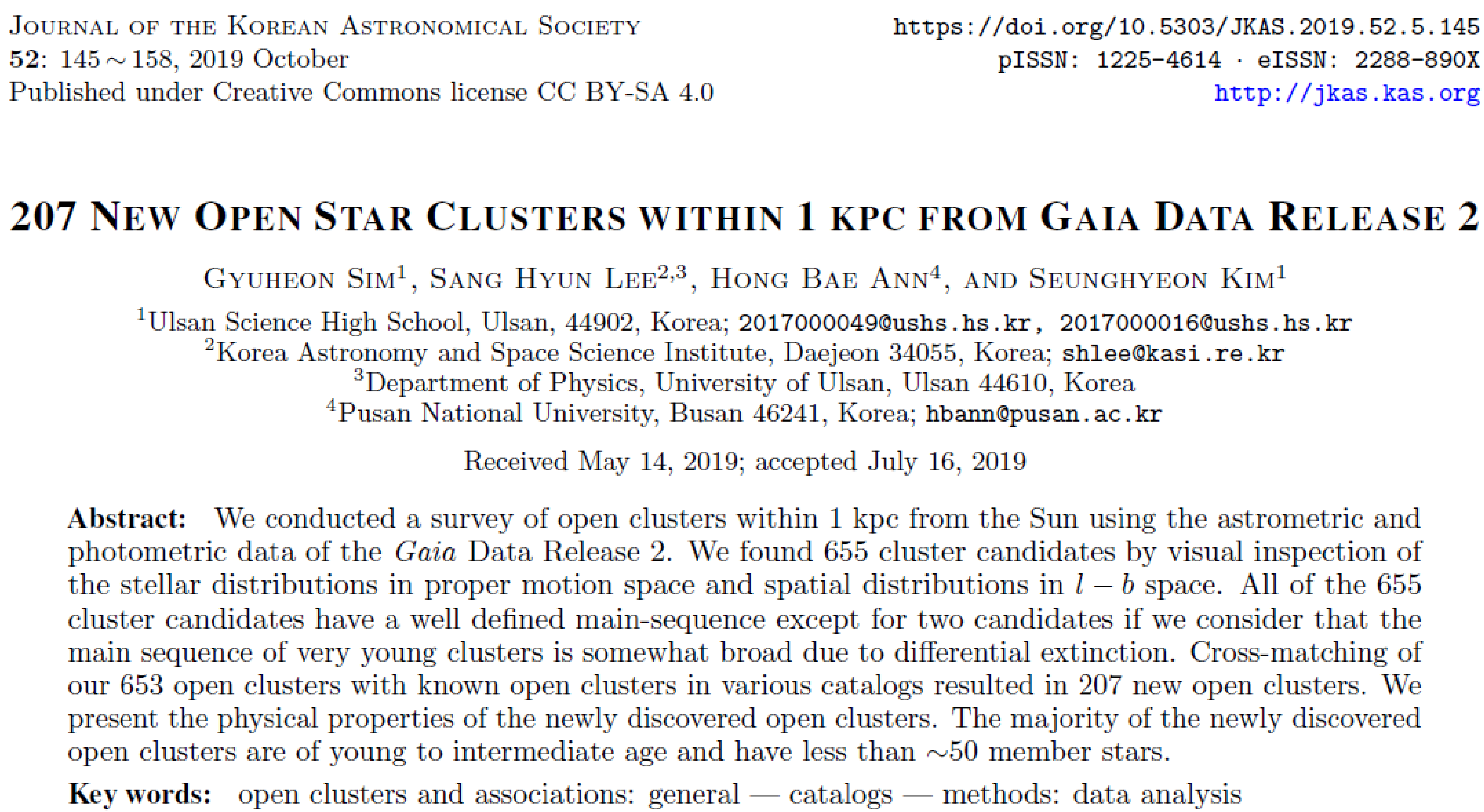
Gaia and new star clusters



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http://jkas.kas.org

207 New Open Star Clusters within 1 kpc from Gaia Data Release 2

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Abstract: We conducted a survey of open clusters within 1 kpc from the Sun using the astrometric and photometric data of the *Gaia* Data Release 2. We found 655 cluster candidates by visual inspection of the stellar distributions in proper motion space and spatial distributions in $l - b$ space. All of the 655 cluster candidates have a well defined main-sequence except for two candidates if we consider that the main sequence of very young clusters is somewhat broad due to differential extinction. Cross-matching of our 653 open clusters with known open clusters in various catalogs resulted in 207 new open clusters. We present the physical properties of the newly discovered open clusters. The majority of the newly discovered open clusters are of young to intermediate age and have less than ∼50 member stars.

Key words: open clusters and associations: general — catalogs — methods: data analysis

Gaia and new star clusters

Astronomy & Astrophysics manuscript no. manuscript
January 22, 2020

Hunting for open clusters in *Gaia* DR2: 582 new OCs in the Galactic disc★

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Received date / Accepted date

ABSTRACT

Context. Open clusters are key targets for both Galaxy structure and evolution and stellar physics studies. Since *Gaia* DR2 publication, the discovery of undetected clusters has proven that our samples were not complete.
Aims. Our aim is to exploit the Big Data capabilities of machine learning to detect new open clusters in *Gaia* DR2, and to complete the open cluster sample to enable further studies on the Galactic disc.
Methods. We use a machine learning based methodology to systematically search in the Galactic disc, looking for overdensities in the astrometric space and identifying them as open clusters using photometric information. First, we use an unsupervised clustering algorithm, DBSCAN, to blindly search for these overdensities in *Gaia* DR2 $(l, b, \varpi, \mu_{\alpha^*}, \mu_\delta)$. After that, we use a deep learning artificial neural network trained on colour-magnitude diagrams to identify isochrone patterns in these overdensities, and to confirm them as open clusters.
Results. We find 582 new open clusters distributed along the Galactic disc, in the region $|b| < 20°$. We can detect substructure in complex regions, and identify the tidal tails of a disrupting cluster UBC 274 of ~ 3 Gyr located at ~ 2 kpc.
Conclusions. Adapting the methodology into a Big Data environment allows us to target the search driven by physical properties of the open clusters, instead of being driven by its computational requirements. This blind search for open clusters in the Galactic disc increases in a 45% the number of known open clusters.

Key words. Surveys — open clusters and associations: general — Astrometry — Methods: data analysis

Gaia and new star clusters

Publications of the Astronomical Society of the Pacific, 132:034502 (18pp), 2020 March https://doi.org/10.1088/1538-3873/ab694d

CrossMark

Sixteen Open Clusters Discovered with Sample-based Clustering Search of *Gaia* DR2

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Abstract

Accurate astrometric parameters and photometric data in three bands for more than 1.3 billion sources (mainly stars) were made available in the recent *Gaia* Data Release 2, allowing us to find new open clusters in the milky Way. We propose a novel sample-based clustering search method with high spatial resolution to search for open clusters (OCs). We used the proposed method to find 16 new OC candidates. Their astrometric parameters are presented, including age, etc.

Key words: methods: data analysis – methods: statistical – open clusters and associations: general

Online material: color figures

Designation of star clusters

- IAU:
  - C *aa bb ± ccd*
  - aa^h bb^m ± 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

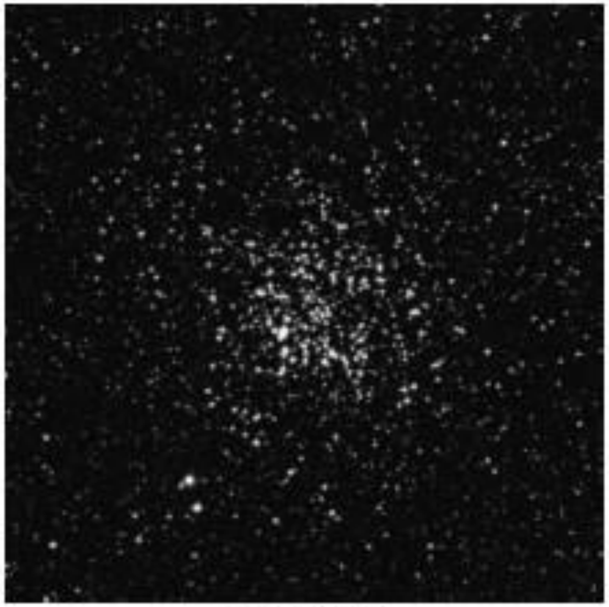
Trumplers classification

- **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

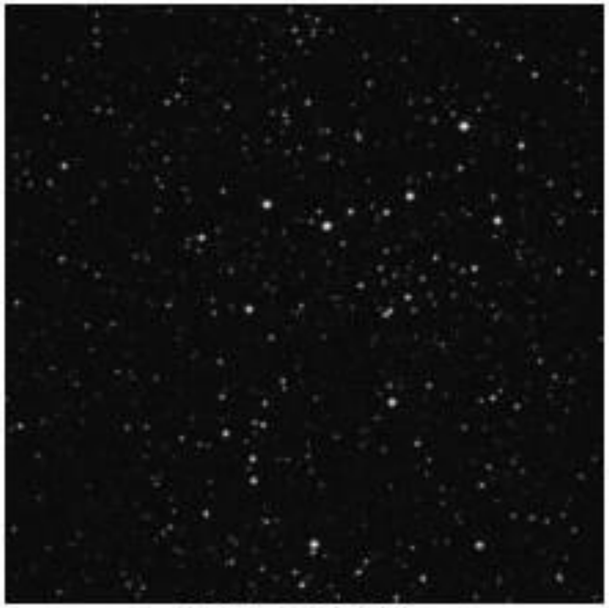
- **Number of Stars in the Cluster**
  - **p** … Poor clusters with less than 50 stars
  - **m** … Medium rich cluster with 50 to 100 stars
  - **r** … Rich clusters with over 100 stars
- Open clusters with any type of nebulosity are denoted with an "**n**" at the end of the classification.


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

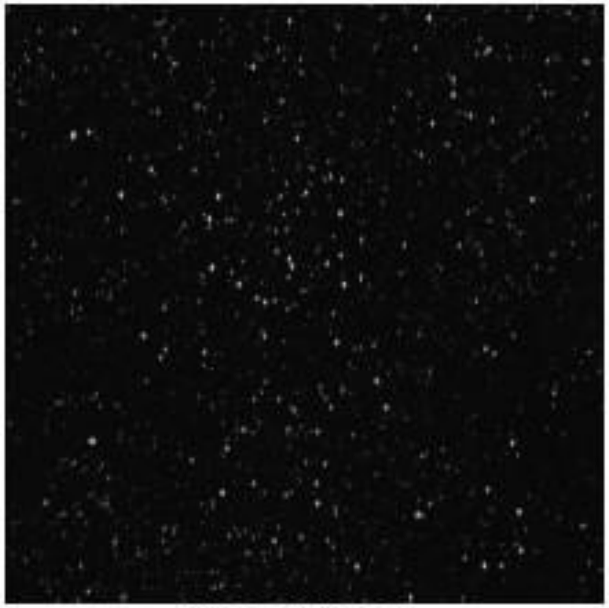


M11 15.0′
Class: I 2 r

M46 15.0′
Class: II 2 r



NGC 6664 15.0′
Class: III 2 m



NGC 6568 25.0′
Class: IV 1 m

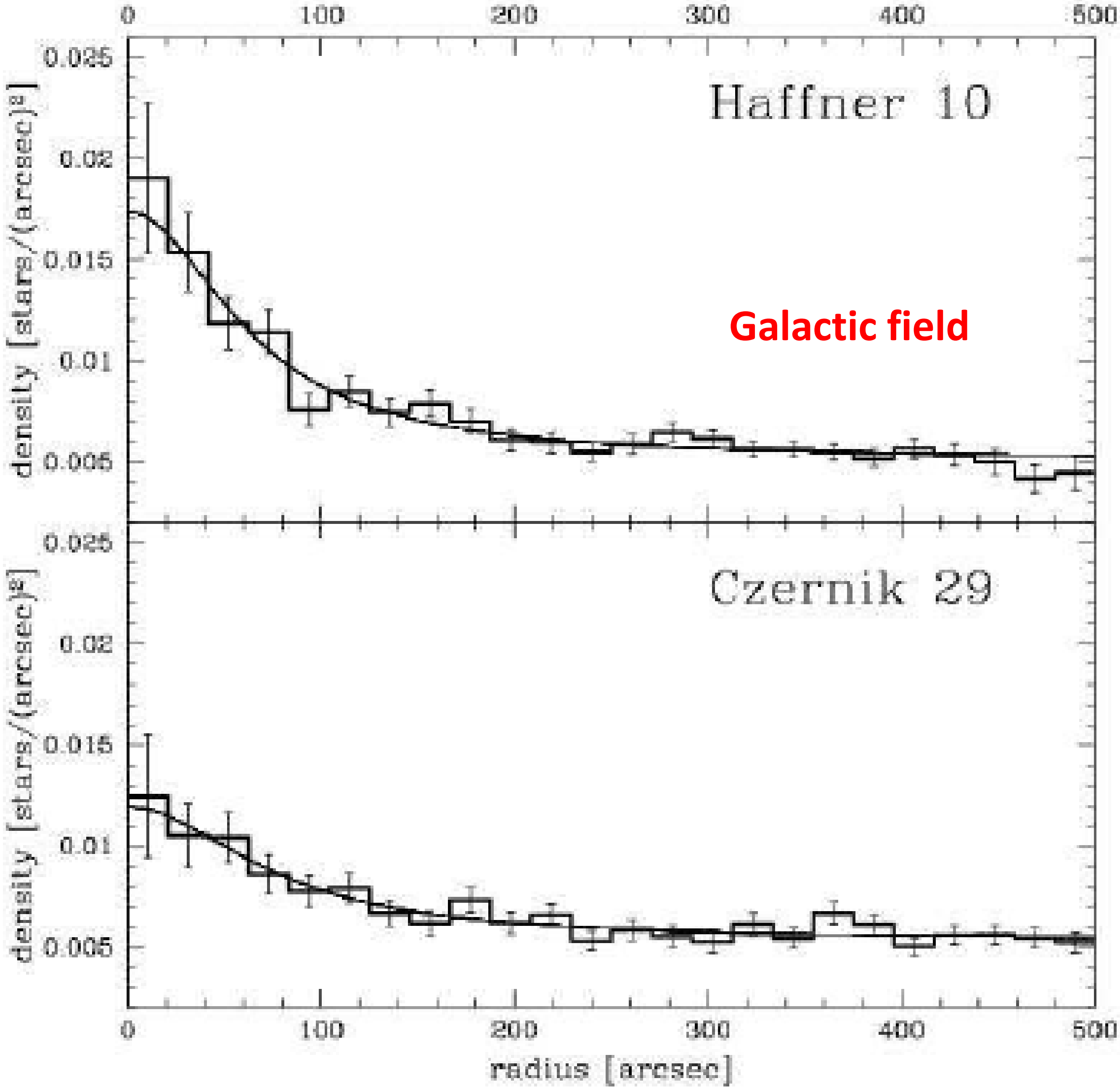
- **Richness Class (Janes & Adler)**
  - **1** … Less than 25 stars
  - **2** … Between 25 and 50 stars
  - **3** … Between 50 and 100 stars
  - **4** … Between 100 and 250 stars
  - **5** … More than 250 stars
- How "good" can the number of members be established?

