Stars and Life

To understand the role of life in the universe, we first have to look at where the ingredients for life come from. These are the percentage of atoms in a typical sample of:

The Sun		Humans		Earth's Crust	
H	91%	H	61%	O	47%
He	9%	O	26%	Si	28%
O	0.078%	C	11%	Al	8%
C	0.033%	N	2.4%	Fe	5%
Ne	0.011%	Ca	0.23%	Ca	3.6%
N	0.010%	Ph	0.13%	Na	2.8%
Mg	0.004%	S	0.13%	K	2.6%

We see that C,N and O are enriched in living organisms by a factor of 300 relative to the typical stuff of stars and the universe as a whole, much of it in the form of water:

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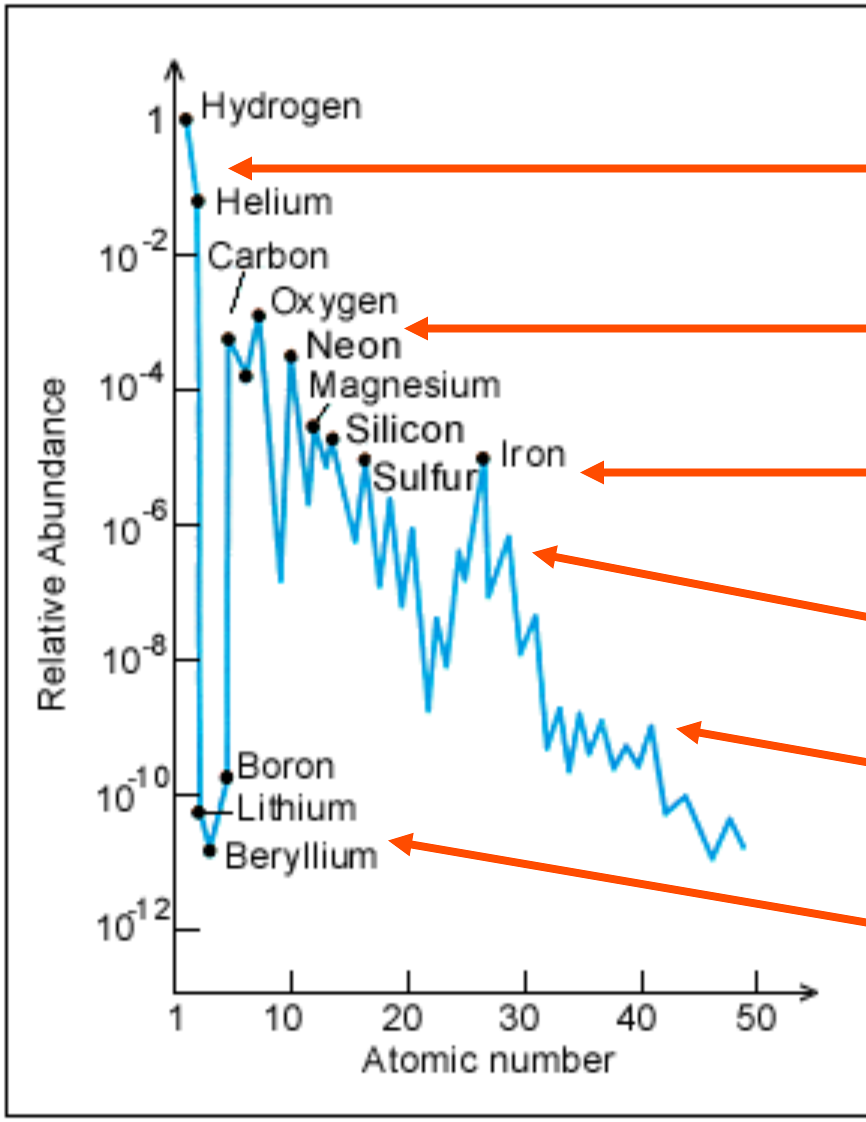
Cosmic Element Abundances



Main features are:

H and He are dominant

Second peak at C, N and O

Third peak at Iron

Overall saw-tooth pattern

Extreme rarity beyond Iron

Light element trough

How can we explain this?

Origin of the Lightest Elements

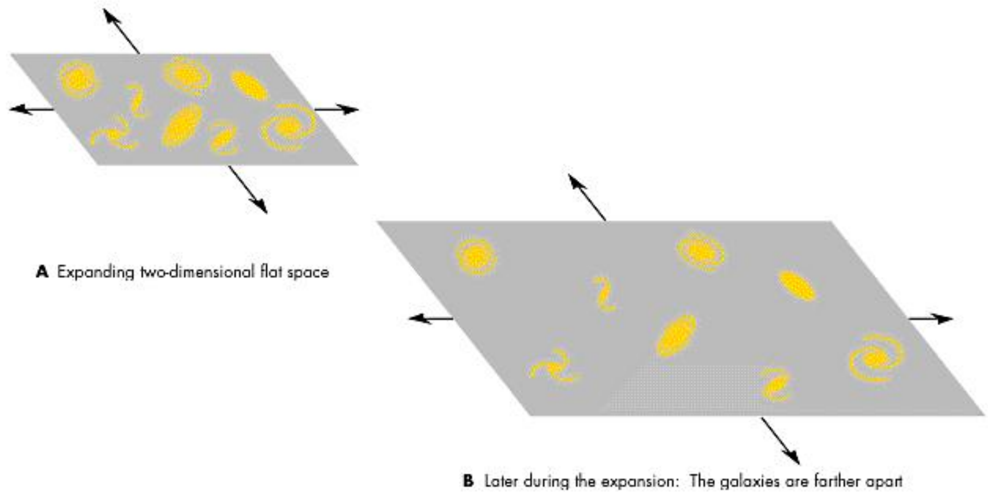
The lightest elements — hydrogen, helium, and a smattering of deuterium (heavy hydrogen isotope) and lithium — were from the big bang itself, produced by fusion in the first three minutes when the universe was as hot as the core of a star like the Sun!

If no stars had formed in the expanding universe, we would not be here to have this discussion, since hydrogen and helium can combine to form…. nothing! Chemistry & biology impossible.

How Do We Know This Happened?

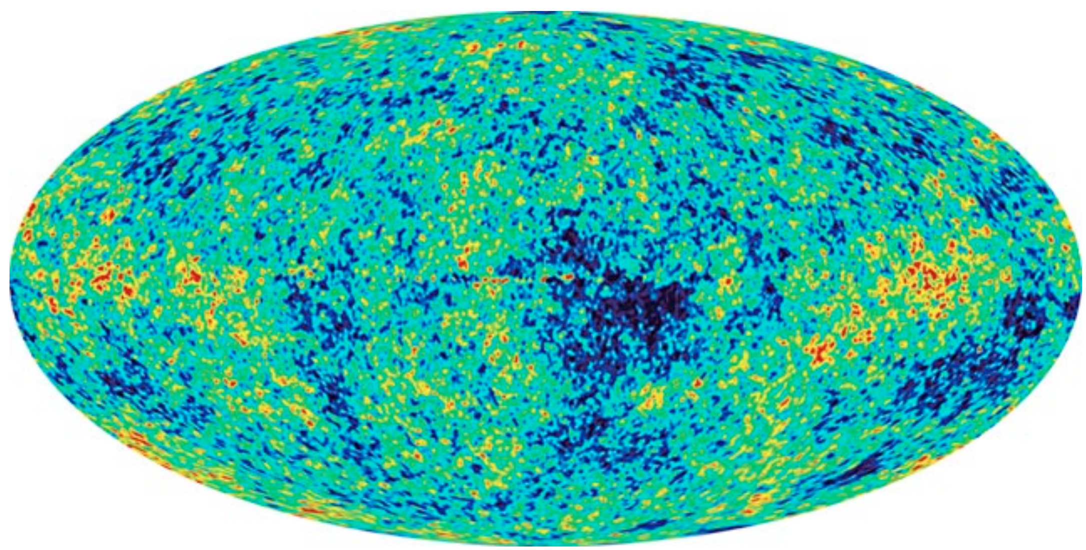
1. Cosmic Expansion

All galaxies moving away from each other, pointing to when the universe was hotter and denser, with an origin 13.7 billion years ago.



2. Microwave Background

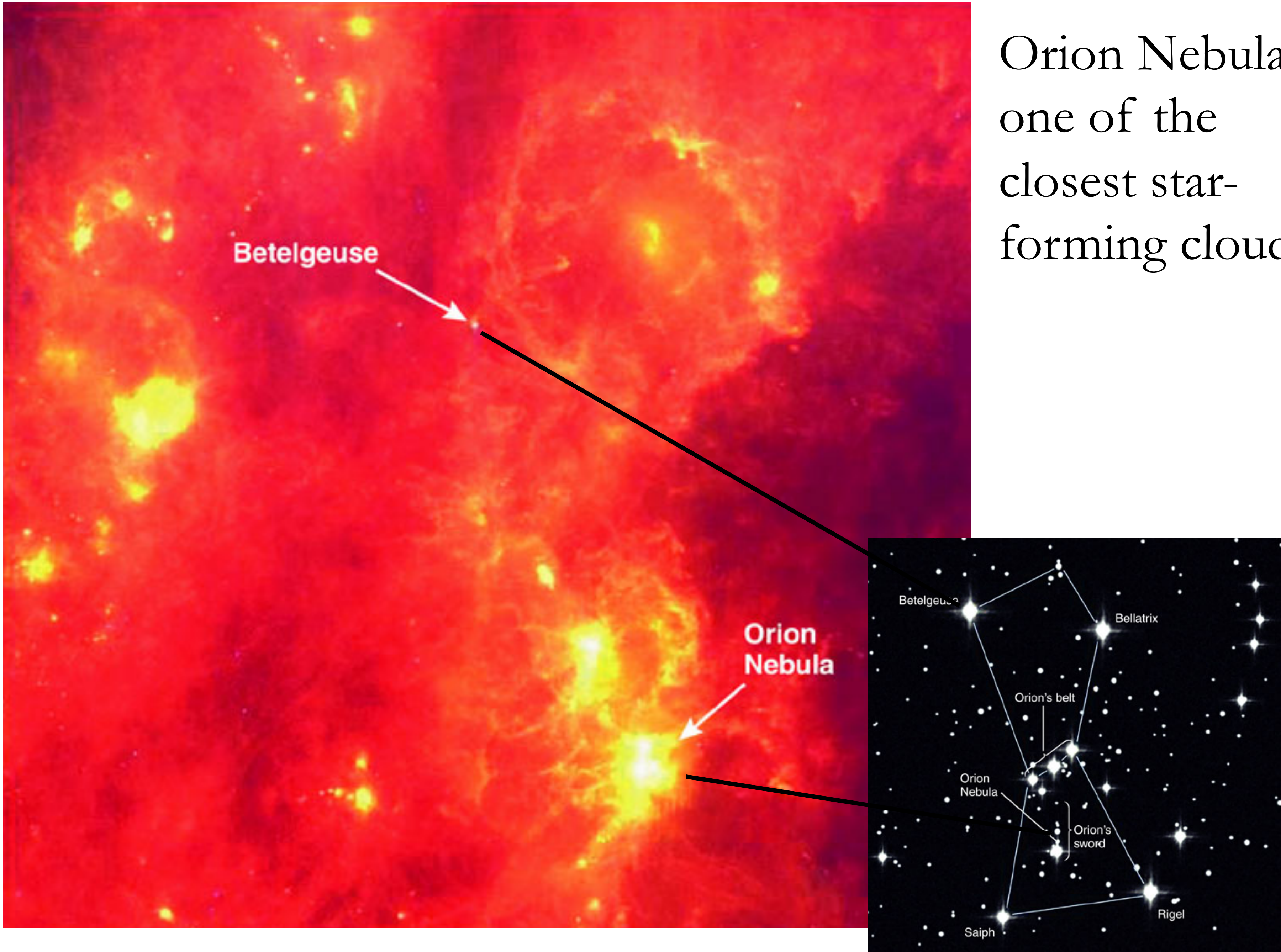
Expansion since the early hot phase has cooled the radiation to microwaves, seen all over the sky at a temperature of only 3K.



