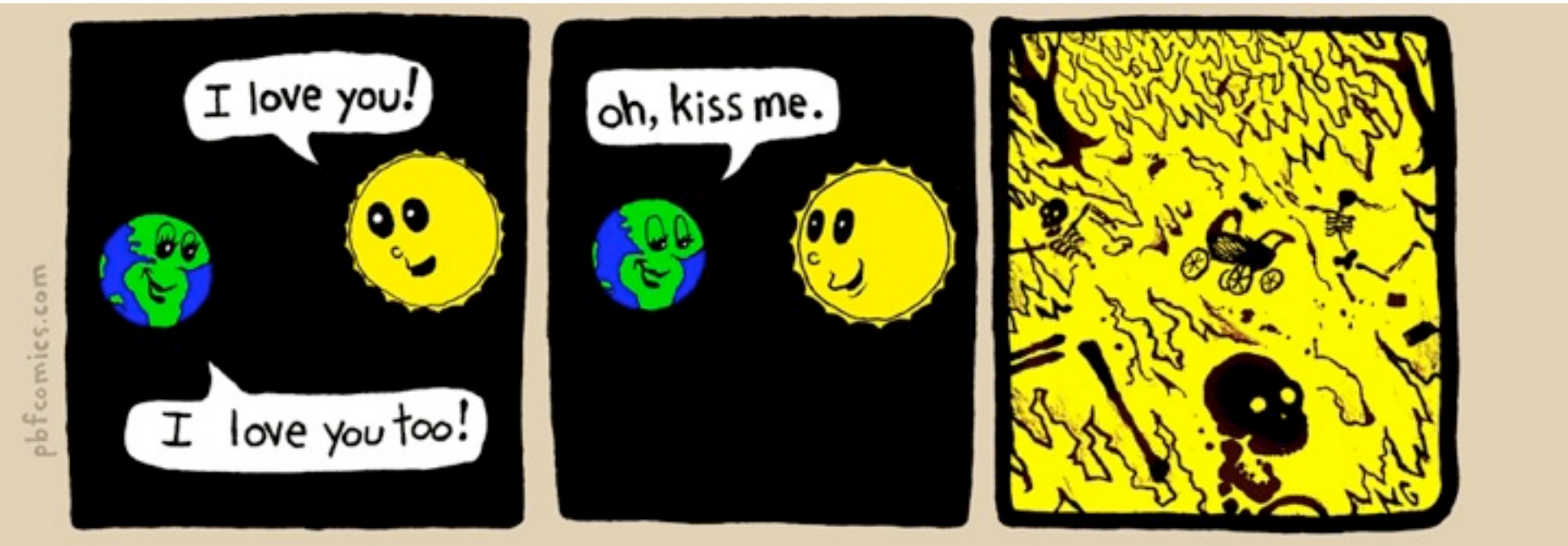
ASTR 150



- **Homework 4** due Monday night
- Night Observing starts next week

- Last time: Mitigation
- Today: The Sun

Music: *Sonne* – Rammstein

Imagine

After being dropped into suspended animation in a Pizza accident a billion years ago, you awake to a crazy new world.

Disregarding the signs warning people to stay underground, you wander outside and see that the Sun is only about 10% more luminous, but it is crazy hot and the oceans are nearly gone.

As you quickly succumb to heat stroke, you wonder what Leslie said about Solar Evolution so many years ago.

Or…..

Imagine

After being transported forward in time after a freak hot tub accident six billion years ago, you awake to a crazy new world.

The Sun is Red? And super hot.

The entire Earth's surface is molten rock during the day, slightly cooling at night.

As you burn in pain, you wonder what Leslie said about Solar Evolution so many years ago.

Top 10 Ways Astronomy Can Kill you or your Descendants

2. Solar Evolution!

The Sun seems eternal, but it is changing. It has already changed quite a bit, and it will end!

I mean rock impact may never happen, but this is going to happen.

The Sun will become a Red Giant, then a White Dwarf, and the party stops!

