Predictions for Galactic Archaeology from numerical modeling

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Talk outline

• The tricks played by radial migration.

• On the formation of the thick disk.

• Predictions from a recent chemo-dynamical Milky Way disk model.

• New chemo-kinematic relation in RAVE giants.
Migration and thick disks
Migrants’ contribution to the disk velocity dispersion in the absence of mergers

Vertical velocity dispersion

- Some increase in velocity dispersion from outward migrators.
- Some decrease in velocity dispersion resulting from inward migrators.
- Negligible overall effect to disk thickening.

Confirmed by Martig et al. (2014a), Vera-Ciro et al. (2014)

Minchev et al. (2012b)
Migrators’ contribution to the disk velocity dispersion in the absence of mergers

Minimal effect of migration confirmed by Vera-Ciro et al. (2014) in a dissipationless high-resolution simulation.
Migration cools the disk during mergers

Migration works against disk flaring

No effect on the vertical velocity dispersion.

Minchev, Chiappini & Martig (2014)
Minimal effect of migration confirmed also by Martig et al. (2014b).

Martig, Minchev and Flynn (2014b)
New insights into the formation of thick disks

- All mono-age disks flare.
All mono-age disks flare.

However, the total population does not.

Thick disk composed of flares, where younger populations are more radially extended.
All mono-age disks flare.

However, the total population does not.

Thick disk composed of flares, where younger populations are more radially extended.
A recent chemo-dynamical evolution model for the Milky Way

Minchev, Chiappini & Martig (2013)
Ingredients

- A high-resolution simulation of a disk assembly in the cosmological context:
  - Gas infall form filaments and gas-rich mergers
  - Merger activity decreasing toward redshift zero
- Disk properties at redshift zero consistent with the dynamics and morphology of the Milky Way:
  - The presence of a Milky Way-size bar
  - A small bulge
  - Bar’s Outer Lindblad Resonance at ~2.5 disk scale-lengths
- A detailed chemical evolution model:
Disk evolution in the cosmological context

Minchev, Chiappini and Martig (2013)
Similar to Chiappini (2009)

Constrained by:

- The solar and present day abundances of more than 30 elements
- The present SFR
- The current stellar, gas and total mass densities at the solar vicinity
- The present day supernovae rates of type II and Ia
- The metallicity distribution of G-dwarf stars
- Only thin disk chemistry used!
Older populations arrive from progressively smaller galactic radii due to their longer exposure to migration.
The metallicity distribution

For both model and observations the MDF peak shifts to lower [Fe/H] with distance from the disk plane.
The vertical metallicity gradient

Schlesinger et al. (2012), G-dwarfs

Bovy model, Rix & Bovy (2013)

Minchev et al. (2013)
The $[\text{Fe/H}]-[\text{O/Fe}]$ relation

Kinematical selection of thin- and thick-disk populations

Ramírez et al. (2013)

- Thick disk
- Thin disk
The $[\text{Fe/H}]-[\text{O/Fe}]$ relation

Model kinematical selection as in observations

Ramírez et al. (2013)
- Thick disk
- Thin disk

Minchev et al. 2013 Model
- Thick disk
- Thin disk
The [Fe/H]-[O/Fe] relation

GIRAFFE spectra of FGK-type stars

Uncertainties

Gaia-ESO data

Recio-Blanco et al. (2014)
The [Fe/H]-[O/Fe] relation

GIRAFFE spectra of FGK-type stars

Gaia-ESO data

Recio-Blanco et al. (2014)
The age-[O/Fe] relation

Haywood et al. (2013)
The age-[O/Fe] relation

Comparison between our model and Haywood et al. (2013)

Blurring insufficient to explain scatter in AMR

Migrators removed in model
The radial metallicity gradient

Minchev, Chiappini & Martig (2014)
The radial metallicity gradient

Interplay among different age groups is important.
The radial metallicity gradient

Inversion in APOGEE gradient at $|z| > 800$ pc

Flaring of mono-age disks results in the inversion of metallicity gradient with increasing distance from disk midplane.

Anders et al. (2014)
Increase of disk scale-length with age: A legacy of inside-out formation

Simulations with strong merger activity at high redshift

- Radial migration cannot compete with inside-out formation.

Bovy et al. (2012a)

Martig, Minchev and Flynn (2014a)
The age-velocity relation

Erased when 30% age errors convolved into simulated data.

Step at 10 Gyr due to strong mergers.

Martig, Minchev and Flynn (2014b)
Scale-height distribution of mono-abundance subpopulations

Bovy et al. (2012c), SEGUE data

Model data

SEGUE G-dwarfs
Bovy et al. (2012)
A new chemo-kinematic relation in RAVE giants

Minchev + RAVE (2014)
Vertical velocity dispersion as a fn of [Mg/Fe] in RAVE

Velocity dispersion drops at [Mg/Fe] > 0.4 dex

Minchev + RAVE (2014)
Vertical velocity dispersion as a function of [Mg/Fe] in RAVE

Separate into [Fe/H] sub-populations

-1.0 [Fe/H]  
-0.8 dex  
-0.45  
-0.3  
-0.17  
-0.04

Velocity dispersion drops at the high-[Mg/Fe] end for each metallicity sub-population

Related to cold old stars migrating from the innermost disk.

Minchev + RAVE, (2013)
Vertical velocity dispersion as a function of $[\text{Mg}/\text{Fe}]$ in RAVE

Related to cold old stars migrating from the innermost disk.
True for all three velocity components

Vertical

Radial

Tangential

RAVE Giants, SN>65
7<r<9 kpc
|z|<0.6 kpc

\[\text{[Fe/H]}\] –1.0, –0.8, –0.45, –0.3, –0.17, –0.04

Model

7<r<9 kpc
0.2<|z|<0.6 kpc
Origin of stars currently in the solar neighborhood

Model
$7 < r < 9 \text{ kpc}$
$0.2 < |z| < 0.6 \text{ kpc}$
Origin of stars currently in the solar neighborhood

Model

$7 \leq r < 9 \text{ kpc}$

$0.2 < |z| < 0.6 \text{ kpc}$

$[\text{Fe/H}]$:

-1.0

-0.8 dex

-0.45

-0.3

-0.17

-0.04
Origin of stars currently in the solar neighborhood

For a given metallicity bin, stars coming from the inner disc are kinematically colder and older.
Cool old stars can arrive from inner disk

Old stars coming from the inner disk are cooler than locally born stars by up to 30 km/s.

Slope becomes negative for the last several Gyr (no significant mergers).

Explains inversion of vel. dispersion - [Mg/Fe] relation in RAVE and SEGUE G-dwarf data.
Summary

- **Radial migration can:**
  - Flare disks during quiescent times.
  - Suppress disk flaring during mergers.
  - Introduce scatter in the AMR.
  - Explain the high metallicity tail.
  - Explain the $[\alpha/\text{Fe}]-[\text{Fe/H}]$ relation (except for gap).

- **Radial migration cannot:**
  - Explain thick disks.
  - Create a gap in the $[\alpha/\text{Fe}]-[\text{Fe/H}]$ relation.
  - Compete with inside out formation.

- **Thick disk composed of the flares of populations of different ages:**
  - age/alpha gradient predicted.
  - results in flattening/inversion in the metallicity gradient at high $|z|$.
  - Blurring insufficient to explain the AMR, migration needed.
  - Velocity dispersion-$[\alpha/\text{Fe}]-[\text{Fe/H}]$ relation may help recover the disk merger history.