

# Cosmic Evolution

# Part 1: Protons to heavy elements

Big Bang occurred 13.7 Billion yrs ago ( $13.7 \times 10^9$  yr)

Only fundamental particles existed for first few minutes

Name	Symbol	Charge	Mass
Proton	p	+	$1.7 \times 10^{-24}$ g
Neutron	n	0	$1.7 \times 10^{-24}$ g
Electron	e	-	$1 \times 10^{-27}$ g
Photon	$\gamma$	0	0
Neutrino	$\nu$	0	$\sim 0$ (very small)

Building blocks of nuclei but only one kind of nucleus

Proton = nucleus of Hydrogen

## Energy of Motion (Kinetic Energy)

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

Gas at Temperature  $T$ ,

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

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

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

Higher  $T \rightarrow$  Higher  $v$ ,  $E$  on avg.

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

As Universe expanded, T dropped

at  $\sim 3$  min,  $T \sim 10^9$  K

A few nuclei form (nucleosynthesis)

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

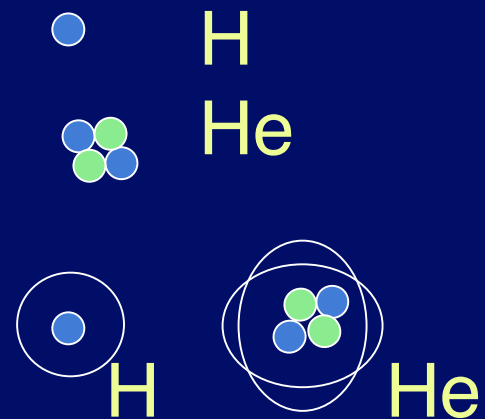
### Composition of Universe at 30 min.

$\sim 94\%$  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 ( $\sim 10^{11}$  to  $10^{12} M_{\odot}$ )

