

Cosmic Evolution

Part 1: Protons to heavy elements

Big Bang occurred 13.7 Billion yrs ago (13.7×10^9 yr)

Only fundamental particles existed for first few minutes

Name	Symbol	Charge	Mass
Proton	p	+	1.7×10^{-24} g
Neutron	n	0	1.7×10^{-24} g
Electron	e	-	1×10^{-27} g
Photon	γ	0	0
Neutrino	ν	0	$< 10^{-33}$ g

Building blocks of nuclei but only one kind of nucleus

Proton = nucleus of Hydrogen

The Bigger Picture

The ordinary matter (protons, neutrons, ...) contain only 4.6% of the mass energy of the Universe. Dark matter contains 23% and the even stranger dark energy accounts for 72%. (most recent numbers)

A Bit of Physics

Energy of Motion (Kinetic Energy)

$$E = \frac{1}{2}mv^2 \quad (\text{if } v \text{ not close to } c)$$

Gas at Temperature T,

$$\text{Avg. Energy } E = \frac{3}{2}kT$$

$$\text{So avg. } v : \quad \frac{1}{2}mv^2 = \frac{3}{2}kT$$

$$v = \sqrt{\frac{3kT}{m}} \equiv \left(\frac{3kT}{m} \right)^{\frac{1}{2}}$$

Higher T \rightarrow Higher v, E on avg.

Simulation of gas properties on the web

http://phet.colorado.edu/new/simulations/sims.php?sim=Gas_Properties

Early Universe so hot that collisions broke apart any complex things that might have formed

As Universe expanded, T dropped
at ~ 3 min, $T \sim 10^9$ K

A few nuclei form (nucleosynthesis)

at ~ 30 min, $T \sim 3 \times 10^8$ K end of nucleosynthesis

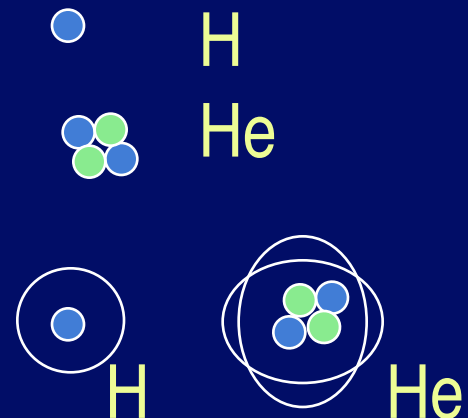
Composition of Universe at 30 min.

$\sim 94\%$ proton

$\sim 6\%$ alpha particle
(and electrons)

At 380,000 years $T \sim 3000$ K

Nuclei + electron \rightarrow Atoms



First Generation Stars

Expanding Universe

But, Gravity collected matter into Stars

Stars now 0.1 to 100 M_{\odot} ; first stars more massive

Later into Galaxies ($M \sim 10^{10}$ to $10^{12} M_{\odot}$)

