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	~ 0 (?)

Building blocks of nuclei but only one kind of nucleus

Proton = nucleus of Hydrogen

Energy of Motion (Kinetic Energy)

$E = \frac{1}{2} mv^2$ (if v 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 ~ 3 min, T ~ 10^9 K

A few nuclei form (nucleosynthesis)

at ~ 30 min, T ~ 3×10^8 K end of nucleosynthesis

Composition of Universe at 30 min.

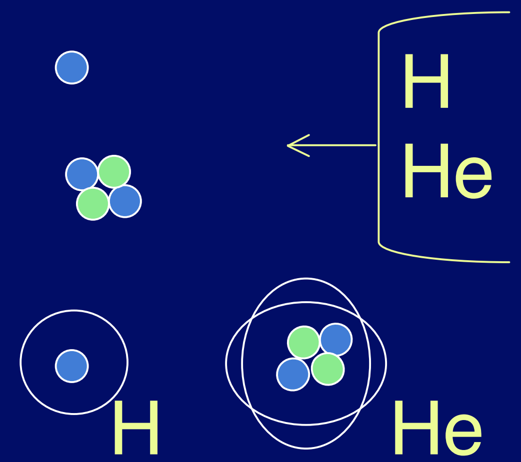
~ 94 % proton

~ 6% alpha part.

(and electrons)

At 3 - 7 × 10^5 years T ~ 3000

Nuclei + electron → Atoms



First Generation Stars

Expanding Universe

But, Gravity → Galaxies (~ 10^{11} to 10^{12} $M_\odot$)

→ Stars (0.1 to 100 $M_\odot$)