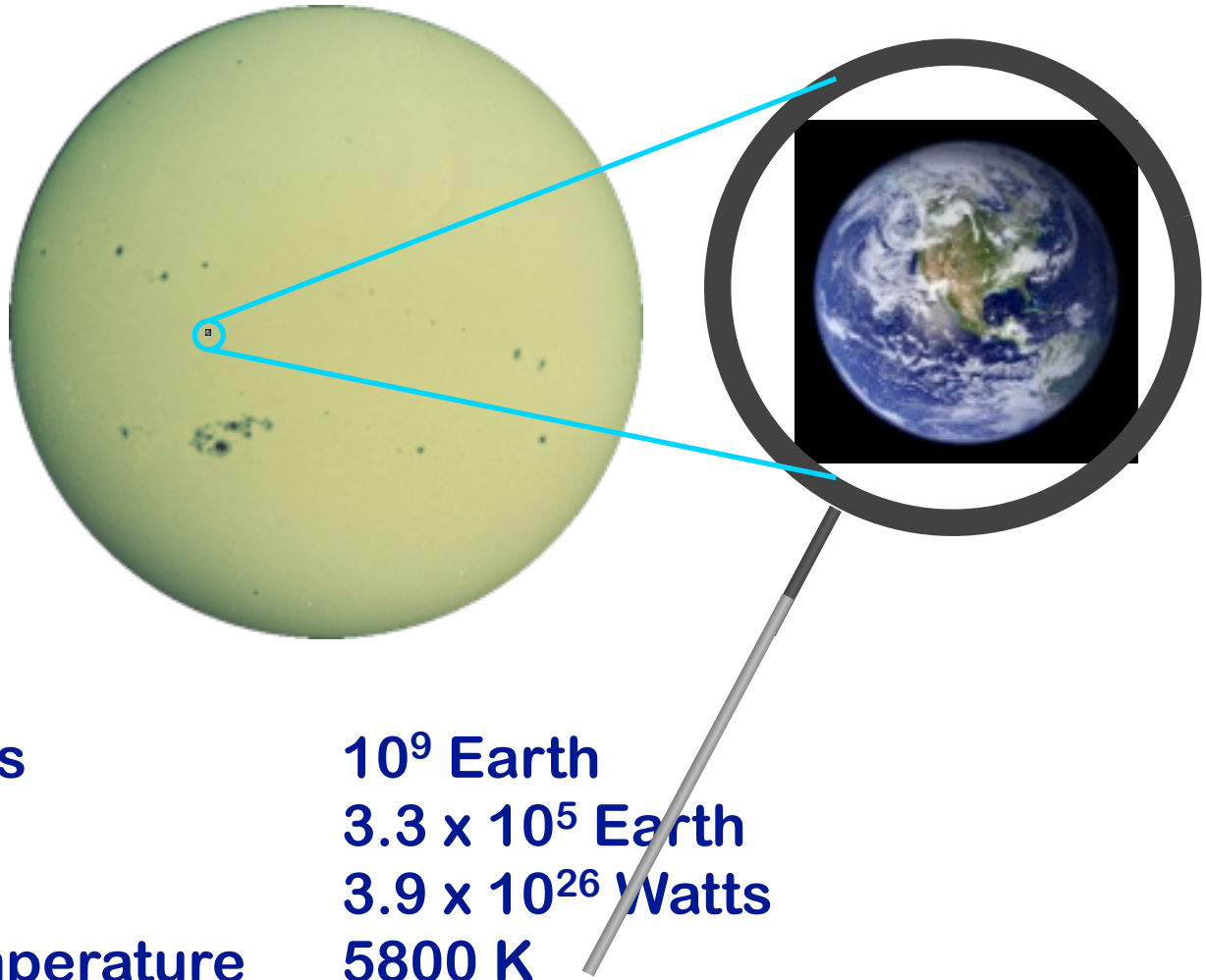
Top 10 Ways Astronomy Can Kill you or your Descendants

2. Solar Evolution!

http://www.youtube.com/watch?v=Qv9d0TM7Z0g

Earth-Sun Comparison

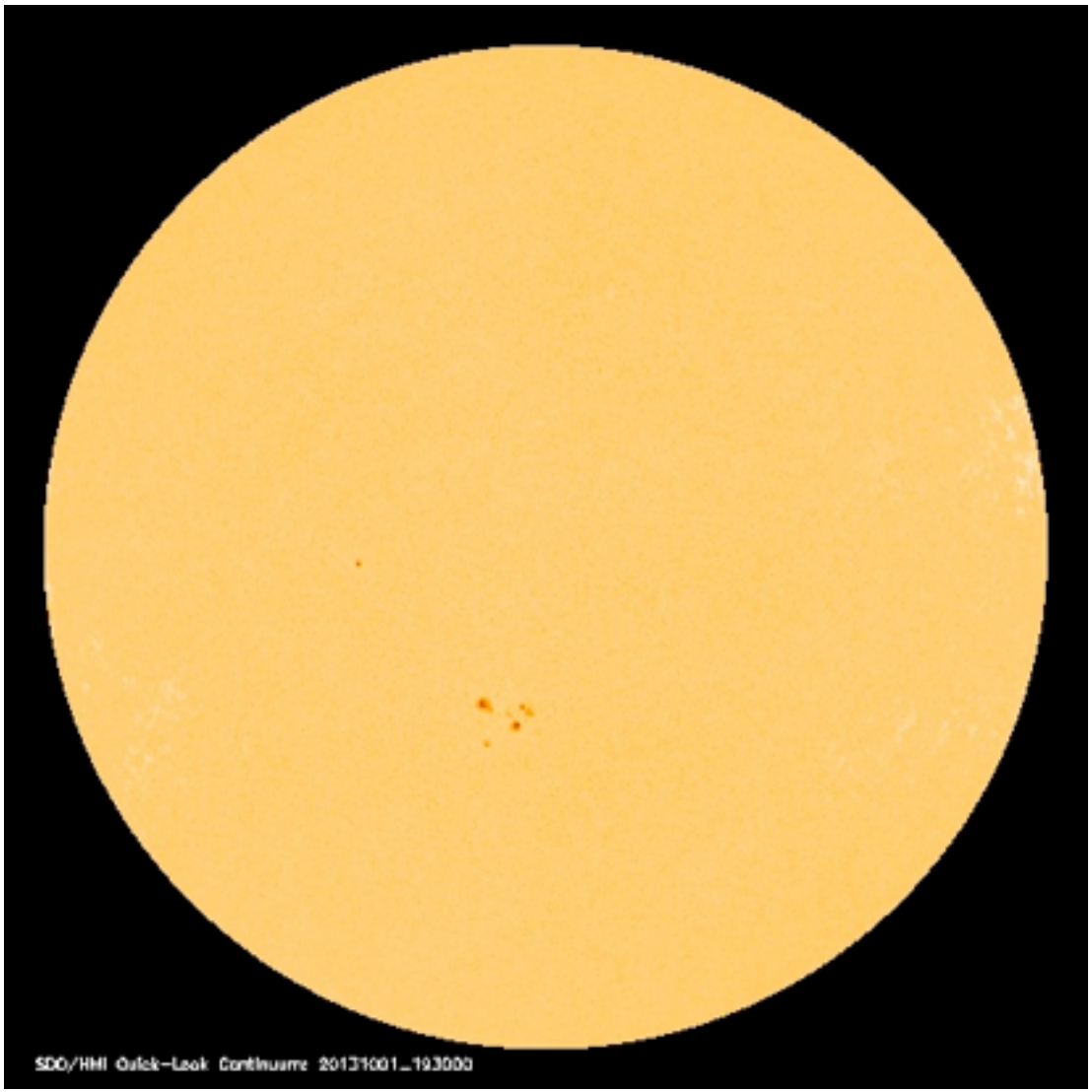
In general, a very typical star. Keep in mind that it is really a ball of gas/ plasma.



