Abundance of Na & Al in the Extremely Metal Poor stars

and the chemical evolution of the Galactic Halo

M. Spite[1], S. Andrievsky[2], F. Spite[1], P. Bonifacio[1,3], R. Cayrel[1], V. Hill[1], P. François[1], S.A Korotin[2]

1-Observatoire de Paris-Meudon, GEPI
2-Astronomical Observatory, Odessa National University, Ukraine
3-CIFIST Marie Curie excellence team

Models of the chemical evolution of the Galactic Halo

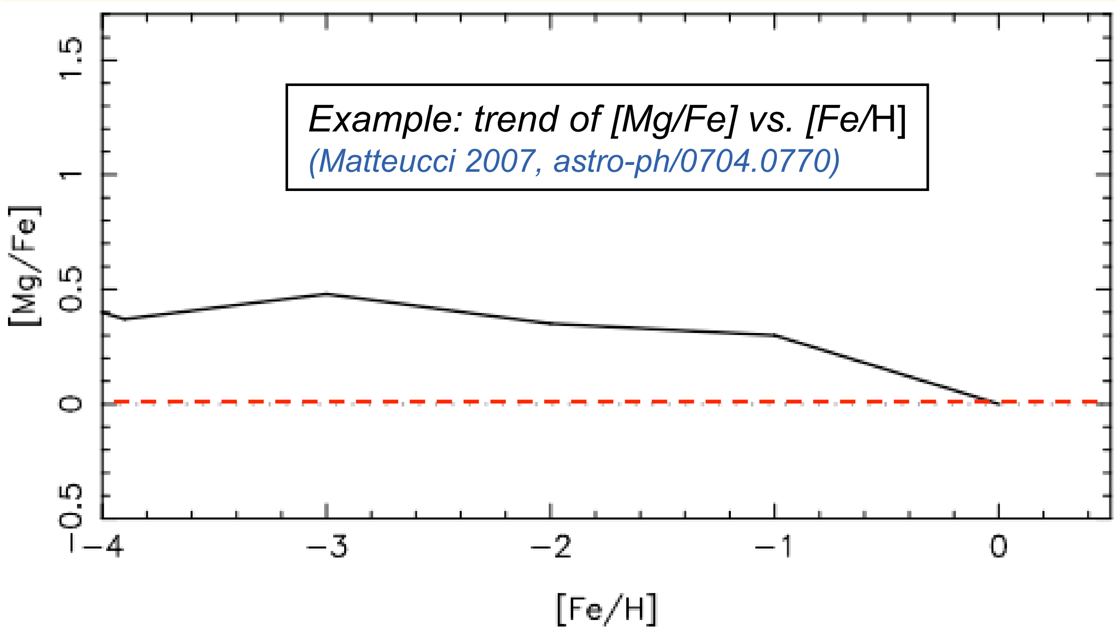
([Fe/H] ≤ -3)

one of the problems : when, at which metallicity, can we consider that mixing in the Galaxy became to be efficient ?

1- Homogeneous models

Mixing of the ISM is very efficient.

At one given time corresponds one metallicity, one chemical composition [Fe/H], [Mg/Fe] ... (no scatter)
The trends are due to the difference of lifetime of progenitors of different masses. *(François et al. 2004, Matteucci 2007)*



At low metallicity the matter is enriched only by the yields of massive supernovae (magnesium-rich) and little by little the enrichment by less massive supernovae (SN I: iron-rich) becomes important and the ratio Mg/Fe decreases.

2- Inhomogeneous models

each SN event triggers star formation in the swept up gas.
The newly formed star inherits the abundance pattern of individual SNe.
(Tsujimoto, 2002, Tominaga, 2007...)

Scatter $\Rightarrow$ IMF

Nucleosynthesis of Na Mg Al

Na, Mg, Al mostly synthesized in the same process: C-shell burning in massive stars (hydrostatic carbon burning)

➢The ratios of these elements should be closely linked

(The explosion expels these elements in the ISM without affecting significantly their yields.)

➢Evolution of the ratios of these elements

=

test of the models of the chemical evolution of the Galaxy.

