PHY 7097 | Modern Astrophysics

Lecture II.

Stellar birth, life and death

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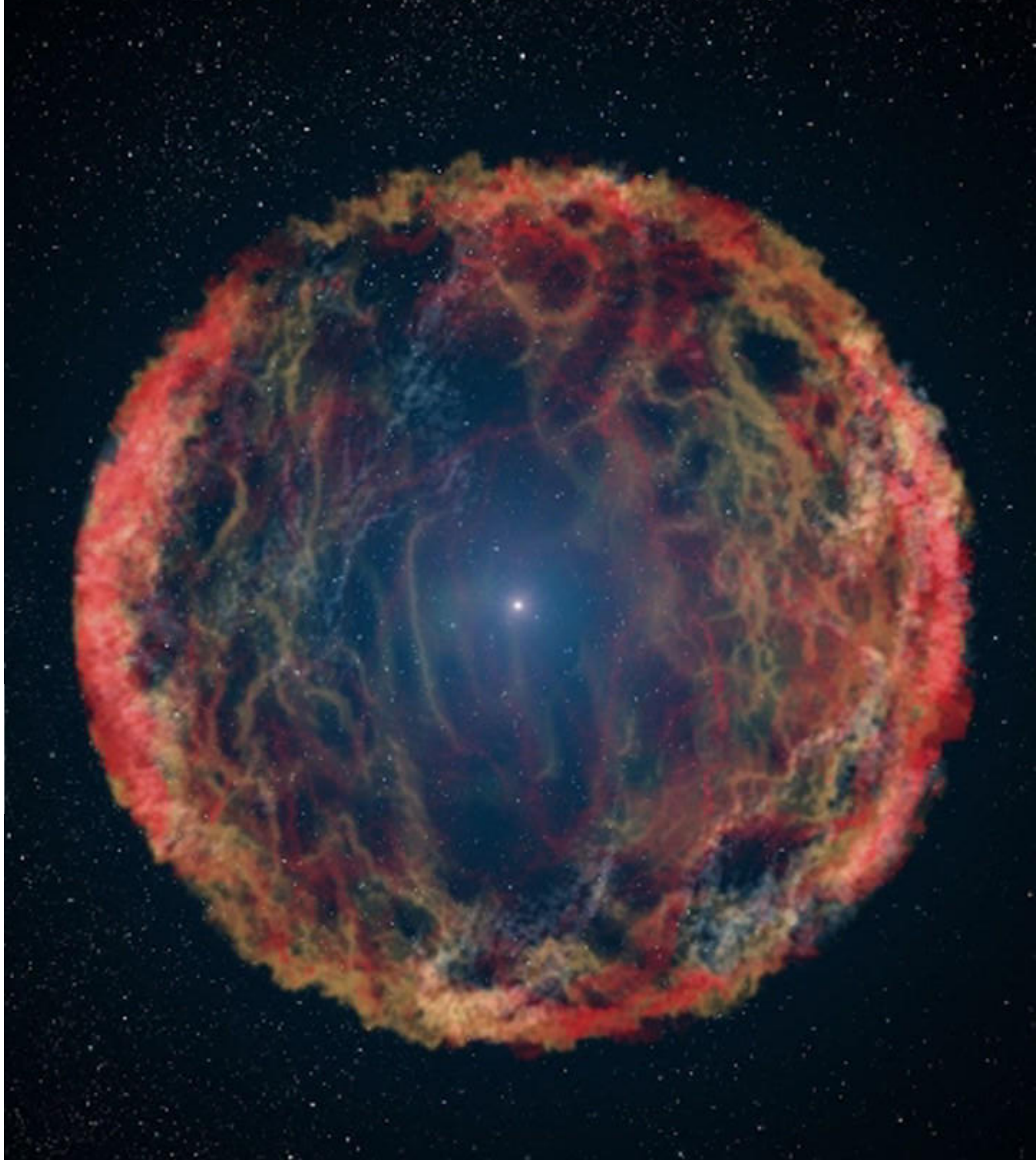
Lecture 2 | Spring 2018



Compact objects and their formation

Week 1.	**Stars' end**. -	Possible ends of stellar life cycles, including white dwarfs, core collapse, and disintegration.
Week 2.	**Neutron Stars. -**	What neutron stars are, how they are formed, and their properties. Neutron star equation of state.
Week 3.	**Black holes -**	What black holes are, how they are formed, and their properties. Schwarzschild radius, spin, charge, mass, hair.
Week 4.	**Supernovae -**	Types, explosion mechanisms, emission properties, remnants.

High-energy emission and its observation

Week 5.	**Accretion -**	Gas accretion onto black holes or neutron stars. Origin of accreted gas, geometry (Bondi/disk).
Week 6.	**Astrophysical particle acceleration -**	Relativistic outflows, their formation, and how they accelerate particles. Cosmic rays, gamma rays, high-energy neutrinos.
Week 7.	**Gamma-ray bursts -**	History, properties, populations.
Week 8.	**Afterglow emission -**	Origin, properties.
Week 9.	**High-energy observatories -**	Most important observatories that detect cosmic rays, gamma rays, and
Week 10.	**The high-energy Universe -**	What has been observed, observational techniques, open questions. Cosmic rays, gamma rays, high-energy neutrinos.

Gravitational waves – sources, detection, use

Week 11.	**Gravitational waves** -	Definition, detection, astrophysical production.
Week 12.	**Compact binaries** -	Formation channels, properties, eccentricity.
Week 13.	**Searching for gravitational waves** -	Search techniques, challenges.
Week 15.	**Cosmology with gravitational waves**	

Multimessenger astrophysics and questions at the frontier

Week 14. **Kilonovae -** ...and other emission from compact binary mergers.