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

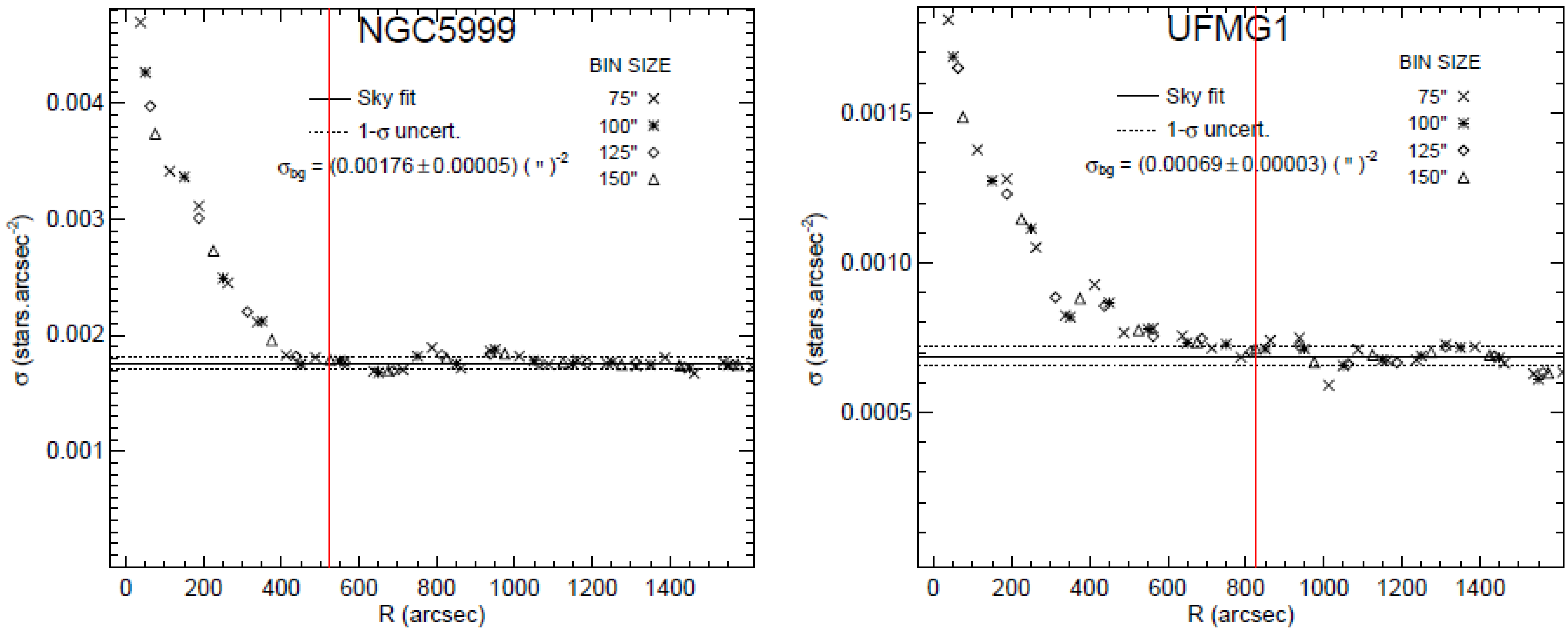
III 2 m

II 2 m



Pietrukowicz et al., 2006, MNRAS, 365, 110

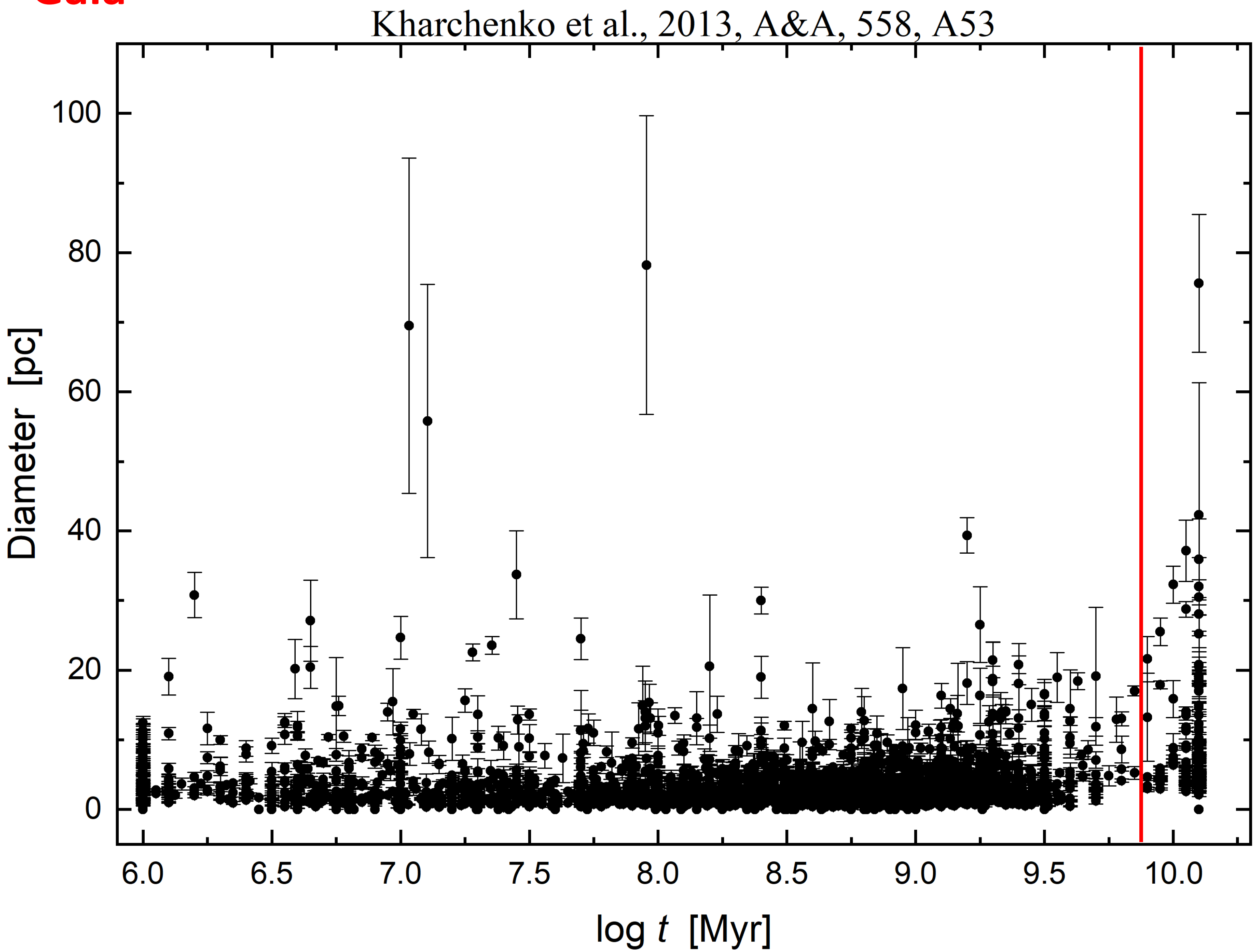
Gaia data



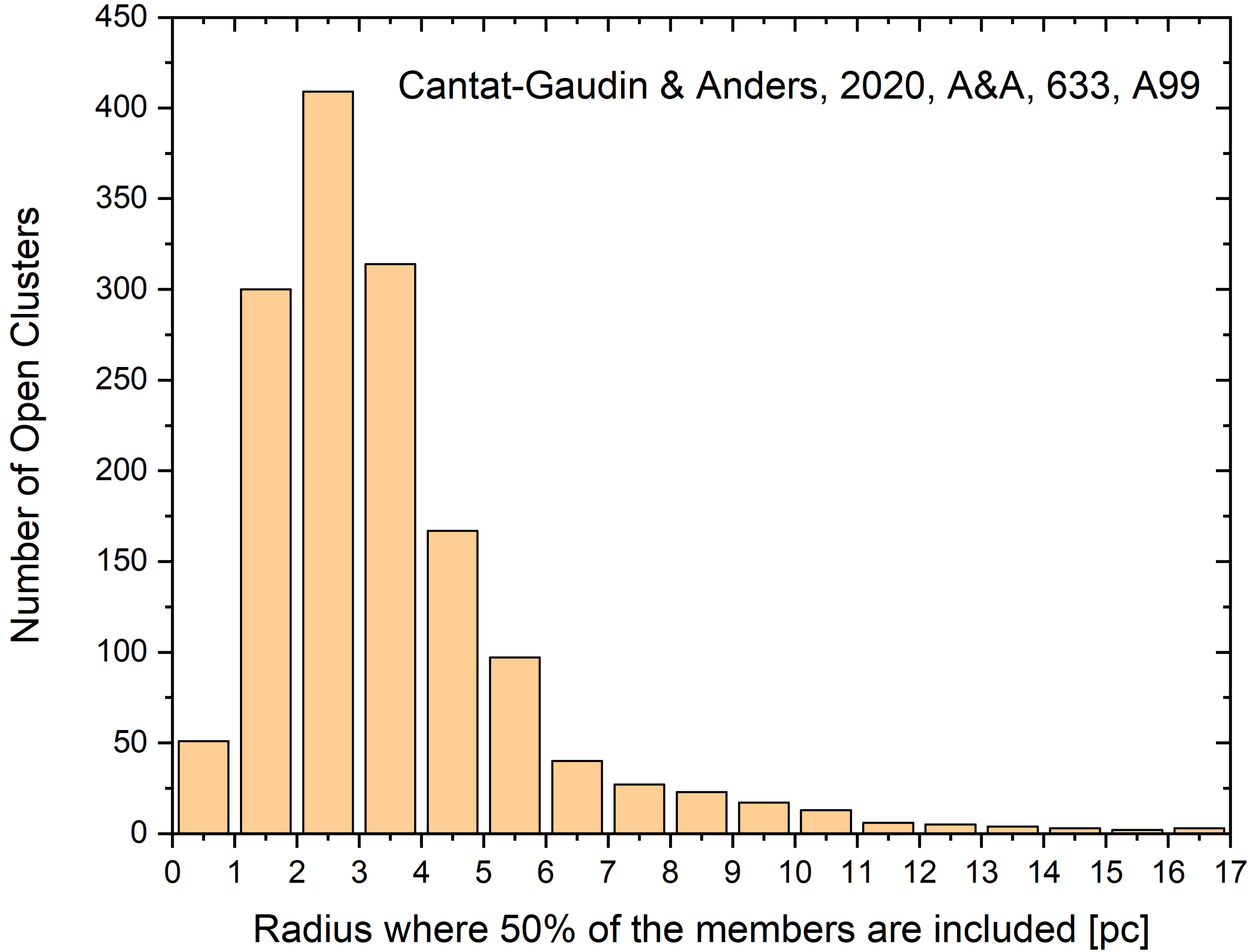
Ferreira et al., 2019, MNRAS, 483, 5508

Diameters of open clusters

Pre - Gaia

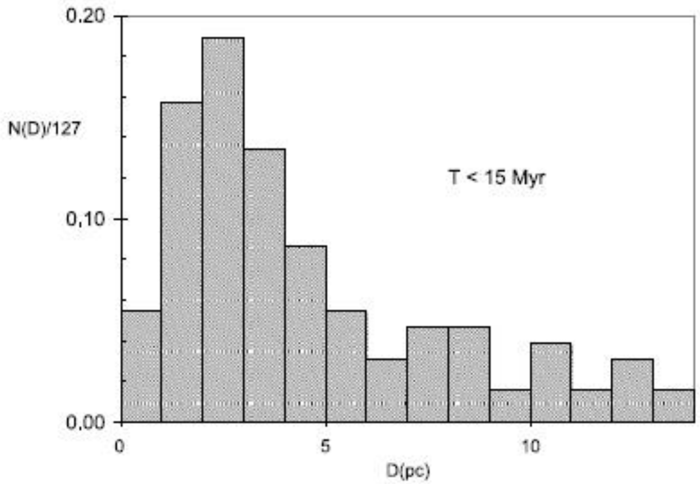


Radii of open clusters

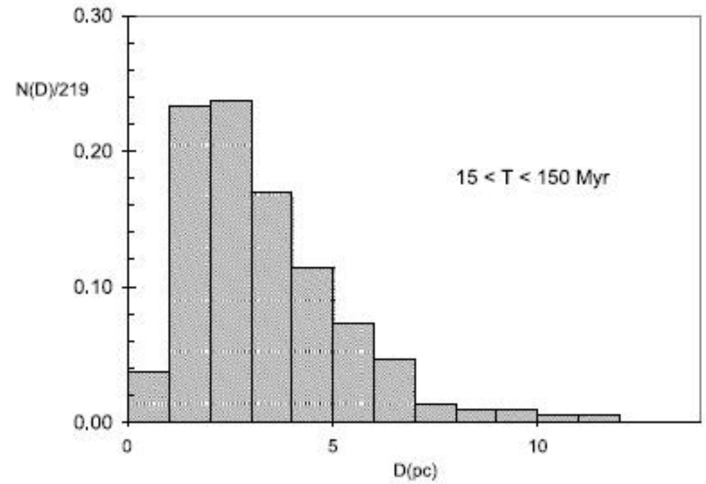


Gaia DR2

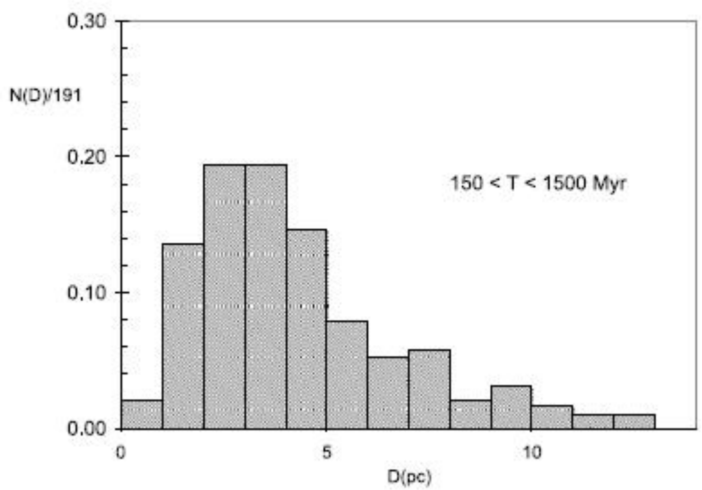
van den Bergh, 2006, AJ, 131, 1559

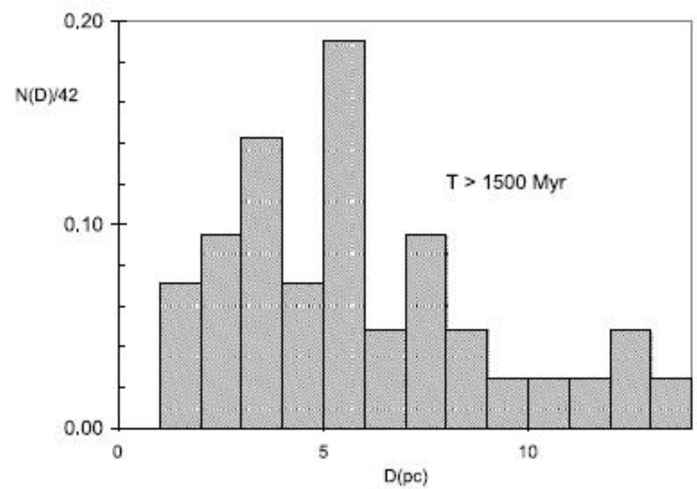


Fɪɢ. 2*a*



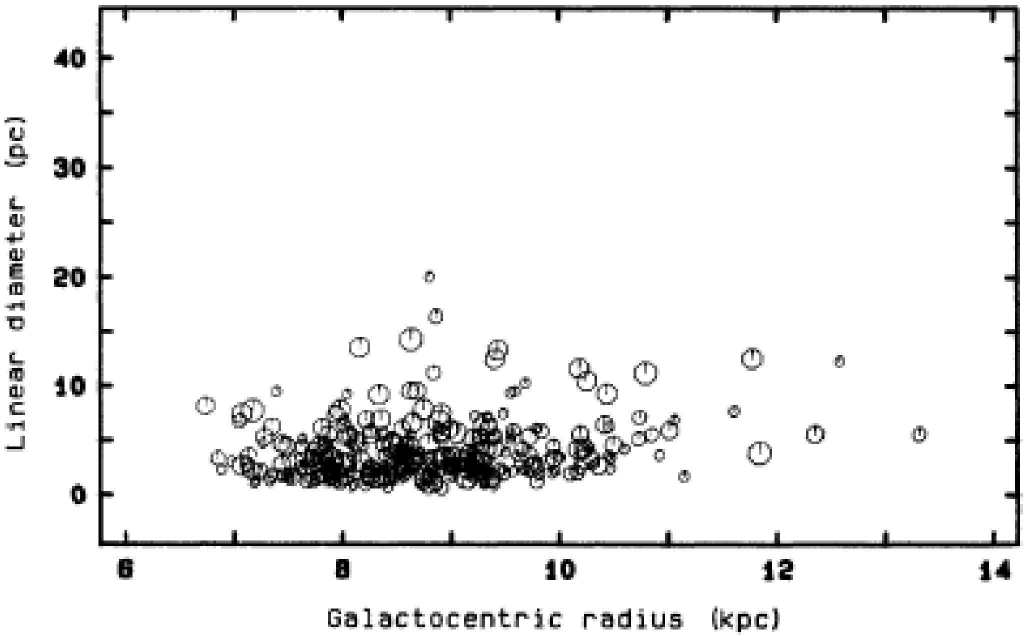
Fɪɢ. 2*b*





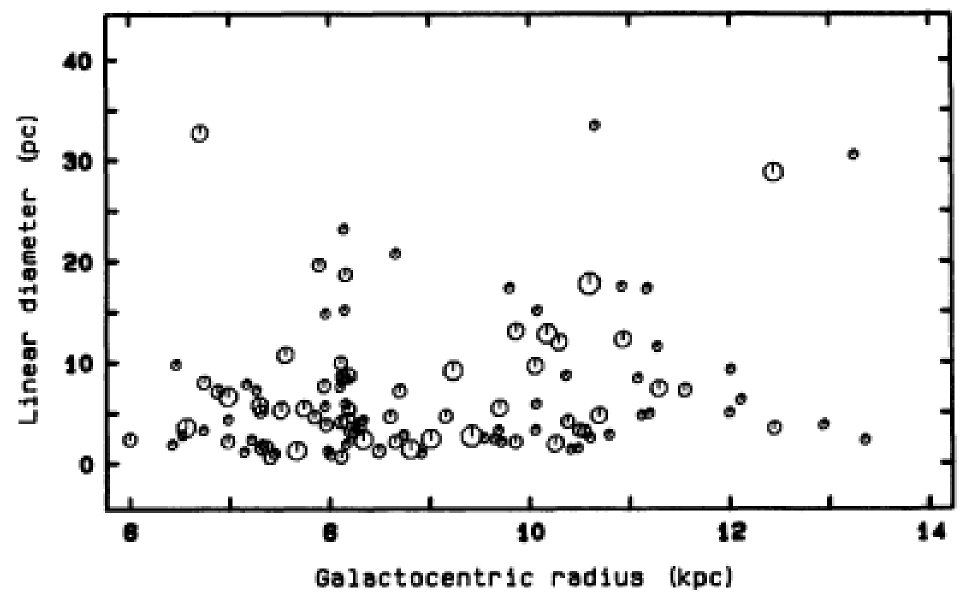
No correlation with the age

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

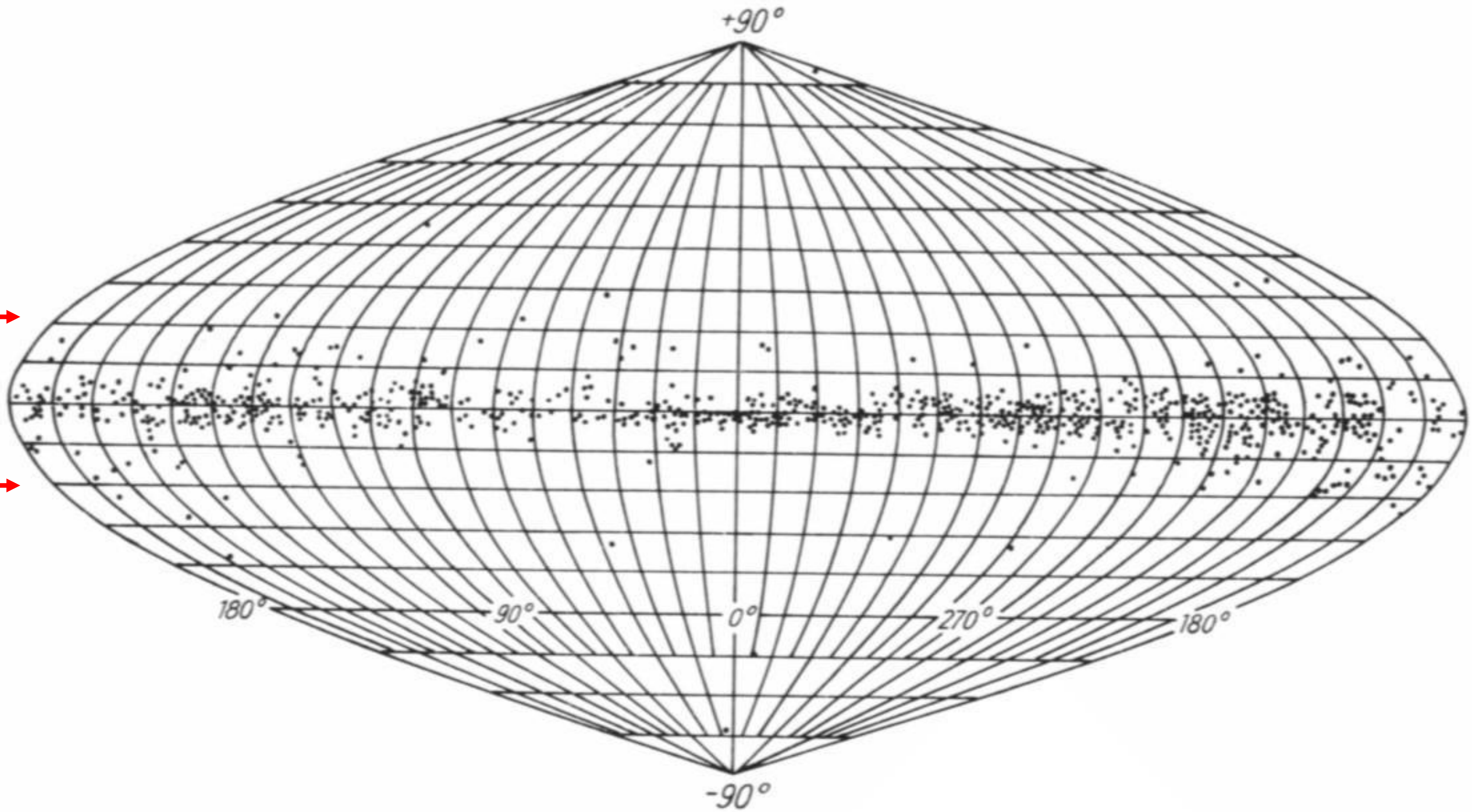


all

young



Galactic Distribution



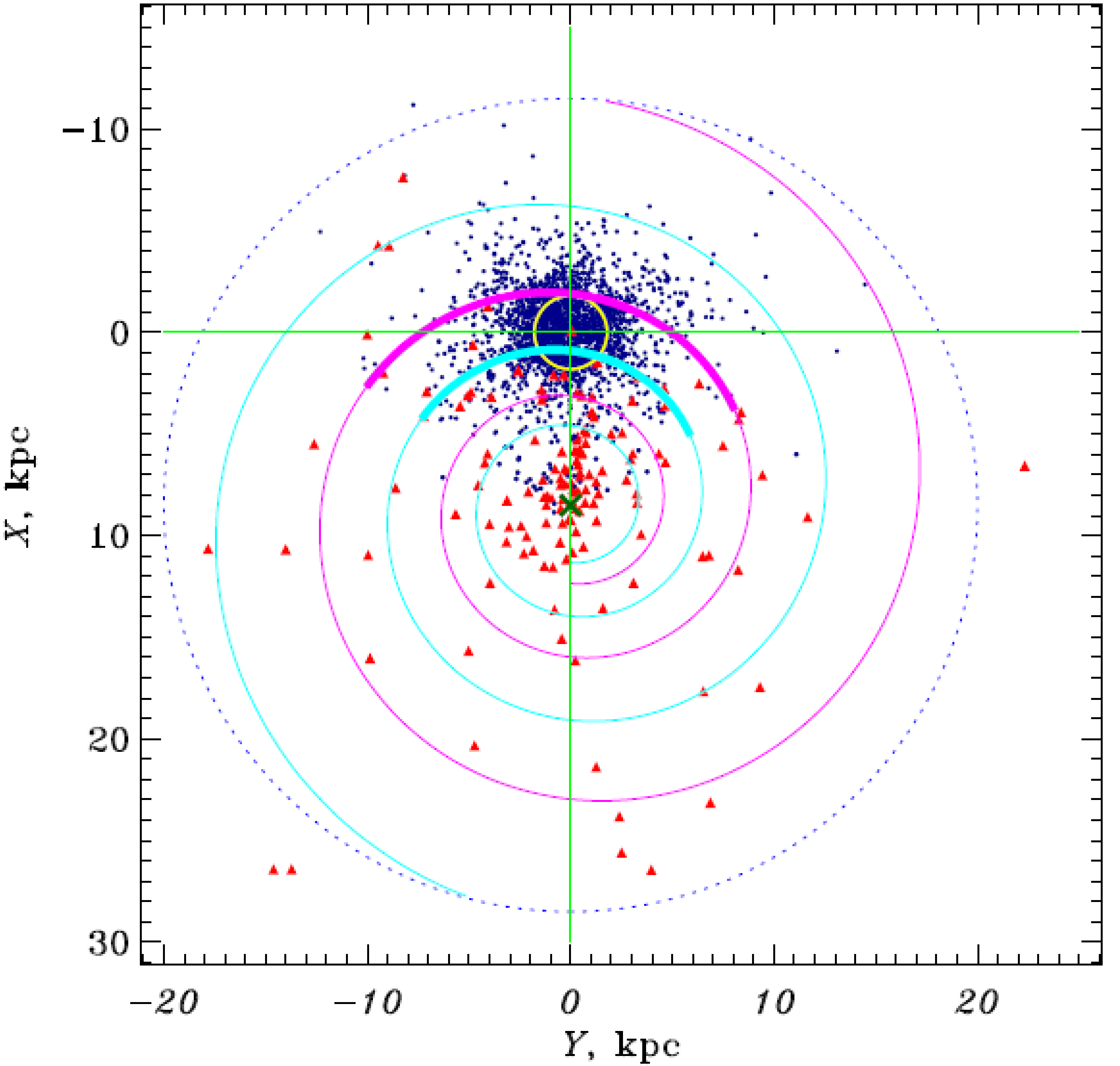
+- 20 degree Galactic latitude

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

Blue dots: OCLs
Red triangles: GCs

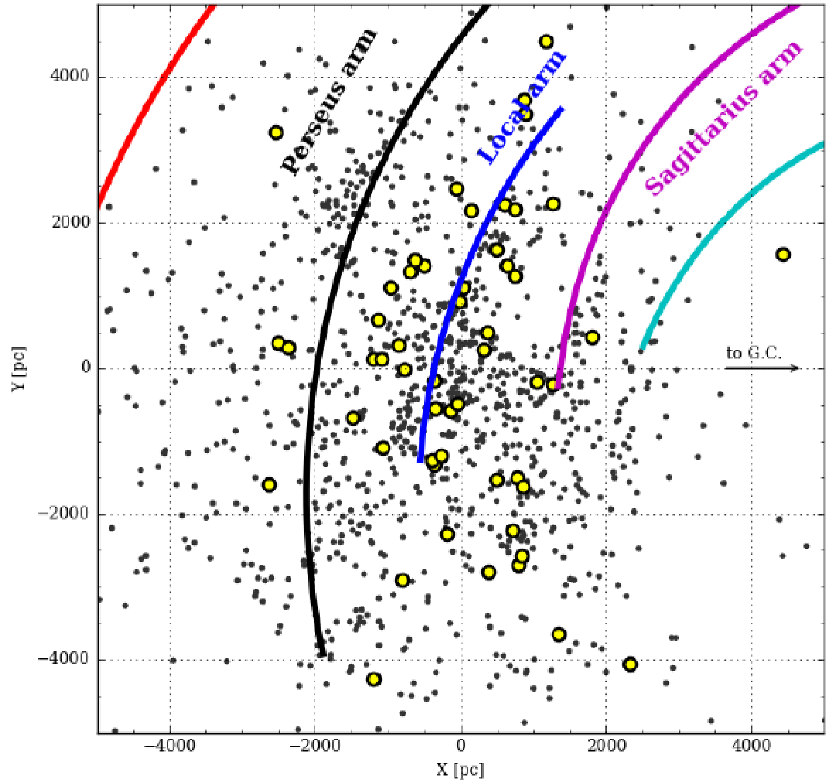
Spiral arms

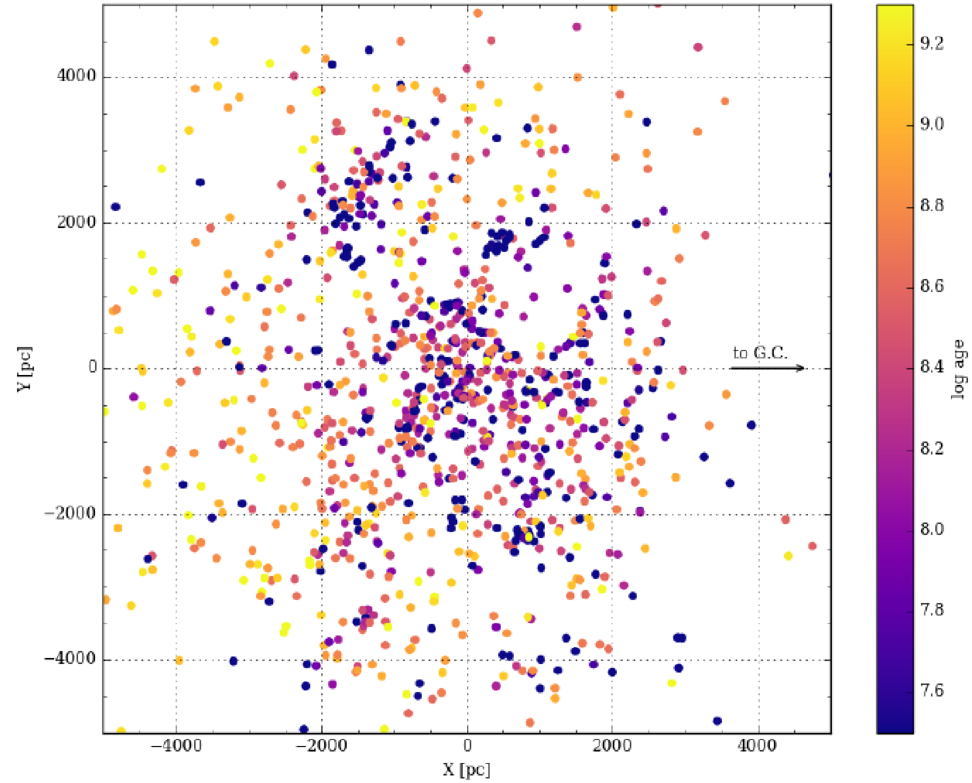
Projection on the Galactic plane



The spiral arms of the Milky Way

Cantat-Gaudin et al., 2018, A&A, 618, A93





Gaia DR1 has not changed our picture of the Milky Way

The spiral arms of the Milky Way

https://ui.adsabs.harvard.edu/abs/2021arXiv210301970P/abstract

Astronomy & Astrophysics manuscript no. aa
March 4, 2021

Galactic spiral structure revealed by *Gaia* EDR3

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ABSTRACT

Using the astrometry and integrated photometry from the *Gaia* Early Data Release 3 (EDR3), we map the density variations in the distribution of young Upper Main Sequence (UMS) stars, open clusters and classical Cepheids in the Galactic disk within several kiloparsecs of the Sun. Maps of relative over/under-dense regions for UMS