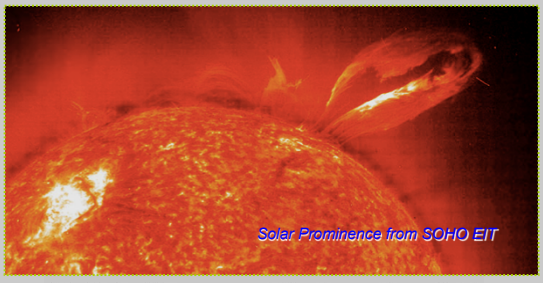
ASTR 1040: Stars & Galaxies



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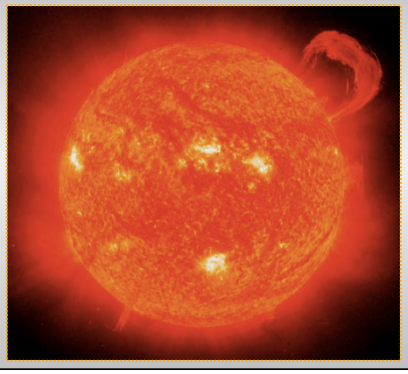
Lecture 6 Thur 30 Jan 2014

zeus.colorado.edu/astr1040-toomre

Topics for Today

- Start with how Sun is put together
- Why is a star spherical, and does not collapse? (Gravitational equilibration)
- Why does it shine, and must it shine? What is the energy source? (Fusion of H to He)
- Complete detail read Chap 14 (Our Star)
- Read S4.1, S4.2 (quarks, leptons, ..)
- New Homework #3 (The Sun) passed out
- Observatory # 2 on Monday Feb 3, signup

Our Nearest Star Chap 14

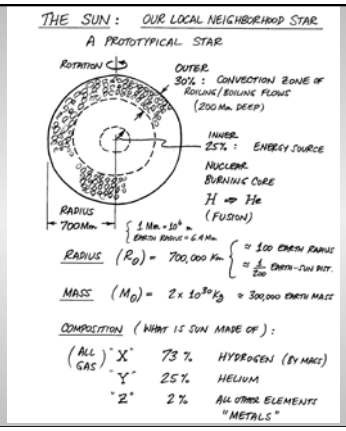


Big Qs about the Sun (and any star)

- Why is a star ROUND ?
- What keeps a star from collapsing inward ?
- What keeps it shining ?
- Why does it rotate and have varying magnetic fields ?

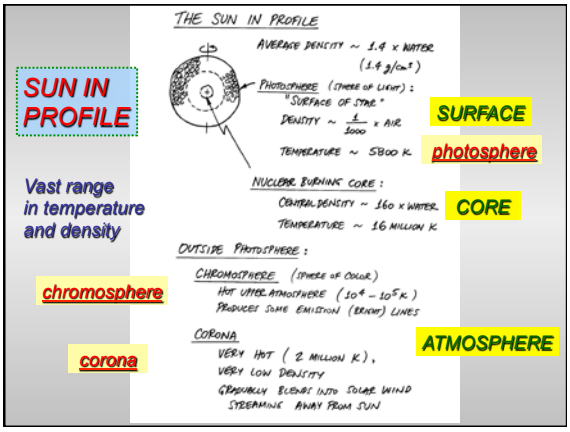
OVERVIEW of the Sun

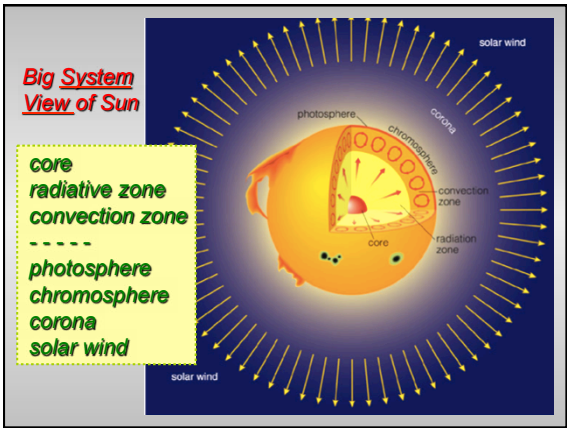
Sun is round, rotates, burns H to He



Sun is a big ball of "plasma"

- Hydrogen and helium are ionized by the high temperature throughout most of star
- Such electrically-conducting GAS is called a PLASMA
- Movement of plasma has currents flowing, builds magnetic fields and electric fields


SUN IN PROFILE
THE SUN IN PROFILE
AVERAGE DENSITY ~ 1.4 x WATER (1.4 g/cm³)
PHOTOSPHERE (SPHERE OF LIGHT):
"SURFACE OF STAR"
DENSITY ~ 1/1000 x AIR
TEMPERATURE ~ 5800 K
NUCLEAR BURNING CORE:
CENTRAL DENSITY ~ 160 x WATER
TEMPERATURE ~ 16 MILLION K
OUTSIDE PHOTOSPHERE:
CHROMOSPHERE (SPHERE OF COLOR)
HOT UPPER ATMOSPHERE (10⁴ – 10⁵ K)
PRODUCES SOME EMISSION (BRIGHT) LINES
CORONA
VERY HOT (2 MILLION K),
VERY LOW DENSITY
GRADUALLY BLENDS INTO SOLAR WIND
STREAMING AWAY FROM SUN
SURFACE
photosphere
CORE
ATMOSPHERE
Vast range in temperature and density
chromosphere
corona


