KINEMATICS OF DISK STARS IN THE SOLAR NEIGHBOURHOOD

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ABSTRACT

Using Hipparcos parallaxes and proper motions together with radial velocity complementary data (Coravel for late type stars and new ground-based data for early type stars) for several thousand B-F type stars, the velocity ellipsoid has been determined as a function of age. The variations with age of the ratio of the velocity dispersions, of the vertex deviation and the age-velocity dispersion relation (AVR) have been estimated.

Our results confirm that mixing is not complete at about $0.8 - 1$ Gyr. The shape of the velocity ellipsoid changes with time, getting rounder from $\sigma_U/\sigma_V/\sigma_W = 1/0.63/0.42 \pm 0.04$ at about 1 Gyr to $1/0.7/0.62 \pm 0.04$ at $4 - 5$ Gyr. The AVR rises to a maximum, thereafter remaining roughly constant; there is no dynamically significant evolution of the disk after about $4 - 5$ Gyr. The velocity dispersion in the direction perpendicular to the galactic plane saturates at about $15 - 17$ km s^{-1} for thin disk stars. The vertex deviation declines with age and remains near zero after 5 Gyr.

Key words: kinematics; velocity ellipsoid; disk heating; vertex deviation.

1. INTRODUCTION

As a first approximation the Galaxy can be assumed to be stationary and axisymmetric. The kinematics of stars in the solar neighbourhood may differ from the kinematics predicted for an axisymmetric and stationary disk (Binney & Tremaine 1987). In particular, the shape and the orientation of the velocity ellipsoid may reflect the existence of small as well as large-scale irregularities. For instance, the vertex deviation (the galactic longitude of the largest principal axis of the velocity ellipsoid) may be non-zero due to the presence of either small-scale irregularities such as spiral arms, gravitational wakes induced by giant molecular clouds, etc. or of large-scale oscillations (i.e. axisymmetric time-dependent distortions or non-axisymmetric distortions) of the galactic disk (Kuijken & Tremaine 1992).

It has long been known that the random velocities of disk stars vary with age. However, due to the lack of accurate kinematical data, a detailed study of the age-velocity dispersion relation has not been possible. Any interpretation of the kinematics of the solar neighbourhood needs also to establish to what extent the stars do form a well-mixed system.

The availability of Hipparcos parallaxes and proper motions together with radial velocity complementary data for about 3000 stars allow to redetermine the velocity distribution functions in the solar neighbourhood on new bases. The gathered sample mostly contains thin disk stars. The variations with age of the shape of the velocity ellipsoid and of the vertex deviation as well as the age-dependence of the velocity dispersion relation are presented.

2. MATERIAL

This study is essentially based on the Hipparcos survey stars for which kinematical data and individual ages have been estimated. Astrometric data (positions, parallaxes and proper motion components) have been taken from the Hipparcos Catalogue (ESA 1997). Radial velocity data have been obtained from the literature (Barbier-Brossat 1997, Duflot 1995) or newly measured in an extensive ground-based programme. For early type stars the new radial velocities were obtained within the framework of an ESO key-programme (Gerbaldi et al. 1989) for southern stars and of a survey carried out at the Observatoire de Haute Provence (Grenier 1997) for northern stars. For late type stars, only a part of the radial velocities of the Coravel ESO key-programme has been used (Udry et al. 1997). From these astrometric and spectroscopic data the velocity components with respect to the Sun (U, V, W) were calculated. U is directed towards the galactic center, V in the direction of the galactic rotation and W perpendicular to the galactic plane. The errors in the velocity components were computed taking into account the errors on the astrometric and spectroscopic data as well as the correlation coefficients between the astrometric parameters (Meillon et al. 1997). A correction for galactic rotation was also included using the Oort's constants A and B given by Kerr & Lynden-Bell (1986).

The shape and orientation of the velocity ellipsoid were then calculated. The corresponding uncertainties were estimated from the errors and correlations on the velocity components.

