Lithium abundances in extremely metal poor turn-off stars

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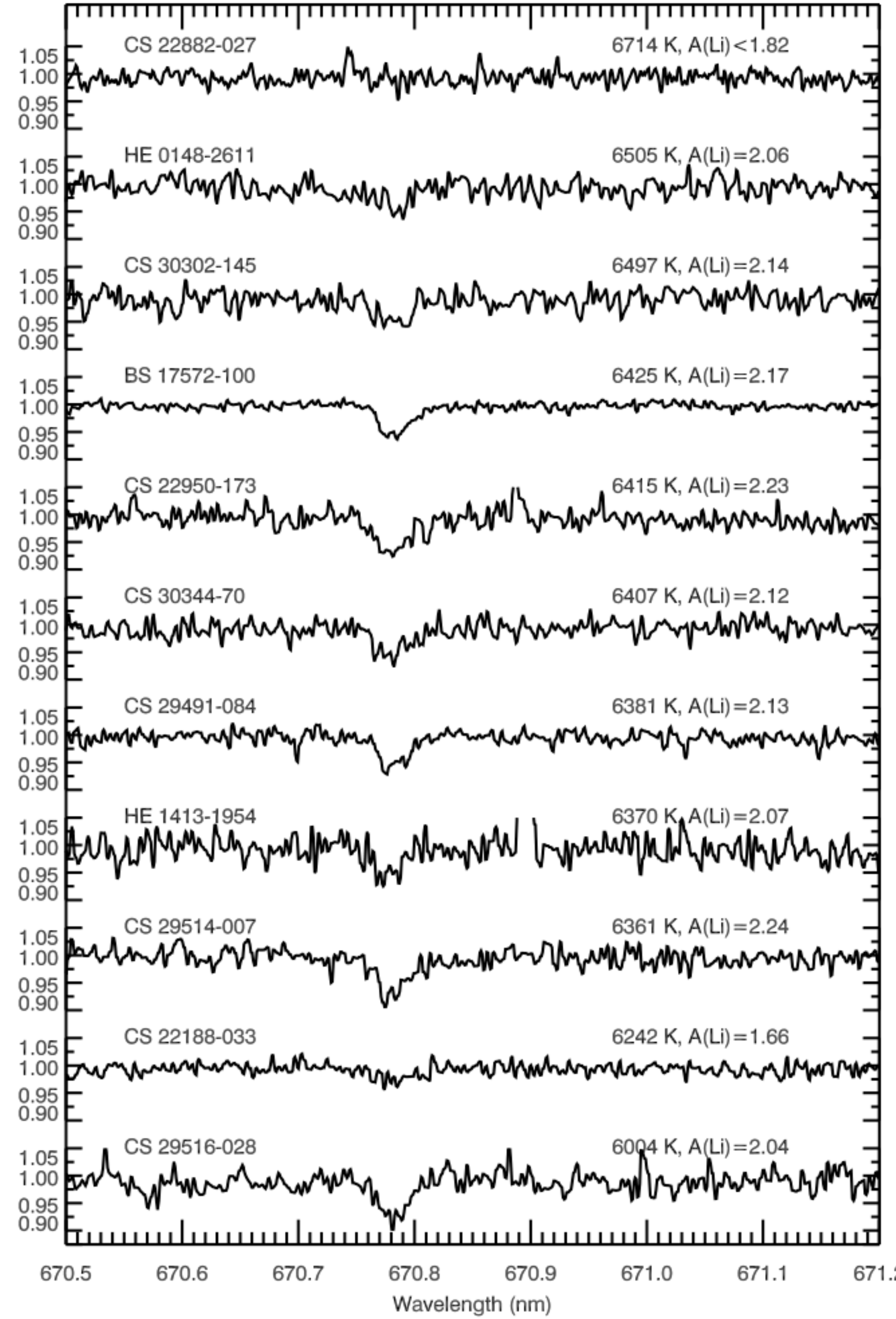
And with...

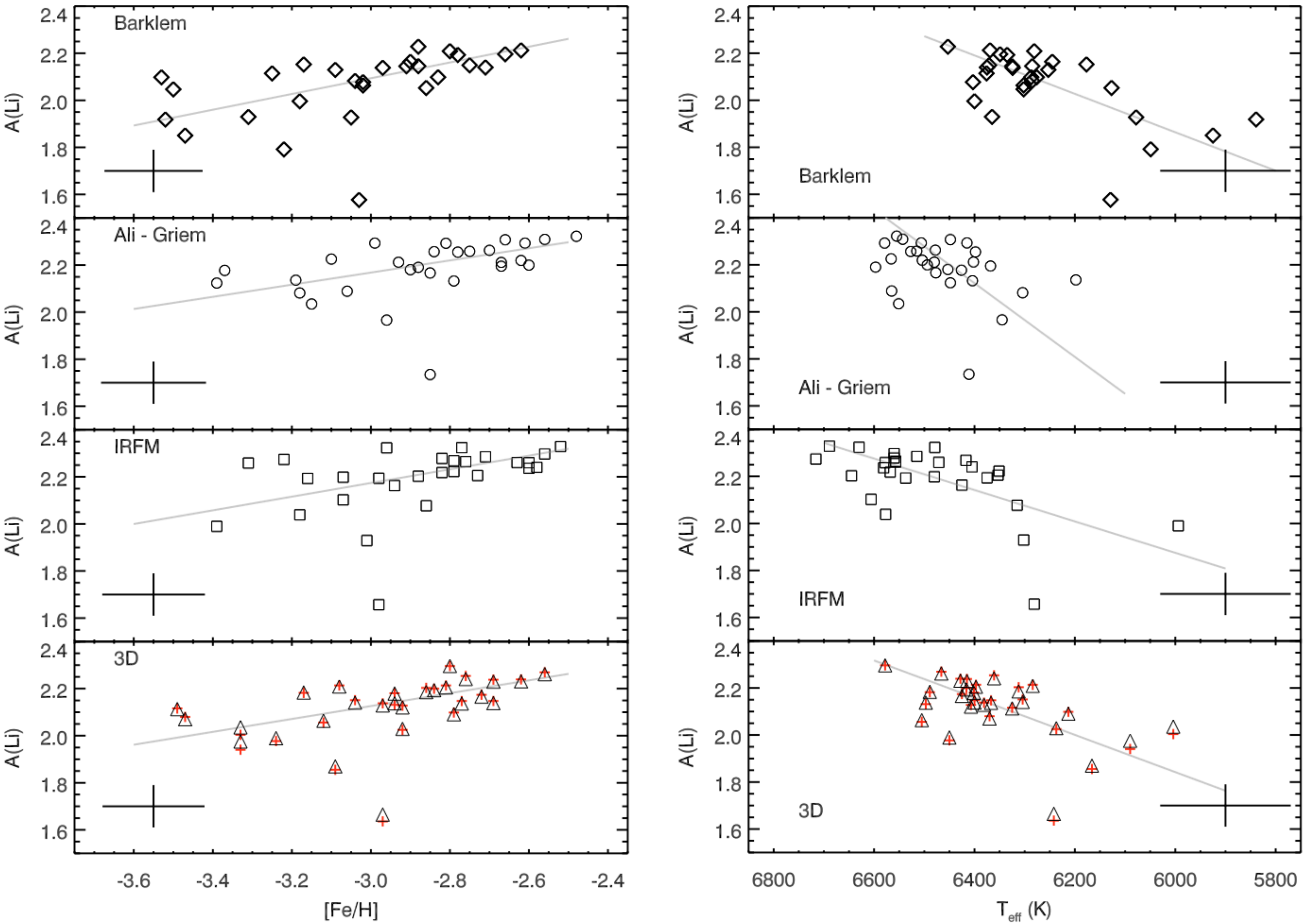
P. Bonifacio, E. Caffau, R. Cayrel, P. François, B. Freytag, L. Monaco, M. & F. Spite, H. G. Ludwig, M. Steffen...

A&A, 522, A26

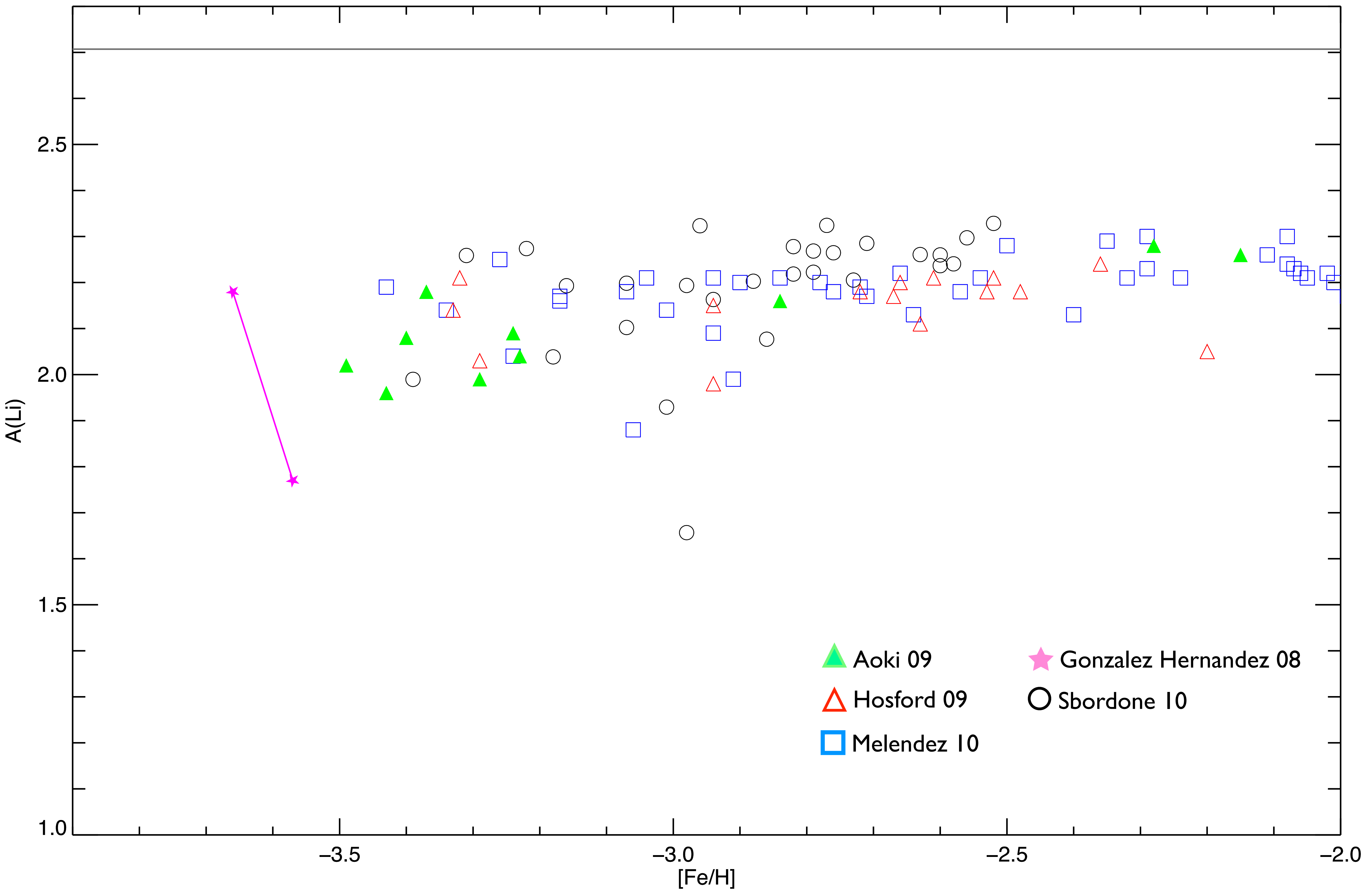
Sbordone et al. 2010 sample...

- 28 Halo dwarf/To stars between [Fe/H]=-2.5 and -3.5
- Full parameter determination with 4 different temperature scales: 3 Hα- based, and IRFM
- "Preferred" Teff and parameters based on 3D CO^{5}BOLD Hα wing profiles and full 3D-NLTE Li doublet spectrosynthesis.
- But I will use IRFM-based temperatures here for "consistency" with other studies.



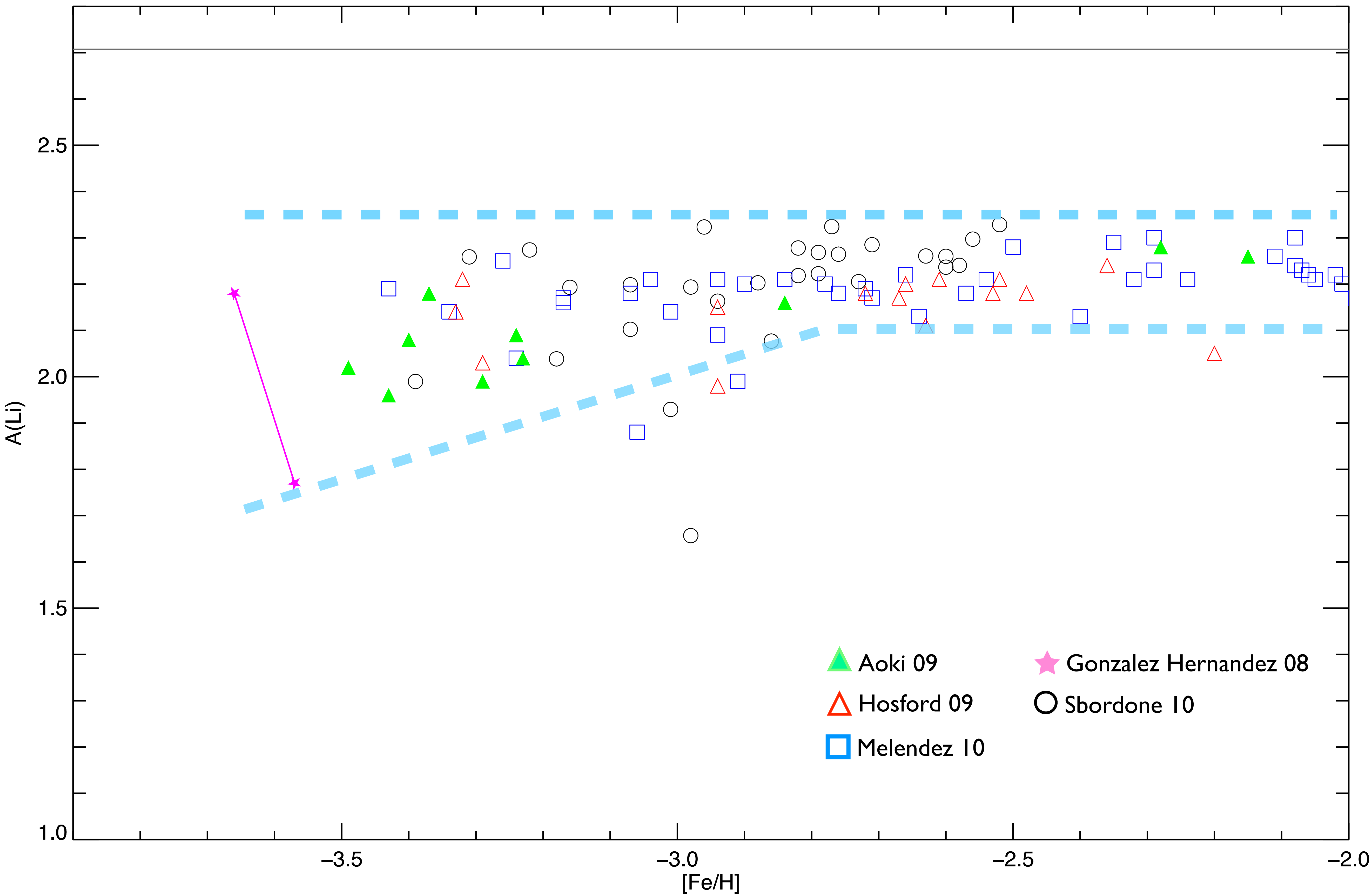

Barklem
Ali - Griem
IRFM
3D
A(Li)
[Fe/H]
T$_{eff}$ (K)

