EGGEN'S MOVING GROUPS: FACT OR FICTION?*

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ABSTRACT

The concept of moving groups is discussed, using the Hipparcos parallaxes and proper motions to compute precise space velocities for about 800 stars included in this project. The V component of the space velocity (in the direction of galactic rotation) has been used as the main membership criterion. Moving group parallaxes have been found to be close to the Hipparcos values. An additional test involving galactic orbit modelling has been undertaken for some of the moving groups, allowing us to monitor the development of a star cluster. It has been possible to simulate the stellar tube formation and to examine various combinations of velocity components in order to find better membership criteria.

Key words: moving groups; galactic orbits.

1. INTRODUCTION

In a series of papers spanning several decades, Olin Eggen has introduced the concept of *moving groups* of stars (e.g. Eggen 1959, 1969, 1970, 1971a,b,c, 1994). The hypothesis is based on the assumption that many stars are formed in a certain region, creating a cluster with a well defined age, position and velocity. Each star will have its own random velocity, in addition to the global mean velocity of the cluster. Presumably, these random velocities are small and evenly distributed in all directions. After several galactic rotations, the original cluster will evaporate, as the result of the initial loss of the lowest mass stars which bind the cluster. The random velocity components in the direction of galactic rotation will stretch the stars into a *tube*. If the Sun happens to fall somewhere inside such a moving group tube, the stars that form the group will be distributed evenly across the sky, but their common motion should allow us to recognize the group members.

Eggen himself has chosen the velocity component in the direction of galactic rotation to be the main membership criterion, with the same value for all the stars in a group. On this basis, he has found about one dozen moving groups incorporating about 1000 stars, the largest ones being the Hyades, Wolf 630, Sirius, Arcturus and 61 Cygni groups.

This paper is part of a larger project started at the University of Canterbury in order to test Eggen's hypothesis. All the stars mentioned in his papers were included in the Hipparcos Input Catalogue (ESA 1992, hereinafter HIC) and the results communicated to the authors in 1997 February (ESA 1997, hereinafter HIP). At the same time, a parallel observational program has been carried out to get precise radial velocities for most of these stars. These measurements are not included here, but they will be combined with the Hipparcos data in due course.

2. FROM EGGEN TO HIPPARCOS

Hipparcos parallaxes and proper motions have been combined with published radial velocities (Hipparcos Input Catalogue) and the space velocities have been computed. We have used the right-handed coordinate system centred at the Solar System barycentre, with the X-axis pointing towards the galactic centre, Y-axis in the direction of galactic rotation (clockwise,

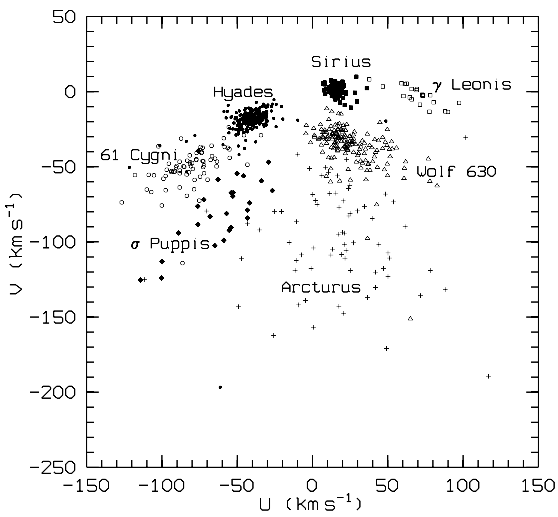

Figure 1. The largest moving groups in the UV plane.

*Based on data from the ESA Hipparcos astrometry satellite.

if seen from the north galactic pole), and Z-axis towards the north galactic pole. Corresponding components of the space velocity vector are U, V and W respectively. It should be noted that Eggen's U velocity points *away* from the galactic centre and has the opposite sign compared to our definition.

