Stellar Evolution

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Protostar

$< 0.8\ M_s$

Brown dwarf

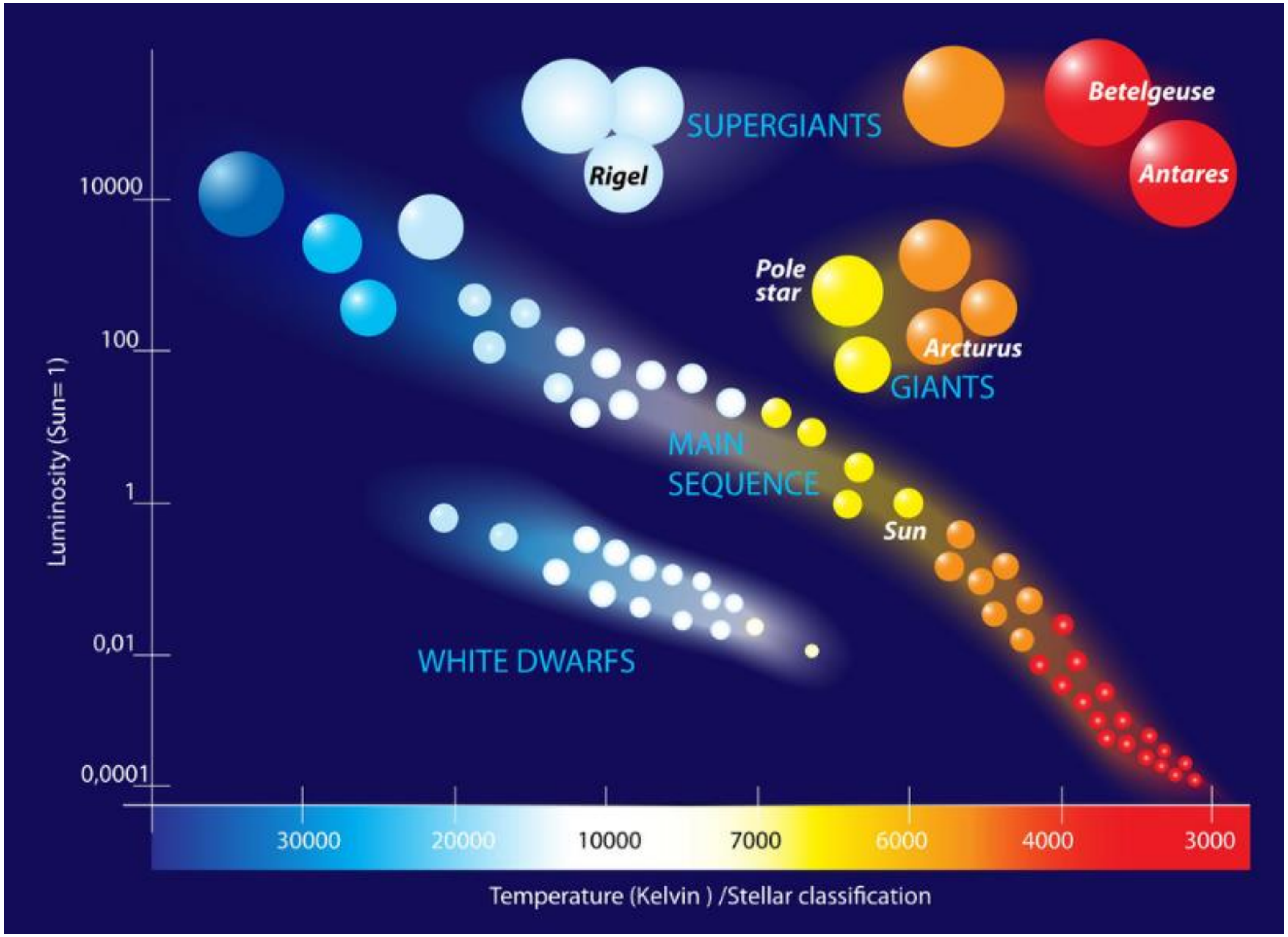
- Unable to fuse Hydrogen
- Thought to fuse Deuterium

$\sim 13\ MJ$

Main Sequence Star

- $H^1 \rightarrow H^2 \rightarrow He$
- Larger stars, shorter time on Main Sequence