A(Li) vs [Fe/H]



2.5
2.0
1.5
1.0
A(Li)
−3.5
−3.0
−2.5
−2.0
[Fe/H]
Aoki 09
Hosford 09
Melendez 10
Gonzalez Hernandez 08
Sbordone 10

A(Li) vs [Fe/H]



2.5
2.0
1.5
1.0
A(Li)
−3.5
−3.0
−2.5
−2.0
[Fe/H]
Aoki 09
Hosford 09
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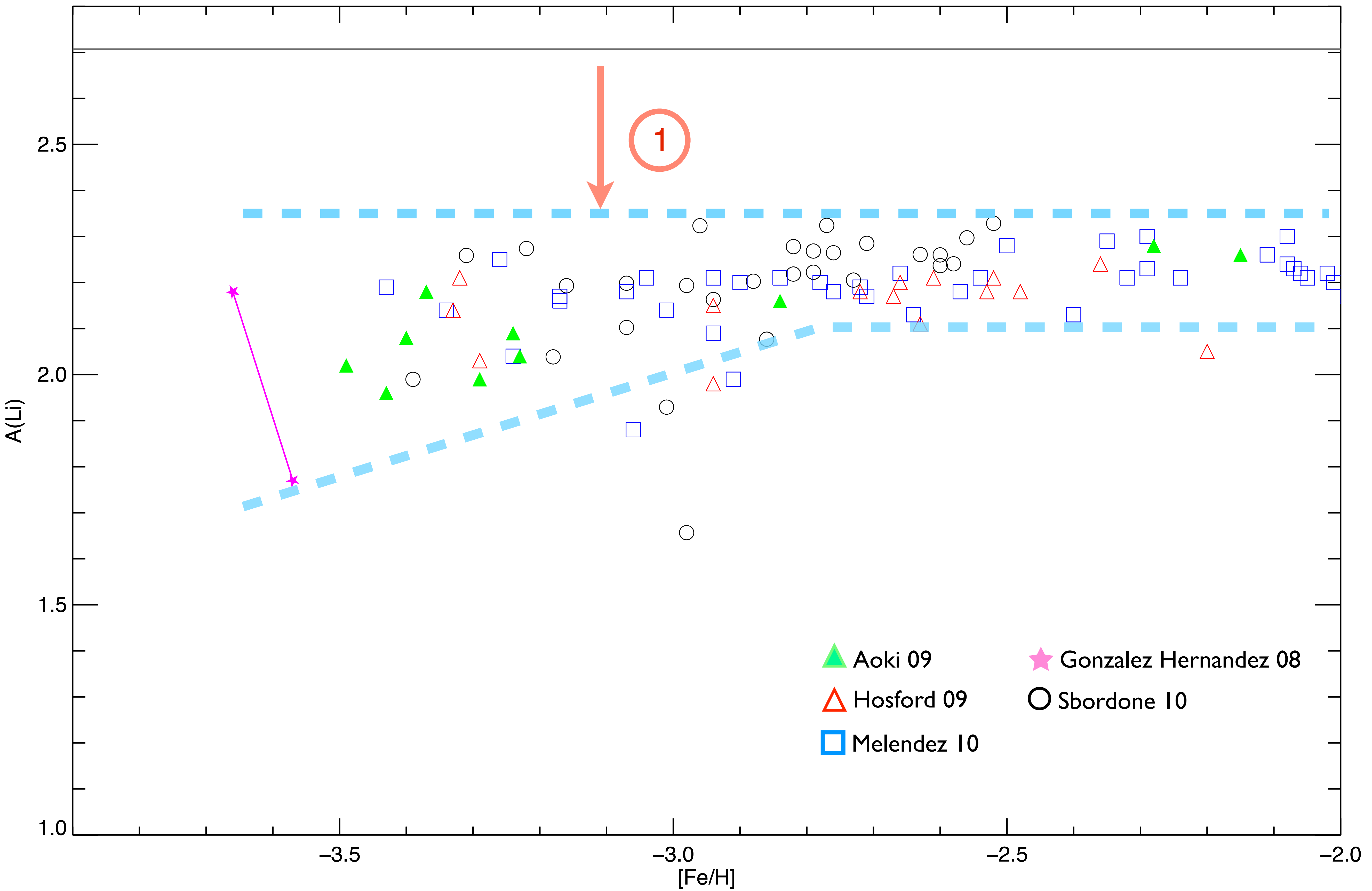
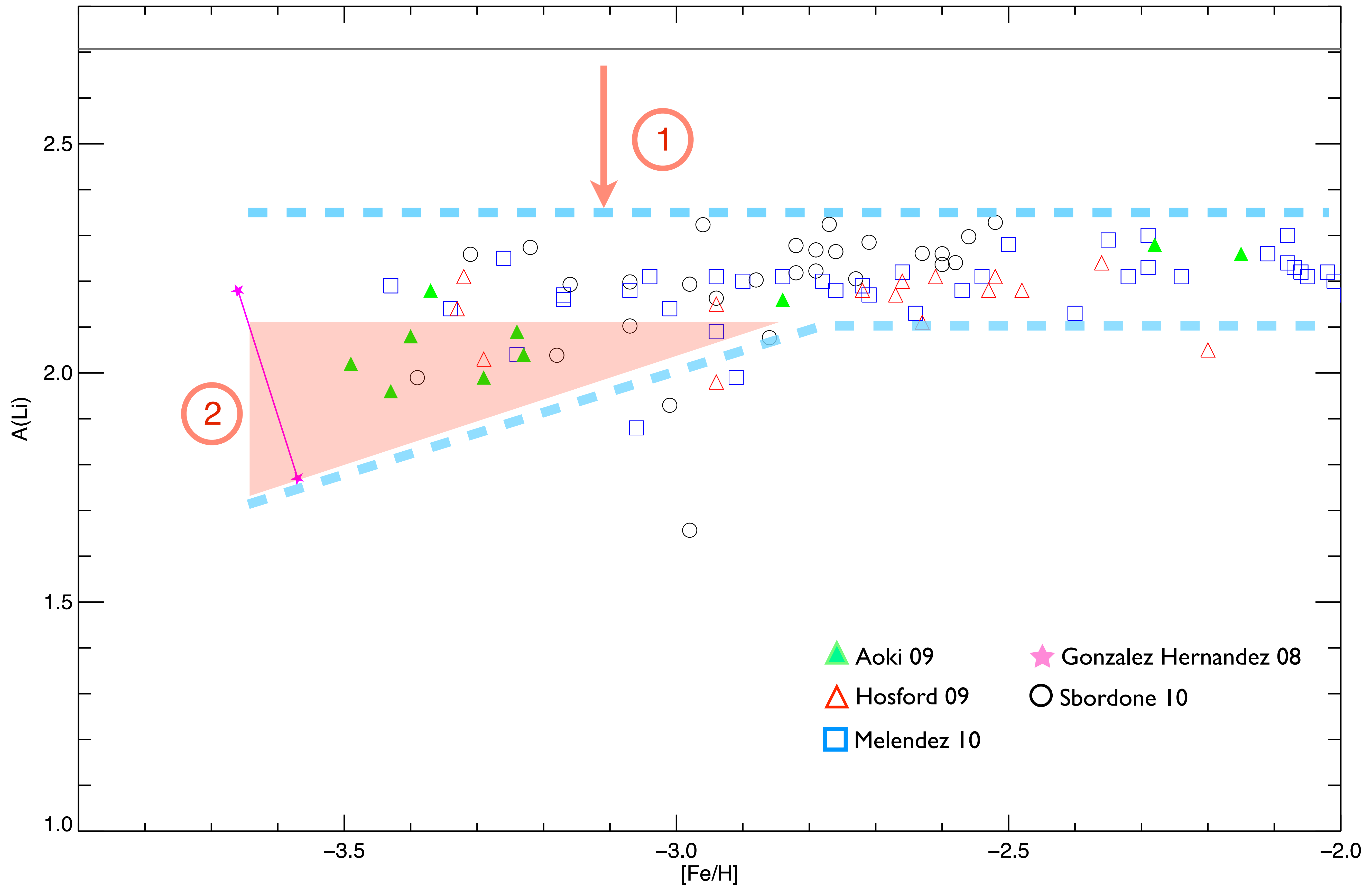
A(Li) vs [Fe/H]


1
Aoki 09
Hosford 09
Melendez 10
Gonzalez Hernandez 08
Sbordone 10
A(Li)
2.5
2.0
1.5
1.0
−3.5
−3.0
−2.5
−2.0
[Fe/H]

A(Li) vs [Fe/H]


1
2
2.5
2.0
1.5
1.0
A(Li)
−3.5
−3.0
−2.5
−2.0
[Fe/H]
Aoki 09
Hosford 09
Melendez 10
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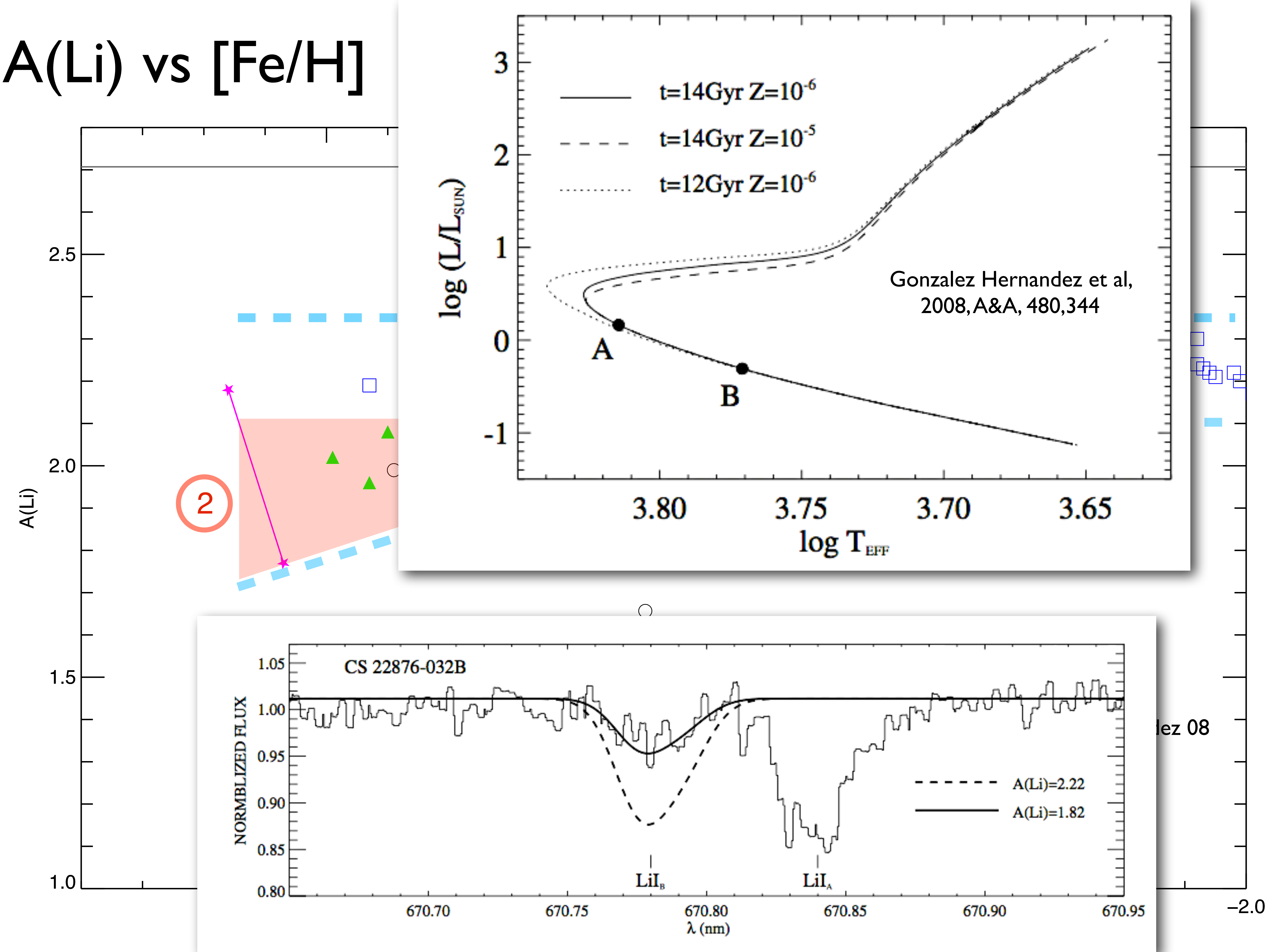
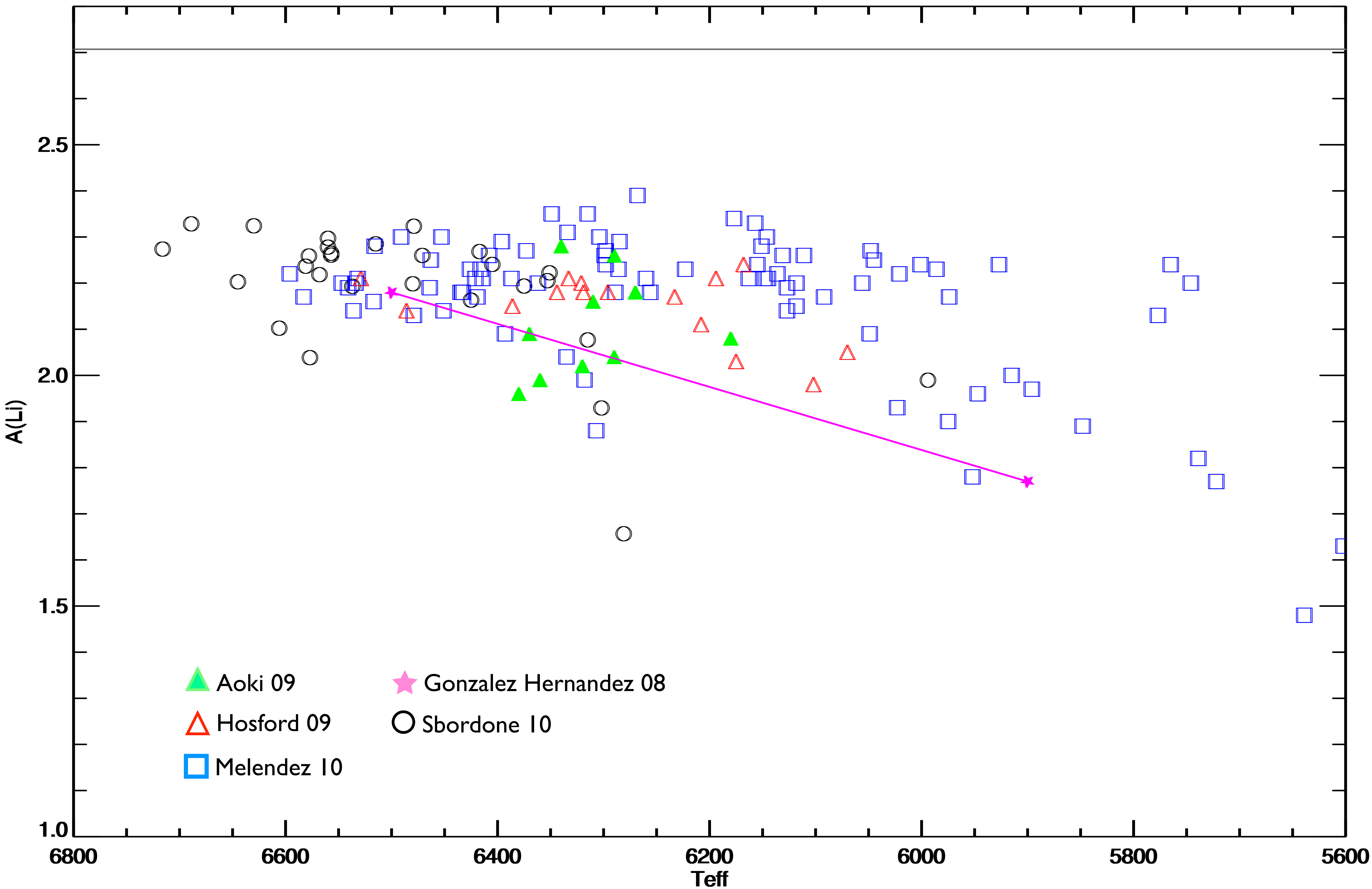
A(Li) vs [Fe/H]



