Designation of star clusters

- IAU:
  - C *aa bb ± 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

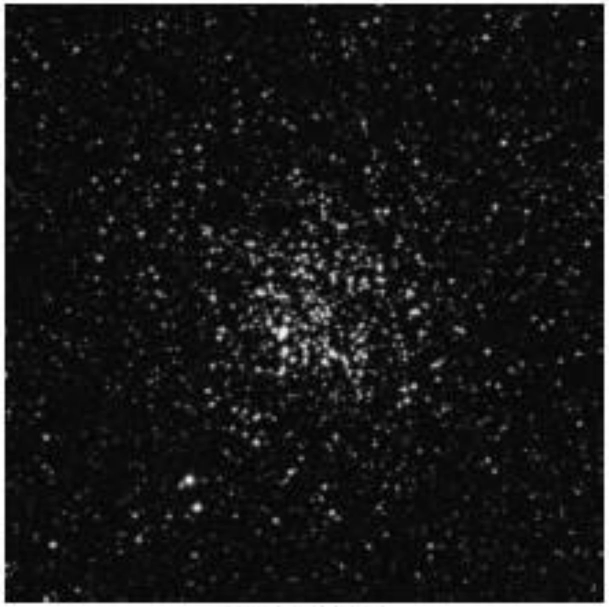
Trumplers classification

- **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

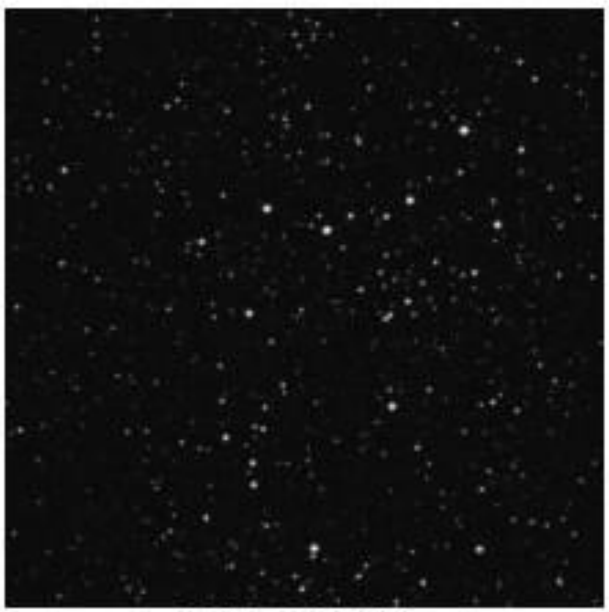
- **Number of Stars in the Cluster**
  - **p** … Poor clusters with less than 50 stars
  - **m** … Medium rich cluster with 50 to 100 stars
  - **r** … Rich clusters with over 100 stars
- Open clusters with any type of nebulosity are denoted with an "**n**" at the end of the classification.

I
II
III
IV
r
m
p
NGC 6791
NGC 7789
NGC 6940
NGC 1817
NGC 436
NGC 7790
NGC 129
DoDz 9
NGC 7788
NGC 1807
NGC 7686
Stock 12

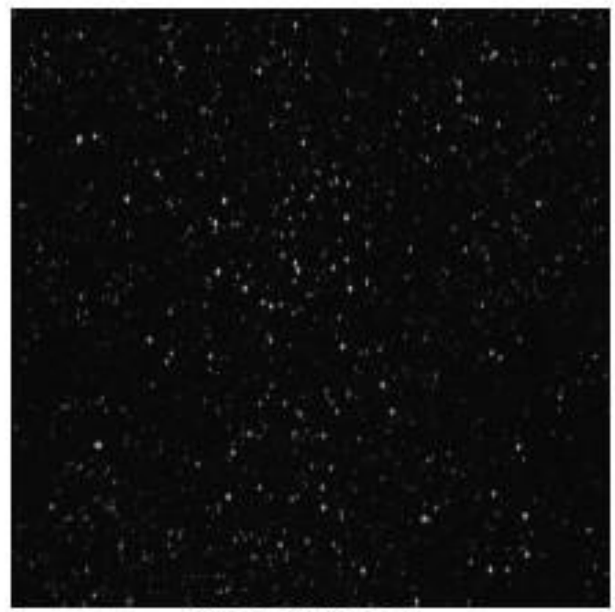


M11 15.0′
Class: I 2 r

M46 15.0′
Class: II 2 r



NGC 6664 15.0′
Class: III 2 m



NGC 6568 25.0′
Class: IV 1 m

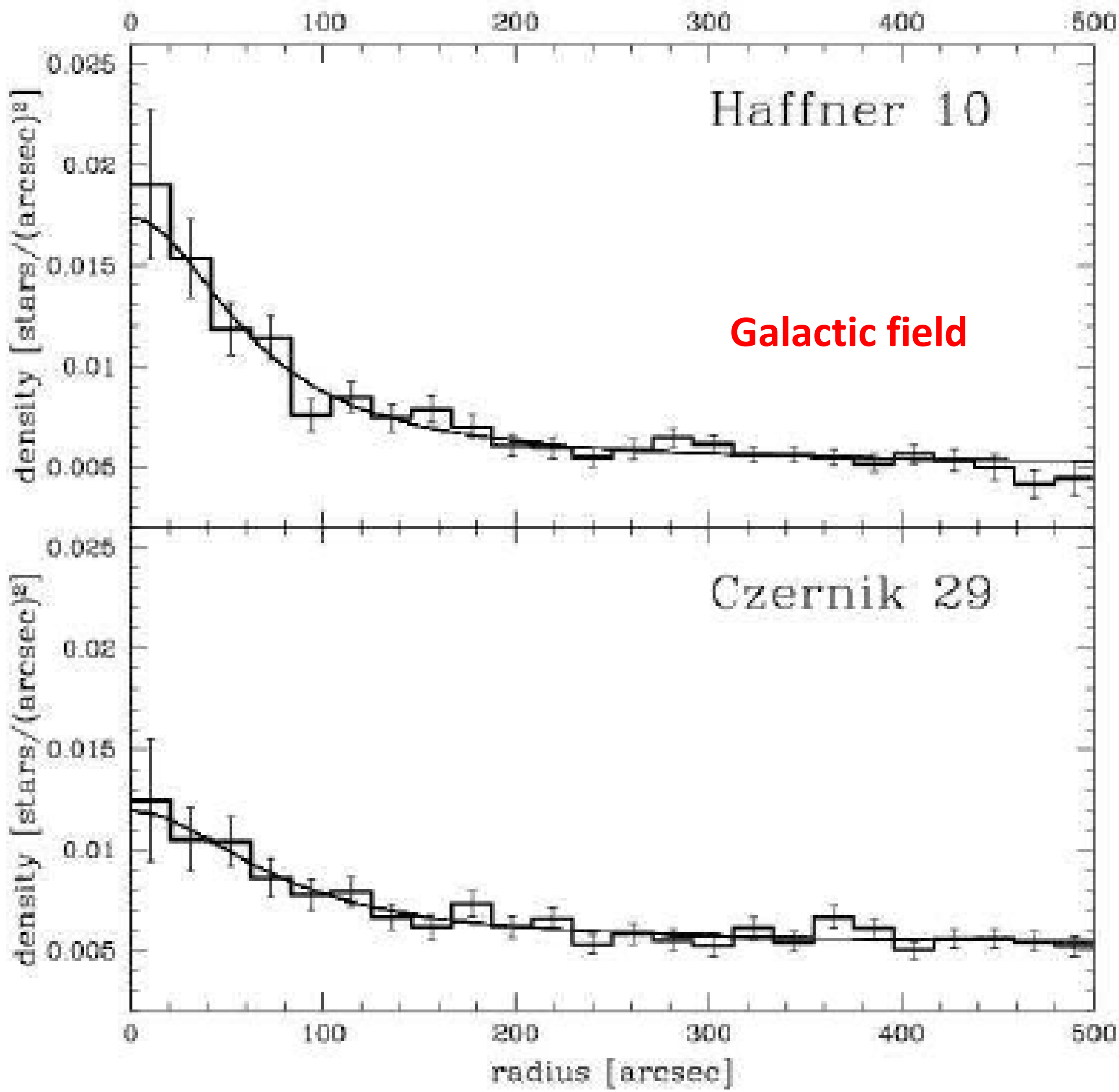
- **Richness Class (Janes & Adler)**
  - **1** … Less than 25 stars
  - **2** … Between 25 and 50 stars
  - **3** … Between 50 and 100 stars
  - **4** … Between 100 and 250 stars
  - **5** … More than 250 stars
- How "good" can the number of members be established?

