PART IV

KINEMATICS AND DYNAMICAL EVOLUTION OF THE GALAXY

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DYNAMICAL HISTORY OF THE STARS IN RELATION WITH AGE, KINEMATICS, ABUNDANCES, BIRTHRATE

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I. RELATIONS BETWEEN AGE - METALLICITY - DISTANCE TO THE GALACTIC PLANE AND KINEMATICS

A large amount of work has been devoted to correlations between kinematic properties and spectral types in order to improve our knowledge of stellar populations in our Galaxy and hence to deduce its structure and evolution. The classical results will not be repeated in the present review paper. However, emphasis will be laid on the sometimes contested correlations between age, abundance, kinematic properties and position in the Galaxy.

One of the first constraints for chemical evolution models should be the relation between metallicity and the ages of stars in the solar neighbourhood. There is no need to stress the importance of the correlations between orbital excentricity, angular momentum, perpendicular motion and UV excess for the clarification of the Galactic collapse model proposed by Eggen, Lynden-Bell and Sandage (1962) (ELS). The difference between halo and disk are evidenced by these correlations. Unfortunately the regions in the (e, δ(U-B)), ($|W|$, δ(U-B)) and (h, δ(U-B)) diagrams, occupied by the disk stars, do not show any significant correlations between kinematic variables and δ(U-B). And yet, the entire history of the Galactic disk, some 10^{10} years, is contained in these regions of the kinematics versus chemical properties diagrams. For instance in Fig. 1 from Eggen, Lynden-Bell and Sandage, I sketched the zone (e, δ(U-B)) where the history of the Galactic disk is hidden. Does the observational uncertainty or the intrinsic dispersion in the metallicity hide a relation between the excentricity and the metallicity or is such a correlation non existent for disk objects?

Eggen and Sandage (1969) in a synthesis of the metallicities and ages of some Galactic clusters arrived at the conclusion that the metal

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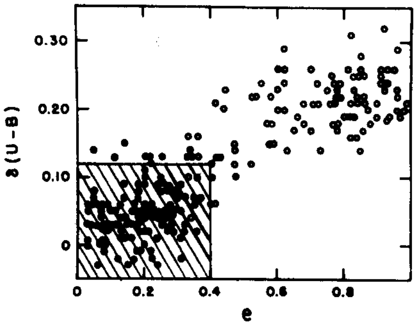

Fig. 1 Diagram of the excentricity versus UV excess according to Eggen, Lynden-Bell and Sandage (1962). There is a clear distinction between the chemical and kinematic properties of the disk objects (dots) and the halo objects (circles). The history of the Galactic disk is hidden in the hatched zone.

enrichment has been negligible since the end of the collapse. This result has been the basis of several chemical evolution models of the Galaxy. It is therefore judicious to look again into the matter and to discuss recent studies on this subject and in particular those of a kinematic nature.

In his research on deficient stars, which were not selected on the basis of proper motion, Bond (1971) concluded that deficiency in heavy elements, measured by Δm_1, was weakly correlated with orbital excentricity if Δm_1 was inferior to 0.08 ([Fe/H] > -1). A similar conclusion was reached for the velocity perpendicular to the Galactic plane $|W|$.

Spectroscopic studies of some objects have revealed old objects or moderately old objects having chemical compositions only slightly different from that of the Sun. The most representative problem of these "abnormal" objects with respect to the monotonic enrichment of the Galaxy is that of the SuperMetalRich (SMR) stars which were discussed in detail by Spinrad (1976) at a symposium devoted to abundance effects in classification. At the same symposium Foy (1976) and Grenier et al. (1976) supported the idea of a moderate or non existent enrichment of the Galactic disk and a high dispersion in the abundances at a given age.

Corresponding to the research stressing the existence, at a given age, of objects with very different abundances, often determined by high dispersion spectroscopy, there is the photometric research stressing average variations. These average variations are often comparable, in order of magnitude, with the uncertainty in the measurement of a star, only the size of the samples (presently on the order of 1000 stars) allows the systematic effect to be seen. Pagel and Patchett (1975) summarized the results obtained by Eggen (1964, 1970), Powell (1972) and Mayor (1974) for the variation in the heavy element abundance as a function of time, Fig. 2. The work of Clegg and Bell (1973), Mayor (1976) using uvbyβ photometry and Hearnshaw (1972) using spectroscopy confirms that a considerable part of the heavy elements have been synthesized during the lifetime of the Galactic disk. Denoting by Δ[M/H] the abundance variation in heavy elements during 10^{10} years, the results are

