Astronomy 210

This Class (Lecture 30):

Solar Neutrinos

Next Class:

Stars: Physical Properties

Solar Observing due April 15th

HW 8 due on Friday.

Outline

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^{+} + \nu$$

ν (Greek letter "nu") = **neutrino**

- Particle produced in nuclear reactions ***only***
- Tiny mass: $m(\nu) < 10^{-6} m(e)$!
- Moves at nearly the speed of light
- ***Very*** weakly interacting

Discovery of neutrino in lab: *Nobel Prize*

10 billion from Sun go through hand every sec
- Reach out!
- Go through your body, Earth, but almost never interact

Neutrinos

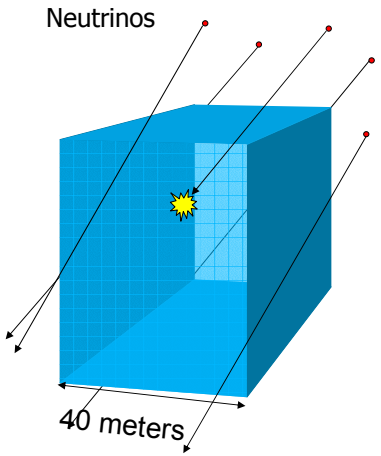
- The Sun's nuclear fusion also produces a particle called a *neutrino*
- Matter is almost transparent to neutrinos
- On average, it would take a block of lead over a quarter of a light-year long to stop one
- Roughly 100 billion pass through every square centimeter of you every second!
- They escape the Sun immediately, not in hundreds of thousands of years

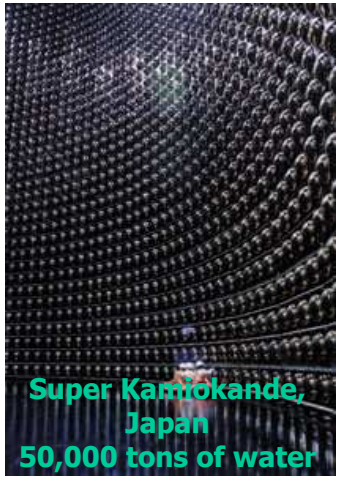
Cosmic Gall

NEUTRINOS, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold shoulder steel and sounding brass,
Insult the stallion in his stall,
And scorning barriers of class,
Infiltrate you and me! Like tall
and painless guillotines, they fall
Down through our heads into the grass.
At night, they enter at Nepal
and pierce the lover and his lass
From underneath the bed-you call
It wonderful; I call it crass.

- *Telephone Poles and Other Poems*, John Updike, Knopf, 1960

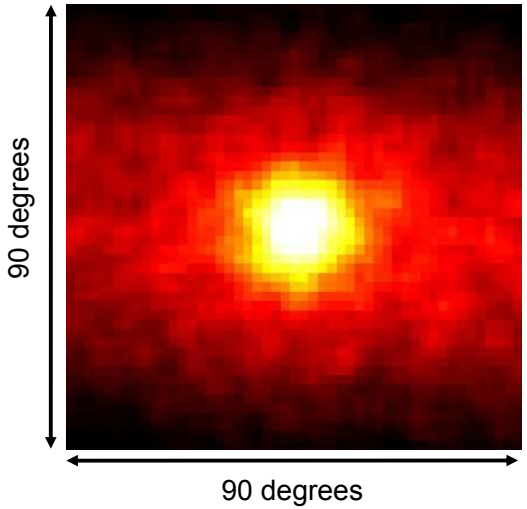
Detecting Neutrinos





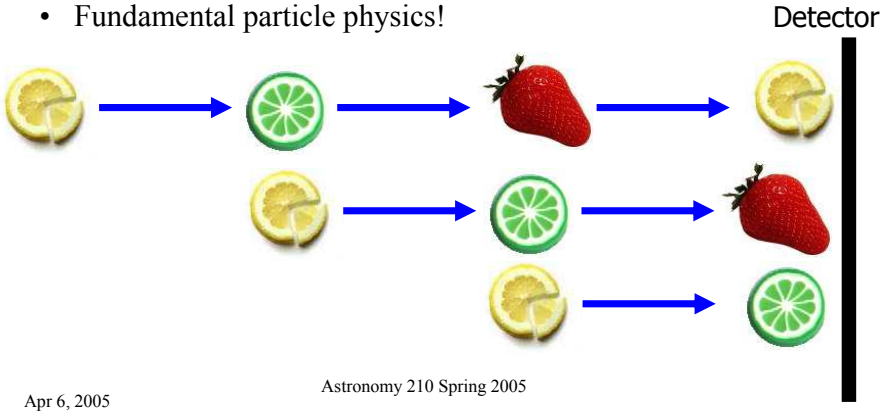
The Sun in Neutrinos

- The **confirmation** that nuclear fusion is happening in the Sun's core (this is how we know its temperature)
- 500 days of data
- As they can only be produced by nuclear processes, our energy source concept must be fundamental!
- These are neutrino telescopes!



