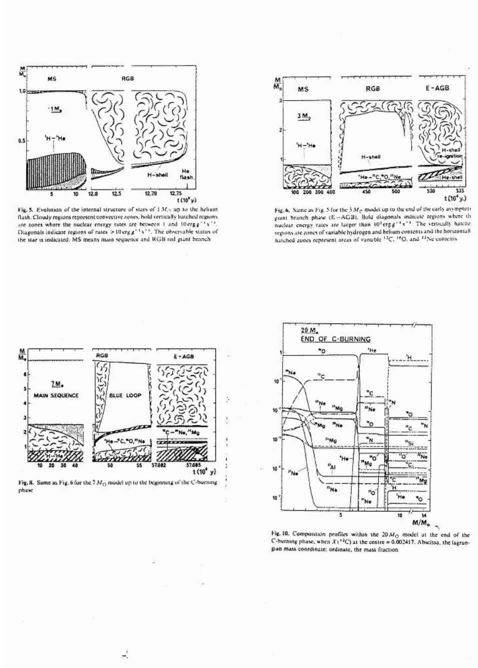
Notes: 1. Extremely massive stars

- Radiation pressure → mass loss by stellar wind during m-s phase at rates of 10^{-5} - 10^{-7} M_{Sun} / yr

  i.e. several M_{Sun} during m-s phase.

- Outer layers (H + He) lost to the star so that products of CNO cycle (N, He) become exposed at surface.

- Shell source regions removed so may not become red-giants.
- will become the Wolf-Rayet stars which have abnormal abundancies of N, O, or C in their atmospheres (hence WN, WO or WC stars); plus dense stellar winds with mass loss ~ 10^{-5} M_{Sun} / yr



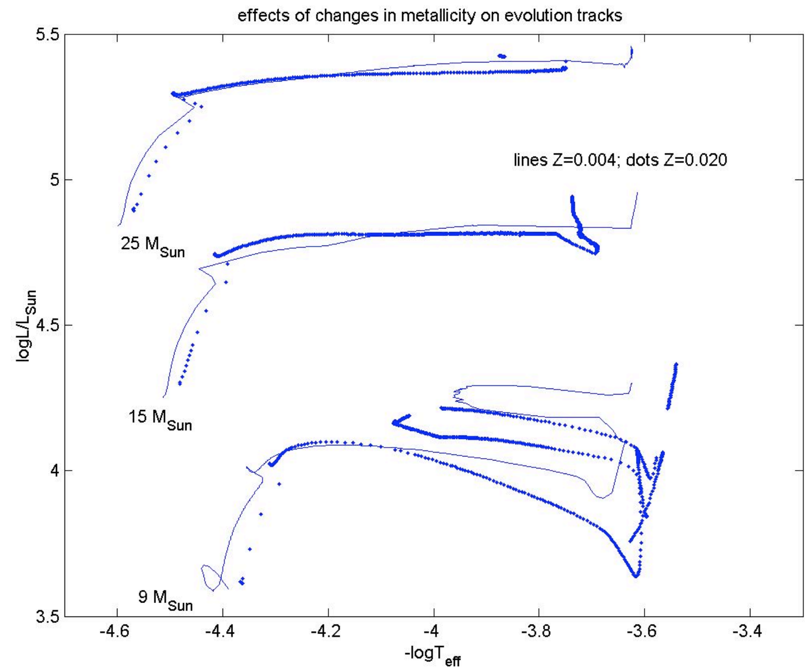
AS 2001 Stellar Structure and Evolution

2. Evolution for metal-deficient stars

- Evolution tracks for pop II stars similar in overall appearance to those for pop I.
- The p-p chain is used for H → He fusion since Z ~ 0.001 - 0.0001.
- All the more massive pop II stars in the MW Galaxy have evolved to their end states

  (> 10^{10} yrs) - but young metal-deficient stars of all masses seen in LMC / SMC .

AS 2001 Stellar Structure and Evolution



- **Obvious difference in evolution tracks is at core He fusion stage:**

  pop II clusters show an extended horizontal branch (h-b).

- **Mass loss at r-g stage (for ALL stars) reduces total mass. For low mass stars the core mass ~ 0.6 M_{Sun}, and the envelope mass determines the location on the h-b.**

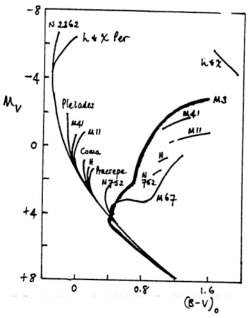
•Thin envelopes (ie smaller radius for same luminosity) at blue end of h-b,

thick envelopes at red end.