How do stars and planets form?

Stars are born in *molecular clouds* consisting mostly of hydrogen molecules, with some heavier elements and dust

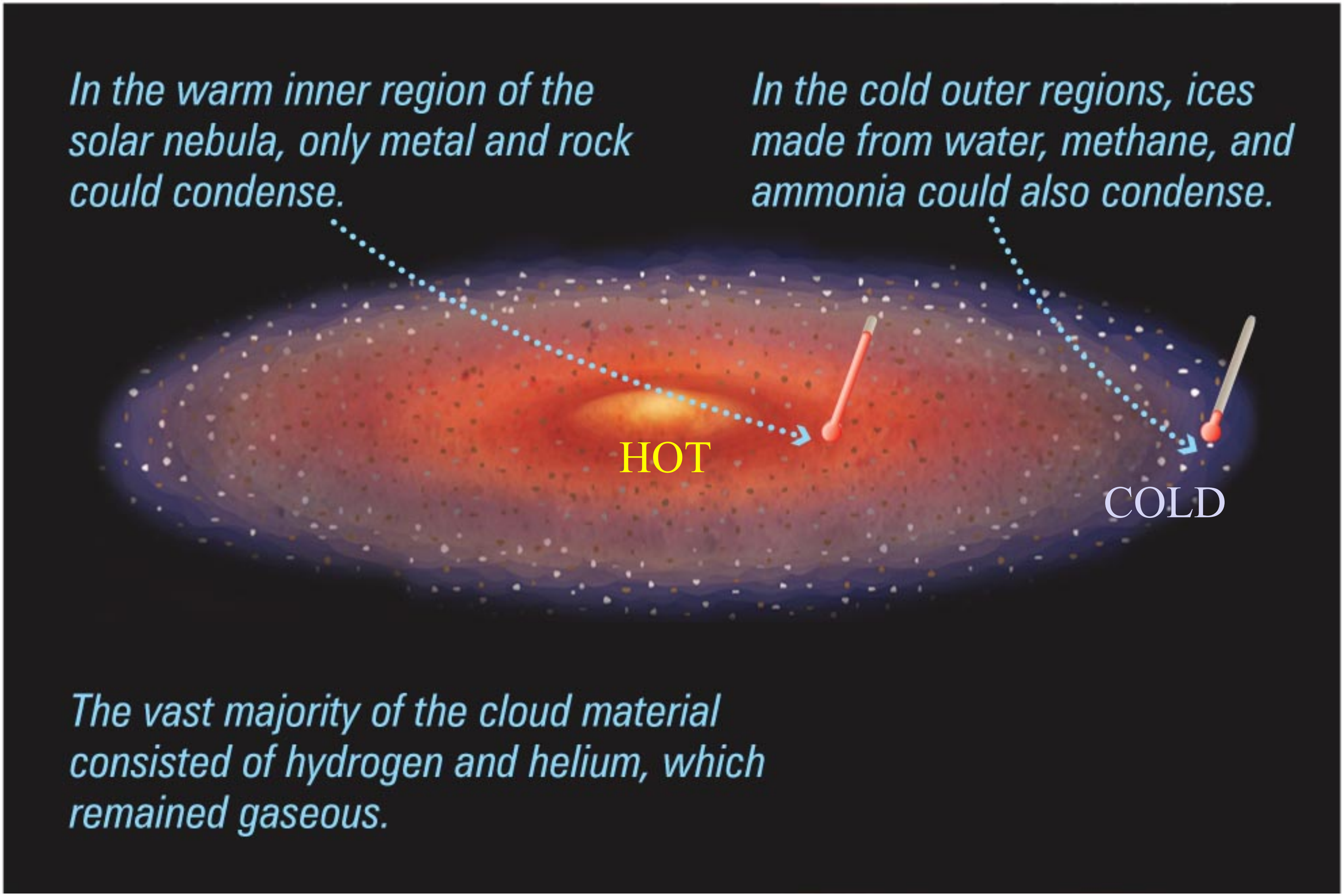

Stars form out of molecular clouds



Orion Nebula is one of the closest star-forming clouds

Infrared light from Orion

Planets form in the solar nebula



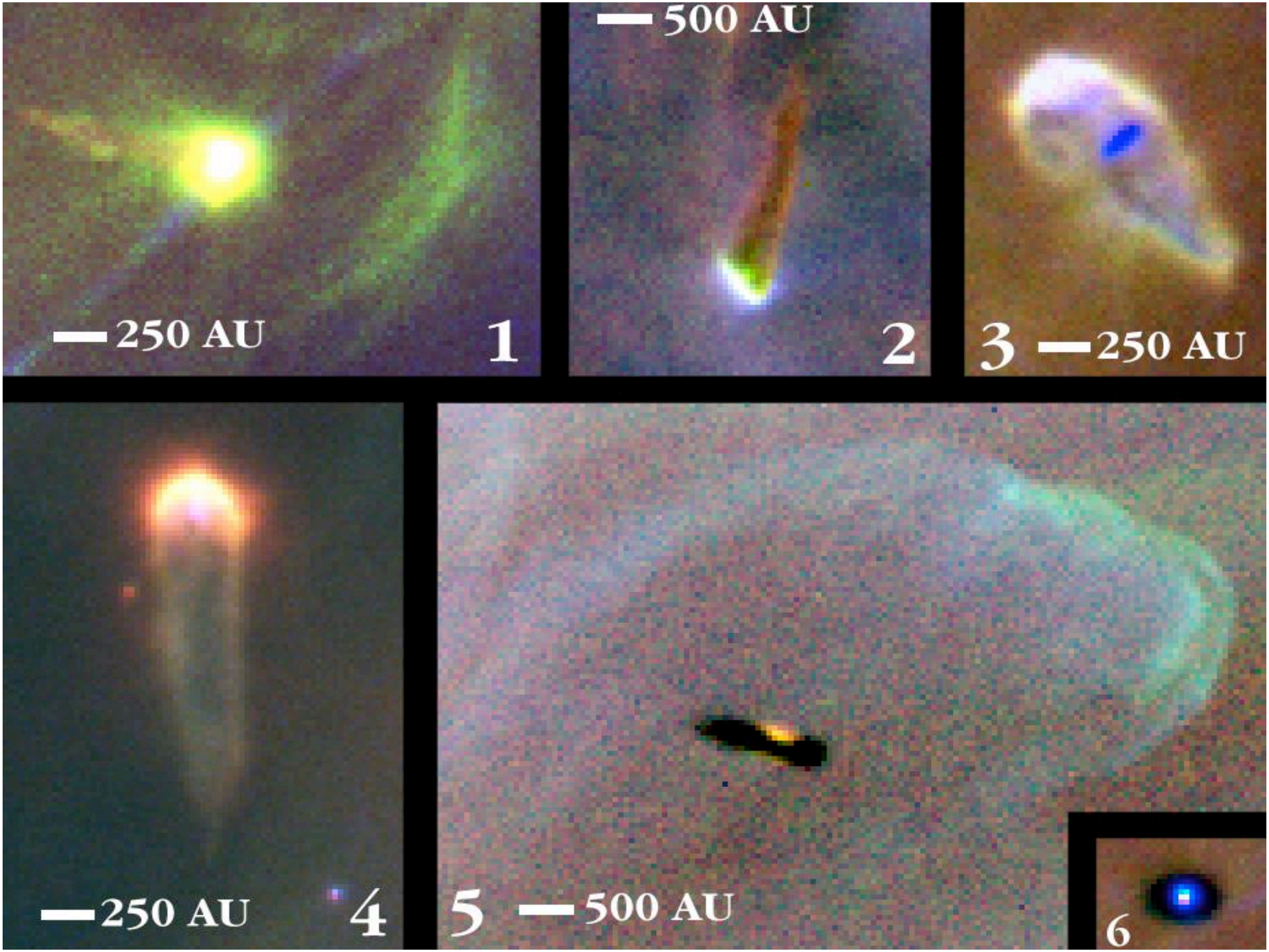

250 AU
1
500 AU
2
3
250 AU
250 AU
4
5
500 AU
6

TABLE 3.1 *Materials in the Solar Nebula*

A summary of the four types of materials present in the solar nebula. The squares in the final column represent the relative proportions of each type (by mass).

	Examples	*Typical Condensation Temperature*	*Relative Abundance (by mass)*
Hydrogen and Helium Gas 	hydrogen, helium in nebula	do not condense	98%
Hydrogen Compounds 	water (H_2O) methane (CH_4) ammonia (NH_3)	$<$150 K	1.4%
Rock 	various minerals	500–1,300 K	0.4%
Metals 	iron, nickel, aluminum	1,000–1,600 K	0.2%

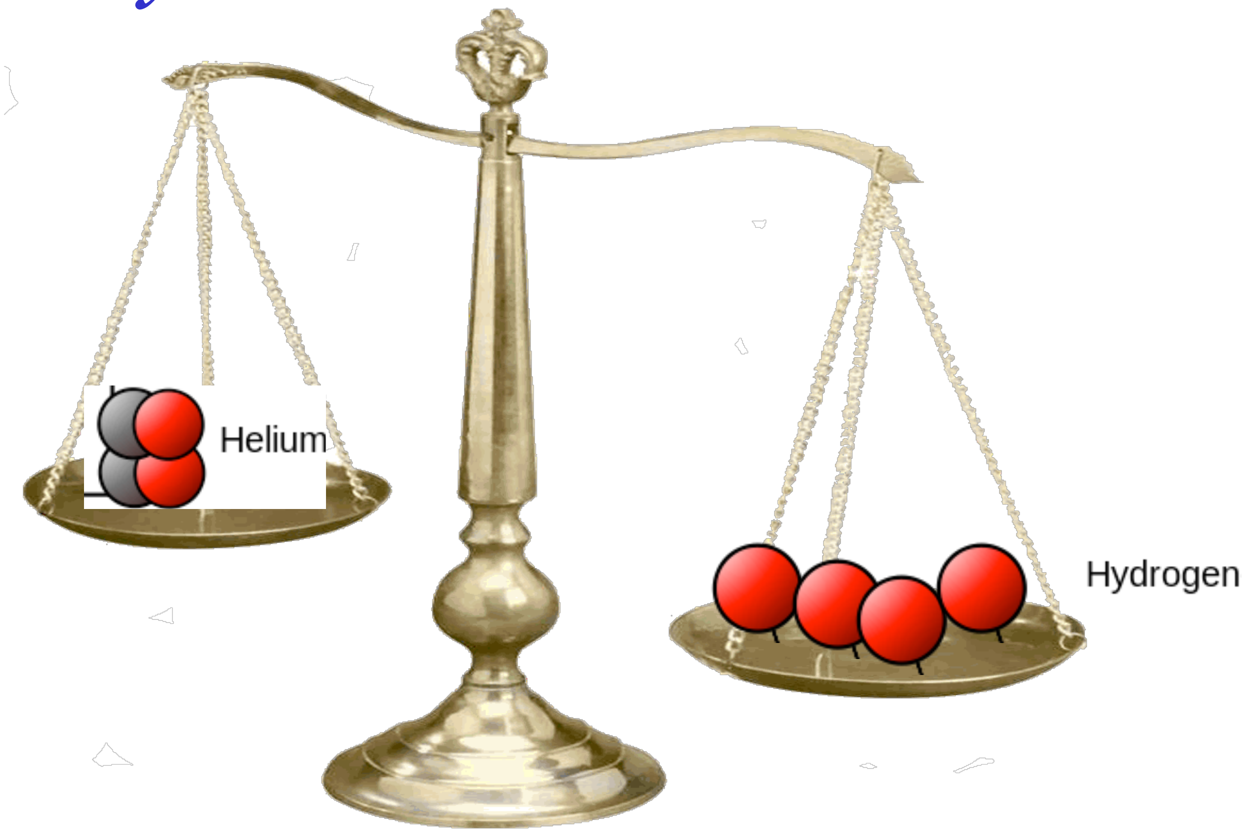
The solar nebula concentrates the heavy elements

Light gases and volatile compounds are driven from the inner solar system by solar radiation

Rocks and metals are not, so they are concentrated by a very large factor

A cluster of many stars can form out of a single cloud.

