How Stars Evolve

- The fate of the Sun
  - Nuclear ash
  - Red giant phase
  - Planetary nebula
  - White dwarf
- Ages of star clusters

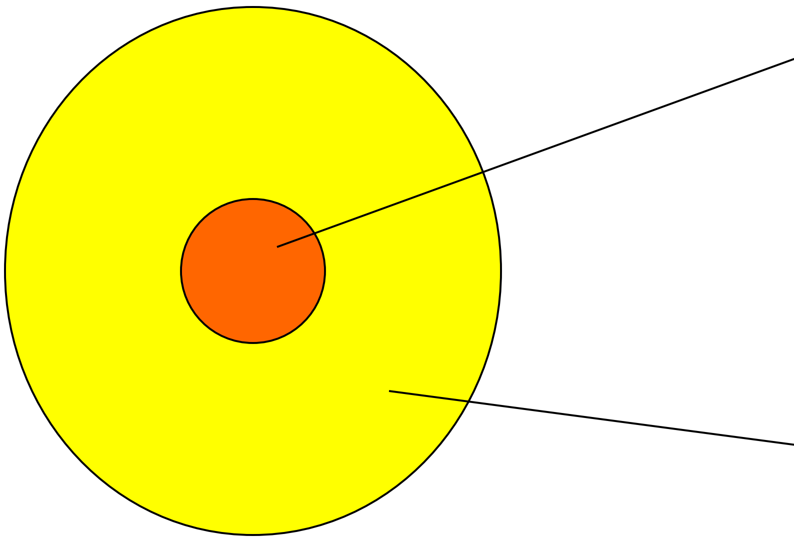
What would happen to a contracting cloud fragment if it were not able to radiate away its thermal energy?

A. It would continue contracting, but its temperature would not change
B. Its mass would increase
C. Its internal temperature would increase
D. It would be happy

The Fate of the Sun

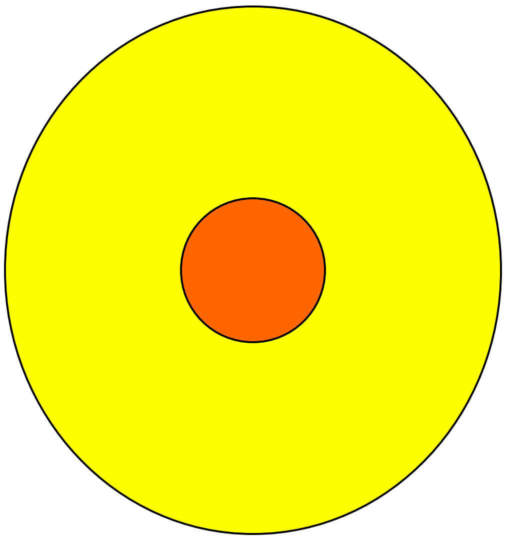
- How will the Sun evolve over time?
- What will be its eventual fate?

