

Designation of star clusters

- IAU:
 - $C aa bb \pm ccd$
 - $aa^h bb^m \pm cc^o.d$, Coordinates (1950.0)
- Catalogues:
 - IC, M(essier), NGC, and OCL
- „Discoverer“, surveys and „special names“
 - Basel, Bochum, Lynga, Melotte, Stock, Trumpler and much more
- Pleiades: C 0344+239, M45, Melotte 22

Classification of open clusters

- Trumpler, 1930, Lick Observatory Bulletin, 420, 154, **three criteria**
 1. **Degree of Concentration**
 2. **Range of Brightness**
 3. **Number of Stars in the Cluster**
- Janes & Adler, 1982, ApJS, 49, 425: definition of a so-called **richness class**
- Open clusters can also be classified on the basis of color-magnitude diagrams

Trumplers classification

- **Degree of Concentration**
 - **I** ... Detached clusters with strong central concentration
 - **II** ... Detached clusters with little central concentration
 - **III** ... Detached cluster with no noticeable concentration
 - **IV** ... Clusters not well detached, but has a strong field concentration

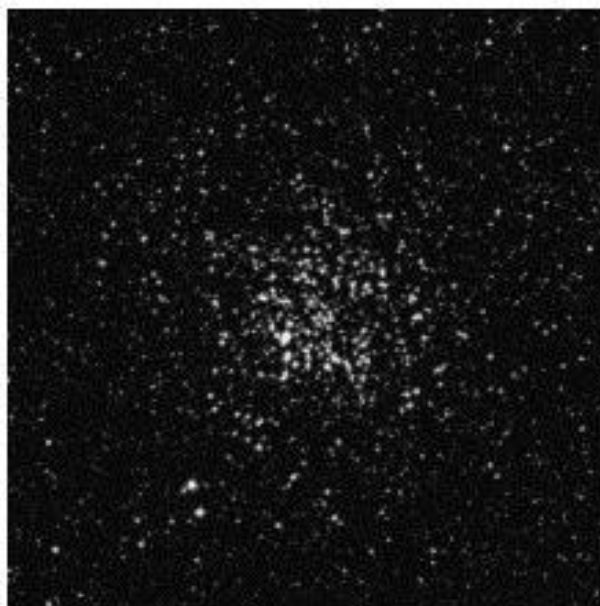
Trumplers classification

- **Range of Brightness**
 - **1** ... Most of the cluster stars are nearly the same apparent brightness
 - **2** ... A medium range of brightness between the stars in the cluster
 - **3** ... Cluster is composed of bright and faint stars

Trumplers classification

- **Number of Stars in the Cluster**
 - **p** ... Poor clusters with less than 50 stars
 - **m** ... Medium rich cluster with 50 to 100 stars
 - **r** ... Rich clusters with over 100 stars
- Open clusters with any type of nebulosity are denoted with an "n" at the end of the classification.





M11 15.0'
Class: I 2 r



M46 15.0'
Class: II 2 r



NGC 6664 15.0'
Class: III 2 m



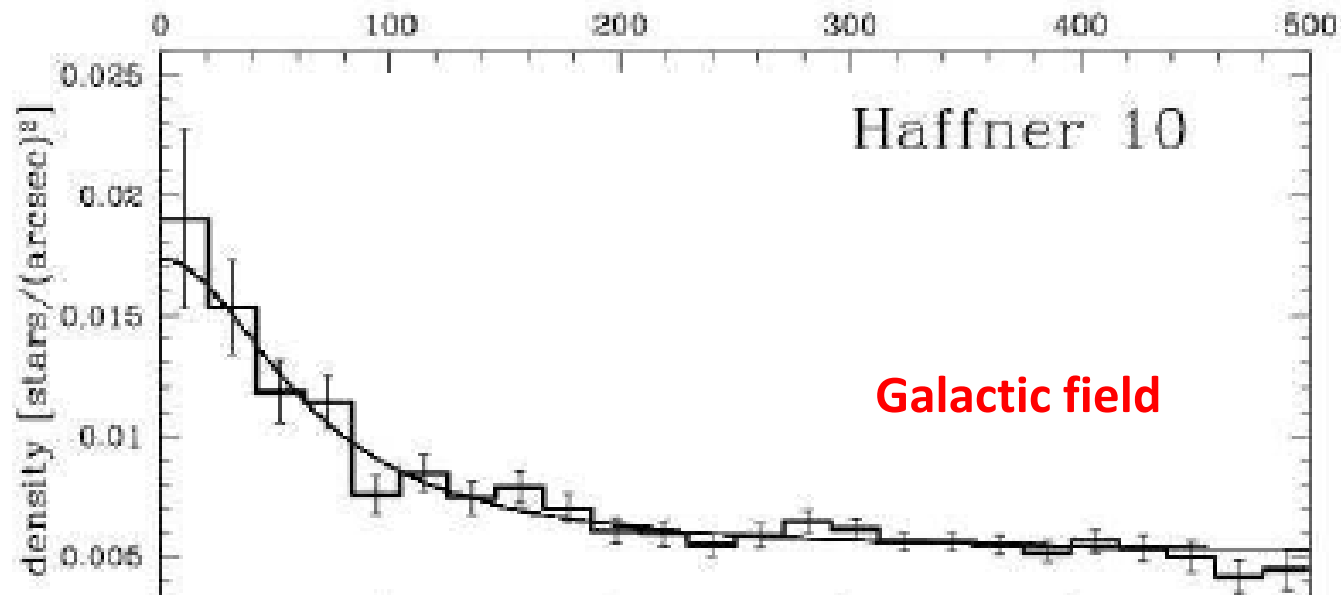
NGC 6568 25.0'
Class: IV 1 m

- **Richness Class (Janes & Adler)**
 - **1** ... Less than 25 stars
 - **2** ... Between 25 and 50 stars
 - **3** ... Between 50 and 100 stars
 - **4** ... Between 100 and 250 stars
 - **5** ... More than 250 stars
- How “good” can the number of members be established?

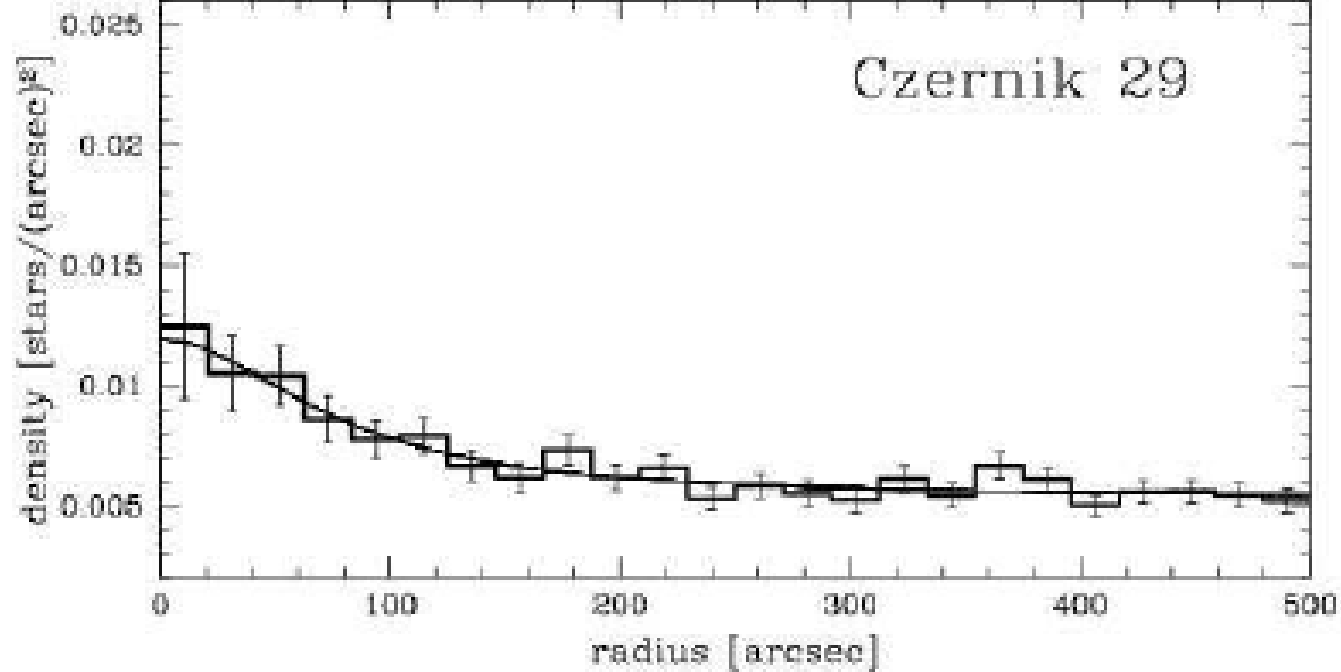
Diameters of open clusters

- How could we determine the diameter of a star cluster?
 1. The determination, for example inspection by eye, should be no problem. Be careful, most open clusters show no real concentration
 2. Count the number of stars (members) in concentric rings around the cluster center
 3. If the derived distribution is not symmetric => go to 1. and shift the coordinates of the center
- This procedure could be easily done via a computer program

III 2 m



II 2 m



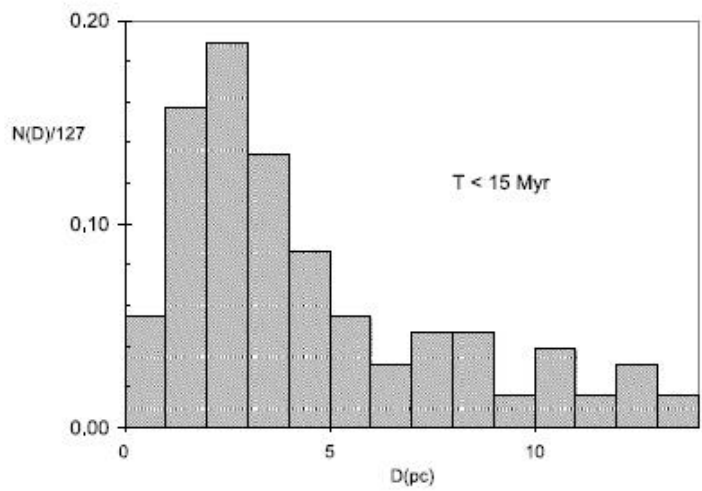


FIG. 2a

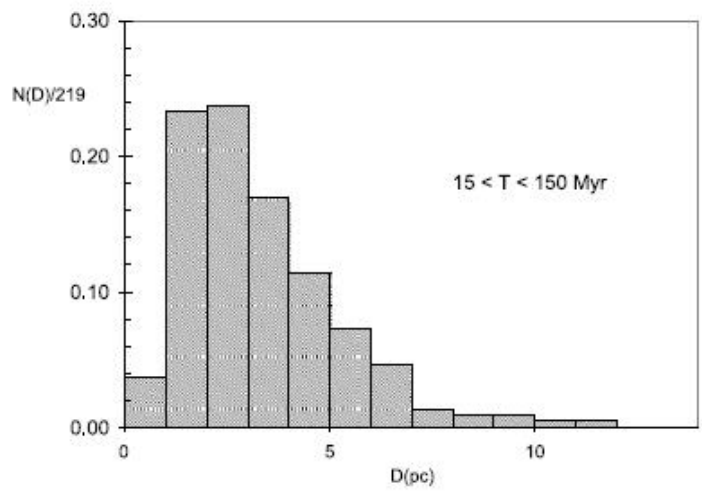
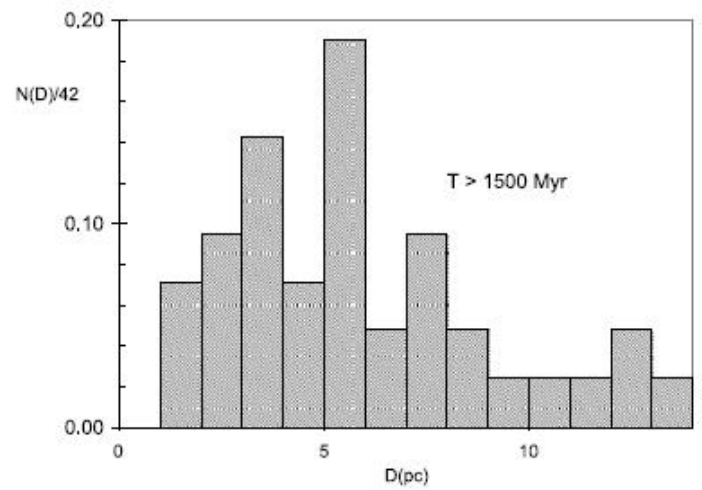
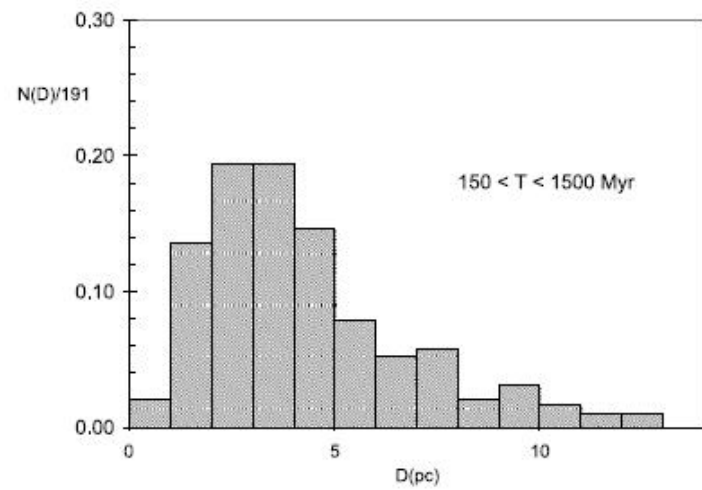
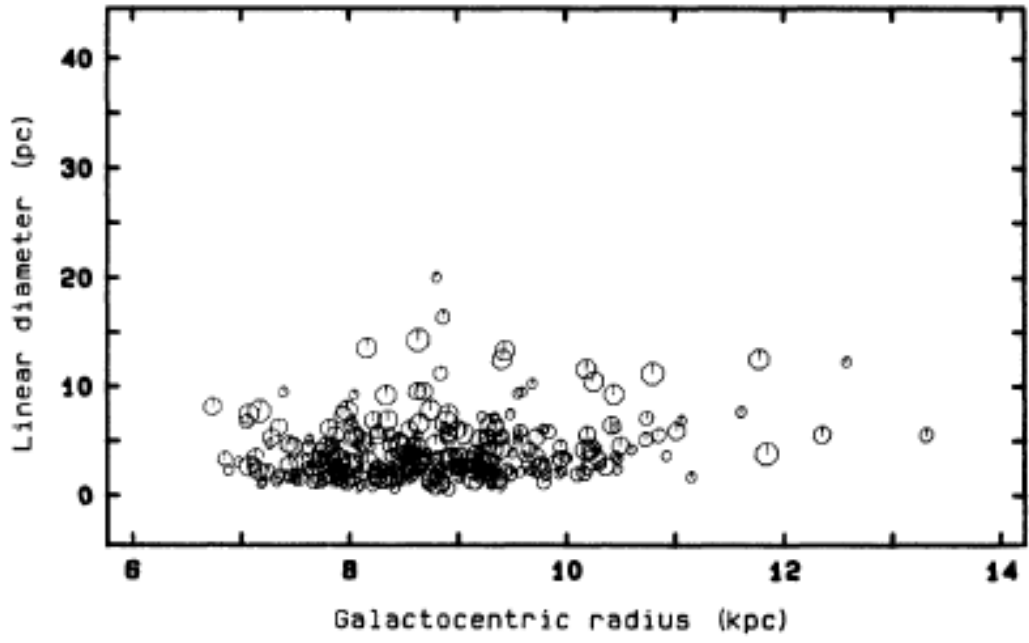


