

New determination of the Galactic abundance gradient using Cepheid variable stars

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Results obtained during my Ph.D
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with the collaboration of :

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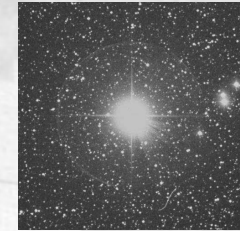
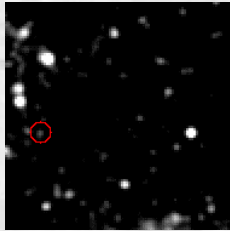
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Francesca Primas (ESO)

Martino Romaniello (ESO)



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groningen

faculty of mathematics
and natural sciences

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Abundance gradients and Cepheids

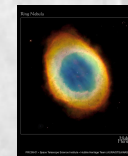
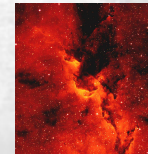
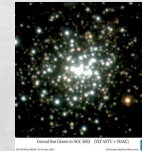
Necessary quantities :

Abundances $[M/H] = \log [M/H] - \log[M/H]_{\odot}$

- Temperature T_{eff}
- Surface gravity $\log g$
- Microturbulent velocity V_t
- Equivalent width of absorption lines EW

+ Distances

\Rightarrow Abundance gradients



Abundance gradients and Cepheids

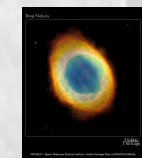
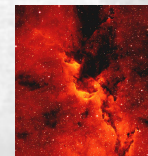
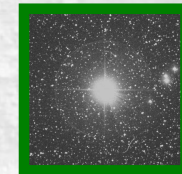
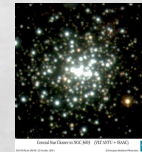
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Cepheids: advantages

- **Excellent distance indicators**
Tool of specific interest inside our Galaxy
- Luminous stars \Rightarrow wide range of distances
- Abundances of many elements can be measured
Not true for most of the other tracers
- Abundances are reliable
Numerous and well defined lines

Cepheids : specific problems

- Cepheids = variable stars
 - Atmospheric parameters vary throughout the period
 - High resolution spectroscopy
 - BUT no simultaneous photometry available
 - ⇒ **How to determine T_{eff} ?**
- Only ~ 800 Galactic Cepheids are known
 - To be compared with the ~2000/1000 known in the LMC/SMC,
~ 800 in M31 and ~ 750 in M33
 - **Not homogeneously distributed :**
most of them are located in the Solar neighbourhood

Current controversy : the slope

- Most of the recent studies support the existence of a gradient
- The value of the slope is controversial

For a given element,
from H II regions, Open clusters, B stars & PNe :
slopes from $-0.02 \text{ dex kpc}^{-1}$ to $-0.07 \text{ dex kpc}^{-1}$

..., Vilchez et al. (1996), Afflerbach et al. (1997), Twarog et al (1997),
Gummersbach et al. (1998), Maciel et al. (1999), Deharveng et al. (2000),
Friel et al (2002), Daflon et al. (2004), Costa et al. (2004)...

- A few recent studies even show no evidence of a gradient
From PNe : $-0.01 \text{ dex kpc}^{-1}$ - Stanghellini et al (2006)

Slope of the gradient and Cepheids

- Different studies based on Cepheids :

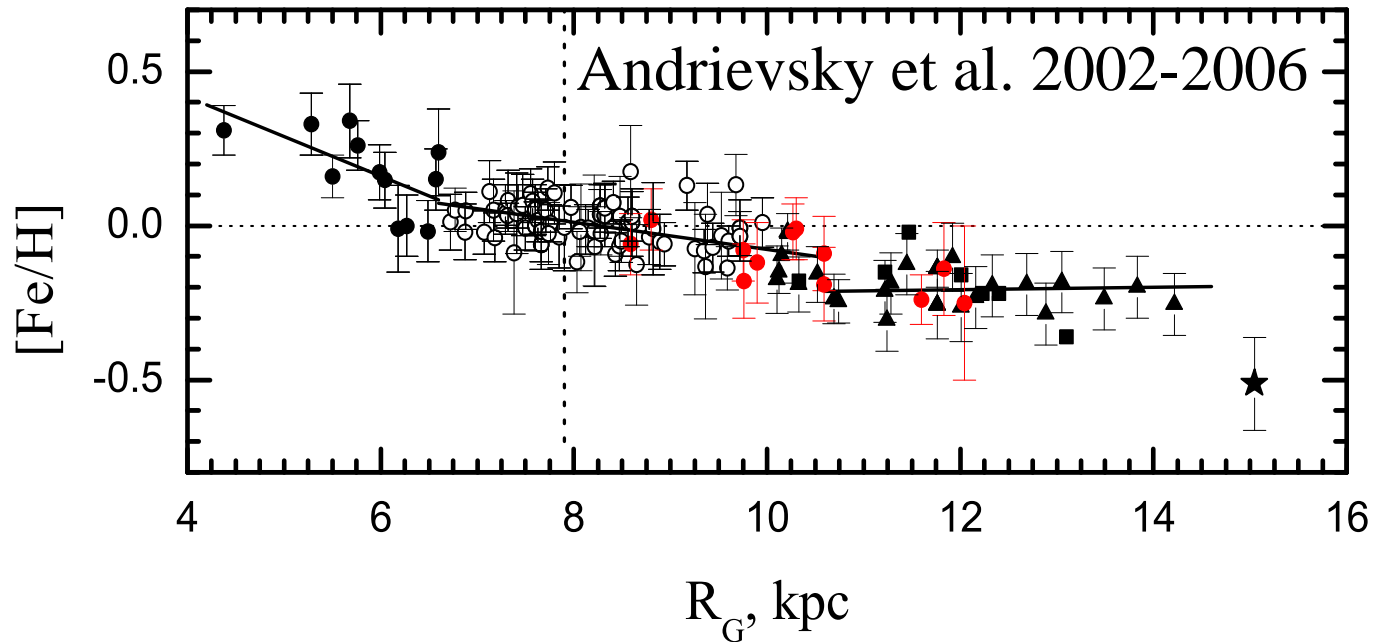
–Harris (1981,1984) :	-0.07 dex kpc ⁻¹	5-15 kpc
–Andrievsky et al. (2002-2006) :	-0.06 dex kpc ⁻¹	4-16 kpc
–Yong et al. (2006) :	-0.052 dex kpc ⁻¹	12-17 kpc
–Lemasle et al. (2007) :	-0.07 dex kpc ⁻¹	5-12 kpc
–Lemasle et al. (2008) :	-0.052 dex kpc ⁻¹	4-16 kpc

- Good agreement on the slope of the iron gradient :

–Twarog et al. (1997)	-0.067 dex kpc ⁻¹	6-15 kpc	(Open clusters)
–Friel et al. (2002)	-0.06 dex kpc ⁻¹	7-16 kpc	(Open clusters)
–Luck et al. (2006)	-0.068 dex kpc ⁻¹	4-14,6 kpc	(Cepheids)
–Lemasle et al. (2008)	-0.052 dex kpc ⁻¹	4-16 kpc	(Cepheids)
–Carraro et al. (2007)	-0.018 dex kpc ⁻¹	12-21 kpc	(Open clusters)

Current controversy : a flattening ?