Hertzsprung–Russell diagram



Main Sequence Stars

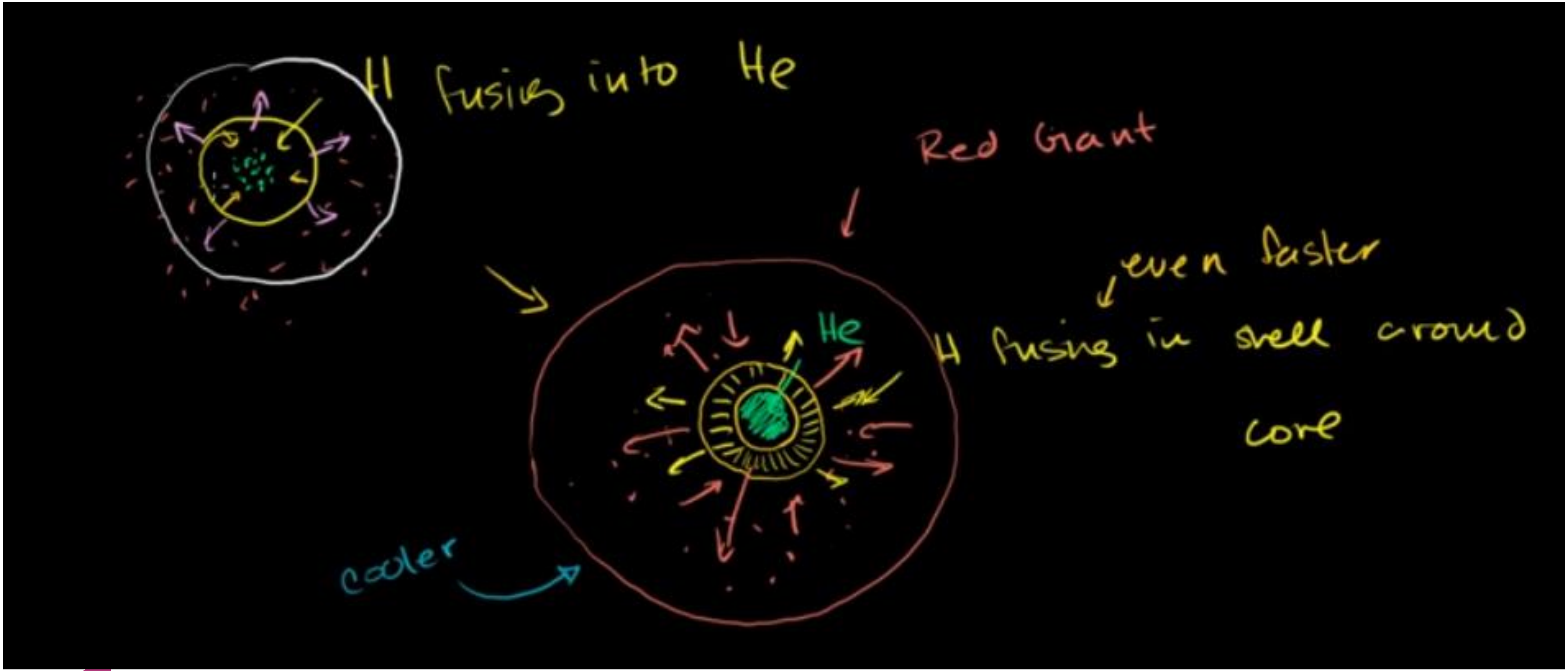
- $> \ 1\, M_s$
  - Go through CNO cycle
  - Become stable quickly
    - Gravity = radiation pressure
  - When H^1 depleted:
    - Radiation pressure << gravity

e^- degeneracy pressure

He fusion – $100M\ K$

Low mass stars

- Not observed ($\sim 0.1\ M_S$)
  - Red dwarves stay on MS for $6 - 12$ tn yrs
  - → White dwarf ($100s$ of bn yrs)
  - H^1 fuses → entirely He
- >0.8 M_S
  - Do become red giants
  - No He fusion
  - Lower luminosity ➔ white dwarf


H fusing into He
Red Giant
even faster
He
H fusing in shell around core
cooler

Medium mass stars $(0.6 - 10Ms)$

- Red giants
  - He core, H shell – red giant branch stars
  - He core
  - $C + He$ core, H shell – asymptotic giant branch stars

Sub giant phase

- Millions - 2 bn yrs
- core degenerate
- Opaque outer layers

Red giant branch phase

- Outer layers convective
- Effects of first dredge up:
  - Lower C^{12}/C^{13} ratios, altered C, N proportions
- He core grows
  - Degenerate
  - > Schoenberg-Chandrasekhar limit
- Increases luminosity

Horizontal Branch

- 0.6 – 2 Ms
  - He flash
- More massive stars
  - Slow ignition of He (no flash)
- Contracts, migrates on HR diagram
- Increases surface temp