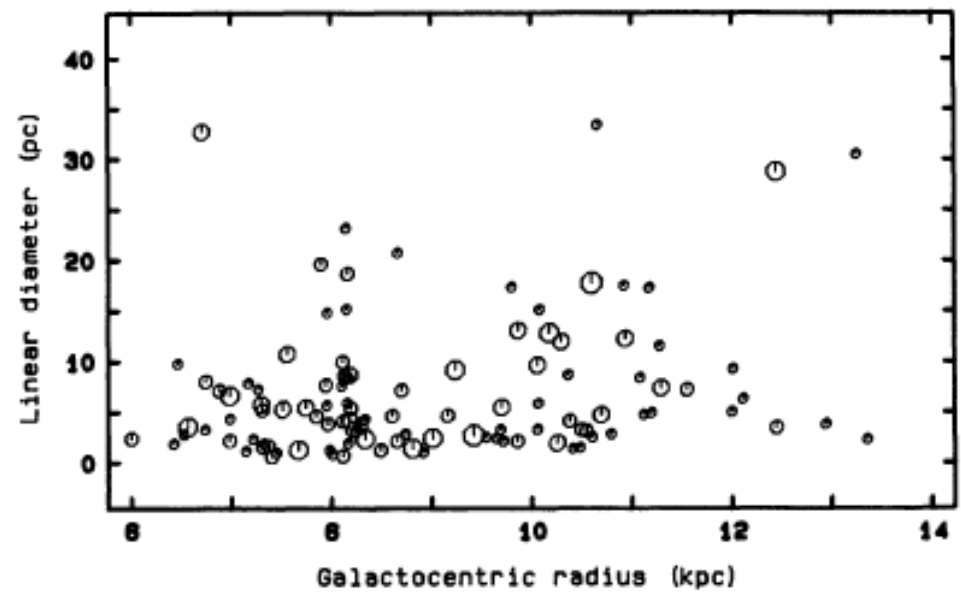
FIG. 2b



No correlation with the age

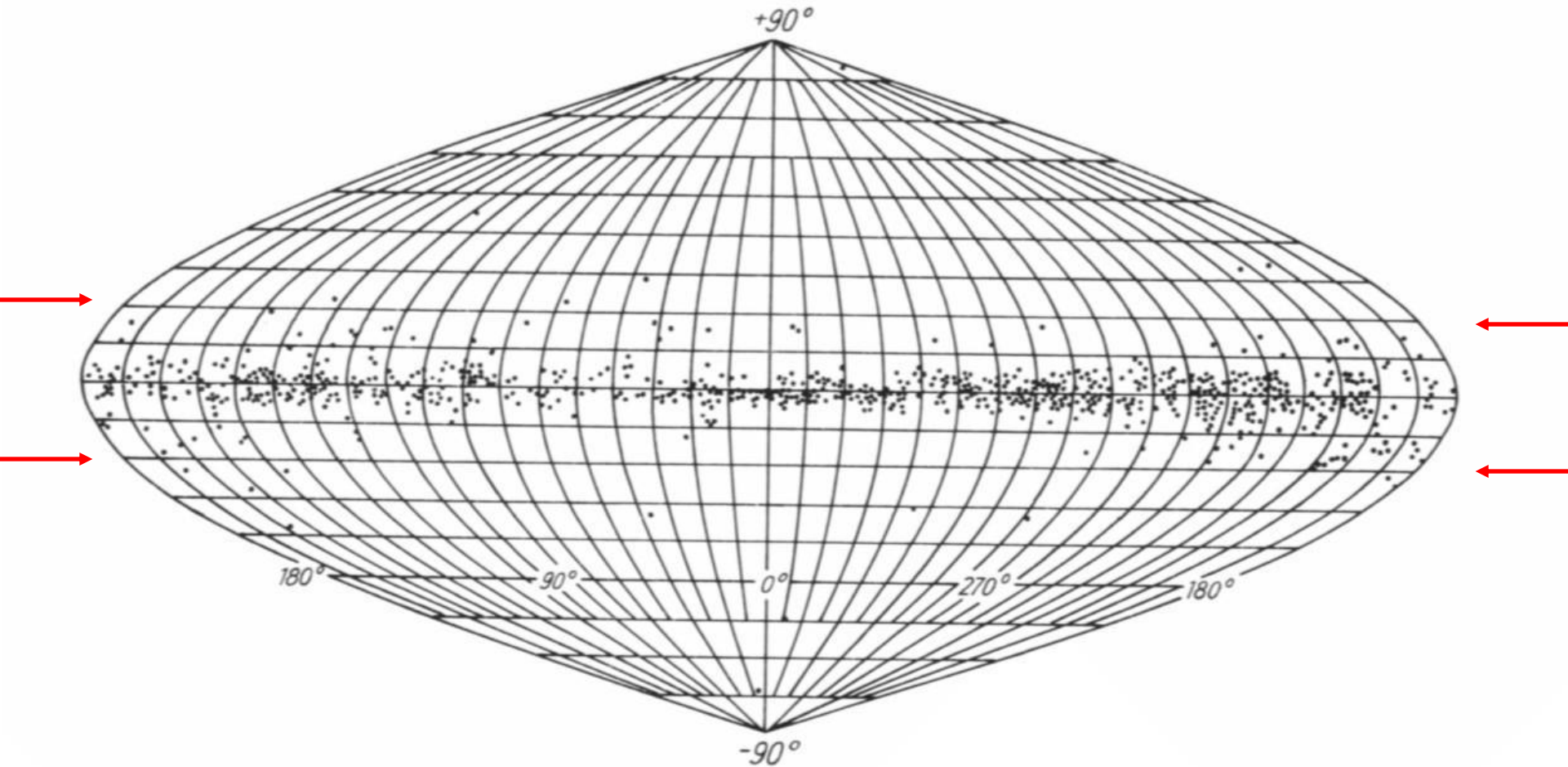


all

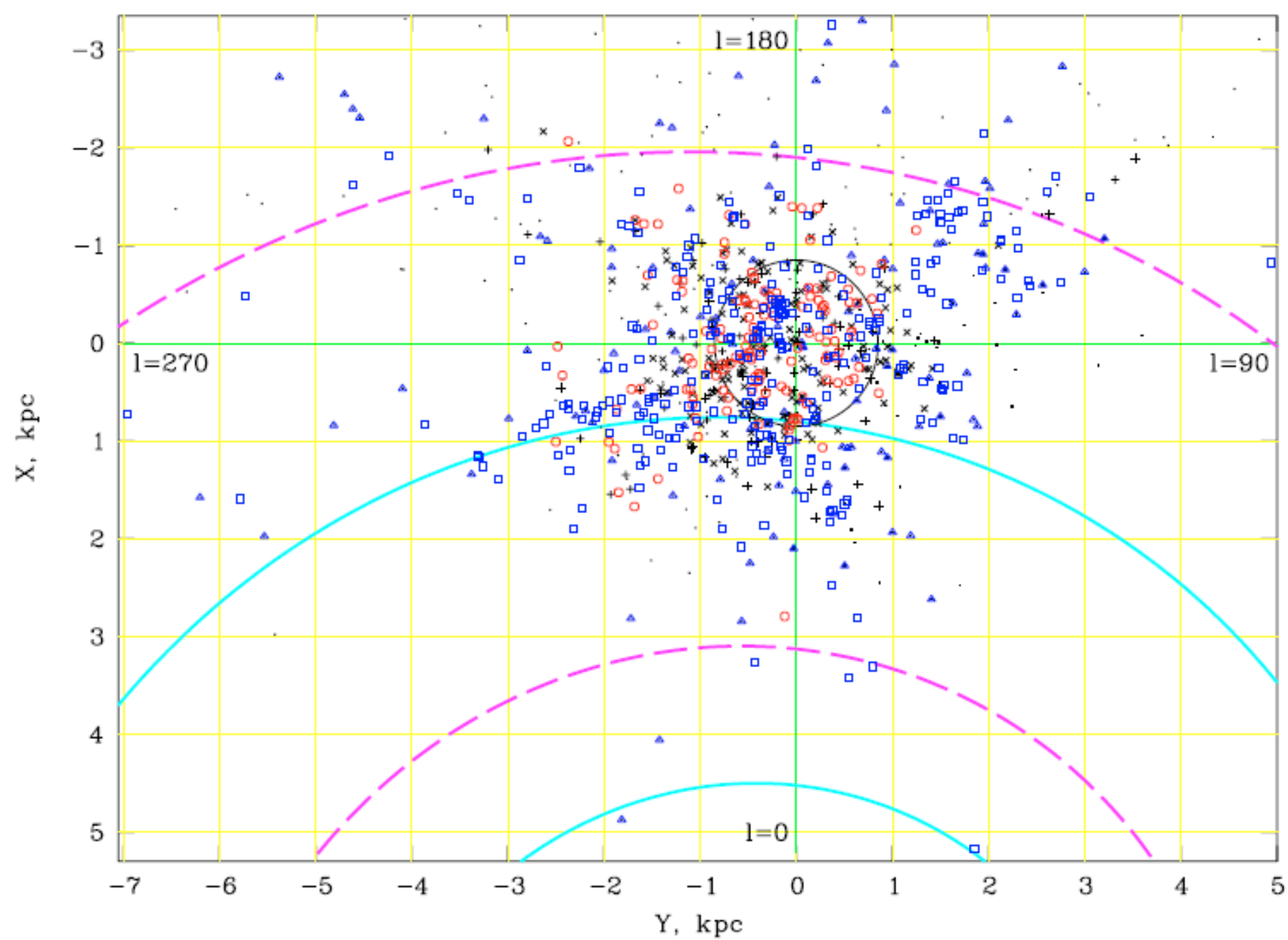


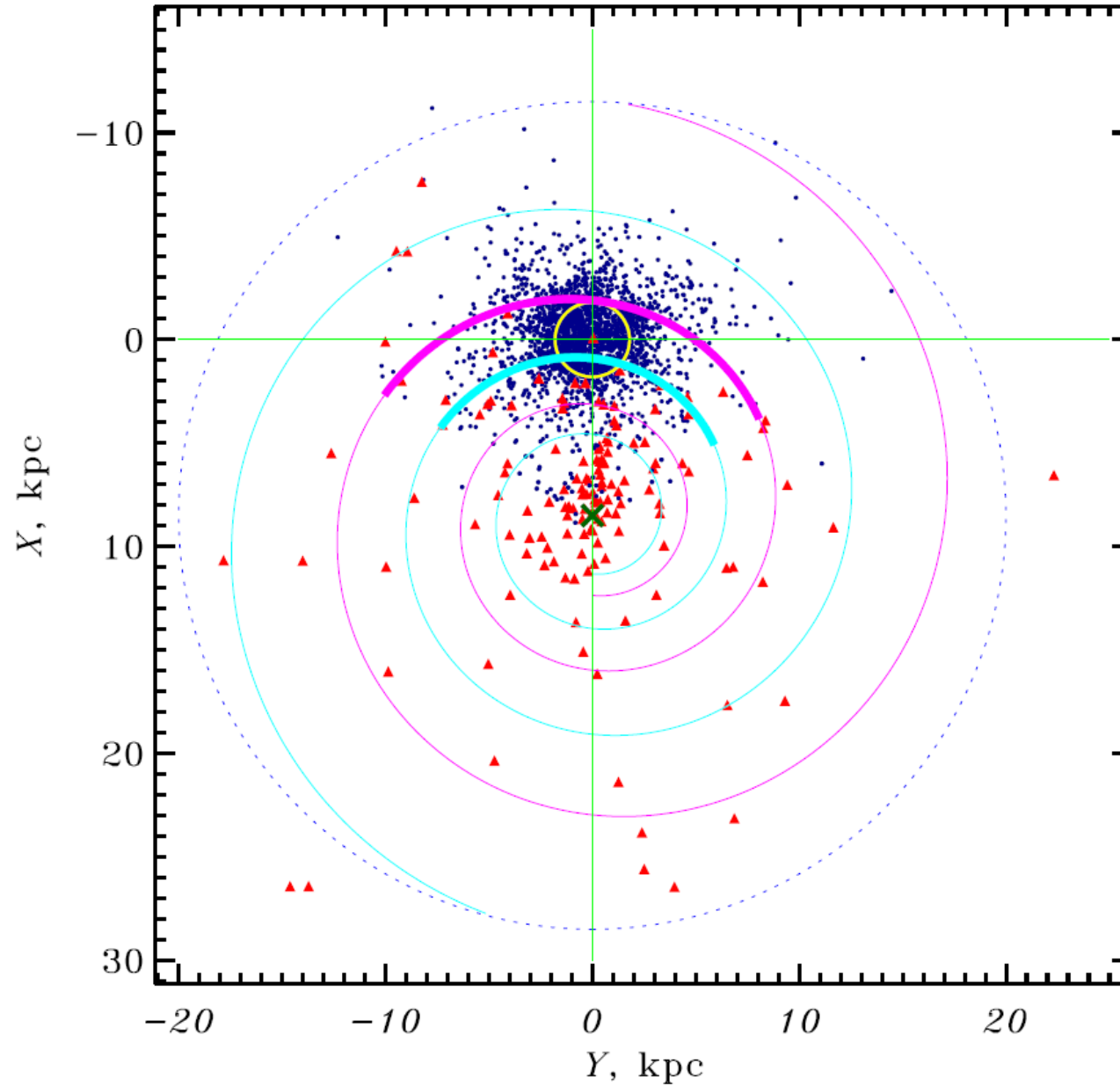
young

Galactic Distribution



+ - 20 degree Galactic latitude





Classification of Globular Clusters: Shapley H. & Sawyer H.B., 1927, Harvard College Observatory Bulletin No. 849, pp.11-14

BULLETIN 849

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A Classification of Globular Clusters. — Notwithstanding a general similarity of globular clusters in size, form, content, and absolute brightness, some deviations from the average have been frequently noted in the course of past studies. Clusters such as Messier 19 and ω Centauri are conspicuously elongated; Messier 62 is strikingly non-symmetrical; N.G.C. 4147 is deficient in giant stars; and for nearly one third of the globular systems the brighter stars are so loosely arranged that from an ordinary examination, photographic or visual, we might place them with the galactic clusters and exclude them from their true class.

It was proposed some years ago (Mt. W. Contr. 161, 7, 1918) that N.G.C. 7492 might be taken as a type of a rather distinct subdivision, called the loose globular cluster, which would include among others Messier 4, Messier 72, N.G.C. 288, N.G.C. 3201, N.G.C. 5466, and I.C. 4499. That such systems are of the globular class is made certain by long exposure photographs which bring out the thousands of faint stars that are never present in even the richest of galactic clusters, and their identity is also often indicated by their high galactic latitude and by the discovery in several of them (M 4, 72, N.G.C. 3201) of many cluster type Cepheid variables.

A detailed examination of the globular clusters on good Bruce photographs, which are available in the Harvard collection for practically all the ninety-five systems now listed as globular, shows that many intermediate forms exist between the loosest and most concentrated clusters. Instead of classing the clusters, therefore, in the two or three broad and obvious categories, we arrange them in finer subdivisions, in a series of grades on the basis of central concentration.

Detailed star counts may or may not agree with our classification. The numerical concentration will certainly depend upon the magnitudes of the stars included in the counts, and because of crowding and Eberhard effect will always be of doubtful value except for the brightest stars. On the other hand, our estimated concentrations are slightly influenced by the quality of the plates and the total brightness and angular diameters of the clusters; but we believe that these factors are not of such consequence that they detract appreciably from the value of the classification.

For the accompanying tabulation, all of the ninety five globular clusters have been classified twice by two observers. Class I represents the highest concentration toward the center, and Class XII the least.

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BULLETIN 849

Asterisks with the N.G.C. numbers mark the clusters (usually bright) which have been chosen as representative of their respective classes. The objects marked with daggers are the eight whose identification as globular clusters is yet considered questionable (H.B. 848). The uncertainty of their classification and that of a few others is indicated by colons.

For the following clusters, superposed stars have interfered somewhat with

CLASSIFICATION OF GLOBULAR CLUSTERS

| N.G.C. | Messier | Class | N.G.C. | Messier | Class | N.G.C. | Messier | Class |
|-----------|---------|-------|--------|---------|-------|--------|---------|-------|
| *104 | | III | 5986 | | VII | 6453 | | IV |
| *288 | | X | 6093 | 80 | II | 6496 | | XII |
| 362 | | III | 6101 | | X | 6517 | | IV |
| 1261 | | II | 6121 | 4 | IX | †6535 | | XI: |
| †1651 | | VIII: | 6139 | | II | †6539 | | X: |
| 1783 | | VII | 6144 | | XI | 6541 | | III |
| 1806 | | VI | 6171 | | X | 6553 | | XI |
| 1831 | | V | 6205 | 13 | V | 6569 | | VIII |
| 1846 | | VIII | *6218 | | IX | 6584 | | VIII |
| 1851 | | II | 6229 | | VII: | 6624 | | VI |
| *1866 | | IV | 6235 | | X | 6626 | 28 | IV |
| 1904 | 79 | V | 6254 | 10 | VII | 6637 | 69 | V |
| 1978 | | VI | 6266 | 62 | IV | 6638 | | VI |
| 2298 | | VI | 6273 | 19 | VIII | 6652 | | VI: |
| 2419 | | VII | 6284 | | IX: | *6656 | 22 | VII |
| *2808 | | I | 6287 | | VII | 6681 | 70 | V |
| 3201 | | X | 6293 | | IV | †6712 | | IX: |
| 4147 | | IX | 6304 | | VI | 6715 | 54 | III |
| 4372 | | XII | 6316 | | III | 6723 | | VII |