- **Hypothesis of a constant gradient strongly debated**
- **Break in the slope in the inner disk ?**
 - Suggested from a handful of Cepheids by Andrievsky et al. (2002b)
 - Agreement on the abundance values : Lemasle et al. (not published yet)
- **Flattening of the gradient toward the outer disk ?**
 - In favor of a flattening :
 - Vilchez et Esteban (1996) - H II regions
 - Twarog et al. (1997); Carraro et al. (2007) - Open clusters
 - Andrievsky et al. (2004) - Cepheids
 - Costa et al. (2004) - PNe
 - Cescutti et al. (2007) - chemical evolution models
 - No flattening :
 - Deharveng et al. (2000); Quireza et al. (2006); Rudolph et al. (2006) - PNe
 - Rolleston et al. (2000) - O-B stars



- Flattening of the gradient toward the outer disk ?

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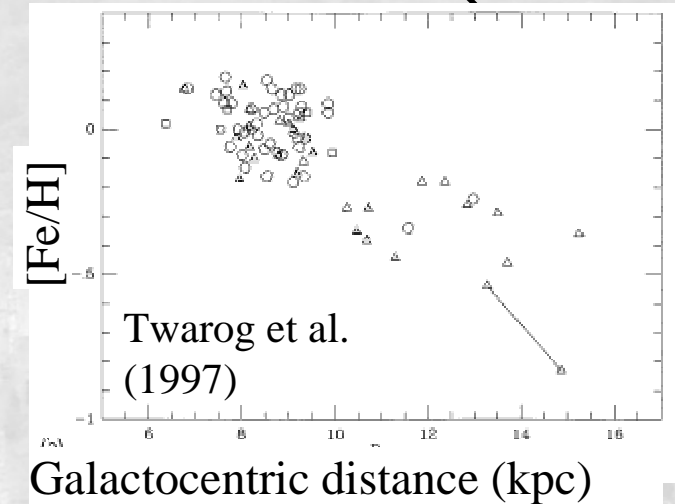
Ceiling value in the outer disk?

› Single level :

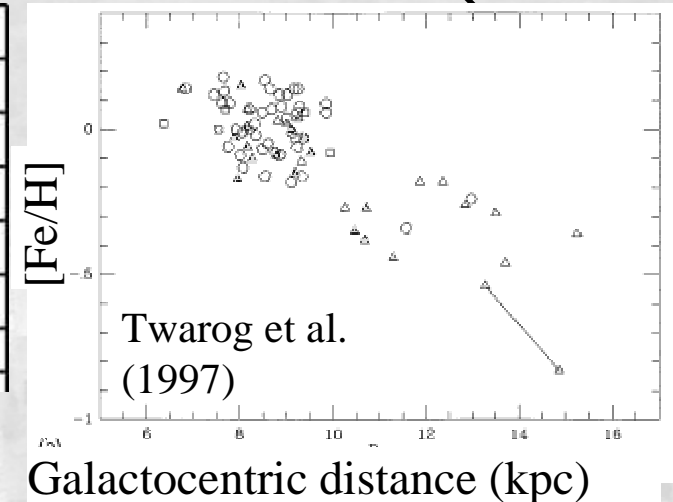
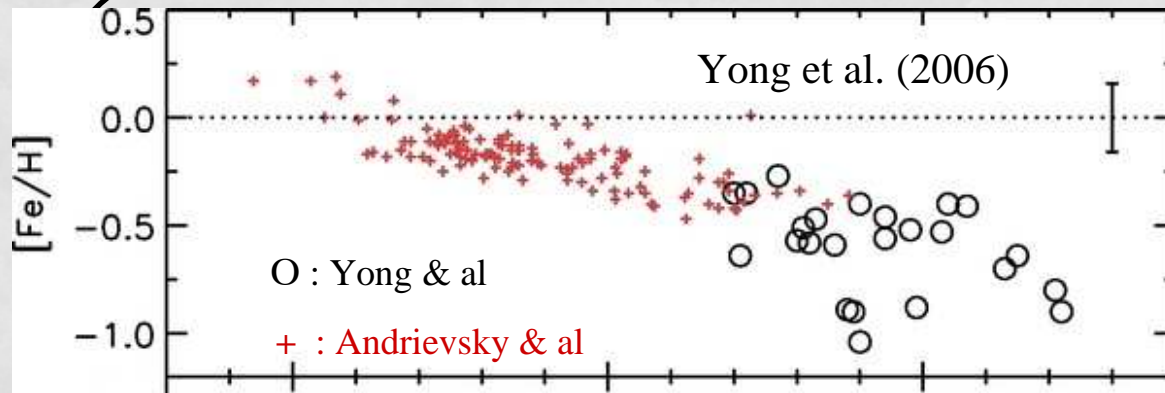
- Twarog et al. (1997) – Open clusters
- Andrievsky et al. (2004) - Cepheids
- Carraro et al. (2007) – Open clusters

› 2 levels :

- Yong et al. (2006) – Cepheids
- 1st level at ~ -0.5 dex, 2nd level at ~ -0.8 dex
- Accretion of metal-poor material in the outer disk ?
- Level at ~ -0.5 dex also reported by Yong et al. (2005); Carney et al. (2005) (Open clusters, red giants)



Current controversy : a flattening ?



➤ 2 levels : Galactocentric distance (kpc)

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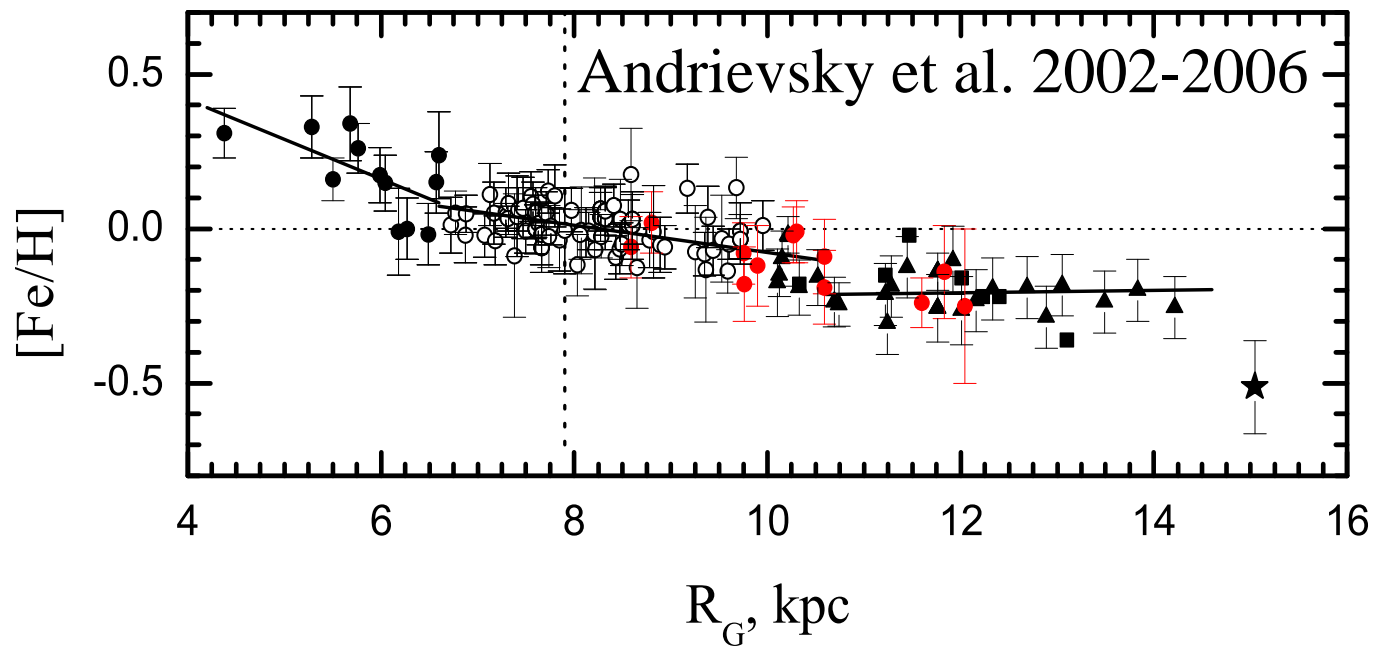
Current controversy : a discontinuity ?