Oldest stars in disk: age $\sim 10^{10}$ years

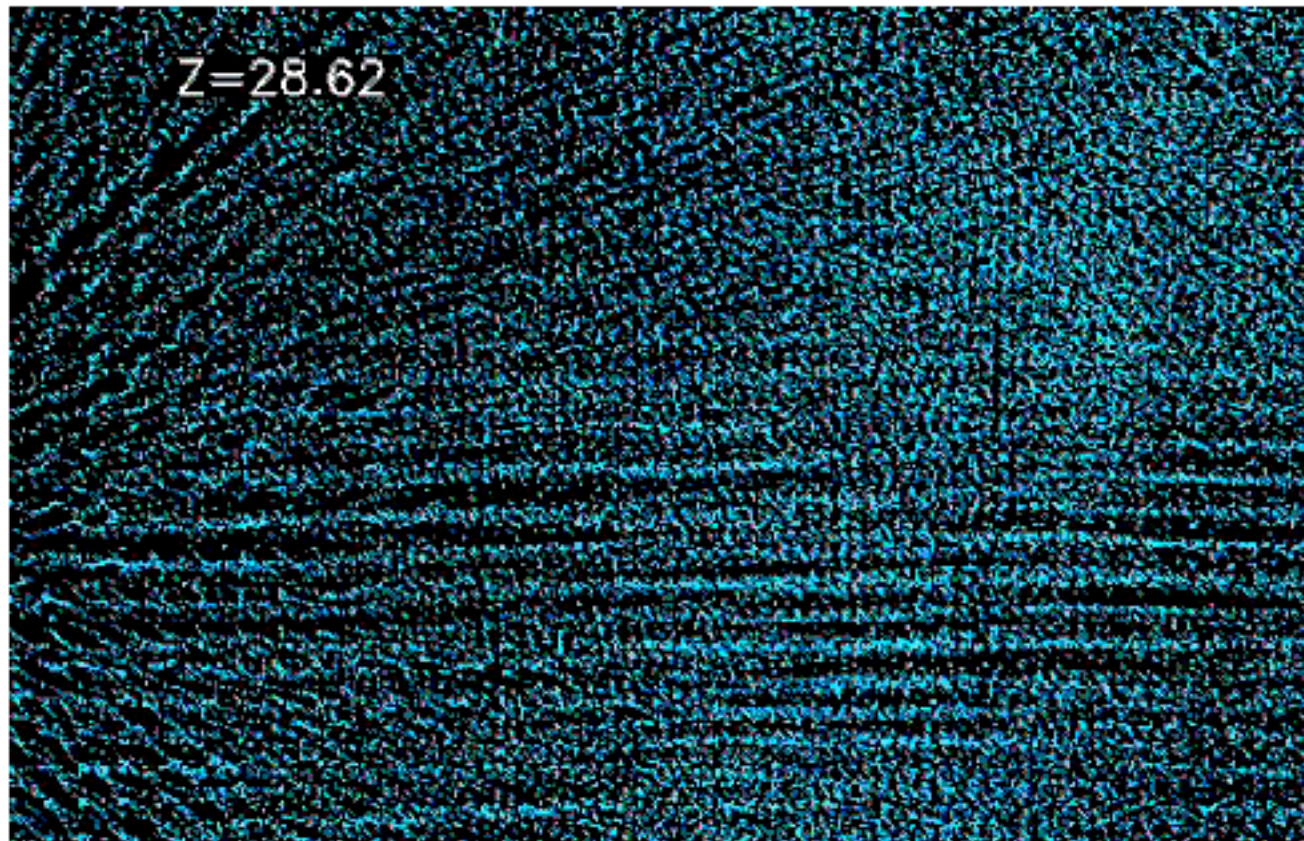
First generation stars \rightarrow No C, O, N, ...

