Origin and structure of the Galactic disc(s)
Schönrich & Binney (2009b)

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Chemical Evolution of Galaxies

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What is the (sub-)structure of the galactic disc?

Study kinematics and chemical composition

Two components: density profile from star counts could not be fit by 1 exponential, but by 2 (Gilmore & Reid 1983)

Thick disc
- High $\sigma$, $\alpha$ enrichment, old
- Formation scenarios: accretion of satellites and/or heating of thin disc during merger events (Chiappini et al. 1997; Reddy et al. 2006)

Thin disc

Schönrich & Binney (2009a): two component disc forms naturally when allowing for radial mixing
Introduction

- What can we observe?
- Solar neighborhood → *Hipparcos* parallaxes, radial velocities, abundances
- Signatures of thin and thick discs
- Relationship between chemistry and kinematics of nearby stars
- Better understanding of sampling criteria and selection effects
Schönrich & Binney (2009a):

- Endpoint of a simulation of chemical evolution within a disc
- Star formation rate (SFR): Kennicutt law
- Gas disc: exponential surface density profile
- New features:
  - Radial flow of gas within the disc
  - Radial migration
Radial migration

Churning
- Over time stars change their angular momenta
- Sellwood & Binney (2002): weak spiral structure causes shift in guiding center of stars
- Corotation resonance with spiral arm
- No disc heating – need to look at individual stars

Blurring
- Change in epicycle amplitude
- Stars move on orbits that are
  - increasingly eccentric
  - inclined towards the Galactic plane
Model assumptions

- Birth radii from Geneva-Copenhagen Survey (Nordström et al. 2004; Holmberg et al. 2007)
- Hot gas does not take part in churning, cold gas and stars do → bias towards impact of churning on old populations
- Gas infall parametrized: cannot obtain this from simulations
  - Measured oxygen gradient
  - Local metallicity distribution

Figure 2. The metallicity distribution of solar-neighbourhood stars: data points from Holmberg et al. (2007); red curve the SB09 model. For the model, total metal abundance is plotted horizontally, while for the data the plotted quantity is the photometric metallicity indicator given in Holmberg et al. (2007).
Model Predictions – stellar density

- Metal enrichment of gas: ISM trajectories move to the right
- Onset of SNIa: decrease of $[\alpha/\text{Fe}]$: trajectories move downward
- Steady state: enrichment balanced with inflow of metal poor material from the IGM
- Metal-poor thick disc
- Thin disc: ridge does not trace chemical history

Figure 3. Logarithmic stellar densities for a simulated GCS stellar sample in the $([\text{Ca/Fe}], [\text{Fe/H}])$ (top panel) and $([\text{O/Fe}], [\text{Fe/H}])$ (bottom panel) planes. Contours have a 0.5 dex spacing. Black lines track the development of the cold ISM in annuli of radii of (from right to left) 2.5, 5.0, 7.5 and 10 kpc.
Model Predictions – rotational velocity

- Correlation $[\text{Fe/H}] - v_{\text{rot}}$
- High $[\text{Fe/H}] \Rightarrow$ low $v_{\text{rot}}$: migrants from small radii
- Effect of churning: increase the chemical heterogeneity of stars with given velocity $V$

Figure 4. The structure of a simulated sample of GCS stars in the ($[\text{Fe/H}], [\text{O/Fe}]$) plane. Contours spaced by 1 dex give the density of stars in this plane, while colour codes the average rotational velocity of the stars found at the point in question – the local circular speed is assumed to be 220 km s$^{-1}$. Black lines give the trajectories of the cold ISM during the model Galaxy’s evolution for galactocentric distances of (from left to right) 10, 7.5, 5, 2.5 kpc.
Figure 5. Same as Fig. 4 with colour coding for age and 0.5 dex spacing for density contours.

Oldest stars most metal rich
Mechanisms

1. $\sigma \propto (\text{age})^3$: older stars have higher dispersions than younger stars born at the same location

2. $\sigma$ increases inwards

→ different scale heights

Figure 6. Velocity dispersions (in km s$^{-1}$) as functions of position in the ([Fe/H], [O/Fe]) plane. The graph is derived for a solar-neighbourhood sample by measuring the velocity dispersions of the populations with a specific chemical fingerprint. Two effects act on the velocity dispersion: the dependence on age mostly induces a top-down gradient following the evolution lines of the ISM. In the perpendicular direction (left to right), velocity dispersion increases with decreasing galactocentric radius. The low dispersion of the Galactic thin disc is visible on the lower-left side, girded by a high-dispersion band running from top left to bottom right.
Model Predictions – metallicity distribution vs height

- Metallicity distribution at high altitudes: early evolution of the disc
- [α/Fe]: bimodal distribution → two components

