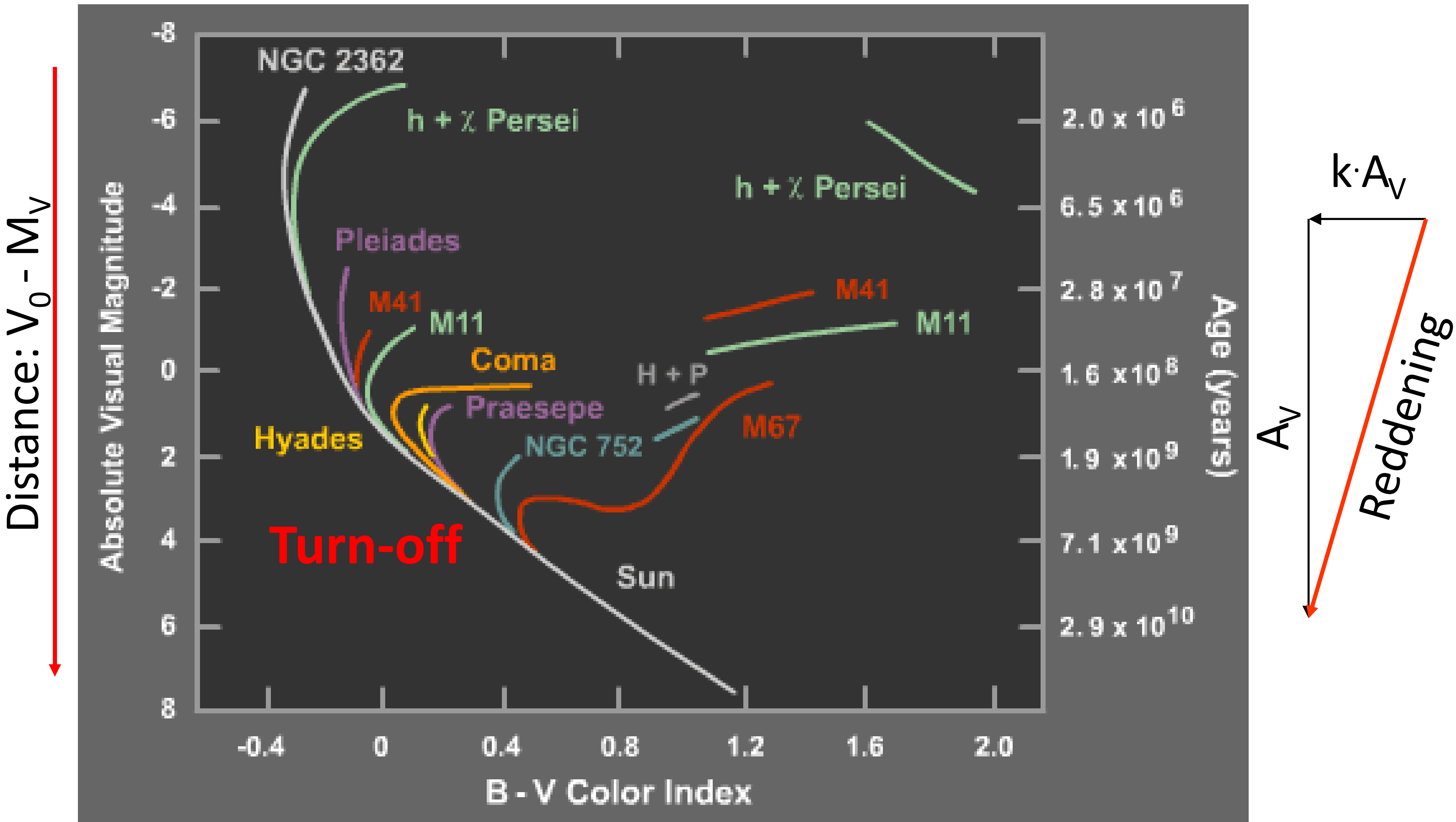
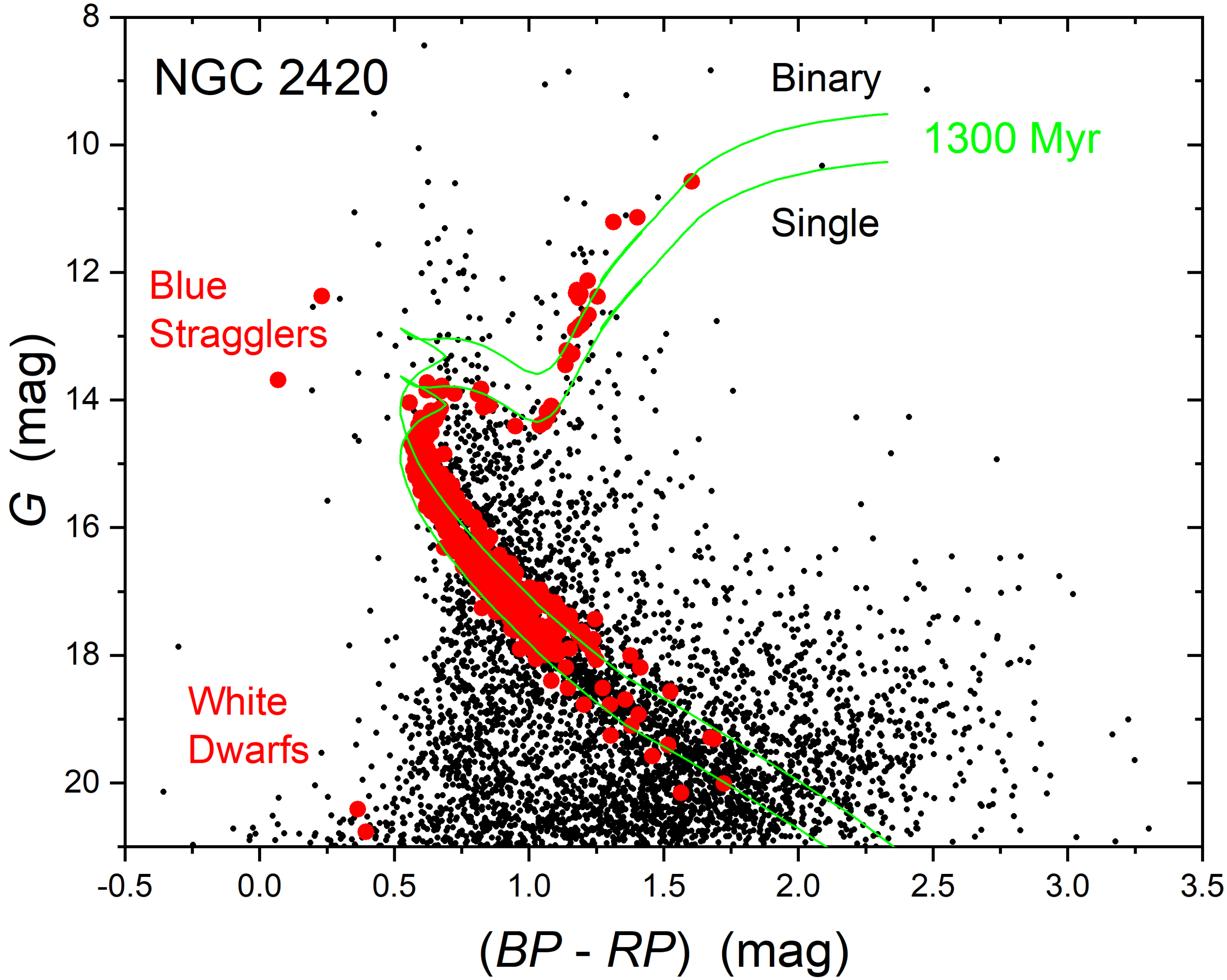
Introduction – Star Clusters II

