Hertzsprung-Russell Diagram, aka Colour-Magnitude Diagram (CMD) and the Colour-Colour Diagram

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The story thus far

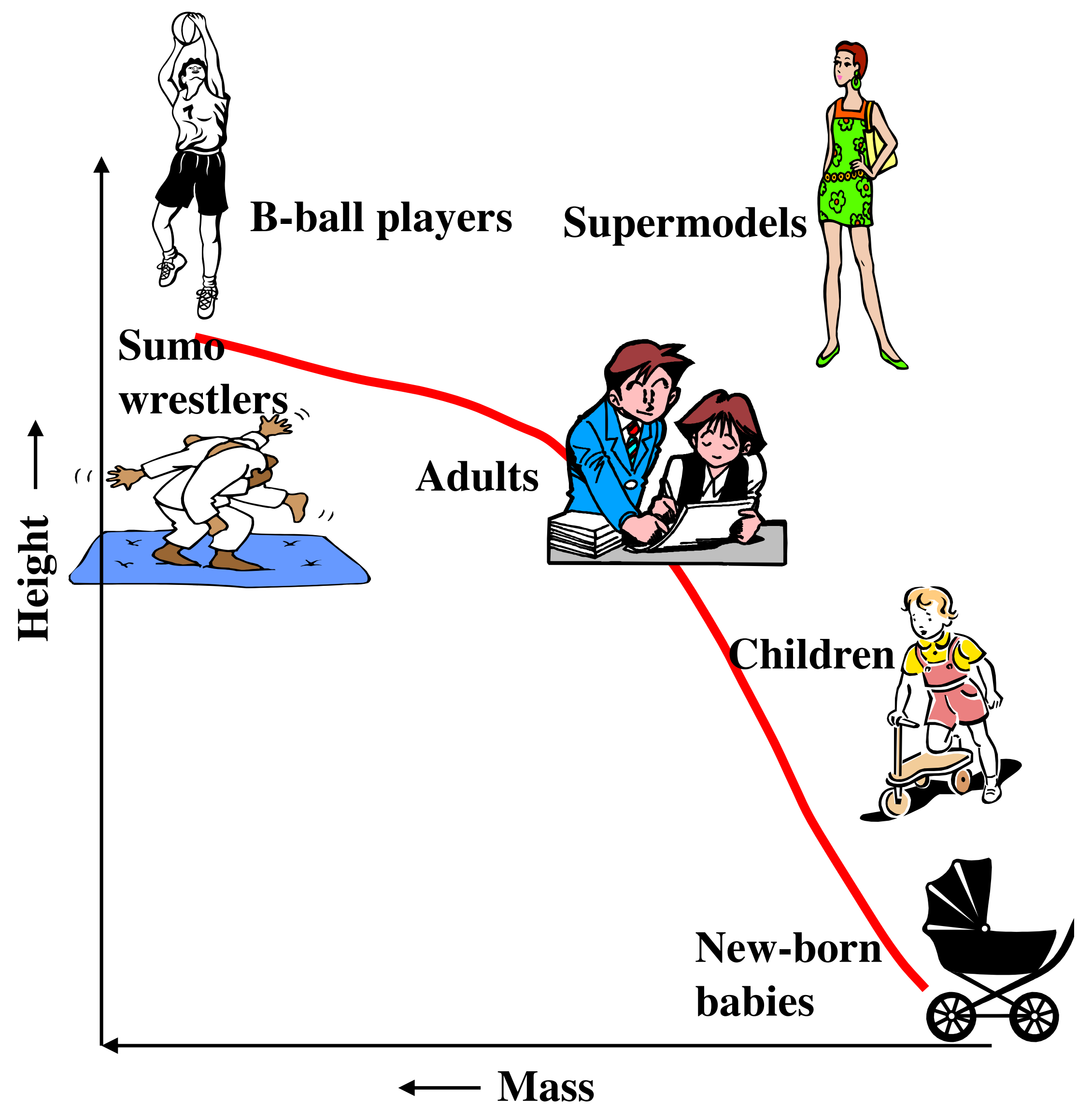
Observed quantity	*Calculated property*
Parallax	Distances, d
Flux, F, at Earth, apparent magnitude (with d + inverse square law)	Luminosities, L (absolute magnitudes)
Colour Index (B-V) (+ black body curve)	Temperatures, T
Spectrum	Temperatures, composition, surface gravity, Luminosity class
Binary stars (visual, spectroscopic, eclipsing)	Masses, Radii

But what about…… ages, how stars are born, how they shine, how they die?

HR Diagram - introduction

- Make a plot of height vs mass for students in class

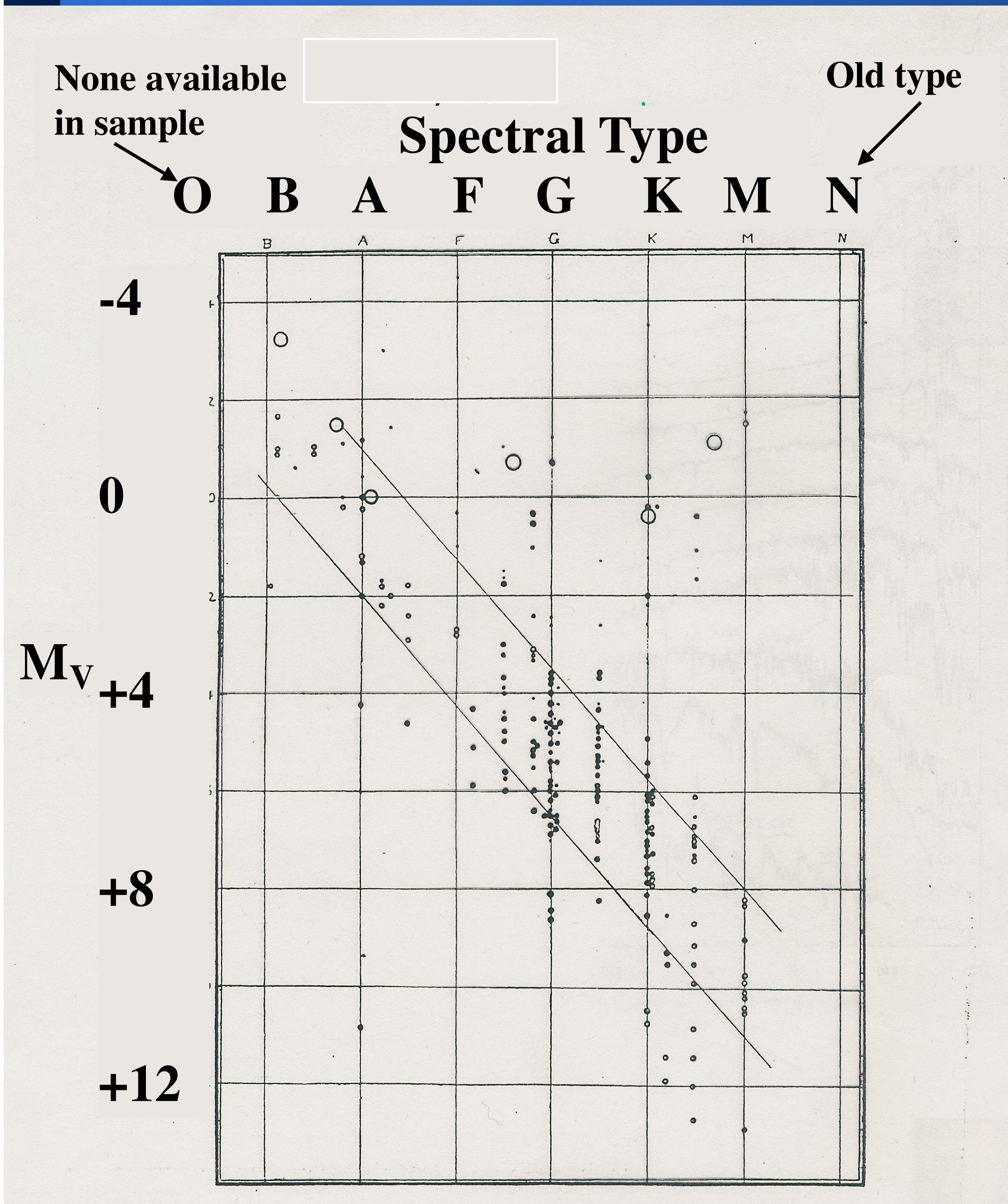
- Height increasing upward - mass increasing to left

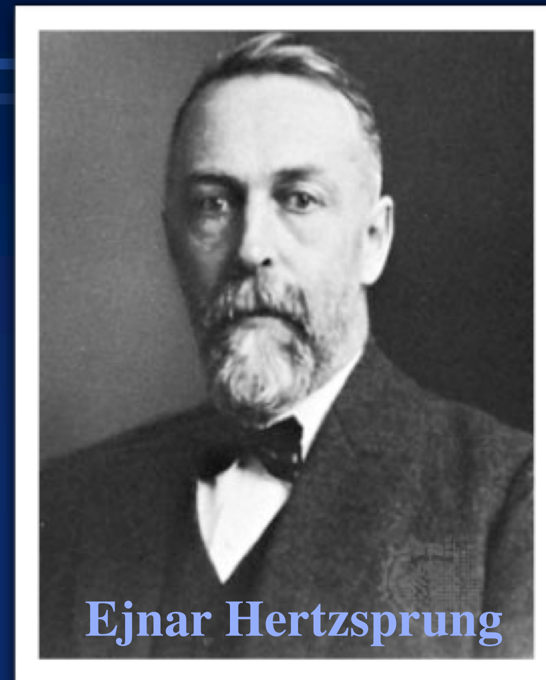


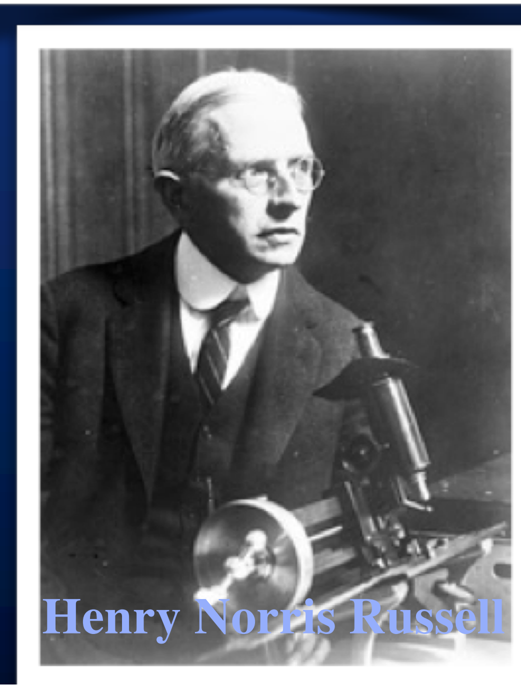
Hertzsprung-Russell Diagram

- A "Stellar Demographic Diagram"
- By turn last century, astronomers aware of a spectral sequence: OBAFGKM
  - *O stars are hot, luminous, most massive;*
  - *M are stars cool, faint, least massive*
- Originally, it was proposed that the spectral sequence was also an evolutionary sequence:
  - *start as hot O stars, use fuel, lose mass,*
  - *cool to die as a dim M star*
- 1905 - amateur astronomer, Hertzsprung, found a correlation between spectral type and absolute magnitude - but stars G and later showed a range in M_V for same spectral type - brighter stars called "giants".
- 1913 - established US astronomer, Henry Norris Russell, found same result.

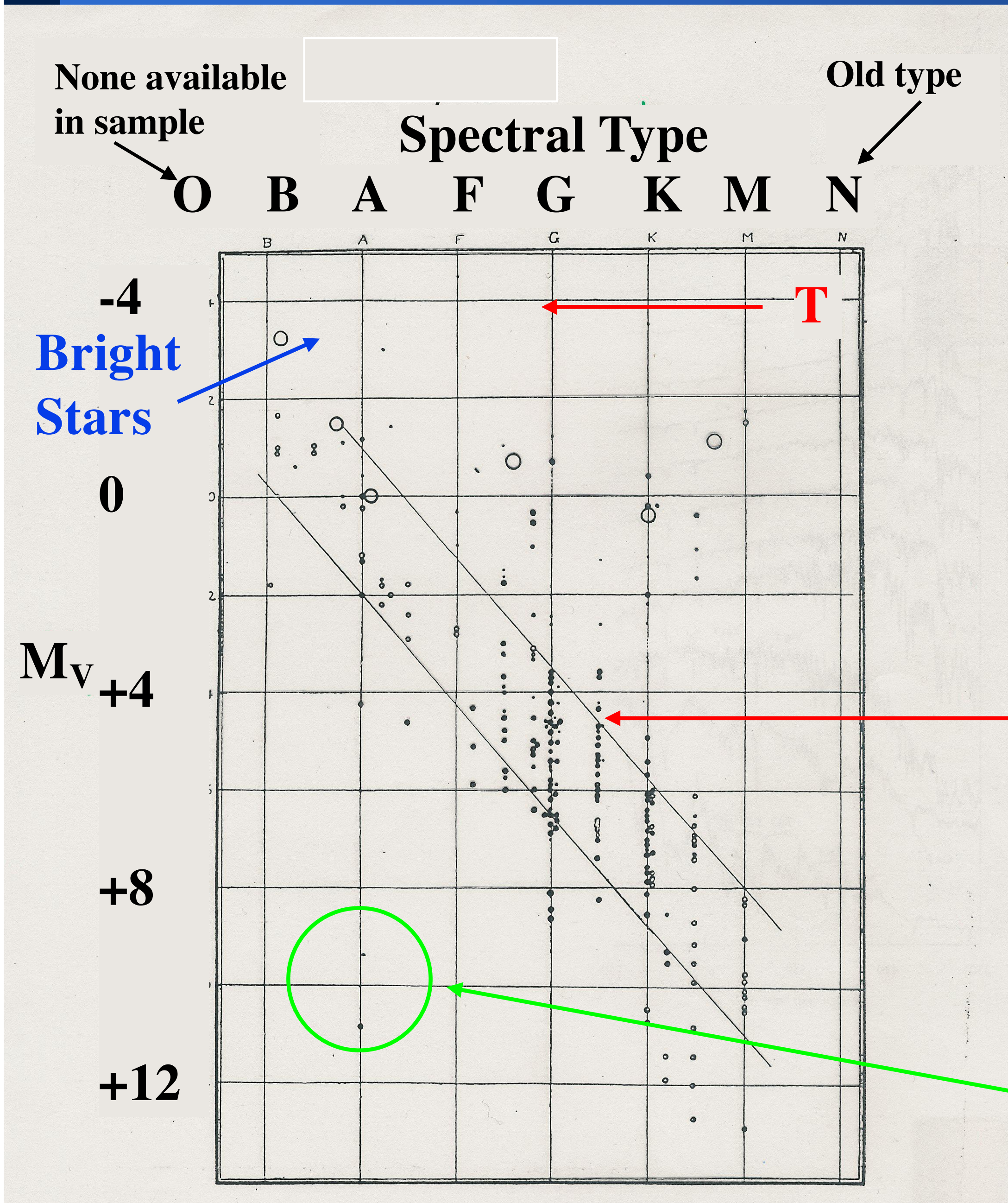
Astronomy's MVD (Most Valuable Diagram)
Hertzsprung-Russell Diagram







