

Exercises I

0. Repetition: Read Appendix A & B in P. Schneider/Extragalactic Astronomy

1. Two astrophysical objects at a distance of 7Mpc have an apparent V-band magnitude of $m_V = 8.4$ and 10.

- Which of them is brighter?
- Calculate their absolute magnitudes and luminosities (V-band).
- If the objects were four times as distant, what would be their apparent magnitudes?
- Imagine both objects are also observed in the U-band, with an apparent magnitude for both of $m_U = 13$, what are the U-V colors and which one is redder/bluer?

2. Assume you have an O5, a B5, and a G2 (like sun) MS star with solar metallicity.

- Place them qualitatively in the Hertzsprung Russel diagram. What are their masses, luminosities and temperatures? Which is the reddest and bluest star?
- Describe for each star what happens after leaving the MS, also physically inside the star, and what are possible end states. Draw typical evolutionary paths in the HR diagram and explain changes in Luminosity/Temperature.
- How would the evolutionary paths in the HR diagram qualitatively change, if the metallicity of each star was only 1/10 solar?

Solutions — Lecture I

1. Two astrophysical objects at a distance of 7Mpc have an apparent V-band magnitude of $m_V = 8.4$ and 10.

— Which of them is brighter?

Lower magnitudes signify a higher relative flux, meaning the object of $m_V = 8.4$ is brighter.

— Calculate their absolute magnitudes and luminosities (V-band).

Get the absolute magnitude from distance modulus (derived from setting inserting flux-luminosity relation with distance at 10pc) :

$$m_V - M_V = 5 \cdot \log_{10}(d) - 5 \Rightarrow M_V = m_V - 5 \cdot \log_{10}(d) + 5$$

$$\text{With } d = 7,000,000\text{pc} \Rightarrow M_V = -20.8 \text{ and } -19.2$$

— If the objects were four times as distant, what would be their apparent magnitudes?

$$\text{At distances } d = 28,000,000\text{pc} \Rightarrow M_V = -23.8 \text{ and } -22.2$$

— Imagine both objects are also observed in the U-band, with an apparent magnitude for both of $m_U = 13$, what are the U-V colors and which one is redder/bluer?

The U-band covers smaller wavelengths than the V-band, meaning the bluer part of the spectrum. The smaller the V magnitude is with respect to the U magnitude (meaning much greater fluxes), the redder the object is.