Oldest stars in disk ~ 10^{10} y old

First generation stars → No C, O, N, …

⇒ No life   No Si, Fe ⇒ No Earthlike planets

But they made "heavy" elements

So later stars could have solid planets, life

Gravitational Potential Energy

For example: Reservoir of water behind dam

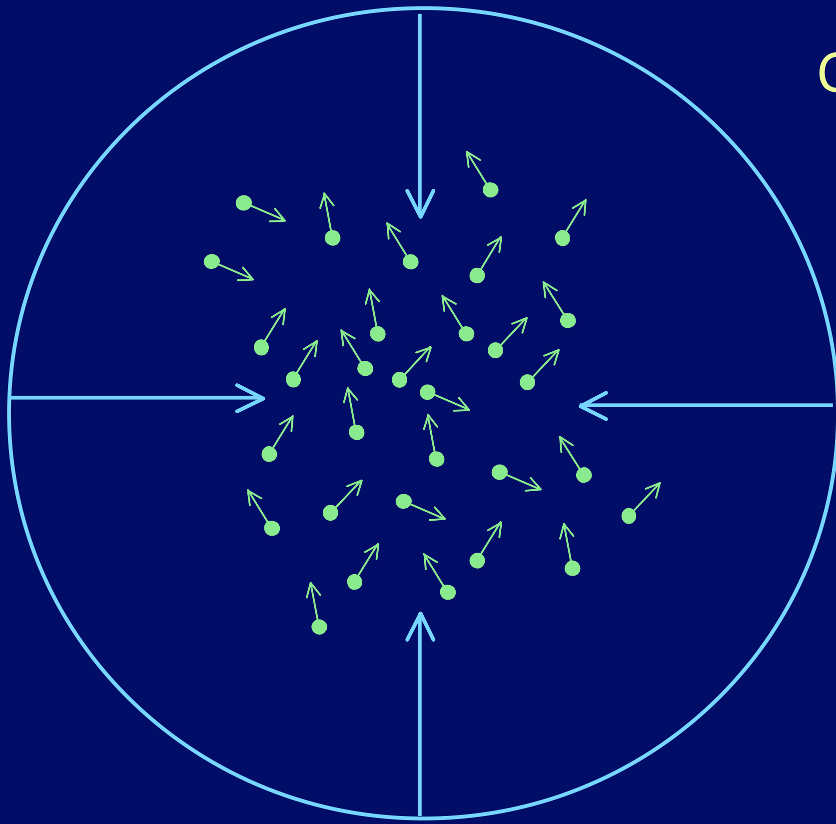
Higher
GPE

Energy released
as water falls

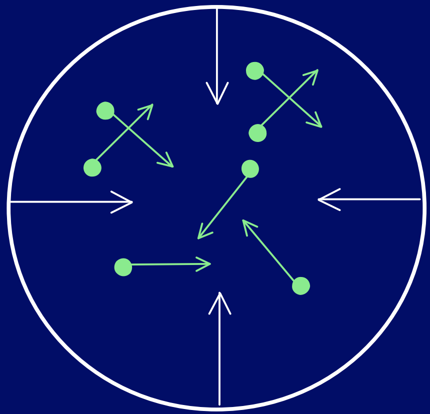
Lower GPE

Consider a clump of Gas collapsing to form a star

Apply to collapsing gas



GPE → Heat



Atoms move faster
Temperature is higher

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

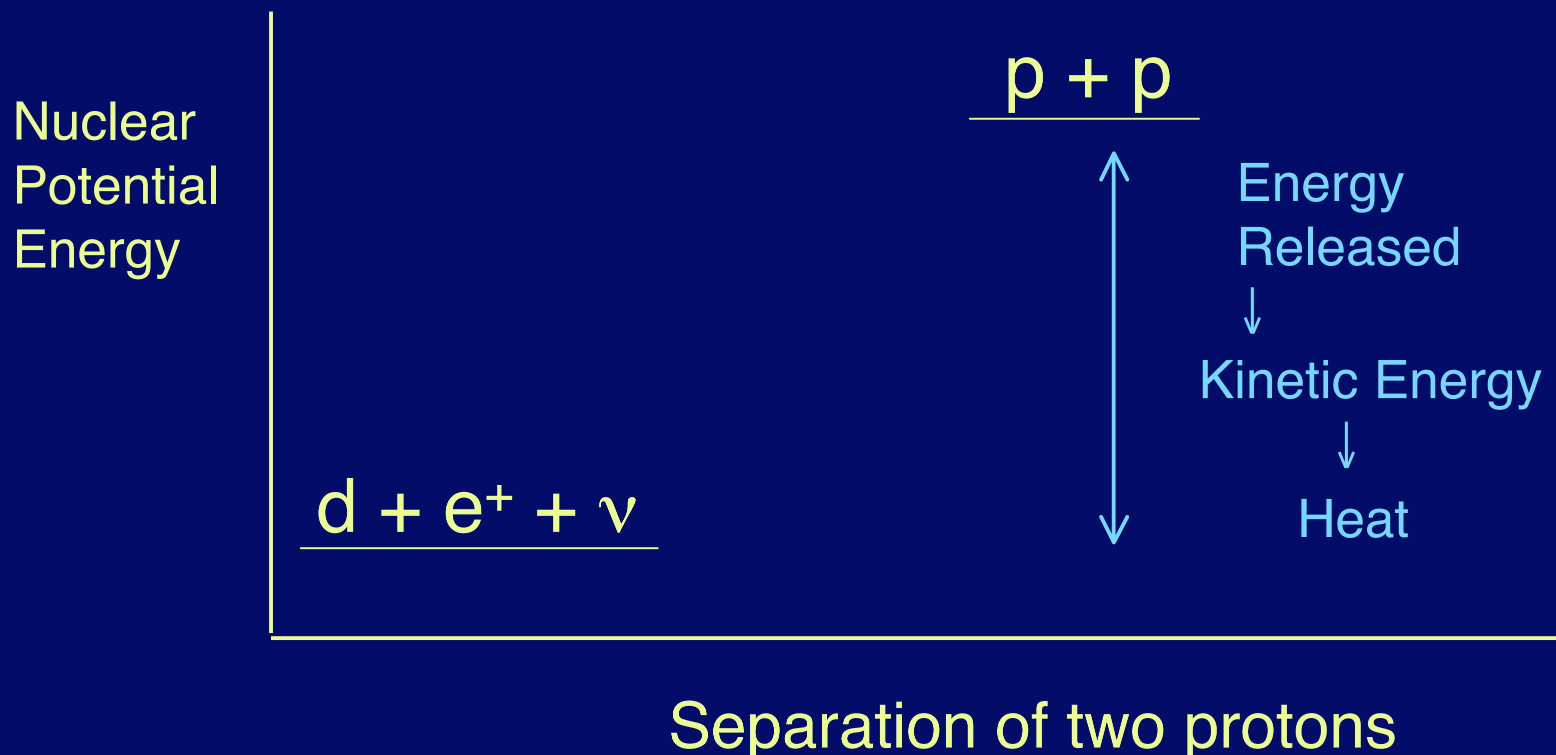
Each has potential energy. Nuclear potential energy can be released by nuclear reactions.

