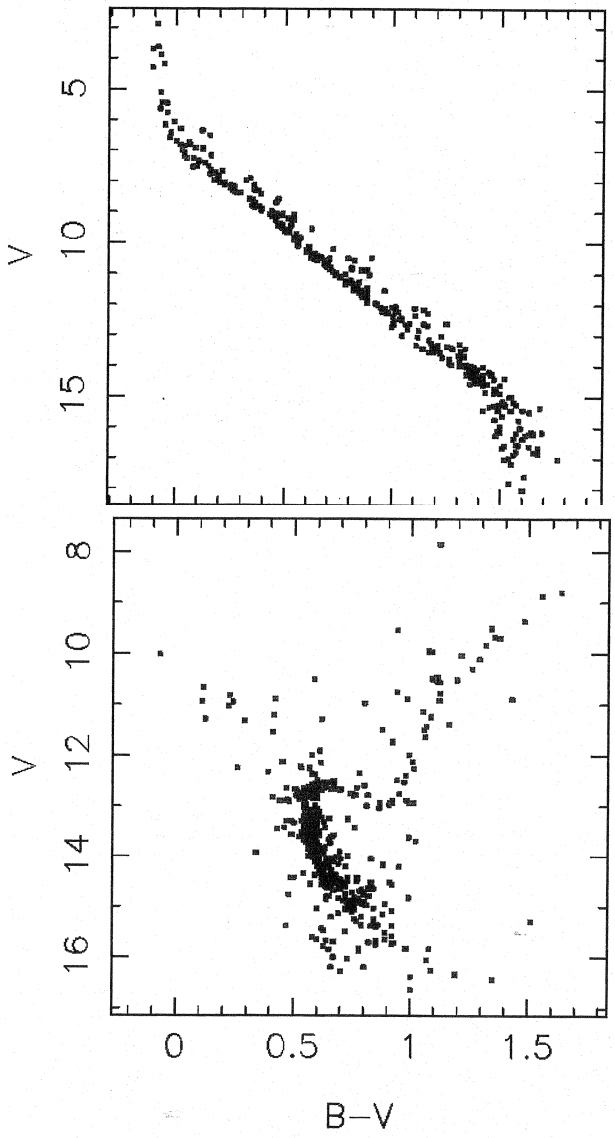
Astr 5465 Feb. 10, 2020

Characteristics of Color-Magnitude Diagrams

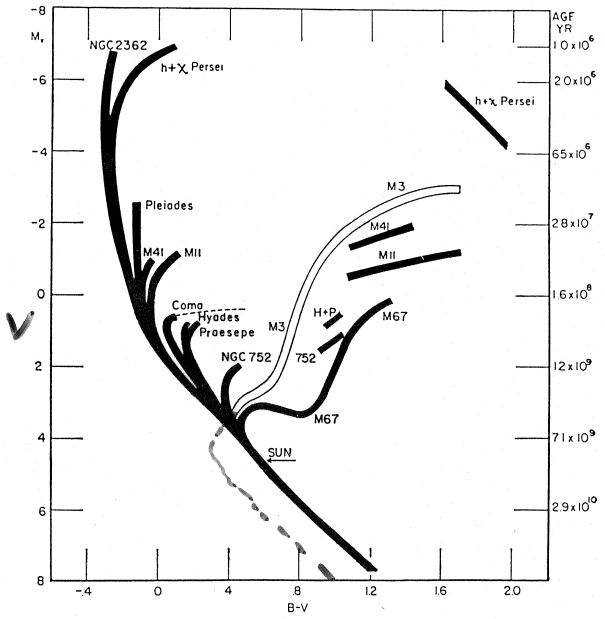
- **Preliminaries:**
- **Shape of an Isochrone (Distribution at a Given Age) Depends on the Bandpasses Used to Construct the CMD**
- **The Turn-off Absolute Magnitude and Color Depends on Both the Age and Metallicity ([Fe/H])**
- **Age:**
- **Turn-off Mass (at a given [Fe/H]) Corresponds to a Particular Luminosity and T_{eff} (color)**
- **Metallicity:**
- **At a Given Luminosity Both the Bolemetric Correction and the Color Depends on [Fe/H].**
- **Most Galactic Clusters are within 0.2 dex in [Fe/H], Globular Clusters Span 1 dex: -2 < [Fe/H] < -1**

