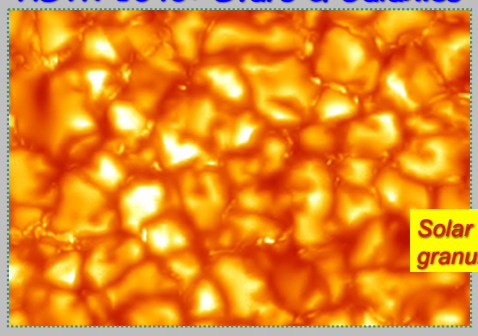
ASTR 1040: Stars & Galaxies



Prof. Juri Toomre TAs: Peri Johnson, Ryan Horton

Lecture 7 Tues 6 Feb 2018

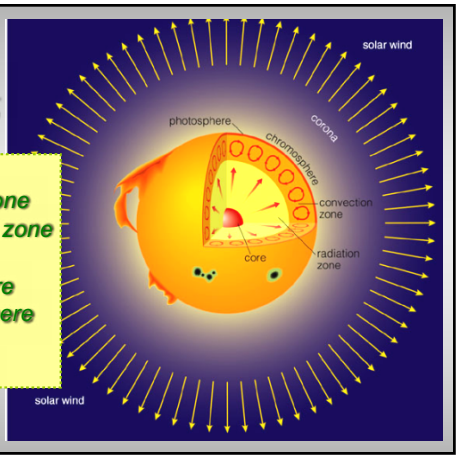
zeus.colorado.edu/astr1040-toomre

Topics for Today and Thur

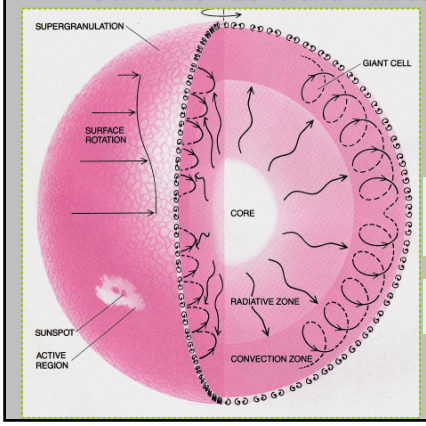
- Consider Sun's energy source (fusion H--He)
- What about the elusive neutrinos ?
- Transport of energy by convection
- Helioseismology: acoustic waves excited by convection to probe interior
- Finish second read of Chap 14 (Our Star), for magnetism discussion on Thurs
- Re-read S4.1, S4.2 (quarks, leptons, ..)
- Observ # 2 this Thur eve, signup again
- HW #2 returned graded

Big System View of Sun

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



Convection Zone and Radiative Interior



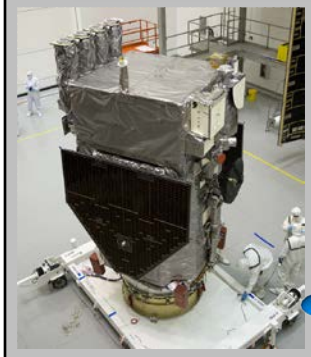
REMINDER

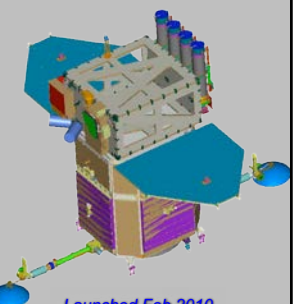
Just below the photosphere:

Deep shell (30%) of very turbulent convection

Drives strong differential rotation

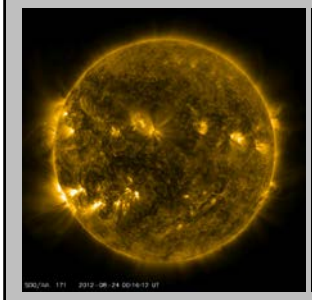
Solar Dynamics Observatory (SDO)



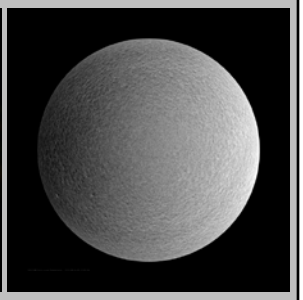


Launched Feb 2010
(4096x4096)

