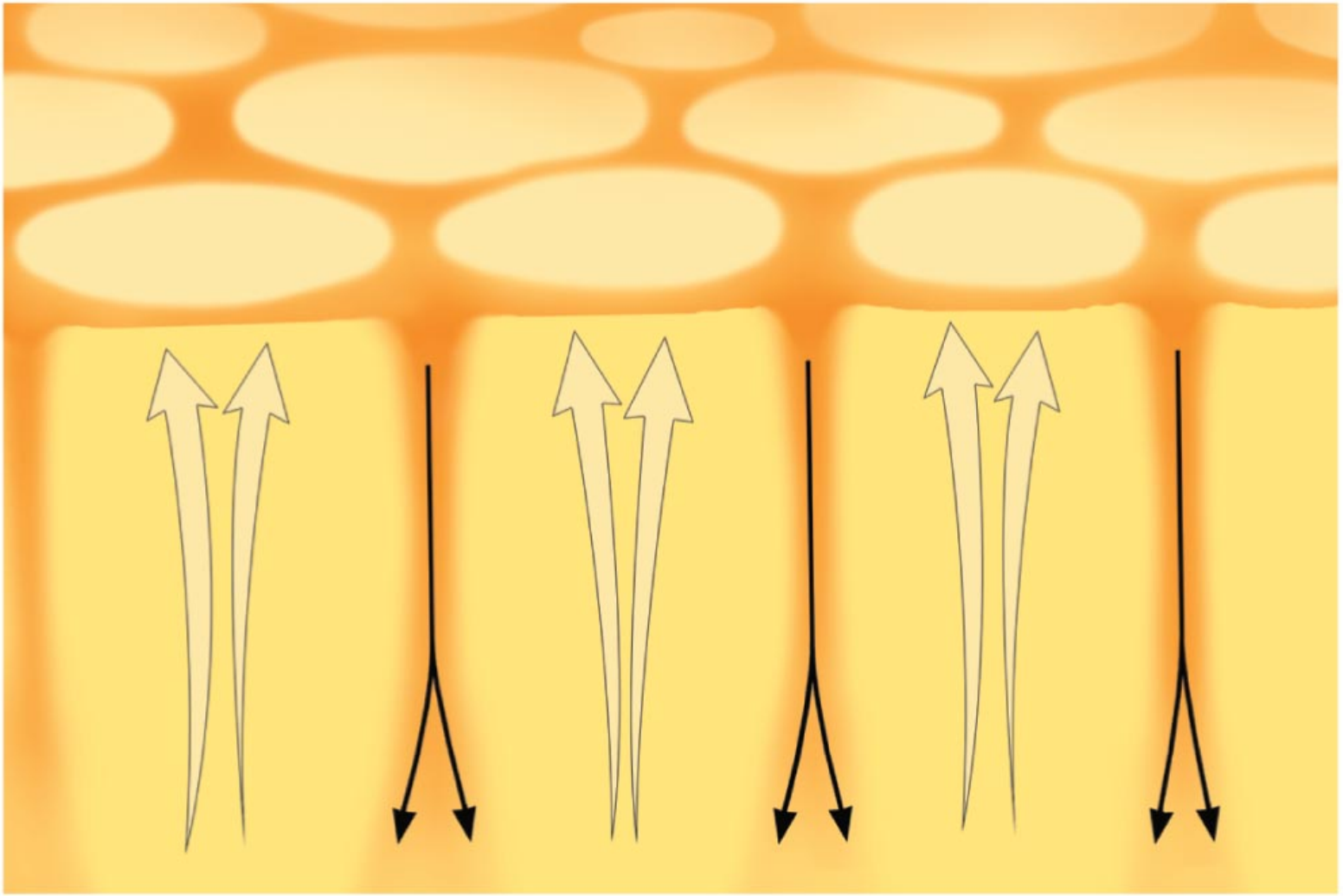
What is the Sun's structure?

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

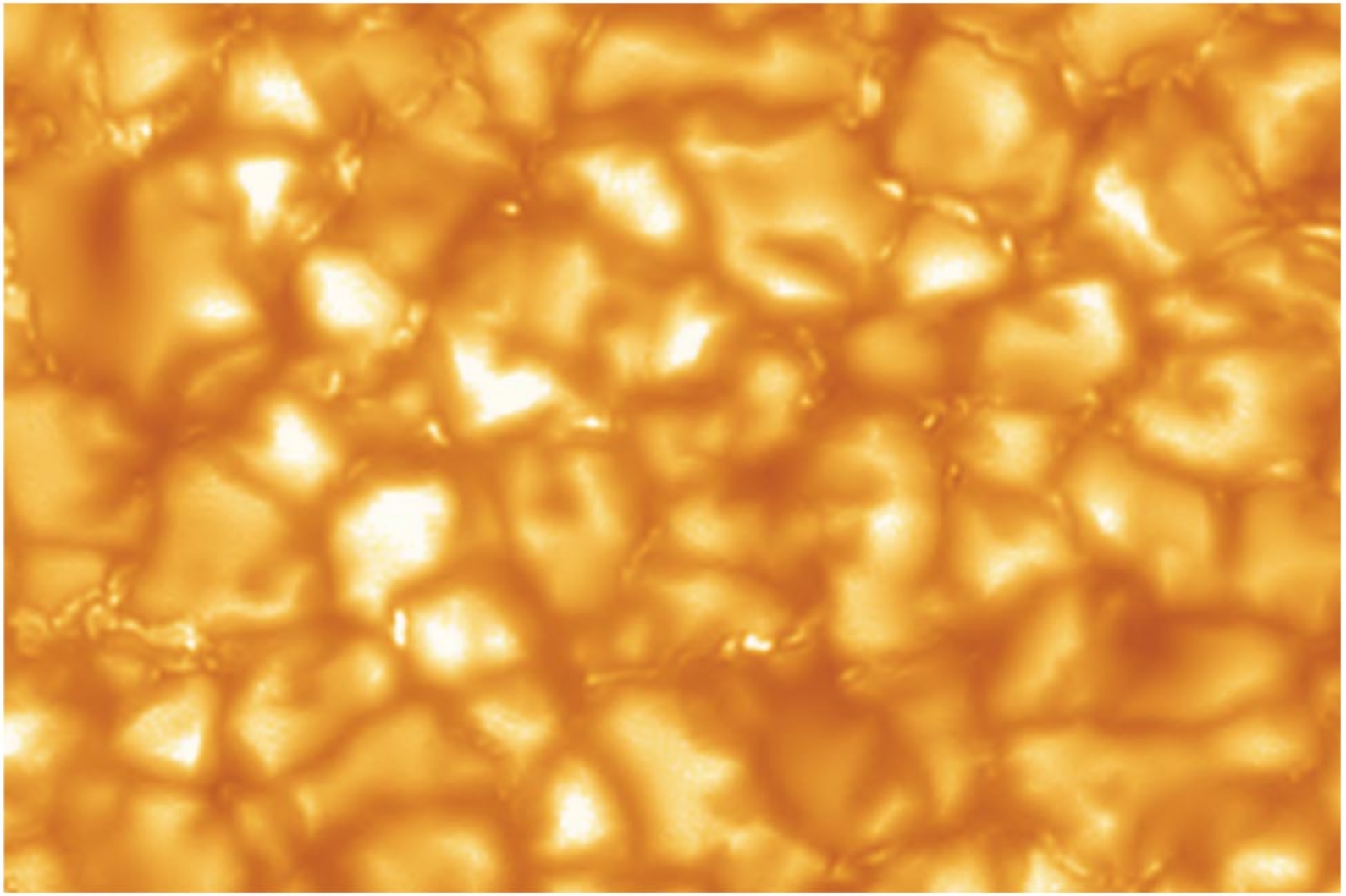




Energy gradually leaks out of radiation zone in form of randomly bouncing photons. It takes millions of years!

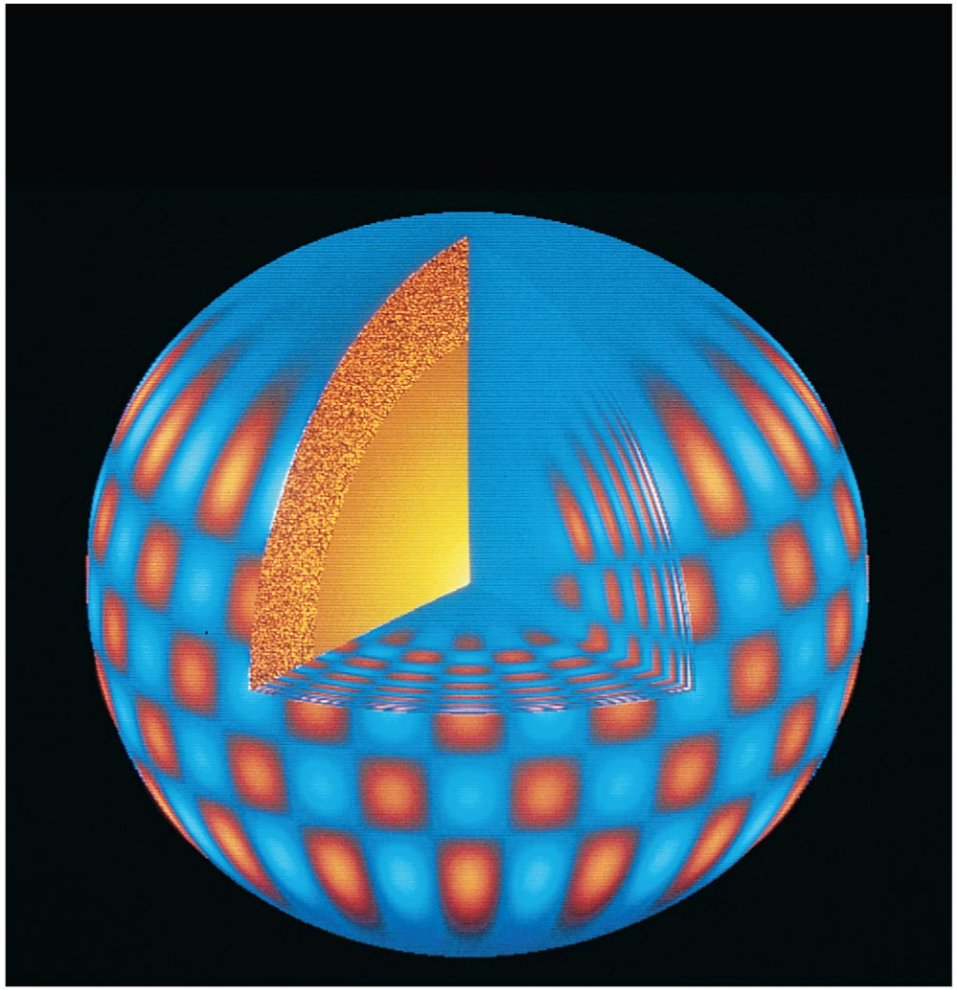


Convection (rising hot gas) takes energy to surface.



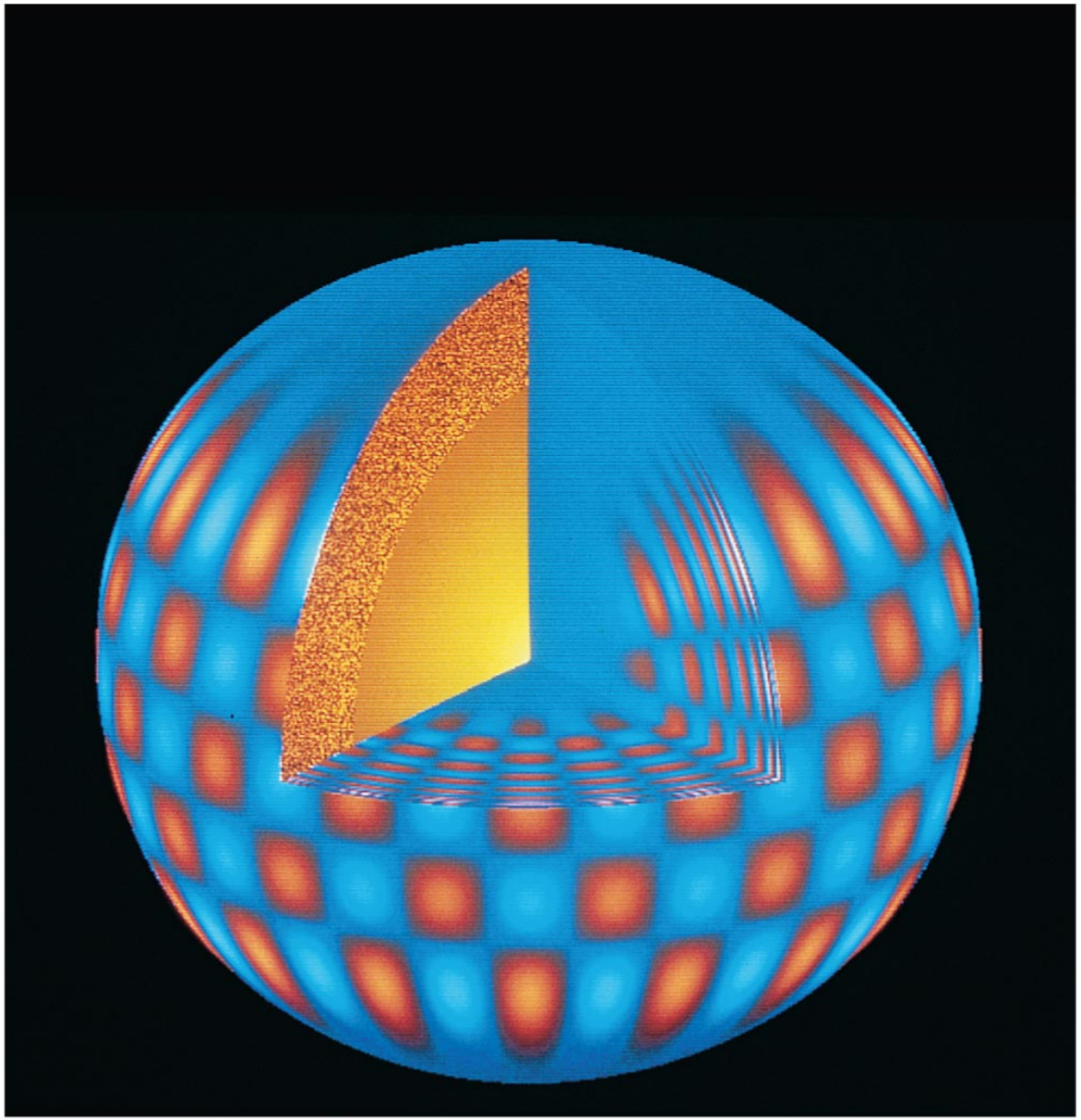
Bright blobs on photosphere show where hot gas is reaching the surface.