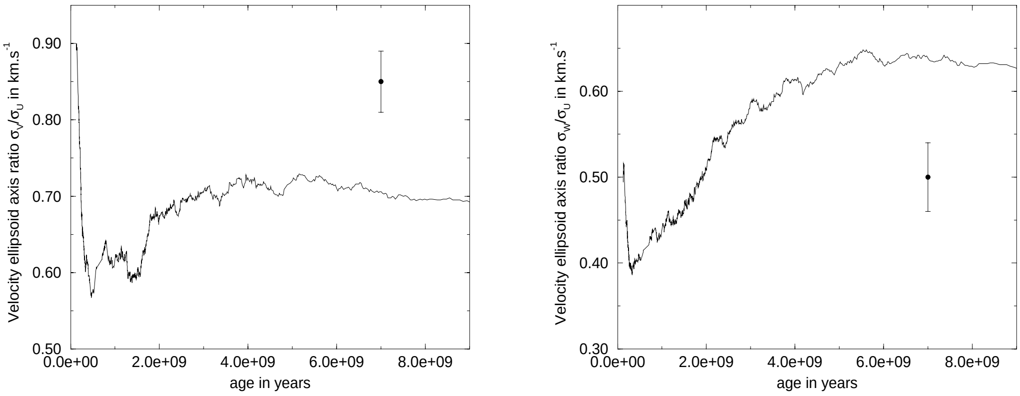

Figure 1. Velocity ellipsoid axis ratios versus age (2812 stars, running average 500 points window).

In order to study the variation of the velocity ellipsoid with age, individual ages were estimated from Bertelli et al. (1994) isochrones. Effective temperatures and [Fe/H] metallicities were derived from Strömgren photometry or taken from the spectroscopic values compiled by Cayrel et al. (1997). Absolute magnitudes were estimated from Hipparcos parallaxes and V-magnitudes were corrected for reddening using Strömgren photometry.

The stars on the giant branch, in clusters and all known binaries, variables and spectroscopically peculiar stars were eliminated. Moreover, only stars with an error on the age determination < 50 per cent and on the velocity components < 15 km s^{-1} were retained. To avoid the contamination by thick disk population stars, stars with total velocities > 65 km s^{-1} were also eliminated. The final sample contains 2812 stars. Most of the stars have metallicities > -0.5 dex and estimated ages smaller than about 10 Gyr (only a few have ages between 10 and 12 Gyr).

3. RESULTS

3.1. The Shape of the Velocity Ellipsoid

The variations with age of the velocity ellipsoid axis ratios (σ_V/σ_U and σ_W/σ_U) are shown in Figure 1. For the coldest populations (ages smaller than about 1 Gyr) the ratio σ_V/σ_U changes from about 0.9 reflecting the rather spherical velocity distribution of the gas to 0.63±0.04 at about 1 Gyr. For such younger objects, the kinematical behaviour is dominated by the presence of moving groups (Sabas 1997, Figueras et al. 1997). For ages > 1 Gyr the ratio rapidly increases up to 0.7±0.04 at about 3 Gyr, then remains unchanged within the estimated errors. The axis ratio (σ_W/σ_U) also varies rapidly with age, from 0.42 ± 0.04 at 1 Gyr to 0.62 ± 0.04 at about 4 Gyr.

The Oort ratio (σ_V^2/σ_U^2) is related to the Oort contants A and B. For a flat galactic rotation curve in the solar neighbourhood, this ratio equals 0.5. The sources quoted by Kerr & Lynden-Bell (1986) give values ranging from 0.36 to 0.5. If we reasonably assume complete mixing after about 1 Gyr, a similar range of values is observed: from 0.36 ± 0.05 to 0.49 ± 0.06 as a function of age. For stars with ages > 1 Gyr, the velocity distribution in each component is consistent with being a Gaussian, according to the Kolmogorov-Smirnov test at the 95 per cent significance level.

3.2. The Age-Velocity Dispersion Relation

In recent years observational evidence showed that the age-velocity dispersion relation (AVR) is more complex than a unique fairly smooth relationship (Strömgren 1987). Figure 2 presents the variation of σ_U, σ_V and σ_W with age. In the diagram three main age zones can be distinguished:

- stars with ages $< 0.8 - 1$ Gyr corresponding to incomplete mixing;
- stars with ages between about 1 and 4 Gyr for which a variation of the shape of the velocity ellipsoid is observed;
- stars with ages between 4 and 10 Gyr for which no trend of the velocity dispersion with age is observed. σ_W increases up to 17 ± 1 km s^{-1} and saturates at 15 km s^{-1} if only the stars with $-0.15 <$ [Fe/H] < 0.15 are kept. The total velocity dispersion is smaller than about 37 ± 2 km s^{-1}.

