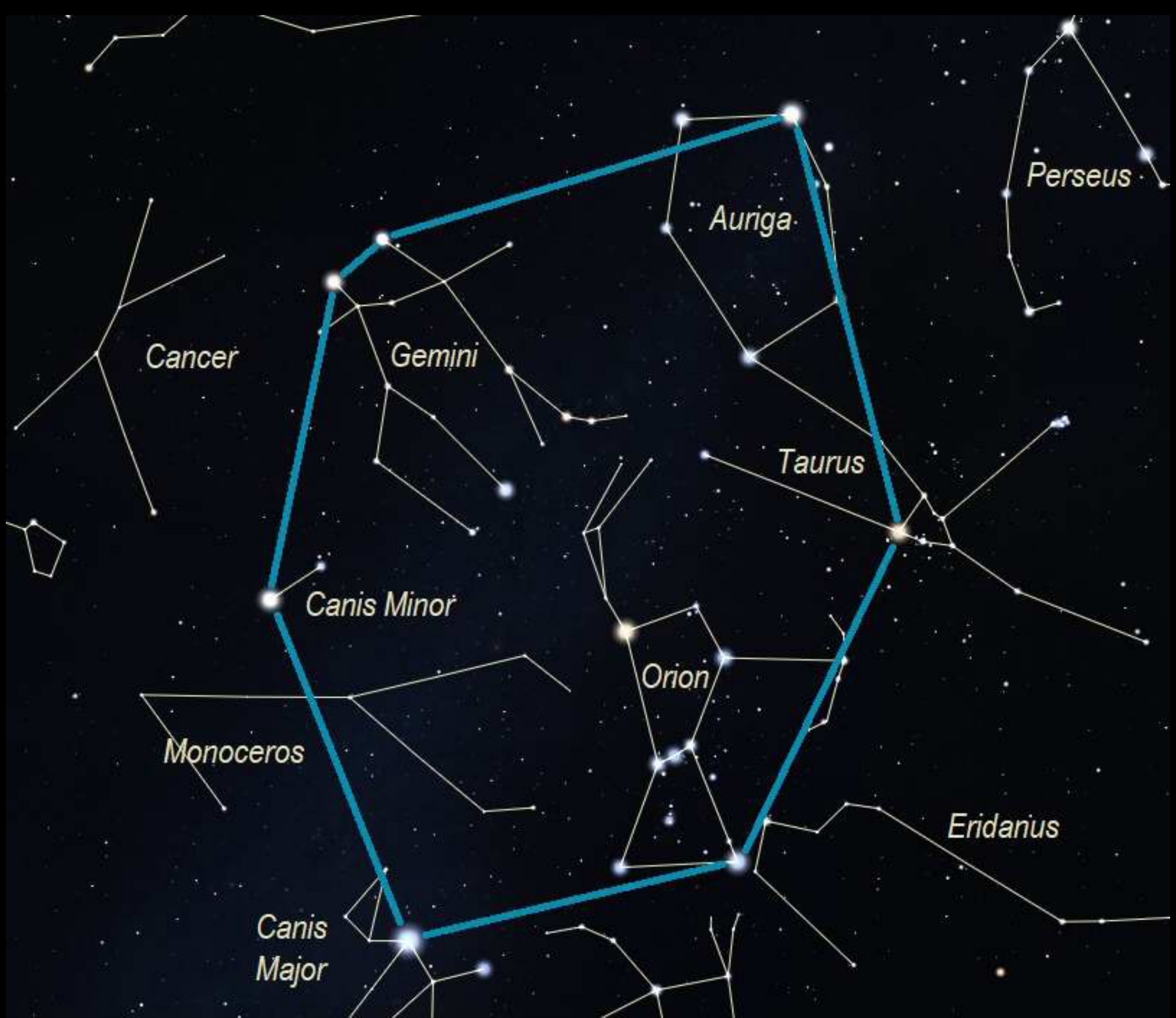
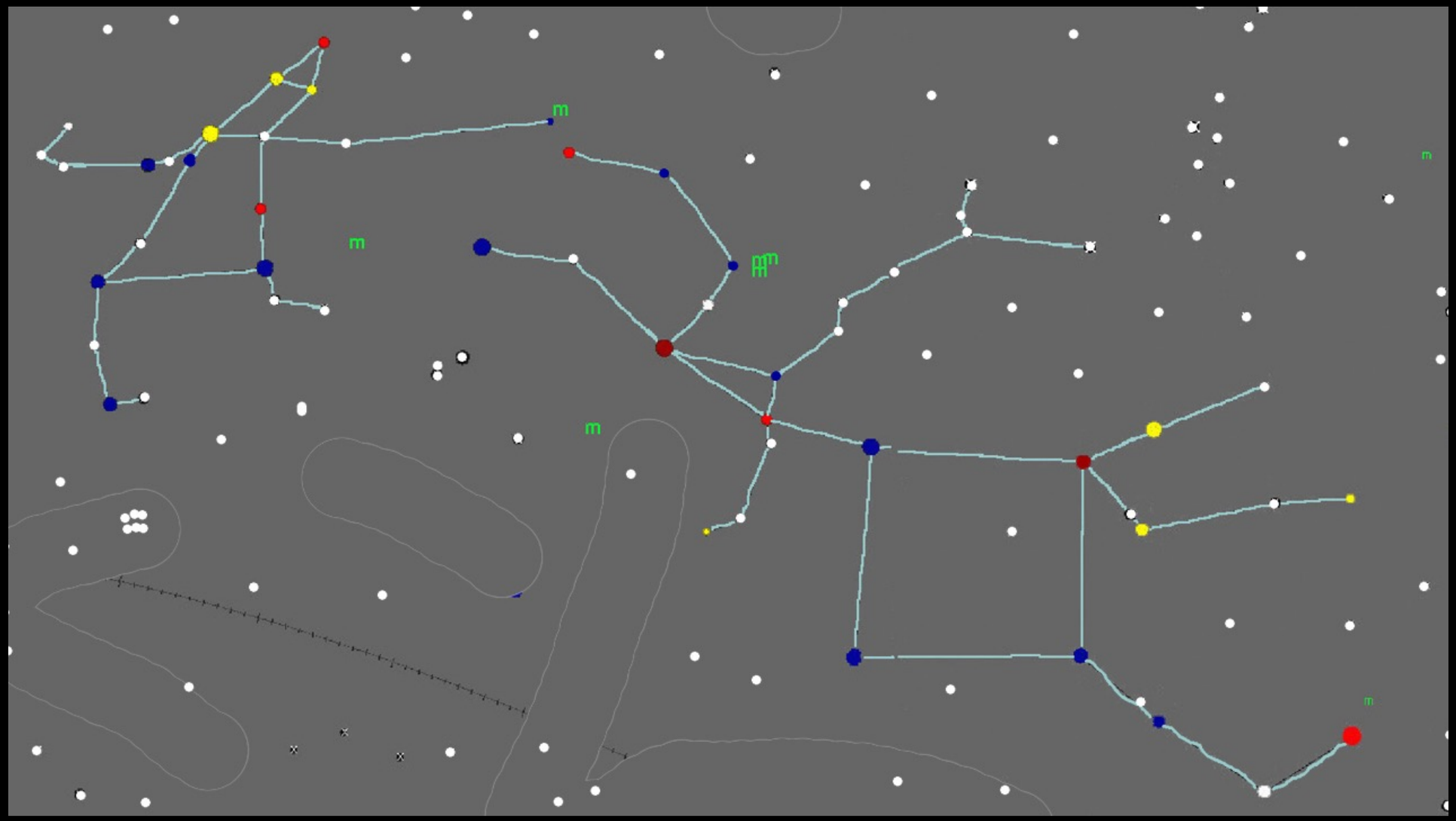

Perseus
Auriga
Cancer
Gemini
Taurus
Canis Minor
Orion
Monoceros
Eridanus
Canis
Major

