The first stars

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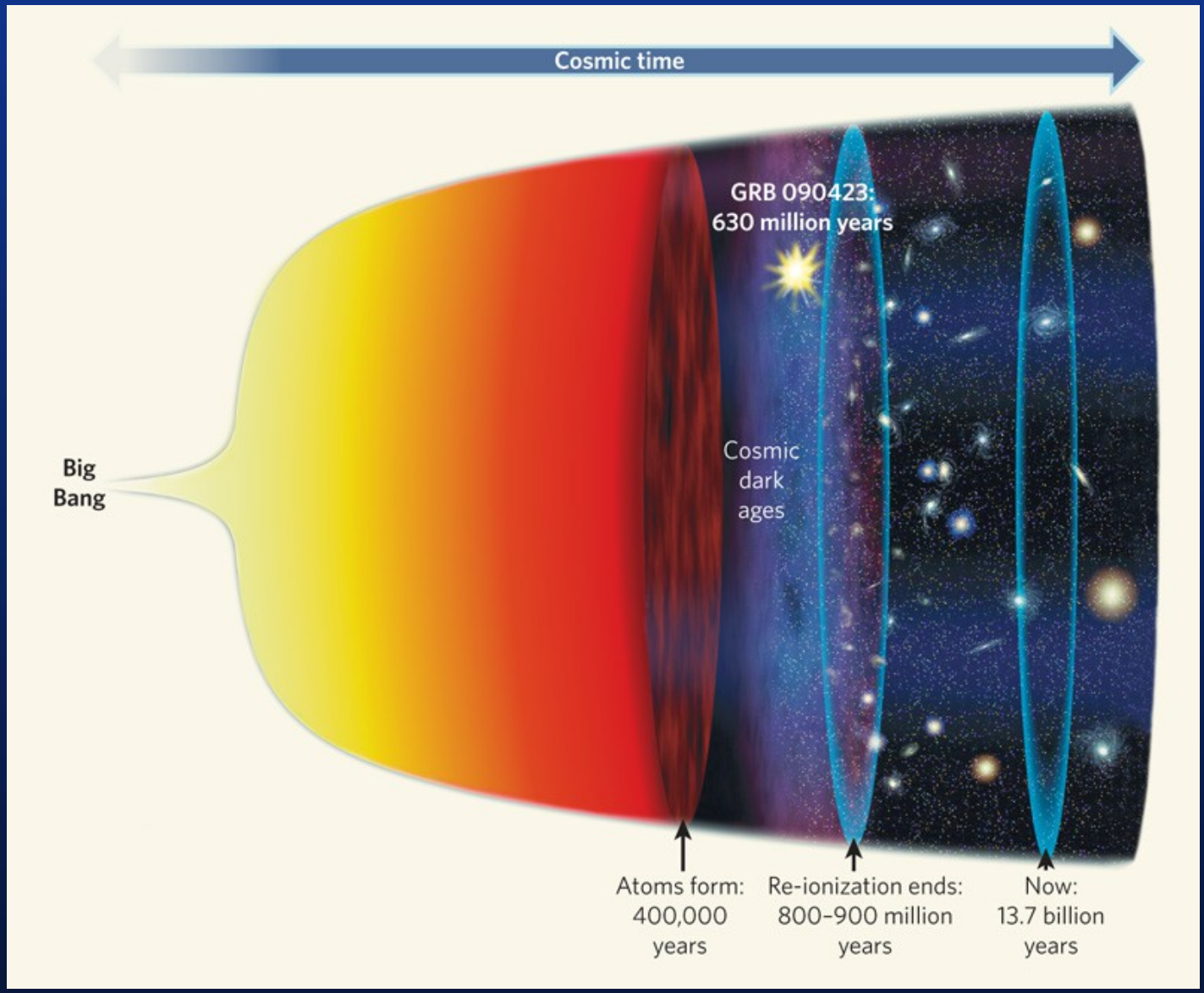
The first stars

What are the first stars ?

How could we find informations about them in the Universe ?

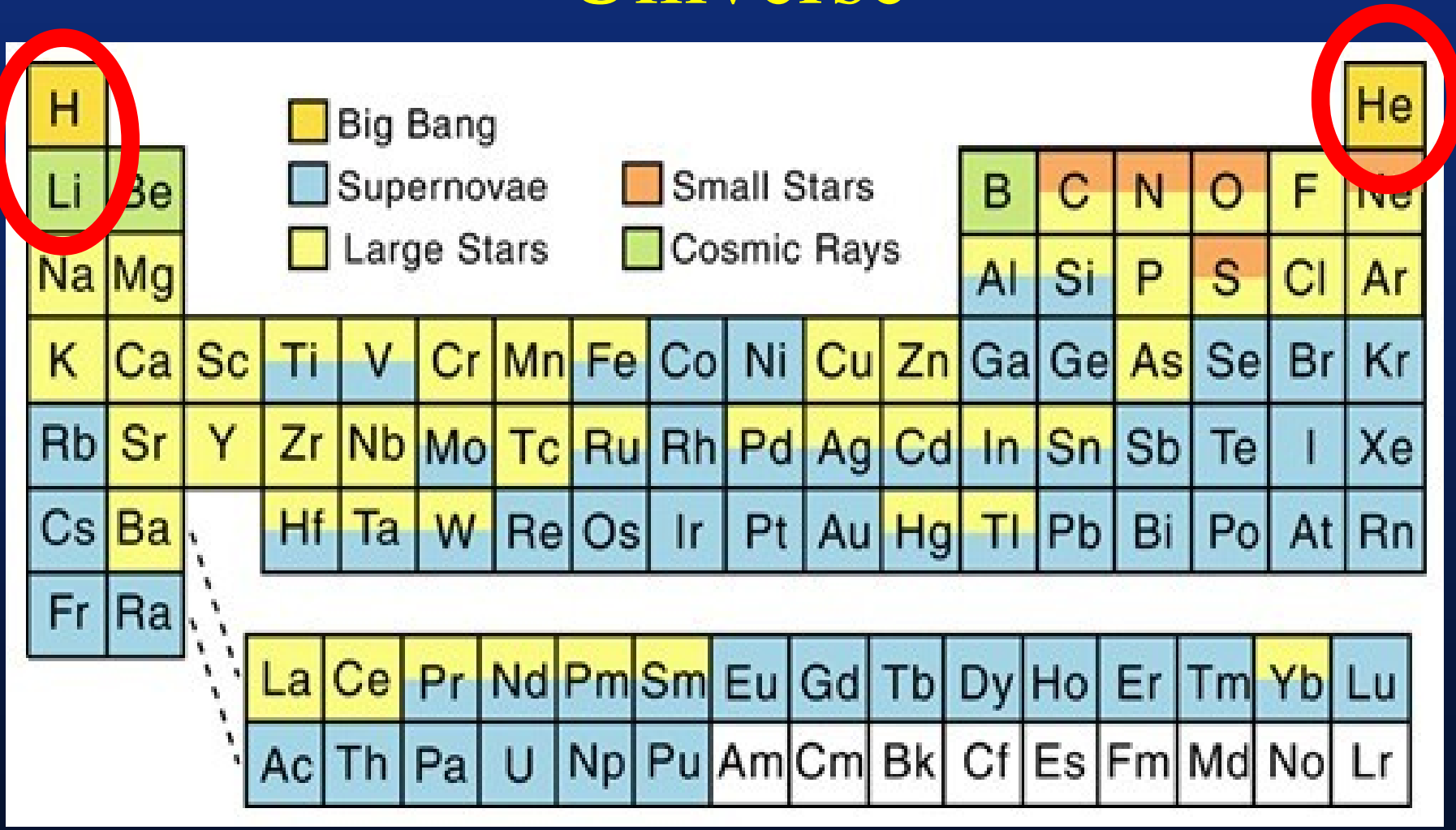
What determines the characteristics of a star ?

The Big Bang



Pristine gas from the big bang:
H, He and Li

The elements composing our Universe



Gas made of very simple element

H, He, Li

3 minutes after the Big Bang the densities and temperatures are too low to continue nuclear fusion.

After few 100000 years, the first chemical reaction starts:

$$H^- + H \rightarrow H_2 + \text{electron}$$

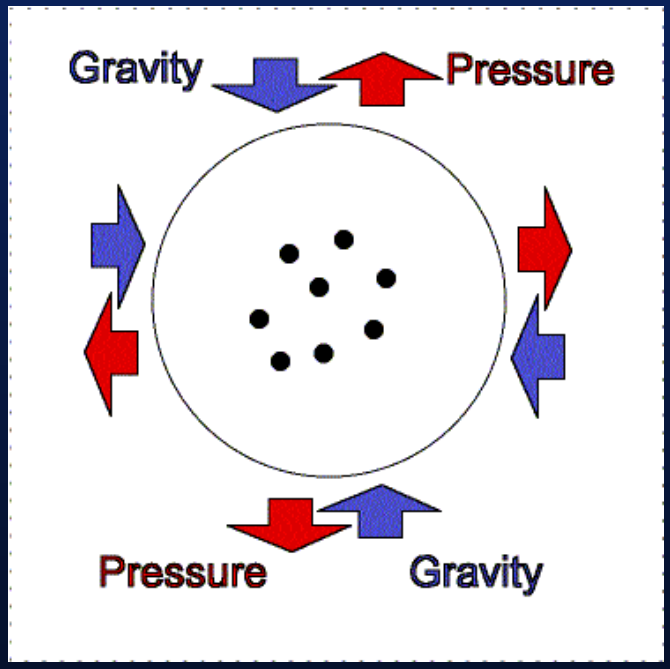
$$H_2^+ + H \rightarrow H_2 + H^+$$

and lead to the formation of the most abundant molecule of the Universe: H_2

Formation of stars

First stars: gas made of simple atoms/molecules.

Gas clouds ⟶
gravitation vs pressure
Overcome pressure to form the star



Formation of the first stars

First stars are thought to be very massives
$\longrightarrow$ 100 times our Sun
Short lifes

After 30 millions years

Life of the first stars

Massive

Short lived

Death of the first stars

How can we find the first stars ?

What we think :

Star with high masses

Short lives and explosive death.

How can we find these stars today?

Search for First stars (not possible)

Supernovae explosion-->

1) Gas with rest from the explosion

2) Next generation of stars

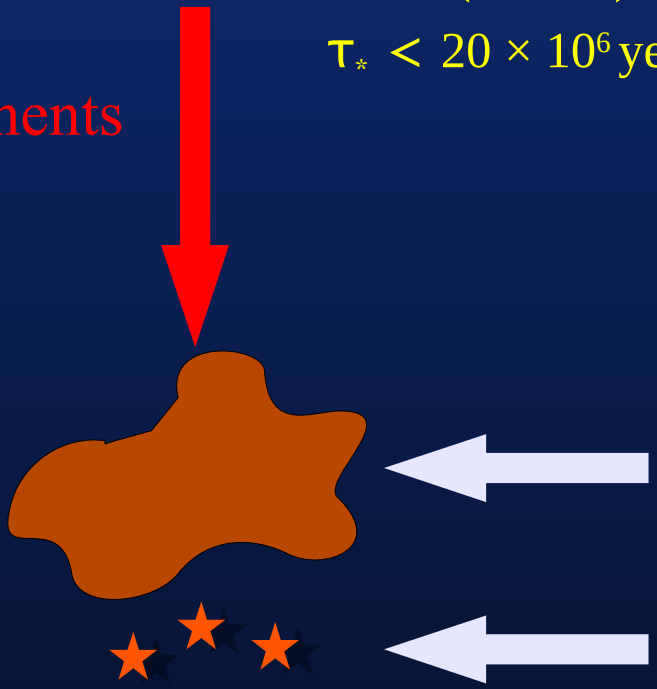
Stellar Archeology

Primordial Stars

M_* (10-300) $M_\odot$?

$\tau_* < 20 \times 10^6$ years

Enrichment in elements
O, C, Fe ..



