

**ASTR 1040: Stars & Galaxies**

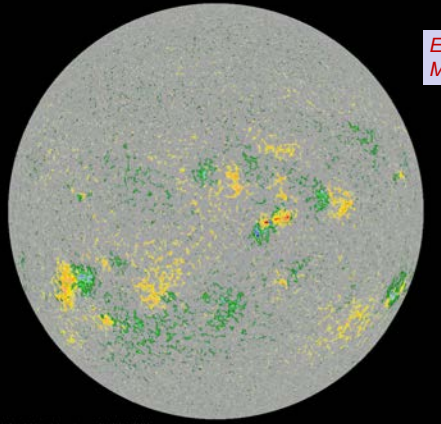


**Solar granulation**

*Prof. Juri Toomre TAs: Ryan Horton, Loren Matilsky  
Lecture 7 Tues 18 Sept 2018  
zeus.colorado.edu/astr1040-toomre*

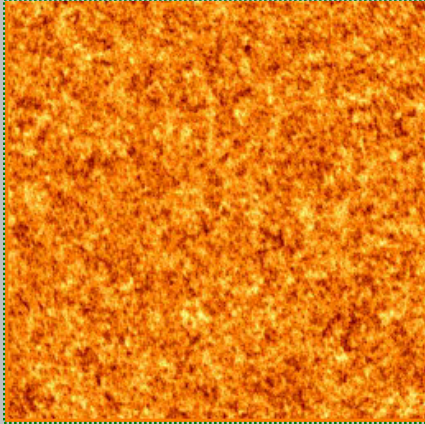
**Topics for Today and Thur**

- 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 # 3 this Thur eve Sept 20, (signup)**