Big System View of Sun
core
radiative zone
convection zone
photosphere
chromosphere
corona
solar wind
solar wind
photosphere
chromosphere
corona
convection zone
radiation zone
core
solar wind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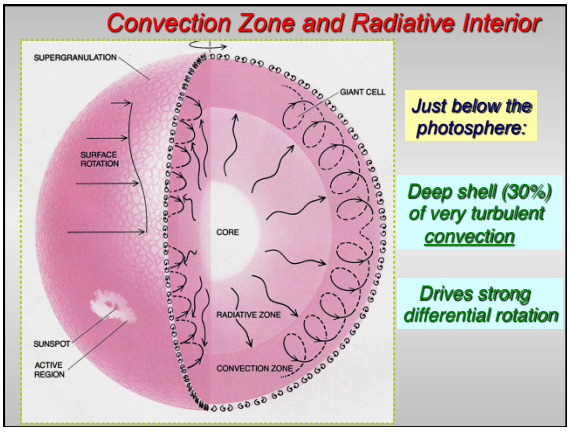
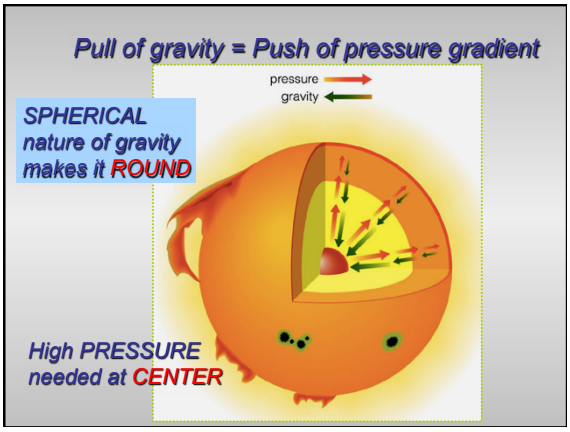
EUV from SOHO

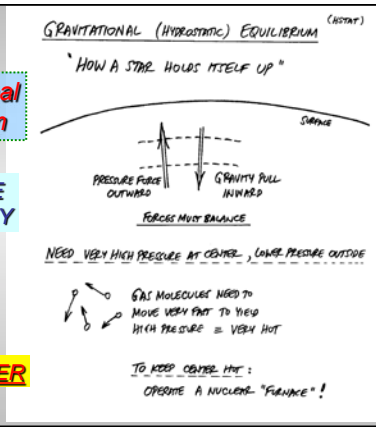

Convection Zone and Radiative Interior
SUPERGRANULATION
GIANT CELL
SURFACE ROTATION
CORE
RADIATIVE ZONE
SUNSPOT
ACTIVE REGION
CONVECTION ZONE
Just below the photosphere:
Deep shell (30%) of very turbulent convection
Drives strong differential rotation


Pull of gravity = Push of pressure gradient
pressure
gravity
SPHERICAL nature of gravity makes it ROUND
High PRESSURE needed at CENTER

Gravitational equilibrium

PRESSURE vs GRAVITY

HOT CENTER



What can a pressure gradient do for you?

Hold up a star, crush a steel drum ….

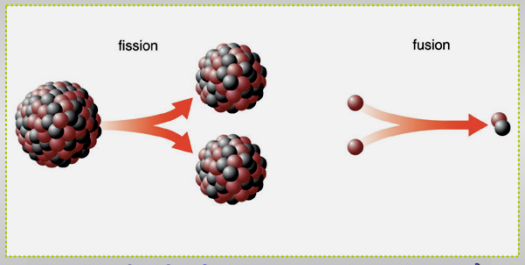
How to get high central pressure?

In gases, plasmas, "equation of state" is roughly

PRESSURE = DENSITY x TEMPERATURE

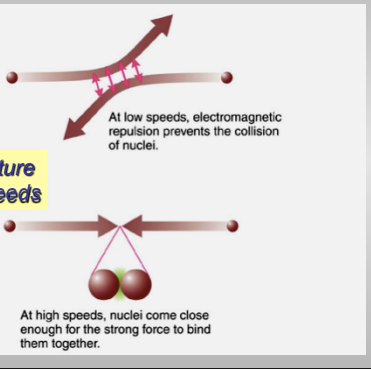
1. *Making the CENTER HOT yields high pressure that keeps star from collapsing*
2. *If really hot, NUCLEAR BURNING can supply the energy that always leaks away from hot places*

Fusion or fission as star's energy source?



