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Cepheids as tracers of the metallicity gradient across the Galactic disk* ⋆

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Abstract.
We present iron abundance measurements, based on high resolution spectroscopy, and accurate distance determinations, based on near infrared photometry, for 34 Galactic Cepheids. The new data are used to constrain the Galactic iron abundance gradient in the outer disk, namely from 10 to 14 kpc. We confirm the flattening of the gradient toward the outer disk. In this region we also found an increase in the metallicity dispersion. Current data do not support the occurrence of a jump in the metallicity gradient for Galactocentric distances of the order of 10-12 kpc.

Key words. Stars: abundances – Stars: supergiants – Galaxy: abundances – Galaxy: evolution

1. Introduction

Galactic abundance gradients are a fundamental input for chemodynamical evolutionary models, since they are the observables typically adopted to validate predictions. Among the different tracers used to determine the Galactic gradients: HII regions, Open Clusters, O/B-type stars, Planetary Nebulae, we chose the Cepheids. The Cepheids present several advantages when compared with other tracers: *i)* they are excellent distance indicators, which is a strong positive feature to provide accurate Galactocentric distances; *ii)* they are also bright enough to allow the study of the gradient over a large range of Galactocentric distances; *iii)* they present a large set of well defined absorption lines, therefore, accurate and precise abundances of many heavy elements can be provided.

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⋆ Based on observations obtained with ESPADONS at the Canada-France-Hawaii Telescope (CFHT) and on observations collected with FEROS at the ESO/MPI 2.2 m. telescope at ESO, La Silla.

Abundance gradients were discovered first in six external galaxies from HII regions by Searle (1971) but their occurrence in the Galaxy was a controversial issue. Indeed, some investigations were in favor of Galactic gradients (D'Odorico et al. 1976; Janes 1979), while others found no correlation between metallicity and distance (Clegg & Bell 1973; Jennens & Helfer 1975).

Even though the presence of Galactic abundance gradients seems widely accepted, the empirical estimates of the slopes are still lively debated. By using HII regions, Vilchez & Esteban (1996) found a slope of -0.02 dex kpc^{-1} , but different authors using the same tracers suggest slopes ranging from -0.039 dex kpc^{-1} (Deharveng et al. 2000) to -0.065 dex kpc^{-1} (Afflerbach et al. 1997). On the other hand, the use of B-type stars gives slopes ranging from -0.042 dex kpc^{-1} (Daflon et al. 2004) to -0.07 dex kpc^{-1} (Gummersbach et al. 1998). The slopes based on Planetary Nebulae range from -0.05 dex kpc^{-1} (Costa et al. 2004) to -0.06 dex kpc^{-1} (Maciel et al. 1999) to the lack of a Galactic metallicity gradient (Stanghellini et al. 2006) . The slopes based on old Open Clusters still show a large spread. By adopting a sample of 40 clusters distributed between the solar circle and $R_G \simeq 14$ kpc, Friel et al. (2002) found a slope of -0.06 dex kpc^{-1} . More recently, Carraro et al. (2007) using new accurate metal abundances for five old open clusters located in the outer disk together with the sample adopted by Friel et al. (2002) found a much shallower global iron gradient, namely -0.018 ± 0.021 dex kpc^{-1} . The global iron slopes based on Cepheids are very homogeneous, and indeed dating back to the first estimates by Harris (1981, 1984), who found a slope of -0.07 dex kpc^{-1} , the more recent estimates provide slopes ranging from -0.06 dex kpc^{-1} (Andrievsky et al. 2002a,b,c; Luck et al. 2003; Andrievsky et al. 2004; Luck et al. 2006) to -0.07 dex kpc^{-1} (Lemasle et al. 2007).

