Abundances in Halo stars

P. Bonifacio

CIFIST Marie Curie Excellence Team

Observatoire de Paris

INAF-Osservatorio Astronomico di Trieste

I will describe results obtained in the last two years in collaboration with a LARGE number of people, in alphabetical order:

J.Andersen, B. Barbuy, T.C. Beers, G. Bihain,
E. Caffau, E. Carretta, R. Cayrel E. Depagne,
A. Ecuvillion, R. Faraggiana, P. François , D. Galli,
R. Gàrcia-Lòpez, R. Gratton, V. Hill, G. Israelian,
G. James, P. Molaro, B. Nordström,
L. Pasquini, B. Plez, F. Primas, S. Randich, R. Rebolo,
T. Sivarani,F. Spite, M. Spite, B. Wolff

Ancient stars (t>13 Gyr) provide the fossil record of the products of the first generation of stars.

Considerable advances in our knowledge of their chemical composition have come from the use of 8m class telescopes.

In particular the ESO-Large programme “First Stars” (PI R. Cayrel, 38 nights at VLT), but also many other parallel efforts

I will try to work my way through the periodic table, starting from the lightest elements

Lithium

It is the most massive nucleus produced during primordial nucleosynthesis

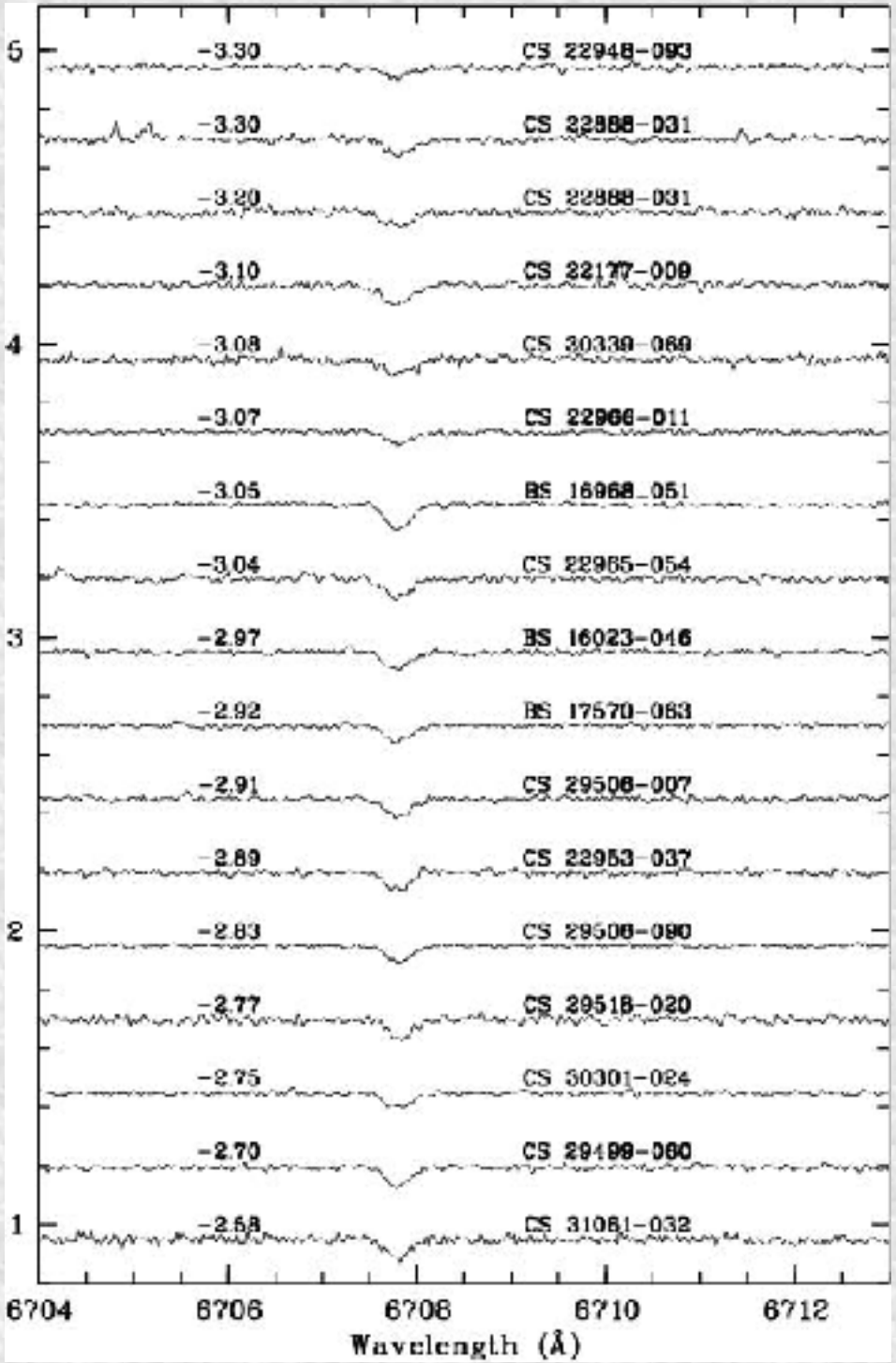
In 1982 Spite & Spite observed that the Li abundance in metal-poor stars was constant (*Spite plateau)* $\Rightarrow$ this is the primordial abundance

Li abundance can be used to derive baryon-to-photon ratio

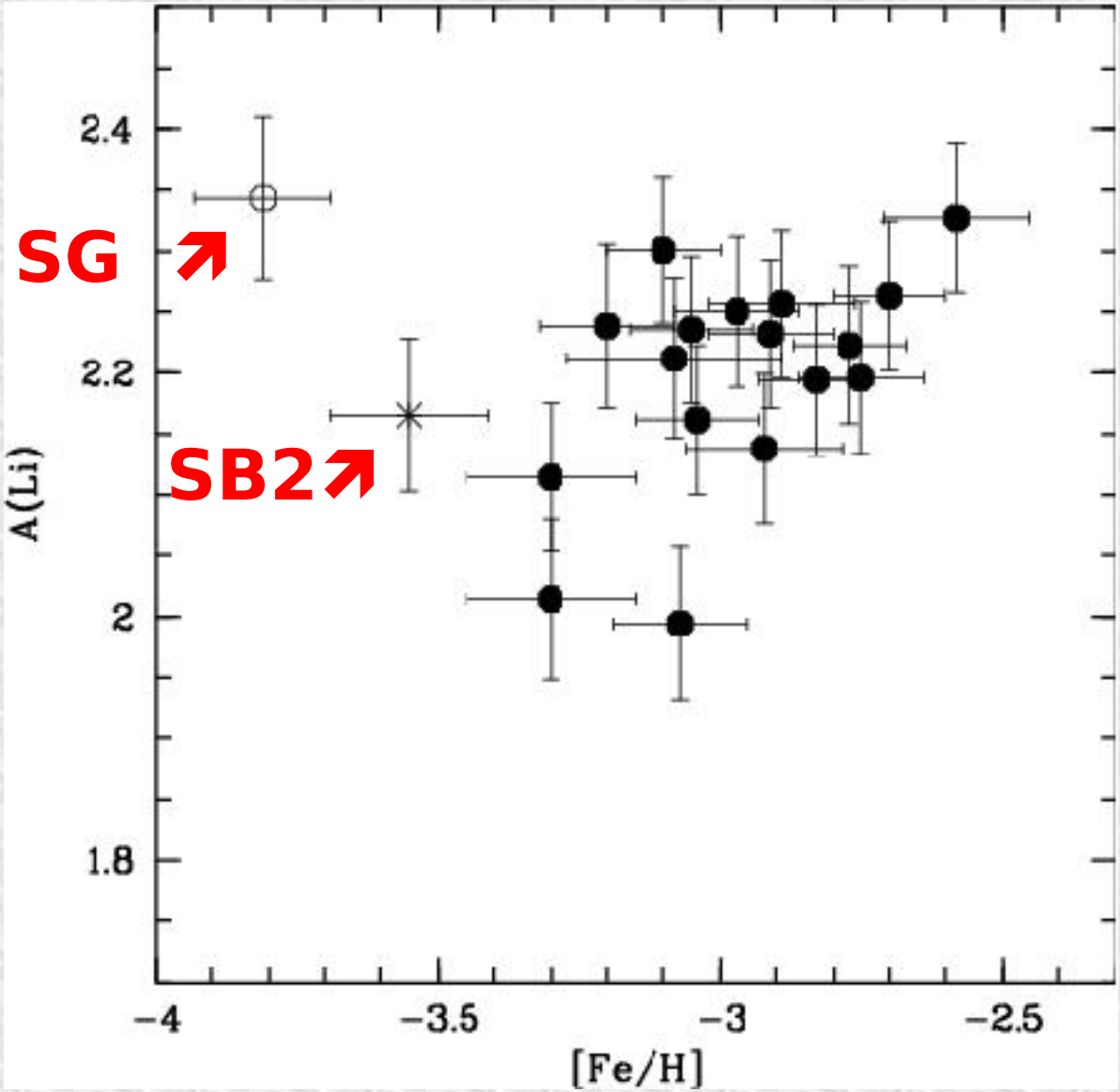
But… 2 main problems

1) baryon-to-photon ratio now measured by WMAP, SBBN implies A(Li)≈2.6; the level of the Spite plateau A(Li)≈2.2 or 2.3 …embarassing

2) there are claims that the plateau is NOT flat (Ryan et al. 1999,… Boesgaard et al. 2005), is this indicating that Li there is not primordial ?
(but then why ? Li depletion ? ….)

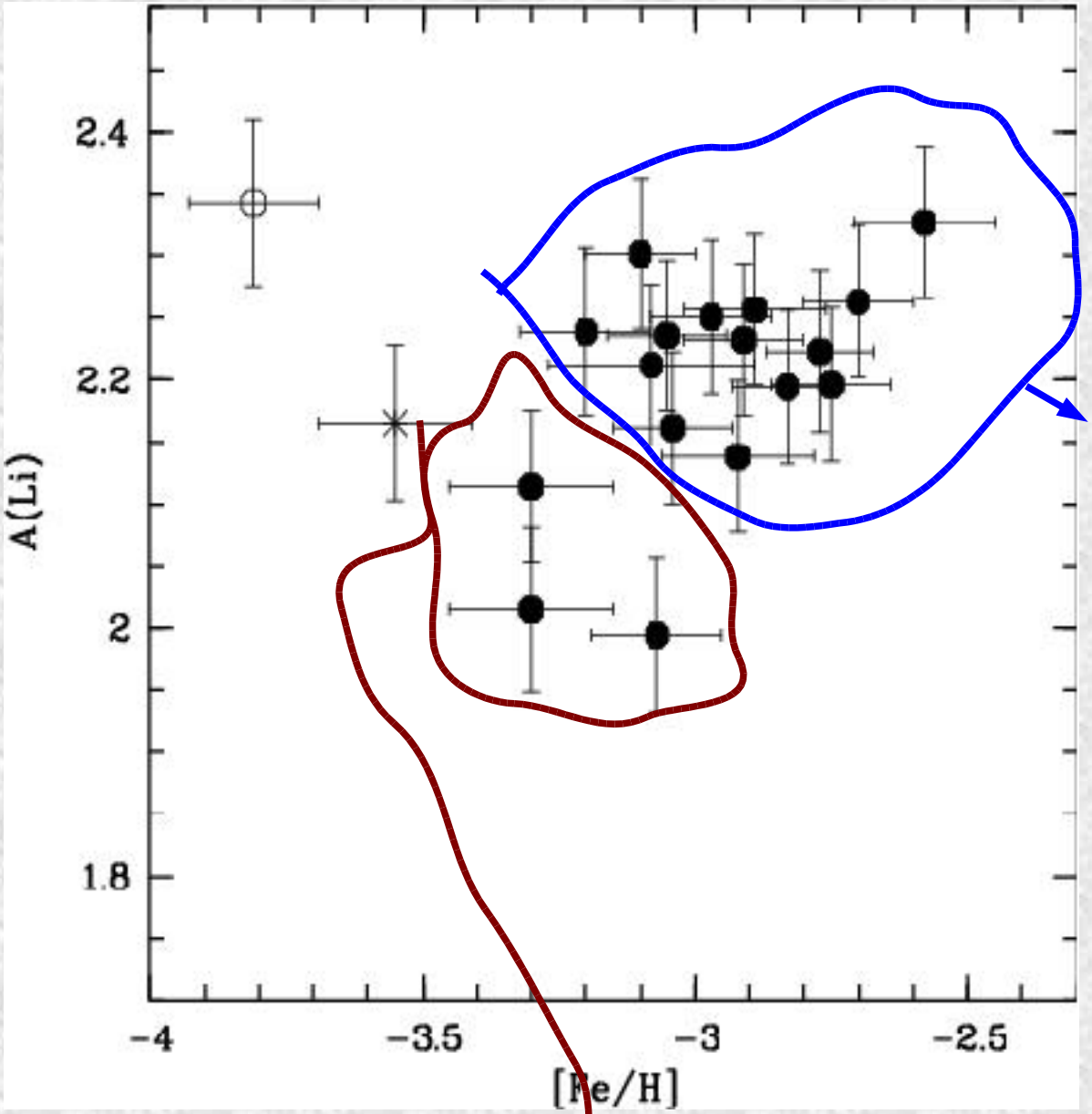


New observations by “First Stars” LP, 17 TO stars
-3.3≤[Fe/H]≤-2.6



<A(Li)> = 2.18 ±0.09

Mean error 0.06 extra scatter ?



<A(Li)>=2.23 ±0.05

<A(Li)>=2.04 ±0.06

SLOPE ?