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

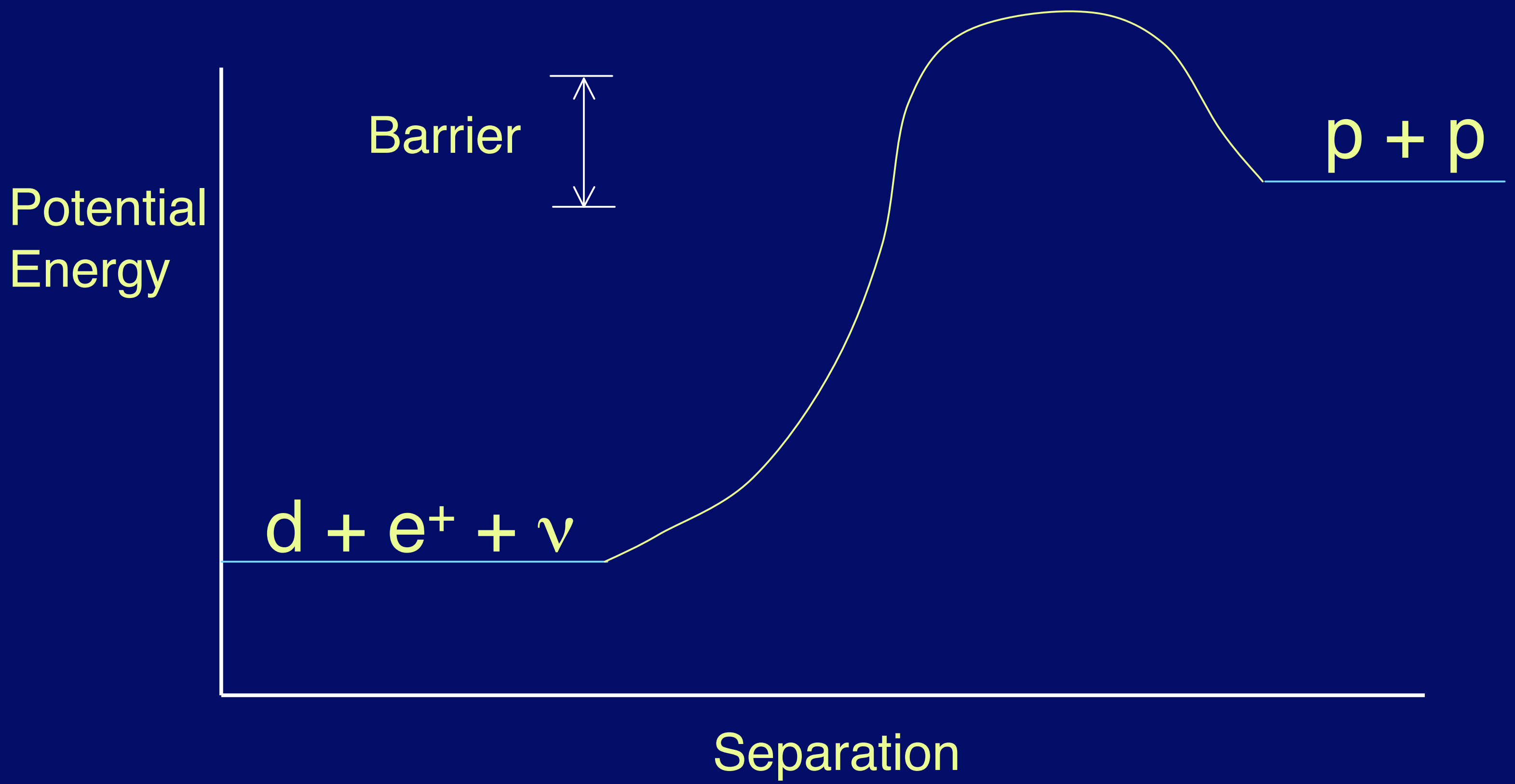
Why do we need high T (~ 10^7 K)?