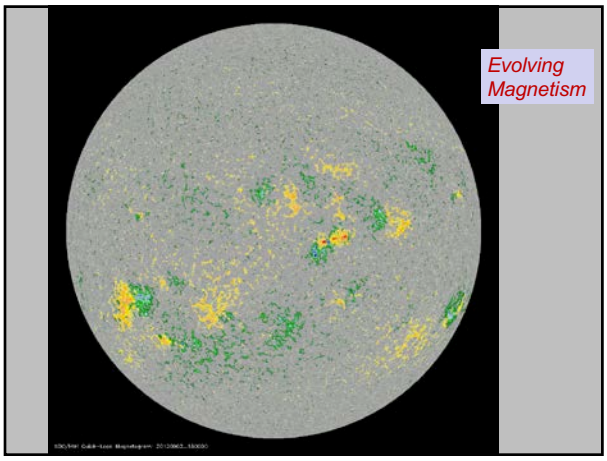
EUV and Visible Images



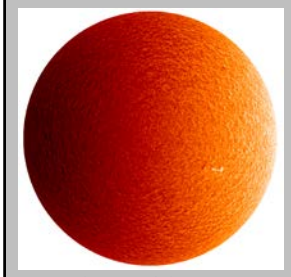
AIA 171 Å
(Low Corona ~ 6×10^5 K)



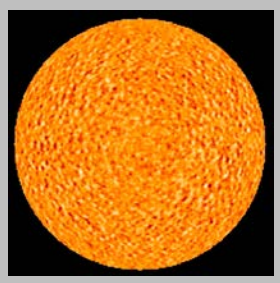
HMI Dopplergrams
(Photosphere ~ 5000 K)



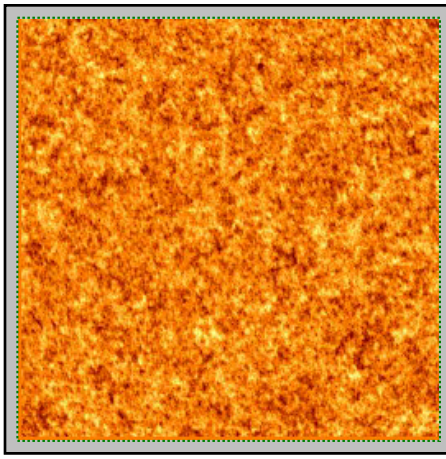
Dopplergrams



Dopplergram of the Sun



Dopplergram sequence with Rotation removed



Radial Velocity
from Michelson Doppler Imager

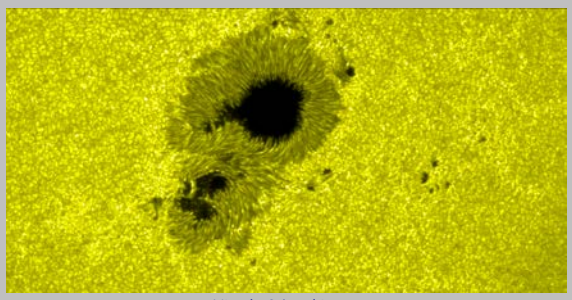
Close-up view

Doppler: ~1000 m/s rms

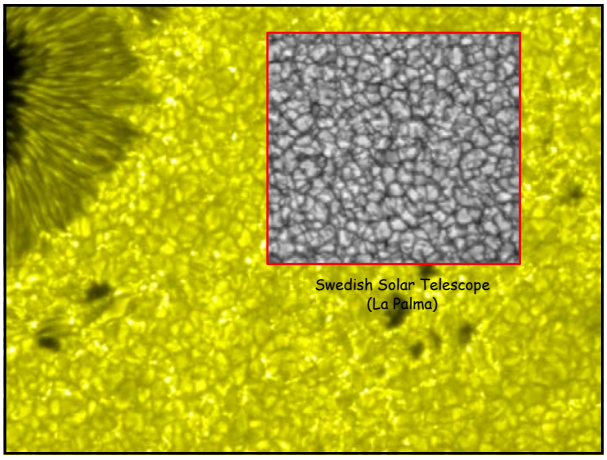
~ 20° across

Excitation of Acoustic Waves

Solar convection in the form of granulation drives broad range of acoustic (sound) waves