\Rightarrow No life No Si, Fe \Rightarrow No Earthlike planets

But they **made** some “heavy” elements

So later stars could have solid planets, life

Movie illustrating galaxy formation



From <http://cosmicweb.uchicago.edu/group.html>

Gravitational Potential Energy

For example: Reservoir of water behind dam



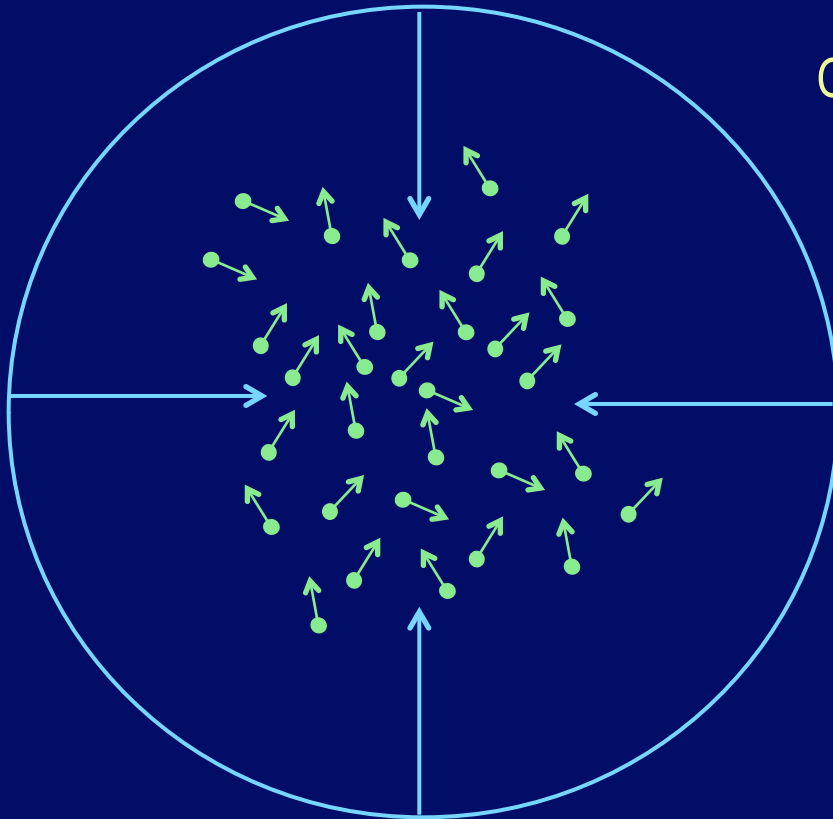
Higher
GPE

Energy released
as water falls

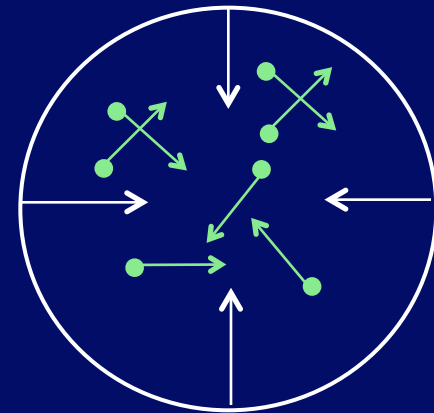
Lower GPE

Consider a clump of Gas collapsing to form a star

Apply to collapsing gas



GPE \rightarrow Heat



Atoms move faster
Temperature is higher

Pause for Demonstration

Back to Formation of First Stars

Collapse released Gravitational Potential Energy

The gas heats up

The Temperature in core reaches 10^7 K

Nuclear reactions begin

Collapse stops

Why?

Nuclear Potential Energy

Four basic forces: gravity, electromagnetic, weak and strong nuclear force

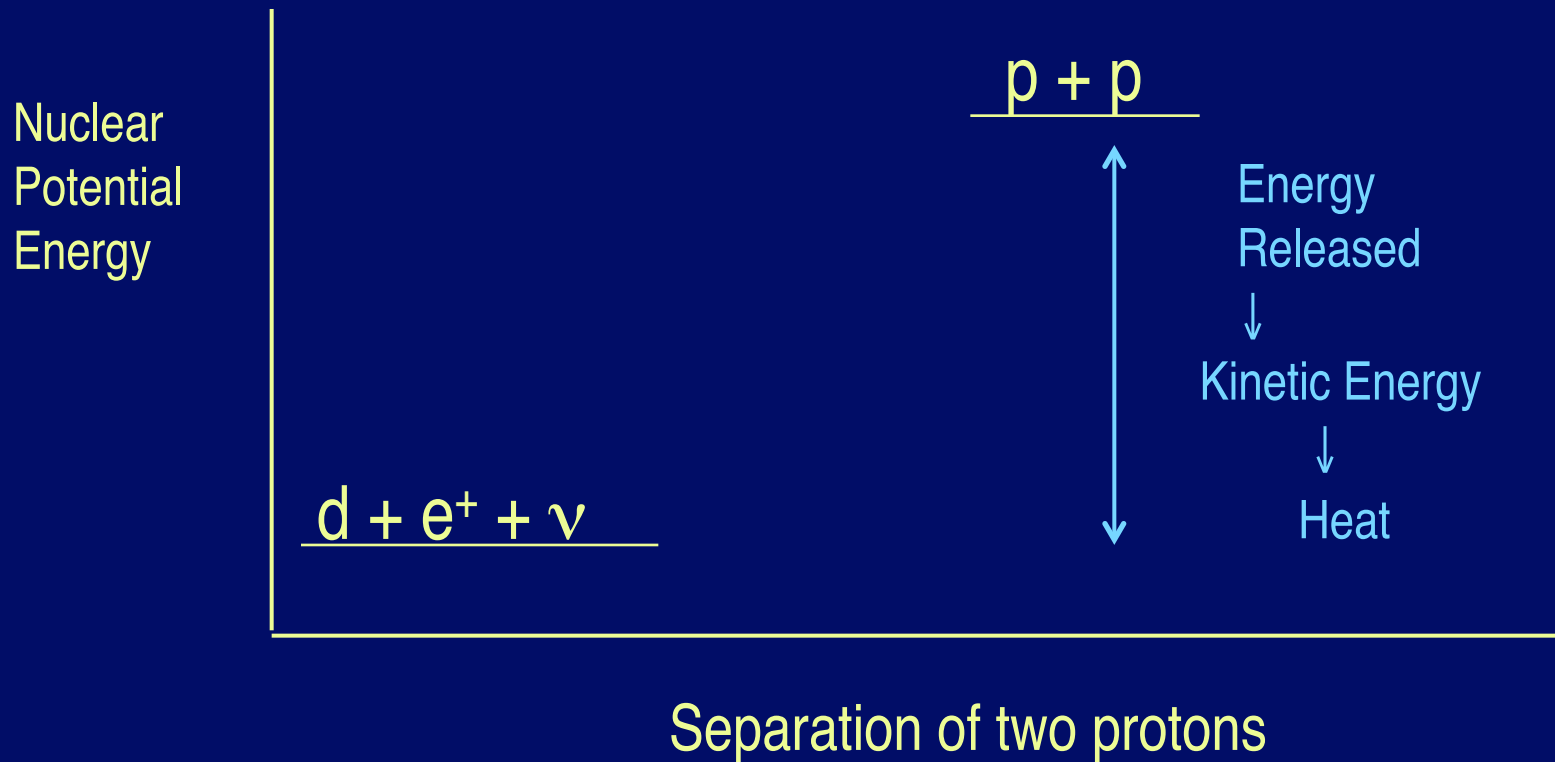
Each has potential energy. Nuclear potential energy can be released by nuclear reactions.

