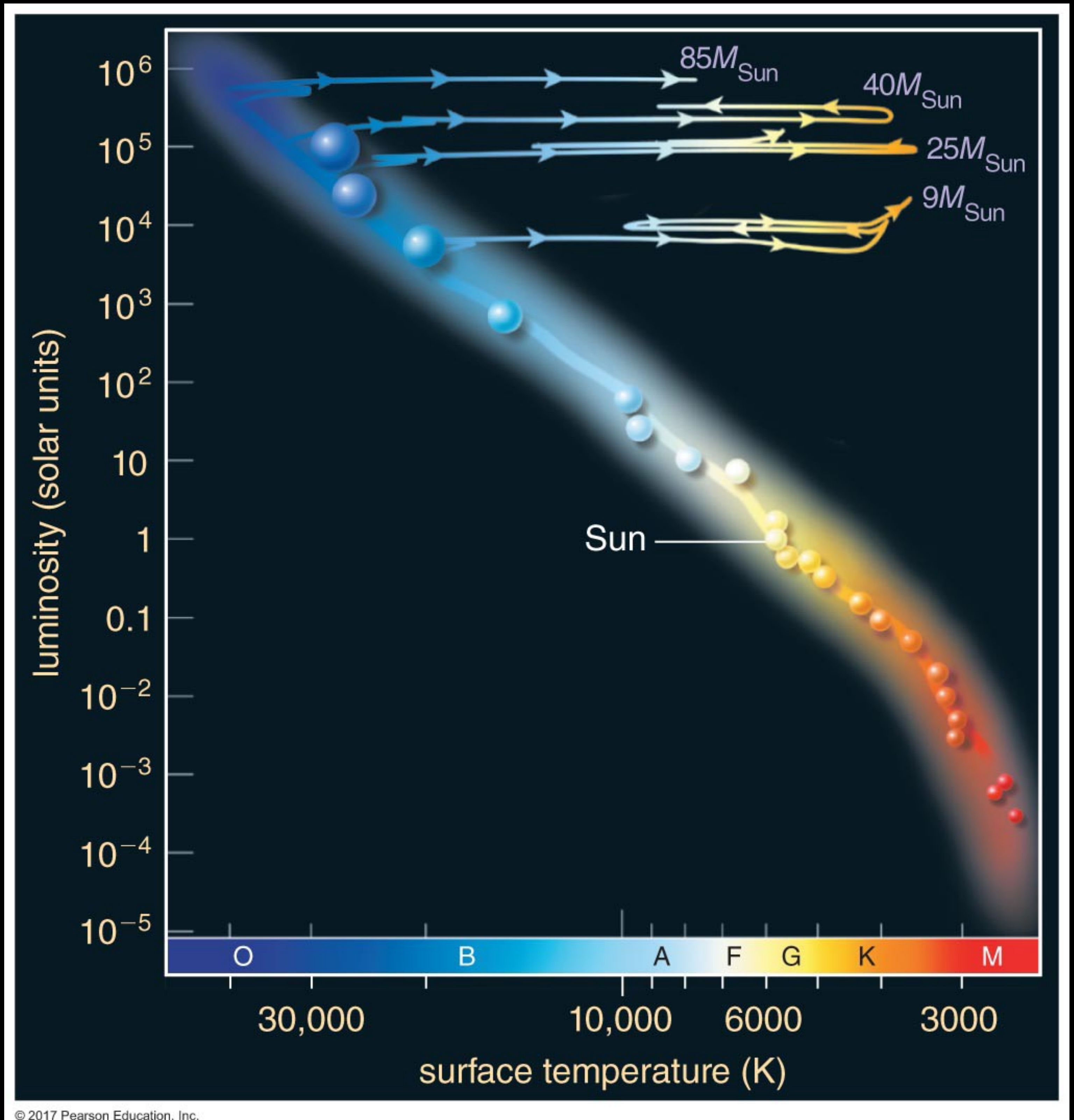
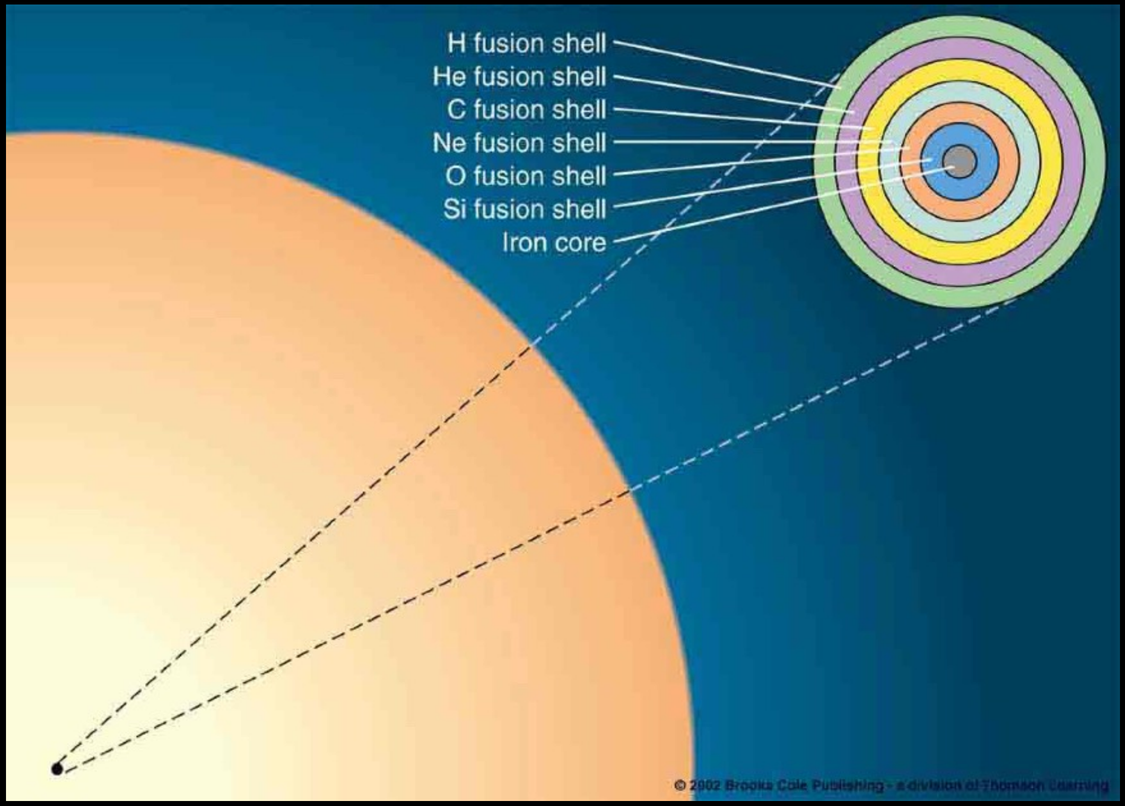
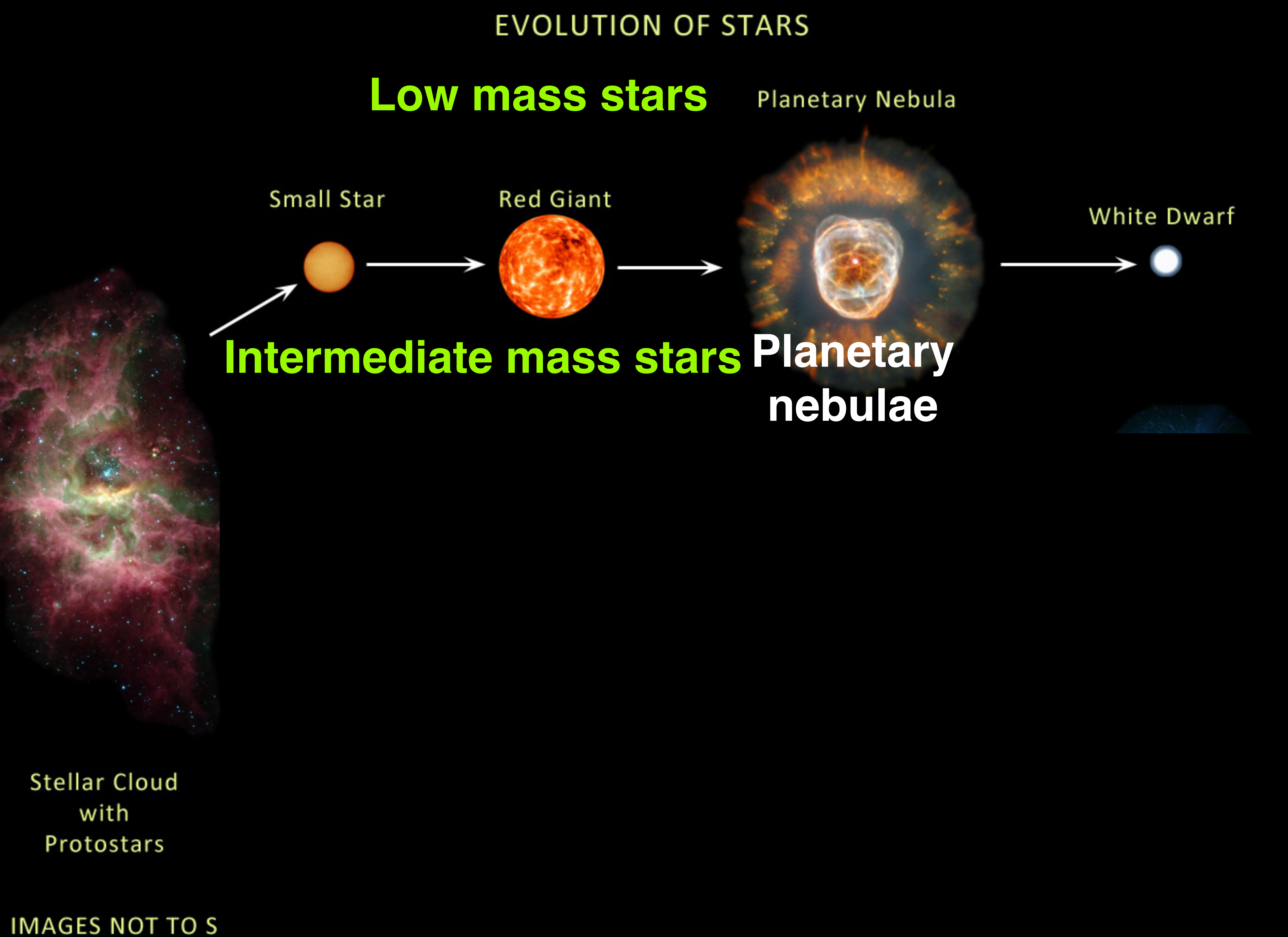
Life tracks of high-mass stars

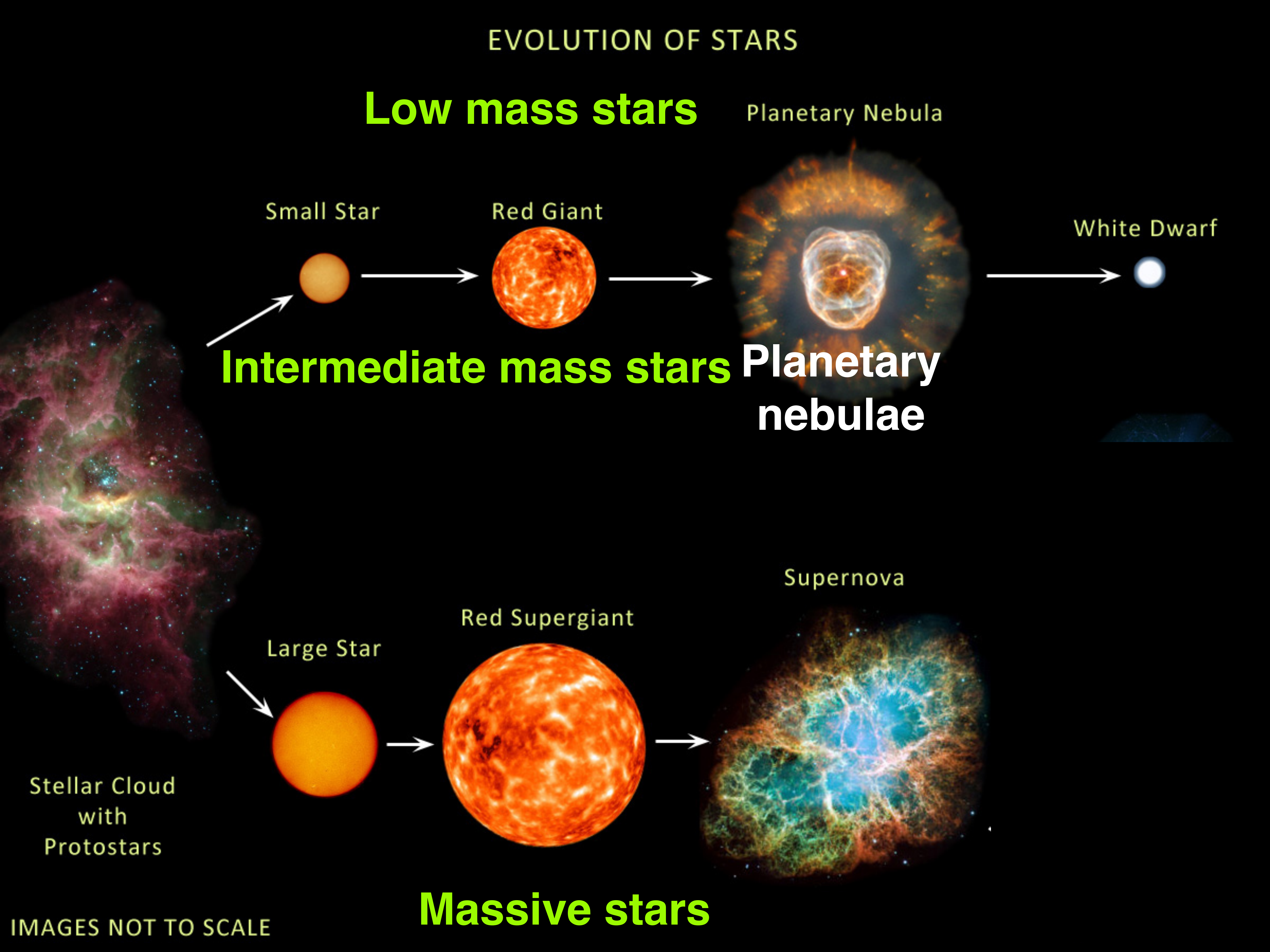


- High Luminosity for entire lifetime (which is short)

- Onion structure until Iron…..




EVOLUTION OF STARS
Low mass stars
Planetary Nebula
Small Star
Red Giant
White Dwarf
Intermediate mass stars
Planetary nebulae
Stellar Cloud with Protostars
IMAGES NOT TO S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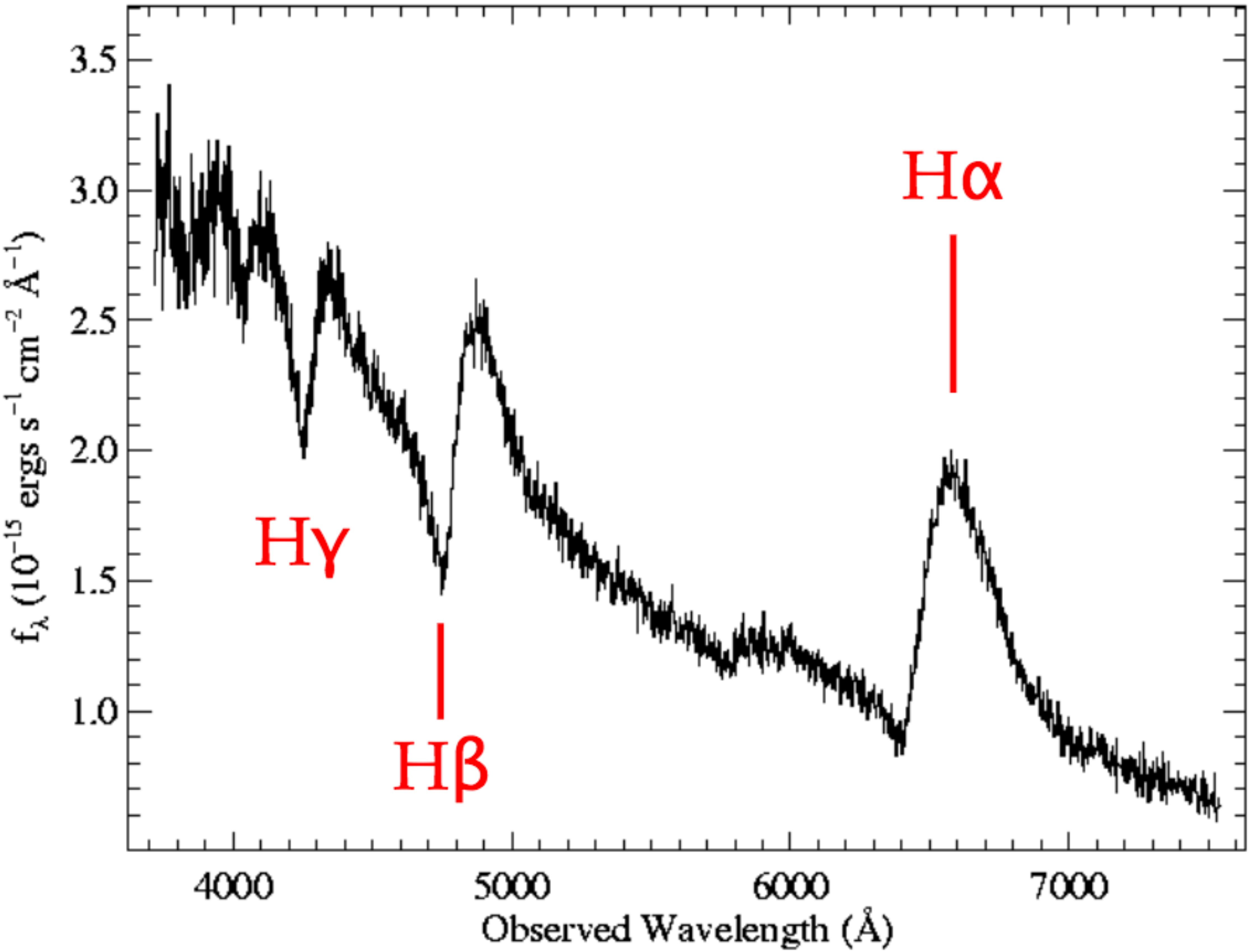
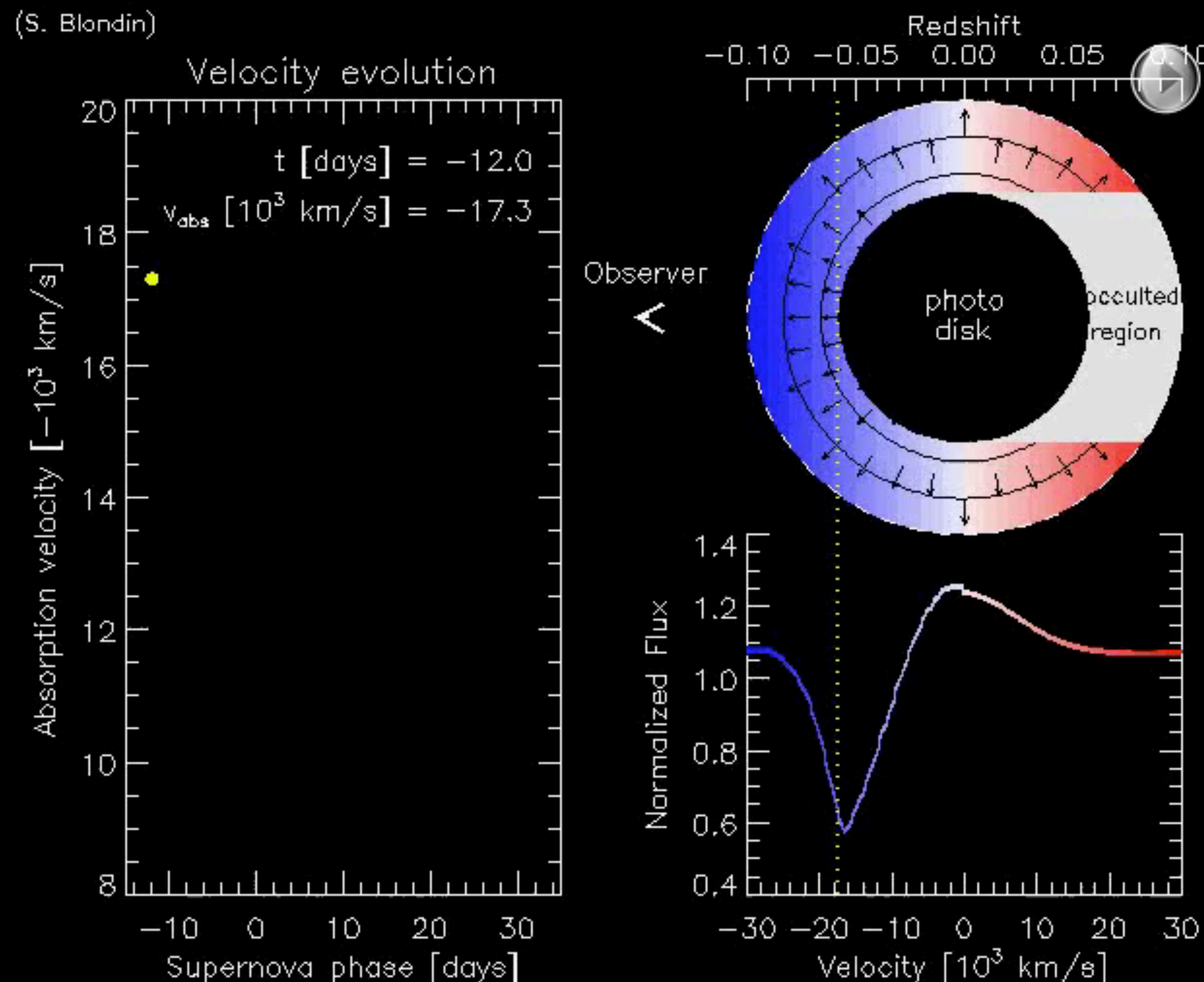
Planetary nebulae
Supernova
Red Supergiant
Large Star
Stellar Cloud with Protostars
Massive stars
IMAGES NOT TO SCALE