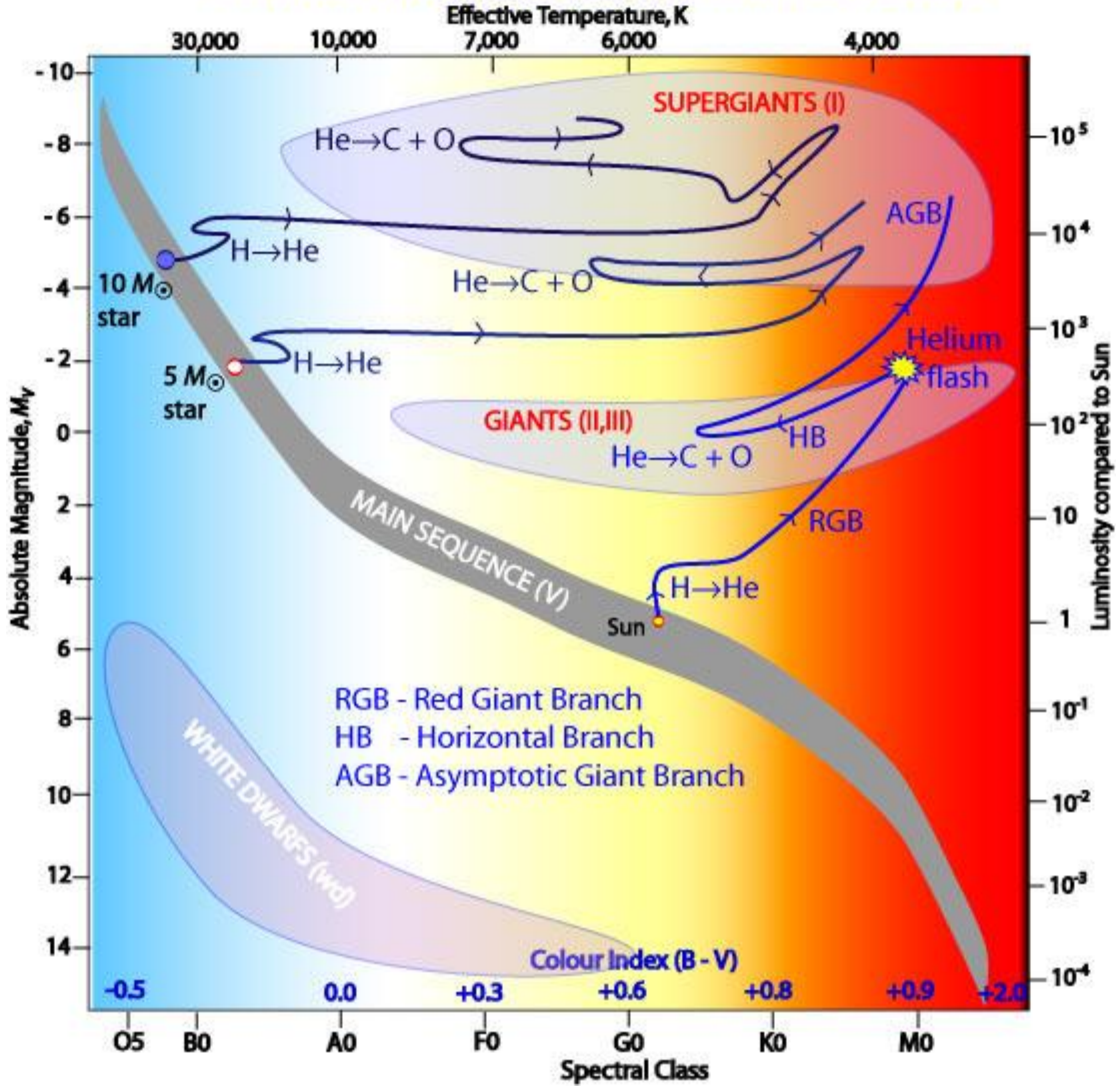
Asymptotic-giant-branch phase

- C, O core
  - H, He fusion in shells
- Thermal pulse
- Second dredge up
  - Forming carbon stars
- Hot bottom burning: C → N or O

Post AGB phase

- Not large enough for C fusion
- Contract further
- Form planetary nebula
- Circumstellar envelope
- Post AGB thermal pulses

Evolutionary Tracks off the Main Sequence



Massive stars ($> \ 9\, M_S$)

- Large core- He ignition before e^- degeneracy
- Collapse into neutron stars or black holes