Why does a star shine?



4 Hydrogen atoms weigh more than 1 Helium atom … Where does the mass go when you convert 4 Hydrogen atoms into Helium?

$E = mc^2$ **Sunlight!**

Why does a star shine?

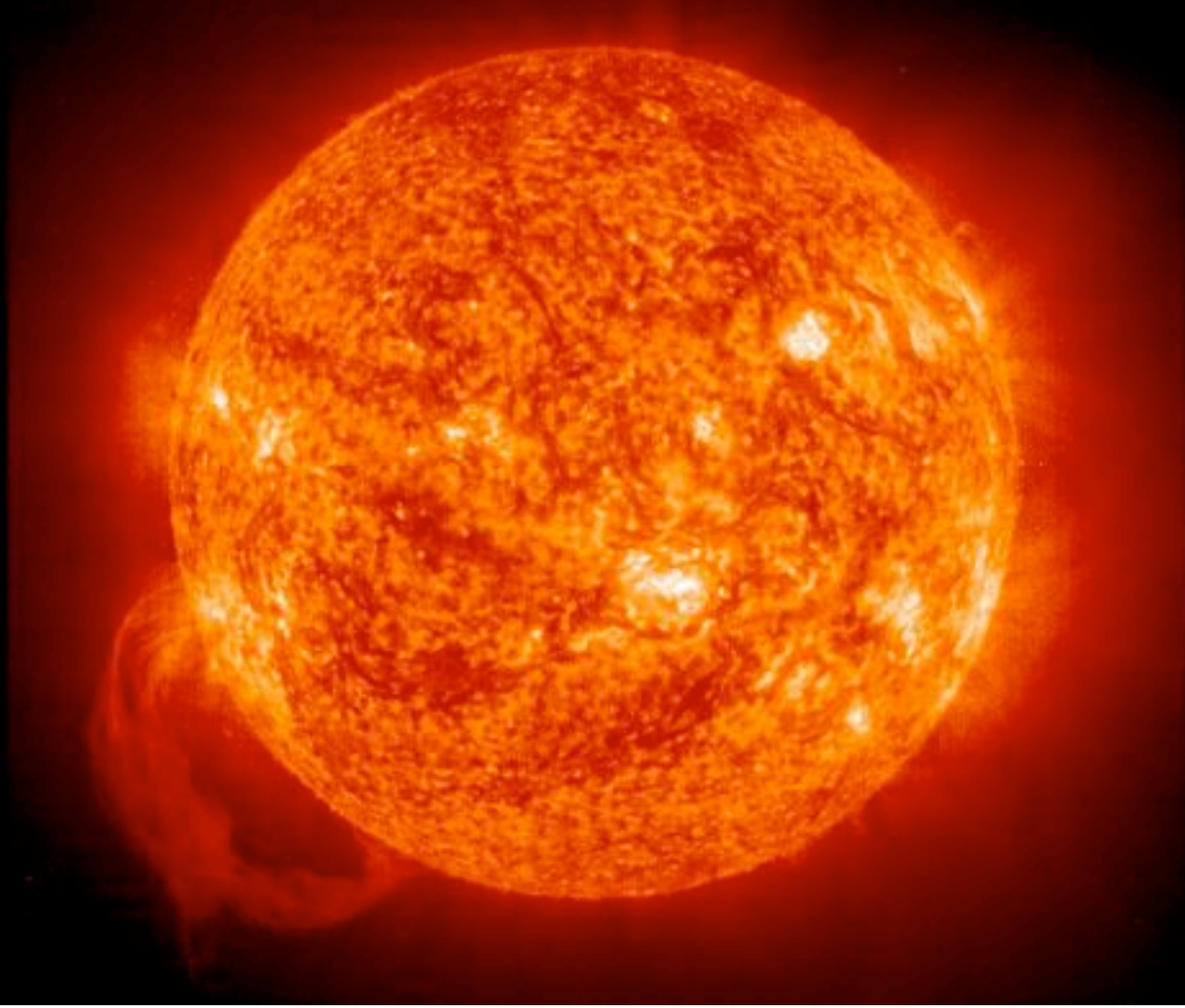
Stars are gravity engines. The pressure of gravity in a star's core raises the temperature to millions of degrees, so hot that atomic nuclei move fast enough to overcome electrical repulsion and "stick" in the process called nuclear fusion.

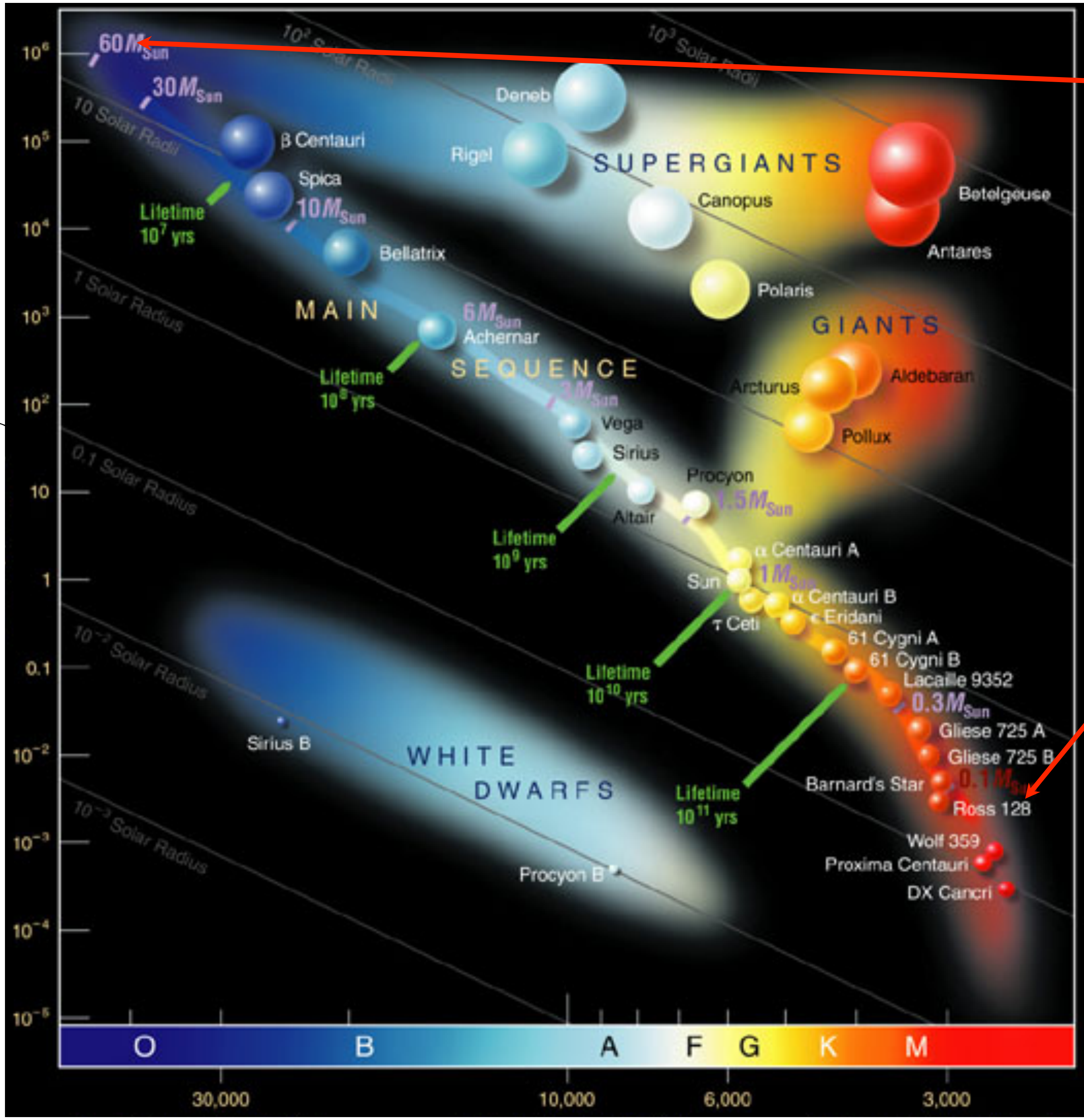
In fusion, the product is slightly lighter than the sum of the nuclei that went into the reaction. The mass difference is converted into energy that makes its way out of the star:

$$E = mc^2$$

Sunlight!

