Chapter 13: High Mass Star Evolution and their Remnants: NSs and BHs

Chapter 13 Reading Assignment due now!

Are your grades in Canvas correct???

Midterms available up front

Turn in extra credit planetarium and public observing reports up front when complete

Nobel Prize in Physics goes to… Astronomers!

Jim Peebles
various contributions to cosmology

Michel Mayor and Didier Queloz
first exoplanet around a main sequence star

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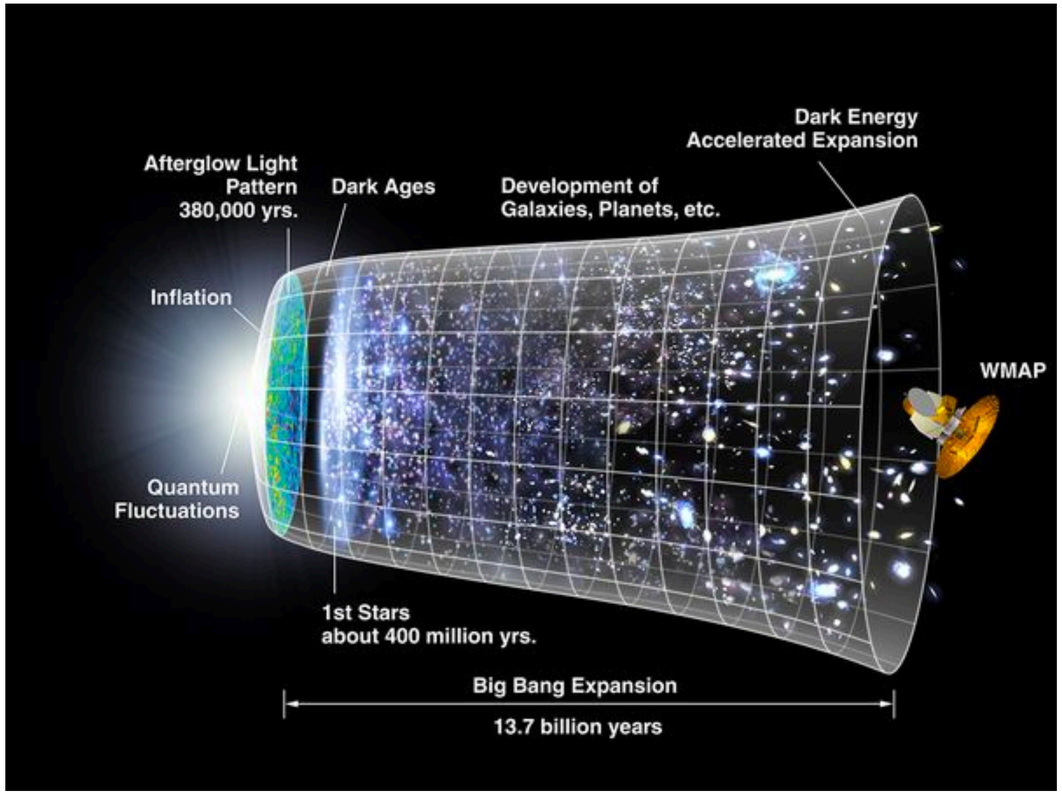
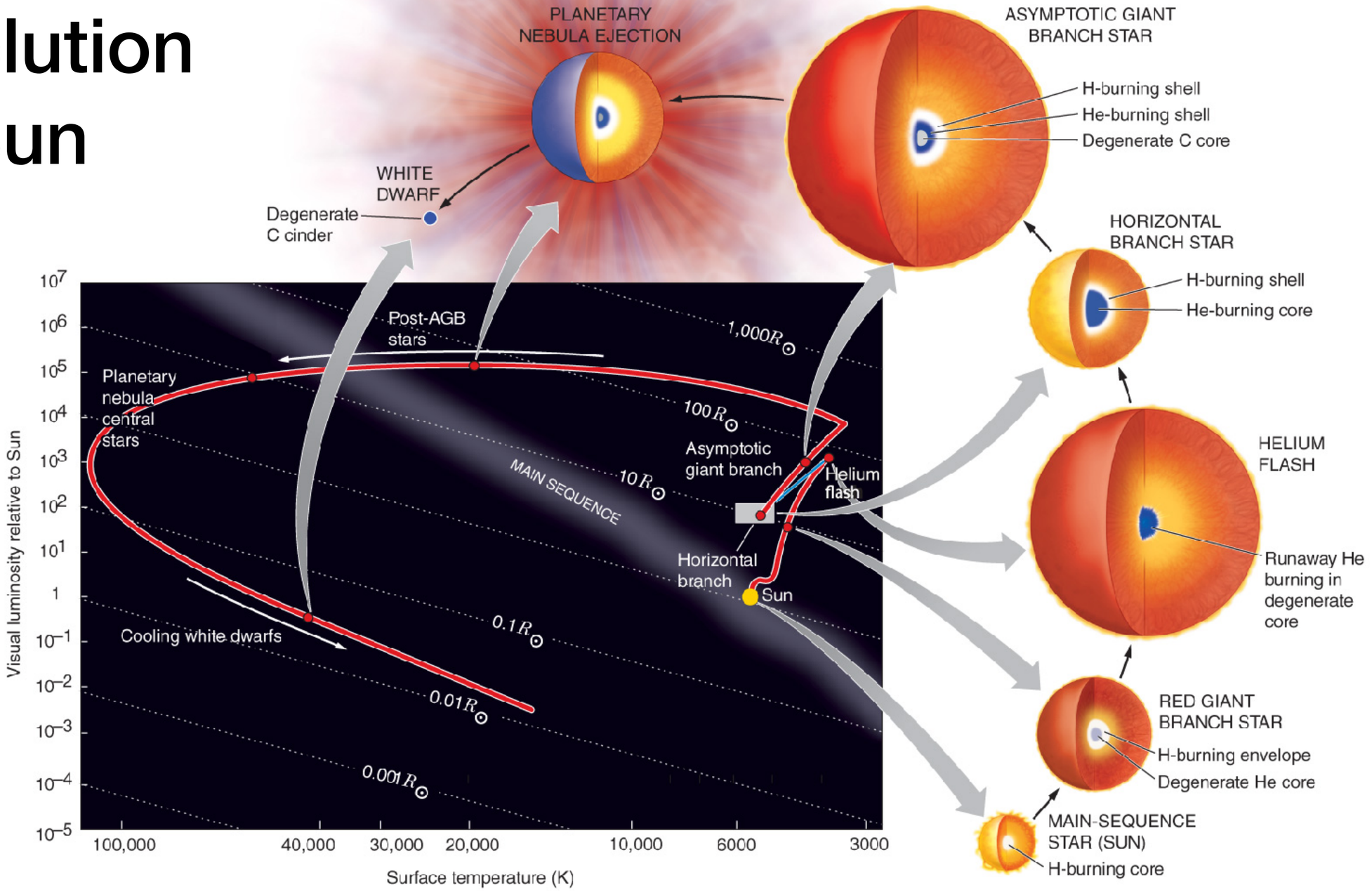
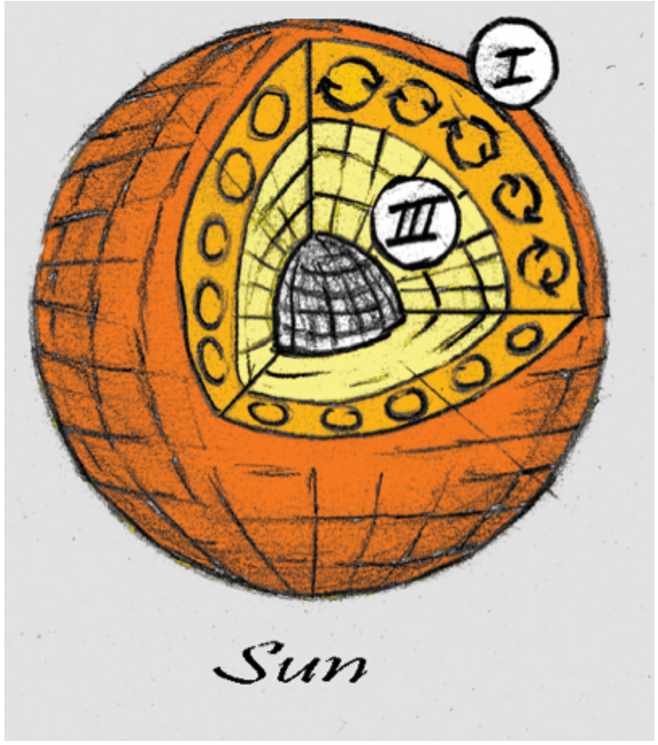


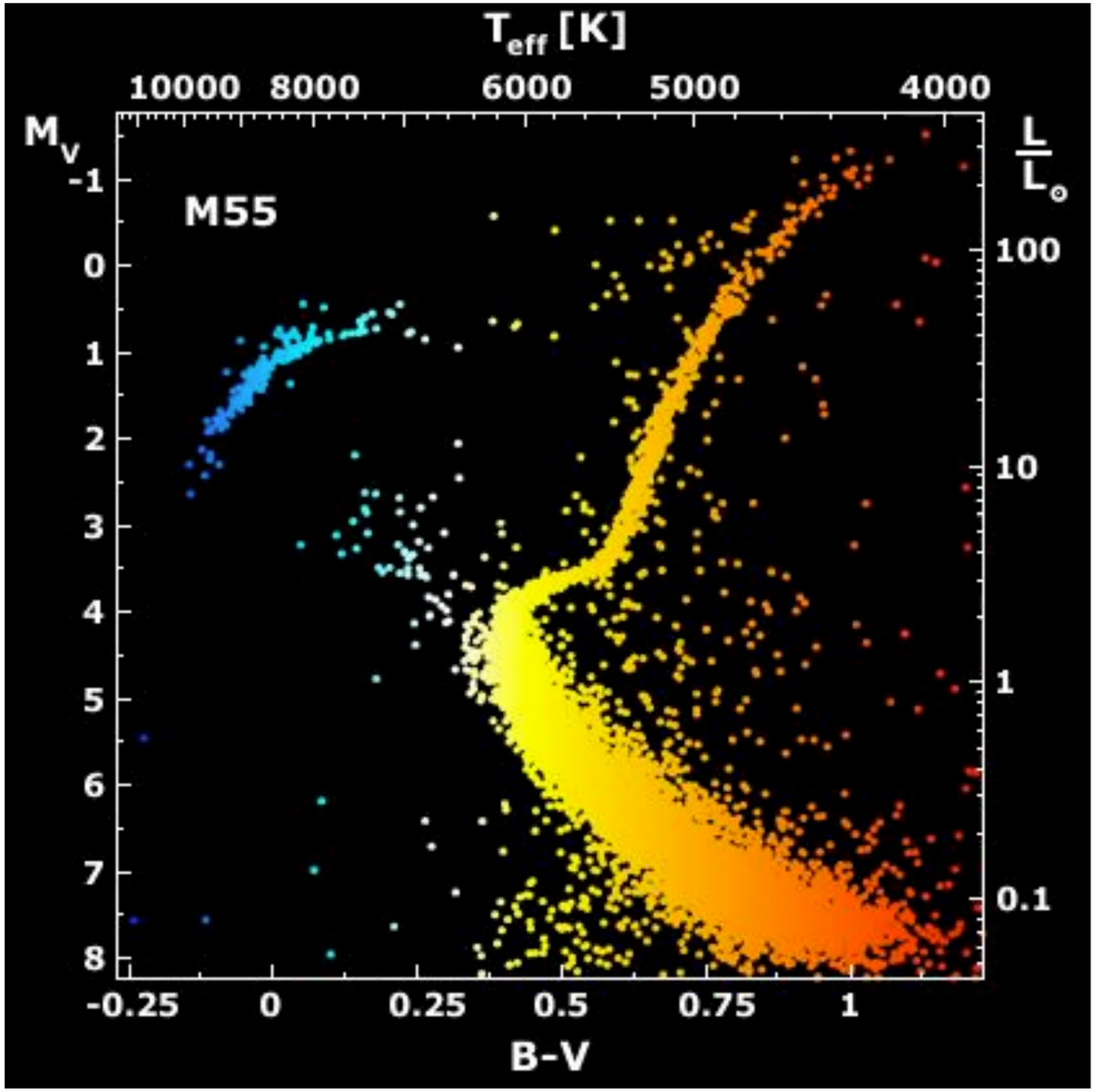
Michel Mayor and Didier Queloz
first exoplanet around a main sequence star

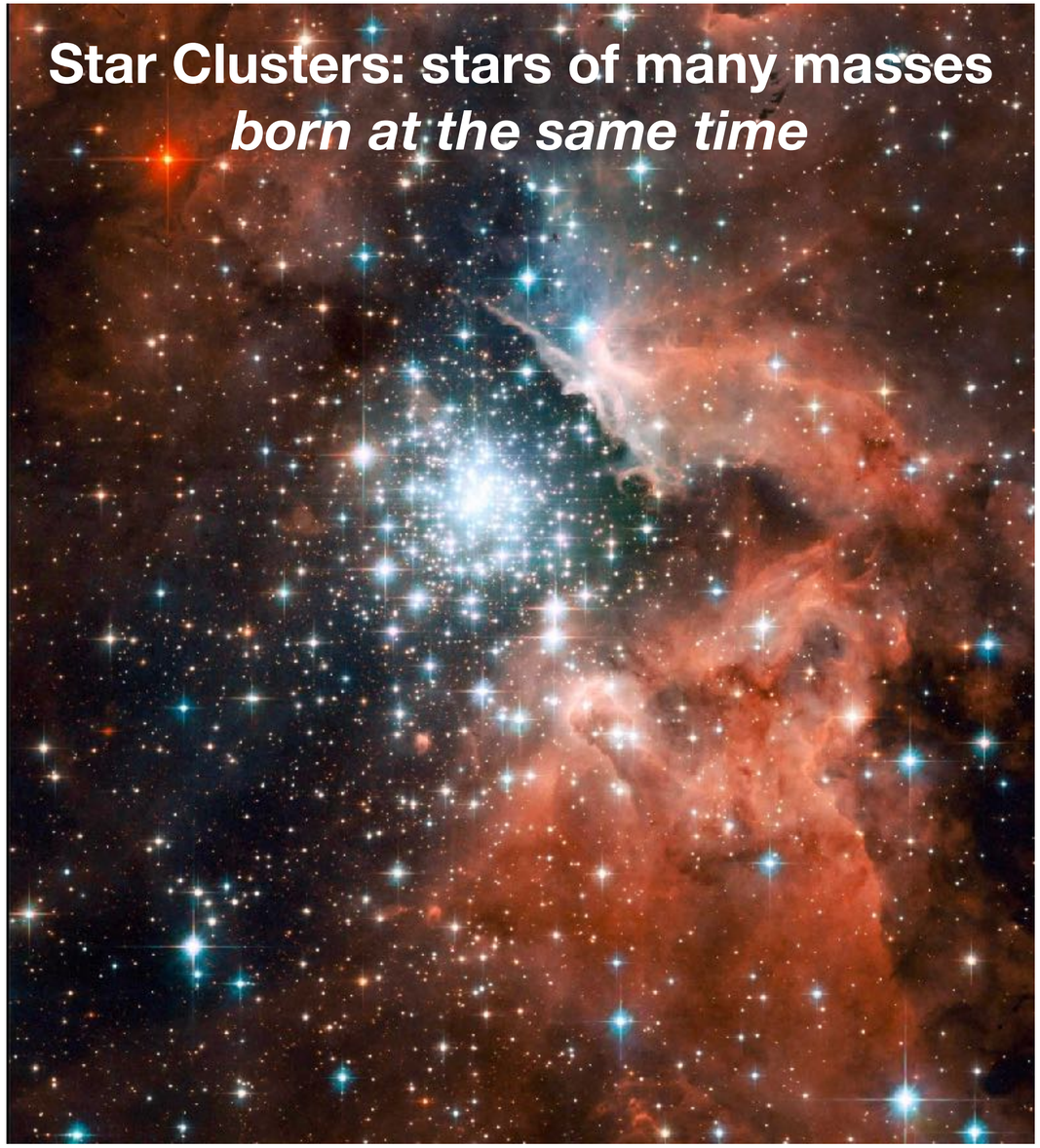
Future Evolution of the Sun

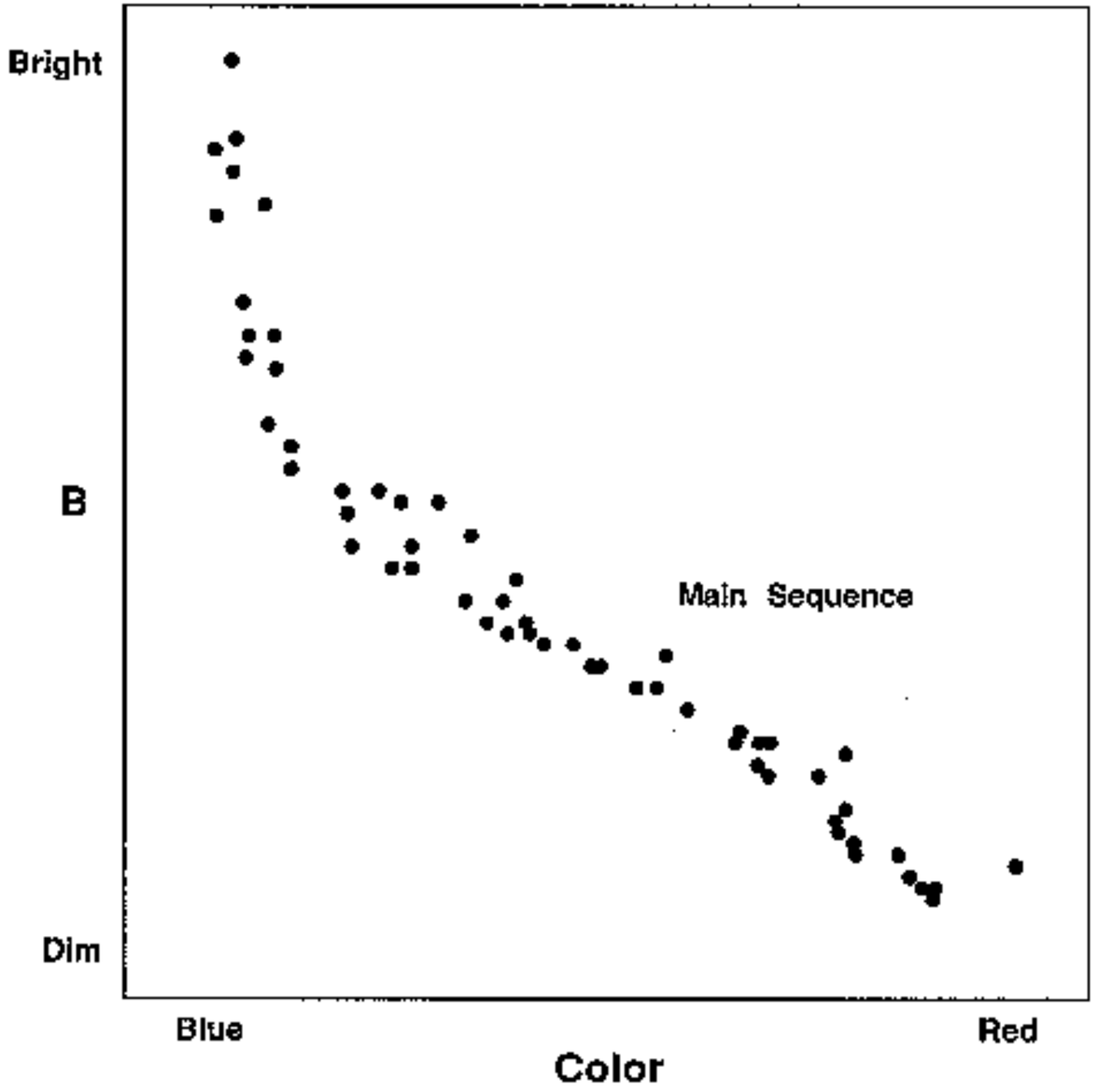


How do we know the different stages of a star's life? We obviously have not been observing stars for long enough to see it go through all the stages.



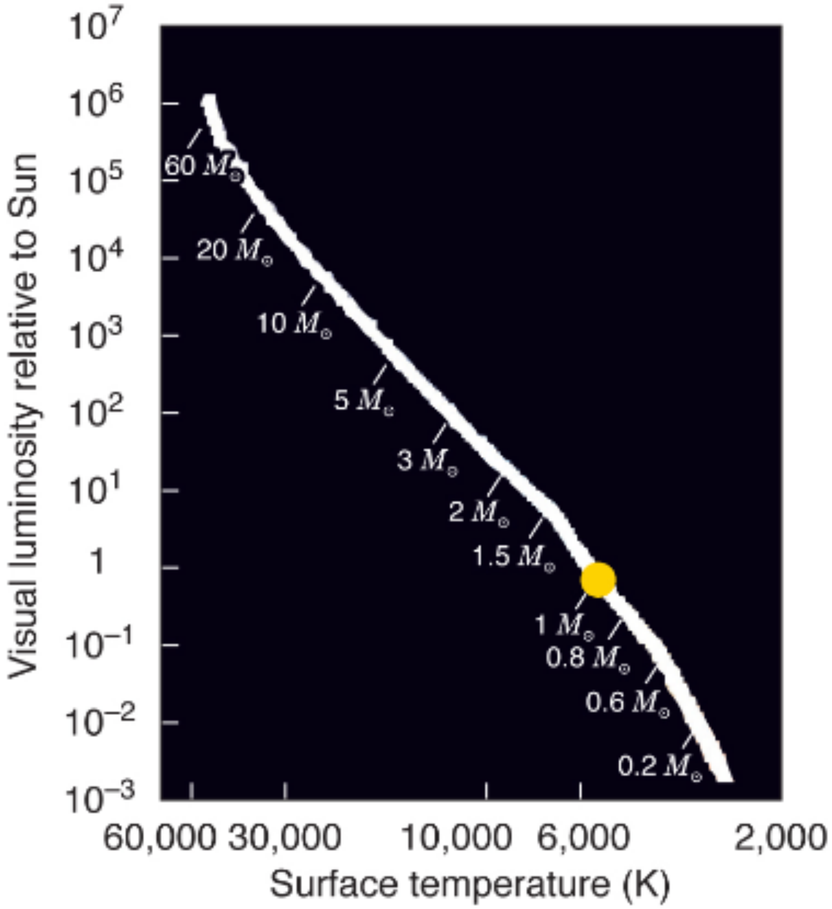



Star Clusters: stars of many masses
born at the same time

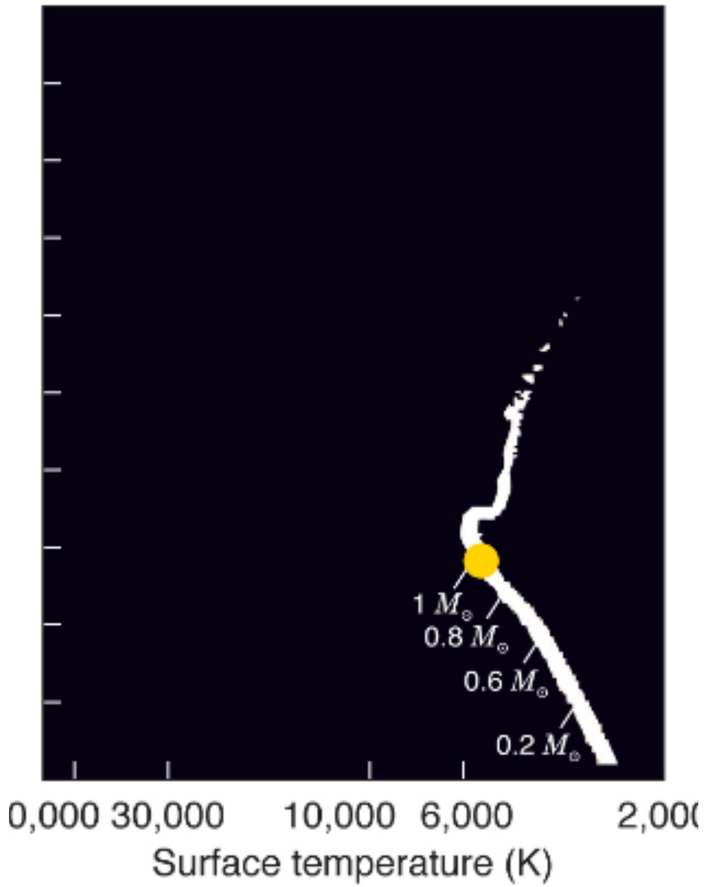

Bright
B
Dim
Main Sequence
Blue
Red
Color

Which of these star clusters is the oldest?

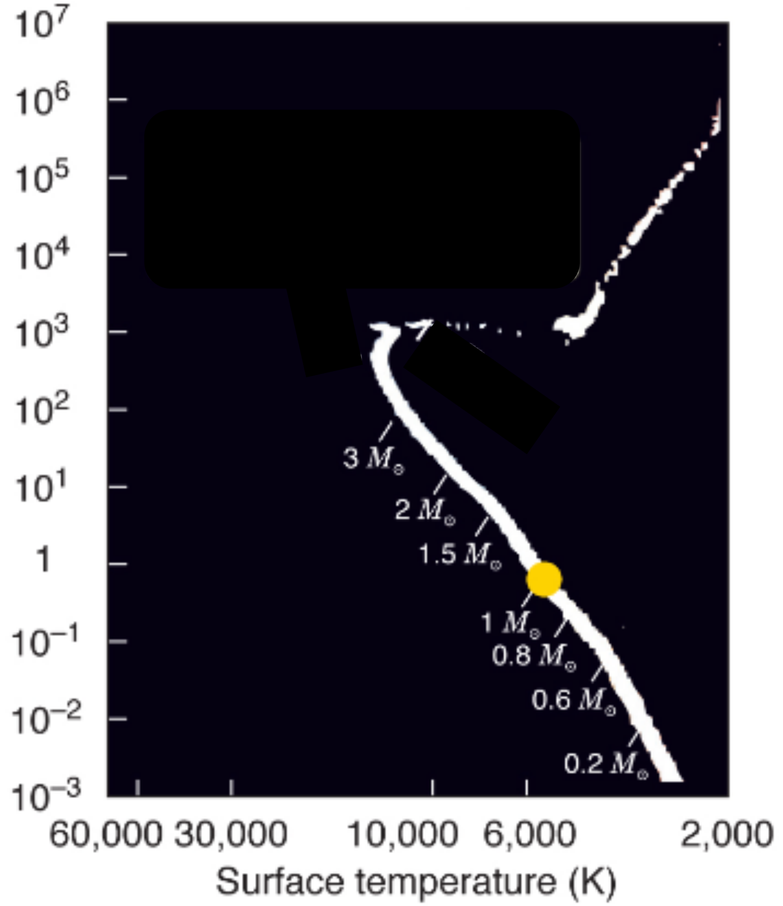
A



B

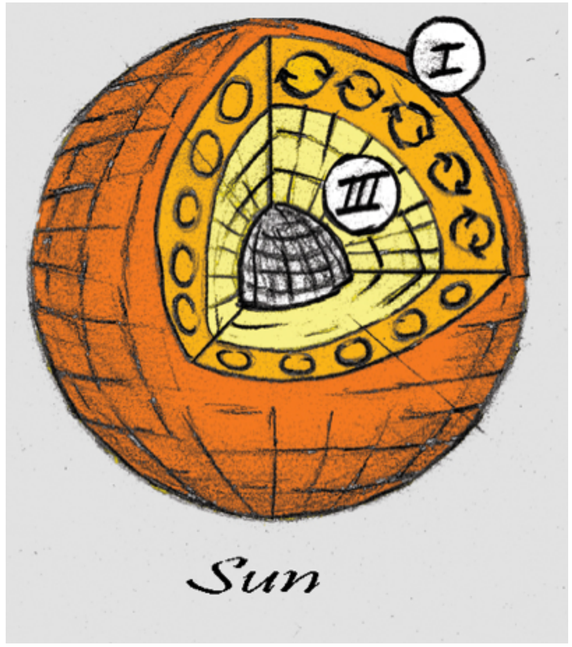


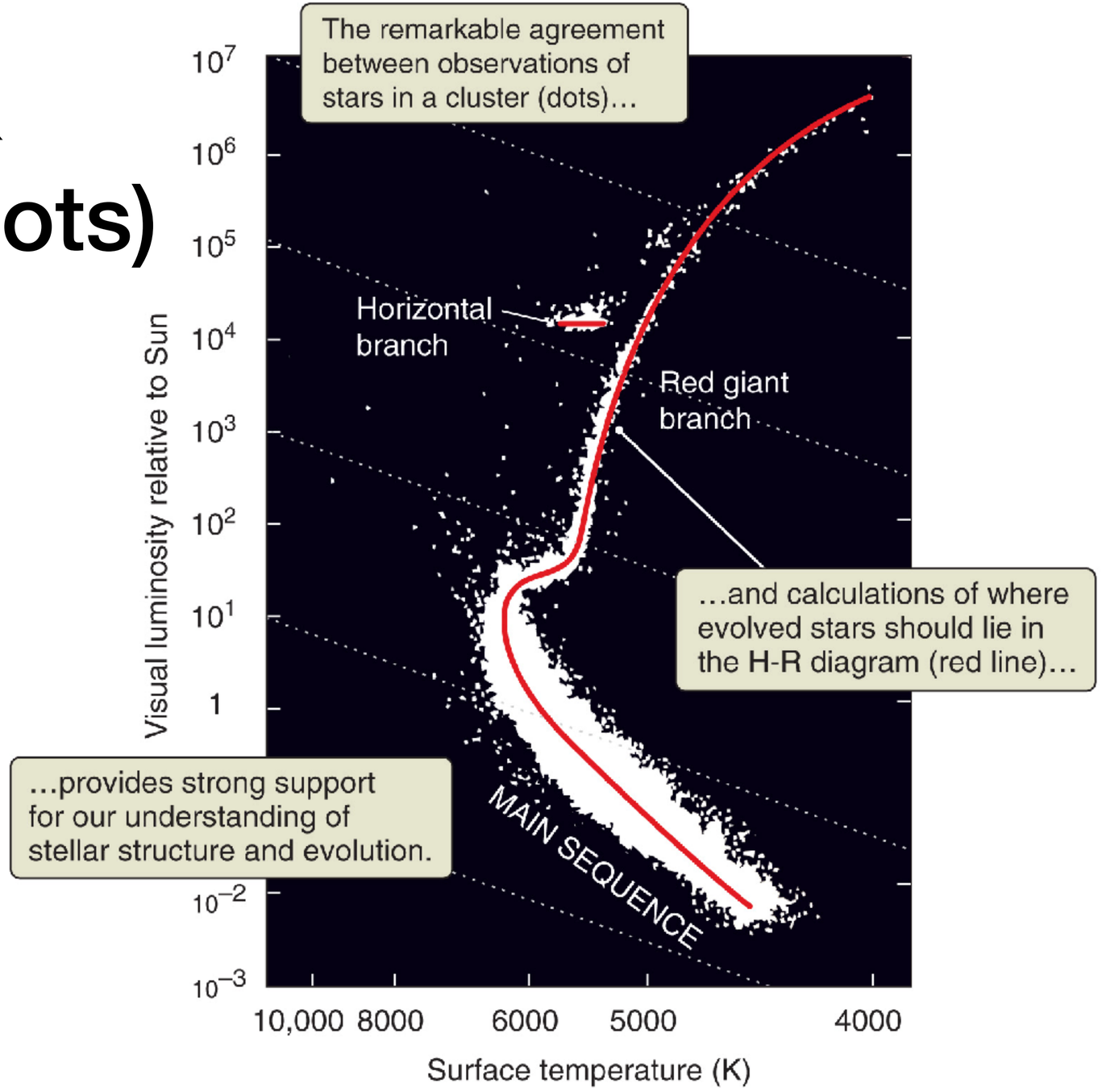
C



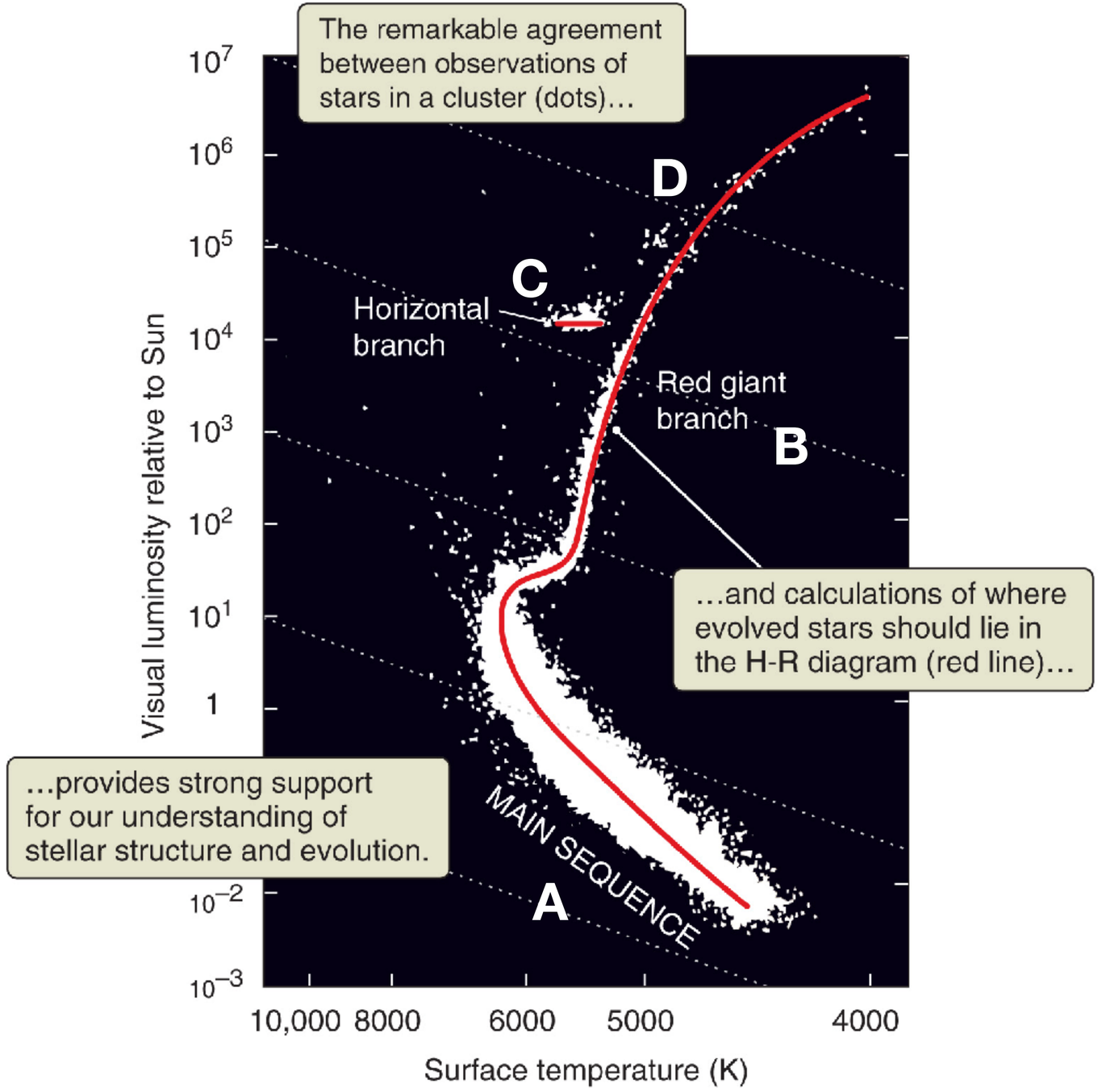
Theory (red line) & Observations (white dots)