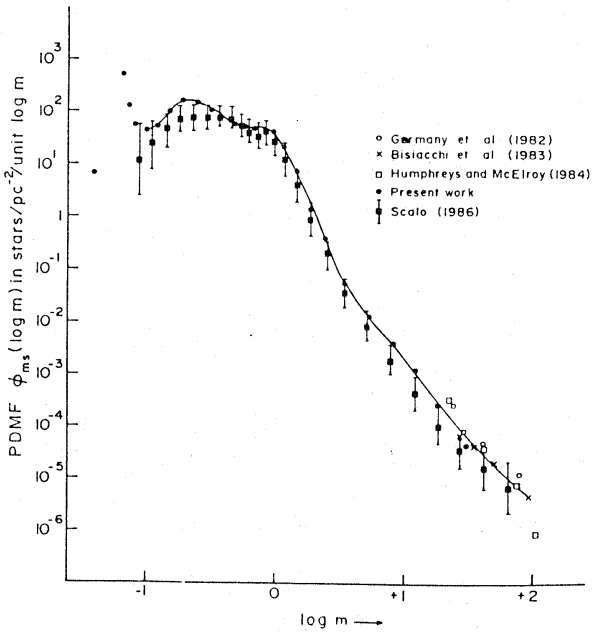


Zero Age Main Sequence

- **Empirically defined by piecing together HR diagrams and CMDs from clusters over range of ages (youngest can show age spread).**
- **Main Sequence lifetime is a strong function of mass.**
  - **Maximum unevolved mass indicates age**
- **Rapid evolution of massive and intermediate-mass stars creates Hertzsprung Gap (fills in for $t > 10^9$ years)**
- **Main Sequence for low metallicity stars displaced blueward.**
- **Initial Mass Function [N(M)] is characterized by a Power-Law (e.g. Rama 1987, AA, 184, 104):**

- **$N(M) = A\ M^{-(1+x)}$**
  - **where $x = 1.8$ for $M > 1\ M_o$ (much fewer massive stars)**
  - **and $x = -1.0$ for $M < 0.8\ M_o$ (approx. constant vs. mass)**