| 4590 | 68 | X | 6333 | 9 | VIII | *6752 | | VI |
| 4833 | | VIII | 6341 | 92 | IV | †6760 | | IX: |
| 5024 | 53 | V | 6342 | | IV | 6779 | 56 | X |
| 5139 | | VIII | †6352 | | XI: | *6809 | 55 | XI |
| 5272 | 3 | VI | 6356 | | II | 6864 | 75 | I |
| 5286 | | V | 6362 | | X | 6934 | | VIII |
| 5466 | | XII | 6366 | | XI | 6981 | 72 | IX |
| 5634 | | IV | 6388 | | III | 7006 | | I |
| I.C. 4499 | | XI | 6397 | | IX | 7078 | 15 | IV |
| 5897 | | XI | *6402 | 14 | VIII | *7089 | 2 | II |
| 5904 | 5 | V | †6426 | | IX: | *7099 | 30 | V |
| 5927 | | VIII | 6440 | | V | *7492 | | XII |
| †5946 | | IX: | 6441 | | III | | | |

- **Class I, II, III:** Visible high stellar density at their core. With a halo around decreasing in luminosity as a function of the distance from the core.



M75 is a globular cluster of class I in Sagittarius.

- **Class IV, V, VI:** The core stellar density is still visible, but is more spread out and not as dense.



M62 is a globular cluster of class IV

- **Class VII, VIII, IX:** The cluster stellar density is more homogeneous and less contrasted.



M22 is a globular cluster of class VII in Sagittarius

- **Class X, XI, and XII:** The cluster surface luminosity is completely homogeneous with no increase in stellar density visible at the core.



M55 is a globular cluster of class XI in Sagittarius

The smaller the number of stars, the higher the core's stellar density.

Definition - Radii

- **Core Radius:** Distance at which the apparent surface luminosity has dropped by half
- **Half-Light Radius:** Distance from the core within which half the total luminosity from the cluster is received
- **Half-Mass Radius:** The radius from the core that contains half the total mass
- **Tidal Radius:** Distance from the center at which the external gravitation of the galaxy has more influence over the stars in the cluster than does the cluster itself

Example

Hilker, 2006, A&A, 448, 171

Table 3. Basic photometric parameters of AM 1, Pal 3, and Pal 14. The second row for each cluster gives the values from Harris' list (1996). $E_{B-V,S98}$ is the reddening value by Schlegel et al. (1998). The magnitude of the horizontal branch V_{HB} and the total apparent V magnitude V_{tot} are not corrected for extinction. The first distance modulus is based on the derivation of the absolute magnitude of the HB using $M_{V,HB} = 0.15[Fe/H]+0.8$, the second one on the isochrone fitting. The distance to the Sun R_{Sun} was calculated from the first distance modulus after correction for extinction with $A_V = 3.1E_{B-V,S98}$.

| Name | RA(2000) | Dec(2000) | $E_{B-V,S98}$ | E_{B-V} | V_{HB} | $(m-M)_{V,HB}$ | $(m-M)_{V,iso}$ | [Fe/H] | R_{Sun} | V_{tot}^a | M_V |
|--------|------------|-----------|---------------|-----------|----------|----------------|-----------------|--------|-----------|-------------|-------|
| | [h:m:s] | [°:':"] | [mag] | [mag] | [mag] | [mag] | [mag] | [dex] | [kpc] | [mag] | [mag] |
| AM 1 | 03:55:02.3 | -49:36:55 | 0.01 | ... | 20.98 | 20.39 | 20.45 | -1.40 | 118.0 | 15.84 | -4.55 |
| | 03:55:02.7 | -49:36:52 | ... | 0.00 | 20.96 | 20.43 | ... | -1.80 | 121.9 | 15.72 | -4.71 |
| Pal 3 | 10:05:31.9 | 00:04:18 | 0.04 | 0.02 | 20.48 | 19.94 | 19.95 | -1.70 | 91.9 | 14.91 | -5.03 |
| | 10:05:31.4 | 00:04:17 | ... | 0.04 | 20.51 | 19.96 | ... | -1.66 | 92.7 | 14.26 | -5.70 |
| Pal 14 | 16:11:00.6 | 14:57:28 | 0.03 | 0.07 | 20.03 | 19.46 | 19.42 | -1.50 | 74.7 | 14.68 | -4.78 |
| | 16:11:04.9 | 14:57:29 | ... | 0.04 | 20.04 | 19.47 | ... | -1.52 | 73.9 | 14.74 | -4.73 |

Table 4. Basic structural parameters of AM 1, Pal 3, and Pal 14. The second row for each cluster gives the values from Harris' list (1996). The last three columns are physical scales based on the distances in Table 3.

| Name | $\mu_{V,central}$ | r_c^a | r_h | r_t^a | $c^{a,b}$ | r_c | r_h | r_t |
|--------|----------------------------|-------------|-------|---------------------|-------------|-------------|-------|----------------------|
| | [mag/arcsec ²] | ['] | ['] | ['] | | [pc] | [pc] | [pc] |
| AM 1 | 23.11 | 0.18 (0.14) | 0.32 | 3.24 (3.29) | 1.26 (1.37) | 6.2 (4.8) | 11.0 | 111.3 (113.0) |
| | 23.86 | 0.15 | 0.50 | 1.92 (4.27) | 1.12 | 5.3 | 17.7 | 68.1 (151.6) |
| Pal 3 | 23.84 | 0.54 (0.40) | 0.72 | 3.34 (3.72) | 0.79 (0.97) | 14.4 (10.7) | 19.3 | 89.3 (99.5) |
| | 23.08 | 0.48 | 0.66 | 4.81 (5.69) | 1.00 | 12.9 | 17.8 | 129.8 (153.5) |
| Pal 14 | 24.92 | 0.70 (1.14) | 1.28 | [5.00] ^c | 0.85 (0.59) | 15.2 (24.8) | 27.8 | [108.7] ^c |
| | 25.55 | 0.94 | 1.15 | 5.26 (4.81) | 0.75 | 20.21 | 24.7 | 113.1 (103.4) |

