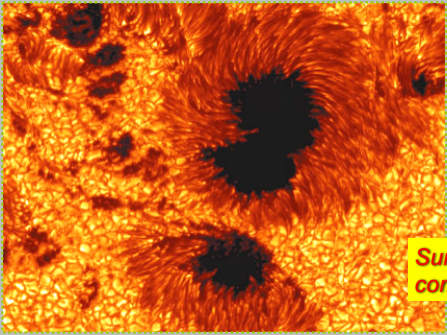


ASTR 1040: Stars & Galaxies



Sunspot complex

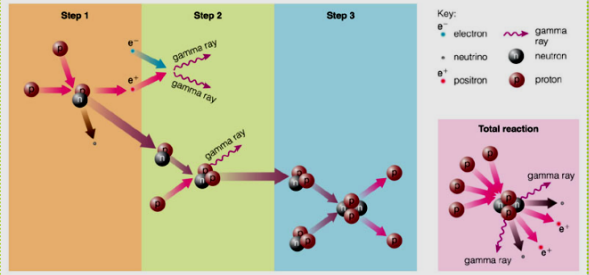
Prof. Juri Toomre TAs: Peri Johnson, Ryan Horton
Lecture 8 Thur 8 Feb 2018
zeus.colorado.edu/astr1040-toomre

Topics for Today and Tues

- 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; *HW #2* Answers; *Observatory #2* tonight
- Review Set for Mid-Term Exam 1 (next Thurs in class)

Proton-Proton (P-P) Chain REMINDER



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/cm²/sec coming through YOU!
- But we can still catch some, using massive underground “detectors”: **BIG PUZZLE**

Big Puzzle: Catching Solar Neutrinos

Visionary: Ray Davis

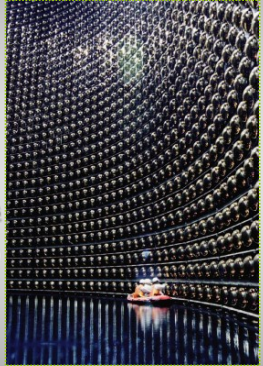
- Located deep underground, rock blocking other particles
- Huge underground vat of dry-cleaning fluid
- Chlorine captures neutrino, becomes radioactive argon
- Only collects 1 neutrino about every 3 days -- even with 100,000 gallons
- Solar theory predicted THREE TIMES more!
- Big hunt started, called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



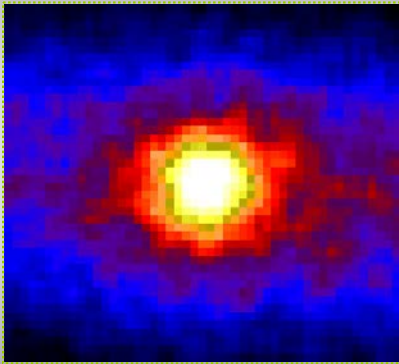
Kamiokande Nickel Mine, Japan

Sudbury Neutrino Observatory (SNO)

- Uses **"heavy water"** -- one H in H₂O replaced by its stable isotope **deuterium** (P+N)
- SNO is capturing **all three types of neutrinos** (electron, muon, tau)
- **"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:

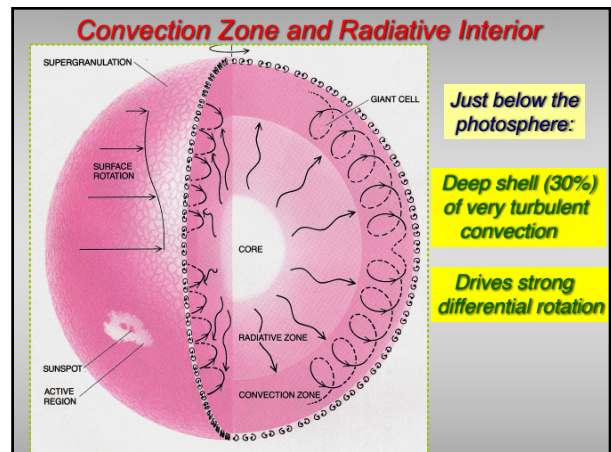
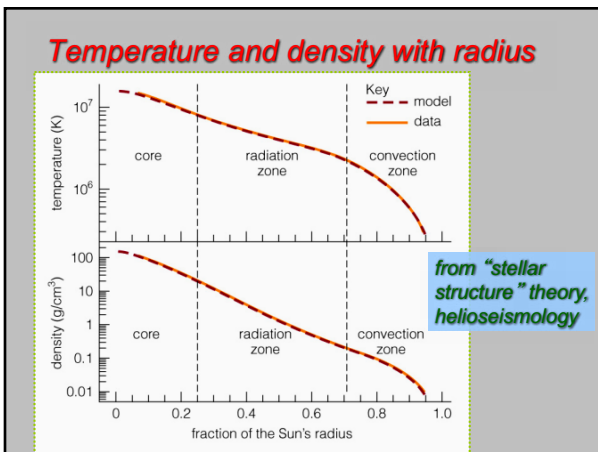
1. Pressure in core will increase, lifting the gas against gravity (core expands)
2. Gravitational energy is created from thermal energy → the gas cools
3. **Energy generation (fusion rate) slows down**