The Solar Neutrino Problem

- Only 1/3 the predicted number of neutrinos is seen!
- It turns out, neutrinos come in three types
  - Neutrinos can change type
  - Experiments only looked for one type
- Fundamental particle physics!



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very little

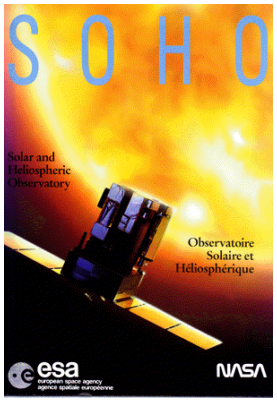
hardly

- *Telephone Poles and Other Poems*, John Updike, Knopf, 1960

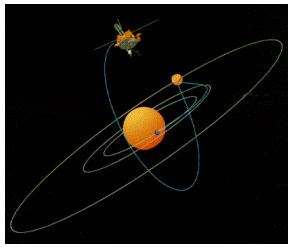
Think-Pair-Share

If we could sustain fusion in the lab we could meet humankind's energy needs forever! Why is it so difficult to achieve this, when stars do it every day?

Spacecraft Observing the Sun



SOHO

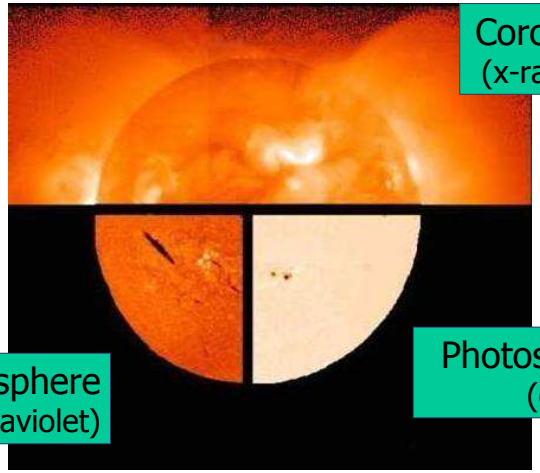


Ulysses

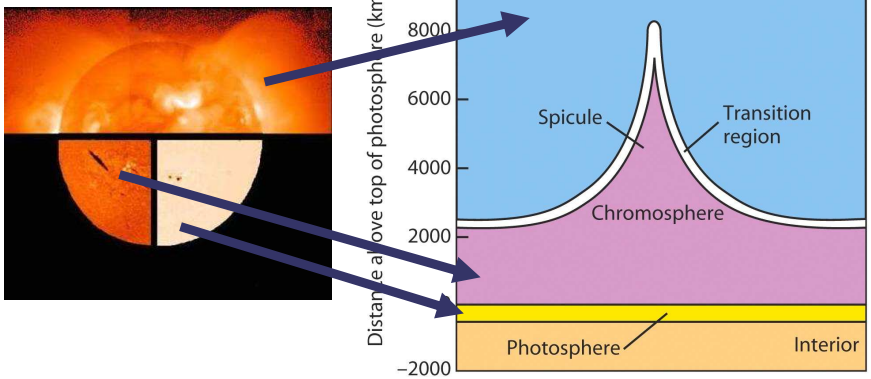
TRACE

RHESSI

The Outer Layers of the Sun

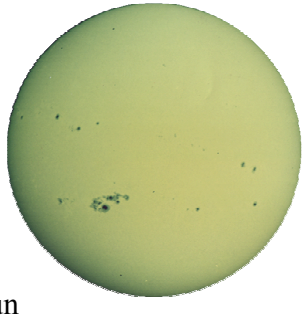


Structure of the Outer Layers



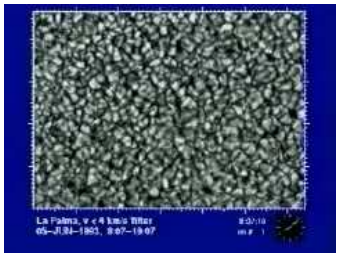
The Photosphere

- Apparent "surface" of the Sun
  - Ionized atoms make the gas highly opaque
- Most of the Sun's light we see comes from the photosphere
- Temperature, about 5800 K
  - Hotter as you go deeper into the Sun



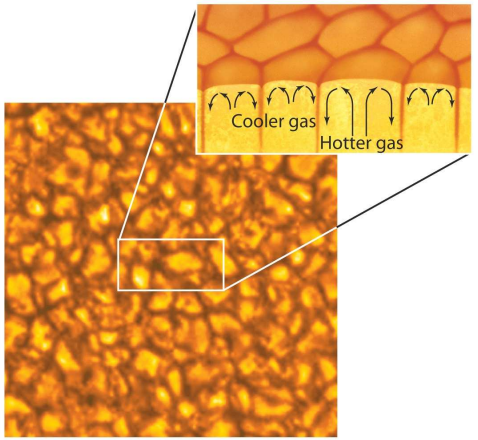
Granules

- The photosphere is not smooth
- Covered in **granules**
  - About 700 km across!
- Like a pot of boiling water

