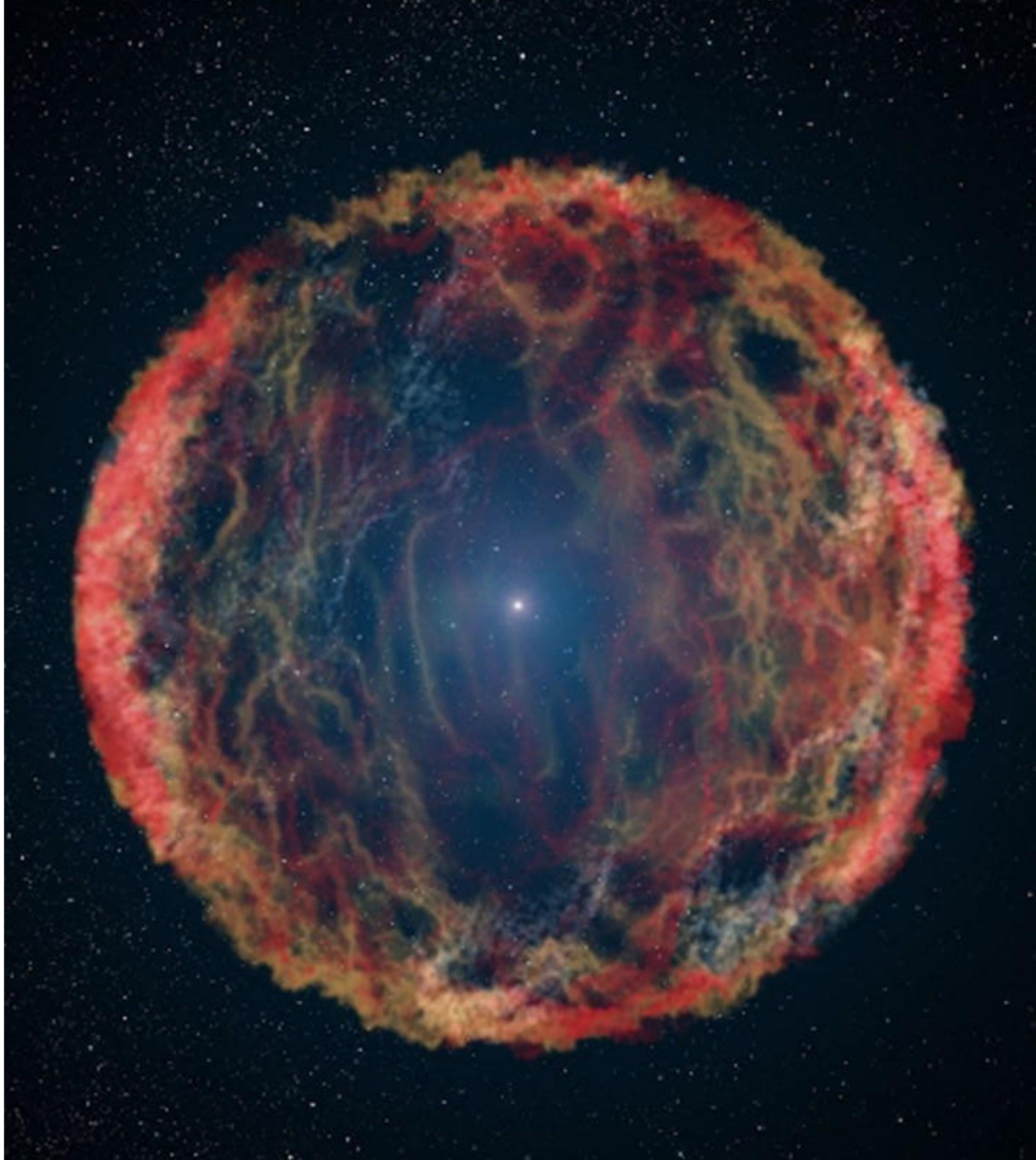
PHY 4905 | Modern Astrophysics

Lecture III.

Stellar birth, life and death

UF UNIVERSITY of FLORIDA

Imre Bartos | Fall 2018



Stellar Evolution

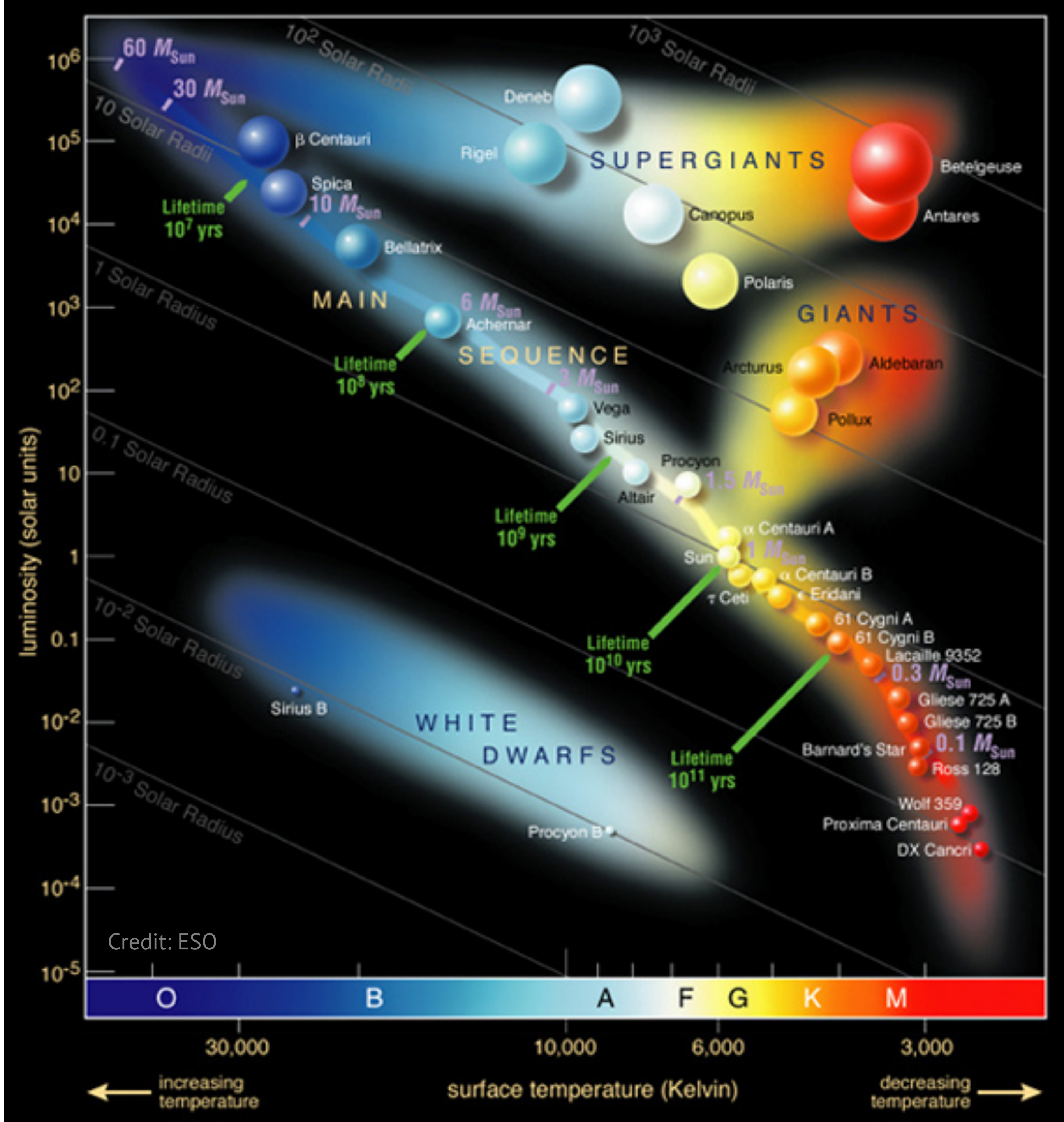
Not everyone will be a star…
Below 0.08 $M_{\odot}$, pressure is too small for fusion.
→ Brown dwarfs

Stars are ~70% H, 30% He, and a trace of "metal."
→ Hydrogen fusion.

Fusion produces heat that halts gravitational collapse.
→ Hydrostatic equilibrium.

Hertzsprung–Russell diagram
Stars stay on the same point for most of their lives.

When H starts running out stars move off of the main sequence.

