Nucleosynthesis in the Universe

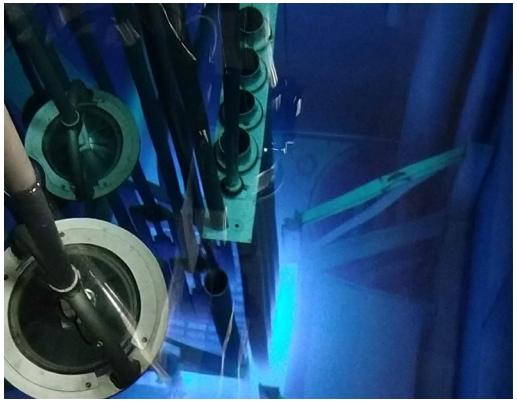
An Introduction

Kelsey Lund

Nuclear Astrophysics

Where do things come from?

How do processes on small (**nuclear**) scales affect large-scale systems in the Universe (**astro**)

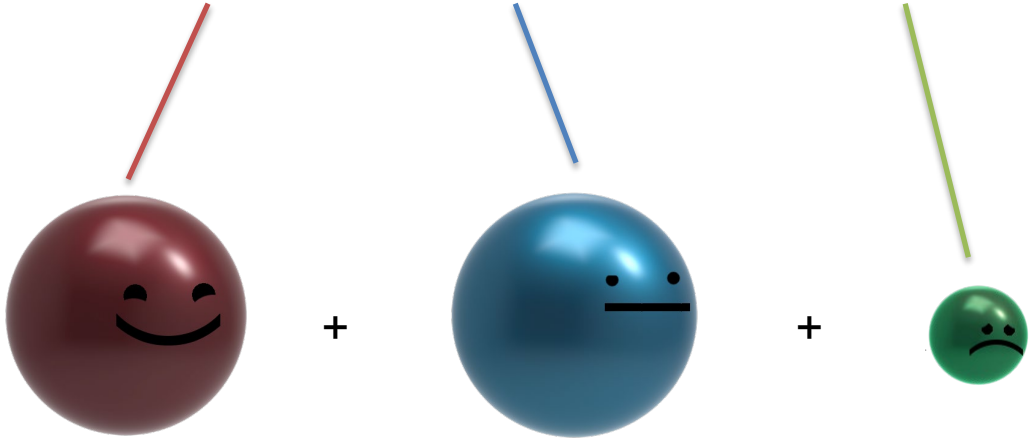


Nuclear Astrophysics

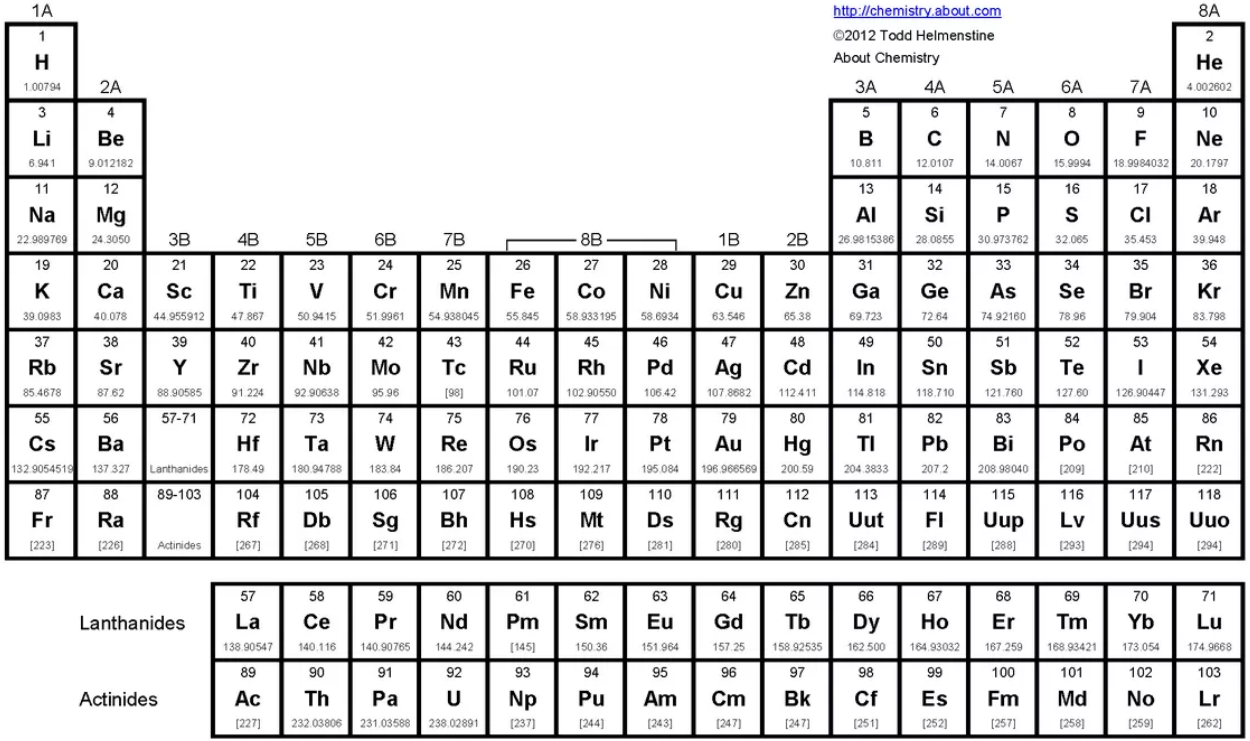
- Atoms as a basic building block of matter: kind of

Nuclear Astrophysics

- Atoms as a basic building block of matter: kind of
- Consist of protons, neutrons, and electrons



- Organize atoms by proton number (Z)
- Useful for chemical properties
- “Protons give an atom its identity, electrons its personality”