Stellar Evolutionary Models

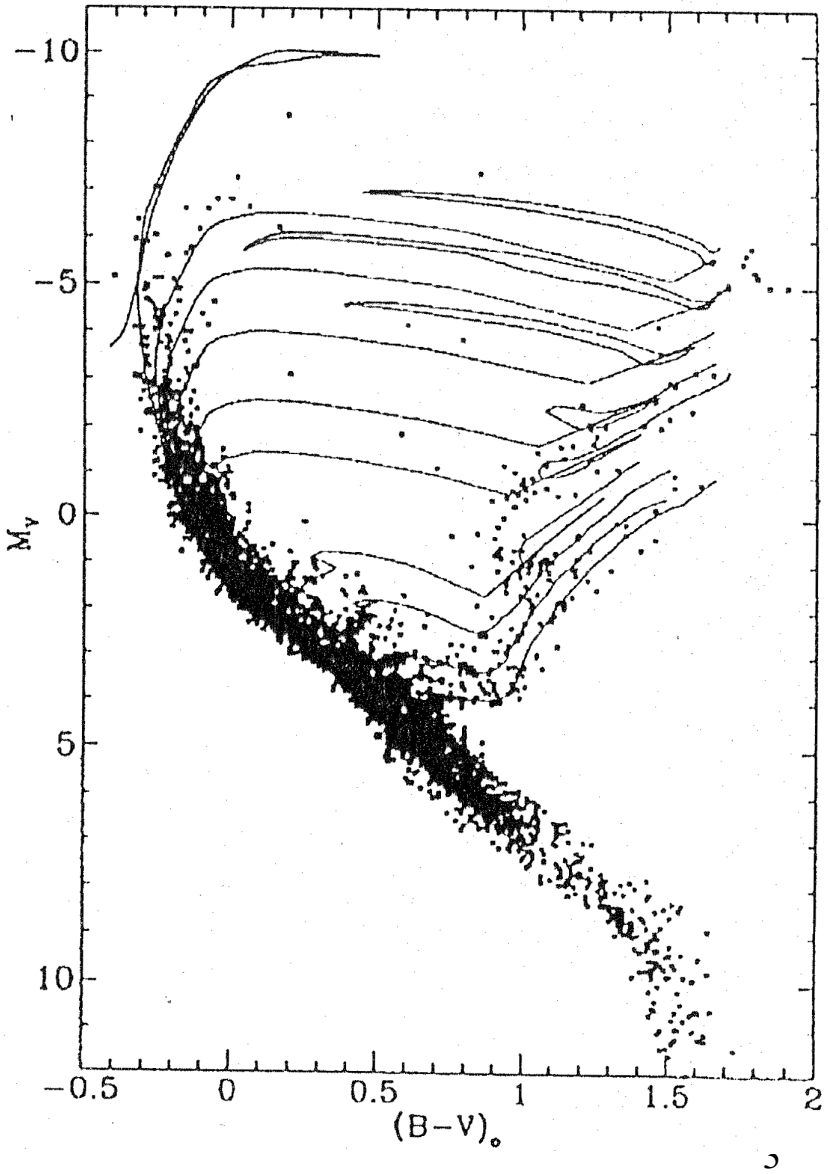
- **Stellar Evolutionary Models can be Used to Parameterize the Turn-off Mass (L_V or $(B-V)_{TO}$] vs Age (e.g. vandenbergh et al. 1996 ARAA, 34, 461)**
  - **Log M(t) = 0.0558 $\log^2$ (t) – 1.338 log (t) + 7.764 (Solar [Fe/H], Y = 0.23), and:**
  - **Log t_9 = -0.41 + 0.37 M_V (TO) – 0.43 Y – 0.13 [Fe/H]**
- **So ΔM_V = 0.03 -> $\Delta T = 10^9$ years**
- **For Y = 0.23 and t > few x 10^9 years (Streniero & Chieffi 1991, AJS 76, 525):**
- **$(B-V)_{TO}$ = 0.3140 + 0.3092 log (t) + 0.2713 [Fe/H] + 0.0543 $[Fe/H]^2$**
- **Models predict observed luminosity function along isochrones suggesting the evolutionary rates are accurate.**
- **Oxygen-Enhanced Models Suggest Younger Ages**
- **Modern models:**

