Individual task #1
(Topics 2 & 4)

Age of the Milky Way from the colour-magnitude diagram of the globular cluster NGC 3201

A **cluster of stars** consists of objects that were formed at the same time in the same gaseous environment (see the end of **Topic 2** and **Topic 4**). Thus, we *initially* consider *a distribution of MS stars having a range of masses and equal metallicity*

OPEN CLUSTERS IN THE MILKY WAY

DSS – NASA/ESA/AURA/Caltech

Cluster	$Z/Z_{\odot}$	age (Gyr)
Pleiades	1.0	0.125
NGC 6705	1.38	0.25
Hyades	1.38	0.625
NGC 7789	0.55	1.5
M67	0.89	4

The cluster is observed at present days, so its *age also plays a role*!

As time goes on, the initial MS stars evolve into RGB, AGB, WD, etc, and the distribution of luminosities and effective temperatures in a L-T_{eff} diagram (or **colour-magnitude diagram ≡ CMD**) depends on its initial metallicity and age (see Table). The values in the Table are representative of real open clusters in the Milky Way (see **Topic 4**)

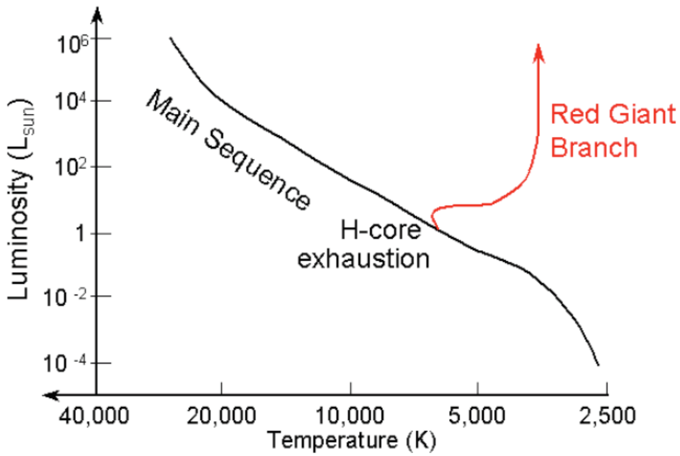
Lifetime vs initial mass

Higher initial mass ⇒ hotter on the main sequence and more short lived

Main sequence lifetime (at solar metallicity) :