Oldest stars in disk  $\sim 10^{10}$  y old

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

# Gravitational Potential Energy

For example: Reservoir of water behind dam



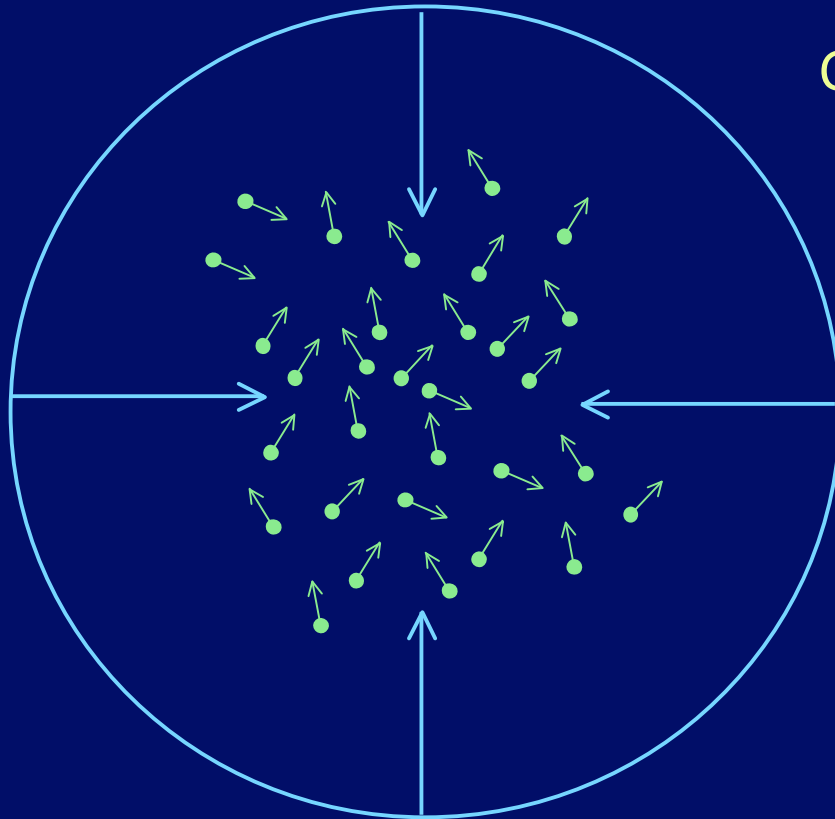
Higher  
GPE

Energy released  
as water falls

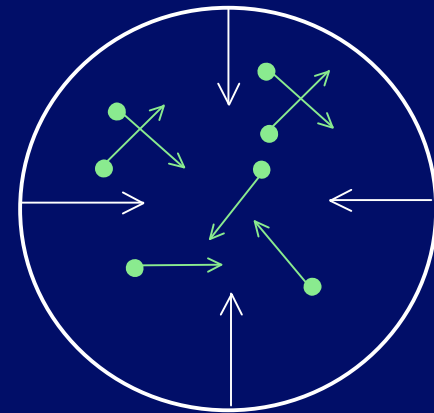
Lower GPE

# 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.

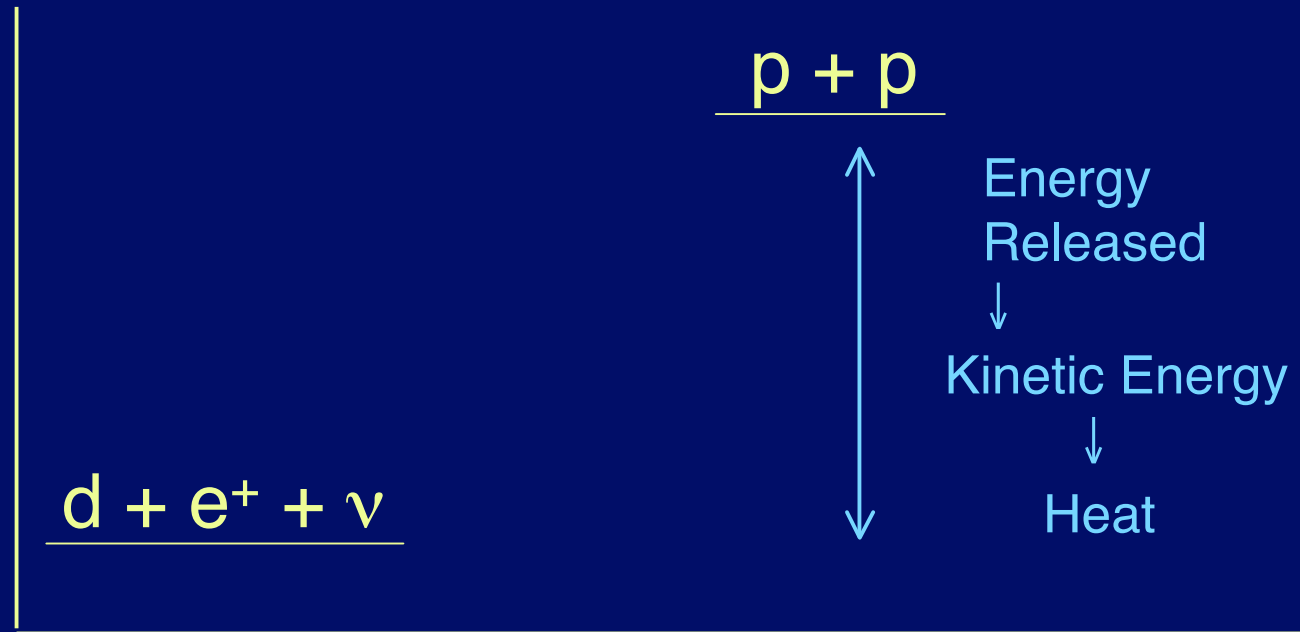
e.g. 1st step:  $p + p \rightarrow d + e^+ + \nu$

d = deuteron = proton + neutron

$e^+$  = positron (antiparticle of electron)

# Nuclear Potential Energy

Nuclear  
Potential  
Energy



Separation of two protons

The energy released by nuclear reactions  
supplies heat  $\rightarrow$  pressure