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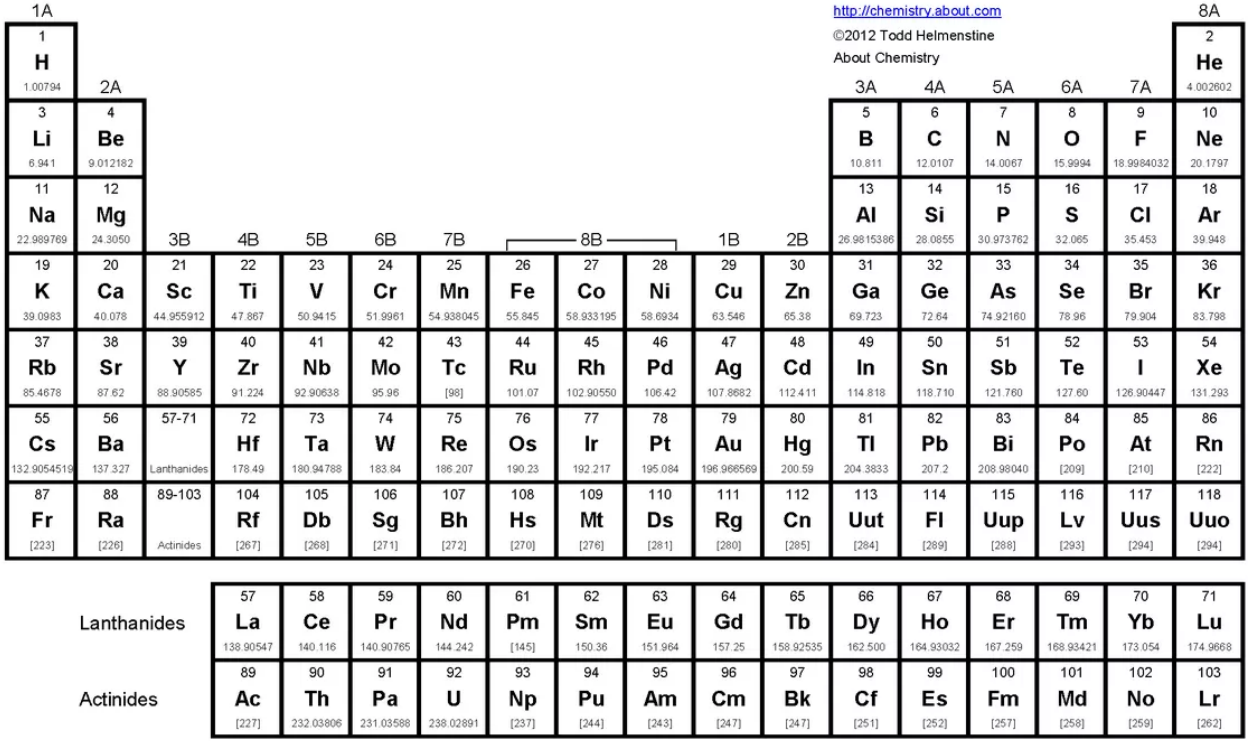
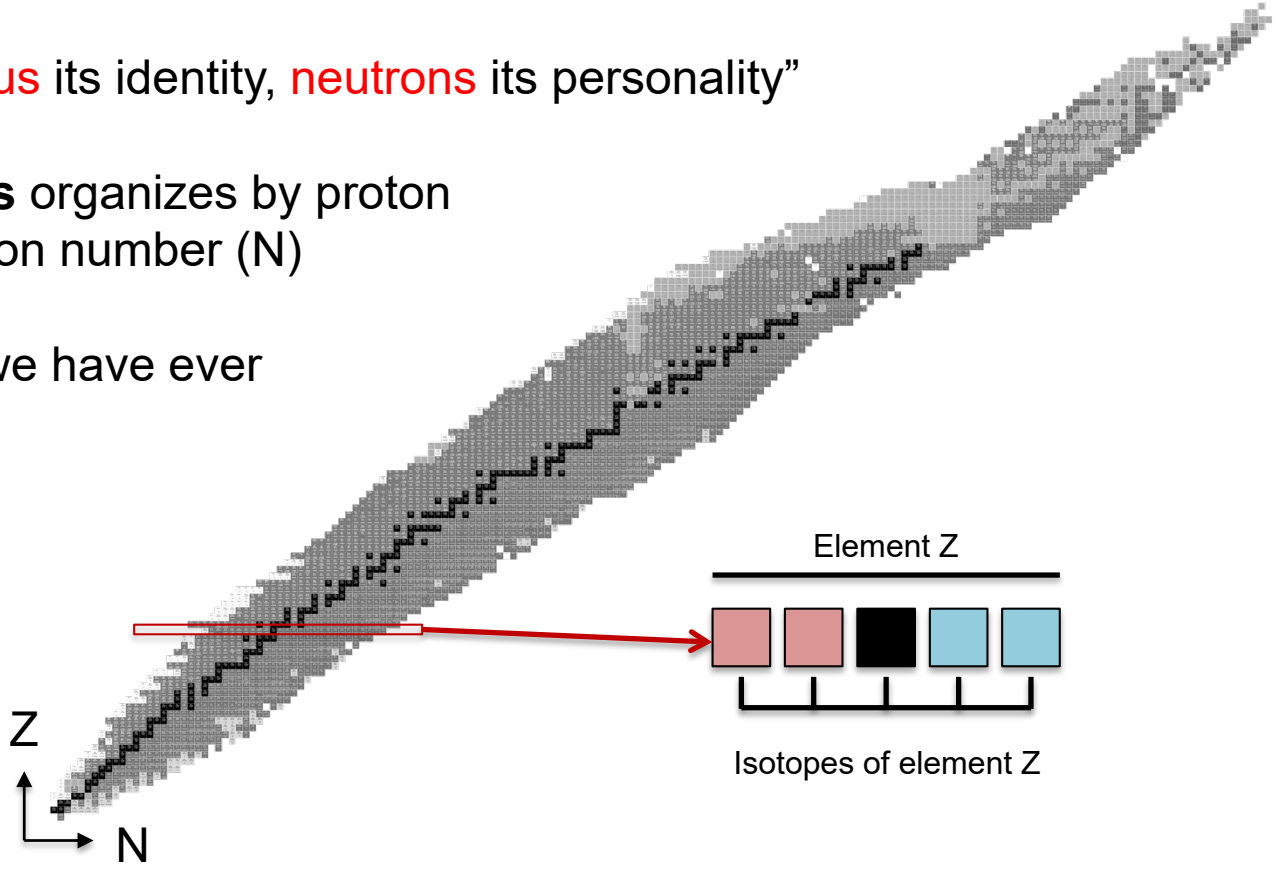


