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

Chapter 13 Reading Assignment due now!

Makeup in-class assignment from Wednesday due now (for late credit)

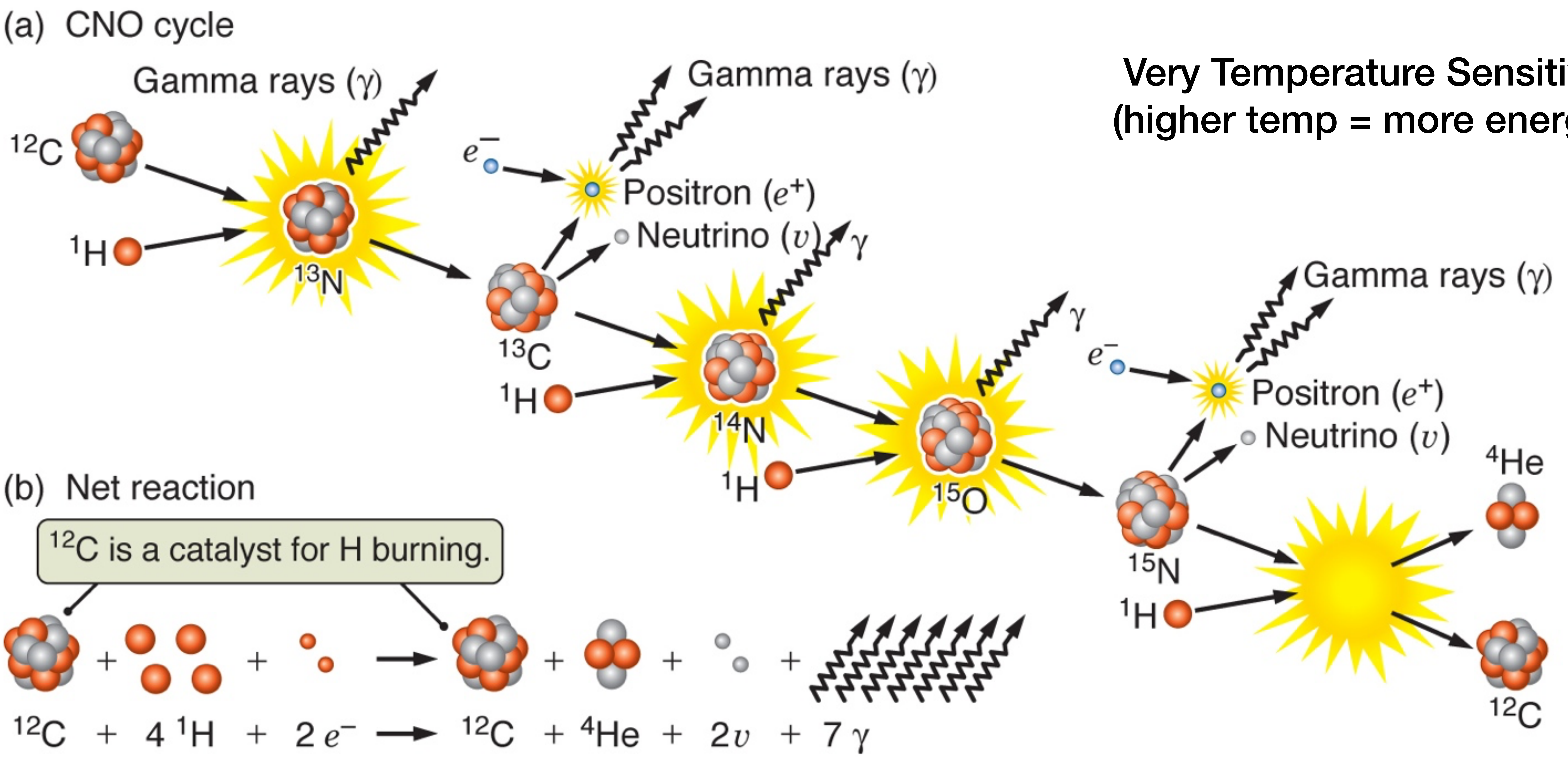
Are your grades in Canvas correct???

Midterms available up front

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

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

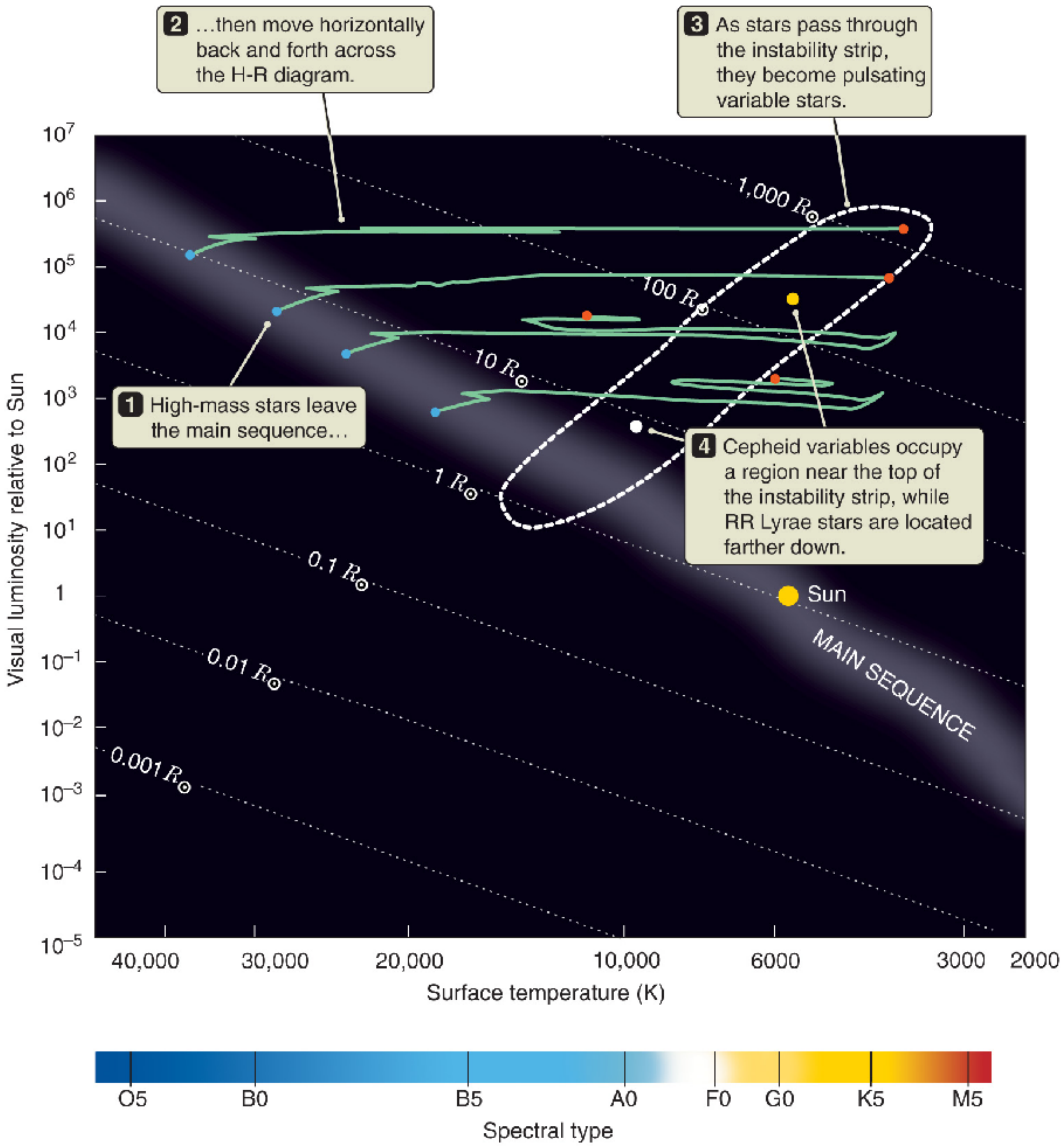
Time spent on the Main Sequence is short: why?

A) CNO is much more efficient

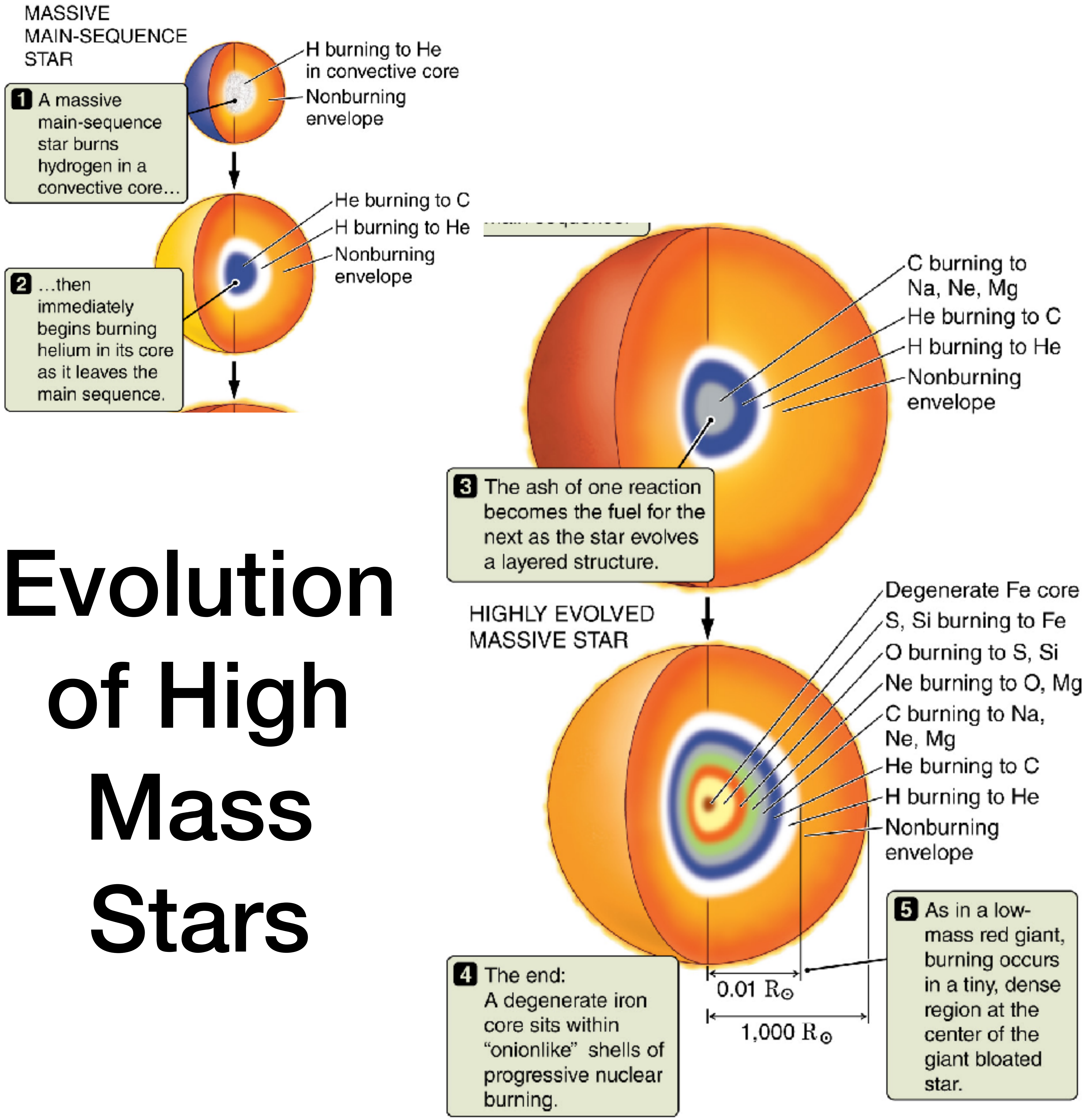
B) Massive stars use up their fuel more quickly

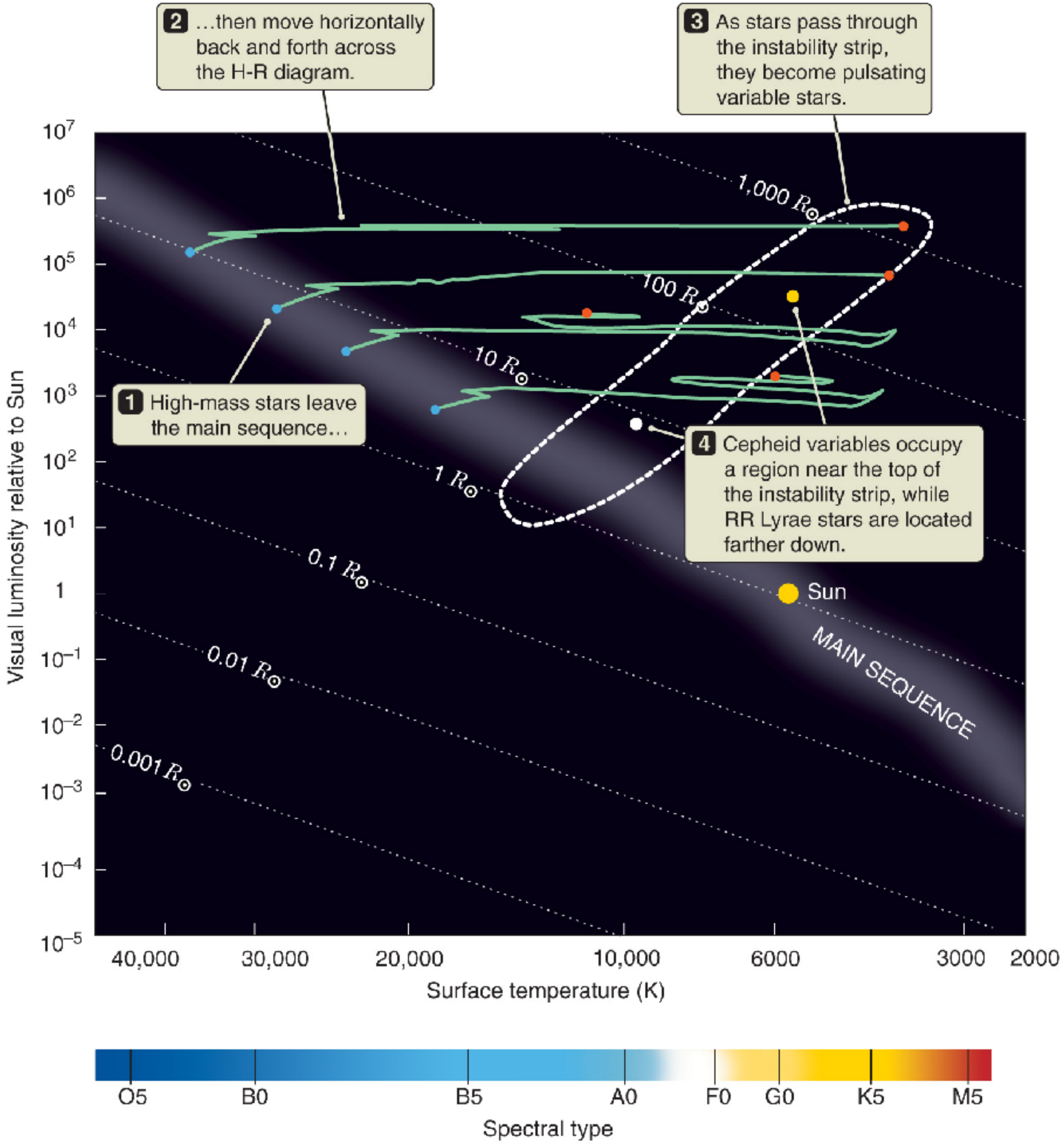
C) Not all the hydrogen in the core gets burned

