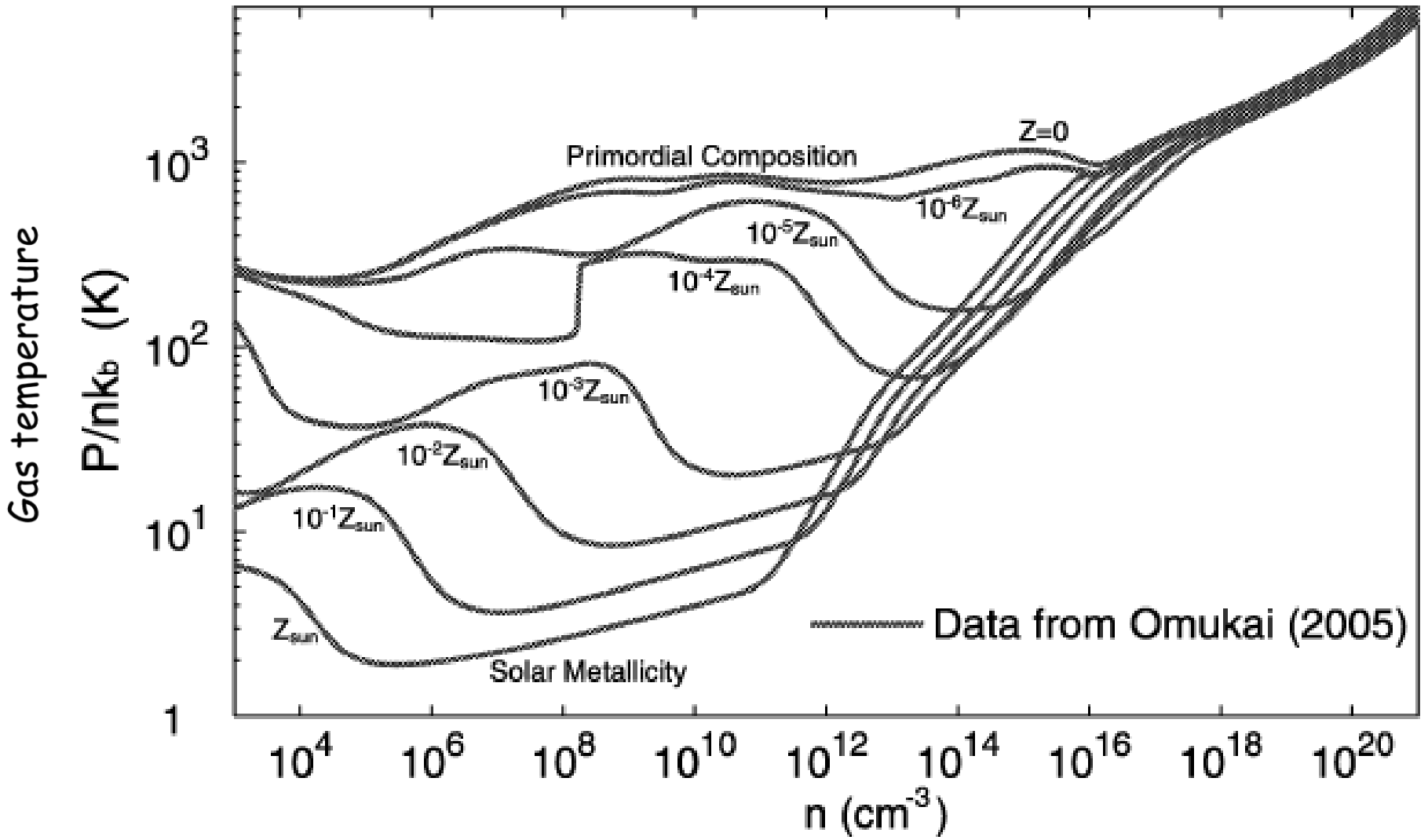
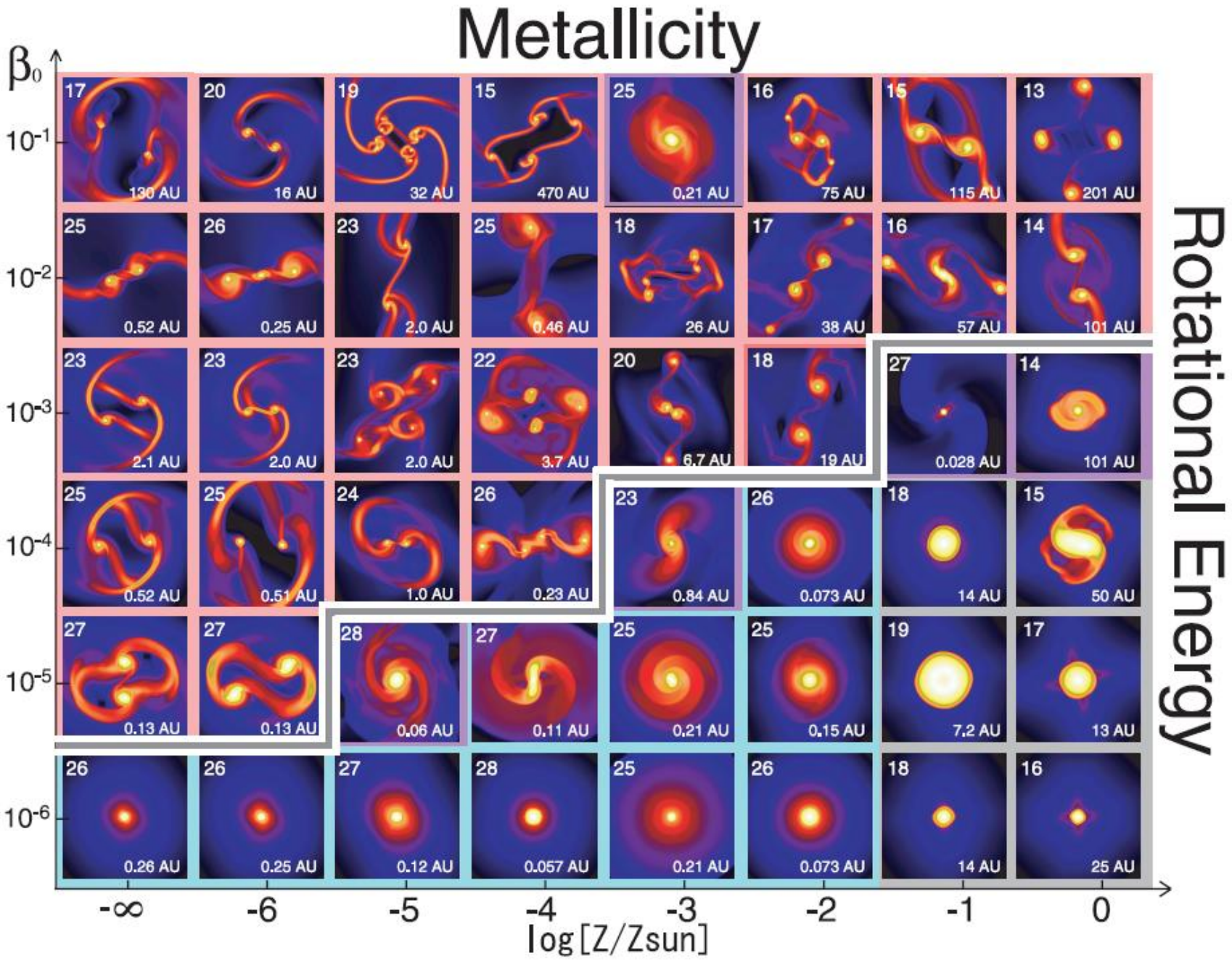
Binary fraction

- Important for the formation and evolution of star clusters
- Critical parameter for the IMF
- Needed for N-body numerical simulations
- Observations are biased in many respects
- Many different types of binary systems