Resists gravity  $\Rightarrow$  stable star

# Electromagnetic Barrier

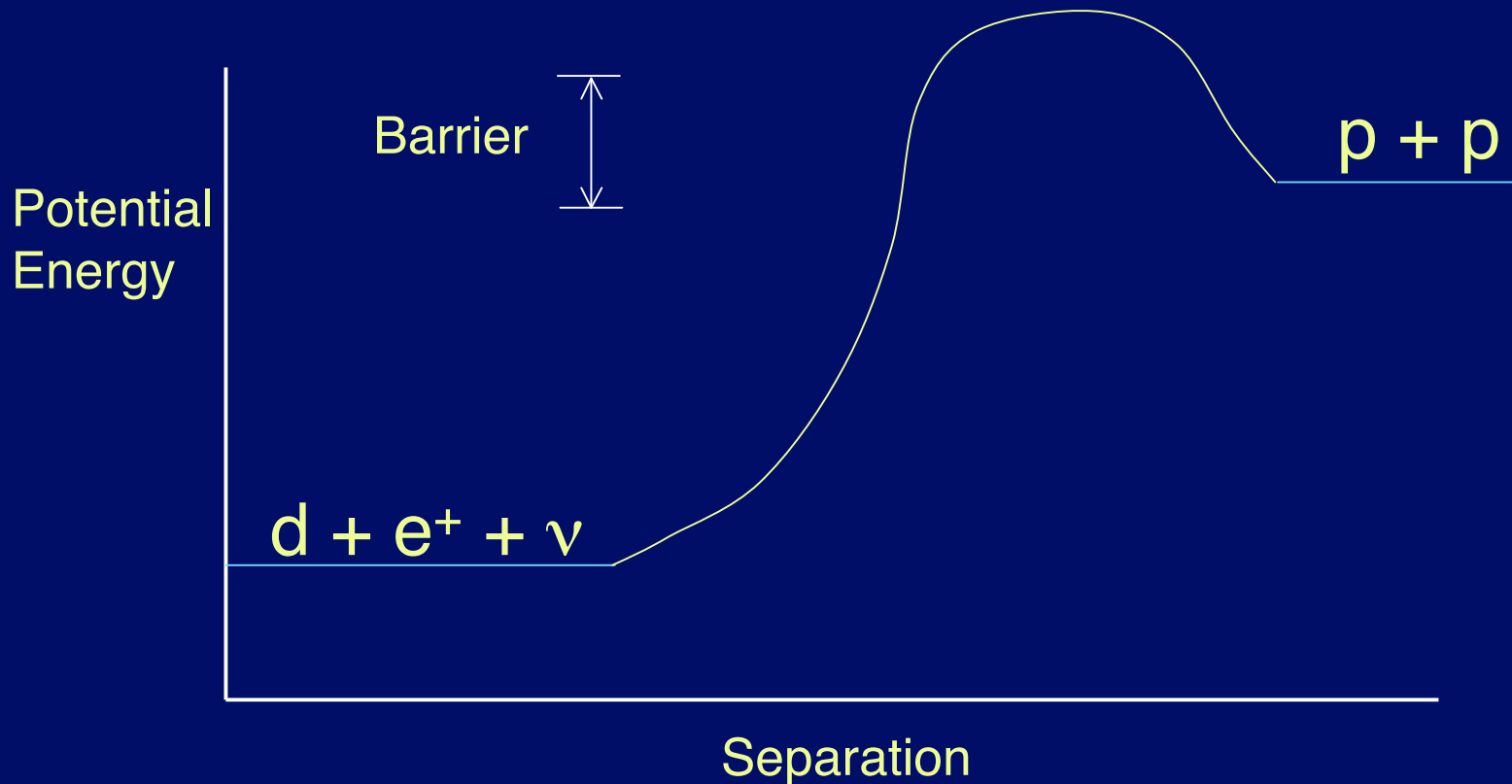
Why do we need high T ( $\sim 10^7$  K)?

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  $\frac{3}{2} k \cdot 10^7 \text{ K}$

Very few can get over barrier

⇒ Stars live a long time rather than exploding

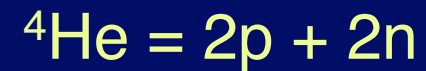
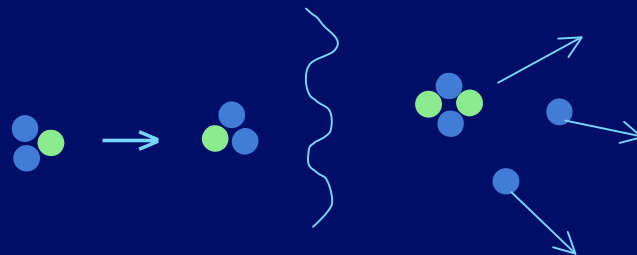
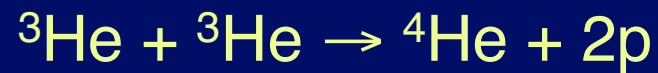
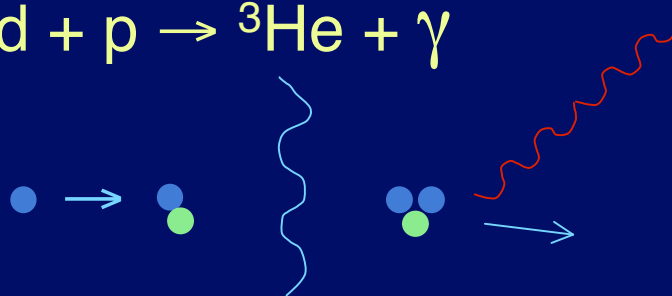
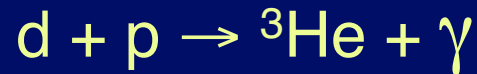