Perseus-Andromeda-Pegasus



O_B Blue_White = 10,000-60,000K

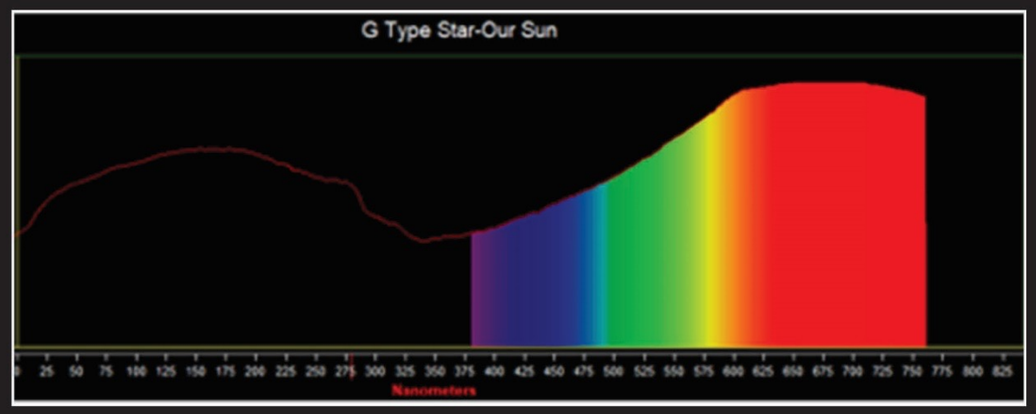
A_F White_Yellow = 6,000-10,000k

G Yellow = 5,000-7,000k

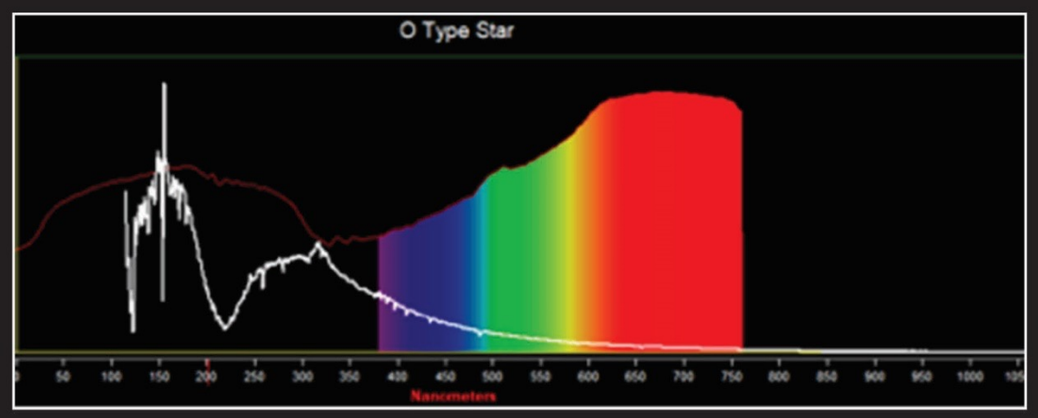
K_M Orange_Red= 1300-5000k

Green = Messier Objects

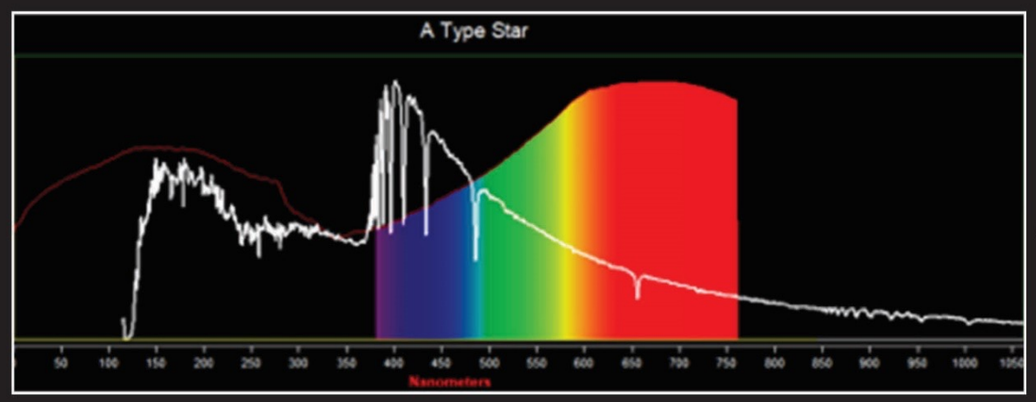
NOTE: Kelvin ≃ C above 1500C


G Type Star-Our Sun
Nanometers

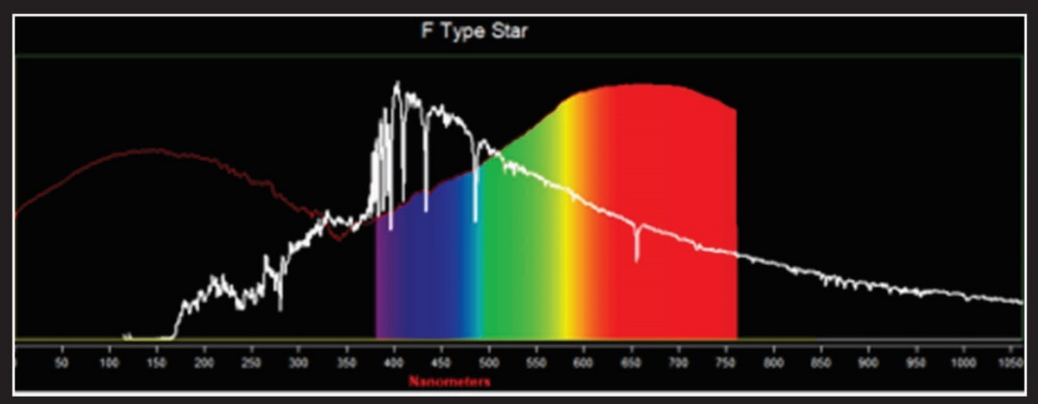
G


O Type Star
Nanometers

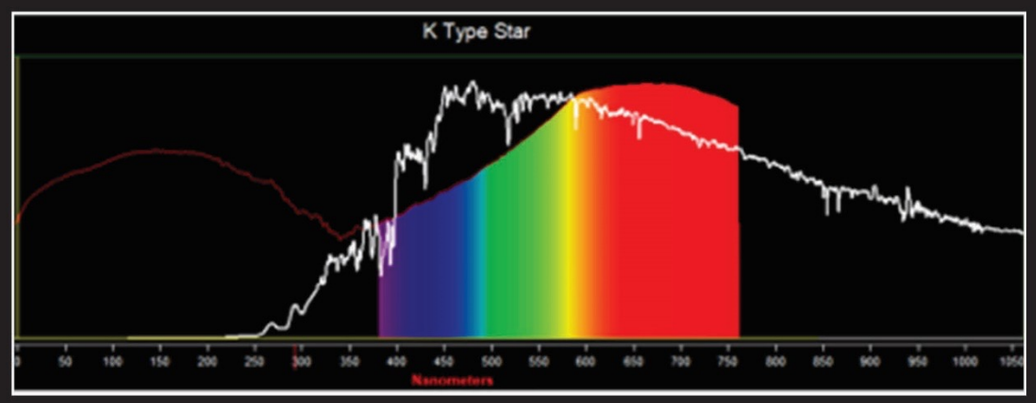
O


A Type Star
Nanometers

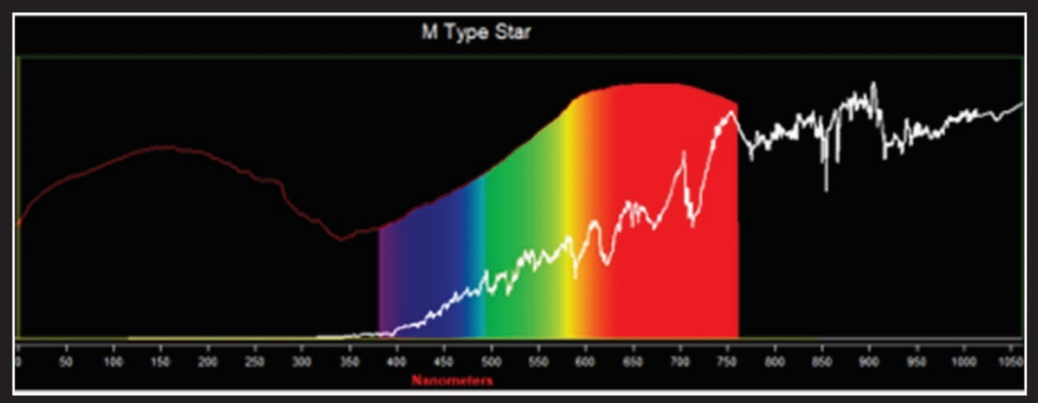
A


F Type Star
Nanometers

F


K Type Star
Nanometers

K


M Type Star
Nanometers

M

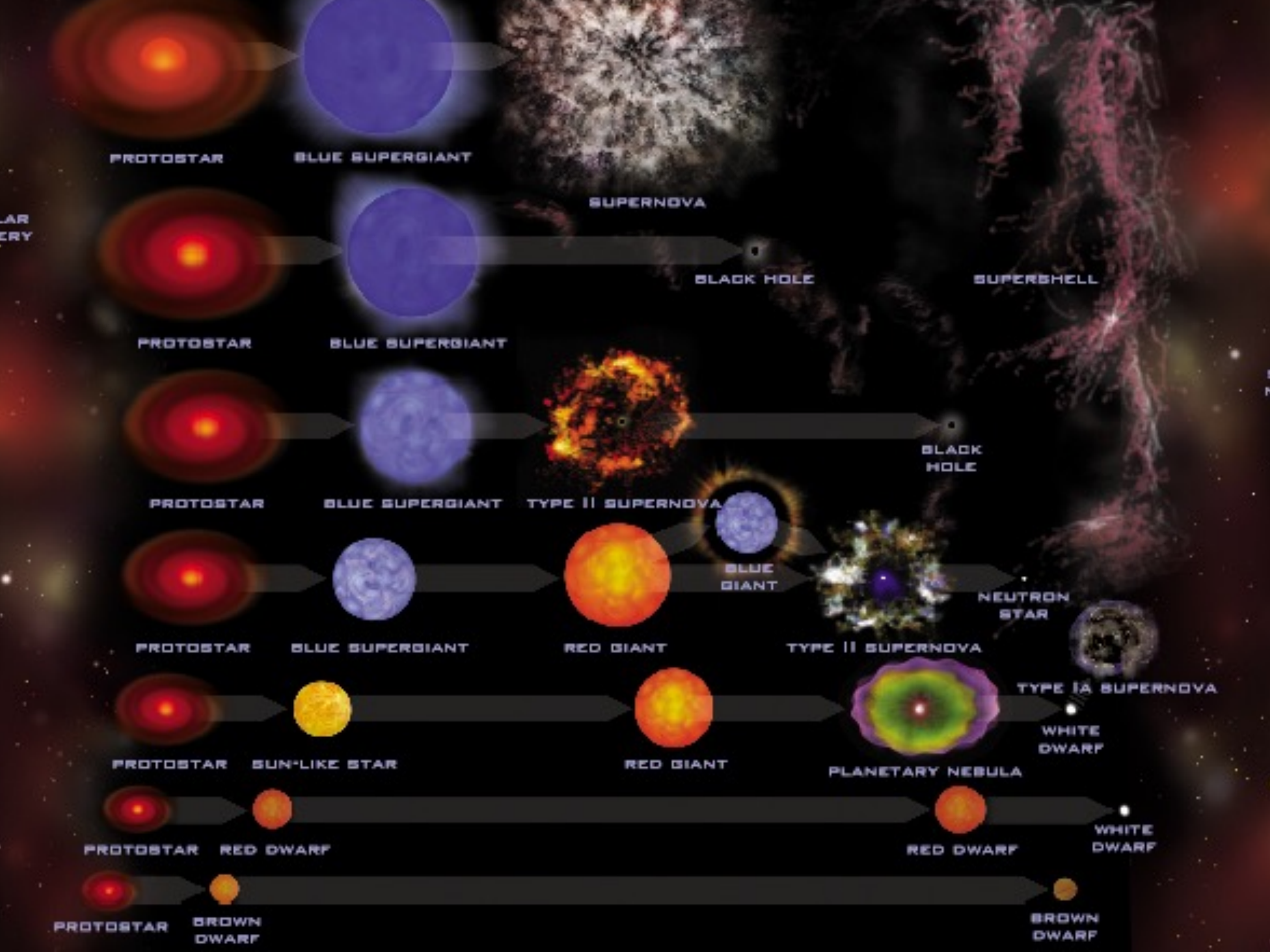
Luminosity (Sun = 1)

