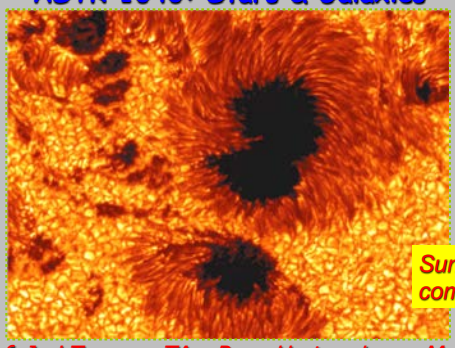
ASTR 1040: Stars & Galaxies



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Lecture 8 Thur 20 Sept 2018

zeus.colorado.edu/astr1040-toomre

Topics for Today and Tues

- P-P chain and mystery of neutrinos produced
- Energy transport by convection (granulation)
- Rich solar magnetism and its cycles
- Sunspots and the "butterfly diagram"
- How to measure Sun's magnetic fields
- Start reading Chap 15: Surveying the Stars
- New Homework #4 passed out; HW #3 due; Observatory #3 tonight by sign-up
- Review Set for Mid-Term Exam 1 (next Thurs in class)

REMINDER

"PROTON – PROTON CHAIN"

A: $^1H_1 + {}^1H_1 \rightarrow {}^2H_1 + e^+ + \nu$ (collide: proton, proton; emit: deuteron, positron, neutrino)

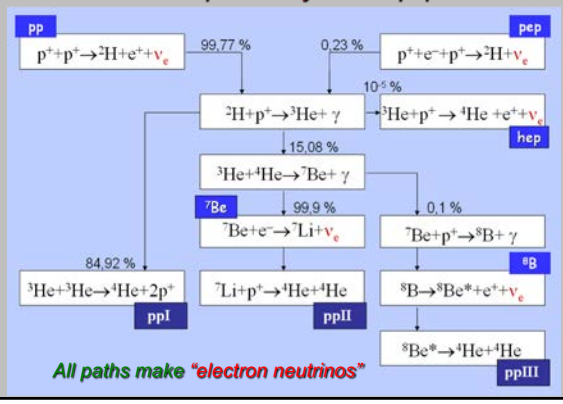
B: $^2H_1 + {}^1H_1 \rightarrow {}^3He_2 + \gamma$; $e^+ + e^- \rightarrow 2\gamma$ (collide: deuteron, proton; light isotope helium, gamma ray photon; positron electron annihilate; emit γ)

C: $^3He_2 + {}^3He_2 \rightarrow {}^4He_2 + 2\,{}^1H_1$ (helium nuclei collide; helium, two protons)

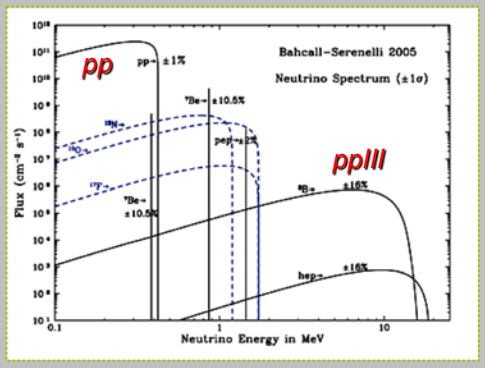
0.7% MASS CONVERTED TO ENERGY ⇒ POWERS SUN ($E = mc^2$)

~ MILLION YEARS FOR ENERGY TO LEAK TO SURFACE!

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

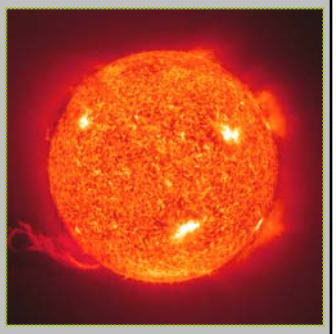
P-P chain makes gamma-ray photons, which "random walk" outwards (getting absorbed, re-emitted), gradually cooling

Takes light about one million years from creation to get out

Heading outward (slow & fast)

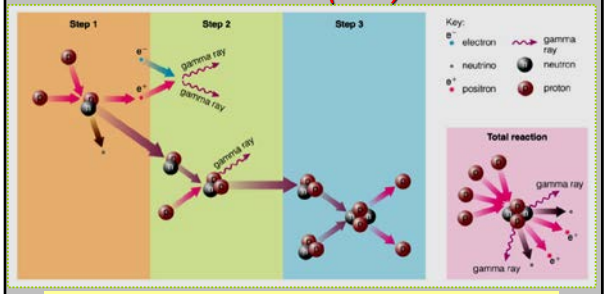
Gamma rays slowly work their way outwards, cool, and become sunlight (about million years)

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!