A(Li)
2.5
2.0
1.5
1.0
−2.0
2
lez 08
t=14Gyr Z=10^{-6}
t=14Gyr Z=10^{-5}
t=12Gyr Z=10^{-6}
log (L/L$_{SUN}$)
log T$_{EFF}$
3.80
3.75
3.70
3.65
A
B
Gonzalez Hernandez et al, 2008, A&A, 480,344
CS 22876-032B
NORMBLIZED FLUX
A(Li)=2.22
A(Li)=1.82
LiI$_B$
LiI$_A$
λ (nm)
670.70
670.75
670.80
670.85
670.90
670.95

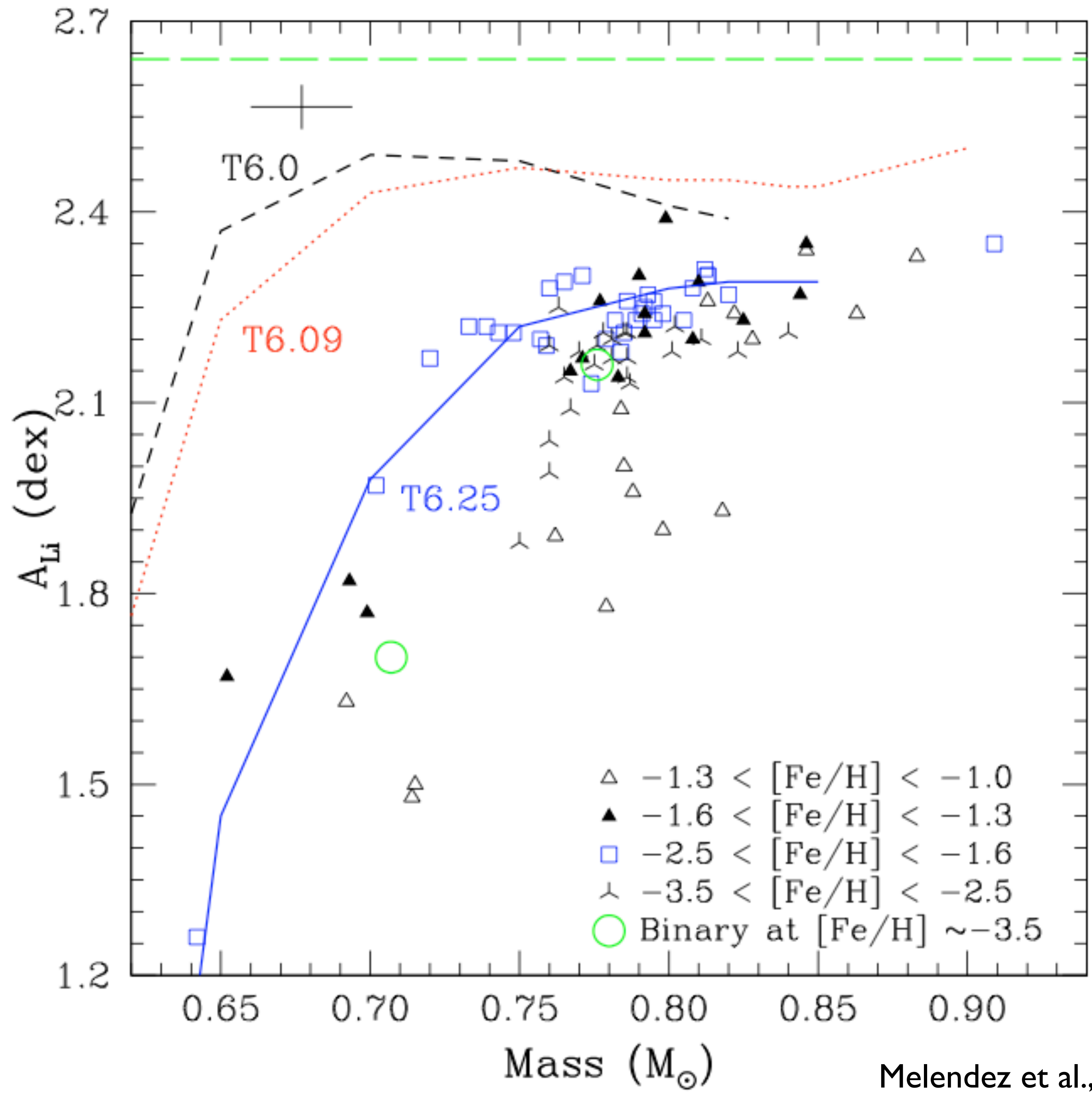
A(Li) vs T_{eff}



A(Li)
Teff
2.5
2.0
1.5
1.0
6800
6600
6400
6200
6000
5800
5600
Aoki 09
Hosford 09
Melendez 10
Gonzalez Hernandez 08
Sbordone 10

Is depletion mass sensitive?

- Melendez et al. 2010 propose that the "meltdown" is the result of stronger Li depletion in lower mass stars.
- TO for given mass is <u>hotter</u> at lower [Fe/H]
- Suggest a temperature-metallicity cutoff:

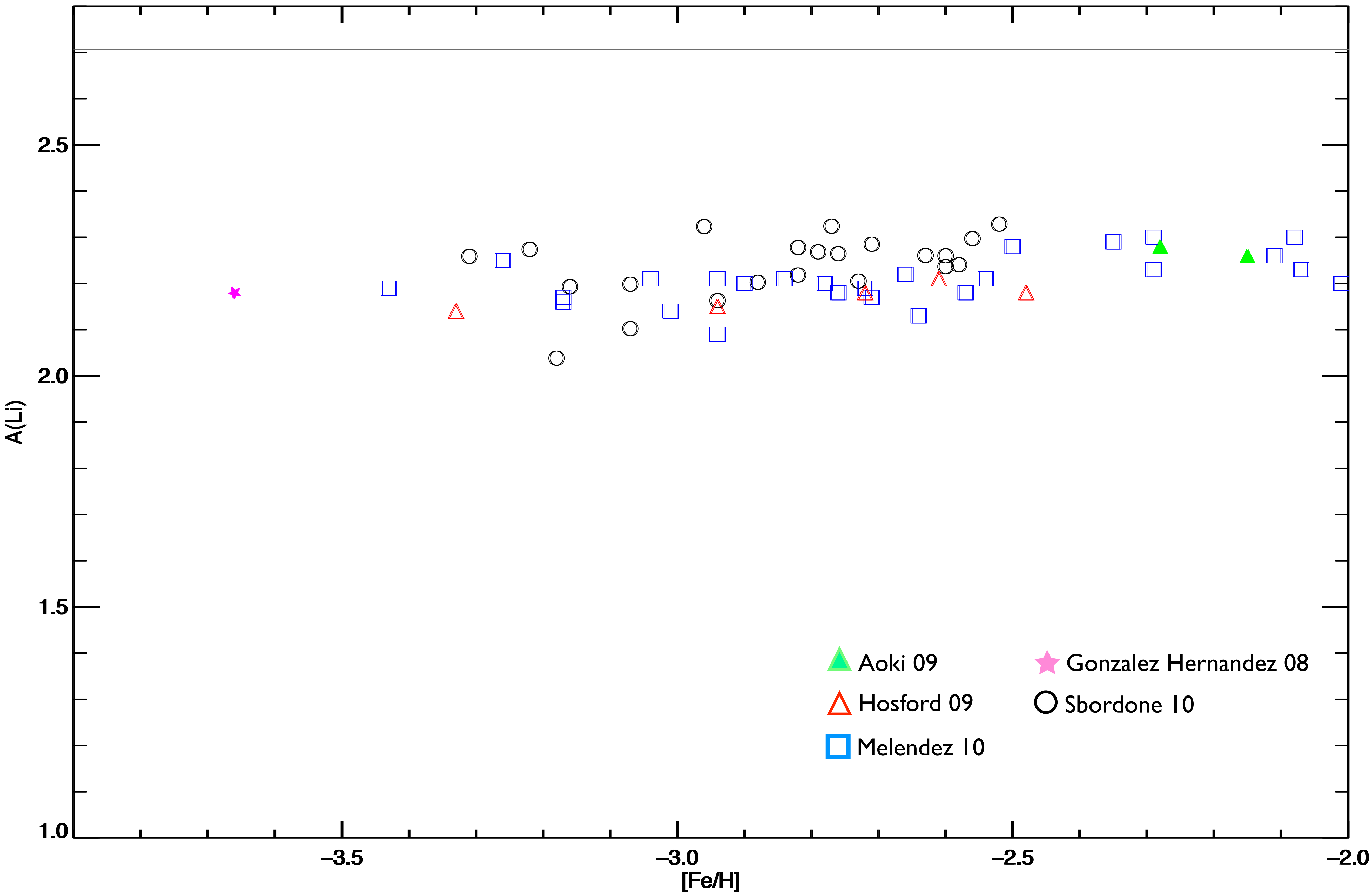


Melendez et al., 2010, A&A, 515, L3

$$\boxed{T_{\rm eff} > 5850 - 180 * [{\rm Fe/H}]}$$

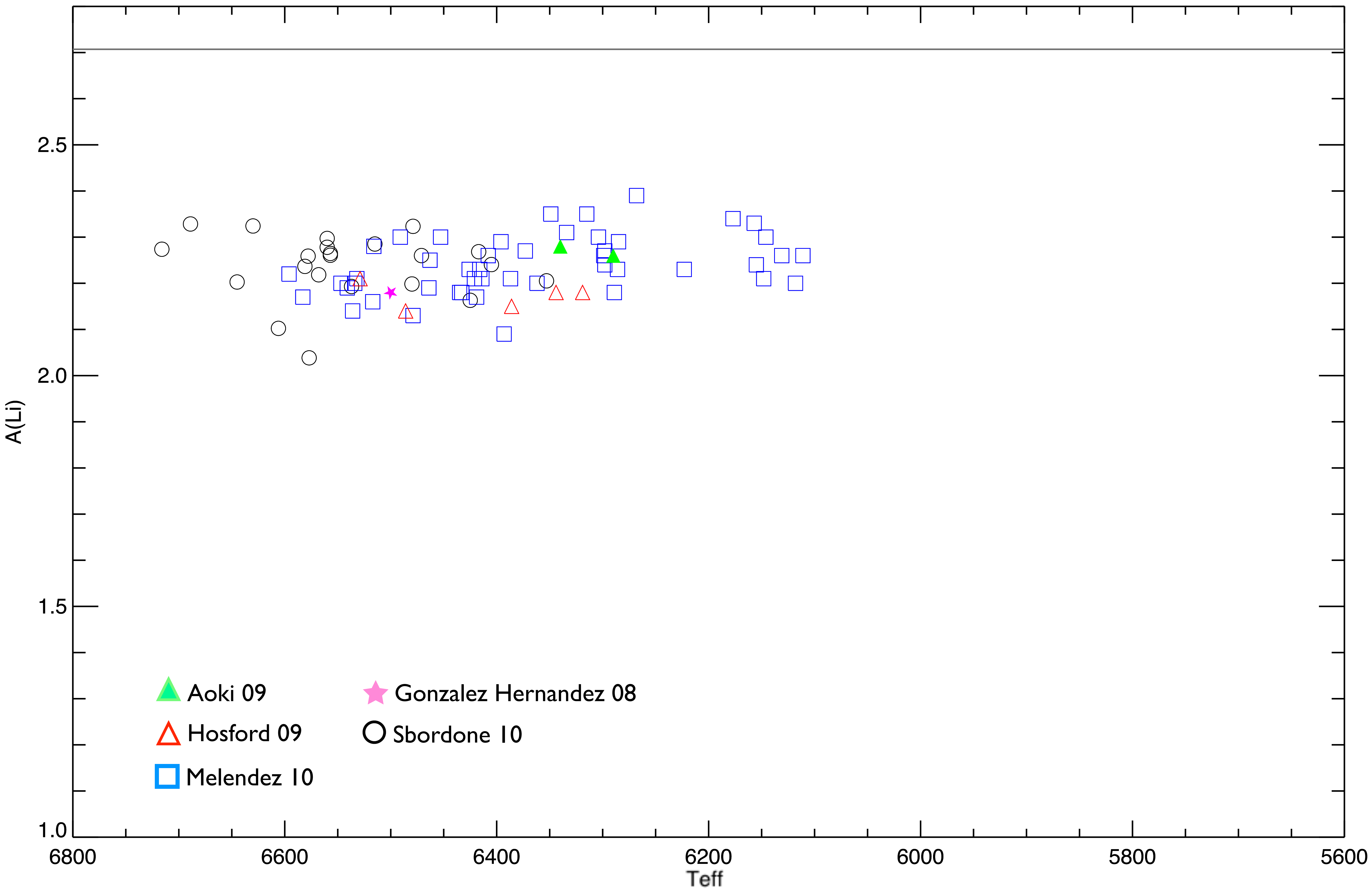
A(Li) vs [Fe/H]

