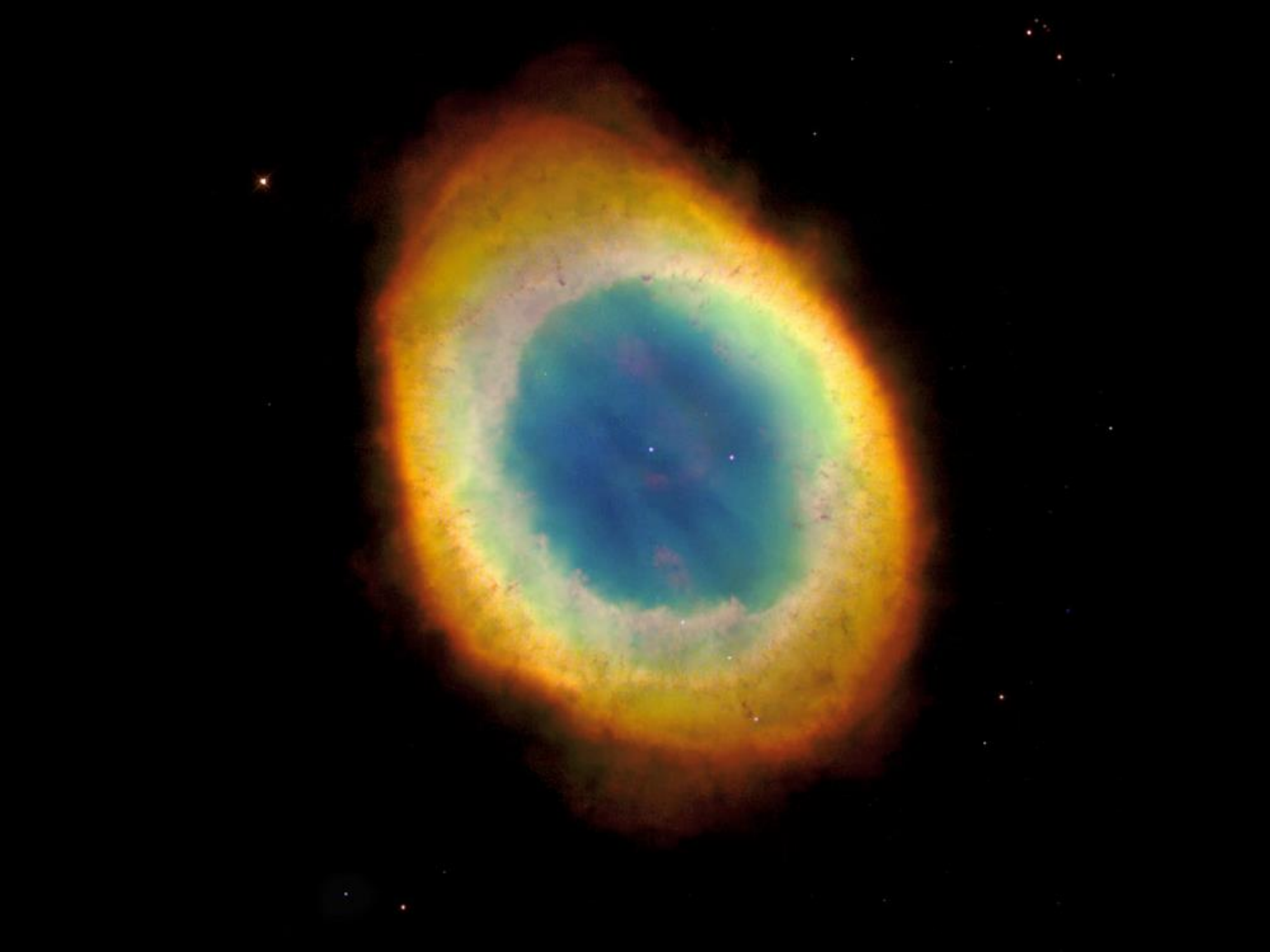
Stars are temporary.

We know this because

— We see the remains of dead stars



We know this because

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We know this because

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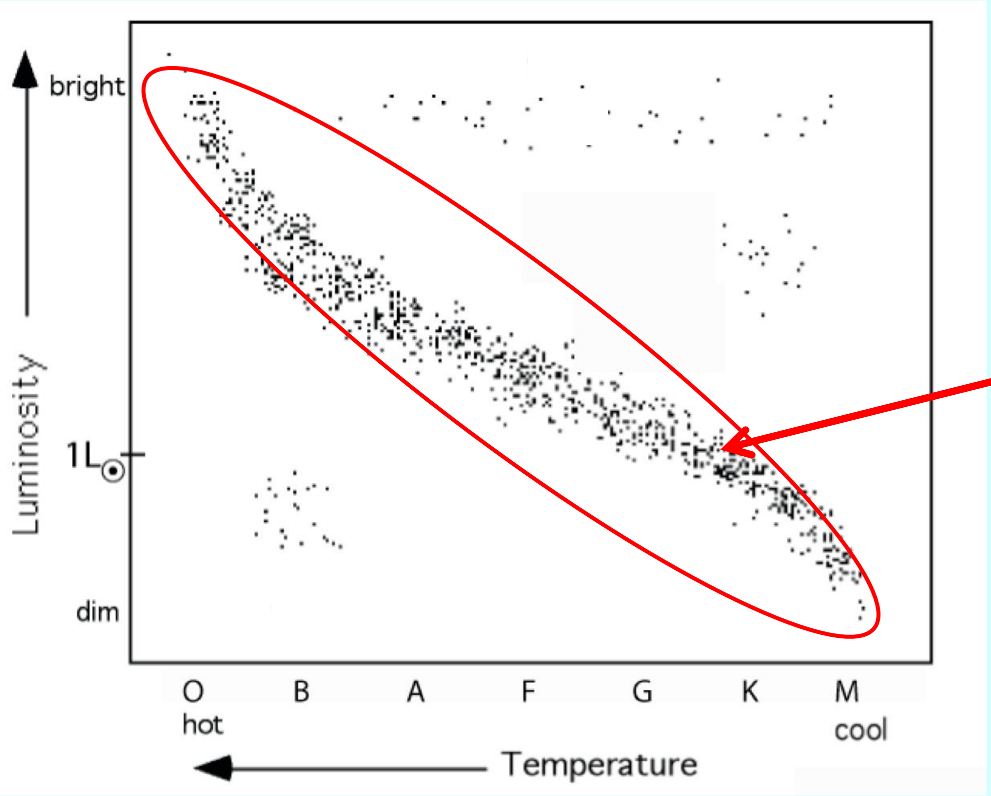
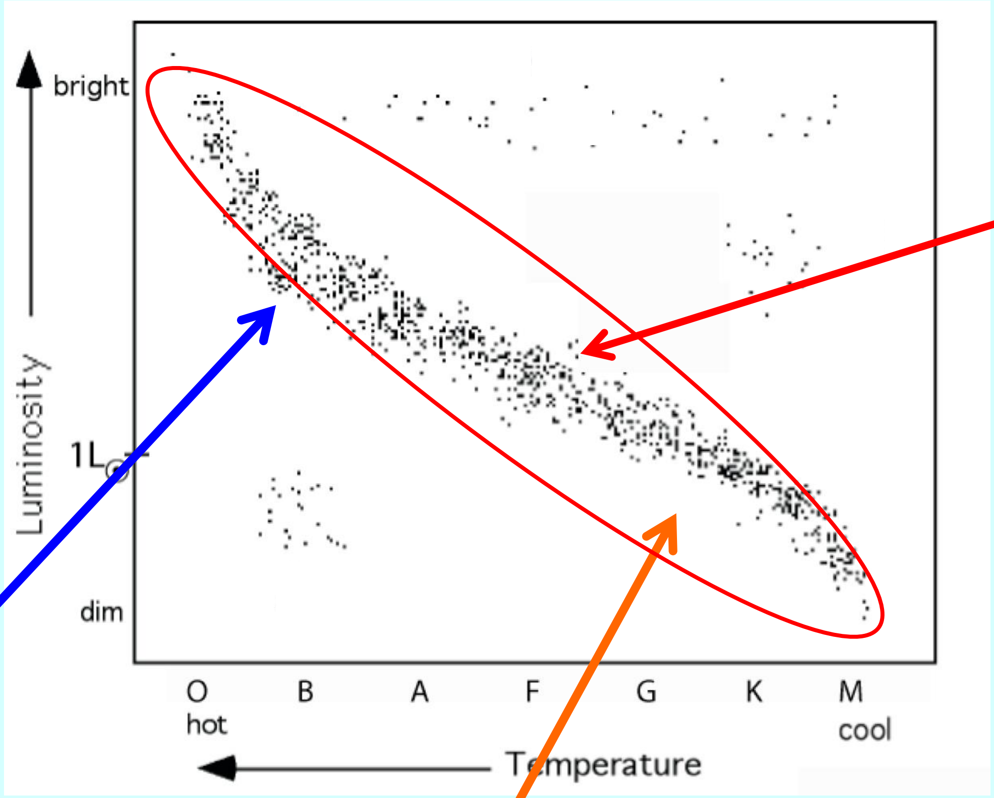
- HR diagram shows us what happens

HR Diagram



main
sequence

HR Diagram



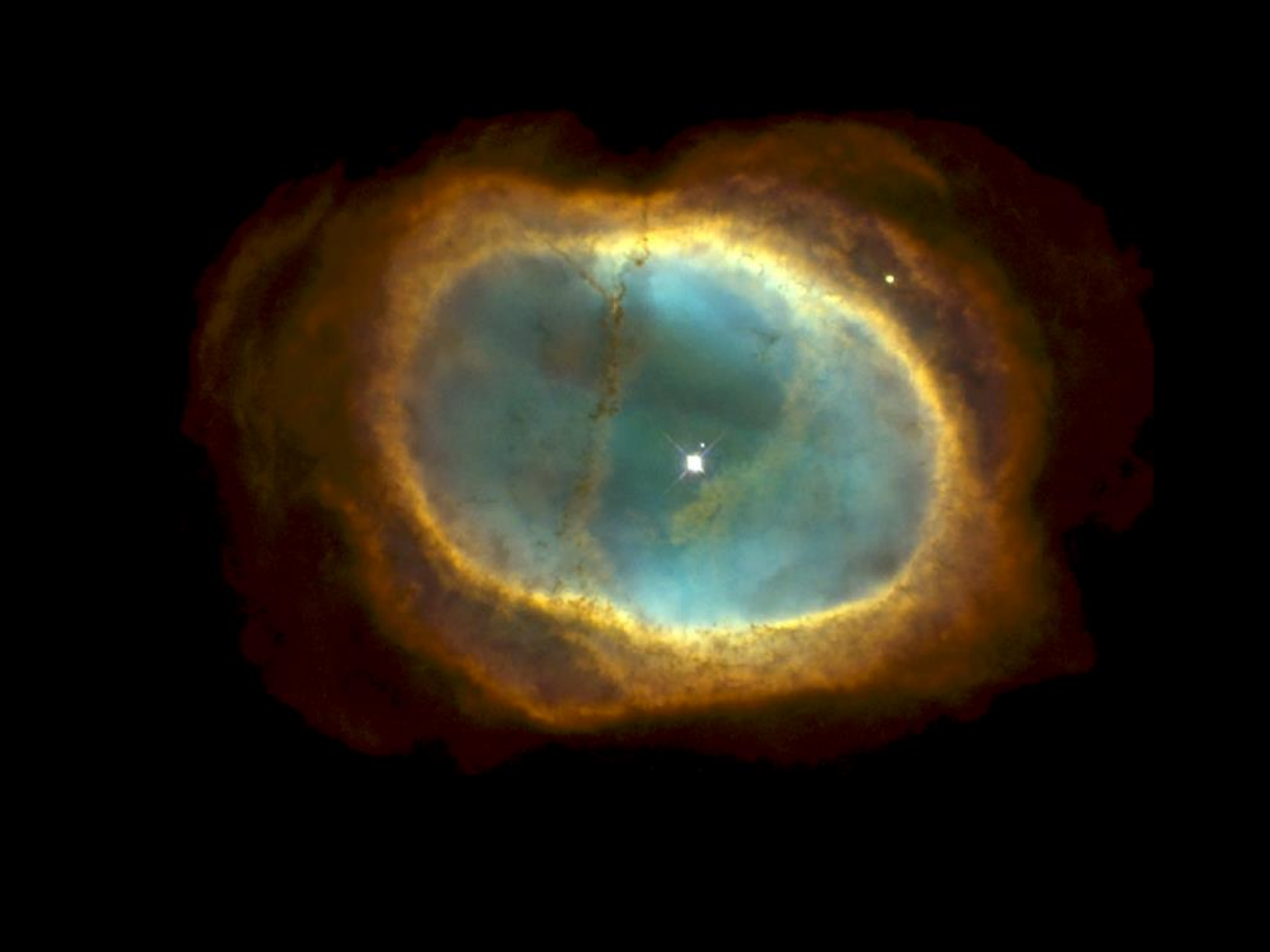
main sequence

highmass,
short time for H-fusion

low mass,
long time for H-fusion

Stars Take different paths to their end depending on how MASSIVE they are.

1 to 3 $M_\odot$ PN + white dwarf



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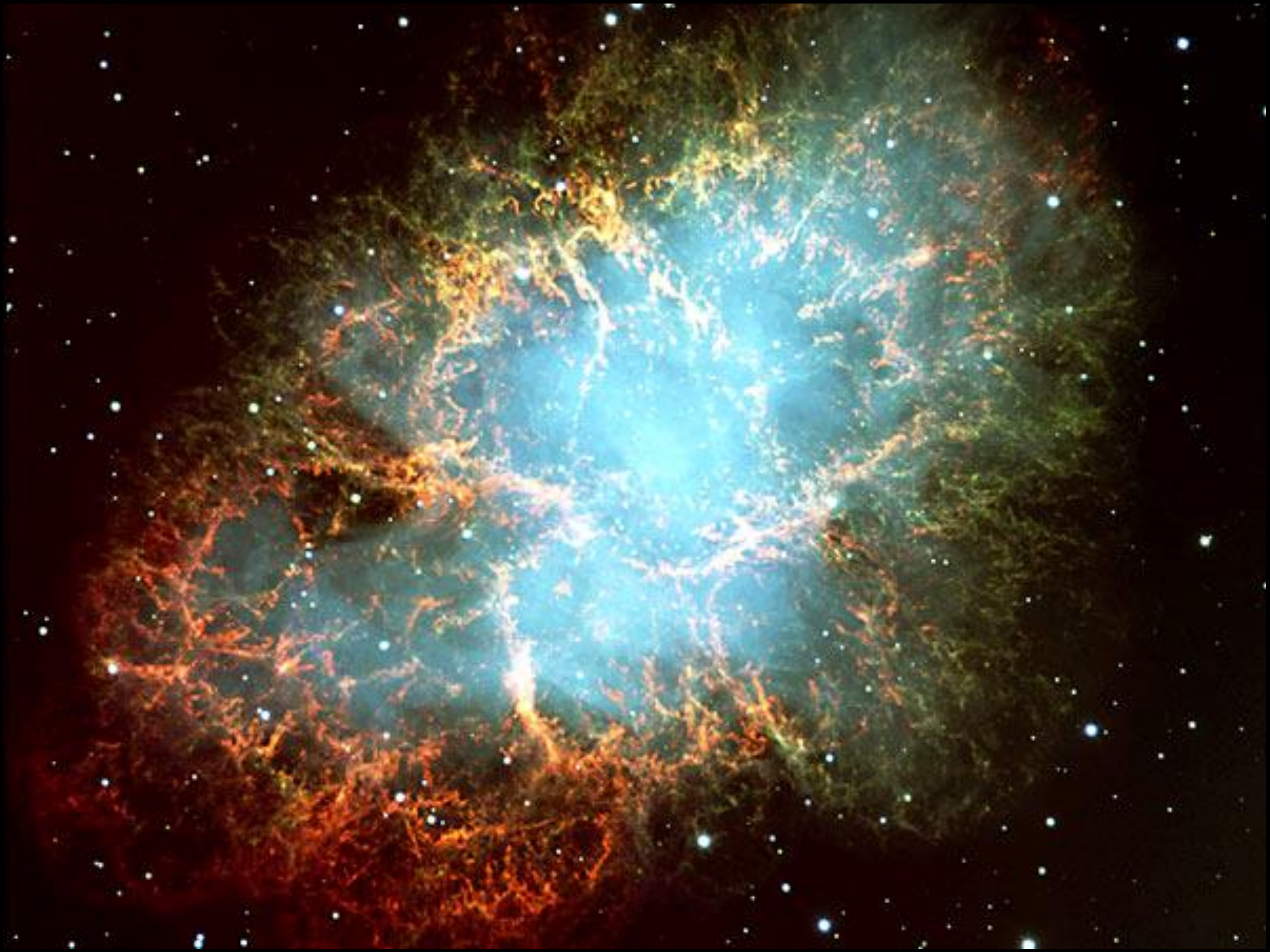

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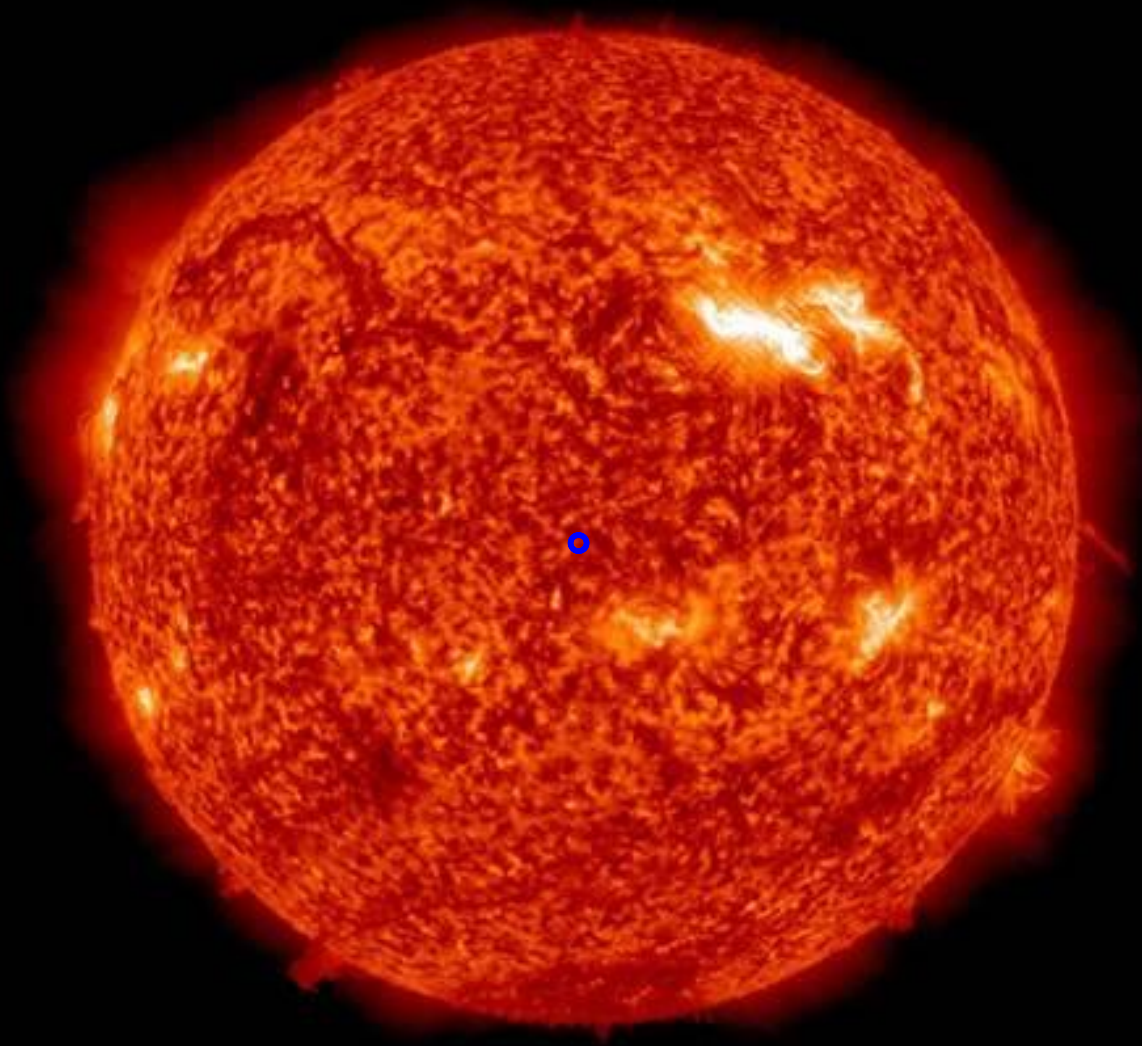
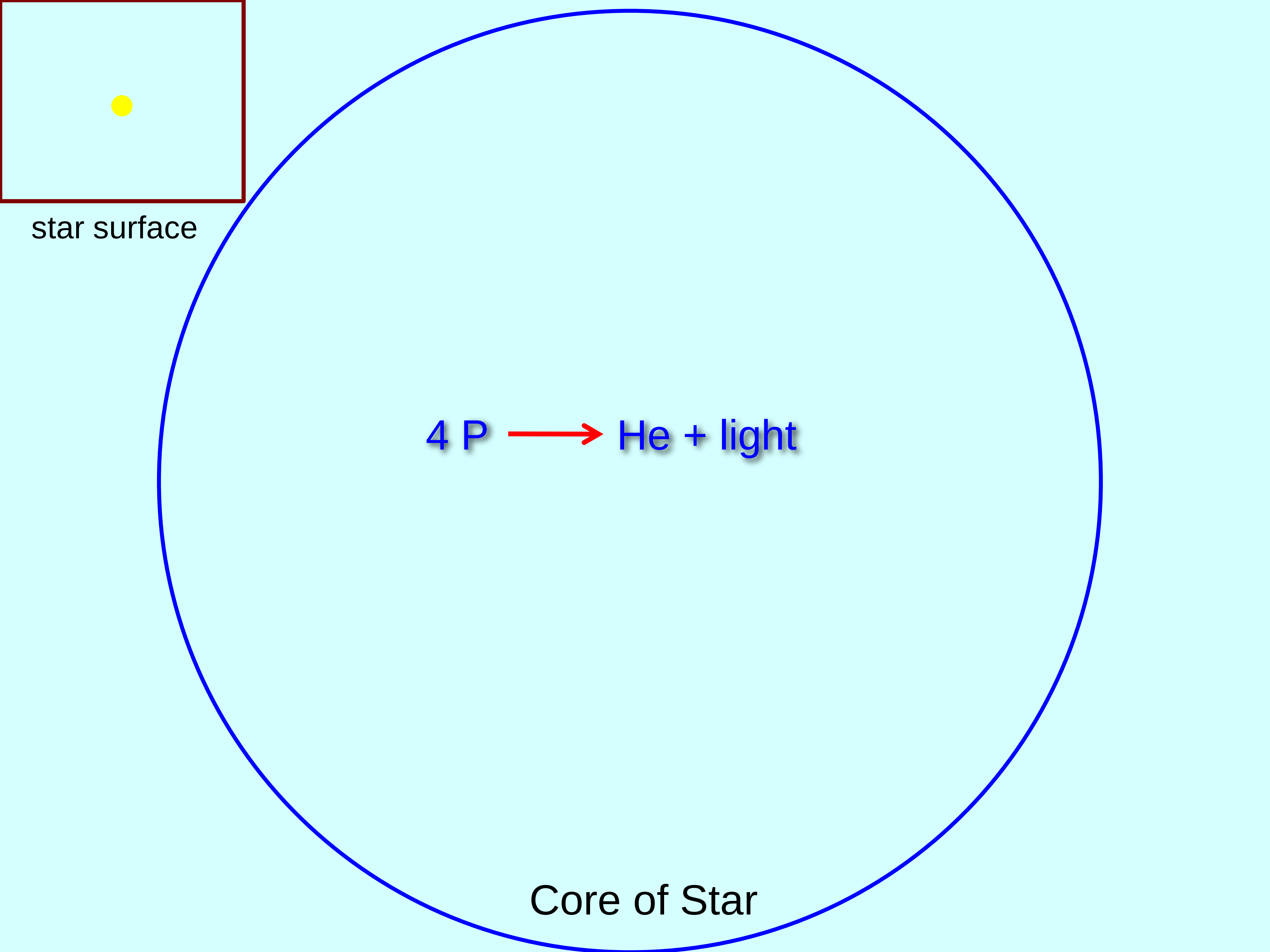
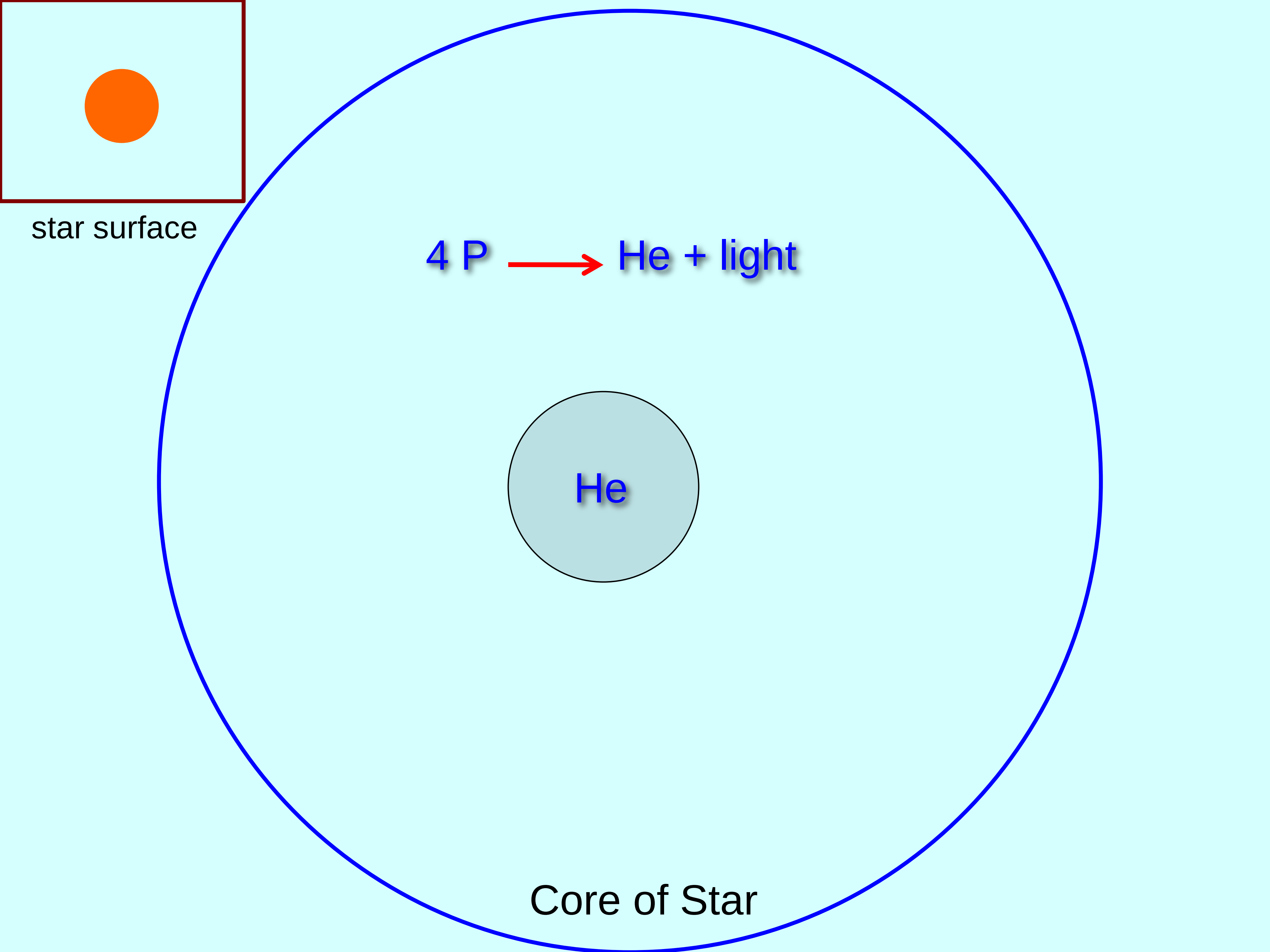
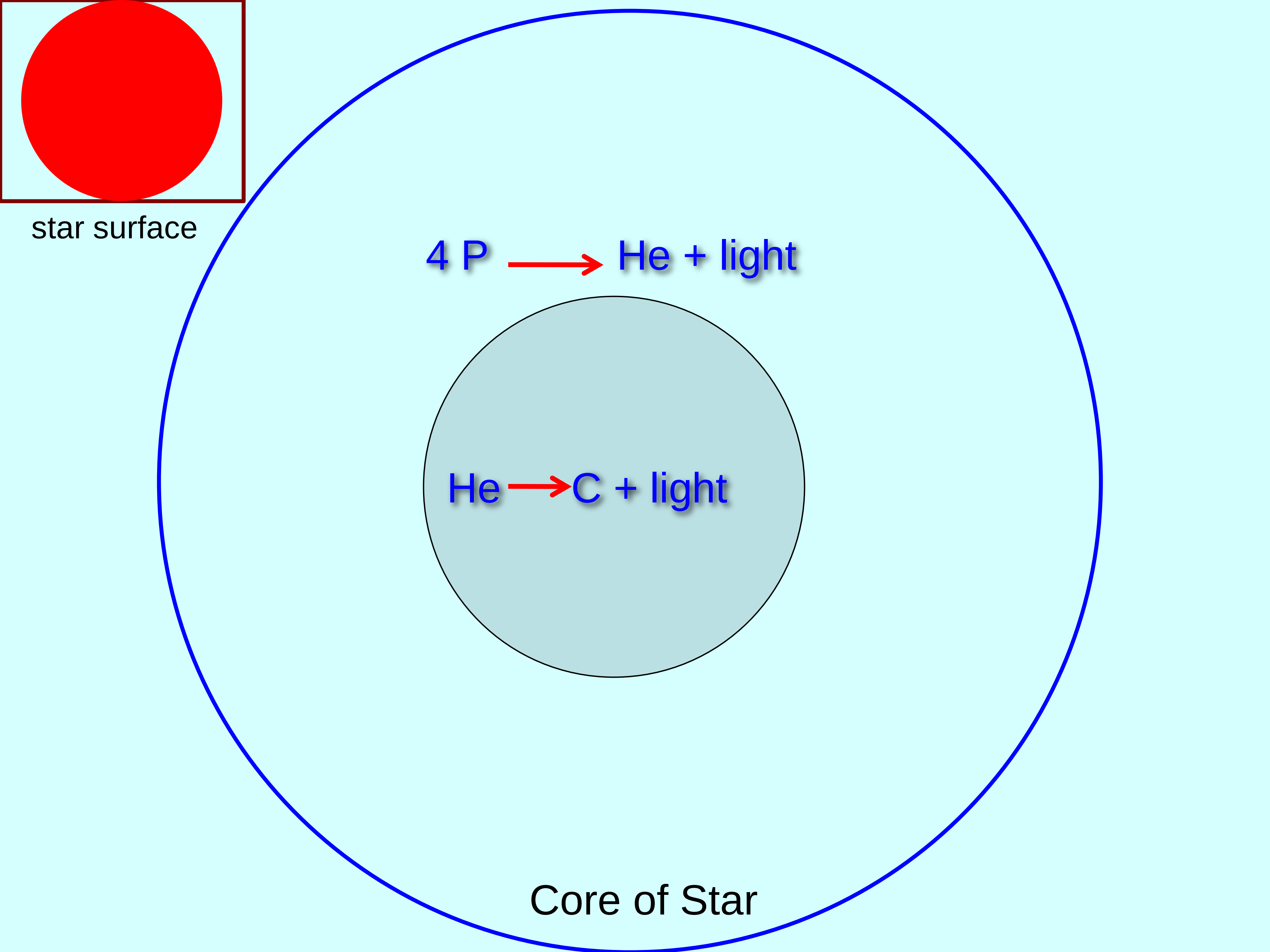
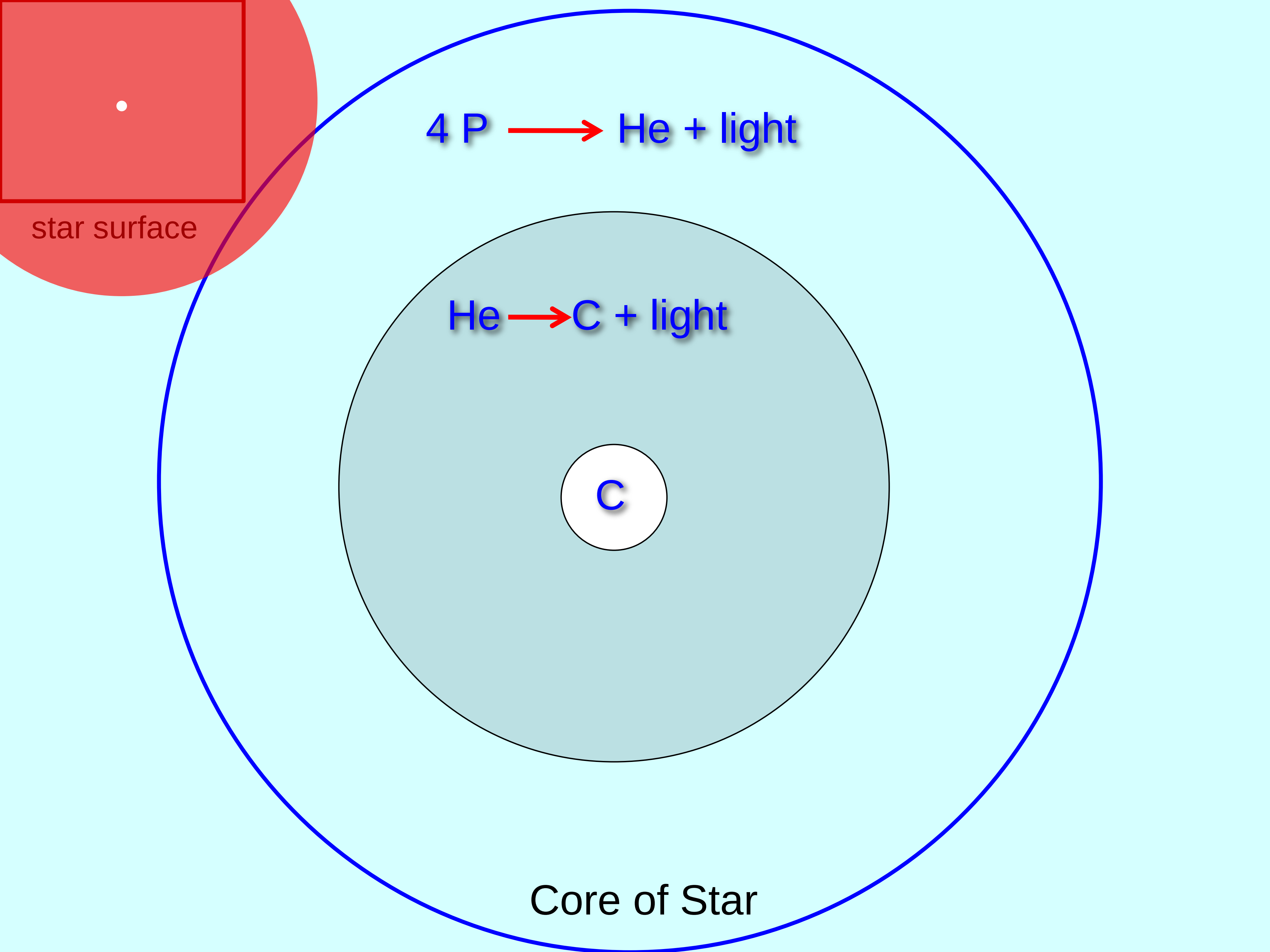



star surface
4 P → He + light
Core of Star


star surface
4 P → He + light
He
Core of Star

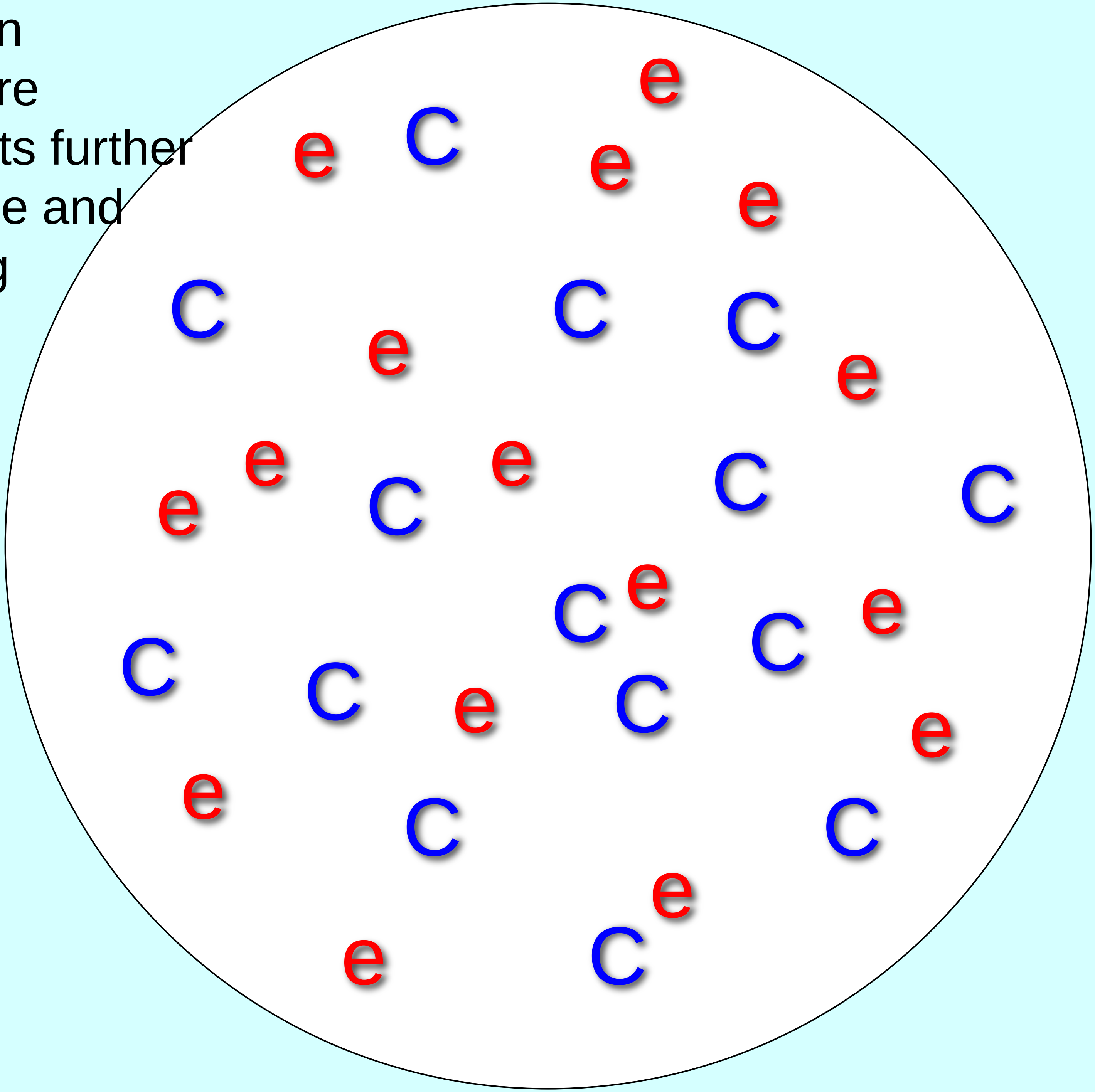


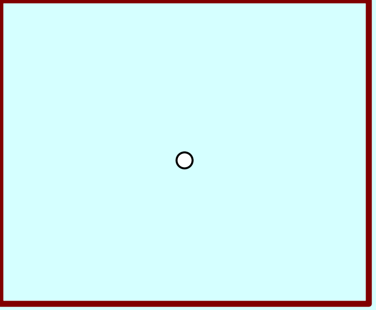
star surface
4 P → He + light
He → C + light
Core of Star