The seven most populated of Eggen's moving groups (Hyades, Wolf 630, Sirius, Arcturus, 61 Cygni, σ Puppis and γ Leonis) are presented in the UV velocity plane in Figure 1. The grouping is reasonably clear, at least for the slowest groups ($V \sim 0$). However, these stars have *already* been selected to have similar motions and we cannot use Figure 1 to prove the existence of moving groups, because it is not a random sample of stars. However, we can use it to investigate some other properties.

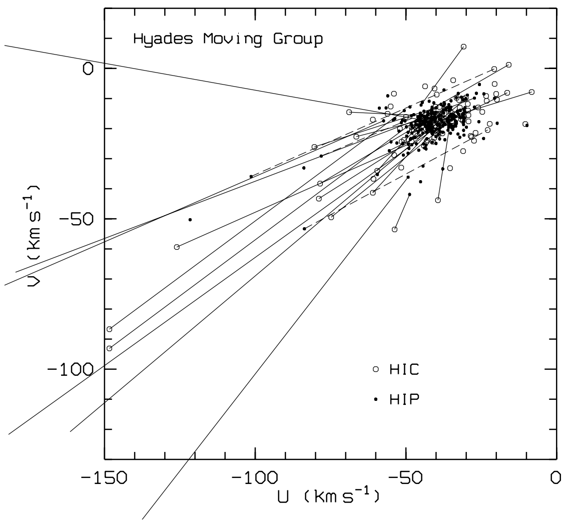

Figure 2. The Hyades moving group in the UV plane. Open circles represent the velocities computed using the parallaxes and proper motions available before the Hipparcos mission (HIC). Some of the points fall outside the bounds of the plot. Filled dots correspond to Hipparcos data (HIP). Lines are used to connect the HIC and HIP positions for some of the stars. Dashed lines indicate when the HIP position pulls a star away from the core of the group.

An important fact about Figure 1 is that all the groups have become *more compact* (i.e. better defined) with the Hipparcos measurements. This is shown in Figure 2 for the Hyades moving group. Many of the stars are moved into the core of the group when the Hipparcos data are used. In only a few cases (dashed lines in Figure 2) are they moved away from the core, possibly indicating that those stars are not group members. The situation is very similar for all of Eggen's groups. For example, the Sirius moving group appears as the most compact concentration of stars in Figure 1. That is especially the case for its *nucleus* stars (i.e. the Ursa Major cluster), confirming some predictions published previously (Soderblom & Mayor 1993).

The dispersions in U and V are also considerably less when Hipparcos data are used (see Table 1). Only the stars with existing HIC data have been used to compute the statistics, with the same sample in all columns. The Arcturus group is the only one with HIP σ_u actually bigger than the HIC value. However, all dispersions in V are at least two times less with Hipparcos data for all the groups.

Table 1. Standard deviations for velocity distributions in U and V for some moving groups when pre-Hipparcos (HIC) or Hipparcos (HIP) data are used.

Group Name	HIC σ(km s^{-1}) σ_u	HIC σ(km s^{-1}) σ_v	HIP σ(km s^{-1}) σ_u	HIP σ(km s^{-1}) σ_v
Hyades	53	43	13	17
Wolf 630	20	29	16	10
Sirius	13	8	4	4
Arcturus	37	86	45	30
61 Cygni	34	25	19	13
σ Puppis	26	36	21	19
γ Leonis	48	36	13	6

These results can be interpreted in two slightly different ways:

- if Eggen's groups are real and all suggested stars are members, they would be expected to appear close to each other in the UV plane, and then the Hipparcos data are indeed much better than the previous astrometric measurements;
- if we take the Hipparcos parallaxes to be the true values and use them to test the moving group concept, then moving groups may be real. To really prove this hypothesis, detailed statistical tests need to be undertaken on a random sample of Hipparcos parallax stars.

The truth is probably somewhere in between. At this stage we cannot claim that all the stars are members.