Not a regular decrease

BUT

2 zones separated by an abrupt discontinuity of ~ 0.2 dex ?

- Suggested first by Twarog et al. (1997) from Open clusters
- Compatible with Cepheids abundances from Caputo et al. (2001)
- Supported by recent data from Cepheids :
Andrievsky, Luck et al. (2002-2006)



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New spectroscopic data

- 36 stars :
 - FEROS / 1,52m (2001) then 2,2 m (2007) ESO (La Silla, Chili)
 - R=48000, spectral range from ~350 nm to ~920 nm
- 27 stars :
 - ESPADONS / 3,6 m CFHT (Mauna Kea, Hawaii)
 - R=80000, spectral range from ~369 nm to ~1048 nm
 - 1 star reobserved with NARVAL / 2m TBL (Pic Du Midi, France)
- Abundances from literature, recalculated distances :
 - 115 stars from Andrievsky et al. (2002-2006), various spectrographs
 - 10 stars from Romaniello et al. (2008), FEROS

Abundances determination

- EW : Semi-interactive code (*fitline*), lines fitted by Gaussians
- Line Depth Ratios method (LDR) : Kovtyukh & Gorlova (2000)
 - 32 analytical relations using LDR of carefully selected lines
 - Rely only on spectroscopy, hence not affected by interstellar reddening
- Classical approach for the other atmospheric parameters :
 - $\log g$: ionization balance between Fe I and Fe II
 - V_t : abundances (per element) do not depend on line strength
- Atmosphere models : OSMARCS
 - Gustafsson et al. (1975); Edvardsson et al. (1993)
 - Parallel planes stratification, Hydrostatic equilibrium, LTE
- Accuracy ~ 0.12 dex for iron

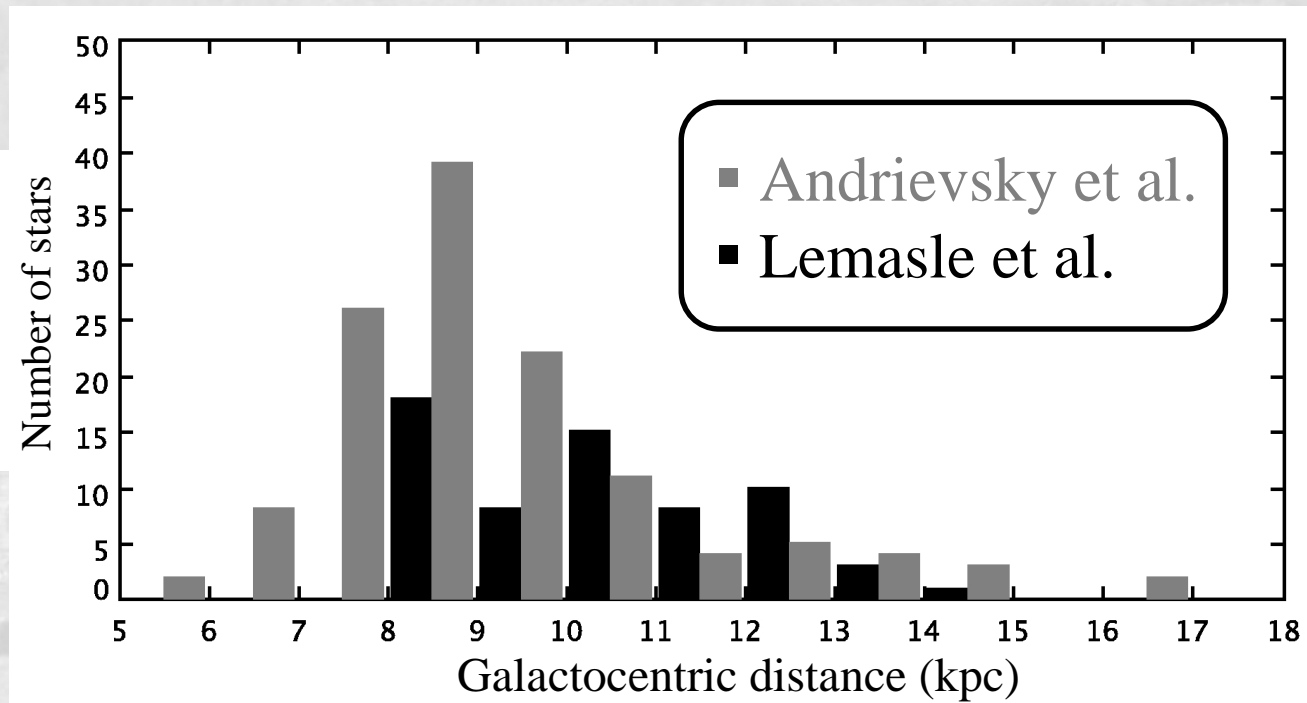
Individual abundances : results

- **Iron abundances for the whole sample (63 stars)**
- Abundances of other elements for a sub-sample
(Work in progress, not published yet)
- Very good agreement with Andrievsky et al. abundances
(Numerous papers between 2002 and 2006)
Differences ≤ 0.1 dex except for 6 stars ≈ 0.3 dex
- Only 3 stars in common with Yong et al. (2006)
 - Discrepancies : 0.31 dex, 0.27 dex, 0.12 dex (YZ Aur, WW Mon, HW Pup)
 - Origin ? Only 3 stars in common \Rightarrow no firm conclusion

Distances determination

- **Based on near-infrared photometry** : J , H , K bands
 - SAAO data (Courtesy of D. Laney)
 - 2MASS data
- Correction for interstellar reddening : Cardelli et al. (1989)
- $E(B-V)$: Fernie et al. (1995)
except if $E(B-V)$ from Laney & Caldwell (2007) available (metallicity effects)
- Period-Luminosity relations : Persson et al. (2004)
- Periods from GCVS : Samus et al. (2004)
except if period changes are reported in the literature

Radial distribution of the sample



Improvement of the sampling in the outer disk,
in particular between 10 and 13 kpc

