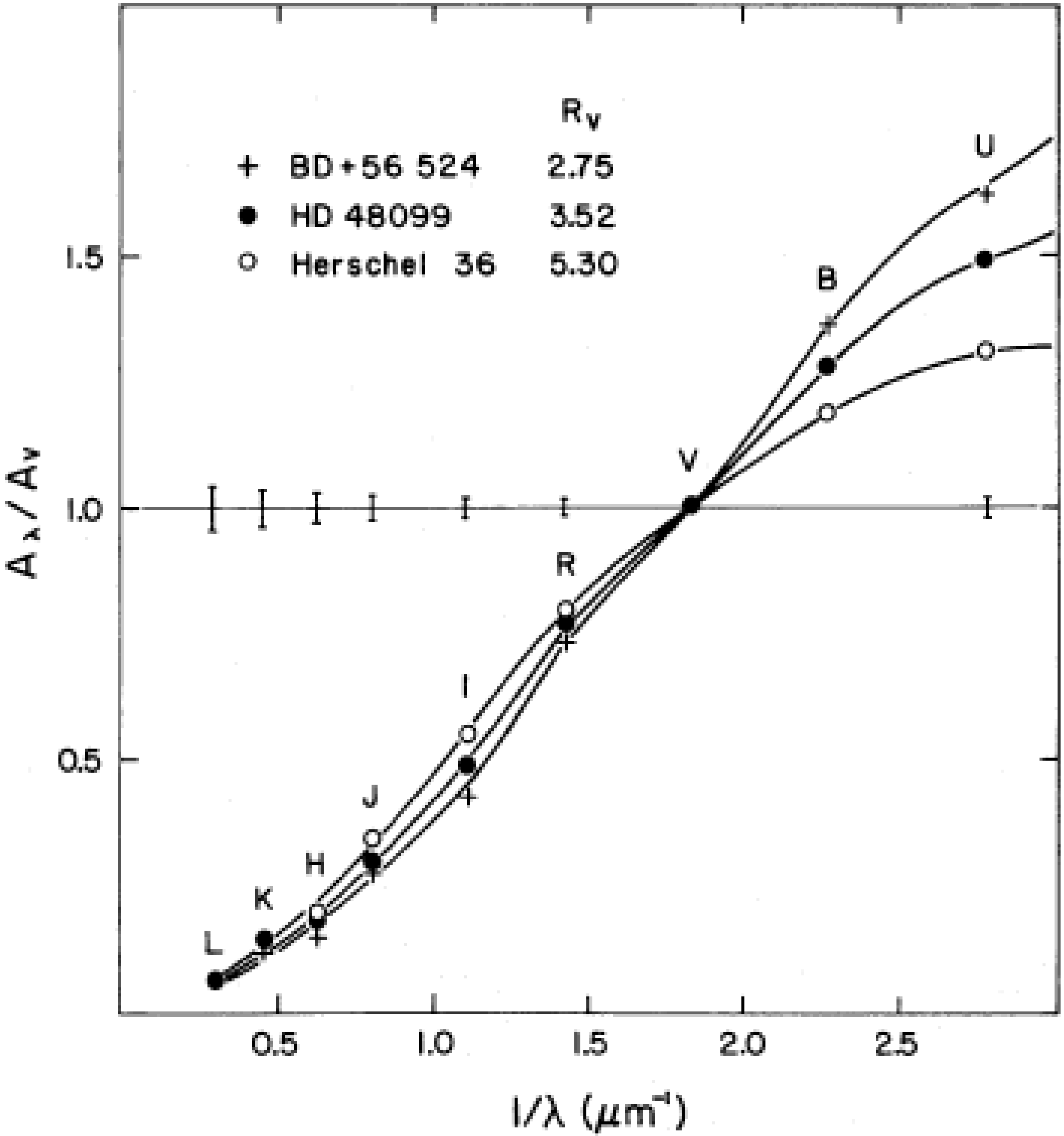
Extinction = Absorption = Reddening

- General extinction because of the ISM characteristics between the observer and the object
- Differential extinction within one star cluster because of local environment
- Both types are, in general wavelength dependent

Reasons for the interstellar extinction

- Light scatter at the interstellar dust
- Light absorption => Heating of the ISM
- Depending on the composition and density of the ISM
- Main contribution due to dust
- Simulations and calculations in Cardelli et al., 1989, ApJ, 345, 245

Cardelli et al., 1989, ApJ, 345, 245



Important parameter:

$R_V = A_V/E(B-V)$

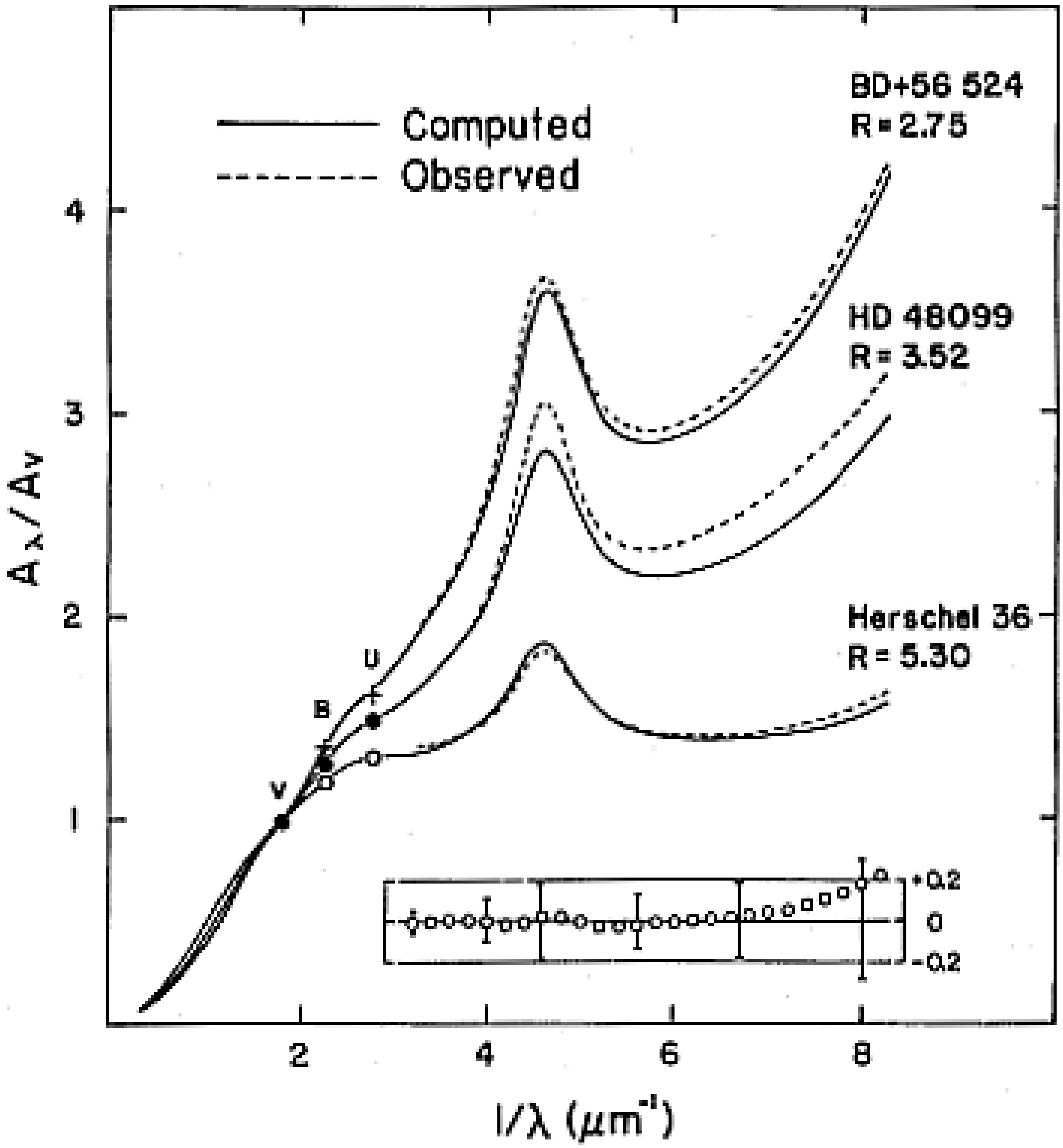
Normalization factor

Standard value used is 3.1

Be careful, different values used!

Depending on the line of sight

Cardelli et al., 1989, ApJ, 345, 245



Dependency of the extinction from R_V

How to derive the reddening?

- From photometric and spectroscopic observations

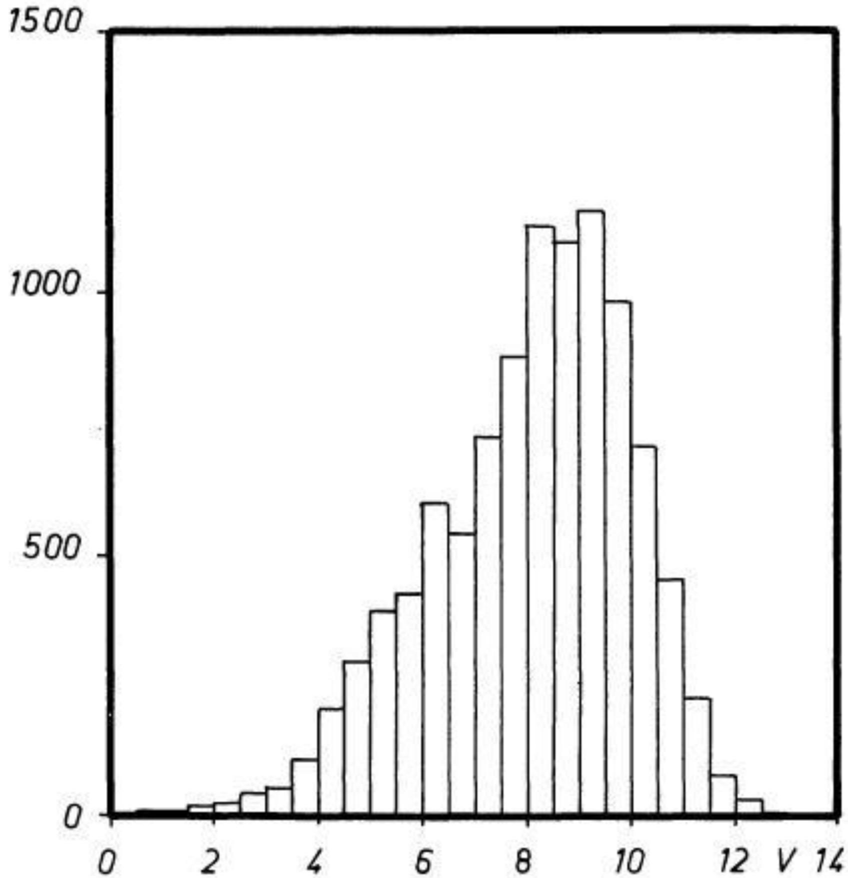


FIGURE 2. — Distribution of the stars *versus* apparent *V*-magnitude.

Classical approach: Neckel & Klare, 1980, A&AS,42, 251

Take all available UBV and Strömgren β photometry

MK classifications

4. **Extinction values and distances.** — The visual extinction A_v can be derived from

$$A_v = R\{(B - V) - (B - V)_0\}. \qquad (2)$$

For R we take the value 3.1.

The intrinsic color $(B\text{-}V)_0$ follows directly from the MK calibration, if the MK type is known. In addition, $(B\text{-}V)_0$ can also be derived from the UBV and β data. The distance moduli are then given by

$$V - M_v - A_v = 5 \lg r - 5. \qquad (3)$$

If we could derive A_v and r by both methods, we could use the mean values of extinction and distance moduli. This was possible for 1 020 stars. Figure 4 shows the frequency distribution of the differences

$$D = (V - M_v(\mathrm{MK}) - A_v(UBV, \mathrm{MK})) - $$
$$- (V - M_v(\beta) - A_v(UBV, \beta)). \qquad (4)$$

Bailer-Jones, 1996, PhD, Cambridge University

SpT	Spectral Type	II	II/III	III	III/IV	IV	IV/V	V
1	O3	-	-	-	-	-	-	-
2	O4	-	-	-	-	-	-	-
3	O5	-8.20	-7.70	-7.20	-6.80	-6.40	-5.90	-5.60
4	O6	-7.60	-7.20	-6.85	-6.50	-6.10	-5.70	-5.40
5	O7	-7.00	-6.80	-6.60	-6.30	-5.90	-5.50	-5.20
6	O8	-6.50	-6.30	-6.20	-5.90	-5.60	-5.30	-5.00
7	O9	-6.00	-5.85	-5.70	-5.50	-5.30	-5.00	-4.70
8	B0	-5.40	-5.20	-5.00	-4.90	-4.80	-4.50	-4.20
9	B1	-5.00	-4.70	-4.40	-4.20	-4.00	-3.80	-3.60
10	B2	-4.80	-4.20	-3.60	-3.35	-3.10	-2.80	-2.50
11	B3	-4.60	-3.85	-3.10	-2.80	-2.50	-2.10	-1.70
12	B4	-4.50	-3.57	-2.55	-2.40	-2.15	-1.75	-1.35
13	B5	-4.40	-3.30	-2.20	-2.00	-1.80	-1.40	-1.00
14	B6	-4.20	-3.05	-1.90	-1.70	-1.50	-1.20	-0.70
15	B7	-4.00	-2.80	-1.60	-1.40	-1.20	-0.80	-0.40
16	B8	-3.80	-2.60	-1.00	-0.85	-0.70	-0.35	0.00
17	B9	-3.60	-2.45	-0.40	-0.30	-0.20	0.15	0.50
18	A0	-3.20	-1.90	0.10	0.20	0.30	0.65	1.00
19	A1	-3.00	-1.75	0.50	0.60	0.70	1.00	1.30
20	A2	-2.90	-1.65	0.70	0.85	1.00	1.30	1.60
21	A3	-2.80	-1.60	0.90	1.05	1.20	1.40	1.80
22	A4	-2.80	-1.55	1.05	1.15	1.30	1.63	1.95
23	A5	-2.70	-1.50	1.10	1.25	1.40	1.75	2.10

