- What is the average density of a white dwarf star?

$$\bar{\rho} = \frac{M}{V} = \frac{3M}{4\pi R^3}$$

$$= \frac{3 \times 0.6 \times 2 \times 10^{30}}{4\pi \left(6000 \times 10^3\right)^3} = 1 \times 10^9 \text{ kg m}^{-3}$$

i.e. 100 000 times more dense than lead.

Star Clusters

- Colour-magnitude diagrams
- Open Clusters
- Globular Clusters
- Chemical evolution
- Stellar populations

Star Clusters

- Star clusters are a collection of stars that are concentrated in space
- They all formed together out of the same cloud and at the same time


ESO/G. Beccari

Colour-Magnitude Diagrams

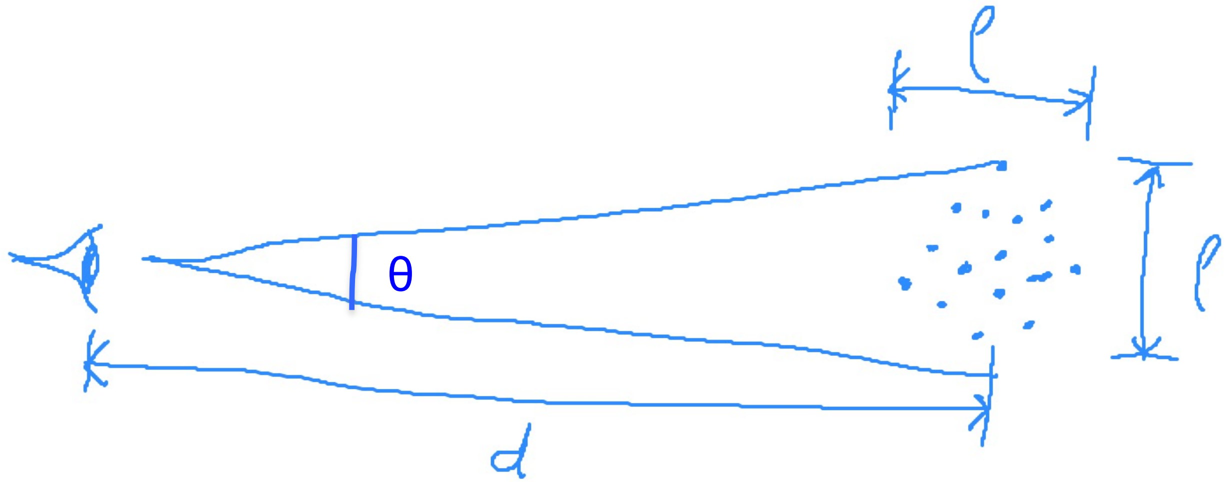
- for star clusters m_V (or V) is equivalent (apart from an offset) to M_V since all stars are at the same distance

$$m_V - M_V = 5\log d - 5$$

- can also use colour, e.g. B-V as a measure of temperature
- hence colour-magnitude diagrams (CMDs) for star clusters are similar to H-R diagrams

Class Example

- Estimate the difference in distance (in pc) between stars on the near and far side of a cluster that has an angular diameter of 1^o at an average distance of 1000 pc?



$$l = \theta d$$

$$= \frac{1 \times 3600}{206265} \times 1000 \text{ pc}$$

$$= 17 \text{ pc}$$

i.e. ~2% error if we assume all the stars are at 1000 pc

Star Clusters

- There are two common types of star cluster
  - Open clusters
  - Globular clusters

Open Clusters

- Typically have of order 1000 members
- Not gravitationally bound – will disperse over time
- Located in spiral arms of spiral galaxies
- Consist of young, hot, blue main sequence stars

