Introducere in astrofizica nucleara

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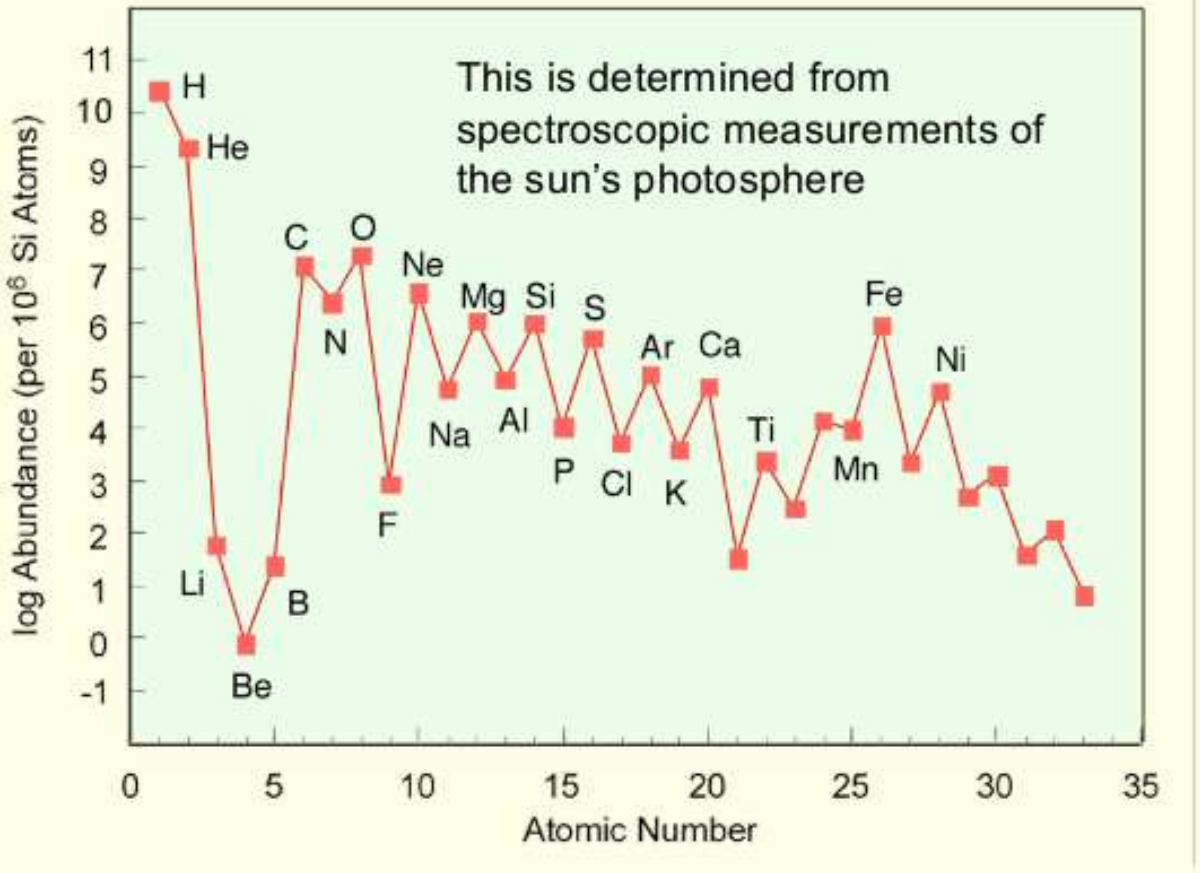
Ce vedem?

