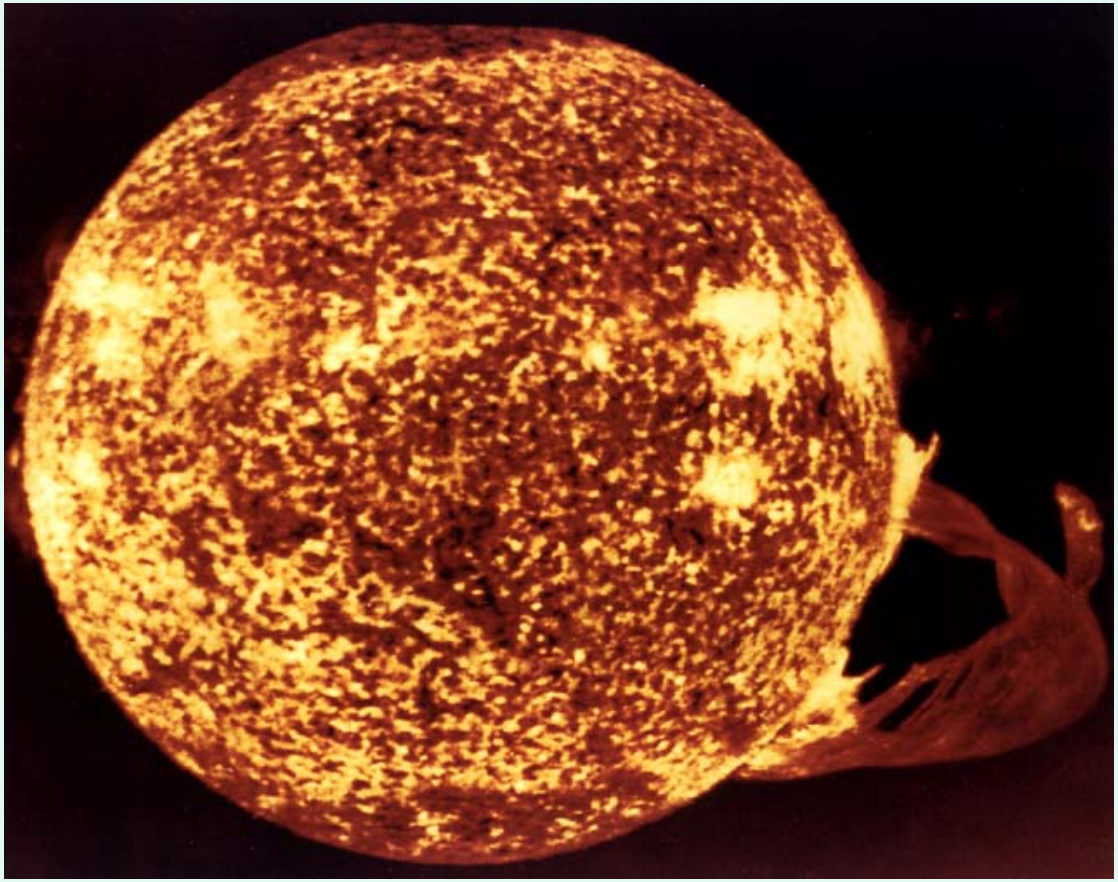
Astronomy 120



Prof. Jeff Kenney

Class 6

June 4, 2018

Reading quiz questions

- #1 should be easy -- This is something you should understand after the reading.

- #2 more challenging -– answer may not be directly given in reading. Think about it, but only for a few minutes, then give your best answer. In most (but not all) cases, this is something you should understand after the lecture.

- #3,4 very helpful for the instructor!

Homeworks

- 3rd HW due *this Thurs June 7*

  this is a double assignment! start now!

- 4th HW due *next Mon June 11*

please write on all HWs:

- *your name, date, astro120, HW#*

Astronomy 120 Overview

Lec 1-5: intro, physics review (FAST)

Lec 6-8: stars (FAST)

Lec 9-14: galaxies, clusters & dark matter (SLOW)

Lec 15-18: active galaxies & black holes (SLOW)

Lec 19-24: cosmology & the universe (SLOW)