We can make a model of any star based on its mass and age

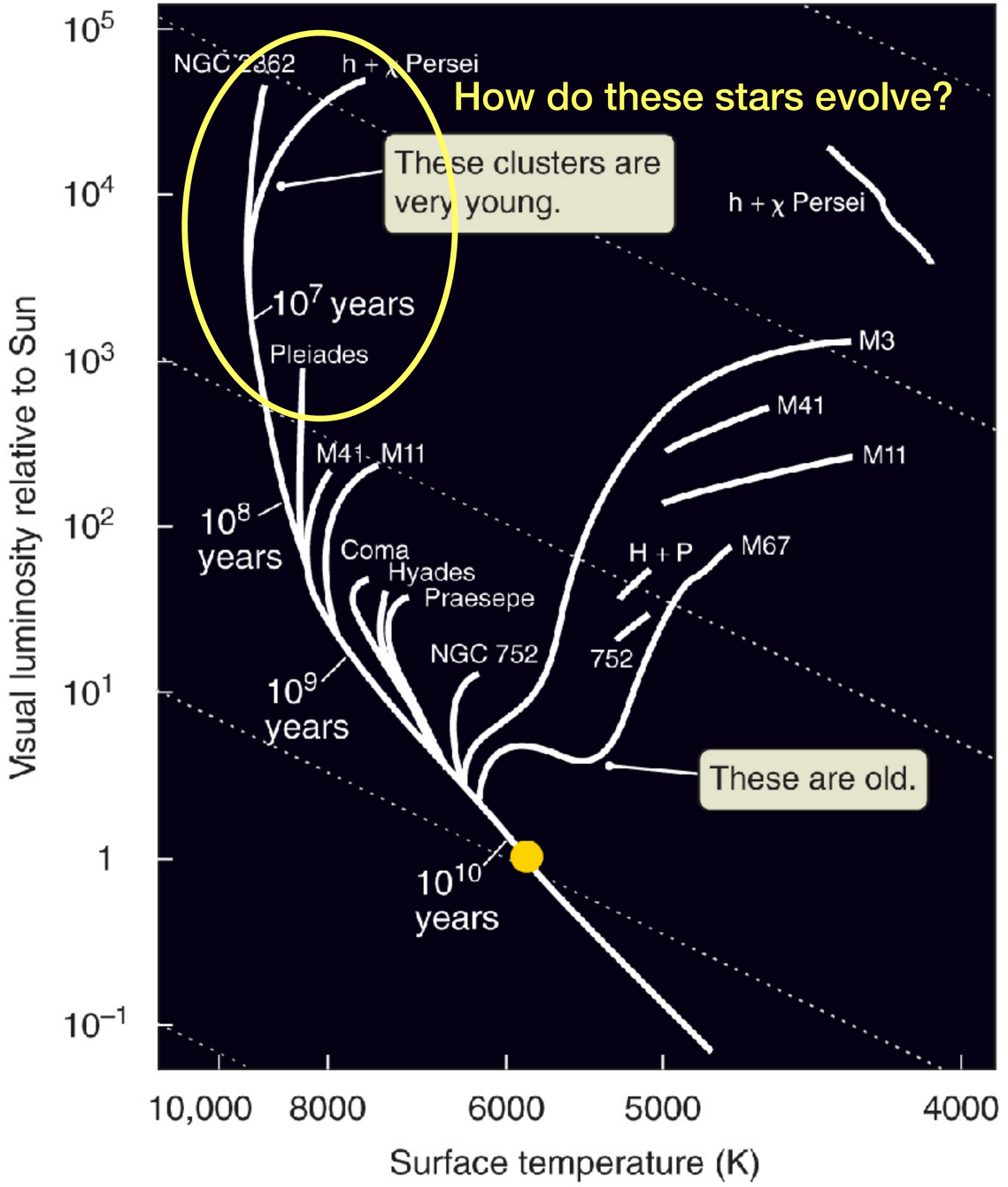




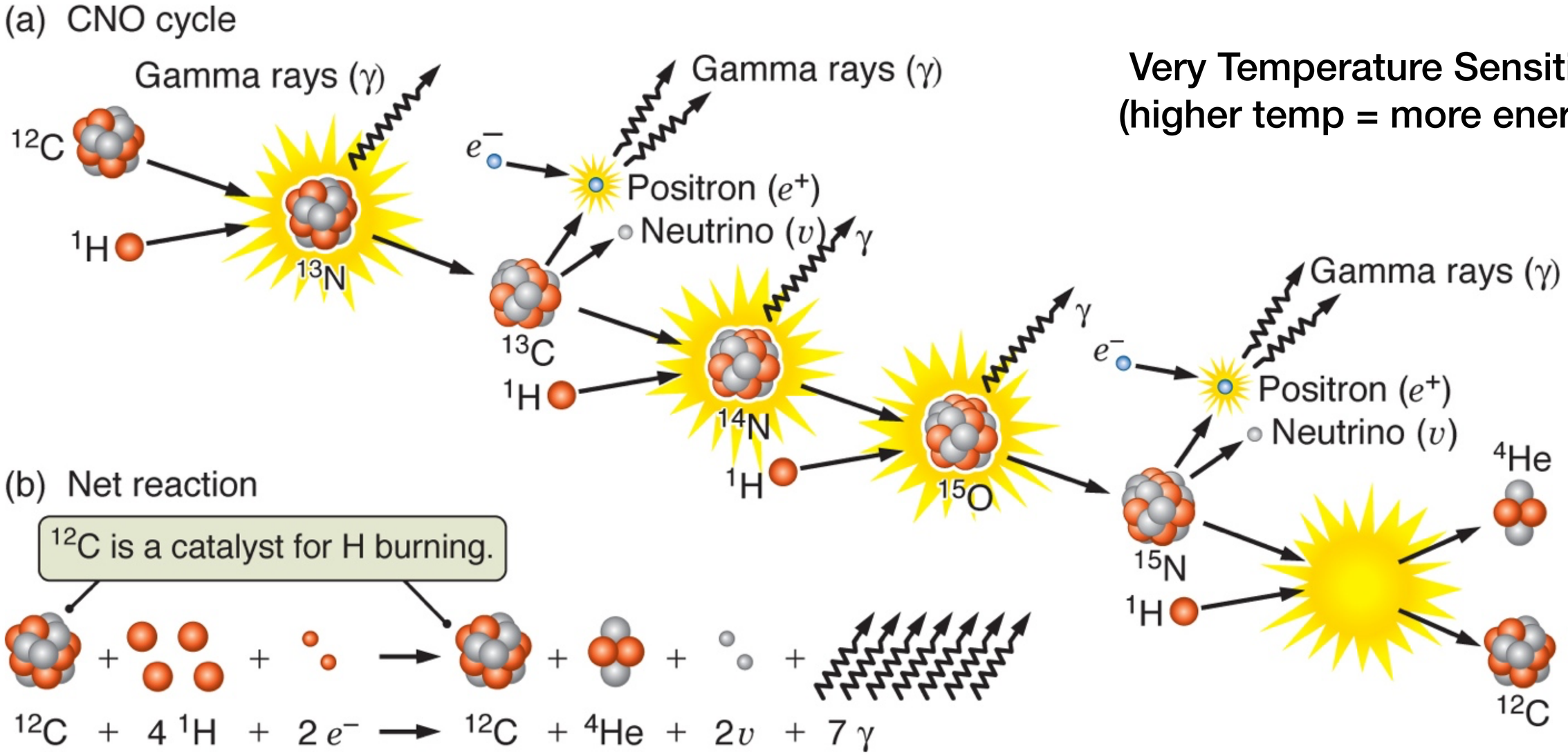
Which stars in this cluster are the most massive?



Because stars in clusters form at the same time, and a star's evolution is determined primarily by its mass, we can observe many clusters and figure out how stars evolve

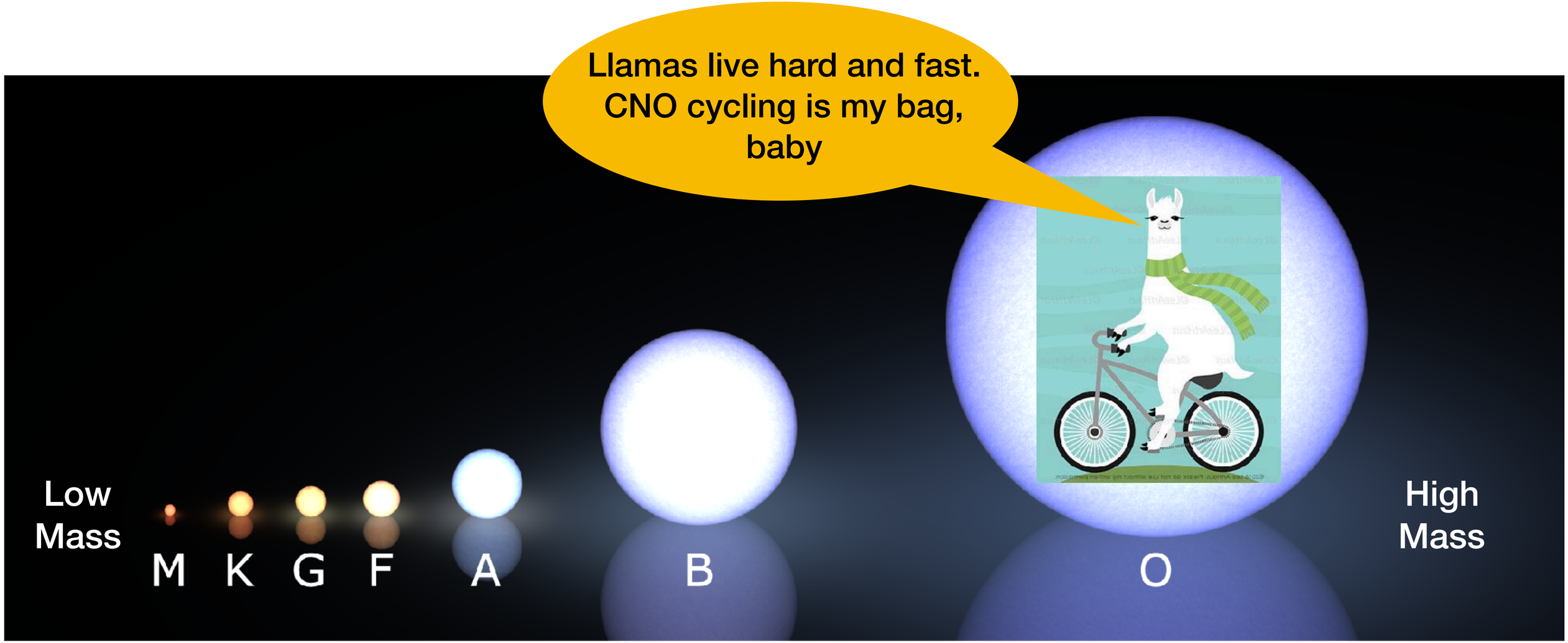


H Burning in High Mass Stars: CNO Cycle



Very Temperature Sensitive
(higher temp = more energy)

High Mass Stars = High Core Temps = CNO



Evolution of High Mass Stars

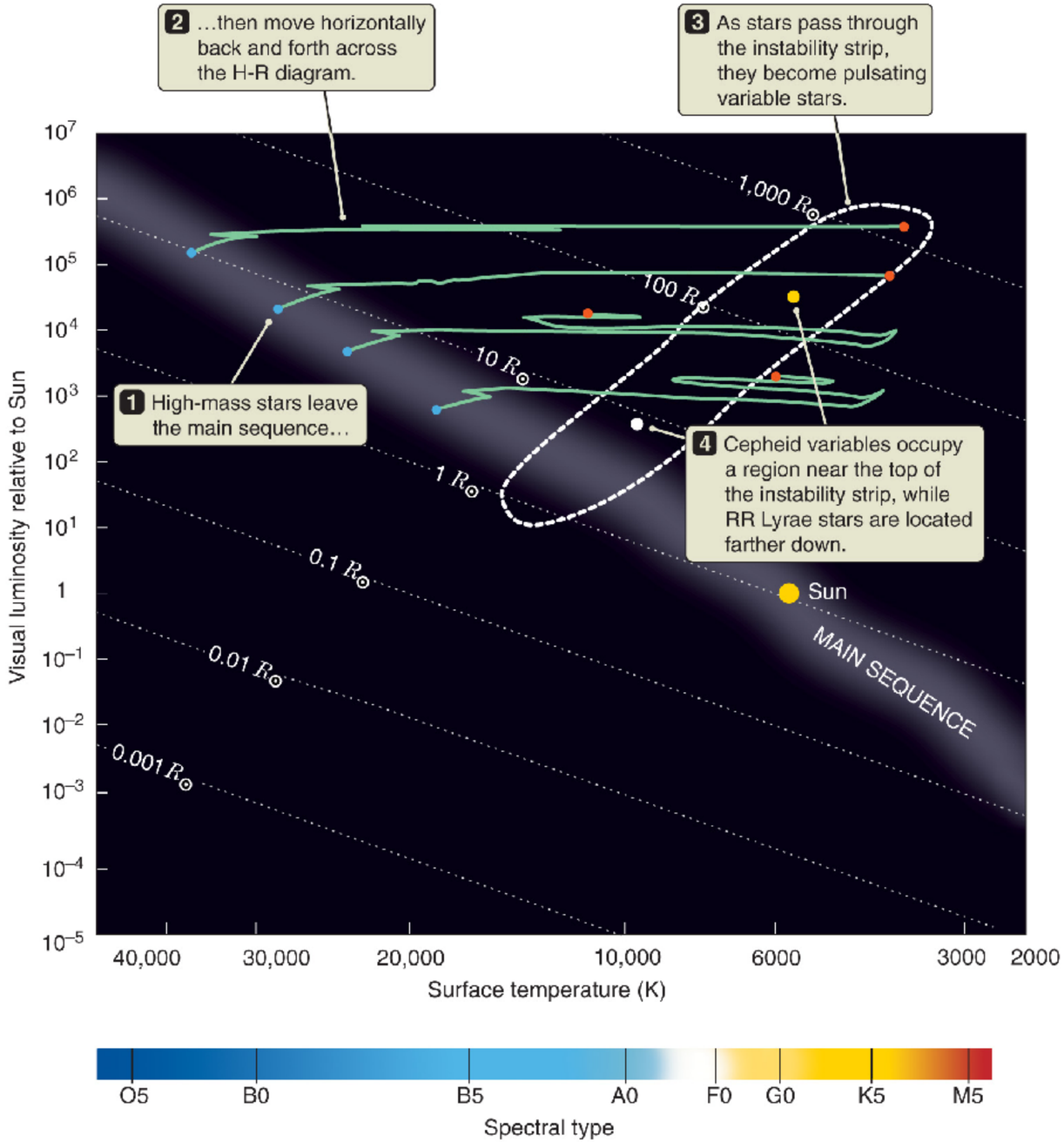
Time spent on the Main Sequence is short: why?

A) CNO is much more efficient

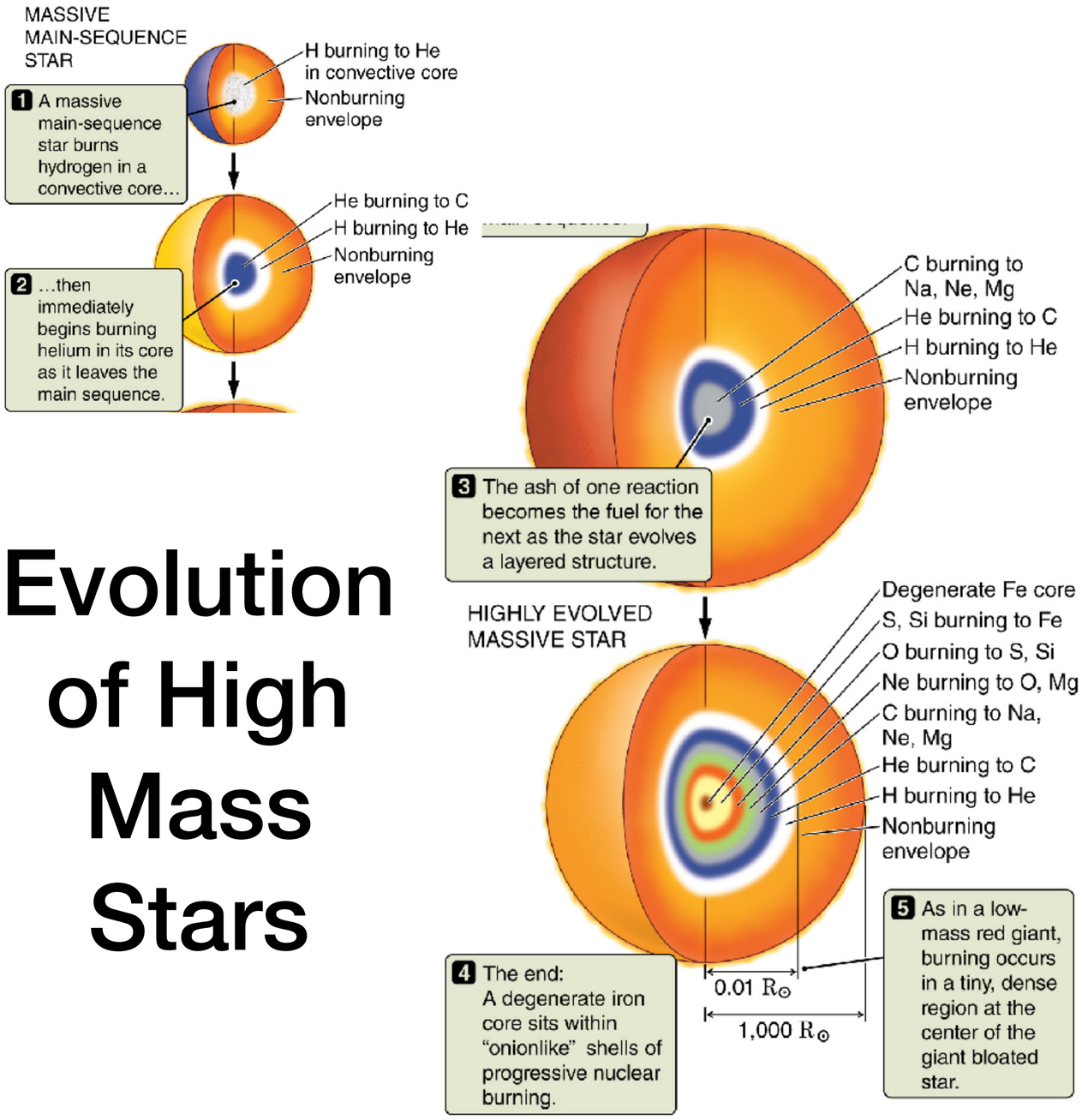
B) Massive stars use up their fuel more quickly

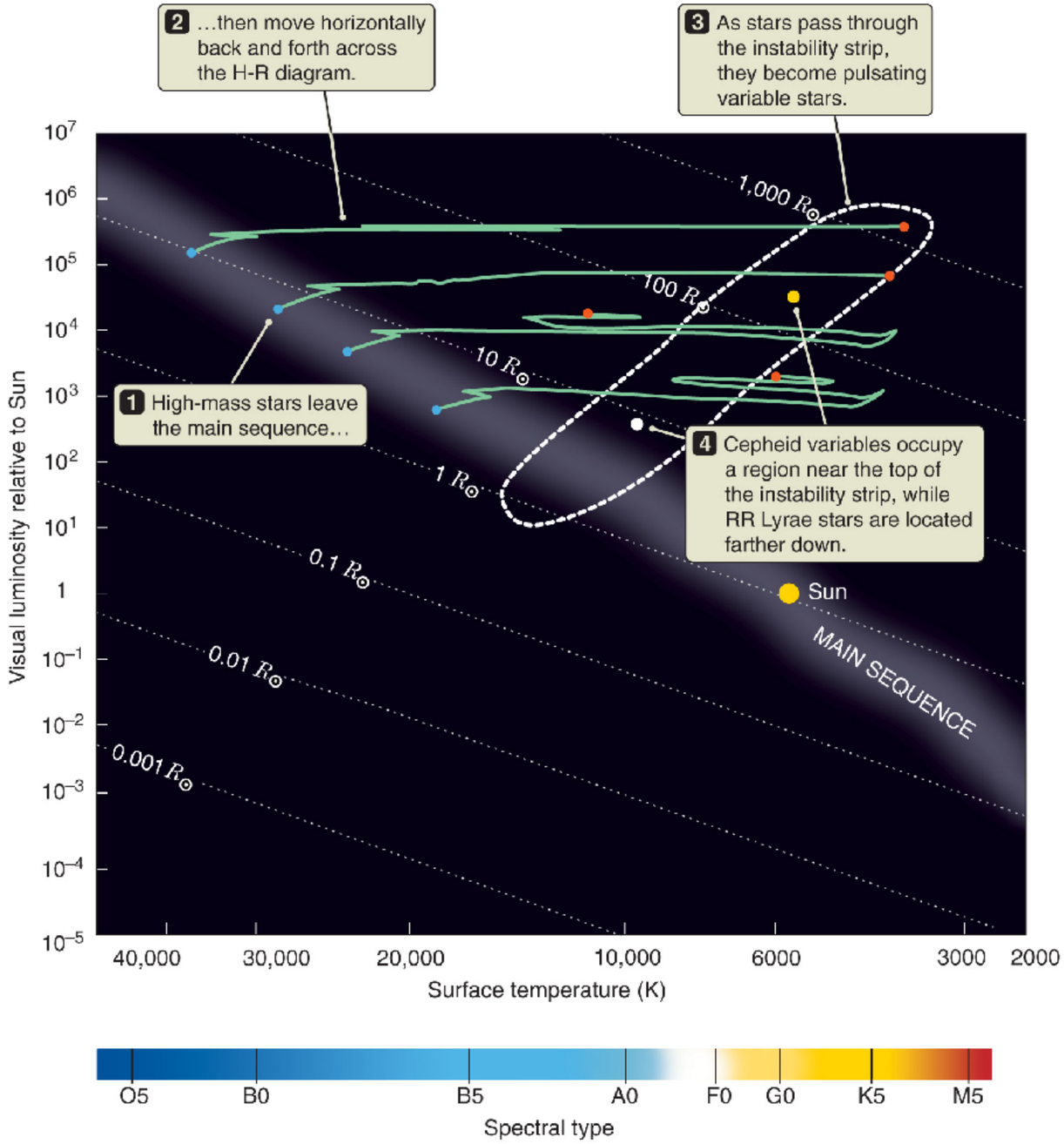
C) Not all the hydrogen in the core gets burned

D) The core is much smaller than a low mass star

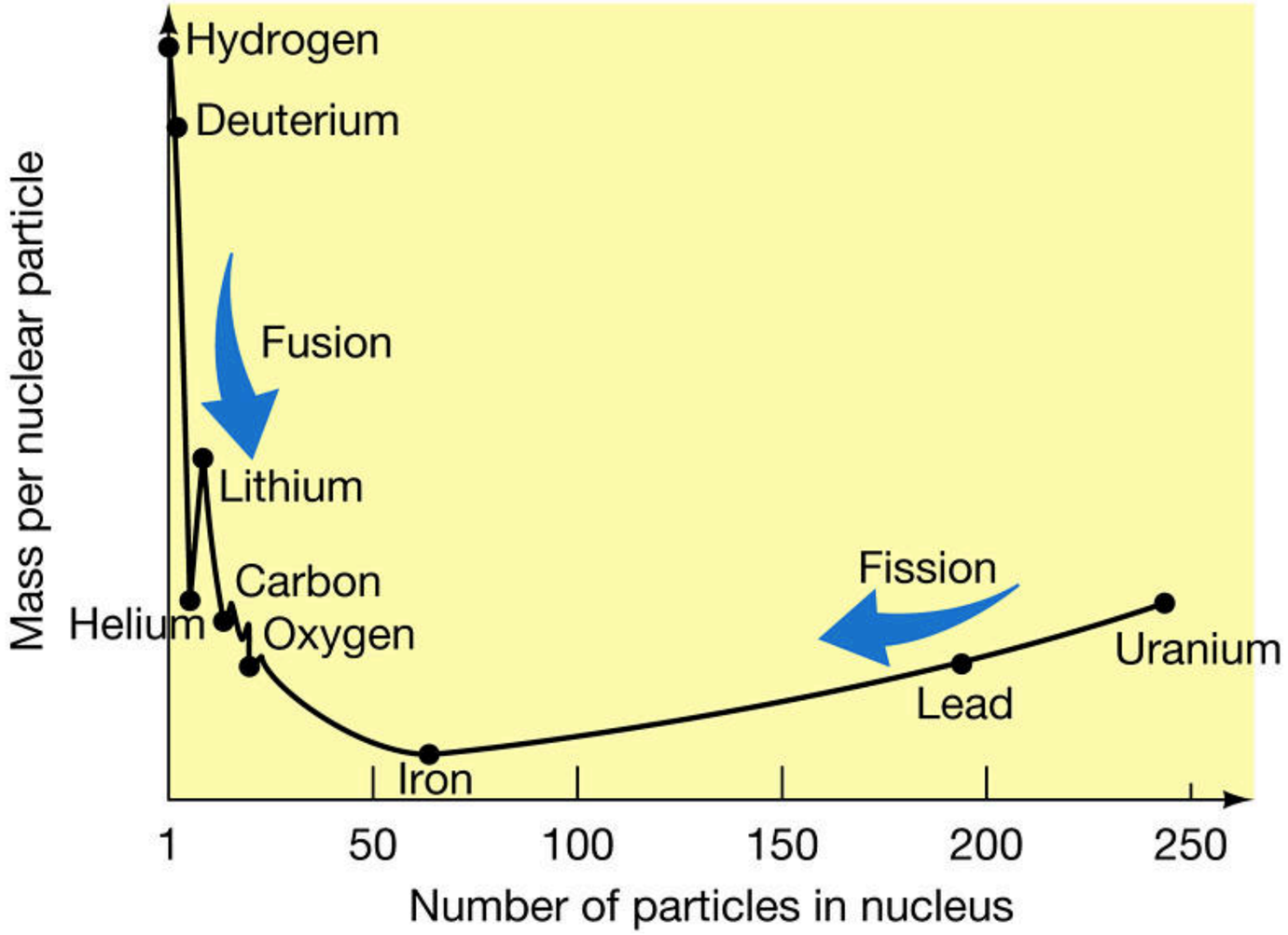


Evolution of High Mass Stars





Based on this graph, what do you think the heaviest element is that is fused inside of stars?



