Introduction to Earth Sciences
ESO 213A

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Department of Earth Sciences

Lecture: Origin of Earth and its internal structure, and building blocks of our planets.

The Science of Geology

- **Geology is the science that pursues an understanding of planet Earth.**
  - **Physical geology examines Earth materials and seeks to understand the many processes that operate on our planet.**
  - **Historical geology seeks an understanding of the origin of Earth and its development through time.**

Origin of the Universe

The universe began about ~13.7 billion years ago

The **Big Bang Theory** states that, in the beginning, the universe was all in one place

All of its matter and energy were squished into an infinitely small point (smaller than atom), and then it exploded. In millionth of a millionth second from smaller than a size of atom to galaxy! All energy

After about 10 billion years, our solar system began to form

Nucleosynthesis

Time	T (K)	Density
10^-43 (s)	10^32	10^96
10^-35 (s)	10^28	10^80
10^-13 (s)	10^16	10^32
15s	3x10^9	10^4
3min	10^9	10^2
10^5 y	4000	10^-20
10^9 y	18	10^-27
13.6x 10^9	2.73	10^-30

At the beginning, the universe was only made of "elementary particles", protons, neutrons do not exist, they were not stable (too hot!).
After 10^{-4} seconds temperature was cool enough to form protons and neutrons
After 3 minutes the universe was cool enough to produce ^{2}H (proton and neutron combined)

This first phase is called **primordial nucleosynthesis.**

.

$$ {}_1^1H + {}_1^1H \rightarrow {}_1^2H + \beta^+ + \nu + 0.422\,MeV $$

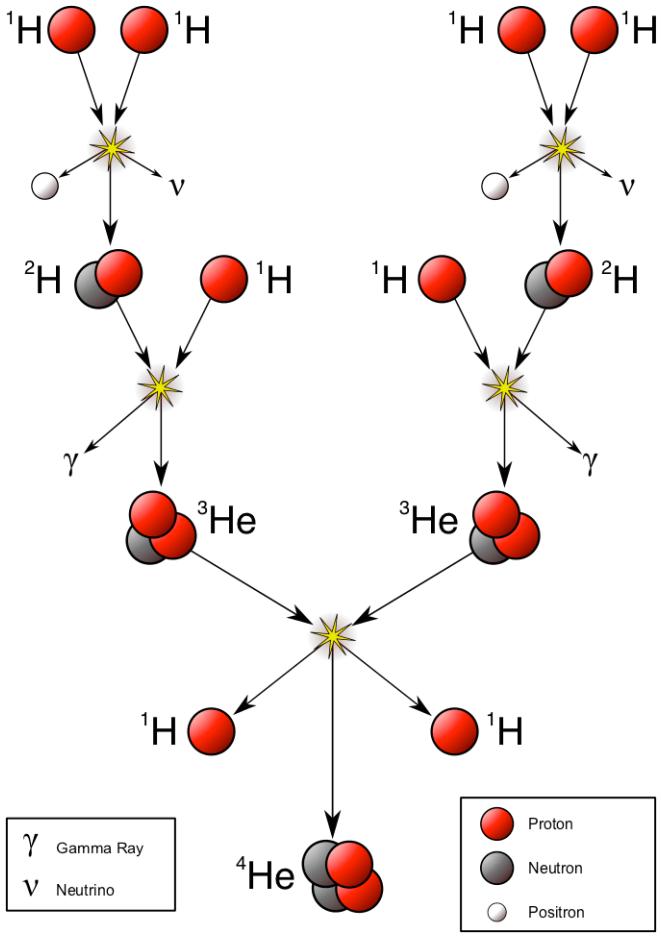
$$ \beta^+ + e^- \rightarrow 1.02\,MeV\,(annihilation) $$

$$ {}_1^2H + {}_1^1H \rightarrow {}_2^3He + \gamma + 5.493\,MeV $$

$$ {}_2^3He + {}_2^3He \rightarrow {}_2^4He + 2{}_1^1H + 12.859\,MeV $$

$$ total: $$

$$ 4{}_1^1H \rightarrow {}_2^4He + 2\nu + \gamma + 19.794\,MeV $$



The Big Bang therefore mainly created H and He, and the first stars were formed (but still no planets)

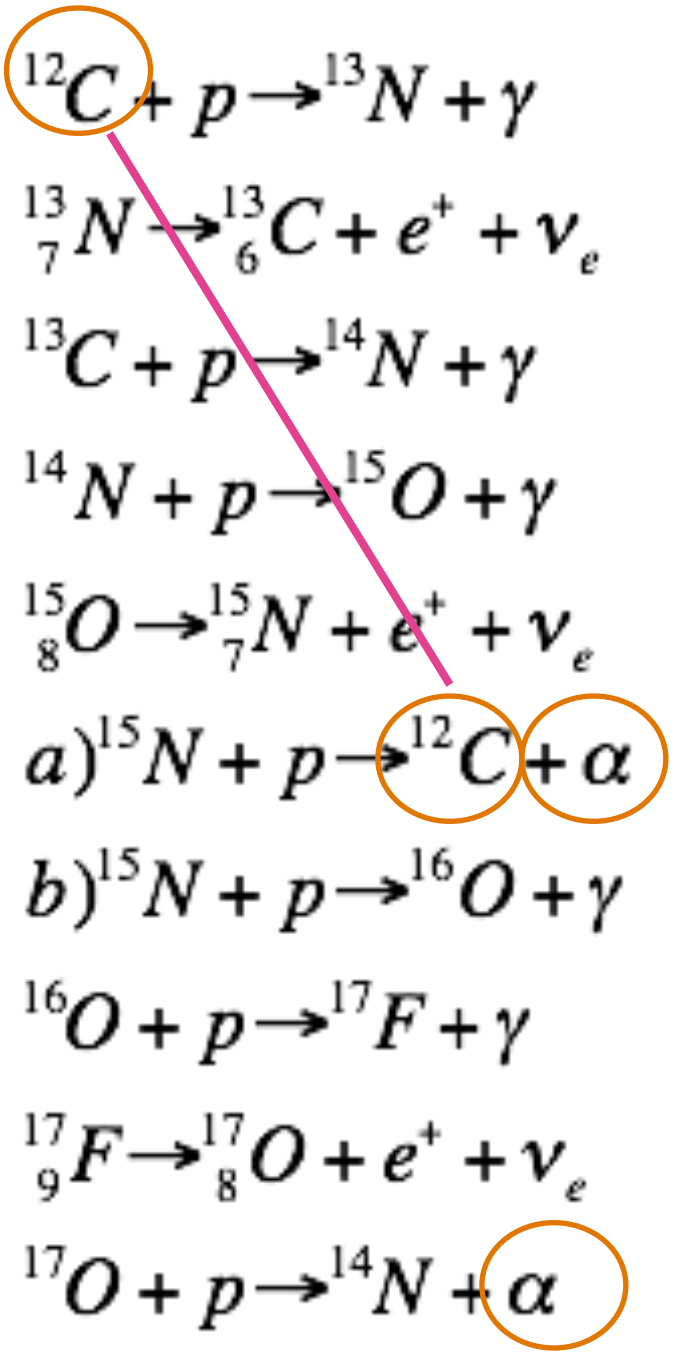
Stars are not only the source of light, its an element factory!

Stellar Nucleosynthesis started more than 12 billion years ago

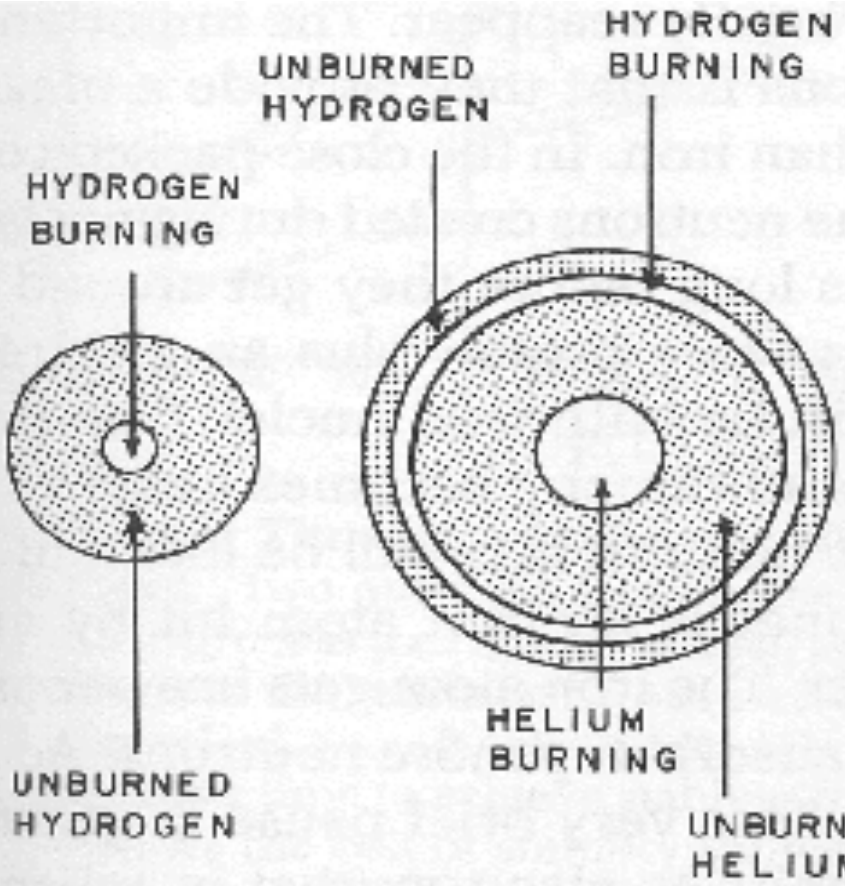
$$^{4}He + ^{4}He \rightarrow ^{8}Be + \gamma$$
$$^{8}Be + ^{4}He \rightarrow ^{12}C + \gamma$$

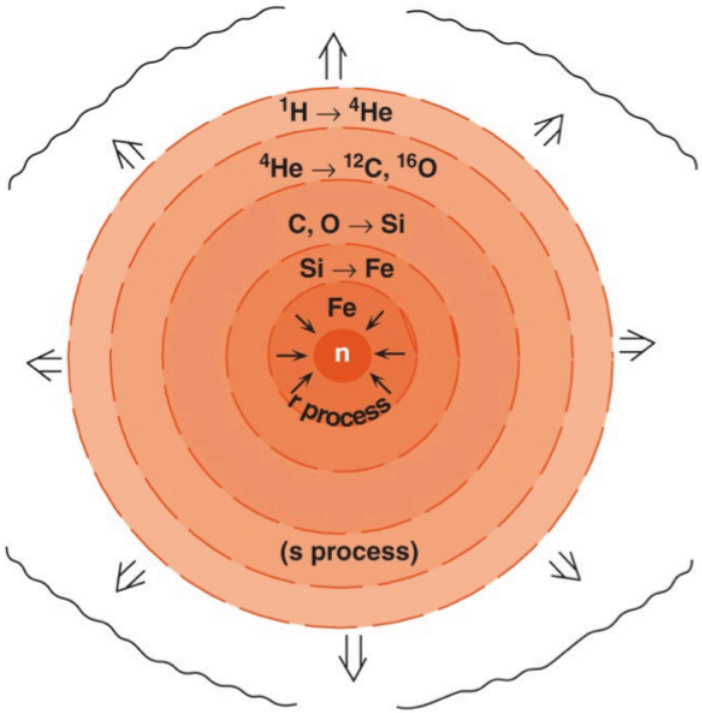
^{8}Be = short half life $7 \cdot 10^{-16}$ sec. Needs fast capture / collision with a-particle.
Needs high density of He, high T,P ->>**RED GIANTS!**

Once the H is exhausted in the stellar core, fusion ceases, and the balance between gravitational collapse and thermal expansion is broken. The interior of the star thus collapses, raising the star's temperature.
The exterior expands and fusion begins in the shells surrounding the core, which now consists of He. This is the *red giant* phase.