Observations

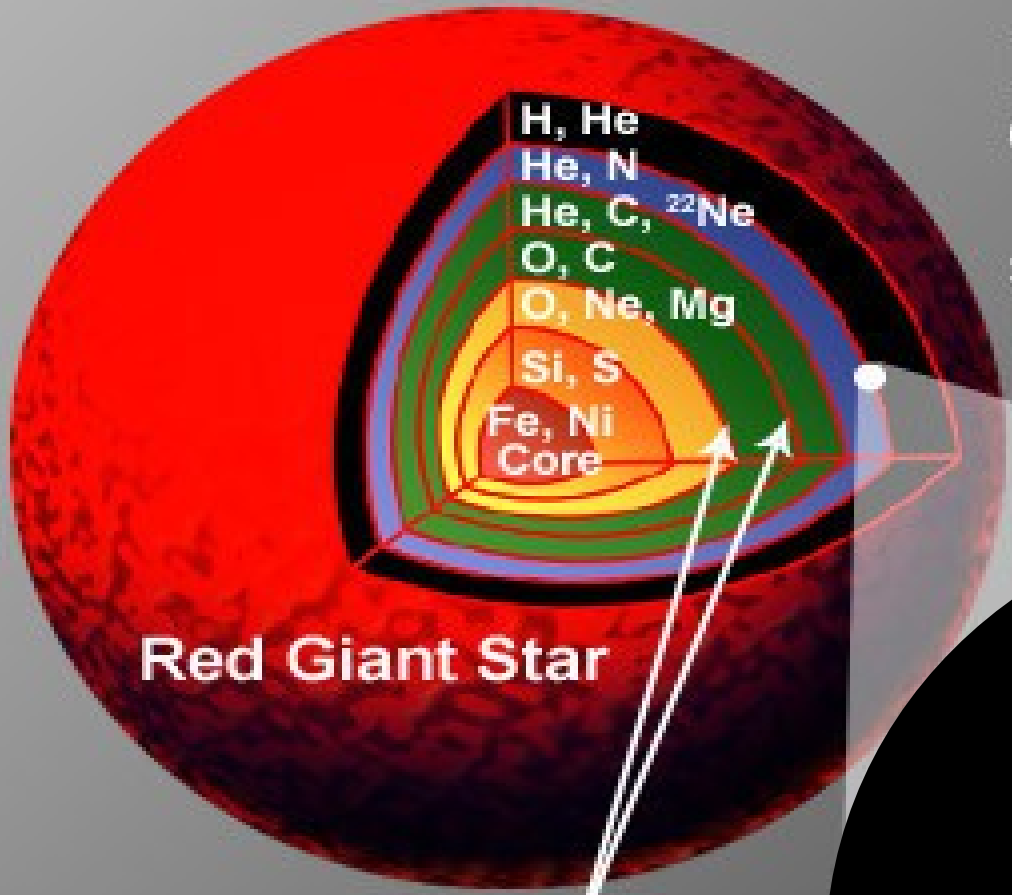
$M_* = (0.1\text{-}100)\ M_\odot$

$\tau_* < 14 \times 10^9$ years

Life of the first stars

Clouds (very simple gas) $\longrightarrow$ very massive star $\longrightarrow$ Supernovae explosion $\longrightarrow$ what has been created is ejected

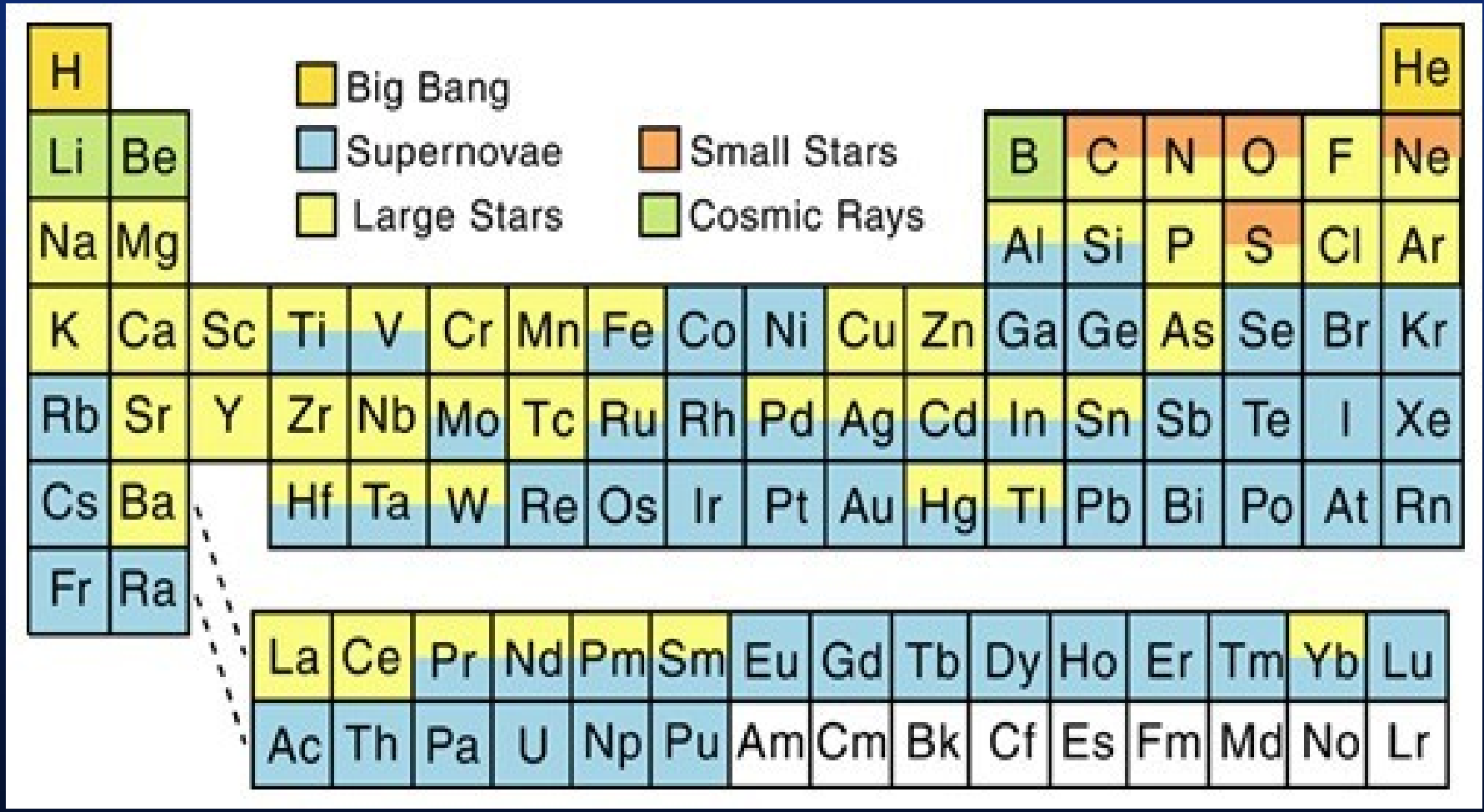
What is created?



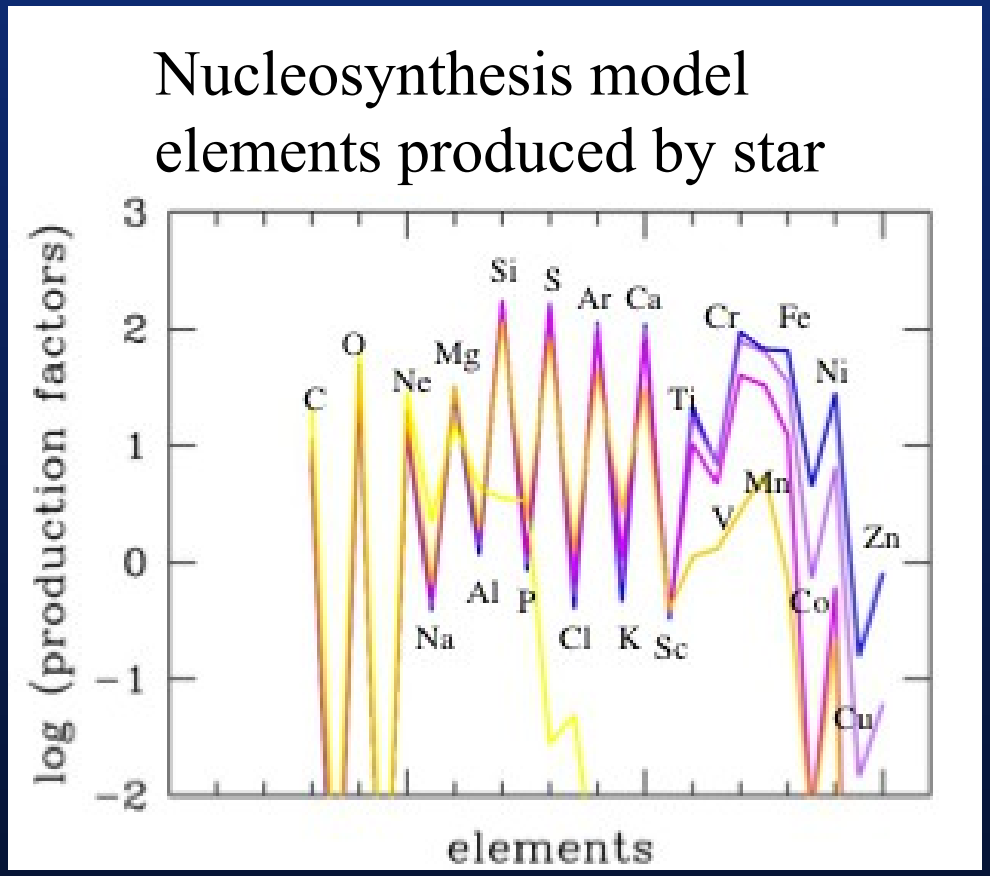
Massive star near the end of its lifetime has an "onion-like" structure just prior to exploding as a supernova