Visual radius	10^9 Earth
Mass	3.3×10^5 Earth
Luminosity	3.9×10^{26} Watts
Surface temperature	5800 K
Central temperature	1.5×10^7 K
Rotation period	25 days

LIVE from the Sun

http://sohowww.nascom.nasa.gov/data/realtime/



Question of Stability

The Sun's size is constant.

- Not expanding or collapsing

  at least on human timescales

But: Sun has huge mass and thus huge gravity

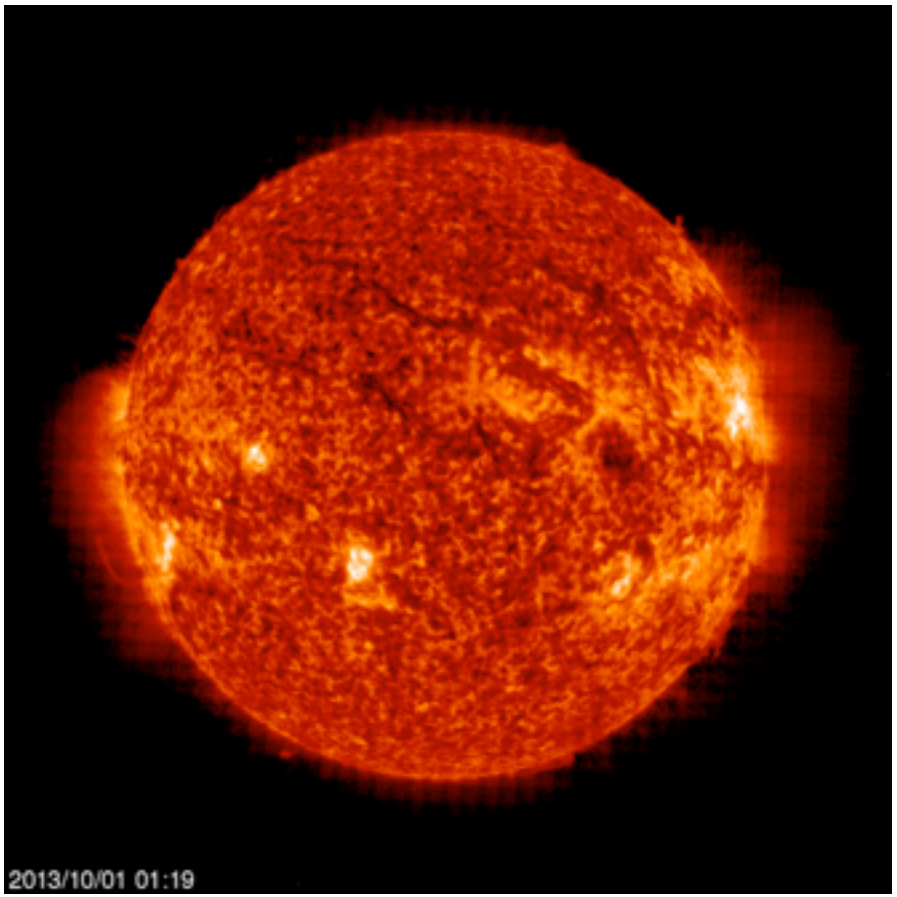
- keeps all planets in orbit
- but also pulls on itself!

Sun made of very hot gasses

- but gasses can flow, be compressed

Why doesn't the massive Sun collapse under its own gravity?