Hydrogen is converted into Helium via nuclear fusion in core of the Sun



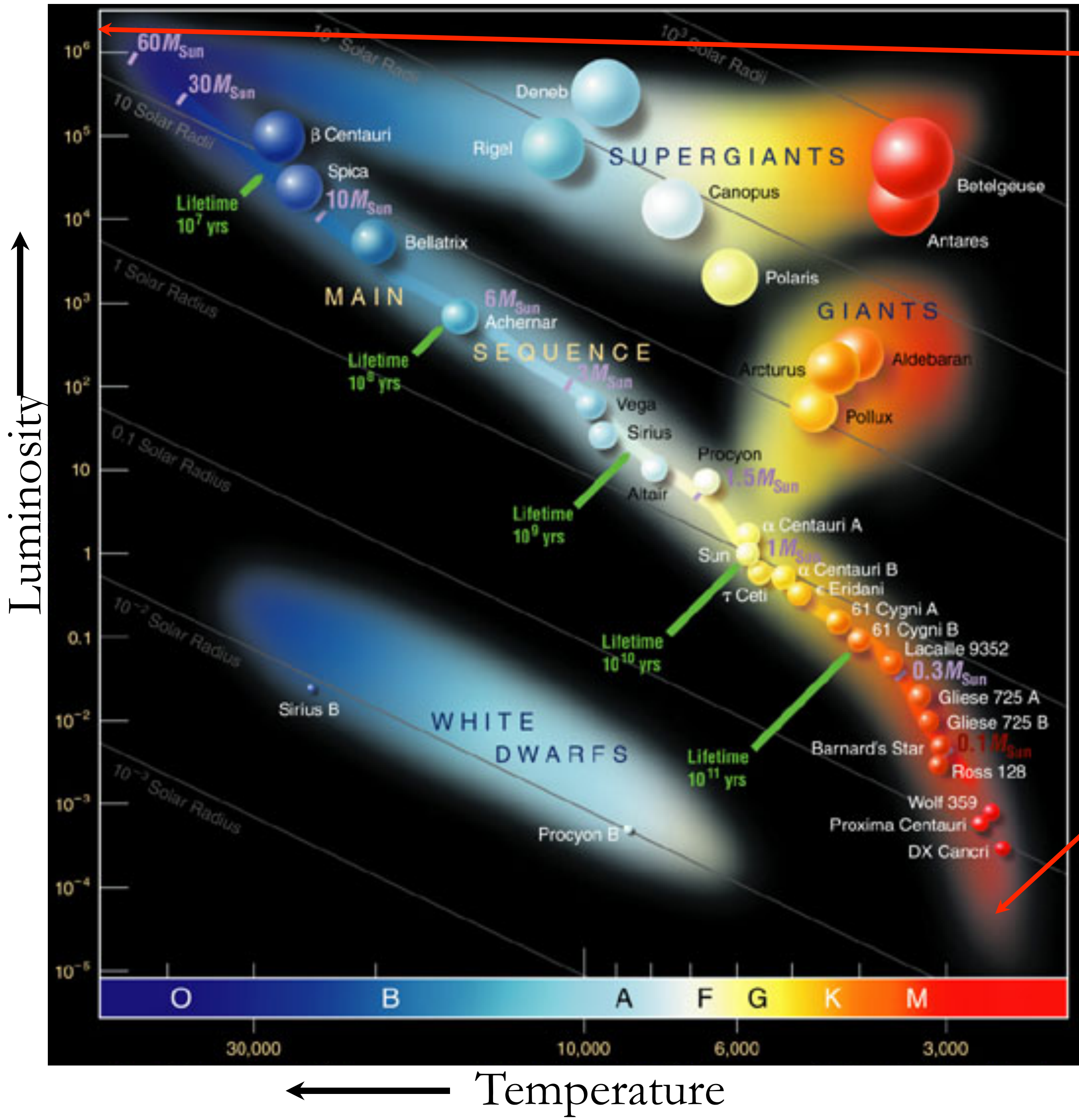


Luminosity

Temperature

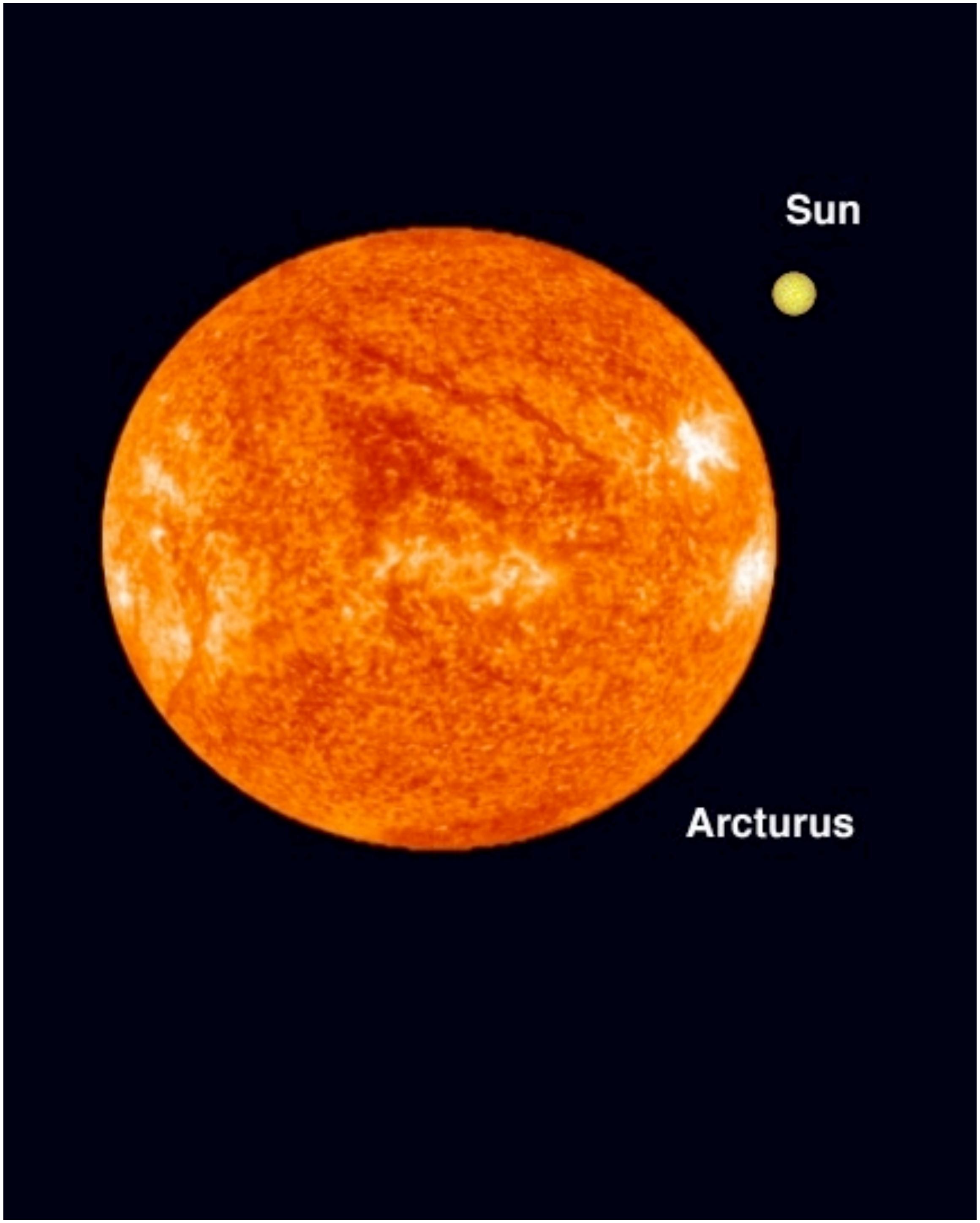
Very massive stars are rare

Low-mass stars are common



Stars more massive than 100 M_{Sun} would blow apart

Stars less massive than 0.08 M_{Sun} can't sustain fusion



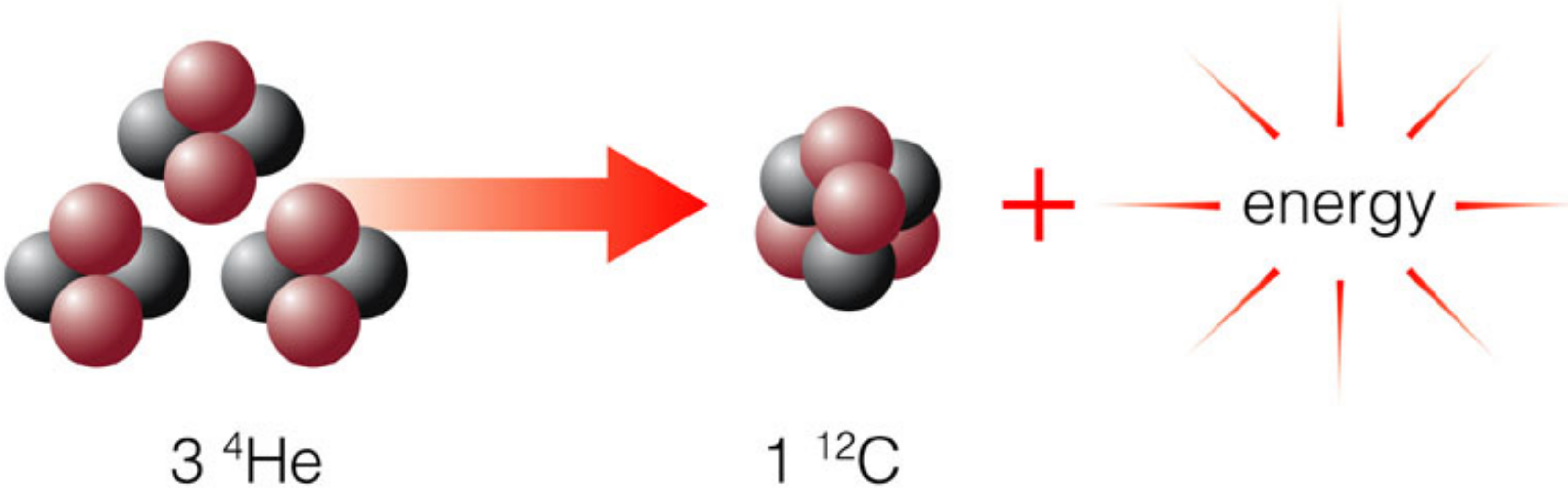
Red Giant Star

- Large, cool (red) star

- Near end of its stellar life … ***done*** with main sequence burning

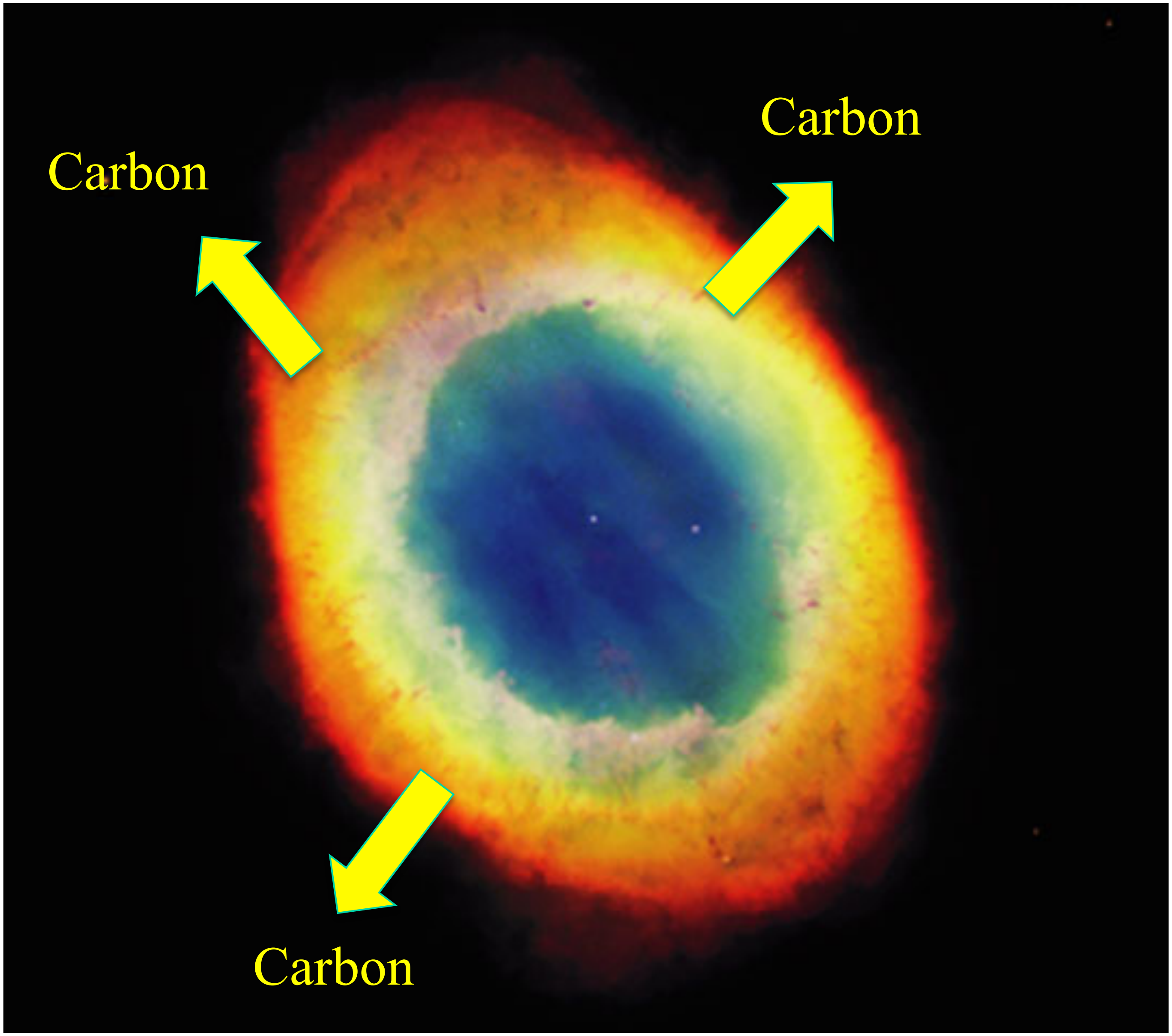
- In 5 billion years … this will be our Sun!