Kendall's τ prob correlation 90% $\Rightarrow$ NO

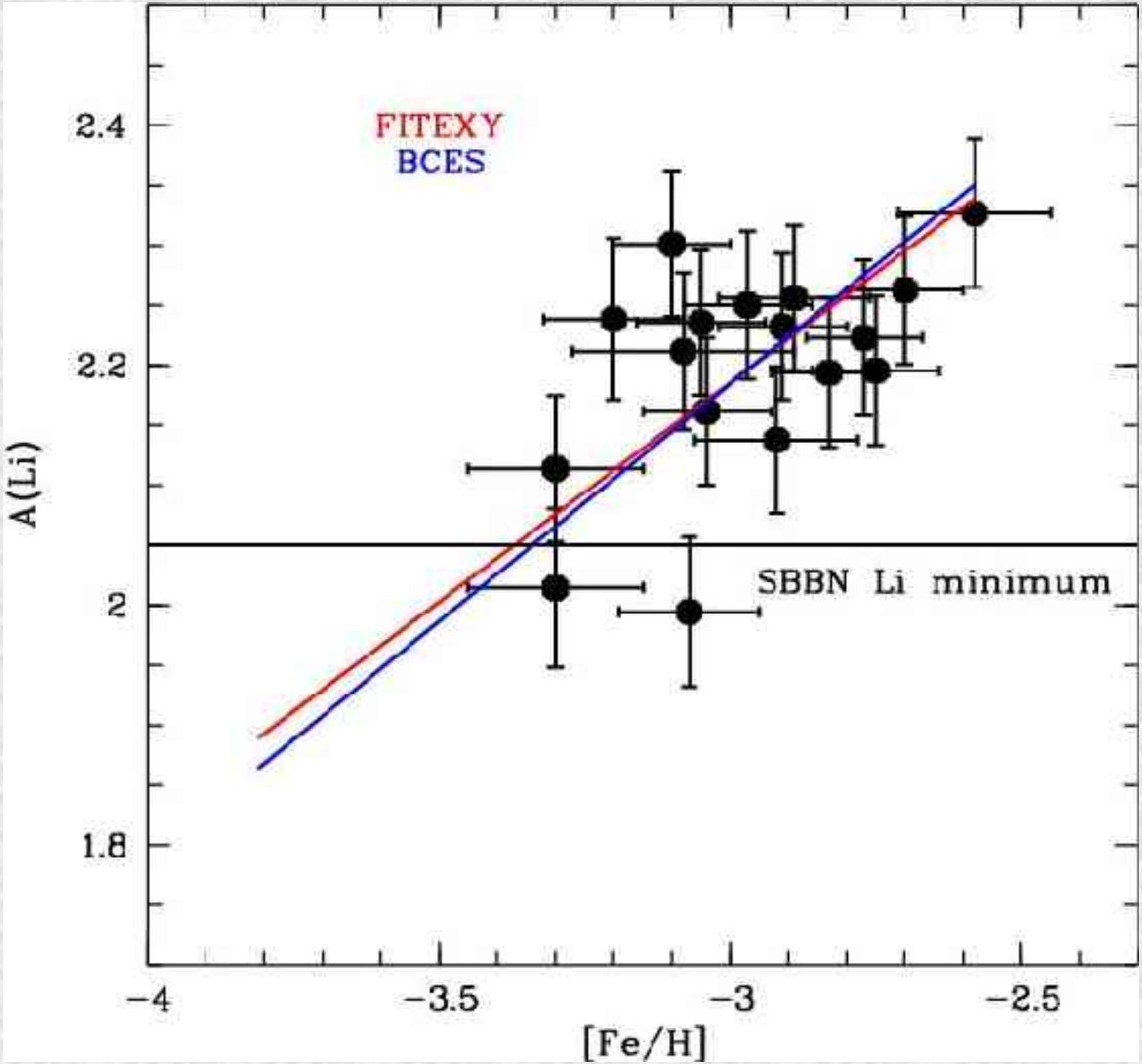
Parametric fits

A(Li) = 3.37(±0.37)+0.40(±0.13) [Fe/H] #BCES

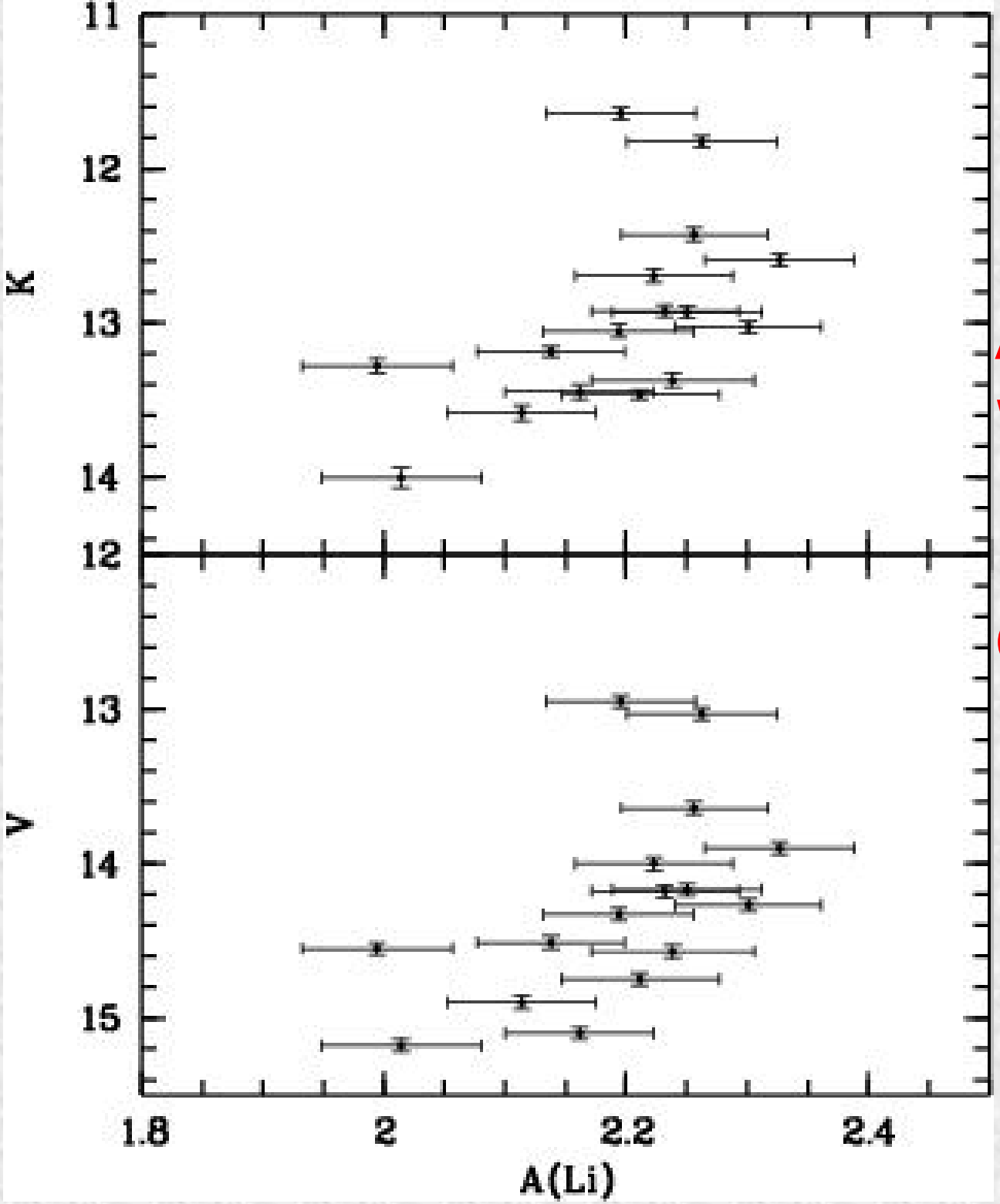
A(Li) = 3.28(±0.36)+0.37(±0.12) [Fe/H] #FITEXY

A(Li) = 2.90(±0.23)+0.24(±0.08) [Fe/H] #FITXY

REASONABLE ?

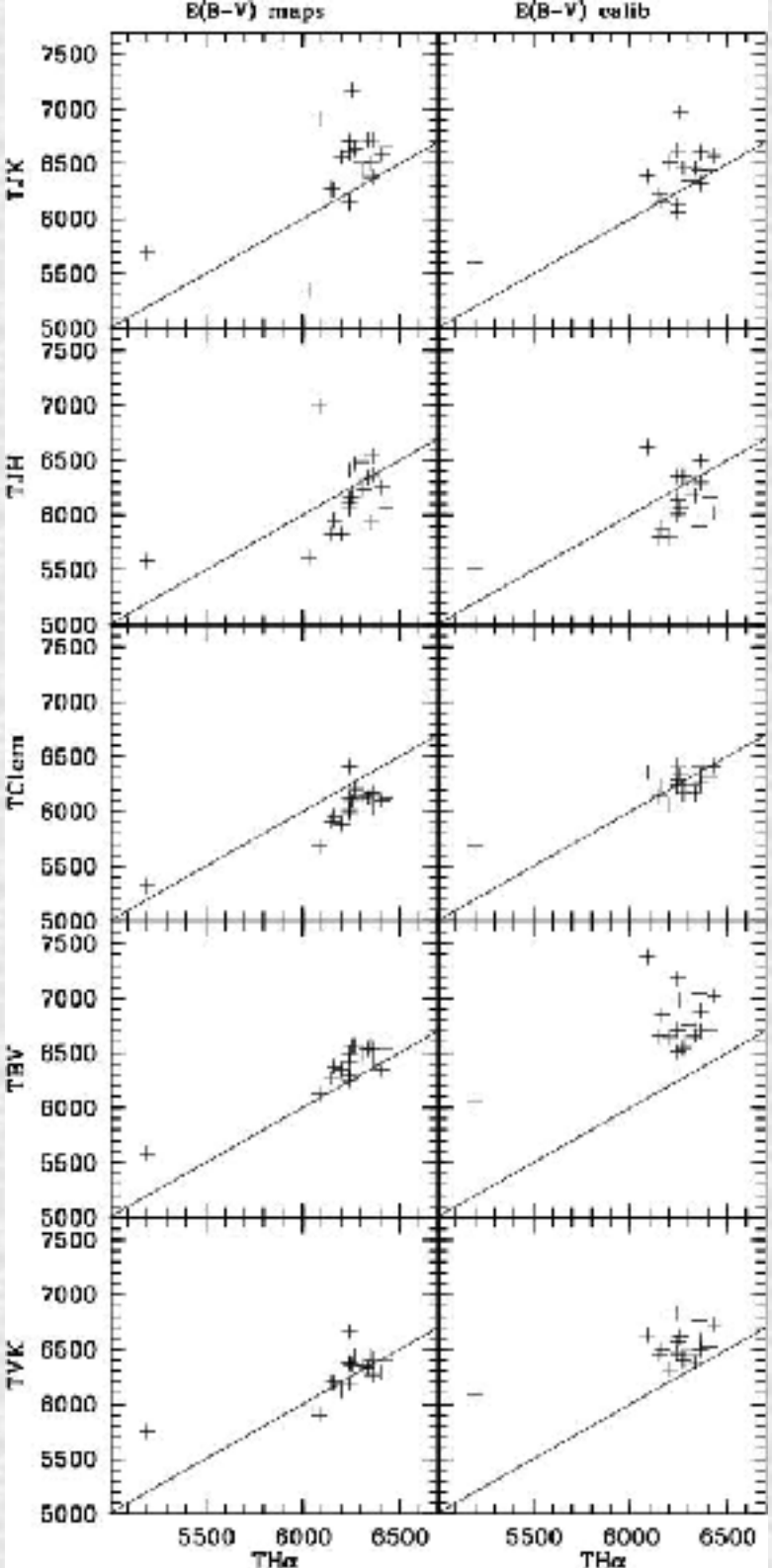


NO !



A(Li) correlated with apparent magnitude.

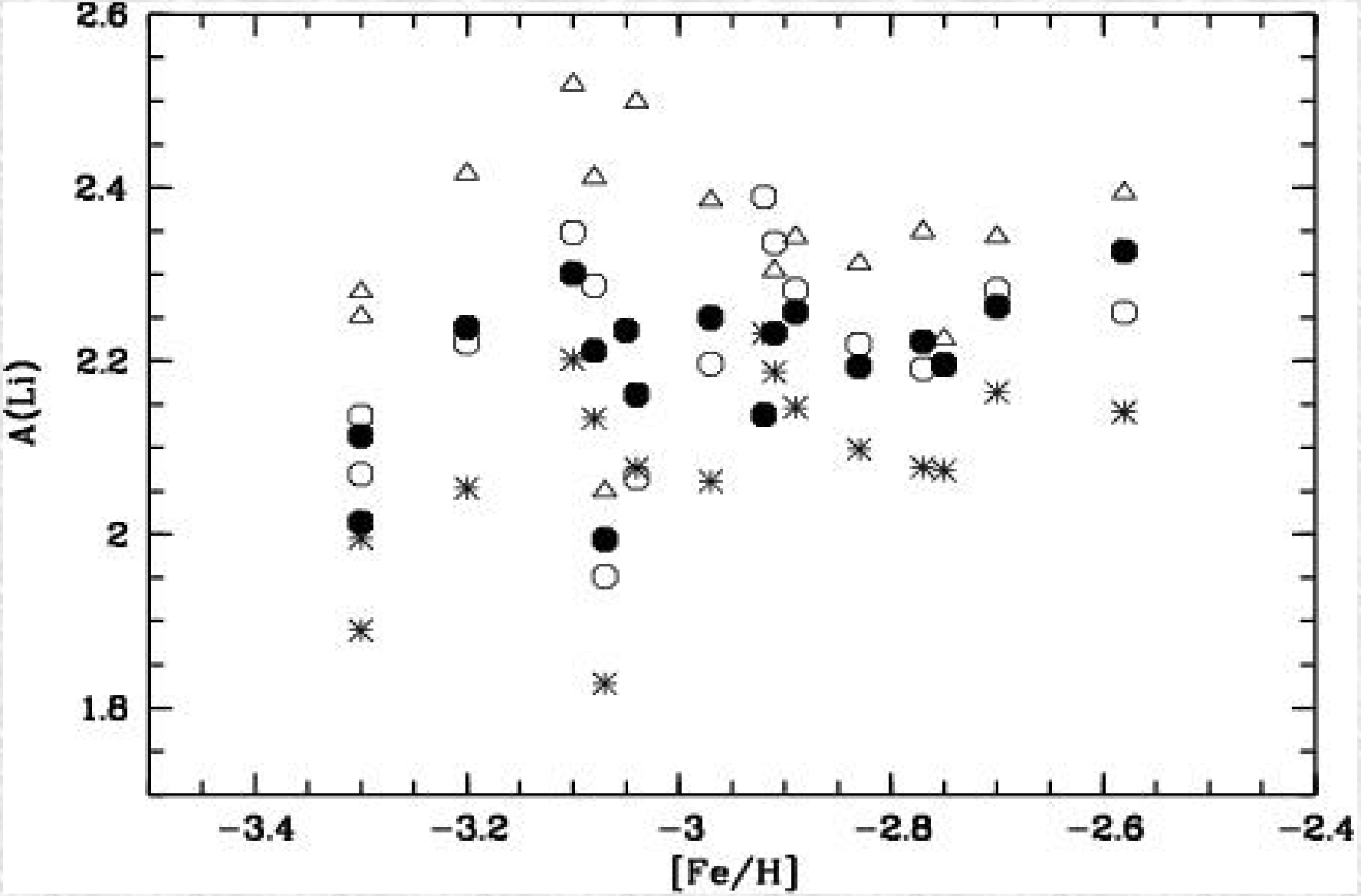
Observational bias ?



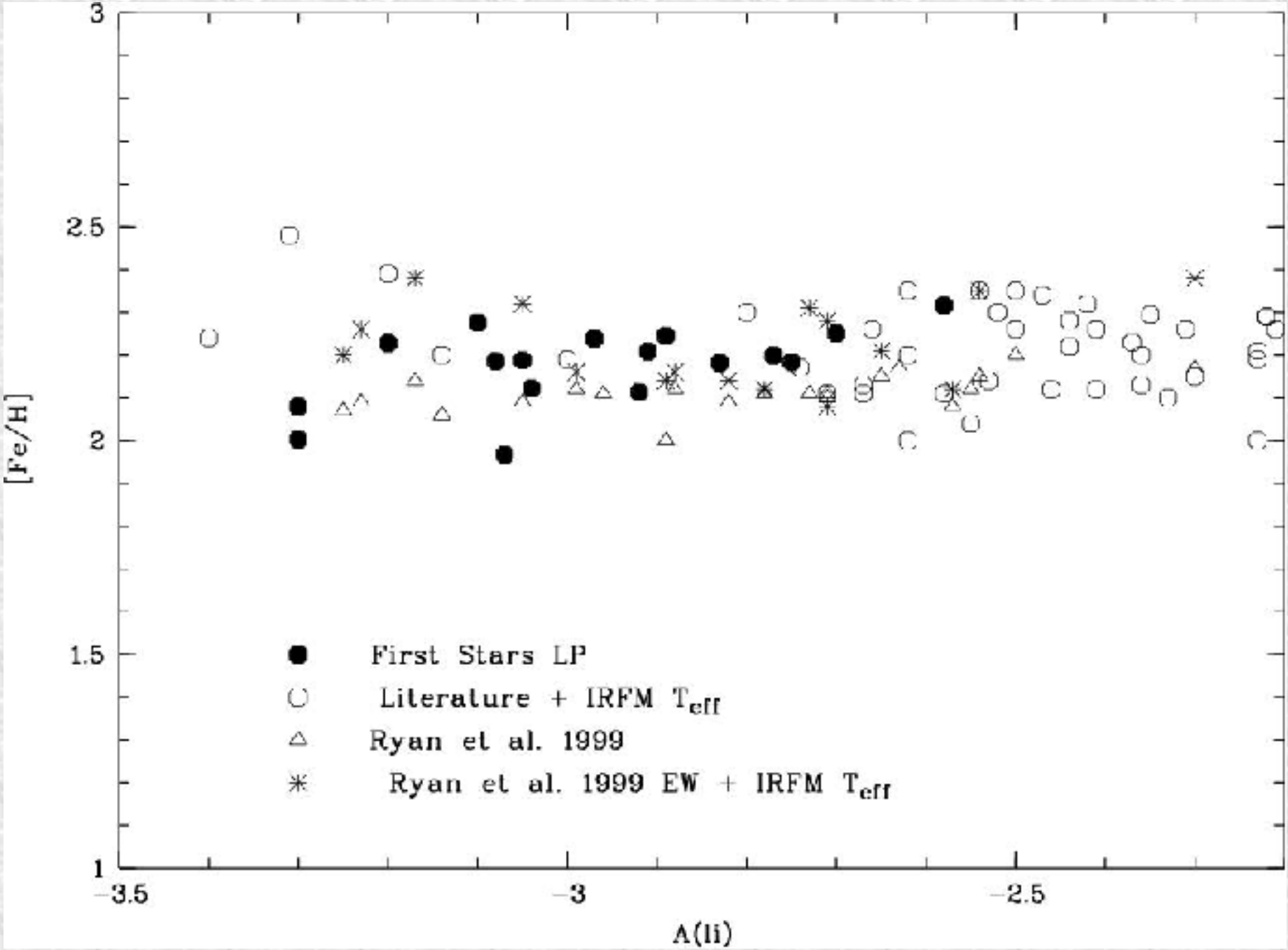
The role of Teff: Halpha compared with several colour Teff...