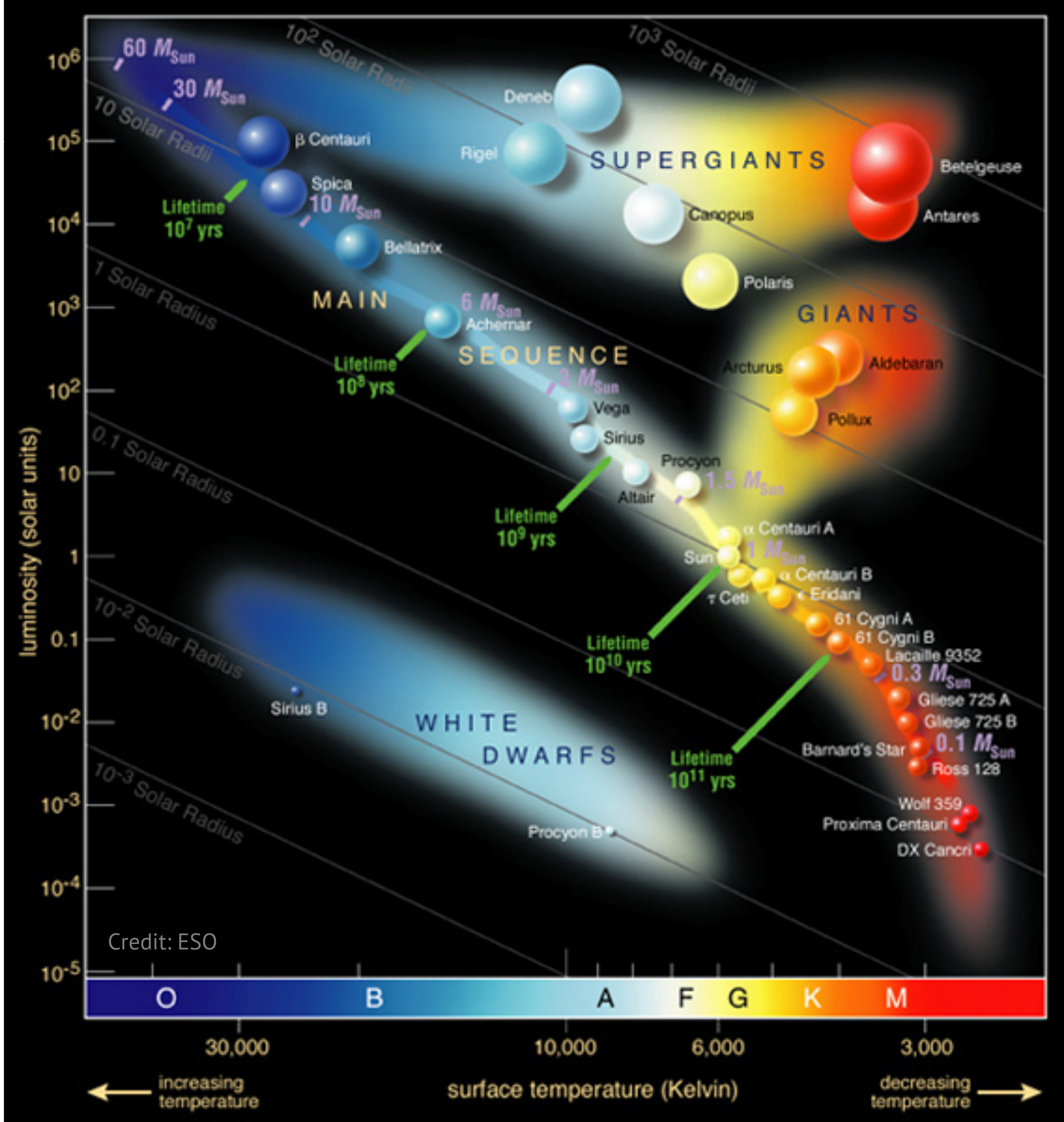


Stellar Evolution II.

Massive stars live fast and die young.

Mass (solar masses)	Time (years)	Spectral type
60	3 million	O3
30	11 million	O7
10	32 million	B4
3	370 million	A5
1.5	3 billion	F5
1	10 billion	G2 (Sun)
0.1	1000s billions	M7

http://www.worldscientific.com/worldscibooks/10.1142/8573

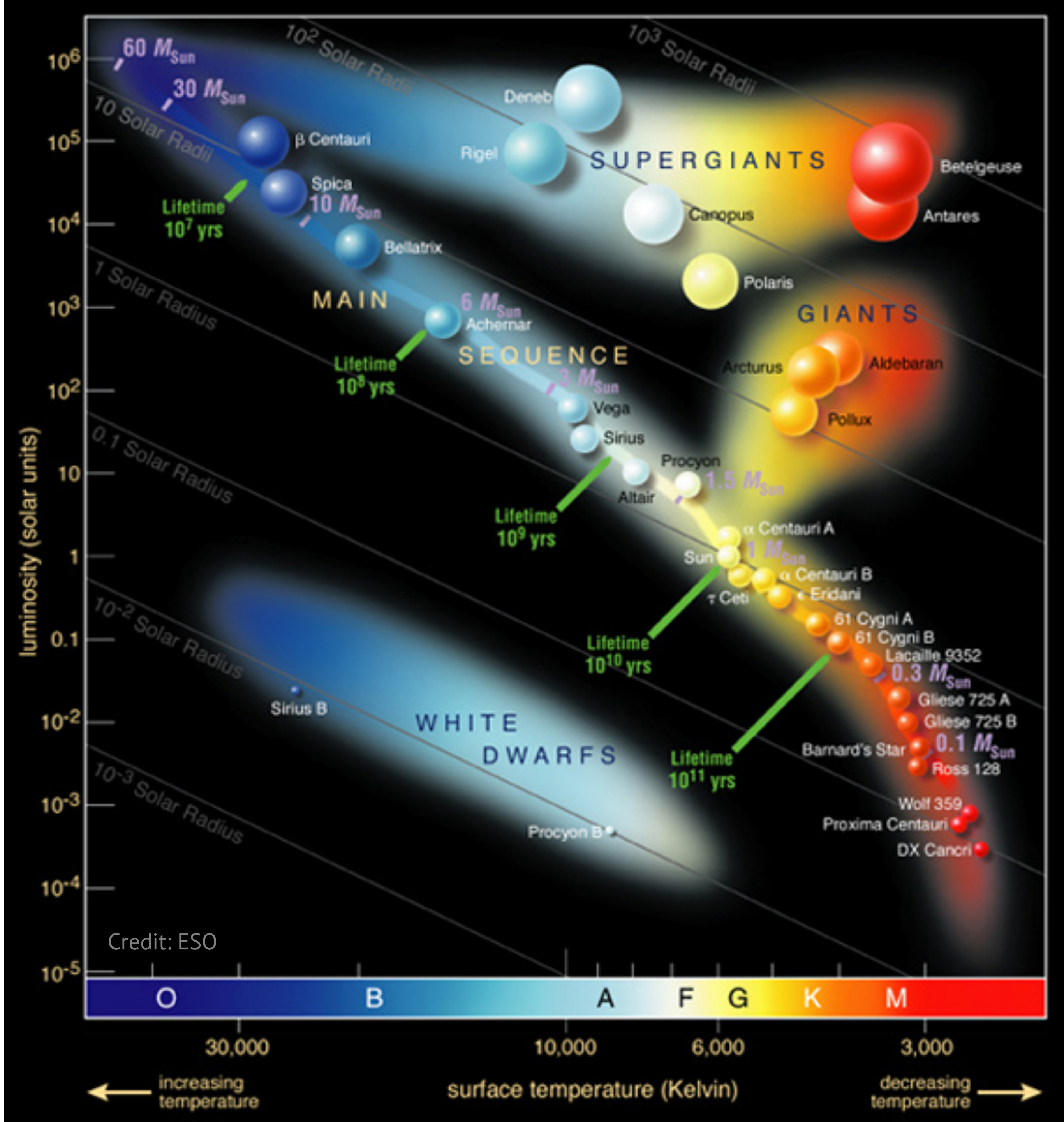


Stellar Evolution III.

White dwarfs – low mass (< 8-10 $M_\odot$) stars run out of fuel → no thermal pressure → shrink.

Giants – e.g. helium burning introduces different equilibrium: increased temperature → stars grow in size and redden.

Supergiants – from the heaviest stars. There are also hypergiants.



Stellar Evolution IV.

Once heavier elements start to play a role, the star moves off of HR.

