Expected Gaia contribution to stellar and Galactic evolution studies:

the role of C, N, O and α-process elements

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Stellar evolution:

1957 –thermonuclear reactions in stars explained

1965 1st dredge-up

1973 extra-mixing

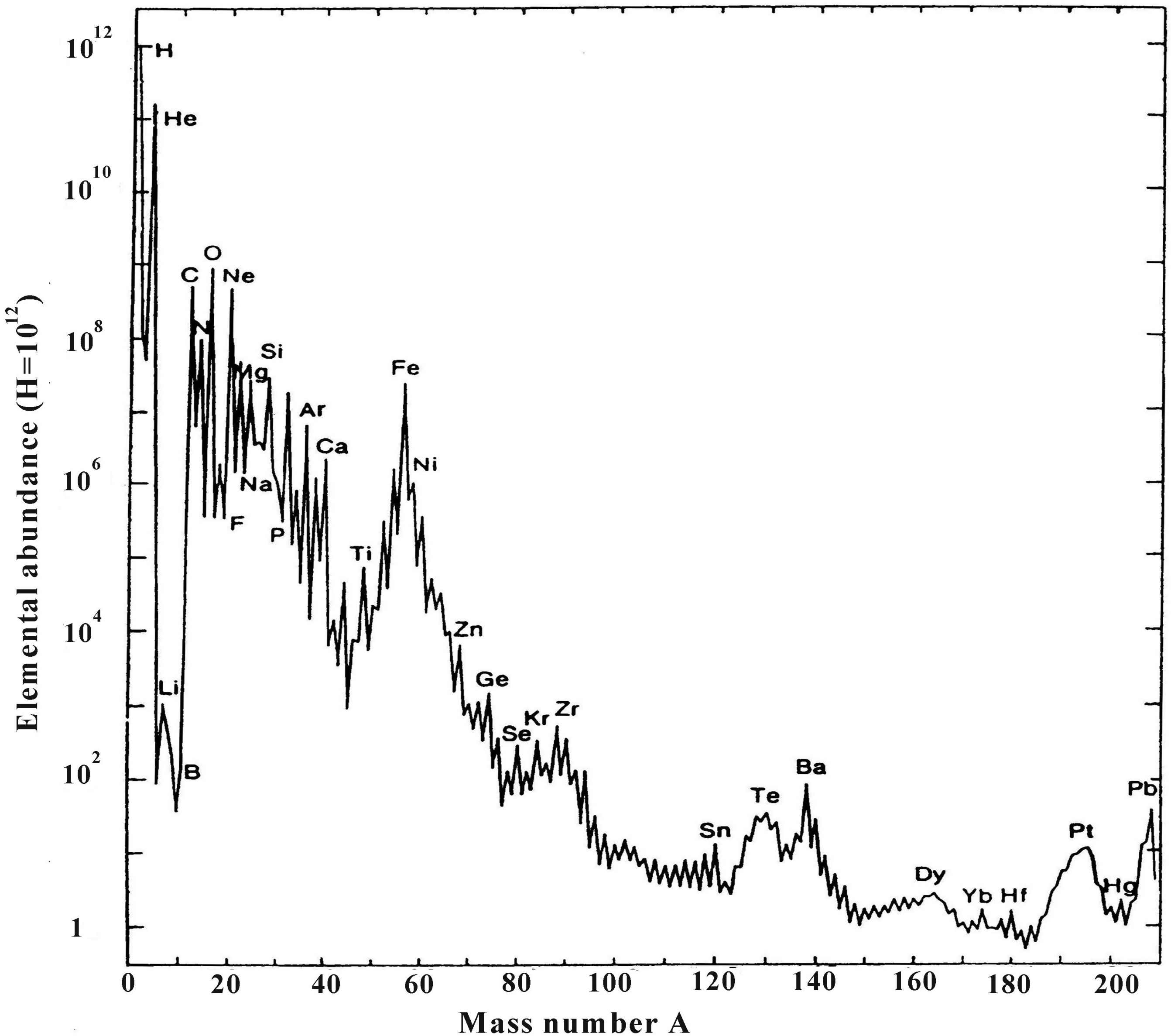
Galactic evolution:

1983 thick-disk

Radial abundance gradients

Kinematic groups

Solar composition



Standard Solar composition

$A_C = 8.52$

$A_N = 7.92$

$A_O = 8.83$

C/N = 3.98

$^{12}C/^{13}C = 90$

1-st dredge-up

Iben (1965)

C decrease 30 %

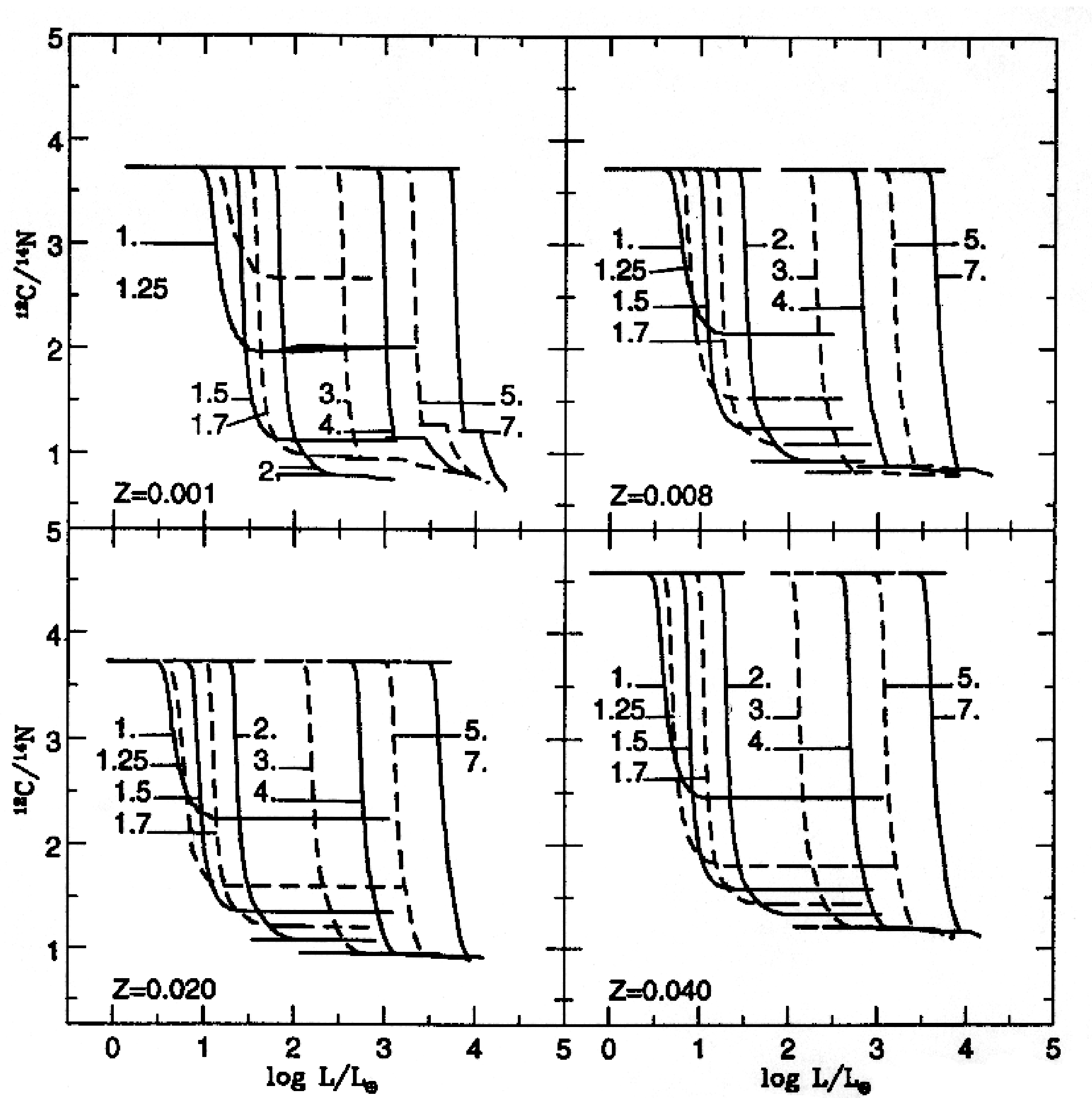
N increase 80 %

O unaltered

C/N ≈ 2.0

$^{12}C/^{13}C \approx 20 - 30$

Charbonnel, 1994, A&Ap, 282, 811



Charbonnel 1994, A&Ap, 282, 811

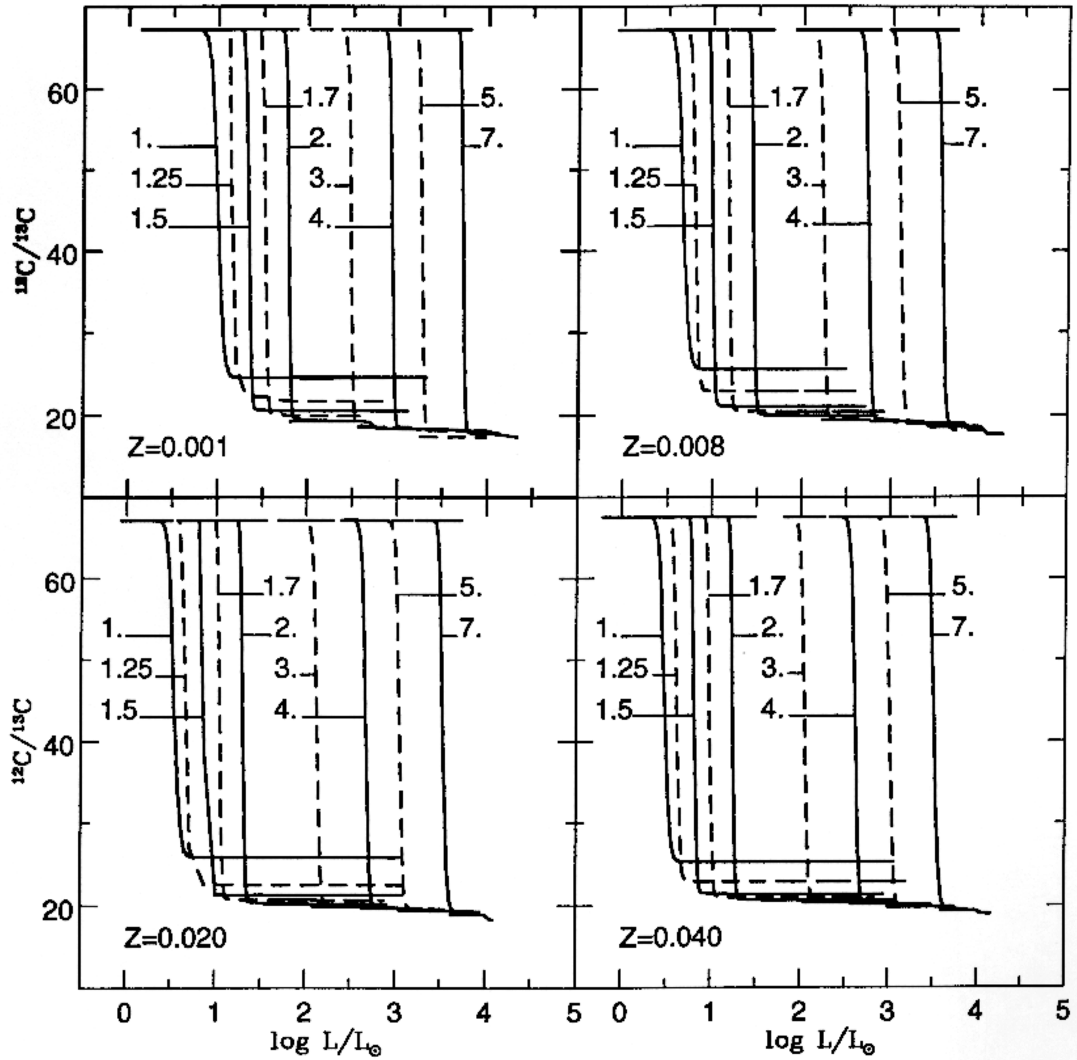


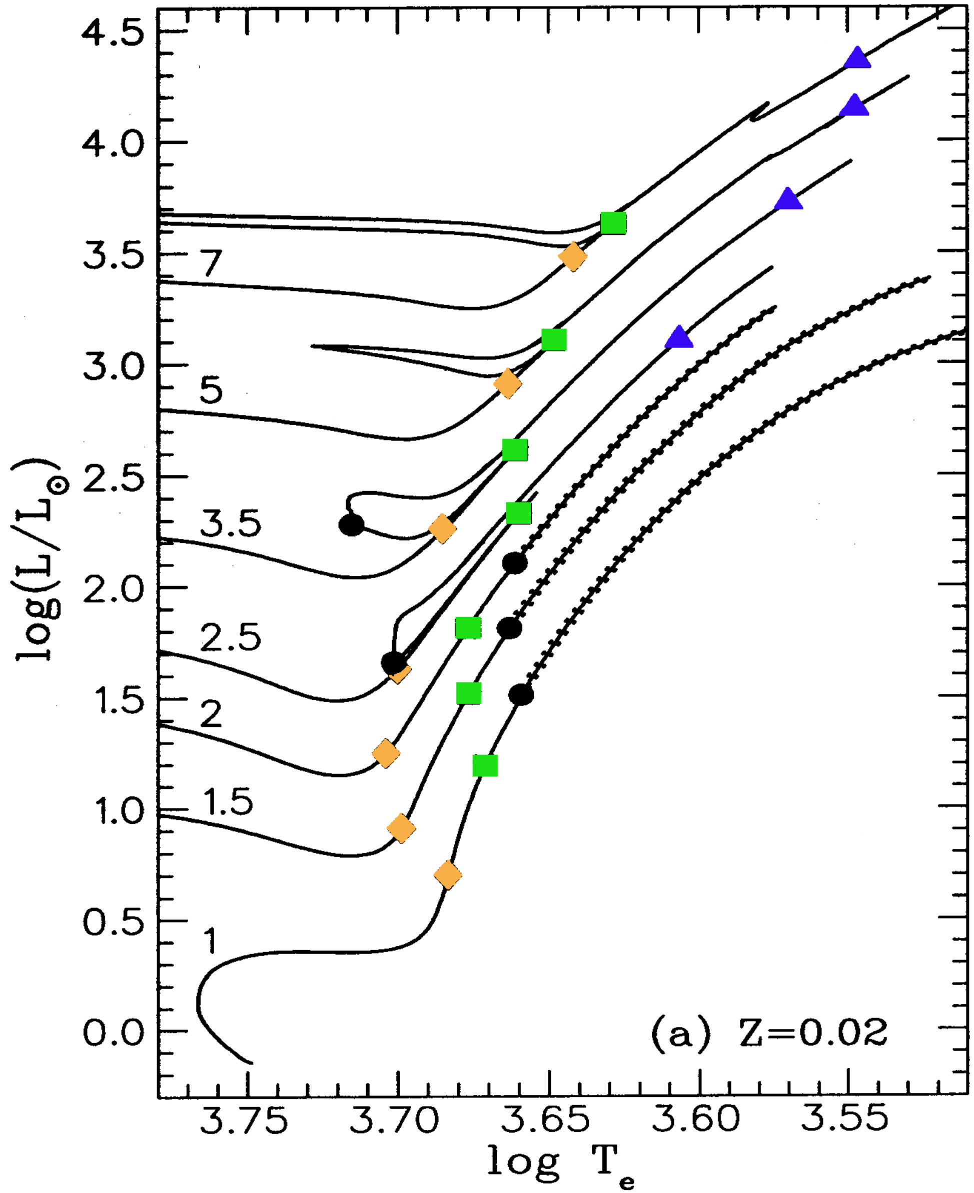
Fig. 2. Evolution of $^{12}C/^{13}C$ (number fraction) as a function of luminosity for stellar masses between 1 and 7 $M_{\odot}$ for different values of the metallicity Z

Boothroyd & Sackman 1999, ApJ, 510, 232

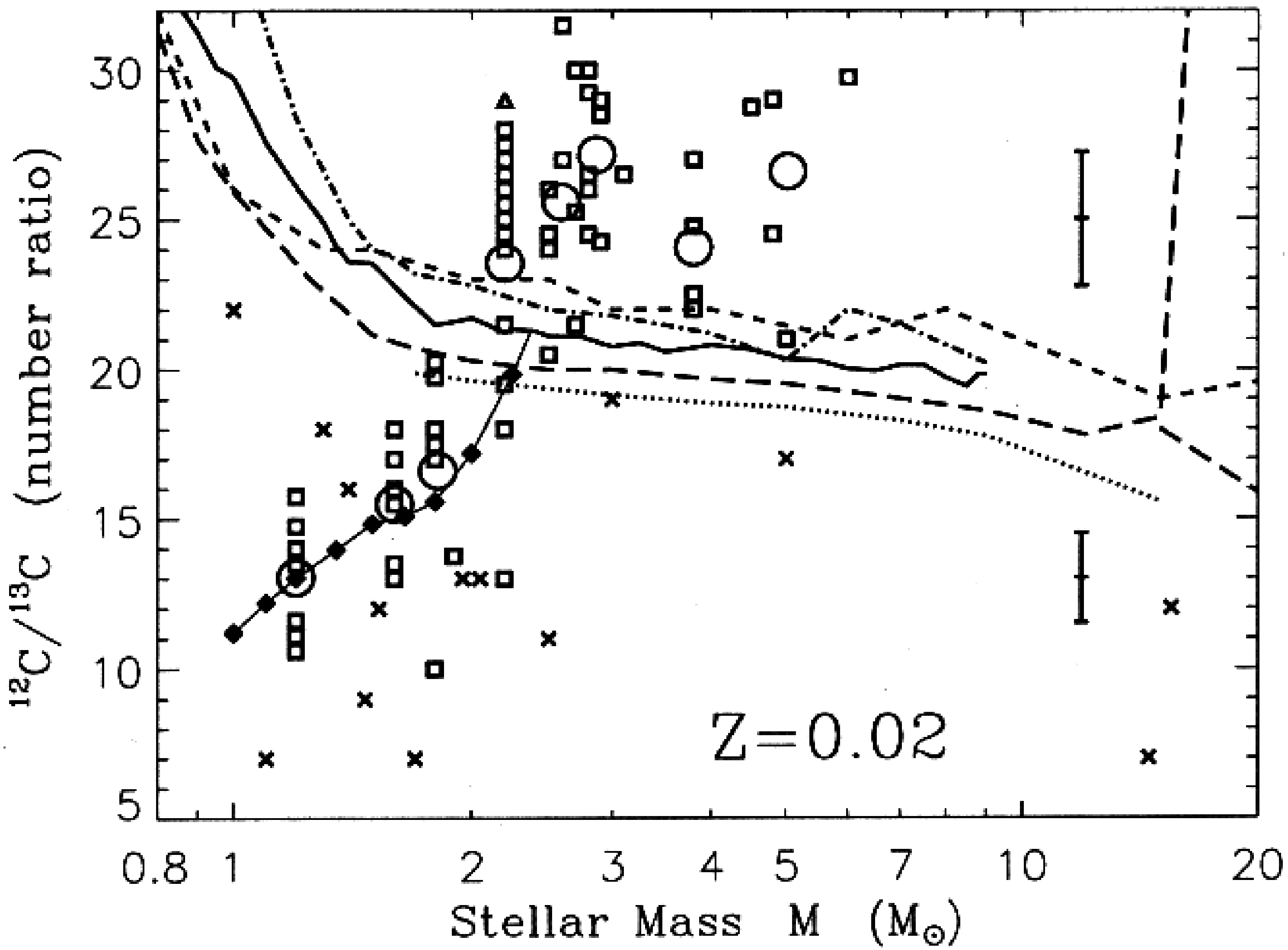
First discrepancies from the standard theory came when :

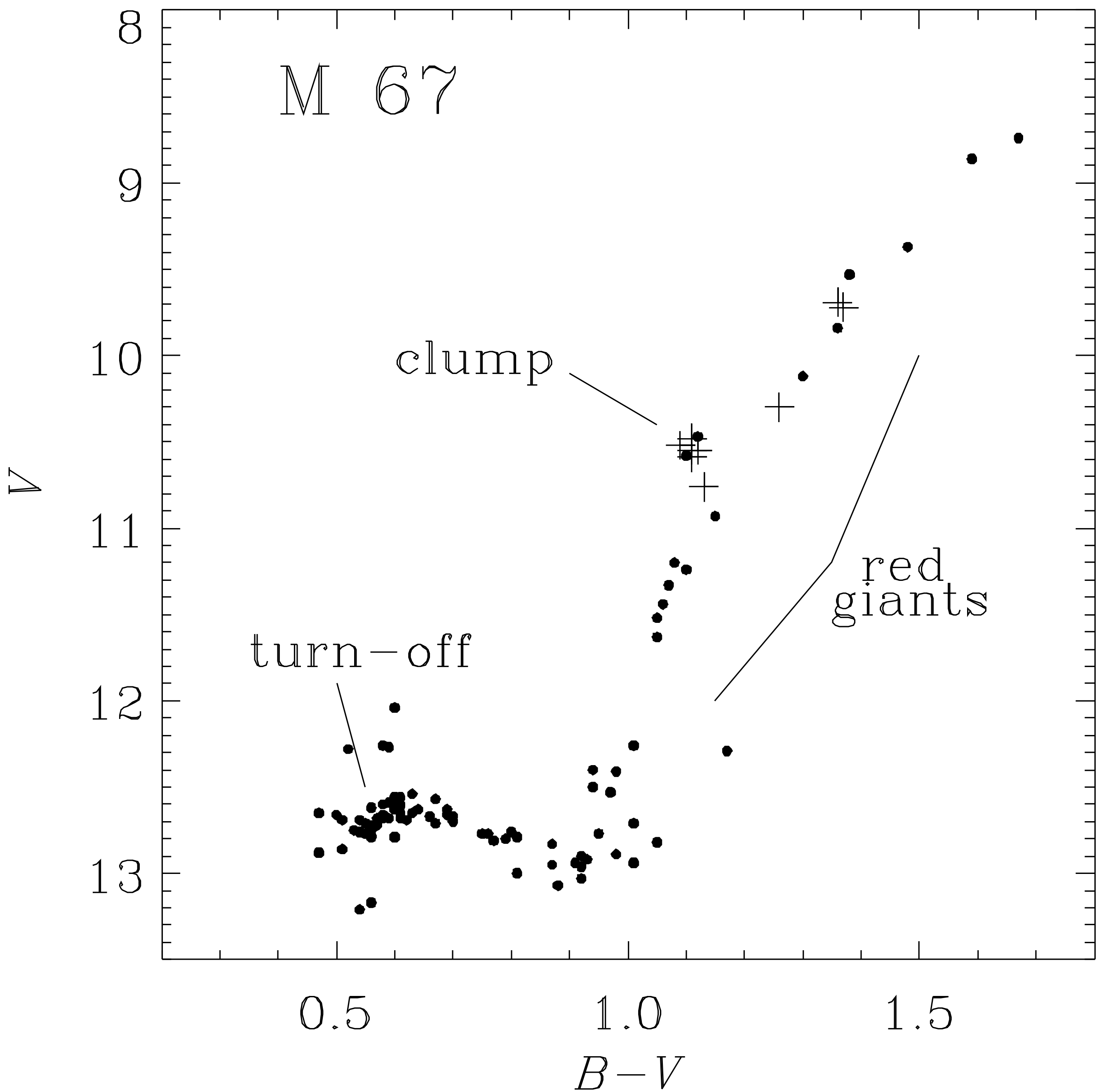
- Arcturus was found to have $^{12}C/^{13}C = 7.2 \pm 1.5$ (Day et al., **1973**)

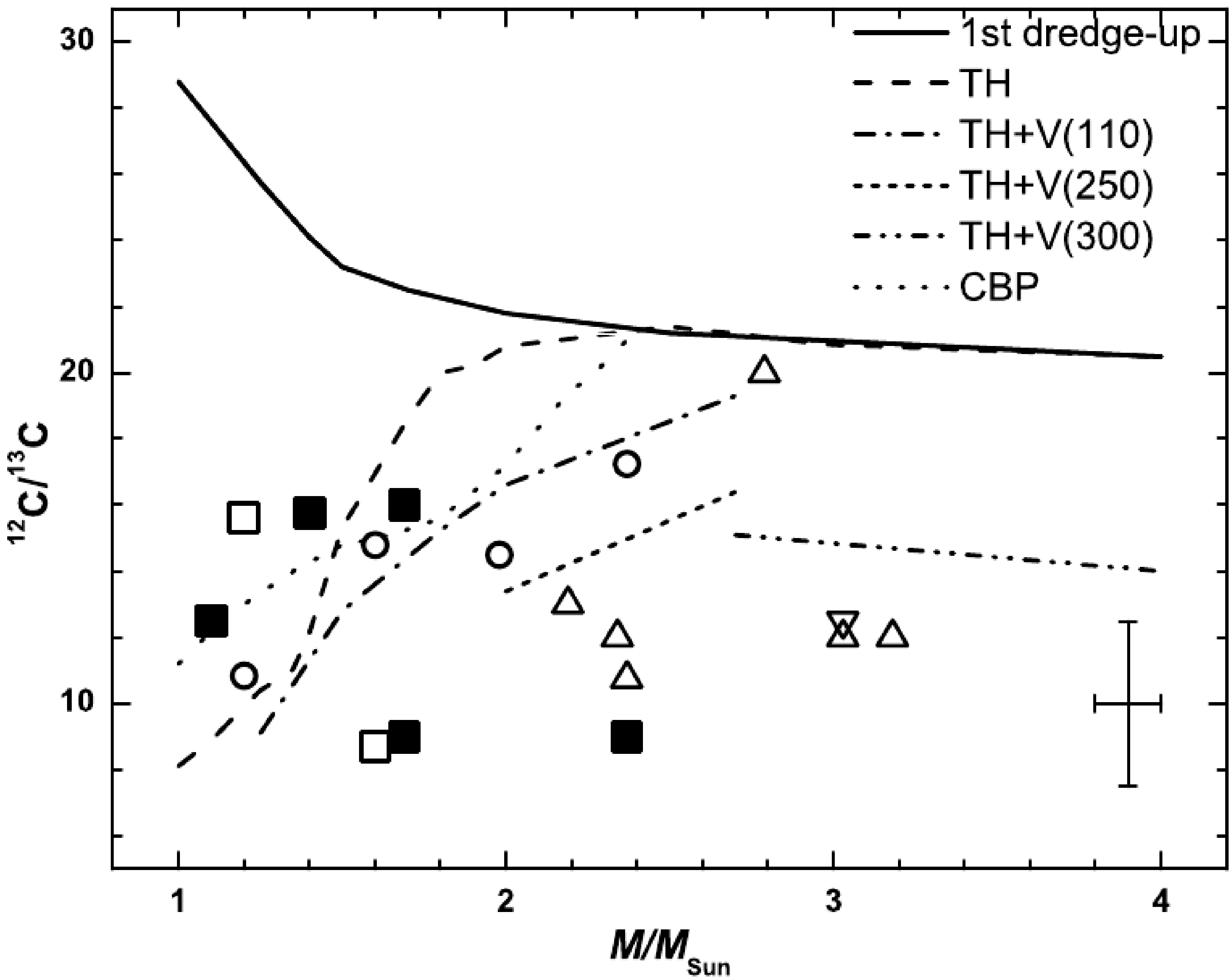
- The enhancement of CN bands was reported for the clump stars in M 67 (Pagel, **1974**)