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



Pietrukowicz et al., 2006, MNRAS, 365, 110 van den Bergh, 2006, AJ, 131, 1559

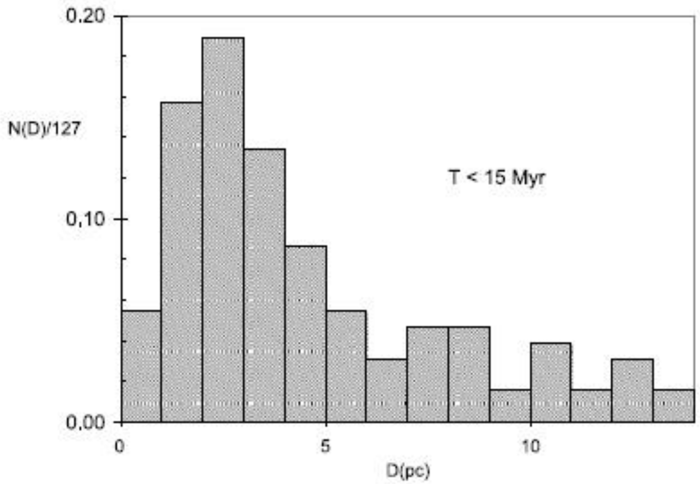


Fig. 2*a*

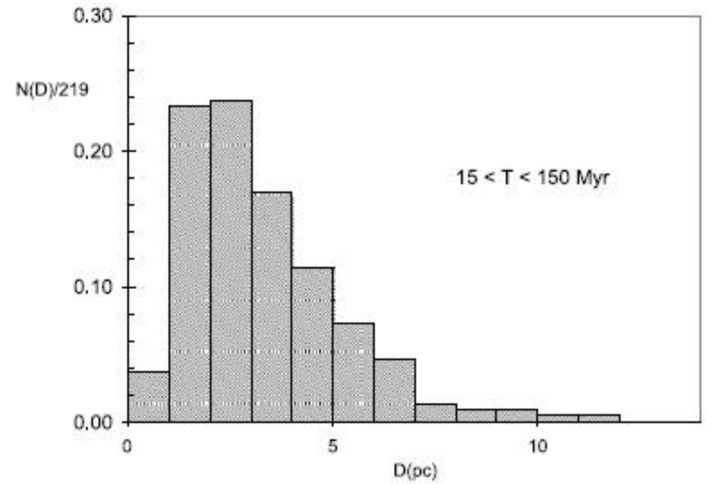
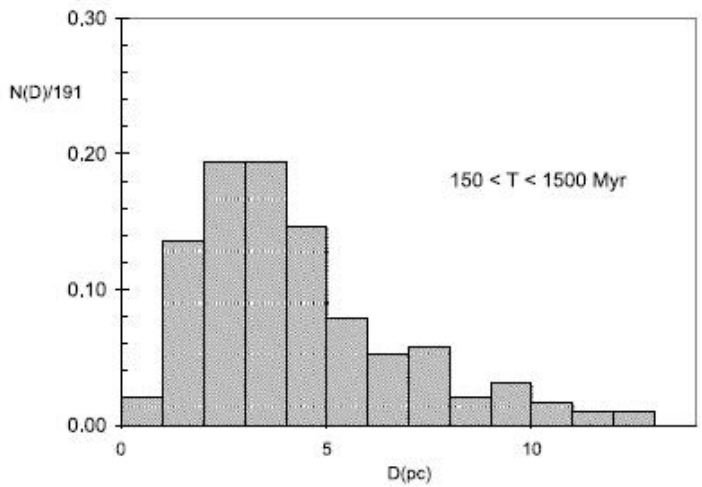
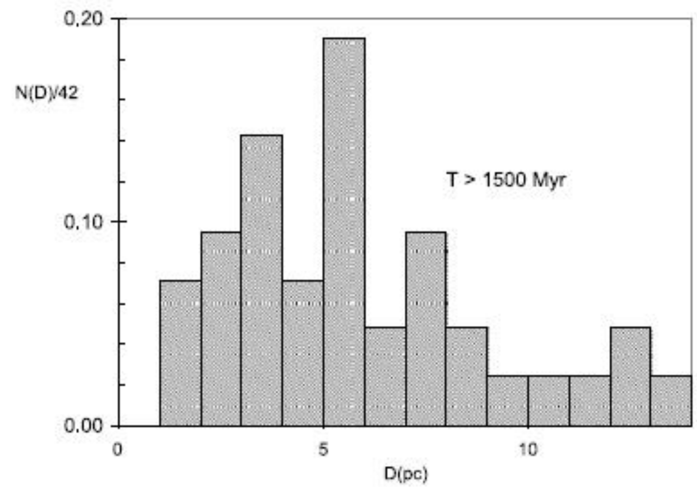


