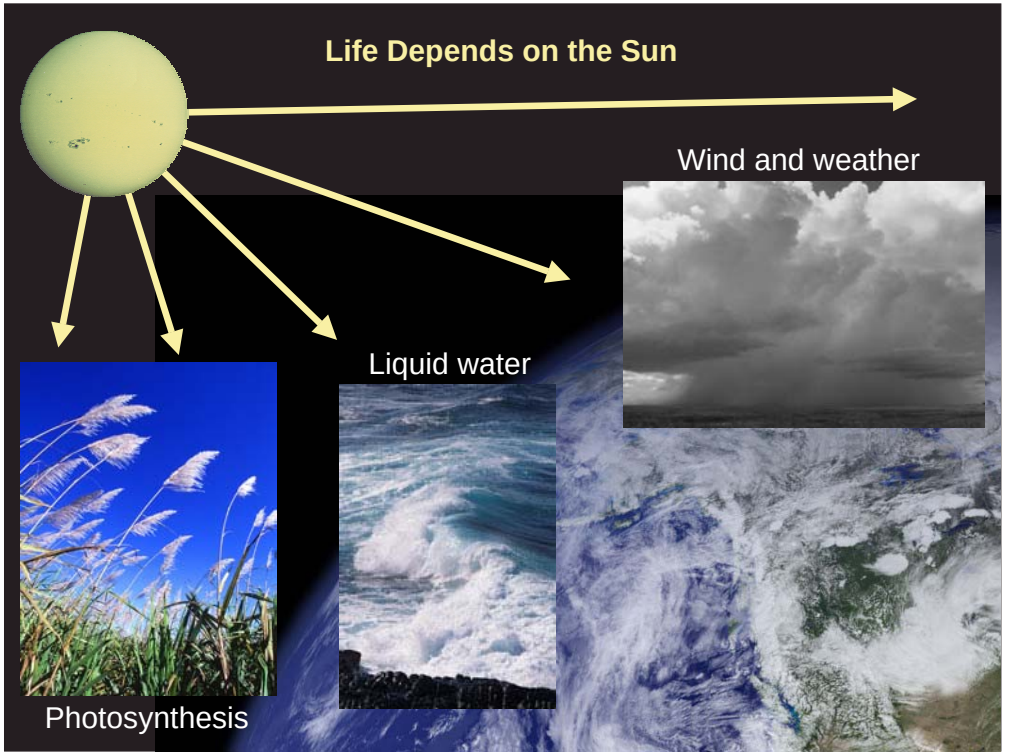
Astronomy 100 – Section 2

As Presented by Paul Ricker

This class:
The Sun II: Interior



Human Cultural Acknowledgment of the Sun's Role

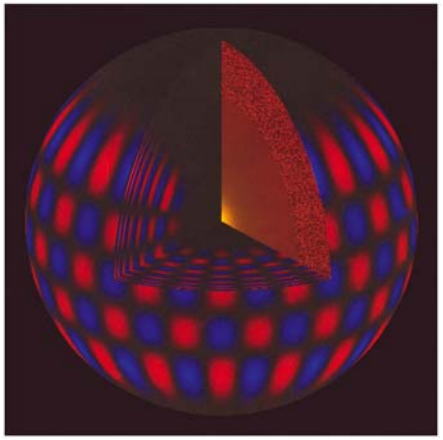

Ancient Egypt – Akhenaton

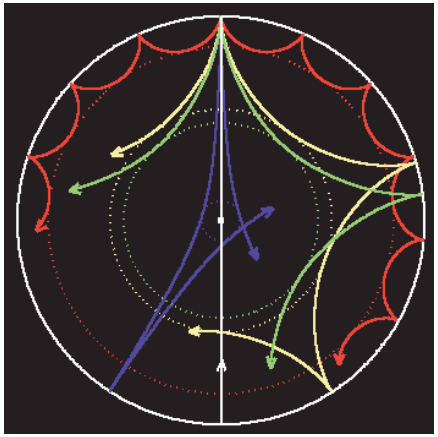

Zia sun symbol – New Mexico

Van Gogh – *Olive Trees with Yellow Sky and Sun*

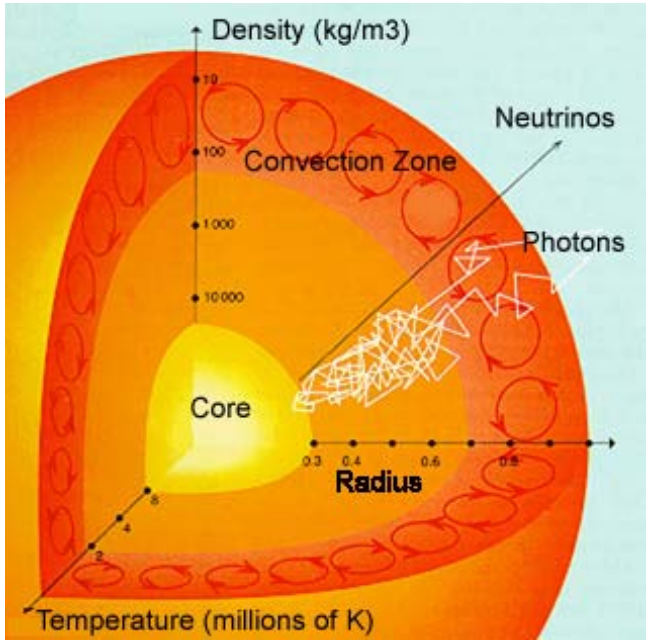
Helioseismology

- Trapped sound waves refract from regions of different density
- Produce characteristic pattern of oscillations on surface