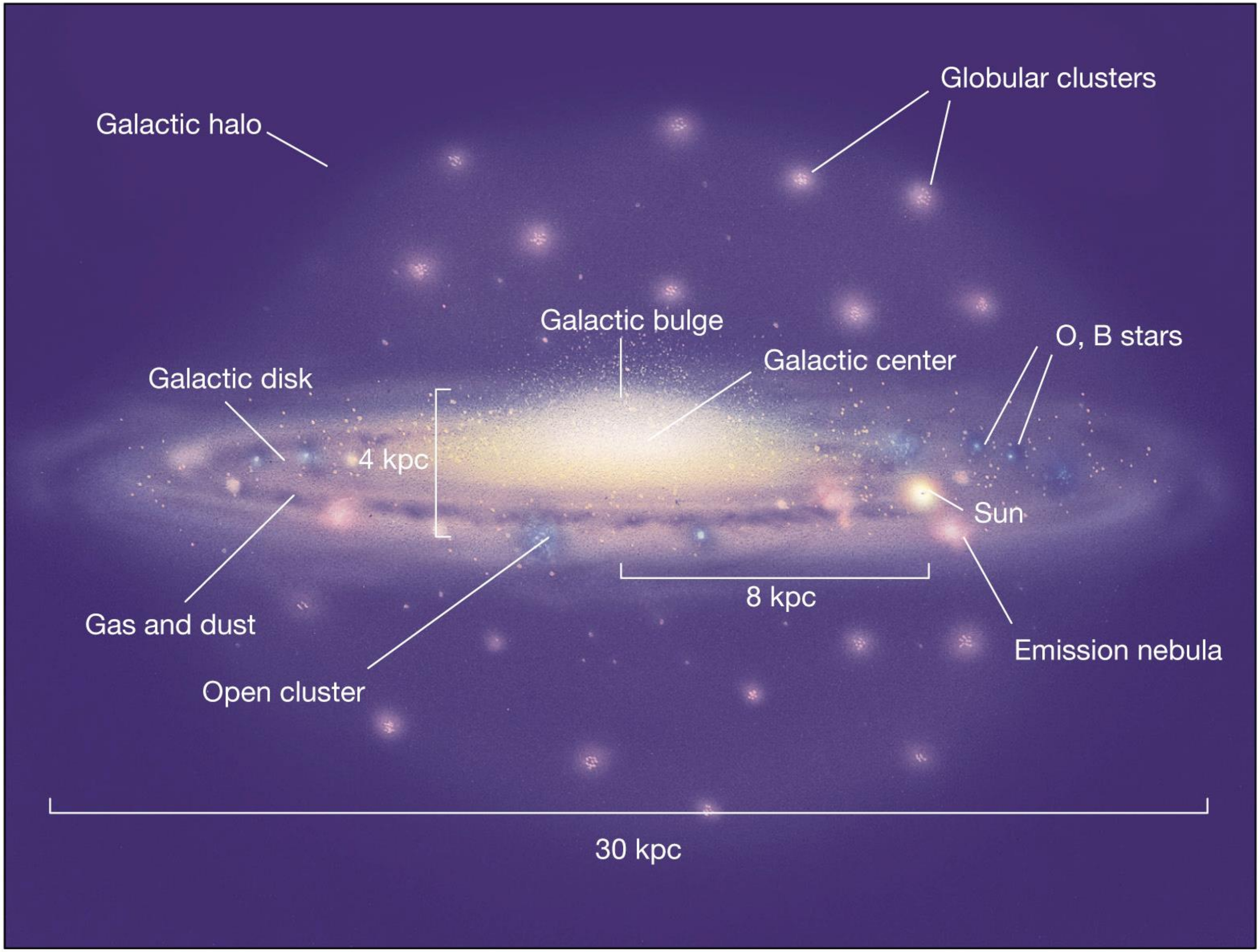


HR Diagrams for Various Open Clusters

Gaia – before and after

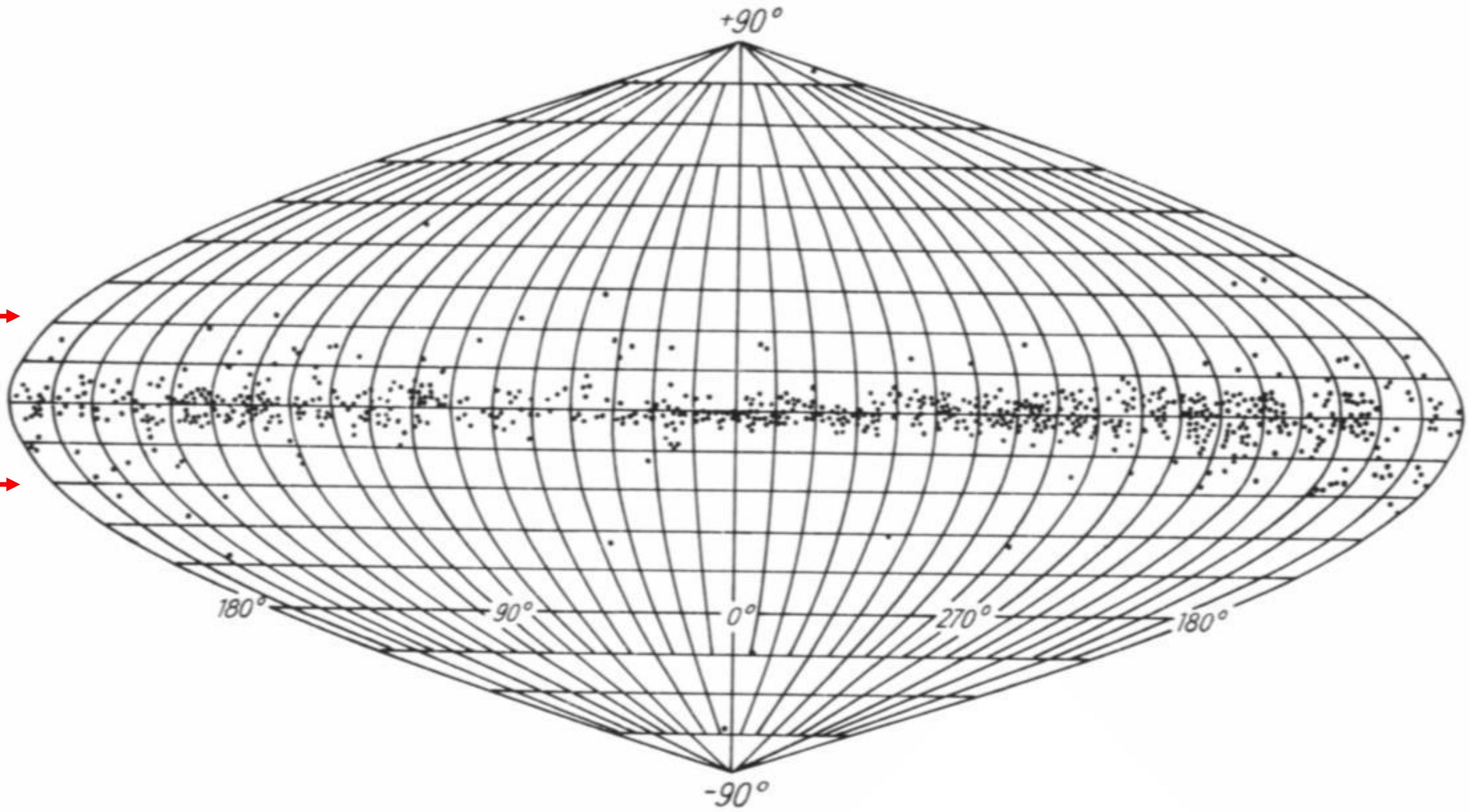


Location of Star Clusters



Credit:
Pearson
Education Inc.