Sun's Structure



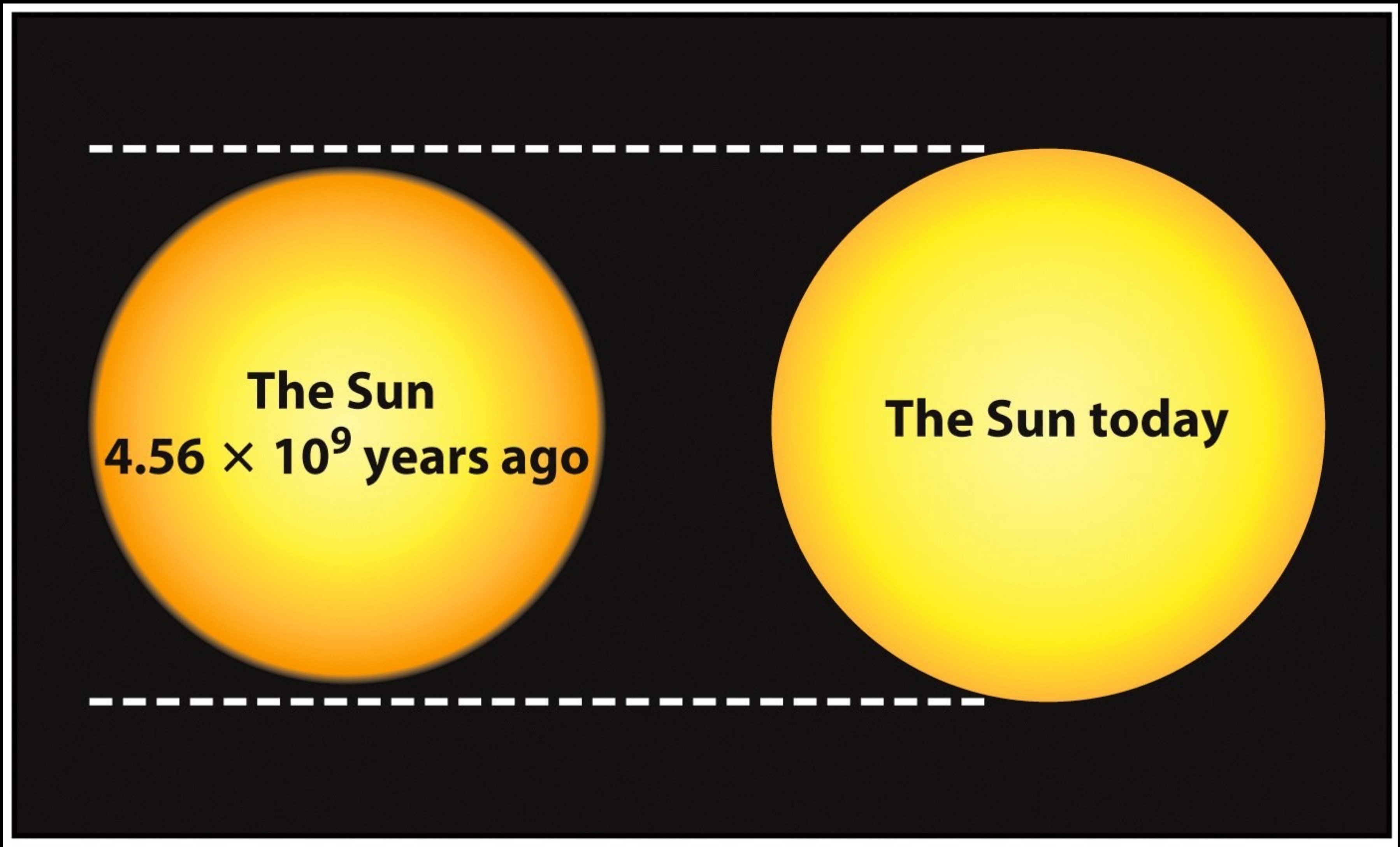
- Core
  - Where nuclear fusion occurs
- Envelope
  - Supplies gravity to keep core hot and dense

Main Sequence Evolution



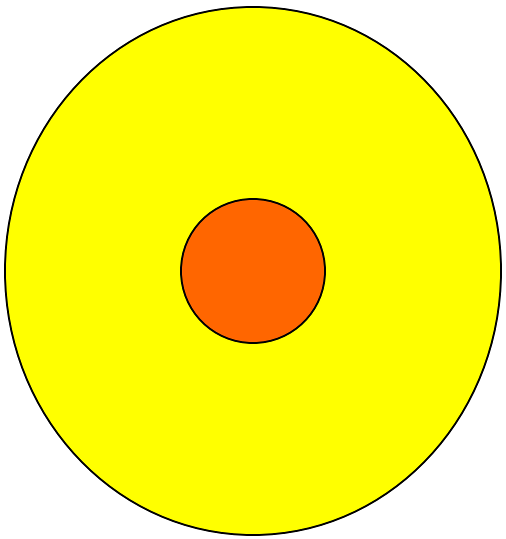
- Core starts with same fraction of hydrogen as whole star
- Fusion changes H $\rightarrow$ He
- Core gradually shrinks and Sun gets hotter and more luminous

