Stars, Galaxies & the Universe Announcements

- **Quiz #5 today in class**
- **HW#5 due Friday (10/1) at 5 pm**
- **From now on, HWs due Friday!!**
- **No labs this week – back to regular schedule next week!**
- **Observing trip instead – TUESDAY AND THURSDAY**
  - Weather looks good – ***please arrive at 7 pm EAST END VAN Hall***
  - Dress warmly and appropriate shoes
  - **Website will be updated if trip is canceled due to weather: http://astro.physics.uiowa.edu/~clang/sgu_fall10/observing_trip.html**
- **Exam #1 grades are posted in ICON and answer keys are also available (both Form A and B) on the course website**
  - No extra credit on exams, but please come see me if you want to talk over your exam – it will definitely help you to better prepare for the next exam

The Sun – our Star

- Powering of the Sun & all stars
- Forms of energy released
- Neutrinos
- Layers of the sun & how energy escapes

How does the Sun Shine?

- Sun has its own energy source
  - main difference between a star and planet
- Sun's energy source not well understood until the 1900s!
- Main constraint: Lifetime of the Sun
  - need a vast, constant generation of energy
  - Sun's age: at least 4.6 billion years old (fossils)
  - most original ideas could not SUSTAIN energy rate
- Additional constraint: Luminosity (energy/s) of the Sun
  - rate of energy generation: 3.9 x 10^{26} Joules/second
  - example: energy released when apple falls a meter!

Possible Solar Heating Mechanisms

1. GRAVITATIONAL COLLAPSE

- pressure of Sun's layers → contraction
- gas temperature increases as gas contracts

→ ***Sun would have started as hundreds of times larger and could only be 25 million years old to produce energy rate!***

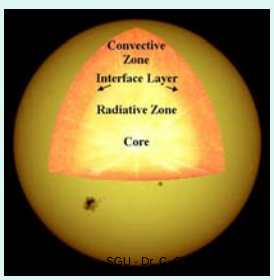
2. COMBUSTION (burning/fire)

- burning of the Sun's fuel: hydrogen, helium
- **Sun would burn itself out in only 10,000 years!!**

Need a more powerful, longer lasting energy source !!

More clues from deep inside the Sun...

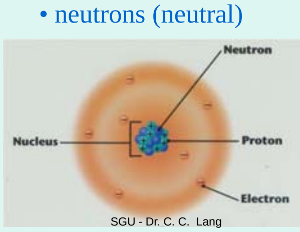
The very core of the Sun is close to 15 million K
→ reservoir of Hydrogen under ***extreme*** *temperatures and pressures*



The Basics of *Nuclear Fusion*

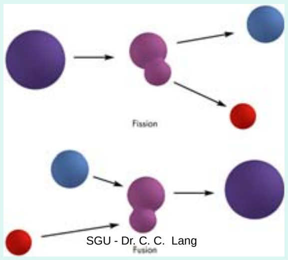
Nucleus: the positively charged concentration of matter at the center of an atom

- protons (positive)
- electrons (negative)
- neutrons (neutral)



Nuclear Interactions

- occur when a nucleus is struck by another nucleus
- extremely rare (but usually there are many nuclei)
- need high density, high temperature (collisions!!)
- in nuclear reactions, ELEMENTS → new ELEMENTS

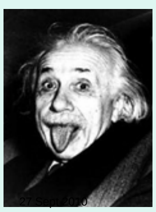


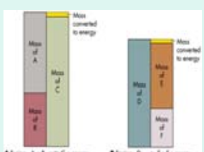
NUCLEAR FUSION!

- 2 nuclei → are converted → into 1 new nucleus
- this process generates ENERGY
- NUCLEAR "ENERGY" is the conversion of mass to energy

$$E=mc^2$$

famous Einstein revelation – **mass=energy**





The slight difference in mass between the initial nuclei and the resulting nucleus is the energy released

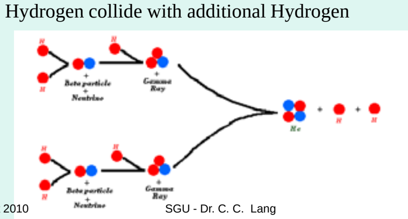
Nuclear Fusion via the Proton-Proton Chain