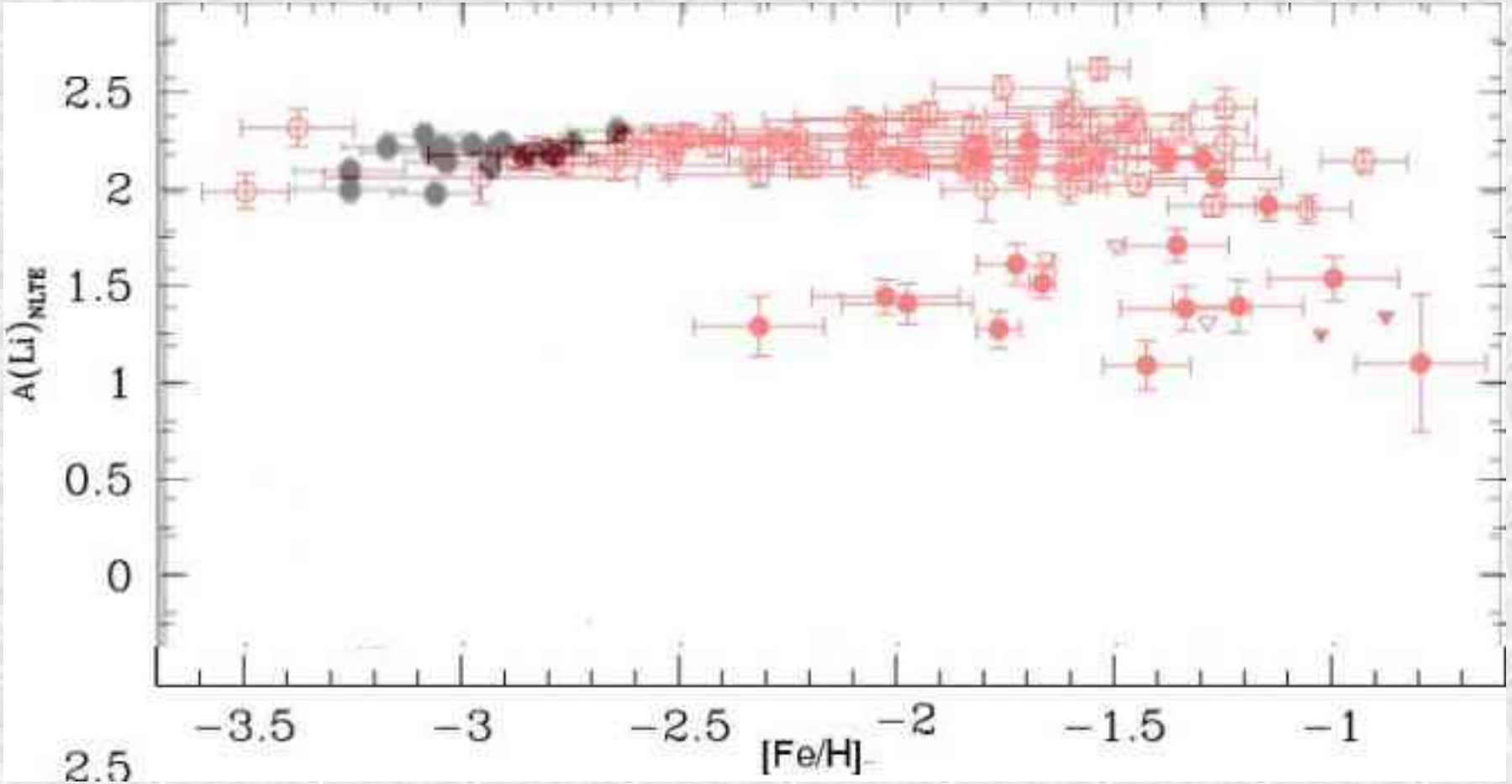
looks like
we do not have a firm grip on Teff...

Differences of up to 400K exist with the different choices



black dot: Halpha Teff; open circle V-K + reddening from maps; open triangles V-K+reddening from calib; asterisks B-V Vandenbergh & Clem (2003)

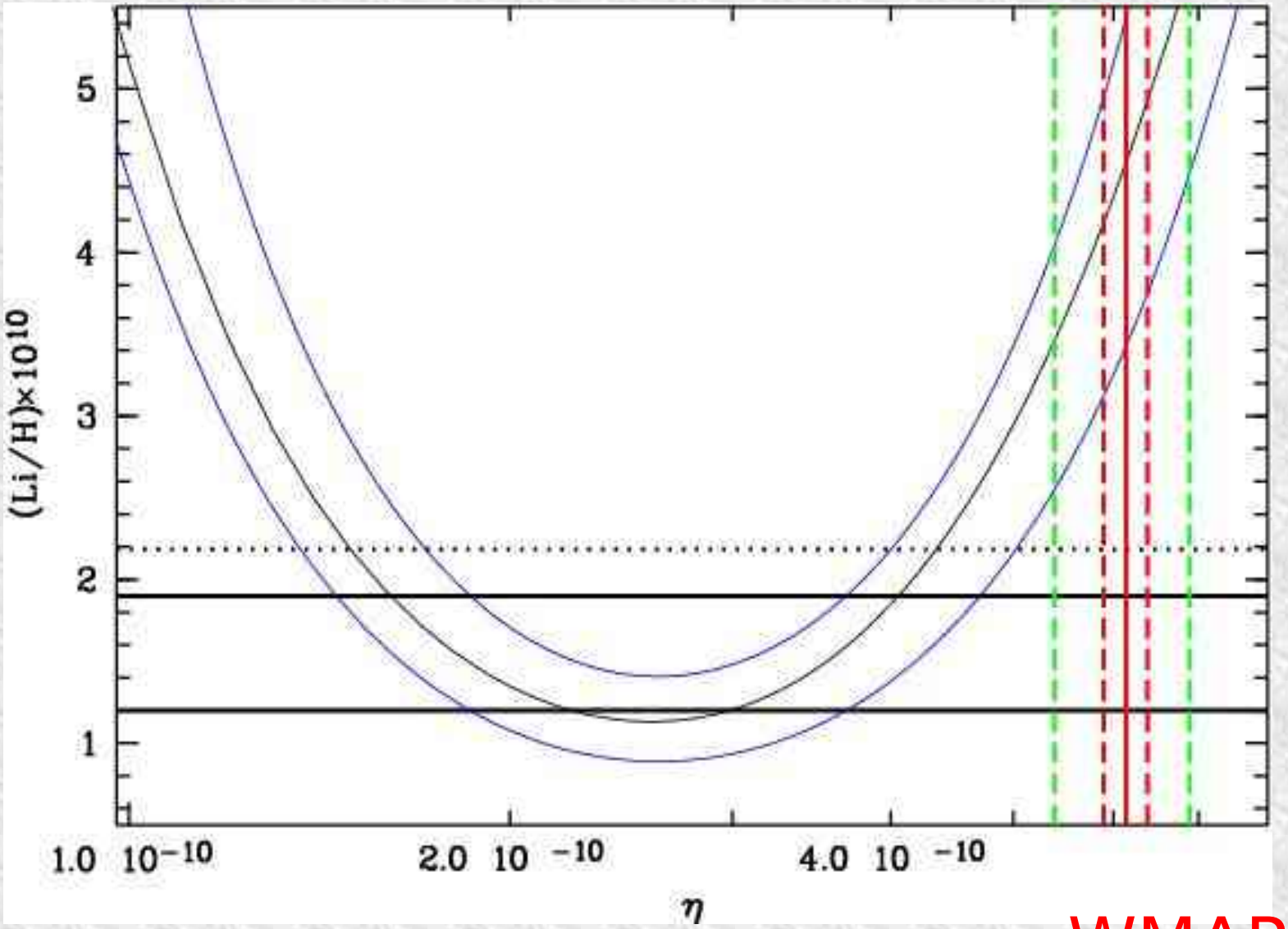

3
2.5
2
1.5
1
[Fe/H]
−3.5
−3
−2.5
A(li)
First Stars LP
Literature + IRFM T_{eff}
Ryan et al. 1999
Ryan et al. 1999 EW + IRFM T_{eff}



Red: Charbonnel & Primas 2005 (astro-ph/0505247)

Black: our data

What is happening below -3.0 ?
Too few stars observed (15)!!



NGC 6397
Field
stars

WMAP
3 sigma

There is some tension

So ?

Li depletion ? but how so uniform ?

Non-standard BBN ?

1) Go back to the telescope & observe more stars with [Fe/H]<-3

2) improve modeling of stellar atmospheres (3D effects ? CO^{5}BOLD models, H. Ludwig)

3) temperature scale (interferometry ? new insight from 3D models ?

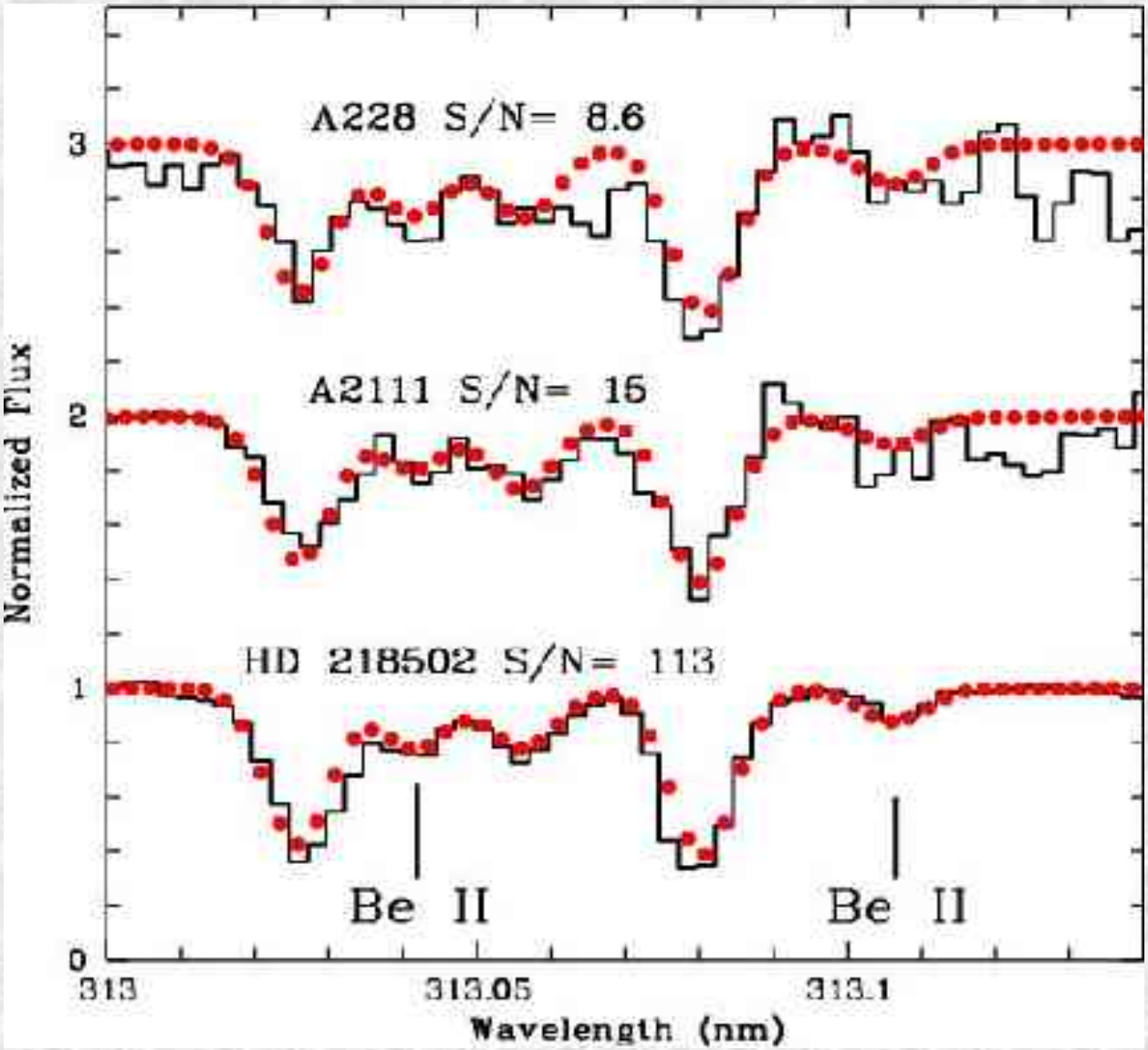
Beryllium

It is not made primordially
It is not made in stars

It is a “pure” product of cosmic ray spallation of CNO nuclei

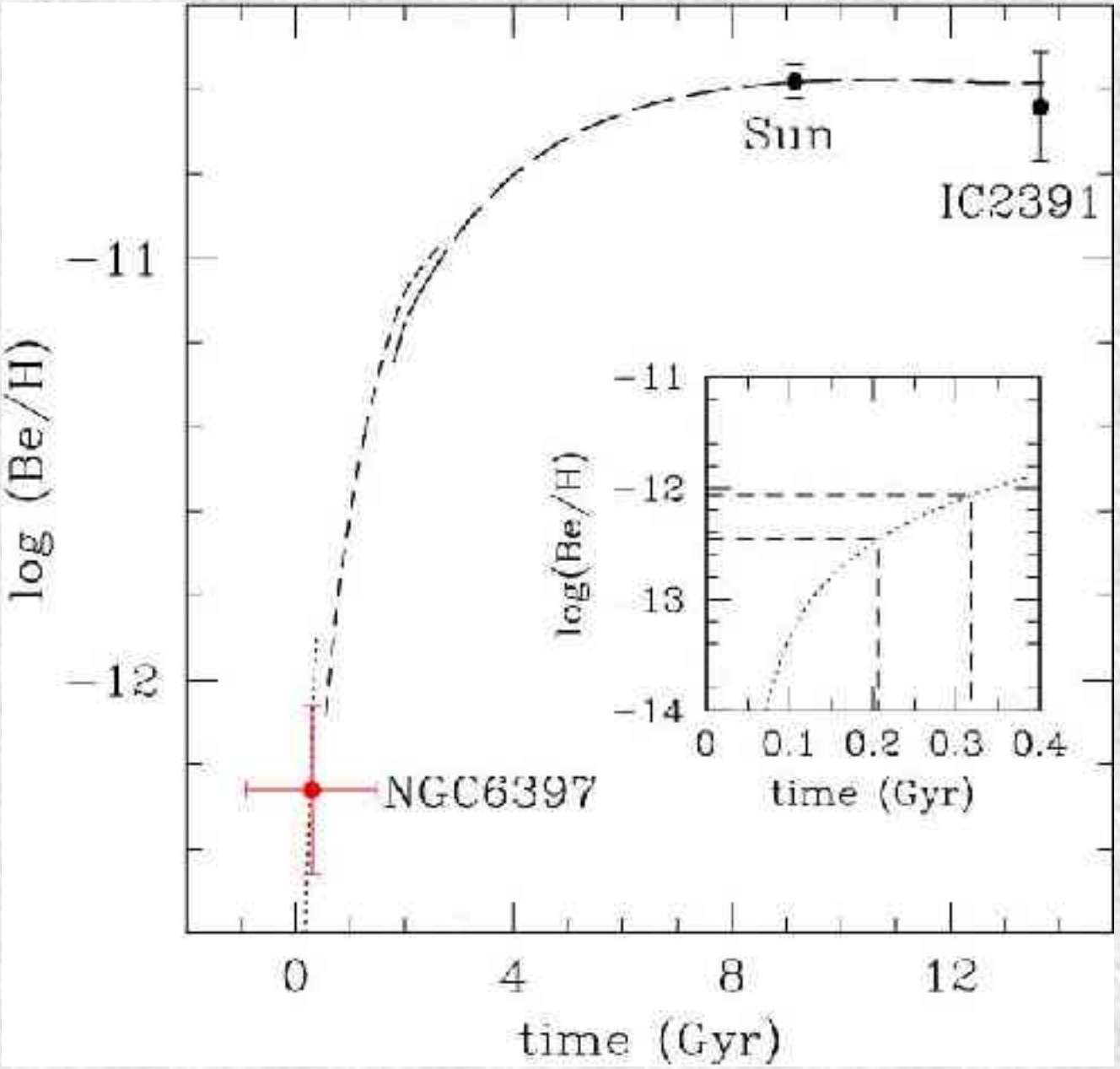
As the Galaxy evolves Be abundance increases in a relatively simply predictable way

is Be a chronometer ?
(Suzuki et al. 2001; Beers et al. 2000).