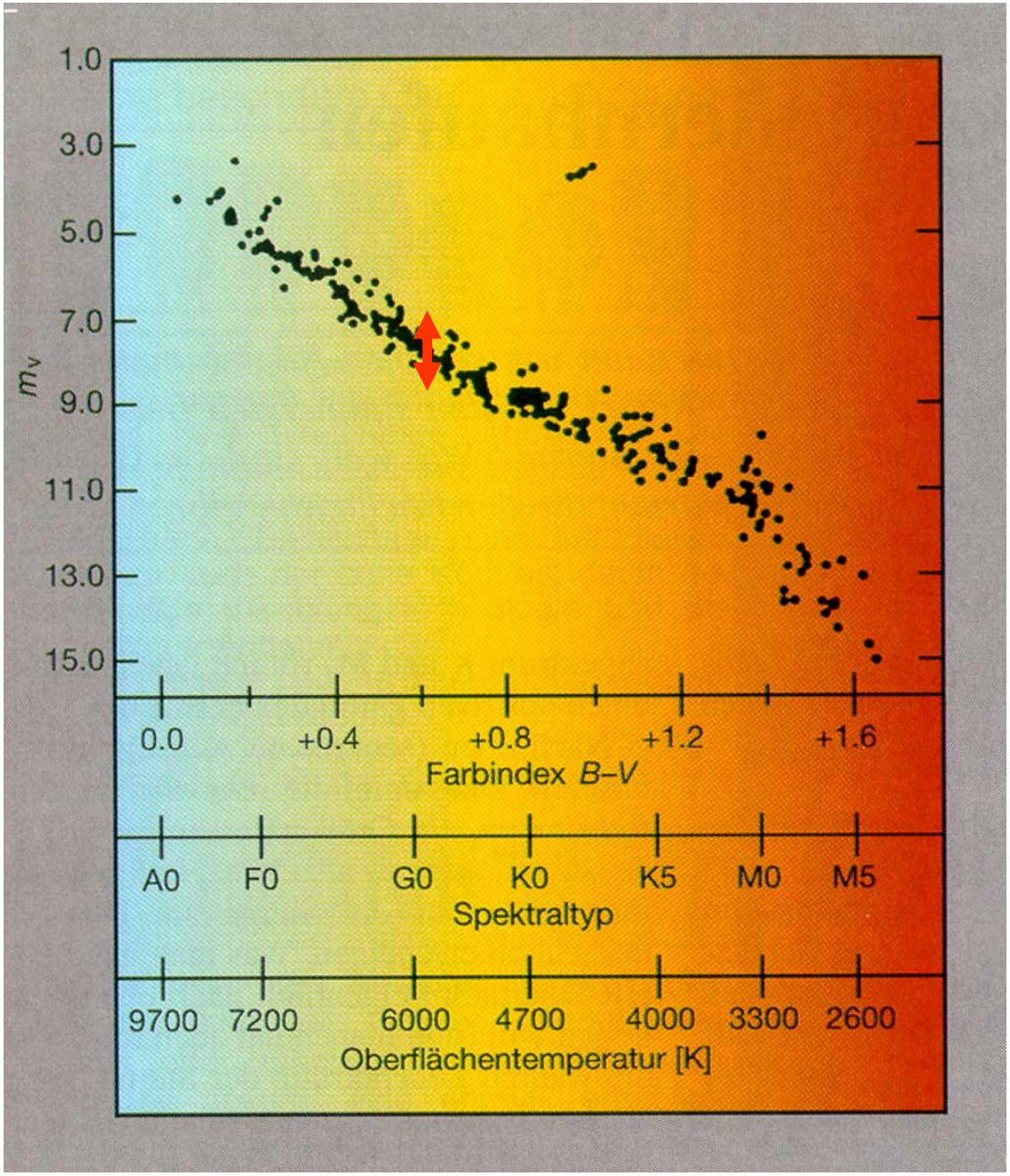
Machida, 2008, ApJ, 682, L1



Different metallicity means different opacity



Lower metallicities seem to favour binary formation



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

Binary system with two components: *A* and B

Magnitudes in Johnson B and V: B_A, V_A, B_B, V_B, B_{AB} and V_{AB}

Colors: $C_A = B_A - V_A$, $C_B = B_B - V_B$ and $C_{AB} = B_{AB} - V_{AB}$

Basic equations for the combined colors:

$$B_{AB} - B_A = -2.5 \log (1 + 10^{-0.4(B_B - B_A)})$$

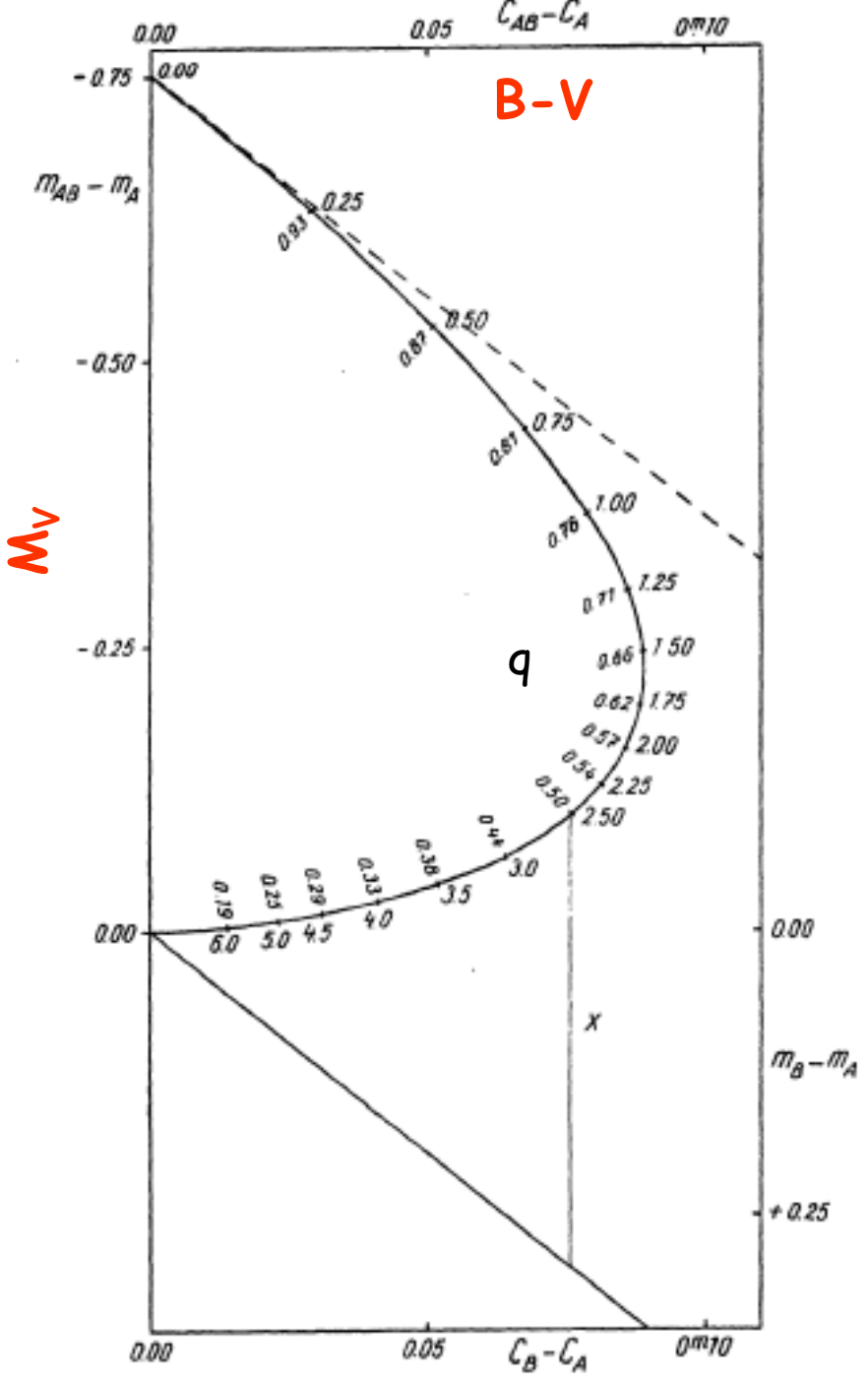
$$V_{AB} - V_A = -2.5 \log (1 + 10^{-0.4(V_B - V_A)})$$

$$C_{AB} - C_A = -2.5 \log [(1 + 10^{-0.4(B_B - B_A)})/(1 + 10^{-0.4(V_B - V_A)})]$$

Linear correlation on the MS: $V = a\,C = a\,(B - V)$

$$V_B - V_A = [(a - 1)/a]\,(B_B - B_A)$$

- What do we need as input?
  1. B and V magnitudes for stars on the main sequence [known]
  2. Magnitude – Color function [known]
  3. Luminosity – Mass function, for example: $L \sim M^3$
  4. Membership probabilities
  5. Reddening free observations



Vertical distance from the main sequence

$$x = a(C_{AB} - C_A) + V_A - V_{AB}$$

Absolute magnitude:

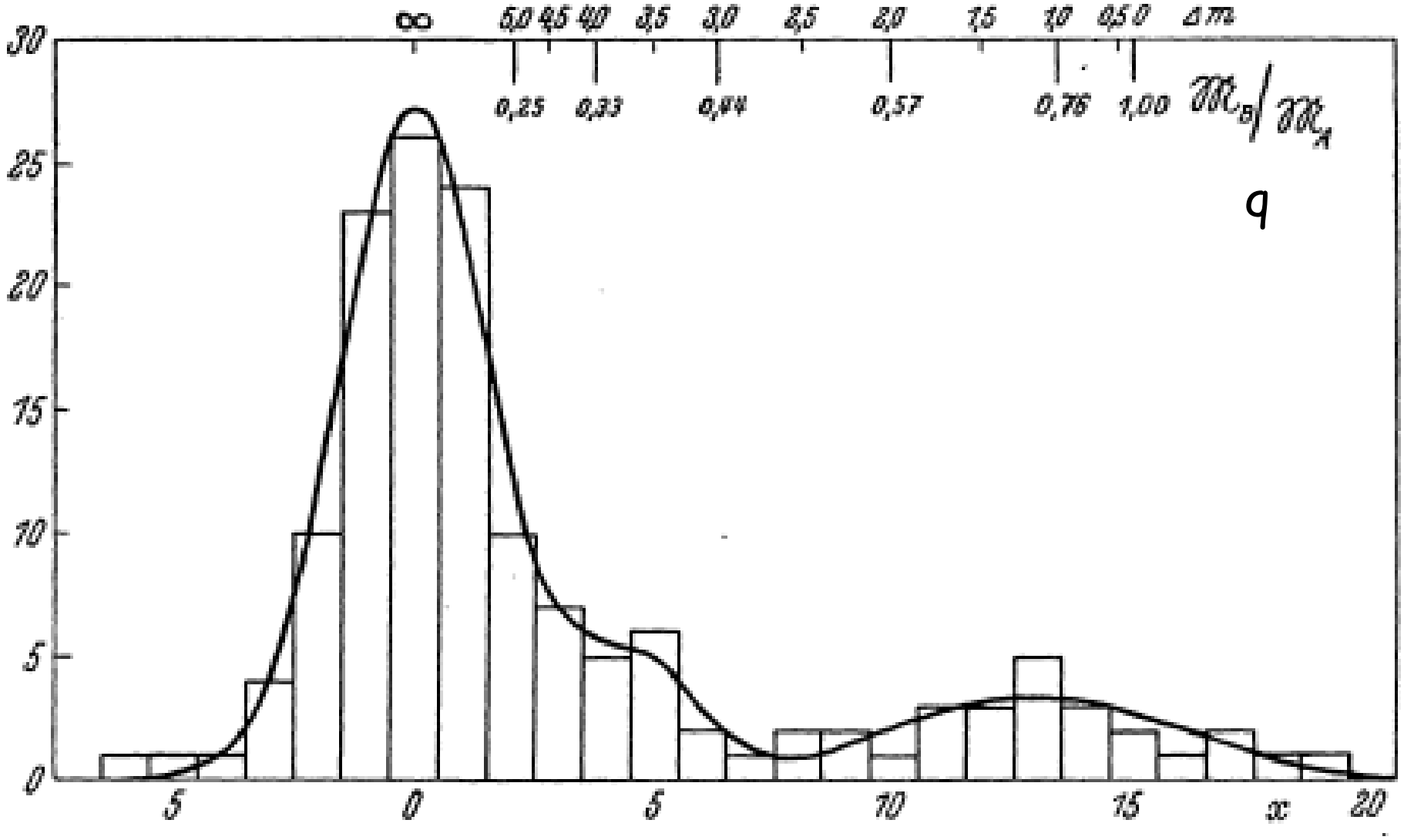
$$M_V = -2.5 \log (L_1 + L_2)$$

Maximum at $L_1 = L_2$ =>

$$M_V = -0.753 \text{ mag}$$

The maximal width of the main sequence due to binary systems is 0.753 mag

Haffner & Heckmann, 1937, VeGeo, 55, 77

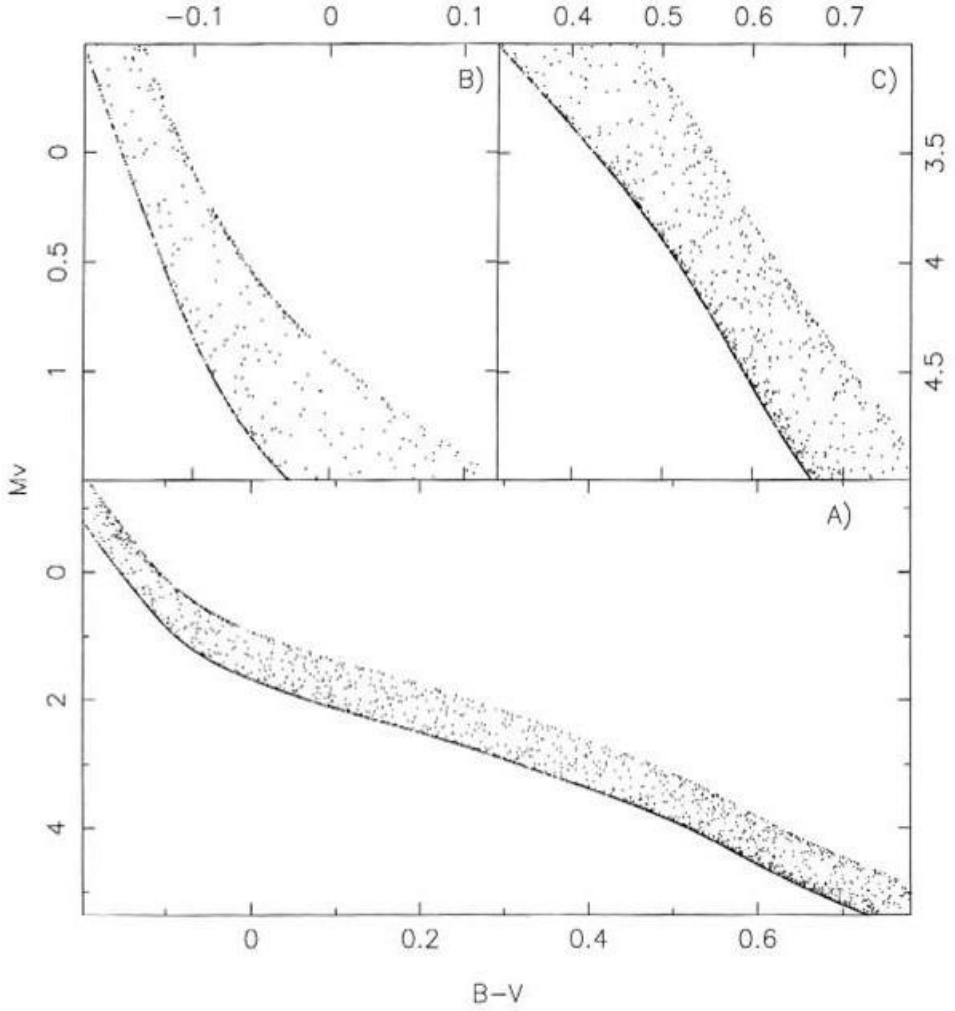


Single stars

Determination of q = Mass ratio of binaries

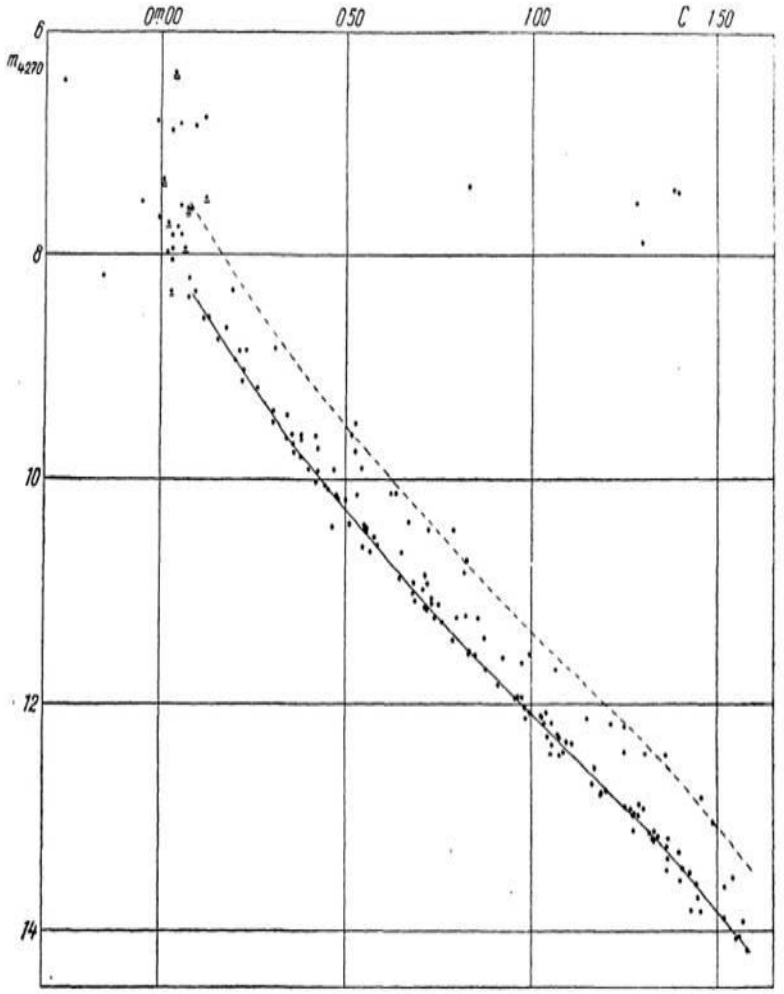
Haffner & Heckmann, 1937, VeGeo, 55, 77

Hurley & Tout, 1998, MNRAS, 300, 977