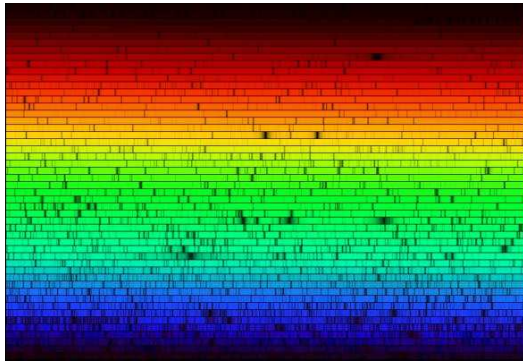


Granules

- Granules are the tops of *convection cells*
- Hot gas from below rises up
- Radiates energy
- Cools and falls back into the photosphere

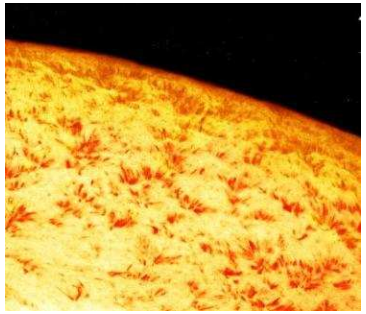


Solar Spectrum Lines



- The Sun shows dark spectrum lines
- Upper part of the photosphere is cooler than the lower part
- Cooler gas around a continuous spectrum source
- Therefore, we get an absorption spectrum!

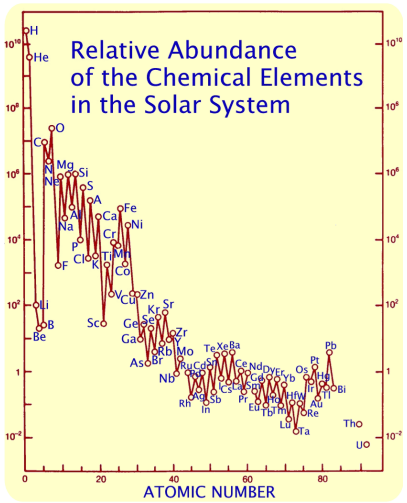
The Chromosphere



- Very sparse layer of gas above the photosphere
- Hot – Over 10,000 K
- Produces very little radiation – too sparse
- Only seen during eclipse or with special instruments
- Helium was first discovered in the chromosphere

Solar Composition

- From the spectrum lines, we can determine the Sun's composition
  - 92% Hydrogen
  - 8% Helium
  - Less than 0.1% other stuff



The Corona

- Sun's outer atmosphere
- Visible only by blocking light from photosphere
- Heated by magnetic activity
- Temperatures about 2 million K
- Hot enough to produce X-rays!

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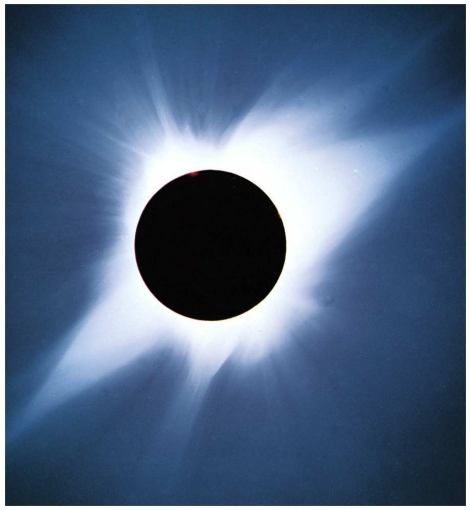
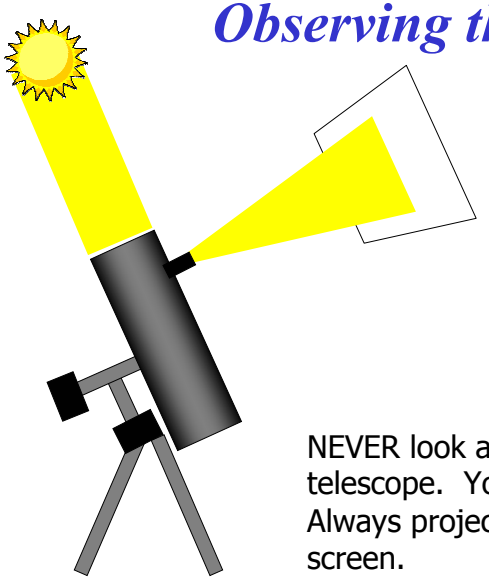
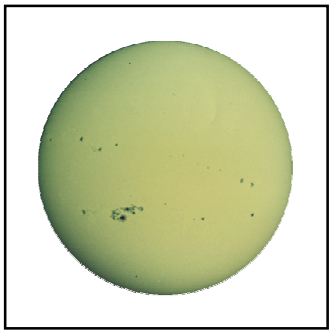