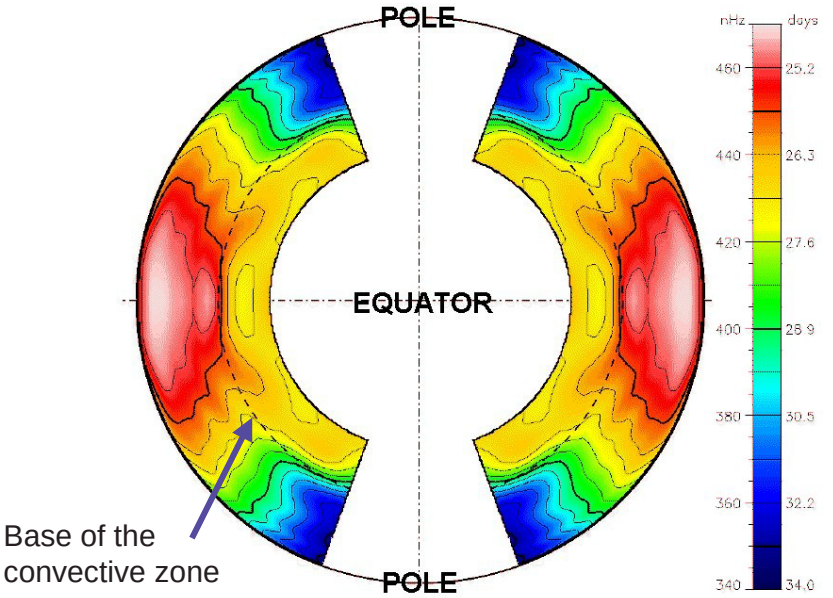




The Interior of the Sun

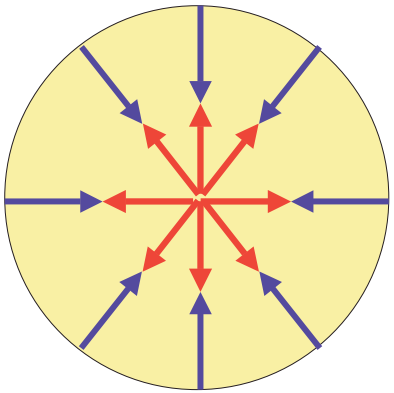


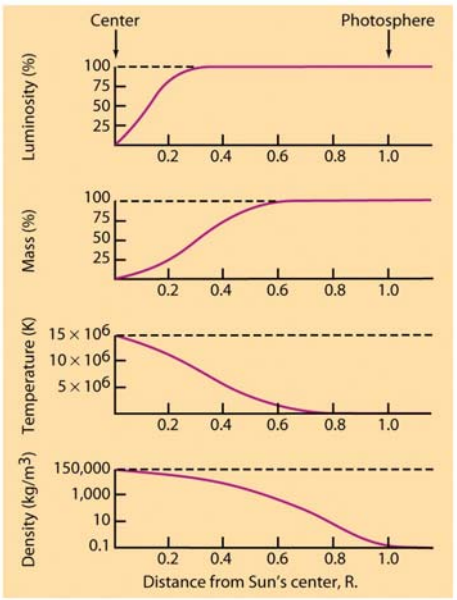
Internal Rotation Speed



Base of the convective zone

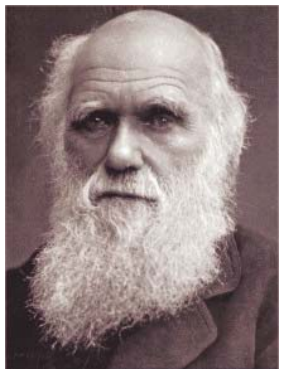
The Battle between Gravity and Pressure



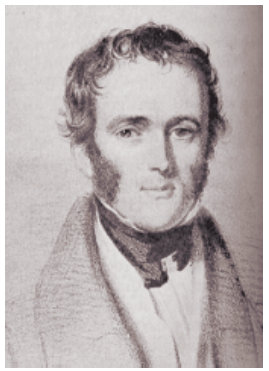


What Holds Up the Sun?

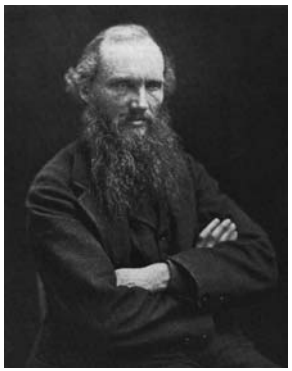
- Without an energy source, Sun would rapidly cool & contract
- Mid-1800s:
  - Darwin: evolution needs Sun & Earth to be > 10^8 years old
  - Lyell: geological changes also needs > 10^8 years
  - Kelvin: gravitational heating gives only a few million years!
- No physical process then known would work!