$$T_{\rm eff} > 5850 - 180 * [{\rm Fe/H}]$$

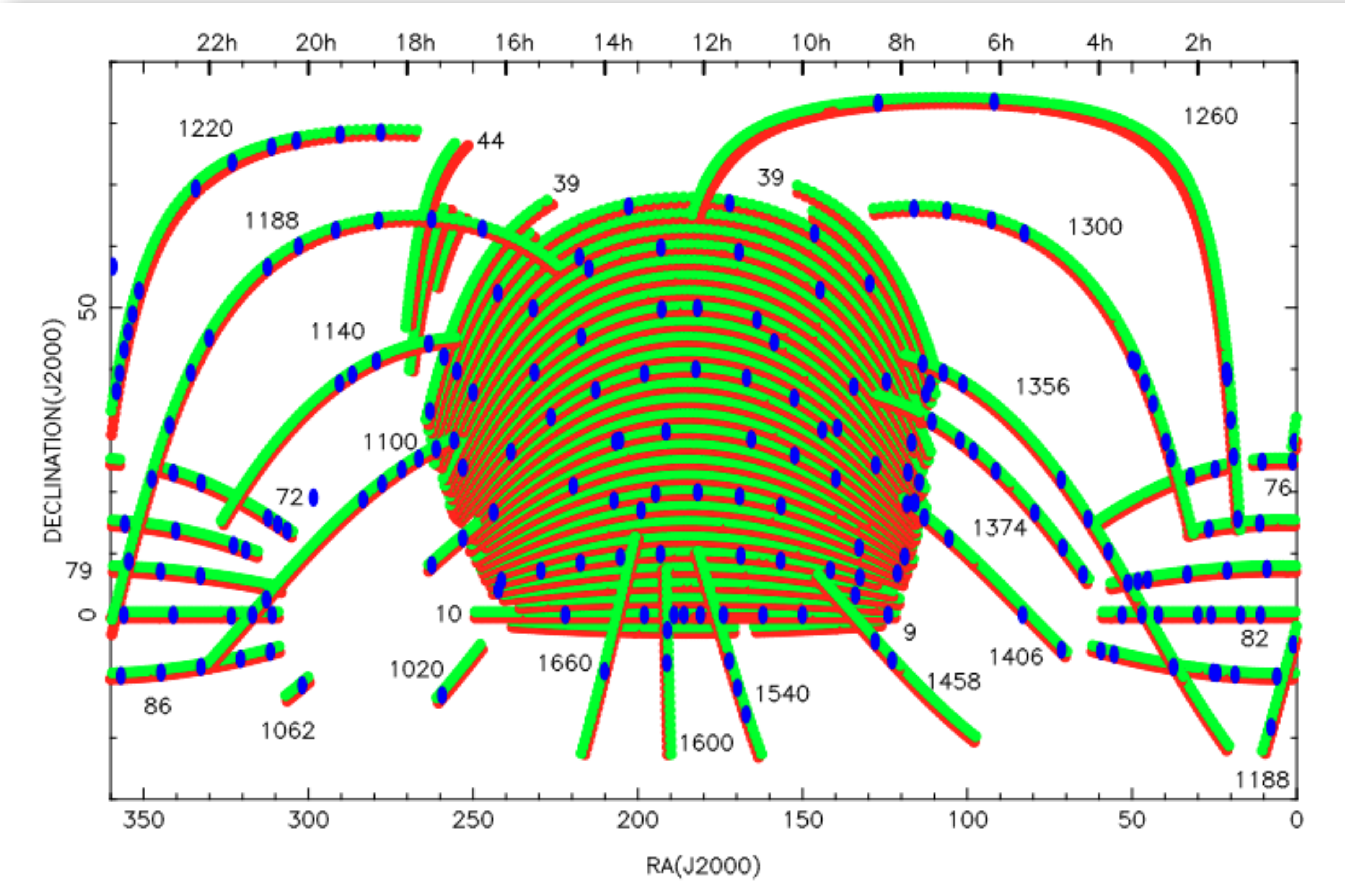


A(Li) vs T_{eff}

$$T_{\rm eff} > 5850 - 180 * [\mathrm{Fe/H}]$$



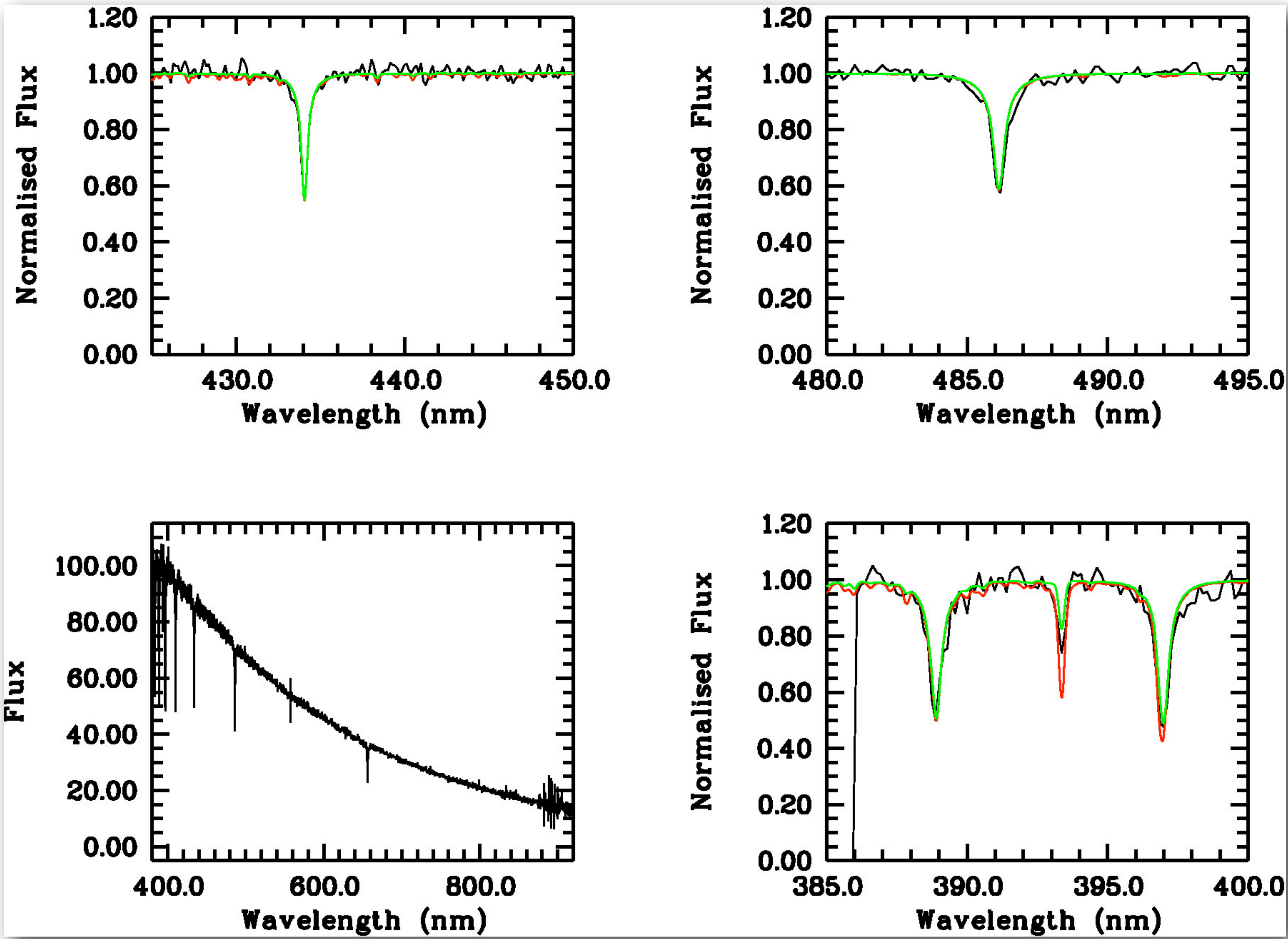
Searching for EMP in SDSS-SEGUE



Yanny et al., 2009, arXiv:0902.1781

- R=2000, moderate S/N spectra for ~25000 candidates extracted from SDSS-SEGUE (DR 5-7)
- Pre-selected in g-z color to pick TO stars (T_{eff}>5500K)
- Preselection removes gravity degeneracy
- SPADA metallicity estimate
- Check by eye on every star with [Fe/H]<-2.5

Searching for EMP in SDSS-SEGUE



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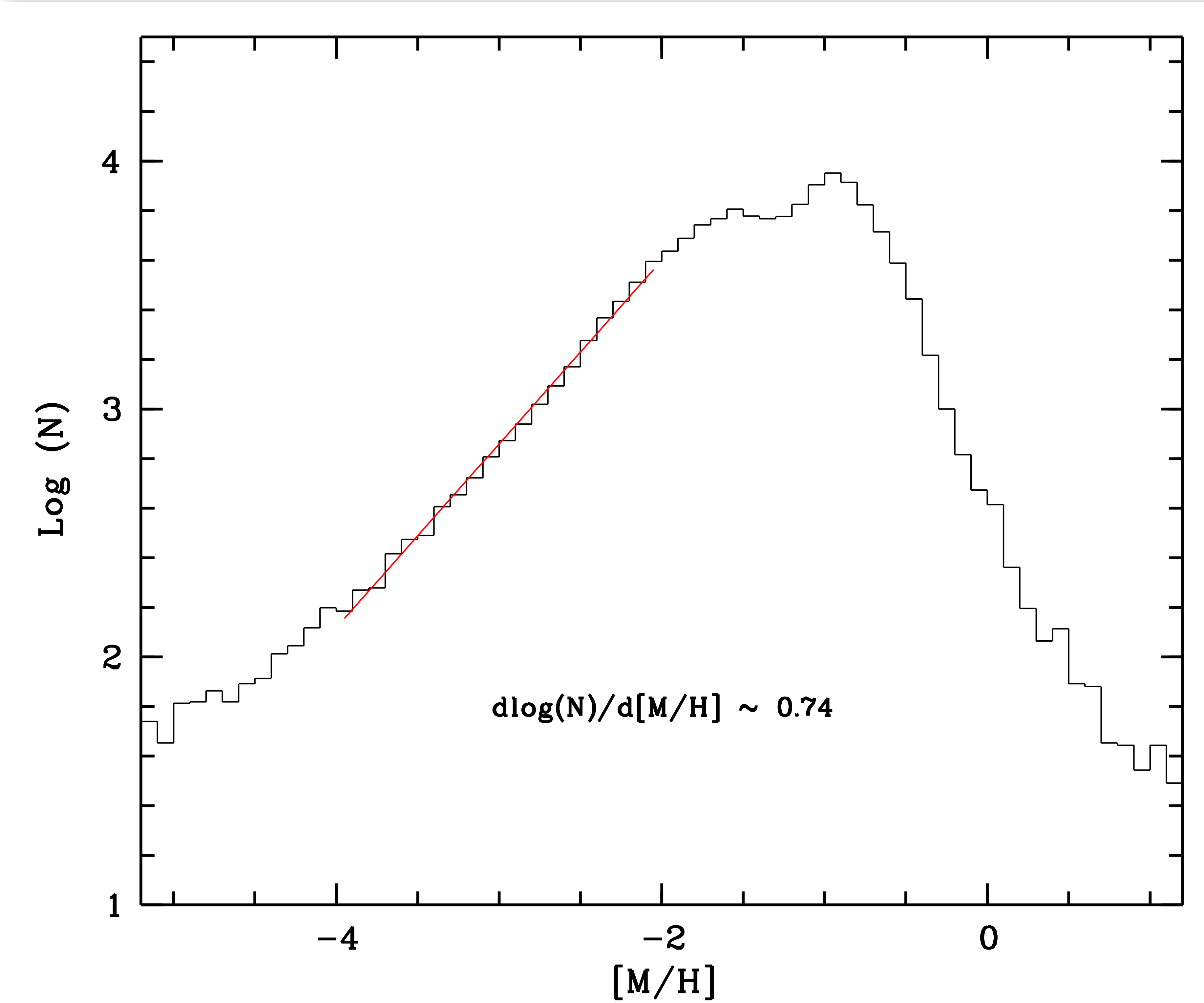

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- SPADA metallicity estimate
- Check by eye on every star with [Fe/H]<-2.5

Ludwig et al., 2008, Physica Scripta, 133, 4037

So far...

- 3 CEMP, UVES (Behara et al., 2010, A&A)
- 2 not-so-EMP (but α-poor) (Bonifacio et al., 2011, AN), farthest (?) dwarf studied, 9.1 Kpc, X-SHOOTER GTO
- 5 EMP ($-3.7<[\mathrm{Fe/H}]<-3.2$) X-SHOOTER GTO (Caffau et al., 2011, A&A)
- 16 EMP ($-3.7<[\mathrm{Fe/H}]<-3.0$) UVES (Bonifacio et al., 2012, A&A submitted), MyGIsFOS automated analysis
- 1 EMP, Mg-rich, C-rich (Sbordone et al. 2012 in prep.)
- 1 HMP, Caffau et al. 2011, Nature, lowest Z star known to date.

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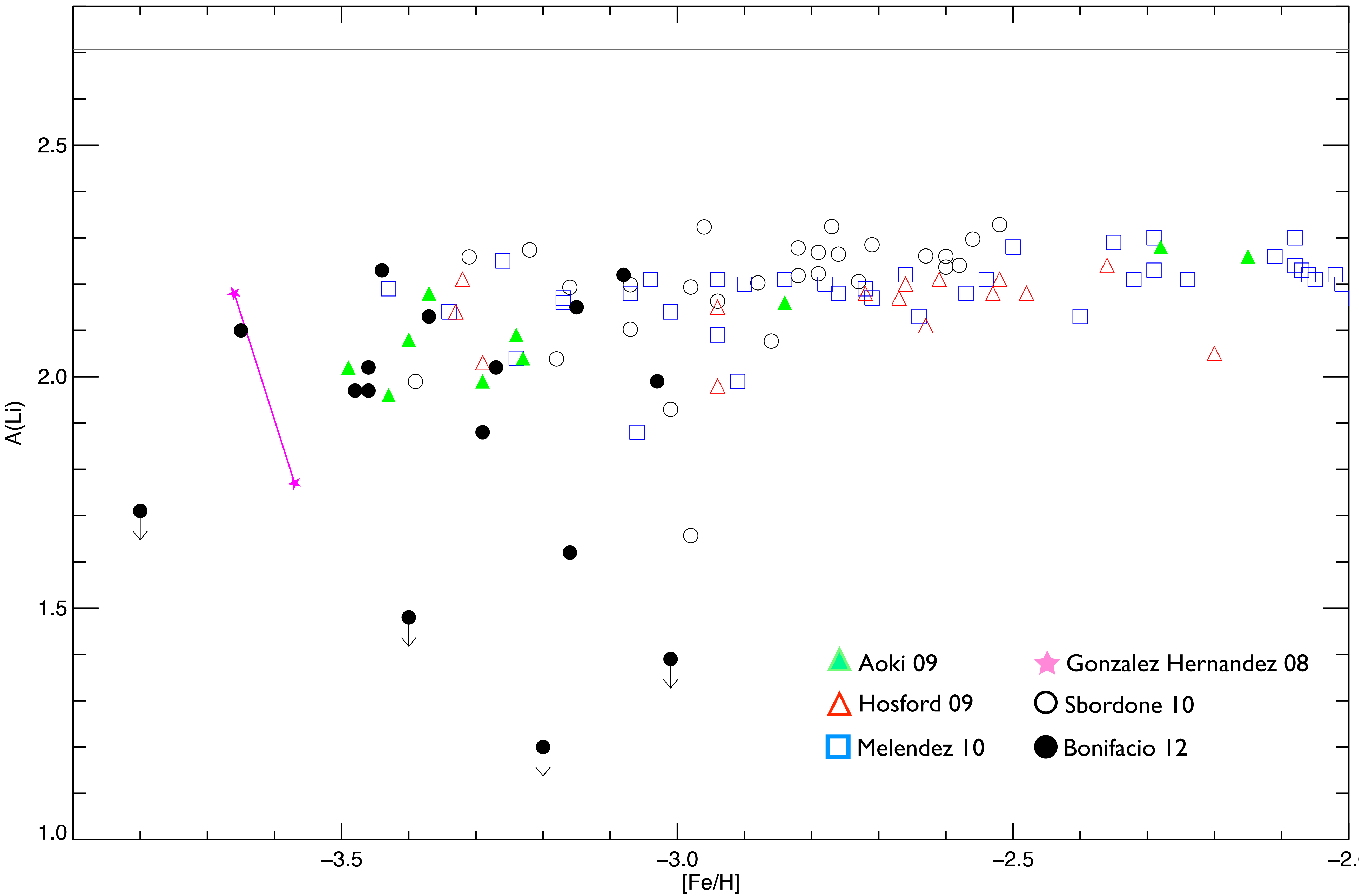
Bonifacio et al 2012 sample