Gradual change in size of Sun



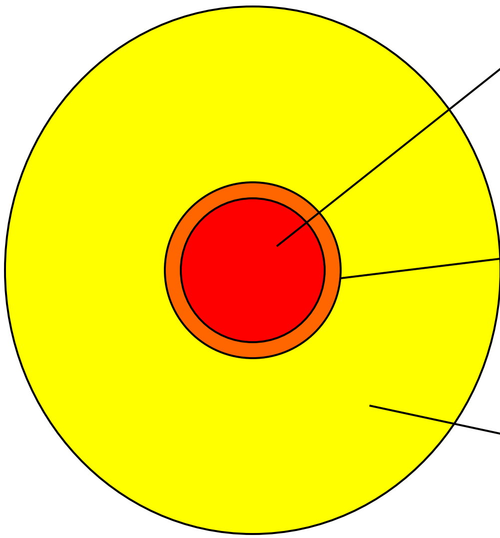
Now 40% brighter, 6% larger, 5% hotter

Main Sequence Evolution



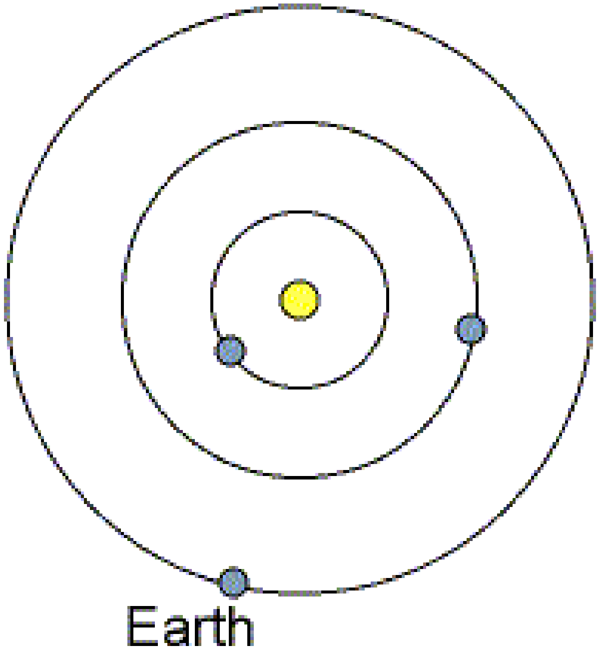
- Fusion changes H $\rightarrow$ He
- Core depletes of H
- Eventually there is not enough H to maintain energy generation in the core
- Core starts to collapse

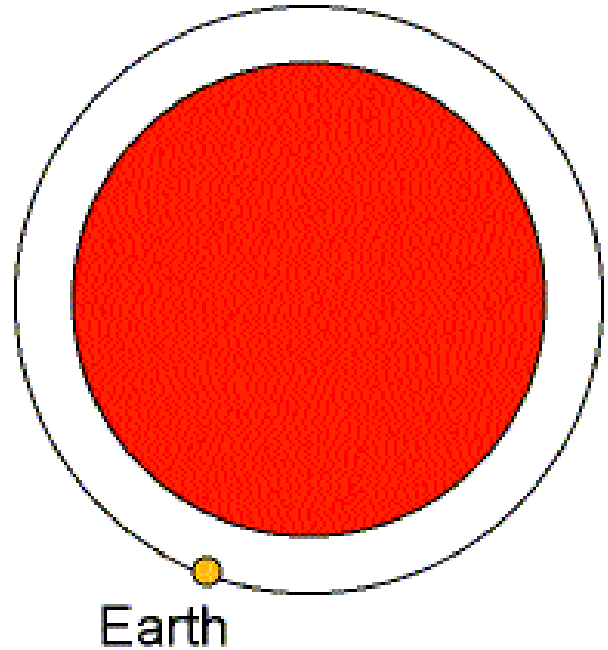
Red Giant Phase



- He core
  - No nuclear fusion
  - Gravitational contraction produces energy
- H layer
  - Nuclear fusion
- Envelope
  - Expands because of increased energy production
  - Cools because of increased surface area