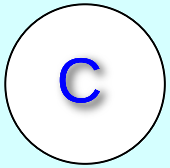
star surface
4 P → He + light
He → C + light
C
Core of Star

electron pressure prevents further collapse and heating

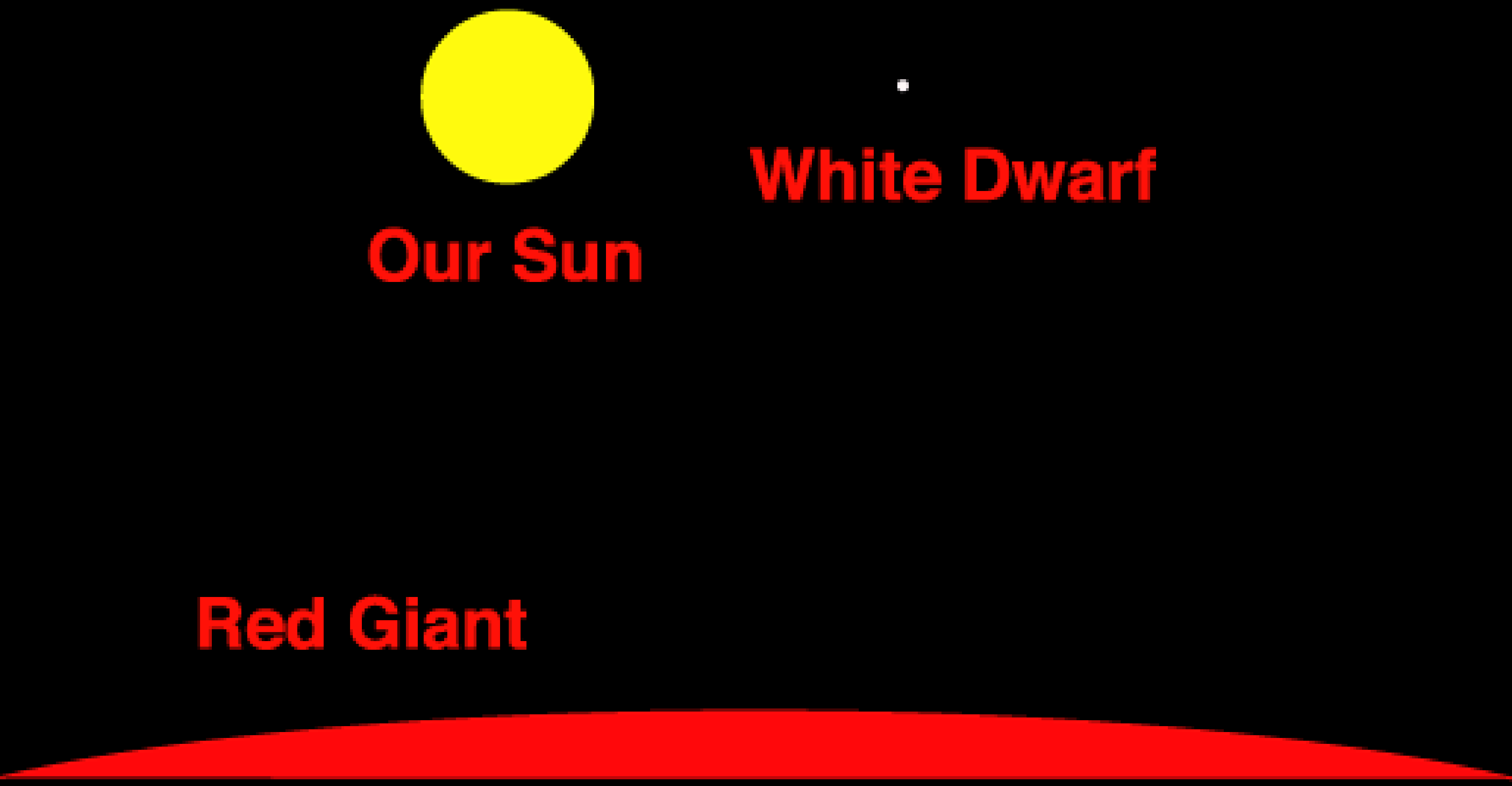


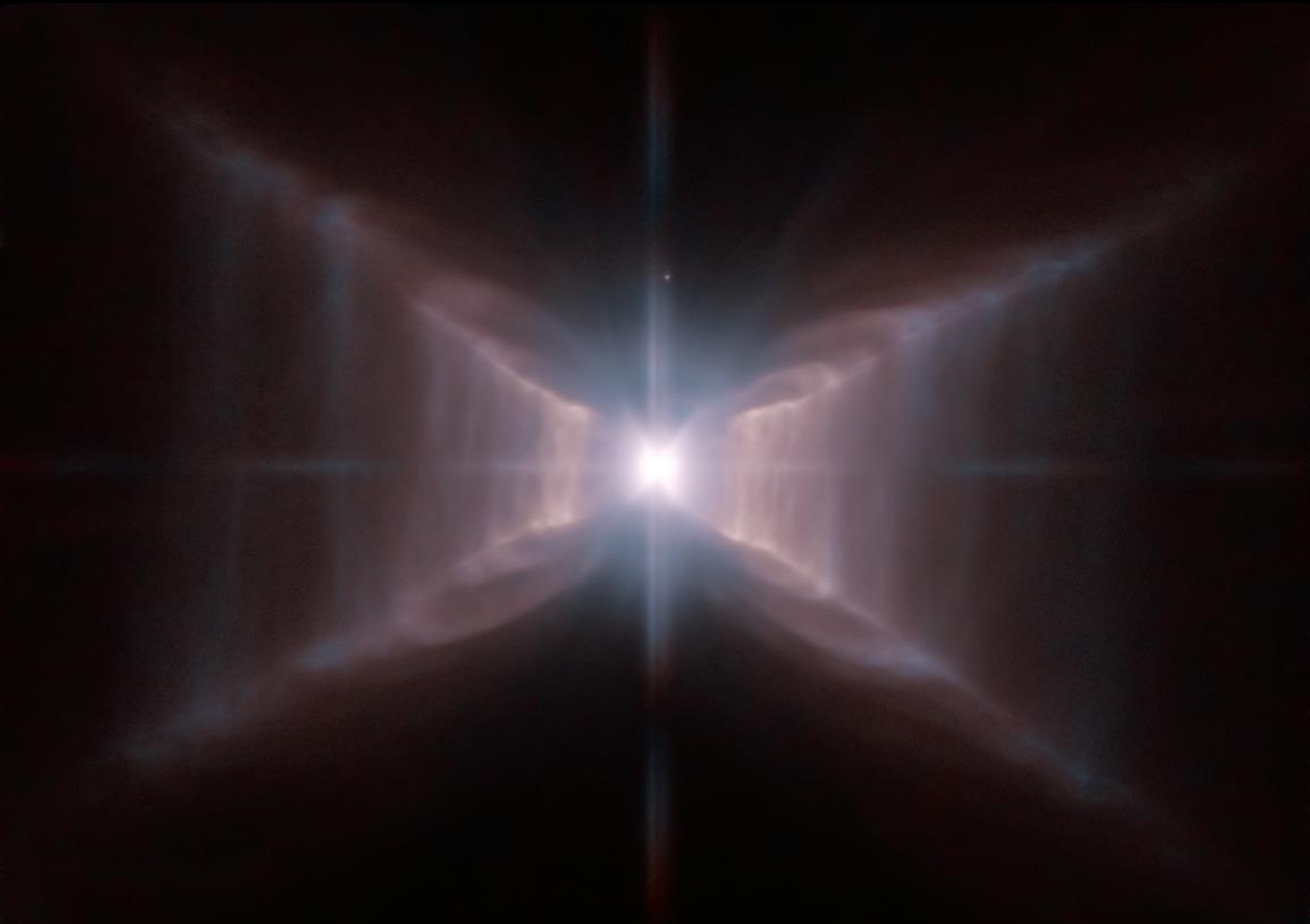


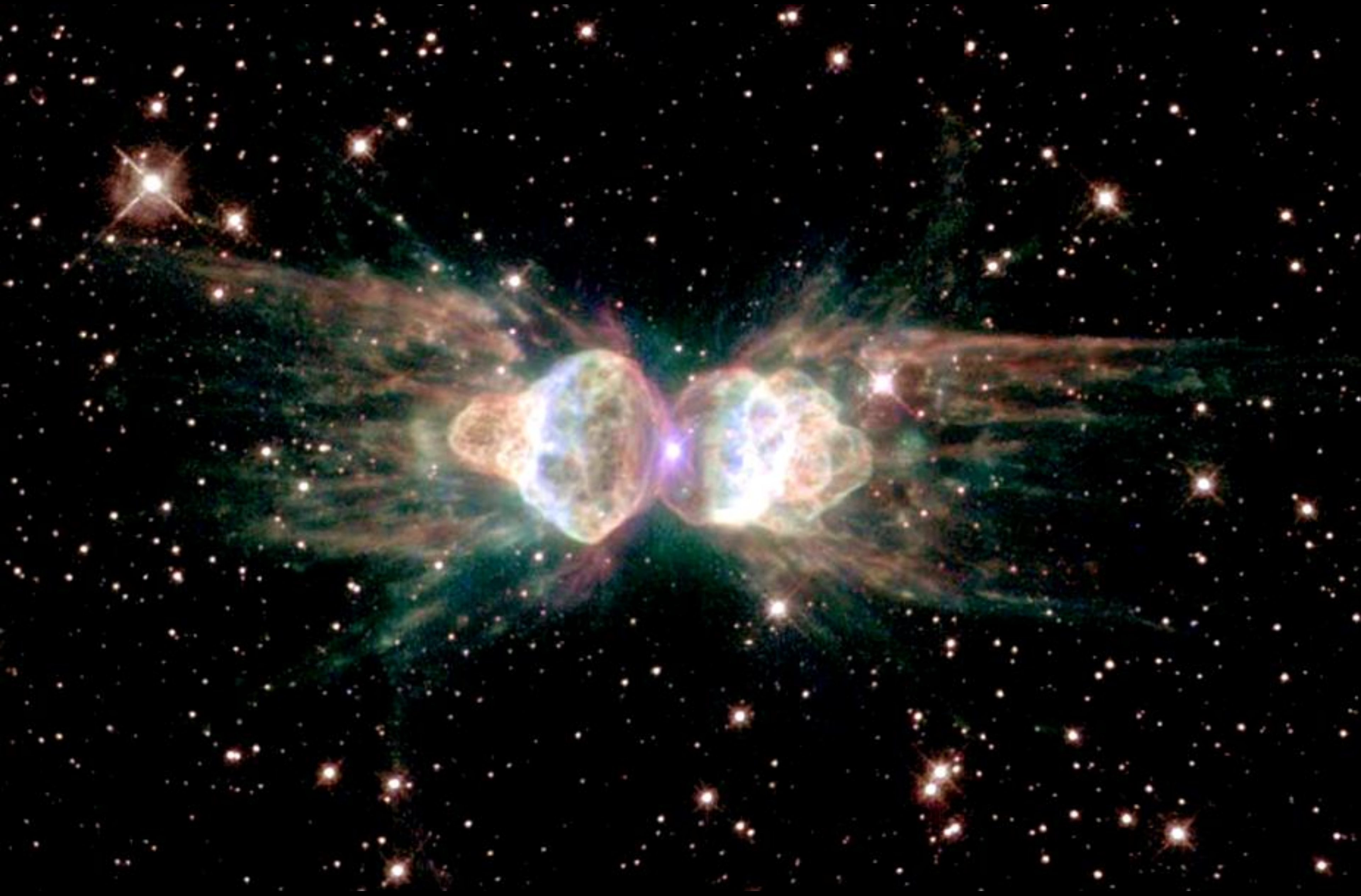
star surface

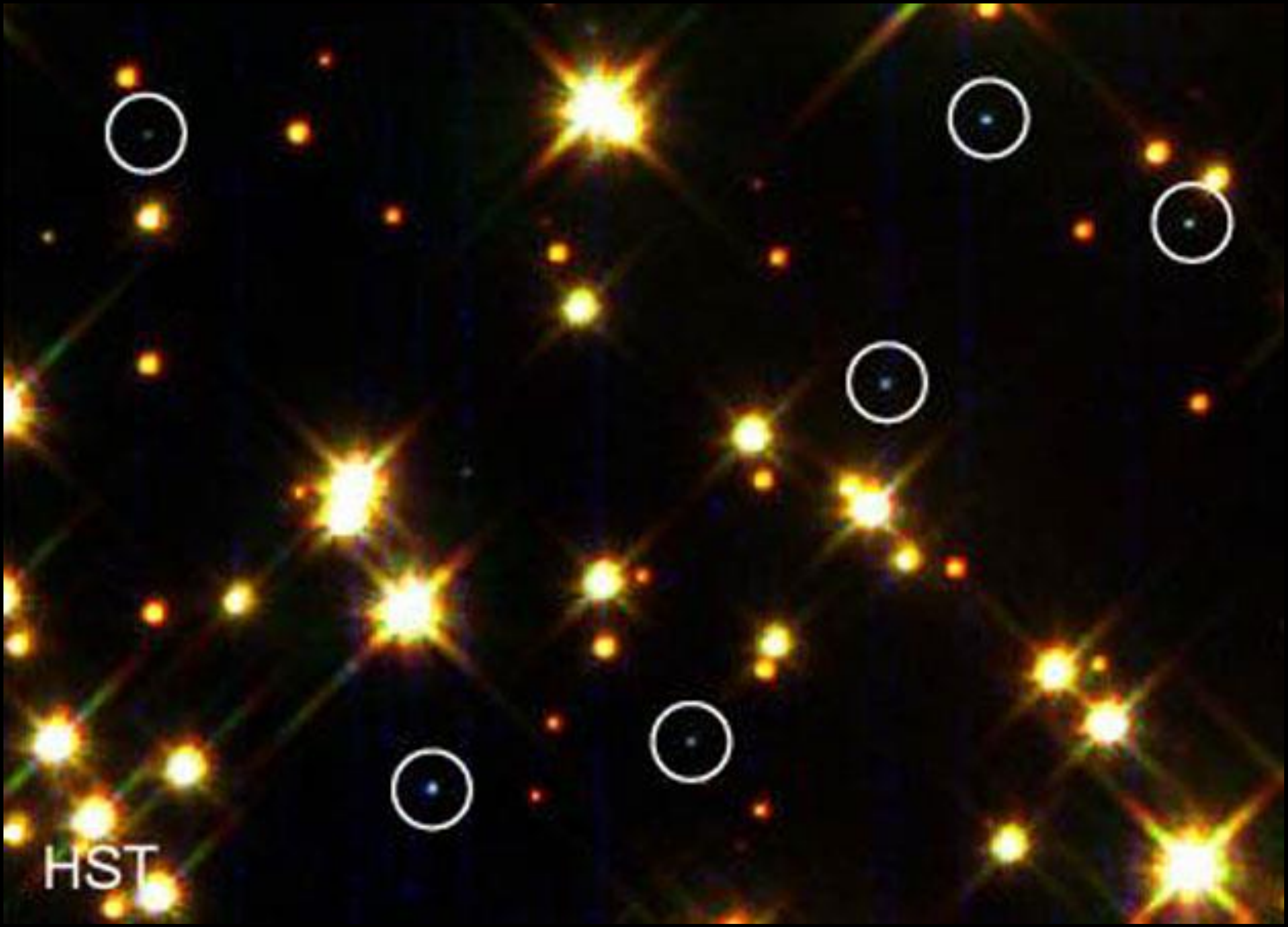


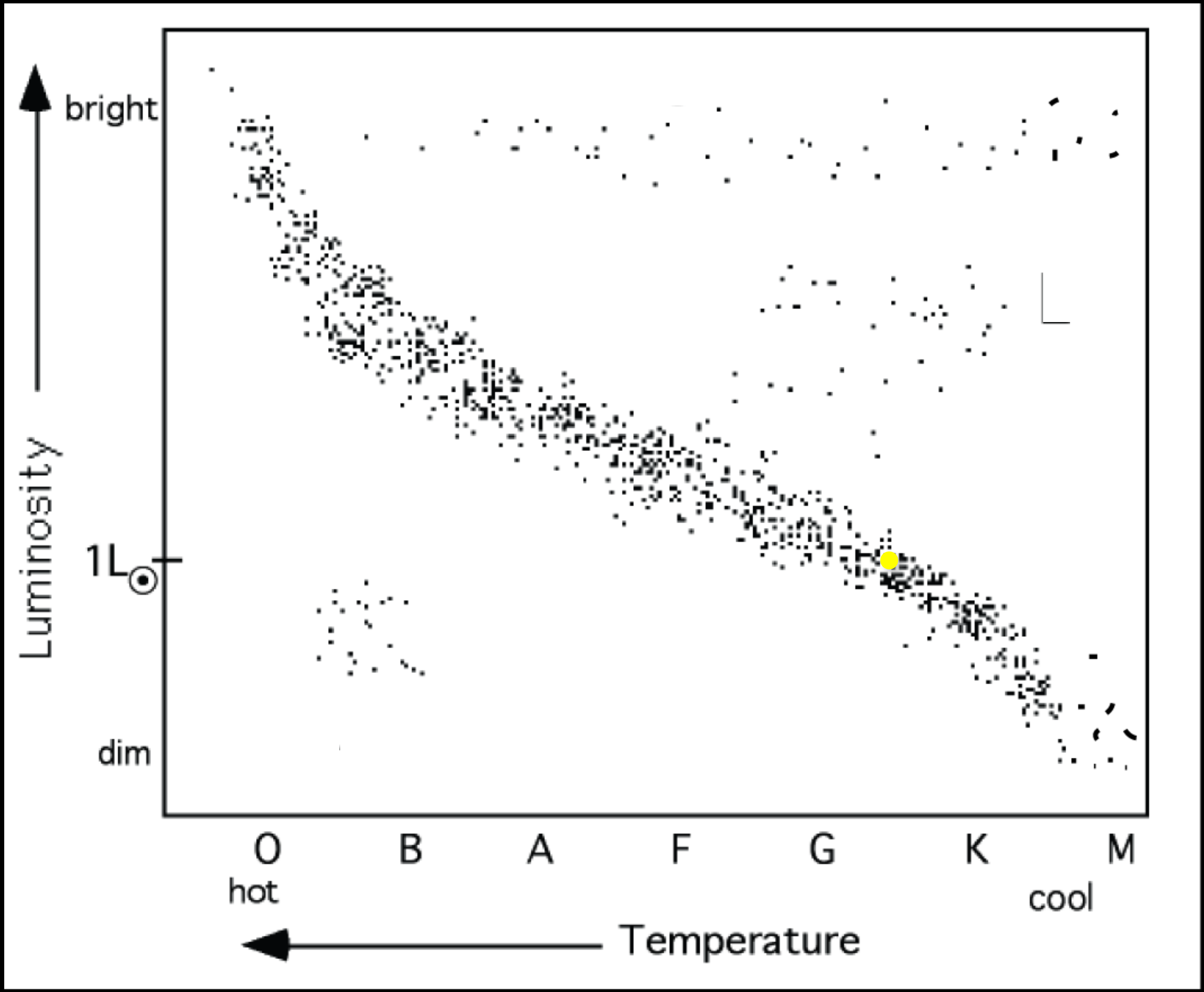
Core of Star: White Dwarf


White Dwarf
Our Sun
Red Giant






HST



our Sun now

4.6x10^9 yrs old

Our Sun in the Future

200 million years from now: too hot to live on earth

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Our Sun in the Future

200 million years from now: too hot to live on earth

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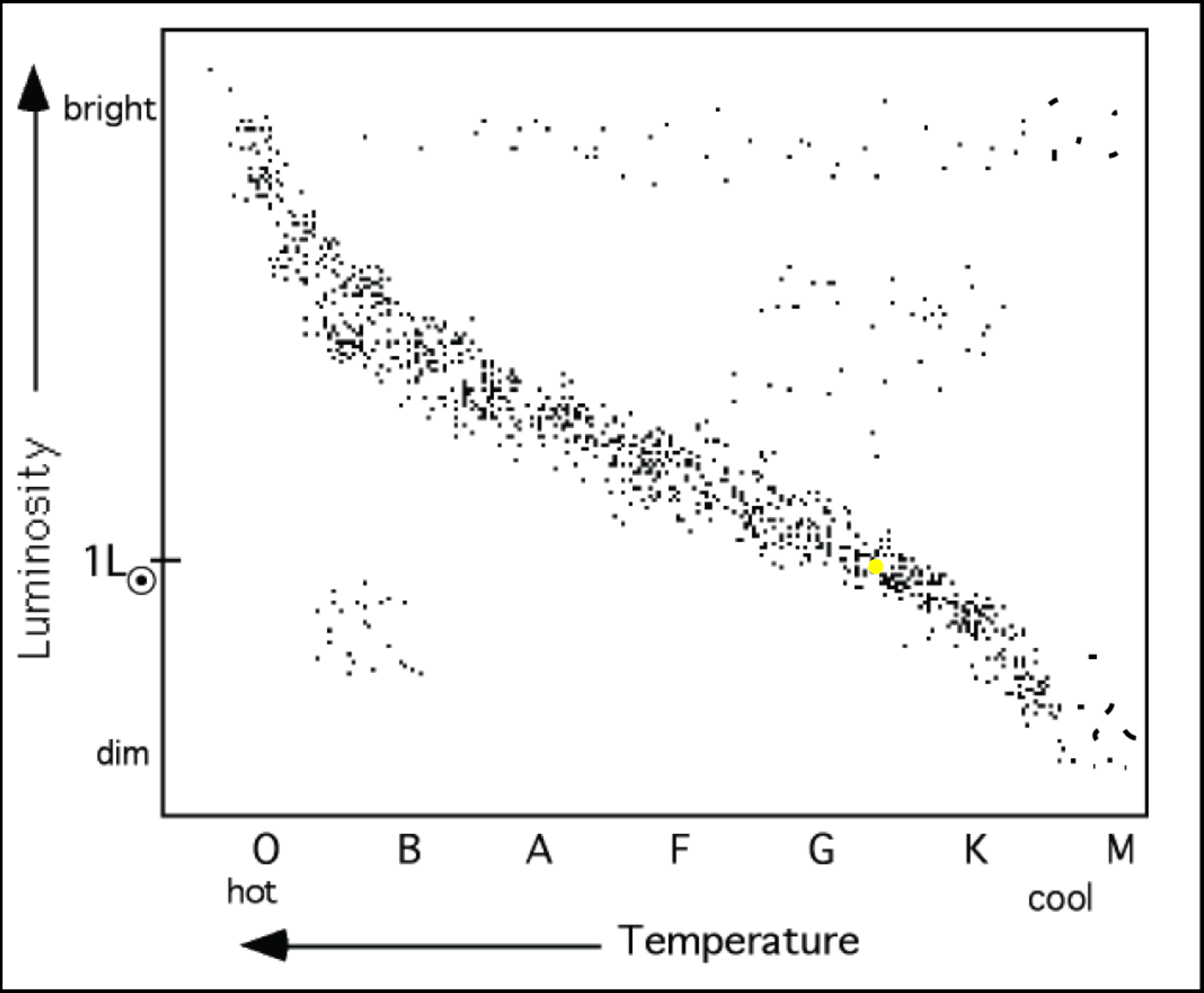
1 billion years from now: surface Sun near Jupiter

4.5 billion yrs from now: Red giant (2,000 x Lsun)

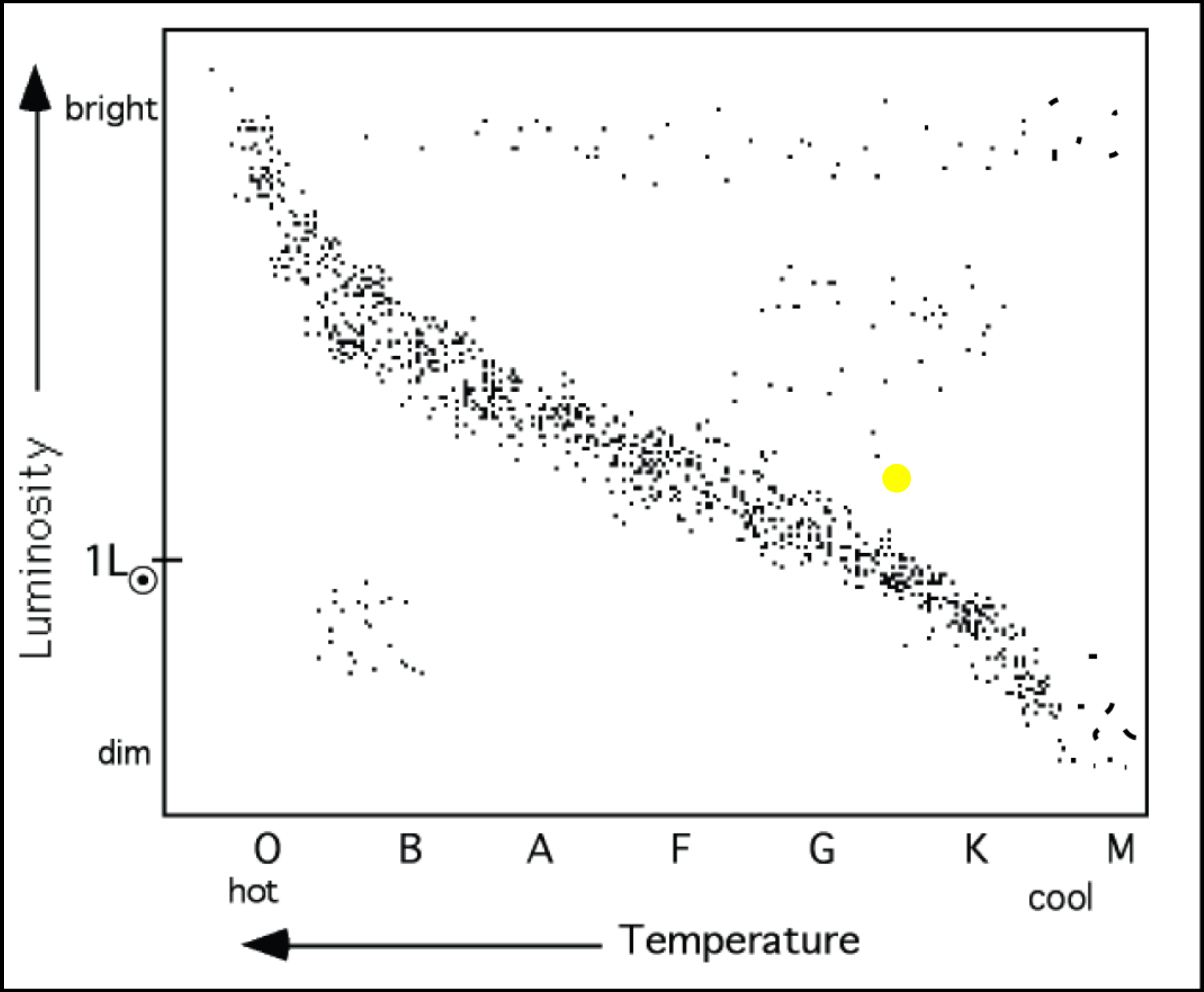
5.5 billion yrs from now: PN and WD

low mass star evolves

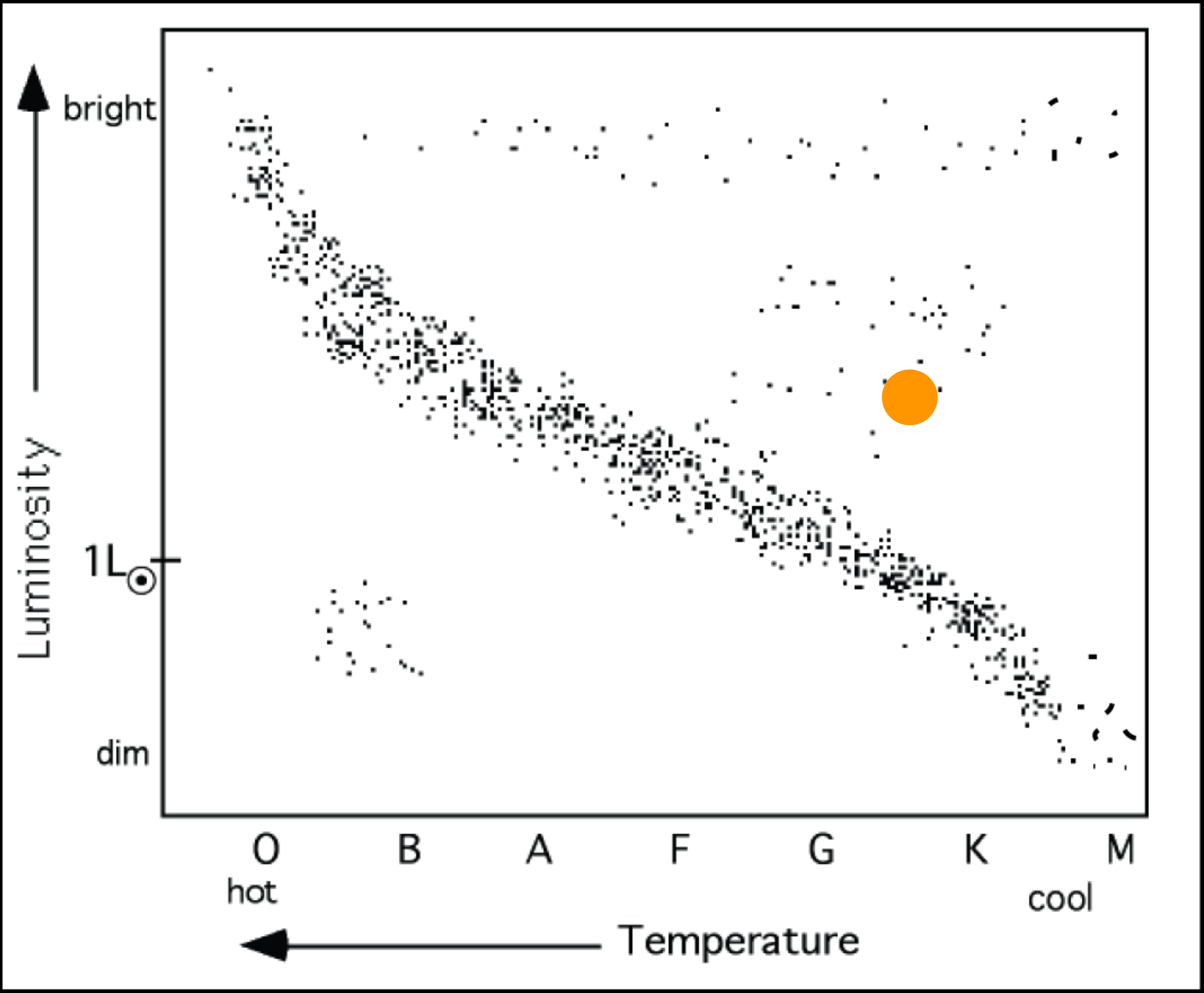


our Sun now

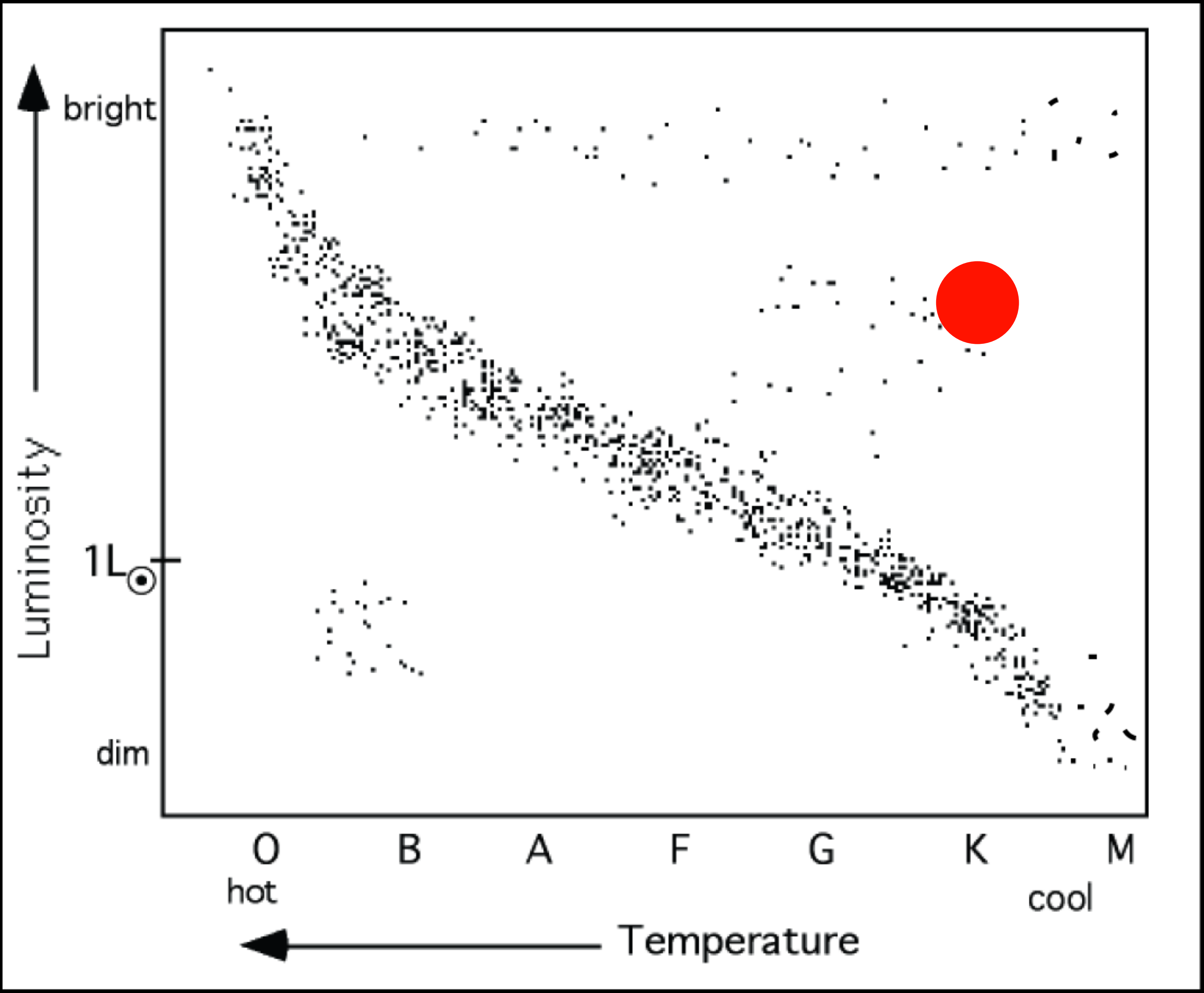
$4.6x10^9$ yrs old



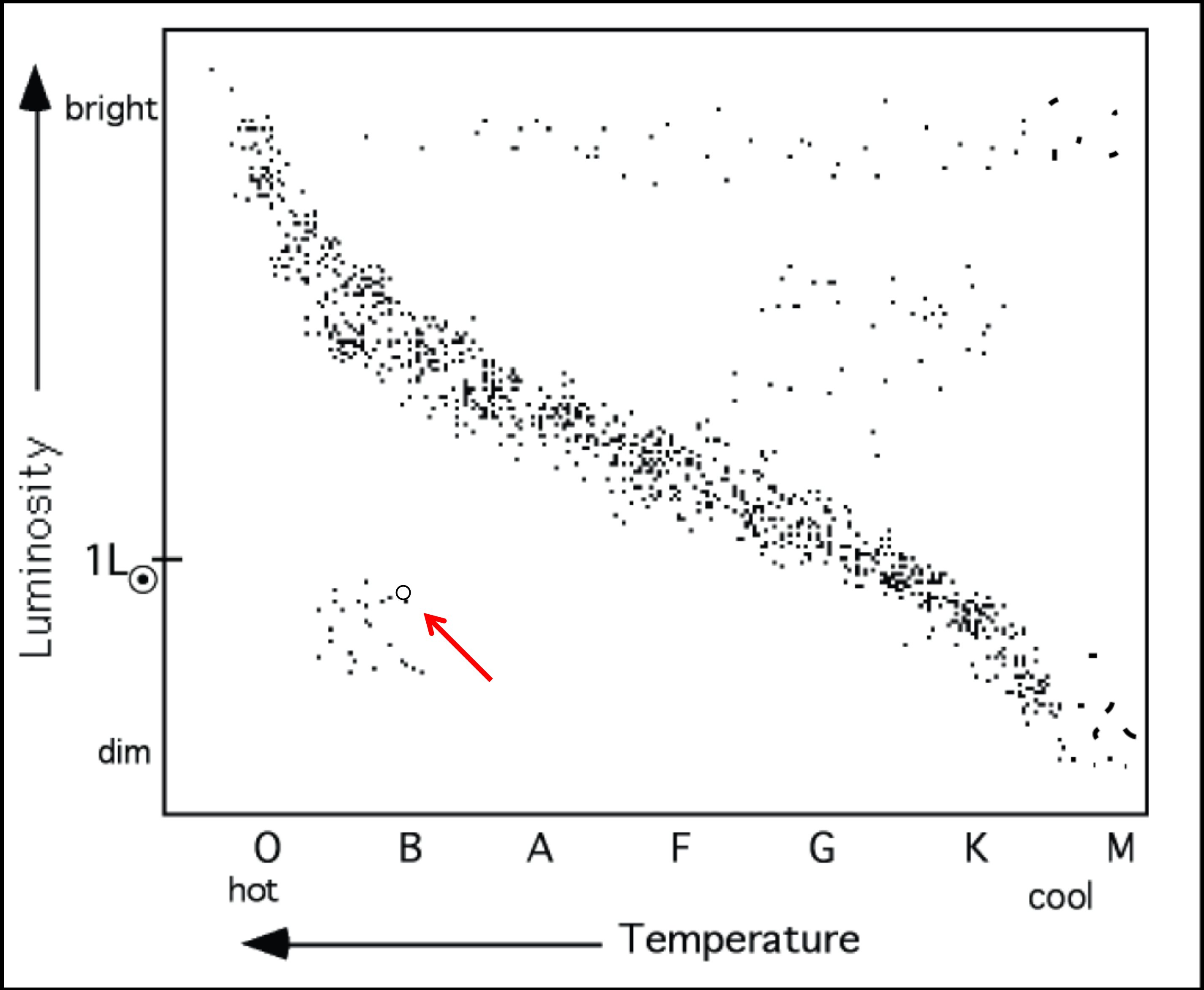
our Sun 10^8 yr from now



our Sun 10^9 yr from now



our Sun 4×10^9 yr from now



our Sun $9x10^9$ yr old, start to end

The more MASSIVE the Star on the MAIN Sequence, the hotter it is on its surface and inside its core, and

the faster it uses up its H fuel

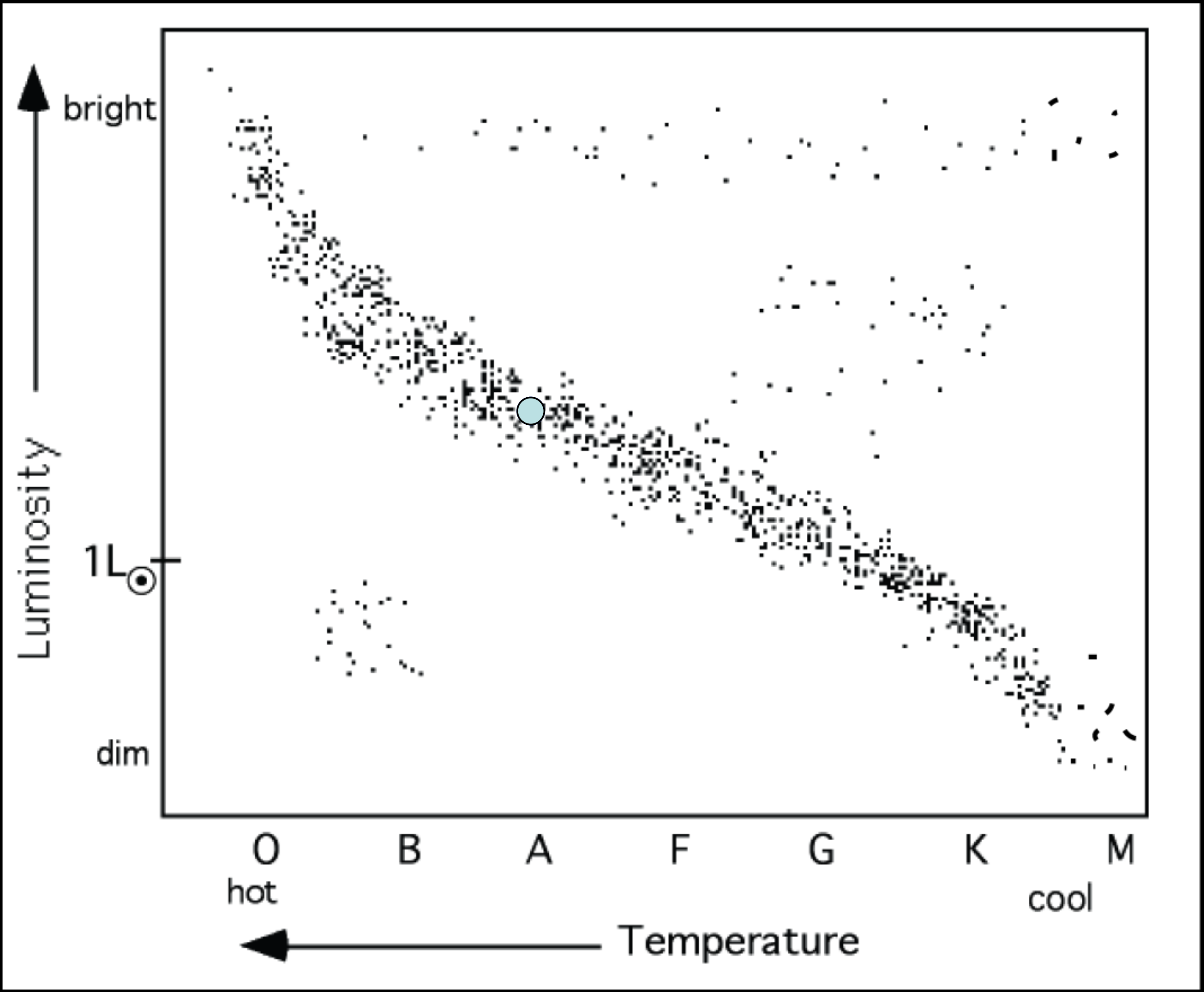
Look at evolution of a star >>M than Sun.