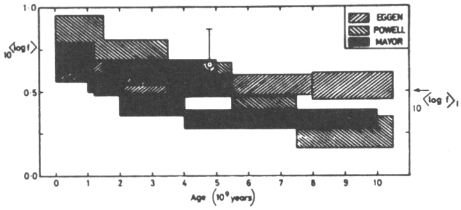

Fig. 2 Time dependence of stellar metal abundance, from the data of Eggen (1964, 1970), Powell (1972) and Mayor (1974). Each error box is centred on the geometric mean abundance of the relevant age group, with a width equal to the range of ages assumed, and a height corresponding to 4 standard errors of the mean of log f.

$\Delta[M/H] \simeq 0.8$	Clegg-Bell 1973
$\Delta[Fe/H] \simeq 0.78 \pm 0.2$	Hearnshaw 1972
$\Delta[M/H] \simeq 0.5$	Mayor 1976

$$\left(\frac{\partial(Z/Z_\odot)}{\partial t} = \frac{0.6 \pm 0.3}{10^{10}\,y}\right)$$

Thus these different studies seem to indicate that the oldest stars of the Galactic disk in the Solar neighbourhood are approximately 3 to 5 times more deficient in heavy elements than the stars presently formed.

Recently McClure and Tinsley (1976) discussed the biases which cast doubt upon the correlations between age and metallicity obtained with UBV photometry. The principal biases involved are specific to UBV photometry and do not affect the stars mentioned before. However, the problems which make these approaches uncertain are considerable and it is interesting to consider the evidence arising from the kinematics versus age and kinematics versus metallicity correlations. In Figs 3 and 4 I have indicated the dispersions in the residual velocities U (direction centre - anticentre) and W (direction perpendicular to the Galactic plane) obtained by Byl (1974), Wielen (1974) and Mayor (1974). The first two papers refer to stars in the Solar neighbourhood (catalogue of Gliese, 1969), the third one to bright F stars. Throughout the three studies the number of samples is on the order of 1000 stars. The point dispersion of these three studies is more representative of the uncertainty associated with the relationship dispersion as a function of age $\sigma_u(t)$ and $\sigma_w(t)$ than with the internal statistical error in these studies. By way of comparison the Y-axis shows the point representative of the B stars proposed by Delhaye (1965). These two diagrams illustrate the satisfactory agreement between the kinematics versus age relations deduced from different stellar samples. These relations are valid only if $z = 0$ and $\varpi = 10$ kpcs.

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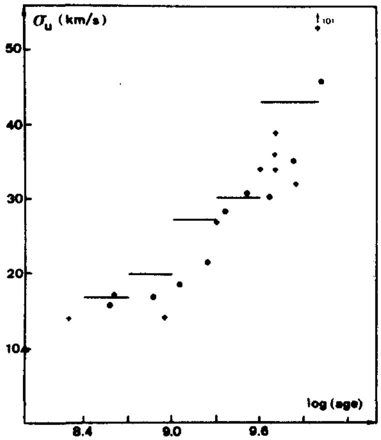