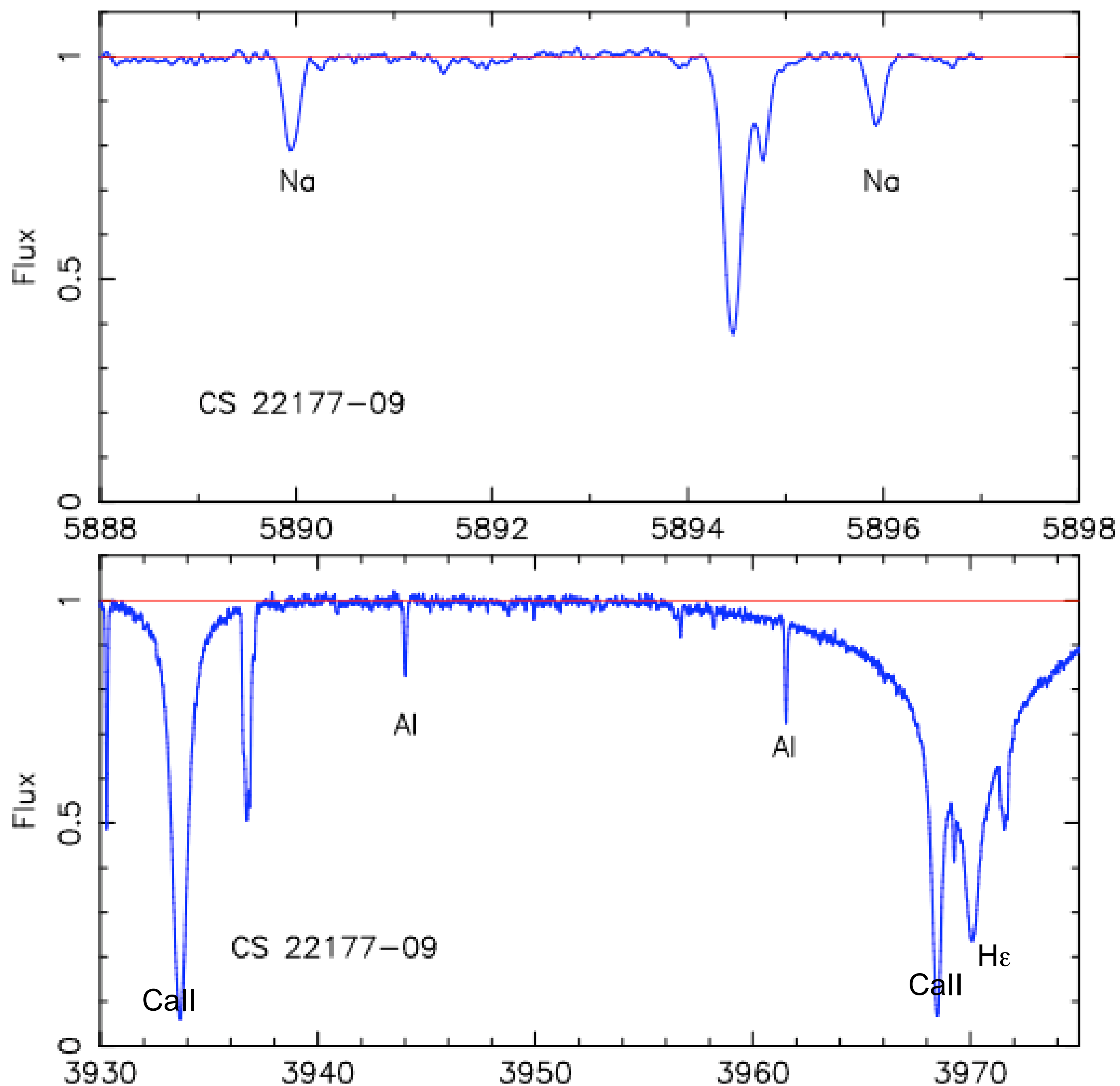
The ESO LP "First Stars"

➔ **homogeneous sample**

51 stars: 18 dwarfs and 33 giants

[Fe/H] ≤ -3 (NOT carbon-rich)

Characteristics of the spectra:
spectrograph UVES at the VLT
Resolution: ≈ 45 000
Complete coverage between 330 nm < λ < 930 nm
S/N ≈ 200 (but depends of λ)



Spectra

CS22177-09

Teff = 6260K
log g= 4.5
[Fe/H]=-3.1

Analysis

Cayrel et al. 2004
Bonifacio et al. 2007

1st STEP: LTE abundance analysis (1D models)

models : OSMARCS Gustafsson 1975, Plez et al. 1992, Edvardsson et al. 1993, Asplund et al. 1997

Temperature :

giants: color indices *B-V* *V-R* *V-K* *V-I* *J-K*

+ Alonso calibration for giants (Alonso, 1999)