Different sets of nuclei are involved in the reactions that occur in each zone

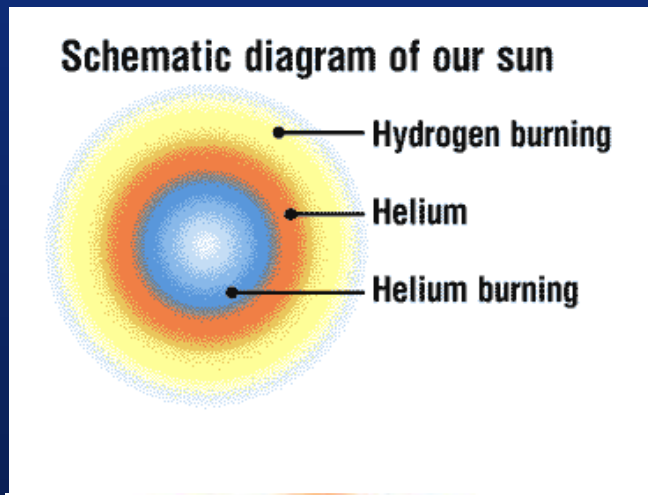
The elements composing our Universe

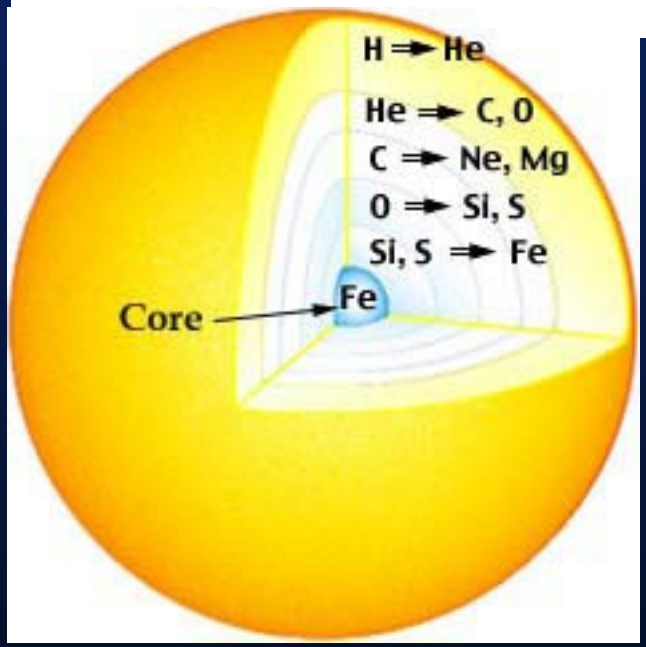


Nucleosynthesis



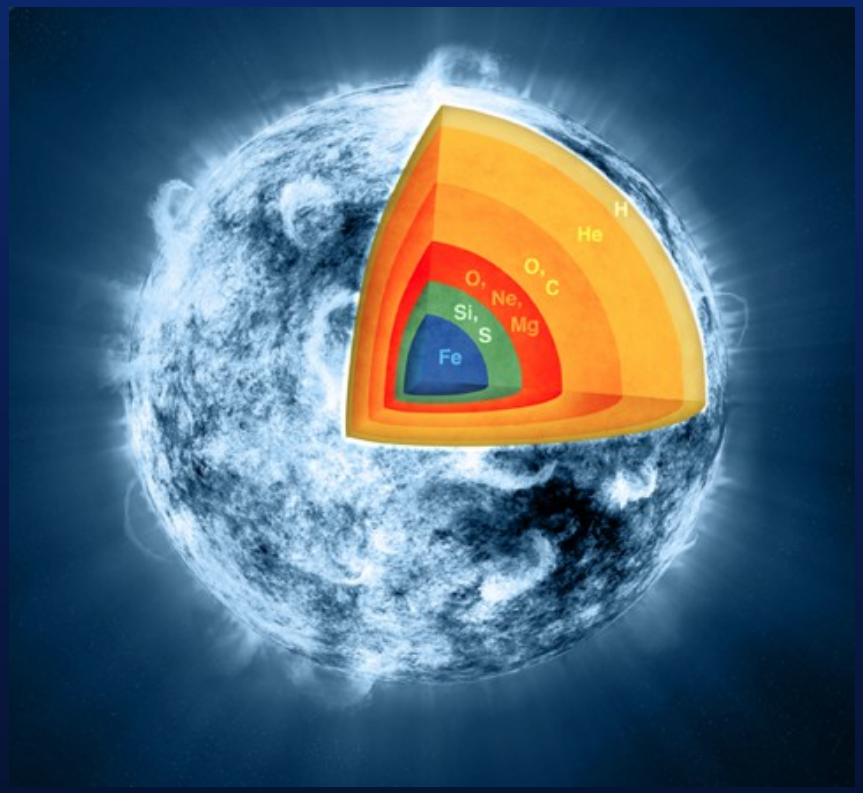
140, 170, 200, 230, 260 Msun

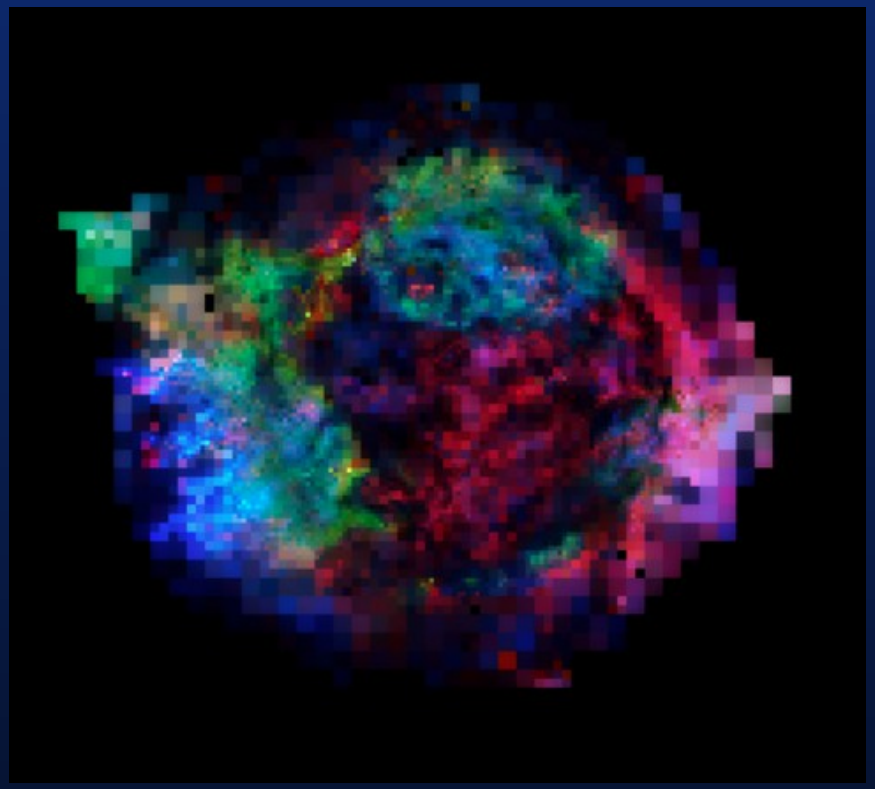




Supernovae explosion

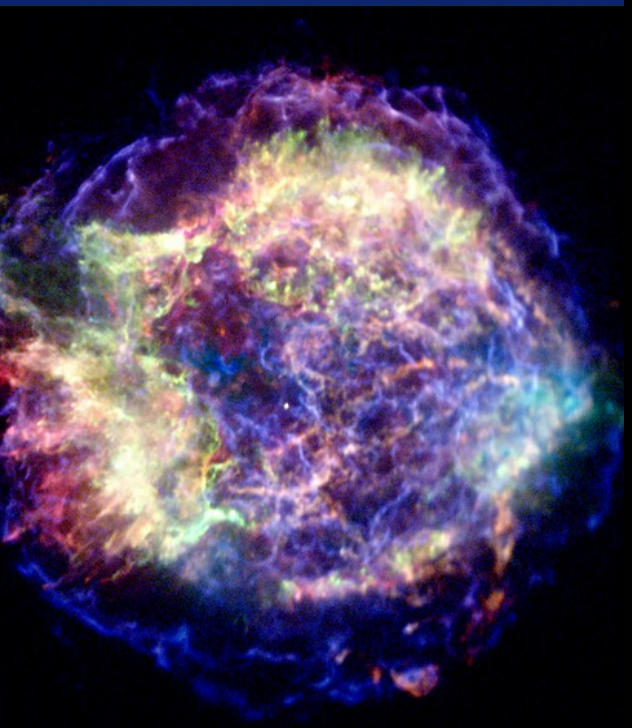
Supernova Explosion Ripped Star's Guts Inside Out

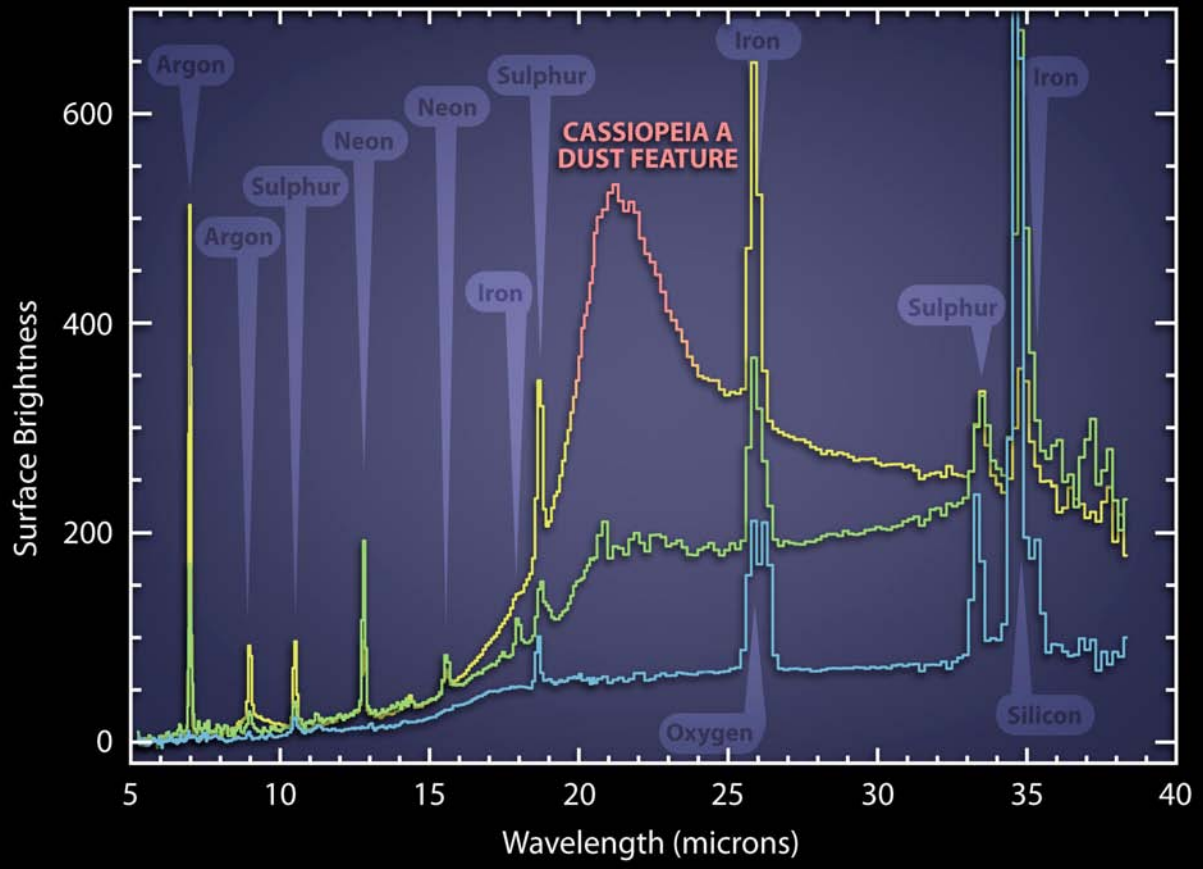




Chandra X ray Cassiopeia A

Supernova explosion





Dust In Cassiopeia A Supernova Remnant

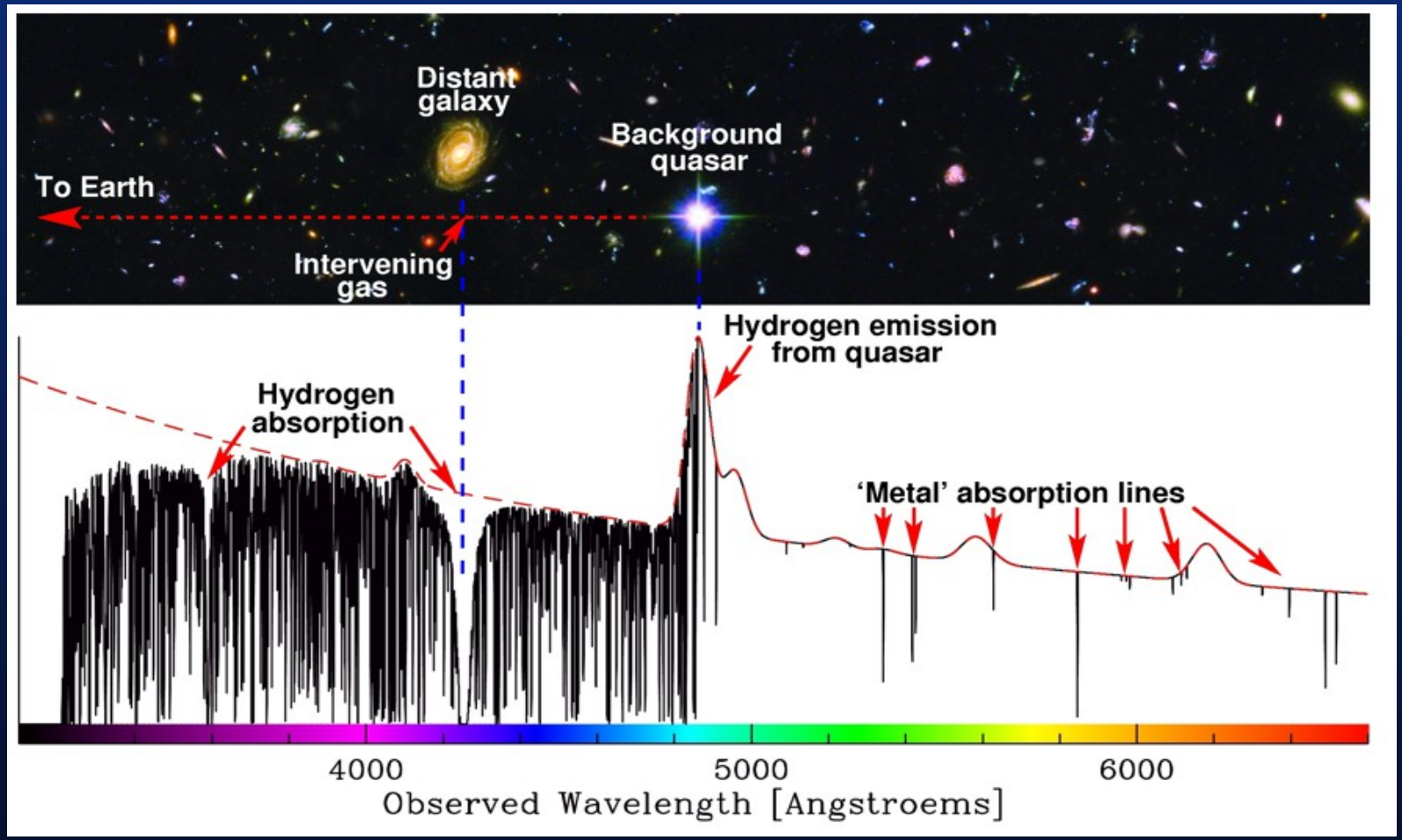
NASA / JPL-Caltech / J. Rho (SSC/Caltech)