Longitudinal distribution of the sample

Polar plot

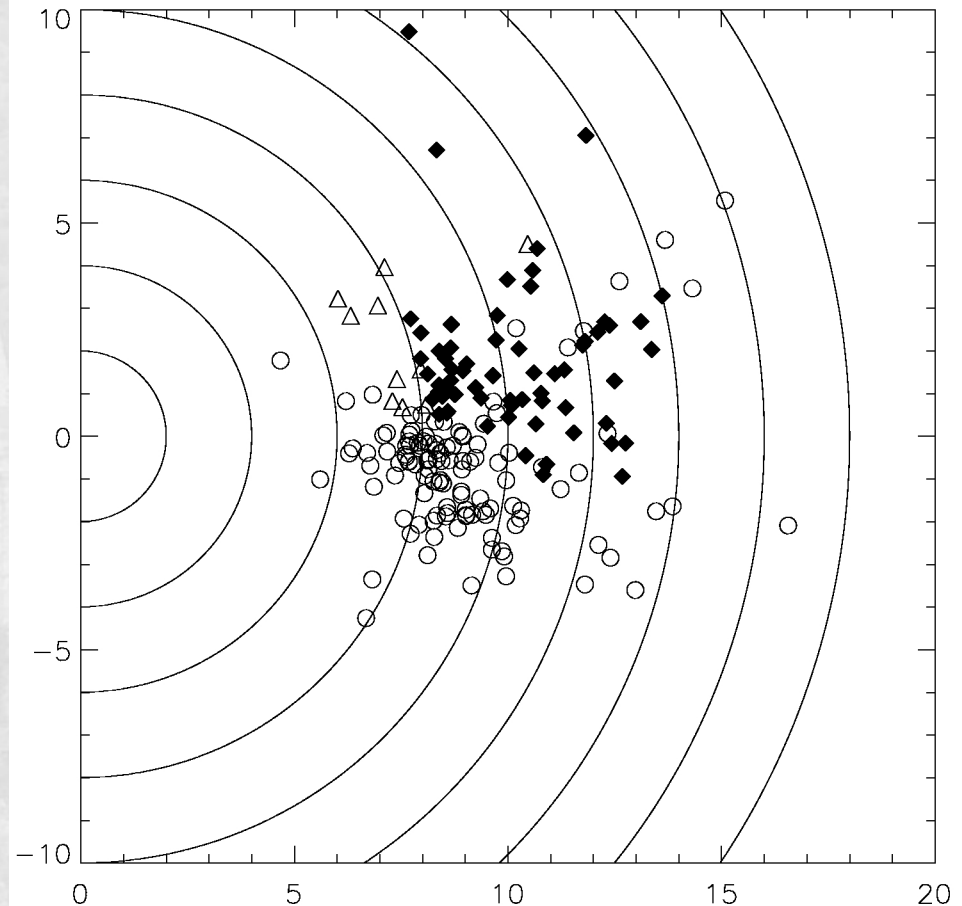
Circles every 2 kpc

Galactocentric distances
labelled on the axes

◆ Lemasle & al

△ Romaniello & al

○ Andrievsky & al



Galactic coordinates (l,b) not convenient

⇒ Galactocentric longitude

Longitudinal distribution of the sample

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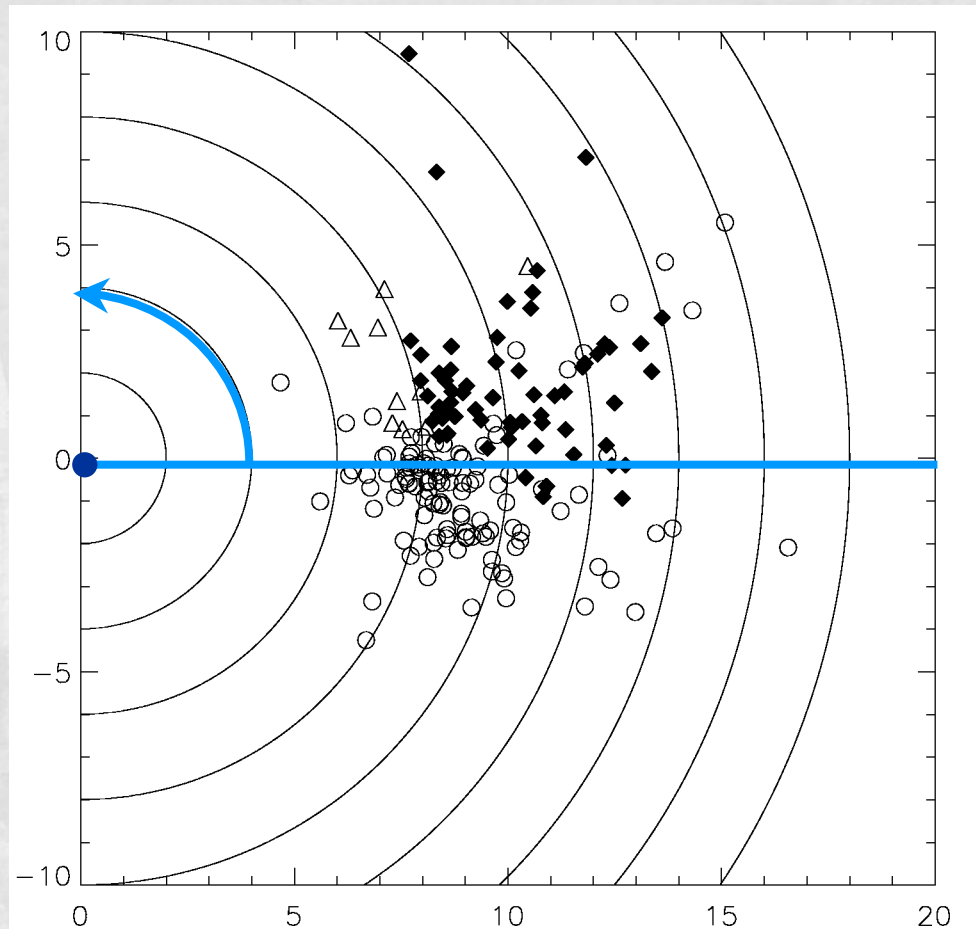
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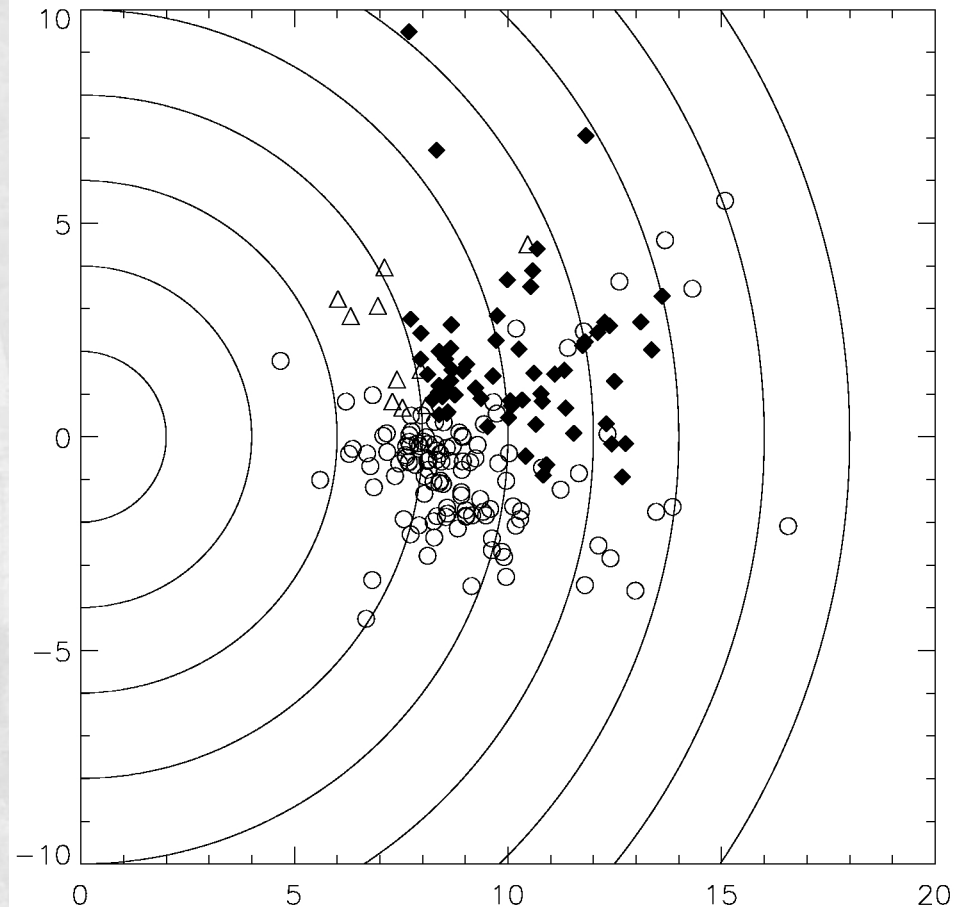