How we know what is happening inside the Sun?



We learn about the inside of the Sun by …

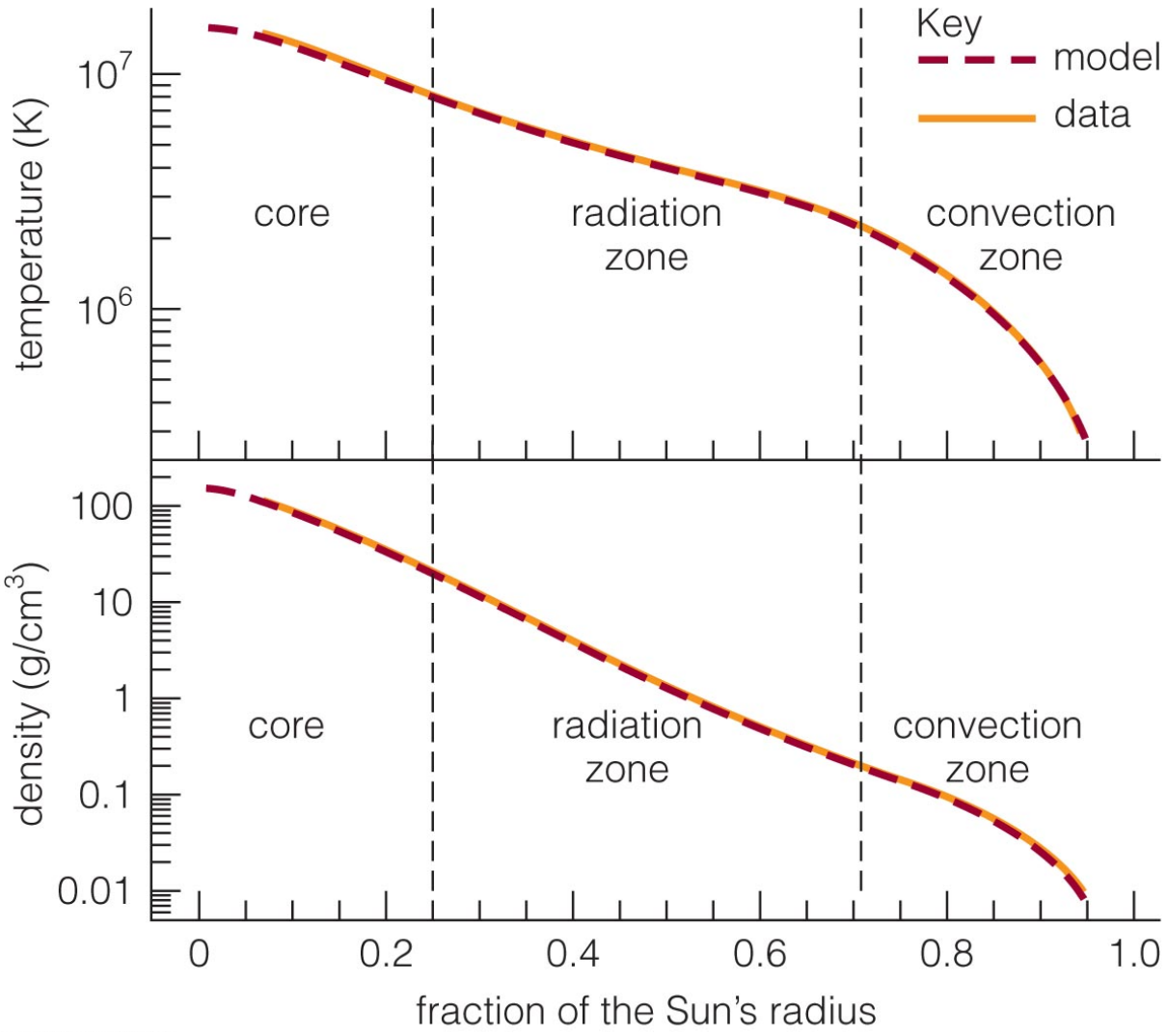
- making mathematical models
- observing solar vibrations
- observing solar neutrinos



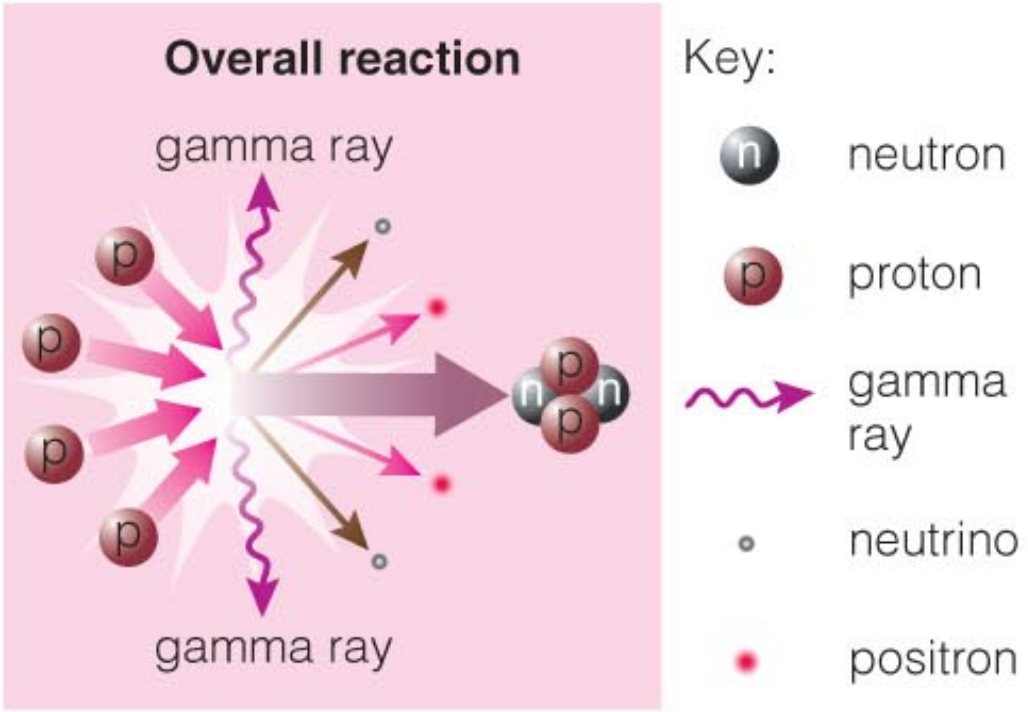
Patterns of vibration on the surface tell us about what the Sun is like inside.

Essentially the same as studying Earthquakes

Somewhat like how the frequencies of a wringing bell could help us understand the stiffness and other qualities of the bell.

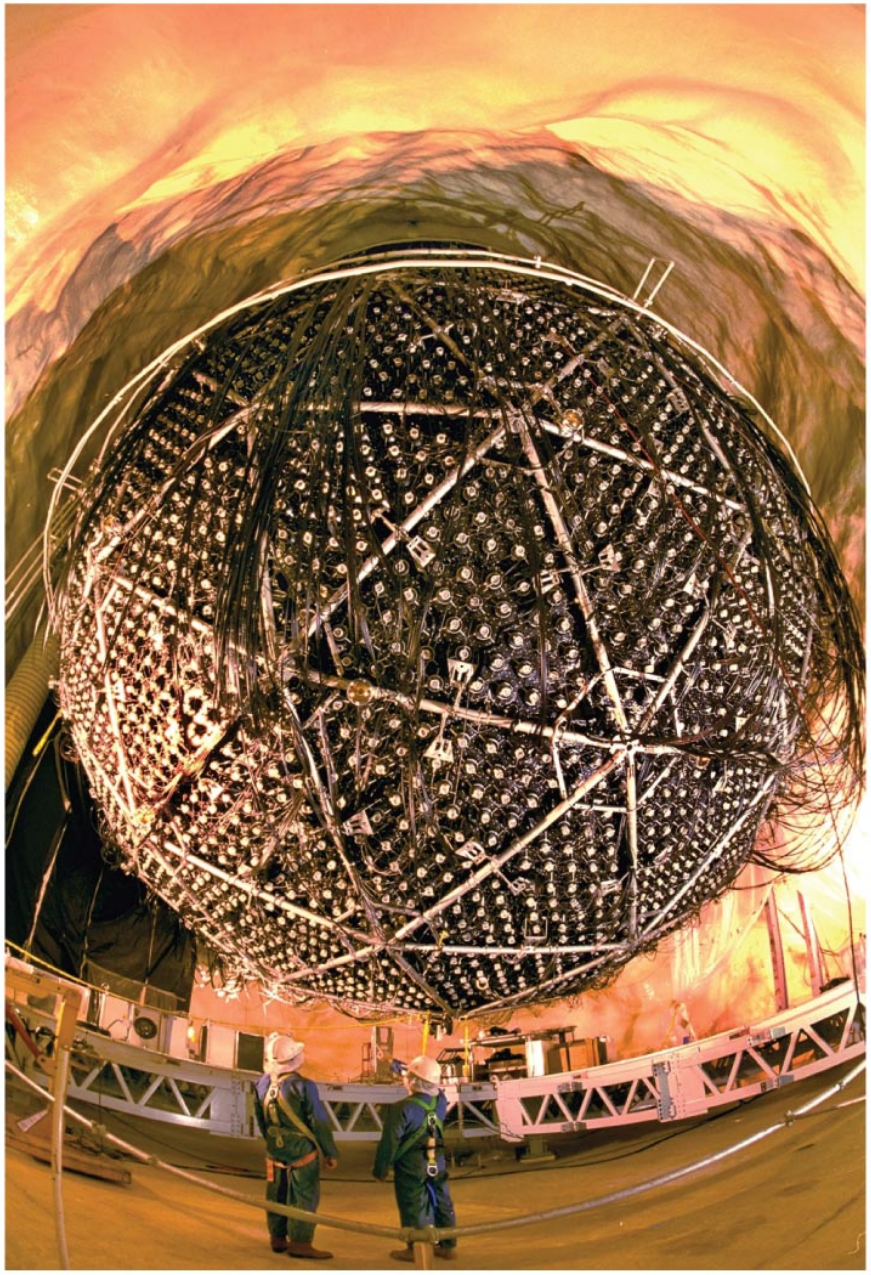


Data on solar vibrations agree very well with mathematical models of solar interior.



Neutrinos created during fusion fly directly through the Sun.

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



- ***Solar neutrinos:***

- These tiny particles fly out of the Sun without interacting with solar matter
- 65 billion (6.5×10^{10}) neutrinos generated by the Sun pass through your thumb (1 cm^2) every second
- It is possible to build a detector that can RARELY detect these particles
- The detection rates now agree with predictions

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?

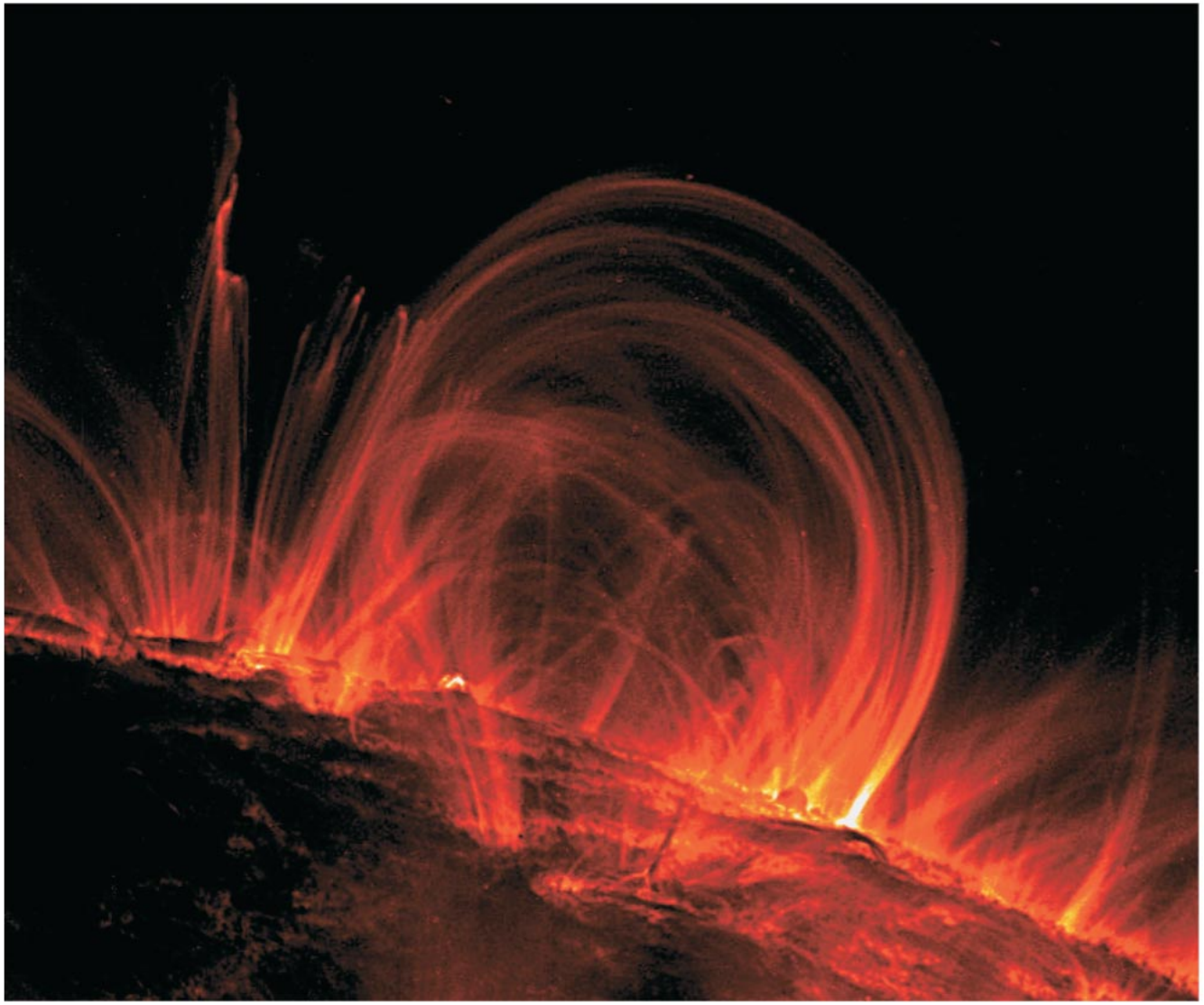
- How does the energy from fusion get out of the Sun?
  - Randomly bouncing photons carry energy through the radiation zone.
  - Rising of hot plasma carries energy through the convection zone to photosphere.
- How do we know what is happening inside the Sun?
  - Mathematical models agree with observations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