$$1. U-V = 13 - 8.4 = 4.6\text{mag (redder)}$$

$$2. U-V = 13 - 10 = 3\text{mag (bluer)}$$

Solutions — Lecture I

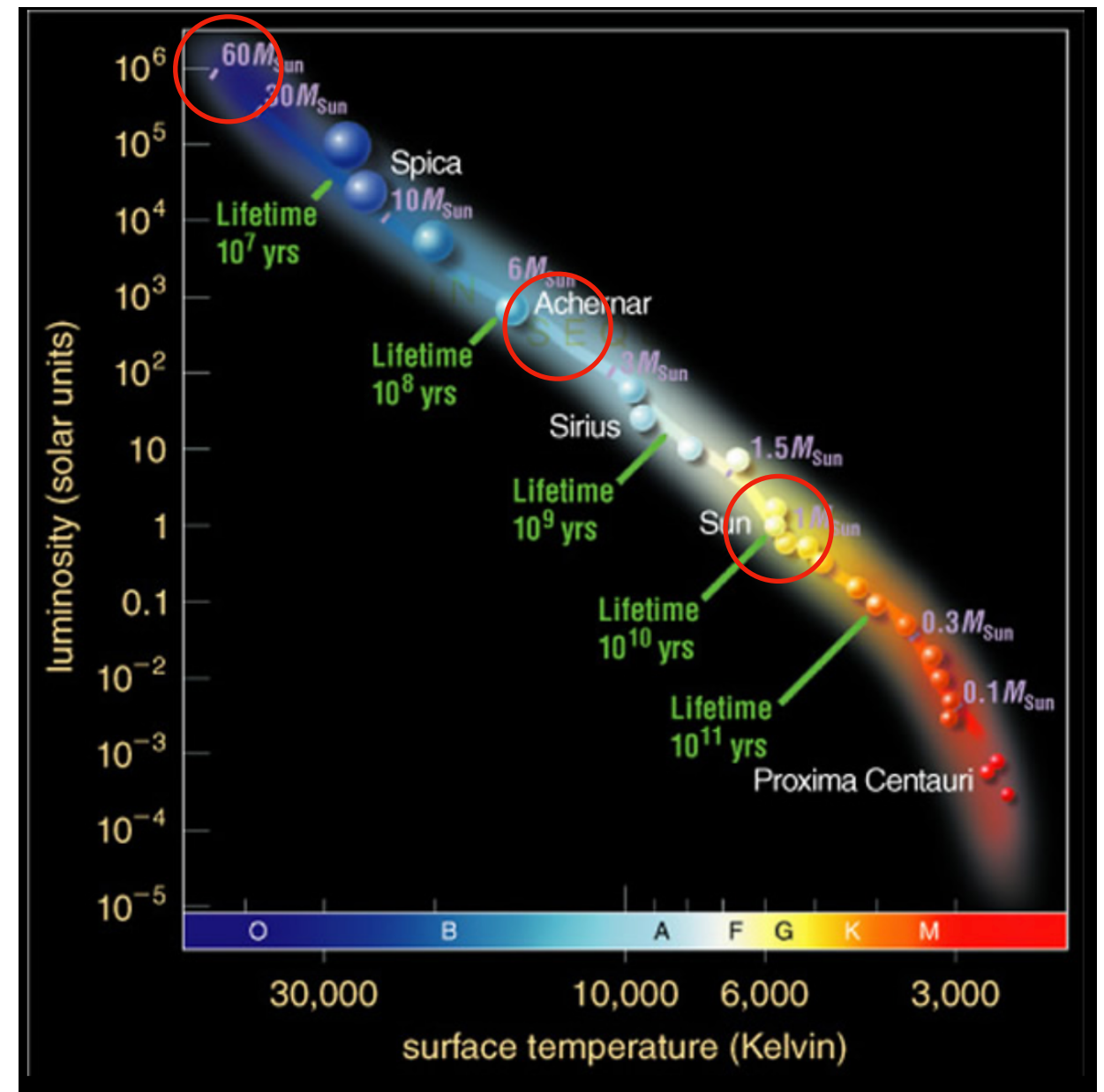
2. Place the stars on the HR-diagramm and find the mass, luminosity, temperature and colour.

From bluest to reddest:

O5: 60 M_{sun} , 790,000 L_{sun} , 45000K, blue

B5: 5 M_{sun} , 600 L_{sun} , 15000K, blue-white

G2: 1 M_{sun} (2e30kg), 1 L_{sun} (3.8e26W) , 5700K, yellow

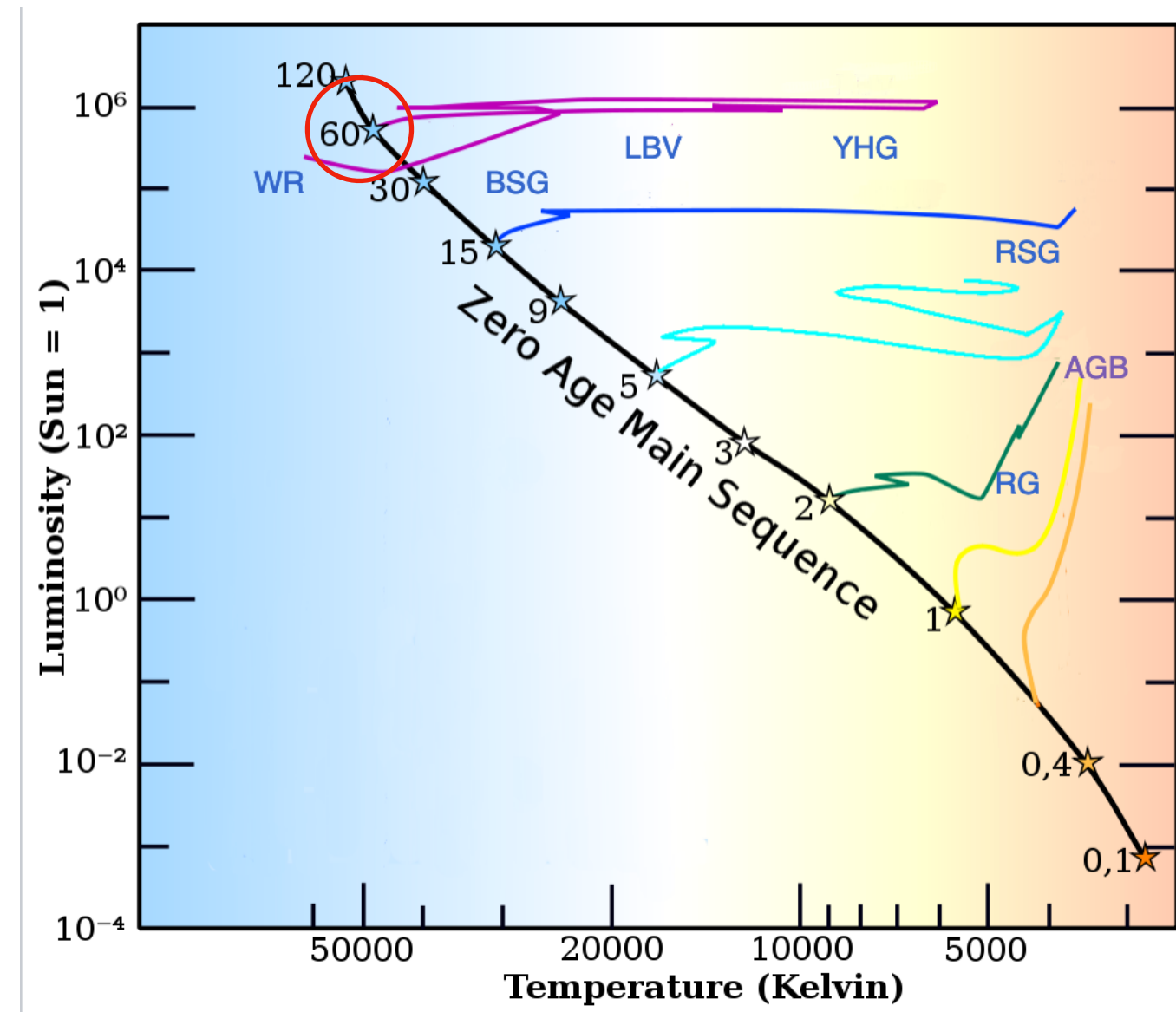


Solutions — Lecture I

What happens after leaving the MS, also physically inside the star, and what are possible end states. Draw typical evolutionary paths in the HR diagram and explain changes in Luminosity/Temperature.

O5 star

On the MS, O5 stars burn hydrogen in their cores via the CNO cycle for several million years. When an O5 star exhausts the hydrogen in its core, nuclear reactions slow down, leading to a contraction of the core (due less support against gravity via radiation pressure) and an expansion of the outer envelope (**H shell burning?**). The star becomes a blue super giant. During this phase, they evolve horizontally on HRD to cooler T, staying at roughly the same luminosity. Then, helium core burning will ignite (**due to H ashes raining on the core**). Depending on the exact mass of the star and other initial conditions, the star could turn into a blue hypergiant, luminous blue variable or a yellow hypergiant. In these phases they can shed their outer layers and heat up again, moving back horizontally towards higher temperatures. The most massive stars ($>60M_{\text{sun}}$) will end up in a Wolf Rayet star, which produce strong stellar winds, before exploding in a violent supernova and leaving behind a neutron star or black hole.