Spitzer Space Telescope • IRS

ssc2007-20b

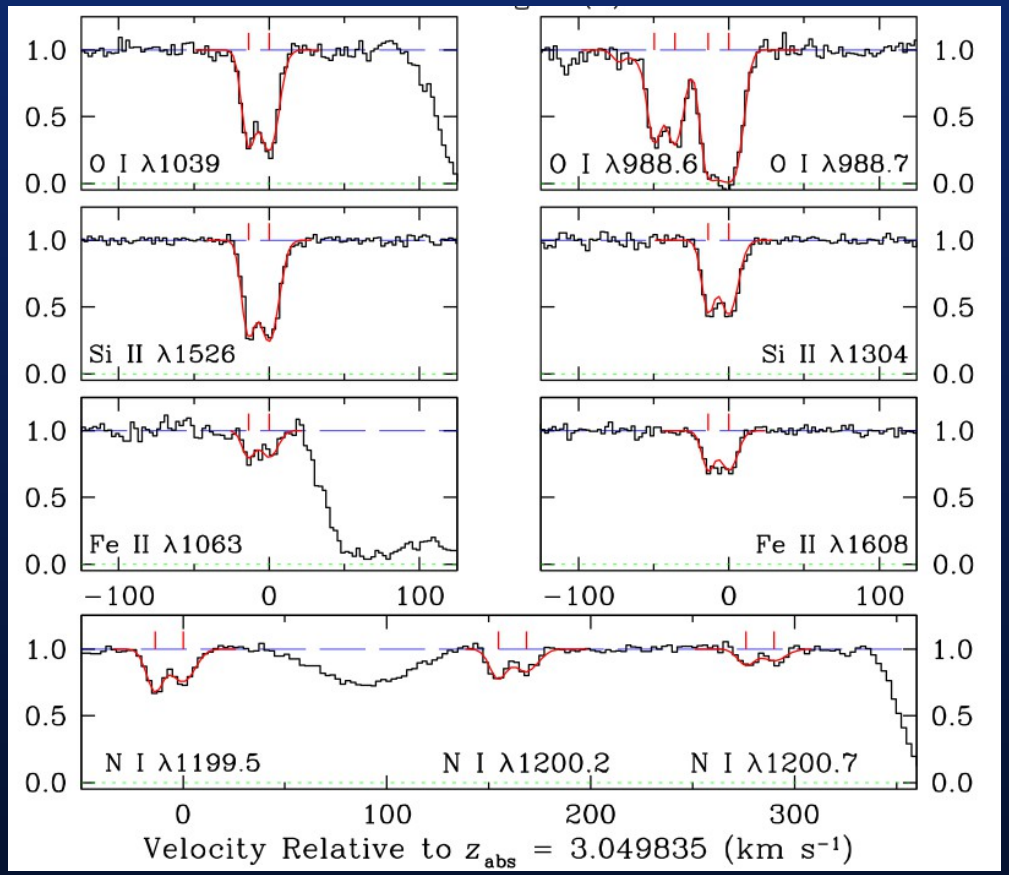
Gas from 1st SN explosion

Damped lyman alpha systems



Gas from 1st SN explosion

Observe 22 clouds with low Fe abundances



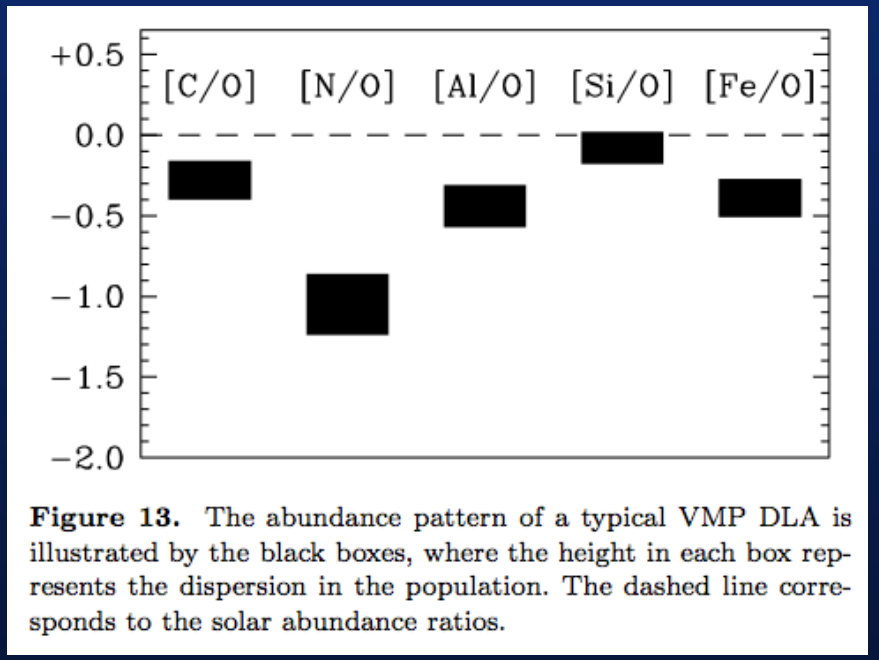
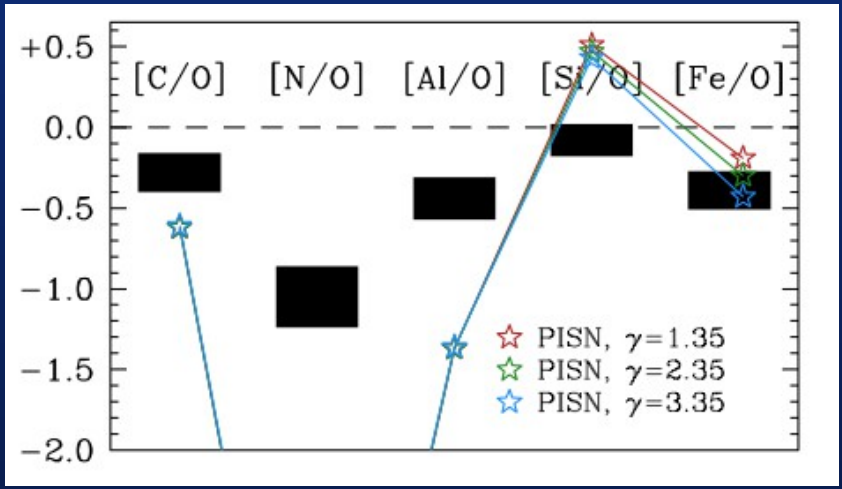


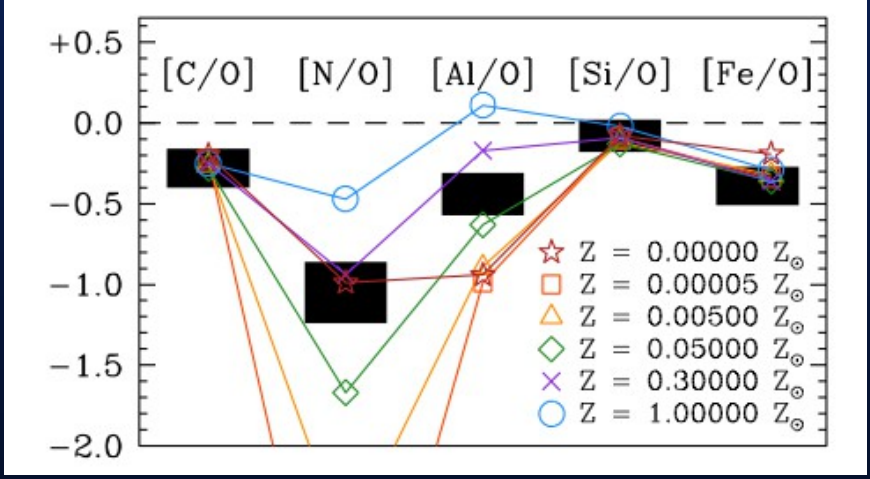
Figure 13. The abundance pattern of a typical VMP DLA is illustrated by the black boxes, where the height in each box represents the dispersion in the population. The dashed line corresponds to the solar abundance ratios.

Cooke et al. 2011

Gas from 1st SN explosion



1st SN explosion → does not reproduce obs.



Explosion from second generation of stars → Need to taken into account to reproduce obs.

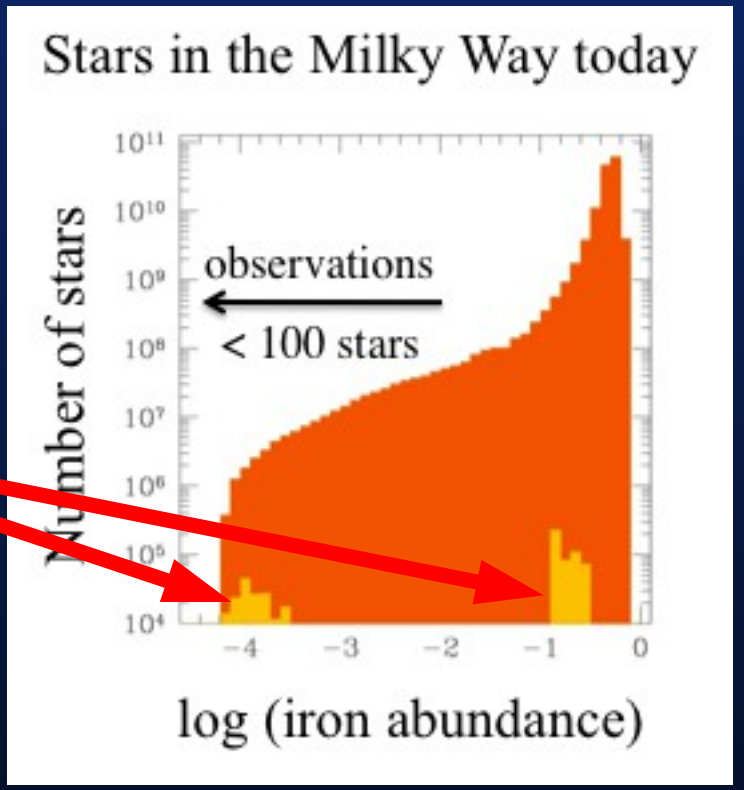
Gas from 1st SN explosion

- Gas from 1st SN explosion has not been observed
- Mixed with explosion from other stars
- No real indication on the first stars of the Universe

Next generation of stars

Nucleosynthesis models → composition of the ejectas that will form the next generation of stars.

Search in our neighborhood
--> some stars could possess the imprints of the 1st stars



Salvadori 2011

Next generation of stars

Team in Japan : observed 150 stars with low metallicity in detail

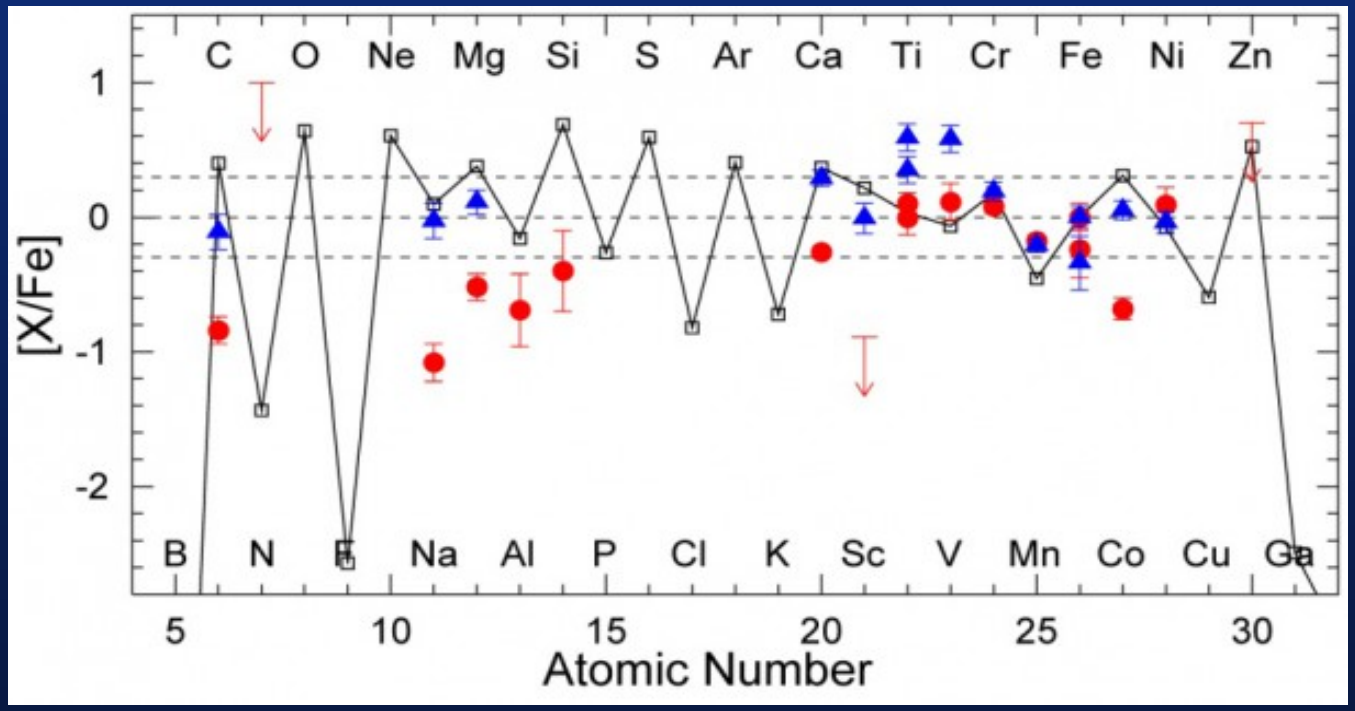
Last august : SDSS J0018-0939

1) Low carbon, magnesium, and cobalt (all considered "metals" in astronomy)