*Low mass stars can make **Carbon***



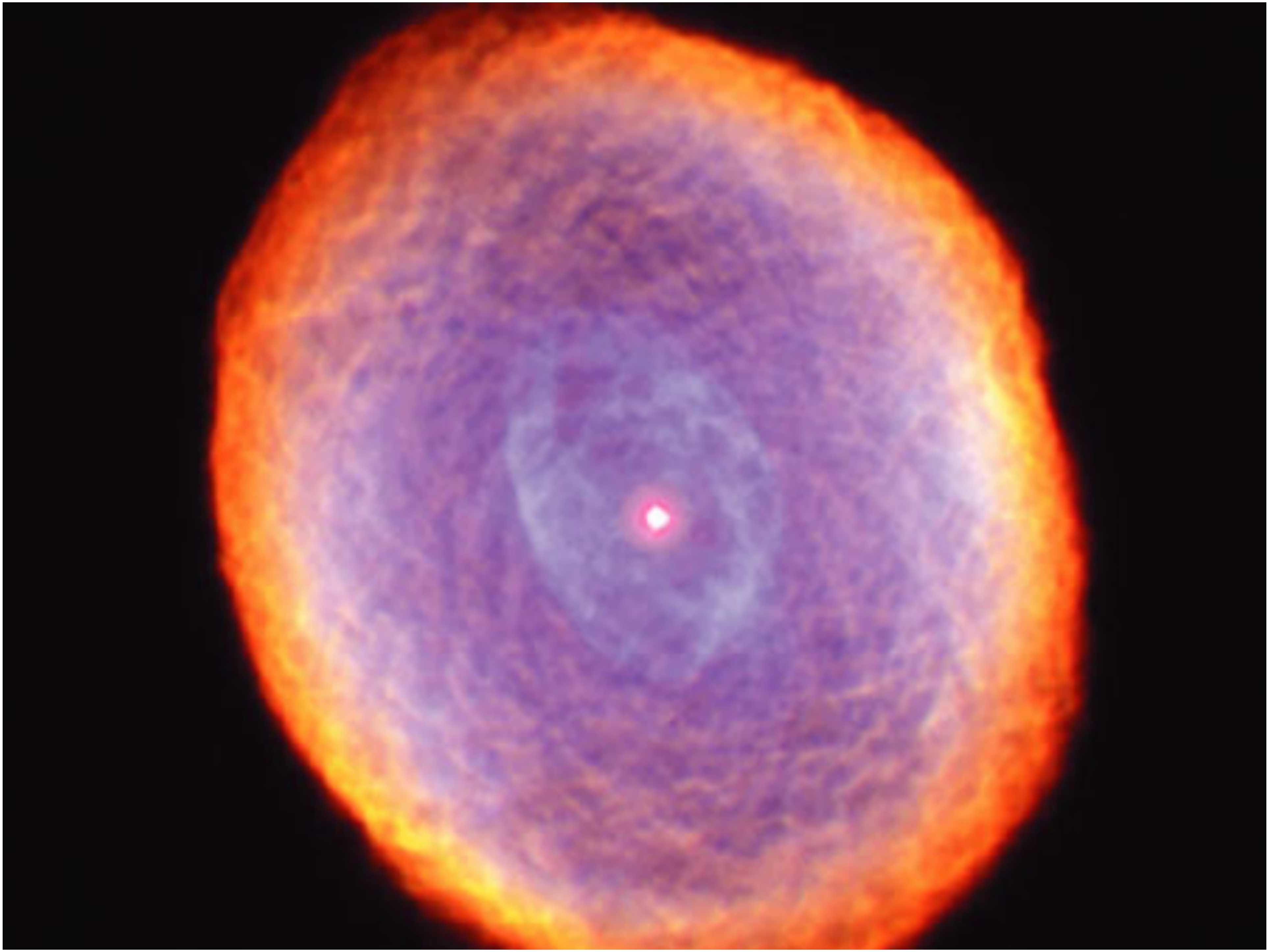
Helium fusion requires higher temperatures than hydrogen fusion because larger charge leads to greater repulsion.

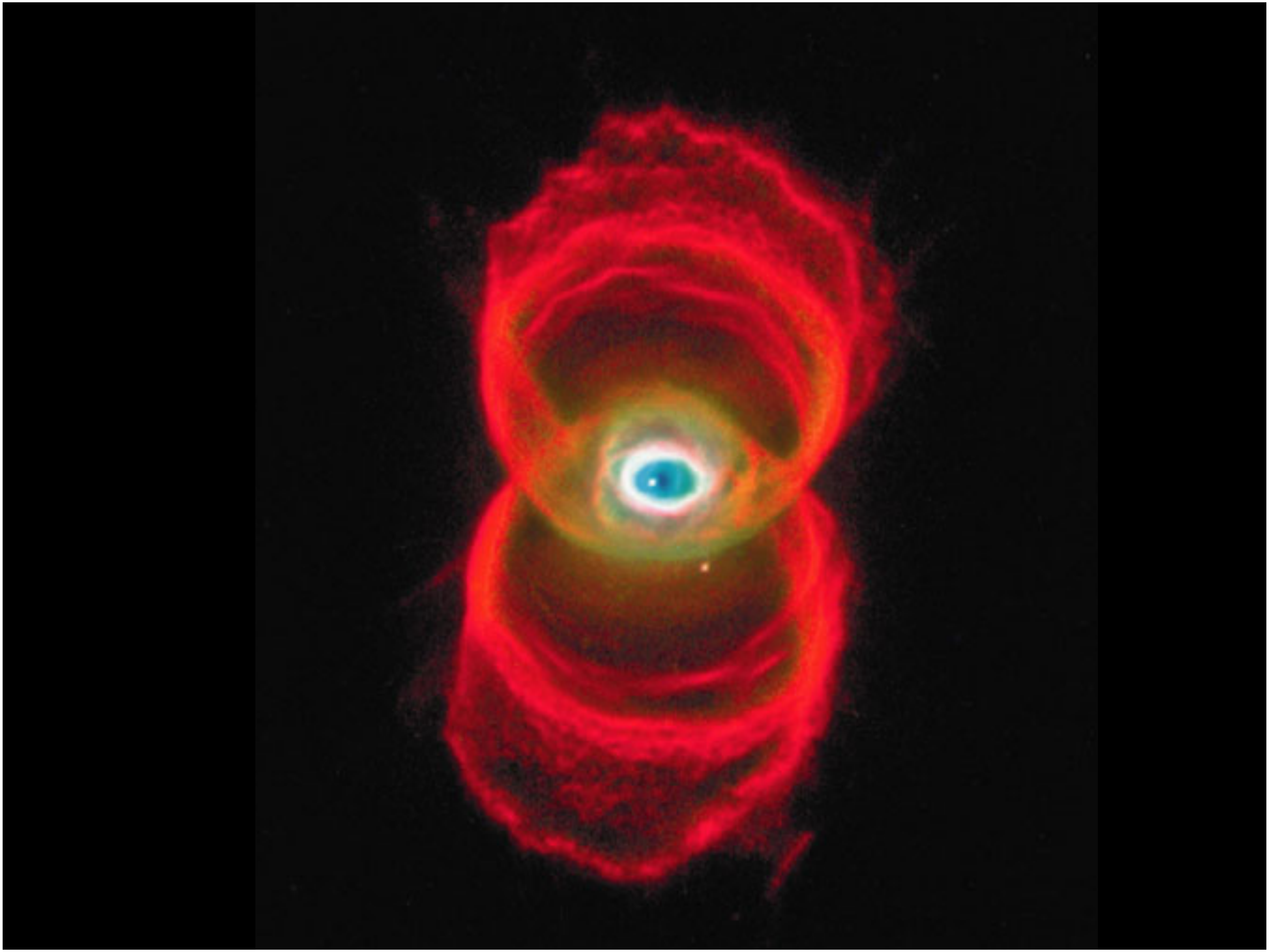
Occurs at end of a star's life.



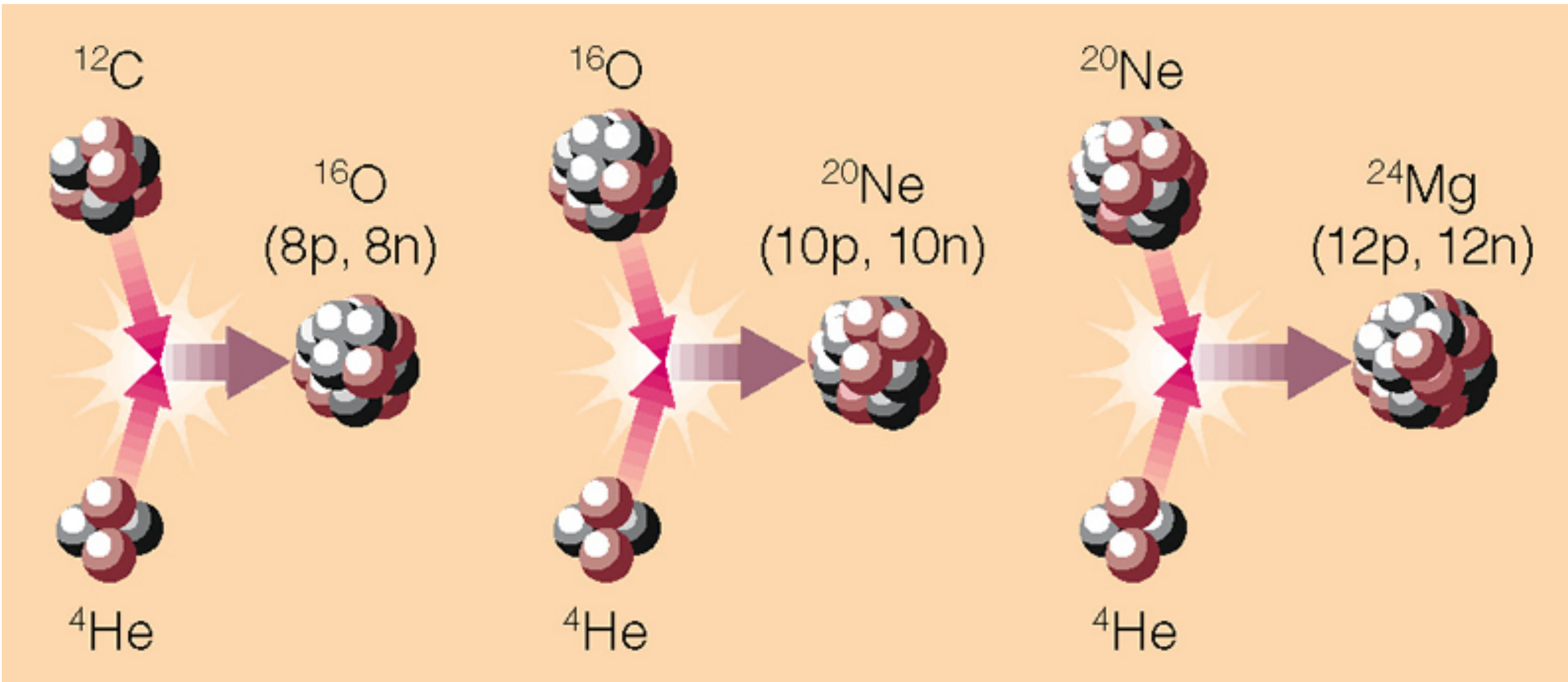
A star like our Sun dies by puffing off its outer layers, creating a *planetary nebula*.