Boothroyd & Sackmann 1999, ApJ, 510,232

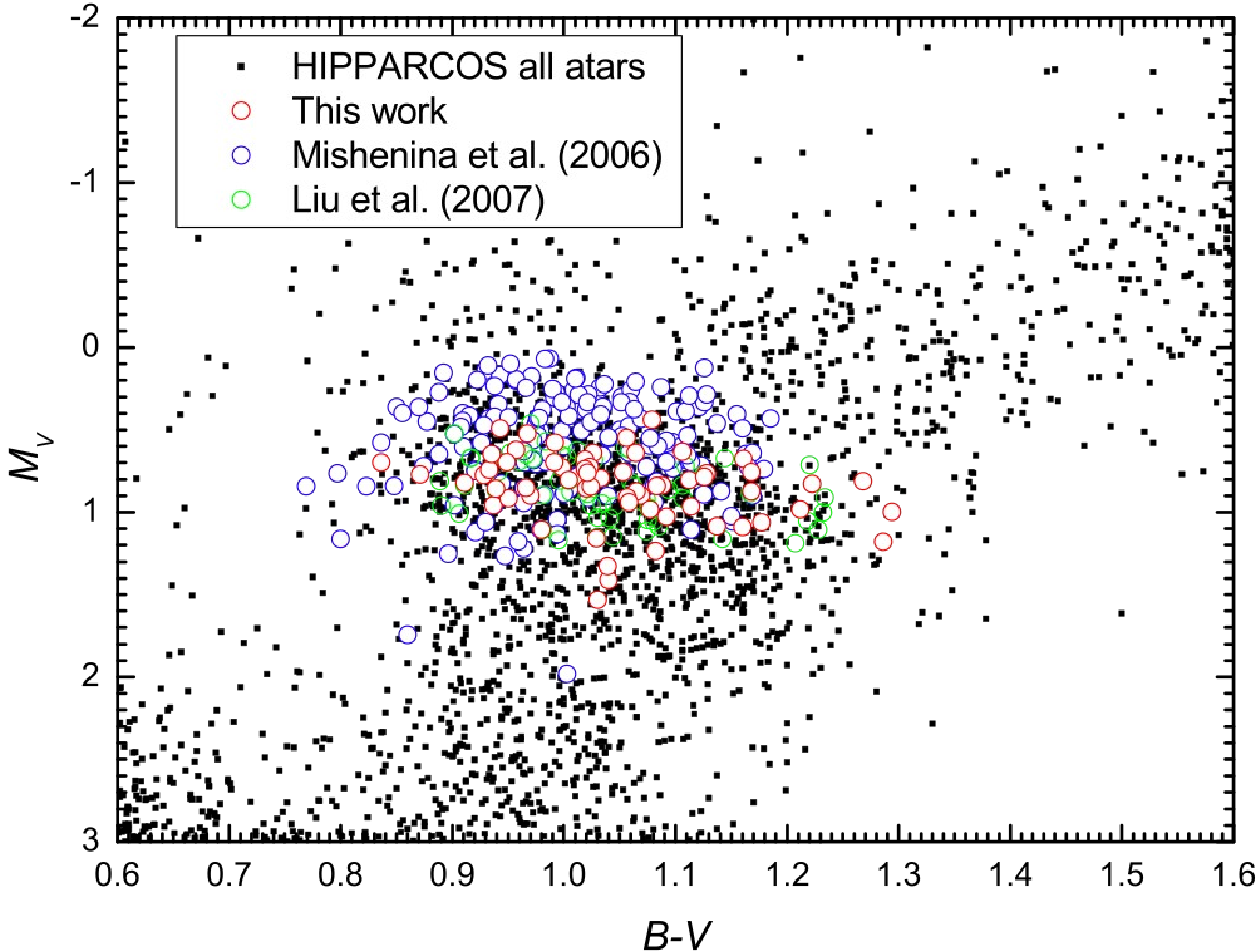


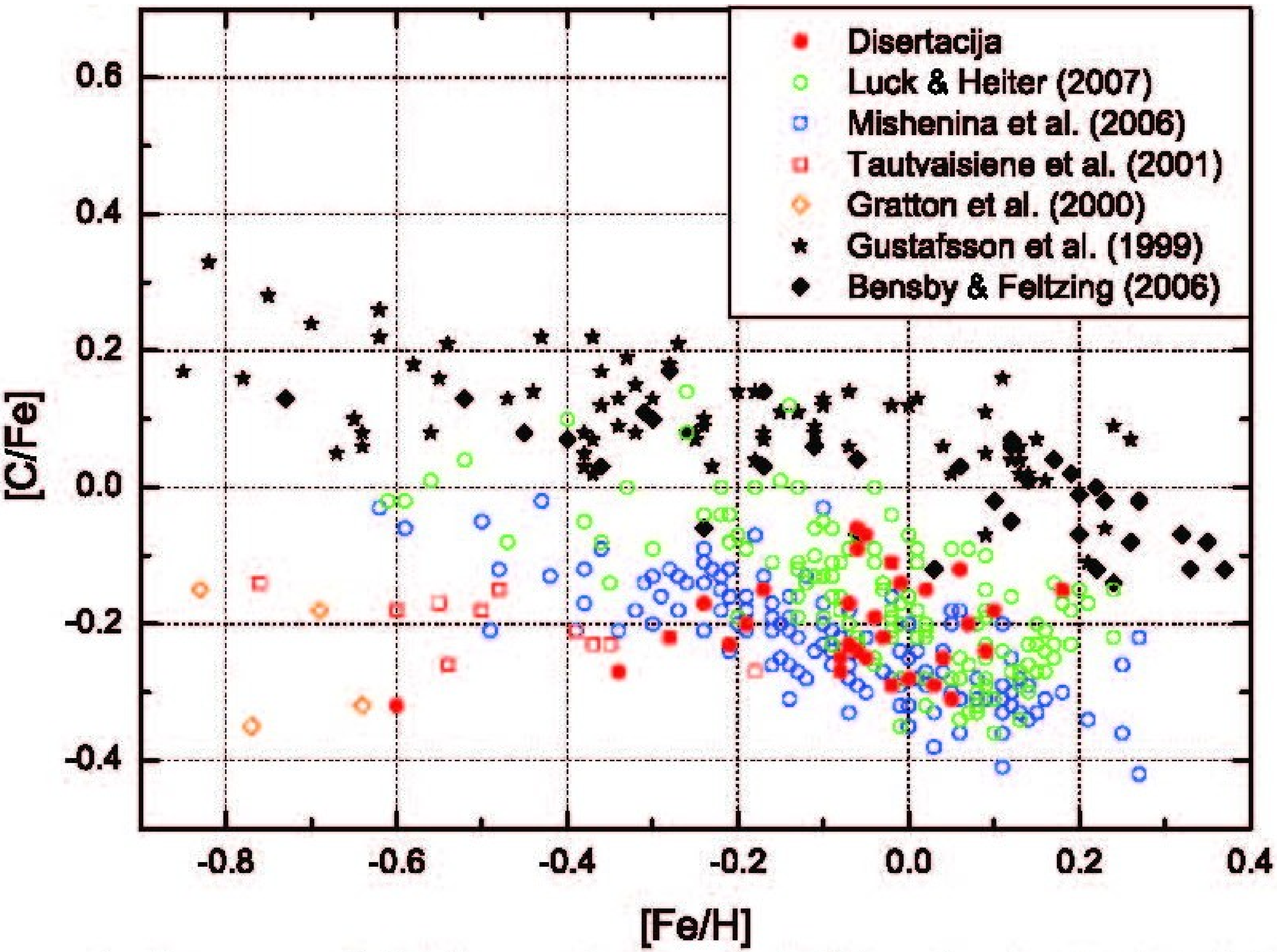

M 67
clump
red giants
turn-off
V
B−V
8
9
10
11
12
13
0.5
1.0
1.5

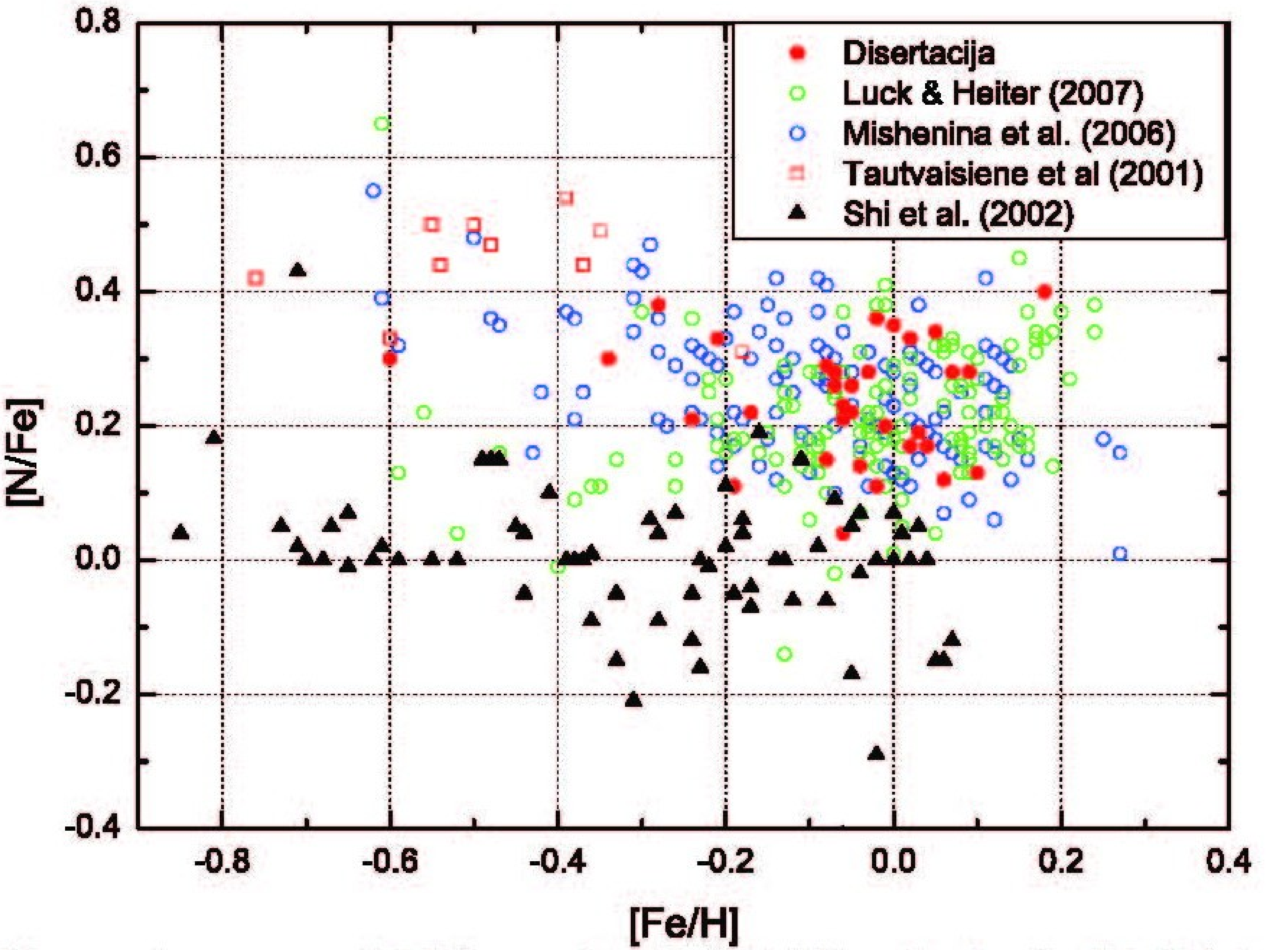


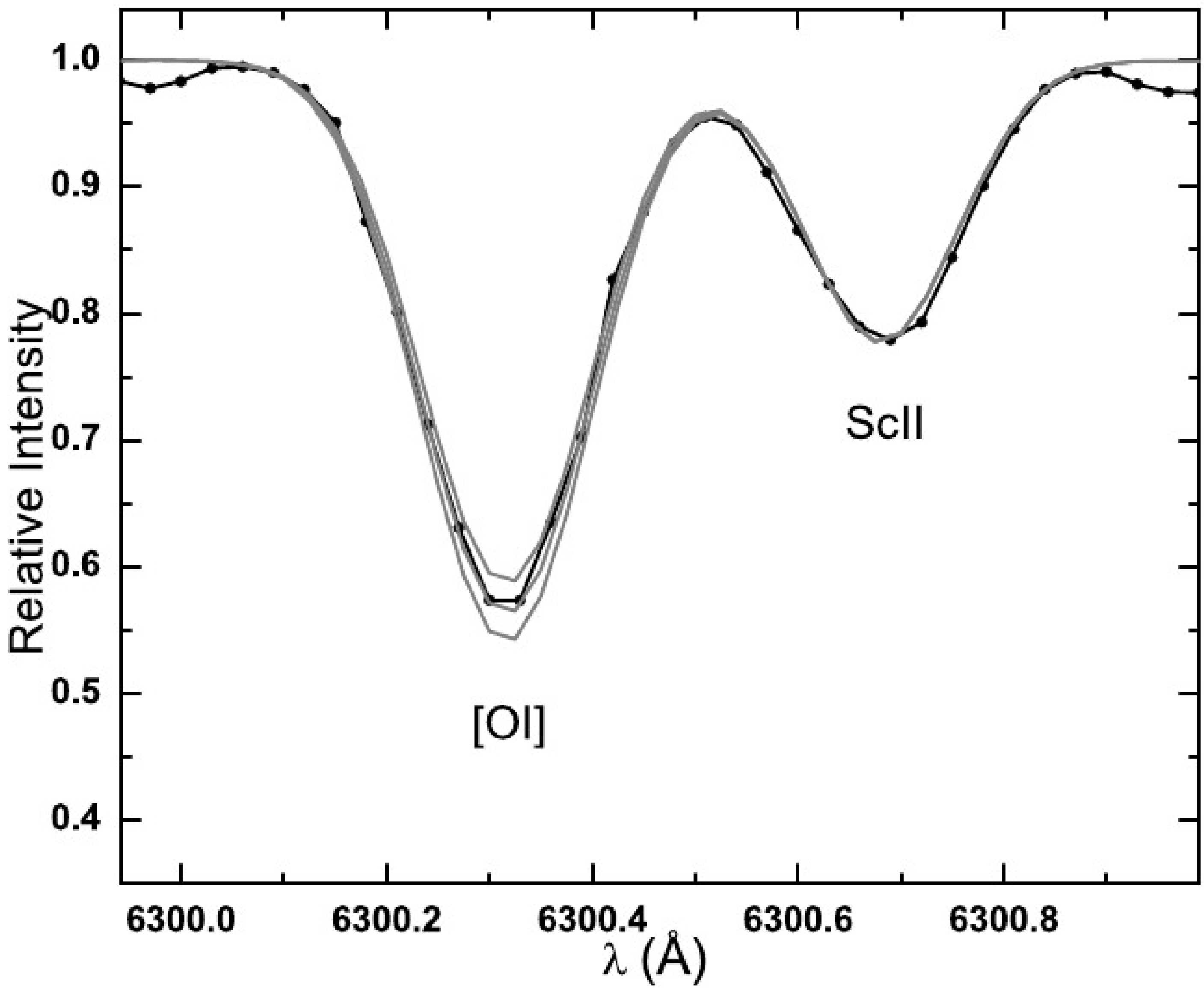
1st dredge-up
TH
TH+V(110)
TH+V(250)
TH+V(300)
CBP
30
20
10
1
2
3
4
$^{12}C/^{13}C$
M/M_{Sun}

Field red clump giants

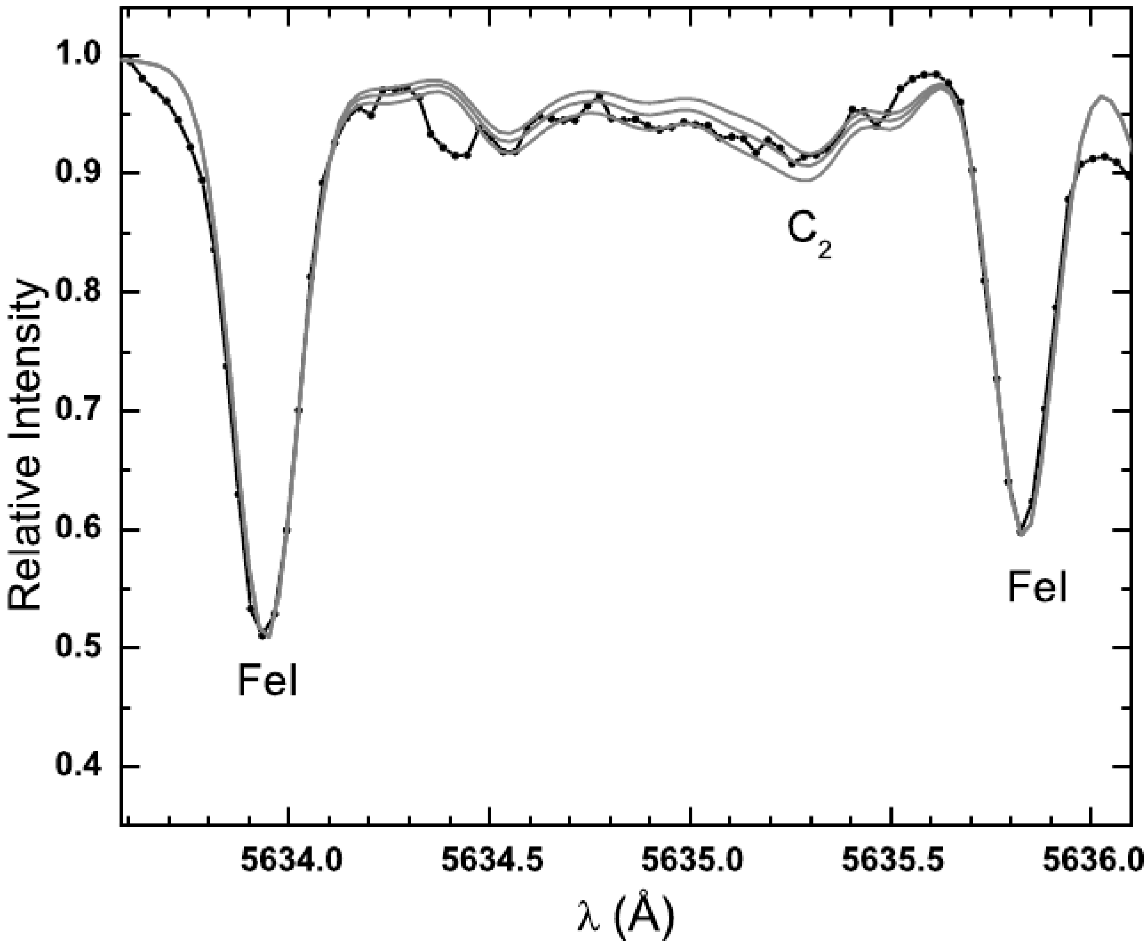



Disertacija
Luck & Heiter (2007)
Mishenina et al. (2006)
Tautvaisiene et al. (2001)
Gratton et al. (2000)
Gustafsson et al. (1999)
Bensby & Feltzing (2006)
[C/Fe]
[Fe/H]
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4

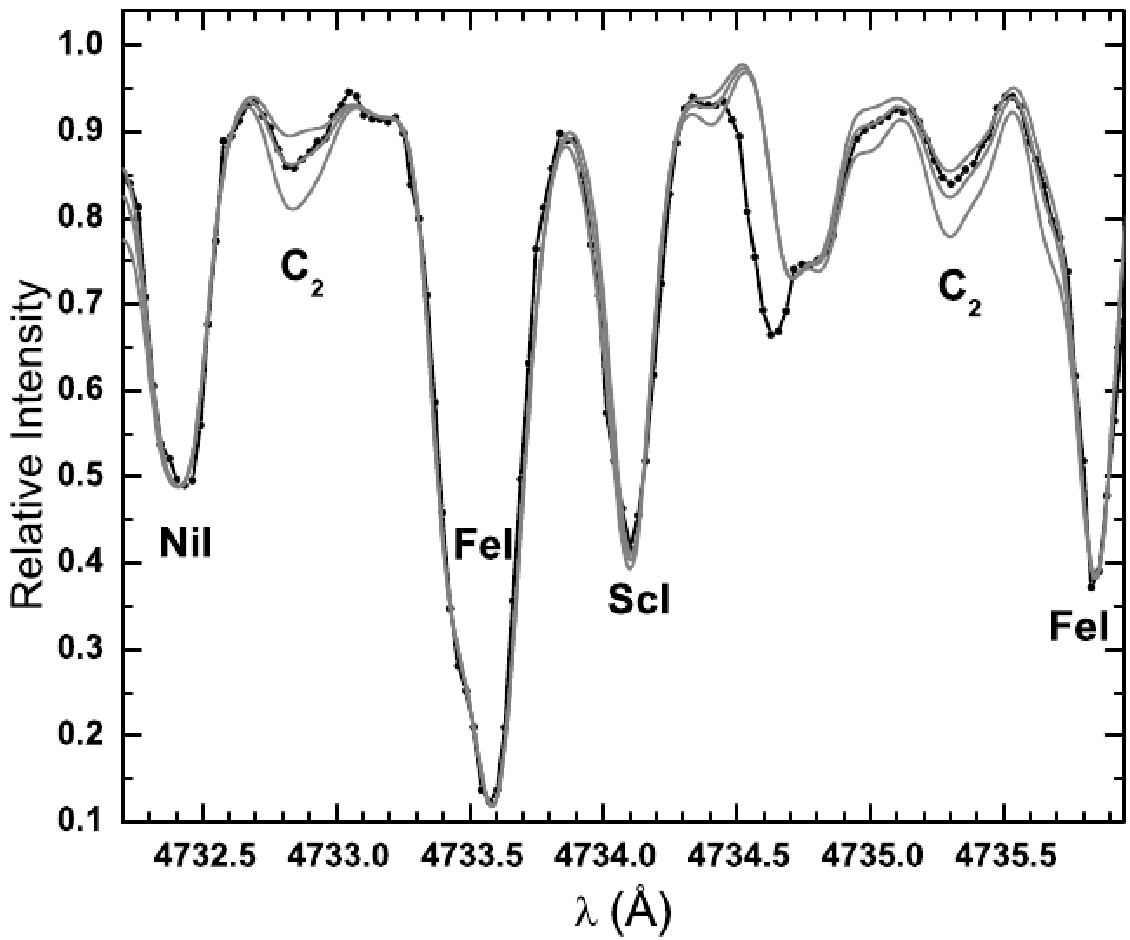

Disertacija
Luck & Heiter (2007)
Mishenina et al. (2006)
Tautvaisiene et al (2001)
Shi et al. (2002)
[N/Fe]
[Fe/H]
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4



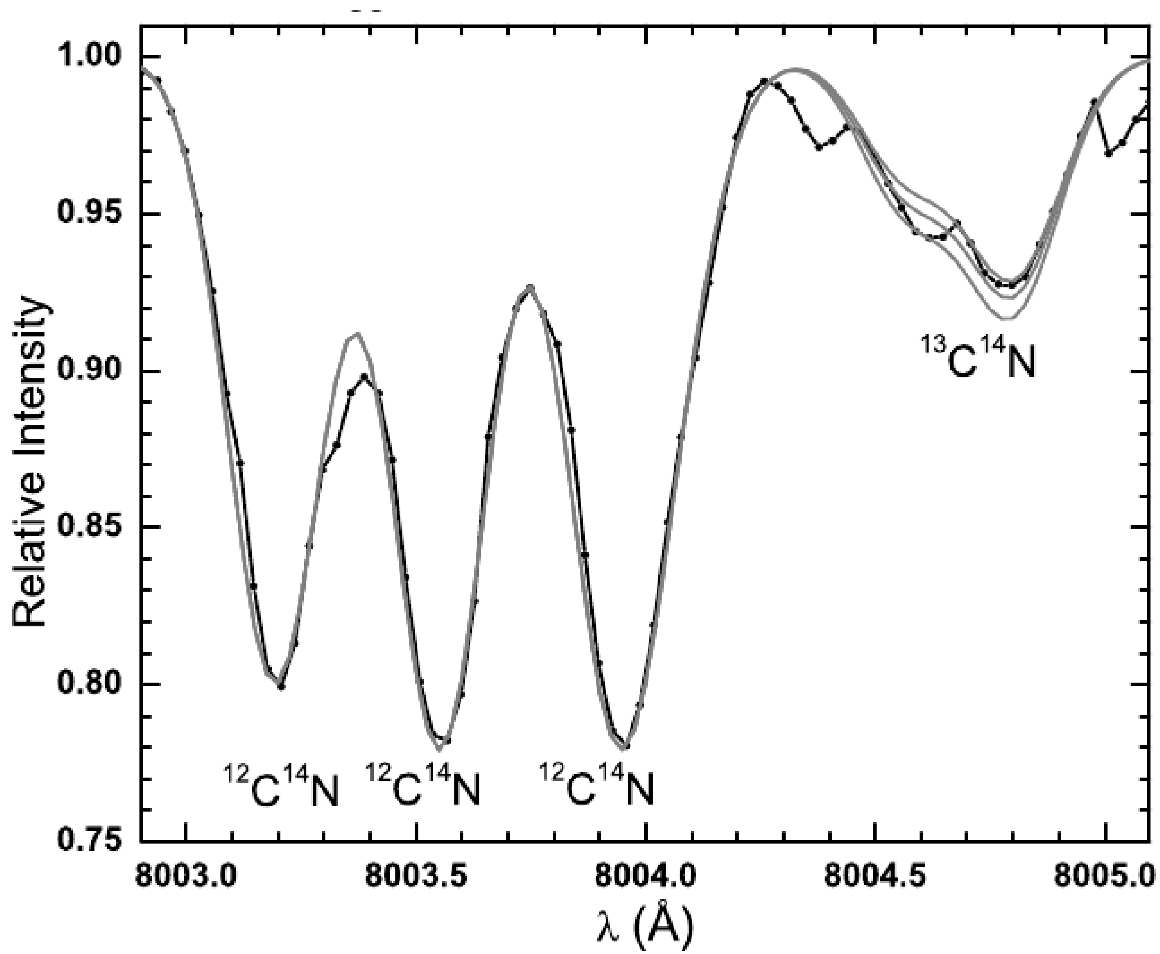
Relative Intensity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
6300.0
6300.2
6300.4
6300.6
6300.8
λ (Å)
[OI]
ScII



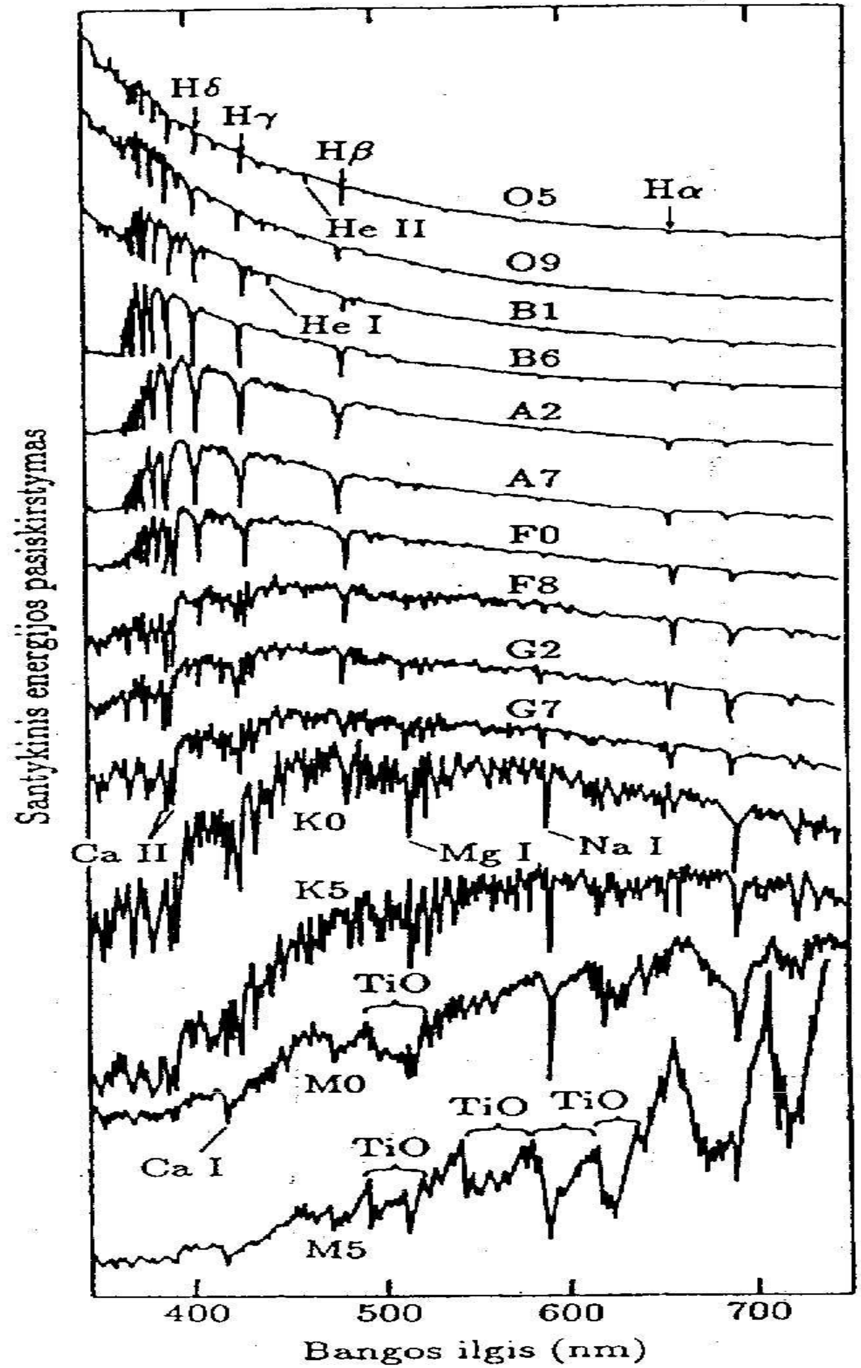
1.0
0.9
0.8
0.7
0.6
0.5
0.4
Relative Intensity
5634.0
5634.5
5635.0
5635.5
5636.0
λ (Å)
FeI
C2
FeI