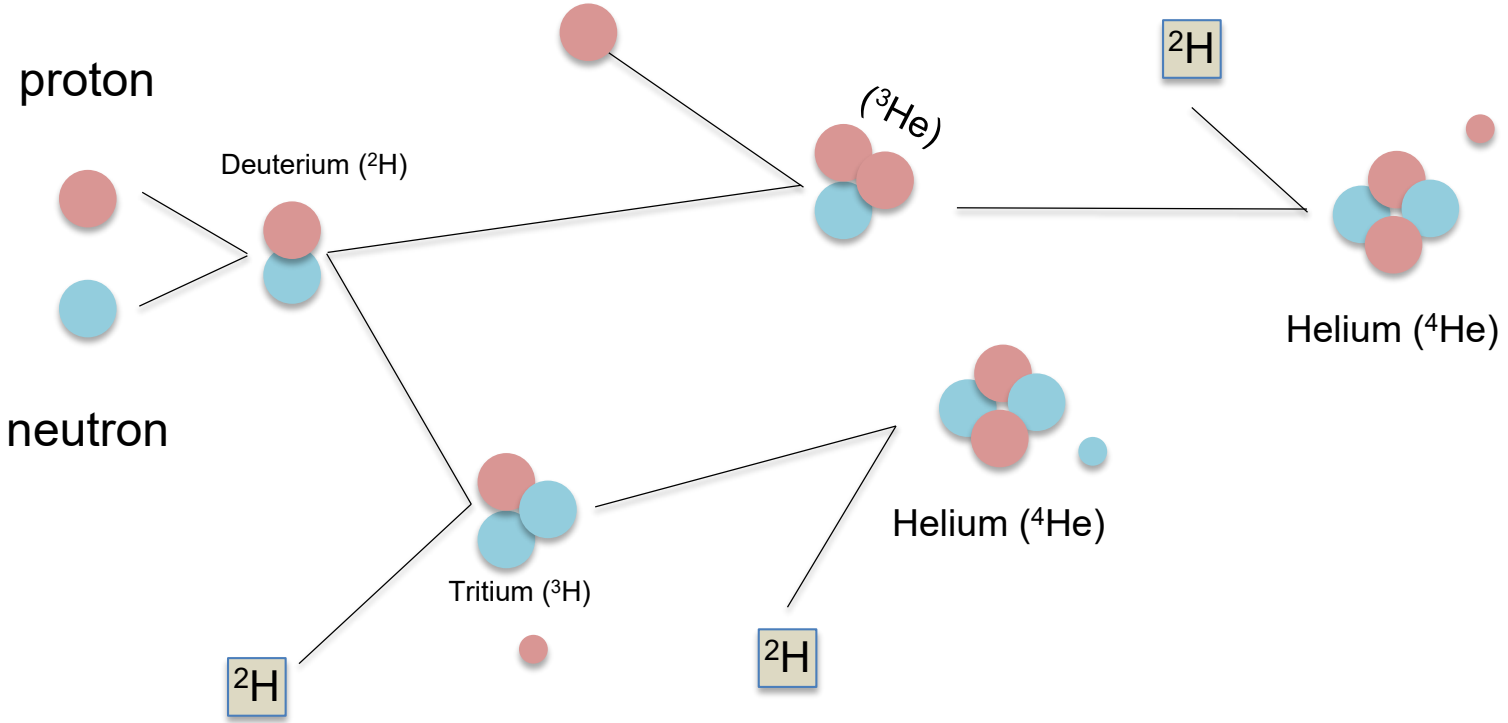
- “Protons give a nucleus its identity, neutrons its personality”
- **Chart of the nuclides** organizes by proton number (Z) and neutron number (N)
- Contains everything we have ever measured



NUCLEOSYNTHESIS

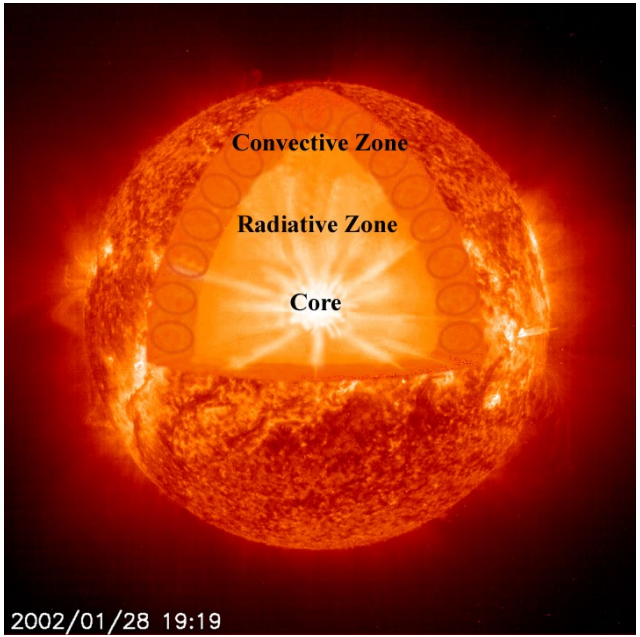
The process of making new nuclei from existing nuclei and nucleons (protons, neutrons)