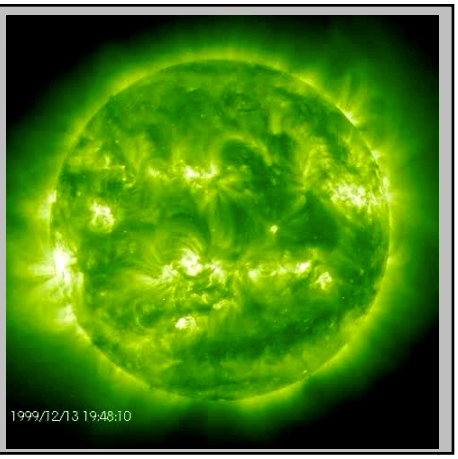


Hinode G-band image

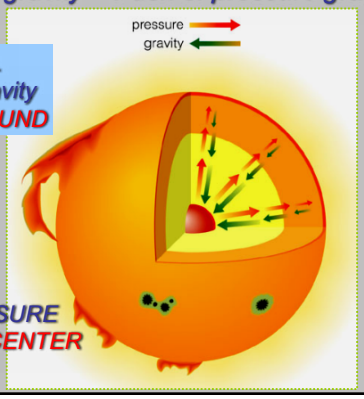


UV view of solar magnetism

SOHO EIT 195 A



Pull of gravity = Push of pressure gradient



SPHERICAL nature of gravity makes it ROUND

High PRESSURE needed at CENTER

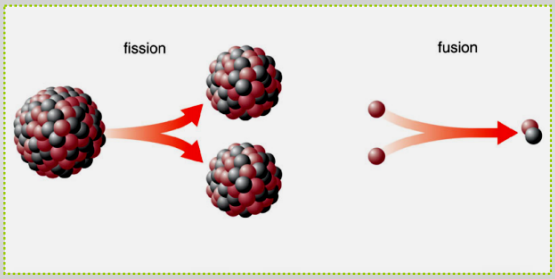
How to get high central pressure?

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

PRESSURE = DENSITY x TEMPERATURE

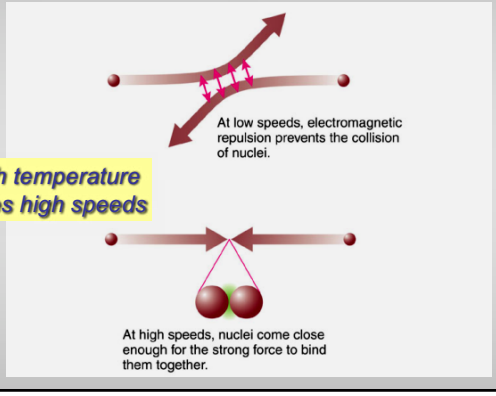
1. Making the CENTER HOT yields high pressure that keeps star from collapsing
2. If really hot, NUCLEAR BURNING can supply the energy that always leaks away from hot places

Fusion or fission as star's energy source?



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

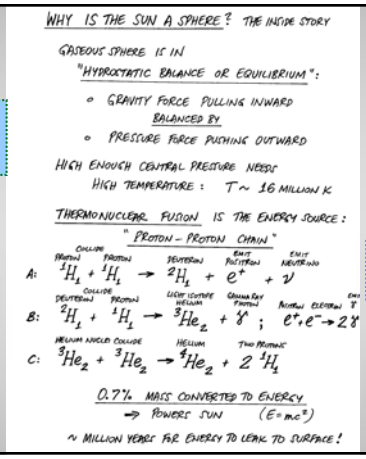
Need high temperatures to make fusion happen