# Questions

- 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

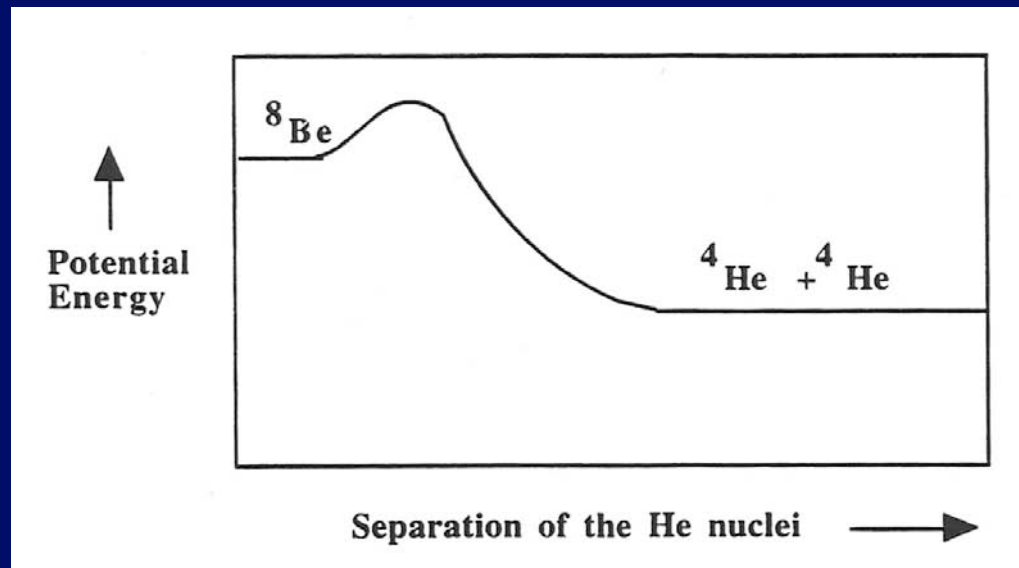
●	proton	p
●	neutron	n
●	positron	e <sup>+</sup>
●	neutrino	ν
~~~~~	photon	γ



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

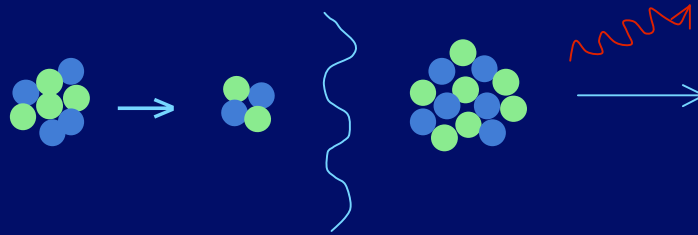
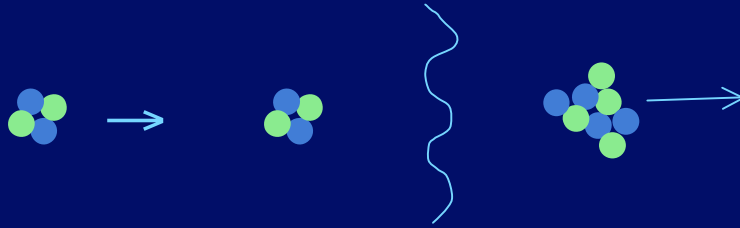


Problem:  ${}^8\text{Be}$  has more nuclear potential energy than parts;  
It is unstable (radioactive).



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





Sulfur



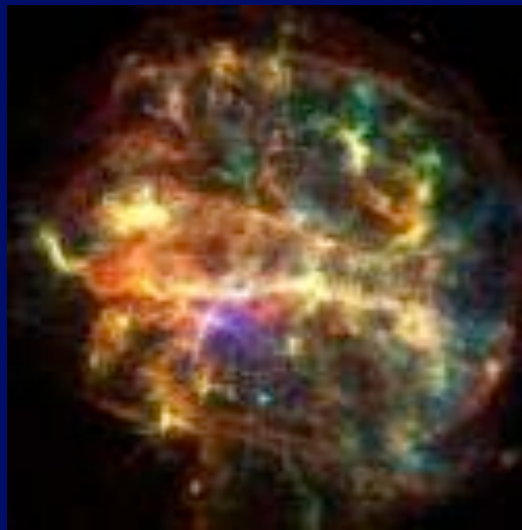
Phosphorus



Silicon

# 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 → heavy elements)