2) peculiarly high level of iron

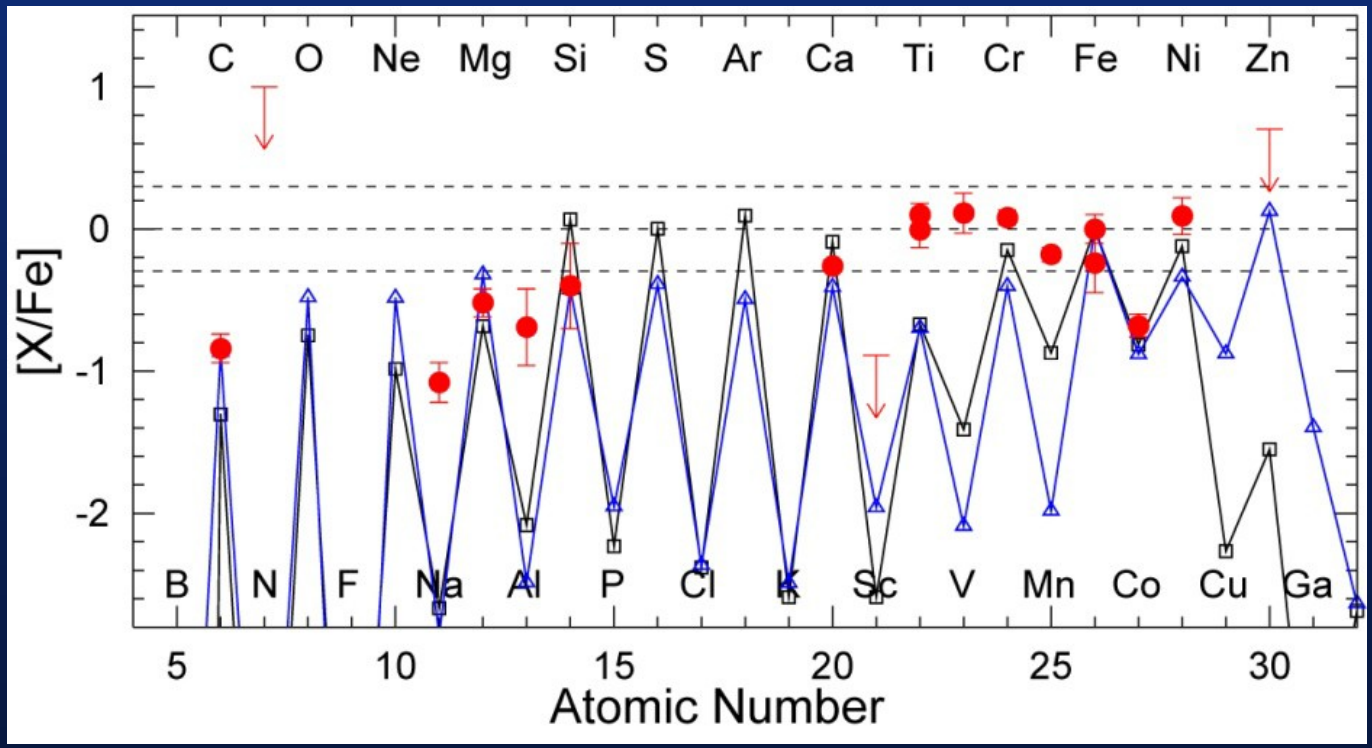
1,000 light-years, 0.5 Msun

SDSS J0018-0939



Nucleosynthesis model for star of few solar masses.
SDSS J0018-0939 (red circles)

SDSS J0018-0939



Nucleosynthesis model for 300 (blue) and 1000 (black) solar masses.
SDSS J0018-0939 (red circles)

SDSS J0018-0939

Progenitor **140** solar masses

This first detection indicates that the first stars were very massive.

The formation of stars

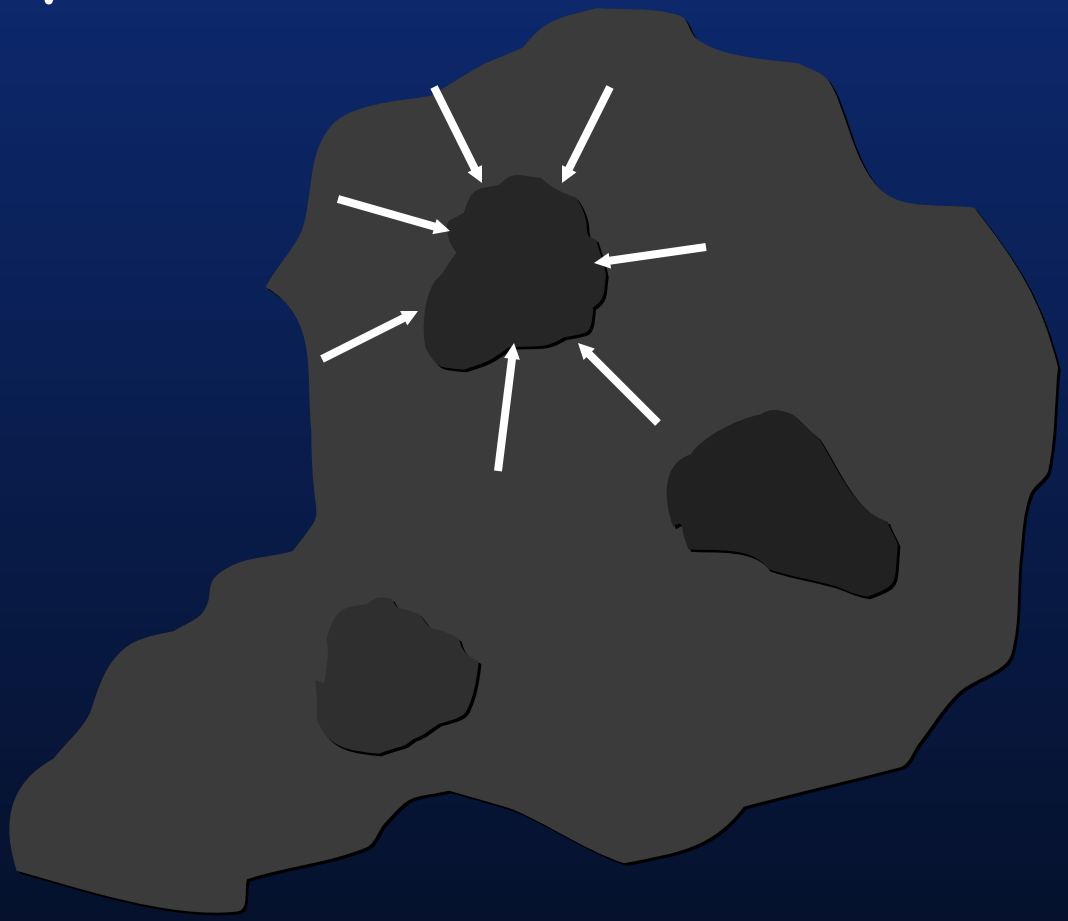
First stars very massives produce metals

Second generation (metal enriched) have lower masses

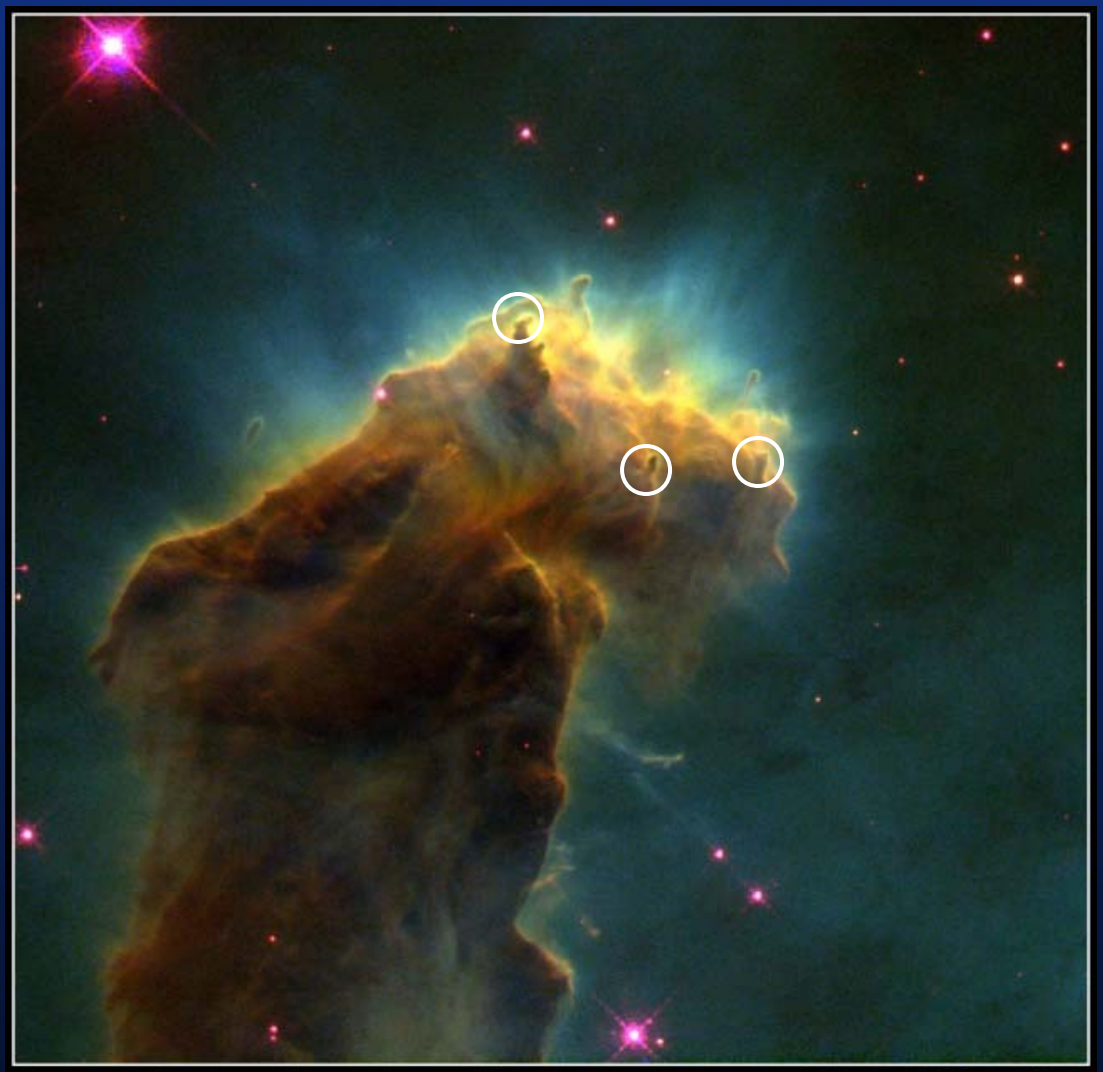
What determines the mass of the stars ?

The birth of stars

In the cloud some gas "fall" under its own gravity



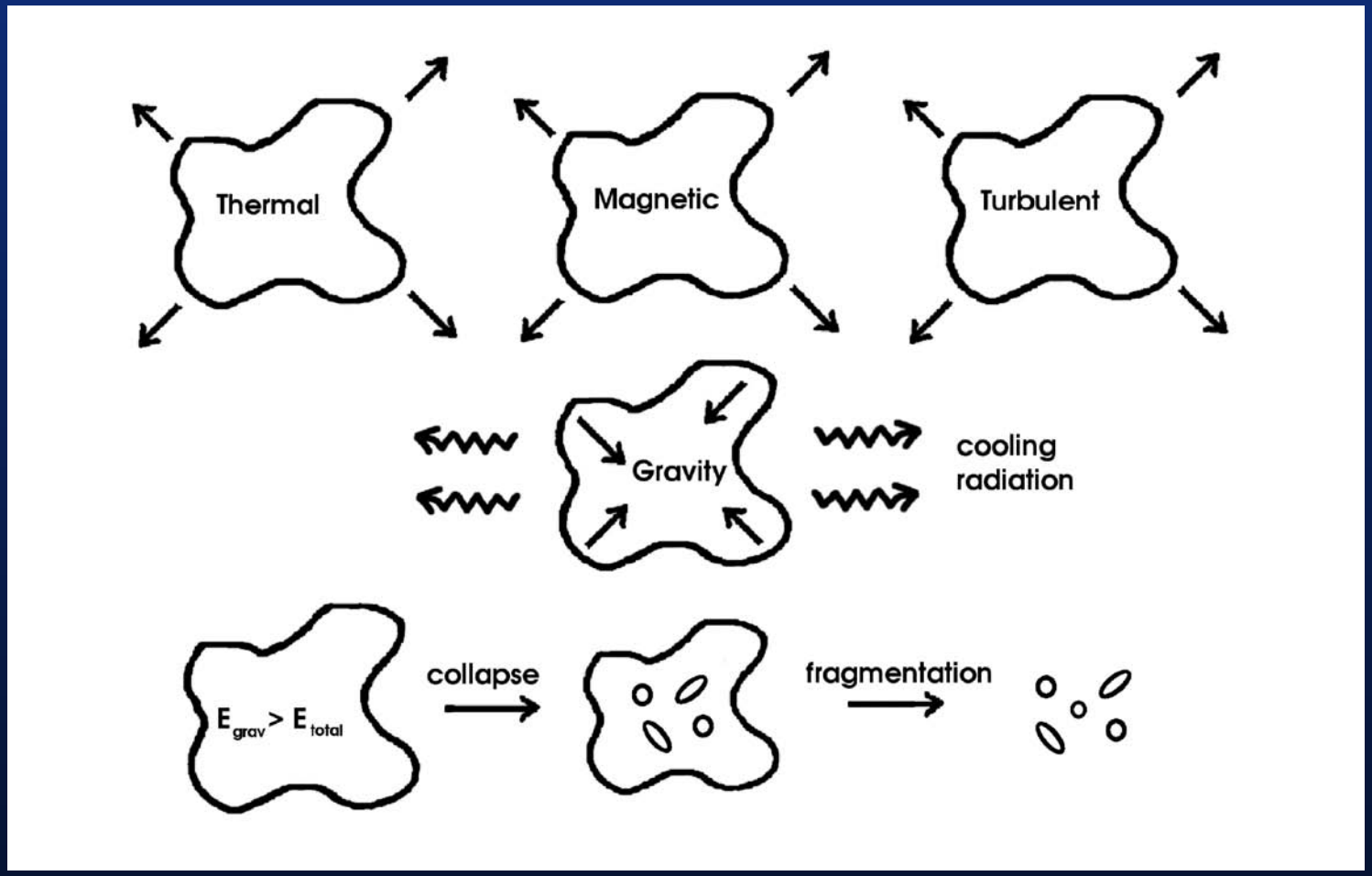
The birth of stars



Star-Birth Clouds · M16 HST · WFPC2

PRC95-44b · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

Formation of stars



Hocuk 2011

Stellar masses

Cloud radius: 5 parsec

(~ 10^{14} km ~10^{6} earth-sun)

