THE STELLAR DISK COMPONENT: DISTRIBUTION, MOTIONS, AGE AND STELLAR COMPOSITION

Gösta Lyngå
Lund Observatory
Lund, Sweden

ABSTRACT

The distribution of the stellar disk component is studied with particular emphasis on the properties of open clusters. A scale height of 80 pc is found for clusters younger than 10^9 years while the scale height is 200 pc for older clusters. A radial metallicity gradient in the disk is confirmed but there seem to be significant abundance variations apart from this. There are radial gradients in age as well as in linear diameter. Kinematically, there are a number of regions in the Milky Way with systematic radial velocity residuals.

1. INTRODUCTION

Because of the distances of the objects and even more because of the extinction of light by interstellar dust, optical studies are usually confined to the nearest one percent of the galactic disk. If we concentrate on luminous stars and are prepared to accept some selection effects we can reach about ten percent of the disk. It is the knowledge about these rather nearby stars that I will review to-day, and it is one of the shaky assumptions of this field that we may draw conclusions regarding the whole of our Galaxy from the nearby stars. I will start by discussing the z distribution of some components, then we shall look at the distribution in the plane of the Galaxy. Various aspects of the grand design will be discussed and then I will review the meagre observational data that exist concerning the distribution of objects with various abundances. A lot of knowledge has lately been gained about the kinematics of stars of various types. I shall only discuss some points here quite briefly - other aspects will be presented by other speakers at this symposium.

There are three reasons why I will discuss open clusters at some length. The main one is that clusters are the part of the stellar component which is most accurately known; distances, radial velocities and abundances are easier to determine accurately for clusters than for

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single stars. The second reason is that much new information has become available lately through the efforts of many people. The third and perhaps the most subjective reason is that I have just finished a collection of quite a lot of data for open clusters enabling me to back up some of my comments about the disk structure. That catalogue is presented as a poster at this meeting.

2. THE Z DISTRIBUTION OF CLUSTERS AND OF DUST

Although professor Strömgren will shortly discuss the z distribution of field stars, I would like to give a short report on what cluster data can give. I will limit the discussion to the closest 1 kpc for two reasons: Firstly, the selection effects increase with distance and secondly, the undulations of the galactic disk make the plane approximation less valid. Closer than 1 kpc there are 78 young open clusters (log (age) < 8.0) with a mean z distance of -15 pc. This is interpreted as due to the sun's position being 15 pc above the plane of symmetry of the Galaxy, quite in accordance with other determinations. The scale height of the distribution is 60 pc. For 86 older clusters we get a scale height of 80 pc. The difference between these values is barely significant as can be seen from Figure 1.There is no clear trend in z distance with age except for the very oldest clusters (log (age) ≧ 9.0) which have a much wider distribution - the scale height is 200 pc for these 38 clusters.

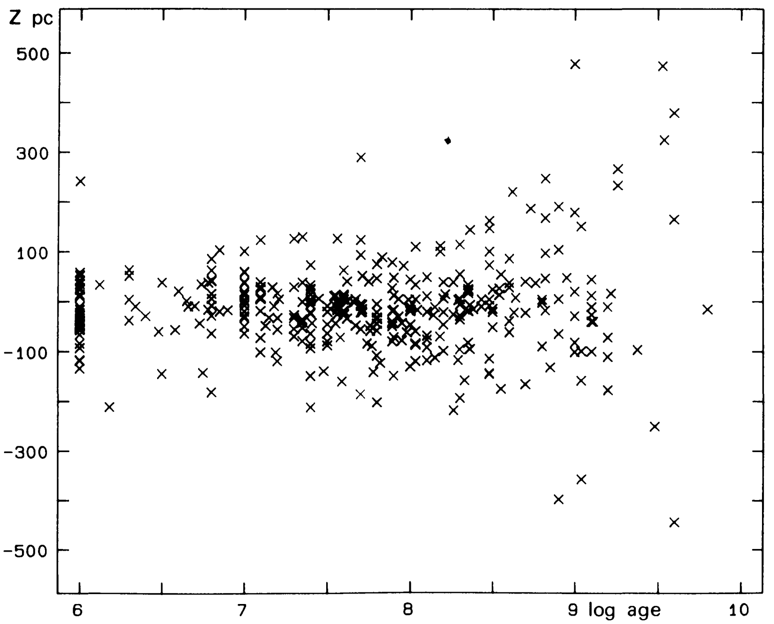

Figure 1. Distance from the galactic plane as a function of log (age).