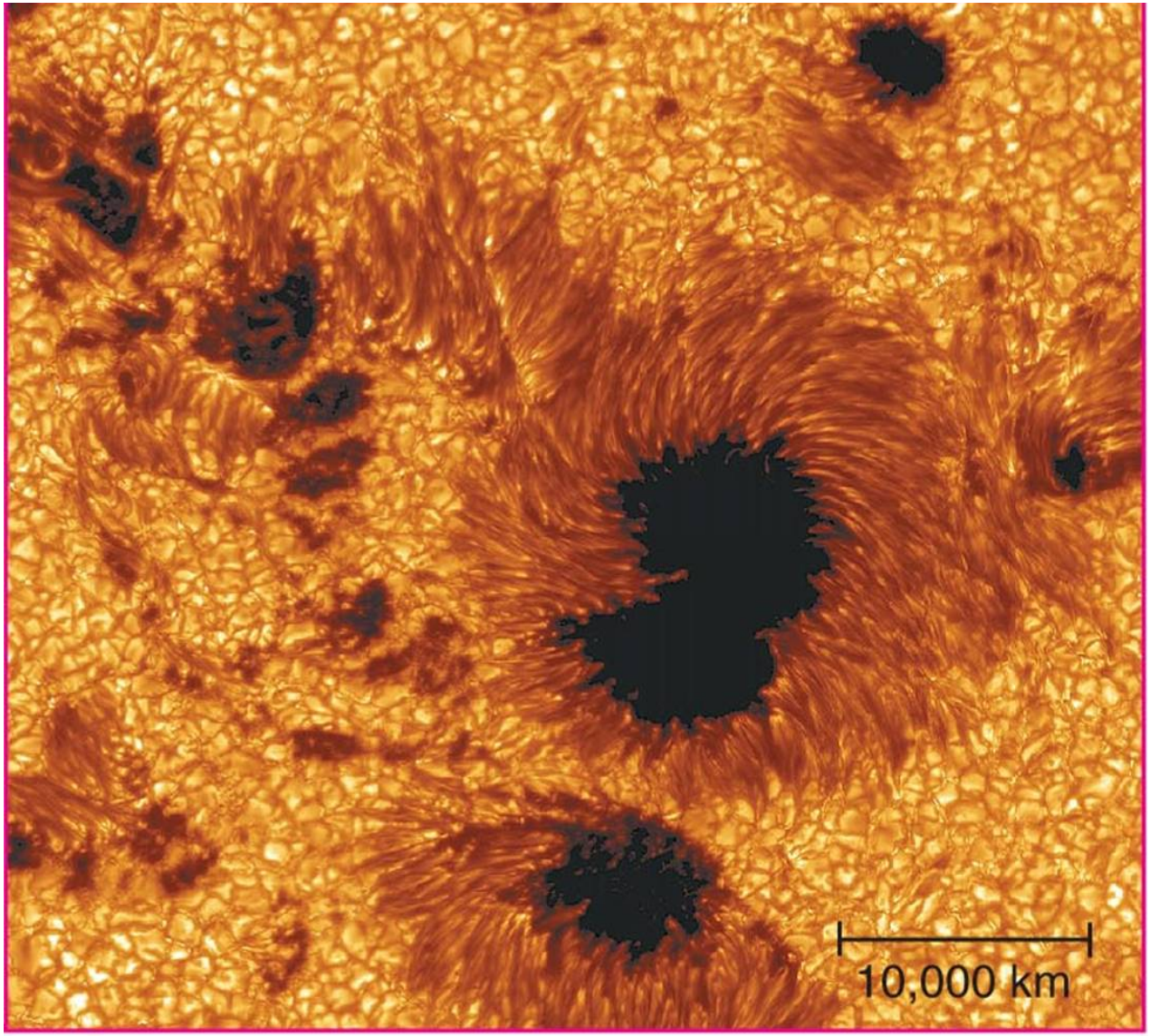
What causes solar activity?



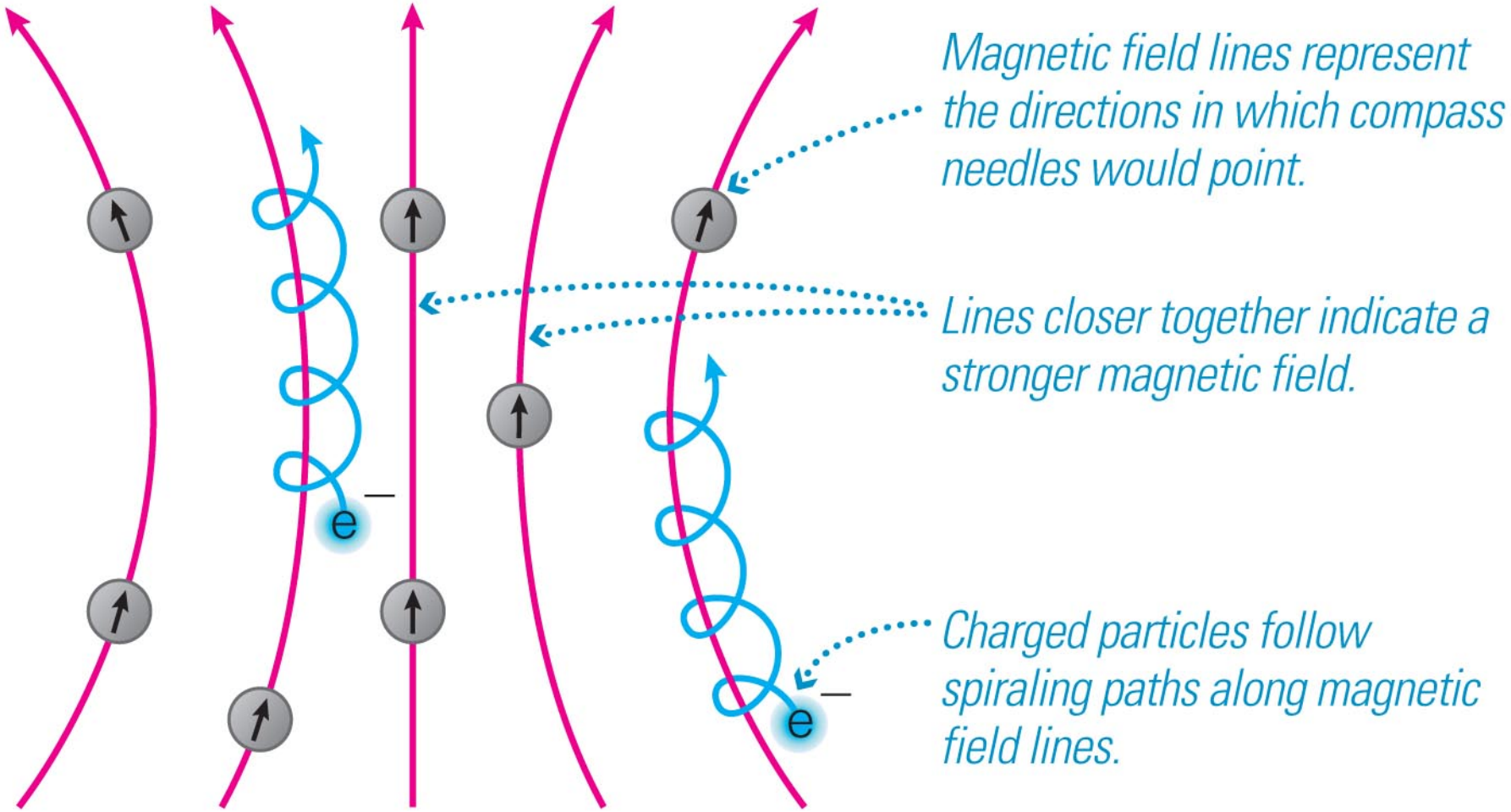
Solar activity is like “weather”.

- Sunspots
- Solar flares
- Solar prominences

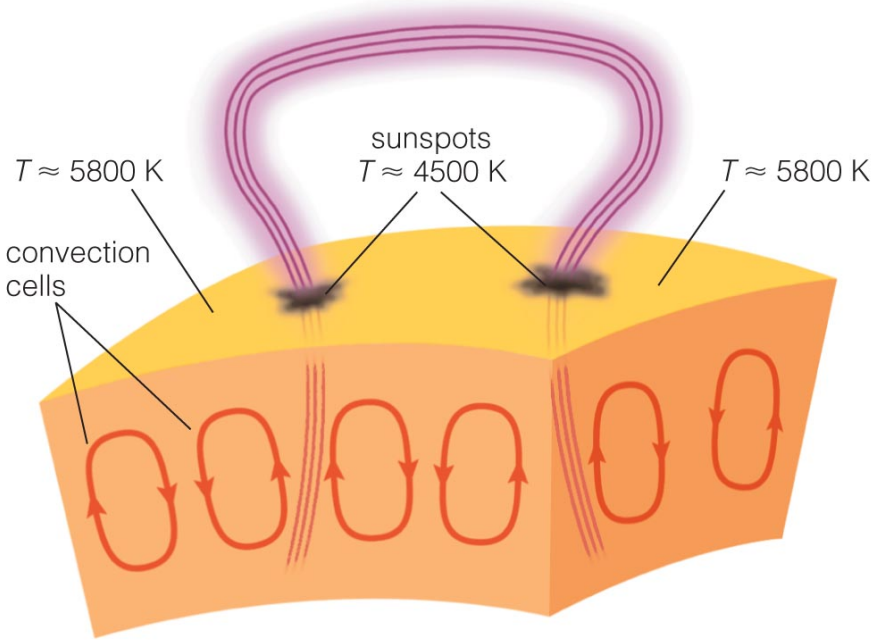
All these phenomena are related to magnetic fields.

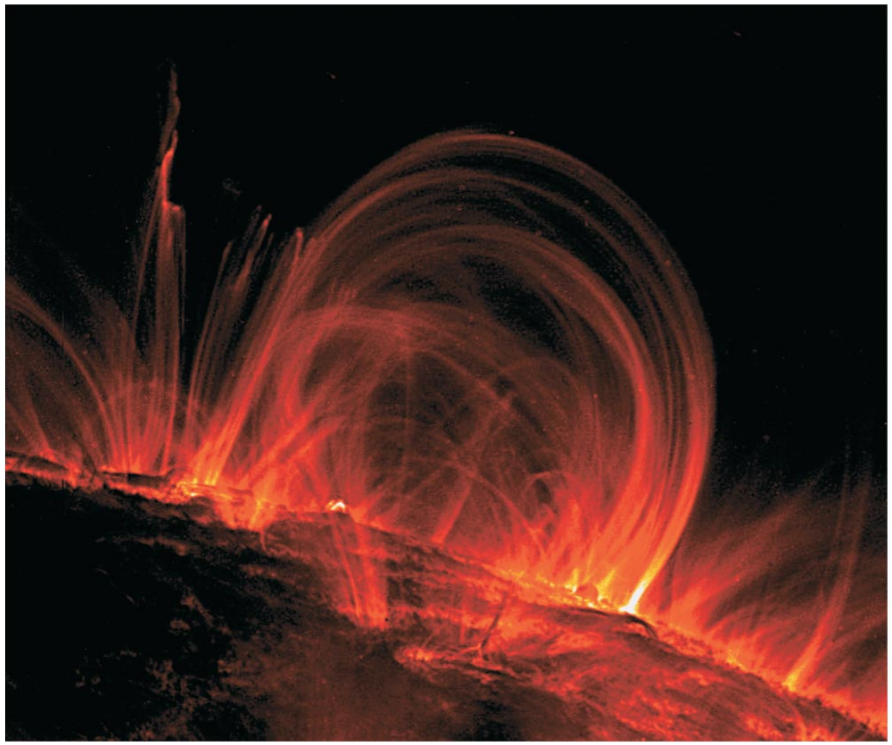


- ***Sunspots***
- Are cooler than other parts of the Sun's surface (4000 K)
- Dark because they are cold
- Are regions with strong magnetic fields

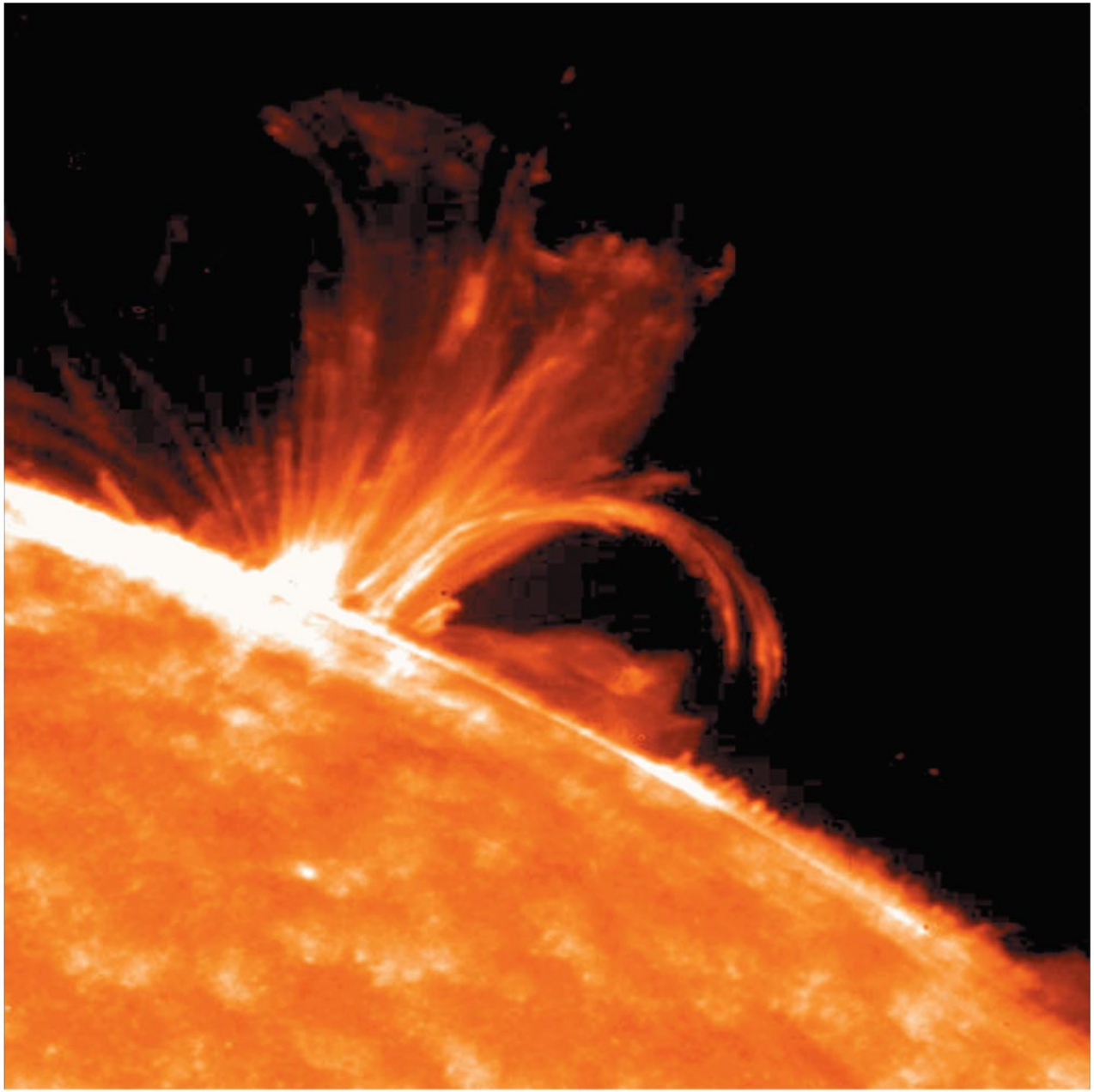


Charged particles spiral along magnetic field lines.