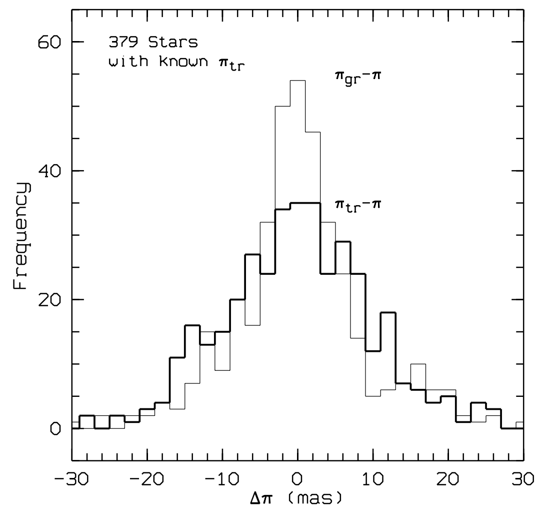

Figure 3. Comparison between the group parallaxes $\pi_{\rm gr}$ and old trigonometric ones $\pi_{\rm tr}$ relative to the Hipparcos values π. Only the stars with previously known parallaxes are plotted.

But a more concentrated grouping certainly indicates both the high quality of the Hipparcos data and the possible reality of moving groups.

It is also interesting to compare the *group* parallaxes π_{gr} with the Hipparcos values π. A group parallax corresponds to such a distance at which a star should be found, in order to have exactly the same V velocity as is adopted for the whole group. Figure 3 shows the stars with previously known trigonometric parallaxes π_{tr}, so the distributions $\pi_{gr} - \pi$ and $\pi_{tr} - \pi$ can be compared. It is obvious that the group parallaxes are closer to the Hipparcos values. This is especially the case for stars with $\Delta\pi$ within ± 5 mas.

A similar distribution can be found for those stars with previously unknown parallaxes. Their group parallaxes are very close to the Hipparcos values. It means that the moving group concept can be used to predict the parallax with an uncertainty of within 5–10 mas. Of course, if the parallax itself is of the same order, this cannot be regarded as a good result. About 30 per cent of all the stars in Eggen's lists have $\pi < 10$ mas and 50 per cent $\pi < 15$ mas. However, there are 40 per cent more stars with $|\Delta\pi_{gr}| < |\Delta\pi_{tr}|$, i.e. those with group parallaxes closer to the Hipparcos values.

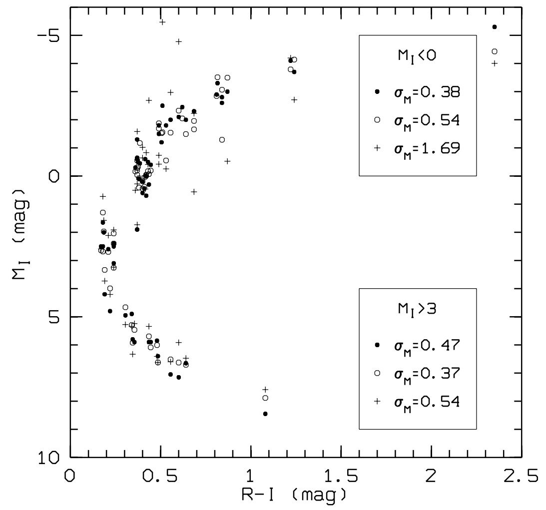

Figure 4. Some Wolf 630 stars in the (M_I, R–I) plane, with three different sources of parallaxes used to compute M_I. Filled dots are Eggen's data based on group parallaxes, while circles and crosses correspond to Hipparcos and pre-Hipparcos, respectively. Standard deviations around a mean locus have been computed for dwarfs and giants separately.

Another way of comparing π_{gr} with π and π_{tr} is to convert them to absolute magnitudes and display them in an HR diagram. If all the stars in a moving group were formed together, their HR diagram must be similar to one for a cluster of the same age, with a well defined locus of stars corresponding to an isochrone. If we simply use the Hipparcos photometry and plot M_V vs $B - V$ for Eggen's groups, the diagrams do not suggest the same age for all the stars, confirming some results published previously (McDonald & Hearnshaw 1983). The situation is somewhat better in the (M_I,$R - I$) plane, see for example the Wolf 630 group in Figure 4. Photometric data have been taken from Eggen (1969), but include only about 30 per cent of the stars. However, the Hipparcos data provide better agreement with the moving group concept than is the case for the old astrometric data.