Plenty of H for fusion, almost no 'heavy' fuel for fission: **H converted to He**

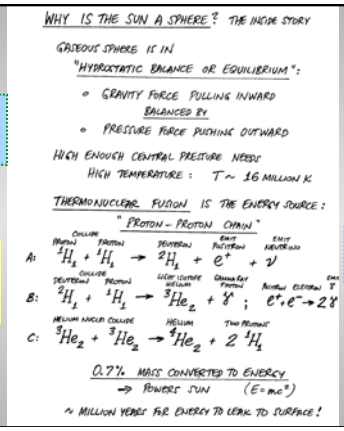
Need high temperatures to make fusion happen



High temperature gives high speeds

SUN as a SPHERE

NUCLEAR BURNING near center



P - P chain

Hans Bethe (1937)

"PROTON – PROTON CHAIN"

A: COLLIDE PROTON + PROTON → DEUTERON + EMIT POSITRON + EMIT NEUTRINO

B: COLLIDE DEUTERON + PROTON → LIGHT ISOTOPE HELIUM + GAMMA RAY PHOTON ; POSITRON ELECTRON EMIT γ

C: HELIUM NUCLEI COLLIDE → HELIUM + TWO PROTONS

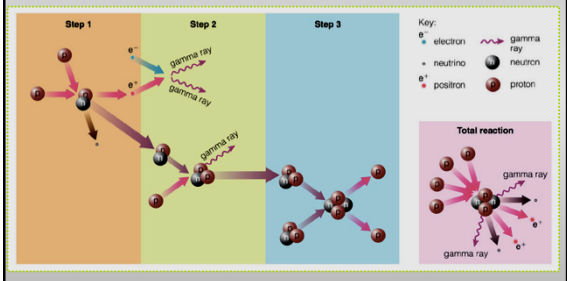
0.7% MASS CONVERTED TO ENERGY

⇒ POWERS SUN ($E = mc^2$)

~ MILLION YEARS FOR ENERGY TO LEAK TO SURFACE!

Proton-Proton (P-P) Chain

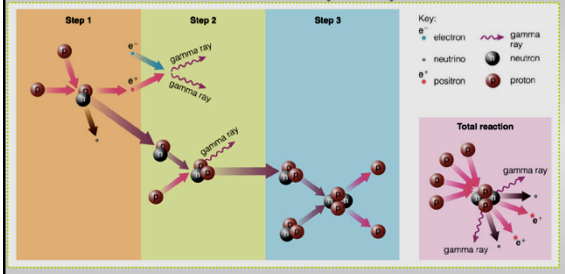
Thermonuclear FUSION



Sun's energy budget (simply put)

- Helium has atomic mass 3.97 times that of hydrogen, NOT exactly 4 times
- Tiny amount of the protons' mass is lost to energy
- $E = mc^2$ (a little mass makes a lot of energy)
- Rates are fast enough that 4 million tons of mass are converted into energy each second!

Proton-Proton (P-P) Chain

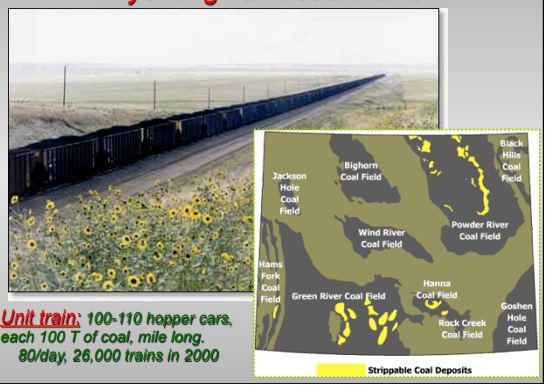


Burn 600 million tons of H every sec, making 596 million tons of He and `4 million tons goes into ENERGY'

Nuclear vs chemical burning

- Nuclear p-p burning :
  1 kg of H becomes 0.993 kg He
- 7 grams releases : 6.3×10^{14} joules
- Same energy released by chemically burning ~20,000 tons of coal !! (2 unit trains)
- Sun's luminosity : (vs 40 W lightbulb)
  $L \sim 3.8\ 10^{26}$ joules/sec (watts)

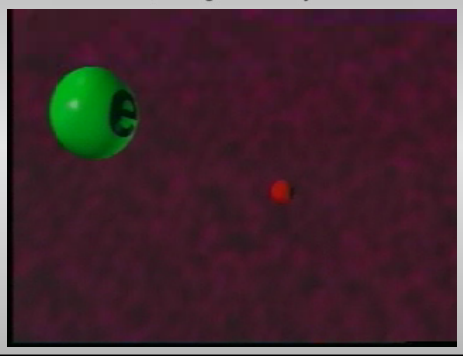
Wyoming "unit coal trains"



Unit train: 100-110 hopper cars, each 100 T of coal, mile long. 80/day, 26,000 trains in 2000

How much is 7 grams compared to 1000 grams (1 kg) ?

Collision of electron with positron (anti-matter): annihilate, two gamma-rays emitted



Proton-proton chain: summary

- *Input:* 6 protons
- *Output:* 1 helium
  2 protons
  2 positrons → gamma rays
  2 neutrinos
  + more gamma rays

4 hydrogens → 1 helium + 2 neutrinos + gamma rays (energy)

DO WE SEE THE GAMMA-RAYS, NEUTRINOS ?