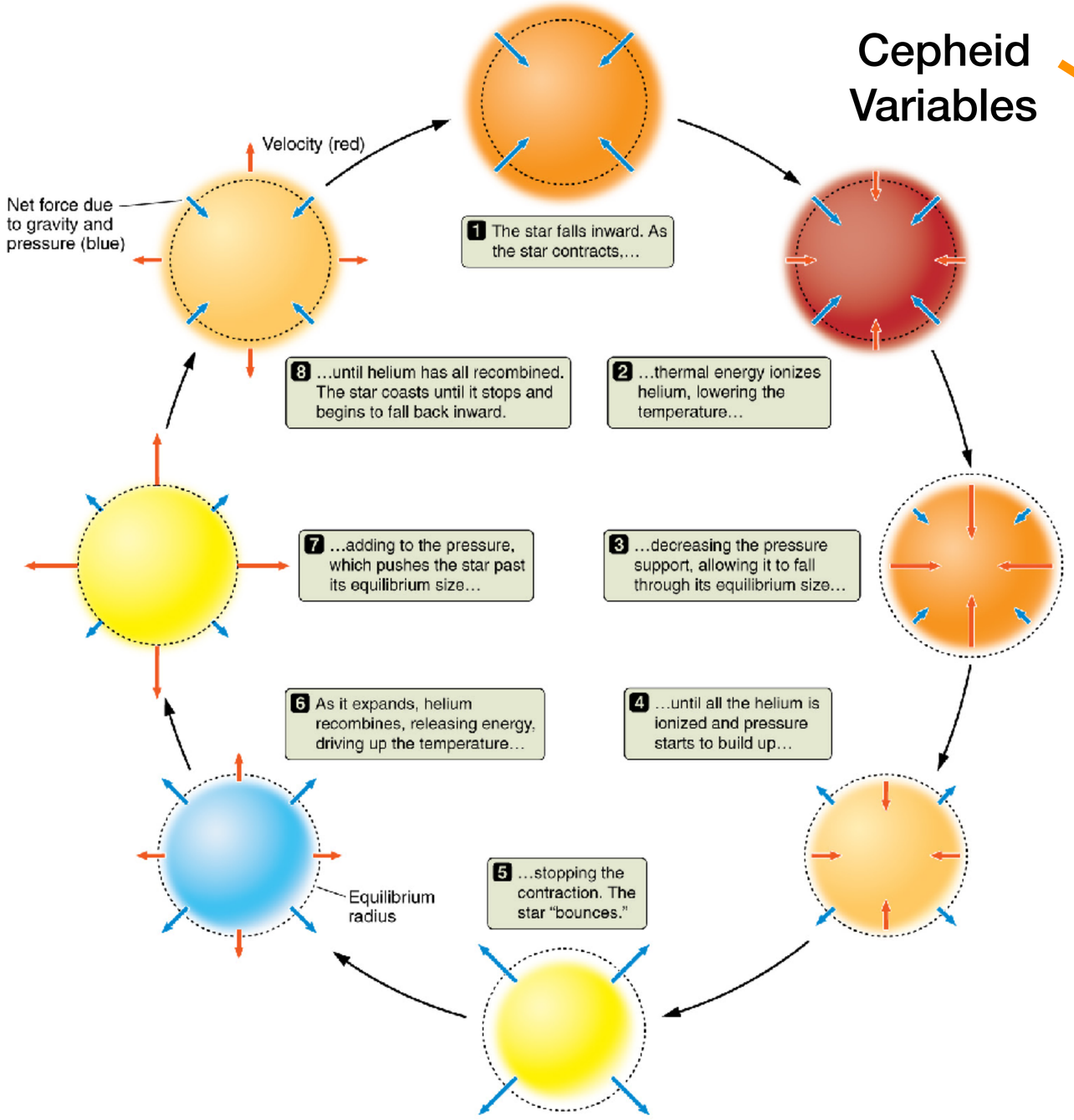
A) Lithium

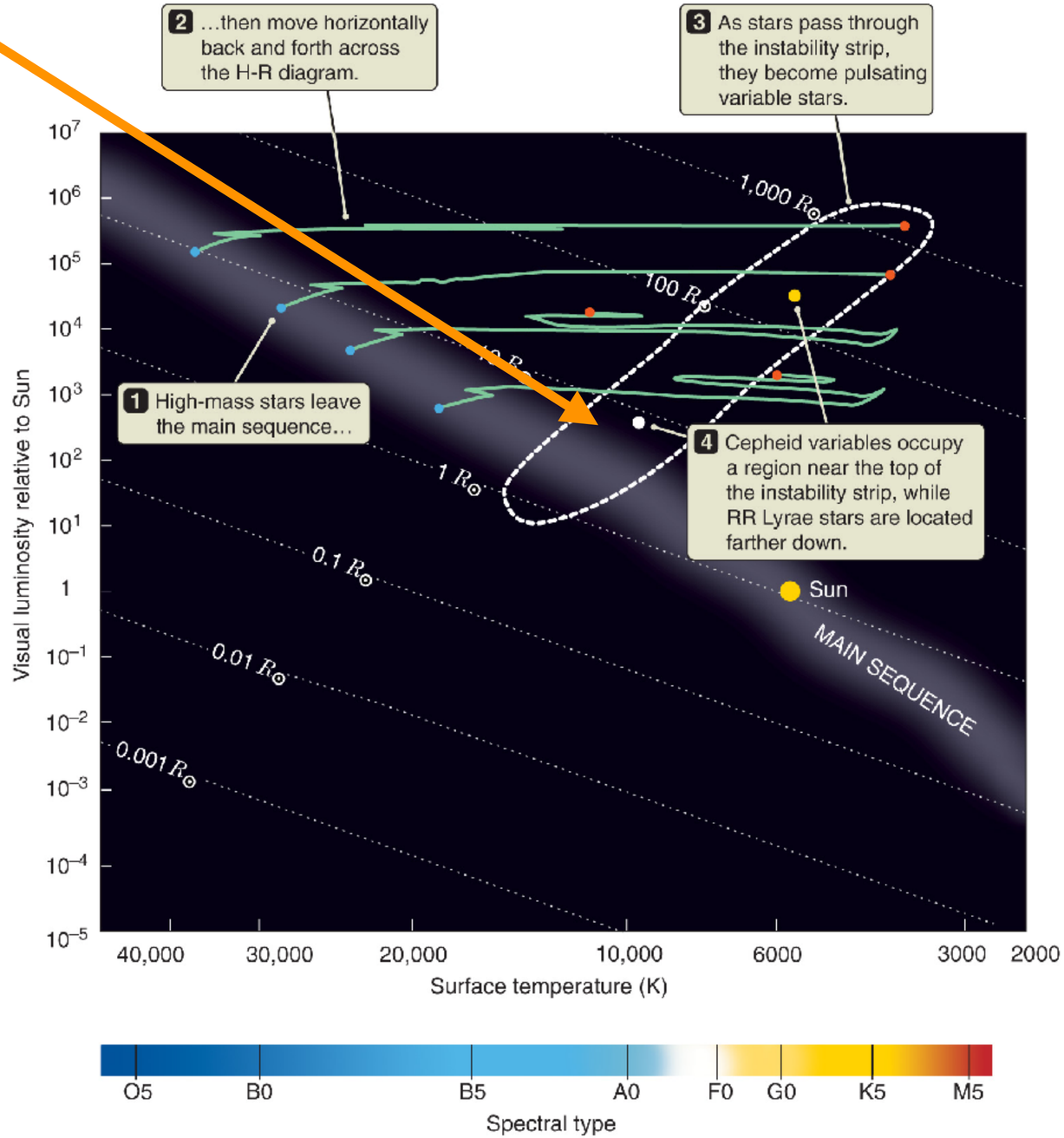
B) Iron

C) Lead

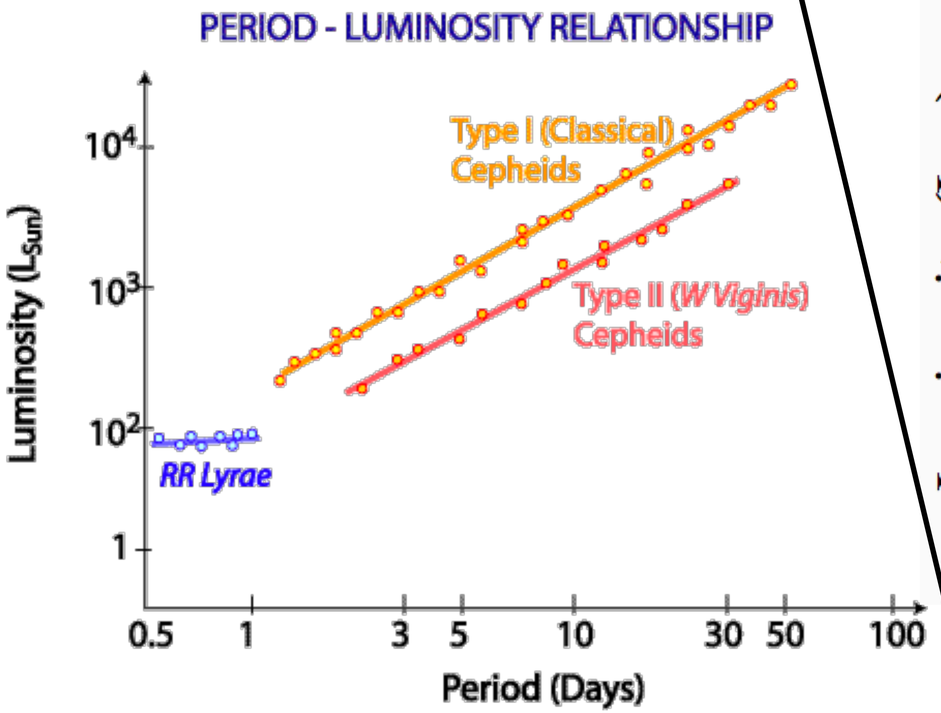
D) Uranium

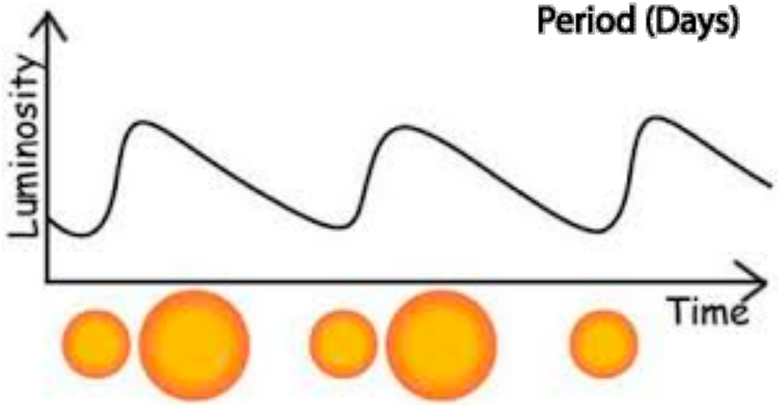
Cepheid Variables





Aside: Standard Candles





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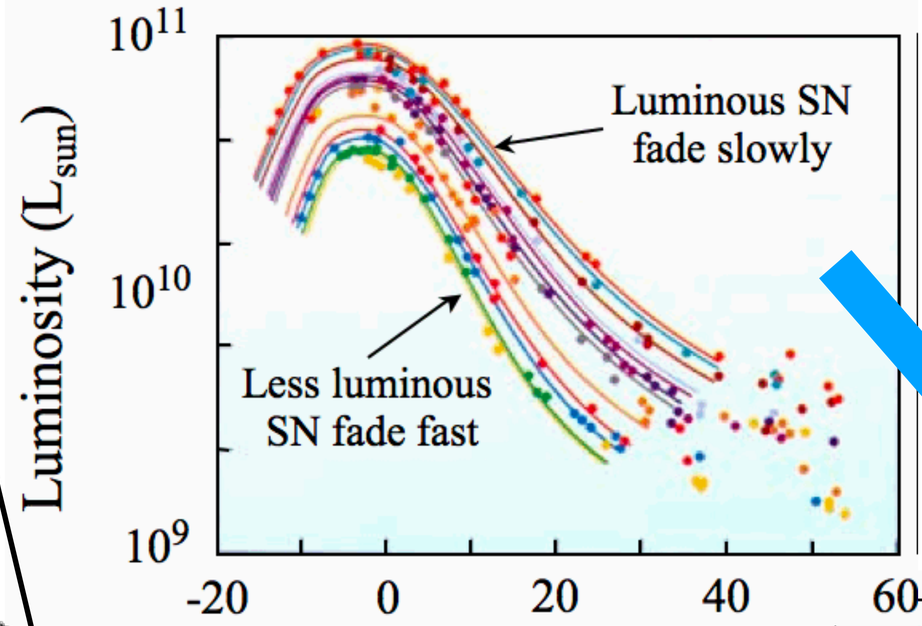
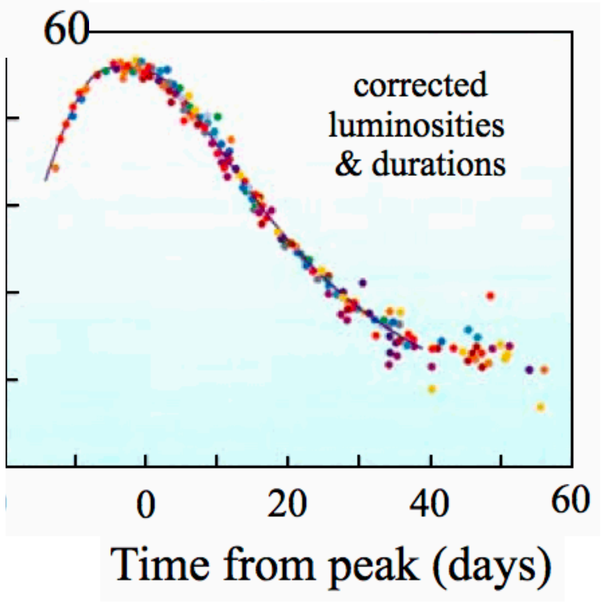
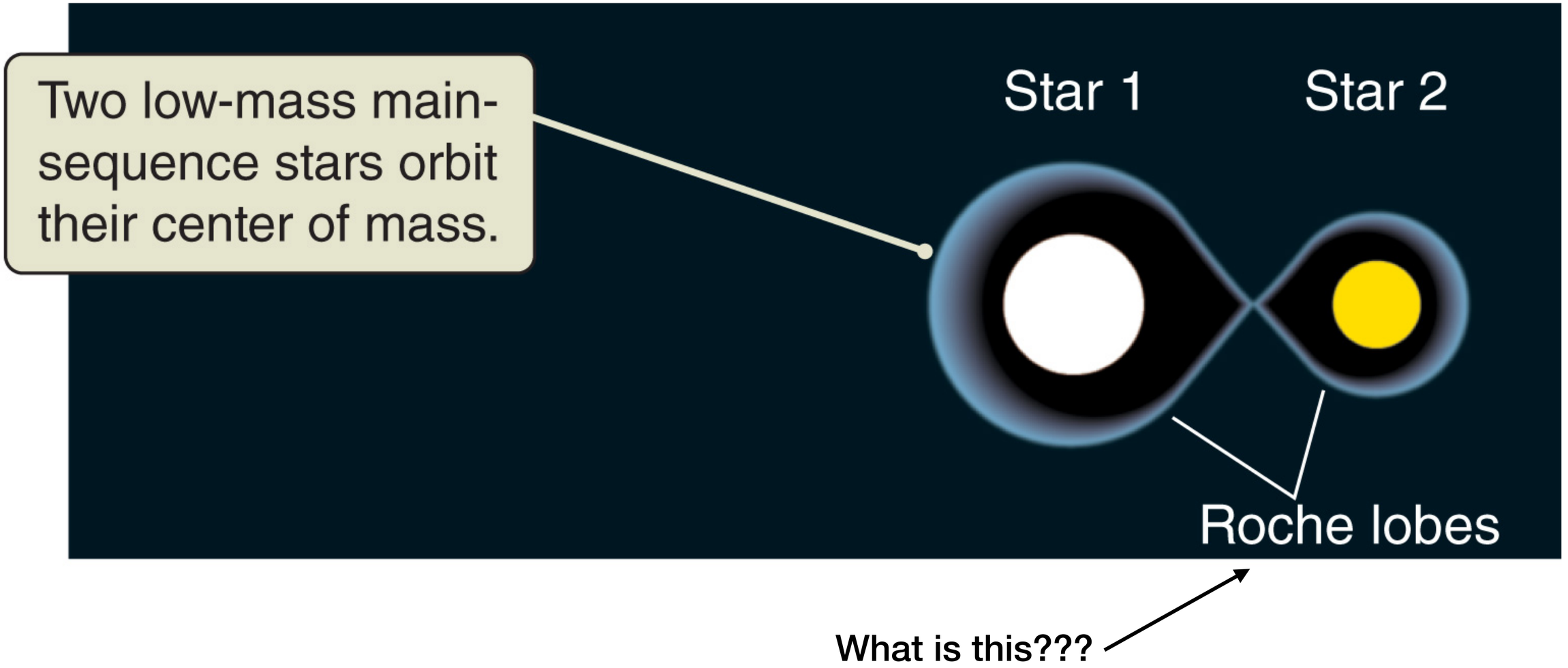


Type Ia Supernovae



What happens when close binary stars evolve?



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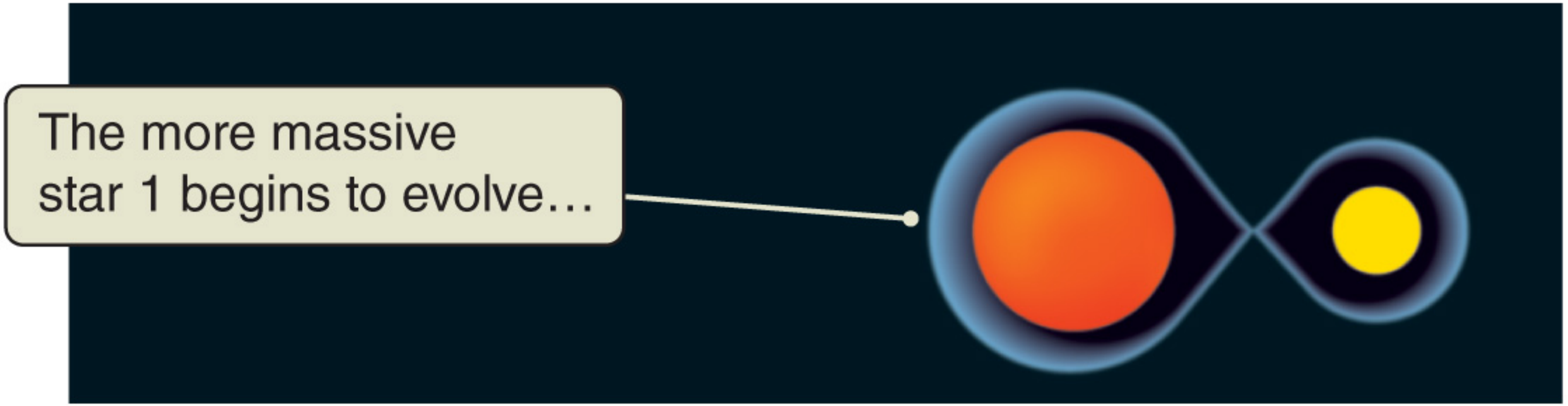

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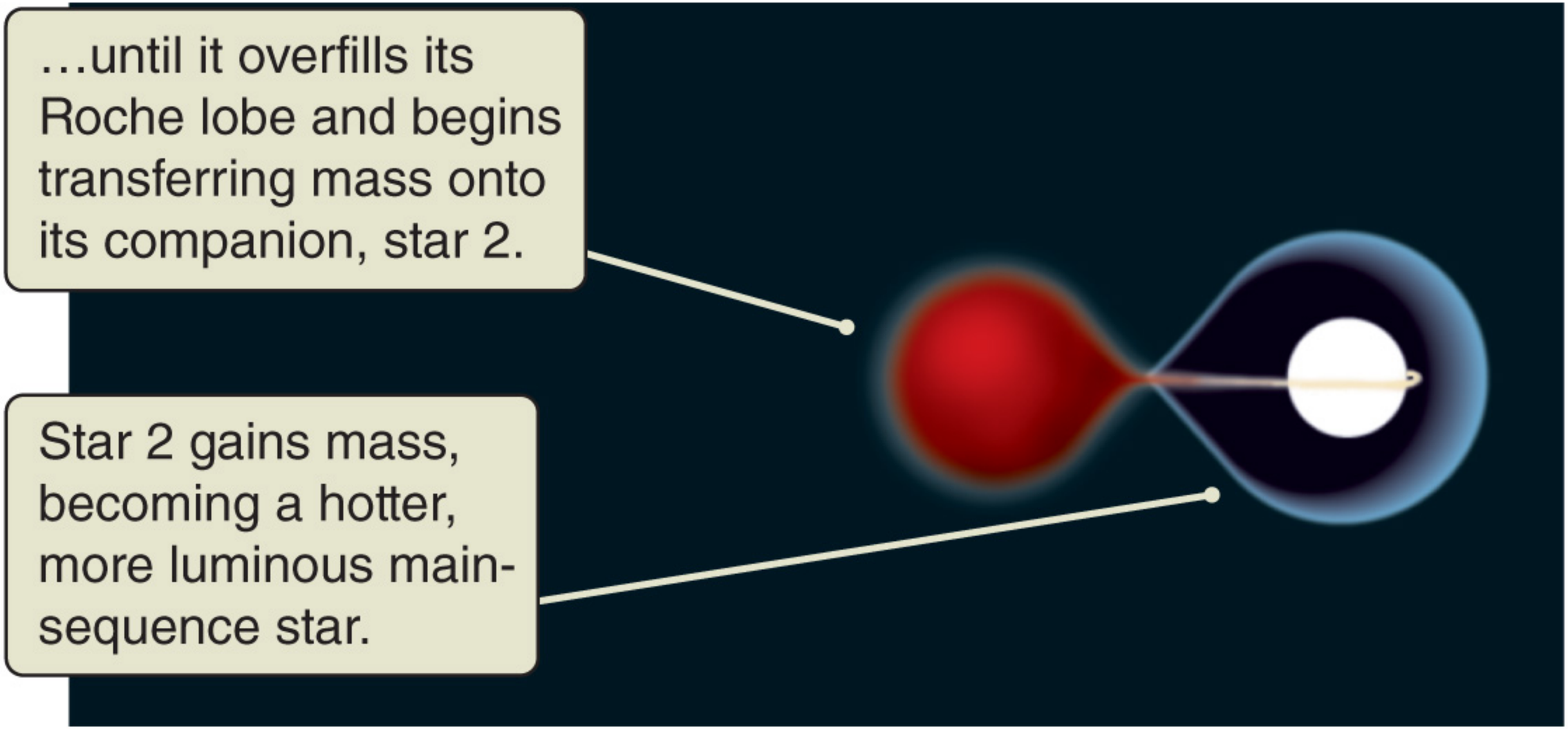

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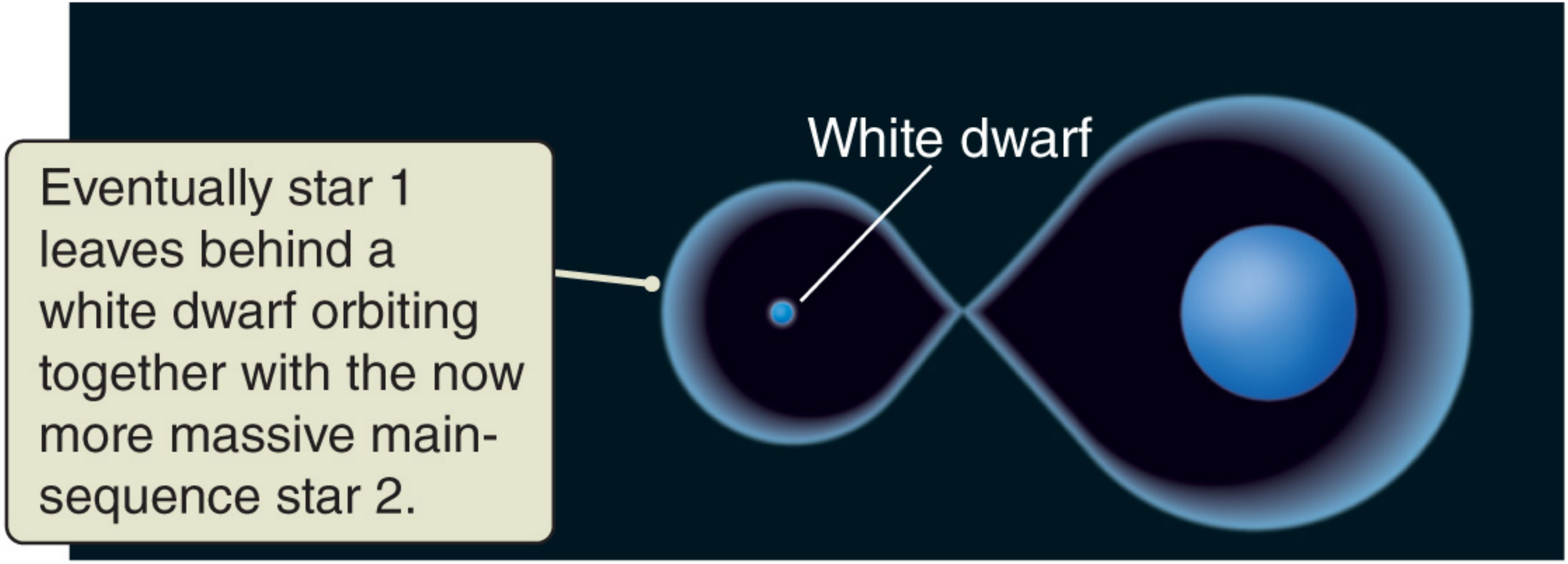

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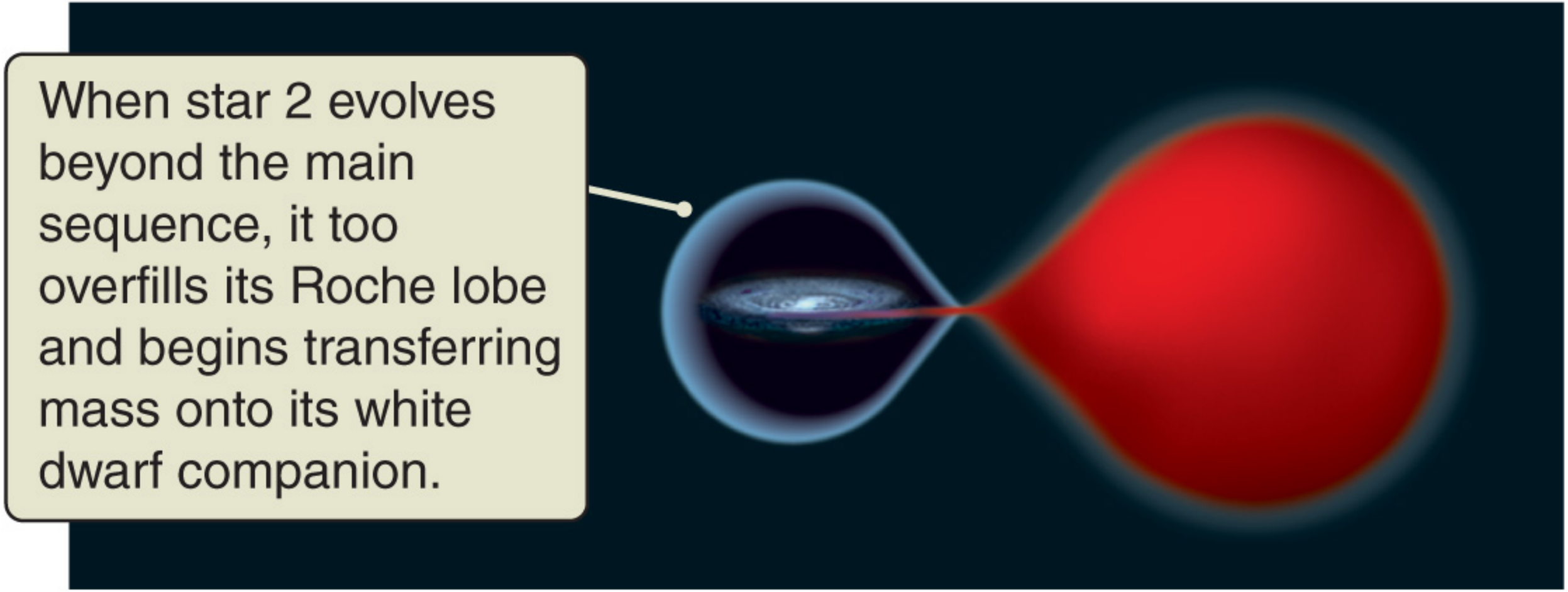

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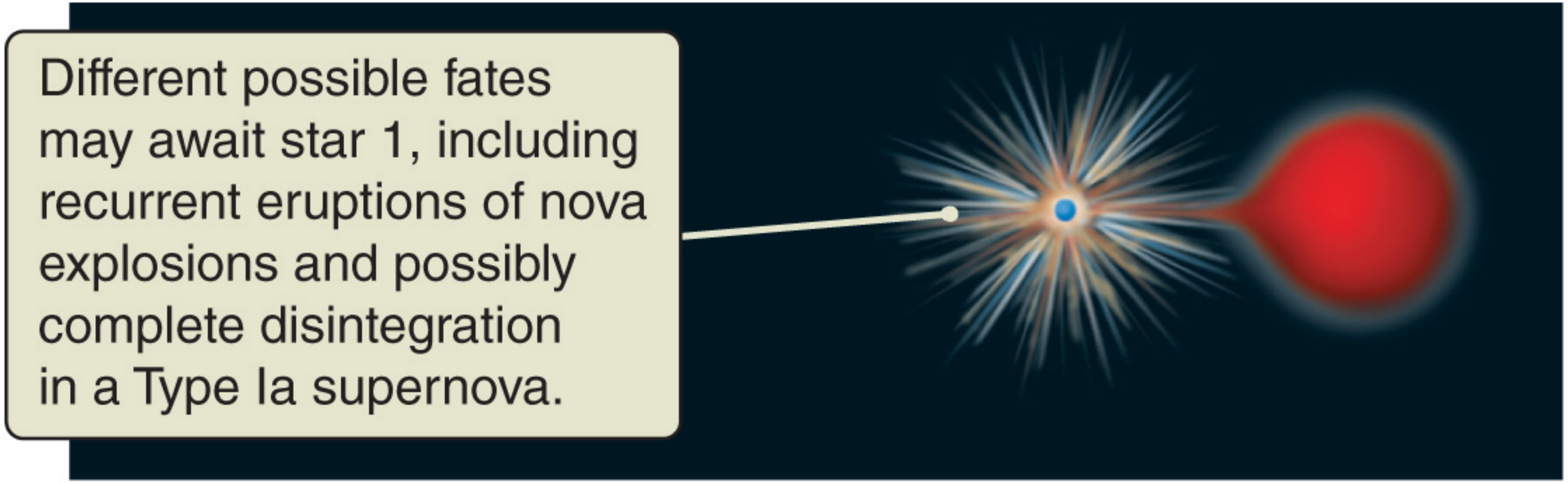

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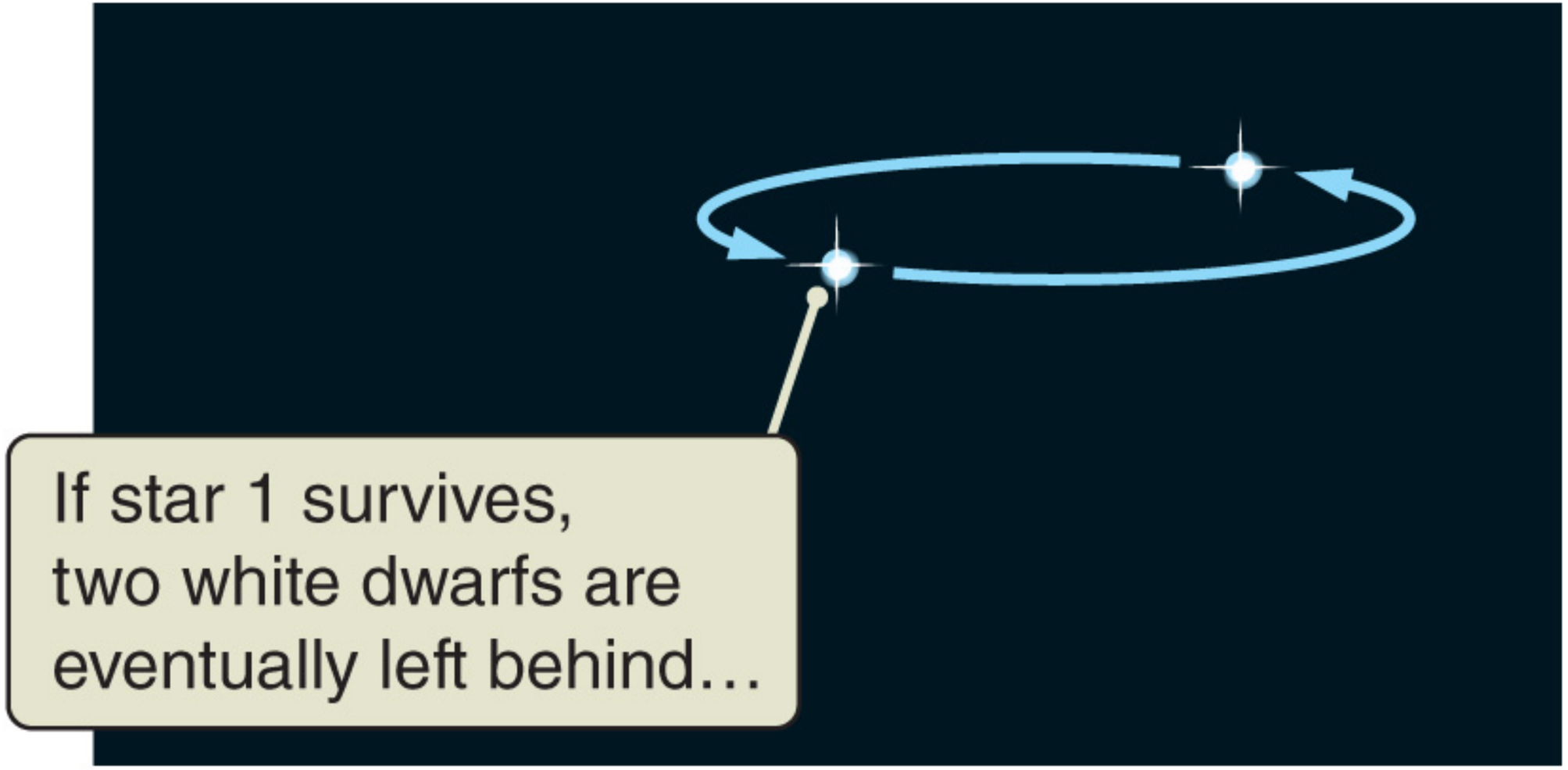

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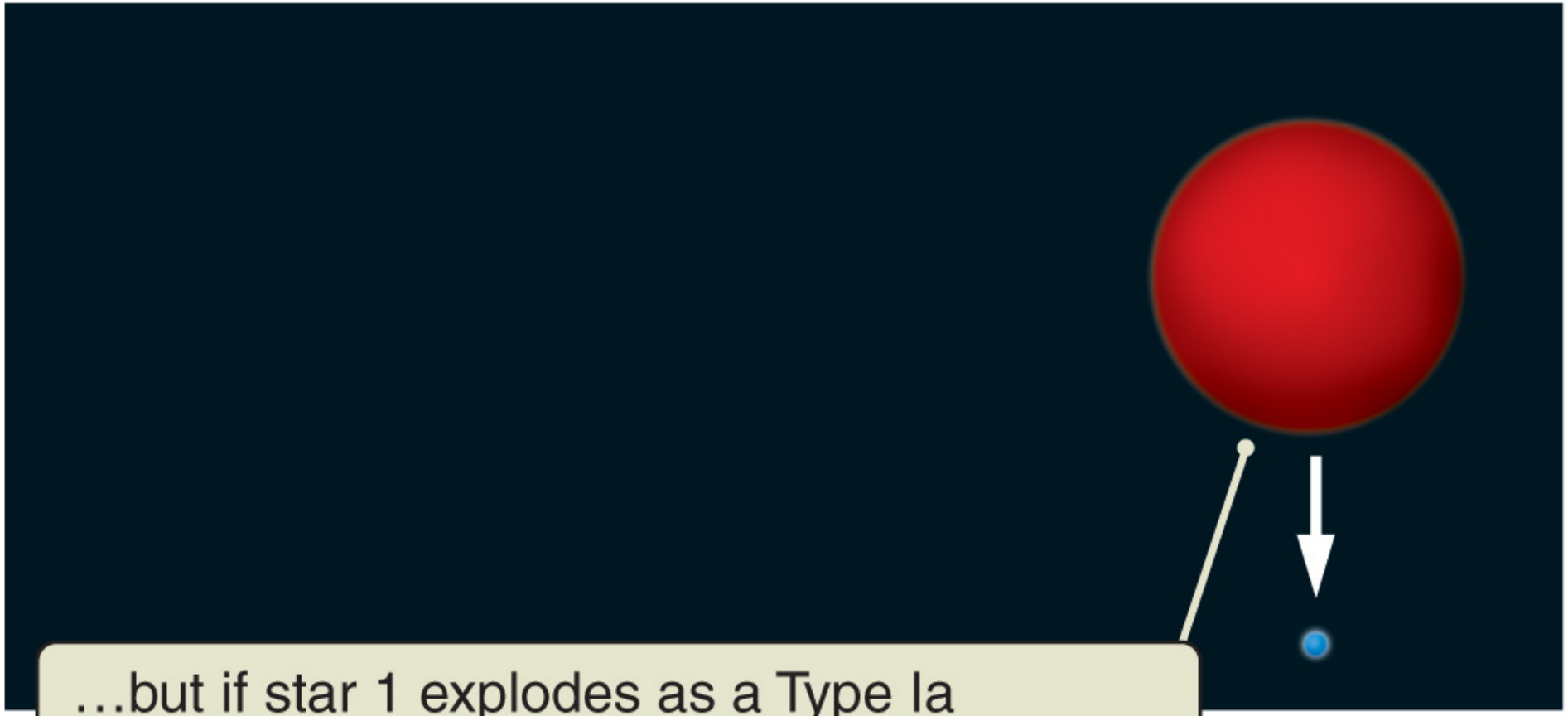
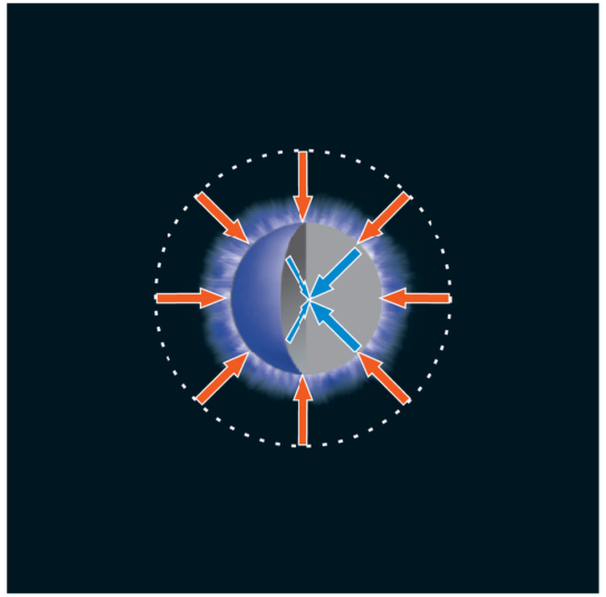


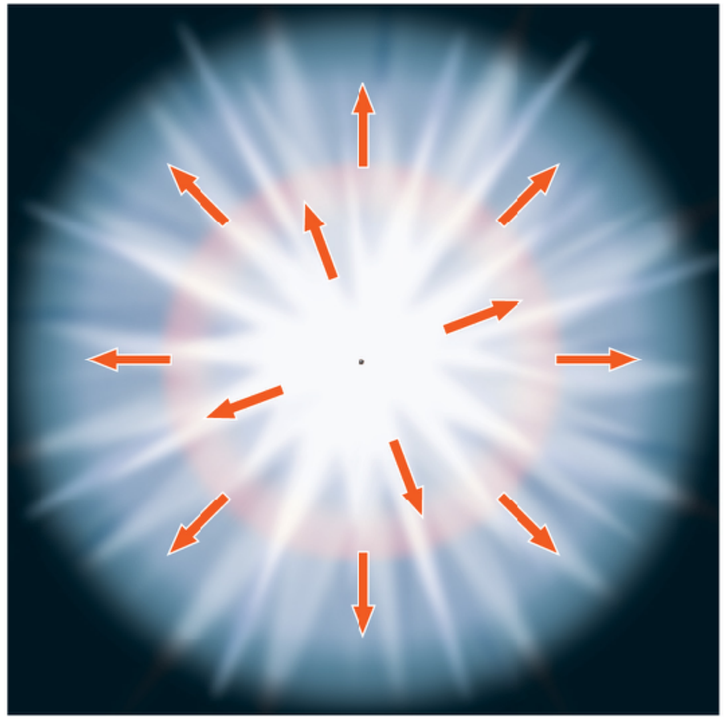
…but if star 1 explodes as a Type Ia supernova, star 2 remains as an isolated giant evolving to become a lone white dwarf.