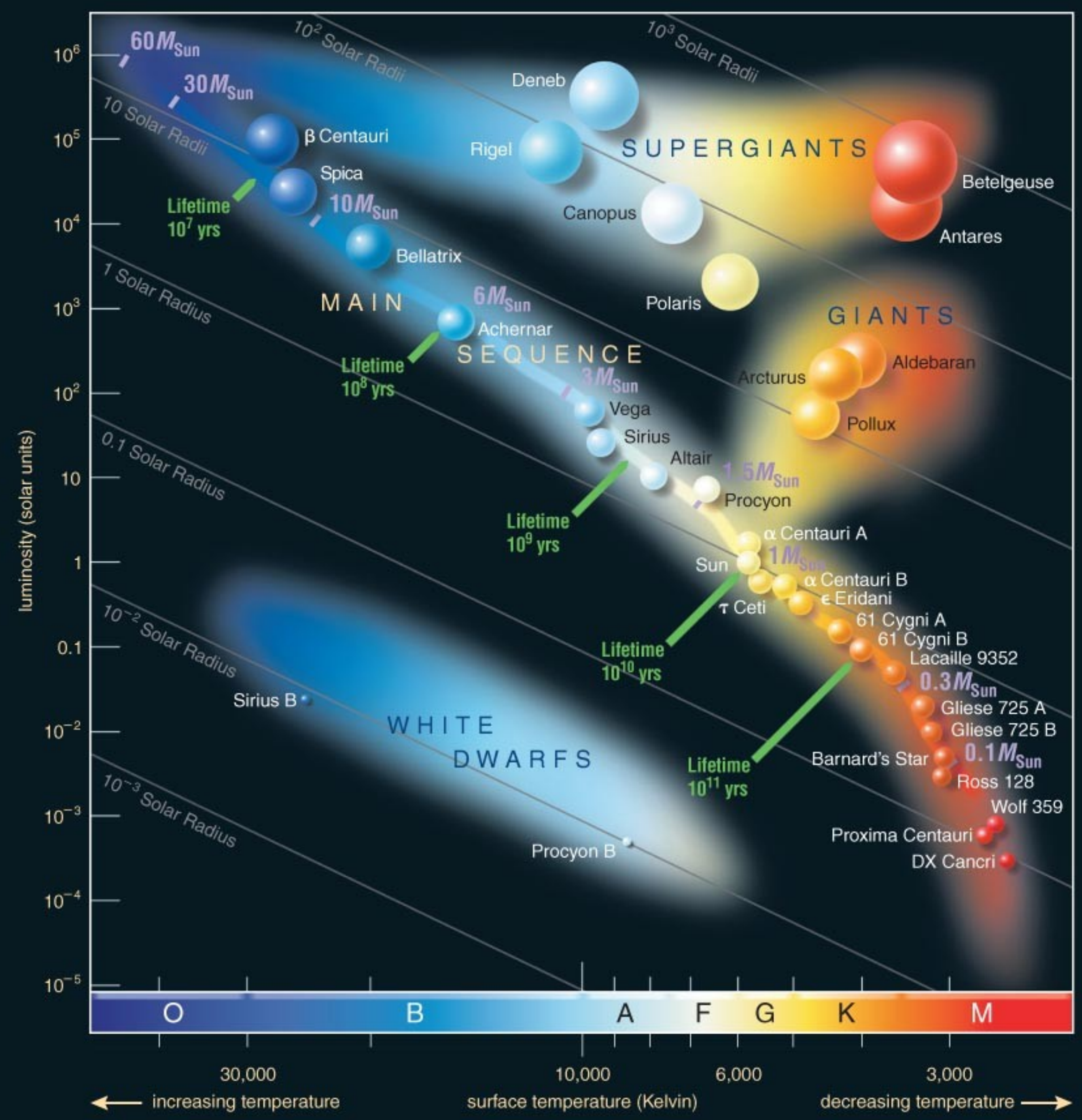
Sun's Red Giant Phase





Now: hot core + warm surface; small size.

Future: very hot core + cool surface. Large size but less mass; very bright.



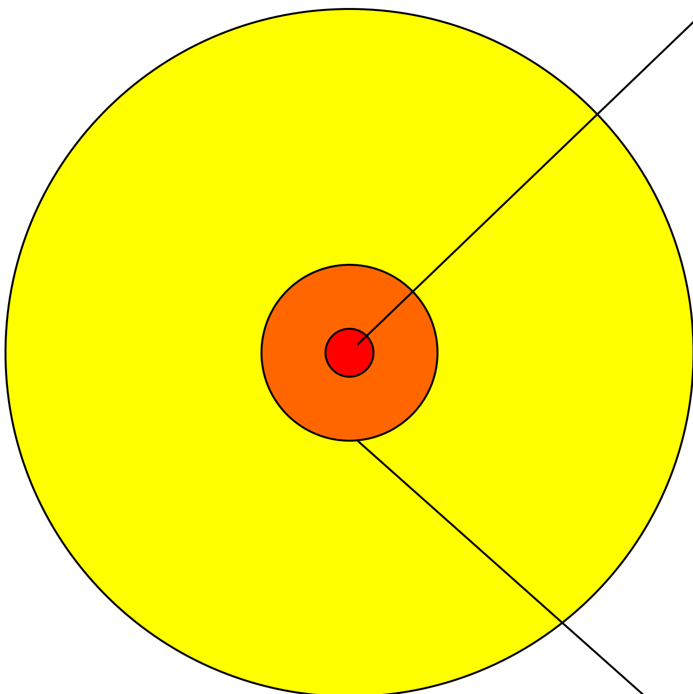
HR diagram

Giant phase is when core has been fully converted to Helium

When hydrogen burning in the core stops, a star like the Sun begins to evolve

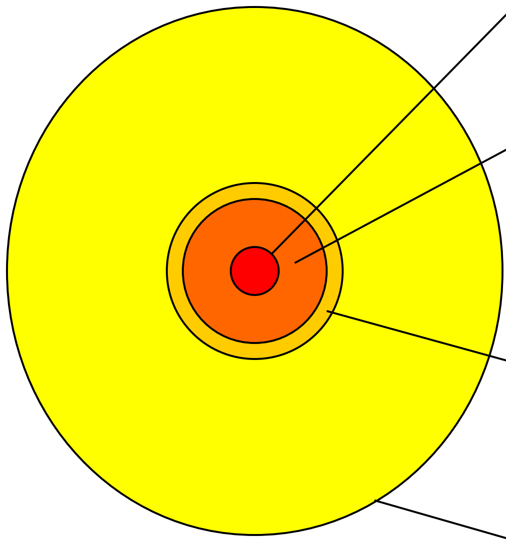
A) To higher surface temperature and higher luminosity
B) To lower surface temperature and higher luminosity
C) To higher surface temperature and lower luminosity
D) To lower surface temperature and lower luminosity
E) Up the main sequence to become an O star