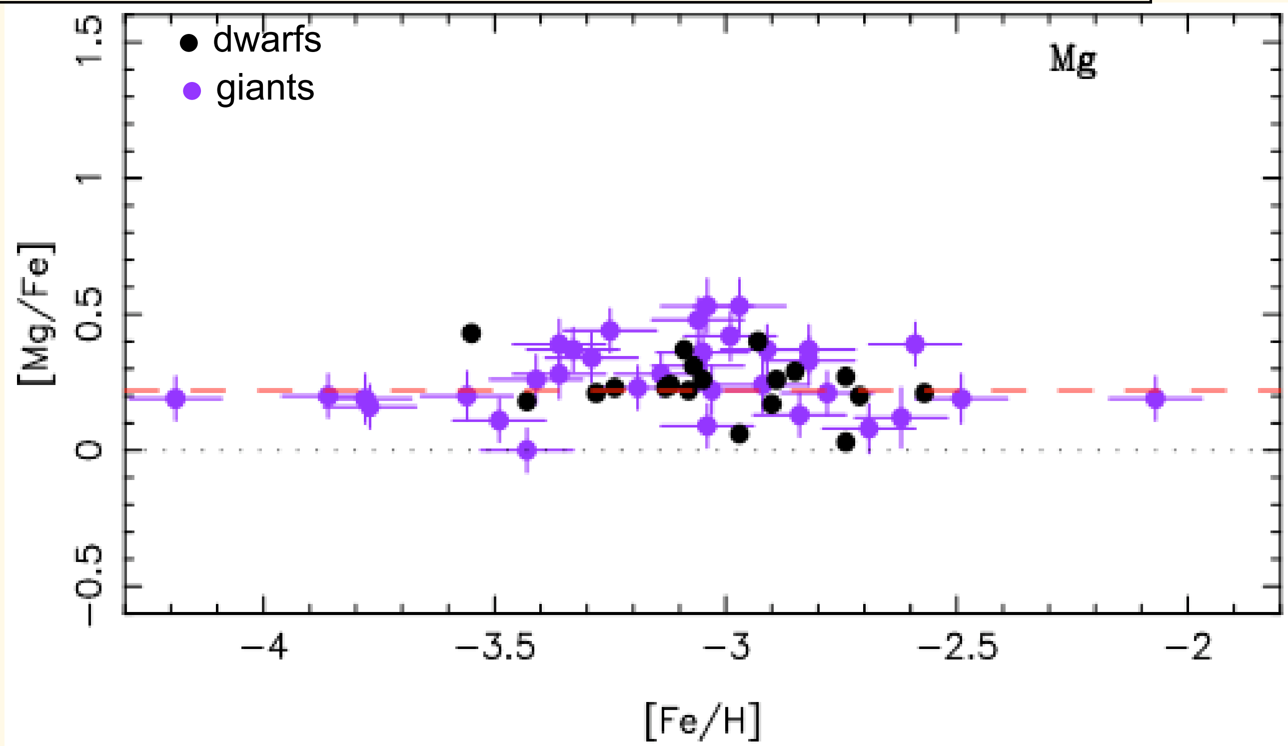
dwarfs: Hα wings

gravity : ionisation equilibrium

v_t : iron abundance independent of the EW of the line

Results

As predicted, magnesium is found overabundant at low metallicity.
[Mg/Fe] is found constant from about [Fe/H]=-2.5 to -4. The scatter is about 0.1.

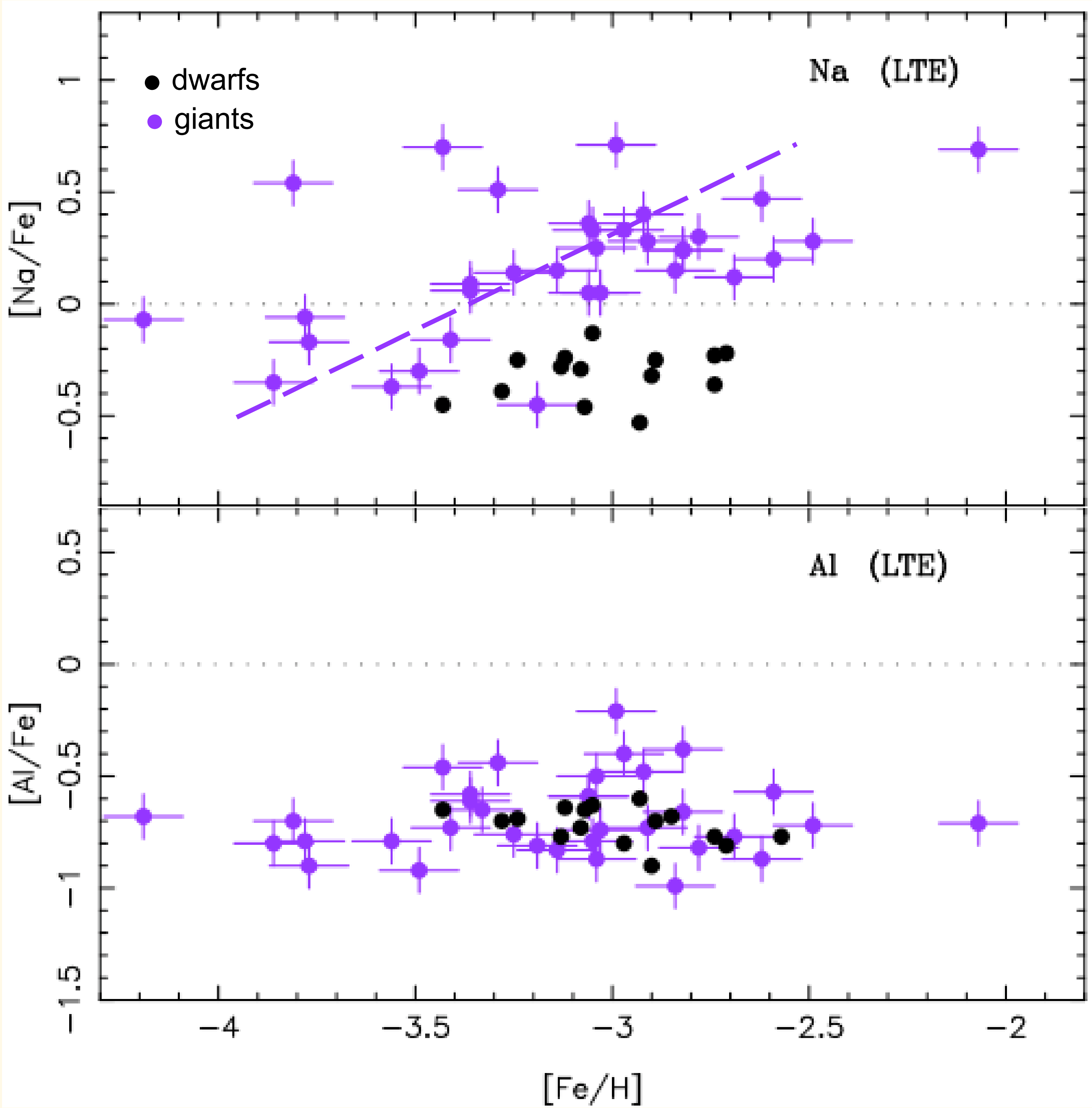


giants only : [Mg/Fe]=0.29 σ=0.14
dwarfs only : [Mg/Fe]=0.22 σ=0.09

Results

If we plot the ratio [Na/Fe] versus [Fe/H] for giants only (violet dots), the scatter is large and it seems that the ratio [Na/Fe] increases with metallicity as it was published in Cayrel et al. (2004).
But when the dwarfs (black dots) are added to the figure the trend disappears...