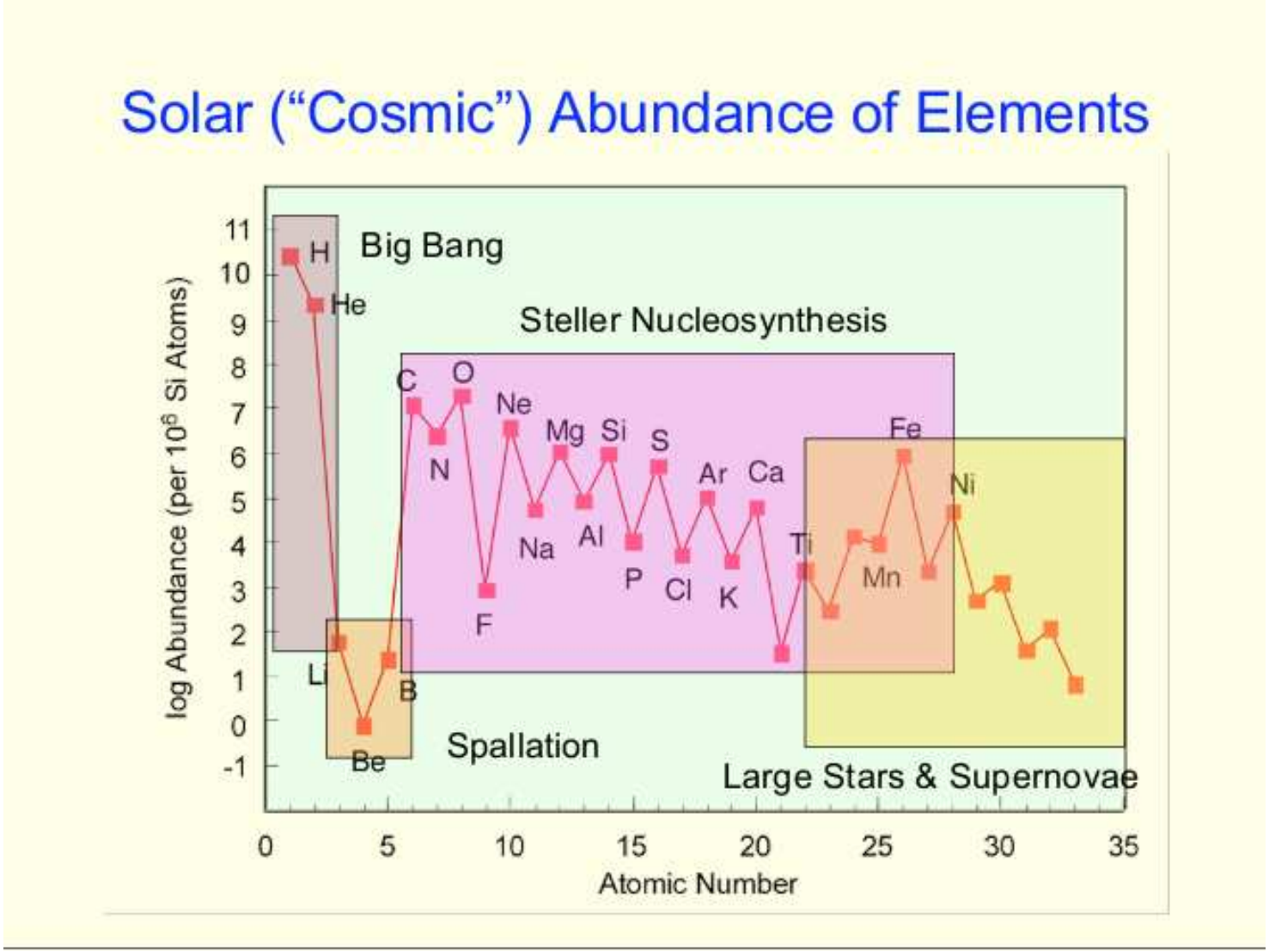
- Compozitia Universului:
  Materie barionica $\lesssim 5\%$
  Materie neagra $\sim 25\%$
  Energie neagra $\sim 70\%$

- Din ce este formata materia barionica?
  H $\sim 74\%$ + He $\sim 25\%$ + elemente grele

Ce vedem?



Ce vedem?



Ce vedem?