Simulation with randomly distributed mass ratios

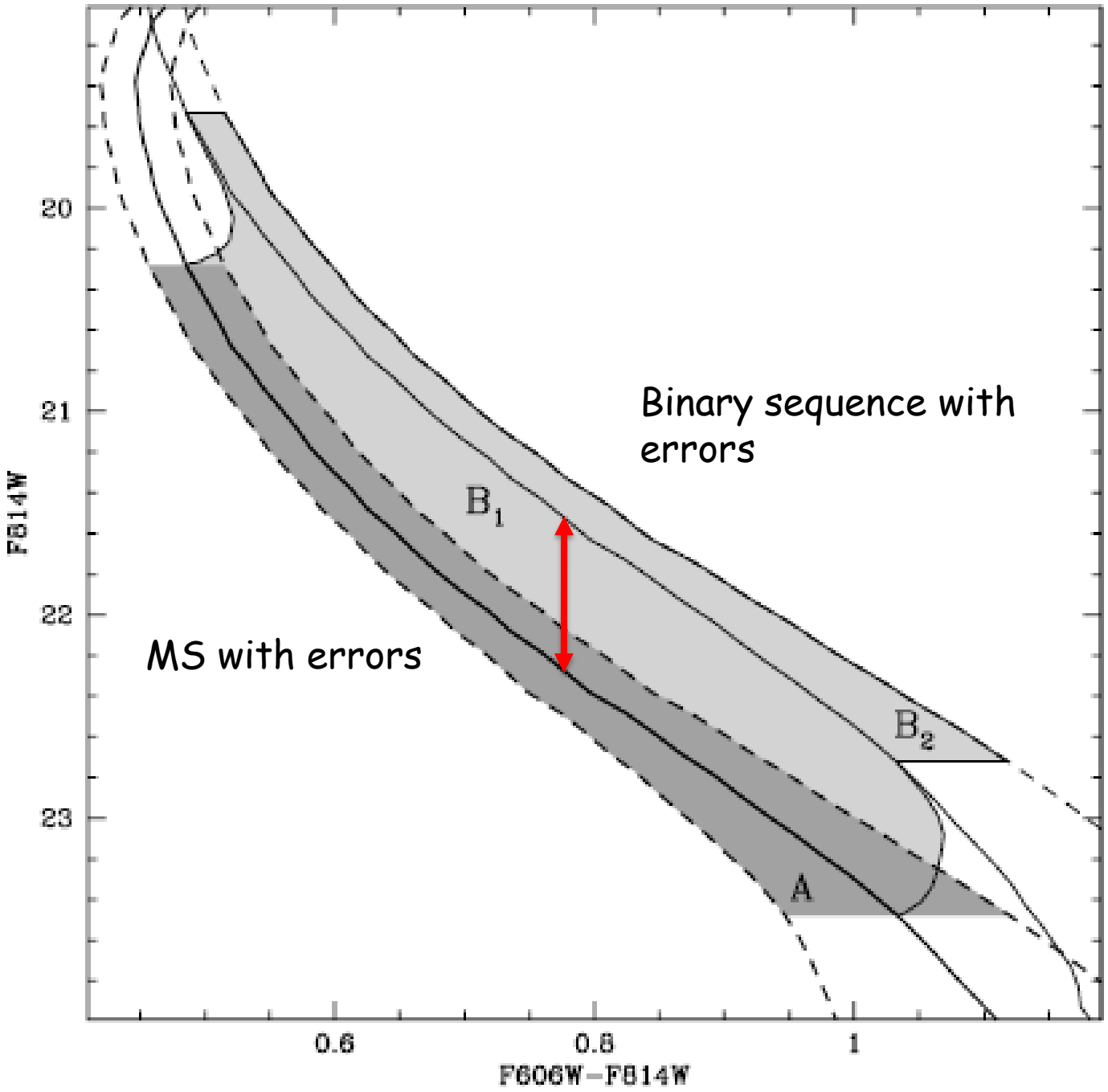
Haffner & Heckmann, 1937, VeGeo, 55, 77



Observations of Praesepe with known binary systems

How to observe the binary fraction?

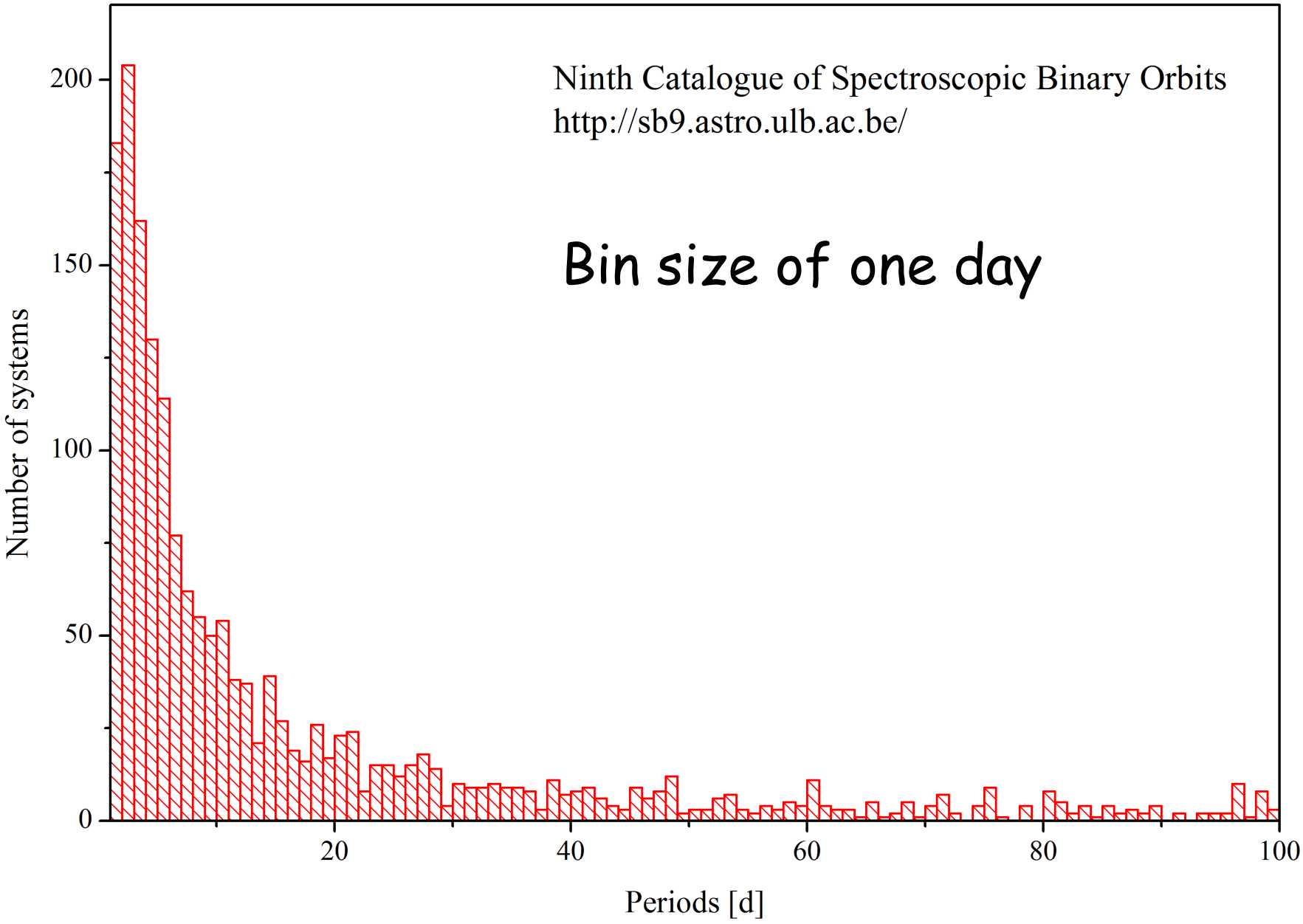
- Photometric observations of star clusters
  1. "Cluster main sequence"
  2. Eclipsing binaries
  3. Positions (astrometric binaries)
- Spectroscopic observations
  1. Radial velocity variability
  2. Direct detection in spectrum (SB2)