The first few minutes

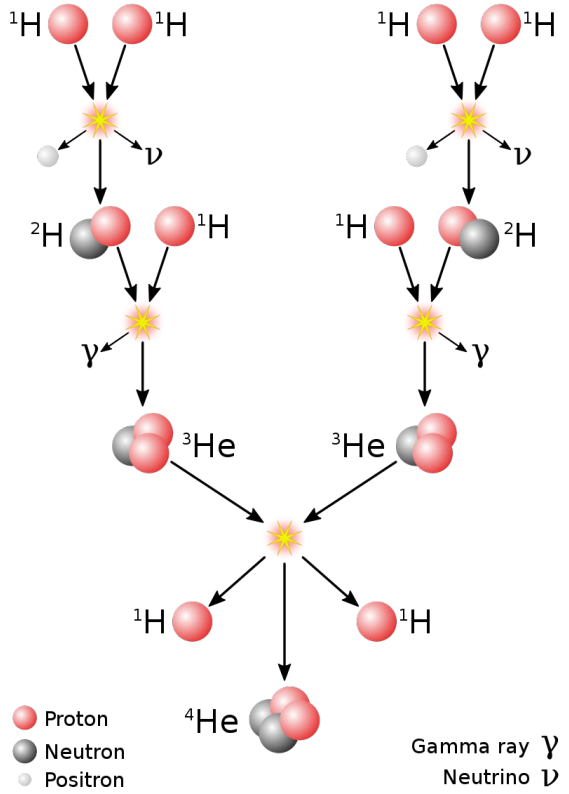


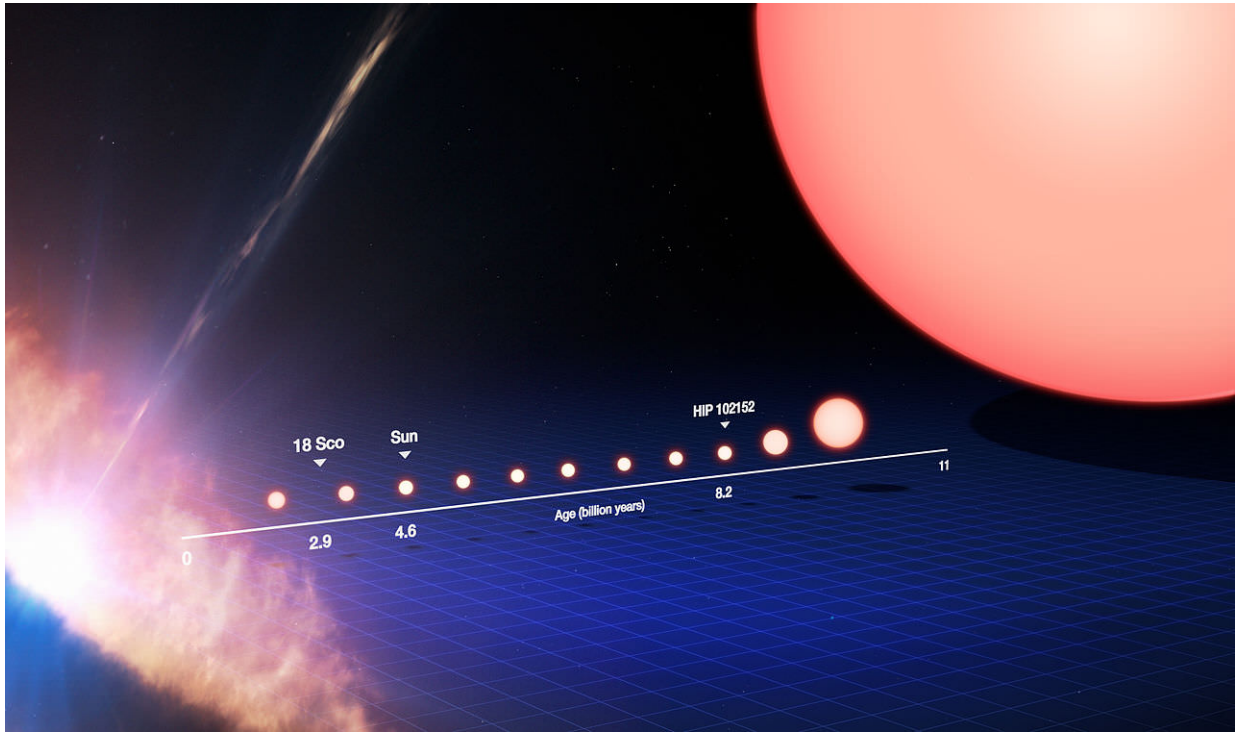
Hundreds of millions of years later...

Stellar Nucleosynthesis: Proton-Proton Chain

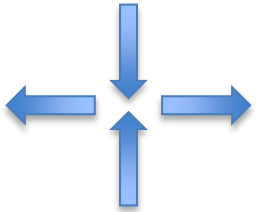


$Mass_{Sun} = 1\ M_{\odot} \sim 2 \times 10^{30} kg$



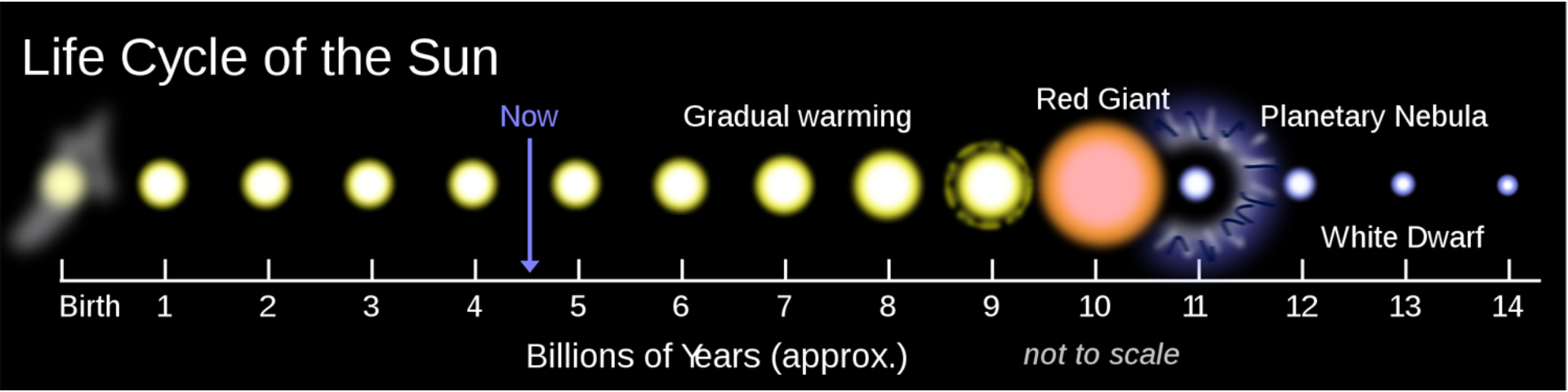


Eventually, the Sun will run out of fuel

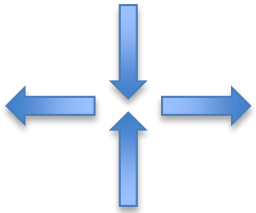


Radiation pressure

Gravity


Life Cycle of the Sun
Now
Gradual warming
Red Giant
Planetary Nebula
White Dwarf
Birth
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Billions of Years (approx.)
not to scale