Charles Darwin

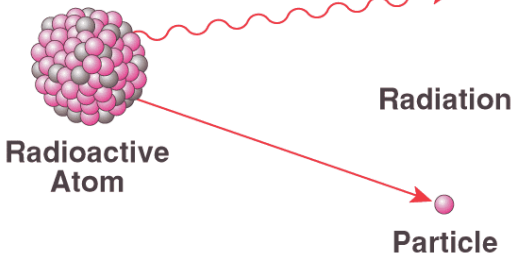


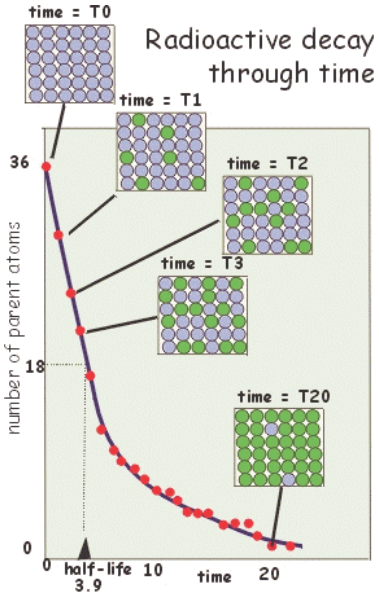
Charles Lyell



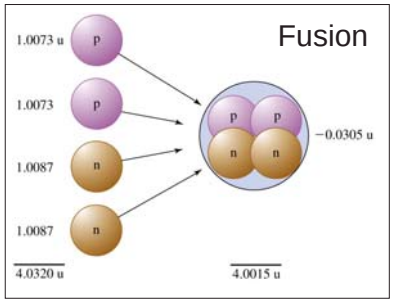
William Thomson, Lord Kelvin

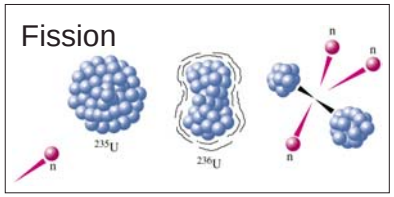
Atomic Nuclei and Radioactivity



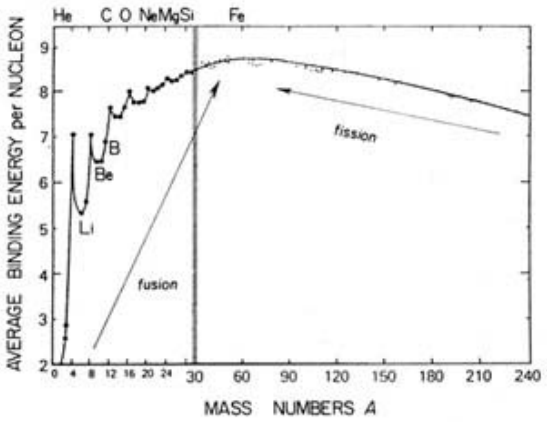


Nuclear Reactions



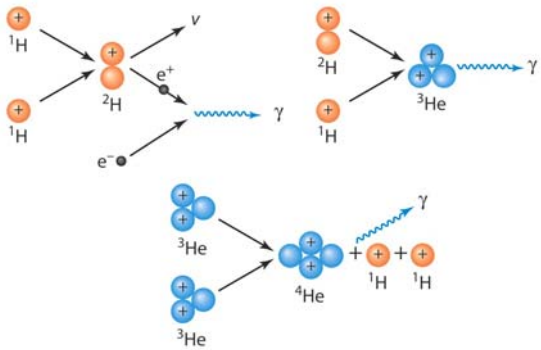


- Atomic nuclei can combine or split
- Release energy in process ($E = mc^2$)
- Light nuclei: fusion
- Heavy nuclei: fission

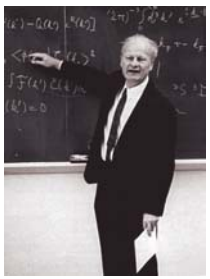


Nuclear Fusion in the Sun's Interior

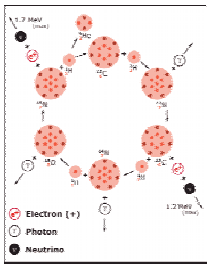
- Proton-proton in stars like the Sun