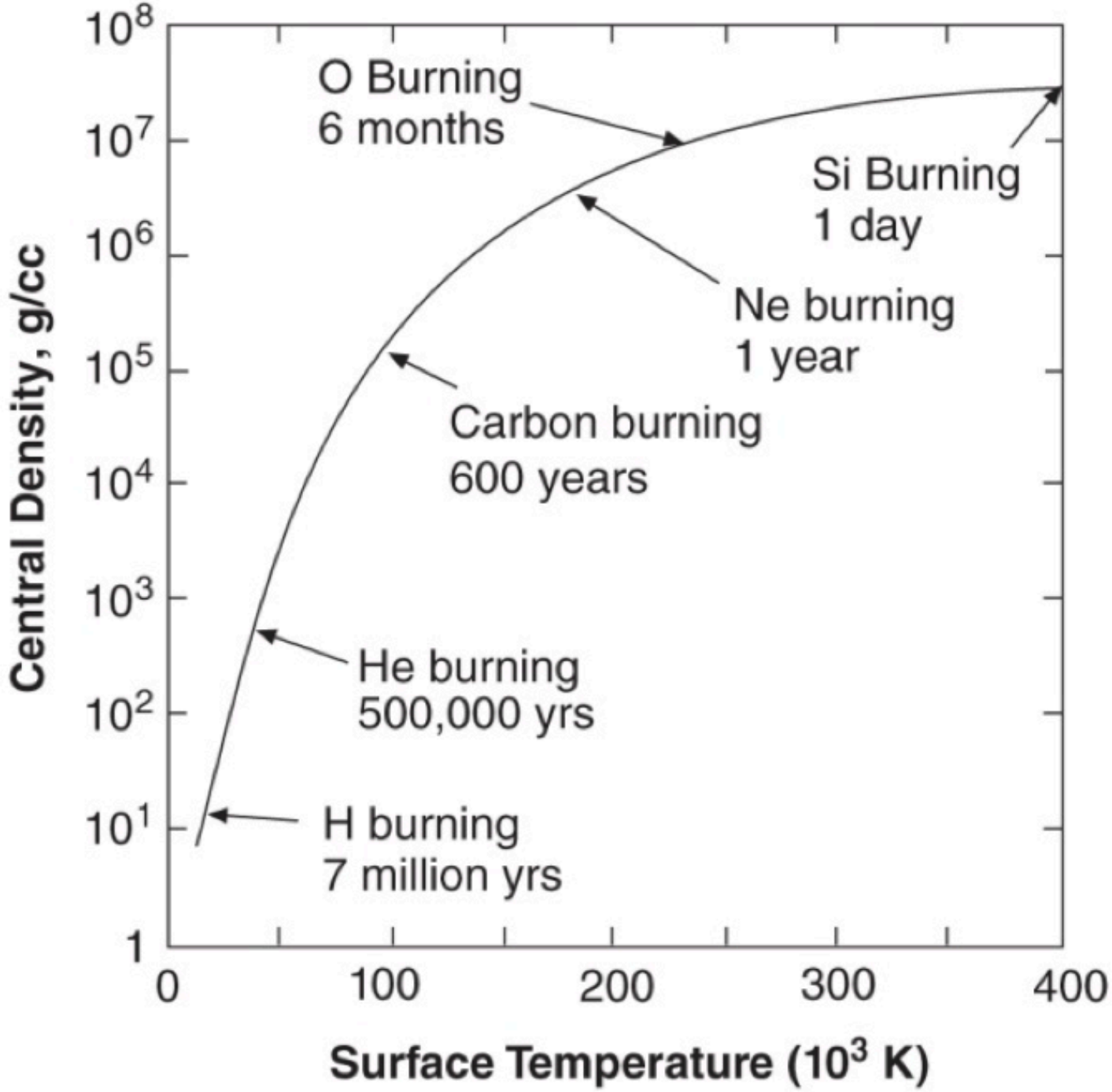


CNO cycle:
2nd generation stars
C is the catalyst

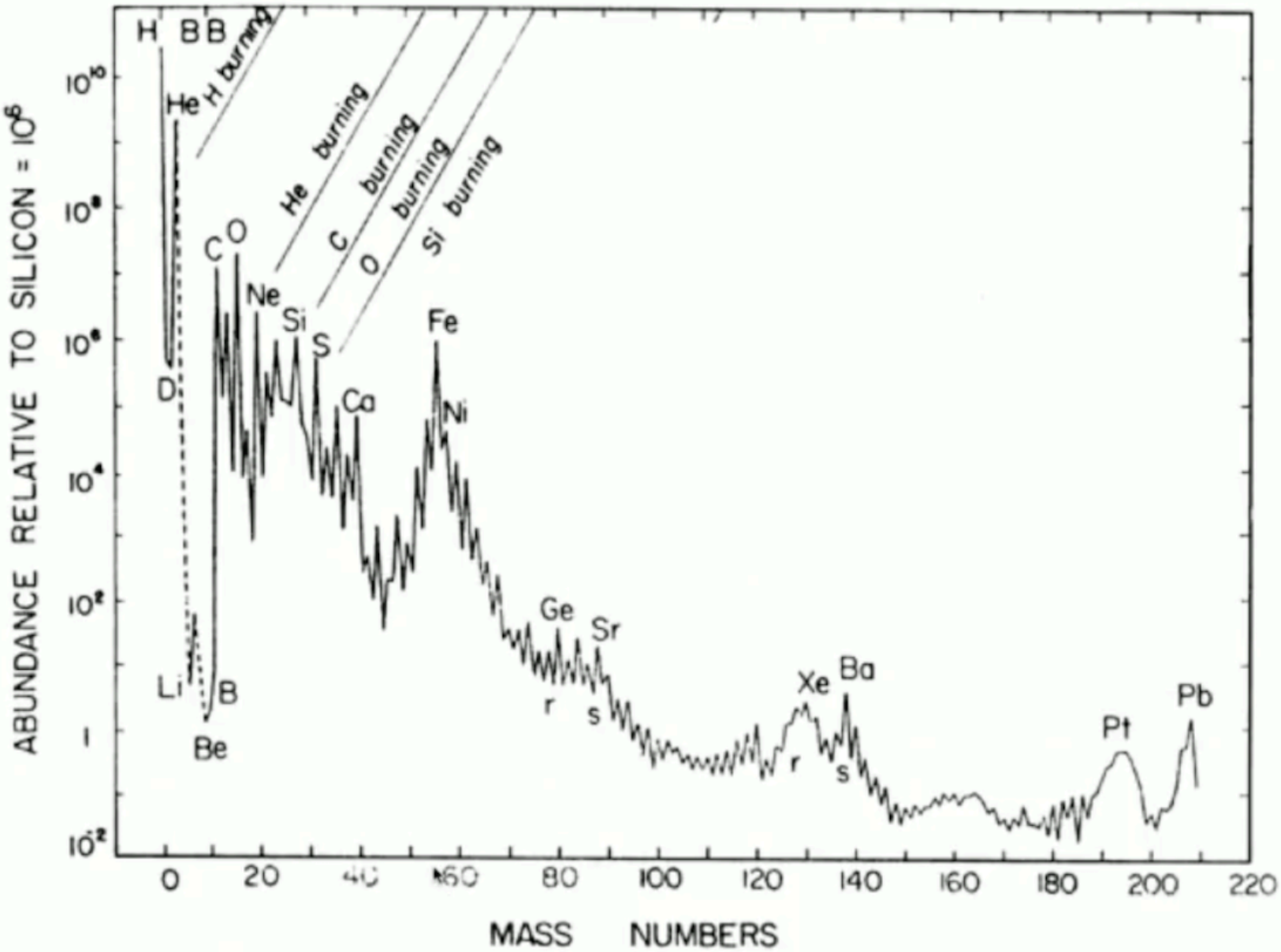




Name of Process	Fuel	Products	Temperature
Hydrogen-Burning	H	He	60×10^6 °K
Helium-Burning	He	C, O	200×10^6 °K
Carbon-Burning	C	O, Ne, Na, Mg	800×10^6 °K
Neon-Burning	Ne	O, Mg	1500×10^6 °K
Oxygen-Burning	O	Mg to S	2000×10^6 °K
Silicon-Burning	Mg to S	Elements near FE	3000×10^6 °K

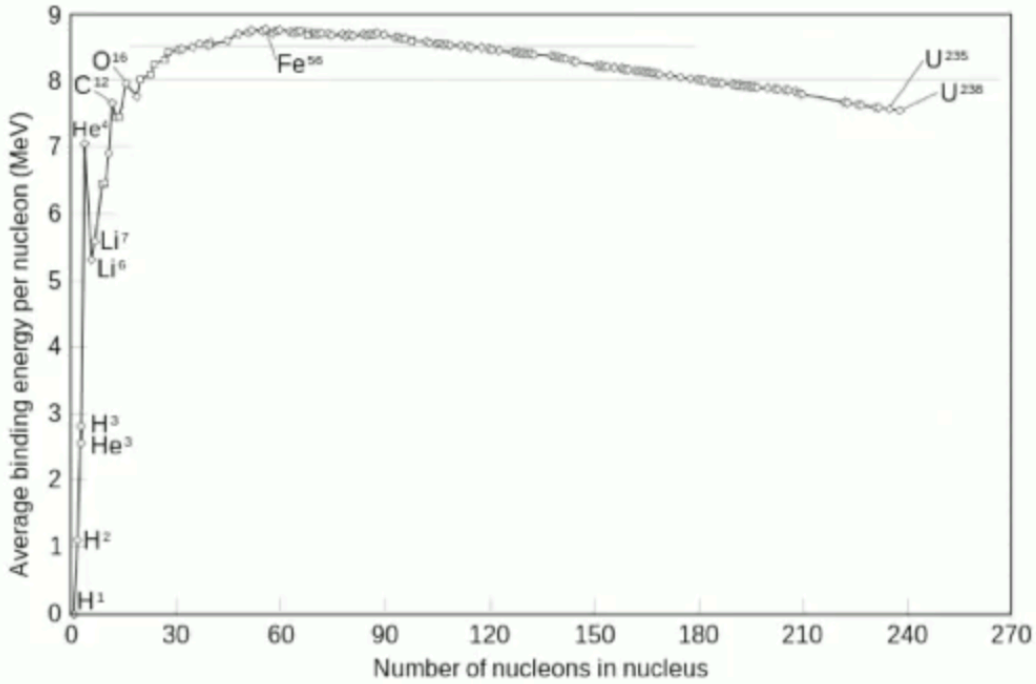

10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
Central Density, g/cc
O Burning
6 months
Si Burning
1 day
Ne burning
1 year
Carbon burning
600 years
He burning
500,000 yrs
H burning
7 million yrs
0
100
200
300
400
Surface Temperature (10^3 K)

Is the universe made of iron?



So what happens beyond iron?