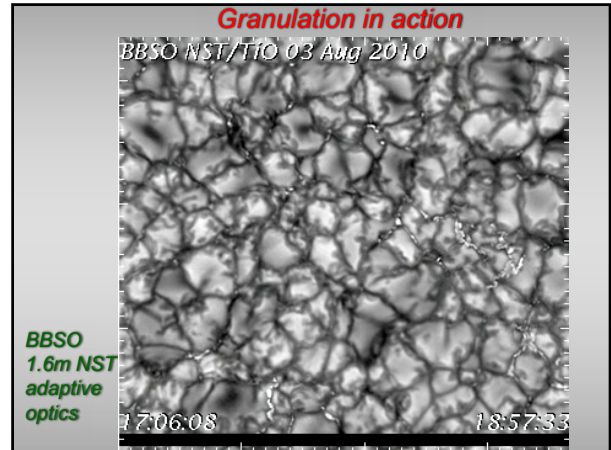
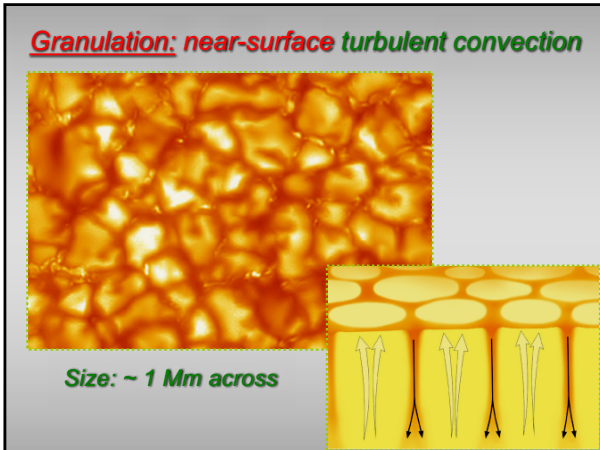
More on solar thermostat

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



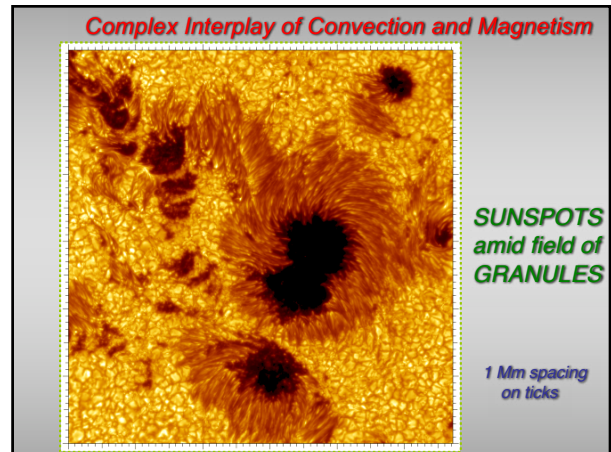
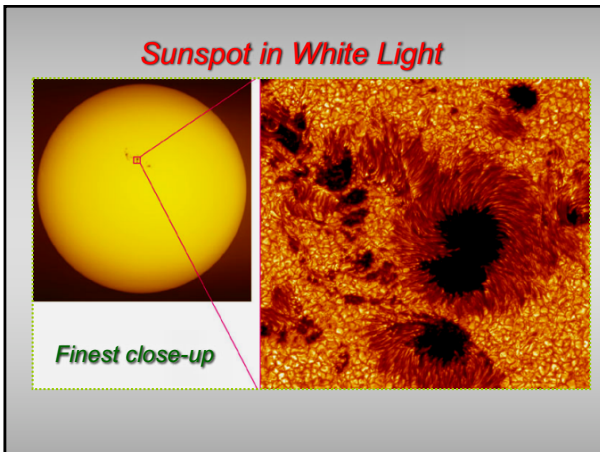
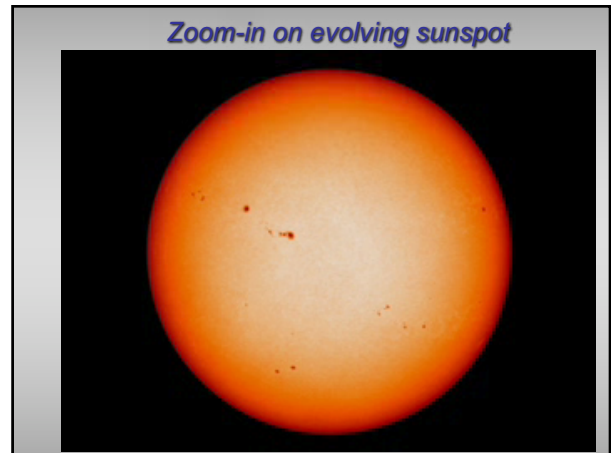