Returning to Figure 1 we can examine the way in which the moving groups are actually grouped in the UV plane. Each group should appear more or less as a horizontal bar, or a flattened ellipse, if Eggen's criterion of constant V is true. What we see, however, is very different. All the groups show some sort of elliptical concentration, but their major axes are tilted in different directions. The dispersions in V seem to be less than in U, but the plot does not confirm the constant V membership criterion. There is even an indication that those groups with $U < 0$ have positive inclinations and those with $U > 0$ have negative inclinations. All the axes apparently converge to around (0,0). The Arcturus group covers a large portion of the UV plane, and does not look like a moving group at all.

Now we must find some physical reasons responsible for distributing the stars that way in the UV plane, and the Hyades moving group (Figure 2) can give us some clue. Practically all the corrections, from pre-Hipparcos to Hipparcos measurements, go in one general direction and that is the actual major axis of the group. It seems that the group shape is actually caused mainly by the parallax uncertainty itself. This becomes even more obvious in Figure 5 (with all moving groups), where each star is presented as a line showing how the U and V components would change if the parallax changed by $\pm\sigma$ (Hipparcos standard error). Note that the parallax errors cause a larger scatter in U and V for the higher velocity old disk moving groups.

In the next section we discuss whether the tilted el-

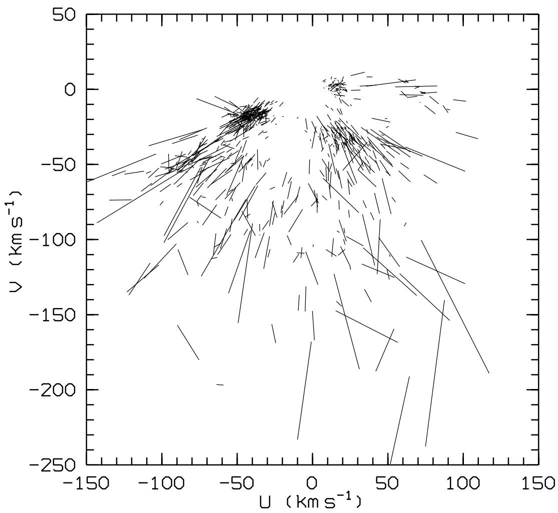

Figure 5. Seven Eggen's moving groups in the UV plane, each star presented as a line, corresponding to a $\pm\sigma$ change in parallax.

liptical distribution of moving group stars in the UV plane can be explained by effects other than that caused by parallax errors. We analyse what the expected distribution of group members would be in velocity space after the original cluster has dissolved.

3. GALACTIC ORBITS

A multi-component (central bulge + disk + dark halo) model of the galactic potential (Flynn et al. 1996), together with an improved Runge-Kutta computing algorithm (Press et al. 1994) have been used to integrate the equations of motion for a hypothetical moving group orbiting around the galactic centre. The Hyades group has been chosen as a model with present parameters:

$$X, Y, Z = -44.4, 0, -18.3 \quad (\text{pc})$$
$$U, V, W = -40, -17, -3 \quad (\text{km s}^{-1})$$

These values have then been converted into the galactocentric ones, using the standard solar distance of $R_o = 8.5$ kpc and circular velocity of $V_o = 220$ km s^{-1}, combined with the height above the galactic plane of $z = 12$ pc (Gilmore et al. 1989), and solar motion of 16.5 km s^{-1} in the direction ($l = 53°$, $b = 25°$) (Binney & Tremaine 1987).