For full syllabus see website www.astro.yale.edu/astro120

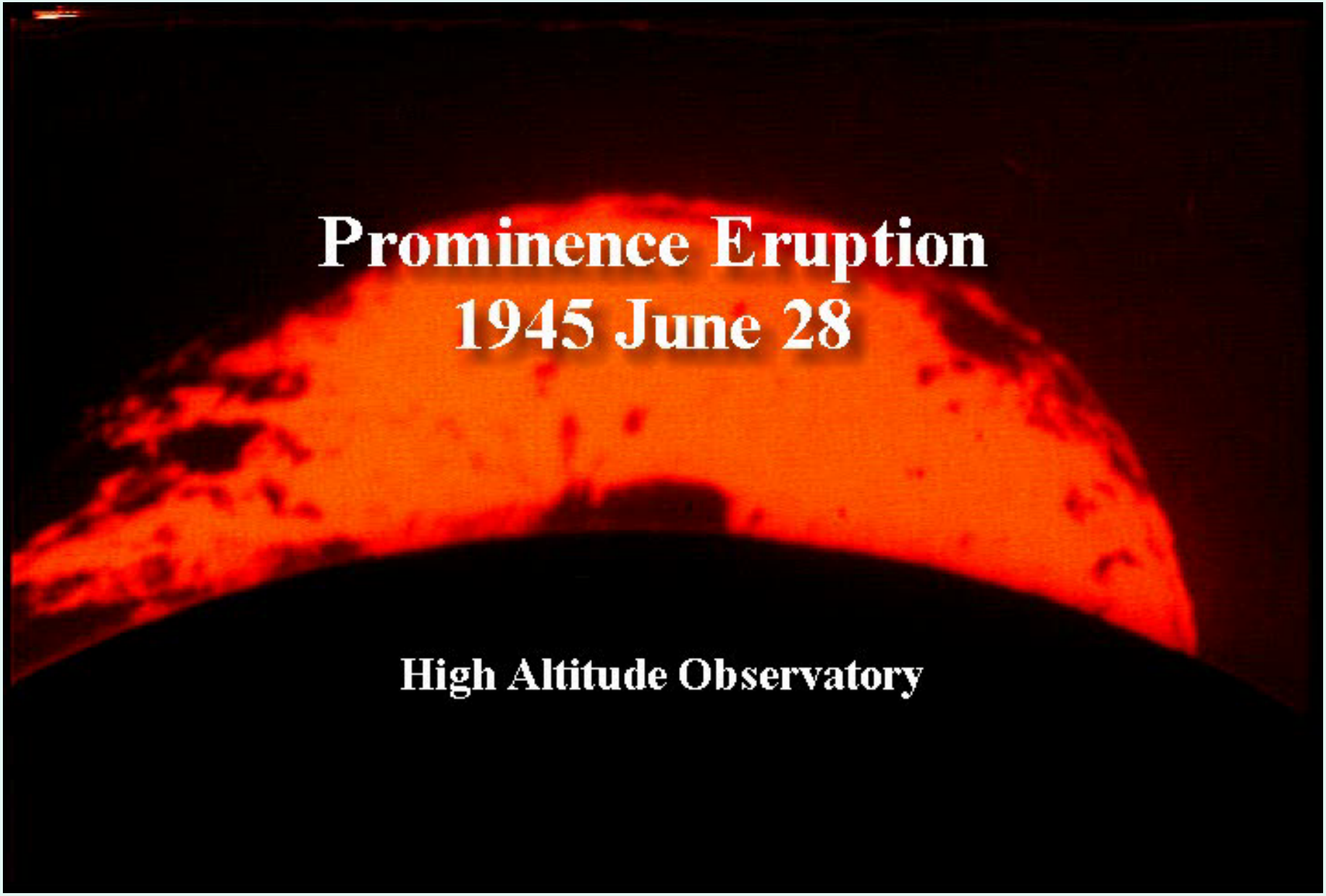
What is a star?

What is the energy source of stars?

GOES-12 SXI

http://sxi.ngdc.noaa.gov

http://www.sec.noaa.gov/sxi


Prominence Eruption
1945 June 28
High Altitude Observatory

Solar Flare
1971 October 10

Big Bear Solar Observatory

What property makes the Sun a star, and the Earth not a star?

A. Temperature
B. Location
C. Mass
D. Composition
E. Density

- Temperature is a pretty good answer but not the best answer. Mass is the best answer.

- If you increase the T of earth to match the sun, it would still not be a star. But if you increase the mass of the earth to match the sun, it would become a star. It would naturally heat up to the sun's temperature.

