A Giant Step: from Milli- to Micro-arcsecond Astrometry
Proceedings IAU Symposium No. 248, 2007
W. J. Jin, I. Platais & M. A. C. Perryman, eds.

doi:10.1017/S1743921308019972

A spectroscopic survey of late-type giants in the Milky Way disk and local halo substructure

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Abstract. We report the results of a survey of late-type giants aimed at understanding the nature of the disk and nearby halo Galactic stellar populations. We have obtained medium resolution (2–4 Å) spectra for 749 late K and early M giants at mid-latitudes selected from the 2MASS catalog with the FOBOS system at Fan Mountain Observatory. These spectra provide radial velocities (RVs) at the 5 km s^{-1} level, spectroscopic [Fe/H] good to $\sigma_{[Fe/H]} = 0.25$ dex, and information on the relative abundances of Mg/Fe and Na/Fe in these stars. Proper motions from UCAC2 are used to search for local substructures, in particular the leading arm of the Sagittarius tidal streamer passing through the solar neighborhood. The combined proper motions and RVs yield full 6D stellar space motions. We have, by way of kinematics, relatively cleanly isolated the thick disk from the typically high velocity substructures that compose the nearby halo.

We find evidence for substructure in the kinematics and metallicities of local halo stars.

Keywords. Galaxy: structure, Galaxy: kinematics and dynamics, Galaxy: formation, astrometry

1. Motivation

The formation and evolution of the Galaxy can be explored through the kinematics and abundance patterns of the present Galactic stellar populations. Key to discriminating formation models are an understanding of the existence of smooth or disjointed transitions in properties and the relation of the thick disk to the halo and thin disk. A further constraint is provided by studies of the kinematics of stars within a stellar stream. For example, tidal debris from the accreted Sagittarius (Sgr) dwarf spheroidal (dSph) galaxy provides an excellent means for probing Galactic structure.

We have collected radial velocities (RVs) that, when combined with proper motions and distances, help to unravel the events that led to the current state of the Galaxy.

2. Data and analysis

The 2MASS catalog (Skrutskie *et al.* 2006) was used to select late-type giants for our study of the thick disk and local halo. It has been established (Bessell & Brett 1988) that M giants can be discriminated from M dwarfs based on their $J-H$ and $H-K$

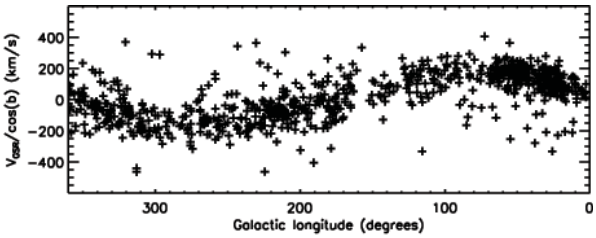

Figure 1. Radial velocity with respect to the Galactic Standard of Rest (GSR).

colors. This technique was used by Majewski *et al.* (2003) to identify streams of M giants from the accreted Sgr dSph galaxy. Photometric parallaxes are estimated using the color-magnitude relations of Ivanov & Borissova (2002). The proper motions used in this survey come from the UCAC2 (Zacharias *et al.* 2004).

Stars in the Galactic disk generally move on nearly circular orbits around the Galactic center and show RVs that fall along a sinusoidal distribution as a function of Galactic longitude. Figure 1 shows the distribution of RVs, with respect to the Galactic Standard of Rest, for the survey stars, where the RVs have been divided by $\cos b$ (this tends to accentuate differences between stars having circular motion from stars on more eccentric orbits). While the majority of the stars appear to be members of the disk based on the RV pattern, there are several notable groupings of outliers. These RV outliers may be associated with tidal debris from an accreted satellite.

Although the resolution of our spectra is not high enough to measure equivalent widths, relative chemical abundances can still be extracted from our spectra by using the Lick spectral indices (Worthey *et al.* 1994). We have combined three Lick indices sensitive to Fe-peak elements for use in calibrating [Fe/H] for our program stars. We use the Lick Mg b and Na D indices to look for relative trends in α/Fe.

3. Results

The distribution of RVs reveals the presence of several groups of stars that deviate from disk-like orbits. These stars also show distinct chemical signatures and may have formed from a gas that underwent a different star formation history than the Galactic disk gas. We find that stars on high-energy orbits are generally more metal poor. This is consistent with the notion of a clumpy halo made up mainly of accreted debris.

Our sample of thick disk stars reveals an asymmetric drift velocity of the thick disk with a vertical gradient of -26 ± 4 km s^{-1} kpc^{-1}. Based on this modest vertical gradient in rotational velocity and the lack of a vertical gradient in the α/Fe-[Fe/H] patterns for our survey, we conclude that our findings support a most likely formation scenario in which the thick disk was formed by the heating of the early disk due to a merger.

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https://doi.org/10.1017/S1743921308019972 Published online by Cambridge University Press