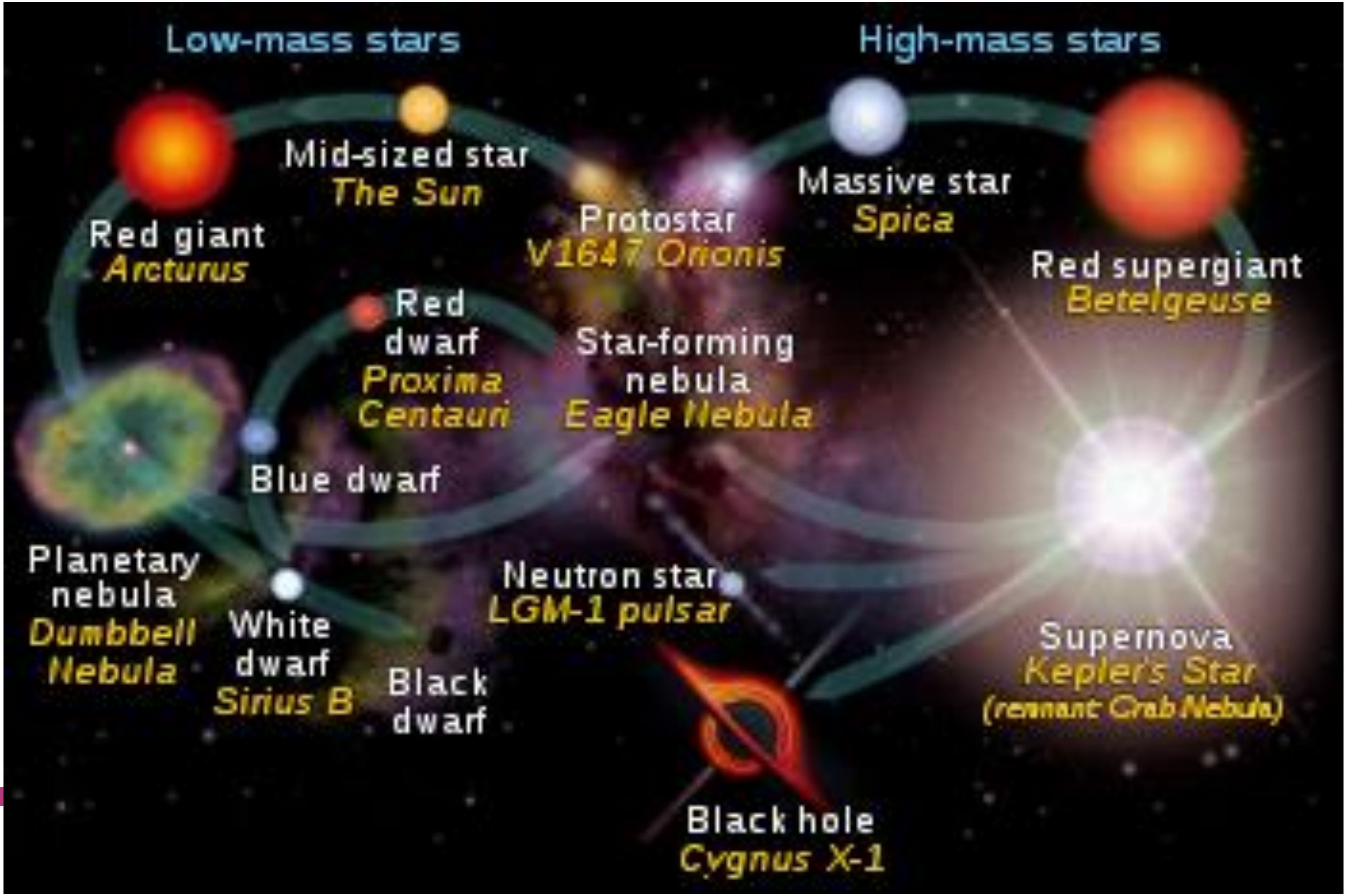
Supergiant evolution $> 40\ M_S$

- Rapid stellar winds – never become red giant
- Retain blue-white colour from MS onwards
- Note: small stars in binary systems
- End of He fusion- C, O core
- Fuses C by alpha process
- Less massive – O, Ne, Mg white dwarf

- Carbon burning - $8 - 9M_S$
- Core- $2.5\ M_S$
- Ne burning before O
  - 8–12 M_S - unstable: e^- capture supernova
- $C \rightarrow Fe$ core: 100s of yrs
- Effective Chandrasekhar mass - $1.34 - 1.8\ M_S$
- Electrons captured
- Supernova / blackhole

Supernovae

- Core collapse:
  - Neutron star
  - Black hole
  - Some energy → supernova
- Shock wave
- Electron capture


Low-mass stars
High-mass stars
Mid-sized star
The Sun
Red giant
Arcturus
Protostar
V1647 Orionis
Massive star
Spica
Red supergiant
Betelgeuse
Red
dwarf
Proxima
Centauri
Star-forming
nebula
Eagle Nebula
Blue dwarf
Planetary
nebula
Dumbbell
Nebula
White
dwarf
Sirius B
Black
dwarf
Neutron star
LGM-1 pulsar
Supernova
Kepler's Star
(remnant: Crab Nebula)
Black hole
Cygnus X-1

Thank you!