Burning phase	Required temperature	Required mean density [g cm^{-3}]	Duration
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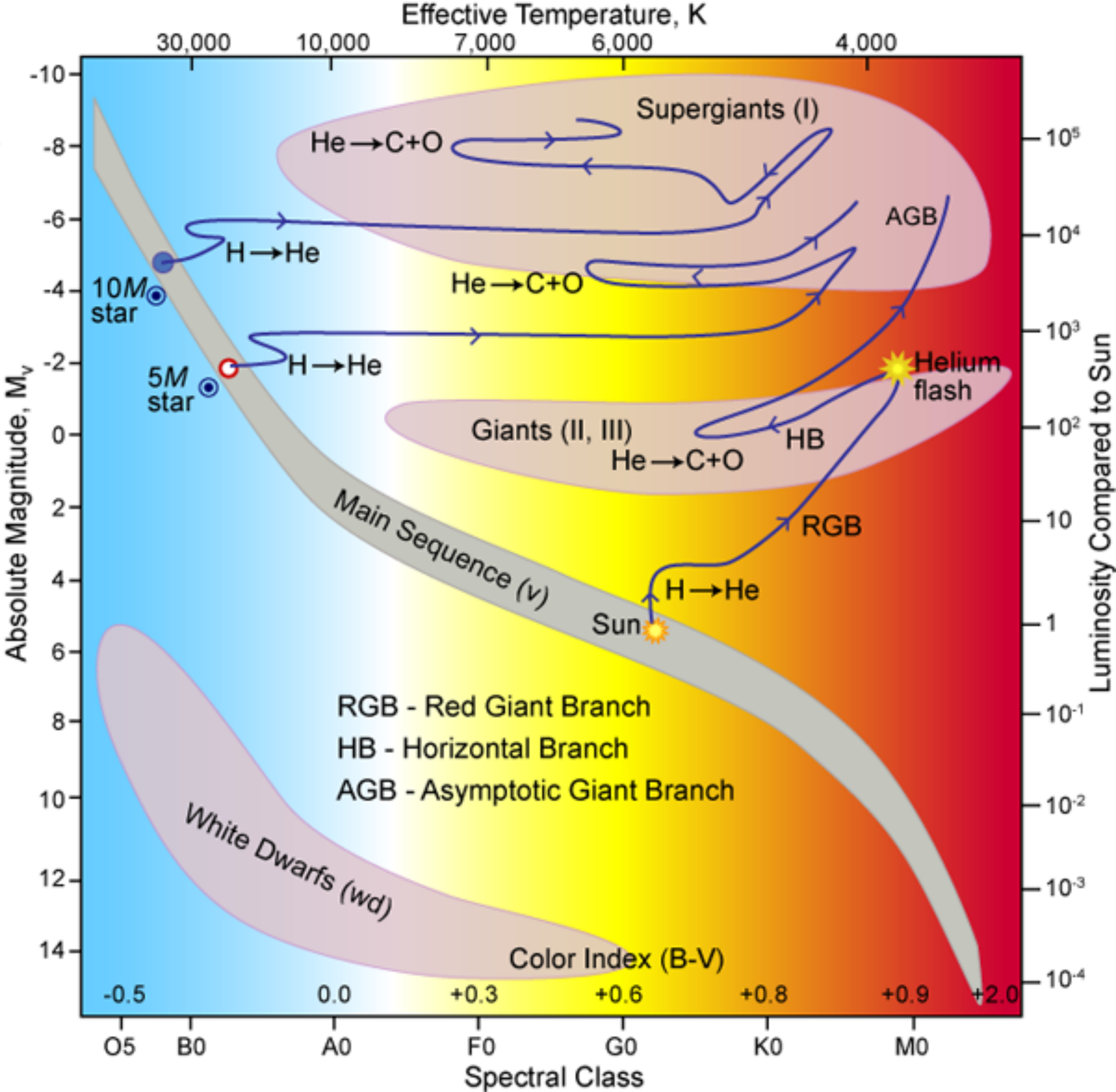
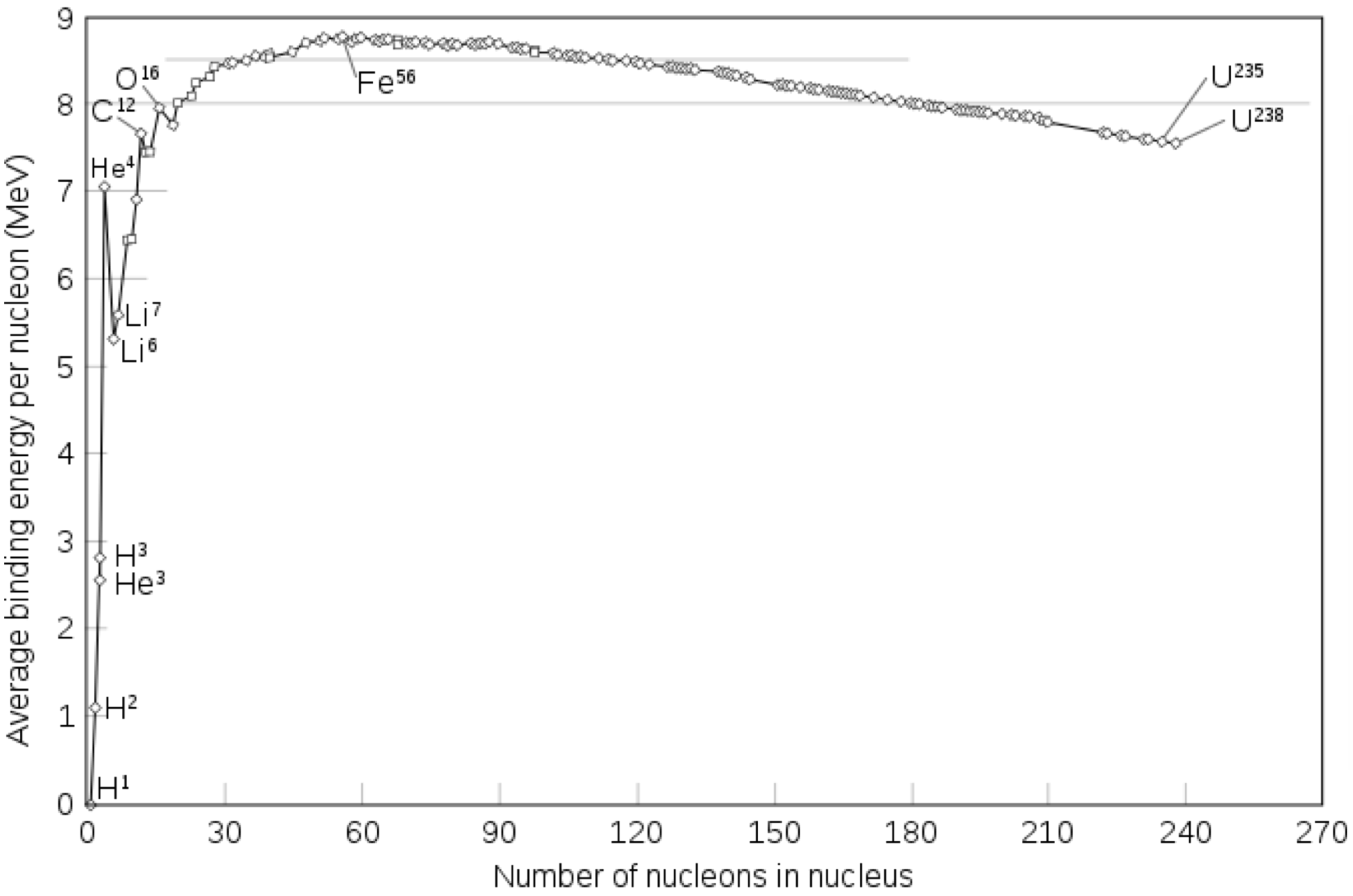
Hydrogen	4×10^7 K	5	7,000,000 yr
Helium	2×10^8 K	700	700,000 yr
Carbon	6×10^8 K	200,000	600 yr
Neon	1.2×10^9 K	4 million	1 year
Oxygen	1.5×10^9 K	10 million	6 months
Silicon	2.7×10^9 K	30 million	1 day

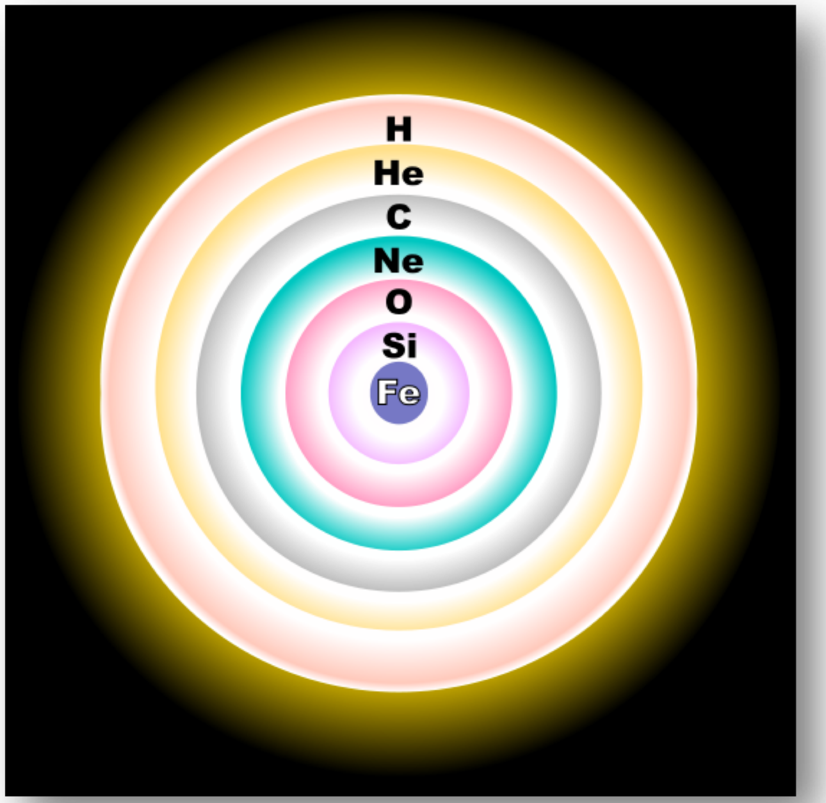
Stages in the life of a 25 solar-mass star

(http://www.astro.cornell.edu/academics/courses/astro201/highmass.htm)



Nuclear binding energy





Iron is the most stable form of matter. This is the final product of nuclear burning.

Stellar winds

Radiation pressure blows off gas/dust from the outer layers of stars.

Metallicity: fraction of elements heavier than He. Typically defined in comparison to Solar metallicity (1%).

More metallicity → more stellar winds.

Higher stellar mass → more wind.

Winds will limit the end-of-life mass of massive stars, especially for high-metallicity stars.

Wolf-Rayet stars: massive stars that lost ~all of their hydrogen envelope to winds.

Population III (Pop III) stars: extremely massive stars only in the early universe (first stars), with no metals.