Example

Hilker, 2006, A&A, 448, 171

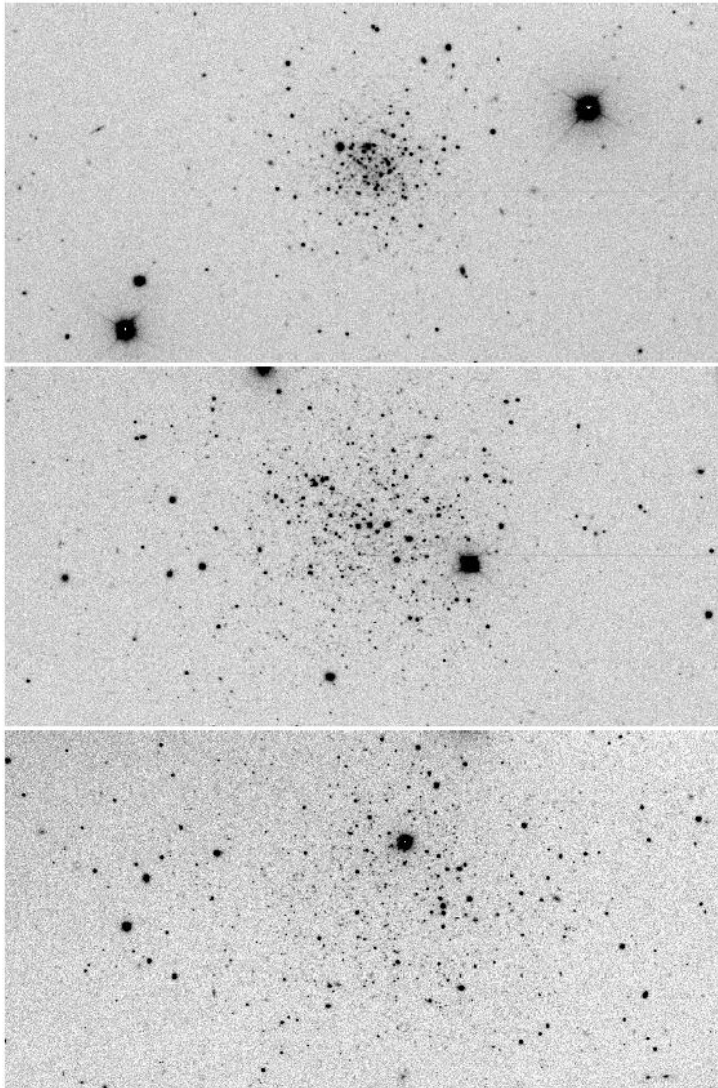


Fig. 1. Excerpts of the combined V images for AM 1 (*top*), Pal 3 (*middle*) and Pal 14 (*bottom*). $4' \times 2'$ sections of the corresponding “master” chips are shown. North is up, East is left.

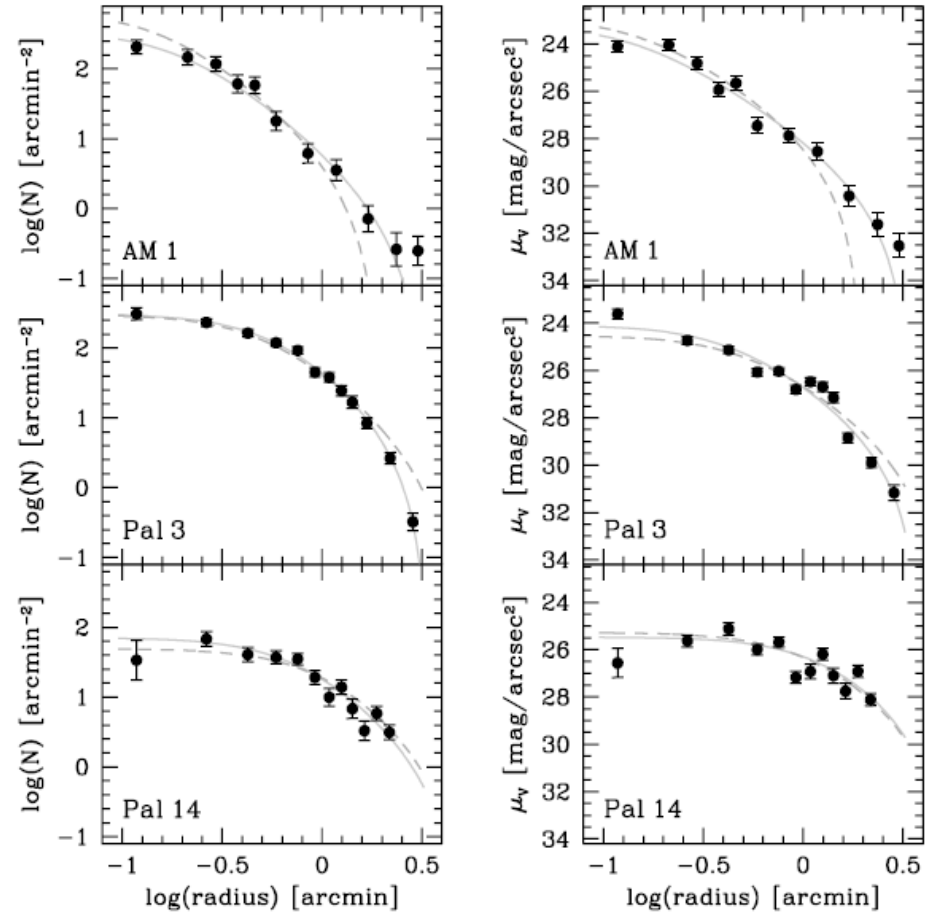
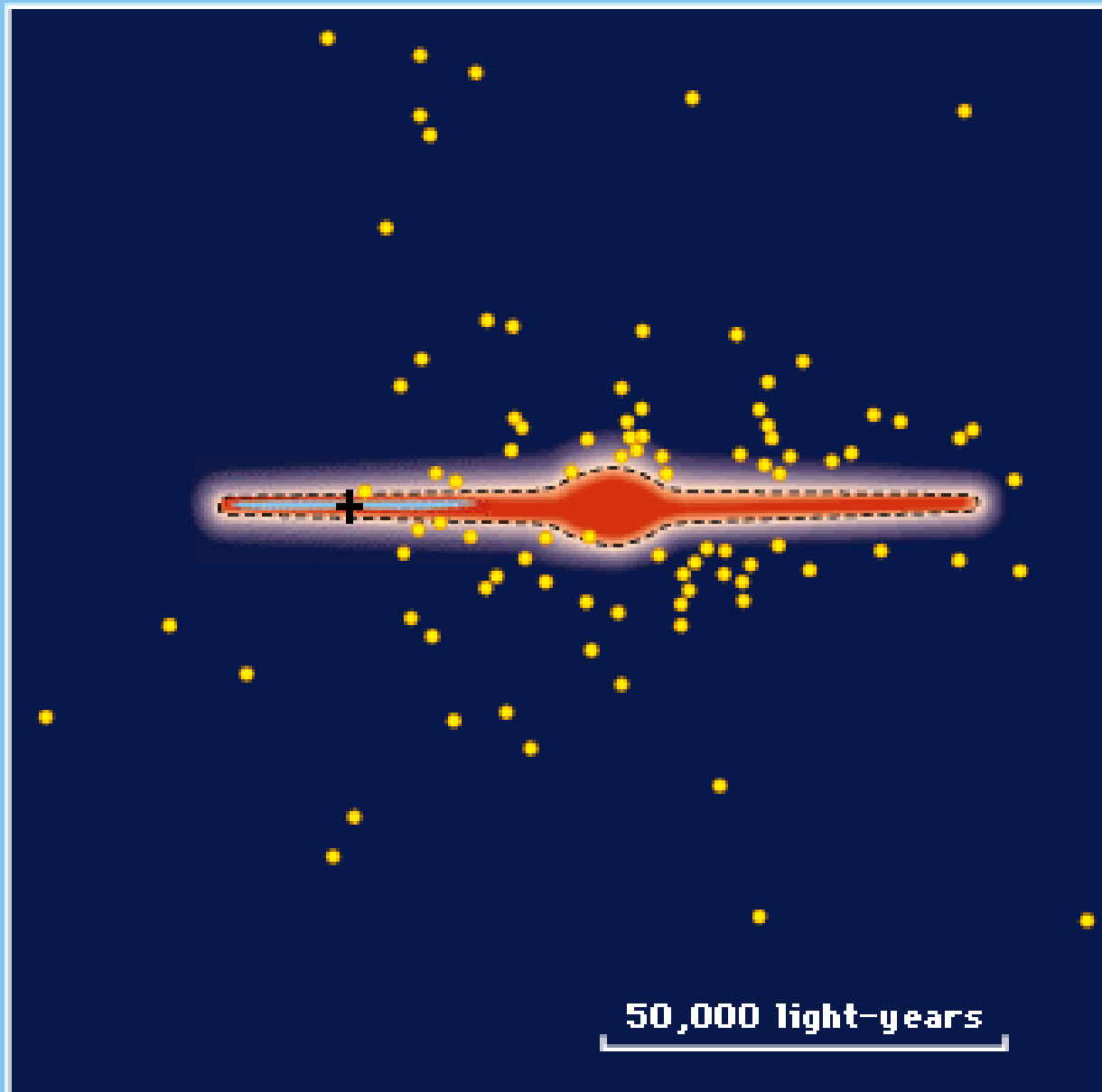


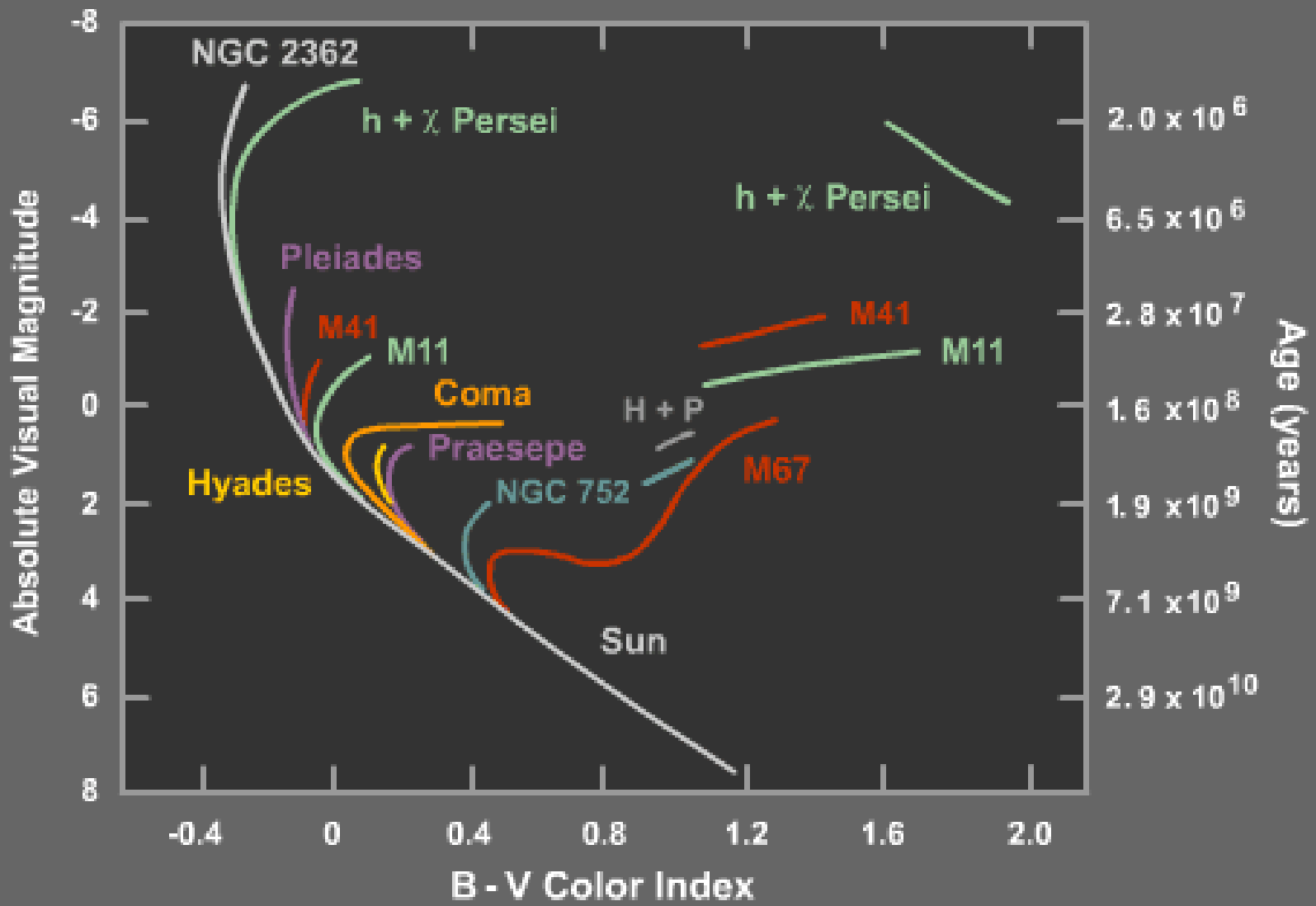
Fig. 10. The surface number density distribution (*left panels*) and the surface brightness distribution (*right panels*) of probable member stars is shown for the three clusters. The grey curves are best-fitting King models. Dashed curves are fits to the distributions when adopting the values for r_c and r_t of Harris' list (1996). The parameters of both fits are given in Table 4.