stars in the Galactic disk are derived using both bivariate kernel density estimators and wavelet transformations. The resulting overdensity maps exhibit large-scale arches, that extend in a clumpy but coherent way over the entire sampled volume, indicating the location of the spiral arms segments in the vicinity of the Sun. Peaks in the UMS overdensity are well-matched by the distribution of young and intrinsically bright open clusters. By applying a wavelet transformation to a sample of classical Cepheids, we find that their overdensities possibly extend the spiral arm segments on a larger scale ($\simeq$ 10 kpc from the Sun). While the resulting map based on the UMS sample is generally consistent with previous models of the Sagittarius-Carina spiral arm, the geometry of the arms in the III quadrant (galactic longitudes $180^\circ > l > 270^\circ$) differs significantly from many previous models. In particular we find that our maps favour a larger pitch angle for the Perseus arm, and that the Local Arm extends into the III quadrant at least 4 kpc past the Sun's position, giving it a total length of at least 8 kpc.

The spiral arms of the Milky Way

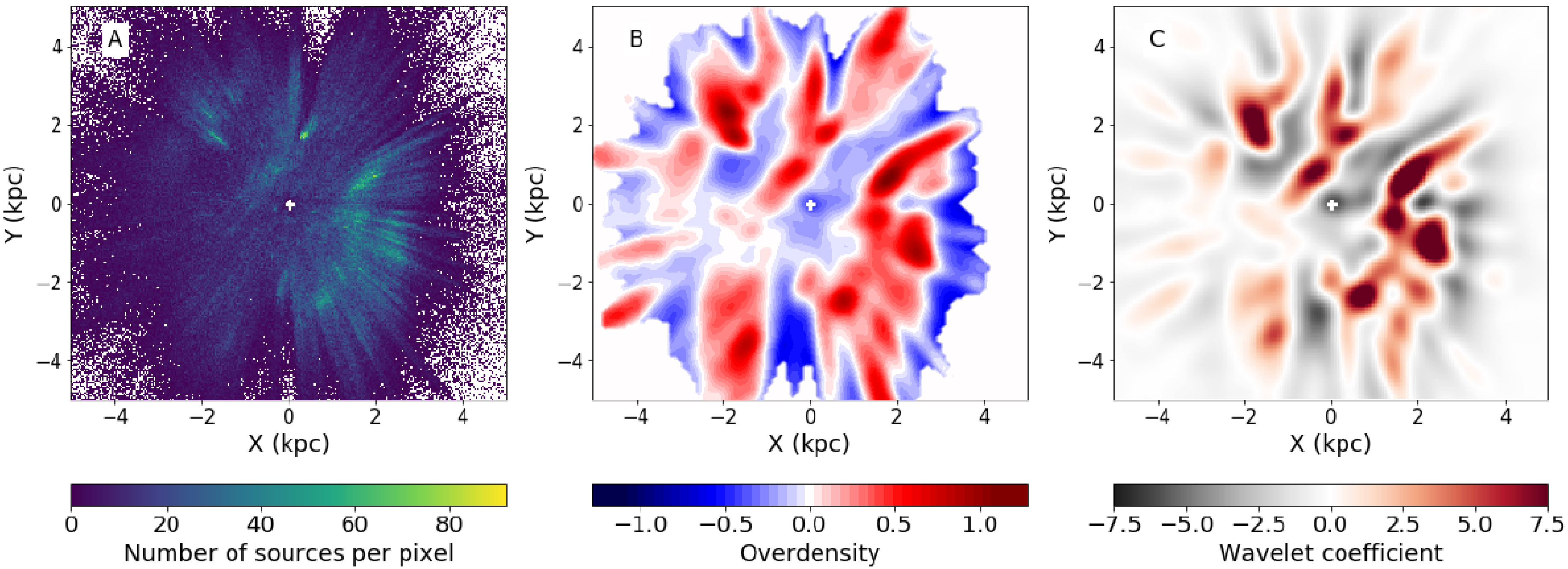


Fig. 1. *Panel A:* Face-on view of the UMS P18 dataset in the Galactic disk. The position of the Sun is shown by the white cross in (X,Y)=(0,0). The Galactic center is to the right, in (X,Y)=($R_\odot$,0), and the Galaxy is rotating clockwise. *Panel B:* Same as Panel A, but showing the measured overdensity, based on a local density scale length 0.3 kpc. Only points with $\Sigma(x, y) > 0.003$ are plotted, in order to remove regions where the statistics is too low. *Panel C:* Same as Panel A, but showing the wavelet transformation at the scale 3 (size~0.4 kpc). A different version of Panel B and C using a larger scale length can be found in Figure B.2 (see Appendix).