Observing the Sun

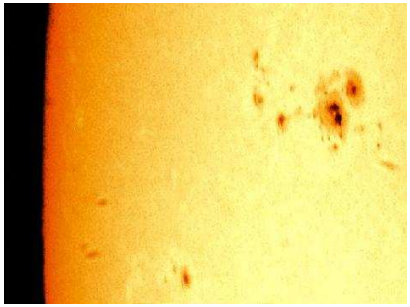


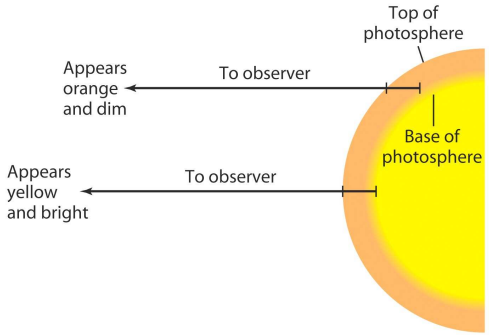


NEVER look at the Sun through a telescope. You will damage your eyes! Always project the Sun's image onto a screen.

Limb Darkening

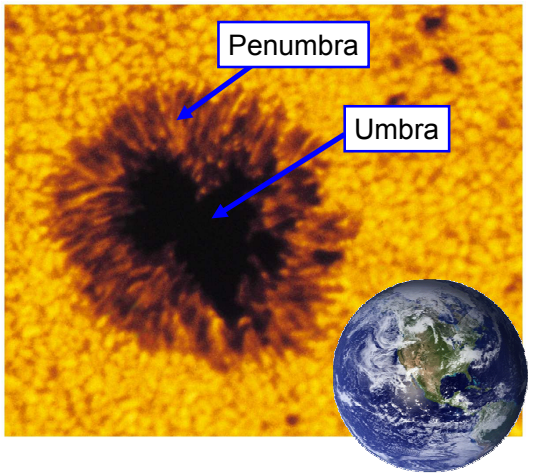
- Sun's photosphere is less bright around the edge (limb)
- Top of the photosphere cooler than the base and thus less bright (remember Stefan-Boltzmann law)





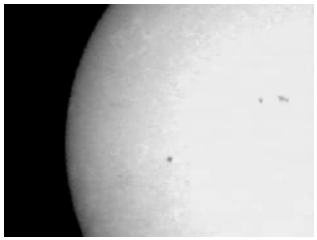
Sunspots

- Dark spots on the photosphere
- Tend to appear in pairs & groups
- Sizes: 1,500 – 50,000 km



Sunspot Motion

- Sunspots' motion reveals the Sun's rotation!
- The Sun spins about once every 25 days at the equator
- At the poles, it spins once every 30 days
- Called **differential rotation**



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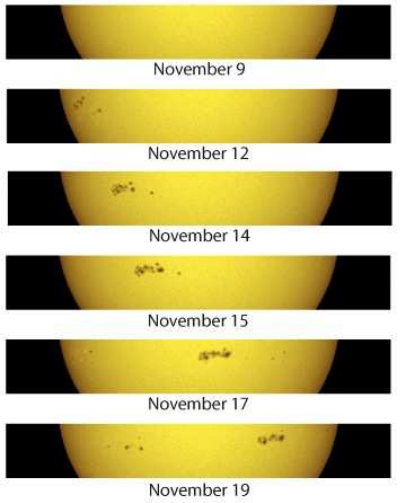
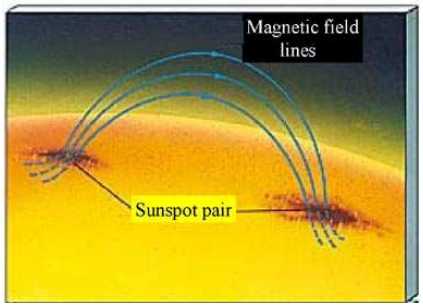
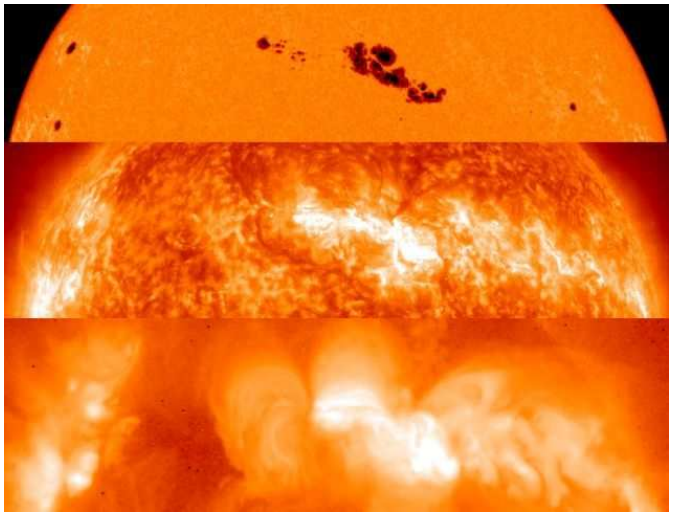


What Causes Sunspots?