Massive Stars: Core-Collapse



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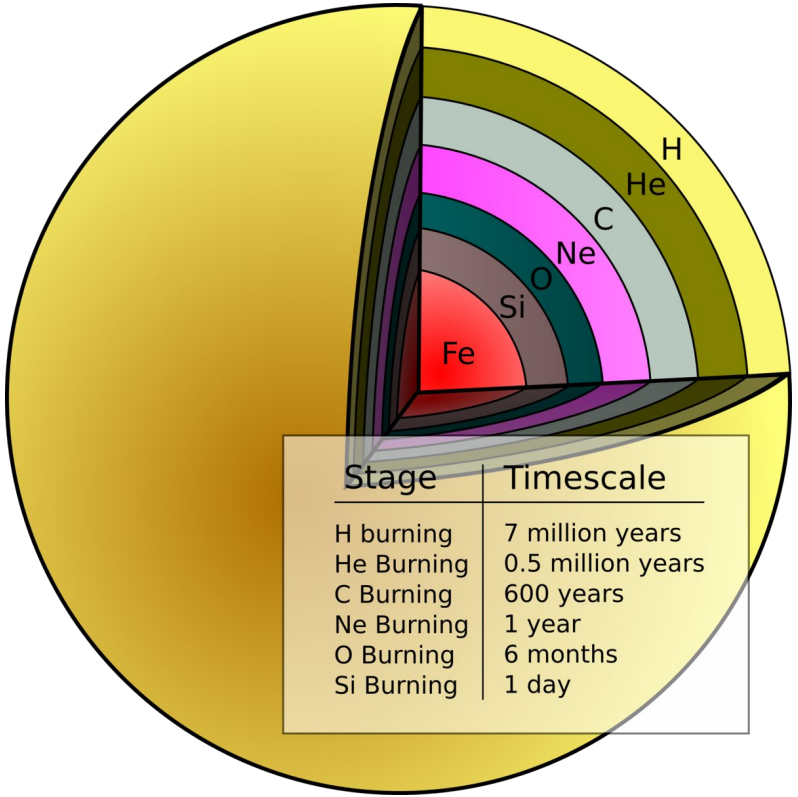