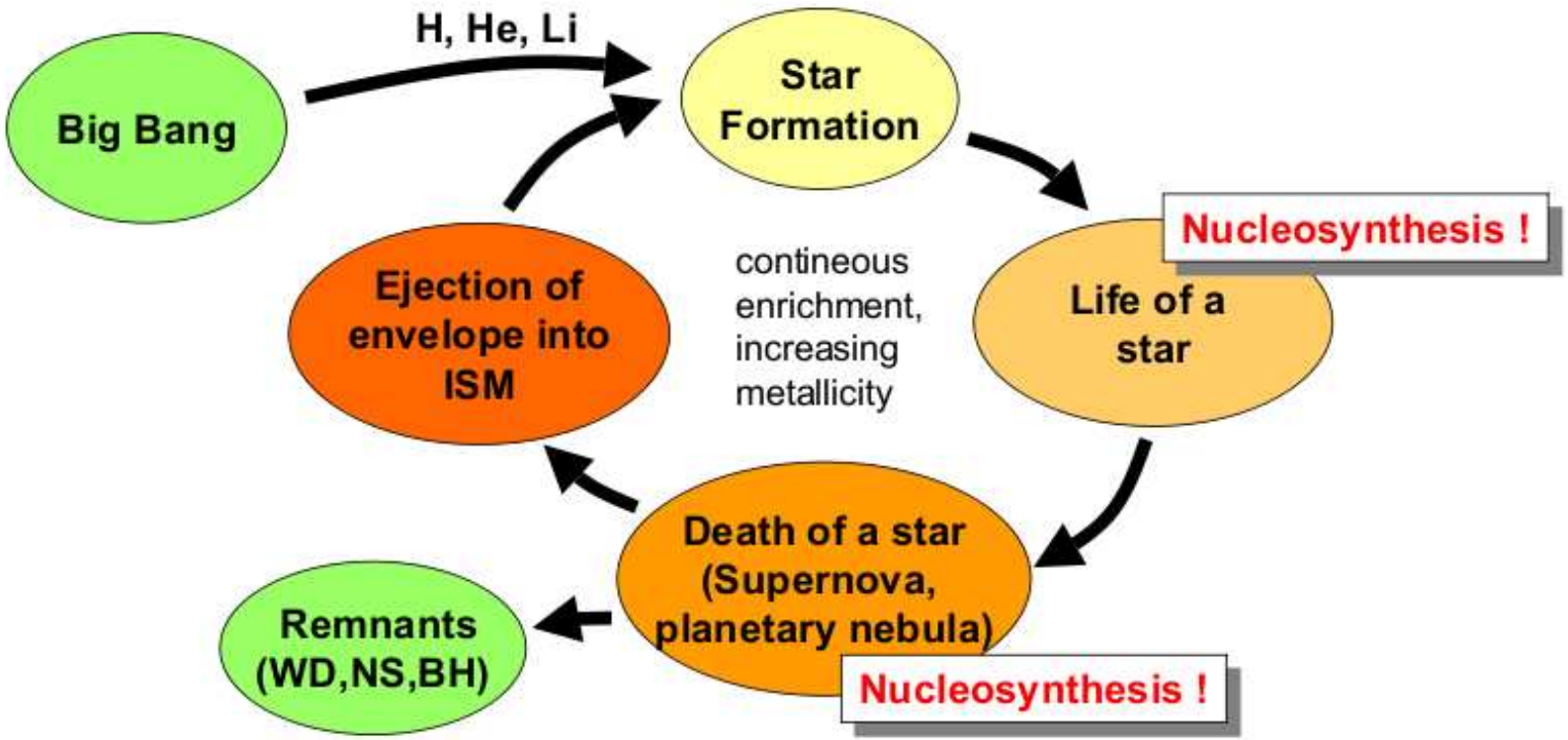
Fuziunea nucleara intre doua elemente usoare (in conditii de presiune si temperatura ridicate) $\rightarrow \Delta m = \Delta E / c^2$.

Nucleosinteza:

- Big Bang (Universul timpuriu, $\sim$ 1 s)
- in interiorul stelelor (Universul tarziu, $>$ 387000 yr)
- in explozii de supernove (Universul tarziu, $>$ 387000 yr)

Ce vedem?

Metal = orice element mai greu decat H, He si Li



BH: Black Hole
NS: Neutron Star
WD: White Dwarf Star
ISM Interstellar Medium

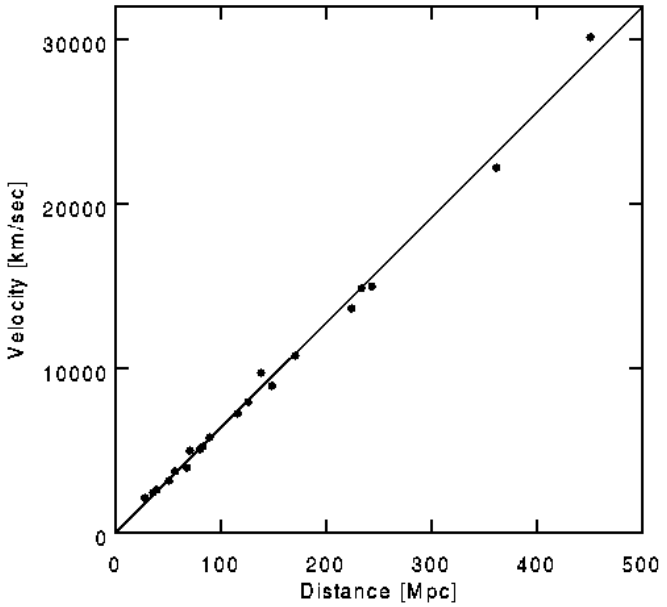
BIG BANG

Teoria Big Bang

- 1915: Einstein, Teoria generala a relativitatii: constanta pentru un Univers static
- 1922/1927: Friedmann + Lemaître, solutiile ecuatiilor lui Einstein indica faptul ca Universul se extinde
- 1929: Hubble, din observatii Universul se extinde