With VLT+UVES Be has been observed in GC NGC 6397. (Pasquini et al. 2004, A&A 426, 651)

Comparison with model provides 0.2-0.3 Gyr AFTER start of star formation



Assuming star formation started ~10^7 years AFTER big bang (13.7 Gyr ago) implies age of 13.5—13.4 Gyr

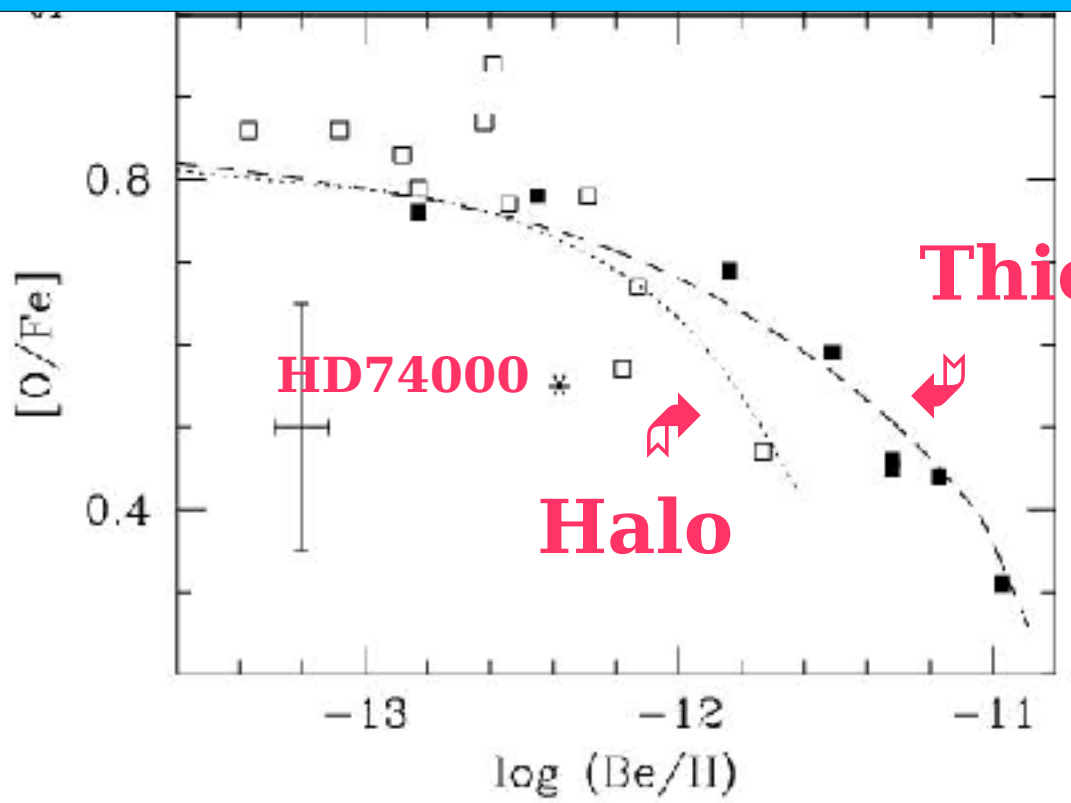
This can be compared to the age derived by MS fitting (Gratton et al. 2003) 13.4±1.4 Gyr

Be-chronology works !

Can apply to field stars ?

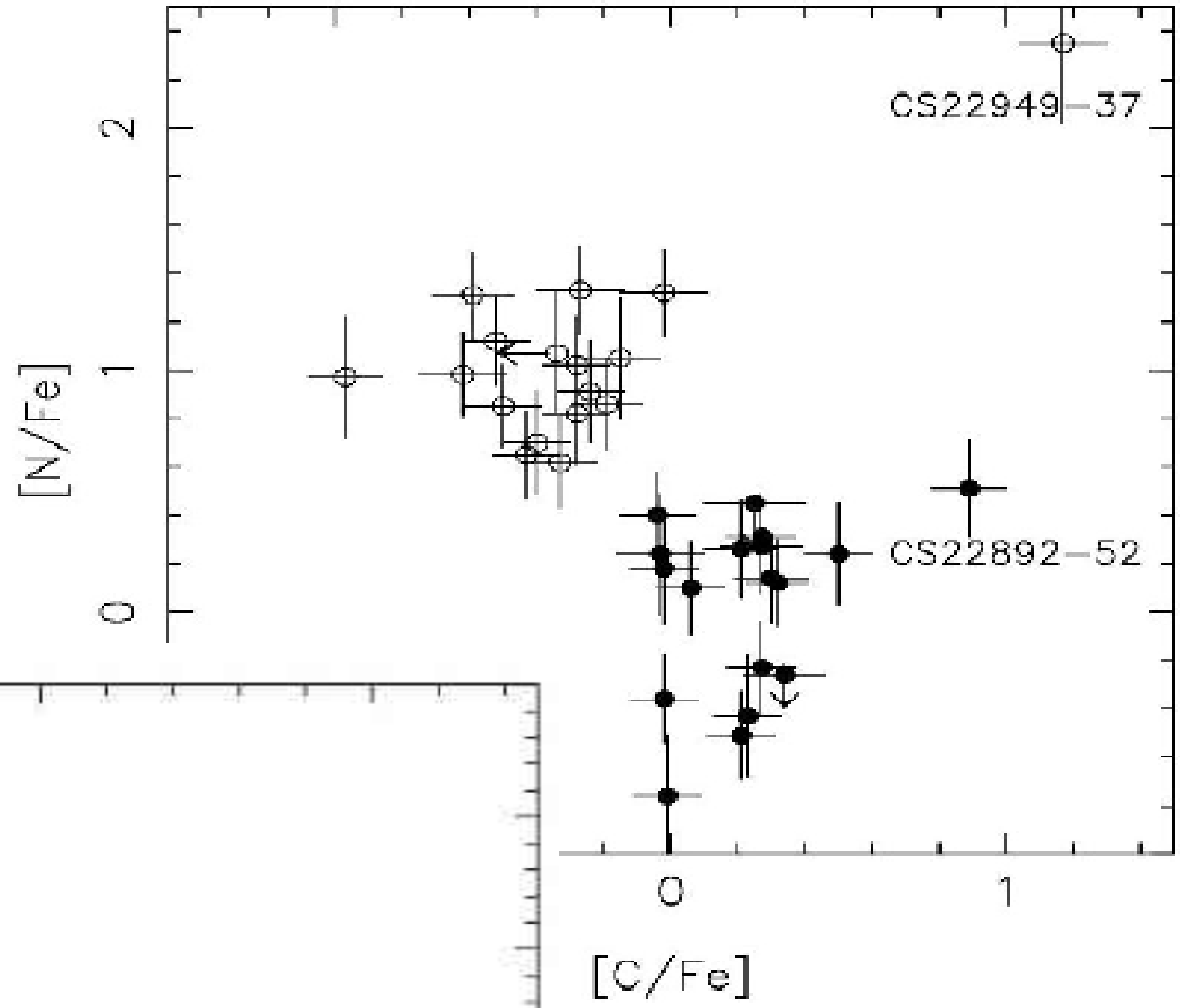
YES !

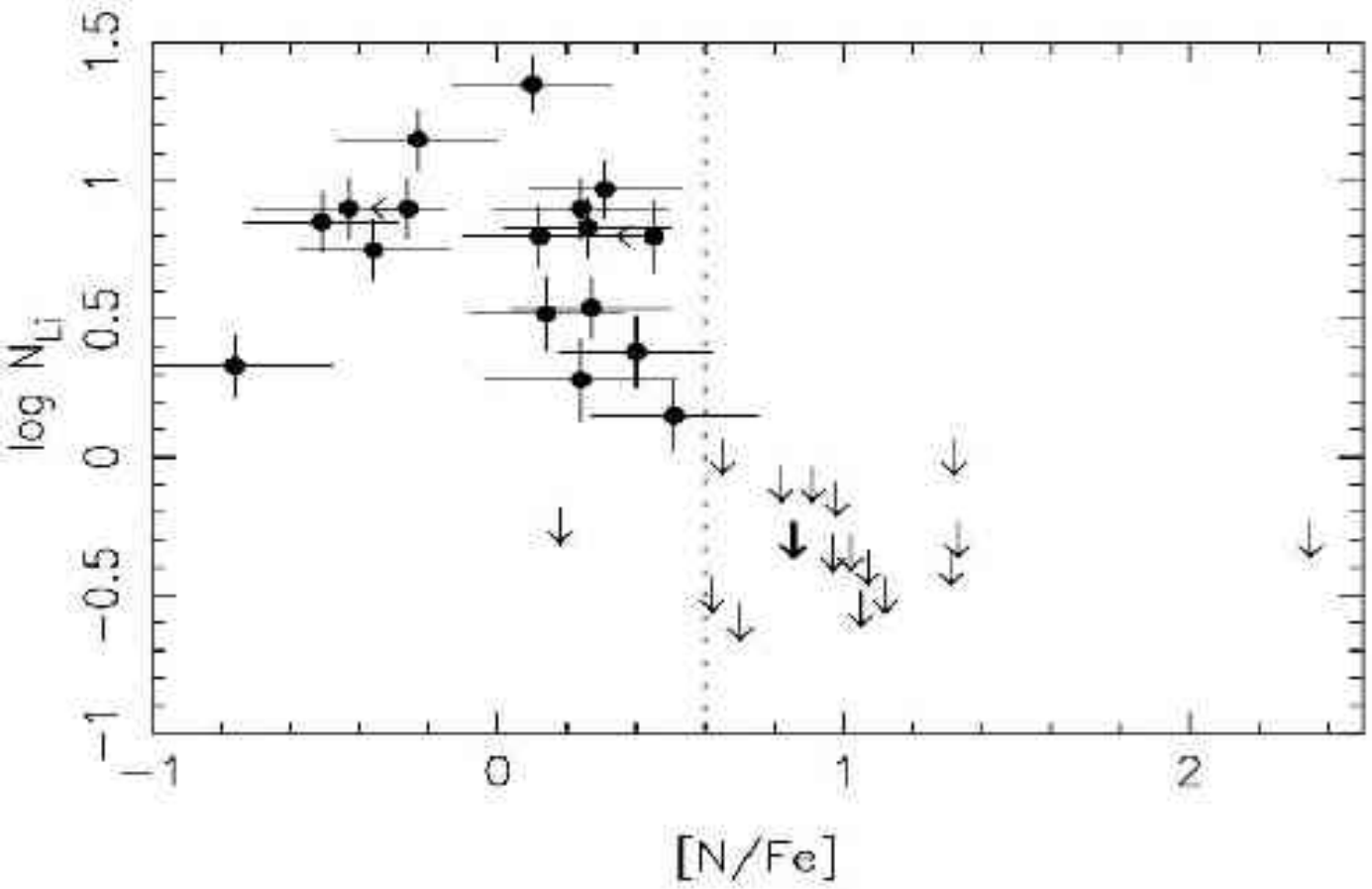
even better: using Be as a "time" variable we can study the evolution of OTHER elements