Galactic Distribution

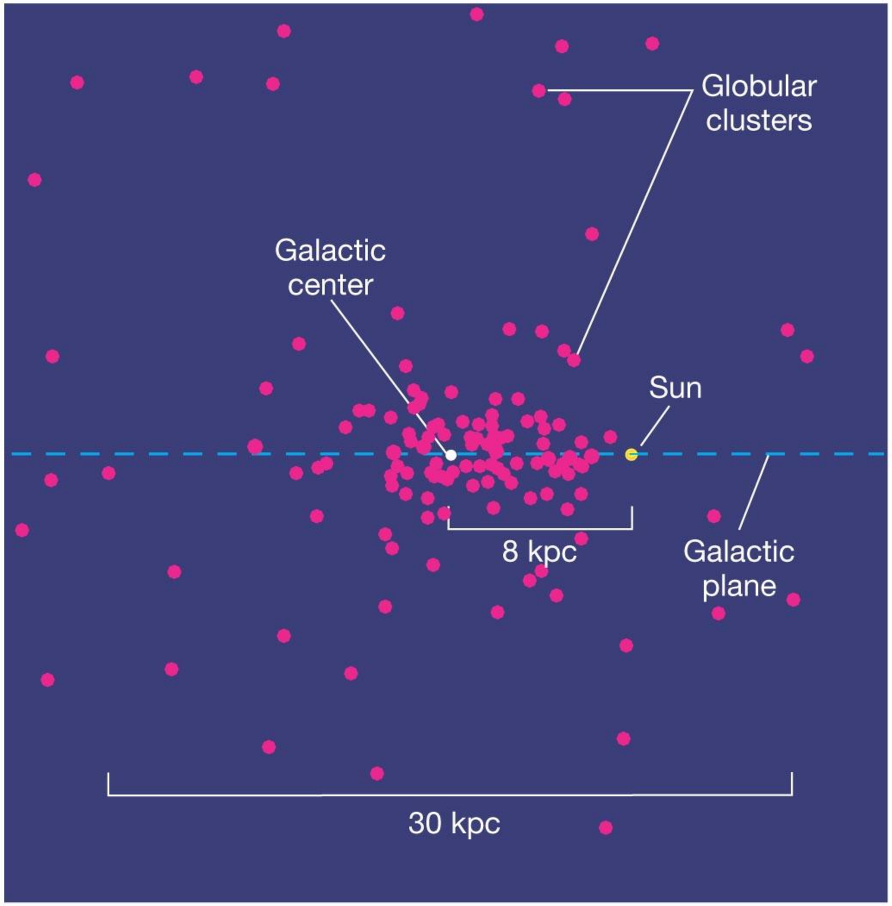


+- 20 degree Galactic latitude

Location of Globular Clusters

- Globular Clusters are found in

1. Galactic Halo – formed there
2. Galactic Bulge – formed there
3. Galactic Disc – path



Star Clusters – tricky to analyze

NGC
7789

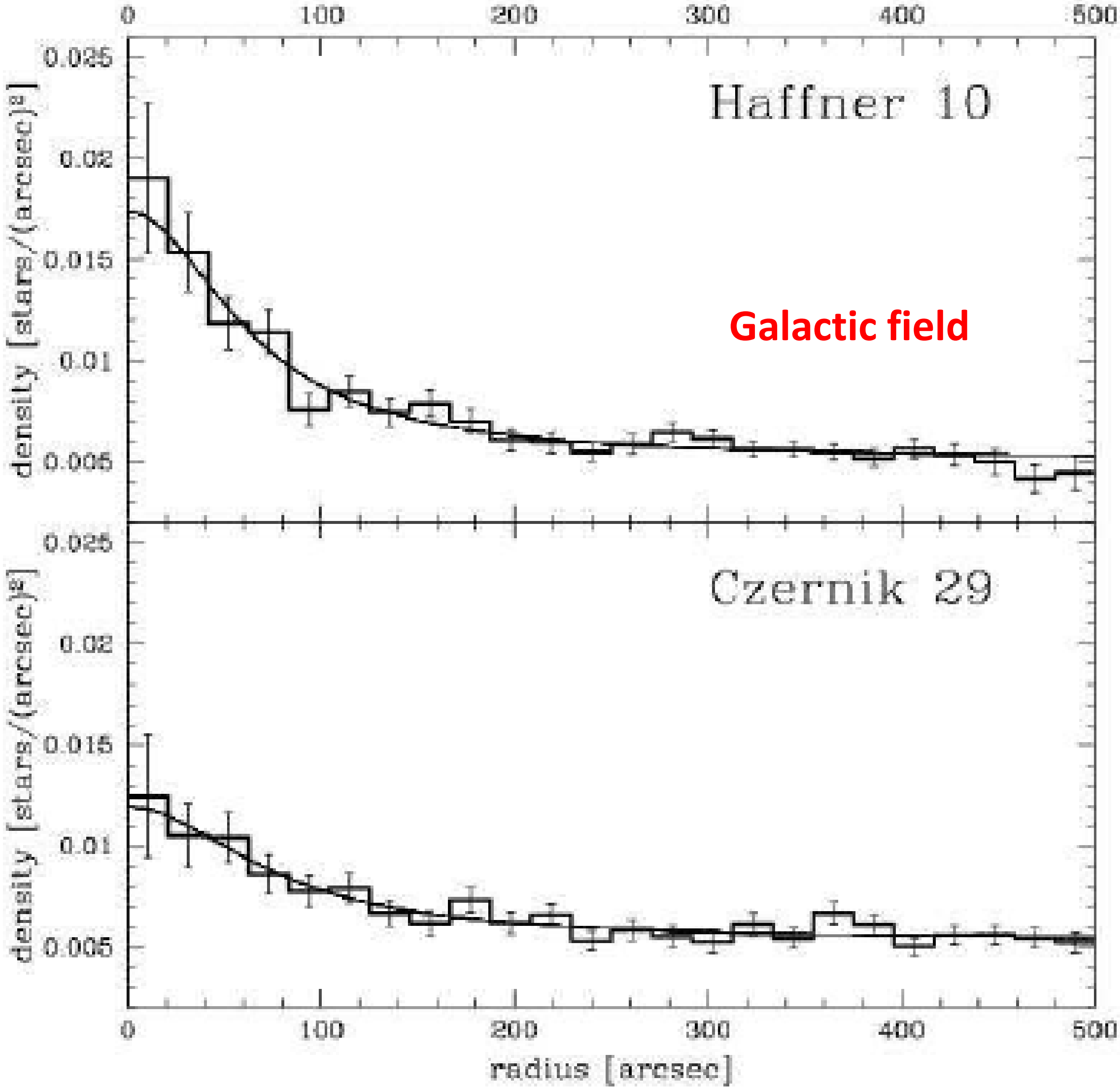
MUO
Kraví hora

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

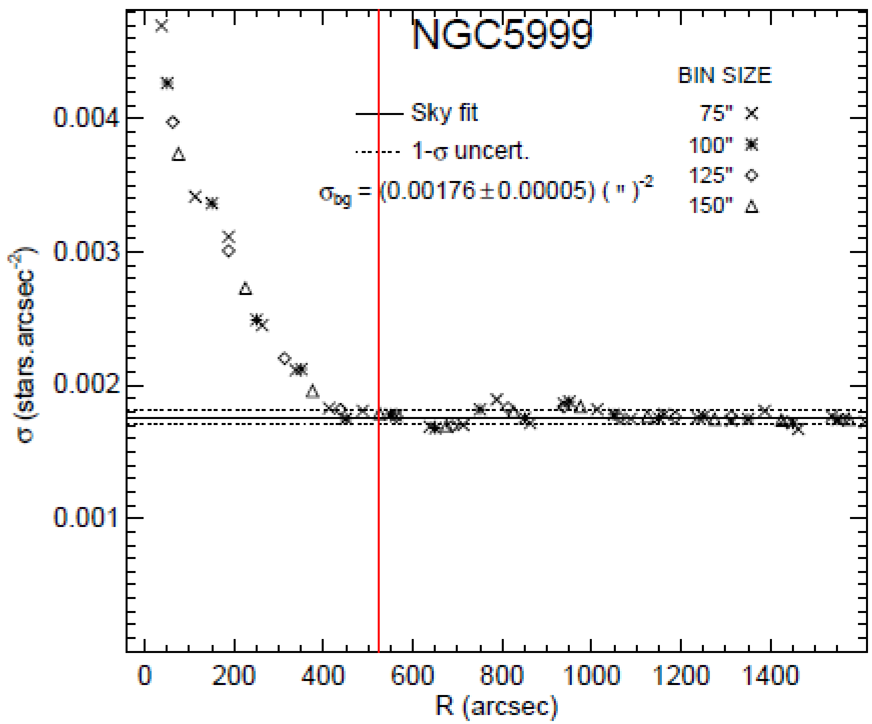
III 2 m

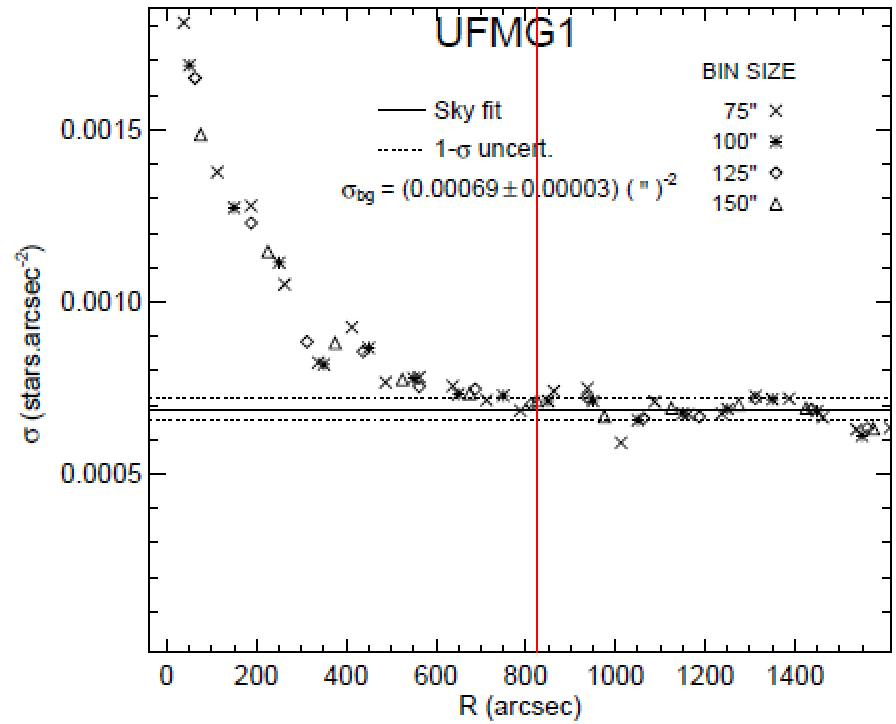
II 2 m



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

Gaia data

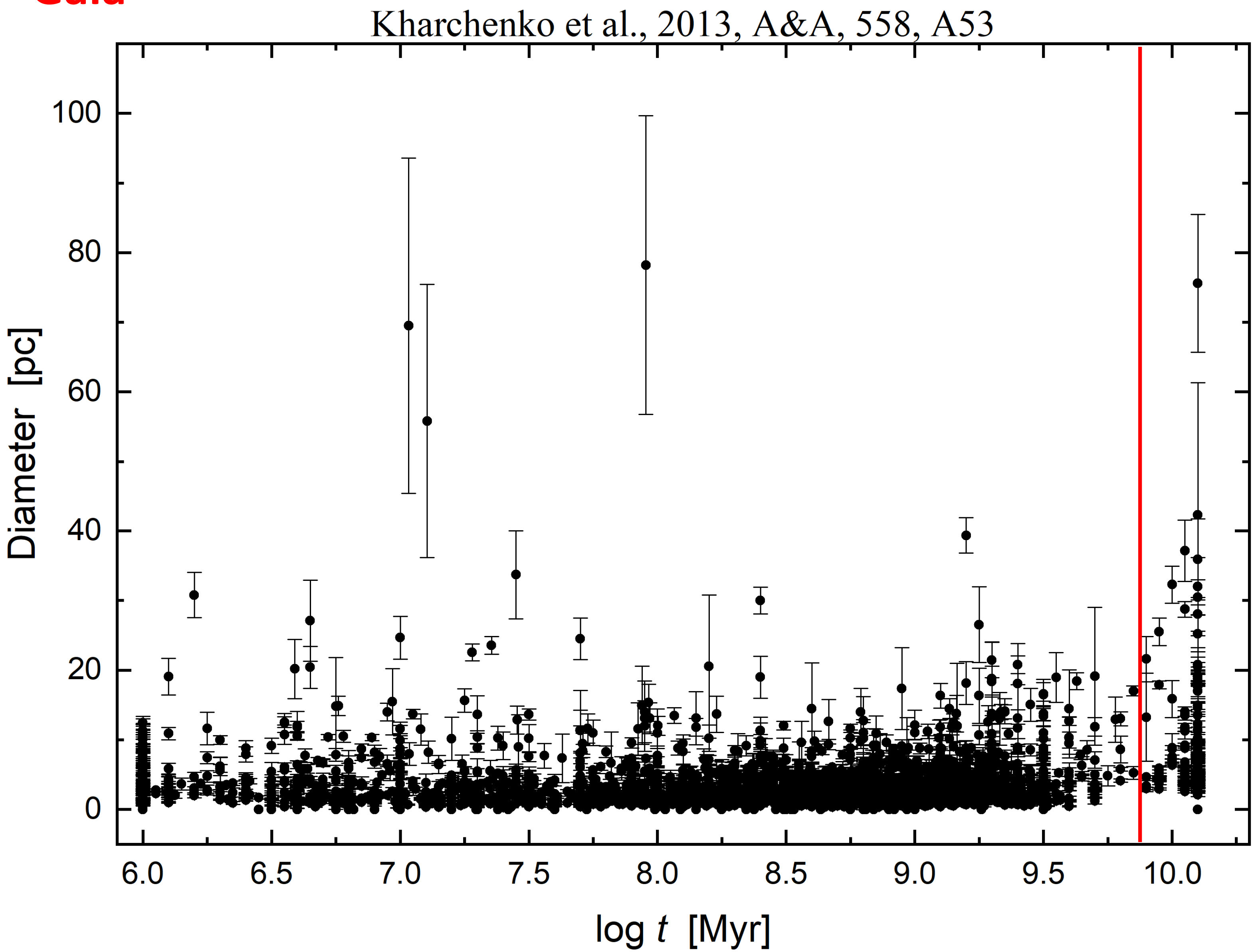




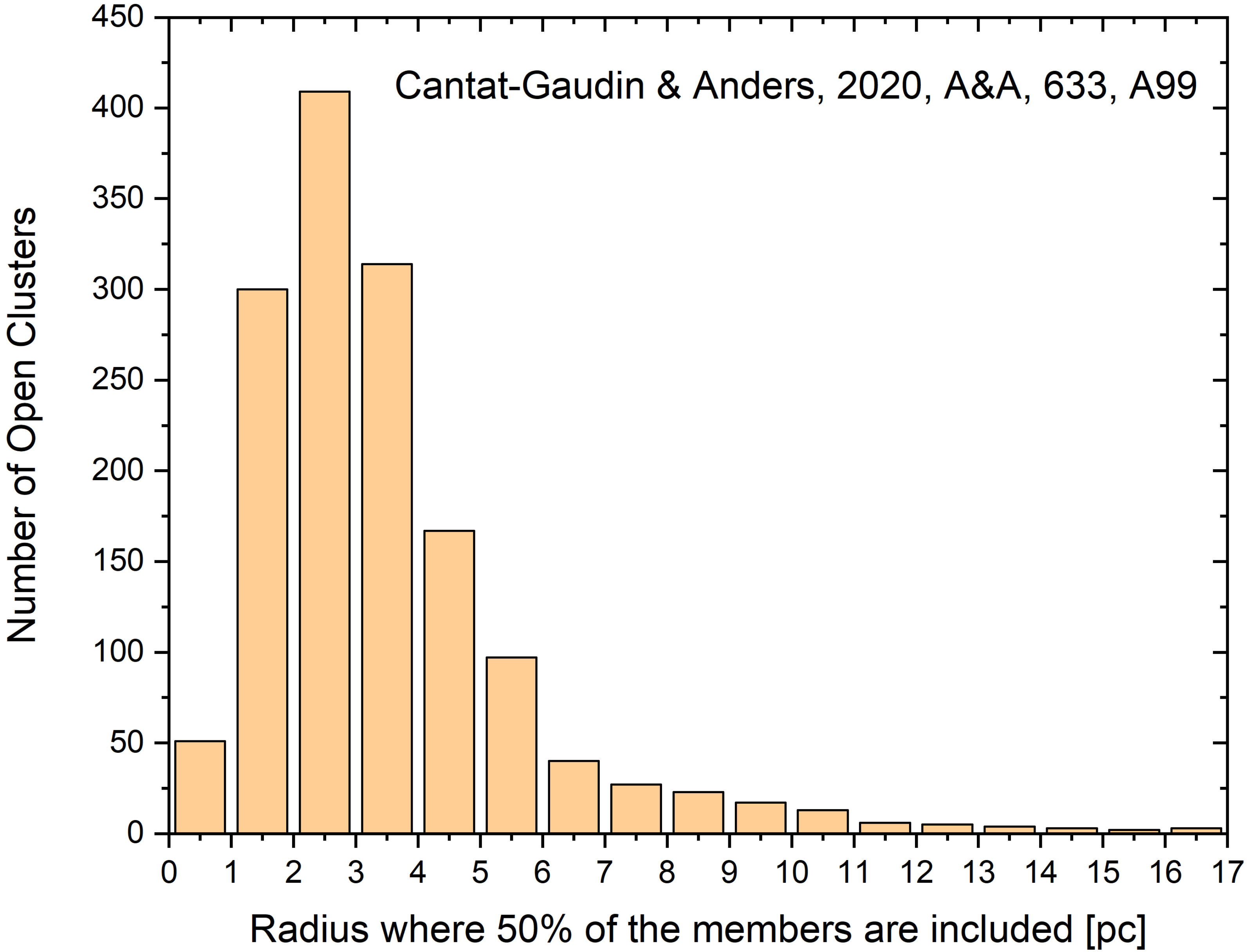
Ferreira et al., 2019, MNRAS, 483, 5508

Diameters of open clusters

Pre - Gaia

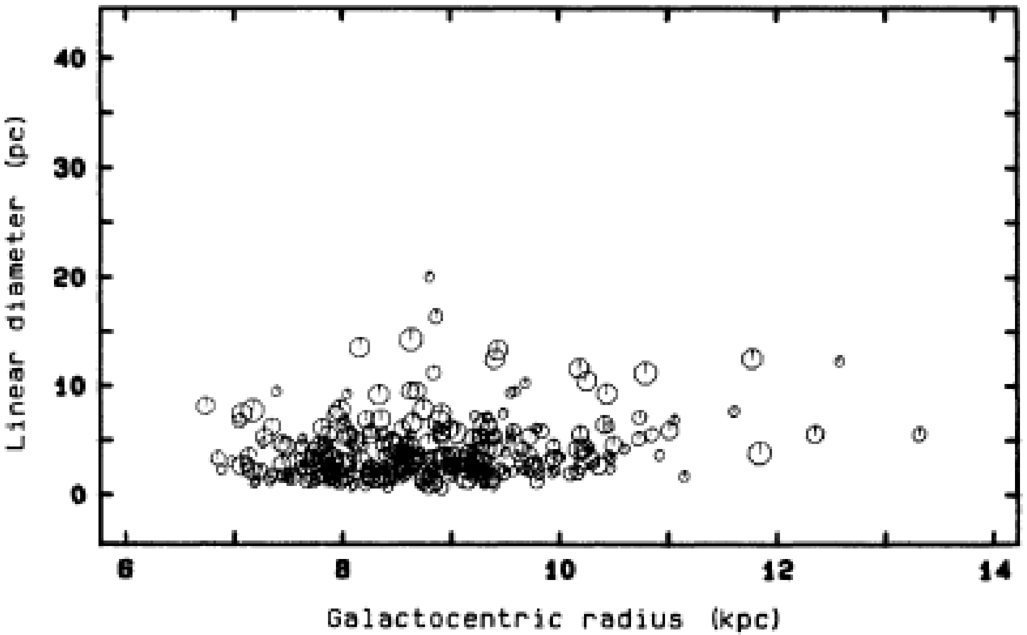


Radii of open clusters