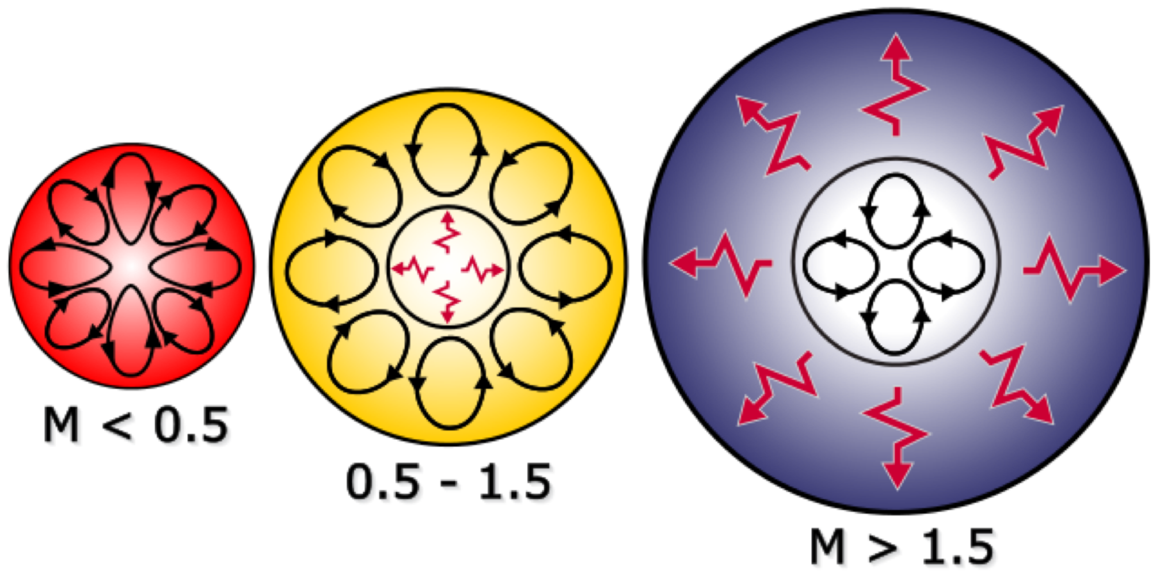
Credit: ESA/Hubble & NASA Acknowledgement: M. Novak

Chemical mixing

There can be convection within the star due to temperature difference / fast rotation / etc.

e.g. in a binaries can align orbit and spin → fast spinning → chemical mixing.

Can affect what is being fused, giant phase as well as stellar winds.



Death

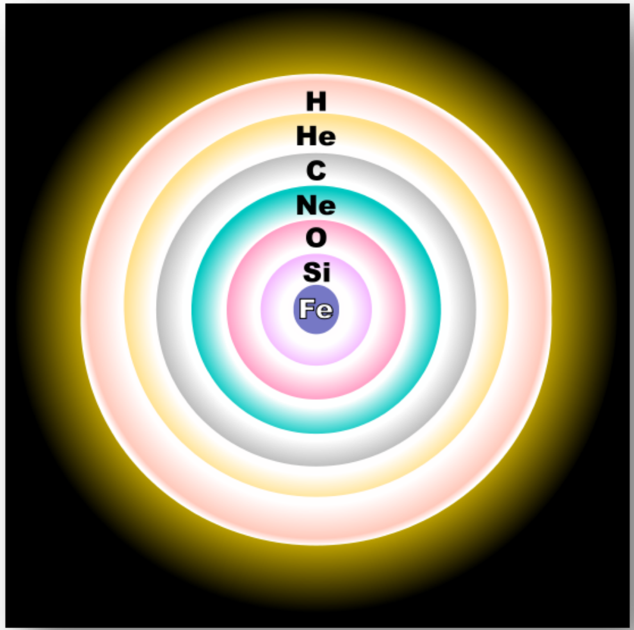
<u>Low mass stars</u> – runs out of fuel --> radiation pressure reduced → shrinks → white dwarf

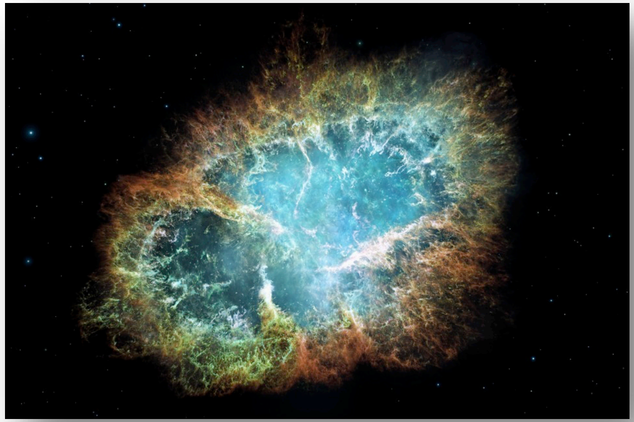
<u>High mass stars</u> – fusion down to iron → iron core → gravitational core collapse → supernova / collapsar

<u>Very high mass stars</u> – high pressure → gamma rays energetic for electron+positron pair production → reduced pressure → gravitational collapse → pair-instability supernova

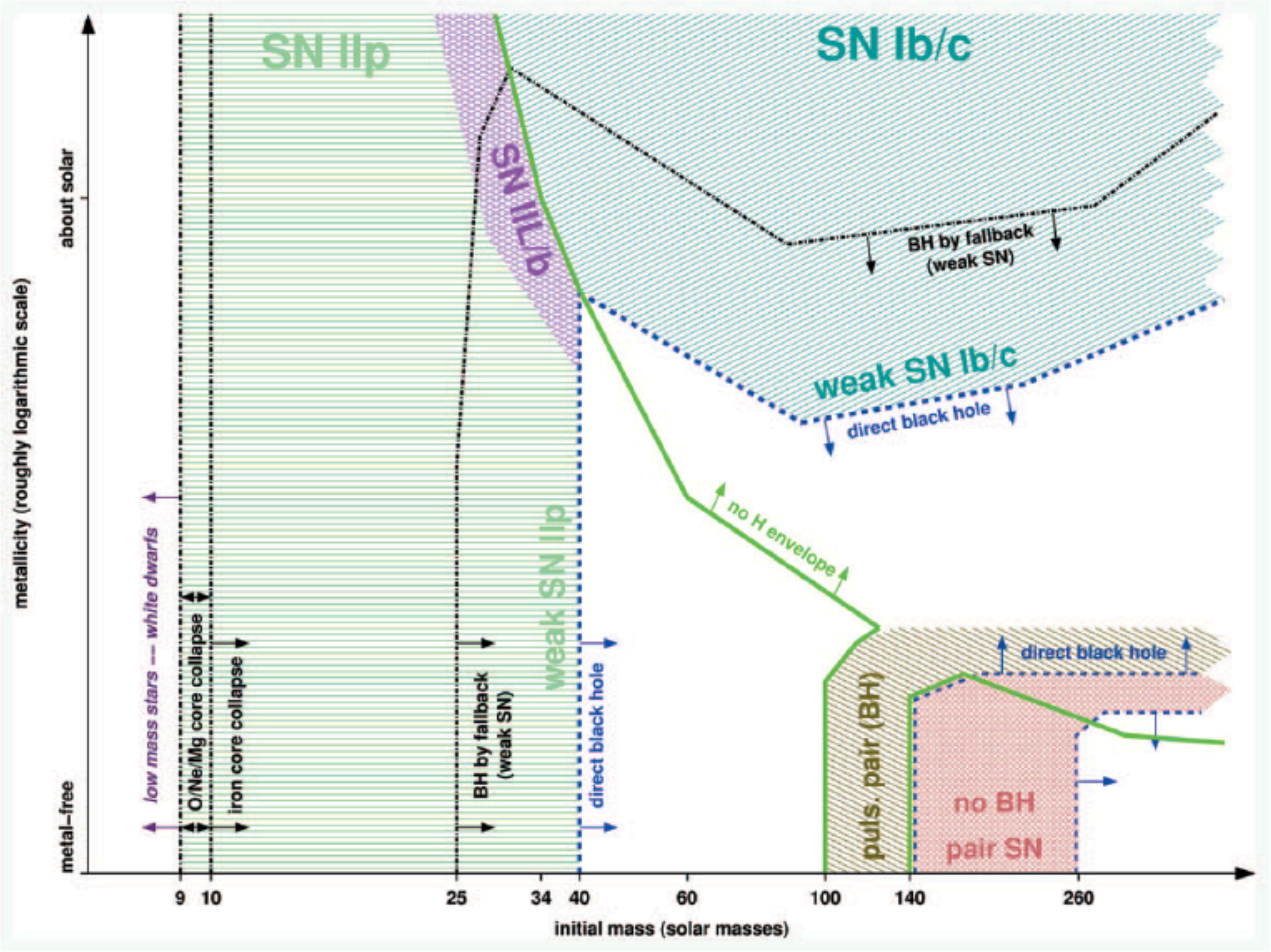
<u>Very high mass stars</u> – high pressure → gamma rays energetic for photodisintegration→ reduced pressure → gravitational collapse → black hole

<u>Infalling matter</u> – needs to get rid of angular momentum → relativistic jet