Dotted line indicates probable outline of the galaxy, a flattened lens-shaped system formed by the stars, as seen edgewise from outside. Eccentric position of the Sun is shown by a cross. Some of the known open star clusters are scattered among the stars in shaded region. Small circles represent globular clusters.

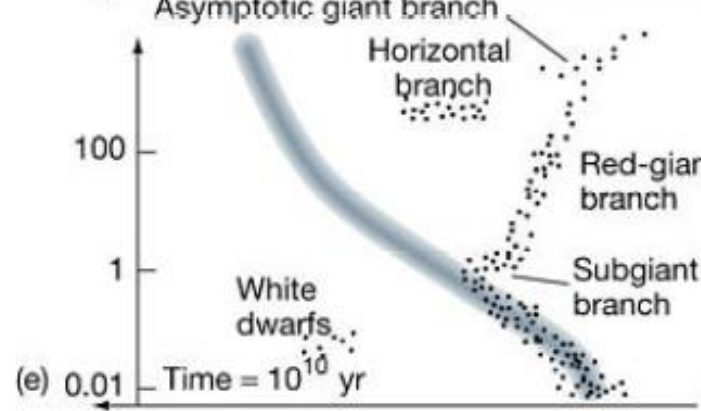
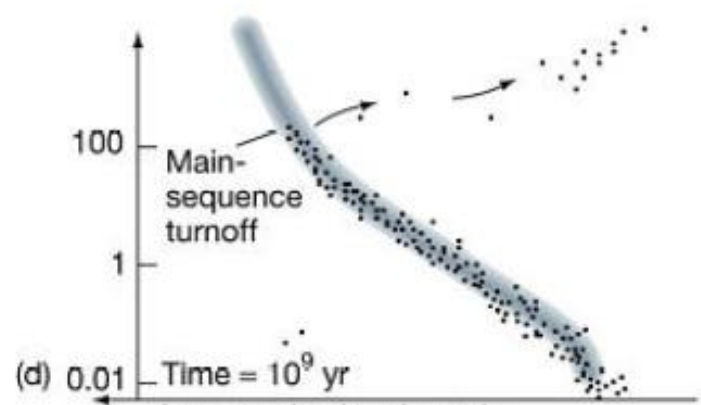
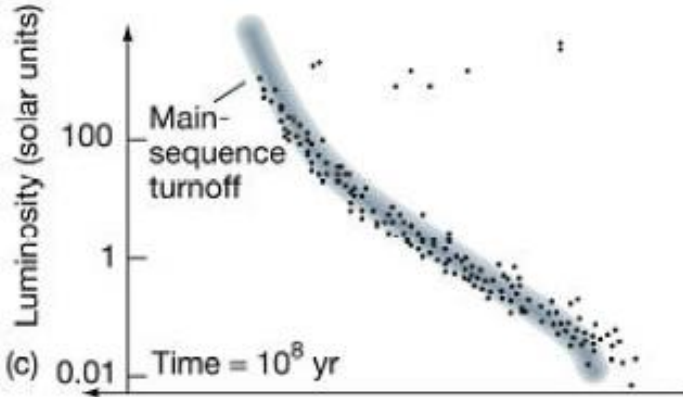
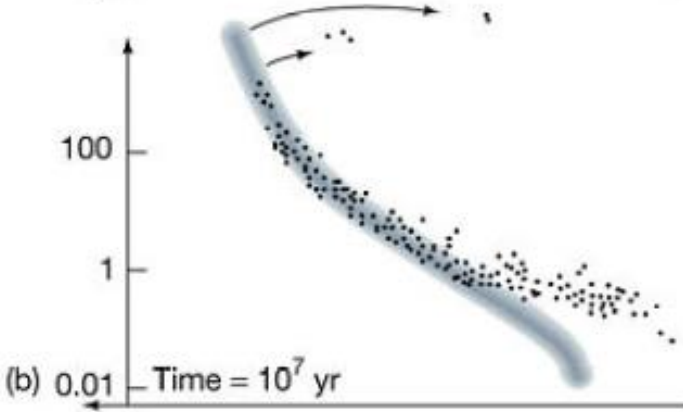
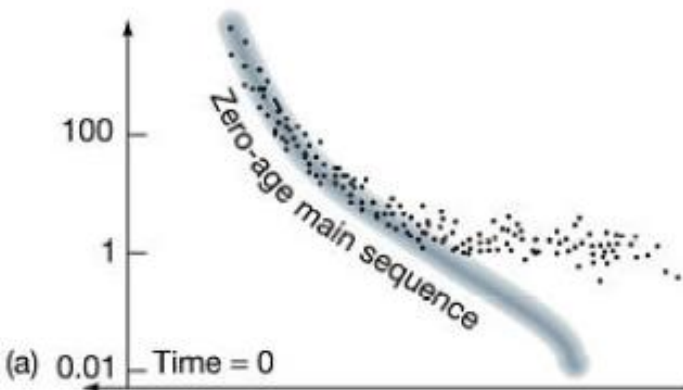
Important observables

- Single stars: „all“ we can think of
- Open clusters
 1. Hertzsprung-Russell-diagram
 2. Kinematic data
 3. Integrated spectra
 4. Integrated colors
 5. Polarimetric measurements



HR Diagrams for Various Open Clusters

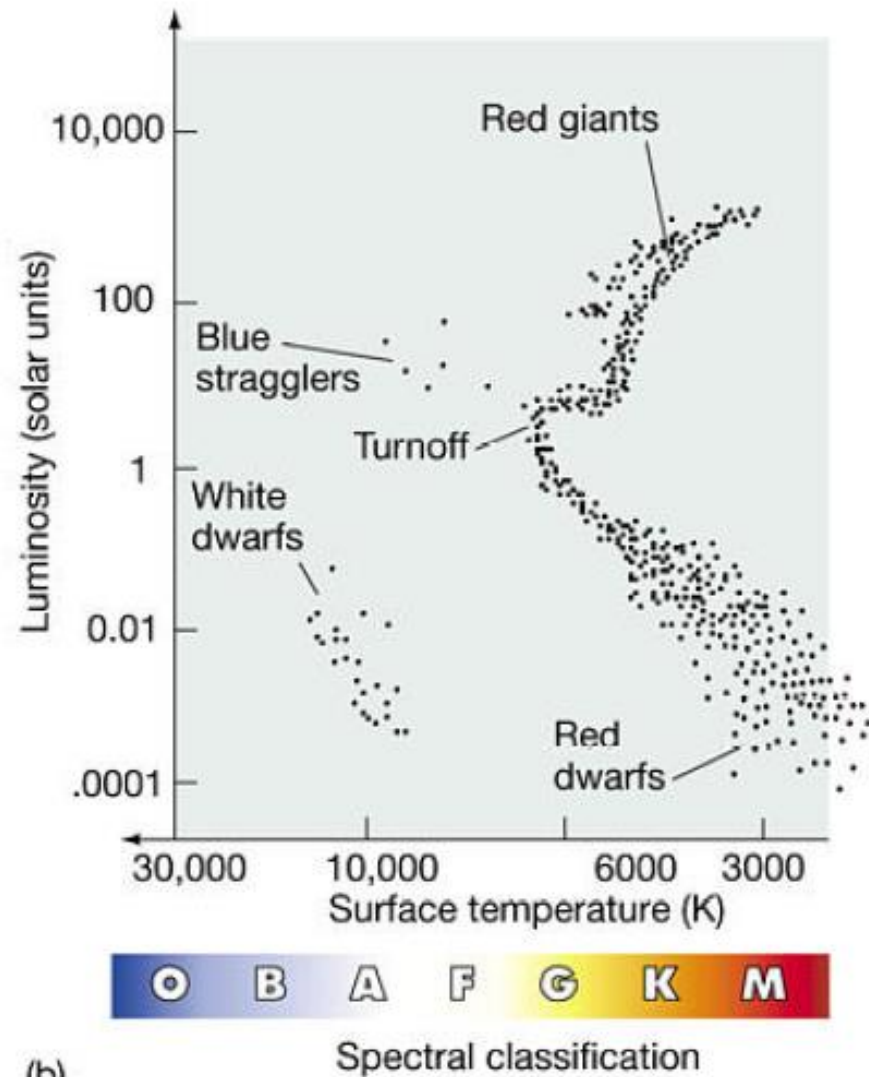
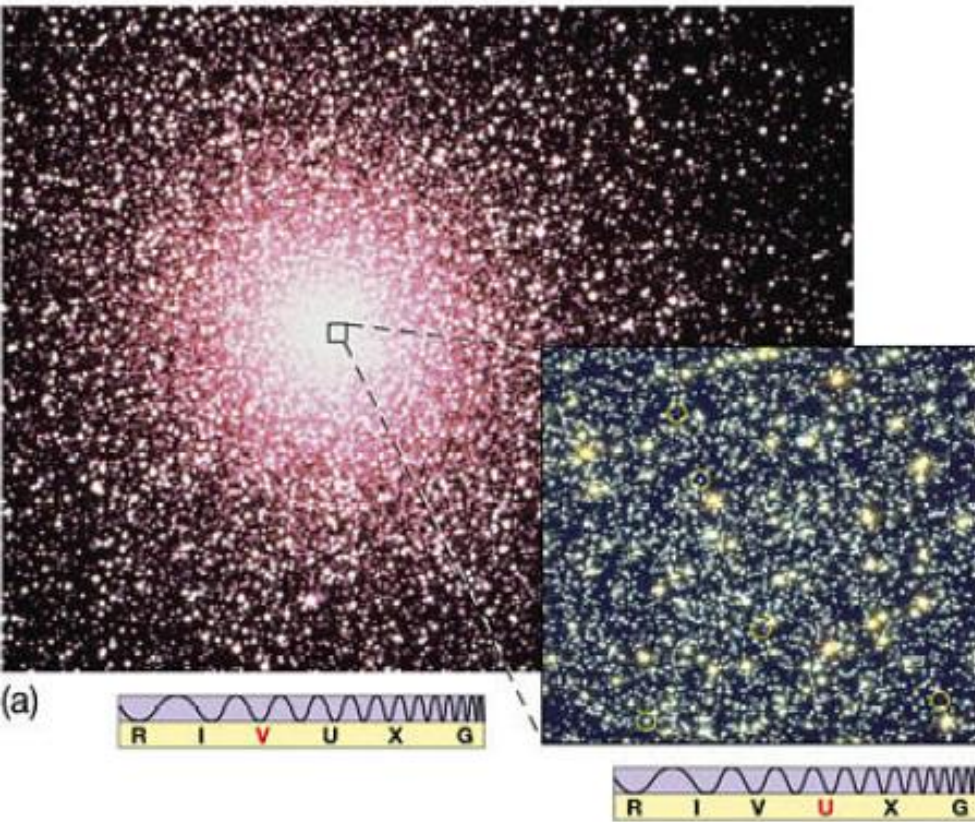
From the Pre-Main Sequence to Globular clusters