High temperature gives high speeds

SUN as a SPHERE

NUCLEAR BURNING near center



WHY IS THE SUN A SPHERE? THE INSIDE STORY

GASEOUS SPHERE IS IN "HYDROSTATIC BALANCE OR EQUILIBRIUM":

- GRAVITY FORCE PULLING INWARD BALANCED BY
- PRESSURE FORCE PUSHING OUTWARD

HIGH ENOUGH CENTRAL PRESSURE NEEDS HIGH TEMPERATURE: $T \sim 16$ MILLION K

THERMONUCLEAR FUSION IS THE ENERGY SOURCE:

"PROTON – PROTON CHAIN"

A: $^1H_1 + {}^1H_1 \rightarrow {}^2H_1 + e^+ + \nu$ (COLLIDE PROTON PROTON; DEUTERON; EMIT POSITRON; EMIT NEUTRINO)

B: $^2H_1 + {}^1H_1 \rightarrow {}^3He_2 + \gamma$; $e^+ + e^- \rightarrow 2\gamma$ (COLLIDE DEUTERON PROTON; LIGHT ISOTOPE HELIUM; GAMMA RAY PHOTON; POSITRON ELECTRON EMIT γ)

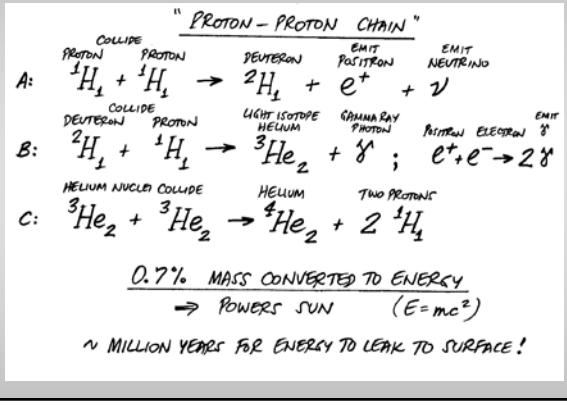
C: $^3He_2 + {}^3He_2 \rightarrow {}^4He_2 + 2\,{}^1H_1$ (HELIUM NUCLEI COLLIDE; HELIUM; TWO PROTONS)

0.7% MASS CONVERTED TO ENERGY ⇒ POWERS SUN ($E = mc^2$)

~ MILLION YEARS FOR ENERGY TO LEAK TO SURFACE!

P - P chain

Hans Bethe (1937)



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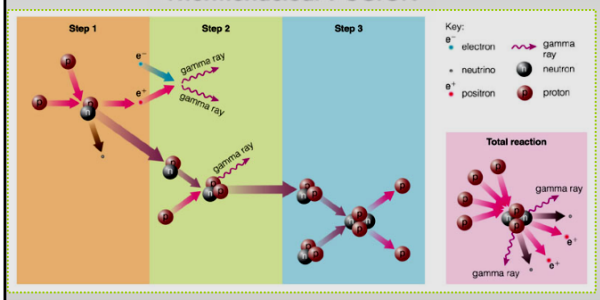
Proton-Proton (P-P) Chain

Thermonuclear FUSION



Clicker Question

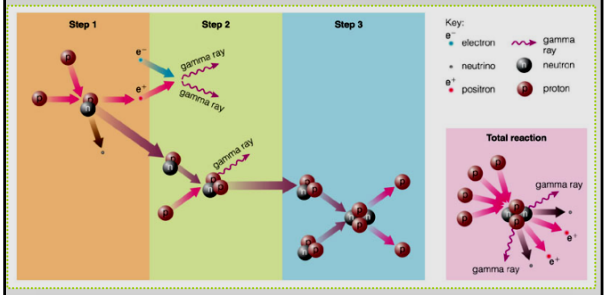
The Sun is made up of (mostly) hydrogen. Yet the P-P chain starts with two protons. Why are they not with their electrons?