Stars Take different paths to their end depending on how MASSIVE they are.

1 to 3 $M_\odot$	PN	+	white dwarf
3 to 8 $M_\odot$	SN	+	neutron star
> 8 $M_\odot$	SN	+	black hole

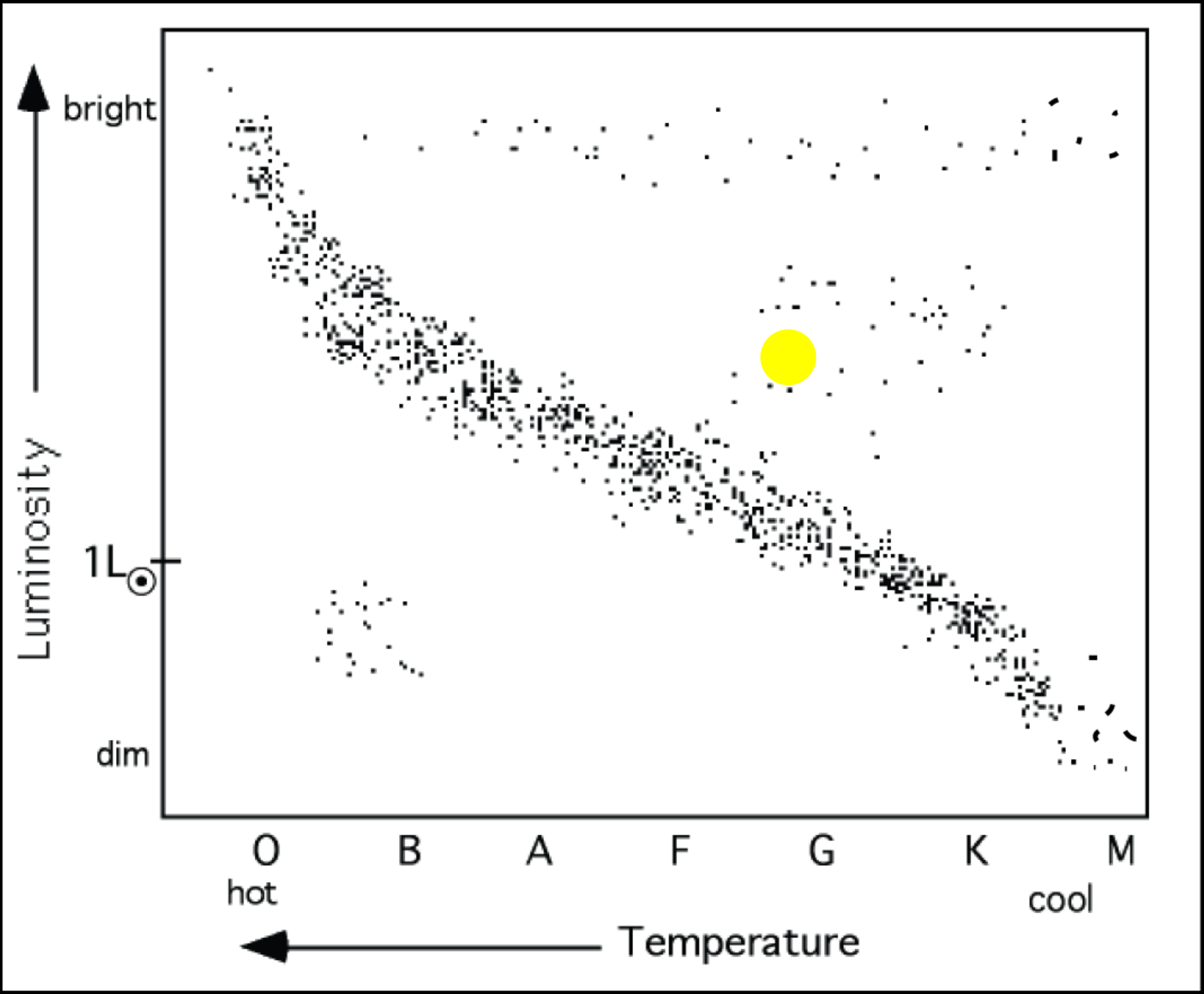
$3\text{-}8\ M_{sun}$

5×10^9 on MS

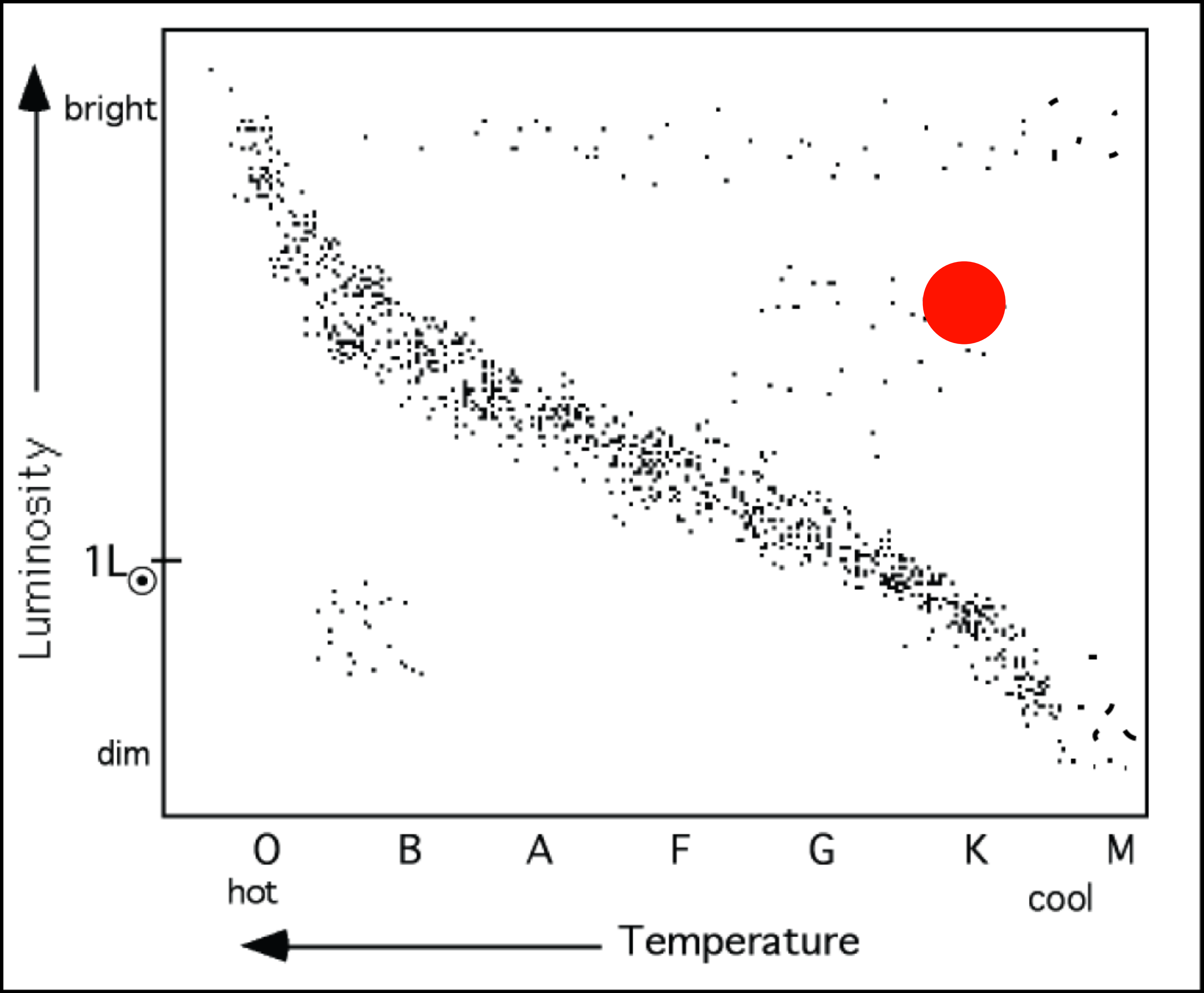


3-8 M_{sun}

3 x 10^9 yrs



massive star ½ $x10^9$ yrs



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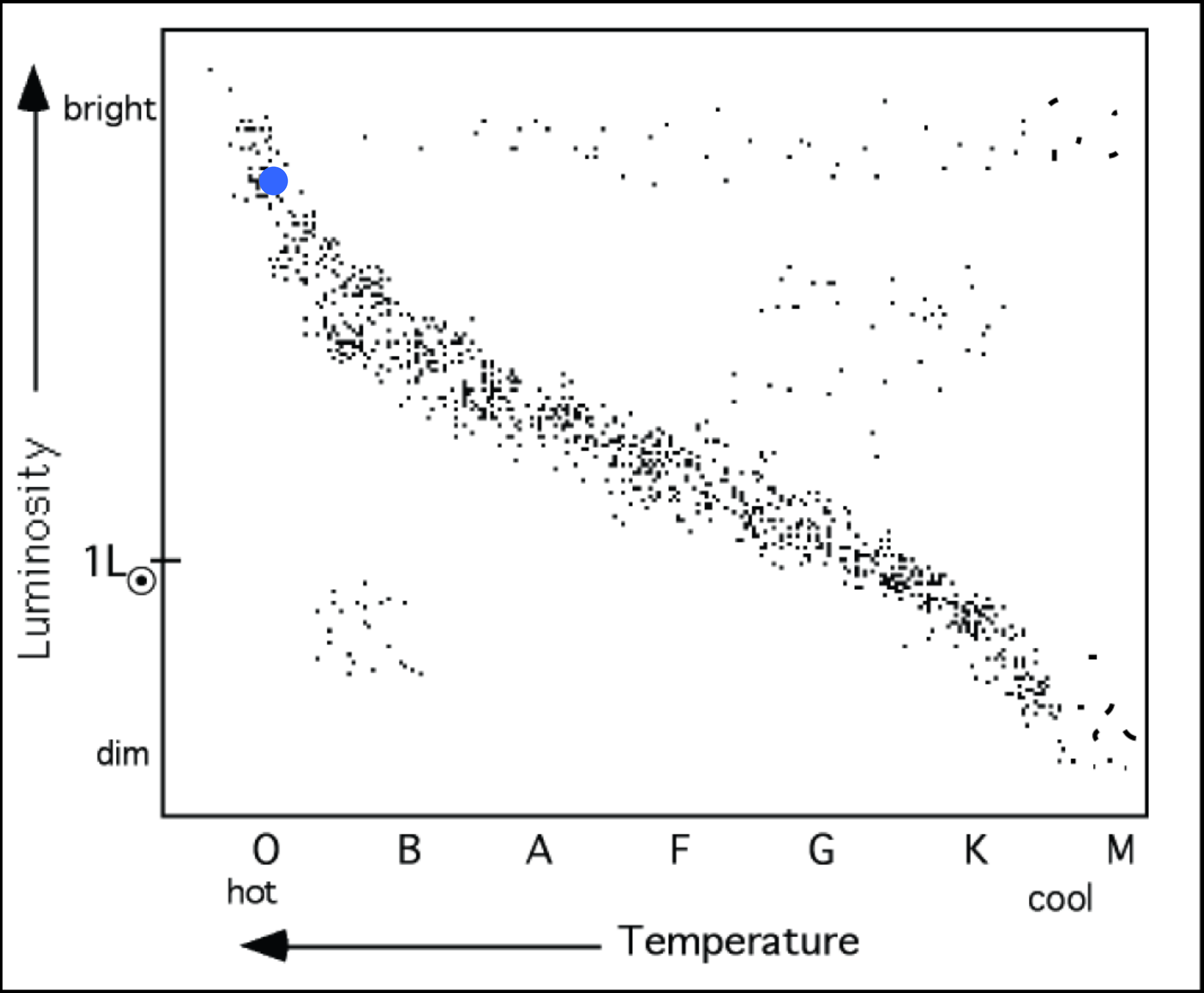
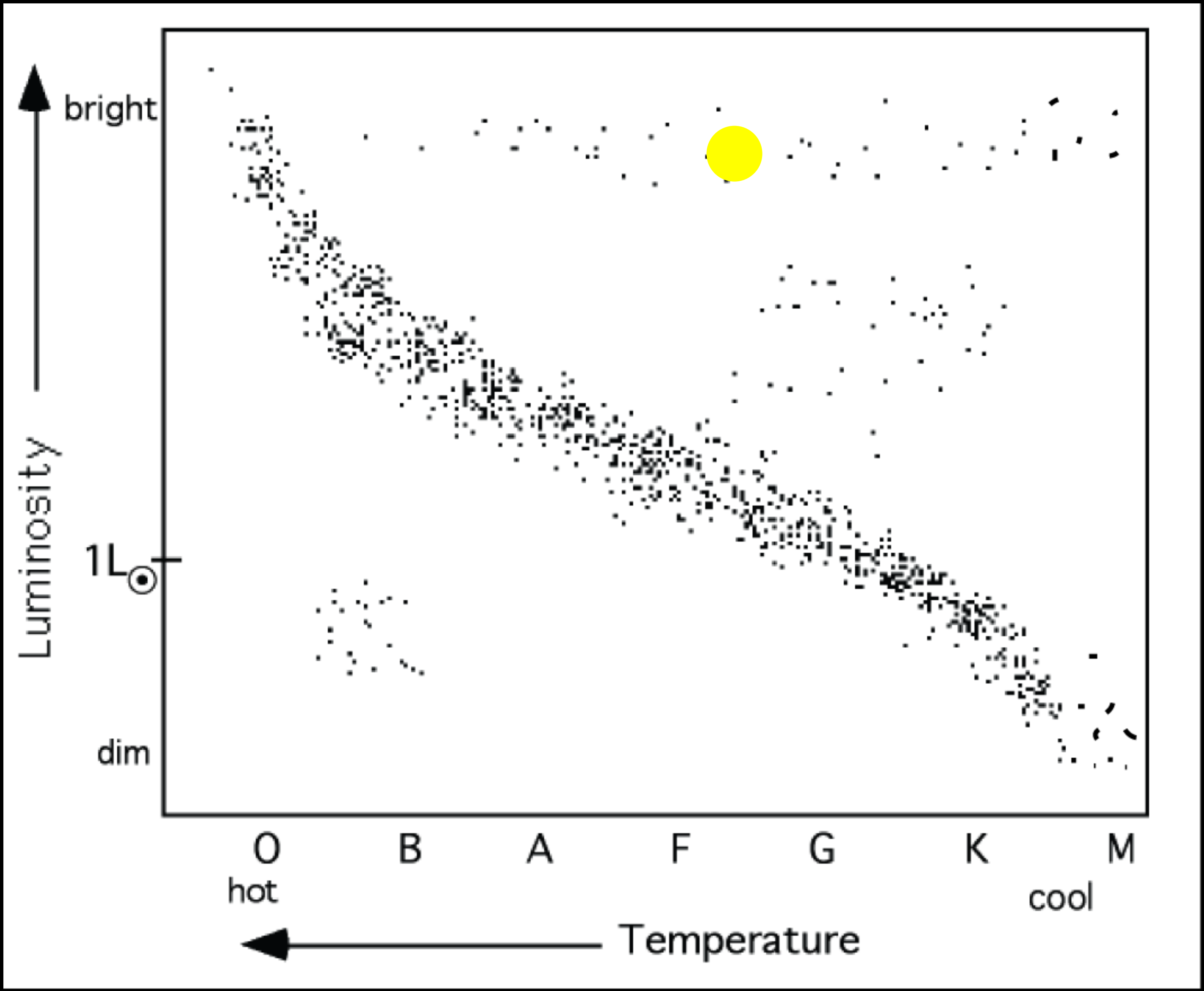
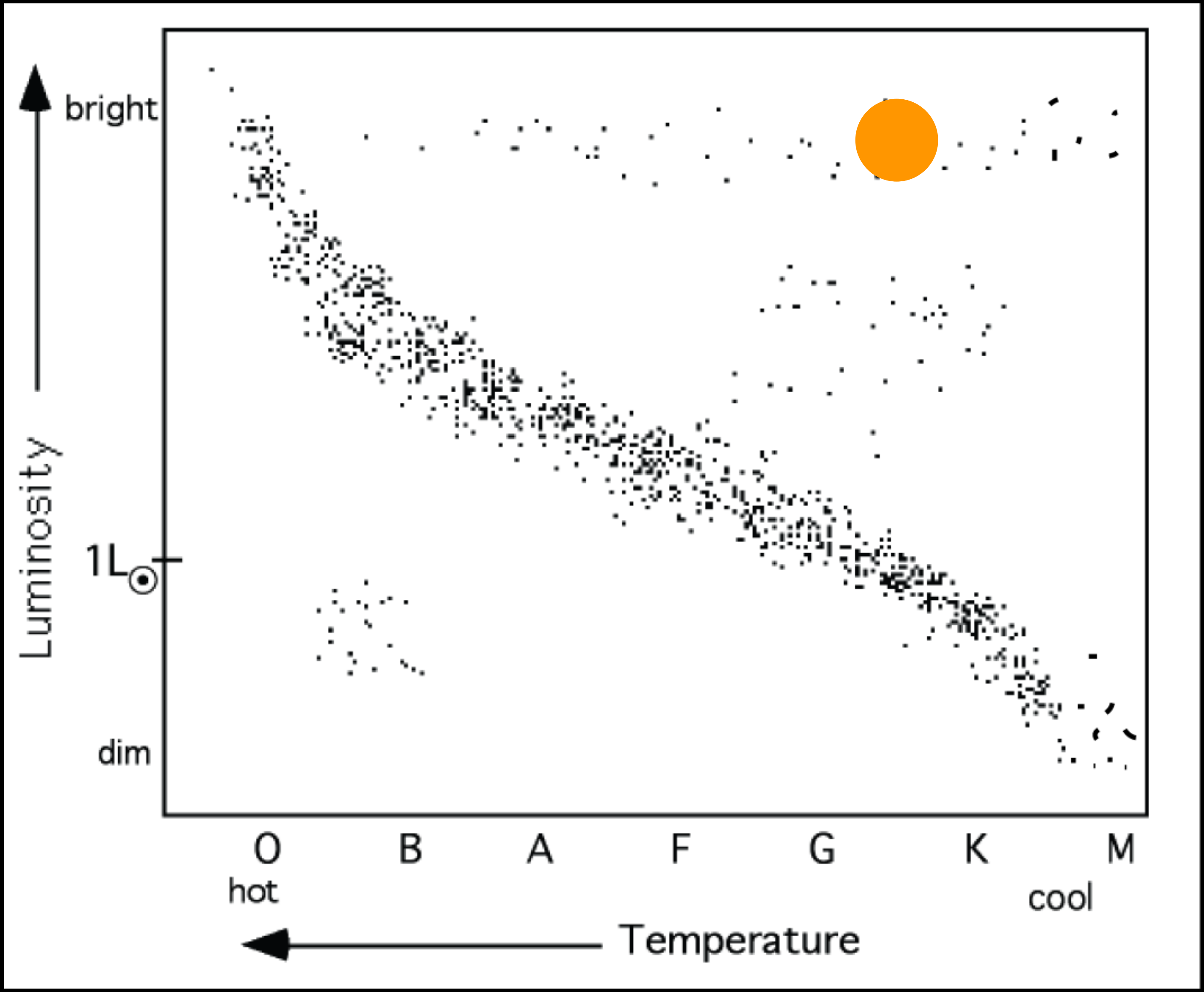
massive star now



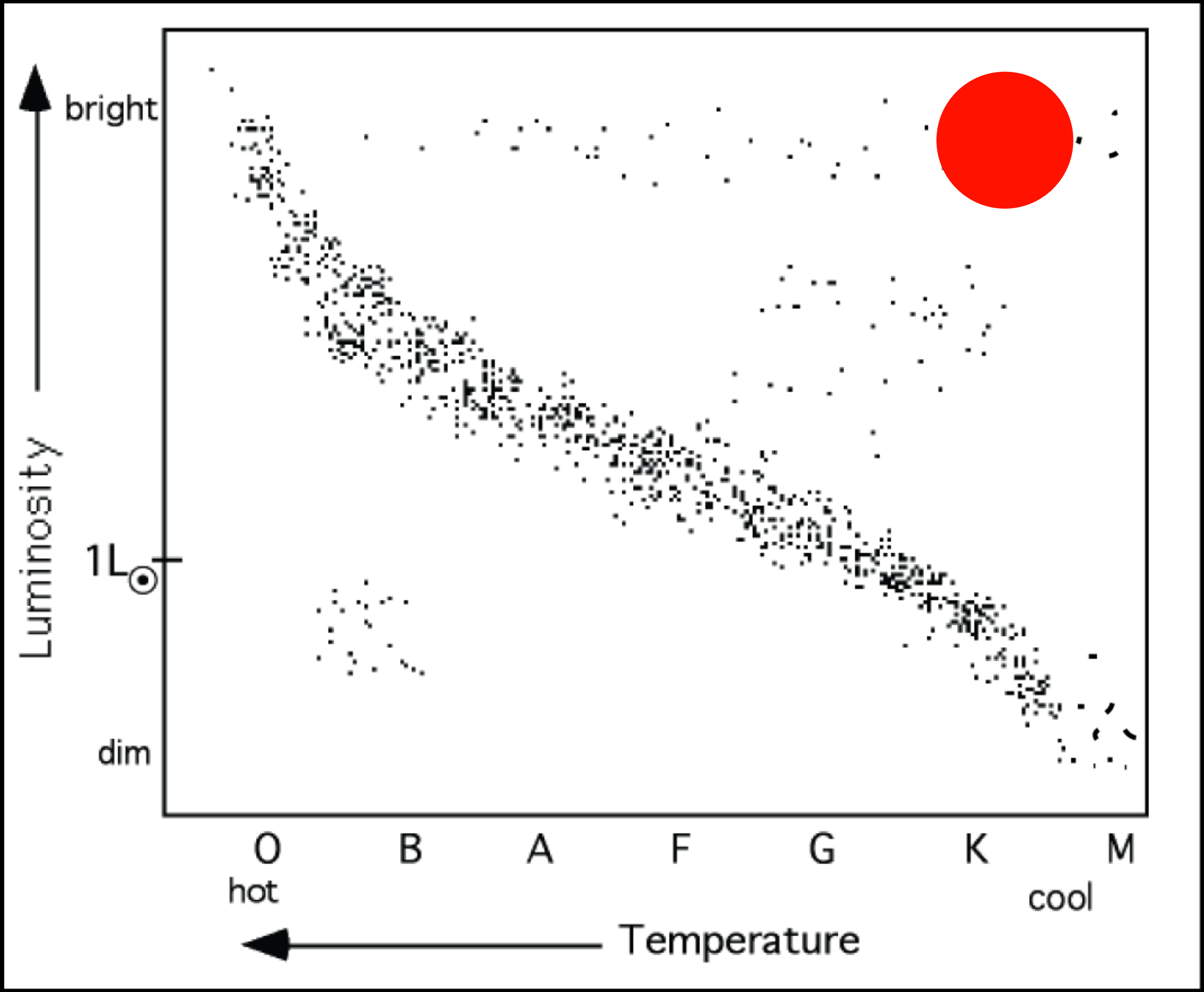
massive star 20×10^6 yrs

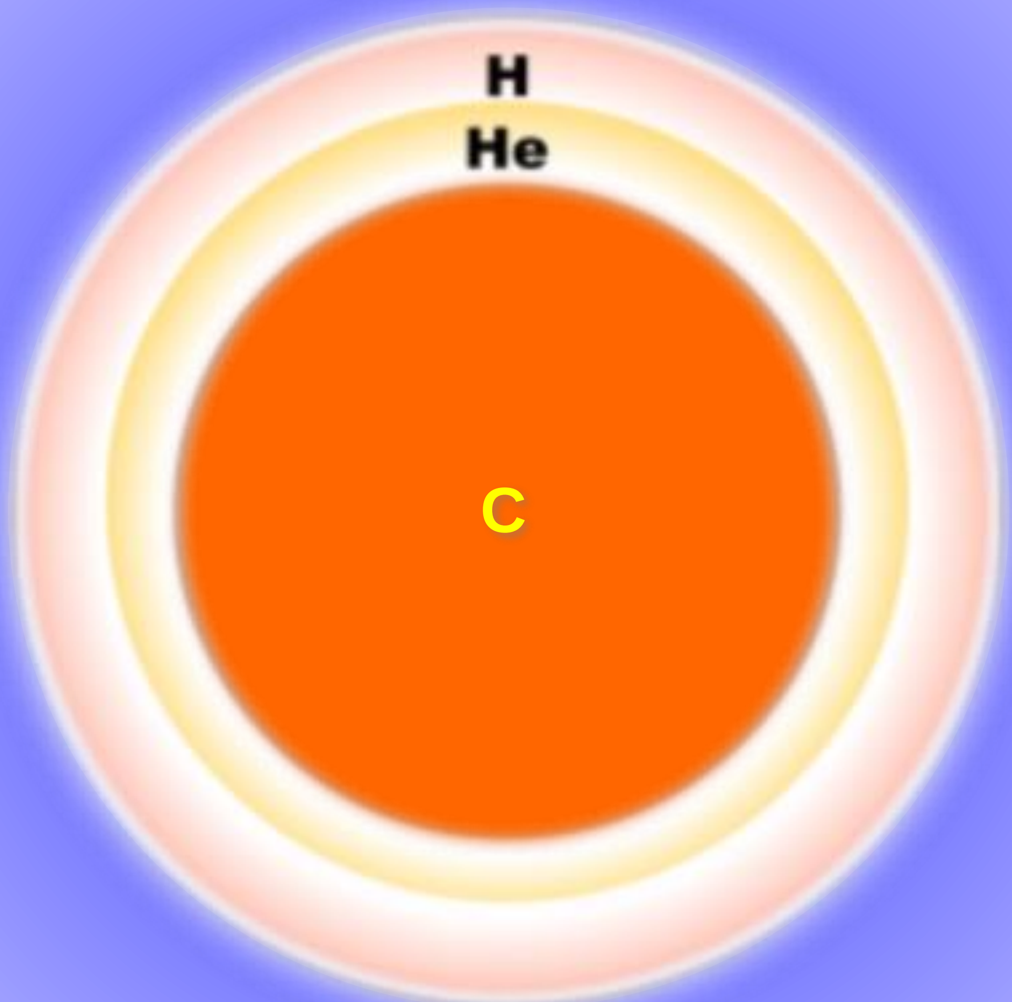


massive
star
$25x10^6$
yrs



massive star 30×10^6 yrs





Massive Stars Continue Fusion
Reactions until they make Iron (Fe)

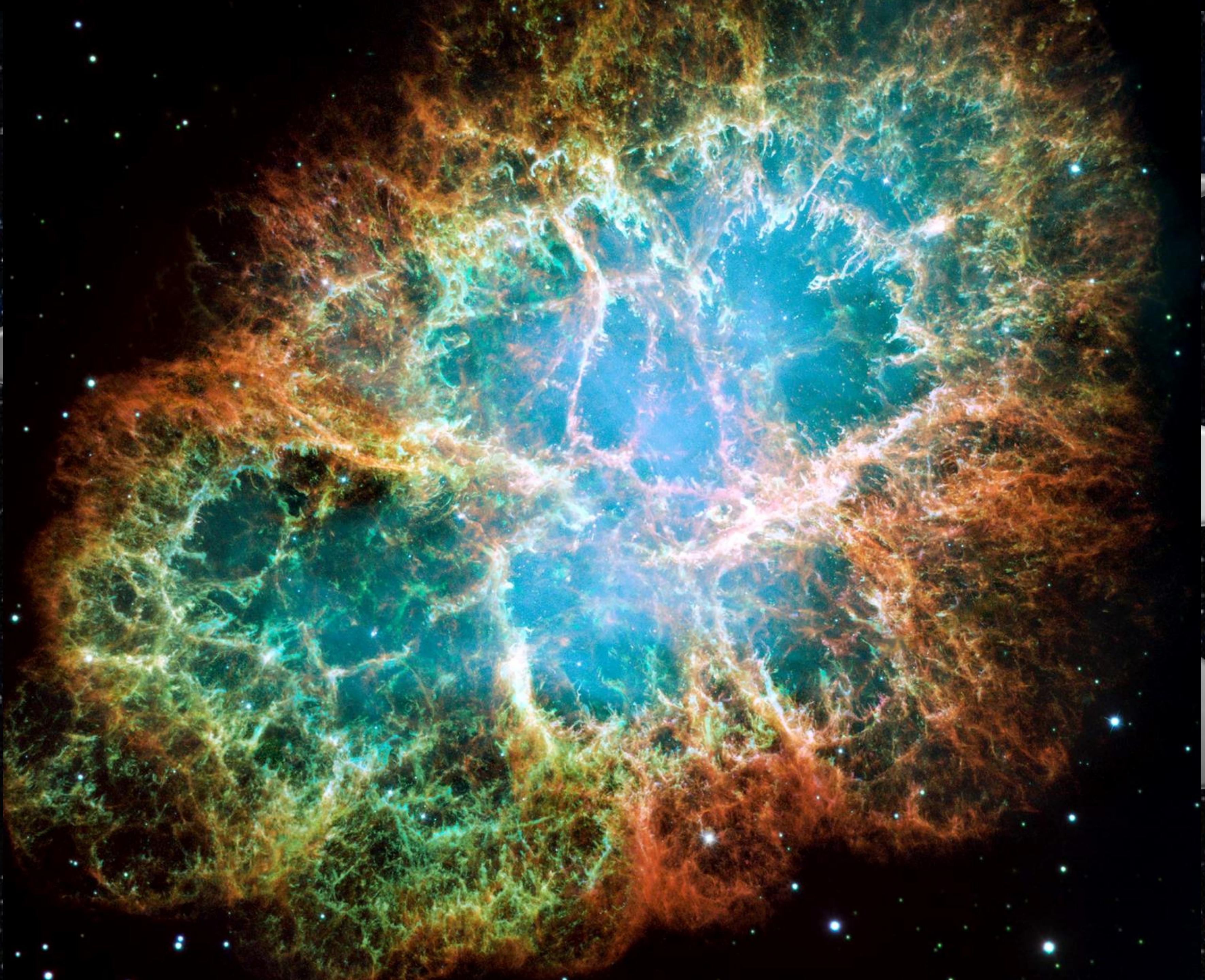
Si ➔ Fe is the last reaction a massive star can make before it explodes.

Massive Stars Continue Fusion Reactions until they make Iron (Fe)

All the fusion reactions have caused the surface of this massive star to bloat up and cool.