REMINDER

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'

Energy = Gamma-ray photons + electron neutrinos

Those Mysterious Neutrinos

MADE BY P-P BURNING IN CORE

- *Mass-less or with very small masses*, travel close to speed of light
- *Don't interact (almost) with other matter:* requires lead wall 1 light year thick to stop a neutrino!
- *Lots of them:* 10^{38} neutrinos/sec from the Sun, 65 billions/cm^2/sec coming through YOU !
- But we can still catch some, using massive underground "detectors": *BIG PUZZLE*

Big Puzzle: Catching Solar Neutrinos

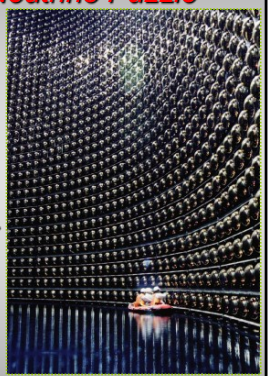
Visionary: Ray Davis

- Located deep underground, rock blocking other particles
- Huge underground vat of dry-cleaning fluid
- Chlorine captures neutrino, becomes radioactive argon
- Only collects 1 neutrino about every 3 days -- even with 100,000 gallons
- Solar theory predicted THREE TIMES more!
- Big hunt started, called *SOLAR NEUTRINO PROBLEM*

Homestake Gold Mine SD

Resolving the Solar Neutrino Puzzle

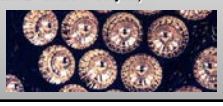
- *Super-Kamiokande* uses massive tank of water to capture neutrinos
- Each rare capture gives flash of light, detected by giant tubes
- Captures lower energy neutrinos from p-p chain, so more sensitive test of fusion
- Suggests some electron neutrinos may change into muon and tau neutrinos during course of flight to us (8 minutes)
- *MSW Neutrino Oscillations* require neutrinos to have some mass!



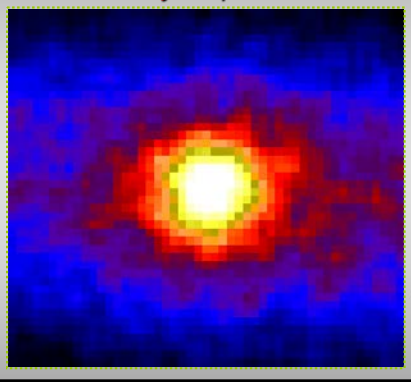
Kamiokande Nickel Mine, Japan

Sudbury Neutrino Observatory (SNO)

- Uses *"heavy water"* -- one H in H_20 replaced by its stable isotope deuterium (P+N)
- SNO is capturing **all three types of neutrinos** (electron, muon, tao)
- *"Solar neutrino problem"* leads to big physics advance (2002 Nobel Phys Prize; Davis & Koshiba) and (2015 Nobel; McDonald & Kajita)



Sun Viewed by Super-Kamiokande



500 day "exposure"

Solar Thermostat

- *Why doesn't the Sun go into a runaway reaction?*

Fusion rate is *VERY sensitive to temperature,*
→ tight feedback loop

CRUCIAL

A. If energy generation (fusion rate) speeds up:

- 1. Pressure in core will increase, lifting the gas against gravity (core expands)
- 2. Gravitational energy is created from thermal energy → the gas cools
- 3. Energy generation (fusion rate) slows down

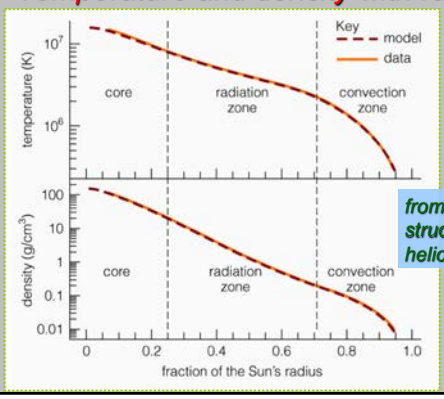
More on solar thermostat

B. However, if energy generation drops:

- 1. Core pressure drops
- 2. Solar core starts to shrink
- 3. Temperature rises
- 4. Fusion rates go up again