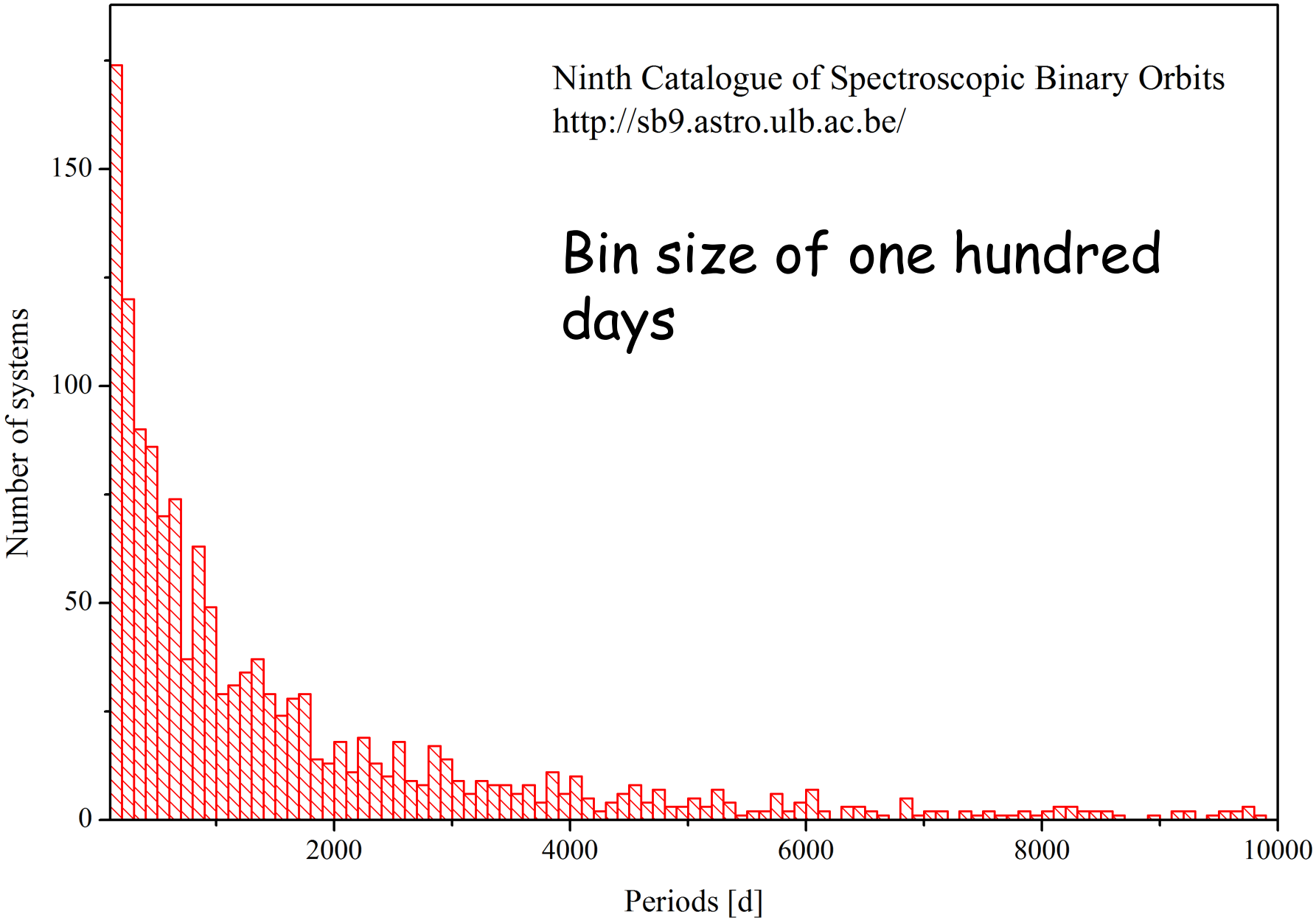


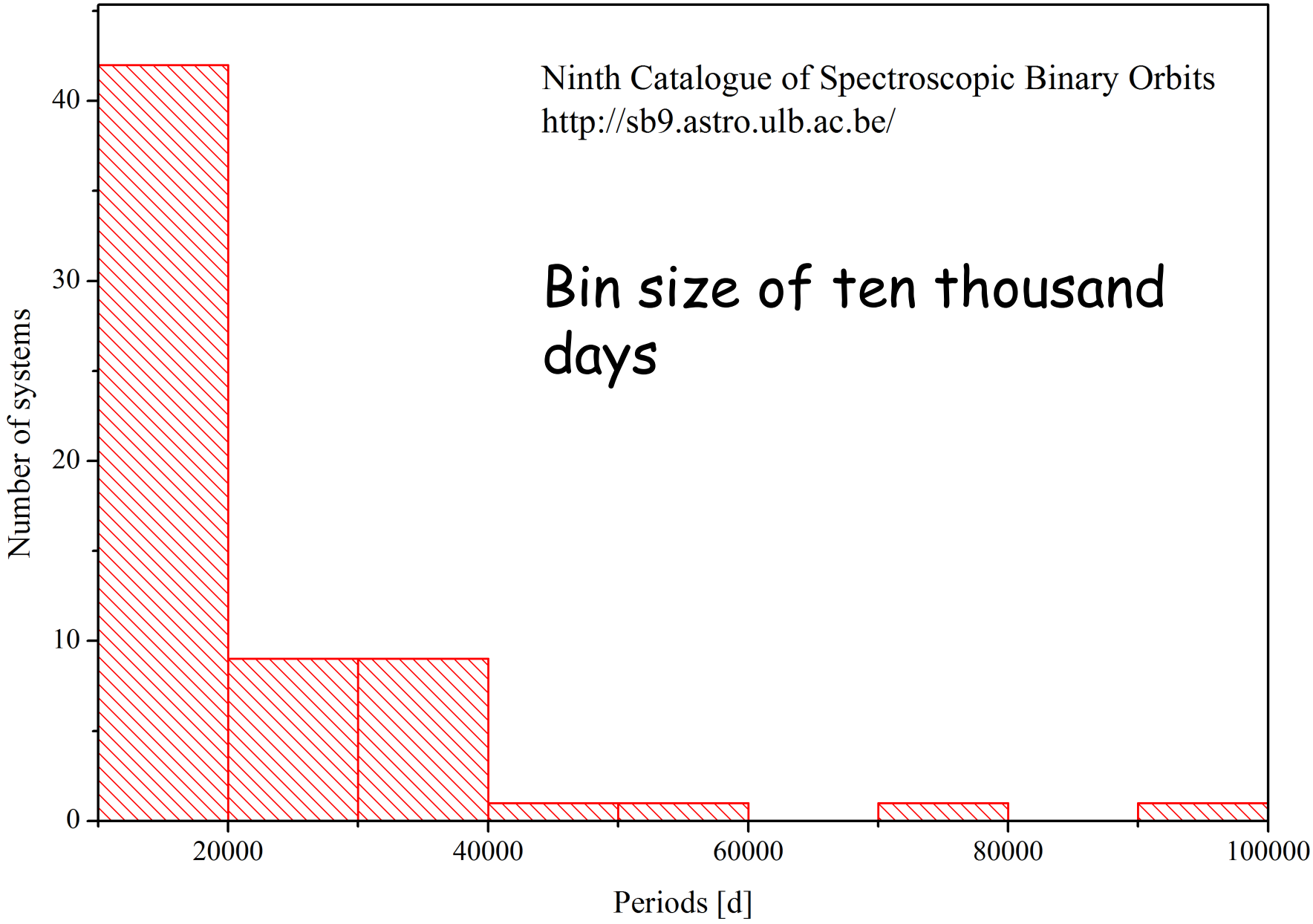
Sollima et al., 2007, MNRAS, 380, 781

HST photometry of Globular Clusters

Count in the areas and do proper statistics


Ninth Catalogue of Spectroscopic Binary Orbits
http://sb9.astro.ulb.ac.be/
Bin size of one day
Number of systems
Periods [d]
0
50
100
150
200
20
40
60
80
100


Ninth Catalogue of Spectroscopic Binary Orbits
http://sb9.astro.ulb.ac.be/
Bin size of one hundred days
Number of systems
0
50
100
150
2000
4000
6000
8000
10000
Periods [d]


Ninth Catalogue of Spectroscopic Binary Orbits
http://sb9.astro.ulb.ac.be/
Bin size of ten thousand days
Number of systems
0
10
20
30
40
20000
40000
60000
80000
100000
Periods [d]