10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

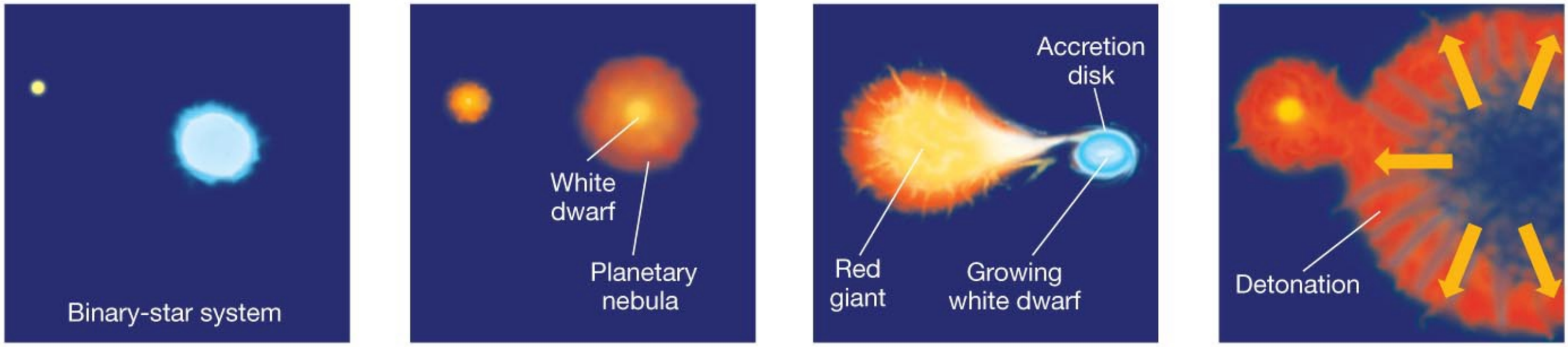
Eta Carinae
Theta[1] C Orionis
1-million-year lifespan
Blue Supergiants
Spica
Rigel
Deneb
Polaris
Mu Cephei
Betelgeuse
Red Supergiants
Antares
Mira
10 million years
Alkaid
Horizontal Branch
Arcturus
Capella Aa
Aldebaran
Red Giants
100 million years
Regulus
Vega
Sirius A
1 billion years
Altair
Alpha Centauri A
Procyon A
MAIN SEQUENCE
10 billion years
Sun
Tau Ceti
Alpha Centauri B
Epsilon Eridani
Sirius B
White Dwarfs
Procyon B
100 billion years
Barnard's Star
Proxima Centauri
Wolf 359
Red Dwarfs
1 trillion years
Star sizes not to scale

S&T DIAGRAM: LEAH TISCIONE

O5 B0 B5 A0 A5 F0 F5 G0 G5 K0 K5 M0 M5 M7
30,000 20,000 10,000 6,000 4,000 2,500
Surface temperature (kelvins)

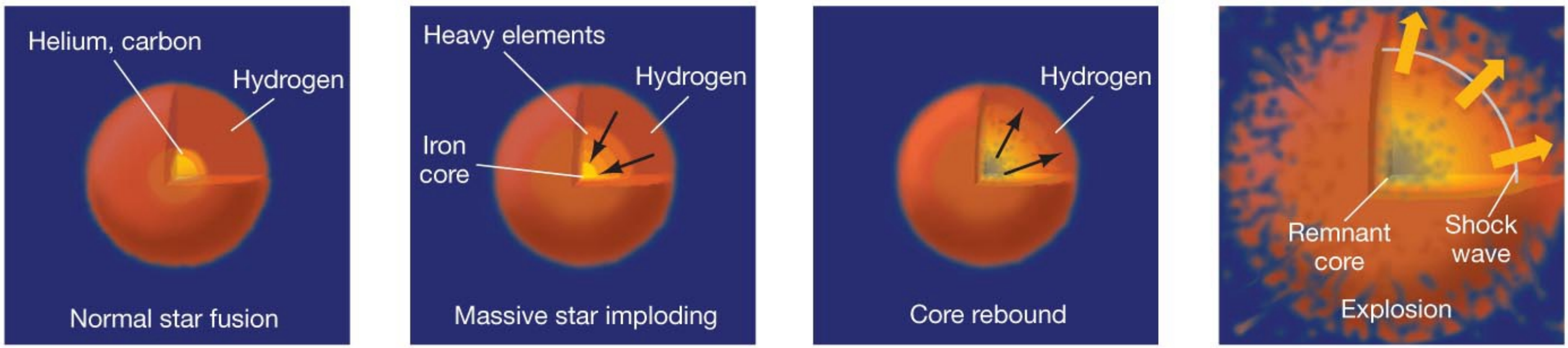

PROTOSTAR
BLUE SUPERGIANT
SUPERNOVA
BLACK HOLE
SUPERSHELL
PROTOSTAR
BLUE SUPERGIANT
PROTOSTAR
BLUE SUPERGIANT
TYPE II SUPERNOVA
BLACK HOLE
PROTOSTAR
BLUE SUPERGIANT
RED GIANT
BLUE GIANT
NEUTRON STAR
TYPE II SUPERNOVA
PROTOSTAR
SUN-LIKE STAR
RED GIANT
PLANETARY NEBULA
TYPE IA SUPERNOVA
WHITE DWARF
PROTOSTAR
RED DWARF
RED DWARF
WHITE DWARF
PROTOSTAR
BROWN DWARF
BROWN DWARF

