2. Correlations between Stellar Properties

2.1 Mass-luminosity relationship (ZG: 12.2; CO: 7.3)

- Most stars obey

$$L_s = \text{constant} \times M_s^{\nu} \qquad 3 < \nu < 5$$

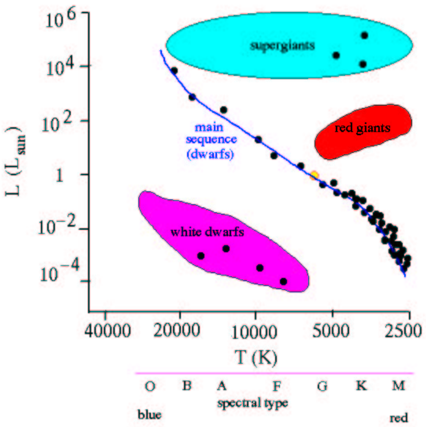
Exercise 2.1: Assuming a Salpeter IMF, show that most of the mass in stars in a galaxy is found in low-mass stars, while most of the stellar light in a galaxy comes from massive stars.

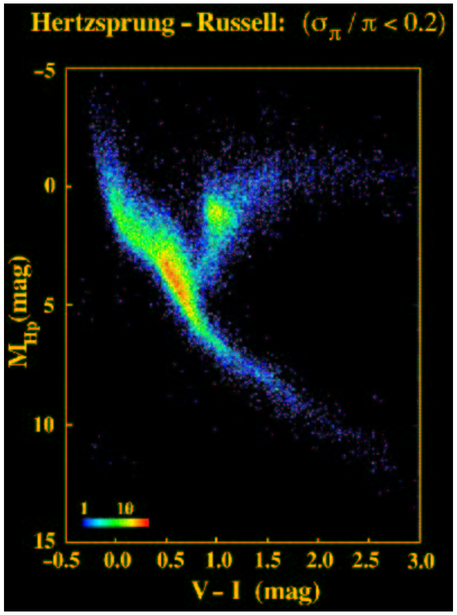
2.2 Hertzsprung–Russell diagram (ZG: 13-3; CO: 8.2) (plot of L_s vs. T_{eff}): and Colour–Magnitude Diagram (e.g. plot of V vs. B-V) From diagrams for nearby stars of known distance we deduce:

1. About 90% of stars lie on the main sequence (broad band passing diagonally across the diagram)
2. Two groups are very much more luminous than MS stars (giants and supergiants)
3. One group is very much less luminous; these are the white dwarfs with $R_s << R_\odot$ but $M_s \sim M_\odot$.

log g − log T_{eff} diagram, determined from atmosphere models (does not require distance)

Hertzsprung-Russell (Colour-Magnitude) Diagram





Hipparcos (1989 - 1993)

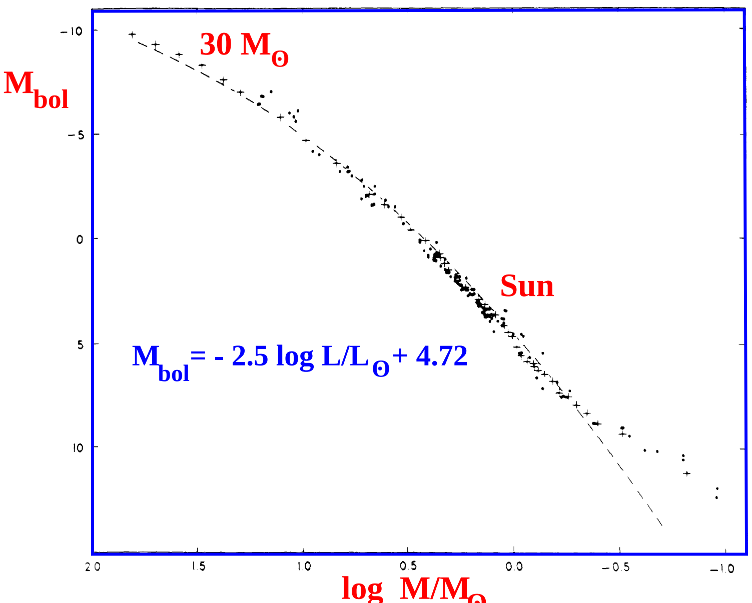


Fig. 2. Mass-luminosity relationship for the luminosity V stars from this paper (plus signs), from Popper (1980) (points) and from Heintze (1973) (broken line).