Helium Flash



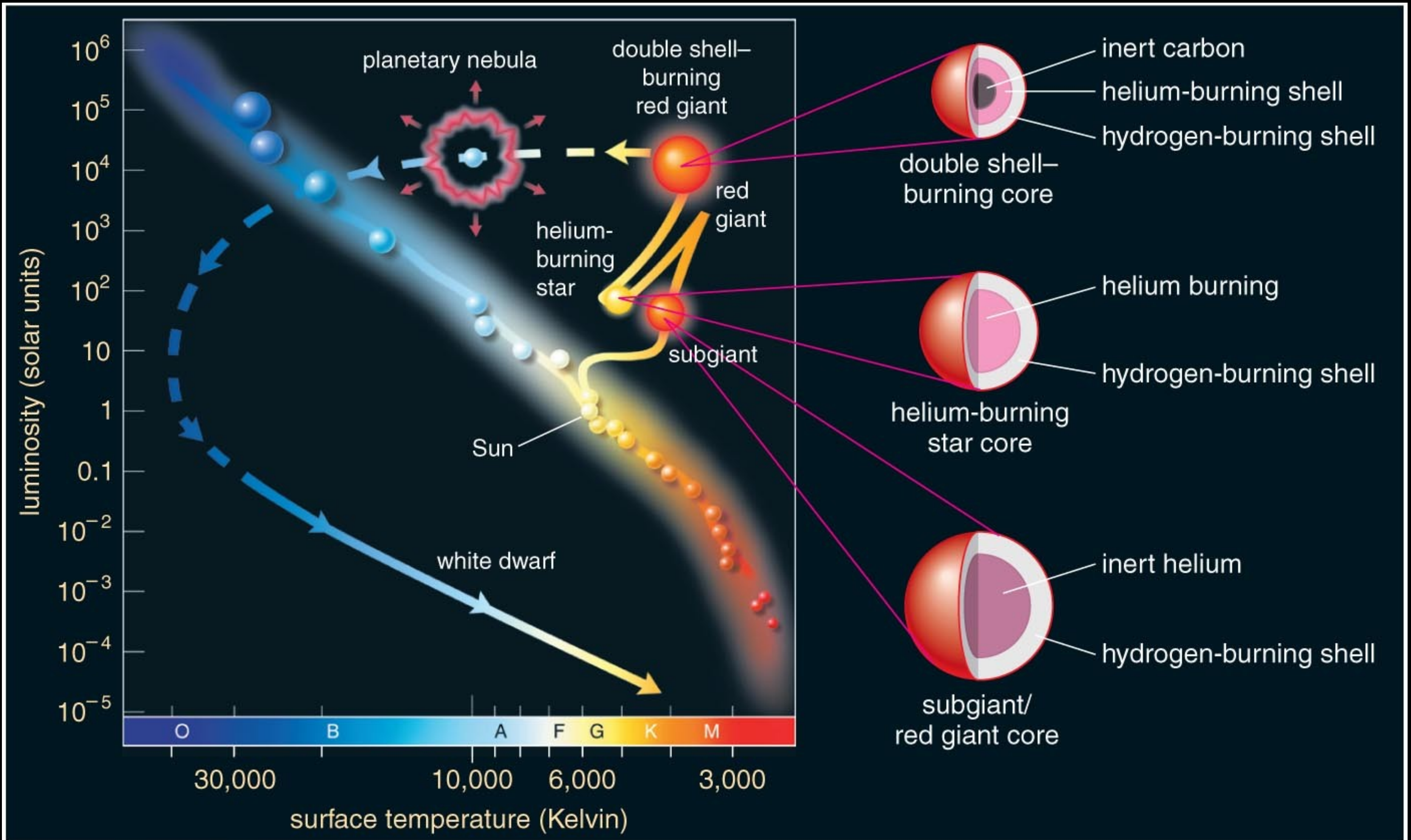
- He core
  - Eventually the core gets hot enough to fuse Helium into Carbon.
  - This causes the temperature to increase rapidly to 300 million K and there's a sudden flash when a large part of the Helium gets burned all at once.
  - We don't see this flash because it's buried inside the Sun.
- H layer
- Envelope