Very roughly: Hydrogen + Hydrogen = Helium + energy

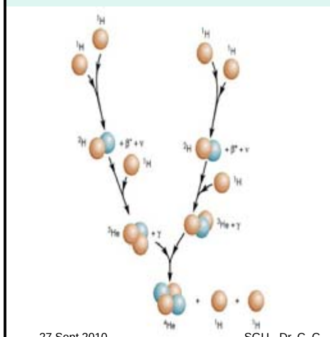
Hydrogen: a single proton
Helium: 4 particles: 2 protons, 2 neutrons

"Proton-Proton Chain"

like a multi-car pile up on the interstate
Hydrogen collide with additional Hydrogen



The proton-proton chain



Elementary particles

- **Protons (orange)** – found in nuclei, positive charge
- **Neutrons (blue)** – found in nuclei, no charge
- Electrons (e^-) – orbit nuclei, negative charge
- Photons (γ) – particles of light (gamma-rays)
- Positrons (b^+) – anti-matter electrons, positive charge (e^+ in book); "beta"-particles
- Neutrinos (ν) – `ghost particles', no charge, can easily pass through normal matter

Nuclear fusion: proton-proton chain

$$4(1H) \rightarrow He^4 + \text{energy}$$

$\mathbf{M_H = 1.673{\times}10^{-27}\ kg}$ $\mathbf{M_{He} = 6.645{\times}10^{-27}\ kg}$

$$\Delta M = 4\,M_{H^1} - M_{He^4} = 4.8 \times 10^{-29}\,\text{kg}$$

$$E_F = \Delta Mc^2 = 4.3 \times 10^{-12}\,J$$

where 1 MeV = $1.6\text{x}10^{-13}$ Joules, and $E_F = 26.7\ MeV$

Heating of the Sun: Nuclear Fusion

Eventually you get ENERGY released when Helium formed!

Hydrogen + Hydrogen + Hydrogen + Hydrogen = Helium +energy

difference in mass converted to energy

Two types of energy:

(1) gamma rays - highly energetic photons, carry energy out
get trapped in Sun's gaseous layers

(2) neutrinos – particles which carry energy with little mass
- do not get trapped in the Sun's gas layers

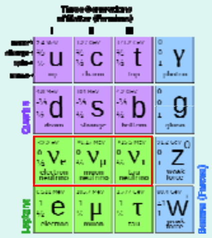
Test of fusion hypothesis: LOOK for neutrinos!

Neutrinos

•**Properties of Neutrinos**

- elementary particles
-travel at/near the speed of light
-perhaps massless (perhaps not)
- neutrinos can come in a variety of "flavors": electron, muon and tau

• 50 trillion solar electron neutrinos pass through the human body every second



Neutrinos

• detection of neutrinos would be proof of nuclear fusion in the core of the Sun

• conversion of H → He produces 10^{38} neutrinos/sec

• each second, 10^{14} neutrinos pass through each m^2 on Earth *...undetected...*

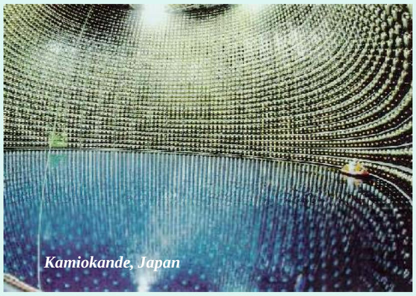
....however, in certain reactions (neutrinos with ^{37}Cl) neutrinos generate radioactive Argon (^{37}Ar)

→ *make "neutrino telescopes" using large vats of dry cleaning fluids: perchlorethylene $C_2 Cl_4$*

Neutrino Detectors across the World

Homestake Experiment in Lead, SD

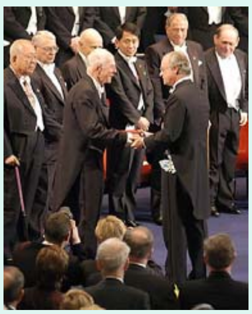
Sudbury Observatory in Sudbury, Ontario, Canada



Super Kamiokande is a large volume of water surrounded by phototubes that watch for the Cherenkov radiation emitted when an incoming neutrino creates an electron or muon in the water.