Concerning the shape of the gradient, the situation is even more complicated. The hypothesis of a linear gradient is very disputed. Several authors favor a flattening of the gradient beyond 10-12 kpc: Vilchez & Esteban (1996) (HII regions), Twarog et al. (1997) (Open Clusters), Andrievsky et al. (2004) (Cepheids), Costa et al. (2004) (Planetary Nebulae). This flattening is also well reproduced by models (Cescutti et al. 2007). In a recent paper, Yong et al. (2006) brought another feature: the flattening may occur with two basement values, the first one at -0.5 dex, a lower value than previous studies, and the second one at -0.8 dex, for which they suspected the possibility of a merger event. On the other hand, independent investigations do not show a clear flattening toward the outer disk, like Rolleston et al. (2000) (O,B stars) and Deharveng et al. (2000) (HII regions). Morever, a change in the slope in the direction of the inner disk was suggested by Andrievsky et al. (2002b) in a study based on a limited sample of Cepheids. In this context it is worth mentioning that the different tracers adopted to estimate the global iron gradient present a handful of objects in the outer disc, i.e. at $R_G \geq 12$ kpc. Finally, we mention that it has also been suggested by Twarog et al. (1997), using Open Clusters, and by Andrievsky et al. (2004), using Cepheids, a jump in the metallicity gradient at $R_G \sim 10 - 12$ kpc, with the iron abundance sharply decreasing by ≈ -0.2 dex. Here we investigate the shape of the gradient in the outer disk and focus our attention on the possible jump in metallicity.

2. Observations and methods

Our data sample includes high resolution spectra of 34 Galactic Cepheids. A large fraction of them (28) were collected with ESPADONS at CFHT, whereas six were collected with FEROS at 2.2m ESO/MPG telescope (Kaufer et al. 1999). Spectra were reduced using either the FEROS package within MIDAS or the Libre-ESpRIT software (Donati et al. 1997, 2006). The data analysis was already described in Lemasle et al. (2007). Suffice it here to briefly mention the main steps of the reduction strategy. The accurate determination of effective temperatures is a critical point in the abundance determination. They are only spectroscopically determined, by using the method of line depth ratios (LDR), described in Kovtyukh & Gorlova (2000). As it relies only on spectroscopy, it is independent of interstellar reddening. These authors proposed 32 analytical relations for determining $T_{\rm eff}$ from LDR of weak, neutral metallic lines.

The other atmospheric parameters (surface gravity *log g* , microturbulent velocity v_t) are determined by imposing the ionization balance between FeI and FeII with the help of curves of growth: iterations on *log g* and v_t are repeated until the best match with the same curve of growth is reached. Abundances are then calculated with an atmospheric model from Edvardsson et al. (1993) based on the following assumptions: parallel plane stratification, hydrostatic equilibrium and LTE. We adopted the scaled-solar chemical abundances suggested by Grevesse et al. (1996). The final internal accuracy in the abundance determination is of the order of 0.1 dex.

Absolute distances were estimated using near infrared photometry ($J, H, K-$band) from the 2MASS catalog. The mean magnitude of these objects was estimated using the template light curves provided by Soszýnski et al. (2005), together with the $V-$band amplitude and the epoch of maximum available in the literature. For ST Tau and AD Gem the data from Barnes et al. (1997) were also used, while for HW Pup the data from Schechter et al. (1992) have been joined to the 2MASS ones. As templates are only for fundamental modes pulsators, the mean near infrared magnitudes for first overtone pulsators are only the single 2MASS measurement. The Cepheid absolute magnitudes were computed using the near infrared period-luminosity relations recently provided by Persson et al. (2004), with an LMC distance modulus of 18.50 mag. Pulsation periods and reddenings are from the Fernie's database (Fernie et al. 1995) and period of first overtone pulsators were fundamentalized. We assumed a Galactocentric distance of 8.5 kpc for the sun (Feast & Whitelock 1997).

3. Results and final remarks

Current iron abundances when compared with previous measurements, mainly from the systematic investigation by Andrievsky et al., show a very good agreement. For 17 stars the abundance difference is very small (<0.1 dex) and for 6 stars it is $\sim$ 0.1 dex. We cannot confirm previous determinations only for 4 stars, for which discrepancies can reach 0.3 dex. To improve the sampling along the Galactic disk, we added to our new data 30 Cepheids from Lemasle et al. (2007), 52 Cepheids from Andrievsky's sample and 11 Cepheids from Mottini et al. (2007), for which both metallicities and infrared photometry were available. The complete sample includes 127 Cepheids with distances based on homogeneous infrared photometry. Among them 27 have Galactocentric distances in the 10-12 kpc range and 13 are located beyond 12 kpc.