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

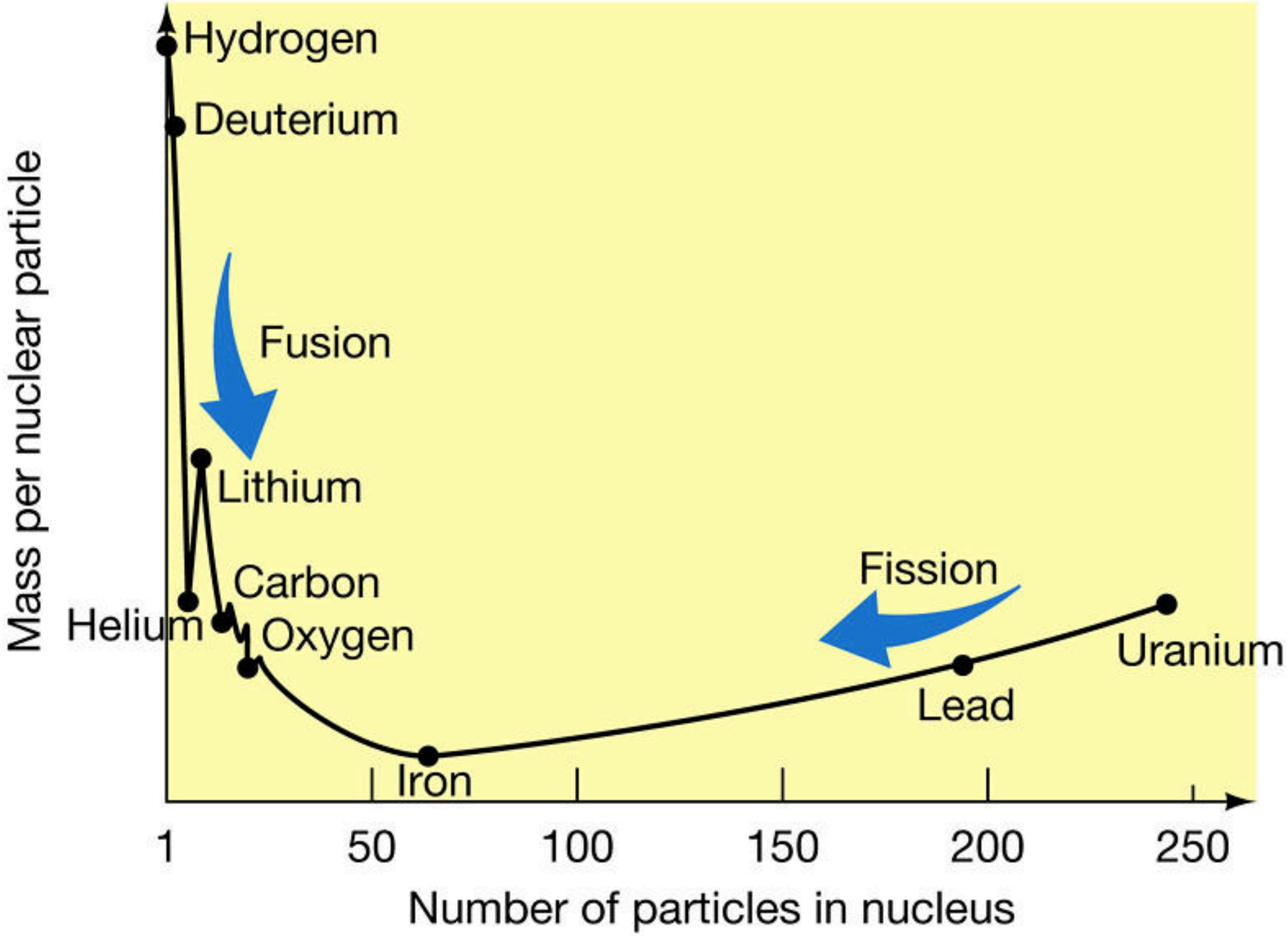


Evolution of High Mass Stars





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



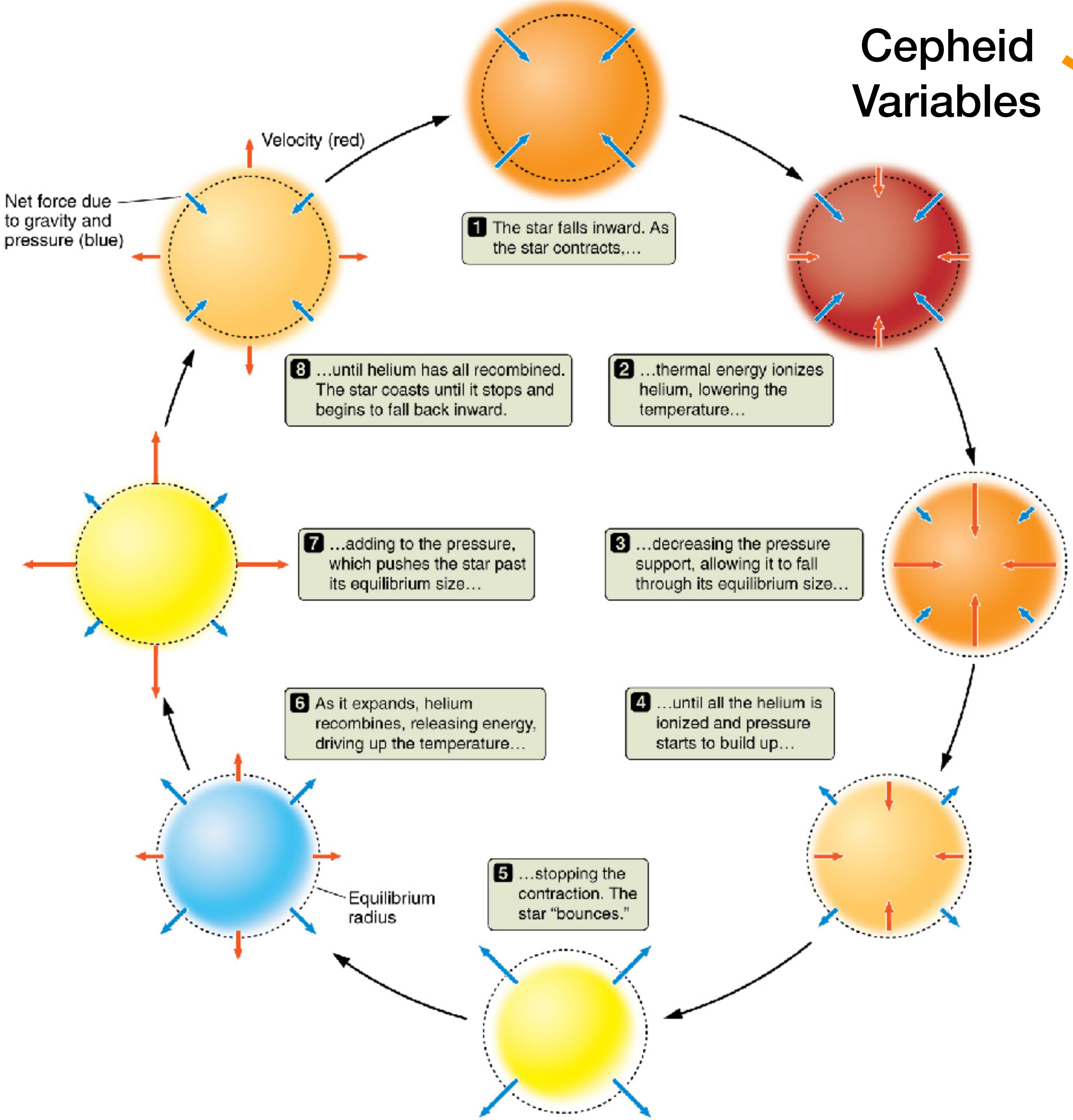
A) Carbon

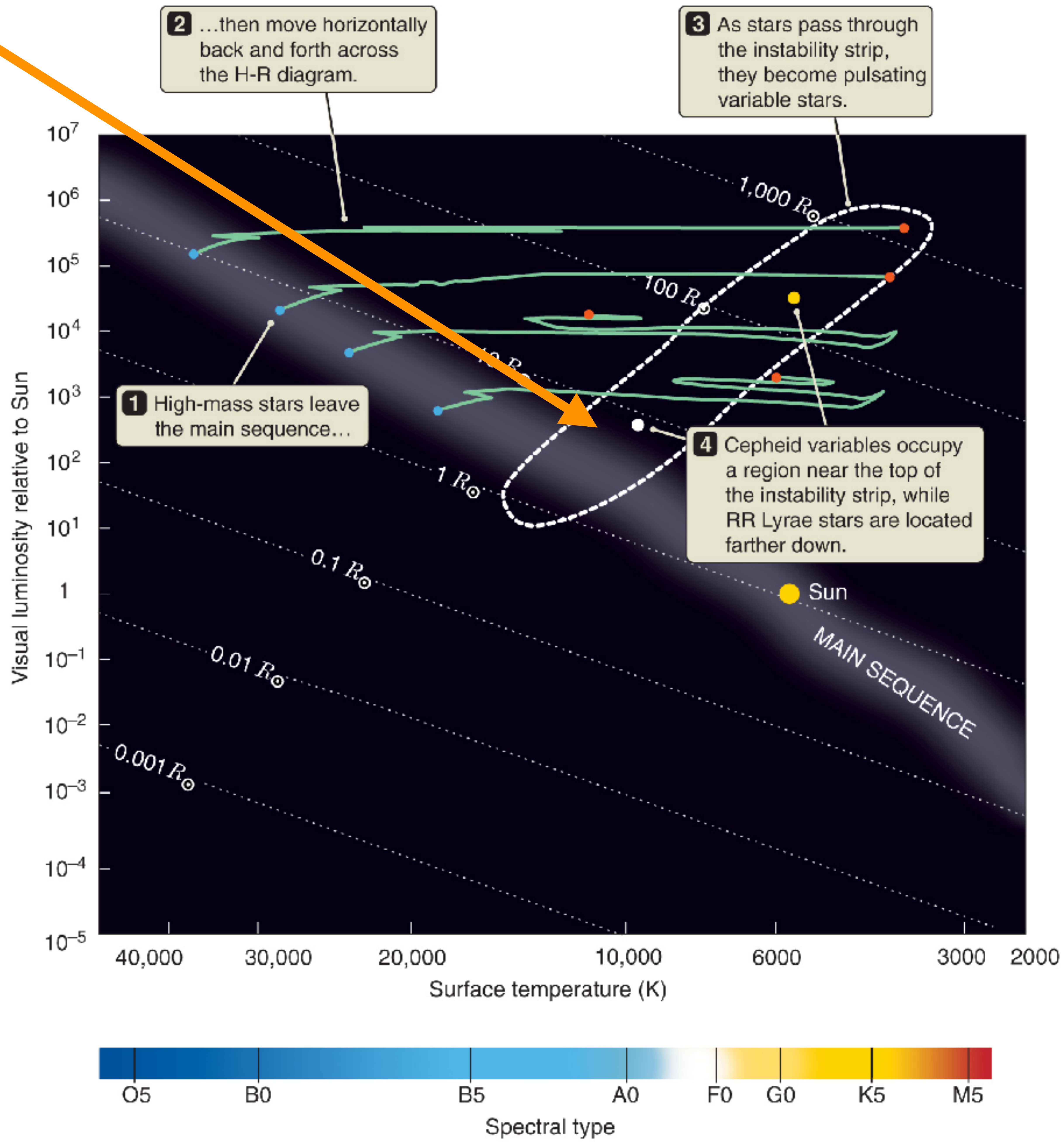
B) Iron

C) Lead

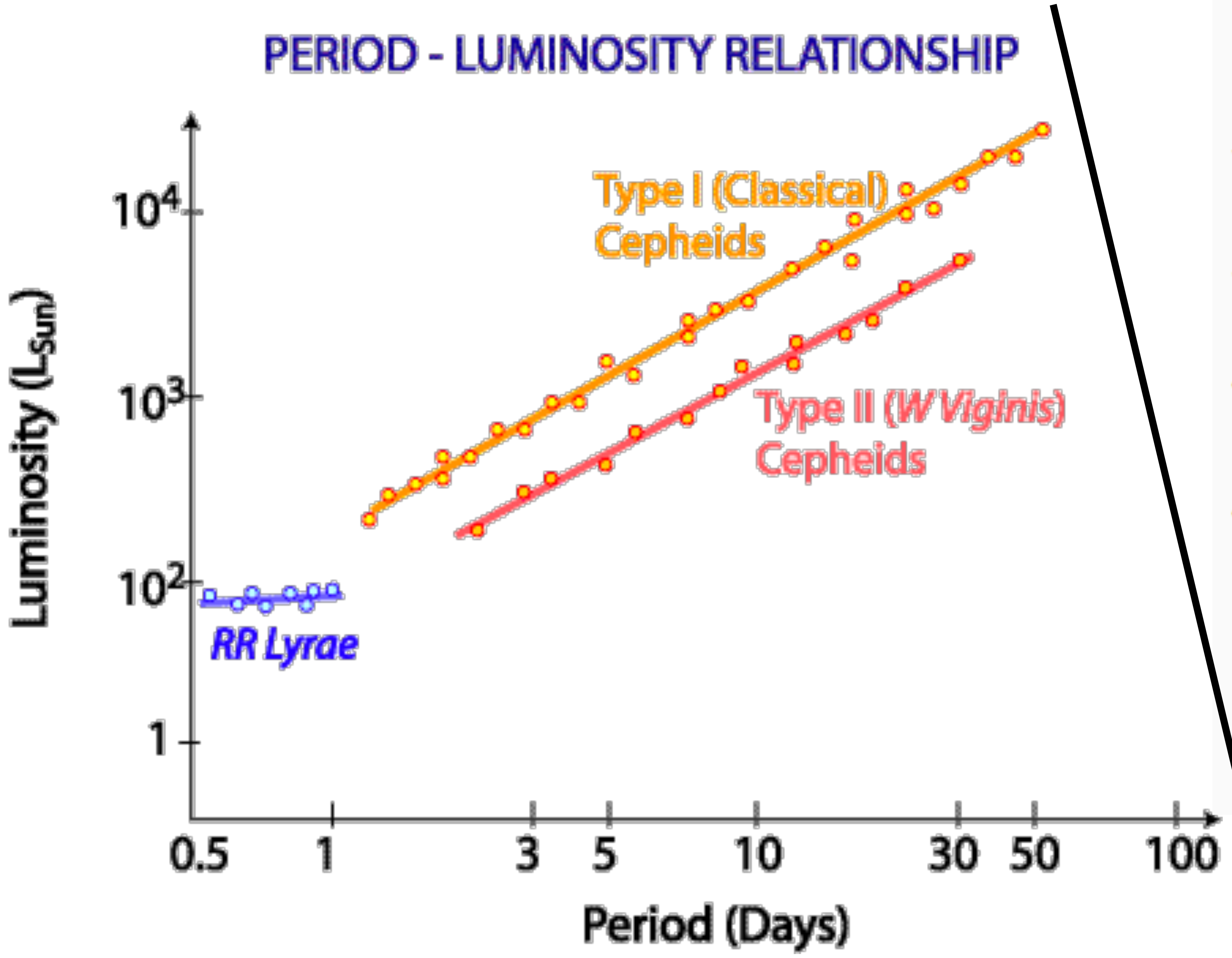
D) Uranium

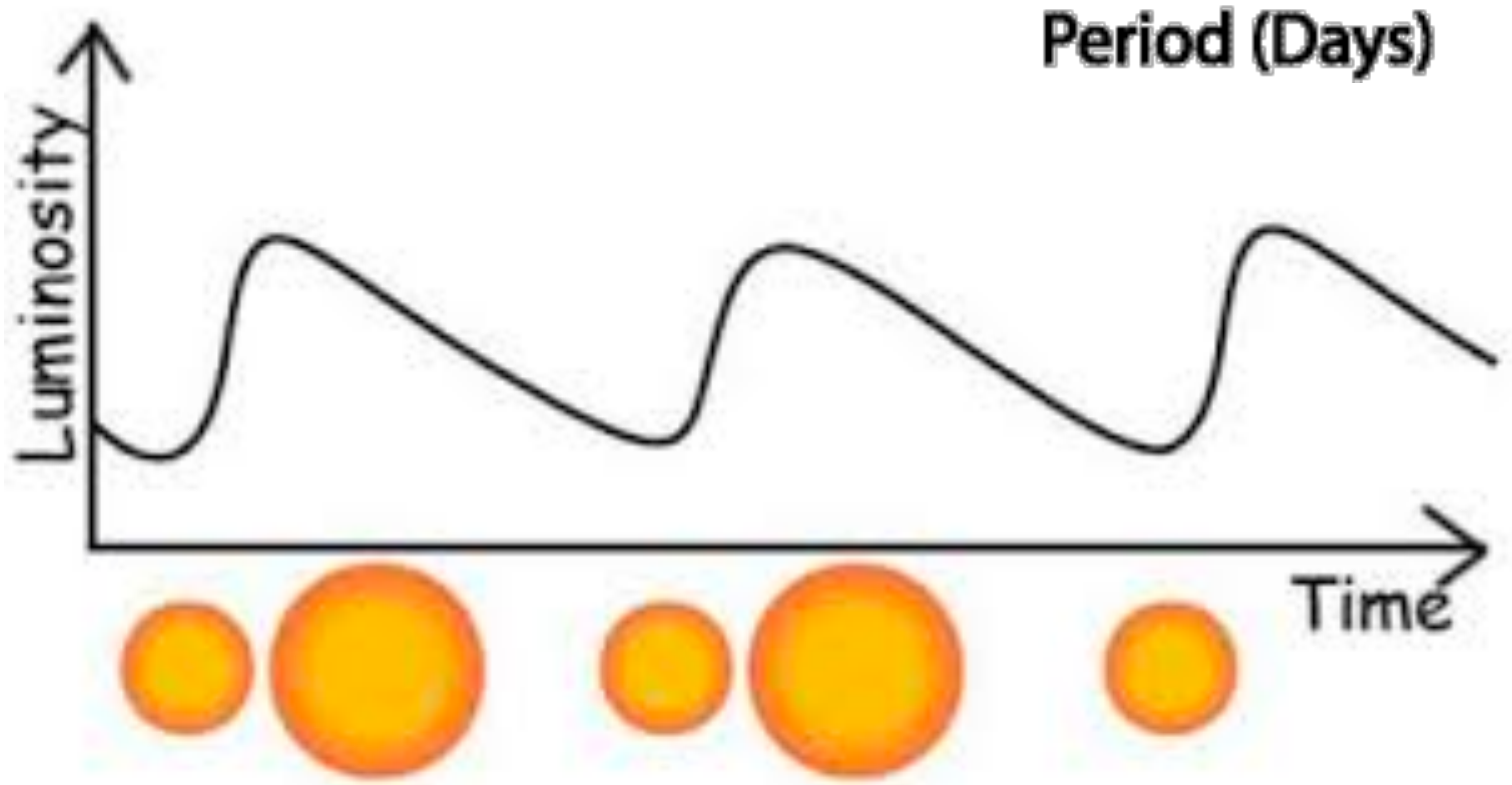
Cepheid Variables



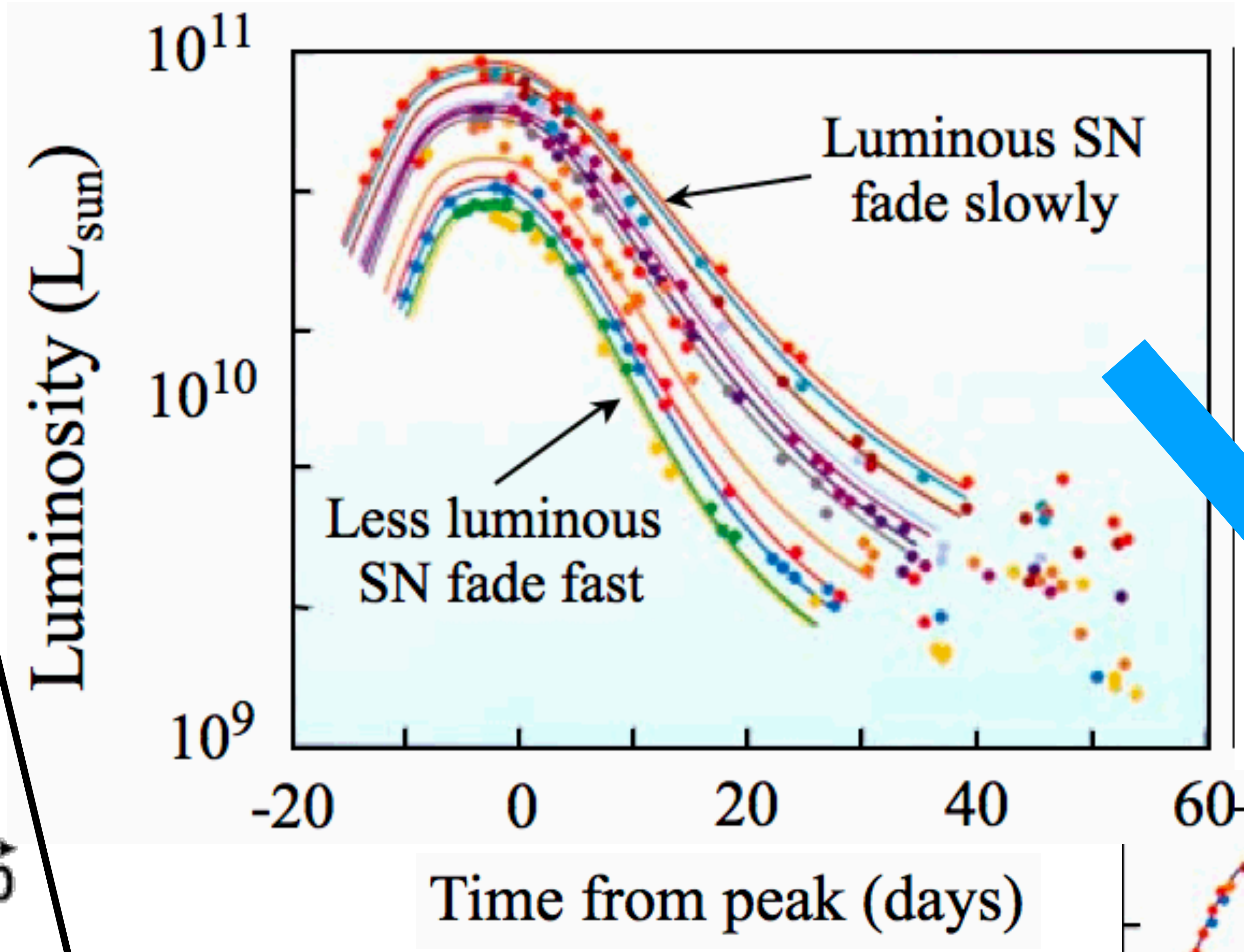


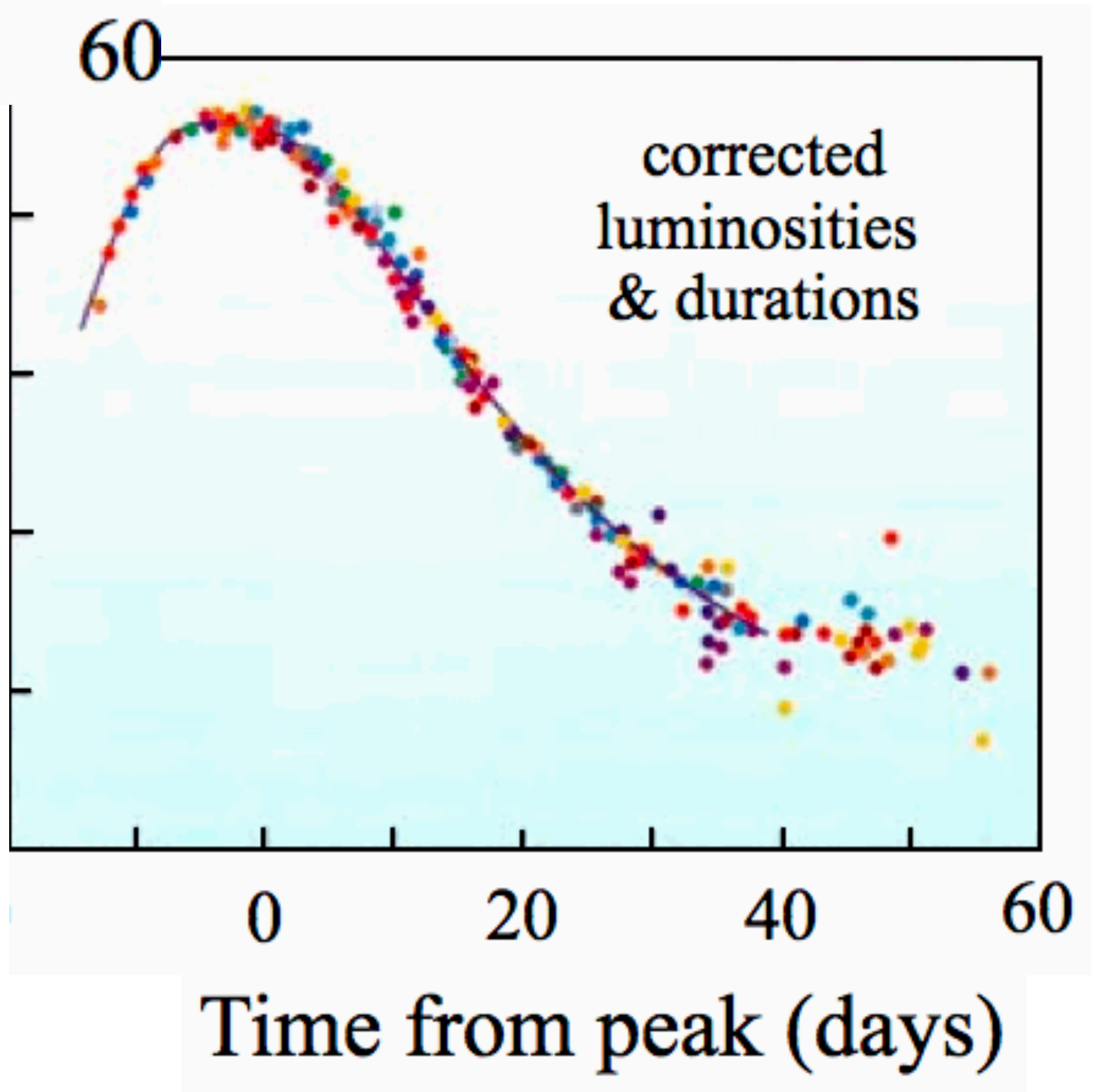
Aside: Standard Candles





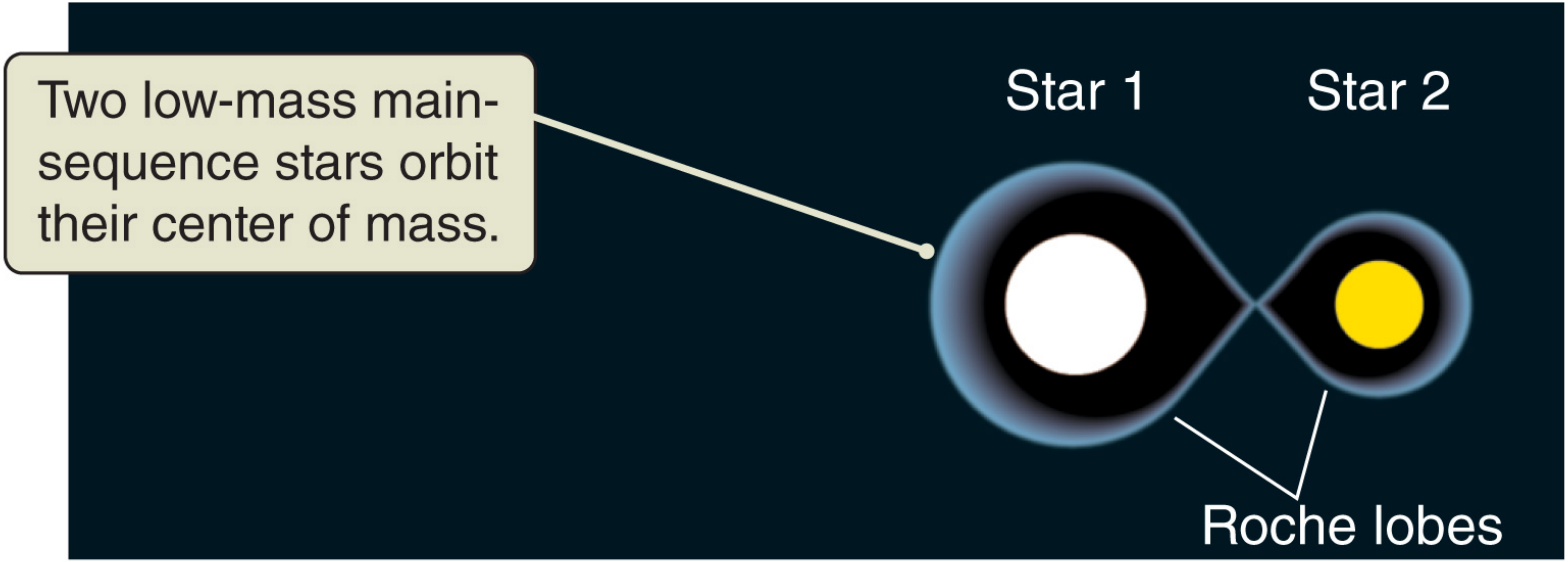
Cepheid Variables





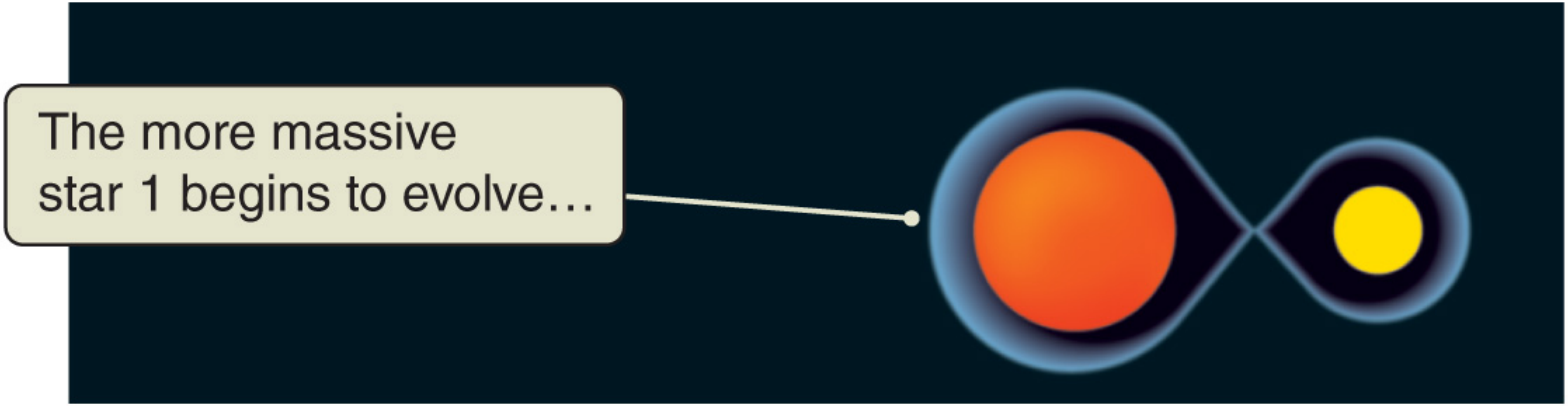
Type Ia Supernovae

What happens when close binary stars evolve?



What is this???

What happens when close binary stars evolve?



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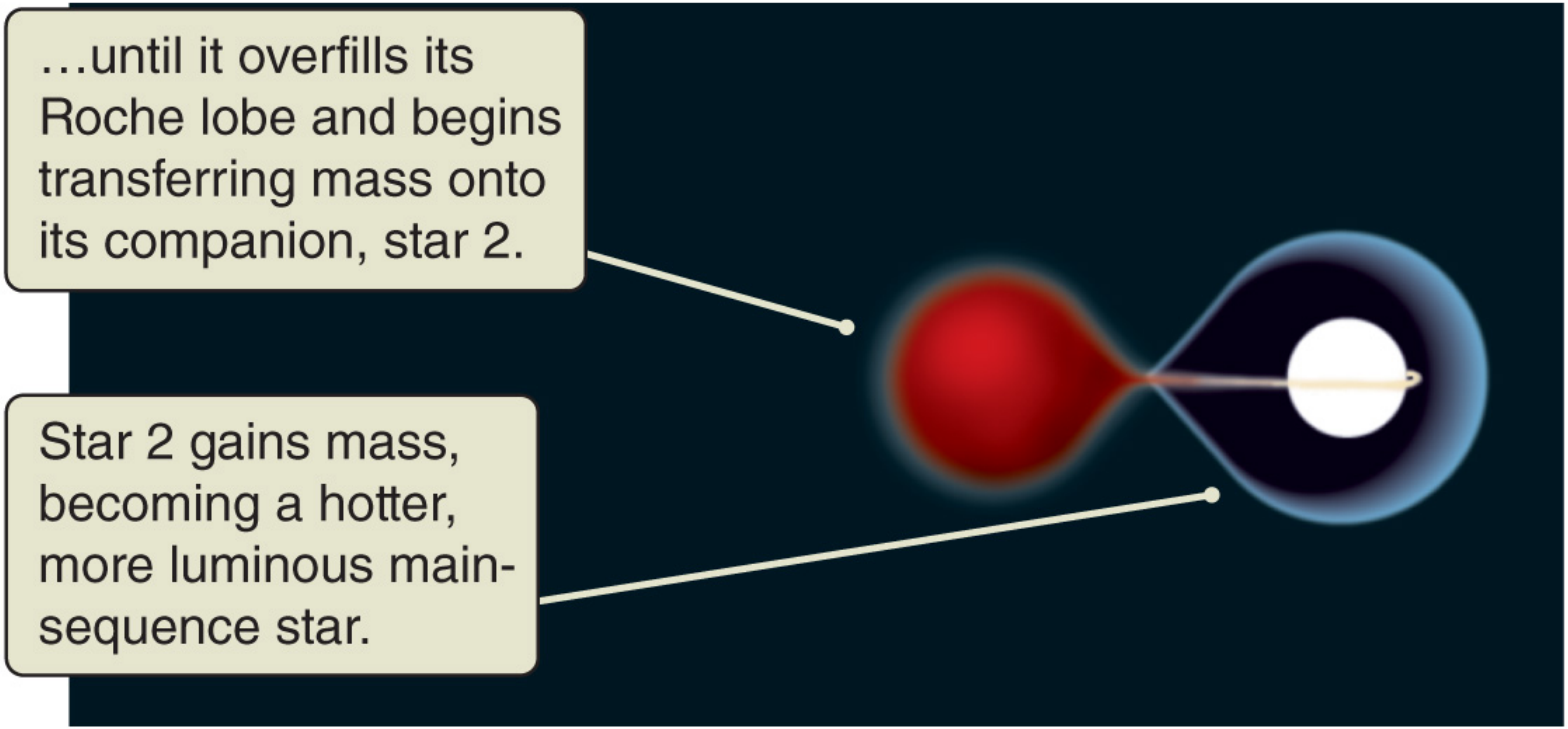

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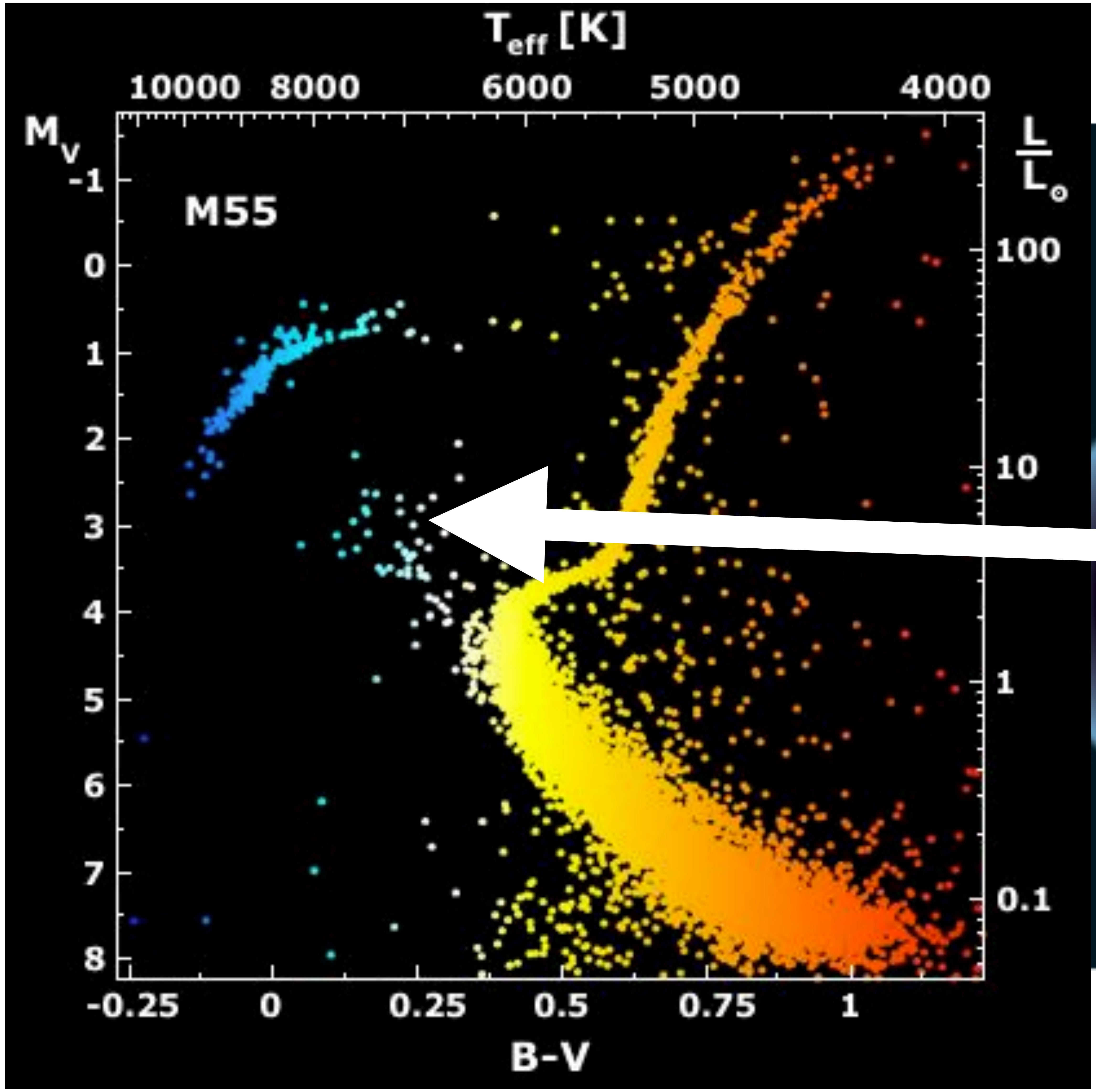

