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Ground-based proper motions of nearby local group galaxies: A progress report for Fornax

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Abstract. Determining the kinematics of the dwarf Spheroidal galaxies (dSph) satellites of the Milky Way (MW) is crucial to estimate the mass of our galaxy, to understand its formation process and that of its satellites, to explain the origin of stellar streams in the MW's halo that seem to be related to these satellites, and to understand the role of tidal interactions in the evolution and star formation history of low mass galaxies and of the halo of our Galaxy. In what follows we briefly explain a ground-based astrometric project that will have an impact on these issues, and present some preliminary results.

Keywords. astrometry, Galaxy: halo, Galaxy: formation, galaxies: dwarf, galaxies: kinematics and dynamics, (galaxies:) Local Group.

1. Introduction

Apart from the two Magellanic Clouds (MCs), the Galaxy possesses several other low mass satellite galaxies. These objects have been discovered in the last few decades mostly as slight over densities of stars on wide angle Schmidt plates. Despite their feebleness they are of vital importance to understand the structure and evolution of the Galactic halo, and presumably also of the Galaxy as a whole. These dwarf galaxies are concentrated near the major galaxies of the Local Group, which means that they have probably had a large influence from interactions with these galactic halos.

1.1. *On the mass of the MW*

One of the few constraints on the gravitational potential of the Galaxy at large galactocentric distances comes from velocities of local group galaxies and halo globulars (Lynden-Bell *et al.* 1983, Zaritsky *et al.* 1989), by means of the use of the virial theorem. Radial velocities alone determine only one component of the space velocity vector, requiring the assumption of a velocity ellipsoid (i.e., the shape of the orbits). This introduces an uncertainty of at least a factor of 2-3 into the estimated enclosed Galactic mass M_{MW}, (e.g., Binney & Tremaine 1987, p. 595-597). Our project will produce reliable space velocities for three dSph galaxies, thus eliminating the need to make any assumptions regarding the orbits. Once all components of are known, we can directly estimate M_{MW} (see Costa et. al 2009). Current state-of-the art PM measurements imply 1σ uncertainties of ~40% for M_{MW} out to 60 kpc. Even though these uncertainties are large, we emphasize that the estimates are free from assumptions regarding the orbit shapes and are far more direct than any other approach. Full space velocities will also enable us to investigate the history of these dSphs through the shape of their velocity ellipsoid, which is sensitive to the history of tidal disruption and dynamical friction. Lastly, we will also be able to confidently compare the properties of the halo of our Galaxy with those determined for other galaxies (e.g., Zaritsky & White 1994).

1.2. *The origin of the MW satellite system and its role in the formation of the Galactic Halo*

Part of the MW halo may have been formed by low mass nearby galaxies. They were possibly drawn into the Galactic halo and finally merged and disintegrated, so that a large part of the field population of the halo could be former dwarf galaxies. This is the Searle & Zinn (1978, SZ) scenario, which suggests that, apart from a gravitational collapse of the proto-galactic cloud which formed the inner halo, and later on the thick and thin disk (ELS scenario, Eggen *et al.* 1962), fragments continued to be accreted for quite a long time. This process might even still be going on today: The discovery of the Sagittarius dSph galaxy being torn apart by the MW (Ibata *et al.* 1994), together with the similarities between dSph and the MW halo (e.g. spatial distribution, chemical abundances, ages) supports the idea that the halo of the galaxy has been formed à la SZ, by accretion of dSph-like fragments (Mateo 1996, Majewski 1993). If this is the case, then the remaining dSph satellites could be the survivors of the early population of dSph that later formed (all or part of) the MW halo. Studies by Kunkel & Demers (1976a, b) indicate that dwarf galaxies seem to lie on a great circle almost perpendicular to the Galactic plane along the Magellanic stream. They calculated a probability for this alignment to be random as statistically very unlikely, while Kunkel (1979) demonstrated that the radial velocities of all the galaxies in the plane and the Magellanic Stream suggested Keplerian motion. In the same line, Lynden-Bell (1976, 1982) favored the idea of two great streams close to one another (the Magellanic Stream which would contain the galaxies Ursa Minor, Draco, Carina, Sextans and the MCs, and the Fornax-Leo-Sculptor Stream). Both scenarios could mean that the dwarf galaxies and the Magellanic stream are remnants of a larger body which has been destroyed by tidal forces imposed on this object by the MW gravitational field. An alternative explanation is that these alignments may simply represent a distribution of orbits that is somehow dynamically favored: Both of the Lynden-Bell streams contain the Galactic Poles, and polar orbits are known to be more stable against tidal decay (Majewski & Cudworth 1993).

