Astron. Astrophys. 362, 563–579 (2000)

ASTRONOMY AND ASTROPHYSICS

A statistical analysis of the metallicities of nine old superclusters and moving groups

B.J. Taylor

Department of Physics and Astronomy, N283 ESC, Brigham Young University, Provo, UT 84602-4360, USA (taylorb@physc2.byu.edu)

Received 21 March 2000 / Accepted 4 May 2000

Abstract. Using both high-dispersion and low-resolution data, the metallicities of nine old moving groups and superclusters are analyzed. These stellar groupings include the HR 1614 and Hyades superclusters and the Wolf 630, ζ Her, 61 Cyg, HR 1614, σ Pup, η Cep, and Arcturus groups. Samples of these stellar groupings are drawn from Eggen's membership lists. Precautions are taken against problems posed by reddening, visual and spectroscopic binaries, and typographical errors in Eggen's lists. When required, the analyses allow for systematic differences between low-resolution and high-dispersion metallicities. It is found that none of the stellar groupings have the small metallicity dispersion found for a selection of galactic clusters. Instead, the metallicity dispersions turn out to be comparable to the dispersion for a random selection of field stars. For most of the stellar groupings, it does not seem possible at present to learn more by analyzing metallicities. However, one can be more definite about three of them: the HR 1614 supercluster, the HR 1614 group, and the Hyades supercluster. Using a membership list from Eggen (1998c) that is based on Hipparcos astrometry, no evidence is found for the existence of an HR 1614 supercluster. To isolate an HR 1614 group, results from a kinematic analysis (Dehnen 1998) are then used to select a tentative list of members from Eggen's group and supercluster lists. From the mean metallicity of the redefined group, it is found that the group is very unlikely to be a random, magnitude-limited sample of stars. A similar result is obtained for a version of the Hyades supercluster derived from 18 of Eggen's membership lists. About 43% of the stars in this version turn out to be members of the supercluster.

Key words: stars: abundances – Galaxy: stellar content

1. Introduction

On 2 October 1998, the death of Olin Eggen interrupted–but did not resolve–a long-standing impasse about moving groups. Despite firm advocacy on Eggen's part, and despite research Eggen performed during about four decades, it appears that he convinced few other stellar astronomers of the existence of old moving groups. Objections of two different kinds have been made. One kind pertains to Eggen's research, while the other kind pertains to the concept of old moving groups as such.

One problem that has been cited is contamination: nonmembers should be scattered into parts of velocity space that are occupied by moving groups (Méndez & Ruiz 1992). A second problem is volatility: as time has passed, Eggen's lists of group and supercluster members have changed markedly in what appear to be arbitrary ways (Soderblom & Mayor 1993, Griffin 1998).[1] A third problem is possible data manipulation: Griffin (1998) has made a prima facie case that Eggen (1992c) chose and sometimes altered some of his input data to produce a predetermined result for the Pleiades supercluster.[2] If Griffin's paper had appeared some years ago instead of shortly before Eggen's death, it could have seriously damaged the credibility of all of Eggen's work on both superclusters and moving groups. (For a reaction to Griffin 1998 that may be widely shared, see Sect. 7.4 of Trimble & Aschwanden 1999.)

There is a fourth problem: evaporation. Allegedly moving groups formed long ago should have evaporated by now (see, for example, Soderblom & Mayor 1993). The present author first heard this objection in a graduate class in 1964. It therefore seems to be the most durable objection to the concept of old moving groups, and it may be the most influential as well.

Note that adverse opinions about this issue have been based largely on appearances and a priori reasoning. When one remembers that astronomy is an observational science (Rubin, quoted by Ferris 1997), it is not obvious that such a disproof should be the final word on the subject of moving groups. This point gains force when one looks at the history of moving-group research. Before Hipparcos, few papers about moving groups (or superclusters) were rigorous enough statistically to inspire firm trust in their conclusions. Moreover, it is only during the last

[1] Eggen's naming system is adopted here: both superclusters and groups contain stars with similar space motions, but only superclusters have convergent points. The terms "group" and "supercluster" are used neutrally, with no commitment for or against their reality being implied. Depending on ease of use, either "group" or "stellar grouping" will be adopted as shorthand for "group and supercluster."

[2] In US law, a "prima facie case" is not conclusive, but is nevertheless strong enough to lead to further formal action when presented in court. The term is borrowed above to describe Griffin's findings as carefully as possible. Obviously it cannot be known what Eggen's intent was when he perfomed the analysis Griffin critiques. On the other hand, it seems fair to say that intentional data manipulation is a possible explanation for the facts Griffin presents. Readers are invited to consult Griffin's paper and assess this issue for themselves.

few years that $a)$ the Hipparcos data have been available and $b)$ statistically powerful analysis engines have been developed to exploit them. It would therefore seem prudent to put skepticism aside while doing further analyses of old moving groups.

Of course, the analysis engines referred to above have been applied to kinematics. In this paper, a complementary approach is taken: statistical analysis is applied to moving-group metallicities. This aspect of the moving-group problem underscores the dissatisfaction expressed above. Conclusions about group metallicities have sometimes been drawn from data for five or fewer stars (Tuominen & Vilhu 1979, Proust & Foy 1988, Zielke 1970). Metallicity histograms have been edited without the benefit of either statistical tests or firm extrinsic evidence for systematic errors (see, for example, Eggen 1977). Conclusions about the metallicity coherence of moving groups have often been drawn by inspecting graphs instead of using statistical tests (again see Eggen 1977). All told, there has been no statistically rigorous assessment of either the mean metallicities or the metallicity coherence of old moving groups.

To improve this situation, one might proceed as follows.

1. For a number of groups, assemble Eggen's membership lists.
2. Select stars from those lists which might contribute to an analysis.
3. For as many of those stars as possible, obtain metallicities that are on a consistent zero point and have known accidental errors.
4. Using formal statistical tests, derive conclusions from those metallicities.

This, in brief, is the algorithm that will be adopted below.

A secondary aim of this paper concerns documentation. In the present author's judgment, pre-Hipparcos papers on moving groups were often not documented well enough, and this has been another reason for reserving judgment about their conclusions. The standards that are proposed here are illustrated in Sects. 2–8. Auxiliary calculations of space motions are required for some stars, and these calculations and the data they require are described in Sect. 2. The groups and most of the membership lists that are used below are considered in Sect. 3. Contributing metallicities are discussed in Sect. 4, and their rms errors are reviewed in Sect. 5. In Sect. 6, the statistical tools that are applied in this paper are described. Corrections and editing of the input data used to derive metallicities are described in Sect. 7. The analyses require test and comparison samples, and these are discussed in Sect. 8.

In Sects. 9–13, results are presented. Analyses of all the stellar groupings considered here are described in Sects. 9 and 10. Follow-up analyses of the HR 1614 supercluster, the HR 1614 group, and the Hyades supercluster are discussed in Sects. 11, 12, and 13, respectively. A summary and recommendations for further work conclude the paper in Sect. 14.

2. Space motions

Space motions will be required below to decide about the reality of the HR 1614 supercluster and to select stars for an analysis of the HR 1614 group. Space motions are obtained from a modified form of the Johnson & Soderblom (1987) algorithm. In its original form, that algorithm requires epoch 1950 coordinates. It is adapted here to epoch 2000 coordinates by using a matrix given by Murray (1989, Eq. (32)). In addition, the Johnson-Soderblom procedure for obtaining rms errors is replaced by numerical differentiation of Eq. (10.12) of Kendall & Stuart (1977). This procedure is straightforward to program.

Besides epoch 2000 coordinates, the data required to calculate space motions include proper motions and parallaxes. These data are drawn from the Hipparcos data base by way of SIMBAD (see Perryman et al. 1997). The Lutz-Kelker (1973) algorithm is converted to a relation between parallax correction and σ_π/π, and it is then applied to the parallaxes. This relation is based on the assumption that the density of nearby stars is uniform. If an extrapolation of the relation would be required, no space motions are calculated.[3]

Radial velocities are also required. For stars that are not known spectroscopic binaries, high-precision radial velocities are used whenever possible. Preference is given to results from photoelectric spectrometers and data of comparable precision. For a number of stars that lack such data, results of lower precision are used. Most of these latter data are of qualities "A" or "B," and they come largely from the catalog of Duflot et al. (1995). Some comparable results from sources listed in SIMBAD or by Barbier-Brossat et al. (1994) are also used. In a few cases where only illustrative space motions are required or where V is insensitive to radial velocity, quality "C," "D," or "E" data are adopted.[4]

For known spectroscopic binaries, this procedure must be modified. Spectroscopic binaries are identified in three ways: from notations in catalogs of photoelectric data, from sources cited in SIMBAD, and from the Batten et al. (1989) catalog. If a γ velocity is available for a given system, it is adopted, whether it is from photoelectric data or not. If no γ velocity is available, no space motions are calculated. Stars that are possible (but not certain) spectroscopic binaries are retained, and are treated as single stars. This is done because the burden of proof for rejecting data should rest on the case for excluding them (see Sect. 7.2).

For some adopted radial velocities, the precision is high enough to make zero-point differences potentially important. The zero point adopted here is that of the Beavers & Eitter (1986) catalog. This choice is supported by the measurements of Neese et al. (1985). Zero-point corrections given by Beavers & Eitter and by Fletcher et al. (1982) are applied as required. It is usually assumed that data that are not from photoelectric spectrometers are on the IAU system. However, this assumption is not made if data are taken from original sources containing pertinent zero-point information. Given the lower precision of

[3] In retrospect, the $n = 3$ relation of Hanson (1979) would have been a better choice in principle (see Fig. 2 of Reid 1998). However, the effects of making the change would be comfortably less than 1σ.

[4] Following Soderblom & Mayor (1993), space motions in the direction of galactic rotation are referred to by using "V," while visual magnitudes are referred to by using "m_V."

most data that are not from photoeletric spectrometers, this procedure is believed to be adequate.

Because rms errors for the space motions are required, rms errors for the input data must receive some attention. Here again, radial velocities require more effort than other kinds of data. For all input data except radial velocities, rms errors are readily available from SIMBAD. For many radial velocities, rms errors are available from original sources.[5] For catalog data of qualities "C," "D," and "E," the SIMBAD errors are used. For quality "B" data, the SIMBAD error of 2.0 km sec^{-1} is scaled up to 3.2 km sec $^{-1}$ (see Griffin 1971). For quality "A" data, the SIMBAD error of 0.9 km $^{-1}$ is cautiously scaled up in the same proportion, to 1.4 km sec^{-1}.

The computer program used to calculate space motions has been tested in two ways. Some tests have been made by using data for fictitious stars. The locations of those stars on the celestial sphere yield simple relations between U, V, or W and one or more input parameters. A test has also been made by using data listed for the Ursa Major supercluster by Soderblom & Mayor (1993). Their UVW values are recovered if no Lutz-Kelker corrections are made. Some differences are found between rms errors quoted by Soderblom & Mayor and those obtained here. However, the differences are never larger than 0.1 km sec^{-1} and so may be attributed to roundoff error.

