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Chemo-orbital evidence from SDSS/SEGUE G dwarf stars for a mixed origin of the Galactic thick disk

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Abstract. About 13,000 G dwarf within $7 < R < 9$ kpc and $0.5 < |z| < 3.0$ kpc from the SDSS/SEGUE spectroscopic survey are used to study the origin of the Milky Way thick disk. Combining [α/Fe] and [Fe/H] measurements with six-dimensional position-velocity parameters, we find that the sample is composed of two distinct stellar populations. The metal-rich population encompasses the thin disk with α-deficient stars and smoothly extends into a thick disk with α-enhanced stars, consistent with an in-situ formation through radial migration. On the other hand, the metal-poor population with enhanced α-abundance, higher scale height, and disperse kinematical properties, is difficult to explain with radial migration but might have originated from gas-rich mergers. The thick disk of the Milky Way seems to have a mixed origin.

1. CHEMO-ORBITAL PROPERTIES OF G DWARF STARS

The formation of the Galactic thick disk is being debated since its discovery [3]. Three standard models are based on external, merger-induced formation: *gas-rich mergers*, *sub-structure disruption*, and *heating by satellites* [1, 2, 9]. A fourth, alternative model, is the in-situ formation of the thick disk through *radial migration* [6]. Here, we study the chemo-orbital properties of G dwarf stars and find evidence for a mixed origin of the thick disk.

We use G dwarfs from the SDSS/SEGUE survey as they do not suffer from significant selection biases, and their positions (including distances), velocities, as well as metallicity [Fe/H] and abundance [α/Fe] (a proxy for age) have been measured with reliable accuries. We apply a star-count correction to the spectroscopic sample through a comparison with photometric data located in the same line of sight within the same color index range. For this study we select those stars with cylindrical radii $7 < R < 9$ kpc and height $0.5 < |z| < 3.0$ kpc.

2. TWO POPULATIONS OF DIFFERENT ORIGIN

When we associate chemical with orbital properties in Fig. 1, we find two populations, different from the bi-modality in number density in [α/Fe] which could be the natural result of the on-set of type Ia supernovae.

The metal-rich population with [Fe/H] $\gtrsim$ 0.6 shows an anti-correlation between the median guiding radius R_g and [Fe/H] —analogue to the rotation-metallicity anti-correlation— for the stars with low α-abundance, but the correlation smoothly disappears with increasing [α/Fe]. At the same time, most metal-rich stars are on near-circular orbits. Fig. 2 shows that the vertical scale height of the population smoothly increases with [α/Fe], i.e., no abrupt change from thin to thick disk. These observations are

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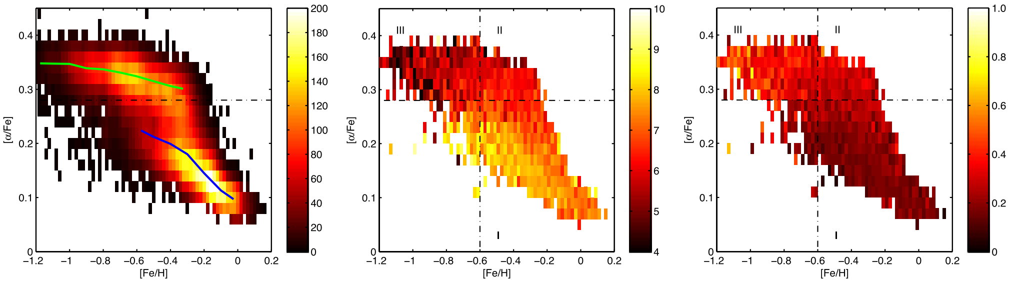

Figure 1. *Left panel:* Star-count corrected density distribution of G dwarf stars in [Fe/H] metallicity versus [α/Fe] abundance. The blue and green lines show the tracks of metal-rich and metal-poor populations, respectively. *Middle and right panel:* Median guiding radius R_g (in kpc) and median eccentricity of the orbits of the G dwarf stars.

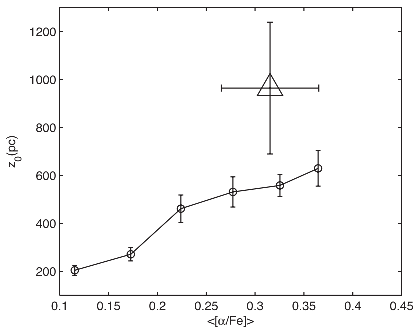

Figure 2. The scale height as a function of [α/Fe] (circles) for stars with [Fe/H]> -0.6. The triangle shows the scale height of the sample with [Fe/H]< -0.6 and [α/Fe]>0.28.

consistent with radial migration models [4, 7], in which metal-rich, old stars born at smaller radii have migrated toward the Solar Neighborhood while remaining on nearly circular orbits, but increasing their vertical height as they encountered a decreasing restoring force.

On the other hand, the metal-poor population with [Fe/H] $\lesssim$ 0.6, mainly consists of old stars with [α/Fe] $\gtrsim$ 0.28, and if any correlation between R_g and [Fe/H] is present, it is a positive correlation. Moreover, the stars are on rather eccentric orbits and the scale height of ~1 kpc is significantly larger than the metal-rich population. Their orbital eccentricity and low metallicity make it unlikely that these stars originated from an old thin disk through radial migration or heating by satellites. In case of sub-structure disruption, an even higher orbital eccentricity and lower metallicity would be expected, as well as lower α-abundance due to the low star-formation rate in nearby dwarf galaxies [8]. However, the observations seem consistent with an origin of this metal-rich population in gas-rich mergers early on in the history of the Milky Way.

Even though it is clear that more quantitative comparisons with formation models are needed, there is rather strong evidence in the chemo-orbital properties of the G dwarfs for a mixed origin of the thick disk of the Milky Way.

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