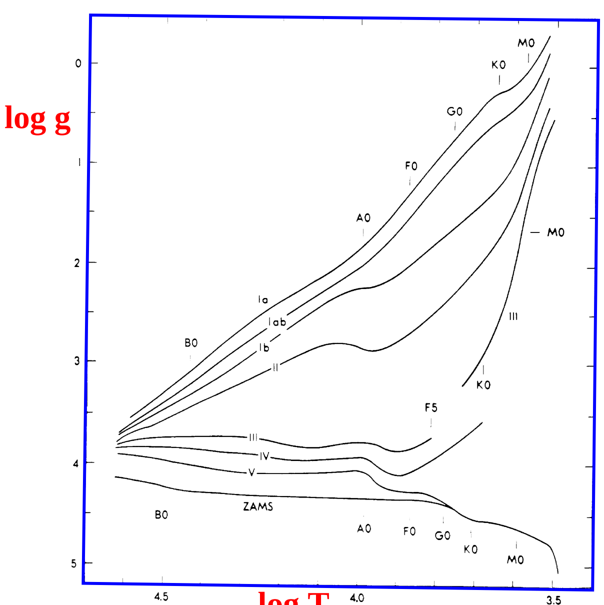


Fig. 3. The diagram log g, log T, for stars of different luminosities plotted from the data of Tab

2.3 Cluster H-R Diagrams

(ZG:13-3, 14-2; OG: 13.4)

- Galactic or open clusters – 10 to 1000 stars, not concentrated towards centre of cluster – found only in disc of Galaxy
- Globular clusters – massive spherical associations containing 10^5 or more stars, spherically distributed about centre of Galaxy, many at great distances from plane.
- All stars within a given cluster are effectively equidistant from us; we are probably seeing homogeneous, coeval groups of stars, and with the same chemical composition. We can construct H-R diagrams of apparent brightness against temperature.

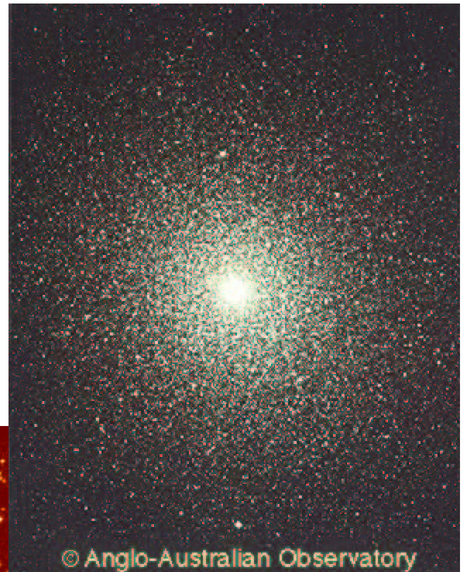
Main features of H-R diagrams:

1. Globular clusters
   (a) All have main-sequence turn-offs in similar positions and giant branches joining the main sequence at that point.
   (b) All have horizontal branches running from near the top of the giant branch to the main sequence above the turn-off point.
   (c) In many clusters RR Lyrae stars (of variable luminosity) occupy a region of the horizontal branch.
2. Galactic clusters
   (a) Considerable variation in the MS turn-off point; lowest in about the same position as that of globular clusters.
   (b) Gap between MS and giant branch (Hertzsprung gap) in clusters with high turn-off point.

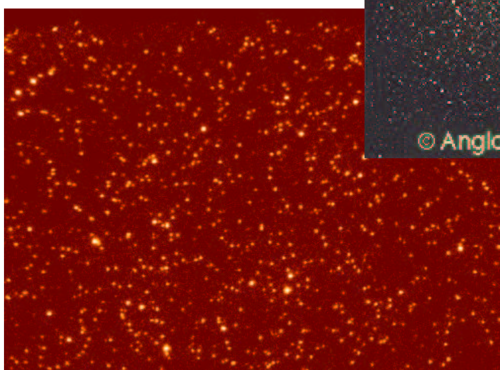
STAR CLUSTERS

Open Cluster (Pleiades)

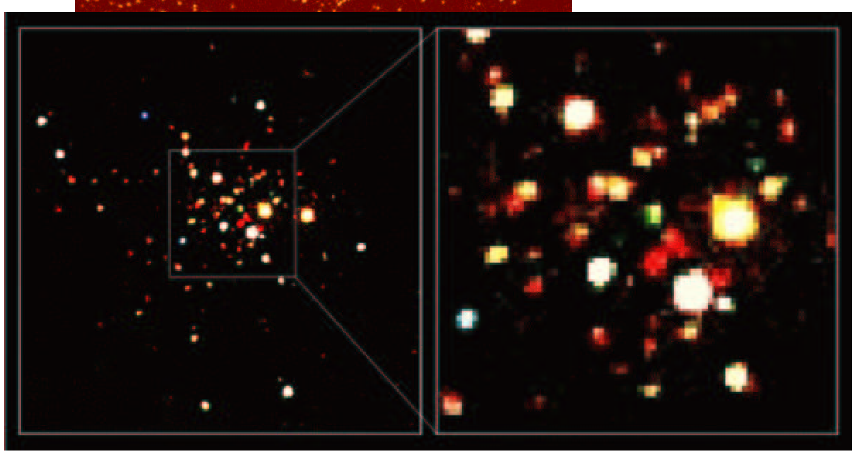
Globular Cluster (47 Tuc)