Hertzsprung-Russell Diagram



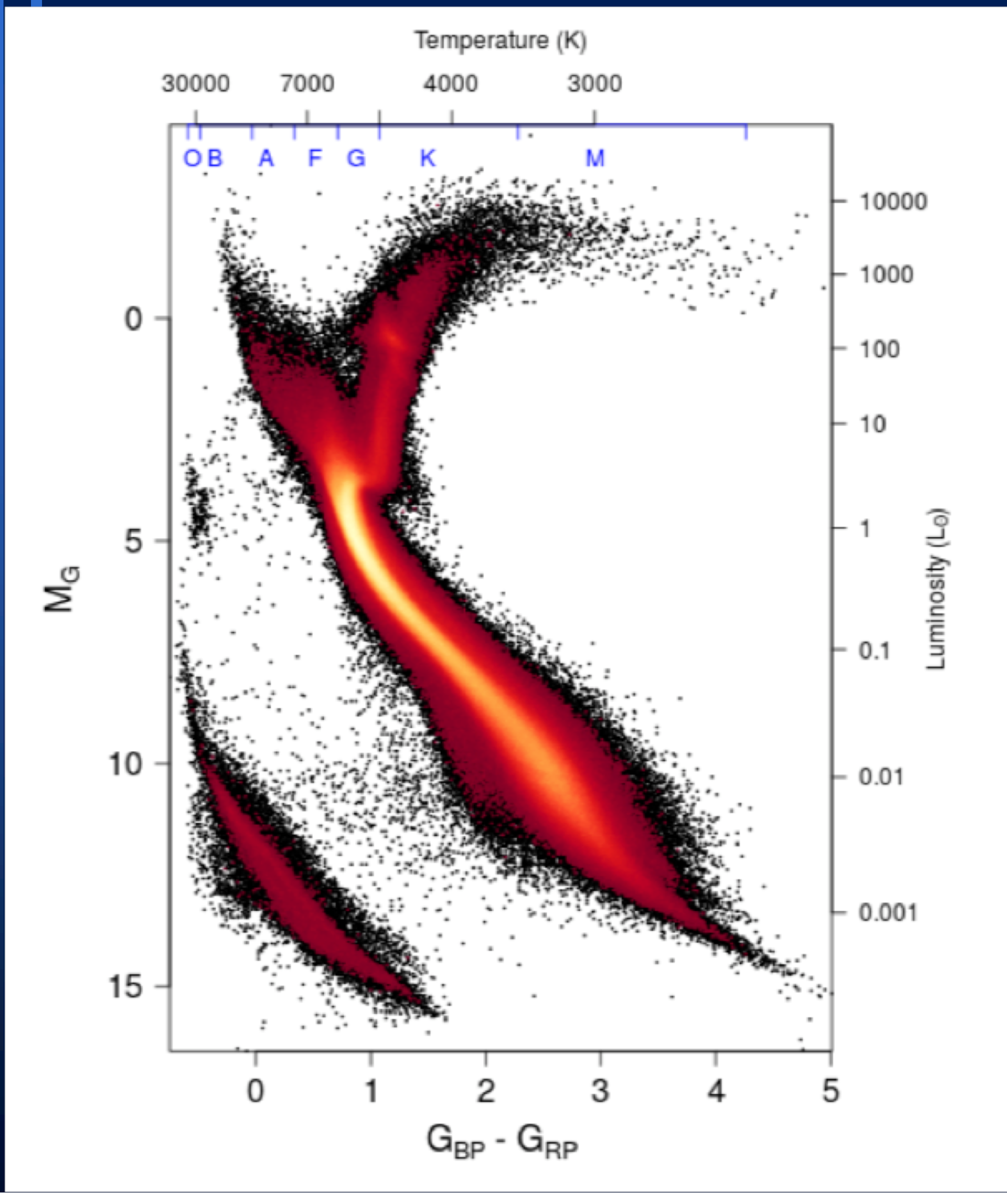
Henry Norris Russell's first diagram: M_V vs spectral type.

Note: T increases to left and bright stars at the top.

Band upper left to lower right is called the Main Sequence. It contains 80-90% of all stars.

White dwarfs at lower left.

Modern HR Diagram – Gaia
4.3 Million Stars Low Extinction



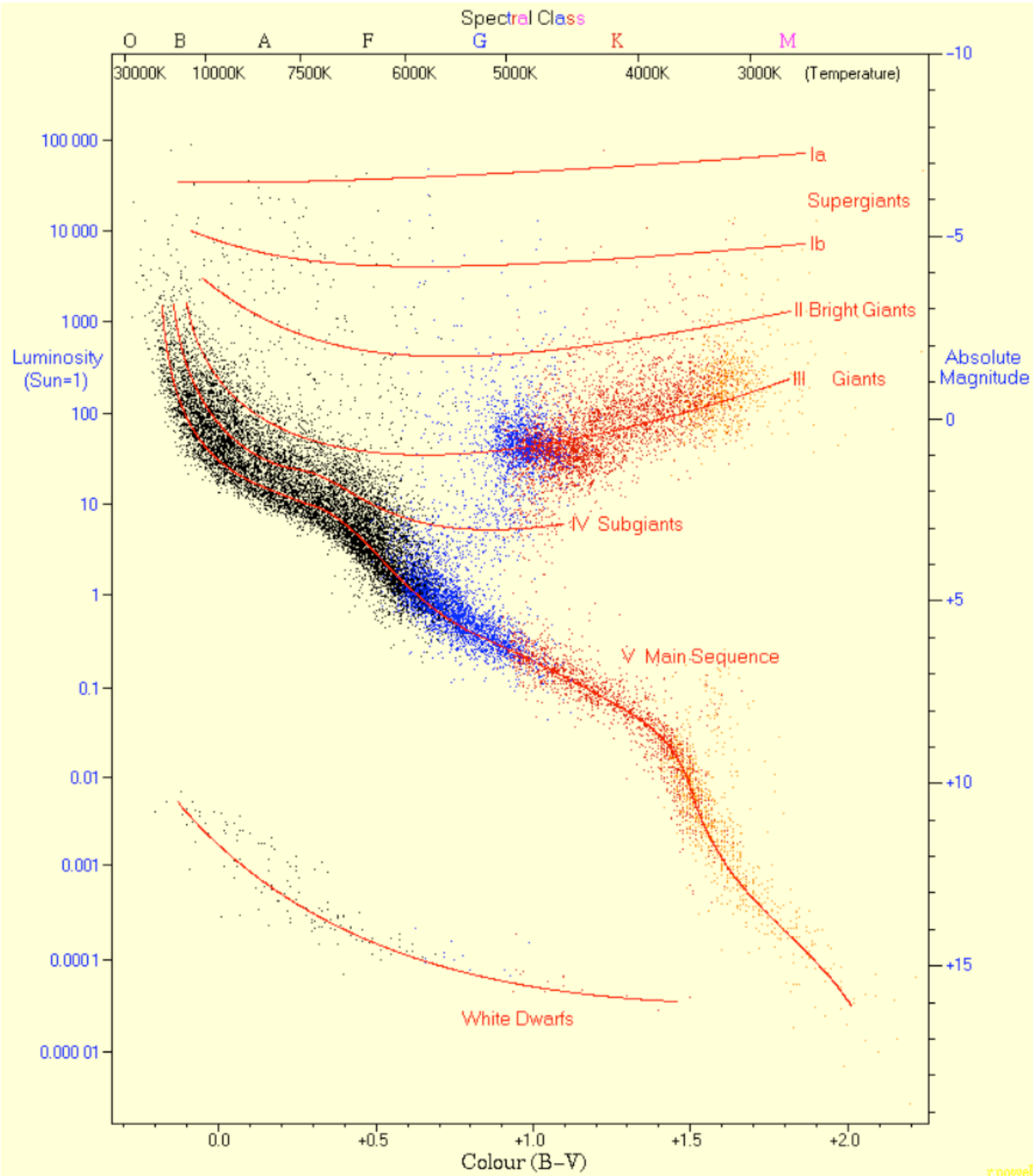
Note:
Most stars in narrow strip – Main Sequence

Stars same colour or T_{eff} have widely different luminosities

Stars above main sequence giants and supergiants

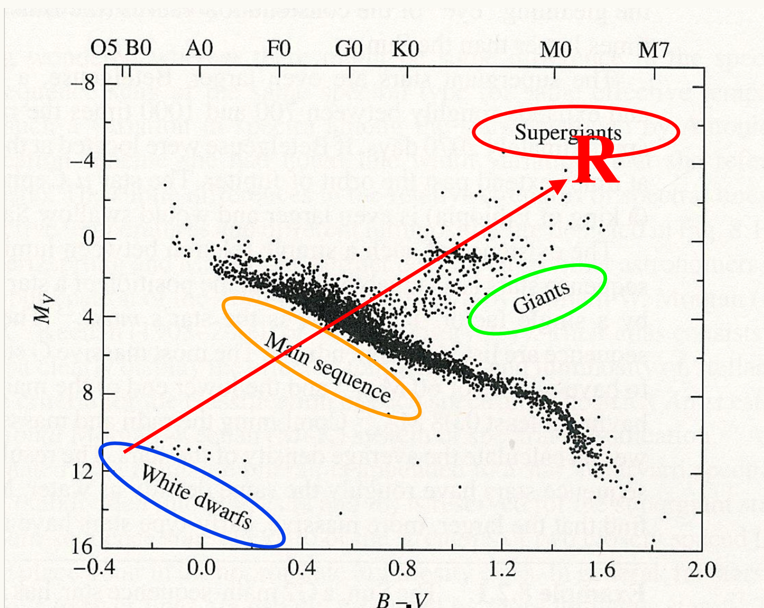
Stars below main sequence sub-dwarfs or white dwarfs

Modern HR Diagram - Hipparcos

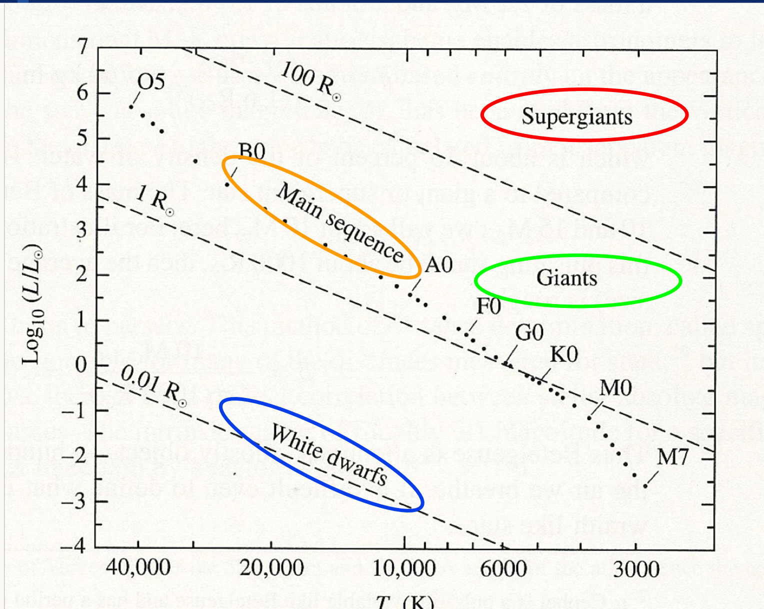


HR Diagram including spectral classes and luminosity classes

Hertzsprung-Russell Diagram



Modern observer's HR diagram



Modern theorist's HR diagram

$L = 4\pi R^2 \sigma T_{eff}^4$

$\rightarrow R_1/R_2 = (L_1/L_2)^{1/2} \times (T_1/T_2)^{-2}$

$\rightarrow$If 2 stars have same spectral type (T_{eff}), brighter star is bigger. Constant radius line has slope 4.