Si ➔ Fe is the last reaction a massive star can make before it explodes

Let's zoom back out of the Star



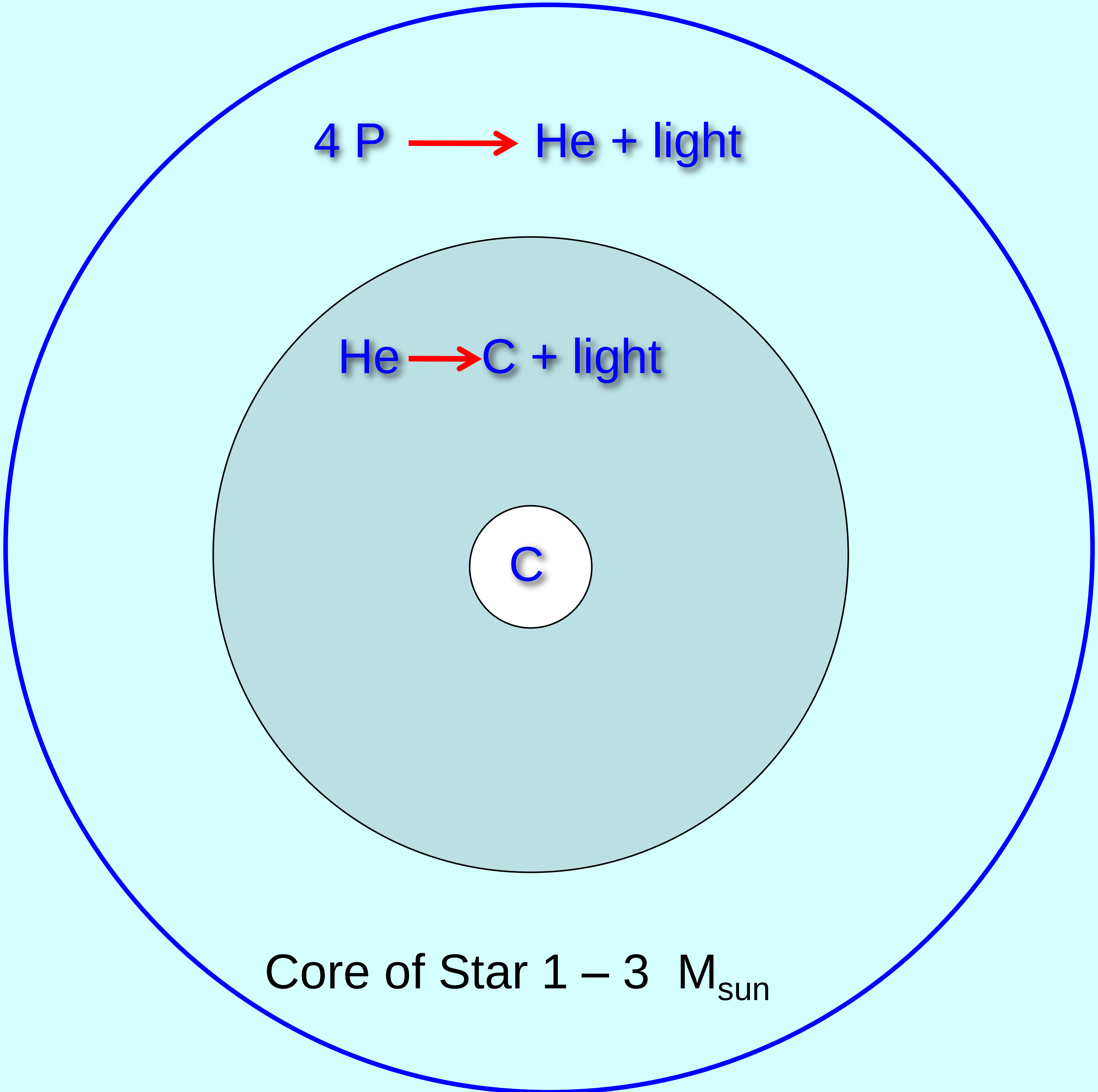
Cosmic Recycling

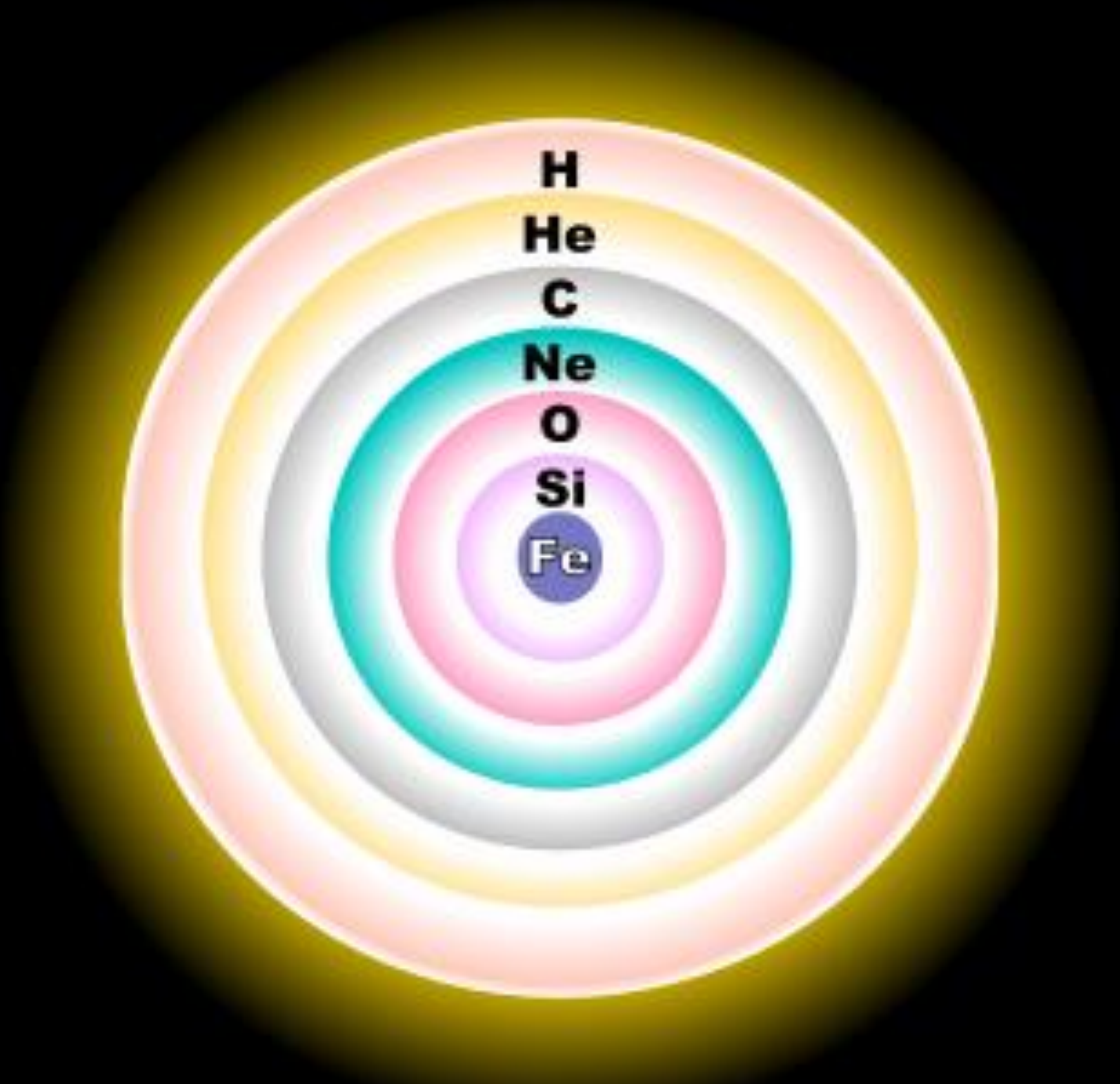
Due to stars that came and went billions of years before us, our Sun and Solar System contain:

Hydrogen	73.77%
Helium	24.29%

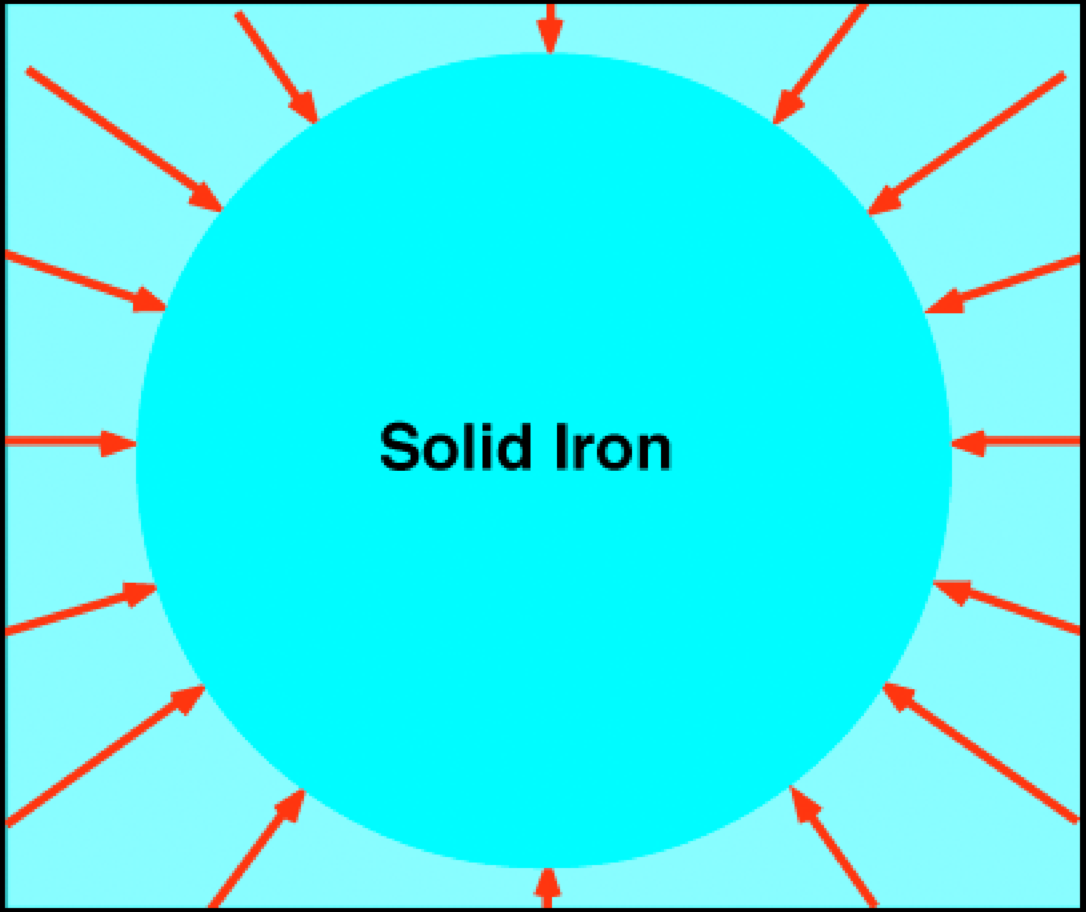
this is what we are made of!

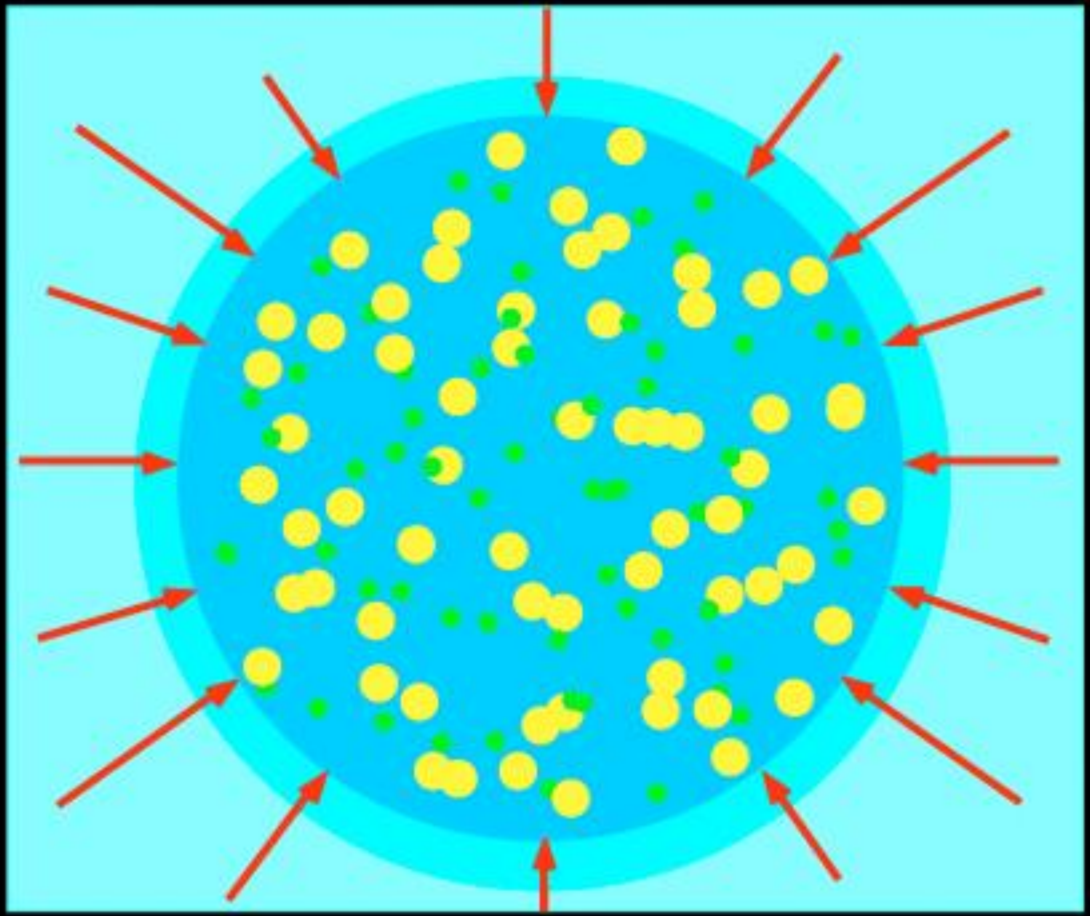
Oxygen	0.77%
Carbon	0.29%
Iron	0.16%
Neon	0.12%
Nitrogen	0.09%
Silicon	0.07%
Magnesium	0.05%
Sulfur	0.04%

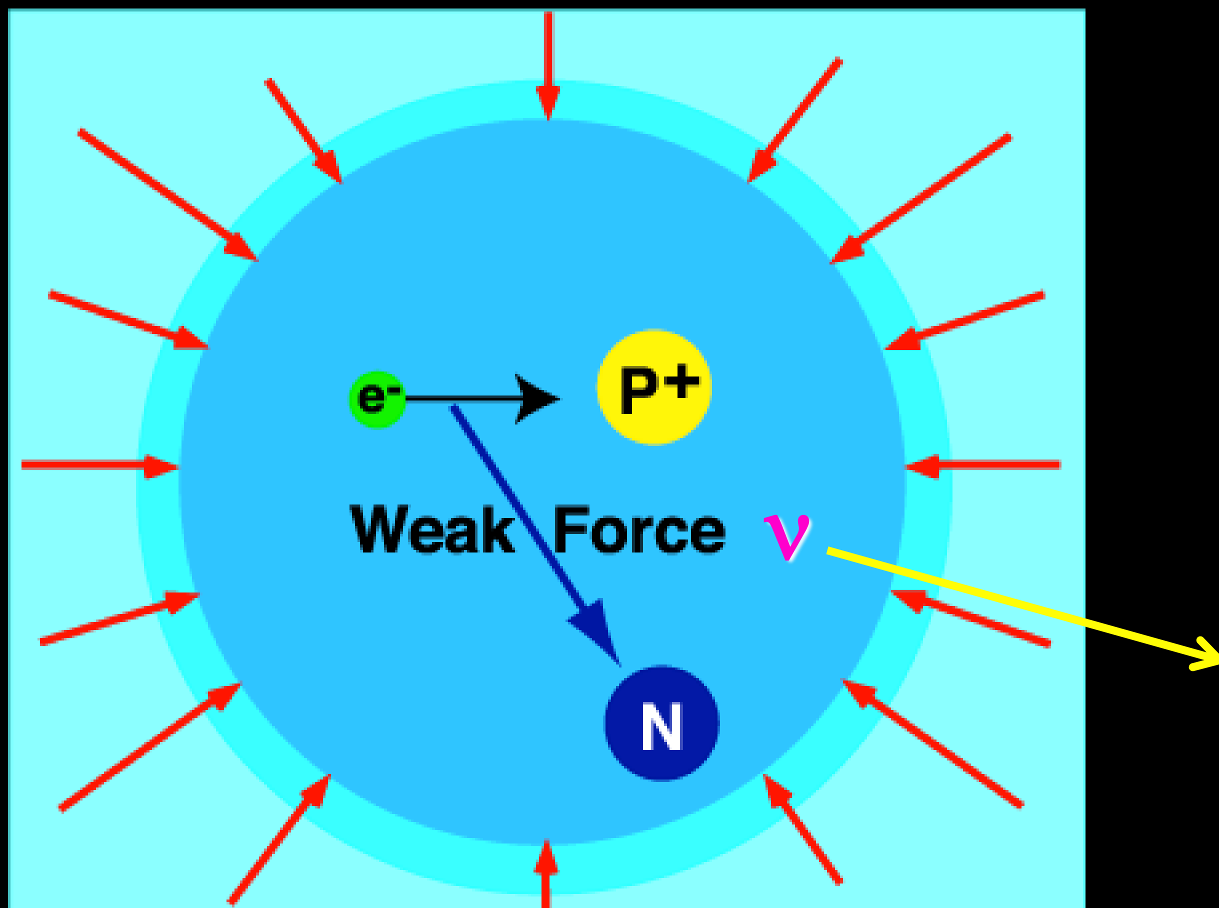

4 P → He + light
He → C + light
C
Core of Star 1 – 3 M_{sun}



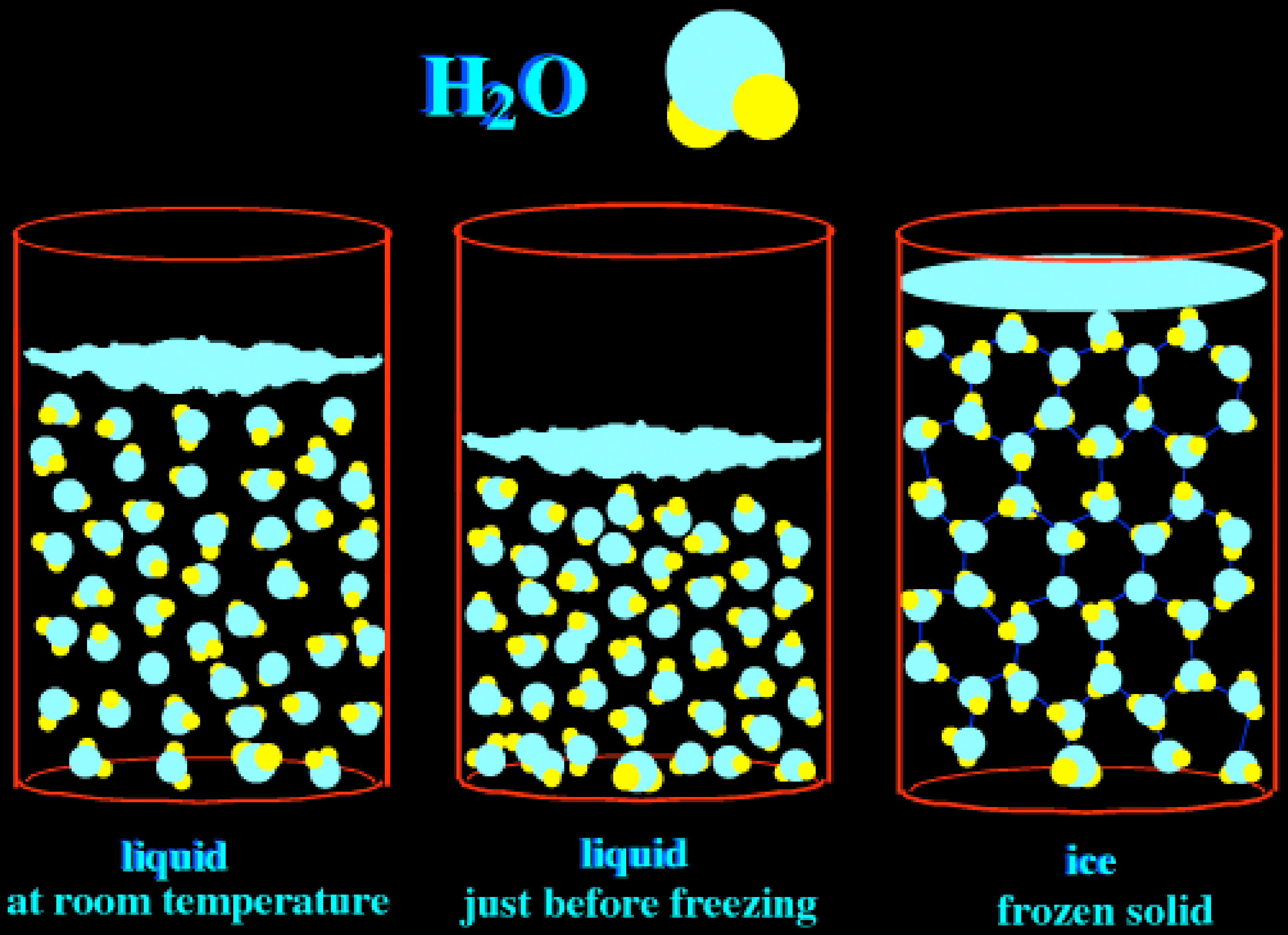
core of a massive star

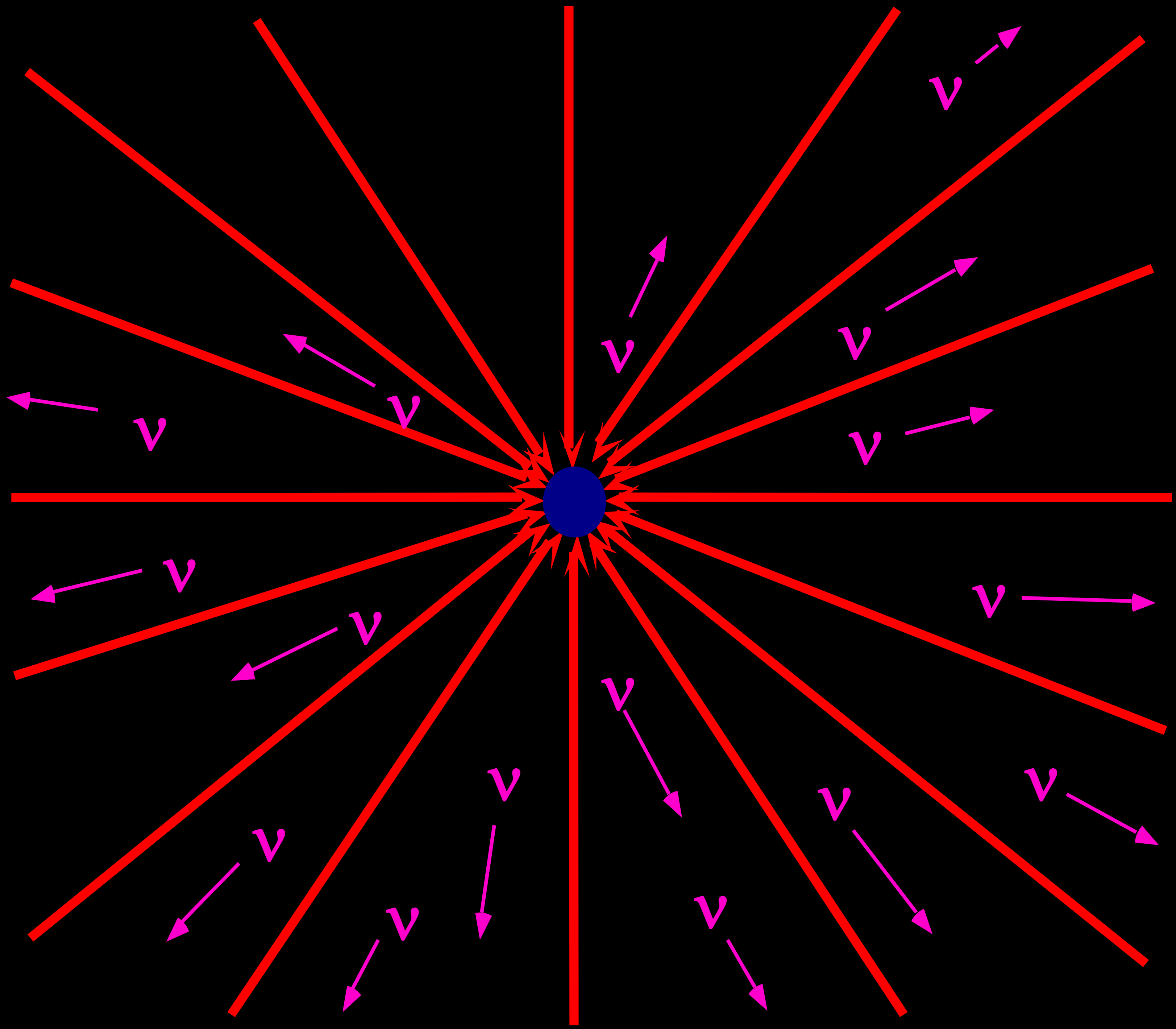

Solid Iron





e-
P+
Weak Force
ν
N


H2O
liquid
at room temperature
liquid
just before freezing
ice
frozen solid


ν
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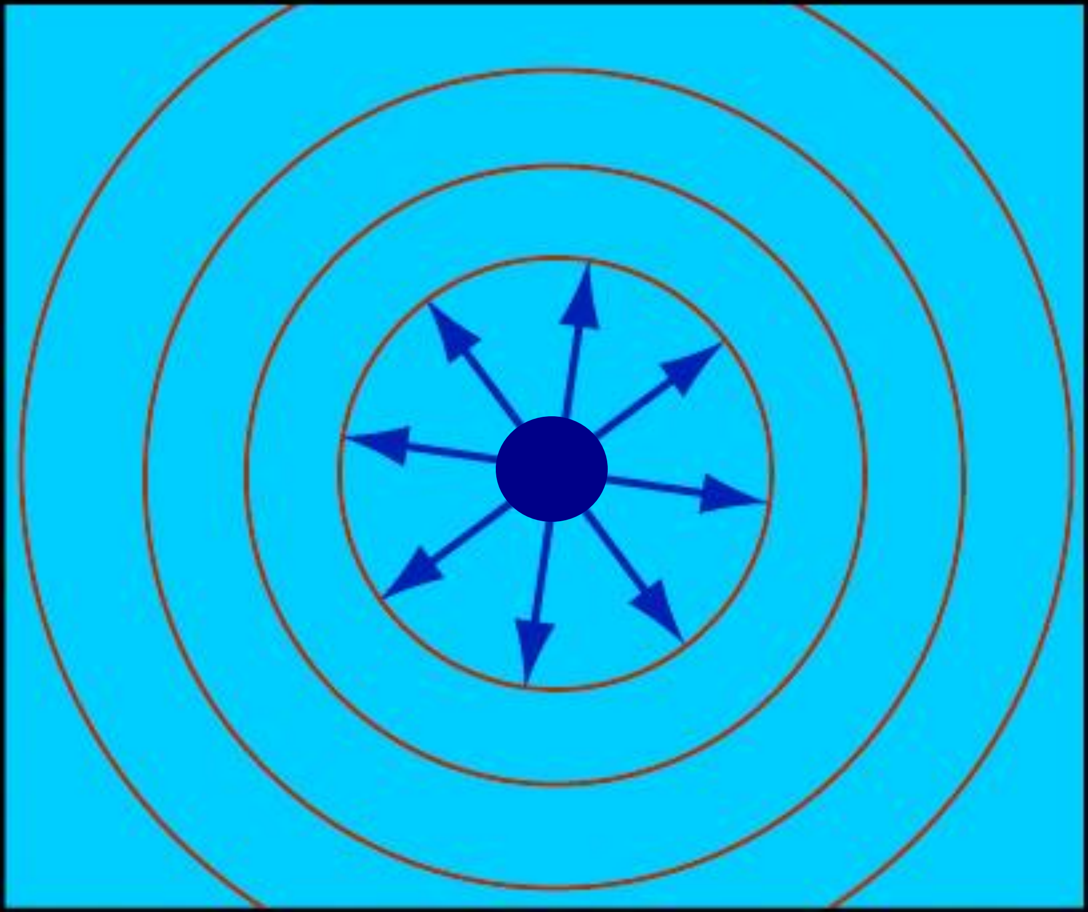
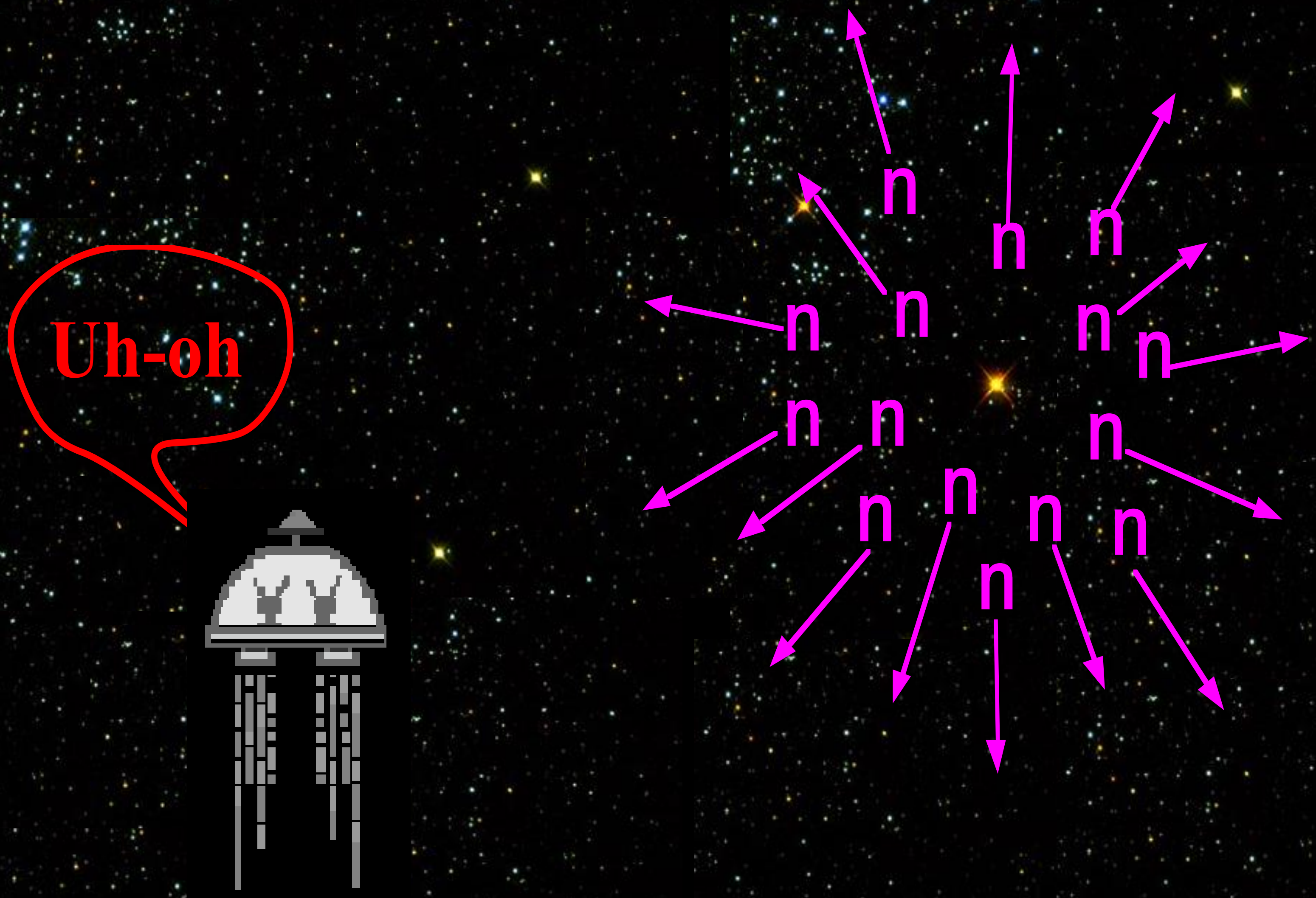
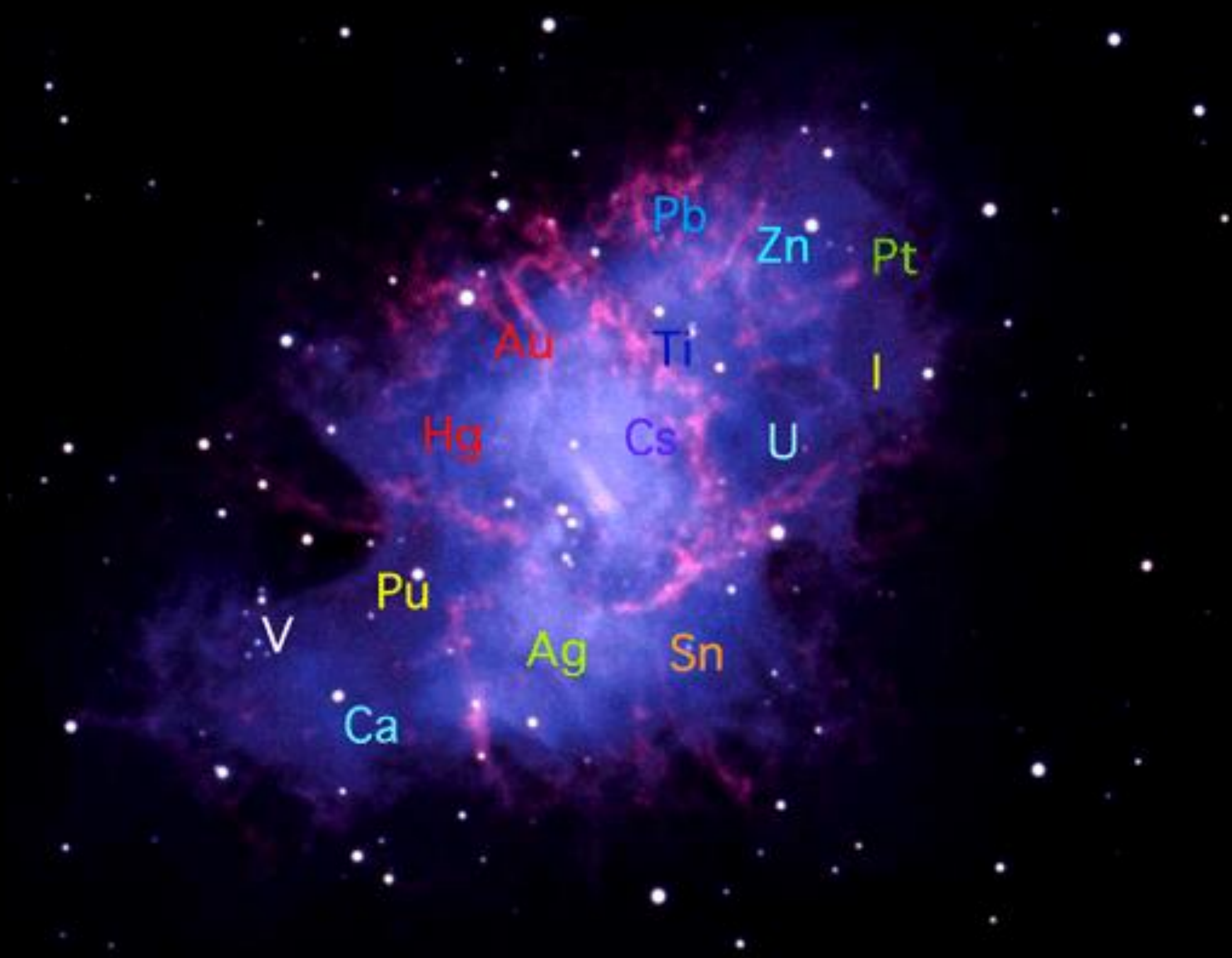
$\frac{1}{1,000}$ **second to rebound as the neutrons crystallize!**

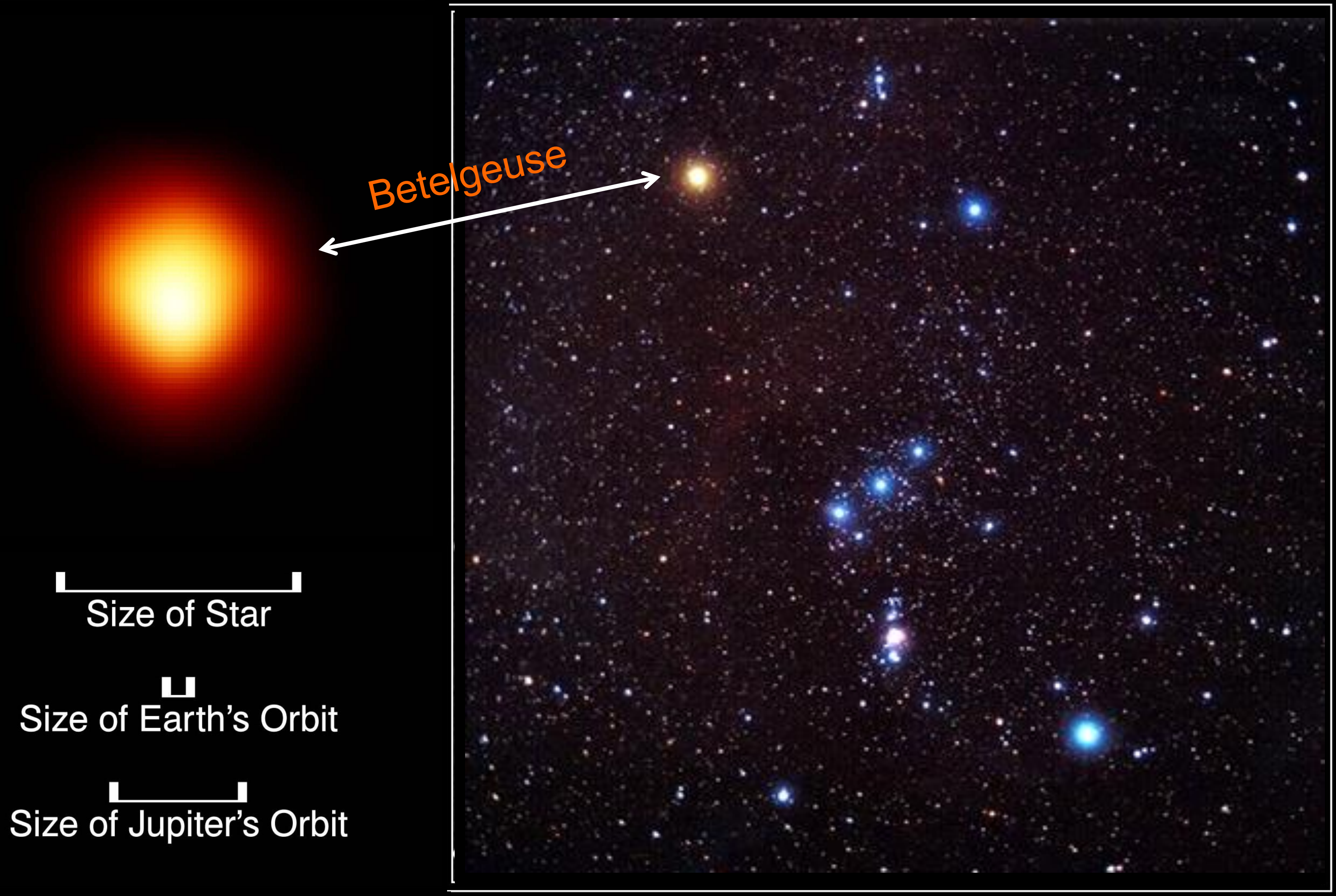


After the neutrino burst, it takes 3 hours for the blast to make it to the surface of the star

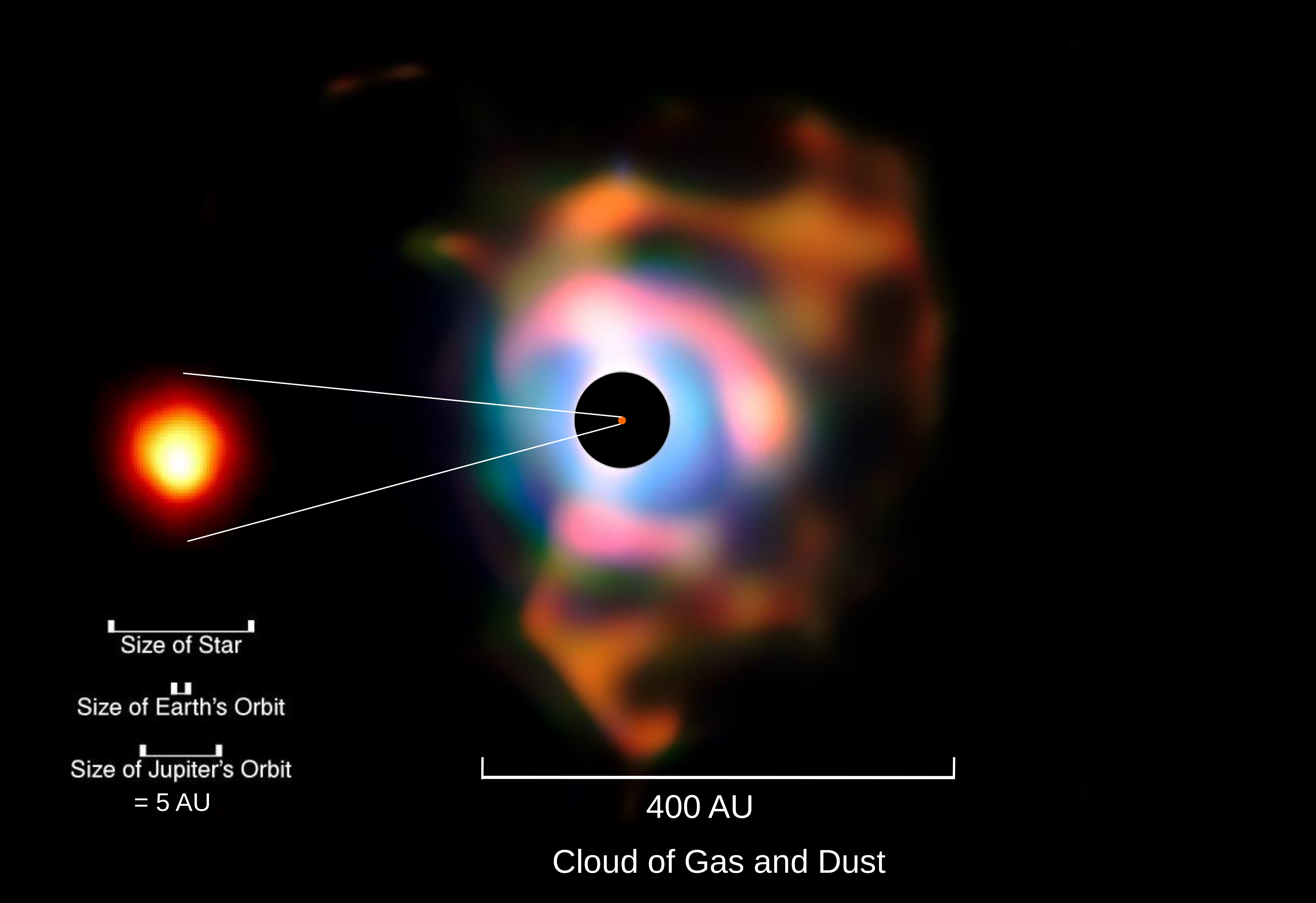




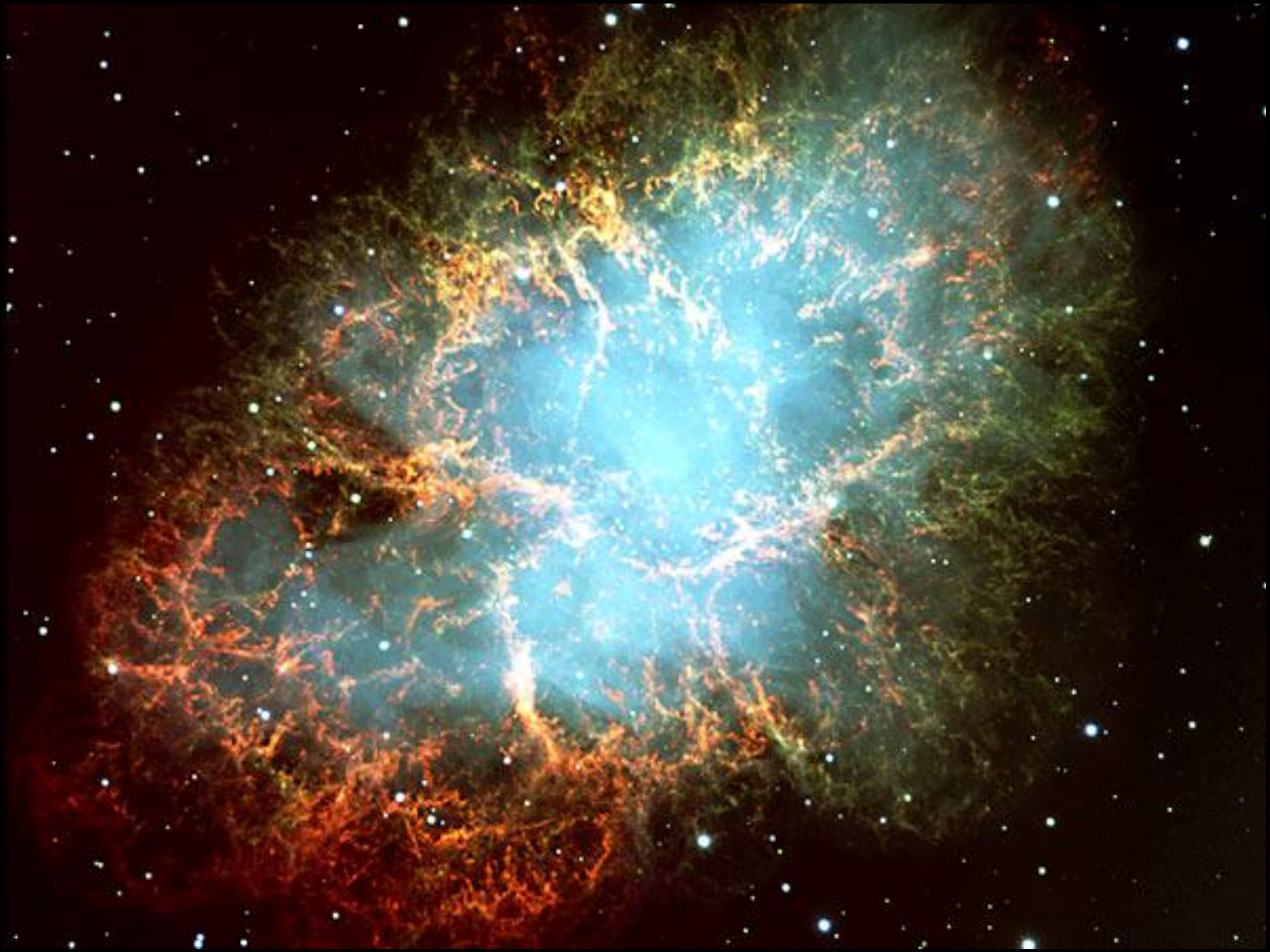
Supernova remnant (SNR)