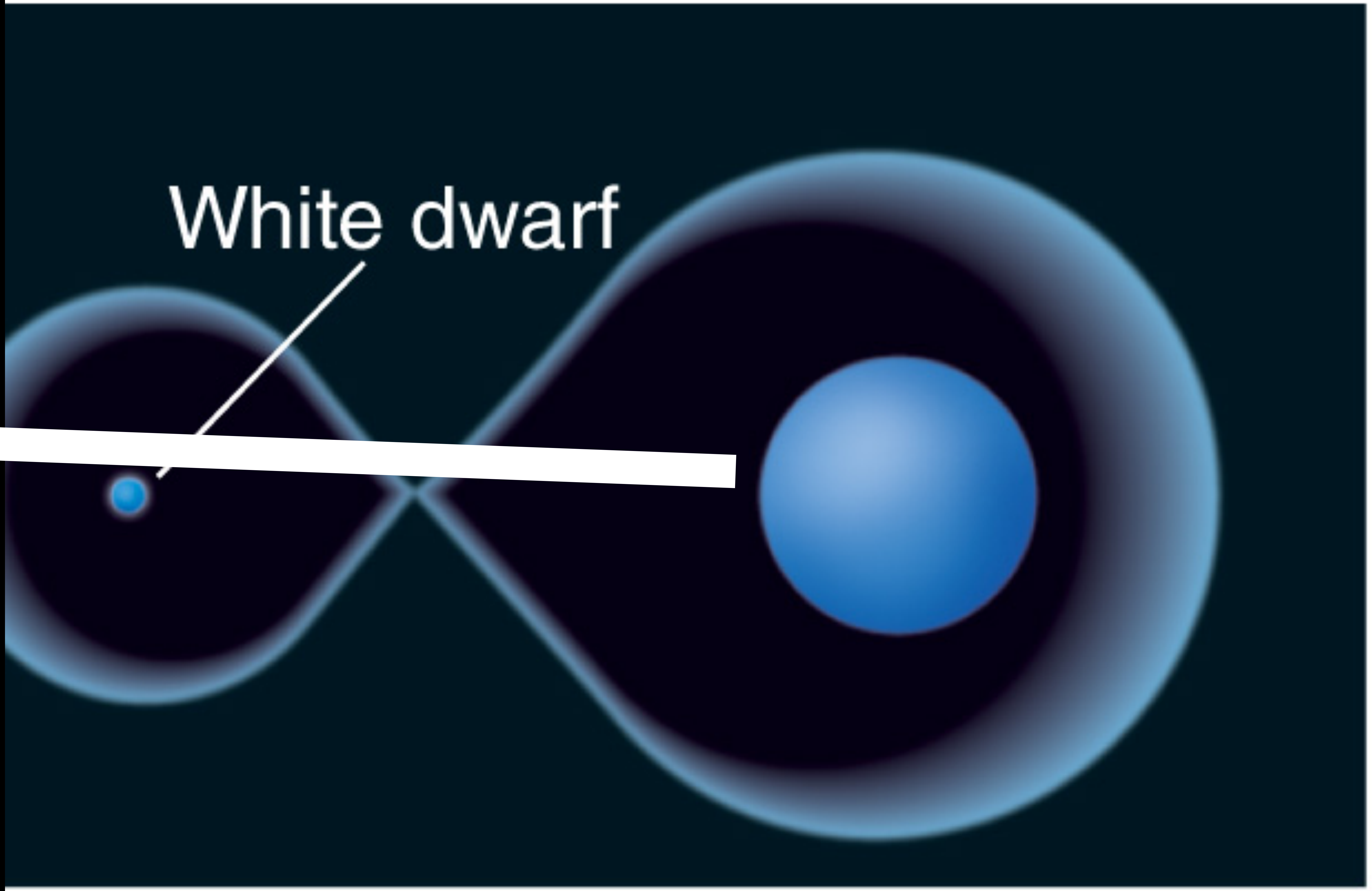

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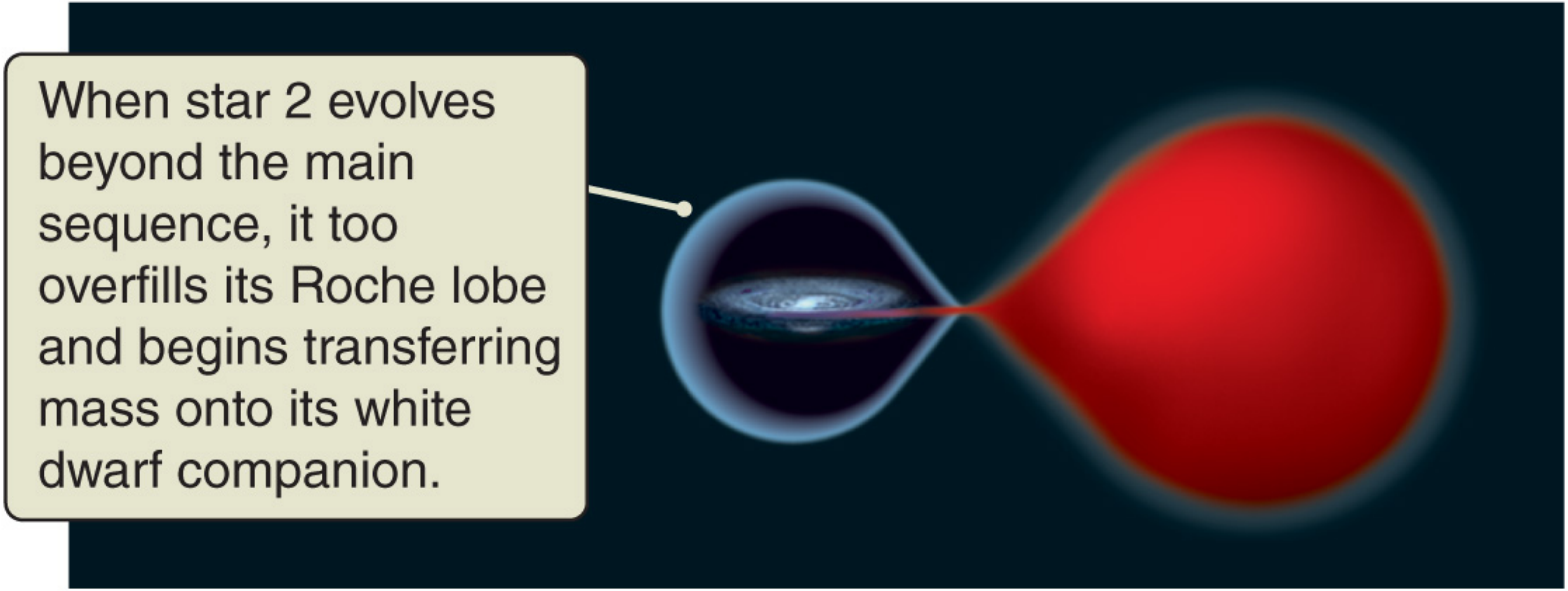
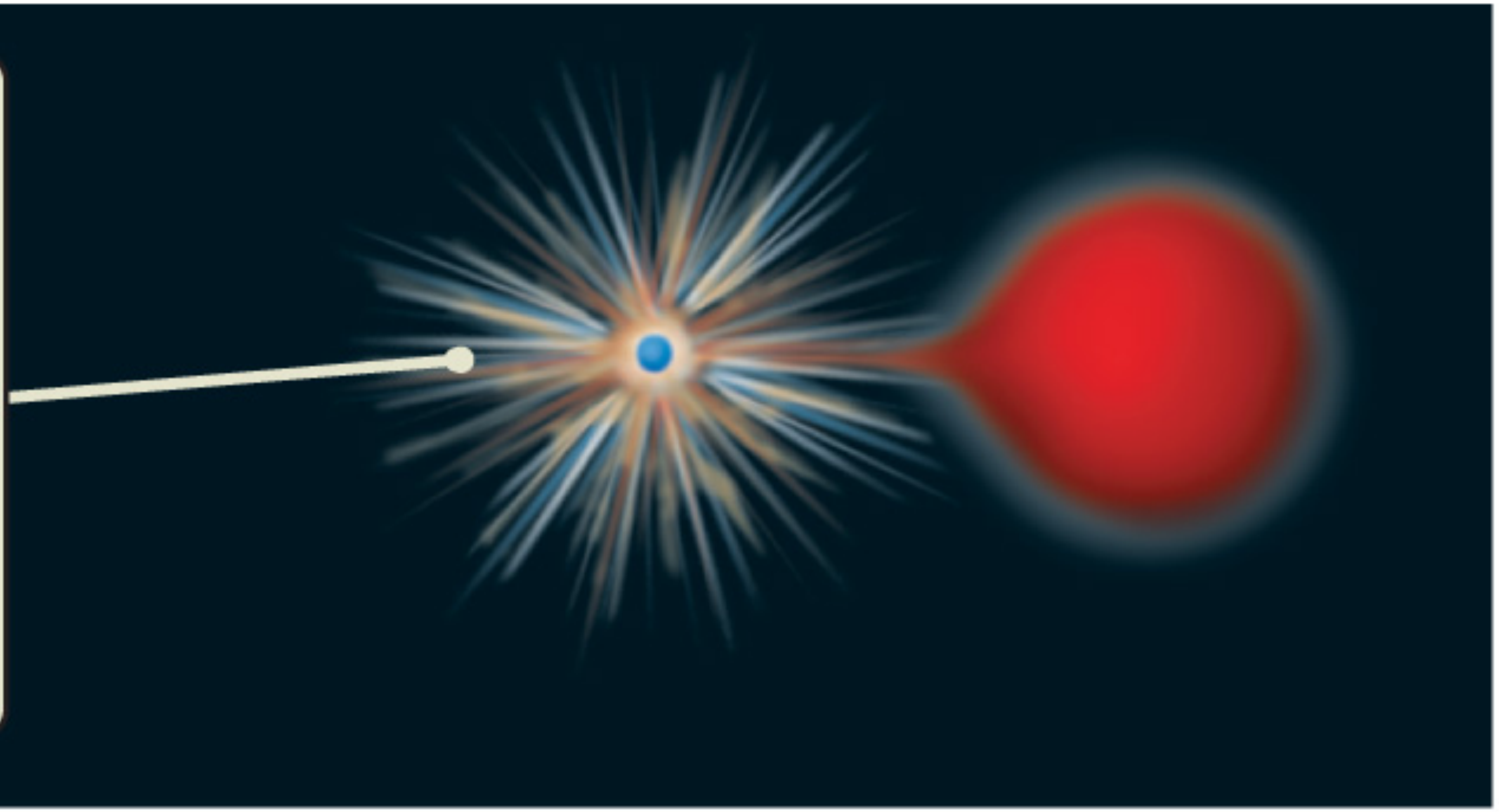


What happens when close binary stars evolve?

A “nova” is what?

A) Material from Star 2 hits the surface of the white dwarf, causing it to heat up
B) Material from Star 2 accumulates on the surface until it’s hot enough to burn (fuse H -> He)
C) Enough material falls on the white dwarf to cause the entire star to explode



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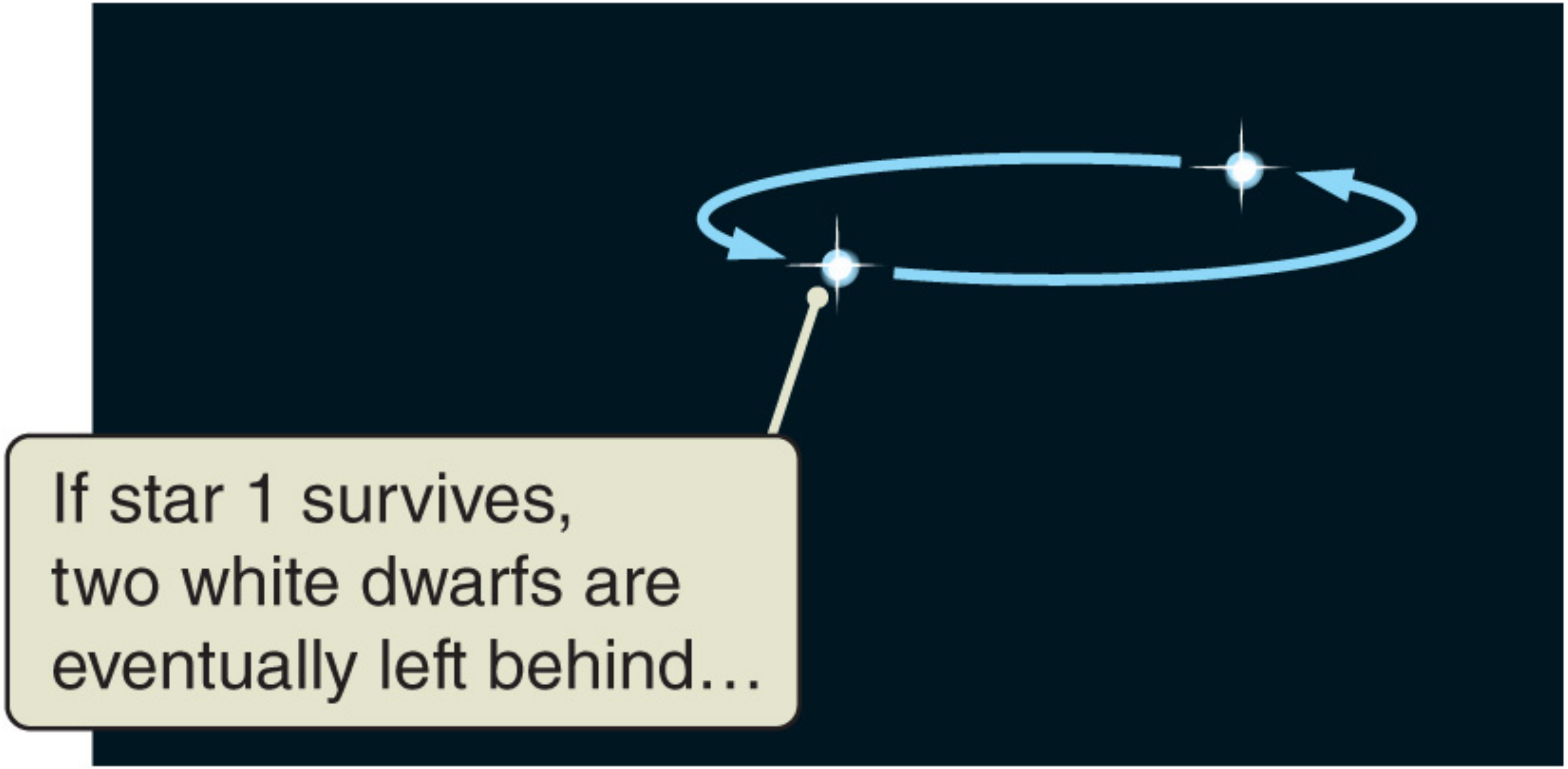

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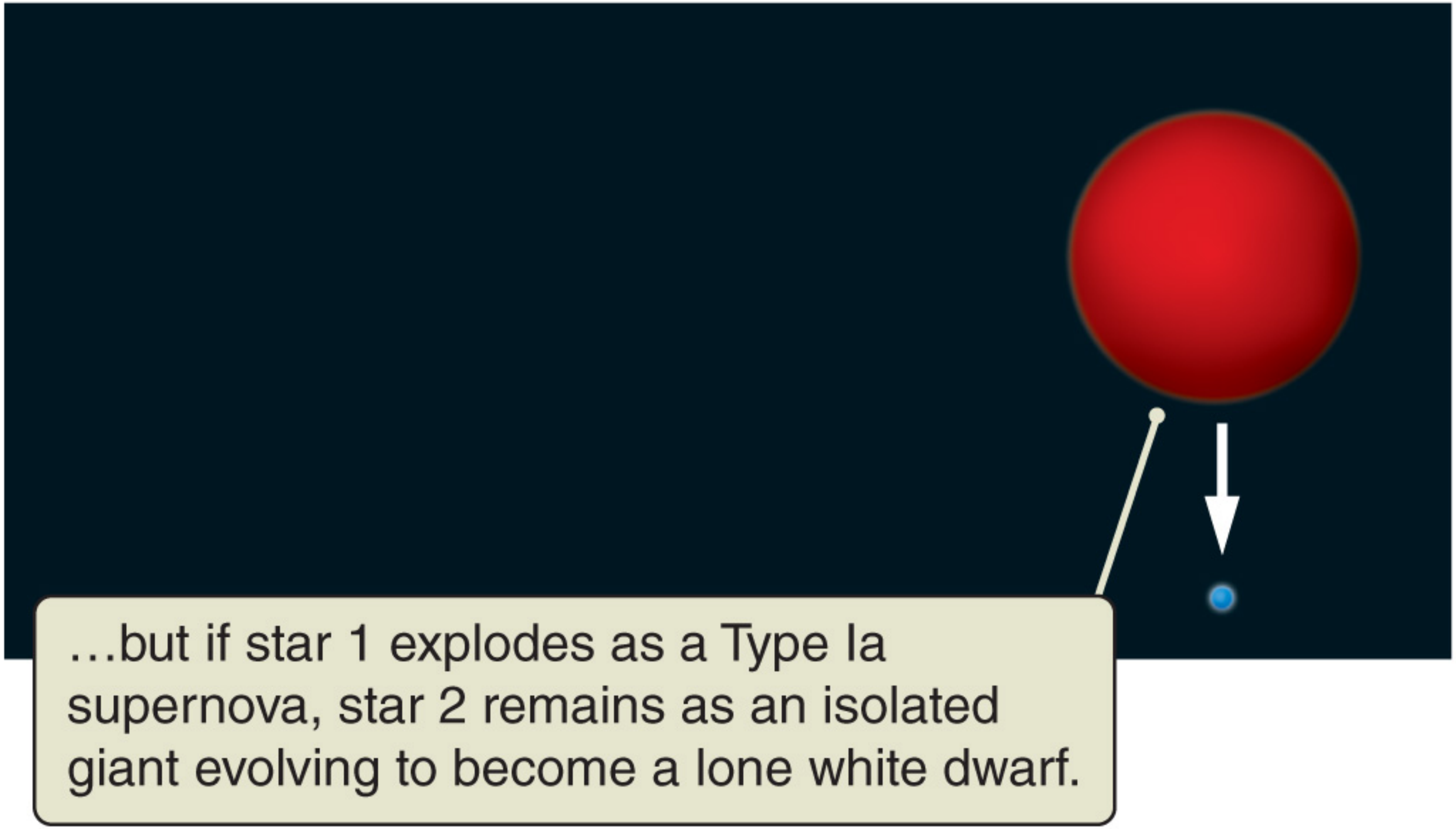
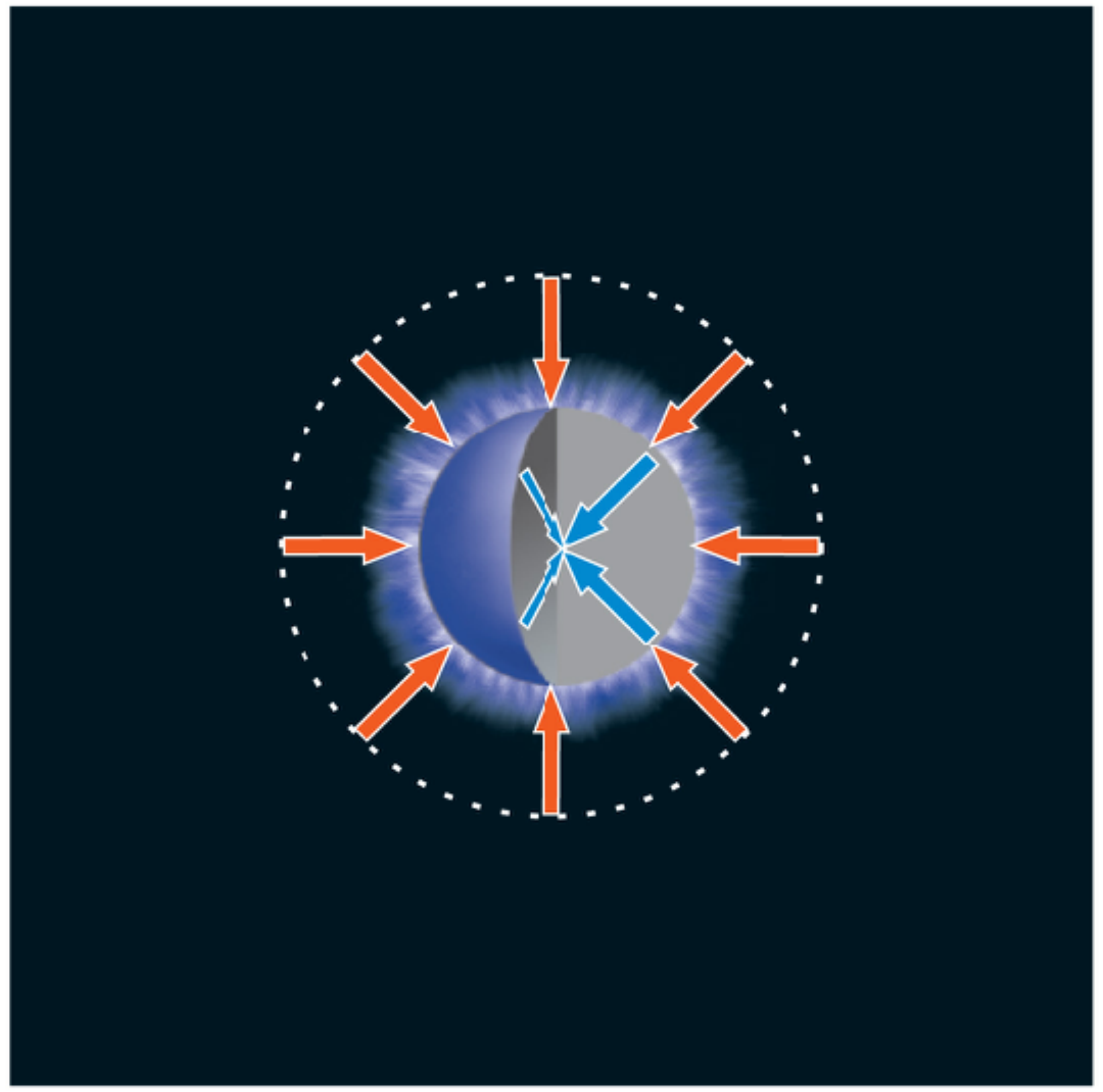
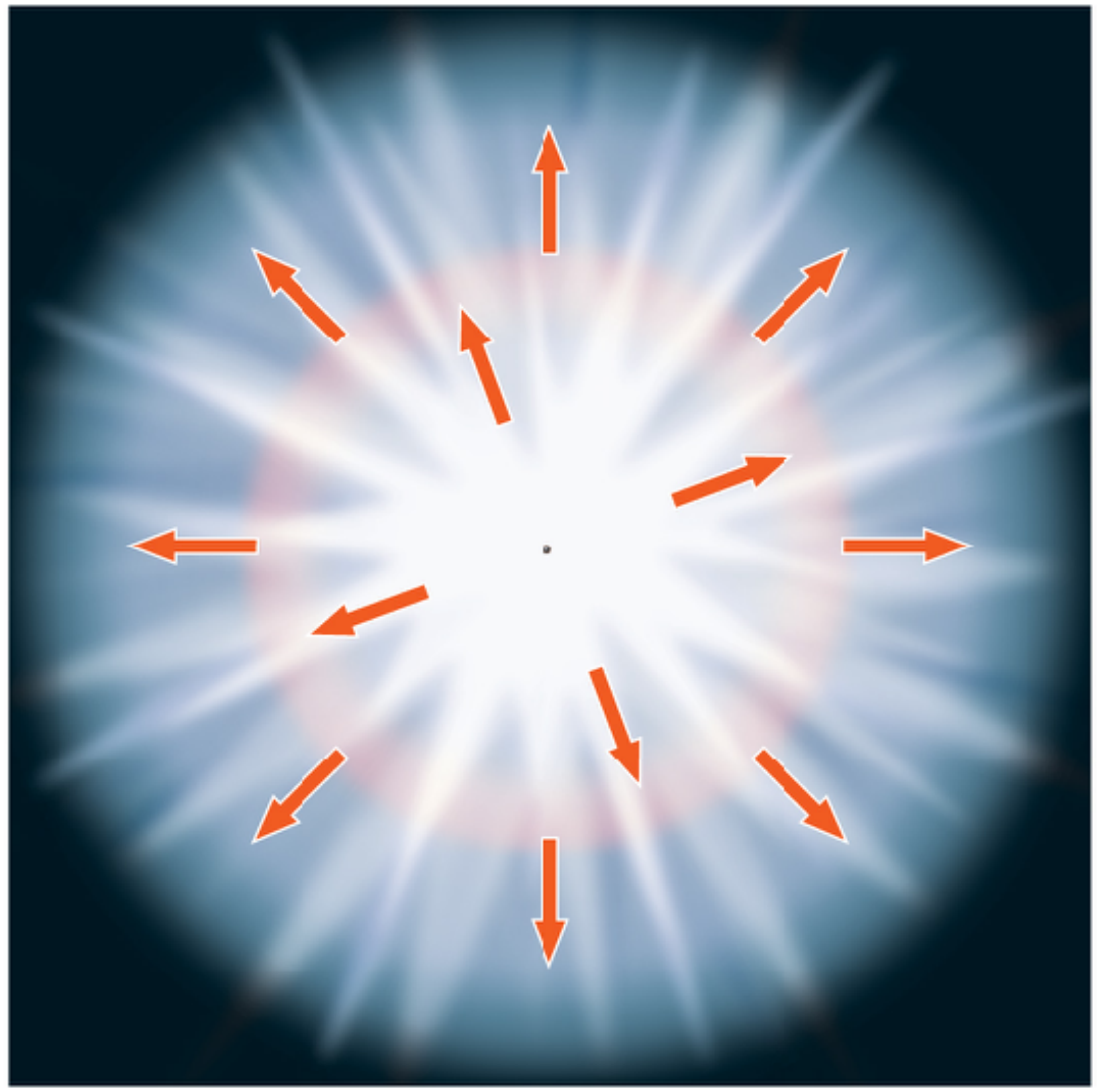


Type Ia Supernovae

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

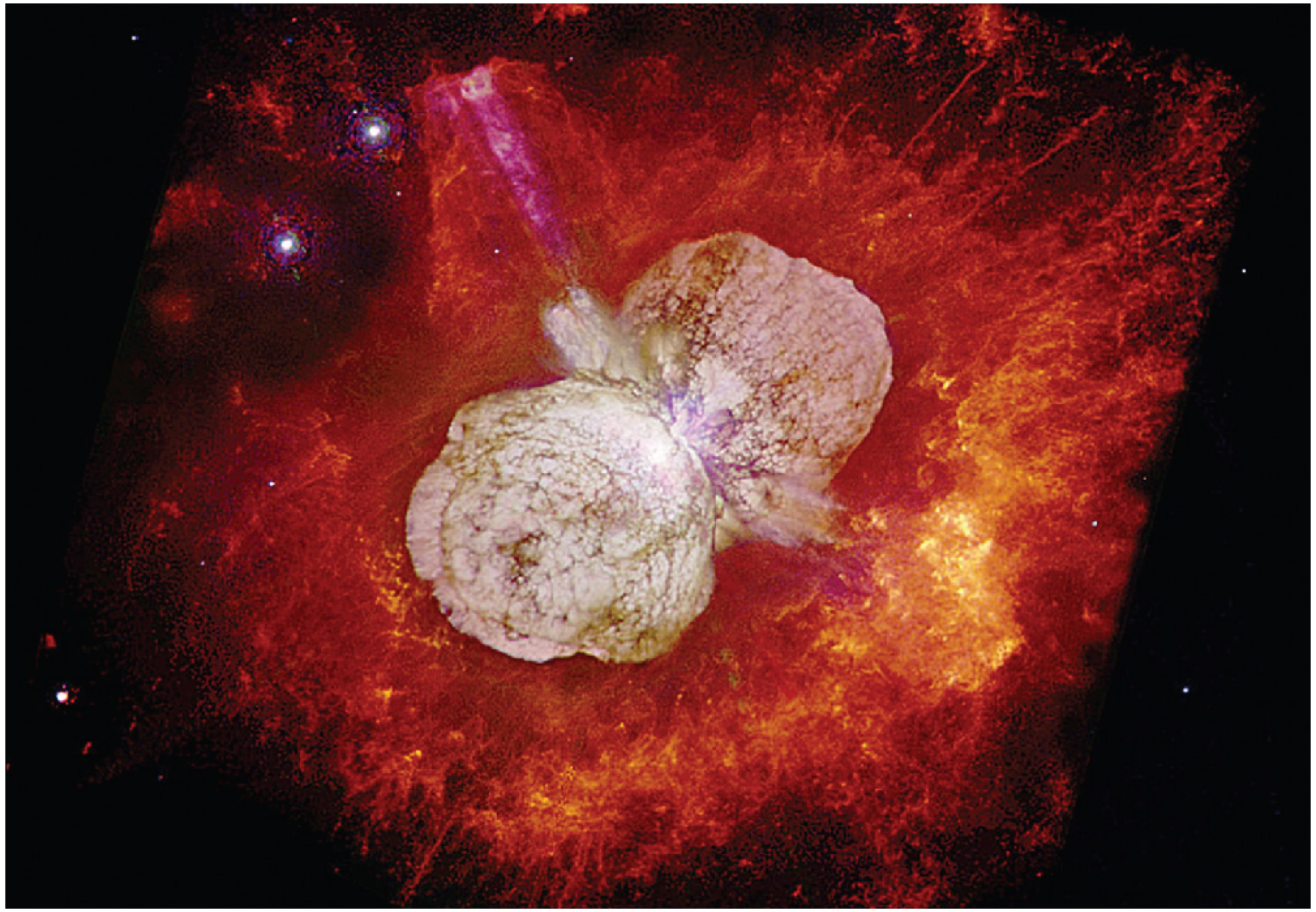


…pushing up the temperature until carbon ignites and burns explosively.



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?

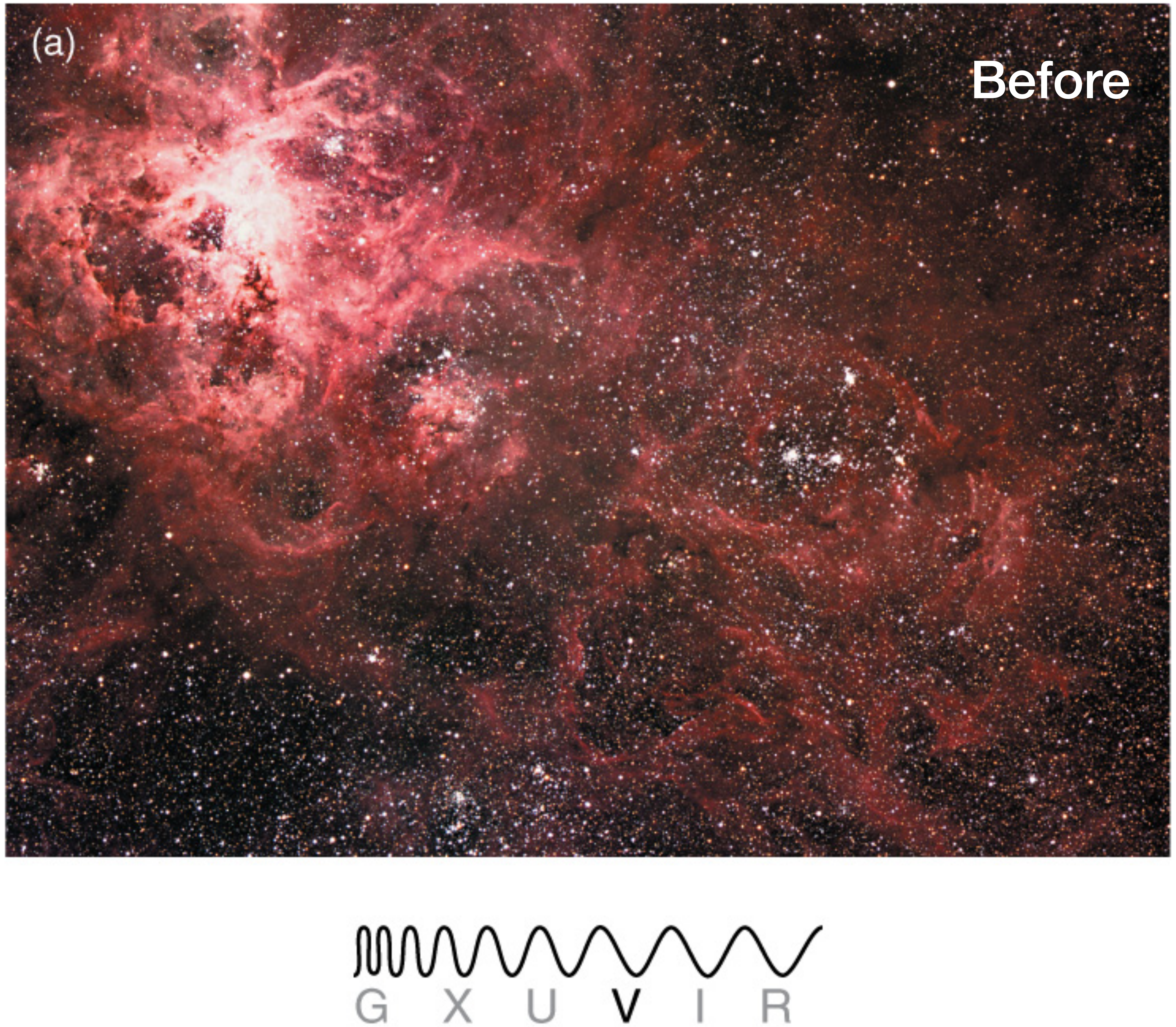
A) High surface temperatures

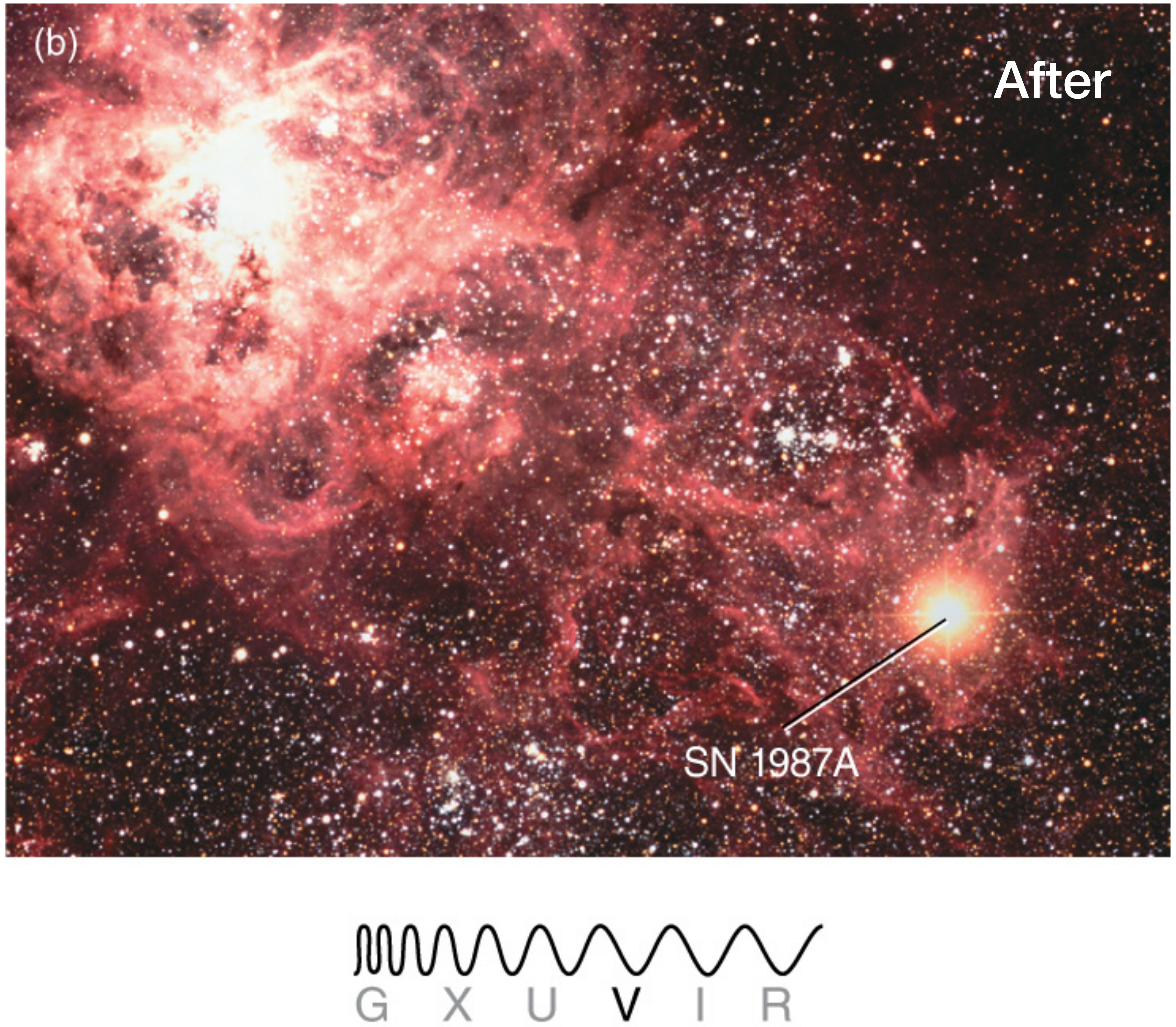
B) Light elements in their atmospheres

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!

