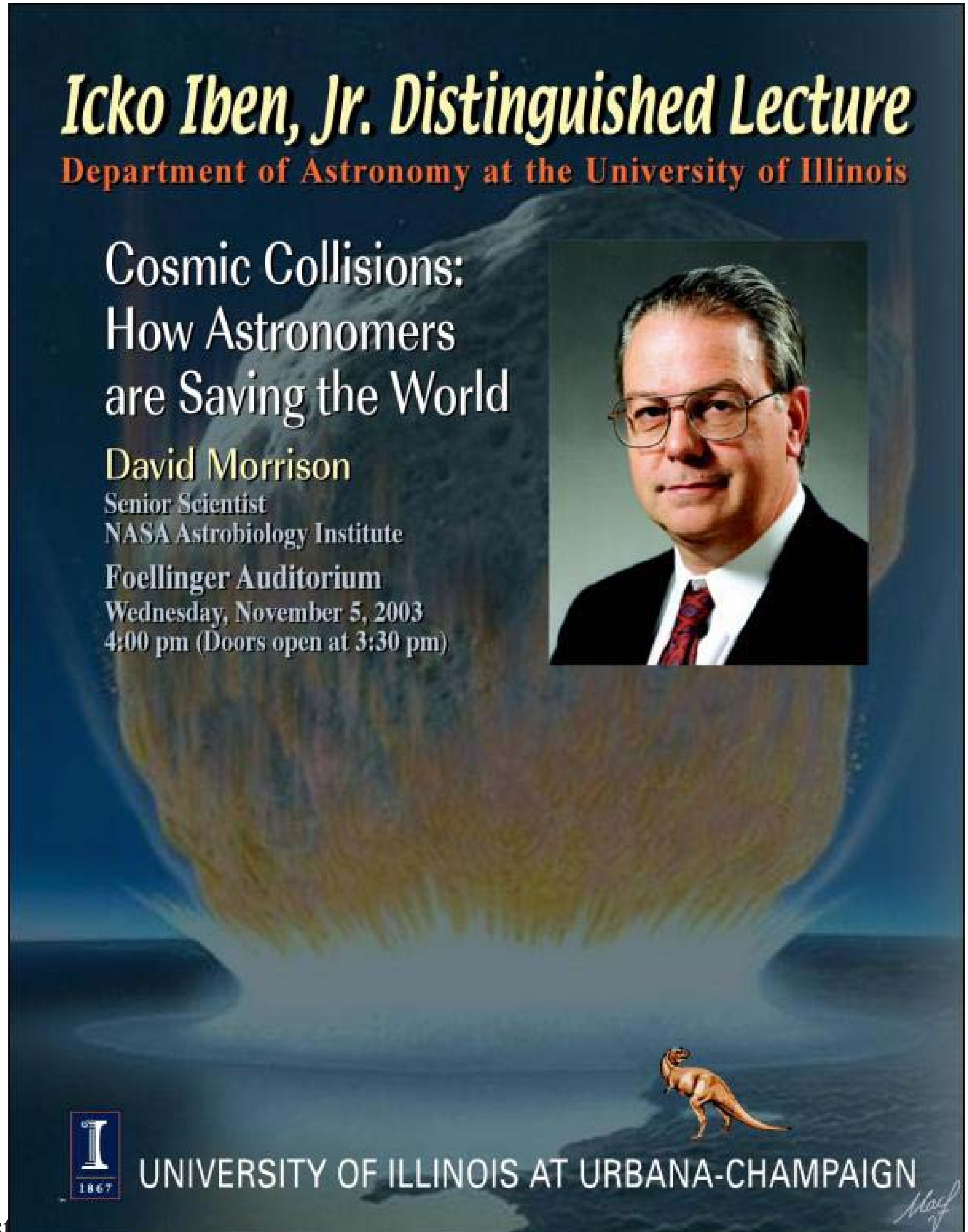
- Next homework is #7– due Friday at 11:50 am– last one before exam.

- Exam #2 is less than two weeks! Friday, November 14th!

- Don’t forget the Icko Iben Lecture is tonight!

<u>Want some extra credit?</u>

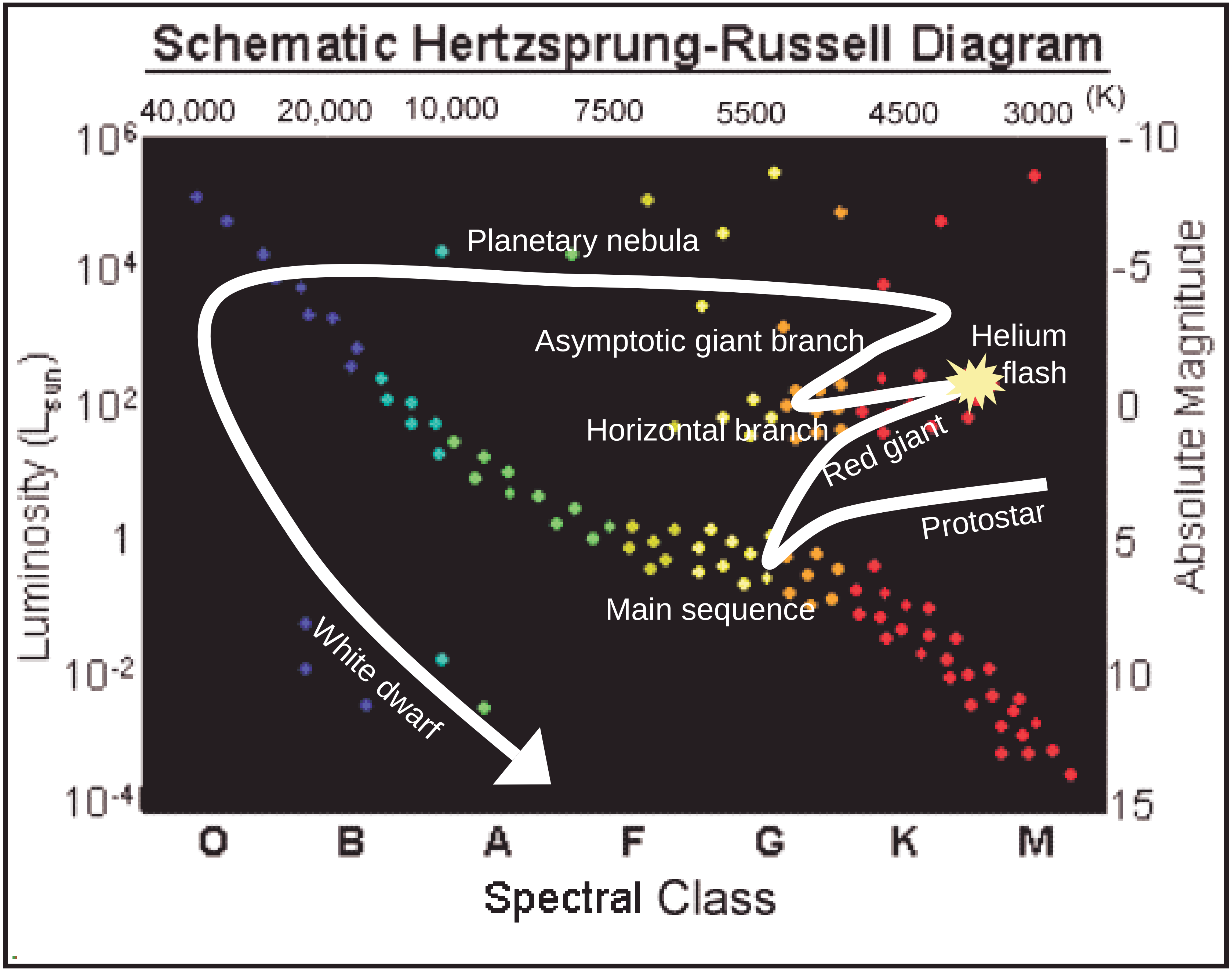
- Download and print report form from course web site
- Attend the Iben Lecture on November 5th
- Obtain my signature *before* the lecture and answer the questions on form. Turn in by Nov. 14th
- Worth 12 points (1/2 a homework)