  http://obswww.unige.ch/Recherche/evol/Geneva-grids-of-stellar-evolution

  http://pleiadi.pd.astro.it/
- **Online models:**

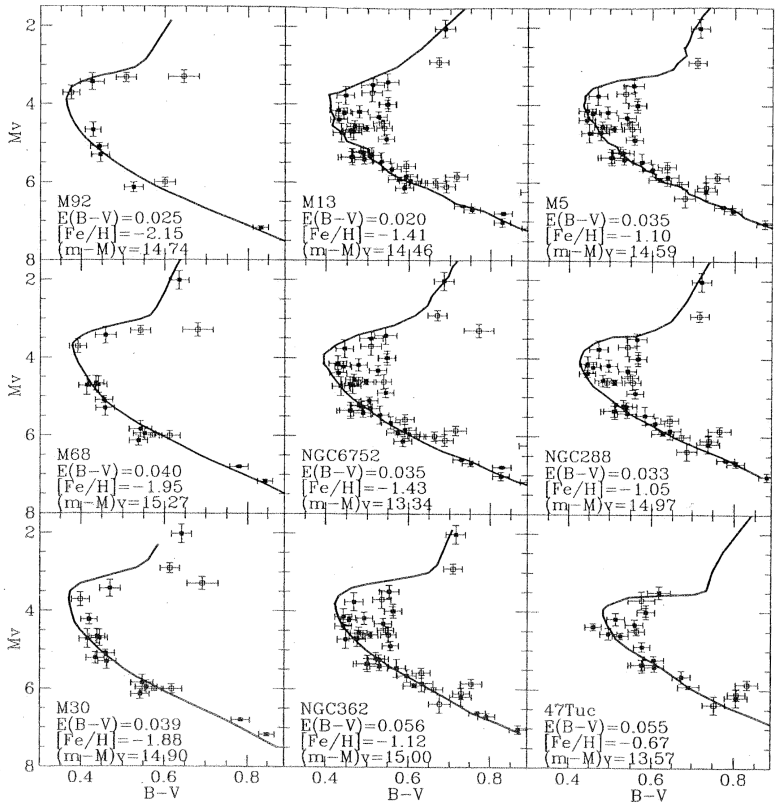
  http://stev.oapd.inaf.it/cgi-bin/cmd

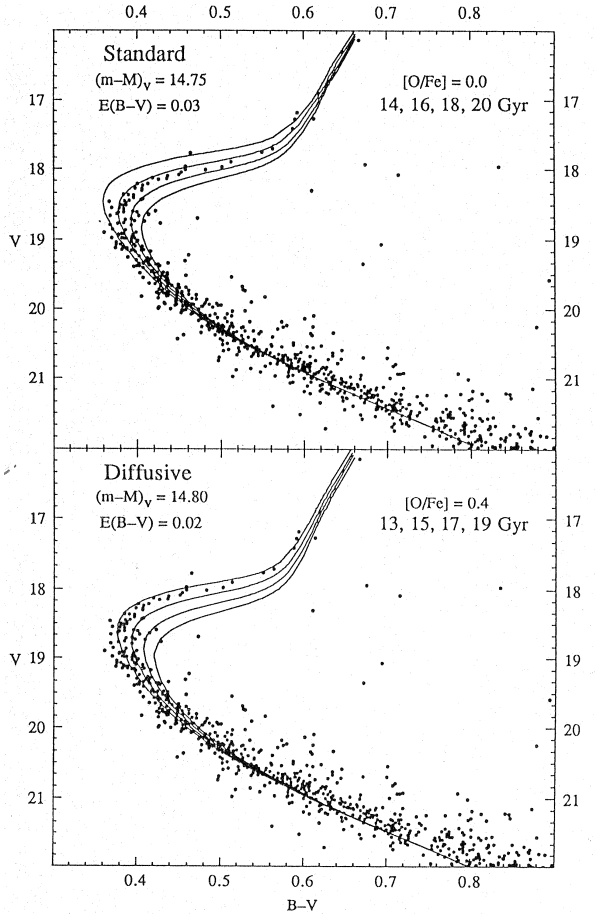
  http://stellar.dartmouth.edu/



Testing Stellar Models and Isochrones

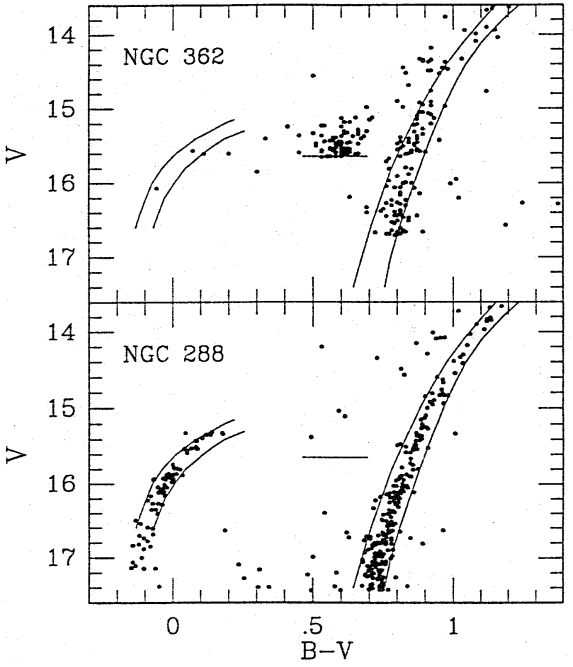
- **Globular Clusters can be Rank-Ordered by Metallicity (spectroscopy of giants)**
- **Isochrone Fitting Requires Knowing the Distance or Metallicity of Cluster**
- **Nearby Sub-dwarfs with Accurate Distances and Known Metallicities for MS Fitting**
- **Pre-Hipparcos:**
  - **Bolte & Hogan 1994 Nature 376, 399**
  - **Vandenbergh et al. 1996, ARAA, 34, 461**
- **Hipparcos:**
  - **Gratton et al. 1997, ApJ 491, 749**
  - **Caretta et al. 2000, ApJ, 533, 215**