A question for Neil DeGrasse Tyson…

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

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Chapter 14 Reading Assignment due on Monday (not yet in Canvas)

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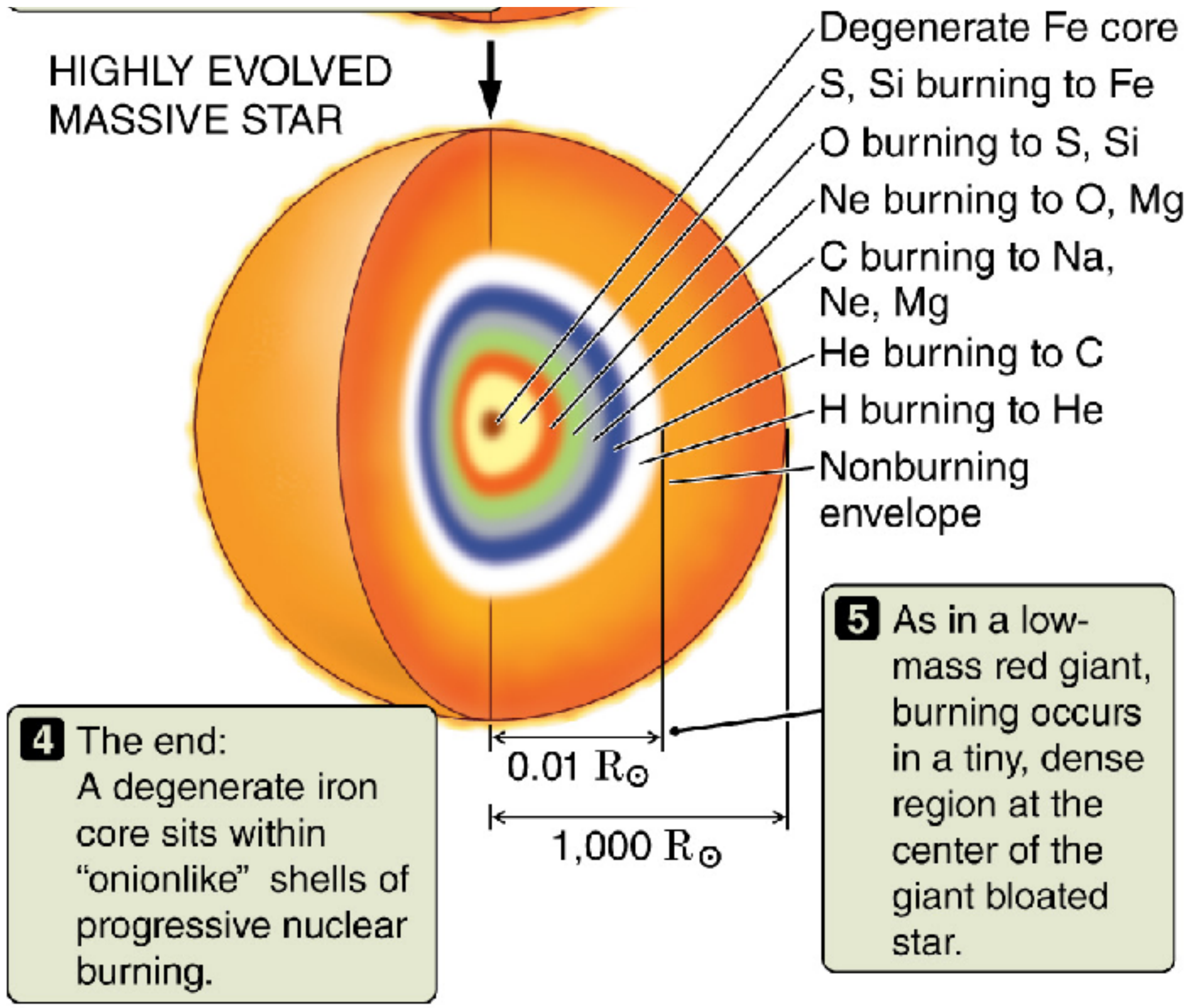
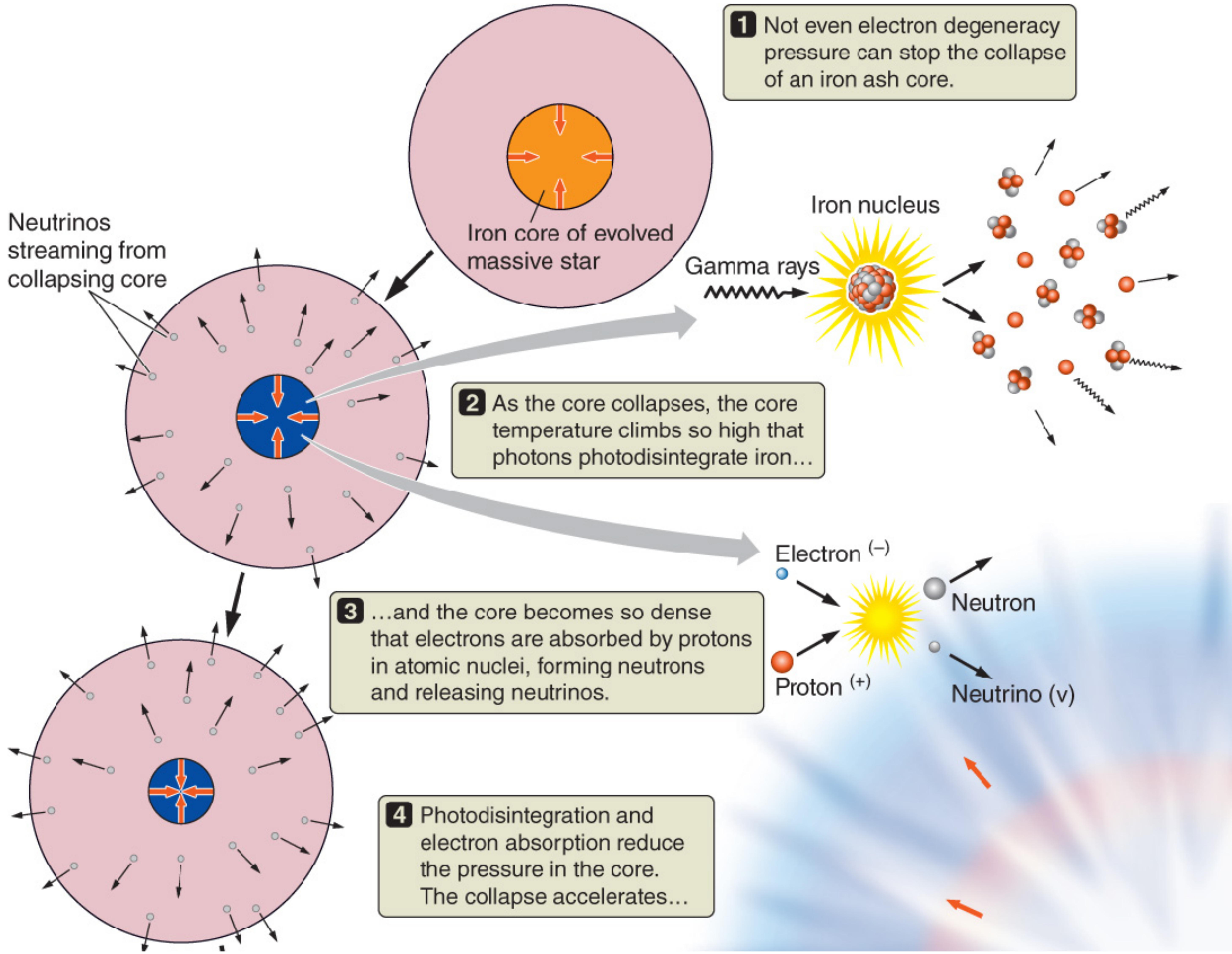
Turn in extra credit planetarium and public observing reports up front when complete

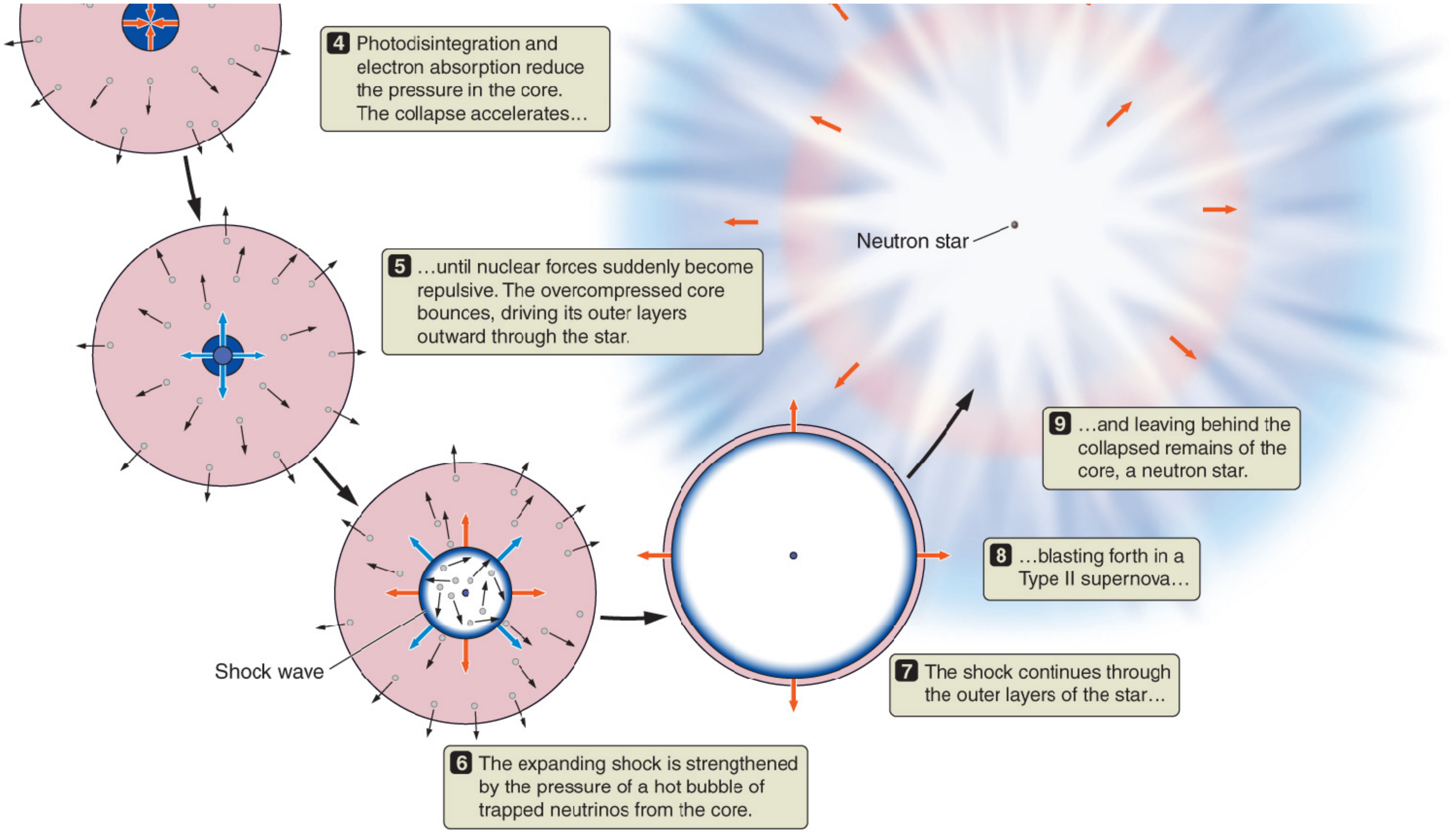
Midterms available up front

Type II Supernovae

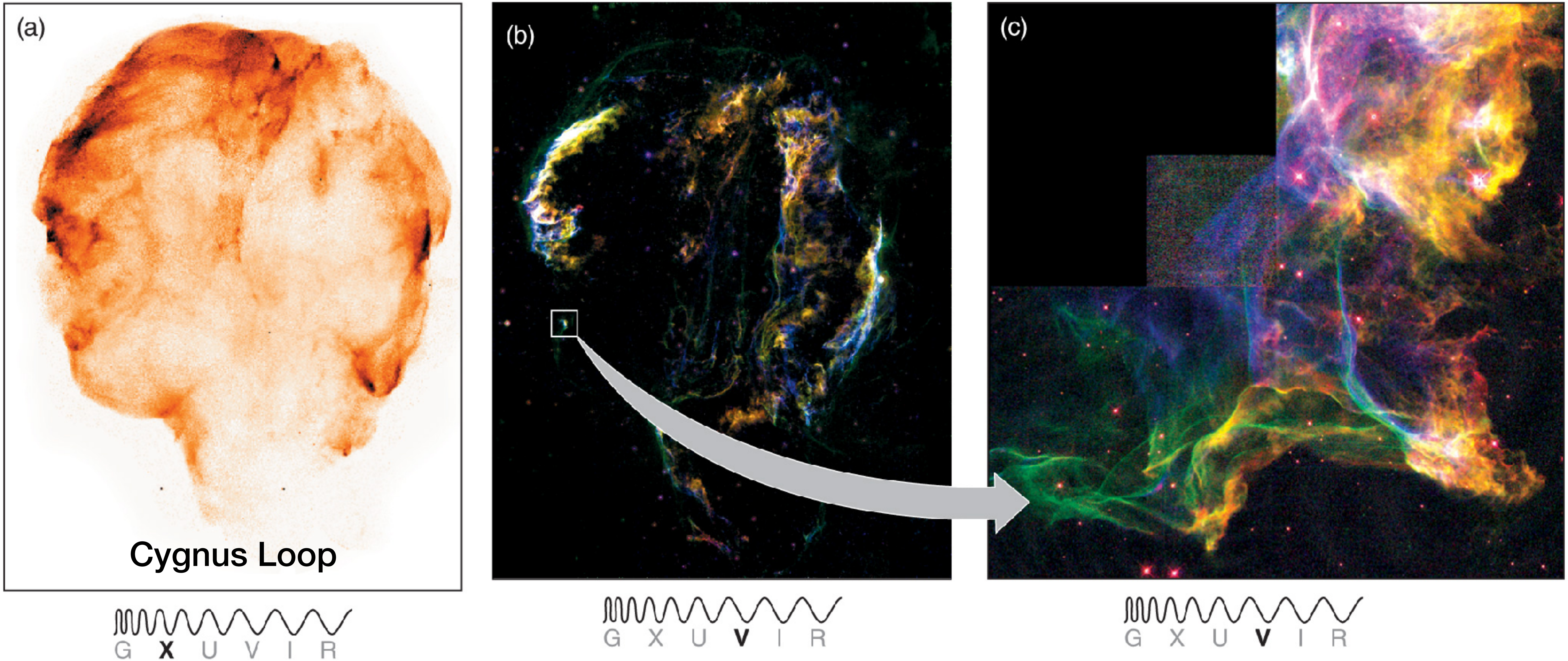




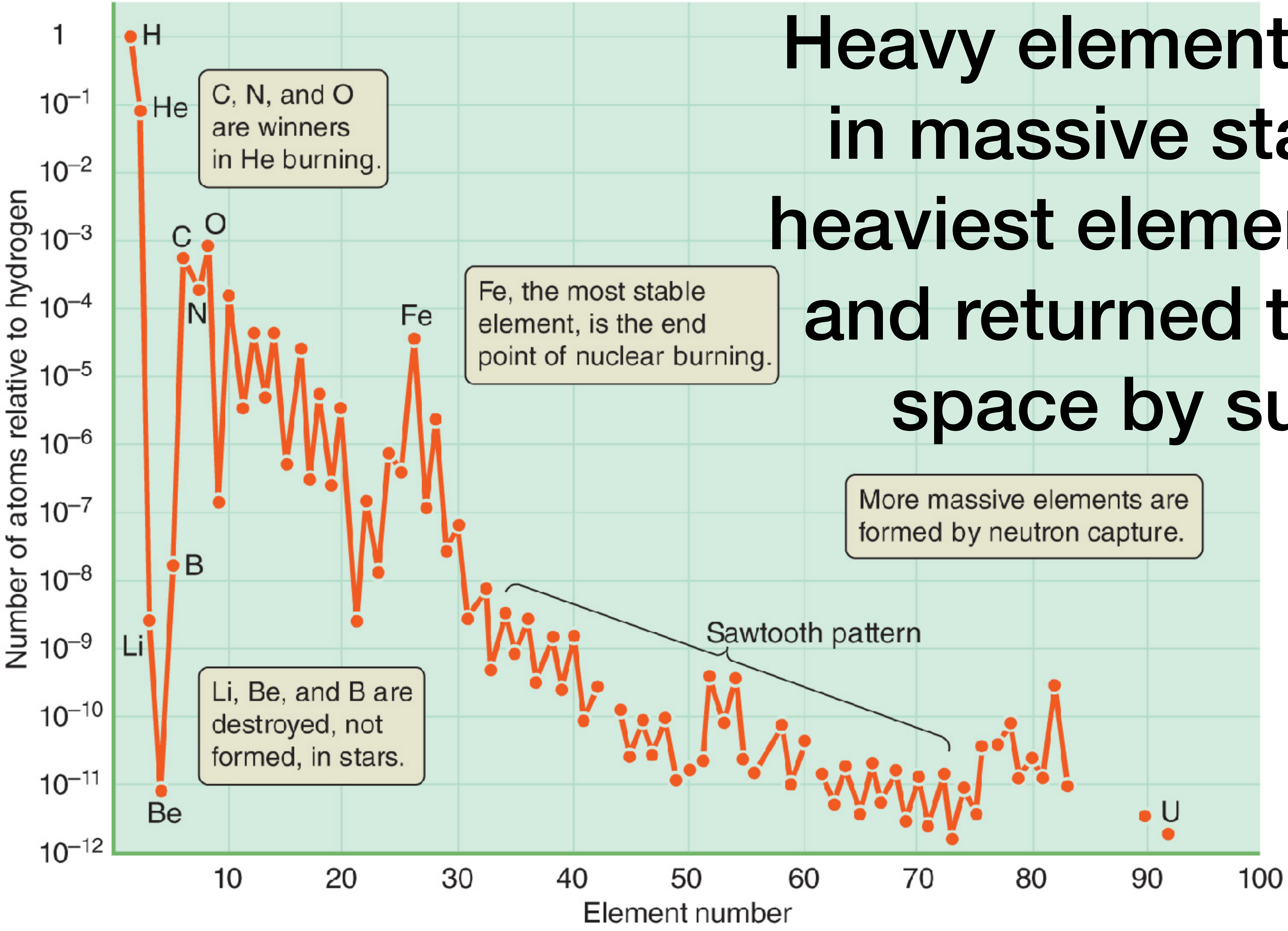
Type II Supernovae



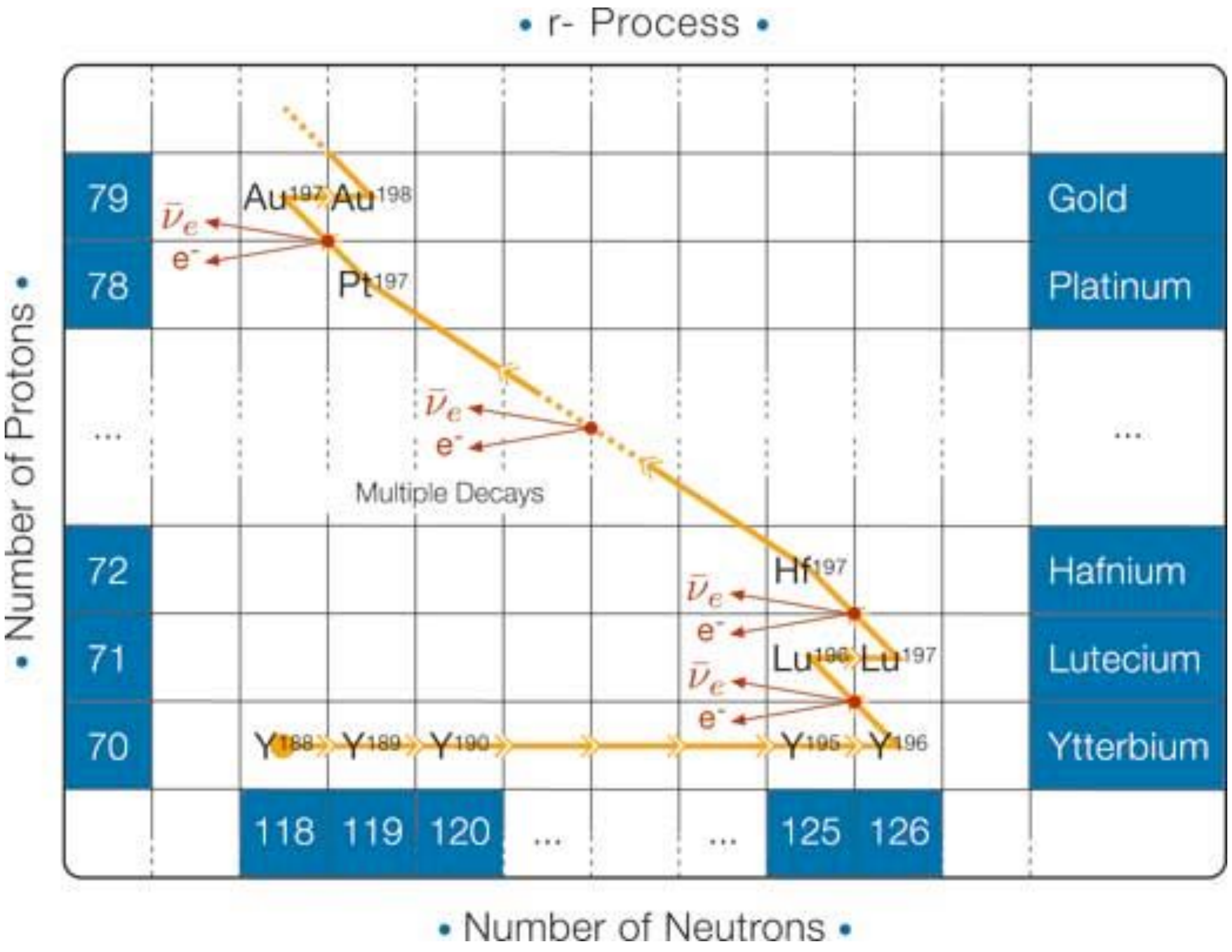
Supernova Remnants

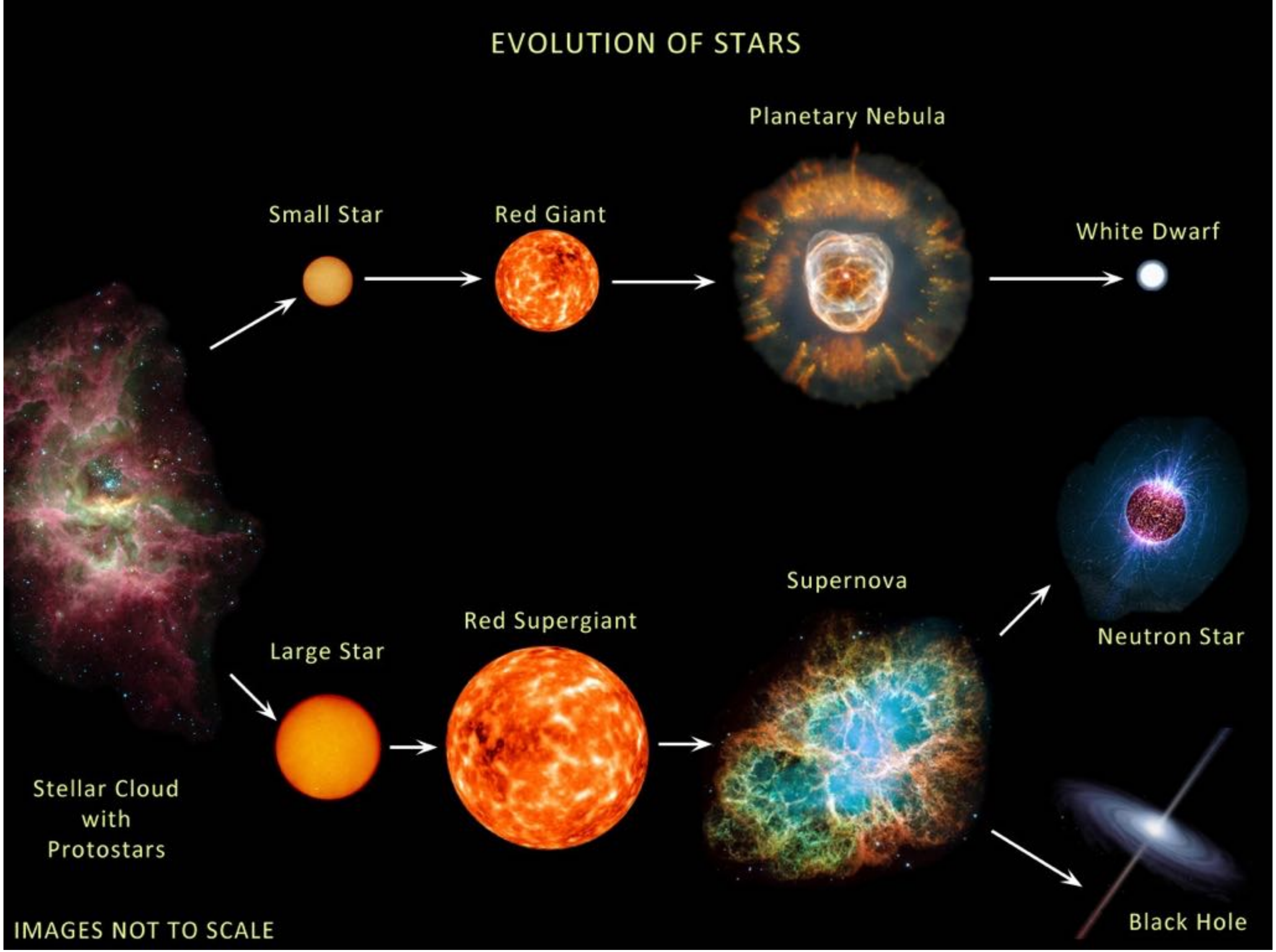


Heavy elements are created in massive stars, with the heaviest elements created in and returned to interstellar space by supernovae



Created in supernovae caused by NS-NS mergers??