3. Selections of groups, superclusters, and membership lists

The stellar groupings analyzed below include the Hyades and HR 1614 superclusters. The Wolf 630, ζ Her, 61 Cyg, HR 1614, σ Pup, η Cep, and Arcturus groups are also considered. These stellar groupings are relatively old, and they contain large proportions of stars for which metallicities can be determined. In addition, their mean metallicities are relatively high. This latter restriction is imposed by the data sources from which metallicities are secured (see Sect. 4).

Eggen has published a large number of membership lists for these stellar groupings. A given list is considered here only if it contains about 20 or more stars for which metallicities can be determined. This restriction makes it possible to obtain a statistically meaningful result for each adopted list. For stellar groupings other than the Hyades supercluster, the source papers by Eggen that are considered in this paper are listed in Table 1. (The source papers for the Hyades supercluster will be listed in Sect. 13.)

Griffin (1998) has noted that for the Pleiades supercluster, only about 1–10% of the stars listed as members by Eggen in the 1970s were still listed as members as of 1992. If this rate of turnover applies to the stellar groupings considered in this paper, some thought must be given to useful ways of obtaining meaningful results from Eggen's lists. However, it appears that pertinent numerical data have not been published for most stellar groupings. To see how serious the problem is, let each list considered here be regarded as an "iteration" of a group. Let the "replacement fraction" R_f be the fraction of stars that appear in a base iteration and are replaced in a previous or subsequent iteration. For iteration i, let $R_f(2)$ be the mean value of R_f for iterations $i+2$ and $i-2$. Similarly, let $R_f(N)$ be the mean of the two replacement fractions that are found when the first and last adopted iterations are compared. Finally, suppose for the sake of argument that each iteration is superior to the last, and that stars might legitimately change status once (from member to nonmember or vice versa) as the membership lists are improved. In this case, few or no stars should change status more than once. To see whether this is so, the fraction of stars with multiple status changes is calculated.

Results from these bookkeeping analyses are listed in Table 2. The HR 1614 group and supercluster are treated as a single stellar grouping at this point. For the moment, the only stellar groupings that are considered have more than two iterations.

[5] However, they are often not quoted in secondary sources. Despite Internet literature access, securing errors from original sources can still be quite laborious. Compilers of future radial-velocity catalogs are invited to include rms errors.

Table 1. Adopted lists of group and supercluster members[a]

Group	Sources
Wolf 630	Eggen 1965, 1969, 1971a, [1971b, 1971e][b], 1972a, [1974a, 1974b][c], [1977, 1978a][c], 1983
ζ Her	Eggen 1960, 1971c
61 Cyg	Eggen 1964, 1969, [1971a][d], [1971b][e], 1989a
HR 1614[f]	Eggen 1978b, 1987, 1989a, 1992b, 1996b, 1998c
σ Pup	Eggen 1970b, 1971c
η Cep	Eggen 1964, 1971c
Arcturus	Eggen 1971d, 1974b, 1977, 1983, 1987; Eggen & Iben 1989, 1991; Eggen 1996b, 1998a, b

[a] For adopted lists of members of the Hyades supercluster, see Table 12.
[b] One of the adopted lists includes stars listed in these two papers but not in Eggen 1971a.
[c] The lists of stars in these papers are combined to form one of the adopted lists.
[d] One of the adopted lists includes stars listed in this paper alone.
[e] One of the adopted lists includes stars listed in this paper and in Eggen 1971a.
[f] A list in Eggen 1998b is not used because it is based on pre-Hipparcos work and appears at the same epoch as the Hipparcos-based list in Eggen 1998c.

Table 2. Volatility tests of Eggen's membership lists

Stellar grouping	$R_f(2)$ [%]	$R_f(N)$ [%]	More than 1 status change [%]
Hyades[a]	57	88	43
Wolf 630	44	53	77
61 Cyg	49	39	41
HR 1614[b]	50	56	27
Arcturus	50	79	61

[a] Omitted: Eggen 1977 (only stars with new photometry), Eggen 1998d (stars with $M_V \leq 4$).
[b] Omitted: Eggen 1978b (partial RA coverage), Eggen 1998c (Hipparcos data).

Stars contribute to this analysis only if their metallicities will be used later on. The values of $R_f(2)$ given in Table 2 are means based on all feasible combinations of iterations. While values of R_f to match those in the Pleiades supercluster are not always found, R_f does turn out to be about 50% in the short term and 40–90% in the long term. In addition, the fractions of stars with multiple status changes range from 25% to 75%.

Clearly limited significance should be attached to results for any given iteration. This conclusion is worth noting because some published analyses of Eggen's groups have been based on a single iteration (see, for example, Méndez & Ruiz 1992). To see what selections of stars might be used instead, a paper by McDonald & Hearnshaw (1983) may be consulted. Those authors considered the color-magnitude diagram of the Wolf 630 group. They noted that for some iterations, Eggen applies either the label "certain members" or other labels that imply unusually high reliability. McDonald & Hearnshaw analyzed a number of those iterations. However, they also took note of all stars that Eggen designated as group members at least once. They attached greatest significance to results they obtained from a list of such stars.

A list of this sort will be referred to below as a "combined" list. In this paper also, results from combined lists will have greatest significance. Results from individual iterations will be used in two ways. At some times, the procedure of McDonald & Hearnshaw will be followed. At other times, results from some or all iterations for a stellar grouping will be used to supplement results from a combined list.

4. Metallicities: input data

4.1. High-dispersion results

The high-dispersion (H-D) results used in this analysis are from catalogs by Taylor (1995, 1999a). The input data for those catalogs are published values of [Fe/H] from diverse papers. Most of the input data are from H-D analyses, while the remainder are from photometry of clusters of weak lines. Zero points are established exclusively from the H-D results.

One of the catalogs contains entries for G and K stars with luminosity classes II-IV (Taylor 1999a). With few exceptions, the values of [Fe/H] for those stars exceed -0.9 dex. The other catalog contains entries for FGK stars on and near the main sequence (Taylor 1995). The metallicity range for those stars is comparable to the range for the evolved stars. All metallicities used here are either drawn from these two catalogs or are based on them indirectly. As a result, analyses are limited to stellar groupings with relatively high metallicities (recall Sect. 3).

If credibility is to be established for the catalogs, the corrections applied to their input data must be described. Opinions about the importance of particular corrections appear to be commonplace. The judgment made here, however, is that trustworthy corrections must be based on pertinent numerical evidence. Corrections are derived only from published evidence of this sort.

Two kinds of correction can be made. "Extrinsic" corrections are from published model-atmosphere results and line data. Corrections to uniform temperature scales are of this sort, as are nLTE corrections. No corrections are based on solar metallicities or f-value systems because the catalog data are, by design, strictly differential relative to the Sun. A second class of "statistical" corrections is obtained from statistical analyses of the input data. Statistical corrections include zero-point offsets and corrections that correlate with photometric colors. (For further information about the corrections, see Taylor 1994b, 1998a, 1999b).

4.2. Low-resolution results

Low-resolution (L-R) data are used to improve the scope and the precision of the data bases to be analyzed. L-R data are adopted only if they are based on the H-D catalogs described above. This is a necessary (but not always sufficient) condition for consistency of zero points. Numerical tests of that consistency will be discussed below (see Sects. 8 and 9).

Griffin & Holweger (1989) criticize the quality of L-R metallicities derived from model atmospheres. Those authors appear to be under the impression that such a procedure is widespread. Like most L-R metallicities, however, those adopted below are from statistical regressions of L-R data against H-D results. For the first four indices listed in Table 3, calibrations derived by Taylor (1999c) are used. For *uvby* data (the fifth entry in Table 3), rezeroed calibrations from Schuster & Nissen (1989) are adopted. Further information about the rezeroing and about the L-R indices used in this paper may be obtained from the footnotes to Table 3. The last three indices listed in that table are not used for reasons to be discussed below (see Sect. 5).

5. Metallicities: rms errors

The metallicities assigned to stars in each group have a certain amount of scatter. Some of that scatter is intrinsic, but the rest is produced by the accidental errors of the adopted metallicities. It is therefore essential to discuss those errors in some detail.

As before, the H-D data will be discussed first. The adopted rms errors for those data are quoted in the catalogs described above. The ultimate source for those errors is scatter in the input metallicities from which the catalogs are constructed. It should be noted that this scatter persists *after* the corrections described above have been made. The scatter is used to either derive or check the rms errors in the catalogs. (For further discussion of these errors, see Taylor 1994b, 1999b).

For L-R data, rms errors are derived in the calibration process. The net scatter around the calibration relations is easily calculated. Part of that scatter is from the known rms errors for the H-D data. The remainder is ascribed to the L-R data, and has been used to calculate rms errors for those data. This has been done by using version 1 of the data-comparison algorithm described below. (See Taylor 1999c and the third tool discussed in Sect. 6.2).

Calculated L-R rms errors are quoted in Table 3. For each of the last three entries in the table, there is an alternative L-R data source that yields metallicities with smaller rms errors.

Table 3. Data used to calculate L-R metallicities

Index	Luminosity classes	Sigma per datum (dex)	Index	Luminosity classes	Sigma per datum (dex)
DDO δCN	II-IV	0.06–0.12	$uvby^{\mathrm{d}}$	IV-V	0.10
G^{a}	II-IV	0.04	$M_1, (R-I)_{\mathrm{E}}$	III	0.11
D^{b}	V	0.09	$\delta_{0.6}(U-B)^{\mathrm{e}}$	V	0.17
$[\mathrm{M/H}]^{\mathrm{c}}$	IV-V	≥ 0.12	$\delta_{0.6}(U-B)^{\mathrm{f}}$	V	0.18

[a] Feature-strength index for giants. See Taylor & Johnson 1987.
[b] Feature-strength index for dwarfs. See Taylor & Johnson 1987.
[c] This quantity is read from the grid of Buser & Kurucz 1992, using $U-B$ and $[(R-I)_{\mathrm{C}} - 0.007$ mag] as arguments. Only data pairs with [(0.31 mag) $\leq (R-I)_{\mathrm{C}} \leq$ (0.66 mag)] are used. The quoted rms error applies if $\sigma(R-I)_{\mathrm{C}} \leq 0.008$ mag and $\sigma(U-B) \leq 0.02$ mag. Otherwise, an additional error is calculated through numerical differentiation of the grid. To obtain values of Cousins $R-I$, both directly-measured values of $(R-I)_{\mathrm{C}}$ and transformed values of $b-y$ and $R-I$ are drawn from the GCPD (Mermilliod et al. 1997). Transformations are from Taylor (1986, 1994a), but some zero points from those sources have been adjusted by comparing $R-I$ data bases.
[d] Data are used only if [(0.22 mag) $\leq b-y \leq$ (0.42 mag)]. The calibrations of Schuster & Nissen 1989 are adopted. The zero point of the F-star (G-star) calibration is adjusted upward by 0.070 (0.046) dex. The rms error of the adjustment is 0.008 (0.013) dex. With these adjustments, the calibrations yield data on the (field-star) zero point of the Taylor 1995 catalog.
[e] The rms error applies at [Fe/H] ~ -0.3 dex. The error has been derived from the following relation: [Fe/H] $= -2.19\,\delta_{0.6}(U-B) - 15.0\,[\delta_{0.6}(U-B)]^2$.
[f] The rms error applies at [Fe/H] ~ -0.3 dex. This error has been derived from a calibration quoted on p. 277 of Binney & Merrifield 1998.