- capture of particles requires energy
- capture of charged particles very unlikely
- neutrons still can be captured



- iron from the earlier burning processes exposed to the neutron flux
- two processes possible:
  - slow neutron capture: s-process
  - rapid neutron capture: r-process

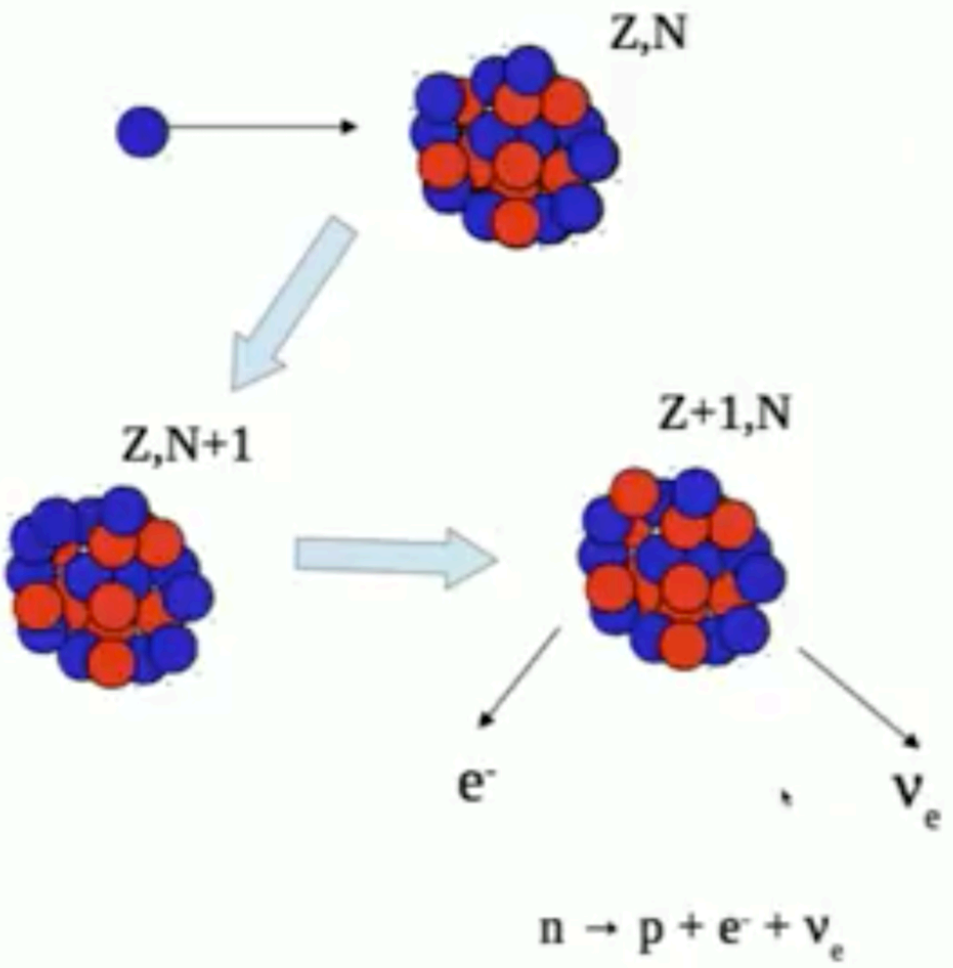
Supernova Explosion

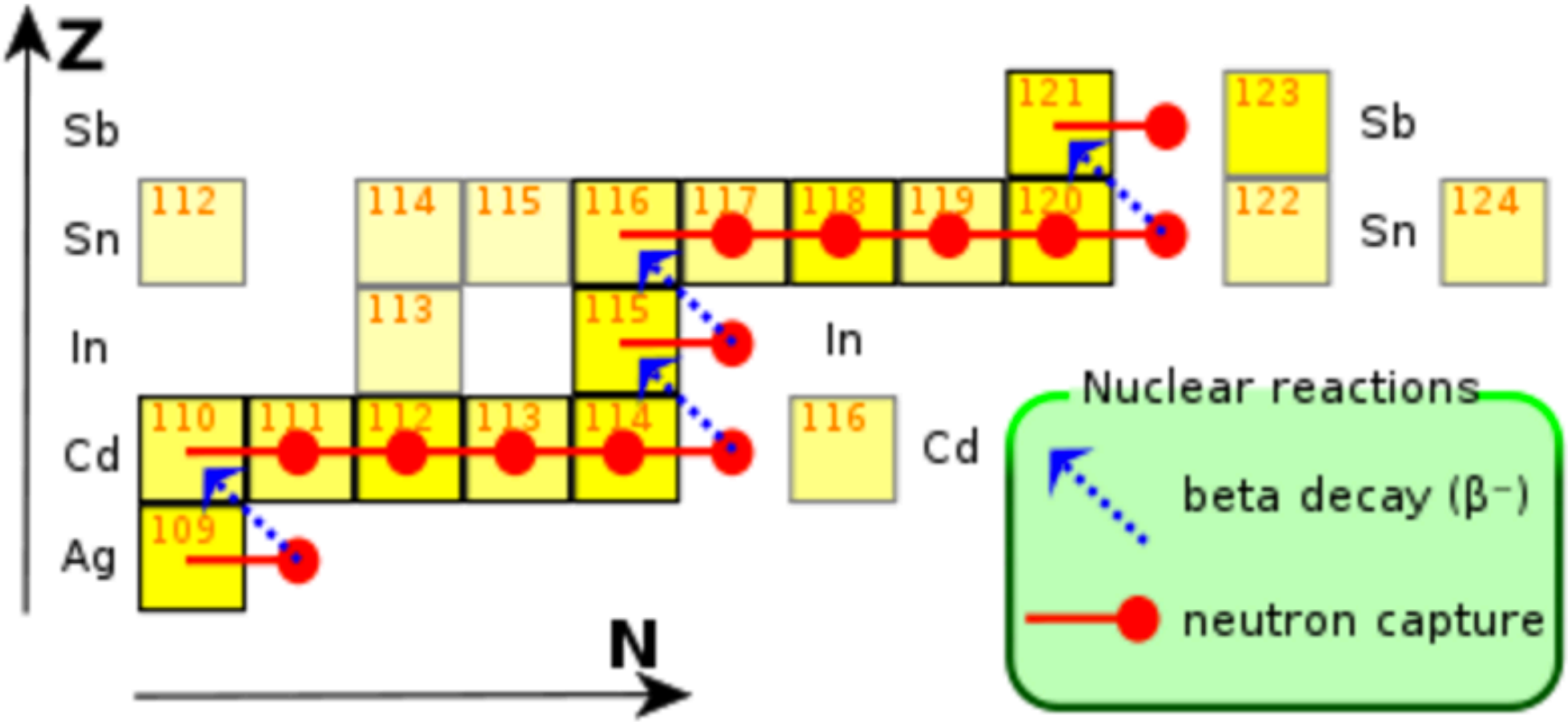
s-process – slow neutron capture

What does it mean 'slow'?

Nucleus half-life – life time of a nucleus before it decays

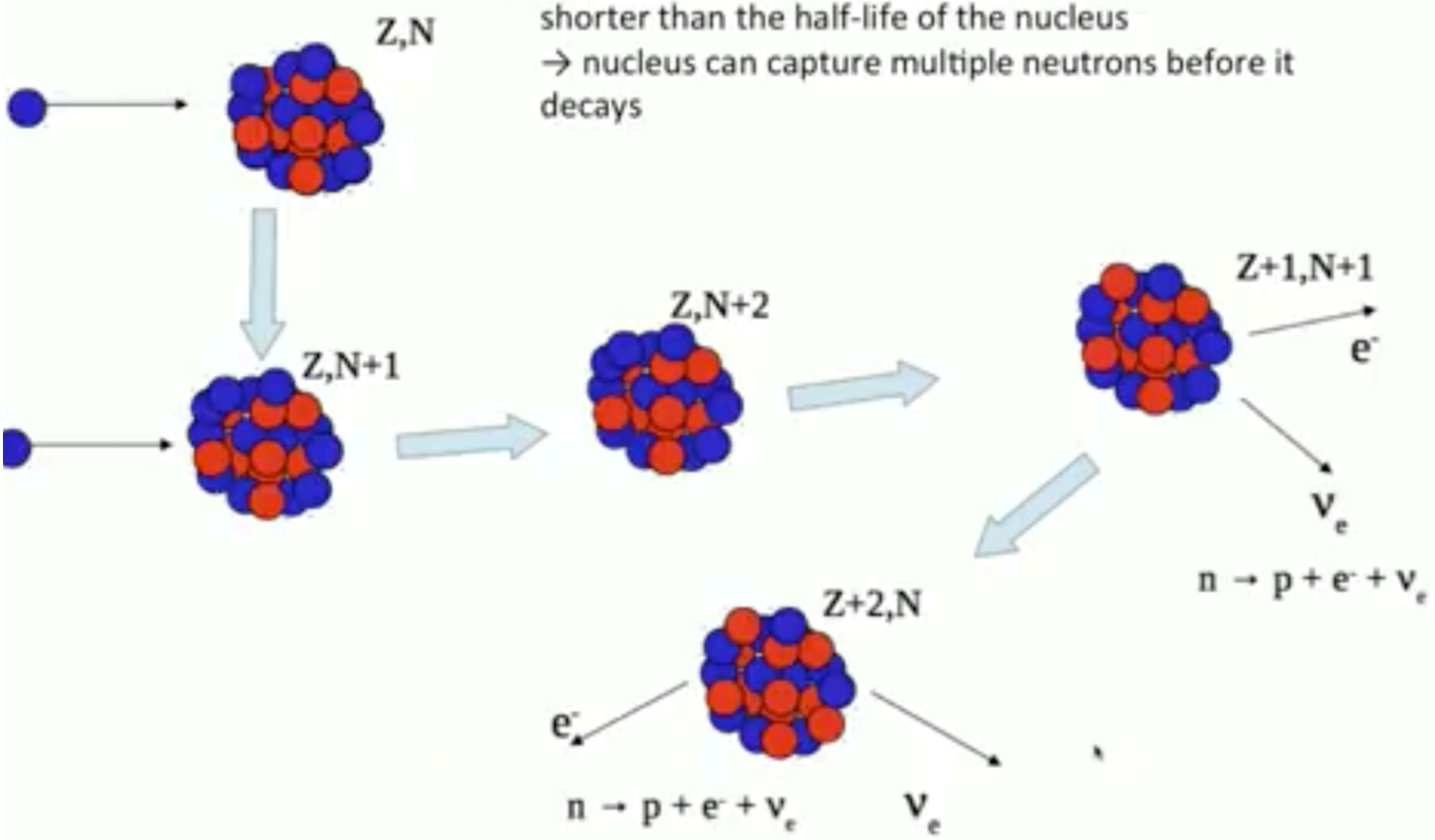
→ 'slow' = time until a neutron is captured is longer than the half-life of the nucleus



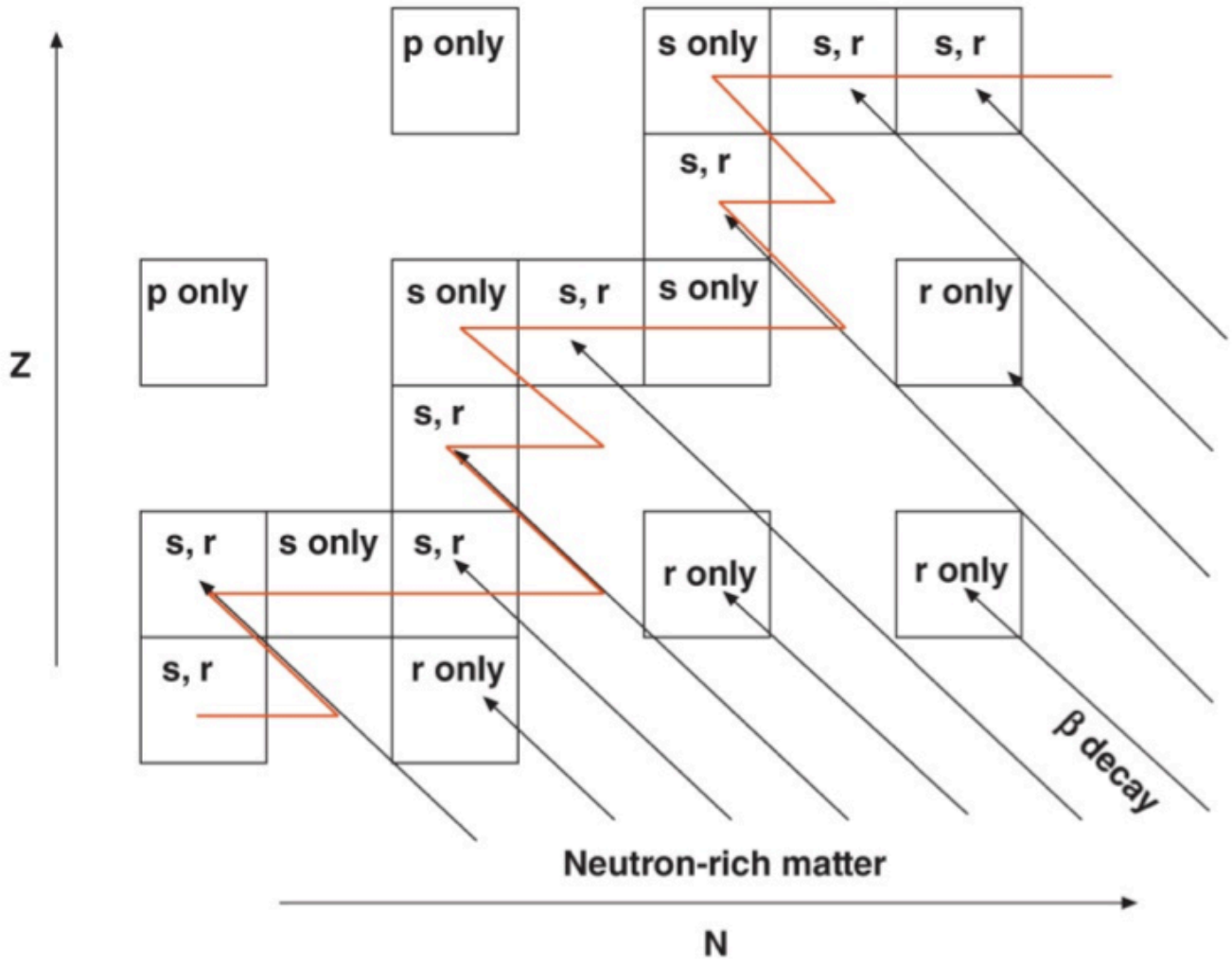

Z
Sb
Sn
In
Cd
Ag
N
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
Sb
Sn
In
Cd
Nuclear reactions
beta decay (β⁻)
neutron capture