Week 16. **Multimessenger astrophysics and open questions**

Logistics

- Course website: http://phys.ufl.edu/courses/phy7097/spring18/
- Main course requirement: final or final presentation
- Office hours: please email and we'll set up a time
- Textbook: none

- Steve Eikenberry has a relevant course on Black Holes and Neutron Stars on Tuesdays and Thursdays

Outline

- Star formation
- metallicity
- Stellar evolution
- Hydrogen burning
- Zero age main sequence, HS diagram
- Stellar zoo (list all names)

Star formation

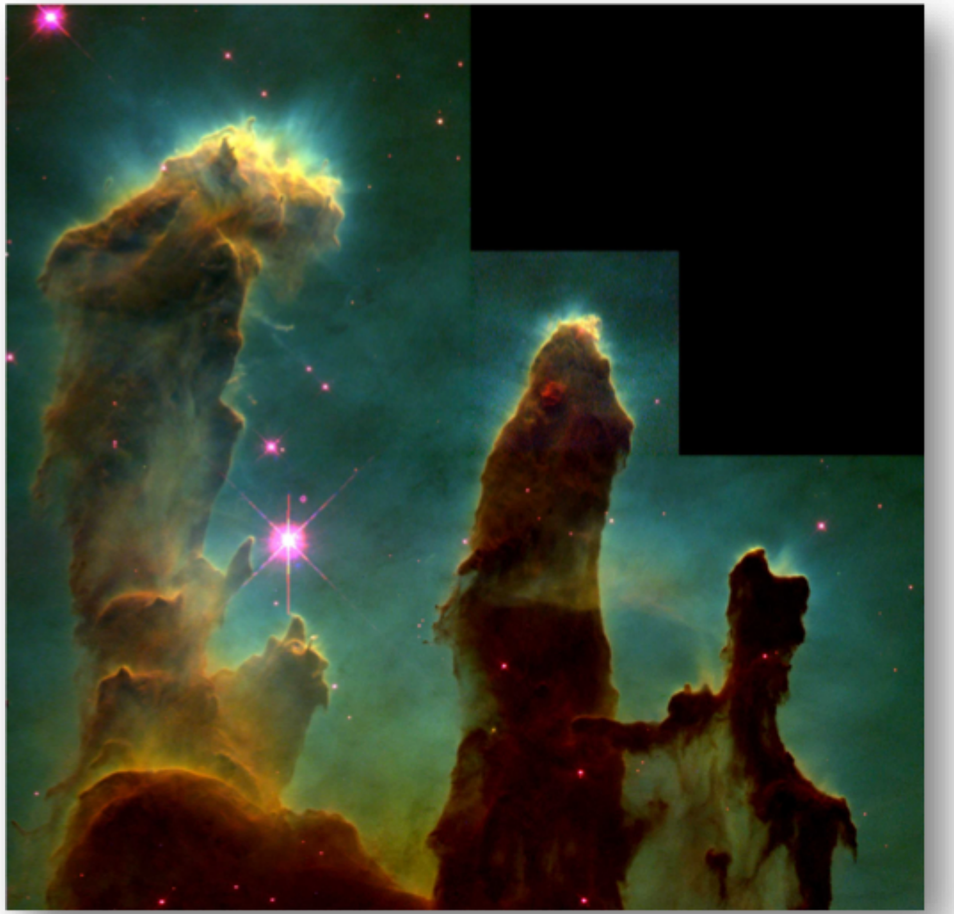
<u>Origin:</u>
- Molecular clouds
- Interstellar gas (MW: 1 particles / cm^3)

Cloud collapses (gravity) and heats up (work)

<u>Can be triggered:</u>
- Galaxy collisions
- Supernova shocks
- Milky Way – arms have higher SF

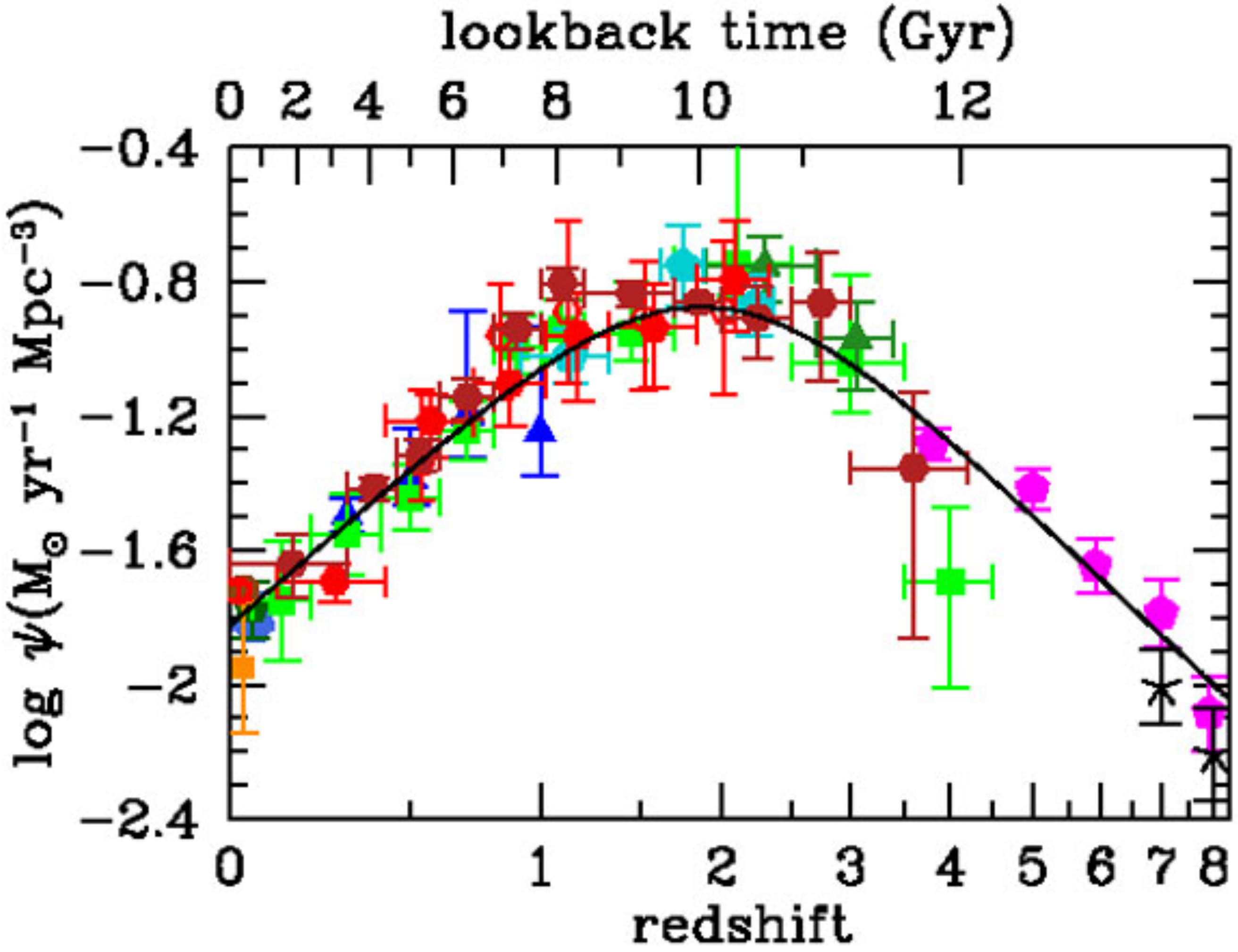
Accreting Supermassive BHs drive relativistic jets that can limit SF.

