GALACTIC ABUNDANCE GRADIENT

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ABSTRACT. This contribution is an overview of three papers (Andrievsky et al. 2002a; 2002b; 2002c) devoted to the metallicity distribution in galactic disc.

1. Introduction

In recent years the problem of radial abundance gradients in spiral galaxies has emerged as a central problem in the field of galactic chemodynamics. Abundance gradients as observational characteristics of the galactic disc are among the most important input parameters in any theory of galactic chemical evolution. Further development of theories of galactic chemodynamics is dramatically hampered by the scarcity of observational data, their large uncertainties and, in some cases, apparent contradictions between independent observational results. Many questions concerning the present-day abundance distribution in the galactic disc, its spatial properties, and evolution with time, still have to be answered.

A number of studies of abundance gradients in the galactic disk have been performed in recent years. The results obtained are rather disparate: from no detectable gradient to a rather significant slope of about $-0.1\,\mathrm{dex\,kpc^{-1}}$.

Usually the following objects are used to derive galactic abundance gradient: hot main sequence B stars, HII regions, planetary nebulae, open clusters.

Compared to other objects supplying us with an information about the radial distribution of elemental abundances in the galactic disc, Cepheids have several advantages:

1) they are primary distance calibrators which provide excellent distance estimates;

2) they are luminous stars allowing one to probe to large distances;

3) the abundances of many chemical elements can be measured from Cepheid spectra (many more than from HII regions or B stars). This is important for investigation of the distribution in the galactic disc of absolute abundances and abundance ratios. Additionally, Cepheids allow the study of abundances past the iron-peak which are not generally available in HII regions or B stars;

4) lines in Cepheid spectra are sharp and well-defined which enables one to derive elemental abundances with high reliability.

As it was shown in Andrievsky et al. (2002a) – Paper I, Andrievsky et al. (2002b) – Paper II the radial abundance distribution within the region of galactocentric distances from 4 to 10 kpc is best described by two distinct zones. One of them (inner: 4.0 kpc $<R_G<$ 6.5 kpc) is characterized by a rather steep gradient, while in the mid part of galactic disc (6.5 kpc$<R_G<$ 10.0 kpc), the distribution is essentially flat (e.g. for iron the gradient is $d[Fe/H]/dR_G \approx -0.03\,\mathrm{dex/kpc}$).

As discussed in Paper I and Paper II, such a bimodal character in the distribution may result from the combined effect of the radial gas flow in the disc and the radial distribution of the star formation rate. We note here that there are conflicting models of the galactic structure, and that possibly the metallicity gradients can help to decide which are the more likely ones. According to Sevenster (1999a; 1999b) and others (see references in Paper I) the bar extends its influence to a co-rotation radius at about 4–6 kpc. In contrast, according to Amaral & Lépine (1997) and others, the spiral arms extend from the Inner Lindblad Resonance which is at about 2.5 kpc, to the Outer Lindblad Resonance, at about 12 kpc, and the co-rotation of the spiral pattern is close to the solar galactic orbit. In the vicinity of a bar we expect to see elongated orbits of stars, and consequently, a small metallicity gradient. On the other hand, according to Lépine, Mishurov & Dedikov (2001) and Paper I an interaction between the gas and spiral waves in the disc forces the gas to flow in opposite directions inside and outside the Galactic co-rotation annulus. This mechanism produces a cleaning effect in the middle part of the disc and consequently a flattening of the metallicity distribution. At the same time, a decreased star formation rate in the vicinity of the galactic co-rotation, where the relative velocity of the spiral arms and of the gas passing through these arms is small, should also result in some decrease in the abundances.

In Andrievsky et al. (2002c) – Paper III we have begun to investigate the radial abundance distribution in the outer disc. The region of primary interest is at a galactocentric radius $R_G \approx 10$ kpc, where according to Twarog et al. (1997) there exists a discontinuity in the metallicity distribution. Such a discontinuity can

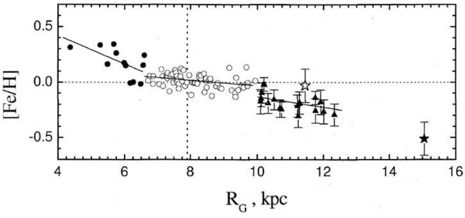

Figure 1: The radial distribution of the iron abundance. *Open circles* - the data from Paper I, *black circles* - the data from Paper II, *black triangles* - Paper III. 2-σ interval is indicated. The position of EE Mon is indicated by *filled asterisk*. The Sun is marked by the intersection of the dashed lines.

be suspected from earlier works of Janes (1979), Panagia & Tosi (1981) and Friel (1995). However, Twarog et al. (1997) were the first to clearly stress this result. Twarog et al. used photometric metallicities (interpreted to imply [Fe/H]) for a large sample of open clusters, and they found that galactic disc breaks into two distinct zones. Between $R_G \approx 6.5 - 10.0$ kpc they found a mean iron abundance $<$[Fe/H]$>$ of ≈ 0 (i.e., the slope is very small, if present). Beyond $R_G \approx 10.0$ kpc the mean $<$[Fe/H]$>$ is ≈ -0.3. This implies a sharp discontinuity at $R_G \approx 10$ kpc.