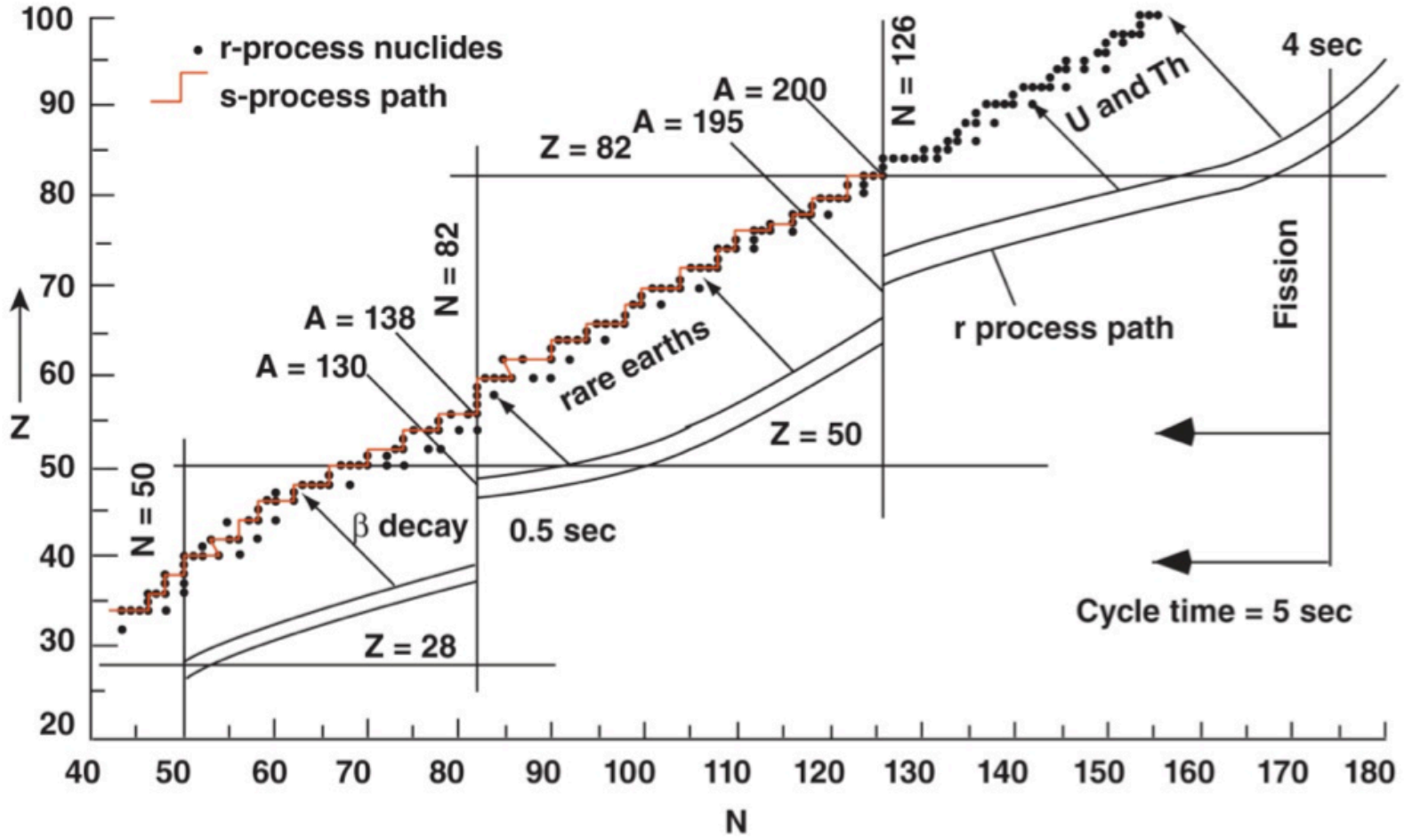
r-process – rapid neutron capture

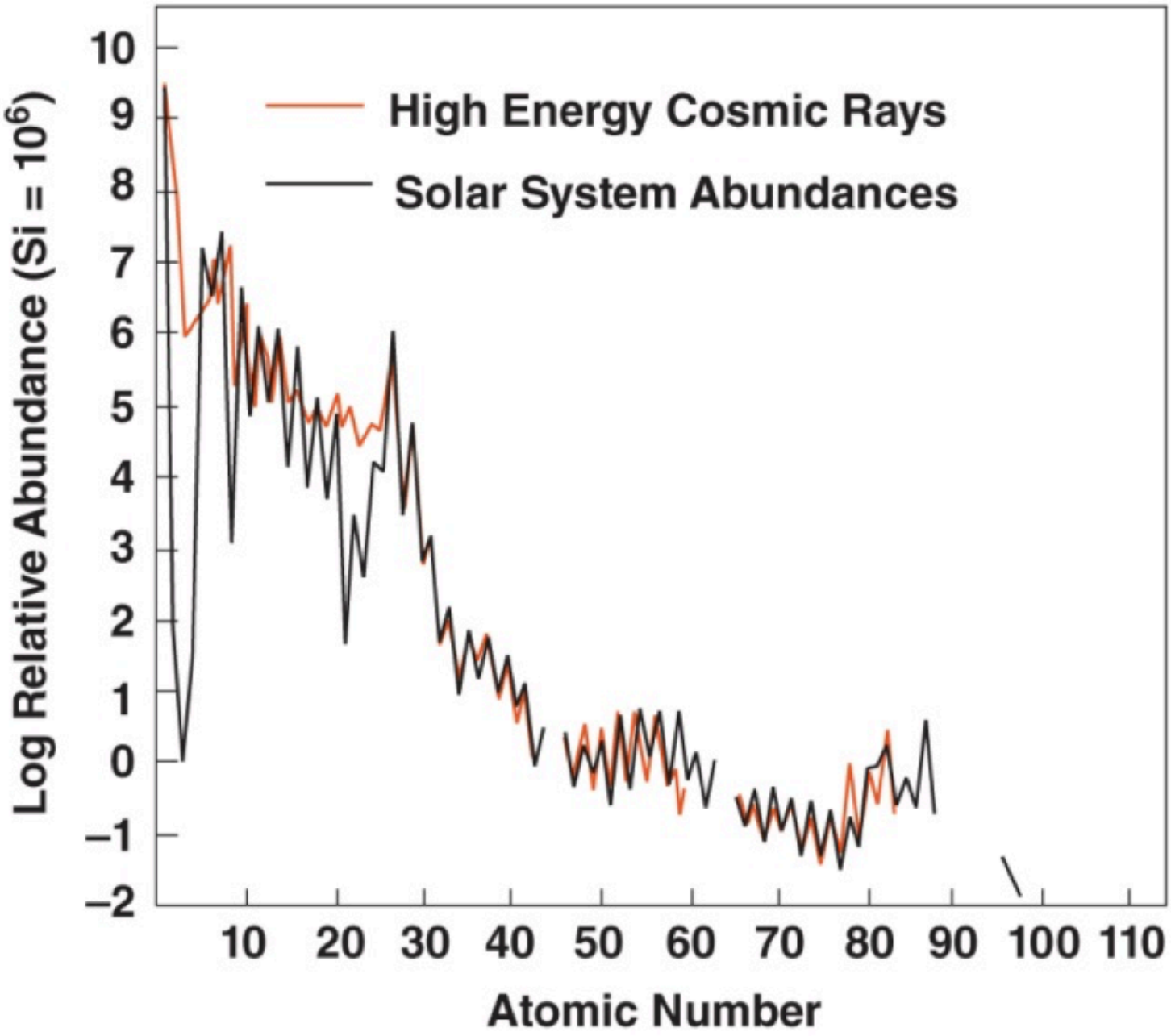
→ 'rapid' = time until a neutron is captured is much shorter than the half-life of the nucleus
→ nucleus can capture multiple neutrons before it decays




Z
64Se 65Se 66Se 67Se 68Se 69Se 70Se 71Se 72Se 73Se 74Se 75Se 76Se 77Se 78Se 79Se 80Se
63As 64As 65As 66As 67As 68As 69As 70As 71As 72As 73As 74As 75As 76As 77As 78As 79As
32
62Ge 63Ge 64Ge 65Ge 66Ge 67Ge 68Ge 69Ge 70Ge 71Ge 72Ge 73Ge 74Ge 75Ge 76Ge 77Ge 78Ge
61Ga 62Ga 63Ga 64Ga 65Ga 66Ga 67Ga 68Ga 69Ga 70Ga 71Ga 72Ga 73Ga 74Ga 75Ga 76Ga 77Ga
60Zn 61Zn 62Zn 63Zn 64Zn 65Zn 66Zn 67Zn 68Zn 69Zn 70Zn 71Zn 72Zn 73Zn 74Zn 75Zn 76Zn
59Cu 60Cu 61Cu 62Cu 63Cu 64Cu 65Cu 66Cu 67Cu 68Cu 69Cu 70Cu 71Cu 72Cu 73Cu 74Cu 75Cu
58Ni 59Ni 60Ni 61Ni 62Ni 63Ni 64Ni 65Ni 66Ni 67Ni 68Ni 69Ni 70Ni 71Ni 72Ni 73Ni 74Ni
28
57Co 58Co 59Co 60Co 61Co 62Co 63Co 64Co 65Co 66Co 67Co 68Co 69Co 70Co 71Co 72Co 73Co
56Fe 57Fe 58Fe 59Fe 60Fe 61Fe 62Fe 63Fe 64Fe 65Fe 66Fe 67Fe 68Fe 69Fe 70Fe 71Fe 72Fe
26
30 32 34 36 38 40 42 44 N


p only
s only
s, r
s, r
s, r
p only
s only
s, r
s only
r only
s, r
s, r
s only
s, r
r only
r only
s, r
r only
β decay
Z
Neutron-rich matter
N