- Magnetic field "loops" popping through the photosphere
- Powerful magnetic activity shuts down convection
  - 5,000 times stronger than the Earth's field
- Gas cools off (4500 K)
- Appears darker than the rest of the photosphere



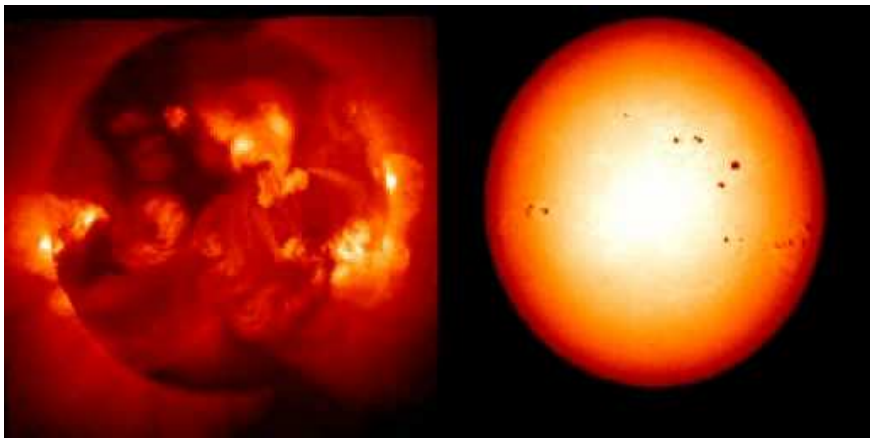
Sunspots and the Outer Layers



Sunspots and the Outer Layers

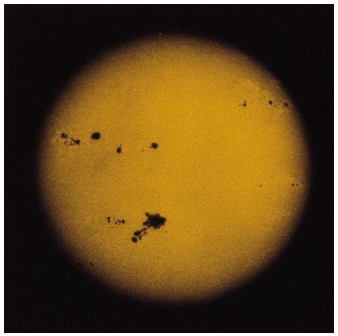
- Sunspots appear as dark spots on the photosphere
- Their magnetic activity actually heats the upper layers
- Regions above sunspots appear bright in the chromosphere and corona

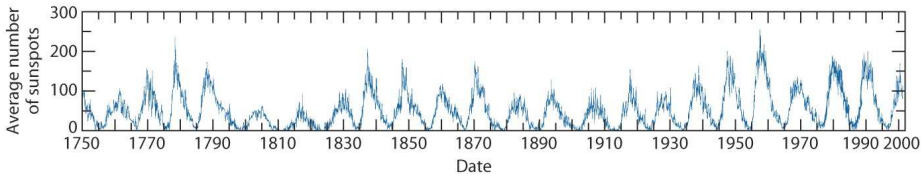
Sunspots in X-rays



The Sunspot Cycle

- The number of Sunspots on the Sun's surface varies
- Reaches a maximum every 11 years