Outline

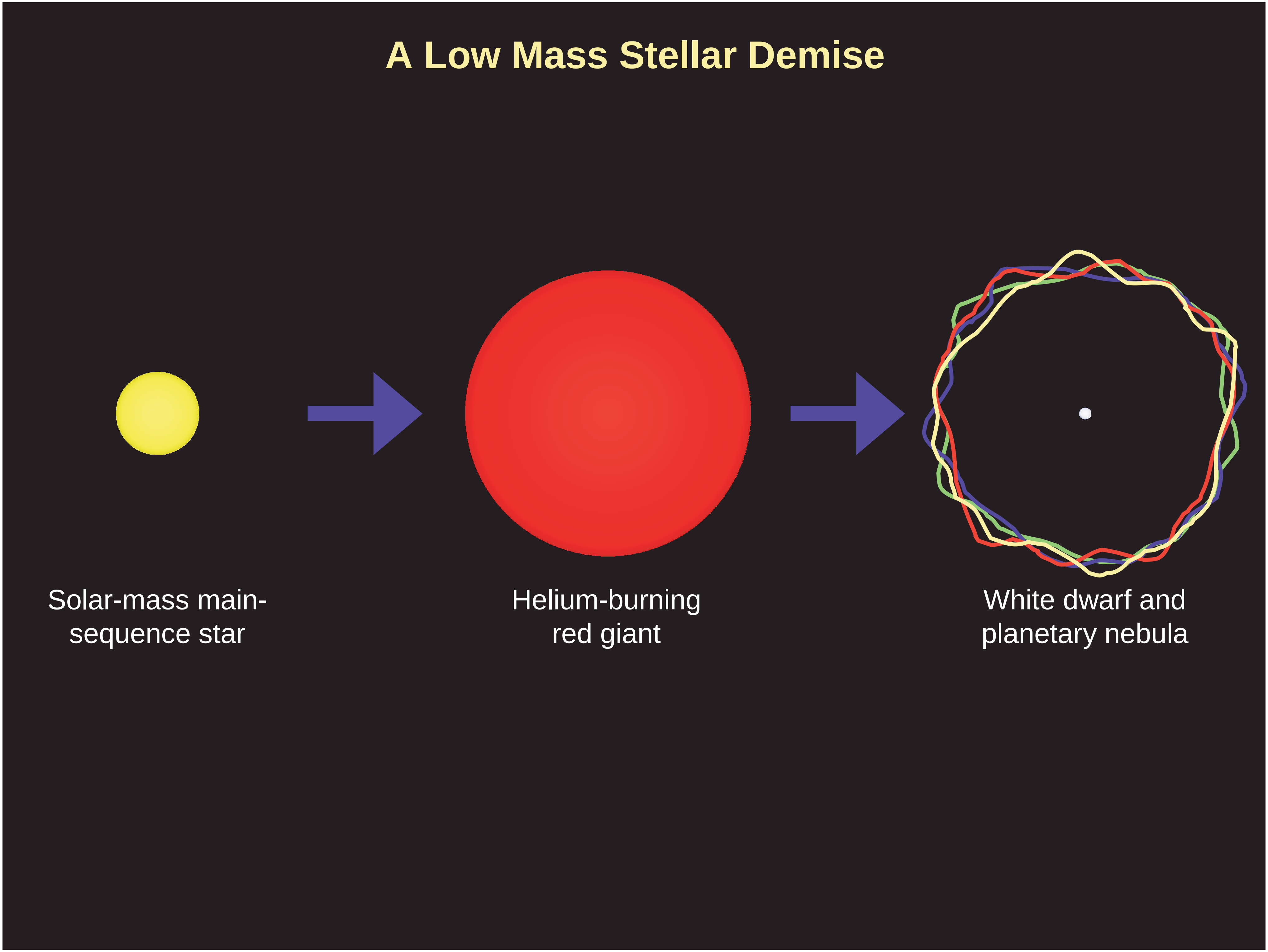
- The end of a low mass star (like our Sun)
  - Main sequence, red giant, helium flash, and planetary nebula and white dwarf
- End of an intermediate mass stars
  - Main sequence, red supergiant, helium flash, blue supergaint, red supergiant, and planetary nebula and white dwarf.
- The end of a massive star

Evolutionary Path of a Solar-Mass Star



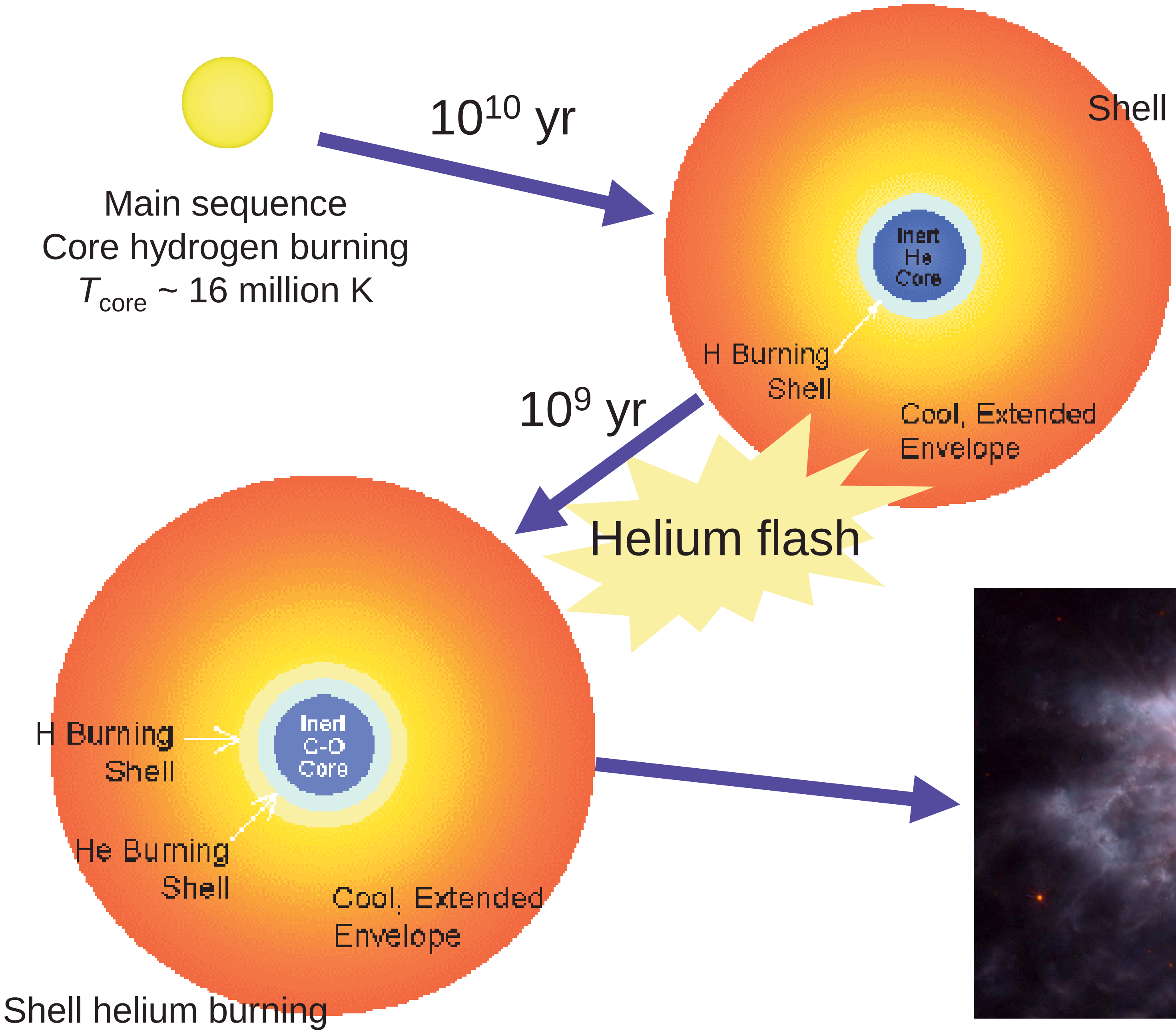
The Life of a 1 Solar Mass Star: $0.4\ M_{Sun} < M < 4\ M_{Sun}$