(a) Type I Supernova

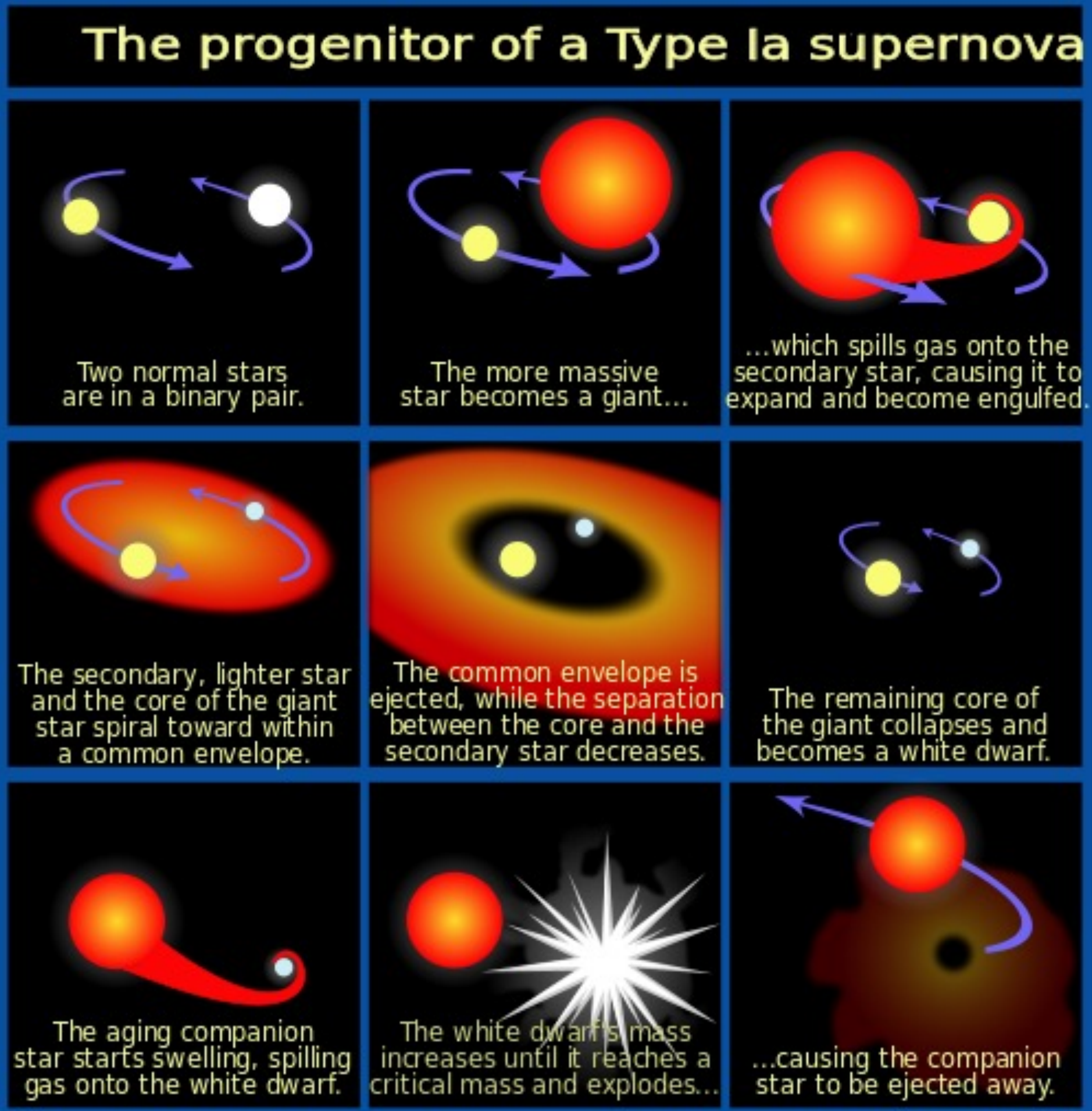


Time

(b) Type II Supernova

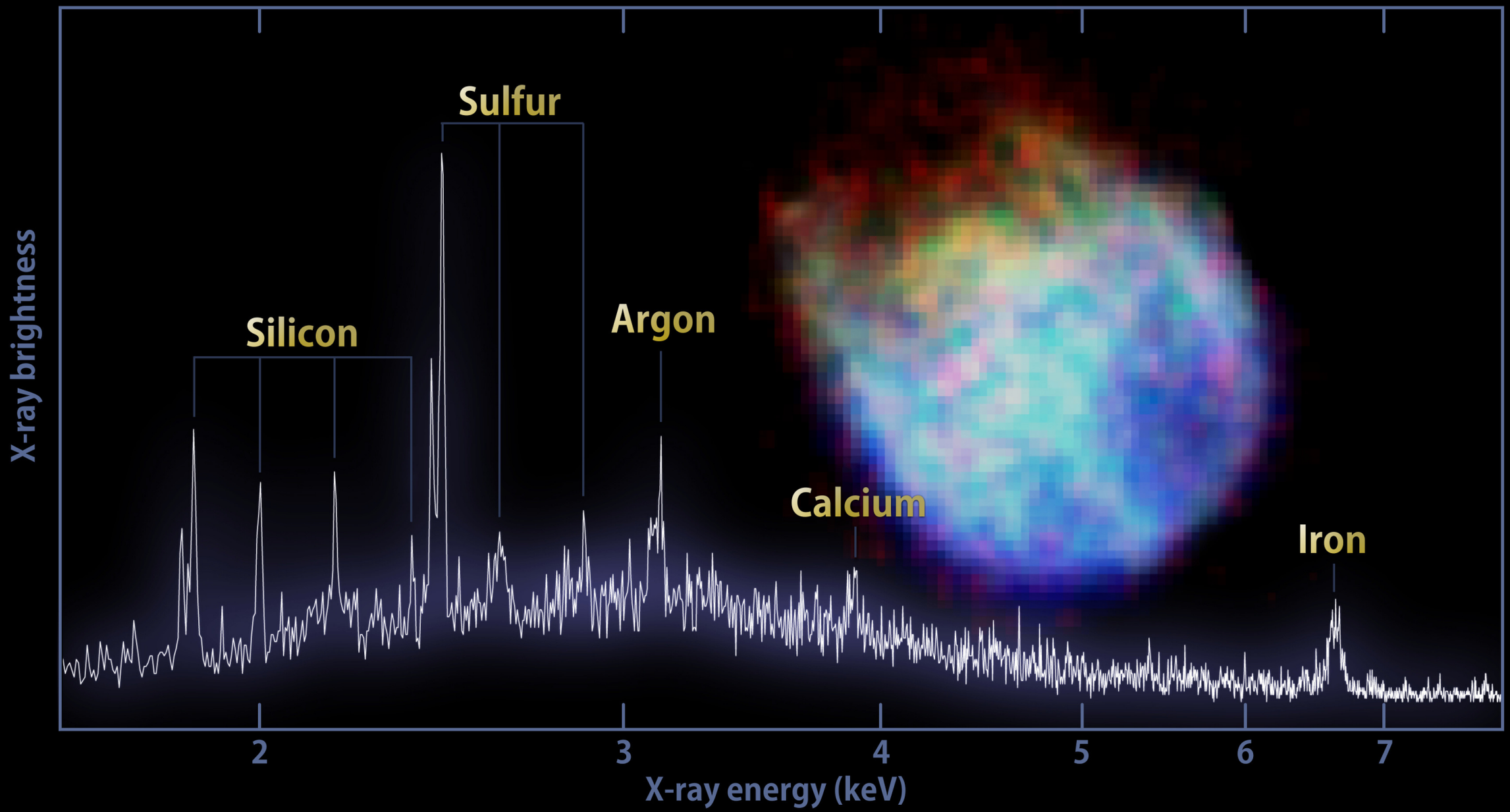


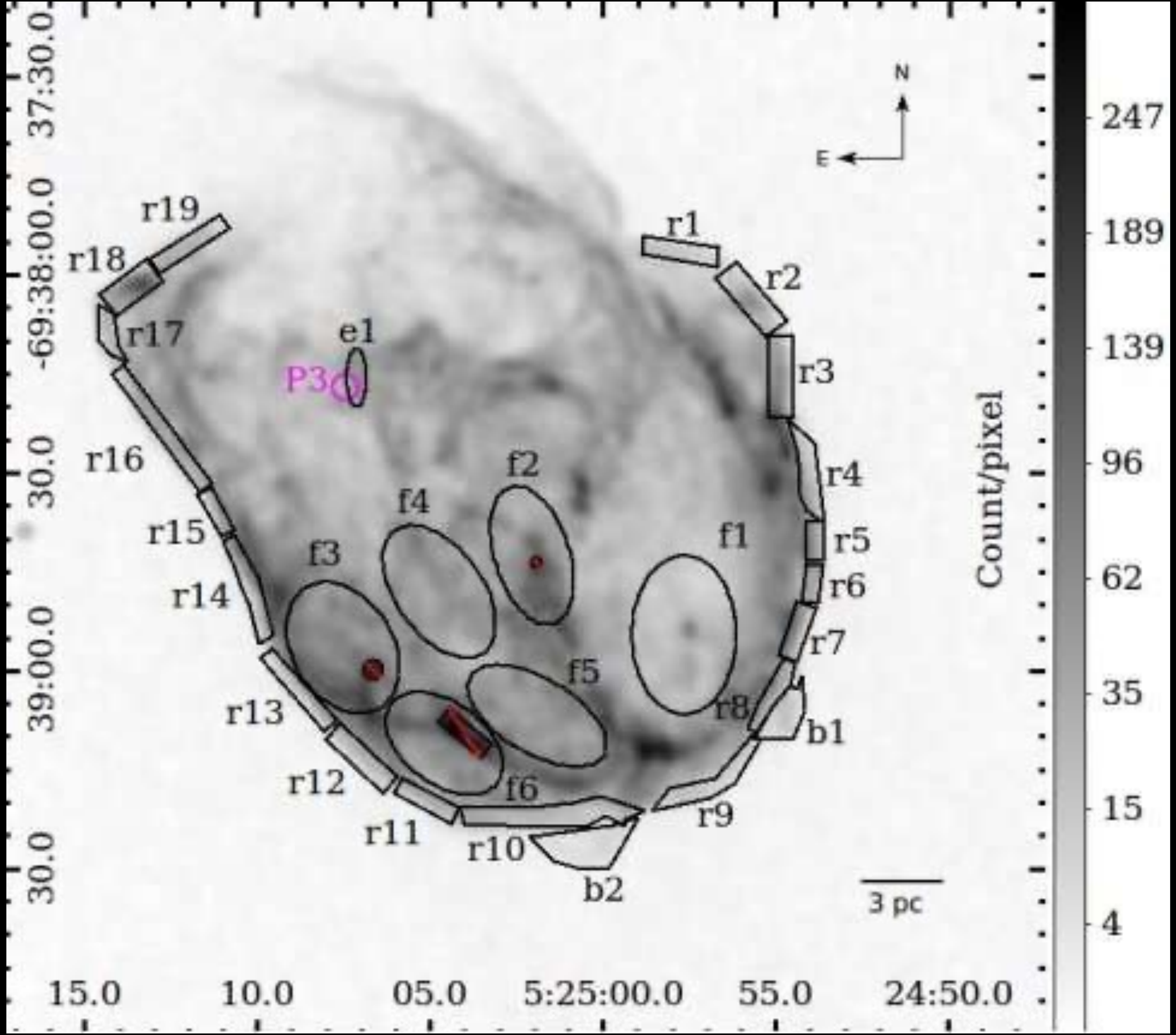
Several SNR in 30 Doradus B
Tarantula Nebula (large HII star forming region)
In LMC

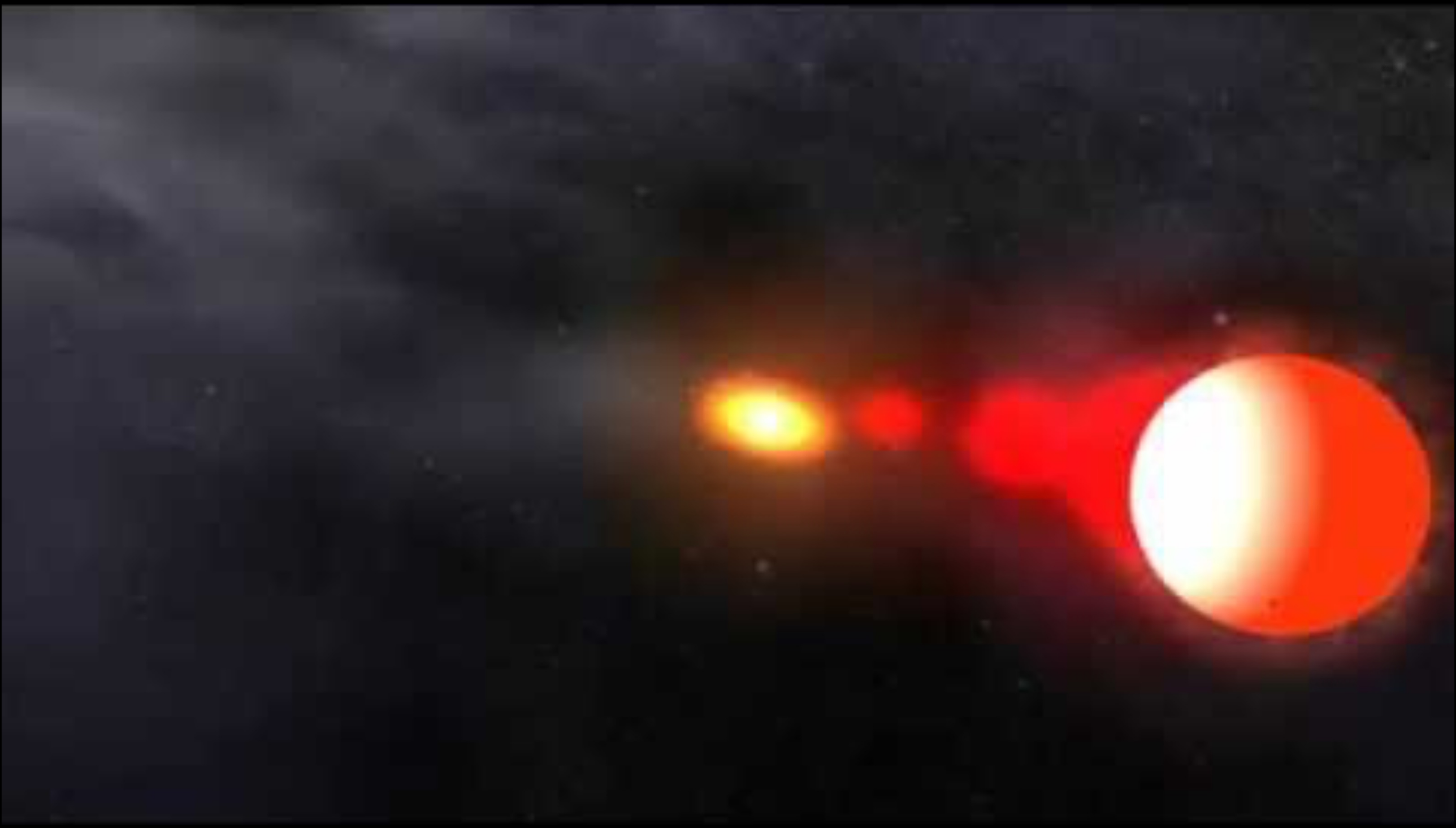


Spectra Show no Hydrogen line BUT a Sharp Silicon line And Initially a bright Nickel line

XRISM Resolve's Recipe for Supernova Remnant N132D




N
E
r19
r18
r17
r16
r15
r14
r13
r12
r11
r10
b2
r1
r2
r3
r4
r5
r6
r7
r8
b1
r9
e1
P3
f1
f2
f3
f4
f5
f6
3 pc
37:30.0
-69:38:00.0
30.0
39:00.0
30.0
15.0
10.0
05.0
5:25:00.0
55.0
24:50.0
Count/pixel
247
189
139
96
62
35
15
4