Relative Intensity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4732.5
4733.0
4733.5
4734.0
4734.5
4735.0
4735.5
λ (Å)
NiI
C2
FeI
ScI
C2
FeI



Relative Intensity
1.00
0.95
0.90
0.85
0.80
0.75
8003.0
8003.5
8004.0
8004.5
8005.0
λ (Å)
12C14N
12C14N
12C14N
13C14N


Hδ
Hγ
Hβ
Hα
He II
He I
O5
O9
B1
B6
A2
A7
F0
F8
G2
G7
K0
K5
M0
M5
Ca II
Mg I
Na I
TiO
TiO
TiO
TiO
Ca I
400
500
600
700
Santykinis energijos pasiskirstymas
Bangos ilgis (nm)

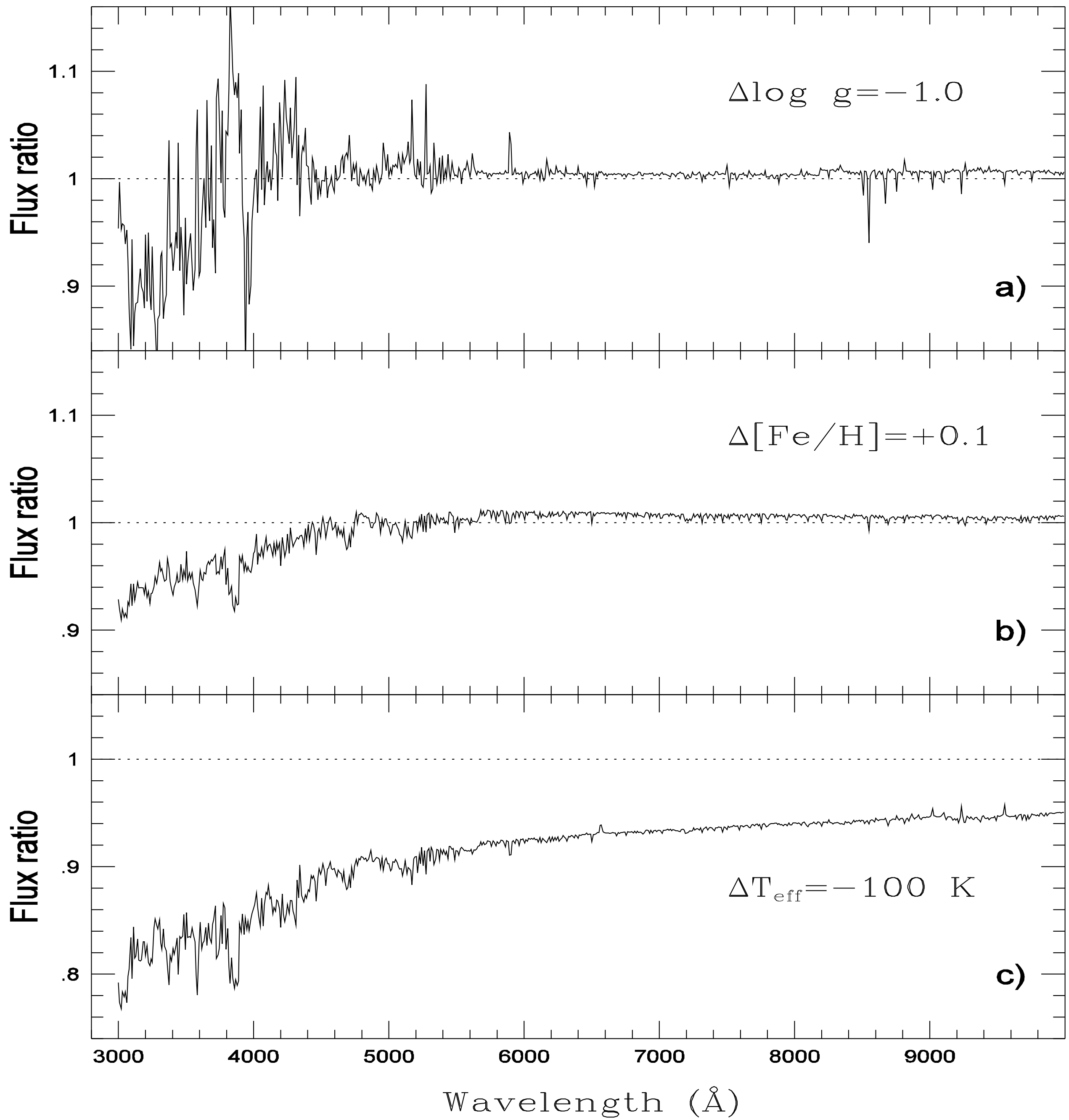
Spectral lines according to siutability

- Oxygen – [O I], IR OH, O I, UV OH
- Carbon – [C I], C_2, CH, C I
- Nitrogen – CN, N I, NH

$T_{eff} = 5500$ K

$\log g = 4.0$

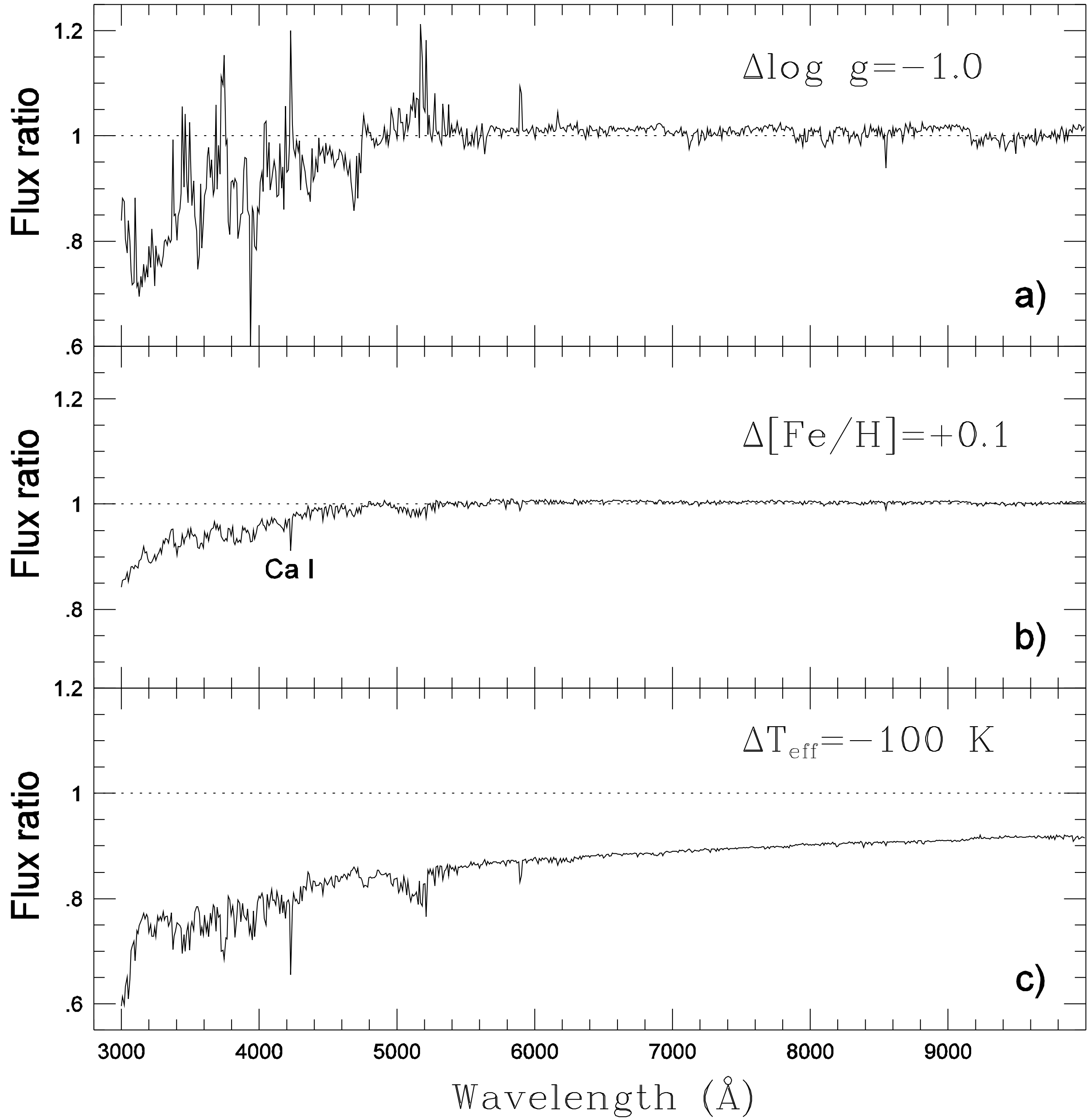
$[Fe/H] = -0.4$



$T_{eff} = 4500$ K

$\log g = 3.0$

$[Fe/H] = -0.4$

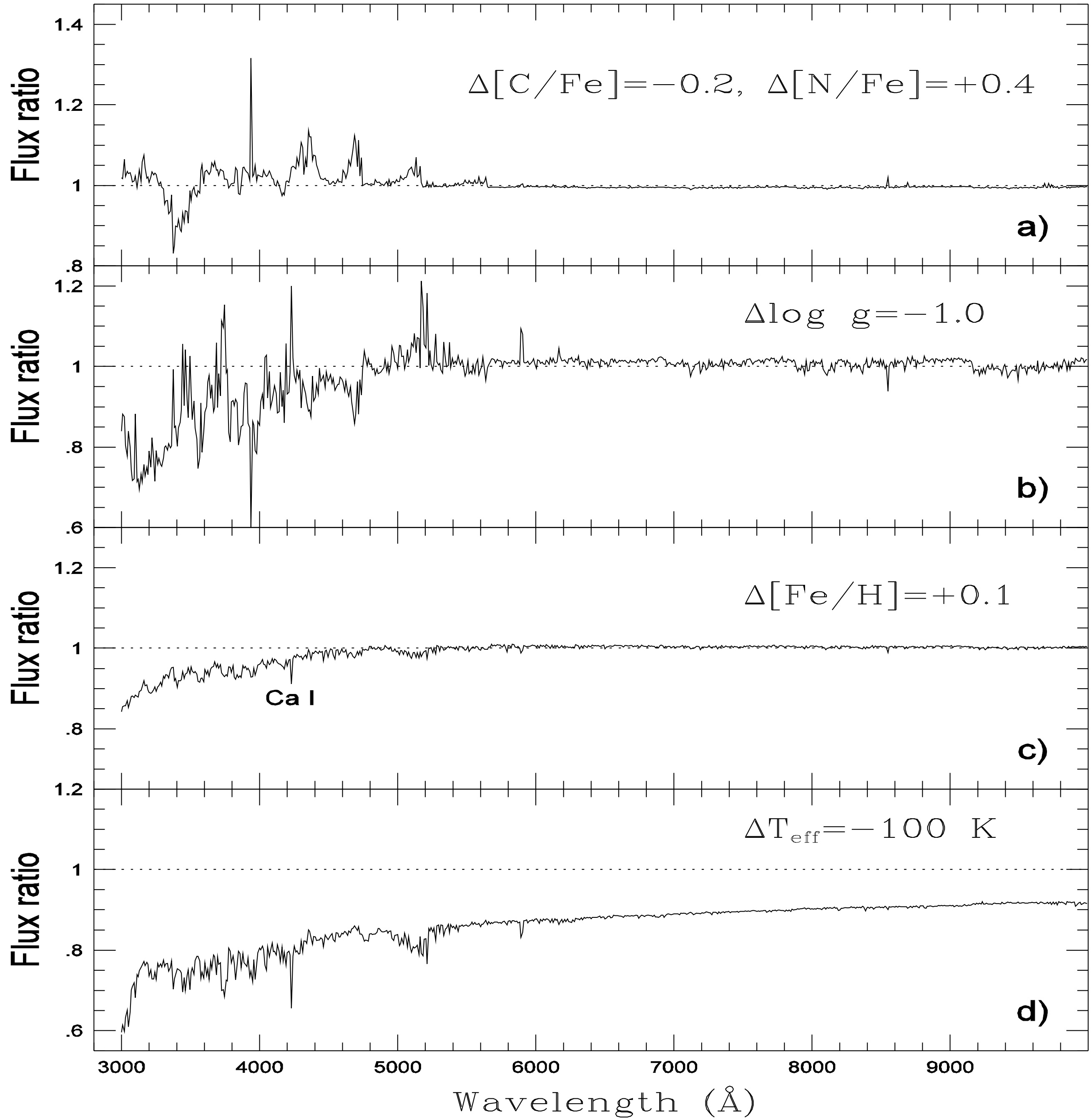


Tautvaisiene, Edvardsson, Bartasiute, 2003, Baltic Astron. 12, 532

$T_{eff} = 4500$ K

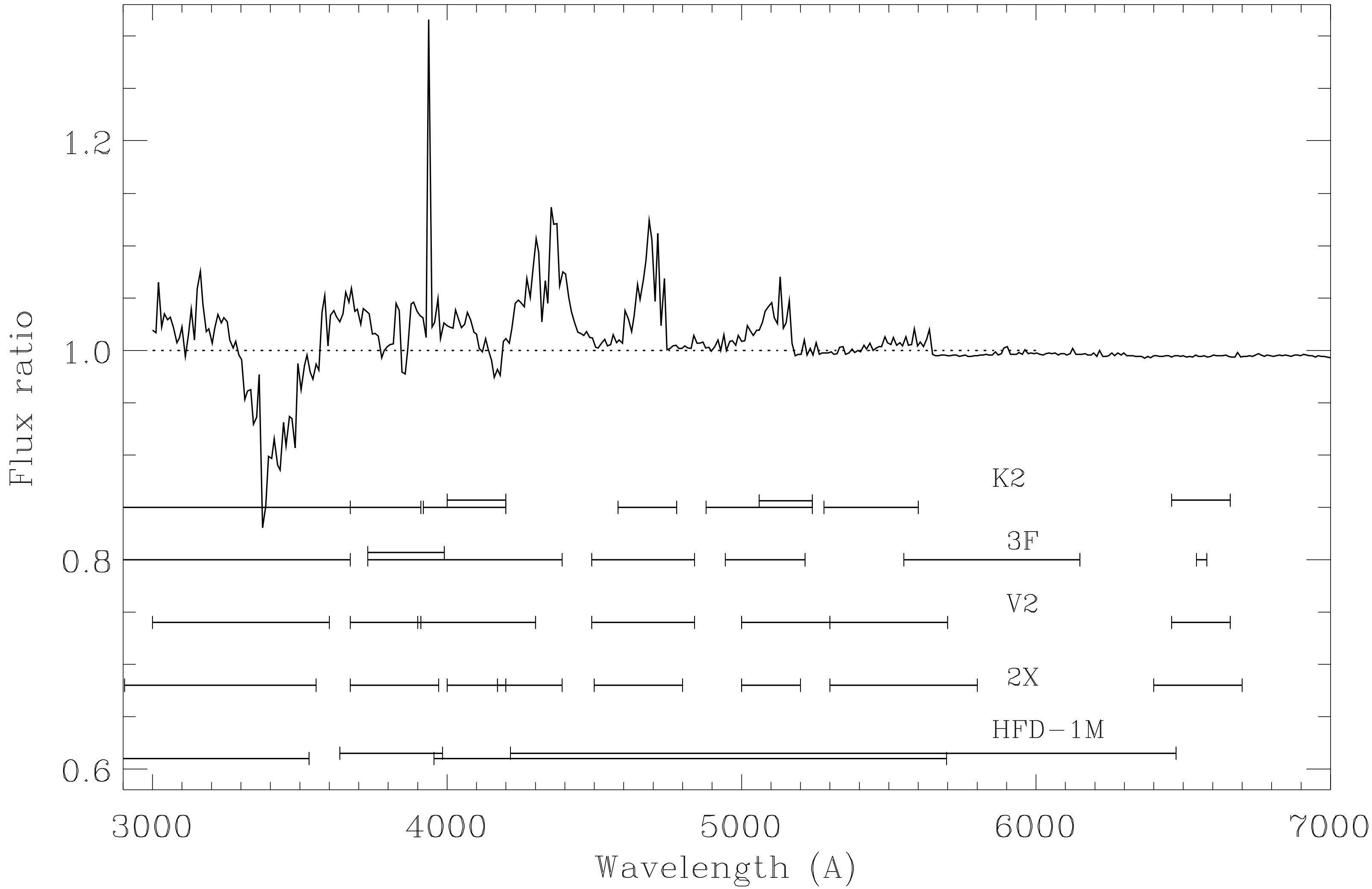
log g = 3.0

[Fe/H] = –0.4



T_{eff} = 4500 K, log g = 3.0, [Fe/H] = –0.4

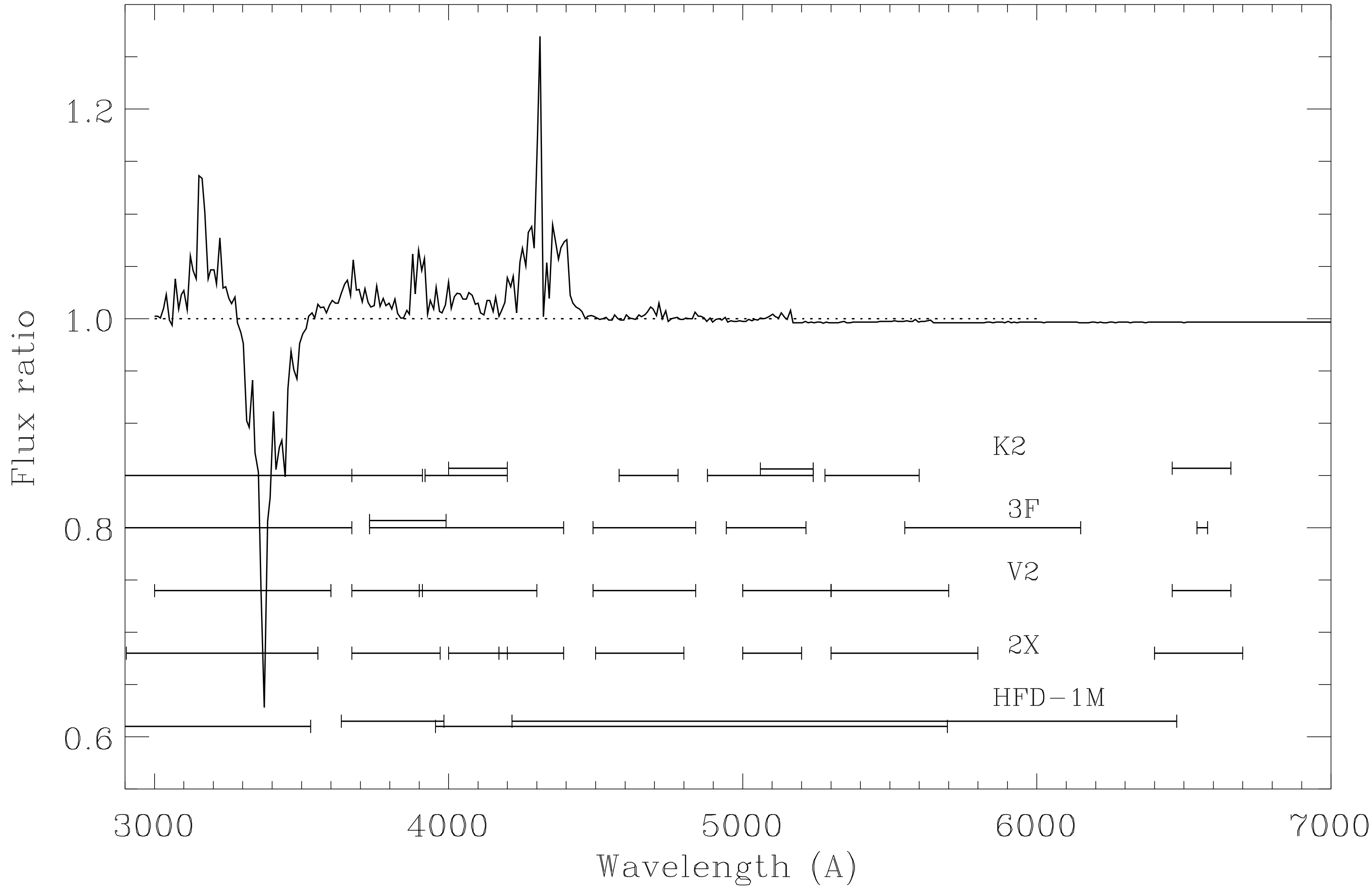
Δ [C/Fe] = –0.2, Δ[N/Fe] = 0.4, C/N = 1



NH λ_0 = 3400 Å, Δλ = 200 Å 8 % 19 mag

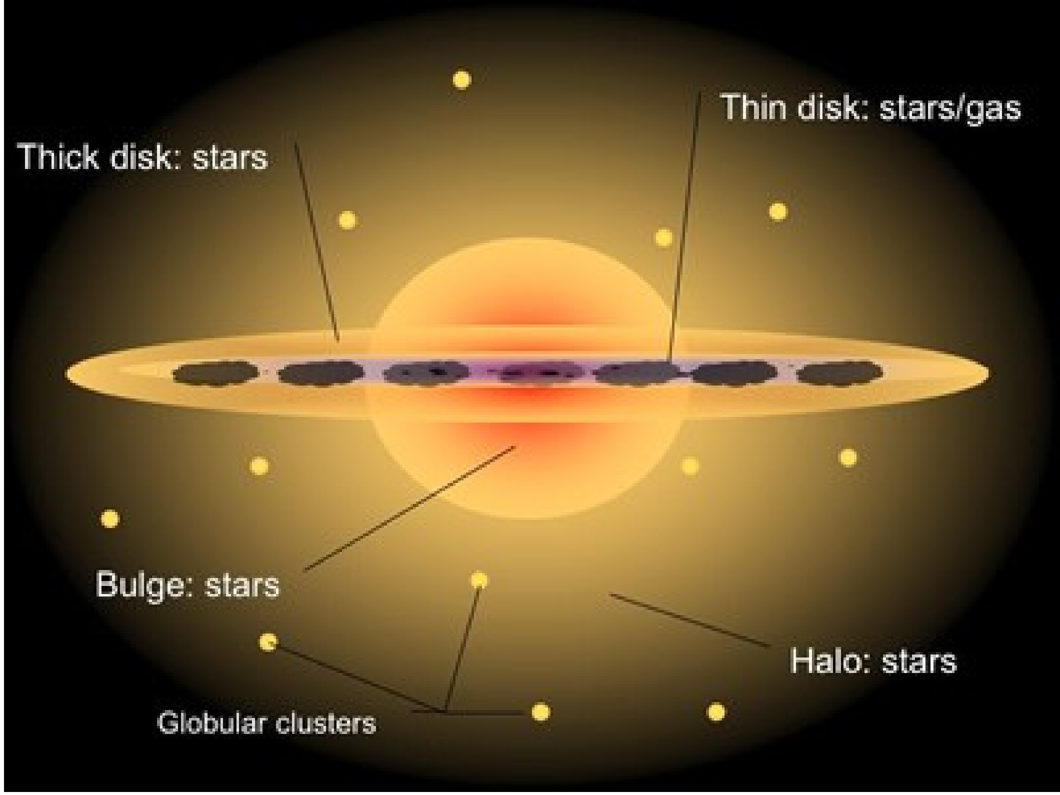
T_{eff} = 5000 K, log g = 2.5, [Fe/H] = –1.5