We first estimated the Galactic gradient for the whole Cepheid sample. Data plotted in Fig. 1 bring forward the following findings:

- The iron gradient shows no evidence of a gap over the Galactocentric distances covered by the current sample.
- The iron gradient is flattening in the outer disk.
- The spread in metallicity is larger in the outer disk, possibly due to local inhomogeneities.

The slope of the linear iron gradient over the entire sample is shallower, -0.058 dex kpc^{-1} , than previously estimated by Lemasle et al. (2007), but the new sample extends toward the outer disk, where the flattening occurs. This slope is in very good agreement with previous determinations from Friel et al. (2002) (Open Clusters) and Luck et al. (2006) (Cepheids). The flattening of the gradient in the outer disk becomes even more evident in Fig. 2. We estimated the slope by using Cepheids located between 10 and 15 kpc and we found -0.019 dex kpc^{-1} . This estimate is in excellent agreement with the slope found by Carraro et al. (2007) using old Open Clusters, i.e. -0.018 ± 0.02 dex kpc^{-1} . Moreover and even more importantly, the two independent estimates suggest, within the er-

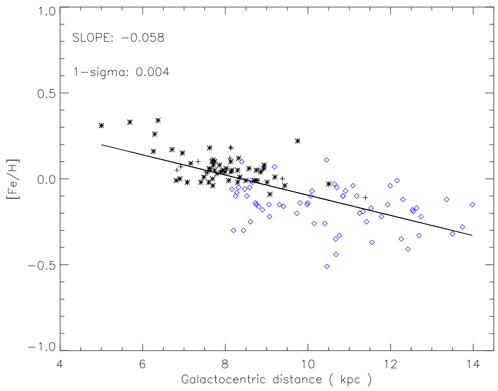

Fig. 1. Galactic radial abundance gradient. The solid line shows the linear regression whose slope and $1-\sigma$ error are labeled. Diamonds mark our data, while asterisks show data from Andrievsky et al. and plus signs display data from Mottini et al.

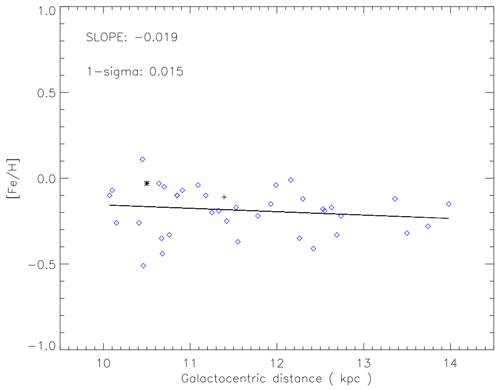

Fig. 2. Same as Fig.1, but for Cepheids with Galactocentric distances ranging from 10 to 15 kpc range.

rors, a very similar metallicity value in the outer disc, namely $[Fe/H] = -0.3, -0.4$.

Several reasons can be invoked to explain the lack of the metallicity gap in our sample. The first one was suggested by Luck et al. (2006), who pointed out that their sample, as well as the one by Twarog et al. (1997) was gathering stars lying approximately at the same Galactic longitude, respectively 190-250 and 130-260 degrees. Moreover, the uncertainties on the distance determination increase with the star distances (especially when the distance is estimated using optical photometry) and could introduce artifact in the distribution. The use of IR photometry and robust primary distance indicators presents several undisputed advantages. Note that the outer disk in strongly undersampled, therefore, the selection of the targets among the few available Cepheids can introduce a bias that can only be removed by increasing the sample size in this region. Finally, we note that the lack of a gap in our iron gradient estimate might be due to the restricted range of longitudes covered by our sample. This relevant point deserves further investigations.

4. Summary

High resolution spectra and accurate distance determinations for 34 Cepheids provided the opportunity to investigate the iron gradient across the Galactic disc. Preliminary results indicate that:

- The Galactic iron gradient presents a linear trend and the slope is ≈ -0.06 dex kpc^{-1} .
- The shape of the gradient is more accurately described by a bimodal distribution, with a higher slope in the central region and a flattening of the gradient in the outer disk. In this region, the spread in metallicity is higher, possibly due to local inhomogeneities. A third zone can be considered in the inner disk, with a break in the slope near 7 kpc, but this region was not explored in our study.
- Current data show no evidence of a jump in the iron gradient for $R_G \sim 10-12$ kpc.

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