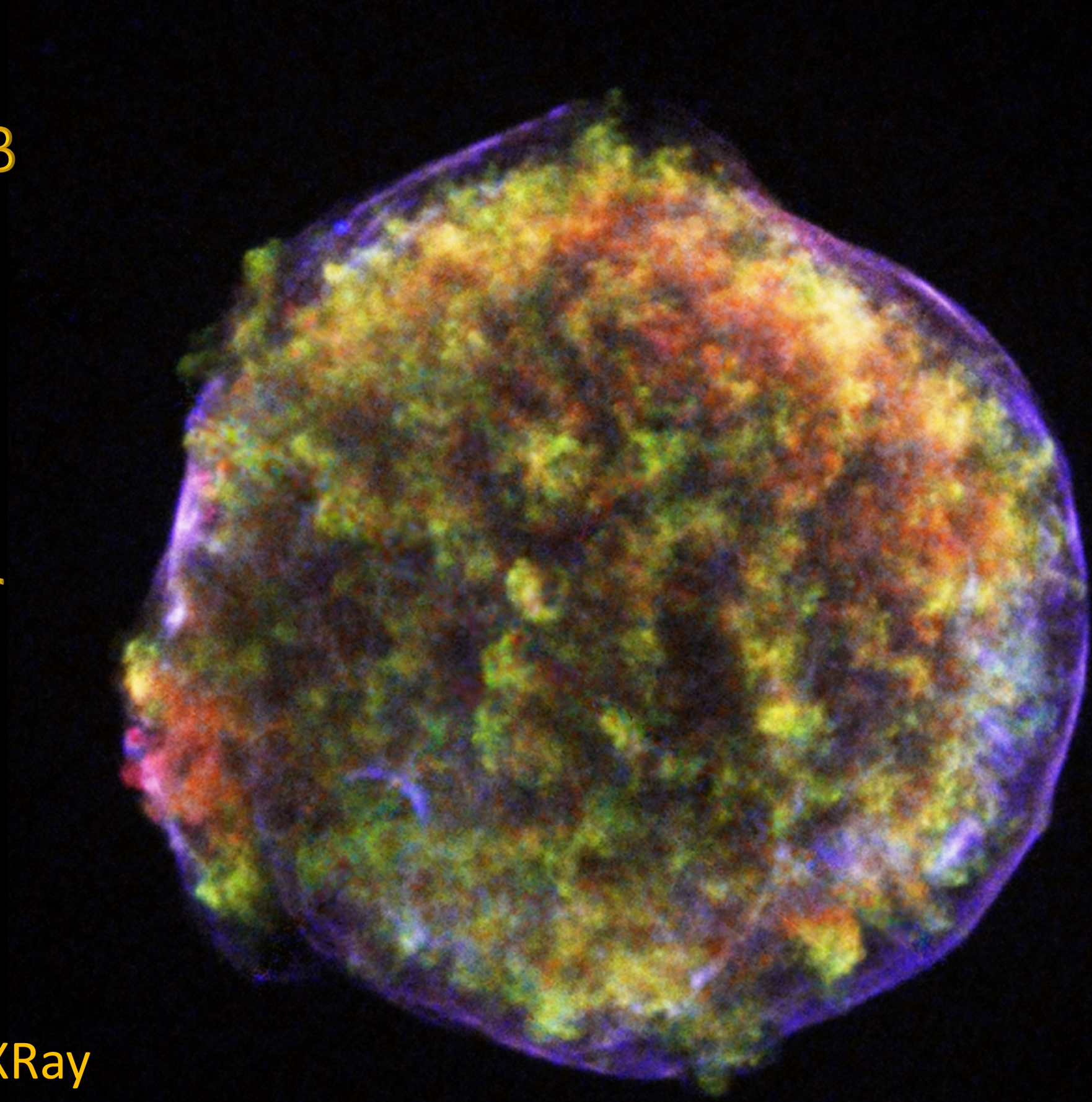
Cassiopeia B
Supernova
Remnant

SNR 1572
Tycho’s star

WISE

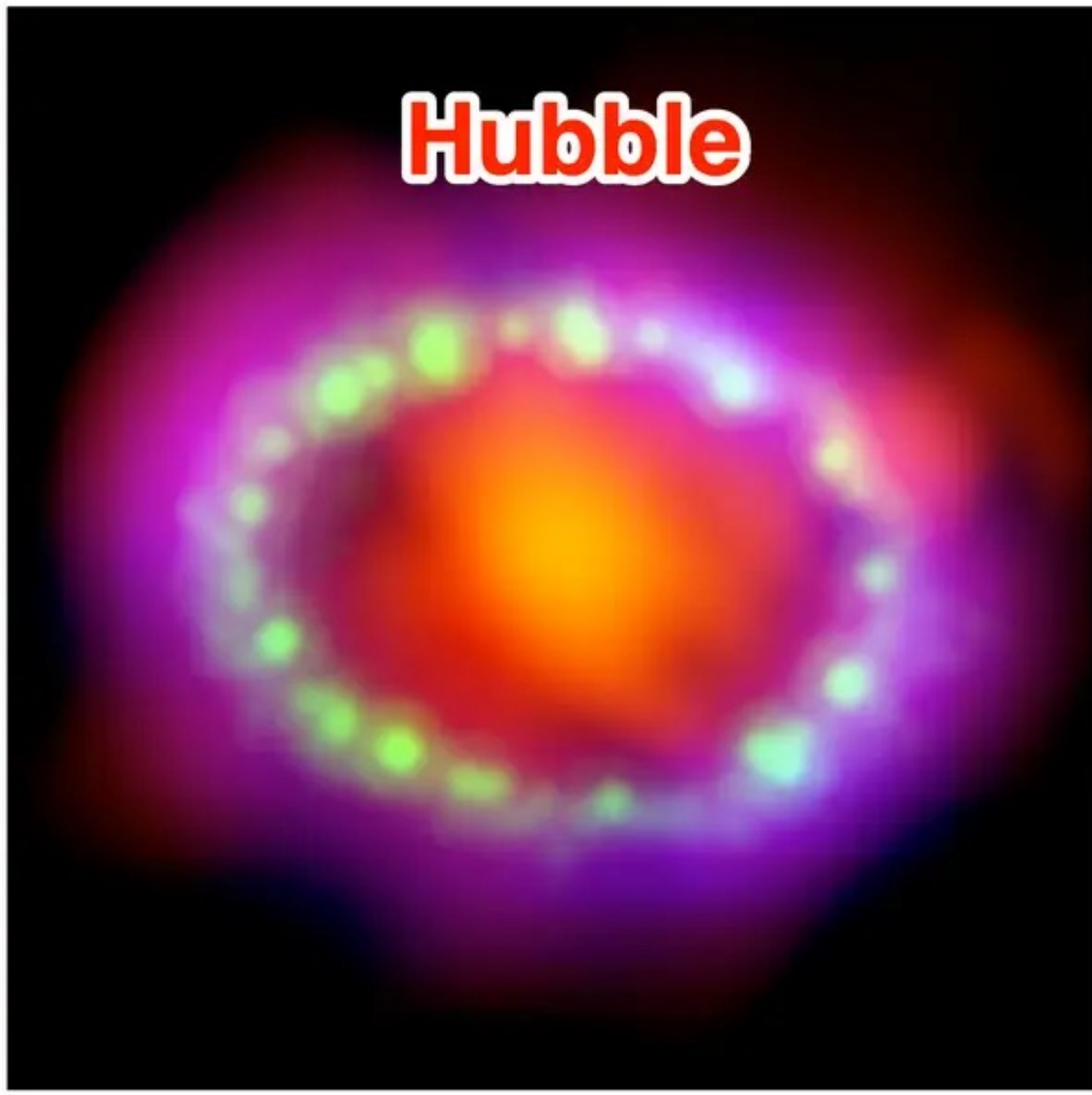
Cassiopeia B
Supernova
Remnant

SNR 1572
Tycho’s star



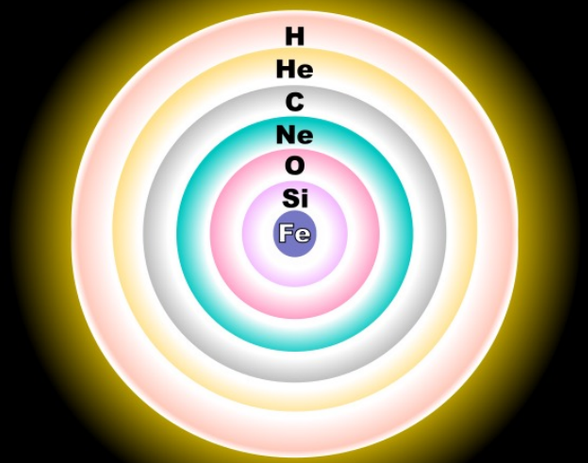
Chandra XRay

Type II Supernova
Core Collapse



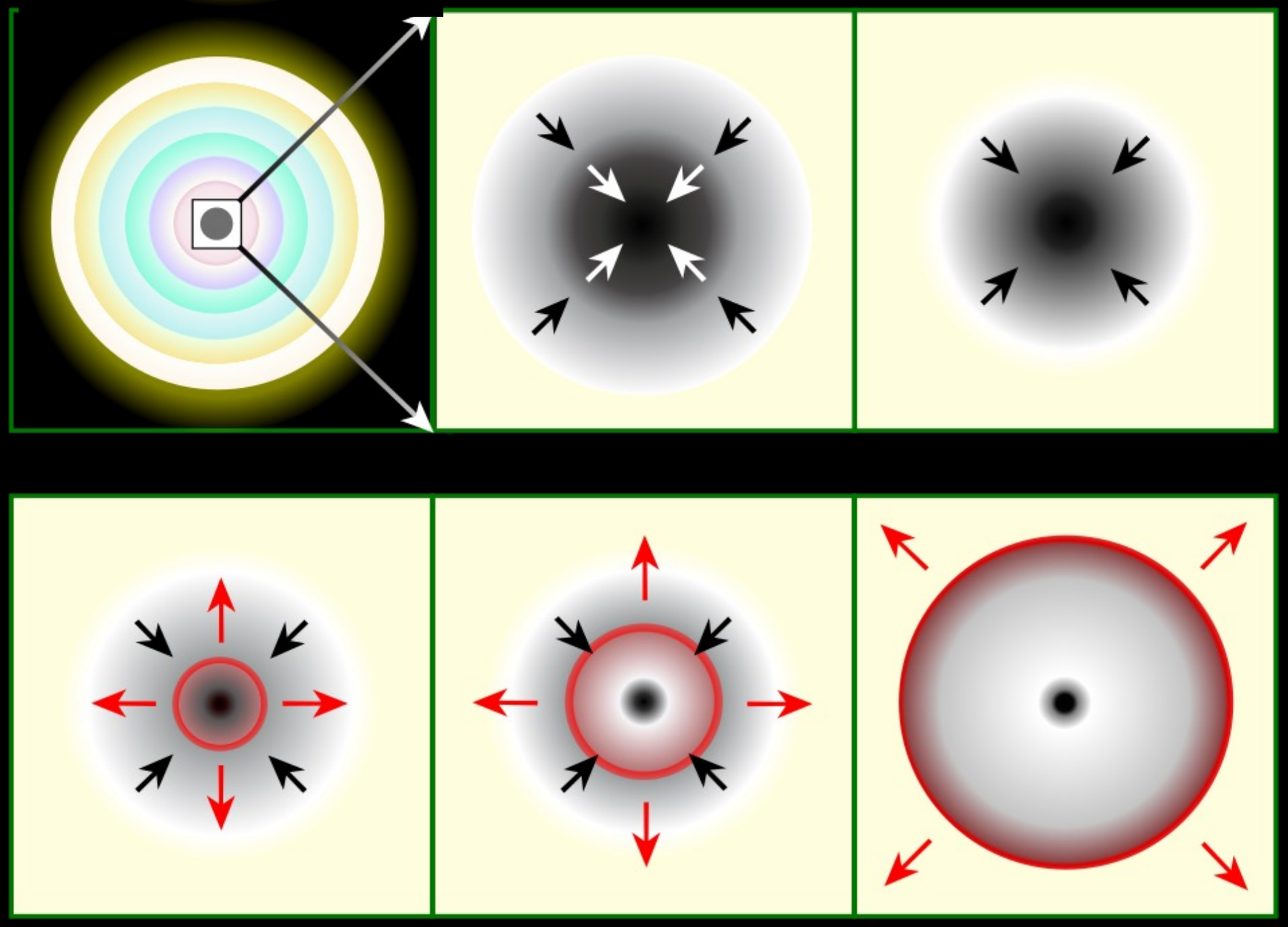
SNR 1987

Supernova 1054 Chaco Cañon Petrogyph



Core > 1.4Ms

Spectra Show weak then strong Hydrogen and Helium lines



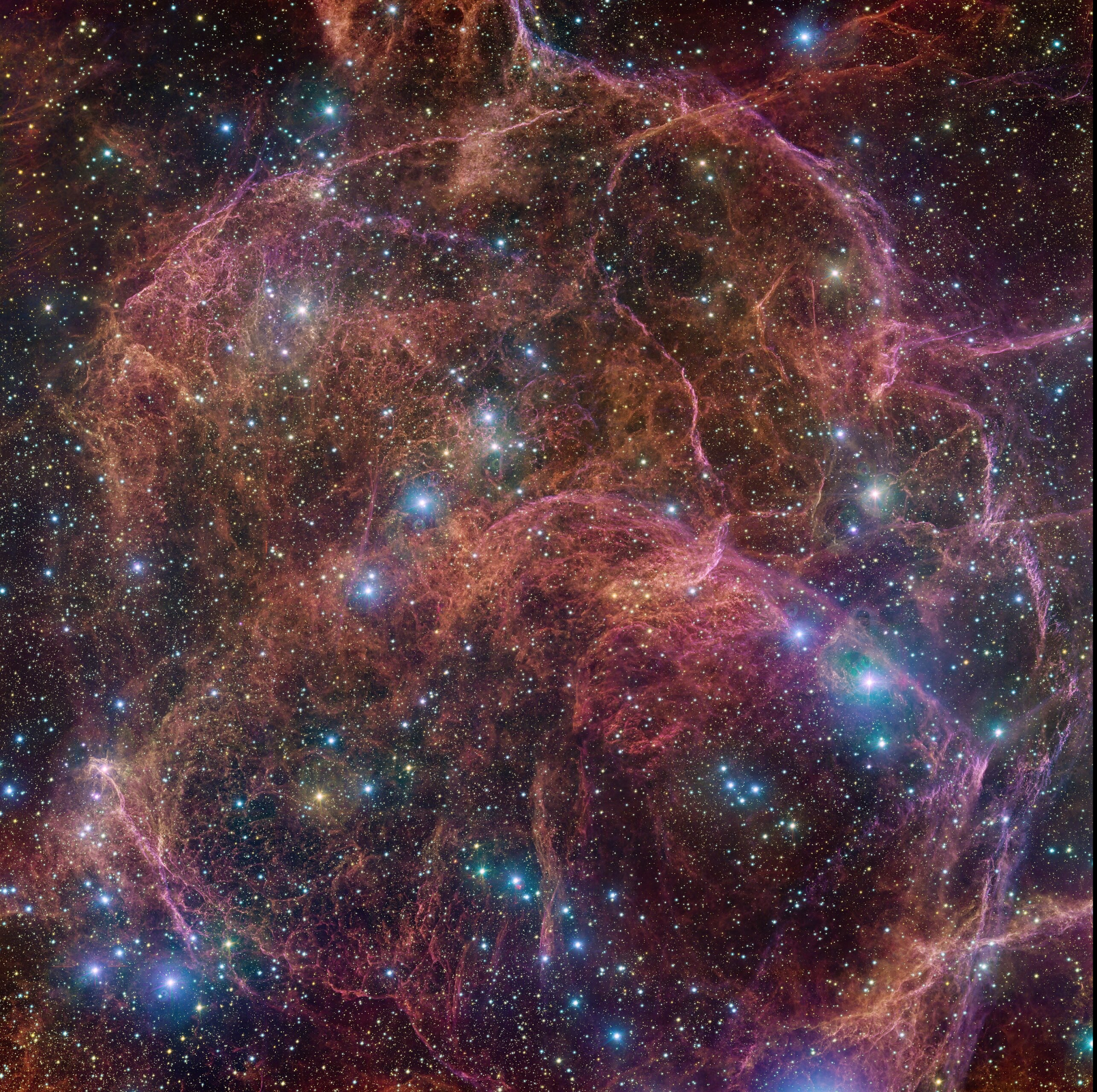
Initially bright Nickel, Iron, Silicon lines