Example of how low mass stars will evolve on the HR Diagram– http://rainman.astro.uiuc.edu/ddr/stellar/archive/suntrackson.mpg


A Low Mass Stellar Demise
Solar-mass main-sequence star
Helium-burning red giant
White dwarf and planetary nebula

Evolution of a Solar-Mass Star

Red giant
Shell hydrogen burning



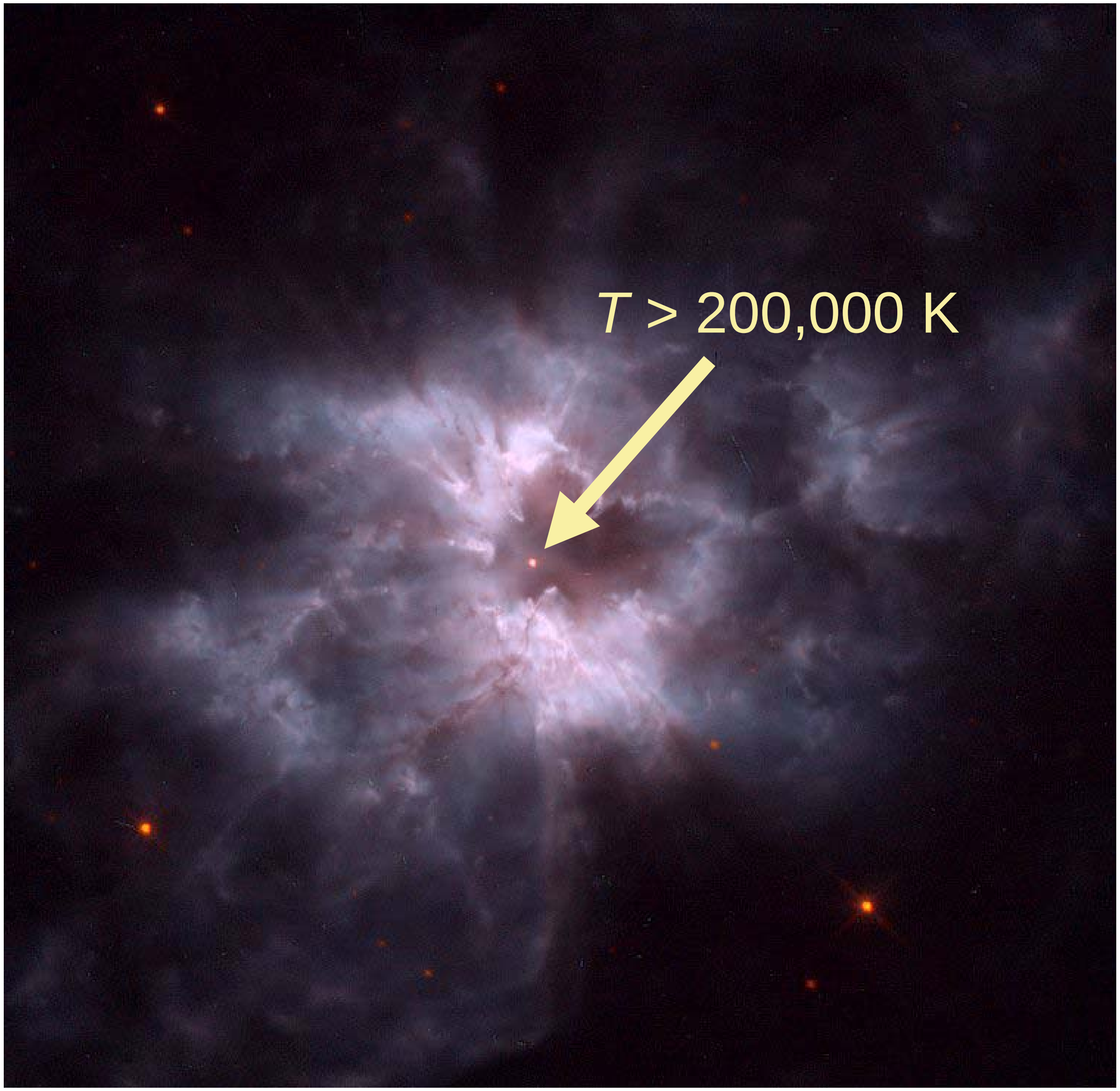
Our Sun has about 5 billion more years left on the main sequence.

Planetary Nebula and White Dwarf

White Dwarfs and Planetary Nebulae

- Outer layers of the red giant star are blown away by radiation from the hot new white dwarf– loses from 20 to more than 50% of its mass