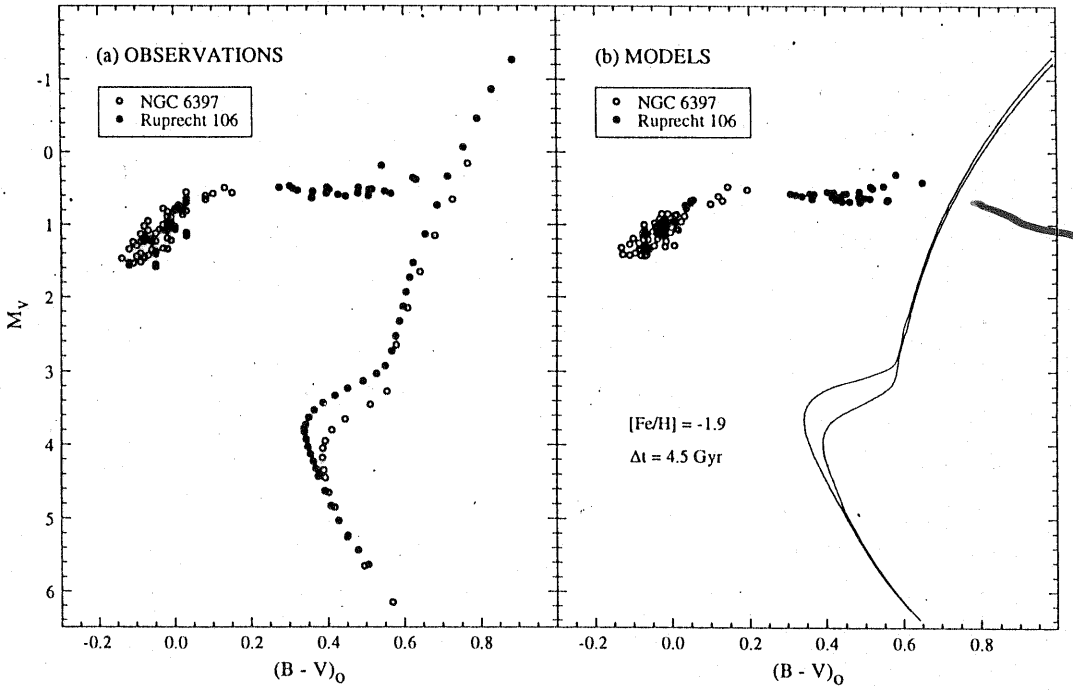


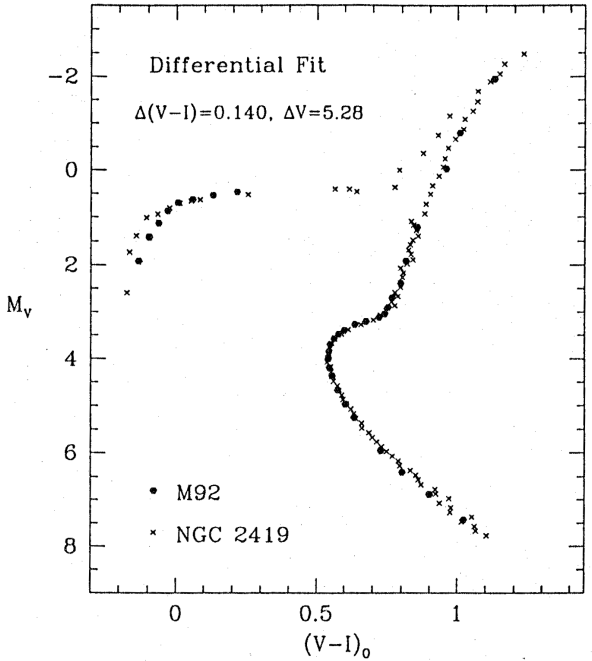


Horizontal Branch Morphology

- **Matching RR Lyrae on HB matches distances**
  - **Different turn-off luminosities: range of ages**
- **Blue-ward Extent of HB Depends upon [Fe/H] (e.g. 47 Tuc vs. M13).**
  - **HB stars lower mass than RGB (mass loss)**
- **Second-Parameter Pairs: sets of two Globular Clusters with the same [Fe/H] but differing HB morphology:**
  - **M13 – M3; NGC 6397 – Rup.106; NGC 288 – NGC 362; M92 – NGC 2419**