EVOLUTION OF STARS
Planetary Nebula
Small Star
Red Giant
White Dwarf
Supernova
Red Supergiant
Neutron Star
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)

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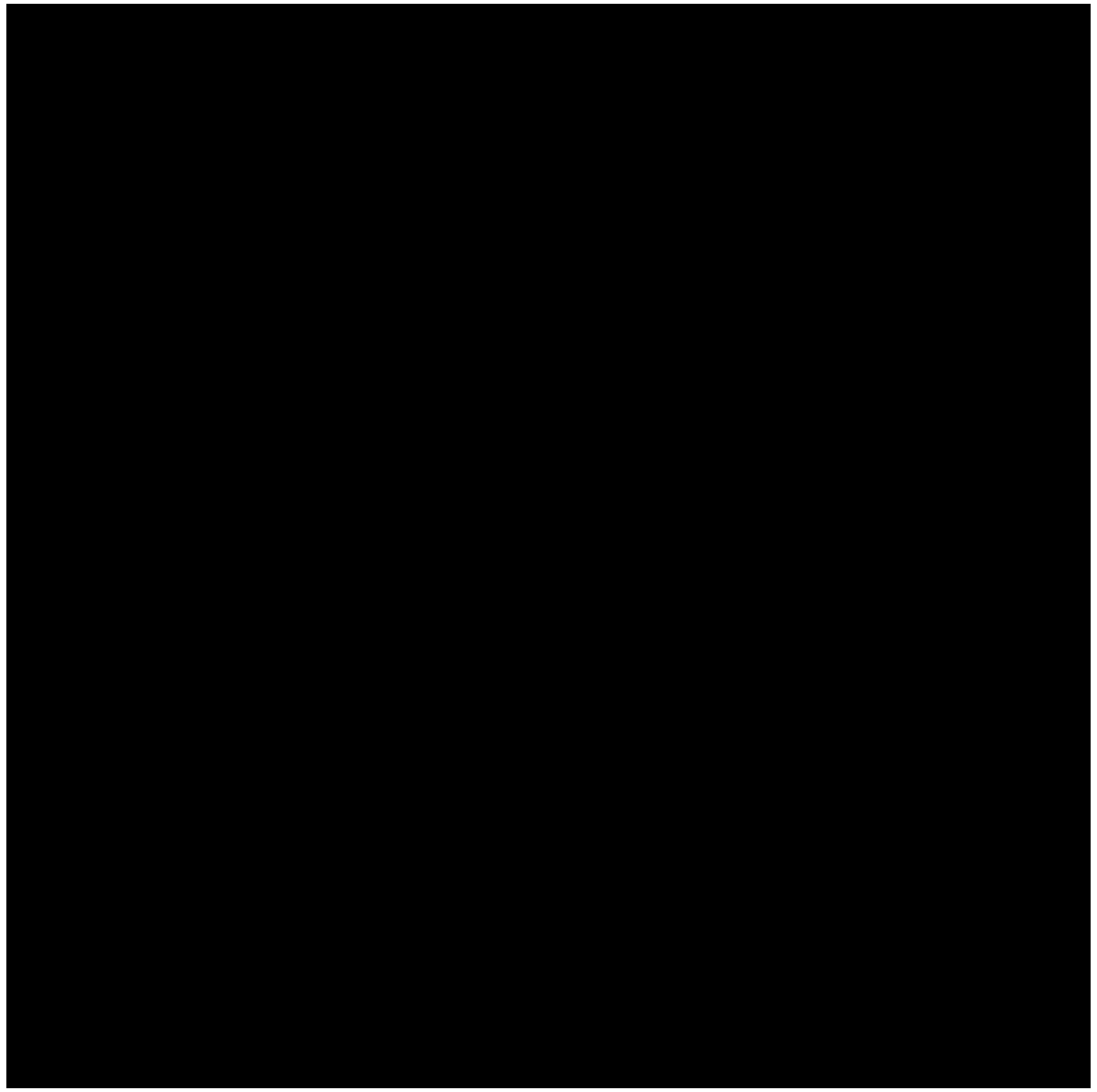
Chapter 14 Reading Assignment due on Wednesday

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

Midterms available up front



Aside: what if the LHC *did* make a black hole?

collapse not instantaneous - the "free fall time" for the Earth to collapse, if all other forces turned off somehow, is about a half hour —> similar to if you drilled a hole through the Earth and fell unimpeded to the center

black hole would still have to grow, plus the solid Earth would take time to "hollow out"

Destruction of Vulcan from the 2009 Star Trek movie

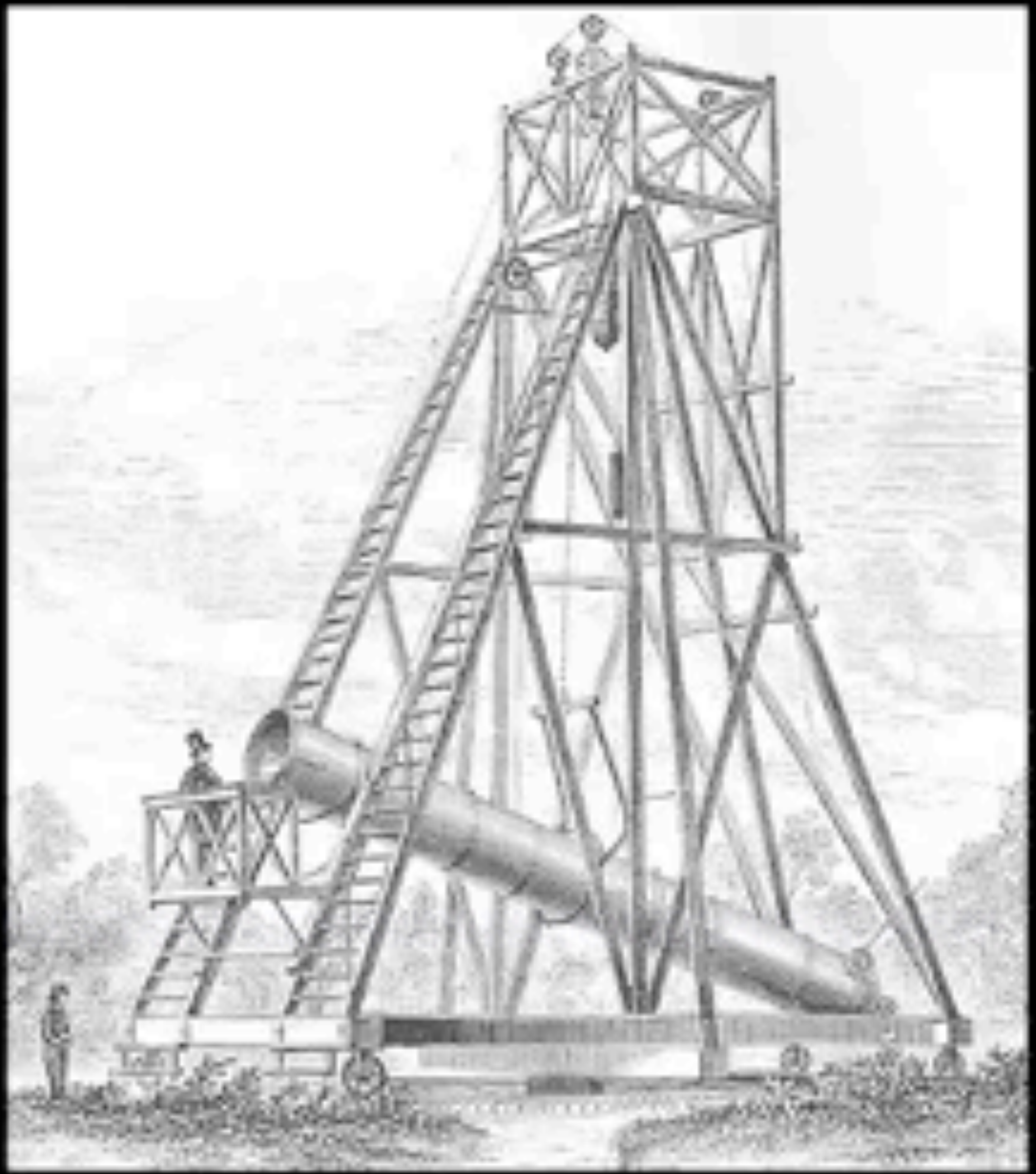
this is just so wrong

Aside: what if the LHC *did* make a black hole?

but the LHC can't make a dangerous black hole at least
—> only accelerates particles to energies of ~10 TeV (10^{14} eV), while cosmic rays hit the atmosphere with energies up to 100 EeV (10^{20} eV), yet we're still here

crew of the Lexx visit Earth, discover it's on the brink of destruction

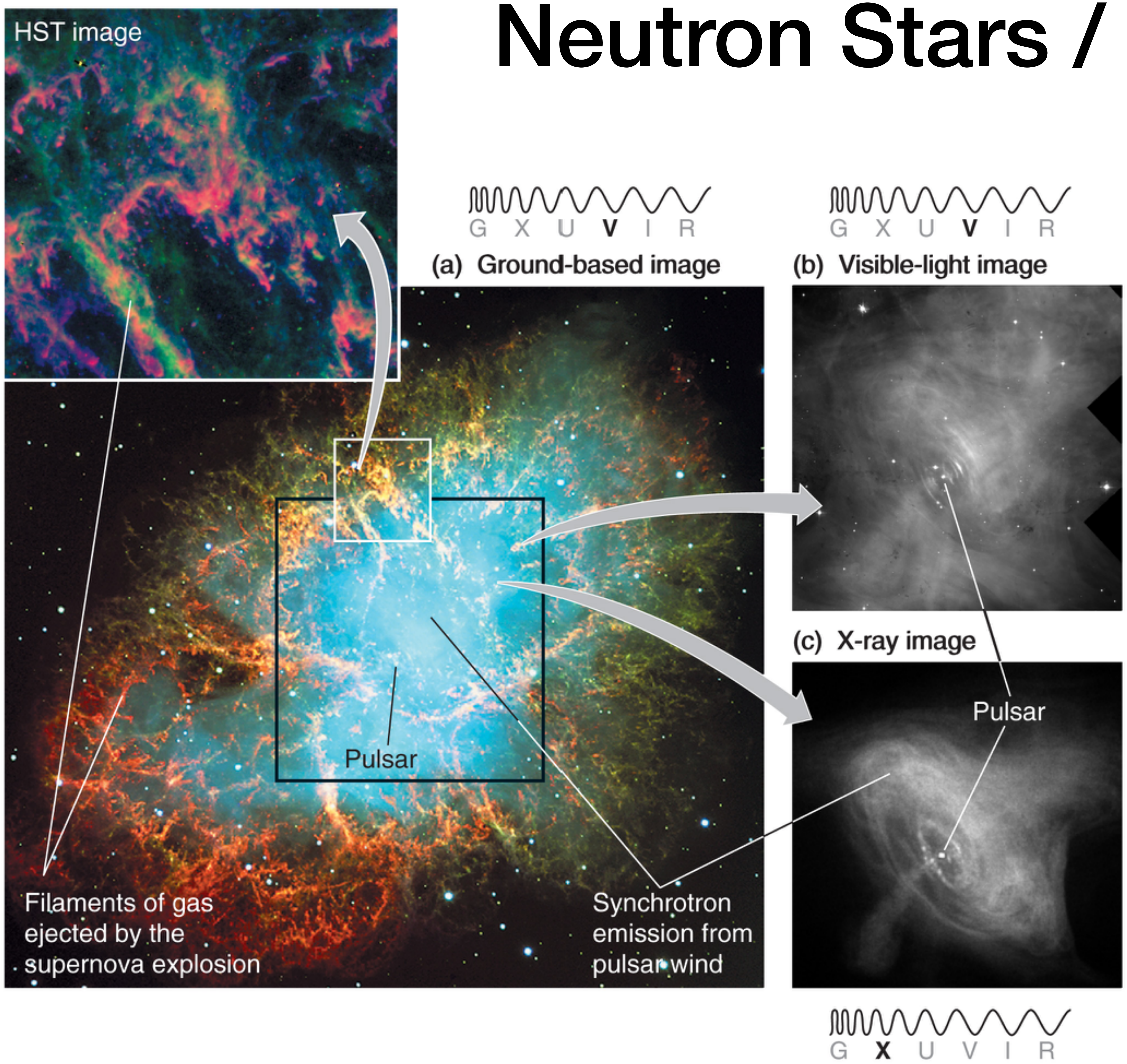
from the sci-fi show *Lexx*, which you should tell no one I told you existed

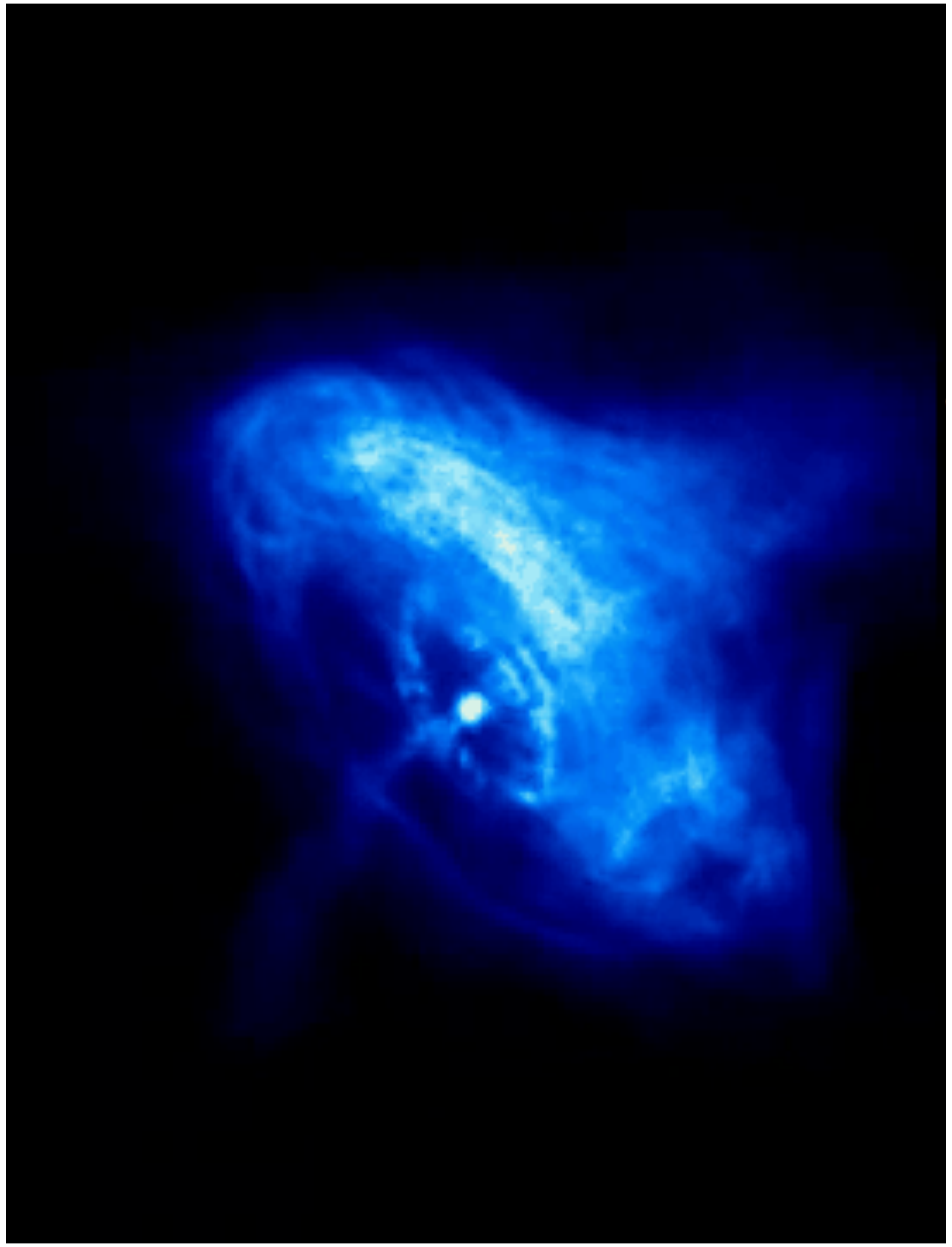


Crab Nebula
1844 Sketch by William Parsons

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

Neutron Stars / Pulsars





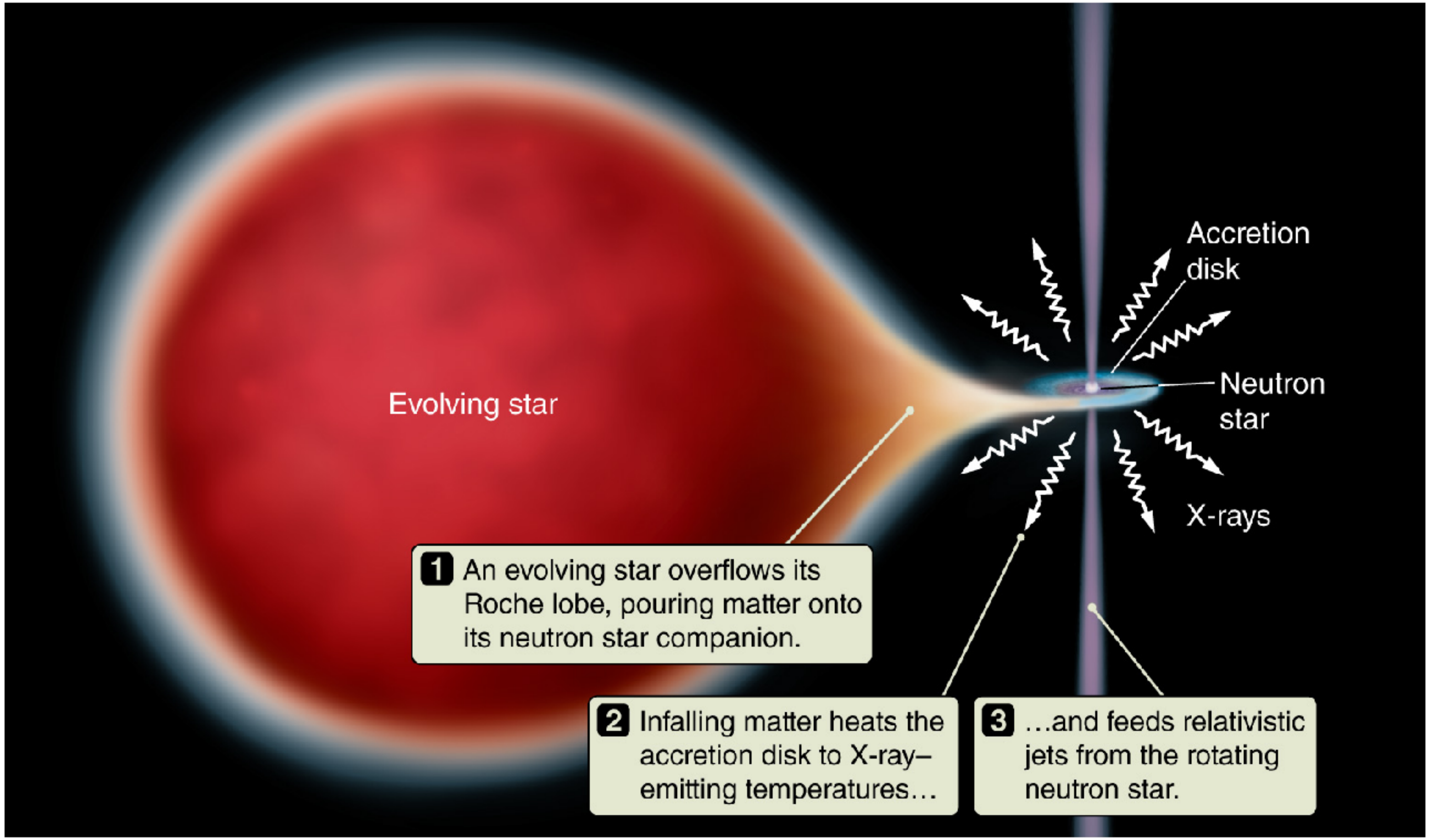
Neutron Stars are born with strong magnetic fields (get stronger as the core collapses)

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

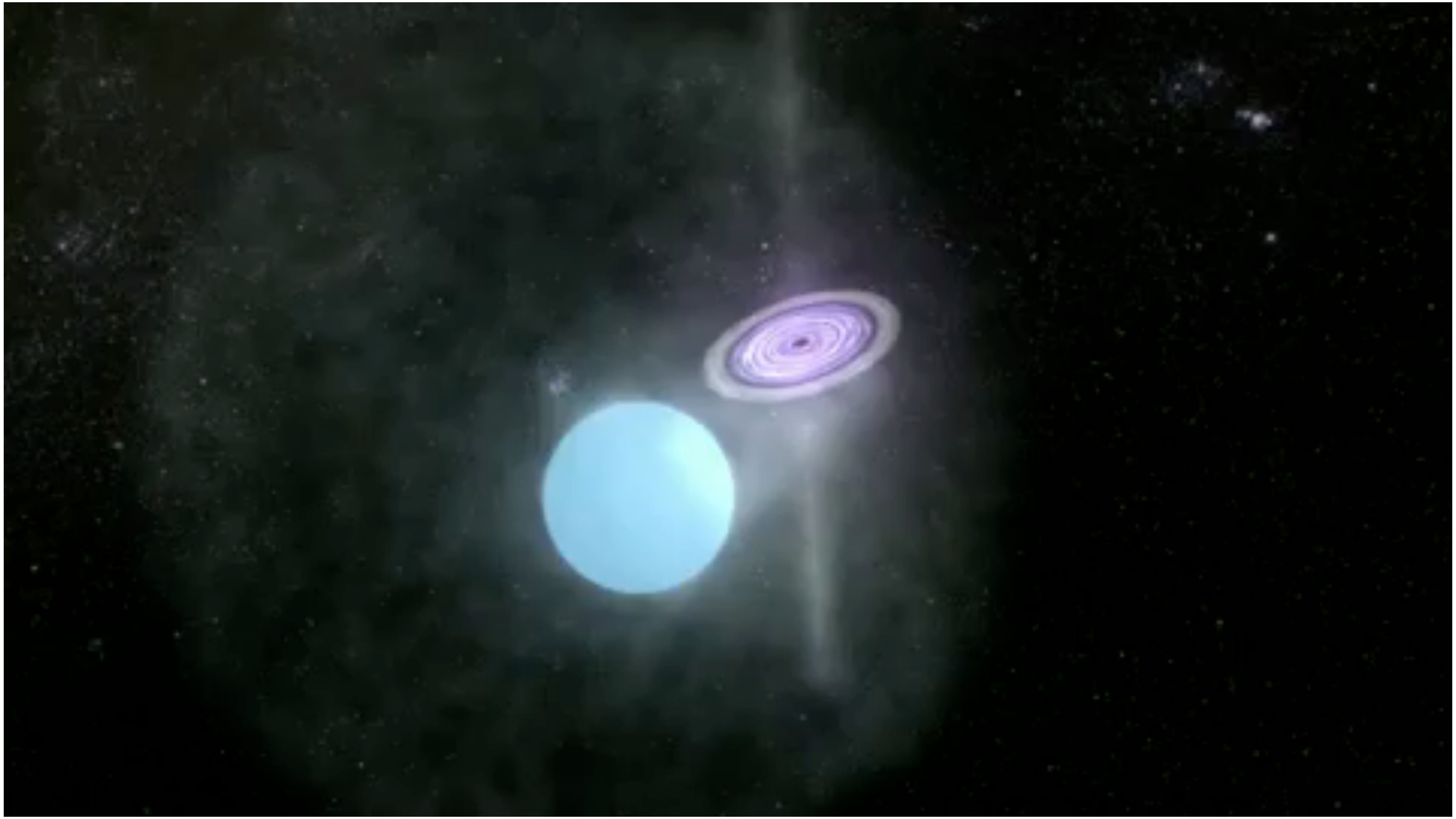
We see the beam once or twice each time the star rotates

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

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

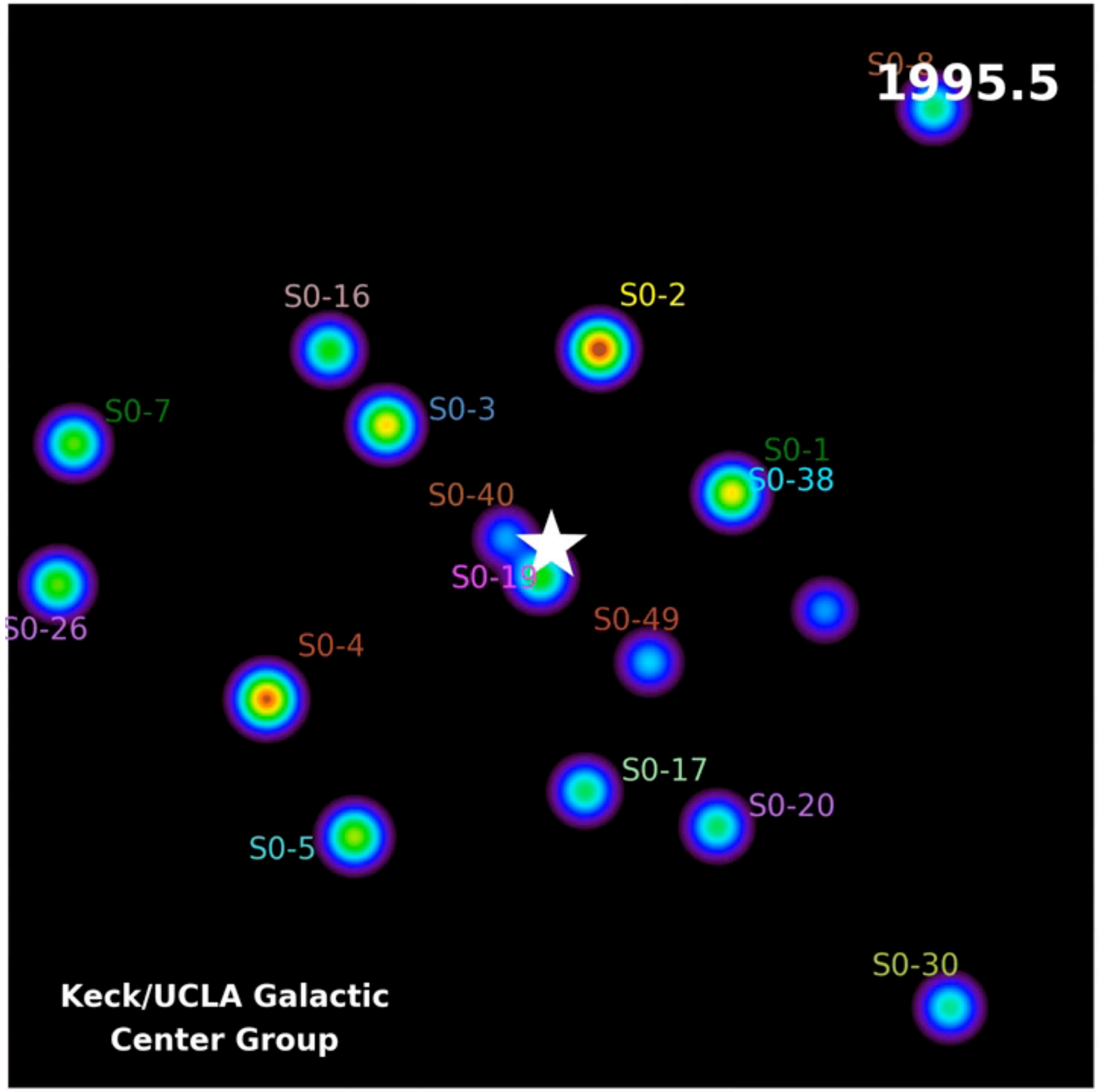


Neutron star accreting material from a high mass star

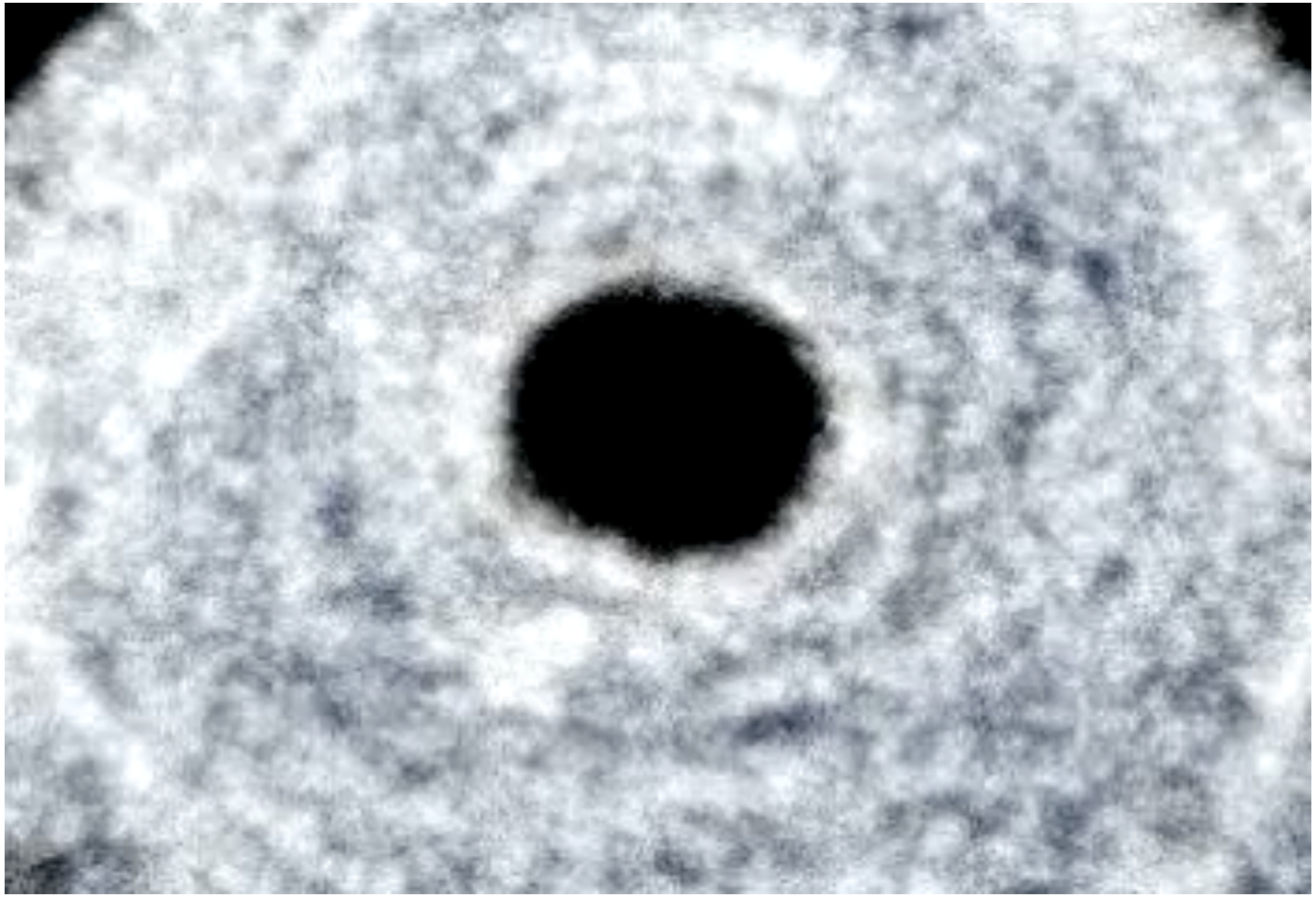


How do we know black holes ACTUALLY exist in the Universe?