For the ratio [Al/Fe] there is no trend with [Fe/H], the agreement between dwarfs and giants is good, but the scatter is rather large.

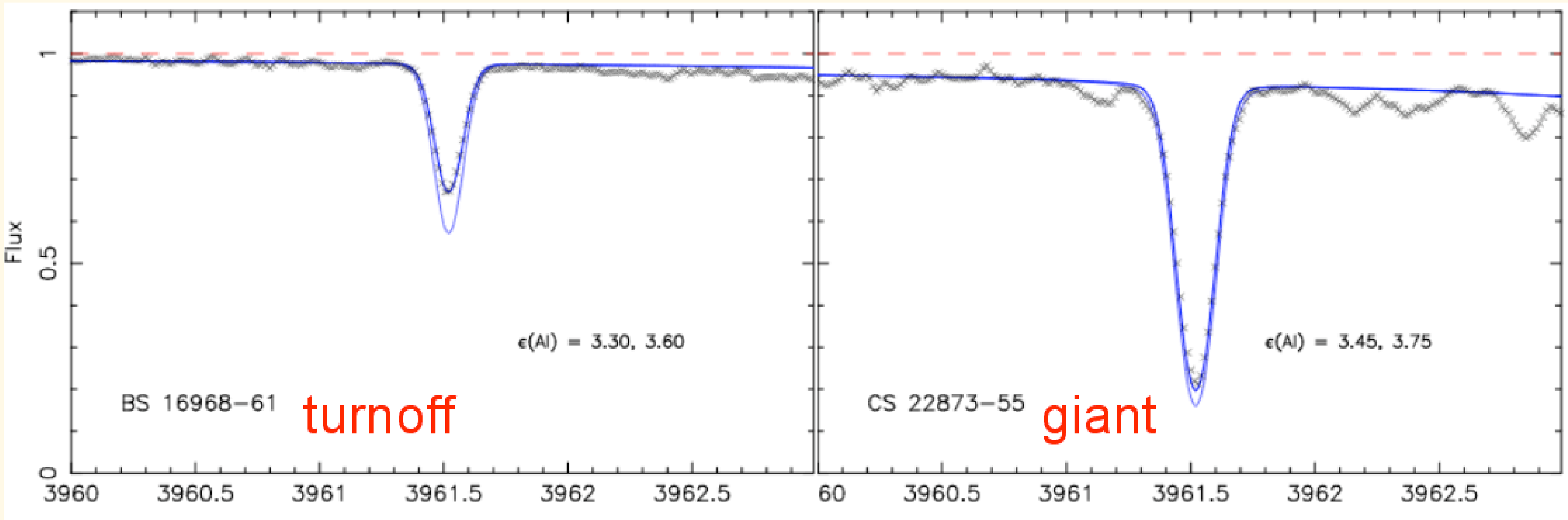


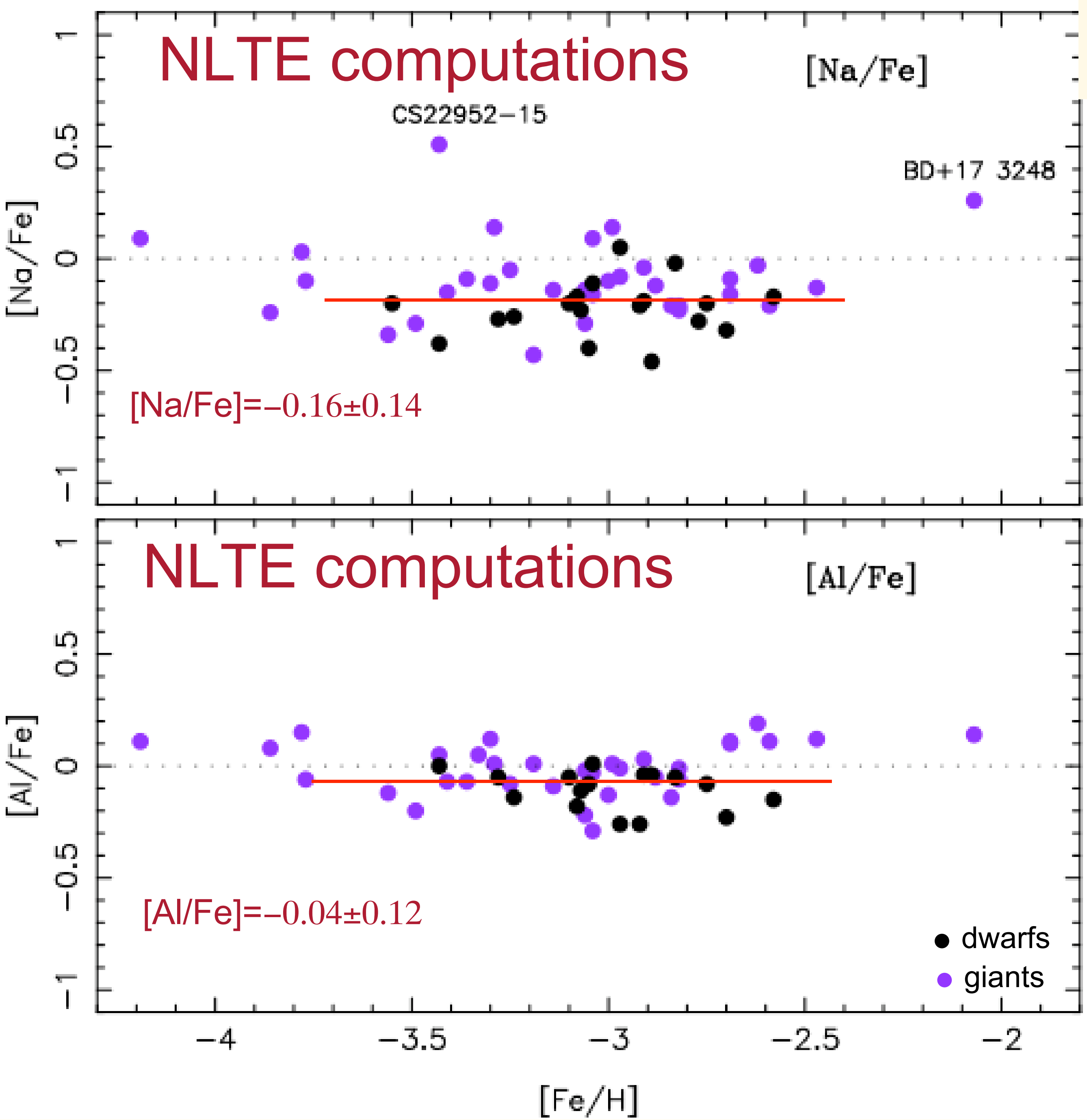
NLTE computations

But... Na ← Na D resonance lines (5890 and 5896 Å)