Open cluster NGC 457. Credit: ROBERT GENDLER/SCIENCE PHOTO LIBRARY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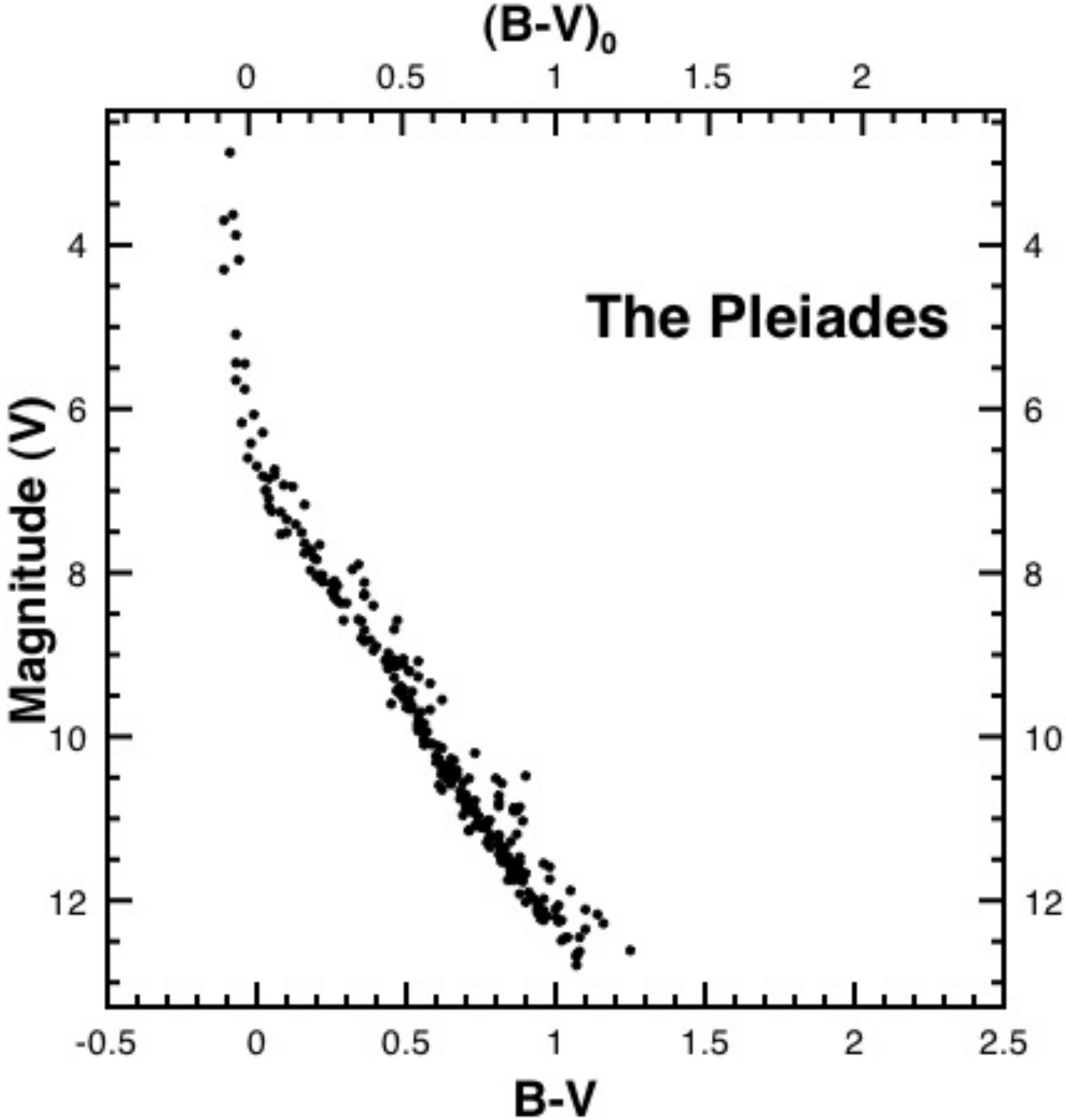
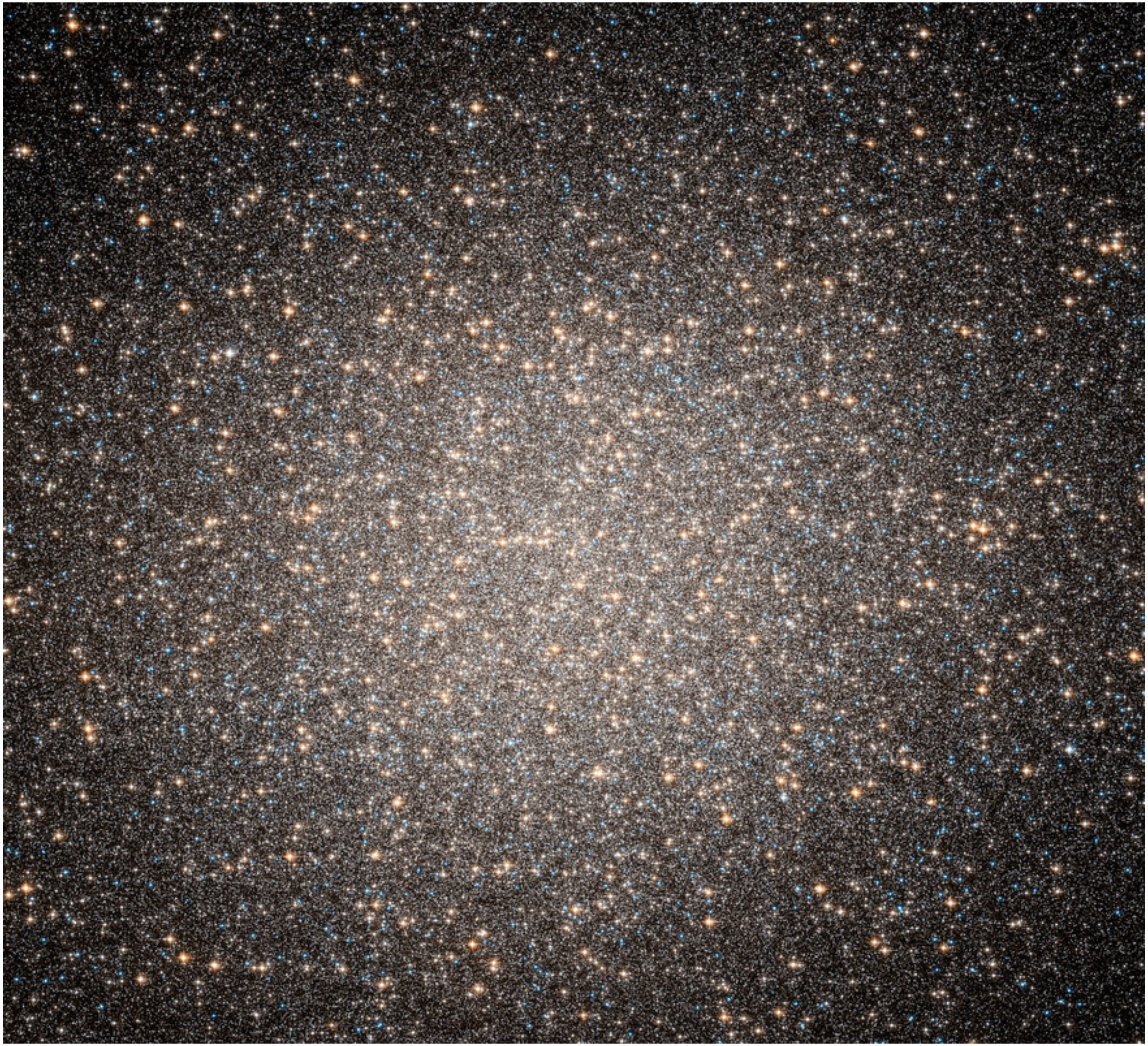