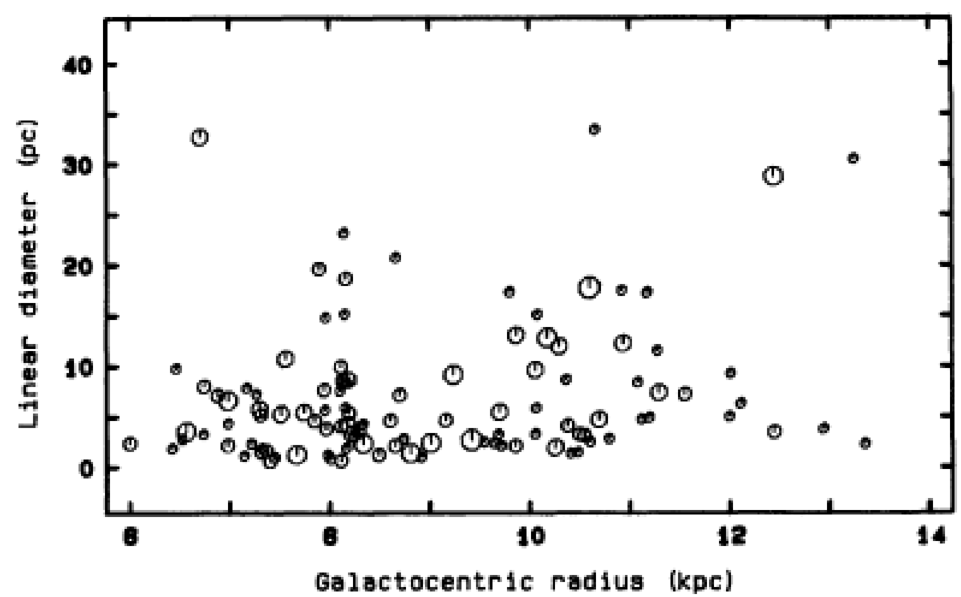


Gaia DR2

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



all



young

Why do Star Clusters dissipate? Differential Galactic Rotation

Total Mass of the Milky Way: $M_{MW} = 2 \cdot 10^{11} \mathrm{M}_{\odot}$

Gravitational acceleration of the complete star cluster g_{OCL} and the individual member g_* :

$$g_{OCL} = \frac{G \cdot M_{MW}}{R_{GC}^2} \quad g_* = \frac{G \cdot M_{OCL}}{(R_{GC} - r)^2}$$

R_{GC} … Distance of the star cluster's centre to the Galactic centre
r … Distance from star to the star cluster's centre

The difference of these two values, is the force, of which "the Milky Way" tries to pull away a star from the cluster

$$g_{MW,*} = \frac{2 \cdot G \cdot M_{MW} \cdot r}{R_{GC}^3} \quad \text{for } \ r \ll R_{GC}$$

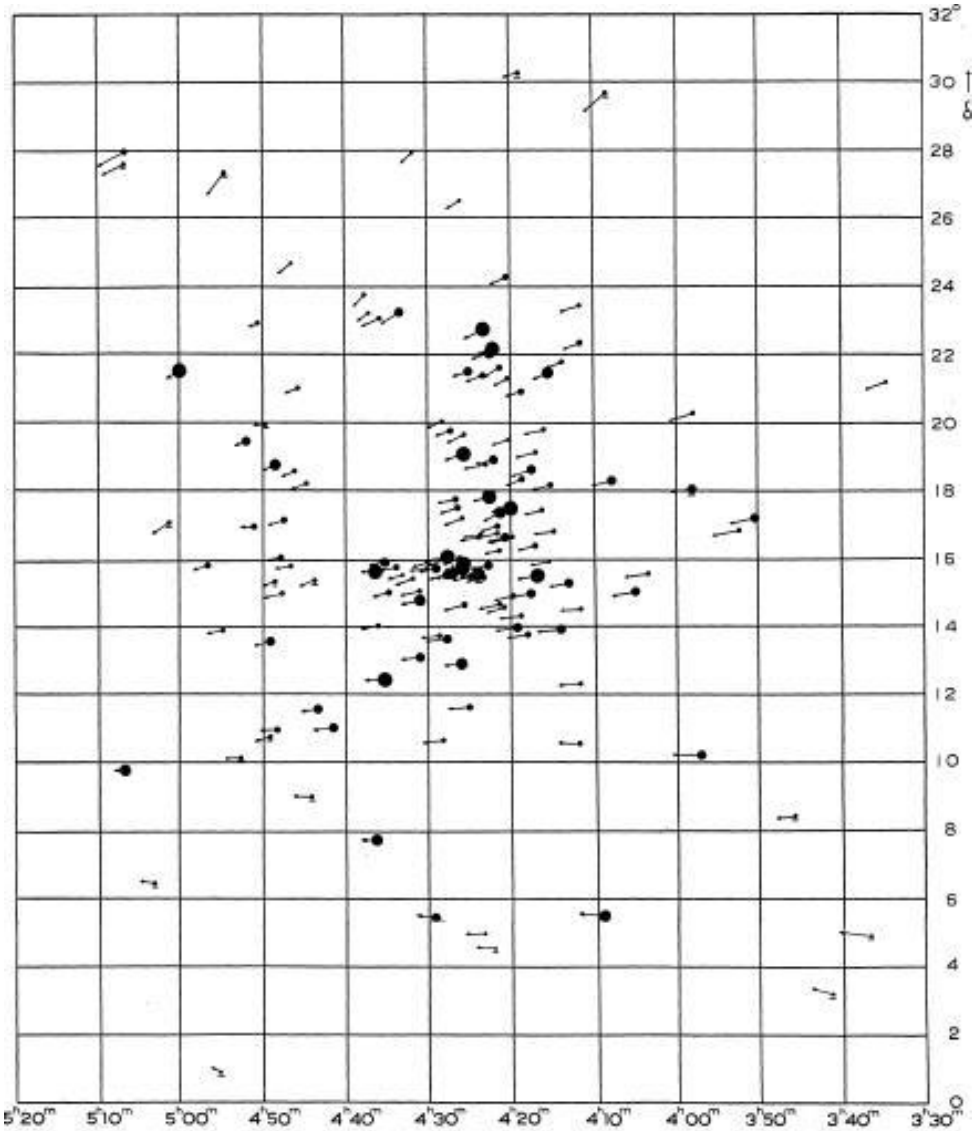
On the other side we have the gravitational force of the star cluster. The stability radius r_s is defined as:

$$\frac{2 \cdot G \cdot M_{MW} \cdot r}{R_{GC}^3} = \frac{G \cdot M_{OCL}}{r_s^2} \quad \Rightarrow \quad r_s = R_{GC} \cdot \left(\frac{M_{OCL}}{2M_{MW}}\right)^{1/3}$$

$$r_s = 10.9 \cdot \left(\frac{M_{OCL}}{1000}\right)^{1/3} \quad \text{for } \ R_{GC} = 8 \text{ kpc in units of } [\mathrm{M}_\odot, \mathrm{pc}]$$

For 1000 $\mathrm{M}_\odot$ => Diameter 20 pc

Common proper motion



Map of the Hyades brighter than $9^m.0$ visual. The size of the dots is a measure for the magnitude of the stars; the arrows show the annual proper motion (1 mm ≈ $0''/^a.030$). Five stars in the very outer regions of the cluster are not shown on the map. Underlined dots indicate stars of which no radial velocity is known.