Al ← resonance doublet (3944 and 3961 Å)
Very sensitive to NLTE effects ⇨ NLTE computations

see: Andrievsky et al. 2007 (and Andrievsky et al. 2007 in preparation)

Al I line at 3961.52 Å





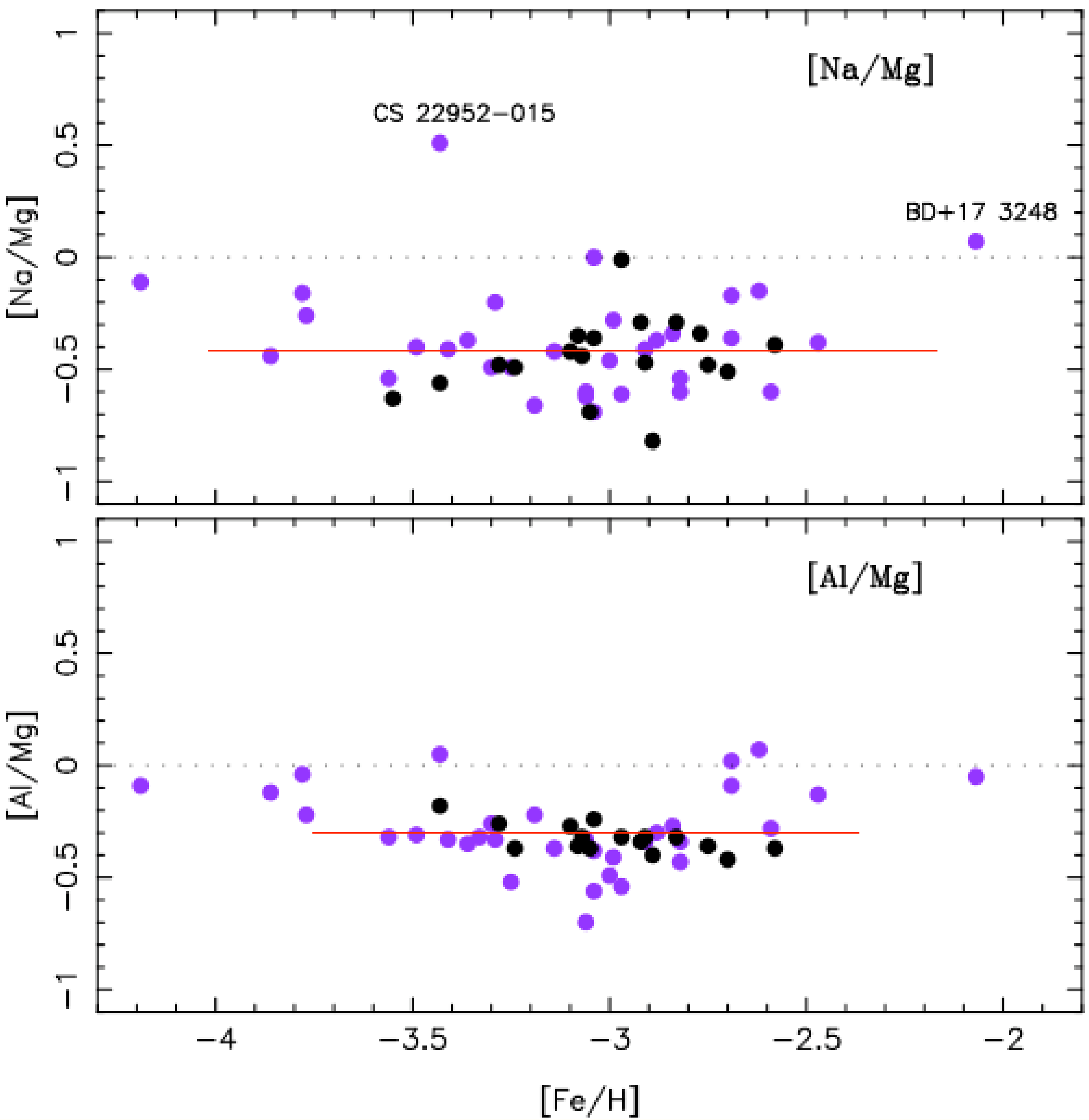
New Results

Na:
2007, Andrievsky et al.