Δ[C/Fe] = –0.5, C/N = 0.3



NH λ_0 = 3400 Å, $\Delta\lambda$ = 200 Å 12 % 19.5 mag

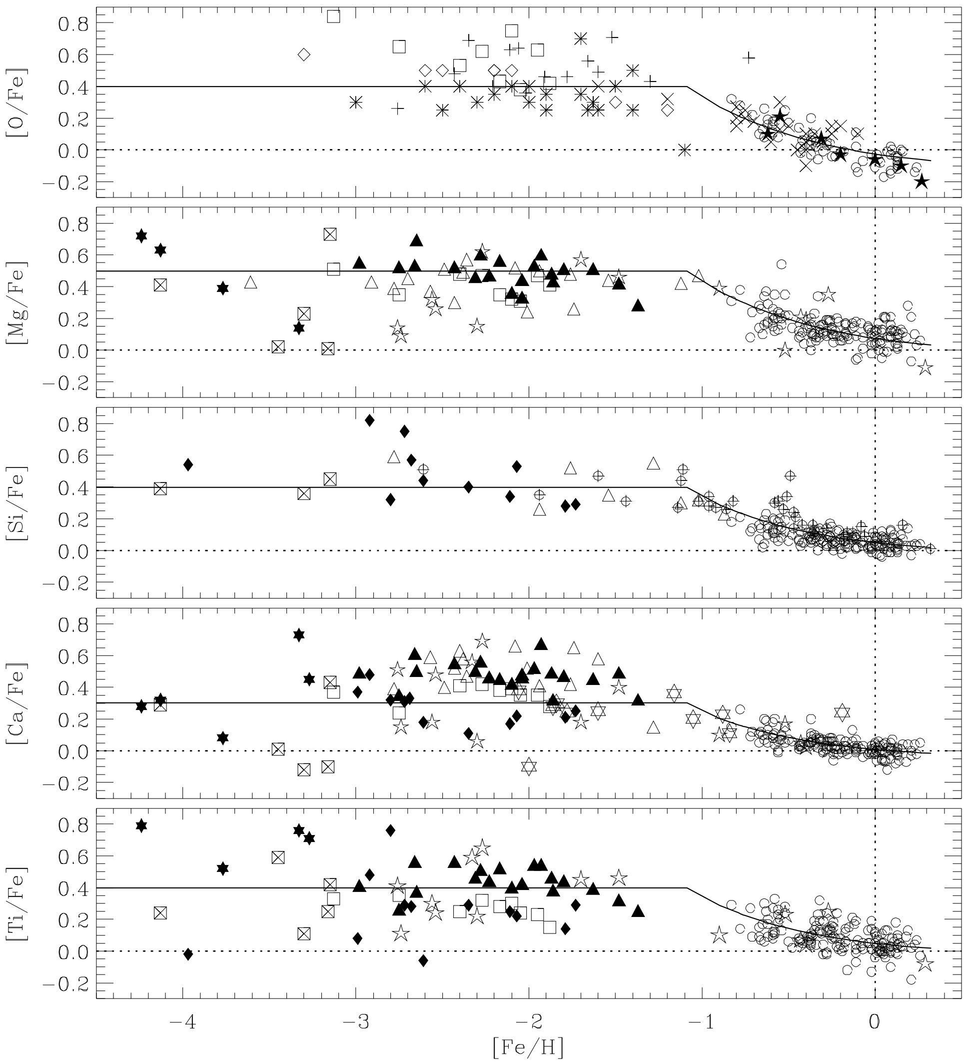
Thick-disk formation

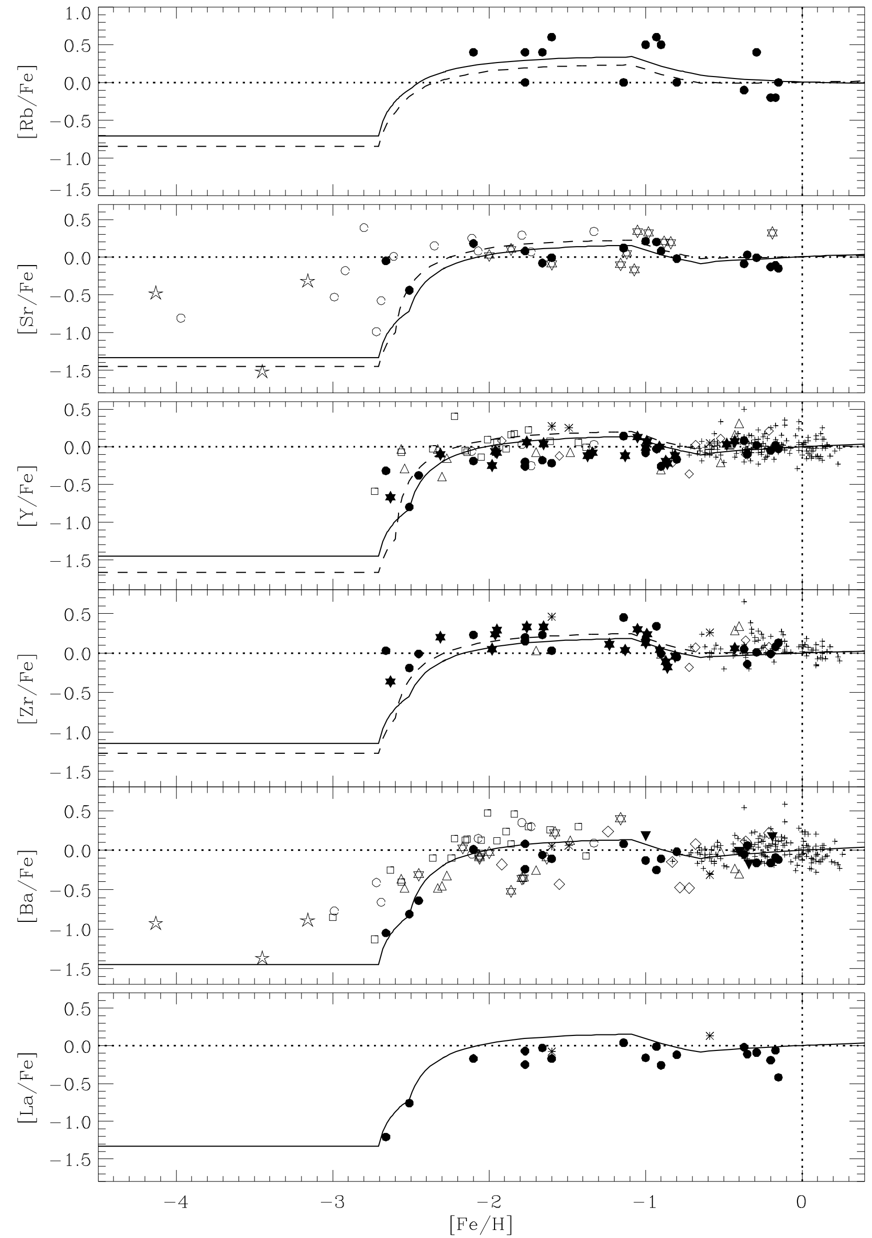


- Fuhrmann 1998
- Proshaska et al. 2000
- Tautvaisiene et al. 2001
- Gratton et al. 2003
- Bensby, Feltzing et al. since 2003
- Reddy, Lambert & Prieto 2006

Milky Way

Pagel & Tautvaisiene 1995, 1997





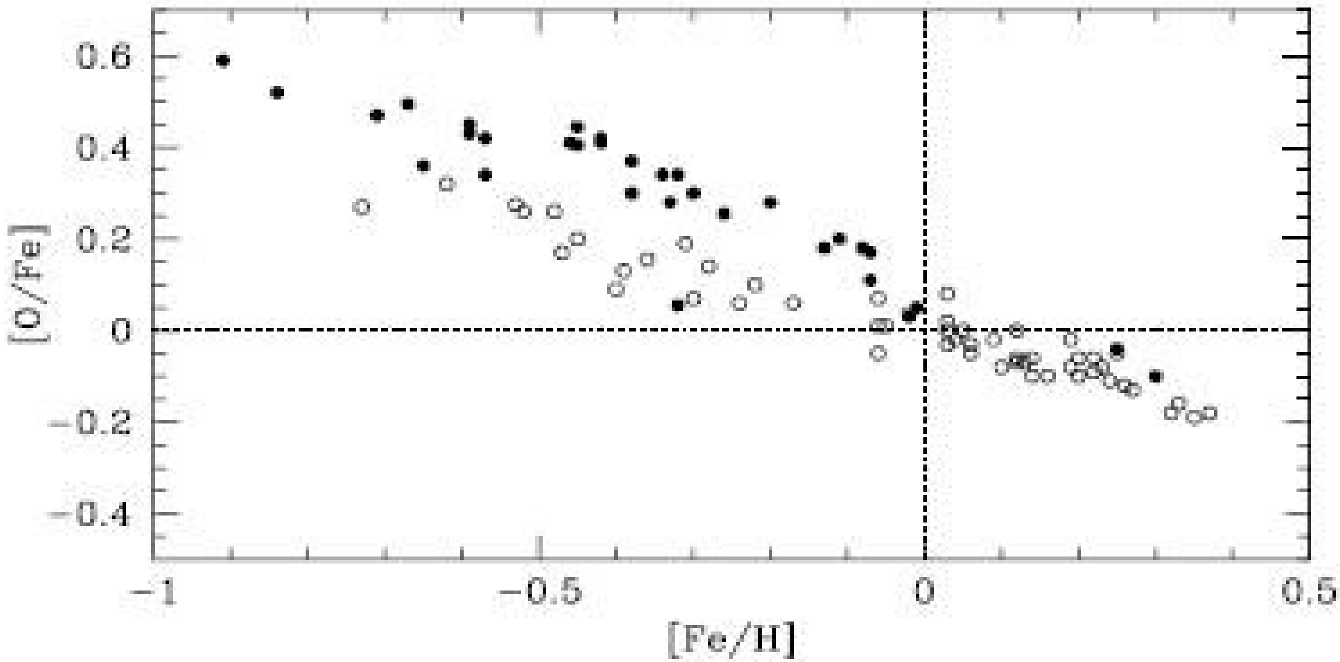
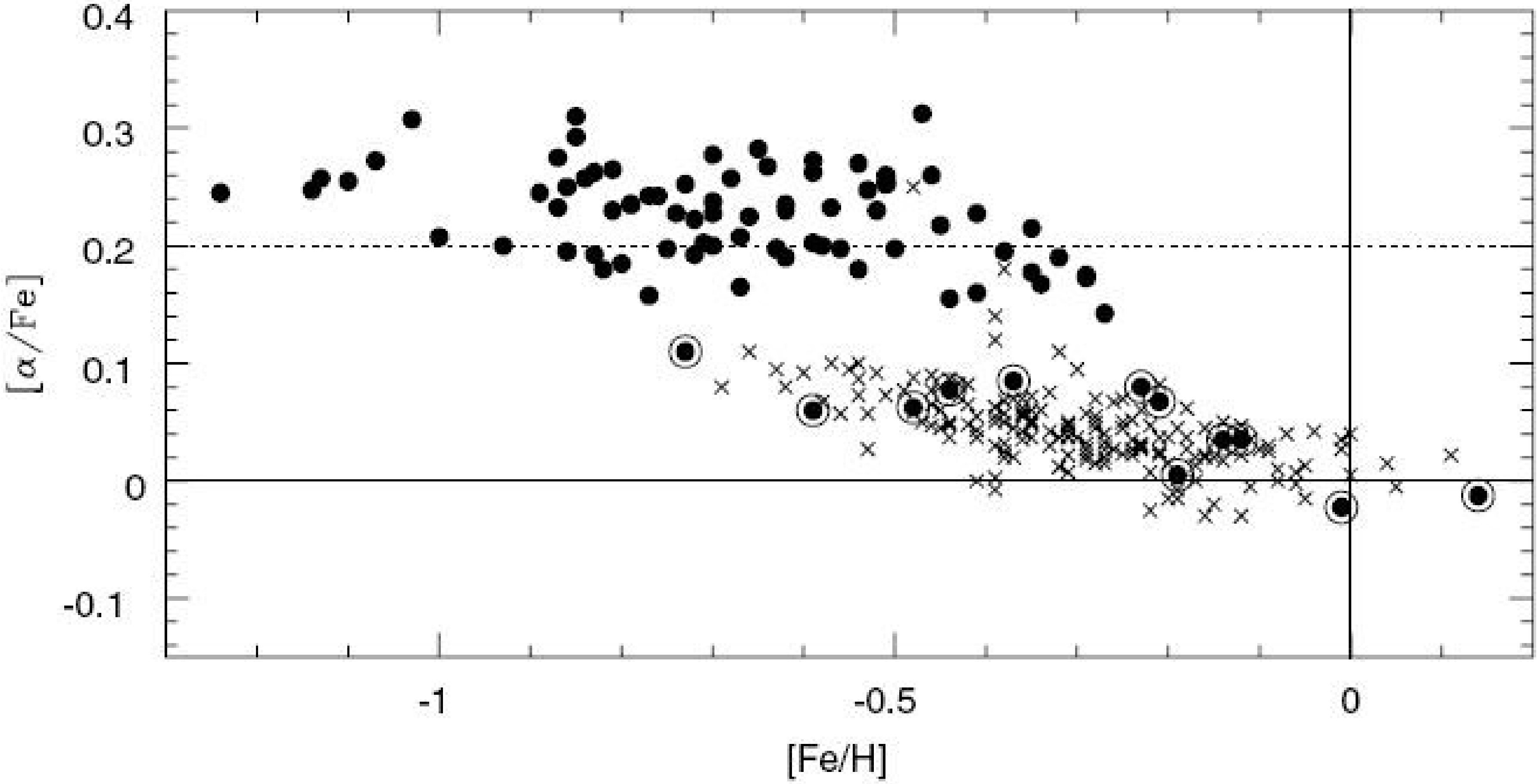


FIGURE 1. [O/Fe] vs. [Fe/H] for stars with kinematics typical of the thick disk (marked with •) and stars with kinematics typical of the thin disk (marked with ○). The data are taken from Bensby et al. (2004a & 2005).


0.4
0.3
0.2
0.1
0
-0.1
[α/Fe]
-1
-0.5
0
[Fe/H]

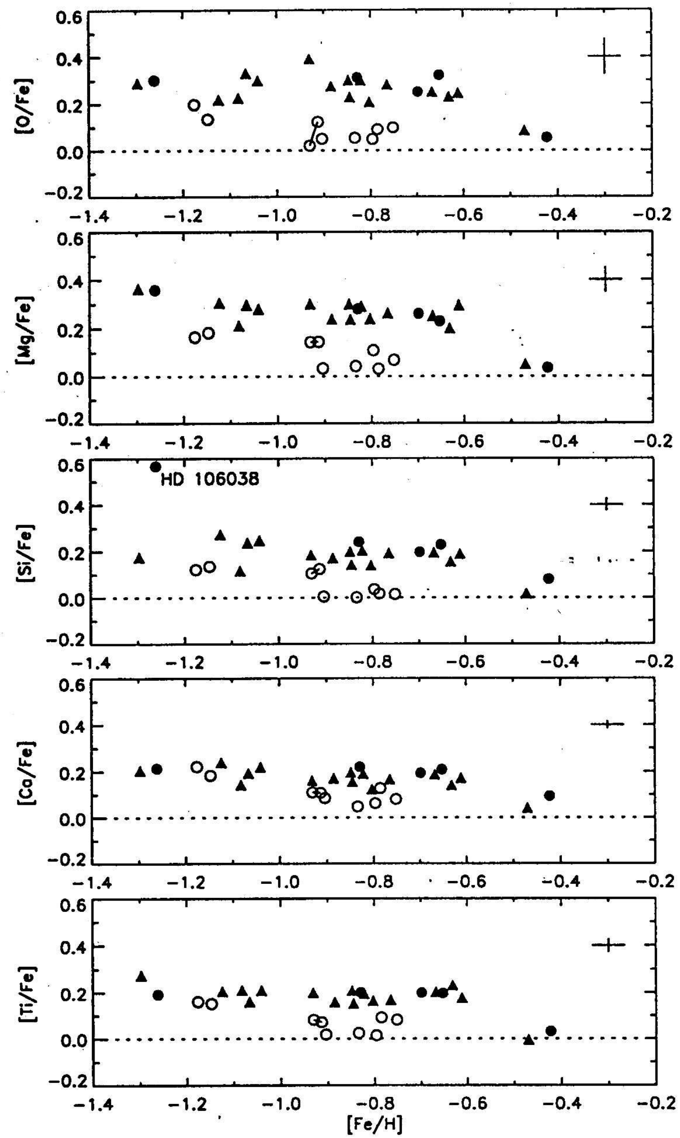
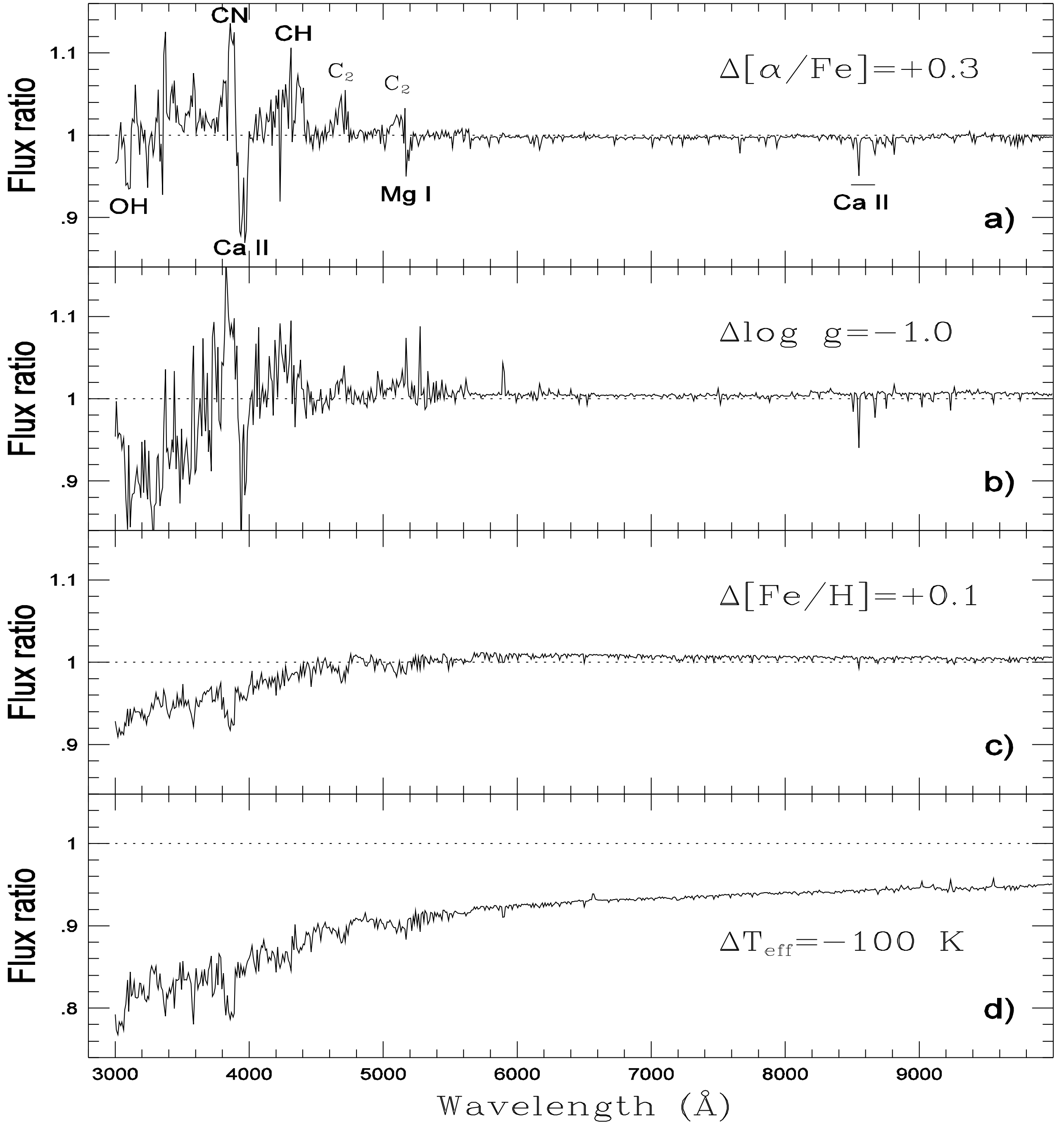


Fig. 4. Abundances of the α-elements relative to iron vs. [Fe/H]. Disk stars are plotted with filled triangles, and halo stars that follow the trend of the disk stars are shown with filled circles. Deviating halo stars are plotted with open circles. The two components of HD 113083 are connected with a straight line. Errors bars corresponding to the precision of the differential abundance ratios are shown to the right in each figure

Teff = 5500 K

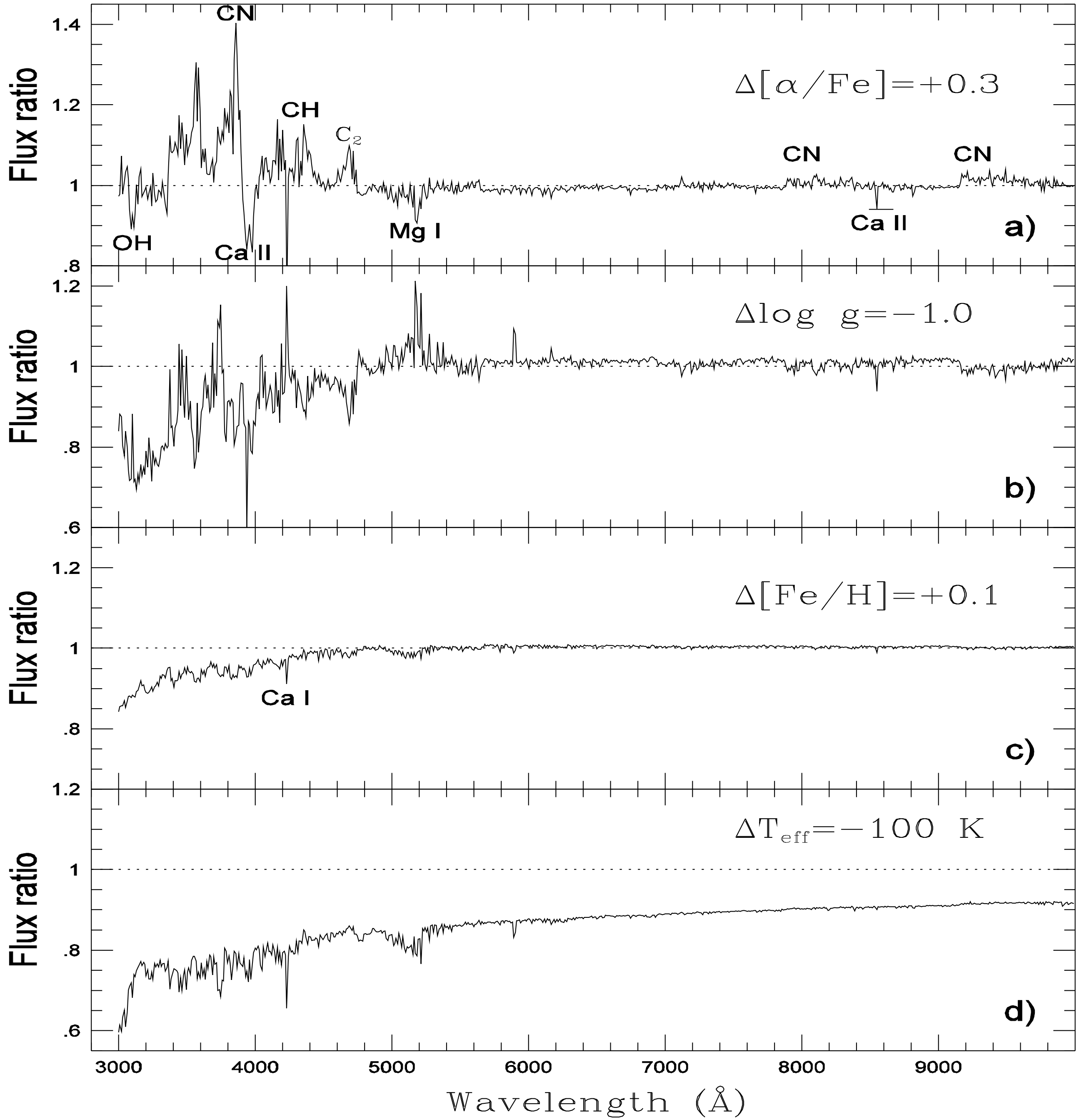
log g = 4.0

[Fe/H] = –0.4



Tautvaisiene & Edvardsson (2002)

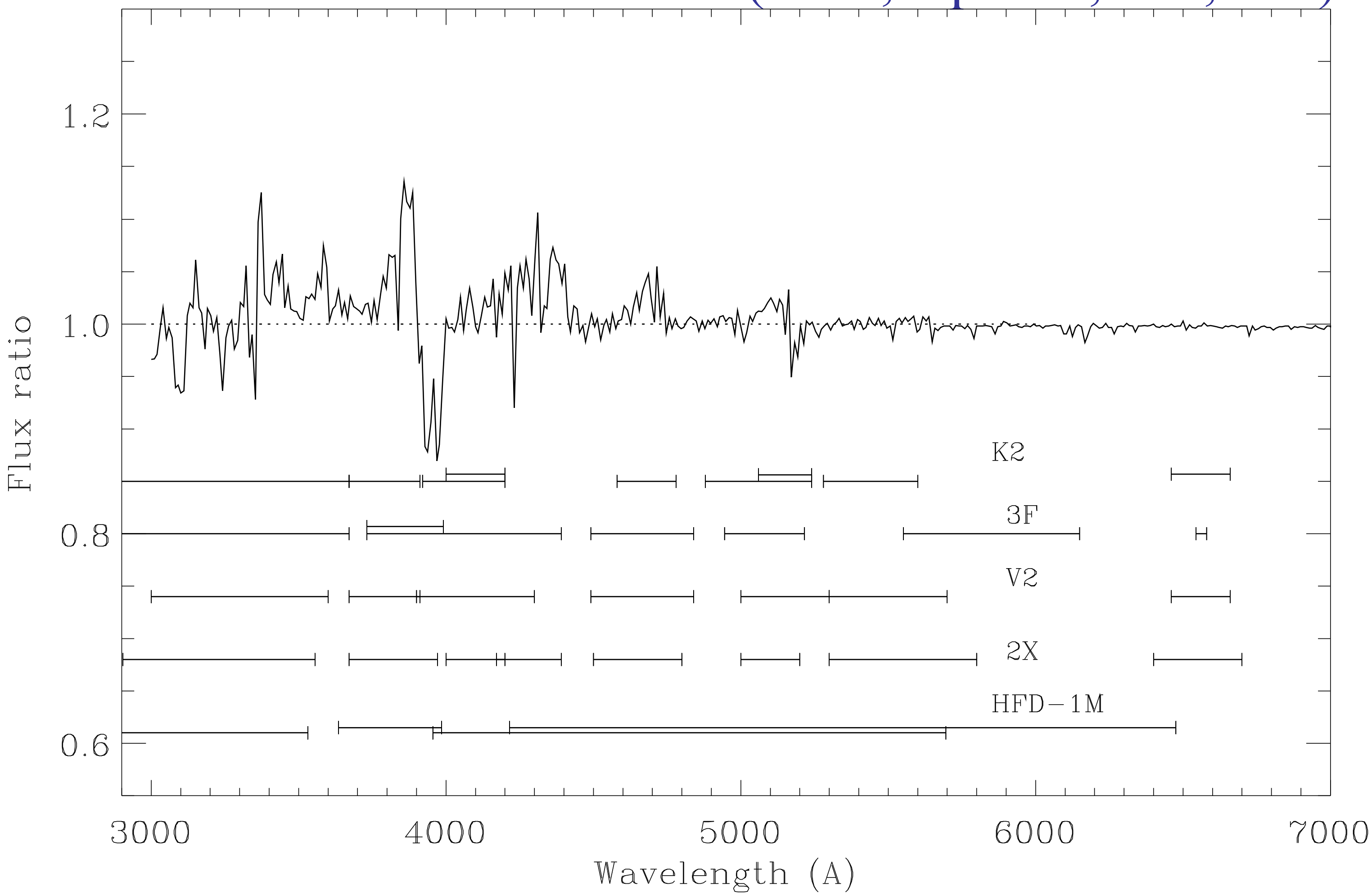
Teff = 4500 K
log g = 3.0
[Fe/H] = –0.4



Tautvaisiene &
Edvardsson
(2002)

Teff = 5500 K, log g = 4.0, [Fe/H] = –0.4, Δ[α/Fe] = +0.3

Tautvaisiene & Edvardsson (2002, Ap&SS, 280, 143)



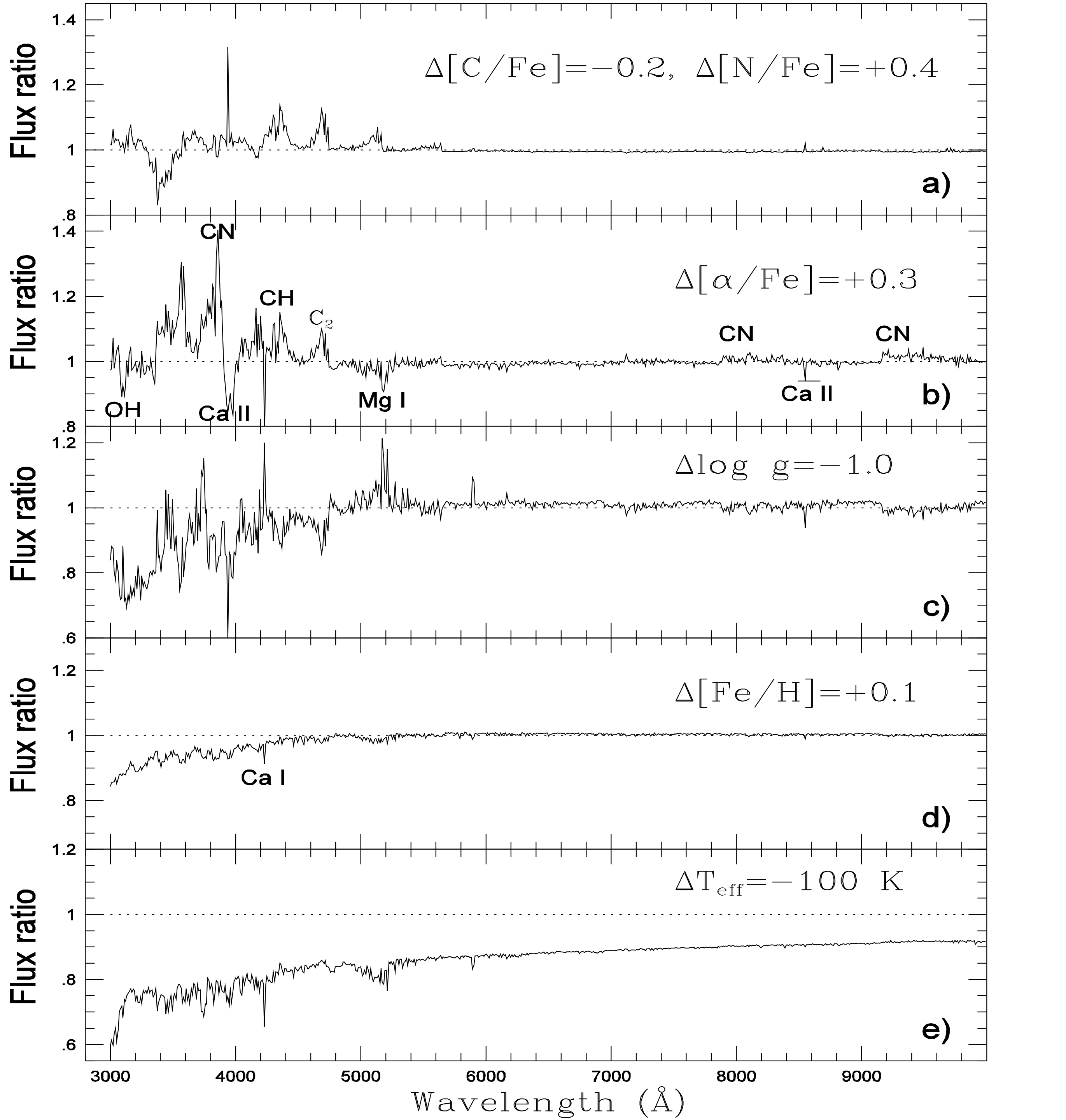
Ca II $\lambda_0 = 3955$ Å, $\Delta\lambda = 100$ Å, 8 – 11 %, 16 – 17 mag

Mg I $\lambda_0 = 5200$ Å, $\Delta\lambda = 80$ Å, 2 – 5 %, 16 – 17 mag

Teff = 4500 K
log g = 3.0
[Fe/H] = –0.4

(a)
[C/Fe] = –0.2
C/N = 1

(b) – (e)
from Tautvaisiene & Edvardsson (2002)



			Dwarfs	Giants
Ca II	$\lambda_0 = 3955$ Å	$[\alpha/Fe] = \pm 0.1$	16.3 mag	17.0 mag
	$\Delta\lambda = 100$ Å	$[\alpha/Fe] = \pm 0.2$	16.7 mag	17.9 mag
Mg I	$\lambda_0 = 5200$ Å	$[\alpha/Fe] = \pm 0.1$	15.6 mag	17.3 mag
	$\Delta\lambda = 80$ Å	$[\alpha/Fe] = \pm 0.2$	16.5 mag	18.2 mag
NH	$\lambda_0 = 3400$ Å	$[N/Fe] = \pm 0.1$		19.0 mag
	$\Delta\lambda = 200$ Å			

CONCLUSIONS I

- For the accurate determination of stellar main atmospheric parameters the influence of C, N, O and alpha-process elements should be taken into account
- Carbon features are abundant in stellar spectra and are sensitive both to mixing processes in stars and to abundances of alpha-process elements
- The best feature for the evaluation of CNO abundance alterations is NH at 3400 Å
- The best features to evaluate abundances of alpha-process elements are Ca II at 3955 Å and Mg I at 5175 Å
- Modern science and technology urges us to receive from space observations more information and of higher accuracy !