Fig. 3

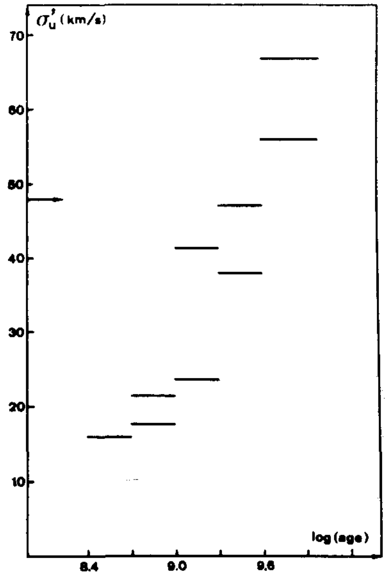

Fig. 5

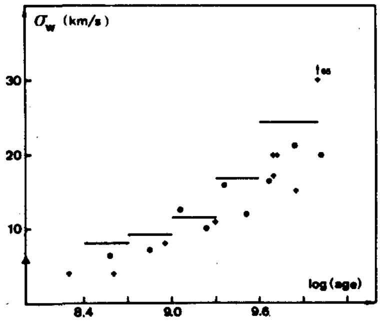

Fig. 4

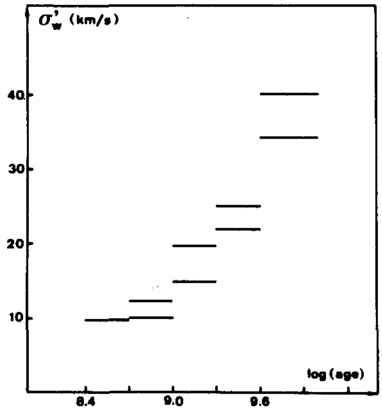

Fig. 6

Fig. 3 Residual velocity dispersions σ_u as a function of time. The dots were obtained by Byl (1974), the crosses by Wielen (1974) and the horizontal lines by Mayor (1974). The first two studies refer to stars in the Solar neighbourhood (Gliese's catalogue). The third however, concerns bright F stars ($m_v \leq 6.5$). $\sigma_u(t)$ is representative of stars with z = 0.

Fig. 4 Residual velocity dispersions σ_w as a function of time for the studies mentioned in the caption of Fig. 3.

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What about their dependence on stellar mass? To my knowledge no evidence has been given so far regarding the relational dependence $\sigma(t)$ with the stellar mass. Although the average stellar mass in Gliese's catalogue is two thirds that of the F star sample, no significant difference can be detected. Furthermore, G stars in emission (σ_u = 17.5 km/s) in Gliese's catalogue (with the exception of a sub-dwarf) are kinematically similar to A dwarfs (σ_u = 17.1 km/s). M dwarfs in emission have a clearly higher dispersion (σ_u = 35.7 km/s). However, if the proportion Ge/G = 7 % permits the age of the Ge dwarfs to be compared to that of the A dwarfs, the proportion Me/M = 38 % shows that the average age of the Me stars is clearly greater.

Note that by interpreting the kinematics versus age relationship in terms of a relaxation mechanism or initial conditions, we need to consider the kinematic properties of all the stars at 10 kpc (and not only the stars presently located in the Galactic plane). Wielen (1974) showed that σ_u for all of Gliese's stars goes from 39 km/s to 48 km/s if one considers the crossing time in the Solar neighbourhood, a non negligible difference with regard to the local stability of the Galactic disk.

Figs 5 and 6 illustrate the relations $\sigma'_u(t)$ and $\sigma'_w(t)$ for which the crossing time of the Galactic plane has been taken into consideration. We notice that the epicycle energy (proportional to σ'^2_u or σ'^2_w) of the objects in the old disk is more than twice that estimated from objects situated in the Galactic disk.

Fig. 7 is taken from Janes' (1975) study devoted to kinematic and chemical properties of a large sample of K giants. This figure illustrates the dependence found between the δCN index of cyanogen and the velocity dispersion perpendicular to the Galactic plane σ_w. This index is correlated with [Fe/H] and can therefore be used as an abundance indicator. Thus the objects used in the δCN, σ_w diagram cover a range in $[Fe/H]_{DDO}$ from -0.65 to +0.25 which is the typical abundance range for Galactic disk stars. This very clear relationship between abundance and kinematics of the disk objects has to be brought closer to the $\sigma_w(t)$ relation given in Fig. 3. The δCN, σ_w relation necessarily implies that an important part of the heavy elements now present in the Galactic disk has been synthesized during lifetime of the disk.

<u>Figs 5 and 6</u> Residual velocity dispersions $\sigma'_u(t)$ and $\sigma'_w(t)$ obtained by considering the crossing time of the Galactic plane. These relations are representative of all stars with ϖ = 10 kpc for any z. The two values at a given age illustrate the effect due to uncertainty in the effective temperature scale. The two T_{eff} scales used here are those given by Morton and Adams (1968) and Oke and Conti (1966).

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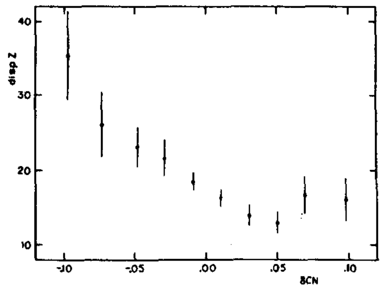

Fig. 7 Relation between δCN and σ_W for the K giants taken from Janes (1975). The objects used in this diagram cover a range in $[Fe/H]_{DDO}$ from -0.65 to +0.25, a typical range for Galactic disk stars.