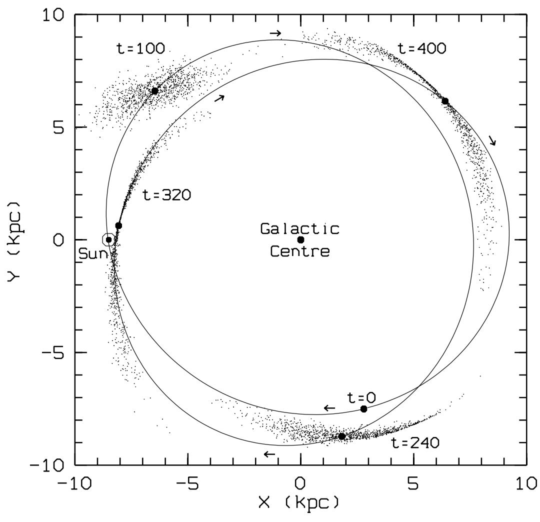

Figure 6. A hypothetical Hyades moving group evolving in time as it orbits around the galactic centre. Time is given in millions of years.

The starting point for the group has been computed by integrating the equations of motion backwards in time, using an arbitrary age of 550 million years. At the starting point ($X \approx 2.8$ kpc, $Y \approx -7.5$ kpc) a cluster of stars has been created, all with the same starting velocity (coming also as a result of the previous integration), plus an additional random component with a standard deviation of $\sigma = 10$ km s^{-1} in all directions. This choice for the dispersion is based on the dispersions found in Eggen's papers (e.g. Eggen 1969).

The gravitational interaction between the stars has been neglected completely. Each star has been regarded as a free particle moving in a static potential. Therefore, the cluster will start dissipating immediately. We can accept this simplification, as long as we are interested in the purely qualitative results of this numerical experiment.

The evolution of such an artificial Hyades group described above is shown in Figure 6. The orbit (for a mean star having no random velocity components) shows two loops, reaching approximately the starting point ($t = 0$) after about 480 Myr. All the other stars move close to this orbit, crossing it periodically. As a result, the original cluster evaporates into a tube. It is always in motion and can have slightly different relative positions in respect to the orbit. Its width is not uniform, having some extremely narrow nodal sections, where the stars appear to be perfectly aligned.

After 550 Myr the moving group will be at about the position of the Sun (Figure 7). Simulations show that the age is a critical parameter. If we assume an age ranging from 520 to 600 Myr we see that the Sun can fall in practically any part of the tube. That will considerably change all the observational facts about the moving group stars in the solar neighbourhood.

A very similar situation is found in the UV plane. Moreover, when the Sun falls into the narrowest part of the XY distribution, it also falls into the narrowest part of the UV distribution. Actually, figure sequences showing all the stars in the XY and UV planes become almost identical, if the velocity figure is rotated anti-clockwise by 90°.

However, we cannot see all the stars that form a group. Even if we can see them, we cannot measure their parallaxes. Only the stars that fall inside our small neighbourhood (about 200–300 pc in radius) can have their motions determined. The bottom right part of Figure 7 shows how these stars are distributed in velocity space. The stars do not have the same V velocity component for all ages. They are dispersed both in U and V, except when the Sun enters the *node* (age 560). The distribution has a rectangular shape (a tilted parallelogram actually), with a characteristic *inclination*, changing rapidly with age. It is also noticeable how the actual width of the distribution in both components changes with the neighbourhood radius.

It would be interesting to find out if we could use these distributions to restore the original velocity dispersion, which would give us additional information about the moving group. But if we simply calculate the dispersions in U and V, we may get some useless results, since the distribution is essentially two-dimensional. The standard deviations for both U and V are presented in Figure 8 as solid lines. The sinusoidal form of σ_u is simply caused by the rotation of the distribution, having minima when the distribution is vertical and maxima when it is horizontal, with a total amplitude of about 7 km s^{-1}. The only difference between the two neighbourhoods is that the σ_u curve for the bigger radius is shifted up by about 1 km s^{-1}. The dispersion in V shows a different behaviour changing relatively slowly, except for the nodal point, where we have an extremely small