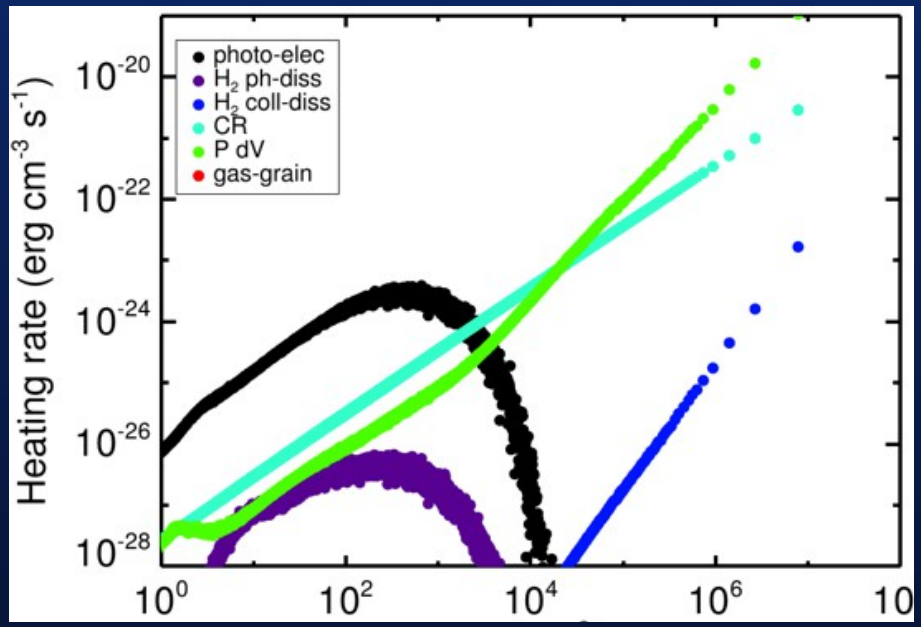
Cloud mass: 12,000 Msun

Turbulent

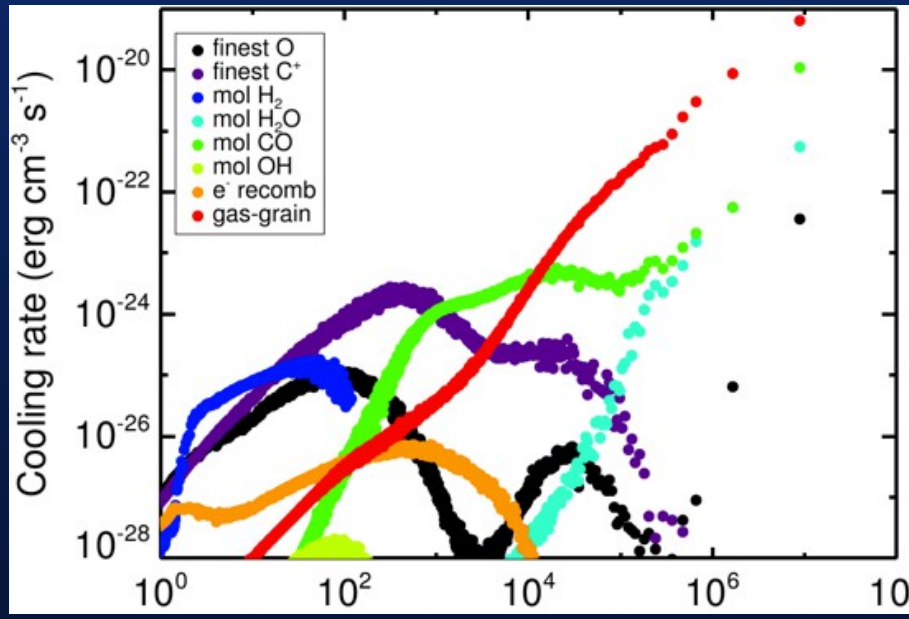
Composition: Milky Way

Why are elements so important ?

Cloud Evolution

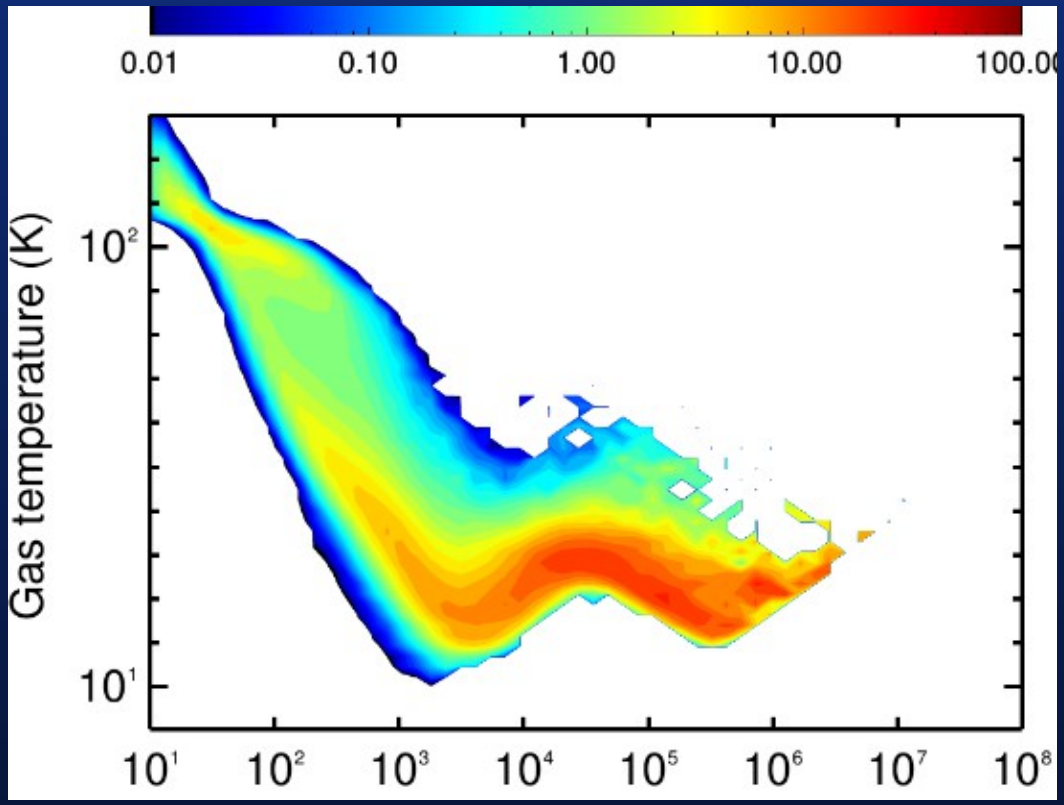


Heating



Cooling

Elements set the gas temperature



Chemical compositon of the cloud sets its temperature
$\longrightarrow$ mass and characteristics of stars

Stellar masses

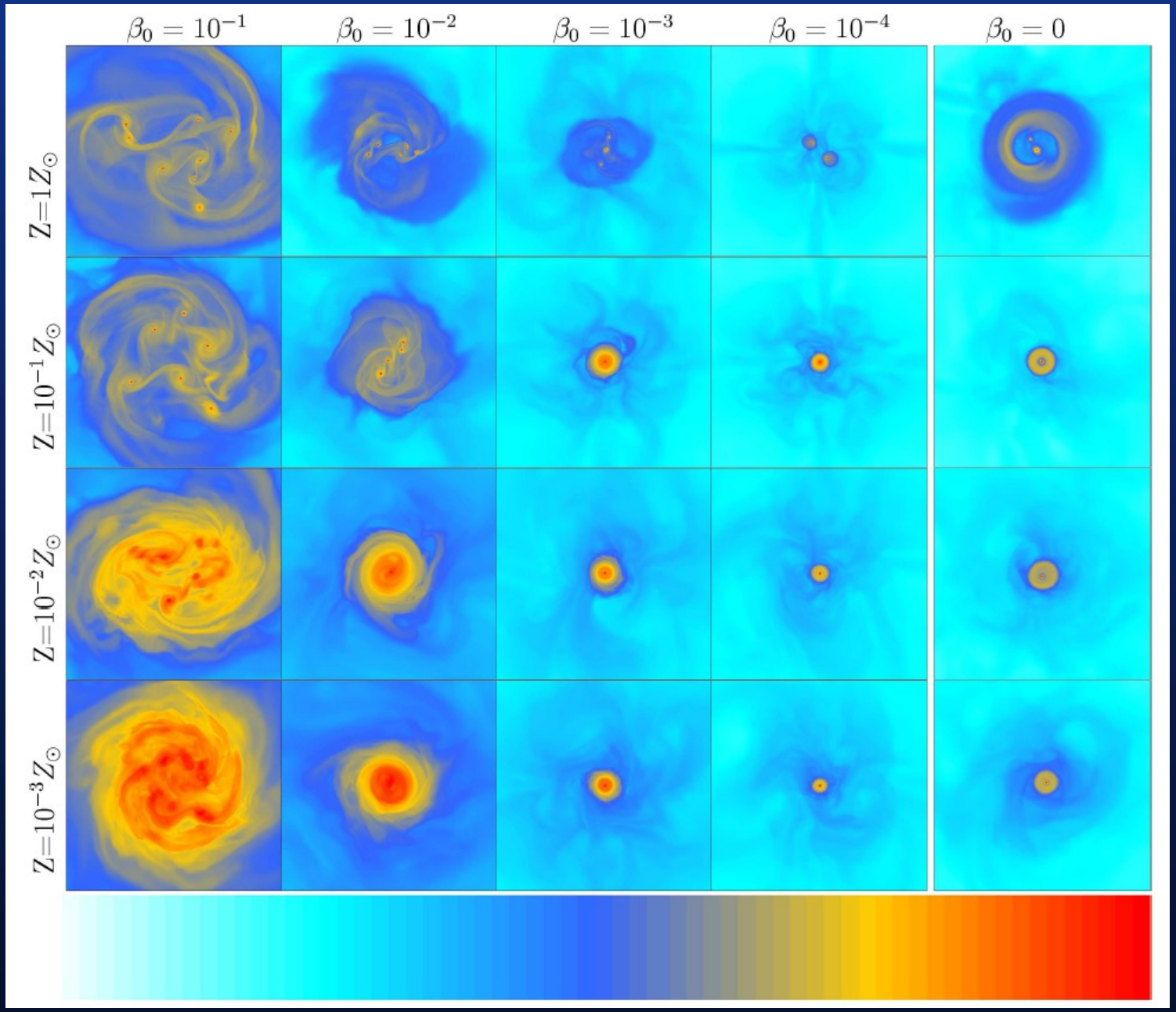
Almost no metals (elements C, O, Fe ..)

Stellar masses

Metals ~ our surrounding (elements C, O, Fe ..)