Assume V = 10 mag and no reddening

O5: -5.6 => 13 000 pc
A0: +1.0 => 630 pc
G0: +4.5 => 125 pc
M0: +8.9 => 15 pc

Assume V = 20 mag and no reddening

O5: -5.6 => 1.3 Mpc
A0: +1.0 => 63 kpc
G0: +4.5 => 12.5 kpc
M0: +8.9 => 1.5 kpc

24	A6	-2.65	-1.45	1.15	1.35	1.60	1.95	2.30
25	A7	-2.60	-1.40	1.20	1.50	1.80	2.10	2.40
26	A8	-2.60	-1.40	1.30	1.65	2.05	2.25	2.50
27	A9	-2.55	-1.35	1.40	1.75	2.10	2.35	2.60
28	F0	-2.50	-1.30	1.50	1.85	2.20	2.45	2.70
29	F2	-2.50	-1.30	1.60	2.00	2.40	2.75	3.10
30	F3	-2.40	-1.20	1.65	2.10	2.45	2.90	3.35
31	F5	-2.30	-1.10	1.70	2.10	2.50	3.05	3.60
32	F6	-2.25	-1.05	1.75	2.15	2.55	3.18	3.80
33	F7	-2.20	-1.00	1.75	2.15	2.60	3.30	4.00
34	F8	-2.20	-1.00	1.75	2.20	2.80	3.50	4.20
35	G0	-2.10	-0.95	1.70	2.15	2.90	3.70	4.45
36	G1	-2.05	-0.90	1.70	2.10	3.00	3.80	4.70
37	G2	-2.00	-0.90	1.60	2.10	3.00	3.90	4.80
38	G3	-2.00	-0.85	1.60	2.05	3.05	4.00	5.00
39	G5	-2.00	-0.85	1.60	2.00	3.10	4.15	5.20
40	G6	-2.00	-0.80	1.50	2.00	3.15	4.23	5.30
41	G8	-2.00	-0.80	1.35	1.95	3.20	4.35	5.50
42	K0	-2.00	-0.80	1.20	1.87	3.20	4.50	5.80
43	K1	-2.00	-0.85	1.00	1.80	3.30	4.70	6.10
44	K2	-2.00	-0.90	0.80	1.80	3.30	4.80	6.30
45	K3	-2.00	-1.00	0.60	1.80	3.40	5.00	6.60
46	K4	-2.10	-1.00	0.20	-	-	-	6.90
47	K5	-2.20	-1.00	0.00	-	-	-	7.50
48	M0	-2.40	-1.00	-1.10	-	-	-	8.90
49	M1	-2.50	-1.10	-0.40	-	-	-	9.60
50	M2	-2.50	-1.10	-0.60	-	-	-	10.30
51	M3	-2.50	-1.20	-0.70	-	-	-	10.80
52	M4	-2.50	-1.20	-0.80	-	-	-	11.40
53	M5	-2.50	-1.30	-0.90	-	-	-	12.30
54	M6	-2.50	-1.30	-1.00	-	-	-	13.20
55	M7	-2.50	-1.40	-1.10	-	-	-	14.00
56	M8	-2.50	-1.50	-1.20	-	-	-	16.50
57	M9	-	-	-	-	-	-	-

TABLE V. The $M_v(\beta)$ calibration.

β (mag)	$M_v(\beta)$ (mag)	β (mag)	$M_v(\beta)$ (mag)
2.560	−6.51	2.720	−0.27
2.570	−5.84	2.730	−0.10
2.580	−5.22	2.740	0.04
2.590	−4.65	2.750	0.18
2.600	−4.12	2.760	0.30
2.610	−3.62	2.770	0.41
2.620	−3.17	2.780	0.51
2.630	−2.75	2.790	0.60
2.640	−2.36	2.800	0.68
2.650	−2.01	2.810	0.76
2.660	−1.69	2.820	0.83
2.670	−1.39	2.830	0.90
2.680	−1.12	2.840	0.97
2.690	−0.87	2.850	1.03
2.700	−0.65	2.860	1.10
2.710	−0.45	2.870	1.17
		2.880	1.24
		2.890	1.31
		2.900	1.39

Crawford, 1976, AJ, 83, 48

Example for the β index

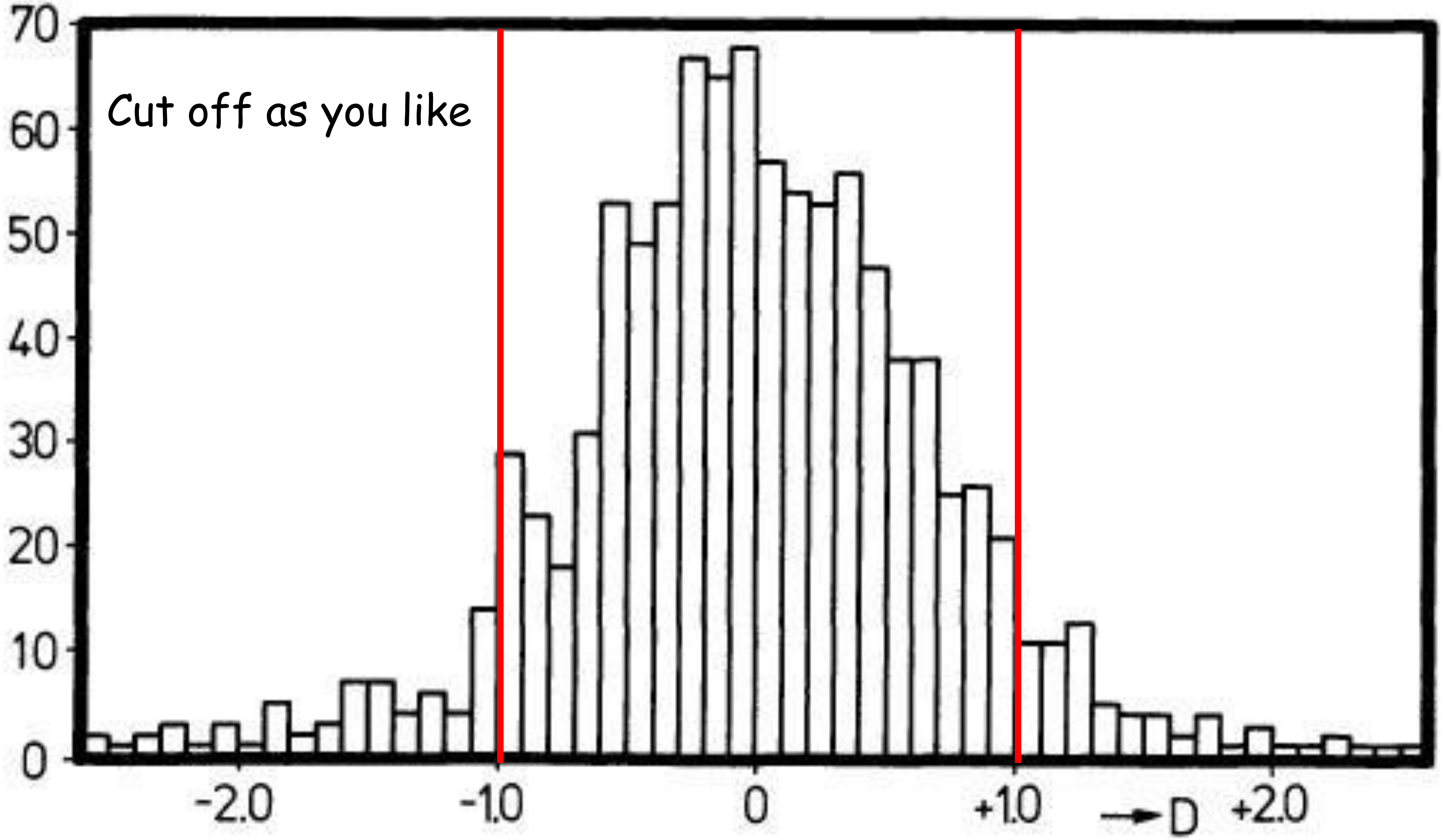


FIGURE 4. — Frequency distribution of the differences between the distance moduli derived from *UBV* + MK and *UBV* + β data.