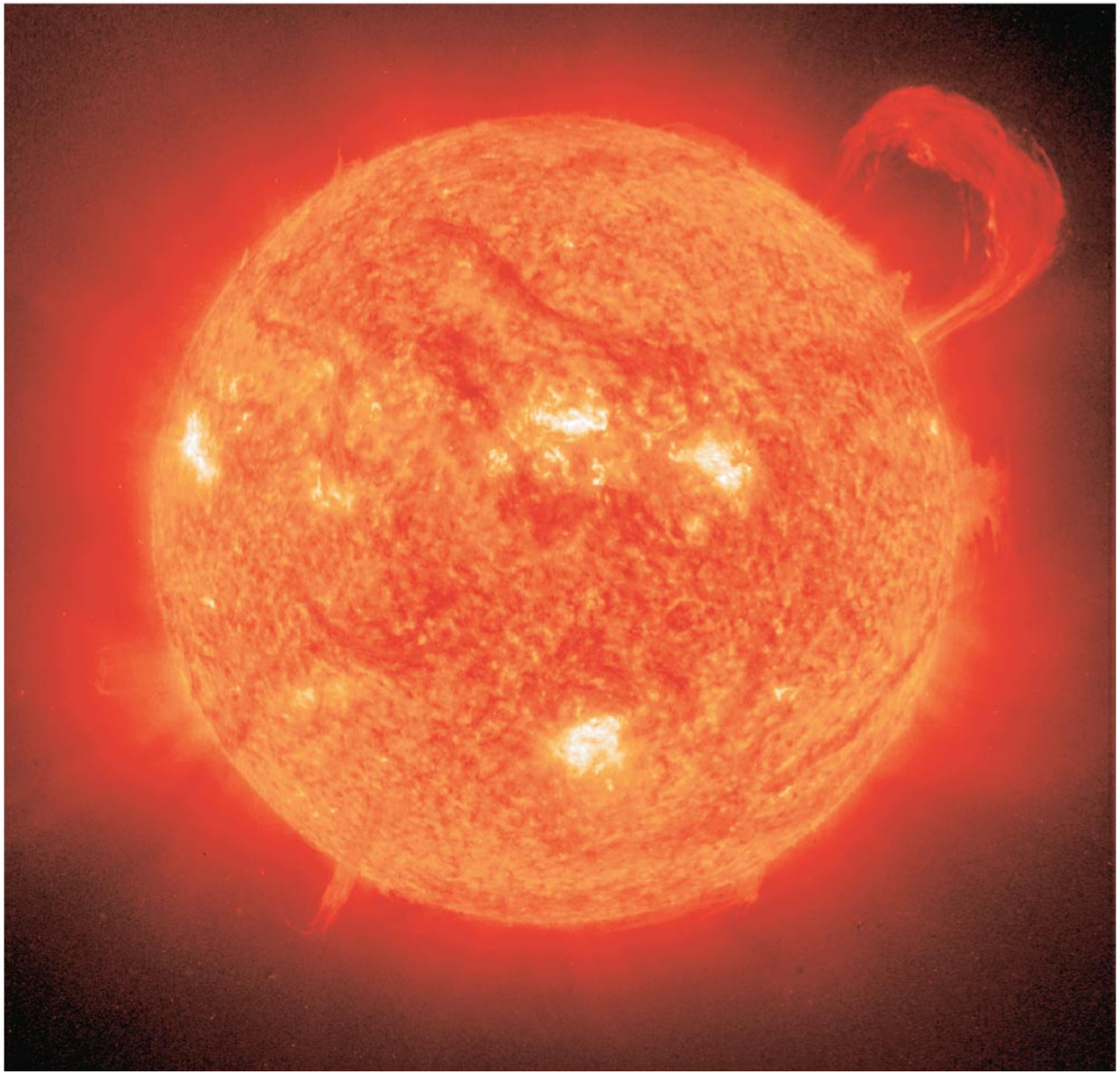




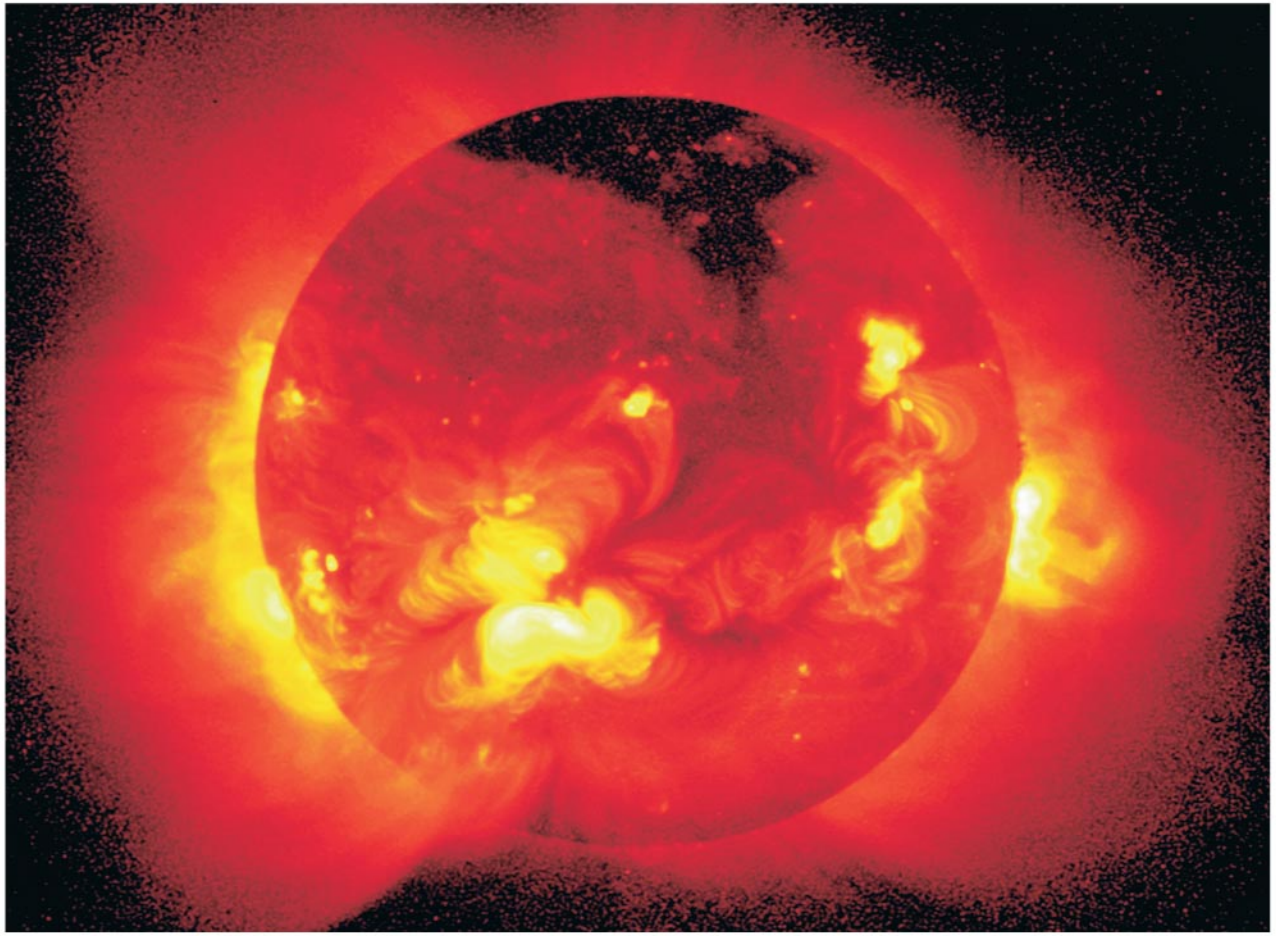
Loops of bright gas often connect sunspot pairs.