Hyades

After the correction of the solar motion

Well known but high accuracy especially for distant clusters is needed

Van Bueren, 1952, BAN, 11, 385

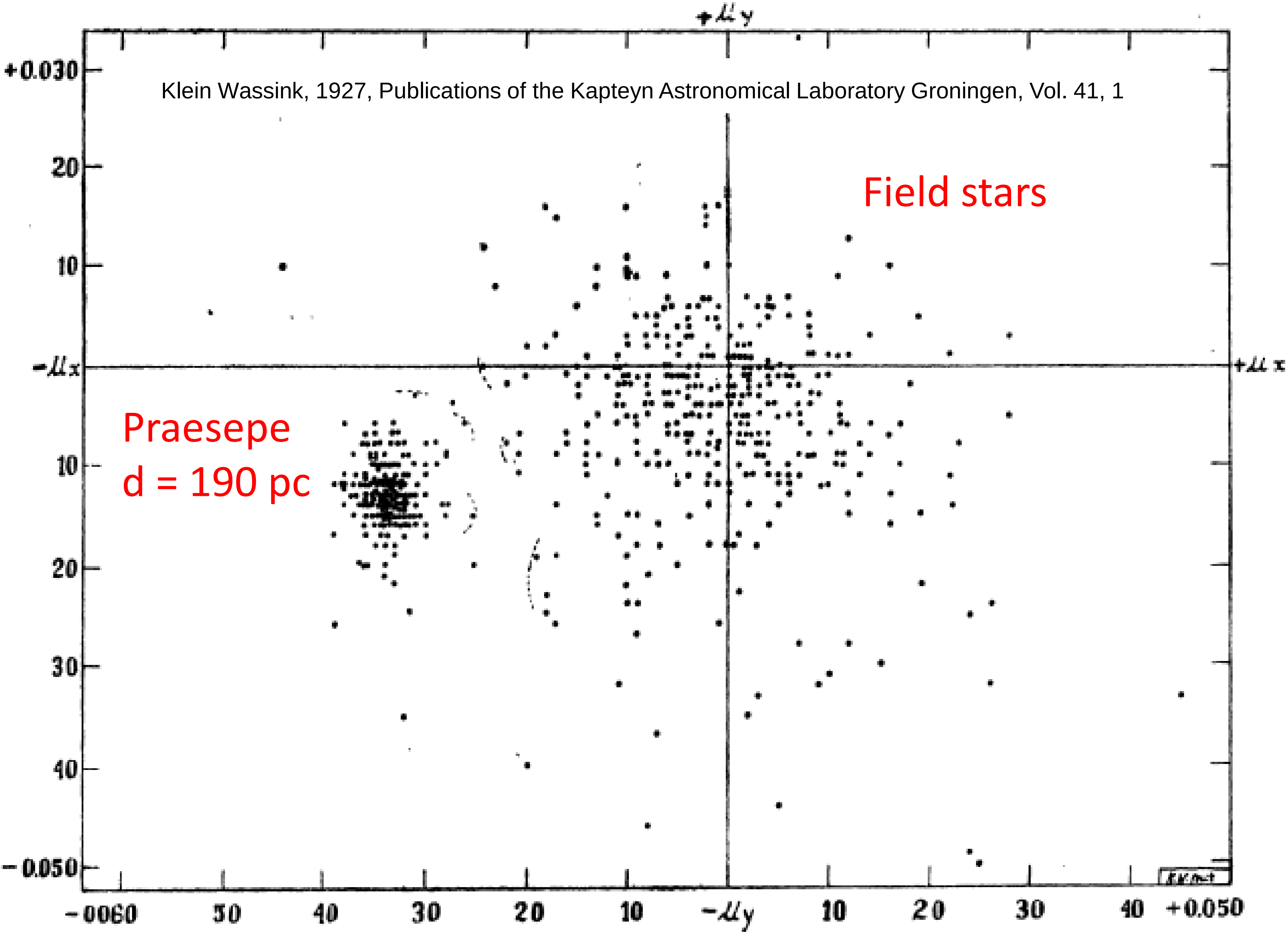
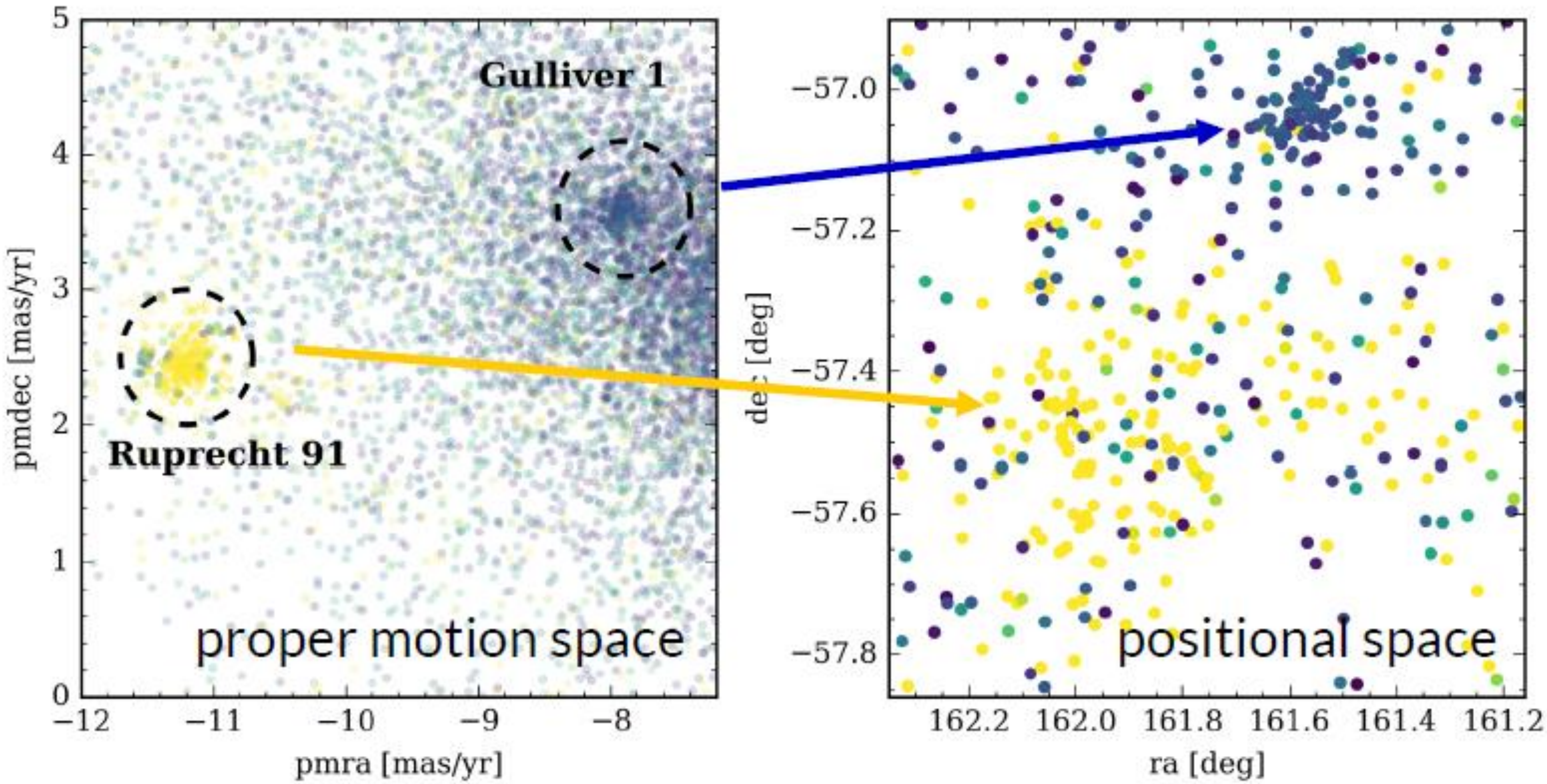


Figure 2. Diagram of the absolute proper motions of the Catalogue; photographic magnitude 6 to 14·0, numbers 1 to 531. The dotted lines separate the Praesepe stars from the backgroundstars.