- Composition: is different, but this is not the reason why one is a star and one is not. It is a by-product of earth being a planet close to the sun.

What is a star?

Big, self-luminous, hot ball of gas (plasma), held together by its own gravity, and powered by nuclear fusion (at some point in its life).

requires mass > 1/10 M_{sun}

Why is the sun a star and the earth not a star? … MASS

More mass →

Stronger gravity ->

Why is the sun a star and the earth not a star? … MASS

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Stronger pressure ->

Gravity will compress and shrink something until EITHER:

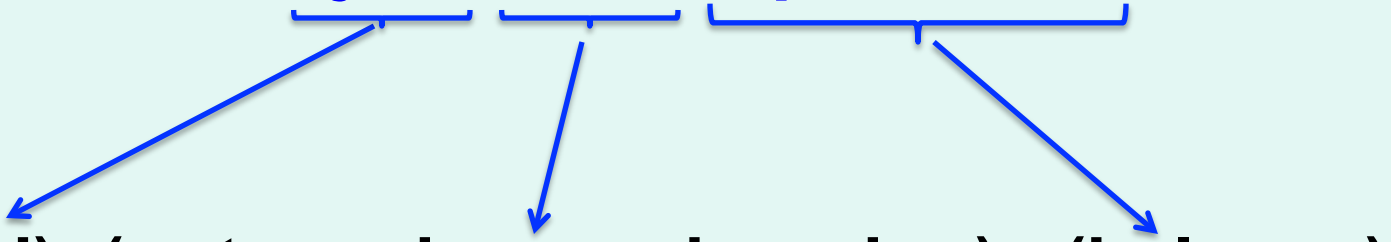
1. The matter exerts enough ***pressure*** to balance it, OR

2. A black hole forms!

Usually matter can ultimately resist gravity by exerting a pressure.

In stars, gravity and pressure are balanced.

Balance is called ***hydrostatic equilibrium.***



(fluid) (not moving or changing) (balance)

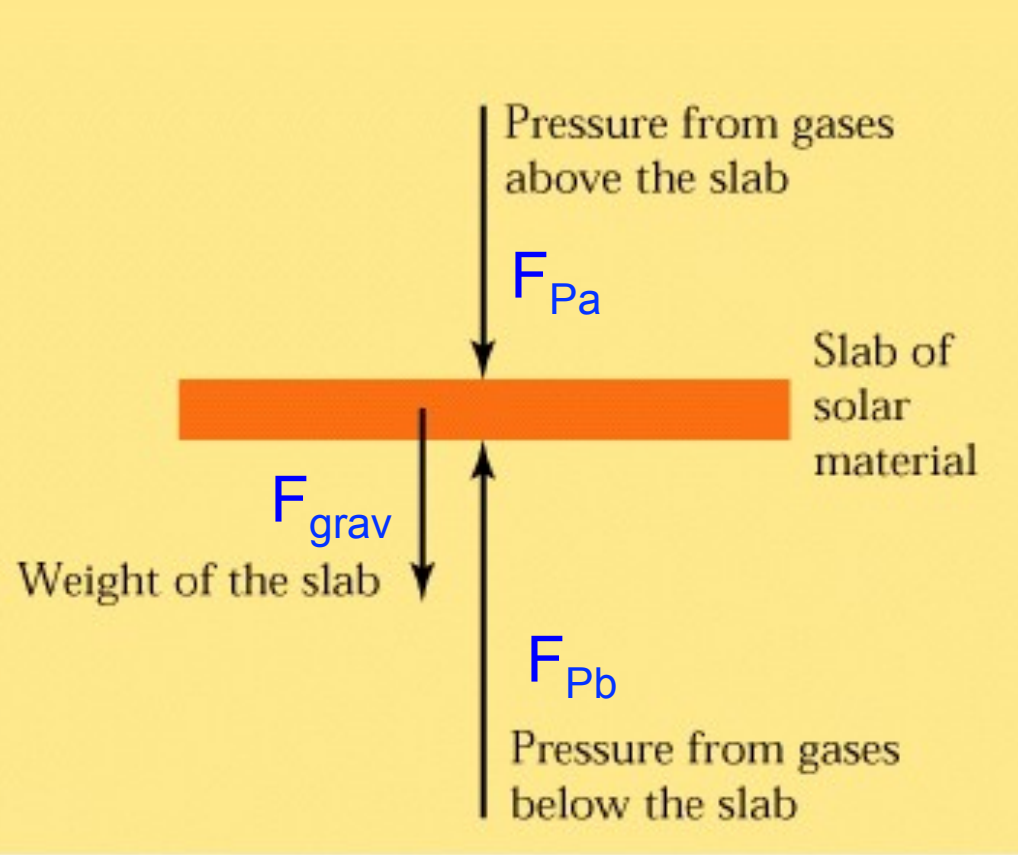
the sun is in hydrostatic equilibrium, not contracting or expanding, but stable everywhere in star; no net forces → forces are balanced