After Helium Ignition

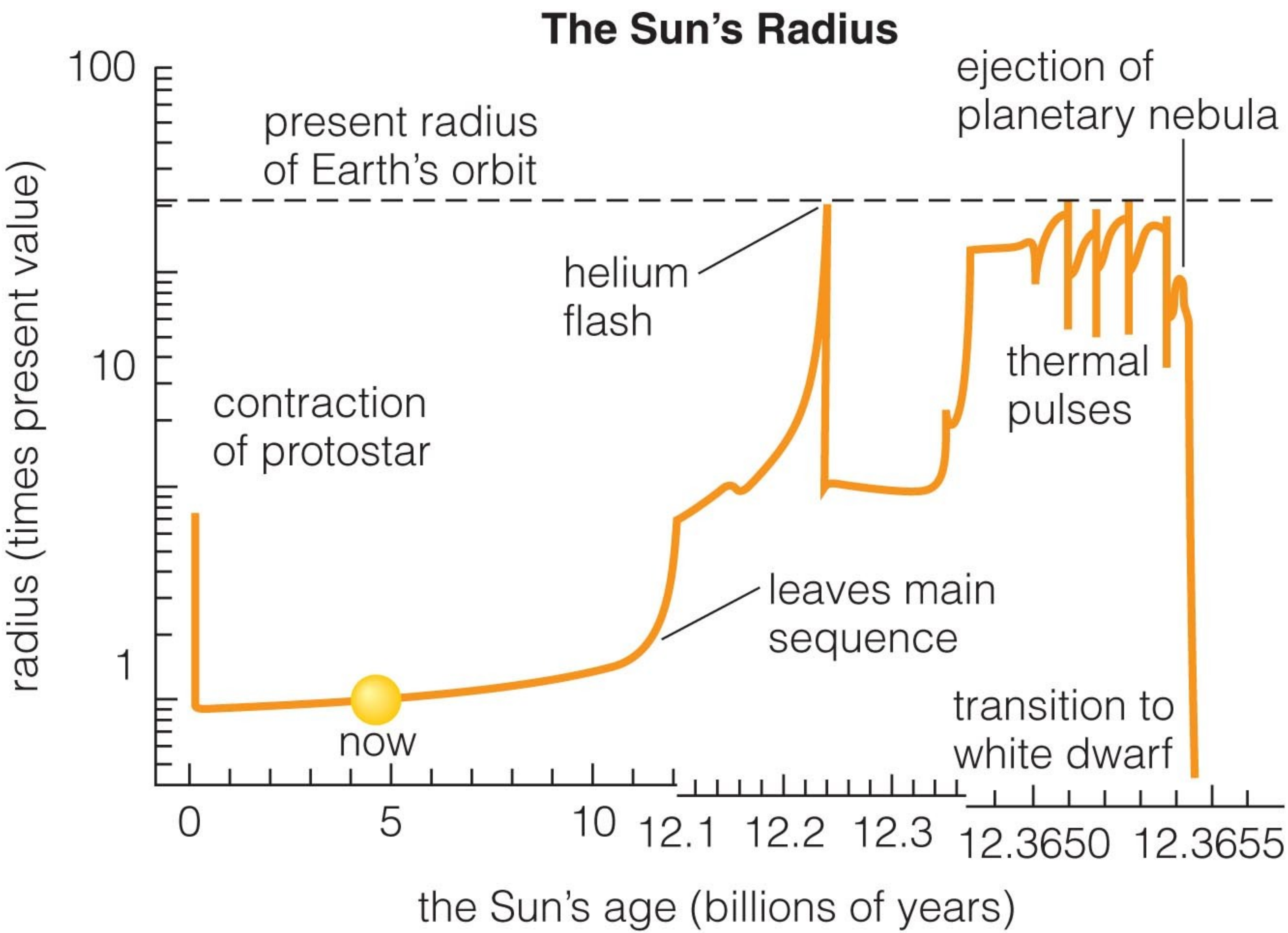


- He burning core
  - Fusion burns He into C, O
- He rich core
  - No fusion
- H burning shell
  - Fusion burns H into He
- Envelope
  - Expands because of increased energy production