R must increase diagonally to upper right in HR Diagram

Supergiants few 100 - 1,000R_{sun}
(e.g. Betelgeuse)

Giants 10 - 100 R_{sun}
(e.g. Aldebaran)

Main Sequence stars 0.1-10R_{sun}
(e.g. Sun)

White Dwarfs 0.01R_{sun}
(e.g. Sirius B)

Class Questions

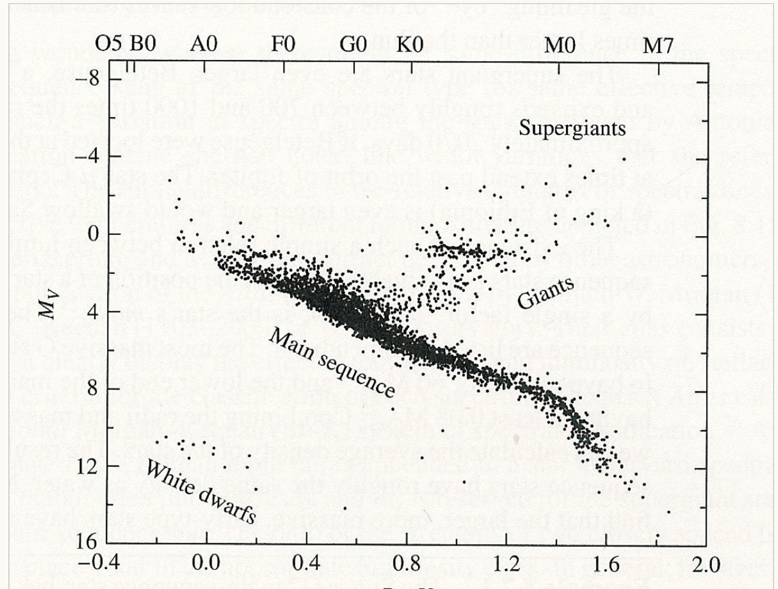
Main sequence is quite tight but the giant branch is much messier. Why?

What does the HR Diagram of a star cluster look like?

Is there an upper limit to how large (massive?) a star can get?
Also how low in mass?

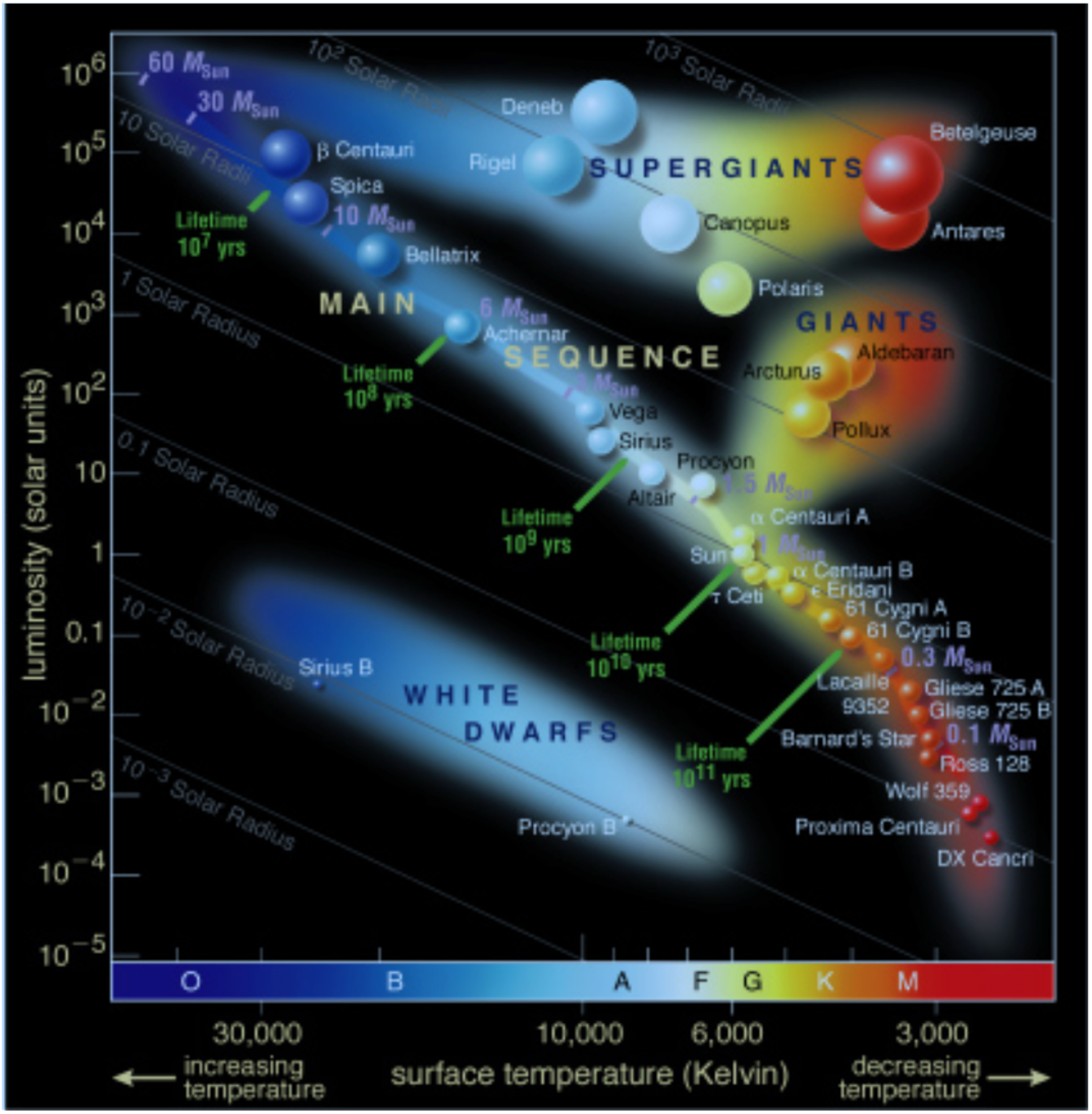
Discuss selection effects.

Why is there a kink in the main sequence around K0 (B-V = 1.5)?



Modern observer's HR diagram

Bright Stars in HR Diagram



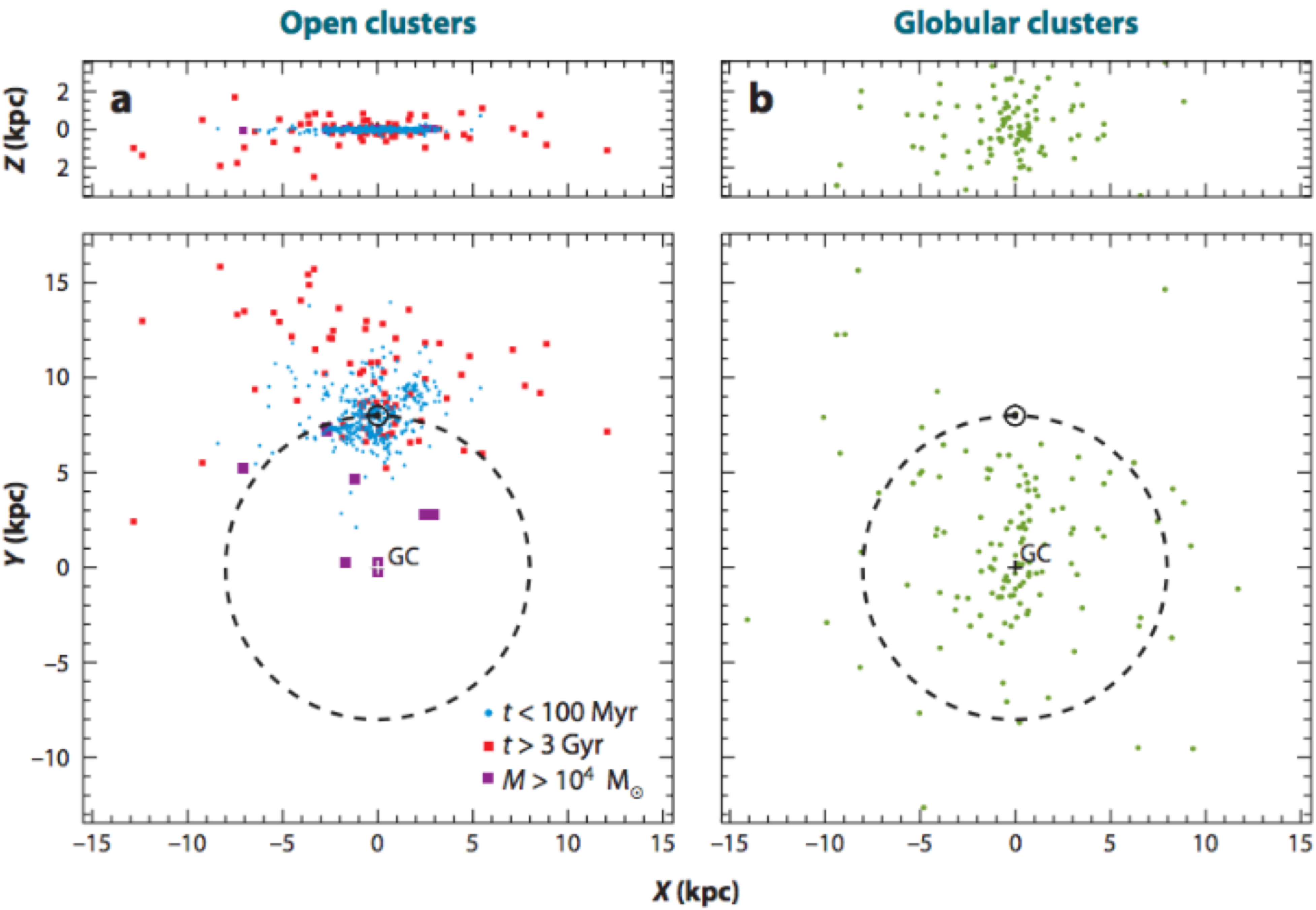
HR Diagram of a Star Cluster

What do we expect it to look like?

What are the advantages over that composed of field stars?

Are there any disadvantages?

Star Cluster Galactic Distribution

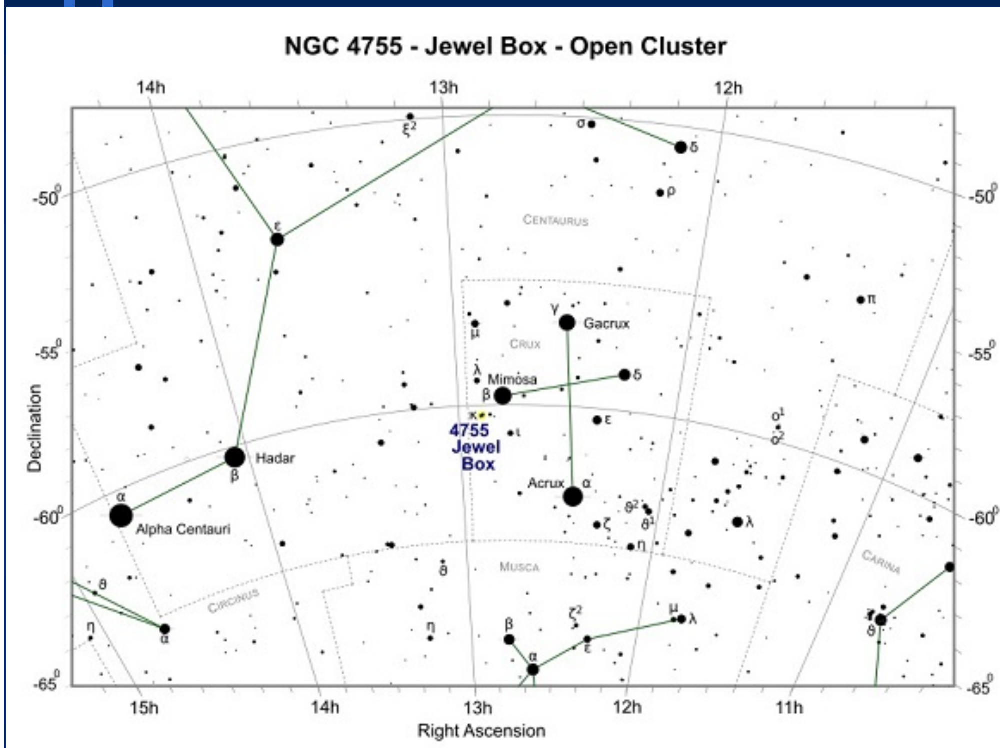


Jewel Box Open Cluster – NGC 4755

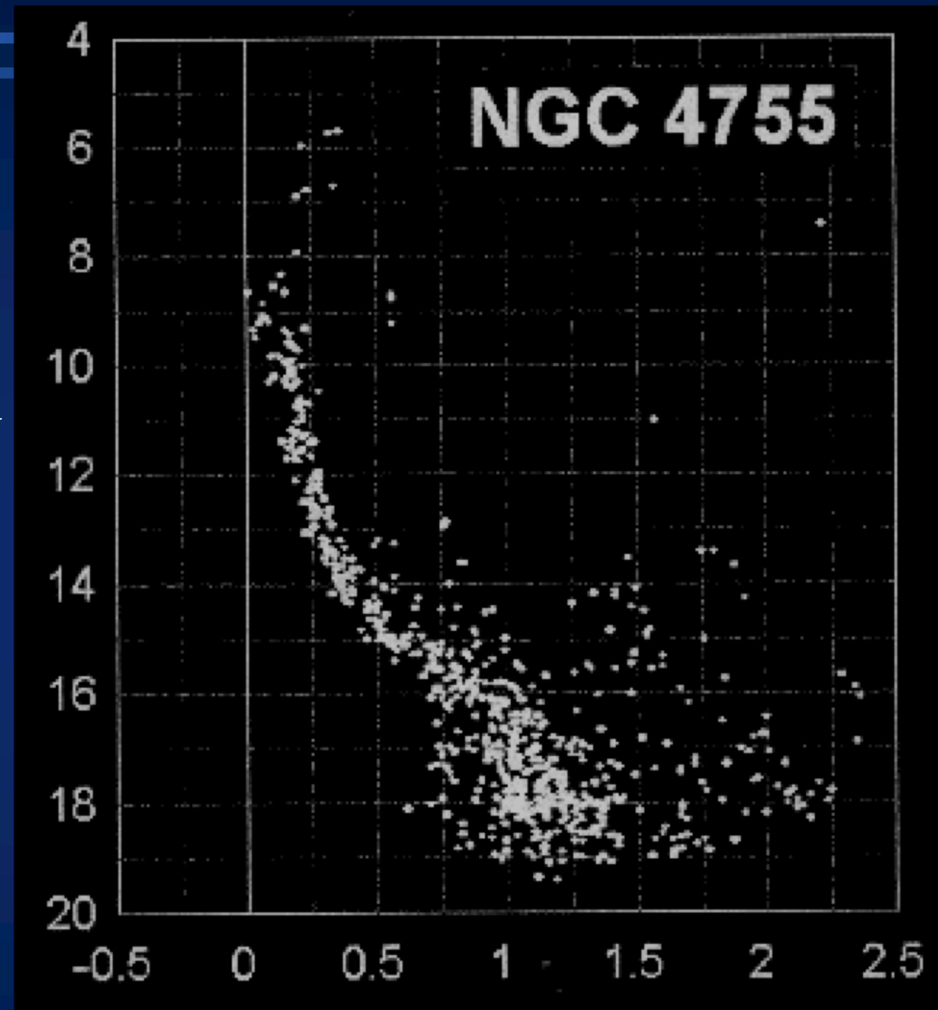
Southern object (Crux) – 2 kpc distant – contains B & M supergiants