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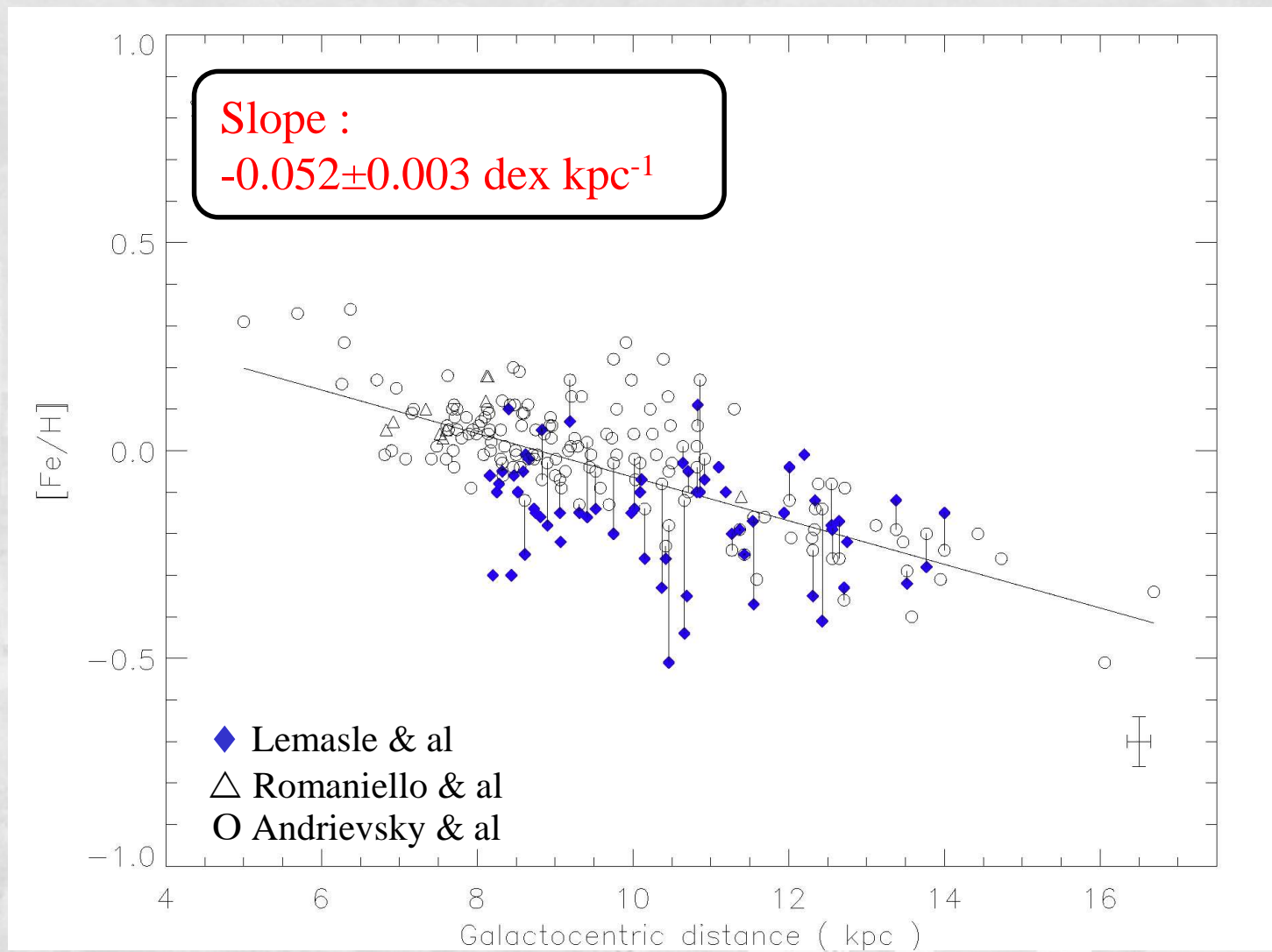
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Galactic coordinates (l,b) not convenient

⇒ Galactocentric longitude

Result : the slope



Result : a flattening of the gradient

Slope of the gradient

Beyond 10 kpc :

$-0.012 \pm 0.014 \text{ dex kpc}^{-1}$

Andrievsky et al. (2004) :

$+0.004 \pm 0.011 \text{ dex kpc}^{-1}$

Carraro et al. (2007) :

$-0.018 \pm 0.02 \text{ dex kpc}^{-1}$

Mean abundances

$\langle [\text{Fe}/\text{H}] \rangle = -0.19 \pm 0.14 \text{ dex}$

Andrievsky et al. (2004) :