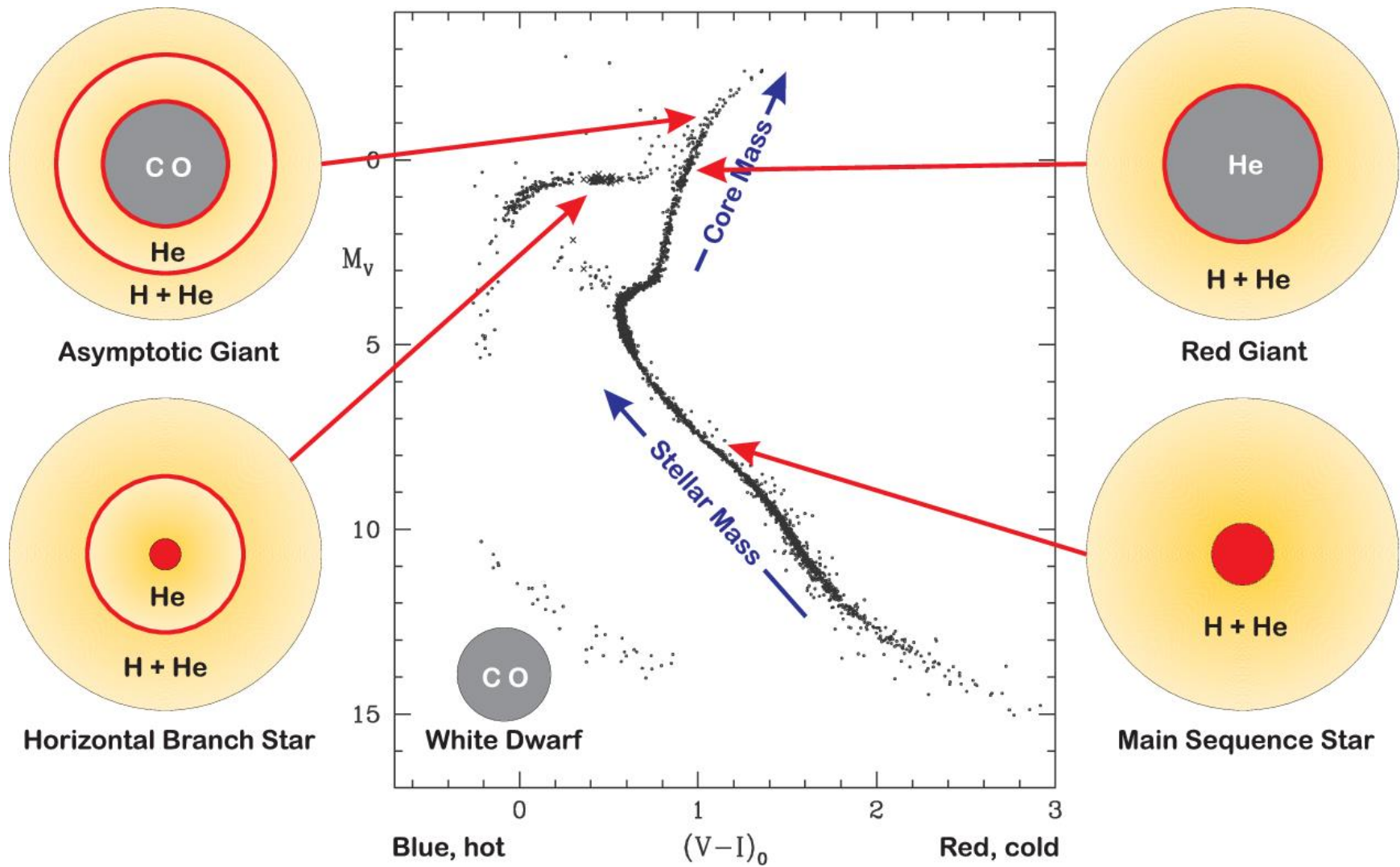
- (a) $t = 0$
- (b) $t = 10^7$ yr
- (c) $t = 10^8$ yr
- (d) $t = 10^9$ yr
- (e) $t = 10^{10}$ yr



47 Tuc



NGC 104: $d = 4500$ pc, $D = 31'$,
 $[Fe/H] = -0.76$ dex, $t = 12$ Gyr

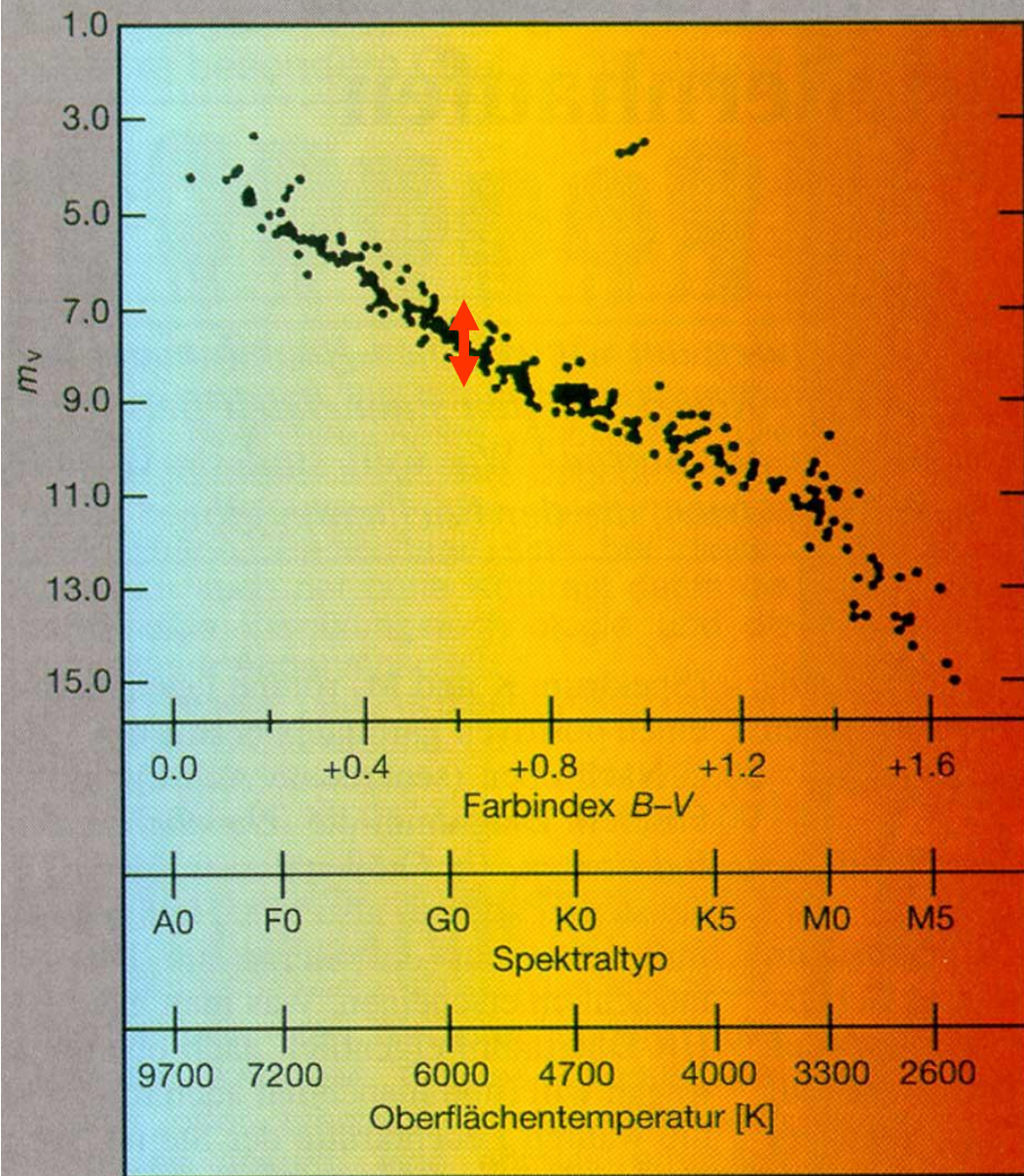


Hyades

$\log t = 8.90$

$d = 45 \text{ pc}$

$[\text{Fe}/\text{H}] = +0.17 \text{ dex}$



↕ Width of Main Sequence
about 1.8 mag in M_V

NO
observational error

A typical example

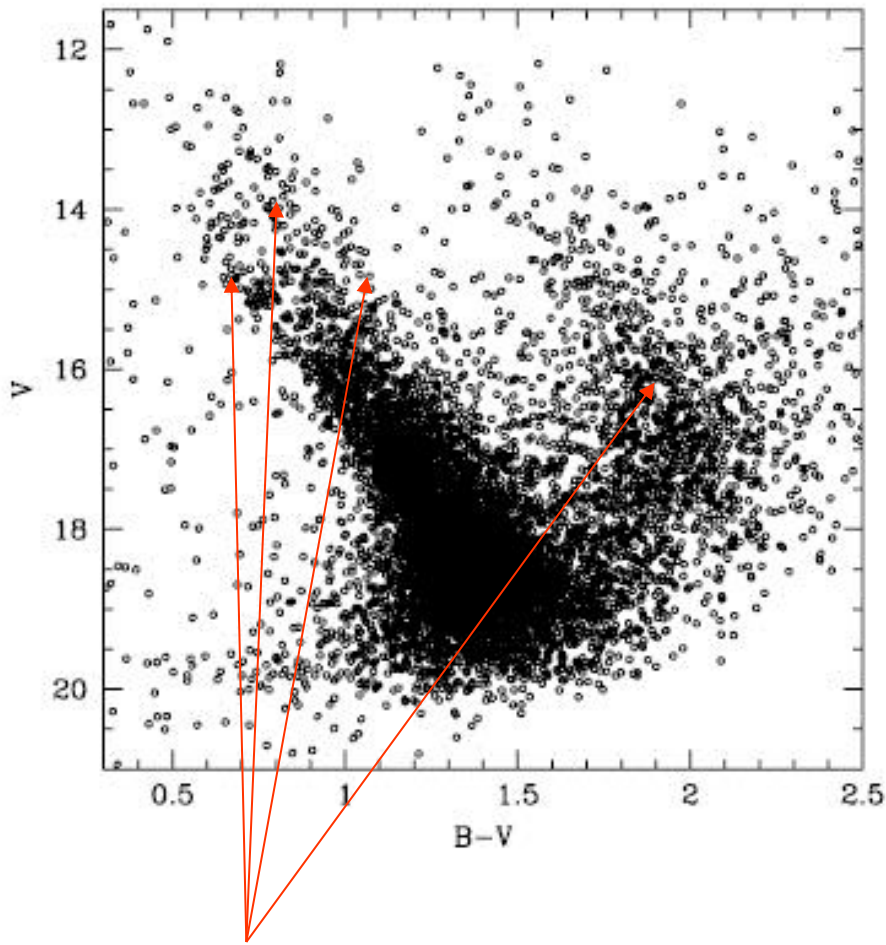
One typical example from the literature:

Piatti et al., 2006, MNRAS, 367, 599: ***First estimates of the fundamental parameters of the relatively bright Galactic open cluster NGC 5288***

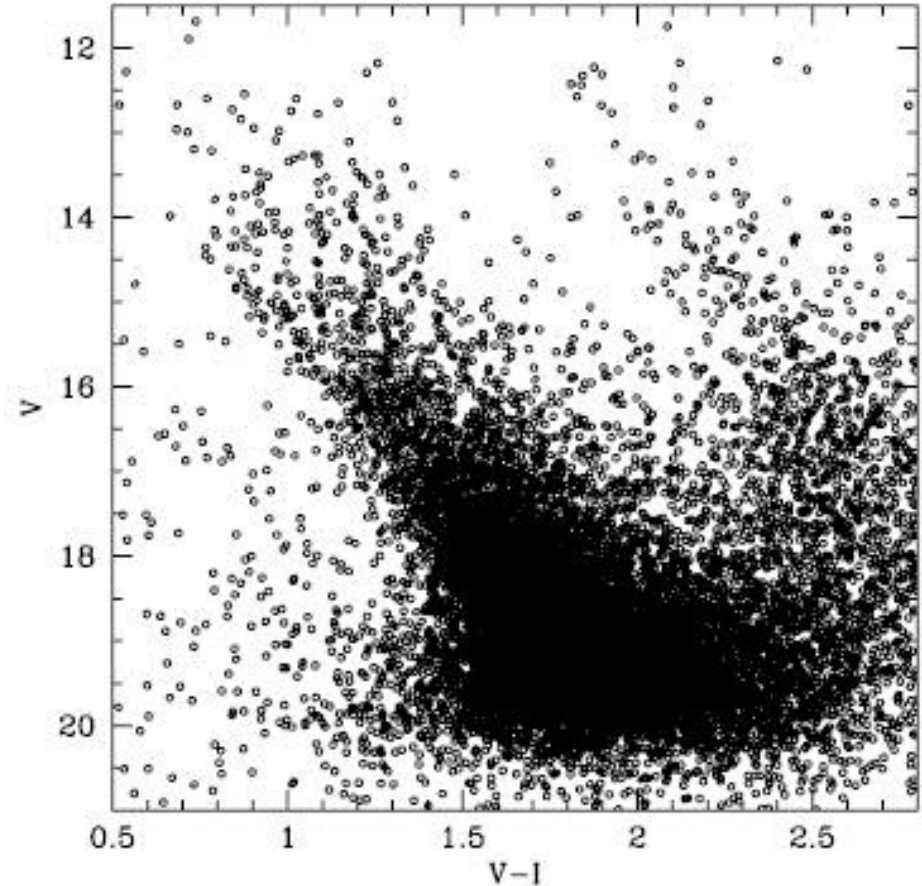
CCD BVI Photometry, 1 Pixel = 0.4'', 13.6x13.6' field,

