Decomposition of the Galactic Disk: Kinematics and Abundances


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Observations

- sample: ~200 F-G dwarfs

- Observations:

  ~400 spectra: two for each star and each one’s S/N ~ 200 – 400 with R ~ 60,000

- Elements:

  27 elements belonging to different nucleosynthesis histories: alpha process, proton capture, Fe-peak
Results: different components

Part I: Galactic Disk

Abundances

Note the increase in scatter at $[\text{Fe/H}] = -0.35$

Reddy et al. 2003
Chen et al. 2000
Fuhrmann 1998
Edvardson et al. 1993
Results: different components

Kinematics

Stars with $[\text{Mg/Fe}] \geq 0.2$ (Bigger symbols)

$V_{\text{lsr}} = -40 - -100 \text{ Km s}^{-1}$
$W_{\text{lsr}} = |100| \text{ Km s}^{-1}$
$[\text{Fe/H}] \leq -0.4$
Age $\geq 10 \text{ Gyrs}$

THICK DISK

$V_{\text{lsr}} = +50 - -40 \text{ Km s}^{-1}$
$W_{\text{lsr}} = |40| \text{ Km s}^{-1}$
$[\text{Fe/H}] \geq -1.0$
Age $< 10 \text{ Gyrs}$

Thin Disk

Reddy et al. 2003
Concept of the Thick disk: Gilmore & Reid, 1983

Figure 6. (a) The density distribution for stars with $4 \leq M_V < 5$ with distance from the Galactic plane. On this scale, a straight line represents an exponential decrease. The fitted lines correspond to exponentials with scale height 300 pc (solid line) and 1350 pc (broken line), and correspond to the 'old disc' and 'thick disc' respectively. (b) As for Fig. 6(a), for stars with $5 < M_V < 6$. 
Sketch of Milky Way

Images of NGC 4762 galaxy showing thin, thick, and bulge components

Freeman & Bland-Hawthorn, 2002
Sample and membership probabilities

\[
P_{\text{thick}} \geq 70\% \ (93)
\]

\[
P_{\text{thin}} \geq 70\% \ (17)
\]

\[
P_{\text{halo}} \geq 70\% \ (23)
\]

Thin/Thick : 33

Thick/halo: 9

[errors in \( Rv \), parallaxes, proper motions are taken into account]
**V-W plane**: thin, thick, halo, and thin-thick

![Diagram of V-W plane showing different stellar components]

- **Thin disk**
- **Thick disk**
- **Halo stars**
Results: \(\alpha\)-process elements

Great majority of thick disk stars show high \(\alpha\)-ratio compared to thin disk

Thick and halo show similar ratios

Few thick disk stars show Thin disk abundances

Dominant contributor SNII
**Results:** Other Mg-like elements

[![Graph showing [X/Fe] ratios for different elements](image)](image)

- **Al**
- **Sc**
- **V**
- **Co**
- **Zn**

Known to behave similar to Fe-peak elements

[X/Fe] ratios are larger for thick disk than thin disk stars (puzzle!)

Implies they dominantly come from SNII.

A challenge to nucleosynthesis groups
Results: Ni-like Elements

Abundance ratios for Na, Cr, Mn, Ni, Cu are same for thin and thick stars at overlapping [Fe/H].

The ratios show function of metallicity only.

Elements are produced in similar proportions in SNI and SNII.
Results: **Cosmic Scatter**

- Observed scatter is comparable to the predicted scatter.
- Implying thick/also thin disk stars formed from well mixed gas.
**Results: Age vs Metallicity**

Thick disk stars are old (8-15 Gyrs) compared to thin disk (1-10 Gyrs).

Mean age for the thick disk is 13 Gyrs (peak).

Halo stars 12-15 Gyrs.

Age of the youngest Thick stars is the age of The oldest thin disk stars.
**Bigger picture:** Formation of Thick Disk?

- **Bottom up**

  Halo – thin – thick disk

- **Top down**

  Halo – thick – thin disk
BOTTOM UP SCENARIOS - I

Kinematic heating of thin disk causes thick disk

Increase $\sigma_u$, $\sigma_v$, $\sigma_w$ of thin disk vs age is fact with theoretical support

But difficult to get $\sigma_v$ of thick disk
Dispersion in kinematics increases with age.

Vlsr for the thick disk is difficult to explain.
Top down SCENARIOS - II

Merger with satellite galaxy (one or more)

A $\Lambda$CDM - View

Thick disk primarily from tidal debris of satellites – 85% older than 10 Gyrs are from satellites

Thin disk mainly from mixed gas (Galactic plus satellites)
Evolution of Thin and Thick Disks: Merger scenario

- [Mn/α]
- [Fe/α]
- [Ni/α]
- [Eu/α]
CONCLUSIONS:

a. Thin and thick disks stars are two different populations of the Galactic disk with different chemical history.

b. \([X/Fe]\) VS. \([Fe/H]\) suggests that the scatter in abundances is comparable to the measurement errors implying both thin and thick disk stars formed from well mixed gas.

c. Abundances in thick disk are mostly attributed to SNII and show no visible trend with metallicity implying thick disk formed quickly may be in a span of 1-3 Gyrs.

d. Abundance data may suggest a merger of gas-rich metal-poor dwarf galaxy in the distant past.
New complications?

If TKTA are real, thick disk star formation ceased at \(-0.3\) if not thick disk has enough gas to sustain SF and form younger stars.
TKTA Stars: Moving groups in the disk

Hercules stream

In U-V plane thick and Hercules stars are indistinguishable.

Famaey et al. 2005