The thickness of the layer of interstellar extinction can be estimated from the reddening of clusters at varying z distances (Lyngå, 1979, 1982) and this method applied to the new material gives a scale height of 130 pc with an average extinction in the plane of 0.75 magnitudes per kpc. This is in good accordance with earlier known values.

3. THE DISTRIBUTION OF CLUSTERS AND OTHER OBJECTS IN THE PLANE

Several people have discussed the lack of old open clusters in the inner parts of the galactic disk (Van den Bergh et al., 1980; Lyngå, 1980; Janes and Adler, 1982). The effect seems to be real; in any case it has remained in spite of the addition of new data. Present knowledge about ages and positions gives the plot shown in Figure 2. This may be interpreted as an effect of shorter relaxation time in the denser inner disk than in the outer disk. Perhaps the massive molecular clouds have tidal effects and thus shorten cluster lives.

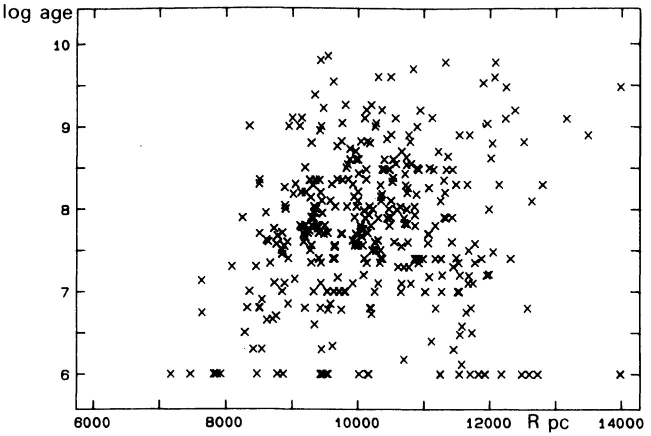

Figure 2. Log (age) as a function of galactocentric radius.

In an attempt to relate the small scale age distribution to a possible grand design, Balazs and myself (1984) try to relate the distances of clusters from recognized spiral arms to the ages of the clusters; naturally the solution is dependent on the grand-design parameters: arm inclination, pattern speed and distance scale. The most surprising of our first results is the arm inclination 7° which is quite different from other results of spiral-arm tracing as given by Humphreys (1979). The existence of a solution does not necessarily mean that the model obtained is the only possible. It does not even follow that a spiral pattern is necessary. What it says is merely that there is an age stratification, which would result as long as the stellar velocity is different from the velocity of the pattern.

The simplified model of spiral structure does not seem sufficient to fully explain the distribution of young objects. Figure 3 shows a graph of the positions of young clusters on the galactic plane. It seems that the large clumps of objects are quite a characteristic property of the distribution. Let me point out that I have limited the graph to a distance of 4 kpc. It is quite possible to find similar features at larger distances but then the selection effects caused by interstellar extinction may be severe. We can compare such features, of the order of 1 kpc, with the groupings of interstellar clouds (Lucke, 1978) or the cepheid complexes (Efremov, 1978). The understanding of such complexes has lately been made possible through the works of Elmegreen and Elmegreen (1983) and others.

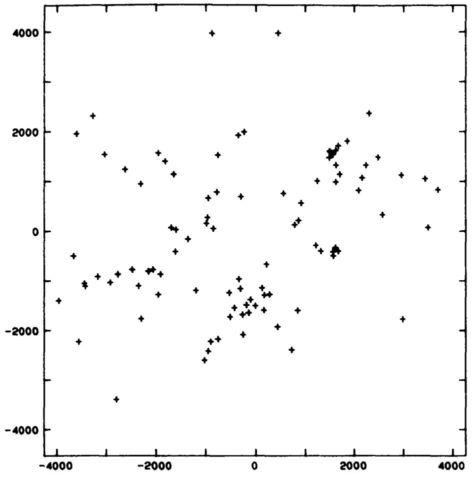

Figure 3. Plot on the galactic plane of positions of young clusters. The Sun is at the origin.