Very young - age ~16 Myr – youngest known open cluster

Jewel Box Open Cluster – NGC 4755



V



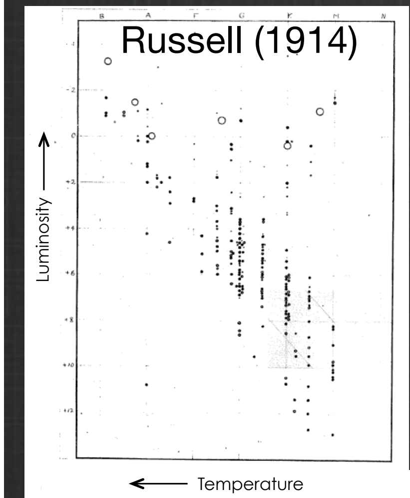
B-V

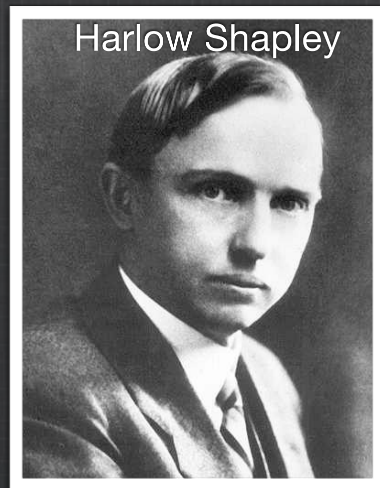
Southern object (Crux) – 2 kpc distant – contains B & M supergiants

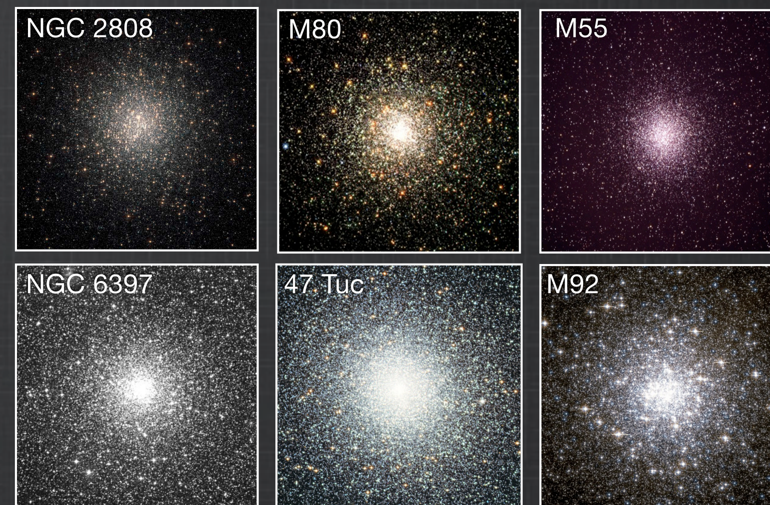
Very young - age ~16 Myr – youngest known open cluster

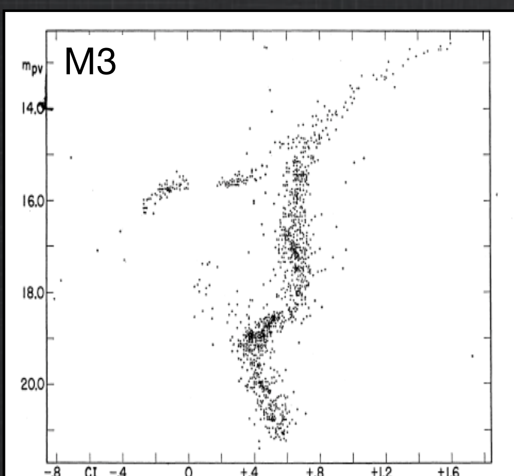
Globular Star Clusters

High Precision Color-Magnitude Relations

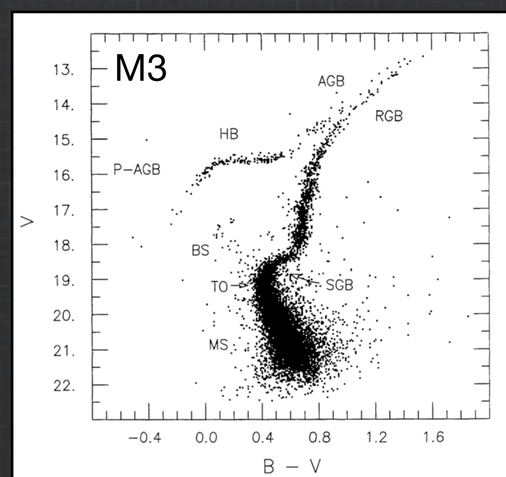








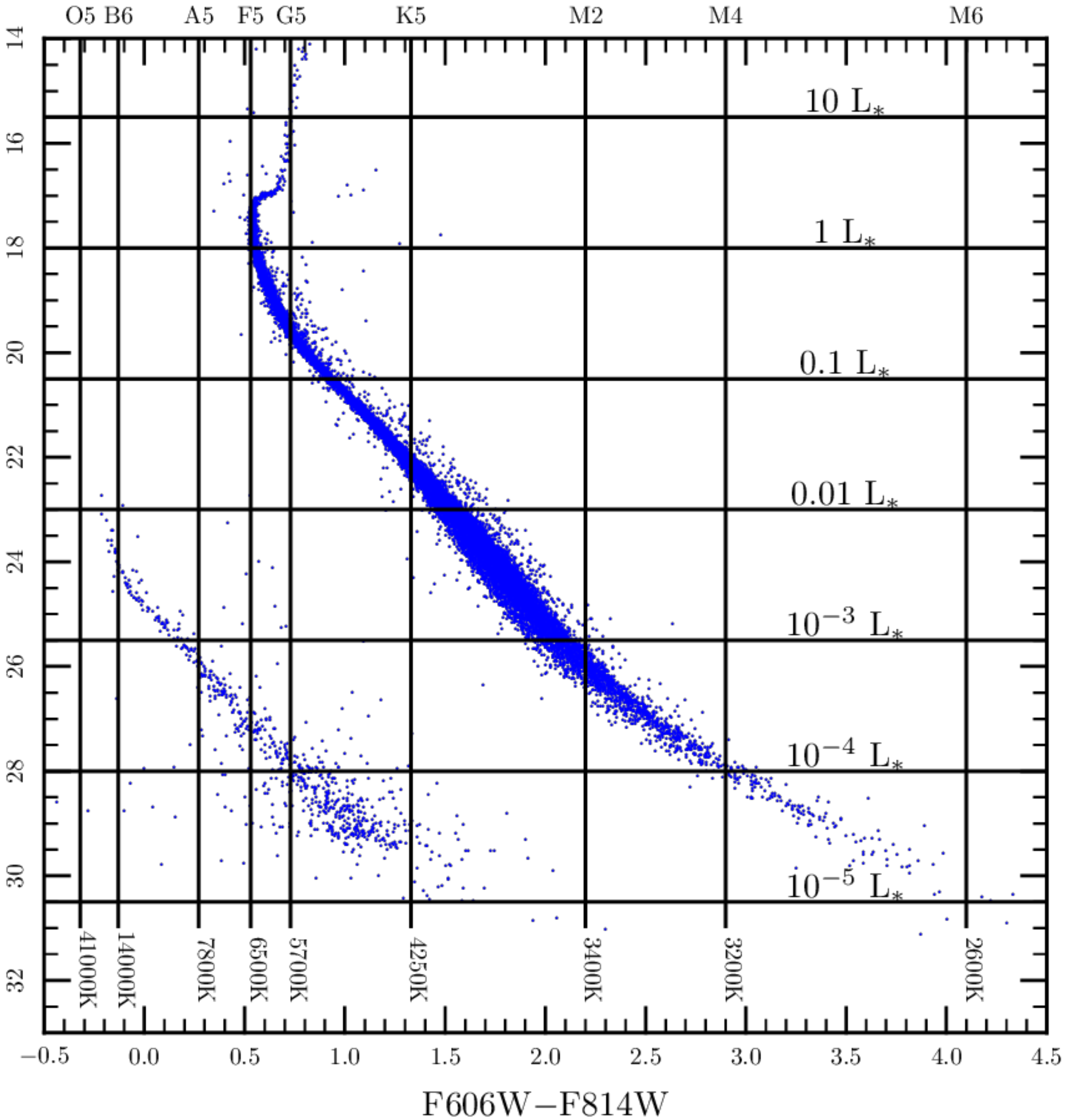
Sandage (1953)



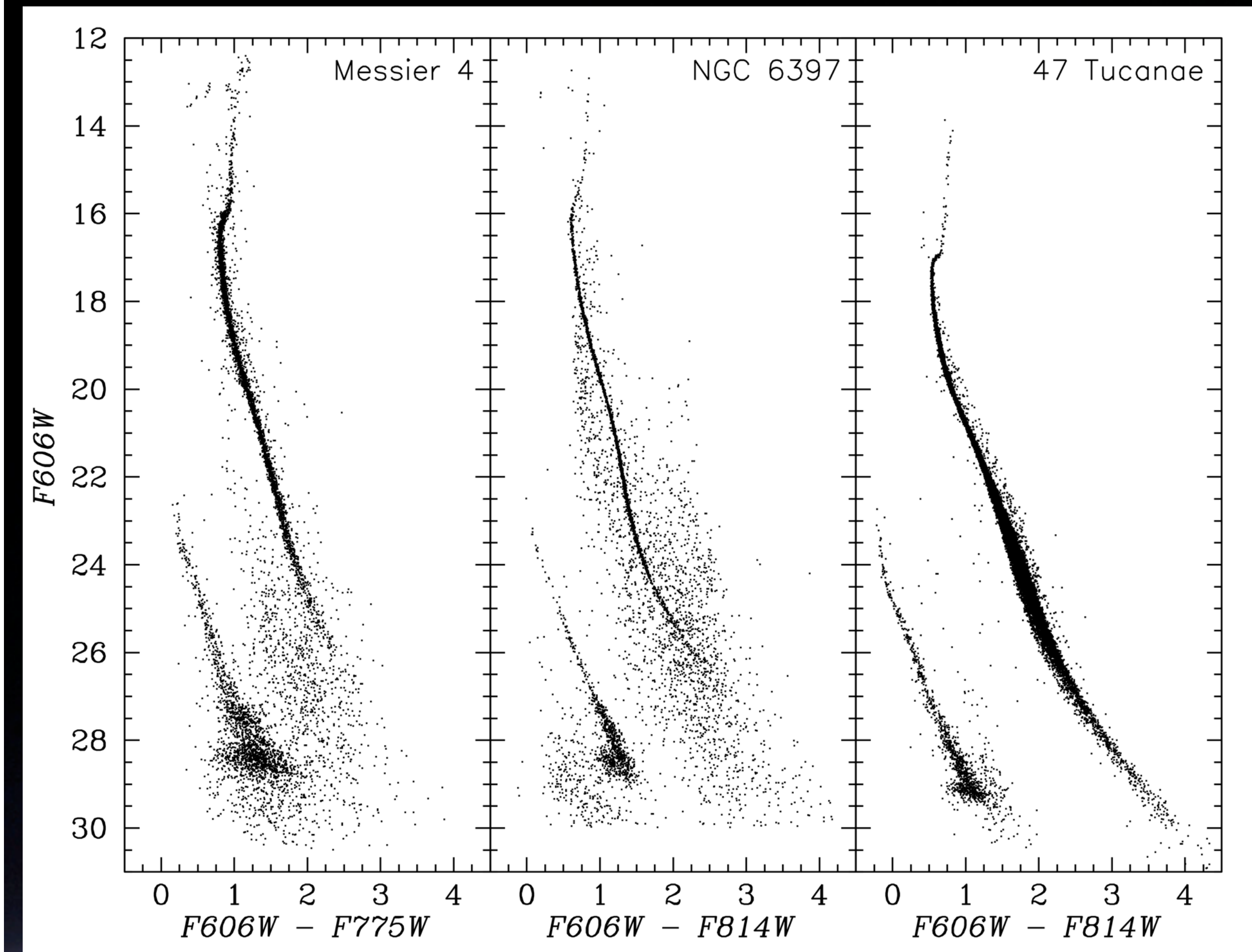
Buonanno et al. (1994)

Generally much more populous than open clusters – see all phases evolution – even short-lived ones