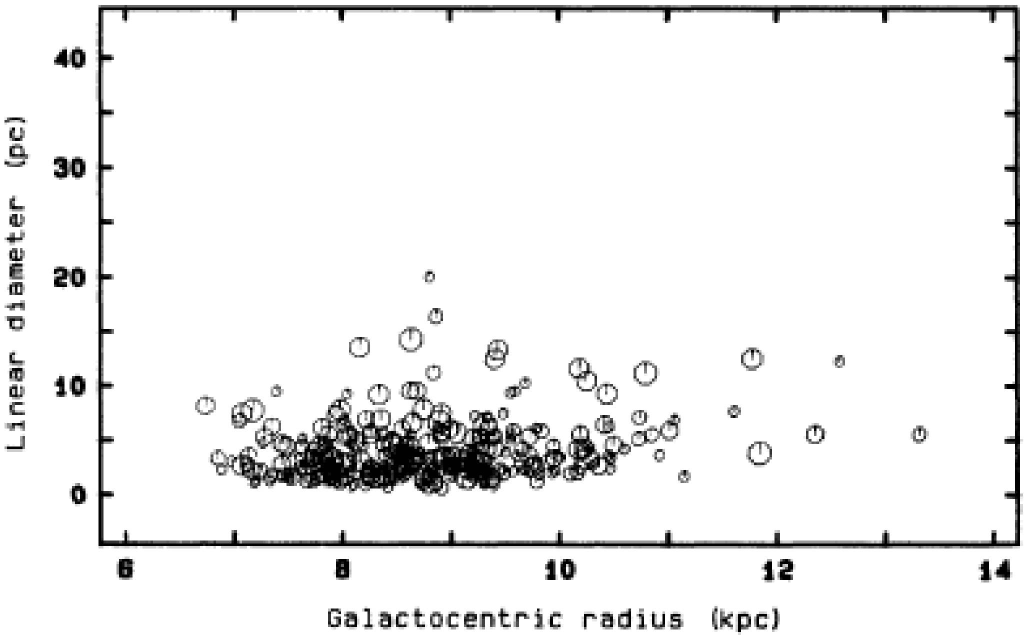
Fig. 2*b*



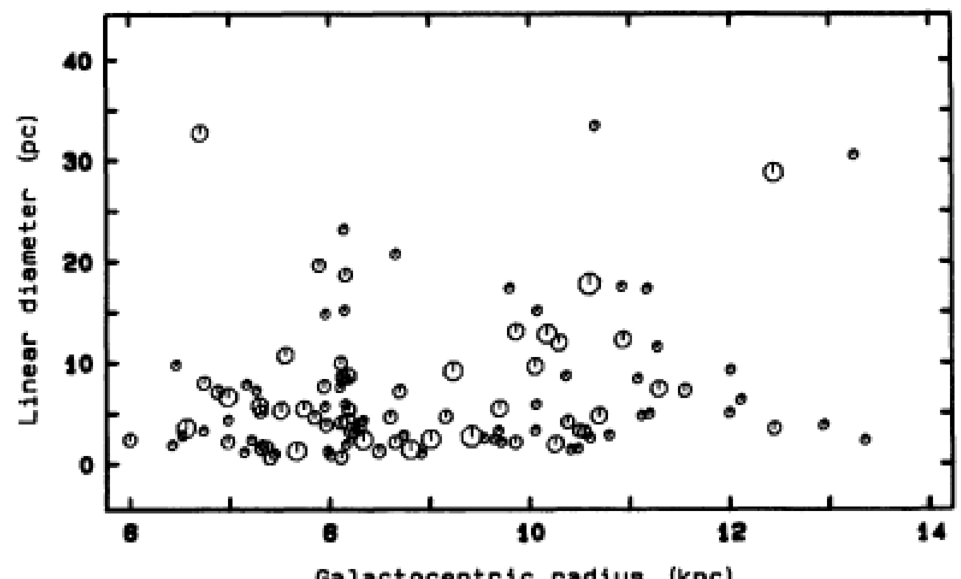


No correlation with the age

Janes et al., 1988, AJ, 95, 771

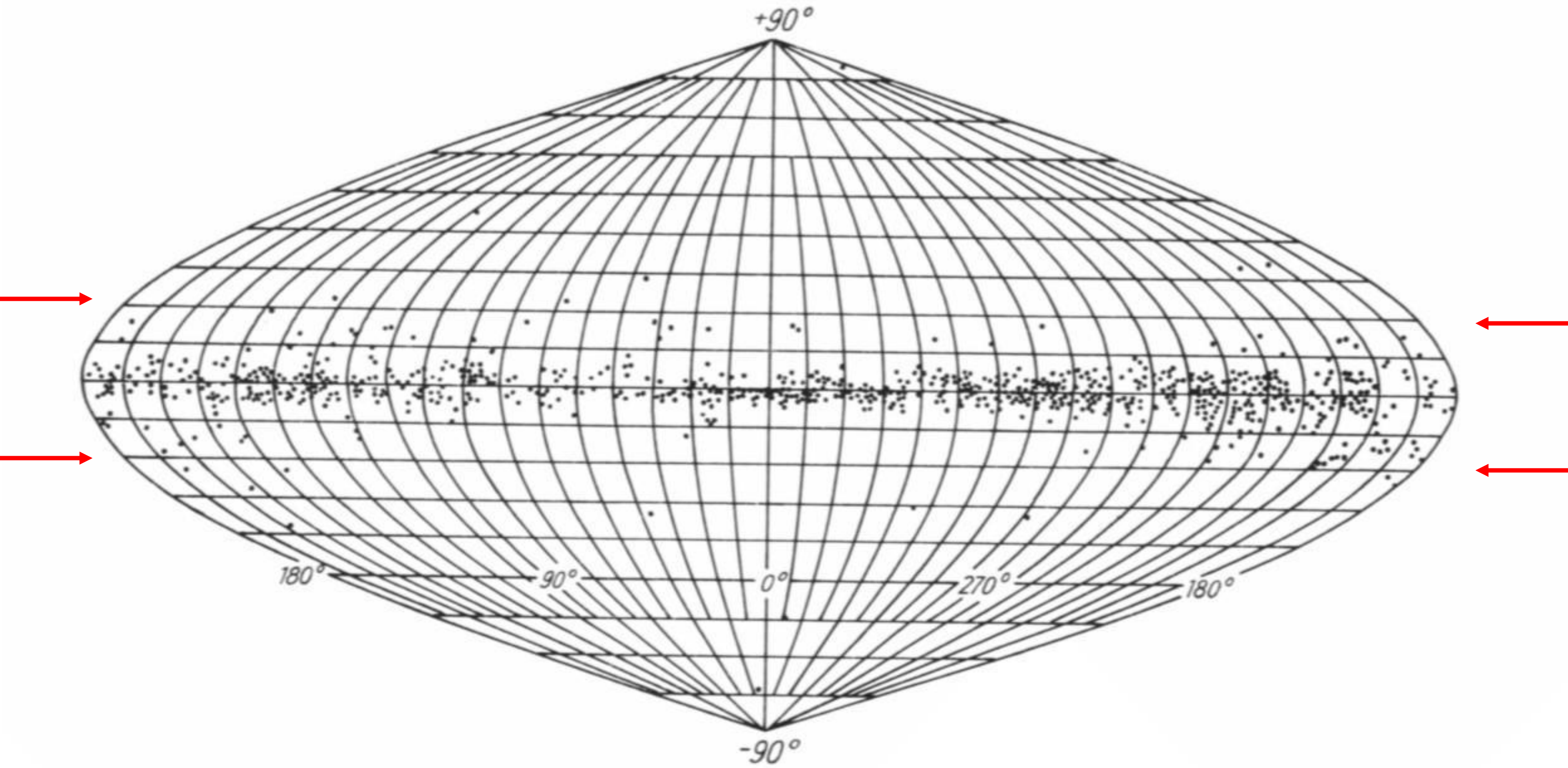


all



young

Galactic Distribution



+- 20 degree Galactic latitude

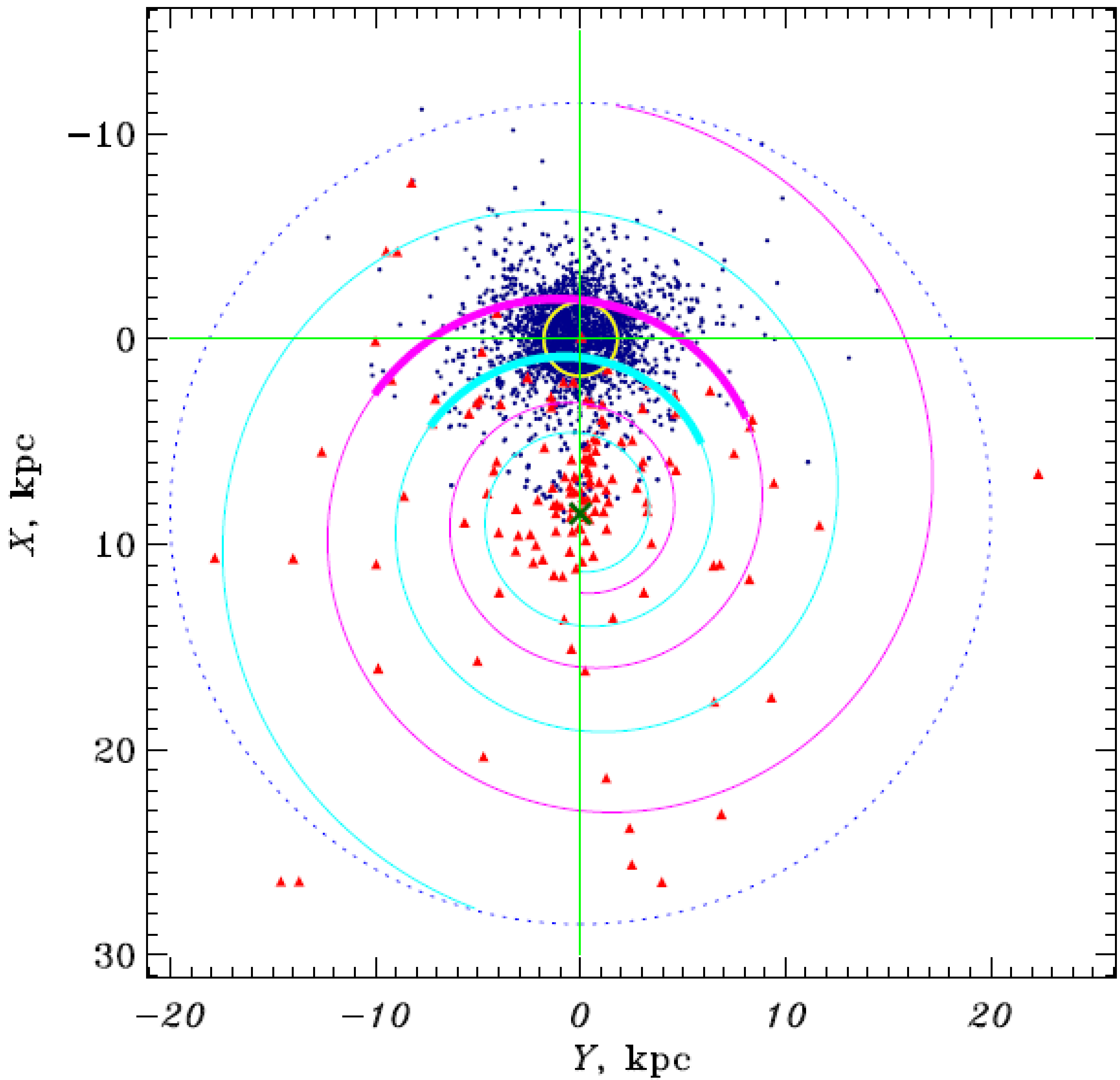
Kharchenko et al., 2013, A&A, 558, A53

Blue dots: OCLs

Red triangles: GCs

Spiral arms

Projection on the Galactic plane



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

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.

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

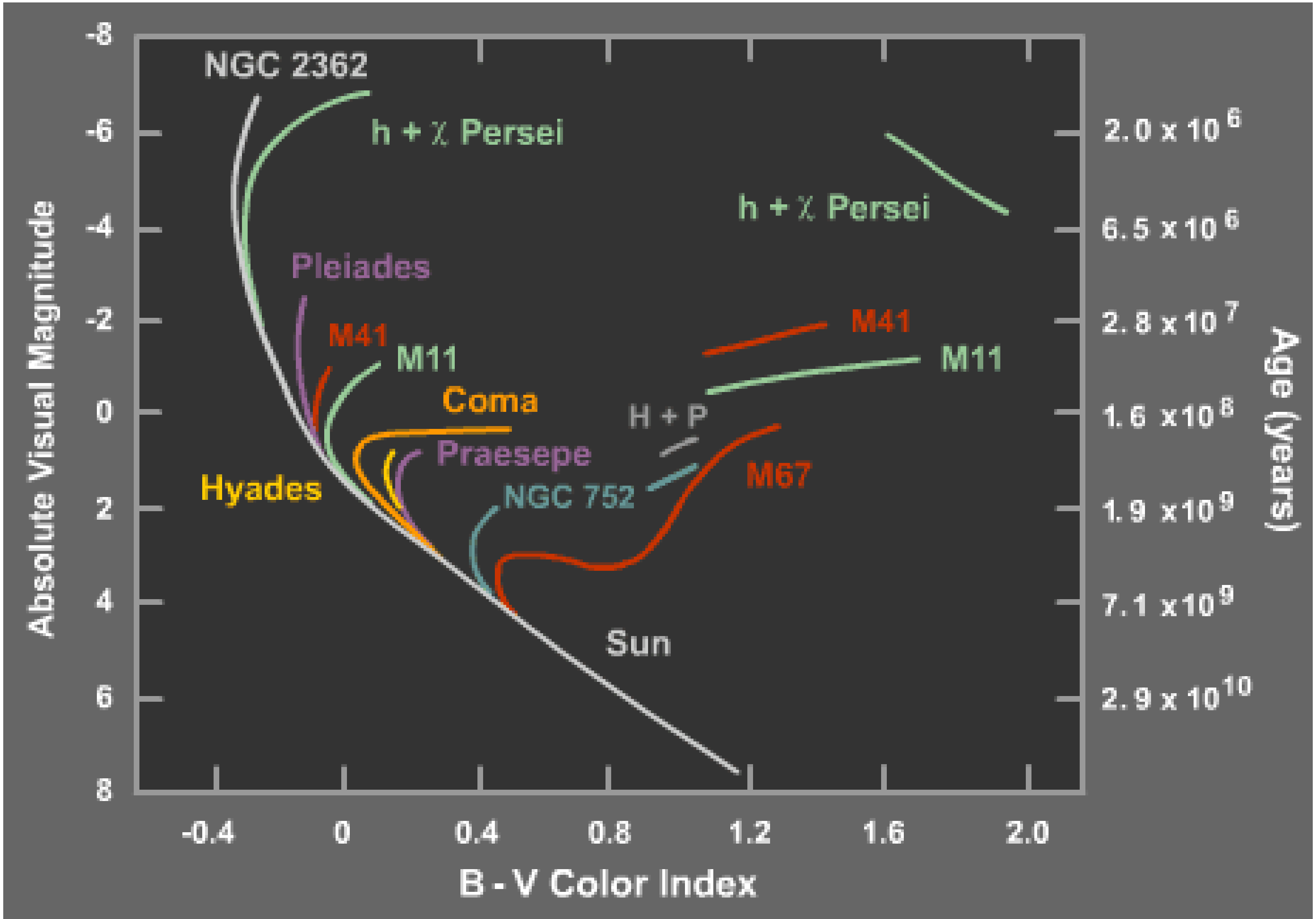
The smaller the number of stars, the higher the core's stellar density.