Type II SN 2001cm

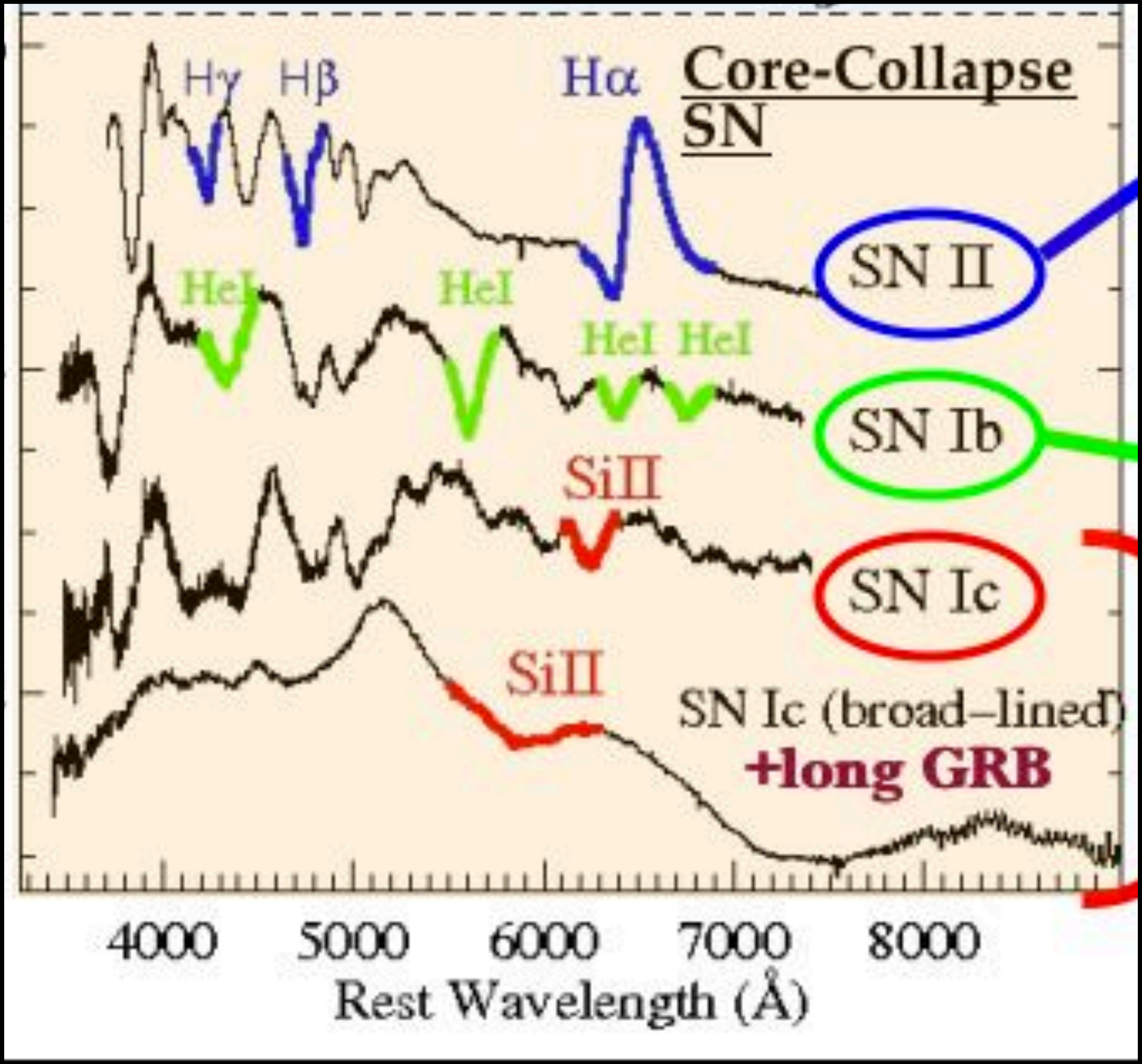


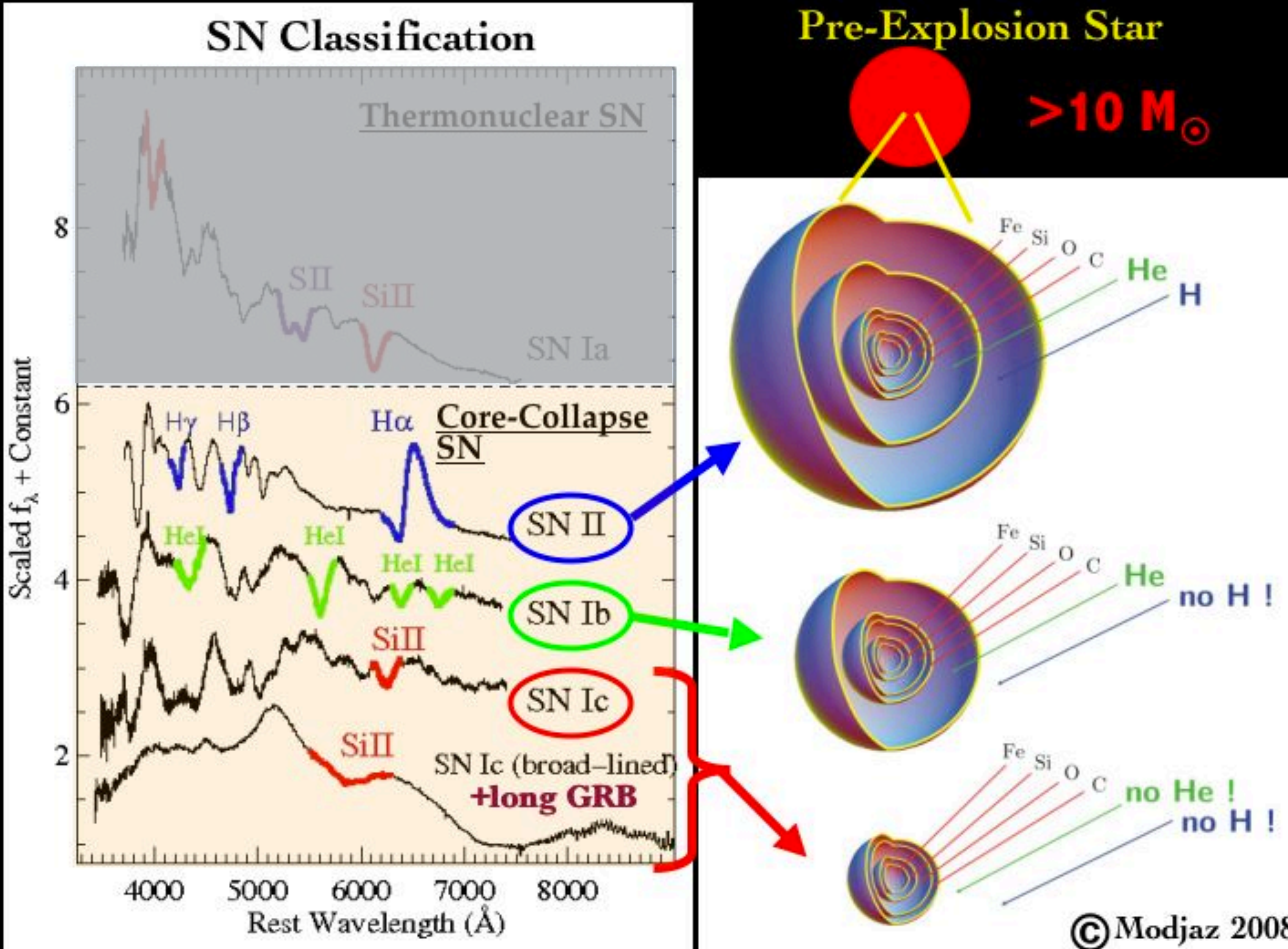
More information from line profiles…

P-Cygni profile



Core Collapse SN types





SN Classification
Thermonuclear SN
SII
SiII
SN Ia
Core-Collapse SN
Hγ
Hβ
Hα
SN II
HeI
HeI
HeI HeI
SN Ib
SiII
SN Ic
SiII
SN Ic (broad-lined)
+long GRB
Scaled f_λ + Constant
Rest Wavelength (Å)
Pre-Explosion Star
>10 $M_\odot$
Fe
Si
O
C
He
H
Fe
Si
O
C
He
no H !
Fe
Si
O
C
no He !
no H !
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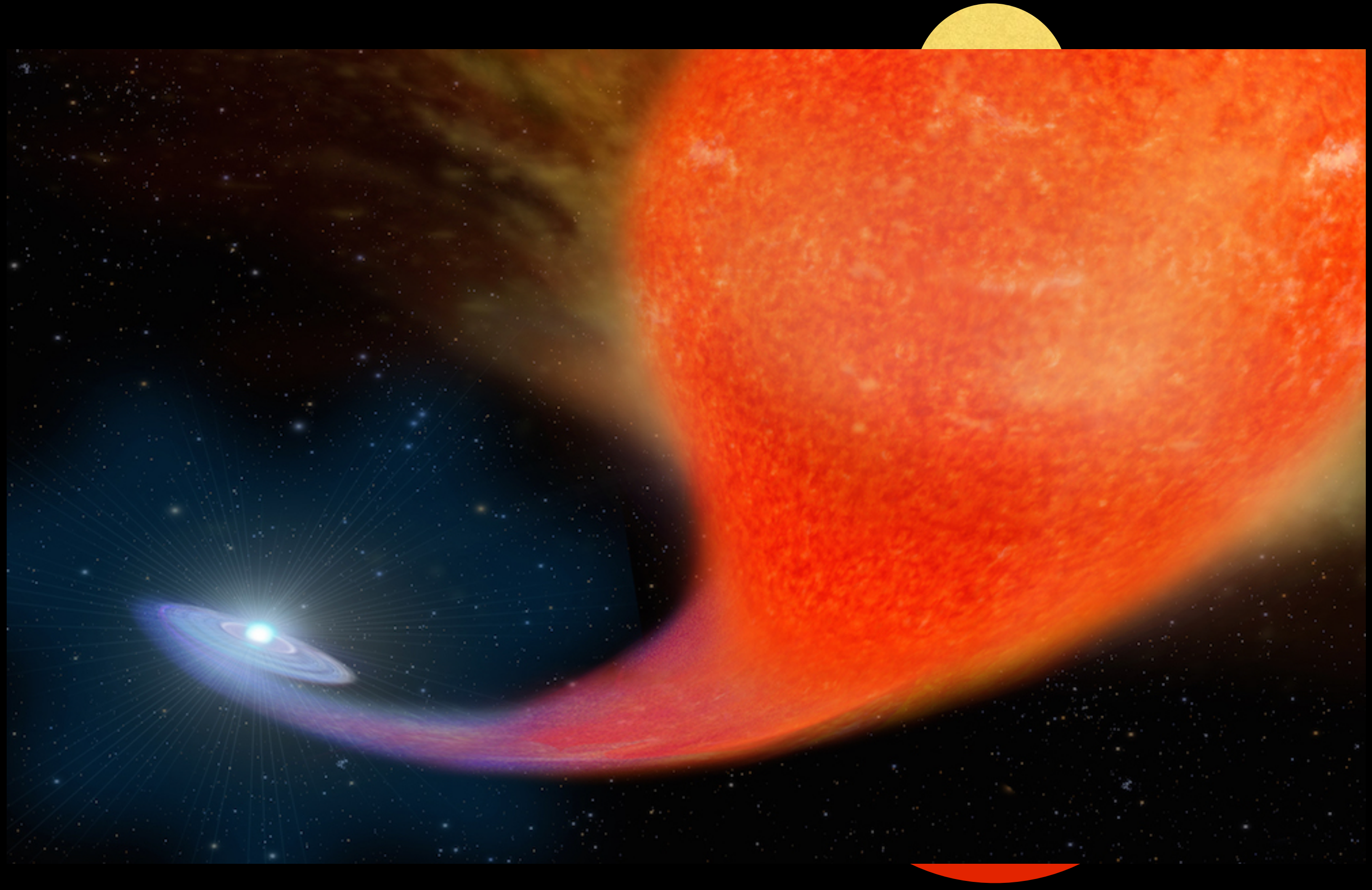
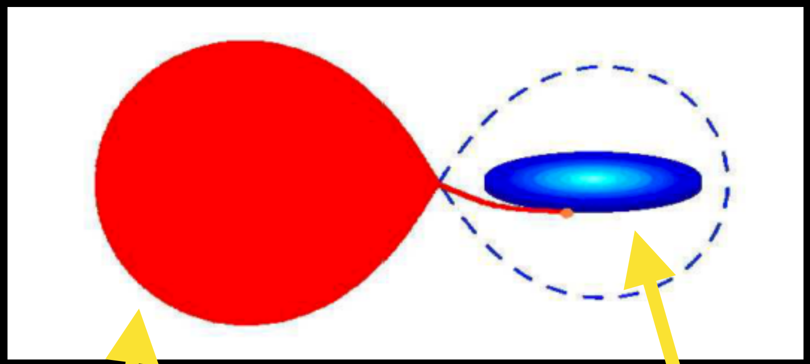
How stars lose the envelope ?

Stellar winds

Binary interaction



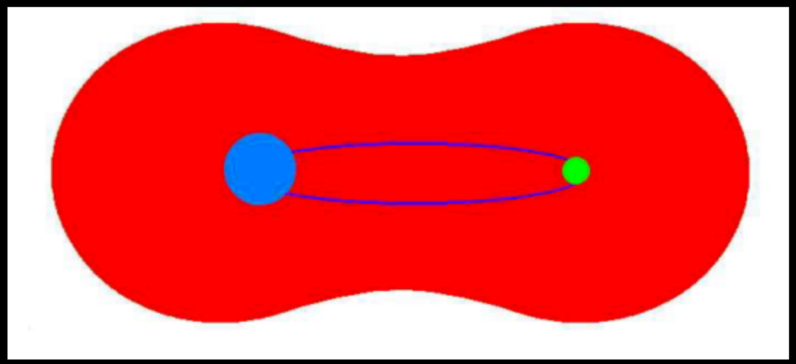
Binary system



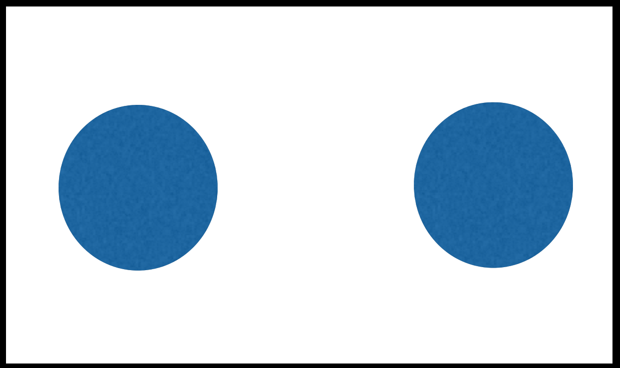
Stable mass transfer

secondary star

primary star



Unstable mass transfer

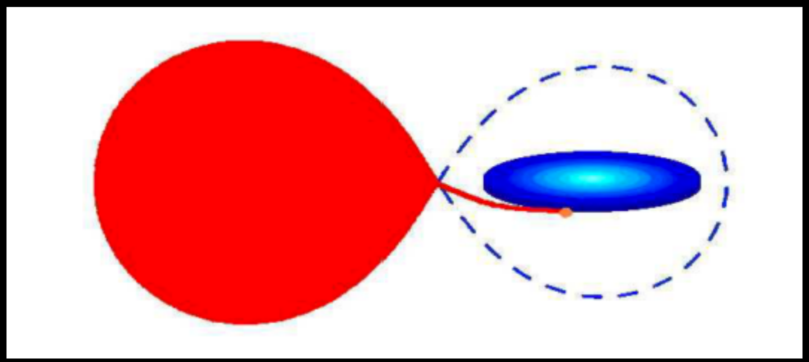


No interaction

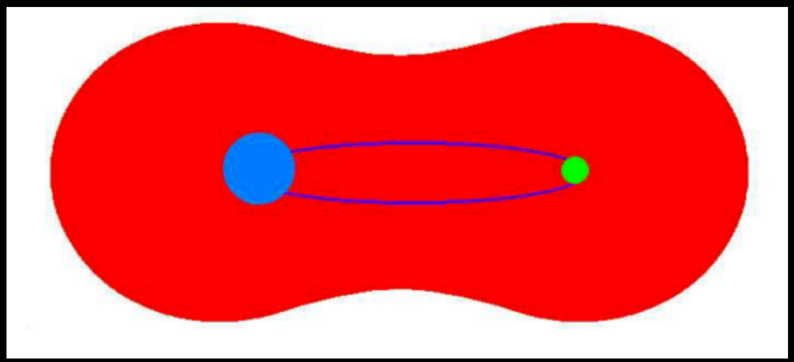
Stable mass transfer is when the primary star has the time to find a new thermodynamic equilibrium with the new mass