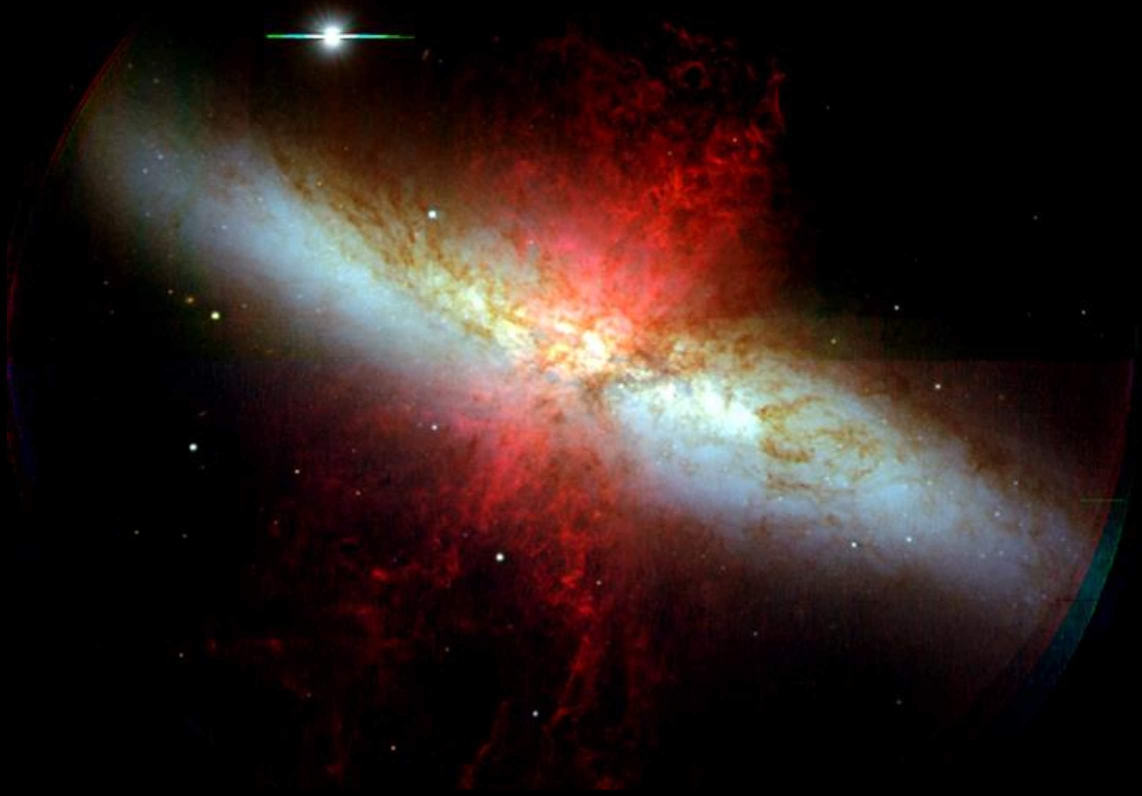


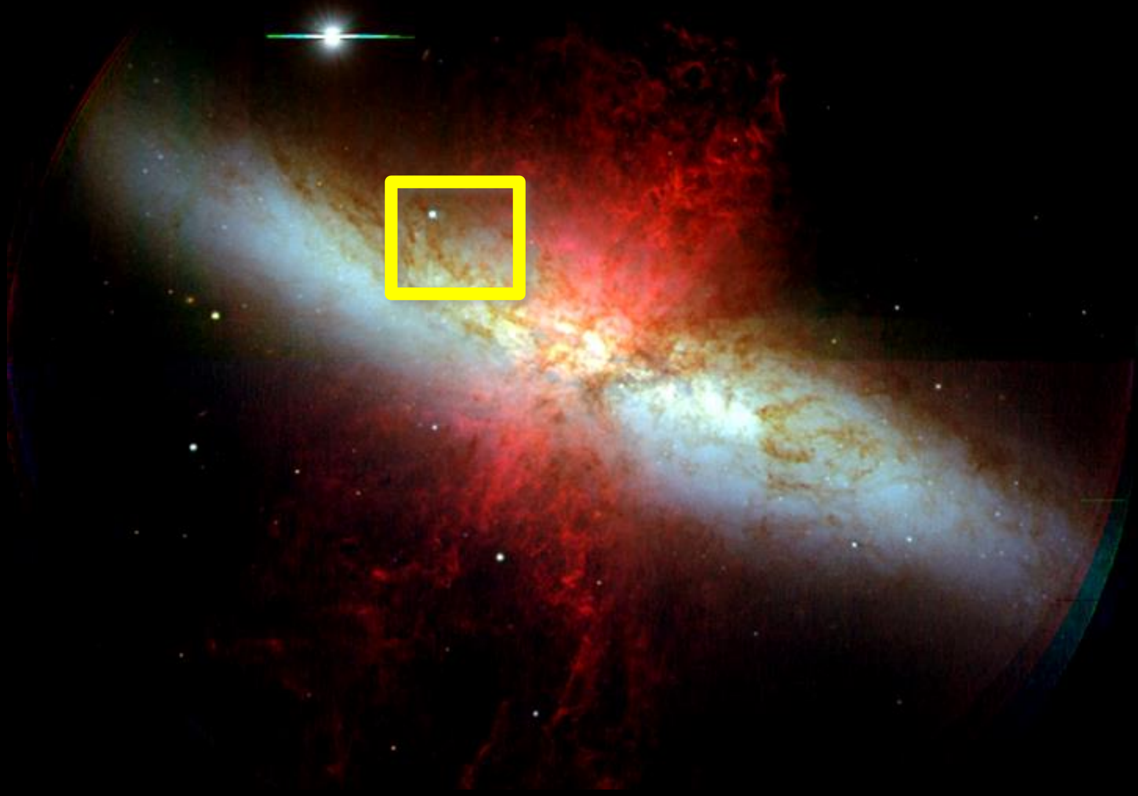
Orion Constellation

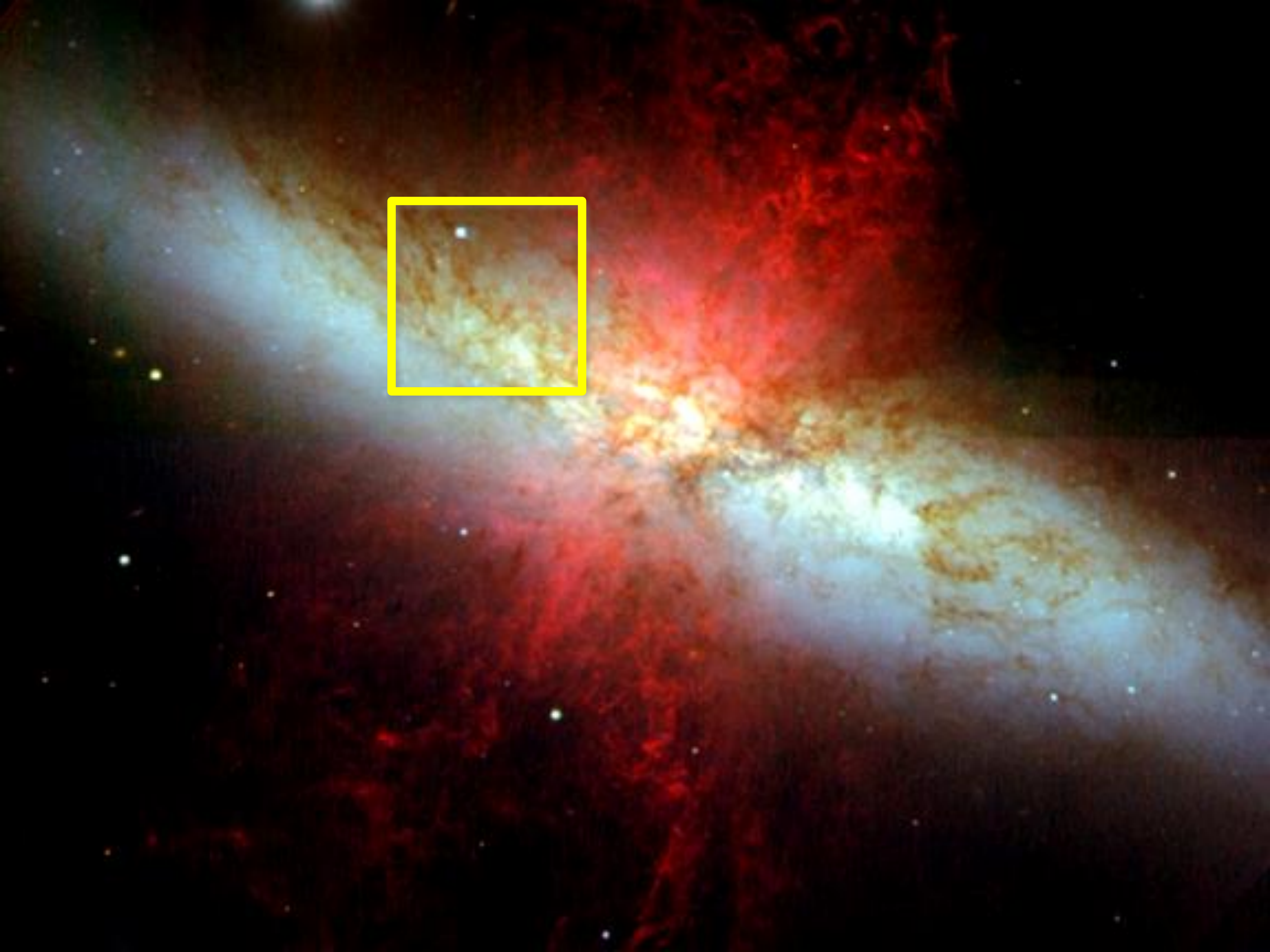


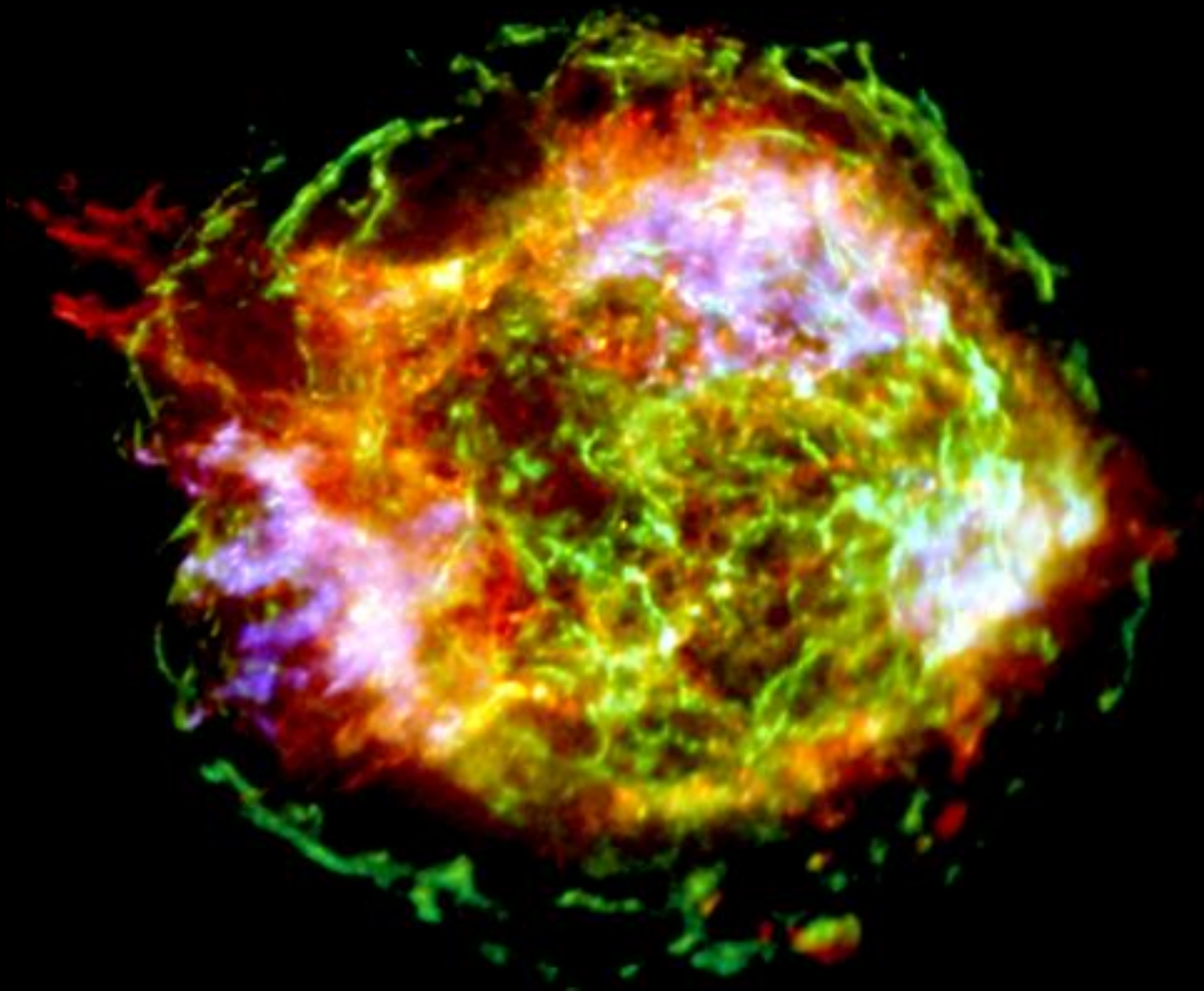
Betelgeuse is ready to go Supernova!