Al:
2007, Andrievsky et al.
(in preparation)

Contrary to the LTE results of Cayrel et al. (2004)
in the halo stars [Na/Fe] does not increase with [Fe/H]. [Al/Fe] is also flat

when -4<[Fe/H]<-2.7 the ratios [Na/Fe] and [Al/Fe] are constant and the scatter is about 0.1.



The scatter is larger when Mg is the reference element ...

Why ?

(See previous slide. The measurement errors cannot explain this difference)

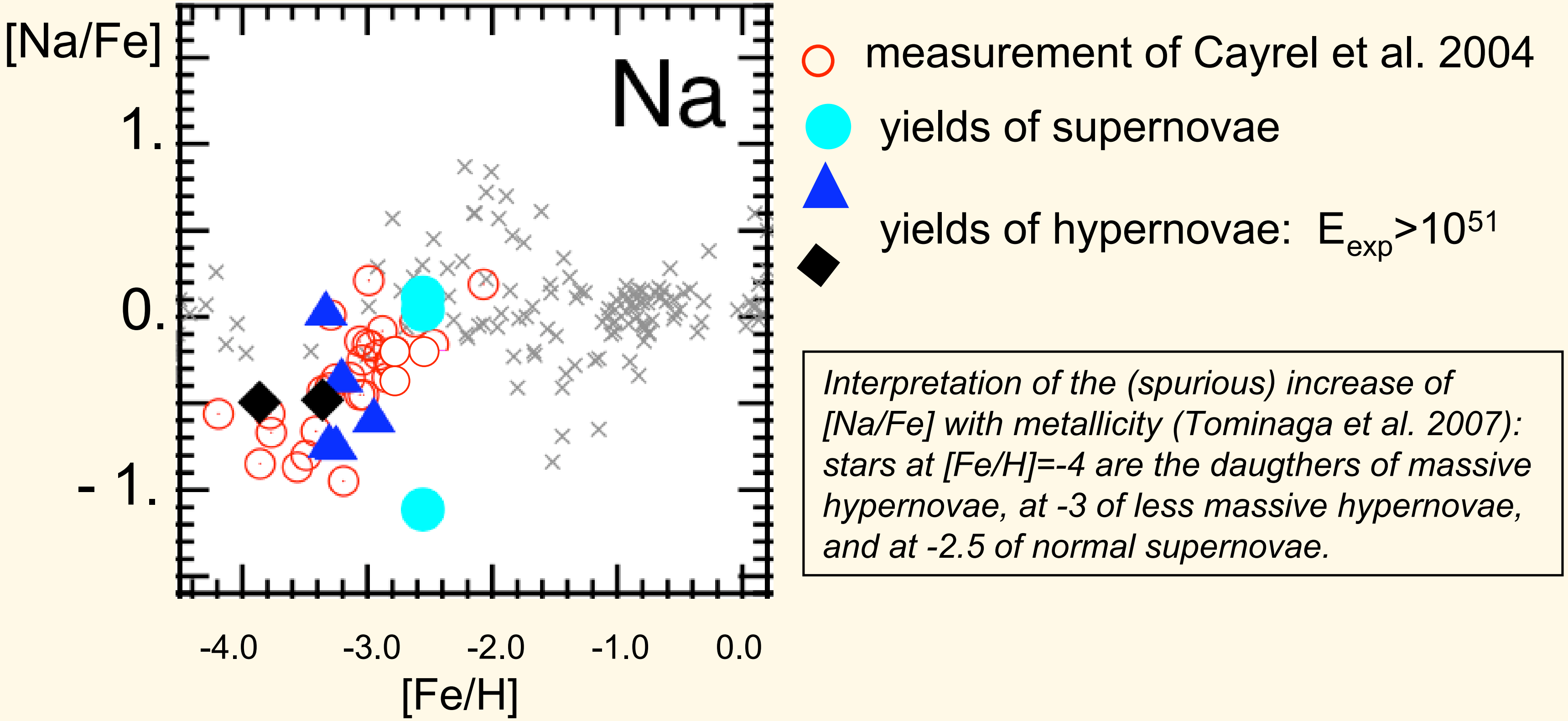
[Na/Mg]≈-0.4
[Al/Mg] ≈-0.3

Comparison to the predictions of the models of the early chemical evolution of the Galaxy

Comparison to the predictions of Tominaga et al. (2007)

inhomogeneous early Galaxy ???