Type Ia Supernovae

If the white dwarf mass exceeds the Chandrasekhar limit, it begins to collapse…

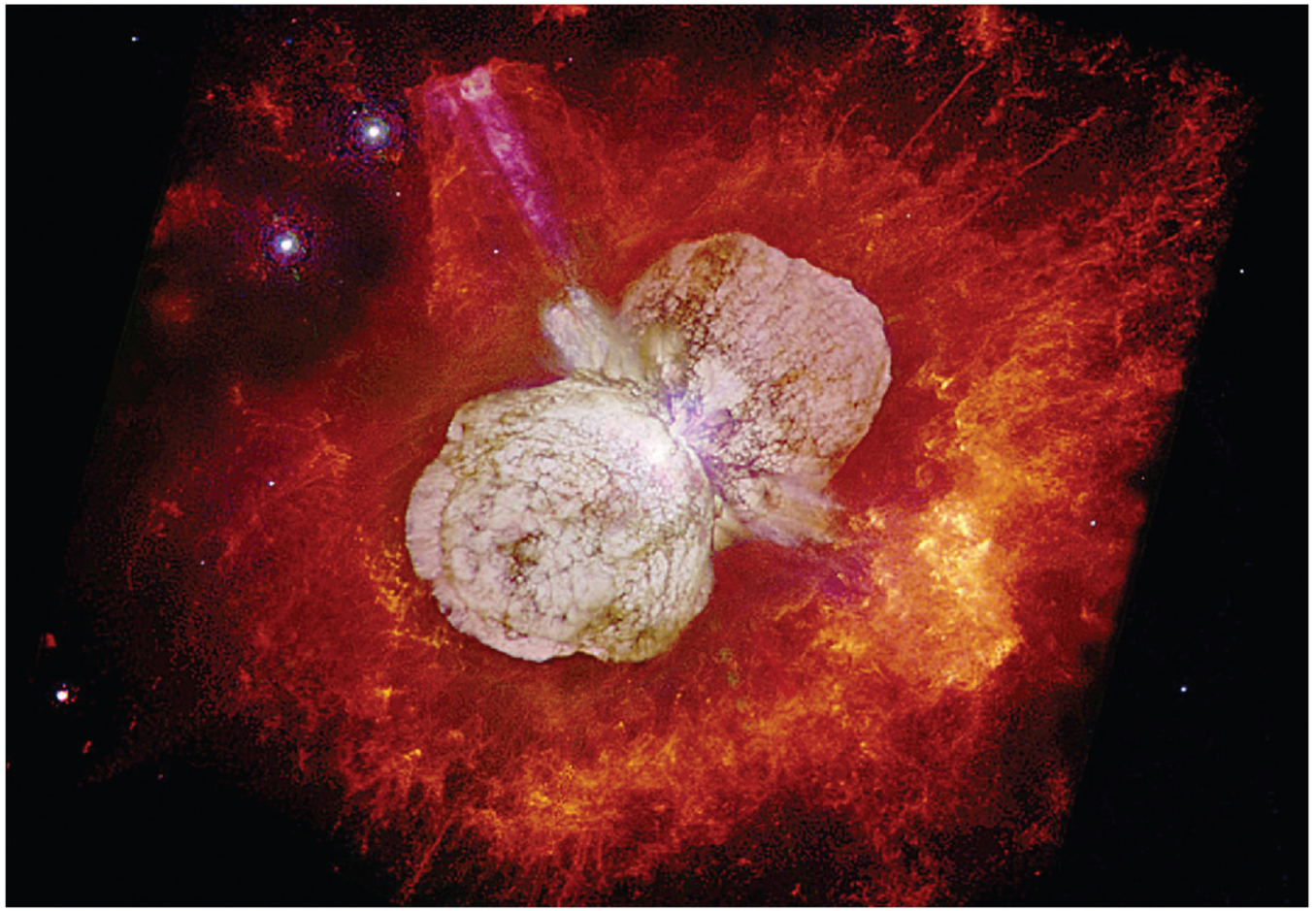


…pushing up the temperature until carbon ignites and burns explosively.



The Type Ia supernova consumes the white dwarf completely.

Back to Massive Star Evolution



Eta Carinae
binary star

What causes massive stars to have strong winds?

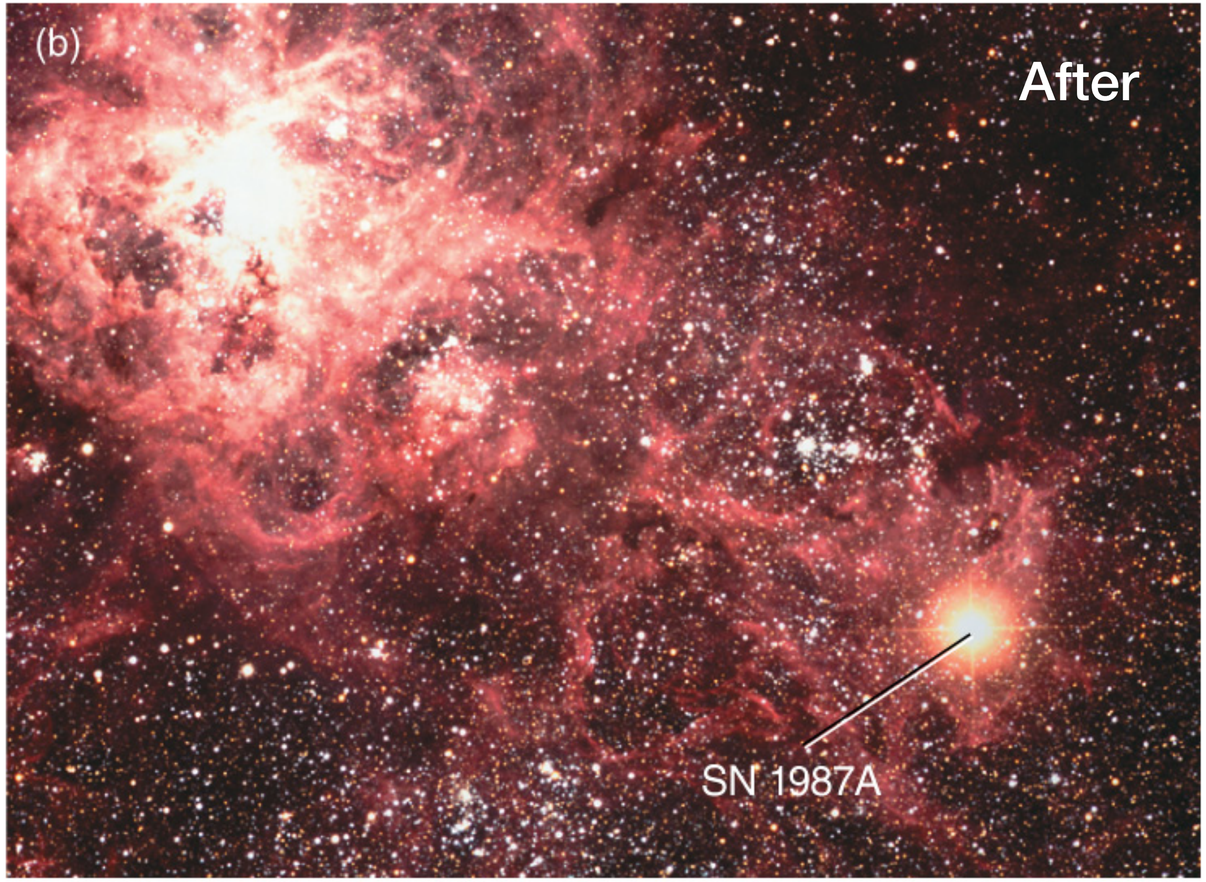
A) High surface temperatures

B) Light elements in their atmospheres

C) Strong radiation pressure (from photons)

D) Like Llamas, they're quite gassy

Type II Supernovae



Betelgeuse: Future Supernova

… were a supernova to go off within about 30 light-years of us, that would lead to major effects on the Earth, possibly mass extinctions. X-rays and more energetic gamma-rays from the supernova could destroy the ozone layer that protects us from solar ultraviolet rays. It also could ionize nitrogen and oxygen in the atmosphere, leading to the formation of large amounts of smog-like nitrous oxide in the atmosphere.

- Mark Reid, Harvard-Smithsonian CfA

430 light-years away (safe distance, unless it explodes as a gamma ray burst pointed at us)

May appear as bright as the full moon, visible during the day!

Chapter 13: High Mass Star Evolution and their Remnants: NSs and BHs

Chapter 14 Reading Assignment due next Tuesday

Turn in extra credit planetarium and public observing reports up front when complete

Stellar Lifetimes worksheet due now!

Are your grades in Canvas correct???

Midterms available up front

How lost are you regarding stellar evolution? (Chapters 12 & 13, the most recent ones)

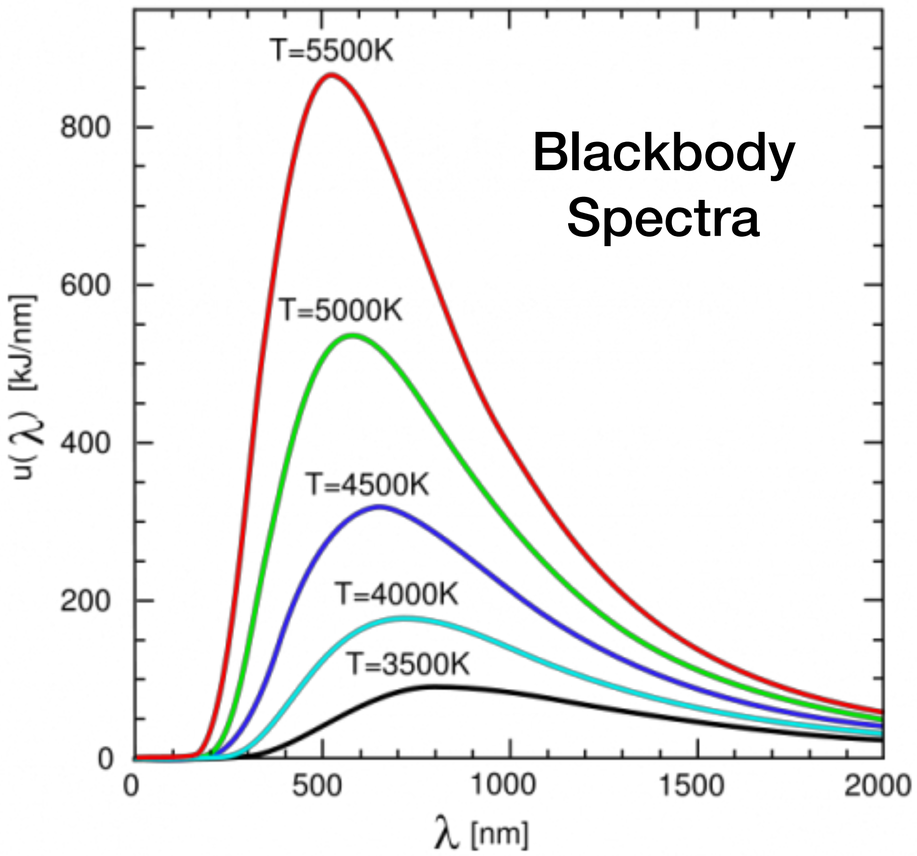
A) Not lost at all - I'm a little bored to be honest

B) It mostly makes sense - I'm following it as well as I followed the material in previous chapters

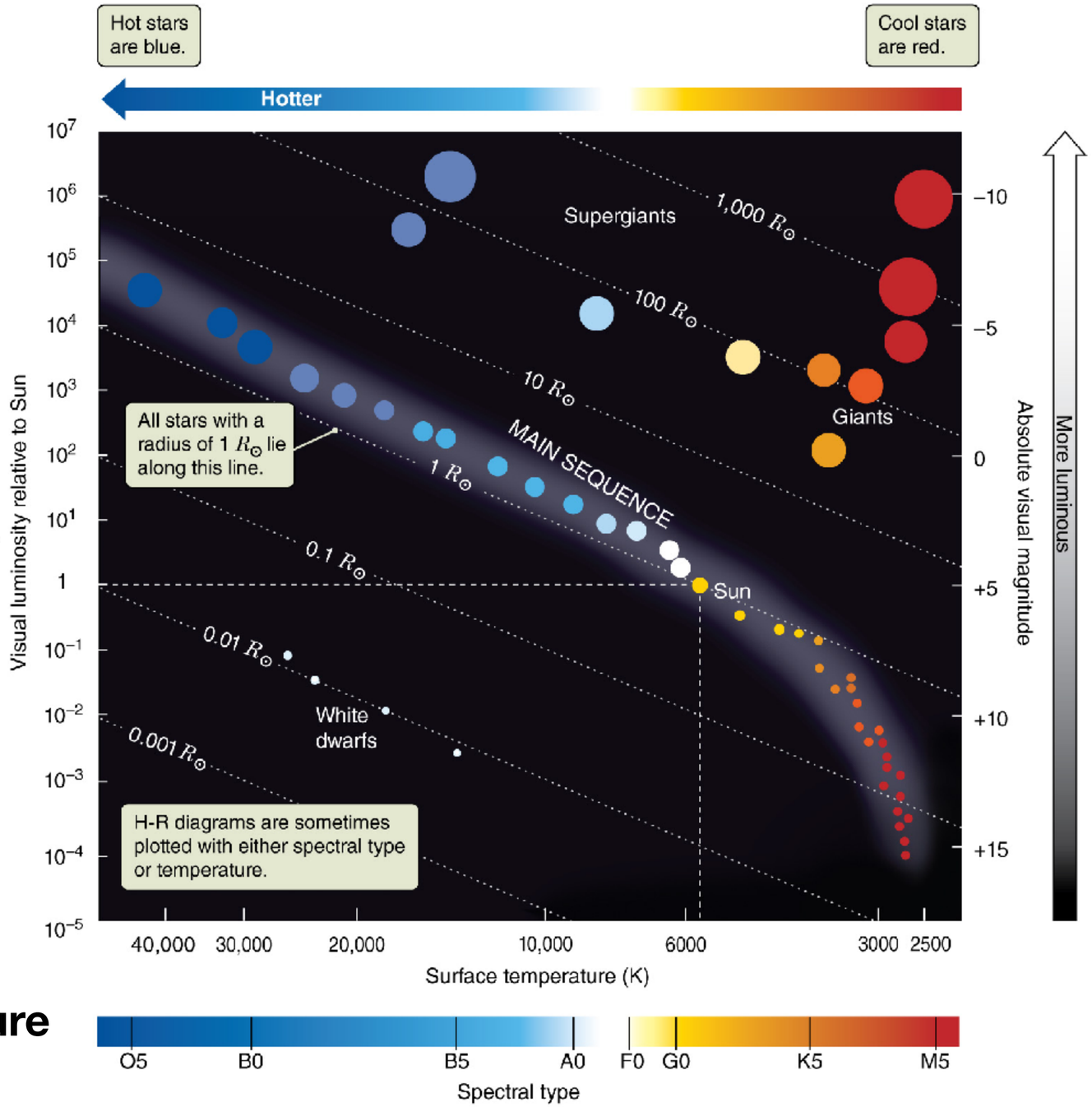
C) It's a lot more confusing - I kind of get it, but am really worried about what I need to know for the next midterm exam

D) What's stellar evolution?

Hertzsprung-Russell (HR) Diagram

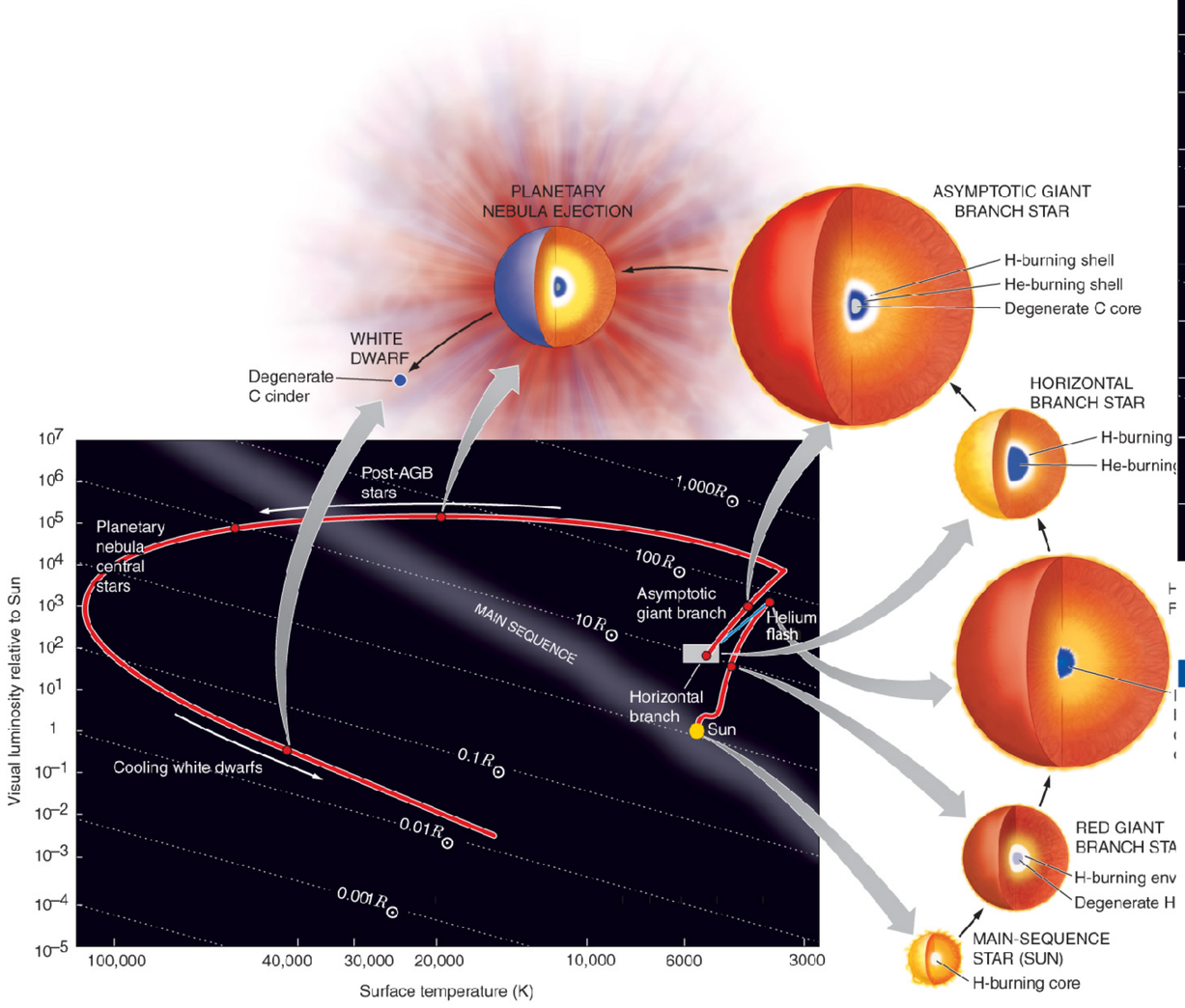


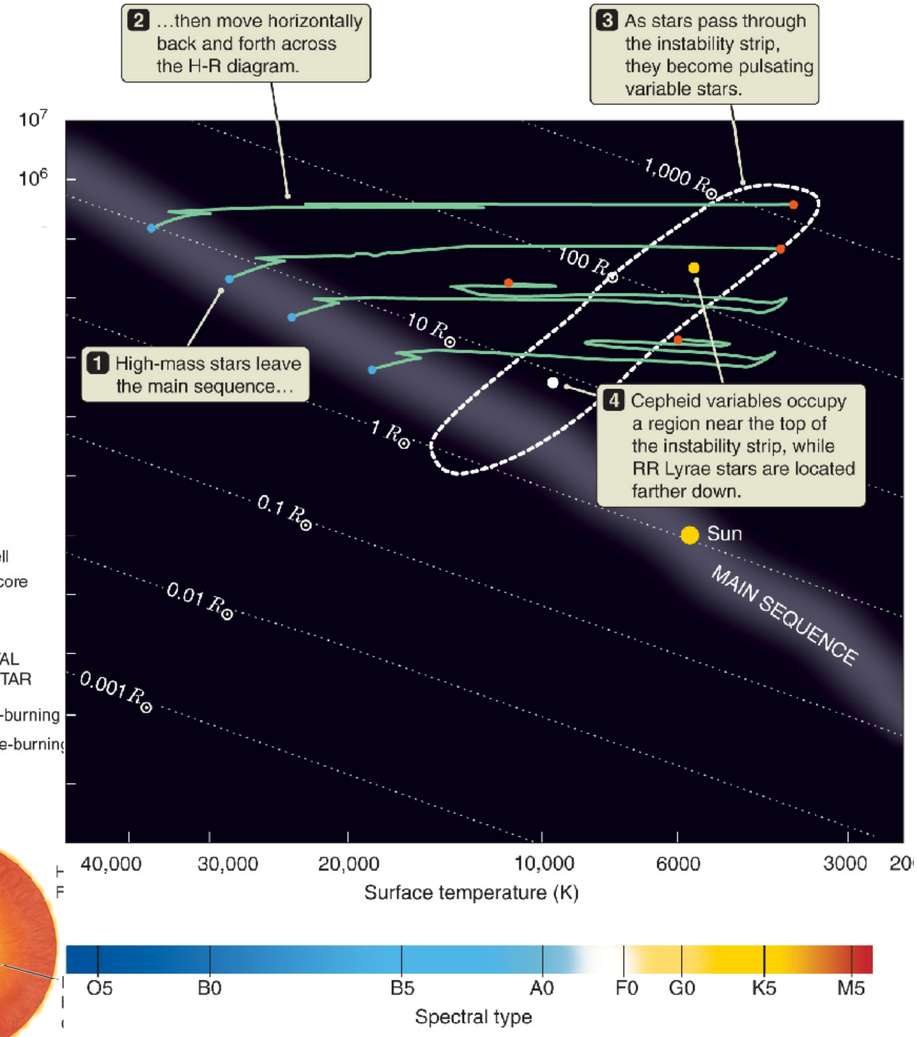
Luminosity (intrinsic brightness) on the y-axis

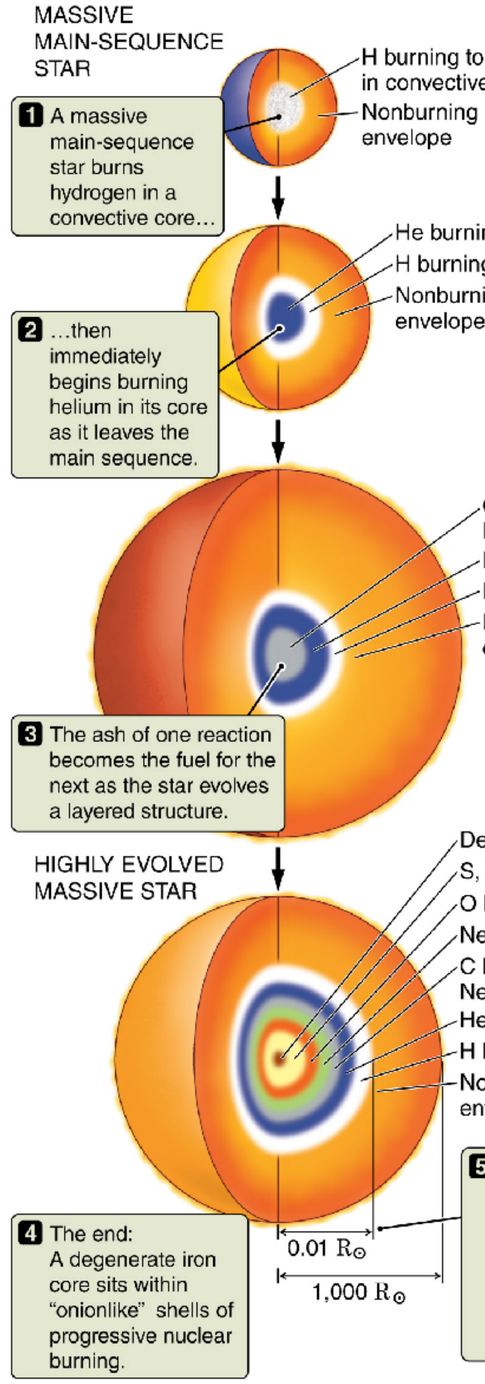


Spectral Type, Color, **Temperature** on the x-axis

Low Mass Star

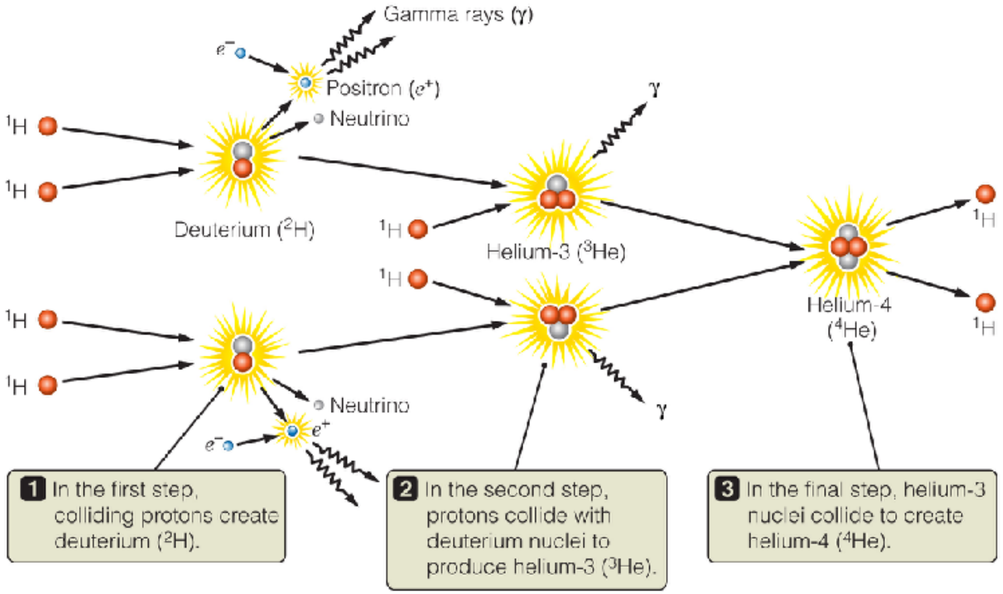


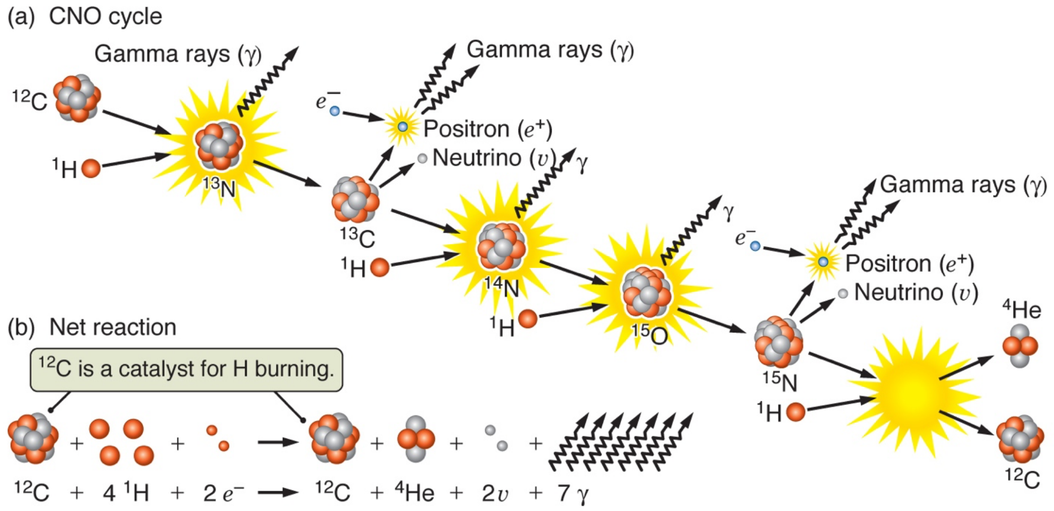




High Mass Star

Nuclear Reactions





Hydrogen or higher atomic number element collides with proton

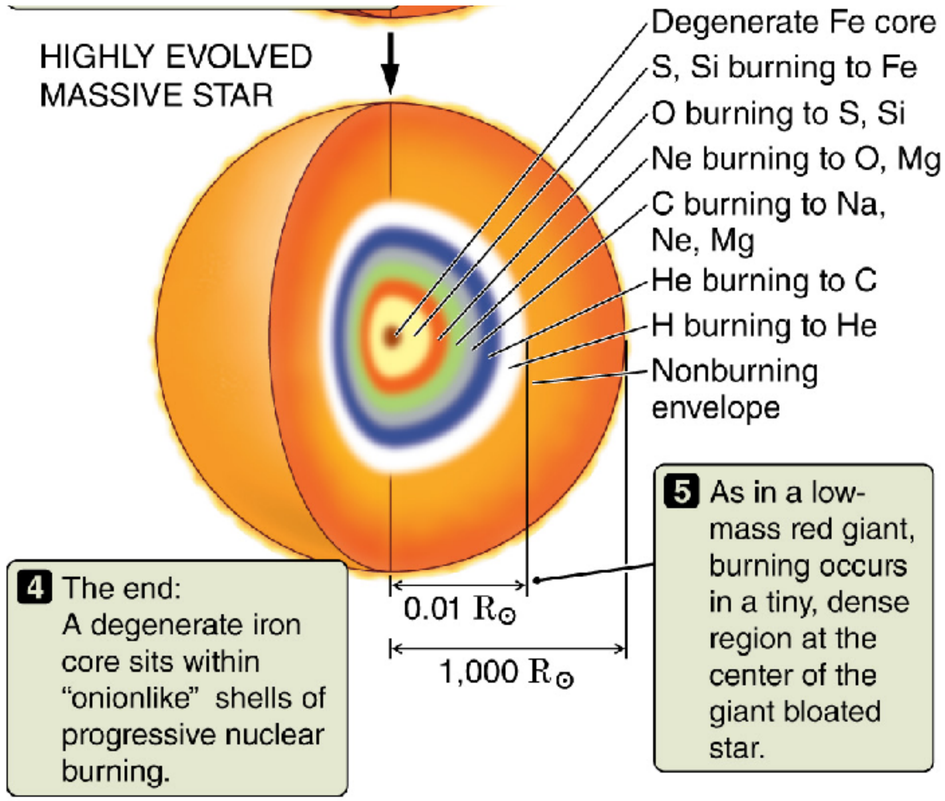
Proton fuses with the element, producing a photon and sometimes a neutrino

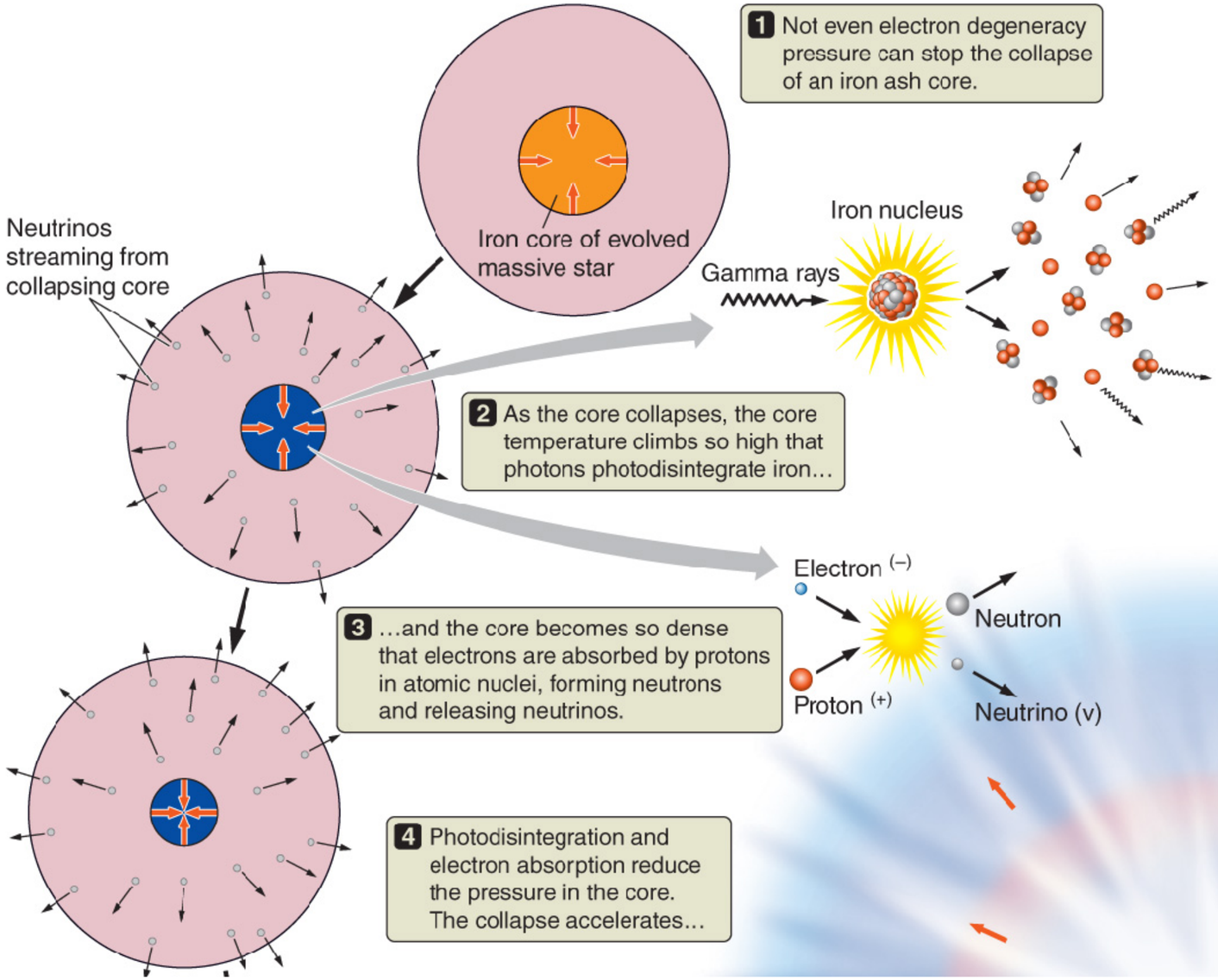
(if the proton turns into a neutron, the new nucleus has to eject a positron [anti-electron] and a neutrino to conserve charge and angular momentum)

Process continues with new elements until temperature can no longer get high enough or Iron (Fe) is all that's left in the core