No other observations available for this open cluster

15688 stars in the complete field



Different „main sequences“
due to fore- and background
populations



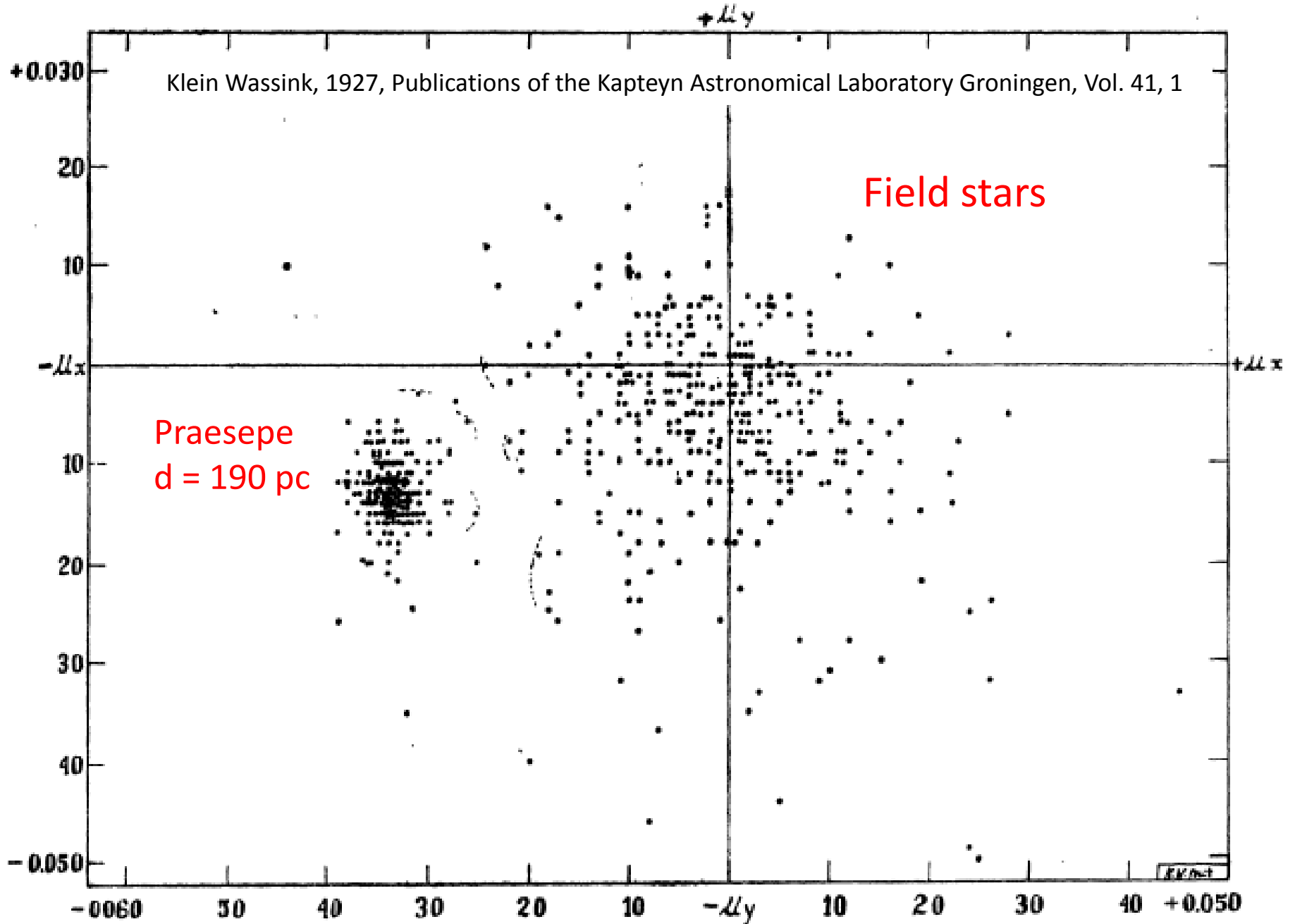
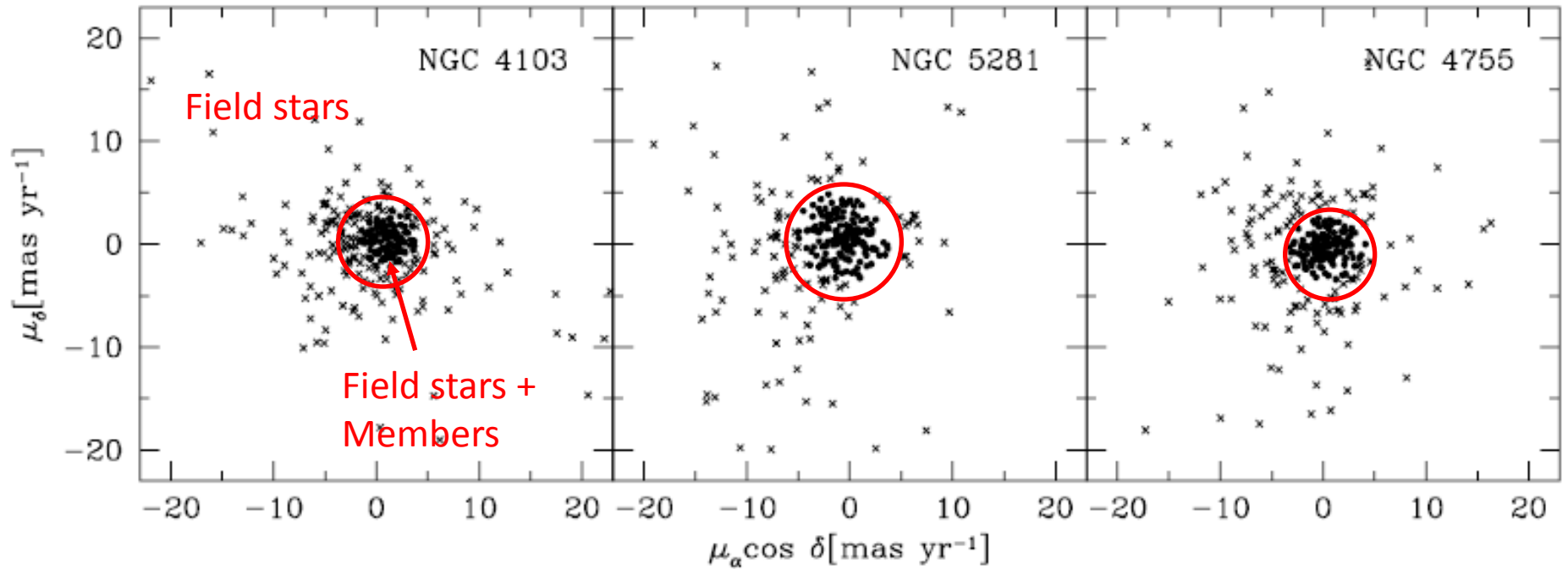


Figure 2. Diagram of the absolute proper motions of the Catalogue; photographic magnitude 6 to 14^o, numbers 1 to 531. The dotted lines separate the Praesepe stars from the backgroundstars.

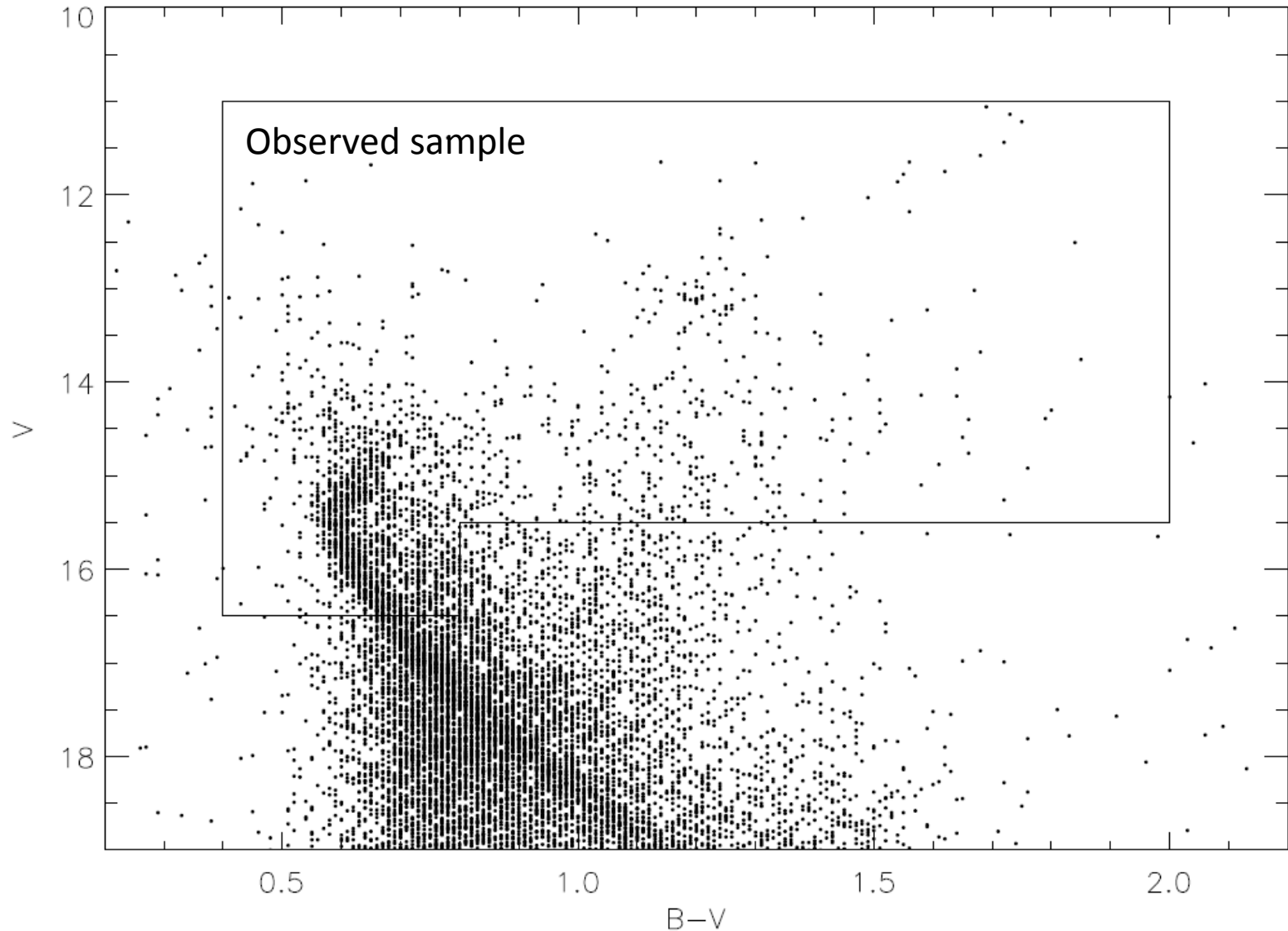


The proper motion for „distant“ star clusters is almost zero.

Only field stars with **large** proper motions can be sorted out.

These are almost only foreground stars.

Hole et al., 2009, AJ, 138, 159: NGC 6819, one of the „best“ cases, more than three measurements for each star, 6571 radial velocities for 1207 stars, 3.5 meter telescope