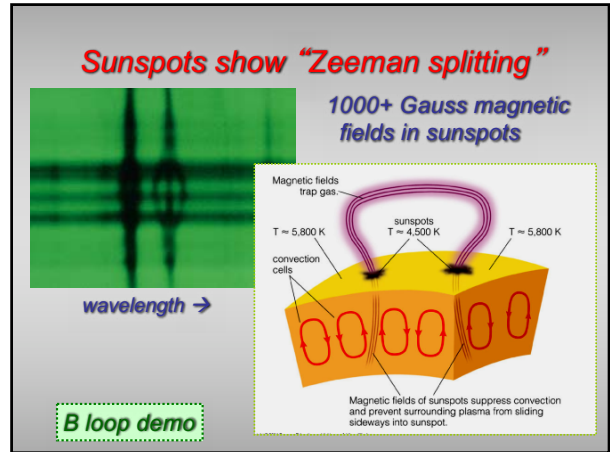
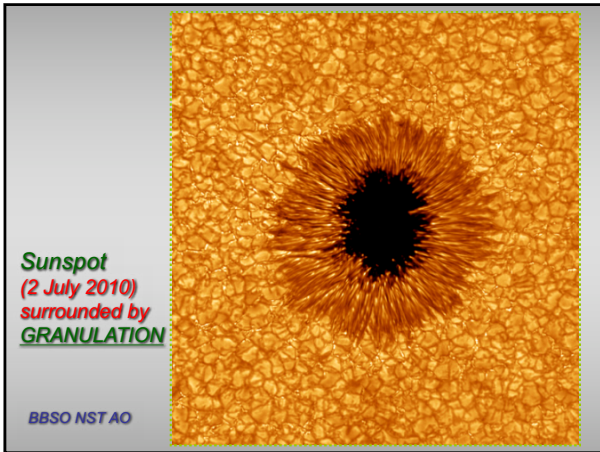
Reading Clicker – Solar Maximum ?

- 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





SOLAR MAGNETISM

SURFACE FEATURES

SUN : SURFACE FEATURES (S. GARRETT)

ROTATION : SEEN FROM MOTION OF SUNSPOTS, AND PROMINENCES

25 DAYS (EQUATOR)
28 DAYS (MID-LATITUDE)
33 DAYS (POLE)

SUN ROTATES "DIFFERENTIALLY"