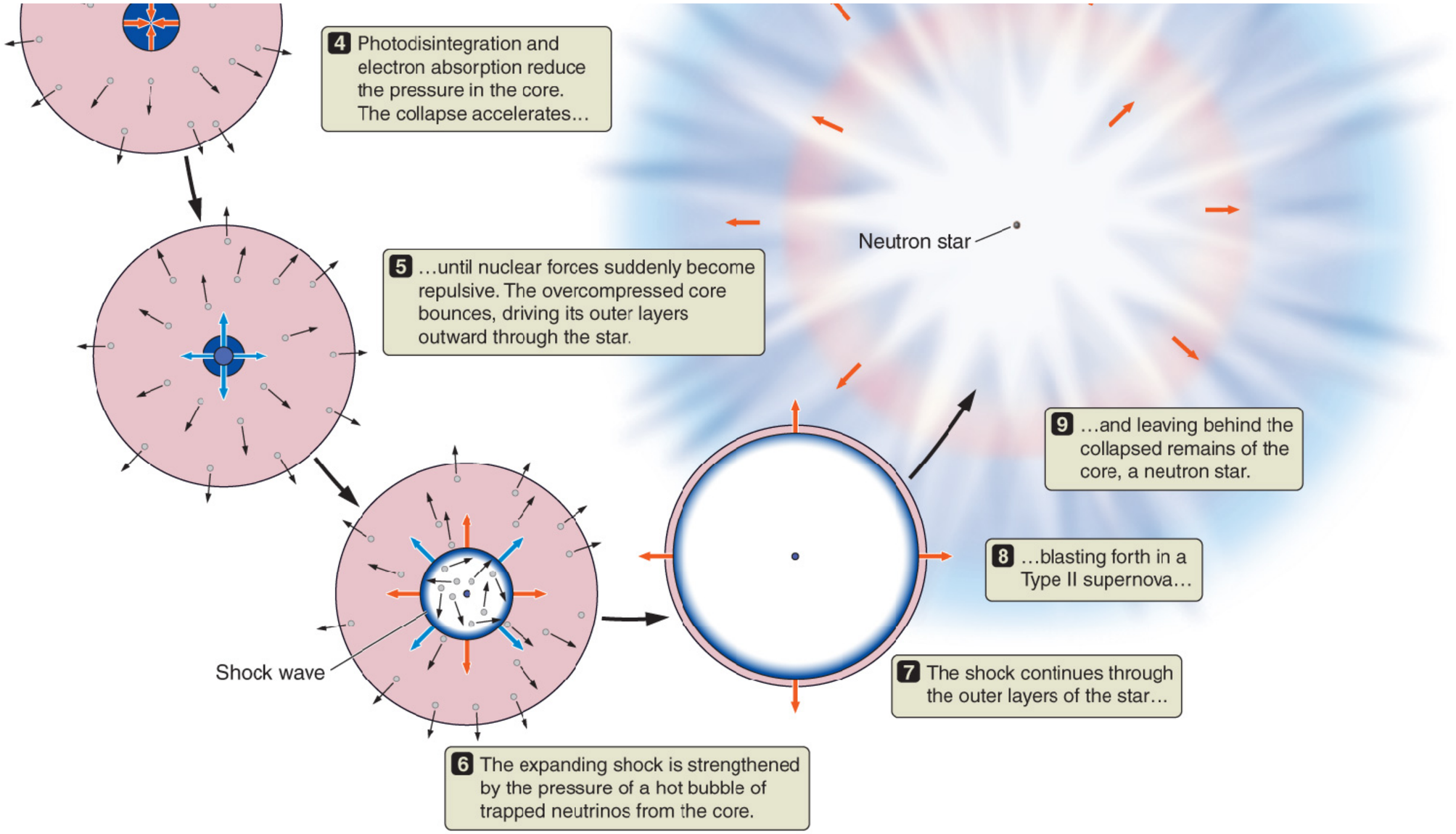
[To fuse Fe, the reaction no longer produces a photon but NEEDS to absorb a photon]

Type II Supernovae

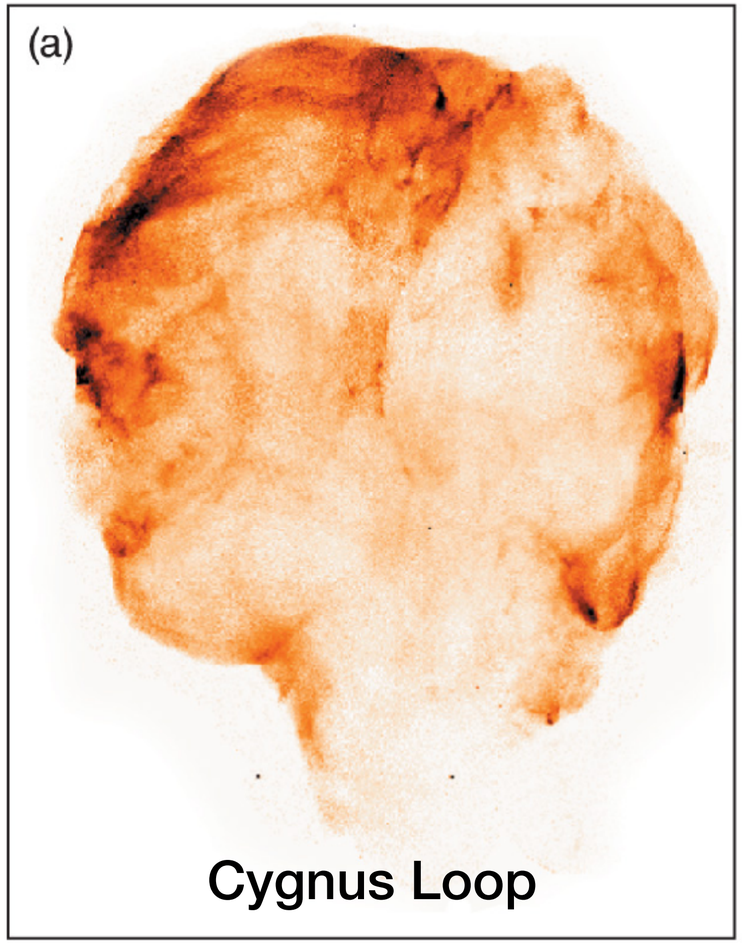


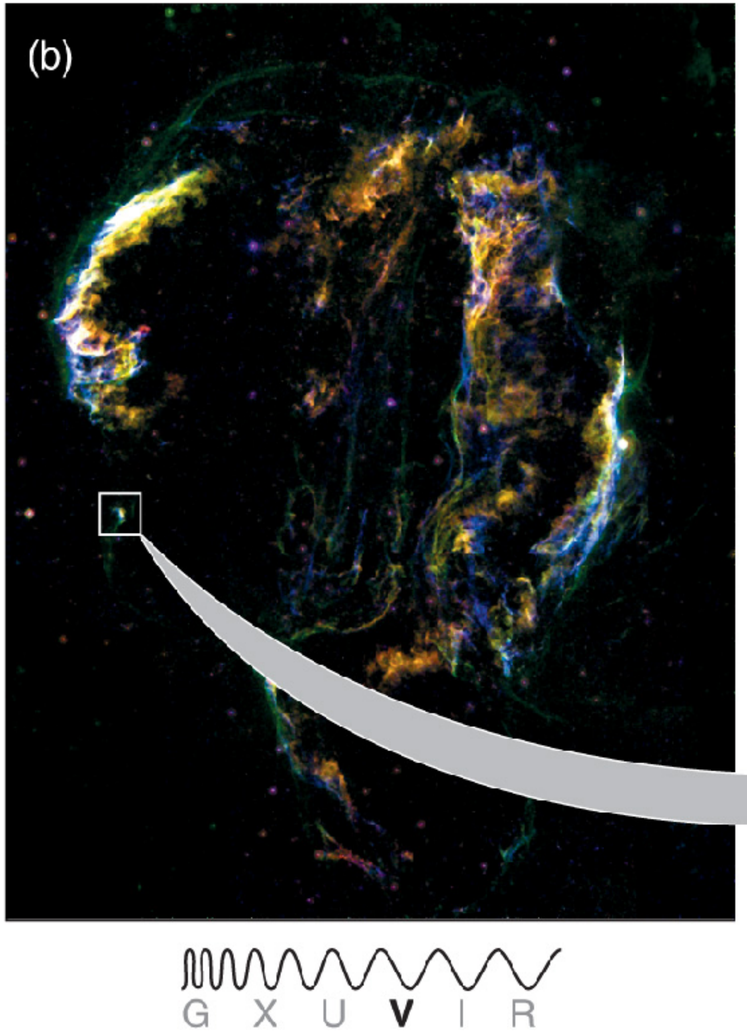


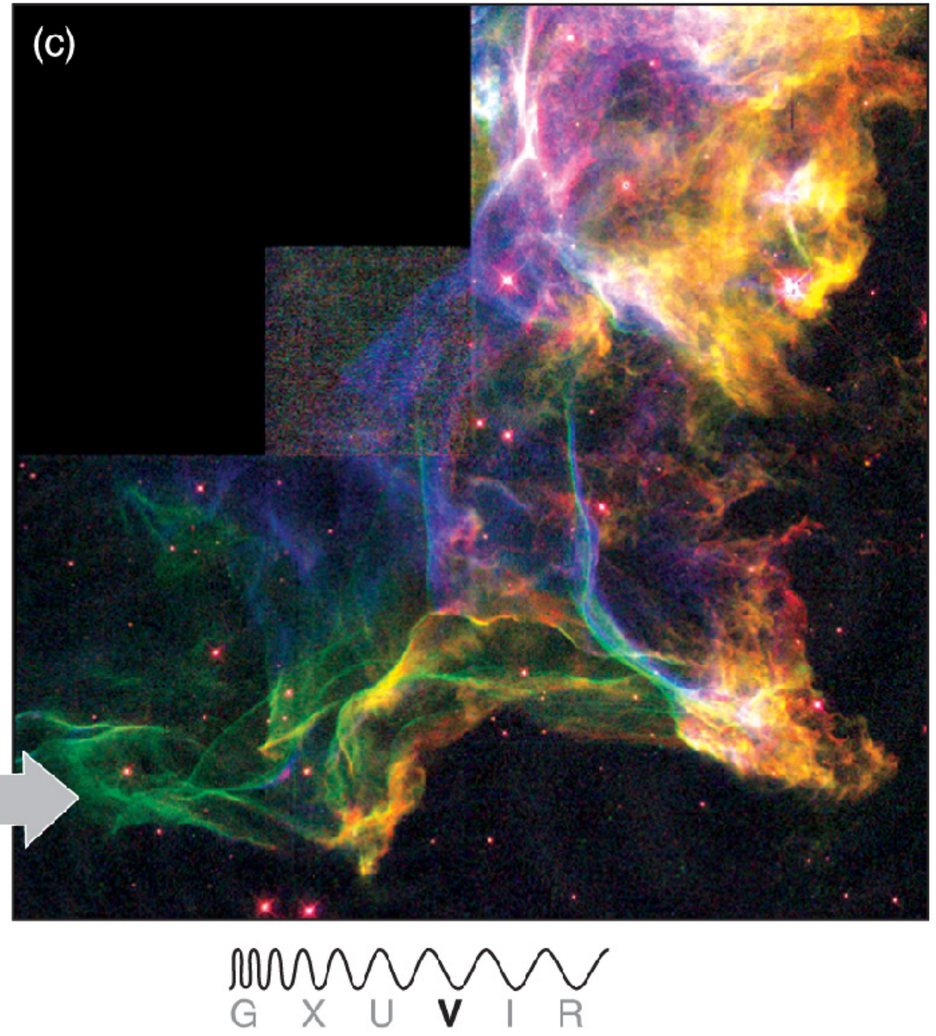
Type II Supernovae

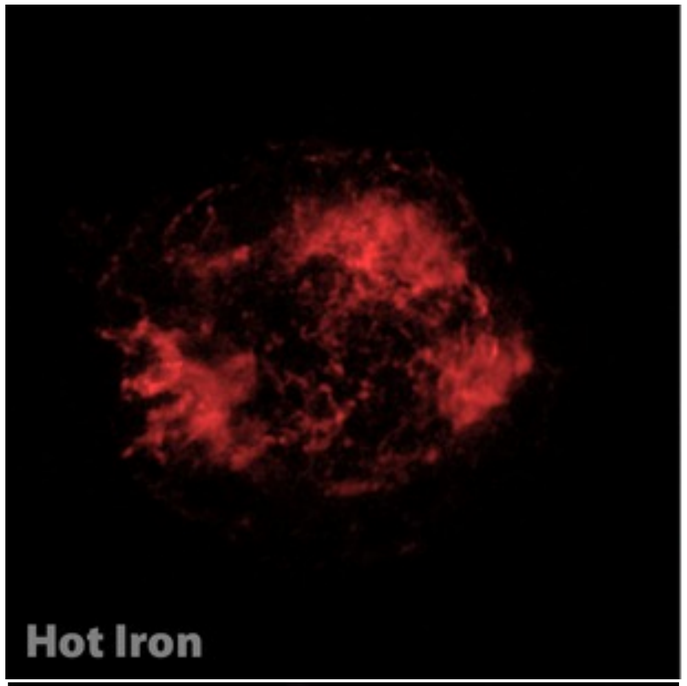


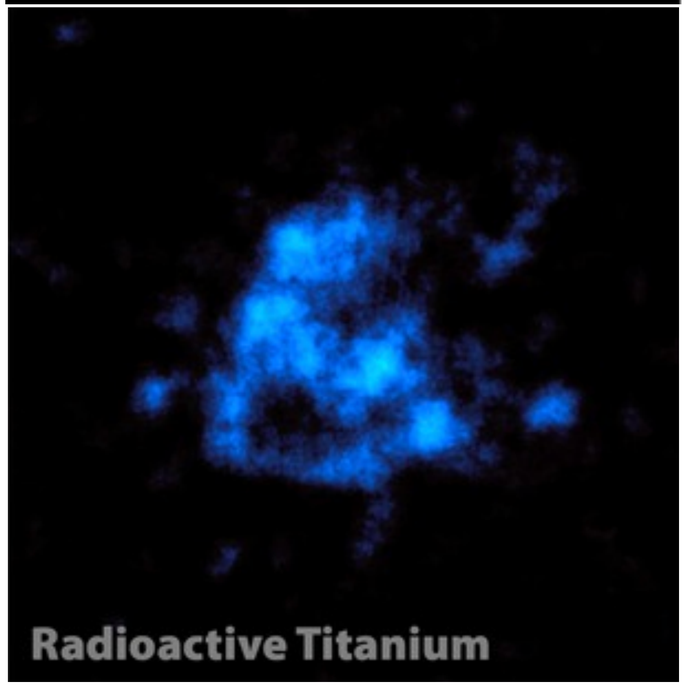
Supernova Remnants

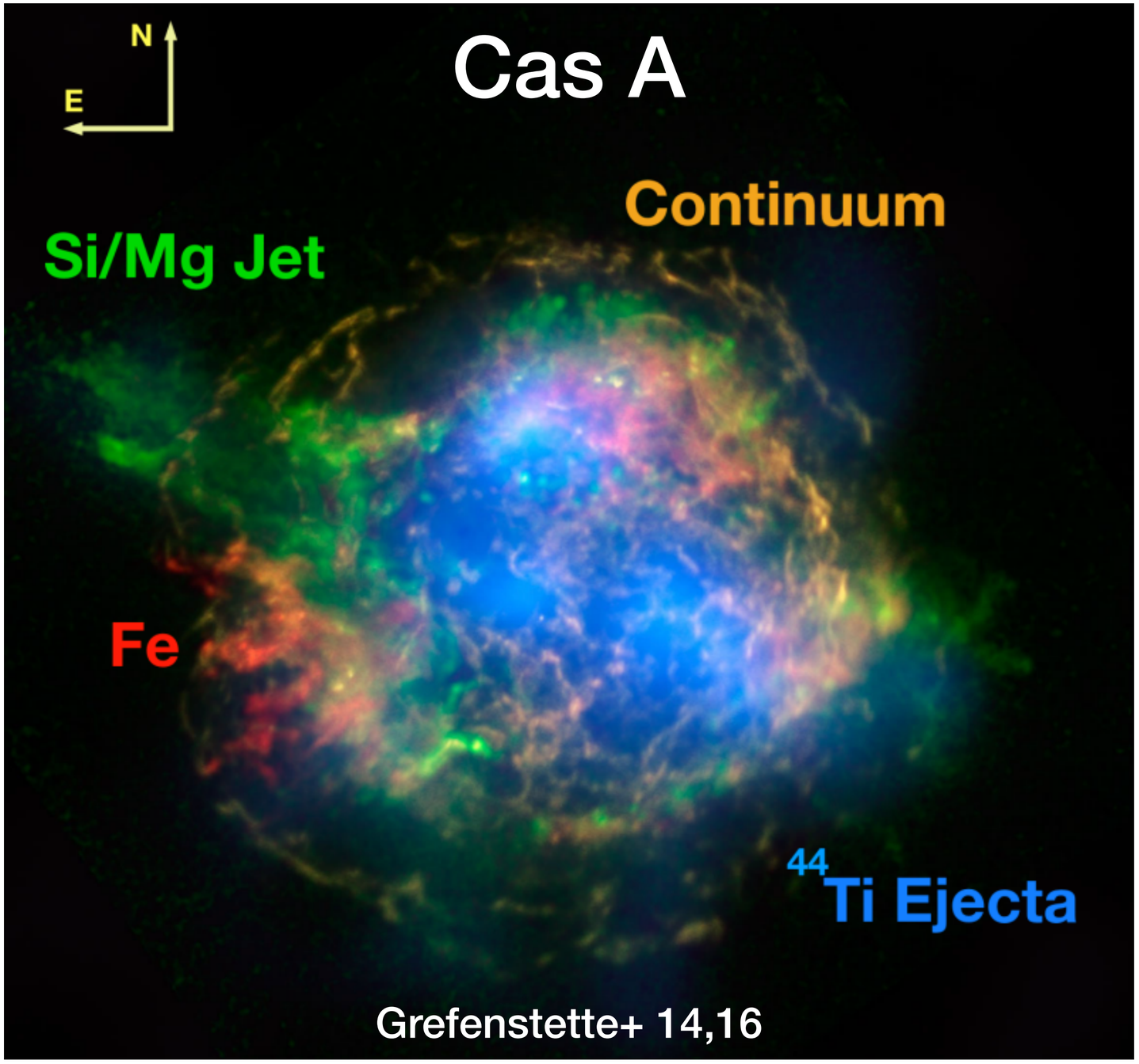




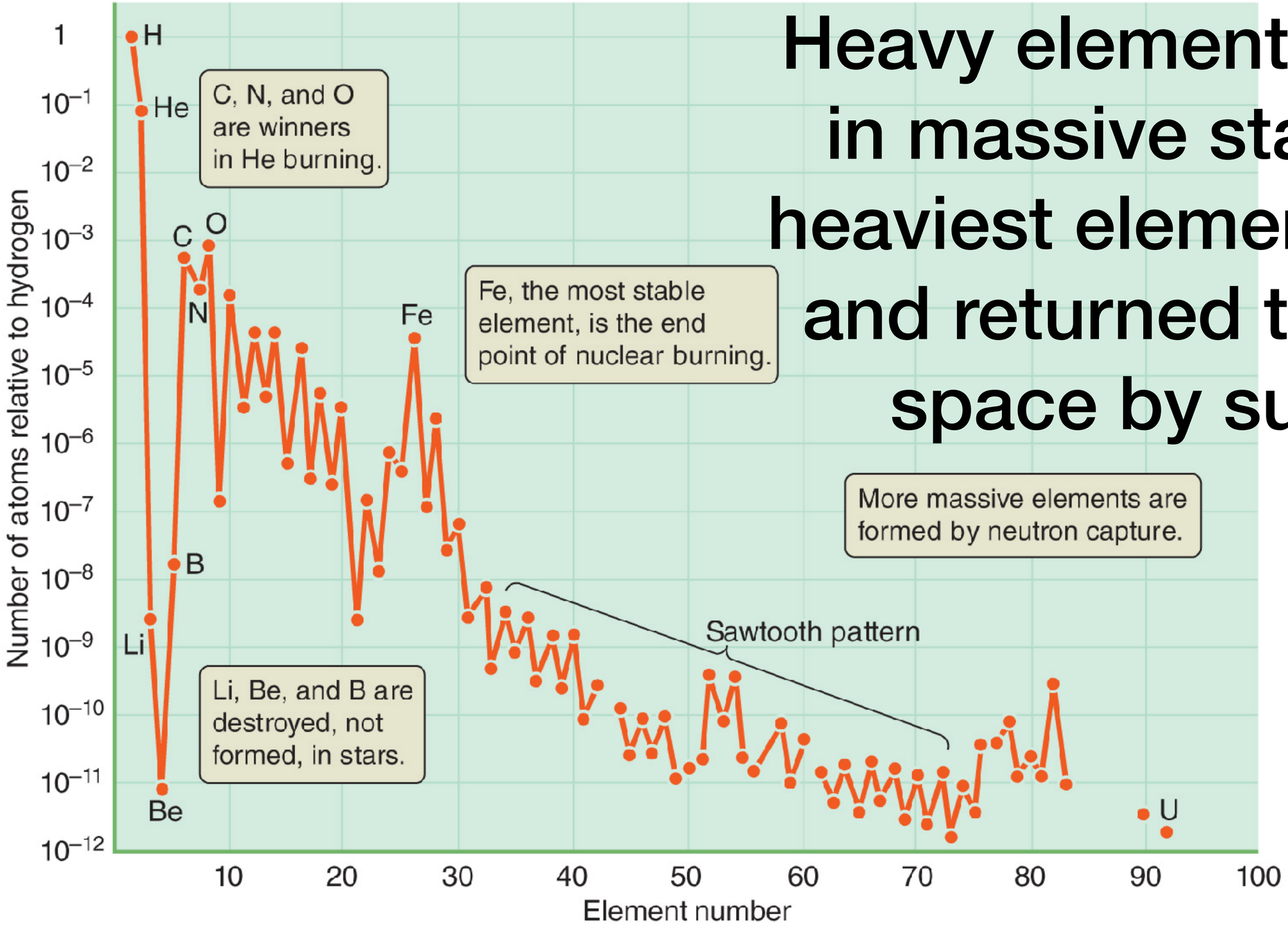



Hot Iron

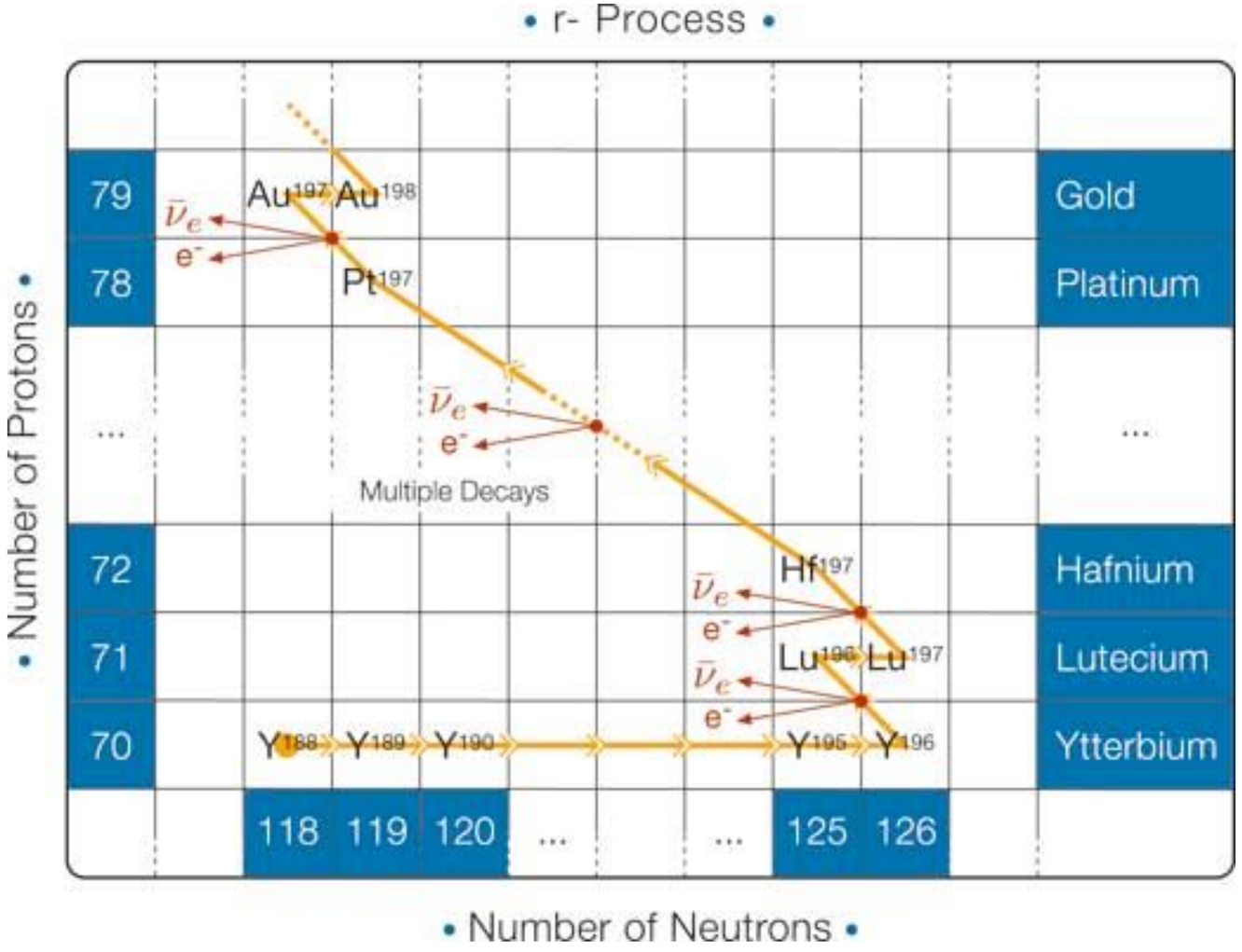

Radioactive Titanium

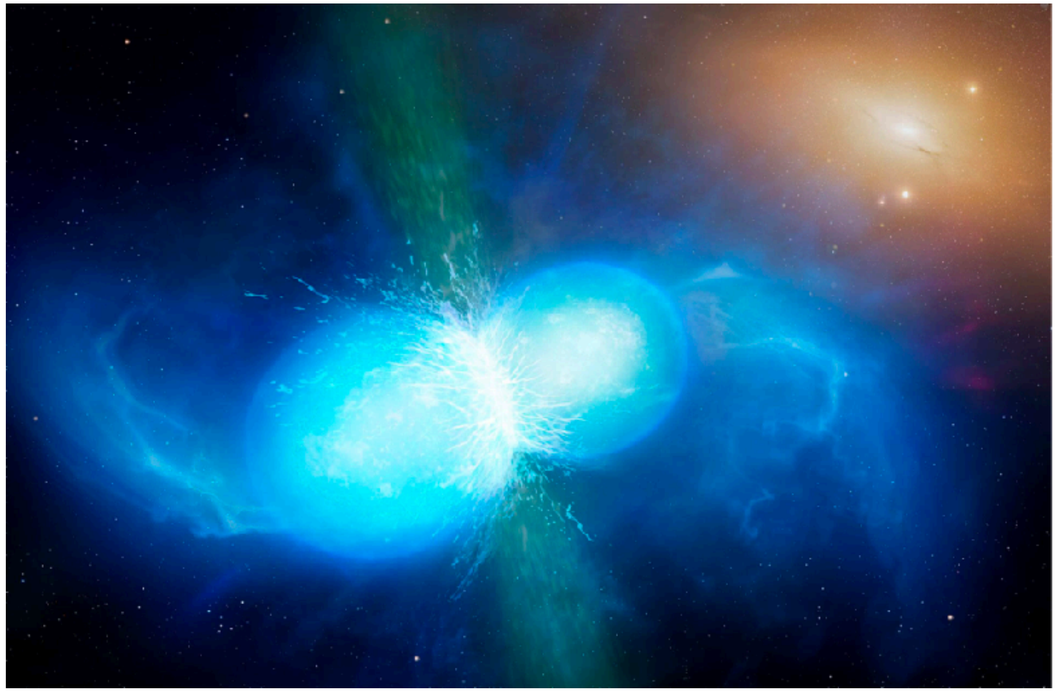

N
E
Cas A
Continuum
Si/Mg Jet
Fe
44Ti Ejecta
Grefenstette+ 14,16

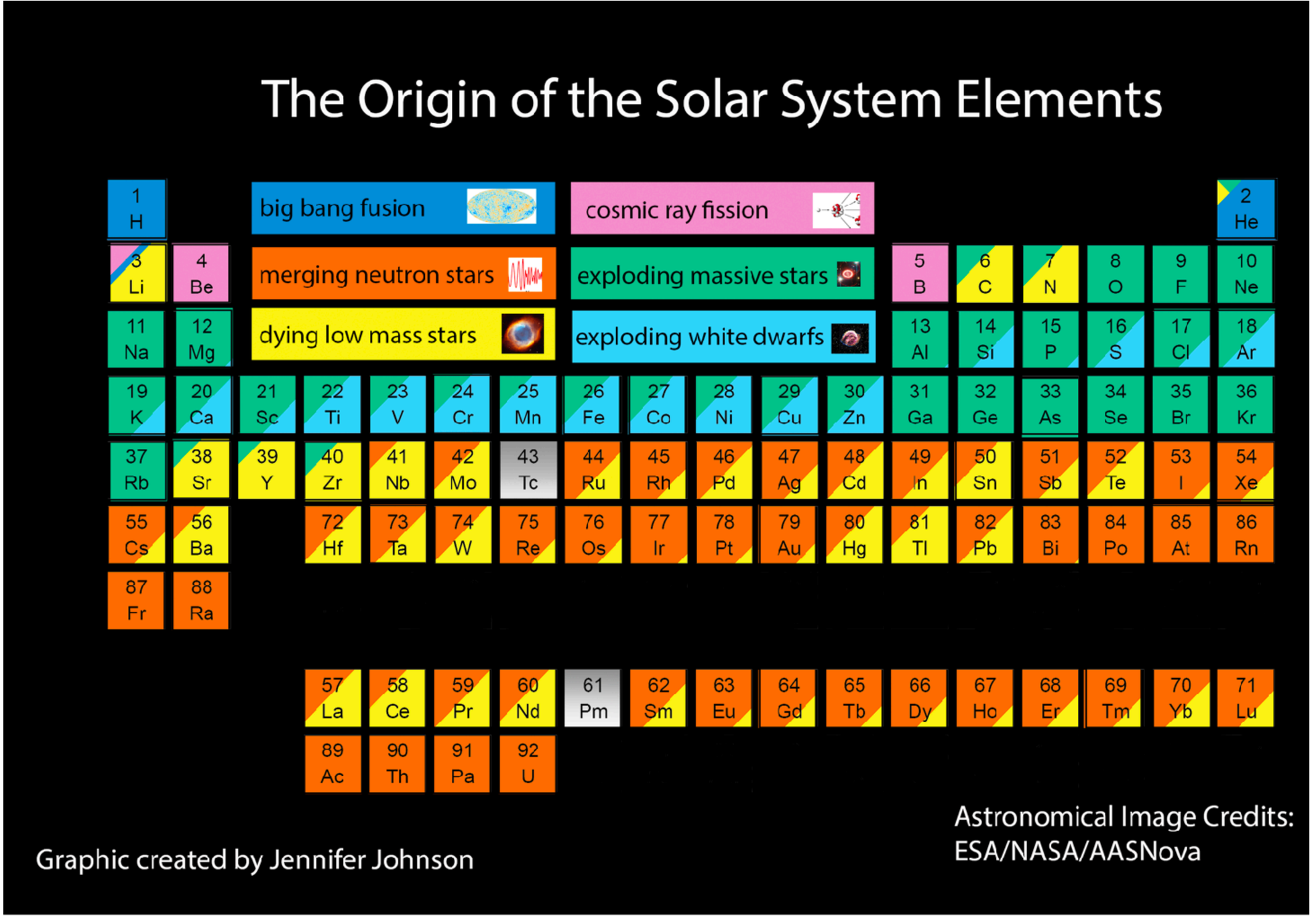
Heavy elements are created in massive stars, with the heaviest elements created in and returned to interstellar space by supernovae



Created in supernovae caused by NS-NS mergers??






The Origin of the Solar System Elements
big bang fusion
cosmic ray fission
merging neutron stars
exploding massive stars
dying low mass stars
exploding white dwarfs
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
Graphic created by Jennifer Johnson
Astronomical Image Credits:
ESA/NASA/AASNova

A question for Neil DeGrasse Tyson…

http://www.youtube.com/watch?v=9D05ej8u-gU

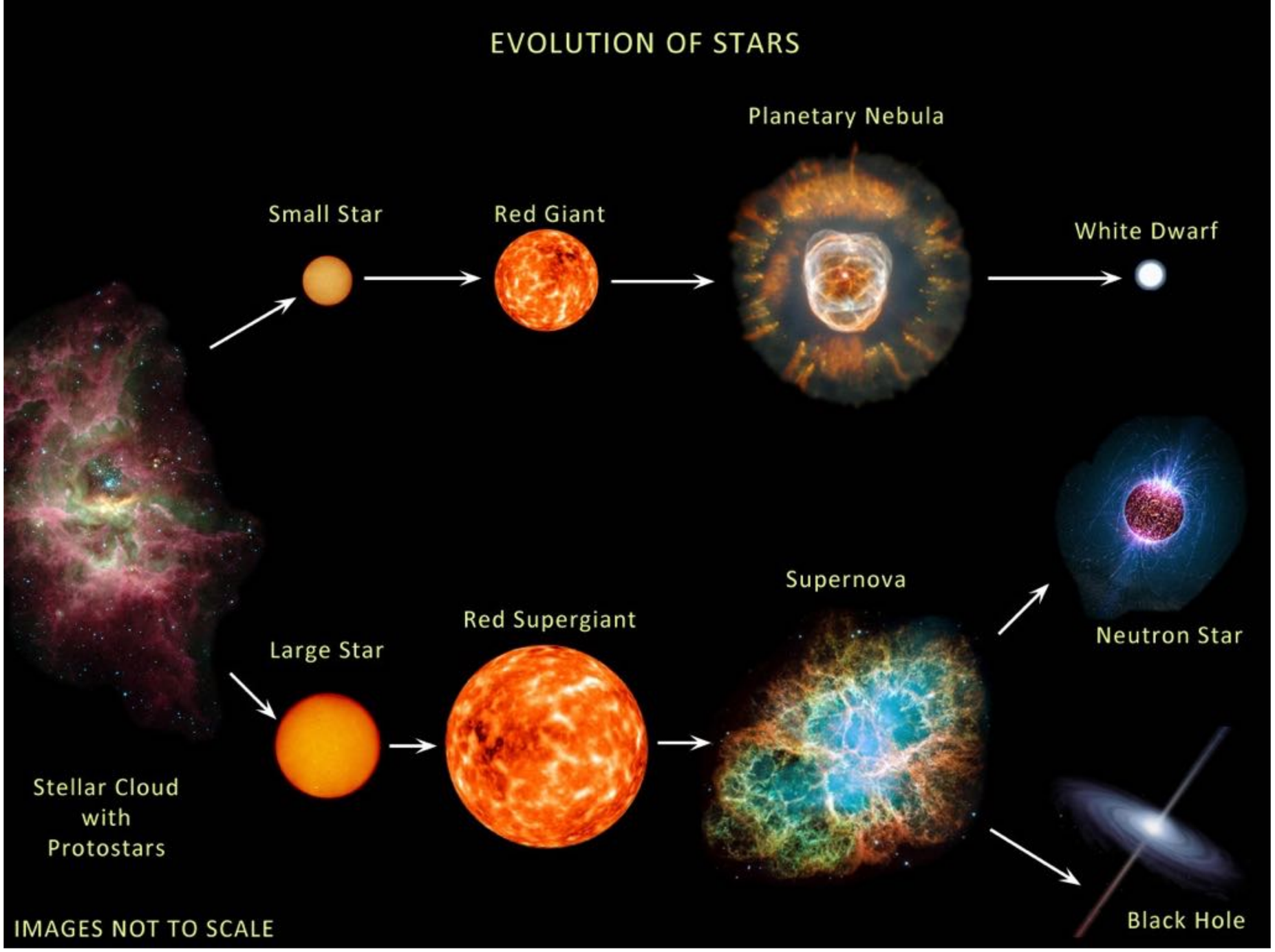
Chapter 13: High Mass Star Evolution and their Remnants: NSs and BHs

Chapter 14 Reading Assignment due next Tuesday

Are your grades in Canvas correct???