Why doesn't the superhot Sun explode?



http://sohowww.nascom.nasa.gov/data/realtime/eit_304/512/

iClicker Poll: Forces in the Sun

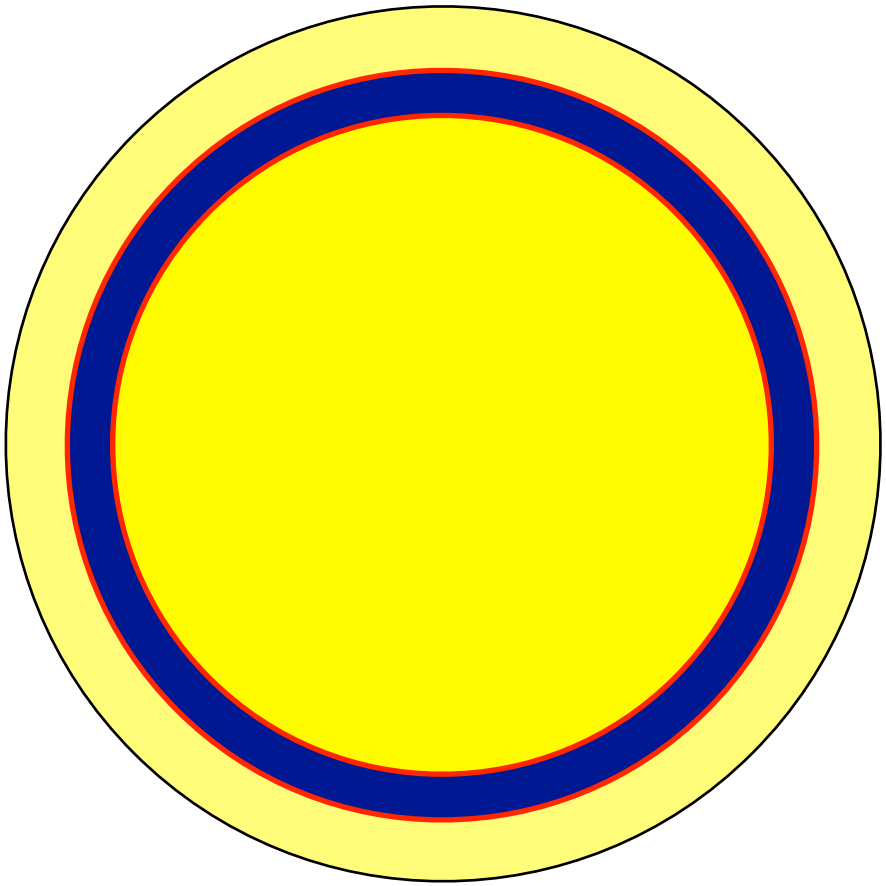
Consider a shell of matter (gas) in the Sun

Sun constant size:

shell is at rest--does not move inward or outward

How many forces act on this shell?

A. zero
B. one
C. more than one



Answer: C

Gravity and heat pressure

Forces in the Sun

Shell has mass:

- feels gravity force=has weight
- pulled toward Sun's center

Newton II: F = ma

- if net force, then acceleration

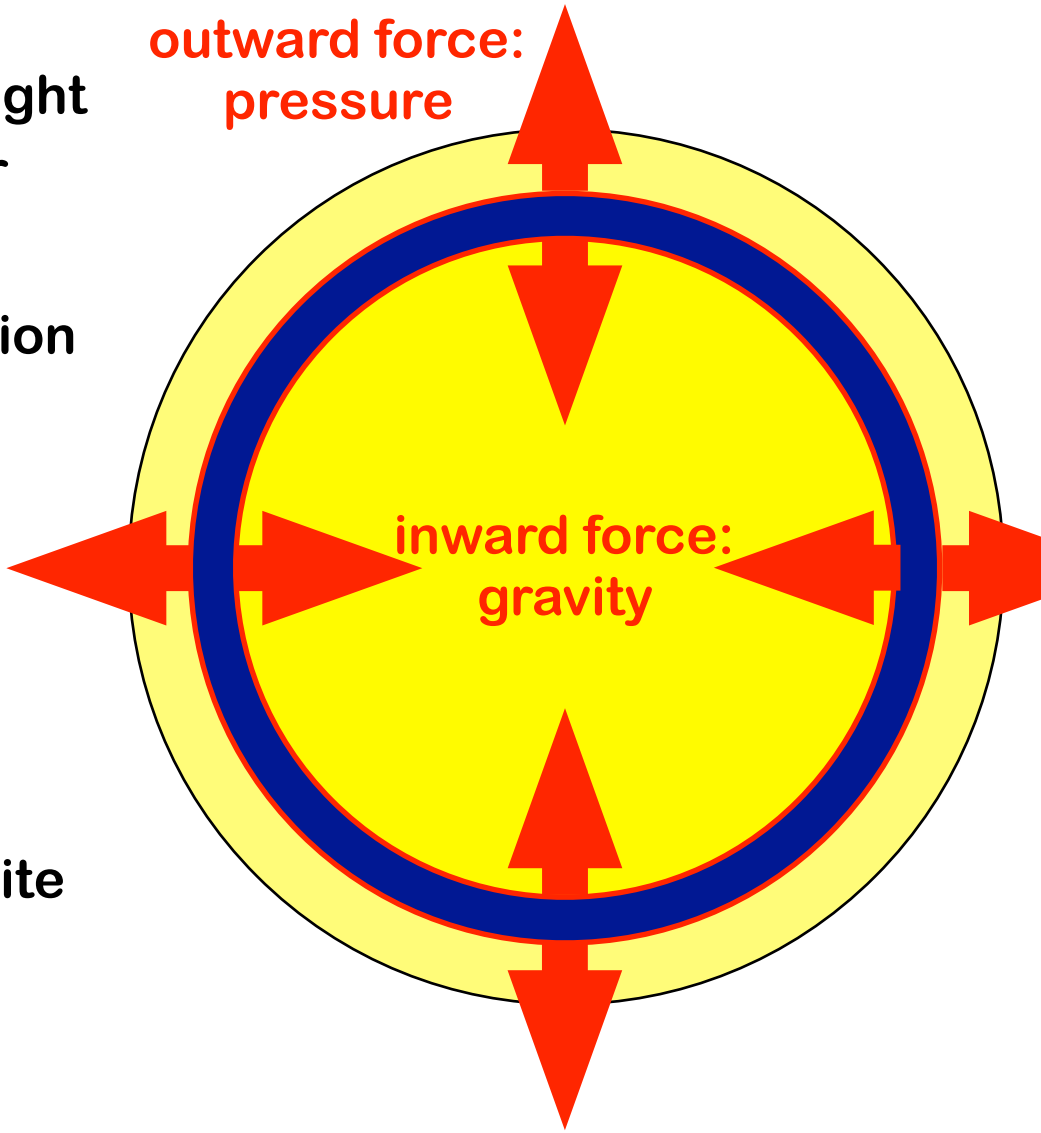
But shell at rest:

- no acceleration: a=0
- so F=0: no net force!

Therefore:

- must be another force on shell
- must be equal to an opposite to gravity!

Key: Sun made of hot gas: pressurized!



Atoms, Pressure, and Temperature

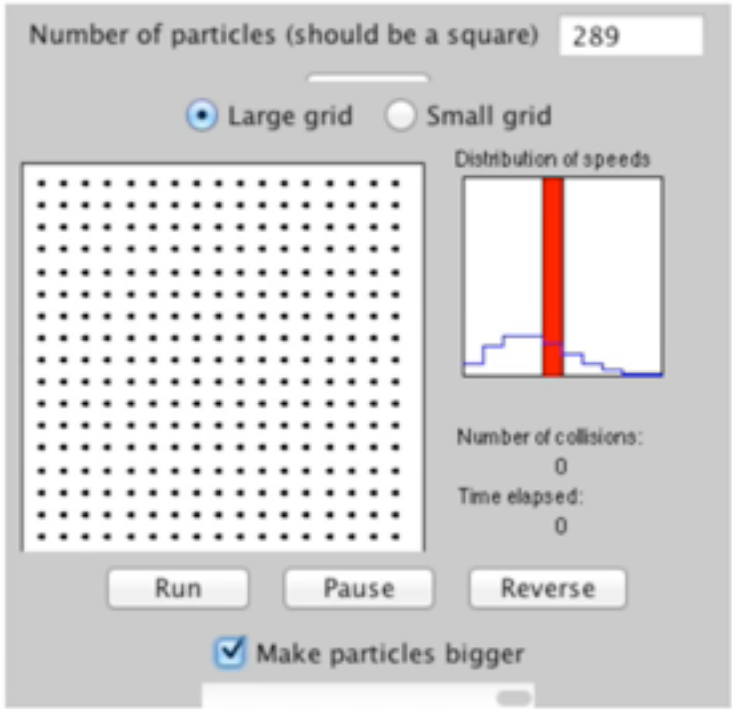
Microscopic, small-scale, view of matter:

- Richard Feynman:
  http://www.youtube.com/watch?v=v3pYRn5j7oI

Matter made of tiny **atoms in constant motion**

In **gasses**:

- Atoms widely separated, travel as free bodies until collide with each other
- Atoms **bombard** walls, "**exert force**!
-



- http://comp.uark.edu/~jgeabana/mol_dyn/KinThI.html

Atoms, Pressure, and Temperature

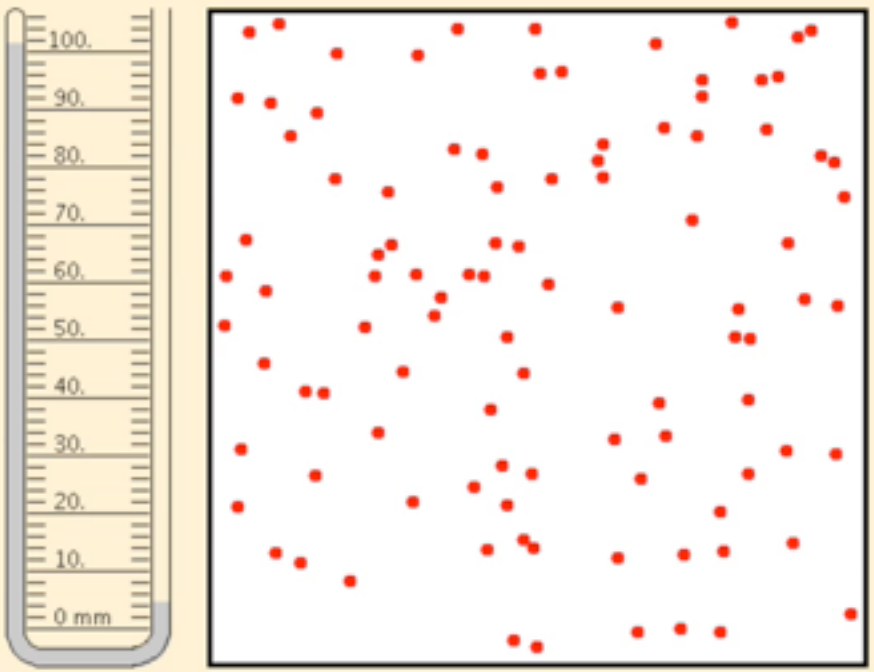
Macroscopic, large-scale picture

average atom speeds ↔ temperature

- Faster atoms ↔ hotter; slower atoms ↔ colder

bombardment & collision forces ↔ pressure

- Faster atoms = hotter = more violent collisions = more pressure
- Cram in more atoms
  = more density
  = more collisions
  = more pressure



Pressure Stable

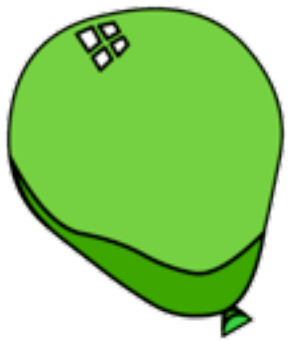
What is pressure?