Unstable mass transfer is when the mass transfer rate is to high and the primary star can not find a new thermodynamic equilibrium with the new mass

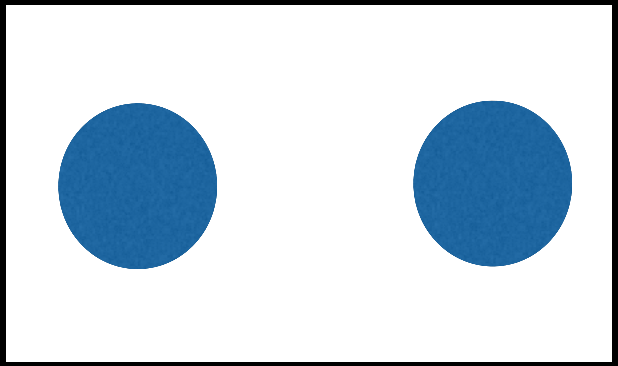
Binary system



Stable mass transfer



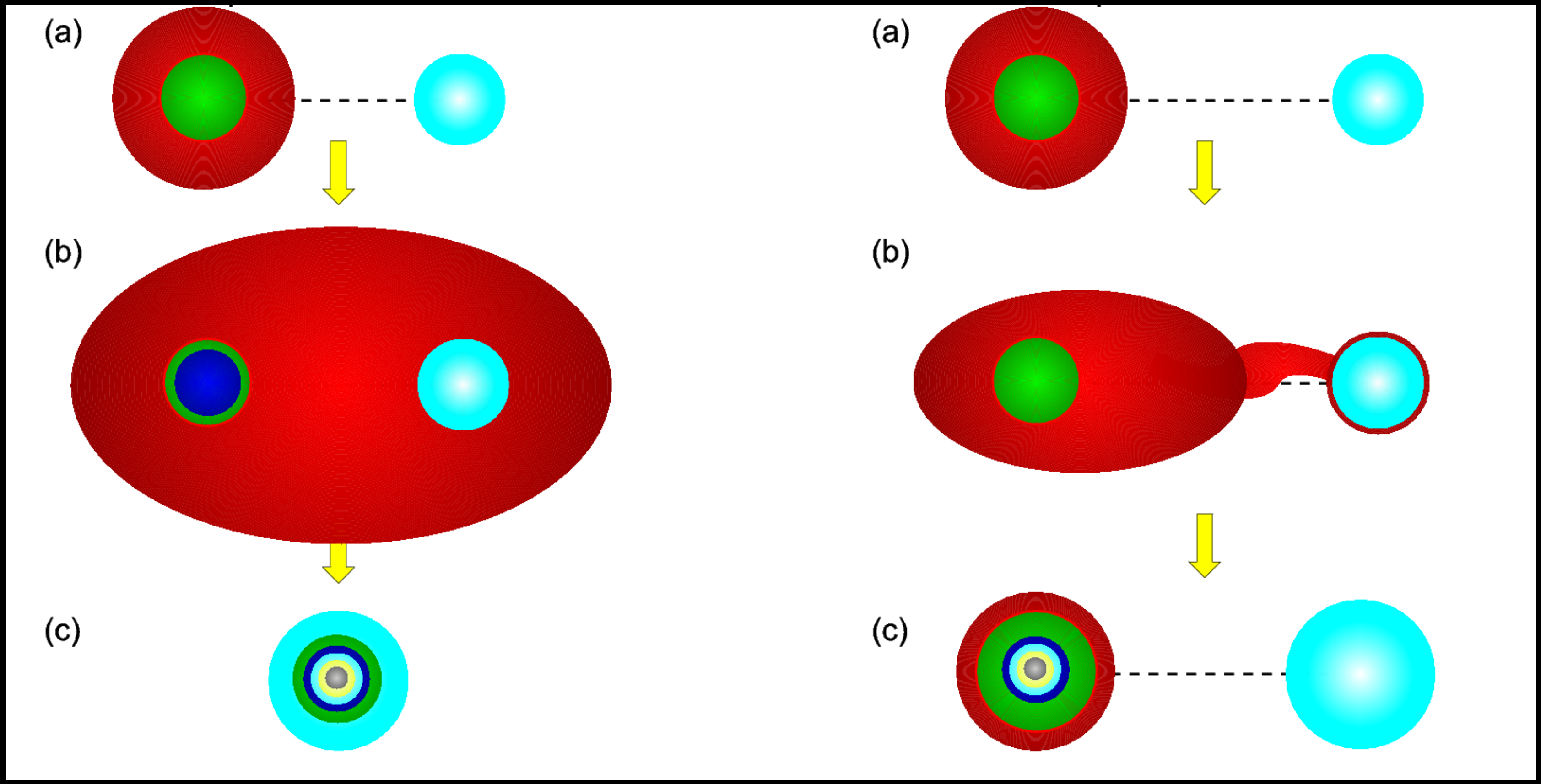
Unstable mass transfer



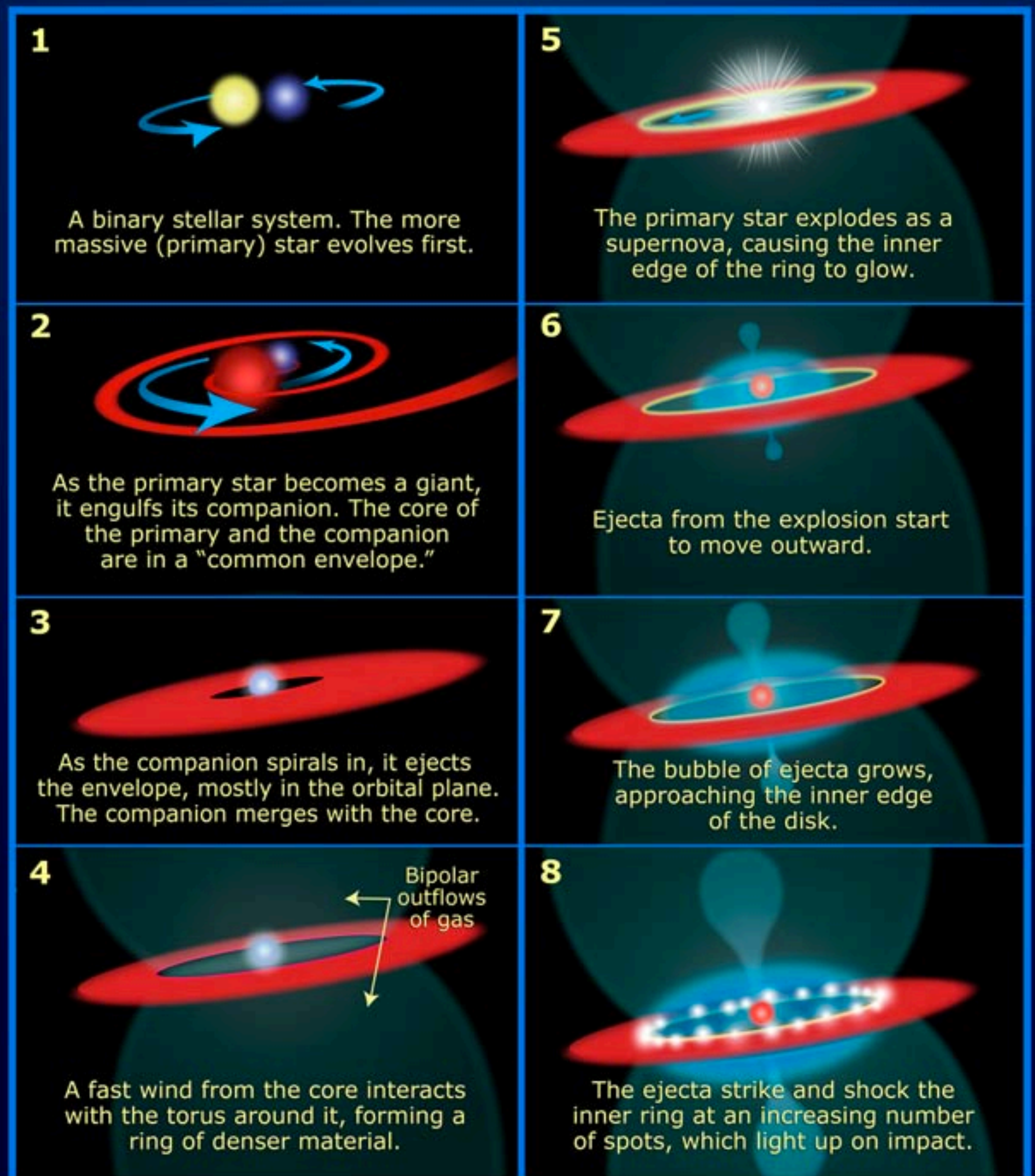
No interaction

Unstable mass transfer may produce the stars to have a common envelope and even to merge to become a single star

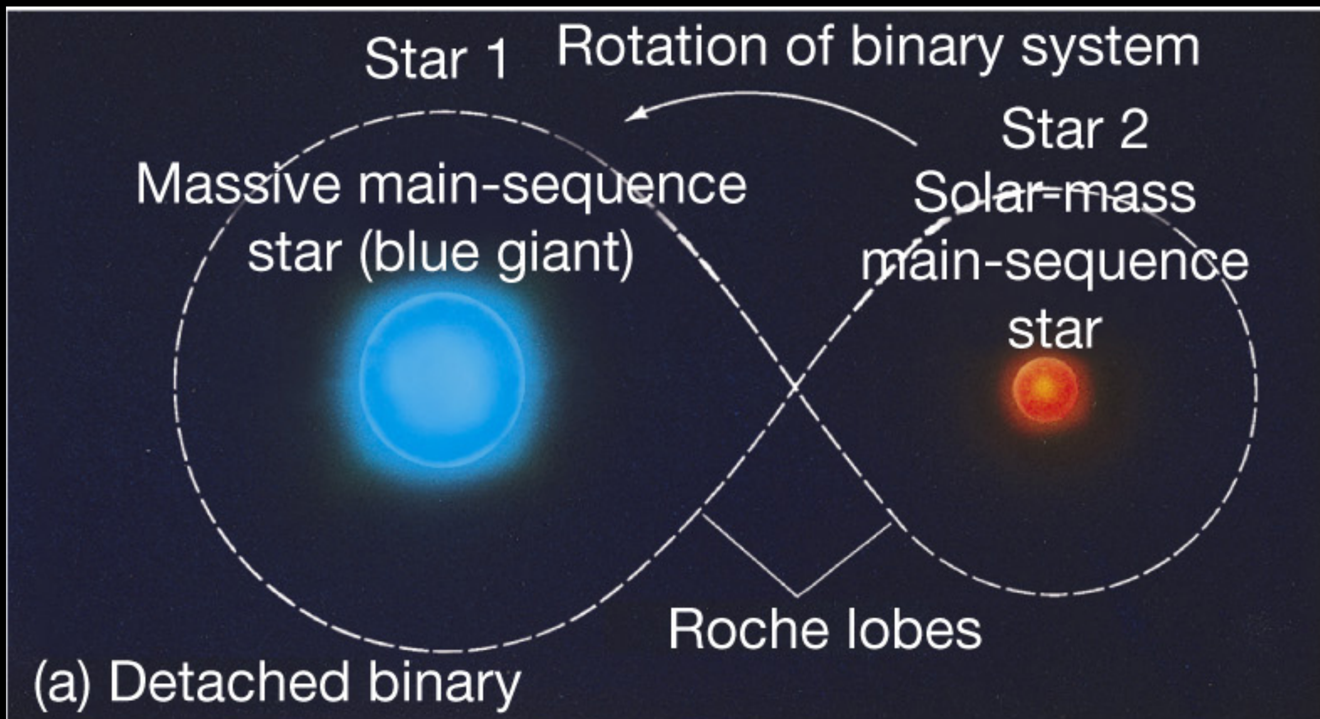
Stable mass transfer may efficiently strip stars of their Hydrogen and Helium layers, giving stripped SNe from massive stars in the range 8-15 solar masses



One theory of the evolution of Supernova 1987A (SN 1987A)



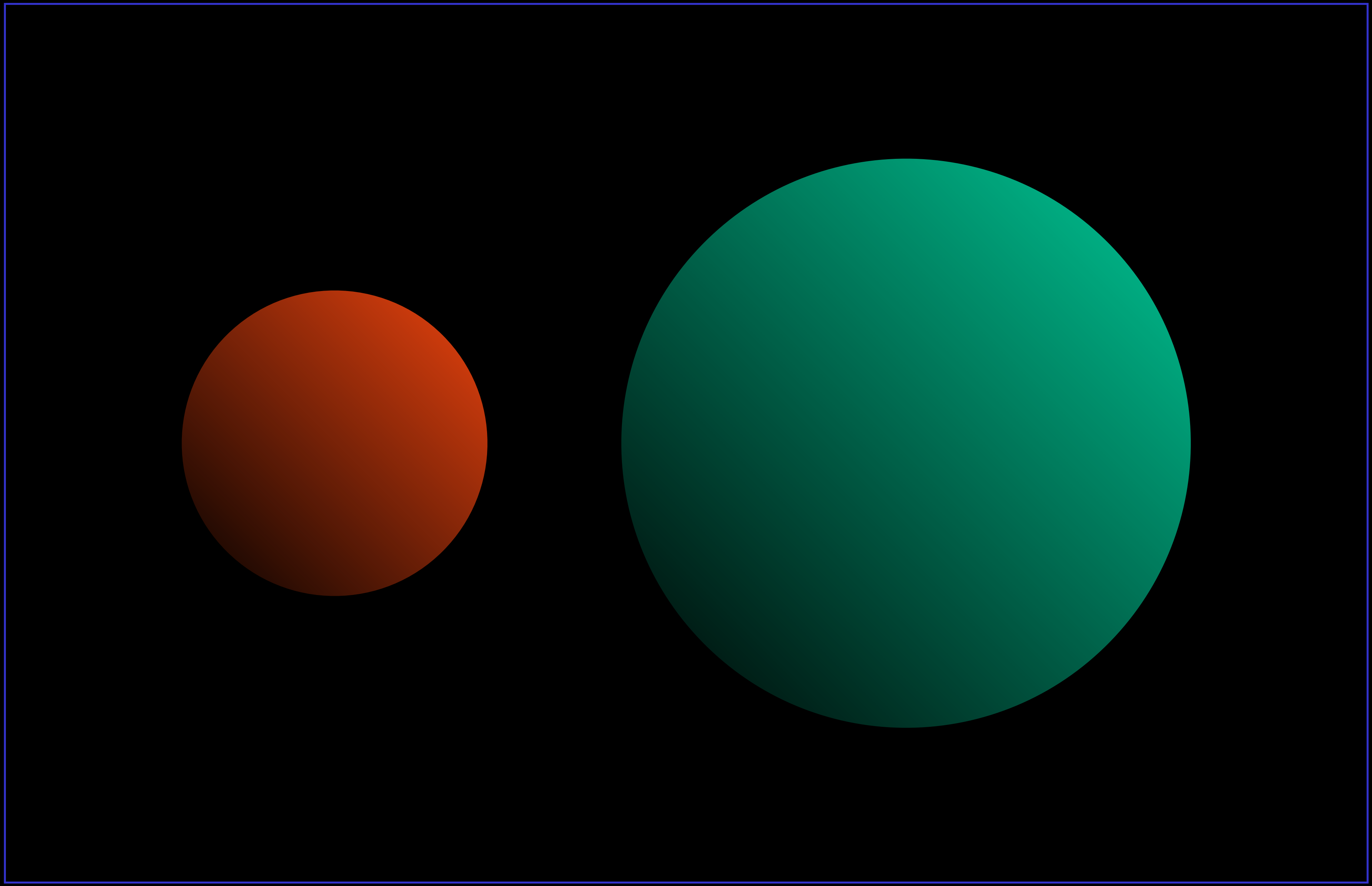
When binary systems interact?



Roche lobes: defines the region in which material is bound to the star by gravity

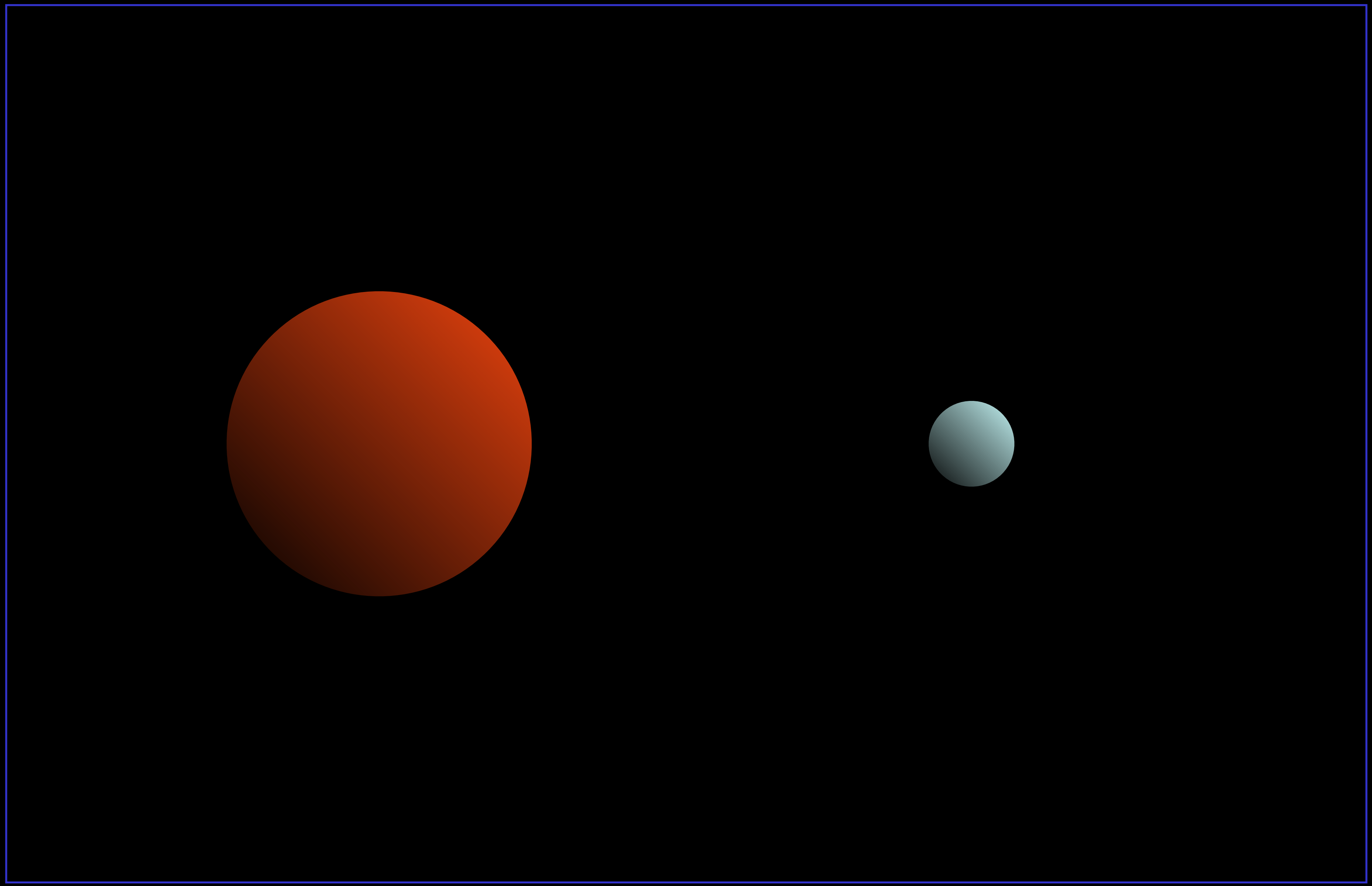
Case A: Mass transfer can happen when the secondary star is still on the main sequence

When binary systems interact?