In an earlier investigation (Lyngå, 1982) I found that linear diameters of open clusters are as an average smaller in the inner part of the Galaxy than in the outer part. The trend is slight and the more homogeneous set of diameter data in my updated catalogue does not show it very well. If, however, only the very youngest clusters are considered there is a trend (see Figure 4), which may be interpreted in terms of variation of the Jeans radius through the Galaxy (Burki, 1980).

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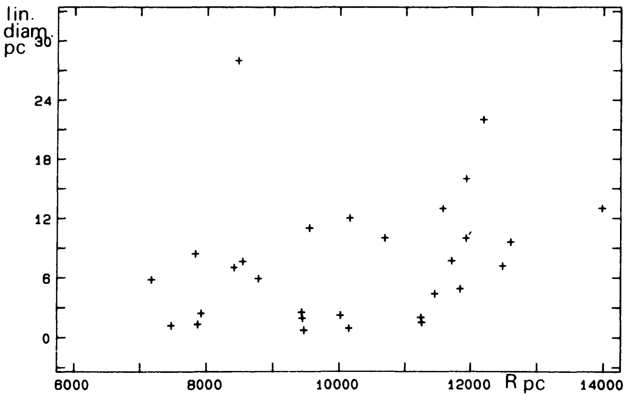

Figure 4. Radial gradient of linear diameter for young clusters.

4. THE METAL ABUNDANCE GRADIENT

That an abundance gradient with galactocentric radius is present for the gas component of the disk has been shown in the review by Peimbert (1979). It would be expected that the same effect is present for young stars; whether it is also present for older stars is a question that bears on the radial mixing properties of the disk. Let us review the evidence:

- Mayor (1976) drew conclusions from uvby studies of nearby stars, the birthplaces of which he found by kinematic evidence. Relating metallicity to galactocentric radius of the birthplace, he obtained a gradient of -0.05 kpc^{-1} from 1000 stars; the young stars gave a steeper gradient.

- Luck (1982) discussed abundances of supergiants on the basis of model - atmosphere calculations; his data give a slope of d[Fe/H]/dR = -0.13. Christian and Smith (1983) add a couple of distant, anticentre F giants with low abundance consistent with a gradient of -0.06 dex.

- Harris (1981) has studied a great number of cepheids, determining a metallicity index from Washington photometry. A gradient of -0.07 dex is found.

- Janes (1979) has indicated that stars in open clusters show a gradient in metallicity of -0.05 kpc^{-1}.

- Panagia and Tosi (1981) have studied young clusters particularly and found a metal gradient of -0.095 kpc^{-1}.

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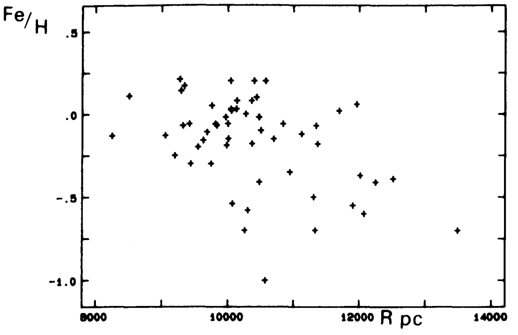
On the question of abundances of clusters I believe that my own catalogue of open-cluster data (Lyngå, 1983) has the most comprehensive information. Figures 5 and 6 are based on data collected there and show plots of abundance against galactocentric radius. We find a gradient of -0.13 kpc^{-1} whether all clusters or only the young ones are used; while there is clear evidence of a gradient, I believe there is more to it than that. Typical imprecision values are, for nearby clusters, about 0.1 dex, and the scatter in these diagrams is much larger.



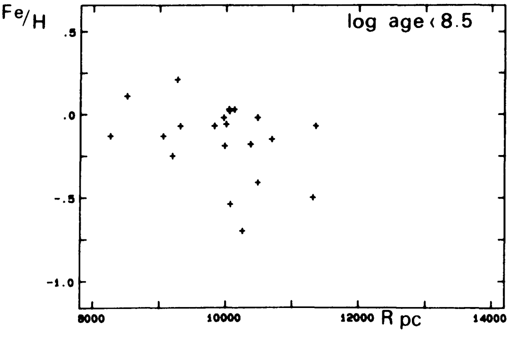


Figure 5 (all clusters) and Figure 6 (young clusters) show that the radial abundance gradient is similar for the two age intervals considered.