Massive stars form in binaries (angular momentum)



HST image of Eagle Nebula.
Credit: NASA, Jeff Hester, and Paul Scowen (Arizona State U.)

Cosmic star formation rate



Non-uniform,
higher in the past.

Peaks around z~2

Needs to be taken into account when studying star formation / supernovae / BH formation / etc.

Depends on many things. E.g., less gas is available today.

$$\psi(z) = 0.015 \frac{(1+z)^{2.7}}{1+[(1+z)/2.9]^{5.6}} \mathrm{M}_\odot \, \mathrm{year}^{-1} \, \mathrm{Mpc}^{-3}$$

Madau & Dickinson 2014 (1403.0007)

Initial mass function

Salpeter function (1955):

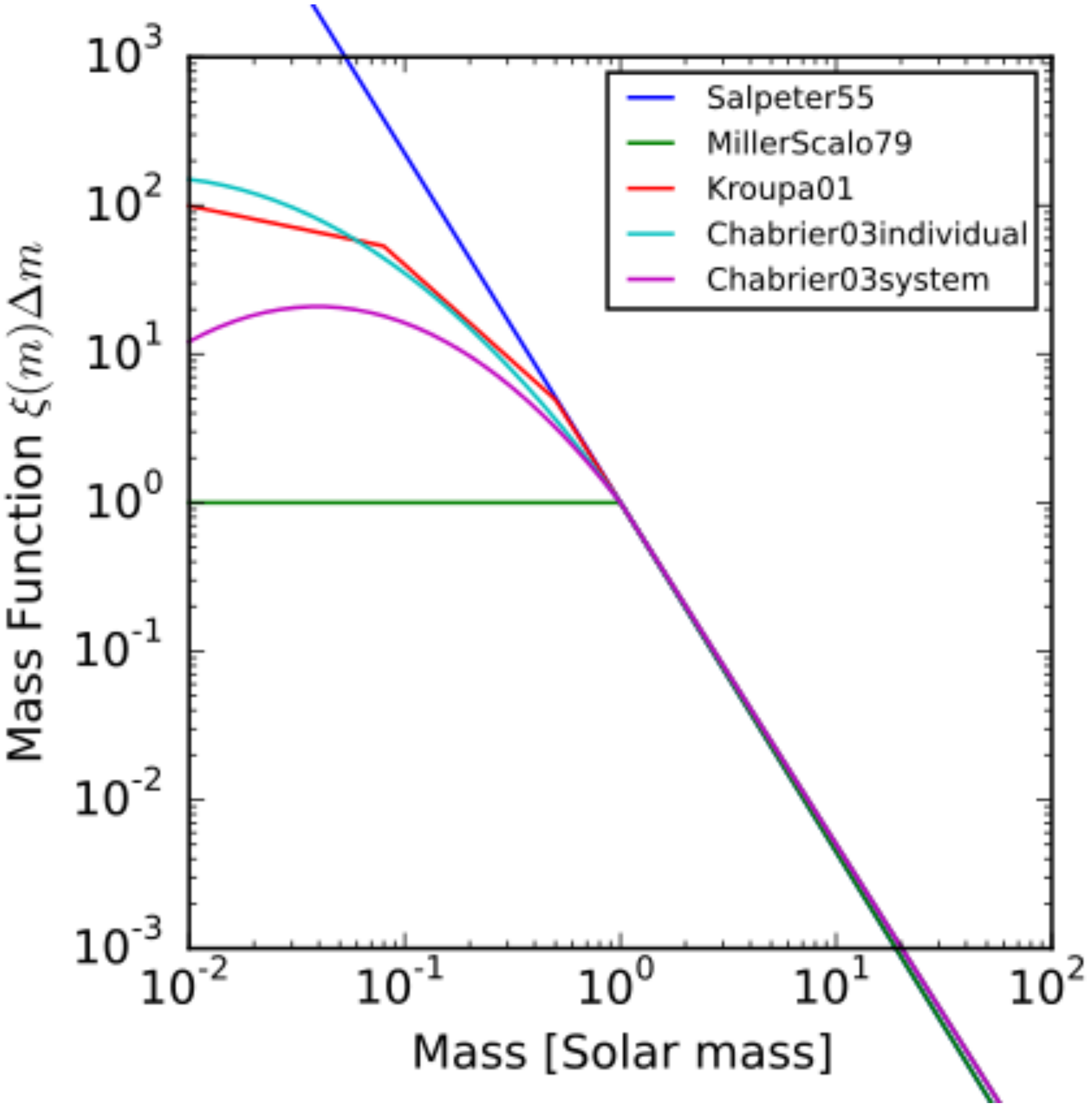
$$\xi(m)\Delta m = \xi_0 \left(\frac{m}{M_{\text{sun}}}\right)^{-2.35} \left(\frac{\Delta m}{M_{\text{sun}}}\right)$$

only applicable ~ above stellar mass

Substellar population is uncertain (see varying models).

Will be important for the distribution of stellar remnants (WD, NS, BH).

Will be important for the BH mass distribution (uncertain).