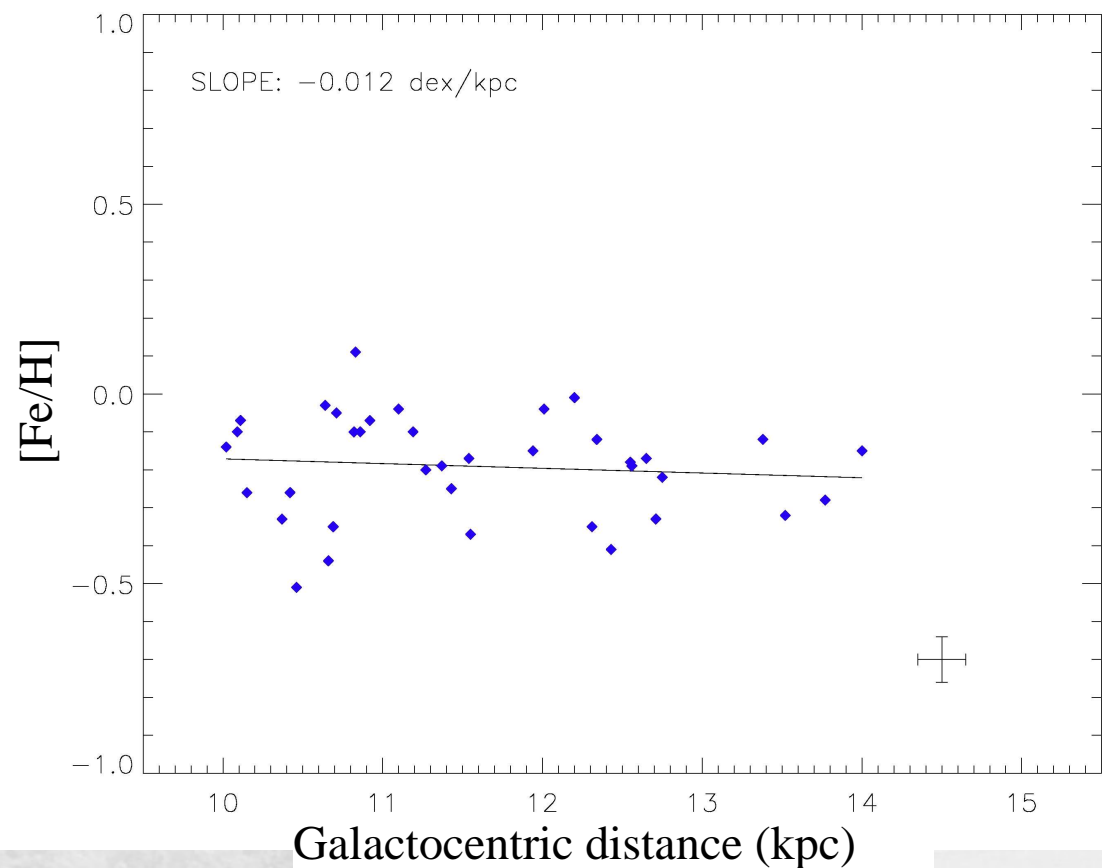
$-0.209 \pm 0.058 \text{ dex}$

Carraro et al. (2007) :

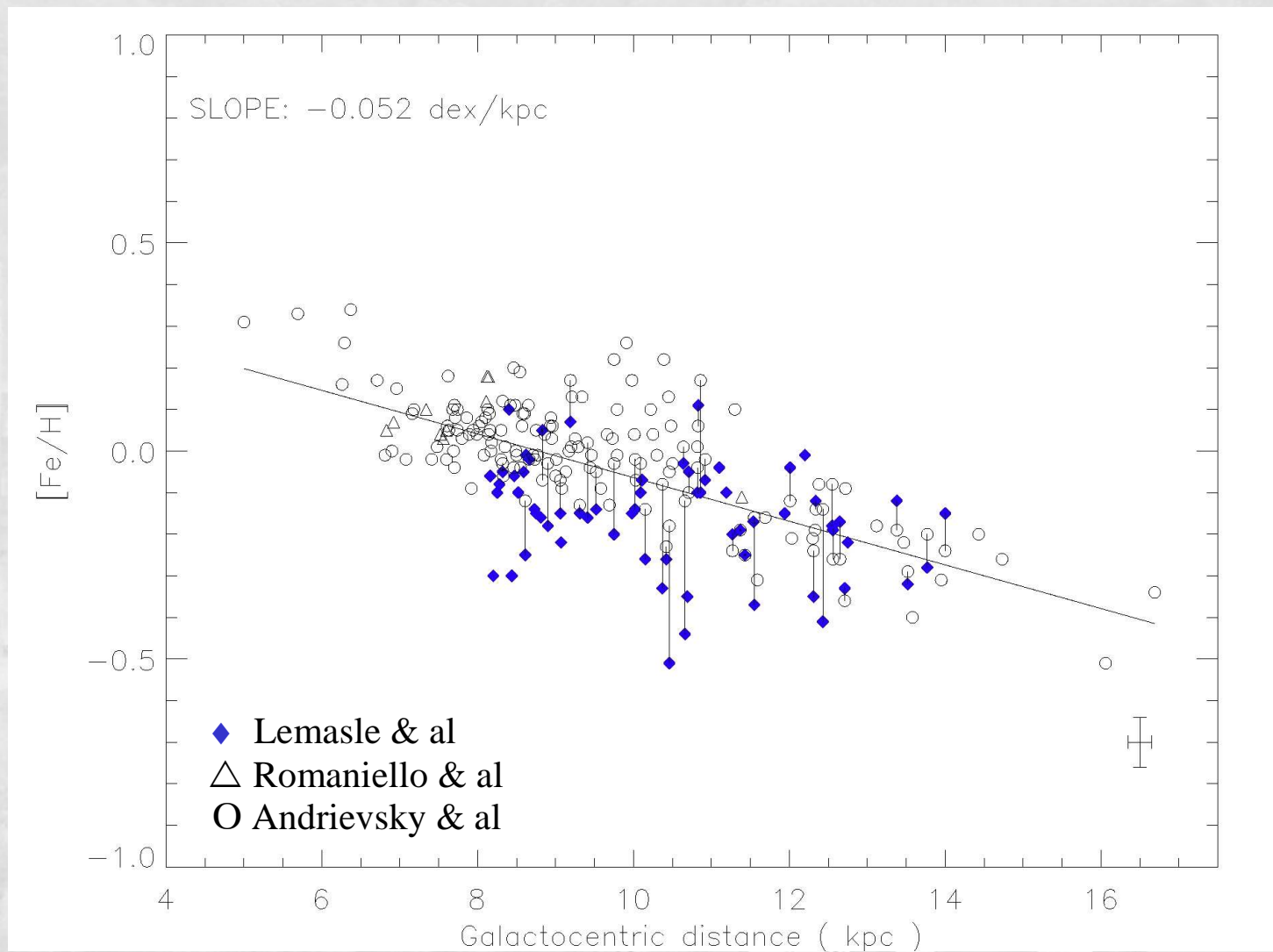
$-0.34 \pm 0.15 \text{ dex}$

Twarog et al. (1997)