- T_{eff} based on $(g-z)_0$ colors, SDSS reddening used
- Cross-check with Hα profiles, IRFM on SDSS calibrators
- Gravity, Vturb, abundances through automated MyGIsFOS analysis
- $-3.8<[Fe/H]<-3.01$, $5786< T_{eff} <6546$, $3.7<\log g<4.6$
- 12 Li abundances, 4 upper limits
- Sbordone et al. (2010) 3D NLTE fitting function used

A(Li) vs [Fe/H]



2.5
2.0
1.5
1.0
A(Li)
−3.5
−3.0
−2.5
−2.0
[Fe/H]
Aoki 09
Hosford 09
Melendez 10
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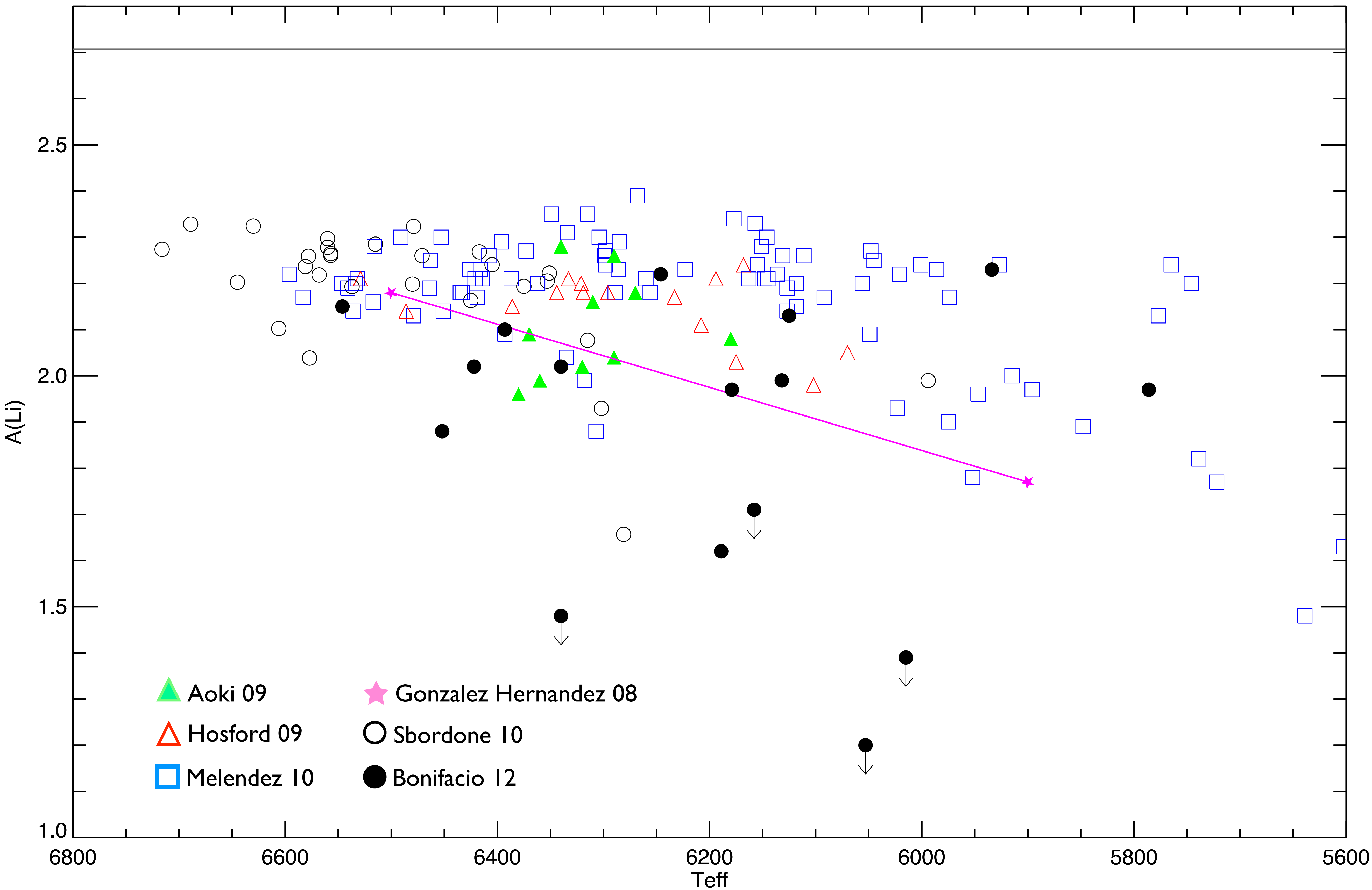
Bonifacio 12

A(Li) vs T_{eff}



A(Li)
Teff
2.5
2.0
1.5
1.0
6800
6600
6400
6200
6000
5800
5600
Aoki 09
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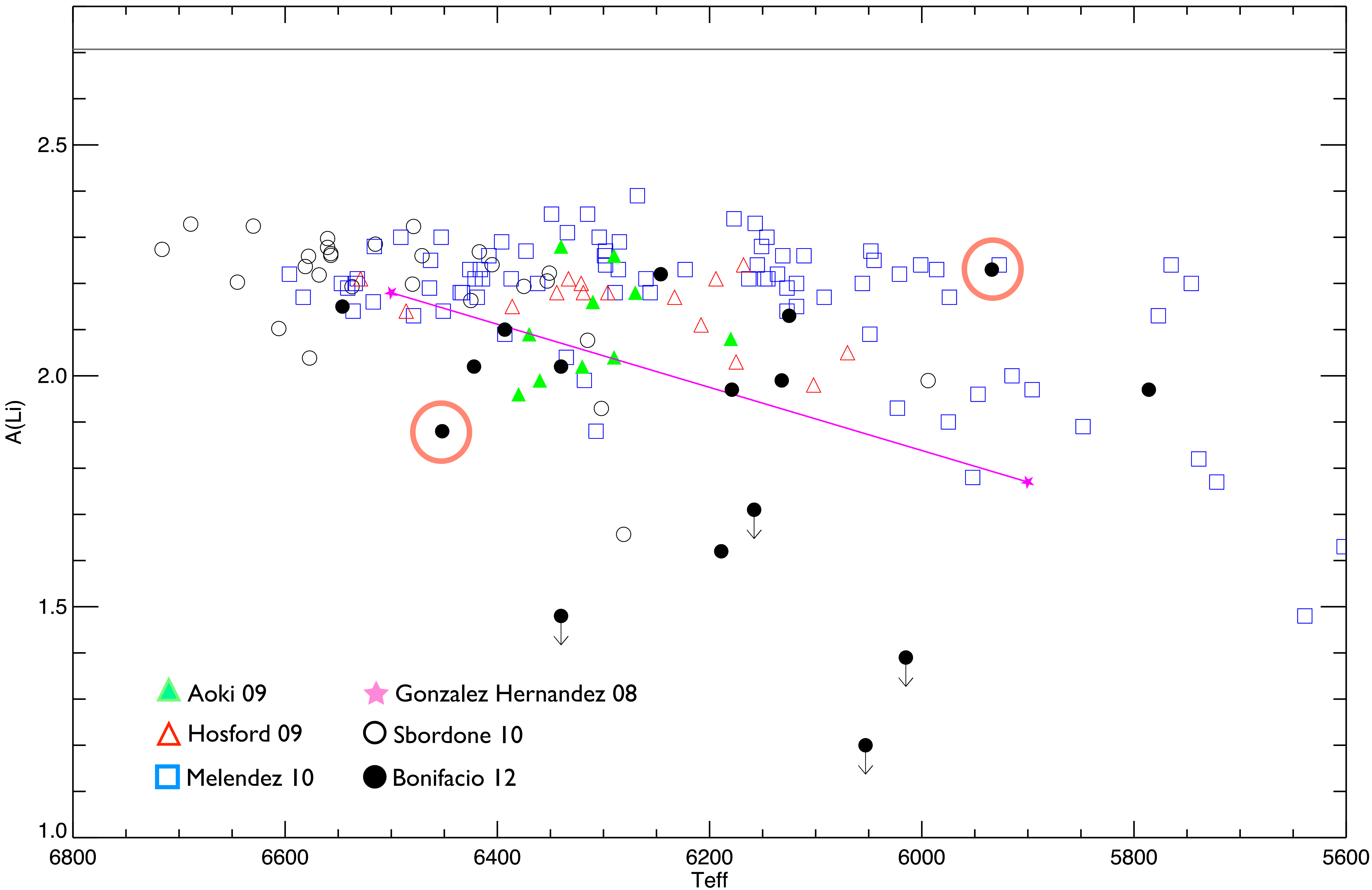
A(Li) vs T_{eff}



Aoki 09
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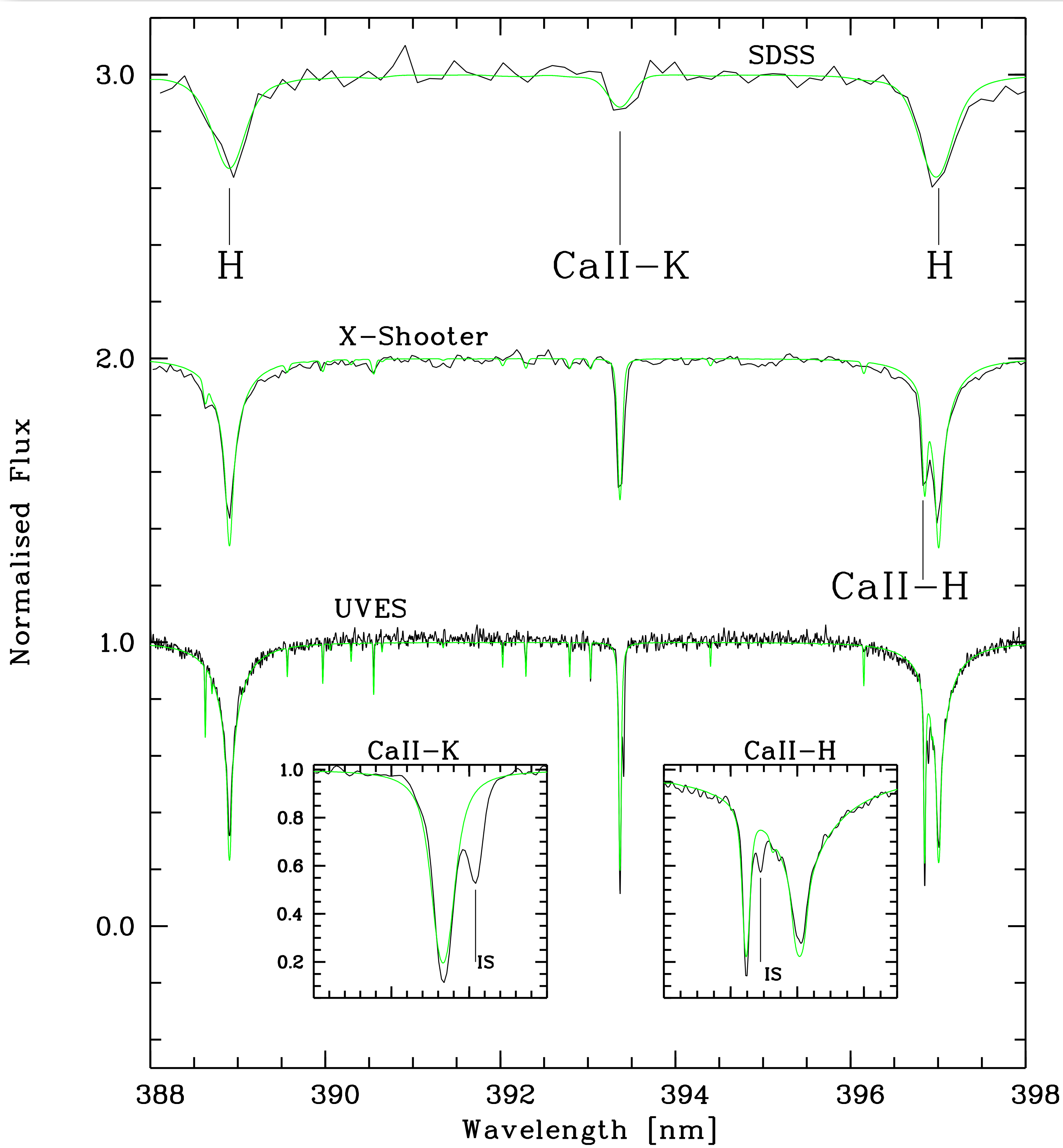
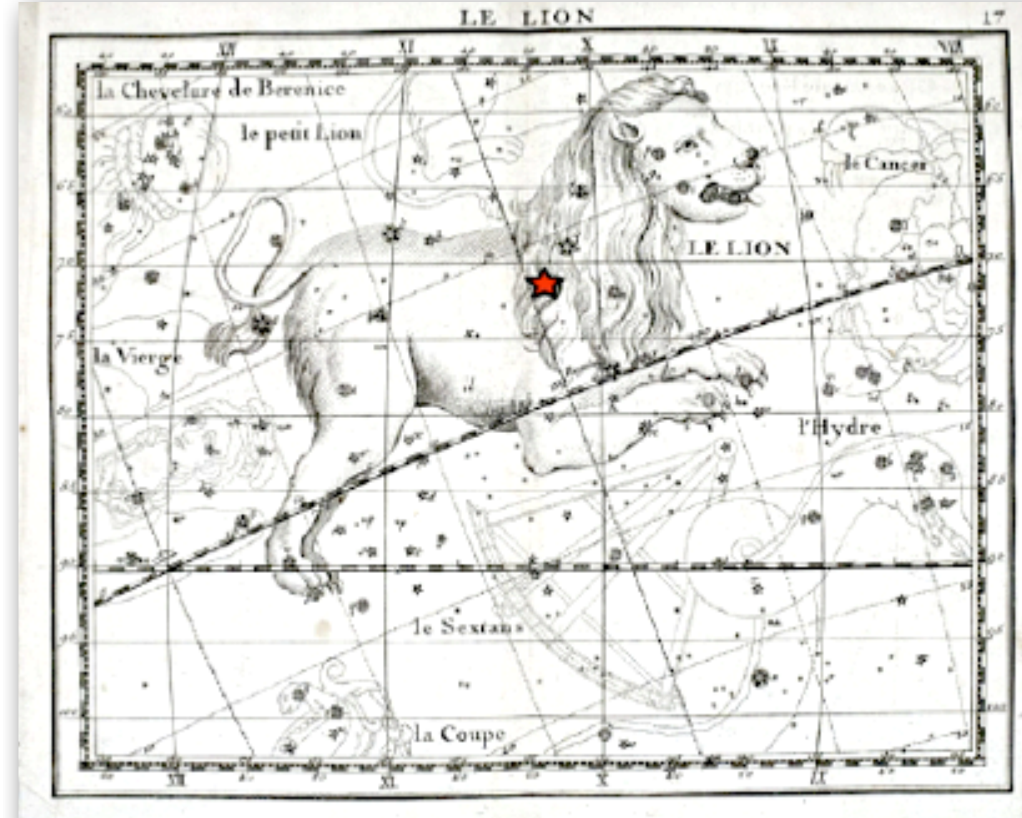
A(Li)
Teff
2.5
2.0
1.5
1.0
6800
6600
6400
6200
6000
5800
5600