Stellar Evolution

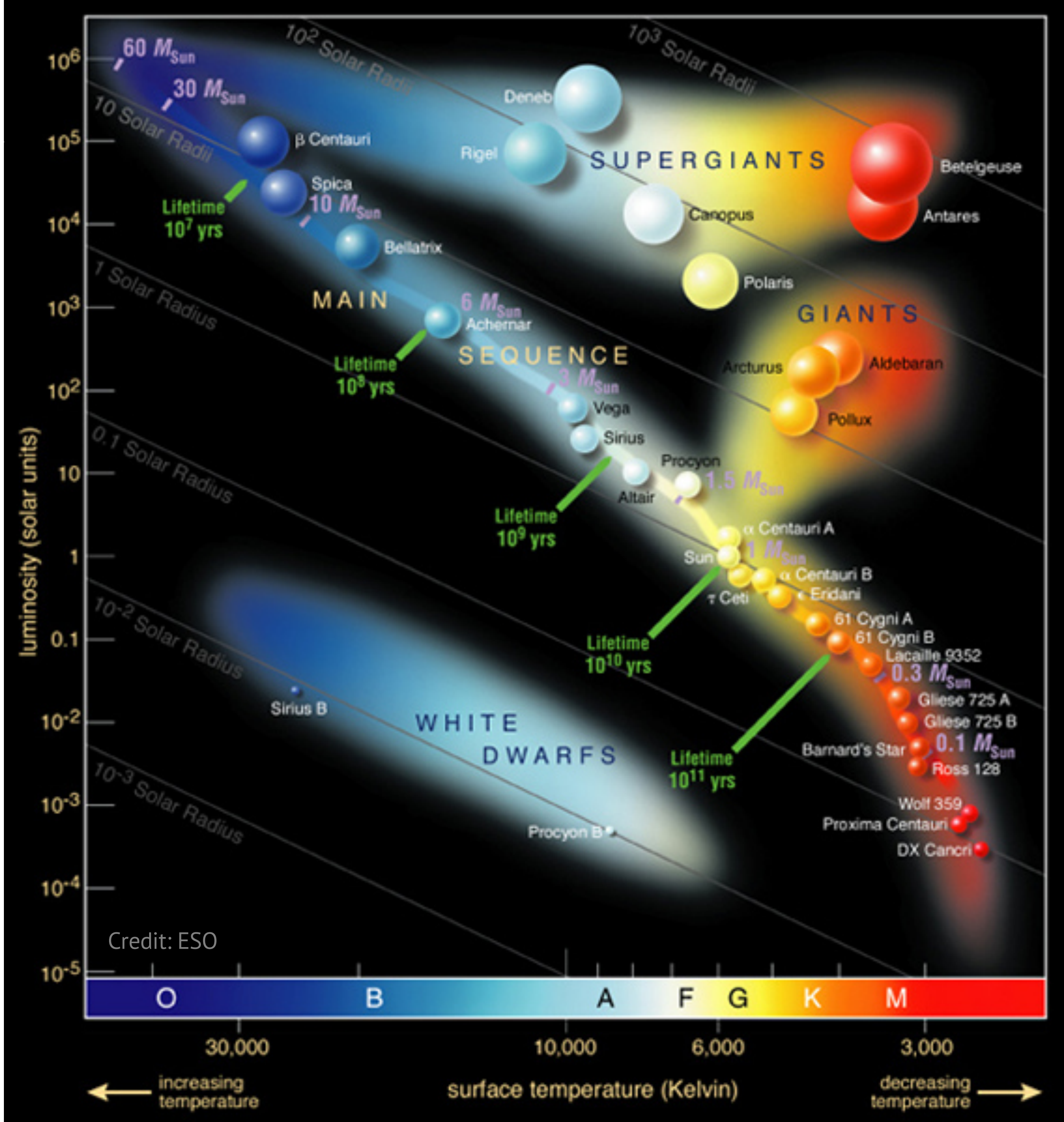
Not everyone will be a star…
Below 0.08 $M_{\odot}$, pressure is too small for fusion.
→ Brown dwarfs

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.

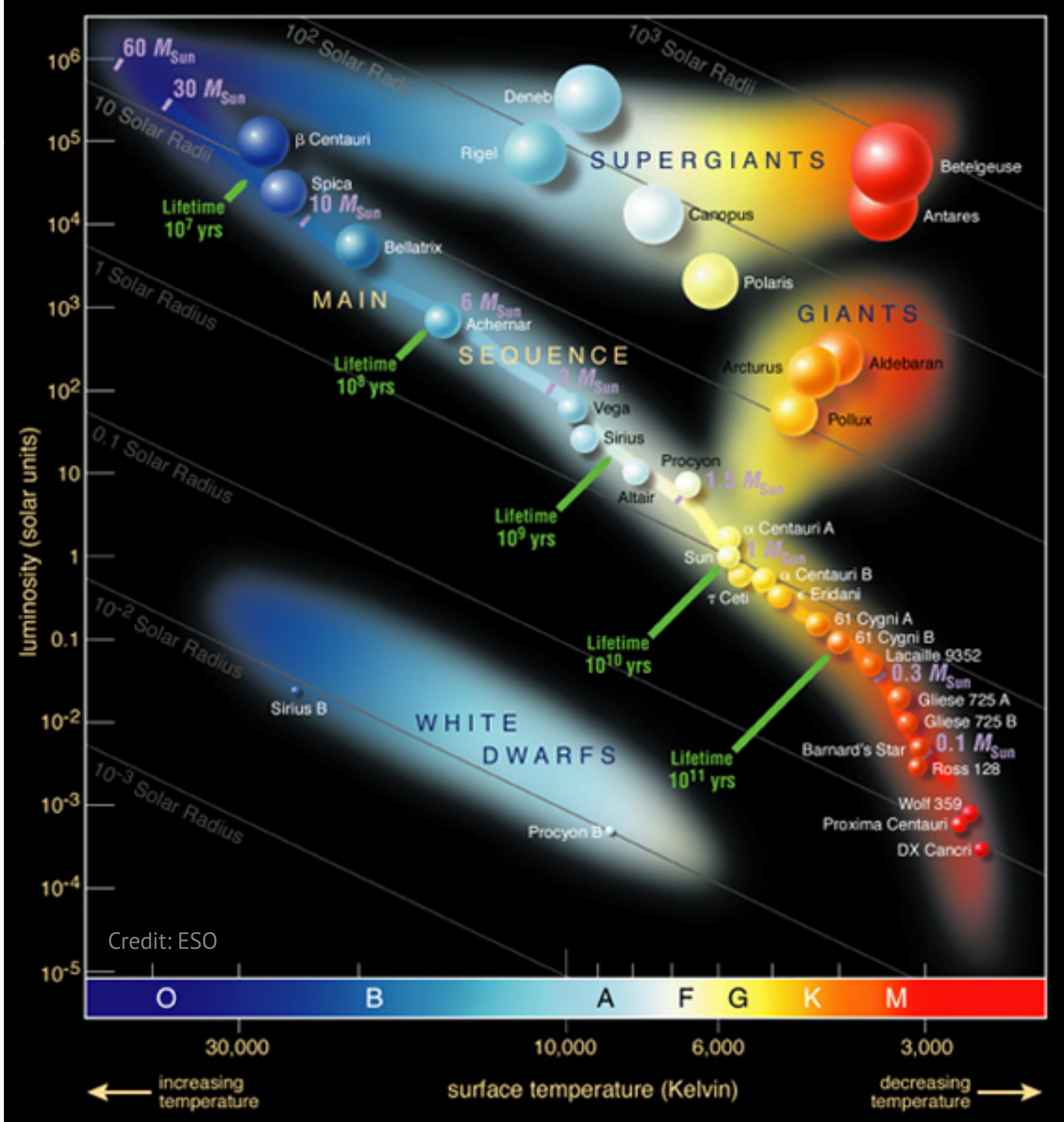


Stellar Evolution II.