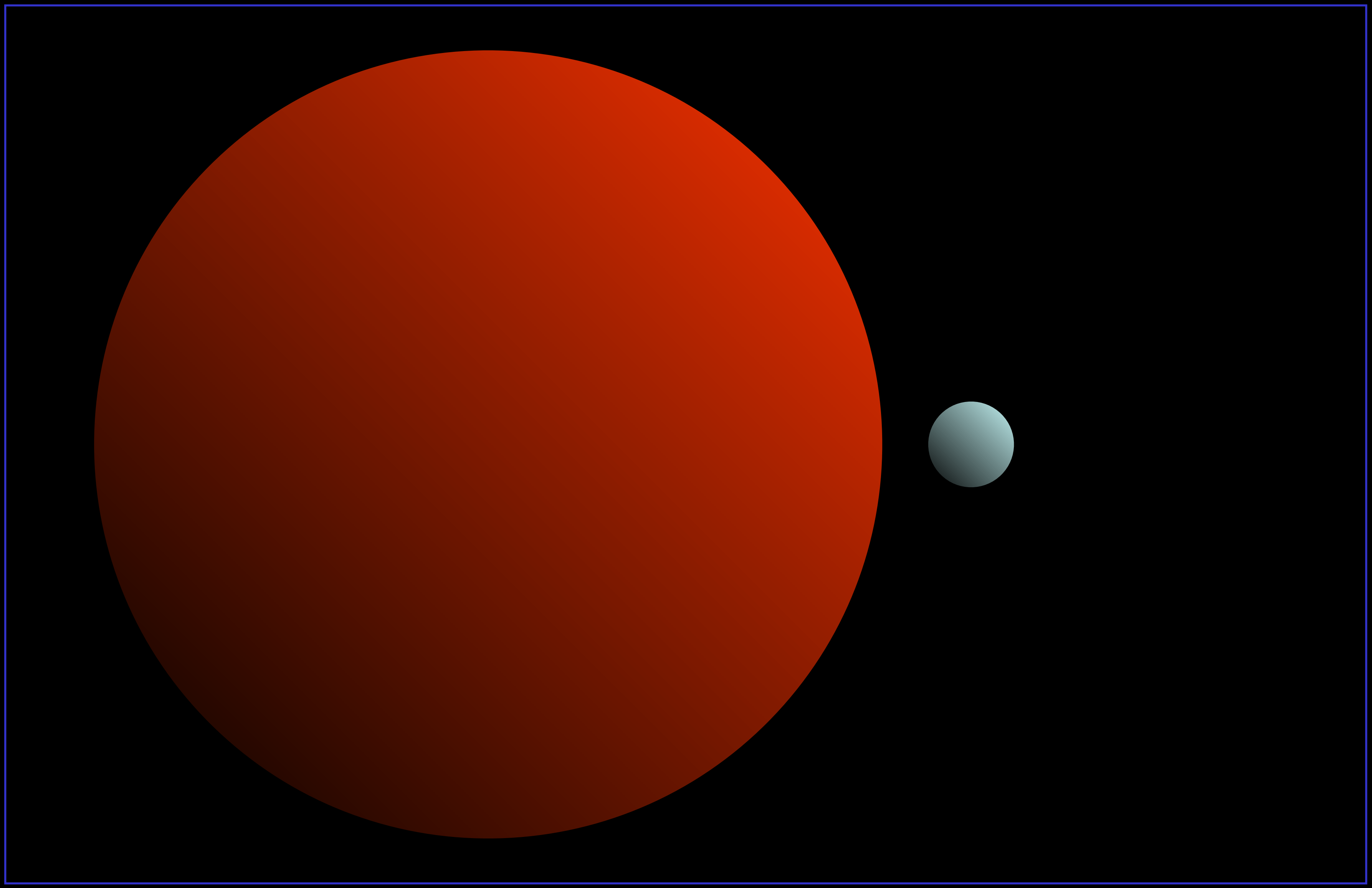
2 main sequence stars

When binary systems interact?



Higher mass star has evolved into a white dwarf

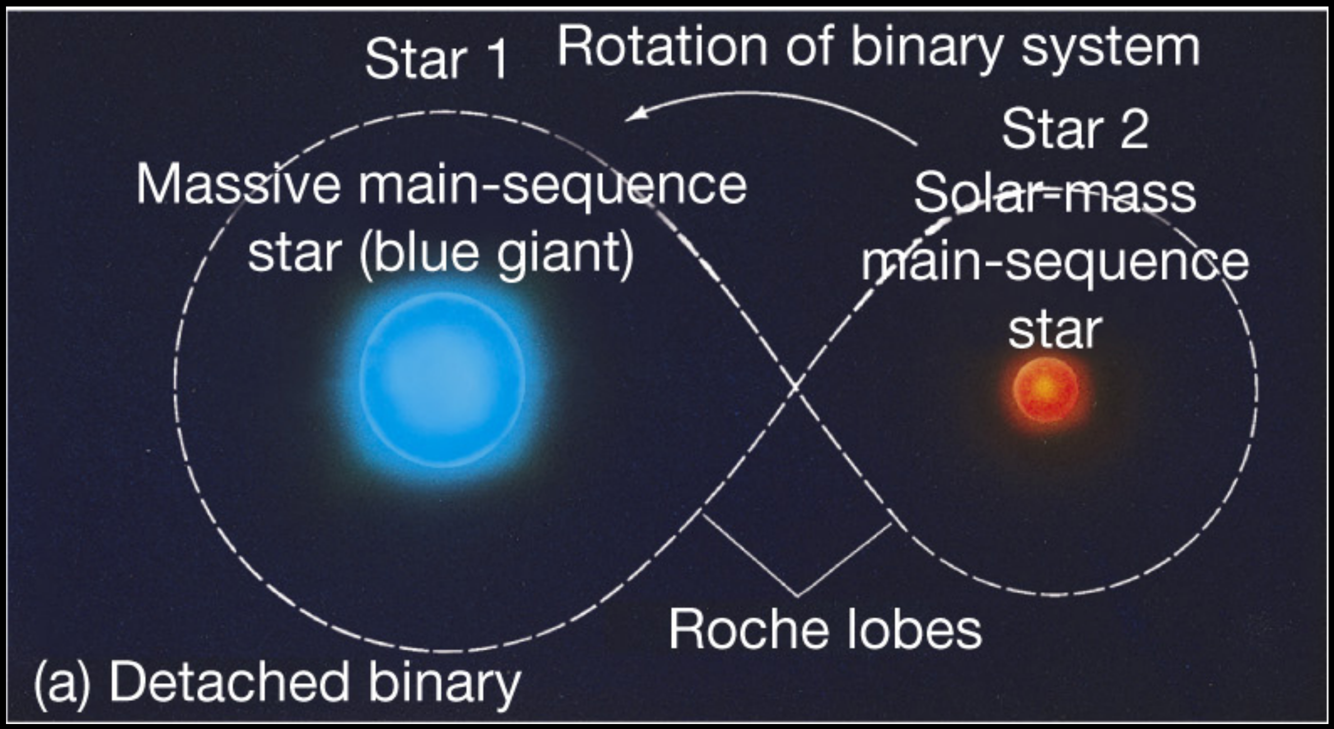
When binary systems interact?

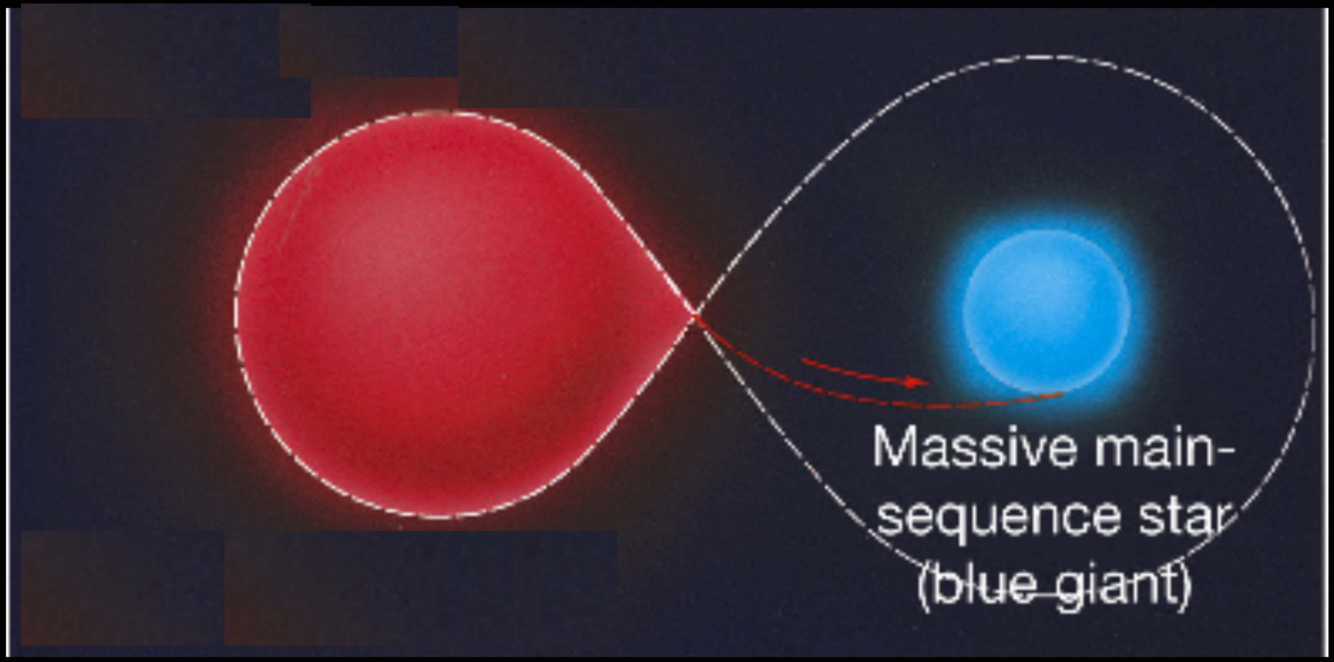


Lower mass star expands into a red giant

and start to transfer mass on the white dwarf!!

When binary systems interact?





Roche lobes: defines the region in which material is bound to the star by gravity

Case A: Mass transfer can happen when the secondary star is still on the main sequence

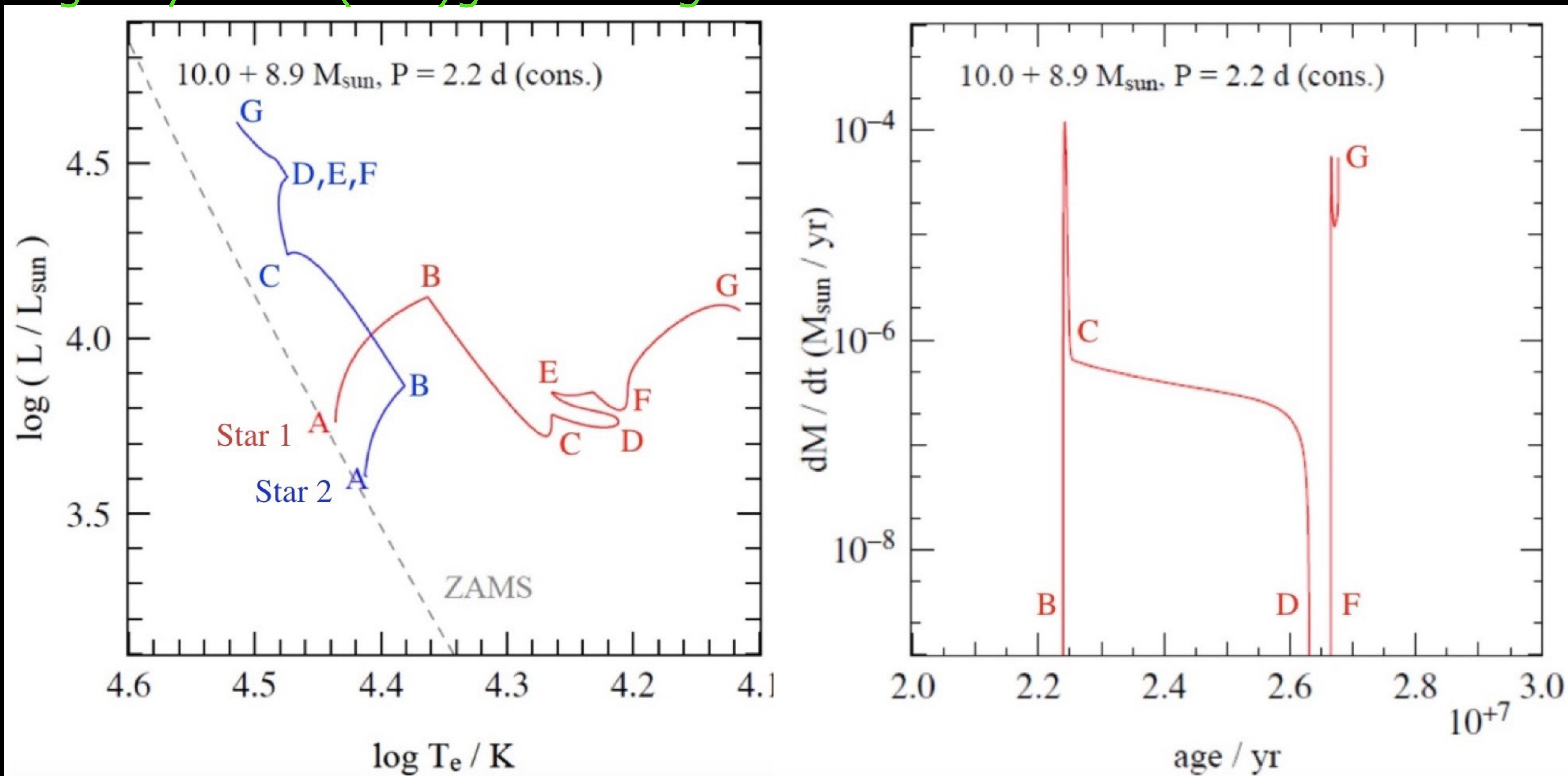
Case B: more likely to happen when one of the two stars will expand and become a RSG

Case C: or when a star expand and become a AGB star

Stars in Binaries: Evolution

Example: Case A

Algol system: (sub)giant filling its Roche lobe + more massive MS star



B: primary (star 1) fills its Roche lobe

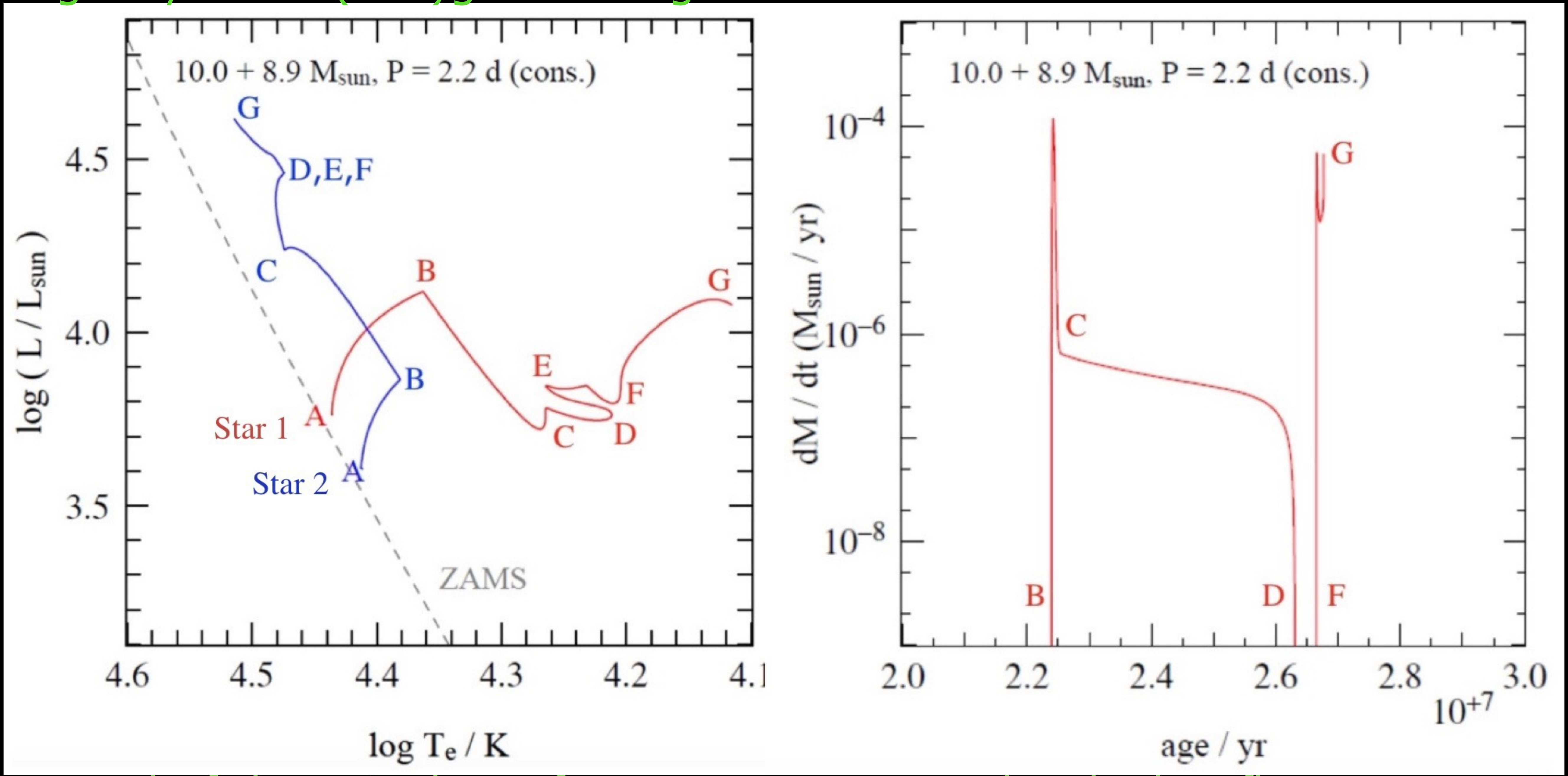
B-C: mass transfers from primary to secondary