For this reason, the data sources listed in the last three entries are not used here. Two of those entries are calibrated values of $\delta_{0.6}(U-B)$ (see, for example, Sandage 1969). Metallicities derived from that index are quite common in the literature.

The relative sizes of the H-D and L-R errors must be considered. Some spectroscopists assume that since H-D data are superior in principle to L-R data, the rms errors for H-D data must be superior as well. There are two problems with this syllogism: it assigns too much weight to a priori reasoning, and it assumes that judgments about systematic and random effects must necessarily be identical. In fact, the two kinds of effect differ fundamentally. The only reliable way to assess random effects is to determine their sizes from numerical analysis. When this is done, one finds that many H-D results have an unknown source of accidental error (see Sect. 5.3 of Taylor 1999b). Partly for this reason, the rms error for H-D results for a given star is quite often larger than the rms error for L-R results for that star. Such situations will be accepted below in a matter-of-fact way, and will play a role in the choices of data to be analyzed. (See the description of “procedure A” in Sect. 8.2).

6. Analyzing the metallicities: statistical tools

6.1. Notation and basic statistical tools

It is assumed here that readers are familiar with variance-ratio, t, and χ^2 tests, and with null hypotheses, false-alarm probabilities (p) and confidence limits ($C \equiv 1-p$). For formal rejection of null hypotheses, the default condition applied below is $p < 0.001$. The reasoning that leads to this condition is given in Appendix A. Exceptions to the rule will be explained as they occur.

Results of statistical tests are reported by using values of $P \equiv -\log p$. When gauging values of P, it will be useful to remember the following list of equivalent values:

1. $P = 1.3$, $p = 0.05$, $C = 0.95$.
2. $P = 3$, $p = 10^{-3}$, $C = 0.999$.
3. $P = 6$, $p = 10^{-6}$, $C = 0.999999$.

As the third entry in the list shows, values of P are somewhat easier to grasp than values of p or C when C is very close to unity.

6.2. More advanced statistical tools

There are five statistical tools used here that are somewhat more advanced than those mentioned above. One of these tools is the unequal-variance t test. A good description of this test is given by Bethea et al. (1985), and a numerical example of the test may be found in the notes to Table 3 of Taylor (1992).

A second tool is a generalized version of the Thompson (1935) t test. This test is used to identify possible wild points. Suppose that in a data set $[x]$ with N members, the datum x_i has an rms error σ_i. Let a weighted average $\langle x\rangle$ for the set be obtained by using weights $w_i = \sigma_i^{-2}$. Then, for entry x_i, let

$$u_i = [x_i - \langle x\rangle]/\sigma_i. \qquad (1)$$

The statistic to be tested is then

$$t_T(i) = u_i \left[\frac{N(N-2)}{(N-1)^2 - N u_i^2}\right] \qquad (2)$$

and has $N-2$ degrees of freedom.

The third of the five tools is a data-comparison algorithm. Only a conceptual summary of this algorithm will be given here; a detailed derivation appears in Taylor (1991, Appendix B, Eqs. (B1) through (B44)). Let “version 1” of the algorithm be considered first. Suppose that data sets $[x]$ and $[y]$ are to be compared, with each set having the same number of members. Suppose further that the set of rms errors $[\sigma_y]$ is known, and that the members of $[x]$ have a single (but unknown) rms error

σ_x. Let the set $[x - y]$ now be calculated. Conceptually, one may say the following: (the scatter produced by the single error σ_x) + (the scatter produced by $[\sigma_y]$) = (the total scatter). Since the last two terms in this equation are known, the first term–and hence σ_x–may be calculated. In addition, a weighted mean offset between $[x]$ and $[y]$ may be obtained. (A version of this technique first appeared in the literature not later than 1971; see Griffin 1971).

The fourth tool is a variation on the third, and is referred to below as "version 2" of the algorithm. Let $[x]$ be replaced by an estimated mean value $\langle y \rangle$. Conceptually, one may now say the following: (inherent scatter) + (the scatter produced by the $[\sigma_y]$) = (the total scatter). The "inherent scatter" is the scatter around $\langle y \rangle$ that would persist if all the σ_y were zero. That scatter is approximated by a Gaussian for which a standard deviation σ_w is calculated. In addition, a weighted mean correction to $\langle y \rangle$ is obtained, and is applied to produce a final value of $\langle y \rangle$.

The fifth tool is random-number modelling. This technique is applied below to the mean metallicity and metallicity dispersion for the Hyades supercluster (see Sect. 13). Random numbers are converted to distributions with zero mean and unit variance by applying an algorithm from Zelen & Severo (1972). At least 10^5 samples are used for each model.

7. Correcting and editing input data

7.1. Reddening corrections

Many of the input data are photometric colors, so some thought must be given to correcting those data for reddening. Fortunately, reddening is not a serious problem because there is little or none of it for the nearby stars from which Eggen assembled his lists (Perry et al. 1982, Tinbergen 1982, Leroy 1993). This condition does result in one drawback: it is quite possible to apply reddening corrections to data for unreddened stars. To limit the number of such mistakes, reddening corrections are applied only if $E(B-V) \geq 3\sigma$.

For class II-IV stars, an adaptation of the Janes (1977) technique is used (see Sect. 5.2 of Taylor (1998a). Reddenings from this technique appear to be independent of metallicity. For late G and K IV-V stars, no reddening corrections are made. Instead, it is assumed that the intrinsic faintness of these stars has enforced a selection of nearby, unreddened examples for moving-group membership.

For F and early G IV-V stars with values of β, those data are combined with values of $(R-I)_{\rm C}$ to estimate reddenings. This technique is based on a discussion in Taylor (1994a), and it yields values of $E(B-V)$ that are quite insensitive to metallicity (see Sect. 5.2 and especially Fig. 4 of Taylor 1994a). For values of $E(B-V)$ from this technique, the rms error is 0.011 mag. The fraction of reddened F-G stars found with this technique is small, so it seems safe to assume that F-G stars without values of β are unreddened.

7.2. Data editing: principles

In addition to reddening corrections, the input data require some editing. Before the editing done below is described, however, the basic principles of data editing will be reviewed. This will be done because those principles are often misunderstood. The risk of overediting data is widely courted (see Appendix A). Moreover, conservative data editing is sometimes challenged by referees who want data to be deleted for specious reasons.

The principal risk of data editing is that it may lead to biased conclusions. Intentional bias is not the only possibility; unconscious bias is at least as likely. Some conservative statisticians do not delete possibly discrepant data at all. If one does not go this far, it is necessary to show referees and other readers that editing does not lead to biased results.

When editing data, a good rule of thumb is to use only information that is a) numerical and b) specific to the data being tested. Generalizations that are not supported by such information may be unproven, irrelevant, or inaccurate, and it is prudent not to risk acting on them. (Recall that an example of an irrelevant generalization was cited in Sect. 4.2.) One acceptable way to edit data is to use extrinsic numerical information that is known to apply to them specifically. Another acceptable way is to consider the locations of the data in histograms. In this latter case, inspection should be used only to identify possible wild points. Final decisions about these data should be based solely on statistical tests. Relying on inspection without the use of such tests is a second risk which should be avoided. The reason is that inspection is biased in the direction of discrepancies and can falsely identify wild points where none actually appear. (An illustration of this problem is described in Appendix B.)

In the discussion to be given in the next subsection, only editing based on extrinsic information will be discussed. A single case of histogram-based editing is mentioned in the notes to Table 7 (see below). Histogram editing that is done to test the sensitivity of results to possible wild points will be discussed in Sect. 10.

7.3. Data editing based on extrinsic information

Data editing requiring extrinsic information is done in response to three problems. One of those problems has been highlighted by Griffin (1998), who notes that some stellar catalog numbers given by Eggen are affected by typographical errors. All catalog numbers used here are therefore verified. This is done by first comparing information from Eggen's papers. Star numbers that appear in more than one paper are deemed to be valid. Star numbers that appear in only one paper are then checked. Depending on the information in Eggen's tables, use is made of m_V, radial velocities, spectral types, proper motions, and catalog numbers other than HR and HD numbers. Most of this information is secured from SIMBAD.

Another potential problem is posed by close visual binaries. The combined light from a binary is not necessarily matched by the light from any single star. To explore this problem, model visual binaries are calculated. The algorithm used for this purpose

Table 4. Data sources for adopted clusters

Kind of data	Cluster(s)	Luminosity class	Data sources
H-D	Hyades	V	Taylor 1994c[a]
DDO	M67	III-IV	Janes & Smith 1984
$uvby$	Hyades, Coma	V	Crawford & Perry 1966[b], Crawford & Barnes 1969a, Taylor & Joner 1992
$uvby$	Praesepe	V	Crawford & Barnes 1969b
D	Hyades	V	Taylor 1970[c], Taylor & Johnson 1987[d]
[M/H]	Hyades	V	Johnson et al. 1962[e], Pesch 1972[e], Taylor & Joner 1985[f], Joner & Taylor 1988[f]

[a] See also the references to original sources in this paper. Taylor 1994c also reviews H-D results for Coma, using rms errors quoted by Taylor 1995. However, there is marginal evidence from a χ^2 test $(P = 2.2)$ that those errors are actually too large. As a result, Coma H-D results are not used here.
[b] In this source, data are found for vB 98 and vB 125. However, data for those stars are not used because they are not members of the Hyades. (See Table IV of Griffin et al. 1988.)
[c] Source for raw data.
[d] Source of D from analyzed raw data.
[e] Used for $U - B$.
[f] Used for $(R - I)_{\rm C}$.

is based on relations in Table 5 of Taylor (1994a). Relations between $U-B$ and $R-I$ from Johnson (1966) and Taylor (1986) are added. For values of [Fe/H] derived from $U-B$ and $R-I$, the modelling reveals that errors as large as 0.36 dex may be expected for some binaries.

The next step is to search Eggen's lists for visual binaries with only combined-light measurements. Such binaries are identified by using the Dommanget & Nys (1994) catalog. It is often assumed that measurements of binaries with separations greater than 8 arc sec refer only to their primaries. However, the General Catalogue of Photometric Data (GCPD; Mermilliod et al. 1997) is also consulted, since it includes notations about combined-light measurements. Editing is then based on a threshold value of 0.10 dex, which corresponds to about 1σ for many calculated values of [Fe/H]. If modelling reveals that the error due to binarity is about 0.10 dex, the metallicity is corrected. For smaller errors, no corrections are made. Data with larger errors are set aside.

Spectroscopic binaries (SBs) are also considered. Since values of m_V(secondary) $-m_V$(primary) are almost never available for SBs, one cannot assess their data in the manner used for visual binaries. With one exception, the adopted solution is to assume that SBs have an equal effect on comparison samples (see below) and groups. The exception is the D index, for which comparisons of Hyades SBs with other Hyads reveal a systematic error. Hyades SBs are identified by using information from Griffin et al. (1988) and Mason et al. (1993), and their values of D are excluded. For field stars, sources mentioned in Sect. 2 are consulted. No known field-star SBs with values of D are used in the analyses.