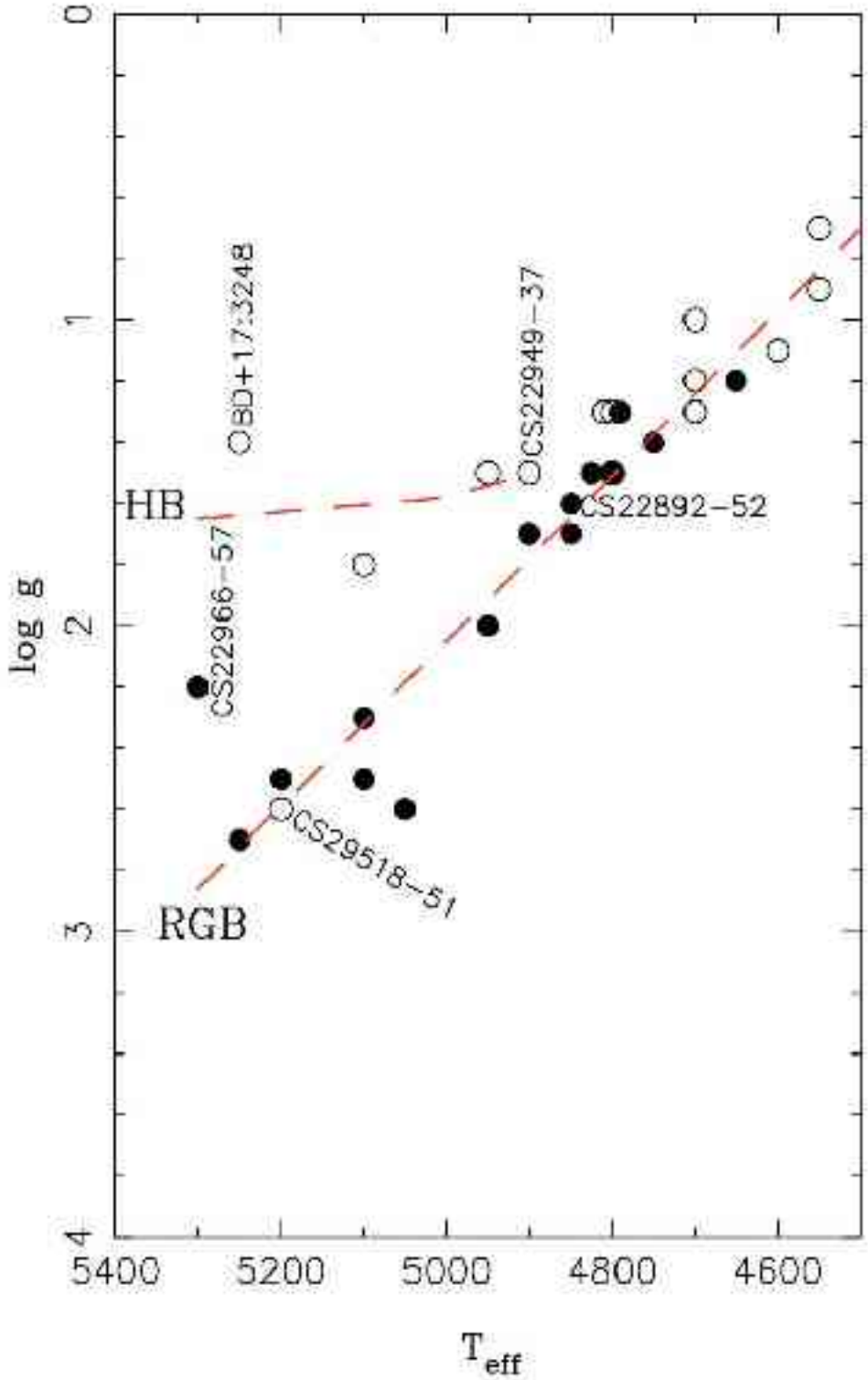
Pasquini et al. 2005 436, L57

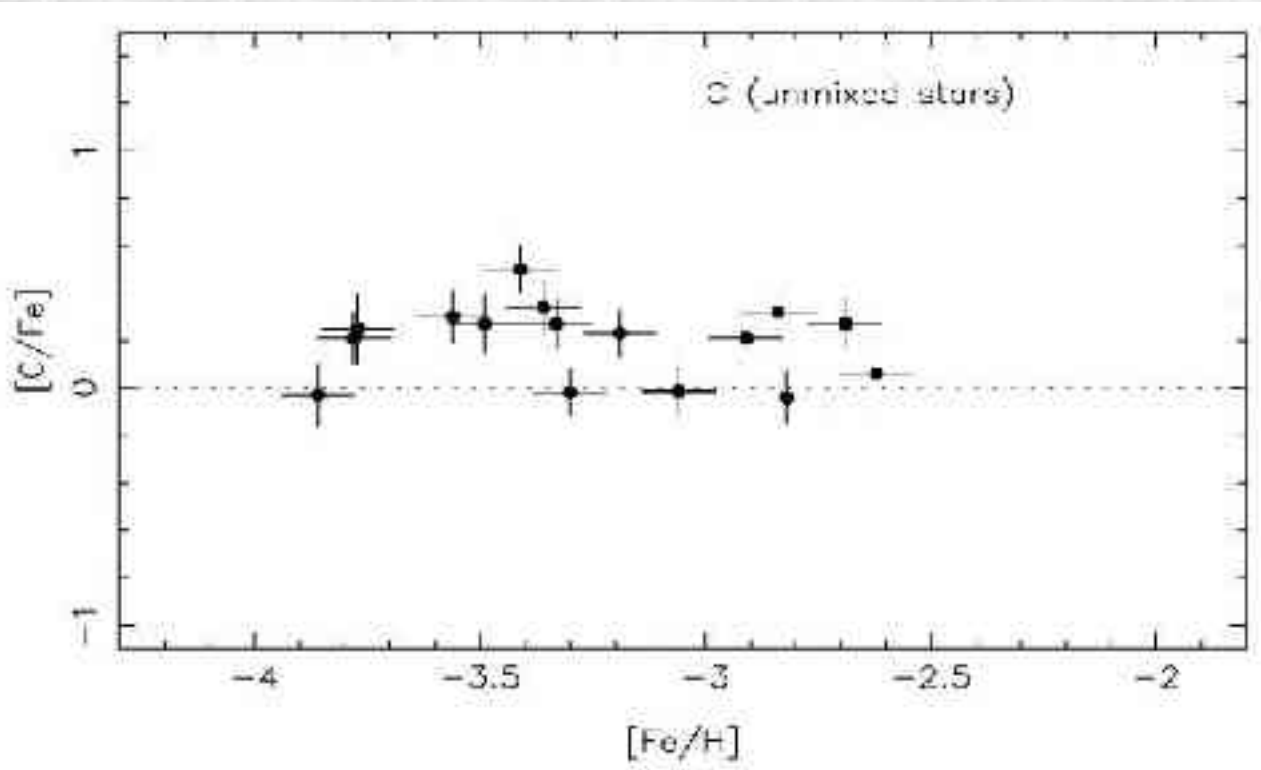
Carbon & Nitrogen

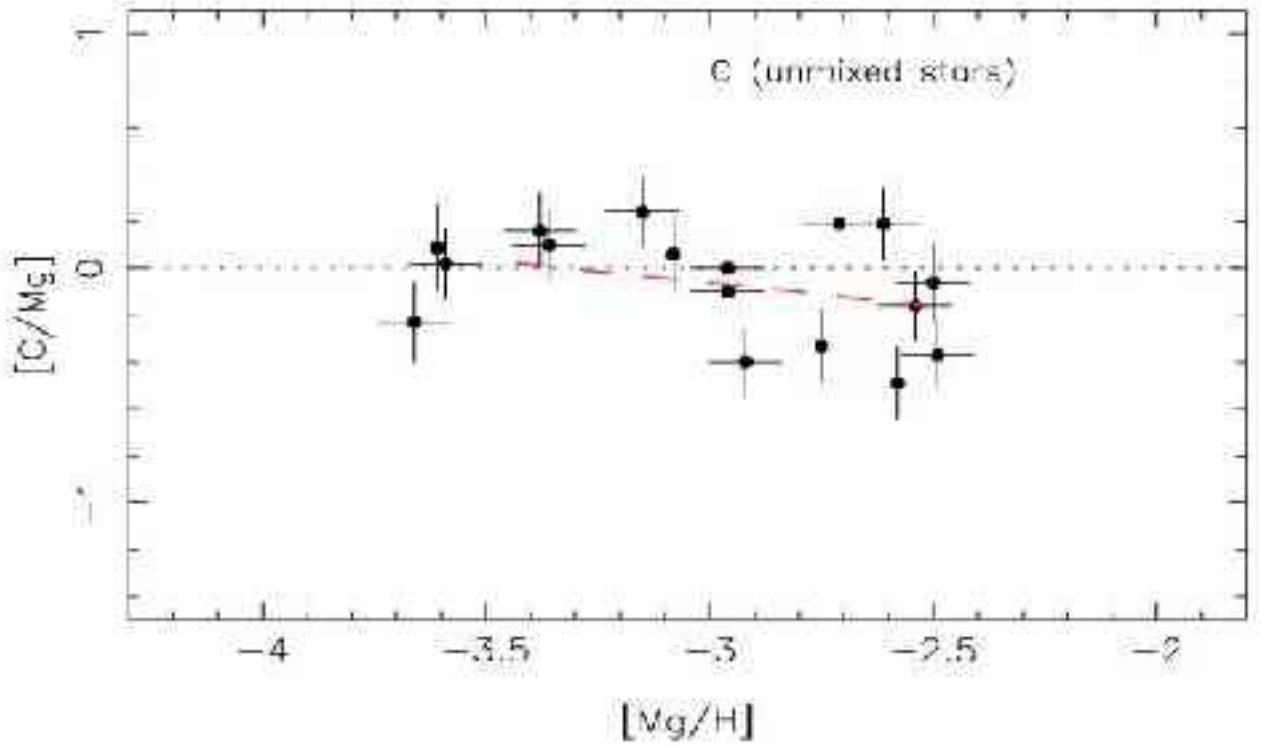


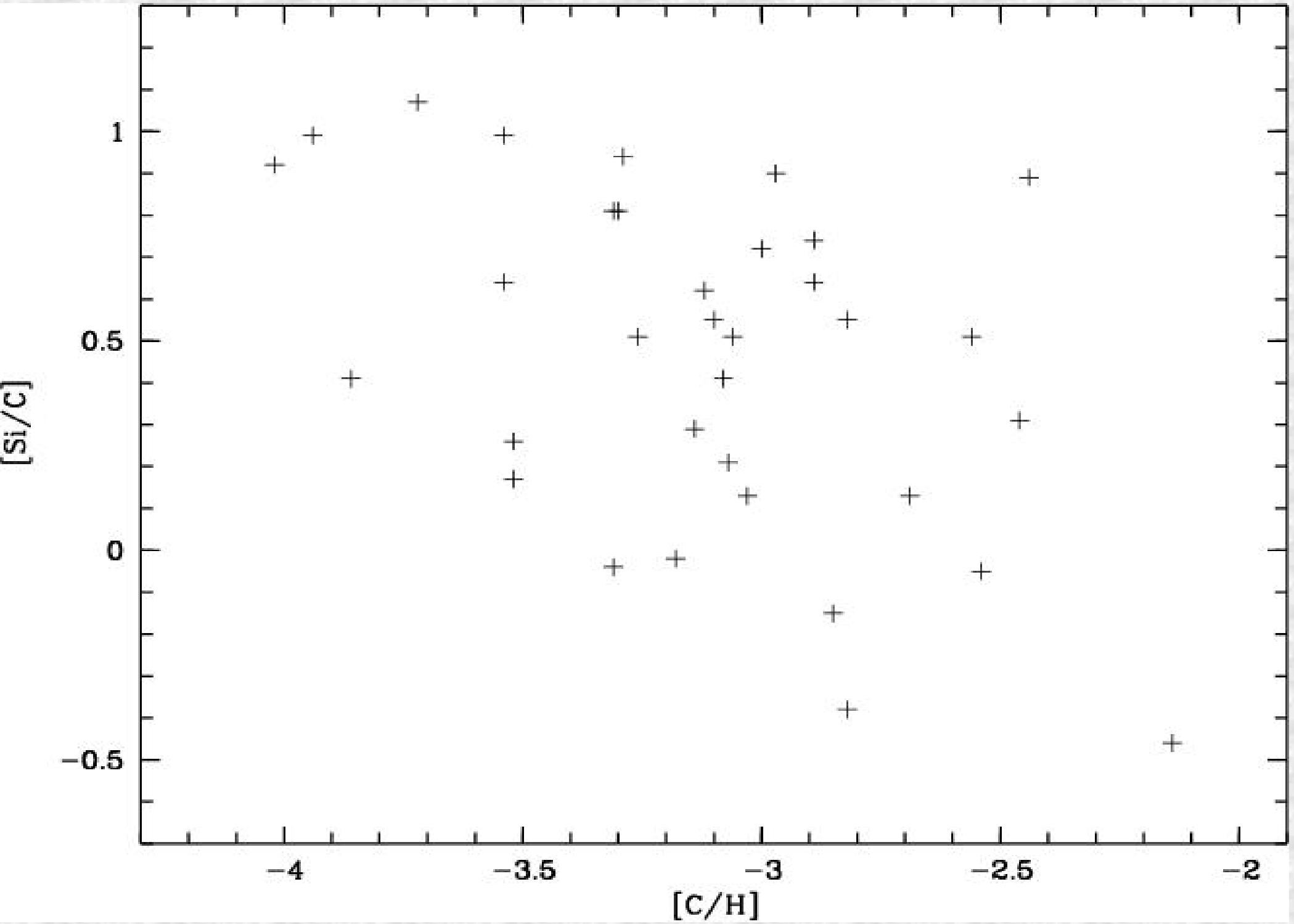


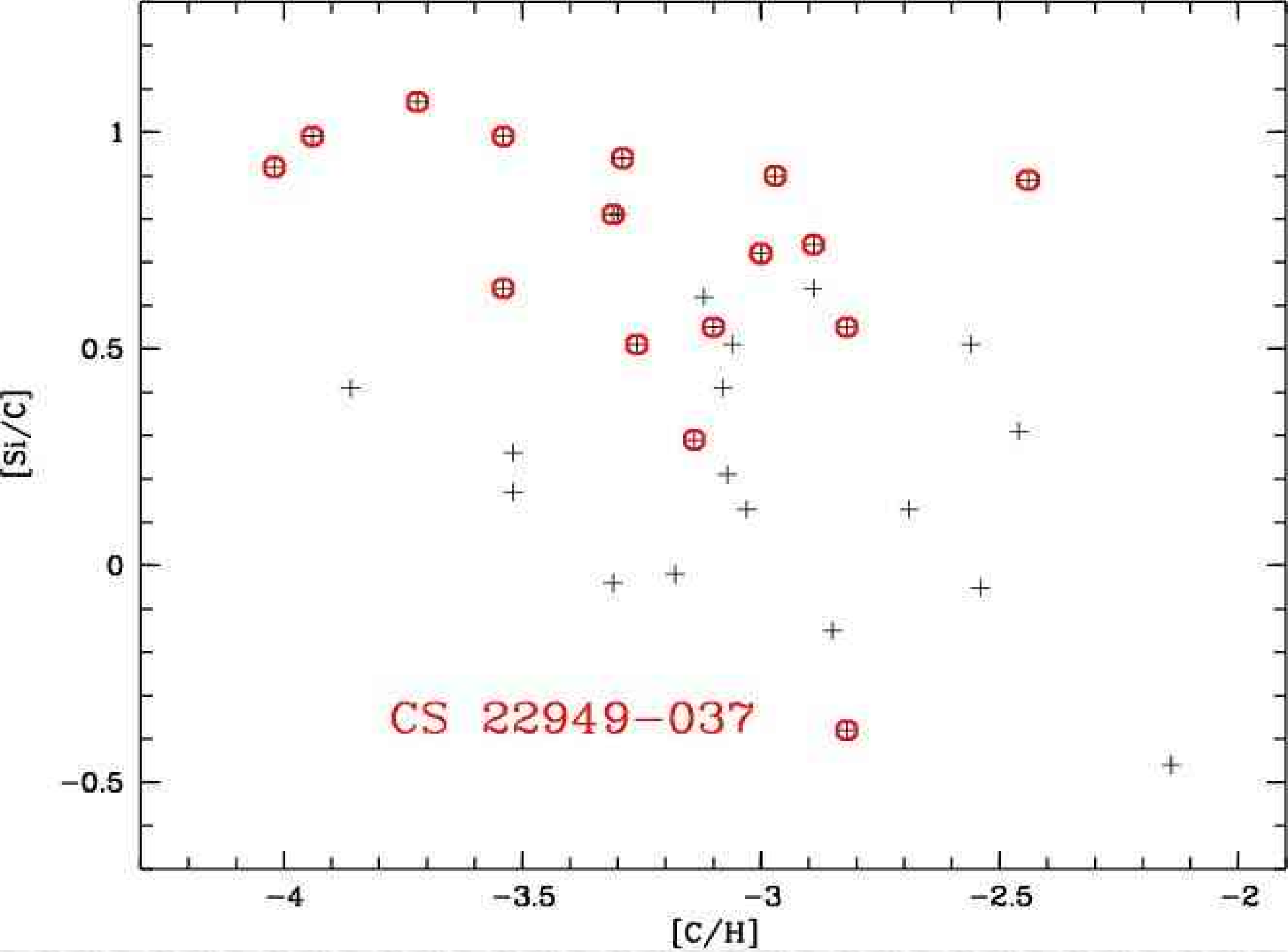
Spite et al. 2005
A&A 430, 655

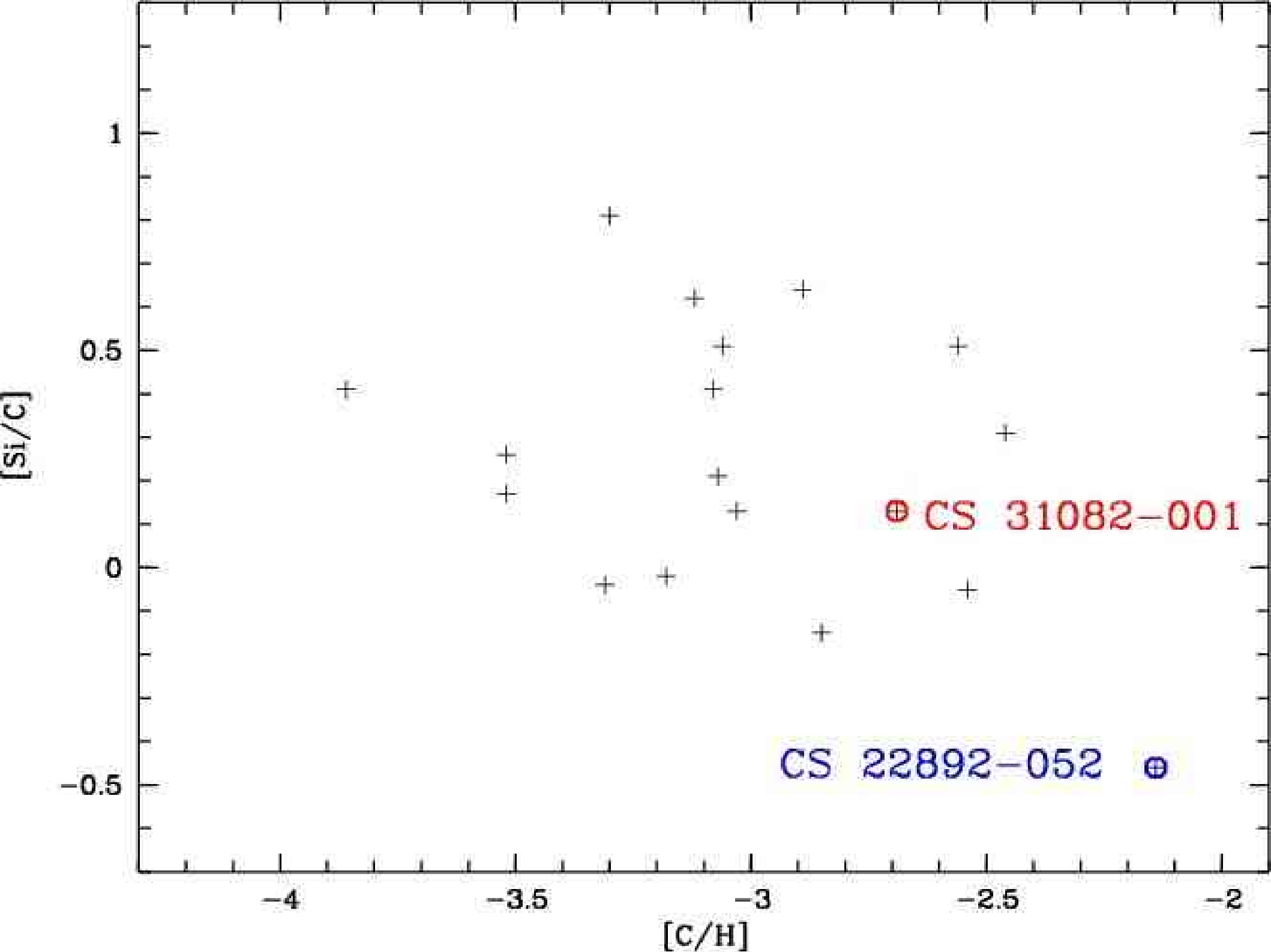

0
1
2
3
4
log g
5400
5200
5000
4800
4600
T_eff
HB
RGB
BD+17:3248
CS22949-37
CS22892-52
CS22966-57
CS29518-51

