A SEARCH FOR MOVING GROUPS IN THE GALACTIC HALO

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Abstract. A new method to search for moving groups, specifically tailored for the *HIPPARCOS* database, is used to search for moving groups among the high velocity stars in this database. Although the sampled volume is small, the high quality of the astrometry makes this search interesting. No moving groups are detected, but limits in the velocity and number of members of possible non-detected groups are given.

1. Introduction

The idea that the galactic halo has been formed to a large extent by the accretion and tidal disruption of satellite systems has been gaining strength. Back in 1976, D. Lynden–Bell pointed out that the Magellanic clouds, several dwarf systems, and some distant globular clusters which are satellites of our Galaxy, lie near two great circles in the celestial sphere (Lynden–Bell 1976). More recently, Lynden–Bell and Lynden–Bell (1995), have analyzed this and other alignments, and identified streams associated to the Magellanic clouds, Fornax, and one possibly associated with the recently discovered dwarf system in Sagittarius (Ibata et al. 1994); additional streams related to outer globular clusters are shown.

Tantalizing evidence for the existence of structure is beginning to appear in surveys of halo stars too. Dionidis and Beers (1989), investigated the clustering properties of 4,400 field horizontal branch stars in the halo, and found an excess 2–point correlation at angular separations of less than $10'$, which at the typical depth of the sample corresponds to linear separations of

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less than 25 pc. Côté et al. (1993) conducted a radial velocity survey of 879 field stars within a 1° field toward $\ell = 277°$ and $b = 9°$; they found a clump of 18 stars within the 74–76 km/s radial velocity bin, where their expected number is only 5. Arnold and Gilmore (1992) have studied a color selected sample of 44 stars in 2 high galactic latitude fields; they found 4 stars at a distance of 30 kpc with a velocity dispersion of less than 12 km/s, and a systematic velocity with respect to the Galactic rest frame of 70 km/s, which they suggest may be the remnants of a disrupted halo cluster. Majewski et al. (1996) have found evidence for clumping in velocity in a study of halo stars toward the North Galactic Pole, in particular, they identified a retrograde rotating, halo moving group. They suggest that discrepancies in the halo kinematics derived from surveys conducted along different line of sights may be the result of a clumpy halo velocity distribution.

One argument used in the past against the accretion scenario is the apparent fragility of galactic disks when subject to accretion events (Tóth and Ostriker 1992). However, Velázquez and White (1997) have recently shown that the inclusion of a dynamically active halo can be an effective shield to the galactic disk.

An important consequence of this accretion scenario is that the phase space portrait of the halo, far from being a smooth distribution, should consist of a patchy aggregation of tidally disrupted systems that have been phase mixed all over the sky, but which retain kinematic memory of their existence as a coherent entity. Johnston et al. (1996) have studied the formation of these features within the context of satellite disruption within the halo of our Galaxy and proposed a method to identify them in sky surveys.

The challenges to discover these moving groups in the halo are enormous due to the distances involved and the fact that they can span large angles in the sky. The availability of an astrometric database of unprecedent accuracy (*HIPPARCOS*, ESA 1997) and the plans for follow ups (e.g. *GAIA*, Lindegren and Perryman 1996), usher a new era of opportunities to search for such moving groups.

2. The Method

The *Hipparcos* database provides positions with a median precision of 0.77 mas, parallaxes with a median precision of 0.97 mas, and proper motions with a median precision of 0.88 mas/yr, for 117, 955 stars (ESA 1997). These are stars in the solar neighborhood brighter than $V \sim 12$, although completeness is achieved for stars brighter than $V \sim 7$–9 (field dependent) only. This information determines three spatial coordinates and the linear velocity on the plane of the sky; the radial velocity being the only infor-

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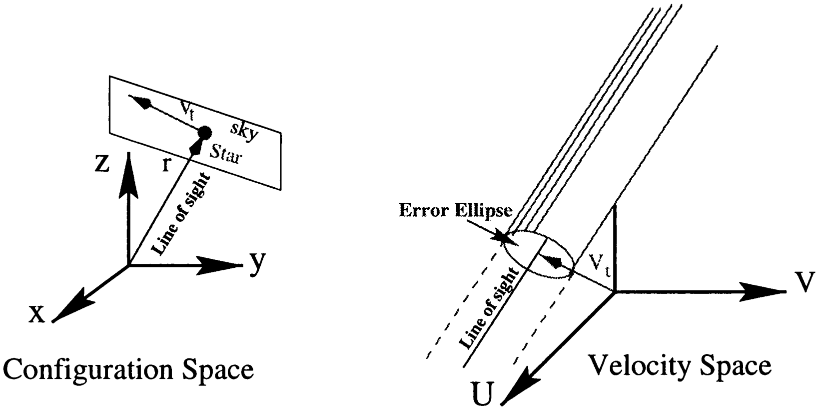

Figure 1. The determination of the spatial position and tangential velocity of a star (left), constrains the corresponding spatial velocity vector to be inside a cylindrical region in velocity space, parallel to the line of sight, offset from the origin by the magnitude of the tangential velocity, and of cross section given by the error ellipse of the latter velocity (right).

mation missing for the full phase space position. This information restricts the star to a line in velocity space, parallel to the line of sight and tangent to the measured tangential velocity vector, as any spatial velocity vector whose tip is on this line will project on exactly the same velocity on the plane of the sky for that particular direction (Fig. 1). In reality, the star's velocity vector is not confined to such a line, but to a "cylinder" of probability whose cross section is given by the uncertainties and correlation in the components of the tangential velocity vector.