  - Hydrogen fused to make helium
  - 0.7% of mass converted to energy
- CNO cycle in more massive stars



The Proton-Proton Cycle



Hans Bethe



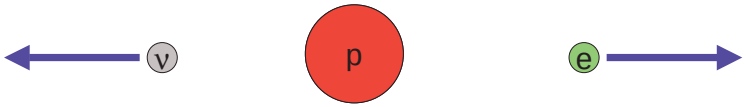
The CNO Cycle

Why Nuclear Fusion Doesn't Occur in Your Coffee

- Fusion requires:
  - High enough temperature (> 5 million K)
  - High enough density
  - Enough time

Neutrinos

- An extremely lightweight, weakly interacting neutral particle
- Produced in radioactive decays and nuclear fusion
- Three different types or “flavors”

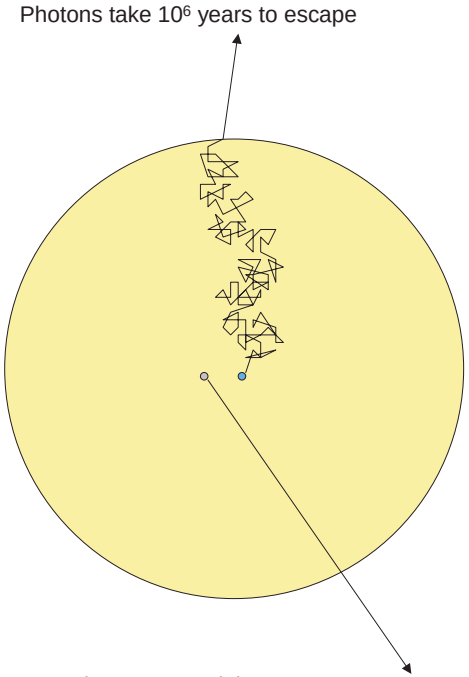


A free neutron…

… spontaneously decays into a proton, an electron, and an (anti)neutrino (half-life ~ 10 minutes)