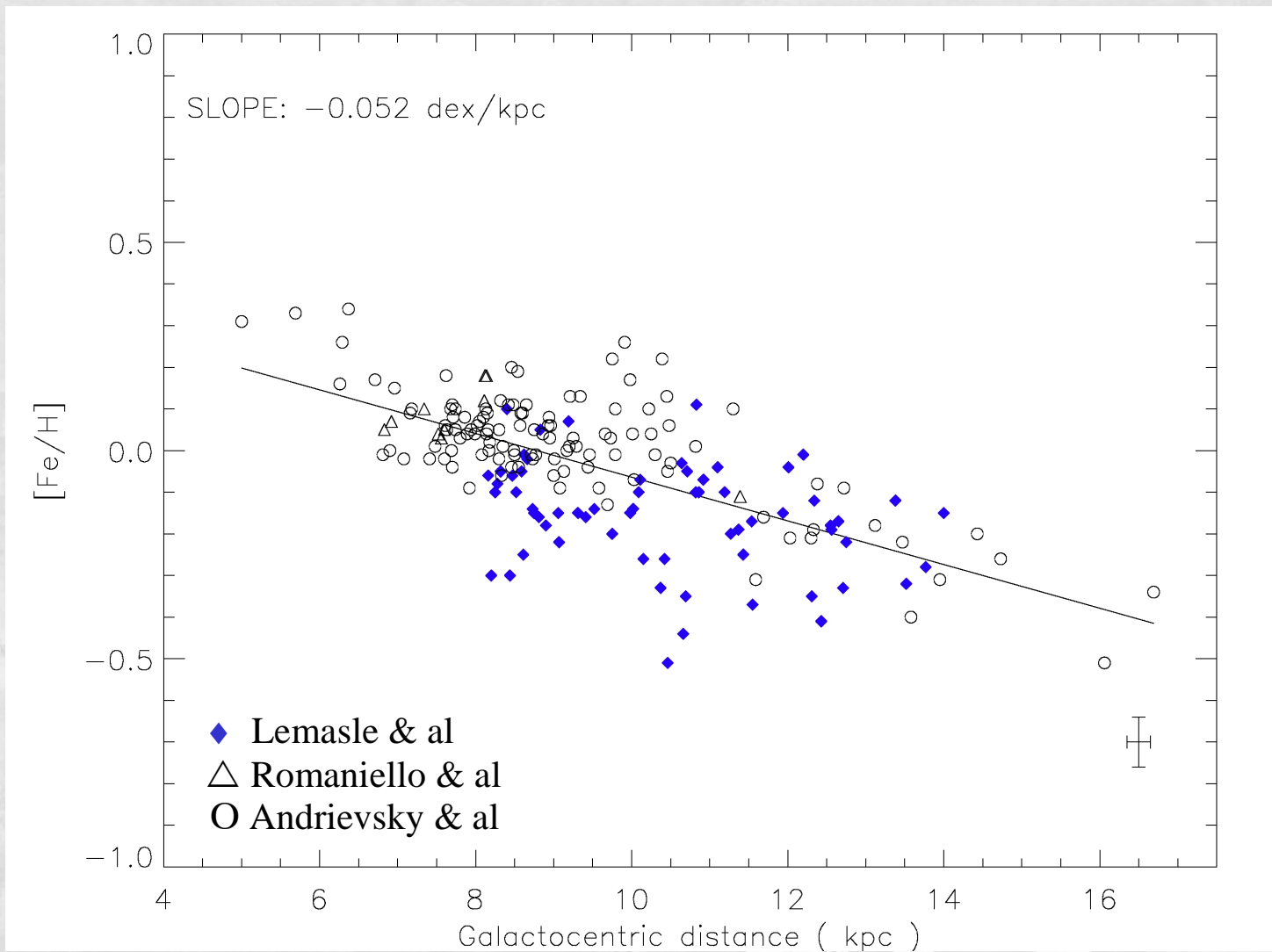
$\approx -0.3 \text{ dex}$



Result : no discontinuity around 10 kpc



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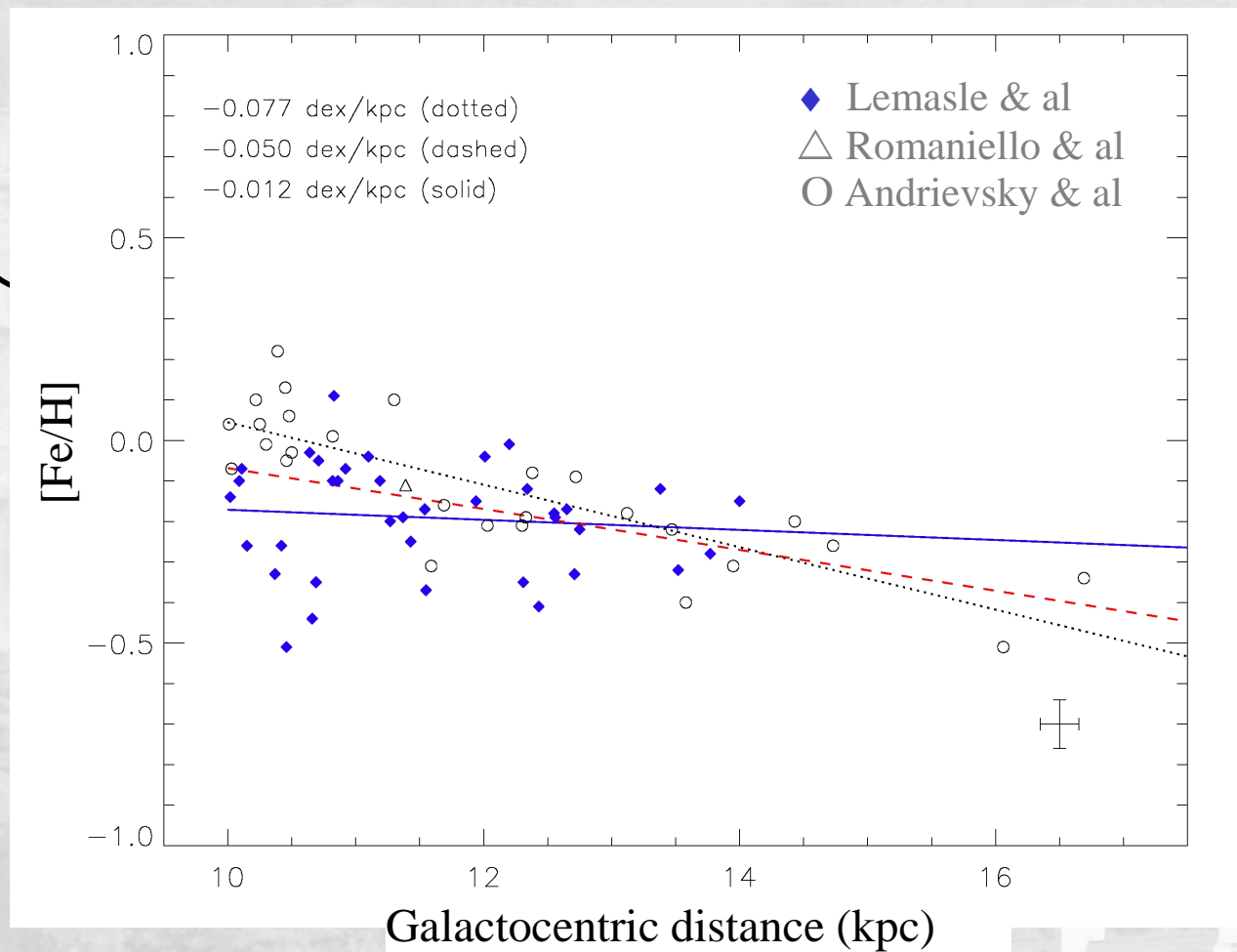
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Results strongly affected by undersampling