8. Test and comparison samples

Breger (1968) appears to have been the first to use comparison samples in an analysis of a moving group. This idea is pivotal and has been adopted here. Two comparison samples and two test samples will be considered.

8.1. *The cluster comparison sample*

Since galactic clusters are the postulated sources of superclusters and moving groups, it is natural to select some galactic clusters as one of the comparison samples. The adopted clusters include the Hyades, Praesepe, Coma, and M67. Since the Hyades supercluster is being considered, the Hyades cluster is a natural choice of comparison sample, and it appears to have been first used in this way by Breger (1968). An advantage the Hyades cluster offers is an extensive set of H-D results that have been collected and analyzed by Taylor (1994c). Coma, like the Hyades, is a cluster with useful Strömgren photometry. Praesepe is included because Eggen (1970a) has compared this cluster to the Hyades group (as it was designated at the time). M67 is included to compensate for the shortage of GK giants in the other three clusters. The data sources consulted for these clusters are listed in Table 4.

8.2. *Kinematically unbiased samples of field stars*

Breger (1968) has also compared the Hyades group to a field-star sample. Two such samples are considered here. The "extended Survey" (Johnson et al. 1987) contains GK class II-IV stars in the Bright Star Catalogue (Hoffleit & Jaschek 1982) that are located in a specified part of the sky. Eggen (1989a) has published a sample which has an explicit upper limit in $(R - I)_{\rm E}$, but is otherwise similar.

At this point, one must decide whether volume-limited or magnitude-limited samples would be more appropriate. Eggen's discussions have therefore been consulted for clues. As far as one can tell from those discussions, Eggen did not construct moving-group lists from volume-limited samples like the

Table 5. Magnitude-limited random samples of field stars

Sample	Mean [Fe/H] (dex)	σ_w (dex)[a]	Number of stars
Taylor & Johnson 1987	-0.125 ± 0.018	0.112(23)	103
Eggen 1989b	-0.115 ± 0.009	0.140(611)	799
Net comparison	-0.116 ± 0.008	0.137(623)	902

[a] The numbers in parentheses are numbers of degrees of freedom.

Gliese-Jahreiss catalog (Gliese & Jahreiss 1979). In addition, Eggen makes no mention of selection procedures that are designed to secure volume-limited samples. It therefore seems fair to assume that Eggen used magnitude-limited samples instead. That assumption is adopted, and (as the reader may have noted) both samples described above are magnitude-limited.

The consistency of the two samples must now be tested. To prepare for the test, each sample is analyzed in the following way. For each star in the sample, the most precise available value of [Fe/H] is chosen. H-D data have no inherent priority; if an L-R datum has a smaller rms error, it is adopted (recall Sect. 5). Version 2 of the data-comparison algorithm is then applied (recall Sect. 6.2). The output from that algorithm includes σ_w (recall Sect. 6.2) and also F, the mean value of [Fe/H] for the sample. This procedure will be referred to below as "procedure A."

Results from procedure A are given in Table 5. An unequal-variance t test shows that the values of F for the two samples do not differ with $P \geq 1.3$. Moreover, a variance-ratio test yields the same outcome for the tabulated values of σ_w. The two samples are therefore combined into a "net comparison" sample, to which procedure A is applied. The resulting values of σ_w and F appear in the third line of Table 5.

8.3. Pseudogroups and numerical tests

Before proceeding with the analysis, one would like to know whether H-D and L-R data yield the same results. One way in which this question is approached is by analyzing pseudogroups. Pseudogroups are groups of field stars that are not known to be related kinematically. By design, they are large enough so that large numbers of both H-D and L-R data are available for them.

For giants, the net comparison sample is treated as a pseudogroup. For dwarfs, a pseudogroup is chosen from the stars used by Taylor (1999c) to obtain L-R calibrations. Only dwarfs with values of [Fe/H] that are ~ -0.7 dex or greater are considered.

Each pseudogroup is analyzed twice by using modified versions of procedure A. In one such version, only H-D data are adopted. In another version, the most precise L-R datum that can be found for each star is adopted. The results from procedure A are values of F$(H-D)$ and F(L-R), respectively. A difference $\Delta F = F$(H-D) $-$ F(L-R) is now calculated. The unequal-variance t test is then used to obtain a 95% confidence interval for the null hypothesis that $\Delta F = 0$. If ΔF falls outside that interval, the null hypothesis is rejected with $P > 1.3$. For values of σ_w, a similar procedure is used, but a ratio is calculated instead of a difference and the 95% confidence interval is obtained by using the F statistic.

Table 6. Tests of L-R results against H-D results for field stars

Statistic	Giants	Dwarfs
Predicted quantity	Δ[Fe/H][a]	Δ[Fe/H][a]
Units	Dex	Dex
Number of H-D data	316	370[b]
Number of L-R data	891	367[b]
Statistic used to make the prediction	t	t
Predicted 95% confidence interval	±0.022	±0.038
Derived value	$+0.018$	-0.004
Predicted quantity	σ_w(LR)	σ_w(LR)
Units	Dex	Dex
Number of H-D data	316	370[b]
Number of L-R data	891	367[b]
Statistic used to make the prediction	F	F
Predicted 95% confidence interval	$0.125 \rightarrow 0.185$	$0.211 \rightarrow 0.267$
Derived value	0.136	0.240

[a] This is the mean H-D value of [Fe/H] minus the mean L-R value of [Fe/H].
[b] Only stars with [Fe/H](HD) greater than about -0.7 dex are used.

The results of these tests are given in Table 6. Note that all of the tested data fall inside their corresponding confidence intervals. If this were not the case, further tests using the default threshold value of this paper ($C = 0.999$; $P = 3$) would be required. As matters stand, results from H-D and L-R data cannot be distinguished from each other. Note, however, that this encouraging conclusion applies specifically to field stars. The importance of this restriction will quickly become clear.

9. A first general analysis

9.1. Choosing an algorithm

Now that preparations have been described in some detail, the principal results of this paper may be presented. The first of those results is based on a paradigm Eggen often used. Suppose that each stellar grouping listed above has evaporated from a single galactic cluster. Suppose further that Eggen's lists contain few or no nonmembers. In this case, the metallicity scatter of each stellar grouping should resemble that of galactic clusters. This hypothesis will now be tested.

First, however, a problem must be surmounted. The success of tests of L-R data for field stars does not guarantee a similar success for clusters. In fact, if the Hyades dwarfs are considered, one definite and two possible differences between H-D and L-R data are found. This is shown in Table 7.

In retrospect, the contrast between the results in Tables 6 and 7 is unsurprising. Consider L-R metallicities in general, and let metallicities derived for field stars from CN bands be considered first. Since these stars were formed under a variety of conditions, their CN strengths may have an intrinsic scatter relative to metallicity. Such scatter is, in fact, the source of most of the rms error range quoted for DDO CN metallicities

Table 7. Differences between L-R and H-D data for the Hyades dwarfs[a]

Kind of data	[Fe/H] difference predicted from field stars (dex)	Actual difference (dex)	P[b]
$uvby$	0.000 ± 0.007	$+0.081 \pm 0.016$	**4.9**
D	0.000 ± 0.019	-0.096 ± 0.033	1.8
[M/H]	0.000 ± 0.012	-0.088 ± 0.025[c]	2.6

[a] The adopted H-D value of [Fe/H] for the Hyades dwarfs is $+0.107 \pm 0.010$ dex (see Taylor 1994c, Sect. 3, and Appendix B). All differences are in the sense "L-R minus H-D."
[b] This is the value of P for a difference between the two quoted means, as determined from an unequal-variance t test. If $P > 3$, P is stated in boldface.
[c] The data pair for vA 135 is a wild point with $P > 6$. Those data are rejected before this average is calculated. The data are retained, however, when $\mathrm{Sc}(0.137)$ is tested (see Tables 8 and 9).

in Table 3. In contrast to field stars, however, cluster stars have a common origin. They can therefore have unusually strong or unusually weak CN bands for their common metallicity. If there is also intrinsic scatter in their CN strengths, a systematic offset may still be detectable. Suppose now that this argument applies to any L-R index, whether it measures CN bands, other localized absorption features, or blanketing. The definite and possible offsets in Table 7 may then be understood.[6]

Procedure A requires H-D and L-R data to have the same zero points. Since one does not know at this point whether cluster offsets will be found in the stellar groupings or not, procedure A must either be modified or set aside. One possible alternative is to restrict procedure A to H-D results and L-R data for which no "cluster offsets" with $P \geq 3$ can be found. However, this approach might leave aside a number of useful data, and it might still be affected by real offsets that cannot be detected at $P \geq 3$ with data analyzed here. A better procedure is to design a statistic that is not sensitive to the offsets in the first place. This is done in the following way. Let $j = (1, 2, 3, 4, 5)$ represent H-D, DDO, *uvby*, D, and [M/H] metallicities, respectively. Let $N(j)$ be the number of data for source j. For the ith datum for source j, let $F_{ij} = \mathrm{[Fe/H]}_{ij}$, and let σ_{ij} be the rms error of F_{ij}. An index $\mathrm{Sc}(\sigma_w)$ is now obtained from the following equations:

$$w_{ij} = \left(\sigma_{ij}^2 + \sigma_w\right)^{-1}, \qquad (3)$$

$$\langle F_j \rangle = \left(\sum_{i=1}^{N(j)} w_{ij} F_{ij} \right) \bigg/ \left(\sum_{i=1}^{N(j)} w_{ij} \right), \qquad (4)$$

$$s_j = \sum_{i=1}^{N(j)} w_{ij} \left(F_{ij} - \langle F_j \rangle \right), \qquad (5)$$

$$\nu_j = N(j) - 1, \qquad (6)$$

$$\mathrm{Sc}(\sigma_w) = \left(\sum_{j=1}^{5} \nu_j \right) \bigg/ \left(\sum_{j=1}^{5} s_j \right). \qquad (7)$$

Systems of equations seldom make complete sense on first examination, so presumably some explanations are in order at this point. In Eq. (5), s_j is χ^2 distributed with ν_j degrees of freedom and so has an expectation value ν_j (Kshirsagar 1983, p. 341). If ν_j is substituted for s_j in Eq. (7), one finds at once that $\mathrm{Sc}(\sigma_w) = 1$. Note, however, that an adopted value of σ_w need not be appropriate for the data being analyzed. If σ_w is in fact too large (too small), $\mathrm{Sc}(\sigma_w)$ will be larger (smaller) than unity. This direct relationship is enforced by defining $\mathrm{Sc}(\sigma_w)$ as a reciprocal value of χ^2/ν [see Eq. (7)]. Finally, the potential problem posed by cluster offsets is resolved by using an *individual* mean metallicity $\langle F_1 \rangle$ for H-D data and corresponding means for each kind of L-R datum. Readers are invited to verify that if a cluster offset δF is added to the F_{ij} for a particular value of j, $\mathrm{Sc}(\sigma_w)$ is unaffected [see Eqs. (4) and (5)].