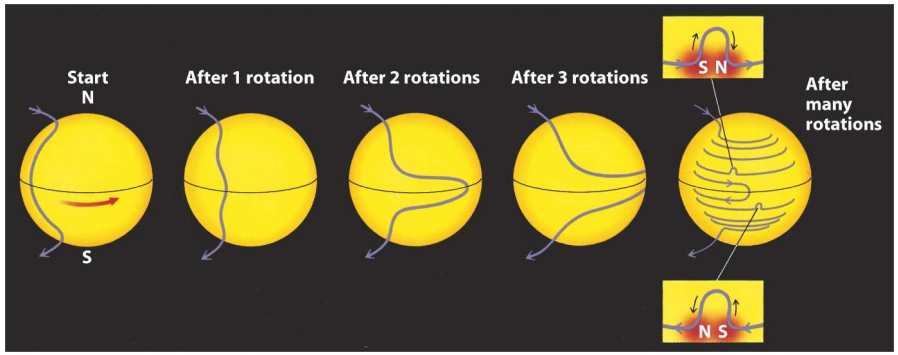




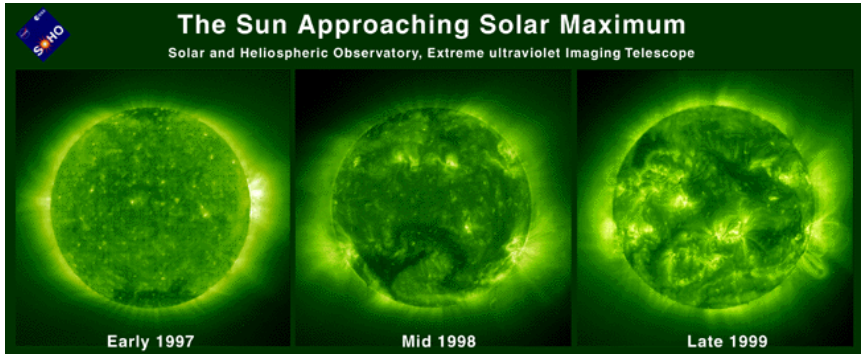
The Magnetic Cycle

- Sun's magnetic field comes from its surface
- Convection and differential rotation twist and wrap magnetic field lines
- When field lines get too twisted, they pop through the surface
  - Makes sunspots!
- Every 11 years, the field breaks apart and reorders itself
  - North and south flip!

The Magnetic Cycle

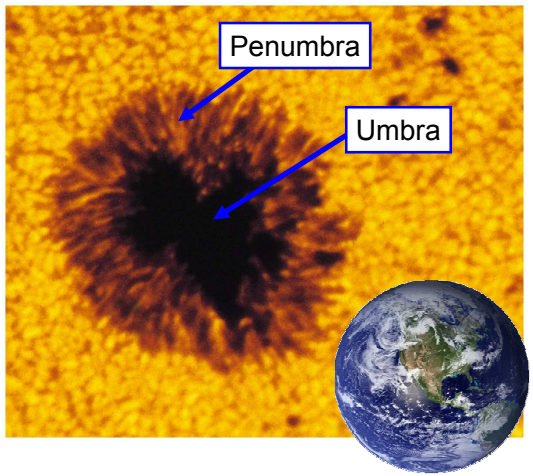


Magnetic Activity on the Sun



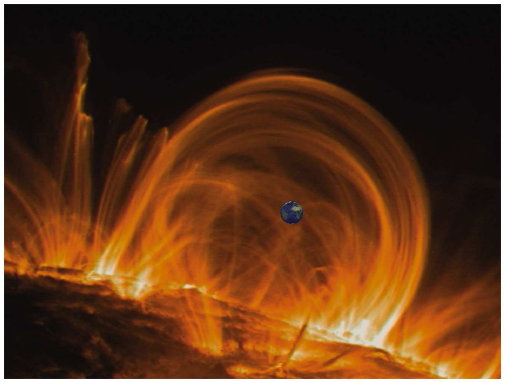
Sunspots - Review

- Caused by strong magnetic field "loops" popping through photosphere
- Convection is shut down

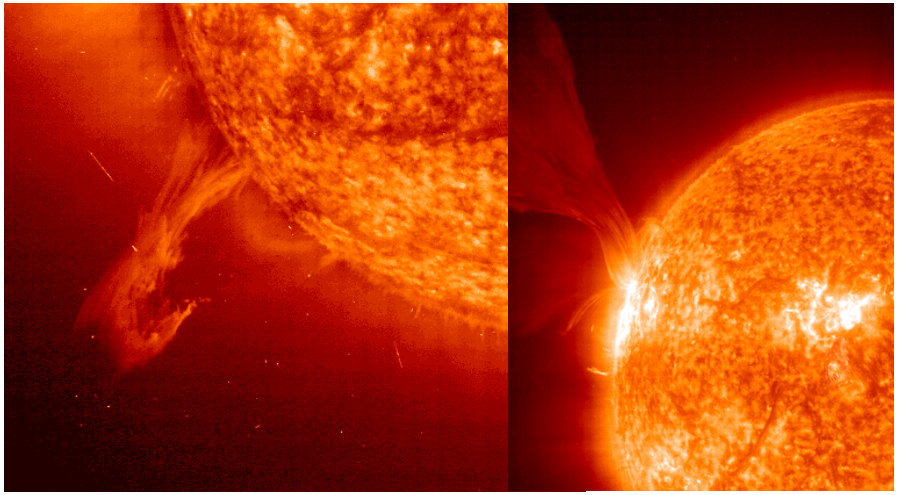


Prominences

- Ropes of gas trapped in magnetic loops
- Almost always associated with sunspots
- Gas can reach temperatures of 50,000 K!