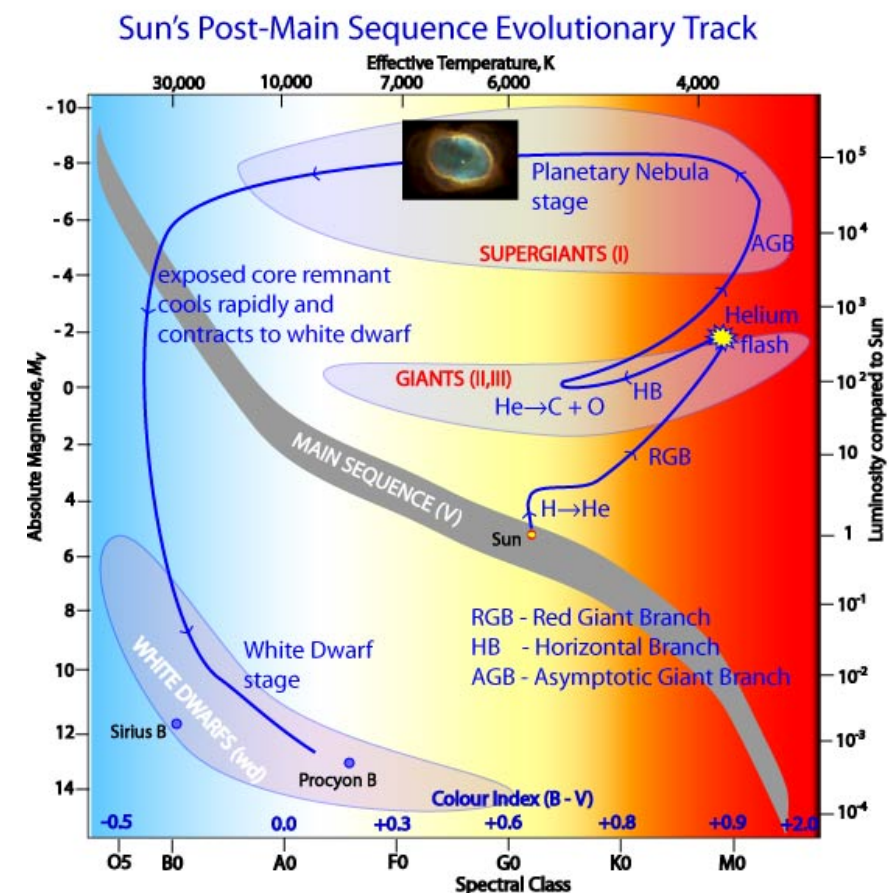
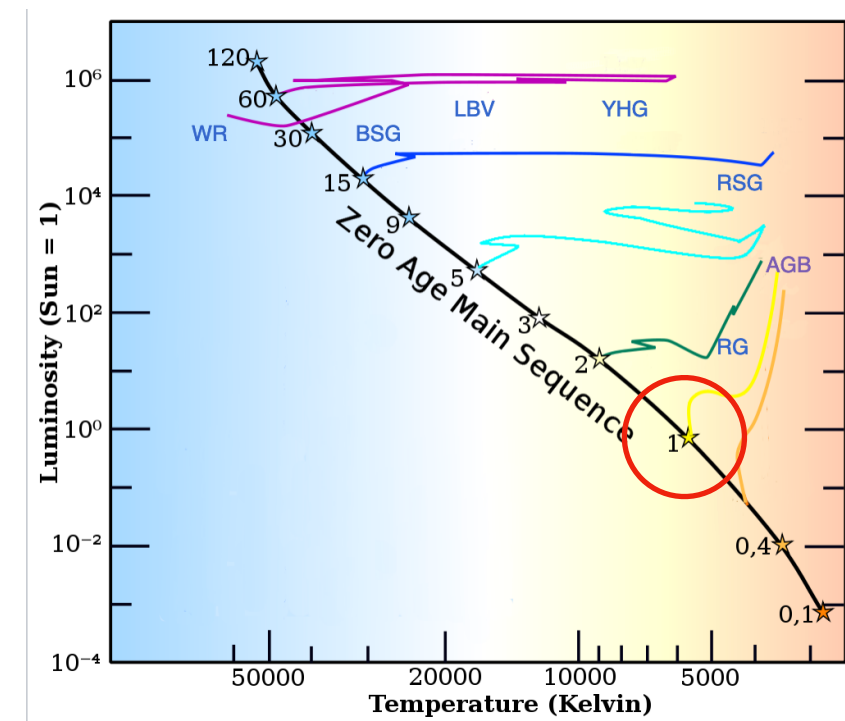