Colour-magnitude diagram of the Pleiades open cluster

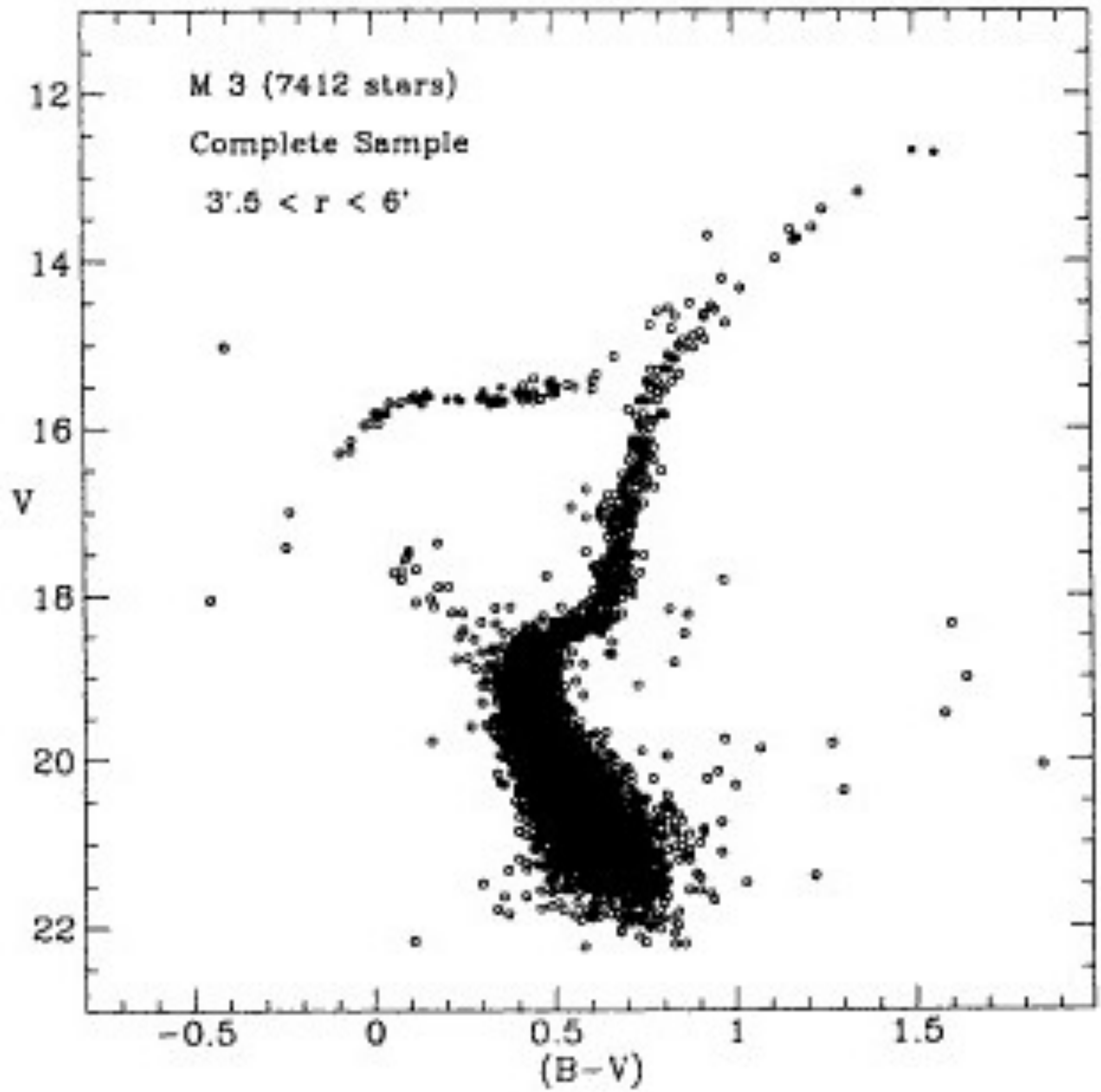
Globular Clusters

- Typically have of order 10^5 members
- Gravitationally bound
- Found in the Galactic halo
- Consist of old, cool, red, stars

Globular cluster M80. HST



Globular cluster Omega Centauri. HST



Colour-magnitude diagram for the globular cluster M 3.

Buonanno, R.; Corsi, C. E.; Buzzoni, A.; Cacciari, C.; Ferraro, F. R.; Fusi Pecci, F. Astron. Astrophys. 290, 69-103 (1994)

Class Example

- Estimate the average separation (in pc) of stars in a typical globular cluster with 10^5 members and a radius of 10 pc. Hint: calculate the number of stars per cubic pc first.