The spiral arms of the Milky Way

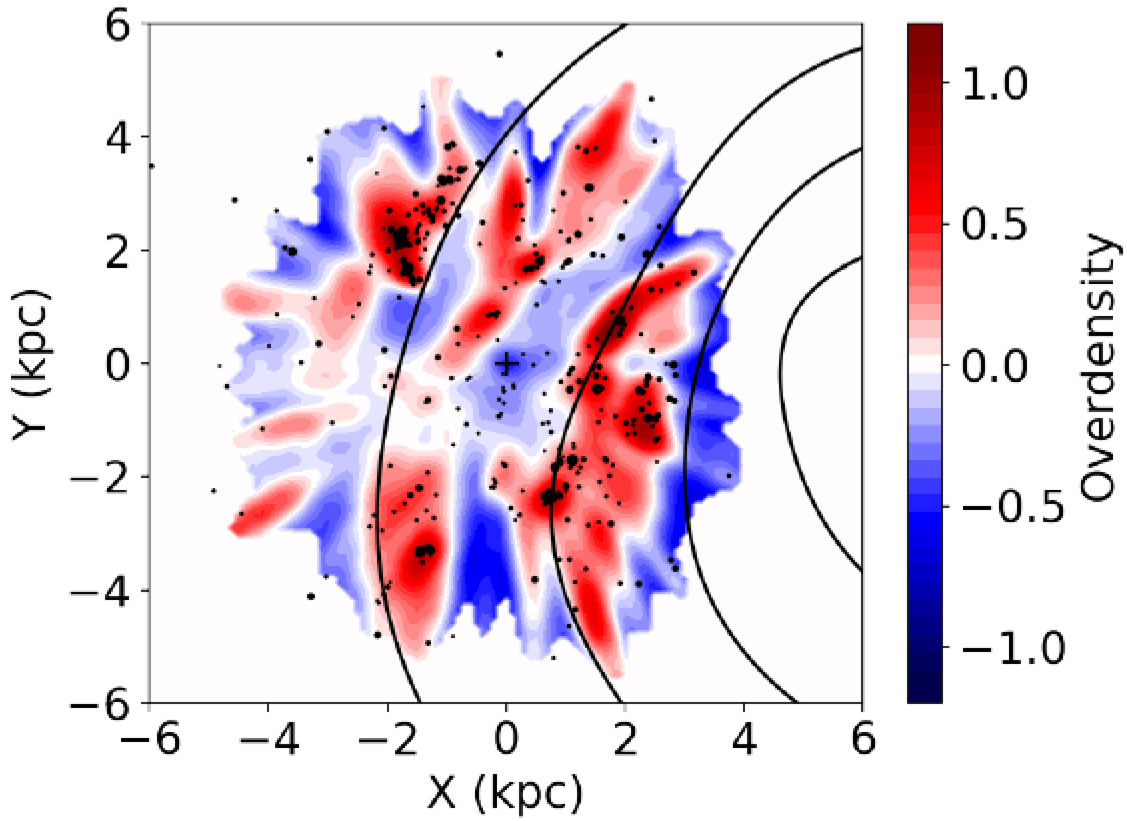


Fig. 3. Same as Figure 1B, but compared to the distribution of the young and instrinsically bright open clusters sample (see Section 2.2), shown by the black dots. The size of the dots is proportional to the number of cluster members brighter than absolute magnitude $M_G > 0$ (see text). Solid lines show the spiral arm model of Taylor & Cordes (1993), based on HII regions.

The spiral arms of the Milky Way

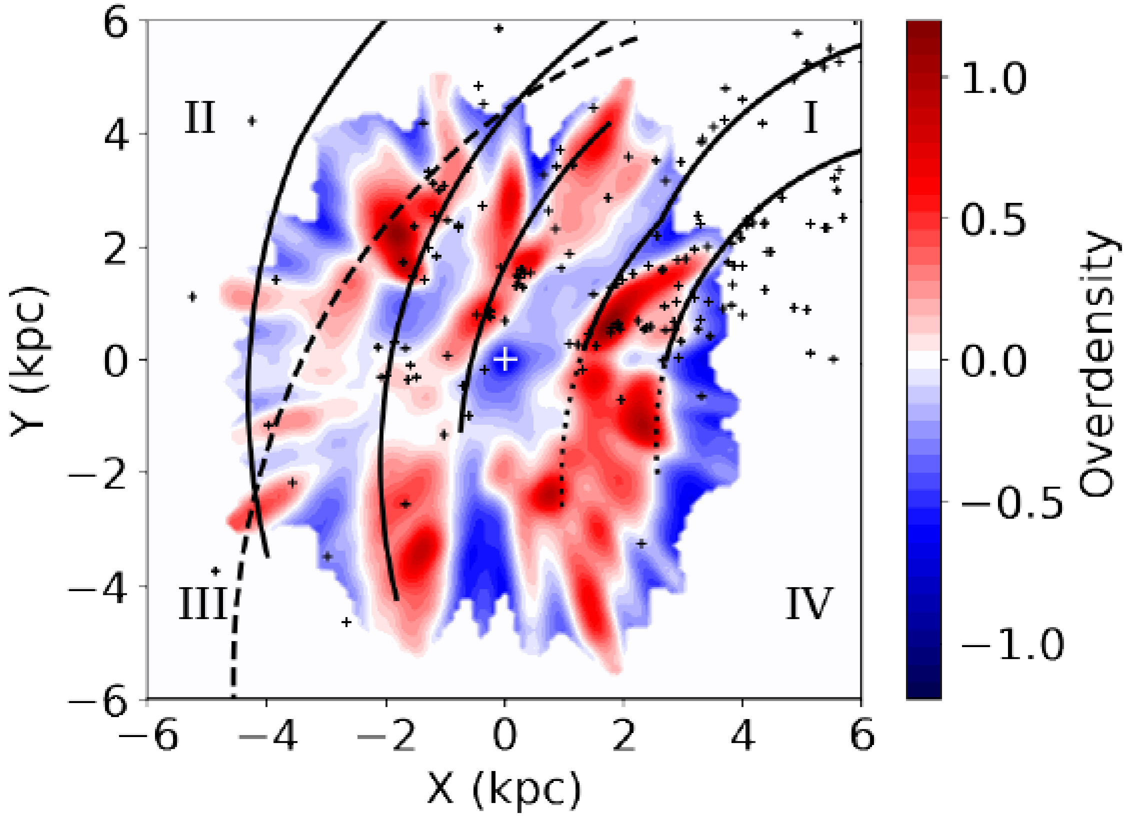
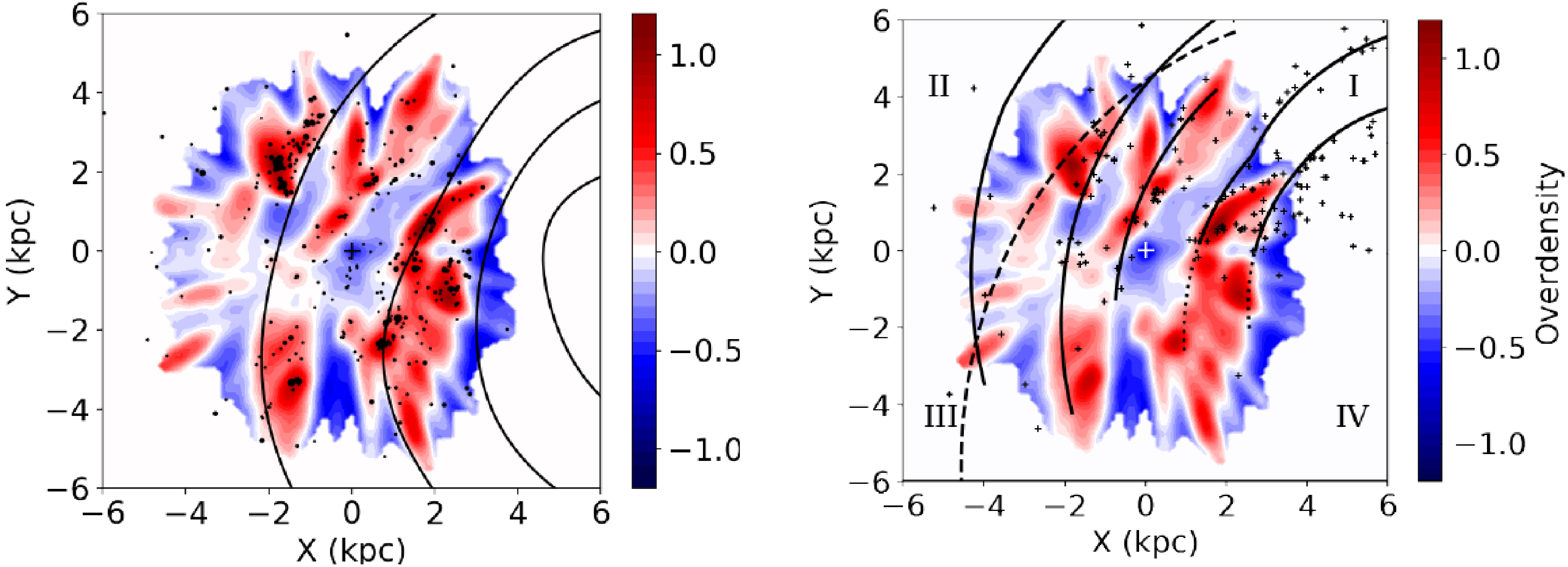


Fig. 5. Comparison between the measured overdensity map presented in this work (Figure 1B), the distribution of the maser sources (black dots) and spiral arm model (solid lines, from left to right: Outer, Perseus, Local, Sagittarius-Carina, Scutum arm) from Reid et al. (2019), and the Perseus arm from Levine et al. (2006) (dashed line). Roman numerals show the I, II, III and IV Galactic quadrants.

The spiral arms of the Milky Way



The spiral arms of the Milky Way

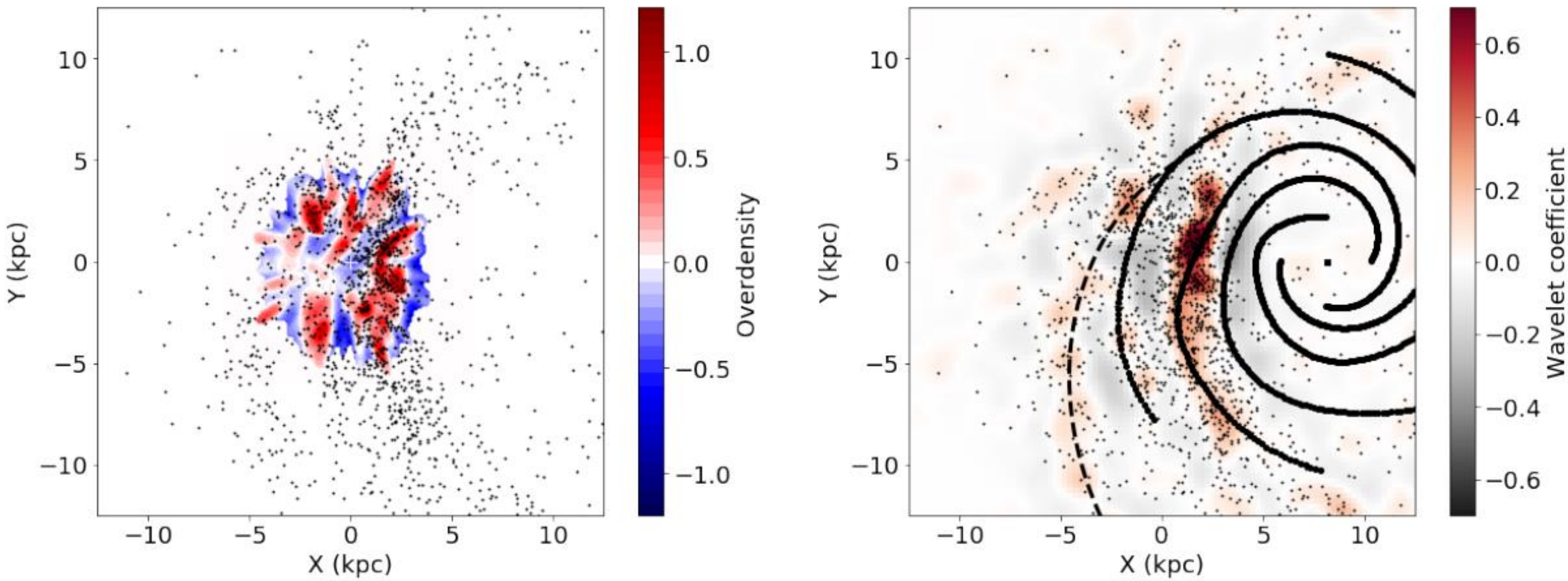
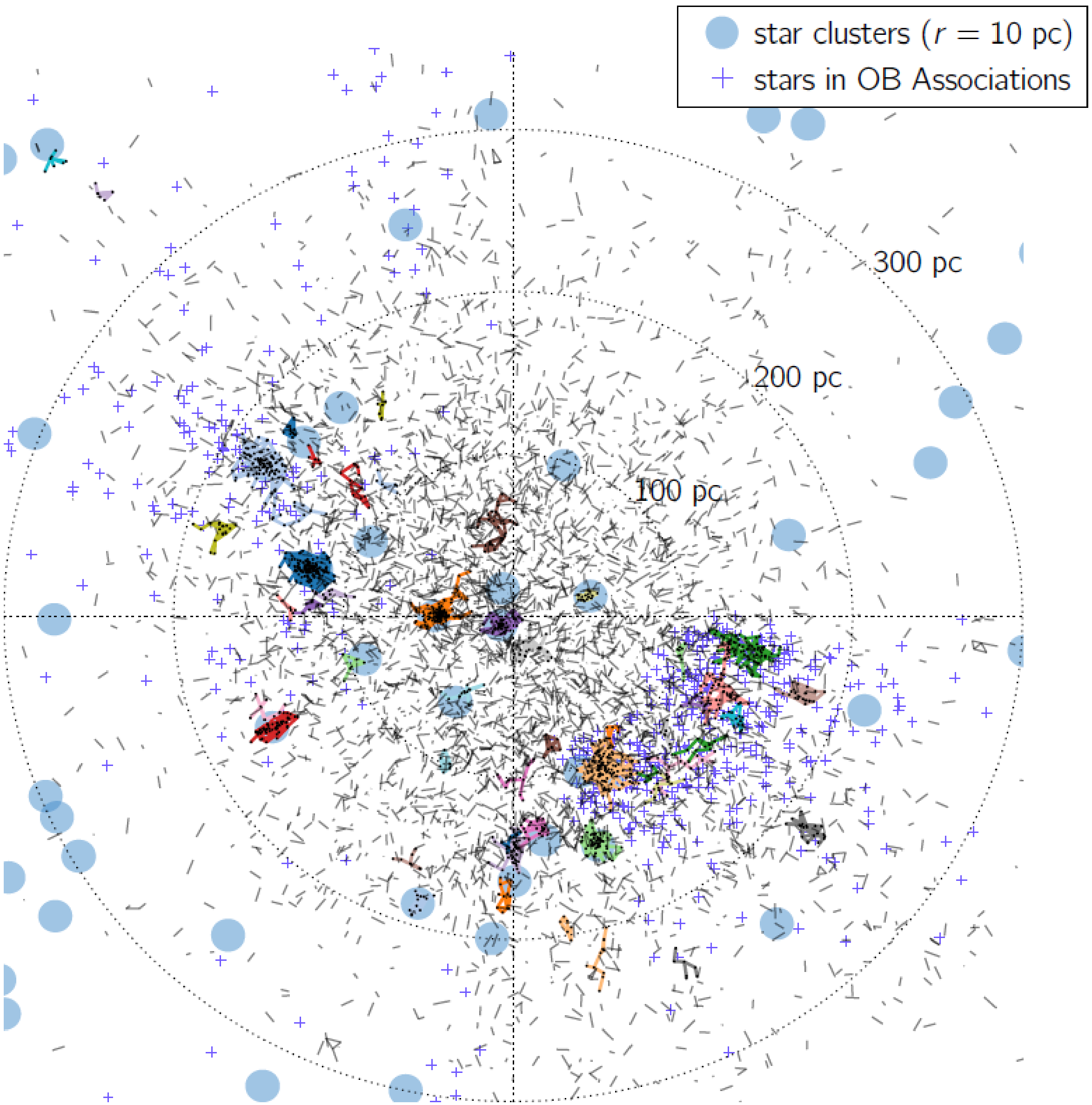


Fig. 4. *Left panel:* Same as Figure 1B, but on a larger scale, and compared to the distribution of the Cepheids sample (black dots). *Right panel:* Wavelet transformation of the Cepheids sample, with oveplotted the positions of the single Cepheids (black dots), the L06 model for the Perseus arm (dashed curve) and the spiral arm model of Taylor & Cordes (1993), based on HII regions (solid lines).