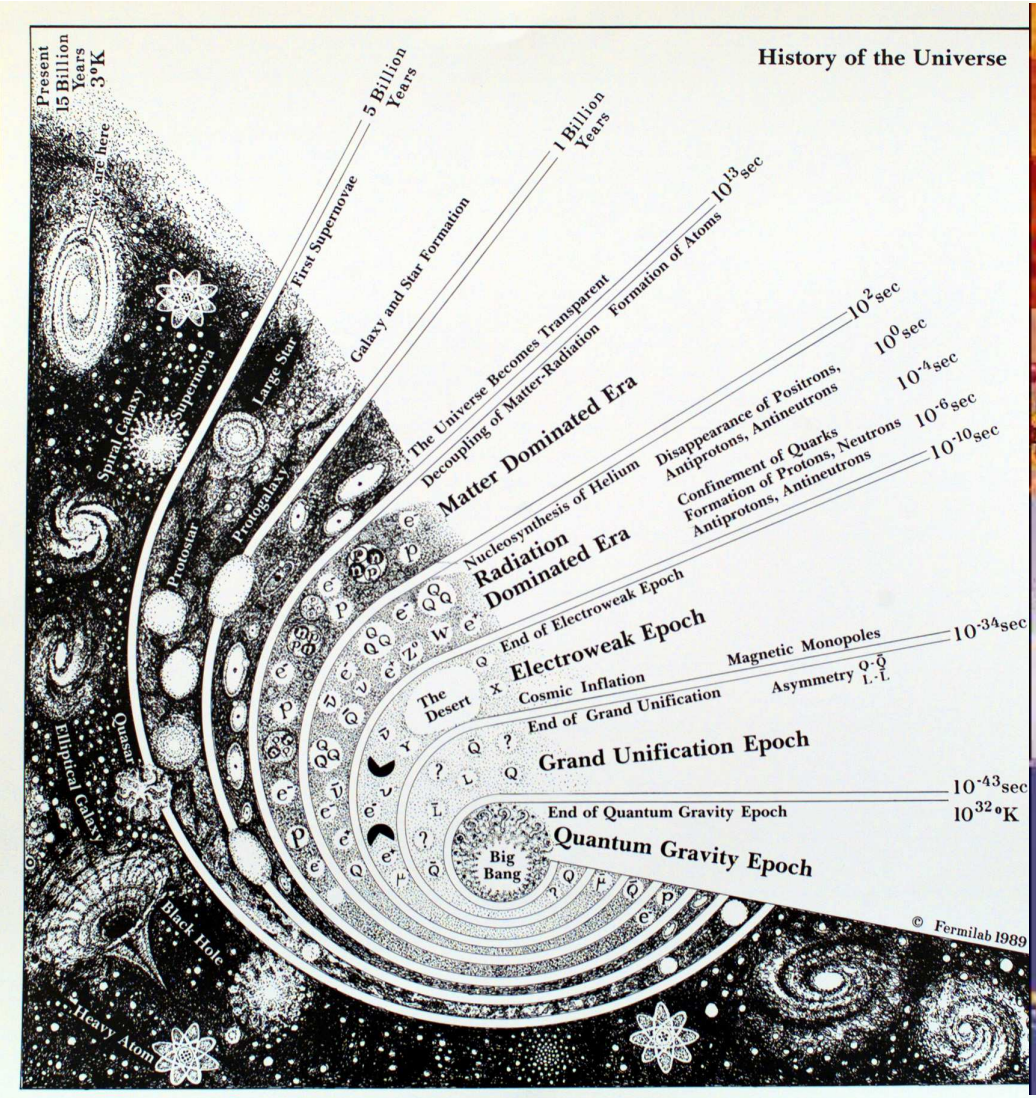
redshift: $1+z=\lambda_o/\lambda_e$
panta = 484 km/s/Mpc = H_0
legea Hubble: $v=H_0 D$
varsta Universului: $t_0 \sim 1/H_0$

timpul Hubble: $10^{10.5}$ yr
(din obs. SN Ia)