47 Tucanae – a Globular Cluster



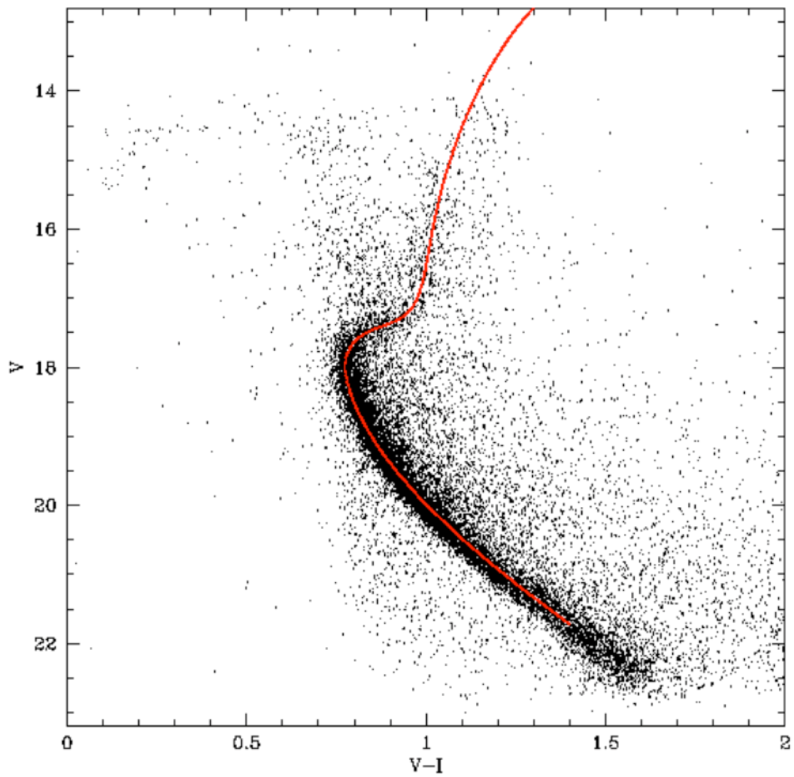
The Current State of the Art



Anderson et al. (2008)
Kalirai et al. (2012)

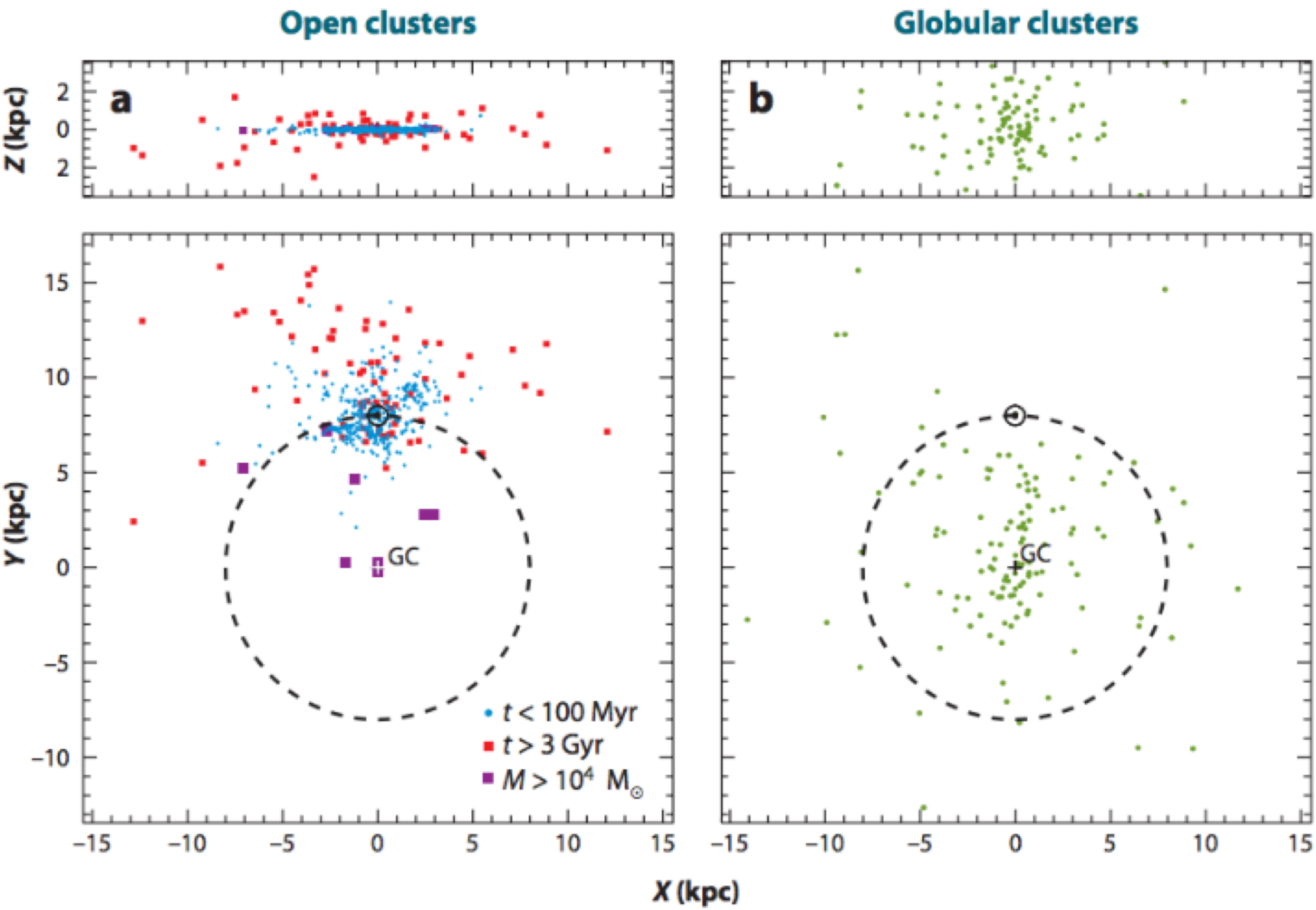
Recent Hubble Space Telescope Programs (PI H. Richer)				
Cycle	Star Cluster	Distance	[Fe/H]	Orbits
9	Messier 4	2.2 kpc	-1.2	123
13	NGC 6397	2.3 kpc	-2	126
17	47 Tuc	4.5 kpc	-0.7	121

Isochrones in HR Diagram

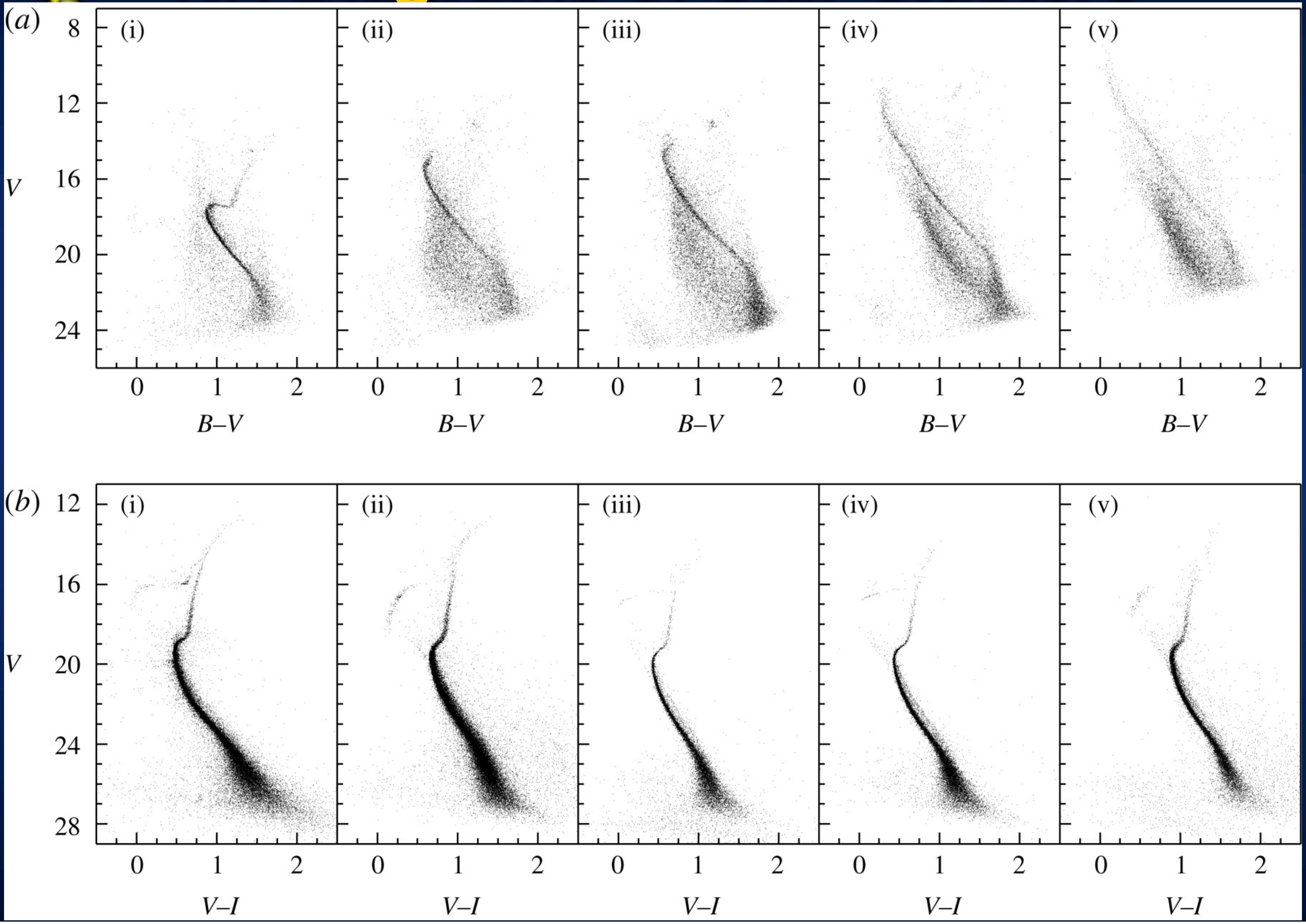


Globular Cluster NGC 3201 – 5.2 kpc. Red line is a theoretical isochrone with age = 12 Gyr.