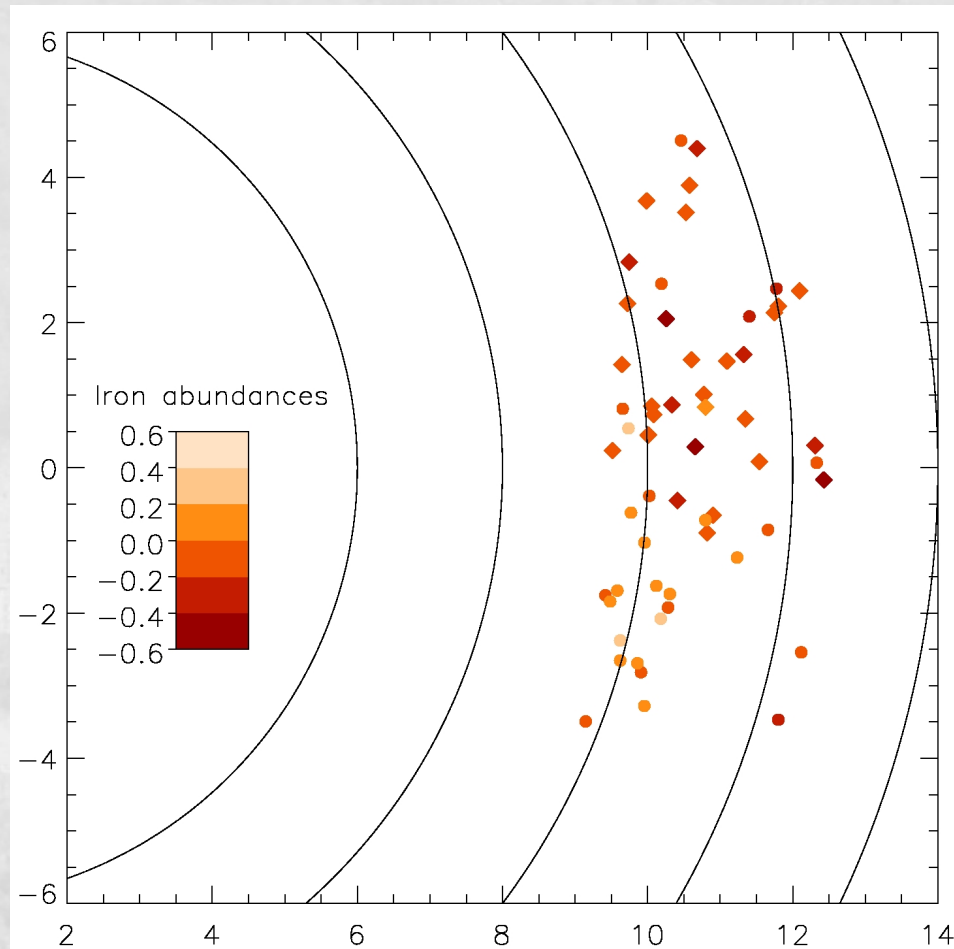
- Only a few Cepheids known
- Abundance determination more difficult
(need of a high S/N)

Result : no discontinuity around 10 kpc

Results strongly affected by undersampling



Result : strong dispersion at $\approx 10-12$ kpc



\nearrow dispersion at $\approx 10-12$ kpc

1 group : high metallicities
(+0.0 – +0.2 dex)

$l \approx 120^\circ$

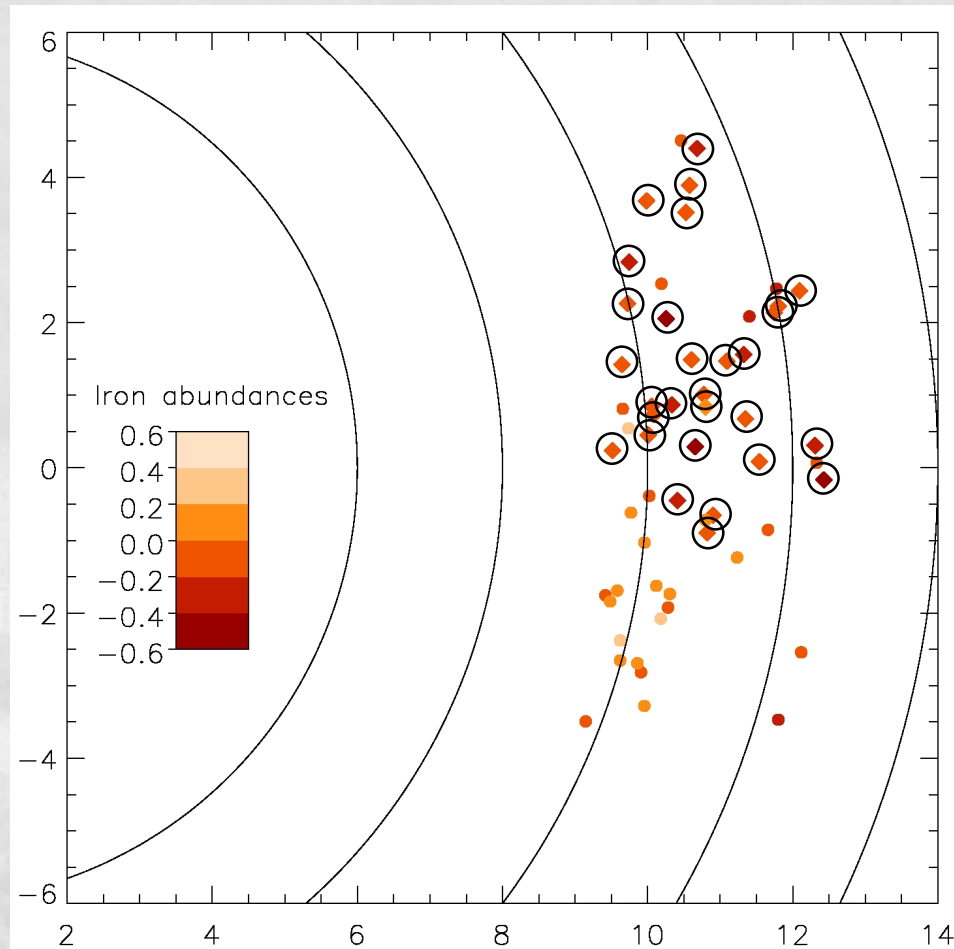
1 group : low metallicities
(-0.2 – -0.4 dex)

$180^\circ < l < 220^\circ$

Dispersion reaches 0.8 dex
(accuracy ~ 0.12 dex)

Metallicity strongly dependent on Galactocentric longitude

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\nearrow dispersion at $\approx 10-12$ kpc

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Summary

- Spectroscopic analysis of 63 Cepheids
- Accurate distances (near-IR photometry) for 188 Cepheids
- Slope of -0.052 ± 0.003 dex kpc⁻¹
- Flattening gradient in the outer disk
 -0.012 ± 0.014 dex kpc⁻¹
 $\langle [\text{Fe}/\text{H}] \rangle = -0.19 \pm 0.14$ dex
- No discontinuity in the gradient
- Gradient depends on longitude

Abundance gradient, Cepheids & GAIA

- Cepheids :

- Discovery of new Cepheids
- Pulsation mode
- Interstellar reddening
- Period change
- Influence of binarity
- Calibration of the P-L relation from astrometry
- Metallicity dependence of the P-L ?

- The Milky Way :

- Metallicity distribution as a function of the position in the disk, both from photometry & spectroscopy
- Dynamics & evolution
- Identification of structures
- Role of mergers