If a group of stars is part of a moving group, their true spatial velocity vectors should lie within a neighborhood whose radius is set by the velocity dispersion of the group. As such, their corresponding cylinders in velocity space should all intersect within this neighborhood. As the probability of a chance intersection drops as the number of cylinders increases, a moving group should stand out against the statistical background if it is numerous enough and/or it is sufficiently constrained in velocity space.

This method has been used quite successfully, in combination with the more traditional convergent point method (Jones 1971), to find new members for OB associations. Results on the identification of new members, down to spectral type F, and refinement of the old membership lists for various associations in 21 fields in the sky, can be found in de Buijne et al. (1997), Hoogerwerf et al. (1997) and de Zeeuw et al. (1997).

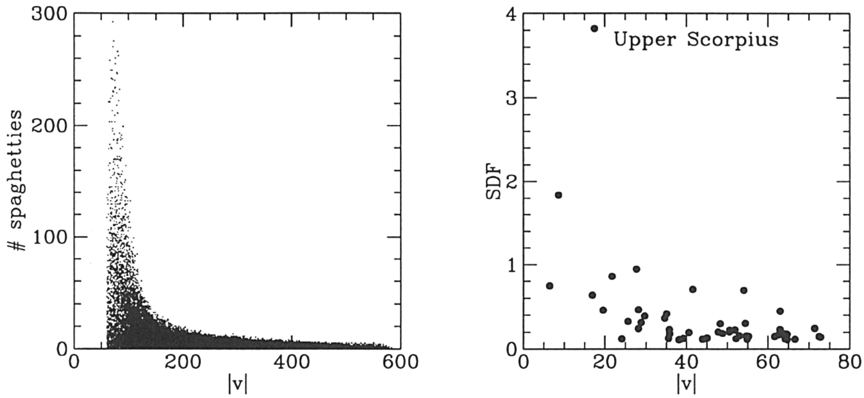

Figure 2. Left: The Magnitude of the velocity of the center is plotted against the number of cylinders (spaghetti) that intersect it, for each sphere searched in velocity space for our halo sample. Right: A similar diagram in which the number of intersections is replaced by the cylinder density function (SDF), directly proportional to the former, for the sample used by de Buijne et al. (1997) to identify the Upper Scorpious Association. The Upper Scorpious association is the point at $|v| \sim 17\,\mathrm{km/s}$ and $SDF \sim 3.8$.

3. The Sample

The vast majority of stars in the *HIPPARCOS* database are disk stars which produce a high background of intersections in velocity space. For this reason, it is necessary to restrict our study to a sample biased toward halo objects. Our sample consists of all stars with astrometry in the *Hipparcos* catalogue whose tangential velocities are larger than 60 km/s, and whose corresponding uncertainties are less than 10 km/s. This results in a list of 3,493 stars with no particular preferred direction in the sky and which lie roughly within 300 pc of the sun. These stars span spectral types from A to M and of all luminosity classes.

4. Results

We have searched in a cube of size 600 km/s in velocity space, excluding the region within 60 km/s of the sun. On this region we laid down a Cartesian grid of 10 km/s spacing; for each grid point, we computed the number of cylinders that pass within a 10 km/s sphere centered at this point. The results are shown in Fig. 2.

The left side of Fig. 2 plots the velocity of the center of the spheres against the number of cylinders that intersect them. At all velocities, the number of intersections distribution of spheres is smooth and tapers off toward large number of intersections; the upper envelope decreasing as the velocity of the spheres increases. There are no obvious spheres anomalously above the envelope in this diagram. Such an anomalous sphere would signal the existence of a suspicious intersection, difficult to explain as a chance occurrence. Contrast this situation with the right side of Fig. 2, which shows a similar diagram but for the 1,426 stars sample within the field $336° < \ell < 4°$, $6° < b < 33°$, in which the Upper Scorpious Association is quite conspicuous (de Buijne et al. 1997).

From Fig. 2 we learn that there are no obvious moving groups within our halo sample. We have examined in detail some points on the envelope of this figure, but in each case, the intersection could be explained as a spurious one. All what we can say at present, is that there are no moving groups in our sample, whose velocity with respect to the sun and number of member stars, places them above the upper envelope that is clearly defined by the left panel of Fig. 2.

This is a no detection result, but we can delineate in Fig. 2 the boundary of the region, within which we can exclude the presence of moving groups, in the *Hipparcos* subsample that we have studied. The sample used is quite small in terms of sampled volume, but the high precision of its information makes this a worthwhile search; particularly in the light of the success of the present method at identifying and refining membership lists, for OB associations in the solar neighborhood.

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