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

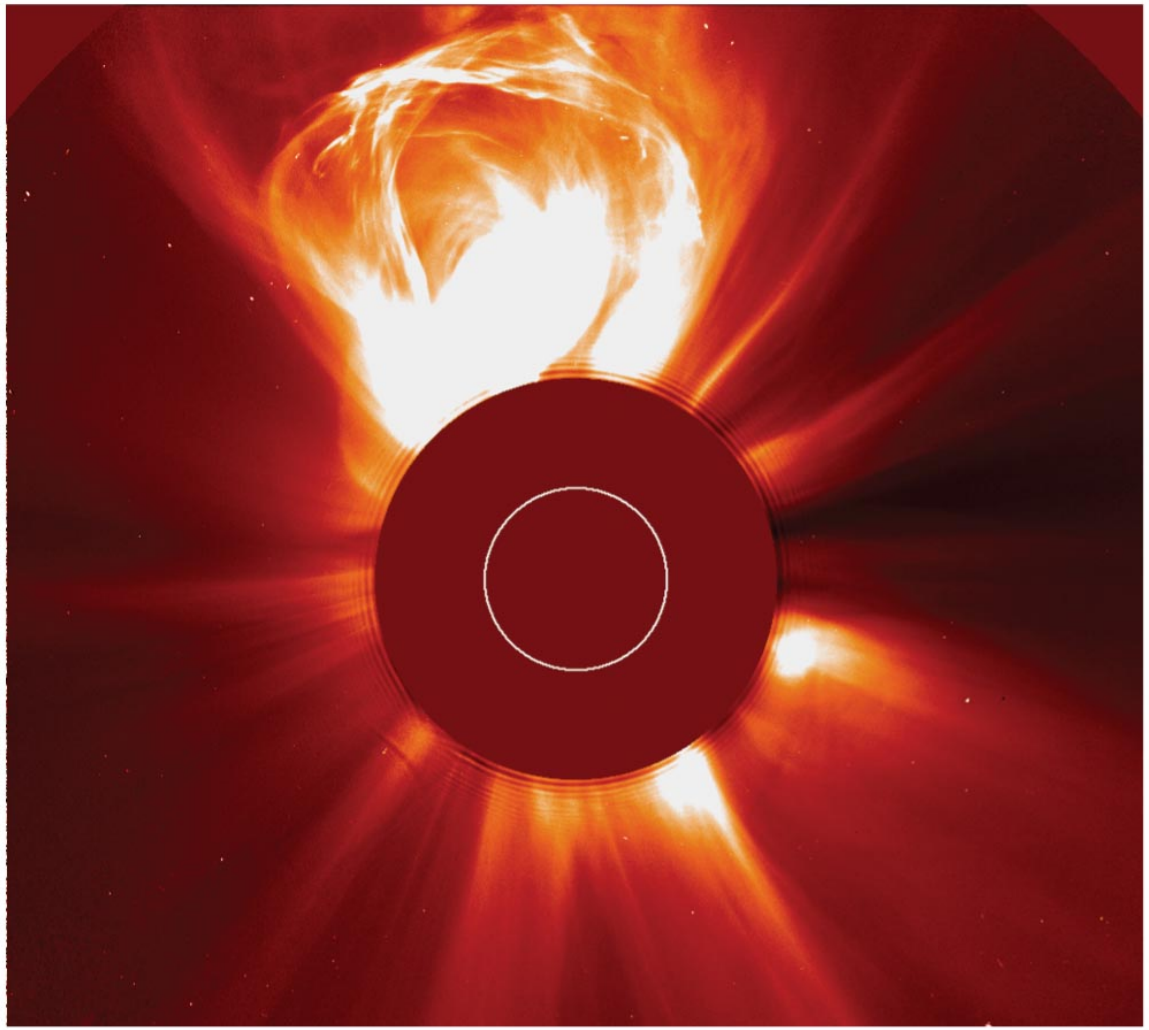


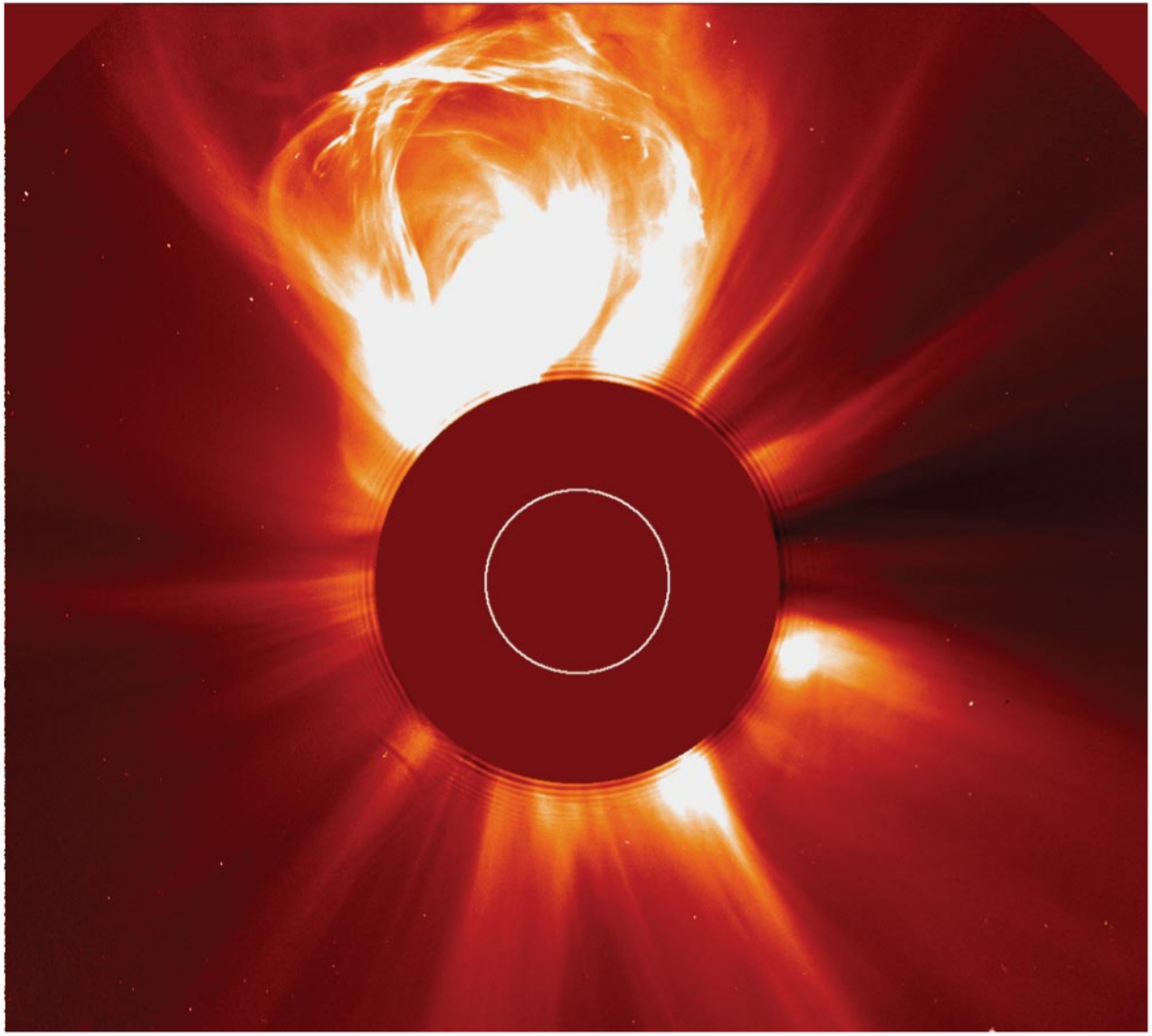
Magnetic activity also causes ***solar prominences*** that erupt high above the Sun's surface.



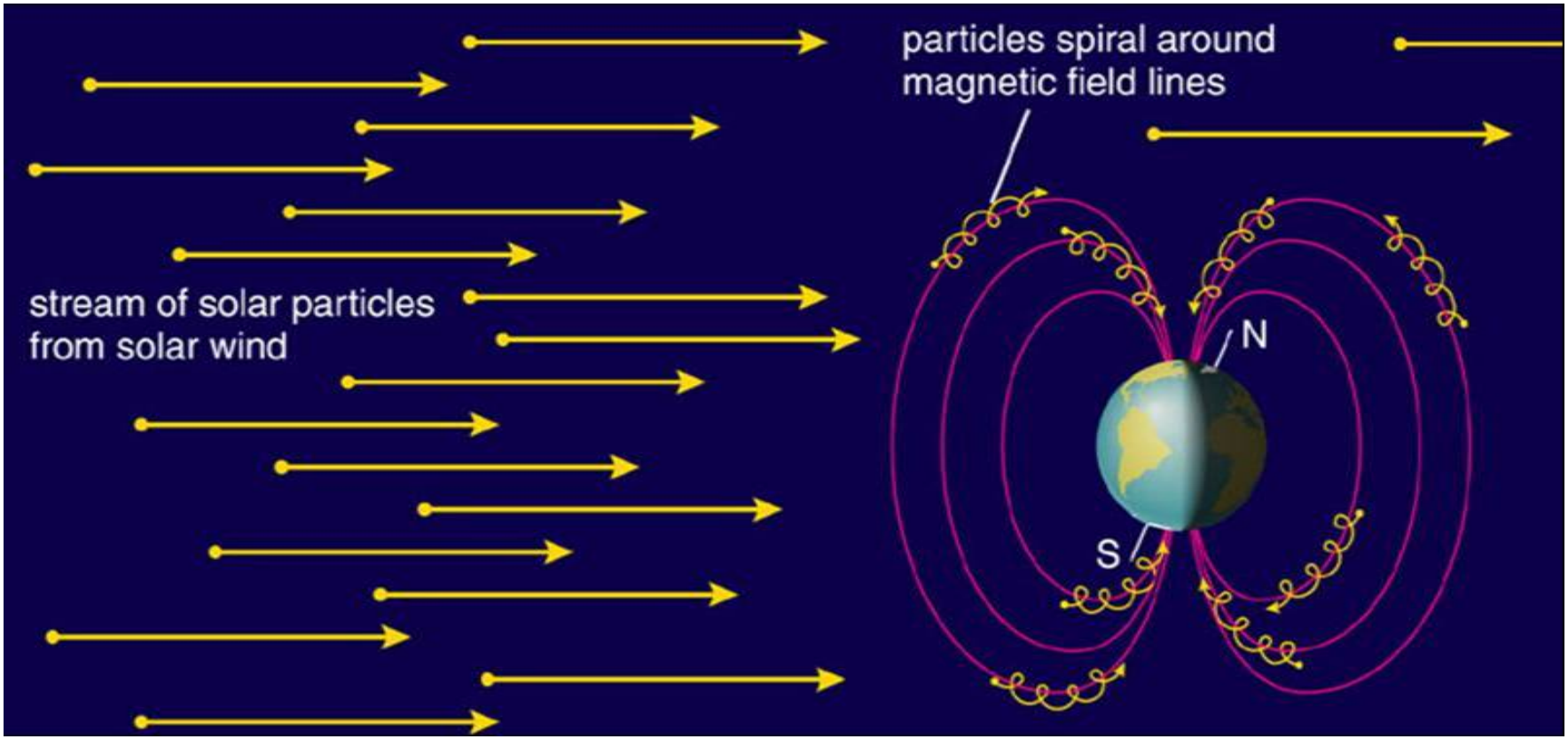
The corona appears bright in X-ray photos in places where magnetic fields trap hot gas.

How does solar activity affect humans?



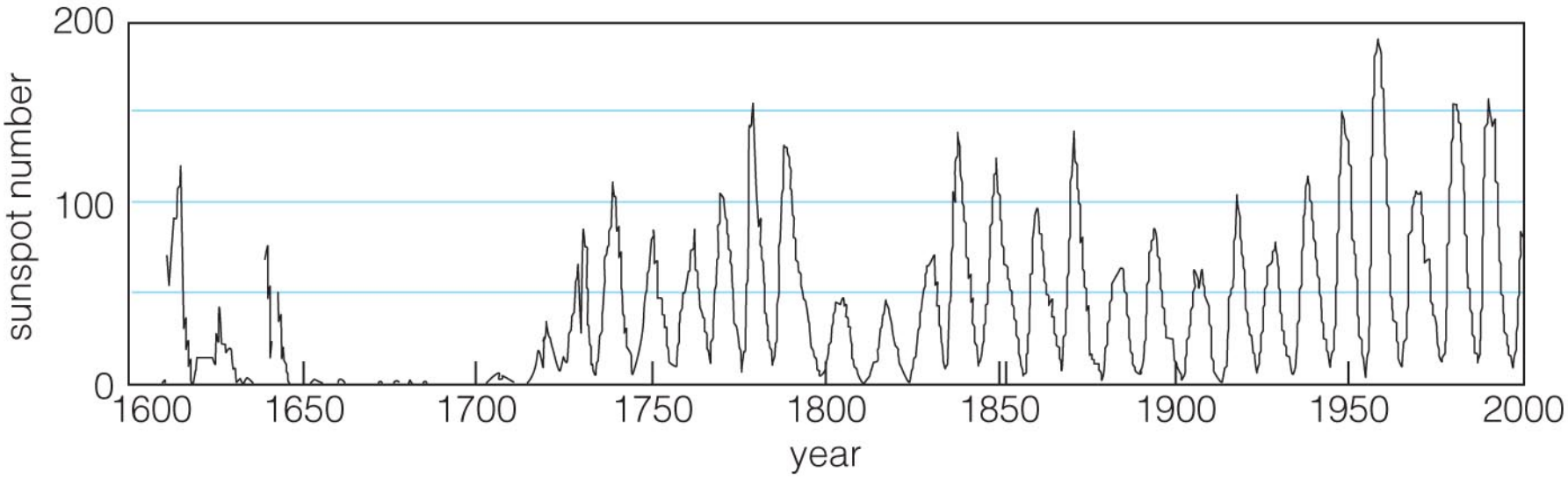


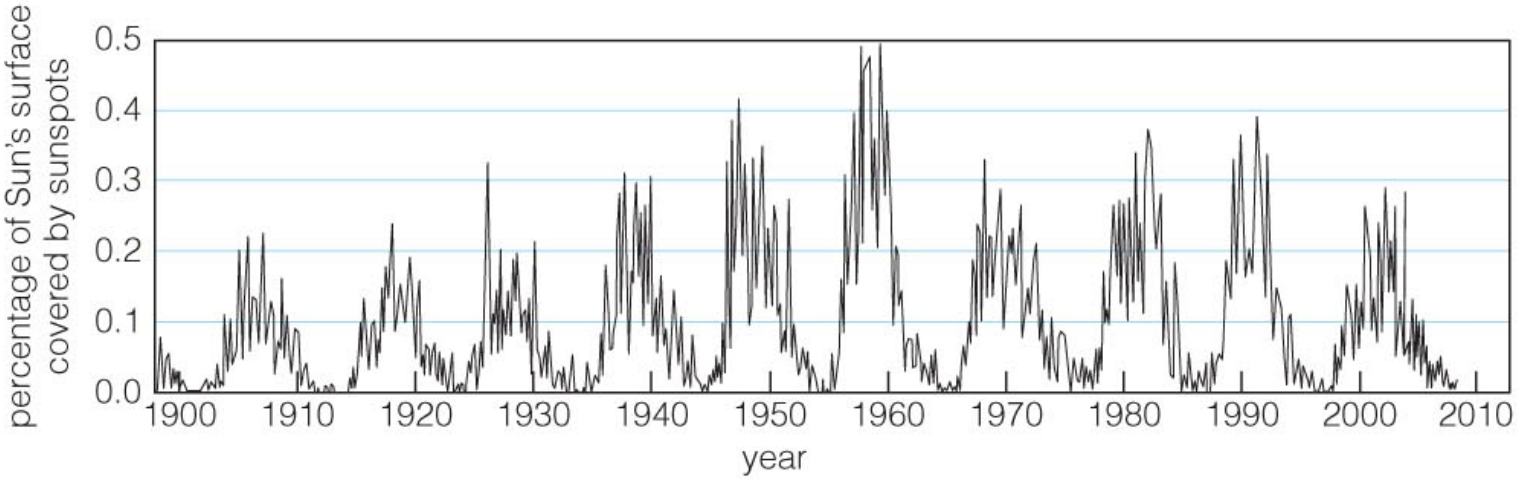
Coronal mass ejections send bursts of energetic charged particles out through the solar system.



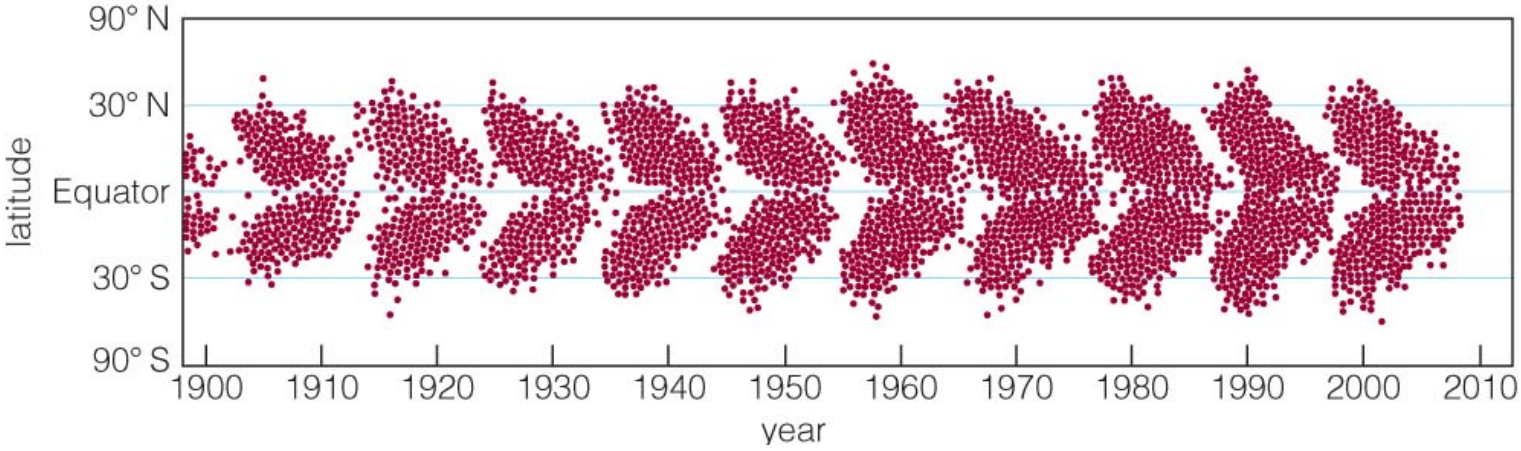
Charged particles streaming from the Sun can disrupt electrical power grids and can disable communications satellites.