An order of magnitude for the abundance variation during the Galactic disk period can be deduced from the δCN - σ_W correlation. δCN varies of 0.15 when σ_W goes from its minimum to σ_W = 35 km/s. If we give the age of the Galaxy to the oldest stars we have

$$\Delta [Fe/H]_{DDO} \simeq 0.7 \quad \text{during the last } 10^{10} \text{ y.}$$

A value comparable to the precedingly recalled variations.

In the Galactic plane the analysis of F stars gives an entirely analogical correlation. Table 1 taken from Mayor (1976) gives the relationship between age, metallicity and the kinematic properties perpendicular to the Galactic plane. This relationship between [M/H] and σ_W allows the estimation of the z-variation of the heavy element concentration. The average stars' metallicity must vary by a coefficient of 2 going from z = 0 to |z| = 500 pcs.

Table 1

Observed correlation between z_{max} and Δ[M/H] the metallicity difference relative to the Hyades. These results are for the bright dF stars $m_v \leq 6.5$). The ages result from the mean of the effective temperature scales of Morton, Adams and Oke, Conti using the β index as a temperature indicator. z_{max} is the maximum distance to the Galactic plane corresponding to a W velocity in the plane equal to σ_W (estimated in the Schmidt potential 1965).

log (age)	$\overline{age}$ (10^9 y)	N	σ_W(km/s)	z_{max}(pc)	$\overline{\delta m_1}$	Δ[M/H]
from 8.7 to 9.0	0.75	135	11	125	0.001	-0.01
from 9.0 to 9.3	1.5	208	17	190	0.016	-0.21
from 9.3 to 9.6	2.7	118	23	270	0.025	-0.35
from 9.6 to 10.4	6.3	57	38	470	0.030	-0.42

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This study of chemical and kinematic properties of local F stars can be related to that of Blaauw and Garmany (1975) for F stars in the direction of the Galactic poles. In fact, these authors establish a definite relation between Δm_1 and $|z|$, Fig. 8. The order of magnitude of the deficiency at 500 pcs with respect to z = 0 is compatible with that deduced from kinematics at z = 0. The stars located at 500 pcs must have an epicyclic energy in z according to their position, that is to say a higher age than stars at z = 0. Again it is very difficult to explain such a result without admitting a significant variation of the average metallicity as a function of time during the lifetime of the disk.

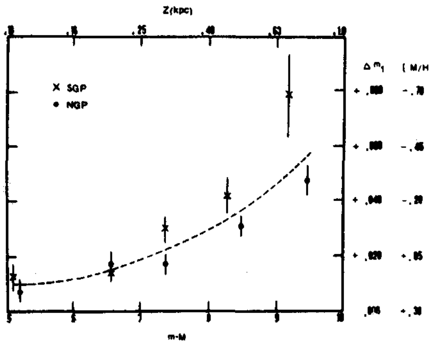

Fig. 8 Relationship between Δm_1 (or [Fe/H]) for F stars at different distances from the Galactic plane, obtained by Blaauw and Garmany (1975).

Boyle and McClure (1975), using DDO photometry, measured the G and K giants associated with Eggen's moving groups. One of their results is illustrated by the orbital excentricity versus $[Fe/H]_{DDO}$ diagram, Fig. 9. Each point on this diagram represents the average of stars in one group. Once more let us emphasize that the correlation (e, [Fe/H]) concerns only Galactic disk objects.

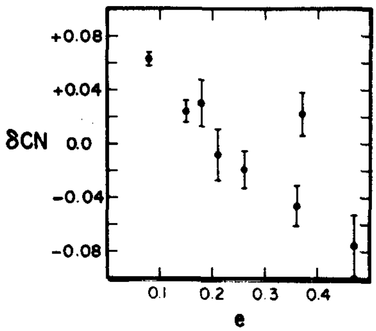

Fig. 9 Relation between the orbital excentricity e of Eggen's groups and the abundance value $[Fe/H]_{DDO}$ deduced from δCN by Boyle and McClure (1975).

Peralta (1975) has analysed the kinematic properties of 631 giants taken from Yoss and Lutz (1971) as a function of the cyanogen index δCN. Again the relationship found between |W| and δCN is clearly defined.

Grenon (1976) has analysed the metallicities and luminosities of cool stars using the Geneva photometry. Fig. 10 illustrates the dependence of $[M/H]_{GEN}$ as a function of the distance from the Galactic plane. The point at z = 0 is deduced from G and K dwarfs in Gliese's catalogue. The values at z ≠ 0 are representative of G and K giants. Once again a variation of the order of a factor 2 is found for the average metallicity between z = 0 and z = 500 pcs.