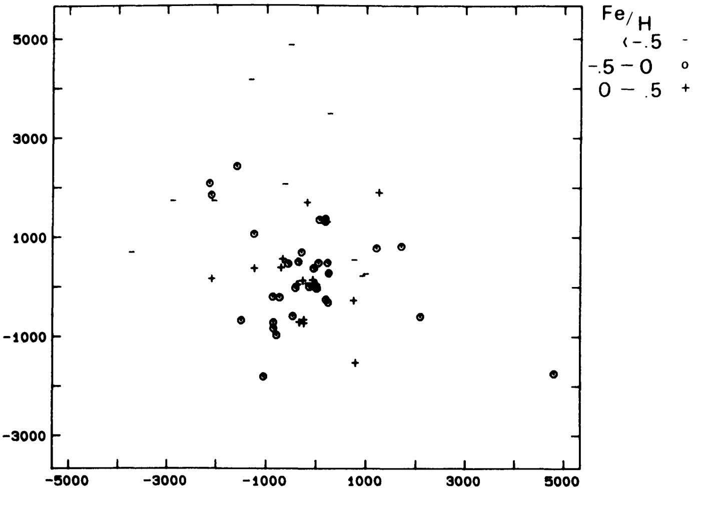


Figure 7. Plot on the galactic plane of [Fe/H].

Figure 7, which is a plot of the cluster data on to the galactic plane, shows a more complex picture. To me it appears that there are rather large regions of similar metallicity and other regions of other metallicities, not in a one-to-one relation with galactocentric radius.

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Such a situation could easily arise if the star formation rate varies throughout the disk. Again we have indications of homogeneity inside certain regions. Wramdemark and myself (1983) have just studied a few clusters in the Gould Belt region with uvby photometry. Clusters that are kinematically and positionally in Gould's Belt also show the same metal abundances; ages for these are around 4×10^7 years, i.e. comparable to the expansion age of Gould's Belt according to Olano (1982).

5. HELIUM DISTRIBUTION

Akin to this picture but actually concerning primordial abundances is the distribution of helium. Nissen (1980) has reported significant differences between the He abundances in relatively young clusters. From λ 4026 photometry he found that Sco-Cen has a value of $Y = 0.28$ while Cep OB III and h + χ Per have $Y = 0.19 \pm 0.01$, extremely helium deficient. Scatter between cluster members was small. Not only is a primordial abundance difference necessary to explain these differences; the finding also requires that mixing in the galactic disk is quite limited. The question whether a helium-abundance gradient is present in the gaseous component does not seem to have been resolved. Peimbert (1979) has reviewed the possibilities; whatever gradient is indicated is, however, much smaller than is needed to explain the differences between the clusters.

6. KINEMATICS OF THE OPEN CLUSTER SYSTEM

Recent determinations of Oort's constants and of the rotation curve of the Galaxy from various data have been summarized by Knapp (1983). Not wishing to repeat this here, I shall only discuss some local deviations from the large-scale pattern and add the results obtained for the radial velocities for 114 clusters which have been calculated by Wramdemark (1983) and are included in my cluster catalogue (Lyngå, 1983).

Systematic deviations of velocities from circular motions have been demonstrated by several authors among whom are Humphreys (1976), Ardeberg and Maurice (1981) and Ardeberg et al. (1985). Interpretations have included effects of massive spiral arms. It is also well established (Lindblad, 1983) that the kinematics of young stars closer than 400 pc are strongly affected by the expansion of the Gould belt complex.

Let us now study systematic effects on the basis of the cluster catalogue. In Figure 8 we have corrected the radial velocities to the local standard of rest defined by B stars and also corrected for differential galactic rotation if a flat rotation curve is assumed (other rotation curves give qualitatively the same picture). We see that there are residuals showing systematic trends. Most notable is the positive excess near us, consistent with the expansion in the Gould Belt system and the predominantly negative residuals at $l \sim 285^{o}$. These clusters have a systematic velocity excess of around -10 km/s which may be compared with the residual velocity for stars and interstellar gas amounting to +6 km/s at $l \sim 295^{o}$ (Ardeberg and Maurice, 1981).