Turn in extra credit planetarium and public observing reports up front when complete

Midterms available up front


EVOLUTION OF STARS
Planetary Nebula
Small Star
Red Giant
White Dwarf
Supernova
Neutron Star
Red Supergiant
Large Star
Stellar Cloud
with
Protostars
Black Hole
IMAGES NOT TO SCALE

Stellar Remnant Activity

Goal: Contrast the end-stages of stars' lives, black holes, neutron stars, and white dwarfs.

Group Activity: Groups of 3-4

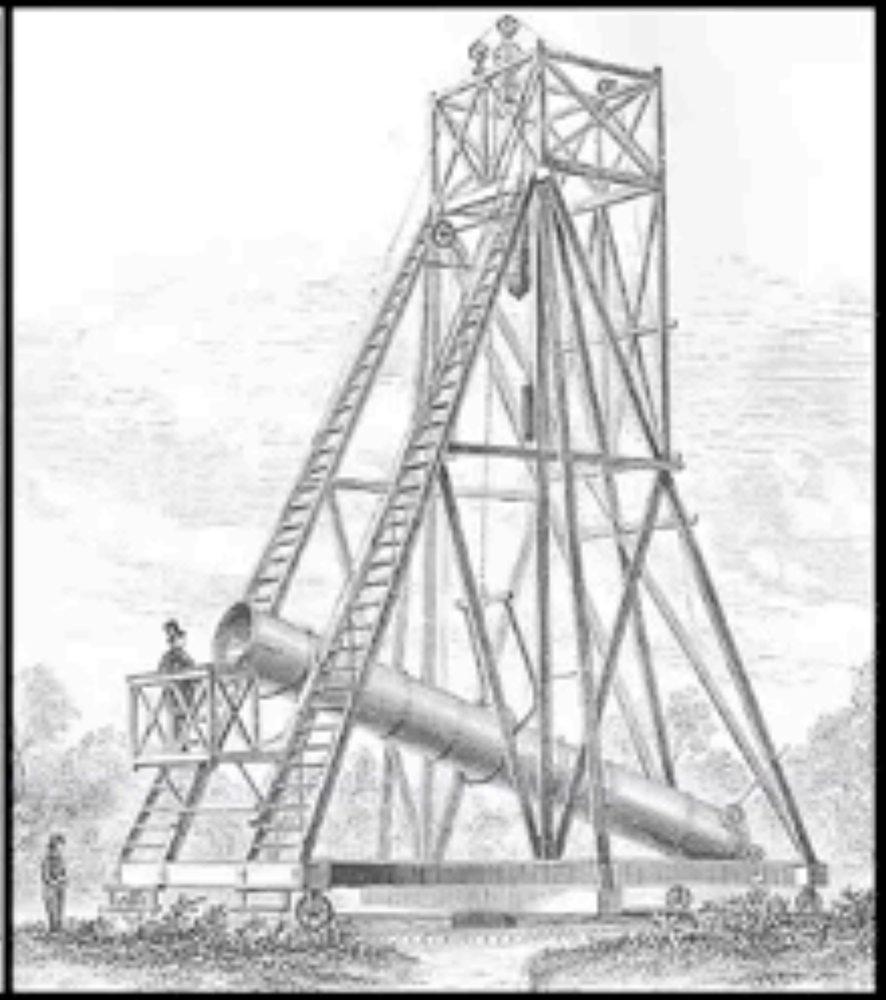
Hand in one sheet for the group

Roles:

Secretary (write on the sheet)

Spokesperson (for class discussion)

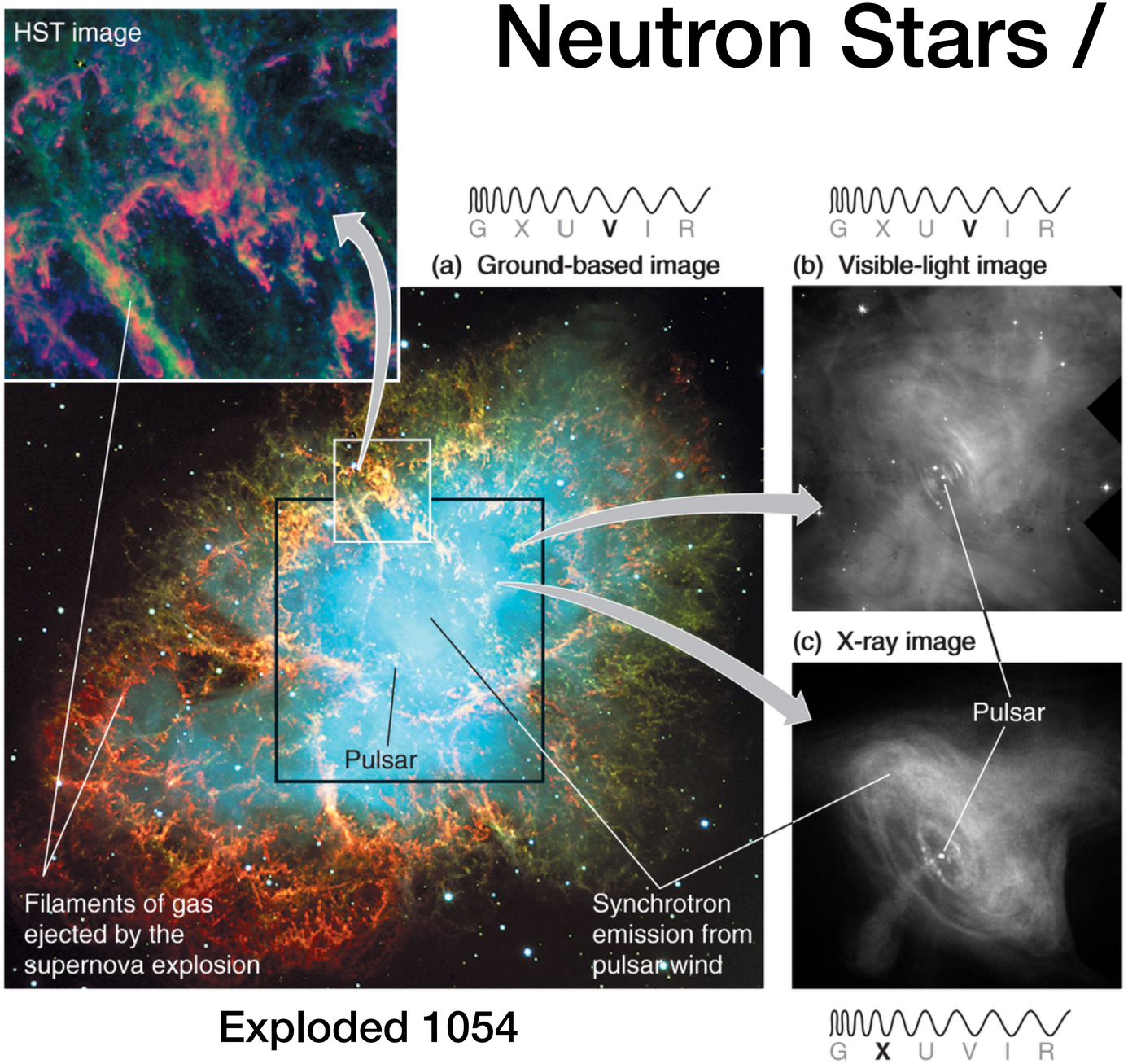
Group Leader (keep on task)



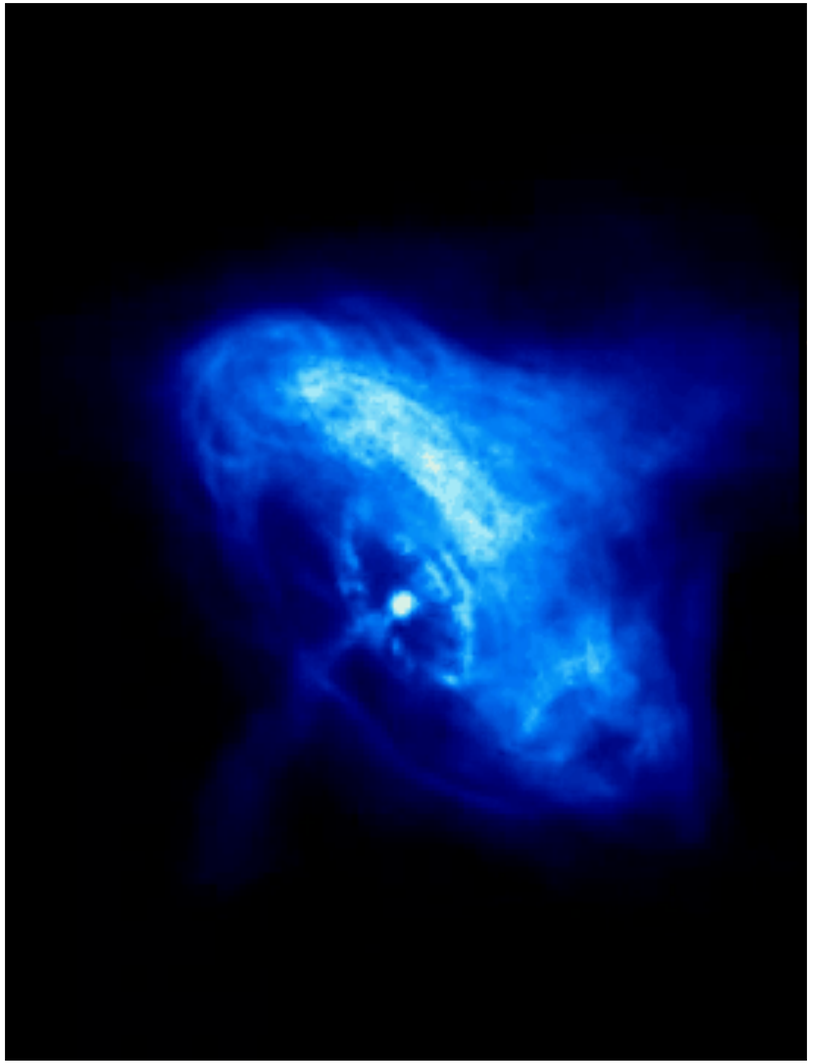
Crab Nebula
1844 Sketch by William Parsons

https://www.youtube.com/watch?v=WTKA2biEVgg

Neutron Stars / Pulsars

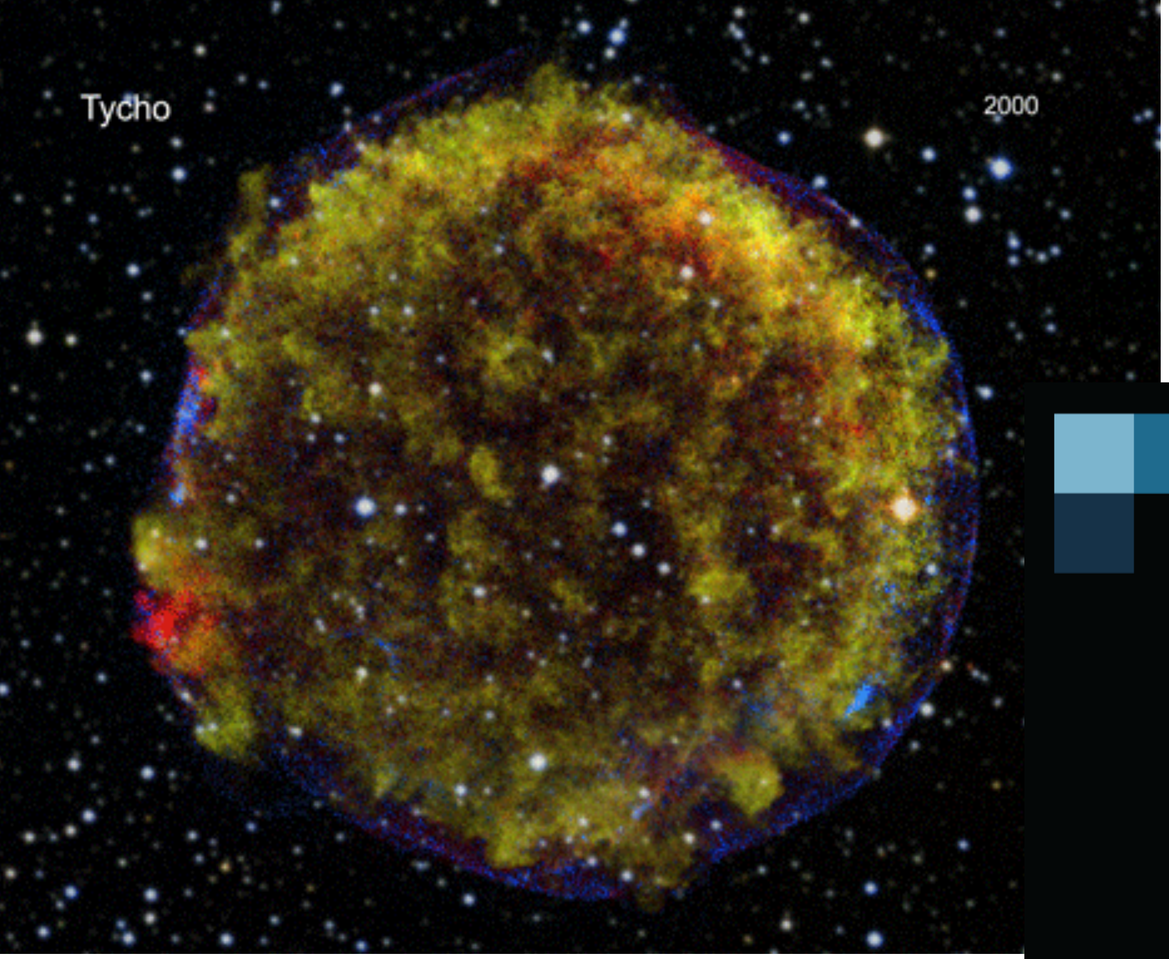


Exploded 1054



Crab Nebula Expansion

https://www.youtube.com/watch?v=_KCCKI9SB90



Exploded 1572

Exploded ~1680

LiveSlides web content

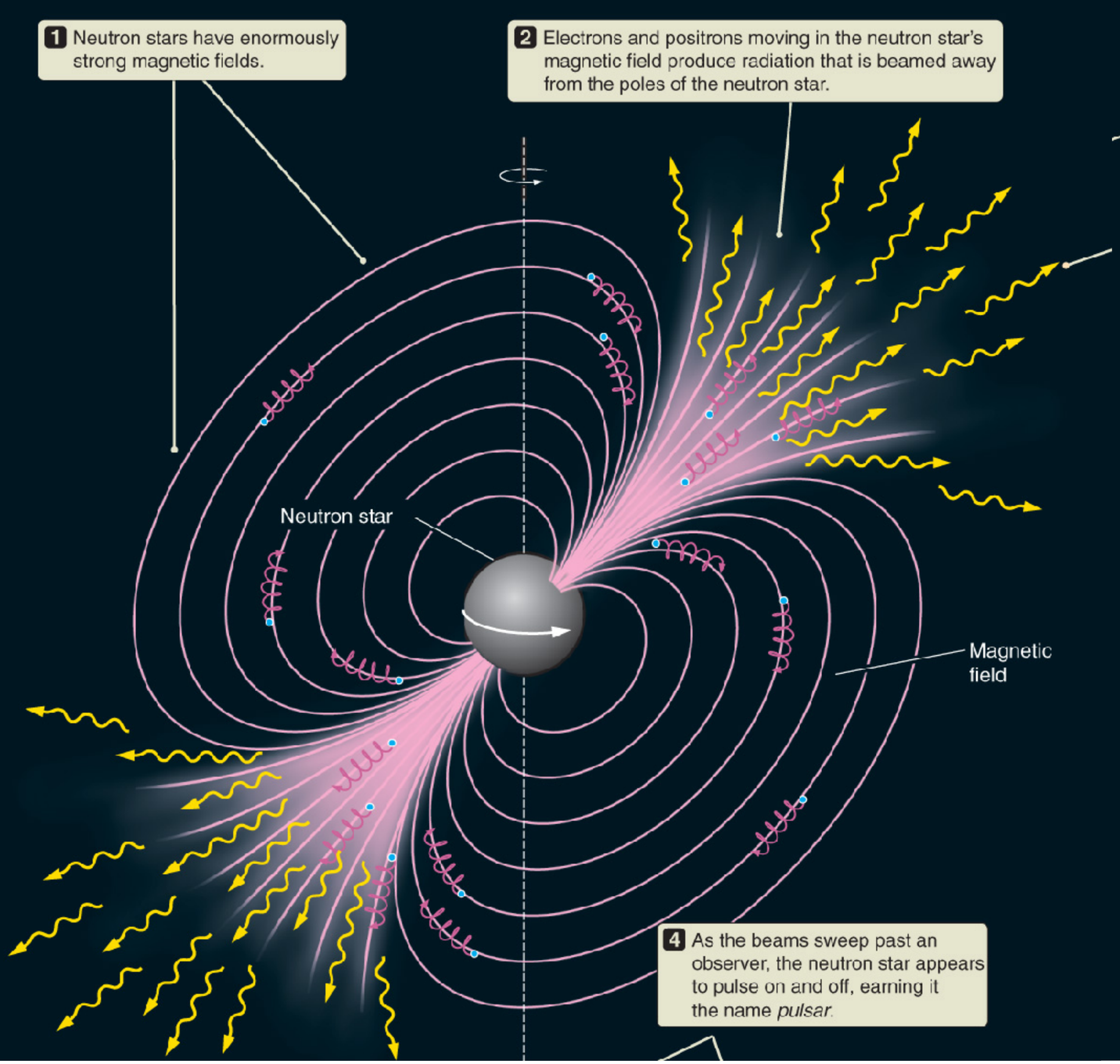
To view

Download the add-in.
liveslides.com/download

Start the presentation.

https://www.youtube.com/watch?v=_diLnFGRSFQ

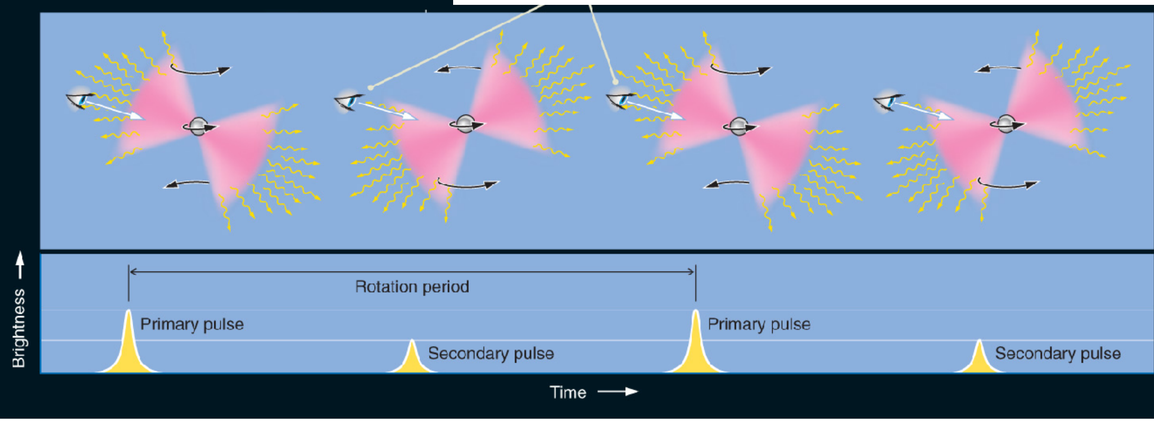
www.youtube.com/watch?v=t5uA1RJsDhw&feature=related



Neutron Stars are born with strong magnetic fields (get stronger as the core collapses)

Field accelerates electrons and positrons, which causes them to emit radiation across the spectrum

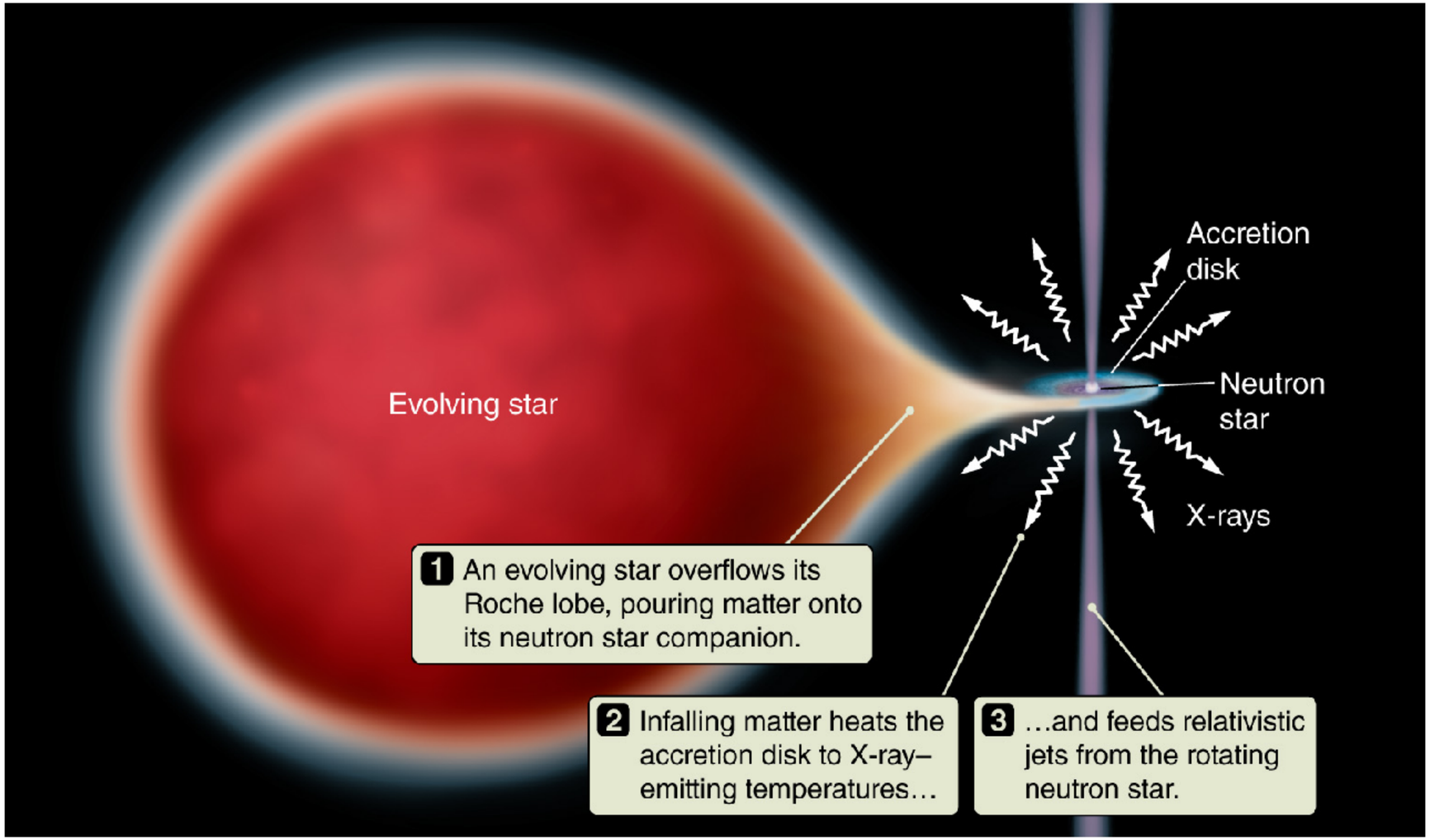
We see the beam once or twice each time the star rotates



https://www.youtube.com/watch?v=jwC6_oWwbSE

Pulsar Computer Simulation

Low magnetic field neutron stars and black holes are observed through accretion



Millisecond Pulsar

https://www.youtube.com/watch?v=MPpDTvYL5ik

Black Widow Pulsar

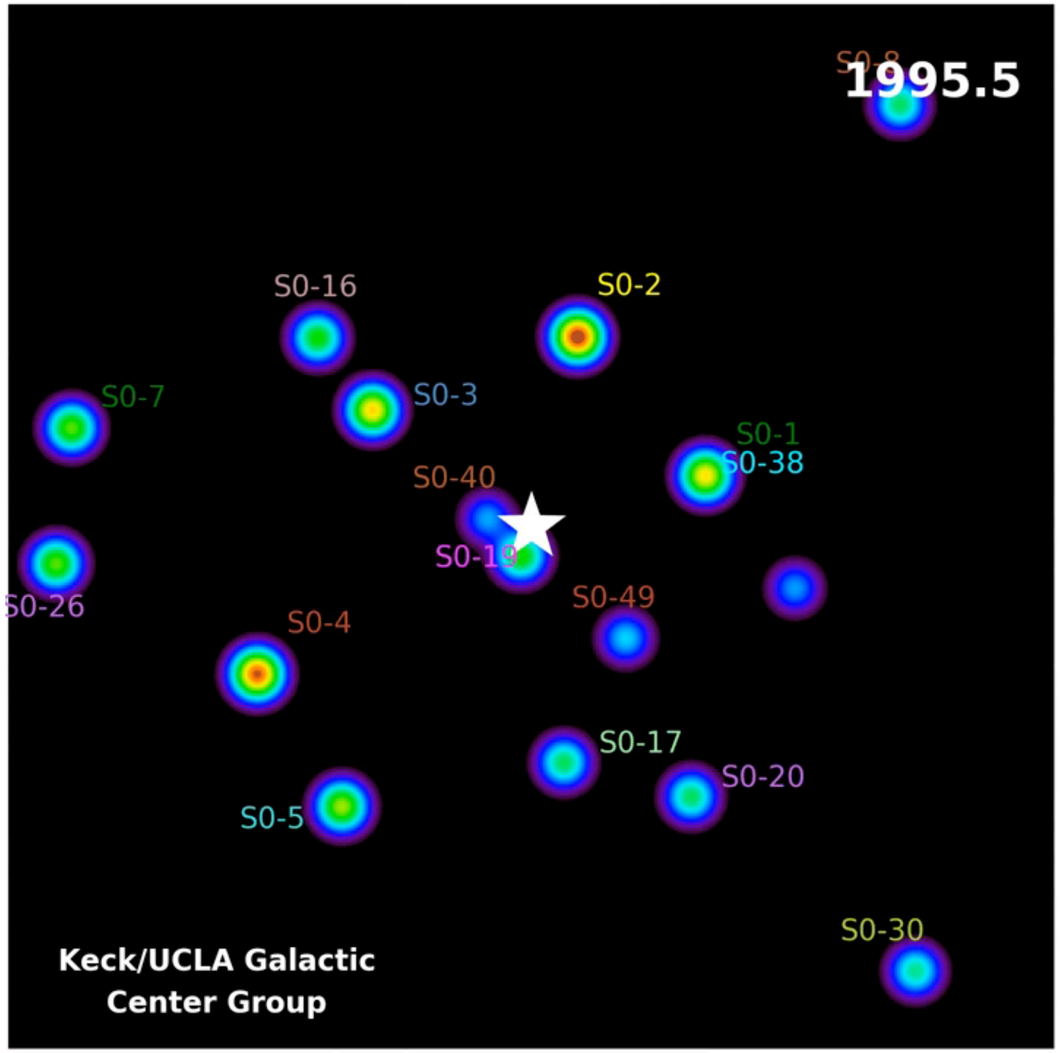
https://www.youtube.com/watch?v=-SoZ1xvCpMw

Official NASA Black Hole Safety Video

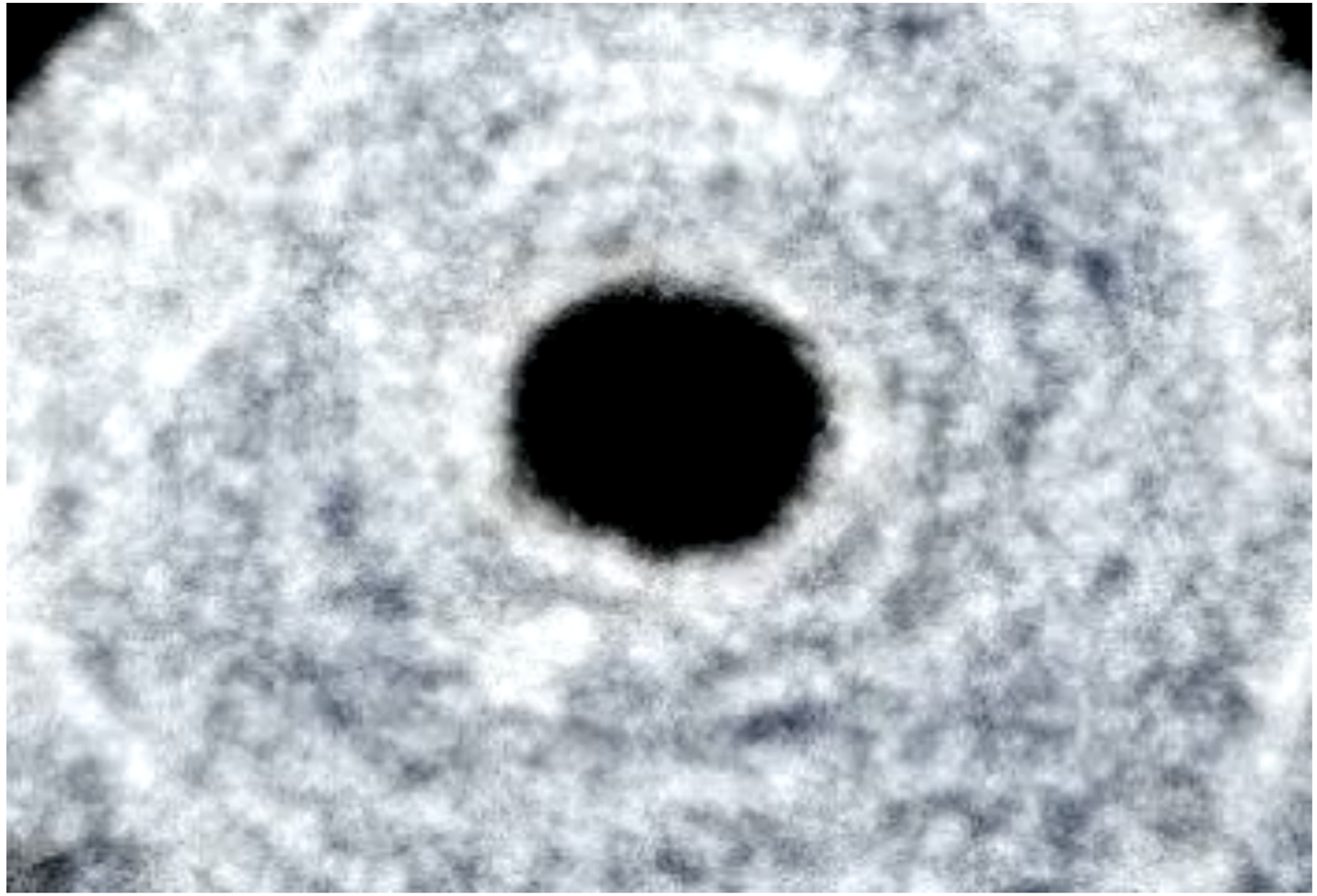
https://youtu.be/aMTwtb3TVIk

How do we know black holes ACTUALLY exist in the Universe?