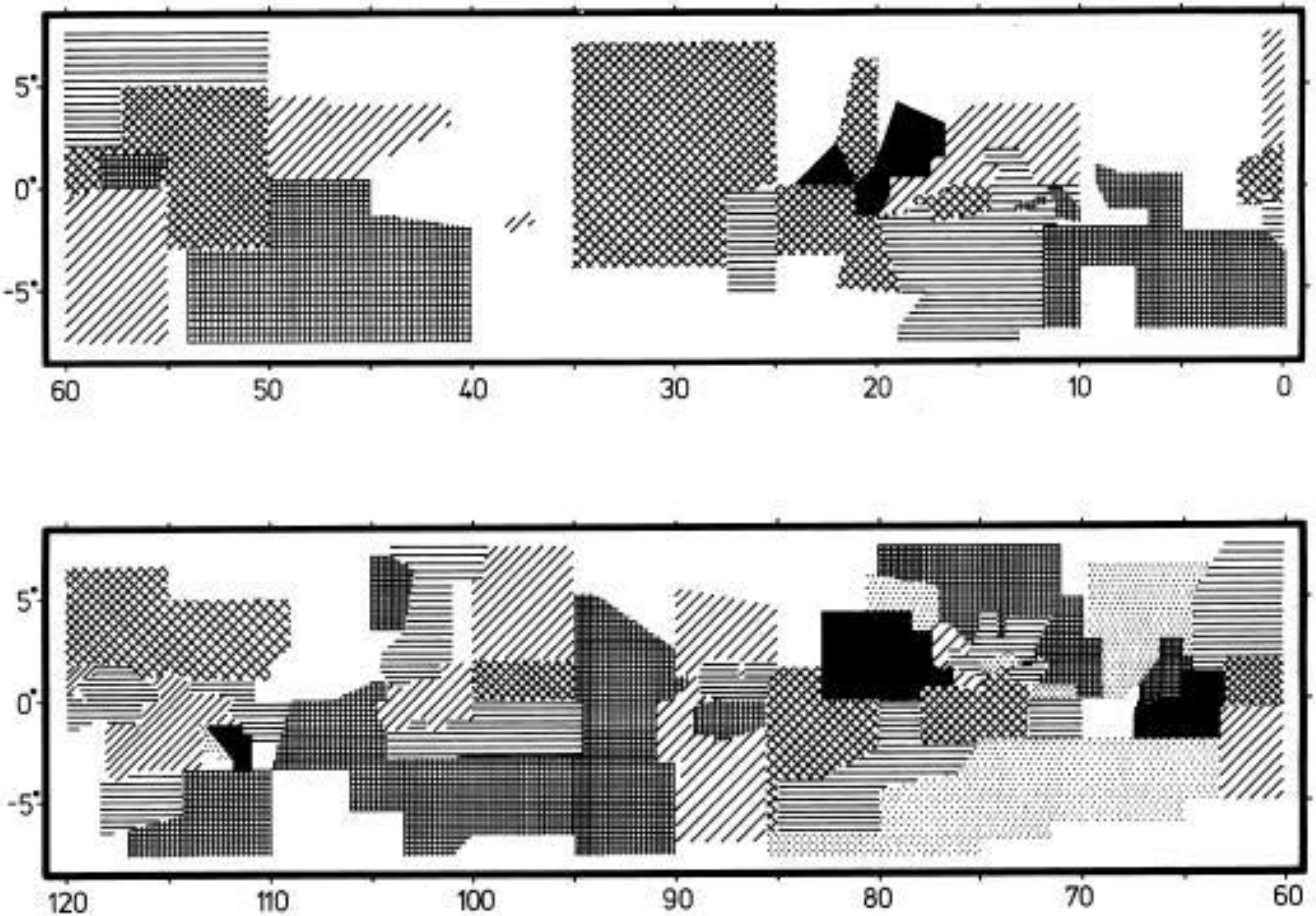
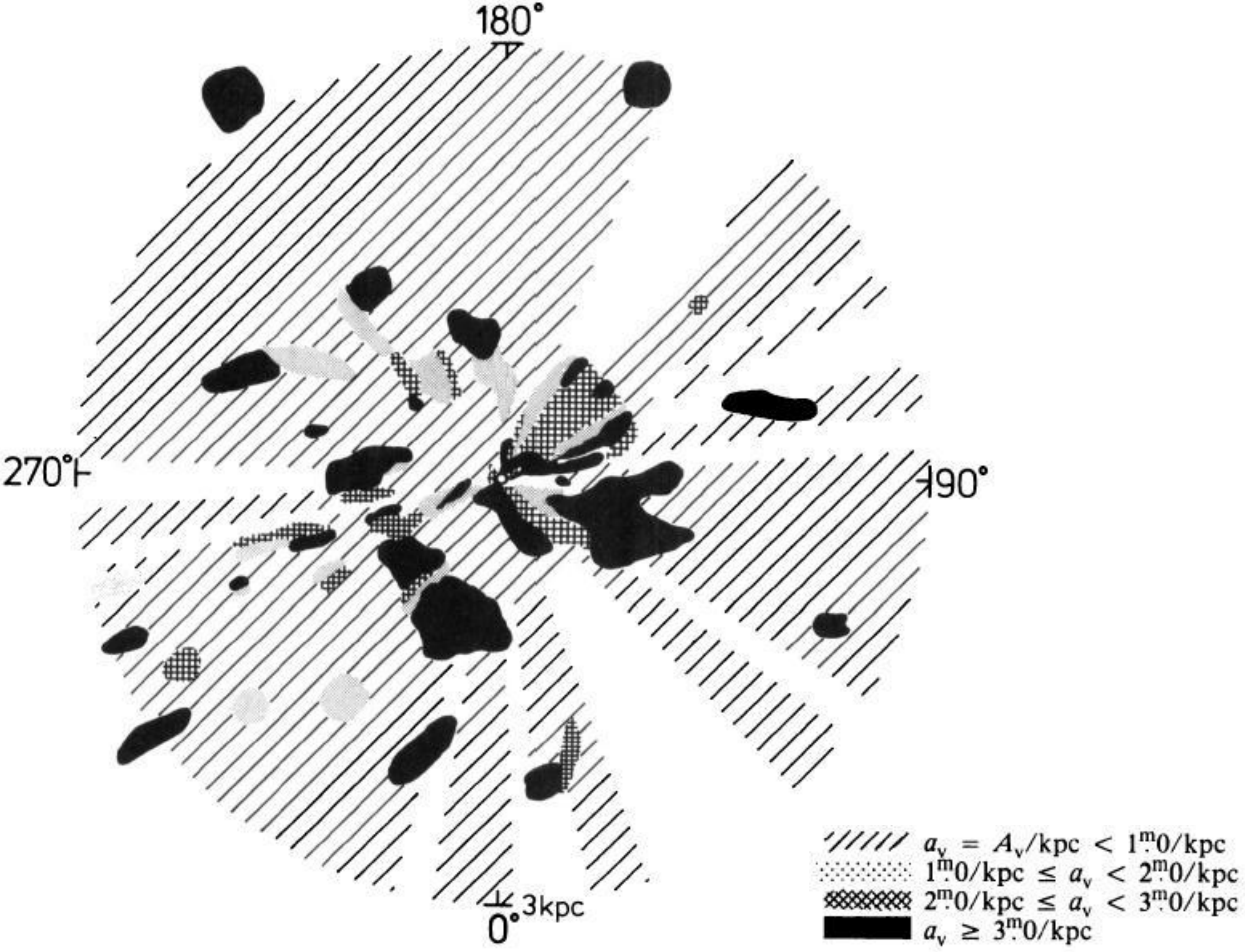
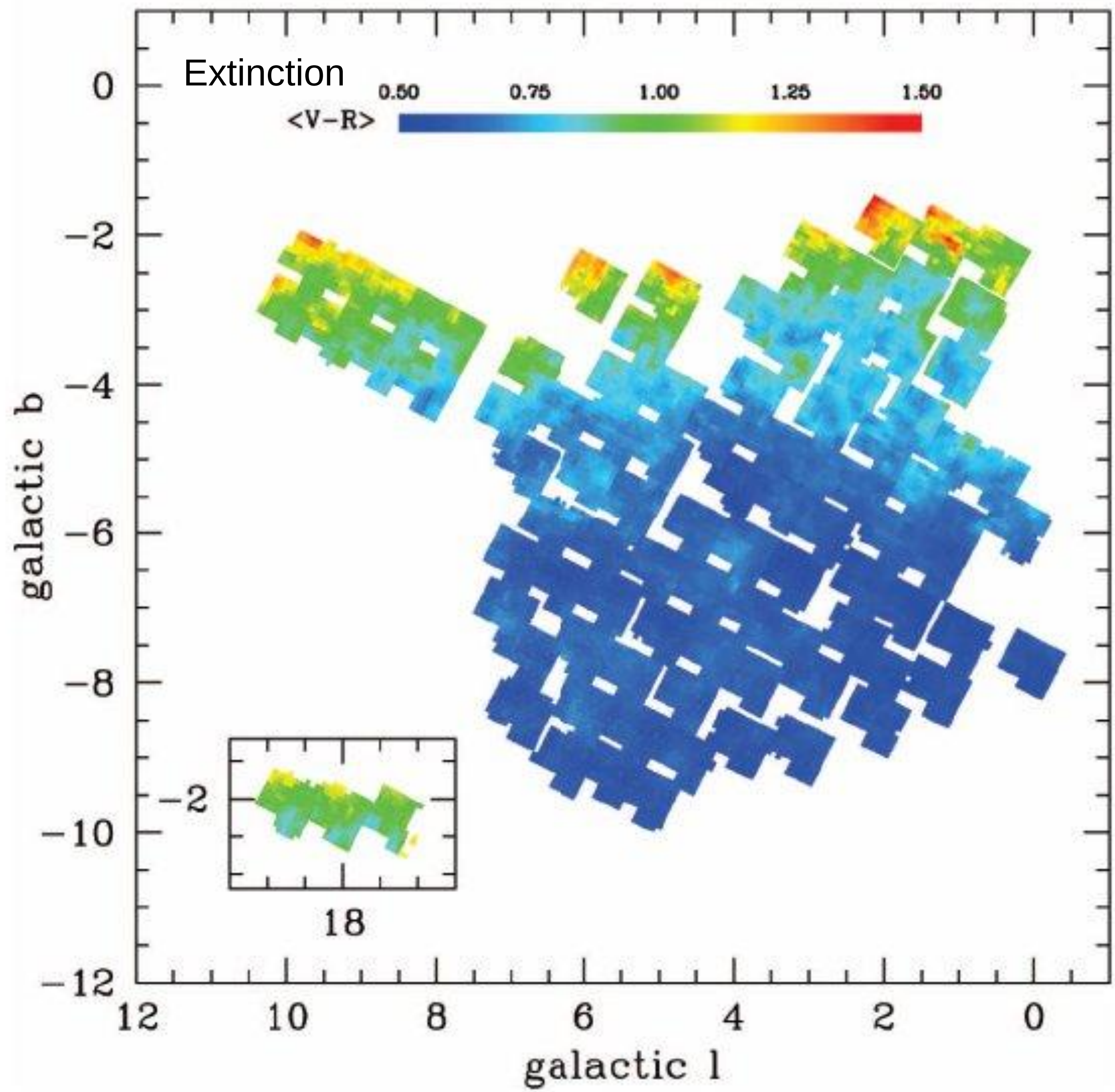
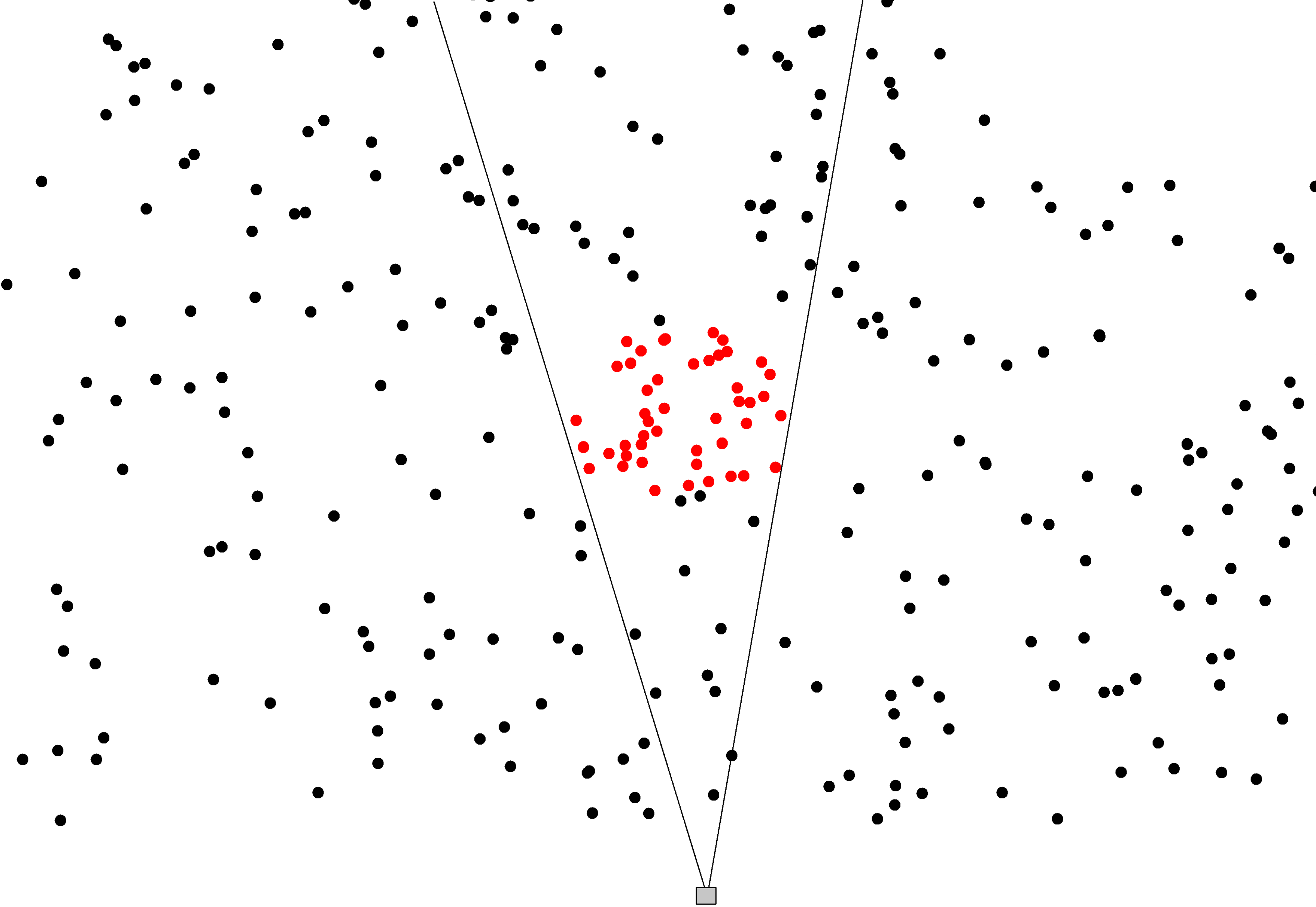


FIGURE 8. — The extinction at r = 1 kpc in the Milky Way.


180°
270°
90°
0°
3kpc
$a_V = A_V/\mathrm{kpc} < 1^m\!.0/\mathrm{kpc}$
$1^m\!.0/\mathrm{kpc} \le a_V < 2^m\!.0/\mathrm{kpc}$
$2^m\!.0/\mathrm{kpc} \le a_V < 3^m\!.0/\mathrm{kpc}$
$a_V \ge 3^m\!.0/\mathrm{kpc}$



Popowski et al., 2003, AJ, 126, 2910



- The absolute diameters are "constant", to about 20 pc
  1. 100 pc: 680′
  2. 1 000 pc: 68′
  3. 50 000 pc: 1.38′

- For near clusters => background
- For "intermediate" clusters => foreground + background
- For distant clusters => foreground

New all-sky surveys

- With all-sky surveys we are able to determine extinction maps in a statistical way
- Several filters in several wavelength regions are needed, for example
  - 2MASS: JHKs
  - UCAC-3: BVR
  - Gaia: filters?
  - More to come

Froebrich & del Burgo, 2006, MNRAS, 369, 2901

The most simple approach of a colour excess method is to measure the apparent brightness of a star at two different wavelengths, m_{λ_1} and m_{λ_2}, and compare the colour $m_{\lambda_1} - m_{\lambda_2}$ with the theoretical value for main-sequence stars or the colour of stars measured in an extinction-free control field $m^{\mathrm{tr}}_{\lambda_1} - m^{\mathrm{tr}}_{\lambda_2}$ (e.g. Lada et al. 1994). The colour excess $\langle\lambda_1 - \lambda_2\rangle$ is defined as

$$\langle\lambda_1 - \lambda_2\rangle \equiv (m_{\lambda_1} - m_{\lambda_2}) - \left(m^{\mathrm{tr}}_{\lambda_1} - m^{\mathrm{tr}}_{\lambda_2}\right). \quad (7)$$

If we assume that this colour excess is entirely due to extinction and, as for the star count analysis, a constant β is valid, we can determine the extinction at λ_2 by

$$A_{\lambda_2} = \frac{\langle\lambda_1 - \lambda_2\rangle}{(\lambda_2/\lambda_1)^{\beta} - 1}. \quad (8)$$

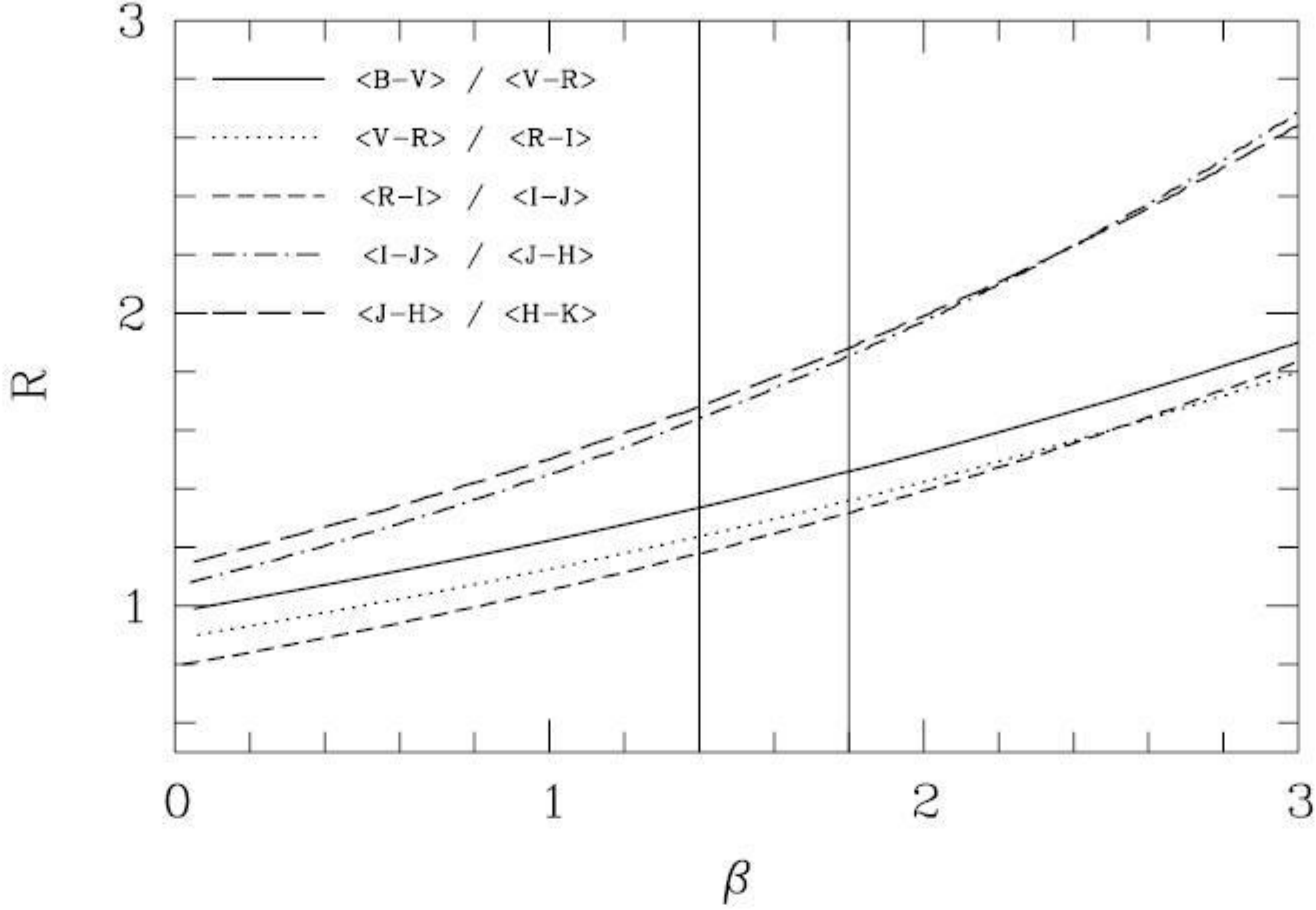
Measuring $\langle \lambda_2 - \lambda_3 \rangle$, with $\lambda_1 < \lambda_2 < \lambda_3$, we as well can determine the extinction at λ_2:

$$A_{\lambda_2} = \frac{\langle \lambda_2 - \lambda_3 \rangle}{1 - (\lambda_3/\lambda_2)^{-\beta}}. \tag{9}$$

The right-hand side of both equations should essentially give the same value. We can define the colour excess ratio $R \equiv \langle \lambda_1 - \lambda_2 \rangle / \langle \lambda_2 - \lambda_3 \rangle$ and obtain the following equation for β:

$$0 = \left(\frac{\lambda_2}{\lambda_1}\right)^{\beta} + R\left(\frac{\lambda_3}{\lambda_2}\right)^{-\beta} - R - 1. \tag{10}$$