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

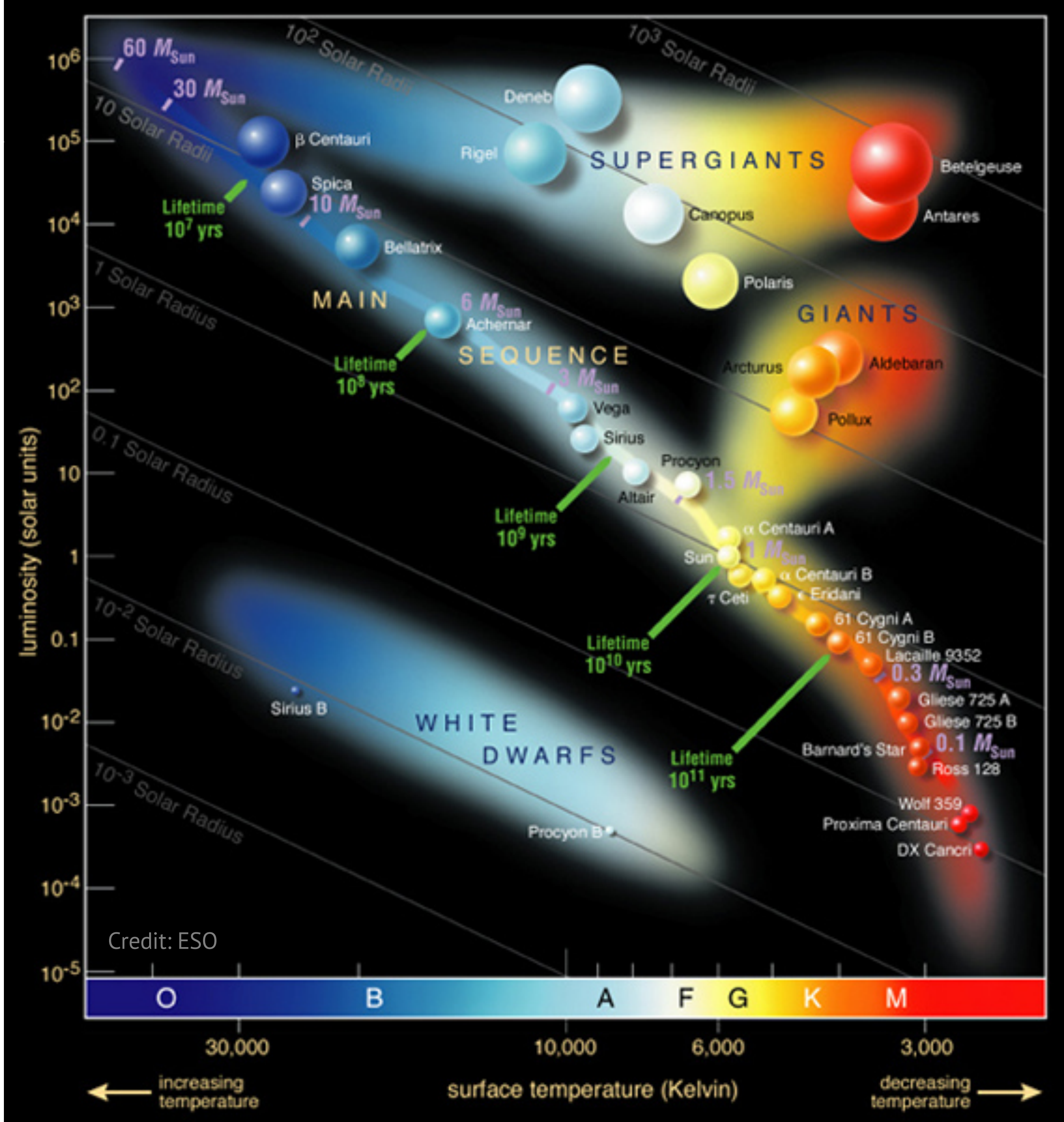


Stellar Evolution III.

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 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.

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.

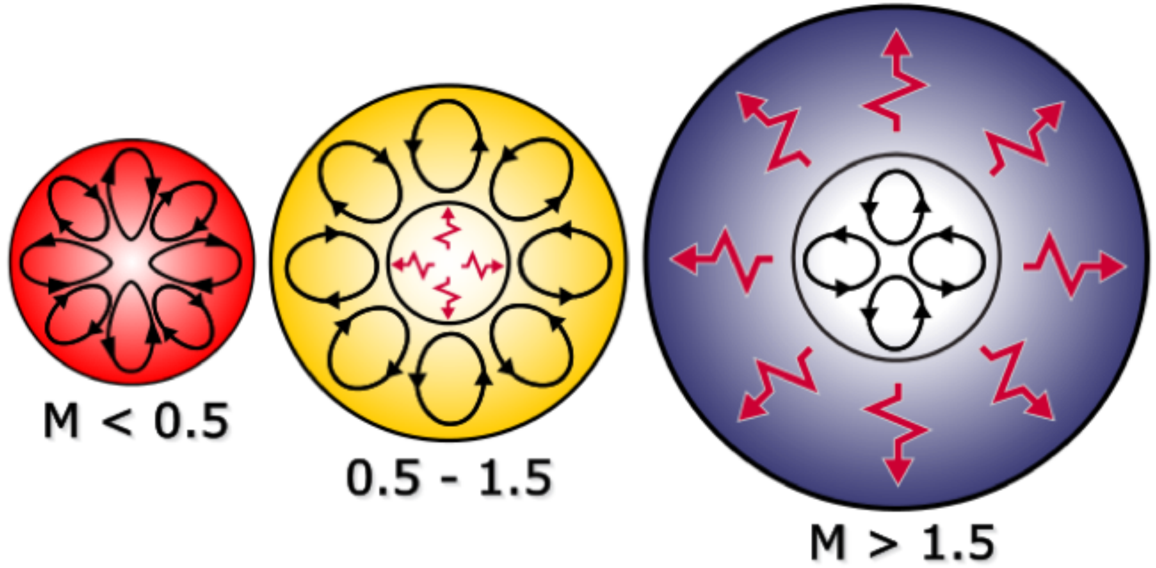
Credit: ESA/Hubble & NASA Acknowledgement: M. Novak