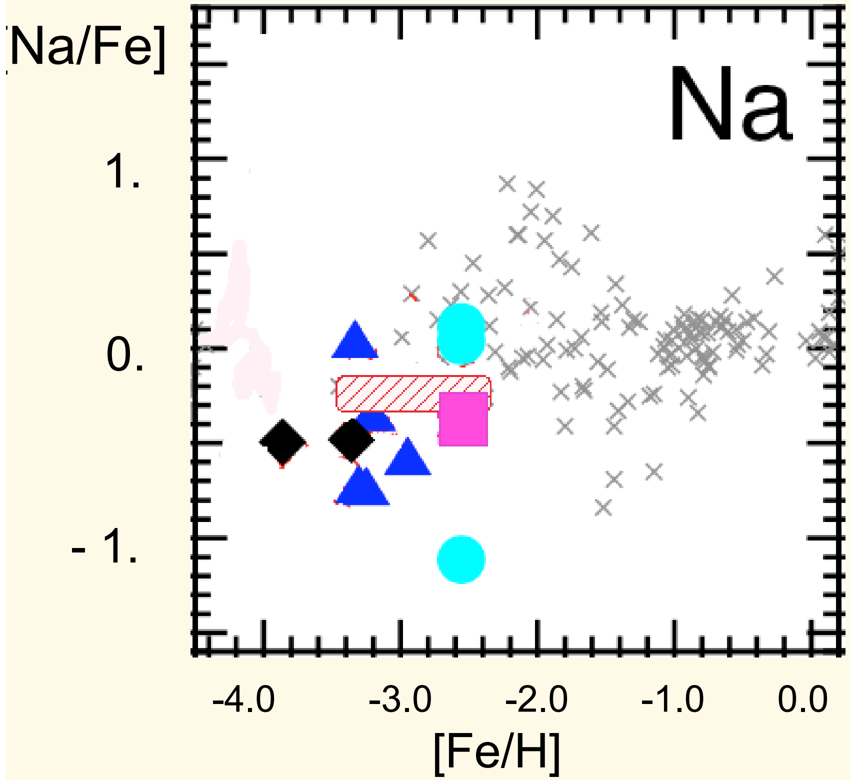
Old LTE measurements



Interpretation of the (spurious) increase of [Na/Fe] with metallicity (Tominaga et al. 2007): stars at [Fe/H]=-4 are the daugthers of massive hypernovae, at -3 of less massive hypernovae, and at -2.5 of normal supernovae.

Comparison to the predictions of Tominaga et al. (2007)

***New** measurements (NLTE computations)*



New NLTE measurements of [Na/Fe]

yields of supernovae

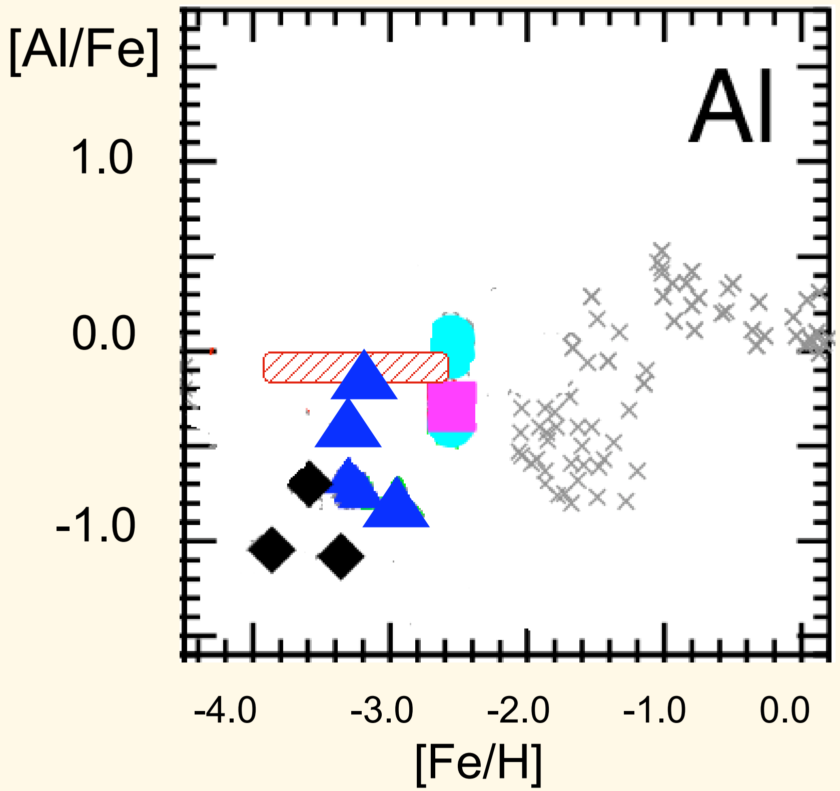
yields of hypernovae: $E_{exp}>10^{51}$

yields of a "mean hypernova-supernova" integrated over the IMF

Our new NLTE measurements of [Na/Fe] are located inside the hatched zone. The mean value corresponds to the yields of a "mean supernova". Thus this new value can be understood if the galactic gas is efficiently mixed from [Fe/H]=-4.

Comparison to the predictions of Tominaga et al. (2007)

***New** measurements (NLTE computations)*



New NLTE measurements of [Al/Fe]