Movement on HR diagram



The Life of the Sun

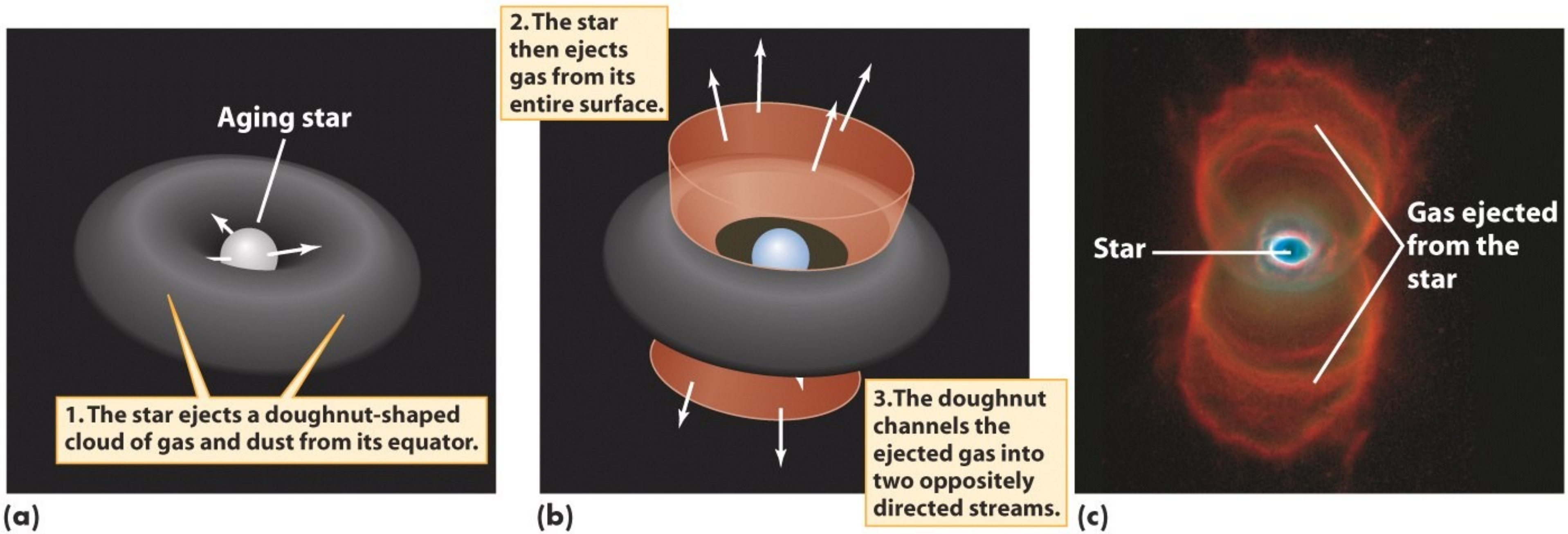


During double shell burning Sun loses mass via winds

- Creates a “planetary nebula”
- Leaves behind core of carbon and oxygen surrounded by thin shell of hydrogen – a white dwarf

White dwarf

- Star burns up rest of hydrogen
- Nothing remains but degenerate core of Oxygen and Carbon
- “White dwarf” cools but does not contract because core is degenerate
- No energy from fusion, no energy from gravitational contraction
- White dwarf slowly fades away…


Aging star
1. The star ejects a doughnut-shaped cloud of gas and dust from its equator.
(a)
2. The star then ejects gas from its entire surface.
3. The doughnut channels the ejected gas into two oppositely directed streams.
(b)
Star
Gas ejected from the star
(c)

Planetary Nebula IC 418

Planetary Nebula NGC 6853 (M 27) - VLT ANTU+FORS1

ESO PR Photo 38a/98 (7 October 1998)