Receiving Nobel Prizes – Fall 2002

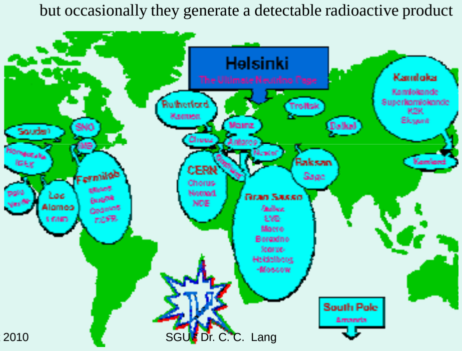
Dr. Masatoshi Koshiba



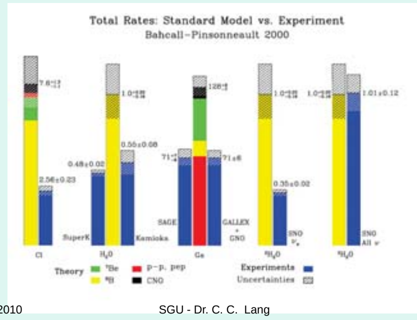
Dr. Ray Davis

Neutrino Detectors across the World

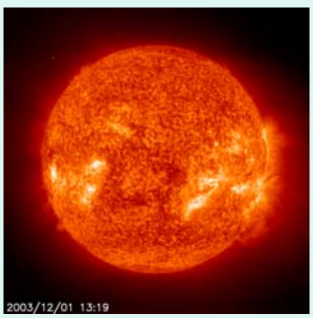
Neutrinos do not interact with matter in the way photons do…
but occasionally they generate a detectable radioactive product



The "NEUTRINO PROBLEM" – *the 'neutrino flux' measured by detectors is only 1/3 of theory value!*



Balance of *gravity* & *pressure* in the Sun

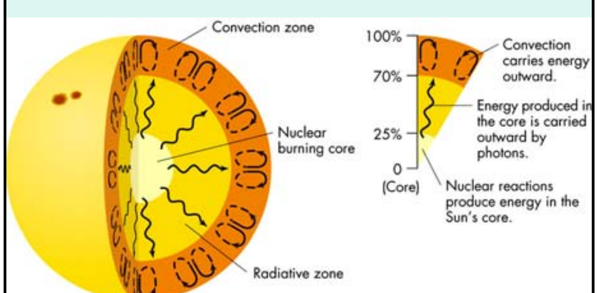


stability of the Sun:

- OUTWARD gas pressure

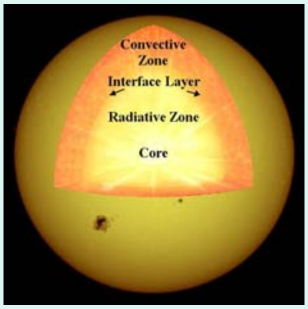
  balanced by

- INWARD gravity of Sun's incredible mass



The interior layers of the Sun

1. The CORE



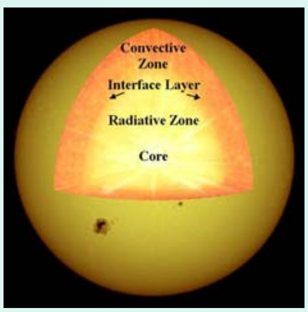
- innermost 25%
- T ~ 15 million K
- the density here is compressed by *entire* weight of Sun

→ 150x density of water!

- region where energy is generated by fusion

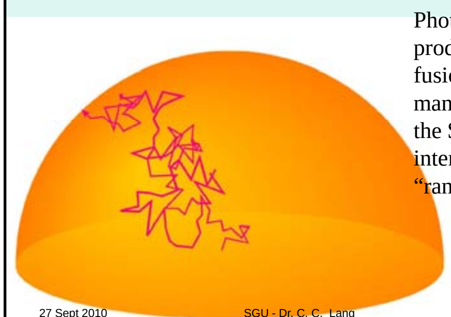
The interior layers of the Sun

2. Radiative layer



- solar "midsection"
- T ~ 1-10 million K
- energetic photons carry energy out of core
- energy lost to gas layers
- eventually, these photons get stuck in the gas layers

Transport of energy through the radiative zone



Photons produced via fusion scatter many times in the Sun's dense interior - a "random walk".