the videos I showed at the beginning showed that the surface of the sun does have activity (very small regions not in equlibrium) but overall the sun is stable

there is also “churning” motion (convection) in sun. stuff moves up & down some. but **no *net* up and down motion.**

stars are not always in hydrostatic equilibrium. They go through phases in which they are not in hydrostatic equilibrium. For example, they blow up. As supernovae. This is definitely not condition of hydrostatic equilibrium.

Hydrostatic equilibrium in star



In hydrostatic equilibrium, forces balance

$F_{tot} = 0$

slab not moving

no net forces

$F_{tot} = F_{grav} + F_{Pa} - F_{Pb}$

all the forces acting on slab

Combine:

$F_{grav} = F_{Pb} - F_{pa} = \Delta F_P$

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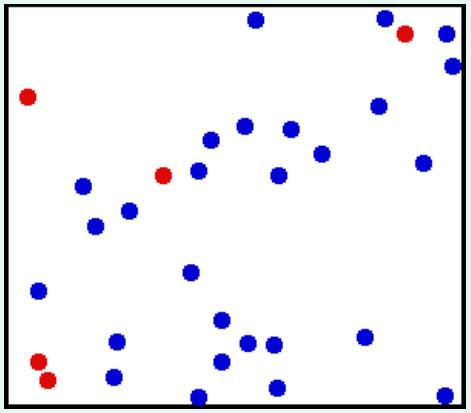
- The kind in the center of normal stars like the sun is “normal” gas pressure, described by Ideal Gas Law $P = k\ n\ T$
- Arises from collisions of particles – gas particles are in motion, and “collide” with one another



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As gas squeezed (i.e. pressure increased) particles pushed toward one another, “collide” more rapidly with one another, & rebound due …. ?

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As gas squeezed (i.e. pressure increased) particles pushed toward one another, "collide" more rapidly with one another, & rebound due to electrostatic repulsion, thus resisting compression.

Strength of pressure depends on

how often and *how hard* collisions are

P = (constant) x density x temperature

$P = k\ n\ T = (k/m_{particle})\ \rho\ T$ **ideal gas law**

n = # particles/volume (not moles!)

ρ= mass/volume = $n\ m_{particle}$

you may be familiar with ideal gas law written another way PV = nRT , n = # moles, V = volume

What is Temperature?

A measure of the speed or kinetic energy of atoms or other particles that make up substance

$\frac{1}{2} mv^2 = 3/2\ k\ T$

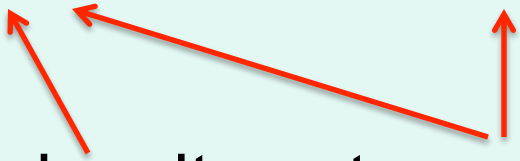
KE per particle = thermal energy per particle

$T = mv^2/3k$ or $T \sim v^2$ v is average speed of particles

The faster the particles are colliding, the higher the temperature

Strength of pressure depends on

how often and ***how hard*** collisions are



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water, people	$\rho \approx 1$ gm cm^{-3}
planets, rocks	$\rho \approx 0.7–5$ gm cm^{-3}
gold or lead	$\rho = 15$ gm cm^{-3}
air at sea level	$\rho = 10^{-3}$ gm cm^{-3}

1 cubic meter of air: m =1 kg
1 cubic meter of water: m = 1000 kg

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density at "surface" of sun is MUCH MUCH lower than density of air!