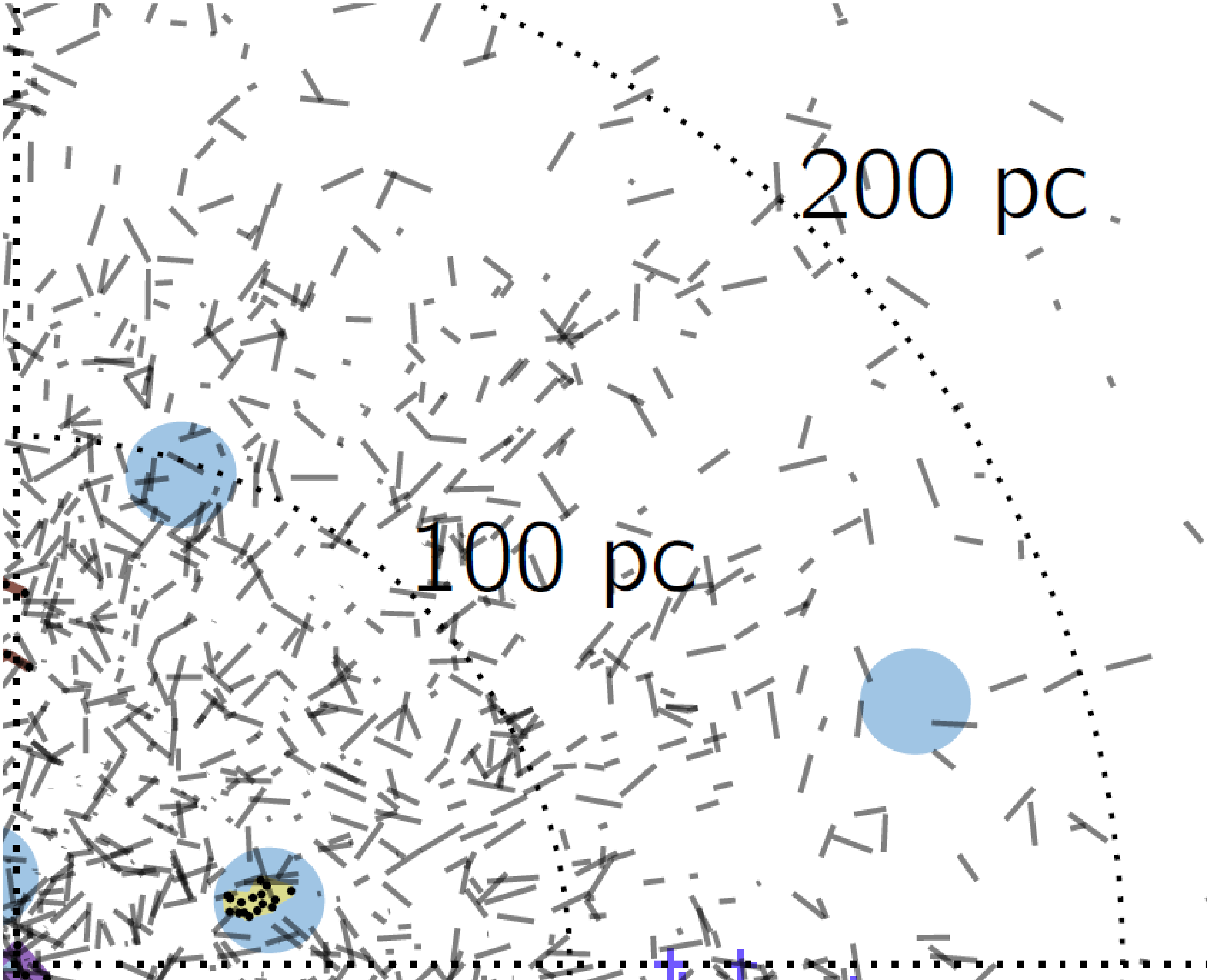
The local motion of the stars



4 555 groups

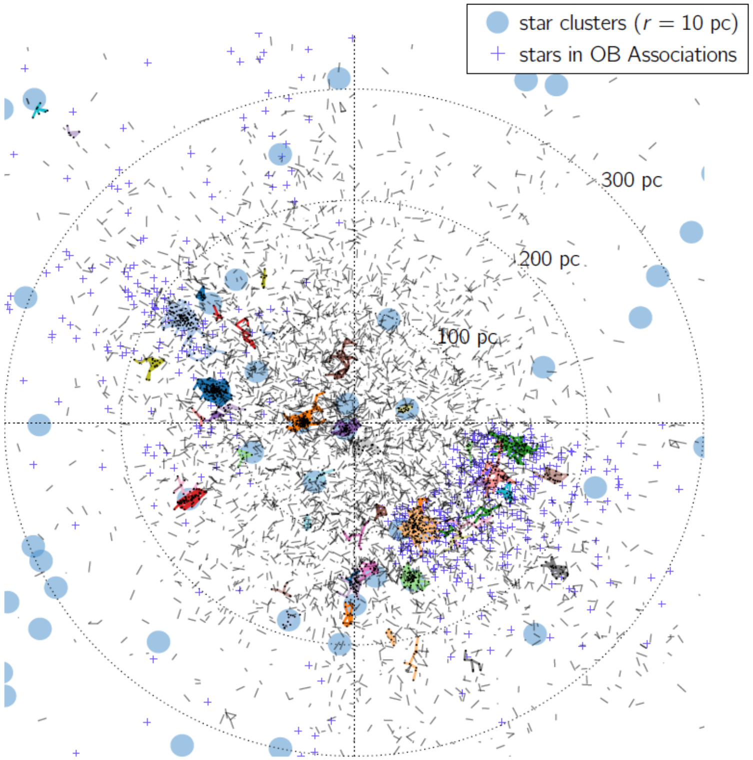
Systematics?

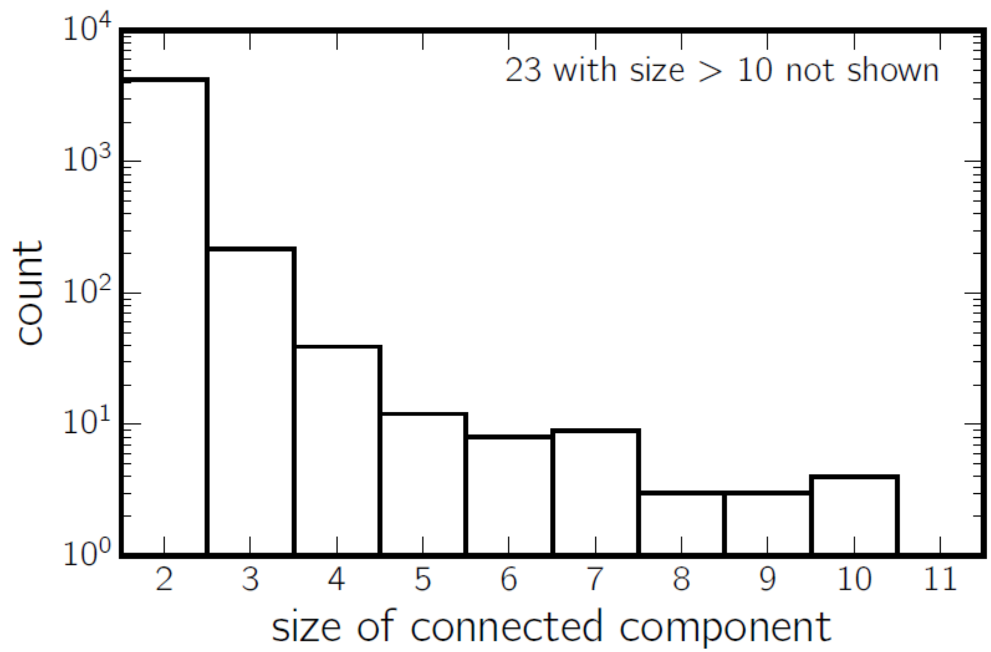
Oh et al., 2017, AJ, 153, 257


200 pc
100 pc

The local motion of the stars

Oh et al., 2017, AJ, 153, 257





4 555 groups

What is the smallest number of members of a star cluster?

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

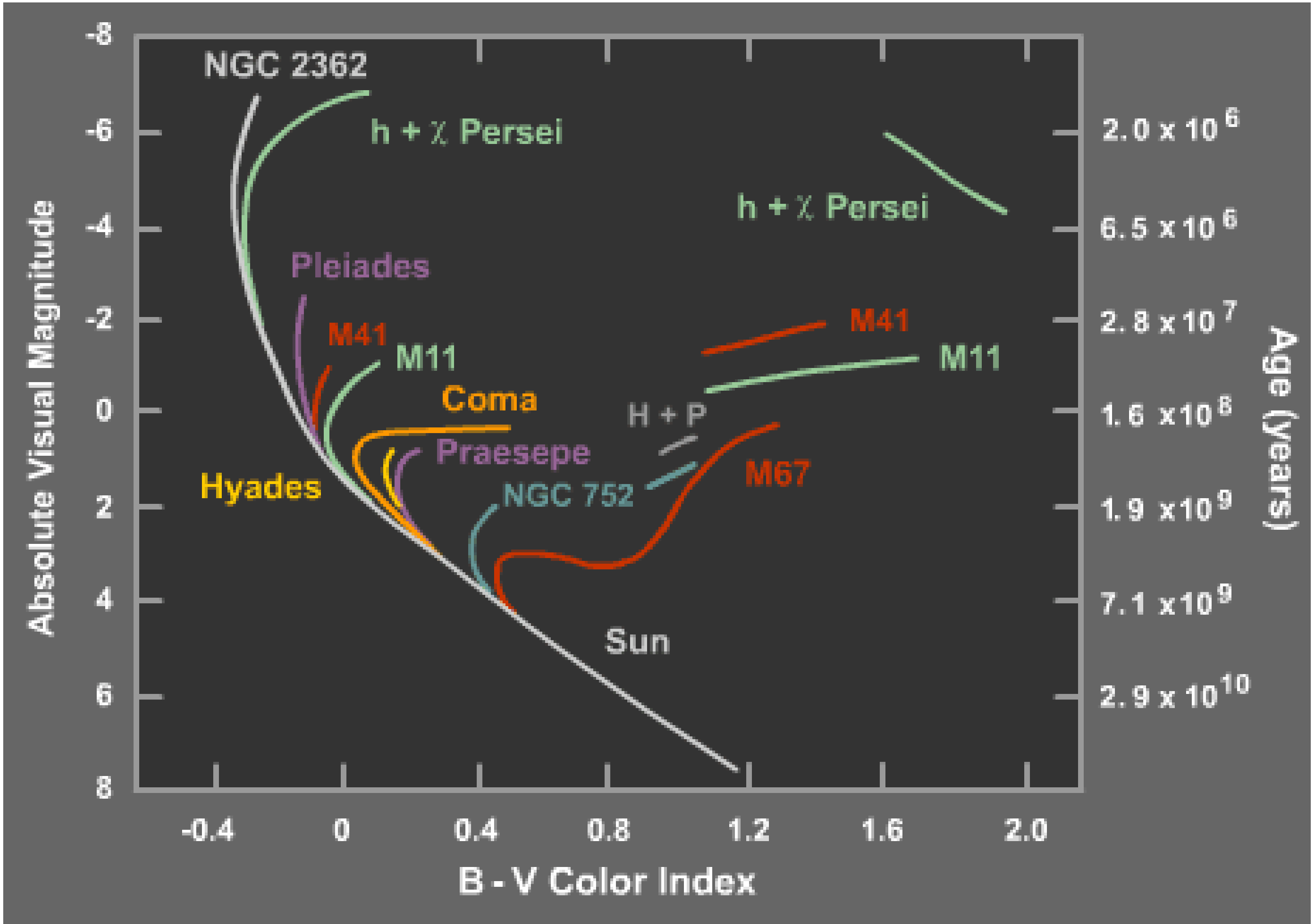
The smaller the number of stars, the higher the core's stellar density.

