Group 1: Resolved stellar populations in galaxy outskirts

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The radial extent of the Galactic thick disk

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Abstract. Based on observational data from the fourth internal data release of the *Gaia*-ESO Survey we probe the abundance structure in the Milky Way stellar disk as a function of galactocentric radius and height above the plane. We find that the inner and outer Galactic disks have different chemical signatures. The stars in the inner Galactic disk show abundance signatures of both the thin and thick disks, while the stars in the outer Galactic disk resemble in majority the abundances seen in the thin disk. Assuming that the Galactic thick disk can be associated with the α-enriched population, this can be interpreted as that the thick disk density drops drastically beyond a galactocentric radius of about 10 kpc. This is in agreement with recent findings that the thick disk has a short scale-length, shorter than that of the the thin disk.

Keywords. Galaxy: disk, Galaxy: evolution, Galaxy: structure, Galaxy: abundances

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1. Introduction

Since the discovery by Gilmore & Reid (1983) that the stellar density as a function distance perpendicular to the Galactic plane could not be fitted with a single exponential density profile, but needed two, the observational evidence for two distinct stellar populations in the Milky Way stellar disk has grown. High-resolution spectroscopic observations of nearby stars have revealed the thin and thick disks appears to be distinct in kinematics, chemical composition, as well as stellar ages. In particular with the thick disk stars being older and more α-enhanced at a given metallicity than the thin disk stars (e.g. Fuhrmann 1998; Bensby *et al.* 2014; Reddy *et al.* 2006; Adibekyan *et al.* 2012). These studies are all based on samples of nearby stars in the Solar neighbourhood, and the question is if these findings persist throughout the Galactic disk.

The first detailed studies of the abundance structure in the inner and outer regions of the Galactic disk were presented by Bensby *et al.* (2010, 2011). They found that the abundance pattern in the inner Galactic disk ($4 < R_g < 7$ kpc) resembles the nearby thin and thick disks (Bensby *et al.* 2010). On the other hand, the abundance pattern in the outer regions of the disk ($9 < R_g < 12$ kpc) was different, with the chemical abundance pattern that we associate with the thick disk appears to be completely absent at galactocentric radii greater than about 10 kpc. This allowed us for the first time to constrain the radial scale-length of the thick disk using chemically tagged stars, and it was found to be much shorter than that of the thin disk (Bensby *et al.* 2011). Previously, in photometric studies that cannot distinguish between the abundance patterns characteristic for the two disks, had found a short scale-length for the thin disk (e.g., Jurić *et al.* 2008).

It is clear that the inner and outer disk regions need to be mapped with larger stellar samples to put solid constraints on the extents and scale-lengths of the thin and thick disks. Studies using data from SDSS has subsequently confirmed the short scale-length for the thick disk (e.g., Cheng *et al.* 2012; Bovy & Rix 2013) and similar results have also recently found by studies using data from APOGEE (e.g., Hayden *et al.* 2015).

In this study we investigate how the abundance structure varies with galactocentric radius using the Milky Way field stars observed with FLAMES-GIRAFFE from the fourth

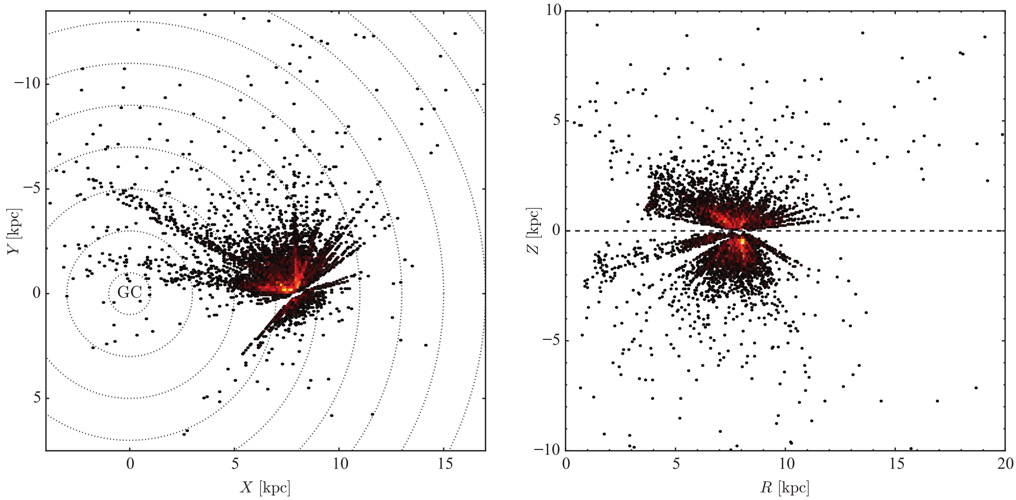

Figure 1. The distribution in the Galactic $X - Y$ and $R - Z$ planes of the 9347 Milky Way field stars in the GES iDr4 that have $S/N > 20$.

internal data release from the Gaia-ESO survey (Gilmore *et al.* 2012). The selection function for the Milky Way field stars is described in Stonkute *et al.* (2016).

