ASTR 1020: Stars & Galaxies

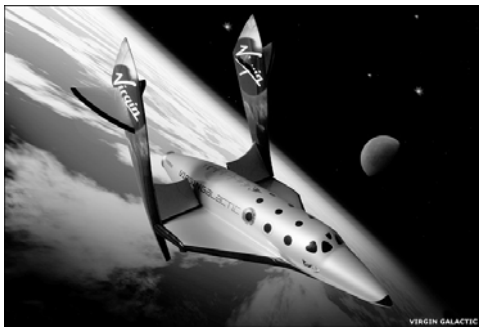
February 1, 2008

• *MasteringAstronomy* Homework on Light & Spectroscopy is due Feb. 4th.

• Reading: Chapter 14, section 14.3.

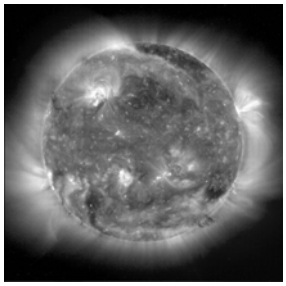
Astronomy in the News

Ryan Martin



Today's Class

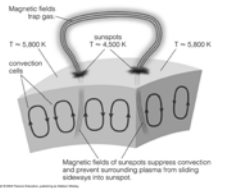
- Energy generation in the Sun.
- Proton-proton chain.
- Sun's energy budget.
- Mysterious neutrinos.

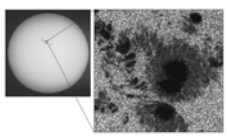


- "Visible surface" of the Sun: photosphere.
- T = only 5800 K.
- Photons free to fly-seen at Earth 8 min later.
- Thermal spectrum, T= 5800 K plus absorption from cooler gasses just on top.

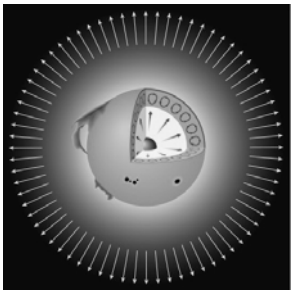
Magnetic Fields in the Sun

- Magnetic fields entrain gas in huge bubbling loops
- Cooler areas at "liftoff" cause dark "sunspots"





- Outer regions are hotter:
- Chromosphere,
- T= 10,000 K, Hydrogen alpha emission from thin gas (pink!)
- Heated by energy twisting and spilling around magnetic field lines?



Corona = outermost parts

T = 1 million K
=>X-rays!

Reading Clicker Question

Imagine that the Sun's energy generation rate (fusion rate) suddenly increases by a factor of 10. What will happen?

A) The Sun will increase in brightness by a factor of 10; after 1 million years the Earth's climate will start to heat, and after another 2000 years, all life will cease.
B) The core of the Sun will quickly expand and cool, slowing the fusion rate to its previous level.
C) The core of the Sun will heat up, causing a runaway reaction and catastrophic explosion.

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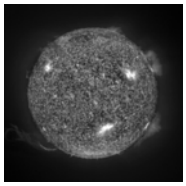

The Sun

Where does all that energy come from?

Nuclear FUSION

(not FISSION)

Hydrogen → Helium

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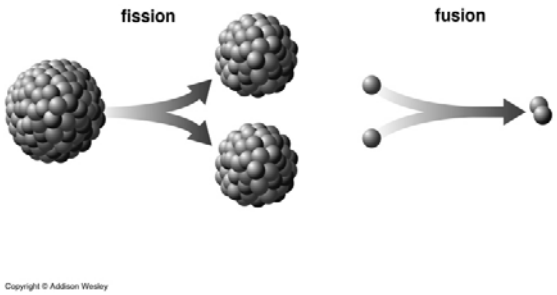

"Where hydrogen is built into helium…"

Hydrogen nucleus = 1 proton

Helium = 2 protons + 2 neutrons

Fusion occurs via the Proton-Proton Chain

4 protons (4 hydrogens) → 1 helium
PLUS Energy!

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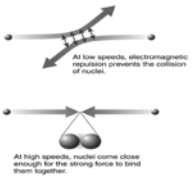
Proton-proton Chain

- Two protons collide at high speeds.
- Normally electric force would keep them apart (two positive charges repel).
- Extreme temperatures mean they have enough energy to overcome this.
- Once very close, the nuclear STRONG FORCE binds the particles together.



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Once the nuclei are crushed together:

P + P → P + N

+

"positron"

+

neutrino

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- P + N = deuterium, an isotope of hydrogen
- Positron is "anti-electron". When it collides with a normal electron, its mass is converted to energy (gamma-rays) via $E = mc^2$
- Neutrino gets away unharmed

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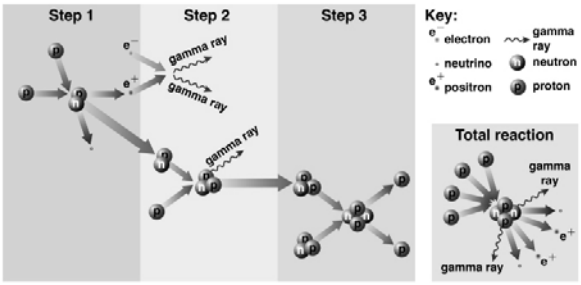
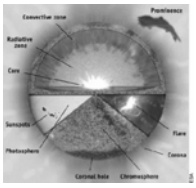
Multiple steps in the process



Proton-proton chain: *The bottom line*



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

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

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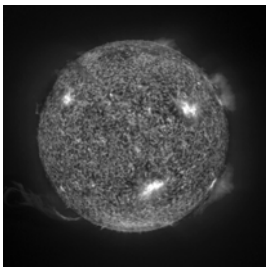
Gamma-rays work their way outwards, cool, and become Sunlight.

Neutrinos don't interact with much, zoom out of Sun and into space, 2% of the Sun's energy



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Energy budget

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

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The Solar Thermostat

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

  Fusion rate is VERY sensitive to temperature,

  → tight feedback loop

If energy generation (fusion rate) speeds up:

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

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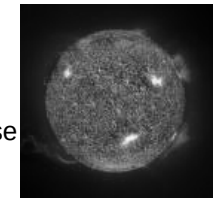
If energy generation drops:



- Core pressure drops
- Solar core starts to collapse
- Temperature rises
- Fusion rates go up again

But,

- Sun is remarkably stable
- Small (30%?) increase in fusion rate over billions of years

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Those Mysterious Neutrinos

- With very small masses, travel close to speed of light.
- Don't interact with other matter: requires a lead wall 1 lightyear thick to stop a neutrino! (Fewer at night...?)
- Lots of them: 10^{38} neutrinos/sec from the Sun, 10^{15} coming through YOU each second!

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Clicker Question: Do you think neutrinos flowing through our bodies are a cause of cancer or other damage?

A) Yes

B) No

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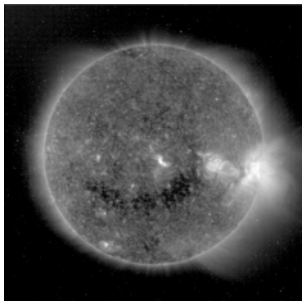
- (B) Neutrinos don't deposit any energy in our bodies- they simply don't do anything to us!



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