Common proper motion

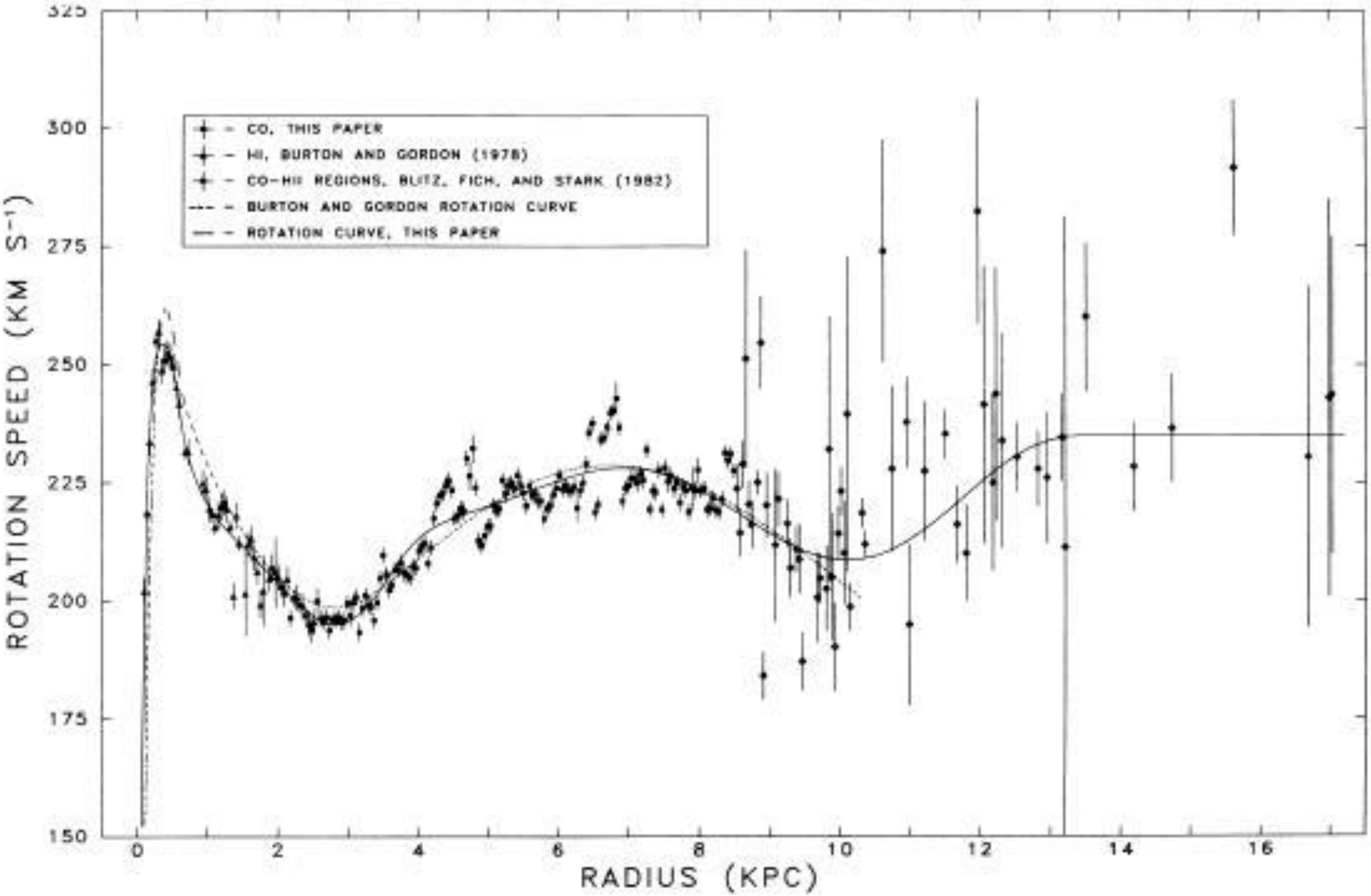


Credit: Tristan Cantat-Gaudin

Dramatic improvement by Gaia even for overlapping star clusters

Kinematical membership criteria

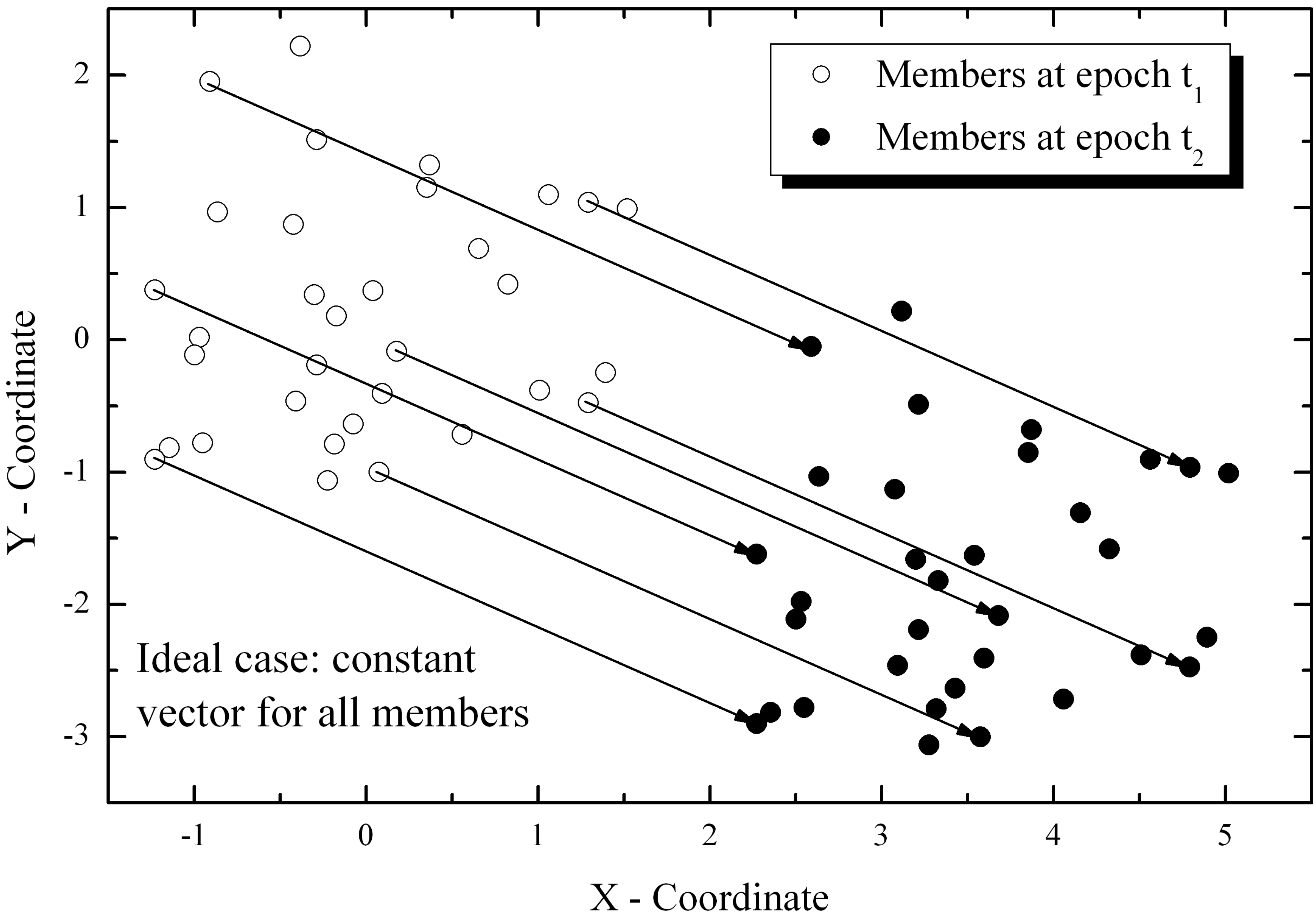
- Members follow the motion of the cluster center of gravity
- Internal velocity distribution
- From best to …
  1. Radial velocity and proper motion
  2. Radial velocity
  3. Proper motion