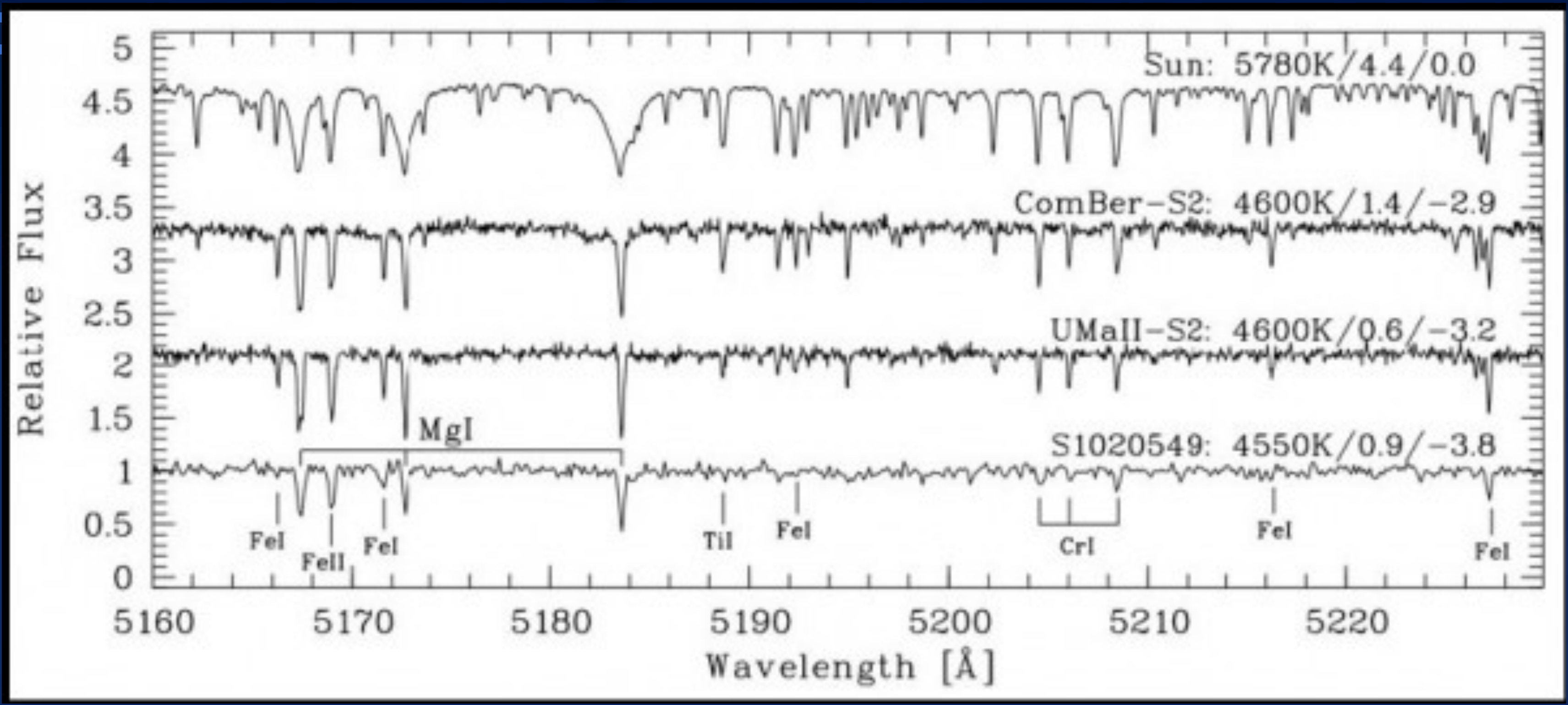
Star Cluster Galactic Distribution



HR Diagrams of Star Clusters



Metallicity Effects in Stars

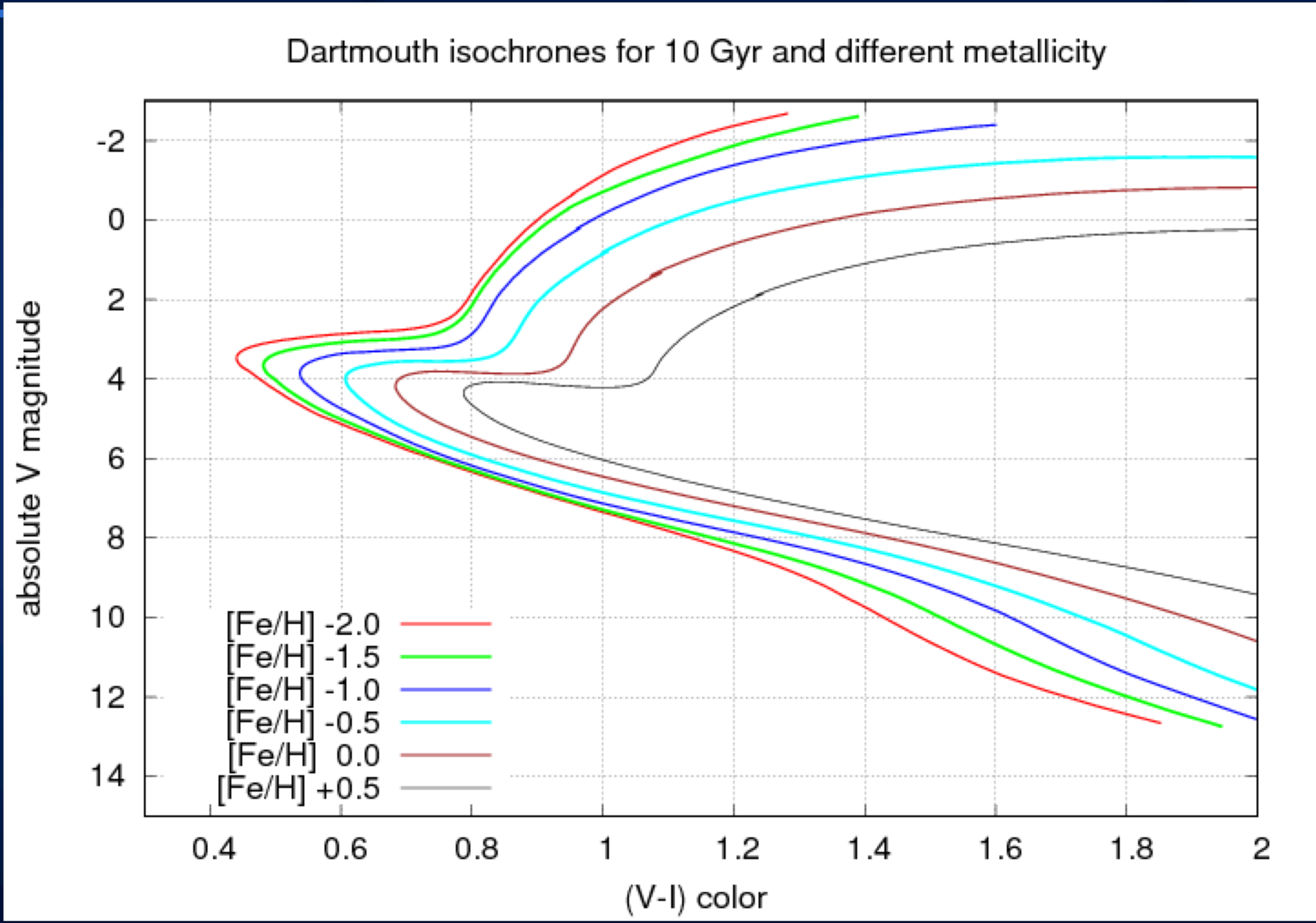


Metal Abundance Characterized by [Fe/H] which is defined as

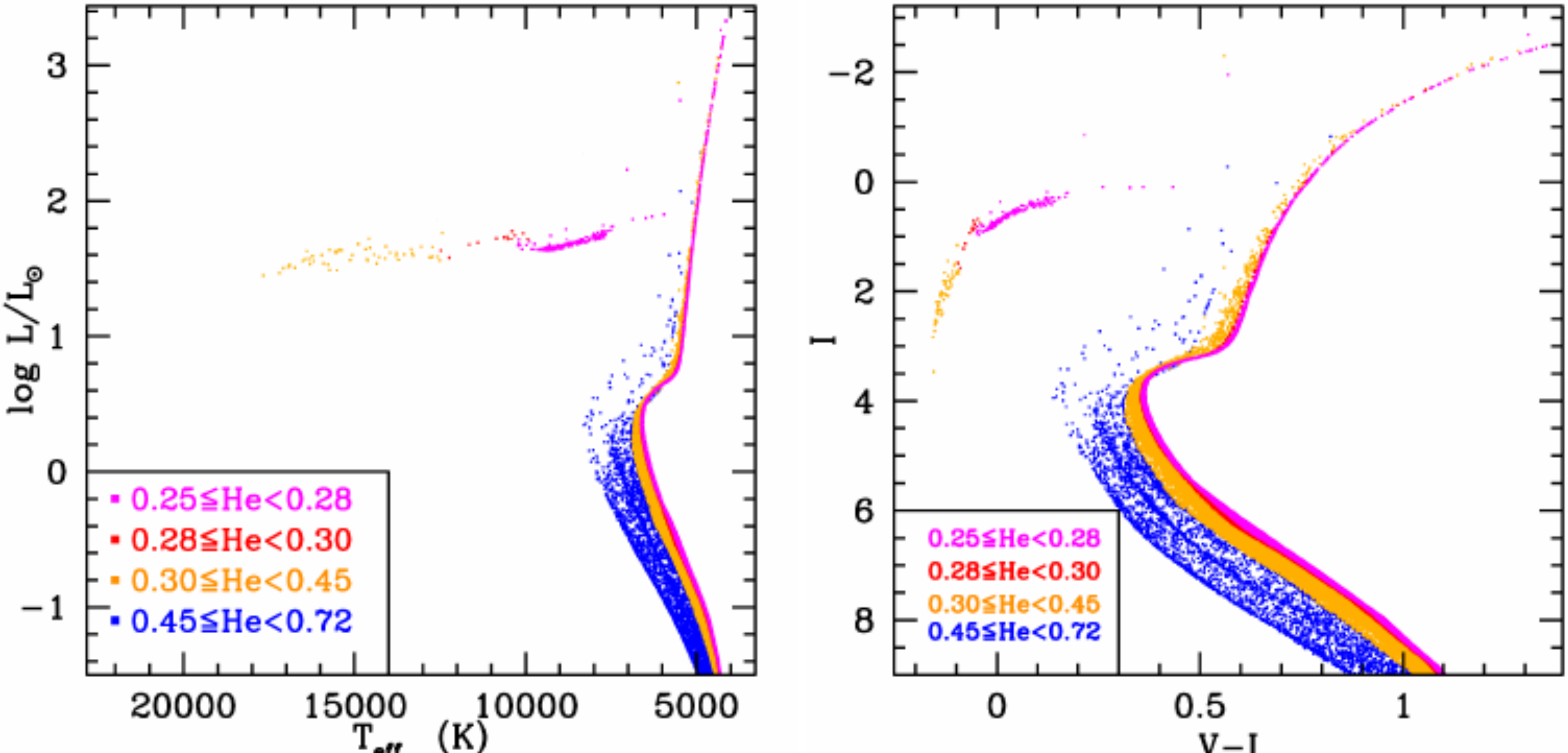
$$[Fe/H] = \log(N_{Fe}/N_H)_{star} - \log(N_{Fe}/N_H)_{sun}$$