Cassiopeia A Supernova Remnant

JWST MIRI

Cassiopeia A Supernova Remnant

JWST NIRcam

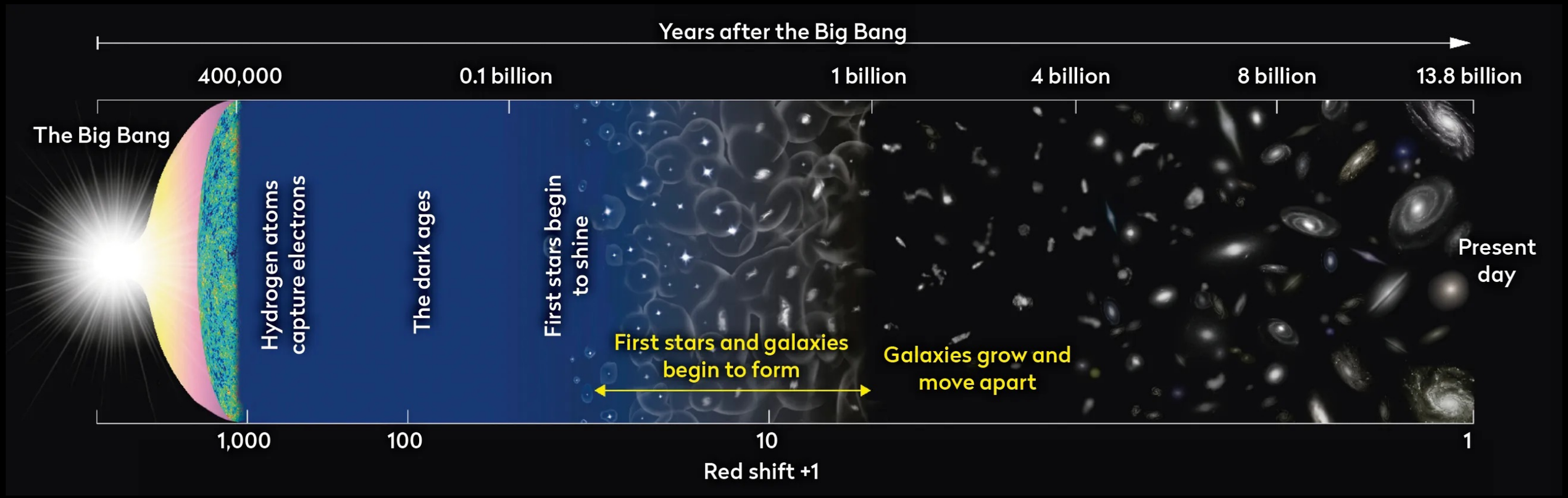


Vela-Pupus Supernova Remnant

VLT, ESO

SNR
S 223,224
Auriga
SPL

NUCLEOSYNTHESIS


Years after the Big Bang
400,000
0.1 billion
1 billion
4 billion
8 billion
13.8 billion
The Big Bang
Hydrogen atoms capture electrons
The dark ages
First stars begin to shine
First stars and galaxies begin to form
Galaxies grow and move apart
Present day
1,000
100
10
1
Red shift +1