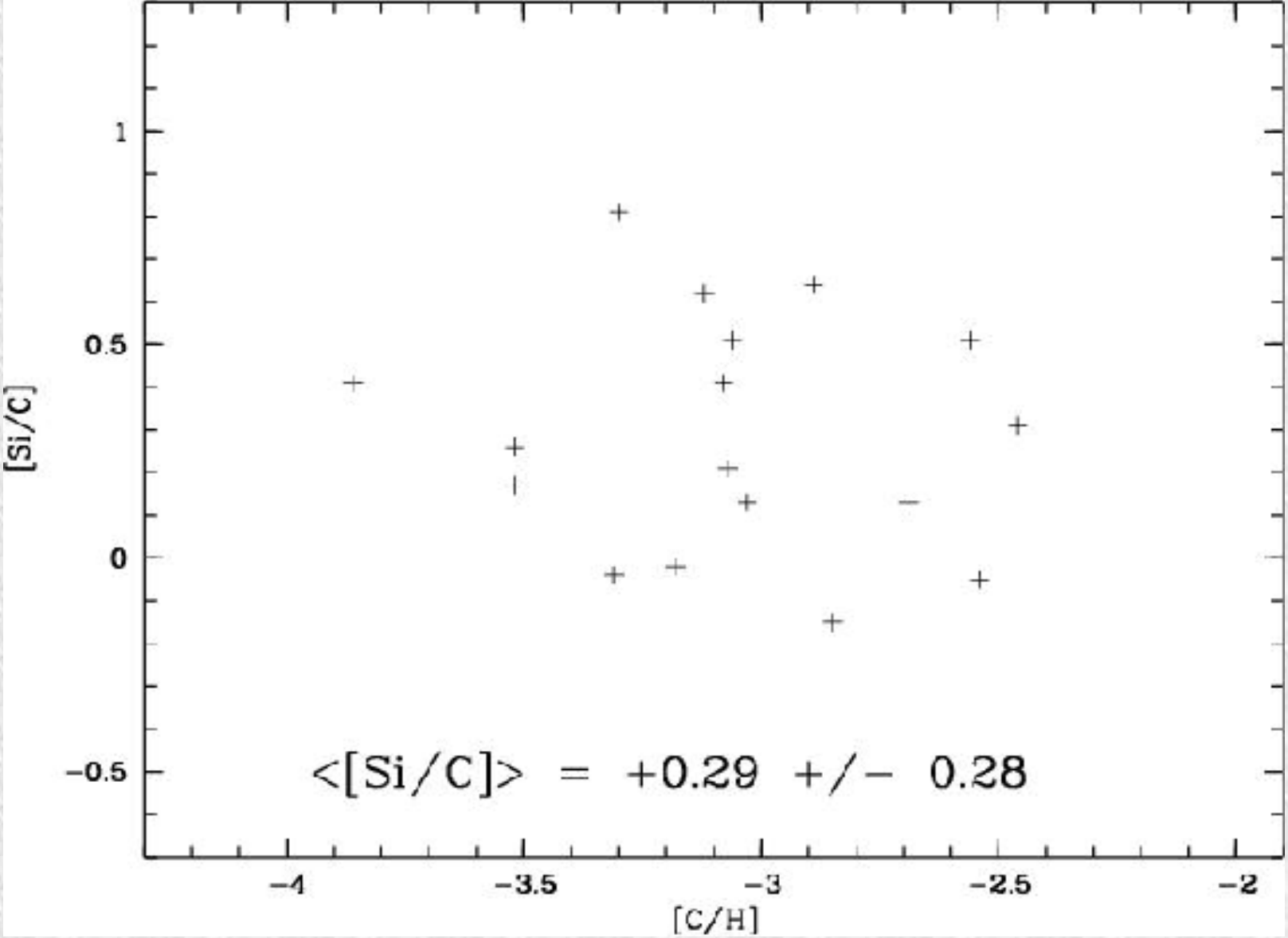

C (unmixed stars)
[C/Fe]
1
0
−1
−4
−3.5
−3
−2.5
−2
[Fe/H]


C (unmixed stars)
[C/Mg]
1
0
−4
−3.5
−3
−2.5
−2
[Mg/H]

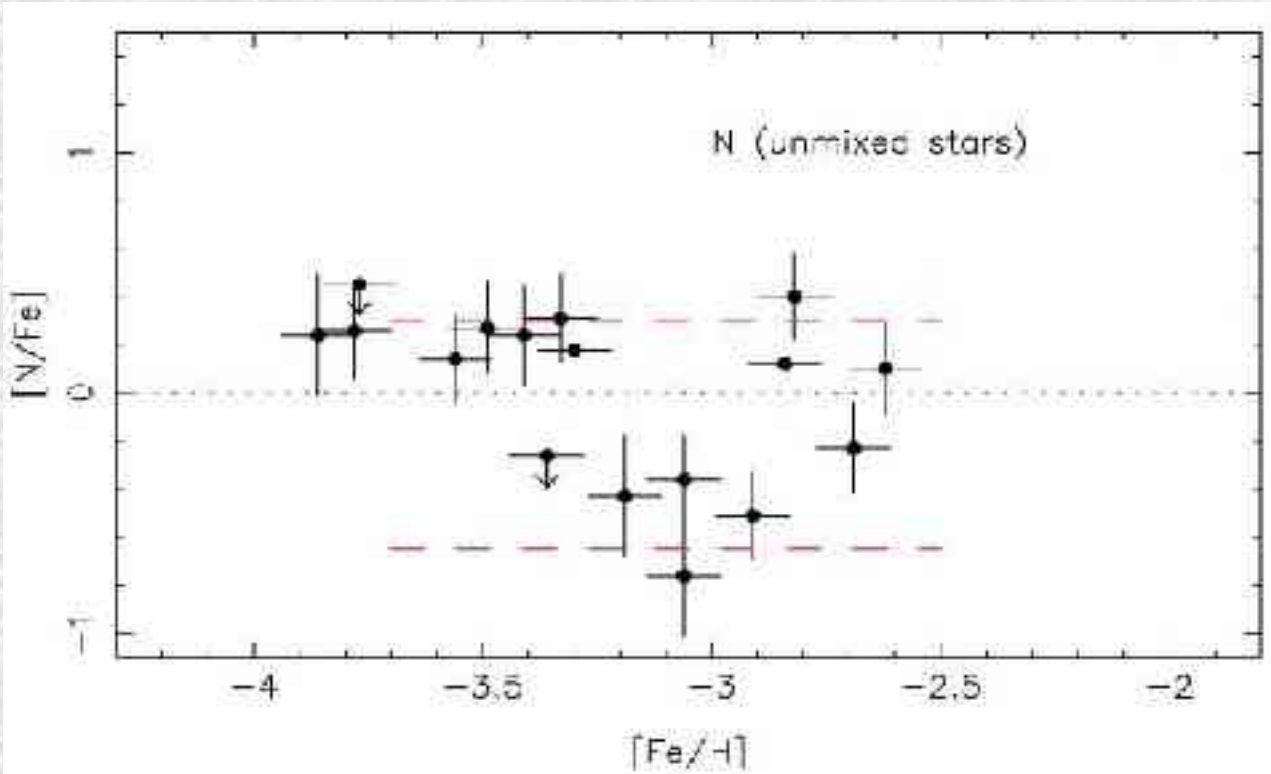

1
0.5
0
−0.5
[Si/C]
−4
−3.5
−3
−2.5
−2
[C/H]

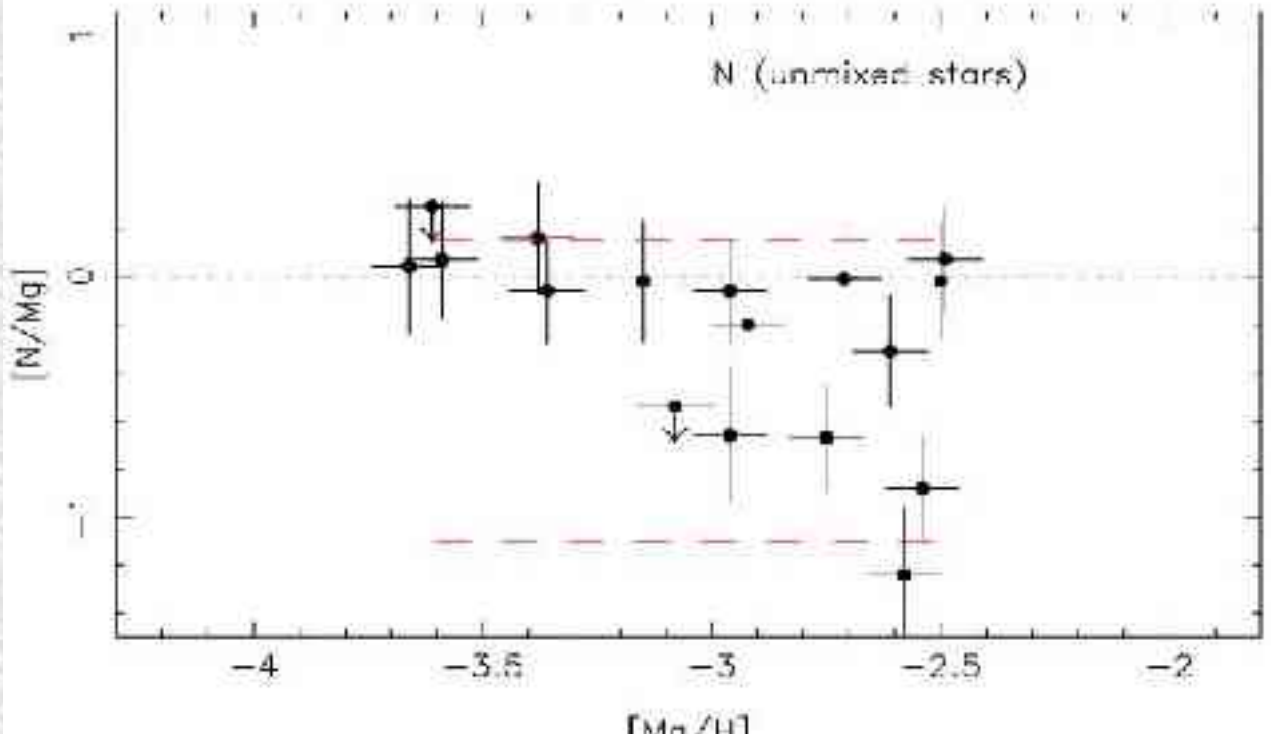

1
0.5
0
−0.5
[Si/C]
−4
−3.5
−3
−2.5
−2
[C/H]
CS 22949−037


1
0.5
0
−0.5
[Si/C]
−4
−3.5
−3
−2.5
−2
[C/H]
CS 31082−001
CS 22892−052

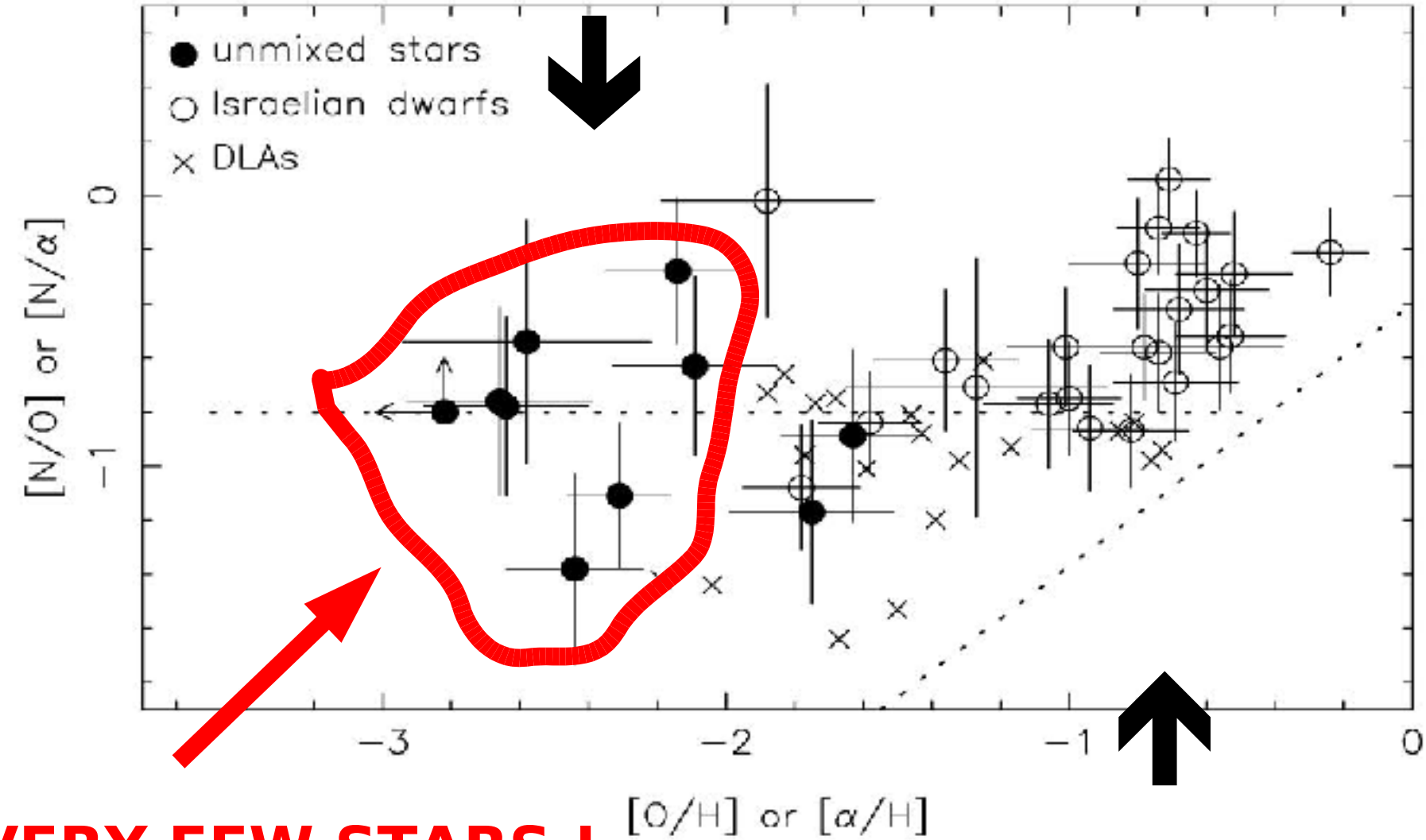


<[Si/Mg]> = 0.22±0.16
<[Mg/C]> = 0.07±0.24


N (unmixed stars)
[N/Fe]
1
0
−1
−4
−3.5
−3
−2.5
−2
[Fe/H]


N (unmixed stars)
[N/Mg]
1
0
−1
−4
−3.5
−3
−2.5
−2
[Mg/H]

Spite et al 2005



VERY FEW STARS !