The Photosphere (visible surface) of the Sun is like

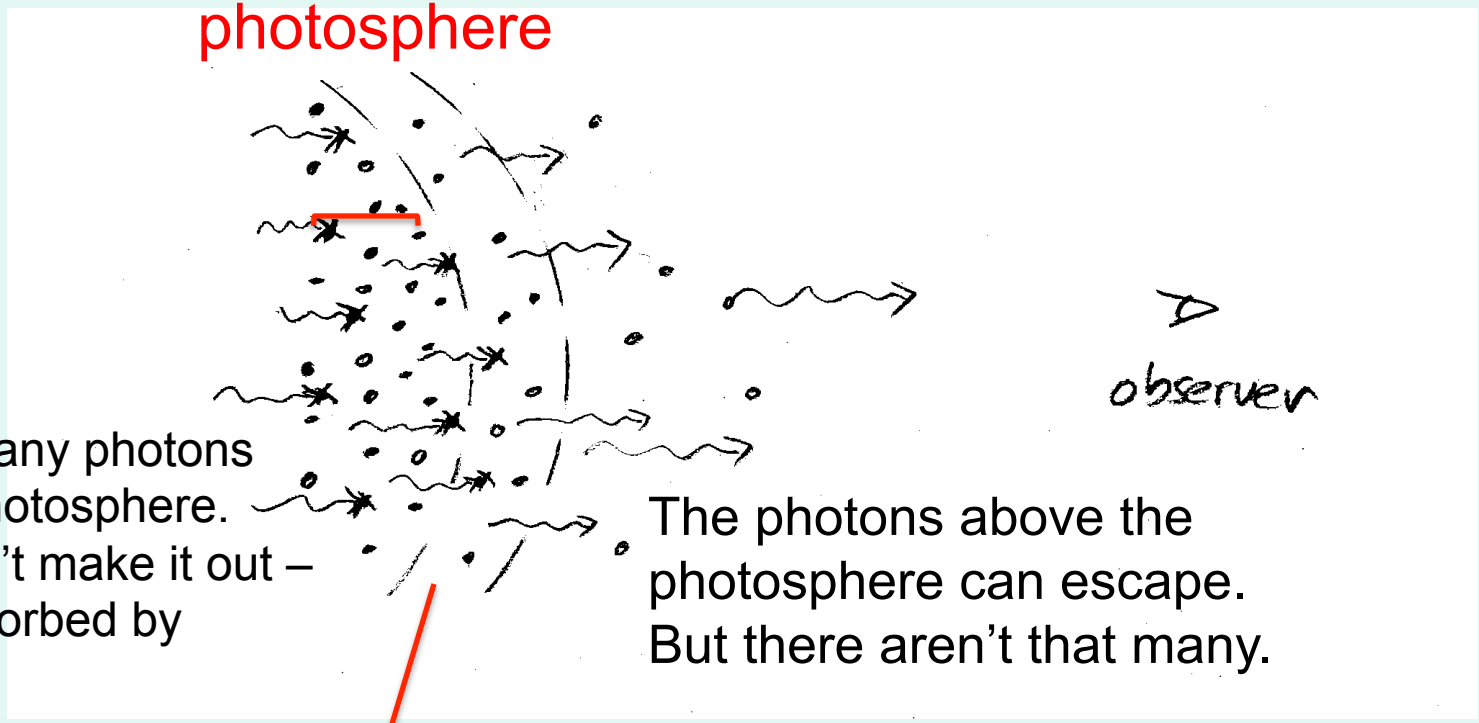
A. The surface of the earth – you could stand on it, if you could survive the intense heat

B. The surface of the ocean - you couldn't stand on it, but you would clearly be able to detect differences above and below it

C. An apparent surface - you would notice very little change as you go through it, as when you fly through a cloud

D. The surface of a trampoline - you could land on it but the intense pressure would push you away again.

What do you see when you look at the Sun?



Most photons that you see originate in the zone (~3000 km thick) called the "photosphere"

Optical depth – concept which describes how far into something you can see. Most photons come from an optical depth of ~1. One cannot see (much) deeper than this.

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density at core of sun is somewhat high …

… 10x denser than anything you have ever held.