Results for open clusters

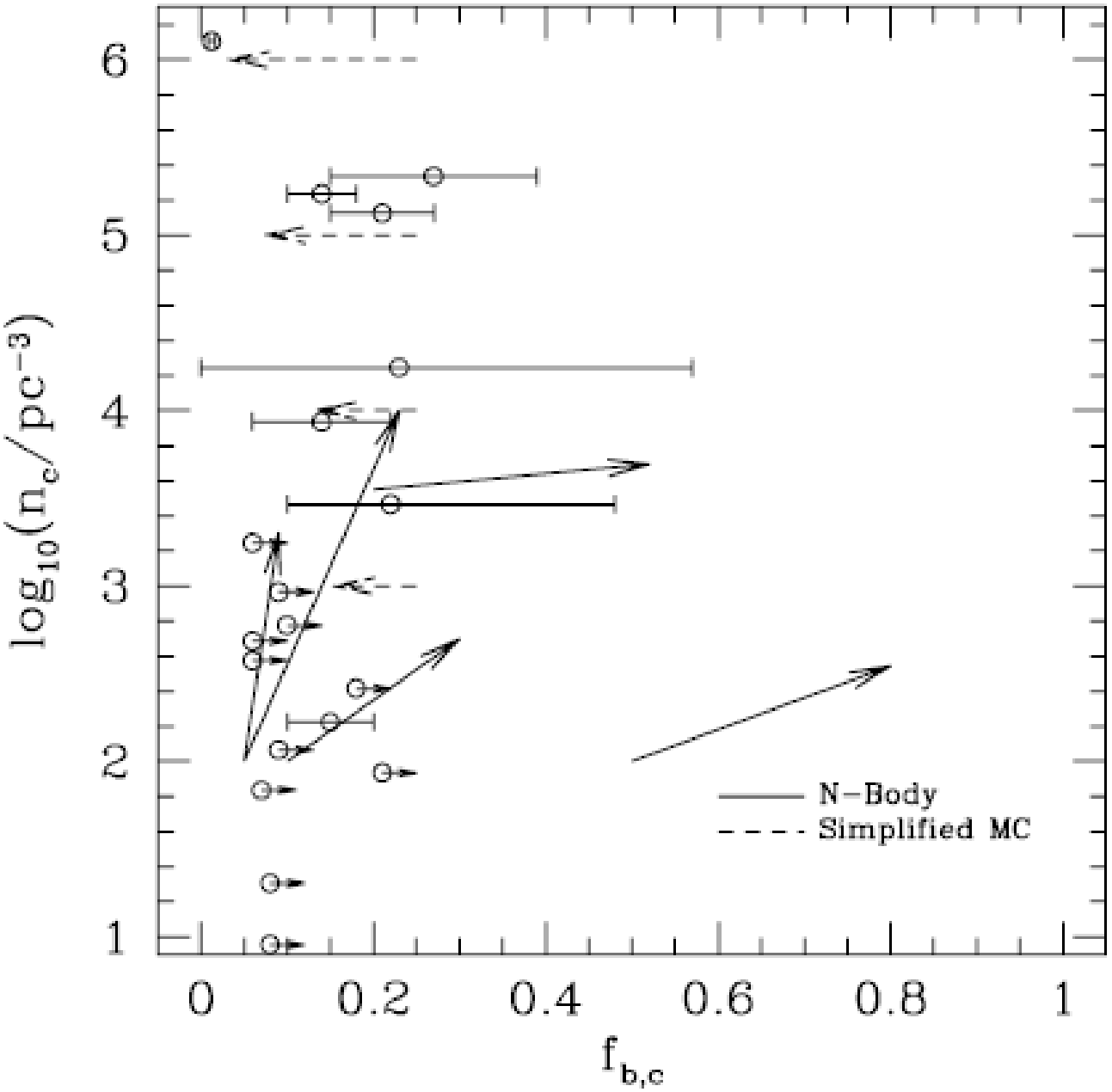
- Sollima et al., 2010, MNRAS, 401, 577
  - NGC 188 (9.63): 21 – 58%
  - NGC 2204 (9.20): 12 – 36%
  - NGC 2243 (9.58): 34 – 70%
  - NGC 2420 (9.08): 17 – 51%
  - NGC 2516 (8.52): 25 – 66%
- Sana et al., 2009, MNRAS, 400, 1479
  - NGC 6611 (6.50): 44 – 67%
- Sana et al., 2008, MNRAS, 386, 447
  - NGC 6231 (6.50): 63% - ?
- Bica & Bonatto, 2005, A&A, 431, 943
  - IC 4651 (9.26): 50 +- 11%
  - NGC 2287 (8.20): 48 +- 45%
  - NGC 2447 (8.60): 21 +- 9%
  - NGC 2548 (8.56): 48 +- 23%
  - NGC 2682 (9.51): 39 +- 16%
  - NGC 3680 (9.20): 25 +- 5%
  - NGC 5822 (9.00): 16 +- 8%
  - NGC 6208 (9.11): 54 +- 30%
  - NGC 6694 (7.85): 18 +- 12%
- Sandhu et al., 2003, A&A, 408, 515
  - NGC 2099 (8.60): ~30%
  - King 5 (9.00): ~30%
  - King 7 (8.80): ~20%

Fregeau et al., 2007, ApJ, 707, 1503

Start at 4 Gyr with 50% binary fraction

Destruction due to

- Stellar evolution
- Dissipation
- Collisions in the core



	f
NGC 288	0.15 ± 0.05
	>0.06
NGC 362	0.21 ± 0.06
NGC 2808	
NGC 3201	
NGC 4590	>0.09
NGC 5053	>0.08
NGC 5466	>0.08
NGC 5897	>0.07
NGC 6101	>0.09
NGC 6362	>0.06
NGC 6397	<0.07
NGC 6723	>0.06
NGC 6752	0.27 ± 0.12
NGC 6792	
NGC 6981	>0.10
M3	
	0.14 ± 0.08
M4	$0.23^{+0.34}_{-0.23}$
M15	~0.07
M22	
M30	
M55	>0.06
M71	$0.22^{+0.26}_{-0.12}$
M92	
Arp 2	>0.08
Terzan 7	>0.21
Palmoar 12	>0.18
Palmoar 13	0.30 ± 0.04
47 Tucane	0.14 ± 0.04

Davis et al., 2008, AJ, 135, 2155

Designation of open 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

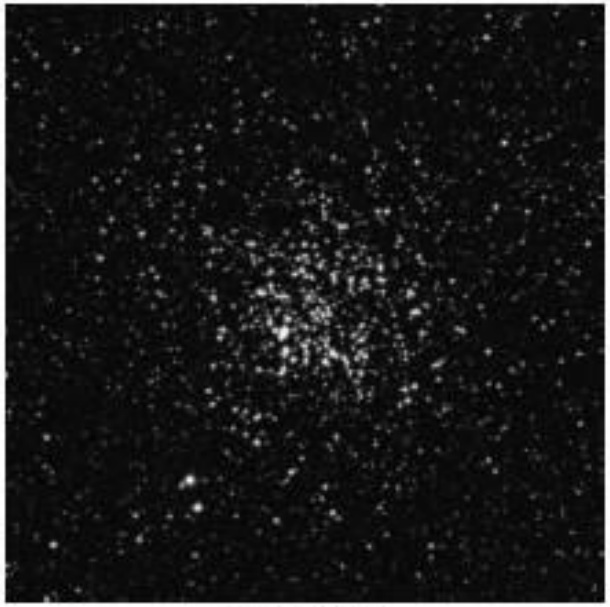
Trumplers classification

- **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

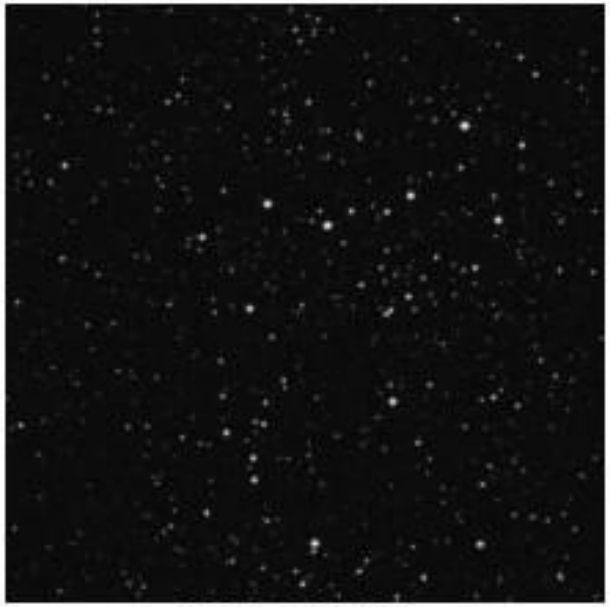
- **Number of Stars in the Cluster**
  - **p** … Poor clusters with less than 50 stars
  - **m** … Medium rich cluster with 50 to 100 stars
  - **r** … Rich clusters with over 100 stars
- Open clusters with any type of nebulosity are denoted with an "**n**" at the end of the classification.