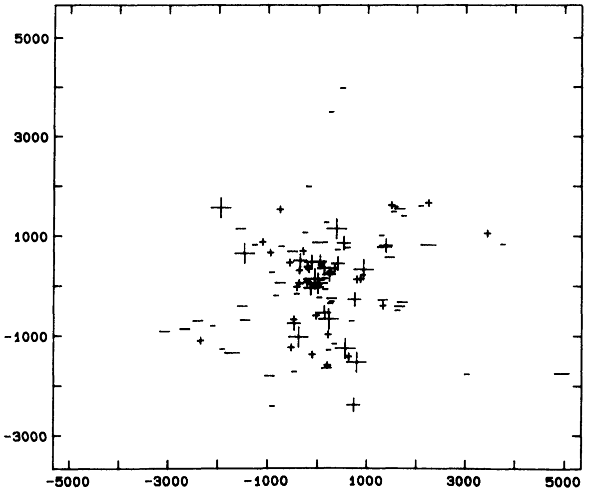

Figure 8. Residuals in radial velocity on the galactic plane.
Symbols are > 20 km/s +
10 to 20 km/s +
0 to 10 km/s +
-10 to 0 km/s -
-20 to -10 km/s –
< -20 km/s —

7. PROBLEMS AND PROSPECTS

What we seem to know well enough is the thickness of the galactic disk as defined from objects < 10^9 years old. There has not been any significant variation in thickness during that time. However, older clusters have a much wider distribution, one which is also shared by the G and later-type stars.

The distribution of abundances can be approximated with a galactocentric gradient but this does not tell the full story. Some regions exist, inside which the metallicity does not vary much but for which it deviates from the metallicity predicted by a gradient. Also the widely differing helium abundances between clusters that Nissen (1980) has pointed out are raising problems. At the time being there may not be enough observations to get a firm hold on any of these questions. However, there are enough clusters to study, so I have hopes for fruitful collection of data in these fields during the next few years.

Whether we should consider the grand design spiral structure as the most important characteristic of our Galaxy, or a clumpy distribution where homogeneous regions of about 1 kpc are typical, is at the moment an open question. Some people favour the one picture, some favour the other. I would rather say: both!

The large-scale kinematics of the disk contains problems which I have only touched upon. However, it is clear from the radial velocities of clusters that systematic deviations from circular motions exist.

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DISCUSSION

J.P. Ostriker: You could calculate from your data a mortality rate for clusters as a function of age in the same way as actuaries do, if you assume an essentially constant birthrate. What fraction of clusters that exist at age 10^7 years still exist at age 10^8 years and at age 10^9 years?

Lyngå: In 10^8 years the number of clusters falls by roughly a factor e. After 10^9 years there should not be any left. Clusters older than 10^9 years are probably truly different.

J.V. Feitzinger: Do you find a correlation between the cluster-diameter and the reddening values? Absorption effects might cause different cluster diameters in different directions.

Lyngå: I find no such correlation.

M.W. Feast: Can I ask a related question? What effect could interstellar absorption have on the clumping you see?

Lyngå: Well, it could have an effect, but not so much out to 2 kpc. Further out, of course, it certainly will. But if a cluster is heavily absorbed, that fact is known. Another selection effect is that people tend to study those clusters that they think are more interesting. I think my catalogue is quite complete out to 1 kpc, and about 30 or 40% complete out to 2 kpc. Beyond that distance I don't really want to do this sort of thing.

R. Güsten: I am somewhat puzzled by the small He abundance you mentioned for some of these open clusters. Could you explain how one derives the He abundance from one line only?

Lyngå: I must refer you to the paper by Nissen (1980).

M.L. Kutner: With regard to the clumpiness in the abundance variations, I note that interstellar isotope-abundance ratios, determined from interstellar molecules, show significant source-to-source variations which can probably not be explained by radiative-transfer effects, chemical fractionation or an overall galactic gradient.

P. Pismis: 1) Have you detected any relationship between the ages and masses of clusters, or between the age and a parameter that may specify the mass? 2) Is there a relationship between the age and the morphology of clusters, for example the smoothness or symmetry in the distribution of stars in a cluster?

Lyngå: 1) Yes, there is quite a clear correlation. If I consider only the bound ones, then the younger clusters have higher masses.
2) I have not looked for a relationship between age and morphology.