Range in [Fe/H] ~ +0.2 - ~ -5.0

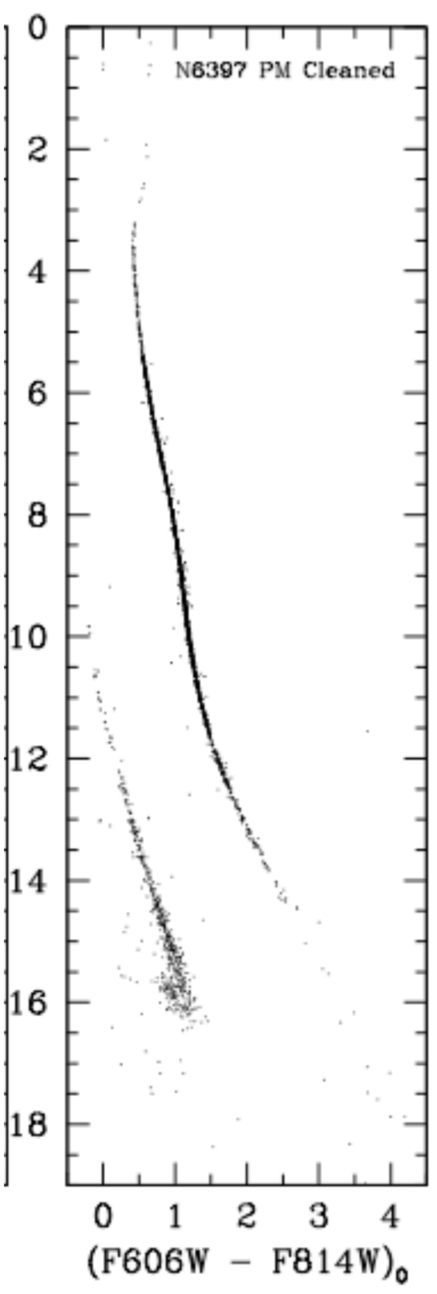
Metallicity Effects in HR Diagram



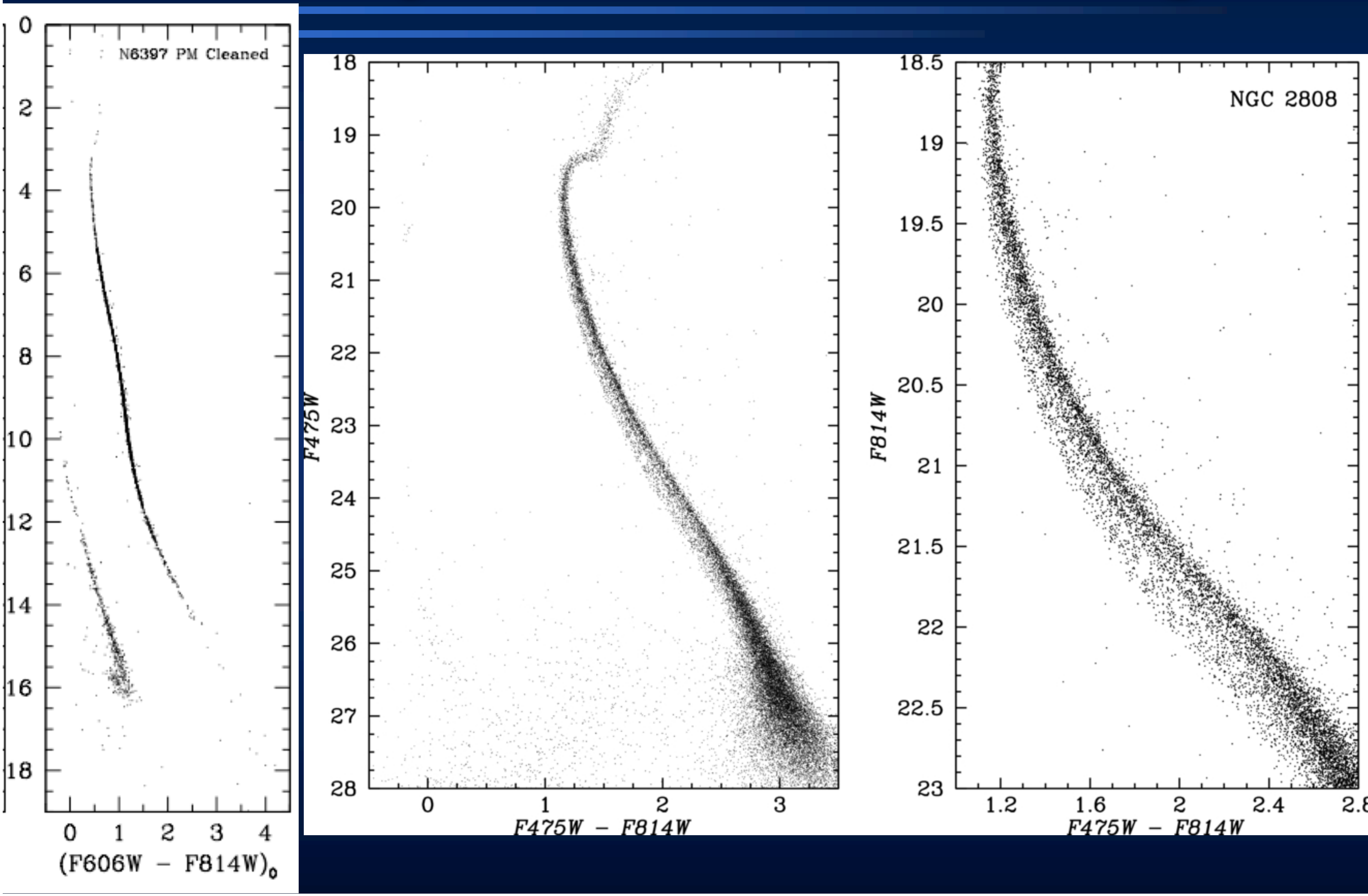
Helium Effects in HR Diagram



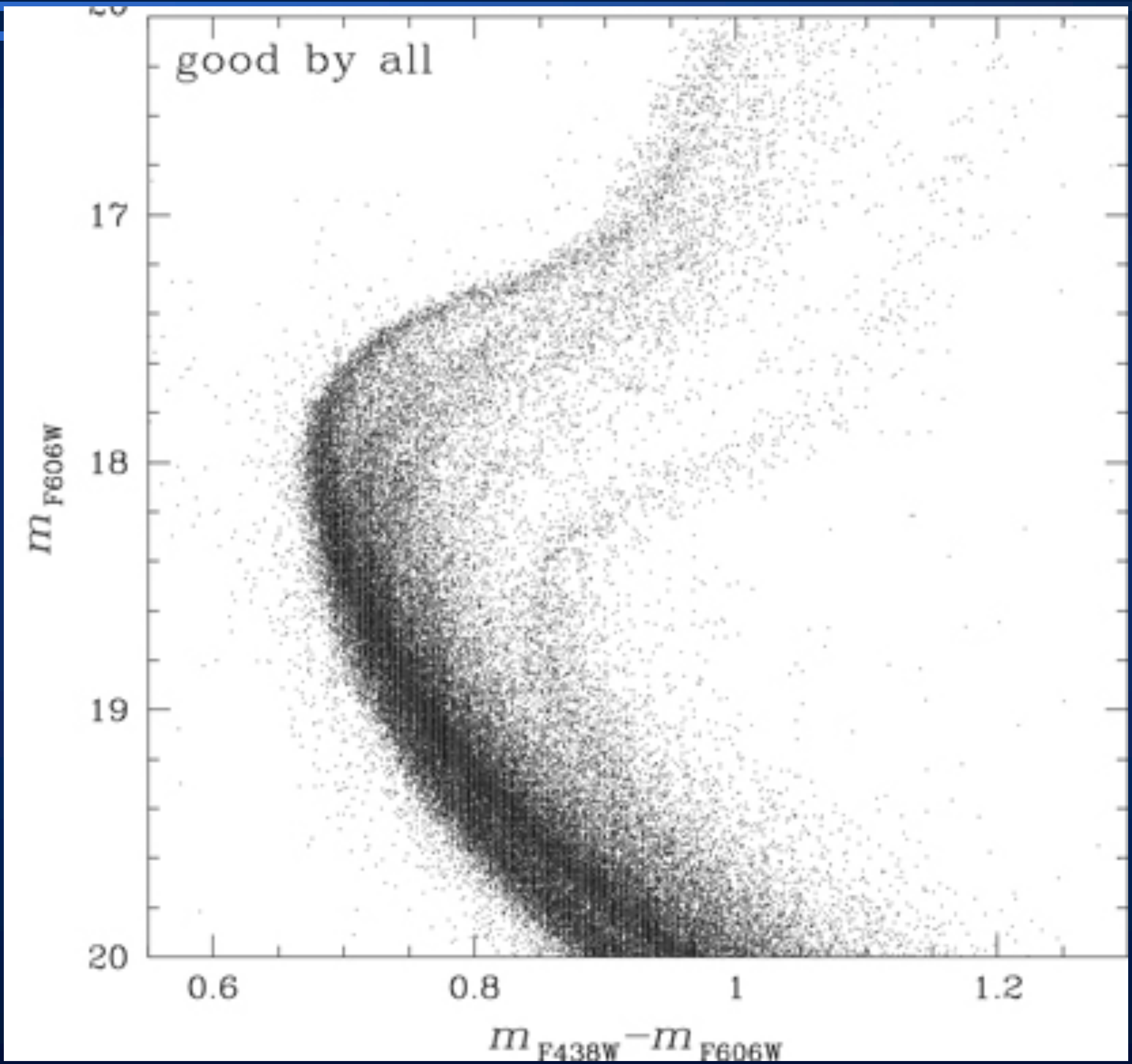
Metallicity Effects in HR Diagram



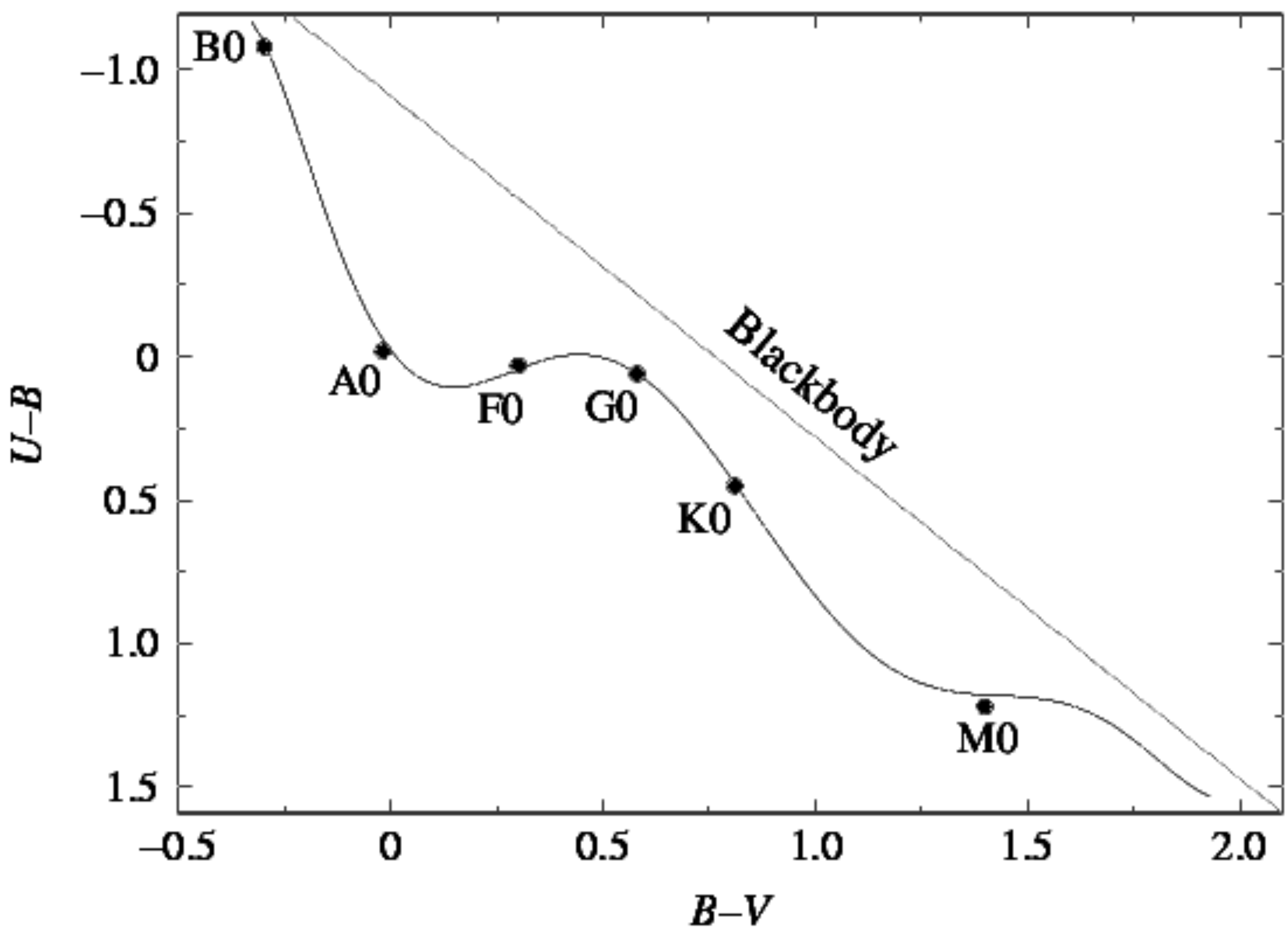
Metallicity Effects in HR Diagram



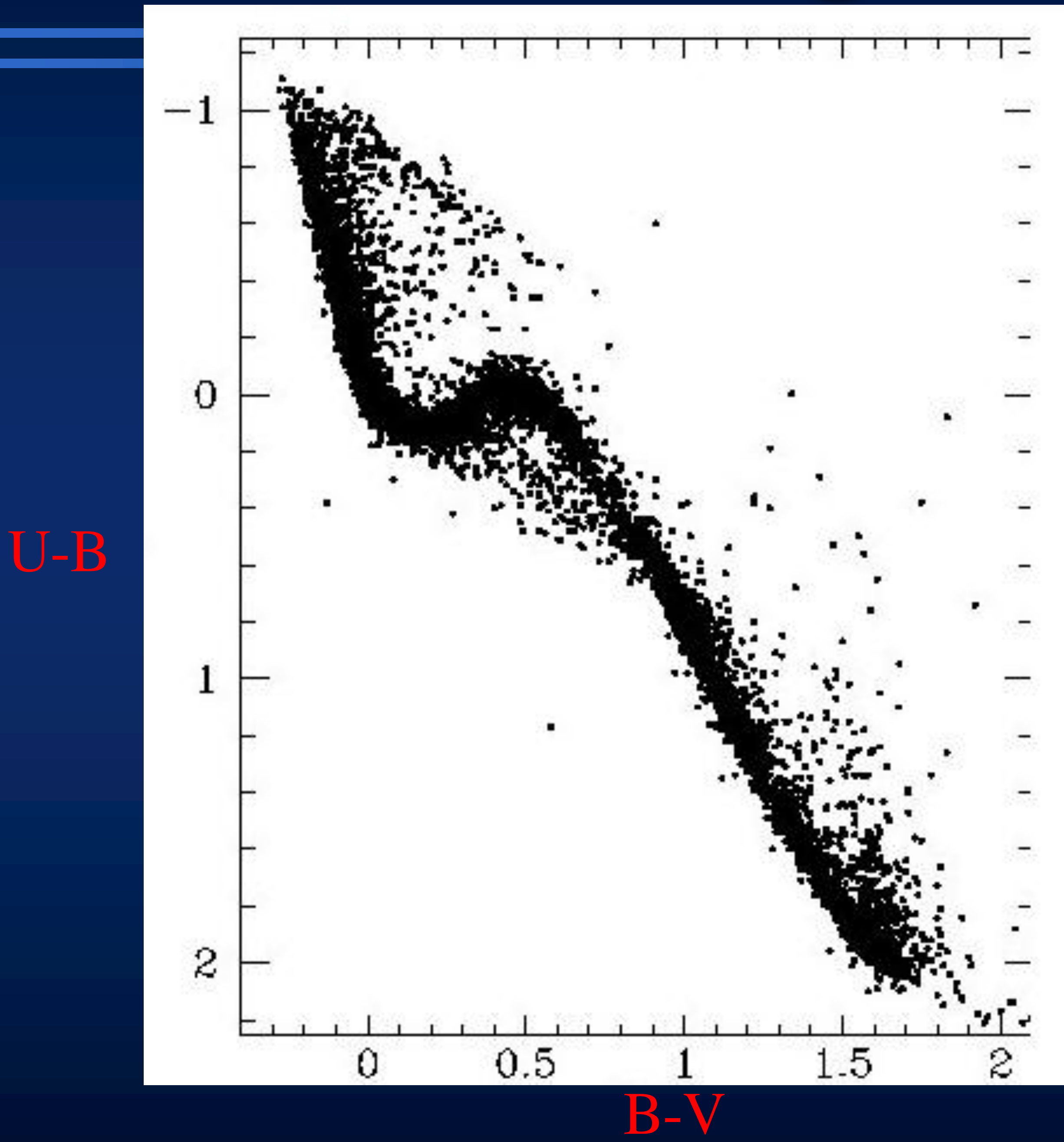
Metallicity Effects in HR Diagram



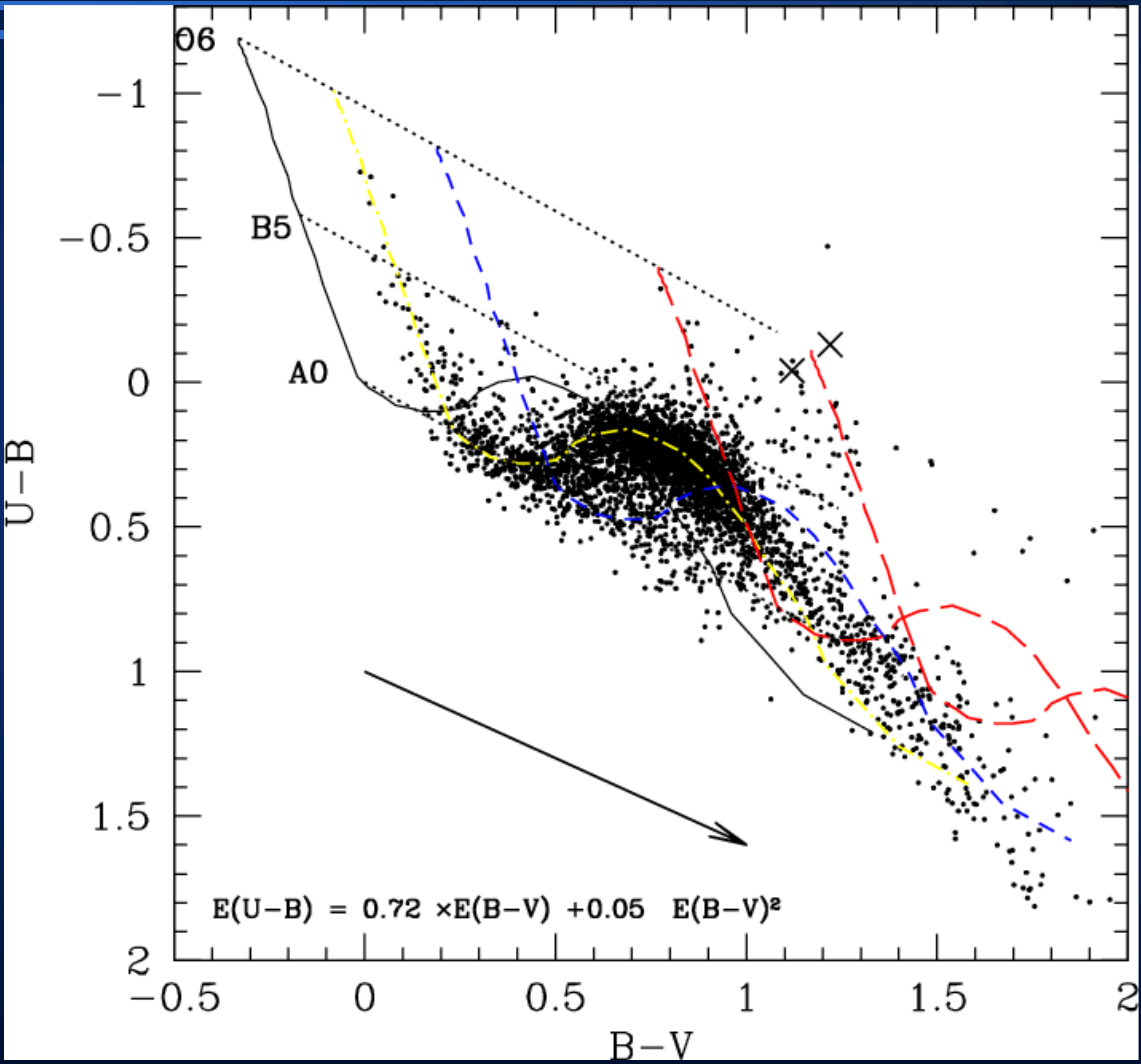
Colour-Colour Diagram - Theory



Colour-Colour Diagram - Data

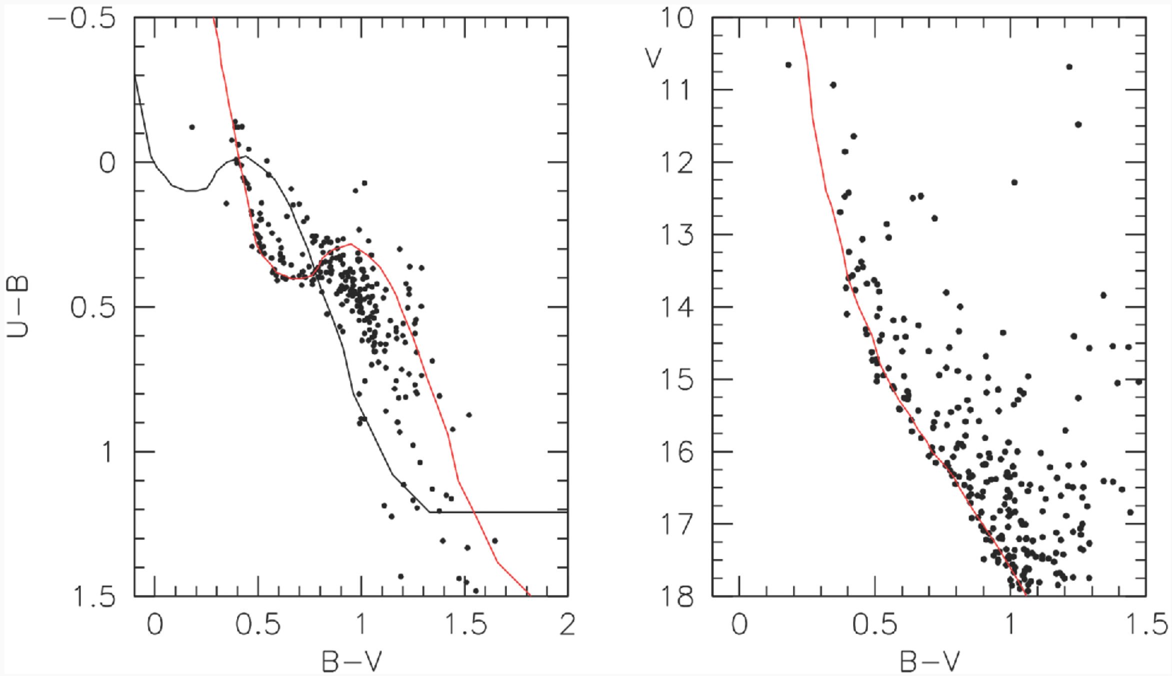


Colour-Colour Diagram - Data



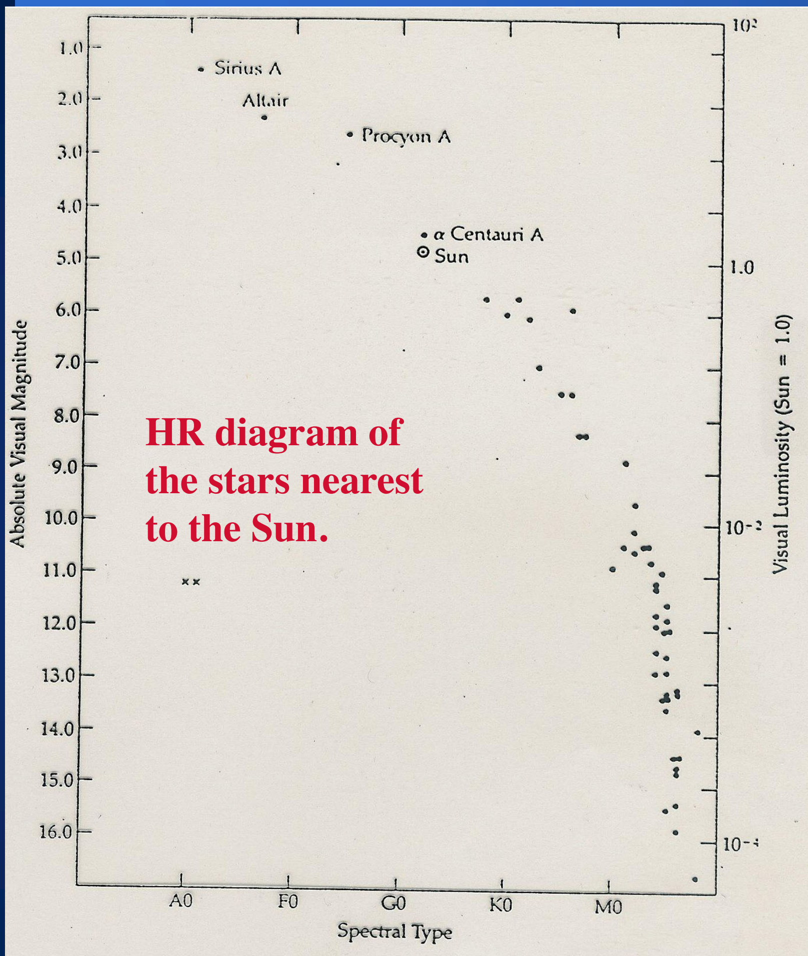
Colour-Colour Diagram - Data

Figure 1.

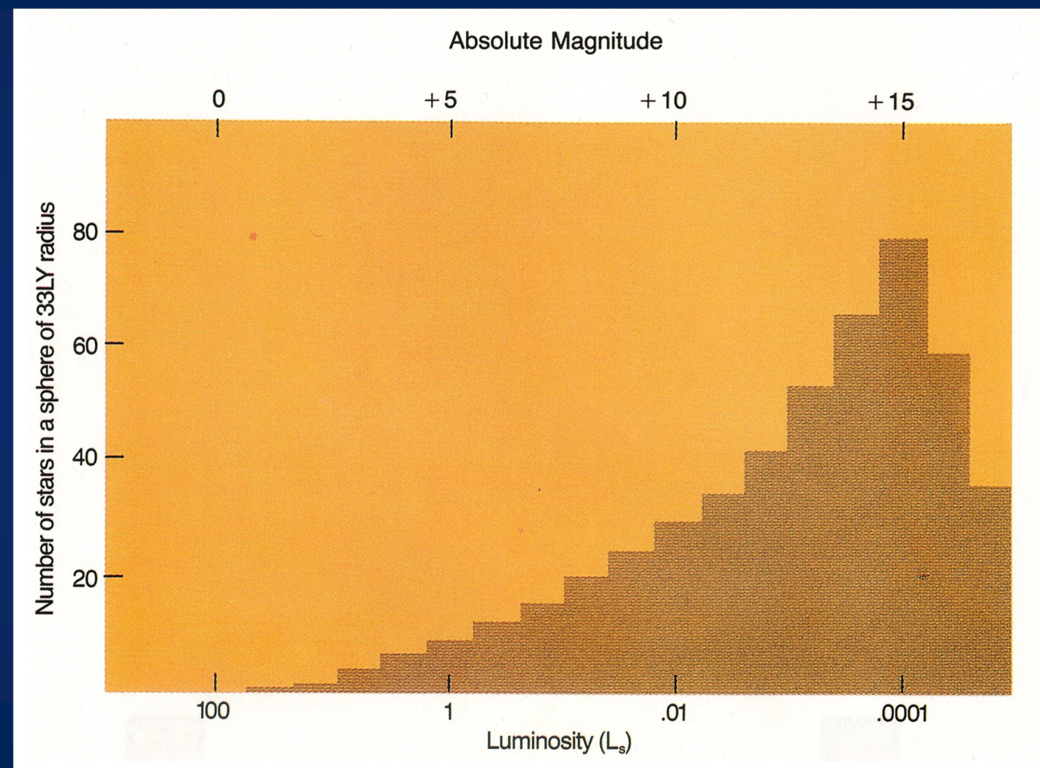


Left-hand panel: colour–colour diagram for Trumpler 22 stars within 4 arcmin from the cluster nominal centre. The solid lines are zero-age main-sequence relations for no-reddening (black