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

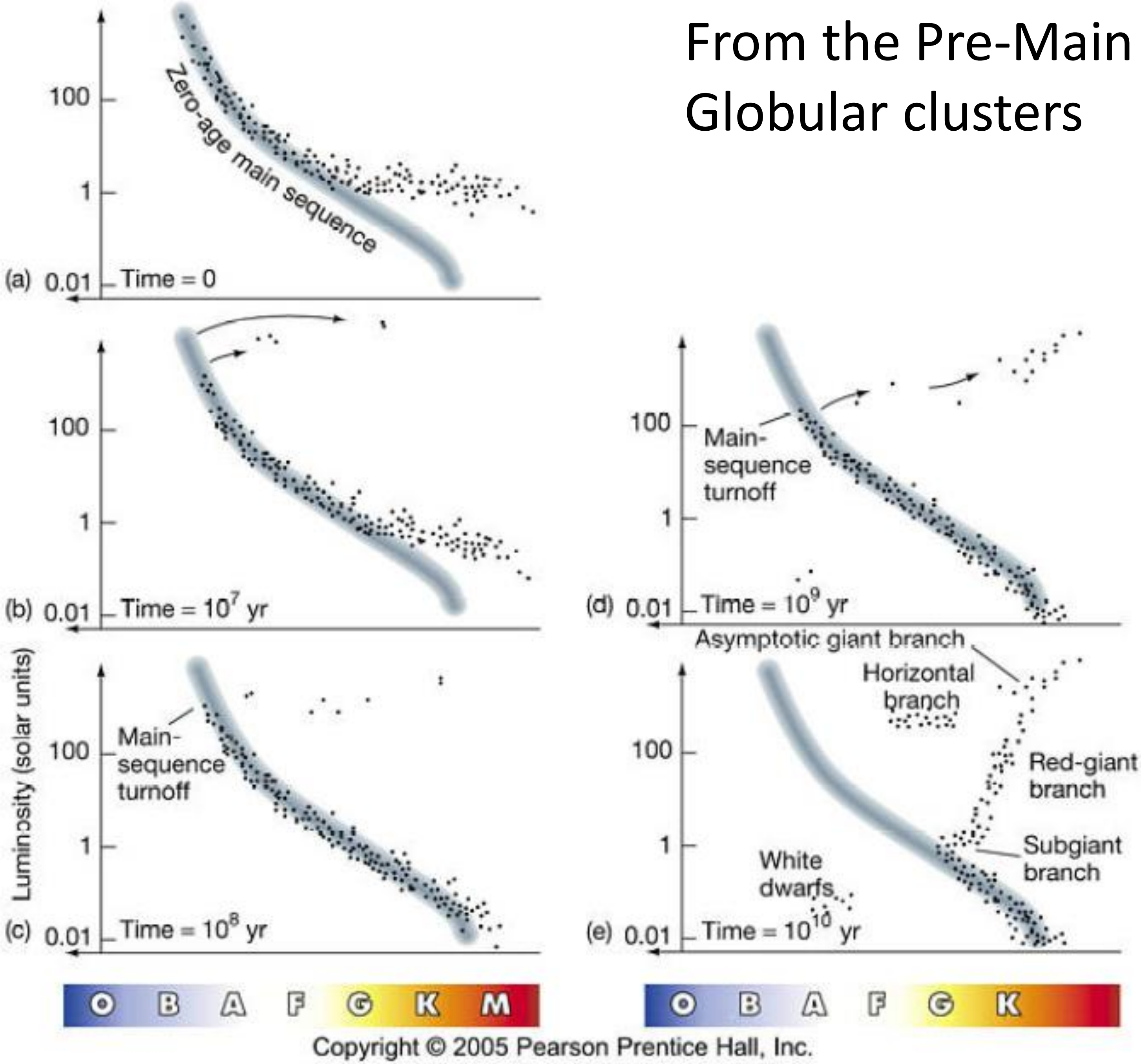
Important observables

- 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) $t = 0$

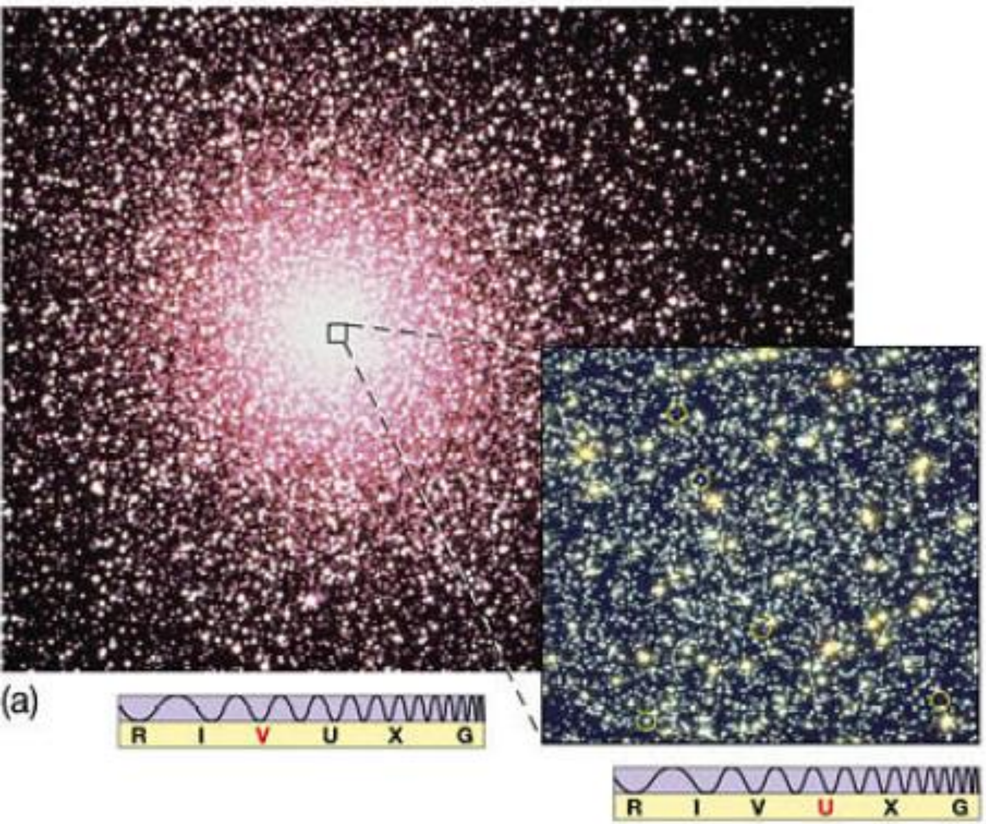
(b) $t = 10^7$yr

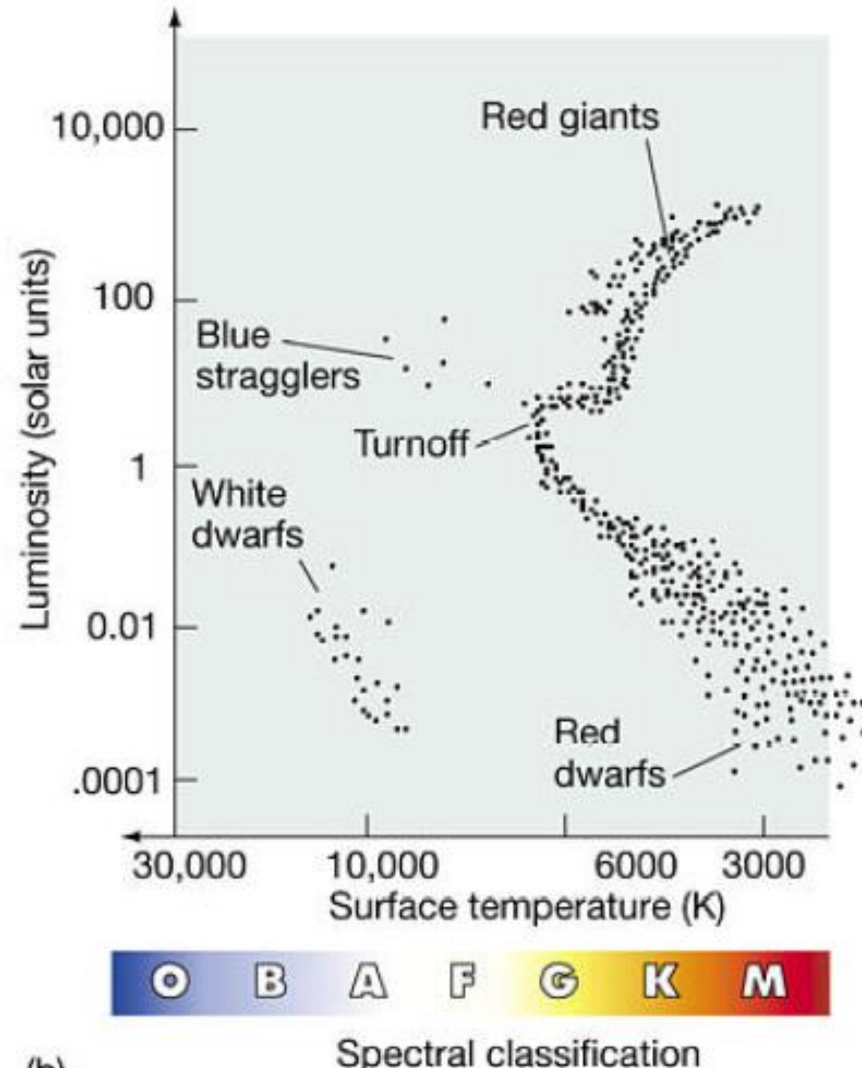
(c) $t = 10^8$yr

(d) $t = 10^9$yr

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

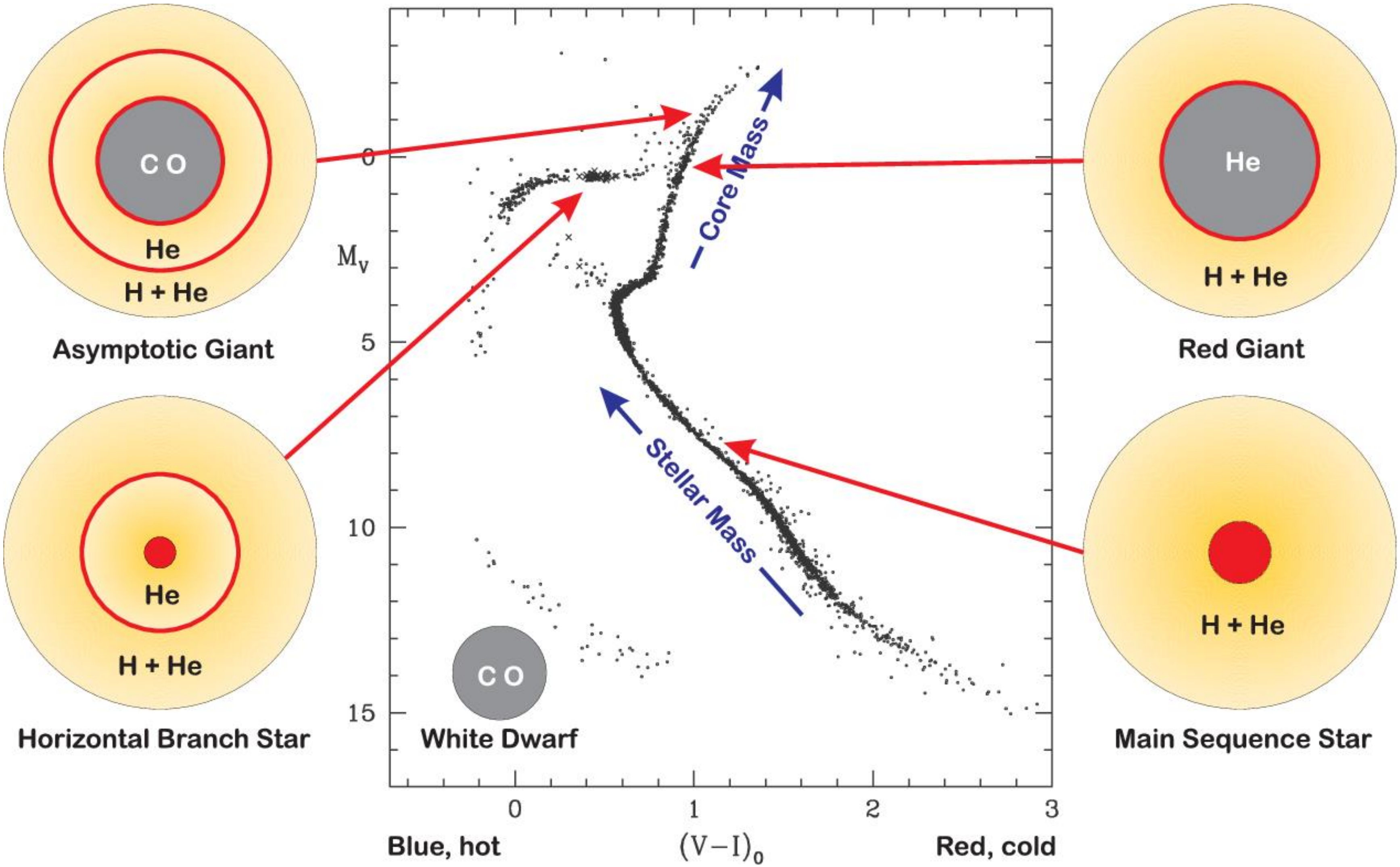
47 Tuc



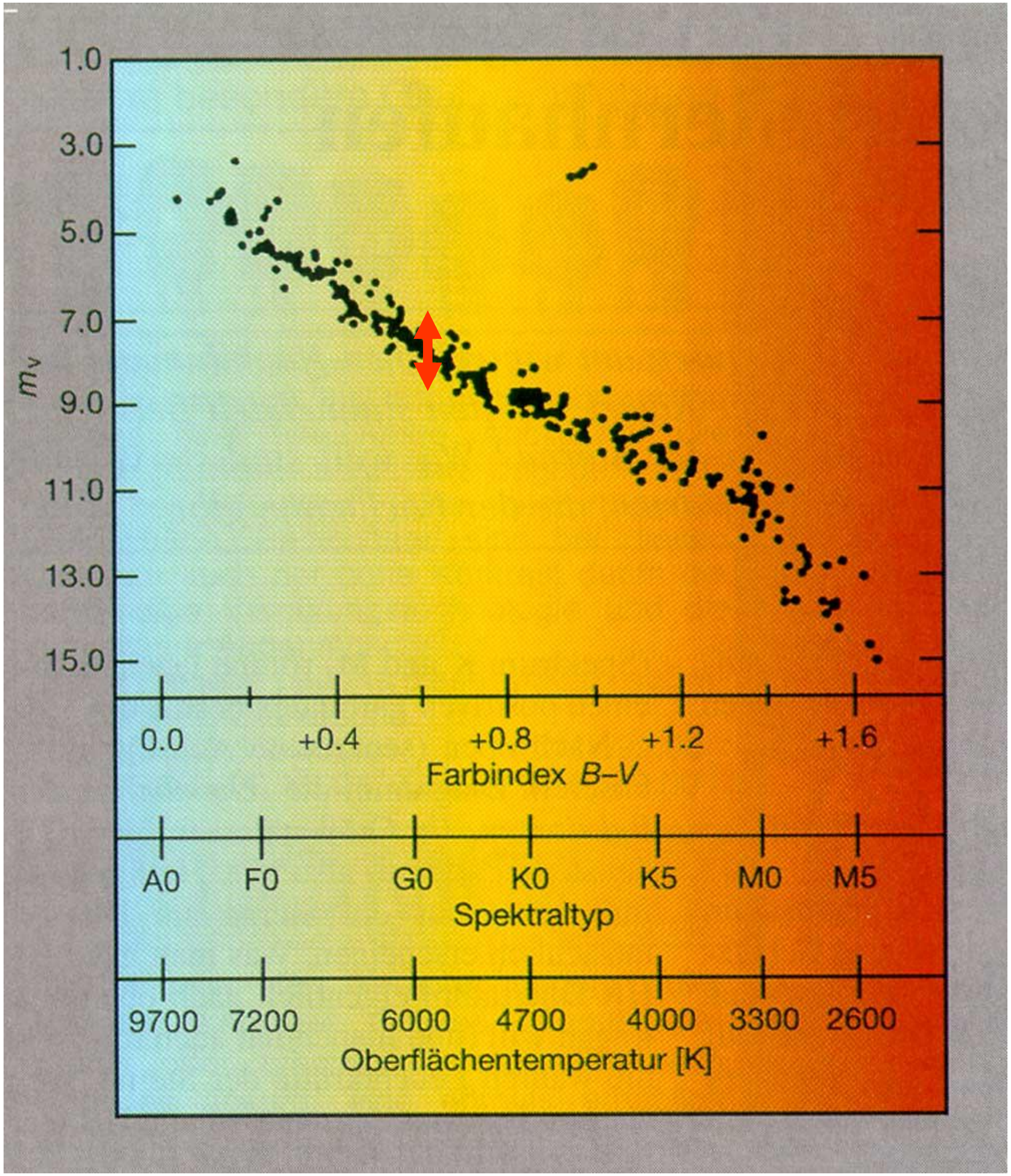


NGC 104: d = 4500 pc, D = 31‘, [Fe/H] = -0.76 dex, t = 12 Gyr

(b)



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

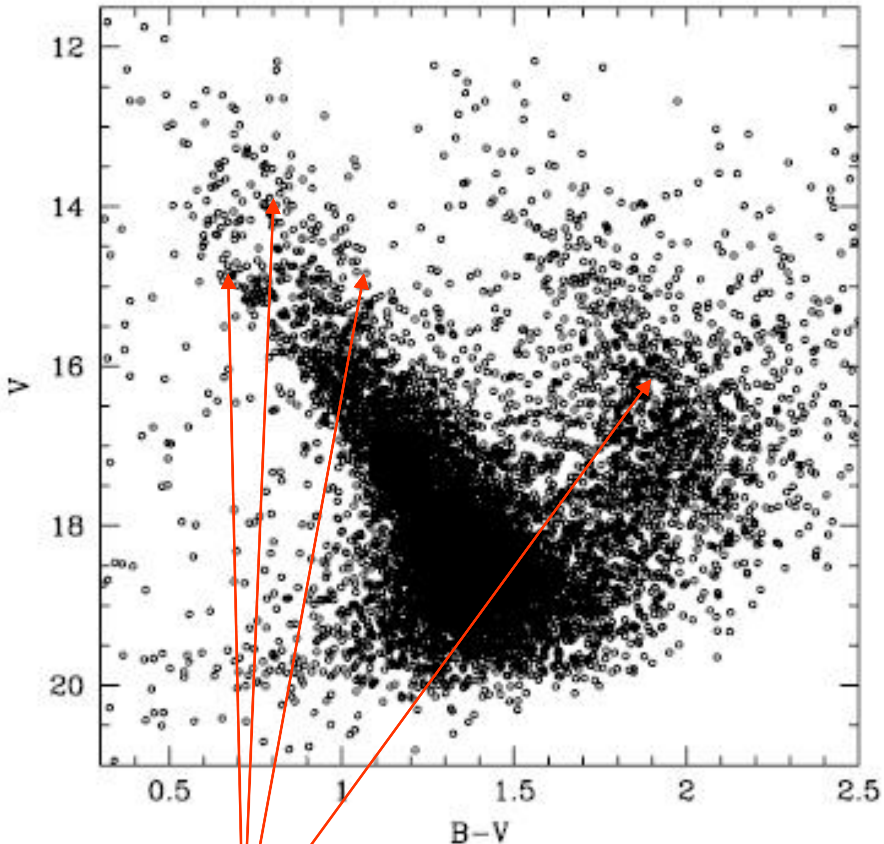
A typical example before Gaia

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***

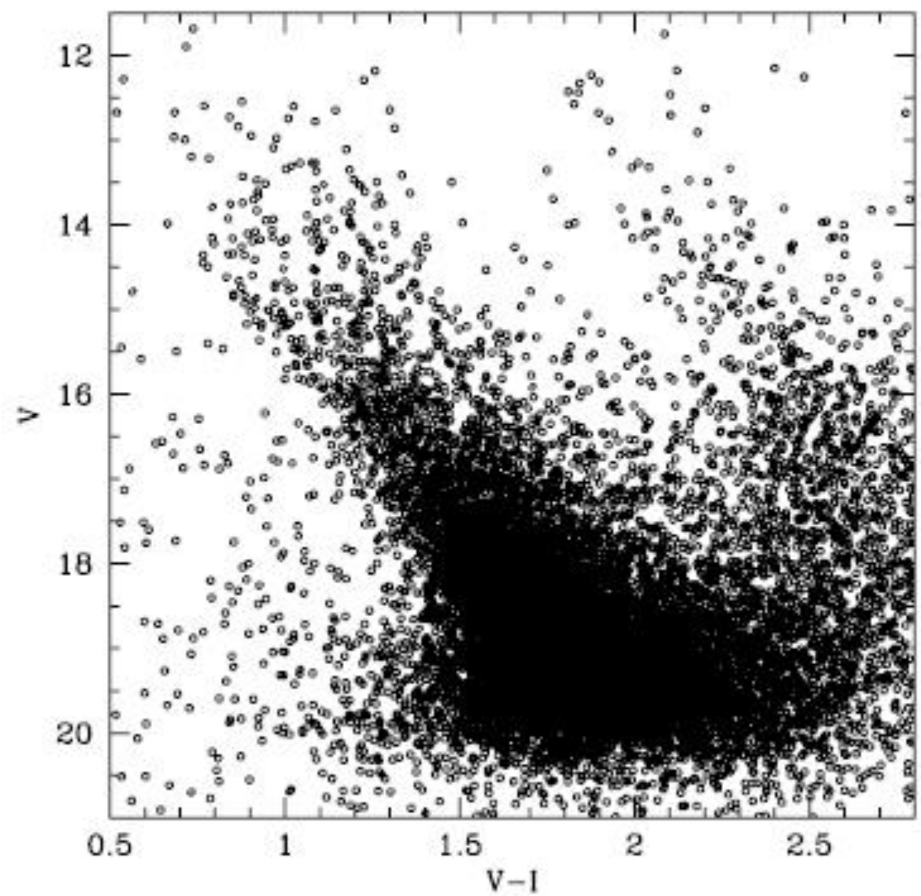
CCD BVI Photometry, 1 Pixel = 0.4´´, 13.6x13.6´ field,