The lion's share: SDSS J102915+172927



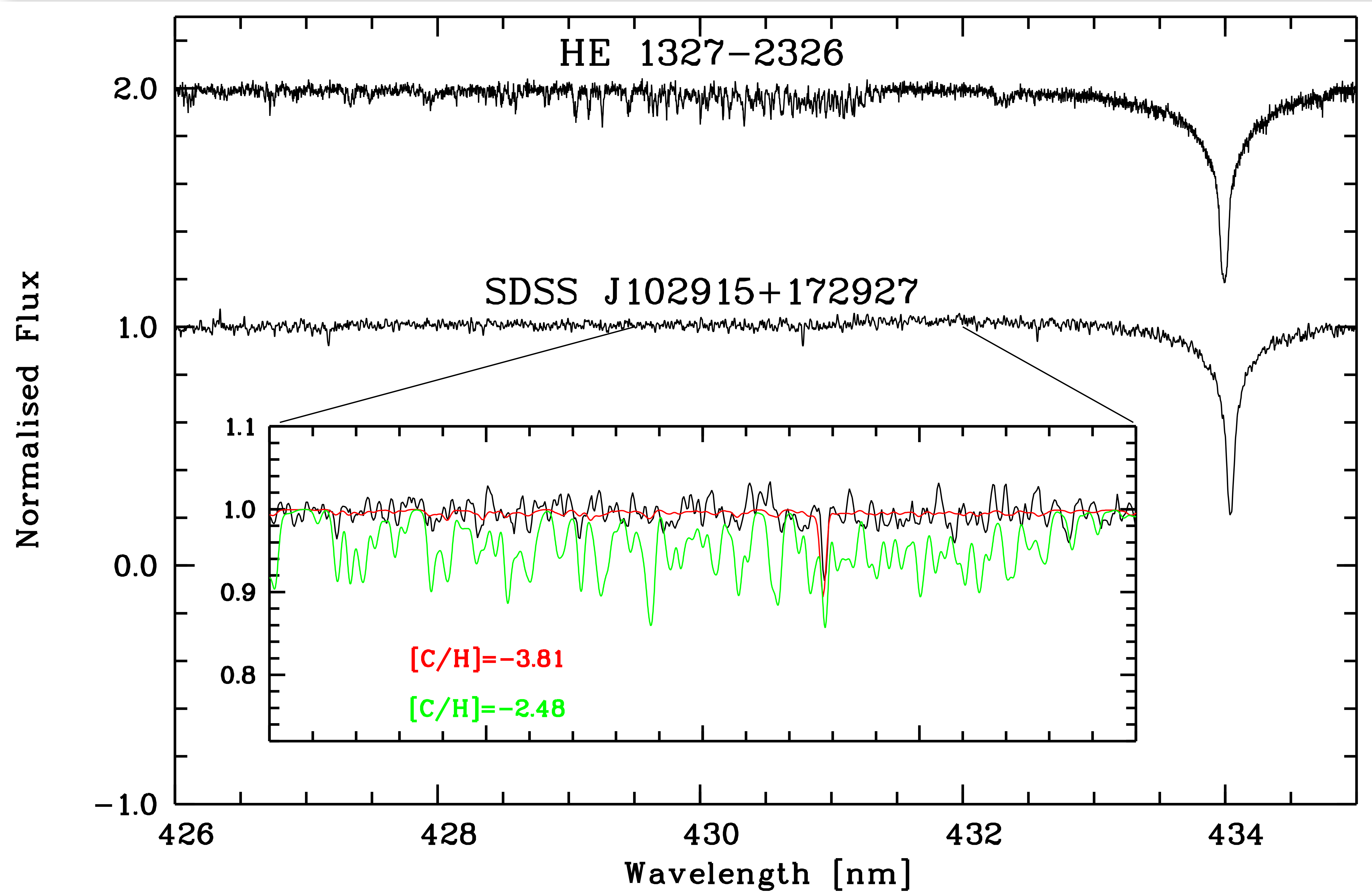


Star	SDSS J102915+172927
RA	10h 29m 15.15s
Dec	+17° 29' 28"
u, mag	17.73
g, mag	16.92
r, mag	16.53
i, mag	16.41
z, mag	16.33
V_{rad}	-35.5
T_{eff}, [K]	5811
$\log g$	4.0
ξ, $\mathrm{km\,s^{-1}}$	1.5
$[\mathrm{Fe/H}]_{3D}$	−5

Caffau et al., 2011, Nature, 477, 67

At last, no carbon...

Caffau et al., 2012, A&A subm.



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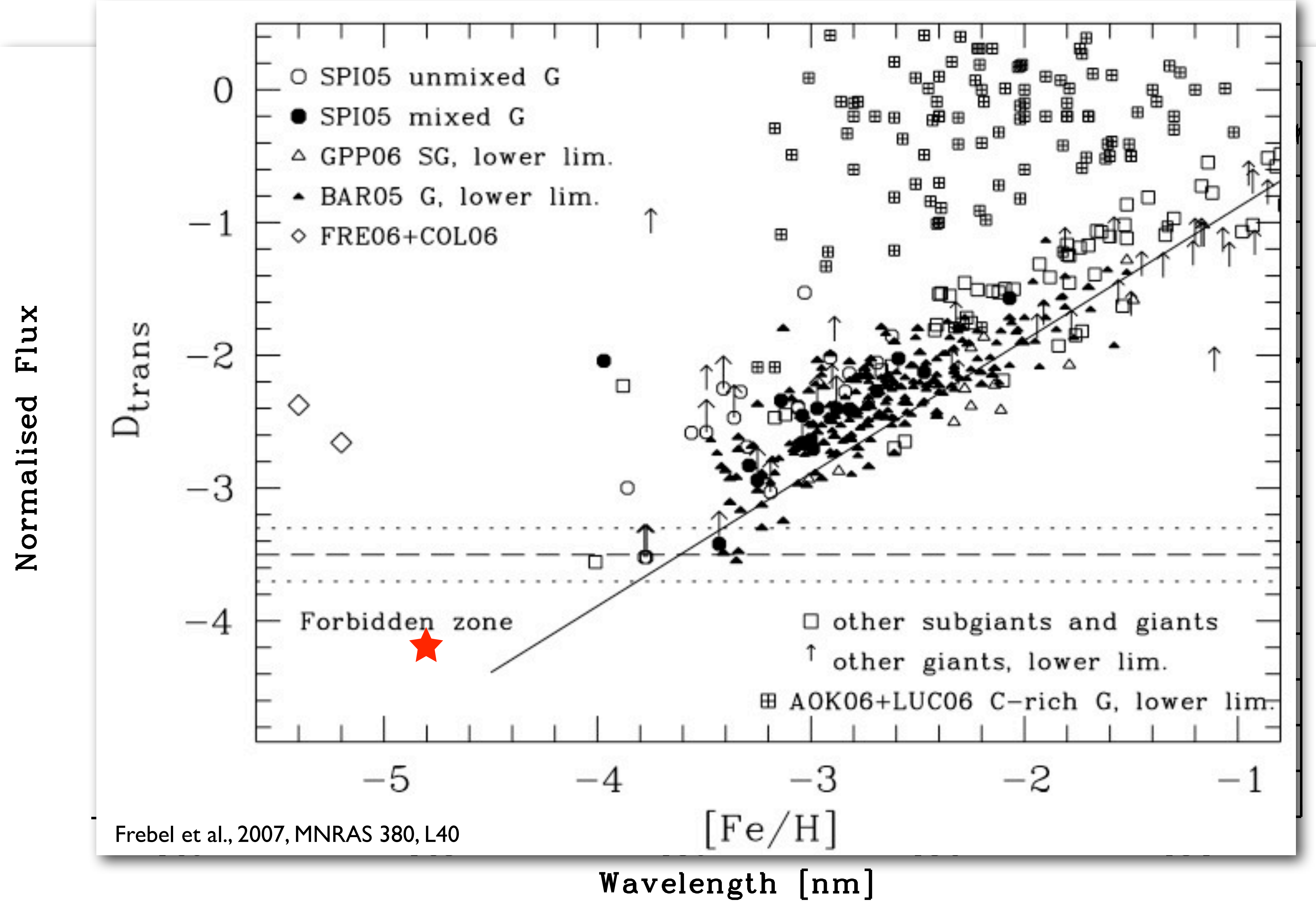

Frebel et al., 2007, MNRAS 380, L40

In fact, exceptionally ordinary

Element	$A(X)$, 3D	[X/H], 3D	[X/Fe], 3D	[X/H], 1D	Number of lines	$A(X)_{\odot}$
C	≤4.2	≤−4.3	≤+0.7	≤−3.8	G band	8.50
N	≤3.1	≤−4.8	≤+0.2	≤−4.1	NH band	7.86
Mg I	2.95	−4.59 ± 0.10	+0.40	−4.68 ± 0.08	4	7.54
Si I	3.25	−4.27 ± 0.10	+0.72	−4.27 ± 0.10	1	7.52
Ca I	1.53	−4.80 ± 0.10	+0.19	−4.72 ± 0.10	1	6.33
Ca II	1.48	−4.85 ± 0.11	+0.14	−4.71 ± 0.11	3	6.33
Ti II	0.14	−4.76 ± 0.11	+0.23	−4.75 ± 0.11	6	4.90
Fe I	2.53	−4.99 ± 0.12	+0.00	−4.73 ± 0.13	44	7.52
Ni I	1.35	−4.88 ± 0.11	+0.11	−4.55 ± 0.14	10	6.23
Sr II	≤−2.28	≤−5.2	≤−0.21	≤−5.1	1	2.92

Caffau et al., 2011, Nature, 477, 67

In fact, exceptionally ordinary

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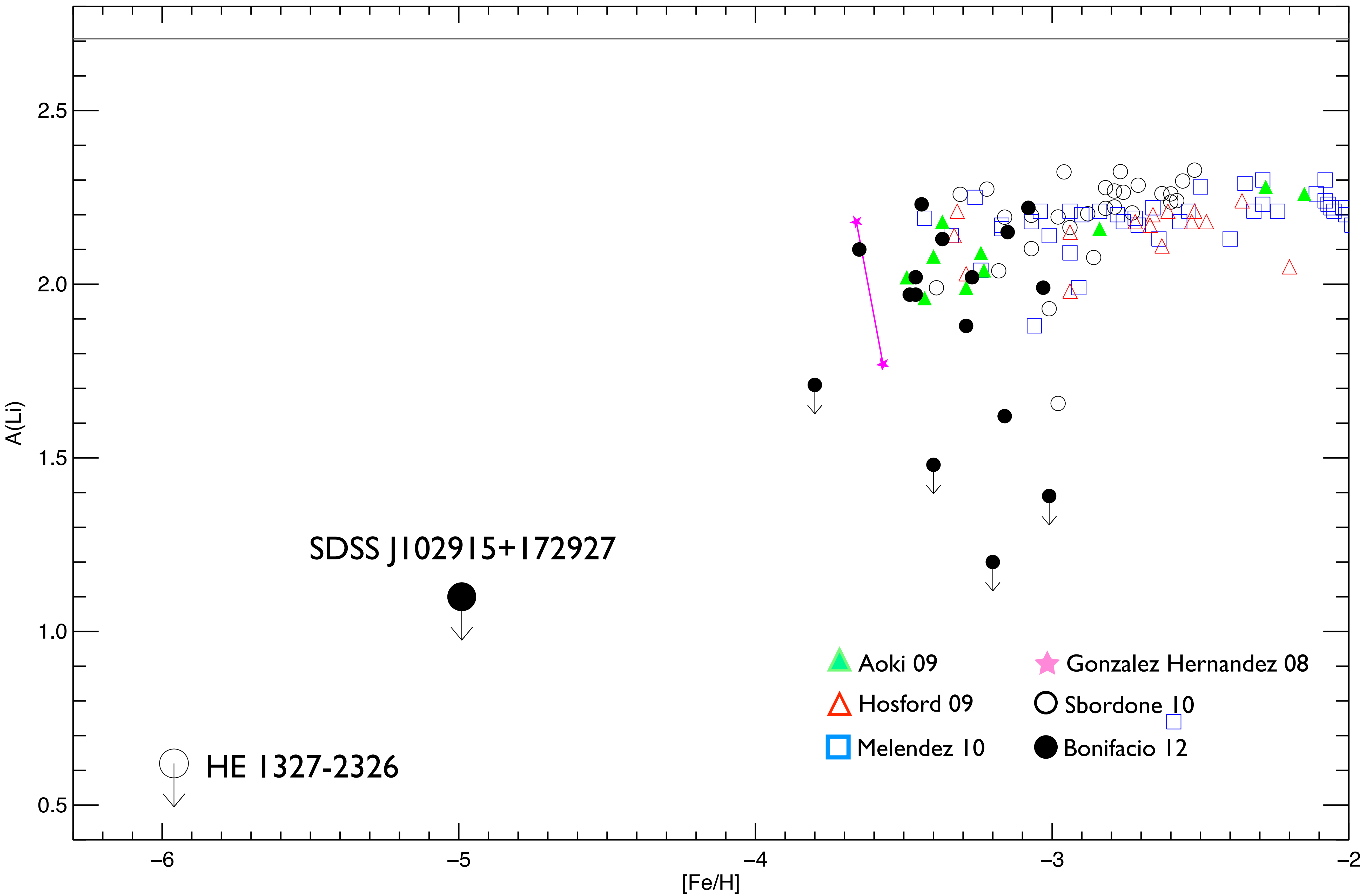
Caffau et al., 2011, Nature, 477, 67

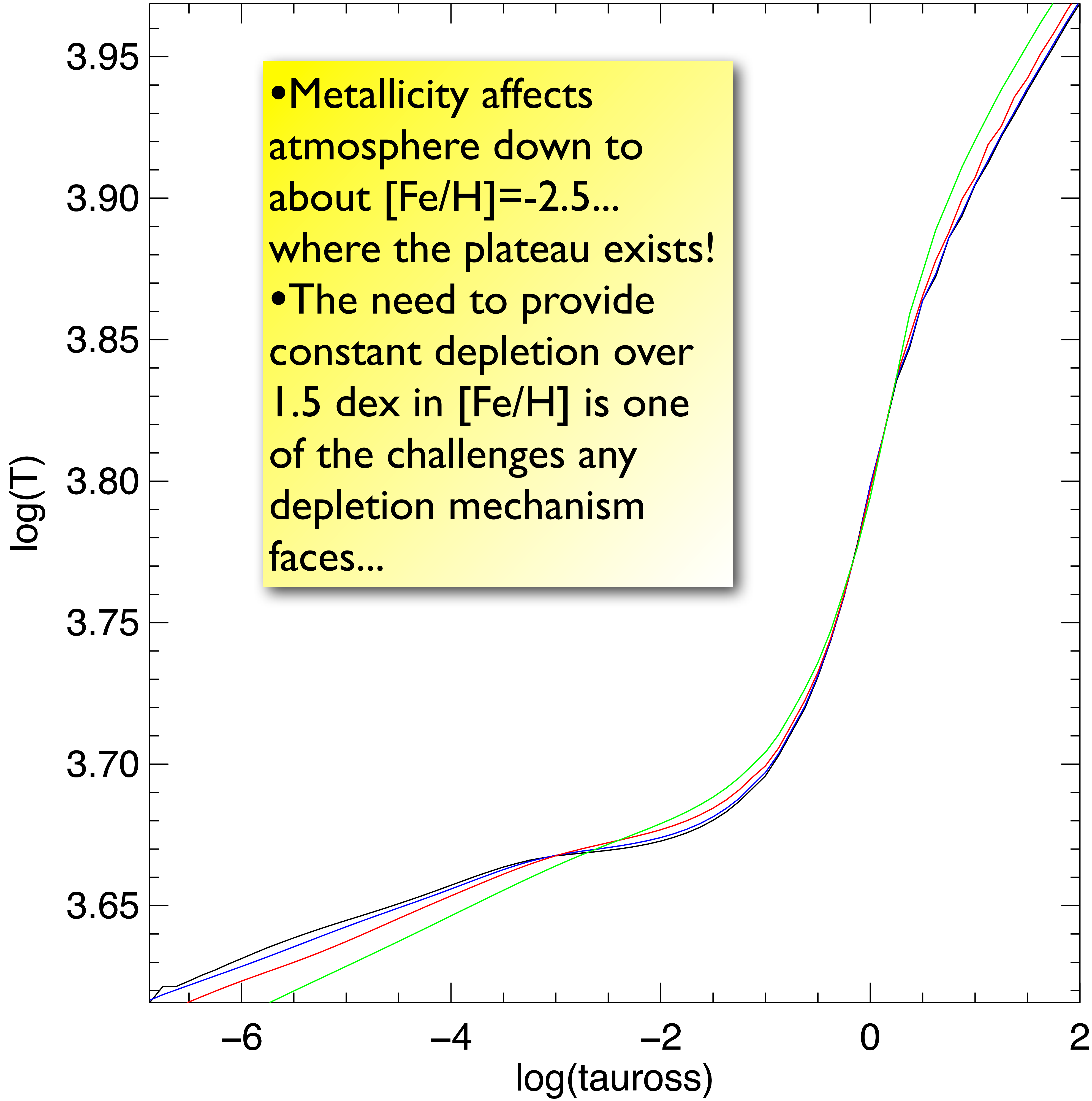
$Z=4.5\ 10^{-5}\ Z_\odot$: the first **real** hyper-metal poor!