**Evolving Magnetism**

SDO/HMI G-Ha-Look Magnetogram 20120822\_180000



**Radial Velocity**  
from Michelson Doppler Imager

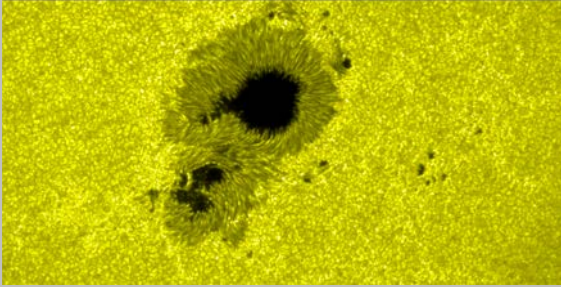
**Close-up view**

Doppler:  
~1000 m/s rms

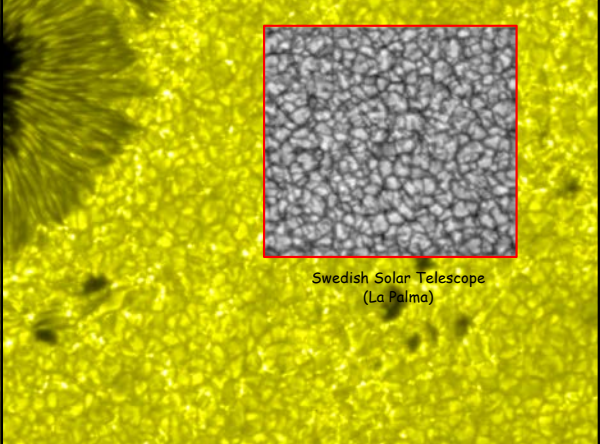
~ 20° across

**Excitation of Acoustic Waves**

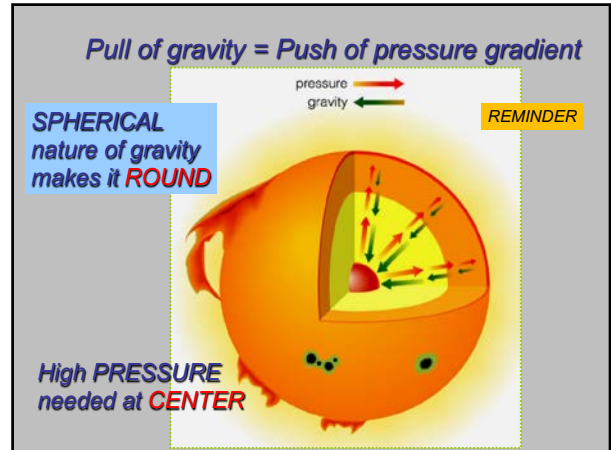
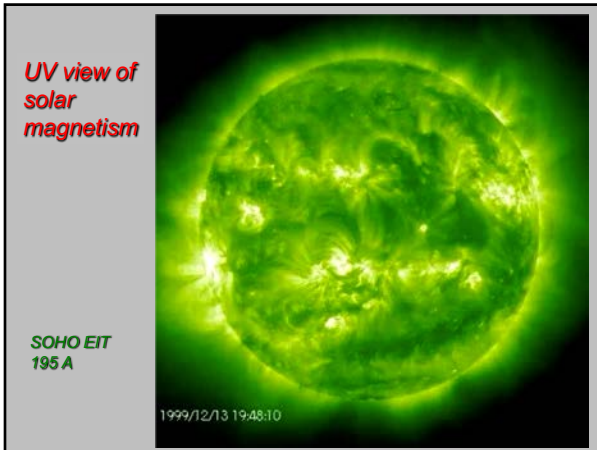
Solar convection in the form of granulation drives broad range of acoustic (sound) waves



Hinode G-band image



Swedish Solar Telescope (La Palma)



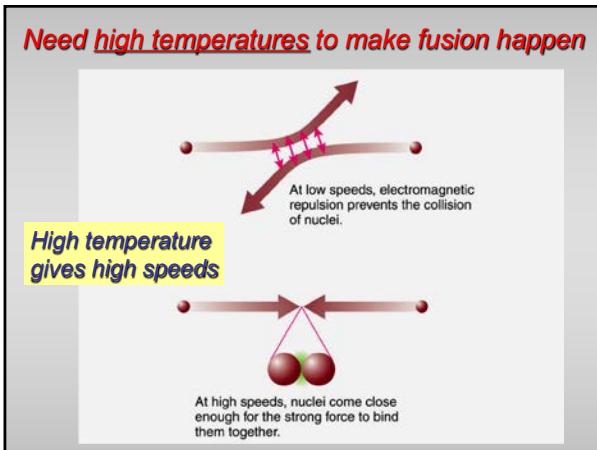
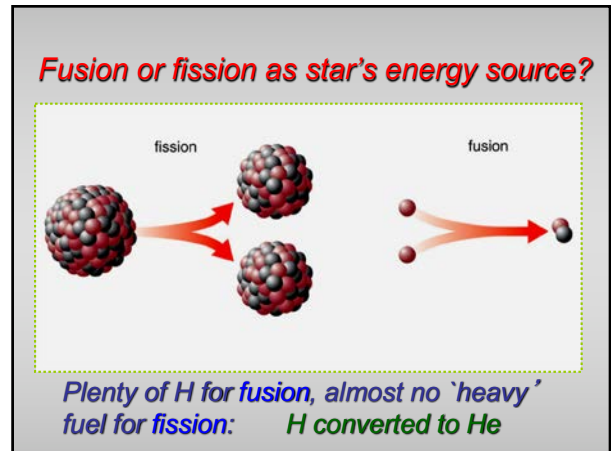
**REMINDER**

**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



**WHY IS THE SUN A SPHERE? THE INSIDE STORY**

GASEOUS SPHERE IS IN "HYDROSTATIC BALANCE OR EQUILIBRIUM":

- GRAVITY FORCE PULLING INWARD
- 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:  ${}^1_1\text{H} + {}^1_1\text{H} \rightarrow {}^2_1\text{H} + e^+ + \nu$

B:  ${}^2_1\text{H} + {}^1_1\text{H} \rightarrow {}^3_2\text{He} + \gamma$ ;  $e^+, e^- \rightarrow 2\gamma$

C:  ${}^3_2\text{He} + {}^3_2\text{He} \rightarrow {}^4_2\text{He} + 2 {}^1_1\text{H}$