2. The inner and outer regions of the disk

The $X - Y$ and $R - Z$ plots in Fig. 1 show that the 9347 stars in the GES iDr4 GIRAFFE sample (with $S/N > 20$) extends over a large range in galactocentric radii and vertical distances above and below the Galactic plane.

Figure 2 shows the [Mg/Fe]-[Fe/H] abundance trends in nine different $R - Z$-bins, representing the inner disk region ($R_{\rm gal} < 7\,$kpc), the solar radius region ($7 < R_{\rm gal} < 9\,$kpc), and the outer disk region ($R_{\rm gal} > 9\,$kpc), with each of the regions split into three subregions with different distance intervals from the Galactic plane. To guide the eye the subplots contain over-plotted fiducial lines representing the abundance trends typical for the thin and thick disks in the Solar neighbourhood. It is evident that the chemical structures in the inner and outer disk regions are very different, with α-rich stars dominating the inner region, and lacking in the outer region that instead is dominated by a slightly more metal-rich and α-poor population, similar to previous findings by Bensby *et al.* (2011); Cheng *et al.* (2012); Bovy & Rix (2013); Hayden *et al.* (2015).

To truly map the relative fraction of thin and thick disk stars as a function of galactocentric radius and height above the plane, and to put further constraints on the scale-lengths of the two disks, one needs to carefully correct for the selection functions of the many different fields that have been observed (Stonkute *et al.* 2016). This is work in progress.

When looking at other galaxies the radial extension of thick disks are always comparable or longer than the thin disks (Comerón *et al.* 2012), while in the Milky Way the opposite seems to be the case (see references above). This discrepancy could largely be due to how the thick disk is defined. In the Milky Way studies the thick disk definition has been based on chemistry, usually the level of α-enhancement, while in studies of external galaxies the definition is based on morphology.

It is evident that more work is needed to map the large-scale structure of the Milky Way disk(s), and to understand what properties that should be used to define the thick

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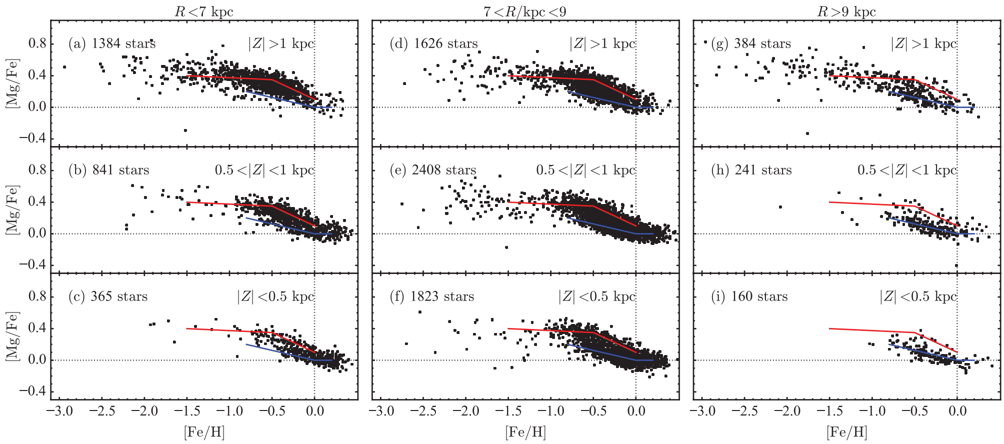

Figure 2. [Mg/Fe] versus [Fe/H] at different intervals of galactocentric radii, and different heights from the Galactic plane. Only stars with $S/N > 20$ are included.

disk: kinematics, abundances, ages, location, or a combination of them all. With several large spectroscopic surveys such as APOGEE (Majewski *et al.* 2015), Gaia-ESO (Gilmore *et al.* 2012), GALAH (De Silva *et al.* 2015) and the upcoming WEAVE (Dalton *et al.* 2014), and 4MOST (de Jong *et al.* 2014) we will have detailed abundances and radial velocities for millions of stars throughout the Galaxy. In combination with distances and proper motions for more than a billion stars from Gaia (Perryman *et al.* 2001), we will have a goldmine for Galactic archaeology.

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