Recently, Caputo et al. (2001) reported a similar result. Those authors calibrated BVI data for a large sample of galactic Cepheids (galactocentric distances from 6 to 19 kpc) as a function of metallicity using non-linear pulsation models. Their results (although not very reliable on a per star basis) suggest that the derived metallicity distribution in the galactic disc can be represented either by a single gradient of $-0.05\,\mathrm{dex\,kpc^{-1}}$, or by a two-zone distribution with a slope of $-0.01 \pm 0.05\,\mathrm{dex\,kpc^{-1}}$ within 10 kpc and $-0.02 \pm 0.02\,\mathrm{dex\,kpc^{-1}}$ in the outer region of the galactic disc. In other words, within each region the metallicity gradient is weak to non-existent, while between these regions a significant change of the metallicity/gradient does occur.

2. Radial abundance distributions: from inner to outer disc

To make the picture on galactic abundance gradients as complete as possible, one can plot data from Paper I–III together Figs. 1–5 display the derived dependencies between the abundances of 25 chemical elements and galactocentric distances. As the iron abundances are the most reliable we will concentrate our discussion on the iron gradient d[Fe/H]/dR_G.

3. Discussion

3.1. Iron abundance gradient

Distances can be separated into three zones: the inner part of the galactic disk (gradient d[Fe/H]/d$R_G \approx -0.13 \pm 0.03\,\mathrm{dex\,kpc^{-1}}$), the mid part of the disk (gradient $\approx -0.02 \pm 0.01\,\mathrm{dex\,kpc^{-1}}$), and a piece of outer disc. For the latter we derive a gradient $-0.06 \pm 0.01\,\mathrm{dex\,kpc^{-1}}$ and a mean [Fe/H] $\approx -0.19 \pm 0.08$ dex. The gradient for each zone was derived from a least-squares fit using the weighted data. Thus, the abundance distribution over the galactocentric distances 4–10 kpc cannot by represented by a single gradient value. More likely, the distribution is bimodal: it is flatter in the solar neighborhood with a small gradient, and becomes steeper towards the galactic center. The steepening begins at the distance about 6.5 kpc.

The transition zone at 10 kpc can be easily identified in Fig. 1. After this point the metallicity drops by approximately 0.2 dex. All the stars in the bin beyond 10 kpc are iron-deficient. The same result is seen in Fig. 3ab of Twarog et al. (1997) which shows their open cluster metallicity values as a function of galactocentric radius. It should be noted that the sample of open clusters used by Twarog et al. consists of the