Only a white dwarf is left behind

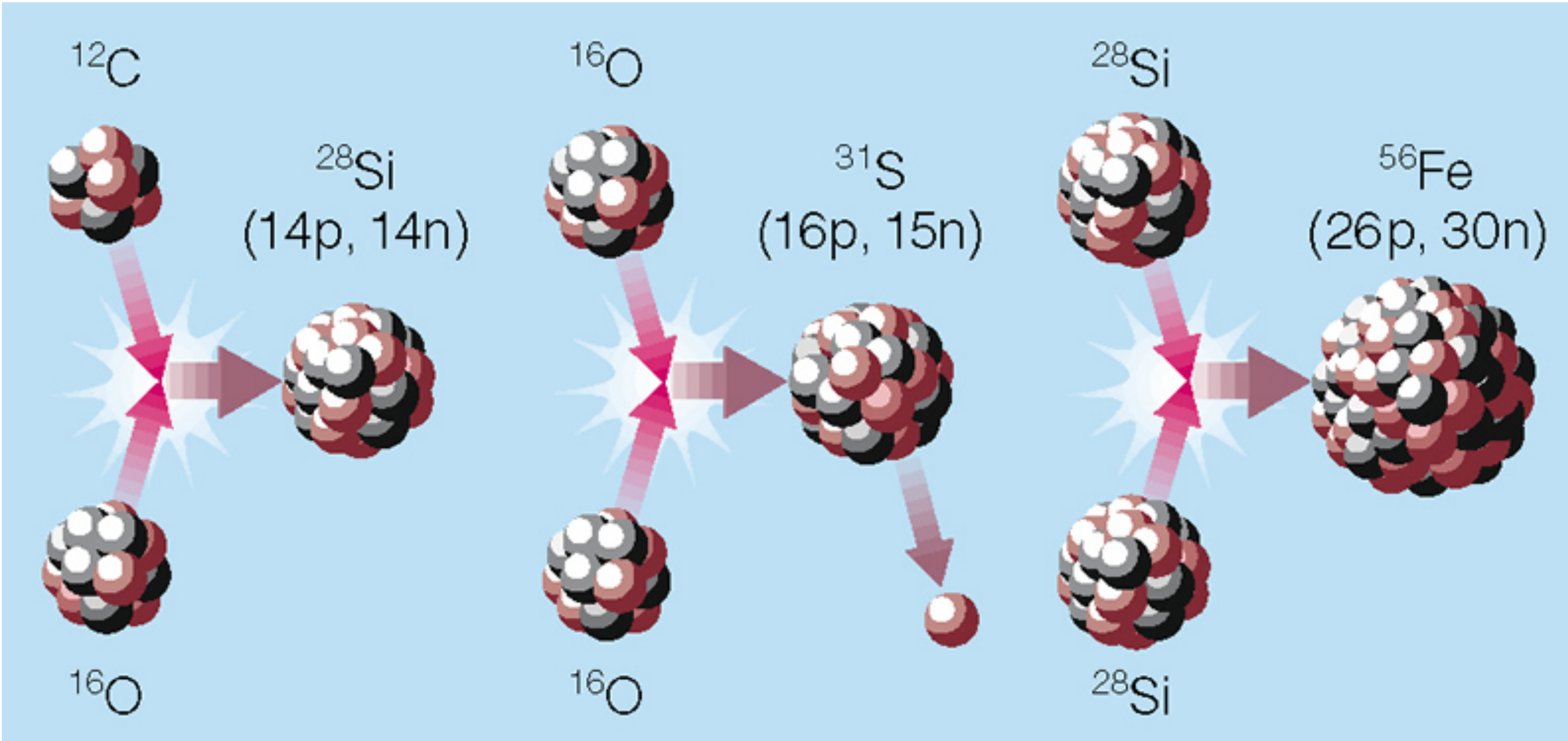




High mass stars make heavy elements

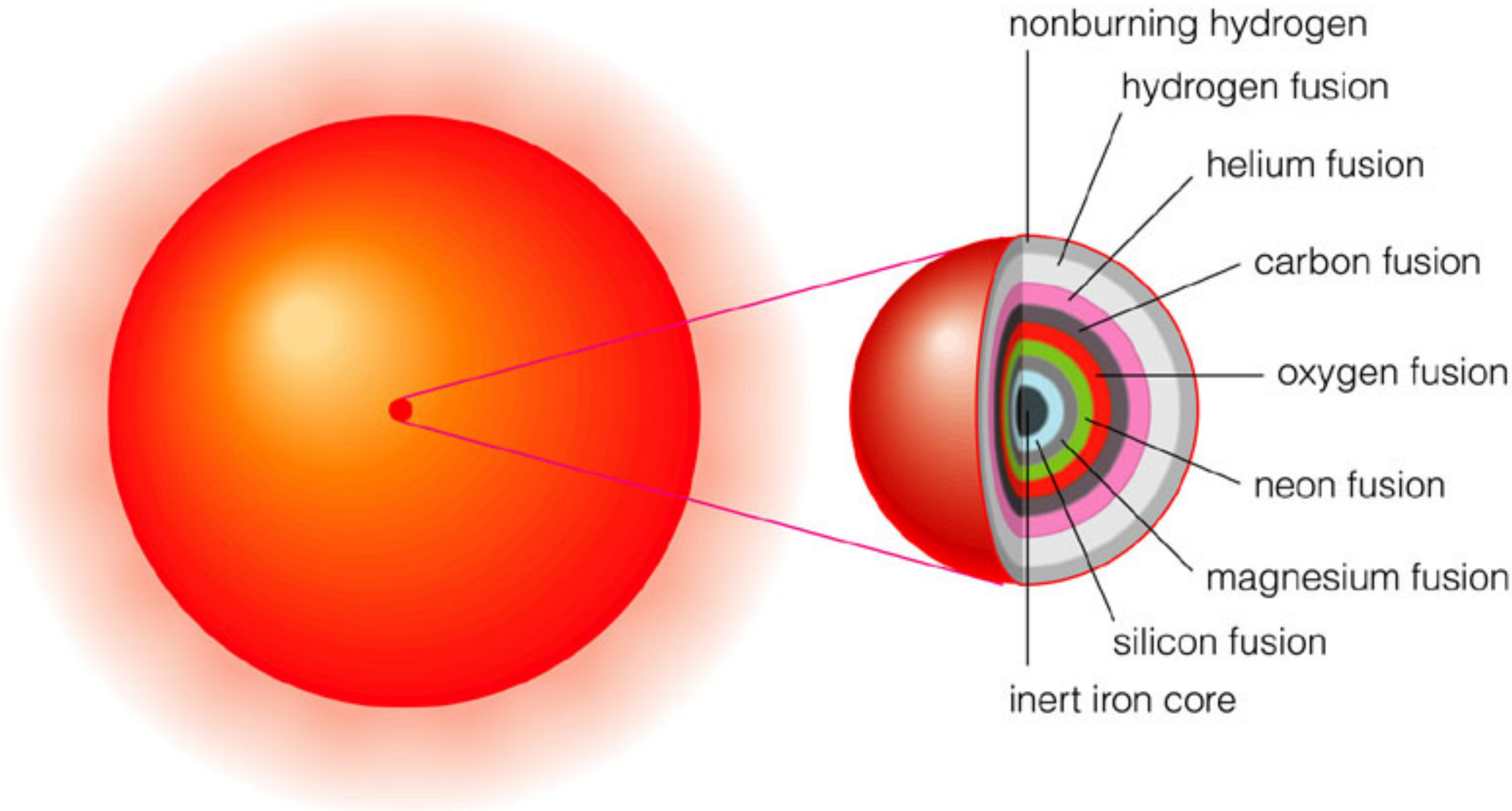


Helium-capture reactions add two protons at a time

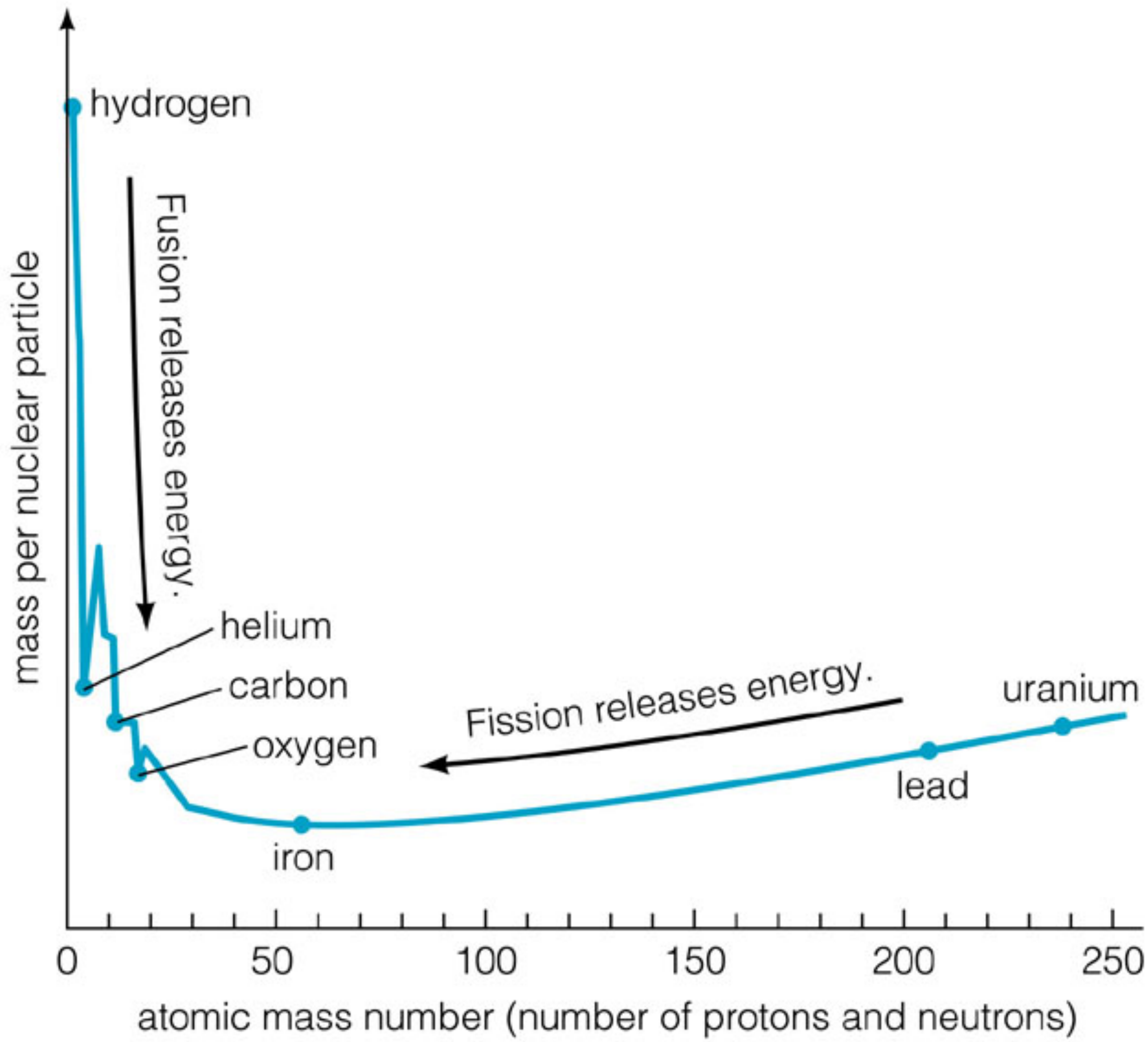


Advanced nuclear fusion reactions require extremely high temperatures, *several billion degrees*

Only high-mass stars can attain high enough core temperatures to create elements up to iron