These different possible explanations can be tested once reliable proper motions (PMs) for these galaxies have been derived: If the dSph are the product of disrupted galaxies, they should share a common angular momentum direction within the stream; instead, if the alignment is due to stable polar orbits, then we would expect transversal velocities aligned along the stream. Finally, in the unlikely case that the alignment is by

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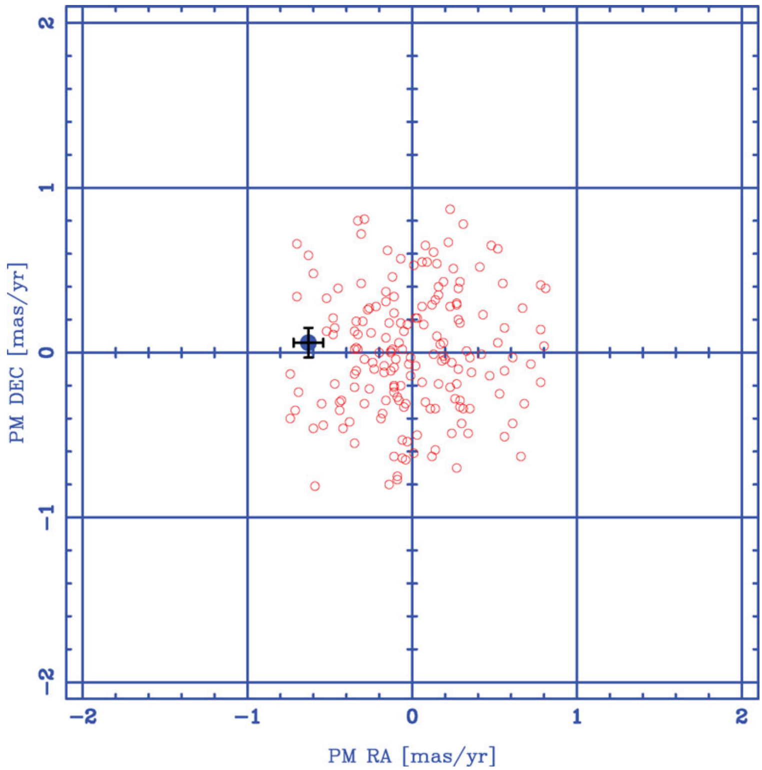

Figure 1. Vector point diagram: The reference stars (Fornax galaxy stars, open circles) are assumed to be moving coherently in space (their intenal velocity dispersion is smaller than our measurement errors). The QSO (solid dot with error bars) shows the reflex motion of the QSO with regards to the Fornax stars. The Fornax center-of-mass PM error is completely dominted by the uncertainty in the QSO reflex motion. Objects with PM > 0.8 mas yr^{-1} have been expunged from the astrometric reference frame.

chance, the transverse velocities should be randomly oriented with respect to the stream direction.

2. Proper Motions

Among the objects whose kinematics could help us solve the problems outlined previously are the Carina, Fornax & Sculptor dSph galaxies, which, on account of being among the closest galaxies to the MW (at distances of 100, 138 and 87 kpc respectively, van den Bergh 1999), are suitable for kinematical studies with present techniques.

To determine the PMs of the dSphs we use the so-called "QSO method". This method consists on measuring at different epochs the positions of QSOs in the background field of the target galaxies with respect to bona-fide galaxy field stars. Because the QSOs can be considered fiducial points, any motion detected for the QSOs will be a reflection of the motion of the local reference system of the target galaxy field stars (see Figure 1). The PMs are determined in the following way: For each field we first determine the barycenter of all the reference stars and then the barycentric distance of the QSO. This is done for all data from different epochs, registered to a single epoch frame. Any changes in the barycentric distance of the QSO reflect the relative PM of the QSO with respect to the reference frame; changing the signs leads to the absolute PM of the target galaxy.