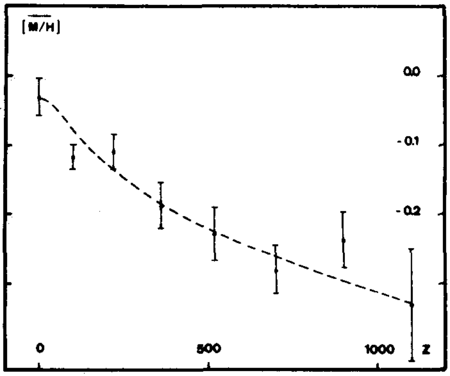

Fig. 10 Dependence of [Fe/H], deduced from the Geneva photometry, applied to the cool stars as a function of their distance from the Galactic plane. Point z = 0 is based on the GK dwarfs in the Solar neighbourhood; the points z ≠ 0 are deduced from the properties of the G and K giants.

In Table 2 we give the value of $[Fe/H]_{GEN}$ versus σ_w derived by Grenon (1977) using the Geneva photometry. The sample consists of Gliese's stars for the four groups with low velocity dispersions. The last line represents the halo objects and is taken from a list of high velocity objects. Once again the variation between the lowest σ_w group and the oldest group of disk stars permits an estimation of the abundance variation.

$\Delta[Fe/H]_{GEN} = 0.6$ during the last 10^{10} y.

Table 2

Relation between the mean metallicity $\overline{[M/H]}$ and the perpendicular velocity dispersions σ_w. The first four groups refer to stars in the Solar neighbourhood (Gliese's catalogue) measured in the Geneva photometric system. The fifth group refers to high velocity stars (Eggen 1964) also measured in the Geneva system (Grenon 1977).

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$[M/H]_{max}$	$[M/H]_{min}$	N	$\overline{[M/H]}$	σ_w (km/s)
+0.6	+0.1	66	0.230	16.5
+0.1	-0.1	83	0.011	14.3
-0.1	-0.4	37	-0.206	25.9
-0.4	-0.9	9	-0.570	33.0
-1.0		27	-1.45	58.0

In this first section, considerable weight has been laid on the average variations. On the other hand, the intrinsic dispersion in the metallicities for a given age and birthplace could as well not be very large (Mayor, 1976). The value obtained in the first study is

$$\sigma_{[Fe/H]} = 0.10 \left({}^{+0.05}_{-0.10}\right)$$

This value is of a statistical nature and it is probable that, for a given age, one finds objects presenting significant abundance differences (see for instance Da Silva, 1975).

The mean of the $\Delta\overline{[M/H]}$ observed variations during the Galactic disk life from the results of Clegg and Bell (1973), Hearnshaw (1972), Mayor (1976) and the two derived here from the correlations $\delta CN - \sigma_w$ (Janes, 1975) and $[M/H]_{GEN} - \sigma_w$ (Grenon, 1977) is

$$\overline{\Delta[M/H]} \approx 0.7 \quad \text{during the last } 10^{10} \text{ y.}$$

I hope that the evidence reviewed in this section will have clarified somewhat the problem of the amplitude of the $\bar{Z}$ variations during lifetime of the Galactic disk. Contrary to the picture furnished for example by the age-abundance relationship for Galactic clusters (Eggen, Sandage, 1969), the kinematic and photometric work on field stars during the past few years is clearly in favour of a considerable augmentation in the mean metallicity during the lifetime of the disk.

II. THE RADIAL GRADIENTS OF METALLICITY AND VELOCITY DISPERSION IN THE SOLAR NEIGHBOURHOOD

The existence of a variation in the mean stellar abundances perpendicular to the Galactic plane is a direct consequence of simultanous increases in σ_w and $\bar{Z}$ with age. In the Galactic plane there exists no simple relationship between $\sigma_u(t)$, $\bar{Z}(t)$ and a radial metallicity variation $\frac{\partial Z}{\partial \varpi}$. ($\varpi$ denotes the distance to the Galactic centre).