- As they expand, they are lit from within by the white dwarf



NGC 2440

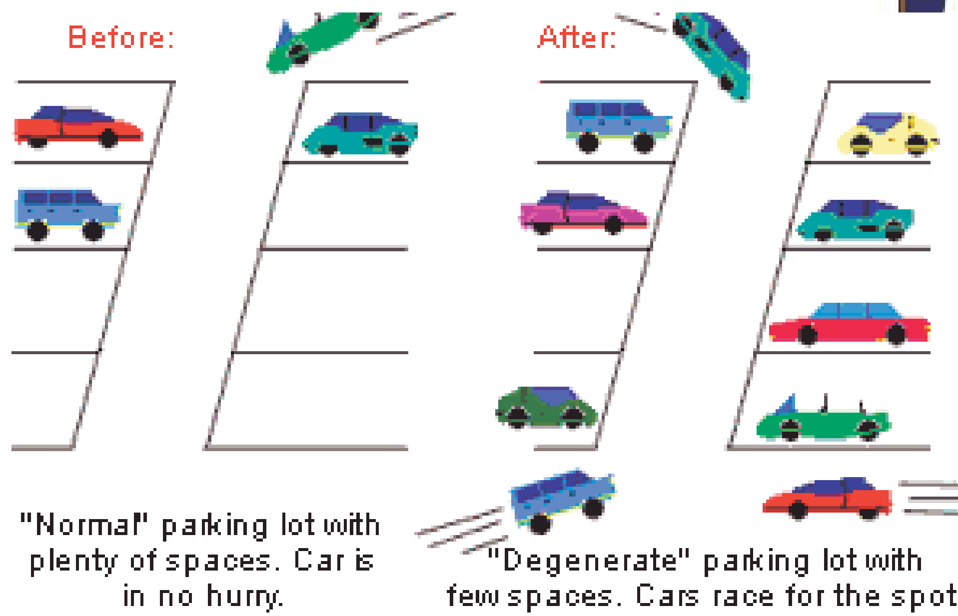
Electron Degeneracy

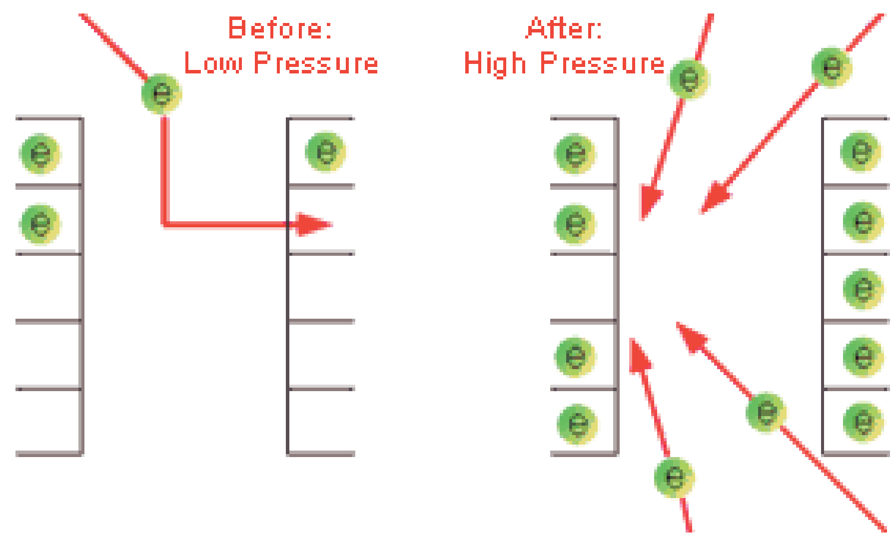
Matter in the core of a normal star

Electron-degenerate matter in a white dwarf
1 ton per cubic cm

Degeneracy Pressure

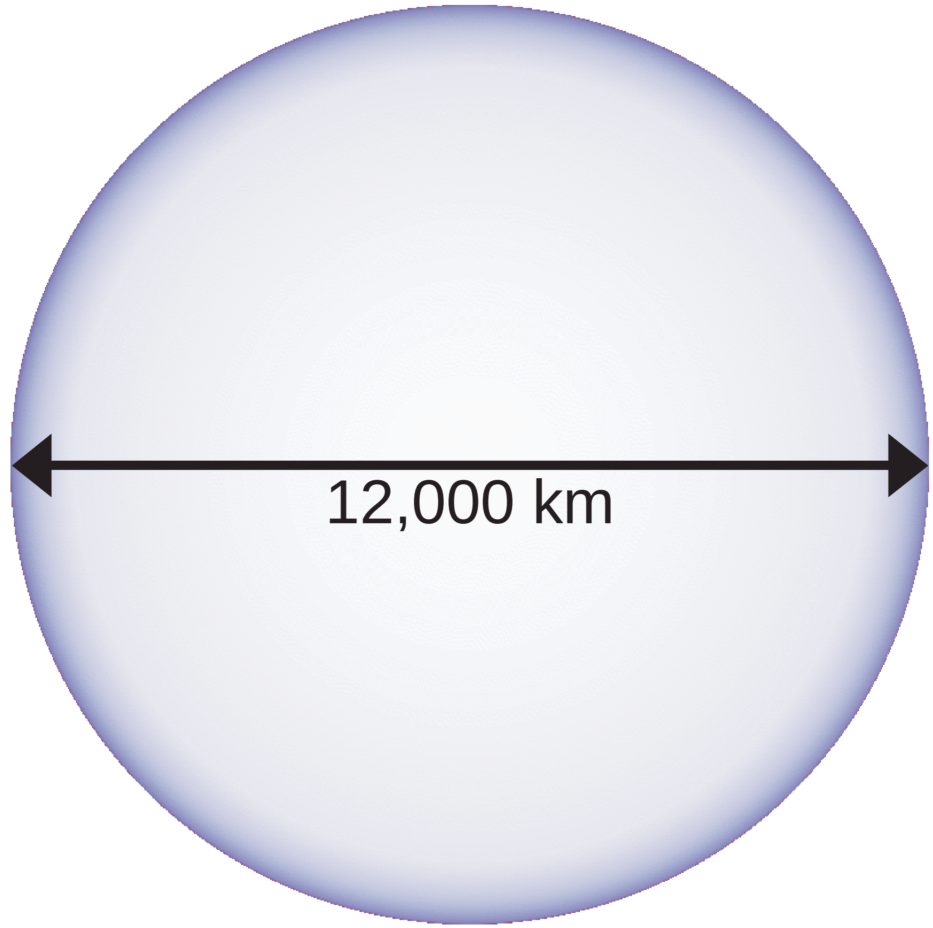
- Electrons are forced into higher energy levels than normal – all of the lower levels are taken
- Effect manifests itself as pressure





NASA

Relative Size of White Dwarf

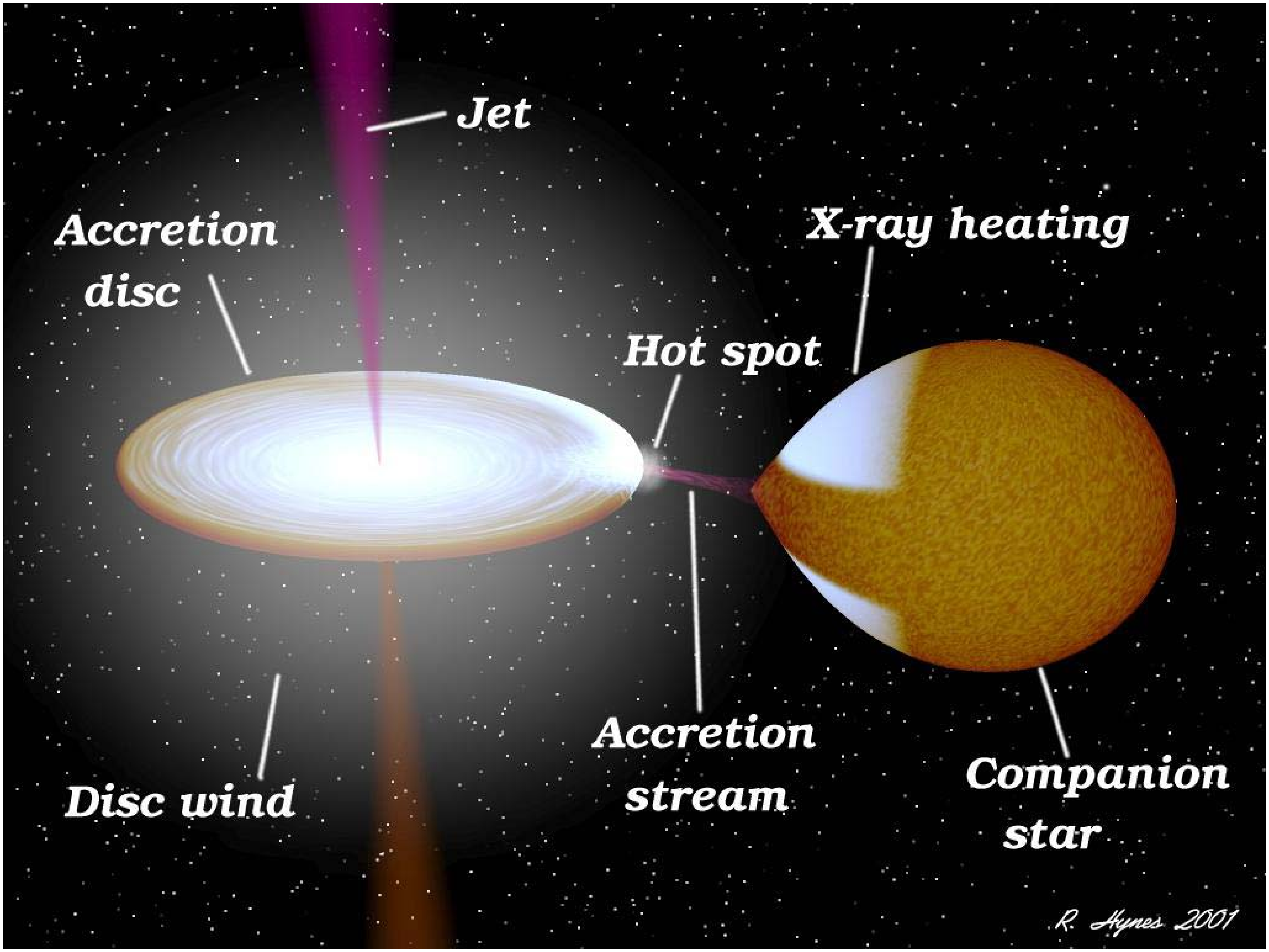


White dwarf– but will weigh about 0.7 Solar Masses

Binary Systems?

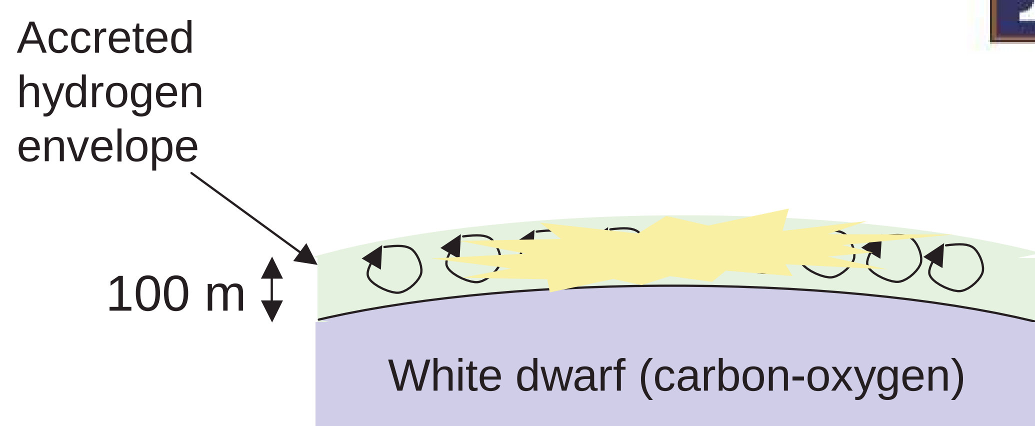
- In a close binary pair of stars with slightly different mass, the first higher mass low-mass stars evolves into a white dwarf.
- Then later on the other stars evolves into a red giant.
- What happens?