Protons have positive electric charge

Like Charges Repel

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

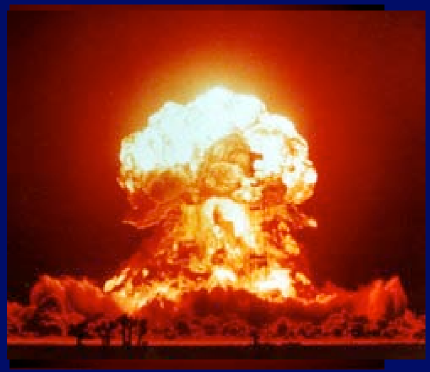
Electromagnetic Barrier



Barrier is really much higher than $\frac{3}{2}\,k \cdot 10^7\,k$

Very few can get over barrier

$\Rightarrow$ Stars live a long time rather than exploding



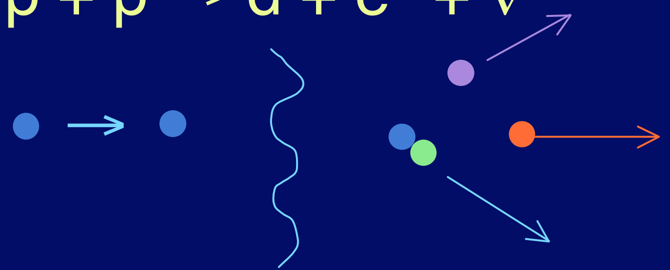
Questions

- 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?