Solutions — Lecture 1

What happens after leaving the MS, also physically inside the star, and what are possible end states. Draw typical evolutionary paths in the HR diagram and explain changes in Luminosity/Temperature.

G2 star

A G2 star also evolves away from the main sequence as its core hydrogen supply (via pp chain) is gradually depleted. As the core contracts and temperature increases, the star expands slightly and becomes a subgiant. During this phase, the luminosity increases, and the star moves upward on the Hertzsprung-Russell diagram. With further core contraction and expansion of the outer envelope, the star transitions into the red giant phase. During this phase, the star becomes significantly larger and more luminous, while its surface temperature decreases. Hydrogen shell burning around the core commences and the star heats further. Once the RG has reached the necessary temperature, Helium burning begins with the unobservable Helium flash, fusing Helium into Carbon and oxygen via the triple-alpha process. The star then enters the horizontal branch, where it stays around the same luminosity. Low metallicity stars will heat up and become bluer, while solar metallicity stars stay around the same colour, called the red clump on the HRD. Instead, it just becomes moderately larger and more luminous over about 100 million years as it continues to react helium in the core. When the helium is exhausted, the star will repeat the expansion it followed when the hydrogen in the core was exhausted. This is the asymptotic-giant-branch (AGB) phase, and the star is alternately reacting hydrogen in a shell or helium in a deeper shell. These are called thermal pulses, and cause rapid mass loss. They end their evolution in this stage, expelling and ionising their outer layers to form a planetary nebula. The core left behind contracts into a white dwarf.