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

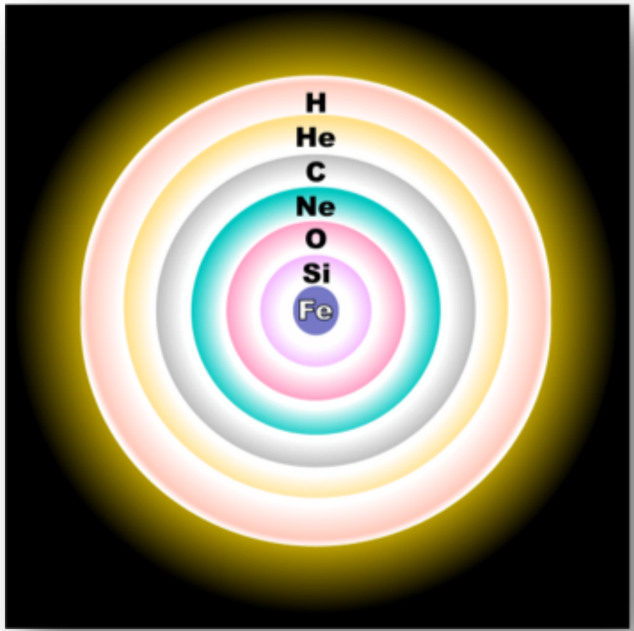
<u>Low mass stars</u> – runs out of fuel --> radiation pressure reduced → shrinks → white dwarf

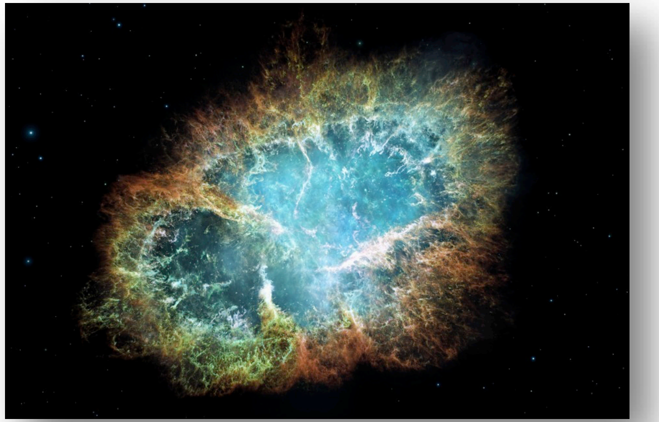
<u>High mass stars</u> – fusion down to iron → iron core → gravitational core collapse → supernova / collapsar

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

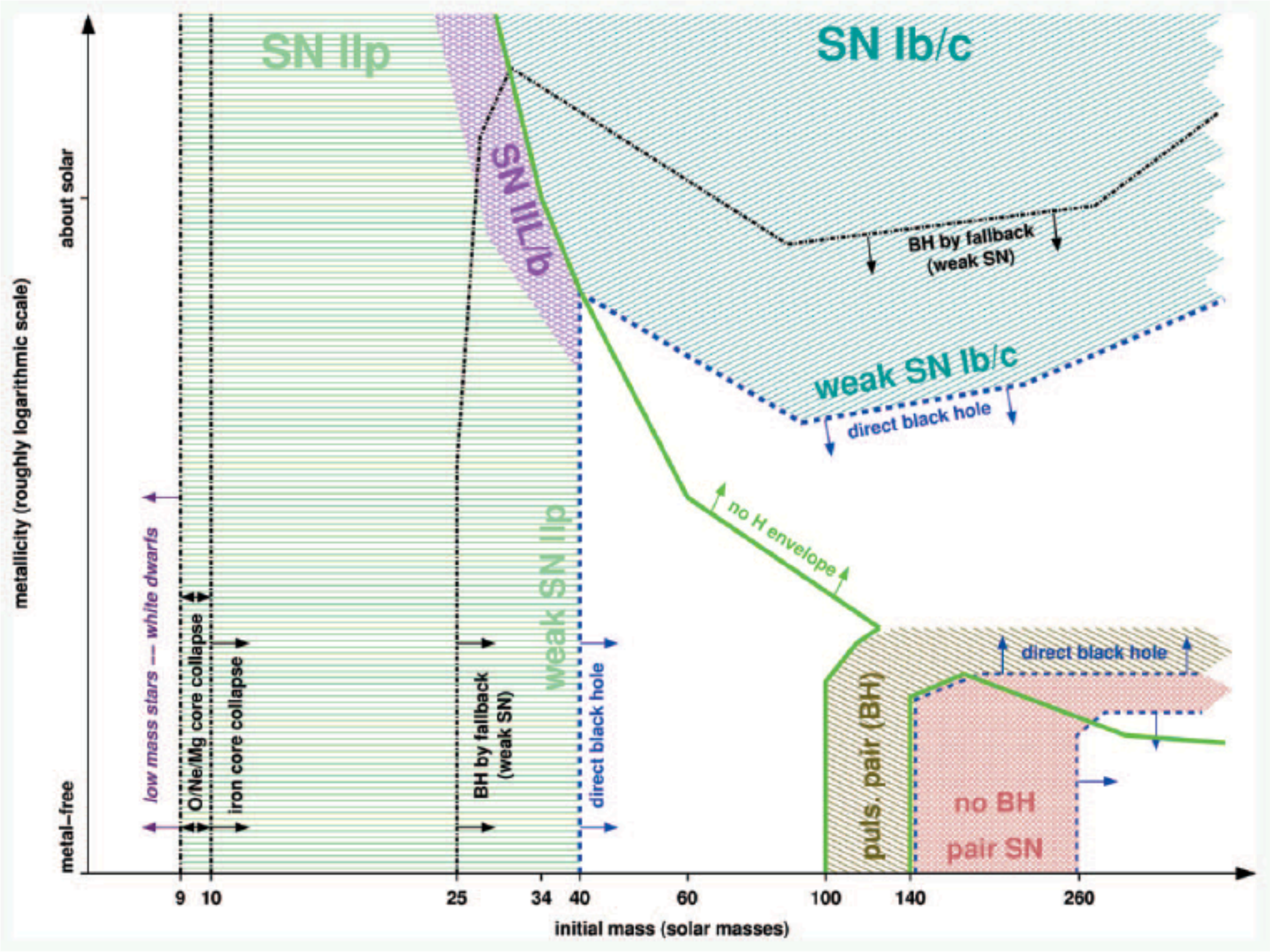
<u>Very high mass stars</u> – high pressure → gamma rays energetic for photodisintegration→ reduced pressure → gravitational collapse → black hole