Going deeper...



Atmospheres
&
Metallicities

T_{eff}=5800K,
log g=4.0
[Fe/H]=-4
[Fe/H]=-3
[Fe/H]=-2
[Fe/H]=-1



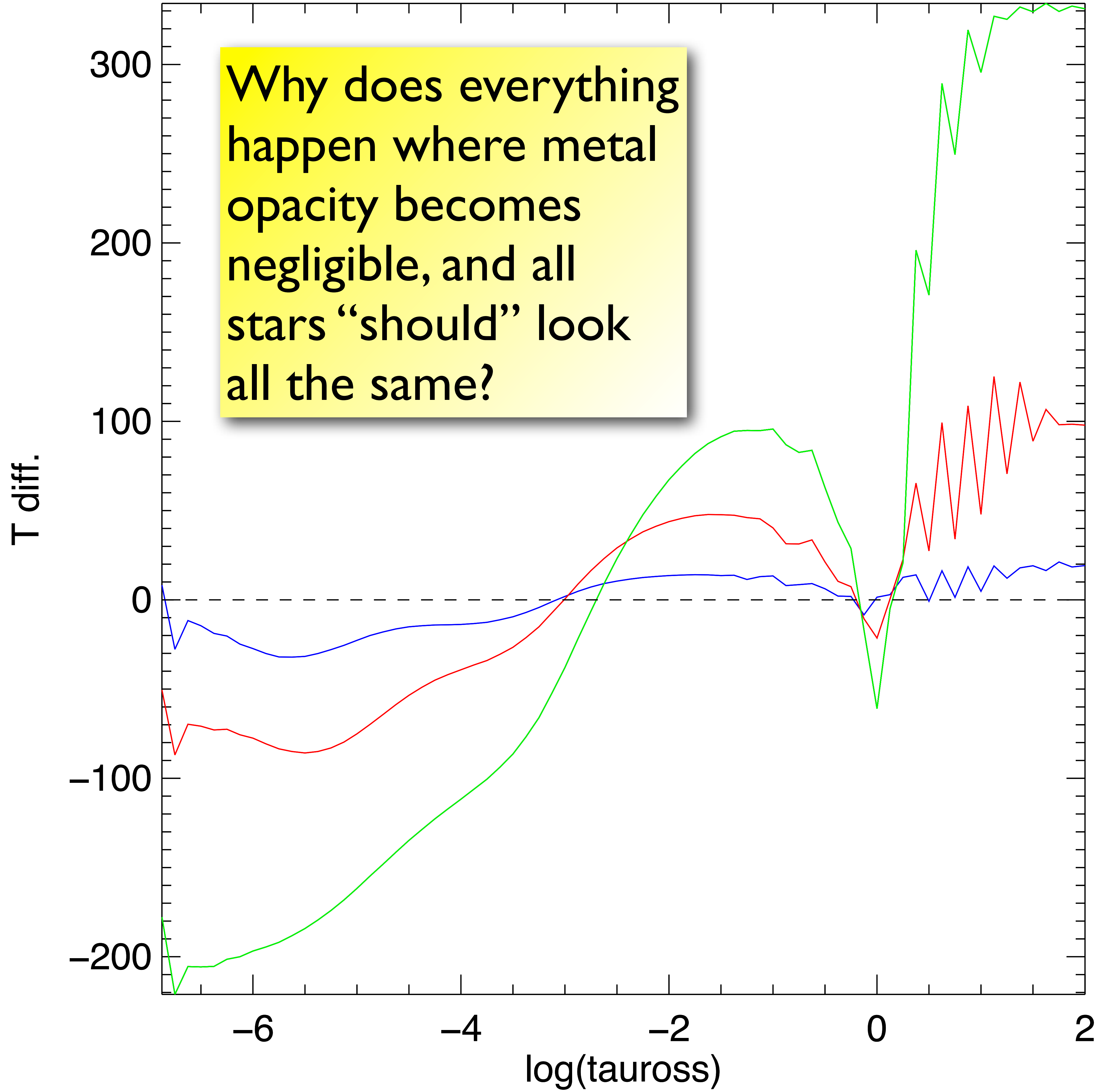
•Metallicity affects atmosphere down to about [Fe/H]=-2.5... where the plateau exists!
•The need to provide constant depletion over 1.5 dex in [Fe/H] is one of the challenges any depletion mechanism faces...

A riddle
(at least for me)

T_{eff}=5800K,
log g=4.0

T diff. w/r to
[Fe/H]=-4
for

[Fe/H]=-3
[Fe/H]=-2
[Fe/H]=-1

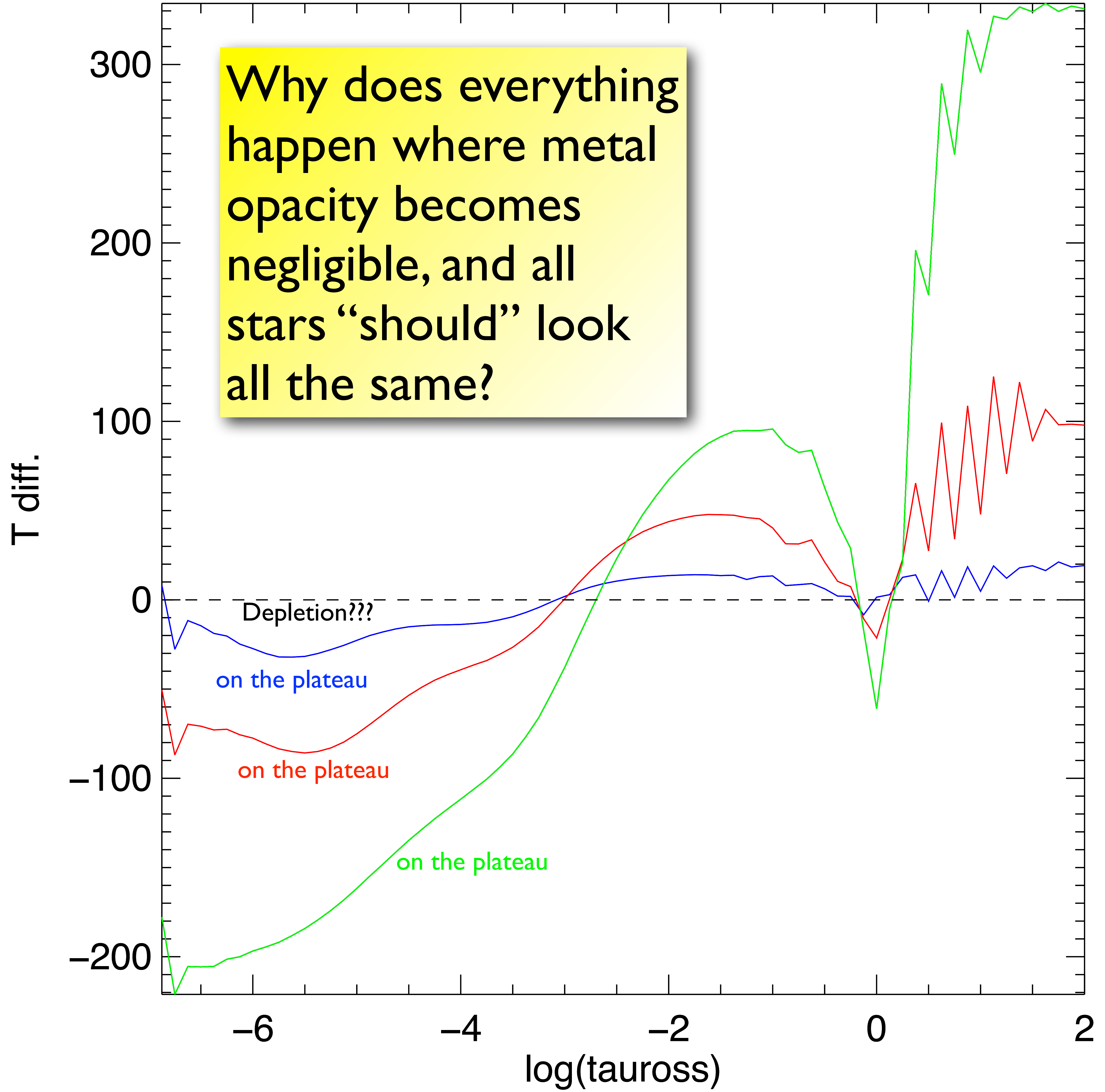


A riddle
(at least for me)