e.g. 1st step: $p + p \rightarrow d + e^+ + \nu$

d = deuteron = proton + neutron

e^+ = positron (antiparticle of electron)

Nuclear Potential Energy



The energy released by nuclear reactions supplies heat → pressure

Resists gravity ⇒ stable star

Electromagnetic Barrier

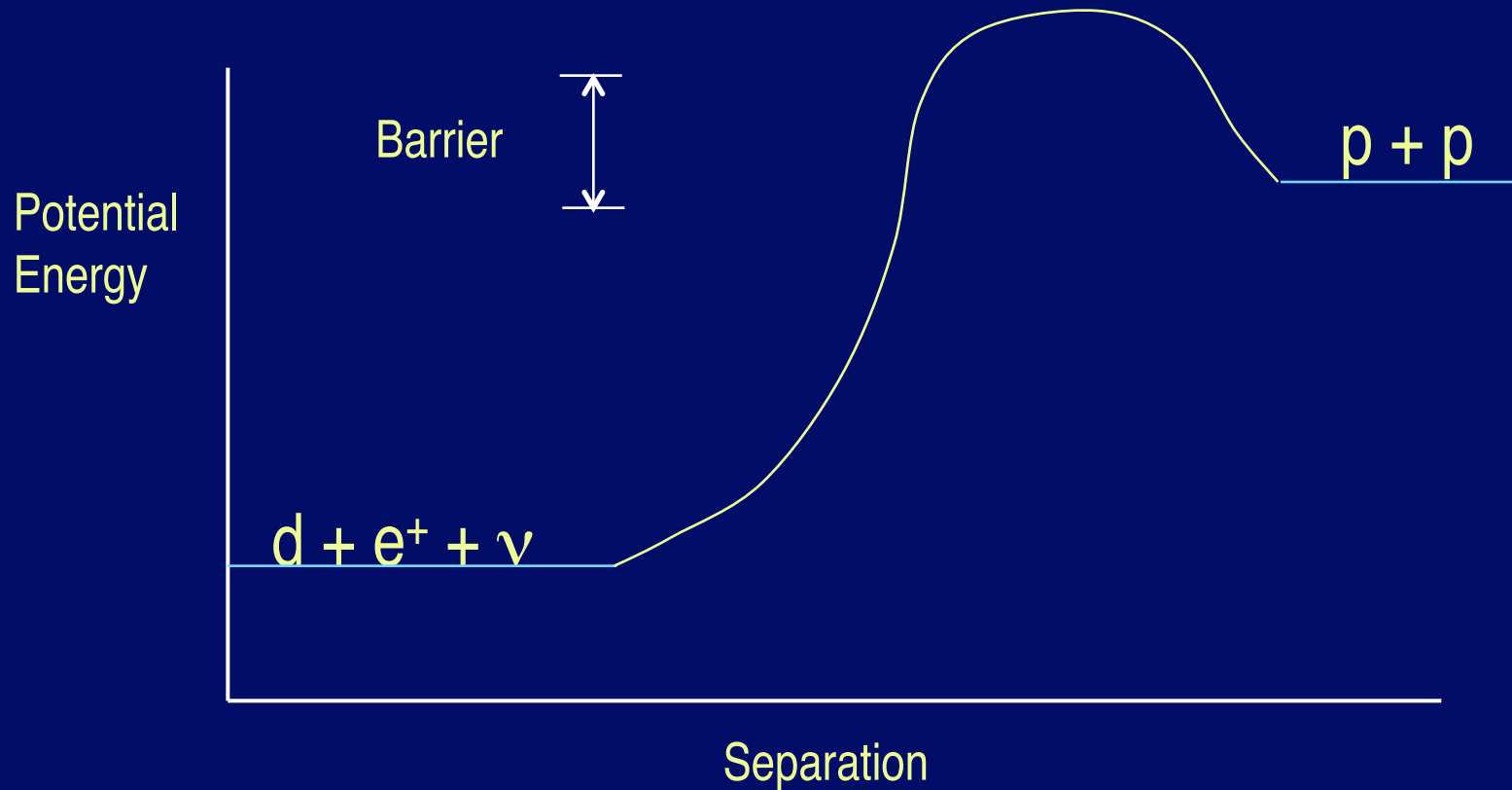
Why do we need high T ($\sim 10^7$ K)?