9.2. Applying the algorithm

A test value of σ_w must now be chosen. The adopted value of σ_w is 0.137. This is the number derived above for field stars in the net comparison sample (see Table 5), so it should be decisively too large for clusters. One would like to know whether it is also too large for moving groups and superclusters.

For each stellar grouping to be tested, an observed value of $\mathrm{Sc}(\sigma_w)$ is obtained by using Eqs. (3)-(7). A predicted value of $\mathrm{Sc}(\sigma_w)$ is also calculated. This is done by carrying cluster values of s_j/ν over to the groups. More specifically, Eq. (5) is replaced by the following relation:

$$s_j'(\mathrm{group}) = [s_j(\mathrm{cluster})/\nu_j(\mathrm{cluster})] \times \nu_j(\mathrm{group}). \qquad (8)$$

Both observed and predicted values of $\mathrm{Sc}(\sigma_w)$ are then tested for statistical significance by using the χ^2 statistic. This algorithm will be called "procedure B."

Procedure B is applied to two sets of data, with the first set including individual iterations. If Eggen indicates that a membership list contains "certain" members, or if he applies some equivalent designation, the list is considered here. Iterations are also included if Eggen finds that their metallicities cohere closely without metallicity editing. The results of these tests are given in Table 8. If σ_w is found to be too small (too large) with $P \geq 3$, $\mathrm{Sc}(\sigma_w)$ is listed in Table 8 in italics (boldface). In addition, the iterations are ordered in the table by the number of stars they contain, with the smallest numbers coming first. For this reason, the first results given in Table 8 are those that are least likely to be statistically significant. Allowing for this effect, one can see that the predicted values of $\mathrm{Sc}(\sigma_w)$ (see the fourth column of Table 8) are quite consistently too large. This means that if the stellar groupings resemble clusters, $\sigma_w = 0.137$ is almost always too large to apply to their metallicity dispersions, as one might expect. On the other hand, the observed values of $\mathrm{Sc}(\sigma_w)$

[6] Note that a systematic L-R offset in a cluster cannot be diminished by averaging. If an L-R metallicity is being considered, it is therefore useful to think of cluster stars as if they were a *single* field star with an irreducible residual from the relation between the L-R index and [Fe/H]. For values of [Fe/H] derived from that index, the mean rms error for the cluster stars is then the same as the rms error for a single field star.

Table 8. Sc(0.137): individual iterations

Group	Iteration	Number of stars	Predicted Sc(0.137)[a]	Observed Sc(0.137)[a]
61 Cyg	1971	21	2.1	0.9
Arcturus	1996	26	*2.1*	0.9
Arcturus	1987	28	*2.0*	**0.4**
Arcturus	1989	29	*2.1*	0.9
Arcturus	1998	33	*2.2*	1.1
Hyades[b]	1992	33	*3.2*	1.4
Wolf 630[c]	1971	38	*2.5*	0.7
HR 1614[d]	1992	39	*2.1*	1.0
HR 1614[d]	1989	49	*2.1*	0.8
Hyades[e]	1966	61	*2.4*	1.2
Hyades[e]	1989	71	*2.5*	0.9

[a] If $P > 3$, a non-roman type face is used. Italics mean that σ_w is too large; boldface means that σ_w is too small.
[b] See Table 10 for a complete list of Hyades iterations.
[c] Only group members designated as "certain" by Eggen are considered.
[d] A number of the stars with data used here may be non-members. See Sect. 12.
[e] See Table 10 for a complete list of Hyades iterations. Stars designated by Eggen as "possible" members or nonmembers are not considered.

(see the fifth column of the table) are about 1 or less and are in roman typeface (with one boldface entry). This means that $\sigma_w = 0.137$ is actually about the right size for the stellar groupings, though it may sometimes be too small. Apparently the metallicity dispersions of the stellar groupings do not in fact resemble those of clusters. Instead, they resemble the dispersions for random collections of field stars.

For combined group lists, results are given in Table 9. At this point, analyses of H-D data alone are done because there are usually enough of them to yield meaningful results. Results from such analyses are given, as are results from H-D and L-R data combined. The reader is invited to inspect Table 9 by using experience gained from Table 8. The conclusions drawn here are much the same as those drawn previously. Note, however, that $\sigma_w = 0.137$ is now too small in a larger fraction of cases than before. Presumably this is a result of having more data from combined lists than are available for individual iterations.

The results of the analyses may be summarized by using membership fractions, which will be designated as f_M. Three states of f_M may be distinguished.

1. $f_M = 1$: the group exists, and there is no contamination by nonmembers.
2. $0 \leq f_M \leq 1$: the group exists, but there is contamination by nonmembers.
3. $f_M = 0$: the group does not exist.

It seems clear that $f_M \neq 1$. If $f_M = 0$, no further tests are required. However, it is not safe to make this assumption, since f_M may lie between 0 and 1 for some or all of the stellar groupings tested. To keep the road of inquiry open, it will therefore be assumed for the present that those groupings exist but are contaminated by nonmembers. Since the metallicity dispersions of the groupings resemble those of the net comparison sample, the contamination must be substantial.

10. A second general analysis

The heavy contamination offers an advantage, since it probably dilutes into insignificance any cluster offsets that may be present. As a result, procedure A may be used again. Recall that that procedure, unlike procedure B, yields mean group metallicities (values of F). This advantage will now be exploited.

Results from procedure A are given in Table 10. Most of the entries in the table are for combined sets. However, entries are also given for a specific iteration of the 61 Cyg group. The scatter in results for various iterations of this group is somewhat greater than average, so results for an example iteration are given. They may be compared to combined-set results to gauge the size of the scatter.

Values of σ_w and $|t_T|$ appear in Table 10, with t_T being the modifed Thompson t statistic discussed in Sect. 6. Each quoted value of $|t_T|$ is the largest value for the stars in a given sample. Note first that the values of σ_w are about as expected from the procedure B results. Note also that the values of $|t_T|$ are all < 5. This shows that the quoted values of σ_w are not produced by a few wild points with (say) $|t_T| \sim 10$–20. To explore this issue further, some analyses are done after the datum for the star yielding the largest value of $|t_T|$ has been deleted. The results of these analyses are not very different from those obtained without editing. (Compare the Table 10 entries with footnotes "f," "g," and "h" to their listed counterparts.)

In Table 10, boldface entries are used to identify results that differ from those for the net comparison sample with $P \geq 3$. With the help of those results, the listed stellar groupings can be divided into four sets. For one set, no detectable differences are found between the stellar groupings and the net comparison sample. This set includes the ζ Her, 61 Cyg, and Wolf 630 groups. For giants in the third of these groups, Boyle & McClure (1975) have presented a DDO CN histogram (see their Fig. 8). They note that their histogram resembles that for a field-star sample. The Table 10 results show that this resemblance persists when statistical tests are employed.

At this point, one must remember that the stellar groupings may be nonexistent instead of being merely contaminated. There seems to be no hope of using metallicities to resolve this ambiguity. Apparently color-magnitude diagrams cannot be used to resolve it either, judging from the results of McDonald & Hearnshaw (1983). For the moment, it appears that judgment about these groups must be derived from kinematic results alone. One notes that the extensive post-Hipparcos kinematic analysis of Dehnen (1998) yields no unambiguous evidence that these groups exist.

A second set of groups includes the σ Puppis and Arcturus groups. These groups have lower metallicities and higher metallicity dispersions than those of the comparison sample. Given the large group values of $|V|$, such results are not surprising. To decide rigorously what they mean, however, one would have to compare them to algebraic relations between V, F, and σ_w for

Table 9. Sc(0.137): combined lists

Group	ν(HD)[a]	Predicted Sc (H-D)[b]	Observed Sc (H-D)[b]	ν(all)[a]	Predicted Sc (all)[b]	Observed Sc (all)[b]
ζ Her	9	5.9	1.0	41	*2.3*	0.7
HR 1614[c]	14	*5.9*	1.0	114	*2.1*	0.8
σ Pup	15	*5.9*	**0.1**	54	*2.4*	**0.2**
η Cep	17	*5.9*	**0.4**	53	*2.6*	**0.5**
Arcturus	21	*5.9*	0.5	140	*2.1*	**0.4**
61 Cyg	22	*5.9*	**0.4**	84	*2.4*	**0.5**
Wolf 630	47	*5.9*	0.6	154	*2.8*	0.8
Hyades	95	*5.9*	0.9	484	*2.7*	0.9

[a] $\nu \equiv$ (number of data) -1.
[b] If $P > 3$, a non-roman type face is used. Italics mean that σ_w is too large; boldface means that σ_w is too small.
[c] A number of the stars with data used here may be non-members. See Sect. 12.

Table 10. Results from procedure A for groups and the Hyades supercluster

Group	Iteration	Approximate V (km sec^{-1})	Mean [Fe/H] (dex)[a]	σ_w (dex)[b]	$\|t_T\|$[c]
Hyades	Combined	-17	$\mathbf{-0.02 \pm 0.01}$	0.16	3.7
Hyades[d]	Combined	-17	$\mathbf{-0.02 \pm 0.02}$	0.15	-
HR 1614[e]	1978–98	-58	$\mathbf{0.01 \pm 0.02}$	0.17	2.7
HR 1614[f]	-	-58	$\mathbf{0.04 \pm 0.03}$	0.14	3.5
Wolf 630	Combined	-31	-0.12 ± 0.02	0.16	4.6
Wolf 630[g]	Combined	-31	-0.11 ± 0.02	0.15	3.0
ζ Her	Combined	-48	-0.12 ± 0.04	0.18	3.7
61 Cyg	Eggen 1964	-50	-0.17 ± 0.03	0.15	2.4
61 Cyg	Combined	-50	-0.20 ± 0.03	**0.19**	3.1
η Cep	Combined	-84	-0.18 ± 0.04	0.23	2.1
σ Pup	Combined	-72	$\mathbf{-0.43 \pm 0.06}$	**0.33**	3.5
σ Pup[h]	Combined	-72	$\mathbf{-0.39 \pm 0.05}$	**0.29**	2.4
Arcturus	Combined	-119	$\mathbf{-0.46 \pm 0.03}$	**0.26**	3.7
Arcturus[j]	Combined	-119	$\mathbf{-0.45 \pm 0.03}$	**0.24**	2.6

[a] If a result in this column exceeds its counterpart for the combined random sample with $P > 3$, the result is stated in boldface. For all such results in this column, $P \geq 5.1$.
[b] If a result in this column exceeds its counterpart for the combined random sample with $P > 3$, the result is stated in boldface.
[c] This is the modified Thompson t index described in Sect. 6b. For each iteration, the largest value of $|t|_T$ found for any star is given.
[d] The mean value of [Fe/H] is from H-D results only. The quoted value of σ_w has been averaged from separate calculations using H-D, DDO, $uvby$, and [M/H] results.
[e] No data for HR 1614 contribute to these results because of a possible disagreement between H-D and L-R metallicities for this star.
[f] An H-D metallicity for HR 1614 is included in this sample ([Fe/H] $\sim +0.2$ dex; Feltzing & Gustafsson 1998). The L-R metallicity from D is ~ 0.4 dex higher, and would increase the derived mean value of [Fe/H] if it were included. See Sect. 12 for further information about this sample.
[g] Data for HD 23841 have been omitted.
[h] Data for HD 211998 have been omitted.
[j] Data for HD 31128 have been omitted.

random samples of disk stars. At present, such relations do not seem to have been published. Here again, one must fall back on the results of Dehnen, who finds evidence for the existence of the Arcturus group but not the σ Puppis group.