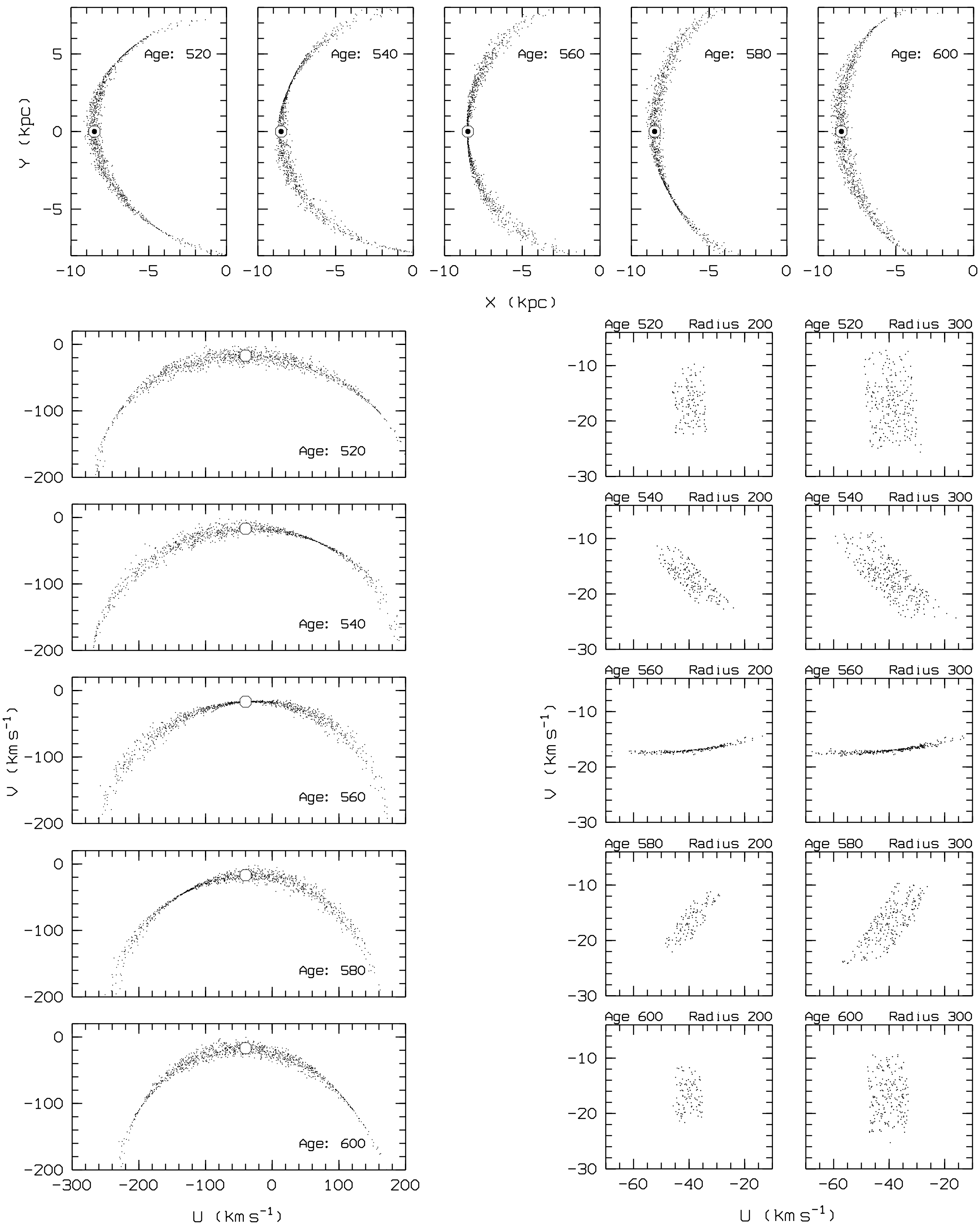

Figure 7. A hypothetical Hyades moving group around the Sun, with different ages (in Myr) used to compute the starting point. Top: All the stars in the XY plane with the Sun at its galactic position. Left: All the stars in the UV plane with the Hyades cluster shown as a circle. Right: Only the stars in the solar neighbourhood (200 and 300 pc in radius).

standard deviation of $\sigma_v = 0.6$ km s^{-1}. A general decreasing trend 'interrupted' by the node is visible, but this change is within 1 km s^{-1}. On either side of the node σ_v is also increased by about 1 km s^{-1} for the 300 pc neighbourhood, but the minimum value remains the same.