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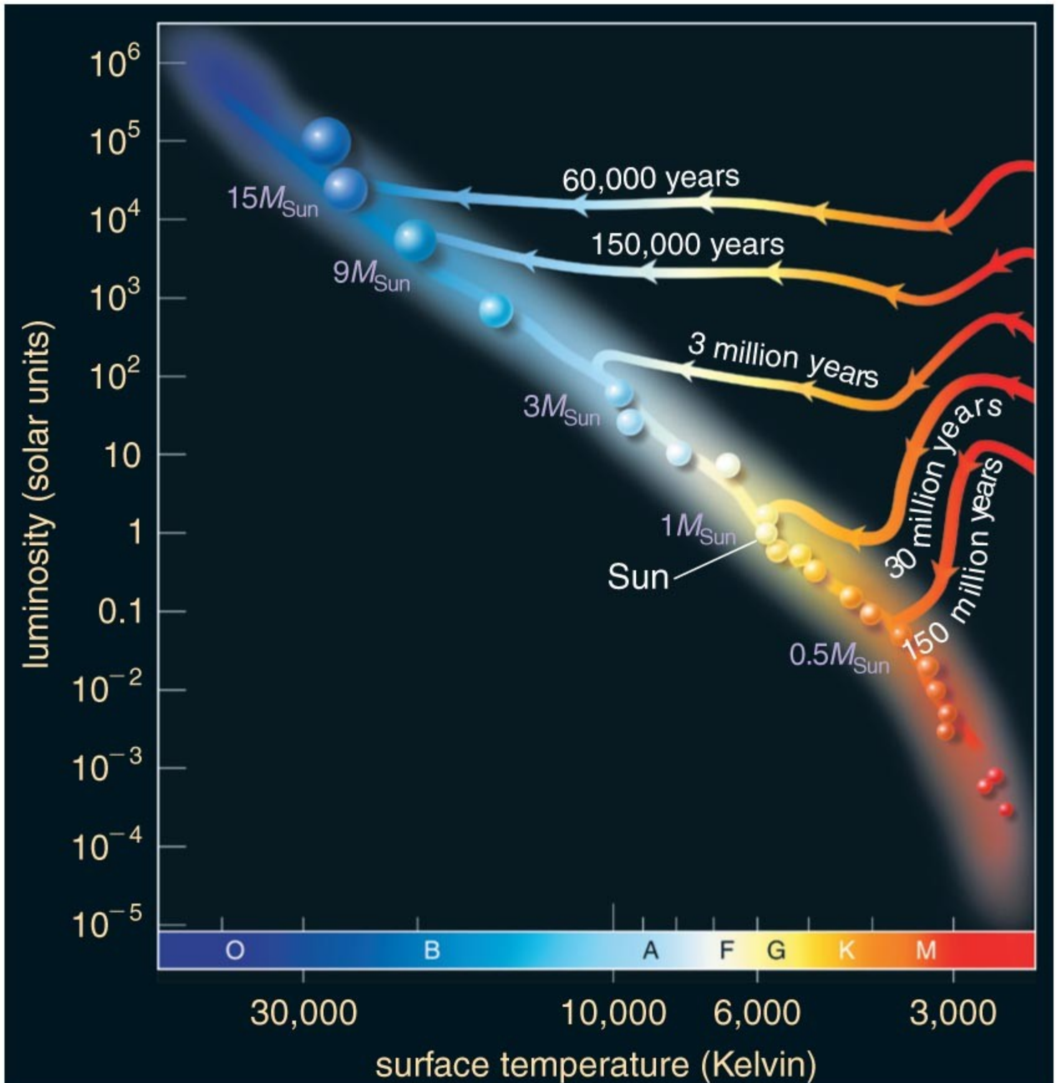
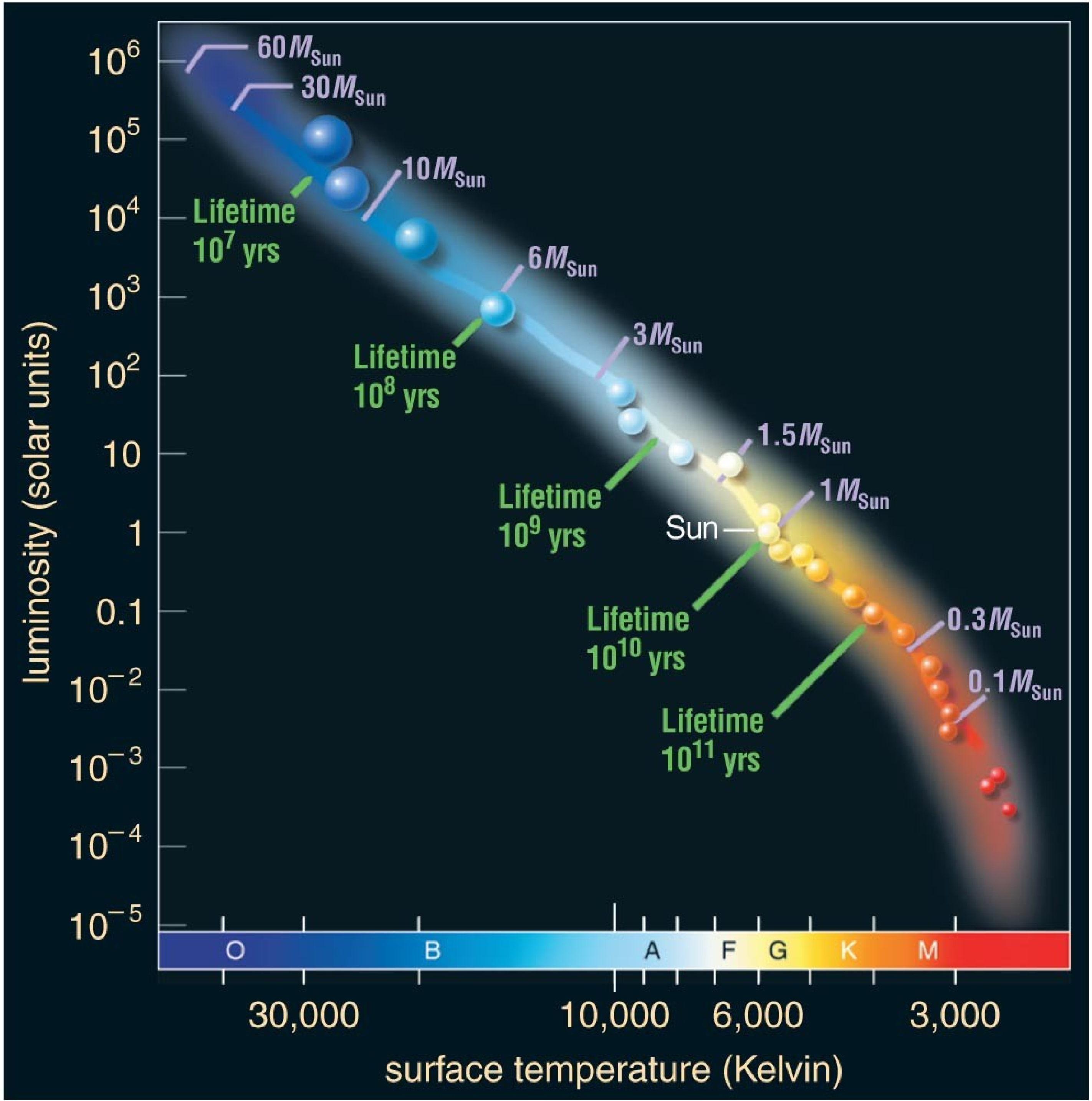
Hourglass nebula

How can we determine the age of a star cluster?

Formation time for different masses



- High-mass stars form fast
- Low-mass stars form slowly



Time on main sequence is set by mass

Turn-off point of cluster reveals age