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

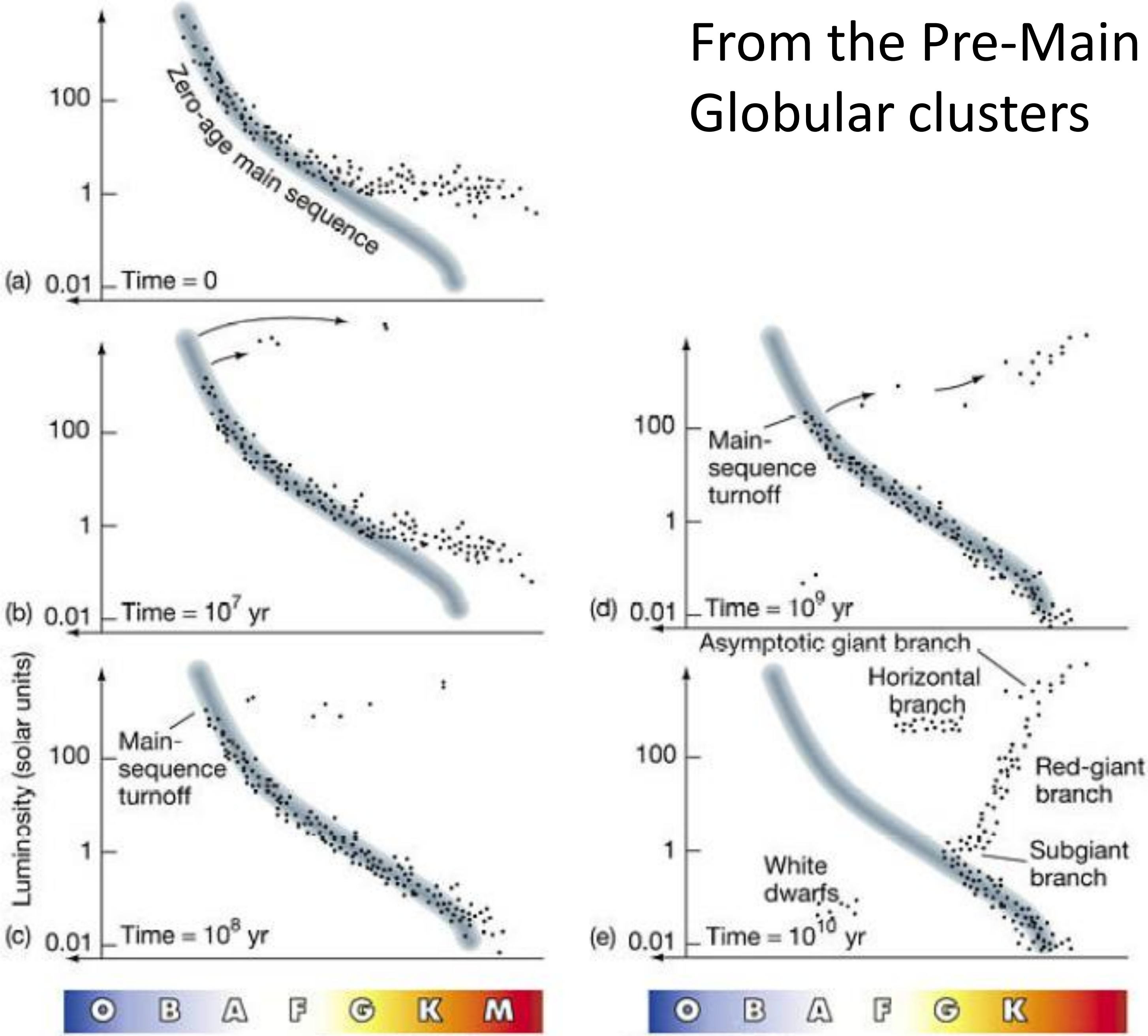
Important observables

- Single stars: „all“ we can think of
- Star 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) $t = 0$