NGC 7789

Vilnius photometry

P (361-387 nm)

X (394-416 nm)

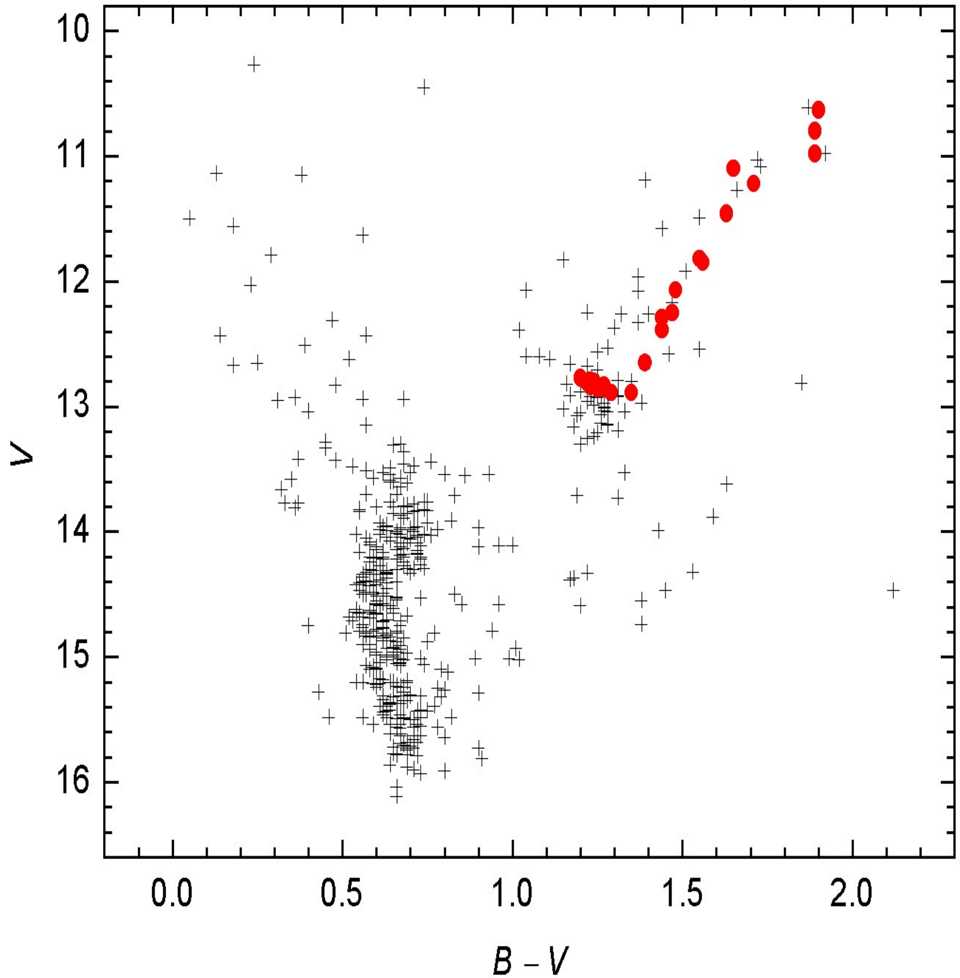
Y (453-479 nm)

Giants 11 stars:

[Fe/H] = –0.21±0.03

Clump 11 stars:

[Fe/H] = –0.15±0.03



Spectral investigations

NGC 7789

$\Delta[C/Fe] \approx -0.2$

$^{12}C/^{13}C \approx 9$

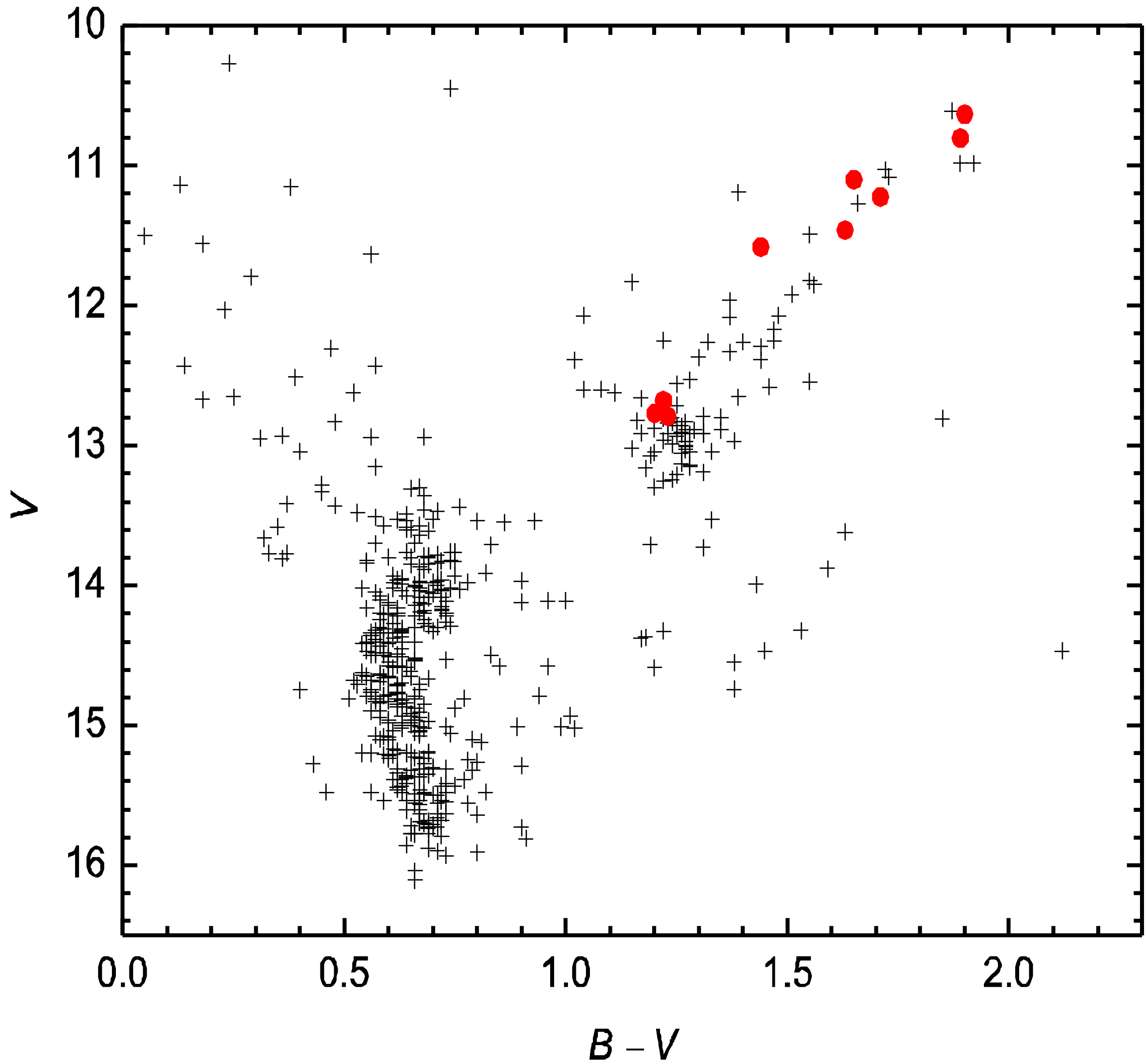
$\Delta[N/Fe] \approx +0.3$

Giants:

$C/N \approx 1.9 \pm 0.5$

Clump:

$C/N \approx 1.3 \pm 0.2$



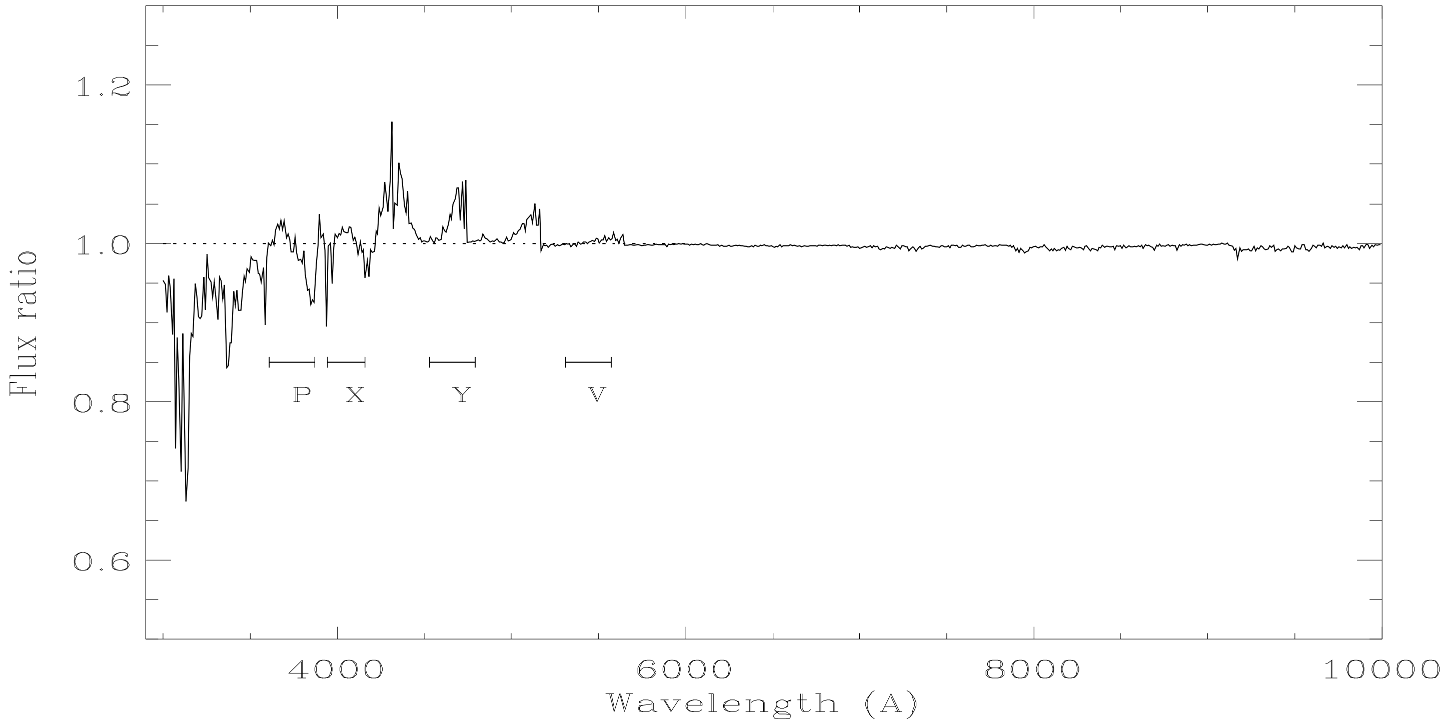
Δ [C/Fe] = –0.2

Δ[N/Fe] = +0.3

T_{eff}=5000 K

log g = 2.5

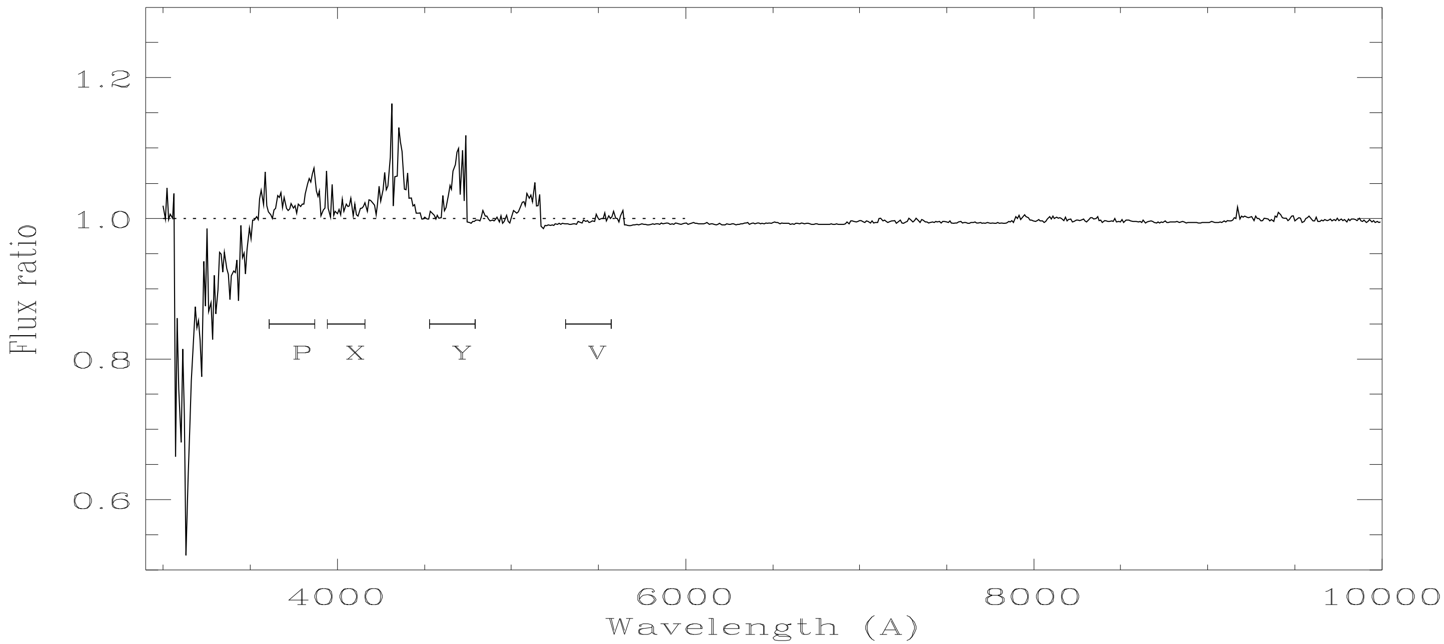
[Fe/H] = 0



T_{eff}=4250 K

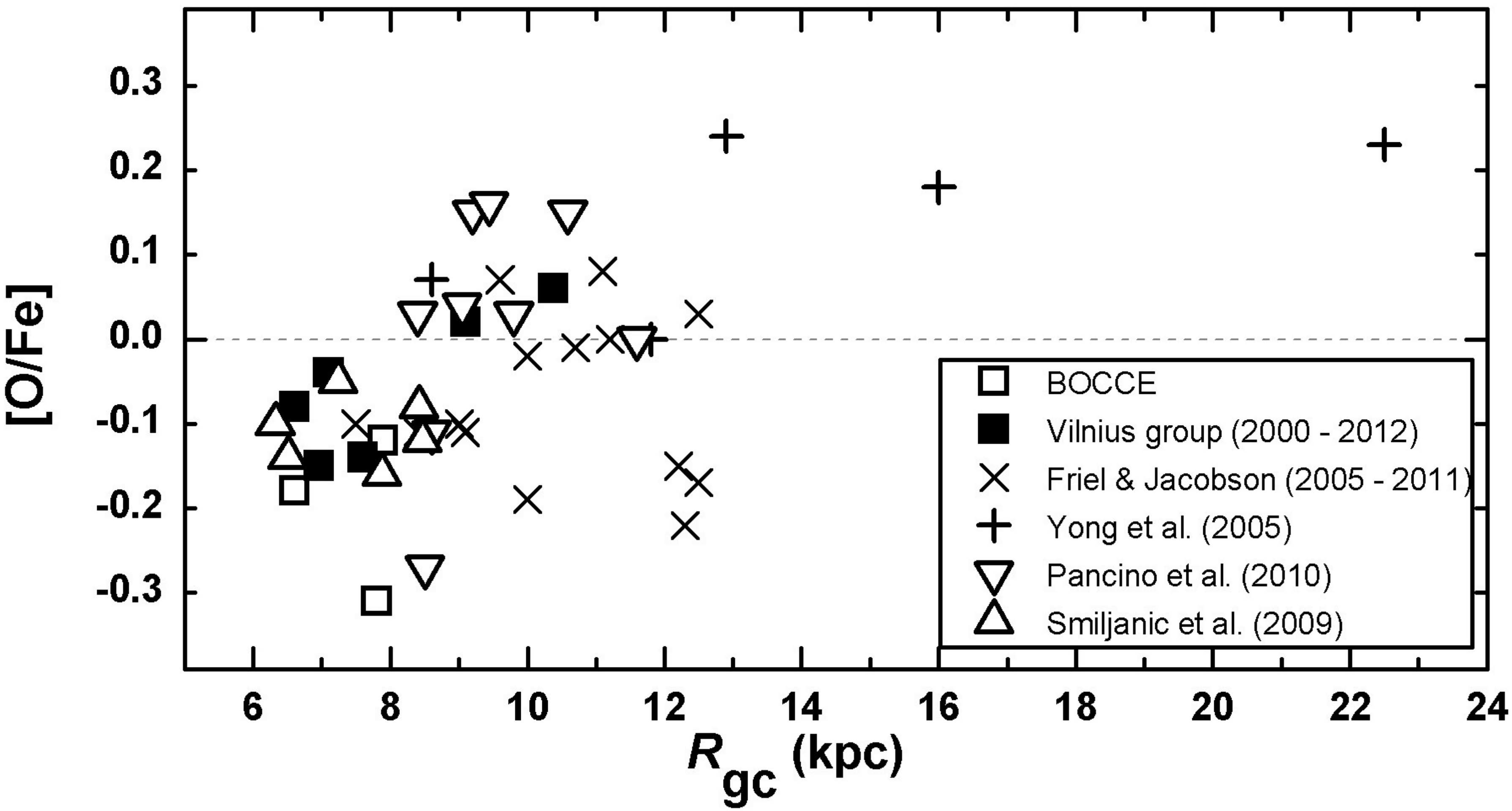
log g = 1.5

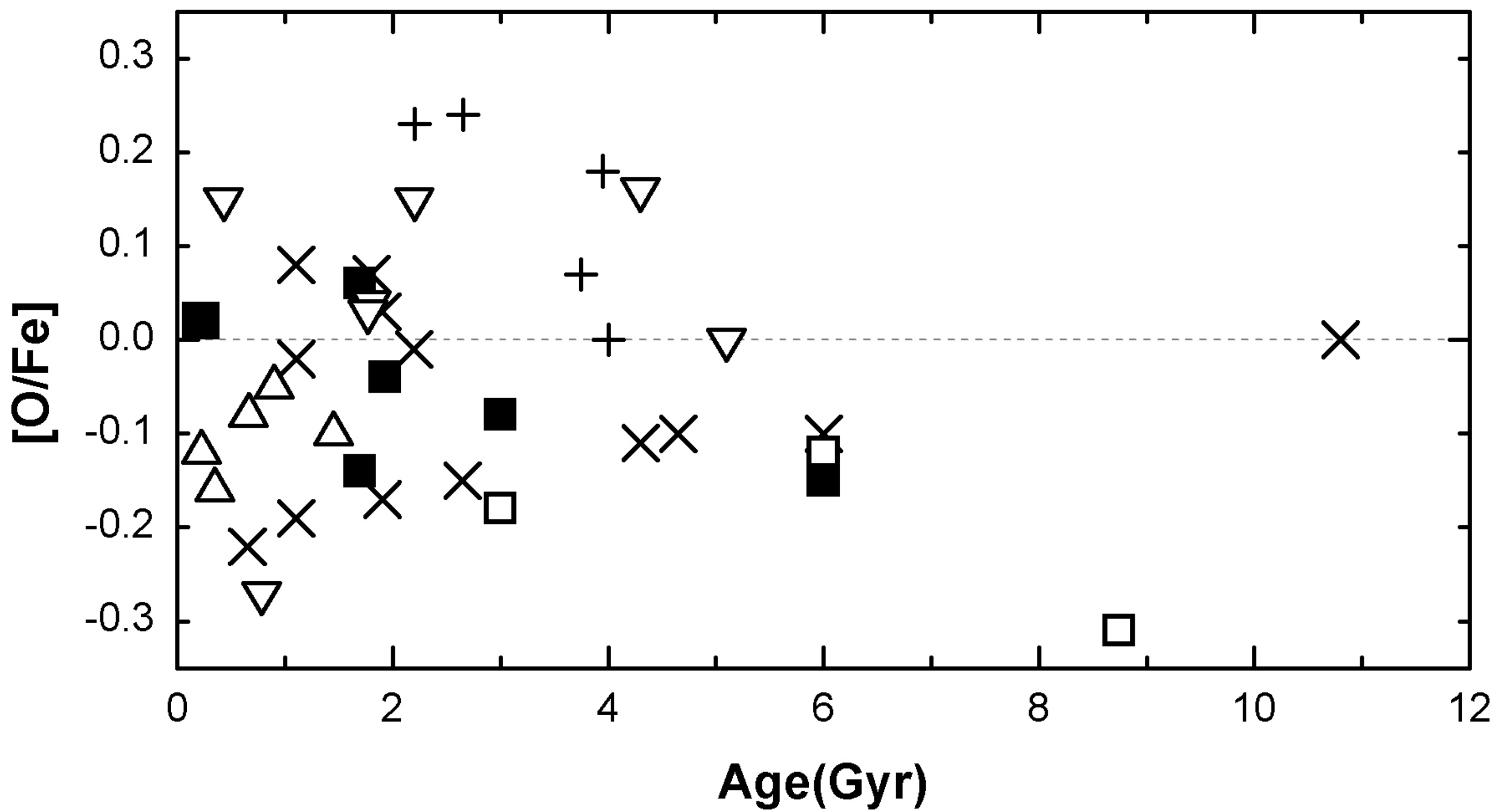
[Fe/H] = 0



Radial abundance gradients of CNO

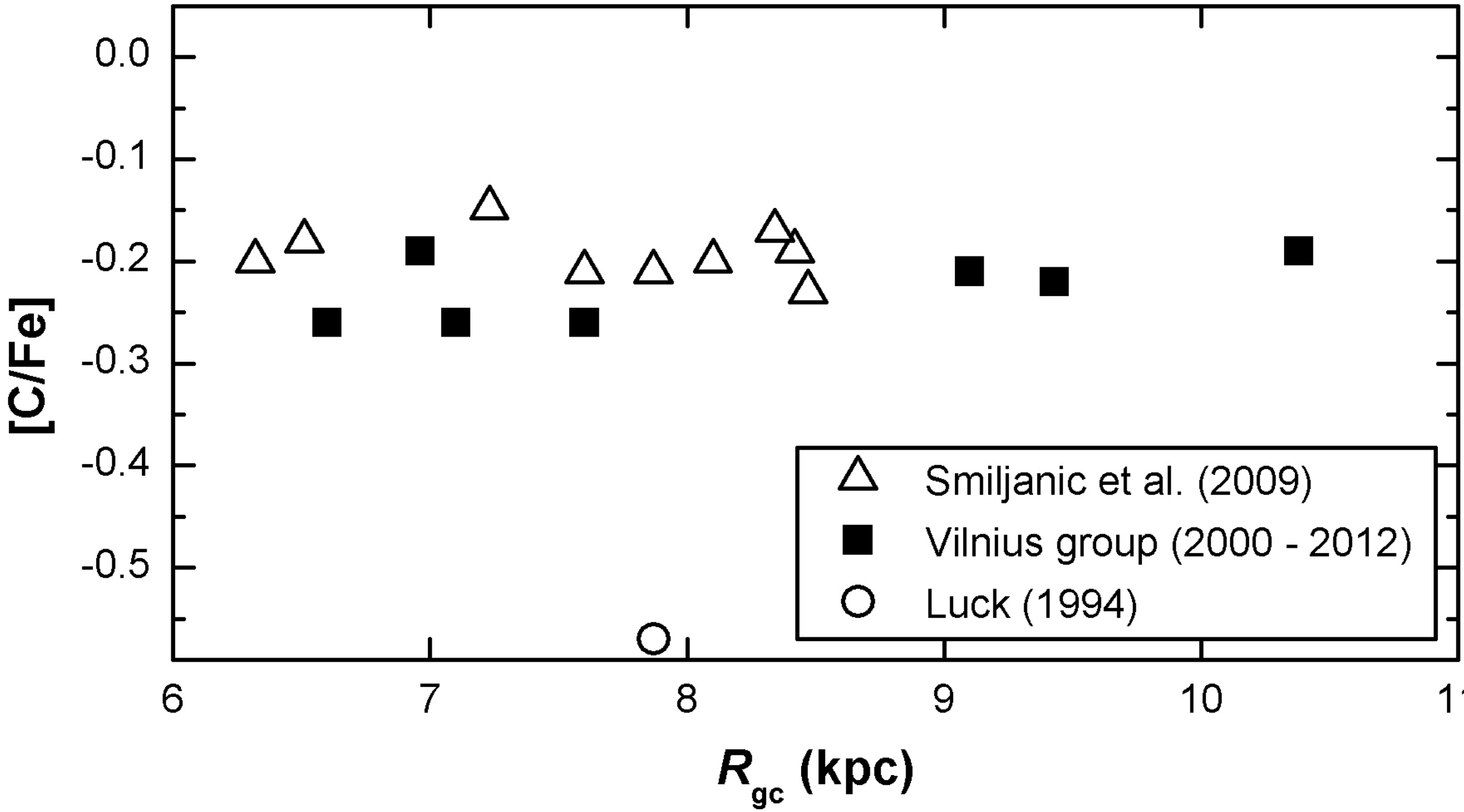
Oxygen in open clusters

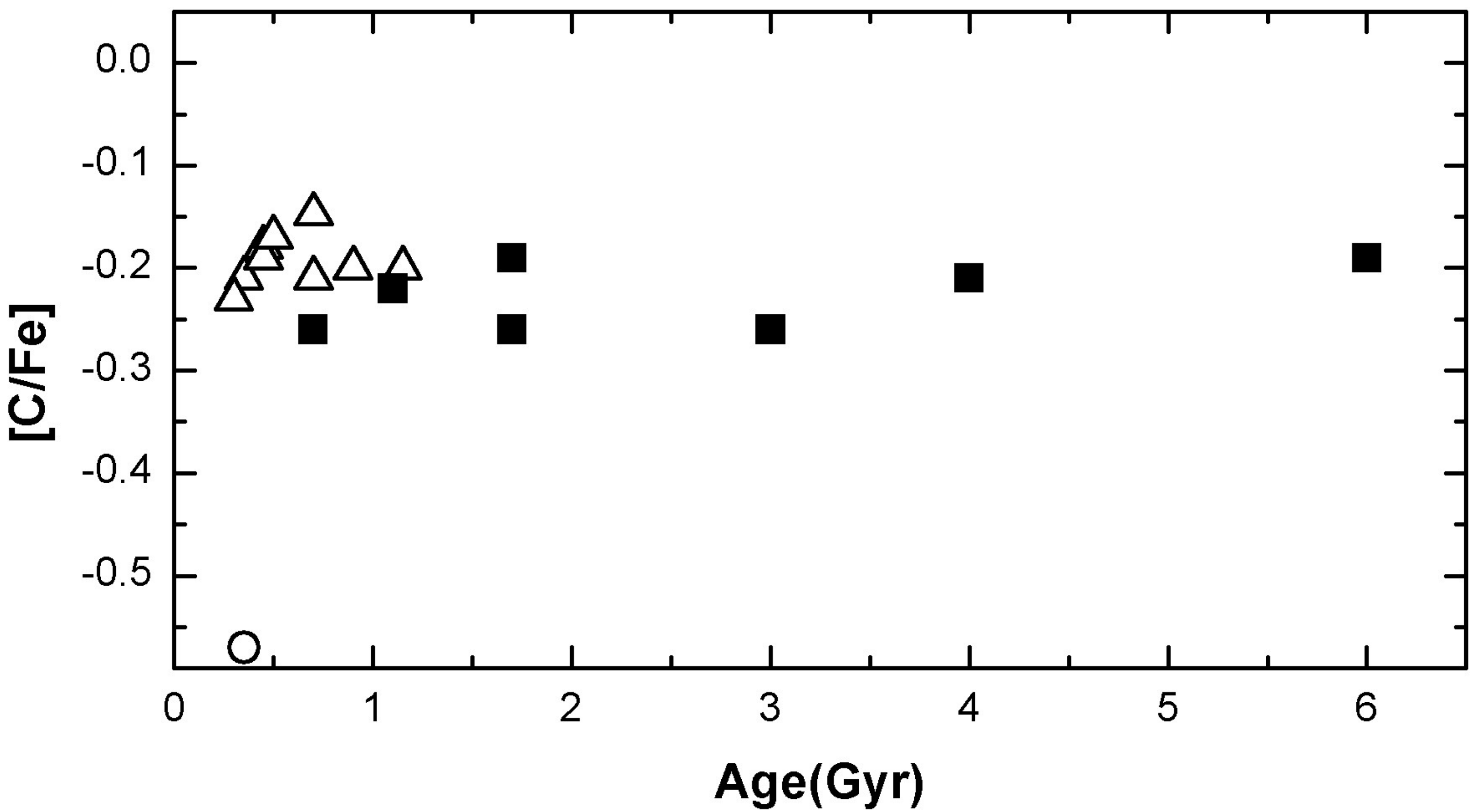




[O/Fe]
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
2
4
6
8
10
12
Age(Gyr)