Oort has shown that it is possible to deduce the radial density gradient of a stellar sub-population of the Galactic disk from its local kinematic characteristics, mainly <V> and σ_u^2 (see i.e. Oort, 1965). Applying this method to groups of K giants with increasing δCN

(approximately 800 giants), Janes and McClure (1972) obtained a local value for the radial metallicity gradient

$$\frac{\partial \overline{[M/H]}_{DDO}}{\partial \bar{\varpi}} = -\ 0.023 \pm 0.011\ \mathrm{kpc}^{-1}$$

Grenon (1972) applying the Geneva photometry to a sample of dwarfs and G and K giants also gets a radial metallicity gradient :

$$\frac{\partial \overline{[M/H]}_{GEN}}{\partial \bar{\varpi}} = -\ 0.050\ \mathrm{kpc}^{-1}$$

This last analysis is based on the correlation observed between the mean orbital radius $\bar{\varpi}$ and $[M/H]_{GEN}$ and not on the asymmetrical drift relation $\langle V\rangle(\sigma_u^2)$.

In their analysis of the uvbyβ photometric and kinematic properties of 200 F stars, Clegg and Bell (1973) arrive at the conclusion that no radial metallicity gradient exists. In fact, this contradictory result with respect to the first two studies cited arises only from an erronious correction of stellar motions. As a matter of fact, the value adopted for the tangential component of the Solar motion ($V_\odot$ = 16 km/s) is surely too high relative to the local circular motion.

Mayor (1976) has analysed the kinematic and photometric properties of about 600 F dwarfs using uvbyβ photometry and 600 G and K giants, using the [Fe/H] values given by Hansen and Kjaergaard (1971). The average value deduced for the metallicity gradient is

$$\frac{\partial \overline{[M/H]}}{\partial \bar{\varpi}} = -\ 0.039 \pm 0.011\ \mathrm{kpc}^{-1}$$

adopting a Solar motion of $V_\odot$ = 10 km/s and is

$$\frac{\partial \overline{[M/H]}}{\partial \bar{\varpi}} = -\ 0.049 \pm 0.011\ \mathrm{kpc}^{-1}$$

for the value $V_\odot$ = 6 km/s. Several arguments stated in this work and in that of Gomez and Mennessier (1976) are in favour of a lower value for the $V_\odot$ component than that which is generally admitted.

If the chemical gradient is analysed starting from the ($\bar{\varpi}$, [M/H]) correlations for different groups of orbital excentricities, one concludes (see Table 6 of Mayor 1976) that the metallicity gradient is a function of age. For instance with $V_\odot$ = 10 km/s

$$\frac{\partial \overline{[M/H]}}{\partial \bar{\varpi}} = -\ 0.076 \pm 0.018\ \mathrm{kpc}^{-1} \quad \text{with } 0.05 < e < 0.15 \text{ for 644 stars}$$

and

$$\frac{\partial [M/H]}{\partial \varpi} = -\,0.021 \pm 0.016\ \mathrm{kpc}^{-1} \quad \text{with } 0.15 < e < 0.40 \text{ for 371 stars.}$$

These gradients are locally valid, that is to say at ϖ = 10 kpc and can not be extrapolated to the centre of the Galaxy. However, the orders of magnitude given here are comparable with the gradient values deduced from observations of HII regions in spiral galaxies. Searle (1971) for instance estimates that O/H varies by a factor of two between the centre and edge of the Galactic disk. D'Odorico et al (1976), studying the planetary nebulae of our Galaxy, deduce a variation in O/H by a factor of three between 8 and 14 kpcs. The gradient thus deduced $\frac{\partial [O/H]}{\partial \varpi} = -\,0.08$ is in agreement with the local [M/H] gradient determined by the kinematics of young objects. Aitken et al (1976) estimate the heavy element abundance as being three times higher in the HII in the Galactic centre relative to Solar values.

I briefly come back to the problem of stars which do not agree with the picture resulting from the average relations $\bar{Z}$ as a function of t, ϖ and z. Given the existence of a large radial abundance gradient, one may attempt to interpret the SMR stars in terms of their birthplaces. Williams (1972) has published a list of evolved stars, probably SMR stars. Calculating the average of the mean orbital radii of these stars, only a small part (approximately 10 %) of the supermetallicity could be interpreted by the existence of a chemical gradient. On the other hand, it appears that the SMR dwarfs can be interpreted in terms of a chemical gradient and a birthplace inside 10 kpc with the dispersion in the metallicity increasing towards the Galactic centre, Grenon (1972). Peralta (1975) has evidenced a group of G and K giants with high U and V velocities having relatively high metallicity. He notes that the radial composition gradient does not seem to explain these stars. These strong CN stars with abnormal kinematic behaviour have already been noted by Janes and McClure (1972).