But what is extreme is the temperature

Why is the sun a star and the earth not a star? … MASS

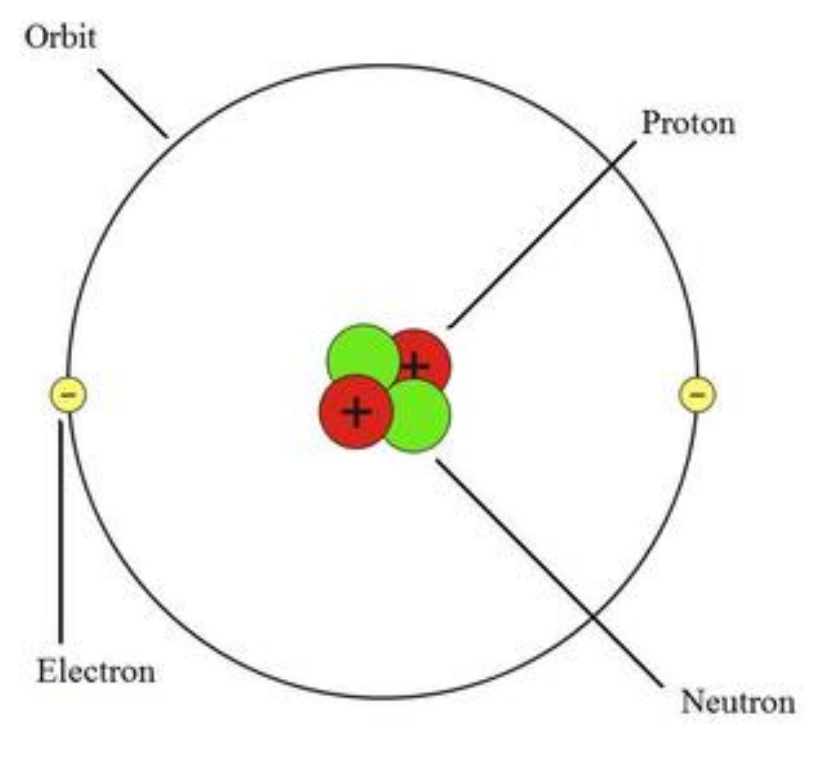
More mass →

Stronger gravity ->

Stronger pressure ->

Higher temperatures ->

Helium atom



Nucleus contains:
Protons (+charge)
Neutrons (no charge)

Electrons (-charge)
in orbits around nucleus

p, e : equal & opposite charges
But very different masses!
$m_p = 1.673 \times 10^{-27}$ kg
$m_n = 1.675 \times 10^{-27}$ kg
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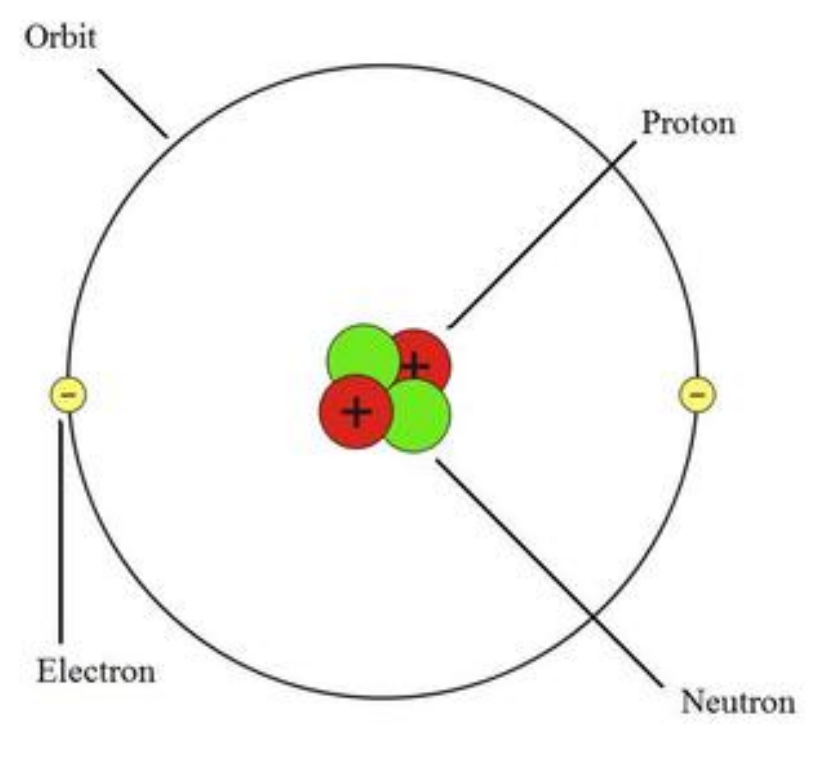