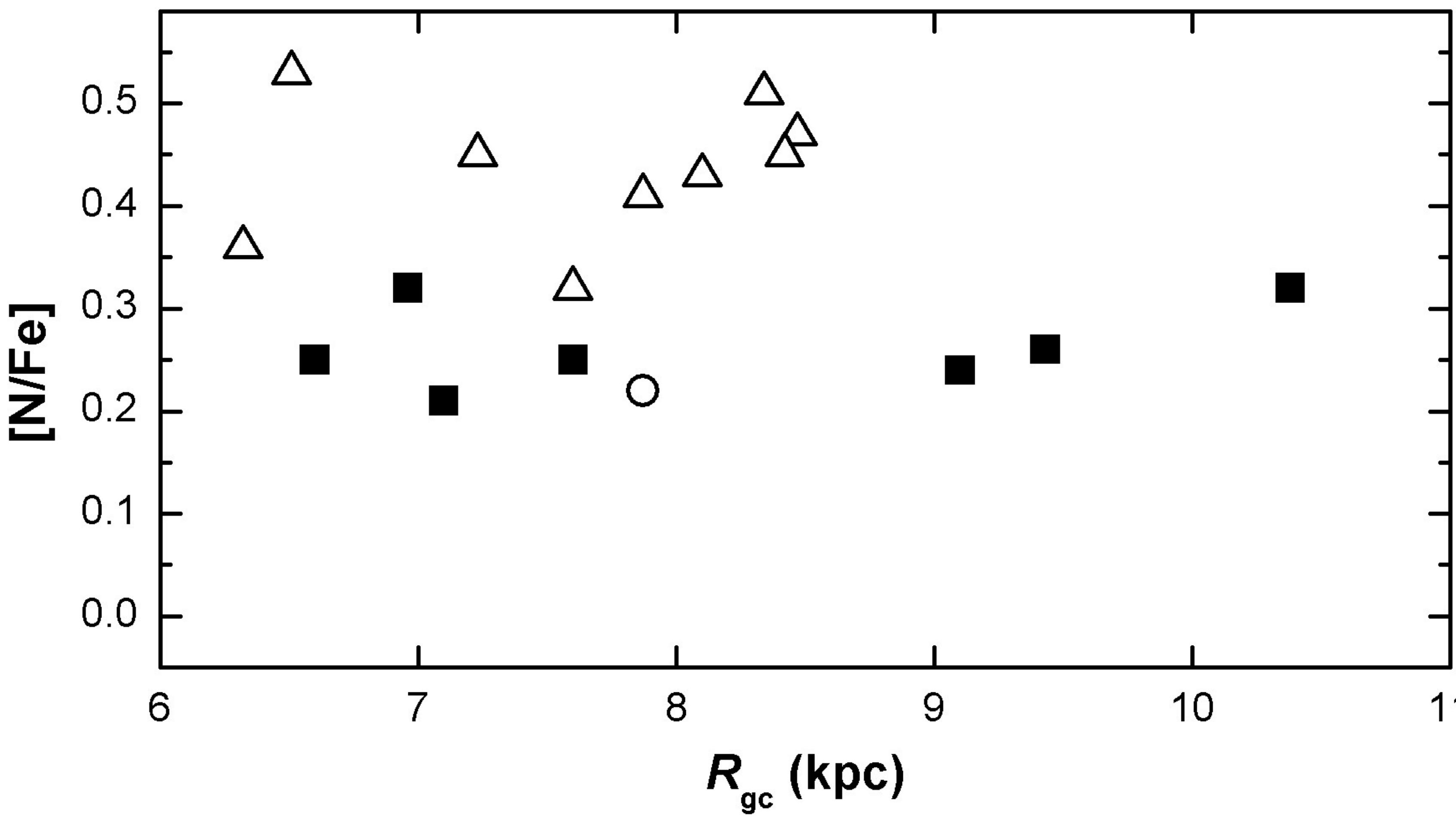
Carbon in open clusters: red clump stars

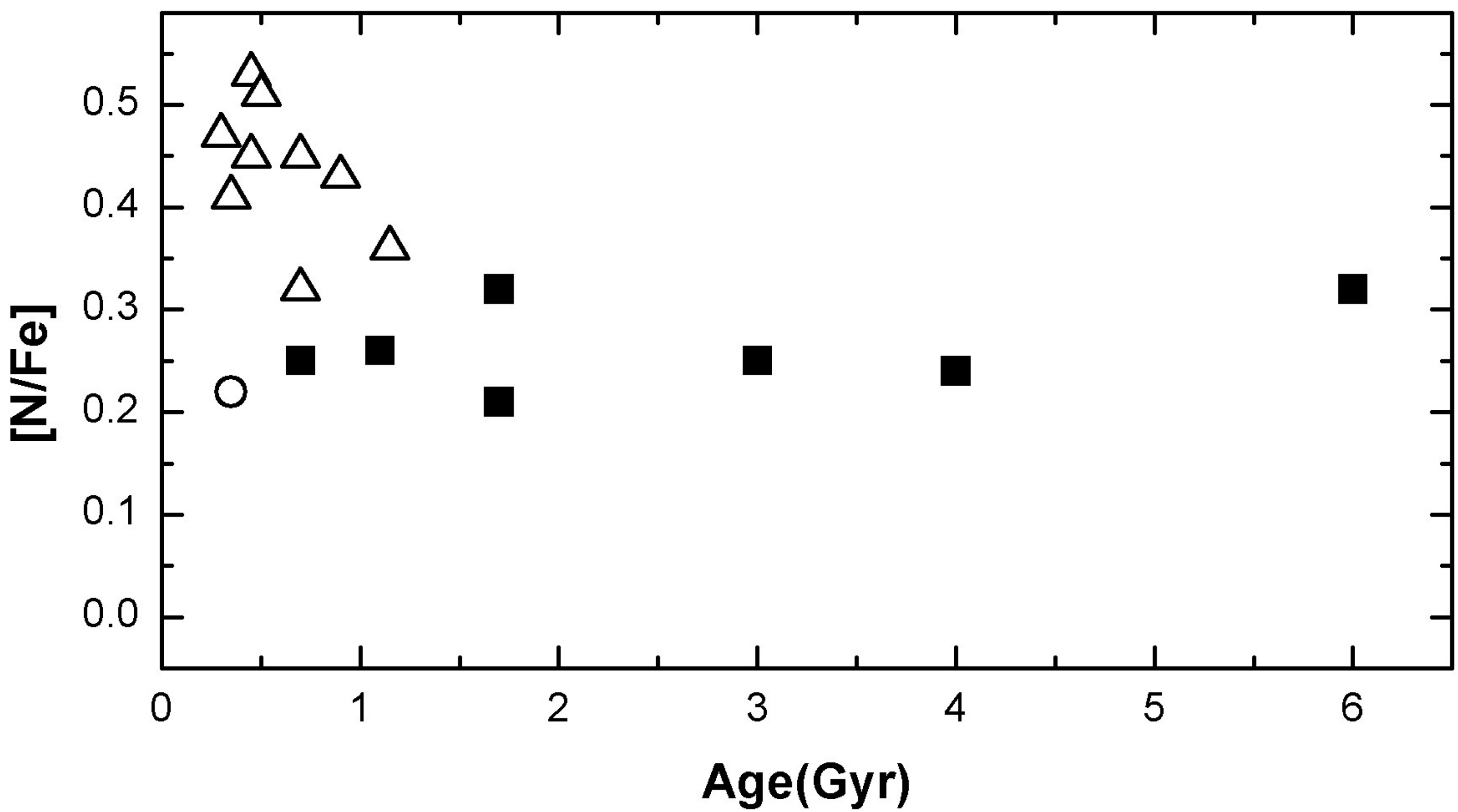




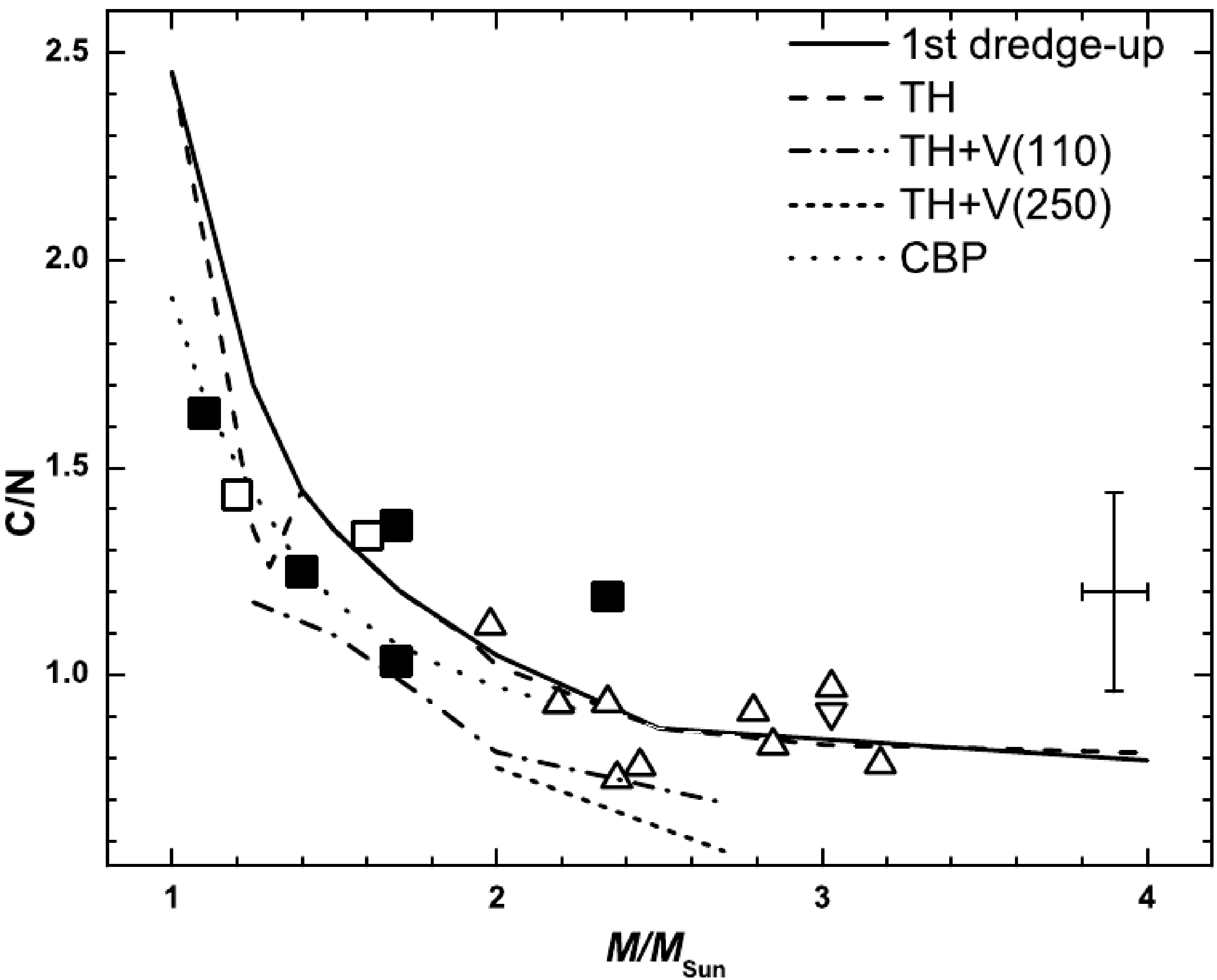
[C/Fe]
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
Age(Gyr)

Nitrogen in open clusters

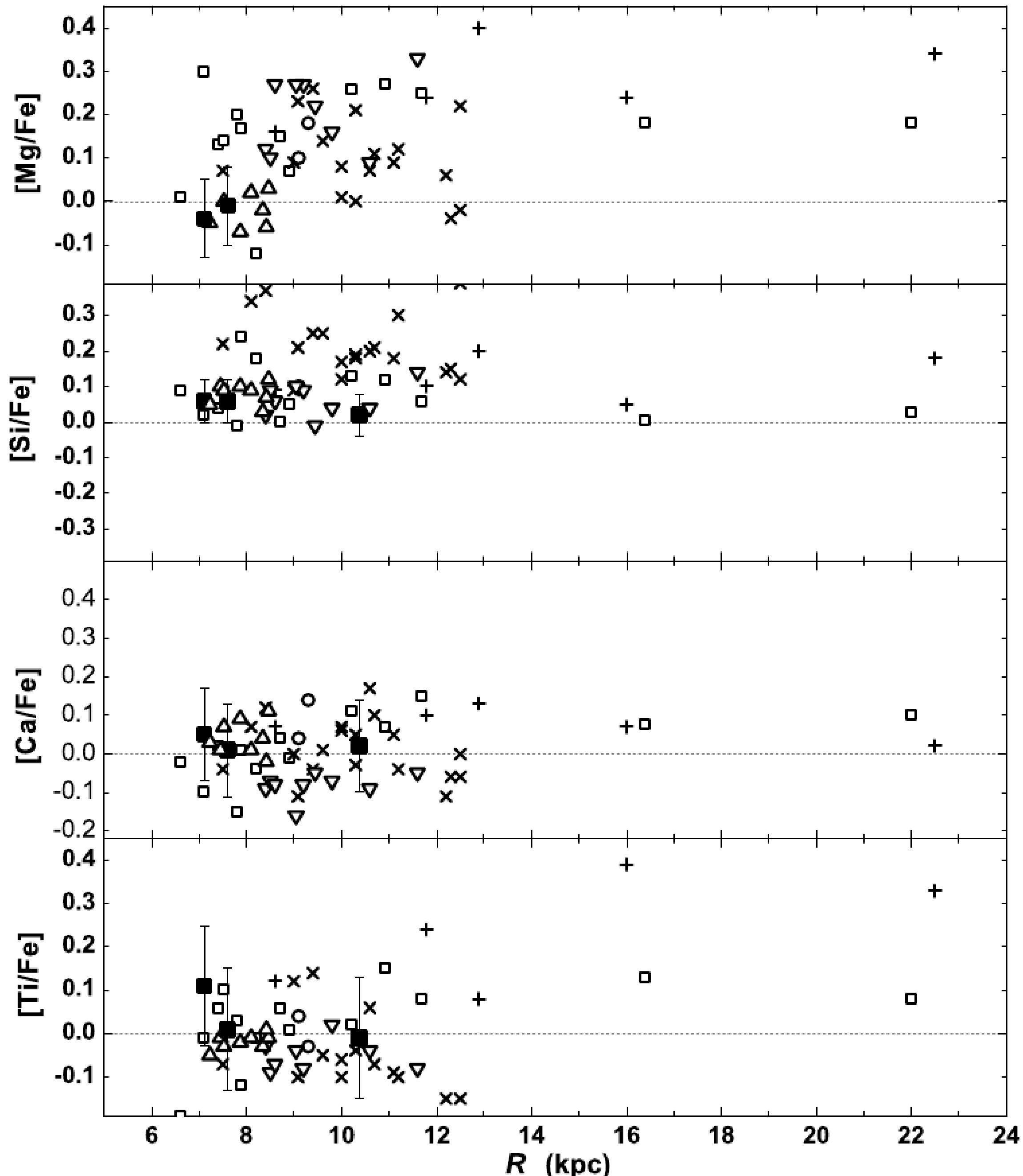


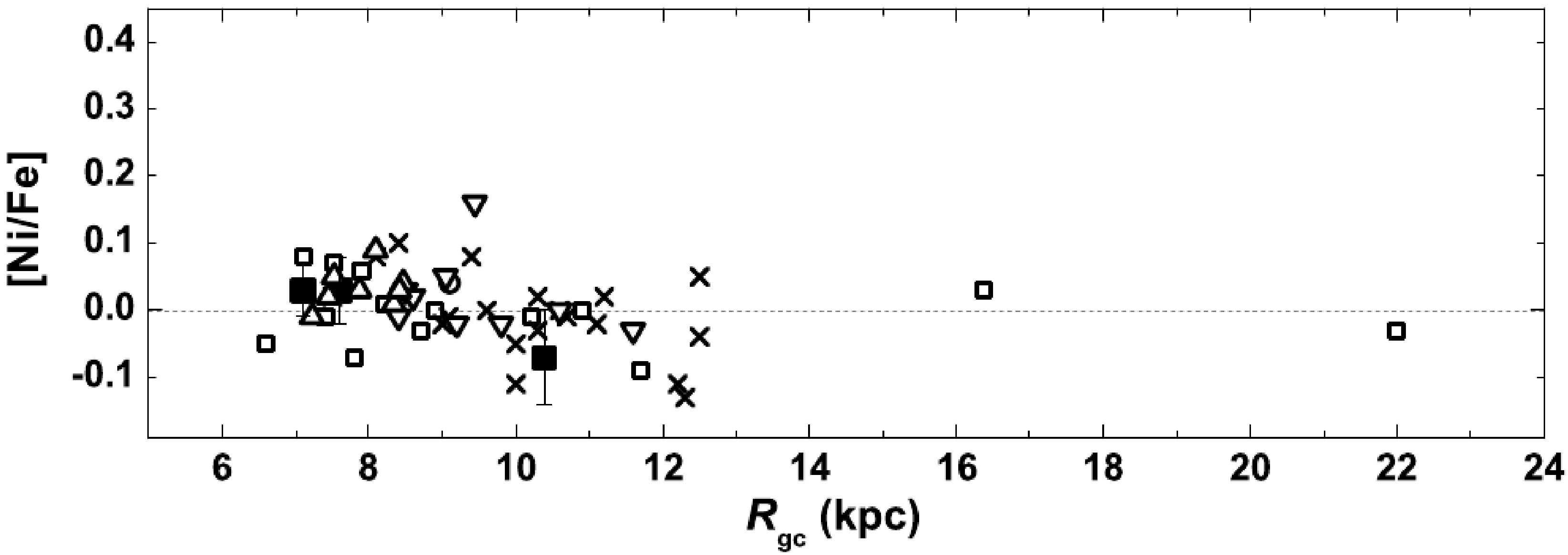


[N/Fe]
0.0
0.1
0.2
0.3
0.4
0.5
0
1
2
3
4
5
6
Age(Gyr)



1st dredge-up
TH
TH+V(110)
TH+V(250)
CBP
C/N
2.5
2.0
1.5
1.0
1
2
3
4
M/M_{Sun}


[Mg/Fe]
[Si/Fe]
[Ca/Fe]
[Ti/Fe]
R_{gc}(kpc)



[Ni/Fe]
0.4
0.3
0.2
0.1
0.0
-0.1
6
8
10
12
14
16
18
20
22
24
R_{gc} (kpc)

Local stellar kinematics from RAVE data: III. Radial and Vertical Metallicity Gradients based on Red Clump Stars

S. Bilir [1⋆], S. Karaali[1]†, S. Ak[1], Ö. Önal[1], N. D. Dağtekin[1], T. Yontan[1],
G. Gilmore[2,3], G. M. Seabroke[4]

ABSTRACT

We investigate radial and vertical metallicity gradients for a sample of red clump stars from the RAdial Velocity Experiment (RAVE) Data Release 3. We select a total of 6781 stars, using a selection of colour, surface gravity and uncertainty in the derived space motion, and calculate for each star a probabilistic (kinematic) population assignment to a thin or thick disc using space motion and additionally another (dynamical) assignment using stellar vertical orbital eccentricity. We derive almost equal metallicity gradients as a function of Galactocentric distance for the high probability thin disc stars and for stars with vertical orbital eccentricities consistent with being dynamically young, $e_v \leqslant 0.07$, i.e. $d[M/H]/dR_m = -0.041 \pm 0.003$ and $d[M/H]/dR_m = -0.041 \pm 0.007$ dex kpc^{-1}. Metallicity gradients as a function of distance from the Galactic plane for the same populations are steeper, i.e. $d[M/H]/dz_{max} = -0.109 \pm 0.008$ and $d[M/H]/dz_{max} = -0.260 \pm 0.031$ dex kpc^{-1}, respectively. R_m and z_{max} are the arithmetic mean of the perigalactic and apogalactic distances, and the maximum distance to the Galactic plane, respectively. Samples including more thick disc red clump giant stars show systematically shallower abundance gradients. These findings can be used to distinguish between different formation scenarios of the thick and thin discs.

