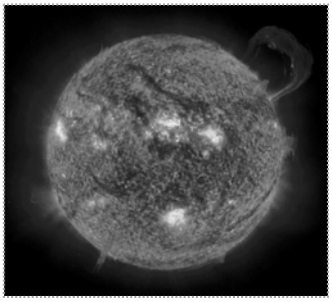
ASTR 1120: Stars & Galaxies



Prof. Juri Toomre TA: Ben Brown

Lecture 10 Wed 2 Feb 05

zeus.colorado.edu/astr1120-toomre

Topics for Today

- Solar neutrinos and catching them
- Different layers of Sun and their roles
- Using helioseismology to probe the inside
- *Next lecture:* Helioseismology, and then to *Solar Magnetism*, and its wild world of sunspots, flares and coronal mass ejections

- *Homework # 3* due this Friday
- *Special SOLAR Day Observing* this Thurs, Feb 4, 11am-1pm (by signup)

Those Mysterious Neutrinos

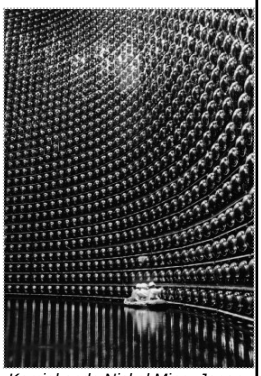
MADE BY P-P BURNING IN CORE

REMINDER

- *Mass-less or with very small masses,* travel close to speed of light
- *Don't interact (almost) with other matter:* requires lead wall 1 light year thick to stop a neutrino!
- *Lots of them:* 10^{38} neutrinos/sec from the Sun, 10^{15} coming through YOU each sec !
- But we can still catch some, using massive underground "detectors": *BIG PUZZLE*

Resolving the Solar Neutrino Puzzle

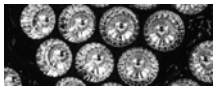
- *Super-Kamiokande* uses massive tank of water to capture neutrinos
- Each rare capture gives flash of light, detected by giant tubes
- Captures lower energy neutrinos from p-p chain, so more sensitive test of fusion
- Suggests some electron neutrinos may change into muon and tau neutrinos during course of flight to us (8 minutes)
- *Neutrino Oscillations* require neutrinos to have some mass!

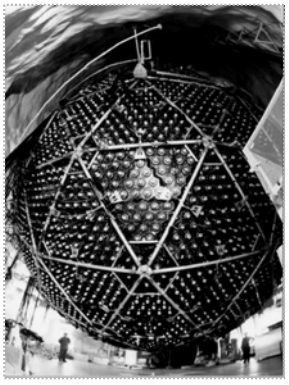


Kamiokande Nickel Mine, Japan

Sudbury Neutrino Observatory (SNO)

- Uses *"heavy water"* -- some H in H_20 replaced by its stable isotope deuterium (P+N)
- SNO is capturing all three types of neutrinos (electron, muon, tao)
- *"Solar neutrino problem"* leads to big physics advance (2002 Nobel Prize; Davis & Koshiba)





Clicker -- Solar Neutrinos

- *Do you think neutrinos flowing through our bodies are a cause of cancer or other damage?*

- *A.* YES, because there are so many and they carry a lot of energy
- *B.* NO, because they don't interact with anything and just flow through

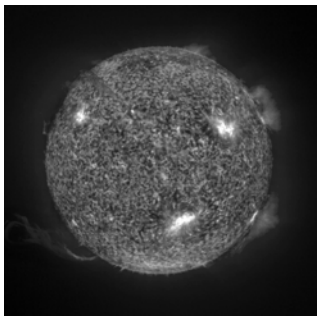
Neutrinos

- B. Neutrinos don't deposit any energy in our bodies- they simply don't do anything to us (or so we think) !

Heading outward (slow & fast)

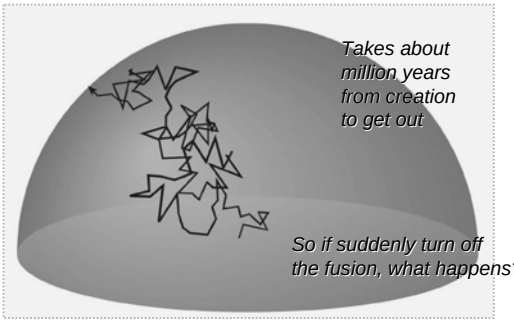
Gamma rays slowly work their way outwards, cool, and become sunlight (about million years)

Neutrinos don't interact with much, zoom right out of Sun and into space, *carry 2% of the Sun's energy* – even travel right through Earth!



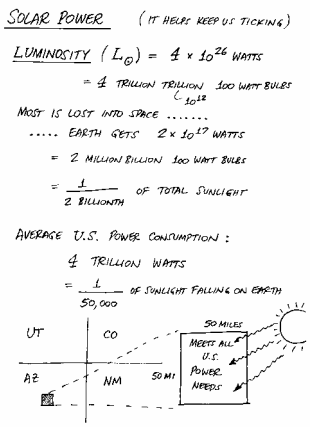
Meanderings of outbound photons

P-P chain makes gamma-ray photons, which "random walk" outwards (getting absorbed, re-emitted), gradually cooling



SOLAR POWER

..or how much is much?