Israelian et al. 2004
A&A 421, 649

Sulphur

alpha element
made by oxygen burning
core, convective shell + explosive

like Si and Ca

VERY difficult to observe in stars
why bother ?

in fact:
1963 Helfer, Wallerstein &Greenstein
1981 Clegg, Tomkin & Lambert
1987,1988 François

HOWEVER

S is relatively EASY to observe in external galaxies, e.g. in DLAs in absorption and in HII extragalatic regions (in emission)

Moreover S forms no dust, therefore it is the ideal alpha element tracer in the gas phase

In fact recently several papers on S

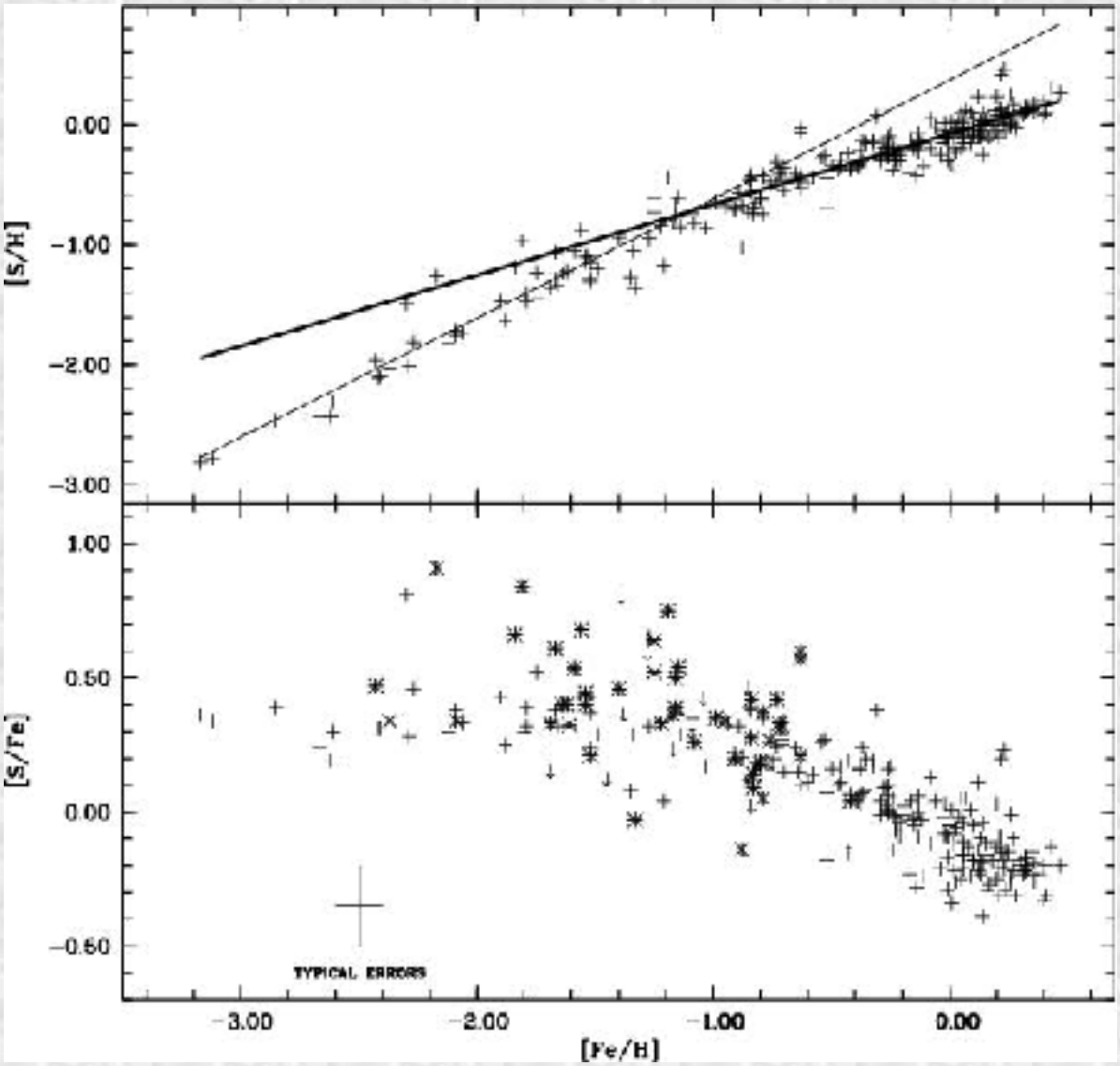
S behaves like Si

YES Chen et al 2002, 2003
Ryde & Lambert 2004
Nissen et al. 2004

NO Israelian & Rebolo 2001
Takada-Hidai et al. 2002

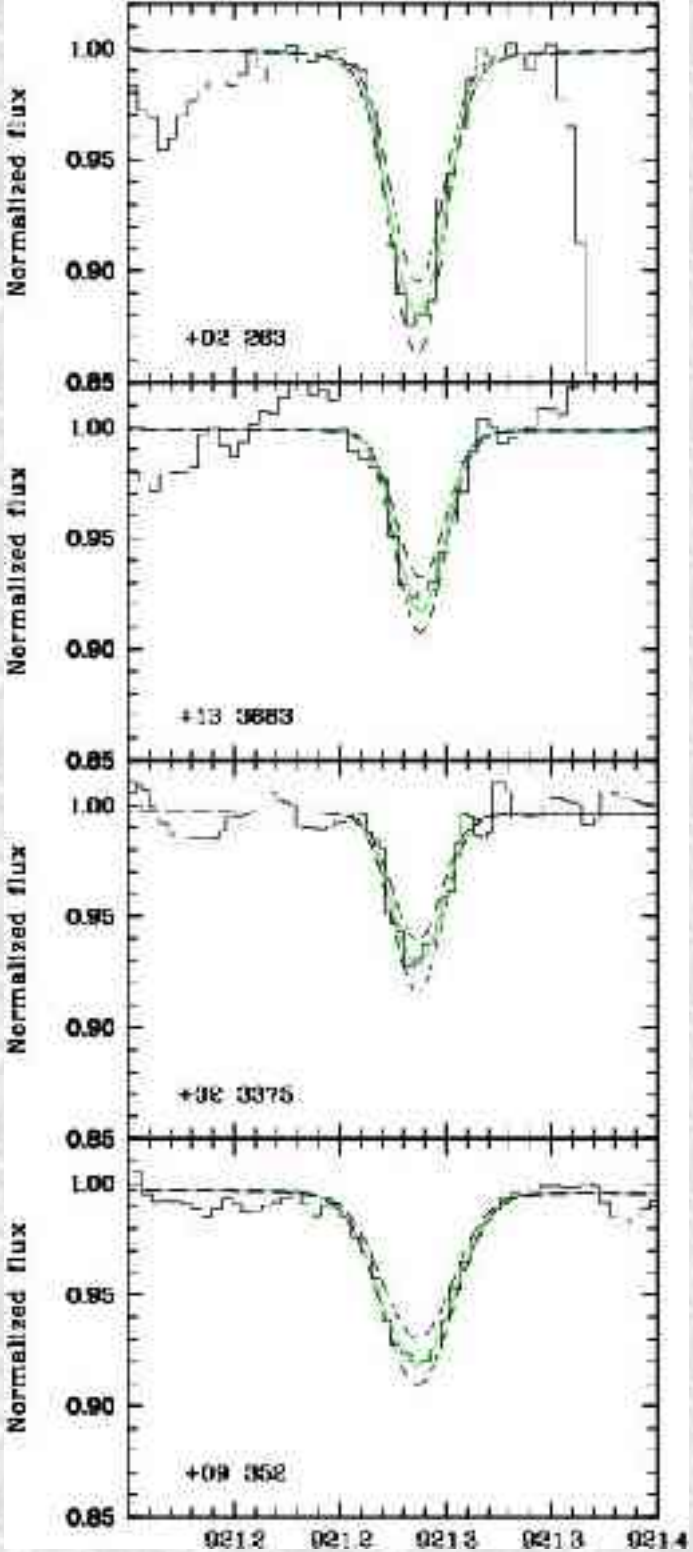
?

Caffau et al. 2005 A&A 441, 553
74 stars, mostly “new”

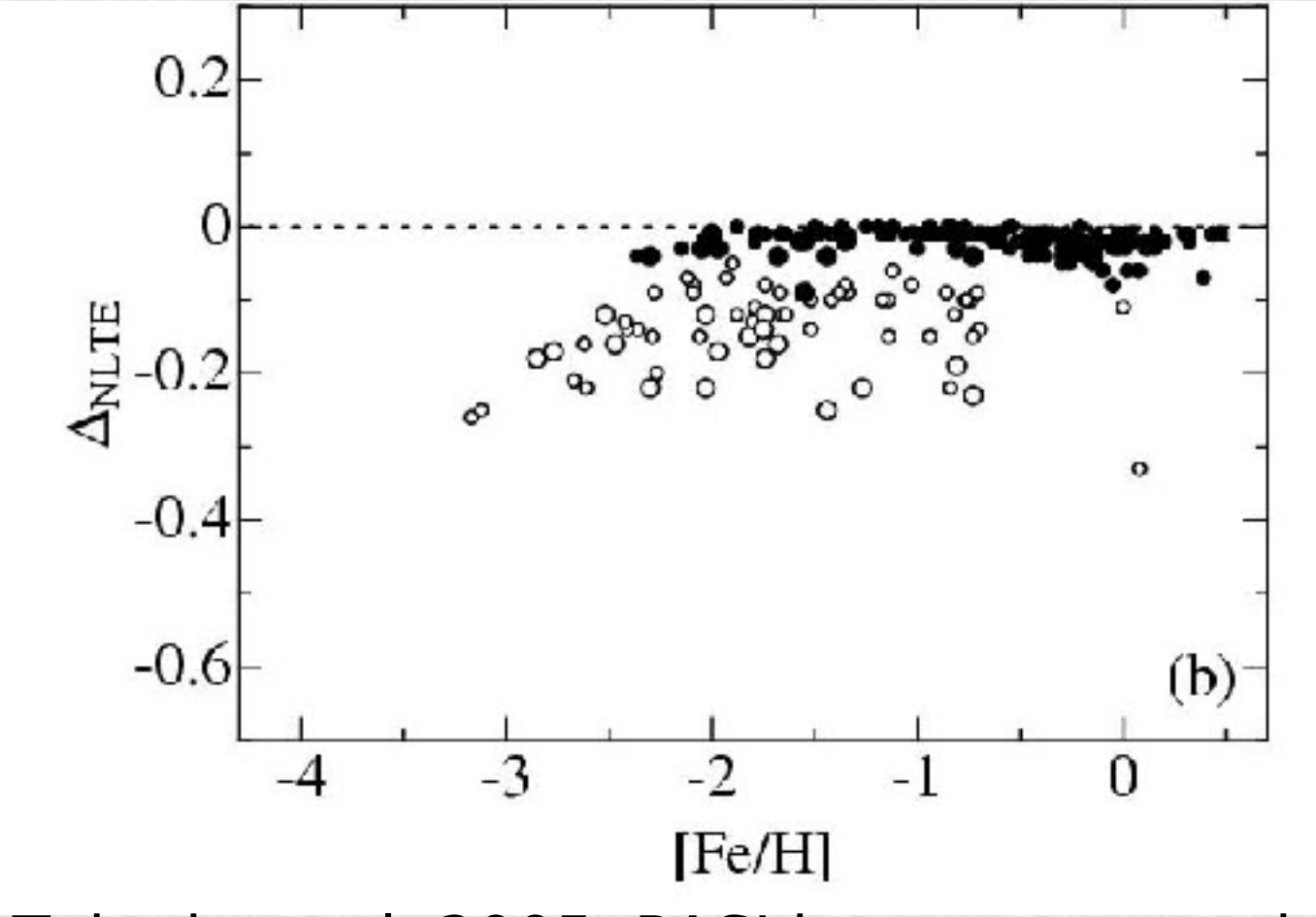


Some stars
are on a “plateau”
others seem to rise

(same lines, same
analysis…)



Very different line strength for stars of ~same Teff, glog and metallicity---> different abundance



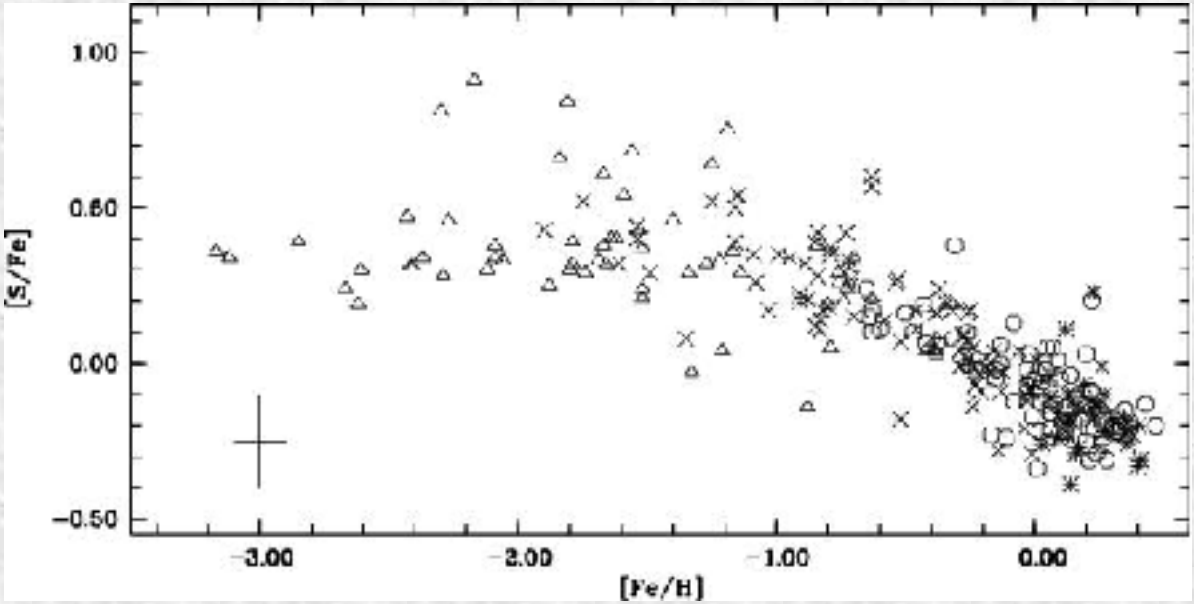
Takeda et al. 2005, PASJ in press astro-ph/0509239
compute NLTE corrections which are large
for mult. 1 (open symbols) and small/neglegible
for mult. 6 (filled symbols)

THIS WORSENS THE DISCREPANCY BETWEEN THE LINES !!!!!!!!

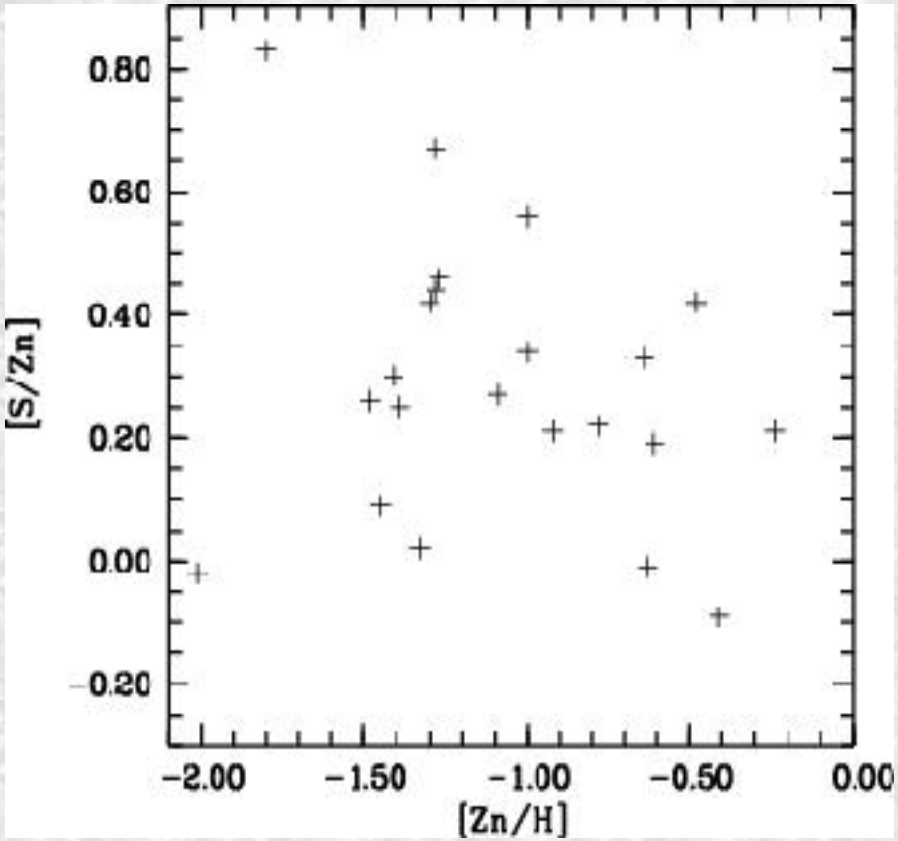
SO ?

3D effects ? to be done, BUT NLTE

different populations ?