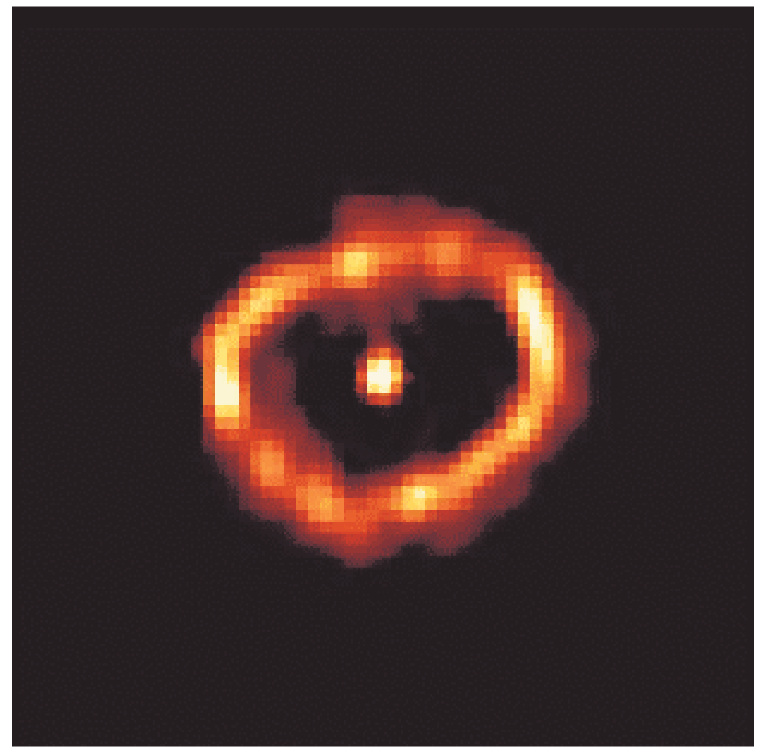
What Happens in Binary Systems?



Novae

- If enough material piles up onto the surface of a white dwarf, can undergo explosive nuclear fusion
- White dwarf blows off this **envelope** and brightens by 100x – 1000x over a period of days – weeks

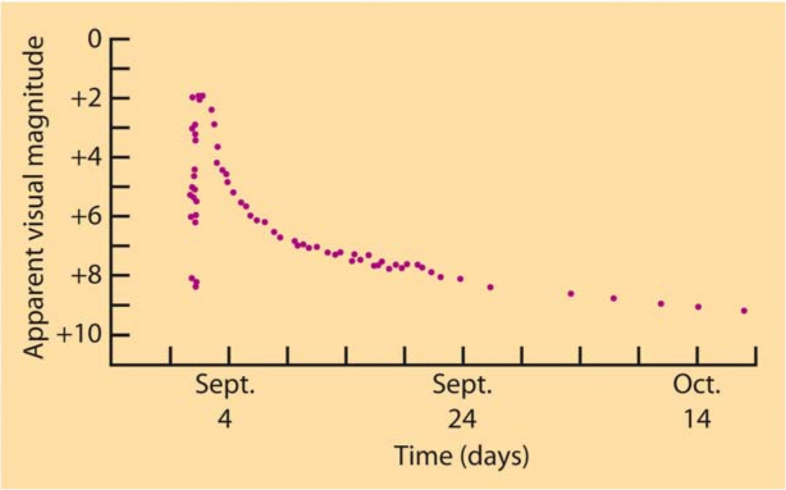


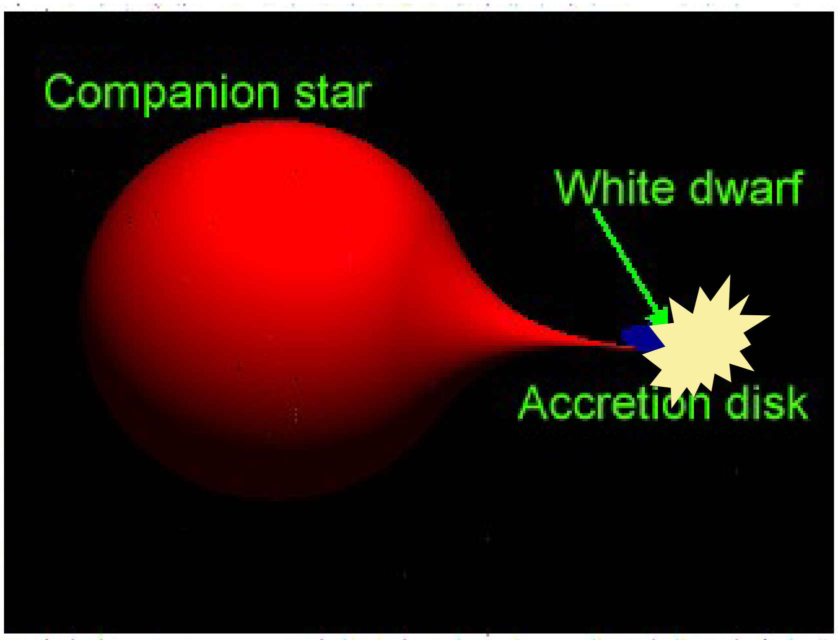


Nova Cygni 1992

Novae

- Process often repeats
- Novae are very common, about 20 in our galaxy a year.
- BUT, it is possible that the whole star can explode– causing a Type Ia Supernova– too much material exceeds the electron degeneracy (1.4 solar masses)