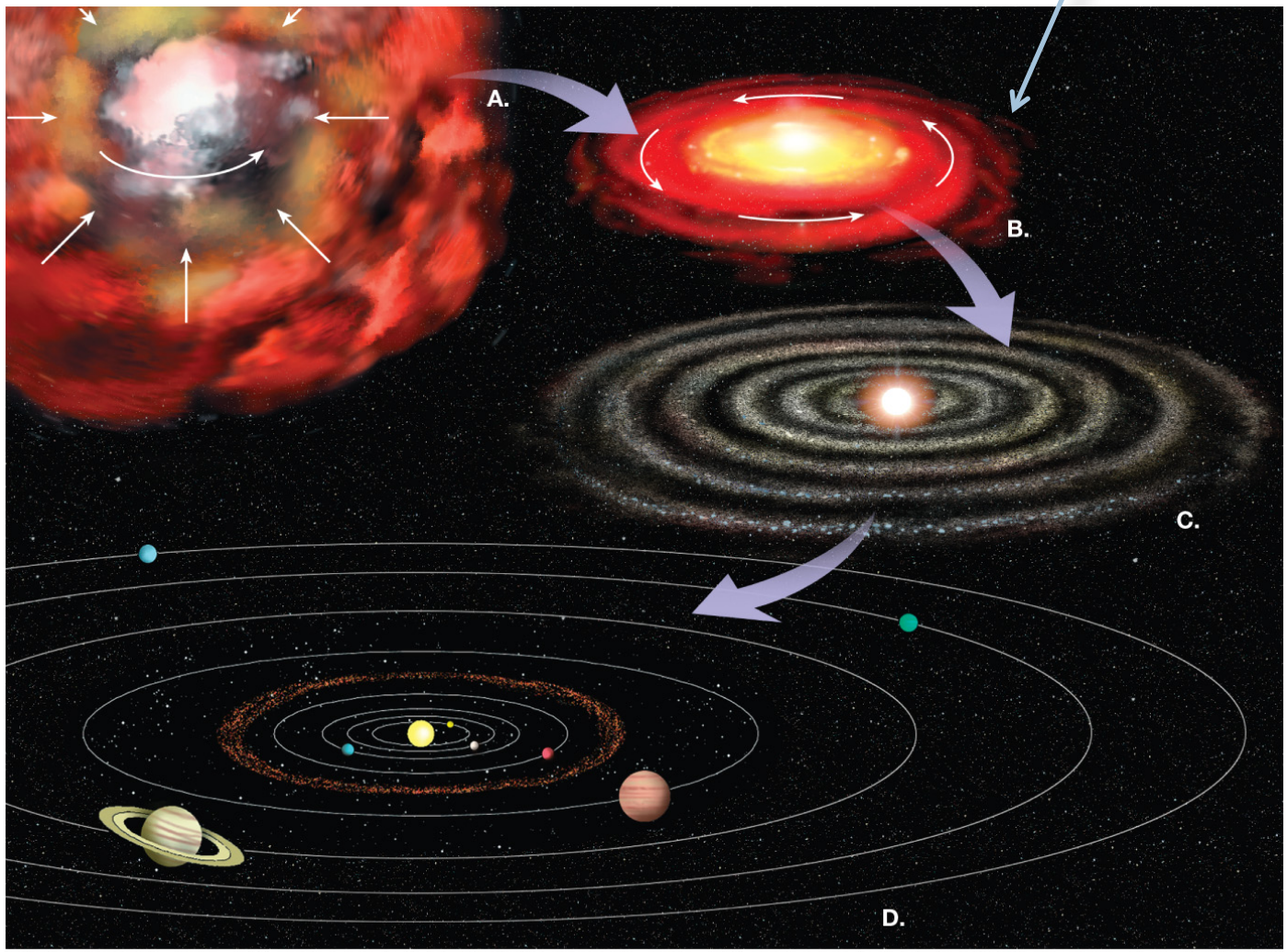

r-process nuclides
s-process path
A = 200
A = 195
Z = 82
N = 126
U and Th
4 sec
A = 138
A = 130
N = 82
rare earths
r process path
Fission
Z = 50
N = 50
β decay
0.5 sec
Cycle time = 5 sec
Z = 28
Z
N
100
90
80
70
60
50
40
30
20
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180


High Energy Cosmic Rays
Solar System Abundances
Log Relative Abundance (Si = 10^6)
10
9
8
7
6
5
4
3
2
1
0
–1
–2
10
20
30
40
50
60
70
80
90
100
110
Atomic Number

Element (H-Fe) factory "stars", supernova explosion along with s-and r-process continued to produce the building blocks of our universe (hydrogen to uranium)

4.57 billions years ago

The Nebular Theory



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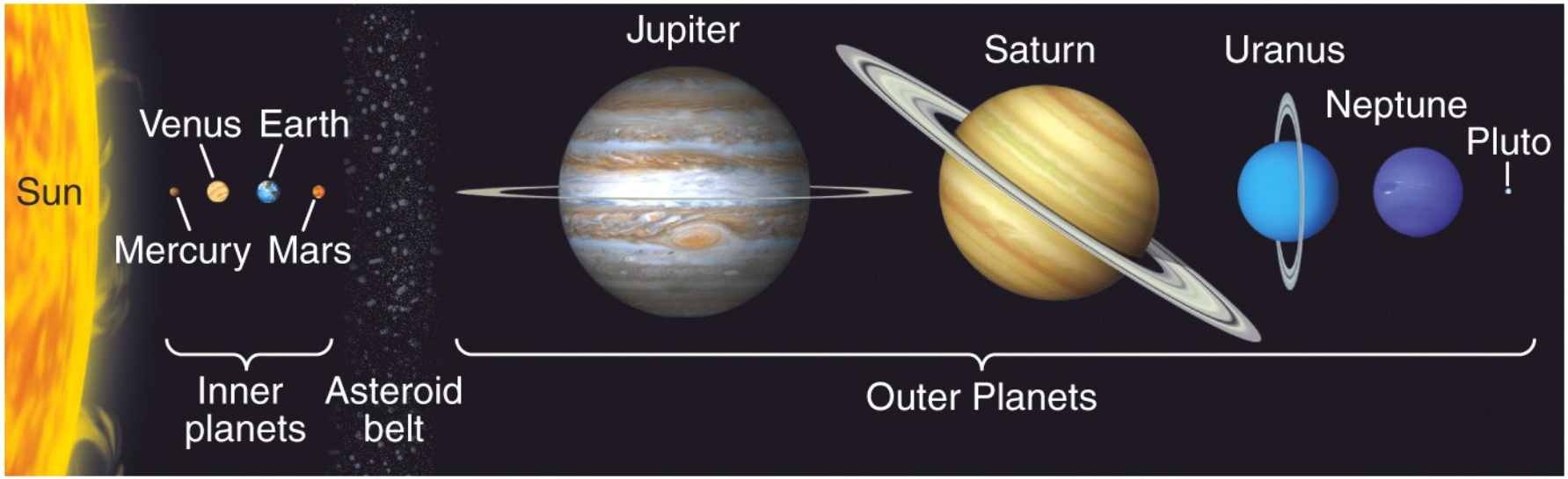
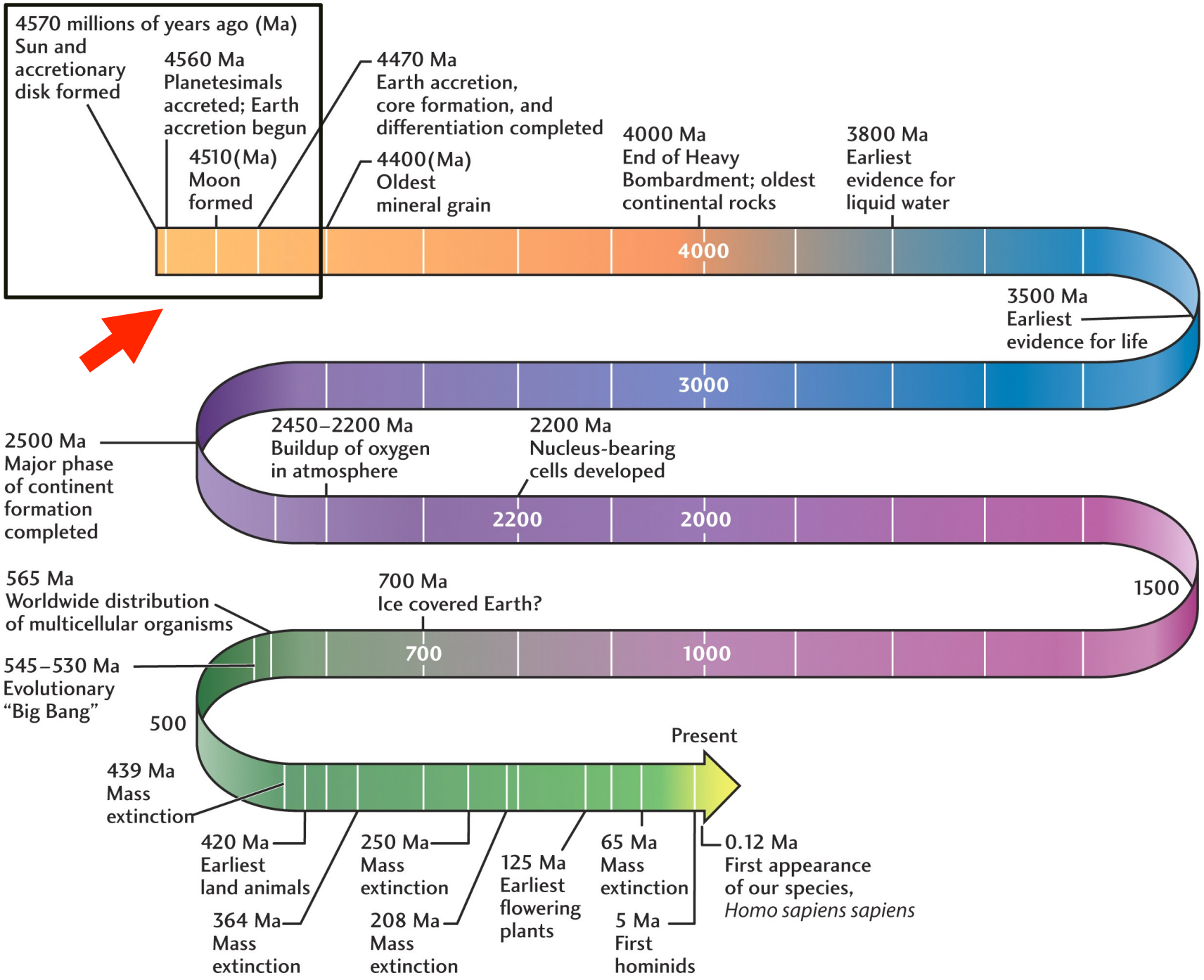

Sun
Venus
Earth
Mercury
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
Inner planets
Asteroid belt
Outer Planets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Sun and accretionary disk formed
4560 Ma
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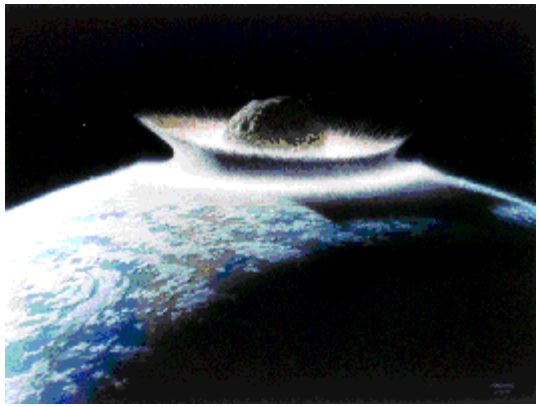
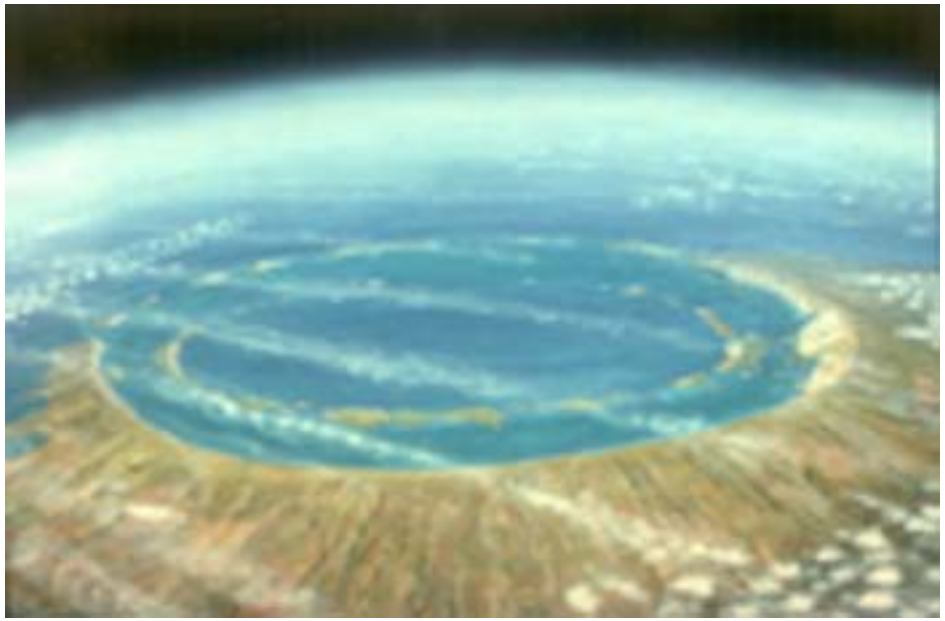
Earth accretion, core formation, and differentiation completed
4400(Ma)
Oldest mineral grain
4000 Ma
End of Heavy Bombardment; oldest continental rocks
3800 Ma
Earliest evidence for liquid water
4000
3500 Ma
Earliest evidence for life
3000
2500 Ma
Major phase of continent formation completed
2450–2200 Ma
Buildup of oxygen in atmosphere
2200 Ma
Nucleus-bearing cells developed
2200
2000
1500
565 Ma
Worldwide distribution of multicellular organisms
700 Ma
Ice covered Earth?
700
1000
545–530 Ma
Evolutionary "Big Bang"
500
Present
439 Ma
Mass extinction
420 Ma
Earliest land animals
364 Ma
Mass extinction
250 Ma
Mass extinction
208 Ma
Mass extinction
125 Ma
Earliest flowering plants
65 Ma
Mass extinction
5 Ma
First hominids
0.12 Ma
First appearance of our species, Homo sapiens sapiens