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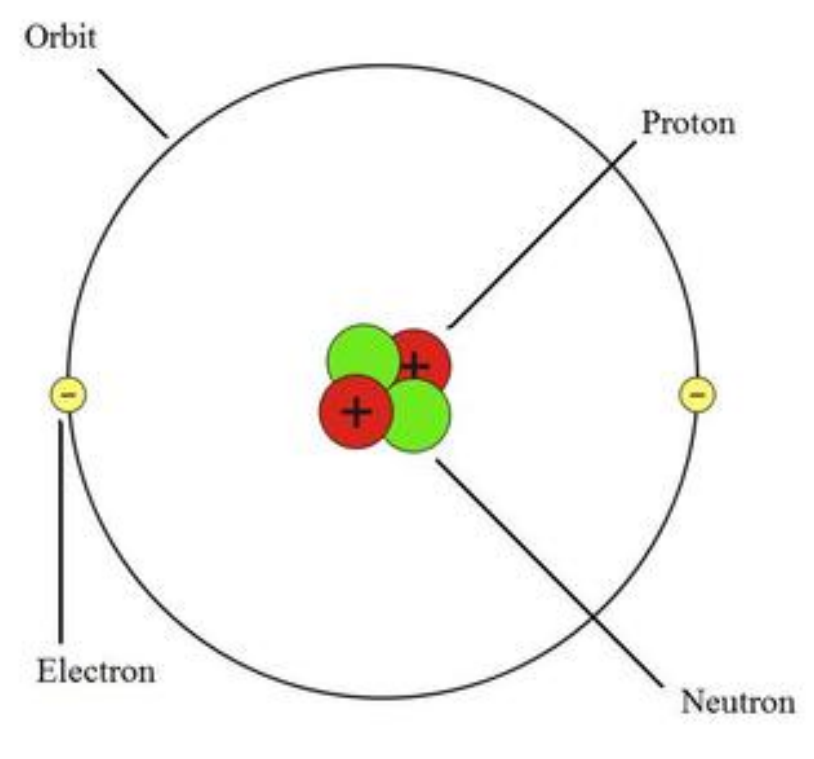

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What holds electron to nucleus?

What holds protons in nucleus together?

4 fundamental forces of nature:

1. gravity (dominant force on large scales in universe)

2. electromagnetism (underlies gas pressure; binds p,e in atoms)
3. strong nuclear force (binds nucleons n,p together)

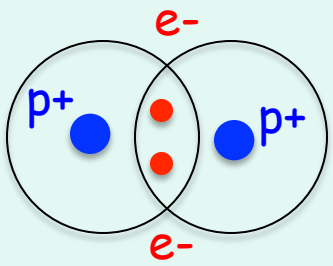
4. weak nuclear force (responsible for radioactive decay of nuclei)

gravity is extremely weak compared to the EM force ….

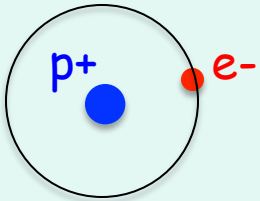
gravity is extremely weak compared to the EM force …. yet is the dominant force on large scales in universe … WHY??

strong nuclear force is strong but ***very short range*** – particles need to be very close to experience much of it

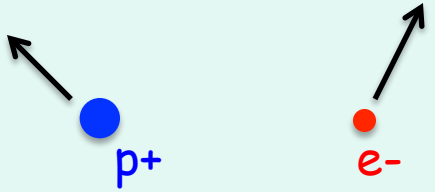
different states of matter: for Hydrogen



H_2 molecule



H atom



H ion (H^{+})

or free proton (H nucleus)
& free electron

no net charge

no net charge

net charges->

plasma

chemistry

atomic physics

nuclear physics

← colder hotter →

fast collisions → fusion

in the core of the sun, **nuclei collide at such high speeds** (since pressure and temperature are so high), **that nuclear reactions occur**