line) and for $E(B - V) = 0.48$ (red line). This latter line nicely fits the bulk of early-type stars. Right-hand panel: colour–magnitude diagram for the same stars as in the left-hand panel. The solid line has been displaced horizontally, by $E(B - V) = 0.48$, and, vertically, by $(m - M) = 13.10$.

Hertzsprung-Russell Diagram



Beware of the selection effects in the HR Diagram

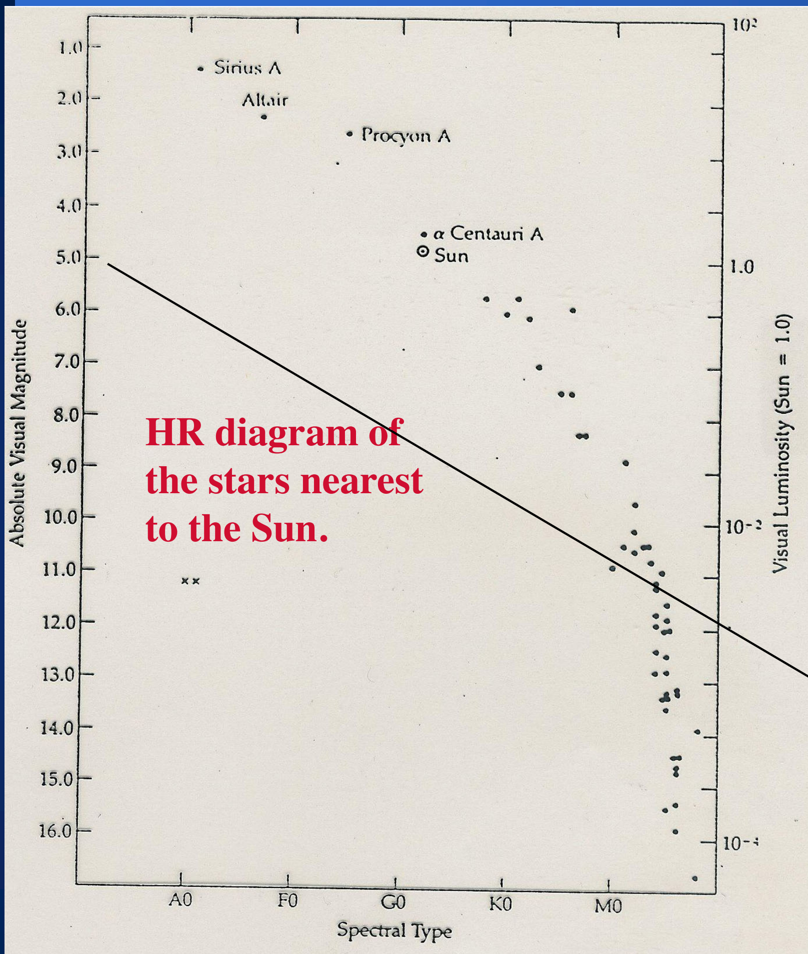


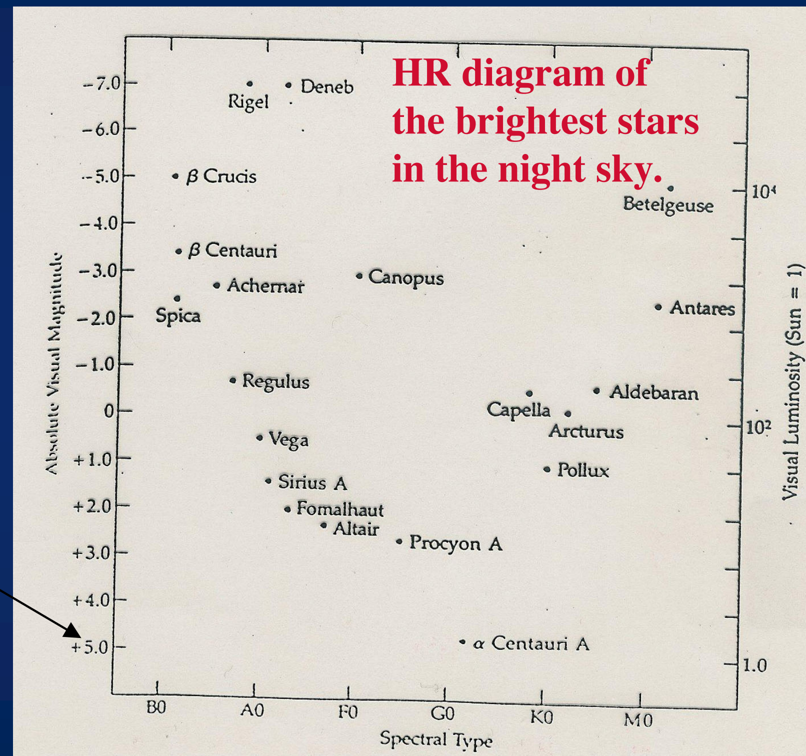
This is a proper sample of faint stars. Note that none of the rarer giant stars are within this volume of space.

Luminosity Function of Stars Near to Sun

Hertzsprung-Russell Diagram

Beware of the selection effects in the HR Diagram





This is a proper sample of faint stars. Note that none of the rarer giant stars are within this volume of space.

The number of giant and supergiant stars is small but they can be seen over vast distances.