Different mechanisms have been invoked to explain the disk heating (Lacey 1992). These results provide a new base for critical tests of these mechanisms and will be discussed in a forthcoming paper.

3.3. The Vertex Deviation

The vertex deviation l_V, the galactic longitude of the largest principal axis of the velocity ellipsoid, is given

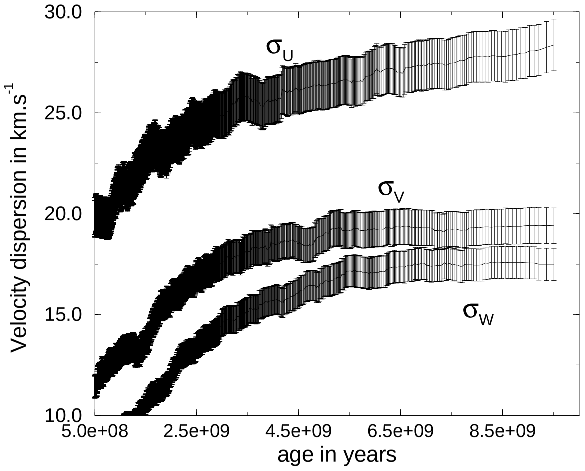

Figure 2. Age-velocity dispersion relation (2812 stars, running average 500 points window).

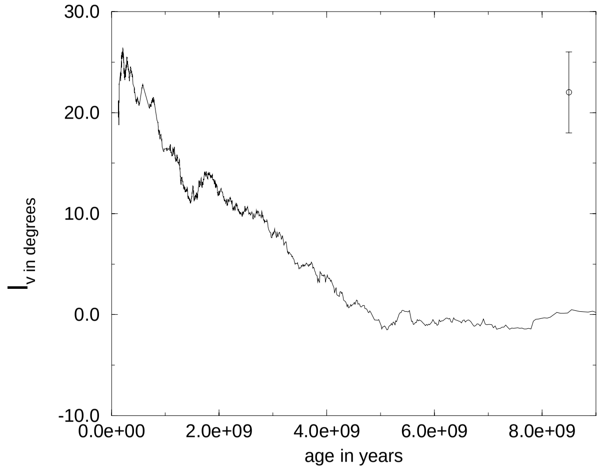

Figure 3. Vertex deviation versus age (2812 stars, running average 500 points window).

by: $\tan(2l_V) = 2(\sigma_{UV}/(\sigma_U^2 - \sigma_V^2))$. Figure 3 shows the variation of l_V with age. As expected, the coldest populations present large vertex deviations (about 20 degrees) reflecting incomplete mixing. For young but well-mixed populations (ages > about 1 Gyr), l_V declines from about 10 degrees to 0 degrees at around 5 Gyr. Between 5 and 10 Gyr, it remains near zero.

4. SUMMARY

The variations with age of the shape of the velocity ellipsoid and of the vertex deviation have been obtained using a sample of thin disk stars of the Hipparcos survey. Our main conclusions are the following:

- the shape of the velocity ellipsoid gets rounder when the age increases. It changes from $\sigma_U/\sigma_V/\sigma_W = 1/0.63/0.42 \pm 0.04$ at about 1 Gyr to $1/0.7/0.62 \pm 0.04$ at $4-5$ Gyr. After that, it remains roughly constant implying that there is no dynamically significant evolution of the disk after $4-5$ Gyr. The velocity dispersion in the direction perpendicular to the galactic plane (σ_W) does not exceed $15 - 17$ km s^{-1} for thin disk stars;
- the vertex deviation remains near 0 ± 4 degrees after 5 Gyr. For well-mixed populations, this result suggests that l_V is mostly caused by small-scale rather than large-scale oscillations, like a nearby spiral arm or other mass concentration;
- the stars in the solar neighbourhood do form a well-mixed system after about 1 Gyr in agreement with previous work (Gómez et al. 1990, Sabas 1997).

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