- 1946: Gamow, Alpher si Herman, in Universul timpuriu s-au format toate elementele
- 1950s: Burbidge, Burbidge, Fowler si Hoyle: toate elementele sau format in stele si explozii de supernove. Nu produce indeajuns He
- in prezent: majoritatea He se produce in BB, insa C si restul elementelor mai grele in stele. Majoritatea Li si Be se produce prin coliziunea radiatiilor cosmice cu C produs in stele
- BB: $t \to 0 \Rightarrow T$ foarte inalte (fizica necunoscuta)
  - scara Planck: masa Planck $m_{Pl} = \sqrt{\frac{\hbar c}{G}} \approx 10^{19}$ GeV, dimensiunea Planck $L_{Pl} = \sqrt{\frac{\hbar G}{c^3}} \approx 10^{-33}$ cm si timpul Planck $t_{Pl} = \sqrt{\frac{\hbar G}{c^5}} \approx 10^{-43}$ s

Teoria Big Bang



Nucleosinteza Big Bang

- $t \lesssim 1$ s dupa BB, raportul neutron:proton este mentinut in echilibru termic

  $p + e^- \longleftrightarrow n + \nu$

  $n + e^+ \longleftrightarrow p + \bar{\nu}$

  iar dupa 1 s neutron:proton ratio = 1:6

- dezintegrarea neutronului

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

- formarea deuteronului (reactie exoterma, 2,2 MeV) $\rightarrow T \sim 10^9$ K, $kT = 0,1$ MeV $\rightarrow$ 100 s $\rightarrow$ neutron:proton = 1:7

  $p + n \longleftrightarrow d + \gamma$

Nucleosinteza Big Bang

- deuteron → nuclee de ^{3}He, ^{4}He si ^{3}H

$$d + n \rightarrow H^3 + \gamma$$
$$H^3 + p \rightarrow He^4 + \gamma$$
$$d + p \rightarrow He^3 + \gamma$$
$$He^3 + n \rightarrow He^4 + \gamma$$

- formarea ^{3}He, ^{4}He si ^{3}H fara emisie de fotoni (mai rapida)

$$d + d \rightarrow He^3 + n$$
$$d + d \rightarrow H^3 + p$$
$$H^3 + d \rightarrow He^4 + n$$
$$He^3 + d \rightarrow He^4 + p$$

- $T \sim 10^8$ K → repulsia electrostatica dintre deuteroni face ca reactia sa se opreasca; ^{1}H = 75% si ^{4}He = 25% din masa barionica

$$d + d \rightarrow He^4 + \gamma$$

- o mica fractiune din He se combina si formeaza Li
^{3}H → ^{3}He (12 yr), ^{7}Be → ^{7}Li (53 days)

NUCLEOSINTEZA IN INTERIORUL STELELOR

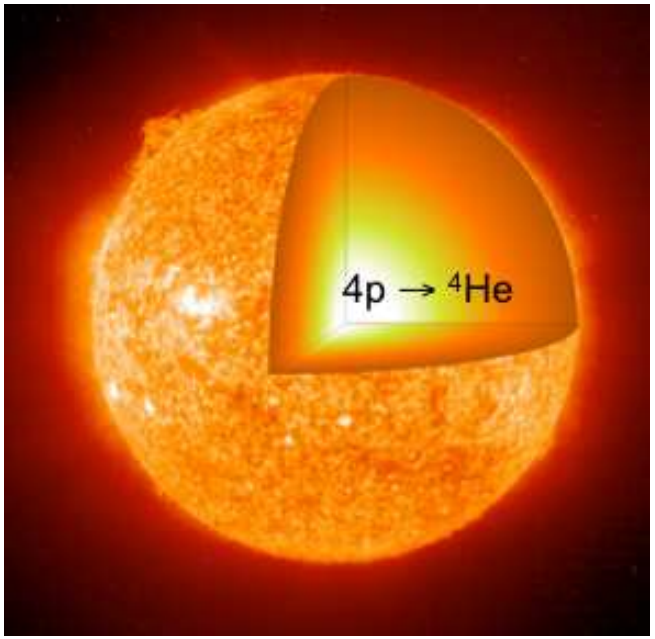
Nucleosinteza in interiorul stelelor

Lantul $p - p$: Bethe (1938)

Arderea H in stele cu $M \leqslant M_{\odot}$, $T \sim 10^6$ K, $\rho \sim 1$ g/cm^3