HST

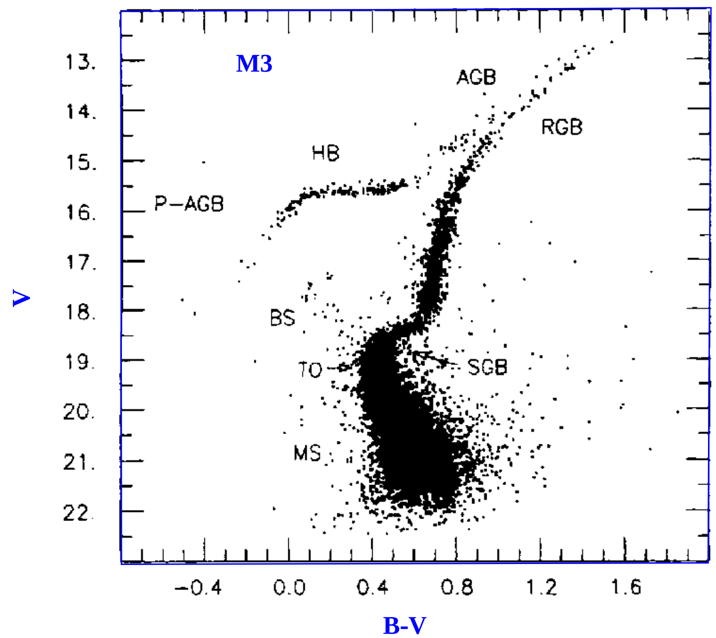


47 Tucanae

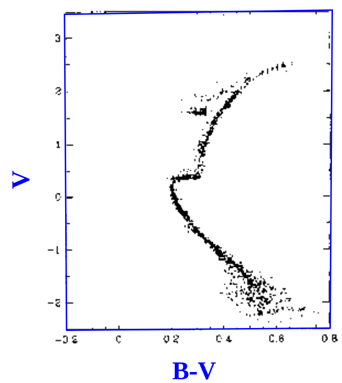


Chandra (X-rays)

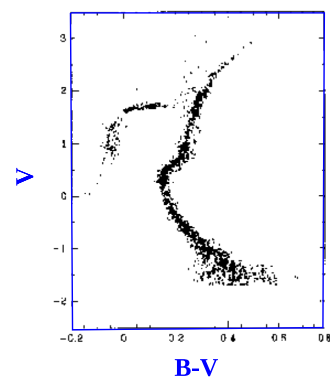
Globular Cluster CM Diagrams



47 Tuc



M15



2.4 Chemical Composition of Stars
(ZG: 13-3; CO: 9.4)

- We deduce the photospheric composition by studying spectra: information often incomplete and of doubtful precision.
- Solar system abundances: Reasonable agreement between analysis of solar spectrum and laboratory studies of meteorites (carbonaceous chondrites).
- Normal stars (vast majority): Similar composition to Sun and interstellar medium
  Typically: Hydrogen 90% by number; Helium 10%; other elements (metals) $\ll 1\,\%$
  (by mass: $X \simeq 0.70$, $Y \simeq 0.28$, $Z \simeq 0.02$)
- Globular cluster stars: Metal deficient compared to Sun by factors of $10 - 1000$,
  Hydrogen and helium normal

Assuming uniform initial composition for the Galaxy, we conclude that about 99% of metals must have been synthesized within stars.

THIS IS THE PRIMARY EVIDENCE FOR NUCLEOSYNTHESIS DURING STELLAR EVOLUTION.

2.5 STELLAR POPULATIONS (ZG: 14-3; CO: 13.4)

Population I: metallicity: $Z \sim 0.02$ (i.e. solar), old and young stars, mainly in the Galactic disc, open clusters

Population II: metallicity: $Z \sim 0.1 - 0.001\, Z_\odot$, old, high-velocity stars in the Galactic halo, globular clusters

Population III: hypothetical population of zero-metallicity stars (first generation of stars?), possibly with very different properties (massive, leading to relatively massive black holes?), may not exist as a major separate population (HE0107-5240, a low-mass star with $Z \sim 10^{-7}$: the first pop III star discovered?)

Stars with peculiar surface composition

- Most stars seem to retain their initial surface composition as the centre evolves. A small number show anomalies, which can occur through:
  1) mixing of central material to the surface
  2) large scale mass loss of outer layers exposing interior (e.g. helium stars)
  3) mass transfer in a binary (e.g. barium stars)
  4) pollution with supernova material from a binary companion (e.g. Nova Sco)

Sub-stellar objects

- Brown Dwarfs: star-like bodies with masses too low to create the central temperature required to ignite fusion reactions (i.e. $M \lesssim 0.08\, M_\odot$ from theory).
- Planets: self-gravitating objects formed in disks around stars (rocky planets [e.g. Earth], giant gas planets [e.g. Jupiter])

Summary II

Concepts:

- How does one determine mass-luminosity relations?
- The importance of the Hertzsprung-Russell and Colour-Magnitude diagram
- Basic properties of open and globular clusters
- The chemical composition of stars (metallicity)
- The different stellar populations
- Difference between stars, brown dwarfs and planets