C-D: mass transfer has settled to the nuclear timescale of star 1

Stars in Binaries: Evolution

Example: Case A

Algol system: (sub)giant filling its Roche lobe + more massive MS star



D: end of the MS phase for primary; star 1 shrinks briefly

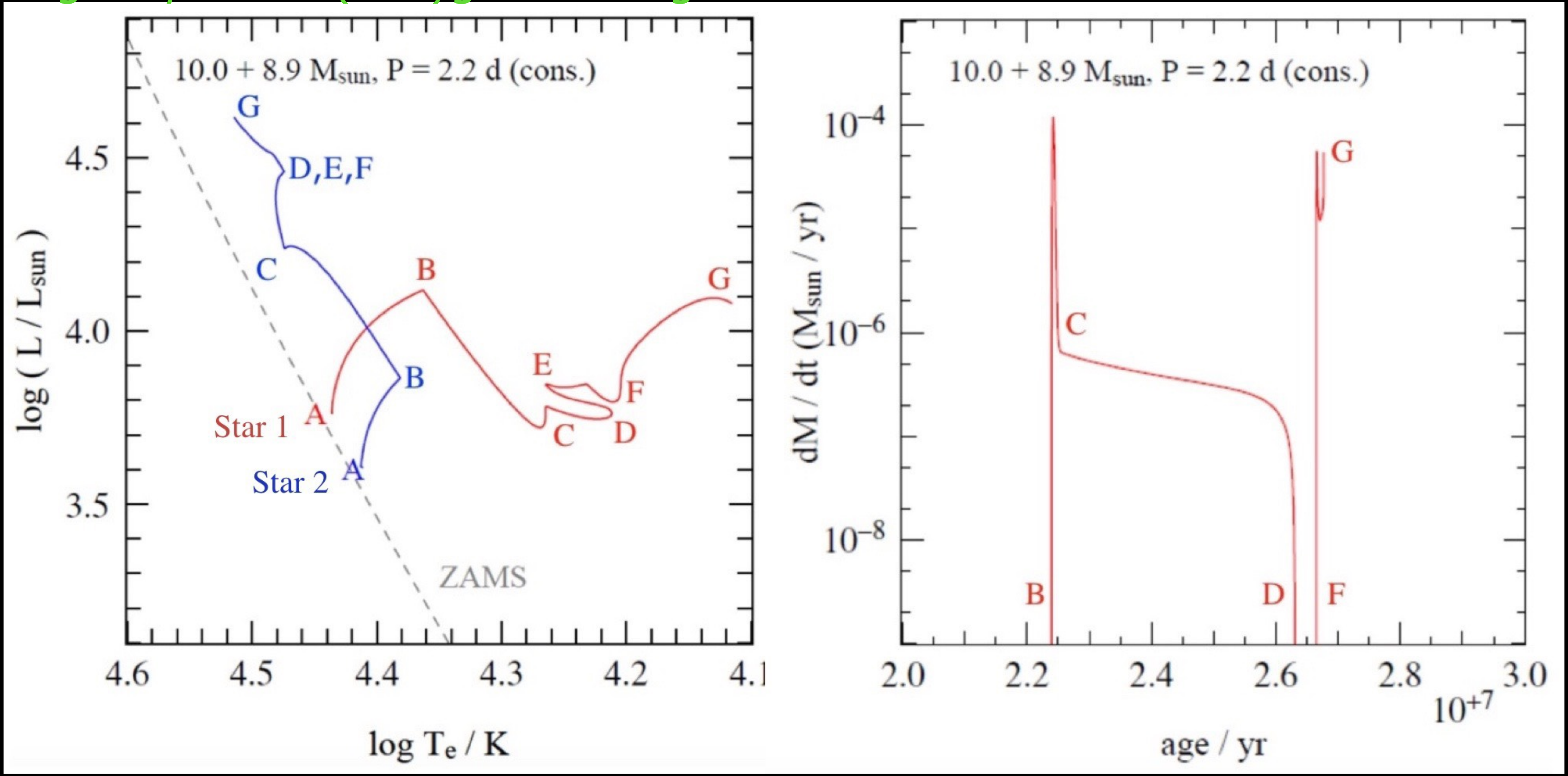
D-E-F: mass transfer stops

F-G: star expands;

Stars in Binaries: Evolution

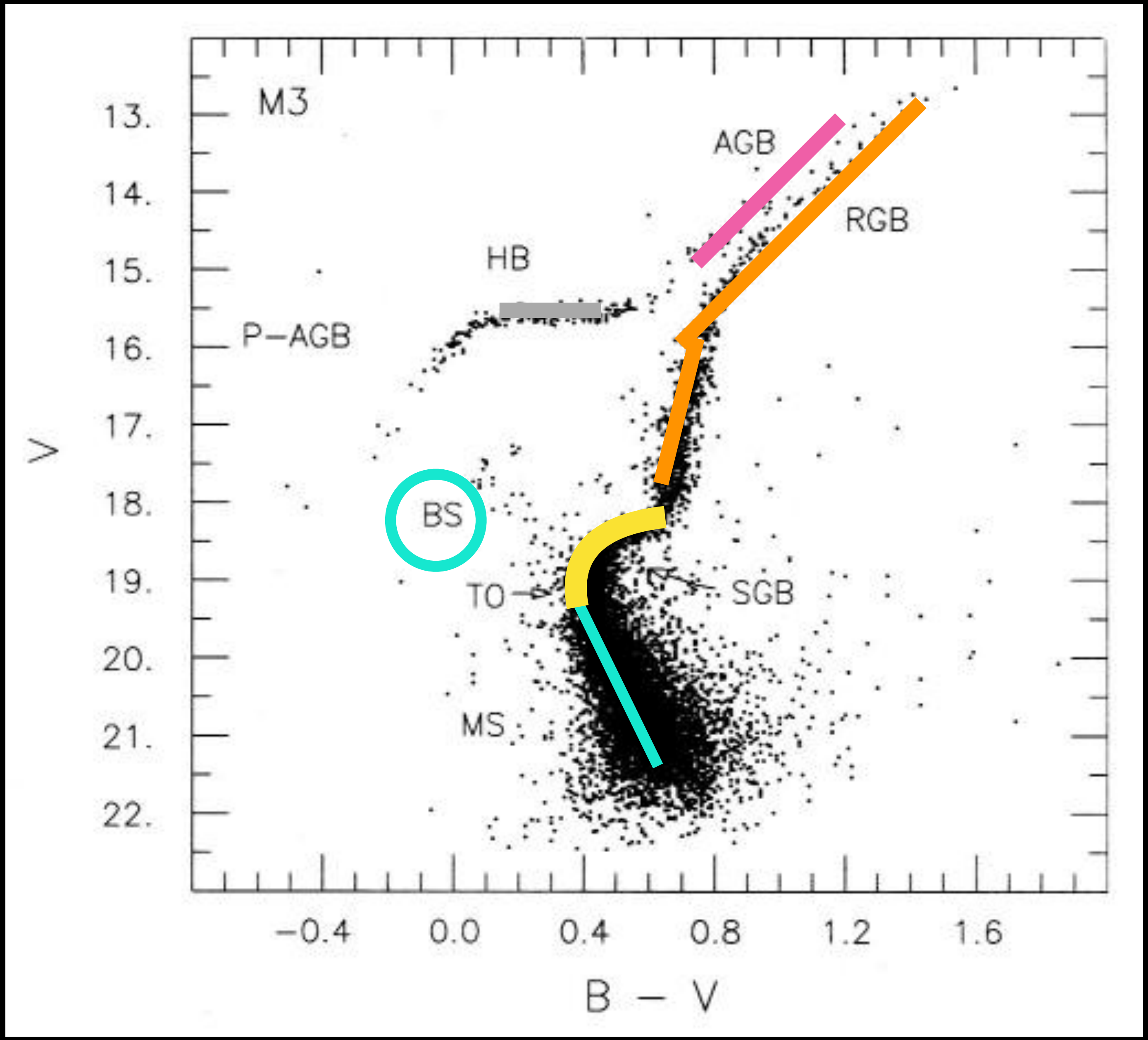
Example: Case A

Algol system: (sub)giant filling its Roche lobe + more massive MS star



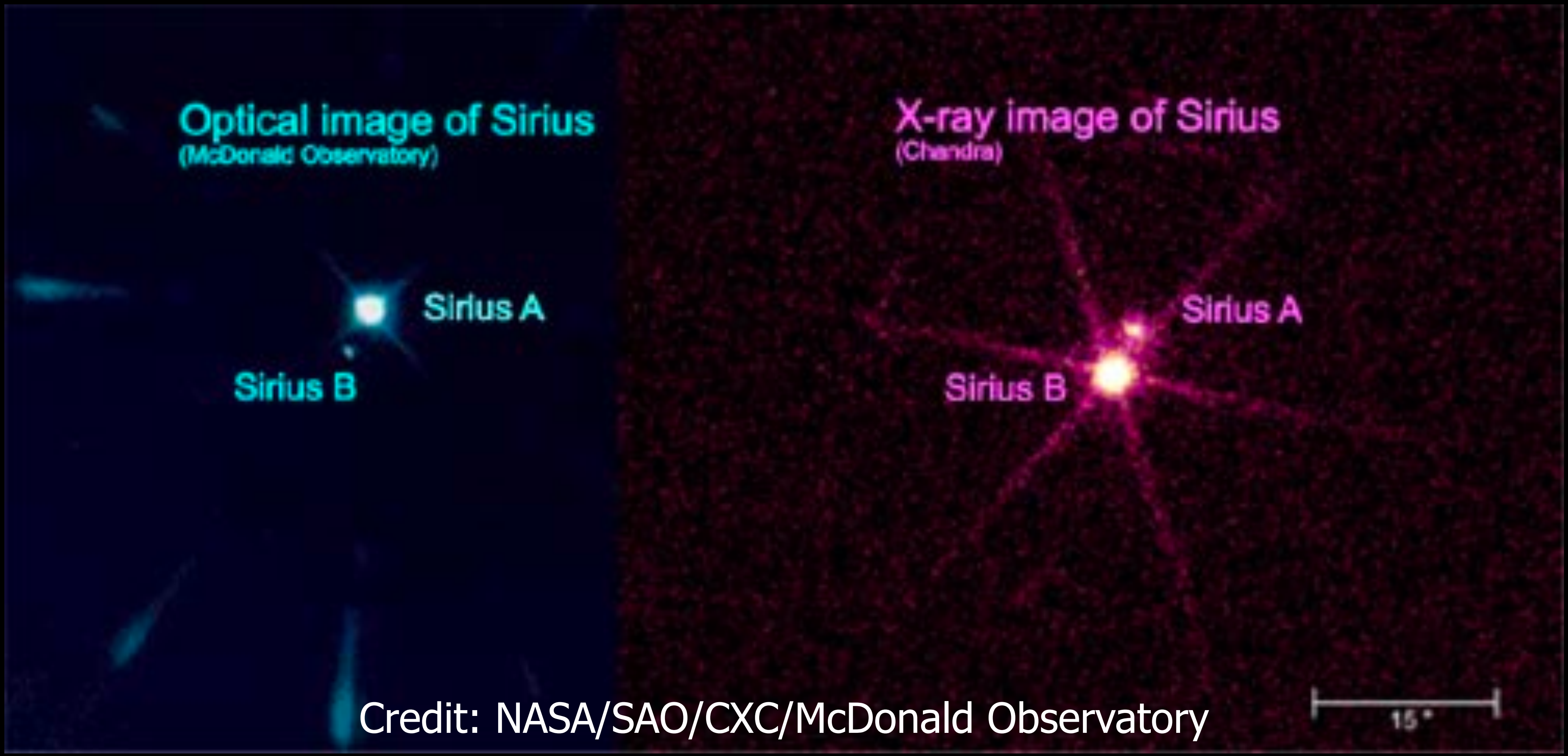
Star 2 can become a **blue straggler**, appearing as a MS star with a mass above the turnoff point.

HR diagram



- MS = Main Sequence
- TO = Main sequence Turn off
- RGB = Red Giant Branch
- AGB = Asymptotic Giant Branch
- HB = Horizontal Branch

Sirius B – the closest known white dwarf

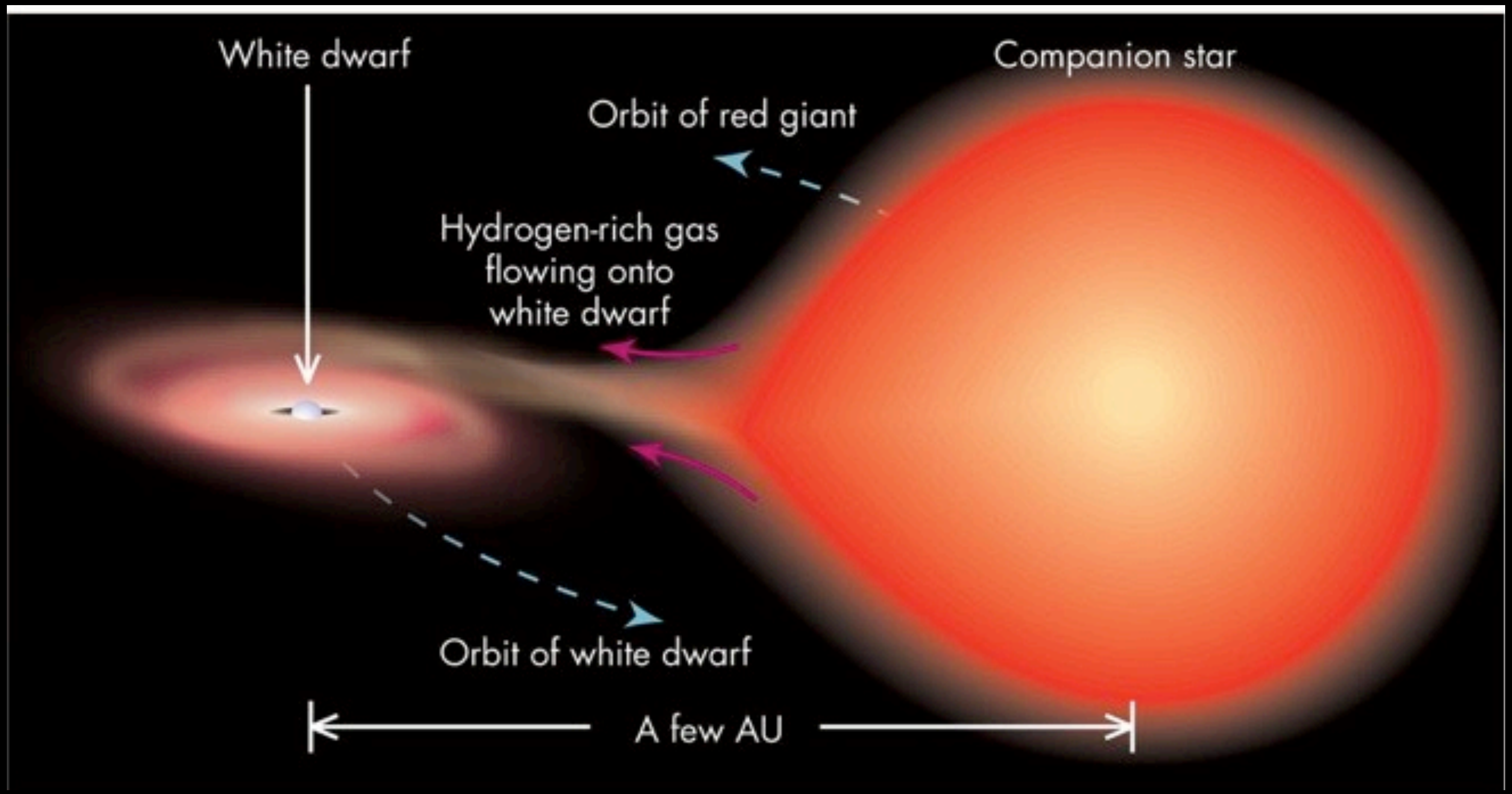


Credit: NASA/SAO/CXC/McDonald Observatory

Sirius B:

- Approximately same mass as the Sun
- Approximately same size as the Earth
- Temperature ~25,000 K (~4 times hotter than Sun)
- About 10,000 times fainter than Sirius A to our eyes… but bright in X-rays!

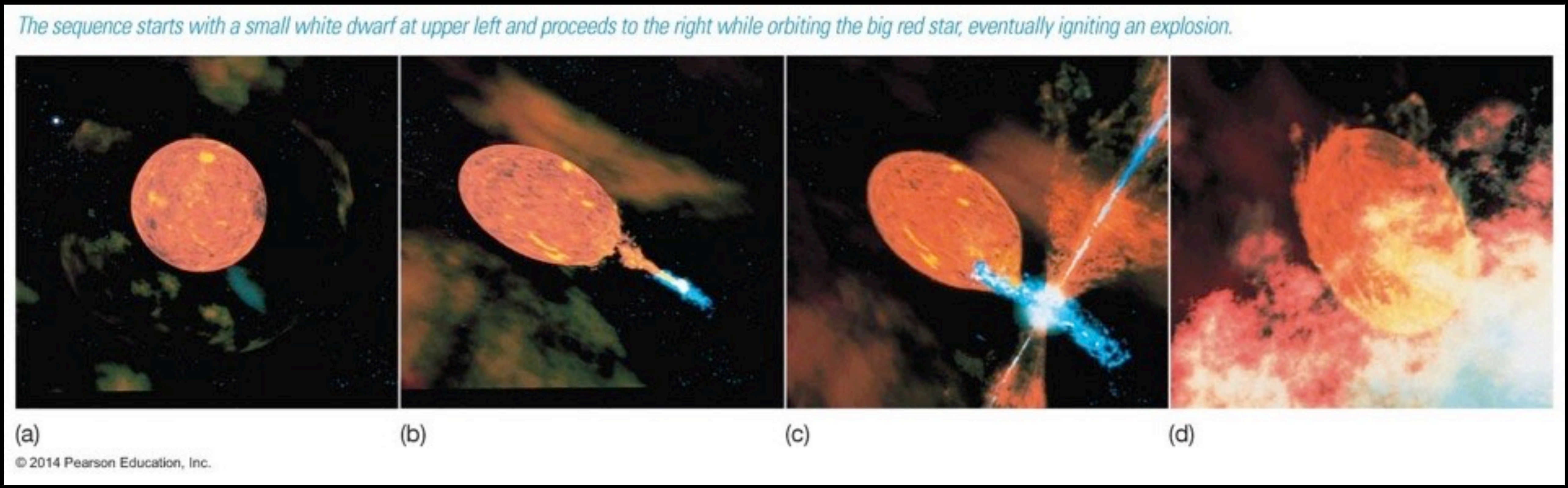
White Dwarfs in Binary Systems



In a binary system, a white dwarf may gravitationally capture gas expelled from its evolving companion

- The captured gas will be rich in hydrogen and represent a fuel source to the white dwarf
- Hydrogen is compressed and heated on the white dwarf's surface