Protons have positive electric charge

Like Charges Repel

As protons approach, repulsion grows,
corresponds to climbing hill of electromagnetic
potential energy

Electromagnetic Barrier



Barrier is really much higher than $k \cdot 10^{\frac{3}{2}} K$

Very few can get over barrier

⇒ Stars live a long time rather than exploding

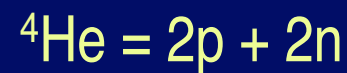
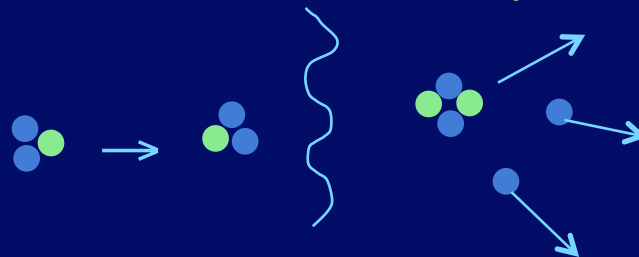
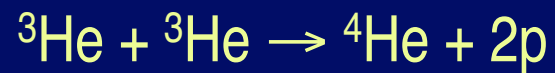
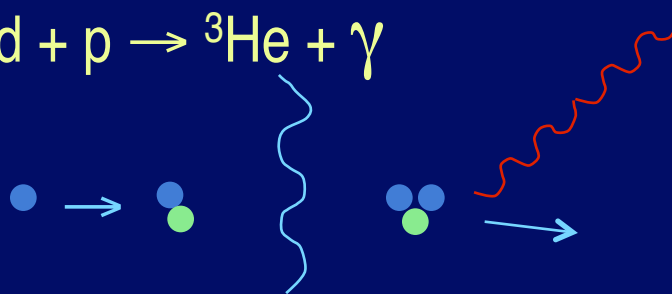
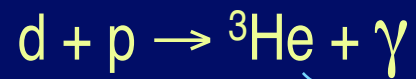
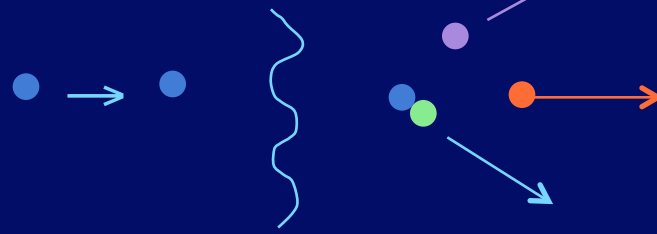


Questions

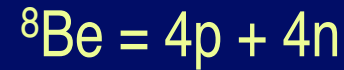
- Why do nuclear reactions produce a long-lived system in star, but an explosion in a bomb?
- What will happen when a star's fuel runs out?