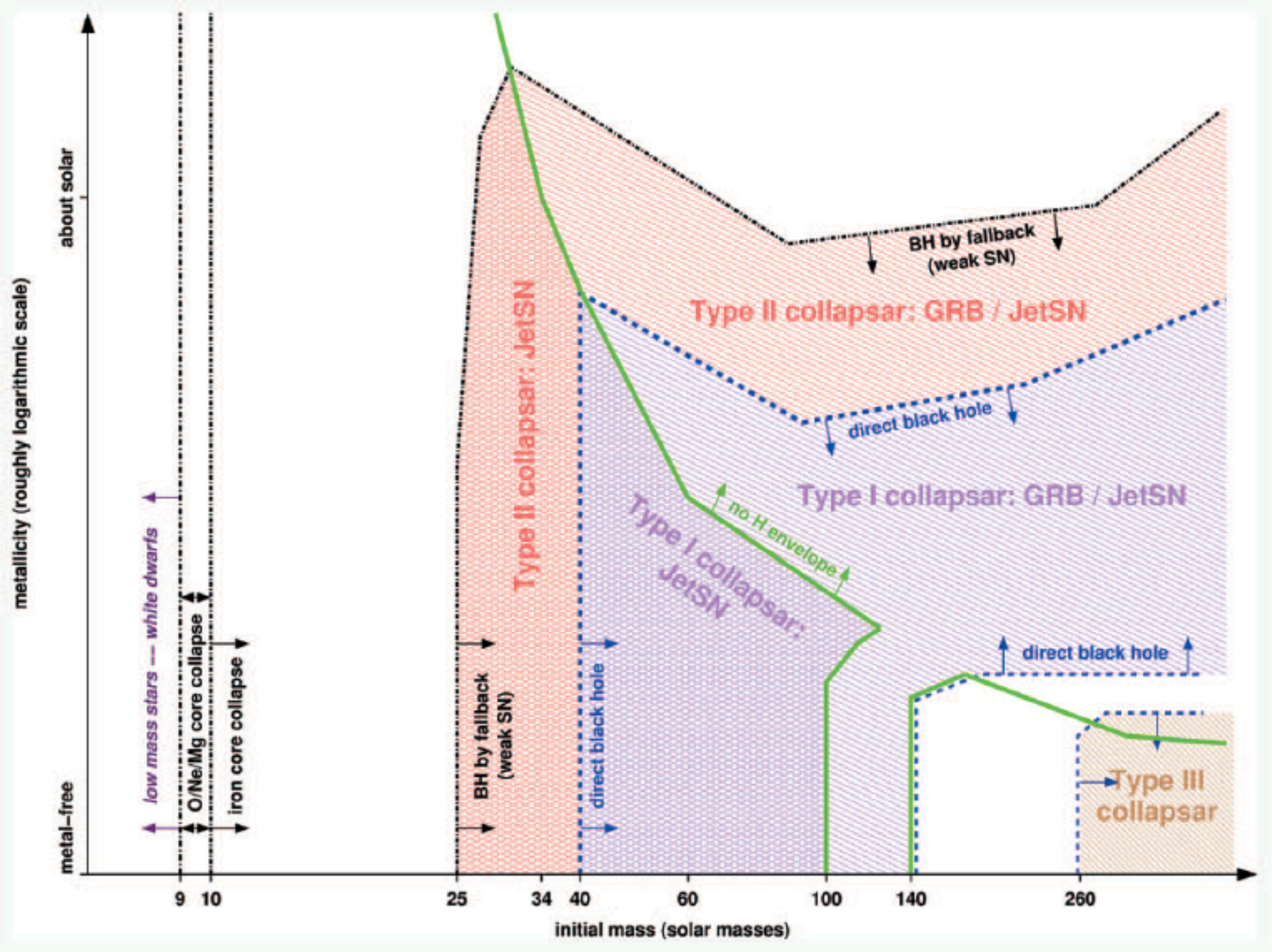


Supernova explosion



Heger+ ApJ 2003

Collapsars



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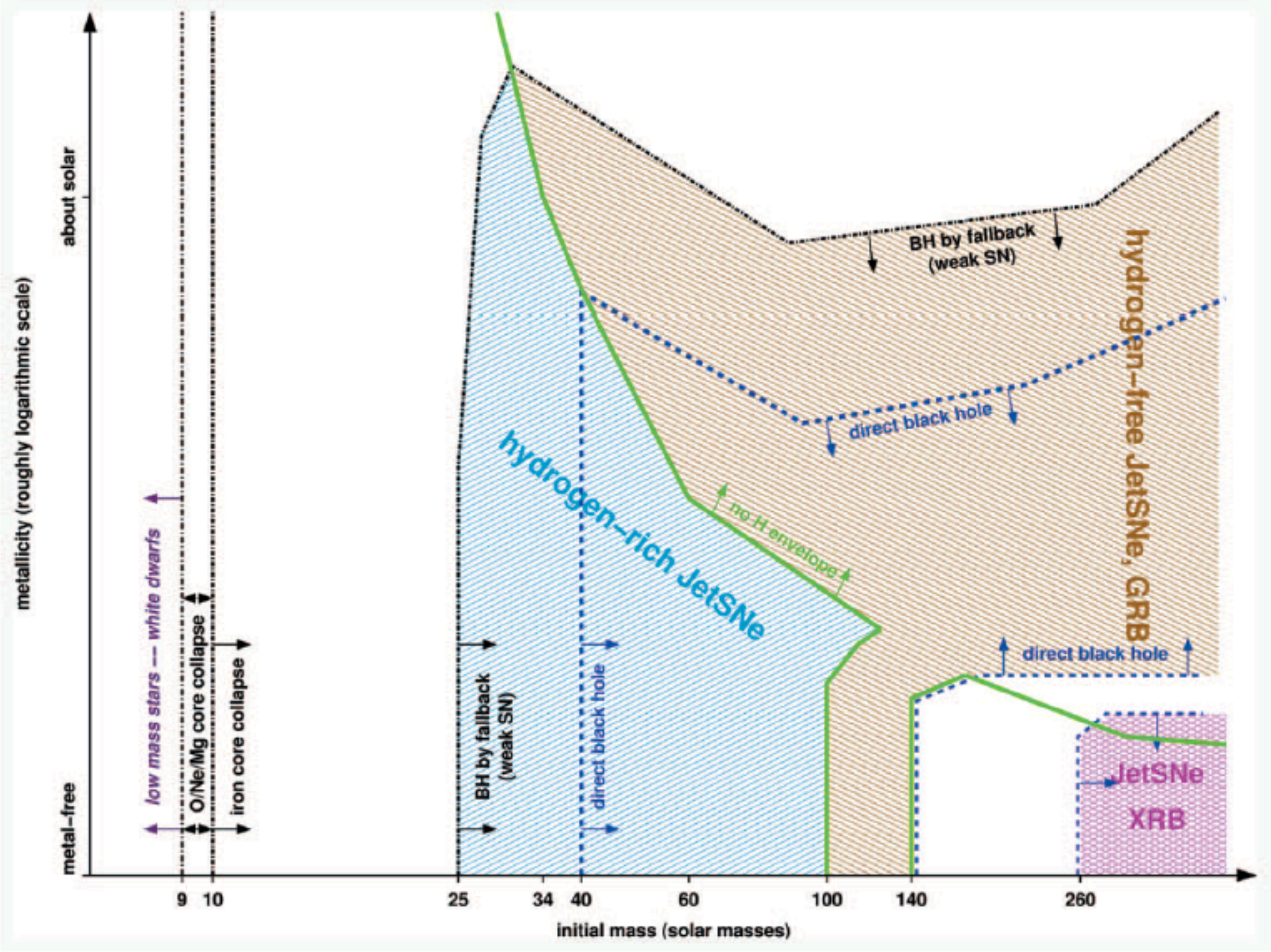
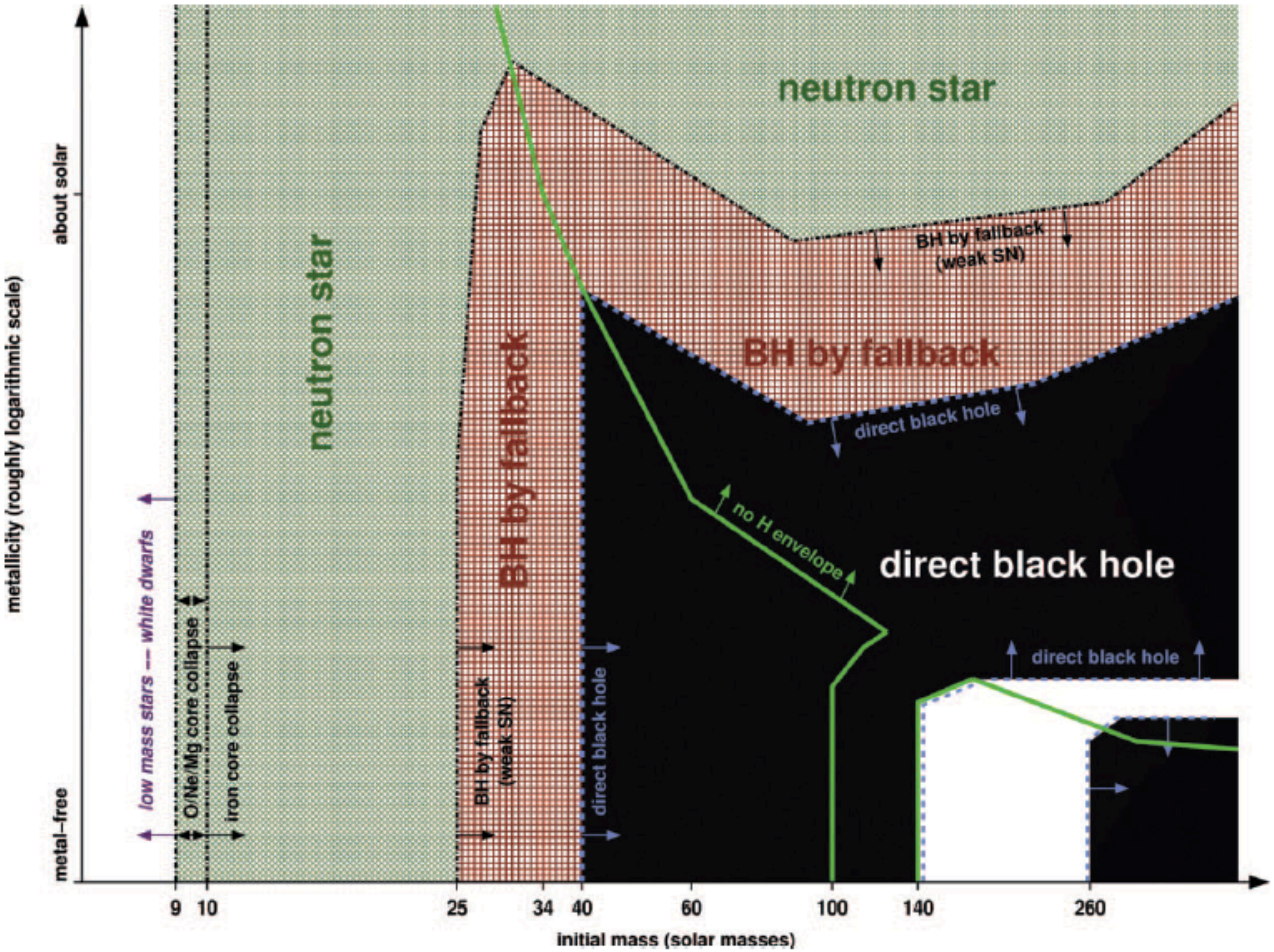
Beamed outflow (jet)