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

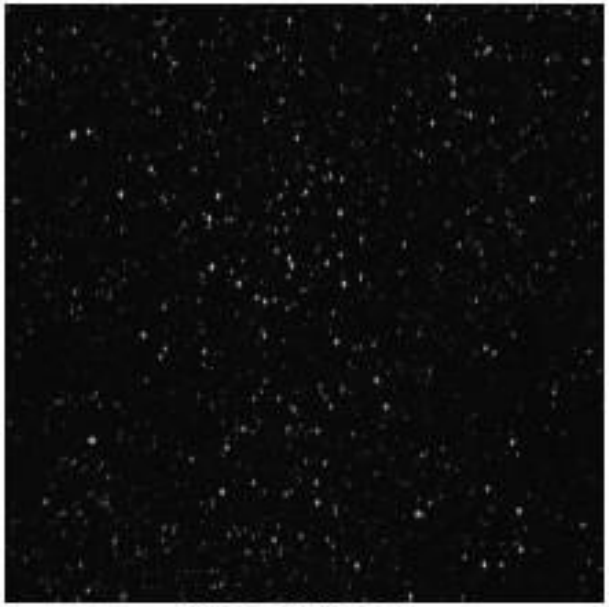


M11 15.0′
Class: I 2 r

M46 15.0′
Class: II 2 r



NGC 6664 15.0′
Class: III 2 m



NGC 6568 25.0′
Class: IV 1 m

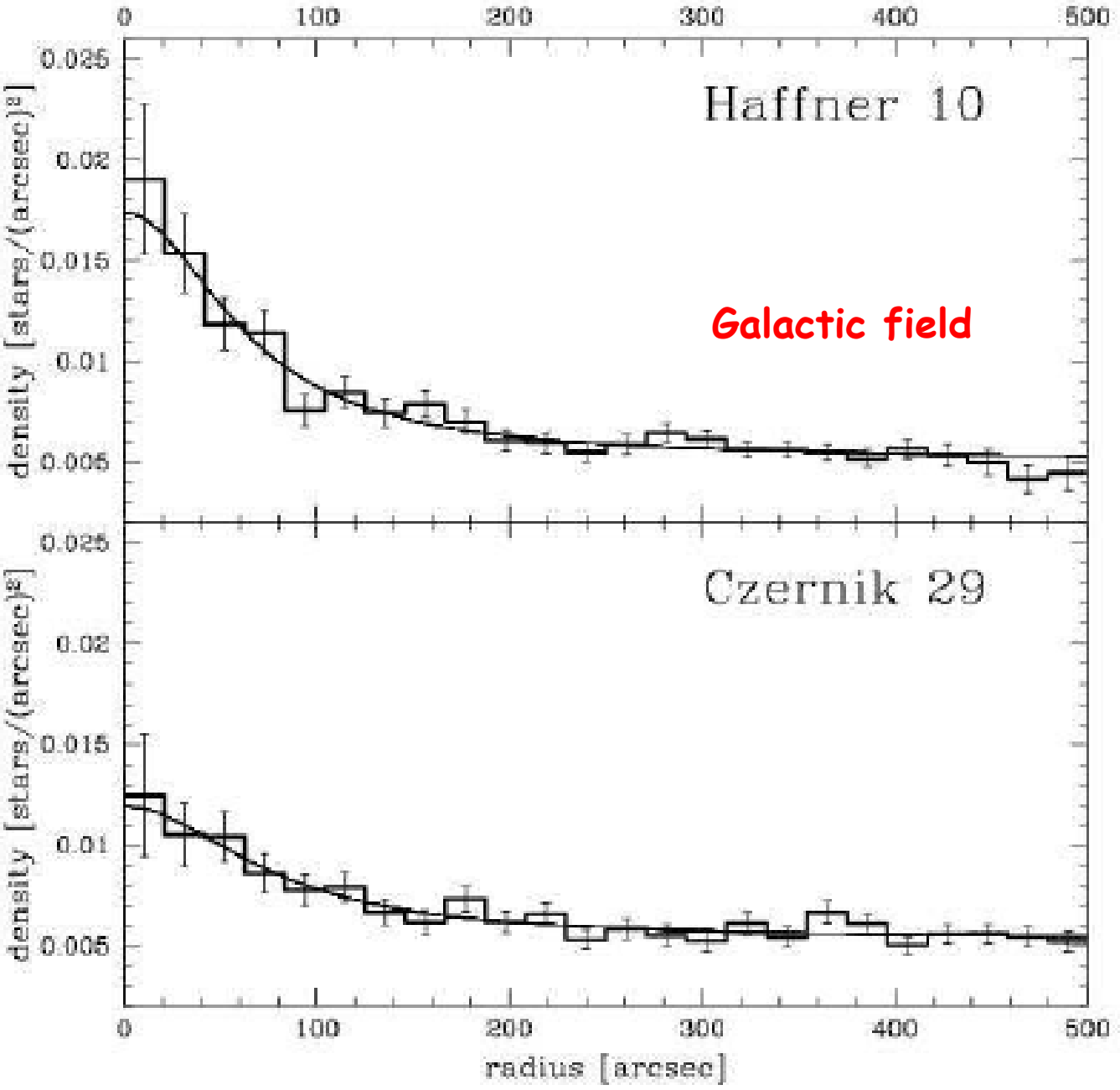
- **Richness Class**
  - **1** … Less than 25 stars
  - **2** … Between 25 and 50 stars
  - **3** … Between 50 and 100 stars
  - **4** … Between 100 and 250 stars
  - **5** … More than 250 stars
- How "good" can the number of members be established?