Stellar Evolution for Intermediate Stars: $4\ M_{Sun} < M < 8\ M_{Sun}$

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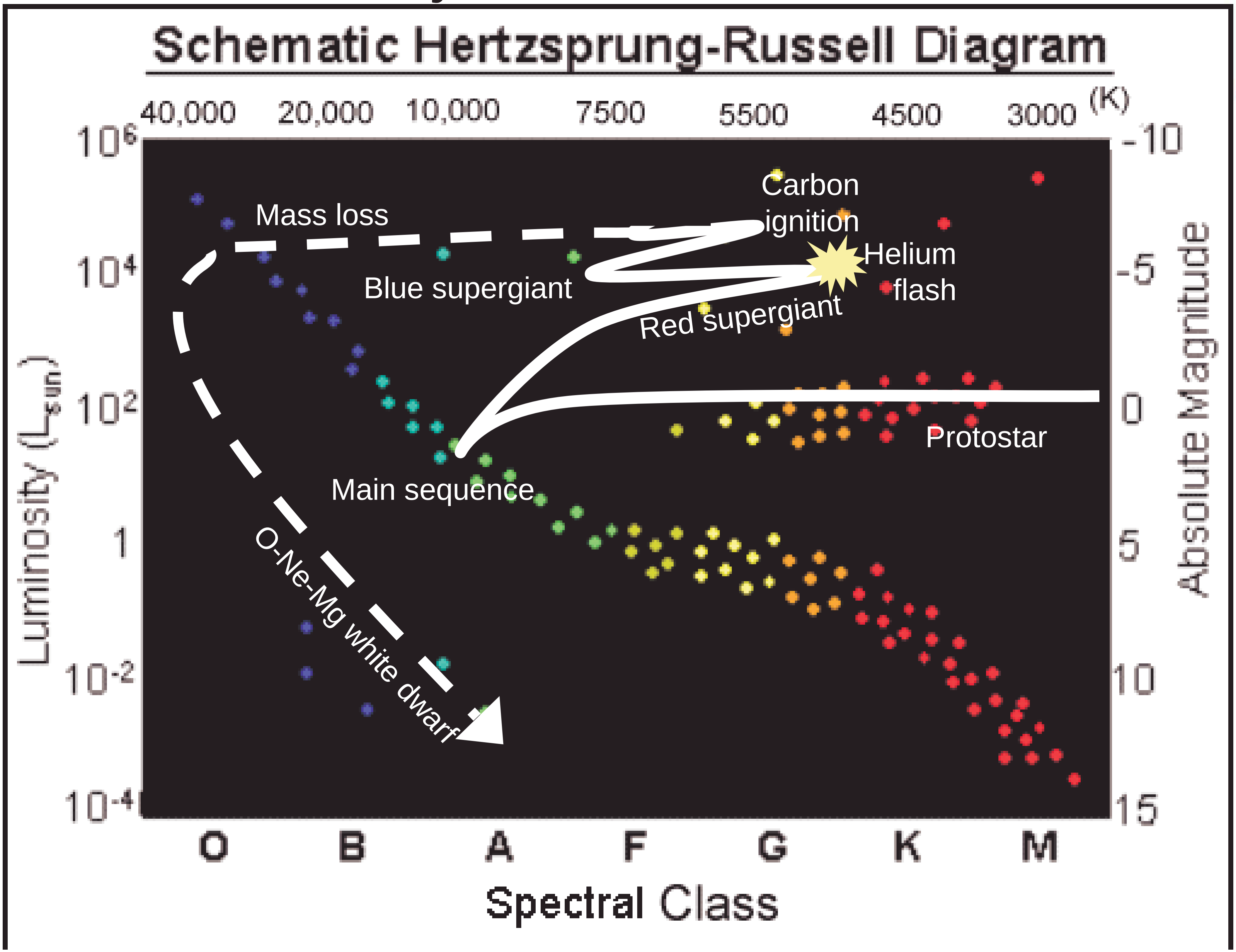
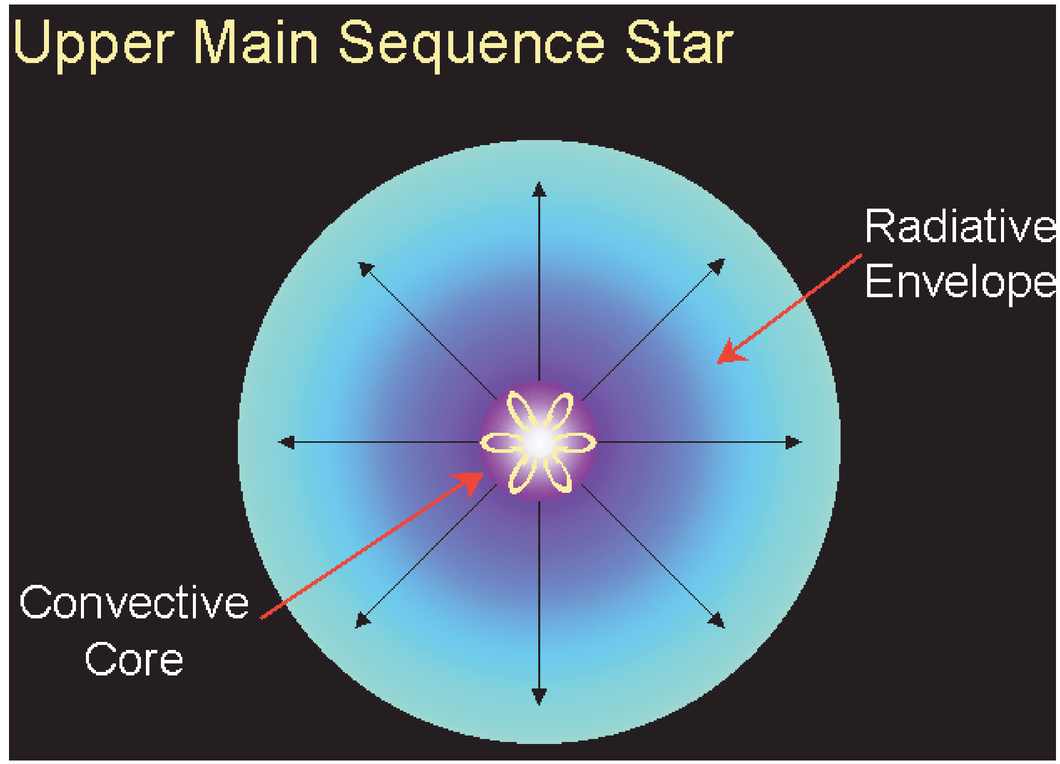
Example of how 8 stars 1 through 8 solar masses will evolve on the HR Diagram– http://rainman.astro.uiuc.edu/ddr/stellar/archive/onetoeighttrackson.mpg

Evolutionary Path for Intermediate Stars



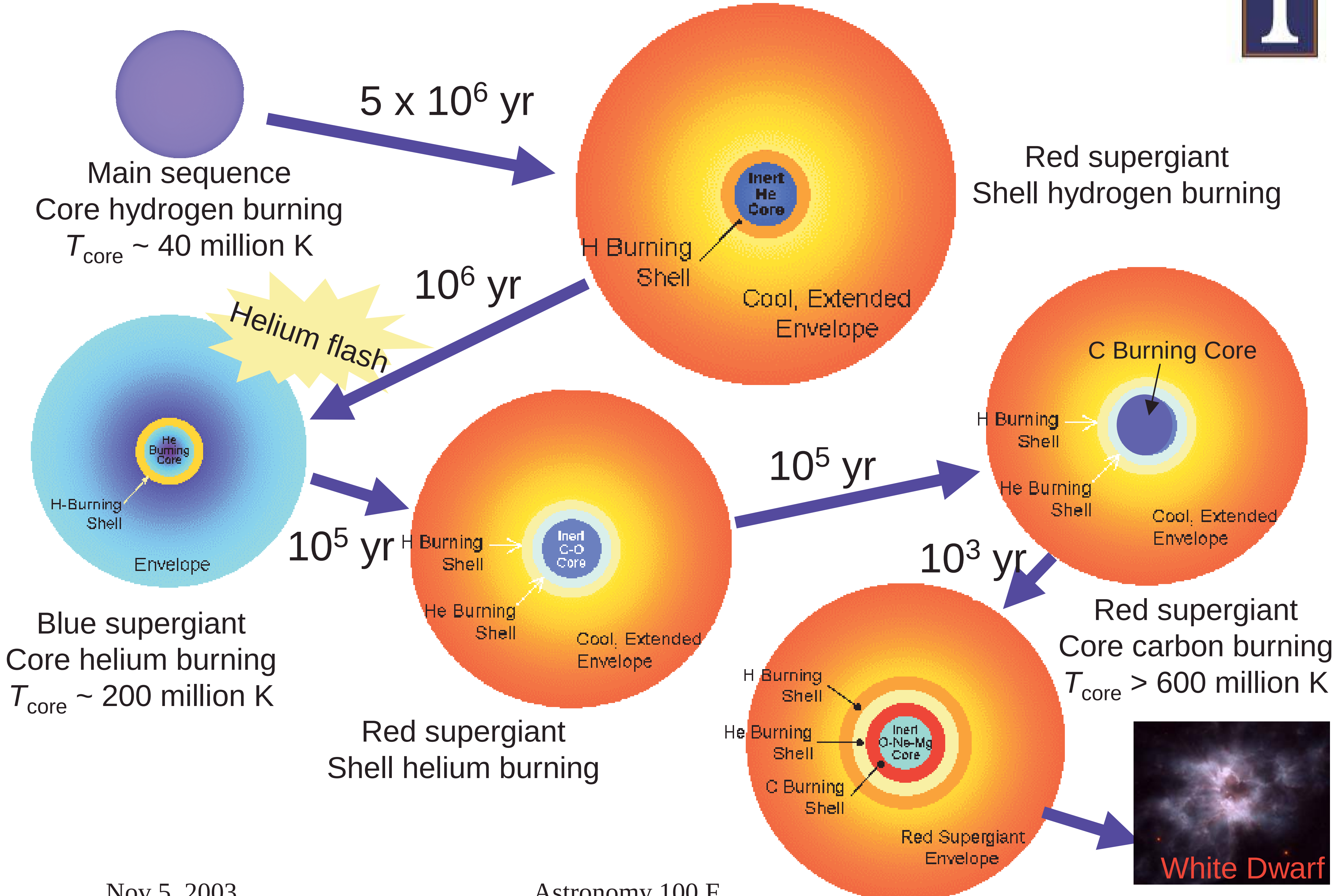
And when the Hydrogen Runs out?