- **Pressure** $= \frac{Force}{Area}$

Pressure of Earth's atmosphere is 14.7 pounds per square inch

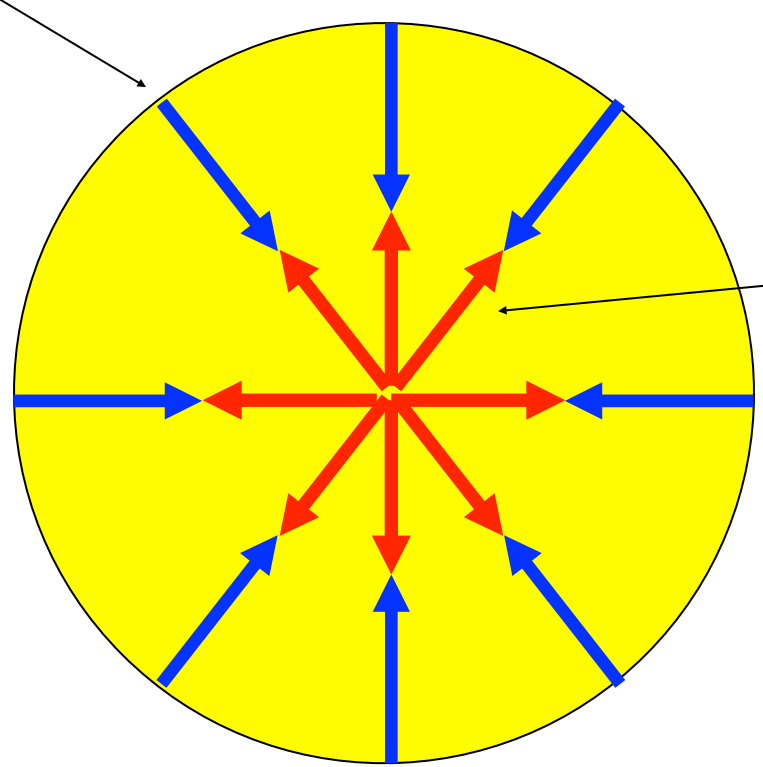
Explain blowing up a balloon?

Forces?



The Battle of The Solar Titans
Gravity vs Pressure

Gravity pushes in



pressure from hot gasses pushes out

This battle long ago fought to standoff:

- gravity compressed Sun -- raised density and temperature
- which raised outward pressure
- until the forces balance!

pressure vs gravity balance: "hydrostatic equilibrium"

iClicker Question

Imagine drastically lowering the temperature of a balloon

...without popping it

What would happen?

A. balloon gets smaller
B. balloon gets larger
C. balloon stays same size

How could we do this experiment?

Experiment: Balloon vs Liquid Nitrogen

Nitrogen:

most abundant element in the air you are breathing

- a gas at room temperature

If cool down enough:

condenses to liquid nitrogen

- same idea as water vapor cools to liquid water
- transition temperature: boiling point
- liquid nitrogen boiling point: -321 ^{o}F = -196 ^{o}C=77 K
- boils at room temperature!

to liquify, have to make very cold

- and then store in high-quality "thermos"--a dewar

Experiment: pour liquid nitrogen on balloon

Why'd that happen?

- Reduce temperature = reduce pressure = balloon collapses

So wait...what was the point? Why did we do this?

Astro-Lesson?

- the Sun's gotta stay hot to remain stable!
- if loses heat source: lose pressure! shrinkage! collapse!

The Facts of Life for the Sun

Fact: the sun constantly radiates energy into space

- and at a huge rate!
- the Sun: a lightbulb with wattage ("luminosity") of 4×10^{26} Watts!