In the preceding section the dependence of the velocity dispersions on age has been amply discussed. What about the radial dependence of the velocity dispersion? The asymmetrical drift relation allows the determination of $\frac{\partial \ell n\, \rho}{\partial \varpi} + \frac{\partial \ell n\, \sigma_u^2}{\partial \varpi}$. The ellipsoidal theory of the Galaxy, Chandrasehkar (1942) predicts a σ_u dispersion independent of ϖ. On the other hand, due to a lack of observational facts, the term $\partial \ell n\, \sigma_u^{\,2}/\partial \varpi$ has been assumed to be zero in the kinematic studies of density gradients, Oort (1965). However, one can check that σ_u cannot be independent of ϖ by considering the local stability of the Galactic disk using Toomre's criteria (1964).

In fact the value $\sigma_{u_\odot}$ for the Solar neighbourhood makes it impossible

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to stabilize the Galactic disk within ϖ = 7 to 8 kpcs. An estimation of $\frac{\partial \ell n\, \sigma_u^2}{\partial \varpi}$ based on the hypothesis $Q = \frac{\sigma_u(\varpi)}{\sigma_u(\varpi)_{min}}$ = cte leads to $\frac{\partial \ell n\, \sigma_u^2}{\partial \varpi} = -\ 0.2\ \mathrm{kpc}^{-1}$ Mayor (1974).

A study of the 3rd and 4th order moments of the local stellar velocity distribution enabled Vandervoort (1975) and Erickson (1975) to calculate this gradient. The value obtained is between -0.19 and -0.23. Thus it seems that locally the approximation Q = const. for all ϖ is justified.

III. STELLAR BIRTHRATE, INITIAL LUMINOSITY FUNCTION AND KINEMATICS

Certain models of the Galactic disk predict a relationship between the stellar birthrate and kinematic properties.

In the hydrodynamical models of the gas disk in the presence of density waves, Roberts (1969), Shu et al. (1972), a relation is naturally established between the kinematic properties of young objects, the rate of formation and the birthplace. This idea is the basis of the studies by Yuan (1969), Grosbøl (1976), Forte and Muzzio (1976) and Wielen (1973) on the migration of stars or clusters in a spiral field. The principle of investigating the birthplaces of young objects directly from their ages and orbits has already been developed by Strömgren (1963).

During the formation of the Galaxy, a relation is naturally established between the birthrate, the birthplace and the kinematic properties. This relationship is the basis for the Galactic collapse model proposed by Eggen, Lynden-Bell and Sandage and the interpretation of the sub-dwarfs.

On the other hand, it might be that the formation of the disk has taken place on a timescale longer than that characterizing the formation of the Galactic spheroidal component, according to Larson's models (1976). In this case the stellar formation, the infall rate and the kinematic properties of the disk objects are also linked. The slow formation model elaborated by Tinsley and Larson (1977) for the Galactic disk predicts correlations between σ_w and the abundances in very satisfactory agreement with the observed relations.

The kinematic properties can also be used as chronometer for estimating the time variation of the initial luminosity function or of the stellar birthrate. Wielen (1974) has studied the luminosity function of low mass stars (non evolved) as a function of their velocity W thus more or less creating age groups. Within the range of the uncertainties no significant variation in the initial mass function ($<1\ m_\odot$) has so far been detected.

Comparing the average kinematic properties of close non evolved stars with the age versus kinematics calibration deduced from F stars, Mayor and Martinet (1976) come to the conclusion that the stellar birthrate has only slightly varied with time, at a distance of 10 kpc from the Galactic centre. The same study reveals a similar conclusion using the comparison between the kinematic properties and the percentage of K and M stars of various increasing HK index groups (calcium re-emission). Although the uncertainties associated with these procedures are considerable, the birthrate in the Solar neighbourhood seems to have decreased, at the most, by a factor 7 during the lifetime of the disk. On the other hand, a constant rate cannot be rejected. Such a result can be compared with the disk Galaxy formation model proposed by Larson (1976). The birthrate predicted for 10 kpc for some of these models shows a moderate variation with time, unfortunately, all detailed comparison is impossible for the time being.

While the initial luminosity function for low masses seems to have varied little with time, Burki (1977) however has shown that for young clusters the mass spectrum of the upper main sequence varies with the distance from the Galactic centre.