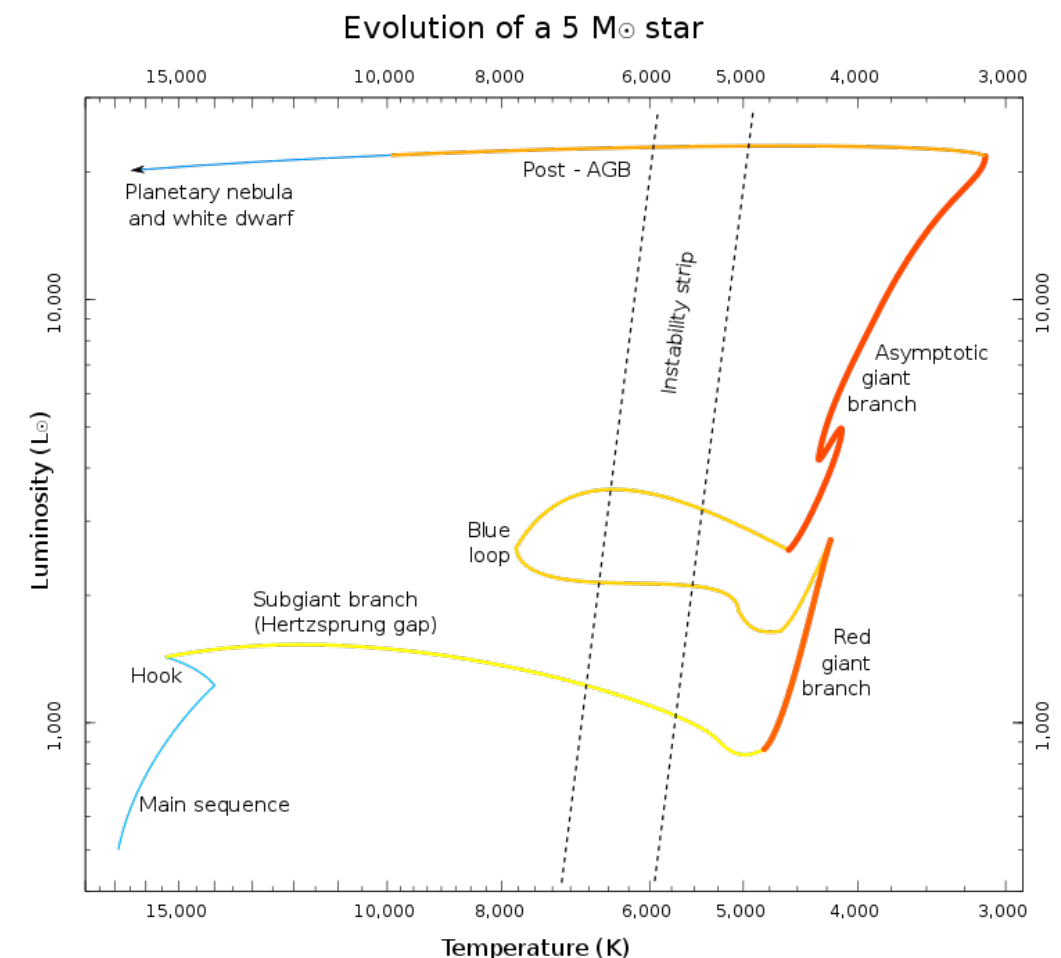
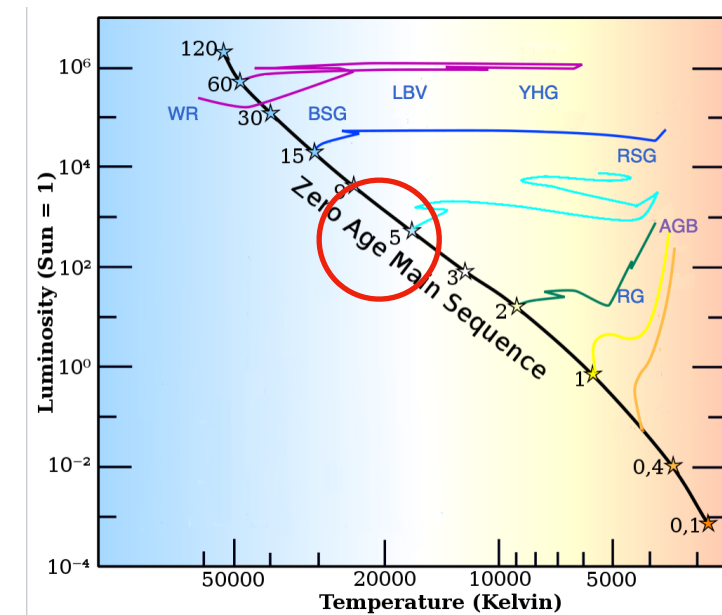


Solutions — Lecture I

What happens after leaving the MS, also physically inside the star, and what are possible end states. Draw typical evolutionary paths in the HR diagram and explain changes in Luminosity/Temperature.

B5 star

Similar, to the other stars, when a B5 star exhausts the hydrogen in its core (CNO cycle) it leads to core contraction and expansion and cooling of the outer envelope. The star becomes a subgiant and moves rapidly across the long track, cooling and changing colour in the process. It then enters the red giant phase, increases in luminosity and quickly starts burning Helium into Carbon and Oxygen. Since the core is not degenerate, there is no flash. In this phase the star undergoes a blue loop, where the temperature rises and then decreases again, while staying roughly at the same luminosity. Like the G2 star, the star then becomes an AGB star and eventually a white dwarf with a planetary nebula.



Solutions — Lecture I

With lower metallicity, we in general expect the resulting paths to produce higher luminosities, bluer colour/larger temperatures (for reason see lecture notes).