Origins of the Elements


The big bang


Dying low-mass stars


White dwarf supernovae


Radioactive decay

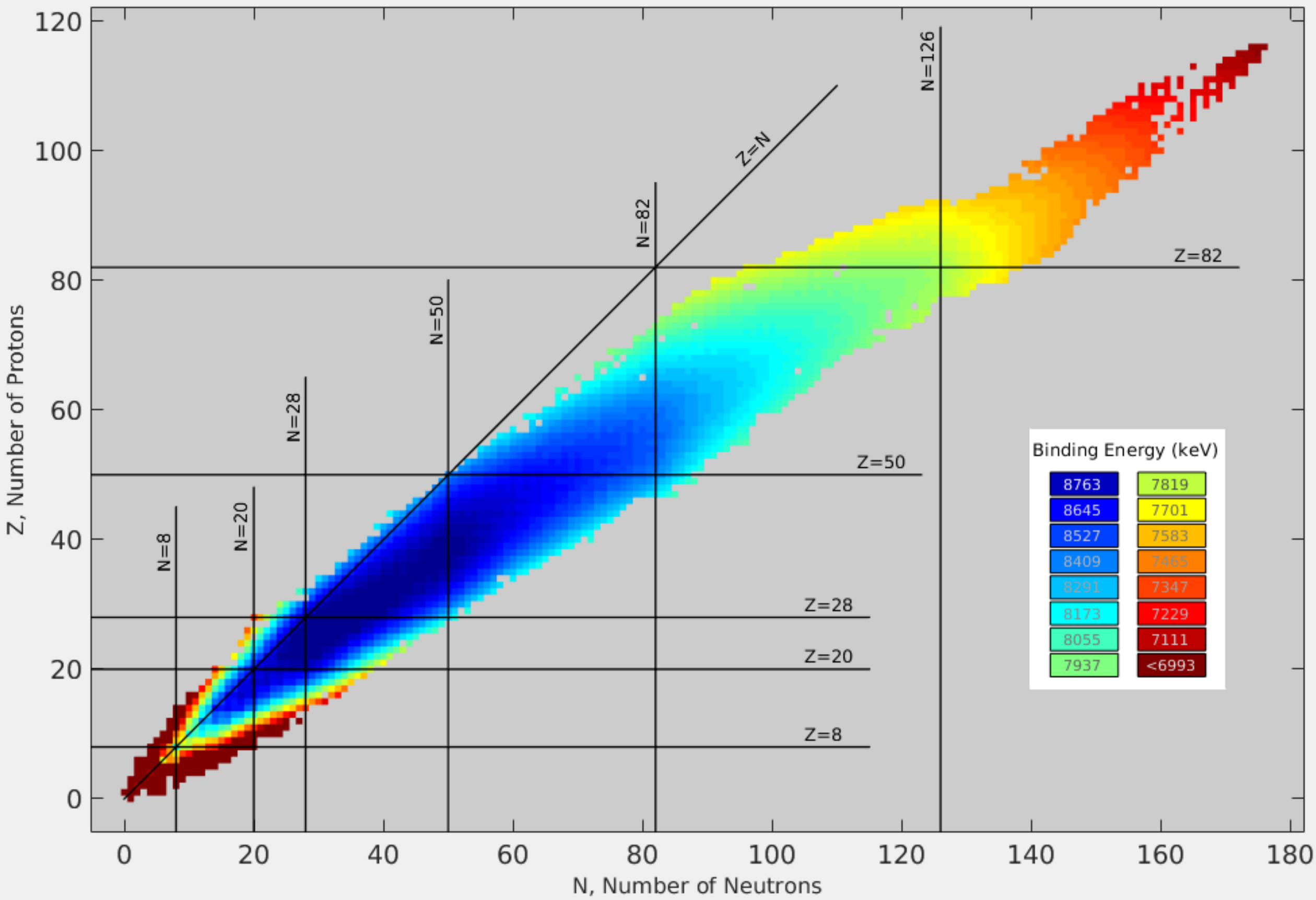

Cosmic ray collisions


Dying high-mass stars


Merging neutron stars

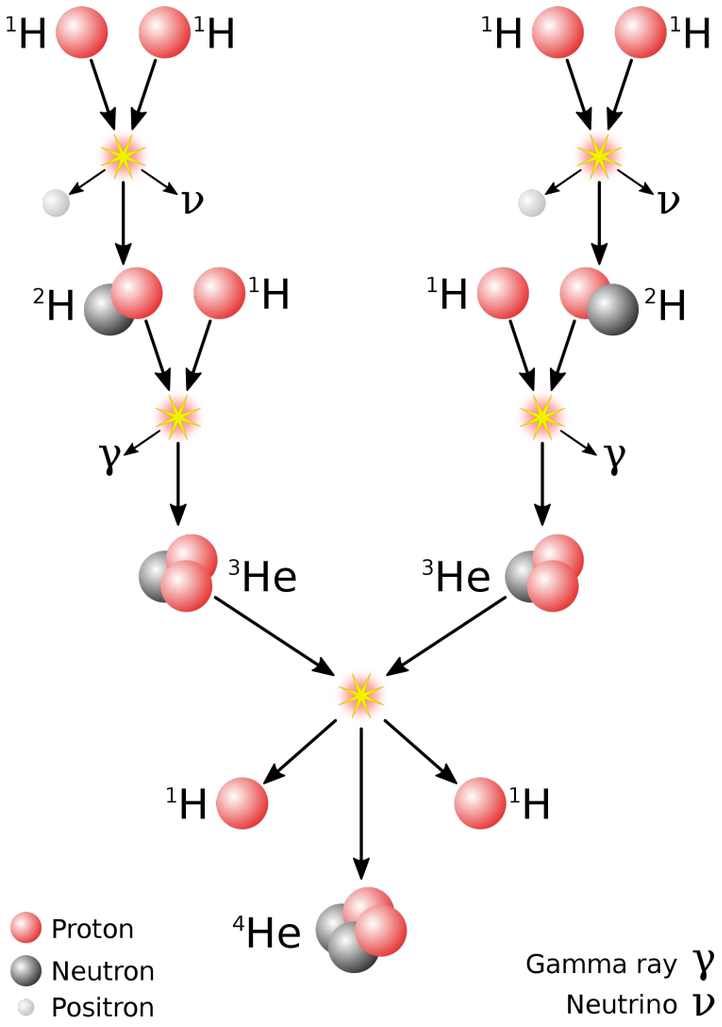

Human-made

This periodic table depicts the primary source on Earth for each element. In cases where two sources contribute fairly equally, both appear.