3. Discussion & Conclusions

The background QSOs on these galaxies have been selected from the works of Tinney *et al.* (1997) and Tinney (1999), who provide lists of spectroscopically confirmed QSOs behind the nearest MW satellite galaxies, and in this paper we report preliminary results from *one* of our Fornax QSO fields.

The selected QSO fields contain, apart from the QSO, other background galaxies, a few MW foreground stars and the stars of the target galaxy (which for an object at moderate to high galactic latitudes represent the vast majority of the star-like objects). In spite of this latter fact, the exact nature of the reference objects with respect to which the "motion" of the QSOs will be measured, must be certified as bona-fide galaxy (in this case Fornax) field stars. This is done through an iterative process (for details see Costa *et al.* 2009).

In Figure 1 we show the vector-point diagram for the QSO (solid dot with error bars) and the bona-fide Fornax stars. Stars with (pseudo-) PMs larger than 0.8 mas yr^{-1} have been eliminated iteratively, resulting in 177 final reference stars. Our final as-measured PM for Fornax from this field yields $(\mu_\alpha \cos\delta,\, \mu_\delta) = (+0.63{\pm}0.09, -0.06{\pm}0.09)$ mas yr^{-1}. This value can be compared with those determined for Fornax from HST-data alone by Piatek *et al.* (2007): $(\mu_\alpha \cos\delta,\, \mu_\delta) = (+0.47 \pm 0.05, -0.36 \pm 0.04)$ mas yr^{-1}, and from a combination of ground-based and HST-based data by Dinescu *et al.* (2004): $(\mu_\alpha \cos\delta,\, \mu_\delta) = (+0.59 \pm 0.16, -0.15 \pm 0.16)$ mas yr^{-1}. A detailed analysis of our data, and a comparisons to previous results will be done once we have measured PMs for all our fields in Fornax.

References

Binney, J. & Tremaine, S. 1987, *Galactic Dynamics, Princeton University Press, Princeton, New Jersey*
Costa, E., Méndez, R. A., Pedreros, M. H., Moyano, M., Gallart, C., Noël, N., Baume, G., & Carraro, G. 2009, *AJ*, 137, 4339
Dinescu, D. I., Keeney, B. A., Majewski, S. R., & Girard, T. M. 2004, *AJ*, 128, 687
Eggen, O. J., Lynden-Bell, D., & Sandage, A. 1962, *ApJ*, 136, 748 (ELS)
Ibata, R., Gilmore, G., & Irwin, M. J. 1994, Nature, 370, 194
Kunkel, W. E. & Demers, S. 1976a, *ApJ*, 208, 932
Kunkel, W. E. & Demers, S. 1976b, *R. Obs. Bull*, 182, 241
Kunkel, W. E. 1979, *ApJ*, 228, 718
Lynden-Bell, D. 1976, *MNRAS*, 174, 695
Lynden-Bell, D. 1982, *Observatory*, 102, 202
Lynden-Bell, D. *et al.* 1983, *MNRAS*, 204, 87
Majewski, S. R. 1993, in *Galaxy evolution: the MW perspective, ASP Conference Series*, v. 49
Majewski, S. R. & Cudworth, K. M. 1993, *MNRAS*, 105, 987
Mateo, M. 1996, *ASP Conf. Ser. 92: Formation of the Galactic Halo...Inside and Out*, 92, 434
Piatek, S., Pryor, C., Bristow, P., Olszewski, E. W., Harris, H. C., Mateo, M., Minniti, D., & Tinney, C. G. 2007, *AJ*, 133, 818
Searle, L. & Zinn, R. 1978, *ApJ*, 225, 357 (SZ)
Tinney, C. G., Da Costa, G. S., & Zinnecker, H. 1997, *MNRAS*, 285, 111
Tinney, C. G. 1999, *MNRAS*, 303, 565
van den Bergh, S. 1994, *ApJ*, 428, 617
Zaritsky, D., Olszewski, E. W., Schommer, R. A., Peterson, R. C., & Aaronson, M. 1989, *ApJ*, 345, 759
Zaritsky, D. & White, S. D. M. 1994, *ApJ*, 435, 599