More filters mean more accurate results



<B−V> / <V−R>
<V−R> / <R−I>
<R−I> / <I−J>
<I−J> / <J−H>
<J−H> / <H−K>
R
β
0
1
2
3

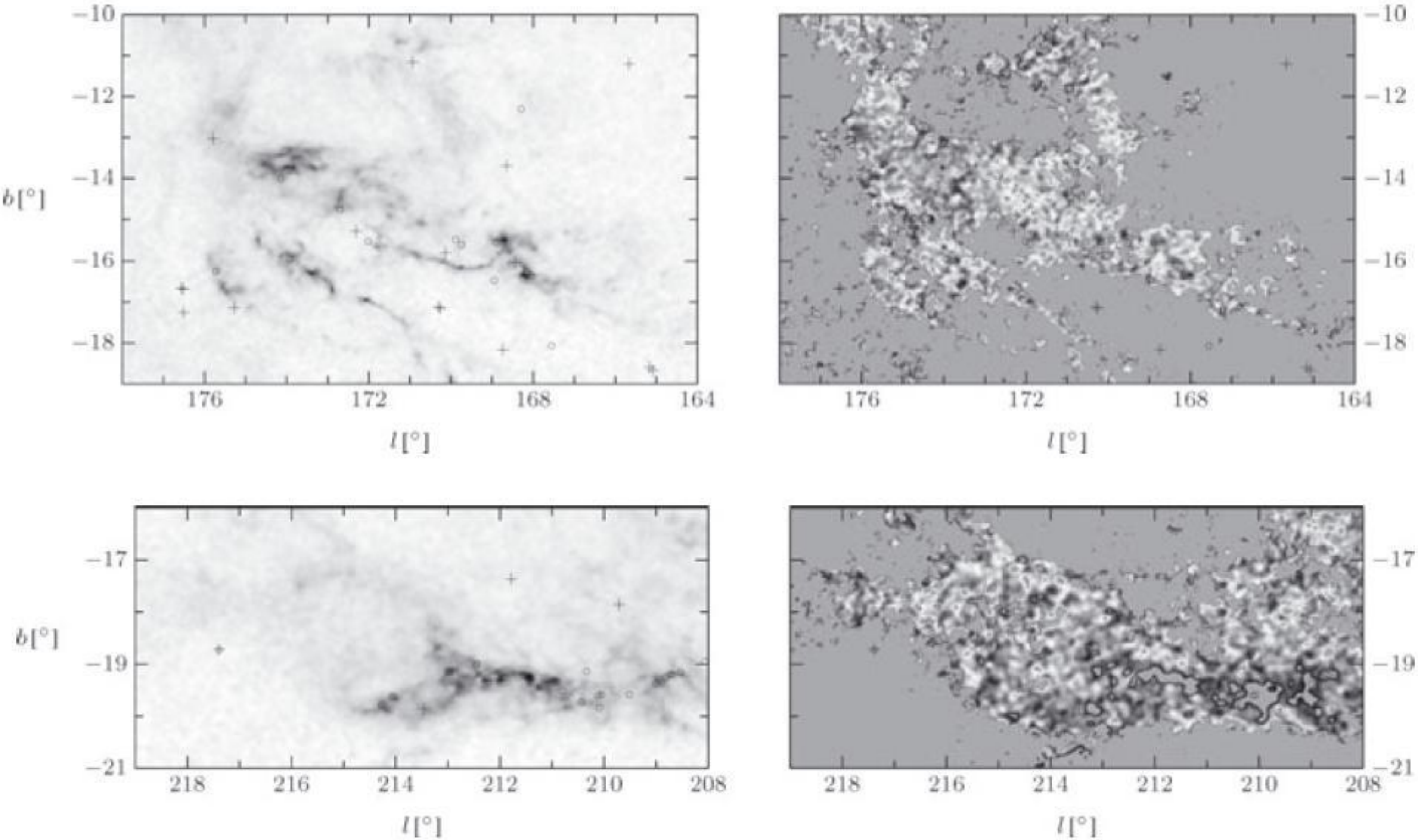
(i) Star count and colour excess extinction maps are calculated without foreground star corrections. These maps are used to determine the opacity index β, which is used to convert the colour excess maps into extinction maps.

(ii) Foreground stars have to be selected. Extinction maps from colour excess are usually less noisy but are less reliable for distant clouds. Thus the extinction map that possesses the larger extinction values should be used for the foreground star selection.

(iii) Now one needs to iterate the first two steps until no further foreground stars are found. Foreground stars cannot be identified in regions without extinction. We thus have to consider the accumulated star count diagram of the foreground stars when determining the extinction map using star counts. Using the colours of the identified foreground stars and Monte Carlo techniques, a colour offset for background regions can be determined.

(iv) The final star count and colour excess maps are used to determine β and to convert the colour excess into extinction maps.

(v) For a most accurate calibration determine the distance correction using the cloud distance and coordinates, as well as the completeness limit of the observations.

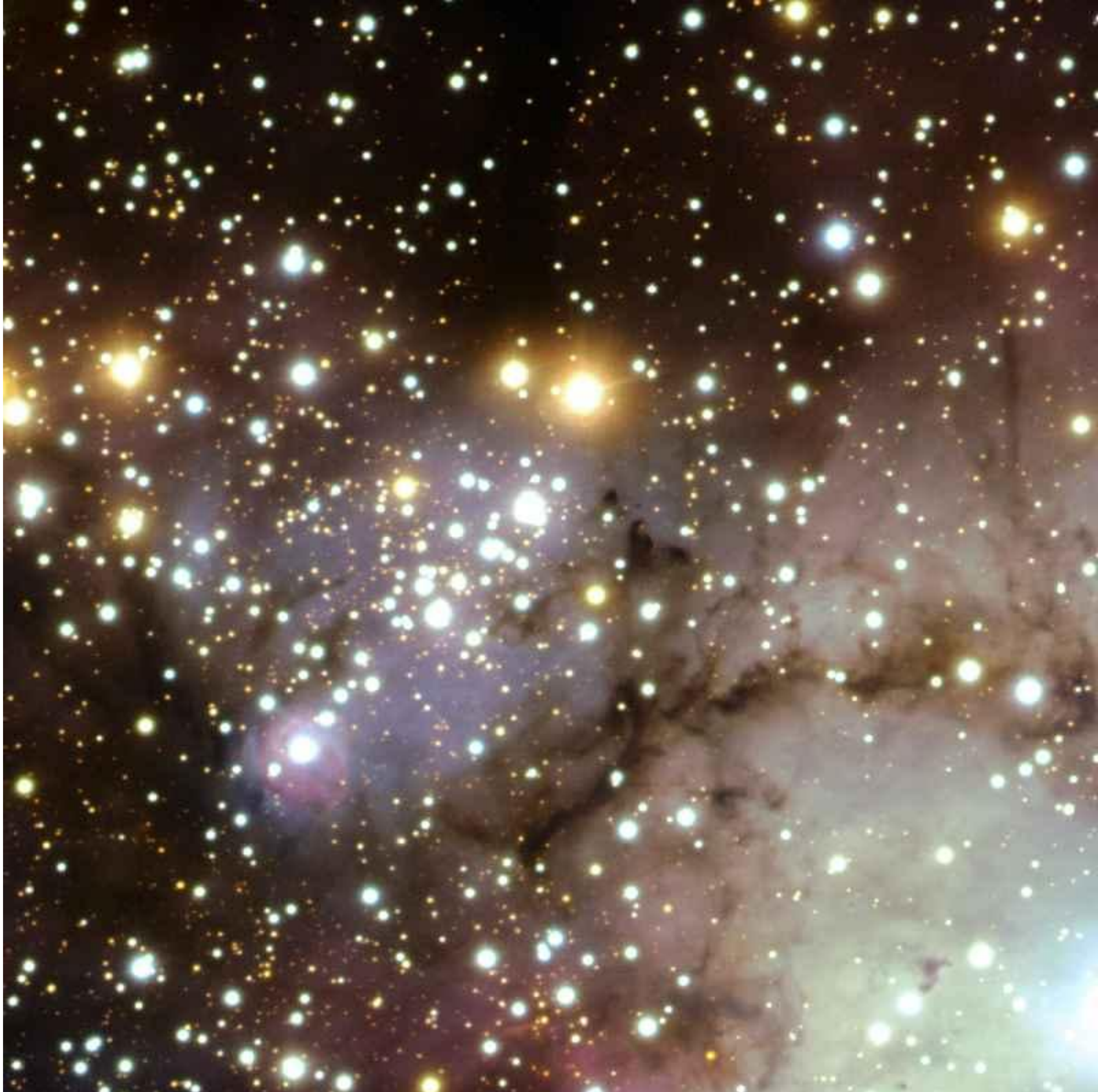


Froebrich et al., 2007, MNRAS, 378, 1447

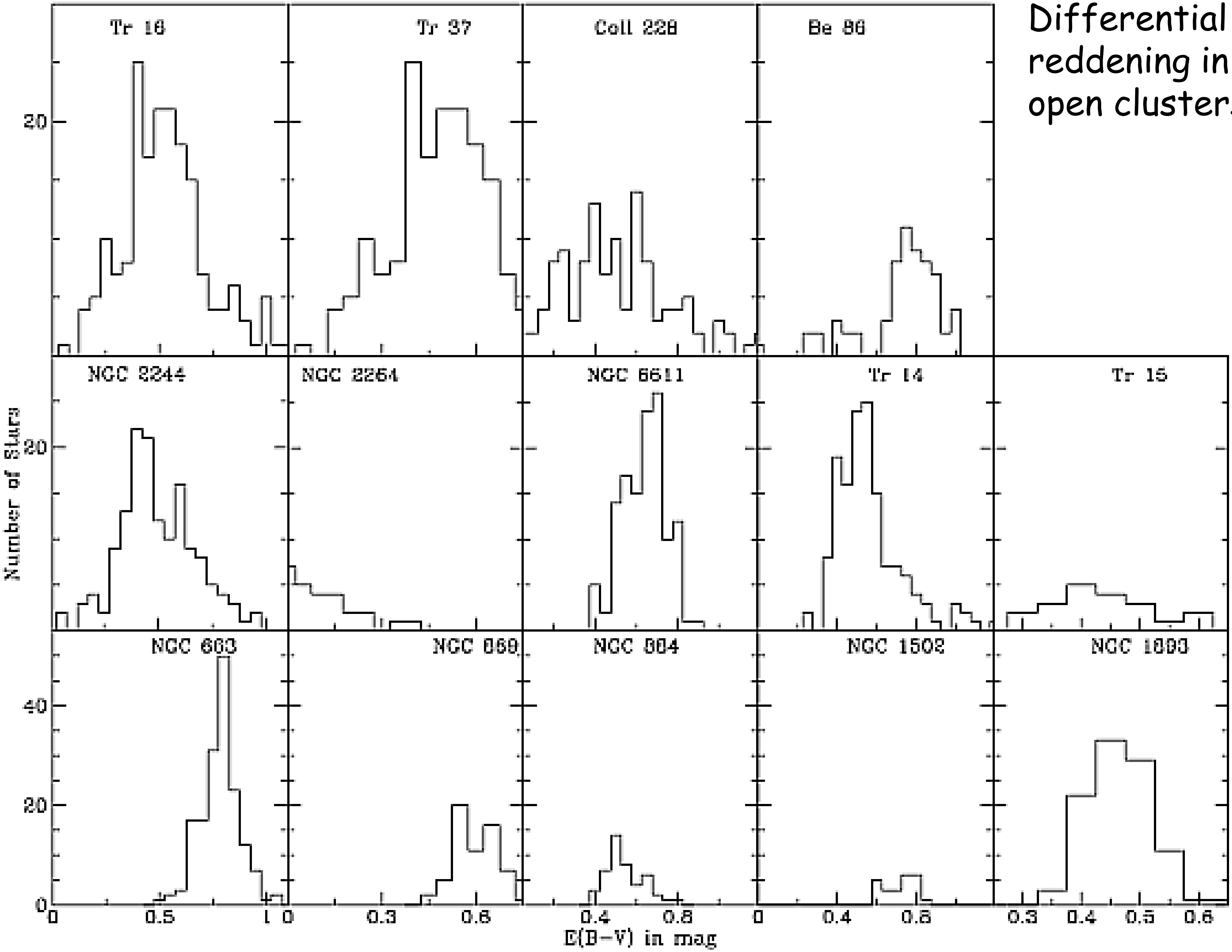
Haffner 18

Age about 8 Myr
d = 6000 pc

differential extinction within the cluster



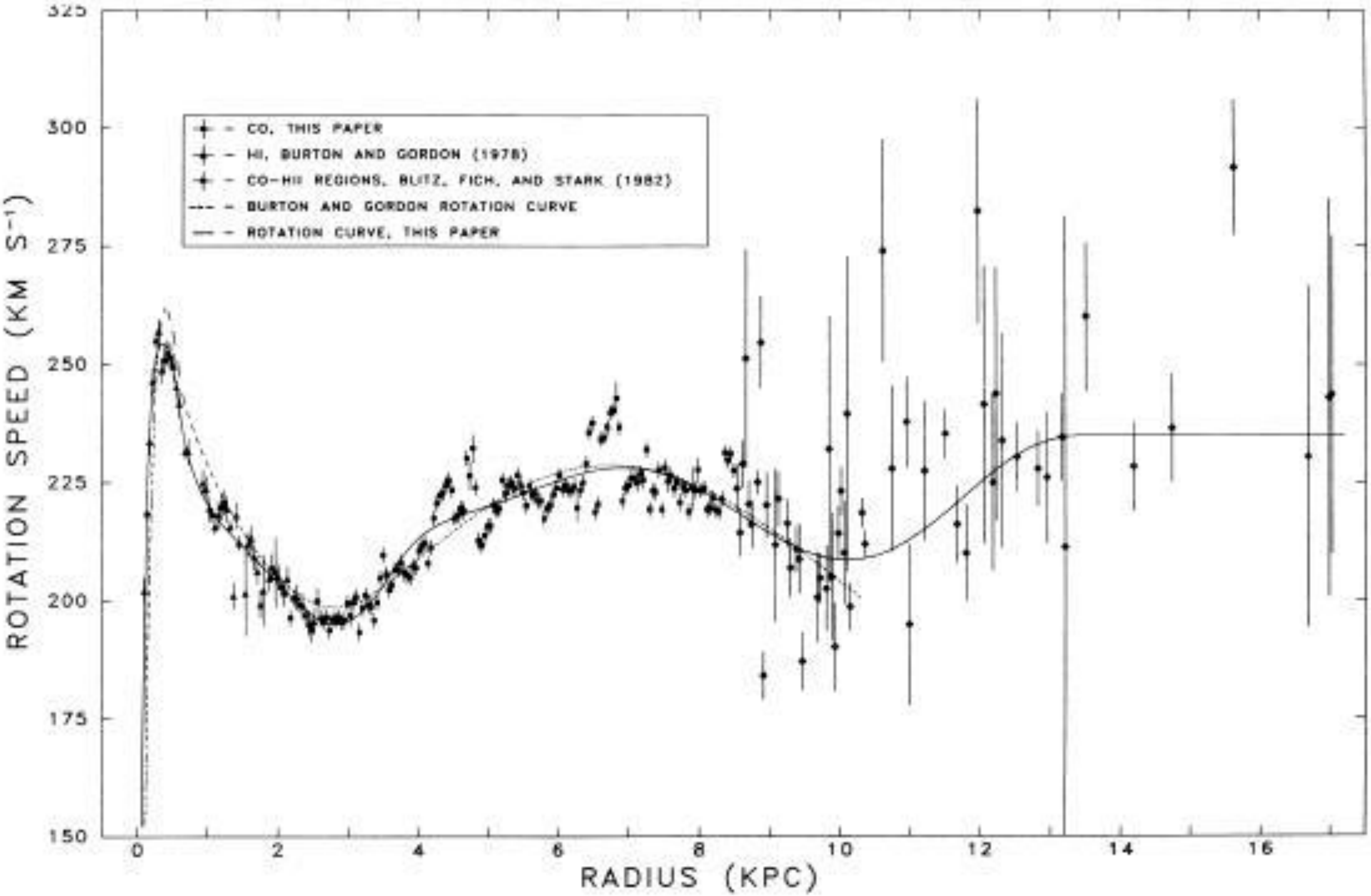
Differential reddening in young open clusters