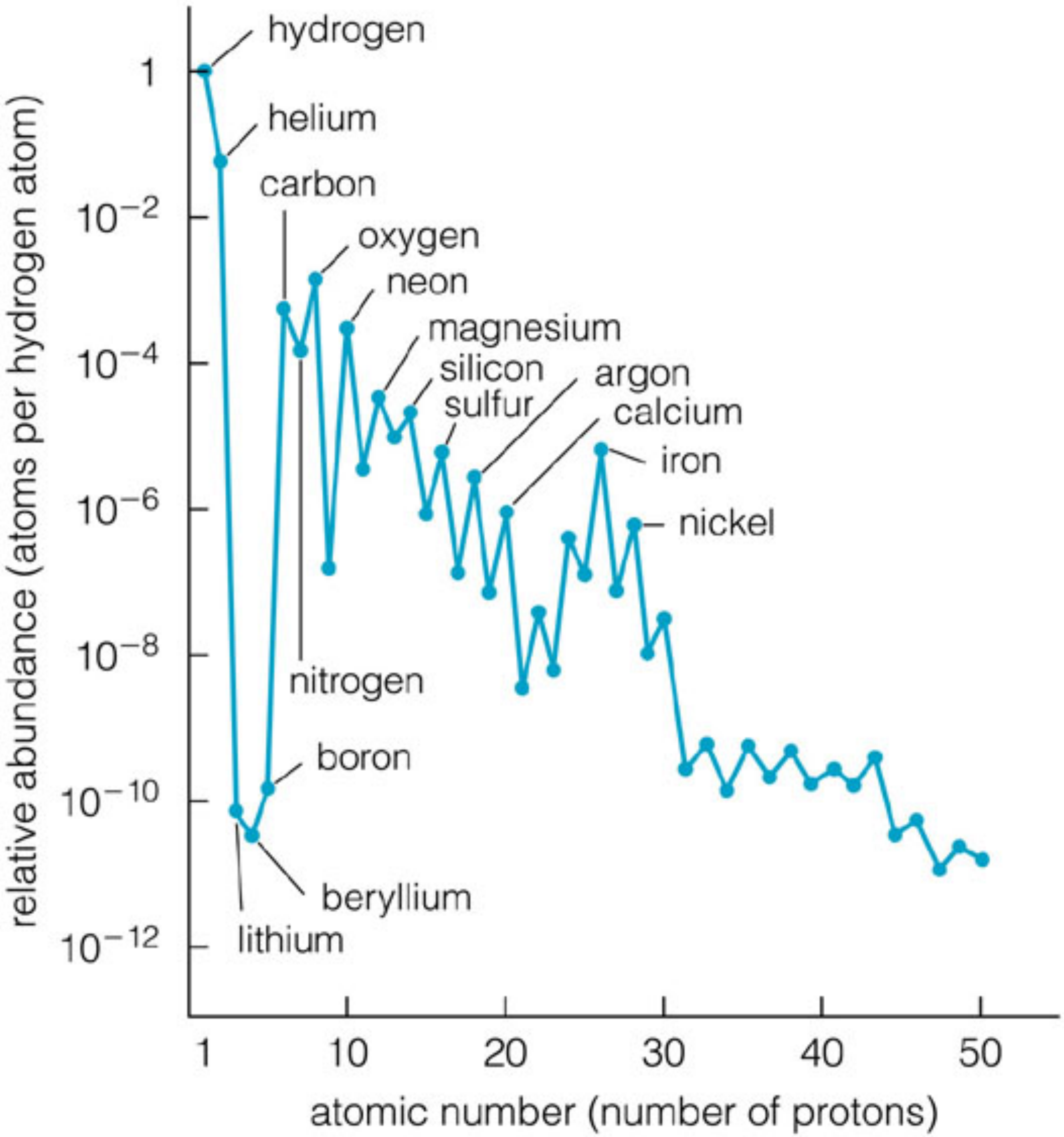


Advanced nuclear burning occurs in multiple shells in a **high mass star**
(our Sun will never get to this stage)



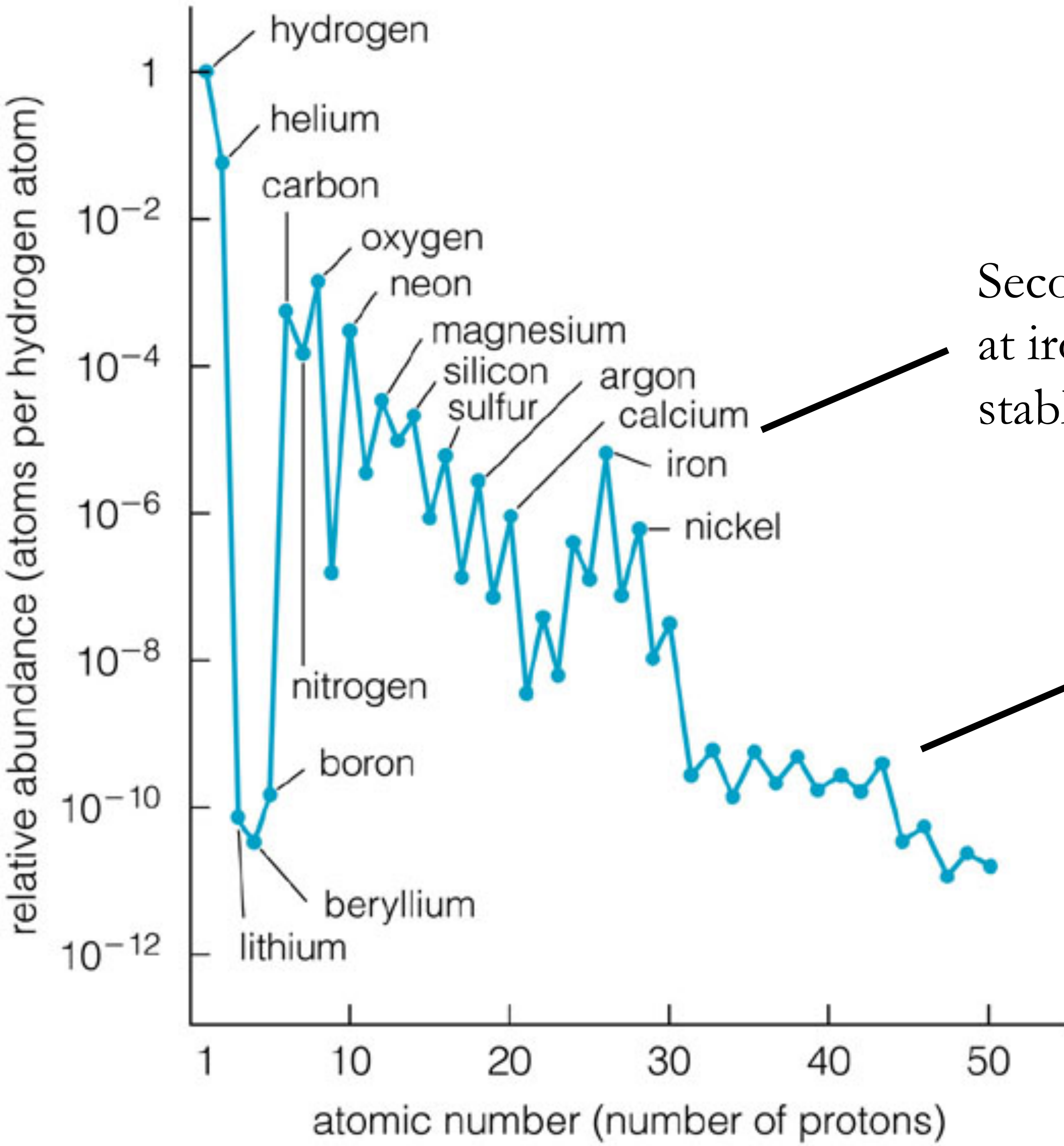
Iron is a dead end for fusion because nuclear reactions using iron do not release energy

Iron is the most stable element; energy must be put in to get fusion past Fe



Evidence for helium capture:

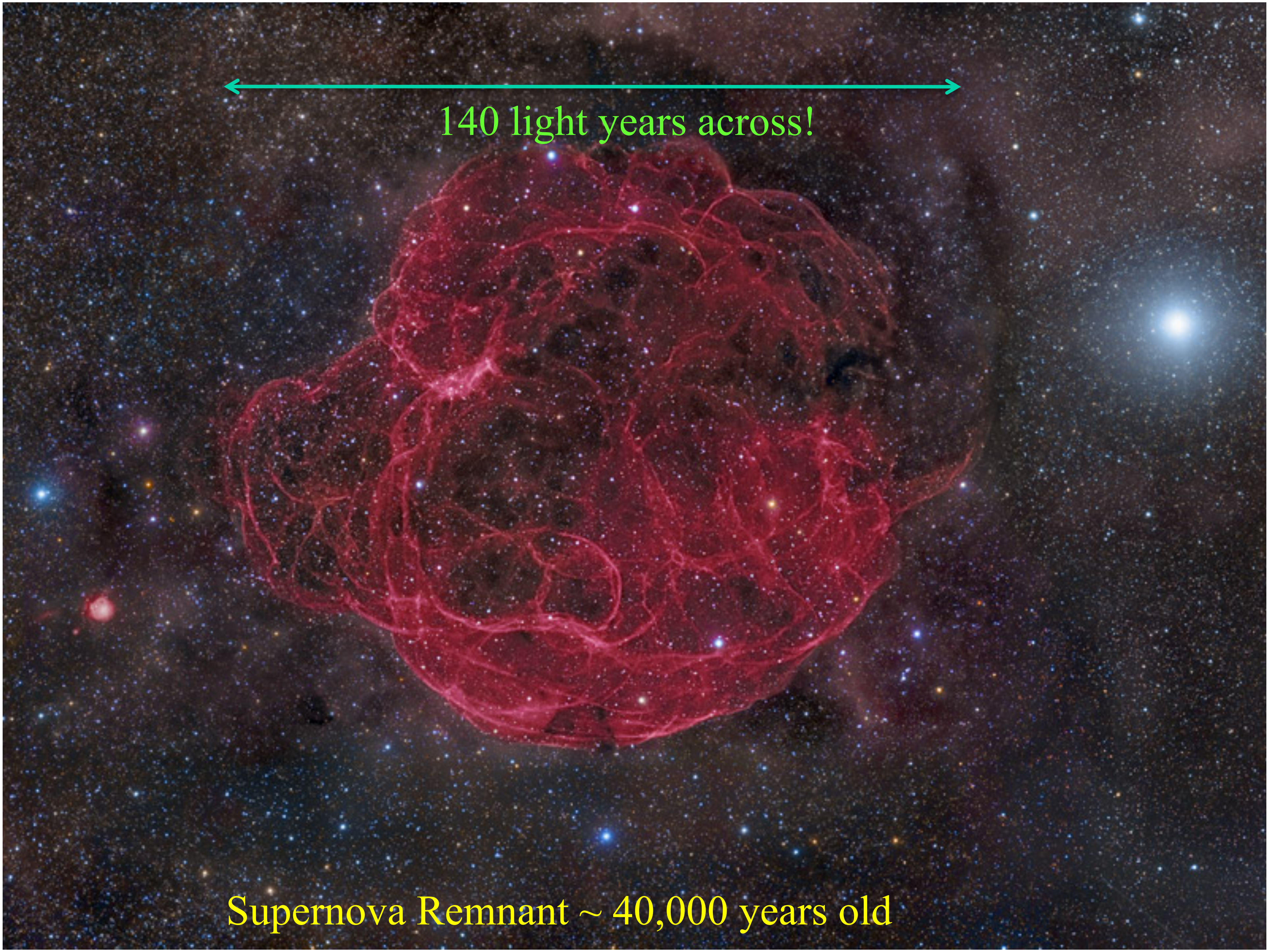
Note the higher abundances of elements with even numbers of protons (the saw tooth…)