Highly suggestive results that black holes exist



Stars orbiting SMBH in center of our galaxy

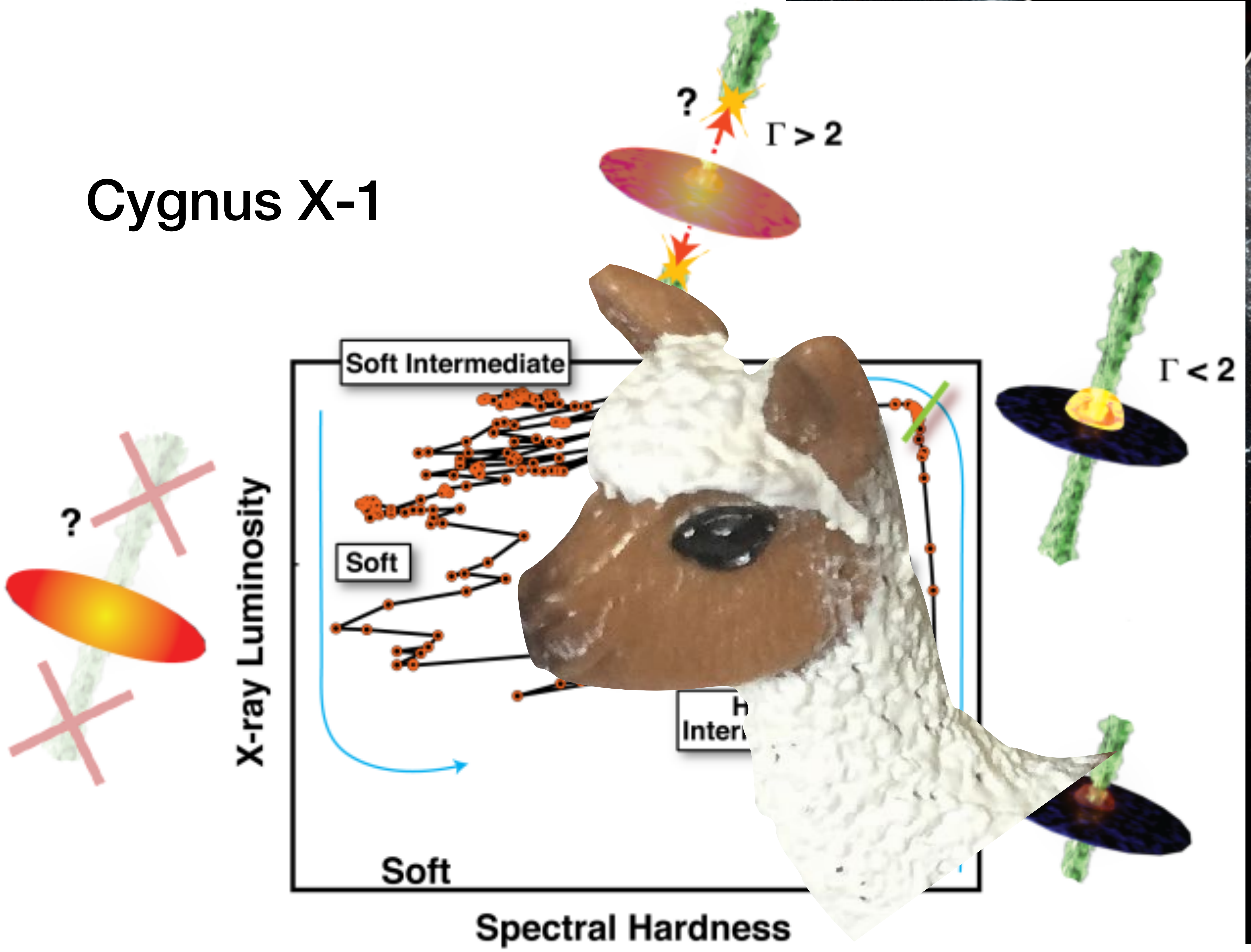


Animation of gas falling into SMBH in M87 galaxy

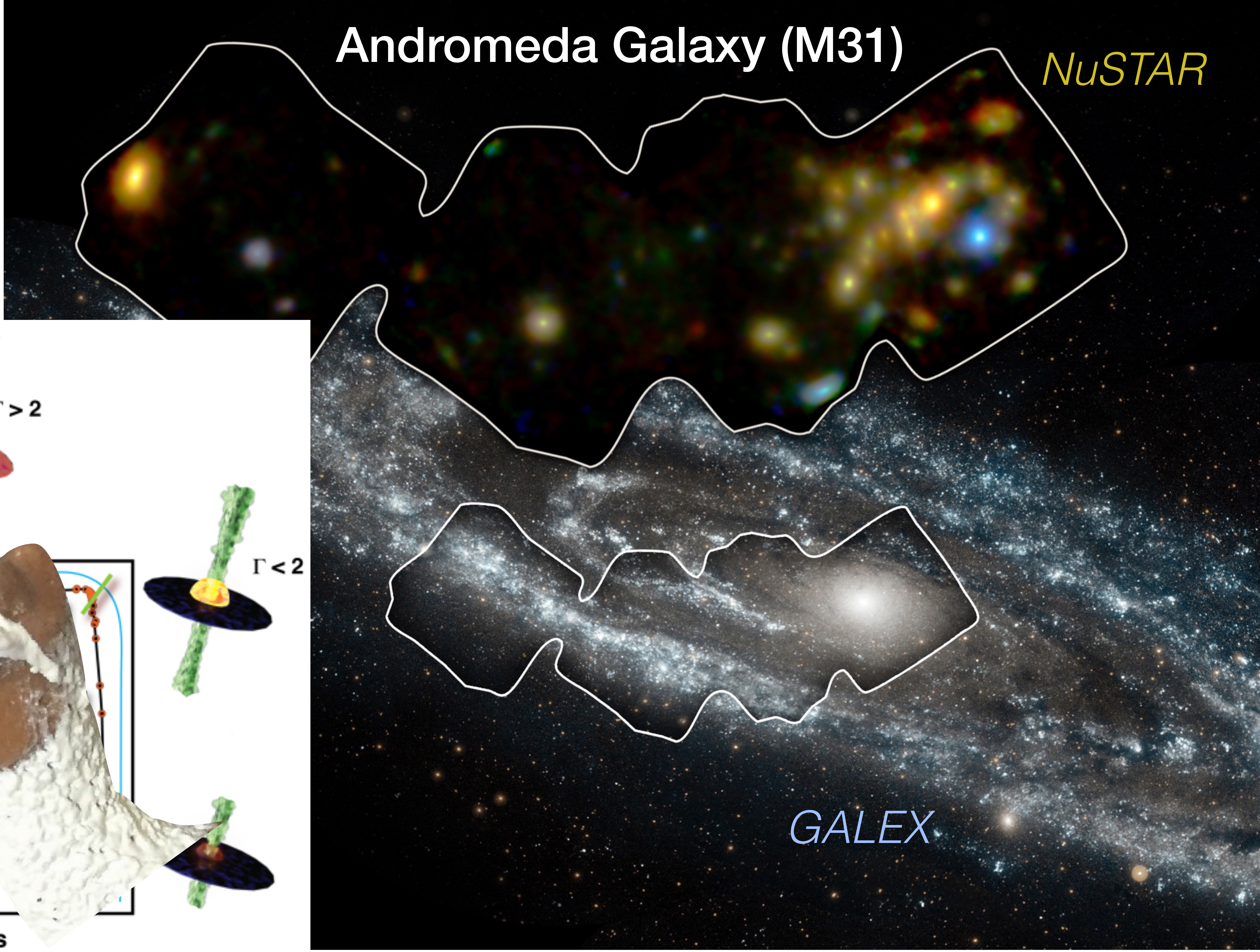
Cygnus X-1: First X-ray source and confirmed black hole

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

Cygnus X-1



?
Γ > 2
Γ < 2
Soft Intermediate
Soft
X-ray Luminosity
Soft
Spectral Hardness



Andromeda Galaxy (M31)
NuSTAR
GALEX

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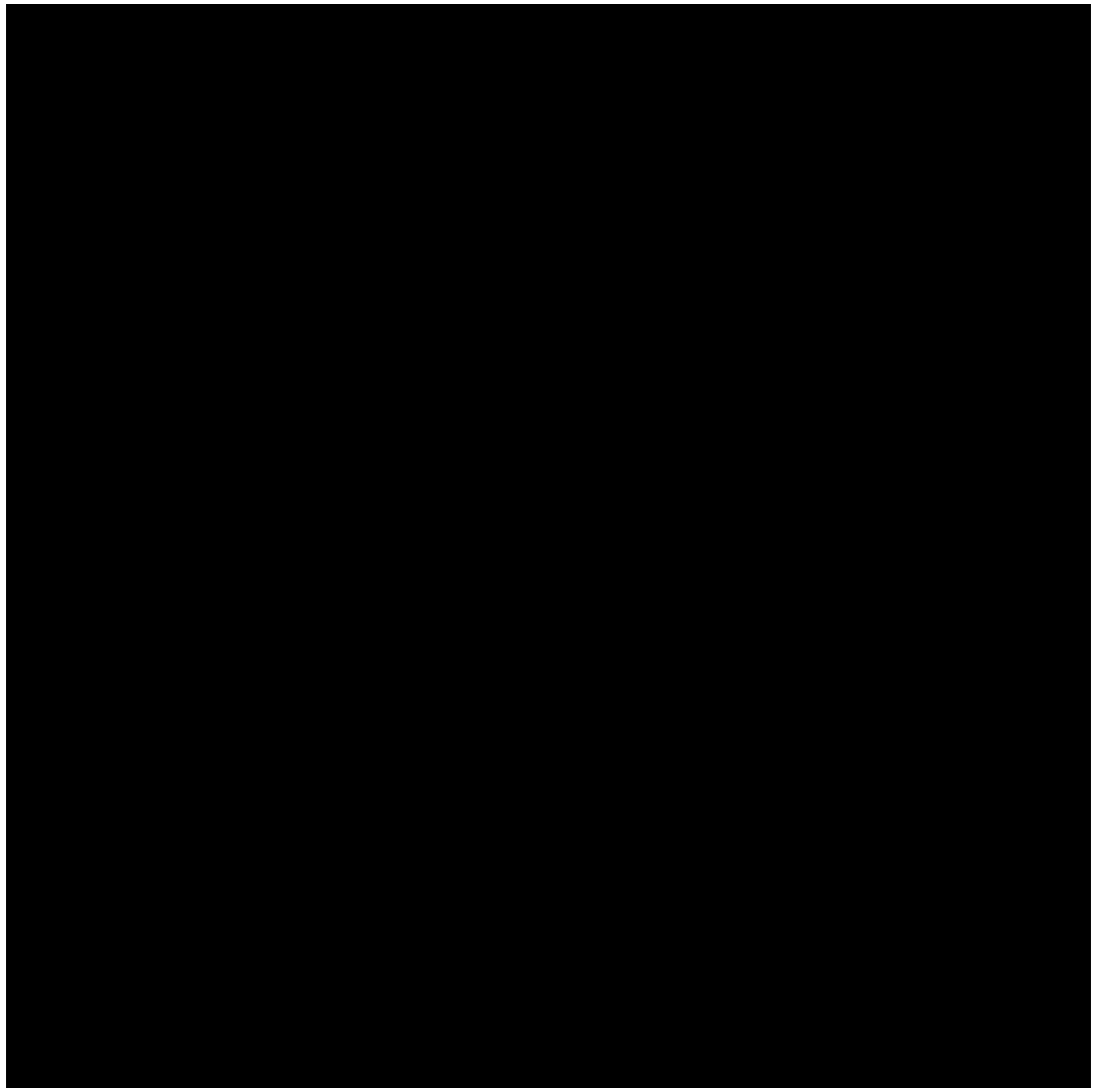

Chapter 14 Reading Assignment due on Wednesday

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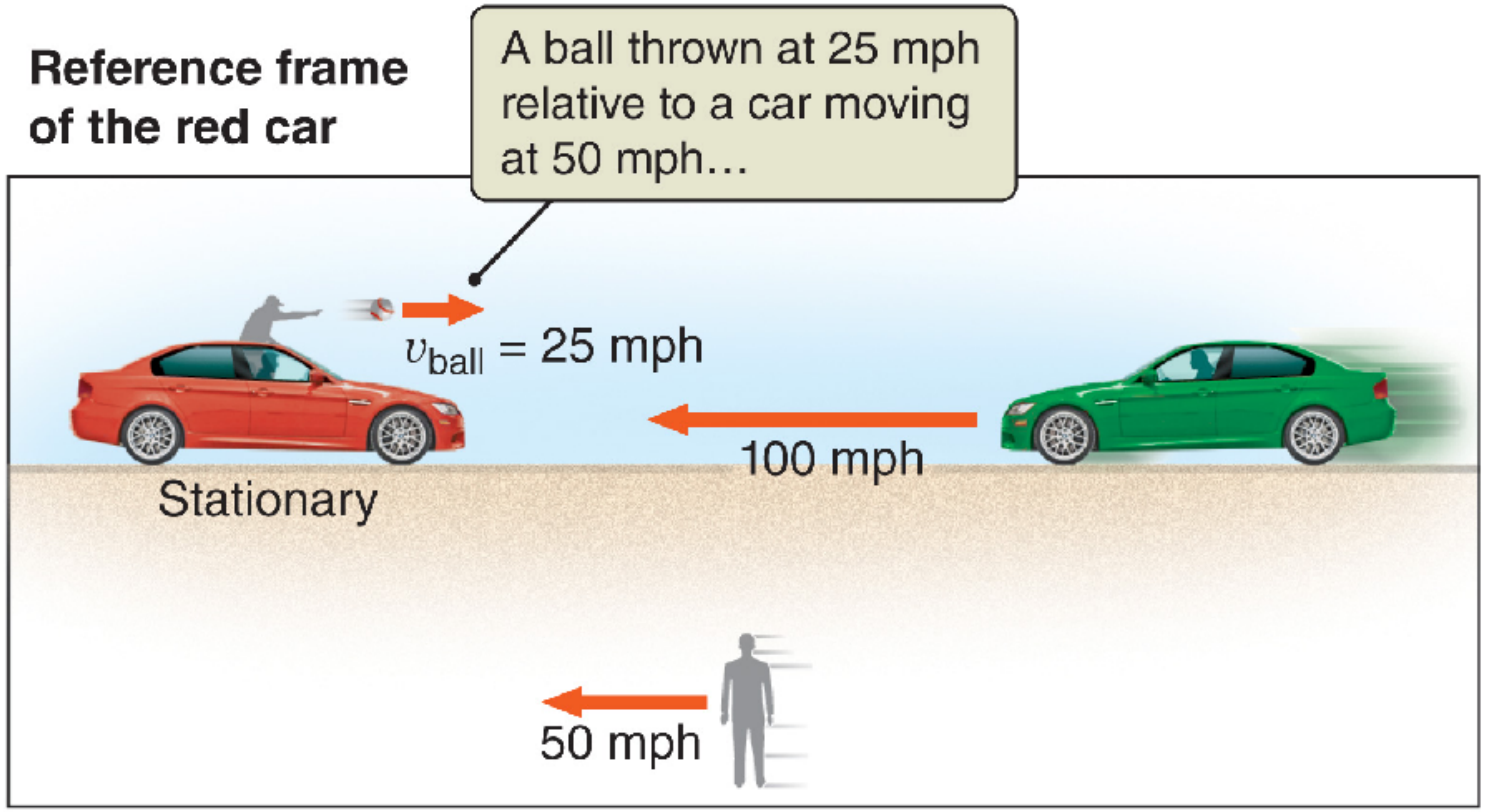
Midterms available up front

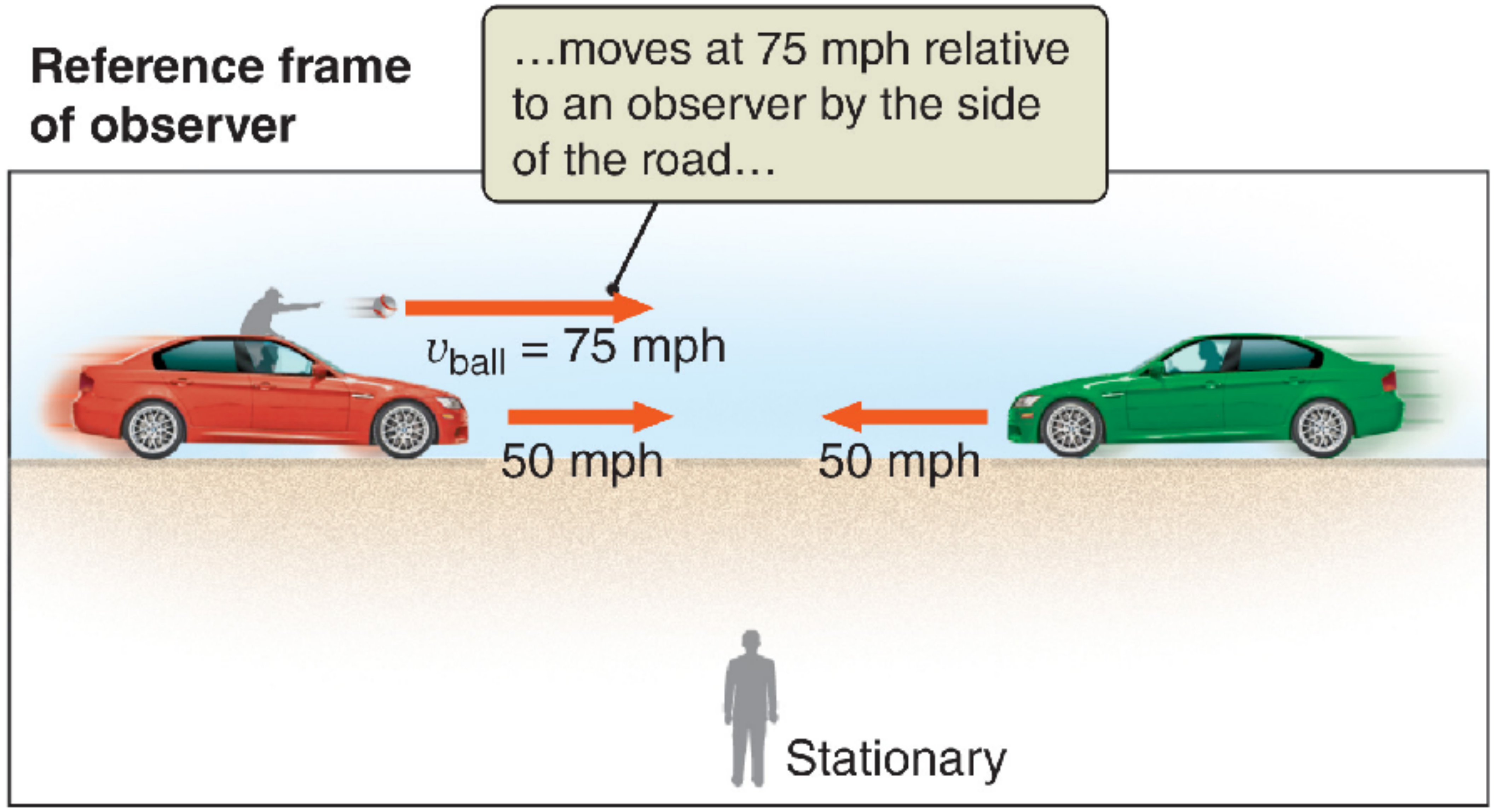
To understand black holes and extreme gravity, we need help from Einstein and Hawking

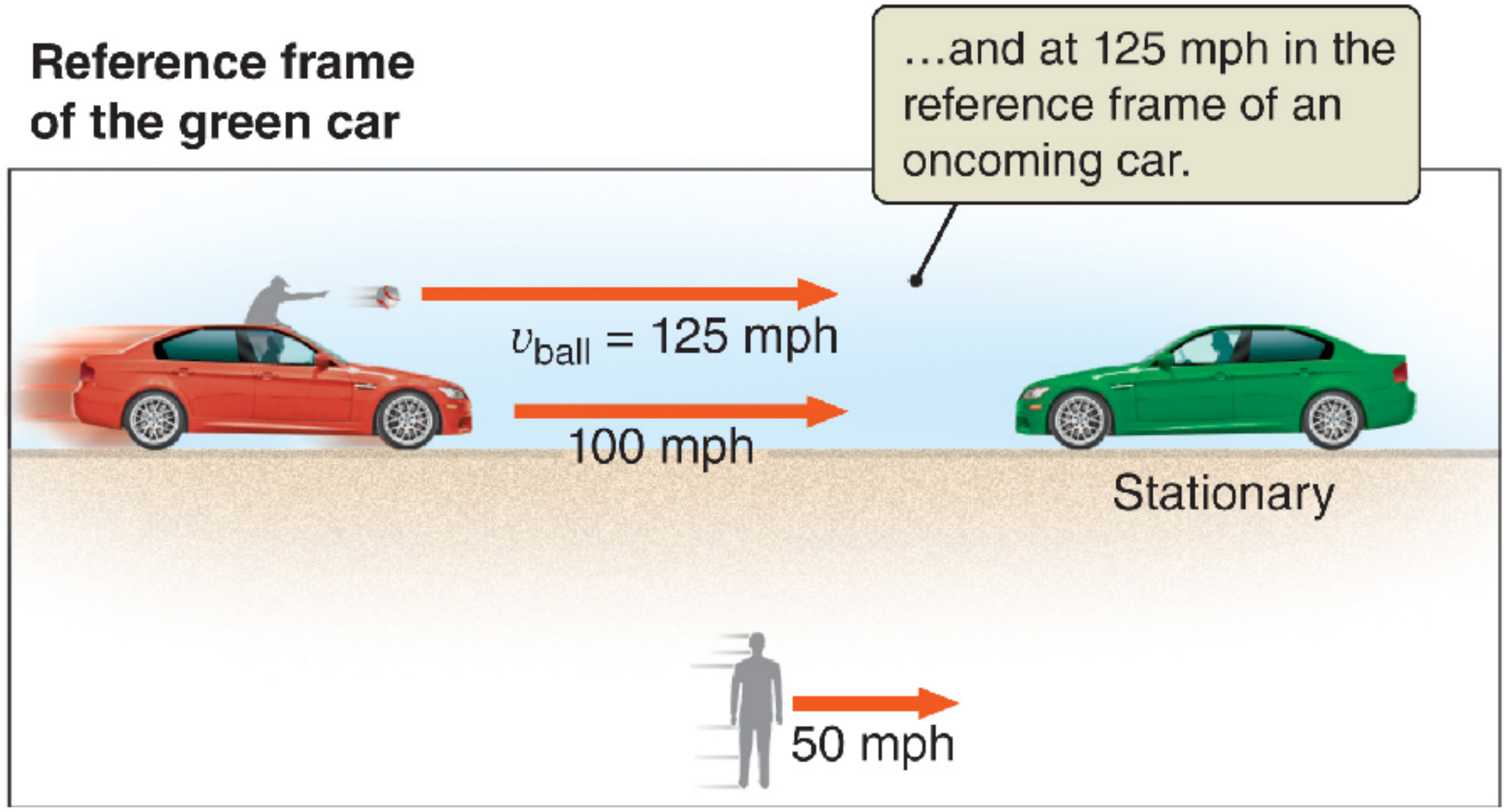
But first, what do you know about black holes and/or relativity?

Reference Frames

In everyday experience velocities simply add…



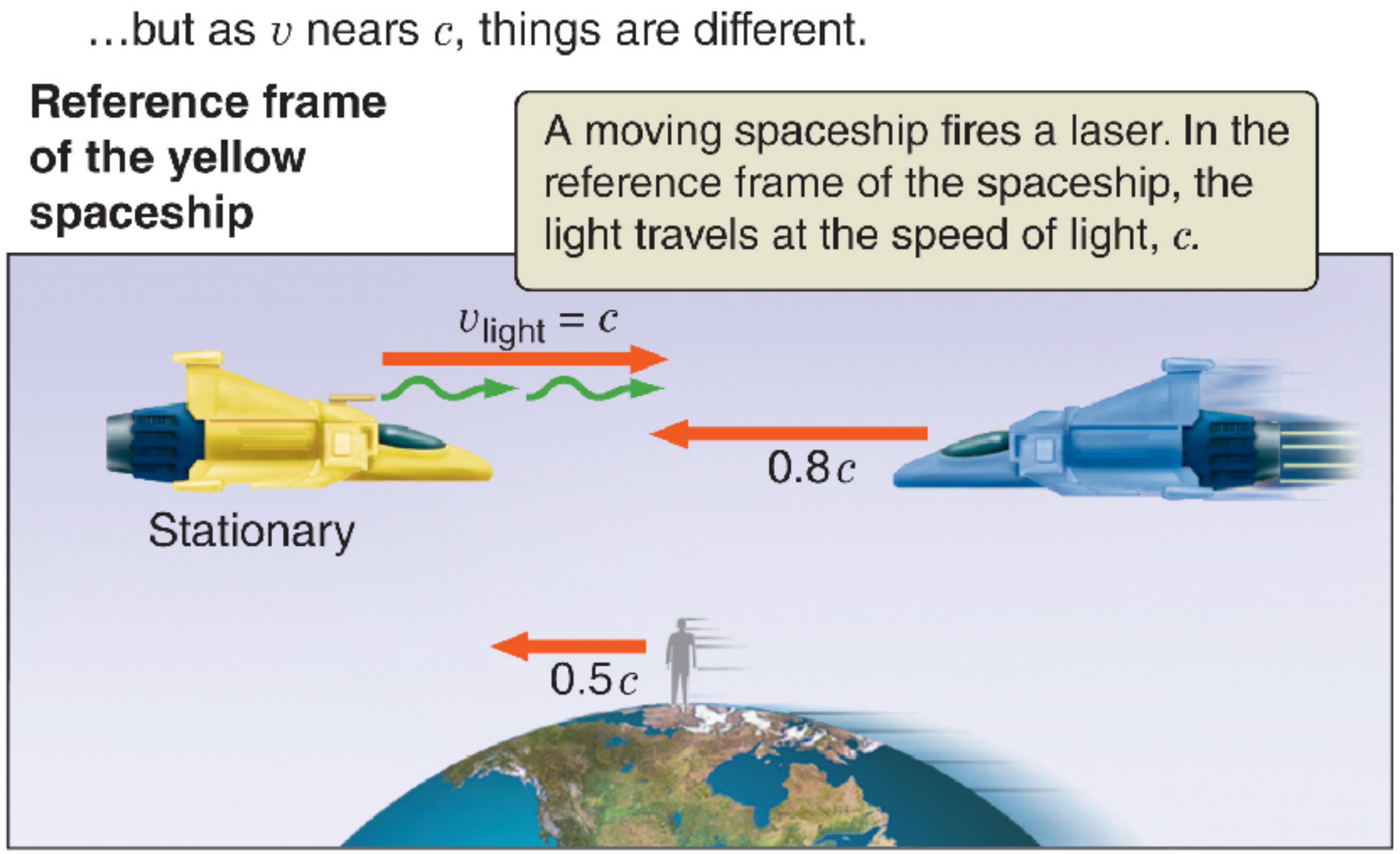


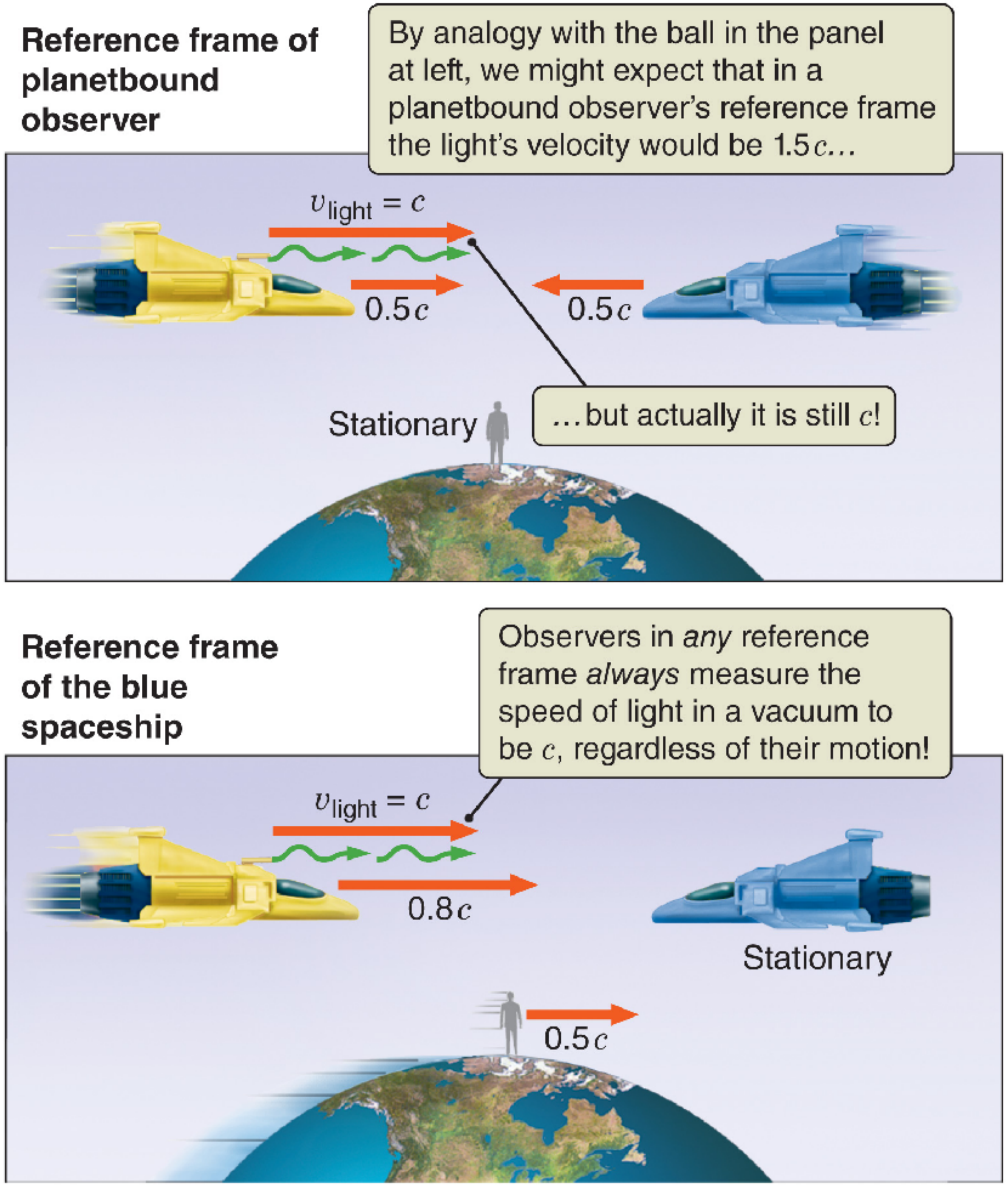


Special Relativity (postulates)