A. *The core is very hot so the electrons are all ionized.*
B. *The electrons have all moved to the outer layers of the Sun.*
C. *The Sun is electrically positive, so all that exists are hydrogen ions.*
D. *Neutral hydrogen only consists of one proton and one neutron in the first place.*

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

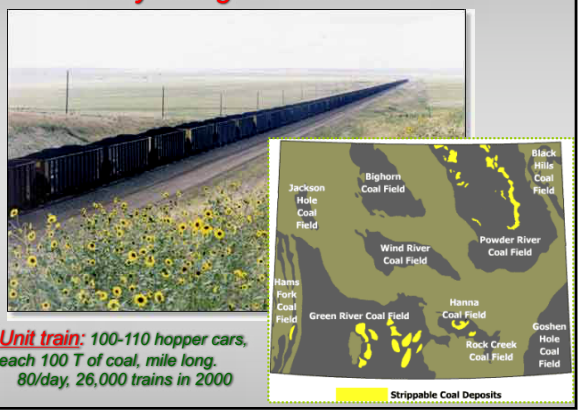


Burn 600 million tons of H every sec, making 596 million tons of He and `4 million tons goes into ENERGY'

Nuclear vs chemical burning

- *Nuclear p-p burning :*
  1 kg of H becomes 0.993 kg He
- *7 grams releases : 6.3 x 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 ~ 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) ?

7 paper clips!

Can high central pressure really hold up a star?

Demo of STEEL DRUM and its fate from pressure force

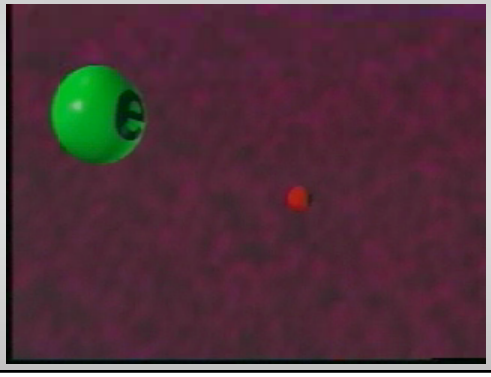
Proton-proton chain: summary

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

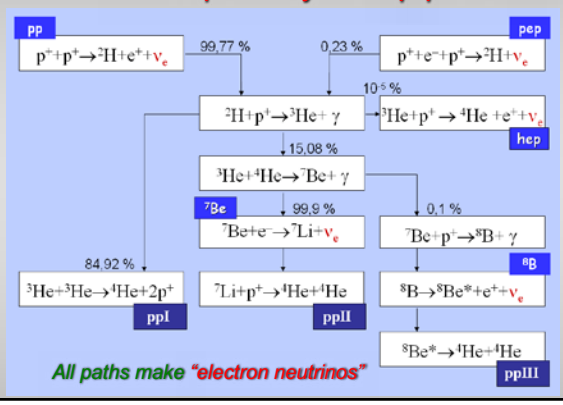
4 hydrogens → 1 helium + 2 neutrinos + gamma rays (energy)

DO WE SEE THE GAMMA-RAYS, NEUTRINOS ?

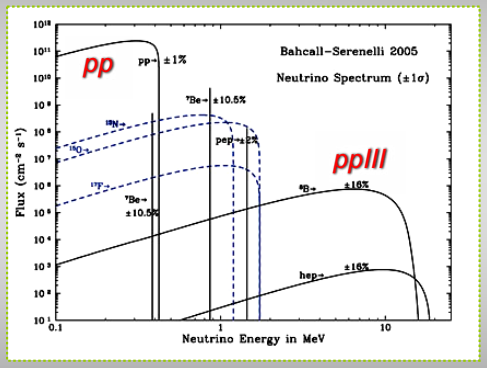
Collision of electron with positron (anti-matter): annihilate, two gamma-rays emitted



Three pathways for "p-p chain"



Solar neutrino energy spectrum



Clicker – Doppler shifts? A.

- *Star moving away from us at 0.01 the speed of light emits a spectral line with a wavelength of 600 nanometers (nm). What is the observed wavelength of that line?*
- *A.* 606 nm
- *B.* 600.6 nm
- *C.* 594 nm
- *D.* 596.4 nm
- *E.* 600 nm

$$\Delta\lambda / \lambda = v/c$$

Meanderings of outbound photons

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

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!