Figure 7. The model’s stellar metallicity distributions at different heights above the plane at $R_0$. Here, we avoided implying a specific selection function by using the mass of a specific population to determine its weight in the distribution. The diagrams are unsmoothed and the scatter comes from the radial (0.25 kpc) and temporal (30 Myr) resolution of the model. Upper
Selection criteria

By chemistry and/or kinematics

Figure 8. Upper panel: a scatter plot for a GCS-like measurement of solar-neighbourhood stars in the ([Fe/H], [O/Fe]) plane. Red dots mark positions of stars, while green crosses mark stars that are selected to the thick disc via the kinematic selection scheme. Lines mark possible criteria to dissect the data with a chemical classification scheme in the ([Fe/H], [O/Fe]) plane. Lower panel: the locations in the ([Fe/H], [α/Fe]) plane of stars with spectrally determined chemical compositions from Bensby et al. (2005), Gilli et al. (2006) and Reddy, Lambert & Allende Prieto (2006).
Selection criteria – chemistry

- Thick disc: age > 6 Gyr
- Intermediate population: age < 10 Gyr
- Thin disc: age < 7 Gyr
- Older stars (thick disc) started before ISM-enrichment due to SNIa
- Bimodal isothermal decomposition of thick disc

Figure 9. The top two panels show the distribution of stars from the three chemically selected populations in $V$ velocity and age. The bottom diagram shows the distribution of stars by the velocity-dispersion parameter of the cohort to which they belong – see the description in text. The distributions are the thin disc (green), the intermediate population (blue) and the thick disc (red). The curve showing the age distribution of the thin disc has been scaled down by a factor of 10 relative to the curves for the other two components. In the other panels, each curve is separately normalized to unity. The steps in the age distribution are artefacts arising from the model’s radial resolution (0.25 kpc); a step is produced as an individual ring passes over the selection criterion.
Selection criteria – chemistry

- Bimodal isothermal decomposition of thick disc
- Division into metal-poor and metal-rich thick discs

*Figure 10.* As Fig. 9 but with the thick-disc split into its metal-weak (purple) and metal-rich (red) parts, the latter being defined to comprise $[\text{Fe/H}] > -0.8$. 
Selection criteria – kinematics

- Selection by chemical composition works well
- BUT: it is much easier to measure velocities
- Kinematic selection more common
- Use model as testing ground for evaluating kinematic selection procedures
- Fit distribution functions (DFs) to thin and thick disc (Bensby et al. 2005)

\[ f(U, W, V) = k f_1 \exp \left( -\frac{U^2}{2\sigma_U^2} - \frac{(V - V_{\text{asym}})^2}{2\sigma_V^2} - \frac{W^2}{2\sigma_W^2} \right) \]

- \( V_{\text{asym}} \) larger for thick disc \( \rightarrow \) stars with lagging rotation more likely to be assigned to thick disc
Evaluating kinematic selection criteria – Toomre plot

- Big overlap between different chemically selected populations
- Kinematic selection cannot be very clean
- Contamination of the thick disc
Evaluating kinematic selection criteria – abundances

- High-α stars assigned to thin disc
- Thin disc not confined to ridgeline of chemical thin disc
- More stars at large radii assigned to thin disc due to low velocity dispersions and high rotation velocities
- Tail of old stars in thin disc

Figure 14. Selection probabilities using the kinematic selection function of equation (2) for the thin (upper panel) and thick disc (lower panel). Blue contours give lines of same selection probability for a star at a certain chemical composition with levels running from 0.01 to 0.91 with a 0.1 spacing for the thin disc and from 0.01 to 0.61 with a 0.05 spacing for the thick disc. Colours encode the selection probability and the green contours show lines of the model’s entire disc population density at a 0.5 dex spacing.
Kinematic selection – comparison to observations

Model: kinematic selection

Observations by Holmberg et al. (2007)

- Consistent within the errors
- Thin : intermediate : thick = 1 : 0.099 : 0.0239 (model)
- Thin : intermediate : thick = 1 : 0.095 : 0.029 (obs)
Conclusions

Conclusion and Outlook

- Chemical decomposition into thin and thick disc
- However: so far detailed chemical analysis only feasible for nearby stars
- Kinematic selection leads to misallocation
- Thin disc: young stars – Thick disc: old stars
- Novelty: radial migration
- "There is absolutely no evidence for the thick disc has a violent origin"
Thank you very much for your attention!
Questions?
References

Bensby, T., Feltzing, S., Lundström, I., & Ilyin, I. 2005, Astronomy and Astrophysics, 433, 185
Holmberg, J., Nordström, B., & Andersen, J. 2007, Astronomy and Astrophysics, 475, 519