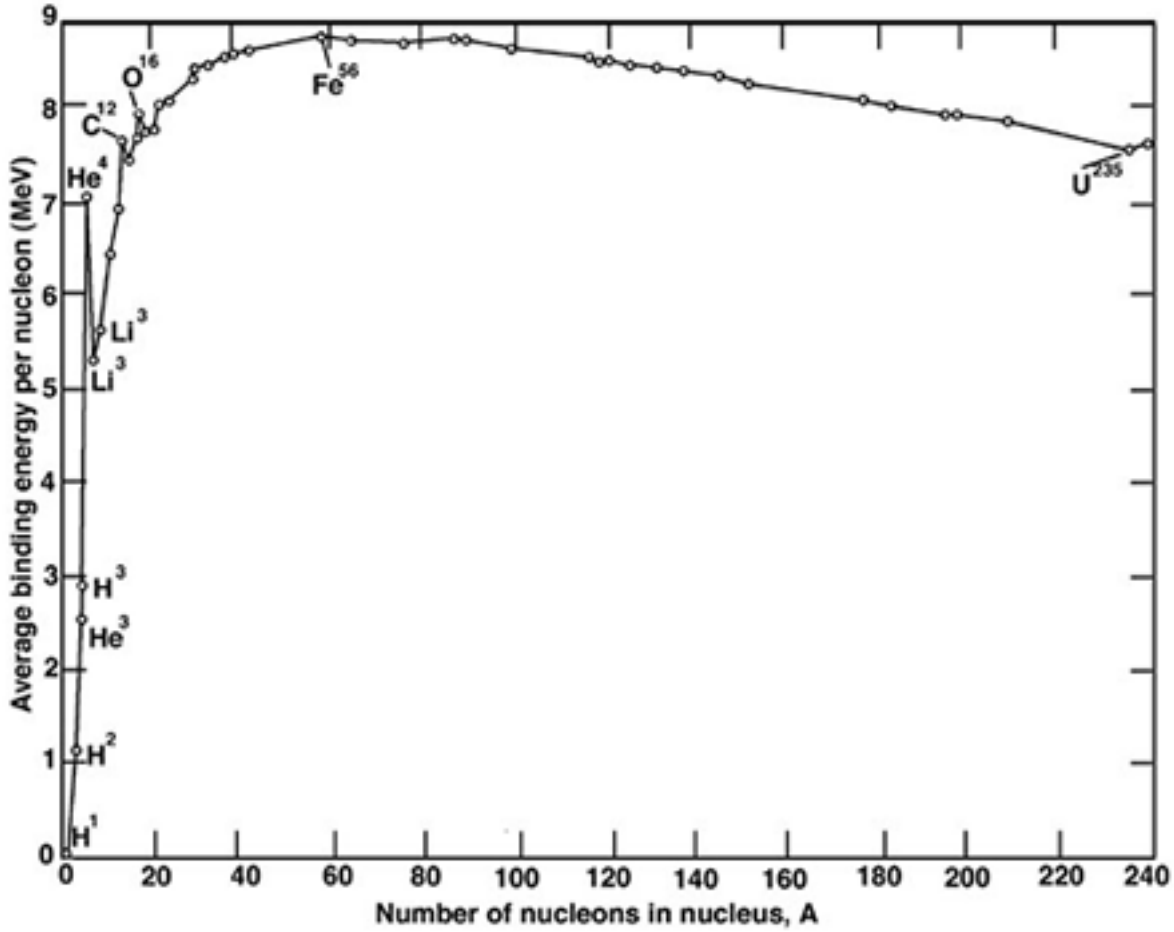
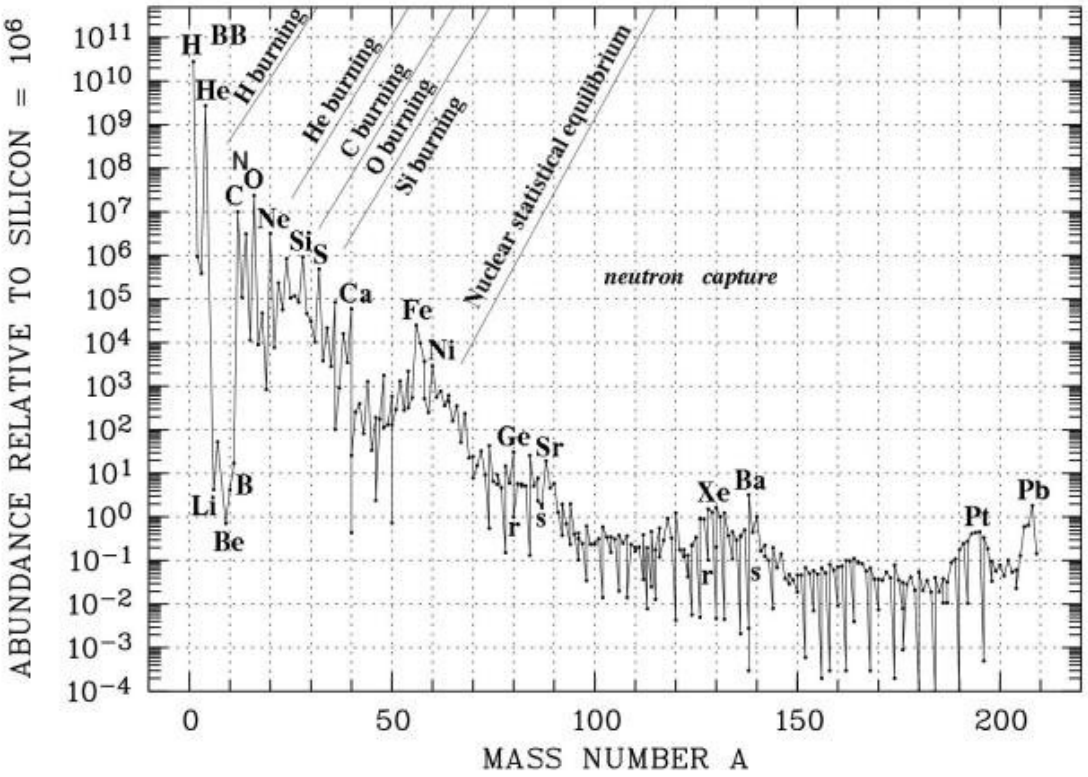
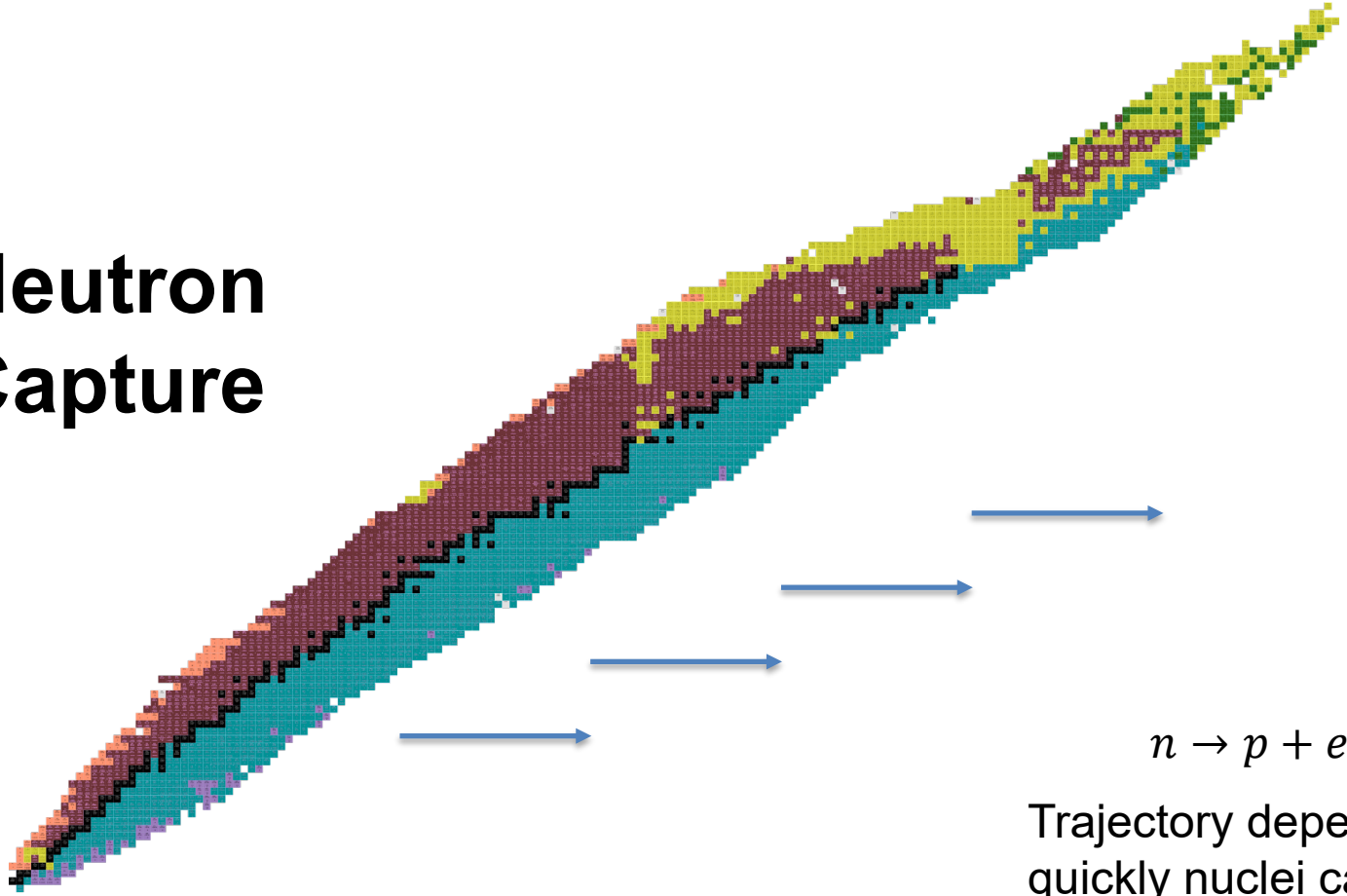