Another way to treat the dispersion in U is to find the actual average horizontal width (s_u) of the distribution in the UV plane at given V. We have done it, for all ages except 560 Myr, by fitting a parabolic line $U = f(V)$ and taking the rms error to be equivalent to the standard deviation. The parameter s_u is presented as a dashed line in Figure 8. It is a slowly changing function very close to the σ_v, except in the node, where we have adopted $s_u = \sigma_u$.

Both σ_v and s_u have very similar values (within 1 km s^{-1}), except for the node, and they are about one half of the starting velocity dispersion. However, more tests are needed to confirm if this can be a general conclusion. In the node itself, the dispersion in V approaches zero (Eggen's criterion), while σ_u takes a value of about the original σ. At this stage we can only say that the observed velocity dispersions cannot be directly related to the original dispersion.

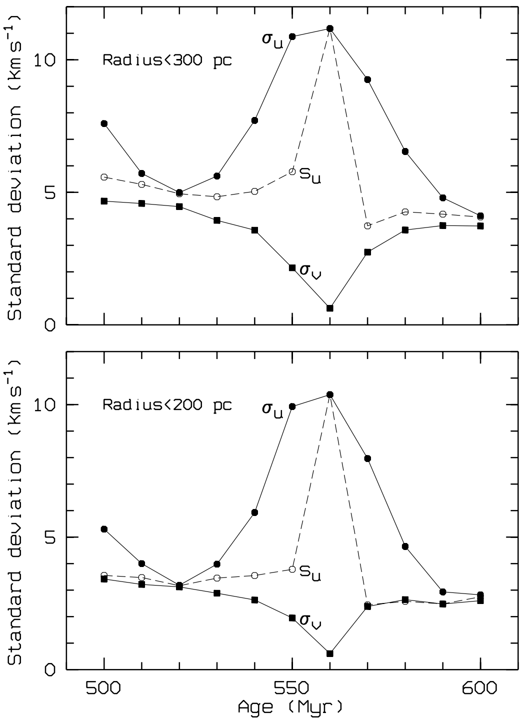

Figure 8. Standard deviations for the velocity distributions in the solar neighbourhood. Filled circles and squares represent σ_u and σ_v respectively, while open circles correspond to the s_u parameter described in the text.

Finally, one must be very careful when drawing conclusions from galactic orbit modelling, because it is very difficult to predict the motion in such a complex system as the Galaxy. After many galactic rotations, the orbits most probably get changed, leading to some unpredictable results. For some of these effects see e.g. Wielen et al. (1996). However, for relatively short time intervals the models can probably give reliable results.

4. CONCLUSION

Hipparcos parallaxes and proper motions have considerably improved the velocity dispersions for all of Eggen's moving groups, compared to the old earth-based astrometric data. They are also in good agreement with Eggen's group parallaxes, possibly confirming the moving group hypothesis. However, the distribution of stars within a moving group in the UV plane does not confirm Eggen's membership criterion of constant V. Substantial scatter in U and V is evident, which may still be partially caused by the parallax uncertainty itself. More tests are needed, especially those involving random samples of stars in the solar neighbourhood. These will be available when the complete Hipparcos Catalogue is distributed.

Numerical simulations, involving stellar orbit modelling for individual stars in the galactic potential, show that both U and V velocity components must be used to create more realistic membership criteria. The distribution of stars in the UV plane depends very much on the actual position of the Sun inside the moving group. The dispersions are also changeable and not clearly related to the starting velocity dispersion of the original cluster.

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