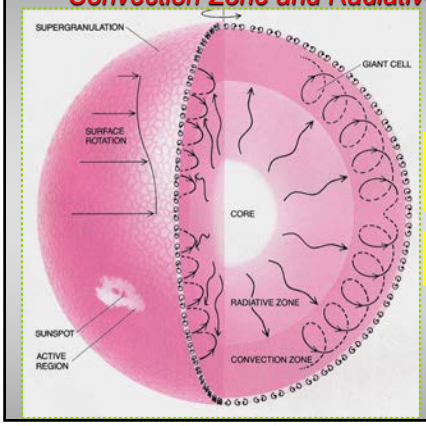
- *Sun is remarkably stable,* only small (30%?) increase in fusion rate over billions of years

Temperature and density with radius



from "stellar structure" theory, helioseismology

Convection Zone and Radiative Interior

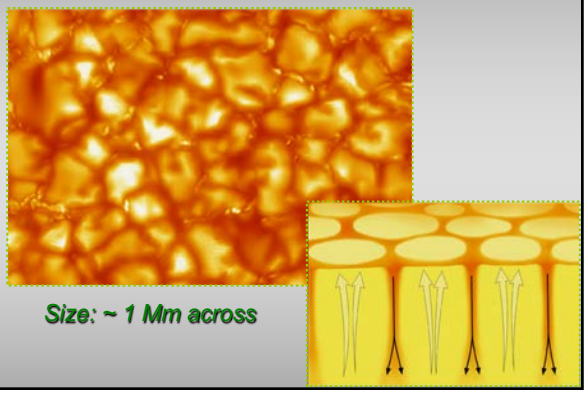


Just below the photosphere:

Deep shell (30%) of very turbulent convection

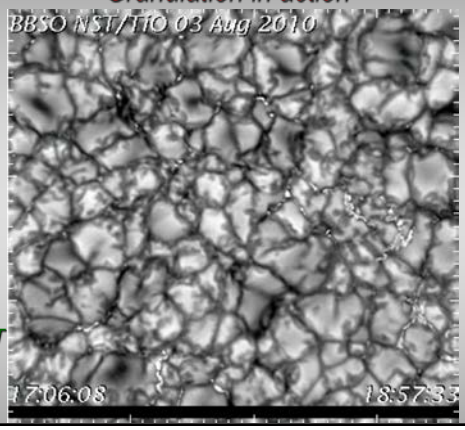
Drives strong differential rotation

Granulation: near-surface turbulent convection



Size: ~ 1 Mm across

Granulation in action



BBSO 1.6m NST adaptive optics

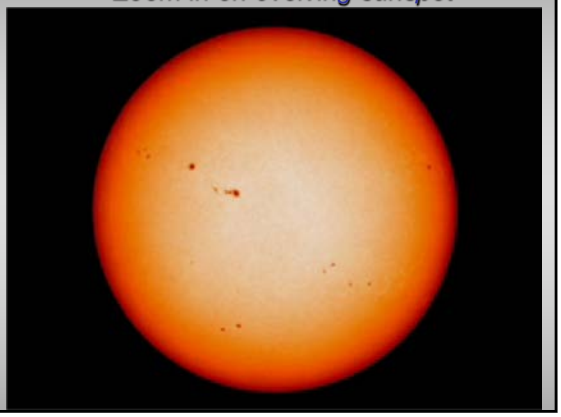
Reading Clicker – Solar Maximum ?

- What observed features characterize the Sun at "solar maximum"?

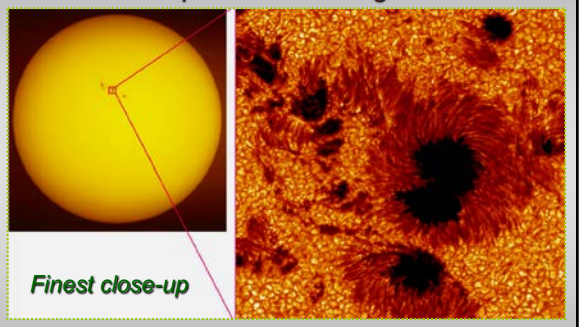
D.