These are in the MS in the Pleiades

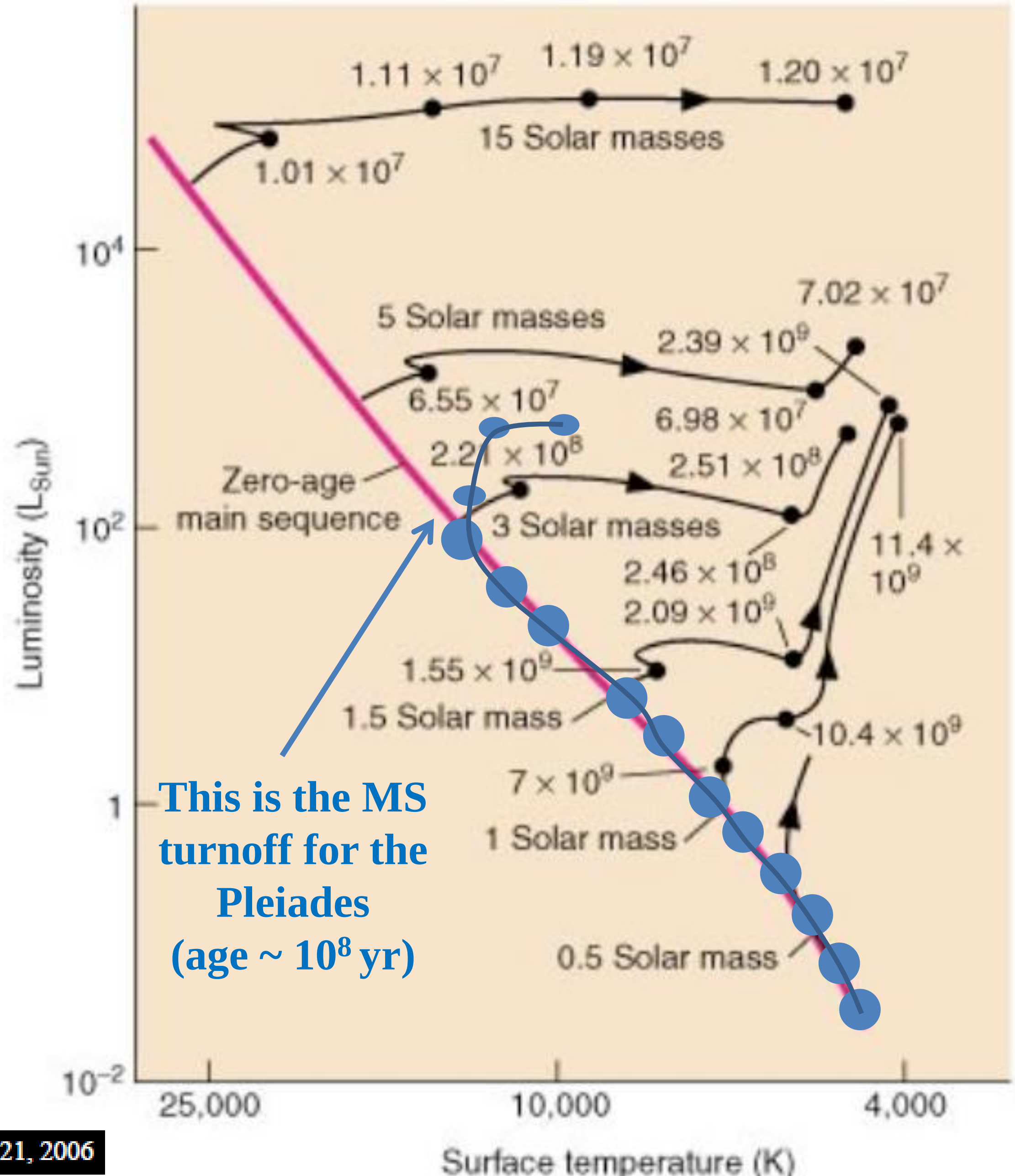
star mass (solar masses)	time (years)	Spectral type
60	3 million	O3
30	11 million	O7
10	32 million	B4
3	370 million	A5
1.5	3 billion	F5
1	10 billion	G2 (Sun)
0.1	1000's billions	M7



Time to reach the red giant stage

short for big stars
→ as low as 10 million (10^7) years

long for little stars
→ up to 10 billion (10^{10}) years for low mass



C. Charbonnel. NIC IX summer school. CERN. June 21, 2006

TWO GLOBULAR CLUSTERS IN THE MILKY WAY

47 Tuc

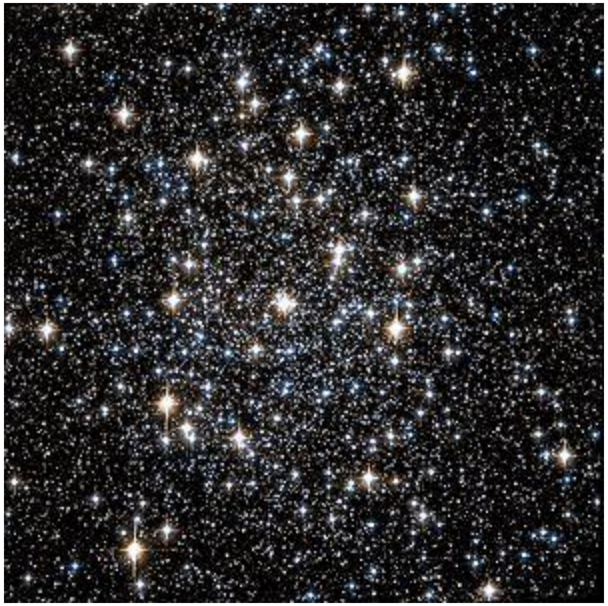
Z = 0.004 , age = 12 Gyr

M92

Z = 0.00014 , age = 13 Gyr

We focus on the globular cluster (GC) **NGC 3201**

NGC 3201 (Wikipedia)