No other observations available for this open cluster



15 688 stars in the complete field

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



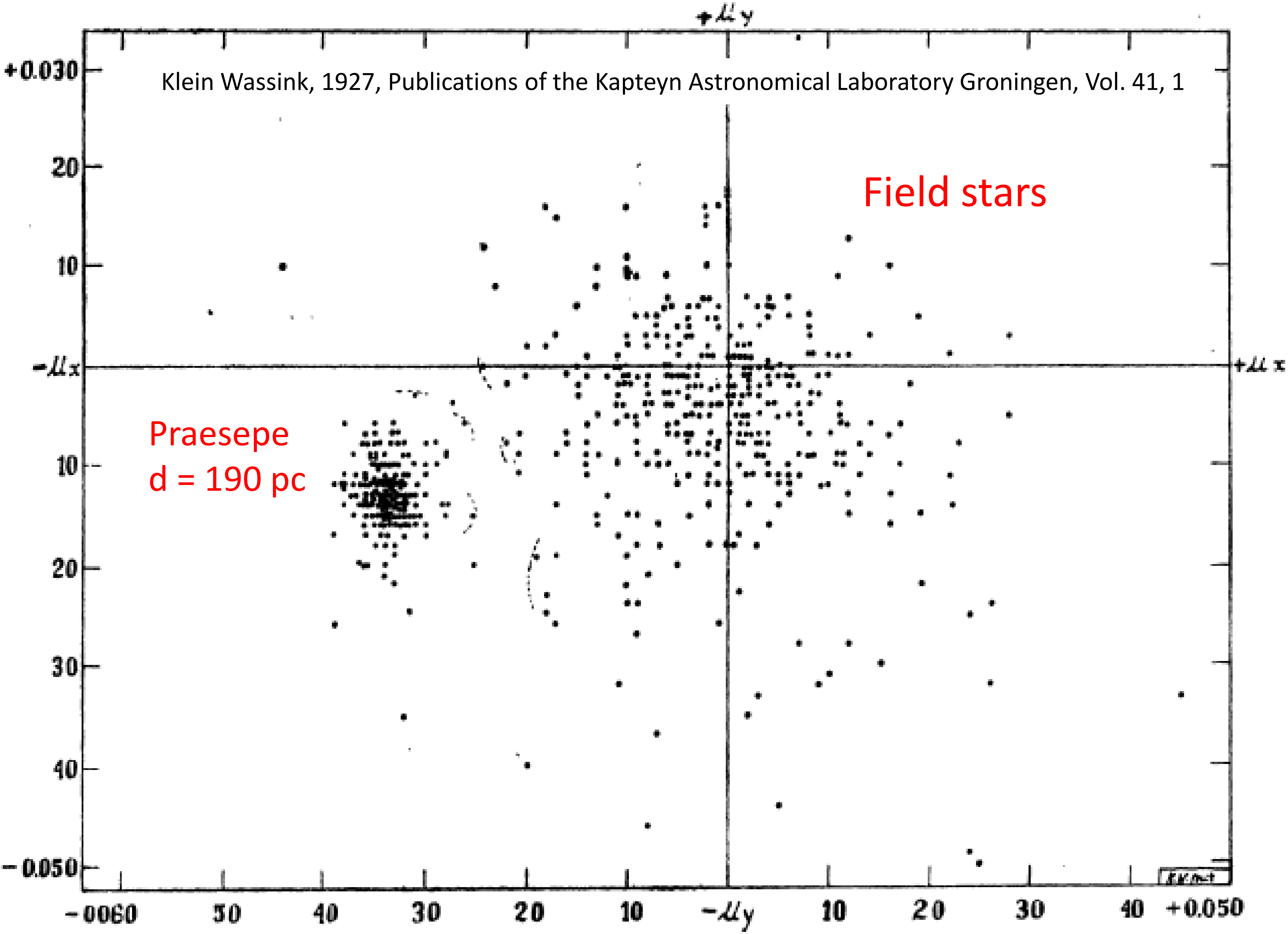


Figure 2. Diagram of the absolute proper motions of the Catalogue; photographic magnitude 6 to 14·0, numbers 1 to 531. The dotted lines separate the Praesepe stars from the backgroundstars.

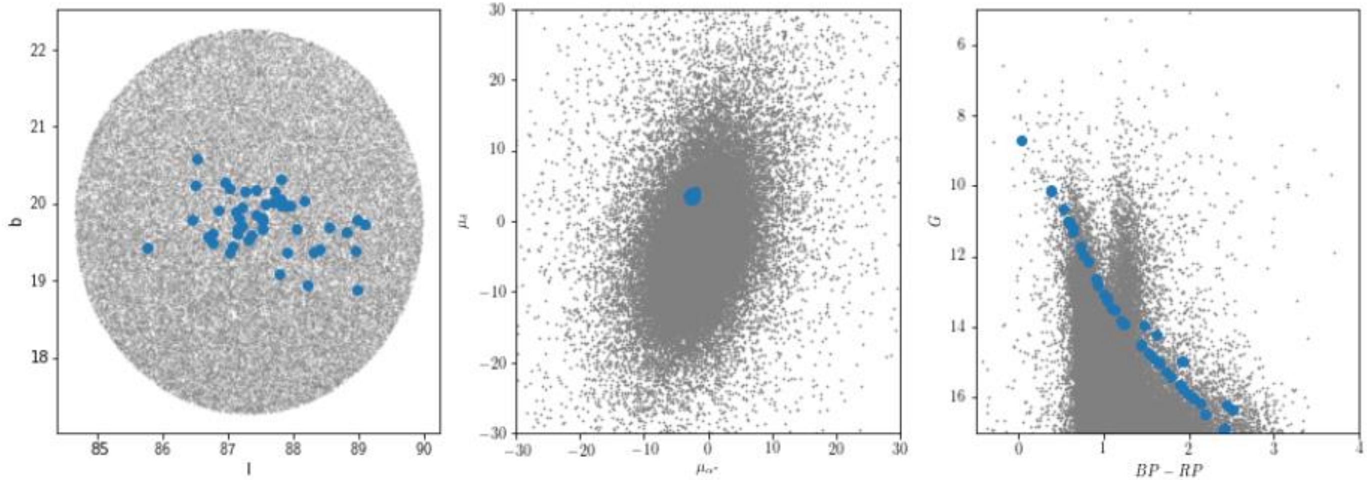
A typical example after Gaia

One typical example from the literature:

Castro-Ginard et al., 2018, A&A, 618, A59: ***A new method for unveiling open clusters in Gaia. New nearby open clusters confirmed by DR2***

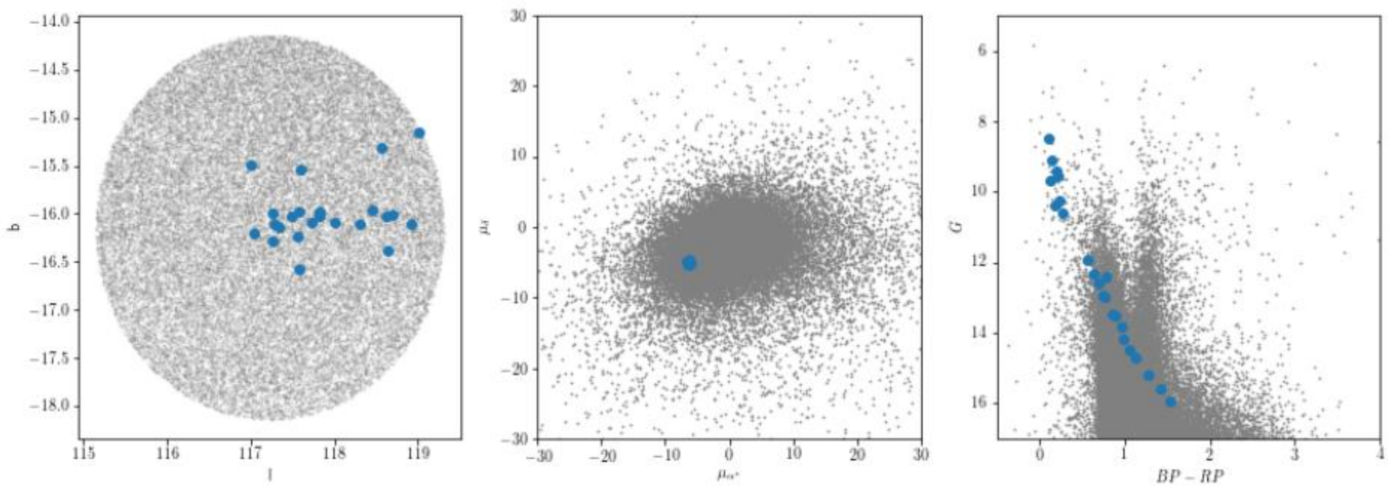
Gaia DR2 G, BP, and RP photometry

Full astrometrical data set



330 pc

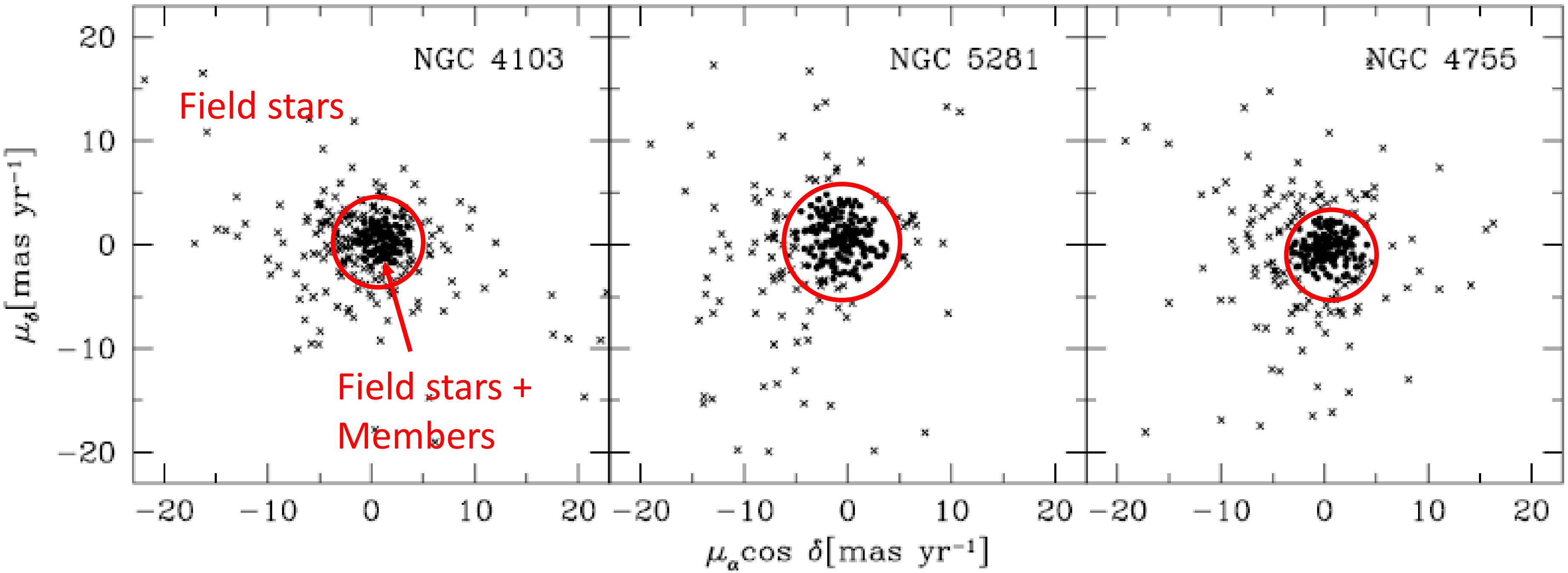
Fig. A.1: Member stars (blue) together with field stars (grey) for UBC1 in (l, b) (left) and in proper motion space (middle). The Color-Magnitude Diagram shows the sequence of the identified members (outlining an empirical isochrone) (right).



440 pc

Fig. A.2: Member stars (blue) together with field stars (grey) for UBC2 in (l, b) (left) and in proper motion space (middle). The Color-Magnitude Diagram shows the sequence of the identified members (outlining an empirical isochrone) (right).

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

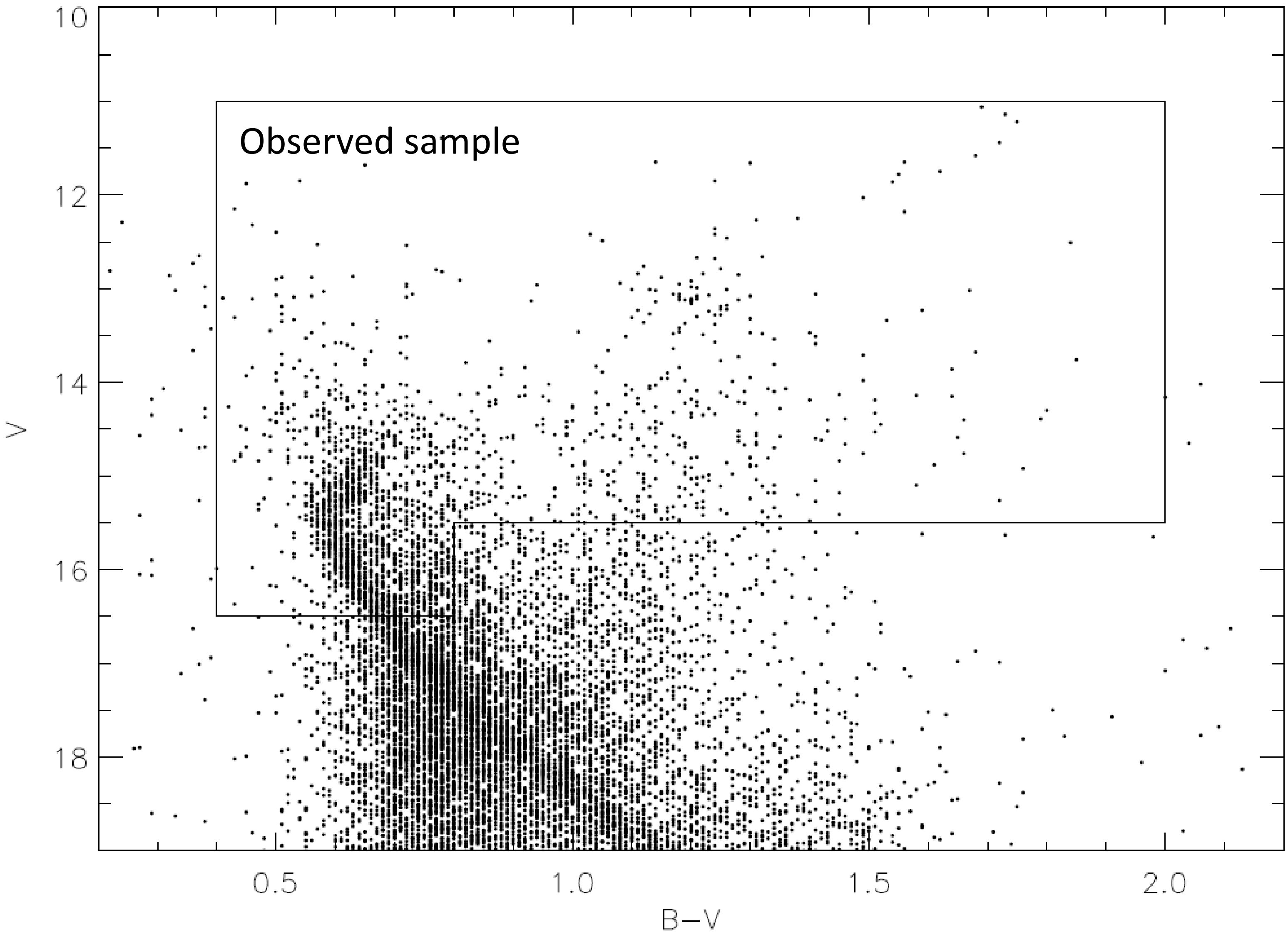


The proper motion for „distant“ star clusters is almost zero.