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

Reference Frames





Special Relativity (postulates)

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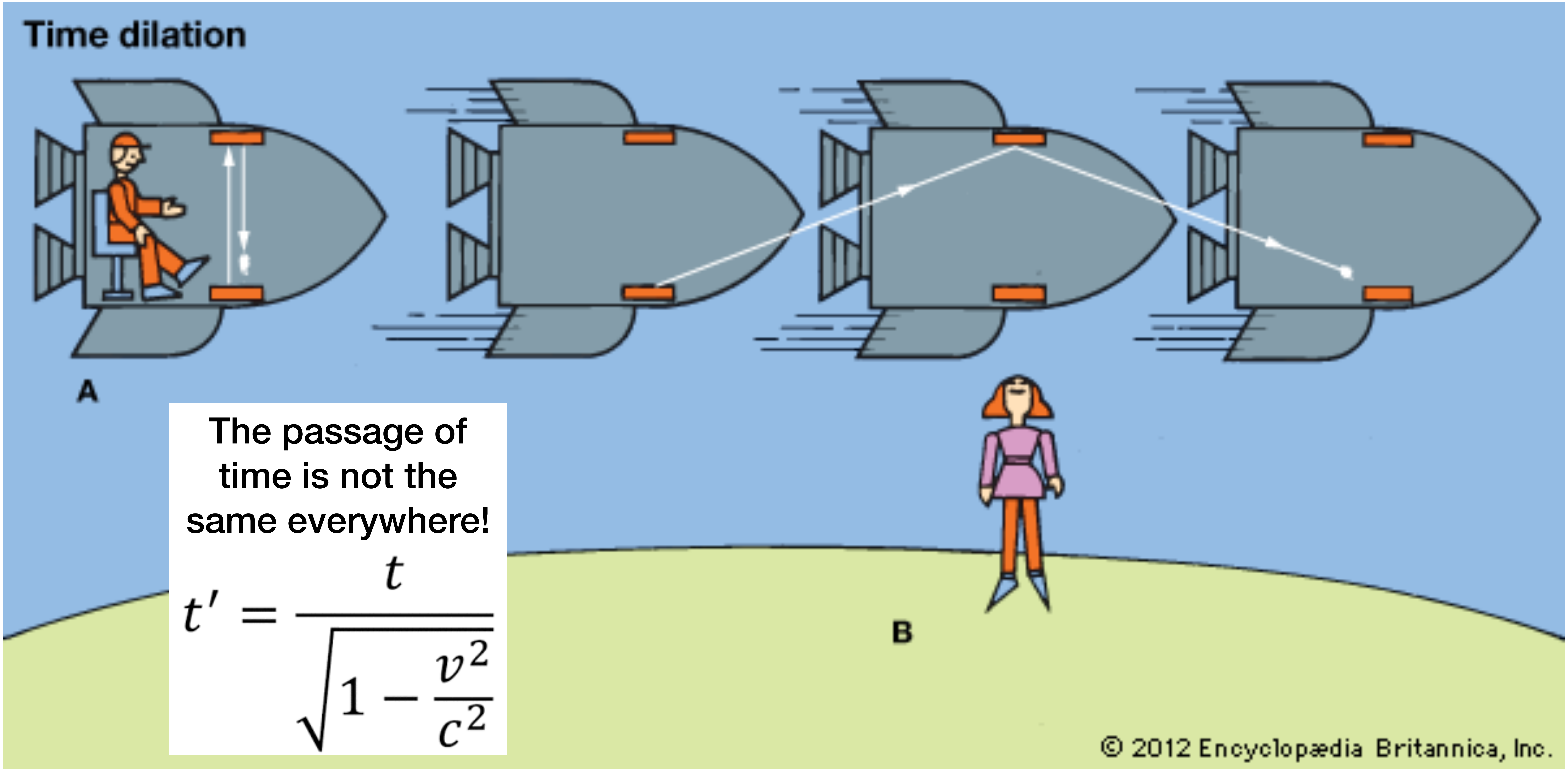
Time Dilation



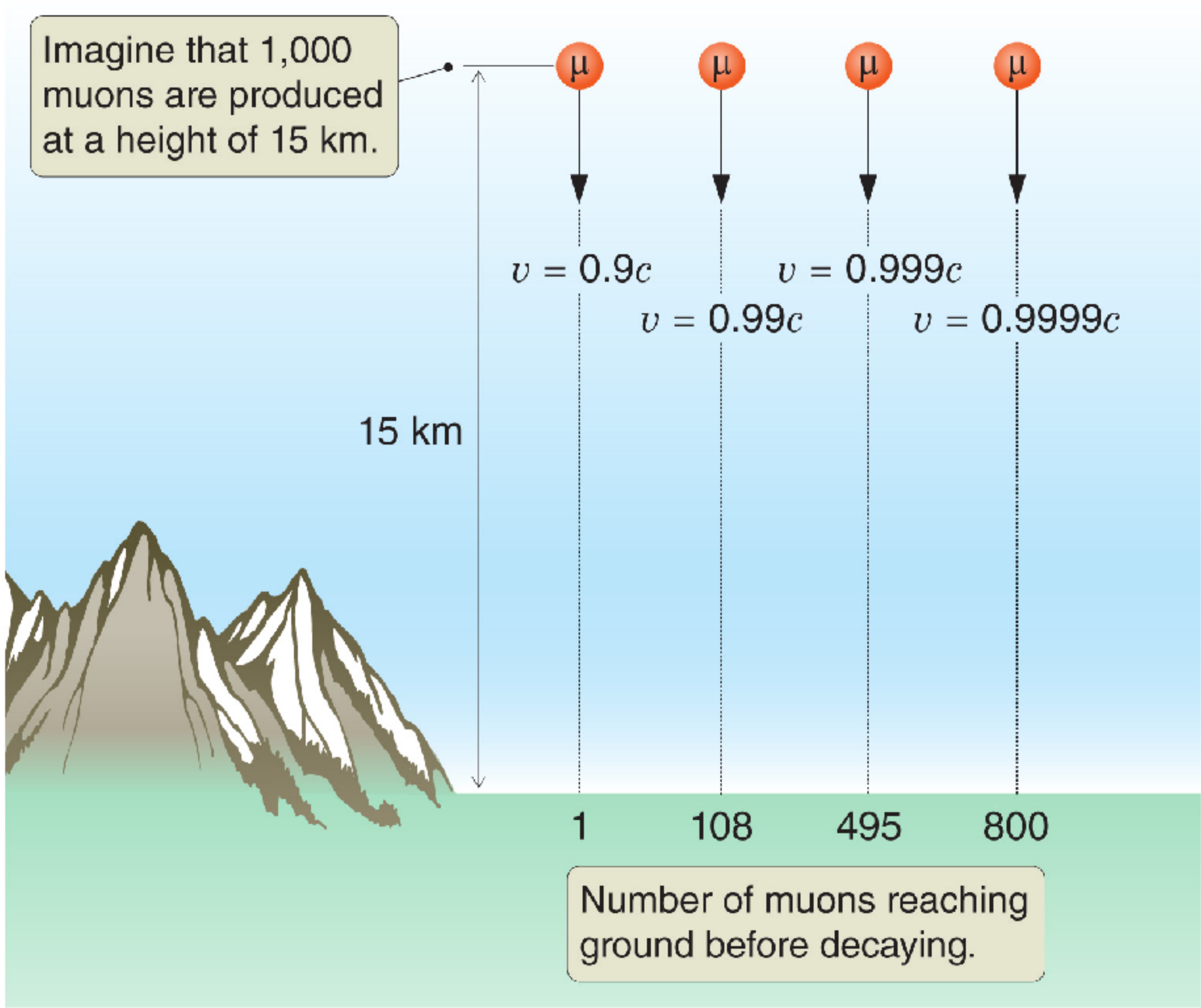
The passage of time is not the same everywhere!

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

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

$E = mc^2$

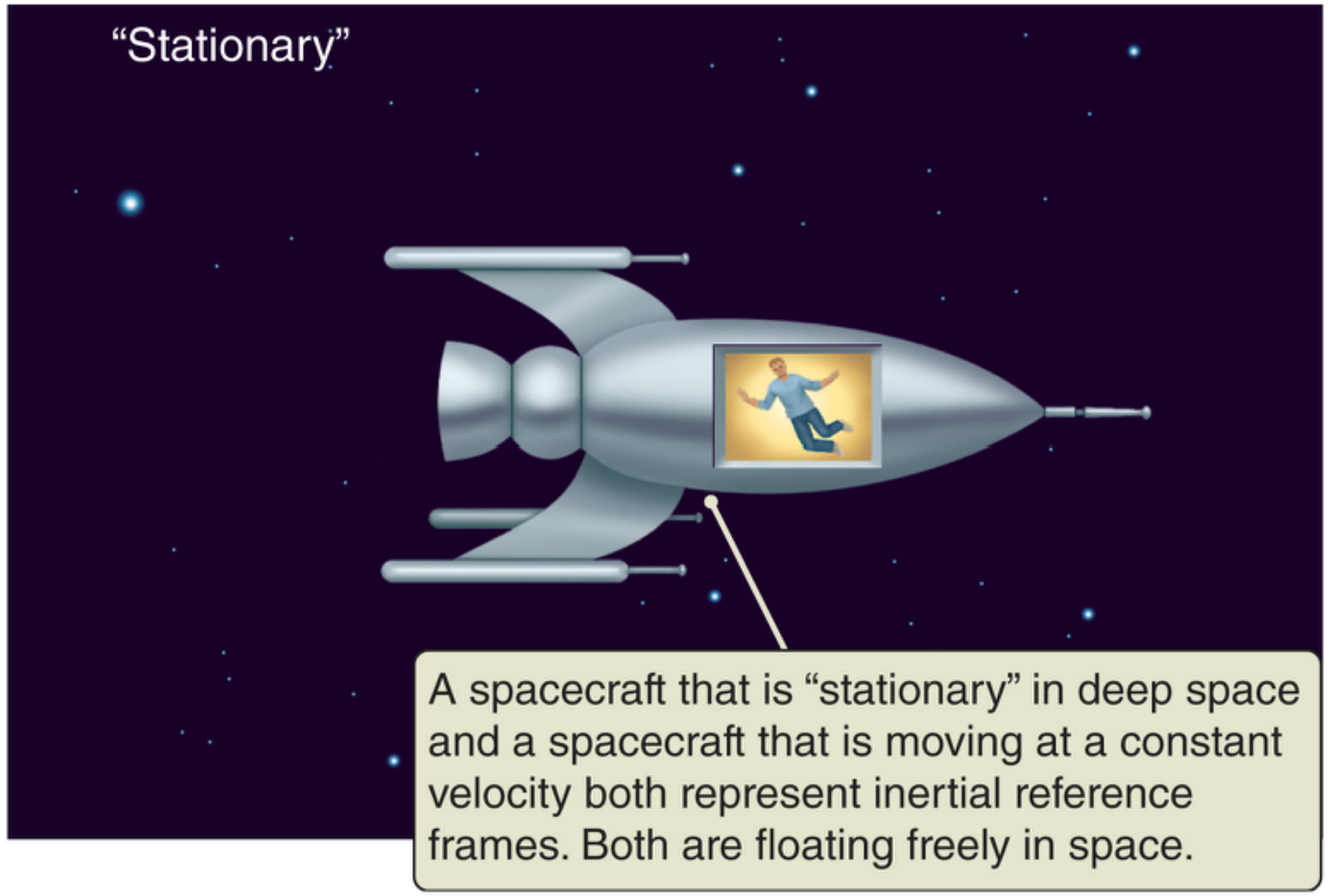
when moving, have kinetic energy
—> increase your mass!

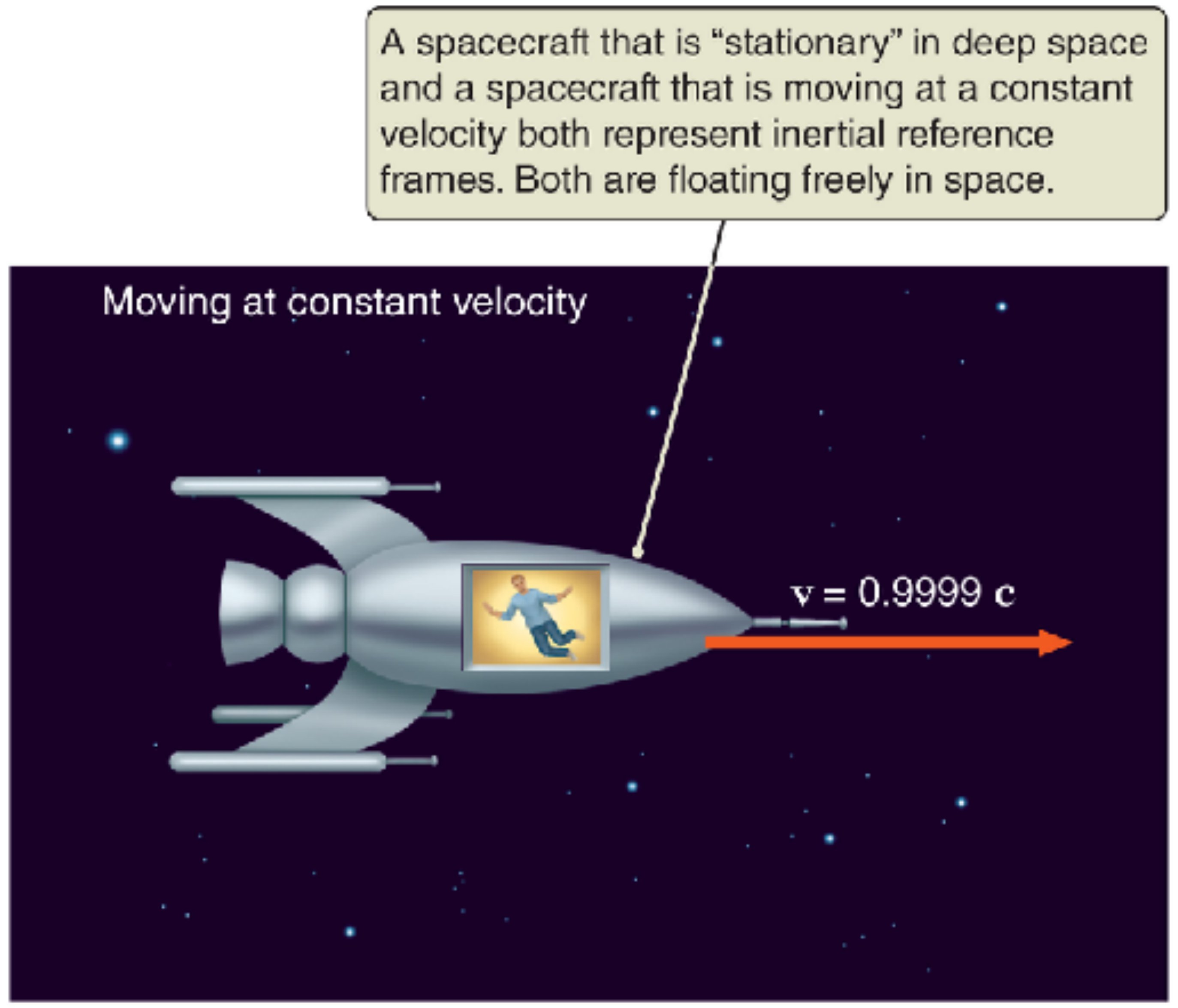
Speed of Light is the universal speed limit (can only approach it)

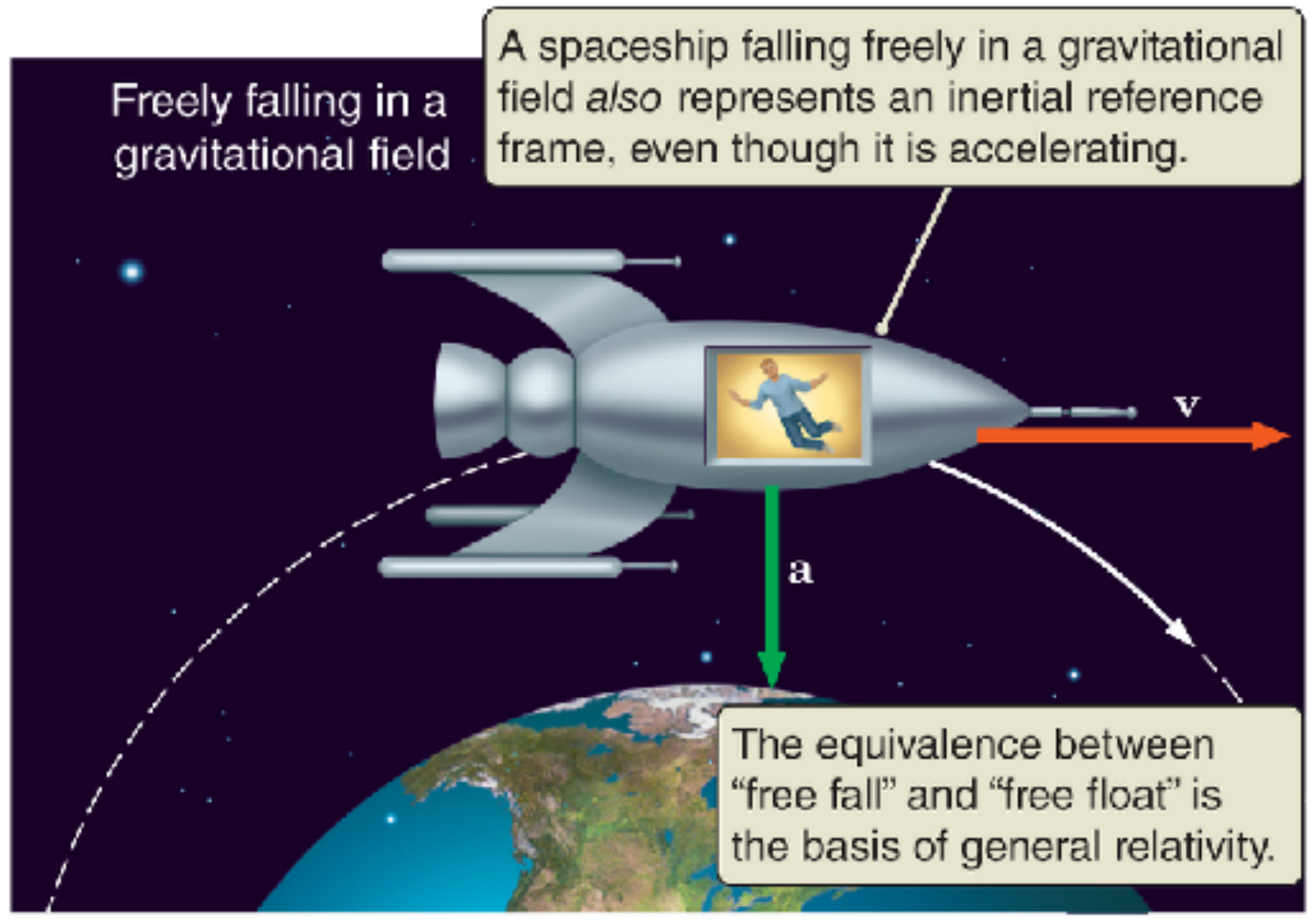
Time passes more slowly for moving reference frames

Length of moving objects contract in the direction of motion

General Relativity: analogous case for gravity







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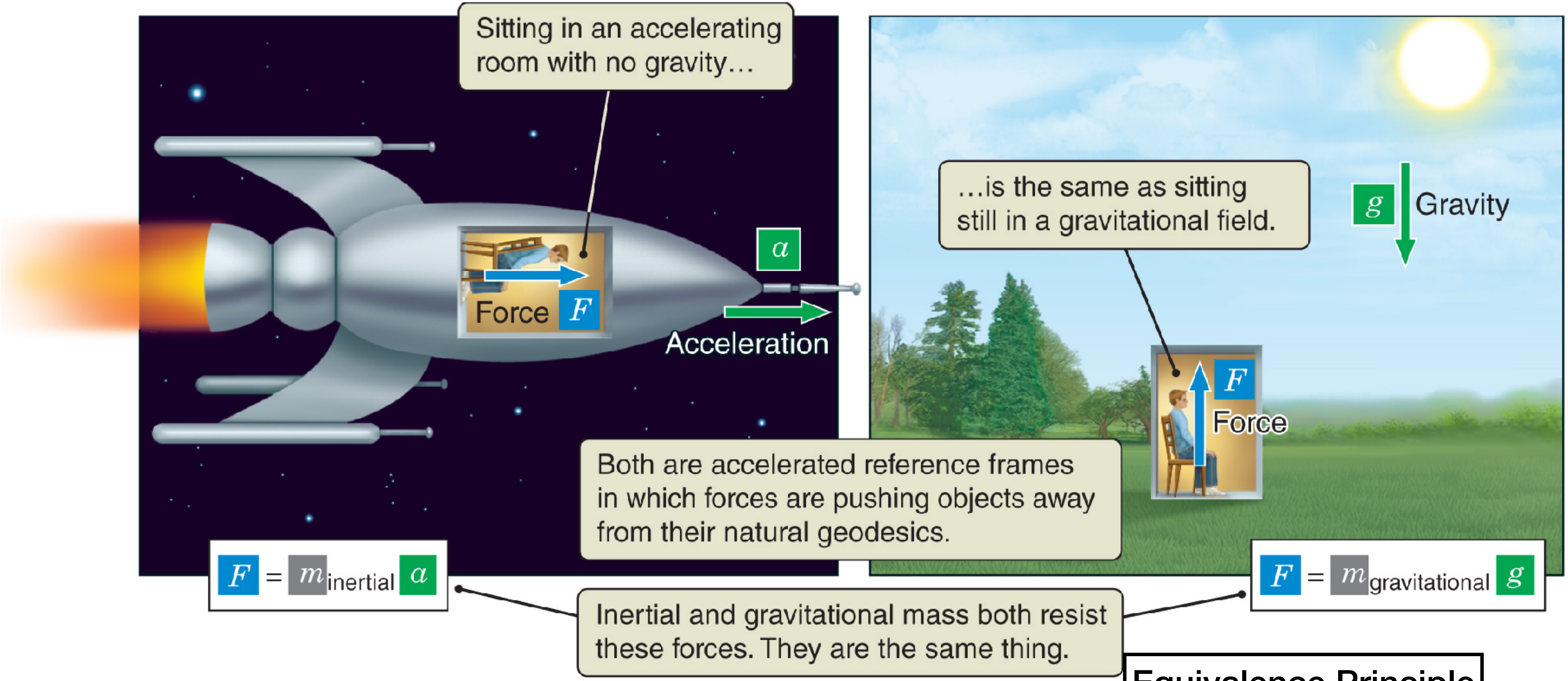
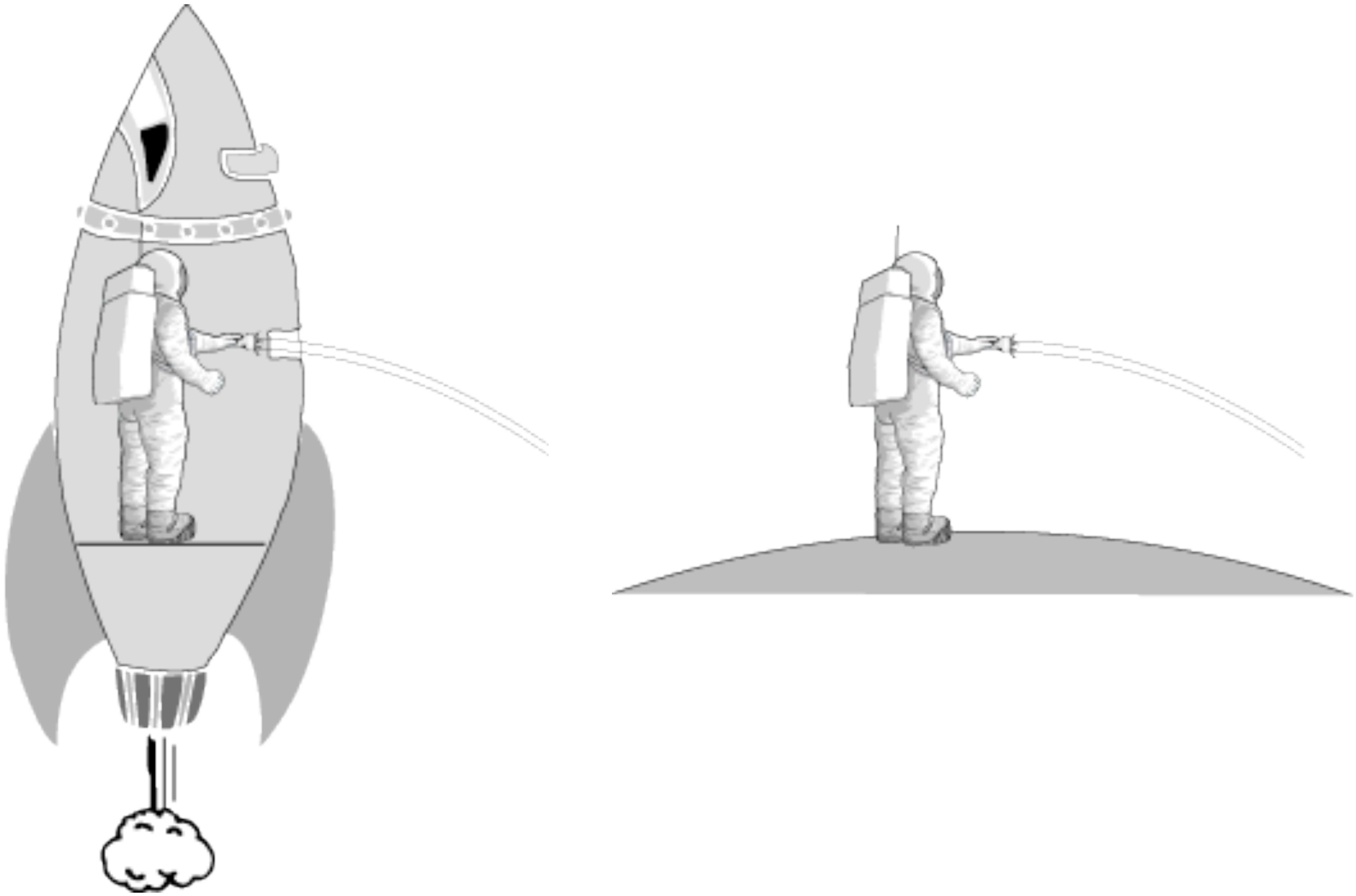
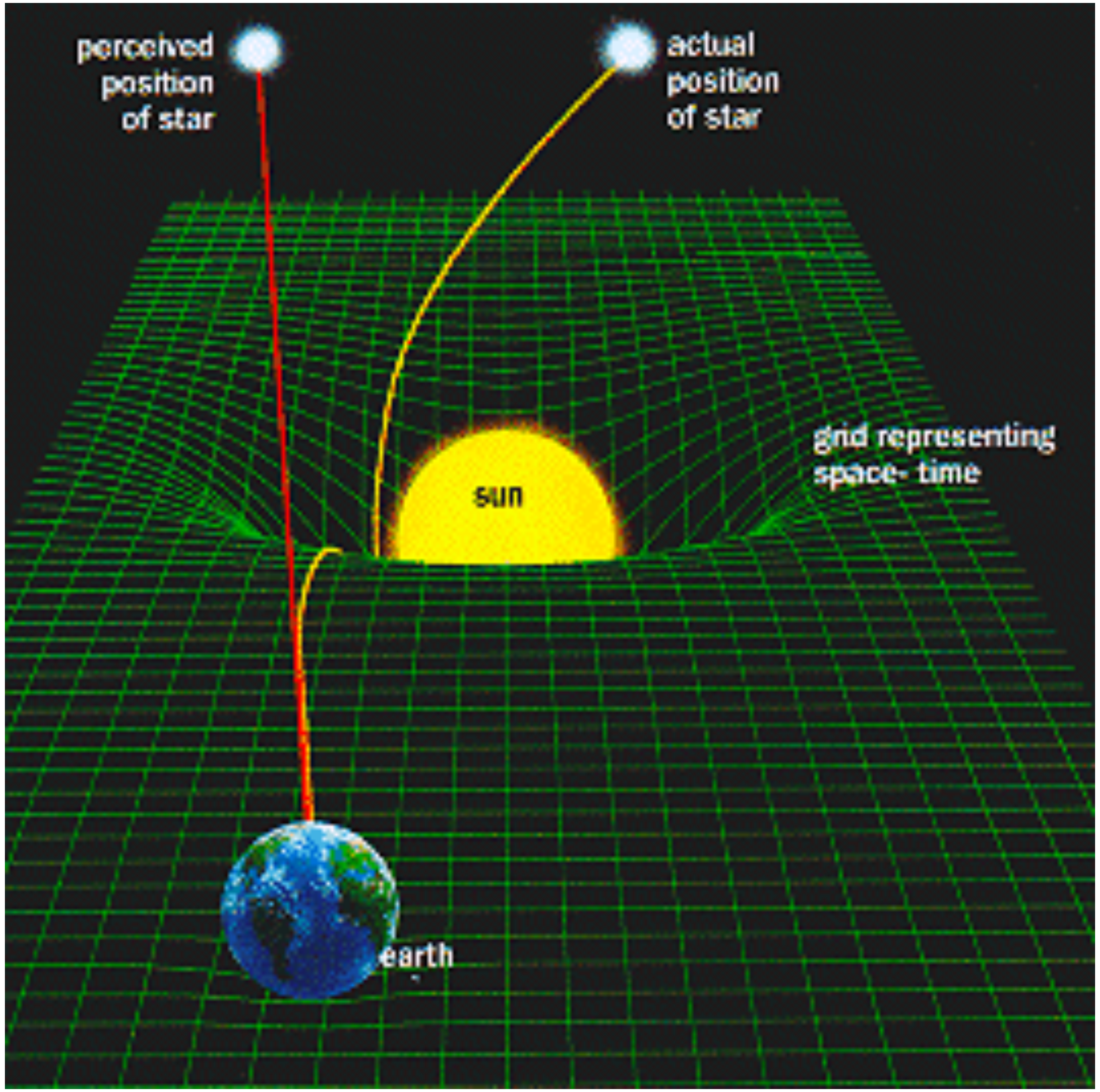