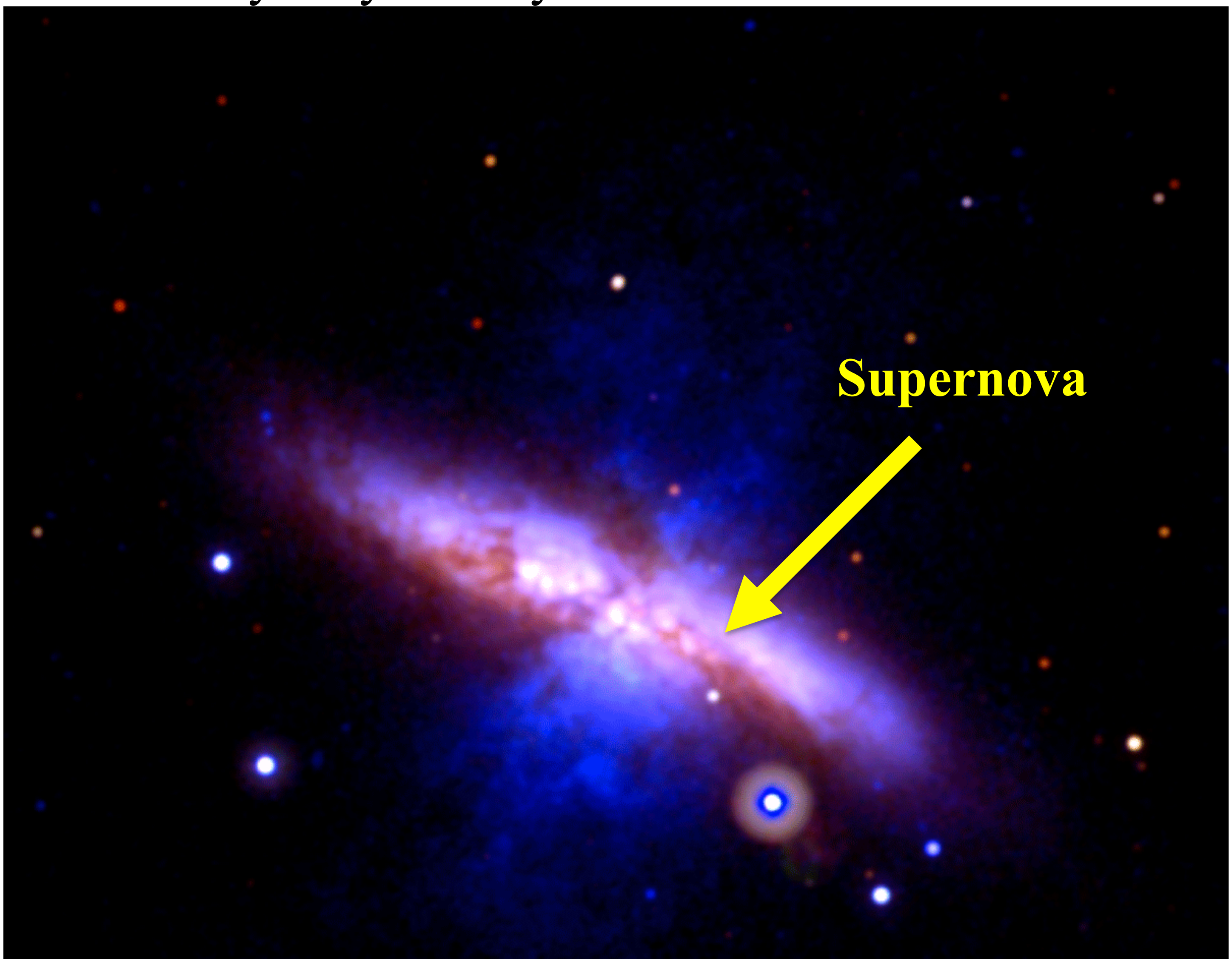
Secondary peak at iron, the most stable element

Elements made during supernova explosion

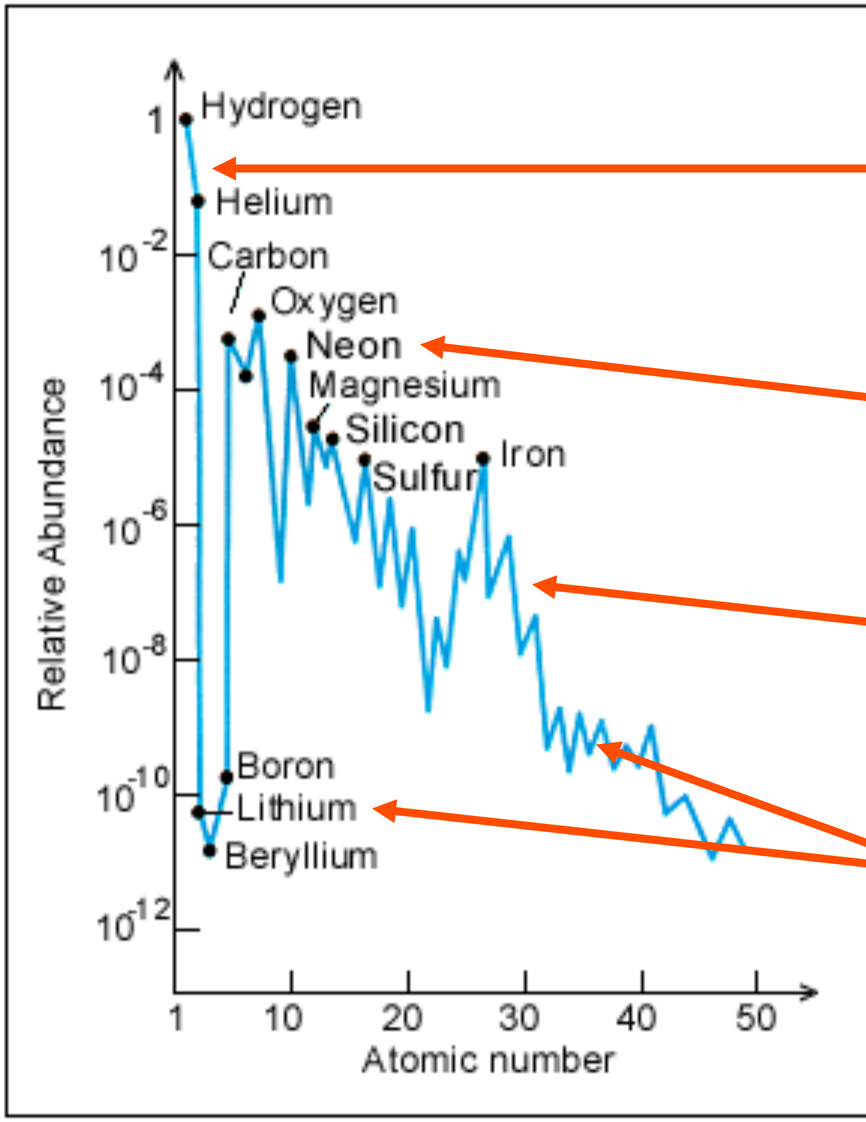
Crab Nebula: Remnant of supernova observed in 1054 A.D.


140 light years across!
Supernova Remnant ~ 40,000 years old

We can see supernova exploding in other galaxies.
The rate of supernova explosions is ~1 per 100 years in the Milky Way Galaxy.



Cosmic Element Abundance



Cosmic chemistry:

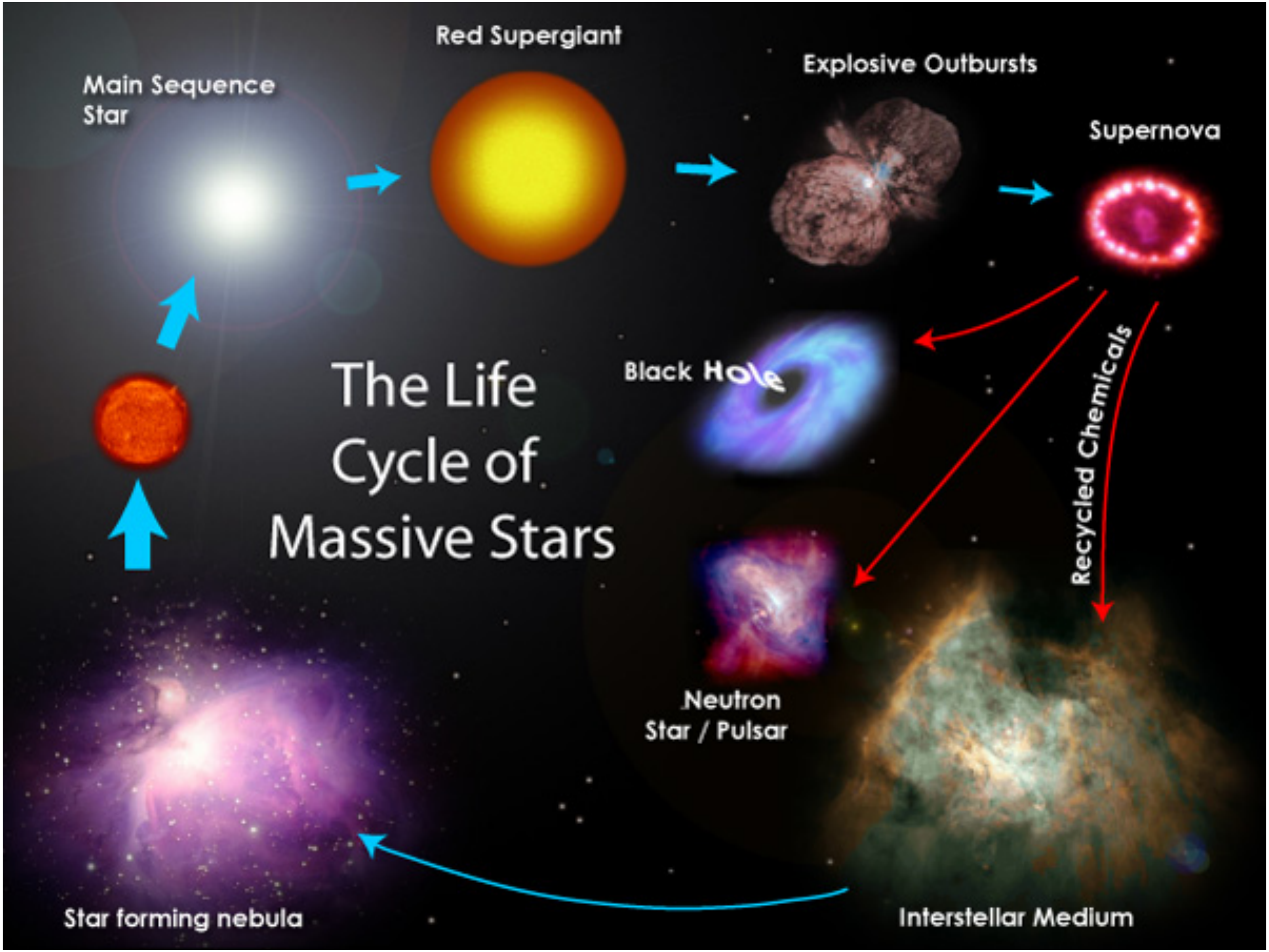
H is fundamental and the He is fused in the early hot big bang

Elements from C to Fe fused in moderately massive stars

Elements beyond Fe are mostly fused in supernova blast waves

Sawtooth is He nucleus added, trough due to unstable atoms

Stars are chemical factories. The universe is built for life!


Main Sequence Star
Red Supergiant
Explosive Outbursts
Supernova
The Life Cycle of Massive Stars
Black Hole
Recycled Chemicals
Neutron Star / Pulsar
Star forming nebula
Interstellar Medium