NGC 3201 by *HST*
(credit: NASA/STScI/WikiSky)

Constellation	Vela
Right ascension (RA)	$10^h\ 17^m\ 36.82^s$
Declination (Dec)	–46° 24′ 44.9″
Distance	16.3 kly (5.0 kpc)
Apparent magnitude (V)	+8.24
Physical characteristics	
Mass	$2.54\times10^5\ M_\odot$
Radius	40 ly
Metallicity	$[Fe / H] = \log (Z/Z_\odot) = -1.24$ dex
Estimated age	10.24 Gyr

1 – DATA THAT WE WIILL USE

THE ASTRONOMICAL JOURNAL, 125:208–223, 2003 January

PHOTOMETRY OF THE GLOBULAR CLUSTER NGC 3201 AND ITS VARIABLE STARS

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TABLE 2

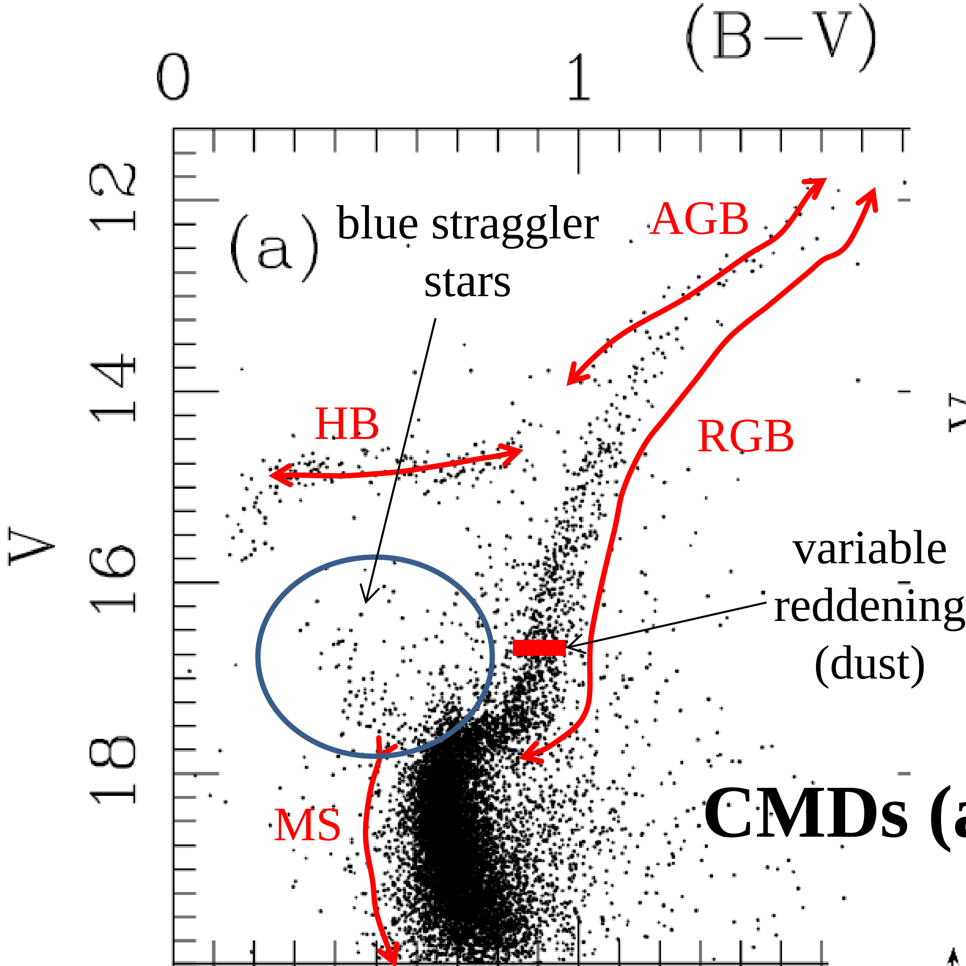
CMD.dat #10,944 stars

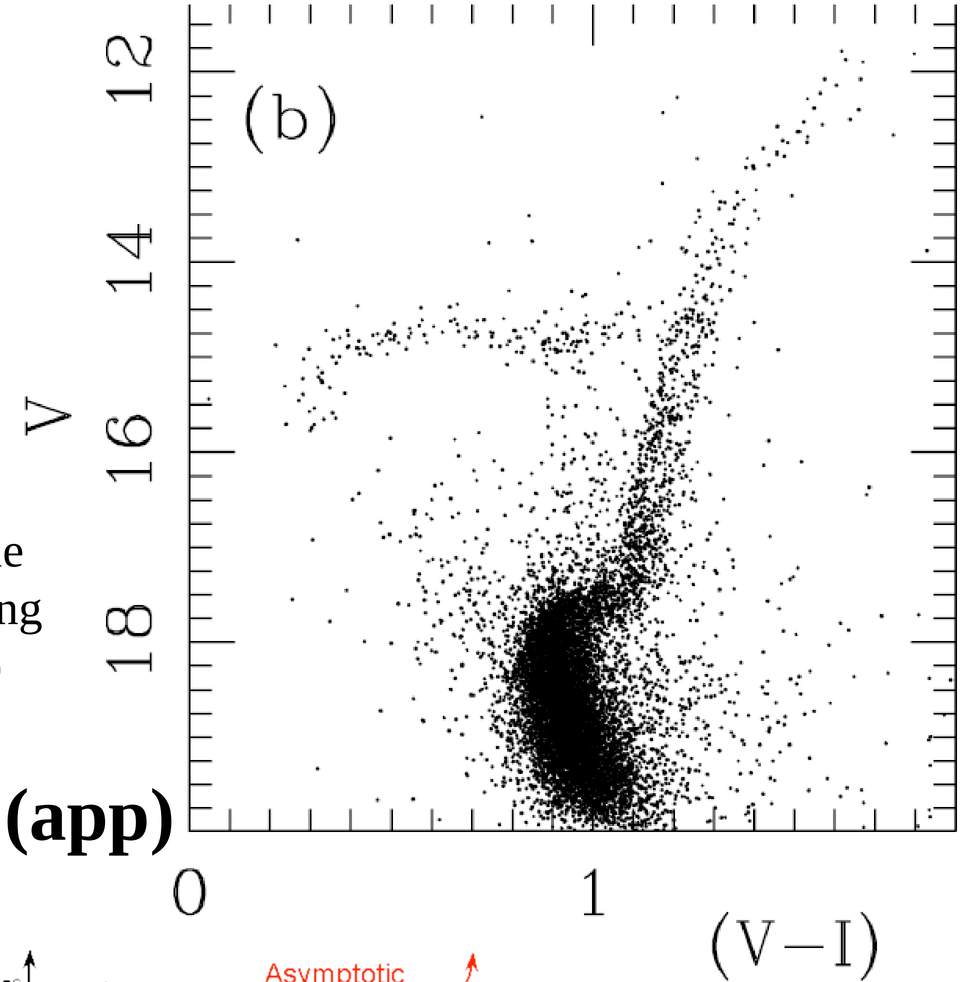
PHOTOMETRY OF NGC 3201 STARS

ID	X_{pix}	Y_{pix}	V	σ_V	B	σ_B	I	σ_I	χ	Σ
1	736.86	1268.73	11.781	0.001	13.352	0.001	10.164	0.001	1.269	−0.065
2	813.82	1175.30	11.812	0.001	13.617	0.001	10.015	0.001	1.346	−0.084
3	798.89	740.11	11.868	0.001	13.433	0.001	10.242	0.001	1.512	−0.152
4	271.33	984.05	11.895	0.001	13.536	0.001	10.226	0.001	1.091	−0.071
5	980.47	1509.81	12.072	0.001	13.607	0.001	10.497	0.001	1.177	−0.047