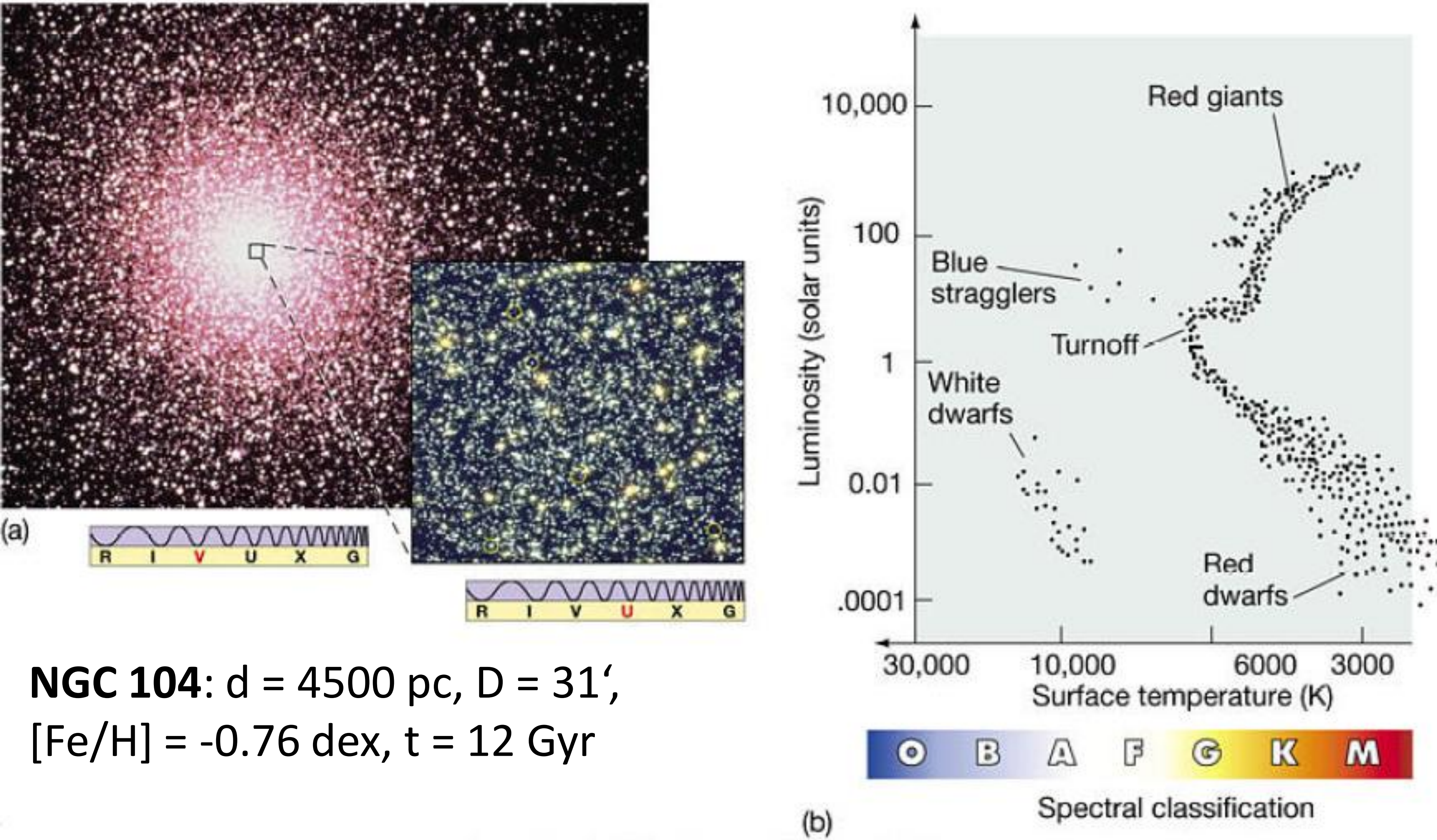
(b) $t = 10^7$yr

(c) $t = 10^8$yr

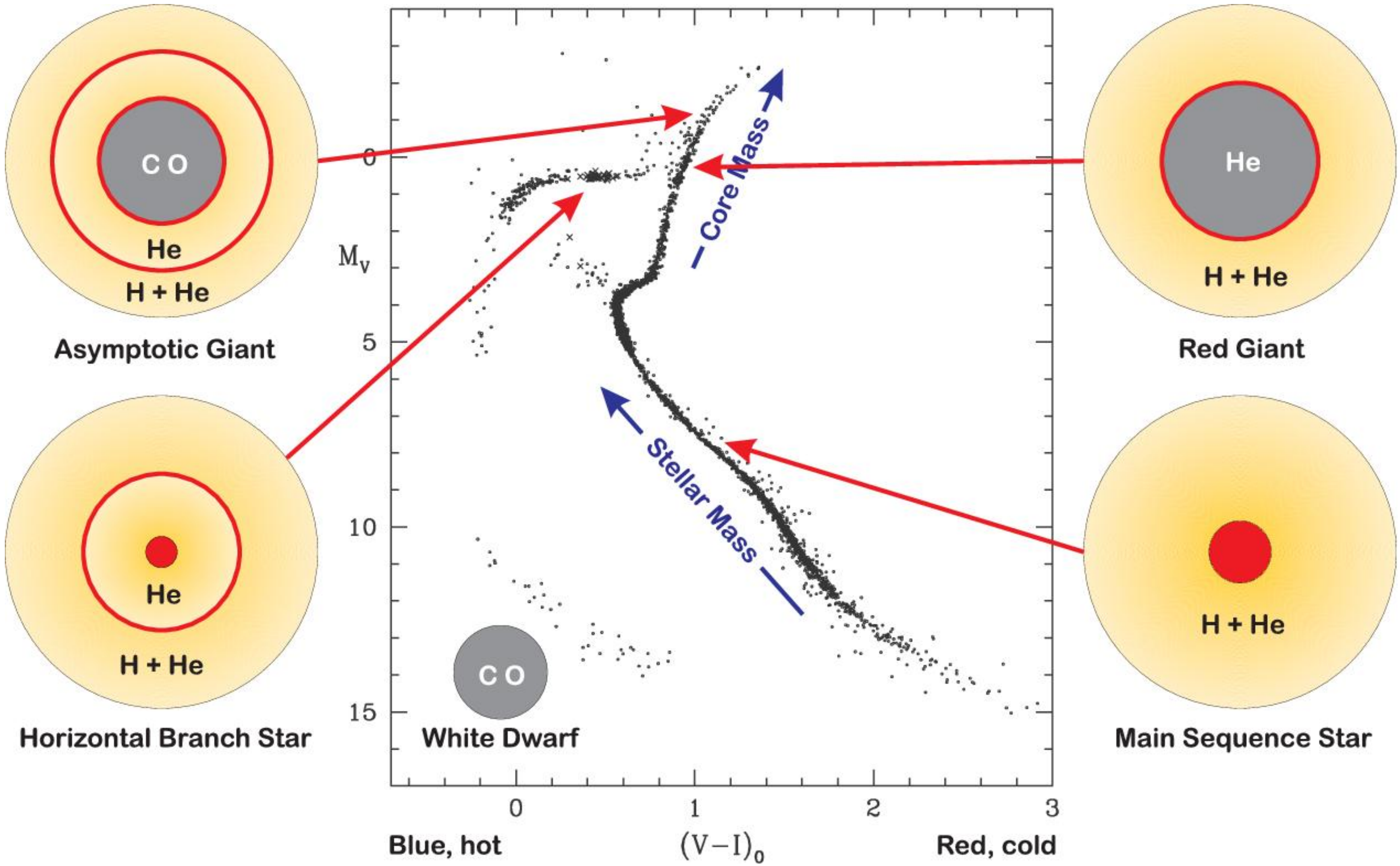
(d) $t = 10^9$yr

(e) $t = 10^{10}$yr

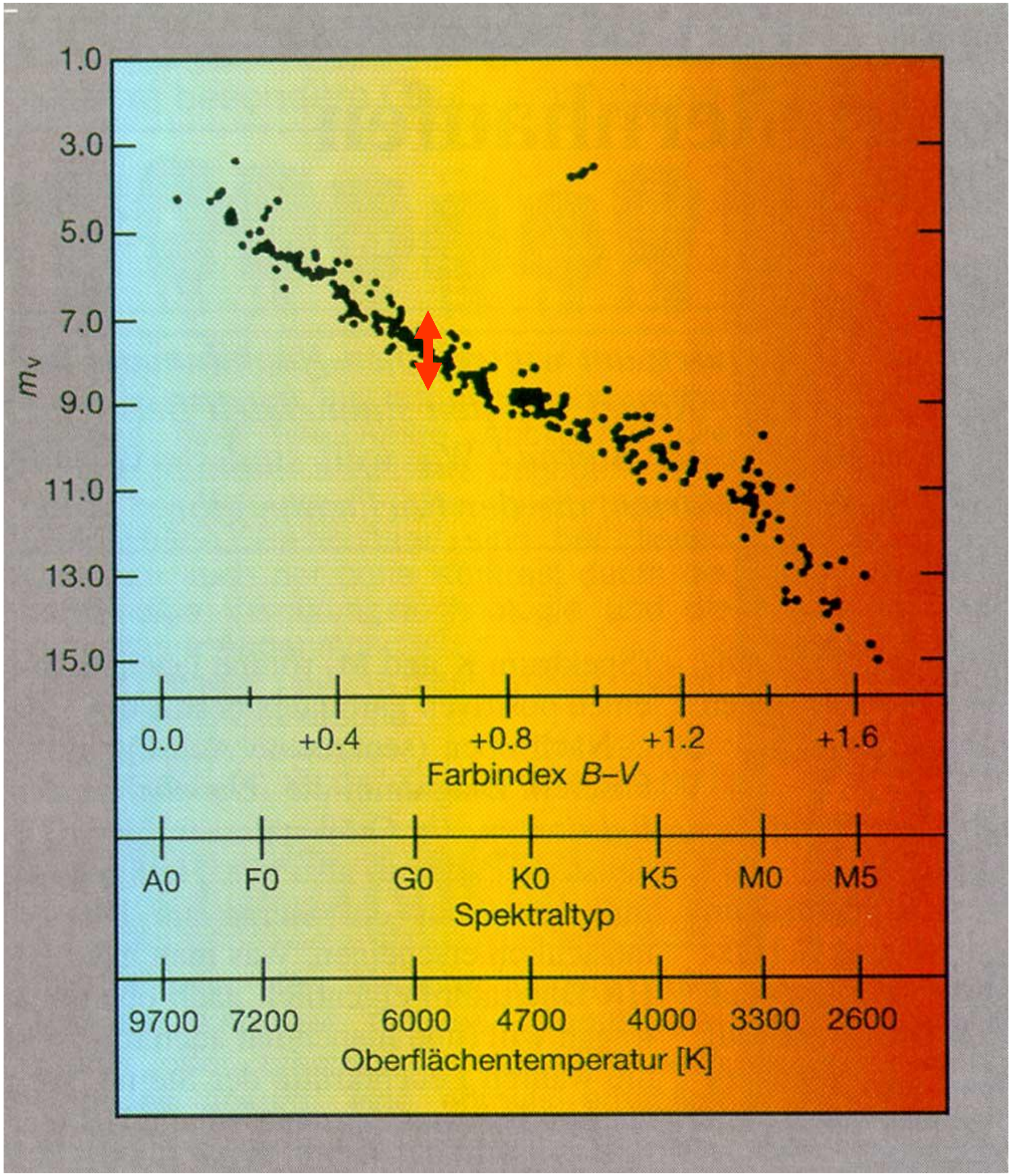
47 Tuc



NGC 104: d = 4500 pc, D = 31′, [Fe/H] = -0.76 dex, t = 12 Gyr



Harris, 2000, Space Telescope Science Institute Symposium Series, Vol. 14, p. 78



Hyades

log t = 8.90

d = 45 pc

[Fe/H] = +0.17 dex

Width of Main Sequence about 1.8 mag in M_V

NO

observational error

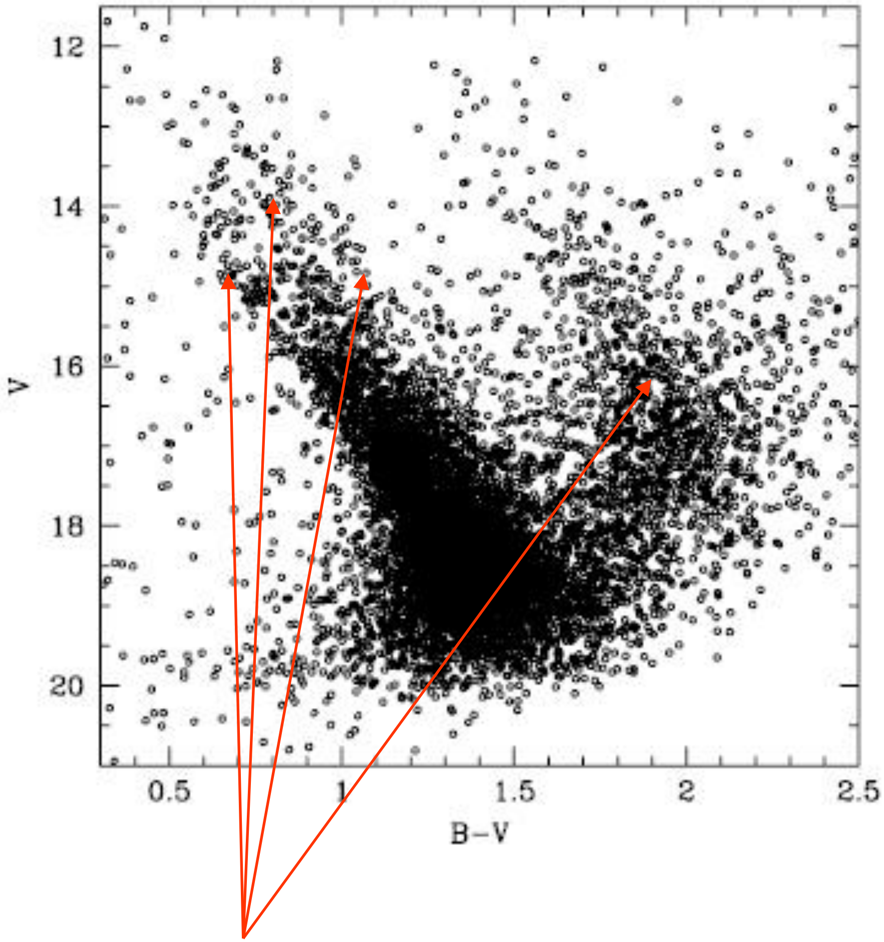
A typical example

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***

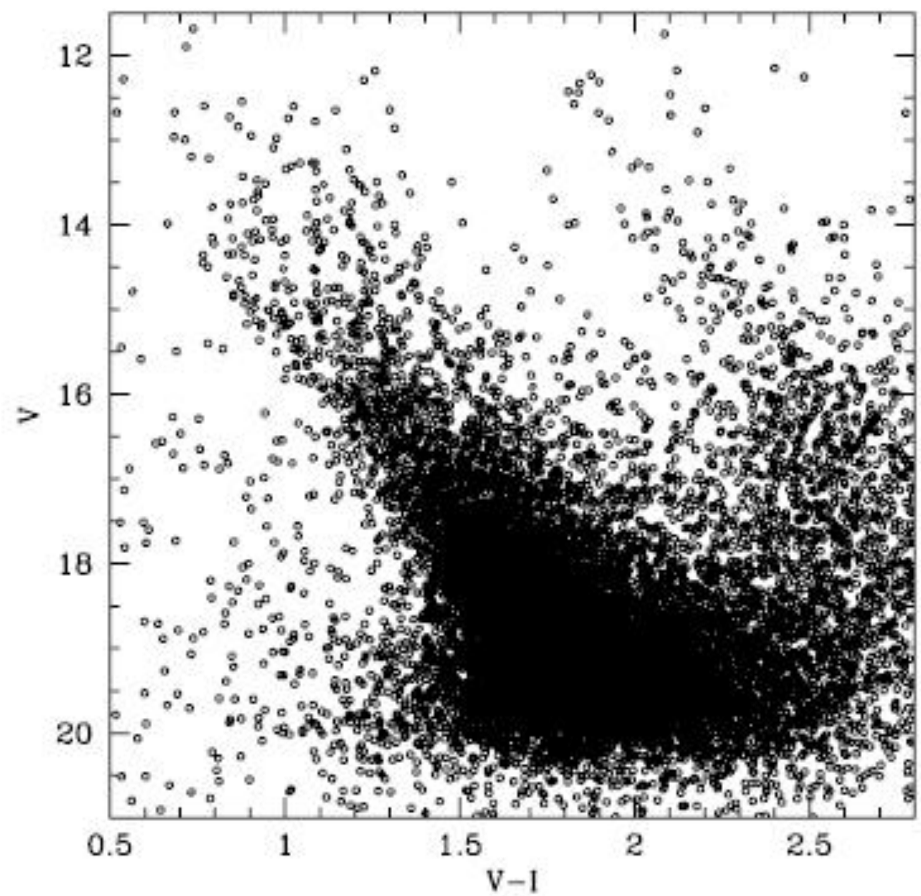
CCD BVI Photometry, 1 Pixel = 0.4´´, 13.6x13.6´ field,