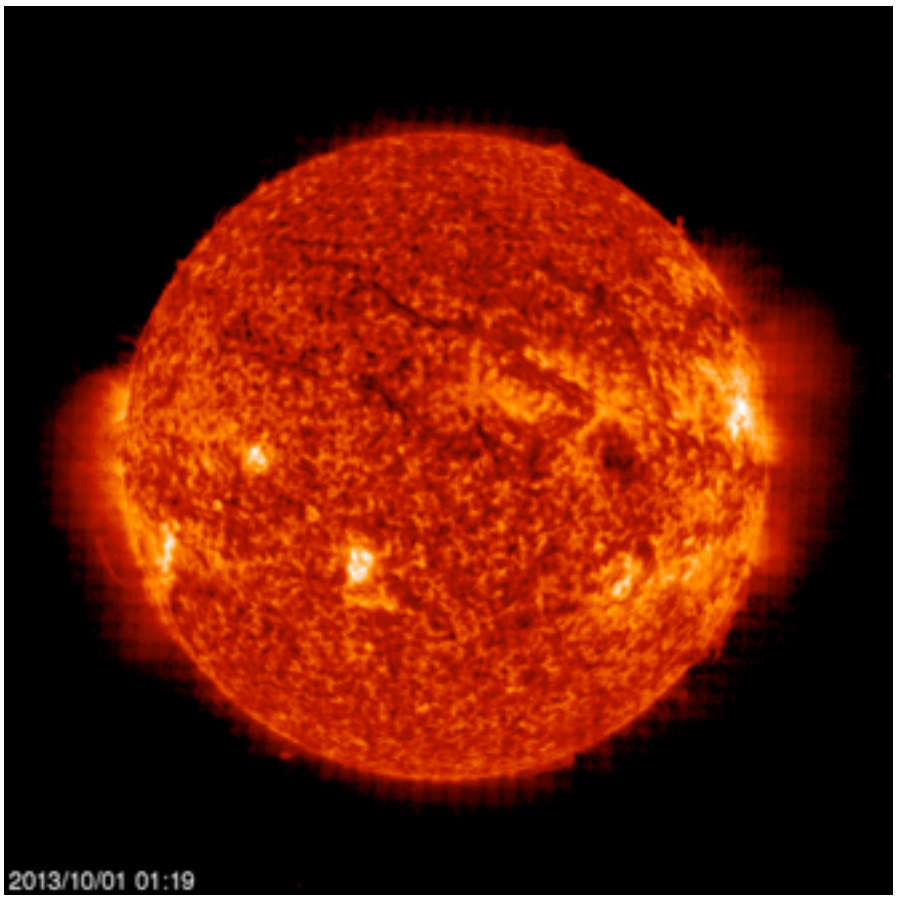
Fact: the Sun has a finite (not infinite) mass

- and thus a finite fuel supply
  (whatever that fuel may be)

Fact: Energy is conserved

- cannot be created or destroyed
- only converted from one form to another
- no free lunch!

Q: therefore?



Consequences of Energy Conservation
The Doomed Stars

the Sun and all stars:

- are constantly releasing energy to the rest of the universe, and
- require fuel, and are unable to "refuel" out of nothing, and
- thus must eventually run of out fuel

Thus:

- all stars – including the Sun – must eventually "burn out"
- = run out of energy = run out of fuel:
- the Sun all stars are doomed to die

Q: important followup question?

the Sun cannot live forever!

But the Sun and other stars are alive today, so…?

- stars alive today were not alive forever
- all stars must be born as well as die
- the Sun and stars have life cycles
- stellar mortality also implies possibility of rebirth!

How does the Sun Shine?

The Sun shines by its own power

- hot glows = emits light

but what keeps the Sun hot?

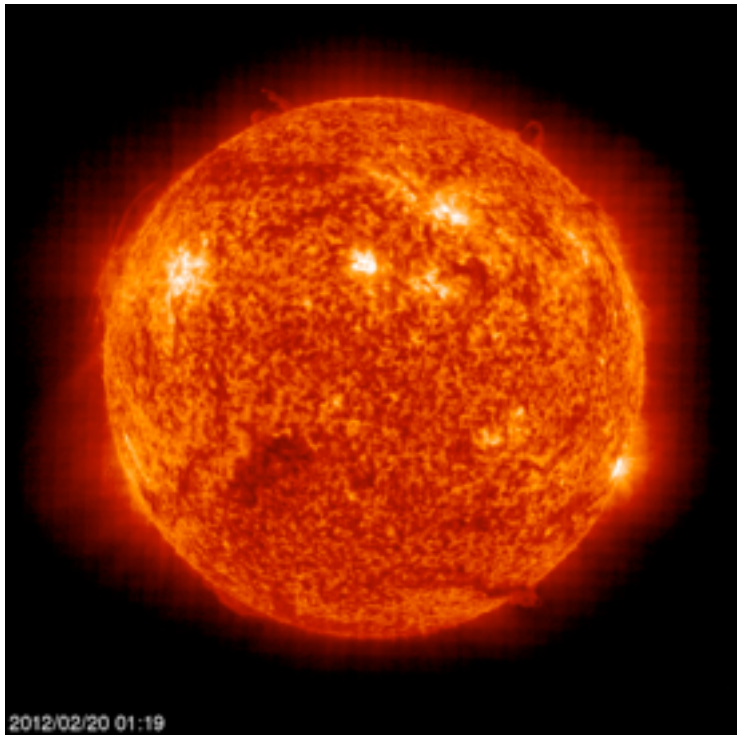
- What energy source is transformed into thermal energy, light energy?

Discuss in groups

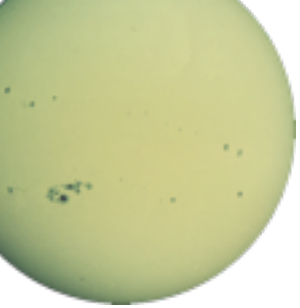
Find at least two plausible answers

even if know right one

Click A when done



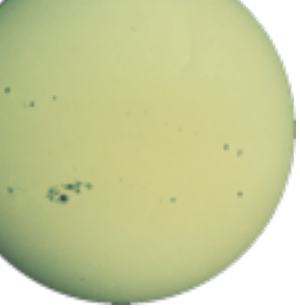
How to Test?



"Flashlight test"

- each energy source represents some amount of "fuel" = "battery charge"
- see how long Sun can stay lit up for each fuel source
- but know needed "lit time":
  at least 4.6 billion years = age of solar system

How to Test?