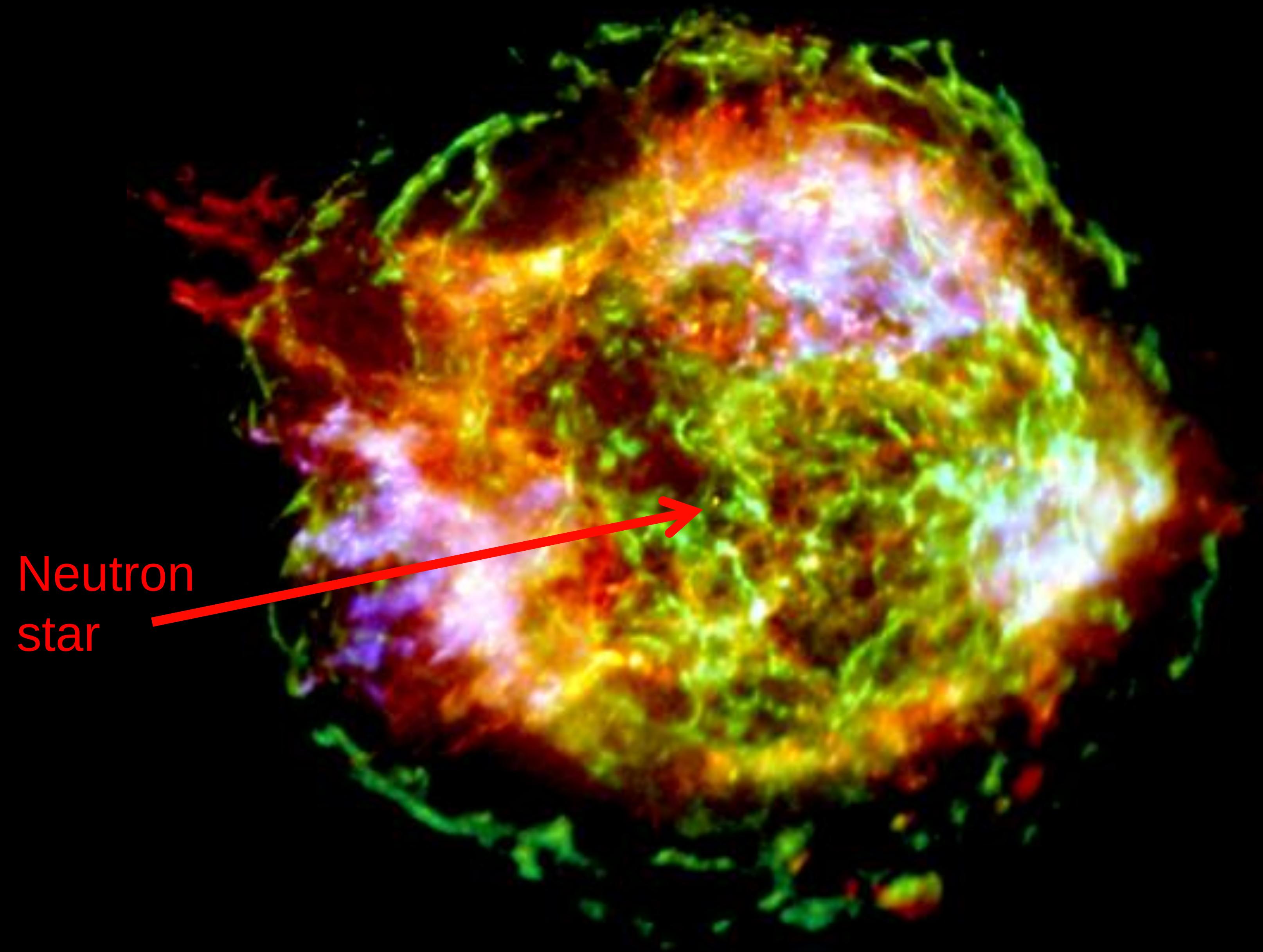




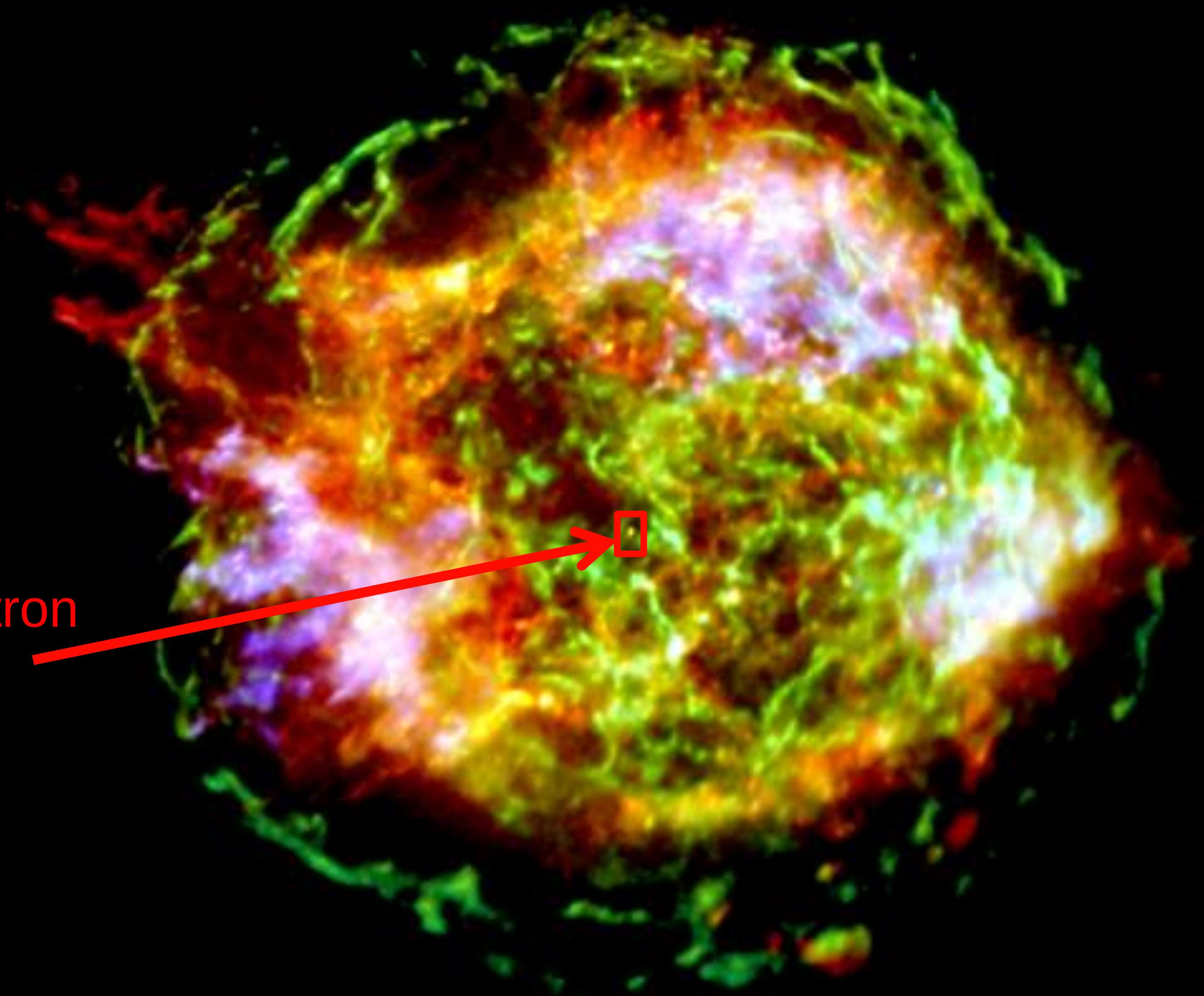




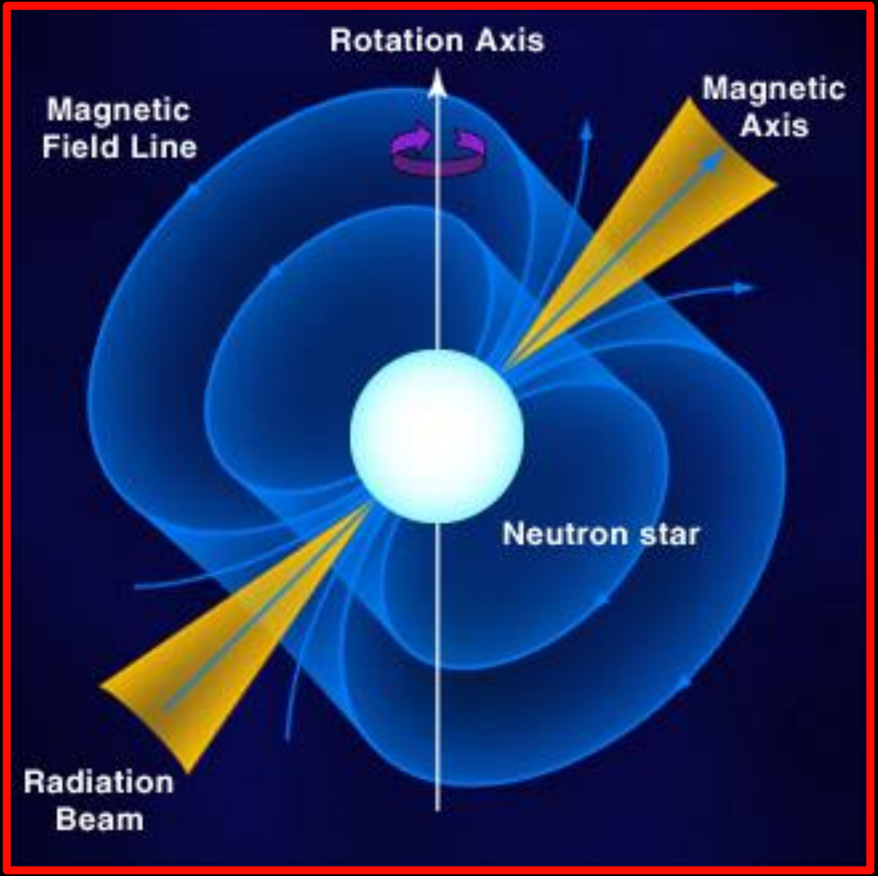
Supernova remnant (SNR) Cas A in x-rays

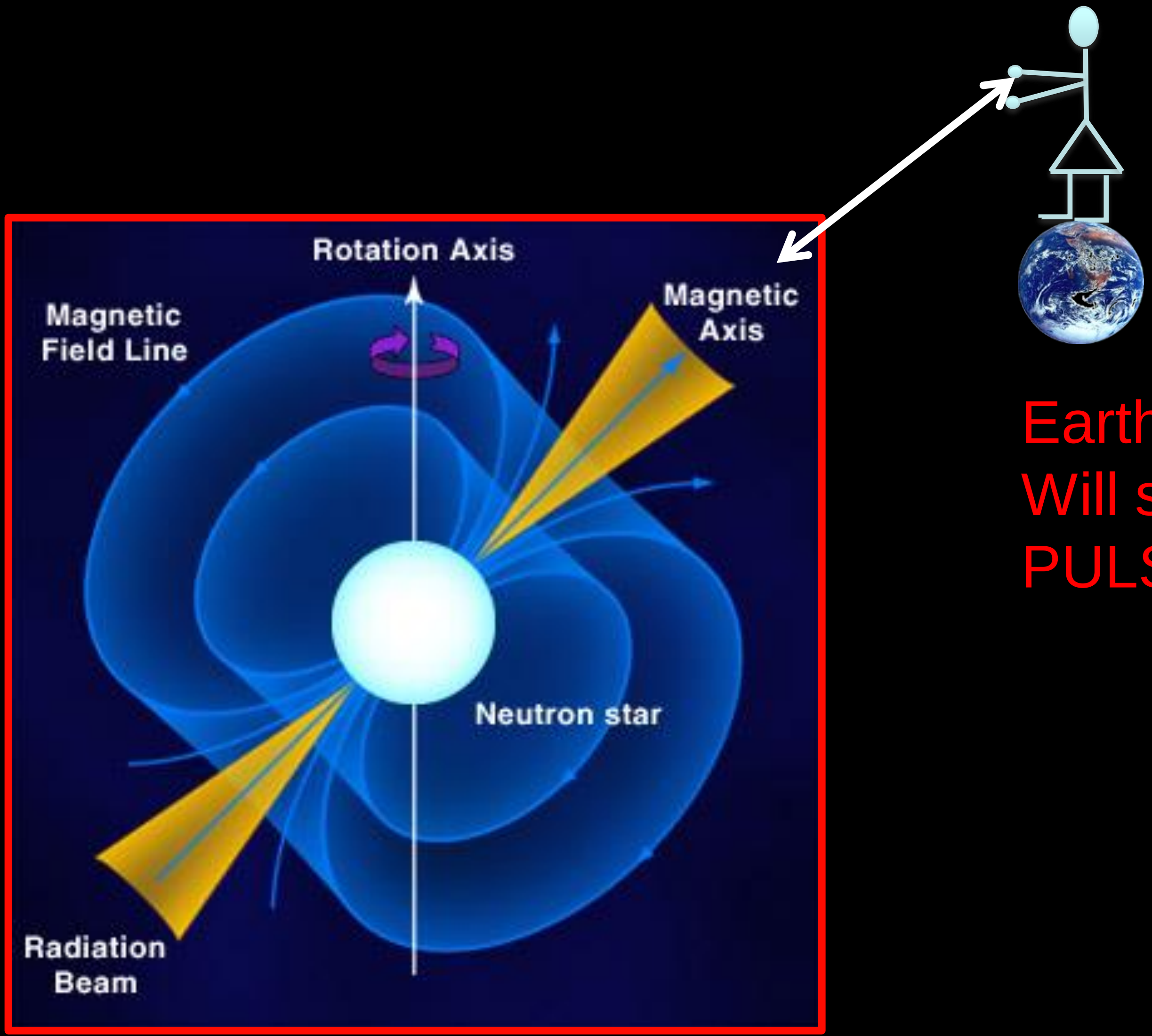


Supernova remnant (SNR) in x-rays



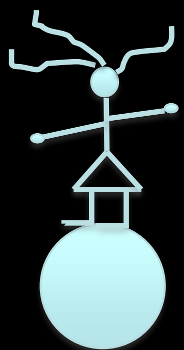
Supernova remnant (SNR) in x-rays

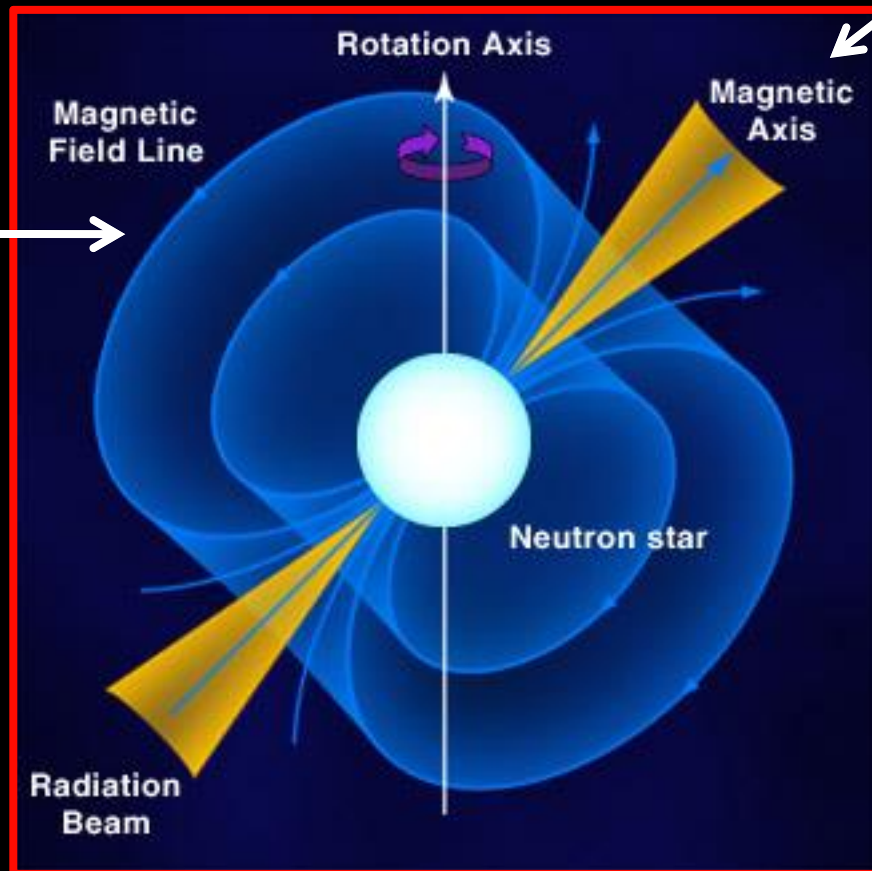

Rotation Axis
Magnetic
Field Line
Magnetic
Axis
Neutron star
Radiation
Beam



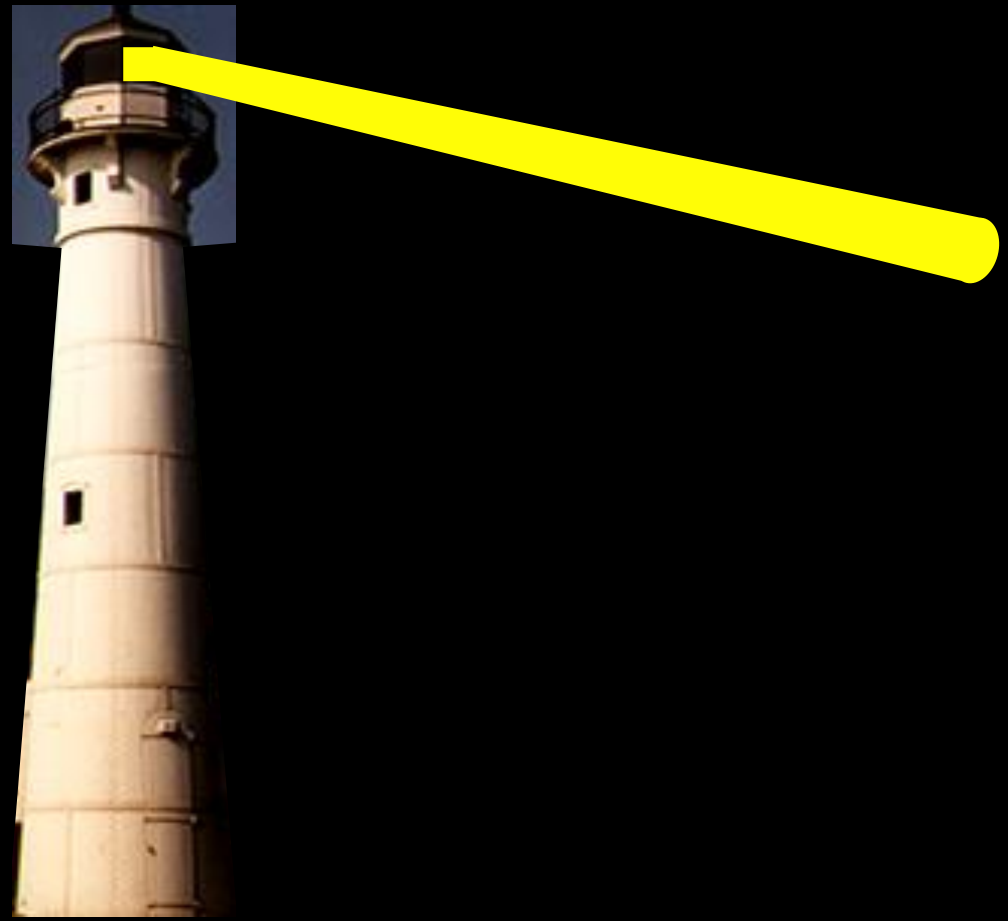
Earth
Will see a
PULSAR

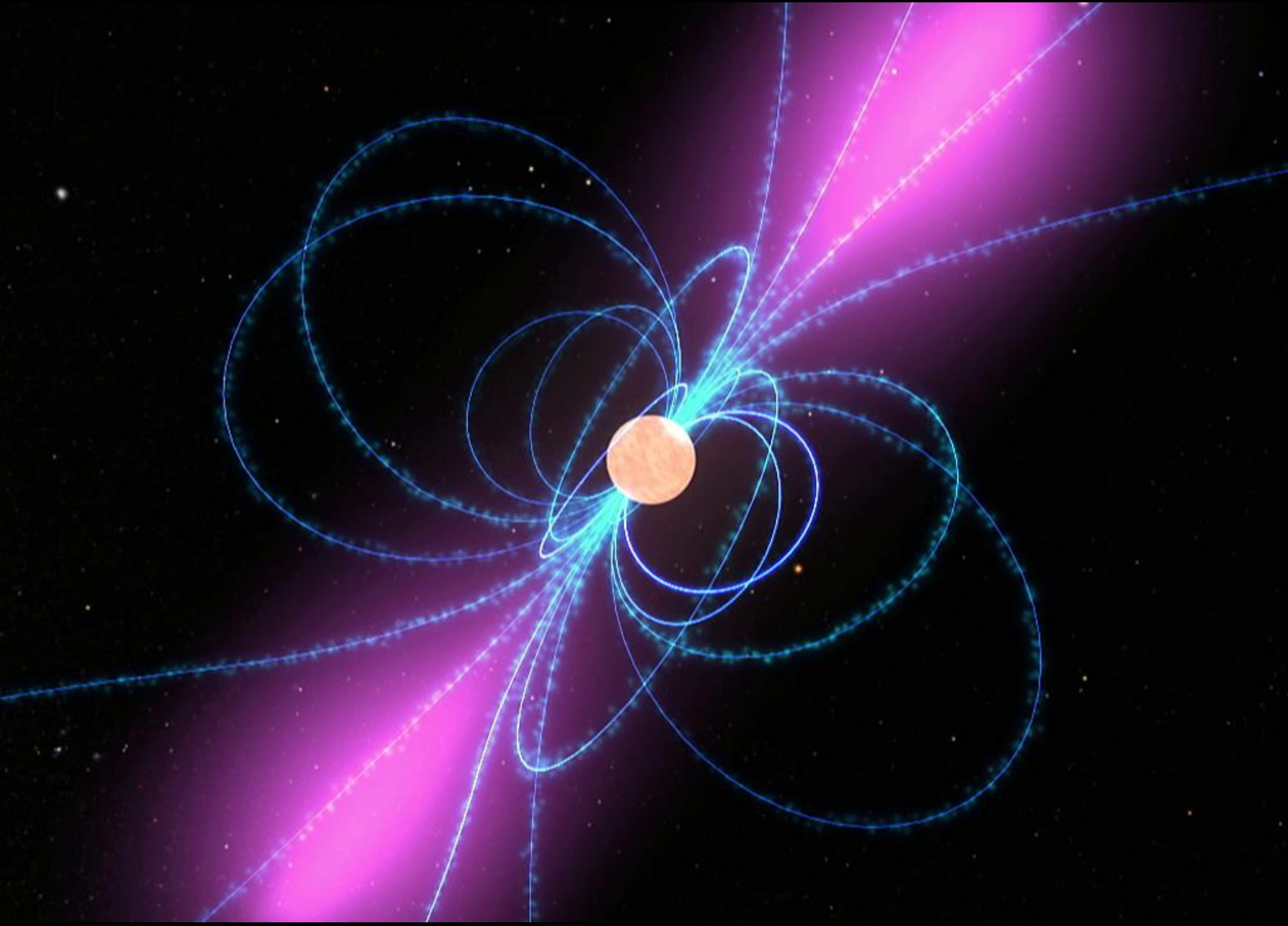
Earth
Will see a
PULSAR





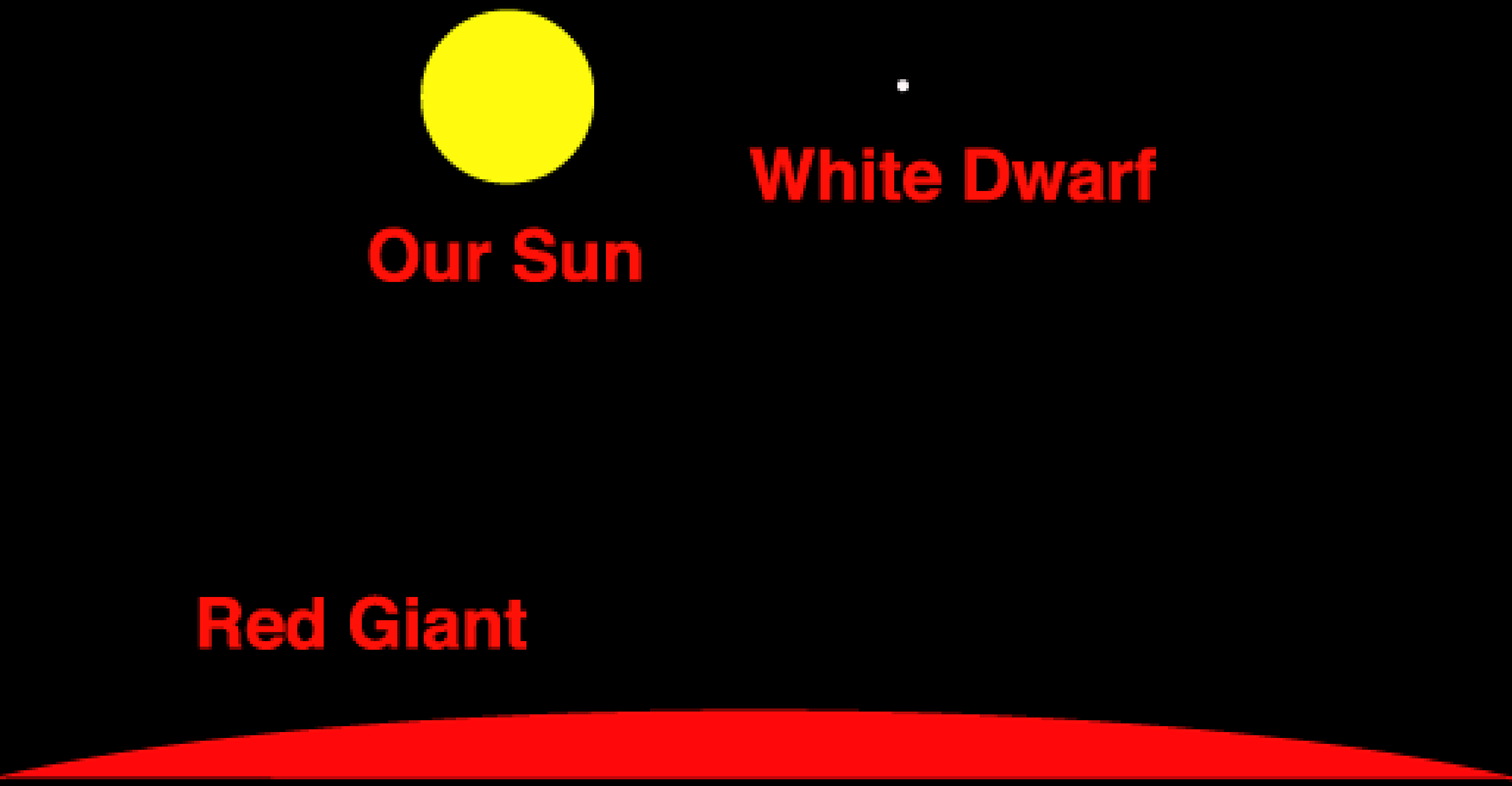
alien planet
will see a
neutron
star





Jocelyn Bell
1969

Jocelyn
Burnell-Bell


White Dwarf
Our Sun
Red Giant

Neutron Star

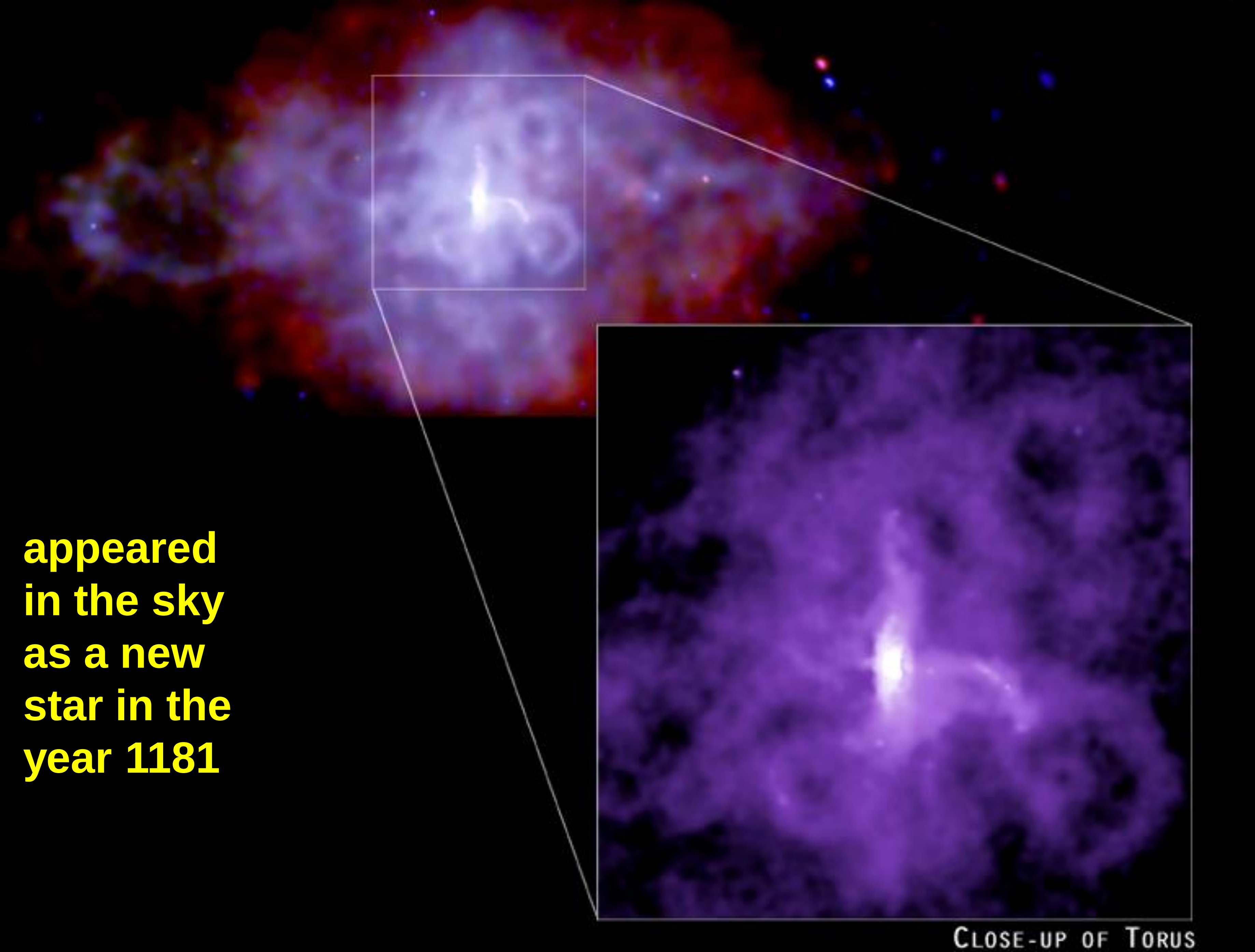
1 tsp = 100 million tons

(weight of 20 million elephants!)

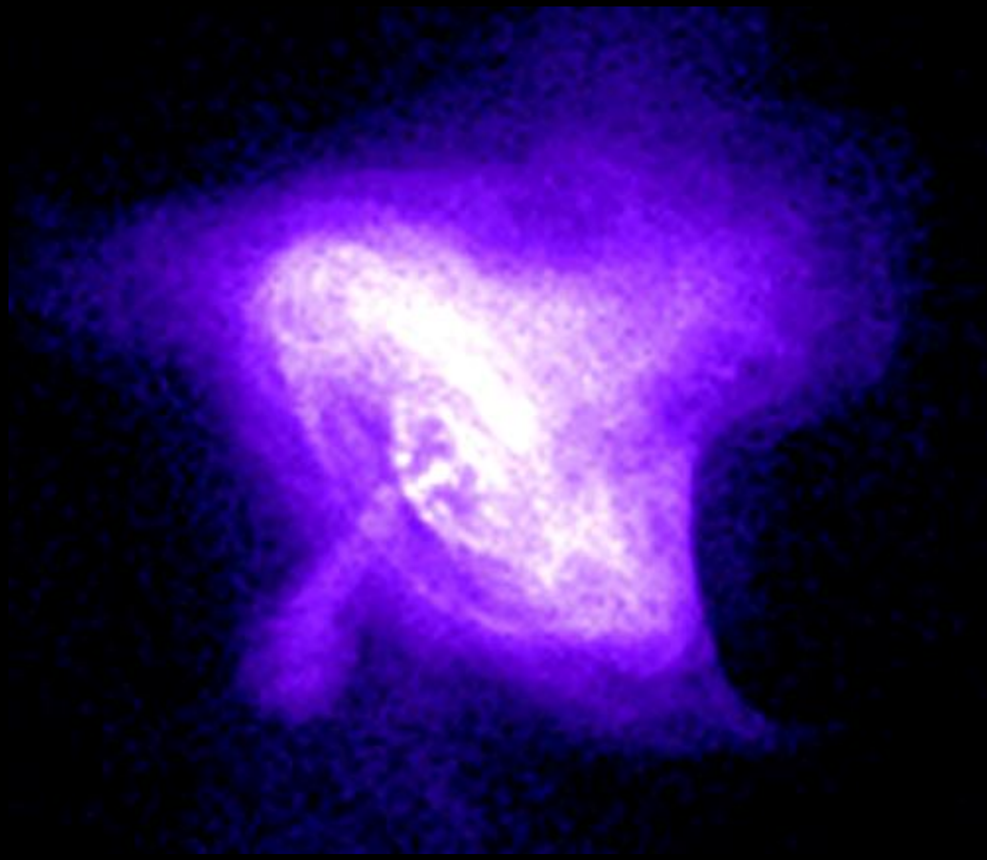
White Dwarf

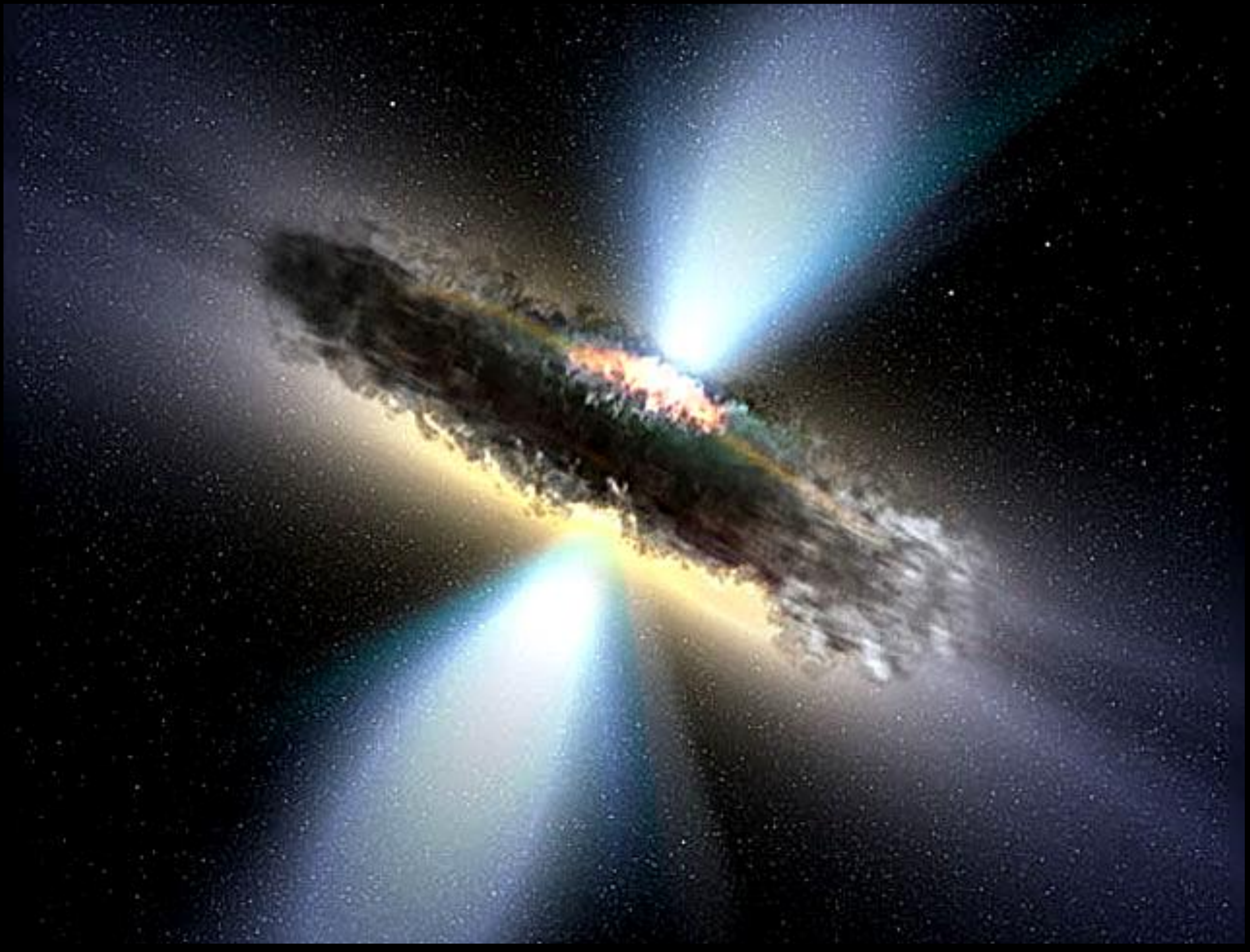
1 tsp = 5.5 tons

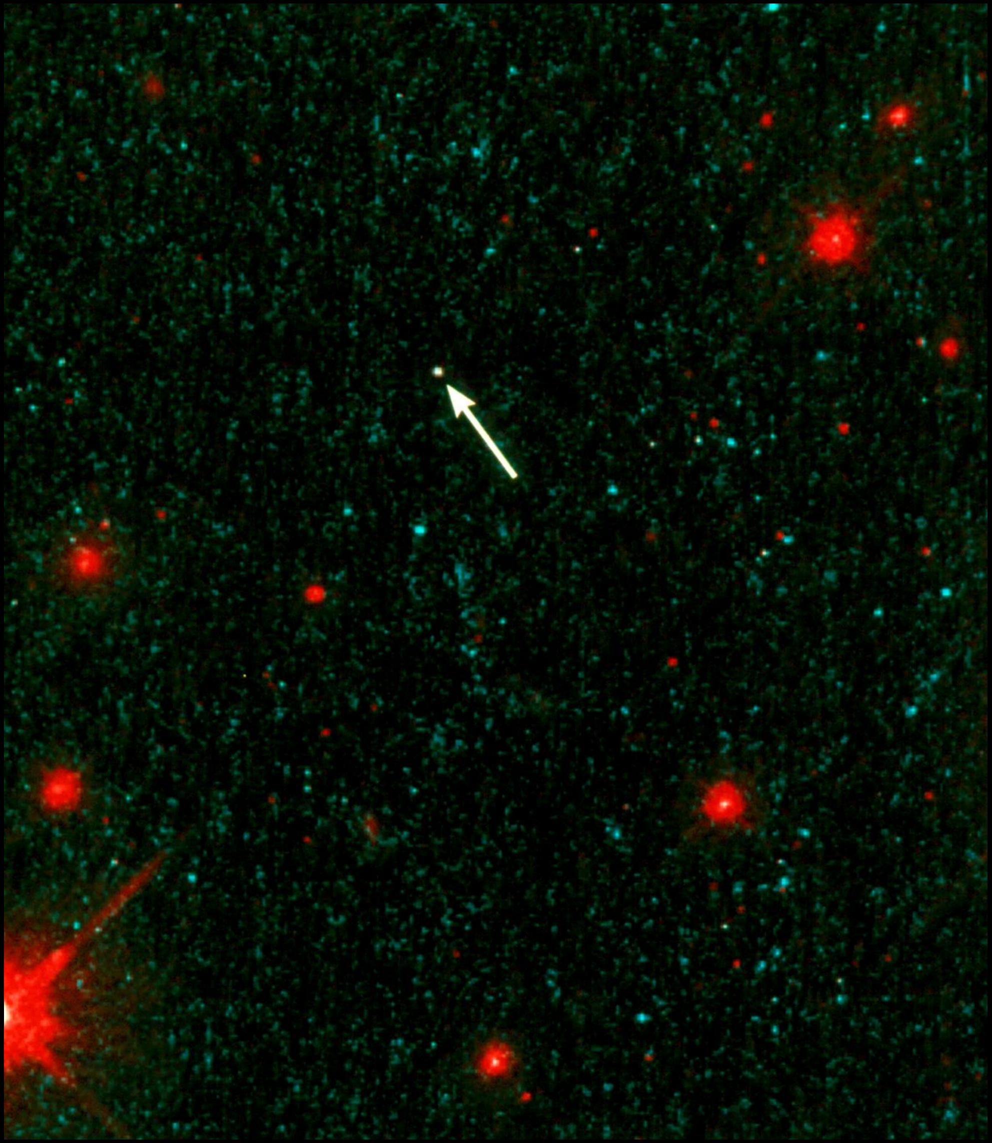
(weight of 1 elephant!)



appeared in the sky as a new star in the year 1181







Stars Take different paths to their end depending on how MASSIVE they are.

1 to 3 $M_\odot$	PN	+	white dwarf
3 to 8 $M_\odot$	SN	+	neutron star
> 8 $M_\odot$	SN	+	black hole

Stars Take different paths to their end depending on how MASSIVE they are.

1 to 3 $M_\odot$	PN	+	white dwarf
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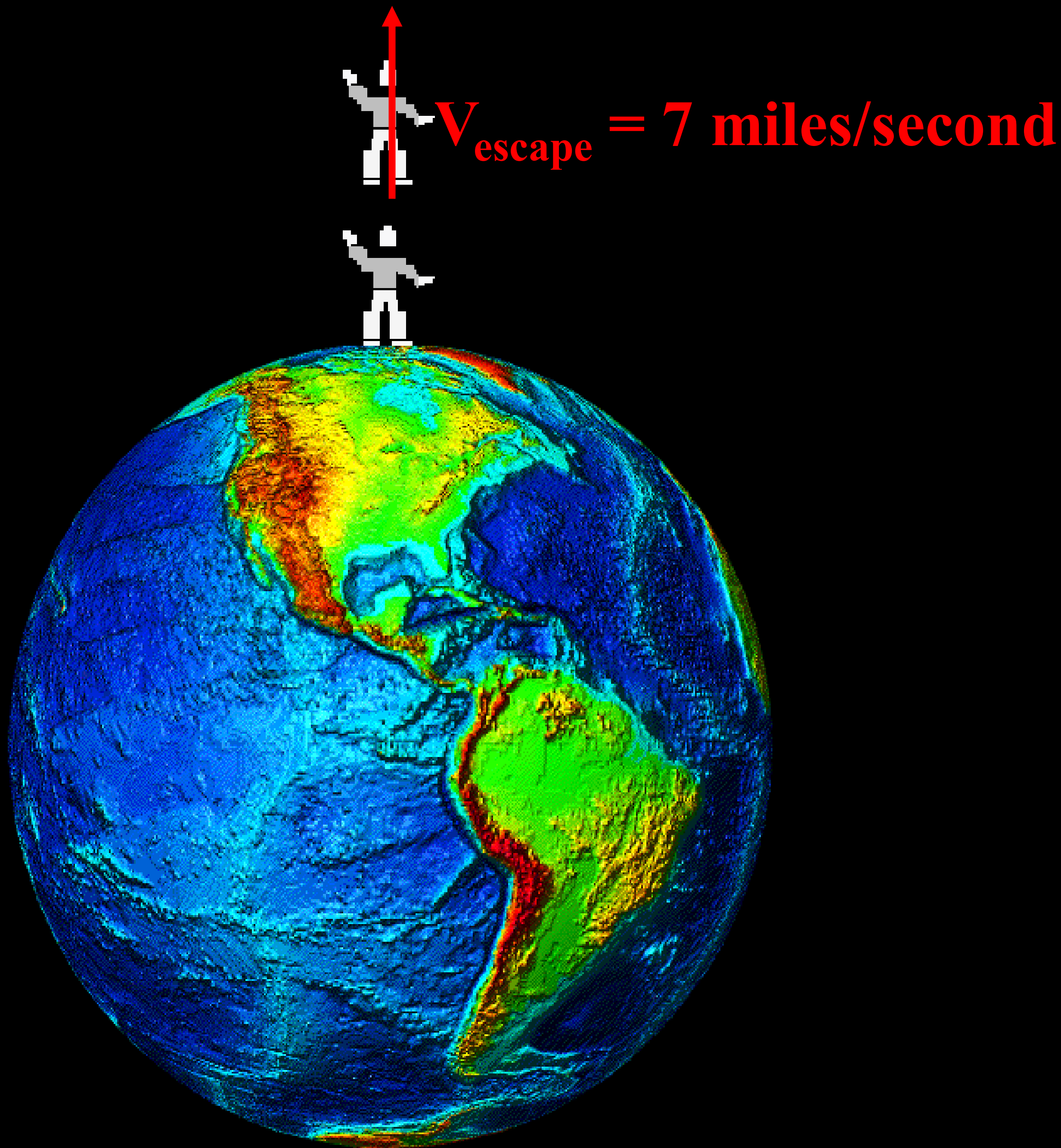
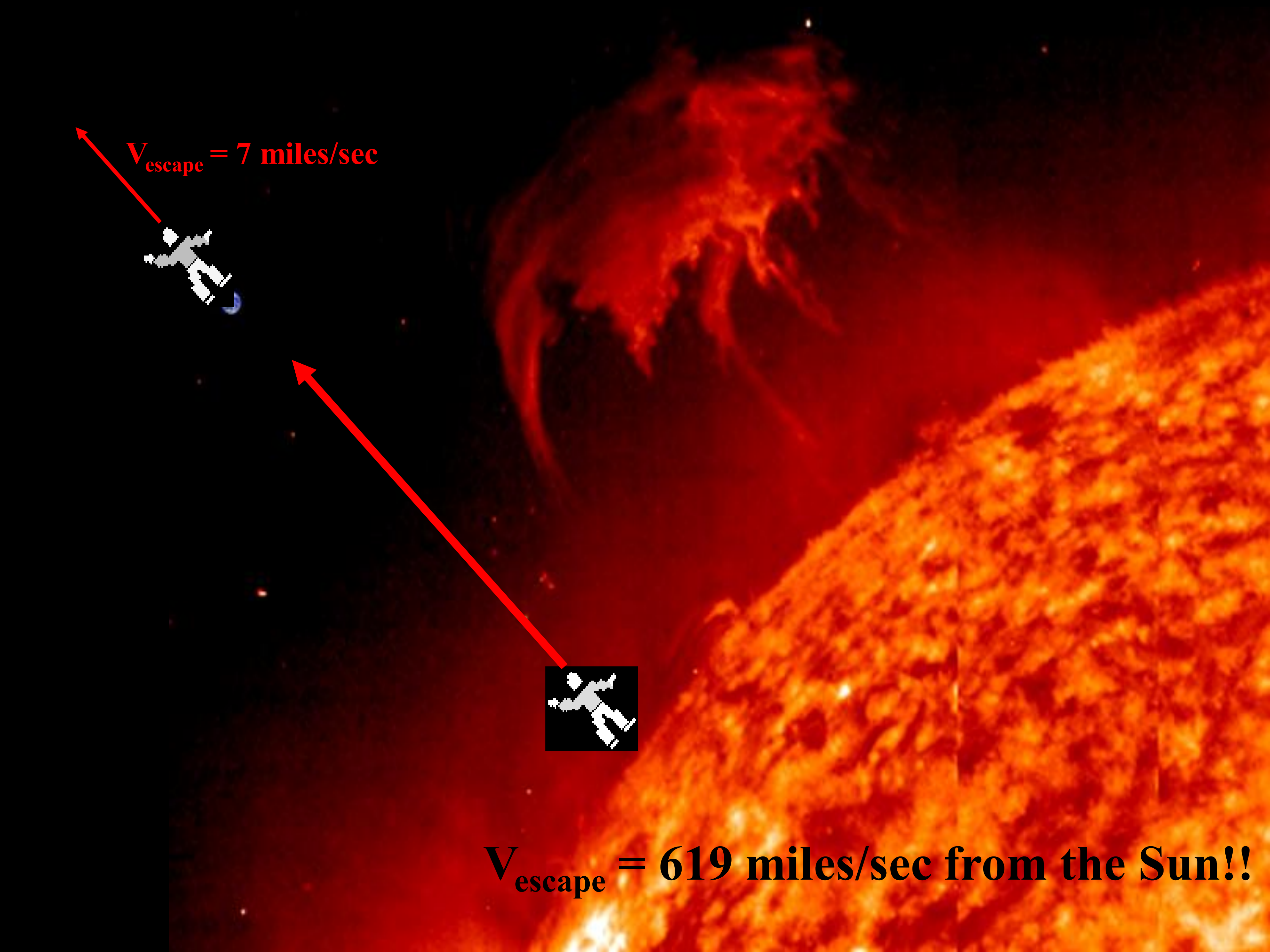
an object whose escape speed is > *c*

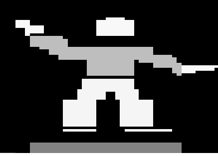

V_{escape} = 7 miles/second


V_{escape} = 7 miles/sec
V_{escape} = 619 miles/sec from the Sun!!

Neutron Star

10 billion ´ your weight on earth!

White Dwarf



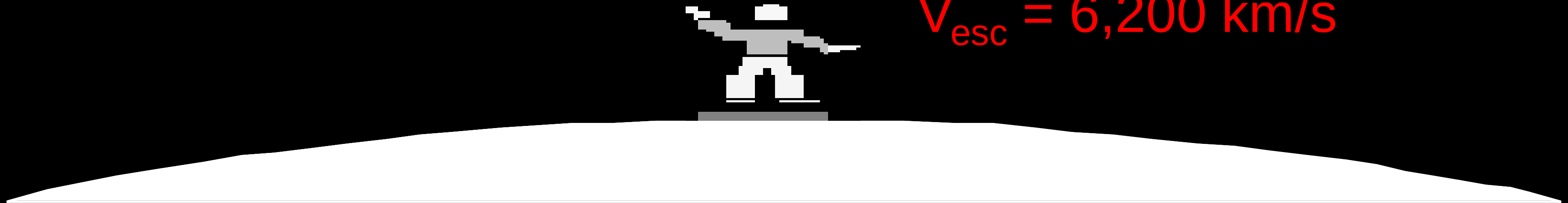
100 thousand ´ your weight on earth!

Neutron Star

V_{esc} = 232,000 km/s

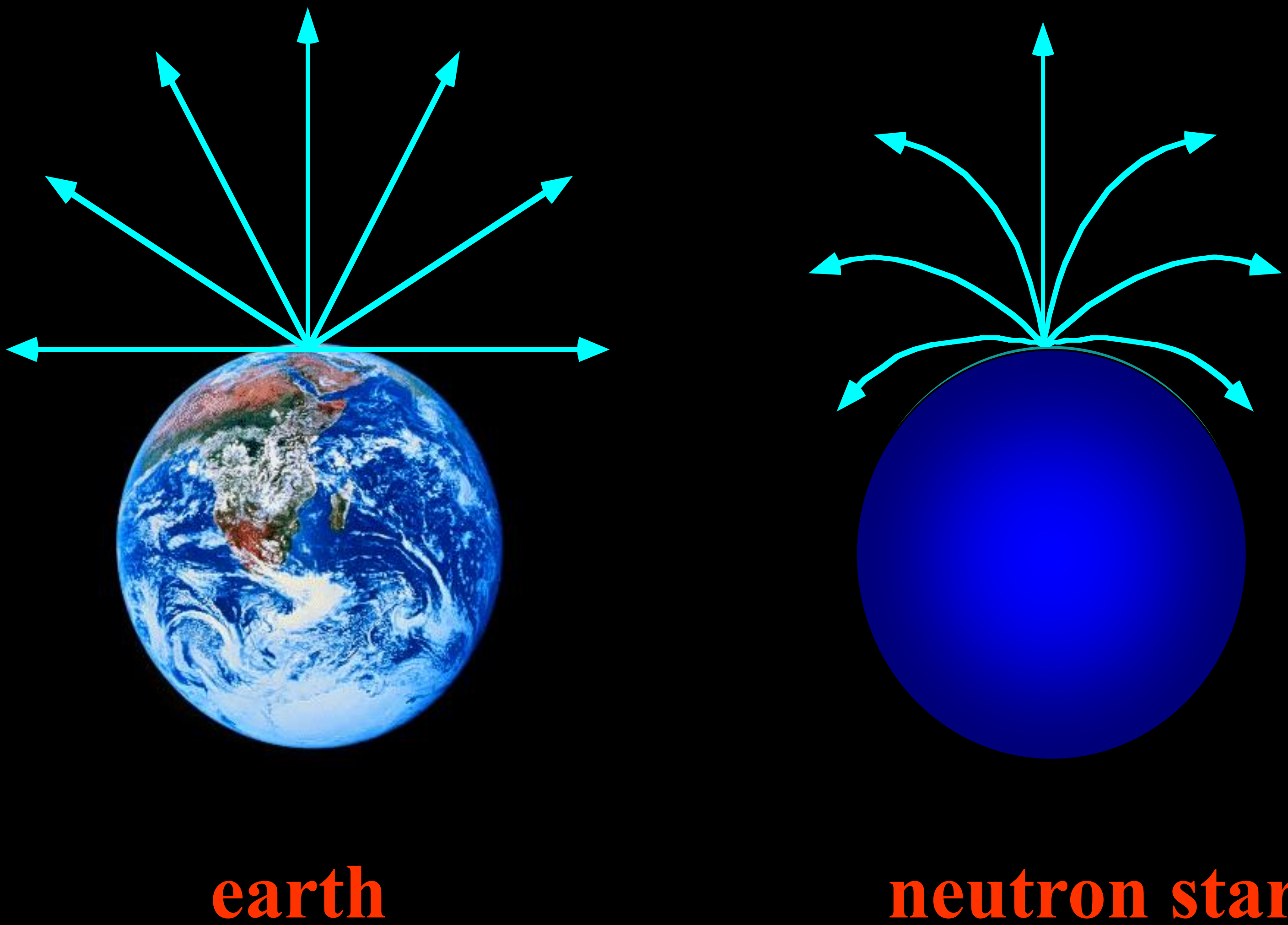
= 78% *c*

White Dwarf



V_{esc} = 6,200 km/s

Light Paths



NEUTRON STAR

Mass in core of 5 M_{sun} Star:	1.0 M_{sun}
Crushed into size:	10 km

gravity canNOT overwhelm the Strong Force

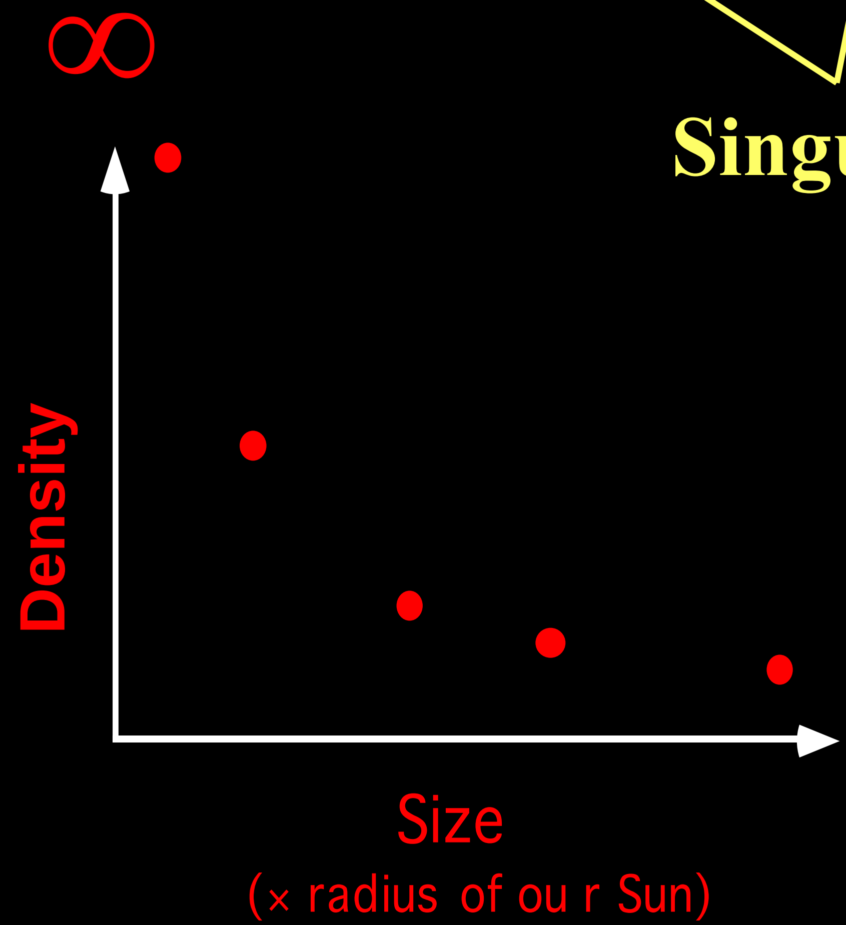
BLACK HOLE

Mass in core of 8 M_{sun} Star: 1.5 M_{sun}

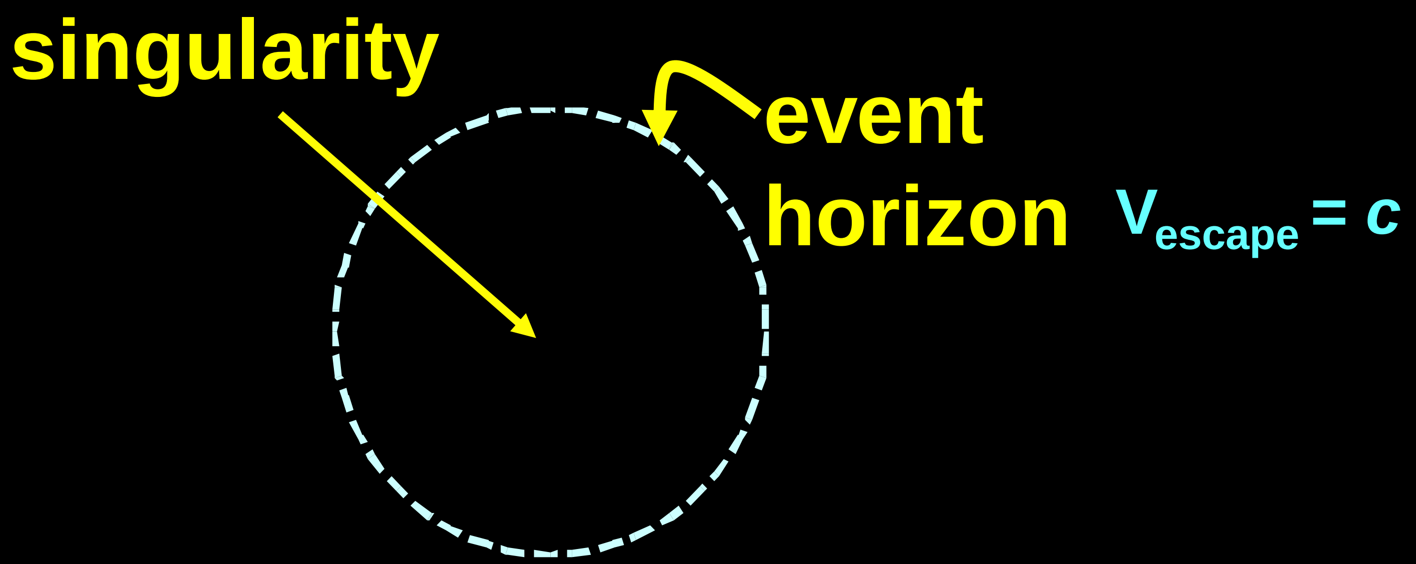
Crushed into size: 0 km

gravity overwhelms the Strong Force

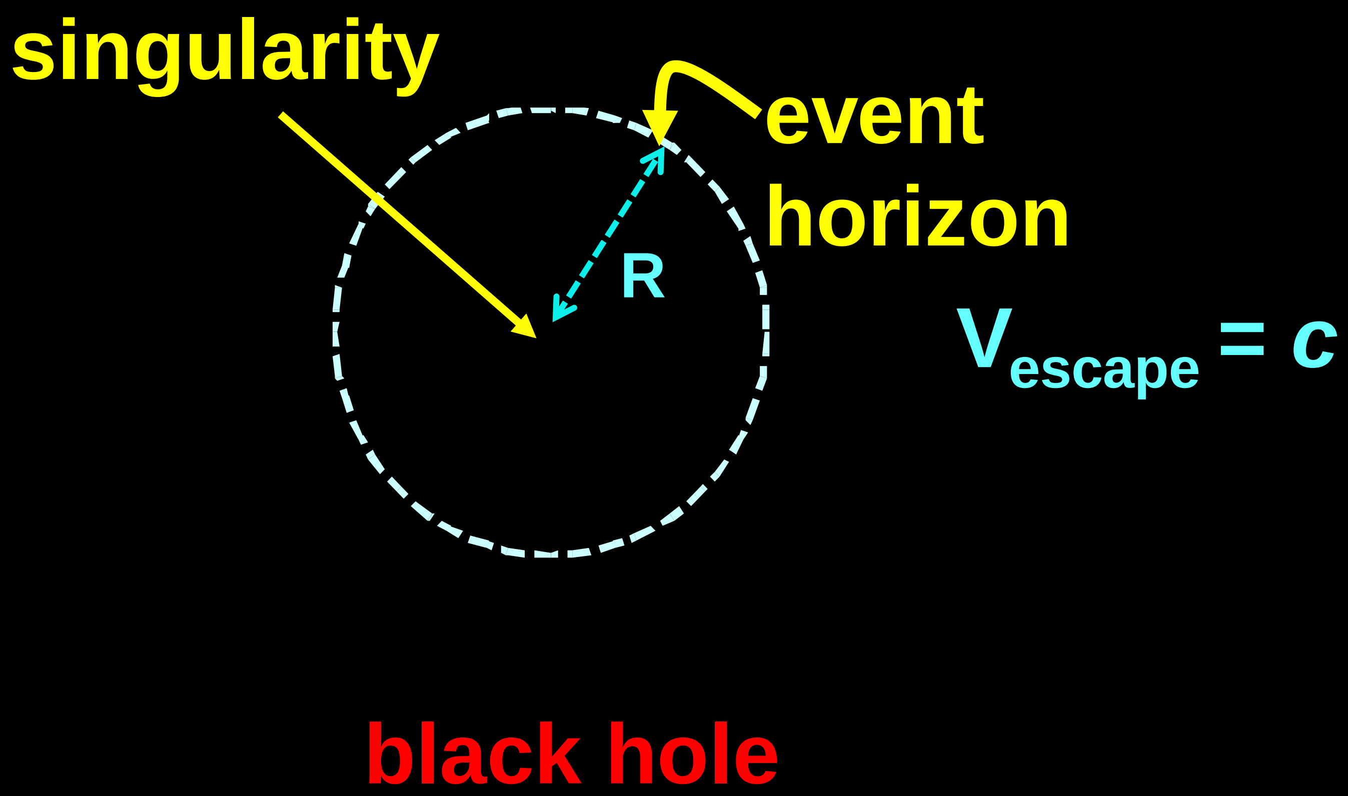
compactness ⟶ $\dfrac{\text{Mass}}{\text{Size}} = \dfrac{1\ M_{sun}}{1/1,000,000,000} = 1,000,000,000 \ (\infty)$