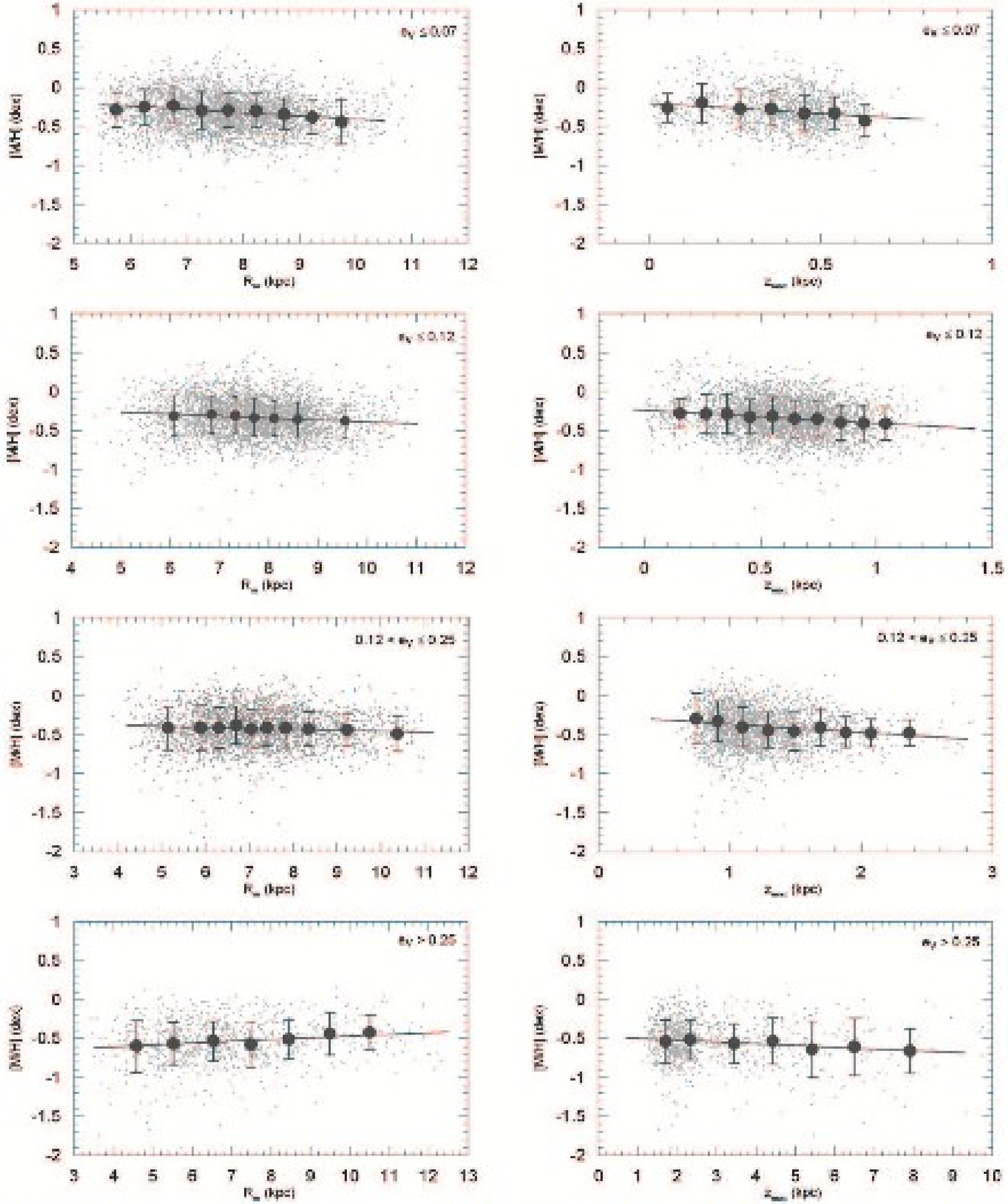
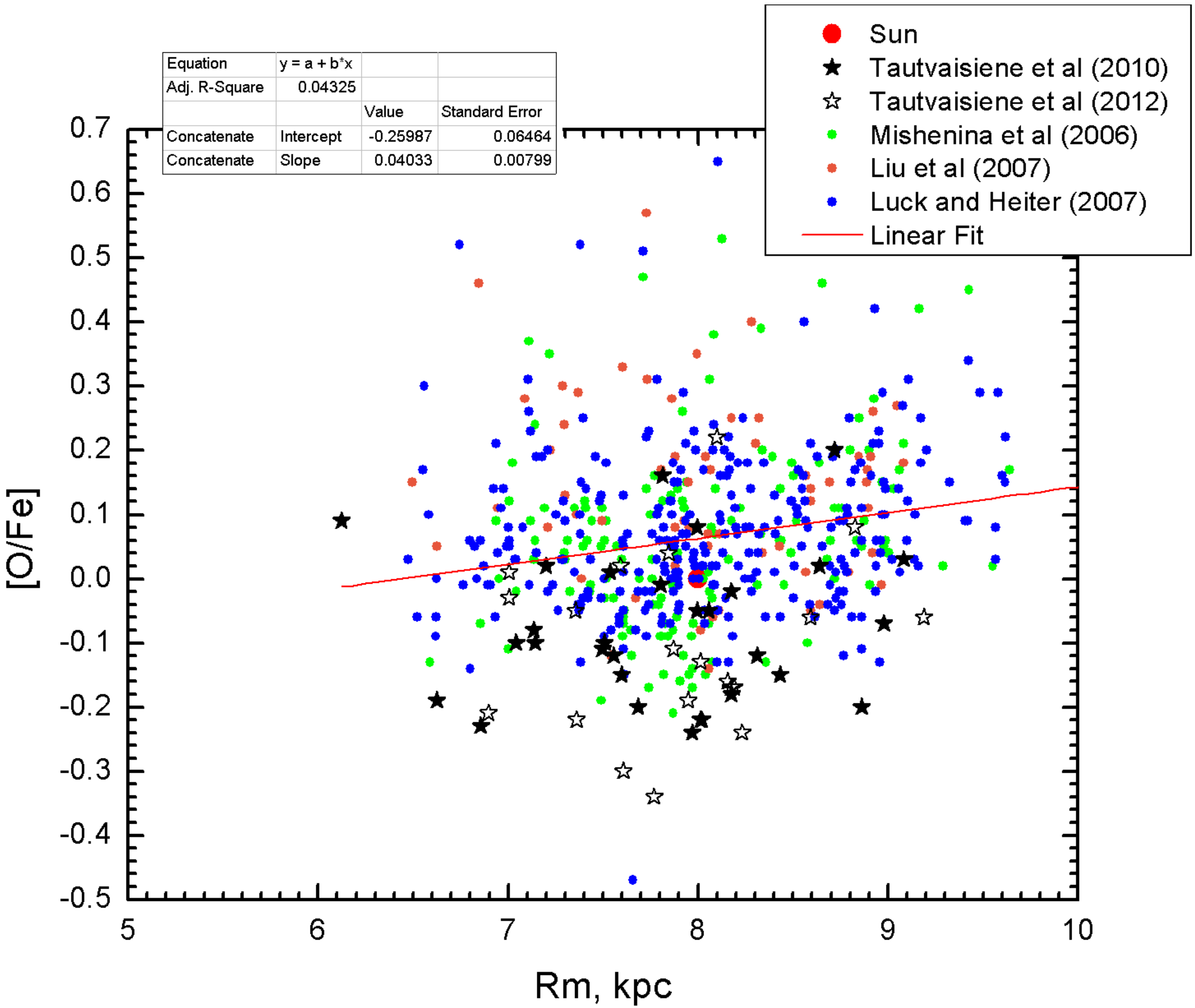
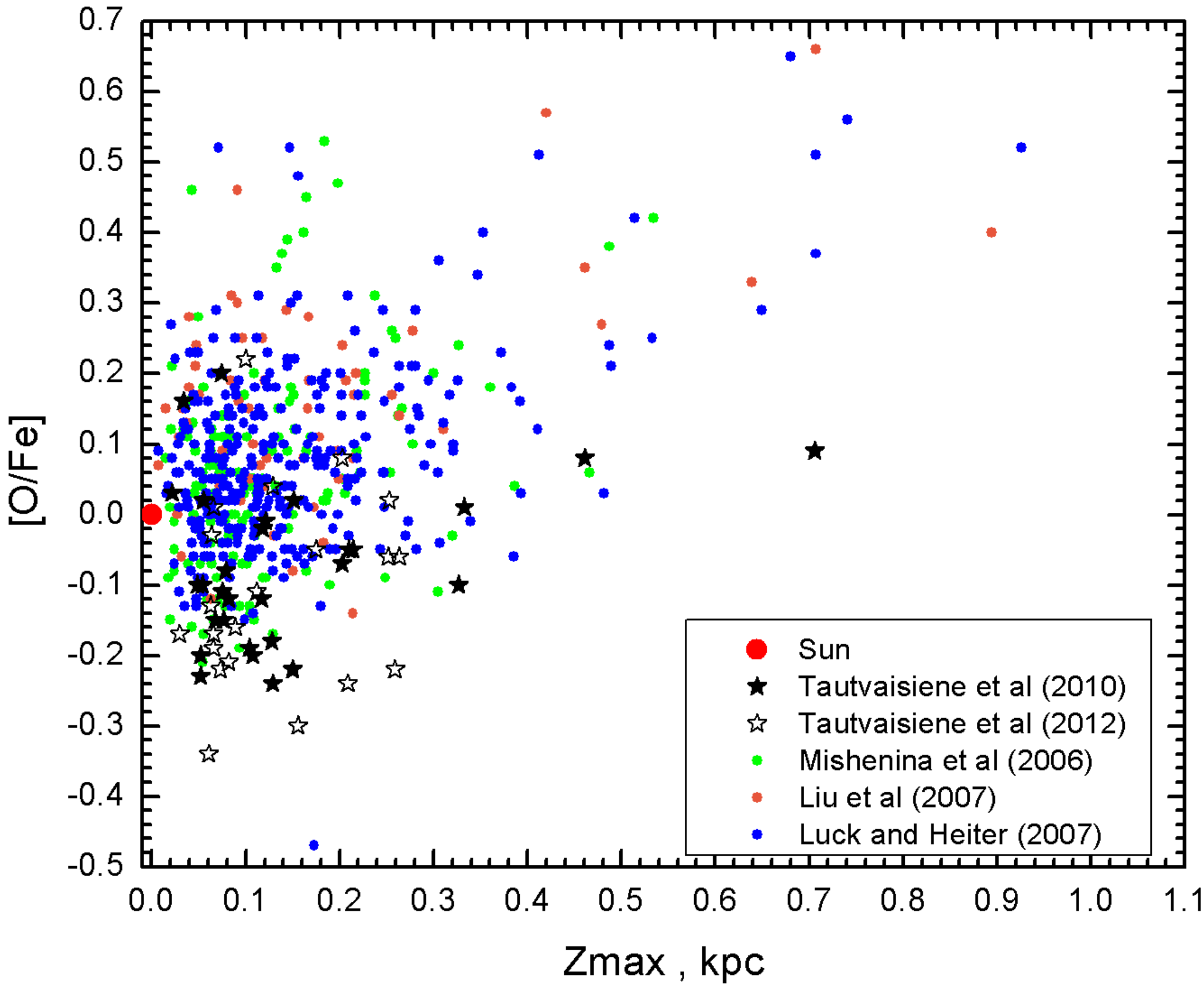
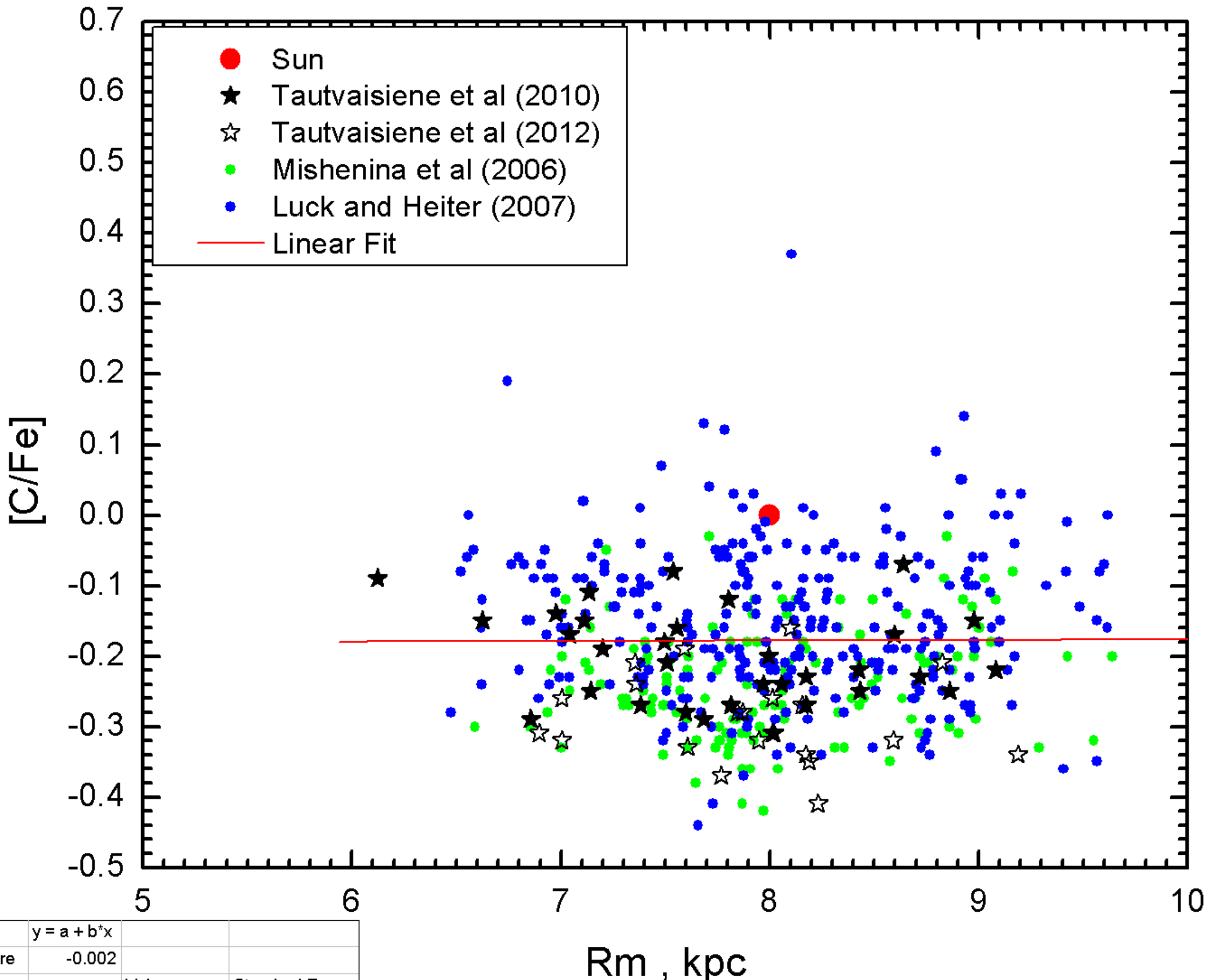


Figure 15. Radial (R_m-$[M/H]$) and vertical (z_{max}-$[M/H]$) metallicity gradients for the red clump sub-samples, subdivided by vertical orbital eccentricity.

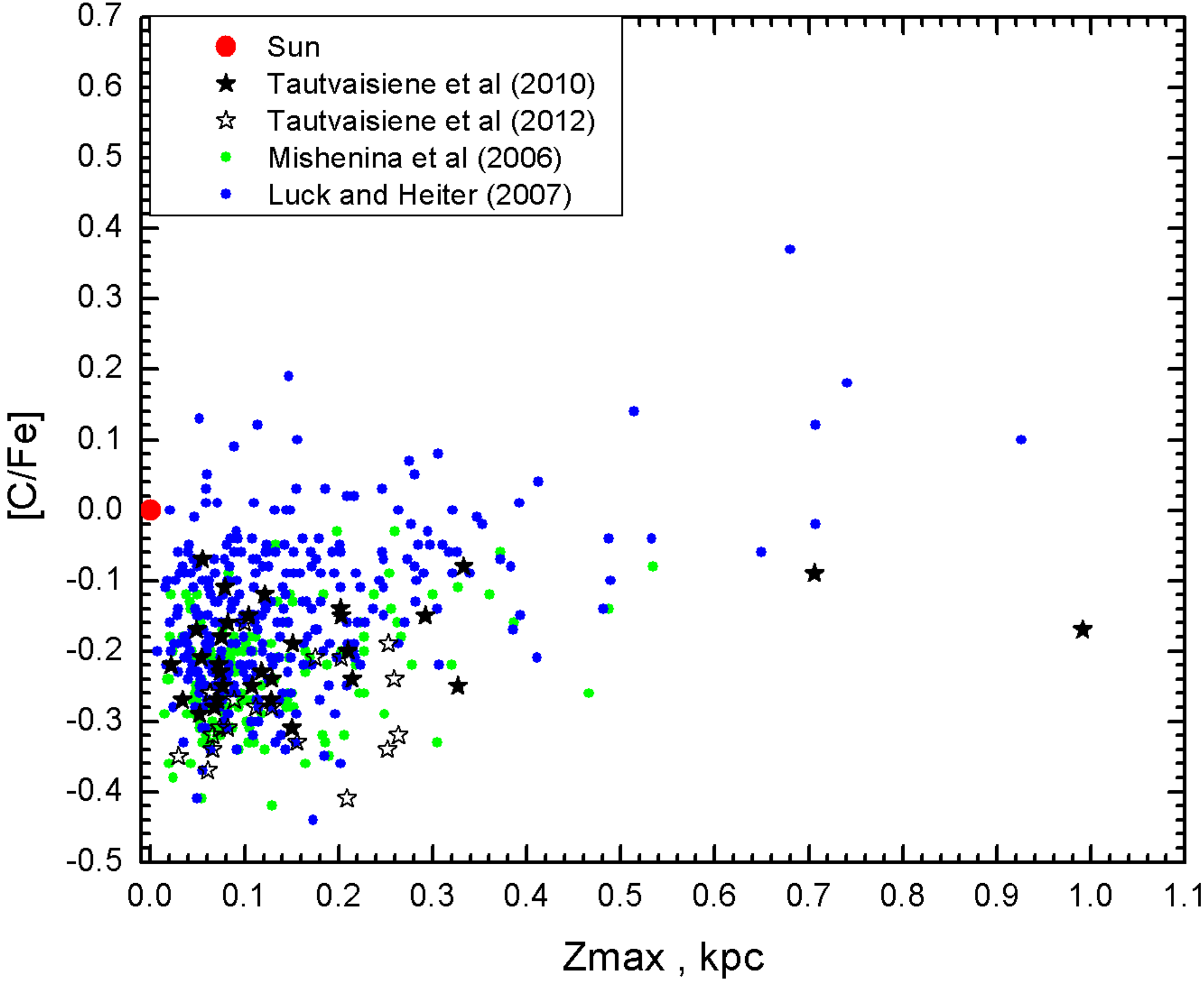

Equation | y = a + b*x
Adj. R-Square | 0.04325
Value | Standard Error
Concatenate | Intercept | -0.25987 | 0.06464
Concatenate | Slope | 0.04033 | 0.00799
Sun
Tautvaisiene et al (2010)
Tautvaisiene et al (2012)
Mishenina et al (2006)
Liu et al (2007)
Luck and Heiter (2007)
Linear Fit
[O/Fe]
Rm, kpc
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
5
6
7
8
9
10

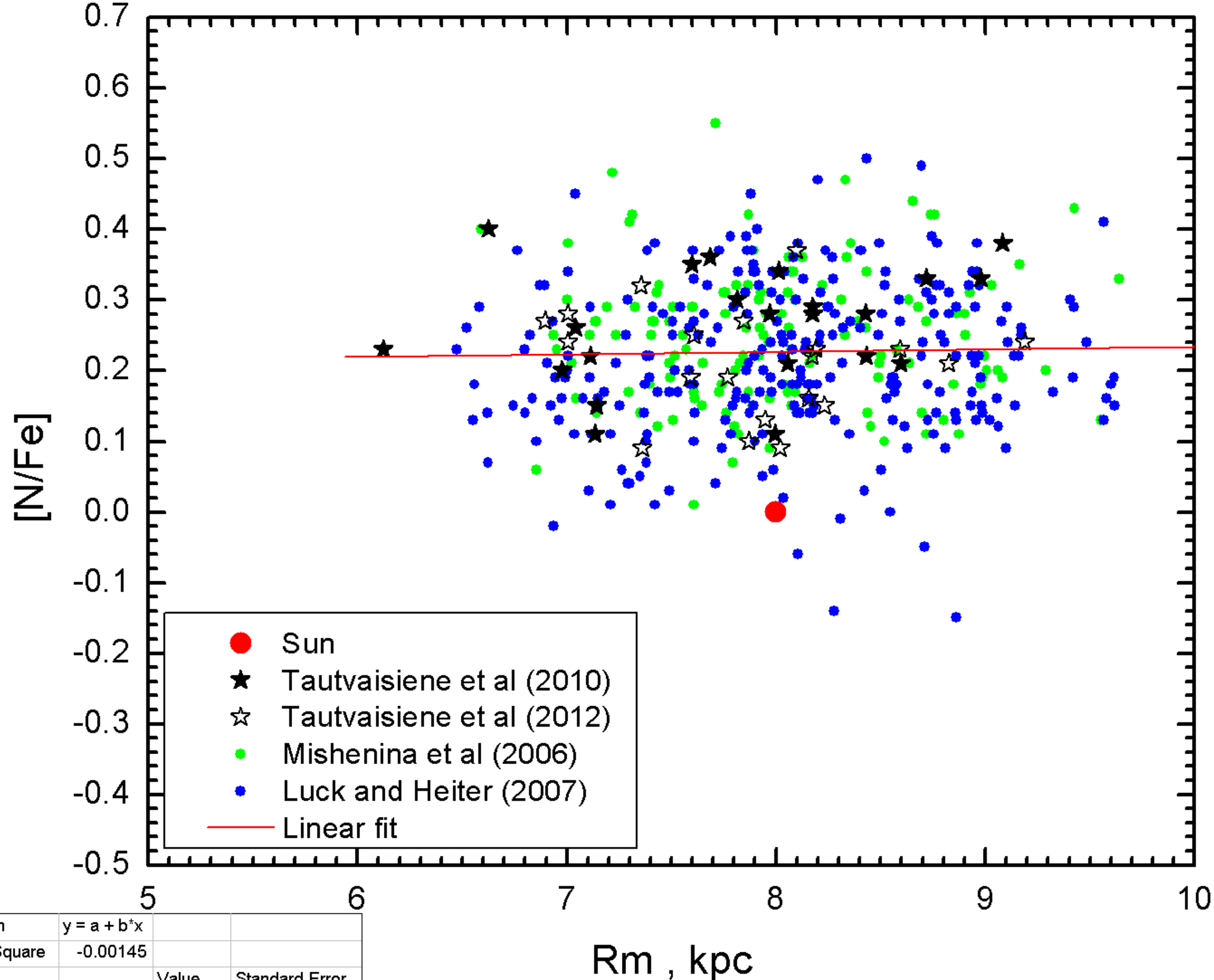


[O/Fe]
Zmax , kpc
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Sun
Tautvaisiene et al (2010)
Tautvaisiene et al (2012)
Mishenina et al (2006)
Liu et al (2007)
Luck and Heiter (2007)

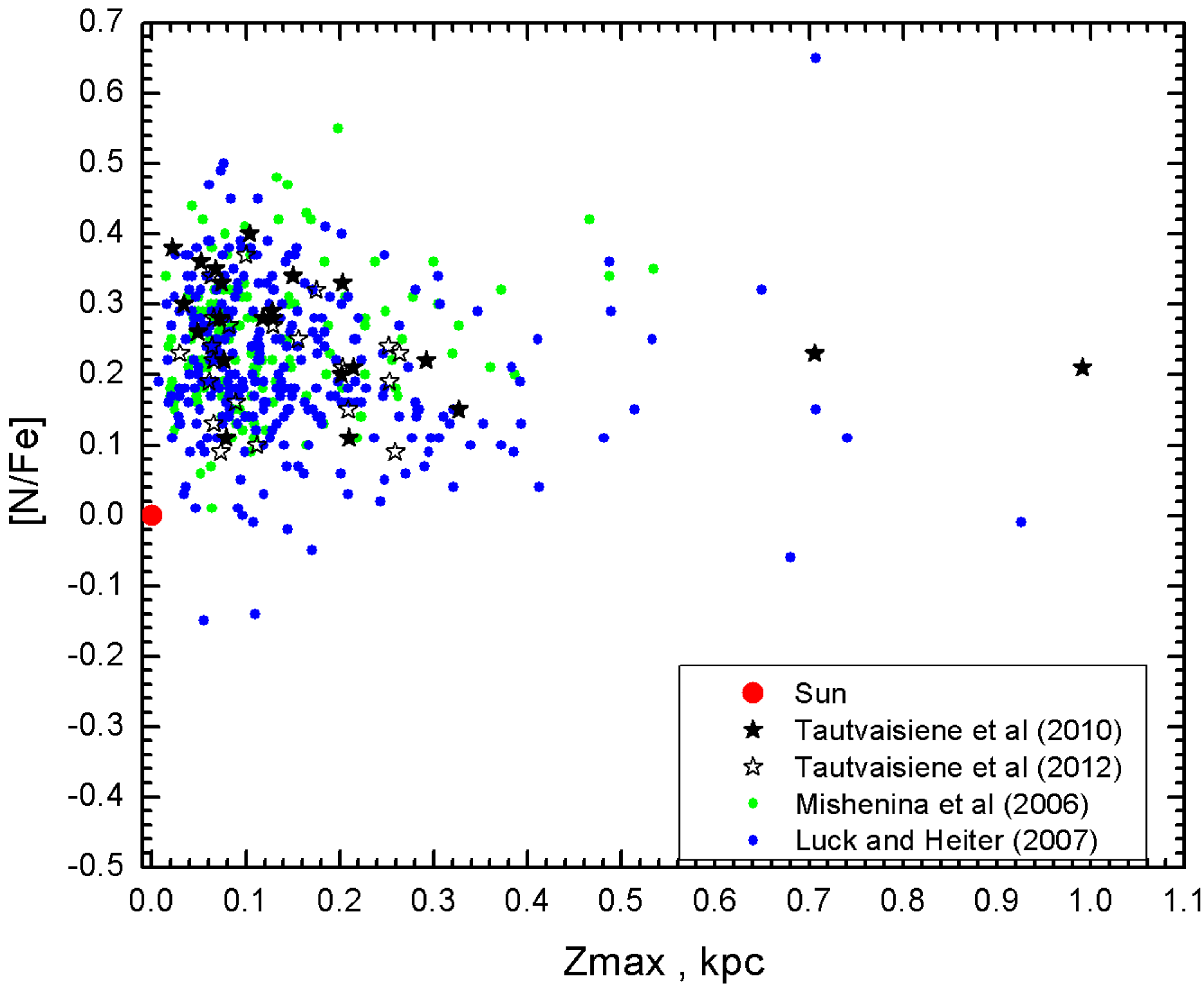


Equation	y = a + b*x		
Adj. R-Square	-0.002		
		Value	Standard Error
Concatenate	Intercept	-0.18482	0.04968
Concatenate	Slope	8.25468E-4	0.00616


Sun
Tautvaisiene et al (2010)
Tautvaisiene et al (2012)
Mishenina et al (2006)
Luck and Heiter (2007)
[C/Fe]
Zmax , kpc
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1

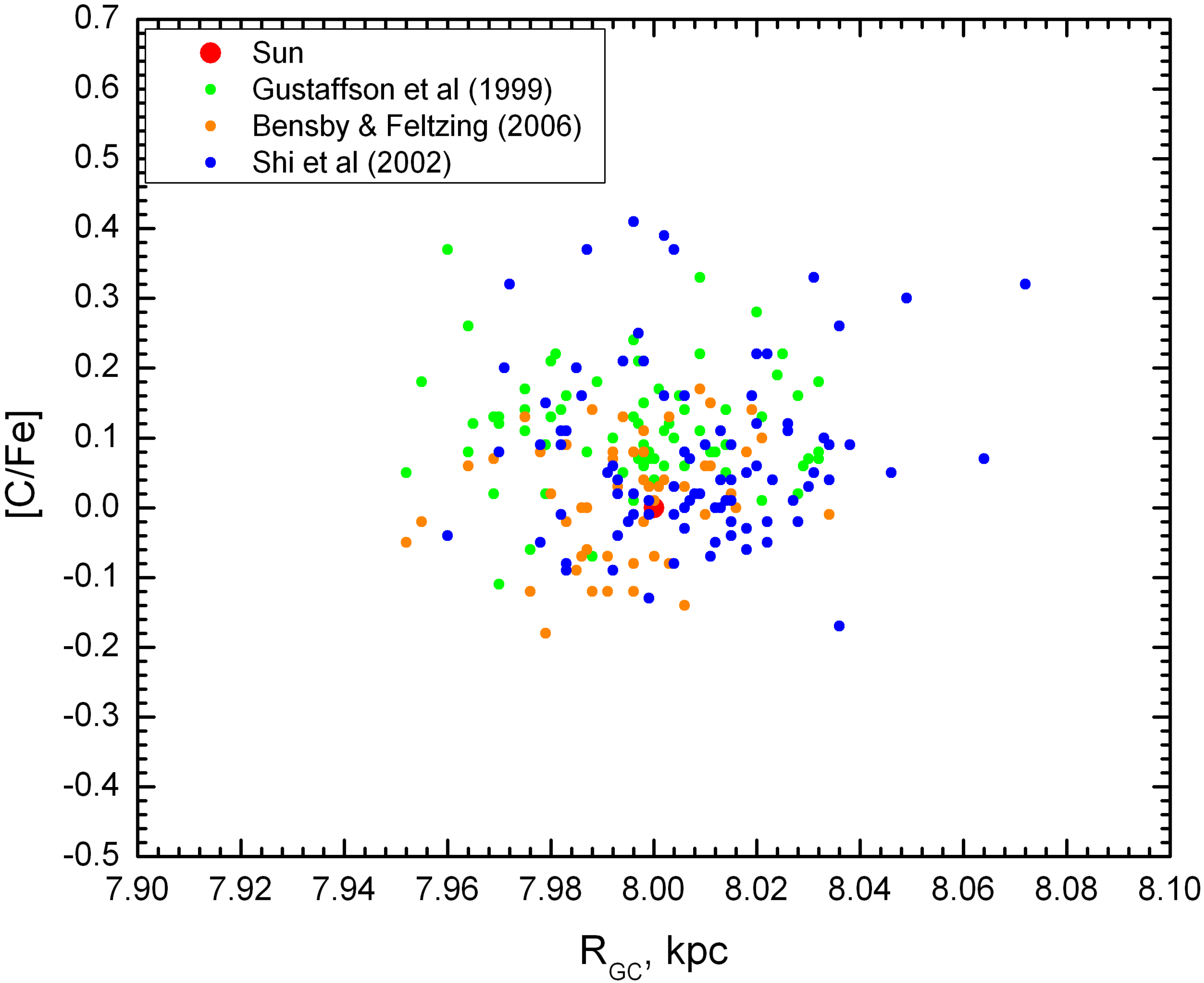


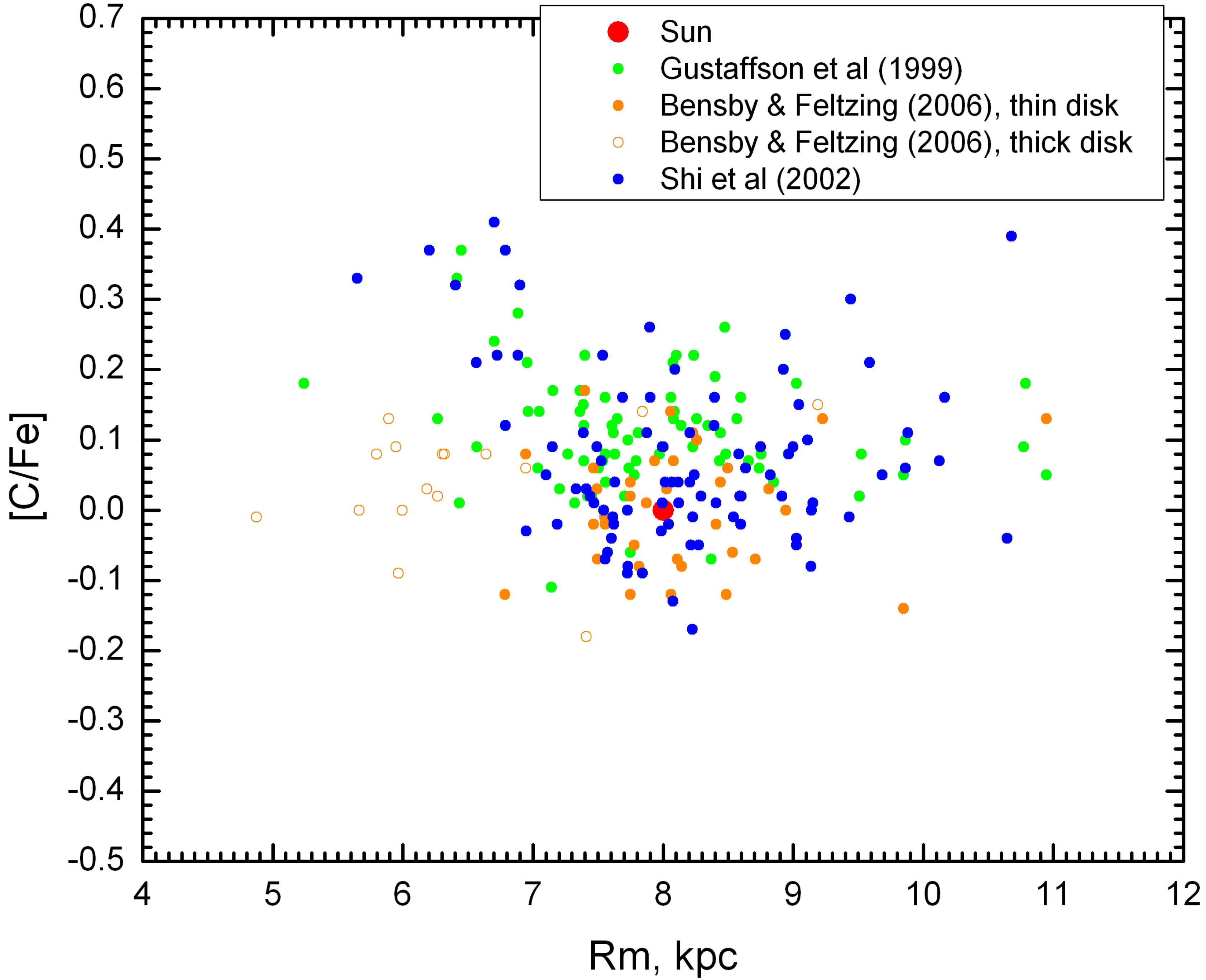
Equation	y = a + b*x		
Adj. R-Square	-0.00145		
		Value	Standard Error
Concatenate	Intercept	0.1976	0.04908
Concatenate	Slope	0.00355	0.00609