Average binding energy per nucleon (MeV)
Number of nucleons in nucleus, A
H1
H2
H3
He3
He4
Li3
Li3
C12
O16
Fe56
U235
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
140
160
180
200
220
240

Explosive Nucleosynthesis!


ABUNDANCE RELATIVE TO SILICON = 10^6
MASS NUMBER A
H
BB
He
H burning
He burning
C burning
O burning
Si burning
Nuclear statistical equilibrium
neutron capture
N
O
C
Ne
Si
S
Ca
Fe
Ni
Ge
Sr
Li
B
Be
Xe
Ba
Pt
Pb
r
s
r
s
0
50
100
150
200

Neutron Capture



Z

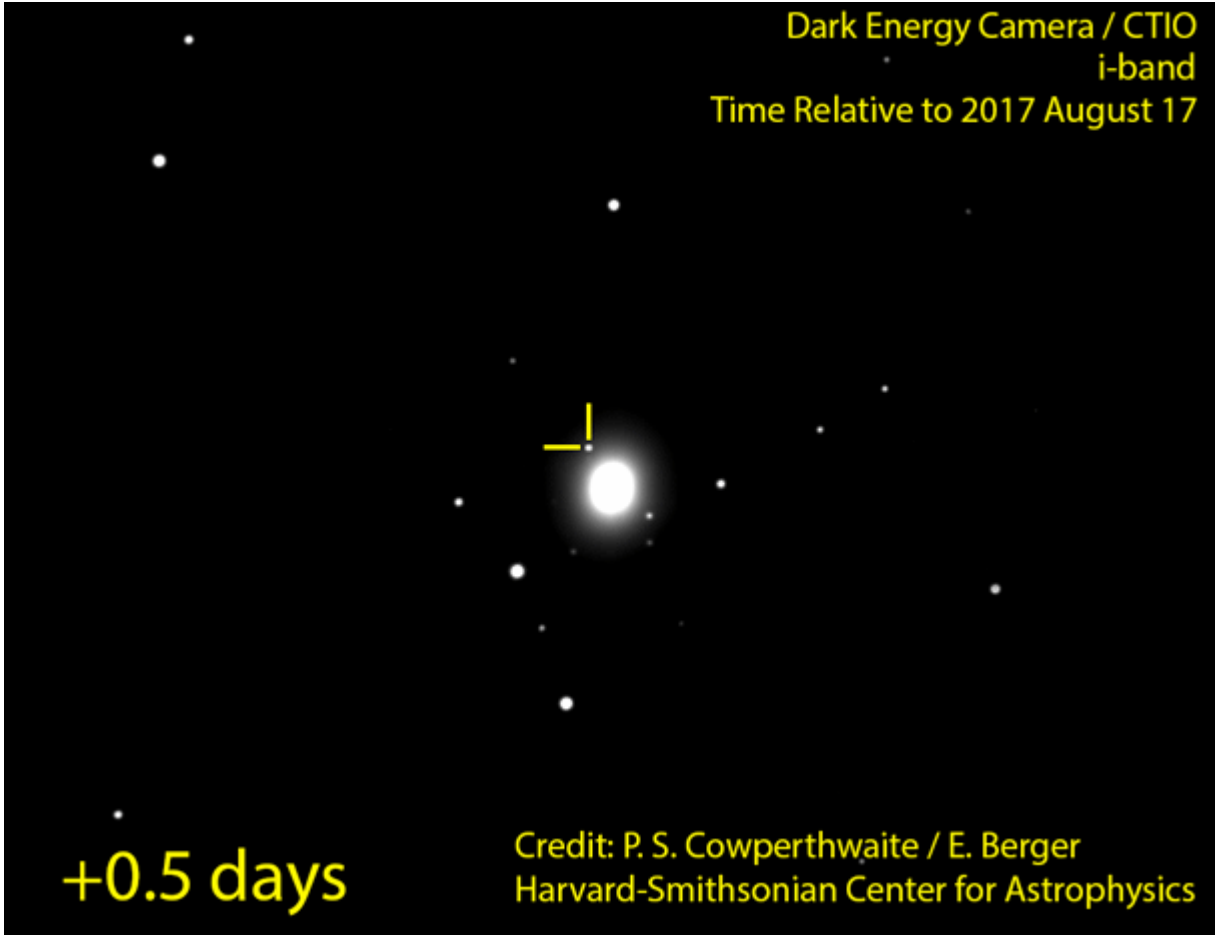
N

$$n \rightarrow p + e^{-} + \bar{\nu}_e$$

Trajectory depends on how quickly nuclei can capture!

An even longer time later….

Neutron Star Mergers



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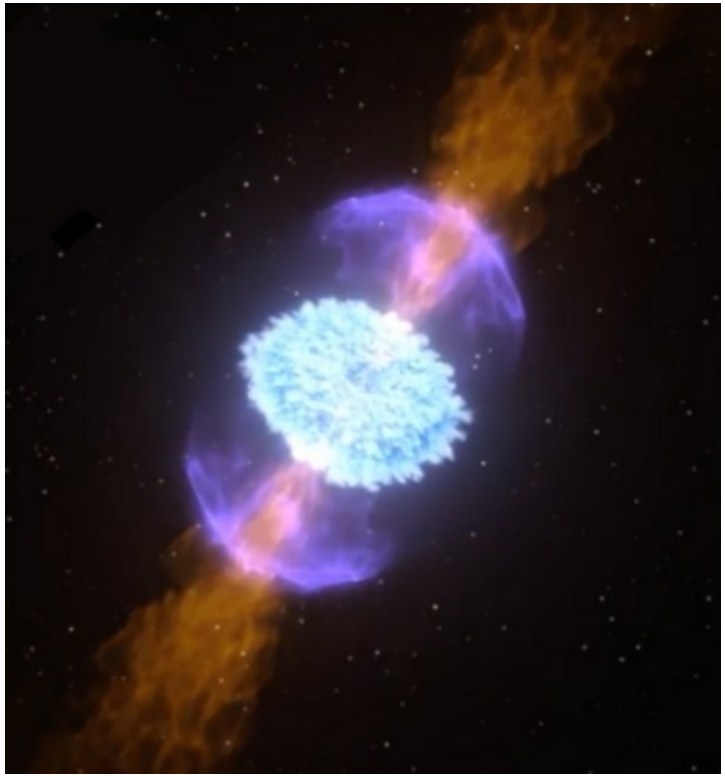
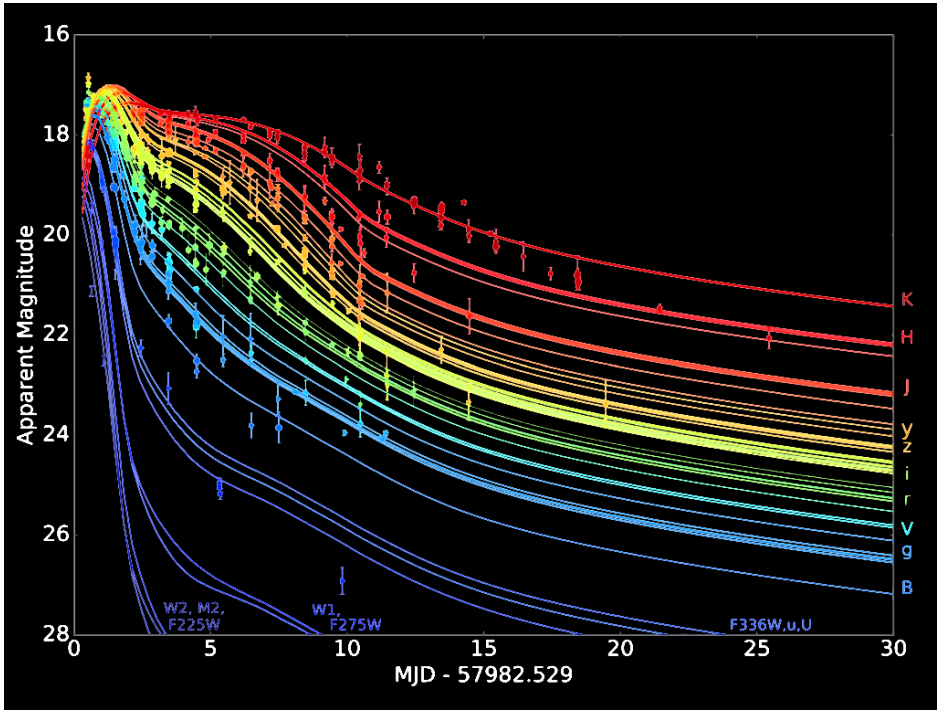
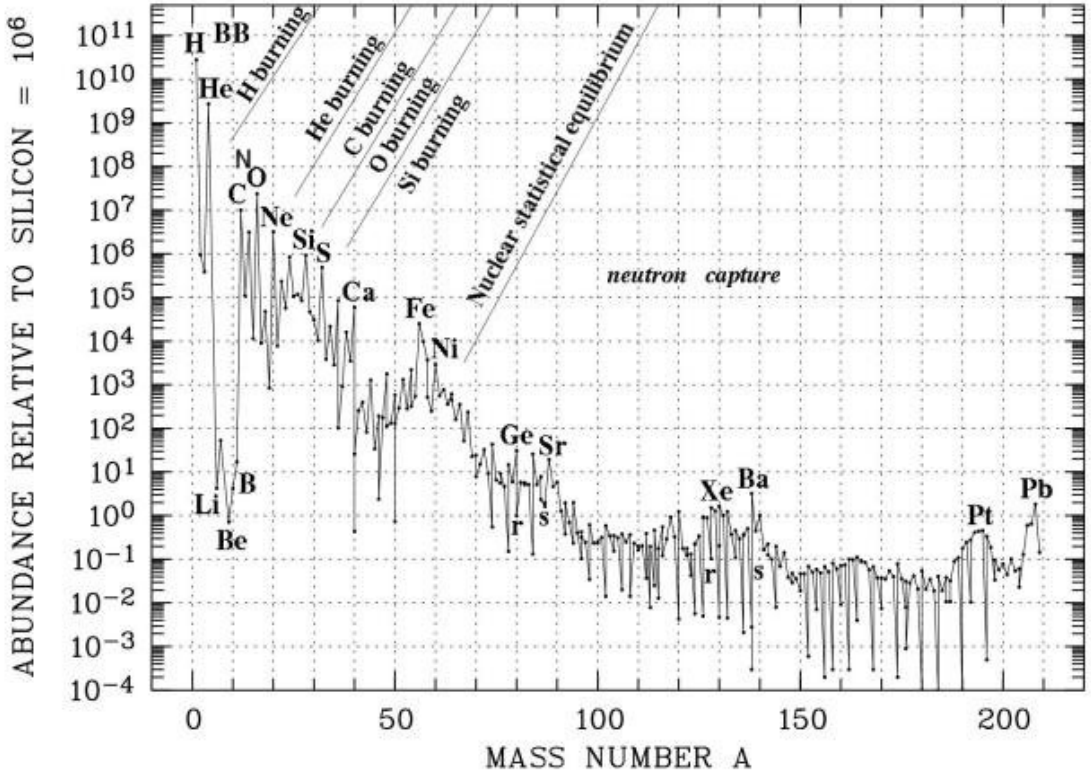