Singularity !!



black hole


singularity
event
horizon
R
V escape = c
black hole

$$V_{esc} = \sqrt{\frac{2\,M\,G}{R}} = c$$

Solve for R by squaring both sides

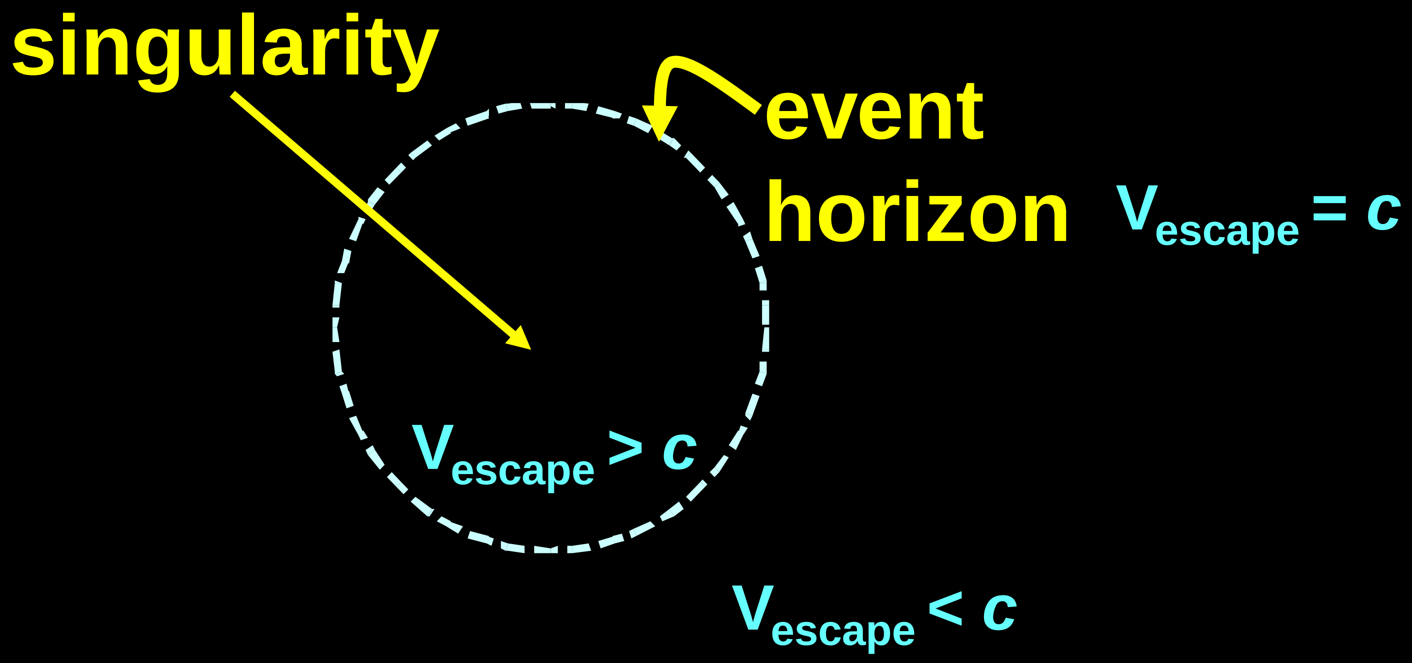
$$V_{esc} = \sqrt{\frac{2\,M\,G}{R}} = c$$

Solve for R:

$$R = \frac{2\,M\,G}{c^2}$$

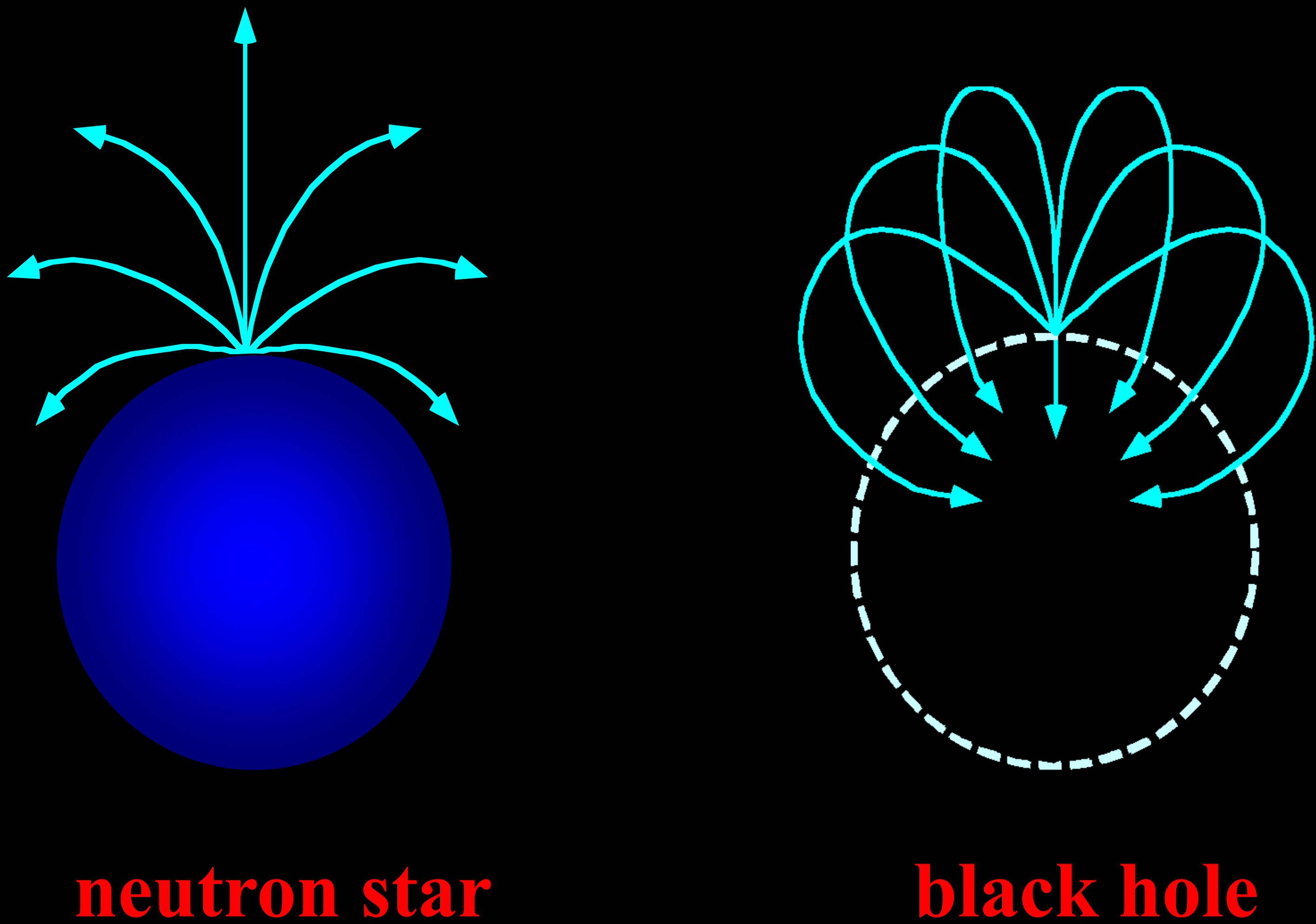
Distance from the singularity where $V_{esc} = c$

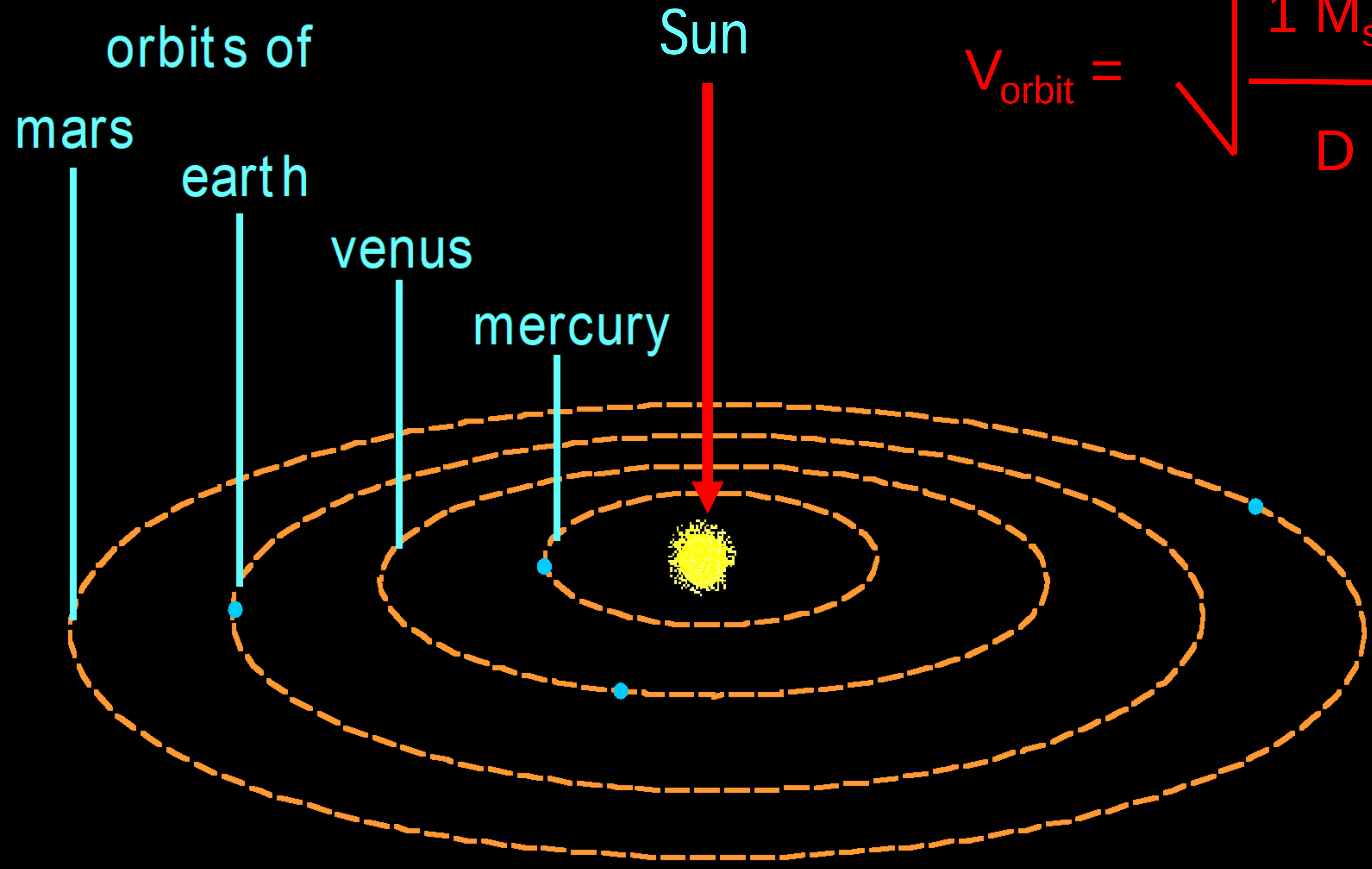
EVENT HORIZON



black hole

Light Paths

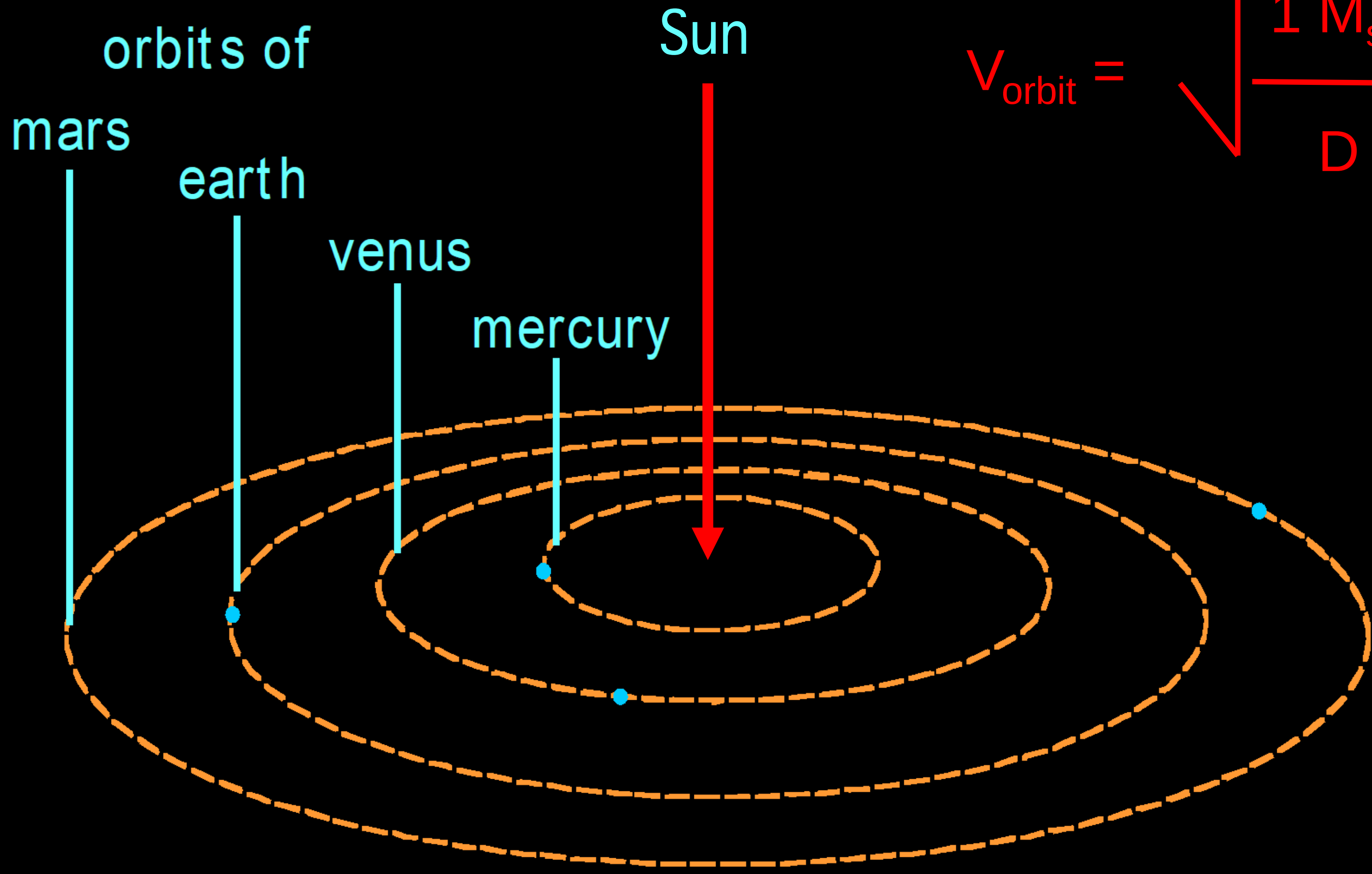




$$V_{orbit} = \sqrt{\frac{1\, M_{sun}\, G}{D}}$$

The Sun Now

$$V_{orbit} = \sqrt{\frac{1\ M_{sun}\ G}{D}}$$



if the Sun were a black hole

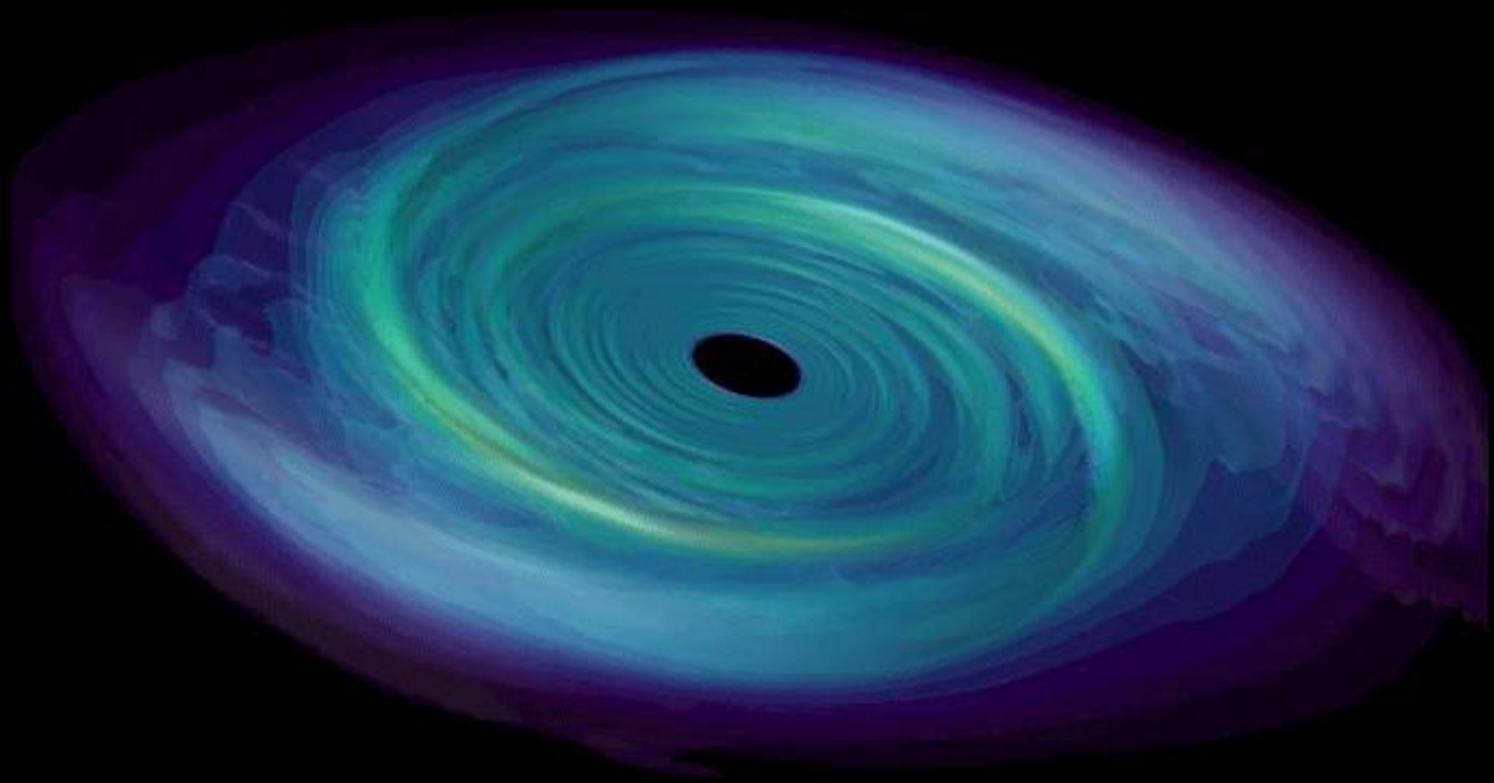
BLACK HOLES

DON'T SUCK !!!

How do we look for BLACK HOLES if LIGHT cannot escape them?

We look for how they interact with their envrironment.

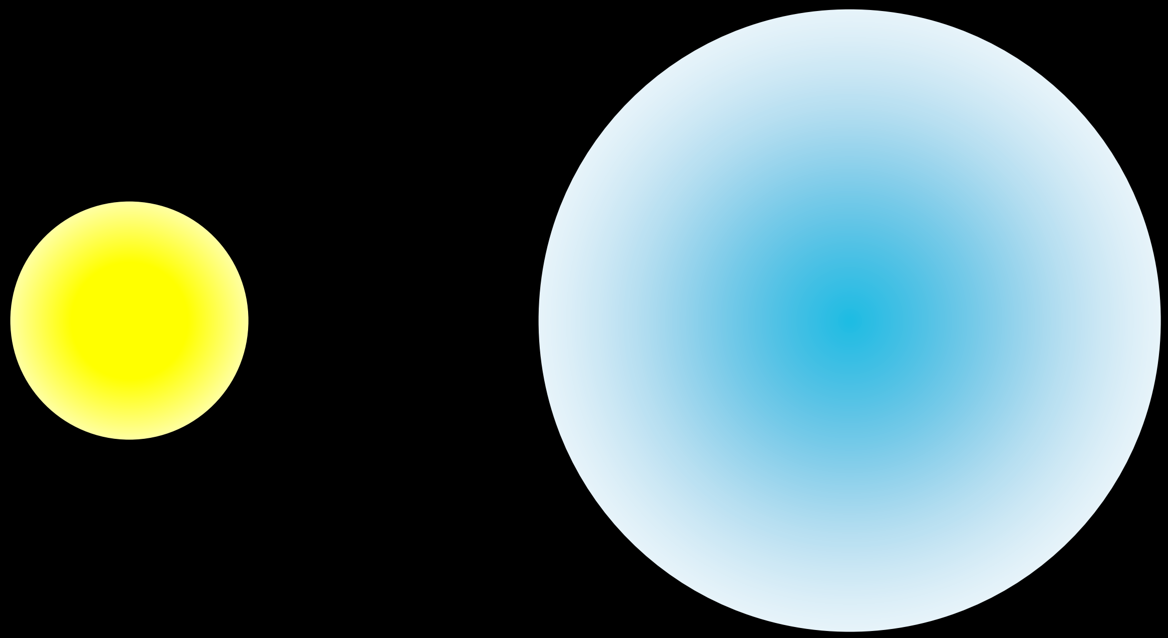
any gas outside the event horizon will orbit VERY FAST.



this causes FRICTION ➔ x-rays

How do we look for BLACK HOLES if LIGHT cannot escape them?

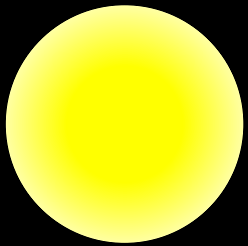
1) a close binary system



$1\ M_{sun}$ $8\ M_{sun}$

1) a close binary system

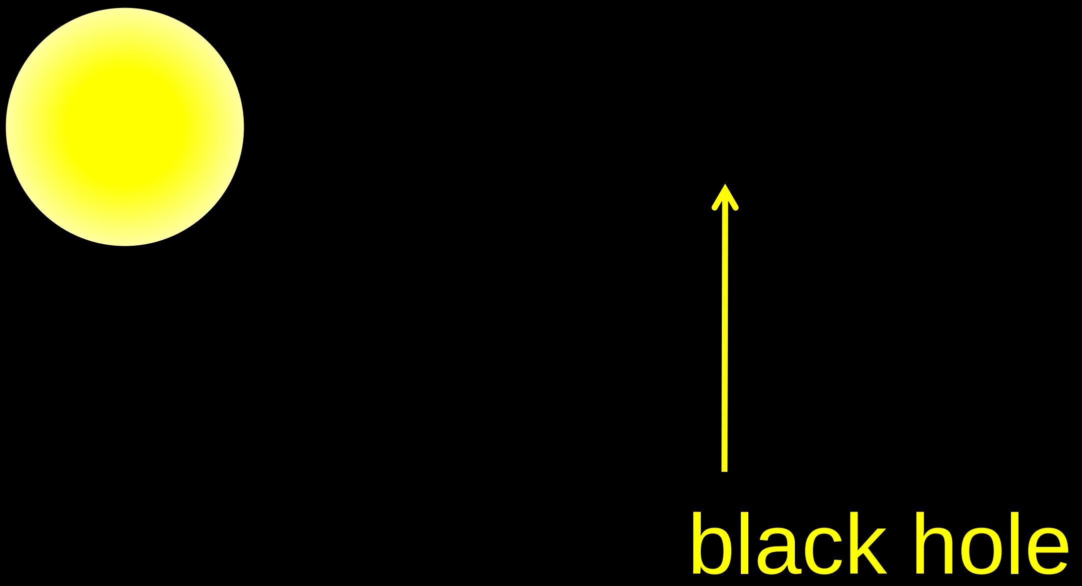
the more massive star evolves first



1 M_{sun} 8 M_{sun}

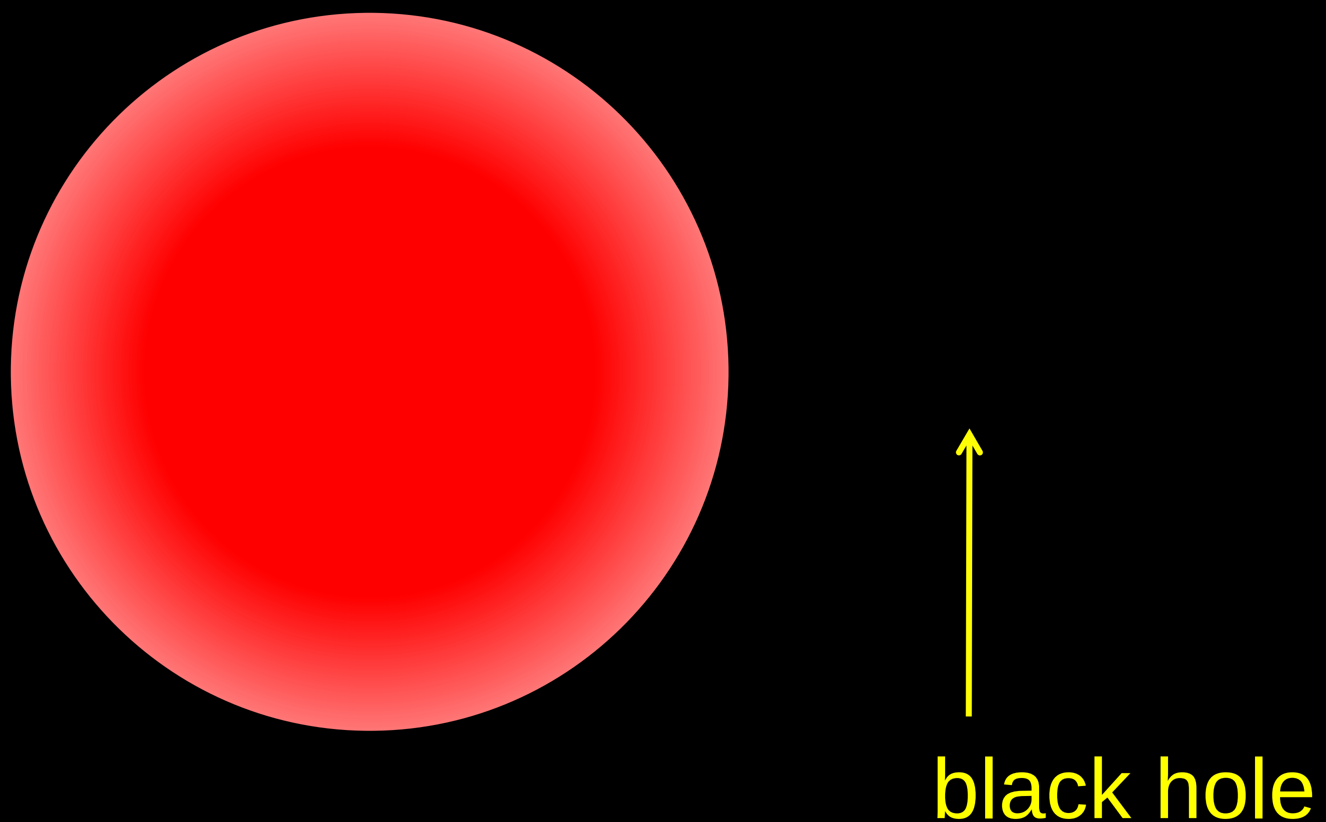
1) a close binary system

the less massive evolves more slowly



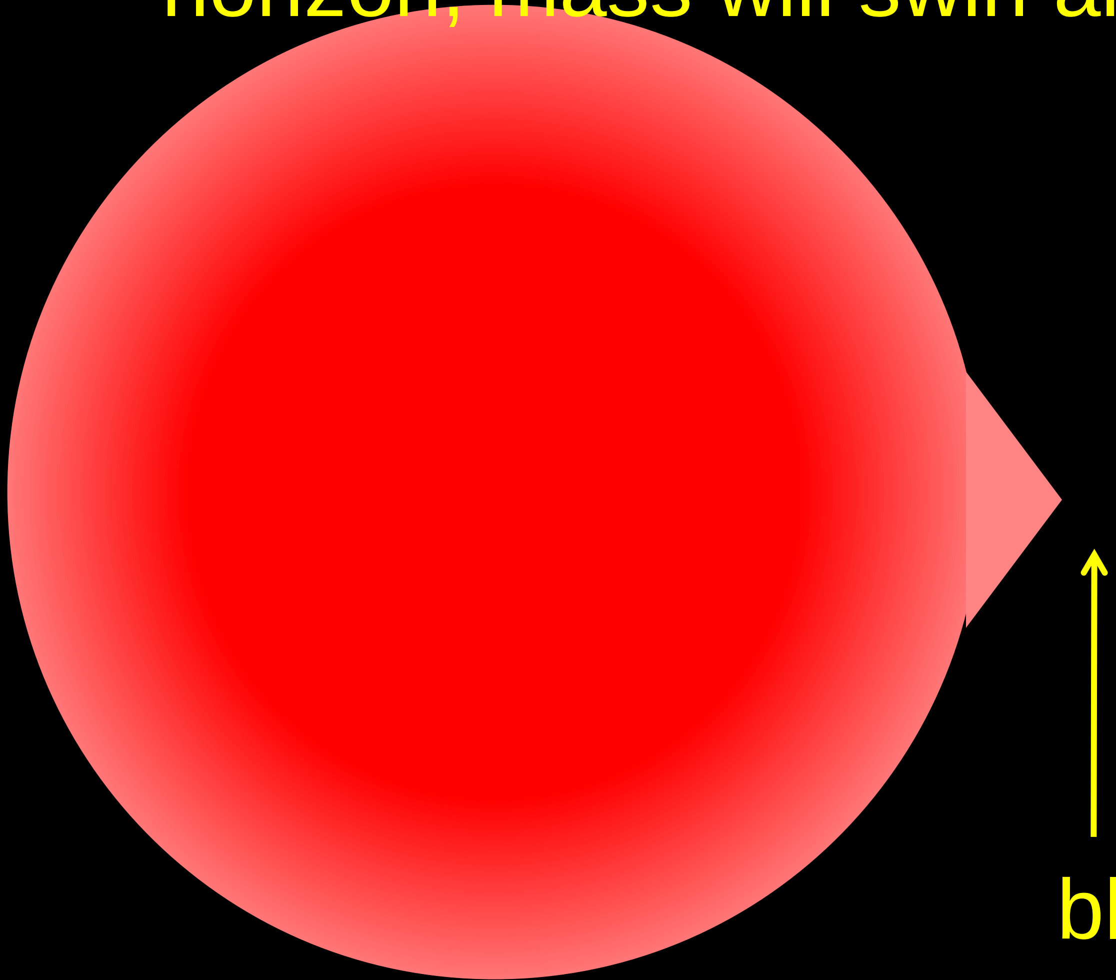
1) a close binary system

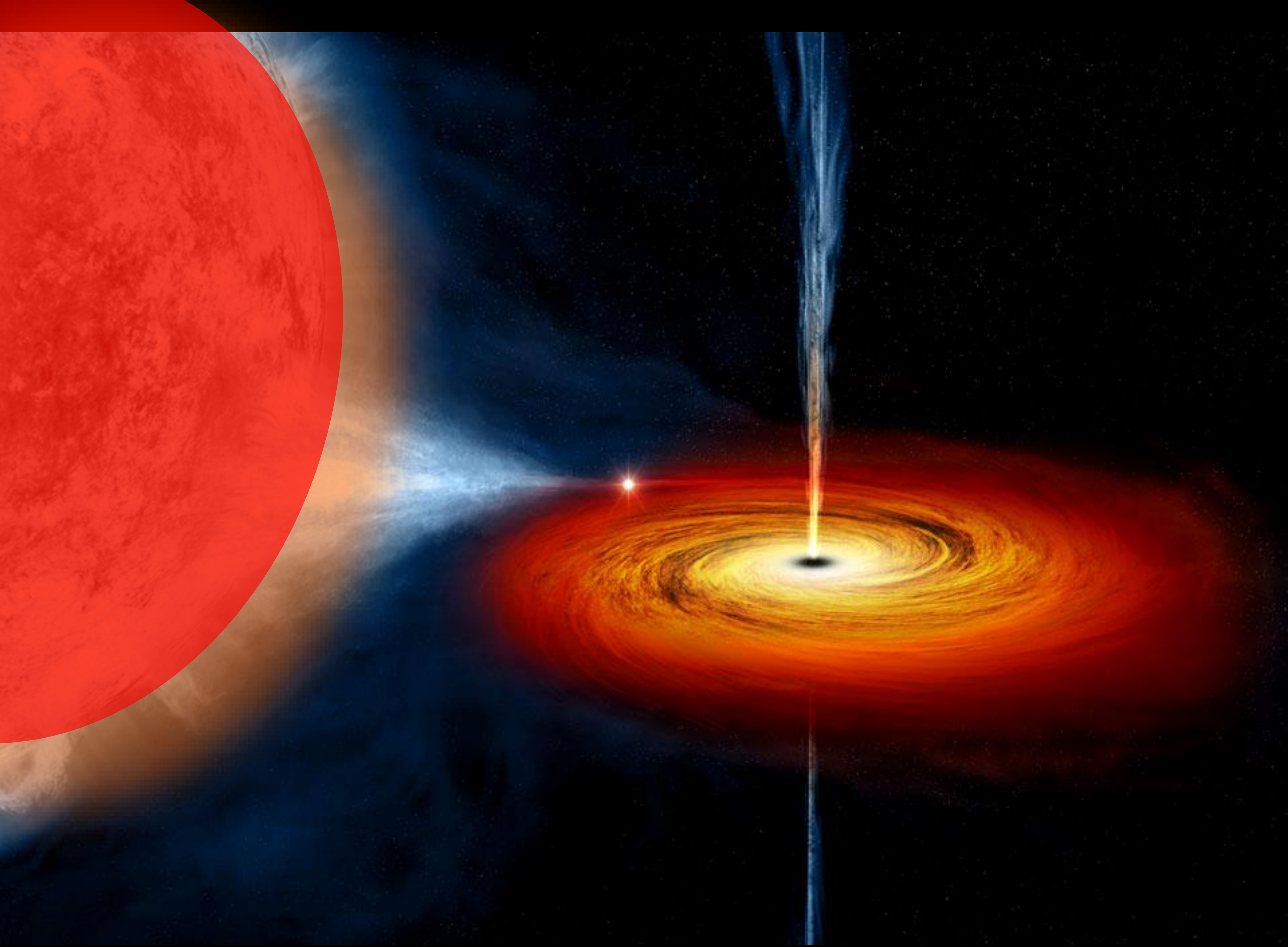
the less massive later becomes a bloated red giant



1) a close binary system

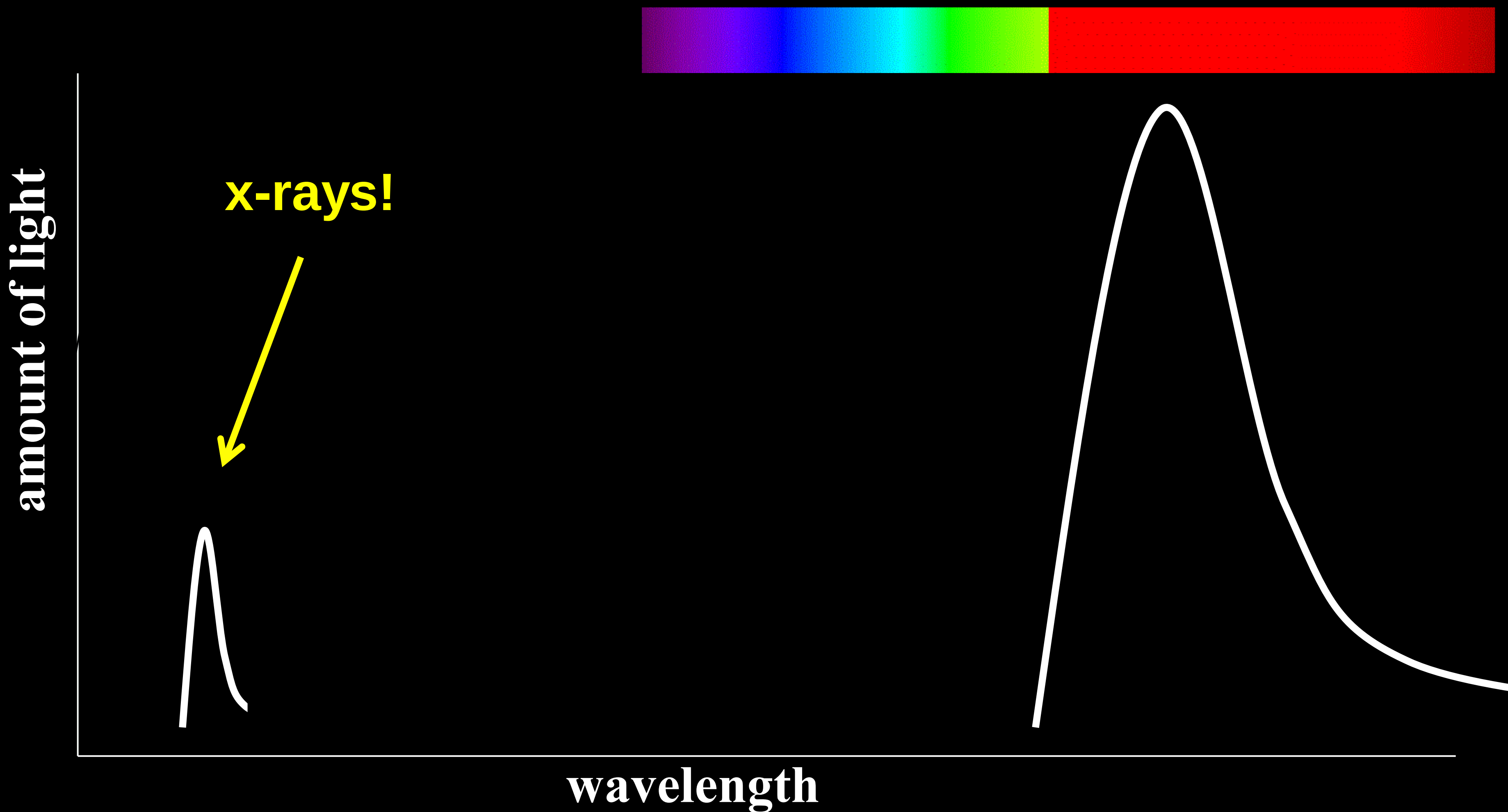
if its surface gets too close to the event horizon, mass will swirl around the bh





1) a close binary system

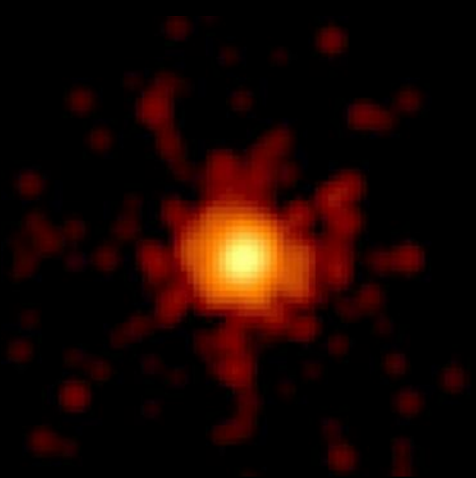
the spectrum will show a cool star emitting x-rays!



