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ILT 1 WEEKS 5–6 PART II

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1. TASK A

The CMD submitted in the previous fortnight shows members of NGC 4755 – an open cluster in Crux. The stars were selected in the SIMBAD database as they all belong to the cluster - all at more or less the same distance, and this simplifies working with apparent magnitudes that are available in the database. Hence, a CMD plot can be constructed with valid color-magnitude relationship without resorting to measuring distance to each star. The CMD submitted in the previous fortnight has V plotted against $(B-V)$, that is apparent V-band mangitude against the color index of a star. Because the SIMBAD data available on NGC 4755 is scarce and does not go deep in magnitude, its fewer than 200 stars plotted make it rather difficult to identify any distinct evolutionary branches. For my assistance interpreting the CMD, I have plotted the same data, however using absolute magnitudes M_V assuming 3,435 pc distance to the cluster (Pandey et al. 2010), and fitted ZAMS calibration curve data (Williams 2003; Pal 2005) over it, shown in red - please see figure 1. The $(B-V)_0$ color index has been corrected for interstellar reddening using $E(B-V) = 0.41$ value (Feast 1963), subtracted from the magnitudes obtained from the database, although it is noted the reddening varies over the cluster region (Sagar 1987). My understanding of this limited sample is that most of the stars have finished arriving on the main sequence in this cluster. Within some time, the most massive and luminous stars in the upper-left corner of the CMD will start to leave the MS and will become red giants. I would say this selection of stars is not enough to assess the age of the cluster with certainty.

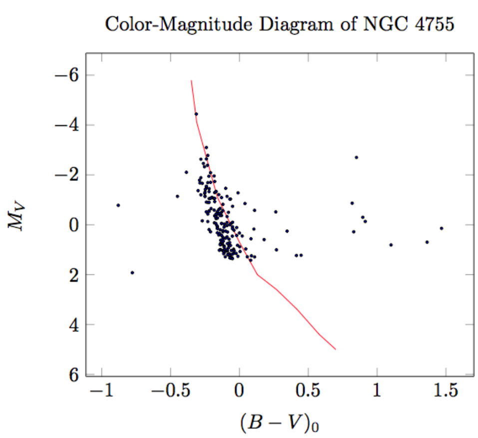

Figure 1. An updated version of the color-magnitude diagram for NGC 4755 showing absolute magnitudes and corrected color indices for stars. ZAMS calibration curve is in red.

Table 1
Selected pair of stars in NGC 4755

Name	Class	M_V	$(B-V)_0$
HD 312079	B1.5V	-3.1	-0.24
Cl* NGC 4755 SBW 304	–	1.422	-0.082

Note. — Spectrometry is unavailable for Cl* NGC 4755 SBW 304, however it fits the main sequence curve.

2. TASK B

Members of cluster were manually selected for the exercises below - see table 1. Cepheid variables were omitted despite some are classified as main sequence in SIMBAD. Because of different processes occurring in stars of varying mass, star masses should be estimated first in order to find the correct coefficients for the estimation of zero-age main sequence luminosities L_{ZAMS}.

We begin with the luminosity-mass relationship for main sequence stars (Freedman et al. 2014):

$$\frac{L}{L_\odot} \sim \left(\frac{\mathfrak{M}}{\mathfrak{M}_\odot}\right)^{3.5} \tag{1}$$

Where luminosity relation can also be defined via bolometric magnitudes (Sparke & Gallagher, III 2007):

$$\frac{L}{L_\odot} = 10^{((M_{bol,\odot} - M_{bol})/2.5)} \tag{2}$$

Using the bolometric correction BC=0.07 for the Sun and its known absolute magnitude $M_\odot$, we find it's bolometric magnitude $M_{bol,\odot}$:

$$M_{bol,\odot} = M_\odot - BC = 4.83 - 0.07 = 4.76 \tag{3}$$

For the stars, we first need to estimate bolometric correction based on their surface temperatures T. For this, we introduce conversion from the known $(B-V)_0$ to T (Ballesteros 2012):

$$T = 4600\left(\frac{1}{0.92(B-V)_0 + 1.7} + \frac{1}{0.92(B-V)_0 + 0.62}\right) \tag{4}$$

And to convert temperature to BC via empirical fit (Reed 1998):

$$BC = -8.499[log(T) - 4]^4 + 13.421[log(T) - 4]^3$$
$$-8.131[log(T) - 4]^2 - 3.901[log(T) - 4] - 0.438 \tag{5}$$

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Table 2
Intermediary calculations

Name	T, K	BC	M_{bol}	$L/L_{\odot}$
HD 312079	14633	-1.25	-1.85	440
Cl* NGC 4755 SBW 304	11279	-0.66	2.08	12

Table 3
Results

Name	$\mathfrak{M}/\mathfrak{M}_{\odot}$	L_{ZAMS}	τ_{MS}, Gyr
HD 312079	5.69	783	0.073
Cl* NGC 4755 SBW 304	2.02	21	0.966

We then adapt equation 3 to find bolometric magnitudes for our chosen pair of stars. Using the results with the equation 2, we estimate $L/L_{\odot}$ for these stars. Findings are provided in table 2.

Inverting the mass-luminosity relationship described in equation 1, we estimate star masses as following:

$$\frac{\mathfrak{M}}{\mathfrak{M}_{\odot}} \sim \left(\frac{L}{L_{\odot}}\right)^{1/3.5} \tag{6}$$

For both of our stars, masses lie within the $2 - 20\mathfrak{M}_{\odot}$ range, thus we use the following equation to find their ZAMS luminosities:

$$L_{ZAMS} = 1.78\mathfrak{M}^{3.5} \tag{7}$$

Since $\mathfrak{M}_{\odot}$ is unity, we can substitute $\mathfrak{M}$ from equation 6. This gives a simple equation for stars within the mass range described above:

$$L_{ZAMS} \sim 1.78L \tag{8}$$

And for the time staying on main sequence, as per the course material:

$$\tau_{MS} \sim \frac{10\mathfrak{M}}{L} Gyr \tag{9}$$

Similarly as above, with $L_{\odot} = 1$, we use the now known $L/L_{\odot}$ value with equation 9. Final results are provided in table 3. The more massive HD 312079 star will spend ∼13 times less amount of time on the main sequence, if compared to the other star, because of its denser core that features faster nuclear burning. Both stars, however, become less luminous as they exist on the main sequence, if compared to the moment when they have joined it. I cannot explain this phenomenon as described by equation 8 with full certainty, however I found mention of high-mass stars may still undergo accretion when they reach ZAMS (Pols 2011), and, perhaps, this explains their increased ZAMS luminosities found here. Both stars are likely to become giant stars as they leave the main sequence, then red supergiants, moving to the upper-right section of the H-R diagram, then undergo planetary nebulae stage and, finally, settle as white dwarfs at the end of their evolution tracks.

This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

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