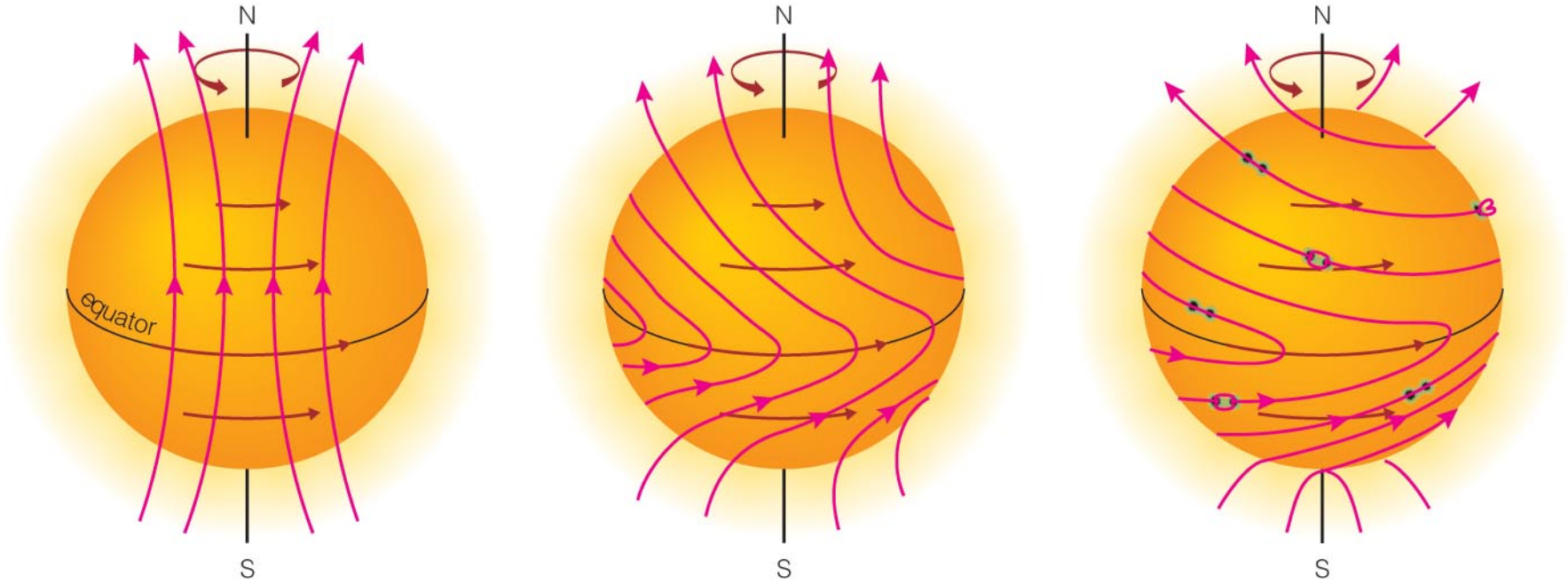
How does solar activity vary with time?





The number of sunspots rises and falls in an 11-year cycle.





The sunspot cycle has something to do with winding and twisting of the Sun's magnetic field.

What have we learned?

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

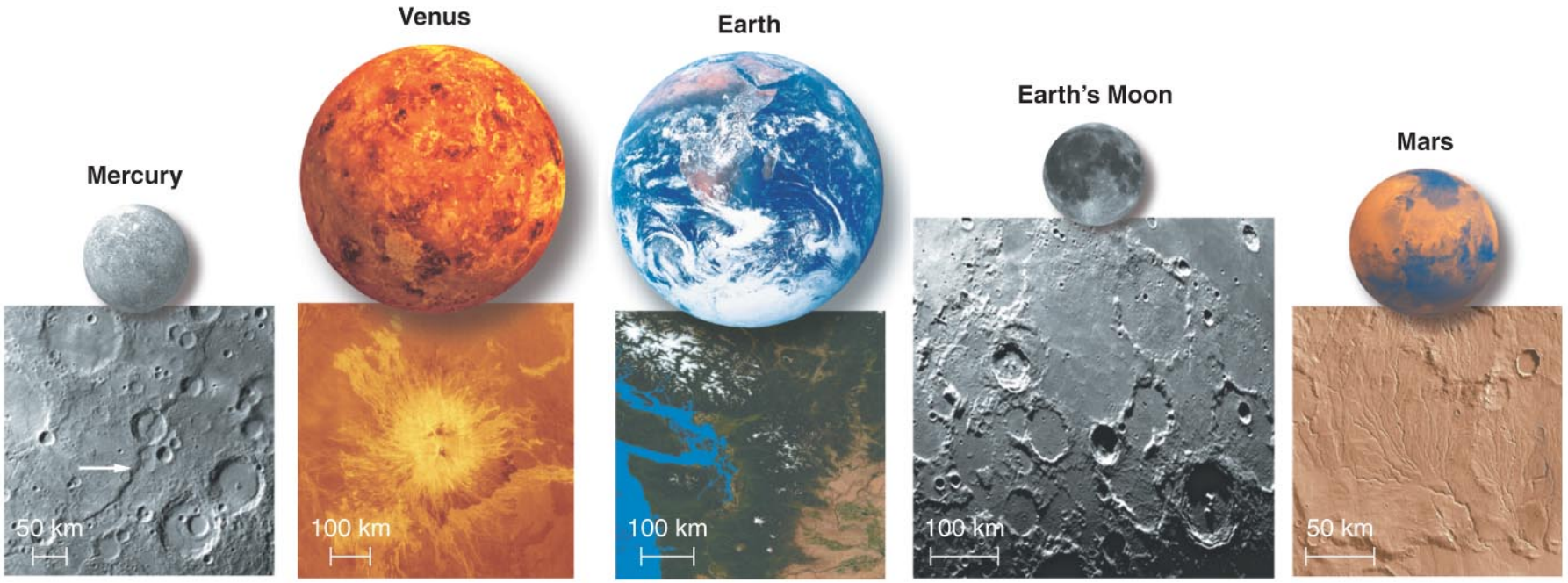
Chapter 9
Planetary Geology:
Earth and the Other Terrestrial Worlds

9.1 Connecting Planetary Interiors and Surfaces

Our goals for learning:

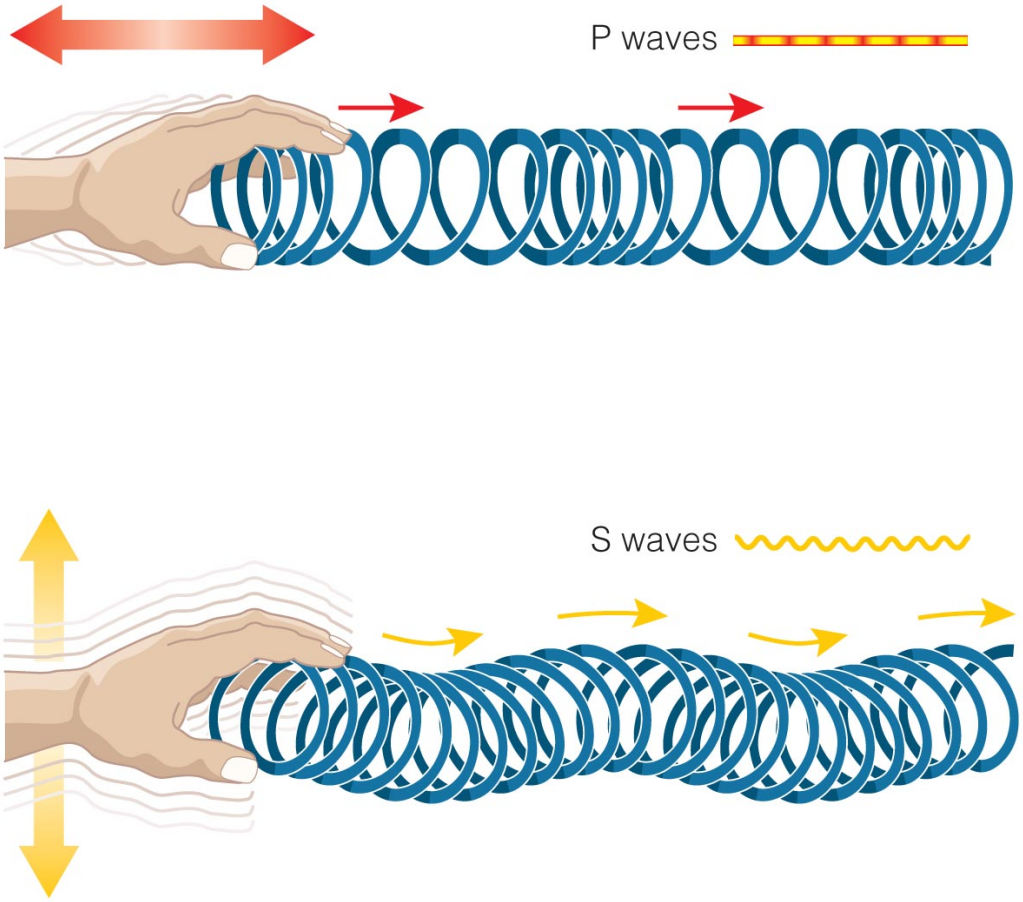
- What are terrestrial planets like on the inside?
- What causes geological activity?
- Why do some planetary interiors create magnetic fields?

What are terrestrial planets like on the inside?



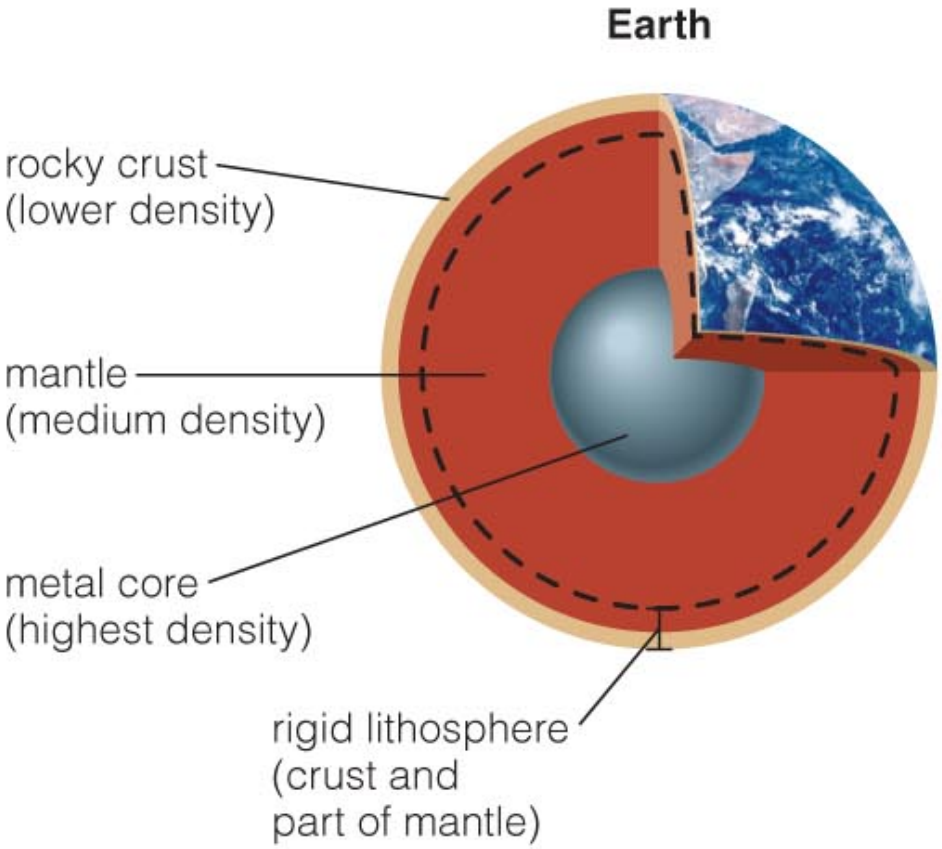
- *Planets are round because gravity overwhelms the strength of rock*
- *The same is not true for small objects like asteroids*

Seismic Waves



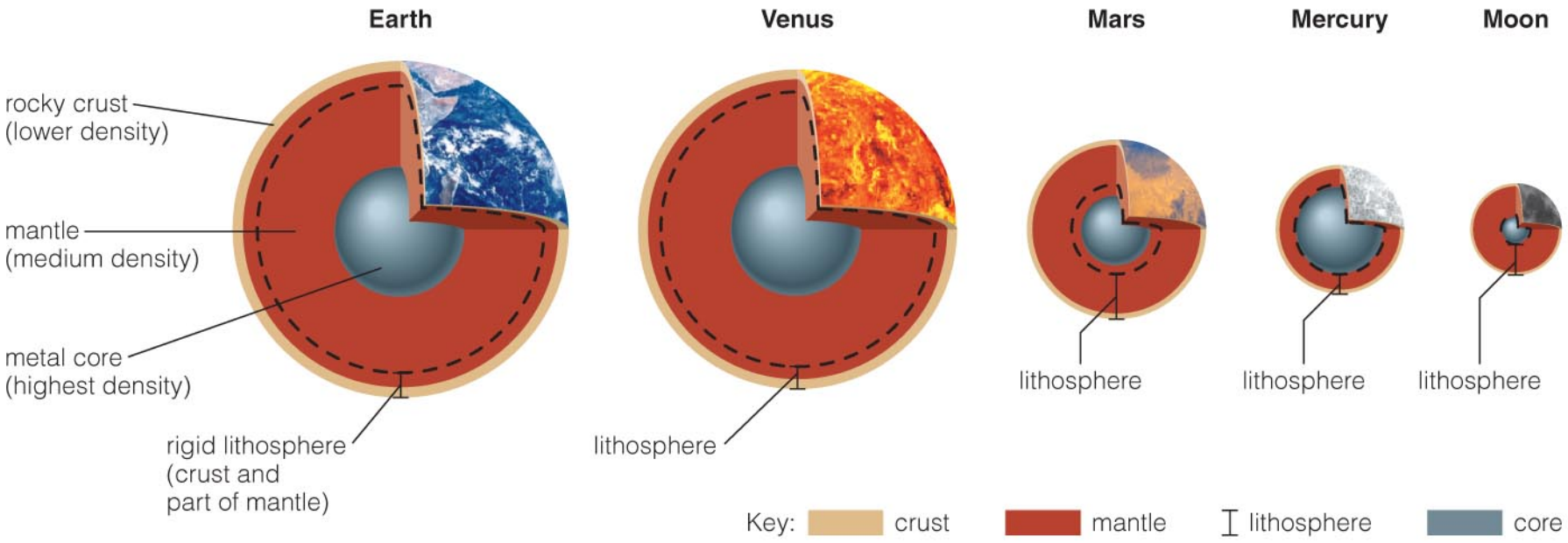
- Vibrations that travel through Earth's interior tell us what Earth is like on the inside.