Yadav & Sagar, 2001, MNRAS, 328, 370

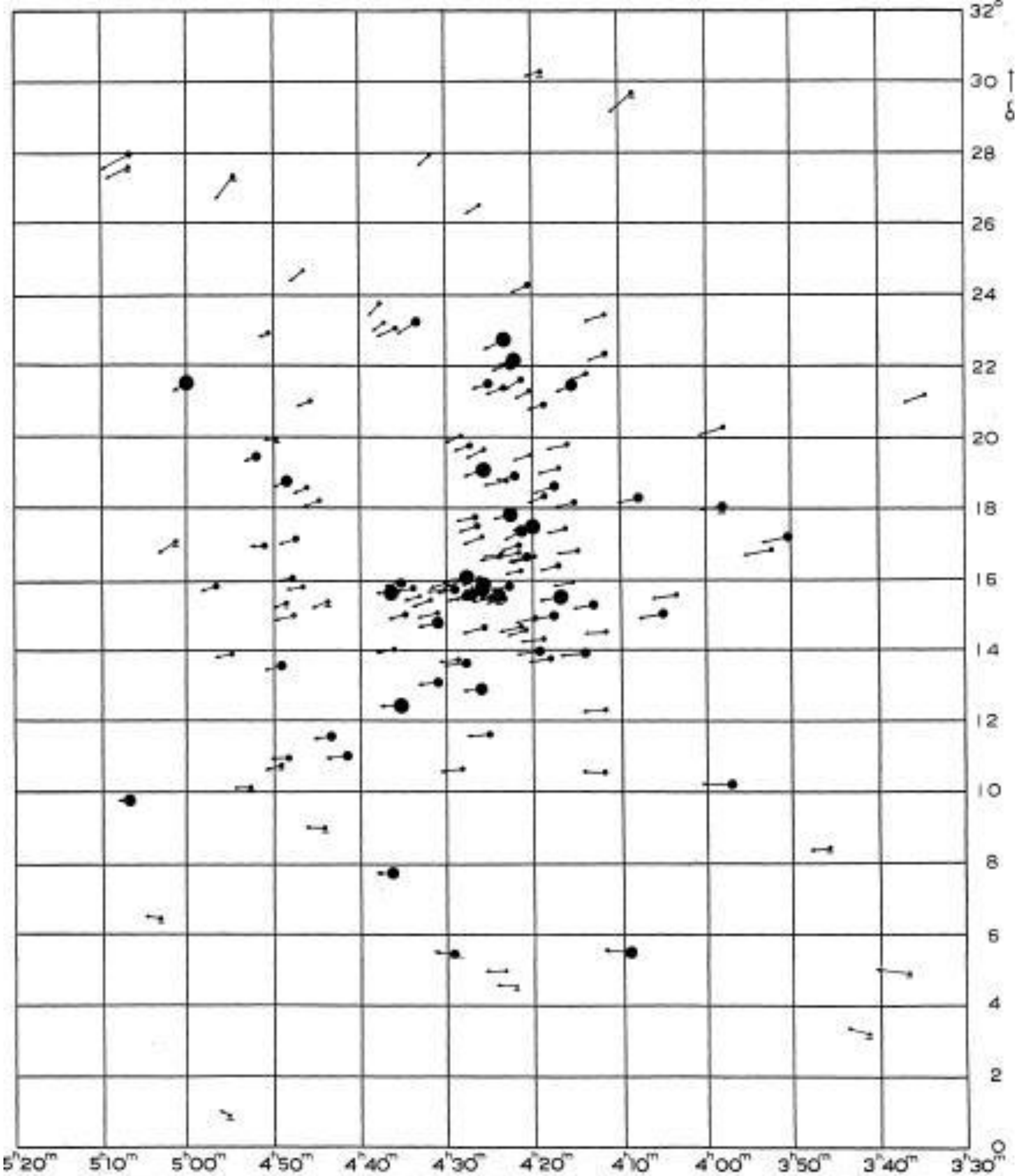
Kinematical membership criteria

- 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

Hyades



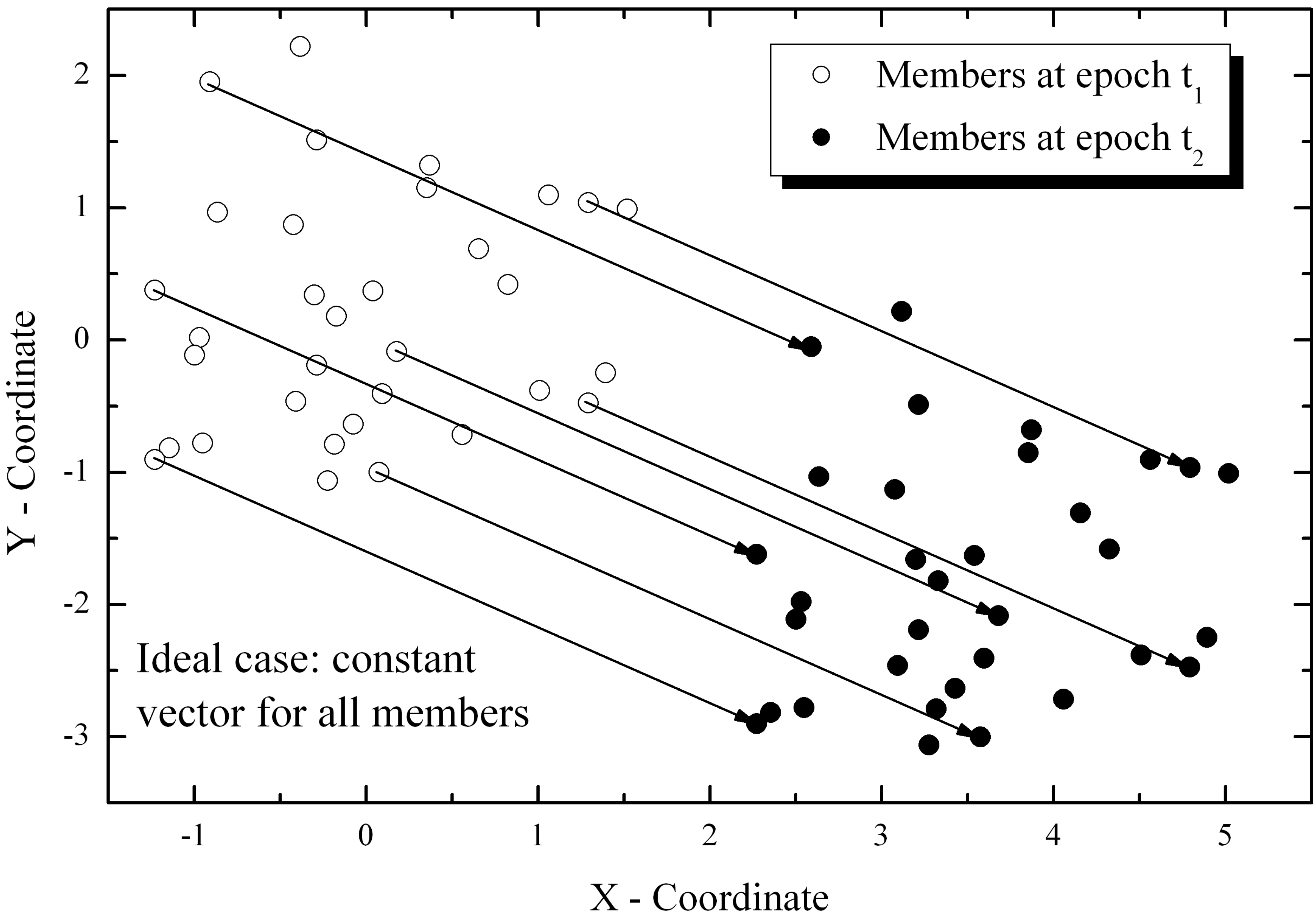
Map of the Hyades brighter than $9^m.0$ visual. The size of the dots is a measure for the magnitude of the stars; the arrows show the annual proper motion (1 mm ≈ 0".030). Five stars in the very outer regions of the cluster are not shown on the map. Underlined dots indicate stars of which no radial velocity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

Van Bueren, 1952, BAN, 11, 385

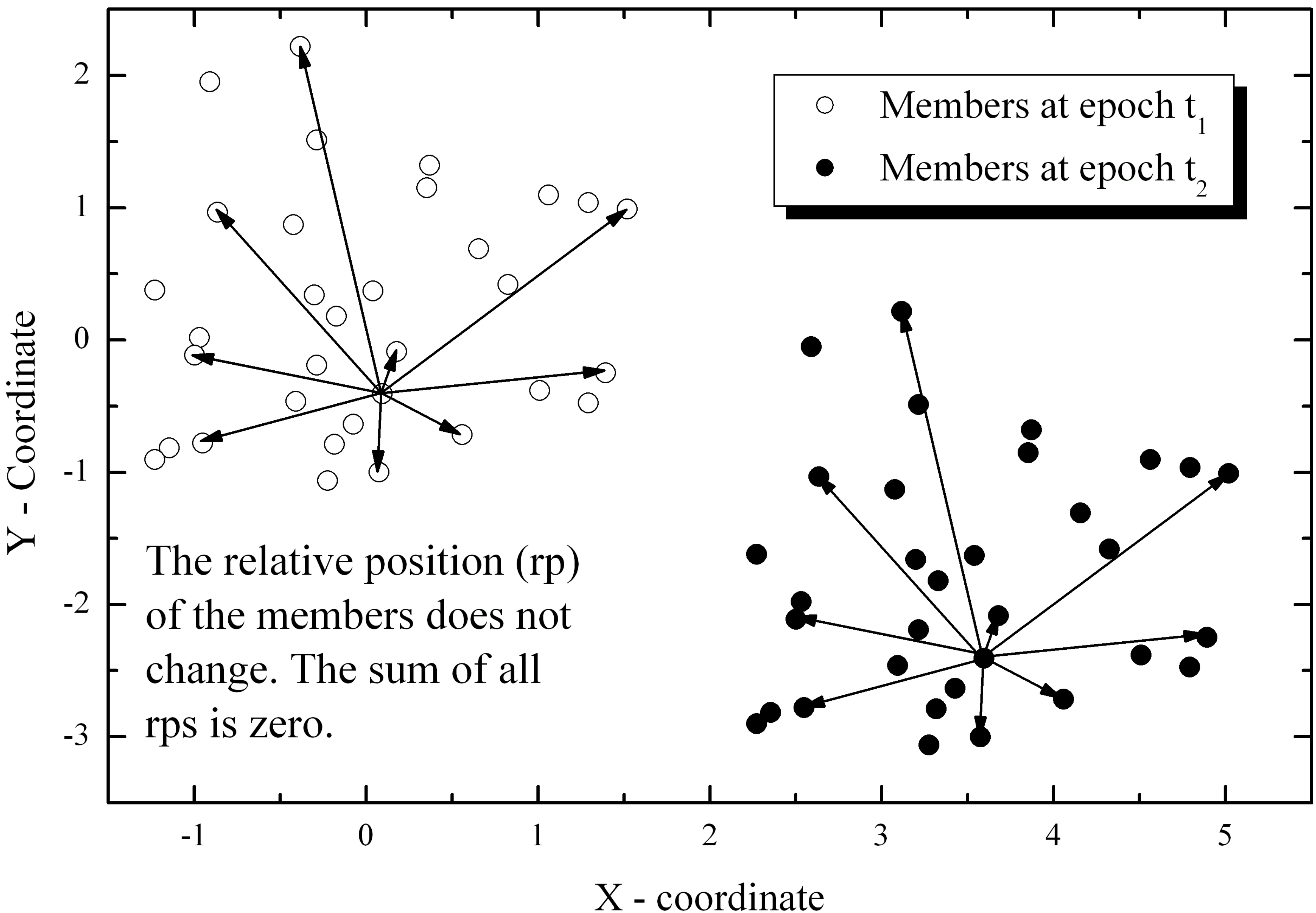
After the correction of the Solar motion