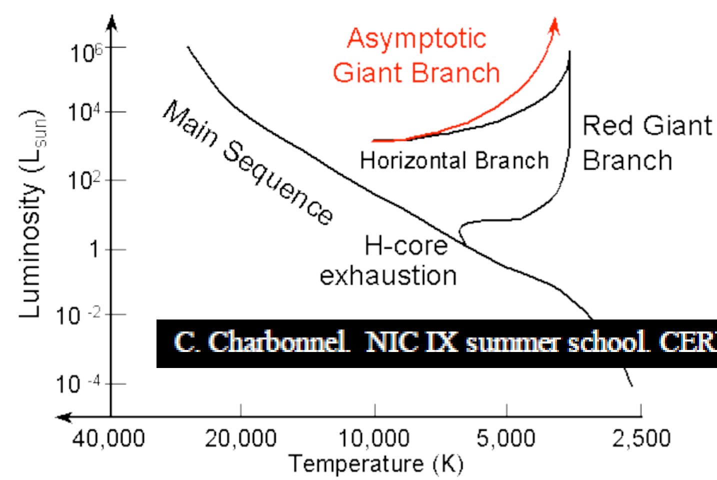
NOTE.—Table 2 is presented in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.

CMDs (app)

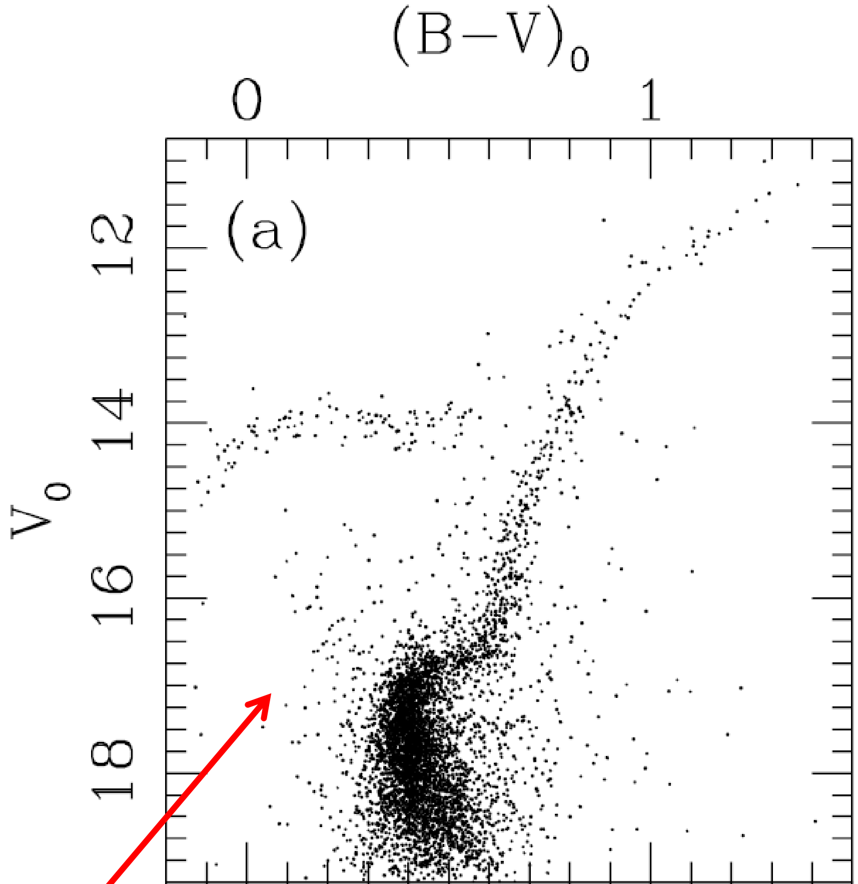




Q1: Show two CMDs (app):
V vs. B – V and V vs. V – I (see figures). Note the presence of blue straggler stars, which were formed later than the rest of stars or are not members of the GC



Q2: Transform the first CMD (app), i.e., V vs. B – V, into a CMD* (app). You have to remove the reddening by interstellar extinction, i.e., correct CMD (app). Table 6 of Layden & Sarajedini displays details on the dust extinction at the positions of 54 RRab Lyrae stars. The E(B–V) values range from 0.18 to 0.37 mag, so there is a variable reddening across the field of view with <E(B–V)> = 0.264 ± 0.005 mag (rms = 0.036 mag). At the XY position of each star, find the nearest RRab star. If the RRab is within 30″ of the star (each pixel has a size of 0.3″), apply the reddening of the RRab to the star; if it is not, omit the star from the dereddened CMD. This approach was used by Layden & Sarajedini