Bombardment From Space

For the first 50 million years of its existence, the surface of the Earth was repeatedly pulverized by asteroids and comets of all sizes

One of these collisions formed the Moon





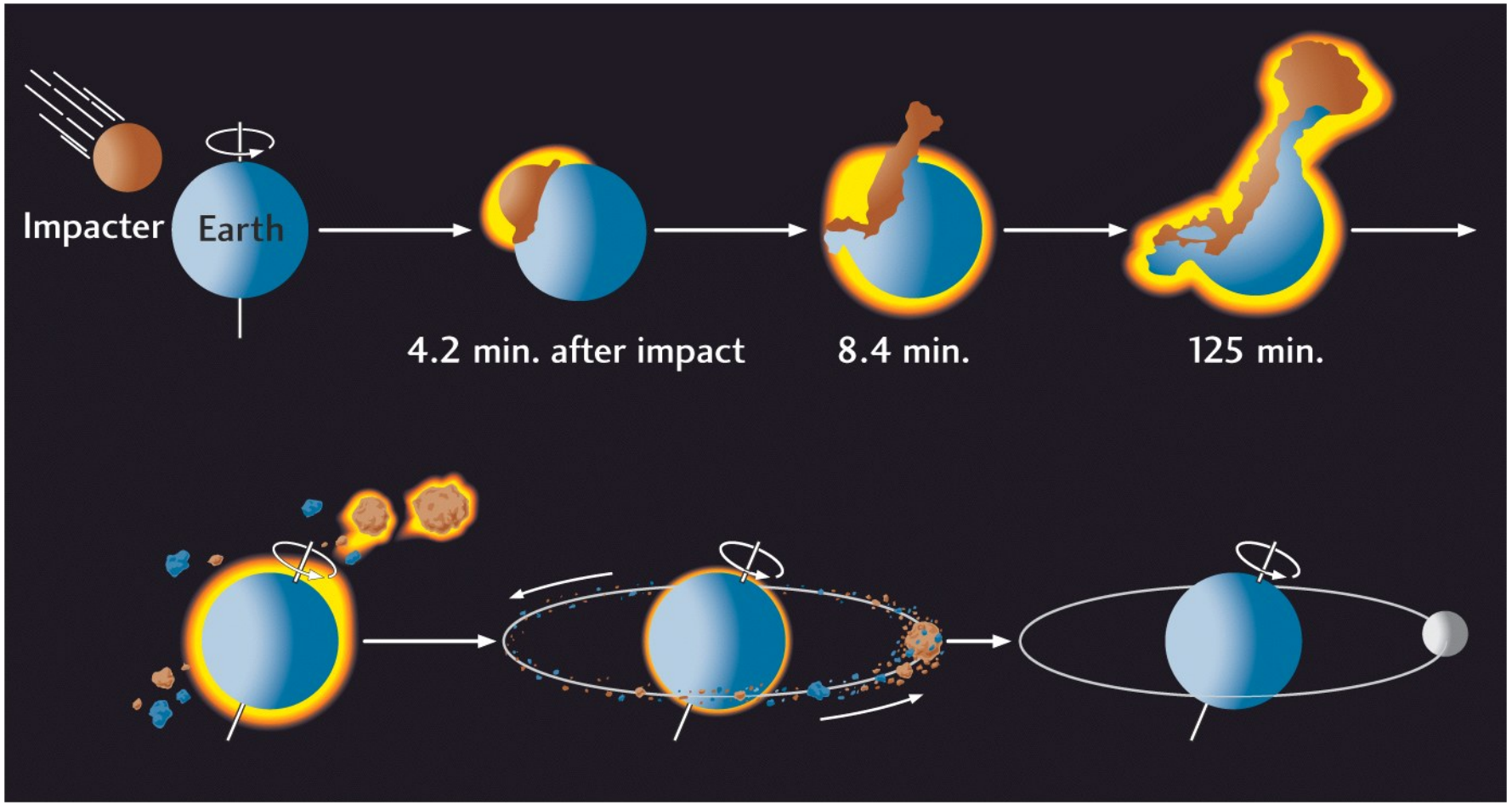
Giant Impact Hypothesis predicts that around 50 million years after the initial creation of Earth, a planet about the size of Mars collided with Earth

This idea was first proposed about 30 years ago, but it took calculations by modern high-speed computers to prove the feasibility

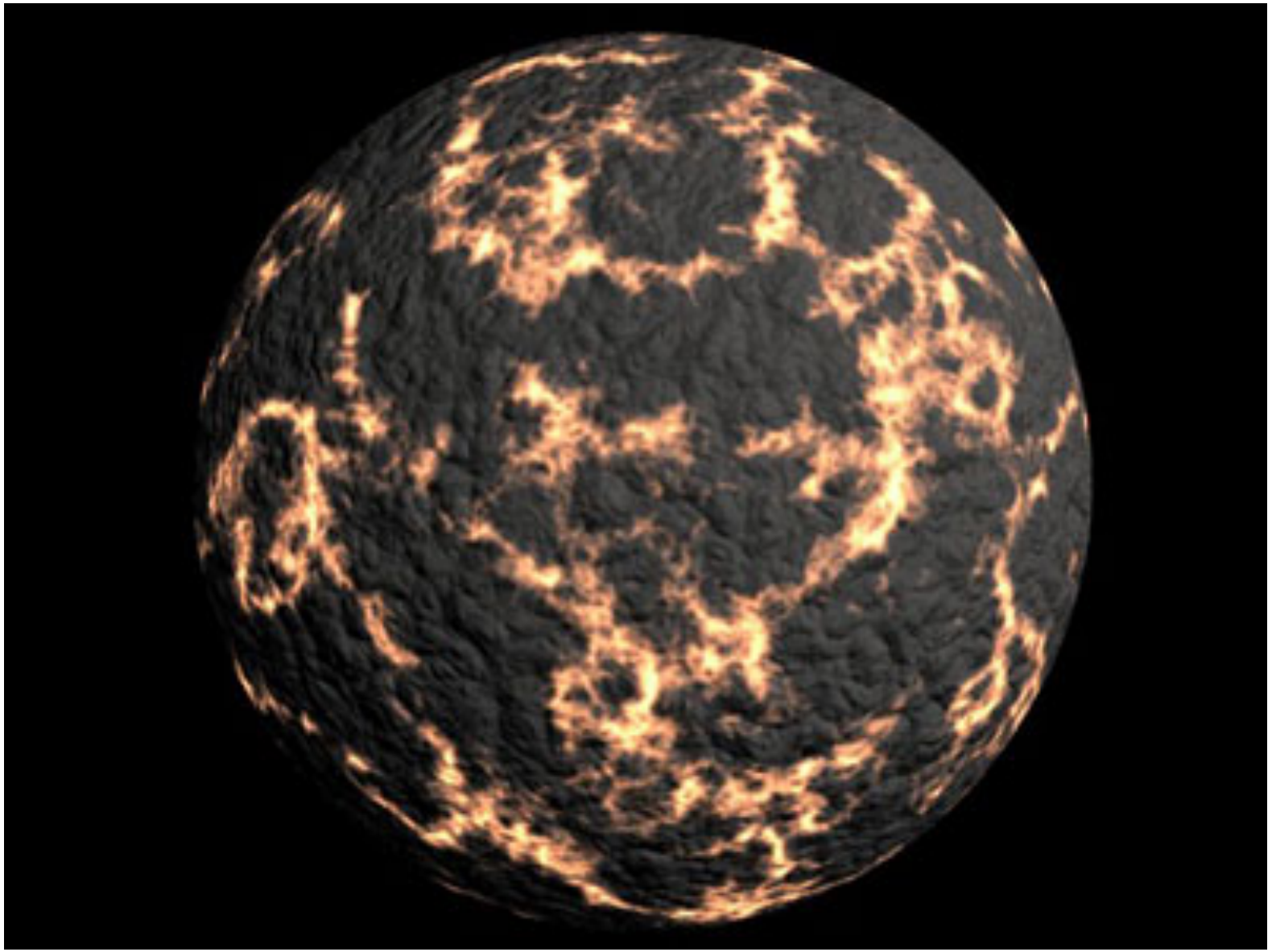
Why Moon Formation is Important?

This collision had to be very spectacular!

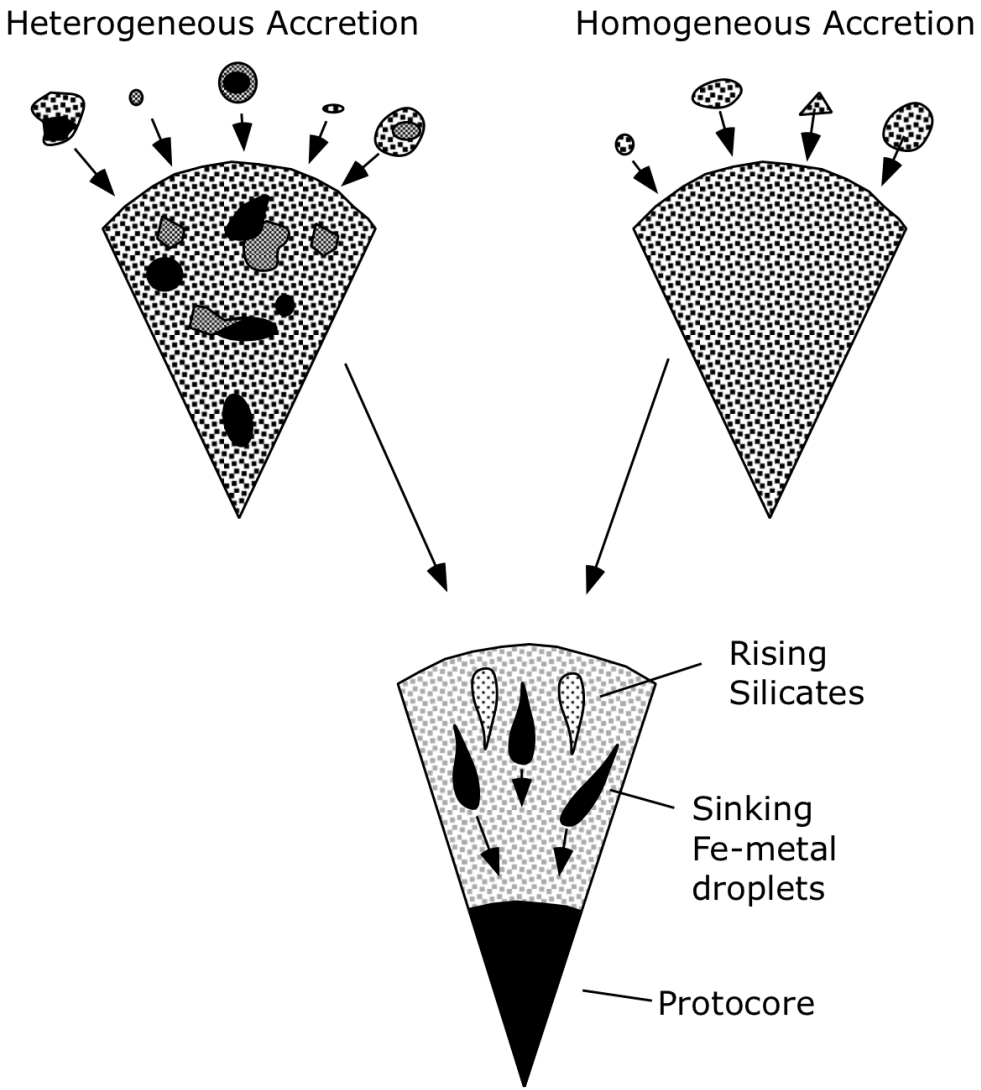
A considerable amount of material was blown off into space, but most fell back onto the Earth