Random Walk

The same formula holds in 2 and 3 dimensions.

For the Sun, the average distance between collisions is about

l = 1 mm. Photons travel at the speed of light, so the time between collisions is

$t = l/c = 10^{-3}$ m $/(3\times10^{8}$ m/s$) = 3\times10^{-12}$ s

The radius of the Sun is $L = 7\times10^{8}$ m. The average number of collisions before a photon escapes is

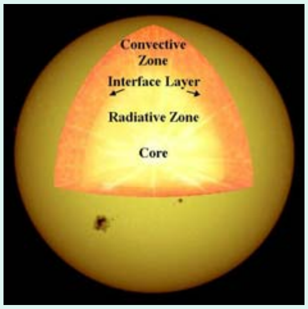
$n = (L/l)^2 = (7\times10^{8}$ m$/ 10^{-3}$ m$)^2 = 5\times10^{23}$

The average photon stays in the Sun for a time

$T = tn = (3\times10^{-12}$ s$)(5\times10^{23}) = 1.5\times10^{12}$ s = **50,000 years**

A **more accurate estimate gives 120,000 years**

The interior layers of the Sun



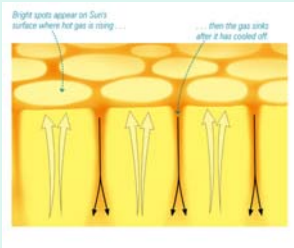
3. Convection region

- outermost 30%
- T ~ 10,000-1 million K
- rising, sinking of gas transports energy

HOT gas rises up
COOL gas sinks down

Convective zone

Evidence for Convection: Solar Granules



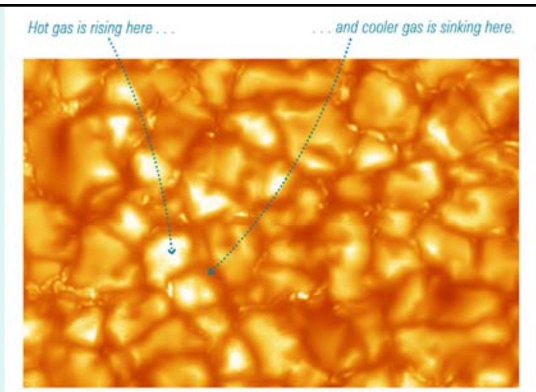
• on the solar surface

• 1000's miles across

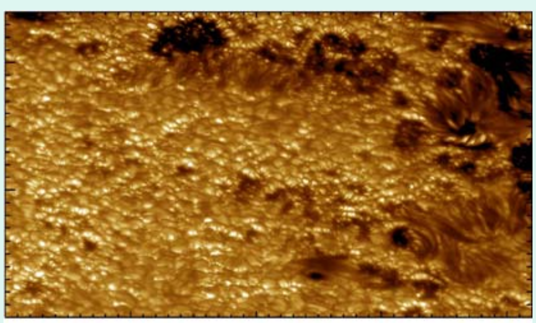
• dark = cooler gas

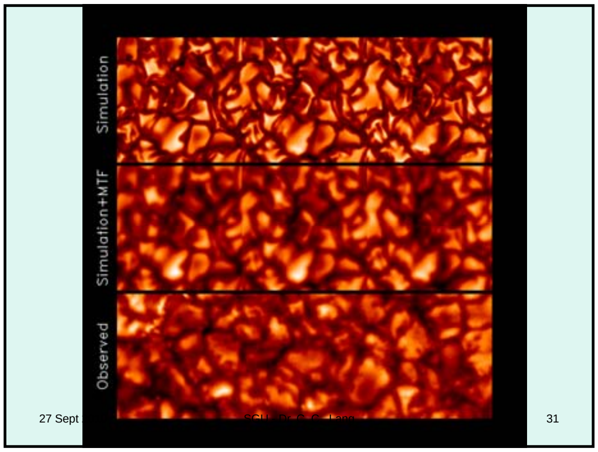
• light = hotter gas

• speed of motion up & down measured by DOPPLER EFFECT!



Solar Granules: courtesy of the Swedish Solar Telescope




Simulation
Simulation+MTF
Observed
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