No other observations available for this open cluster



15 688 stars in the complete field

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



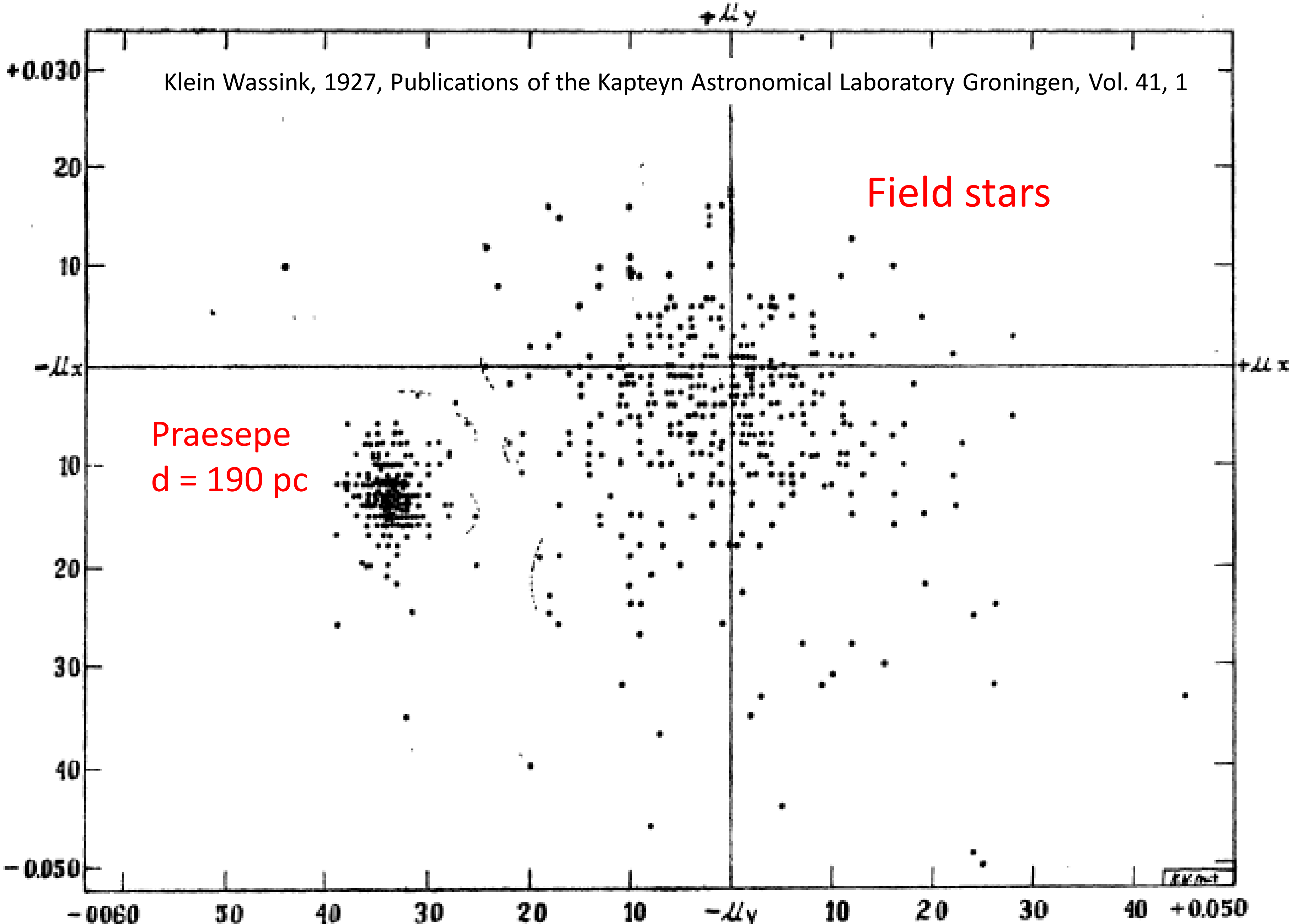
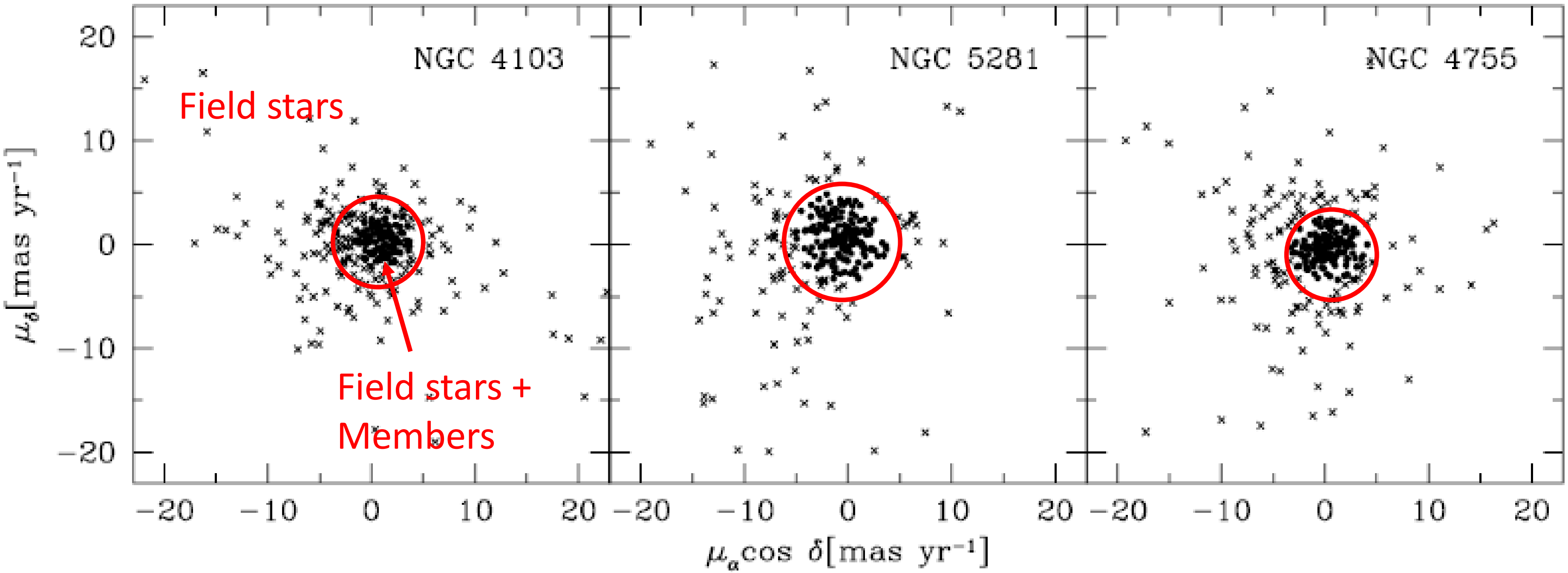


Figure 2. Diagram of the absolute proper motions of the Catalogue; photographic magnitude 6 to 14·0, numbers 1 to 531. The dotted lines separate the Praesepe stars from the backgroundstars.

Sanner et al., 2001, A&A, 369, 511 (Hipparcos and Tycho data)

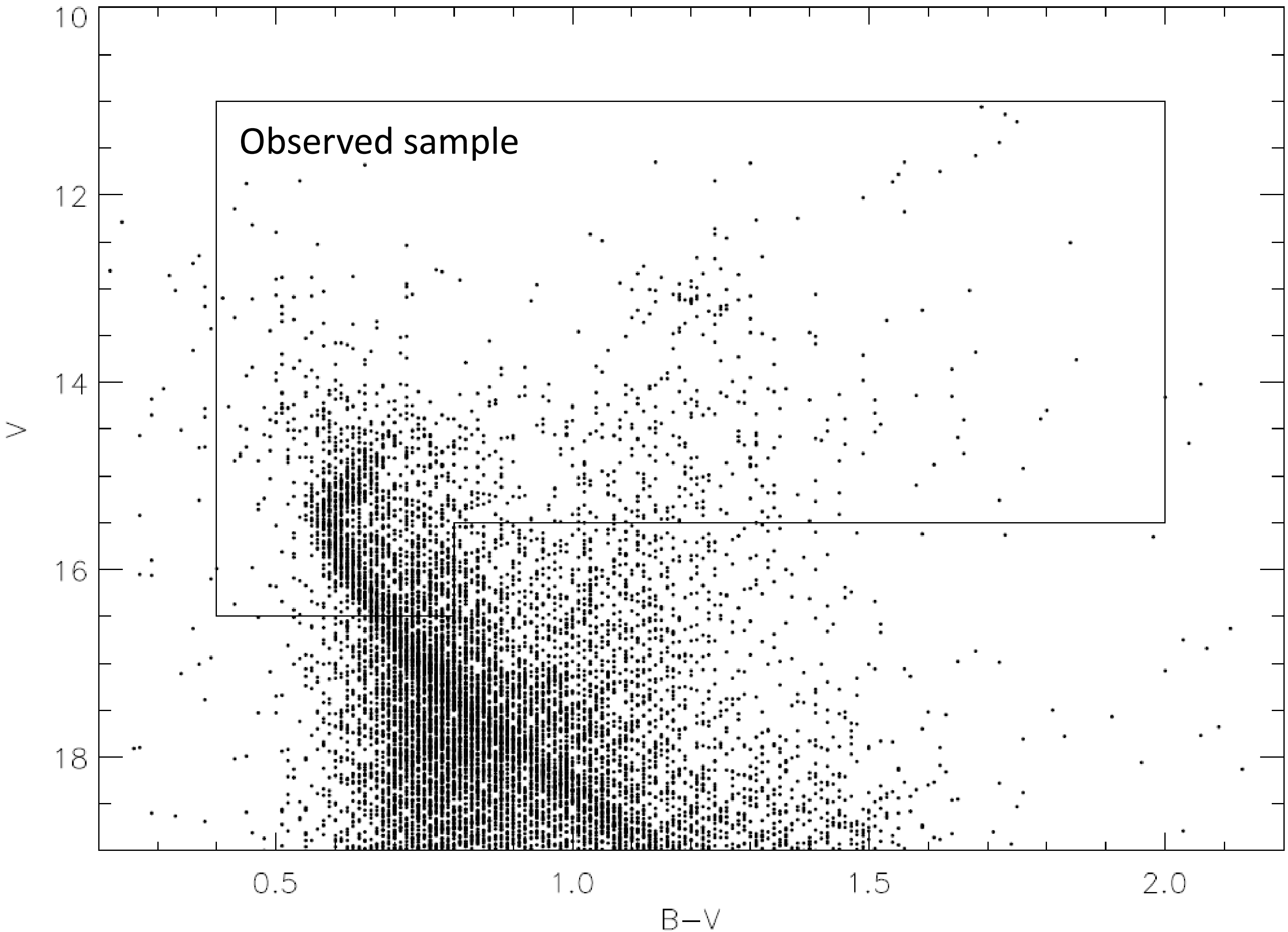


The proper motion for „distant“ star clusters is almost zero.