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



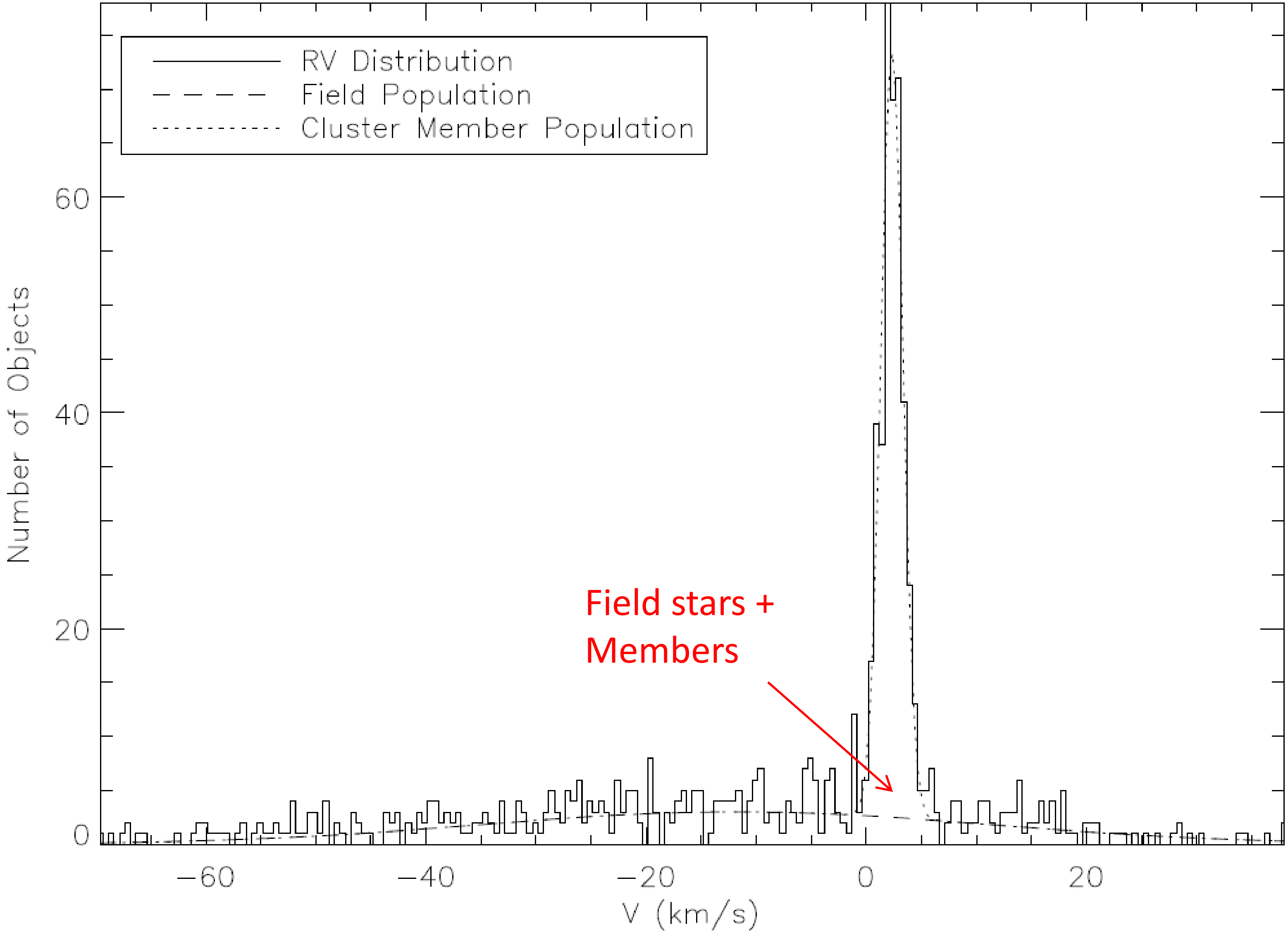
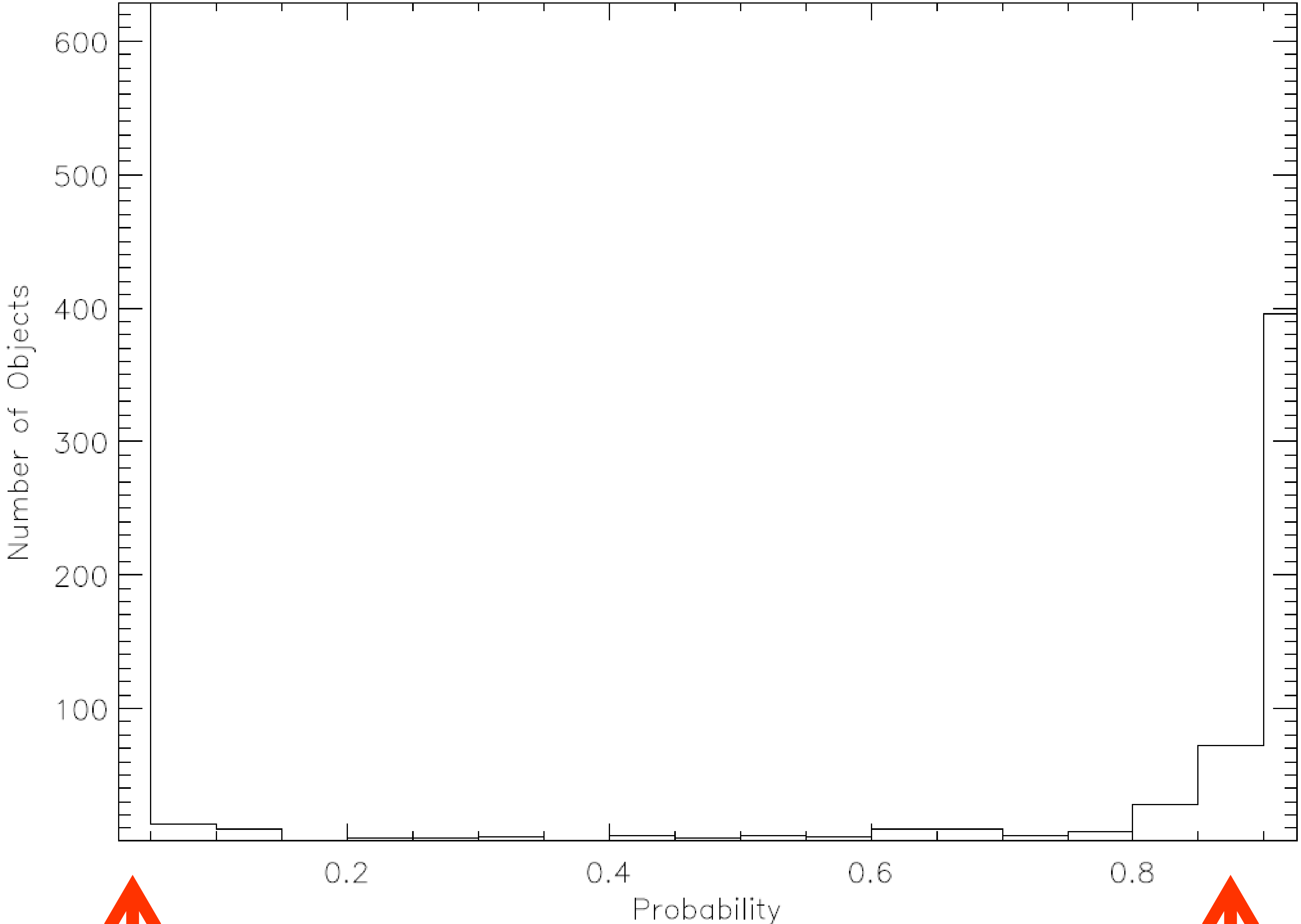


Table 3. Gaussian Fit Parameters For Cluster and Field RV Distributions

	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

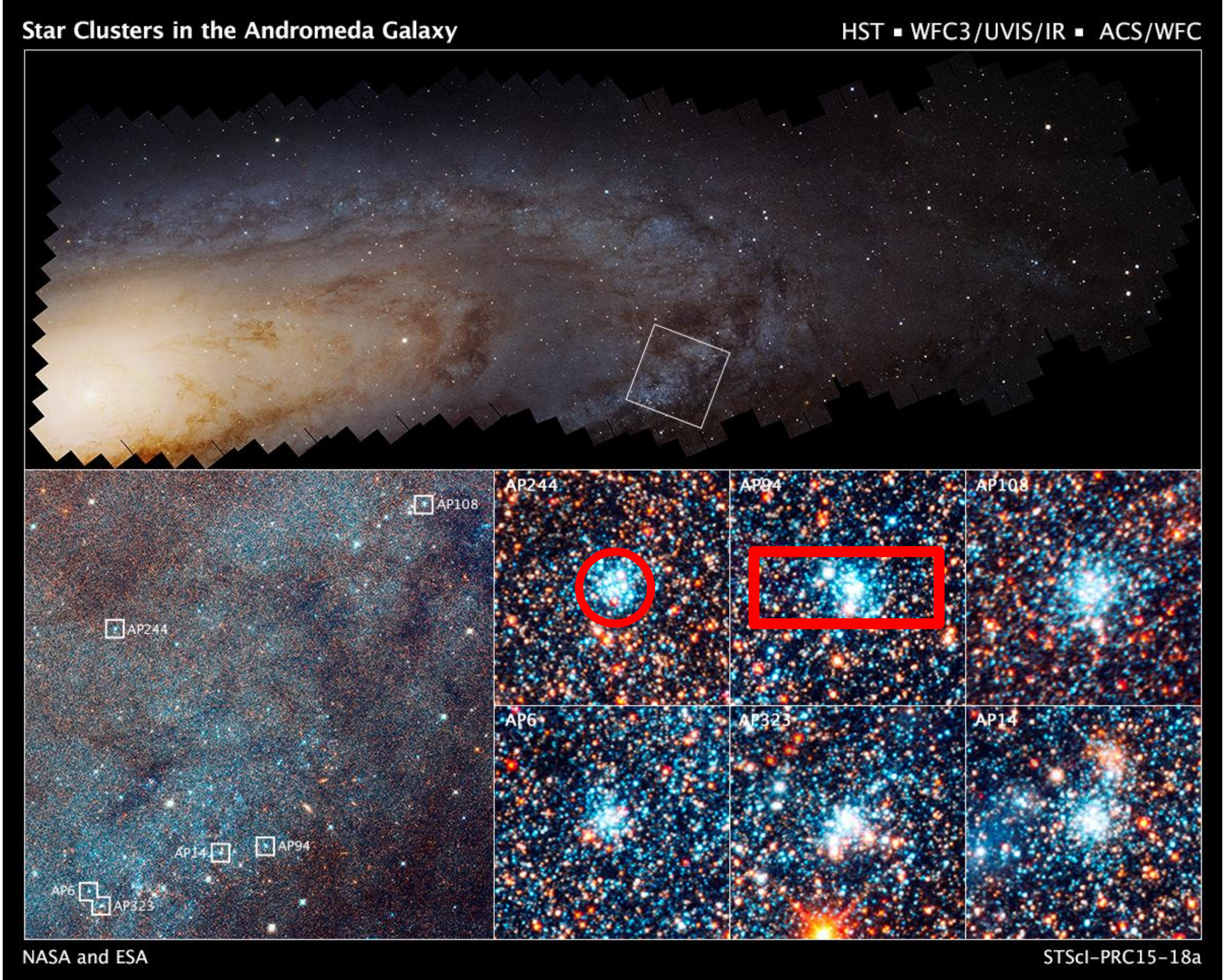


members

non-members

Integrated properties

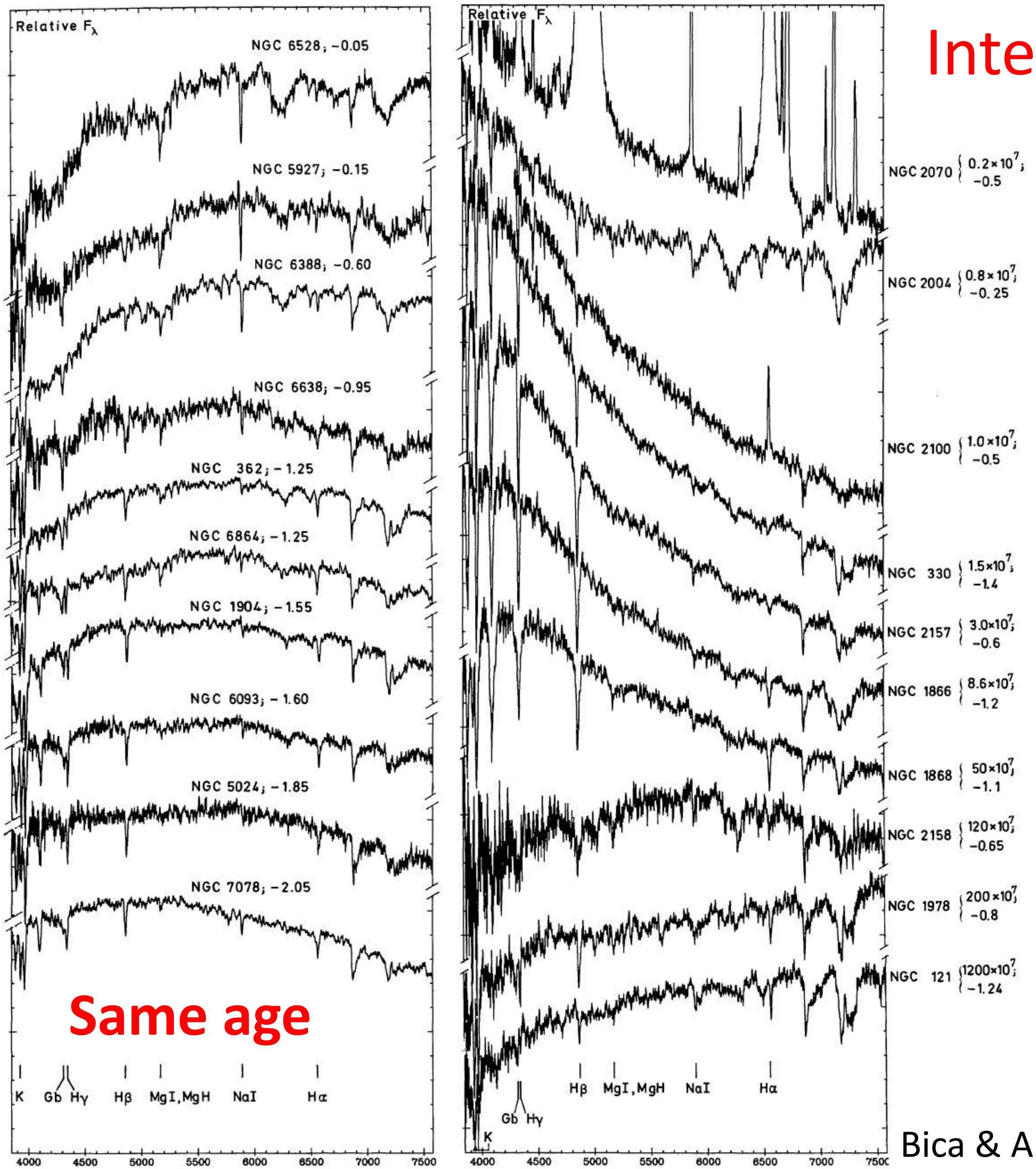
- Integrated spectra and colors
- Especially interesting for distant and extragalactic star clusters
- "Think small"
- Pleiades: 2^{o}


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

Z



Age

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

Integrated colors

“HRD diagram”

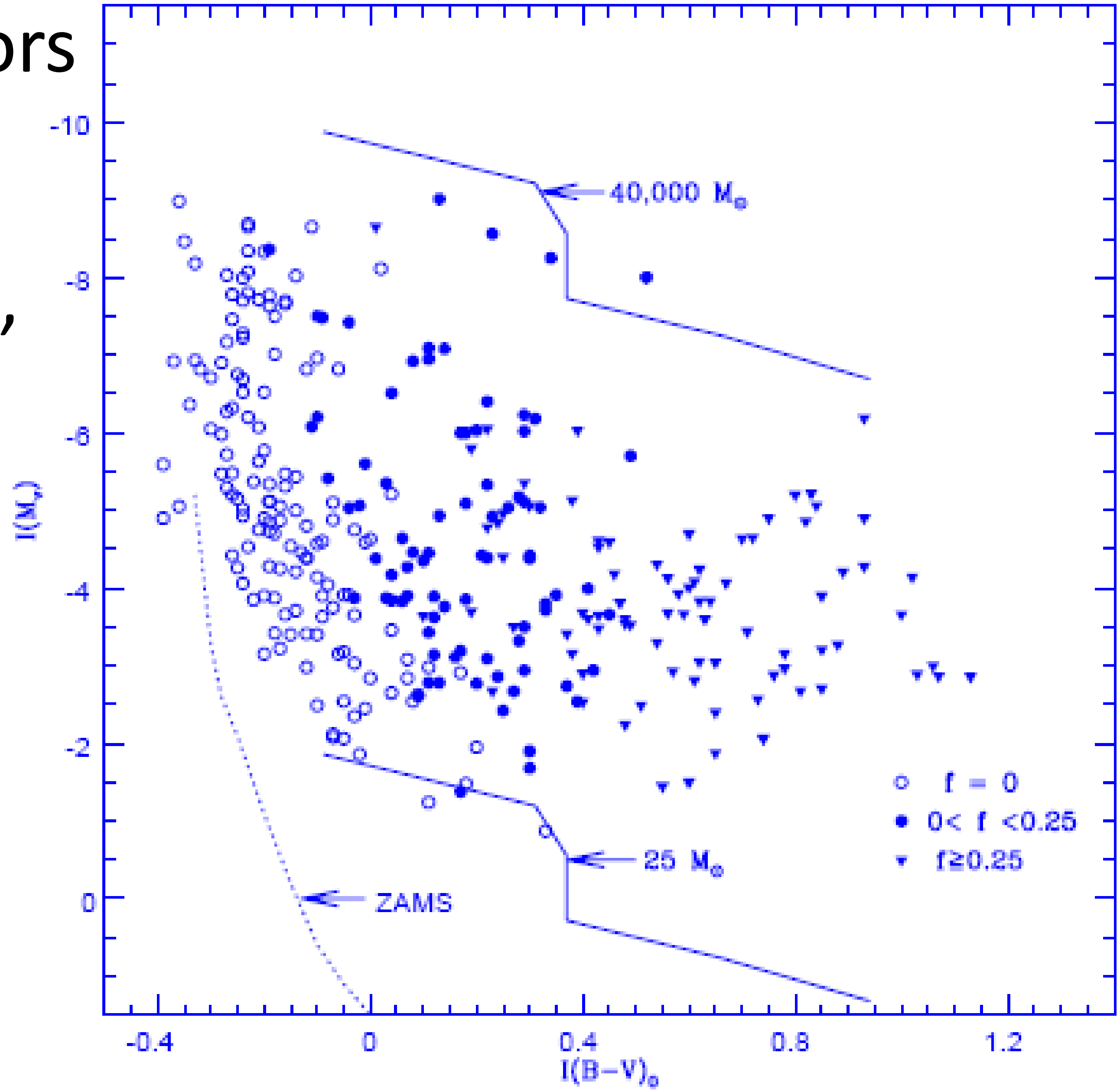


Fig. 2. The $I(M_V)$, $I(B-V)_0$ diagram. f is the fraction of red giants/supergiants in the open clusters.

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