And more…



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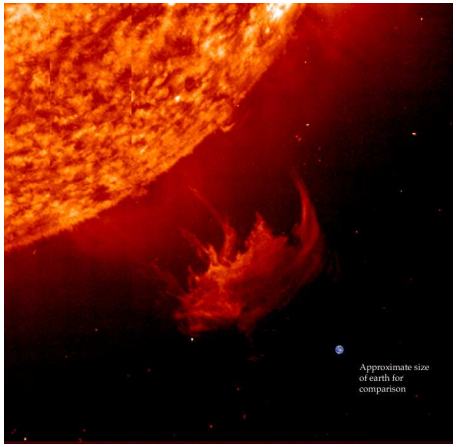
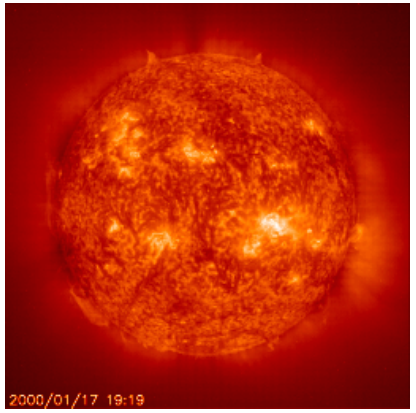
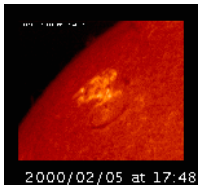
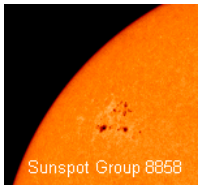


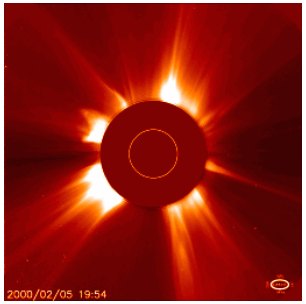


Solar Flares

- Explosive releases of magnetic energy above sunspot groups
- Occur when magnetic loops get tangled
- A "short-circuit" of the magnetic field

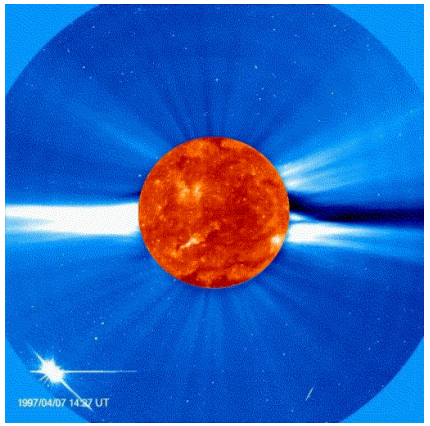






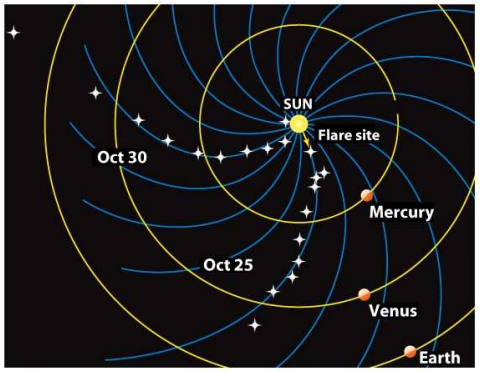
Coronal Mass Ejections

- Huge bubbles of gas ejected from the Sun
- Often associated with flares and/or prominences
- 2 trillion tons of ionized gas hurled into the solar system
  - Can have catastrophic effects on satellites
- 2-3 day at solar maximum
  (1 per week normally)



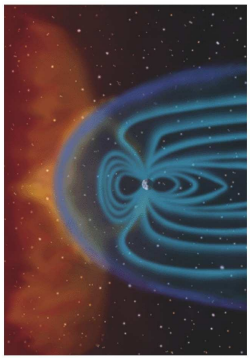
Solar Wind

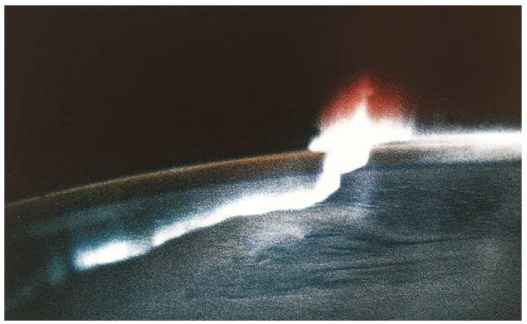
- Some of the gas in the Sun's corona is moving fast enough to escape the Sun's gravity
- Accelerated by the Sun's magnetic field
- Flows out into the solar system
- Made of charged particles



Space Weather

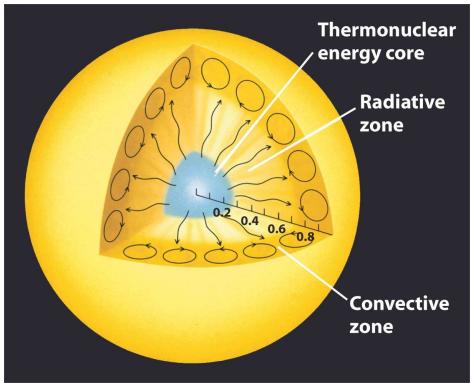
- Solar wind and mass ejections interact with the Earth, producing *aurorae*
- Also can disrupt satellites