The Early Earth Heats Up (Magma Ocean)



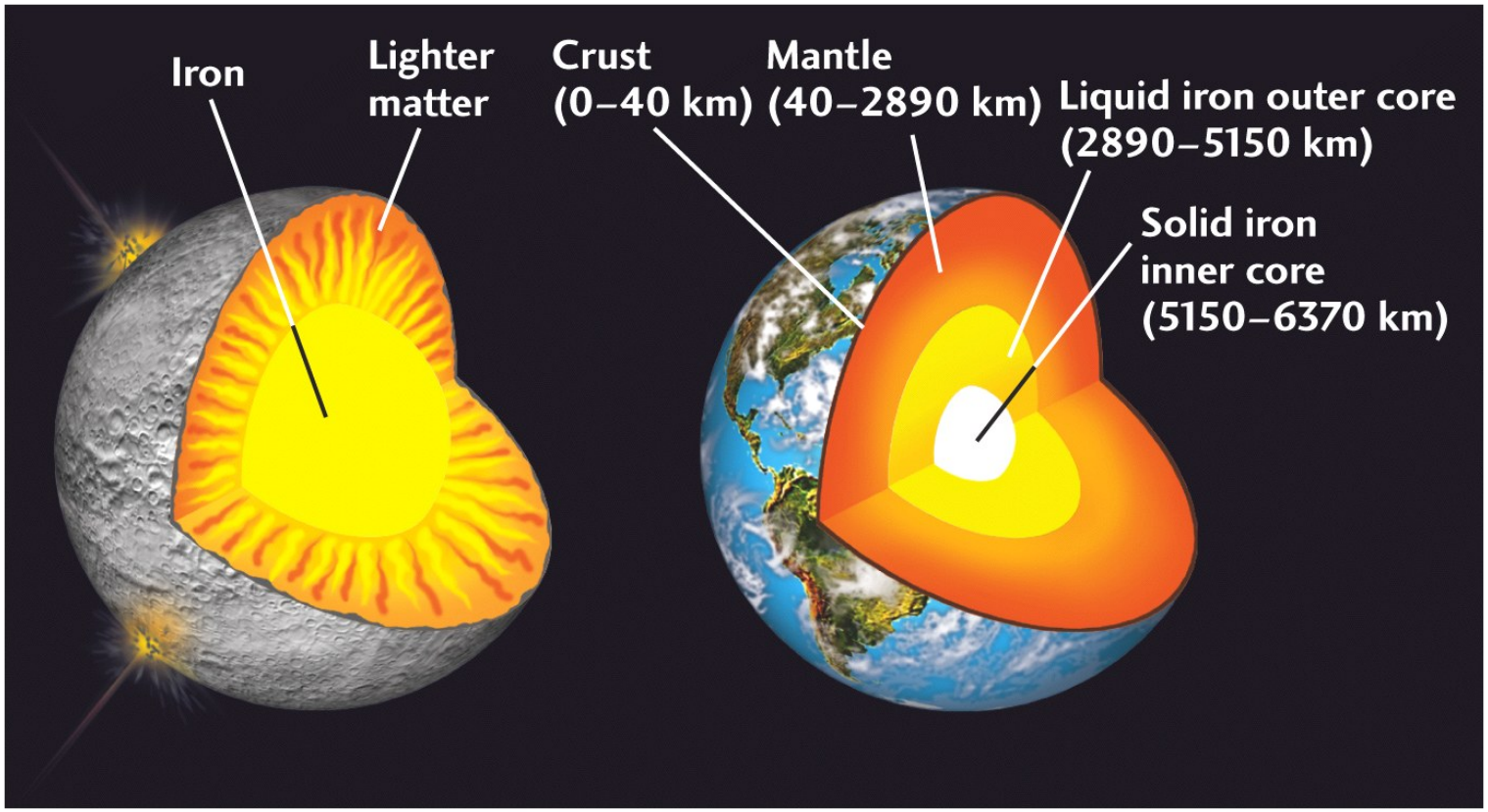
Origin of the Earth's Internal Layering

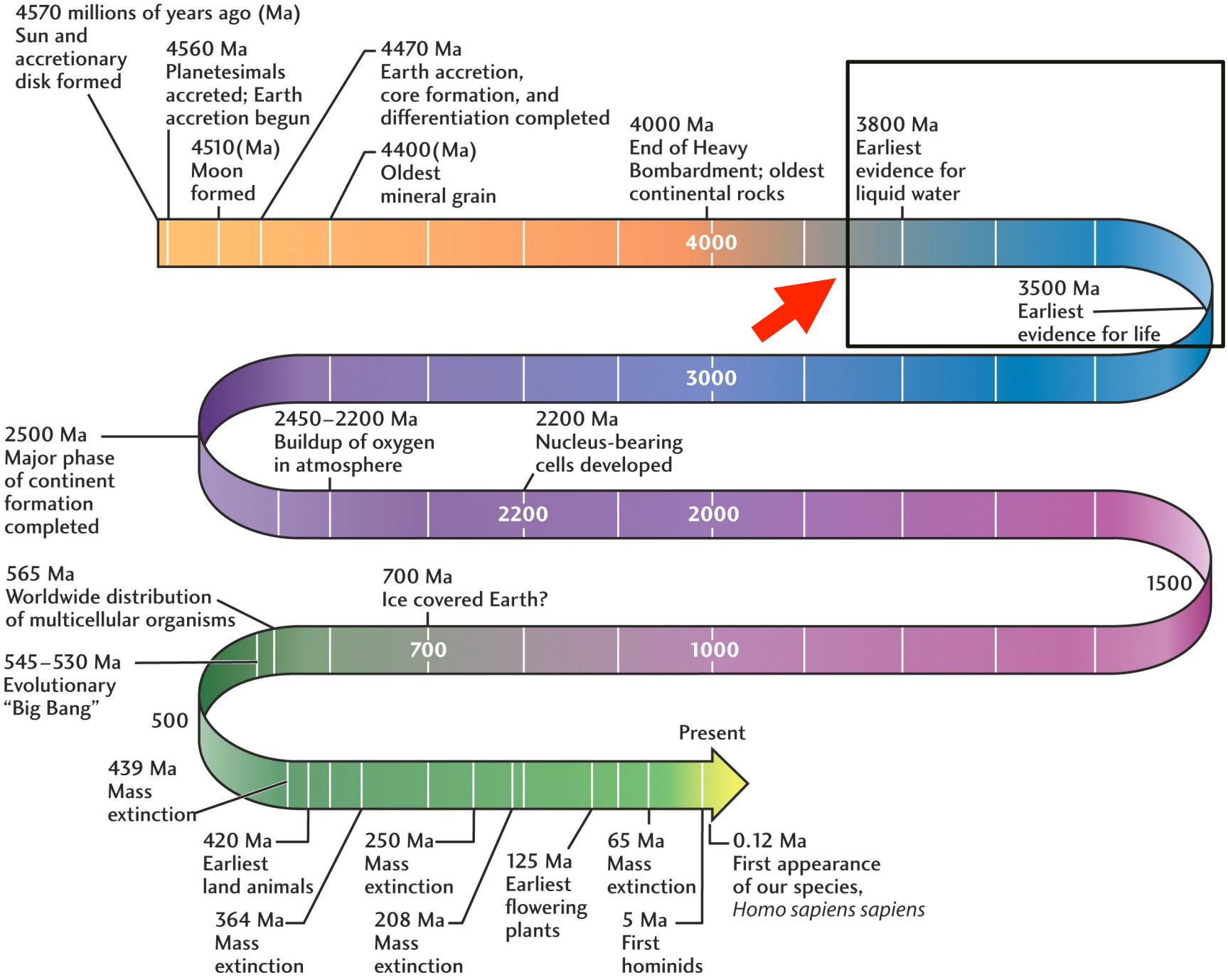


Origin of the earth by accretion of planet-forming materials.

Earth's Magnetic Field

This global chemical differential was completed by about 4.3 billion years ago, and the Earth had developed a inner and outer core, a mantle and crust

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Oldest mineral grain
4000 Ma
End of Heavy Bombardment; oldest continental rocks
3800 Ma
Earliest evidence for liquid water
4000
3500 Ma
Earliest evidence for life
3000
2500 Ma
Major phase of continent formation completed
2450–2200 Ma
Buildup of oxygen in atmosphere
2200 Ma
Nucleus-bearing cells developed
2200
2000
1500
565 Ma
Worldwide distribution of multicellular organisms
700 Ma
Ice covered Earth?
700
1000
545–530 Ma
Evolutionary "Big Bang"
500
Present
439 Ma
Mass extinction
420 Ma
Earliest land animals
364 Ma
Mass extinction
250 Ma
Mass extinction
208 Ma
Mass extinction
125 Ma
Earliest flowering plants
65 Ma
Mass extinction
5 Ma
First hominids
0.12 Ma
First appearance of our species, Homo sapiens sapiens

The Evolving Atmosphere

Right after its creation, the Earth is thought to have had a thin atmosphere composed primarily of helium (He) and hydrogen (H) gases

The Earths gravity could not hold these light gases and they easily escaped into outer space

Today, H and He are very rare in our atmosphere

For the next several hundred million years, volcanic out-gassing began to create a thicker atmosphere composed of a wide variety of gases

The gases that were released were probably similar to those created by modern volcanic eruptions

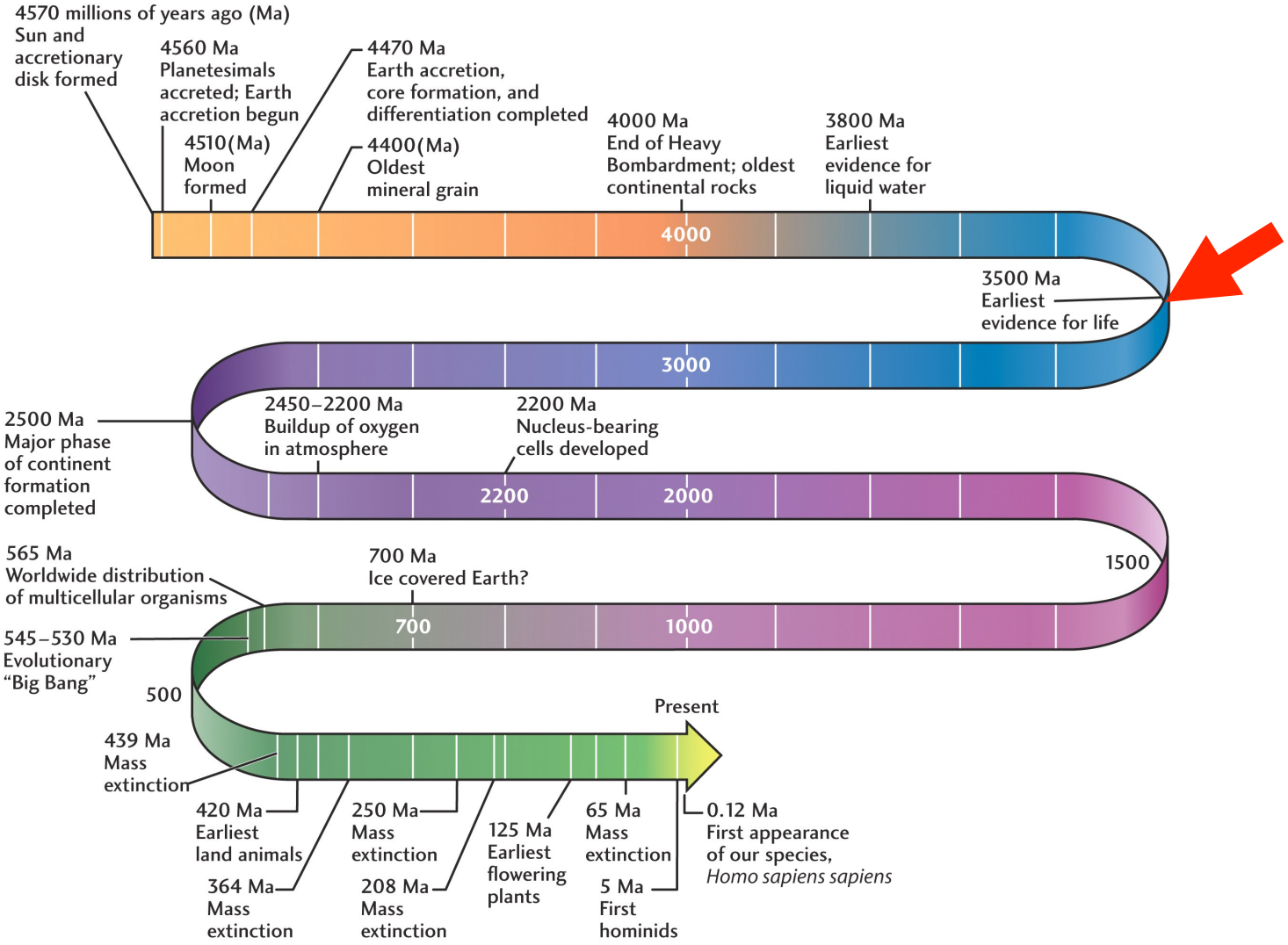
Creating the Oceans

It is hypothesized that water vapor escaping from the interior of the Earth via countless volcanic eruptions created the oceans (this took hundreds of millions of years)

By 3.5 billion years ago, when the Earth was a billion years old, it had a thick atmosphere composed of CO_2, methane, water vapor and other volcanic gases

O_2 is still Missing!