0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
[N/Fe]
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
Zmax , kpc
Sun
Tautvaisiene et al (2010)
Tautvaisiene et al (2012)
Mishenina et al (2006)
Luck and Heiter (2007)

Dwarfs


Sun
Gustaffson et al (1999)
Bensby & Feltzing (2006)
Shi et al (2002)
[C/Fe]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
7.90
7.92
7.94
7.96
7.98
8.00
8.02
8.04
8.06
8.08
8.10
R_{GC}, kpc



Sun
Gustaffson et al (1999)
Bensby & Feltzing (2006), thin disk
Bensby & Feltzing (2006), thick disk
Shi et al (2002)
[C/Fe]
Rm, kpc
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
4
5
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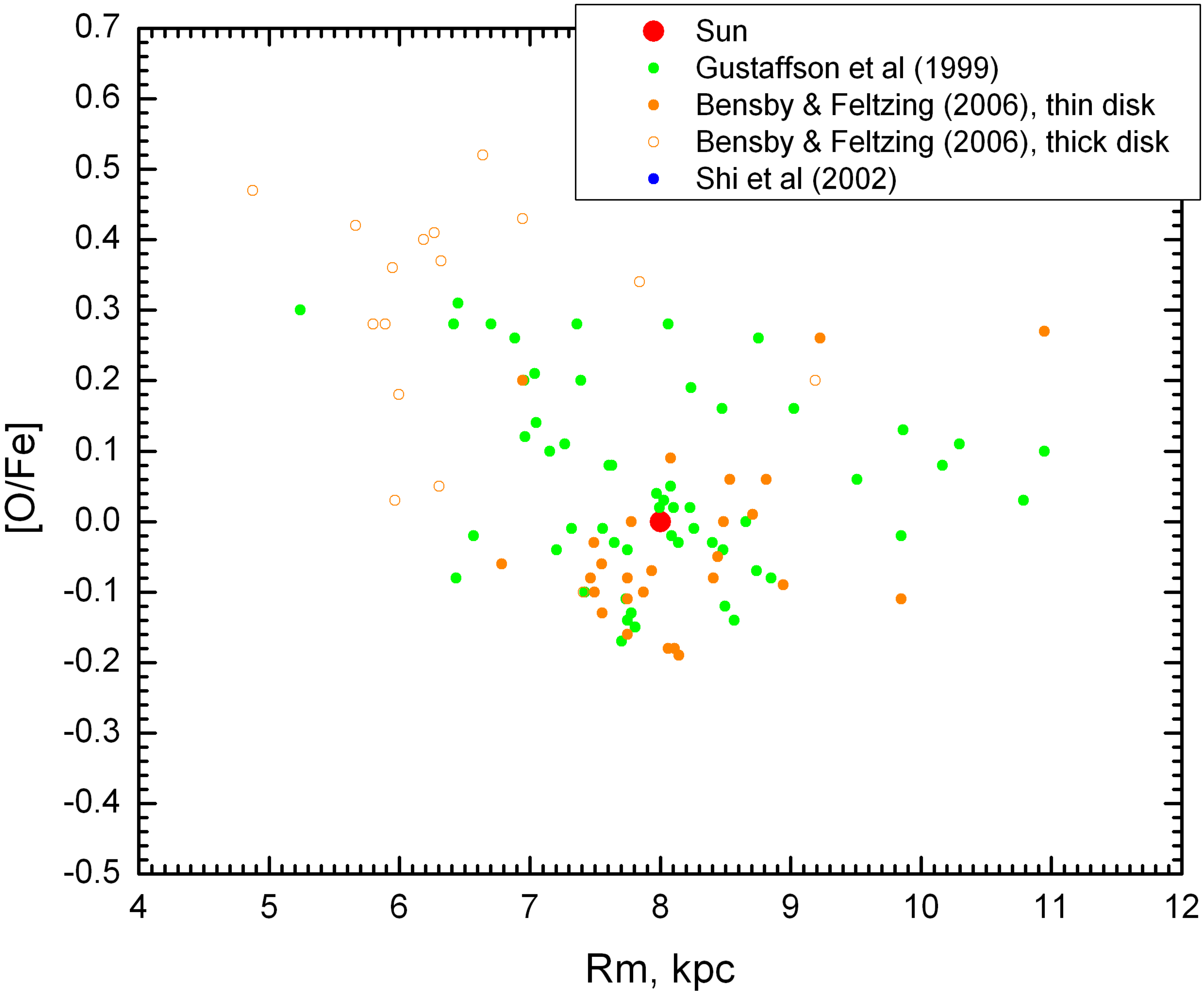
11
12


Sun
Gustaffson et al (1999)
Bensby & Feltzing (2006), thin disk
Bensby & Feltzing (2006), thick disk
Shi et al (2002)
[O/Fe]
Rm, kpc
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
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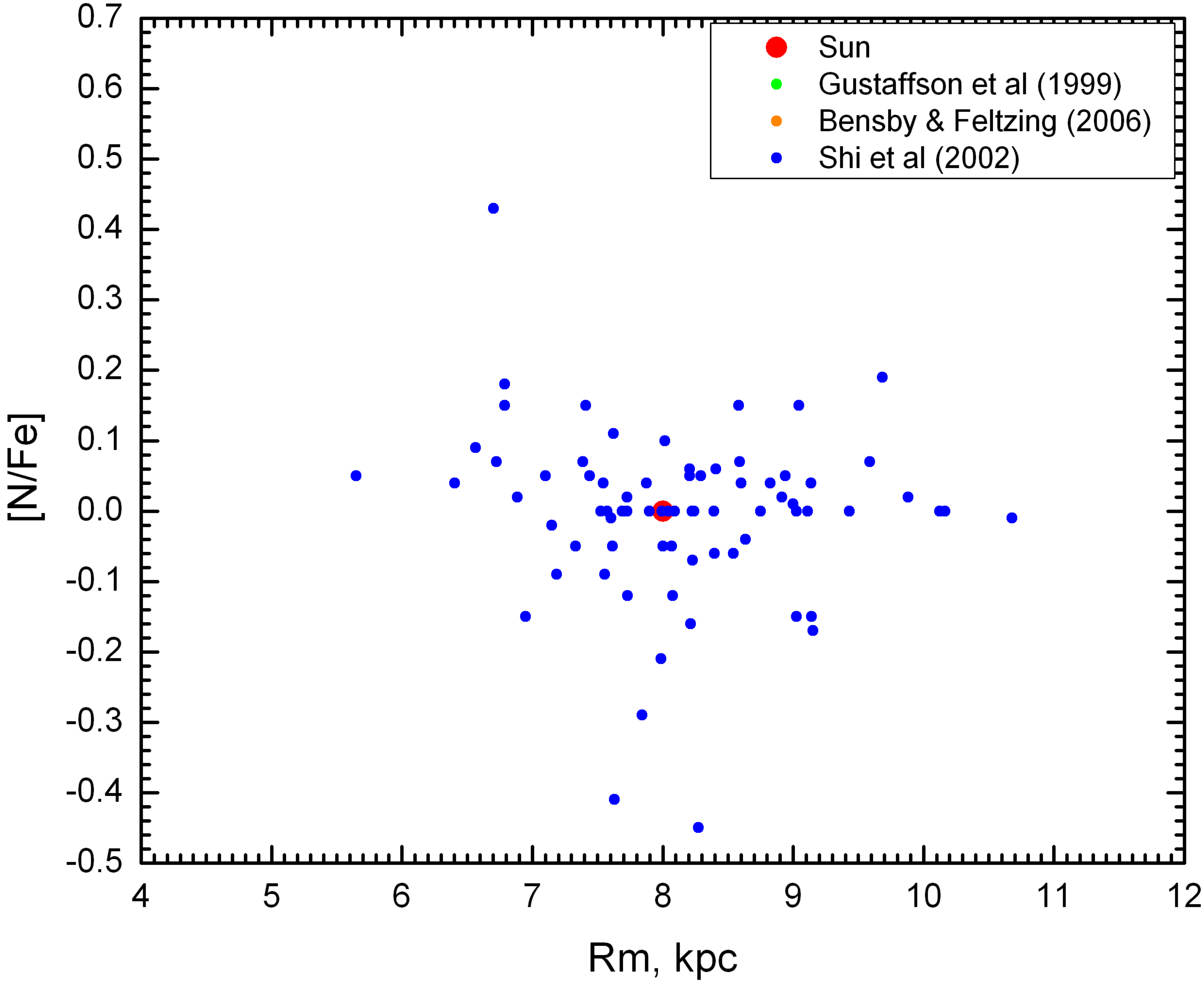
Sun
Gustaffson et al (1999)
Bensby & Feltzing (2006)
Shi et al (2002)
[N/Fe]
Rm, kpc
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
4
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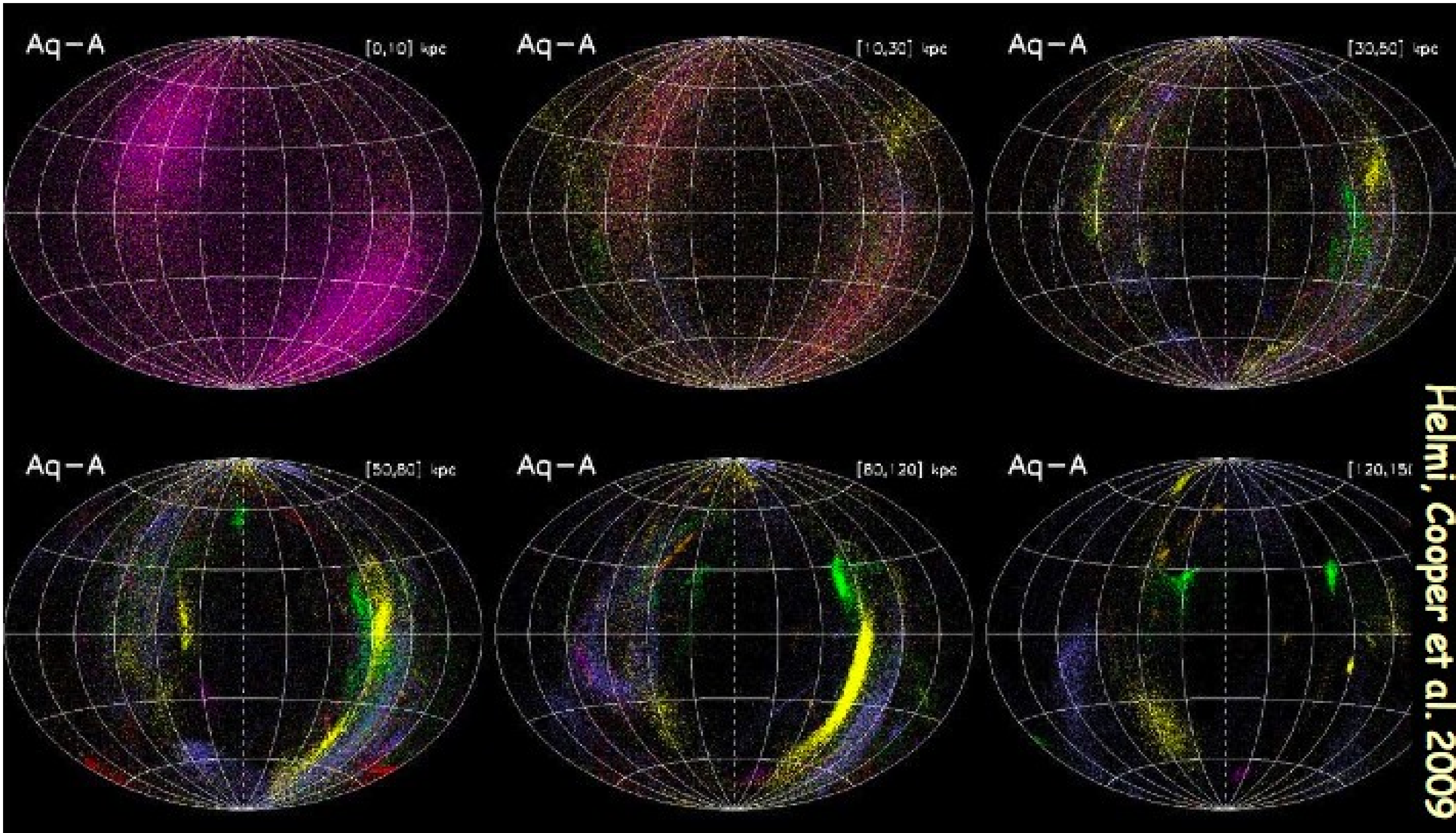
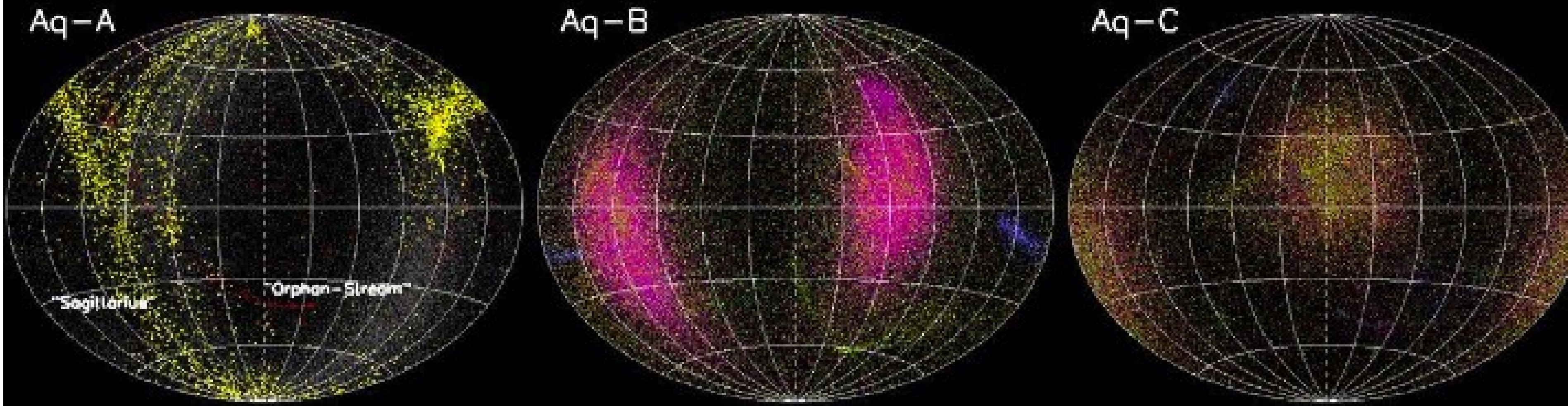
11
12

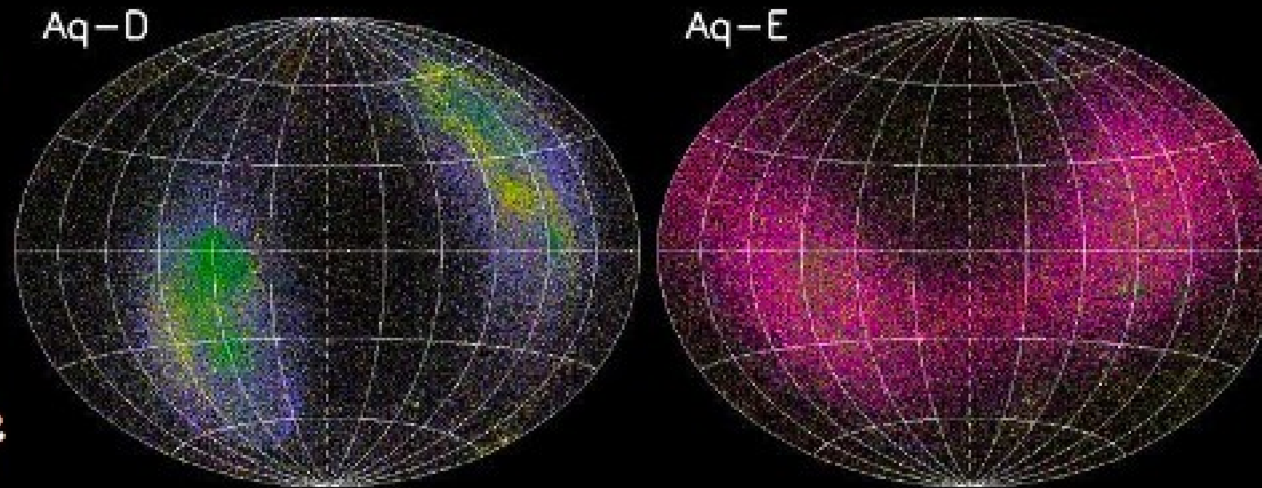
Conclusions II

- Work on stellar CNO abundance radial gradients in the Galactic disk is on its initial stage
- Stars of the thin and thick discs should be analysed separately
- Giants of the same evolutionary stage also may be useful
- Most trustful spectral features should be used
- Promising results to come from AMBRE, APOGEE, Gaia-ESO Sp. Survey, Gaia, etc.

Chemical composition of kinematic groups





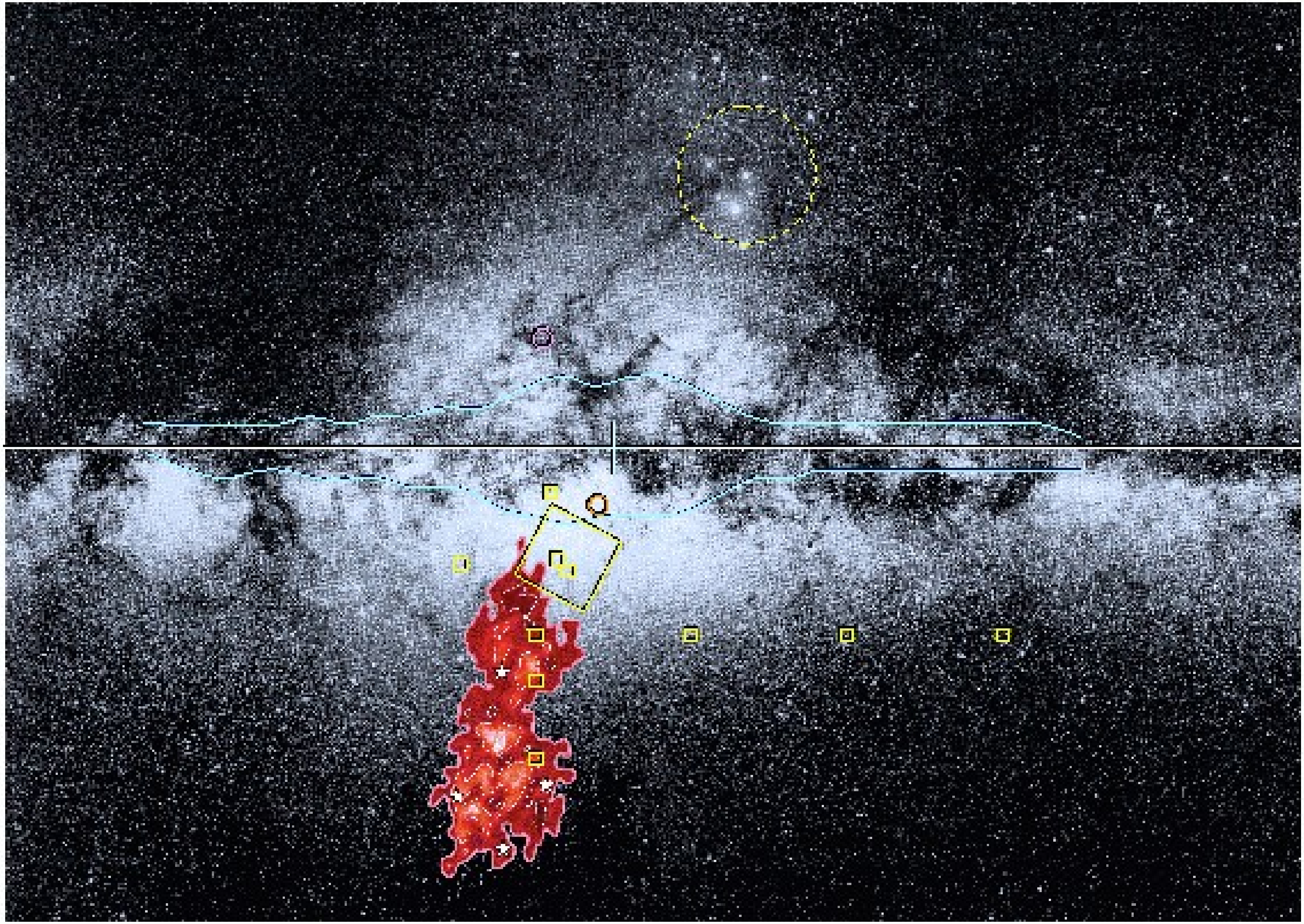


Broad/diffuse features dominant

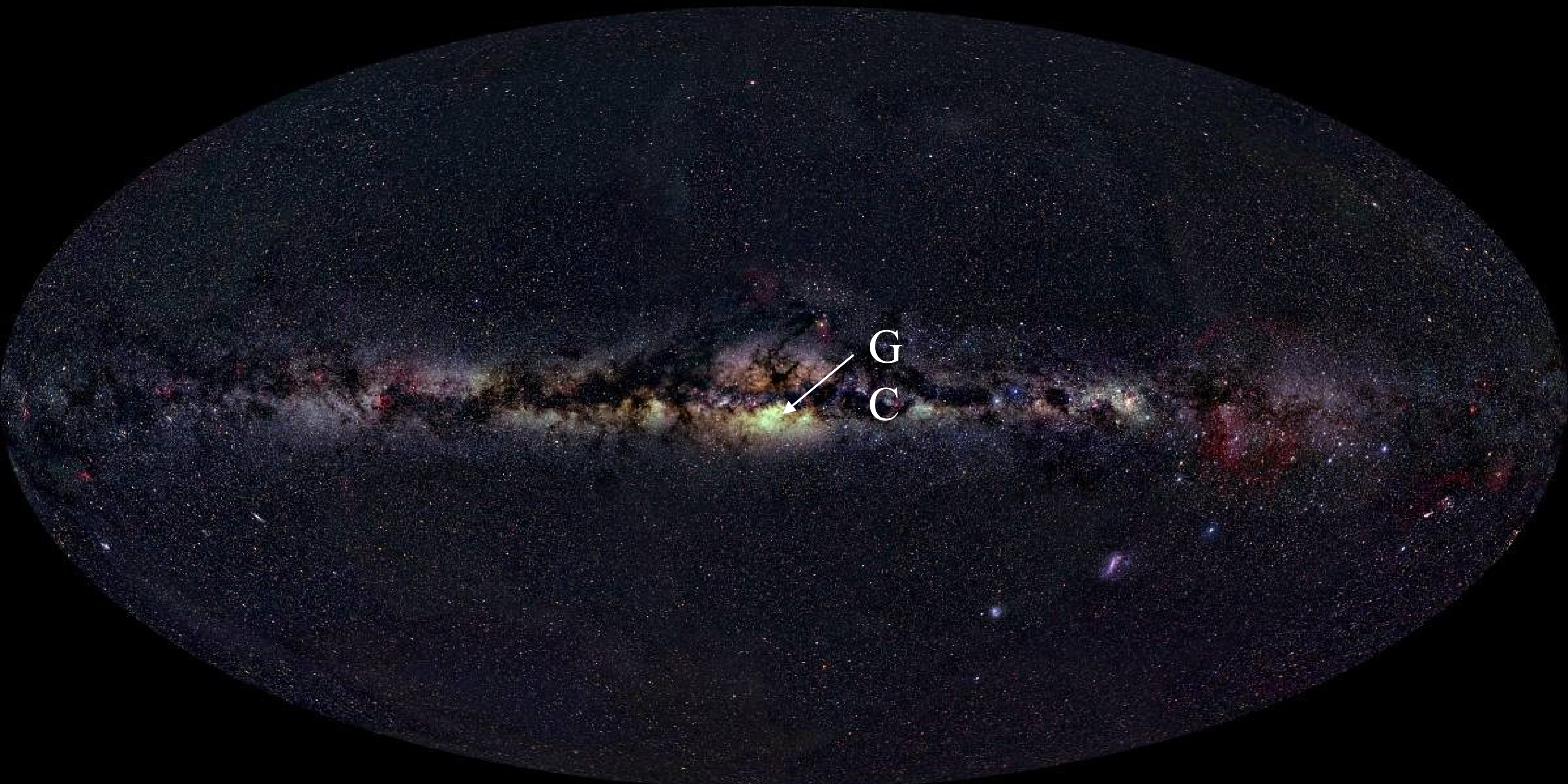
Narrow streams also present

Sgr and O-stream visible in the Aq-A sky!

Helmi, Cooper et al. 2009



The Deep Sky



Spectra of one thousand million of stars from *Gaia* space observatory will be provided starting from 2014