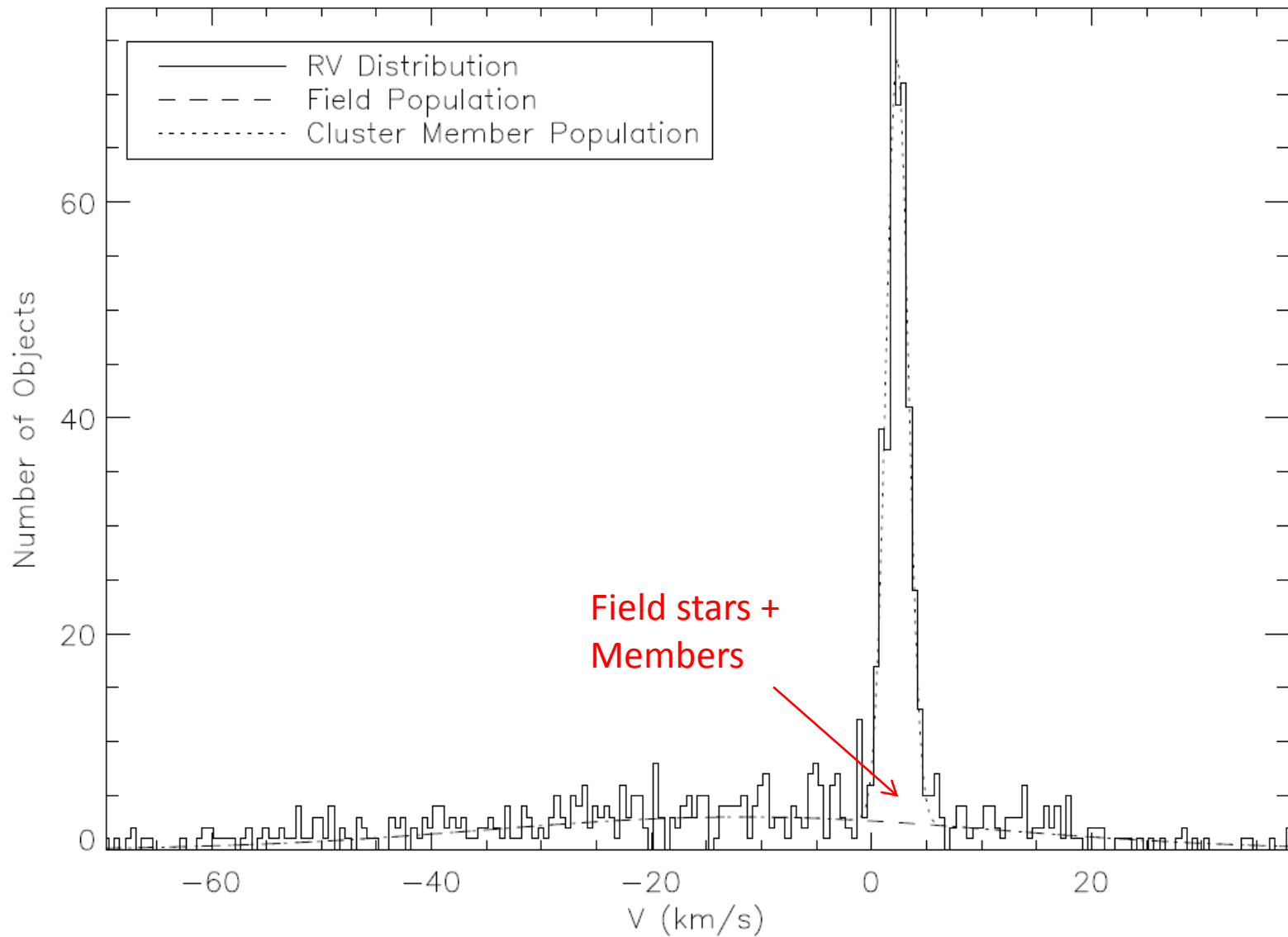
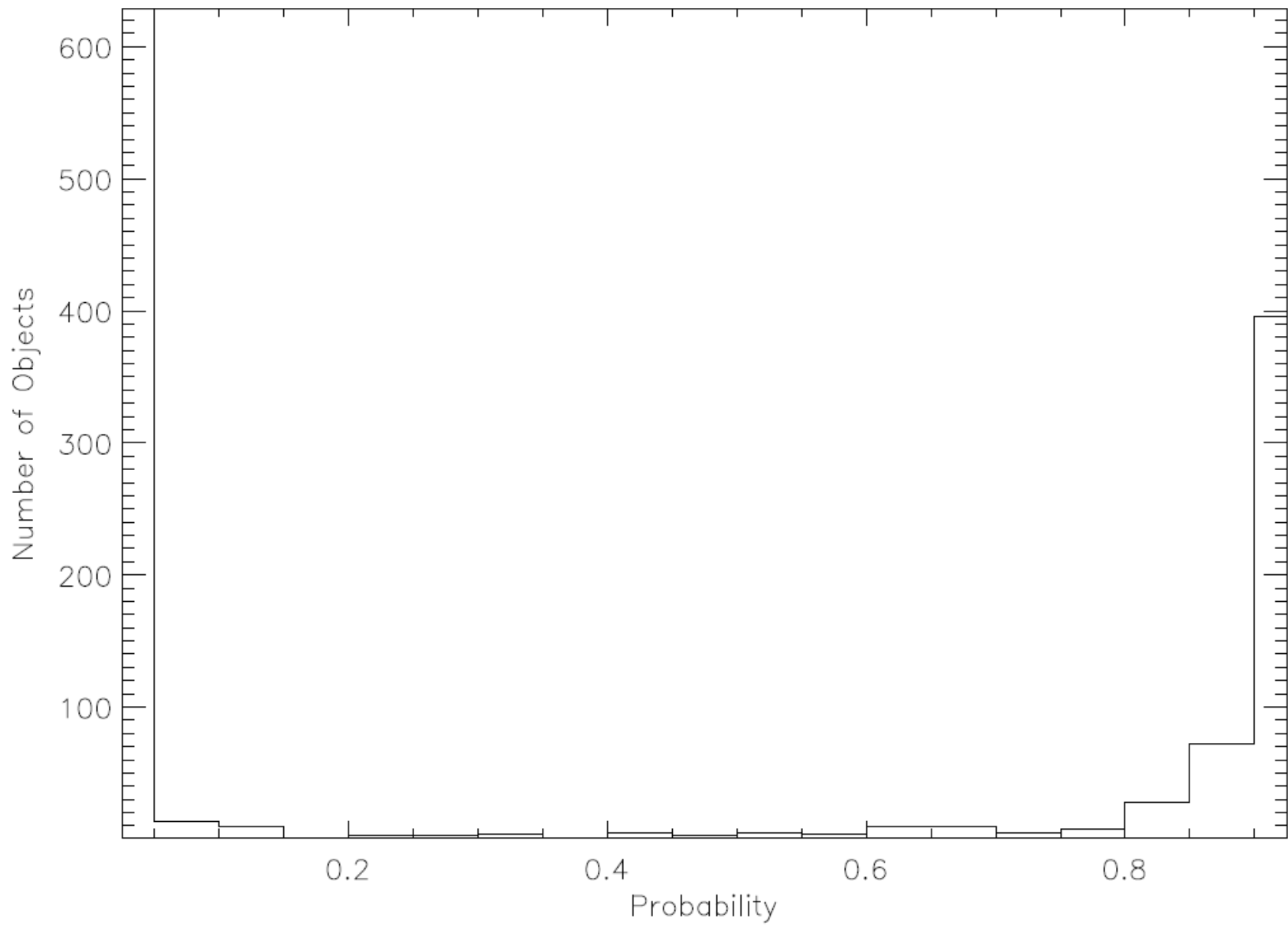
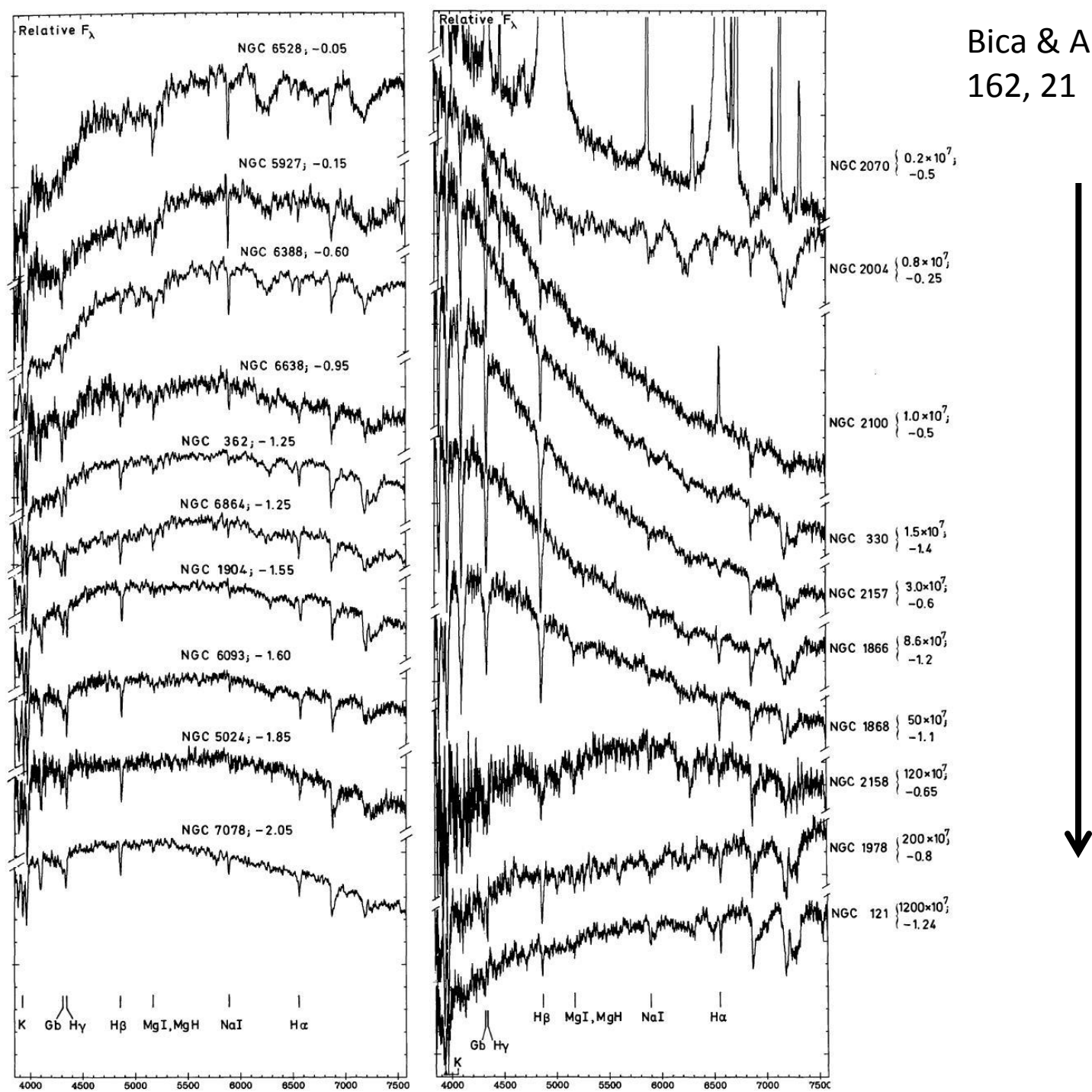


Table 3. Gaussian Fit Parameters For Cluster and Field RV Distributions

| | Cluster | Field |
|---------------------------------------|---------|-------|
| Ampl. (Number) | 57.2 | 3 |
| \overline{RV} (km s ⁻¹) | 2.3 | -12 |
| σ (km s ⁻¹) | 1.0 | 23 |





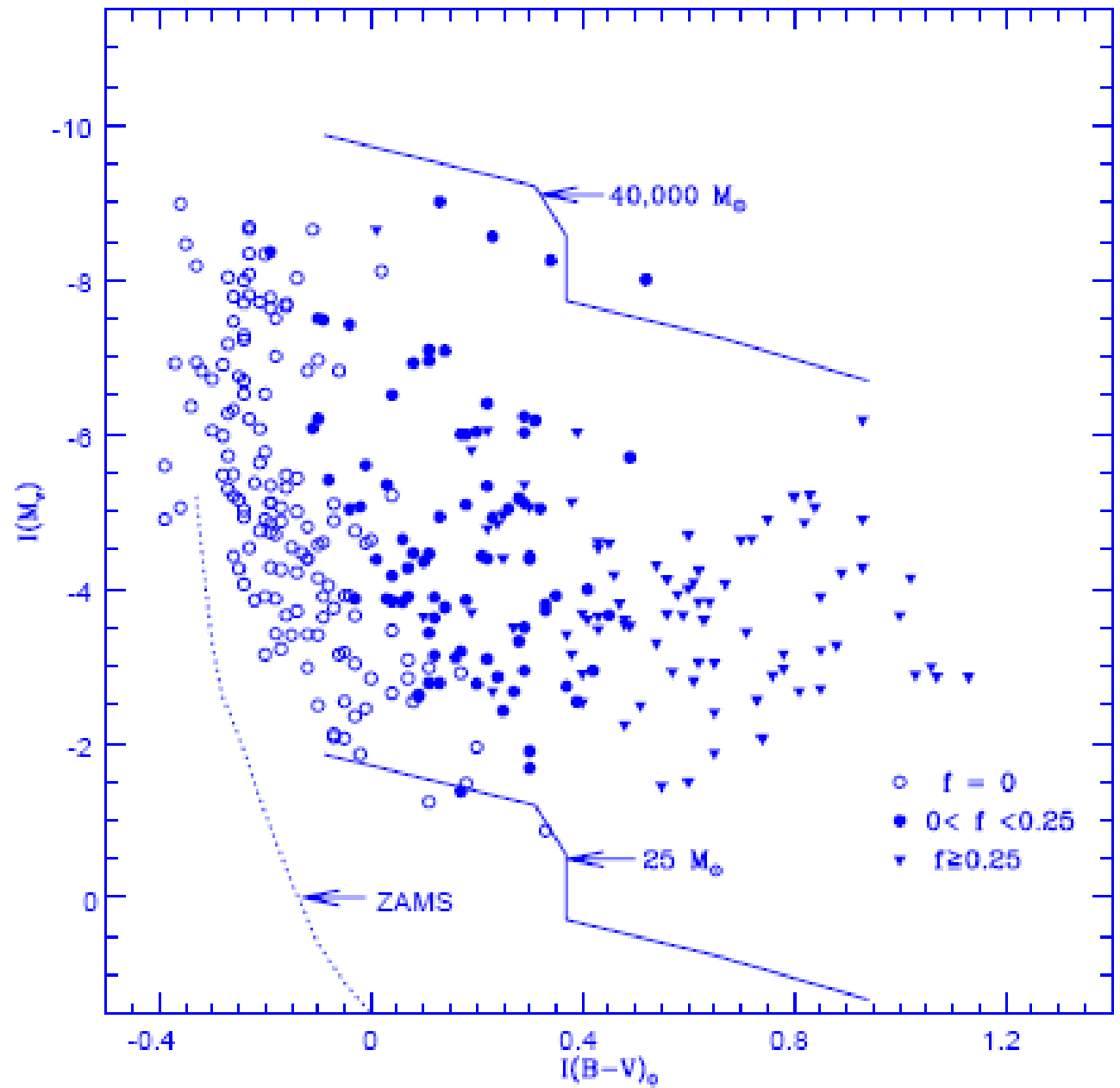


Fig. 2. The $I(M_V)$, $I(B-V)_0$ diagram. f is the fraction of red giants/supergiants in the open clusters.