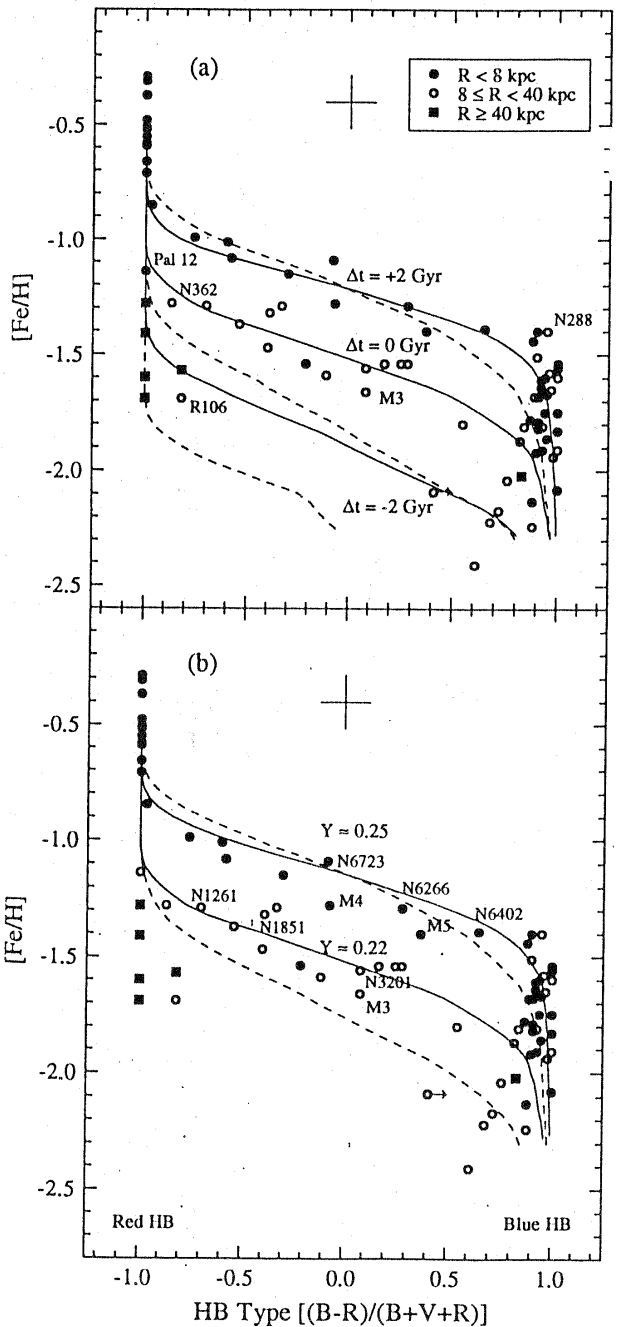






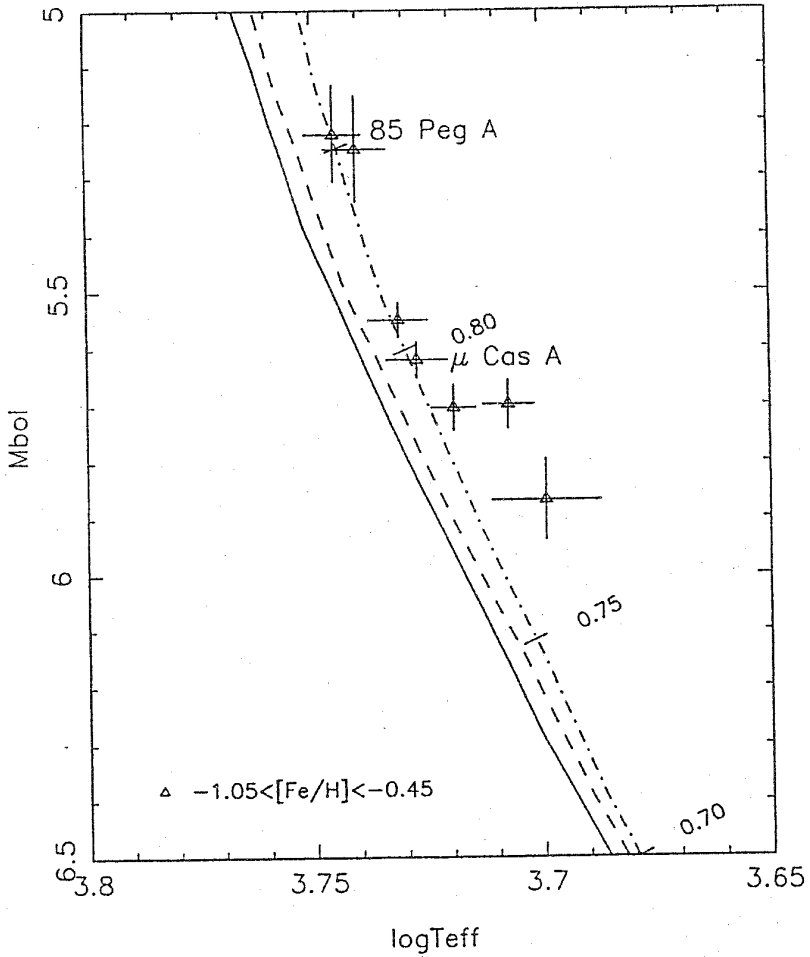
Horizontal Branch Morphology - II

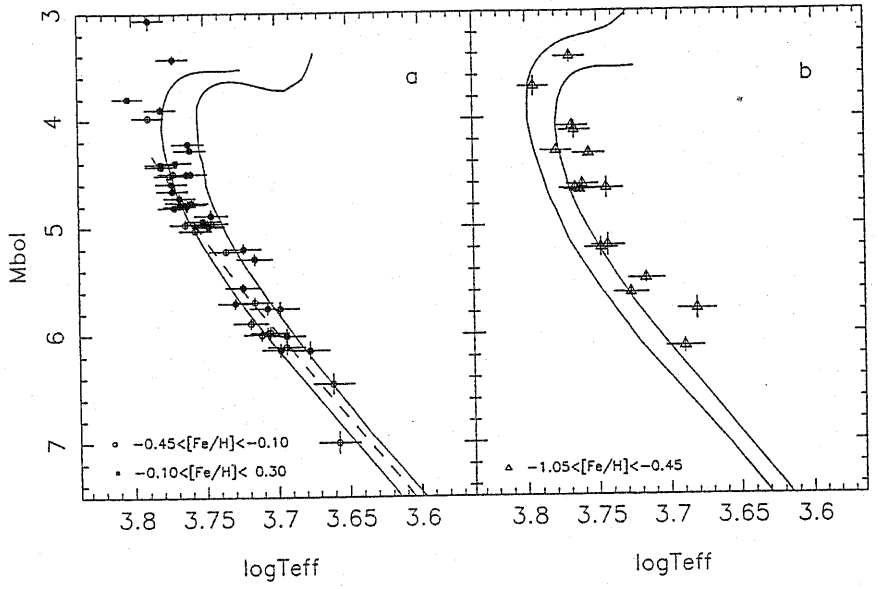
- **HB morphology can be quantified (e.g. Lee et al. 1994, ApJ, 423, 248):**
-
- **HB Type: (#B - #R)/(#B + #V + #R) correlates with [Fe/H] but with a spread.**