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



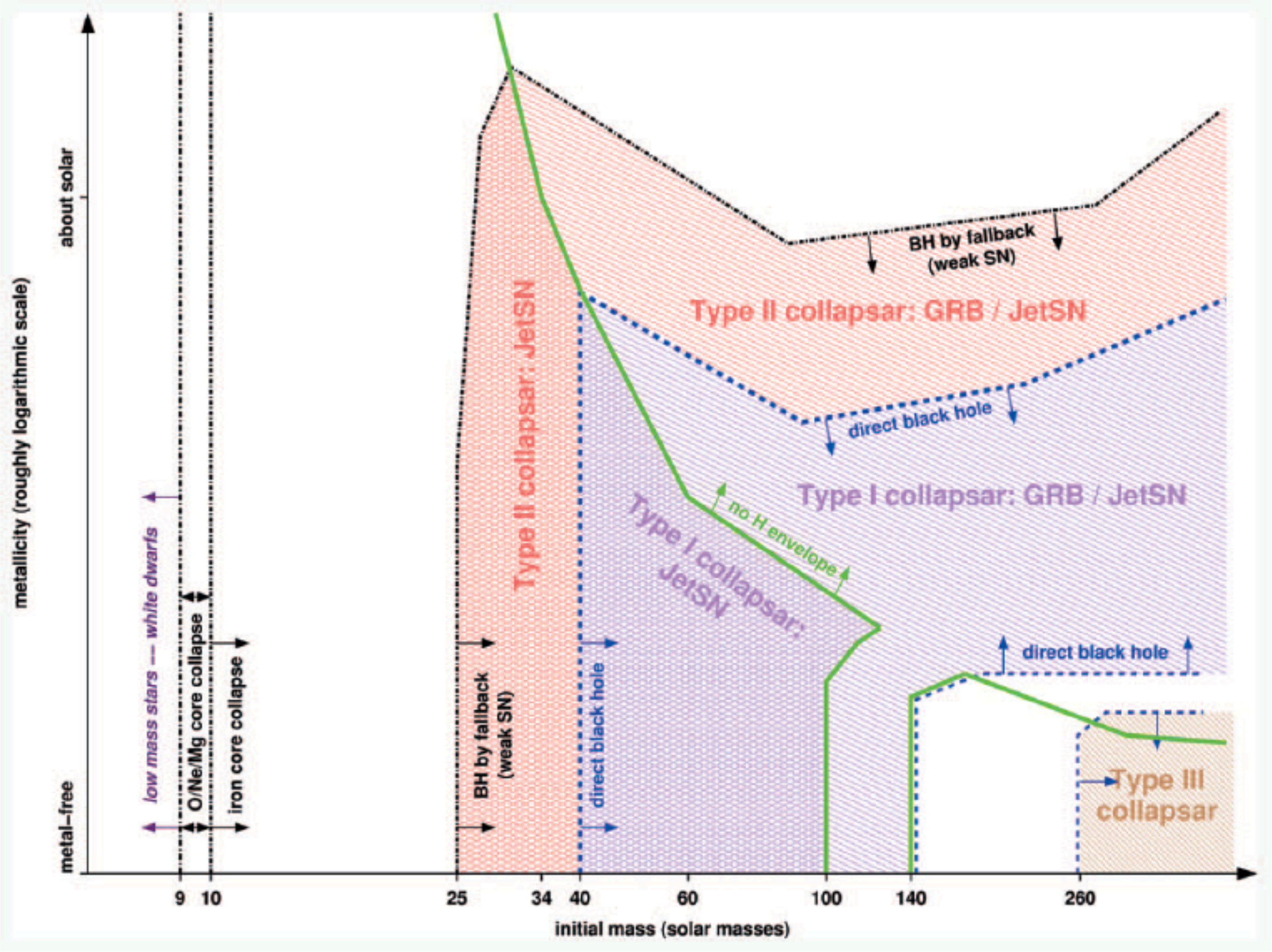


Supernova explosion



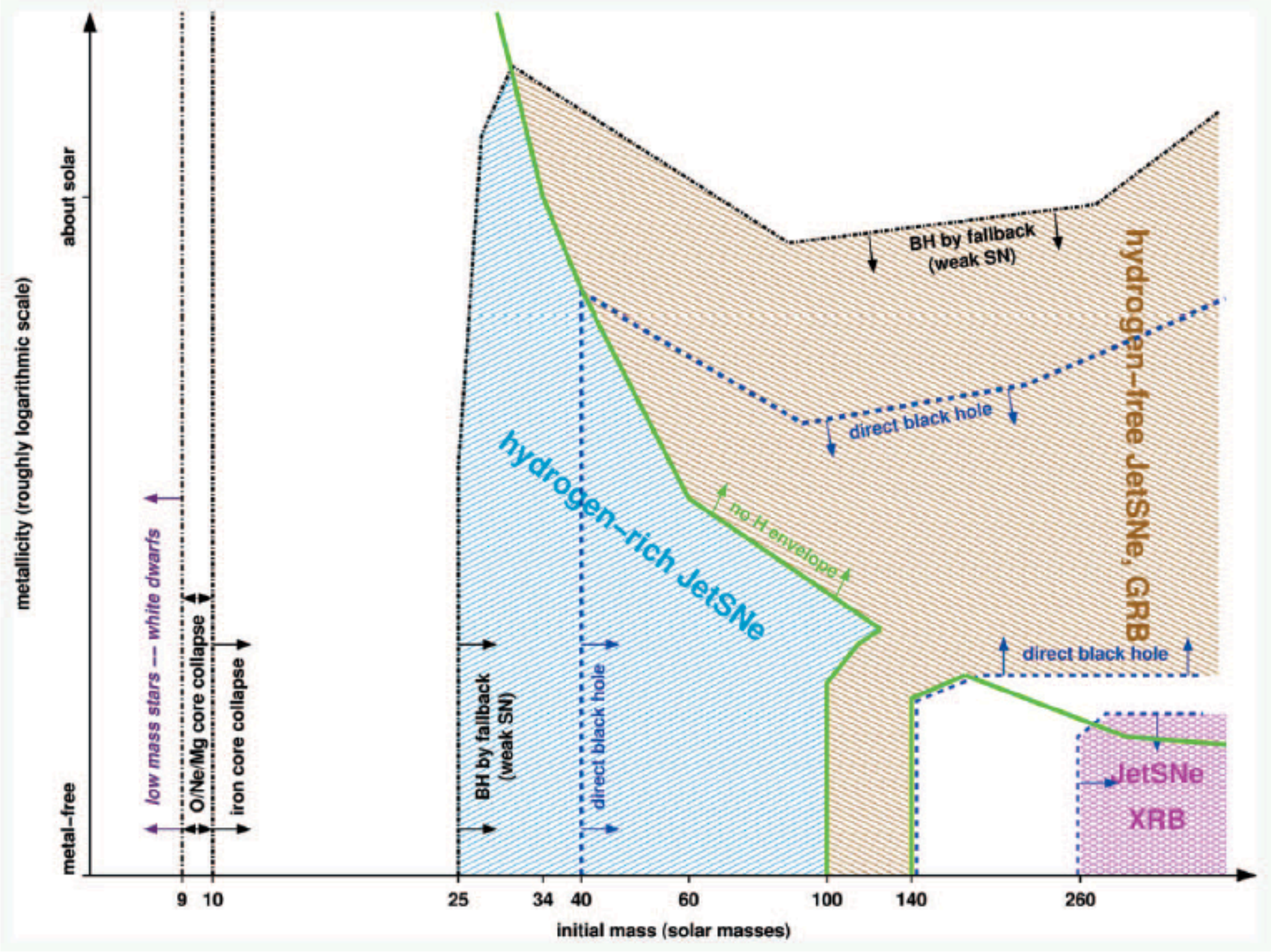
Heger+ ApJ 2003