- A. Sun becomes much brighter
- B. Sun emits light of longer wavelengths
- C. Sun rotates faster at the equator
- D. Many sunspots are visible on surface
- E. All of the above

Zoom-in on evolving sunspot

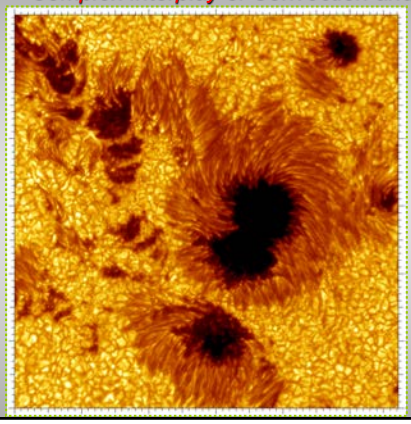


Sunspot in White Light



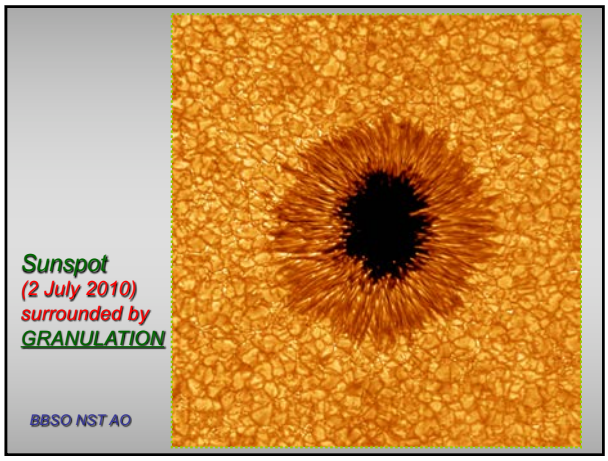
Finest close-up

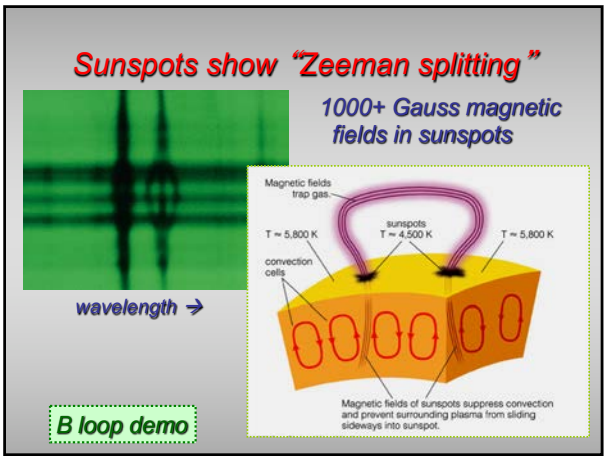
Complex Interplay of Convection and Magnetism