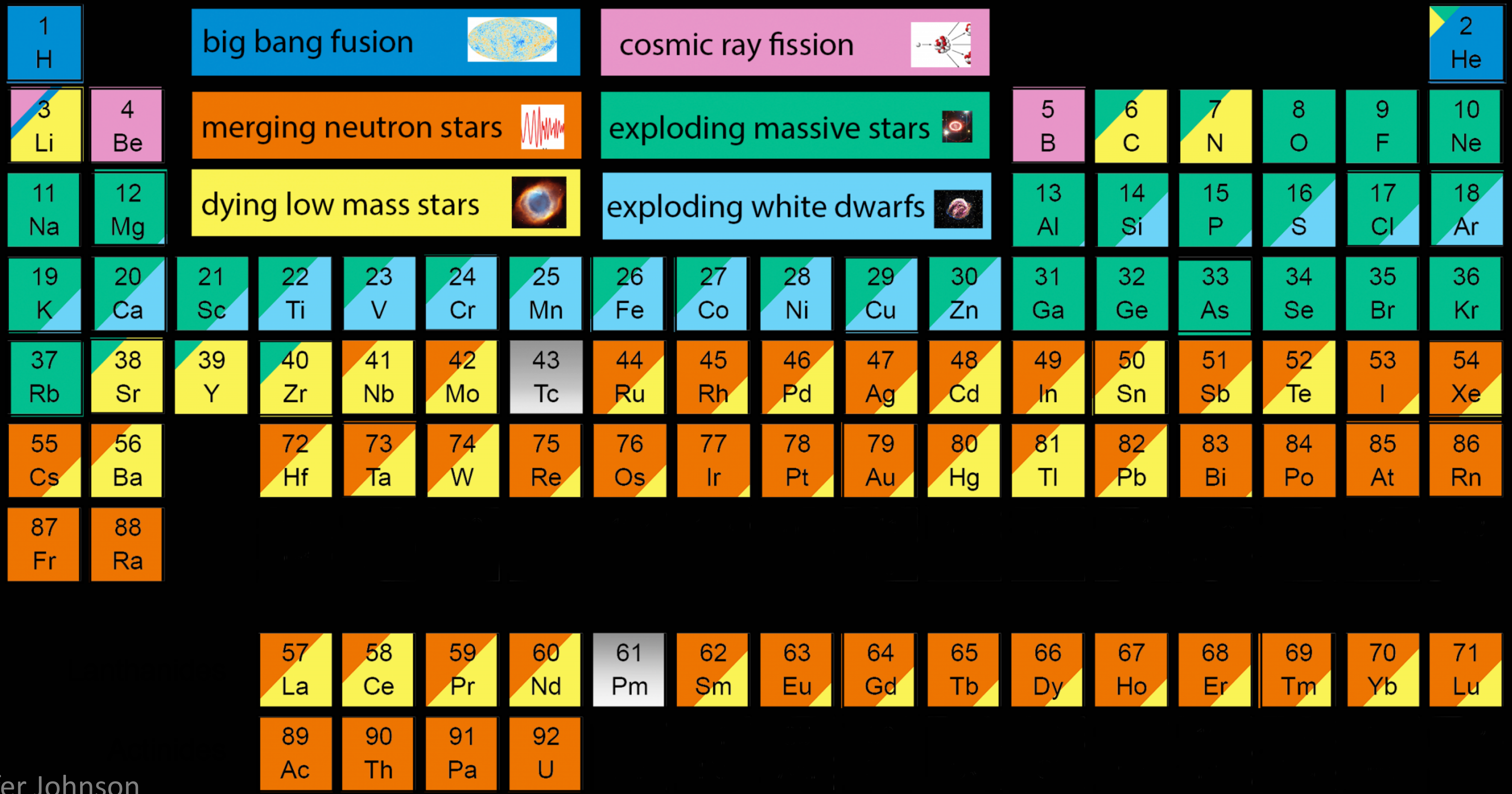
Heger+ ApJ 2003

Remnant



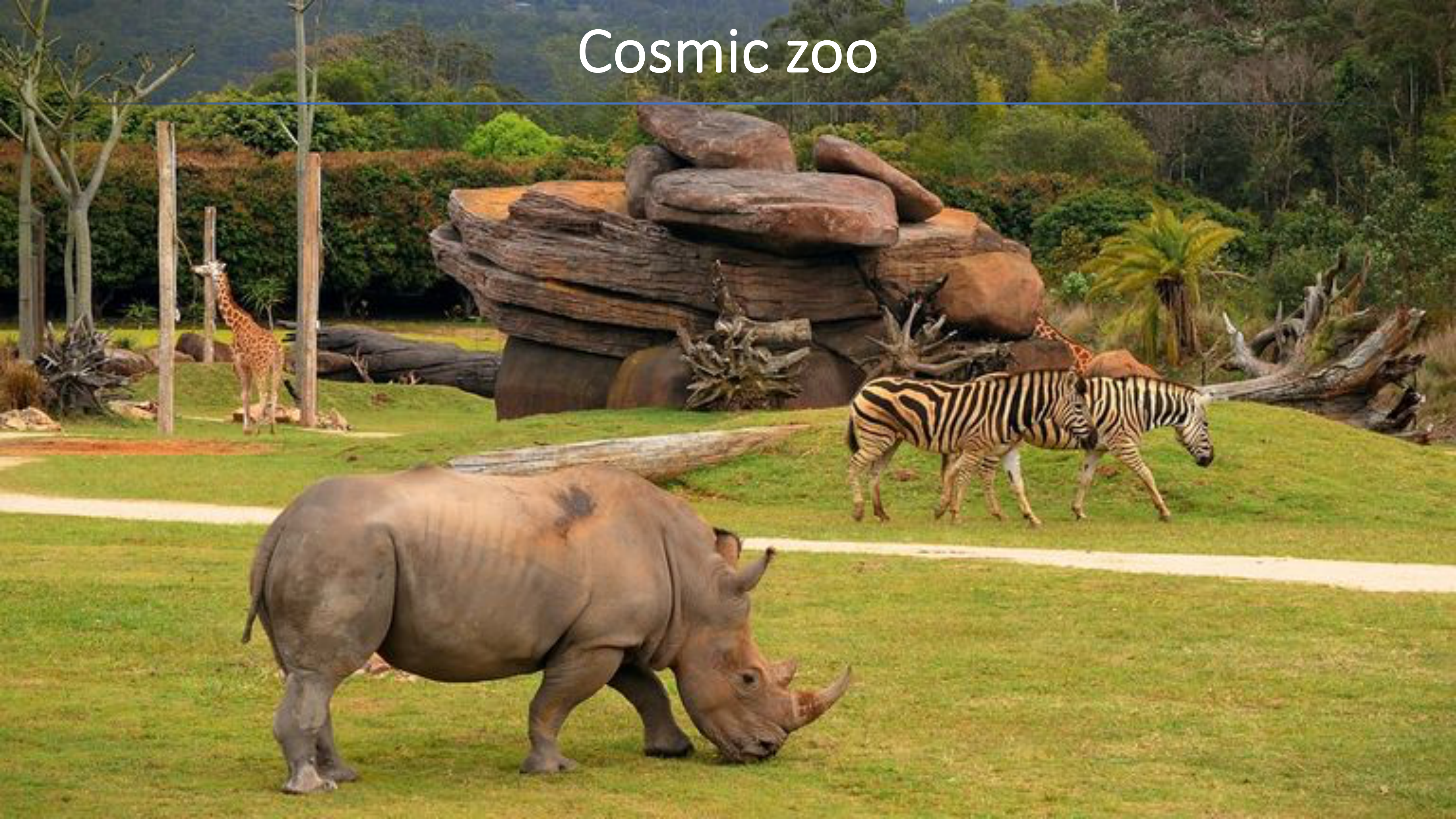
Heger+ ApJ 2003

The Origin of the Solar System Elements

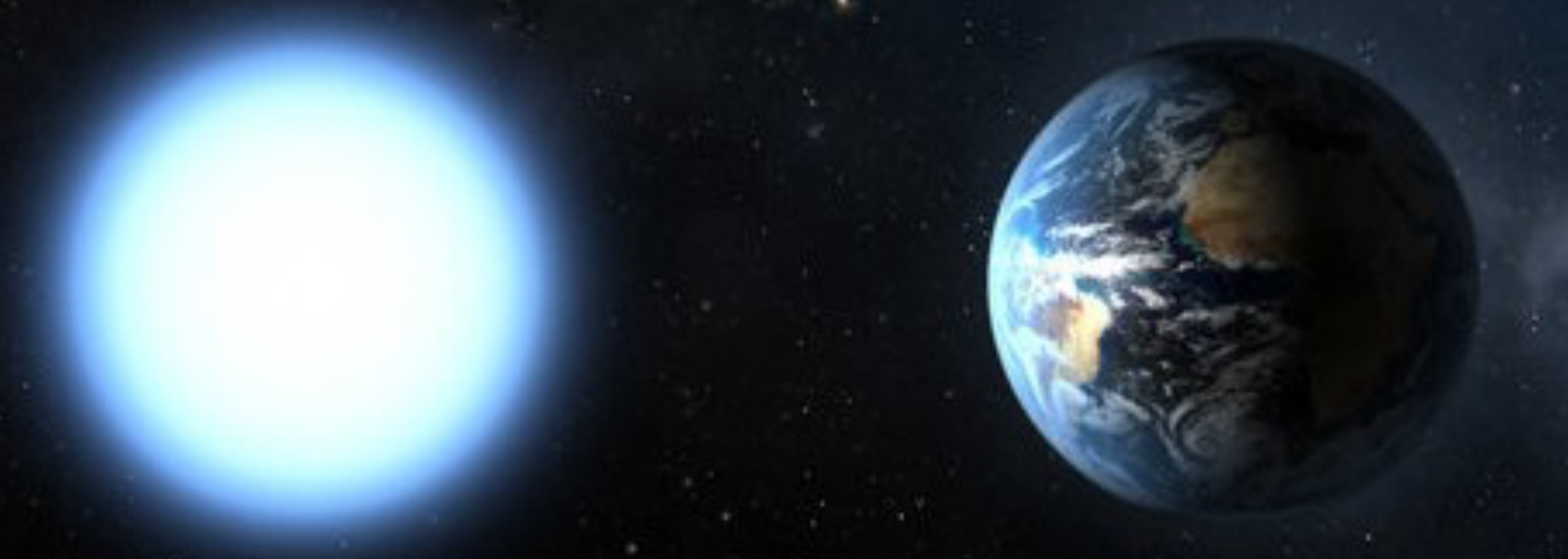


Jennifer Johnson

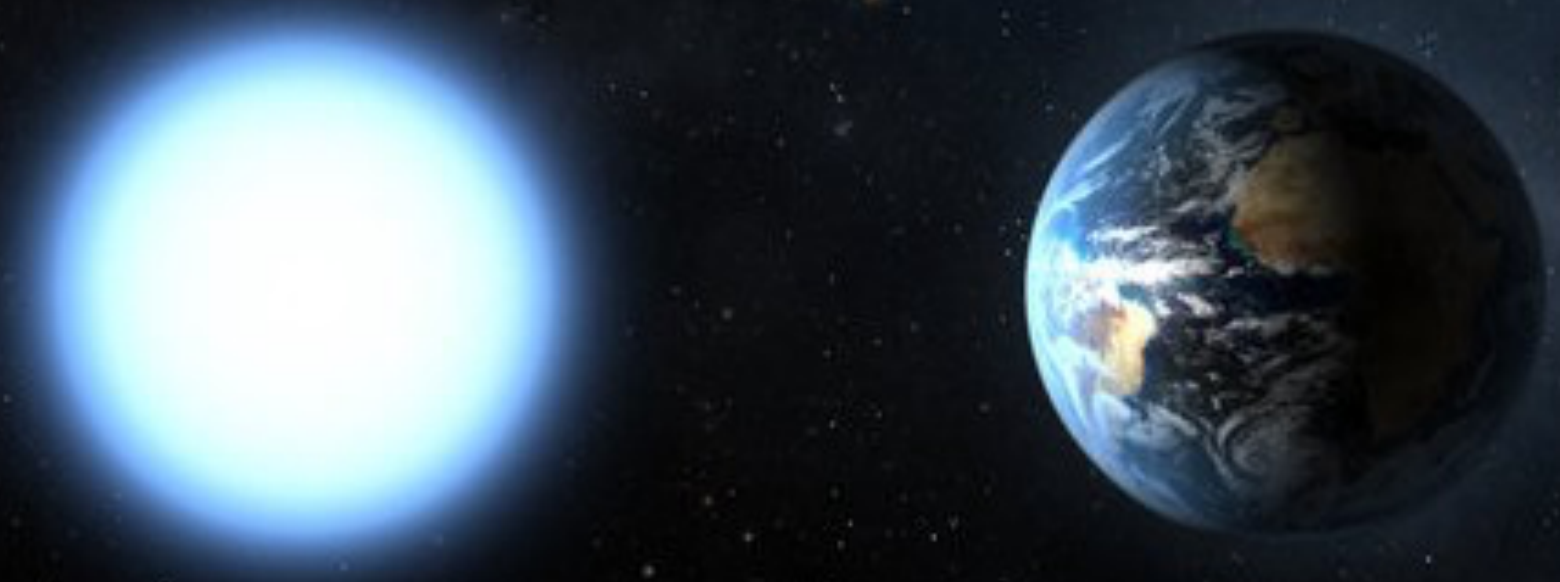
Cosmic zoo



White dwarfs



White dwarfs



$$T = 2\pi\sqrt{\frac{a^3}{G\left(M_1 + M_2\right)}}$$

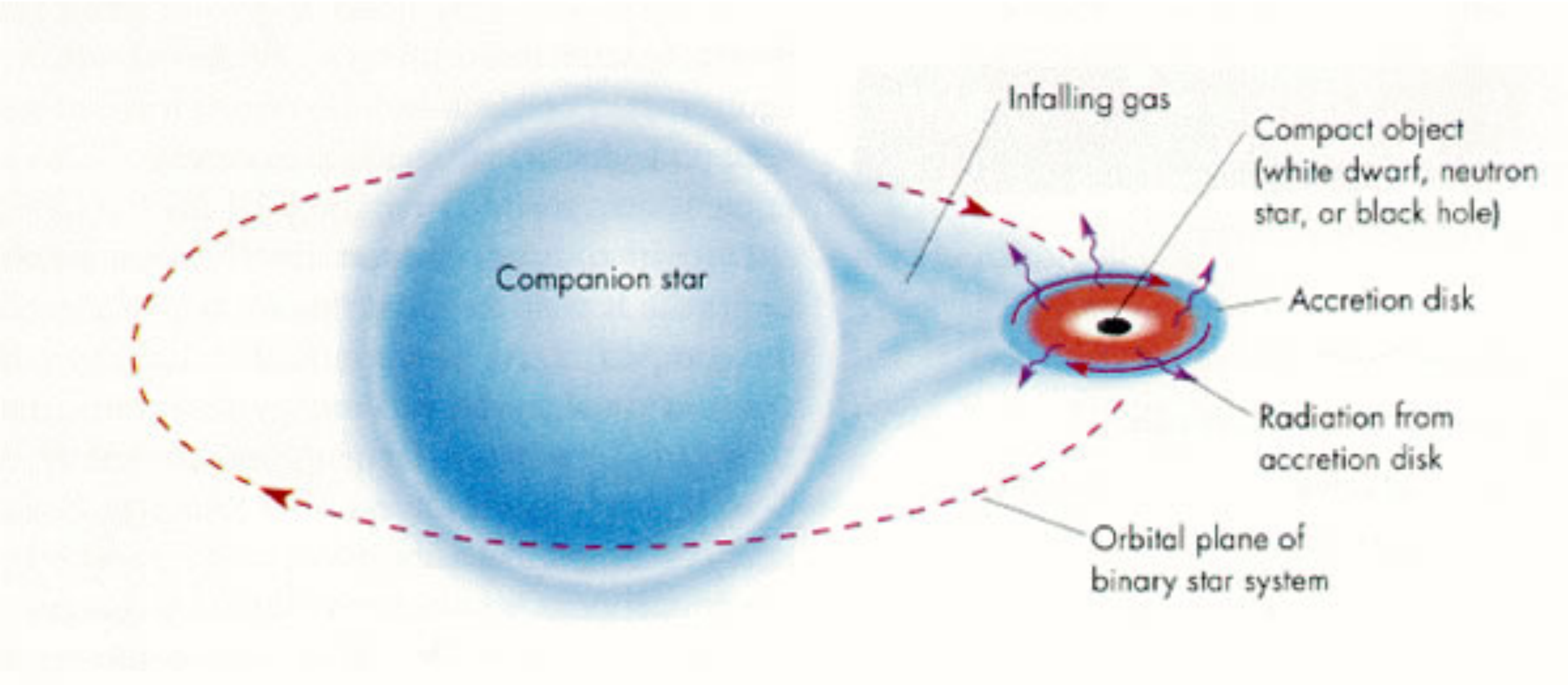
Classification

Absorption line and light curve

<table>
<tr><td rowspan="3">Type I
No hydrogen</td><td colspan="3">Type Ia
Presents a singly ionized silicon (Si II) line at 615.0 nm (nanometers), near peak light</td><td>Thermal runaway</td></tr>
<tr><td rowspan="2">Type Ib/c
Weak or no silicon absorption feature</td><td colspan="2">Type Ib
Shows a non-ionized helium (He I) line at 587.6 nm</td><td rowspan="6">Core collapse</td></tr>
<tr><td colspan="2">Type Ic
Weak or no helium</td></tr>
<tr><td rowspan="4">Type II
Shows hydrogen</td><td rowspan="3">Type II-P/L/N
Type II spectrum throughout</td><td rowspan="2">Type II-P/L
No narrow lines</td><td>Type II-P
Reaches a "plateau" in its light curve</td></tr>
<tr><td>Type II-L
Displays a "linear" decrease in its light curve (linear in magnitude versus time).[47]</td></tr>
<tr><td colspan="2">Type IIn
Some narrow lines</td></tr>
<tr><td colspan="3">Type IIb
Spectrum changes to become like Type Ib</td></tr>
</table>

https://en.wikipedia.org/wiki/Supernova

Novae



http://astro.hopkinsschools.org

Core collapse supernovae

Most relevant:
Iron-core collapse

When iron core reaches Chandrasekhar mass (1.4 Msun) when it overcomes electron degeneracy

Typical energy released: 10^53 erg

Can we estimate this?