Nucleosynthesis Again

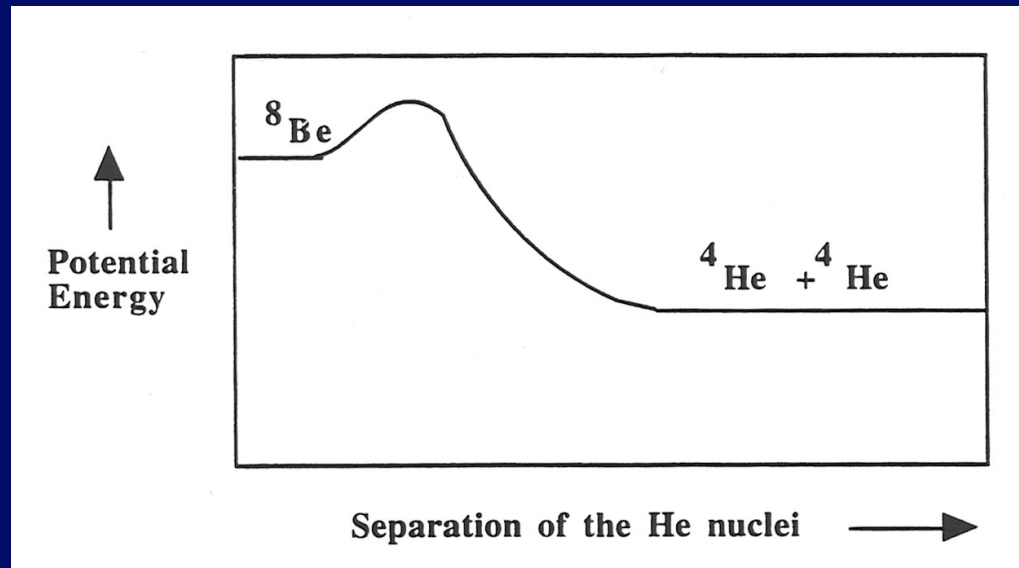
●	proton	p
●	neutron	n
●	positron	e ⁺
●	neutrino ν	
~~~~~	photon	$\gamma$



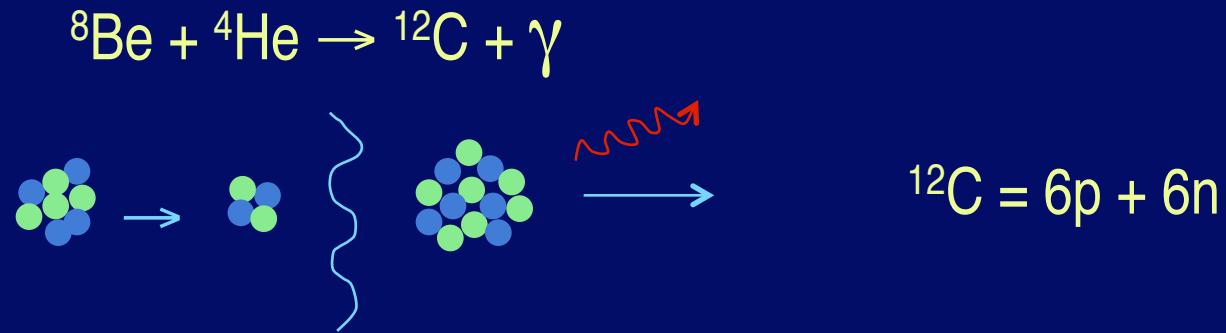
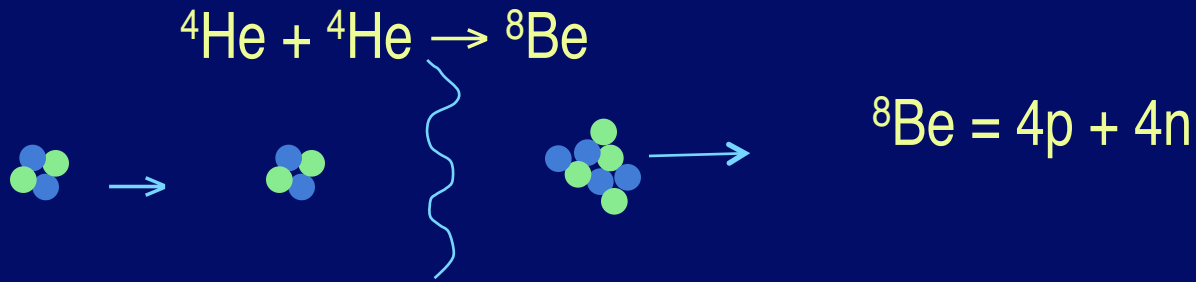
How to get past helium? We need C, O, N, P, S, ...



Problem:  ${}^8\text{Be}$  has more nuclear potential energy than parts;  
It is unstable (radioactive).



To get carbon, we need another  ${}^4\text{He}$  to hit  ${}^8\text{Be}$   
before  ${}^8\text{Be}$  falls apart



# Questions

- What was needed to make the bioelements?
- Are any missing?
- How do the bioelements get out of the star?



# Summary

Heavy elements needed for life were created by early generations of massive stars.

Except for H, we are made of star debris

Natural forces (Gravity, EM, Nuclear) produced first evolution of matter from simple to complex  
(protons  $\rightarrow$  heavy elements)