A third set of groups includes the η Cep group alone. There is no evidence in Dehnen's results that this group exists. If one nevertheless assumes that it does exist, its high value of $|V|$ suggests that its metallicity properties should resemble those of the Arcturus group. Instead, they resemble those of the net comparison sample. Exactly what this means, however, cannot be determined until the relationships between V and metallicity for disk stars are available in algebraic form.

A fourth set of stellar groupings includes the HR 1614 group and supercluster and the Hyades supercluster. These stellar groupings turn out to have mean metallicities that exceed those of the net comparison sample. The mean field-star metallicity seems to be independent of V for $|V| < 60\,\mathrm{km\ sec^{-1}}$, so these enhancements cannot be explained at once as V effects (see Fig. 10.36 of Binney & Merrifield 1998, which is based on data by Nissen & Schuster 1991 and Carney et al. 1996). Further analyses of the stellar groupings in this set seem warranted.

11. The HR 1614 supercluster

The next issue considered is the existence or nonexistence of the HR 1614 supercluster. Tests to resolve this question will be made on the "Hipparcos version" of the supercluster (Eggen 1998c). Presumably this version is the most definitive of those that Eggen has published.

In one test for the reality of this supercluster, Eggen derives a parallax π(cluster) for each of its stars by using a convergent point. He then obtains a mean value of π(cluster) $-\pi$(Hipparcos) from all the supercluster stars. Eggen lists pertinent data for those stars in his Table 1, with rms errors for the Hipparcos parallaxes being included. By inspecting that table, one finds two notable anomalies. For HD 210277, π(cluster) $-\pi$(Hipparcos) $\neq 0$ at the 11σ level. For HR 1614 itself, the corresponding residual differs from zero at the 18σ level.

To look into this problem more closely, a modified version of a test that Eggen applies to groups is used. In this test, the value of V for each group star is compared to a target value V_t. The procedure used here differs from that of Eggen in two ways: Lutz-Kelker corrections are applied, and rms errors in V are used to gauge departures from V_t. (Recall that the procedures used to calculate space motions were described in Sect. 2.)

The results of the calculations are given in Table 11. Since the radial velocities used in this analysis often differ from those used by Eggen, they are given in the table along with literature sources. Particular attention should be paid to the values of t that are listed in the table. Those data are not values of the Thompson t statistic described in Sect. 6. Instead, they express residuals from V_t in units of rms error (see note "a" to Table 11).

Inspection of the listed values of t yields the following results. For two stars considered by Eggen, σ_π/π is too large for the simplest possible Lutz-Kelker correction to be applied. These stars may be set aside without influencing the rest of this discussion. For a number of other stars, V is within 2σ of V_t. However, this agreement has limited meaning because $\sigma(V)$ is relatively large. HD 203875 is the most prominent member of this class. As before, there is a substantial residual for HD 210277. Likely the most striking listings, however, are for HR 1614 itself. When Eggen first discussed the HR 1614 group, the available data for HR 1614 yielded a value of V that is within 1σ of V_t (see the first entry for HR 1614). However, the $\pm 2\sigma$ uncertainty in V was nearly $15\,\mathrm{km\ sec^{-1}}$. Now that V can be calculated from Hipparcos astrometry and photoelectric radial velocities, it differs from V_t by 12σ (see the second entry for HR 1614).

In Eggen's procedure, an error-free value of V_t is adopted. For the sake of argument, that procedure has been followed up to this point. If the rms error of V_t is $1\,\mathrm{km\ sec^{-1}}$, HD 210277 and HR 1614 are discrepant by 7.5σ and 4.4σ, respectively. In both cases, the hypothesis that the residual is zero is rejected with $P > 4$. No other changes worth noting take place in the summary given above. Moreover, if the velocity dispersion of the Hyades cluster is typical, the rms error of V_t is not actually likely to be much larger than $0.23\,\mathrm{km\ sec^{-1}}$ (Gunn et al. 1988). It therefore seems fair to conclude that Eggen's analysis does not yield evidence for an HR 1614 supercluster.

Table 11. Values of V for the HR 1614 supercluster

HD	t^{a}	Calculated V (km sec^{-1})	Radial velocity (km sec^{-1})	Source[b]
405[c]	–	–	–	–
120323[d]	–	–	–	–
181480[c]	–	–	–	–
115467	0.3	-55.9 ± 6.8	$+24.8 \pm 3.2$	DFM95
HR 1614[e]	0.5	-61.6 ± 3.7	$+27 \pm 5$	DFM95
213042	0.5	-59.9 ± 1.2	$+5.9 \pm 3.4$	DFM95
12051	0.6	-59.4 ± 0.9	-35.0 ± 0.1	DMH91
17660	0.7	-61.1 ± 1.7	-28.1 ± 0.2	T92
31452	0.7	-62.4 ± 3.5	$+14.9 \pm 6.7$	FS86
203875	1.0	-71 ± 12	-20 ± 20	E66
99946[f]	1.6	-67.1 ± 4.4	-15.0 ± 0.7	PCRR99
96511[g]	2.6	-62.6 ± 1.0	-46.2 ± 0.7	S24
114092	3.4	-43.5 ± 4.6	-12.3 ± 0.2	DMM99
HR 1614[h]	12.0	-54.8 ± 0.4	$+21.6 \pm 0.2$	BE86, T92
210277	12.7	-50.3 ± 0.7	-21.0 ± 0.1	DMH91, T92

[a] $t = |\,\sigma_V^{-1}[V + 59.5 + 0.026X]\,|$ km sec^{-1}. See Eggen 1998c. X is in pc. The unit vector for X points away from the galactic center.
[b] BE86 = Beavers & Eitter 1986, DFM95 = Duflot et al. 1995, DMH91 = Duquennoy et al. 1991, DMM99 = de Medeiros & Mayor 1999, E66 = Evans 1966, FS86 = Fouts & Sandage 1986, PCRR99 = Pribulla et al. 1999, S24 = Sanford 1924, T92 = Tokovinin 1992. All data are reduced to the zero point of BE86.
[c] No result is quoted because σ_π/π is too large for a reliable Lutz-Kelker correction to be applied. See Lutz & Kelker 1973.
[d] On astrophysical grounds, Eggen 1998c argues that the Hipparcos parallax of this star may be incorrect. The purpose of this table can be accomplished without considering this star, so its data are set aside.
[e] Result for epoch 1978. It is assumed that Eggen 1978b uses the radial velocity that would later appear in Duflot et al. 1995. See Eggen 1978b for the adopted proper motion.
[f] AW UMa; eclipsing binary.
[g] Spectroscopic binary (Duflot et al. 1995).
[h] Result for epoch 1998. The Hipparcos proper motion (Perryman et al. 1997) is used here.

12. The HR 1614 group

It is now worth asking whether a list of group members can be found that is more secure than Eggen's list of supercluster members. In response to this concern, it seems prudent to use Eggen's lists of group and supercluster members to reconstruct the group. As it happens, there are two additional incentives for doing this. When Eggen first discussed the group in print, he excluded 18 stars because of their low blanketing in a plot of $b - y$ versus $(R - I)_\mathrm{E}$ (see Table 3 and Fig. 4b of Eggen 1978b). The excluded stars have since played a very limited role in Eggen's work on the group and supercluster. One would like to know whether they would appear in a group selected solely on kinematic grounds. This question gains force when one notes that the stars were set aside before the Hipparcos astrometry appeared. Presumably there is now an improved observational basis for deciding about their membership.

A second resource that is now available is the results of Dehnen's analysis. Dehnen has isolated a small region of UV space which he identifies with the HR 1614 group. The group definition adopted here differs from Dehnen's, but is nonetheless based on his results. A V range from -54 to -62.4 km sec^{-1} is adopted (see Fig. 3, panel B4, of Dehnen 1998). If V for a star falls in this range or is no more than 1σ outside it, the star is accepted as a group member. This procedure isolates stars with data points that fall within Dehnen's UV limits. It also includes stars with data that fall in a nearby ridge in one of Dehnen's contour plots (again see Fig. 3, panel B4, of Dehnen 1998). If the HR 1614 group exists, it is admittedly unlikely that all the stars selected in this way are actually group members. The aim is instead to accept dilution by nonmembers, but to limit it to an amount that does not prevent detection of the group.

The source lists for the group includes the 18 stars mentioned above, plus a combined sample (recall Sect. 3) containing stars that Eggen has included in the group or supercluster at least once. The 38 stars that are selected from these lists include two that Eggen set aside in 1978, plus HR 1614 itself. The results of an analysis for these 38 stars are given in Table 10 (see the second entry for the HR 1614 group, and also refer to note "f"). Neither this analysis nor the one described in Sect. 10 recovers Eggen's canonical group metallicity ([Fe/H] $= +0.10$ dex). However, the derived group metallicity does exceed that of the net comparison sample with $P = 5.2$. Apparently a combination of kinematic and metallicity analyses has isolated a group that may well exist.

13. The Hyades supercluster

For the other stellar grouping chosen for further analysis, there is a history of disagreement. Before Hipparcos, no consensus about the existence of the Hyades supercluster emerged from kinematic analyses (compare Ogorodnikov & Latyshev 1968 and Ratnatunga 1988). Rather strikingly, post-Hipparcos analyses have not changed this state of affairs. Dehnen (1998) and Chereul et al. (1999) find that the supercluster exists, but it makes no meaningful appearance in the results of de Bruijne (1999) or those of Skuljan et al. (1999).

Before testing for the existence of this supercluster by using Eggen's membership lists, one must do some editing of those lists that is not required for other stellar groupings. Some of Eggen's lists include members of the Hyades cluster that are not identified as such (see especially Eggen 1985d). Such stars have been deleted by using GCPD and SIMBAD identifications. As a result, the analyses that follow apply to the Hyades supercluster alone.

As before, procedure A is used to obtain values of F and σ_w. These parameters are derived from a combined sample and also a number of iterations. Membership fractions are then estimated from the values of F in the following way. Let F now be the mean metallicity for a given sample. Let F_H and F_{NC} be the metallicities of the Hyades and the net comparison sample, respectively. Then

$$f_H = (F - F_{NC})/(F_H - F_{NC}). \quad (9)$$

The adopted value of F_H is $+0.104 \pm 0.009$ dex (Taylor 1998b; see Appendix B of this paper for a discussion of this result). An rms error for f_H is obtained by error propagation with an assumption that there is no covariance among the contributing errors (see Eq. (10.12) of Kendall & Stuart 1977).