Determination of the kinematical membership

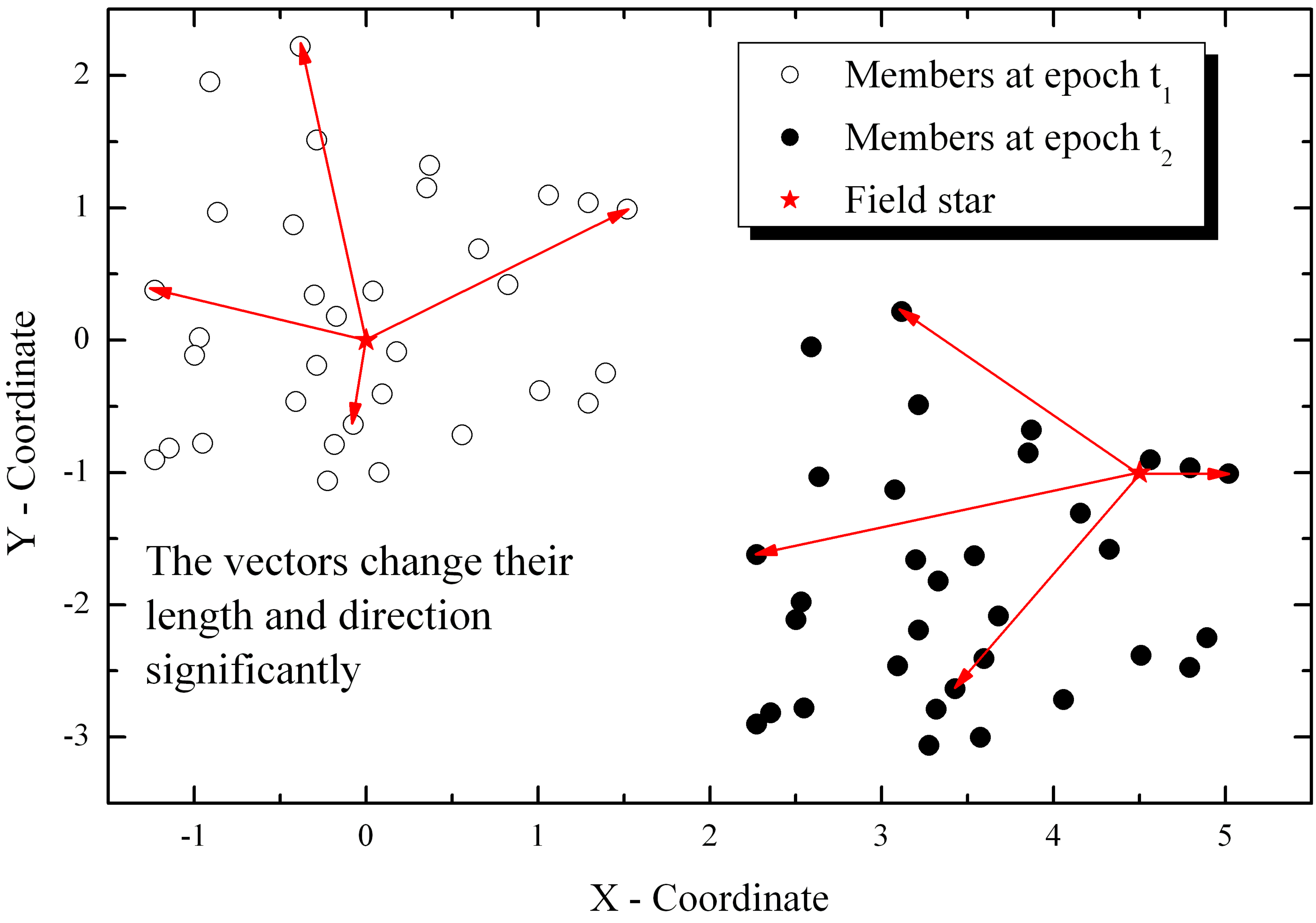
- Three possibilities:
  1. Observation of the position at two difference times (= epochs), with a very large time basis. First photographic plates around 1860, largest time scales about 150 years
  2. Proper motions of stars in the direction of the Declination α and Right Ascension δ
  3. Radial velocity 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 t_1
Members at epoch t_2
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

Mathematical method

- Measurement of the position (X, Y) at two different epochs t_1 (´) and t_2 (´´) for each star
- Calculate the absolute distance in X and Y for both epochs and each star individually

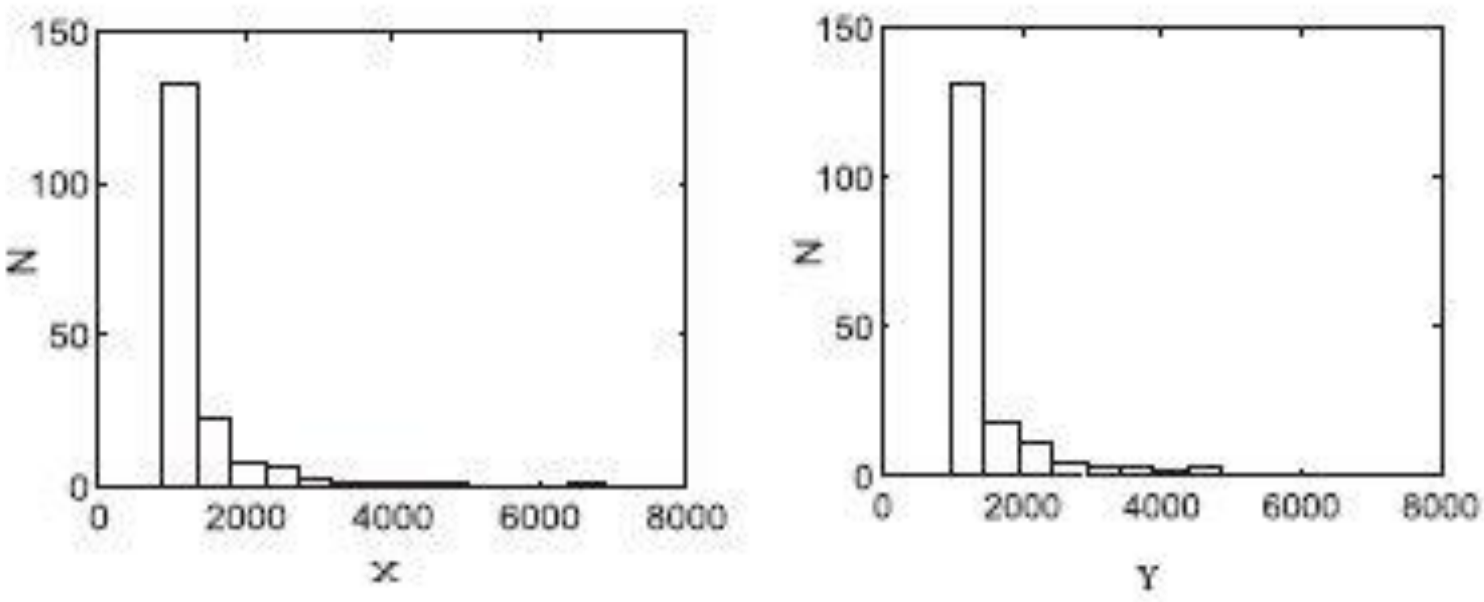
$$S'_{x_i} = \sum_{j=1}^{N} |x'_i - x'_j|, \qquad S'_{y_i} = \sum_{j=1}^{N} |y'_i - y'_j|, \qquad (1)$$

$$S''_{x_i} = \sum_{j=1}^{N} |x''_i - x''_j|, \qquad S''_{y_i} = \sum_{j=1}^{N} |y''_i - y''_j|, \qquad (2)$$

- Determine the differences of the absolute distances

$$\delta S_{x_i} = S'_{x_i} - S''_{x_i}, \qquad \delta S_{y_i} = S'_{y_i} - S''_{y_i}, \qquad i = 1, ..., N. \qquad (3)$$

- Plot the histograms of the differences of the absolute distances. The members have to group around the minimum of the distributions (ideal case: minimum = zero).



Example from Javakhishvili et al., 2006, *A&A*, 447, 915 for Collinder 121

Now we need a mathematical formalism to describe the membership probability from the distributions

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

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

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

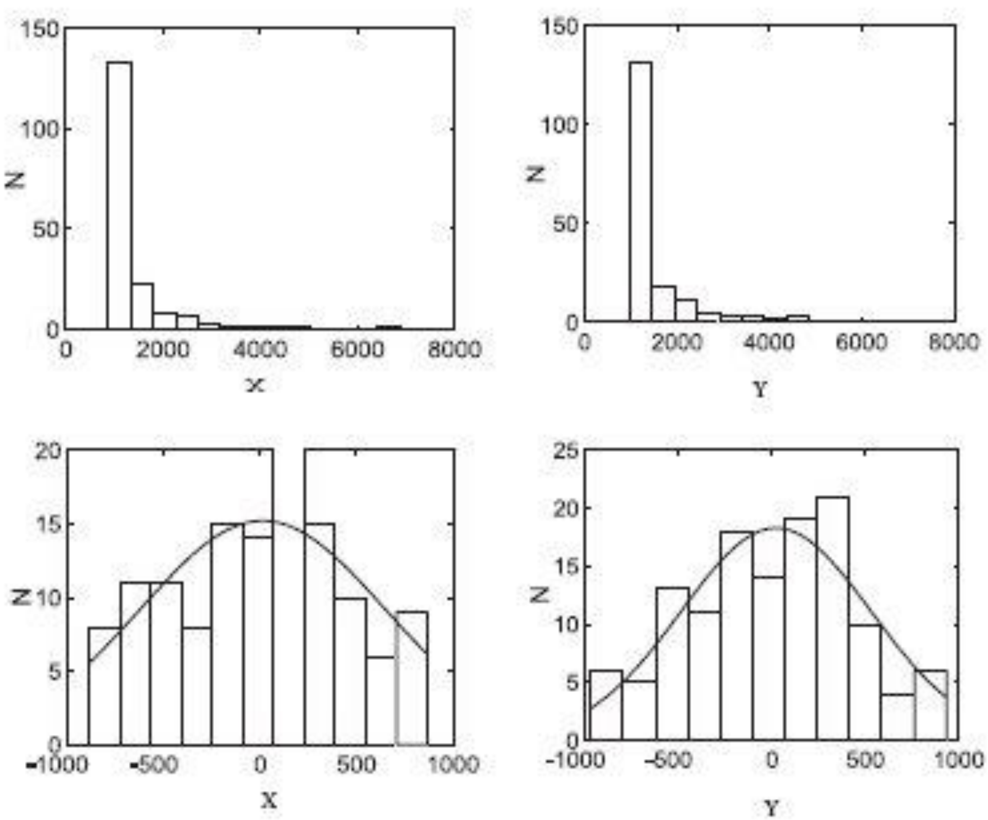
- Plot the histograms of the differences of the absolute distances
- The distributions are fitted with Gaussian functions

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

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

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

$$p = p_x * p_y. \tag{8}$$



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

From these diagrams, the membership probability can be exactly determined

- In the same way, the proper motions in α and δ can be used, the basic equations and the determination of the membership probability is exactly the same

$$\delta\mu_{\alpha_i} = \sum_{j=1}^{N} |\mu_{\alpha_i} - \mu_{\alpha_j}|, \qquad \delta\mu_{\delta_i} = \sum_{j=1}^{N} |\mu_{\delta_i} - \mu_{\delta_j}| \qquad (9)$$

$$\tilde{\delta}\mu_{\alpha_i} = \sum_{j=1}^{N} (\mu_{\alpha_i} - \mu_{\alpha_j}), \qquad \tilde{\delta}\mu_{\delta_i} = \sum_{j=1}^{N} (\mu_{\delta_i} - \mu_{\delta_j}). \qquad (10)$$

But the errors of ground based proper motions are rather large, most catalogues are complete to V < 11 mag only. This limits us, currently, to distances of about 1000 pc.

GAIA Satellite: Start 2011, up to 5000 pc (?)

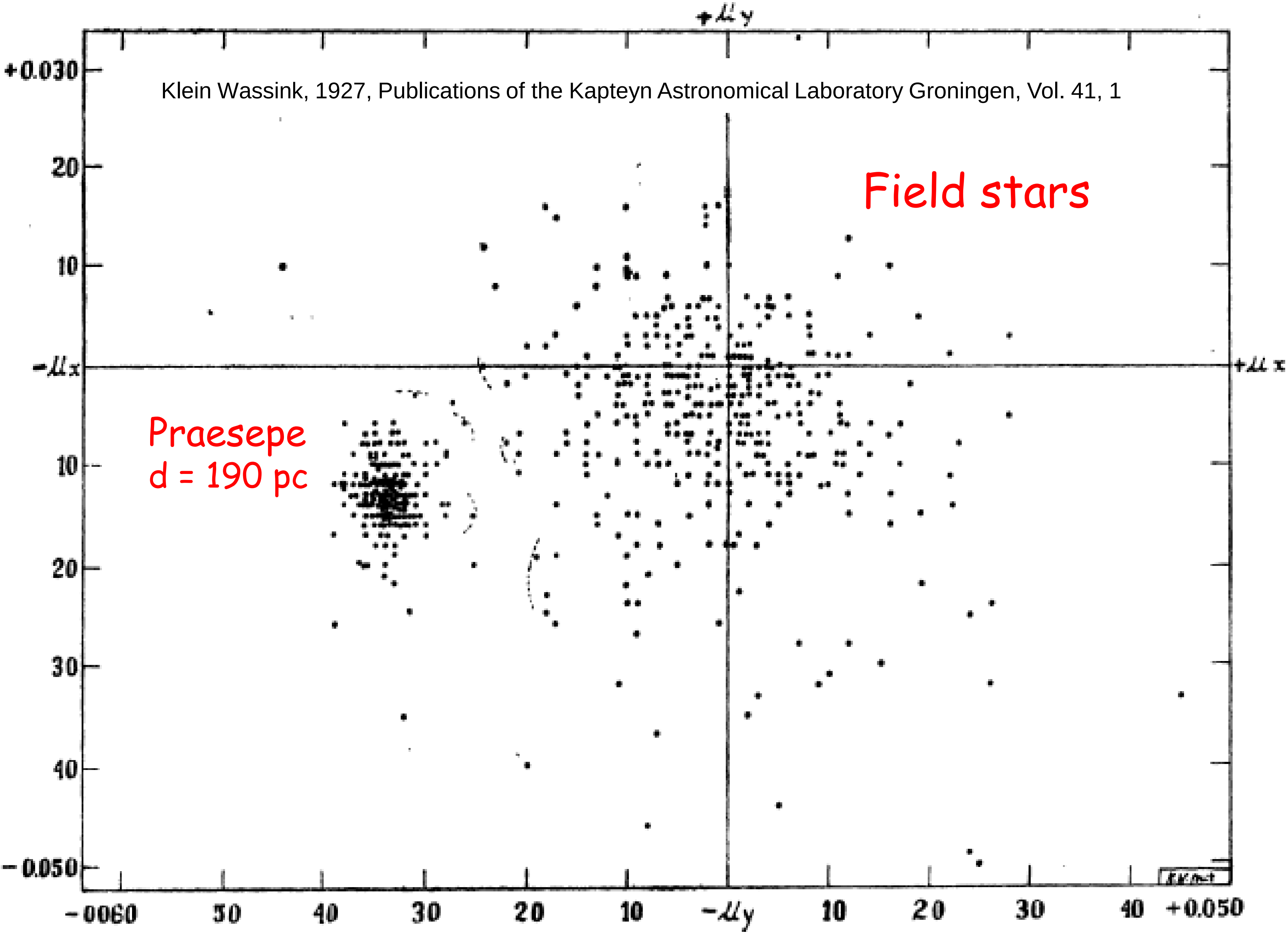
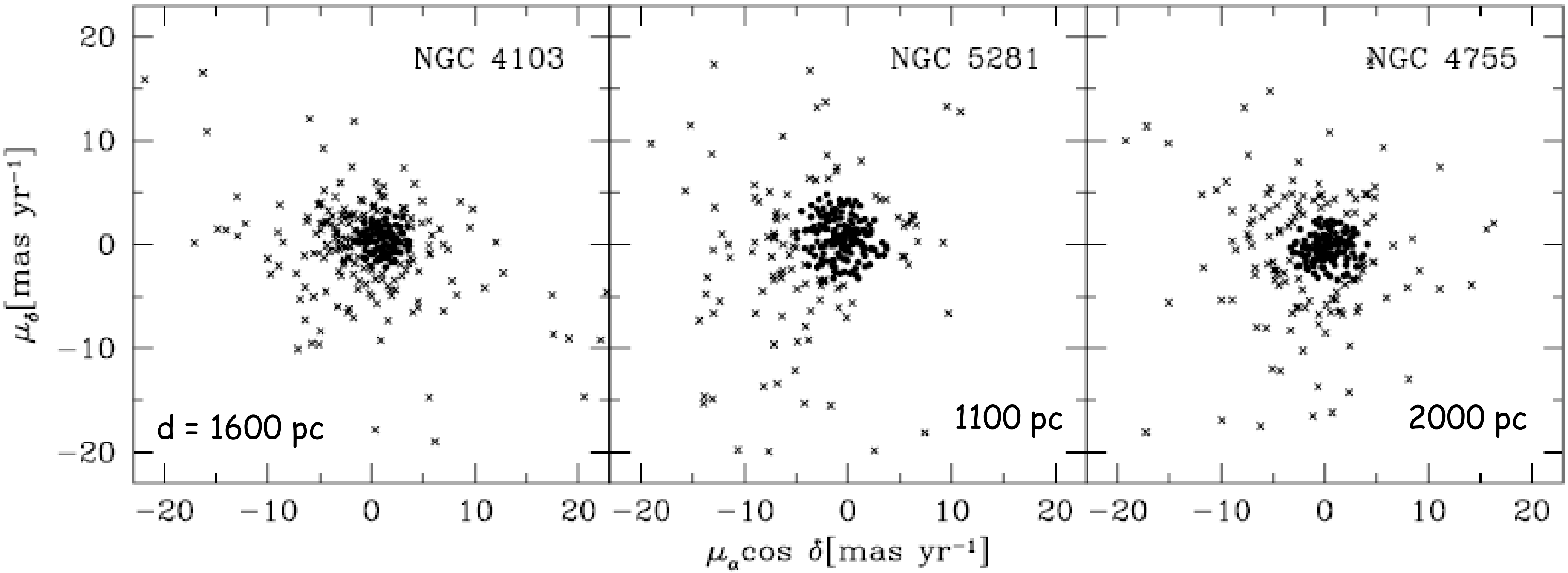