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



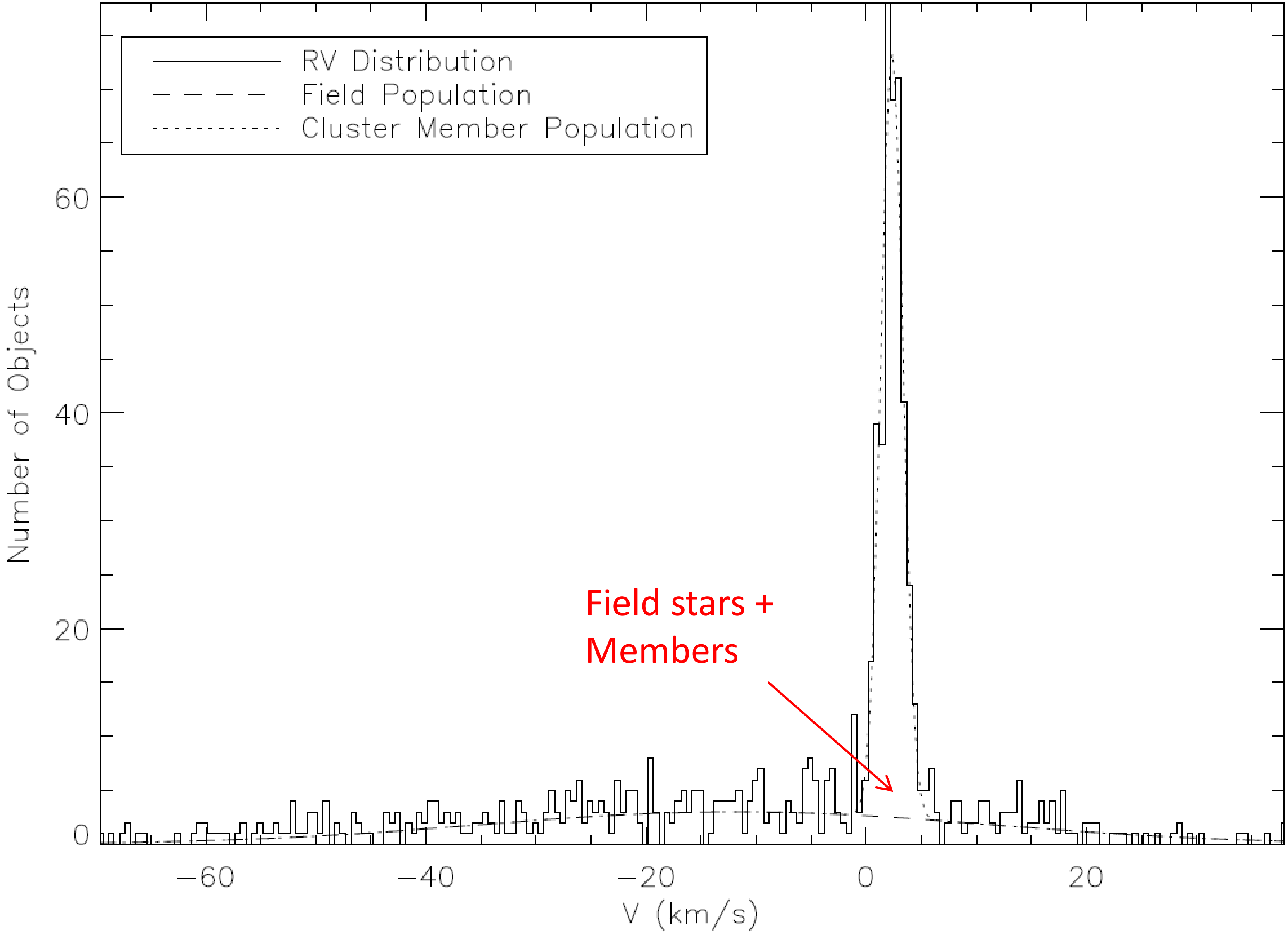
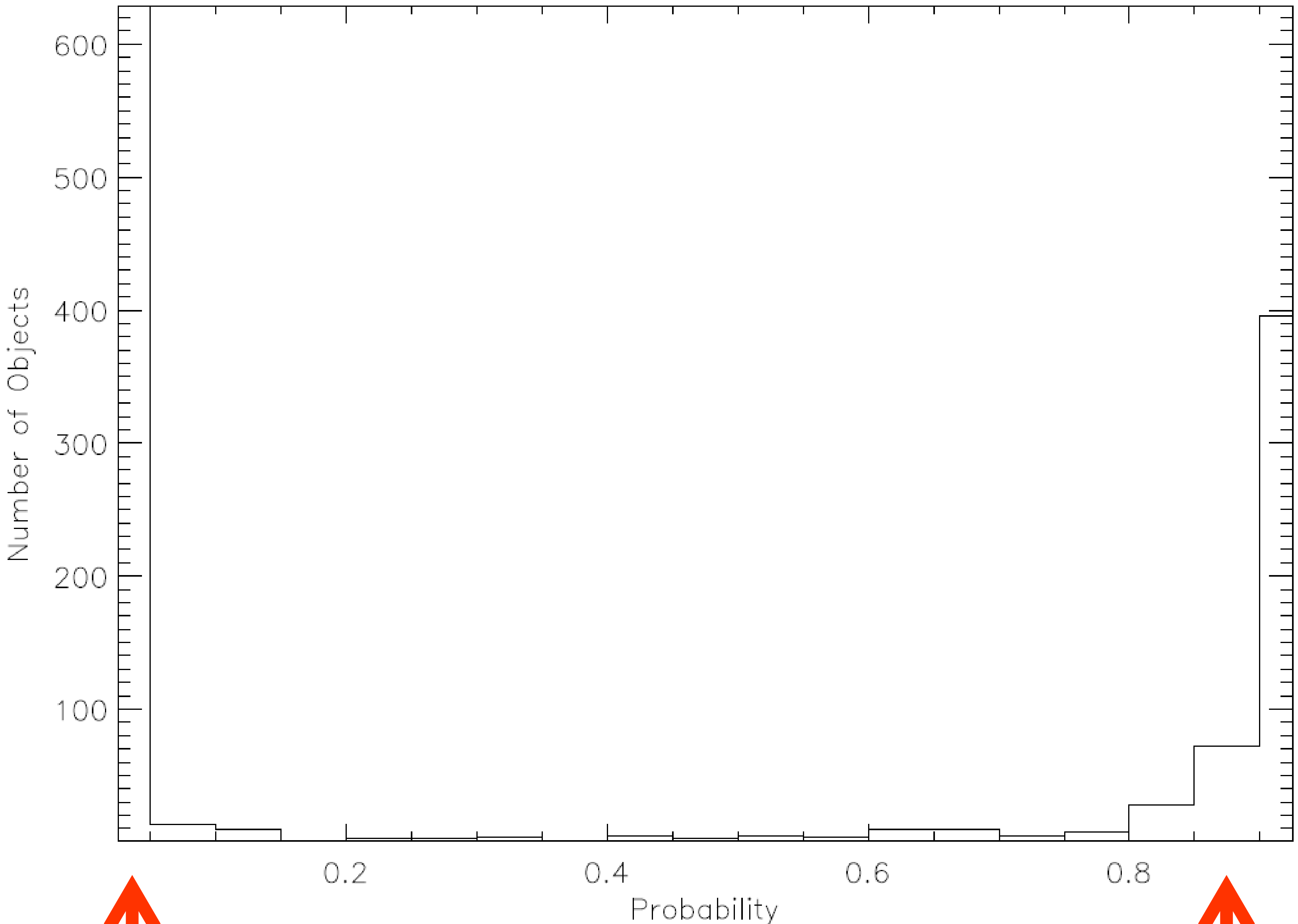