Values of f_H for individual iterations are given in Table 12. As one might expect, there is little to choose among them. In particular, note that a value of f_H is given for stars that Eggen deemed to be nonmembers (see the second entry for Eggen 1970b). A value of f_H is also given for stars listed by Eggen in the same paper as members. These two values of f_H may be compared by using an unequal-variance t test. They are not found to differ with $P \geq 3$, which is another way of saying that the membership fraction in Eggen's list of nonmembers is effectively the same as it is for Eggen's list of members. A similar result is found for lists of members and nonmembers given by Eggen (1989a).

Note that the results for the individual iterations suggest that $f_H \neq 0$. To see whether this is true, one may analyze the combined sample. In this case, f_H is found to be 0.43 ± 0.05 (again see Table 12). A t test shows that this value of f_H differs from zero with $P > 6$. However, it should be remembered that for the Hyades supercluster specifically, the offsets given in Table 7 for the Hyades cluster may be pertinent. To be as sure as possible that they are not, one may derive a value of f_H from H-D data alone. The result is 0.46 ± 0.08, and it also differs from zero with $P > 6$. It seems hard to escape the conclusion that Eggen's membership lists include two kinds of stars. About half of the stars are nonmembers, but the other half have similar space motions and similarly high metallicities and so may be part of a Hyades supercluster.

Consider next these high-metallicity stars. If it could be shown that their metallicities have the same dispersion as that of the Hyades cluster, the case for the Hyades supercluster would be strengthened. Here, unfortunately, no meaningful result can be obtained at present. For the combined sample, a value σ_w(CS) can be derived by using procedure A. A second value can be obtained by averaging from separate H-D, DDO, $uvby$, and [M/H] solutions. The two results agree well, showing that cluster offsets are not a serious problem in this case (compare the first two entries in the fourth column of Table 10). Random-number modelling can then be used to find values of σ_w for mixtures of Hyades-cluster stars and field (net comparison) stars. These results can then be compared to the value of σ_w(CS) from procedure A. When this is done, however, it is found that σ_w for the possible Hyades-cluster contribution can be as large as 0.137 dex. More specifically, a variance-ratio test formally rules out this hypothesis with a value of P of only 1.3. As a result, one cannot rule out the possibility that the alleged contribution

Table 12. Membership fractions for versions of Hyades supercluster

Version	Description	f_H(%)	Version	Description	f_H(%)
Eggen 1970b[a]	Members	66 ± 10	Eggen 1984/5[d]	. . . .	64 ± 12
Eggen 1970b[a]	Nonmembers	58 ± 18	Eggen 1985/6[e]	. . . .	62 ± 10
Eggen 1971e	F stars	121 ± 22	Eggen 1989a[f]	Members	62 ± 10
Eggen 1972b	K III	34 ± 8	Eggen 1989a[f]	Nonmembers	31 ± 9
Eggen 1974a	K III	48 ± 10	Eggen 1992a	. . . .	56 ± 16
Eggen 1977[b]	K III	59 ± 10	Eggen 1996a	. . . .	25 ± 10
Eggen 1977[c]	K III	68 ± 12	Combined[g]	. . . .	43 ± 5

[a] For this source, values of f_H for members and nonmembers do not differ ($P < 1.3$).
[b] Not edited.
[c] Outliers have been deleted by Eggen.
[d] From Eggen 1984a, b, c, 1985a, b, c.
[e] From Eggen 1985d, 1986.
[f] For this source, values of f_H for members and nonmembers do not differ ($P = 1.9$).
[g] From H-D data only, f_H is $46 \pm 8\%$.

from the Hyades cluster is actually from a mixture of sources with a metallicity dispersion resembling that of a random sample of field stars. The best that can be said at this point is that a contribution from the Hyades alone is the most economical way to explain the non-zero combined-sample value of f_H.

14. A summary and comments

To conclude this paper, a summary of results will be combined with recommendations for future work and other comments.

1) For iterations without metallicity editing done by Eggen, the metallicity dispersion resembles that of a random sample of field stars and is substantially larger than the dispersion for selected galactic clusters.
2) No evidence for the existence of an HR 1614 supercluster is found by analyzing Eggen's (1998c) membership list. However, a version of the HR 1614 group can be found for which the hypothesis of nonexistence is formally rejected with $P > 5$. For the Hyades supercluster, the corresponding hypothesis is rejected with $P > 6$. At present, metallicities cannot be used to make meaningful judgments about the existence or nonexistence of the other stellar groupings that are considered.
3) For the stellar groupings that appear to exist, Eggen's lists include a substantial fraction of nonmembers. This is an issue for which a brief historical review is in order. The problem of nonmembers was brought to the fore by Breger (1968), and it emerges with particular clarity from the statistical analysis of McDonald & Hearnshaw (1983). Breger drew attention to the problem of inferring the properties of a star from its membership in a contaminated stellar grouping. In the future, it might be prudent to do this only if $f_M \geq 0.95$ for a given list of group members. If possible, it would also be worthwhile to compile group lists with higher values of f_M than those that apply for Eggen's lists.
4) Before more work is done on group metallicities, it would be useful to derive algebraic relations between V and metallicity from random samples of field stars (recall Sect. 10).
5) Reaction to Eggen's work can profitably be used to raise refereeing standards. This can be done if attention is first shifted from Eggen's scholarship to the standards adopted by the referees of Eggen's papers. Recall first the statistically fallacious test of group membership that Eggen (1998c) used (see Sect. 11). That test appeared in Eggen's papers for some 28 years without detection of the problem (note Eggen 1970b). Radial-velocity sources are another pertinent issue. Despite the fact that radial velocities were often as important to Eggen's work as proper motions, it was rare for Eggen to mention the sources of his adopted radial velocities. If referees had raised this issue, they might have been led to ask why Eggen was not making greater use of high-precision photoelectric results (note the sources listed in Table 11 for radial velocities for HR 1614). If there is to be some guarantee that improved results will be published for moving groups and superclusters, it seems likely that referees must pay increased attention to both statistics and documentation.
6) Finally, the issue of a priori judgment may be raised again. Readers are invited to decide what outcomes they would have predicted for the tests described in Sects. 12 and 13 if they had not read the abstract of this paper. Given the state of opinion about Eggen's work on stellar groupings (see Eggen 1995), it seems likely to the present author that most readers would have predicted that nothing at all would be found. It is also worth noting that if the history of physics were better known among astronomers, they would be fully warned about the dangers of a priori reasoning from the events surrounding the overthrow of parity (see Crease & Mann 1986, pp. 203–210). The need to set aside a priori reasoning and to gauge the moving-group issue strictly from numerical evidence is again stressed.

Acknowledgements. This paper is based on extensive use of SIMBAD and the GCPD, and almost certainly could not have been produced without the help of those extensive online resources. I sincerely thank all the professionals who produce and maintain them. I also thank Mike and Lisa Joner for proofreading this paper carefully. Page charges for this and the other papers in this series have been generously underwritten by the College of Physical and Mathematical Sciences and the Physics and Astronomy Department of Brigham Young University.

Table B.1. Mean values of [Fe/H] for the Hyades

Entry number	Source	[Fe/H] (dex)
1	Perryman et al. 1998, as stated by those authors	0.14 ± 0.05
2	Perryman et al. 1998, averaged from original data sources[a]	0.141 ± 0.009
3	Entry 2 data with Taylor 1994b analysis[b]	0.121 ± 0.013
4	Entry 3 result with correction to Chaffee et al. 1971 data[c]	0.107 ± 0.011
5	Dwarfs only, Taylor 1994c data base[d]	0.107 ± 0.010
6	Entry 5 averaged with results for giants (Taylor 1998b)[e]	0.104 ± 0.009

[a] An unweighted average is quoted. The value of σ *per datum* from these data is 0.059 dex.
[b] This analysis includes corrections to a uniform temperature scale and the use of weights based on rms errors.
[c] The correction is from the "Utrecht" solar EW zero point (Moore et al. 1966) to the "Liège" zero point (Rutten & van der Zalm 1984). For a discussion of this correction, see Sect. 3.4 of Taylor 1994c.
[d] Sources yielding this datum are listed in Table 1 of Taylor 1994d. Four of those sources (Klochkova & Panchuk 1988, Nissen 1981, Tomkin & Lambert 1978, and Wallerstein 1962) do not contribute to entry 1. Perryman et al. 1998 use data from Boesgaard & Budge 1988, while Taylor 1994d considers those data to have been superseded by those of Boesgaard 1989.
[e] The mean from analysis "D" is used. If the mean from analysis "I" is adopted instead, the mean quoted here changes by less than 1σ.

Appendix A: establishing confidence limits

In statistics, there is a widespread convention of adopting $C = 0.95$ as a minimum threshold for rejecting null hypotheses. It is worth noting, however, that this choice is indeed a convention and is not mandated by principle. This point may be underscored by considering the following problem. Suppose that one draws a sample of 1000 allegedly random numbers, converts them to data with zero mean and unit variance, and then searches them for wild points. If wild points are to be detected with $C = 0.95$, then $p = 0.05$. For *genuine* data falling outside the adopted confidence interval, the expected number $Np = 50$. Strictly speaking, judgments about Np are arbitrary. However, it still seems unlikely that a conservative statistician would regard the deletion of 50 valid data as conservative data editing. Note that a risk of this sort appears whenever N is large. Because N can in fact be very large for modern data sets, the risk of overediting is often courted, as noted in the text. (The illustrative problem given above is from Taylor 1996, Appendix A.)

The solution to this problem that is adopted here is to give Np priority when choosing a threshold value of p. Consider the value of N first. Some 57 group and supercluster versions are tested, with two tests being done per version. Allowing for some additional tests, $N \sim 120$. If $p = 10^{-3}$ is adopted, $Np \sim 0.12$. Note that this number is actually larger than its counterpart for an isolated test with $C = 0.95$, since then $p = Np = 0.05$. If one focuses on Np and is not distracted by the conventional value of p, it can be seen that $p = 10^{-3}$ is not an excessively conservative choice in this context. This value of p is adopted in this paper.

Appendix B: The Hyades metallicity

Because Perryman et al. (1998) have derived a mean value of [Fe/H] for the Hyades, it is necessary to explain why that result is set aside while that of Taylor (1998b) is adopted. Pertinent reasoning is given in Table B.1, which should be largely self-explanatory. However, it is worthwhile to add two notes to that table. For one thing, the error range quoted by Perryman et al. cannot readily be recovered. It is close–but not identical–to the rms error *per datum* for the original data from which Perryman et al. calculated their mean metallicity. An rms error *of the mean* for the Perryman et al. data is given in the second line of Table B.1.

Another point of interest concerns two data that are not used by Perryman et al. Those data are for vB 52 and vB 39. In the paper on which the editing is based (Cayrel et al. 1985), data for these two stars are set aside without use of statistical testing. Fortunately, a simple test may be made. Inspection of the Cayrel et al. data suggest that their rms errors are all comparable. If one assumes that they are in fact identical, the Dixon (1951) r_{20} statistic may be applied. To do this, let the n data of Cayrel et al. be arranged in order of decreasing size. (The reverse order may also be used for Dixon tests, but order by decreasing size is appropriate for testing the smallest data in a sample.) Now, for vB 52, calculate

$$r_{20} = (F_n - F_{n-2})/(F_n - F_1), \quad \text{(B.1)}$$

with $F \equiv$ [Fe/H]. The result is $r = 0.27$. From tables given by Dixon, one finds that the datum for vB 52 is formally rejected from membership in the Cayrel et al. sample with $C = 0.55$. The same result is obtained for vB 39. For tests using Dixon statistics, the minimum threshold value of C is 0.975 (see Keeping 1962, p. 200). Since this condition is clearly far from being satisfied, the data for vB 52 and vB 39 are retained.