Flavors

Electron neutrino Muon neutrino Tau neutrino

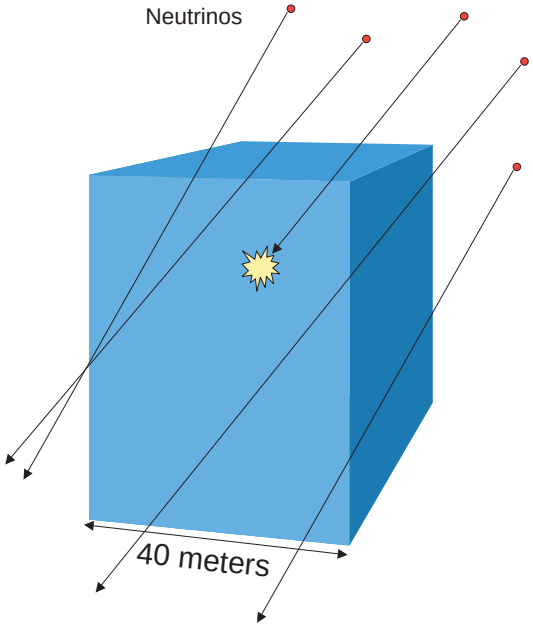


COSMIC GALL

Neutrinos, they are very small.
They have no charge and have not 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.

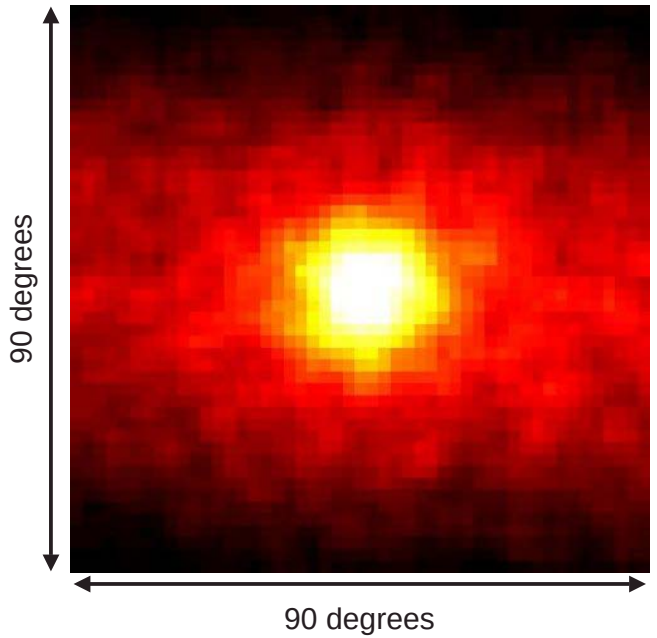
– John Updike

Detecting Neutrinos



Super Kamiokande
Mozumi Mine, Japan
50,000 tons of water

The Sun as Seen in Neutrinos by Super-Kamiokande



500 days
of data

The Solar Neutrino Problem

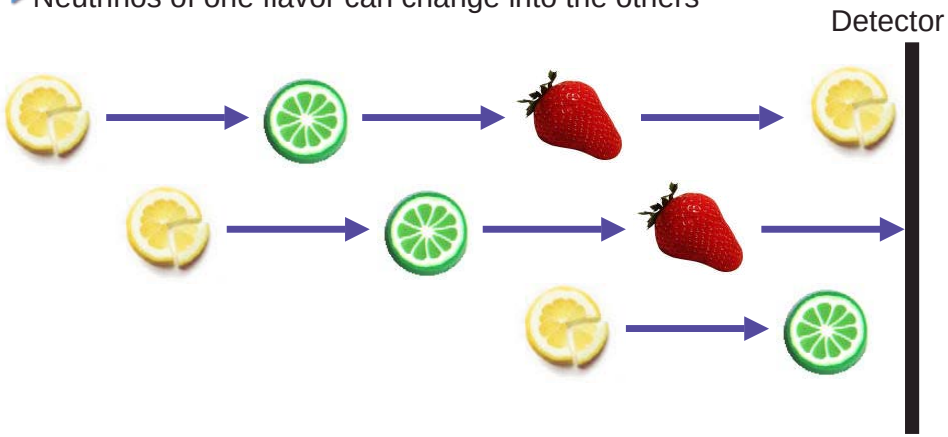
- Only ~ 1/3 of the electron neutrinos expected are seen!

Ray Davis & John Bahcall

Homestake Neutrino Detector

The Solar Neutrino Problem – Resolution

- Neutrinos have (a little) mass
- Neutrinos of one flavor can change into the others



Questions?