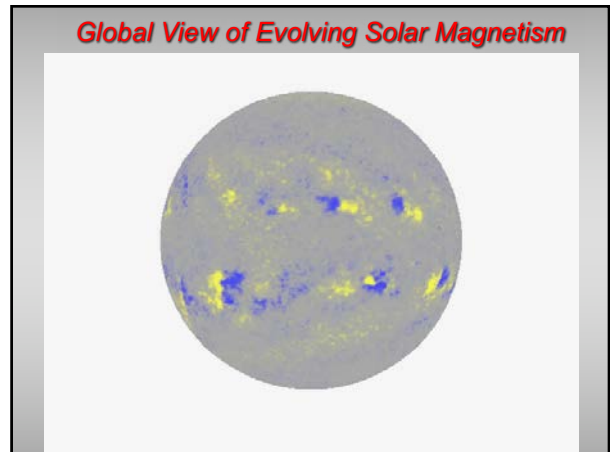
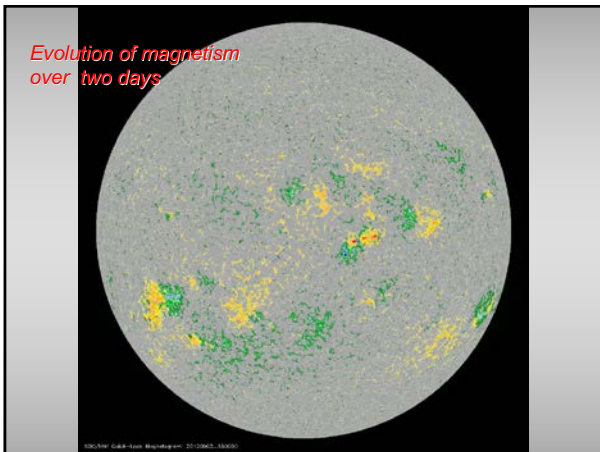
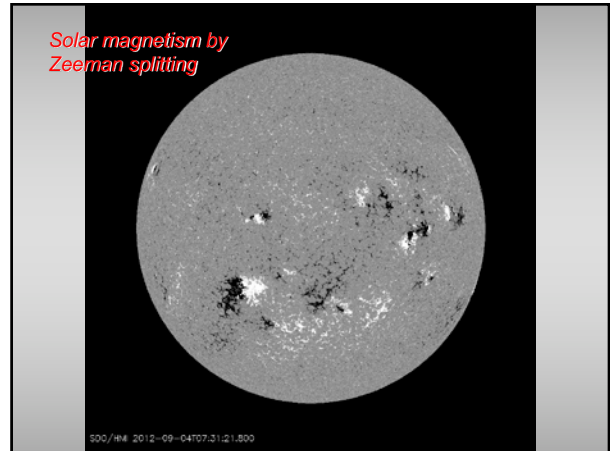
SUNSPOTS: COOL SPOTS (4000K), STRONGLY MAGNETIZED. EXHIBIT 11-YEAR CYCLE OF "ACTIVITY"

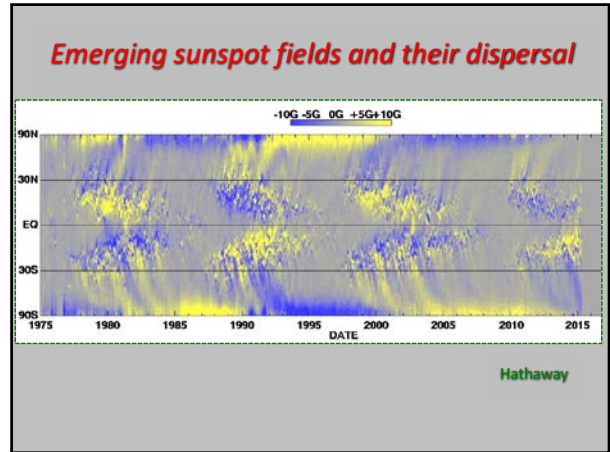
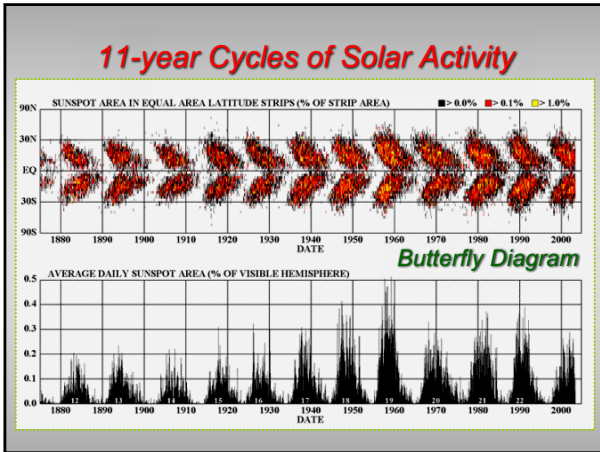
FLARES: INTENSE MAGNETIC STORMS

PROMINENCES (FILAMENTS) : SEVERES OF GAS IN CURVA (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 (H α) LINE





Let us make some plasma!
Demo of TESLA COIL
(Nikola Tesla, not just Musk's all-electric car!)
Powerful electric fields reach out