99% is released as neutrinos

What is the neutrino flux at Earth?

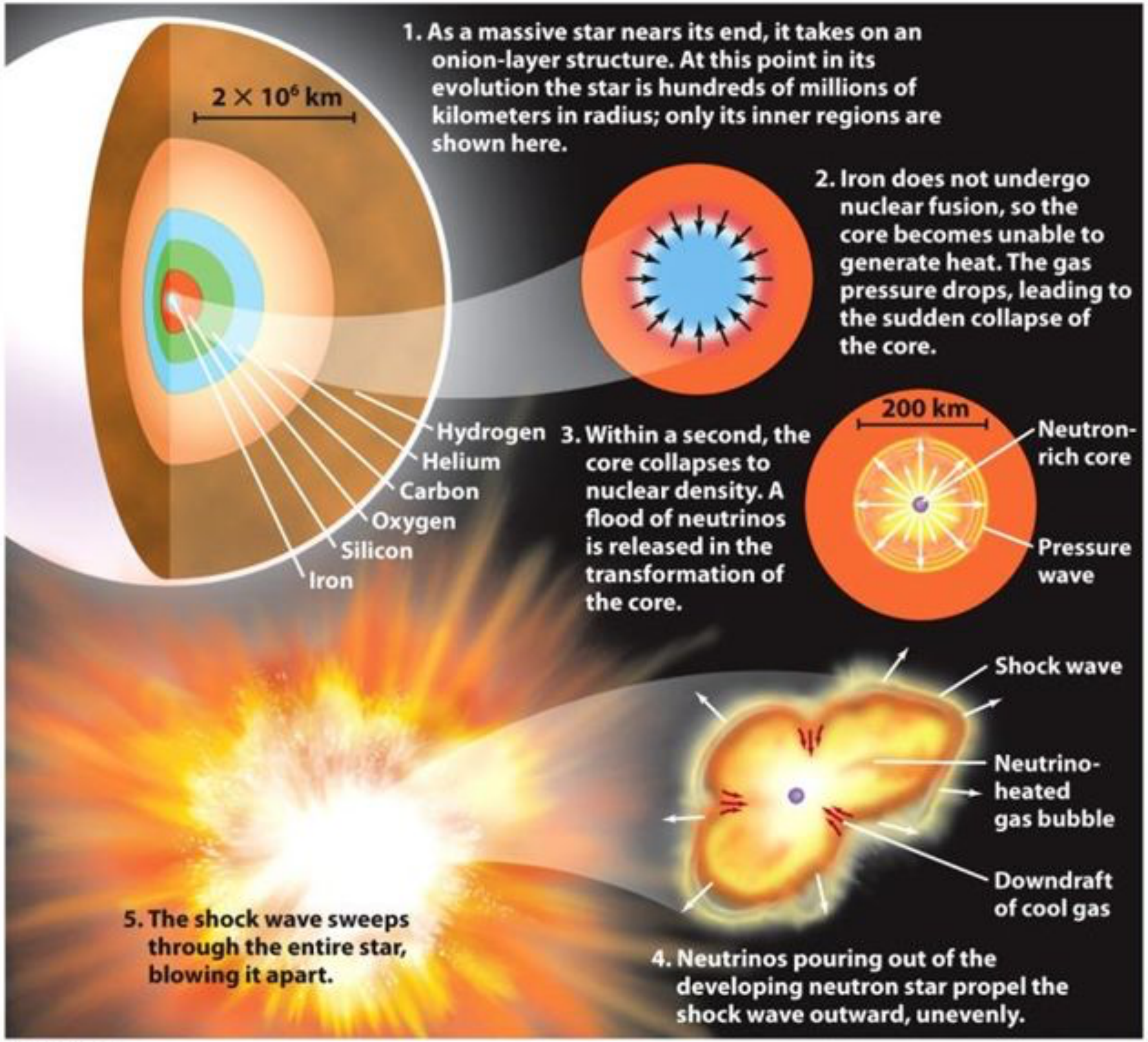
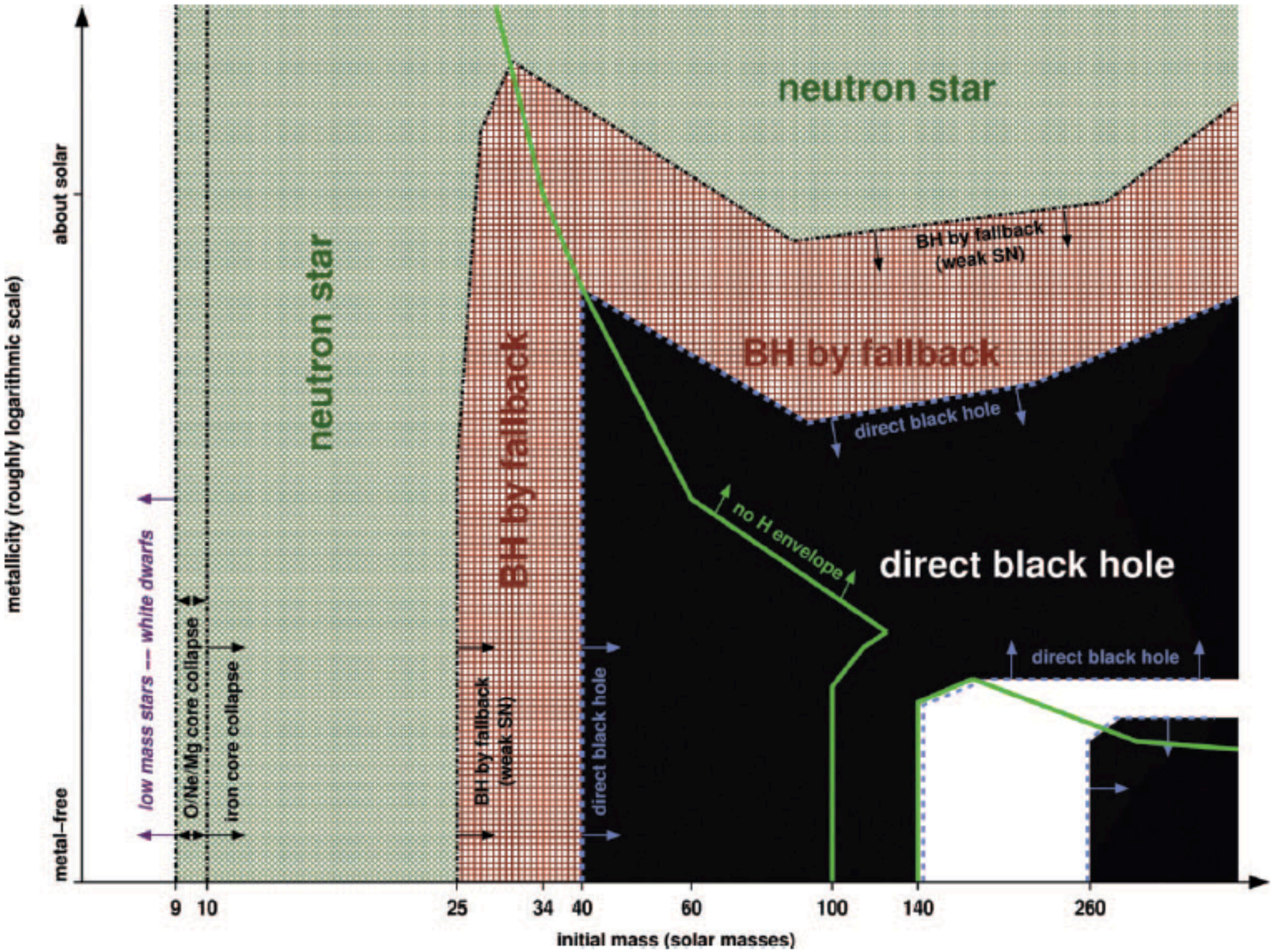


Figure 20-14
Universe, Tenth Edition
Illustration by Don Dixon, adapted from Wolfgang Hillebrandt, Hans- Thomas Janka, and Ewald Müller, "How to Blow Up a Star," *Scientific American*, October 2006

Remnant



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