Gravity:

- Seems like a good idea
- A contracting Sun does release gravitational energy
- But only enough for 20 million years

Chemical:

- If the Sun was made from TNT, something that burns very well, then it would last for only 20,000 years

Rotational:

- if Sun's spin slowed down, and somehow harness the energy, would only last for about 100 years!

Need something more powerful!

The Nuclear Option

the only workable solar power source:

- **nuclear energy**

The Sun is a vast nuclear reactor

in its hot core, hydrogen is converted to helium

by nuclear reactions

nuclear "burn time" about 10 billion years

Q: why is this good news?

Note how we concluded this:

- **needed quantitative info (numbers: "burn times")**
- **to answer qualitative question "What powers the Sun"**

example of the power and necessity of number crunching

Fusion in the Sun

Fusion is a kind of nuclear reaction

Nuclear reactions

- one kind of nucleus transformed into another
- but nucleus defines element type:
- in nuclear reactions: atoms changed from one element to another!
- alchemy!

Fusion

- reactions where two nuclei combine to make a new, more massive nucleus
- "light" nuclei combine to make "heavy" nuclei

Fusion in Sun

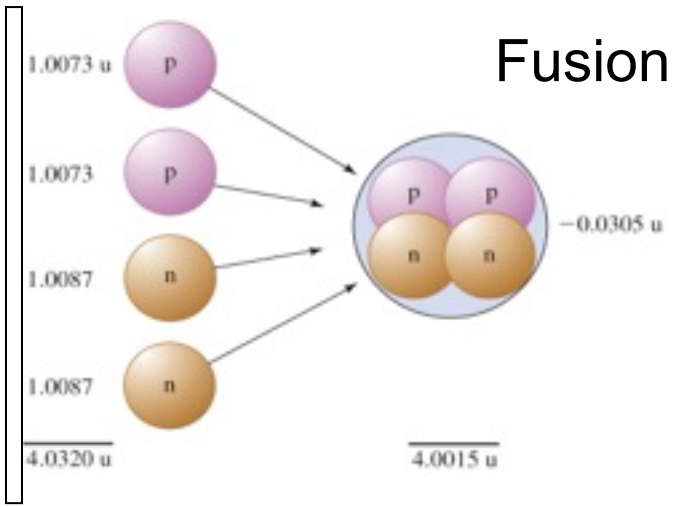
- a series ("chain") of reactions changes $\text{hydrogen} \longrightarrow \text{helium}$
- specifically: $4p \longrightarrow {}^4\text{He}$

  where "helium-4" ${}^4\text{He} = \boxed{2p, 2n}$

Fusion vs. Fission

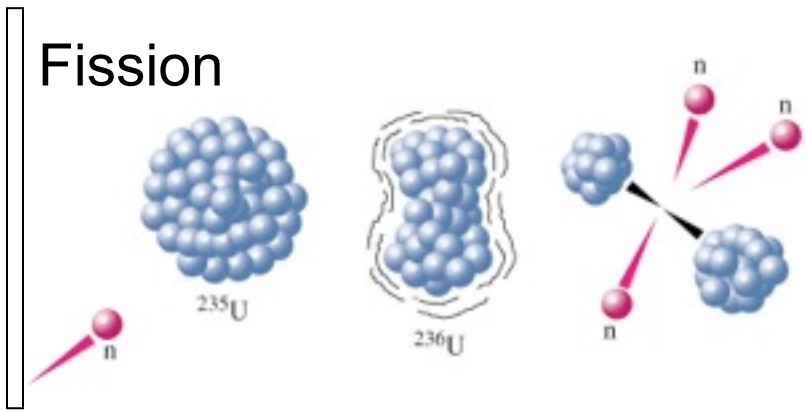
Light nuclei: fusion

- Fuse together light atoms to make heavier ones
- Happens in the Sun
- H-Bomb

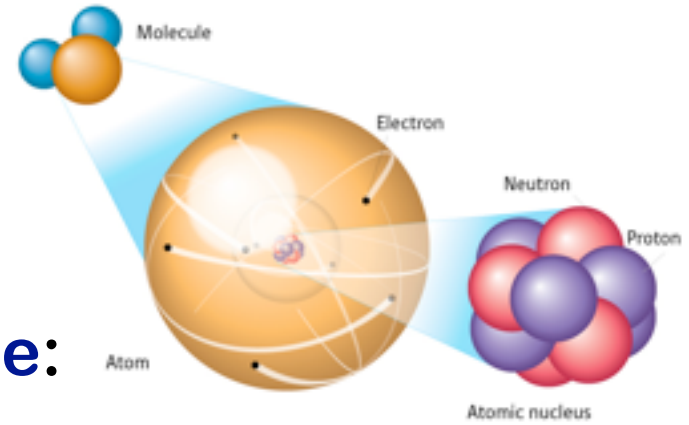


Heavy nuclei: fission

- Break apart heavier atoms into lighter ones
- Used in power plants
- A-Bomb



Why don't nuclei fly apart?



Atomic nuclei:

- very small
- contain protons: electric charge +1

but two positive charges feel force:

- electrical repulsion
- another inverse square force: strongest when protons close

in nucleus: protons very close

- electrical repulsion huge!

If this were the whole story, nuclei should explode! Atoms could not exist!

Q: Why don't nuclei explode?

Discuss, and Click A when you have an answer