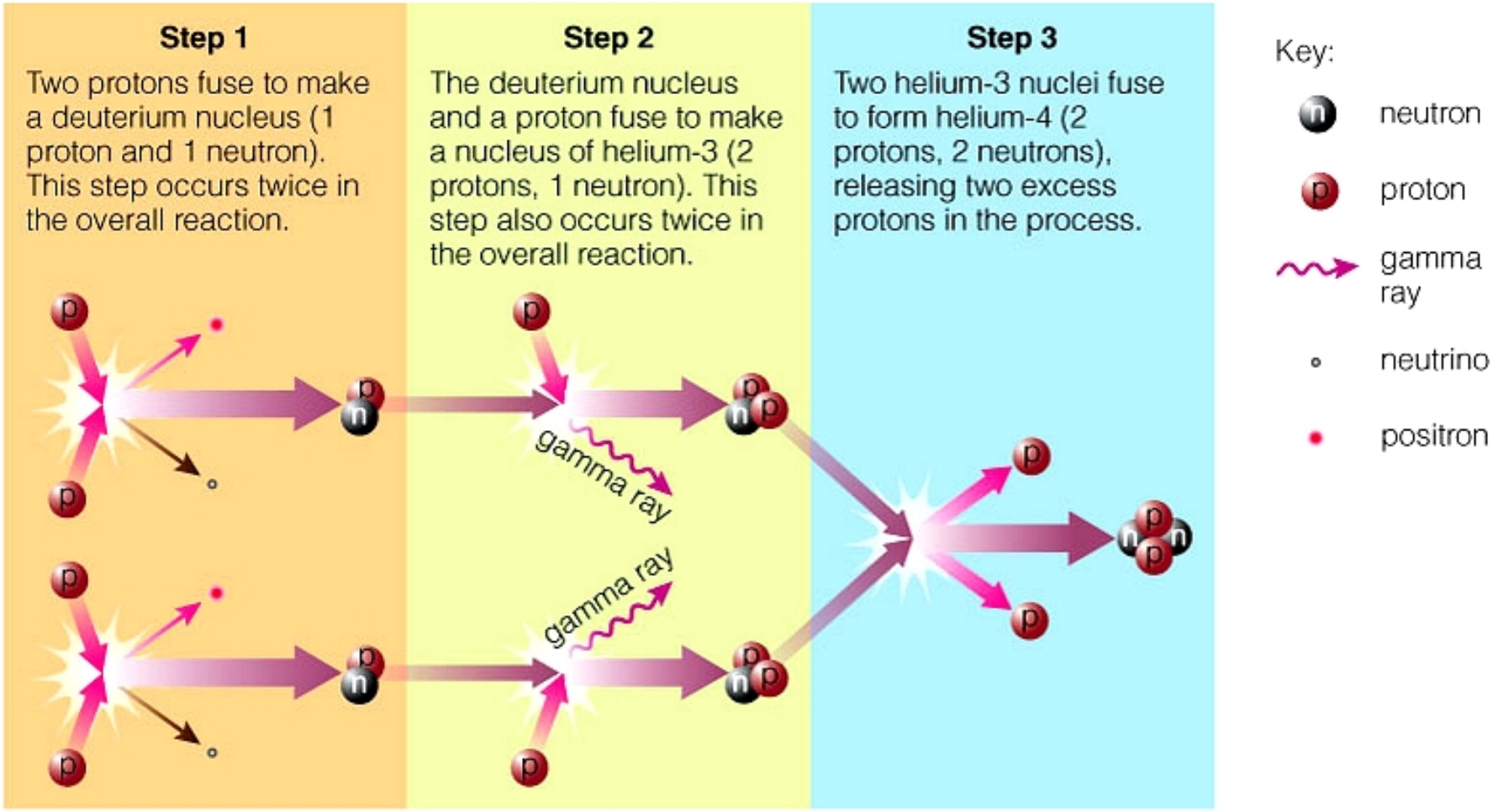
nuclei get close enough to one another that attractive, short range nuclear force can overcome repulsive electric force -> nuclei stick together, or fuse

sun & stars emit tremendous amounts of energy

Where does this energy come from?

Nuclear fusion

Hydrogen Fusion by the Proton-Proton Chain



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Nuclear fusion !!

Need mass > 1/10 M_{sun} to have star

Why is the sun a star and the earth not a star? … MASS

More mass →

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Stronger pressure ->

Higher temperatures ->

Nuclear fusion !!

Need mass > 1/10 M_{sun} = 10^{-1} M_{sun} to have star

Mass of Jupiter ~ 10^{-3} M_{sun}

Mass of earth ~ $3x10^{-6}$ M_{sun}

The core of the Sun is undergoing the same process of nuclear fusion that occurs when a hydrogen bomb explodes. Why does the Sun not explode?

A. Because it is an ionized plasma of electrons and nuclei

B. It is exploding

C. Neutrinos carry energy away from the core, cooling it

D. The huge energy release is contained by the pressure of the overlying material

E. Congress cannot agree on an explosion policy