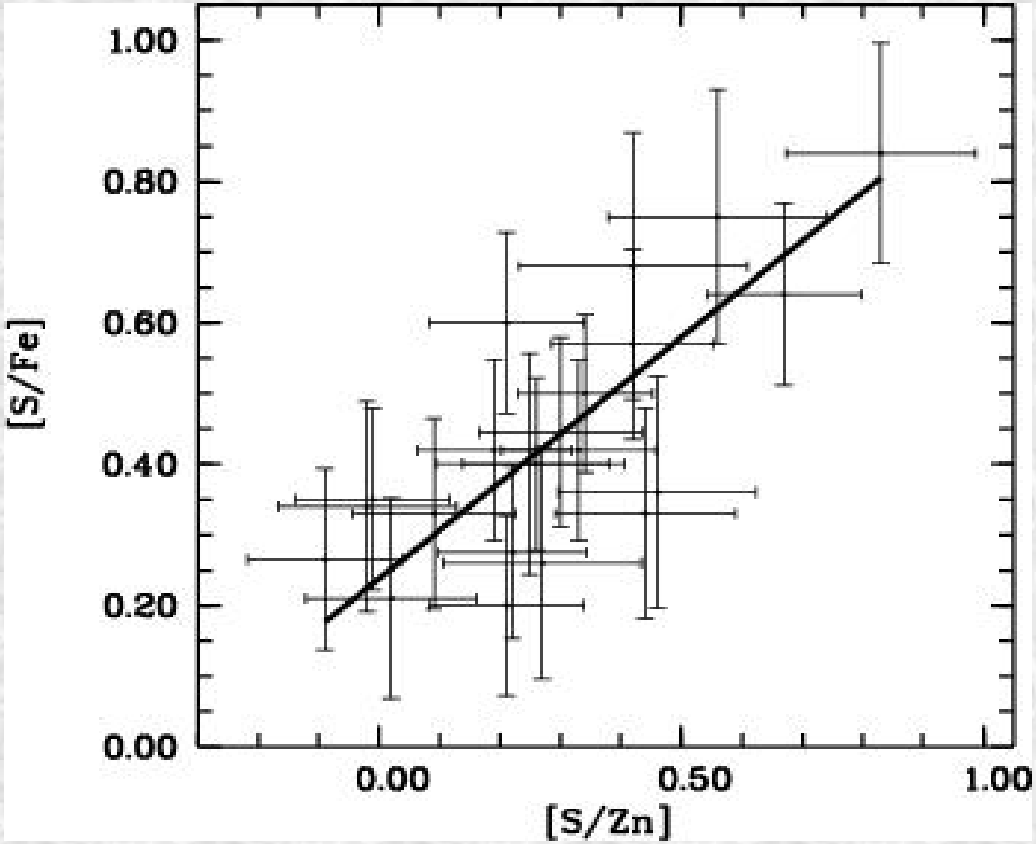


NO KINEMATICAL DISTINCTION.....



Similar picture in [S/Zn] vs. [Zn/H]

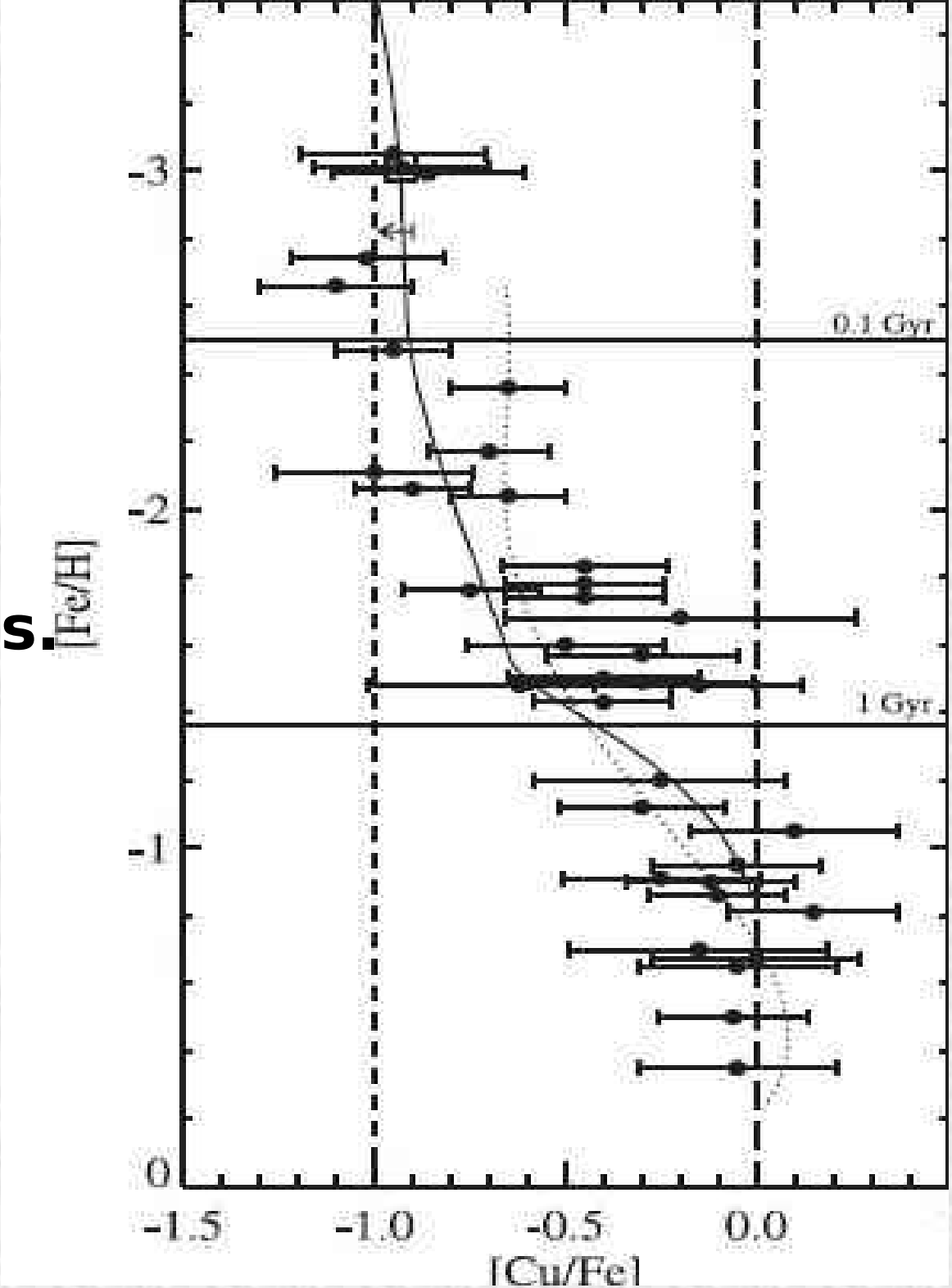
As far as I can tell [S/Zn] correlates VERY WELL with [S/Fe]



Copper

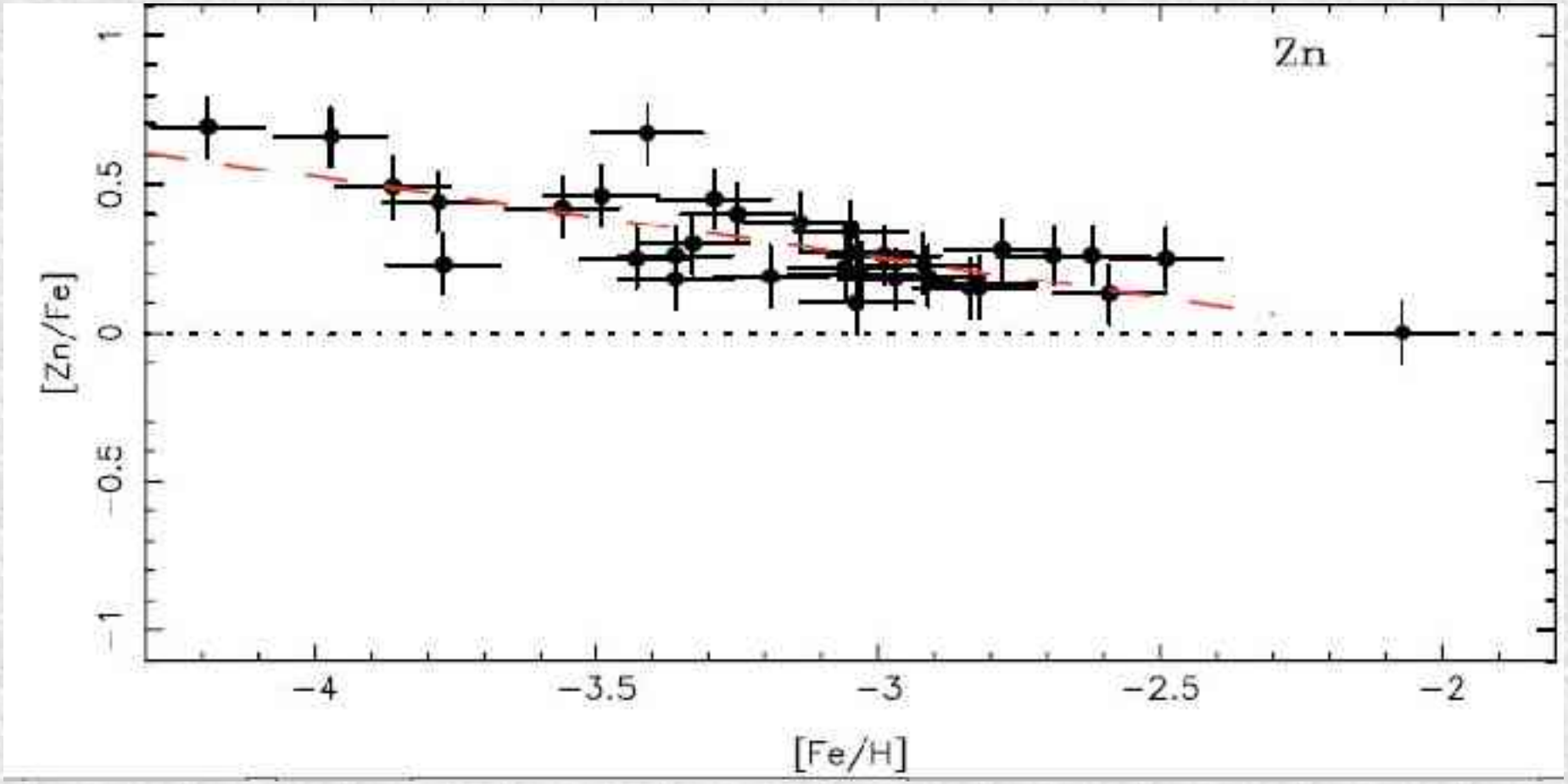
Well defined decrease with decreasing [Fe/H] plateau (?) at the lowest metallicities.

Bihain et al. 2004 A&A 423, 777

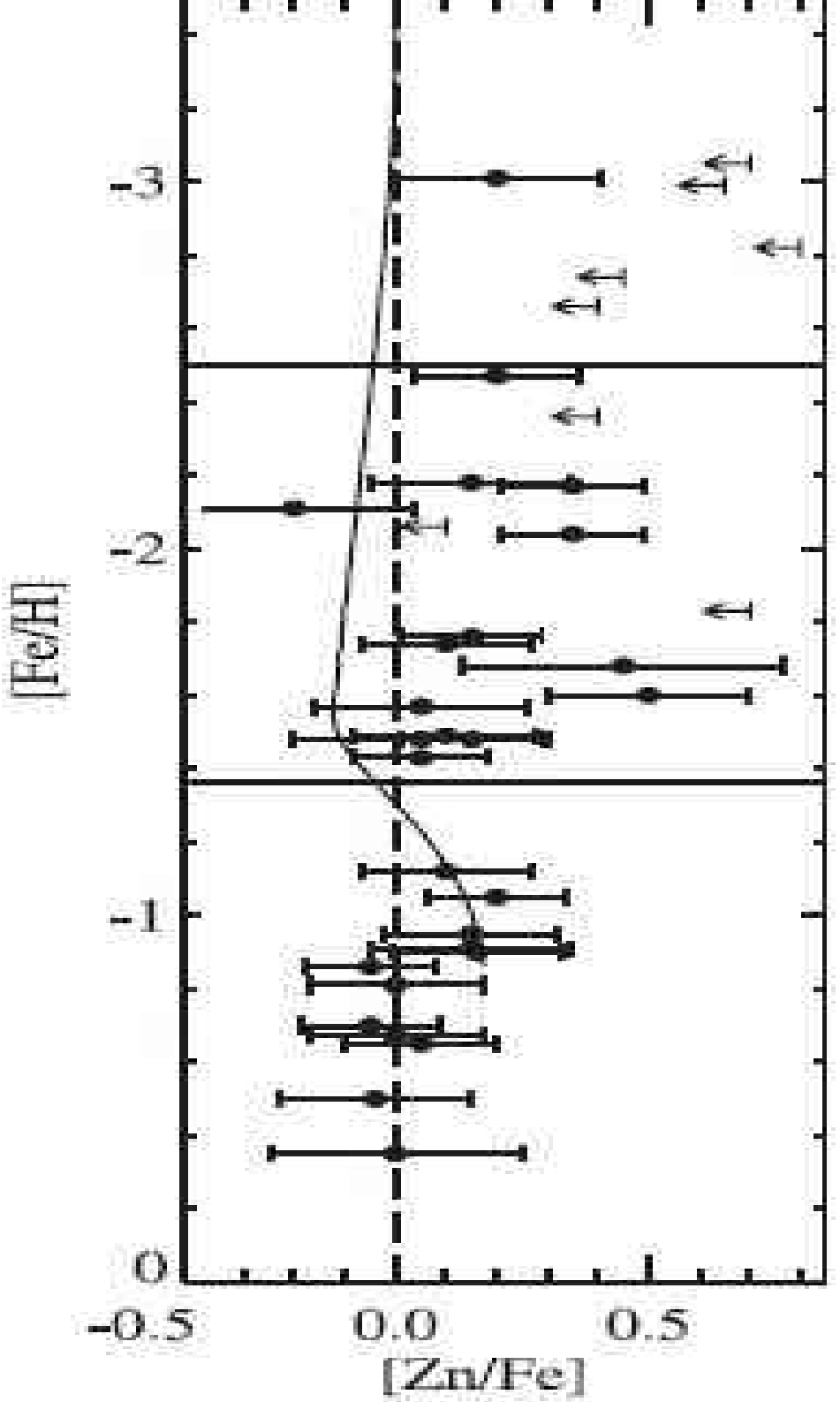


Zinc

Clear rise at the lowest metallicities
Cayrel et al. 2004 A&A 413, 1117



However down to [Fe/H]~-2 essentially [Zn/Fe]~0



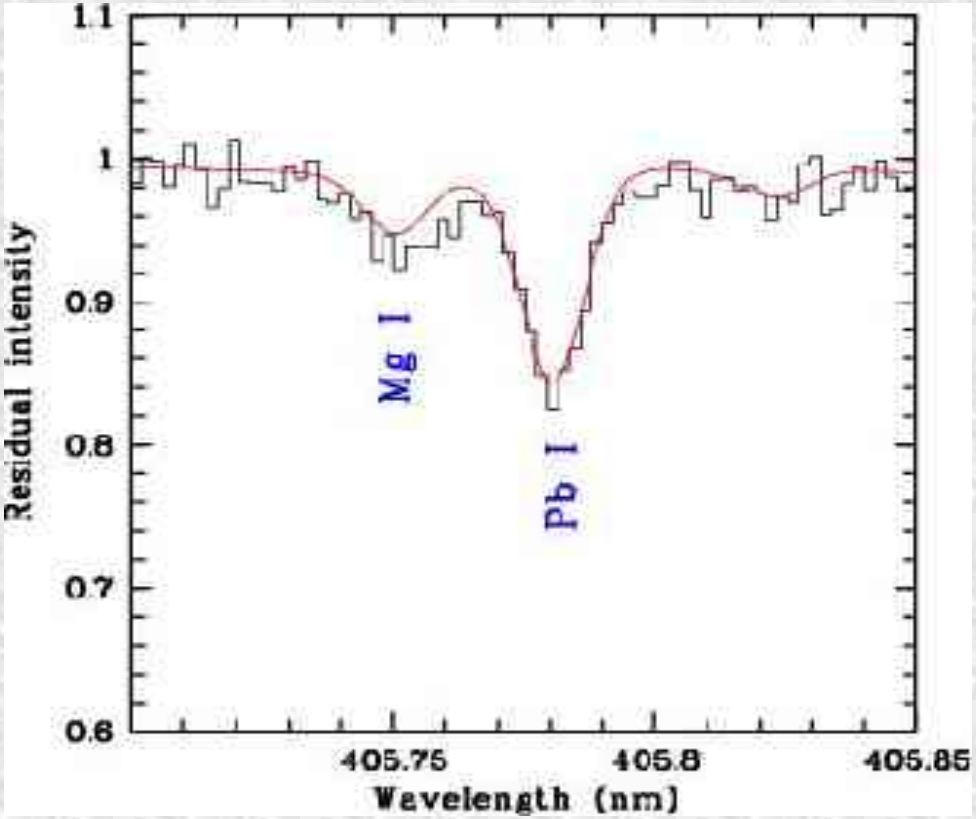
Lead

Produced mainly by s-process in solar composition material

Low metallicity stars DO make s-process and heavy nuclei are favoured because of the high n/seed ratio

CS 29497-030
[Fe/H]=-2.8 [Pb/Fe]=+3.5

Sivarani et al. 2004, 413, 1073



Lead in CS 31082-001 (“Hill's star”) here Pb MUST be made by r-process (?) A(Pb)=-0.55, very low ! Essentially what we expect from decay of Th and U.....so....??

Plez et al. 2005 A&A 428, L9