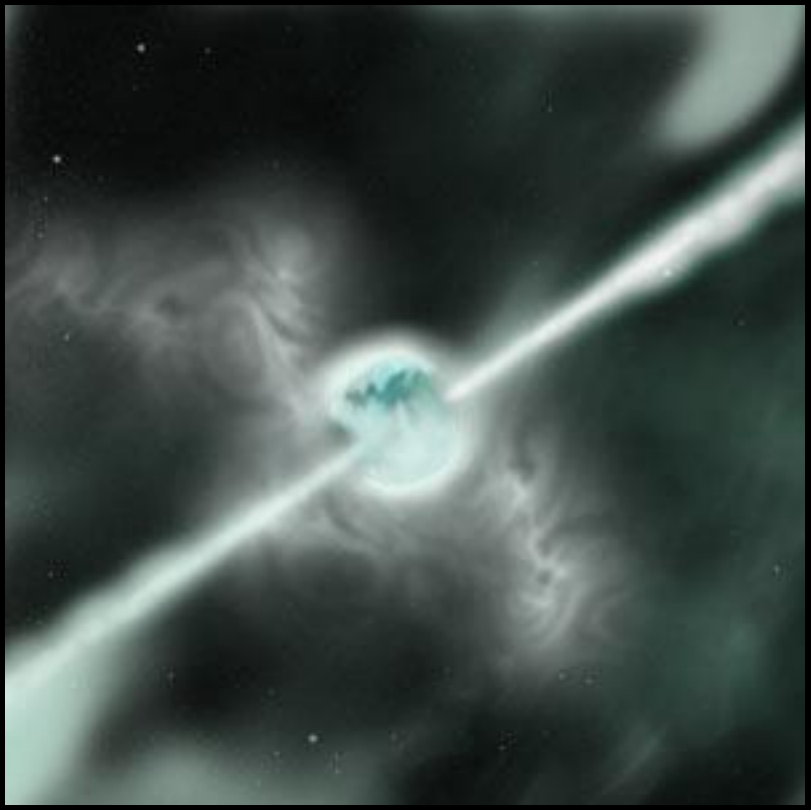
Gamma-Ray Bursters

RADIO image of WR 104 at 8,000 l-y. dusty swirl caused by interaction with close companion star — you are looking down the pole of the star.

GRB130427A dissipated in a few hundreds seconds 1000 times the energy our Sun will produce within its 10-billion years lifespan



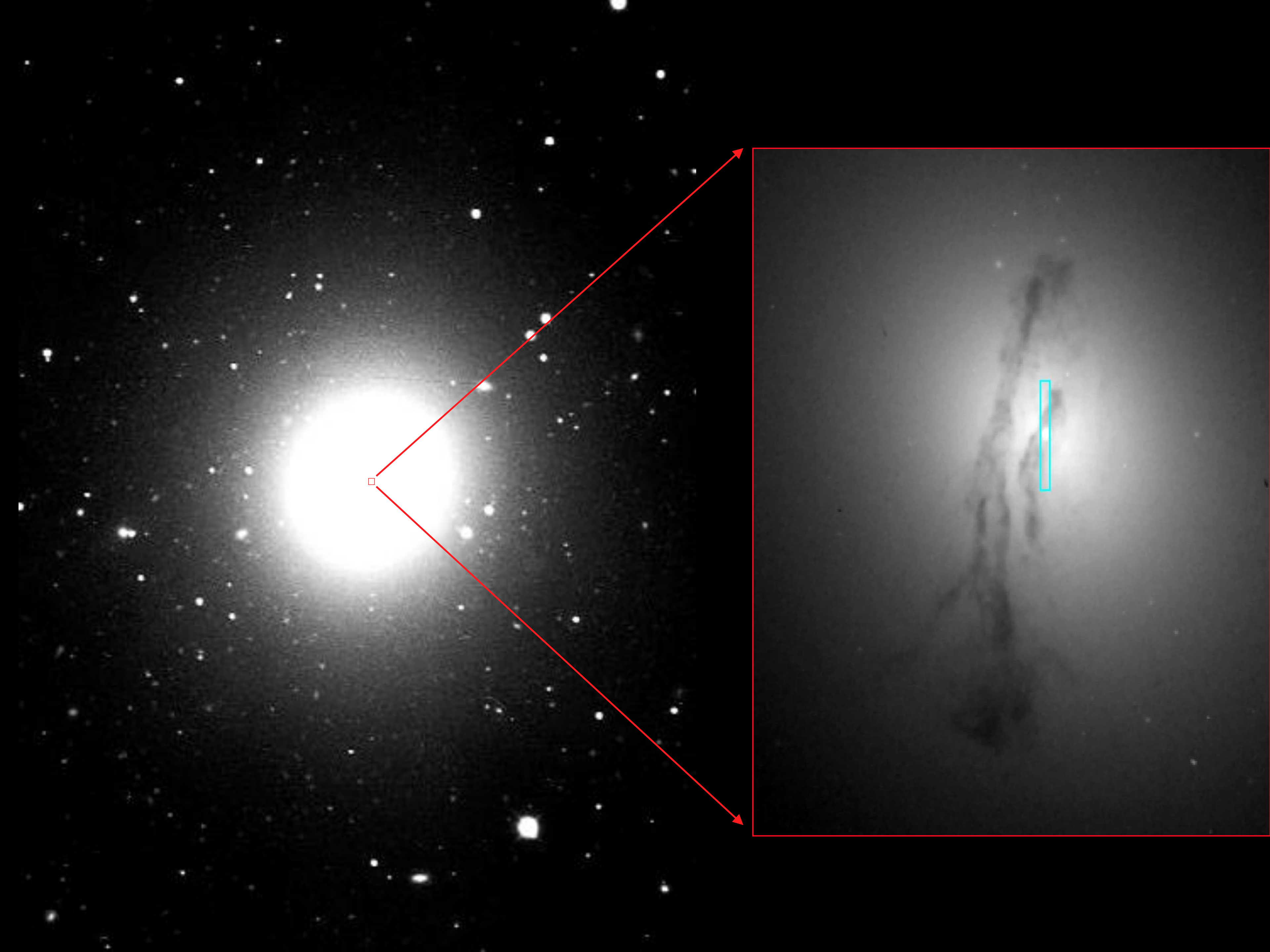
xray image of GRB 130427

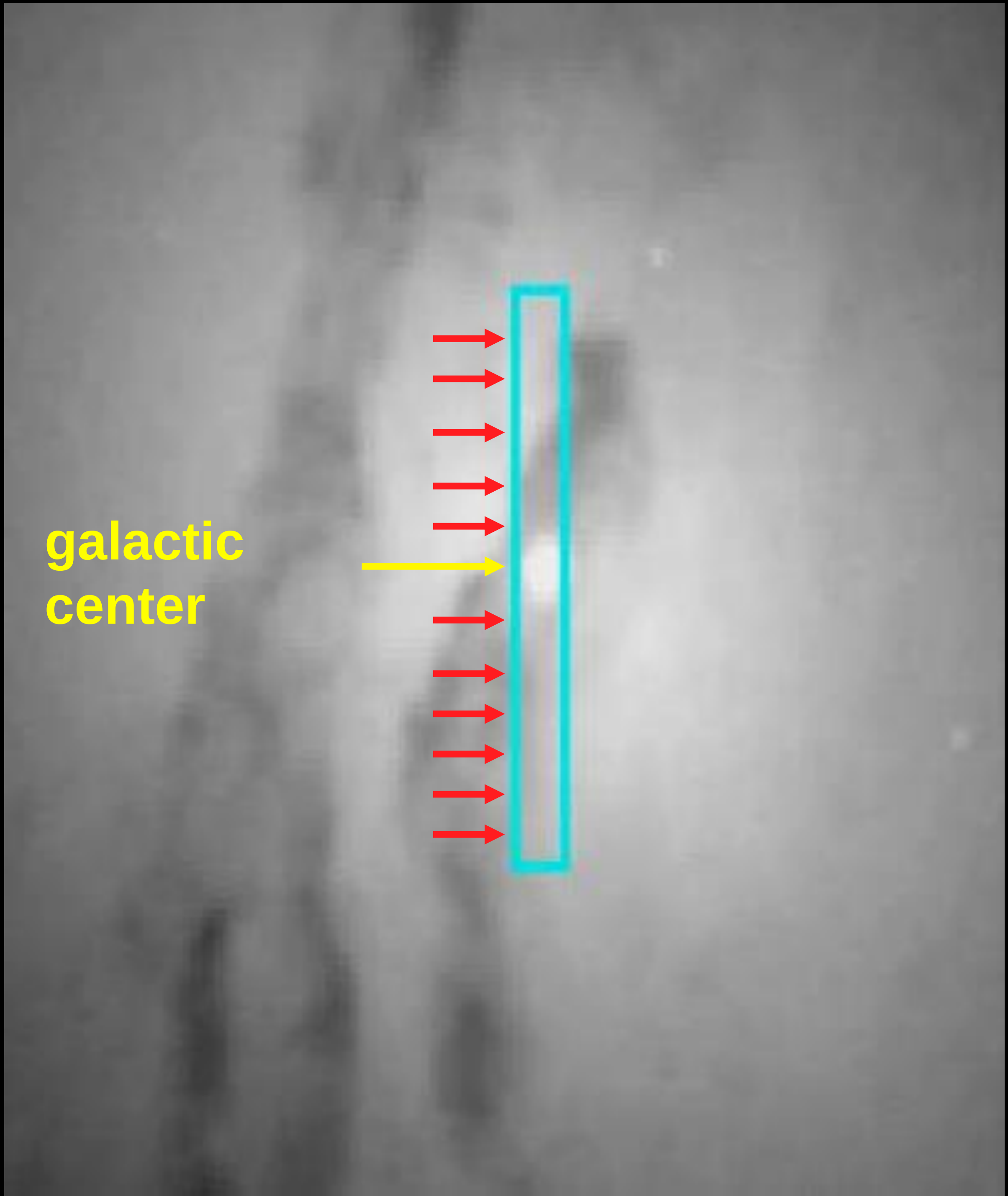


artist depiction of a SN beaming a GRB

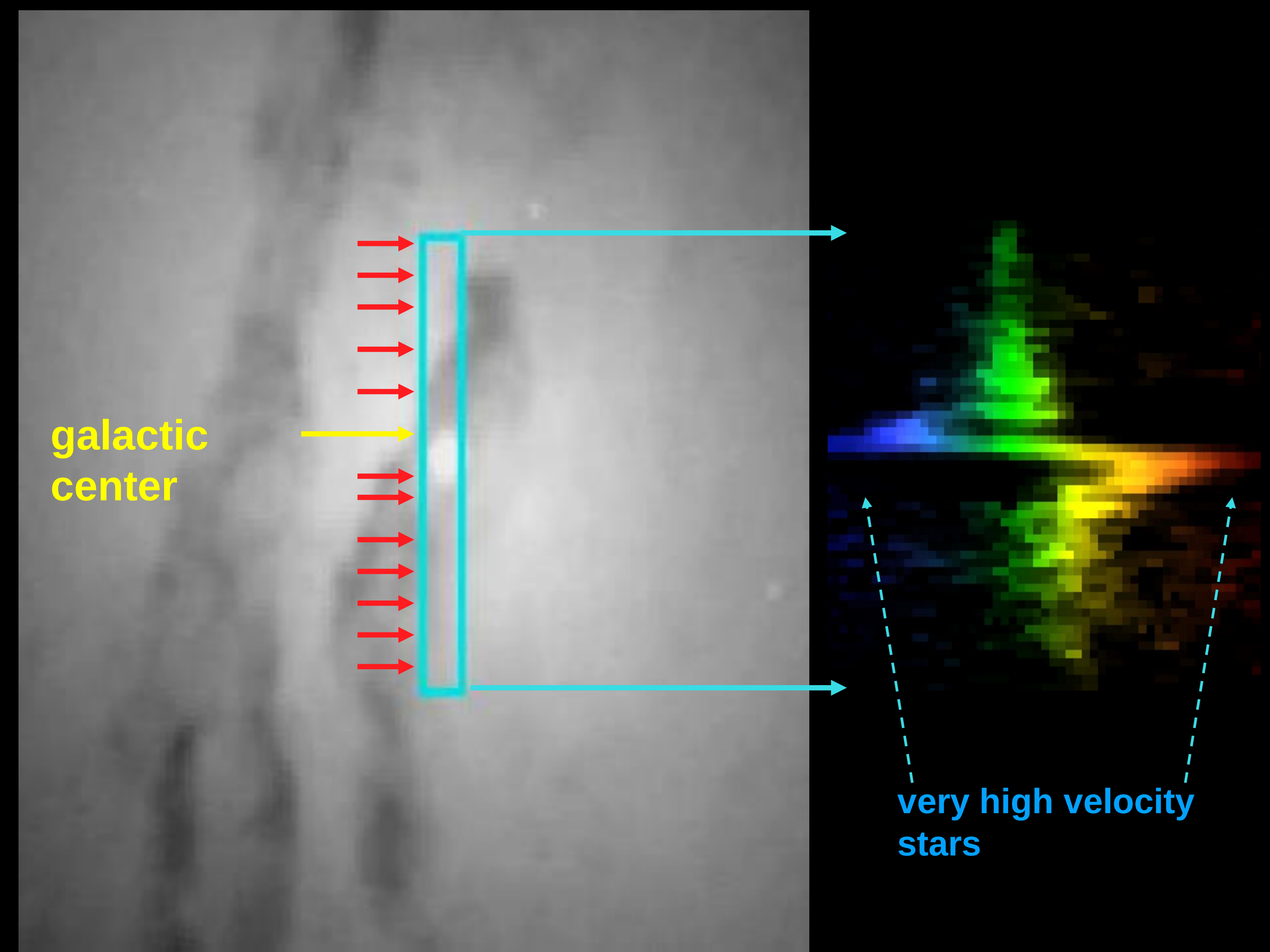
2) centers of galaxies

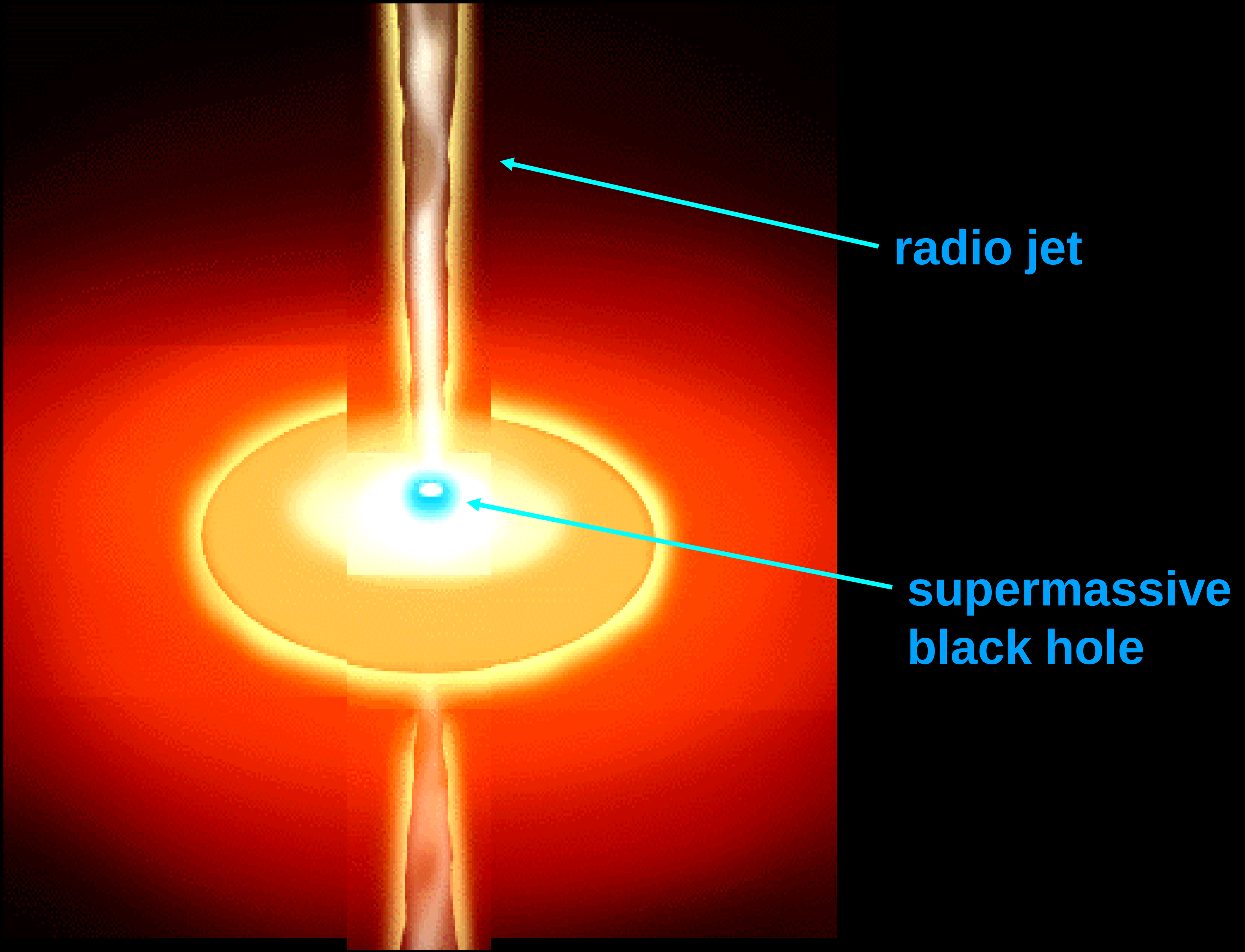
Galaxy M84

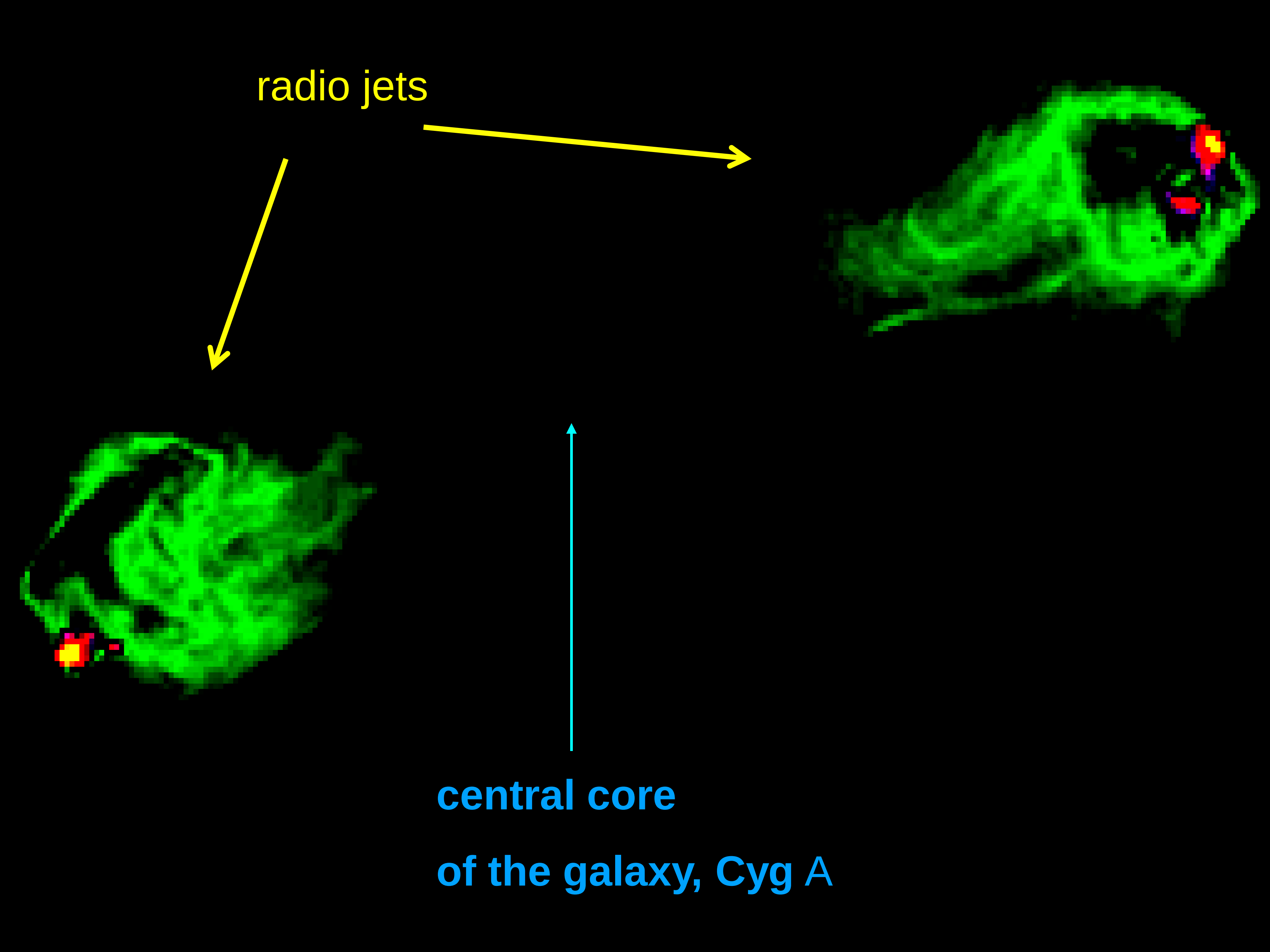




Take a spectrum at each loacation passing through the center of the galaxy

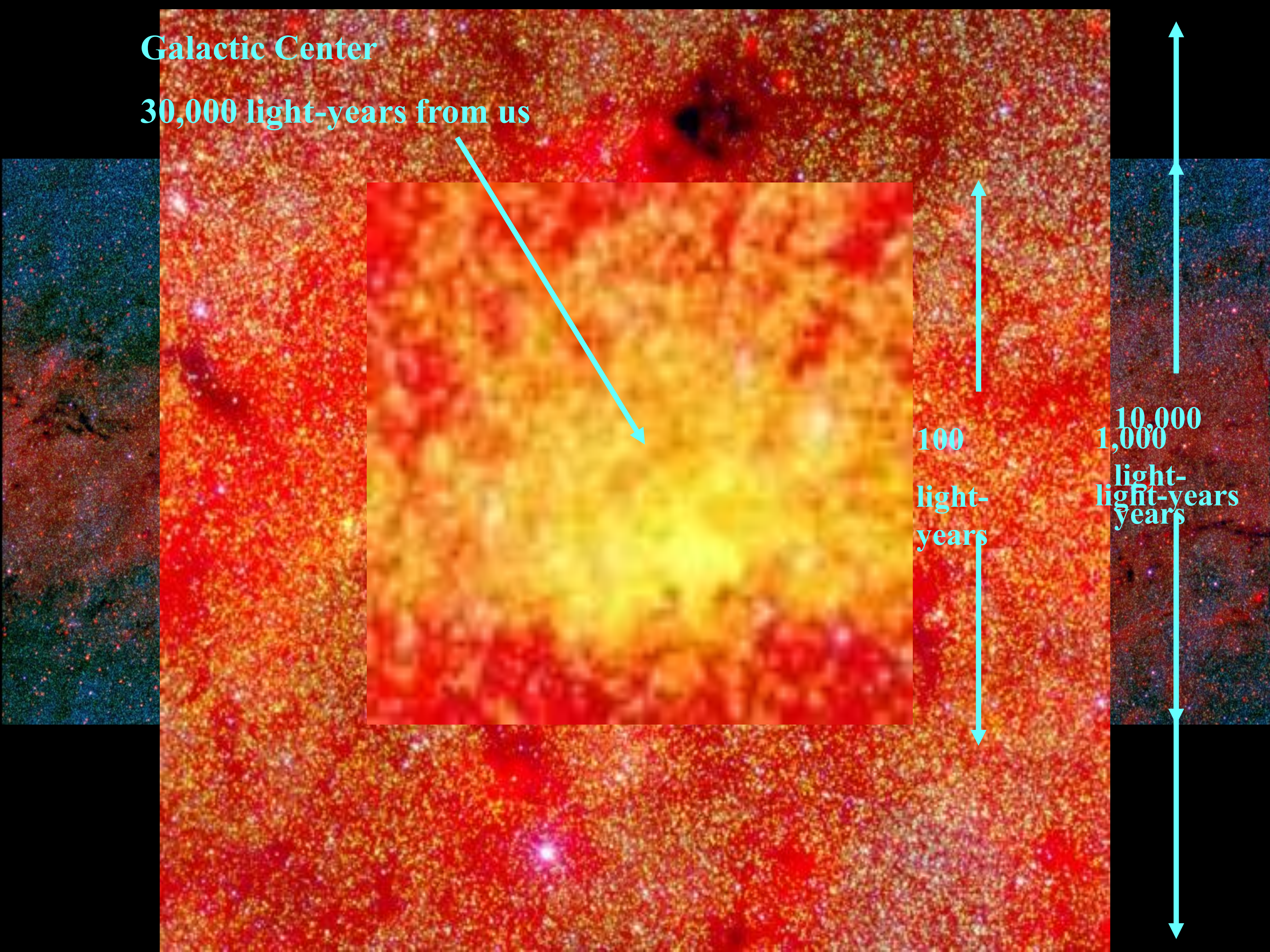

galactic
center
very high velocity
stars


radio jet
supermassive
black hole

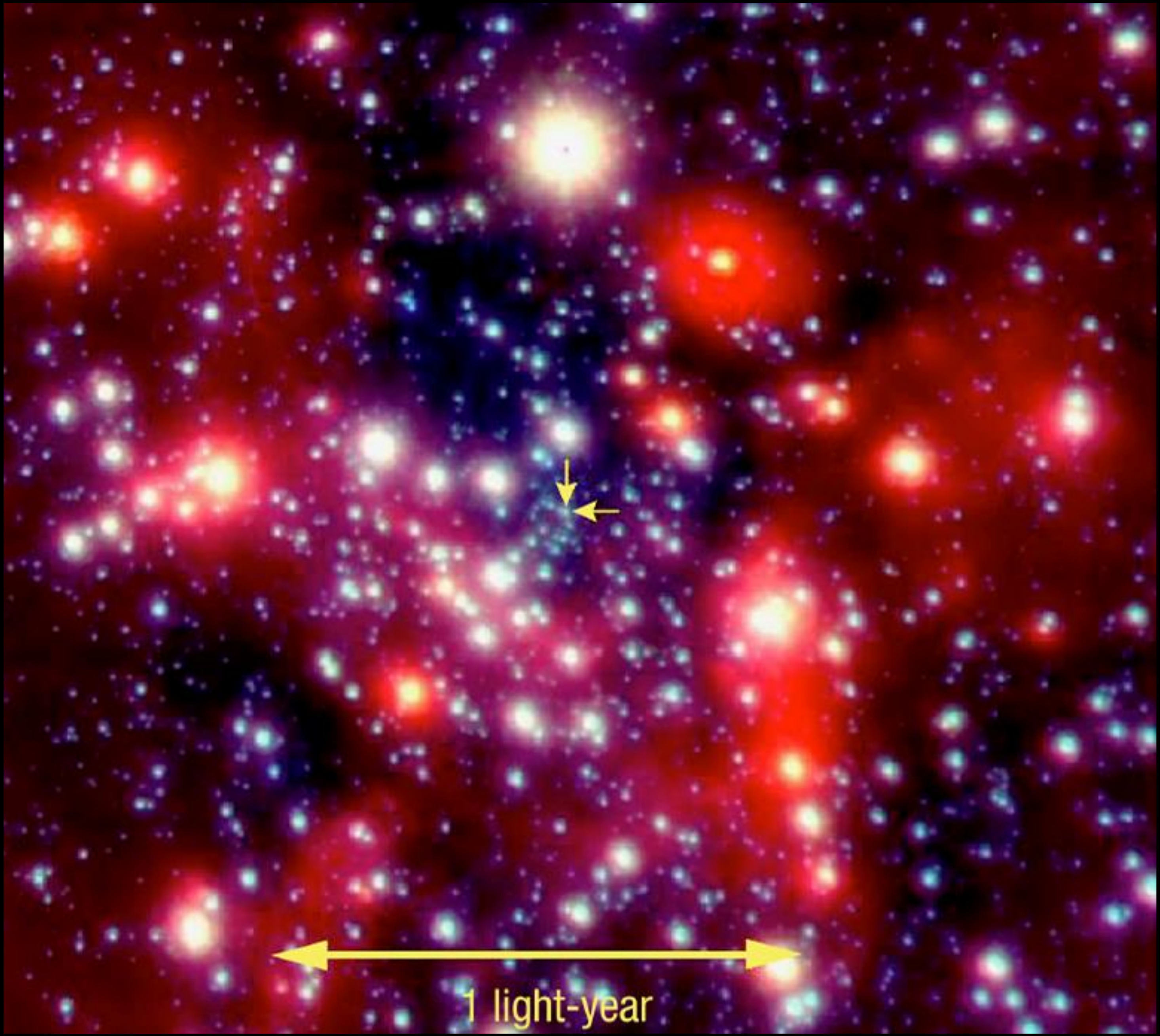

radio jets
central core
of the galaxy, Cyg A

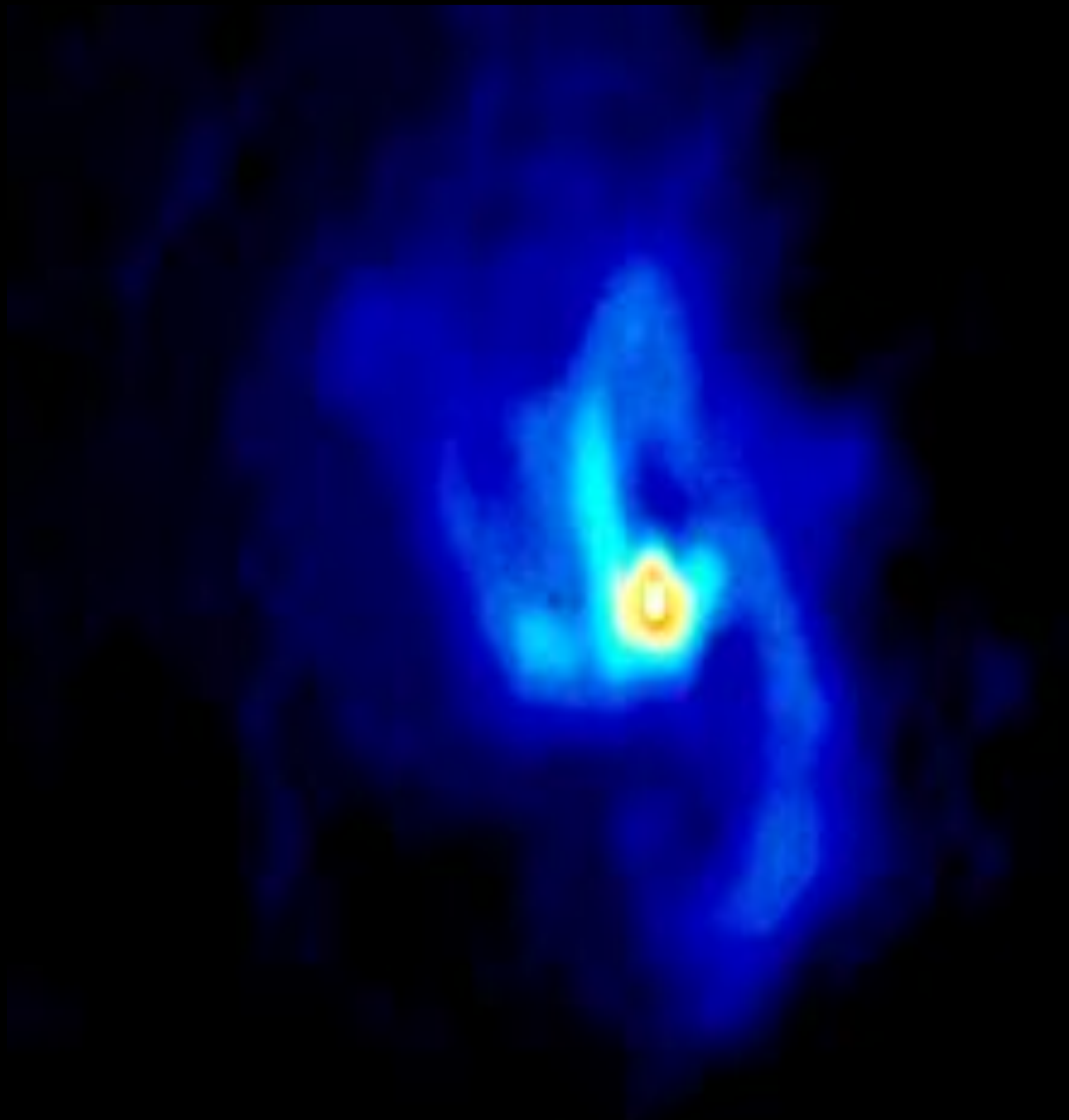
cartoon of Milky Way

Inner Region of Milky Way

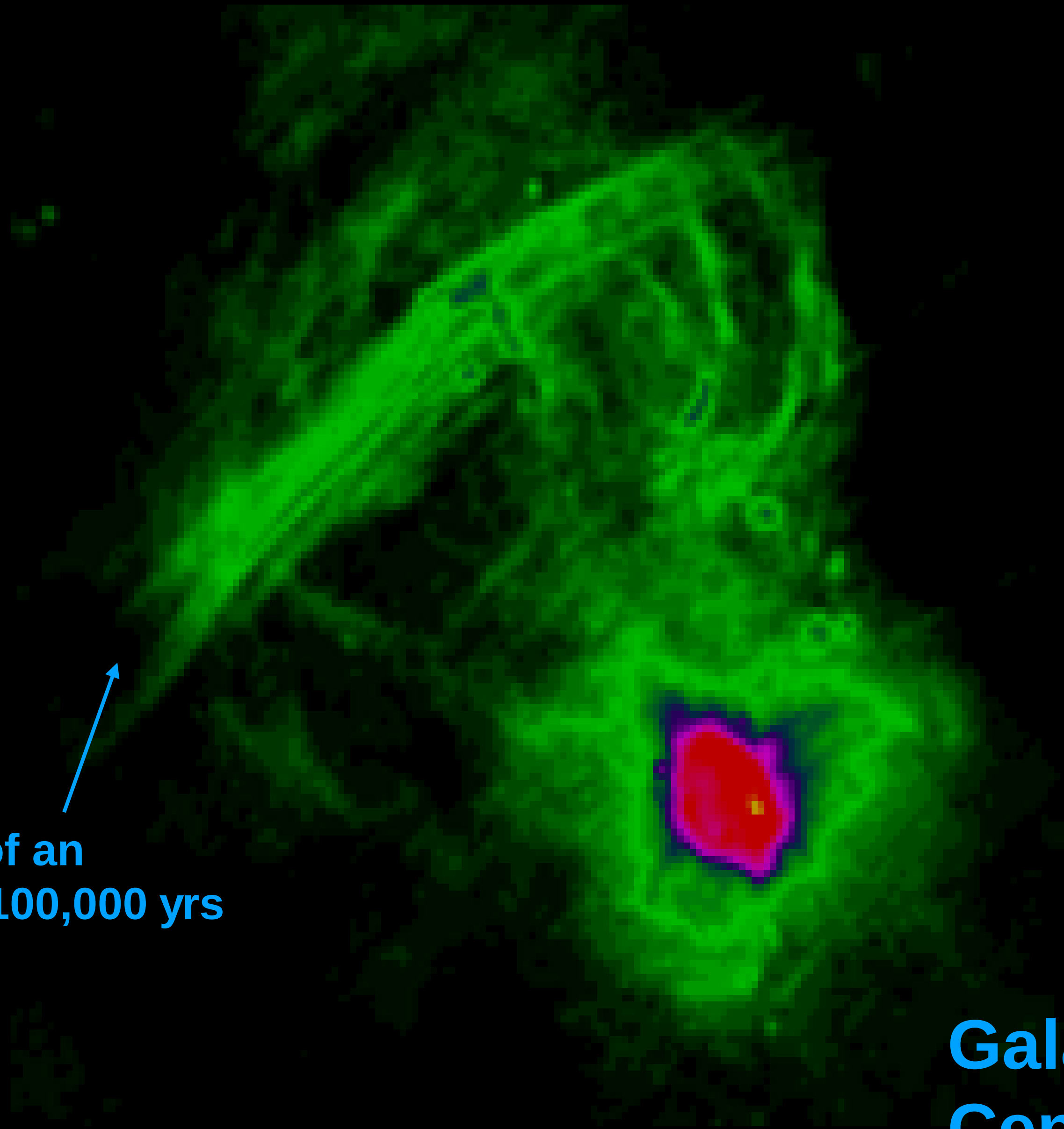

Galactic Center
30,000 light-years from us
100
light-
years
1,000
light-years
10,000
light-
years

Galactic Center in x-rays


1 light-year



Galactic Center in radio light



remnants of an explosion 100,000 yrs ago

Galactic Center in radio light