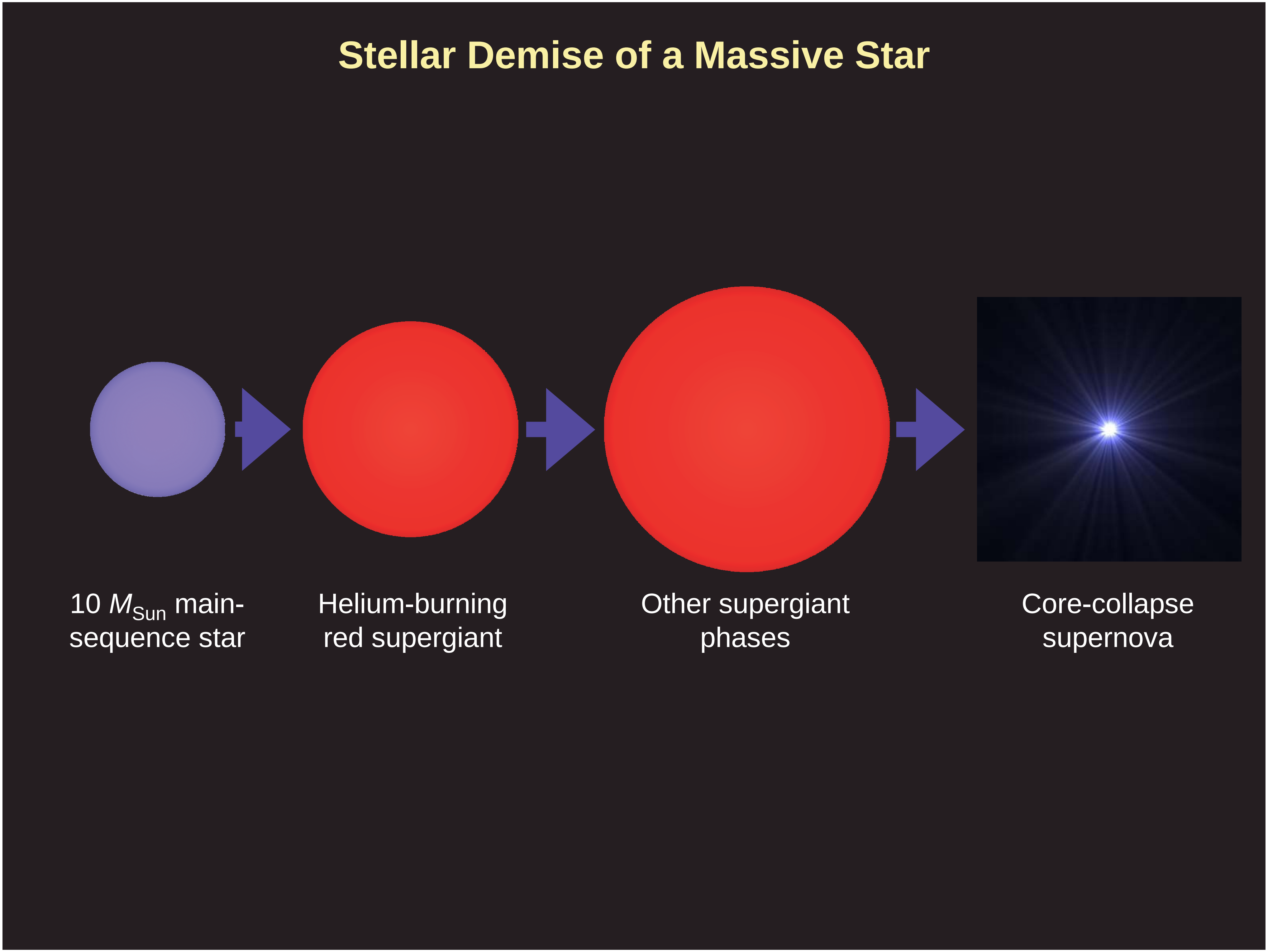
- The more massive stars have convective cores and radiative envelopes, but still very similar to low-mass in the first few stages.
- First the hydrogen is burned in the core– still not hot enough to burn helium
- Then the core starts to shrink a little– hydrogen shell burning (around the inert helium core) starts.
- This stops the collapse, and actually the outer envelope expands quickly becoming a Red Supergiant….but then…



http://www-astronomy.mps.ohio-state.edu/~pogge/Ast162/Unit2/LowerMS.gif

Evolution of an Intermediate-Mass (> 4 M_{Sun}) Star




Stellar Demise of a Massive Star
10 M_{Sun} main-sequence star
Helium-burning red supergiant
Other supergiant phases
Core-collapse supernova

Stellar Evolution for Massive Stars: $M > 8 M_{Sun}$

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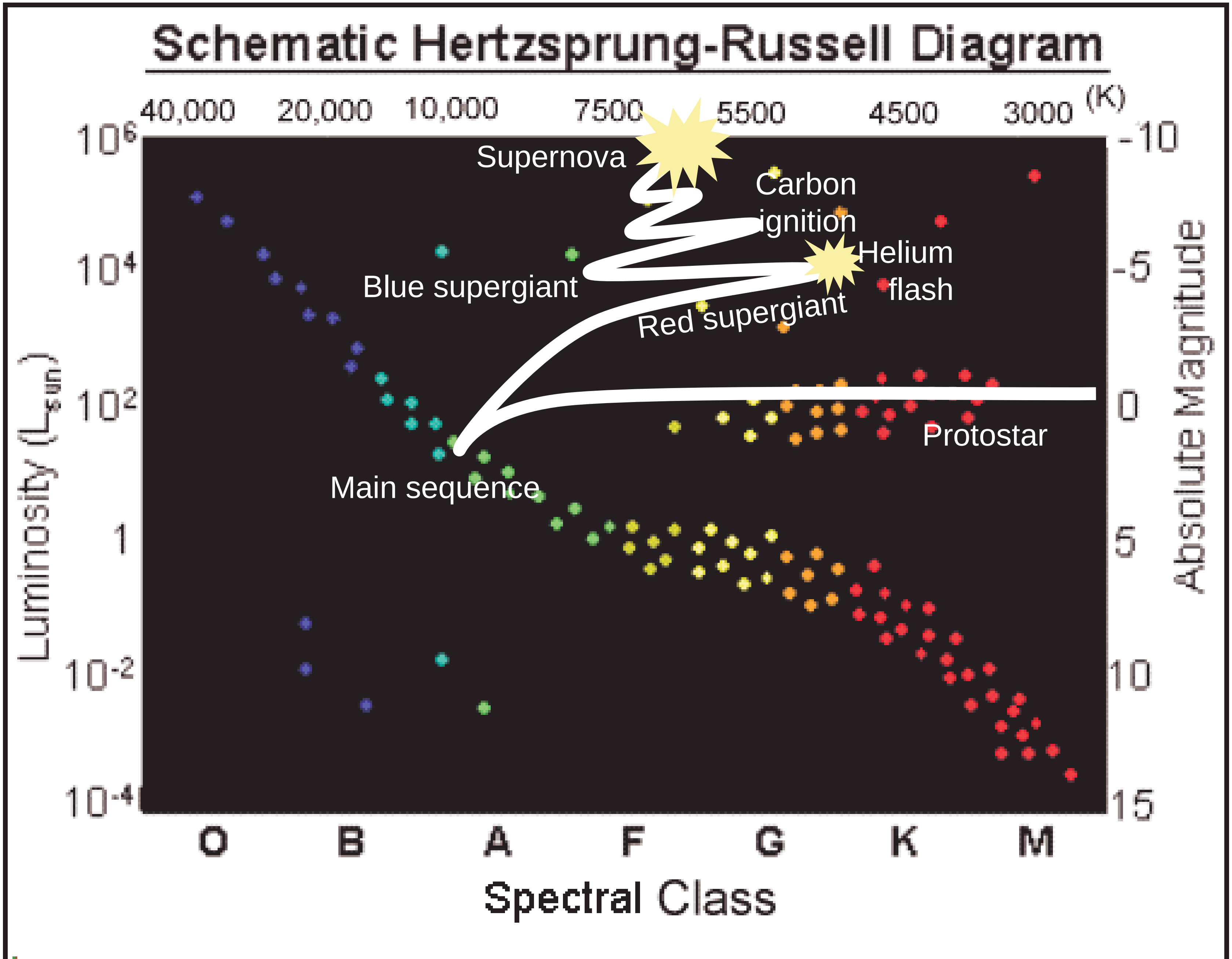
Example of how a 15 solar mass star will evolve on the HR Diagram– http://rainman.astro.uiuc.edu/ddr/stellar/archive/highmassdeath.mpg