References

Barbier-Brossat M., Petit M., Figon P., 1994, A&AS 108, 603
Batten A.H., Fletcher J.M., McCarthy, D.G., 1989, Publ. Dominion Astrophys. Obs., Vol. 17
Beavers W.I., Eitter J.J., 1986, ApJS 62, 147
Bethea R.M., Duran B.S., Boullion T.L., 1985, Statistical Methods for Engineers and Scientists, 2nd ed. New York: Dekker
Binney J., Merrifield M., 1998, Galactic Astronomy. Princeton, New Jersey: Princeton University Press

Boesgaard A.M., 1989, ApJ 336, 798
Boesgaard A.M., Budge K.G., 1988, ApJ 332, 410
Boyle R.J., McClure R.D., 1975, PASP 87, 17
Breger M., 1968, PASP 80, 578
Buser R., Kurucz R.L., 1992, A&A 264, 557
Carney B.W., Laird J.B., Latham D.W., Aguilar L.A., 1996, AJ 112, 668
Cayrel R., Cayrel de Strobel G., Campbell B., 1985, A&A 146, 249
Chaffee F.H. Jr., Carbon D.F., Strom S.E., 1971, ApJ 166, 593
Chereul E., Crézé M., Bienaymé O., 1999, A&AS 135, 5
Crawford, D.L., Barnes J.V., 1969a, AJ 74, 407
Crawford, D.L., Barnes J.V., 1969b, AJ 74, 828
Crawford D.L., Perry C.L., 1966, AJ 71, 206
Crease R.P., Mann C.C., 1986, The Second Creation. New York: Macmillan
de Bruijne J.H.J., 1999, MNRAS 306, 381
de Medeiros J.R., Mayor M., 1999, A&AS 139, 433
Dehnen W., 1998, AJ 115, 2384
Dixon W.J., 1951, Ann. Math. Stat. 22, 68
Dommanget J., Nys O., 1994, Comm. Obs. R. Belgique, Ser. A, N. 115
Duflot M., Figon P., Meyssonnier N., 1995, A&AS 114, 269
Duquennoy A., Mayor M., Halbwachs J.-L., 1991, A&AS 88, 281
Eggen O.J., 1960, MNRAS 120, 430
Eggen O.J., 1964, Royal Obs. Bull. No. 84
Eggen O.J., 1965, Observatory 85, 191
Eggen O.J., 1969, PASP 81, 553
Eggen O.J., 1970a, PASP 82, 99
Eggen O.J., 1970b, Vistas in Astron. 12, 367
Eggen O.J., 1971a, ApJS 22, 389
Eggen O.J., 1971b, ApJ 165, 317
Eggen O.J., 1971c, PASP 83, 251
Eggen O.J., 1971d, PASP 83, 271
Eggen O.J., 1971e, PASP 83, 741
Eggen O.J., 1972a, MNRAS 159, 403
Eggen O.J., 1972b, PASP 84, 406
Eggen O.J., 1974a, PASP 86, 129
Eggen O.J., 1974b, PASP 86, 162
Eggen O.J., 1977, ApJ 215, 812
Eggen O.J., 1978a, ApJ 221, 881
Eggen O.J., 1978b, ApJ 222, 203
Eggen O.J., 1983, AJ 88, 813
Eggen O.J., 1984a, AJ 89, 839
Eggen O.J., 1984b, AJ 89, 1350
Eggen O.J., 1984c, AJ 89, 1358
Eggen O.J., 1985a, AJ 90, 74
Eggen O.J., 1985b, AJ 90, 333
Eggen O.J., 1985c, AJ 90, 1046
Eggen O.J., 1985d, PASP 97, 807
Eggen O.J., 1986, PASP 98, 423
Eggen O.J., 1987, In: Gilmore G., Carswell B. (eds.), The Galaxy. Dordrecht: Reidel, p. 211
Eggen O.J., 1989a, Fundamentals of Cosmic Phys. 13, 1
Eggen O.J., 1989b, PASP 101, 45
Eggen O.J., 1992a, AJ 104, 1482
Eggen O.J., 1992b, AJ 104, 1906
Eggen O.J., 1992c, AJ 104, 2141
Eggen O.J., 1995, AJ 110, 2862
Eggen O.J., 1996a, AJ 111, 1615
Eggen O.J., 1996b, AJ 112, 1595
Eggen O.J., 1998a, AJ 115, 2397
Eggen O.J., 1998b, AJ 115, 2435
Eggen O.J., 1998c, AJ 115, 2453
Eggen O.J., 1998d, AJ 116, 284
Eggen O.J., Iben, I., Jr., 1989, AJ 97, 431
Eggen O.J., Iben, I., Jr., 1991, AJ 101, 1377
Evans D.S., 1966, Royal Obs. Bull. 110, 185
Feltzing S., Gustafsson B., 1998, A&AS 129, 237
Ferris T., 1997, The Whole Shebang. Simon & Schuster, New York
Fletcher J.M., Harris H.C., McClure R.D., Scarfe C.D., 1982, PASP 94, 1017
Fouts G., Sandage A., 1986, AJ 91, 1189
Gliese W., Jahreiss H., 1979, A&AS 38, 423
Griffin R.E.M., Holweger H., 1989, A&A 214, 289
Griffin R.F., 1971, MNRAS 155, 1
Griffin R.F., 1998, Observatory 118, 223
Griffin R.F., Gunn J.E., Zimmerman B.A., Griffin R.E.M., 1988, AJ 96, 172
Gunn J.E., Griffin R.F., Griffin R.E.M., Zimmerman B.A., 1988, AJ 96, 198
Hanson R.B., 1979, MNRAS 186, 875
Hoffleit D., Jaschek C., 1982, The Bright Star Catalogue, 4th ed. New Haven: Yale University Observatory
Janes K.A., 1977, PASP 89, 576
Janes K.A., Smith G.H., 1984, AJ 89, 487
Johnson D.R.H., Soderblom D.R., 1987, AJ 93, 864
Johnson H.L., 1966, ARA&A 4, 193
Johnson H.L., Mitchell R.I., Iriarte B., 1962, ApJ 136, 75
Johnson S.B., Joner M.D., Taylor B.J., 1987, ApJS 63, 983
Joner M.D., Taylor B.J., 1988, AJ 96, 218
Keeping E.S., 1962, Introduction to Statistical Inference. Princeton: D. Vam Nostrand,
Kendall M., Stuart A., 1977, The Advanced Theory of Statistics, 4th ed., vol. 1. London: Griffin
Klochkova V.G., Panchuk V.E., 1988, Astrofiz. Issled. Isv. Spets. Astrofiz. Obs. 26, 14 (Engilsh translation: 1990, Bull. Spec. Ap. Obs.– North Caucasus 26, 11)
Kshirsagar A.M., 1983, A Course In Linear Models. New York: Dekker
Leroy J.L., 1993, A&A 274, 203
Lutz T.E., Kelker D.H., 1973, PASP 85, 573
Mason B.D., McAlister H.A., Hartkopf W.I., Bagnuolo W.G. Jr., 1993, AJ 105, 220
McDonald A.R.E., Hearnshaw J.B., 1983, MNRAS 204, 841
Méndez R., Ruiz M.T., 1992, AJ 103, 911
Mermilliod J.-C., Mermilliod M., Hauck B., 1997, A&AS 124, 349
Moore C.E., Minnaert M.J.G., Houtgast J., 1966, The Solar Spectrum, 2935 Å to 8770 Å. Government Printing Office, Washington, D.C.
Murray C.A., 1989, A&A 218, 325
Neese C., Detweiler H.L. Yoss K.M., 1985, PASP 97, 78
Nissen P.E., 1981, A&A 97, 145
Nissen P.E., Schuster W.J., 1991, A&A 251, 457
Ogorodnikov K.F., Latyshev I.N., 1968, SvA 12, 279
Perry C.L., Johnston L., Crawford D.L., 1982, AJ 87, 1751
Perryman M. A. C., Lindegren L., Kovalesky J., et al., 1997, A&A 323, L49
Perryman M.A.C., Brown A.G.A., Lebreton Y., et al., 1998, A&A 331, 81
Pesch P., 1972, ApJ 178, 203
Pribulla T., Chocol D., Rovithis-Livaniou H., Rovithis P., 1999, A&A 345, 137
Proust D., Foy R., 1988, Ap&SS 145, 61
Ratnatunga K.U., 1988, AJ 95, 1132
Reid I.N., 1998, AJ 115, 204
Rutten R.J., van der Zalm E.B.J., 1984, A&AS 55, 143

Sandage A., 1969, ApJ 158, 1115
Sanford R.S., 1924, ApJ 59, 359
Schuster W.J., Nissen P.E., 1989, A&A 221, 65
Skuljan J., Hearnshaw J.B., Cottrell P.L., 1999, MNRAS 308, 731
Soderblom D.R., Mayor M., 1993, AJ 105, 226
Taylor B.J., 1970, ApJS 22, 177
Taylor B.J., 1986, ApJS 60, 577
Taylor B.J., 1991, ApJS 76, 715
Taylor B.J., 1992, PASP 104, 500
Taylor B.J., 1994a, PASP 106, 452
Taylor B.J., 1994b, PASP 106, 590
Taylor B.J., 1994c, PASP 106, 600
Taylor B.J., 1995, PASP 107, 734
Taylor B.J., 1996, ApJS 102, 105
Taylor B.J., 1998a, PASP 110, 699
Taylor B.J., 1998b, PASP 110, 708
Taylor B.J., 1999a, A&AS 134, 523
Taylor B.J., 1999b, A&AS 135, 75
Taylor B.J., 1999c, A&AS 139, 63
Taylor B.J., Johnson S.B., 1987, ApJ 322, 930
Taylor B.J., Joner M.D., 1985, AJ 90, 479
Taylor B.J., Joner M.D., 1992, PASP 104, 911
Thompson W.R., 1935, Ann. Math. Stat. 6, 214
Tomkin J., Lambert D.L., 1978, ApJ 223, 937
Tinbergen J., 1982, A&A 105, 53
Tokovinin A.A., 1992, Catalogue of radial velocity measurements. Moscow: Moscow Univ. Press
Trimble V., Aschwanden M., 1999, PASP 111, 385
Tuominen I.V., Vilhu O., 1979, In: Les Eleéments et Leur Isotopes dans l'Univers, 22nd Liège Colloquium. Inst. d'Astrophys., Univ. de Liège, p. 355
Wallerstein G., 1962, ApJS 6, 407
Zelen M., Severo N.C., 1972, In: Abramowitz M., Stegun I. (eds.) Handbook of Mathematical Functions. New York, Dover.
Zielke G., 1970, A&A 6, 206