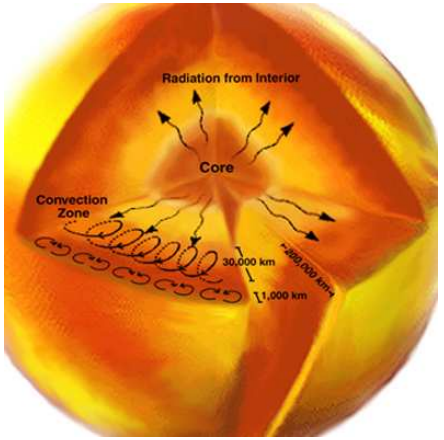
The Solar Interior

- Inside the core
  - Central density over 10 times that of lead
  - 15 million K!
- Core contains 40% of the Sun's mass
  - Enough fuel to last 10 billion years
  - Currently about halfway through its fuel supply



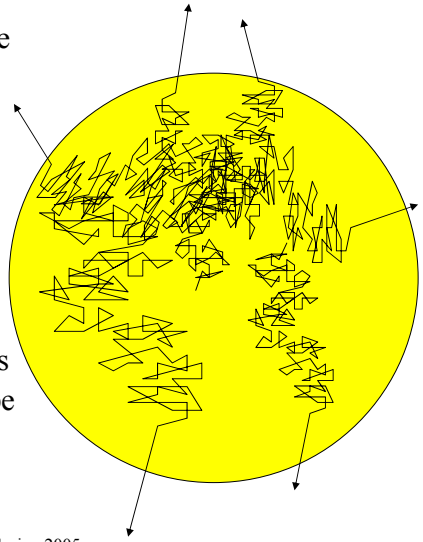
The Radiative Zone

- Just outside the core
- Temperature is too low for nuclear fusion
- Insulates the core, keeps it hot
- Quiet, stable
- Energy from the core moves out by radiation



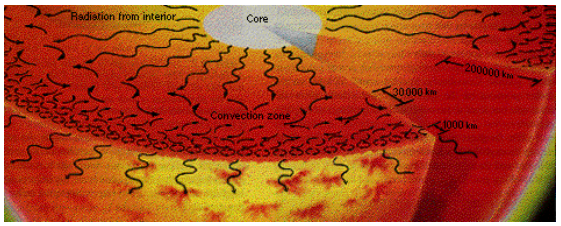
Inside the Radiative Zone

- Photons created by fusion in the core
- Absorbed by atoms and re-emitted as multiple lower-energy photons
- This is repeated over and over again
- Takes hundreds of thousands of years for the energy to get from the core to the outer layers
- Remember that neutrinos escape the Sun immediately!



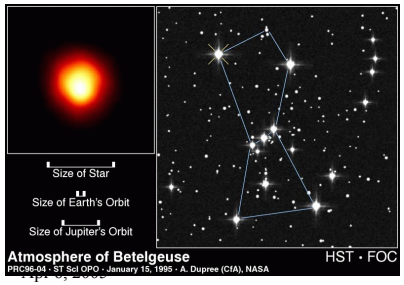
The Convective Zone

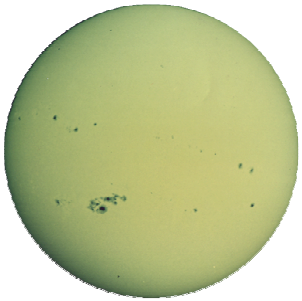
- Outside the radiative zone
- Transports energy by convection rather than radiation
- Hot gas rises, cool gas falls
- Photosphere is the very top of the convective zone

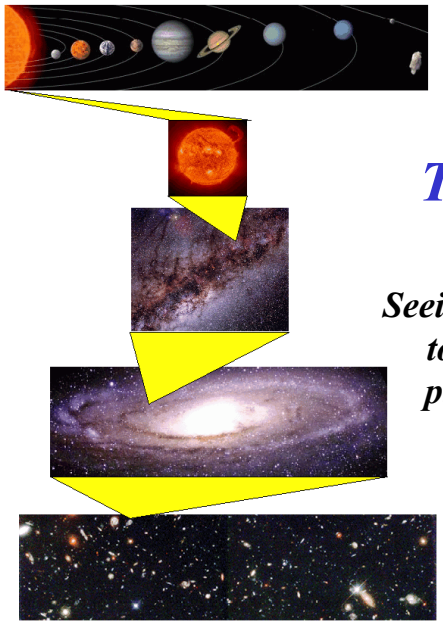


Stars as Suns

- The Sun is a nuclear reactor, but I'm saying much more than that: Sun is a typical star
- So all stars are run by thermonuclear fusion
- Night sky, Universe lit up ultimately by dense nuclear furnaces scattered everywhere
- How do we know Sun is typical?







Astronomy: The Big Picture

Seeing how all these pieces fit together into a coherent picture of our Universe!