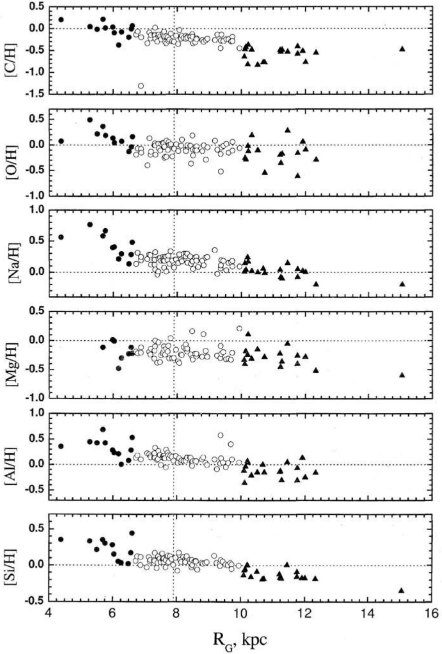

Figure 2: Same as Fig. 1, but for elements C–Si

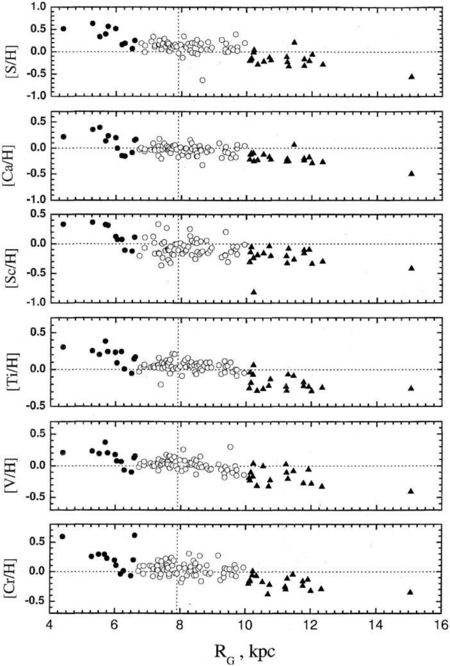

Figure 3: Same as Fig. 1, but for elements S–Cr

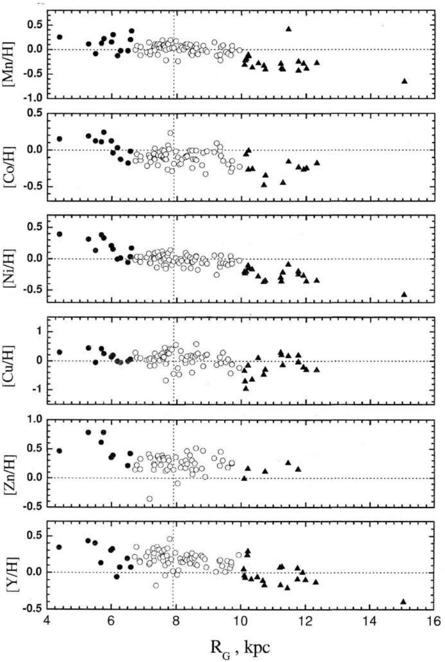

Figure 4: Same as Fig. 1, but for elements Mn–Y

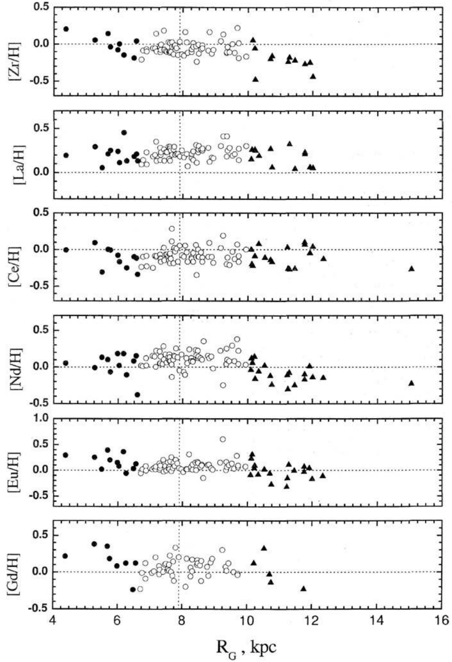

Figure 5: Same as Fig. 1, but for elements Zr–Gd

clusters with ages spanning from 1 to 5 Gyr. Thus, the youngest clusters used for the gradient study are approximately 10 times older than Cepheids. By comparing the iron abundance gradient from Cepheids with that from open clusters one would, in principle, estimate how the abundance gradient evolved with time. Nevertheless, in practice it is difficult to realize, because any conclusion will suffer from the rather high uncertainty of the open cluster data. The only we can state confidently is that the discontinuity of the metallicity distribution has really survived over several Gyrs, until now.

3.2. A possible explanation for some observed features

Recently Mishurov et al. (2002) produced a detailed model of chemical evolution of the galactic disc, taking into account the effect of co-rotation, to explain our data presented in Papers I and II. The new data presented in Paper III, suggest that the model of Mishurov et al. (2002) is basically correct, but that the co-rotation radius should be slightly shifted to about 10.5 kpc. The discontinuity in the metallicity distribution at 10 kpc is possibly explained by the gap in the gas density distribution that is associated with co-rotation (see Lépine, Mishurov & Dedikov (2001)). If we divide the Galactic disc in a large number of concentric rings, the gas from neighbouring rings tends to mix due to supernova explosions, stellar winds, cloud collisions, etc., that do not respect the frontiers between concentric rings. This mixing is equivalent to a diffusion term, and tends to smooth out metallicity gradients in the gas (and therefore, in recently formed stars). However, the gas density gap associated with co-rotation, which is observed in the 21 cm hydrogen line as discussed by Lépine, Mishurov & Dedikov (2001) is possibly a barrier that avoids contact between the gas at $R_G > R_c$ and $R_G < R_c$ and allows the existence of two distinct zones.

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