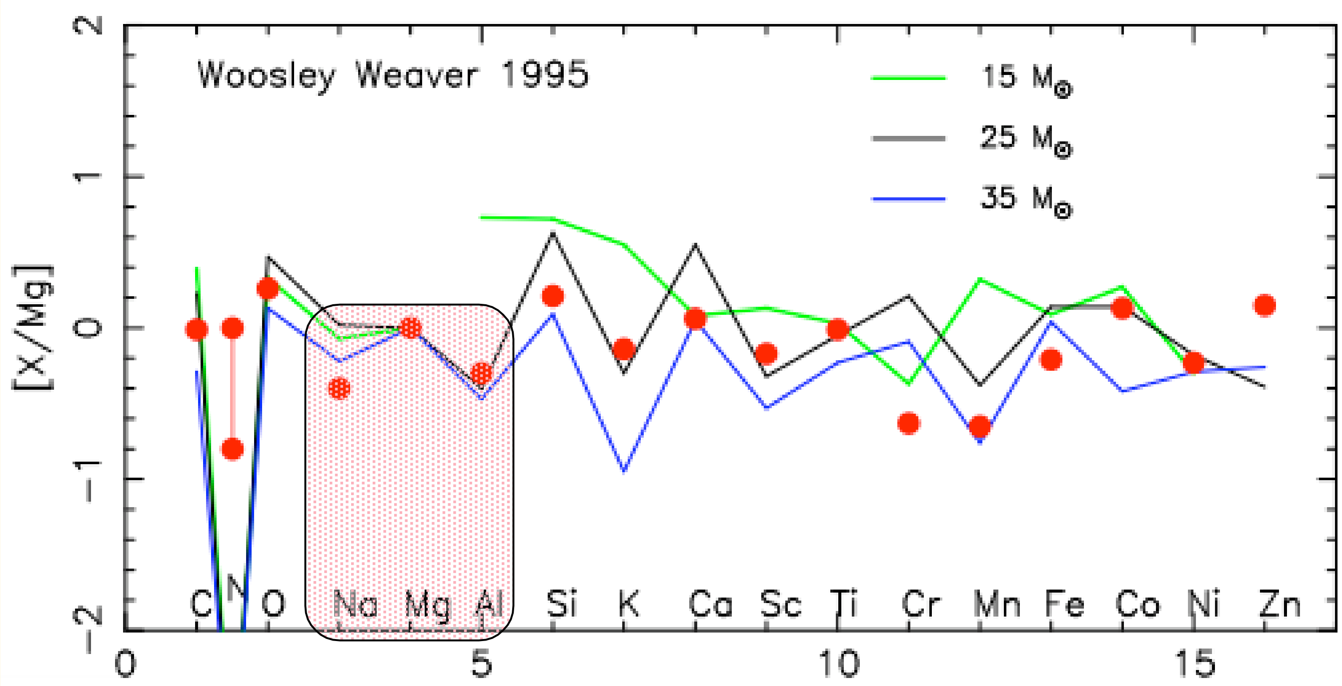
yields of supernovae

yields of hypernovae: $E_{exp}>10^{51}$

yields of a "mean hypernova-supernova" integrated over the IMF

The new measurements inside the hatched zone correspond rather well to the predictions of the mean supernova and can be understood if the galactic gas is efficiently mixed from [Fe/H]=-4.

Comparison with the computations of Woosley & Weaver



Comparison of our measurements "●" to the predictions of Woosley & Weaver (1995) for different masses of SN II.

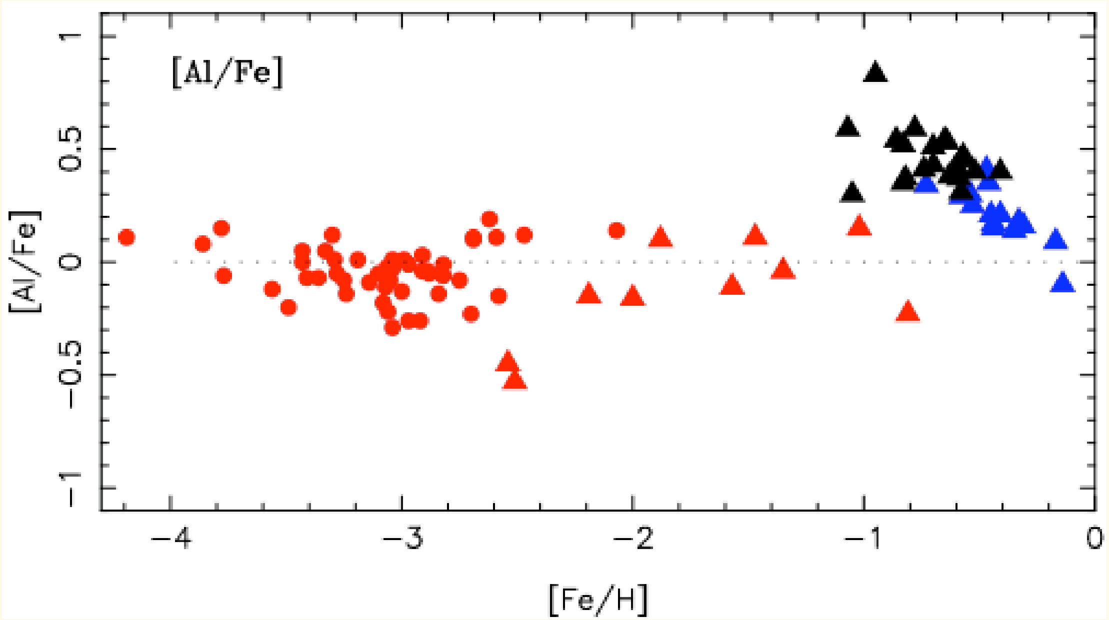
With these new measurements the fit is rather good, (better than it was).

Evolution of [Al/Fe] in our Milky Way

(Gehren et al. 2006)

only NLTE computations

- ▲ thin disk (Gehren)
- ▲ thick disk (Gehren)
- ▲ halo (Gehren)
- ● halo (ESO-LP)



thick disk stars: [Al/Fe] ≈ +0.5
halo stars: [Al/Fe] ≈ 0.0

The triangles represent the NLTE measurements of Gehren et al. in the thin disk, the thick disk and the halo.
The red dots are our NLTE measurements in the most metal-poor halo stars.
We confirm the low value of the ratio [Al/Fe] in the halo stars.
On the contrary (following Gehren et al. 2006) this ratio is large in the thick disk stars. This could imply a different origin of the thick disk.

Conclusion

☛ As soon as [Fe/H] > - 4 the Galactic gas in the halo seems to have been efficiently mixed *(if the yields of Tominaga et al. 2007, are adopted)*.

☛ [Al/Fe] ≈ +0.0 in the halo

≈ +0.5 in the thick disk (following Gehren et al 2006)

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