•So....extent of h-b in globular clusters reflects differences in mass-loss rates for individual stars at the r-g stage.

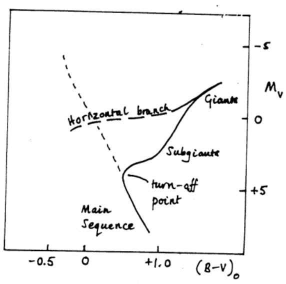
3. Colour - magnitude diagrams of star clusters

- Stars in cluster formed from same gas cloud at approx. same time.
- Hence appearance of C-M diagram reflects age of cluster
- e.g after 10^8 yrs,
  - M > 8 M_{Sun} stars evolved to end states
  - M ~ 5 M_{Sun} stars are core He fusion red / yellow supergiants (Classical Cepheid variables)
  - M < 5 M_{Sun} stars still on m-s



Composite H-R diagram for open clusters (with globular cluster M3 for comparison)

Schematic H-R diagram of a globular cluster



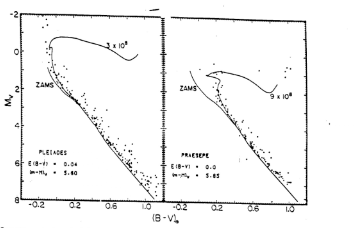


FIG. 7.—Comparison on the observational plane of selected isochrones (*solid curves*), as tabulated in this study, with published observations (*filled circles*) of the Pleiades and Praesepe star clusters. The sources of the photometry are given in Table 4. In each case, the cluster name and the adopted reddening and apparent distance modulus are specified in the lower left-hand corner. Isochrone ages in years are indicated near the base of the red-giant branch.

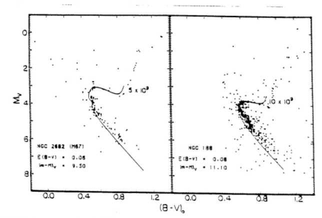
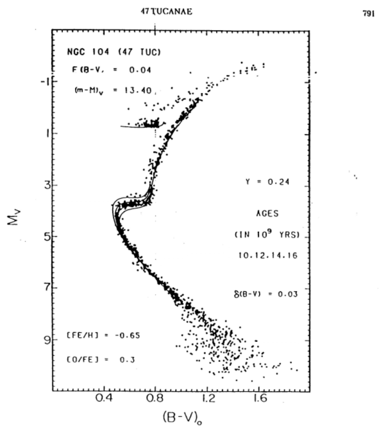


FIG. 9.—Analogous comparisons to those given in Fig. 7: in this case the theoretical isochrones are compared with published data for M67 and NGC 188.



- **Age of cluster determined by matching ISOCHRONE lines to C-M diagrams**

  NB: isochrone line - locus of evolution stages of stars of different masses at a given time.

- **e.g Pleiades ~ 3×10^8 yr**
  Praesepe ~ 9×10^8 yr
  M67 ~ 5×10^9 yr
  globular clusters ~ 15×10^9 yr

End states of stars

- Stars lose significant amounts of mass via stellar-wind processes at various stages:

  - low-mass stars: r-g and p-n stages
  - high mass stars: m-s and r-g stages

- Hence majority of stars end as white dwarfs with C + O cores + He - rich envelopes; more massive stars produce O - Ne - Mg cores .

WHITE DWARFS

Observations

- $M \sim 0.6\ M_{Sun}$
- $R \sim 0.01\ R_{Sun}$
- $M_V \sim +10$ to $+15$
- Sp. type B0 to M

Physics

- escape velocity = $(2GM / R)^{1/2} \sim 10^7\ ms^{-1}$ (!)
- mass density $\sim 10^9\ kgm^{-3}$
- electron-degeneracy pressure

  (remember....indep of temp, dep on density) helps support the star against own gravity

Size

- W-D cools by emission of radiation, and stays at constant radius; cooling time ~ 10^9 yrs

- theoretical models give good agreement with observations and find that $R \propto M^{-1/3}$
  - i.e. a more massive WD has a smaller radius

∴ upper limit to W-D mass of 1.4 M_{Sun} - the Chandrasekhar limit - i.e. upper limit to mass of WD that can be supported by electron degeneracy pressure.