Very little is known about the centre-anticentre variations of the kinematic properties at the time of stellar formation. However, the existence of the chemical gradient, the gas density variation, the rate of compression due to spiral shock waves must have an influence on the gas turbulence and hence on the initial dispersions in the residual velocities. The discovery of a variation in the average axial rotation velocities with ϖ by Burki and Maeder (1977) seems to indicate that either the gas turbulence or the fragmentation mechanisms depend on the distance from the Galactic centre.

IV. THE PHYSICAL MECHANISMS SUGGESTED FOR INTERPRETING OF THE RELATIONSHIP BETWEEN AGE AND KINEMATICS

In the first three sections the observational facts regarding Galactic disk objects have been emphasized. The mechanisms invoked to explain the radial chemical gradient or the temporal evolution of the metallicity are discussed separately in other reviews.

The three kinds of mechanisms have been proposed for the relationship between age and kinematics : relaxation mechanisms, initial conditions and properties of the metric.

The initial idea of the relaxation mechanisms is that the Galactic disk was stabilized very early (possibly after a rapid collapse forming

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the Galaxy) and that the kinematic properties, during stellar formation in the disk, were similar to those observed at present for young objects. Since then, a mechanism is needed to explain the increase in the dispersions with time. The interaction of stars with massive clouds of interstellar matter or irregularities in the gravitational field have been invoked by Spitzer and Schwarzschild (1958), Julian (1967), Woolley and Candy (1968), Wielen (1977) etc.

The interaction of the stars with the non stationary spiral density waves is the basis of Barbanis and Woltjer's study (1967). The adjustment of the stellar kinematic conditions at the time of birth to the gravitational field of the spiral wave can be used to explain the variation of the velocity dispersions during the first Galactic rotations (Wielen 1974). All these mechanisms are effective in increasing the velocity dispersions of the least dispersed objects. However, they are hardly sufficient to explain the σ_u' and σ_w' dispersions observed for old disk objects.

The kinematic properties of the sub-dwarfs and other halo objects are interpreted by their initial conditions. The excentricities and angular momenta of the sub-dwarfs have been considered by ELS as evidence in favour of a rapid collapse of the protogalaxy, that is to say in a period of some 10^8 years. Isobe (1974) has recently considered the population of the UV plane by sub-dwarfs using the hypothesis of a rapid collapse. The predicted distribution seems to be incompatible with the velocity distribution of the sub-dwarfs whereas a collapse on a longer timescale would be more satisfactory. On the other hand, Larson's models (1976) for the formation of spiral galaxies show the necessity of two distinct timescales for the formation of the spheroidal and disk components of the Galaxy. The disk component clearly needs a longer timescale than the free fall time. The kinematics-age relationship of the objects of the old (or moderately old) disk would thus be simply explained (Tinsley and Larson 1977).

Moreover, I would like to mention a mechanism which might have had a certain influence on the kinematics versus age relations on the one hand, but in a general manner on the chemical as well as dynamical history of the Galaxy. Following Dirac's work a regain of interest has recently been manifested for a covariant gravitational theory with regard to gauge transformations (see for instance Canuto et al, 1977). For the time being no observational test seems to contradict this theory. In this context a paper by Maeder (1977) on mechanics with gauge invariance clearly shows that the temporal evolution of the excentricities of a stellar orbit could be important on a timescale comparable to the lifetime of the Galaxy.

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V. DISCUSSION

The order of magnitude of the observed variations of the kinematical parameters and the metallicity with the age is probably correct. However, extremely limited trust should be put in the detailed forms of the Z(t) or σ(t) functions. In fact the dating of stars having ages between 0 and 10^{10} years with metallicity between approximately [Fe/H] = - 1 and + 0.3 is very uncertain. In particular, the dating is uncertain because of the uncertainty in the mixing length and its dependence on Z, the variation of Y with time and the uncertainty in the effective temperature scales.

The order of magnitude of the ϖ and z variations of the metallicity given by diverse techniques seems to be in reasonable agreement. However, the difference possible between the metallicity gradient of the young and old objects obtained through the kinematics must be confirmed by other techniques. In effect, the least dispersed stellar sub-populations are so sensitive to perturbations in the potential that the ($\langle V \rangle$, σ_u^2) relation for these stars might not satisfy the hypothesis used in establishing the asymmetrical drift equation.

As far as the stellar birthrate as a function of time is concerned, I do not know whether we dare pretend that the order of magnitude is known but in any case the details of its temporal or spatial dependence is completely undetermined.

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