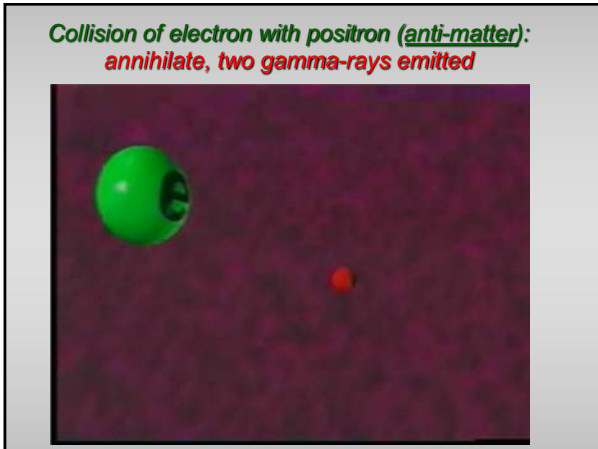
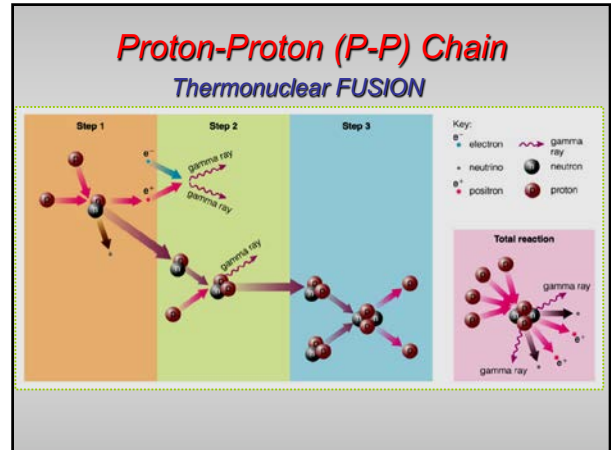
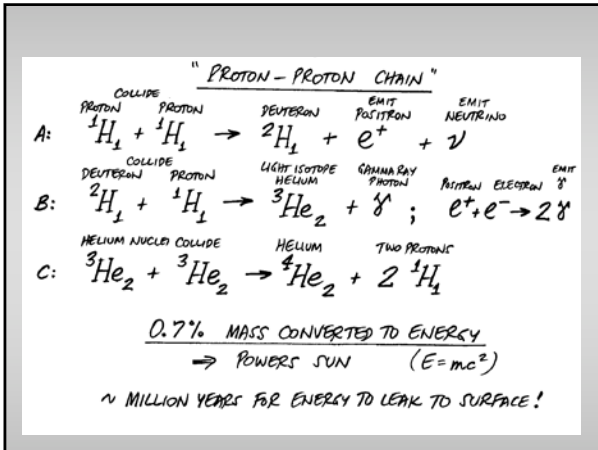
**0.7% MASS CONVERTED TO ENERGY**  
 $\Rightarrow$  POWERFUL SUN ( $E = mc^2$ )  
 $\sim$  MILLION YEARS FOR ENERGY TO LEAK TO SURFACE!

**SUN as a SPHERE**

**NUCLEAR BURNING near center**

**P-P chain**

**Hans Bethe (1937)**



### 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?*

- The core is very hot so the electrons are all ionized.
- The electrons have all moved to the outer layers of the Sun.
- The Sun is electrically positive, so all that exists are hydrogen ions.
- 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 :  $6.3 \times 10^{14}$  joules
- Same energy released by chemically burning ~20,000 tons of coal !! (2 unit trains)
- Sun's luminosity : (vs 40 W lightbulb)  
 $L \sim 3.8 \times 10^{26}$  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!

### 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 ?**

Now turn this Fiske Planetarium to

**COLORADO SKIES**

and the full-dome projection of  
significant star groupings,  
including near Eta Carina and  
especially the Orion Nebula in many  
different wavelength views

Now let us turn to the  
full-dome Lucas production

**"Solar Superstorms"**