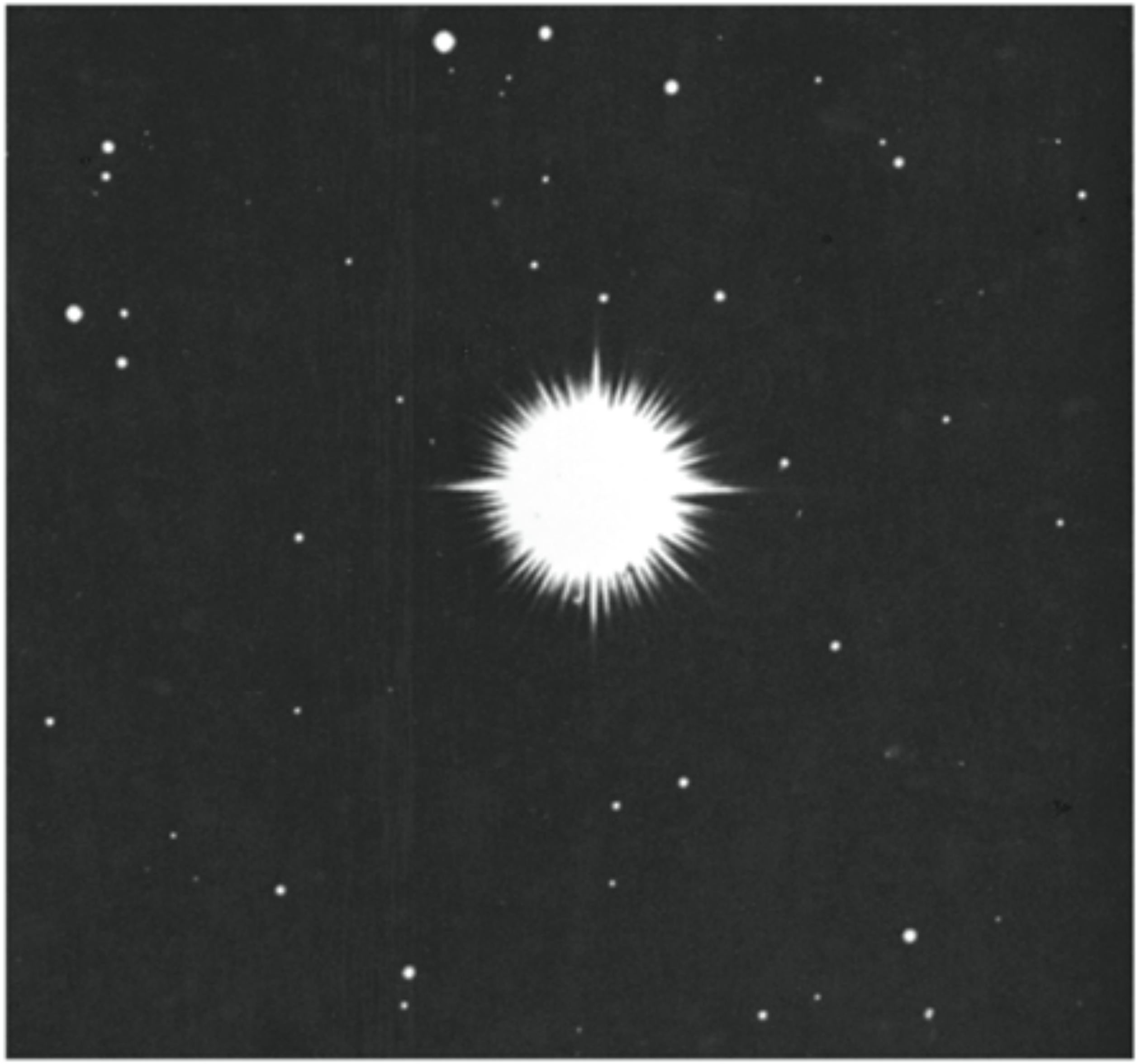
White Dwarfs in Binary Systems



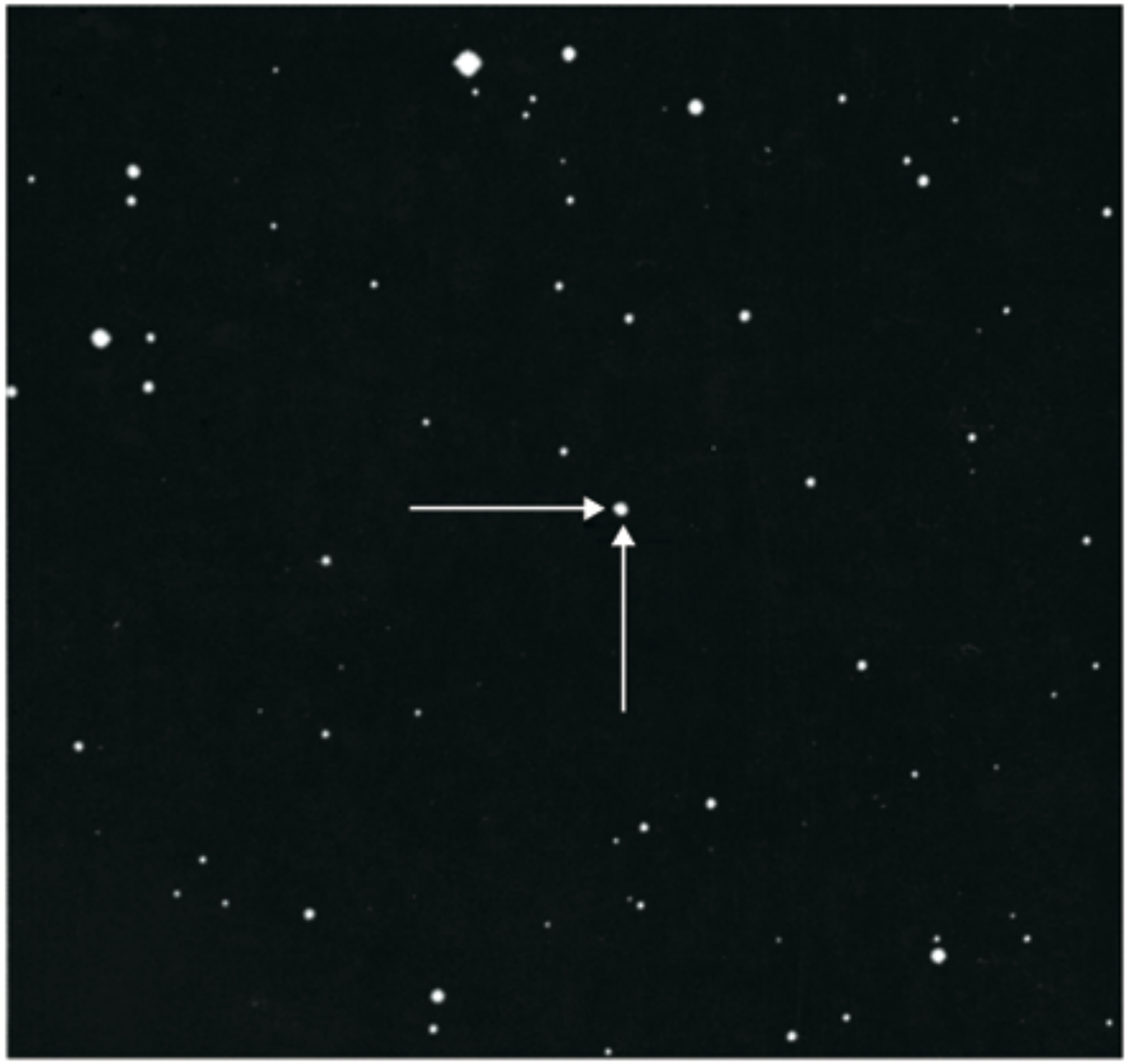
The gas eventually reaches ignition – a fusion reaction in a degenerate gas results in an explosion: a nova

Novae may occur repeatedly for the same white dwarf

Nova

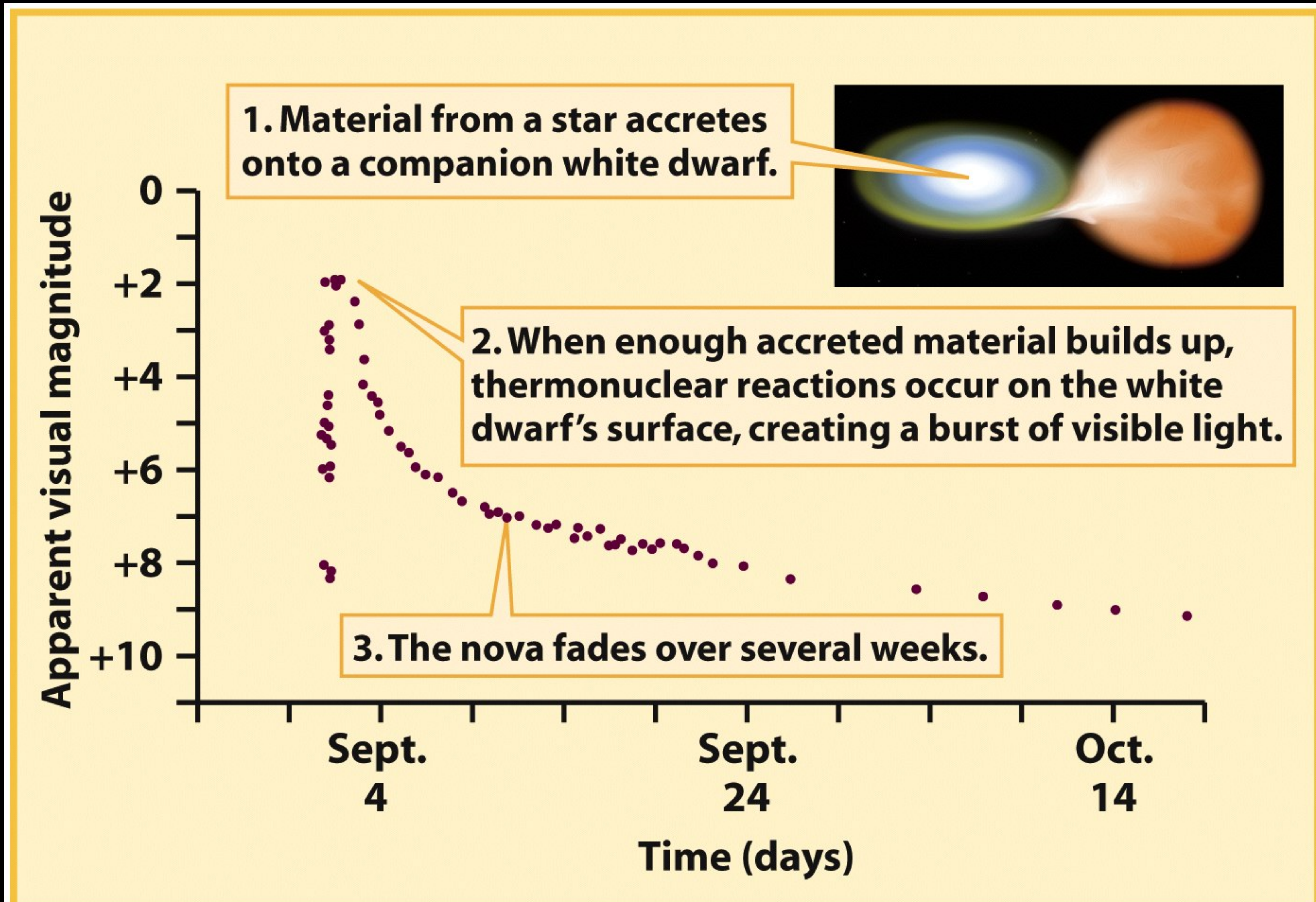


(a) Nova Herculis 1934 shortly after peak brightness



(b) Two months later

Nova

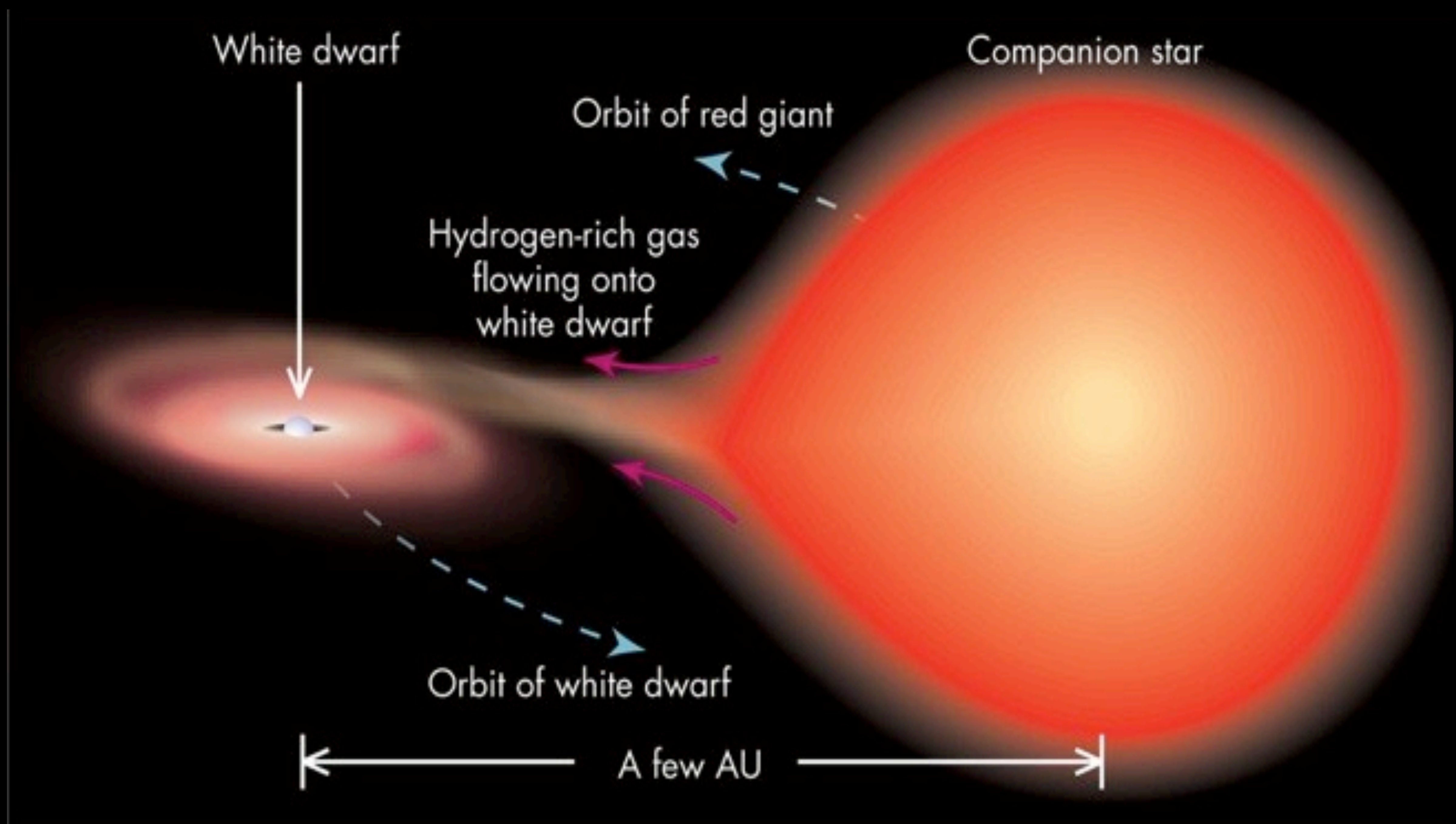


1. Material from a star accretes onto a companion white dwarf.
2. When enough accreted material builds up, thermonuclear reactions occur on the white dwarf's surface, creating a burst of visible light.
3. The nova fades over several weeks.
Apparent visual magnitude
0
+2
+4
+6
+8
+10
Sept. 4
Sept. 24
Oct. 14
Time (days)

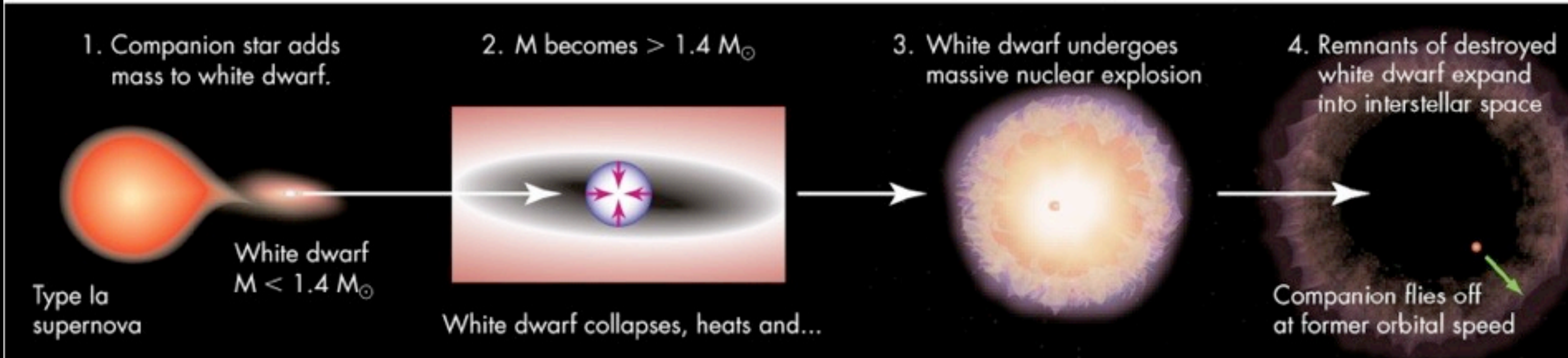
White Dwarfs in Binary Systems

Adding mass to a degenerate white dwarf makes it shrink and increases its internal pressure to offset the increased gravity

There is a limit to how much the white dwarf can shrink - eventually the radius shrinks to zero! The Chandrasekhar limit!