Highly suggestive results that black holes exist



Stars orbiting SMBH in center of our galaxy



Animation of gas falling into SMBH in M87 galaxy

Cygnus X-1: First X-ray source and confirmed black hole

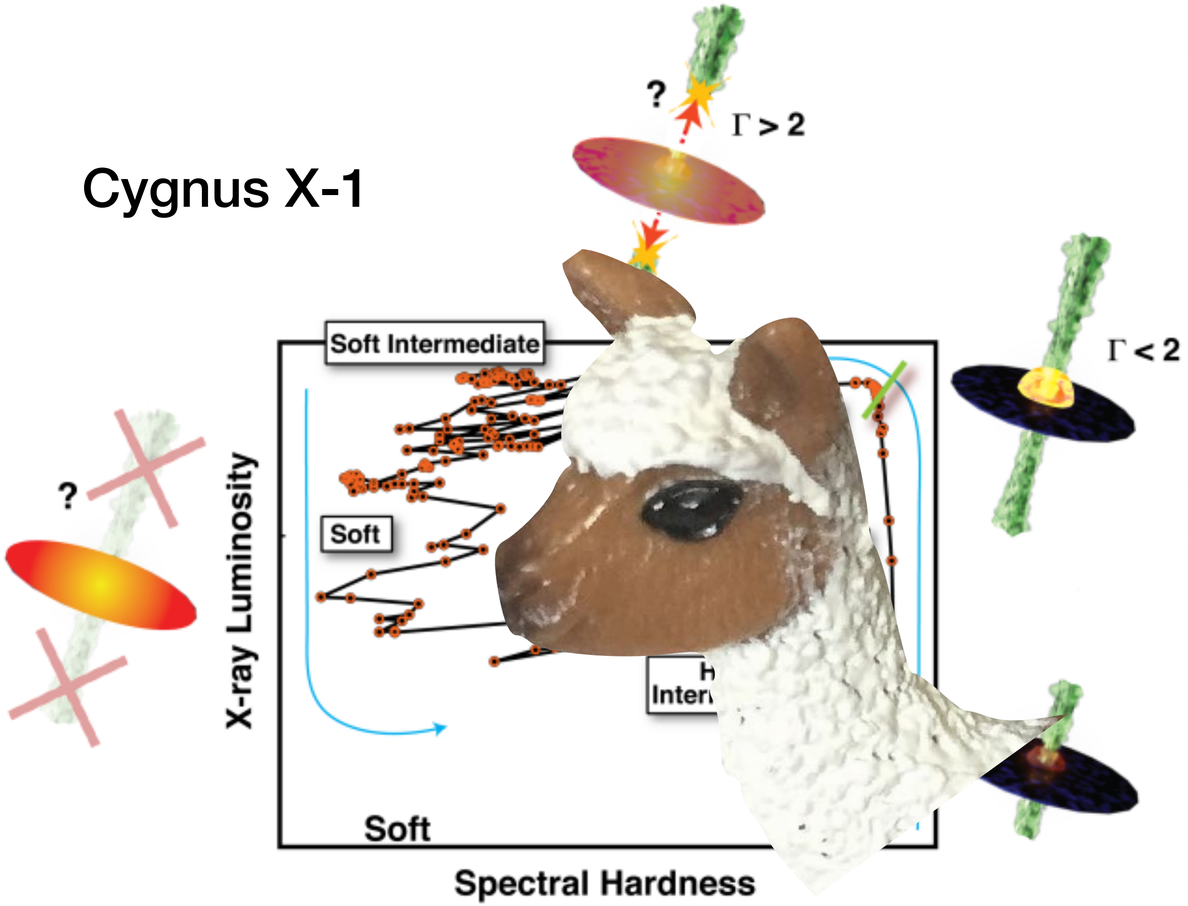
https://www.youtube.com/watch?v=ZdjCpSCh02g

Andromeda Galaxy (M31)

NuSTAR

GALEX

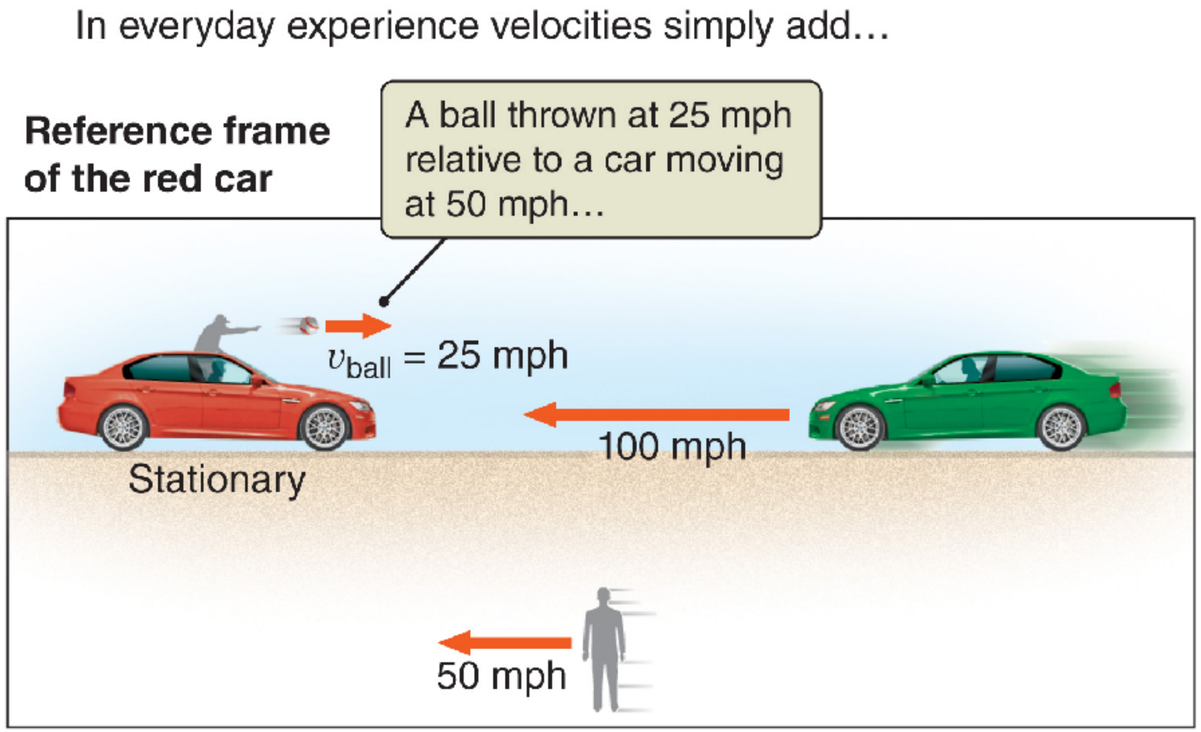
Cygnus X-1

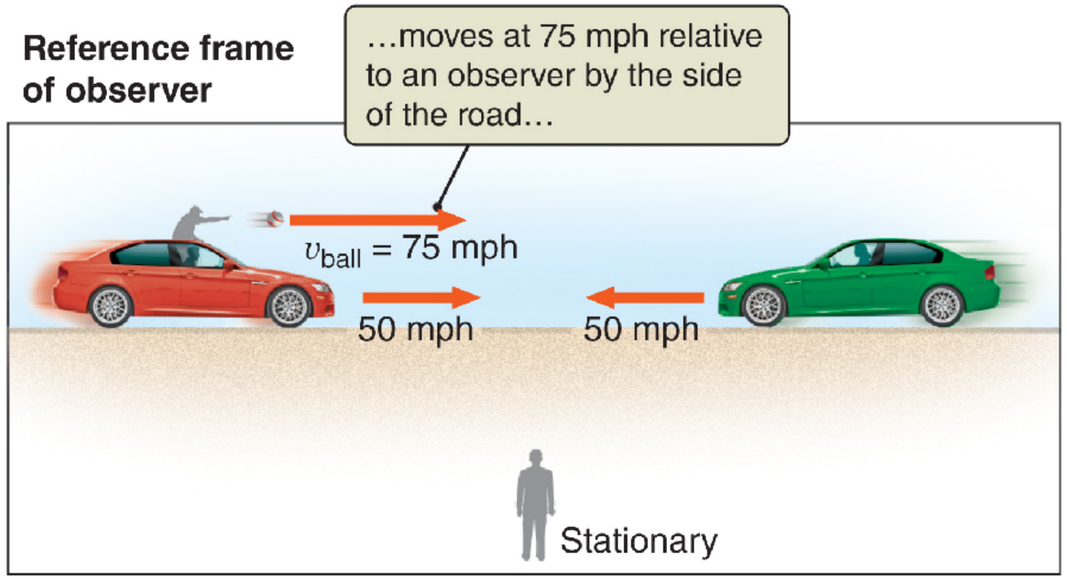


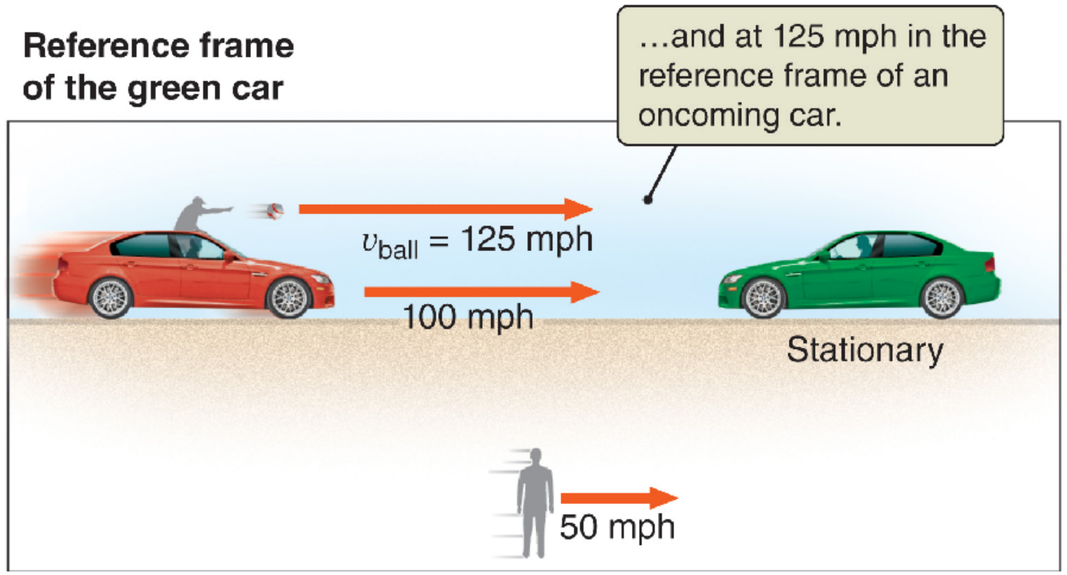
To understand black holes and extreme gravity, we need help from Einstein and Hawking

But first, what do you know about black holes and/or relativity?

Reference Frames





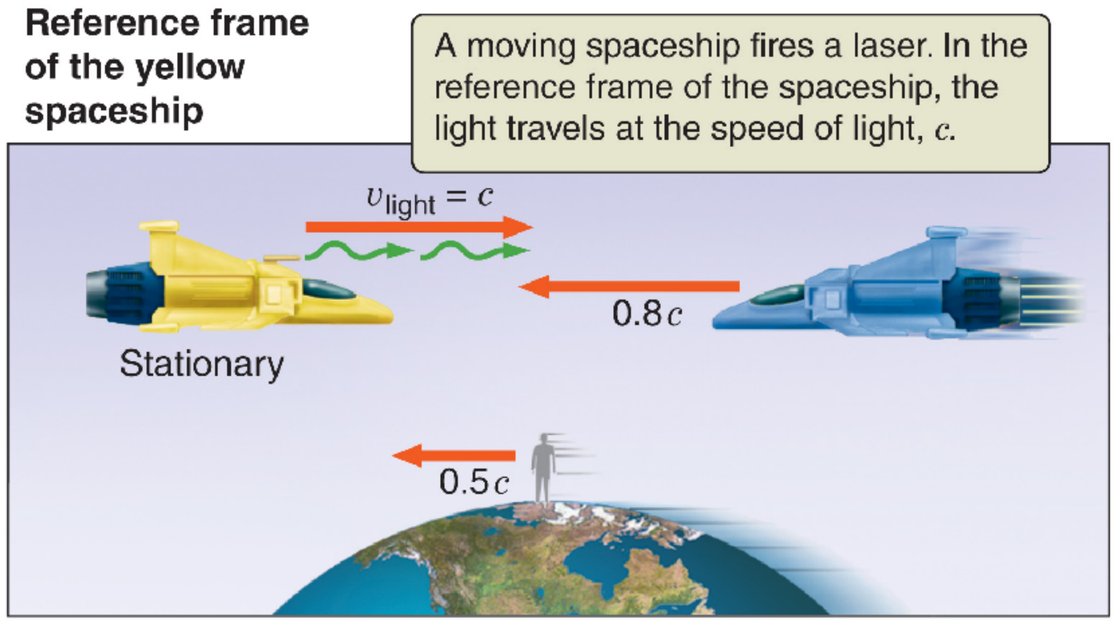


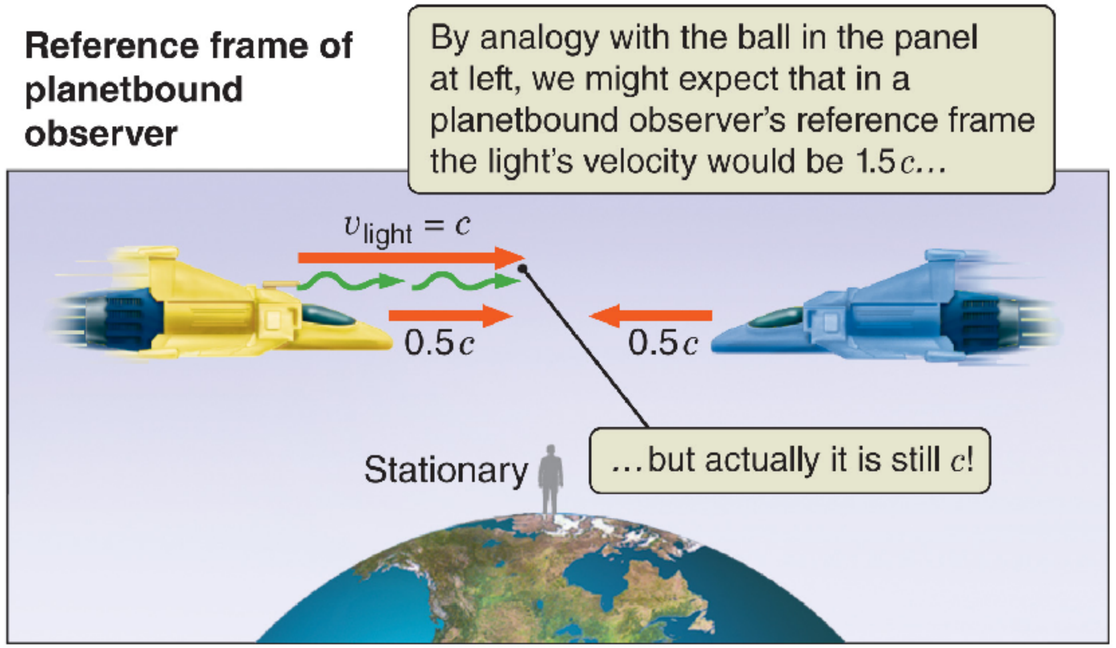
Special Relativity (postulates)

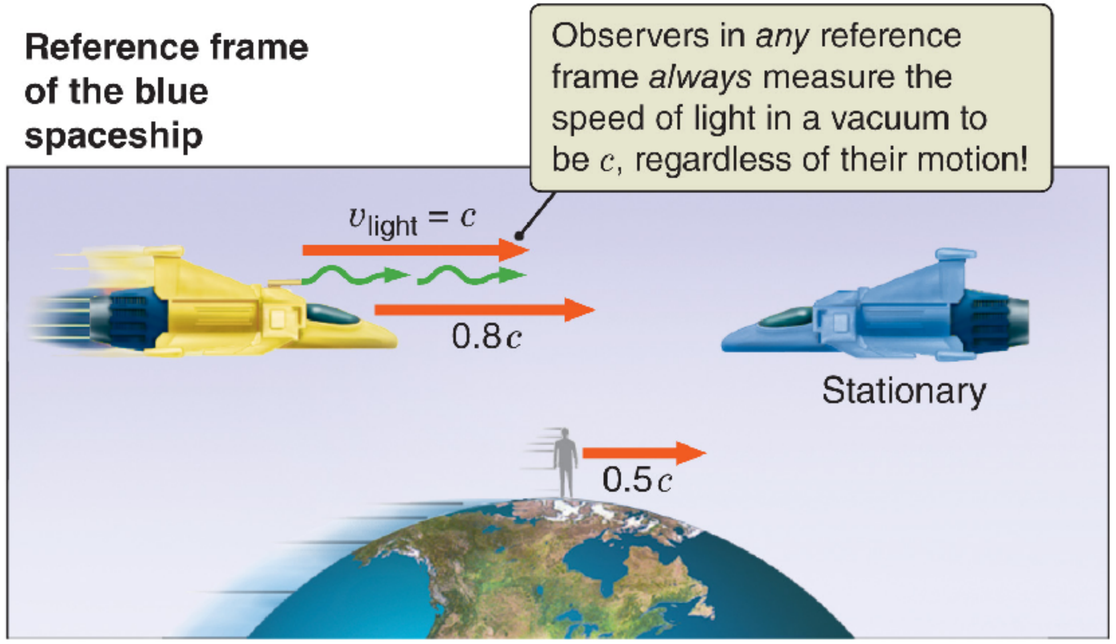
1) Physical laws same for all reference frames
2) Speed of light is always measured to be *c*

Reference Frames

…but as v nears c, things are different.



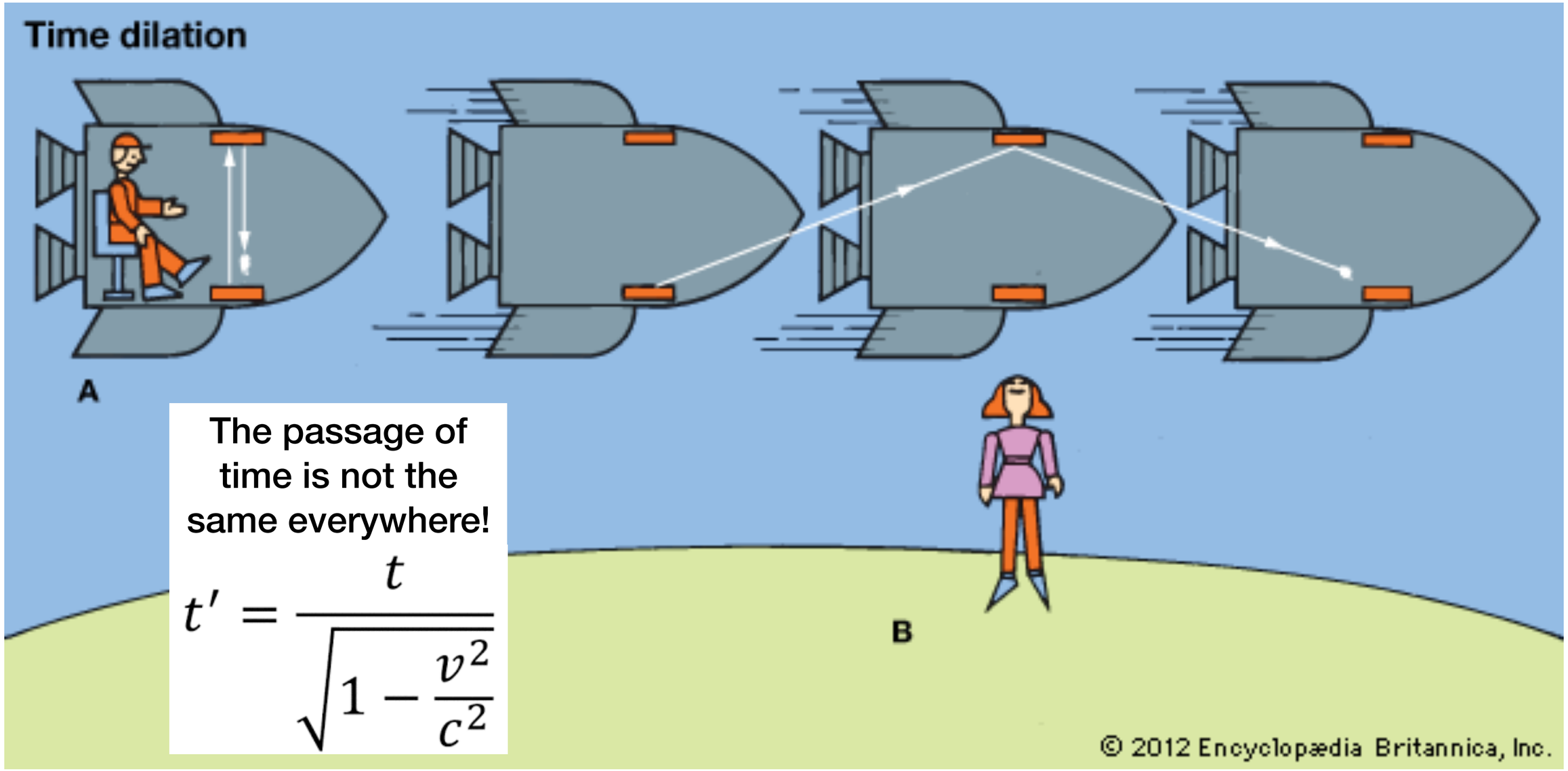




Special Relativity (postulates)

1) Physical laws same for all reference frames
2) Speed of light is always measured to be *c*

Time Dilation



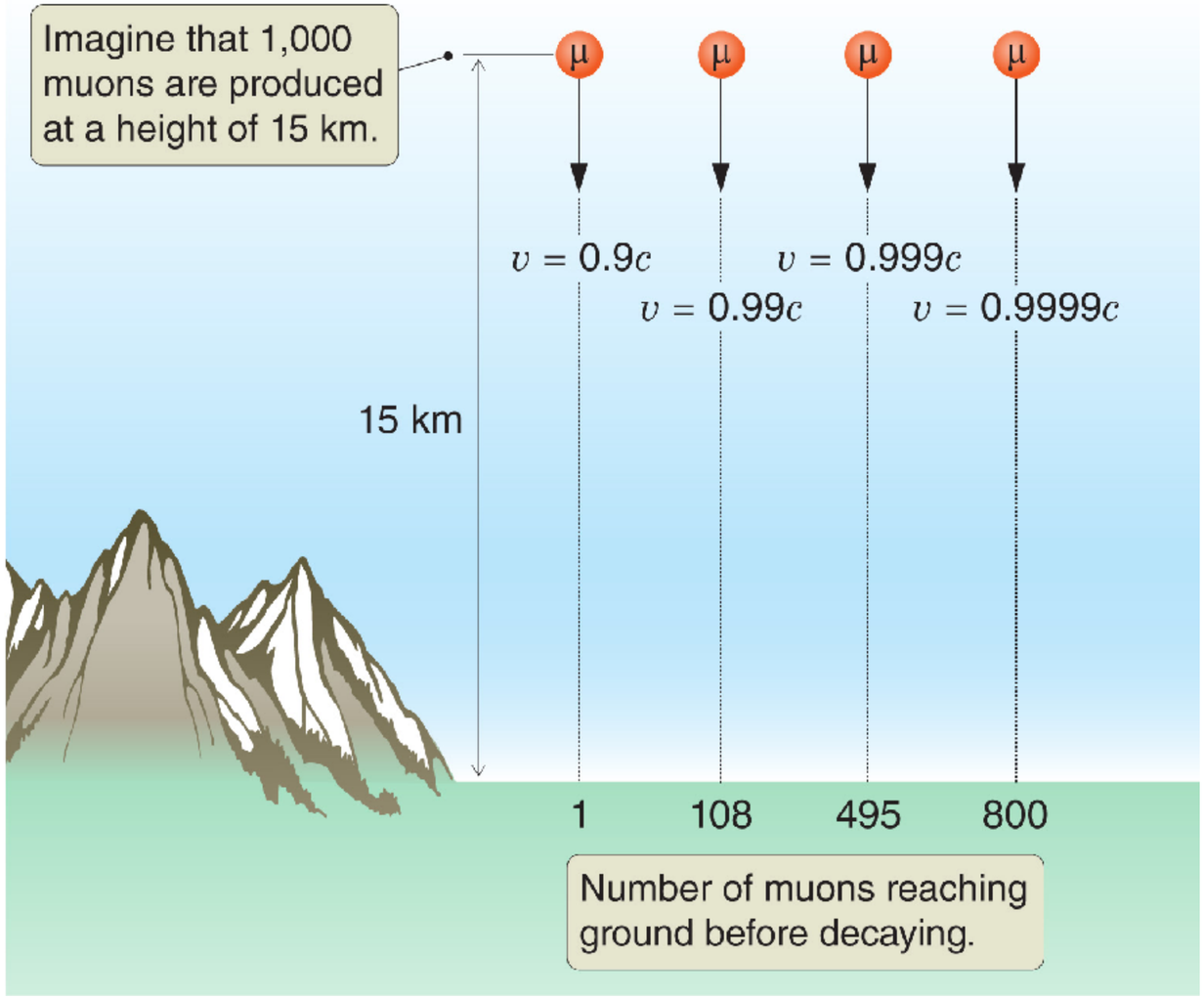
The passage of time is not the same everywhere!

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Muons created by cosmic rays colliding with the atmosphere exhibit time dilation

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Faster a muon is traveling, the slower time passes for it, so it survives longer before decaying



Implications of Special Relativity

$E = mc^2$

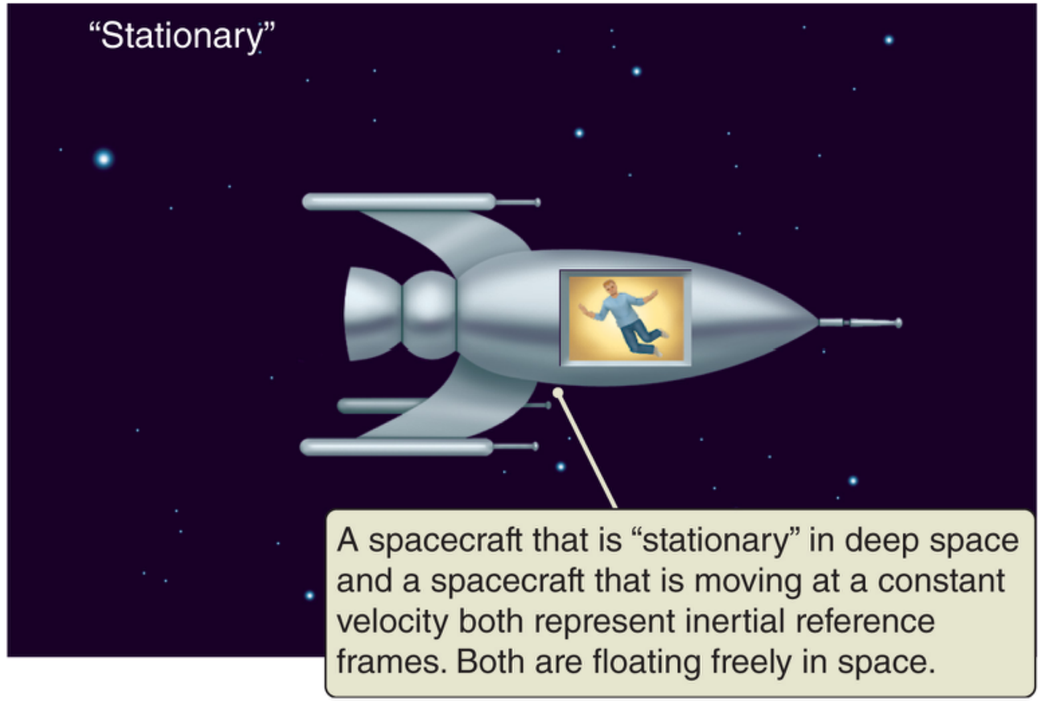
when moving, have kinetic energy
—> increase your mass!

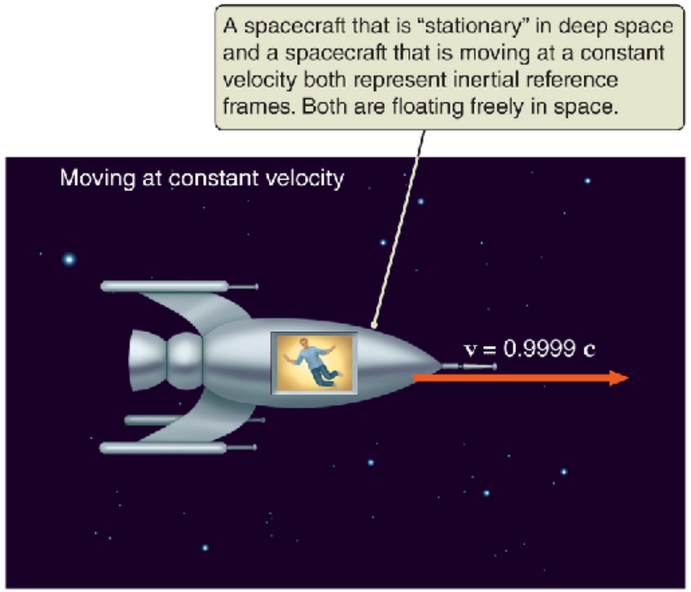
Speed of Light is the universal speed limit (can only approach it)

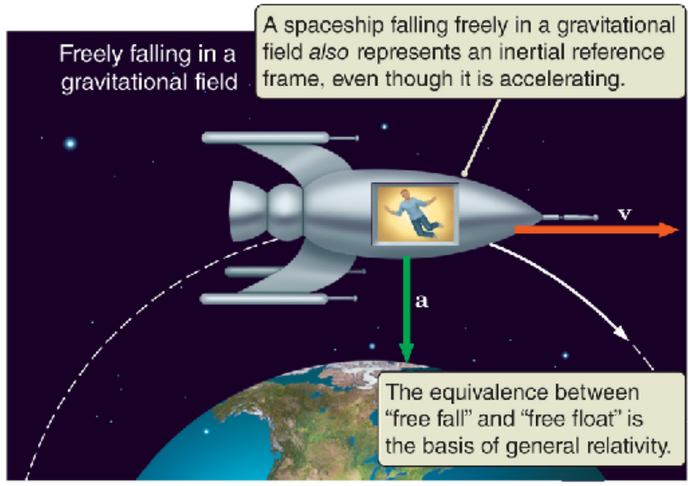
Time passes more slowly for moving reference frames

Length of moving objects contract in the direction of motion

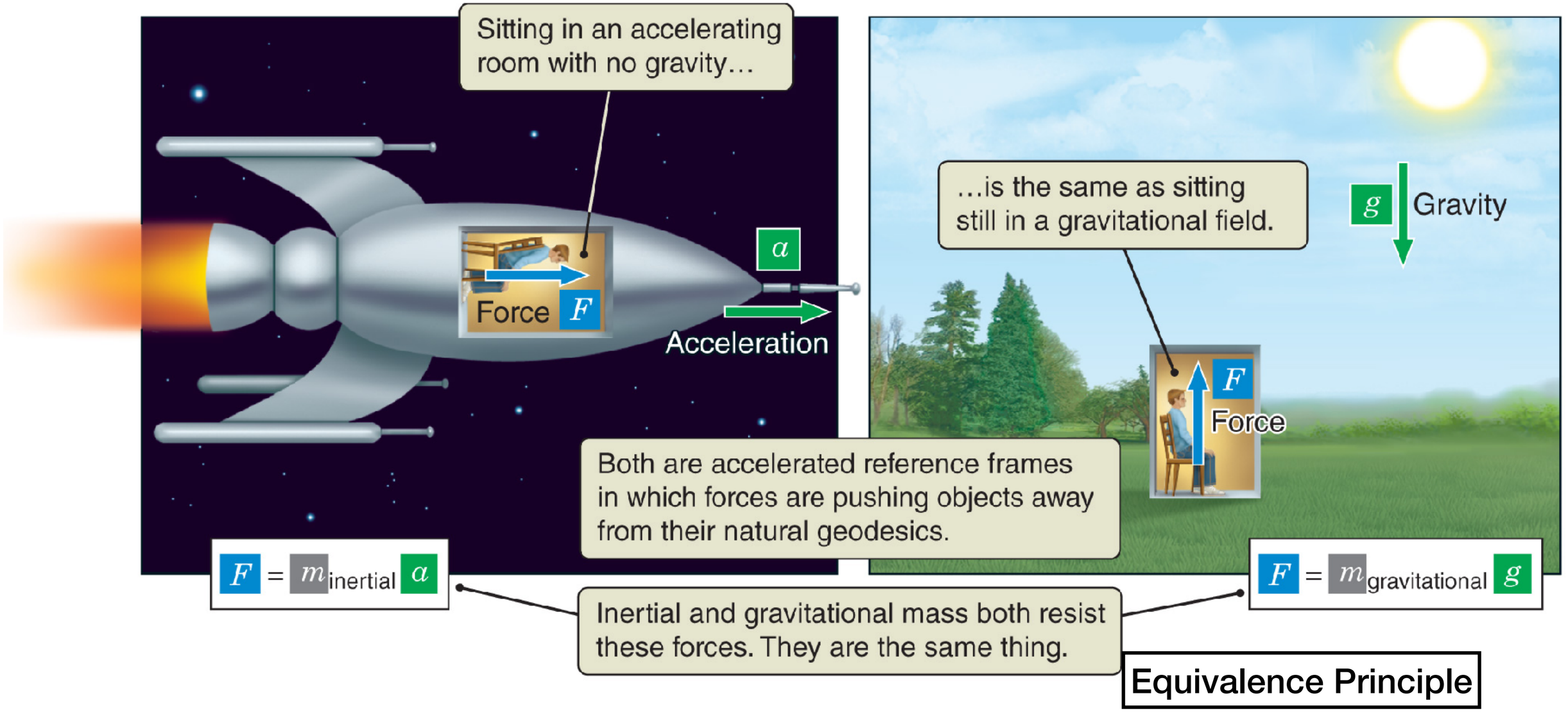
General Relativity: analogous case for gravity