All sunlight falling on 50 mile x 50 mile patch is US energy use

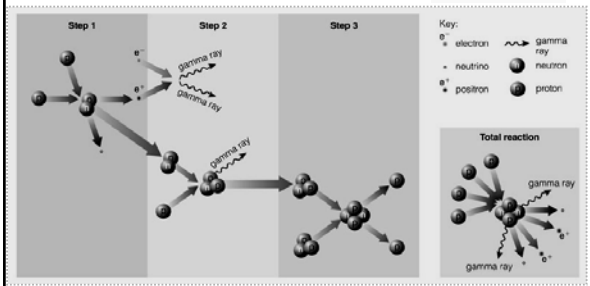
Reading Clicker Q *D.*

- *How much fuel (hydrogen) does the Sun BURN (fuse by nuclear means) every second to make all its light?*

- A. 200 tons
- B. 2000 tons (2 thousand tons)
- C. 2,000,000 tons (2 million tons)
- D. 600,000,000 tons (600 million tons)

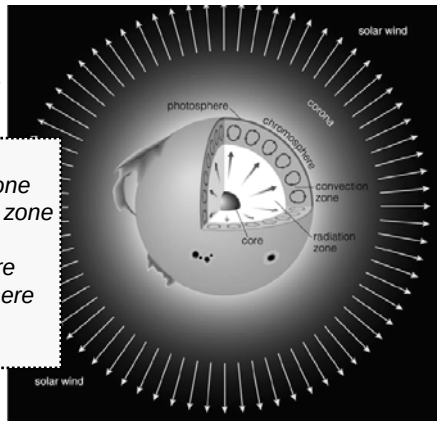
Proton-Proton (P-P) Chain

Thermonuclear FUSION *REMINDER*



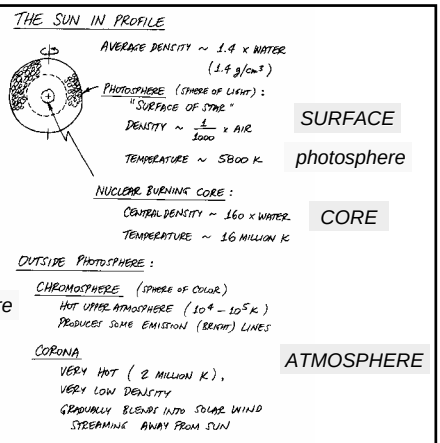
Burn 600 million tons of H every sec, making 596 million tons of He and `4 million tons goes into ENERGY'

Big System View of Sun



core
radiative zone
convection zone
- - - - -
photosphere
chromosphere
corona
solar wind

SUN IN PROFILE



Vast range in temperature and density

SURFACE

photosphere

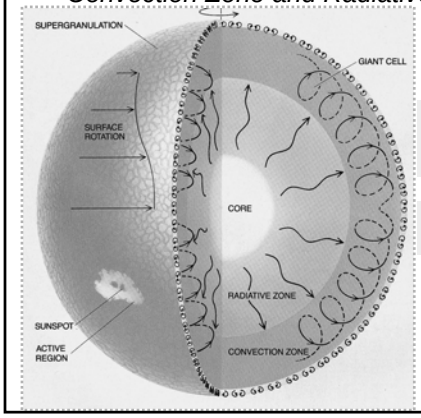
CORE

chromosphere

corona

ATMOSPHERE

Convection Zone and Radiative Interior



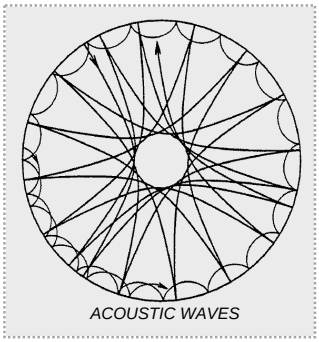
Just below the photosphere:

Deep shell (30%) of very turbulent convection

Drives strong differential rotation

But how do we know this?

Helioseismology: *Millions of sound waves available to probe solar interior*



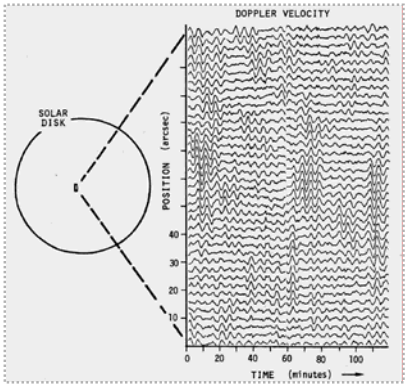
ACOUSTIC WAVES

Some waves noodle just below the surface

Others almost make it to the center

All excited by turbulent granulation visible in photosphere

Five-Minute Oscillations at Solar Surface



OSCILLATING PATCHES

How Sound Makes A Surface Bounce

- Sound waves inside Sun cause the photosphere to move up and down, with "five-minute oscillations"
- Can detect these with Doppler imaging of gas at solar surface ("see" the sound)
- *Time for demos of SOUND waves*