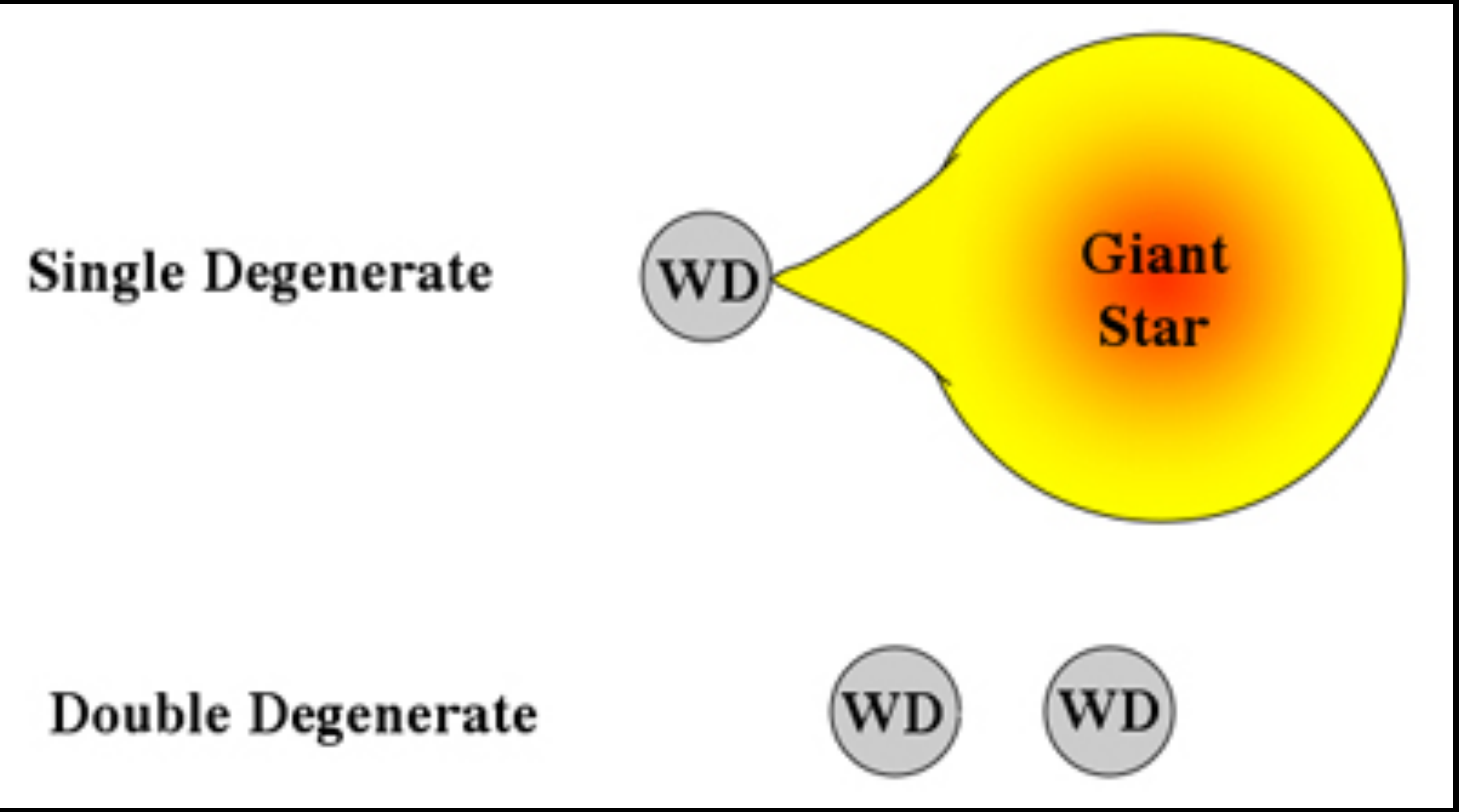


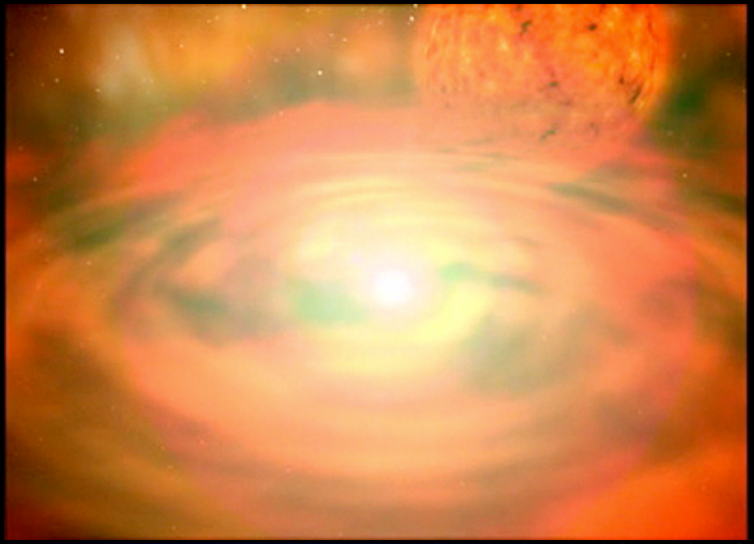
Type I Supernova



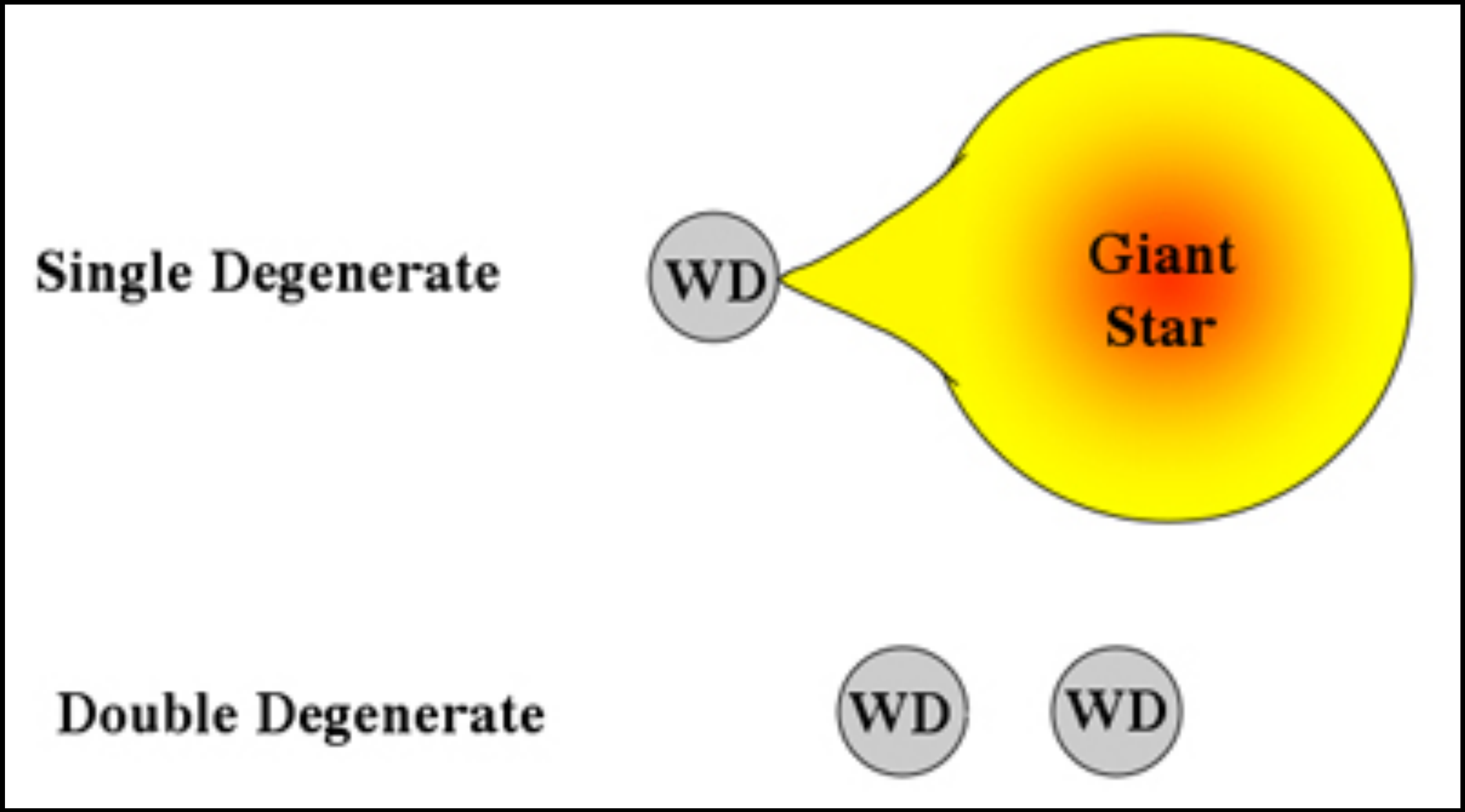
- The result of a white dwarf accreting enough mass to exceed the Chandrasekhar limit:
- The white dwarf collapses, igniting carbon and oxygen
- The fusion ignition blows the star apart creating heavy elements in the process (e.g., silicon, nickel, and iron)
- The resulting supernova (Type I) can be 5-10 billion times as bright as the Sun

Type I Supernova





Type I Supernova



Increase the mass

Increase the temperature

Burn Carbon-Oxygen in degenerate conditions

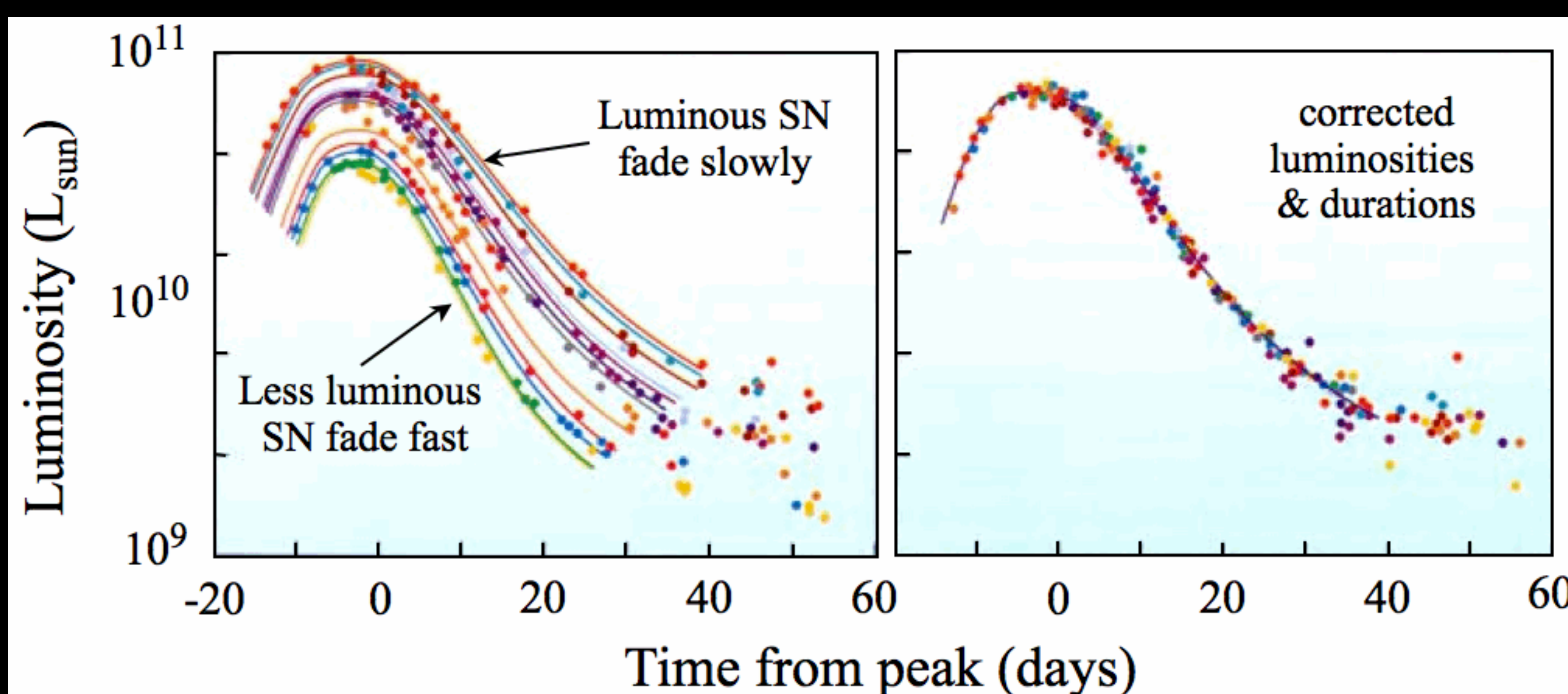
Boom !!!!

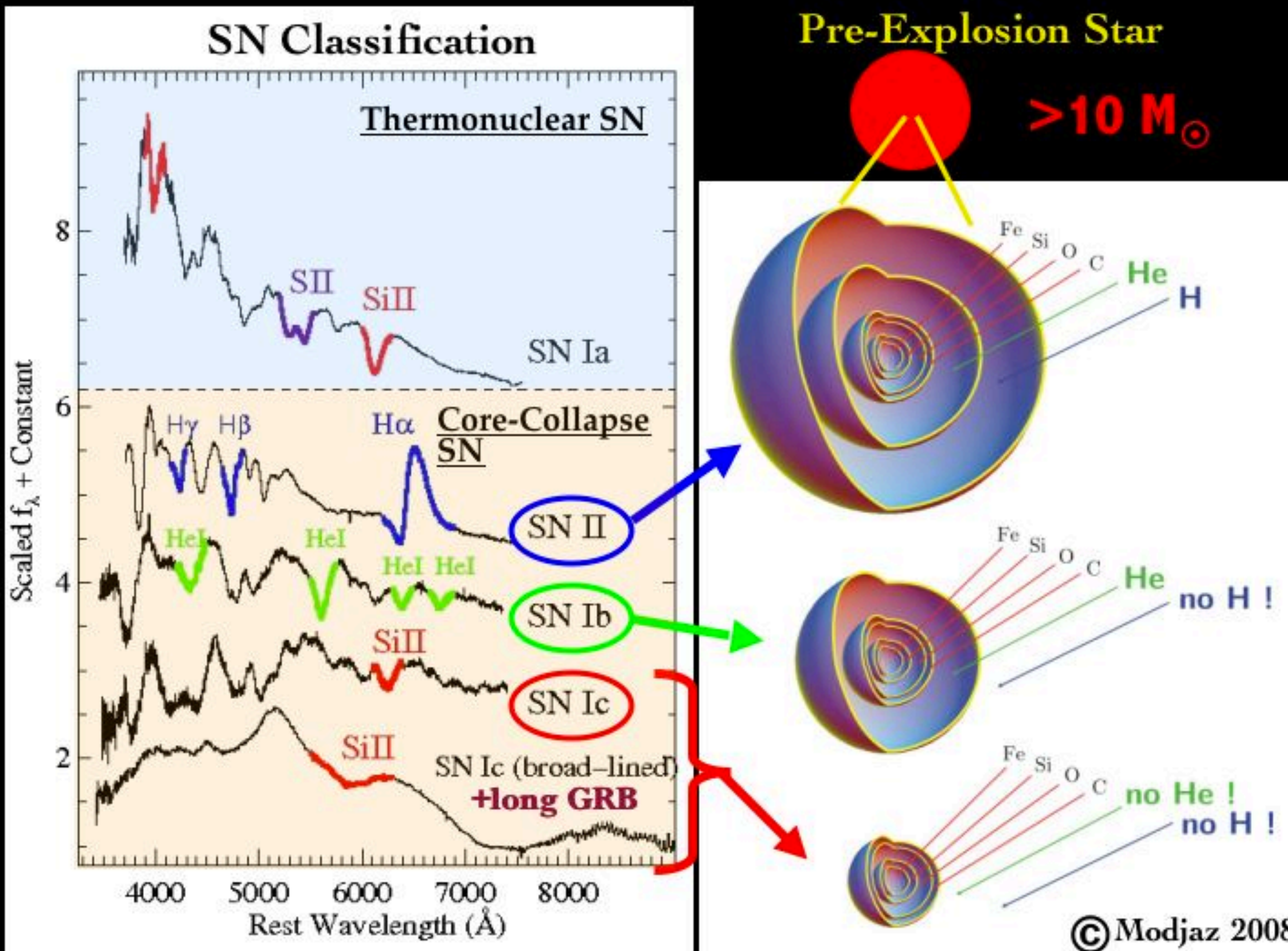
Type I Supernova

The explosion happen when the White Dwarf ~ 1.4 Msun

Fuel energy is always almost the same

SNe Ia are standard candles





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HeI
HeI
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SiII
SN Ic
SiII
SN Ic (broad-lined)
+long GRB
Scaled f_λ + Constant
Rest Wavelength (Å)
8
6
4
2
4000
5000
6000
7000
8000
Pre-Explosion Star
>10 $M_\odot$
Fe
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C
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O
C
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no H !
Fe
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no H !
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Two types of supernova

Massive star supernova (star mass > 8 $M_\odot$)

- Iron core stops fusing new elements, because it cannot release any more energy
- Core reaches the mass limit and collapses into a neutron star
  - Total explosion!
  - **"core collapse supernova"**

White dwarf supernova (star mass < 8 $M_\odot$)

- Star stops fusing new elements, because it is not hot enough (not enough mass!). It becomes a white dwarf.
- Gains mass from a companion, and eventually reaches the mass limit
- Entire white dwarf undergoes runaway nuclear fusion
  - Total explosion!
  - **"thermonuclear supernova"**

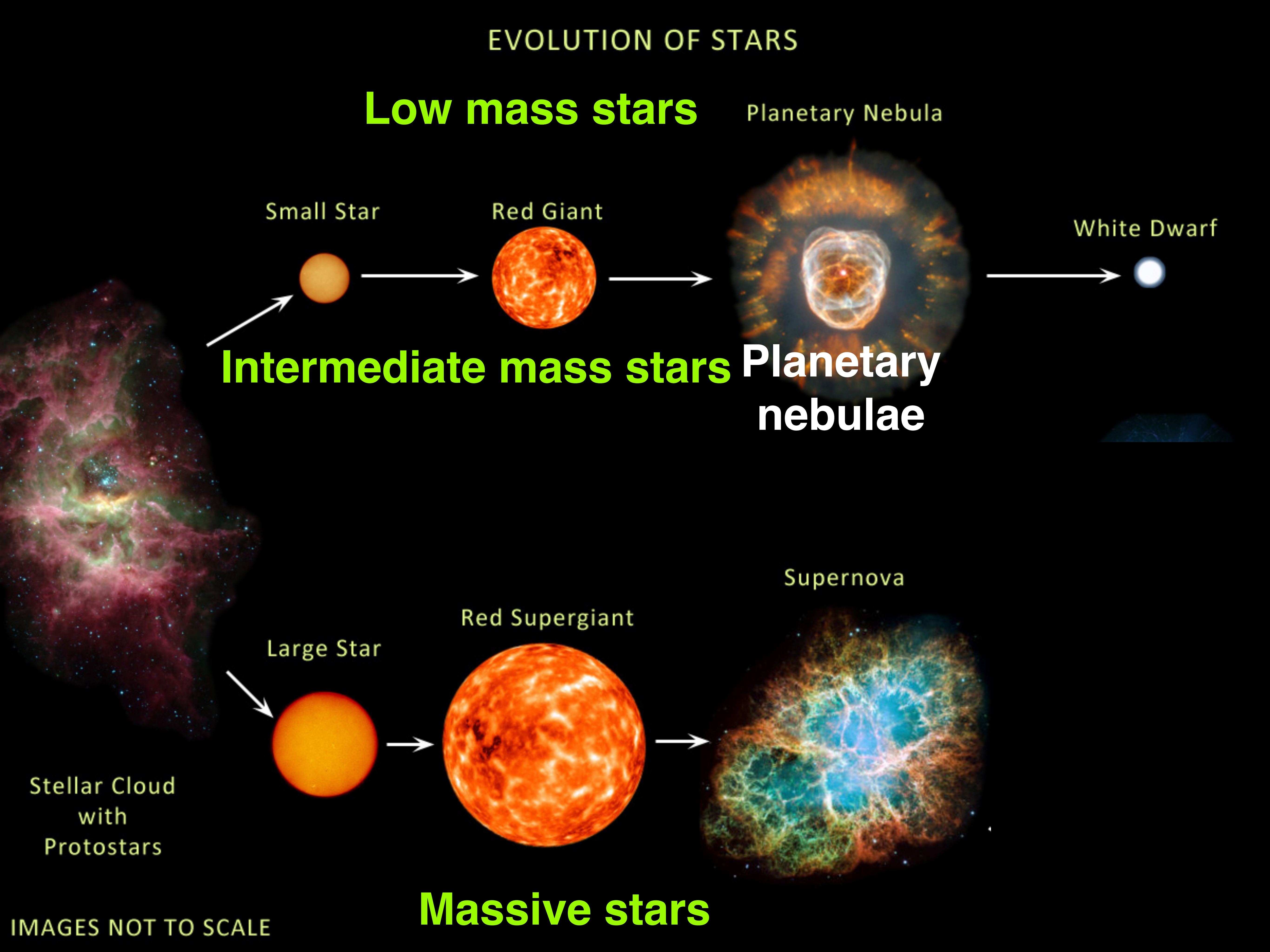
What is left over after a supernova?