Collapsars



Heger+ ApJ 2003

Beamed outflow (jet)



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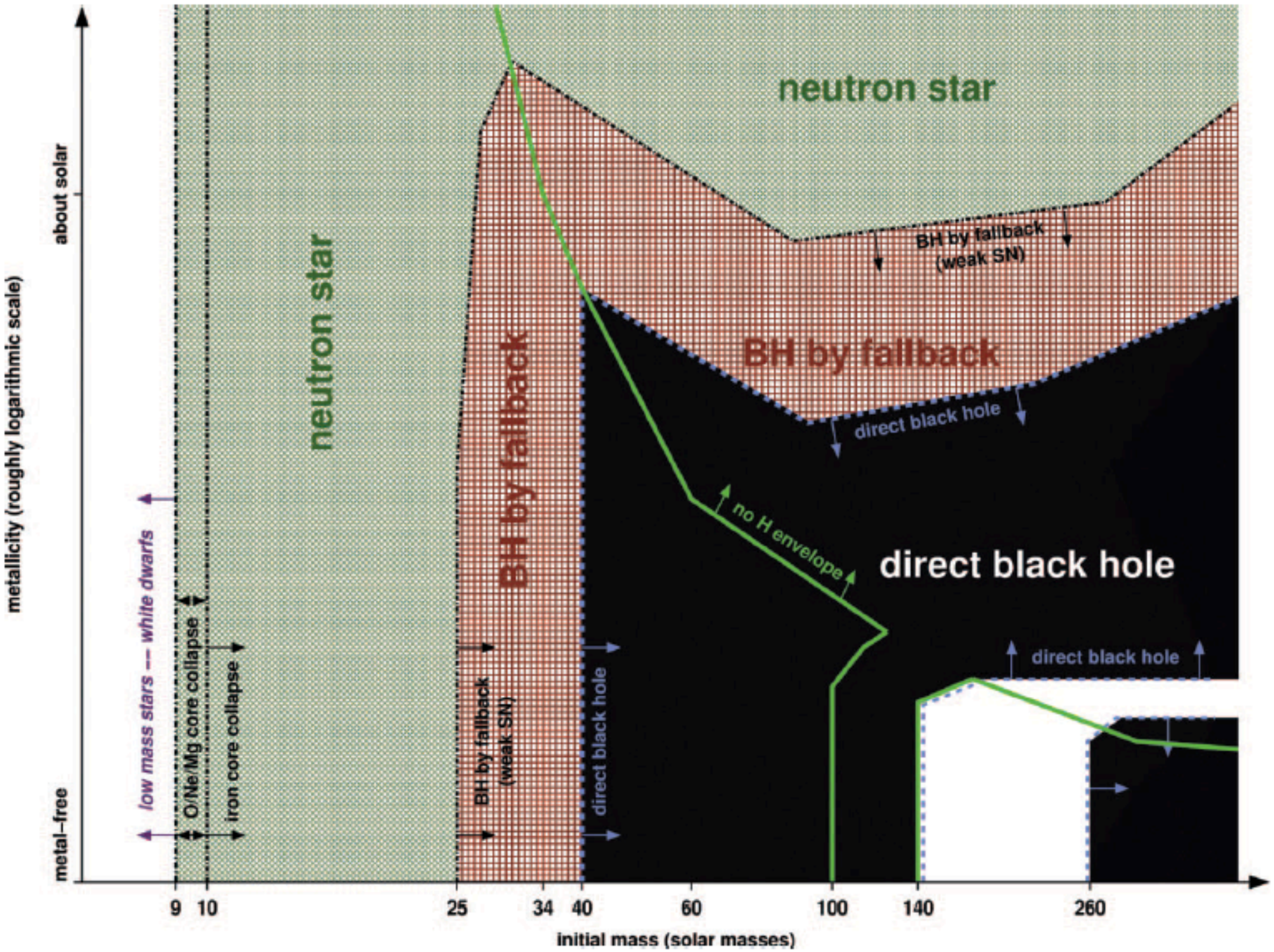
Remnant



Heger+ ApJ 2003