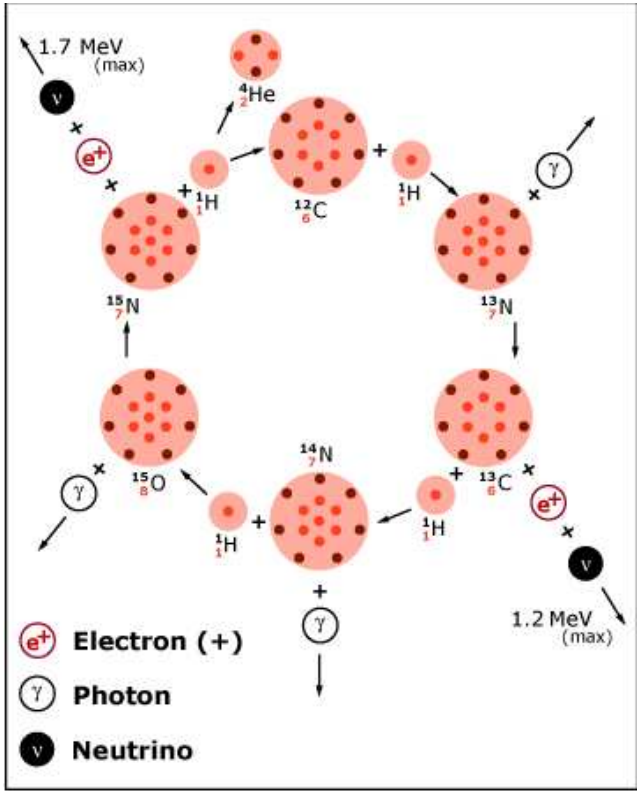
$$^1H + {}^1H \rightarrow {}^2H + \gamma$$
$$^2H + {}^1H \rightarrow {}^3He + \gamma$$
$$^3He + {}^3He \rightarrow {}^4He + 2^1H + \gamma$$

Plus urme de Li, Be si B



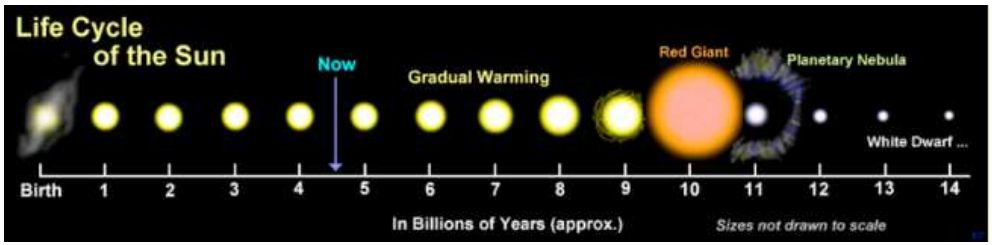
Nucleosinteza in interiorul stelelor

Ciclul CNO, Weizsäcker (1938)
Arderea H in stele cu:
$M > M_{\odot}$, $T \sim 10^7$ K
Se formeaza un nucleu de He din 4 nuclee de H



Procesul α-triplu: dupa arderea H, steaua intra in faza de gigantica rosie, $T \sim 10^8$ K, $\rho \sim 10^4$ g/cm^3 cu reactiile

$$^4He + {}^4He \rightarrow {}^8Be + \gamma$$
$$^8Be + {}^4He \rightarrow {}^{12}C + \gamma$$
$$^4He + {}^{12}C \rightarrow {}^{16}O + \gamma$$



Nucleosinteza in interiorul stelelor

s-process = slow neutron capture

In giganticele rosii, arderea O si Si produce neutroni
Densitatea fluxului de neutroni: $10^6 – 10^{11}$ cm^3
Neutronii pot fi capturati si se pot forma izotopi dincolo de 56

$$^{56}Fe + n \rightarrow {}^{57}Fe$$

$$^{57}Fe + n \rightarrow {}^{58}Fe$$

$$^{58}Fe + n \rightarrow {}^{59}Fe$$

Neutronii sunt capturati intr-un timp mult mai lung decat cel pentru dezintegrarea β
Dupa fiecare capturare de neutron, nucleu rezultat are timp pentru a se dezintegra

$$^{59}Fe \rightarrow {}^{59}Co + \gamma$$

NUCLEOSINTEZA IN EXPLOZII DE SUPERNOVE

Nucleosinteza in explozii de supernove

r-process = rapid neutron capture

Tot materialul convertit in Fe $\rightarrow$ nu se mai elibereaza energie !

Colaps gravitational $\rightarrow$ explozie de supernova

Formarea nucleelor cu $Z > 26$ prin captare de neutroni

Densitatea fluxului de neutroni este foarte mare ($> 10^{20}$ cm^3)