CMD* (app)

$$A(V)/E(B-V) = 3.045$$

$V = V_0 + A(V)$, $A(V) \equiv$ visual extinction
$B - V = (B - V)_0 + E(B–V)$
$E(B–V) \equiv$ colour excess $= A(B) - A(V)$

1 – SIMULATED ISOCHRONES

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

FEBRUARY I **2000**, PAGE 371

Astron. Astrophys. Suppl. Ser. **141**, 371–383 (2000)

Evolutionary tracks and isochrones for low- and intermediate-mass stars: From 0.15 to 7 $M_\odot$, and from $Z = 0.0004$ to 0.03

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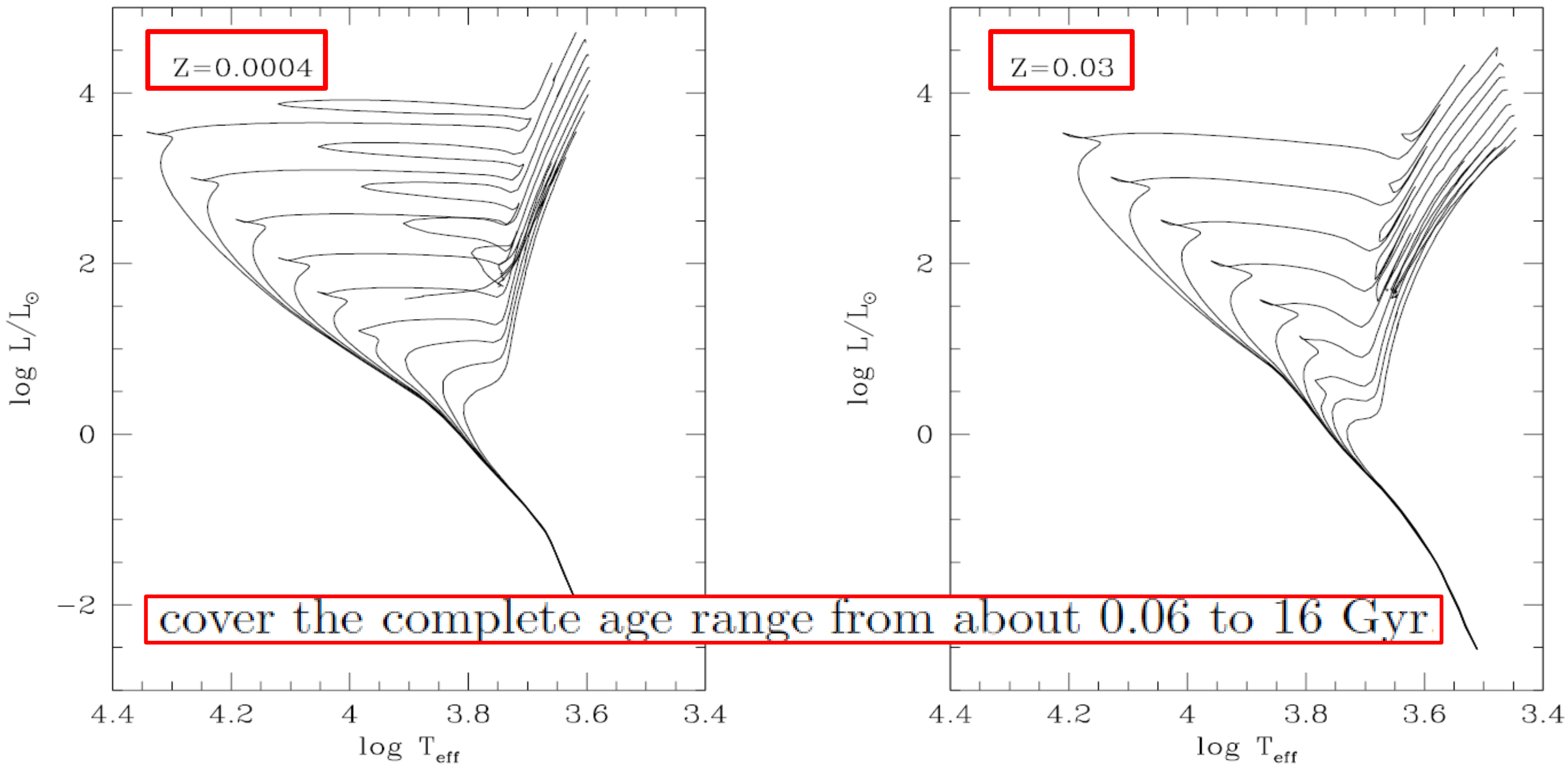
● the evolutionary phases extend from the zero age main sequence (ZAMS) till either the thermally pulsing AGB regime or carbon ignition.