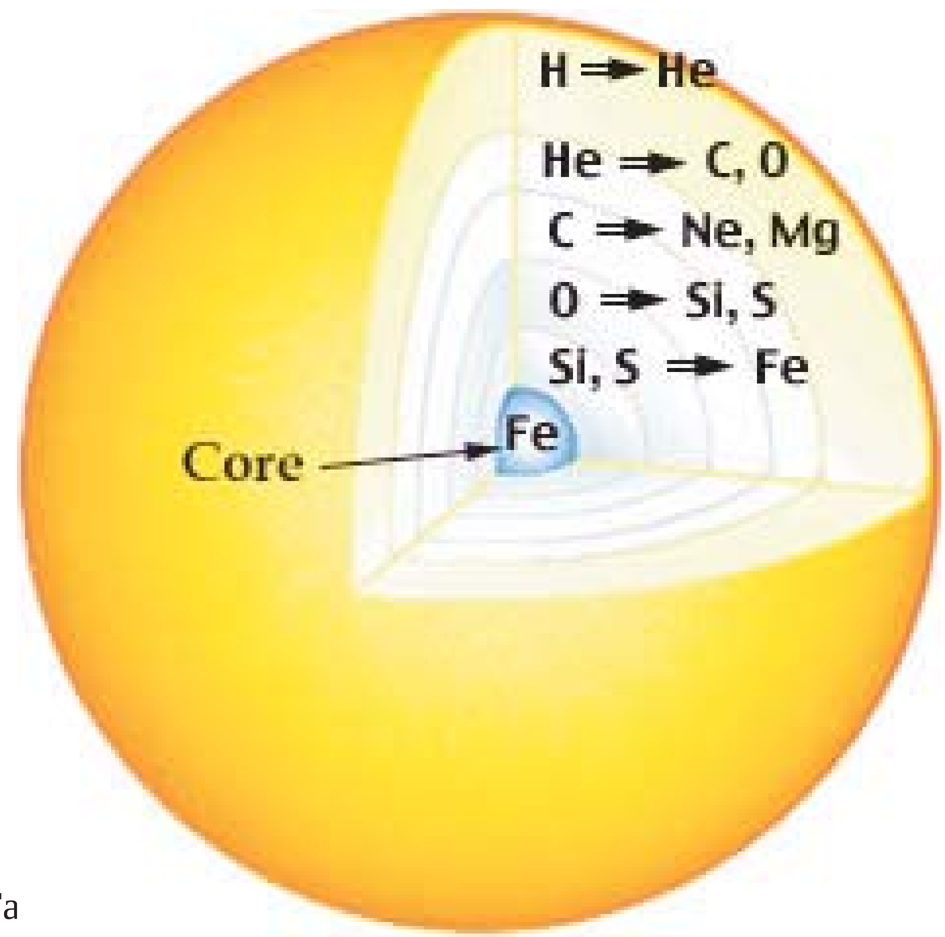
Evolutionary Path of High-Mass Stars



High Mass Stars

- These are very similar to the intermediate mass stars, but as they have more mass, they can “burn” heavier and heavier atoms in the fusion process.
- Until they create Iron– after that it takes energy to produce heavier atoms
- Nothing left!

Stage	Temperature (million K)	Duration
H fusion	40	7 million yr
He fusion	200	500,000 yr
C fusion	600	600 yr
Ne fusion	1,200	1 yr
O fusion	1,500	6 months
Si fusion	2,700	1 day



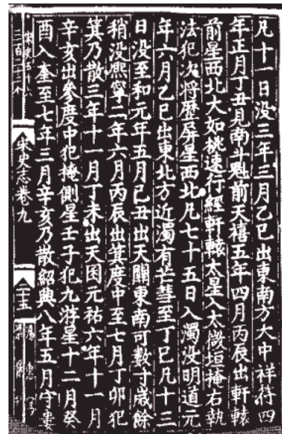
Game Over!

Supernova Explosions in Recorded History

1054 AD

- Europe: no record
- China: “guest star”
- Anasazi people

    Chaco Canyon, NM: painting


凡十一日没三年三月乙巳出東南方大中祥符四
年正月丁丑見南斗魁前天禧五年四月丙辰出軒轅
前星西北大如桃速行經軒轅大星入太微垣掩右執
法犯次將歷屛星西北凡七十五日入濁没明道元
年六月乙巳出東北方近濁有芒彗至丁巳凡十三
日没至和元年五月己丑出天關東南可數寸歲餘
稍没熙寧二年六月丙辰出箕度中至七月丁卯犯
箕乃散三年十一月丁未出天囷元祐六年十一月
辛亥出參度中犯掩側星壬子犯九游星十二月癸
酉入奎至七年三月辛亥乃散紹興八年五月守婁
宋史志卷九

Modern view of this region of the sky:

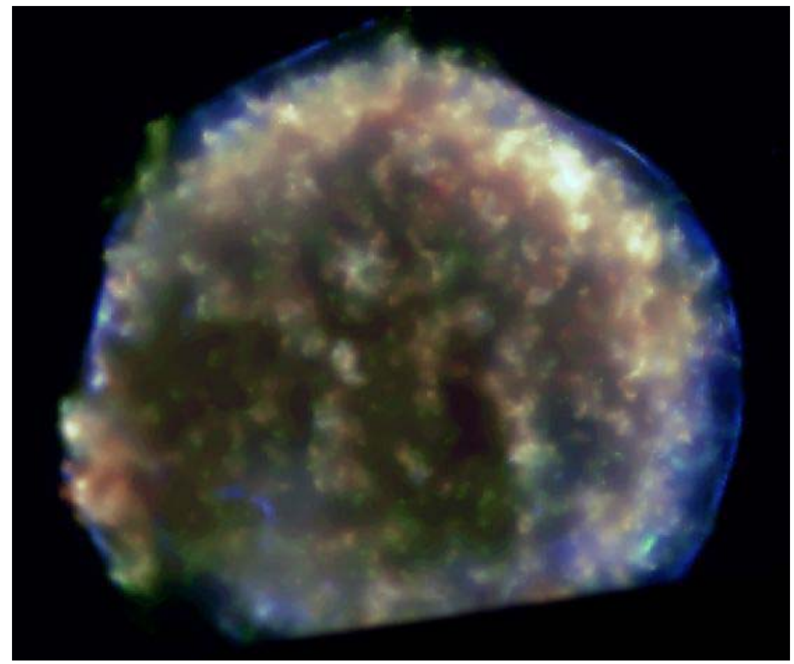
Crab Nebula—remains of a supernova explosion

Supernova Explosions in Recorded History

November 11, 1572

Tycho Brahe

A “new star”
(“nova stella”)



Modern view (X-rays):

remains of a supernova explosion

November 11, 1572
Tycho Brahe

On the 11th day of November in the evening after sunset ... I noticed that a new and unusual star, surpassing the other stars in brilliancy, was shining ... and since I had, from boyhood, known all the stars of the heavens perfectly, it was quite evident to me that there had never been any star in that place of the sky ...

I was so astonished of this sight ... A miracle indeed, one that has never been previously seen before our time, in any age since the beginning of the world.