Figure 2. Diagram of the absolute proper motions of the Catalogue; photographic magnitude 6 to 14·0, numbers 1 to 531. The dotted lines separate the Praesepe stars from the backgroundstars.

Sanner et al., 2001, A&A, 369, 511



object	$\mu_\alpha \cos\delta$ [mas yr^{-1}]	μ_δ [mas yr^{-1}]
NGC 4103	$+0.91 \pm 1.4$	$+0.36 \pm 1.4$
field	-0.92 ± 5.0	$+0.27 \pm 5.0$
NGC 5281	-0.70 ± 2.1	$+0.67 \pm 2.1$
field	-4.36 ± 7.0	-1.08 ± 7.0
NGC 4755	$+0.18 \pm 1.7$	-0.32 ± 1.7
field	-1.71 ± 6.5	-0.99 ± 6.5

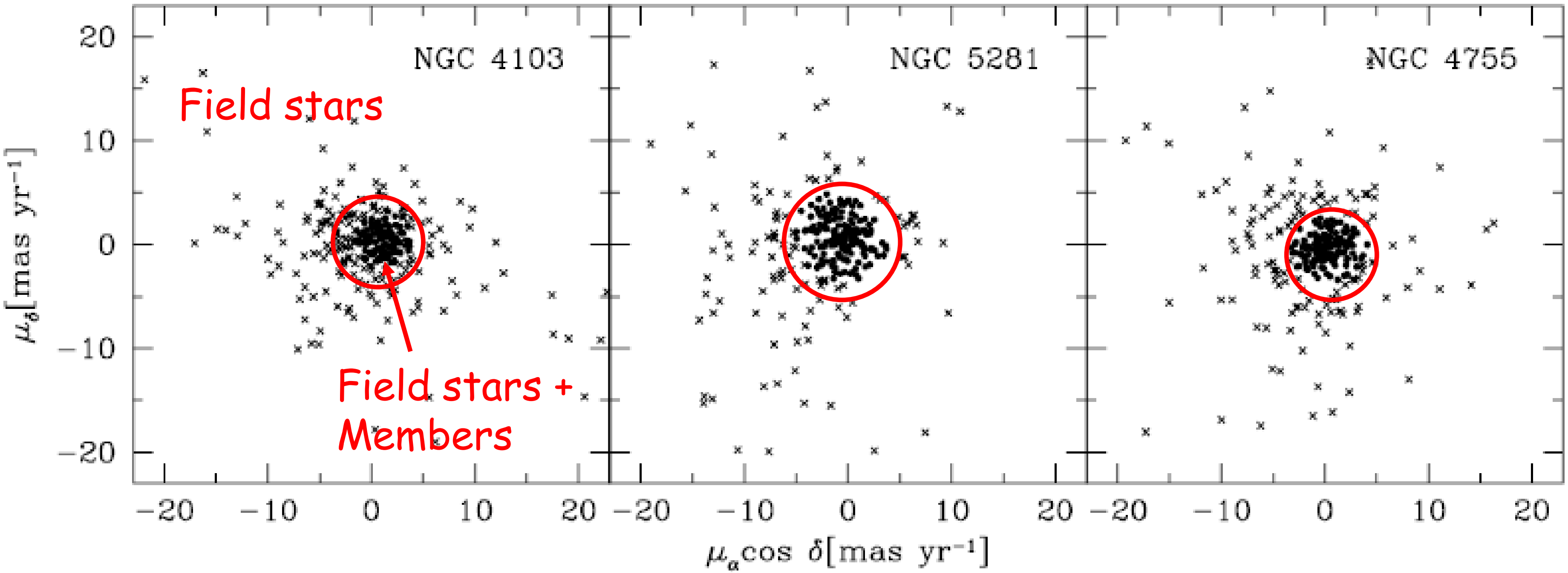
Mean values

TYCHO2 data

$$\mu_\alpha \cos\delta = -6.4 \pm 4.6 \text{ mas yr}^{-1}$$
$$\mu_\delta = +0.3 \pm 3.9 \text{ mas yr}^{-1}$$
$$\mu_\alpha \cos\delta = -7.3 \pm 4.8 \text{ mas yr}^{-1}$$
$$\mu_\delta = -2.0 \pm 4.3 \text{ mas yr}^{-1}$$
$$\mu_\alpha \cos\delta = -2.9 \pm 3.9 \text{ mas yr}^{-1}$$
$$\mu_\delta = -1.3 \pm 4.3 \text{ mas yr}^{-1}$$

Absolute values after „Sun correction“

Sanner et al., 2001, A&A, 369, 511



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.

Kharchenko et al., 2004, AN, 325, 439

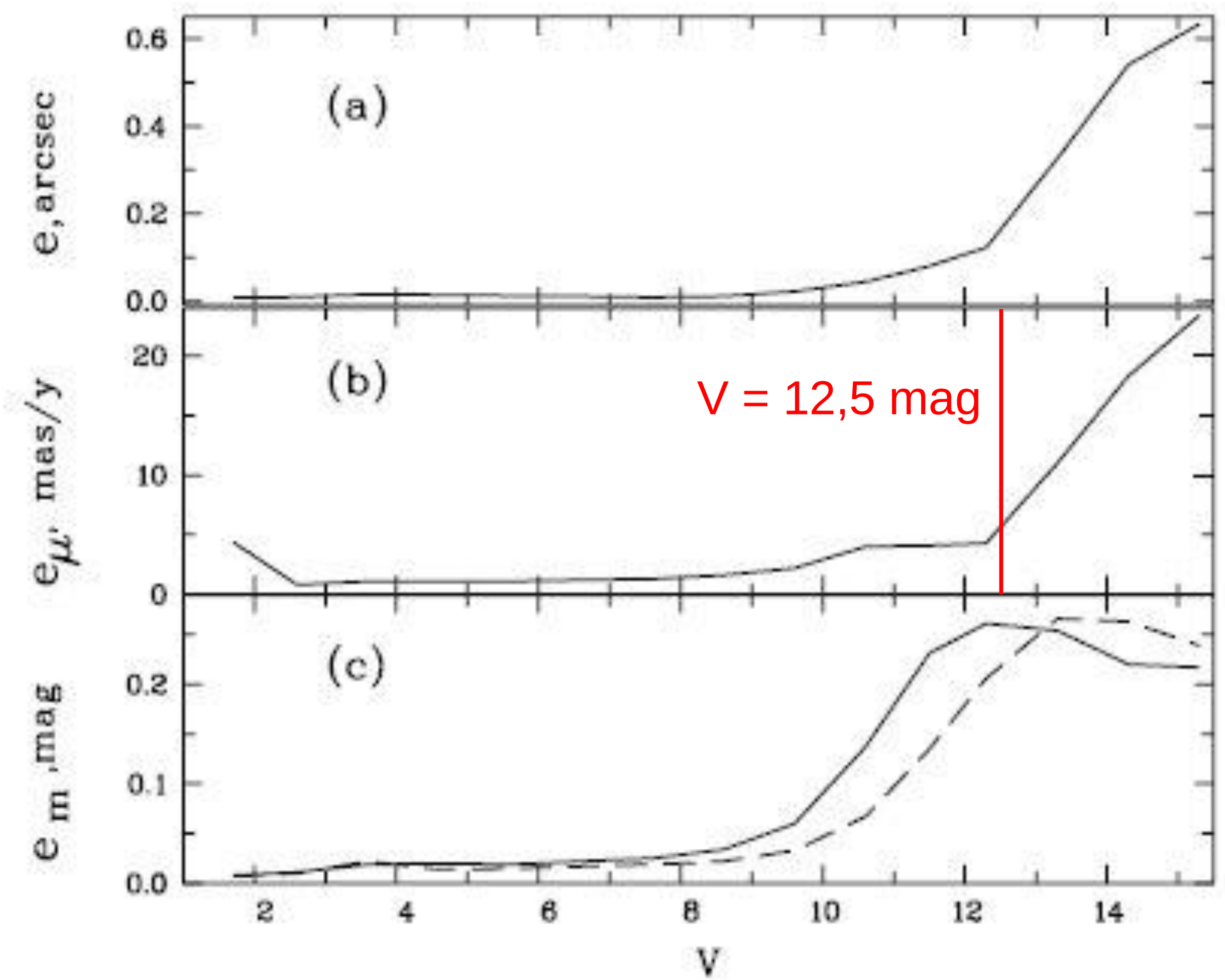


Fig. 1. The mean *rms* errors of equatorial coordinates (a), proper motions (b), stellar magnitudes V - solid line, and B - dashed line (c) in dependence on V magnitude in the ASCC-2.5.

All-sky Compiled Catalogue of 2.5 Million Stars: ASCC-2.5

Includes Johnson BV photometry, coordinates, proper motions and radial velocities

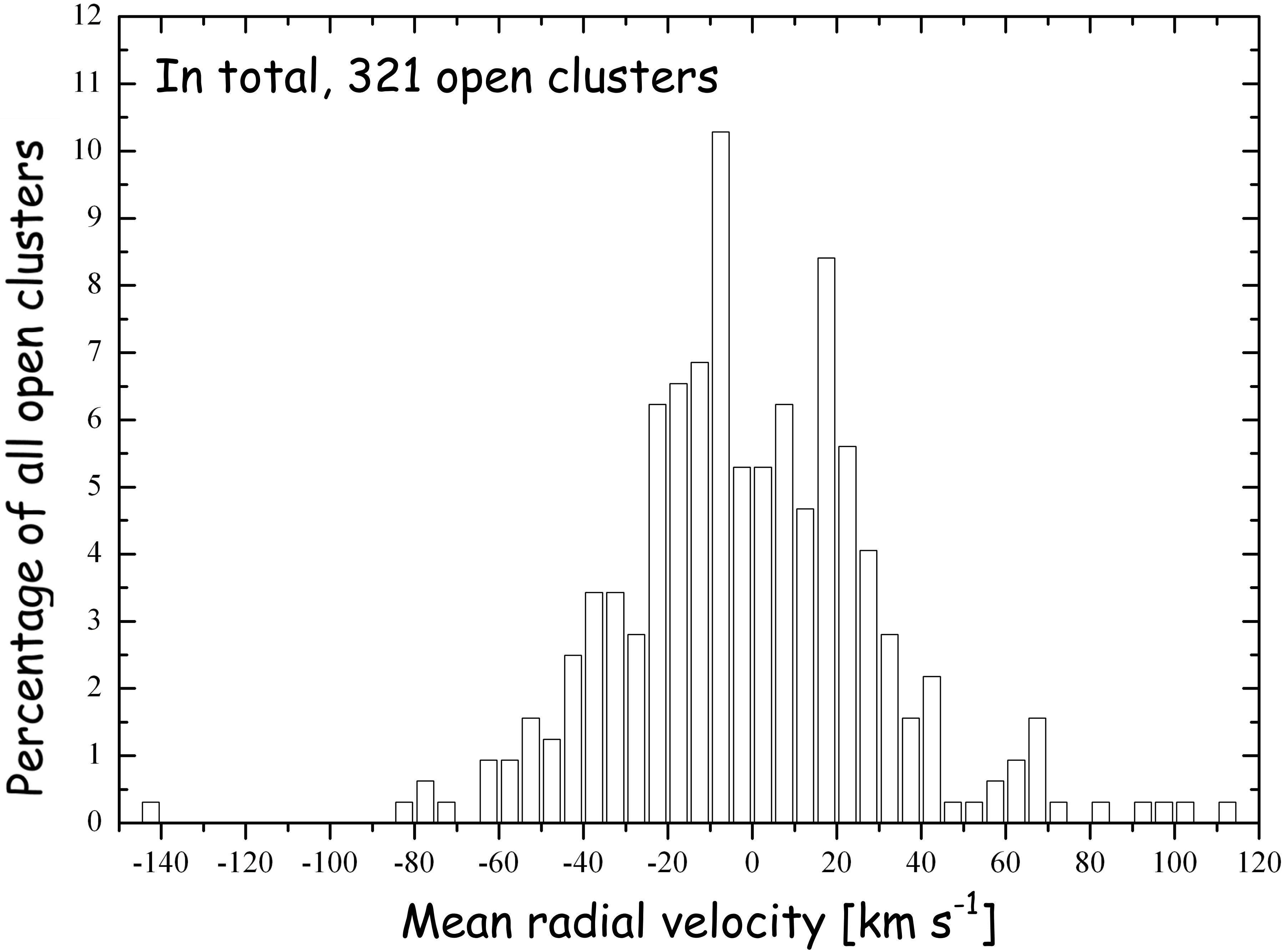
Useable limit at V = 12.5 mag

1000 pc: M_V = +2.5 mag (F0)
2500 pc: +0.5 mag (A0)
5000 pc: -1 mag (B5)