Big Picture

Big Picture


ABUNDANCE RELATIVE TO SILICON = 10^6
MASS NUMBER A
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C
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Si
S
Ca
Fe
Ni
Ge
Sr
Li
B
Be
r
s
Xe
Ba
Pt
Pb

Thank you!

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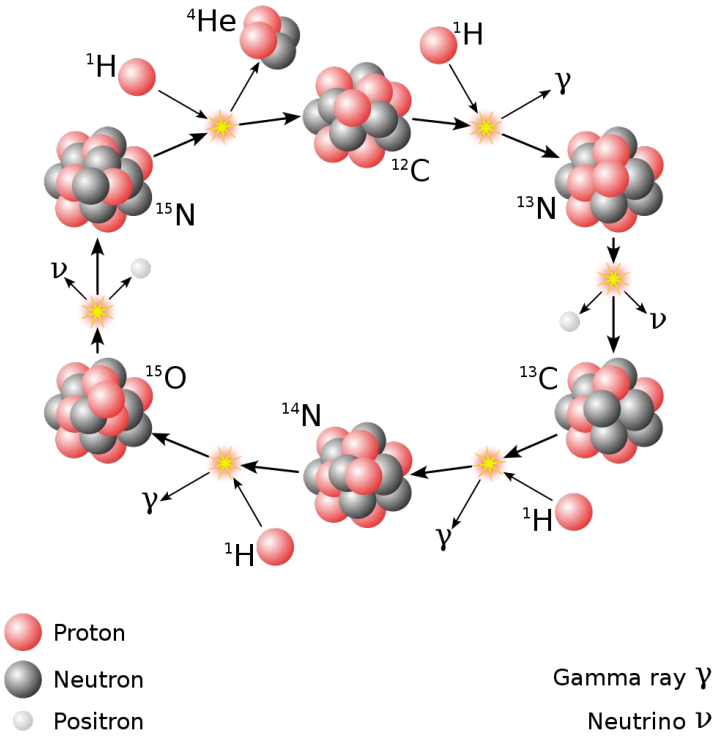
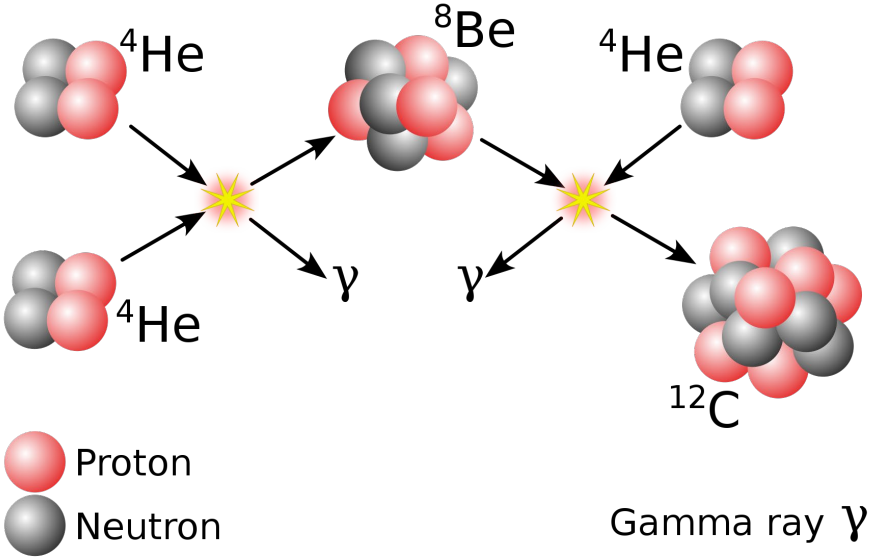
Stellar Nucleosynthesis: CNO Cycle



Occurs in larger stars (>1.3 $M_\odot$), where higher temperatures are possible

Stellar Nucleosynthesis: Triple-α Process



Needs very high temperatures!