Abundance distribution in the Galactic thick disk

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Discovery of thick disks

Discovery of the Galactic thick disk

Thin disk:
- scale height: 250 pc
- normalisation: 98%

Thick disk:
- scale height: 1400 pc
- normalisation: 2%

The Galactic thick disk - rotation

- Rotational lag and velocity dispersion
- lags the LSR by ~40-50 km/s
- higher velocity dispersions

The Galactic thick disk - metallicity

- Average metallicity: 
  \[\text{[Fe/H]} = -0.6\]

- Intermediate to the thin disk and the halo

Fuhrmann’s study is 85% volume complete for all mid-F type to early K-type stars down to $M_v=6.0$, north of dec=$-15^\circ$, within a radius $d<25$pc from the Sun.

Two types of stars:

- Old stars with high $[\text{Mg/Fe}]$ ratios
- Young stars with low $[\text{Mg/Fe}]$ ratios

Sizes of circles scale with the ages of the stars.

Kinematically selected samples

Kinematically selected samples

- Reddy et al. (2003, 2006)
Many more studies........, most agree that the thick disk is:

- kinematically hot
- old, ages > 8-9 Gyr
- relatively metal-poor
- alpha-enhanced
- approximately 10% of the stars in the Solar neighbourhood are thick disk stars
Red giants in the inner and outer disk

- 44 inner disk K giants
- 20 outer disk K giants
- Observed with MIKE@Magellan
  - $R \sim 55000$
  - $S/N > 100$
- Analysed in the same way (and by the same person!) as the disk and bulge giants in Alves-Brito et al. (2010)
- Truly differential analysis between the bulge, the inner disk, the thin and thick disk in the SN, and the outer disk
Kinematic properties

The red circles show typical values for the thin disk stars in the Solar neighbourhood.

Both the inner and outer disk samples contain stars with cold and hot kinematics. If things are similar to what is seen in the solar neighbourhood we should have picked both thin and thick disk stars in the inner and the outer disk samples.
Abundances

Thin and thick disk red giants in the solar neighbourhood

Alves-Brito et al. (2010)
Abundances

**Inner disk red giants**


**Thin and thick disk red giants in the solar neighbourhood**

Alves-Brito et al. (2010)
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**Inner disk red giants**

**Thin and thick disk red giants in the solar neighbourhood**
Alves-Brito et al. (2010)

**Outer disk red giants**
Abundances

Where is the $\alpha$-enhanced outer thick disk?

(at majority of the stars are located at a distance from the galactic plane where the thick disk should be the dominating population)
Scale-lengths of the thin and thick disks

Red lines show the distance from the plane where the number densities of thin and thick disk stars are equal.

\[ \begin{align*}
L_{\text{thick}} &= 3.6 \text{ kpc} \\
L_{\text{thin}} &= 2.6 \text{ kpc} \\
H_{\text{thick}} &= 0.9 \text{ kpc} \\
H_{\text{thin}} &= 0.3 \text{ kpc} \\
\rho_{\text{thick}} &= 0.12 \\
\rho_{\text{thin}} &= 0.88
\end{align*} \]

(Juric et al. 2008 SDSS data)

Red circles: alpha-enhanced stars
Blue circles: no alpha-enhancements
A short thick disk scale-length

Red lines show the distance from the plane where the number densities of thin and thick disk stars are equal.

\[ L_{\text{thick}} = 2.0 \text{ kpc} \]
\[ L_{\text{thin}} = 3.6 \text{ kpc} \]
\[ H_{\text{thick}} = 0.9 \text{ kpc} \]
\[ H_{\text{thin}} = 0.3 \text{ kpc} \]

Red circles: alpha-enhanced stars
Blue circles: no alpha-enhancements
A short thick disk scale-length with varying scale-height

Red lines show the distance from the plane where the number densities of thin and thick disk stars are equal.

\[ L_{\text{thick}} = 2.0 \text{ kpc} \]
\[ L_{\text{thin}} = 3.6 \text{ kpc} \]

Scale-heights \( H_{\text{thick}} \) and \( H_{\text{thin}} \) vary linearly with \( R_{\odot}/L \).

Red circles: alpha-enhanced stars
Blue circles: no alpha-enhancements
Fig. 6.— Best-fit thin and thick disk scale lengths. The blue shading shows the reduced $\chi^2$ values using the fractions of high- and low-$\alpha$ stars as a function of $R$ and $|Z|$ as a constraint. The thin yellow contours show the constraint of the total stellar density as determined by Jurić et al. (2008). Our best estimate of the thin and thick disk scale lengths using both constraints are $L_{\text{thin}} = 3.4^{+2.6}_{-0.9}$ kpc and $L_{\text{thick}} = 1.8^{+2.1}_{-0.5}$ kpc, marked by the large orange cross. The 68% contour for the combined constraint is shown as the thick dashed orange line. The published values of Jurić et al. (2008) and Bensby et al. (2011) are indicated in green and purple, respectively.

5620 stars from SEGUE
Microlensed bulge dwarfs
A bulge - thick disk connection?

Metal-poor bulge dwarfs have average metallicity of $[\text{Fe/H}] \sim -0.6$

....and they are all old

and

alpha-enhanced as the thick disk in the Solar neighbourhood

$\alpha$-enhanced red giants in the inner disk has average metallicity of $[\text{Fe/H}] = -0.6$

Average metallicity of the thick disk in the Solar neighbourhood is $[\text{Fe/H}] = -0.6$

(e.g. Carollo et al. 2010)
A bulge - thick disk connection?

Metal-poor bulge dwarfs have average metallicity of $[\text{Fe/H}] \sim -0.6$

...and they are all old and alpha-enhanced as the thick disk in the Solar neighbourhood.

$\alpha$-enhanced red giants in the inner disk have average metallicity of $[\text{Fe/H}]=-0.6$

No metallicity gradient in the thick disk!
No metallicity gradient.....

Figure 7. Metallicity [Fe/H] vs. Galactocentric radius $R$ in four $|Z|$ slices. Light blue points indicate the SEGUE data. The weighted median metallicity and the derived linear fit are shown as red squares, with the numerical values in the bottom left of each panel. The blue triangles and values in parentheses show the results we would have obtained if no corrections for known selection effects had been applied. The spacing of the symbols indicates the radial distribution of the targets. Open symbols and pluses/crosses are open clusters and Cepheids from the literature (see Section 7.2 for details). The sizes of the open cluster symbols indicate their ages (smaller symbols for younger clusters). At low $|Z|$ (< 0.5 kpc), our derived gradient is consistent with published values. At high $|Z|$ (> 0.5 kpc), the constant [Fe/H] is consistent with the cluster metallicities reported by Yong et al. (2005) in the outer disk.

Challenges......

• The Milky Way has no distinct thick disk (Bovy et al. 2012)......

  • ....but J. Cheng (2012) used essentially the same data set and found two distinct populations and that the thick disk has a short scale length...

  • .... and Veltz et al (2008) using ~22000 RAVE stars and finds two distinct populations associated with the thin and thick disks

  • .... and ......?

• To what degree is radial migration important?
  (Rok Roskar)

  • is radial migration responsible for the lack of a radial metallicity gradient in the thick disk?