Without reddening => correlation with age

Radial velocities

- Advantages:
  1. Correlated with the galactic rotation only
  2. Possible to measure for most distant cluster members
- Disadvantages:
  1. High-resolution high S/N spectrum nedeed
  2. Faintness of members for distant clusters


In total, 321 open clusters
Percentage of all open clusters
Mean radial velocity [km s-1]
0
1
2
3
4
5
6
7
8
9
10
11
12
-140
-120
-100
-80
-60
-40
-20
0
20
40
60
80
100
120

Determination of the radial velocity

- Doppler shift of spectral lines

$$\Delta\lambda = \frac{v_R \lambda}{c}$$

- Determine the central wavelength of the shifted line
- Better accuracy if
  1. Instrumental resolution ($\lambda/\Delta\lambda$) is higher
  2. Signal-To-Noise ration (S/N) is higher
  3. vsini of star is lower
  4. The number of measured lines is higher

λ [Å]	5	10	30	100
3500	0,058	0,117	0,350	1,167
4000	0,067	0,133	0,400	1,333
4500	0,075	0,150	0,450	1,500
5000	0,083	0,167	0,500	1,667
5500	0,092	0,183	0,550	1,833
6000	0,100	0,200	0,600	2,000
6500	0,108	0,217	0,650	2,167
7000	0,117	0,233	0,700	2,333
7500	0,125	0,250	0,750	2,500
8000	0,133	0,267	0,800	2,667

R_V [km s^{-1}]

Δλ [Å]

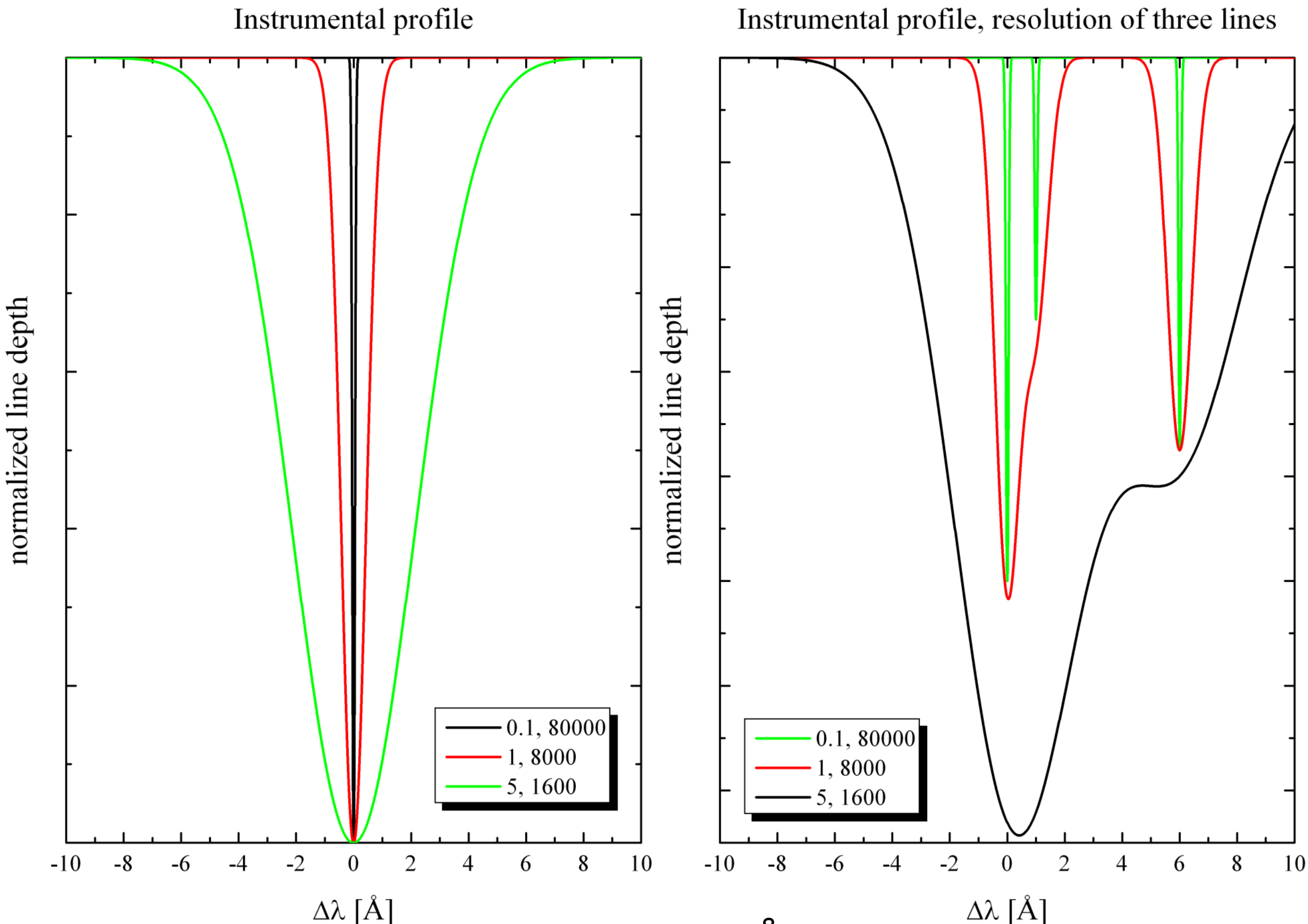
Instrumental profile defined by the resolution:

$$IP(\Delta\lambda) = \exp\left[-0.5\left(\frac{(\lambda-\Delta\lambda)}{\sigma}\right)^2\right] \text{ with } \sigma = \frac{FWHM}{2.355}$$

Rotational broadening:

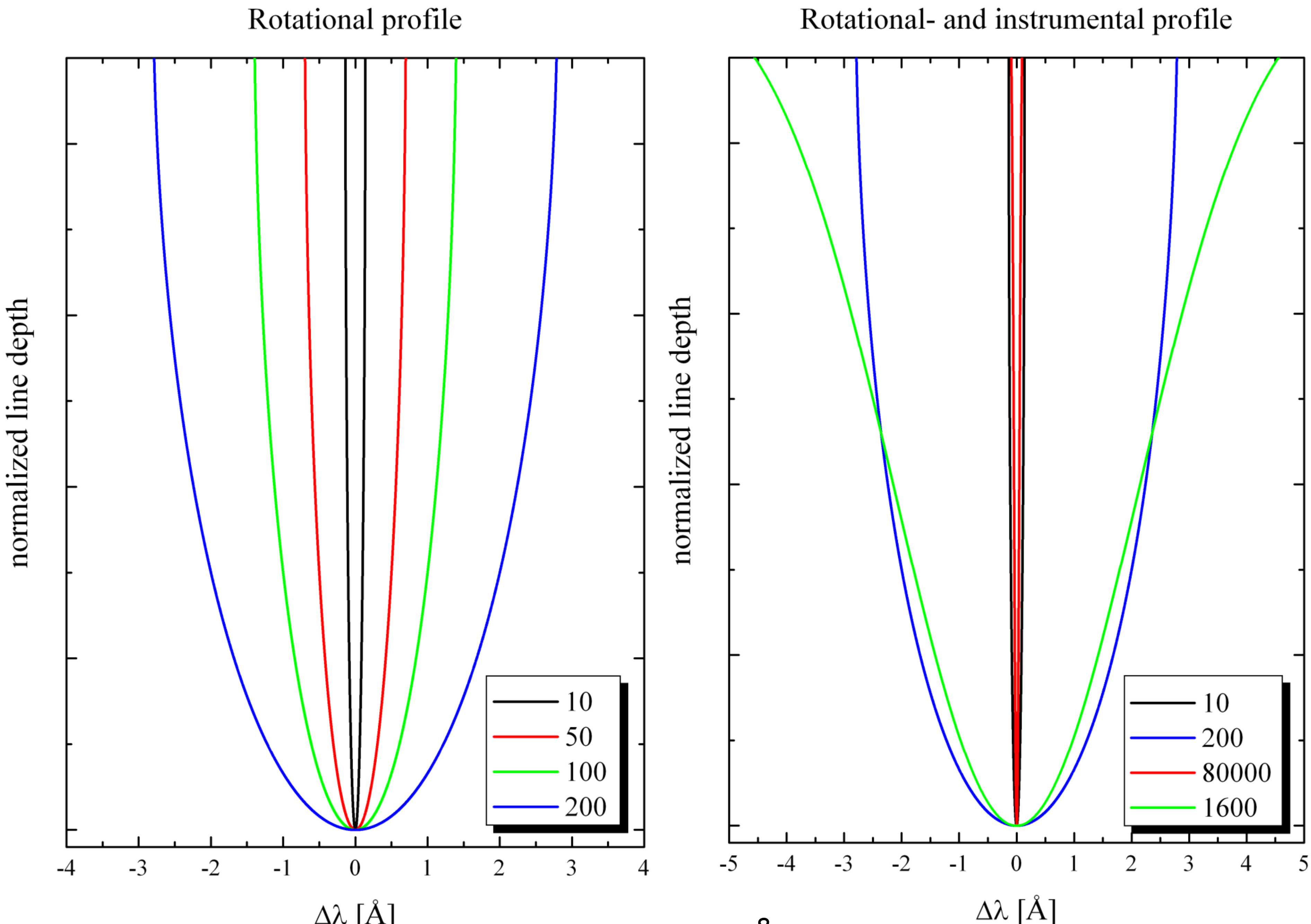
$$RP(\Delta\lambda) = c_1\sqrt{x} + c_2 x \quad \text{with} \quad x = 1 - \left(\frac{\Delta\lambda}{\Delta\lambda_L}\right)^2$$

$$\Delta\lambda_L = \lambda \frac{v \sin i}{c}$$



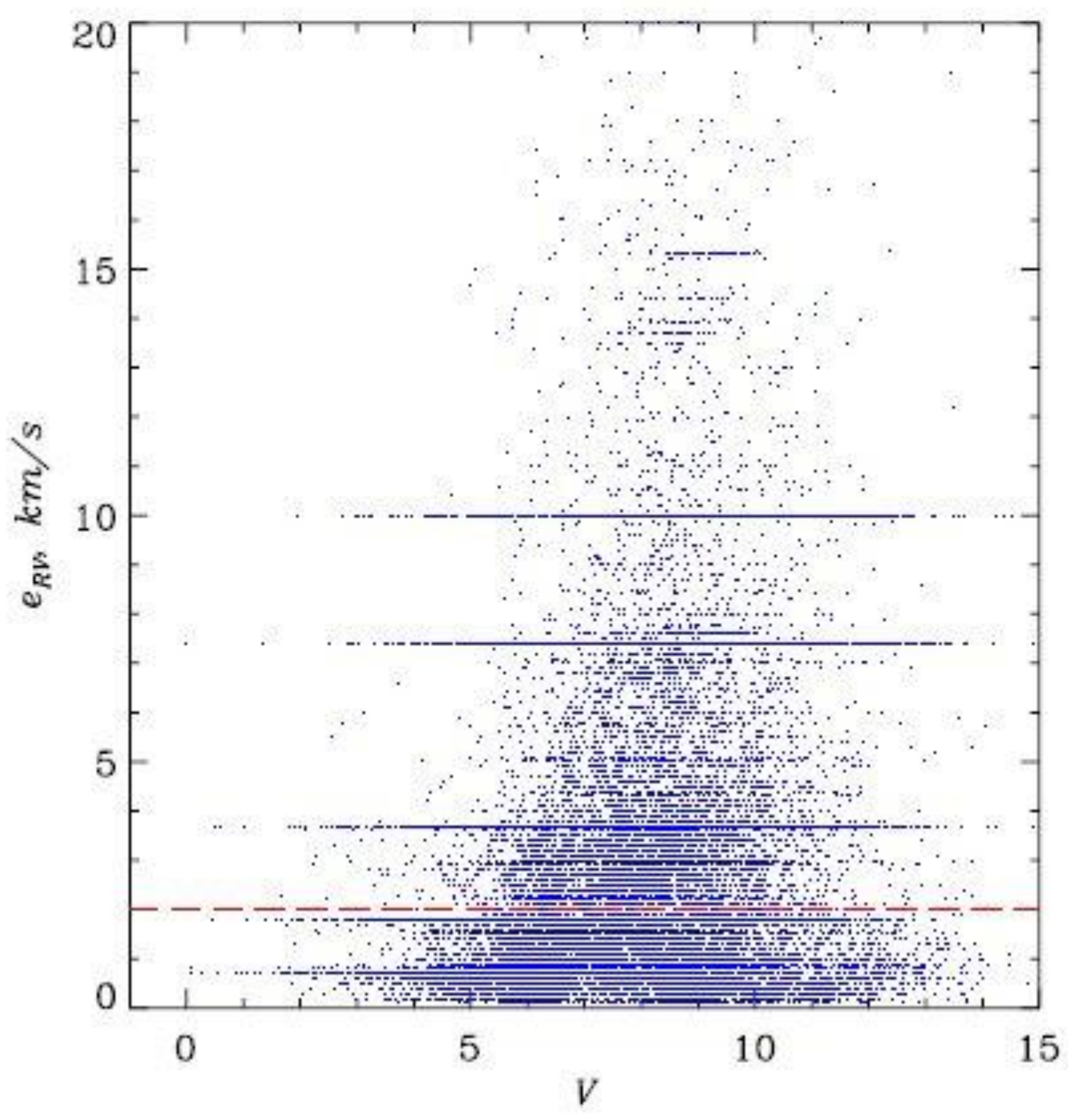
Instrumental profile
normalized line depth
0.1, 80000
1, 8000
5, 1600
-10 -8 -6 -4 -2 0 2 4 6 8 10
Δλ [Å]
Instrumental profile, resolution of three lines
normalized line depth
0.1, 80000
1, 8000
5, 1600
-10 -8 -6 -4 -2 0 2 4 6 8 10
Δλ [Å]

for λ = 4200Å



for λ = 4200Å

Kharchenko et al., 2004, AN, 325, 439



All-sky Compiled Catalogue of 2.5 Million Stars: ASCC-2.5

No correlation of the error with the V magnitude