- **Most of spread is explainable as Δt (Richer et al. 1996, ApJ, 463, 602) but outliers suggest something more, ΔY (e.g Johnson & Bolte 1998, AJ 115, 673)?**

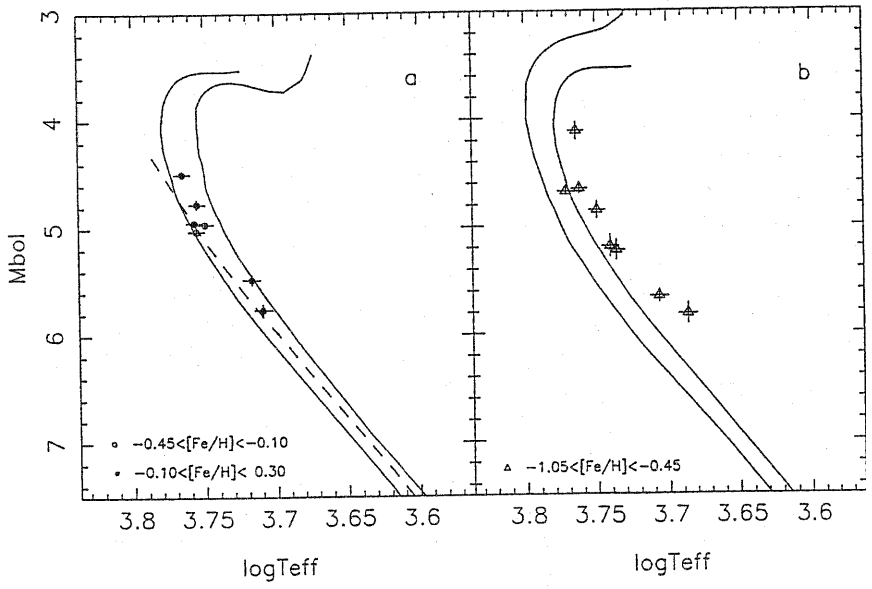


Testing Models with Hipparcos

- **Nearby stars with precision distances (Hipparcos)**
  - **Isochrones fit higher metallicities very well**
  - **Not so good for lowest metallicities**