●● From all these tracks, we derive the theoretical isochrones in the Johnson-Cousins $UBVRIJHK$ broad-band photometric system.



ISOCHRON.tsv

This data file contains **isochrones**, i.e., L-T_{eff} curves for different ages and metallicities. The file also includes absolute blue and visual magnitudes (M_B and M_V), so it is possible to build CMDs (abs): M_V vs. $(B - V)_0$, where $(B - V)_0 = M_B - M_V$. If we wish to compare these simulated CMDs (abs) with the observational CMD* (app), the distance to the GC is required

Q3: You need the distance to infer V_0 values from absolute magnitudes M_V (see below). Take the distance in the Layden & Sarajedini's paper: d = 4.87 kpc, and then build and show CMD*s (abs): V_0 vs. $(B - V)_0$, for

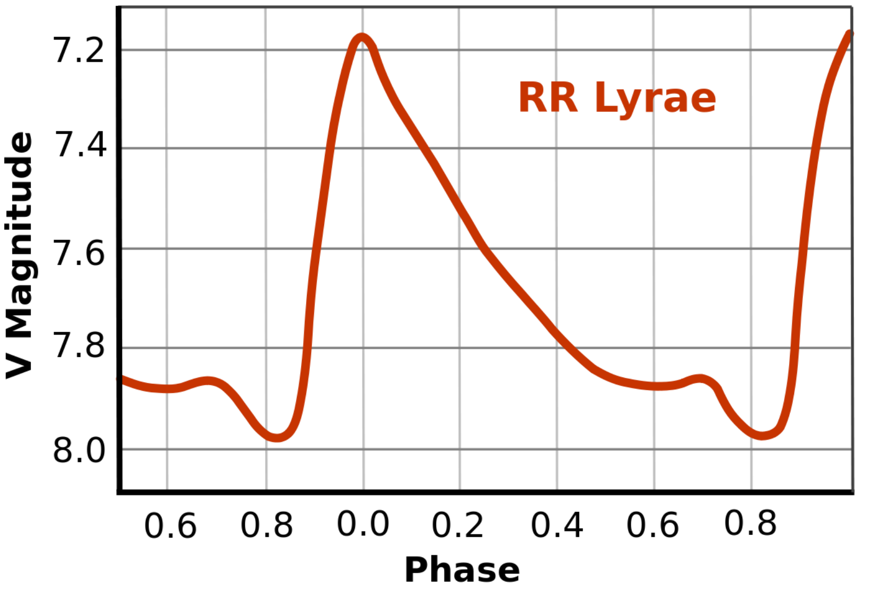
(1) Z = 0.0004, ages = 10, 12.6, and 15.9 Gyr,