← Rotation

Metallicity →



Stellar masses

Characteristics of stars (mass, multiplicity) $\longrightarrow$ composition of the parent cloud

Simulations $\longrightarrow$ first stars are very massive

1st observations $\longrightarrow$ first stars ~100 Msun

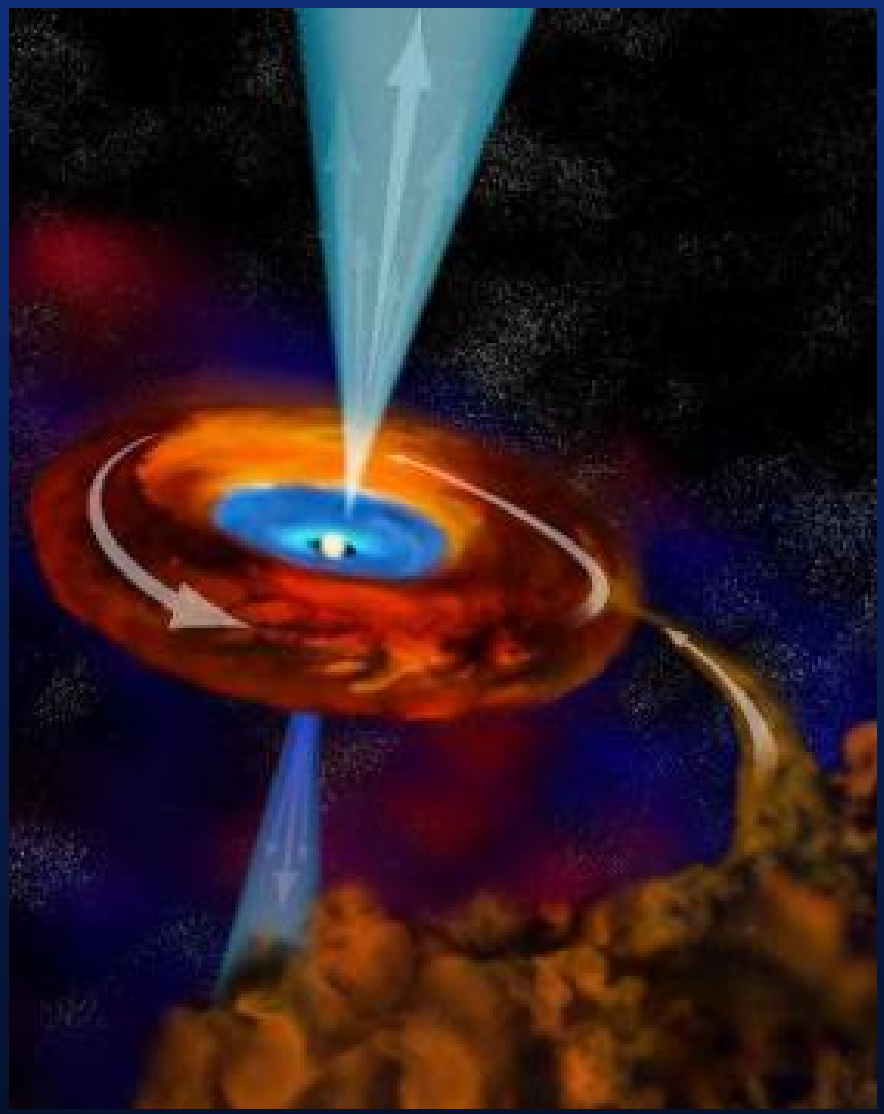
Thank you for your attention

The birth of stars

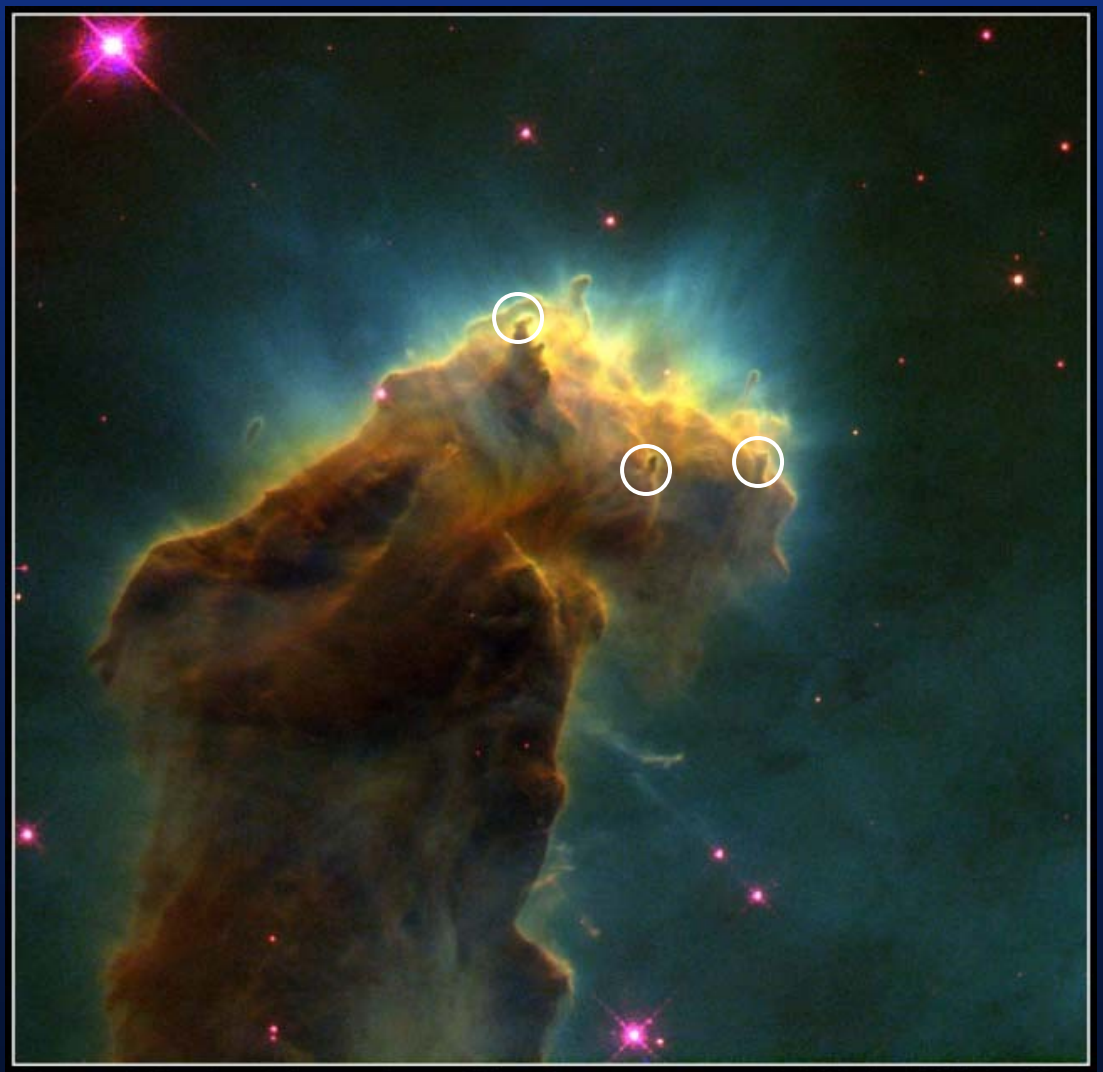
The cloud is rotating

$\longrightarrow$

Central star + disk



The birth of stars



Star-Birth Clouds · M16 HST · WFPC2

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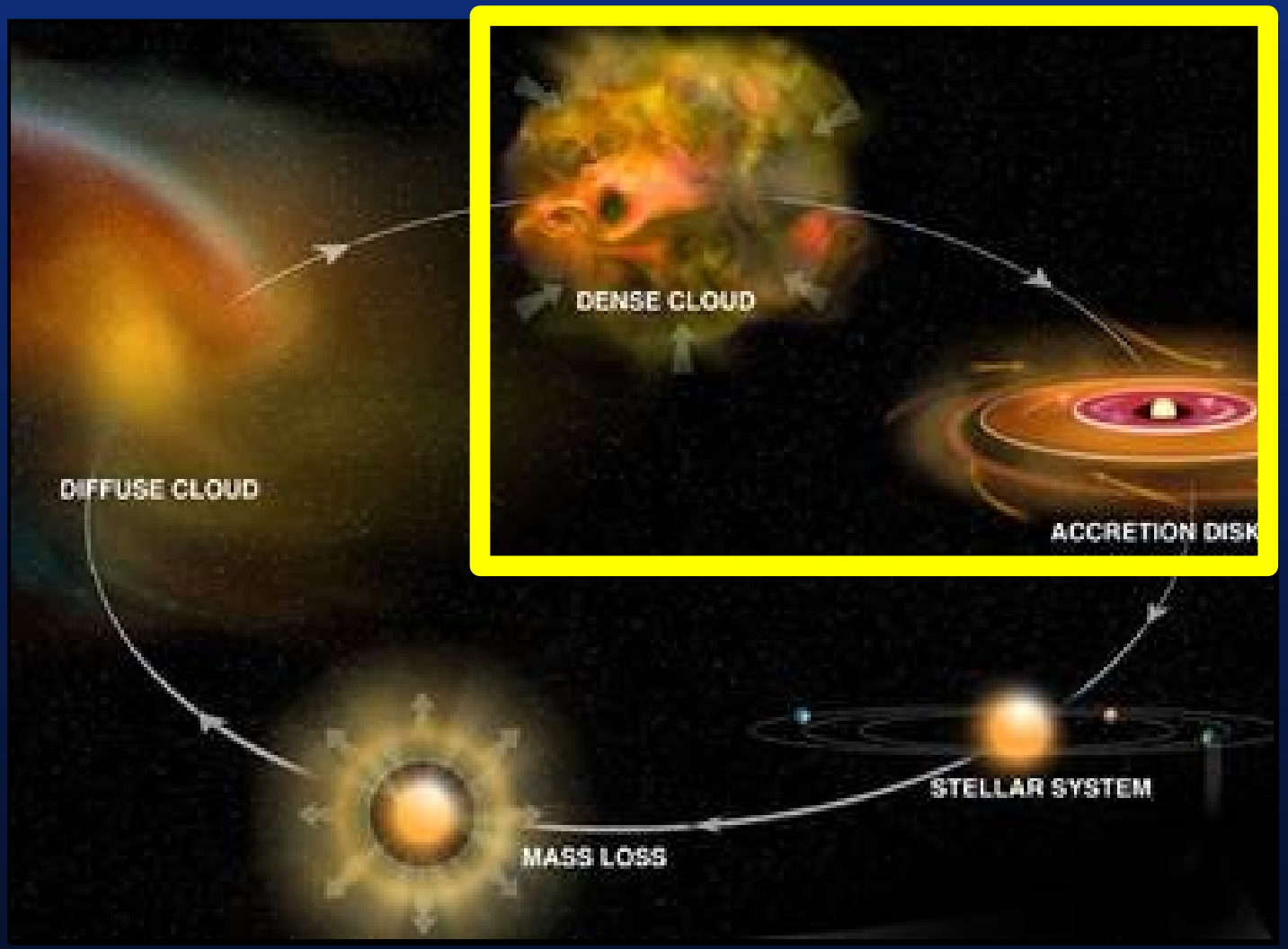
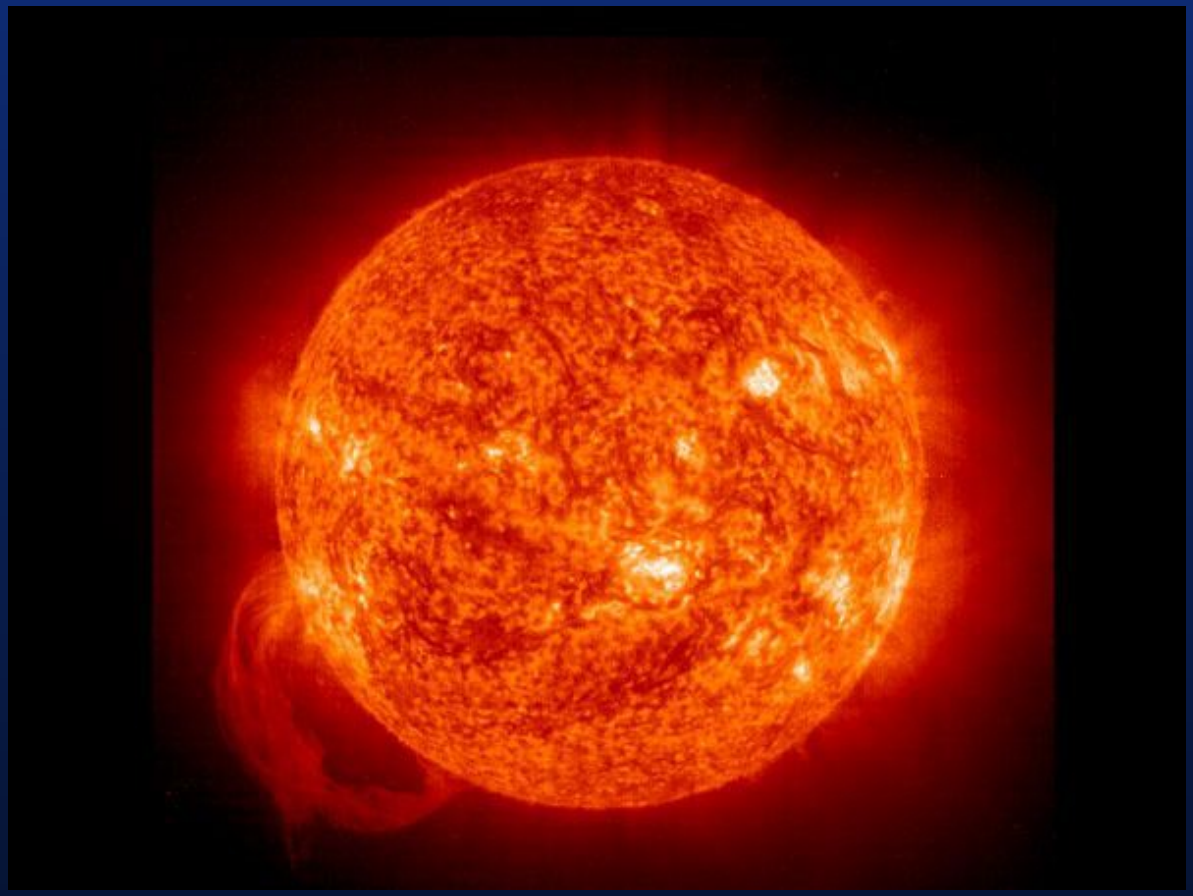
The birth of stars