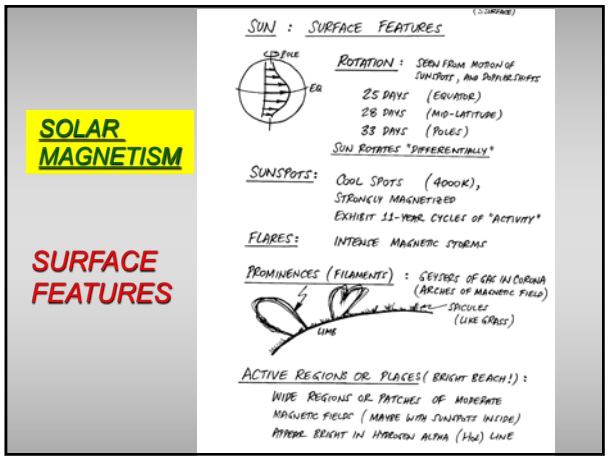


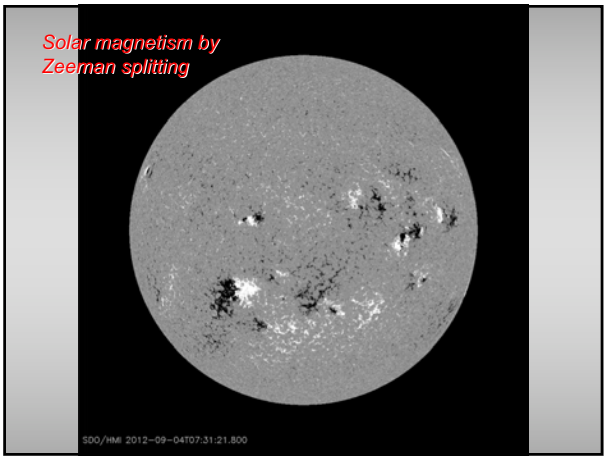
SUNSPOTS amid field of GRANULES

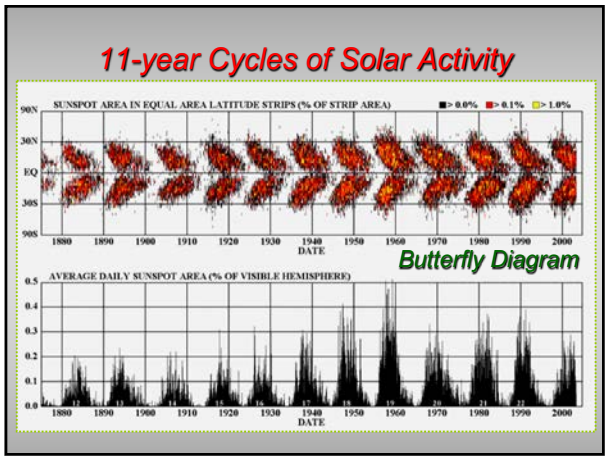
1 Mm spacing on ticks

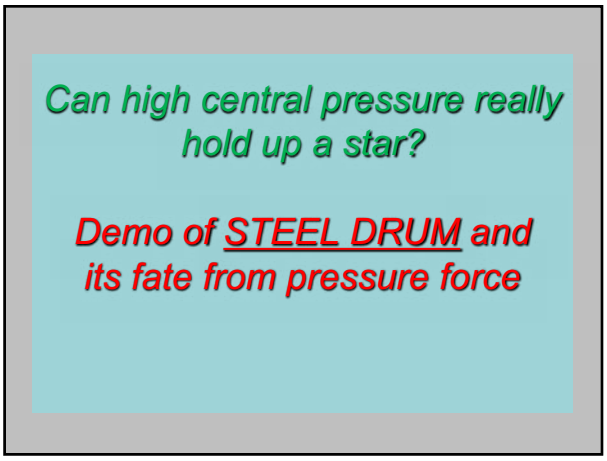

Sunspot
(2 July 2010)
surrounded by
GRANULATION
BBSO NST AO


Sunspots show "Zeeman splitting"
1000+ Gauss magnetic fields in sunspots
wavelength →
B loop demo
Magnetic fields trap gas.
sunspots
T ≈ 4,500 K
T ≈ 5,800 K
T ≈ 5,800 K
convection cells
Magnetic fields of sunspots suppress convection and prevent surrounding plasma from sliding sideways into sunspot.


SOLAR MAGNETISM
SURFACE FEATURES
SUN : SURFACE FEATURES
ROTATION : SEEN FROM MOTION OF SUNSPOTS, AND DOPPLER SHIFTS
25 DAYS (EQUATOR)
28 DAYS (MID-LATITUDE)
33 DAYS (POLES)
SUN ROTATES "DIFFERENTIALLY"
SUNSPOTS: COOL SPOTS (4000K), STRONGLY MAGNETIZED
EXHIBIT 11-YEAR CYCLES OF "ACTIVITY"
FLARES: INTENSE MAGNETIC STORMS
PROMINENCES (FILAMENTS) : GEYSERS OF GAS IN CORONA (ARCHES OF MAGNETIC FIELD)
SPICULES (LIKE GRASS)
ACTIVE REGIONS OR PLACES (BRIGHT BEACH!) :
WIDE REGIONS OR PATCHES OF MODERATE MAGNETIC FIELDS (MAYBE WITH SUNSPOTS INSIDE)
APPEAR BRIGHT IN HYDROGEN ALPHA (Hα) LINE


Solar magnetism by Zeeman splitting
SDO/HMI 2012-09-04T07:31:21.800


11-year Cycles of Solar Activity
SUNSPOT AREA IN EQUAL AREA LATITUDE STRIPS (% OF STRIP AREA)
> 0.0% > 0.1% > 1.0%
90N
30N
EQ
30S
90S
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
DATE
Butterfly Diagram
AVERAGE DAILY SUNSPOT AREA (% OF VISIBLE HEMISPHERE)
0.5
0.4
0.3
0.2
0.1
0.0
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
DATE


Can high central pressure really hold up a star?
Demo of STEEL DRUM and its fate from pressure force