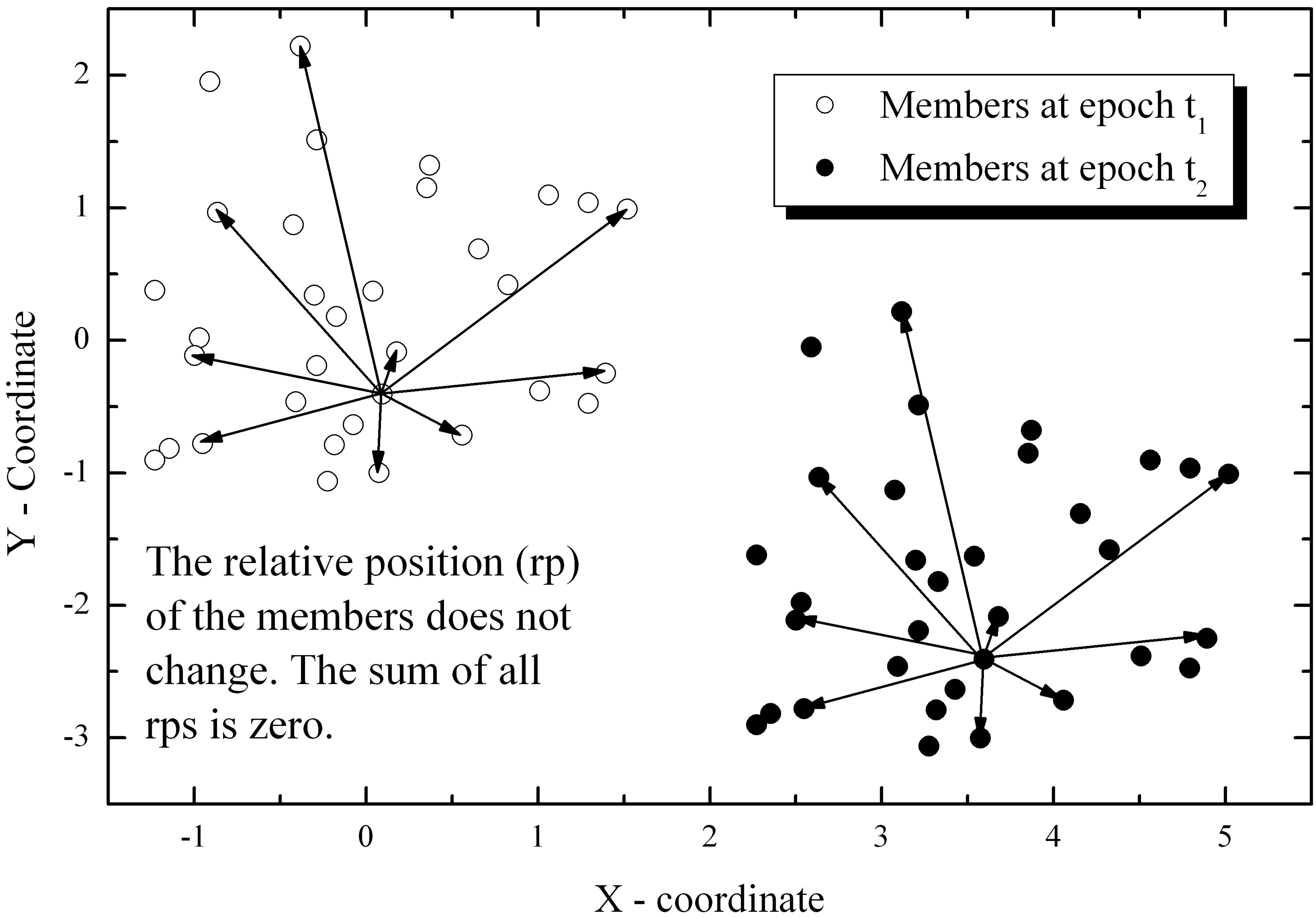


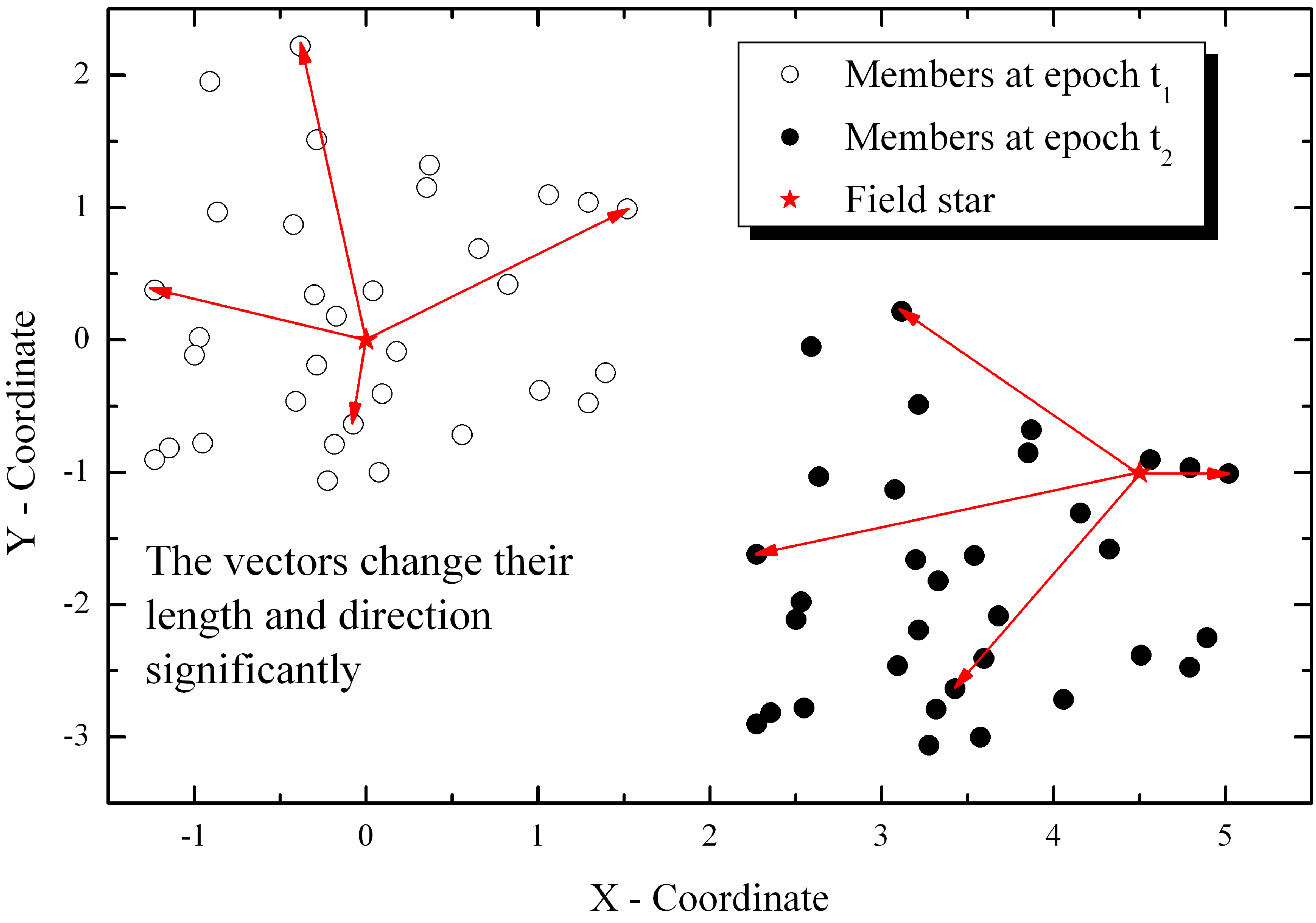
Clemens, 1985, ApJ, 295, 422

Determination of the kinematical membership

- Three possibilities:
  1. Observation of the position at two difference times (= epochs), with a very large time basis. First photographic plates around 1860, largest time scale about 160 years
  2. Proper motions of stars in the direction of the Declination α and Right Ascension δ
  3. Radial velocity measurements


Members at epoch t_1
Members at epoch t_2
Ideal case: constant
vector for all members
Y - Coordinate
X - Coordinate
2
1
0
-1
-2
-3
-1
0
1
2
3
4
5


Members at epoch t_1
Members at epoch t_2
The relative position (rp) of the members does not change. The sum of all rps is zero.
Y - Coordinate
X - coordinate
2
1
0
-1
-2
-3
-1
0
1
2
3
4
5



Members at epoch t1
Members at epoch t2
Field star
The vectors change their length and direction significantly
Y - Coordinate
X - Coordinate
2
1
0
-1
-2
-3
-1
0
1
2
3
4
5

- Calculate the absolute distance in X and Y for both epochs and each star individually

$$S'_{x_i} = \sum_{j=1}^{N} (x'_i - x'_j), \qquad S'_{y_i} = \sum_{j=1}^{N} (y'_i - y'_j). \qquad (4)$$

$$S''_{x_i} = \sum_{j=1}^{N} (x''_i - x''_j), \qquad S''_{y_i} = \sum_{j=1}^{N} (y''_i - y''_j). \qquad (5)$$

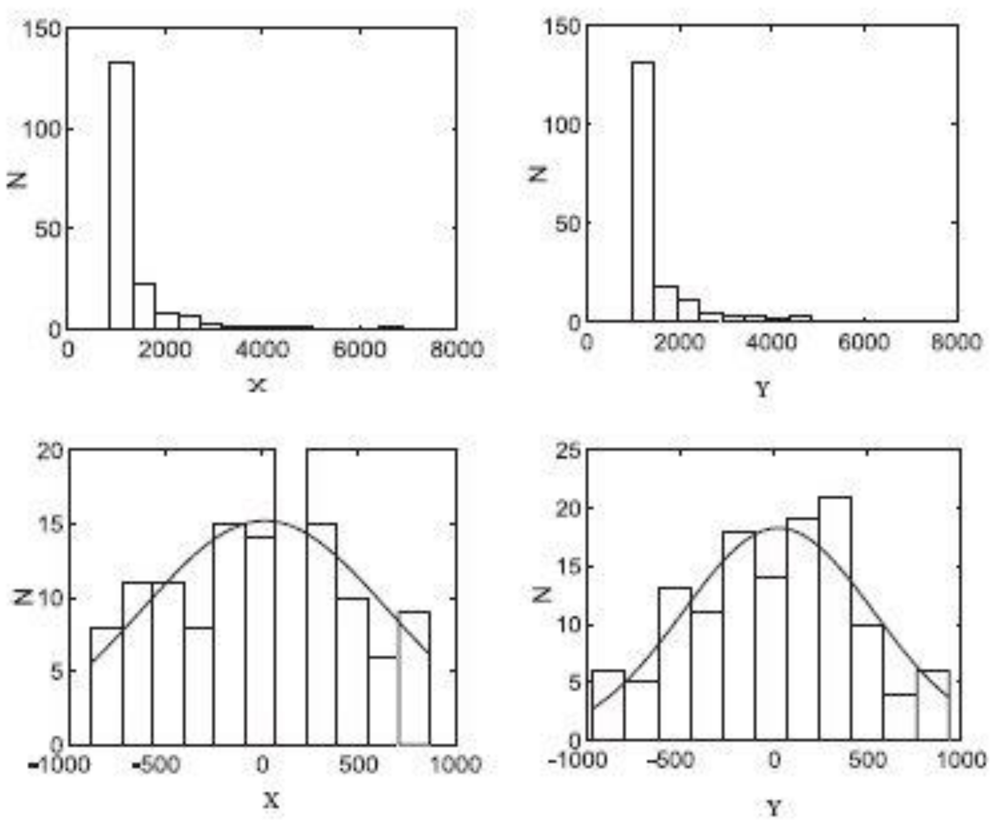
- Plot the histograms of the differences of the absolute distances
- The distributions are fitted with Gaussian functions

$$f(x) = \frac{A_x}{w_x\sqrt{\pi/2}} e^{-2\left(\frac{x-x_0}{\sigma_x}\right)^2}, \qquad f(y) = \frac{A_y}{w_y\sqrt{\pi/2}} e^{-2\left(\frac{y-y_0}{\sigma_y}\right)^2}, \qquad (6)$$

- The probability p, if a star is member of the star cluster is defined as

$$p_x = \mathrm{e}^{-2\left(\frac{x-x_0}{\sigma_x}\right)^2}, \qquad p_y = \mathrm{e}^{-2\left(\frac{y-y_0}{\sigma_y}\right)^2}. \qquad (7)$$

$$p = p_x * p_y. \qquad (8)$$



Javakhishvili et al. (2006, A&A, 447, 915) for Collinder 121

From these diagrams, the membership probability can be exactly determined