Earth's Interior



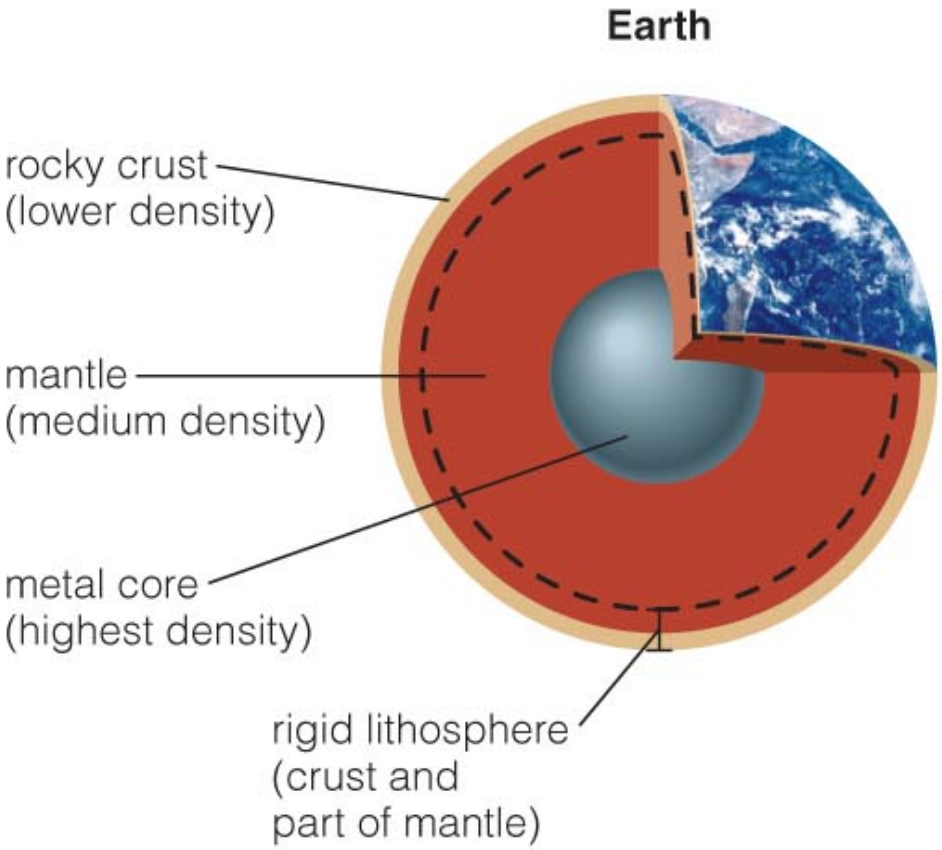
- **Core:** highest density; nickel and iron
- **Mantle:** moderate density; silicon, oxygen, etc.
- **Crust:** lowest density; granite, basalt, etc.

Terrestrial Planet Interiors



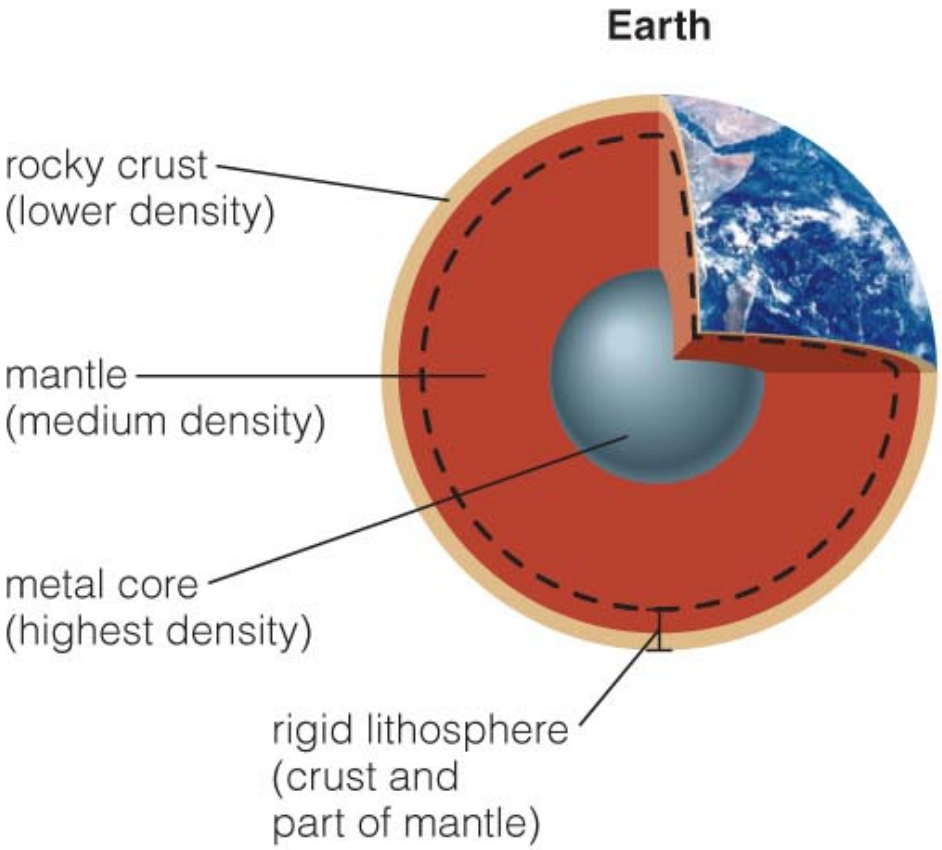
- Applying what we have learned about Earth's interior to other planets tells us what their interiors are probably like.

Differentiation



- Gravity pulls high-density material to center.
- Lower-density material rises to surface.
- Material ends up separated by density.

Lithosphere

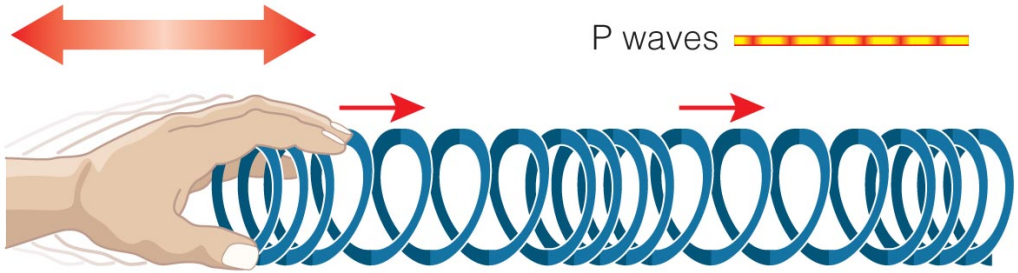


- A planet's outer layer of cool, rigid rock is called the *lithosphere*.
- It "floats" on the warmer, softer rock that lies beneath.

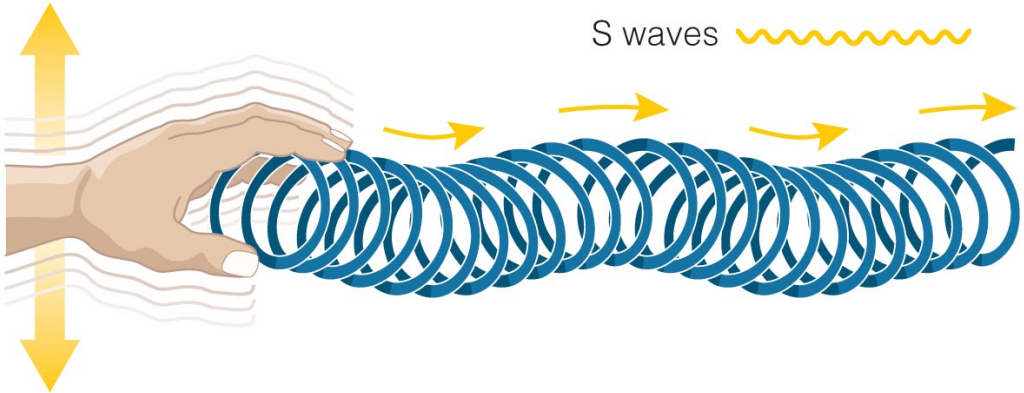
Strength of Rock

- Rock stretches when pulled slowly but breaks when pulled rapidly.
- The gravity of a large world pulls slowly on its rocky content, shaping the world into a sphere.

Special Topic:
How do we know what's inside a planet?

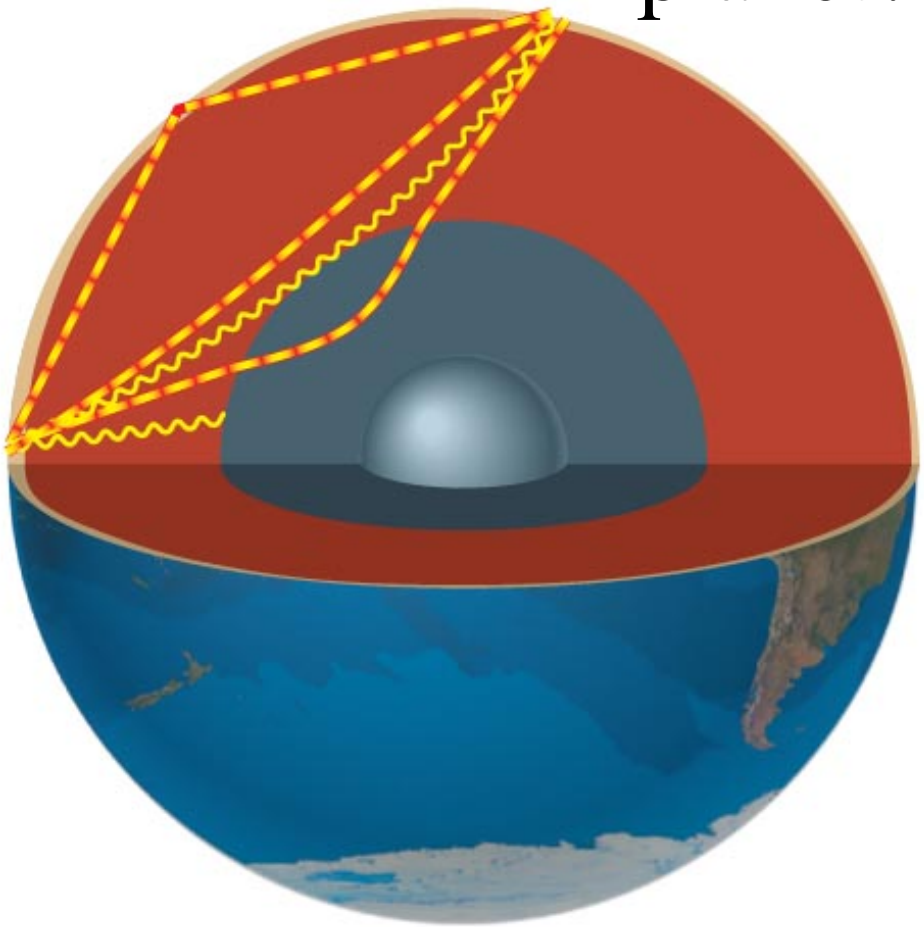


- P waves push matter back and forth.



- S waves shake matter side to side.

Special Topic:
How do we know what's inside a planet?



- P waves go through Earth's core, but S waves do not.
- We conclude that Earth's core must have a liquid outer layer.

Clicker Question

What is necessary for *differentiation* to occur in a planet?

a) It must have metal and rock in it.

b) It must be a mix of materials of different density.

c) Material inside must be able to flow.

d) All of the above

e) b and c

Clicker Question

What is necessary for *differentiation* to occur in a planet?

a) It must have metal and rock in it.