Table 3. Gaussian Fit Parameters For Cluster and Field RV Distributions

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

Hole et al., 2009, AJ, 138, 159

Hole et al., 2009, AJ, 138, 159

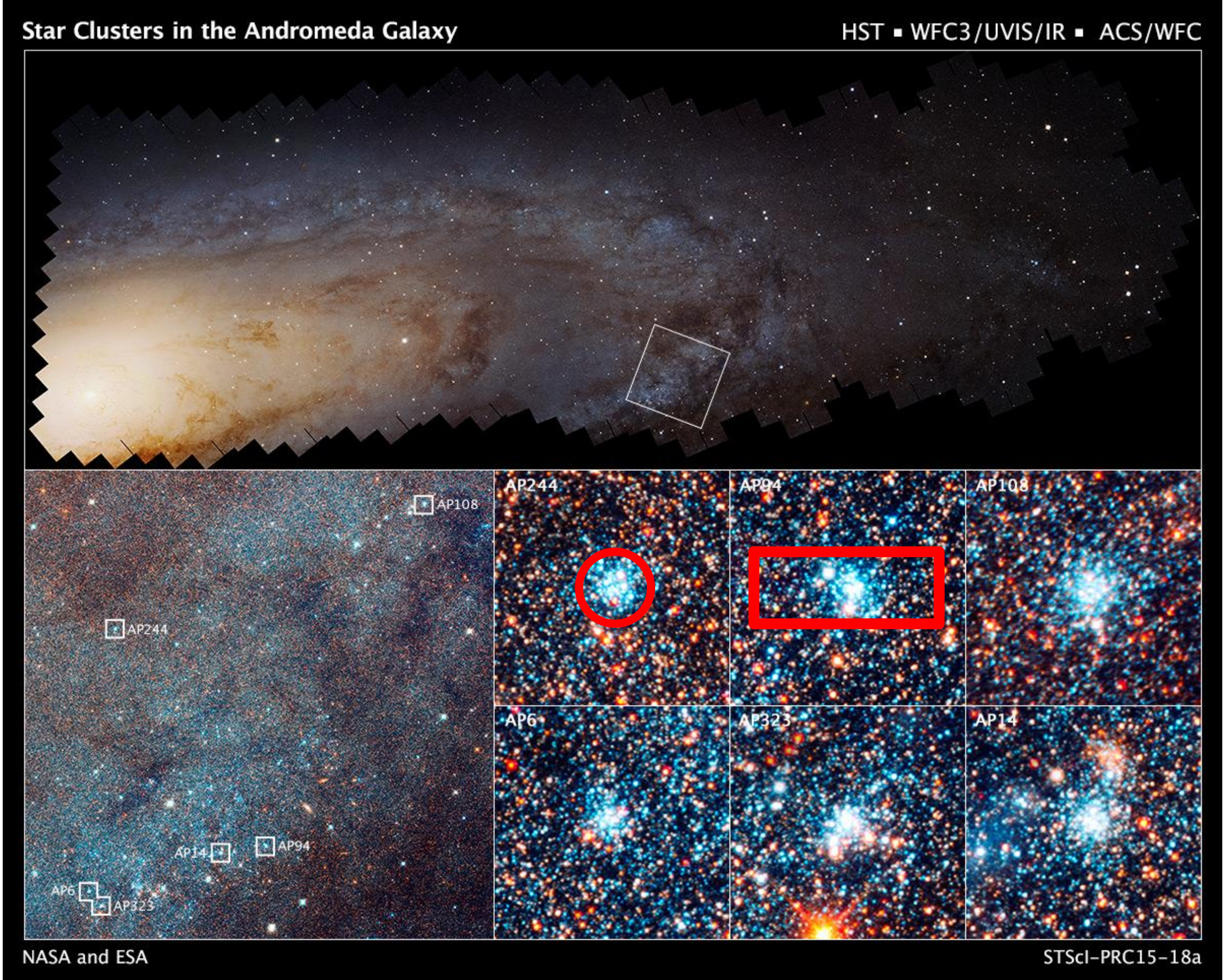


members

non-members

Integrated properties

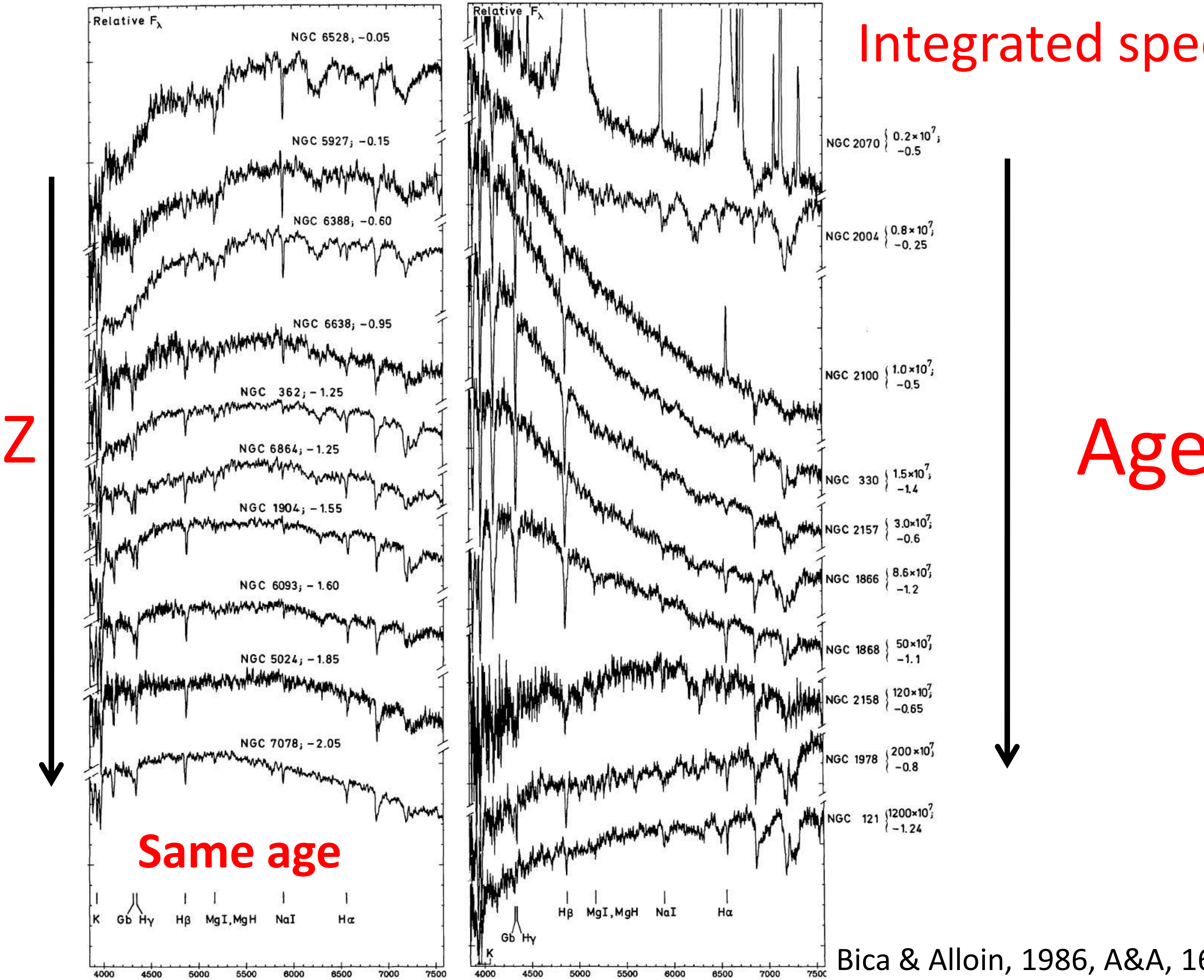
- Integrated spectra and colors
- Especially interesting for distant and extragalactic star clusters
- “Think small”
- Pleiades: 2^{o}



Star Clusters in the Andromeda Galaxy
HST ▪ WFC3/UVIS/IR ▪ ACS/WFC
AP108
AP244
AP14
AP94
AP6
AP323
AP244
AP94
AP108
AP6
AP323
AP14
NASA and ESA
STScI-PRC15-18a

1’

Integrated spectra



Bica & Alloin, 1986, A&A, 162, 21

Integrated colors

“HRD diagram”

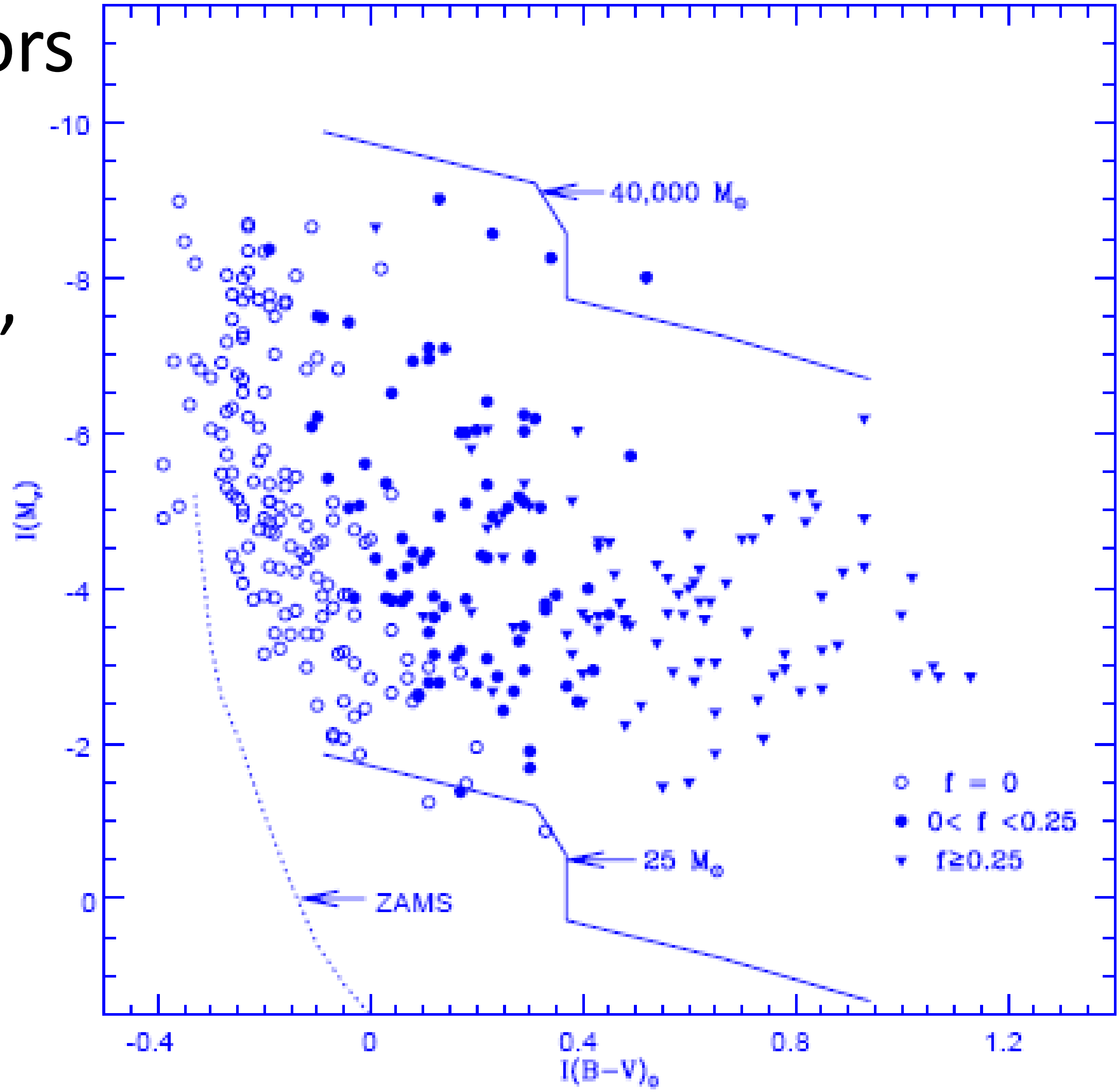


Fig. 2. The $I(M_V)$, $I(B-V)_0$ diagram. f is the fraction of red giants/supergiants in the open clusters.

Lata et al., 2002, A&A, 388, 158