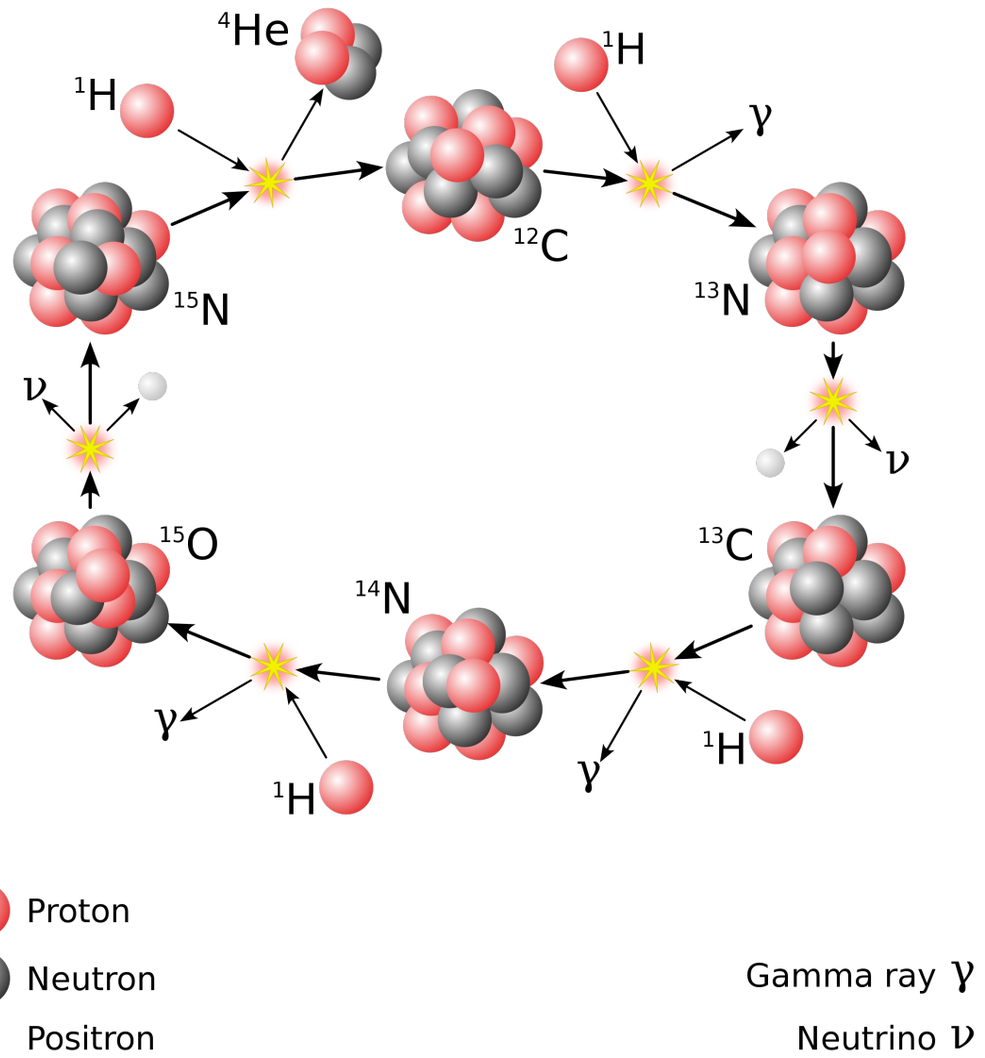


Atomic Nuclides

Nuclear Fusion
Main Sequence Star Reactions



P-P process



C-N-O process

H,He

He,N

He,C,^{22}Ne

O,C

O,Ne,Mg

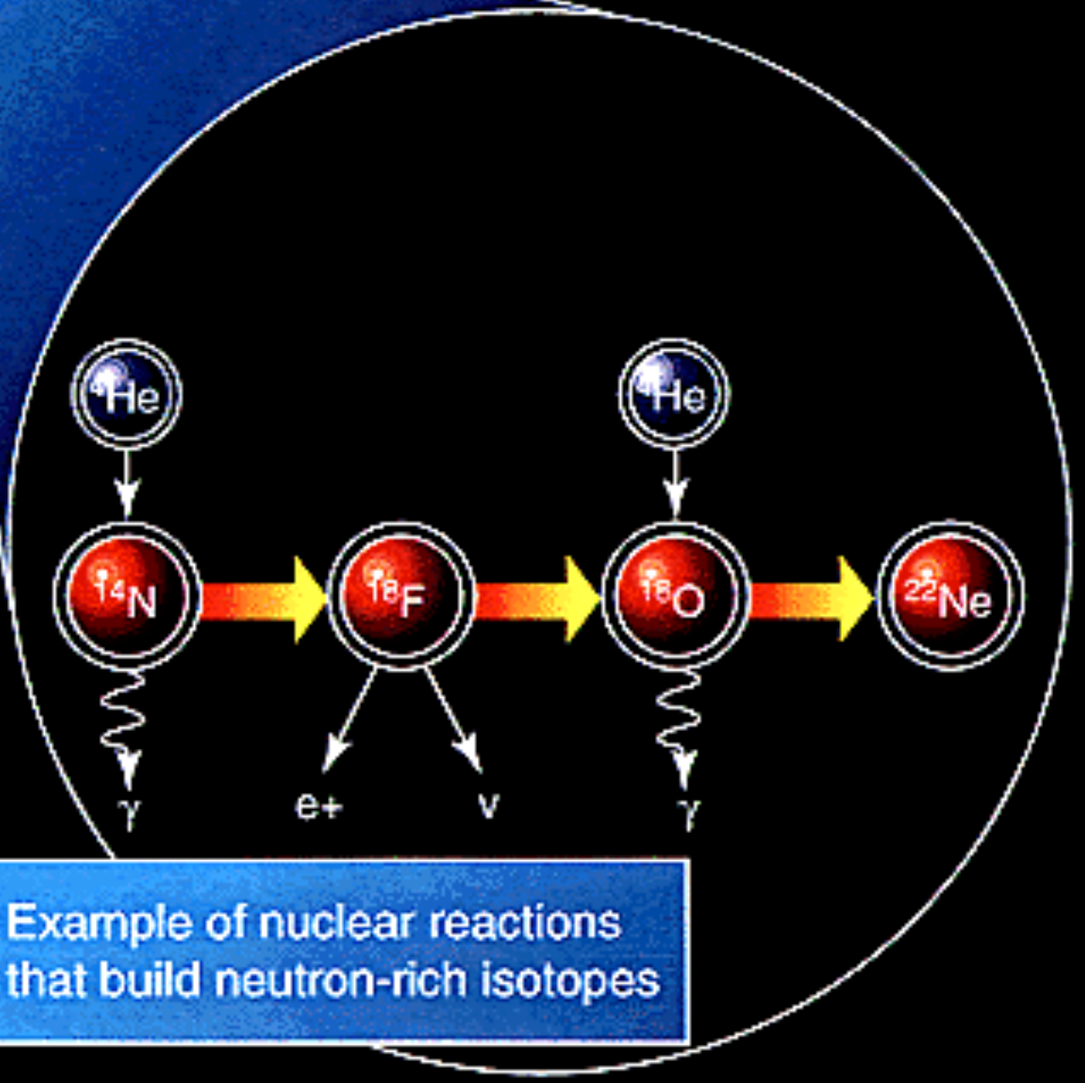
Si,S

Fe,Ni core

Red Giant Star

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

Nuclear burning occurs at the boundaries between zones

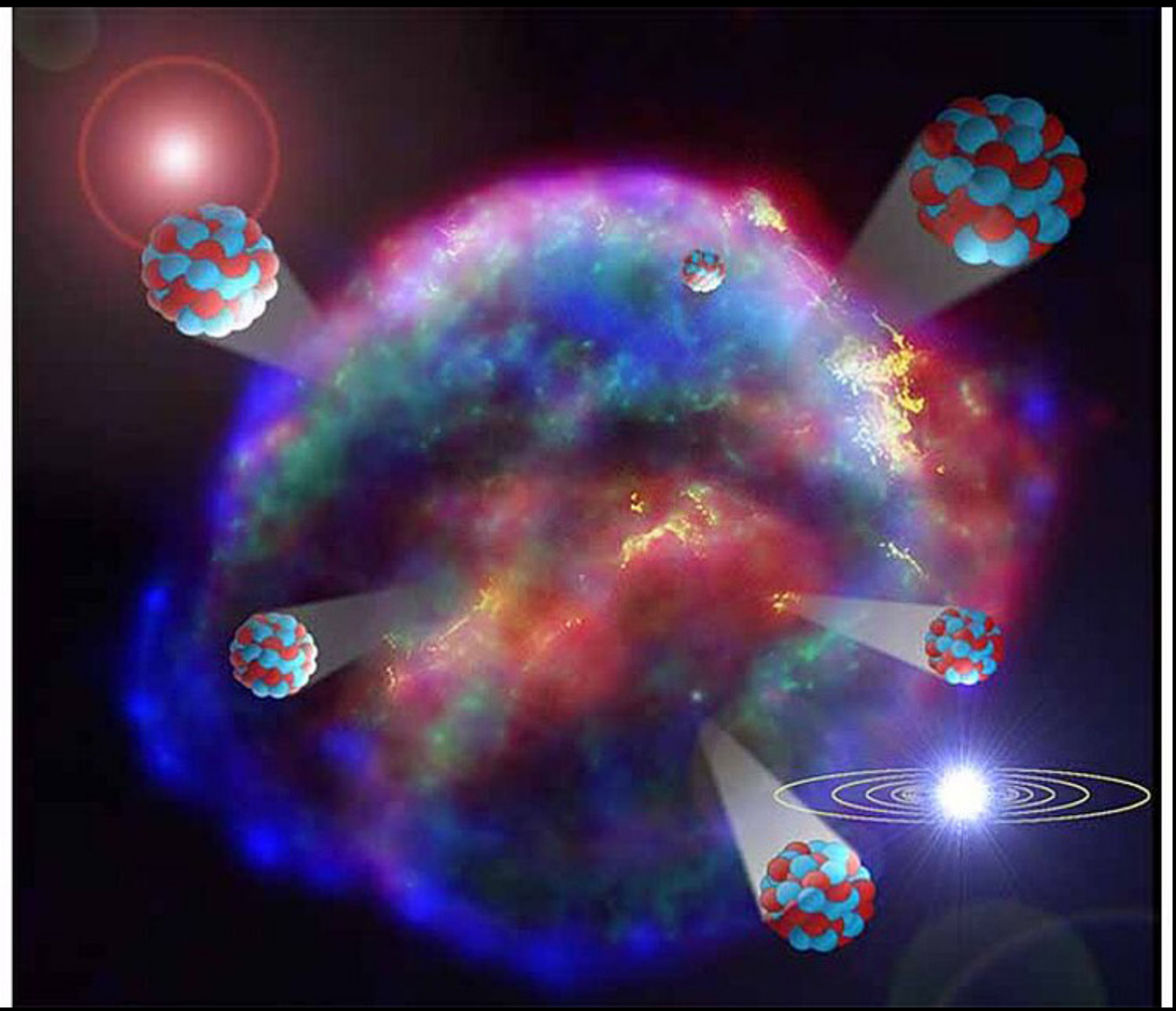


Example of nuclear reactions that build neutron-rich isotopes

Nuclear Fission

Neutron Star collision

r-process



Artist rendering

Nuclear Fission

$$^{236}_{92}U \longrightarrow {}^{90}_{38}Sr + {}^{144}_{54}Xe + 2\ {}^{1}_{0}n$$

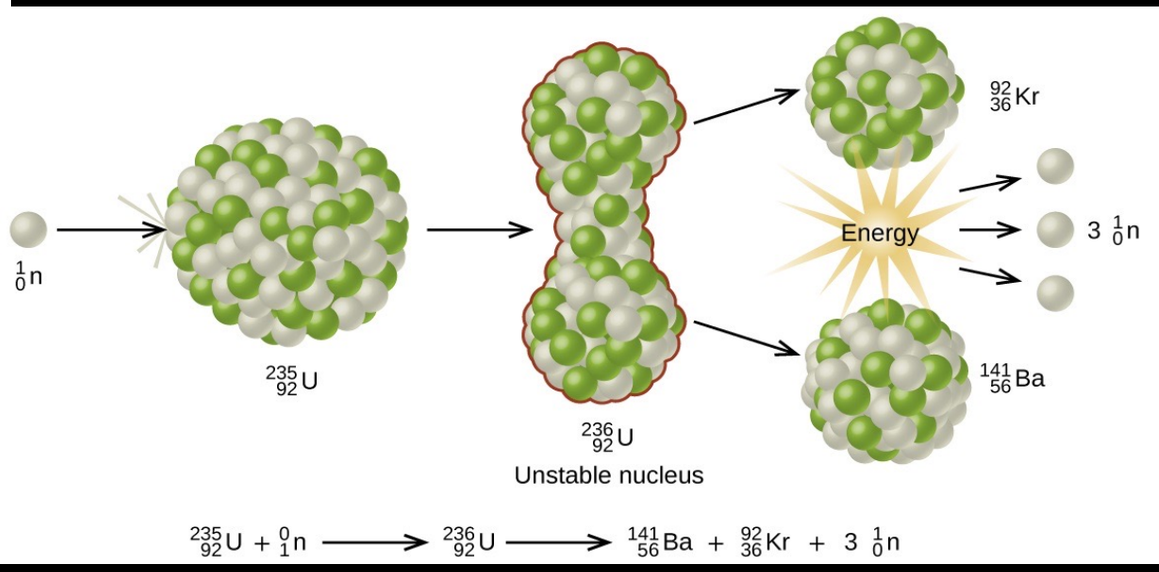
$$^{236}_{92}U \longrightarrow {}^{87}_{35}Br + {}^{146}_{57}La + 3\ {}^{1}_{0}n$$

$$^{236}_{92}U \longrightarrow {}^{96}_{37}Rb + {}^{137}_{55}Cs + 3\ {}^{1}_{0}n$$

$$^{236}_{92}U \longrightarrow {}^{137}_{52}Te + {}^{97}_{40}Zr + 2\ {}^{1}_{0}n$$

$$^{236}_{92}U \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\ {}^{1}_{0}n$$

Typical Uranium pathways



Kilonovae

Hypernovae

Extrinsic collisions

Standard Model of Elementary Particles

three generations of matter (fermions)

interactions / force carriers (bosons)

	I	II	III		
mass	≈2.2 MeV/c²	≈1.28 GeV/c²	≈173.1 GeV/c²	0	≈125.11 GeV/c²
charge	⅔	⅔	⅔	0	0
spin	½	½	½	1	0
	u	c	t	g	H
	up	charm	top	gluon	higgs
	≈4.7 MeV/c²	≈96 MeV/c²	≈4.18 GeV/c²	0	
	−⅓	−⅓	−⅓	0	
	½	½	½	1	
	d	s	b	γ	
	down	strange	bottom	photon	
	≈0.511 MeV/c²	≈105.66 MeV/c²	≈1.7768 GeV/c²	≈91.19 GeV/c²	
	−1	−1	−1	0	
	½	½	½	1	
	e	μ	τ	Z	
	electron	muon	tau	Z boson	
	<1.0 eV/c²	<0.17 MeV/c²	<18.2 MeV/c²	≈80.360 GeV/c²	
	0	0	0	±1	
	½	½	½	1	
	ν_e	ν_μ	ν_τ	W	
	electron neutrino	muon neutrino	tau neutrino	W boson	

QUARKS

LEPTONS

GAUGE BOSONS
VECTOR BOSONS

SCALAR BOSONS