Equivalence Principle

Space-time is curved





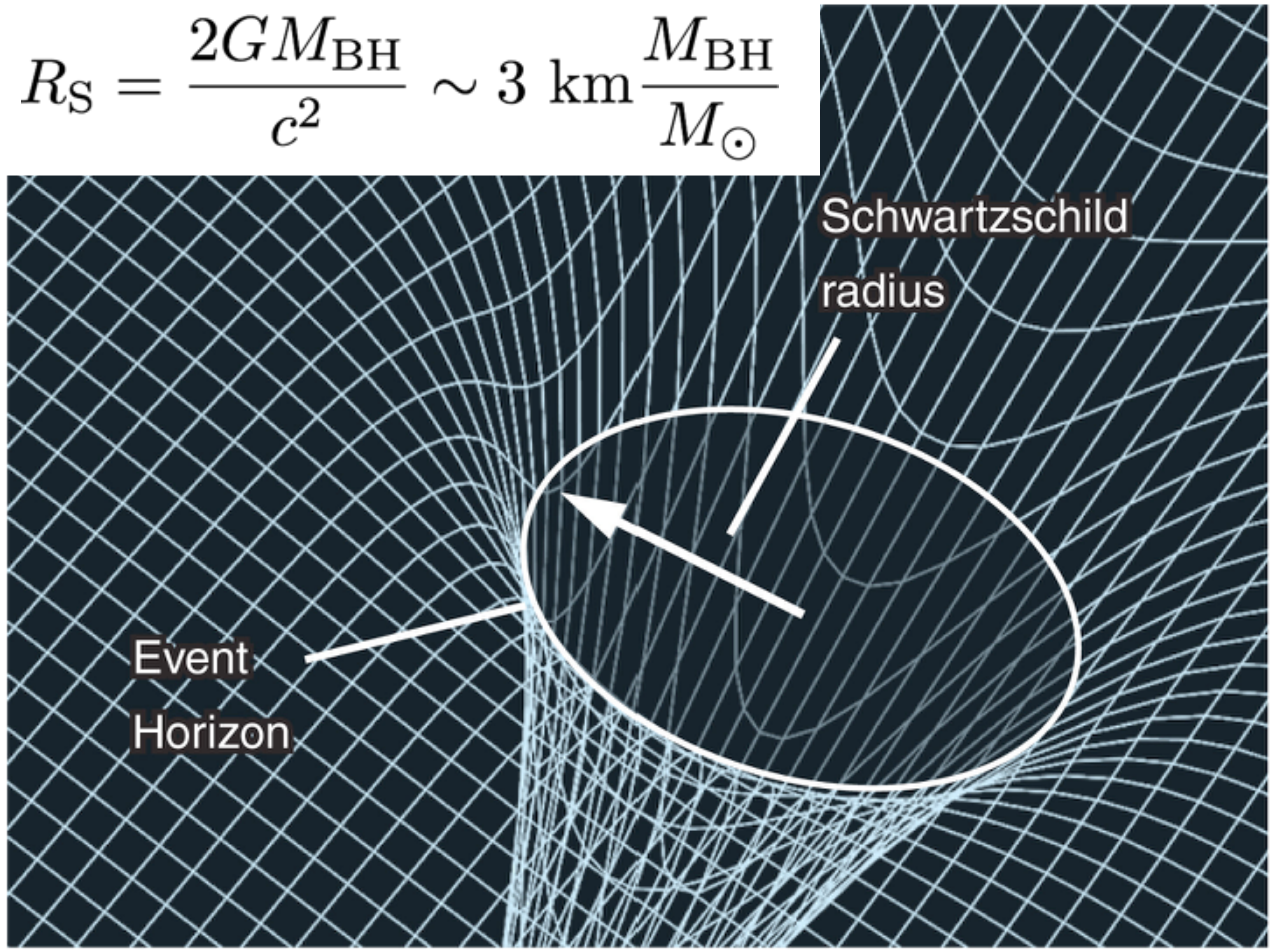
Gravitational Redshift

What are Black Holes?

Particular solutions to Einstein's equations of General Relativity

Inevitable end-state of ultra-dense matter

$$R_\mathrm{S} = \frac{2GM_\mathrm{BH}}{c^2} \sim 3\ \mathrm{km}\frac{M_\mathrm{BH}}{M_\odot}$$



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

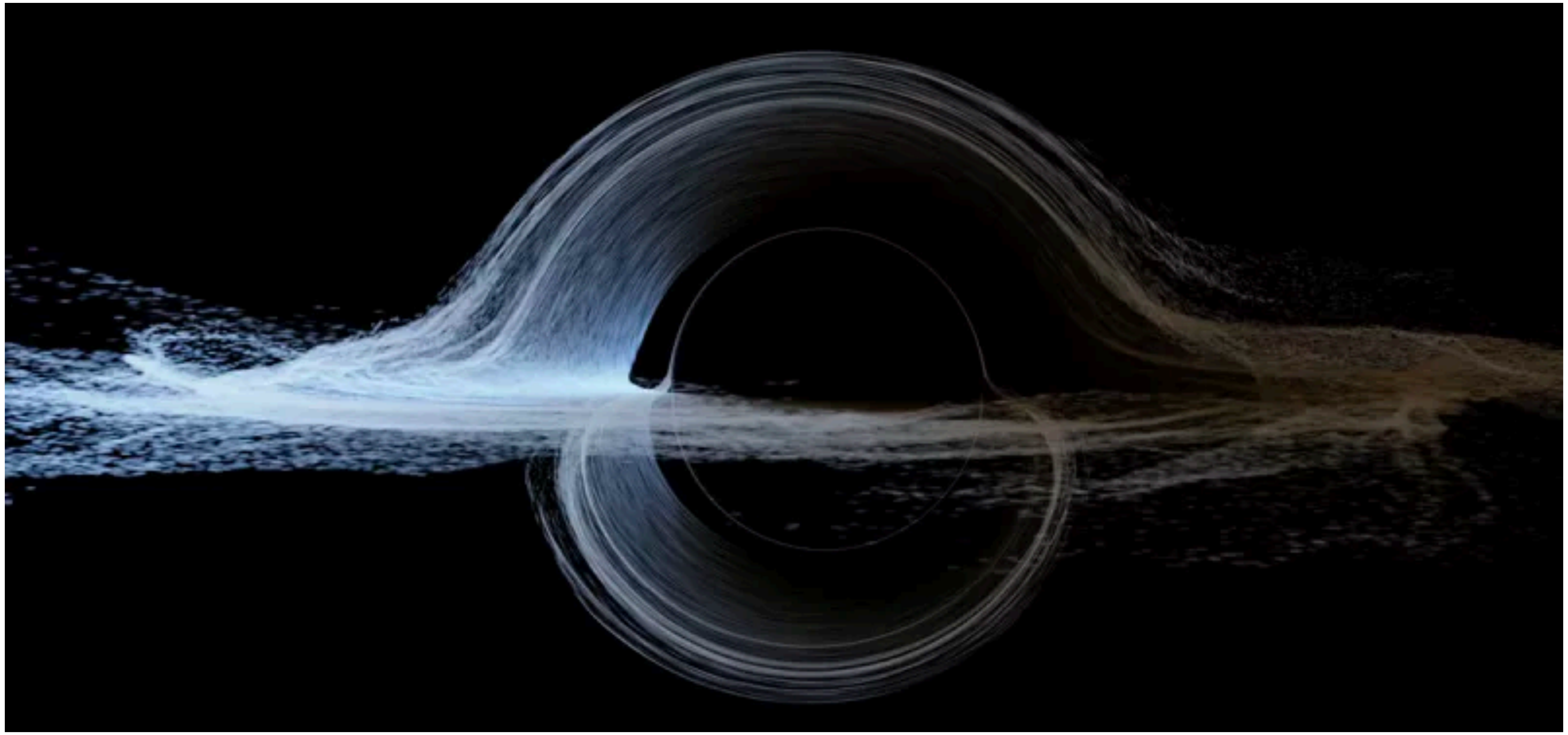
Matter inside the event horizon must fall to the center, toward the *singularity*

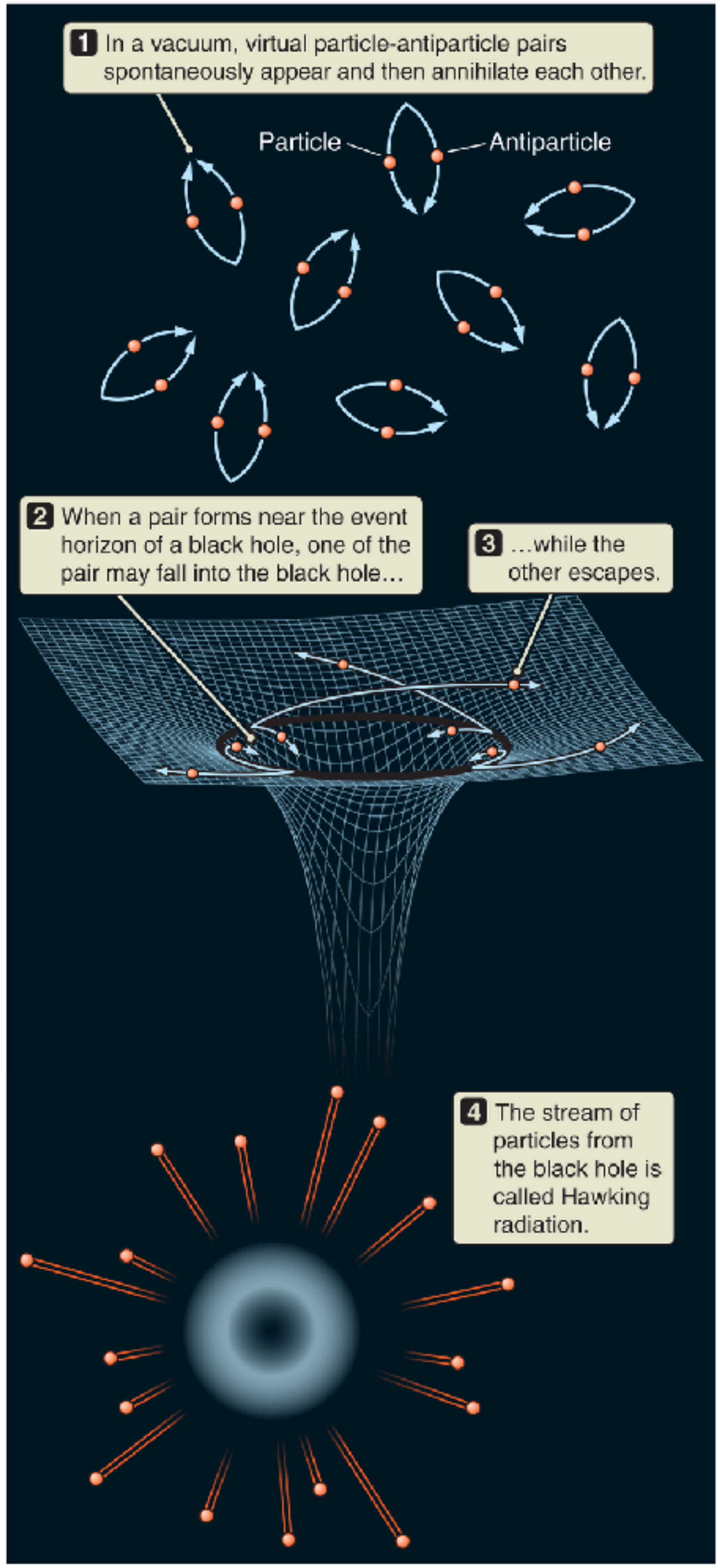
Black holes have "no hair" - defined only by their mass, charge, and spin (rotation)
—> all other info about what formed it is lost

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 <u>Hawking radiation</u>
Hawking himself popularized the explanation used in the textbook, but that explanation is wrong!

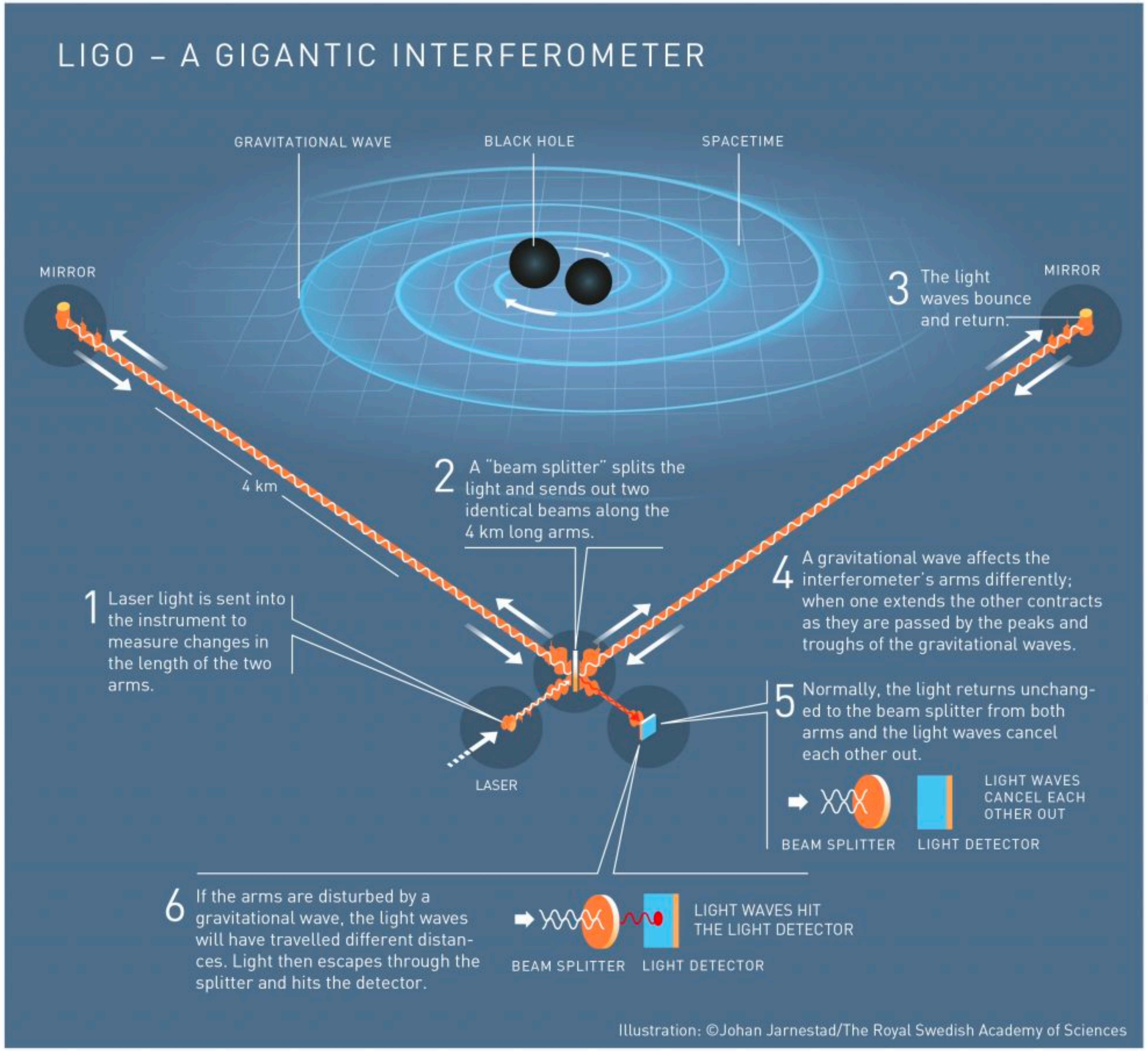
The virtual "particles," which have large quantum waveforms (uncertainty in their position is as large as the black hole), separate at a distance several times larger than the event horizon

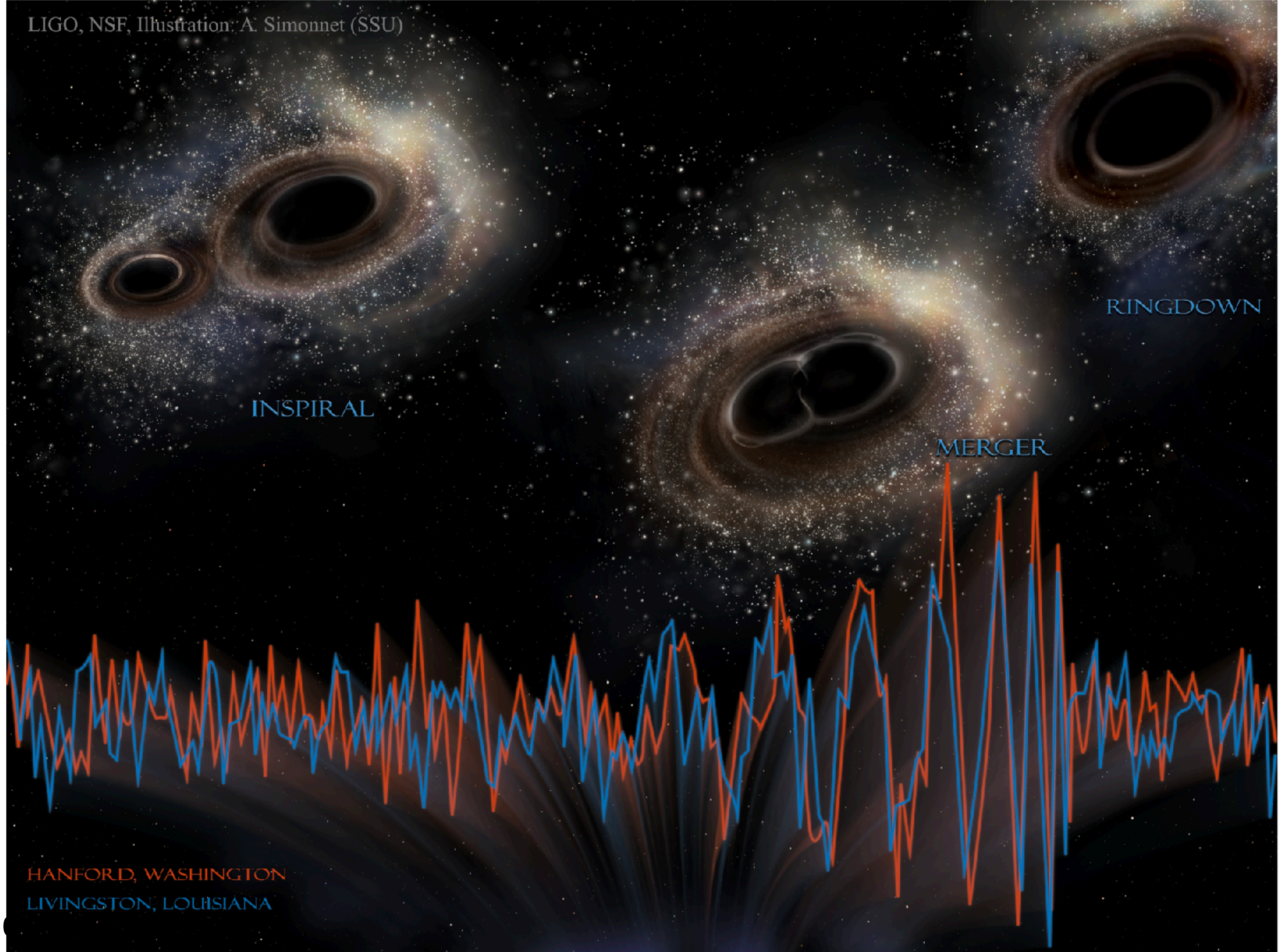
They result mainly from space-time changing dynamically when the black hole forms, creating thermal radiation

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)

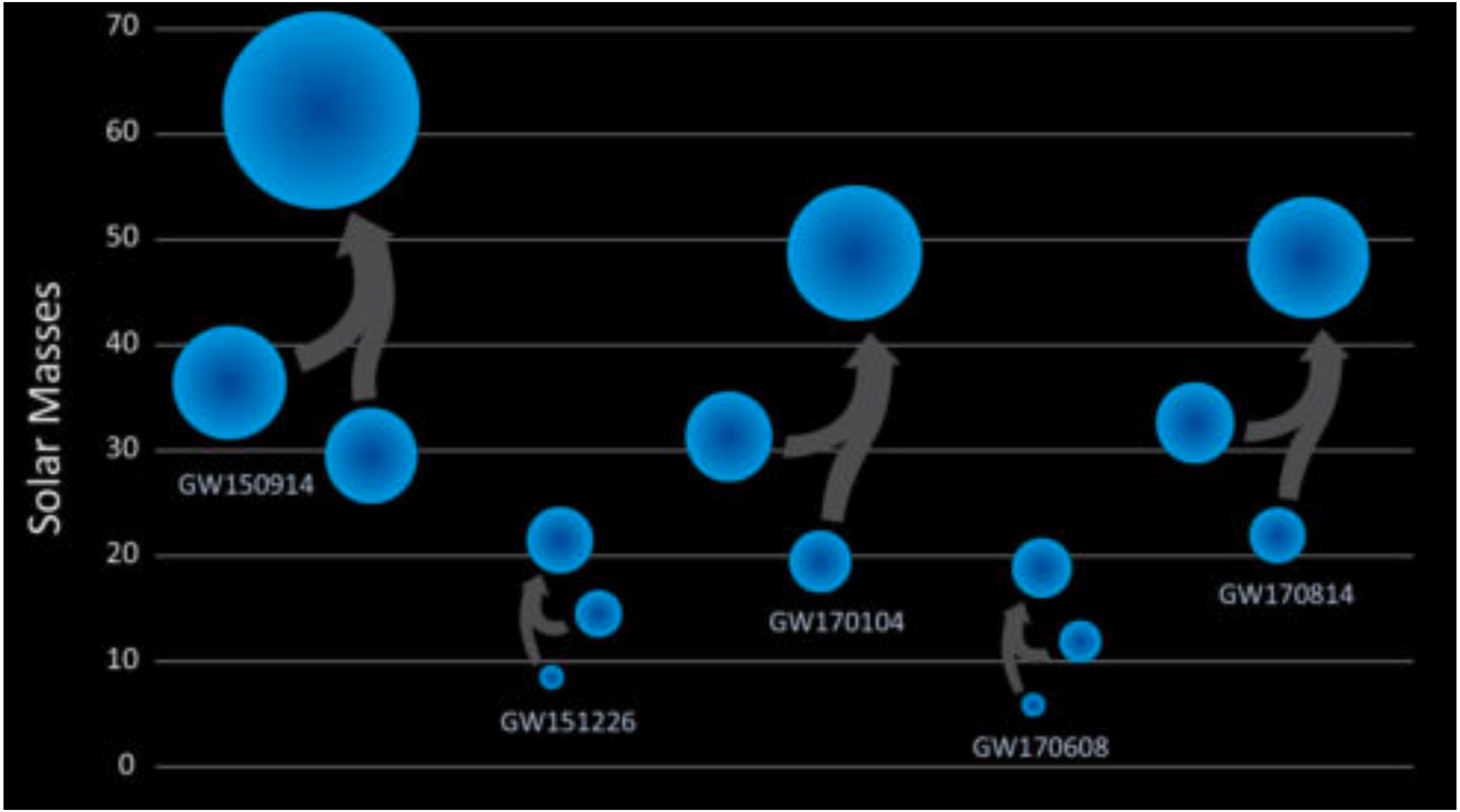
Gravitational Waves: LIGO!

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



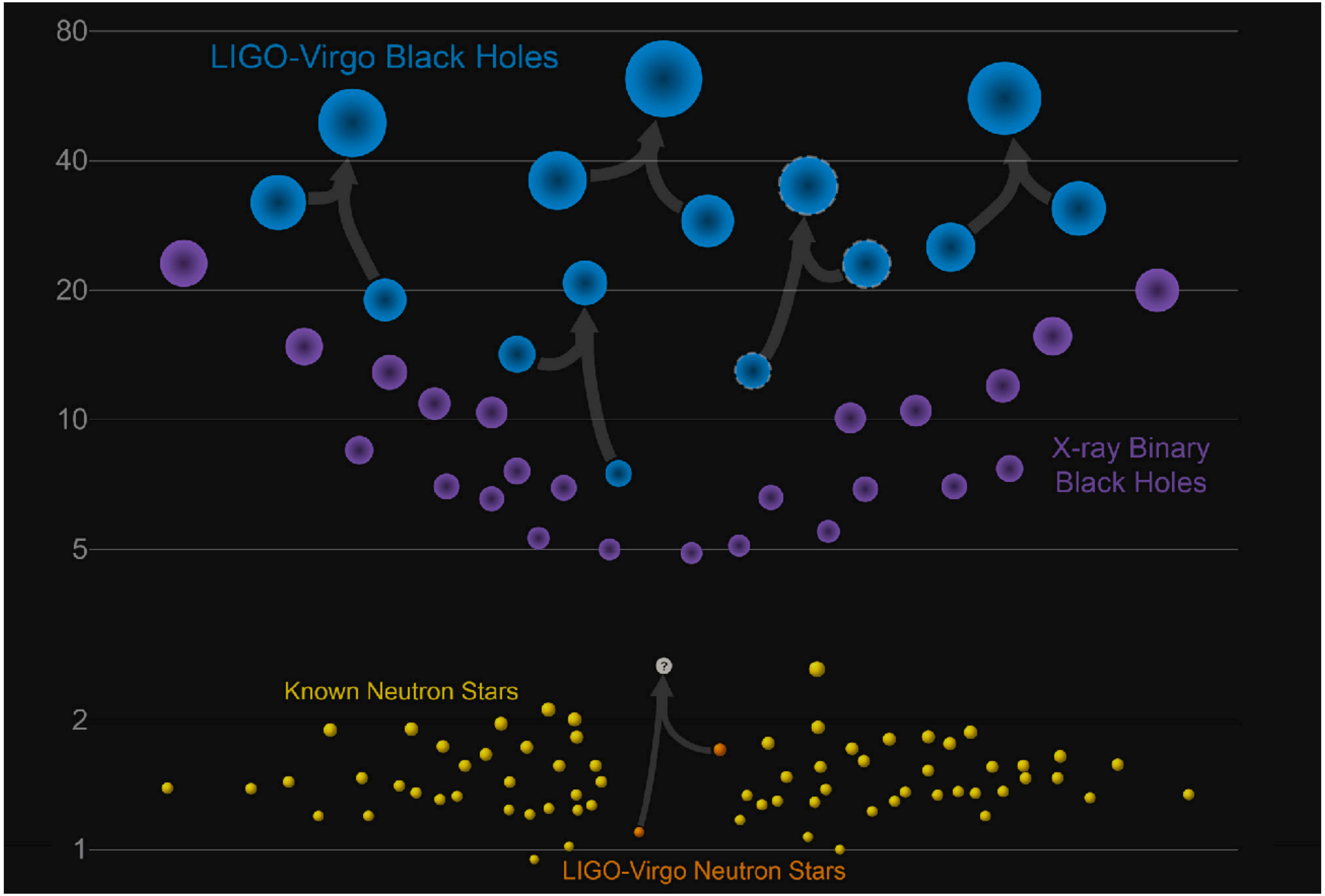

LIGO, NSF, Illustration: A. Simonnet (SSU)
INSPIRAL
MERGER
RINGDOWN
HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA

First 5 BH-BH mergers



BHs and NSs with known masses

Solar Masses



First NS-NS merger, explosion also seen