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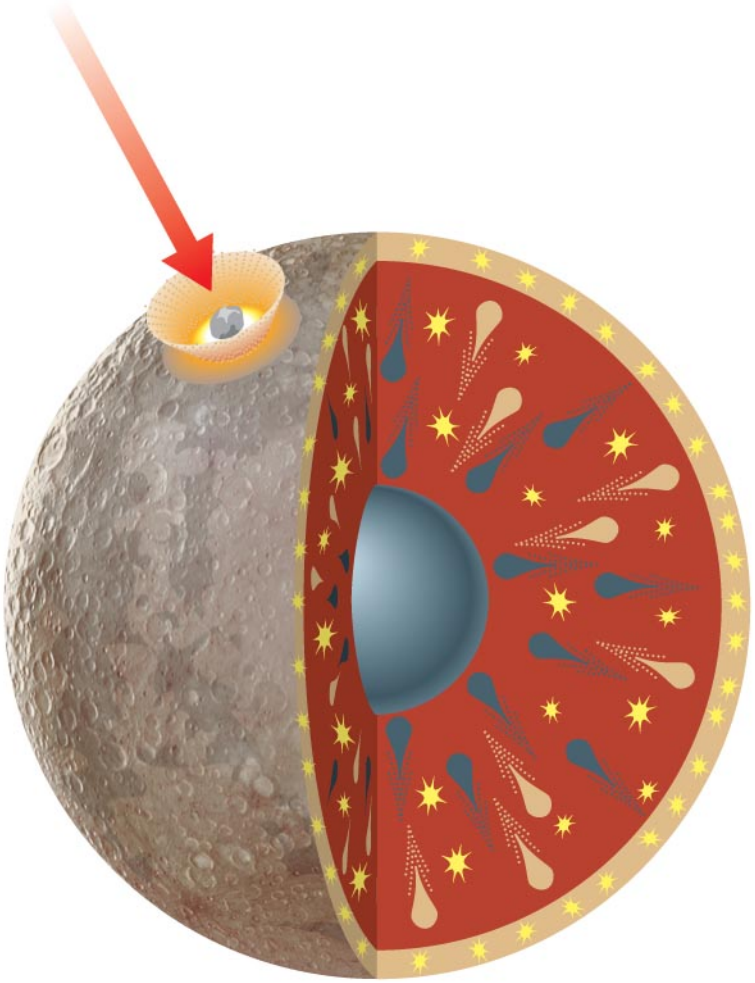
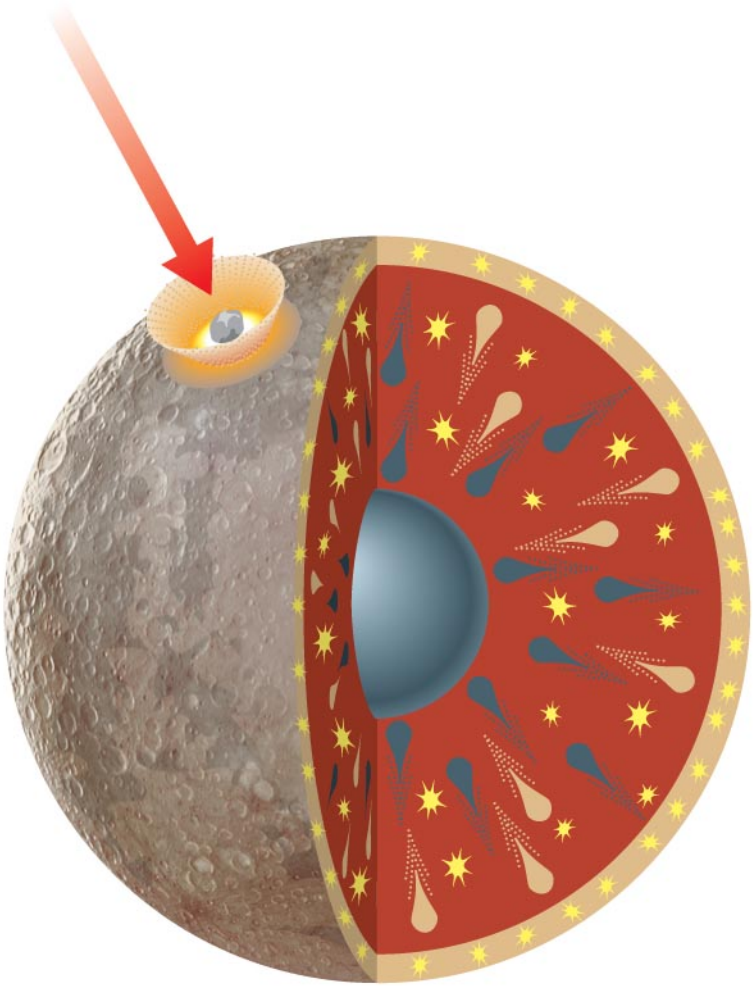
What causes geological activity?



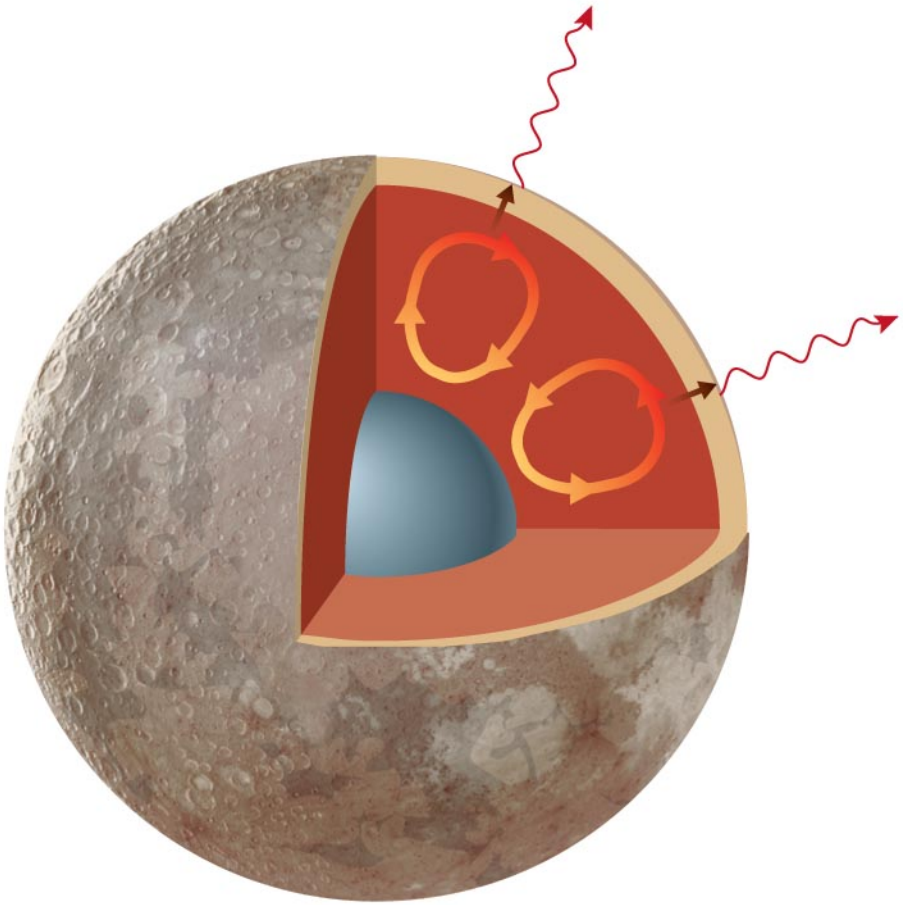
Heating of Planetary Interiors



- Accretion and differentiation when planets were young
- Kinetic energy of planetesimals → heating up planet

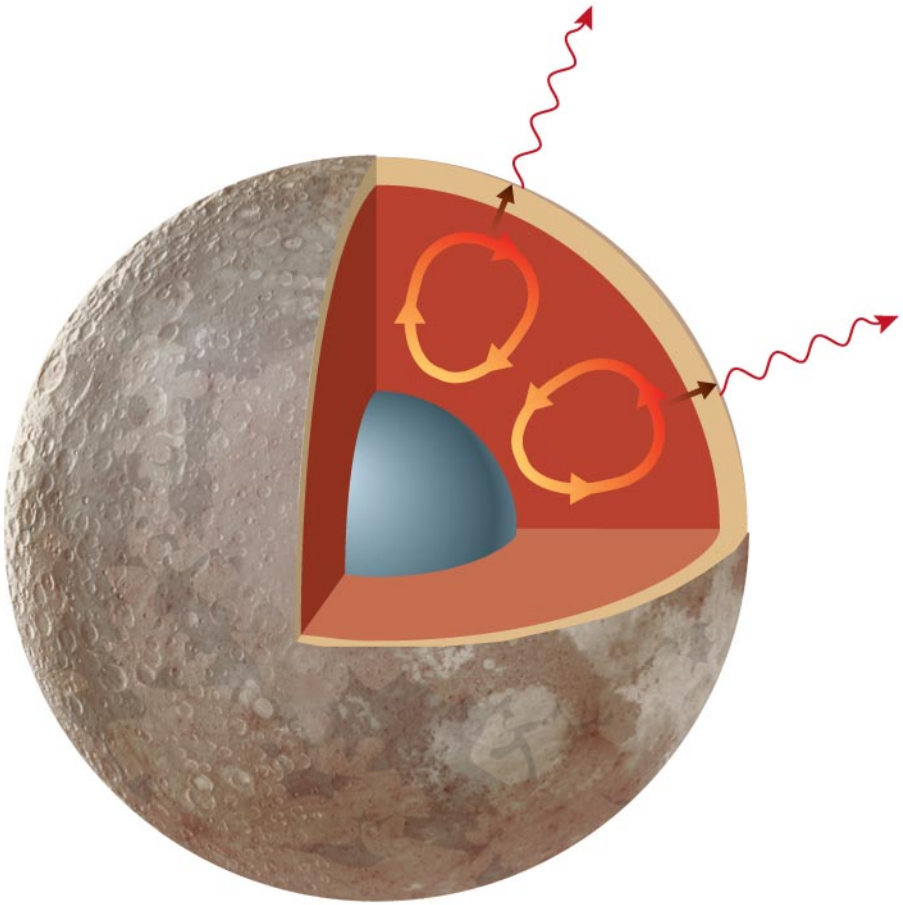
- Radioactive decay is most important heat source today
- Emission of gamma rays and fast-moving nucleons →heating up planet

Cooling of Planetary Interiors



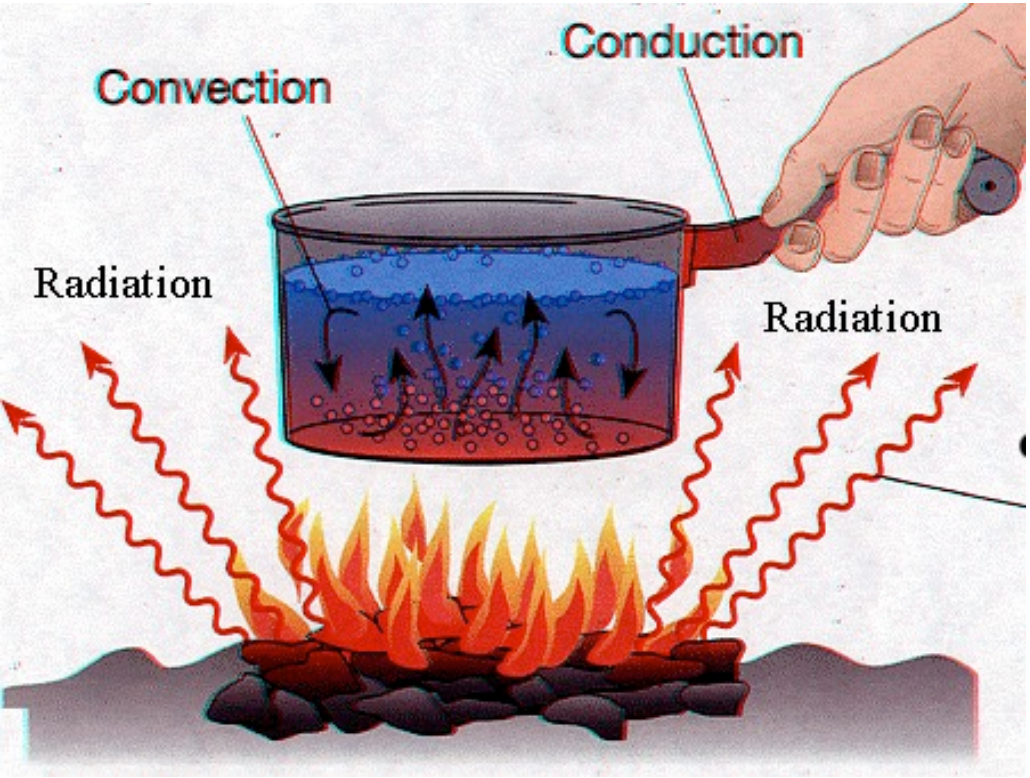
- **Convection** transports heat as hot material rises and cool material falls.
- **Conduction** transfers heat from hot material to cool material.
- **Radiation** sends energy into space.

Cooling of Planetary Interiors



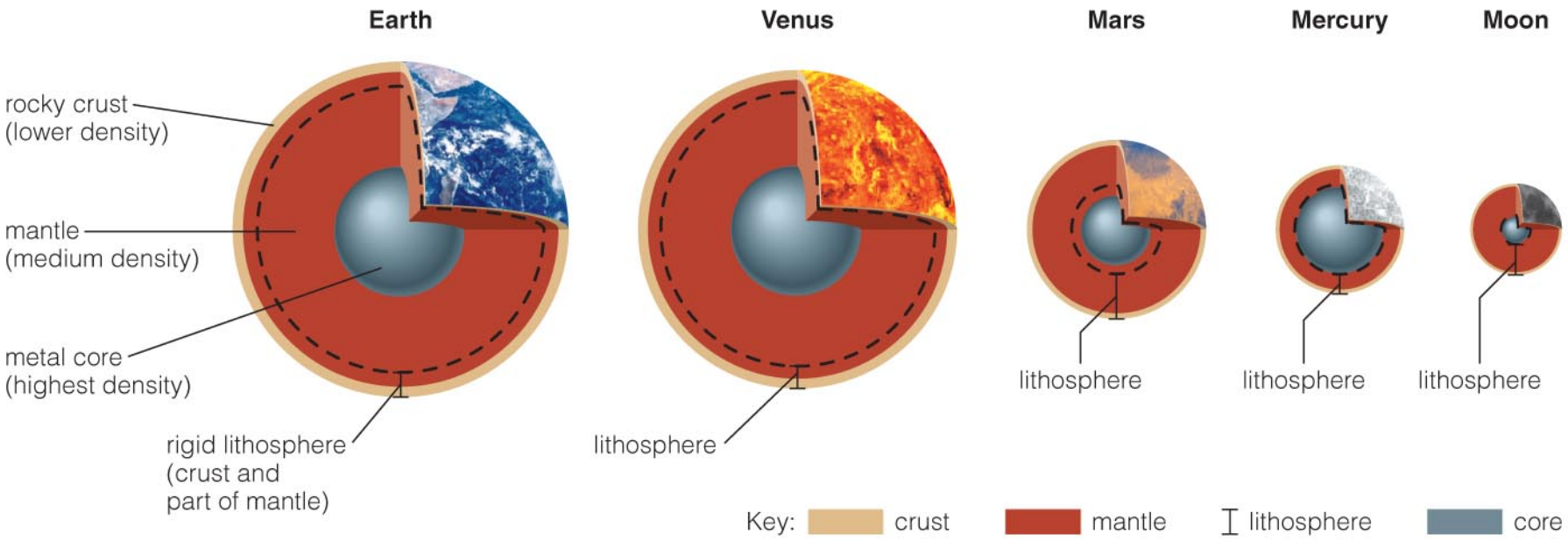
- **Convection** is slow in planets since the material is malleable rock, not liquid.
- Speed of ~1 cm/ year, means 100 Myr overturn time from bottom of mantle to top

Convection, Conduction, and Radiation



- **Convection:** motions of macroscopic hot and cold "blobs" of material. Efficient if material is mobile
- **Conduction:** transfer of energy at the molecular level—vibrations. Works best at high density
- **Radiation:** transfer of energy via photons. Efficient at low density with los opacity

Role of Size



- Smaller worlds cool off faster and harden earlier.
- The Moon and Mercury are now geologically "dead."

Surface Area–to–Volume Ratio

- Heat content depends on volume.
- Loss of heat through radiation depends on surface area.
- Time to cool depends on surface area divided by volume:

$$\text{Surface area–to–volume ratio} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$$

- Larger objects have a smaller ratio and cool more slowly.