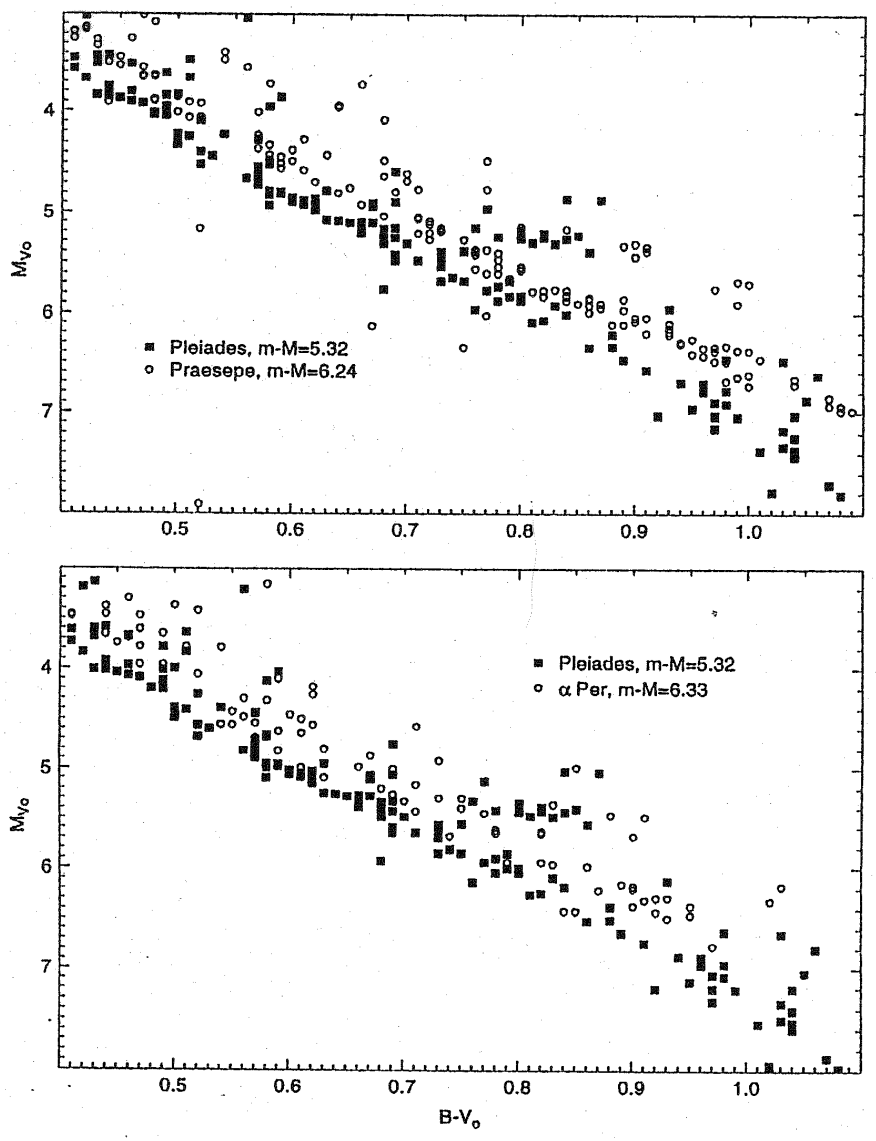






Testing Models with Hipparcos - II

- Nearby Galactic clusters with precise distances have discrepant main sequences.
- Metallicities are well known (Solar)
- Additional unaccounted for physics?
  - Rotation is likely suspect
  - Newer models (Geneva) allow for mixing from differential rotation.
- Despite some uncertainties models look pretty good at describing simple stellar populations.



Evidence for Distinct Populations in Omega Centauri

- **The Luminous Globular Cluster Omega Cen is Well Known for Having Anomalous Colors**
- **(Searle & Zinn 1980s)**
- **Deep, High-quality CMDs from HST Reveal Distinct Stellar Populations**
  - **Bellini et al 2010, AJ 140, 631**
- **Evidence for Distinct Ages & Metallicities**
  - **Separate Turn-off Luminosities**
  - **Complex Horizontal Branch**
  - **Offset Main Sequences**
  - **Extended Main Sequence (Blue Stragglers)**