Remember, today our atmosphere contains 21% oxygen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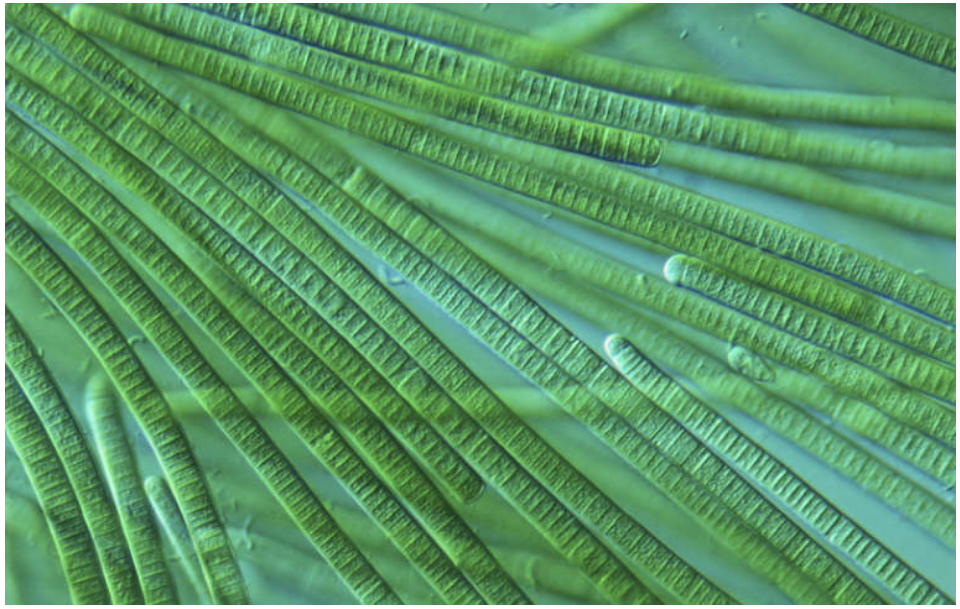
Cyanobacteria, commonly called blue-green algae, is a phylum of bacteria that obtain their energy through photosynthesis



This was the first life on Earth

Evidence of Early Life

These 3.5 billion year old fossilized algae mats, which are called stromatolites, are considered to be the earliest known life on earth

They are found in Western Australia

A billion Year Old Earth

These stromatolite fossils, found in Glacier National Park, half a planet away from Australia, also may be 3.5 billion years old

Stromatolites are formed in shallow seas or lagoons when millions of cyanobacteria (a primitive type of bacteria) live together in a colony

Banded Iron Formations (world will not exist without Fe)

How do we know that there was no oxygen in the early Earth atmosphere?

Oxygen oxides native iron and created minerals such as hematite (iron oxide which is F_2O_3)

Simply put, water and oxygen creates rusts out of iron

Banded Iron Formations

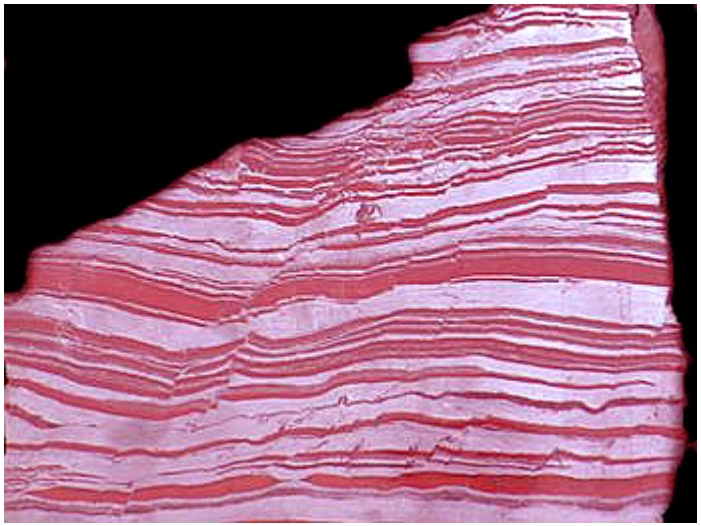
The structures consist of repeated thin layers of iron oxides, either magnetite or hematite, alternating with bands of iron-poor shale and chert

Banded Iron Formations

BIFs are primarily found in very old sedimentary rocks, ranging from over 3 to 1.8 billion years in age

Banded Iron Formations

It is hypothesized that the banded iron layers were formed in sea water as the result of free oxygen released by photosynthetic cyanobacteria combining with dissolved iron in the oceans to form insoluble iron oxides, which precipitated out, forming a thin layer on the seafloor



All about Earth's History. What about future

Oxygen Evolution in the Atmosphere

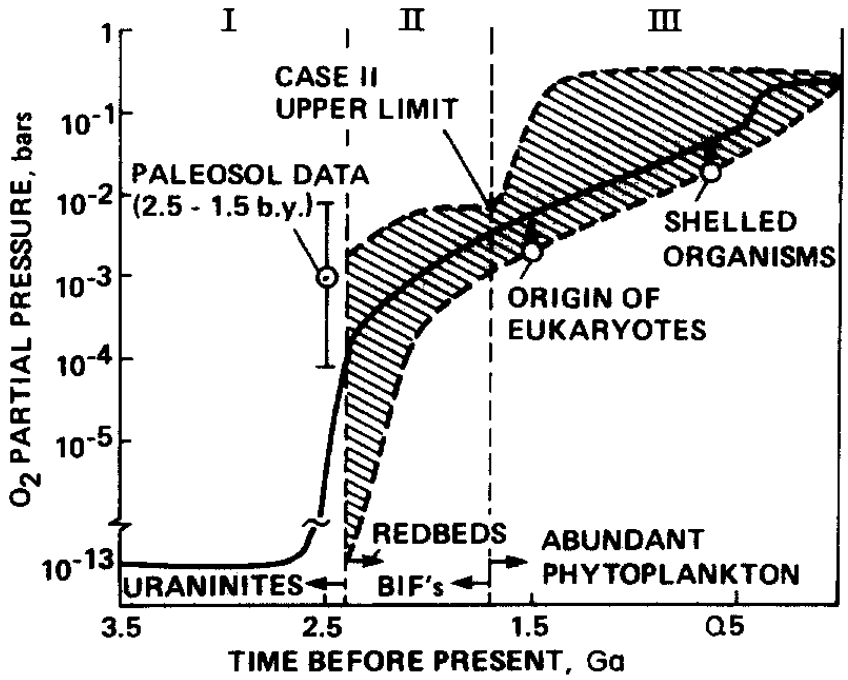
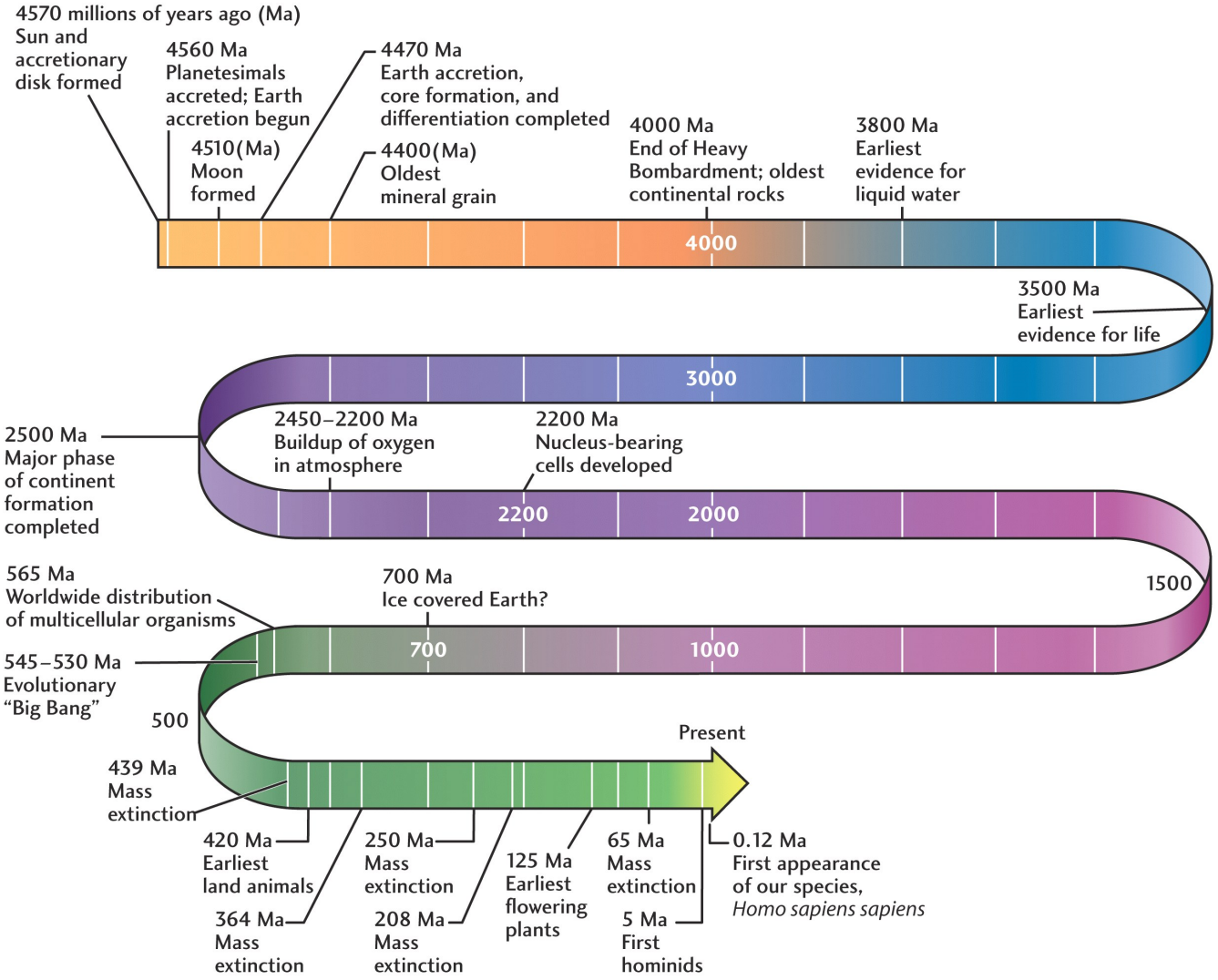


Fig. 7. Estimated change in pO_2 over geologic time. Again, the solid curve is a best guess, and the shaded area represents the range of uncertainty. The point labelled 'paleosol data' is derived from the results of Holland and Zbinden (1986), assuming that pCO_2 = 0.05 bar.

Kasting 1987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