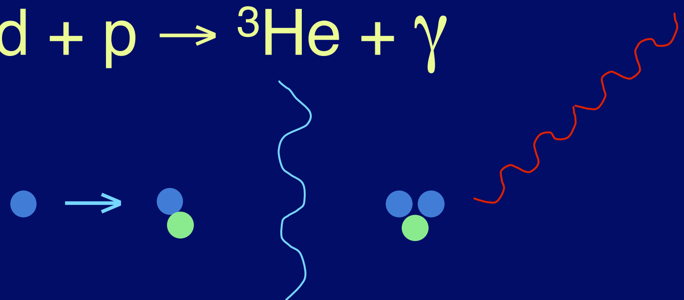
Nucleosynthesis Again

proton	p	
neutron	n	
positron	e^+	
neutrino	n	
photon	γ	

$$p + p \rightarrow d + e^+ + \nu$$

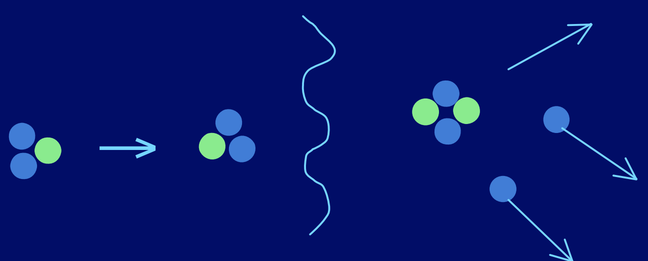


$$d + p \rightarrow {}^3He + \gamma$$



$$^3He + {}^3He \rightarrow {}^4He + 2p$$

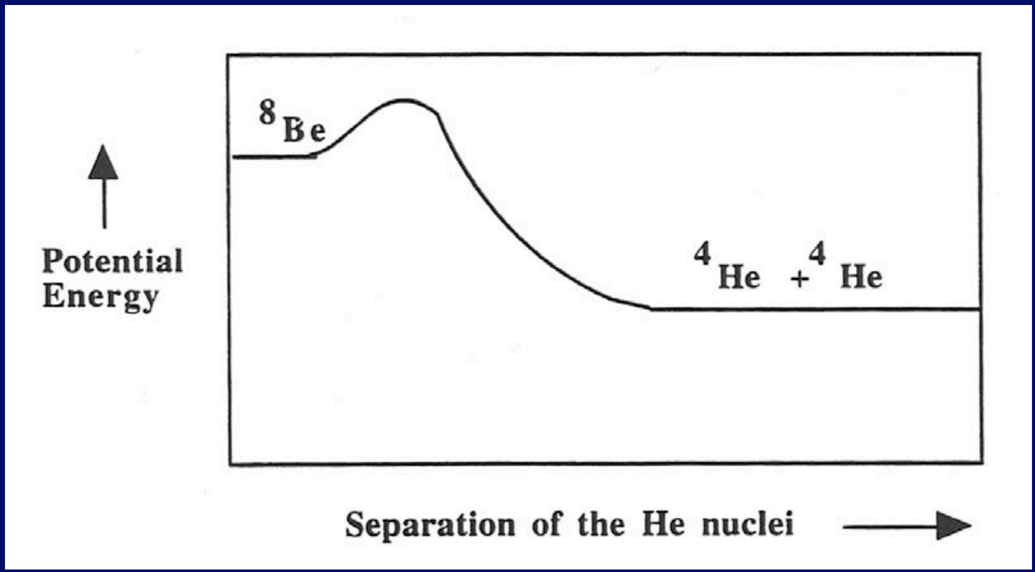
$$^4He = 2p + 2n$$



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

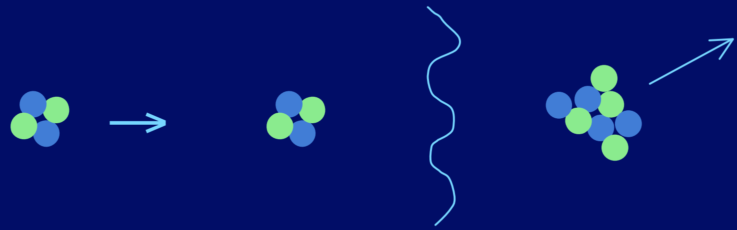
$^{4}He + ^{4}He \rightarrow ^{8}Be$ $^{8}Be = 4p + 4n$

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



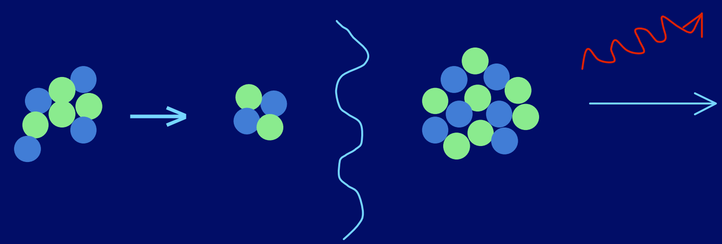
Need another ^{4}He to hit ^{8}Be before it falls apart

$^{4}He + ^{4}He \rightarrow ^{8}Be$



$^{8}Be = 4p + 4n$

$^{8}Be + ^{4}He \rightarrow ^{12}C + \gamma$



$^{12}C = 6p + 6n$

$^{4}He + ^{12}C \rightarrow ^{16}O$

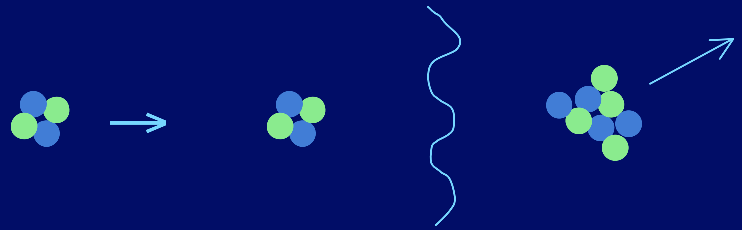
$^{16}O = 8p + 8n$

$^{16}O + ^{16}O \rightarrow ^{32}S + \gamma$ Sulfur

$^{16}O + ^{16}O \rightarrow ^{31}P + p$ Phosphorus

$^{16}O + ^{16}O \rightarrow ^{28}Si + ^{4}He$ Silicon

$$^{4}He + {}^{4}He \rightarrow {}^{8}Be$$



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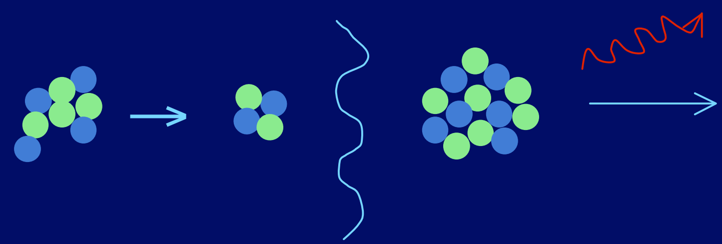
$$^{8}Be + {}^{4}He \rightarrow {}^{12}C + \gamma$$



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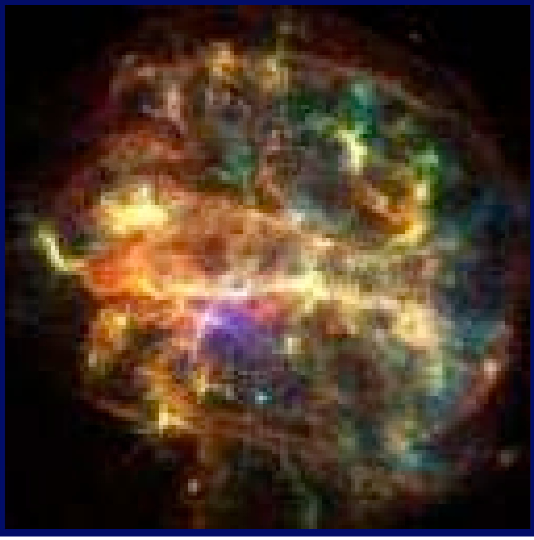
Questions

- 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

($p \rightarrow$ heavy elements)