Stars birth, life and death

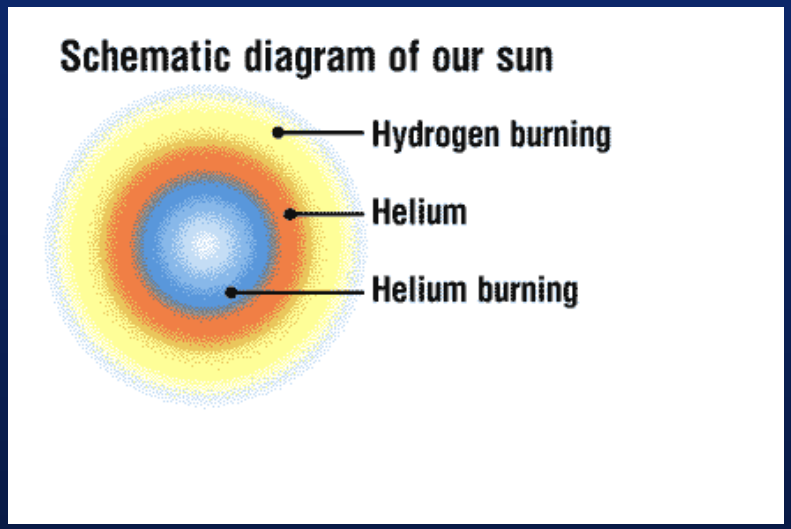


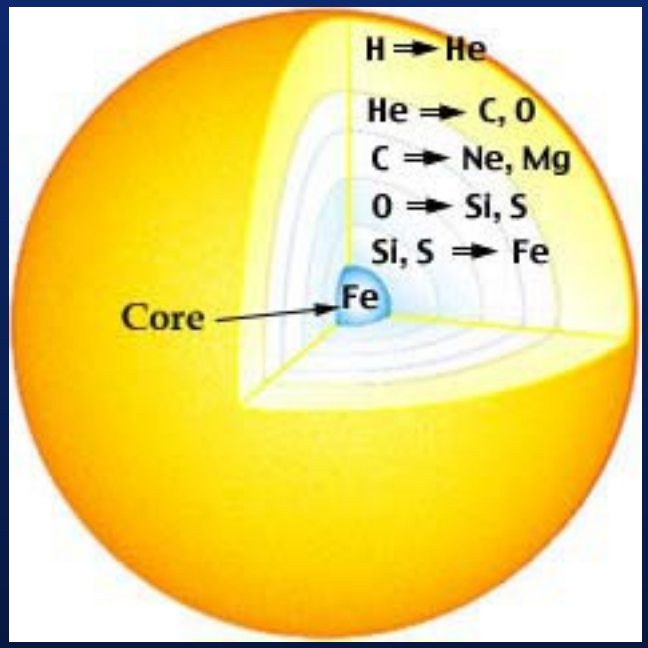
The life of stars



Nulear reactions

The life of stars





Small stars → He

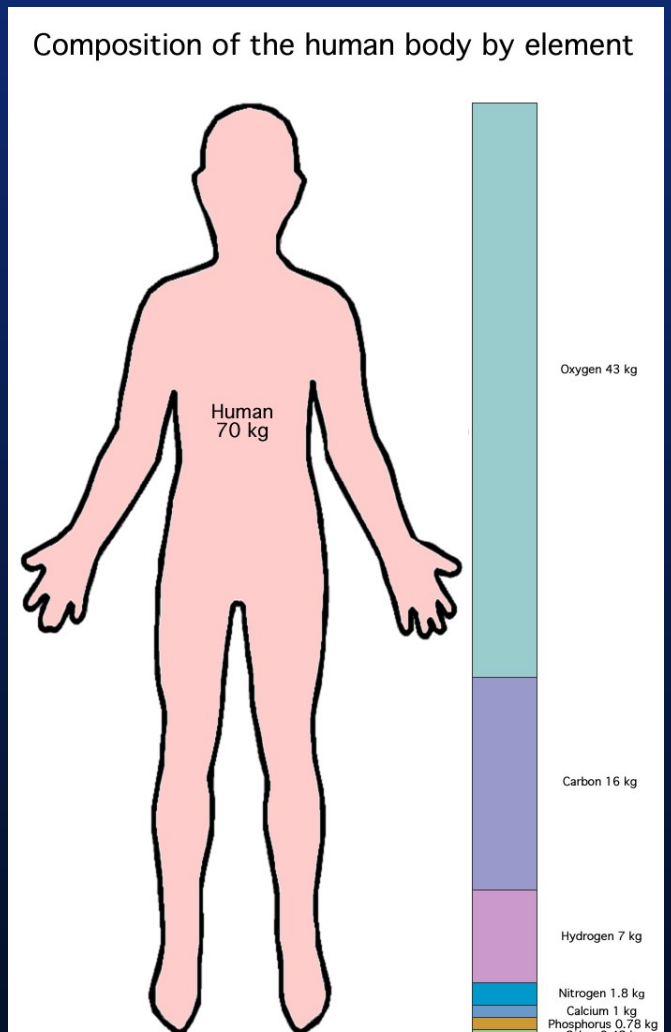
10 billion years

Massive stars → Fe

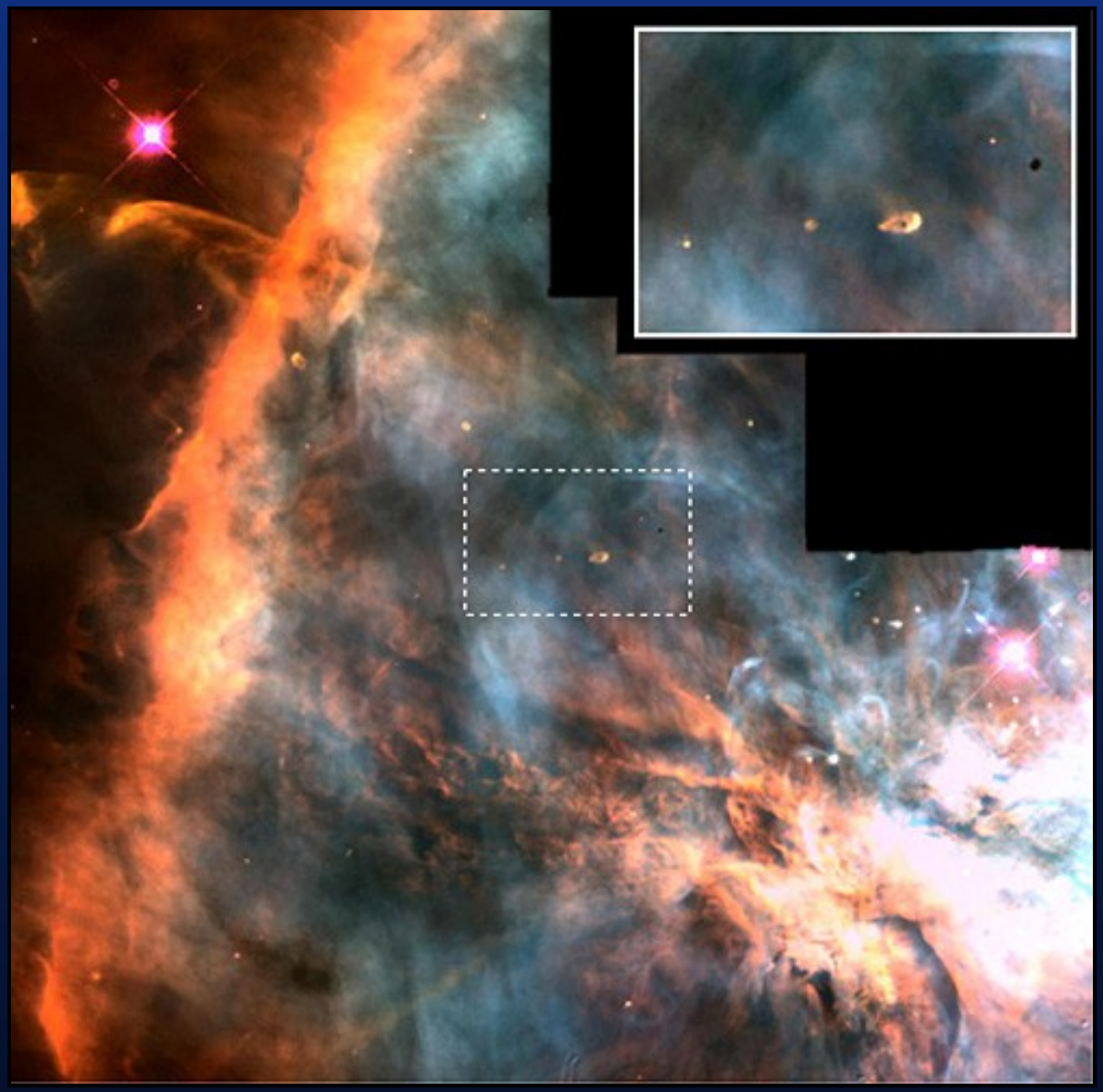
8 million years

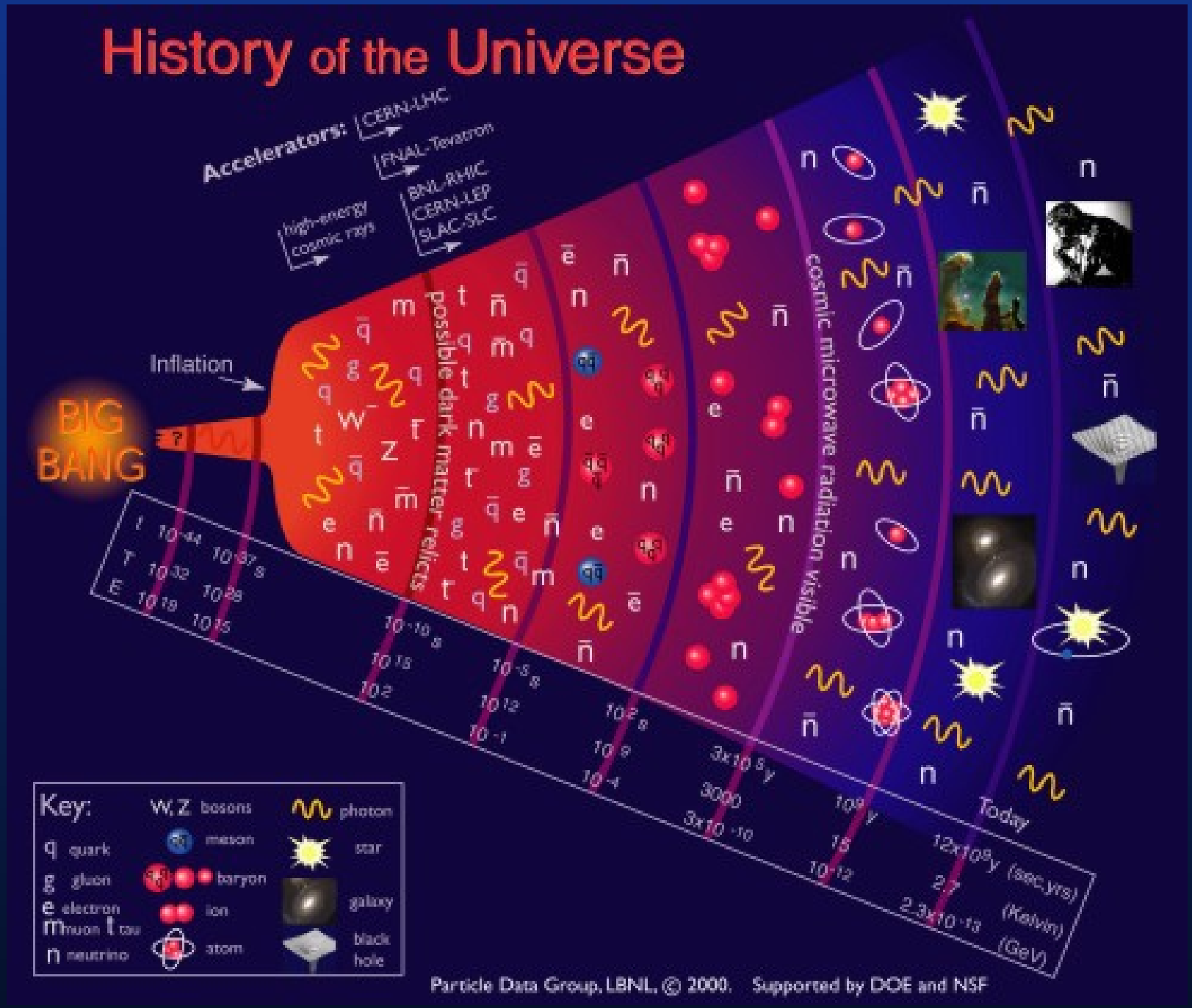
We are made of STAR STUFF

90 % of the consituents of the human body were made in stars



A star is born




History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relics
cosmic microwave radiation visible
Today
Key:
q quark
g gluon
e electron
m muon
t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
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Cosmic matter cycle