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

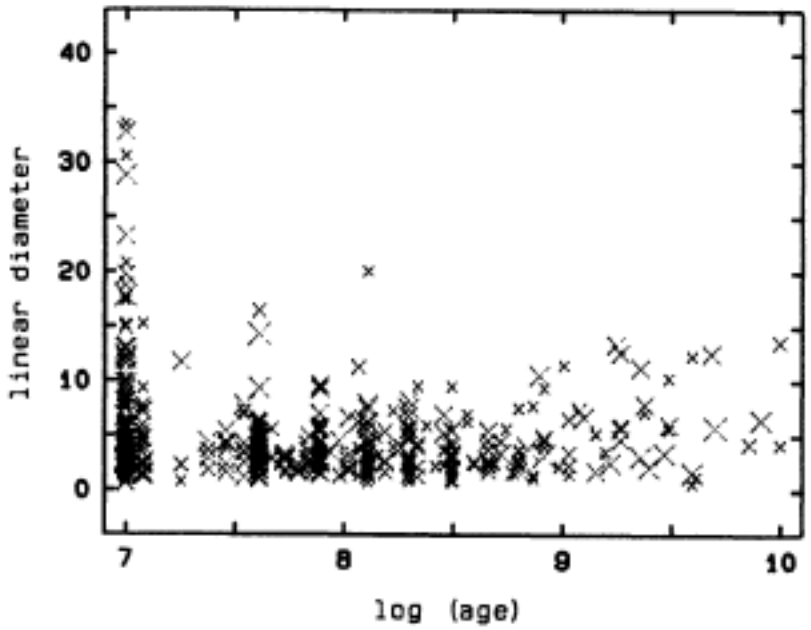
III 2 m

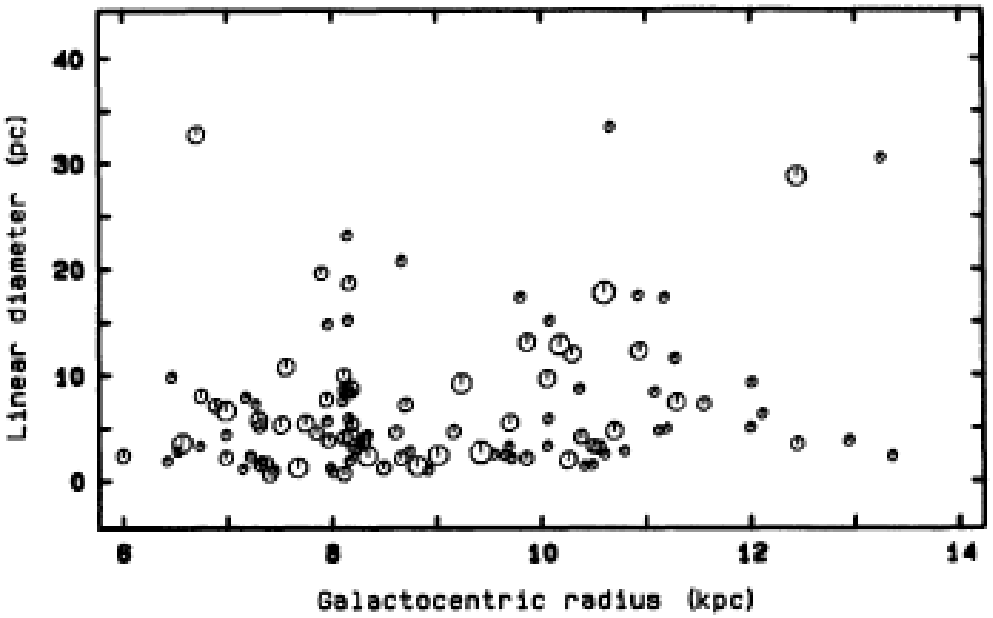
II 2 m

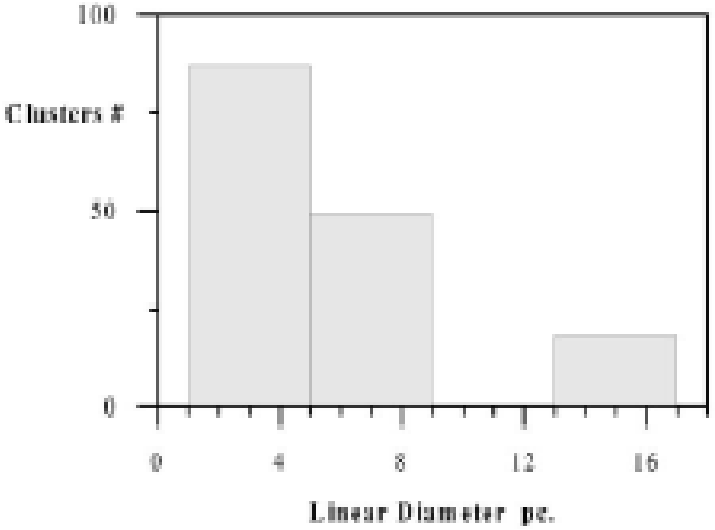


Pietrukowicz et al., 2006, MNRAS, 365, 110

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



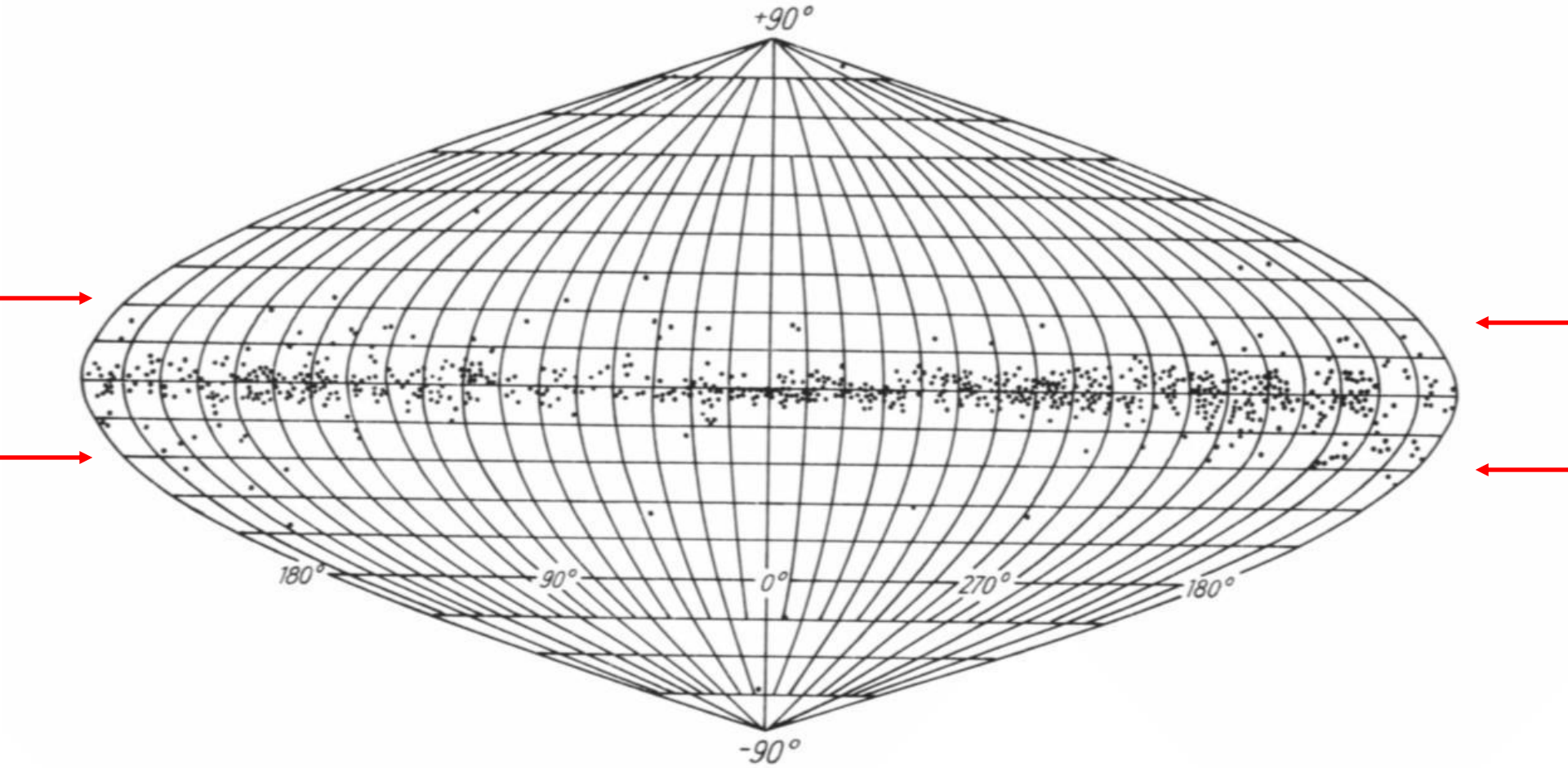




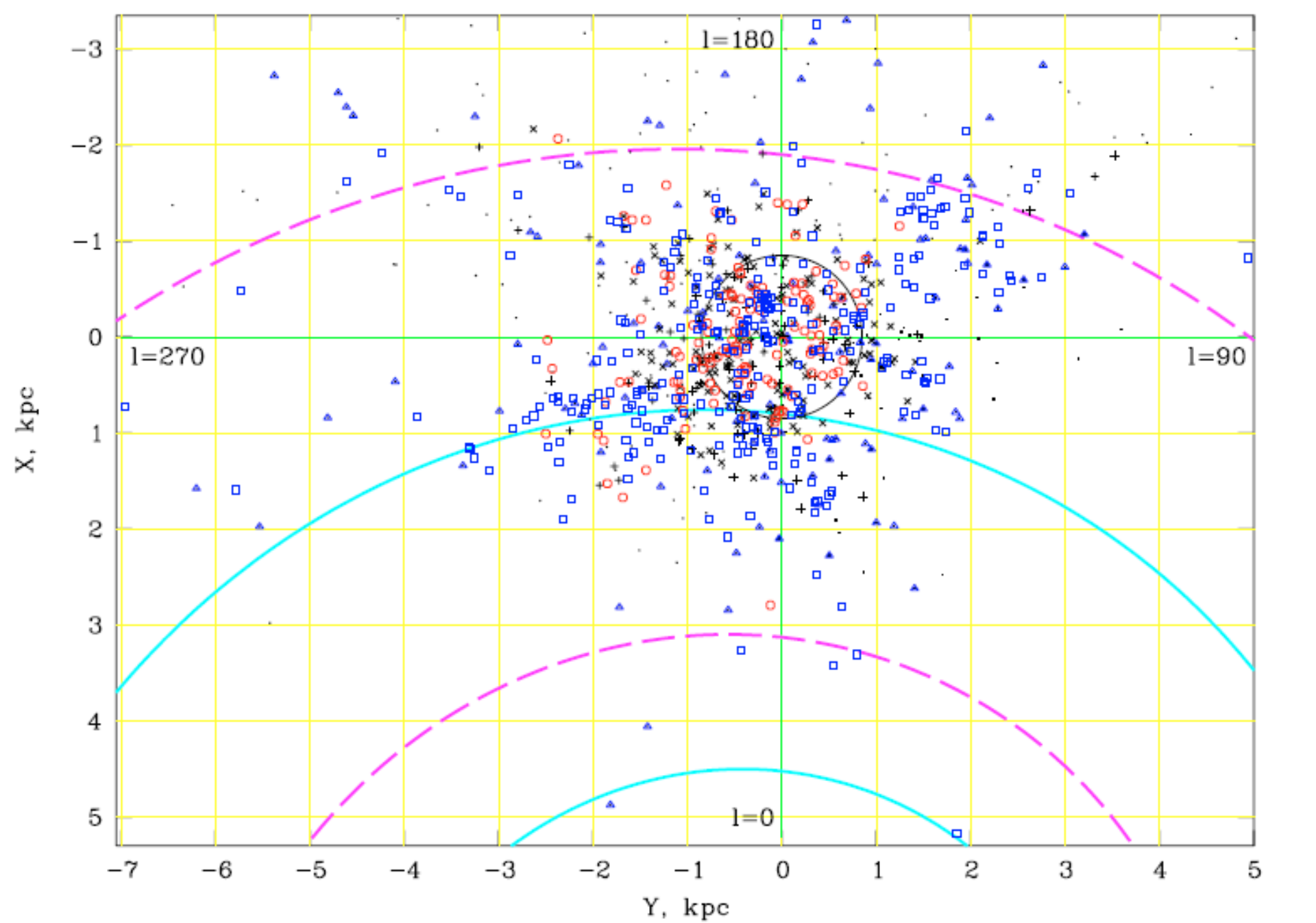
No correlation with the age and the distance to the Galactic distance

Tadross, 2001, New Astronomy, 6, 293

Galactic Distribution



+- 20 degree Galactic latitude



Piskunov et al., 2006, *A&A*, 445, 545