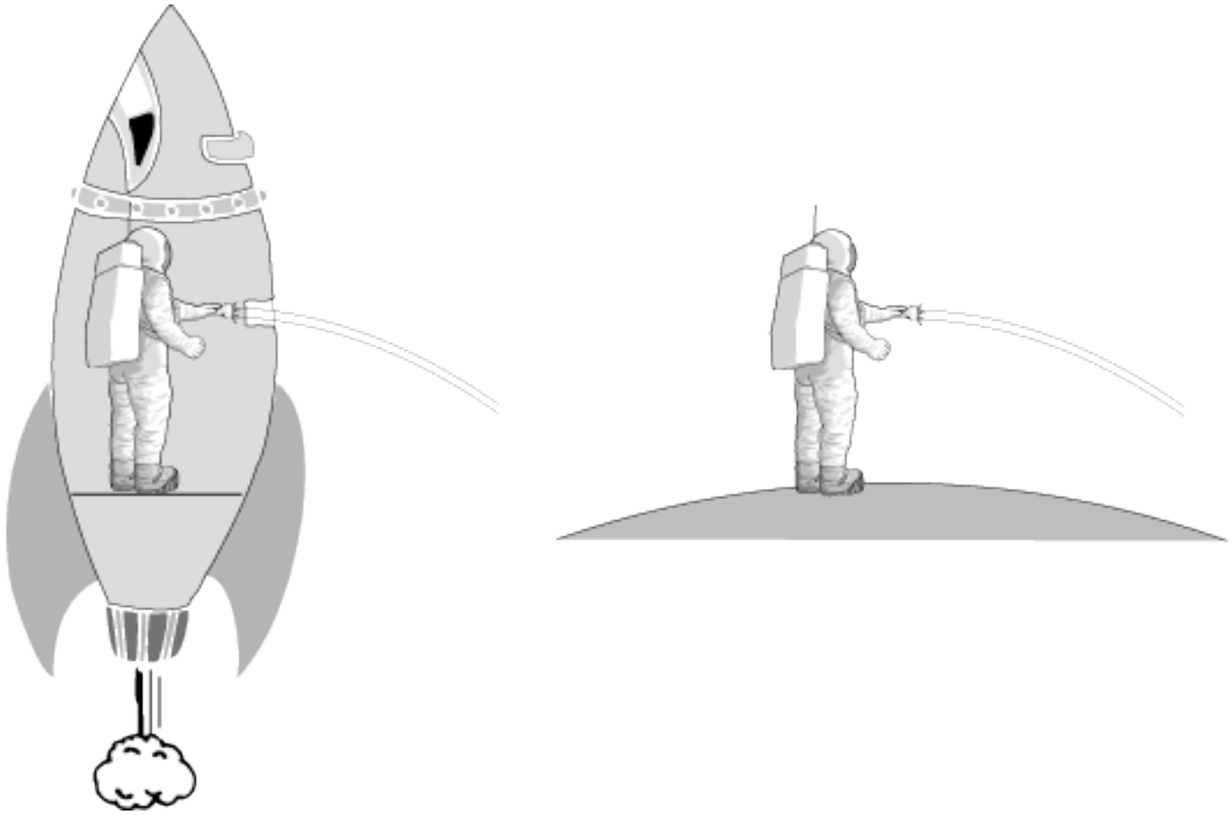


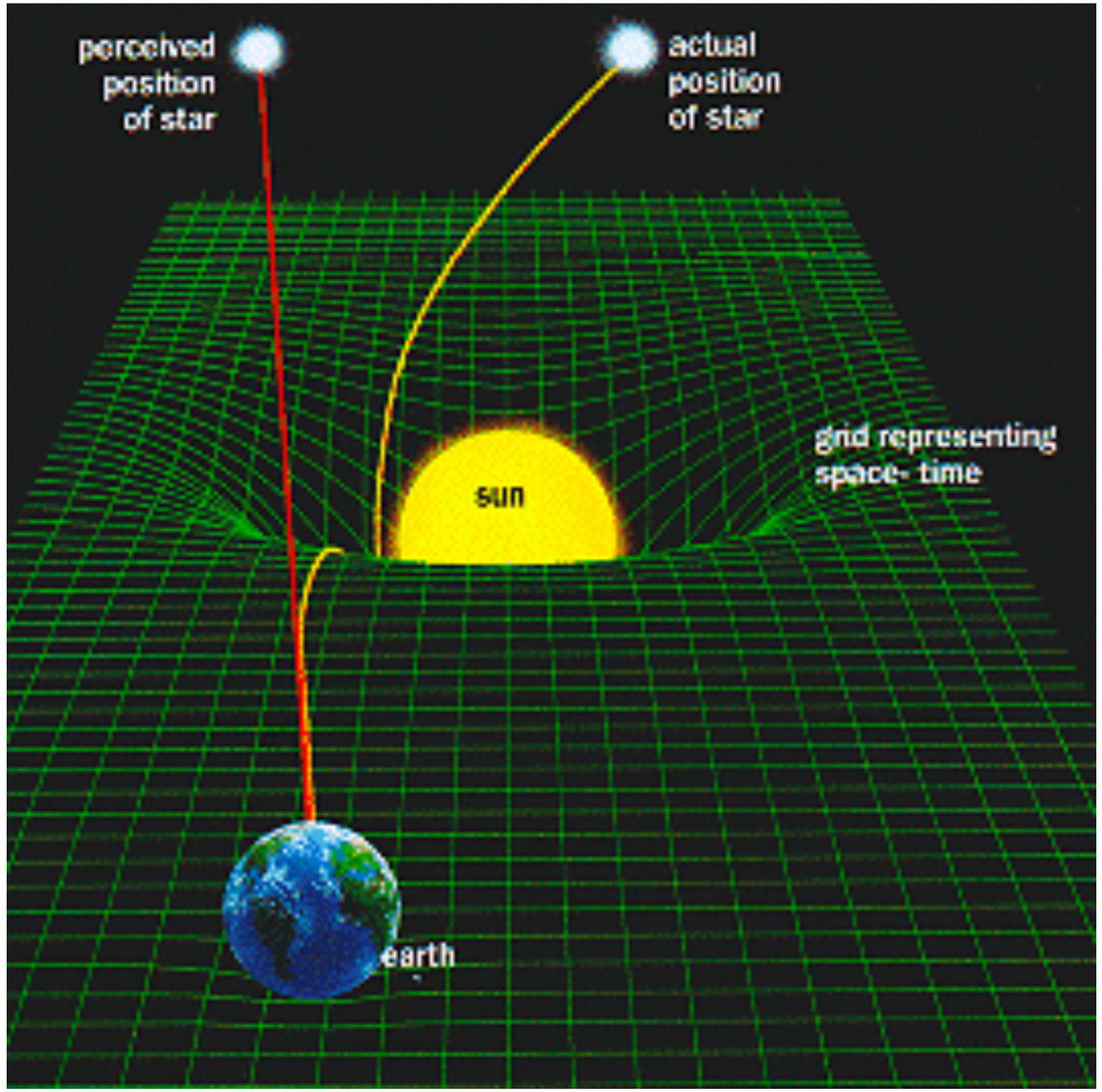


General Relativity: analogous case for gravity

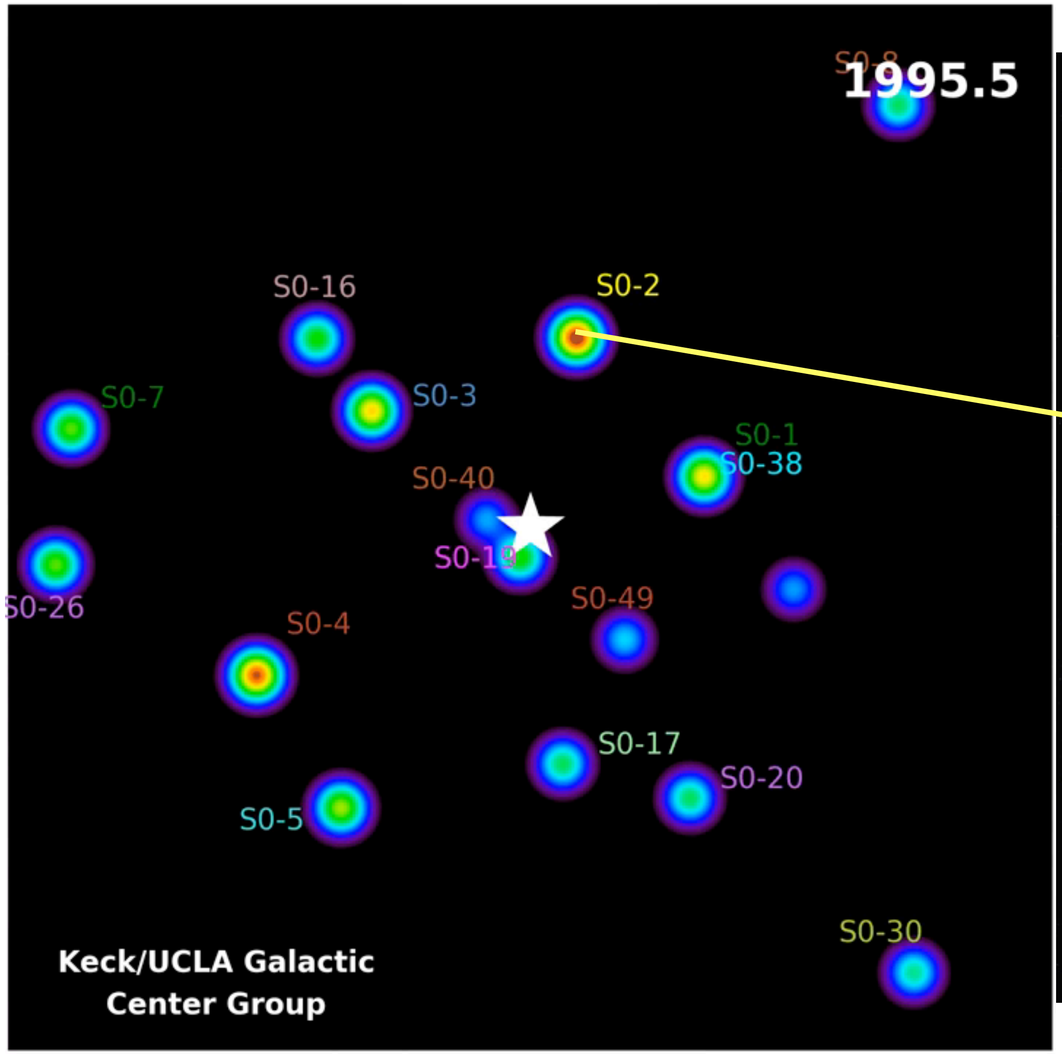


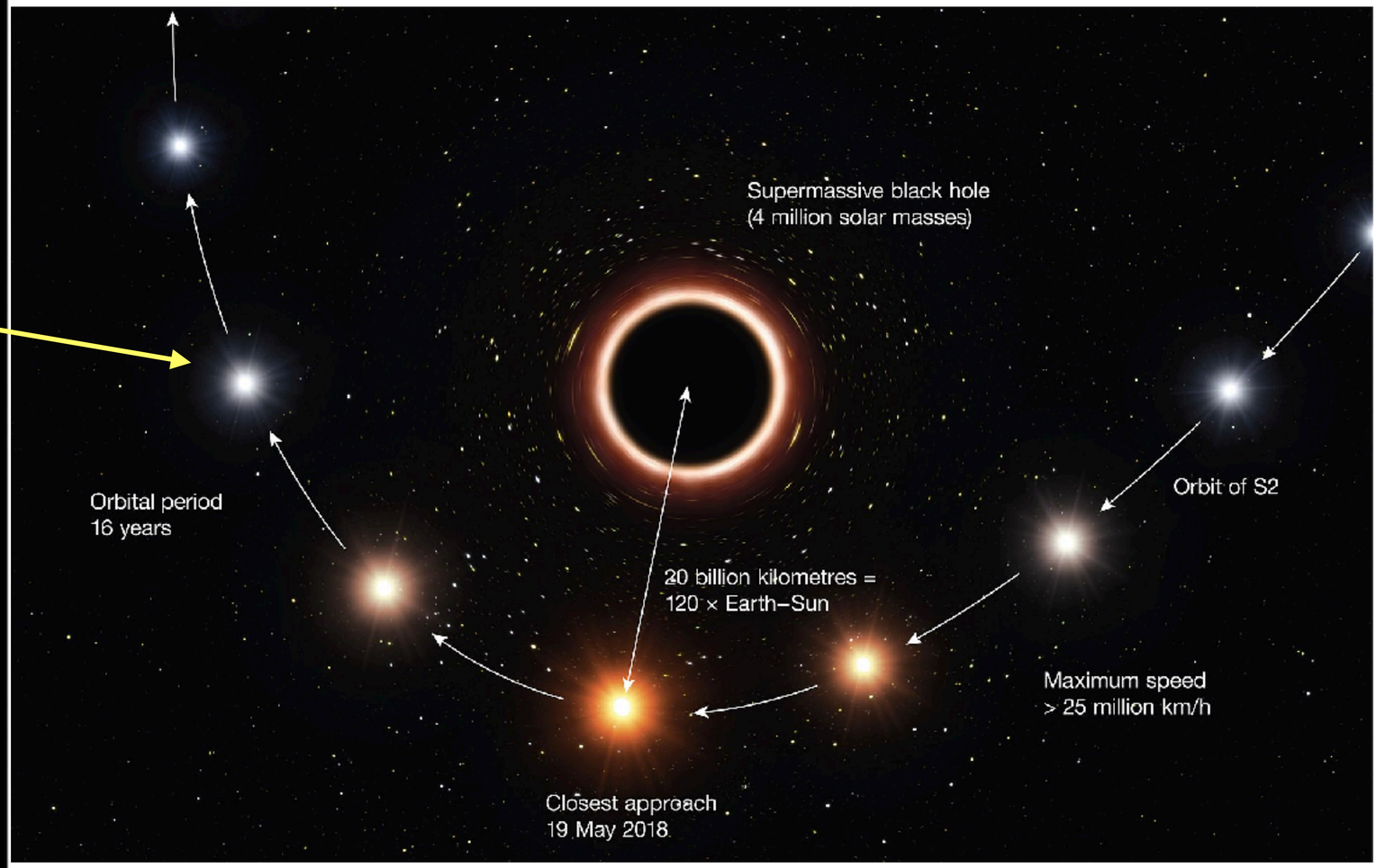
Space-time is curved





Gravitational Redshift

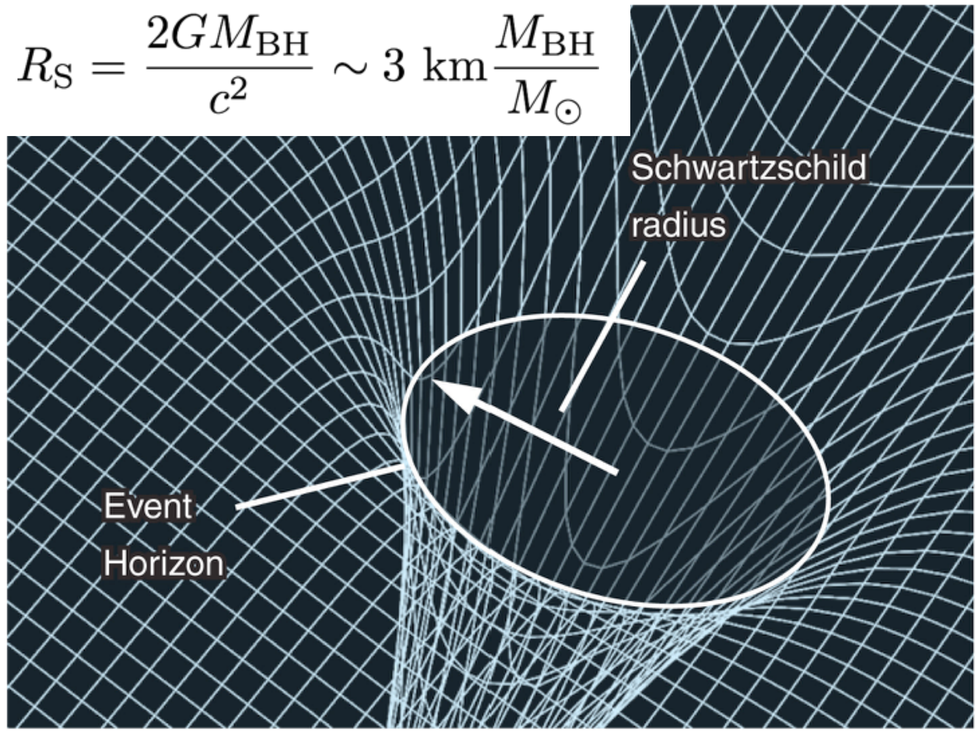




What are Black Holes?

Particular solutions to Einstein's equations of General Relativity

Inevitable end-state of ultra-dense matter



Inside the event horizon, the *escape velocity* is larger than the speed of light (c)

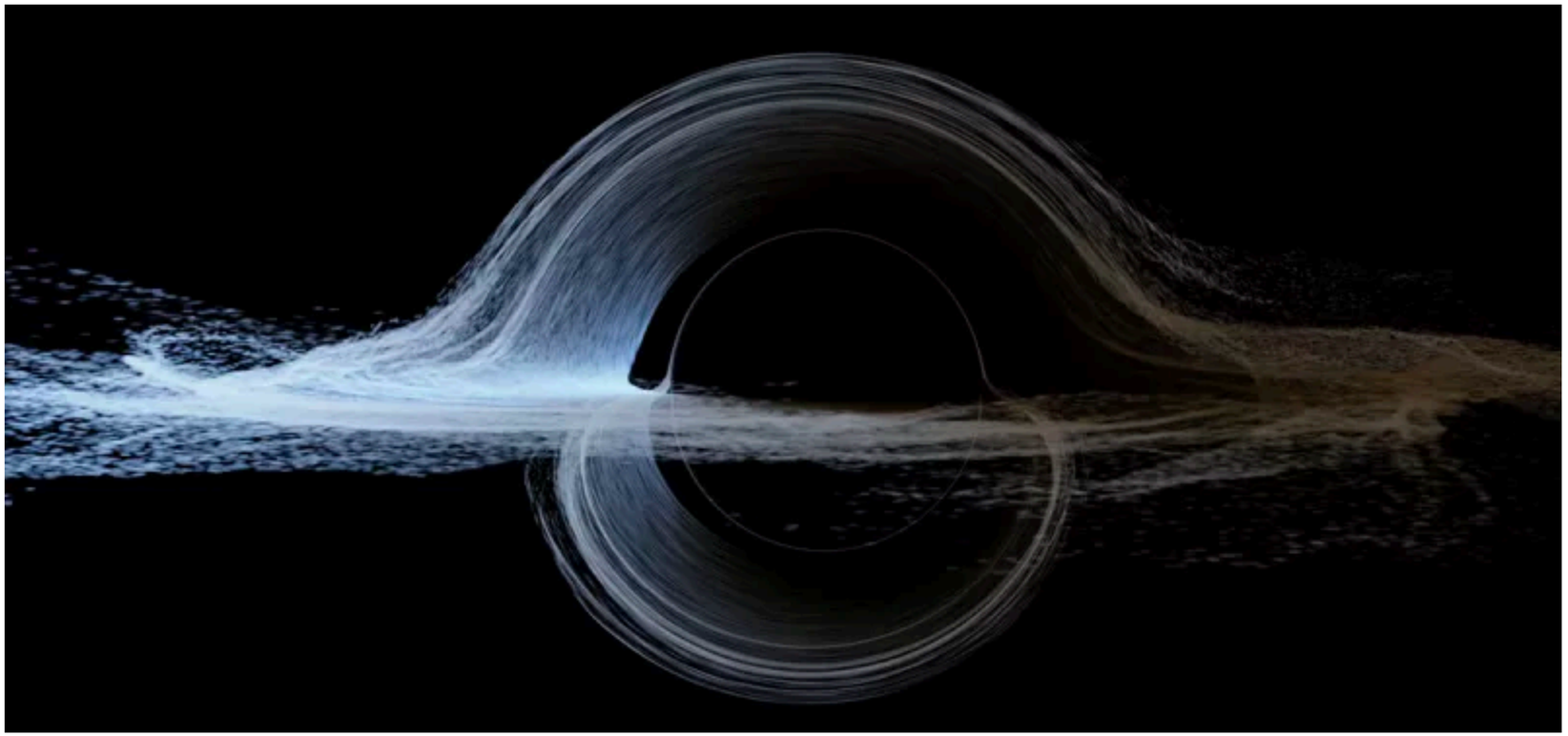
Matter inside the event horizon must fall to the center, toward the *singularity*

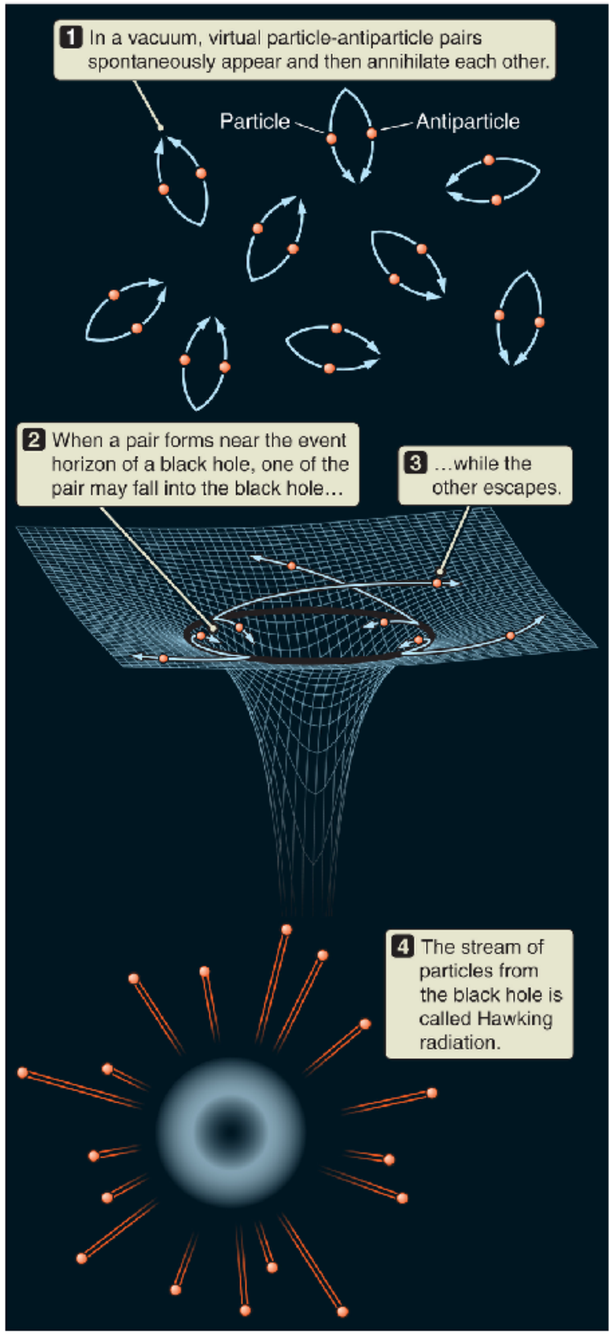
Black holes have "no hair" - defined only by their mass, charge, and spin (rotation)
—> all other info about what formed it is lost

The black hole in *Interstellar*

called Gargantua, b/c it's supermassive (like the one in the centers of galaxies)

keeps Matthew McConaughey from "spaghettification" as he crosses the event horizon
—> stellar mass black holes have huuuuuge tidal forces here that would kill you!





Black holes are not completely black after all

Emit Hawking radiation

Hawking himself popularized the explanation used in the textbook, but that explanation is wrong!

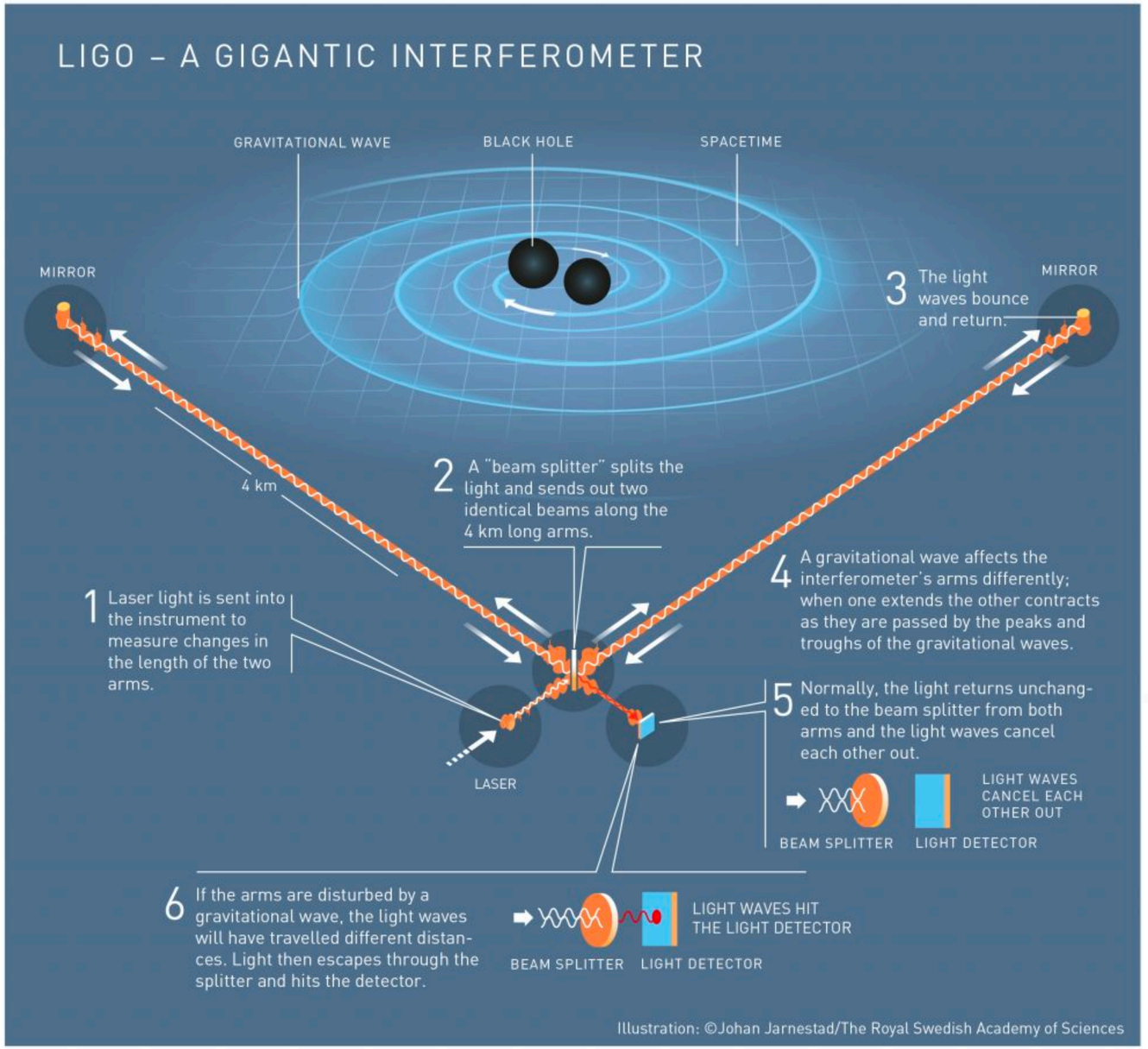
The virtual "particles," which have large quantum waveforms (uncertainty in their position is as large as the black hole), separate at a distance several times larger than the event horizon

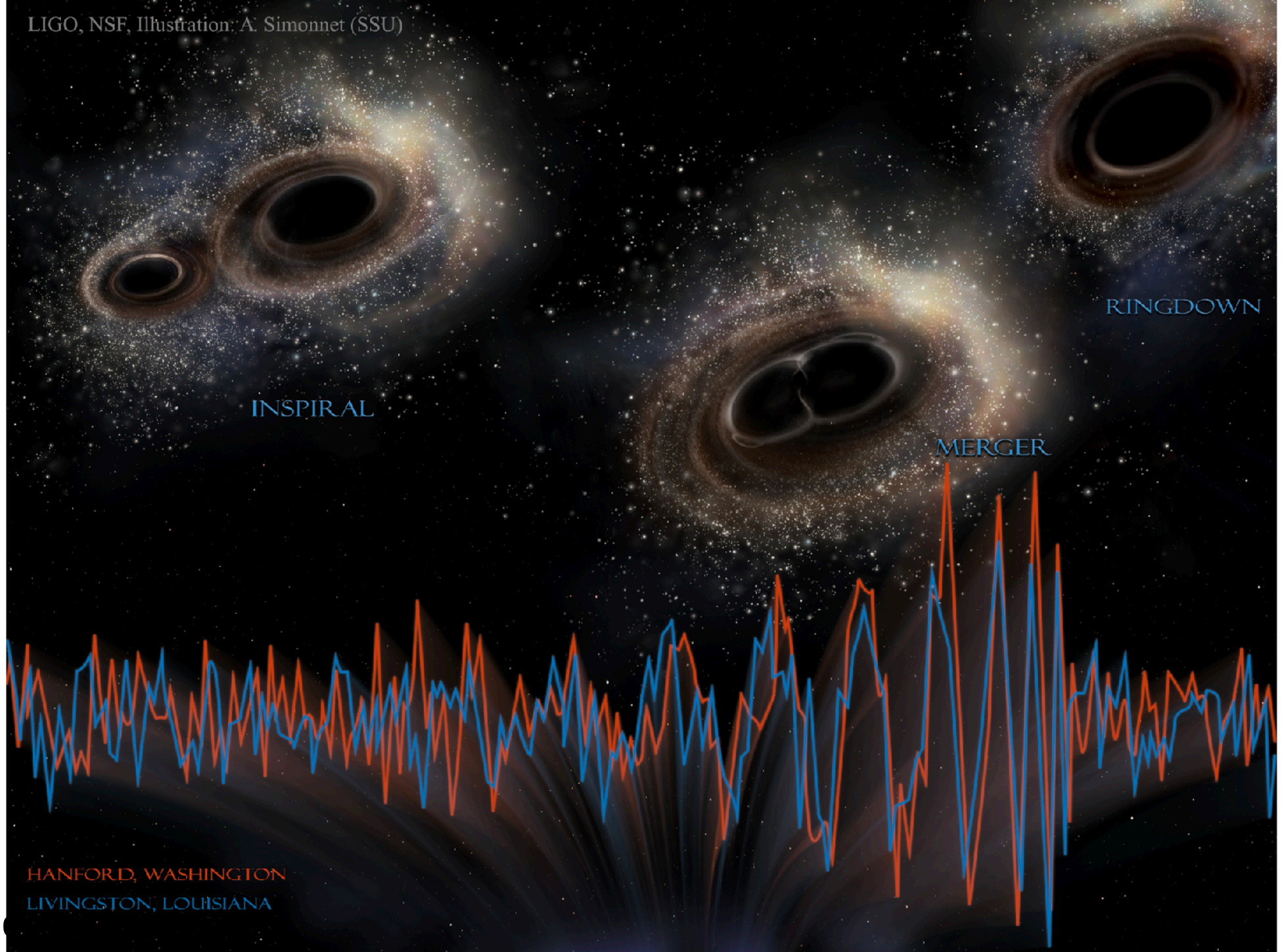
They result mainly from space-time changing dynamically when the black hole forms, creating thermal radiation

Temperature is very tiny, but carries away energy, causing the black hole to lose mass ($E=mc^2$), but it takes a looooong time (~10^{66} years)

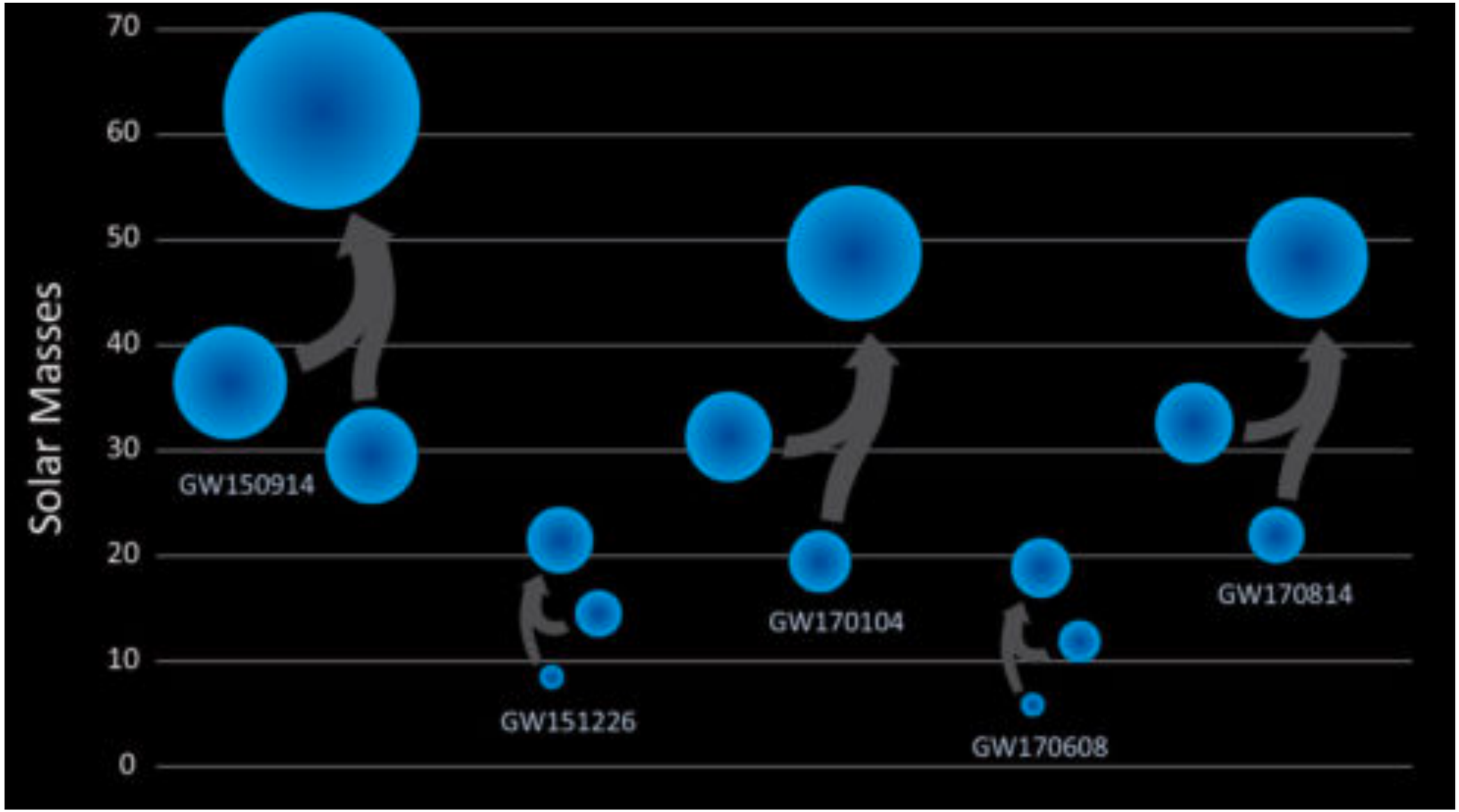
Gravitational Waves: LIGO!

Virgo facility near Pisa, Italy
other detectors in Louisiana and Washington state

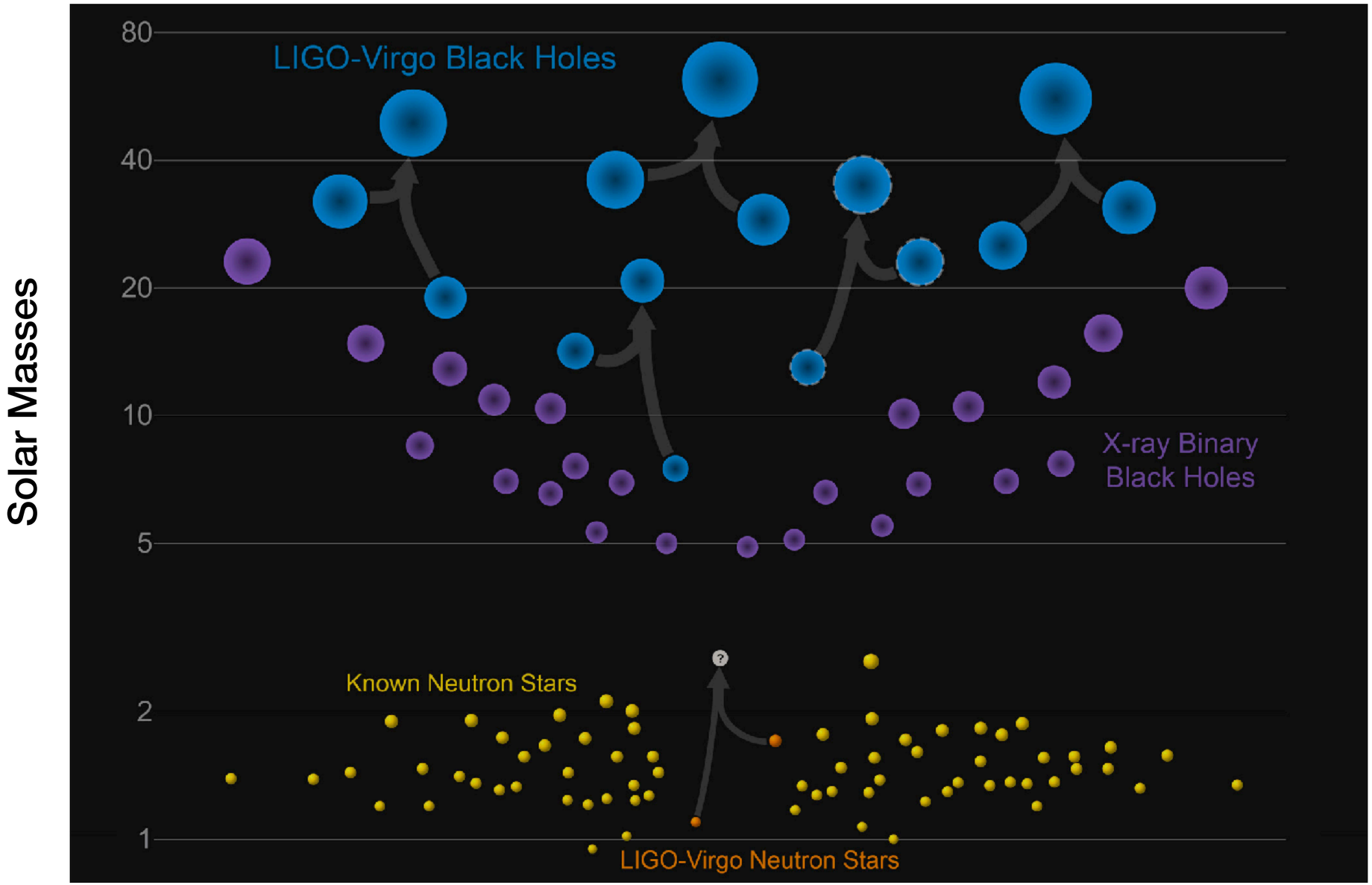



LIGO, NSF, Illustration: A. Simonnet (SSU)
INSPIRAL
MERGER
RINGDOWN
HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA

First 5 BH-BH mergers



BHs and NSs with known masses



First NS-NS merger, explosion also seen