Massive star supernova (star mass > 8 $M_\odot$)

- Core collapses into a ball of neutrons
  - **Neutron star**
  - If there is too much mass, it will collapse into a **black hole**
    - Black hole forms if the star's initial mass was $\gtrsim 30\ M_\odot$

White dwarf supernova (star mass < 8 $M_\odot$)

- The entire white dwarf suddenly fuses into a ball of iron
- Explosive energy of fusion blows the entire star apart
  - Nothing left! White dwarf turns into a cloud of ejected gas.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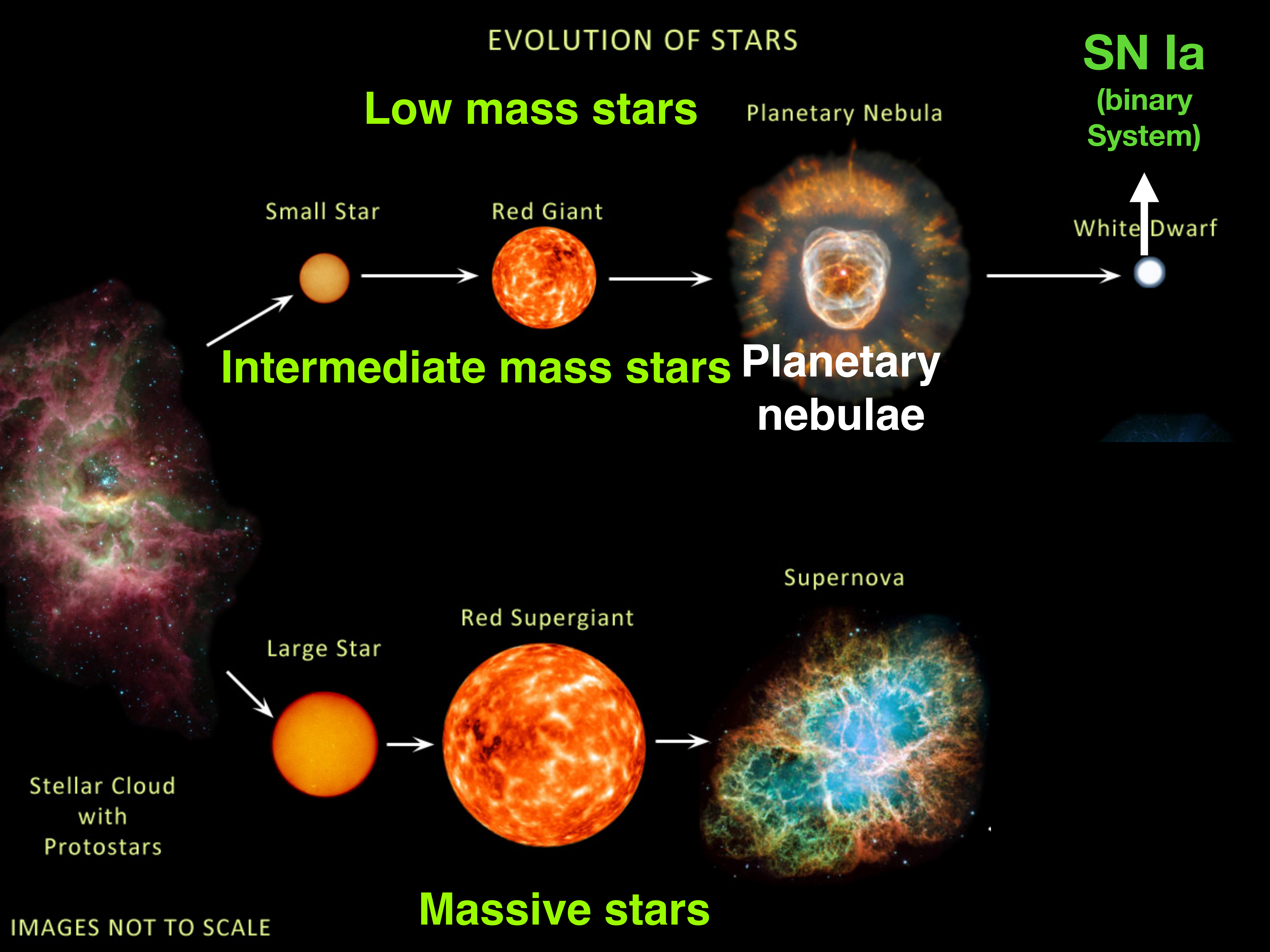
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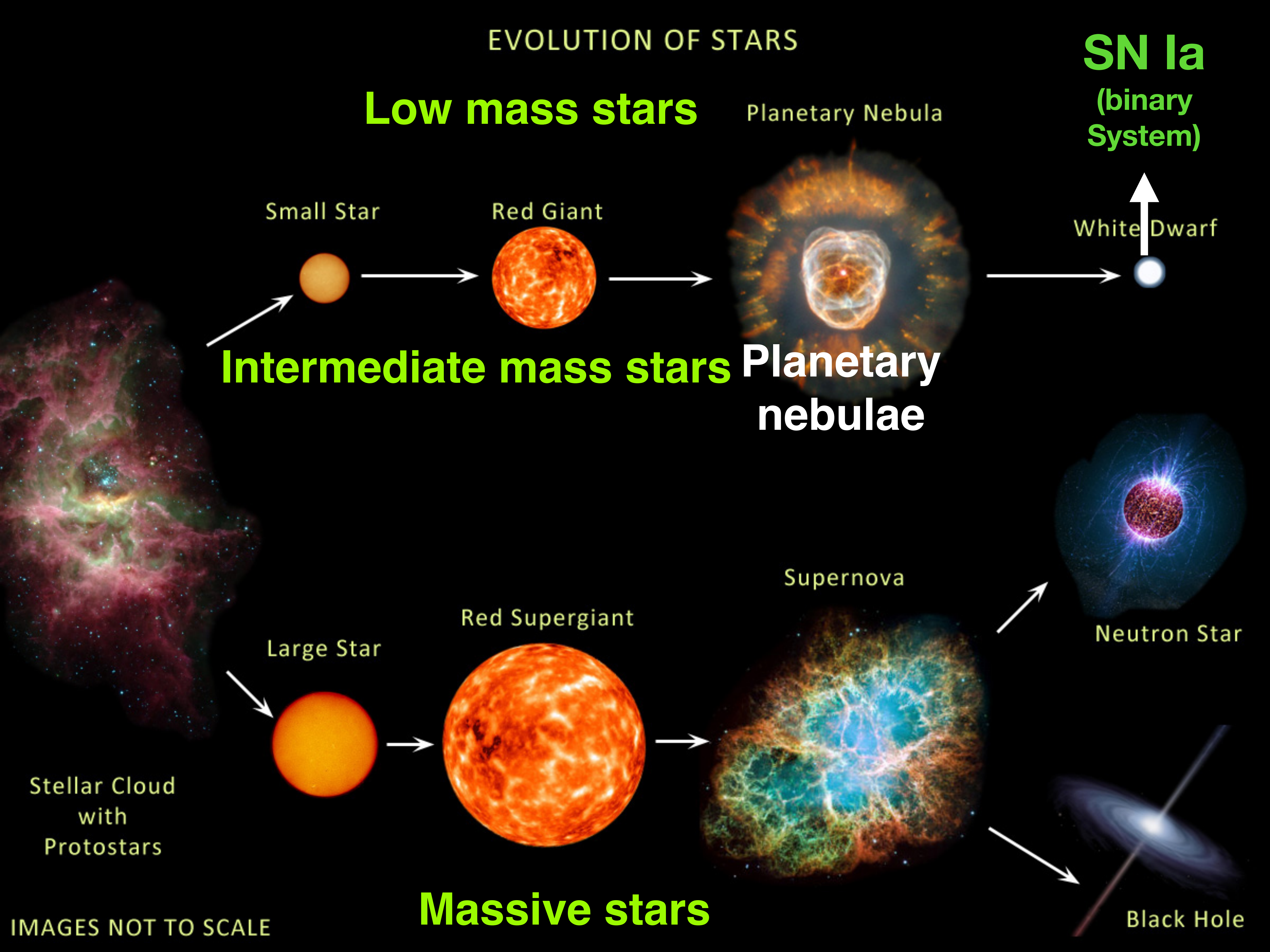

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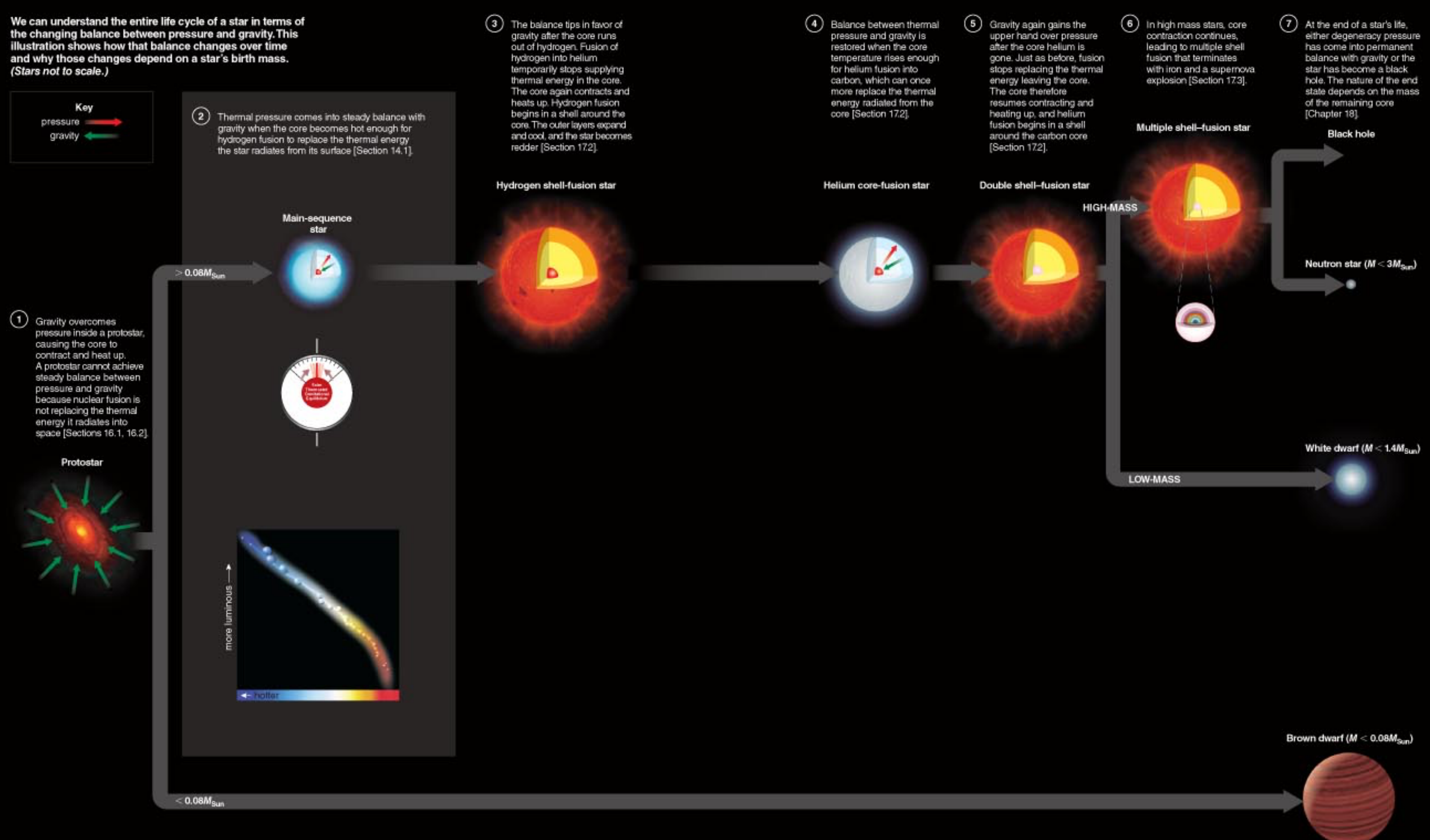
Intermediate mass stars
Planetary nebulae
Supernova
Red Supergiant
Neutron Star
Large Star
Stellar Cloud with Protostars
Black Hole
Massive stars
IMAGES NOT TO SCALE

The Stellar Graveyard: what is left over at the end of a star's life?

A battle of gravity vs pressure!

- If initial mass is > 8 M$_\odot$, the star will run out of fuel for fusion, and core will collapse: **Neutron Star or Black Hole**

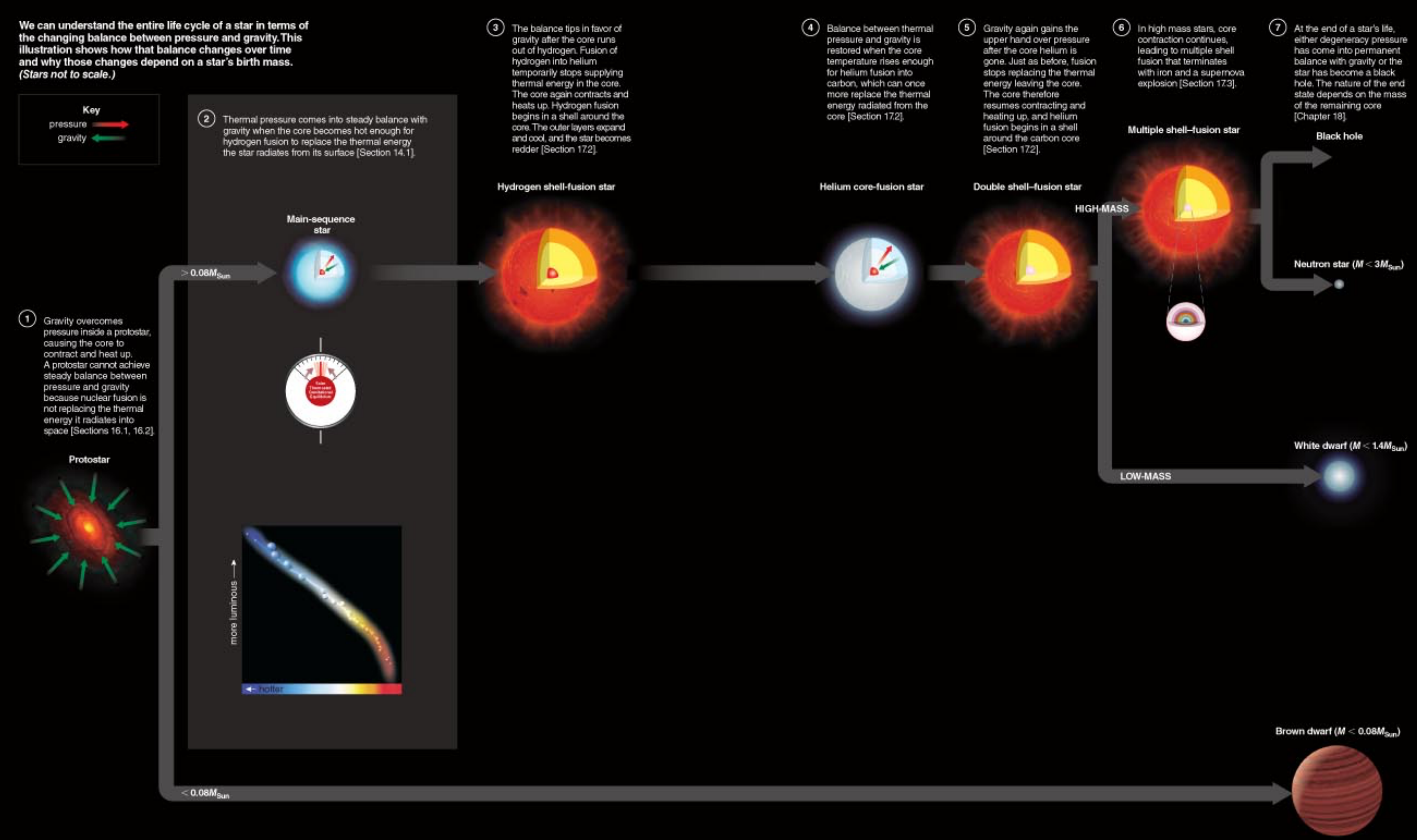


High mass:
Neutron star or **black hole**

The Stellar Graveyard:
what is left over at the end of a star's life?

A battle of gravity vs pressure!

- If initial mass is 0.08 - 8 M☉, the star will not be hot enough to continue fusion: **White Dwarf**



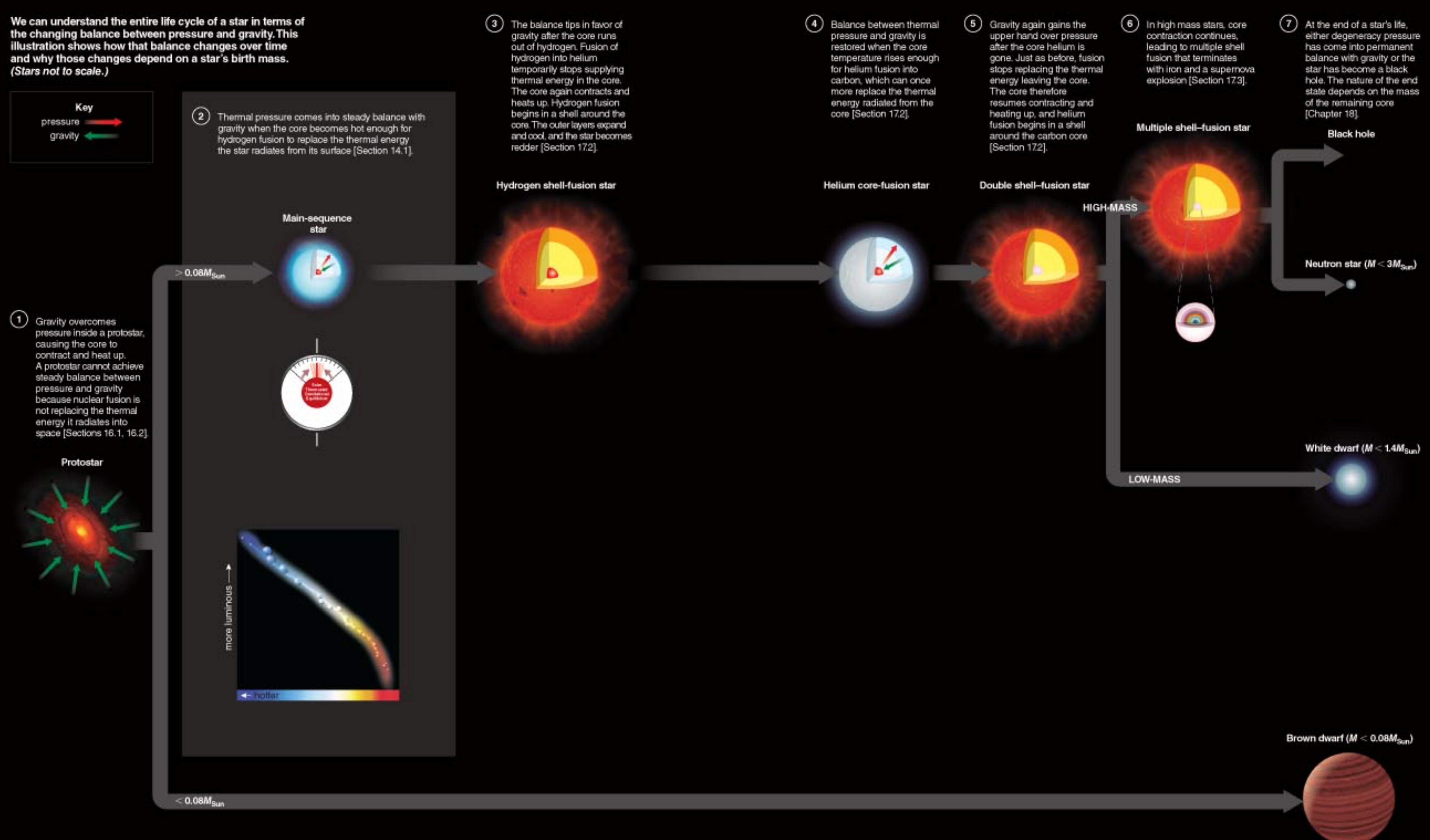
High mass:
Neutron star
or **black hole**

Intermediate and low mass:
White Dwarf

The Stellar Graveyard: what is left over at the end of a star's life?

A battle of gravity vs pressure!

- If initial mass is < 0.08 $M_\odot$, the "star" will never become hot enough for hydrogen fusion: **Brown Dwarf**



High mass:
Neutron star
or **black hole**

Intermediate and low mass:
White Dwarf

Very Low mass:
Brown Dwarf

Stellar Evolution Review (All masses in units of solar masses.)