- Number density of stars

$$n = \frac{N}{V} = \frac{N}{\frac{4}{3}\pi R^3} = \frac{10^5}{\frac{4}{3}\pi 10^3} = 24 \text{ stars pc}^{-3}$$

- Typical separation

$$x \approx \frac{1}{n^{\frac{1}{3}}} \approx \frac{1}{24^{\frac{1}{3}}} \approx 0.3 \text{ pc}$$

- Much closer than in the rest of Galaxy

Chemical Evolution

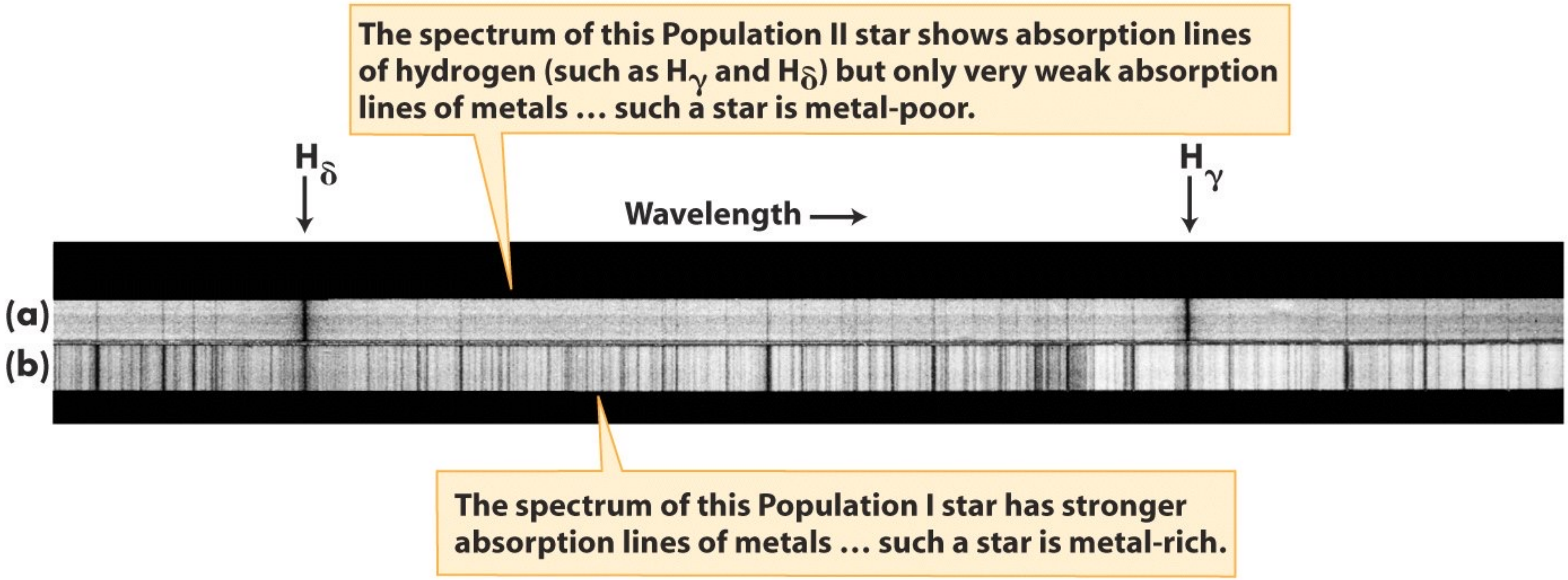
- The first stars to form were made from material left over from the Big Bang
- This was almost pure hydrogen and helium
- Nucleosynthesis within stars due to fusion of light nuclei produces heavy elements
- These are returned to the interstellar medium via supernovae explosions and planetary nebulae

Supernova remnant

Planetary nebula

NASA HST

- This enriched material is then the raw material for the next generation of stars
- Hence, successive generations become progressively more enriched in heavy elements or ‘metals’
- Can be tracked by measuring the composition via the spectra of stars



From Universe Textbook

Stellar populations

- Stellar populations are divided into two groups
- Population I stars
  - young
  - 10^7 to 10^9 years
  - metal-rich
  - >1% metals by mass
  - ongoing or recent star formation
  - e.g. open clusters

- Population II stars
  - old
  - 10^{10} years
  - metal-poor
  - ~ 0.1% metals by mass
  - no star formation for a long time
  - e.g. globular clusters

Summary

- Colour-magnitude diagrams for star clusters enable us to determine their age
- They are a key tool in the study of stellar and galaxy evolution
- Stellar populations are divided into old, metal-poor stars and young, metal-rich stars

Class Example

- The enriched material ejected during the planetary phase is expanding at a typical speed of 10 kms^{-1}. How many years before it reaches other stars at distances of ~1 pc?