(2) Z = 0.0004, age = 5.01 Gyr, and

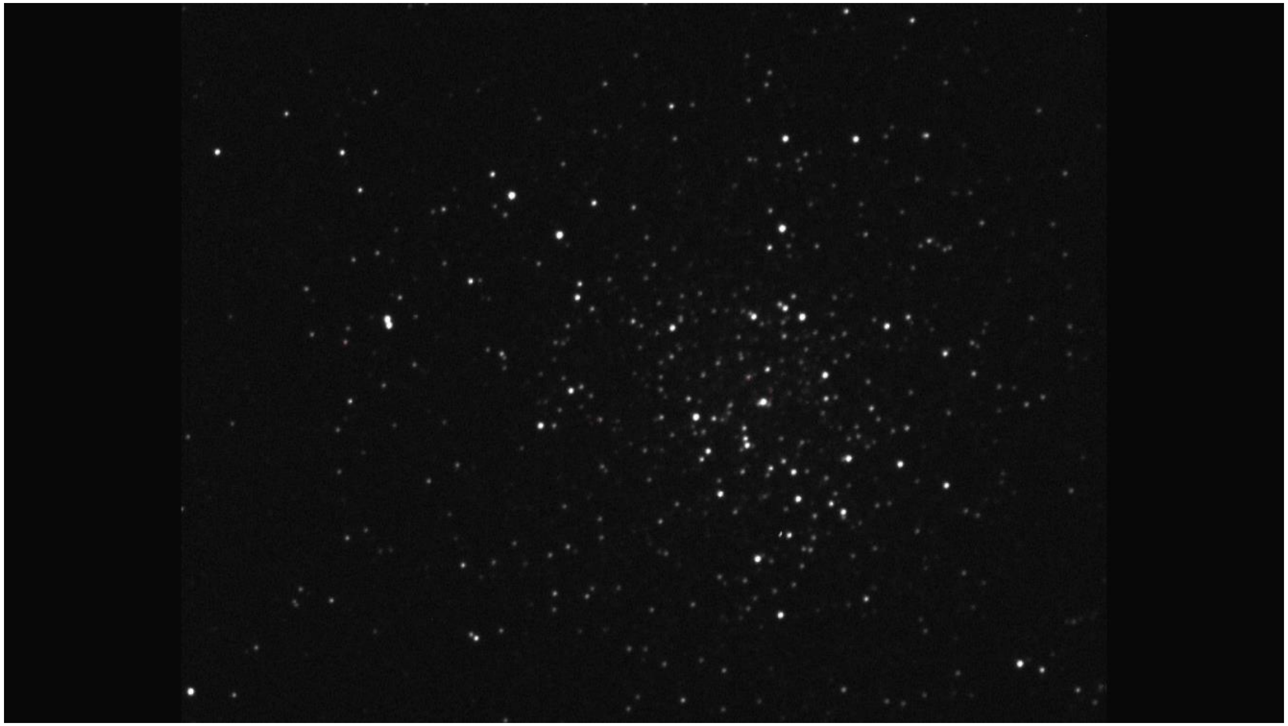
(3) Z = 0.004, age = 12.6 Gyr

$$\boxed{V_0 = M_V + 5 \log d - 5}$$

A simple way to measure the distance to the GC is to use its variable stars. For example, RR Lyrae stars in the GC (e.g., https://openstax.org/books/astronomy/pages/19-3-variable-stars-one-key-to-cosmic-distances)



RR Lyrae stars in NGC 3201



(a) See also https://www.youtube.com/watch?v=sXJBrRmHPj8

(b) You can also measure the distance to NGC 3201 using five frames of the GC (at different observing times) and a Python code. It is new and easy-to-do!

https://www.jimmynewland.com/wp/astro/measuring-the-milky-way-with-stars/

Teaching with Code: Globular Cluster Distance Lab
James Newland

Res. Notes AAS 4, 118 (2020)

Q4: Compare the CMD* (app) to the CMD*s (abs) for (1) in Q3. Additionally, in two independent figures, draw the CMD* (app) along with the CMD* (abs) for (2) and (3) in Q3. Discuss whether the following statements are true or not:

(a) NGC 3201 is a metal-poor cluster ($Z = 0.02\ Z_{\odot}$) that was formed at the same time as the Sun (age of ~ 5 Gyr)

(b) NGC 3201 is an old cluster (age of ~ 13 Gyr) with $Z = 0.2\ Z_{\odot}$

(c) NGC 3201 is a metal-poor, old cluster with $Z = 0.02\ Z_{\odot}$ and an age of ~ 13 Gyr.

Taking the previous discussion into account, give an age range for the Milky Way

The simulated MS turnoffs play a key role to distinguish between different values of the age and metallicity