T_{eff}=5800K,
log g=4.0

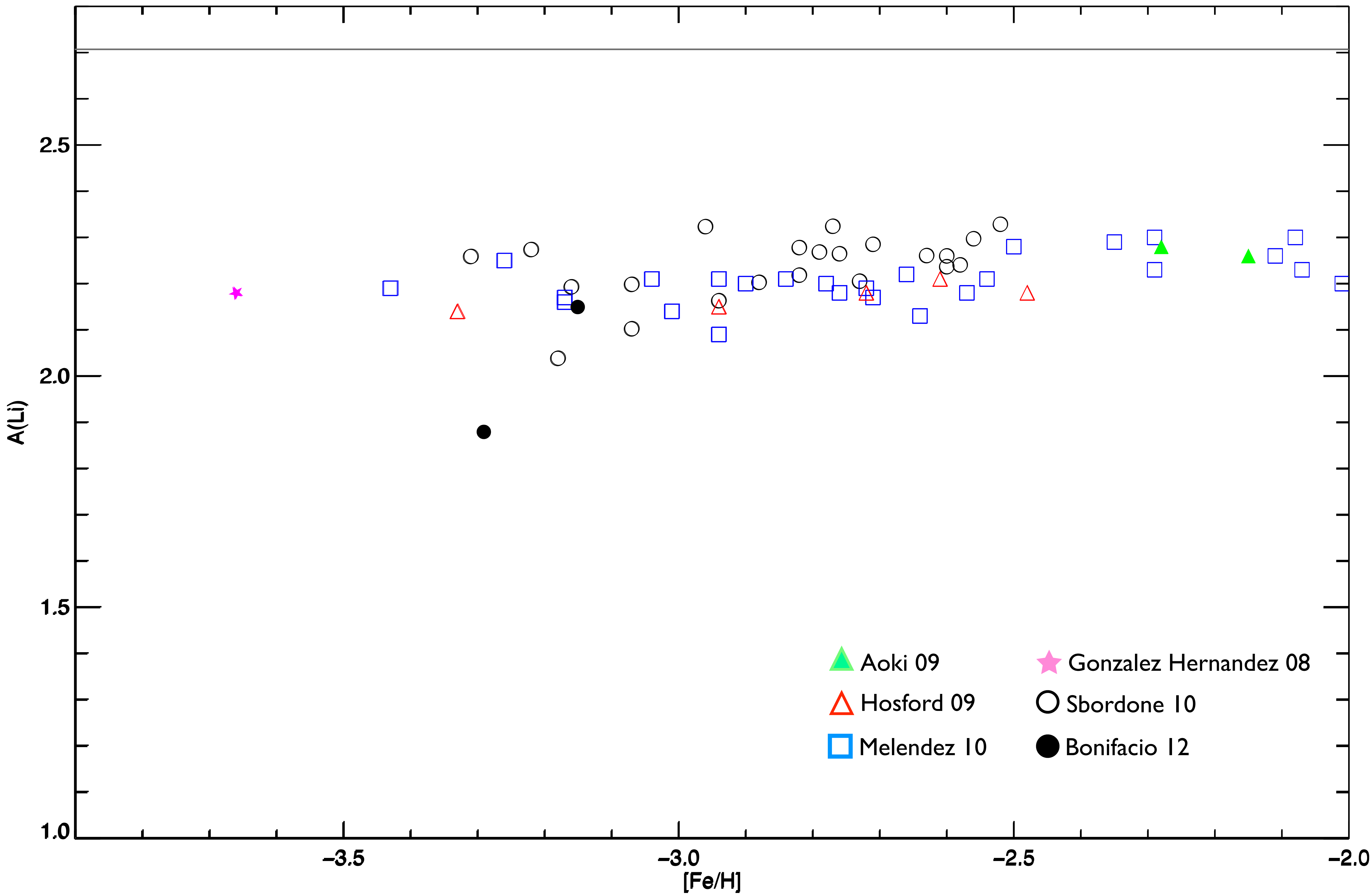
T diff. w/r to
[Fe/H]=-4
for

[Fe/H]=-3
[Fe/H]=-2
[Fe/H]=-1

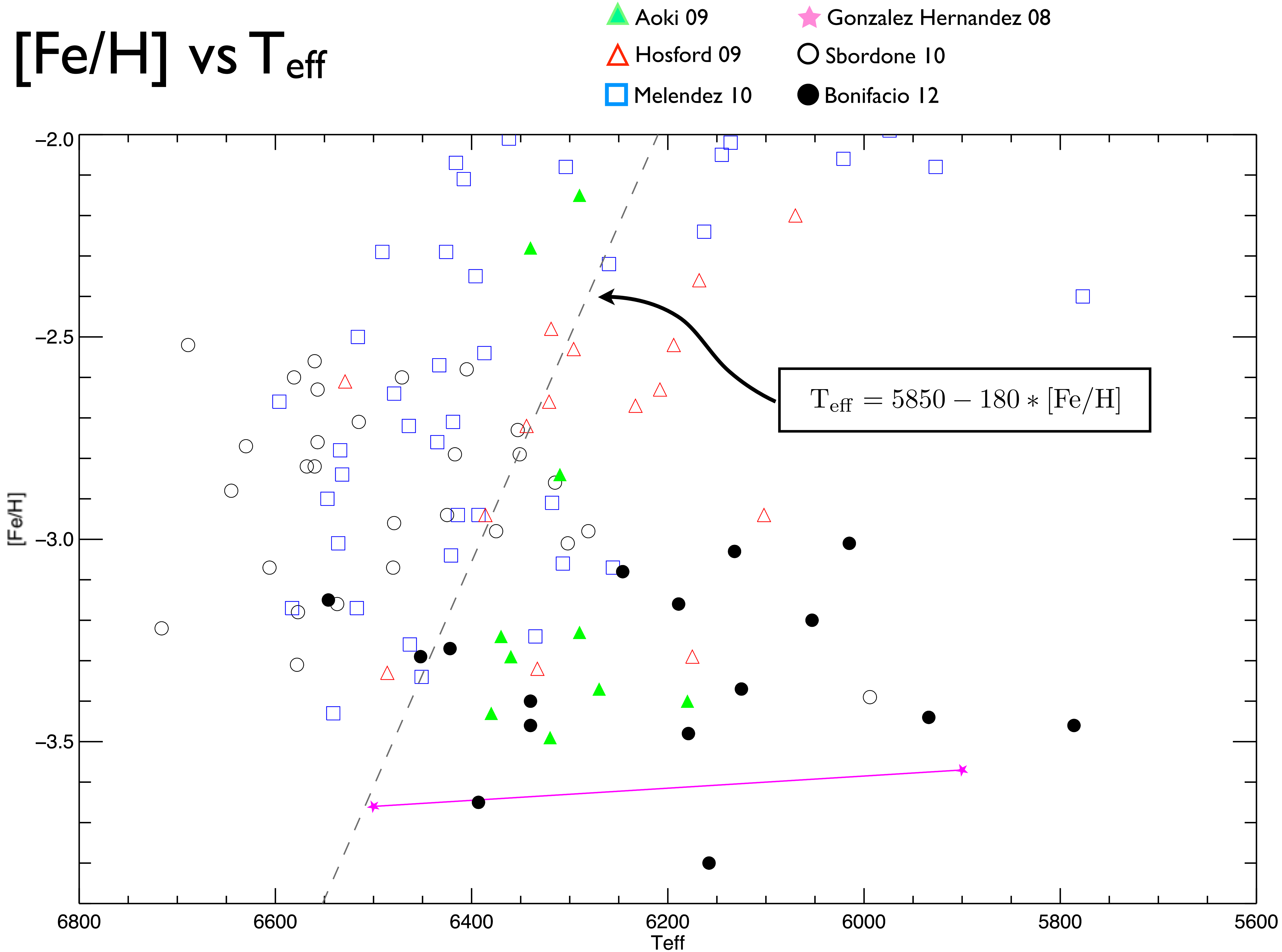


A(Li) vs [Fe/H]

$$T_{\rm eff} > 5850 - 180 * [\mathrm{Fe/H}]$$

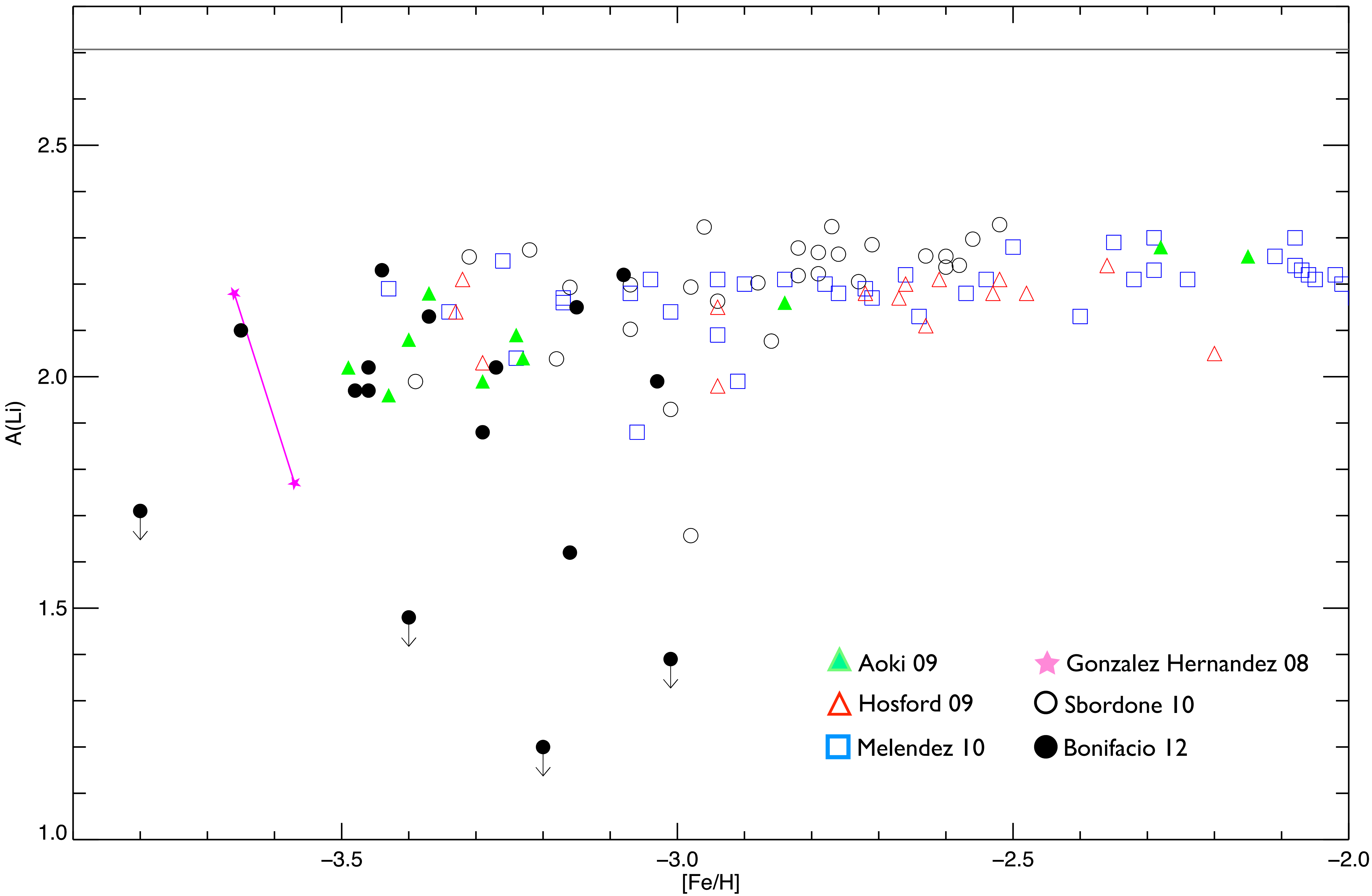


[Fe/H] vs T_{eff}



Aoki 09
Hosford 09
Melendez 10
Gonzalez Hernandez 08
Sbordone 10
Bonifacio 12
$T_{eff} = 5850 - 180 * [Fe/H]$
[Fe/H]
Teff
−2.0
−2.5
−3.0
−3.5
6800
6600
6400
6200
6000
5800
5600

A(Li) vs [Fe/H]



2.5
2.0
1.5
1.0
A(Li)
−3.5
−3.0
−2.5
−2.0
[Fe/H]
Aoki 09
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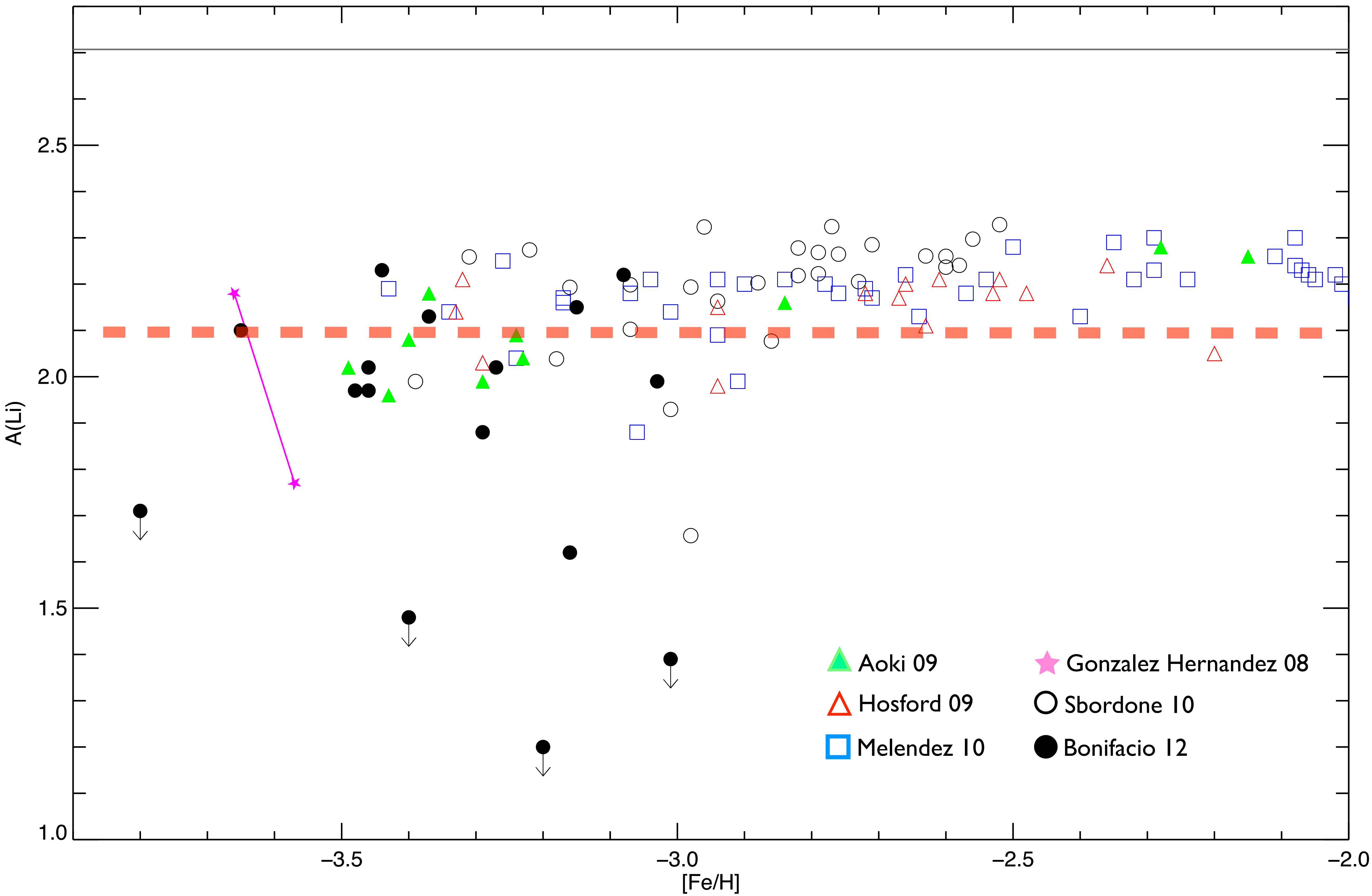
A(Li) vs [Fe/H]



2.5
2.0
1.5
1.0
A(Li)
−3.5
−3.0
−2.5
−2.0
[Fe/H]
Aoki 09
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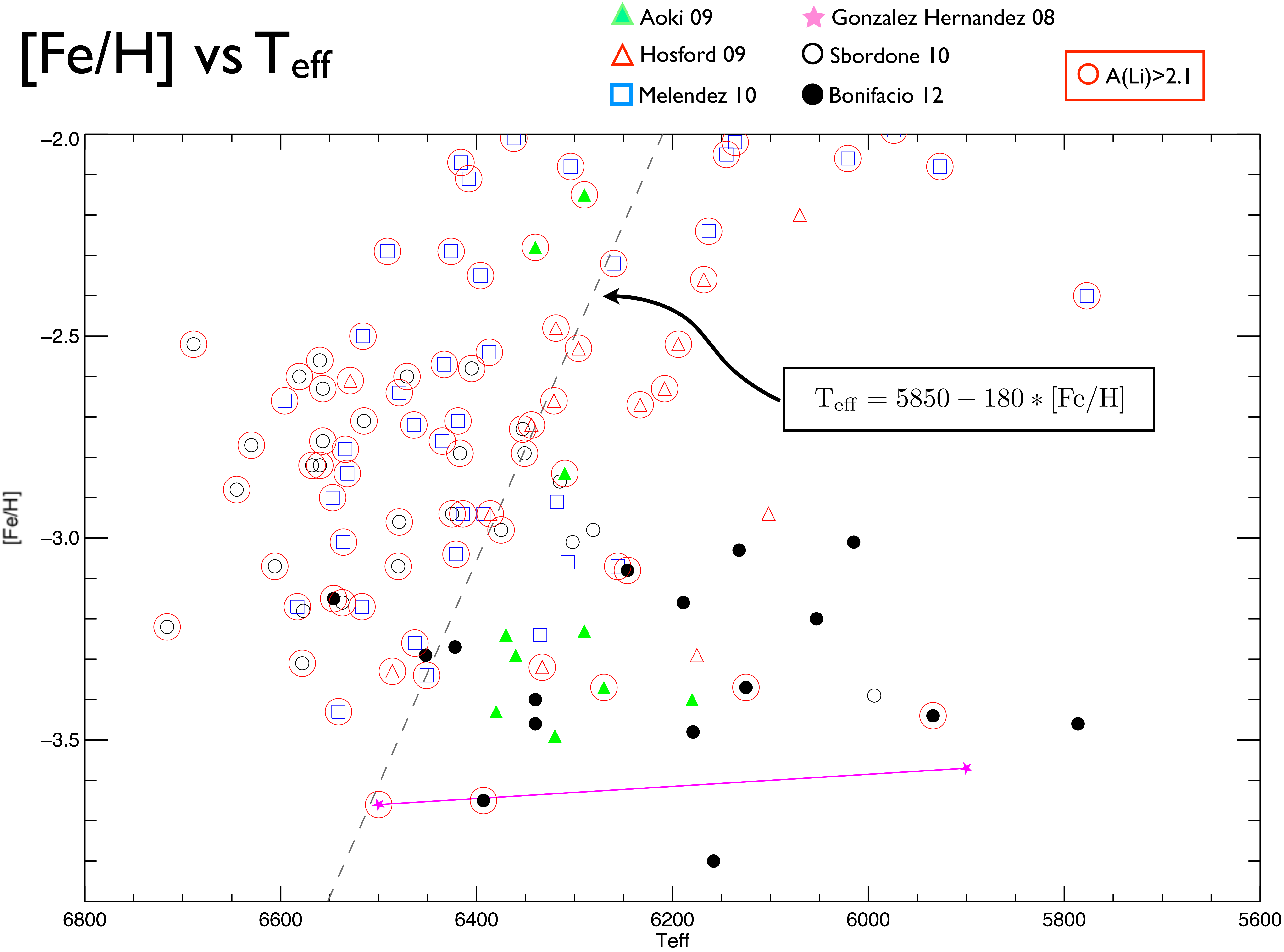
[Fe/H] vs T_{eff}



Aoki 09
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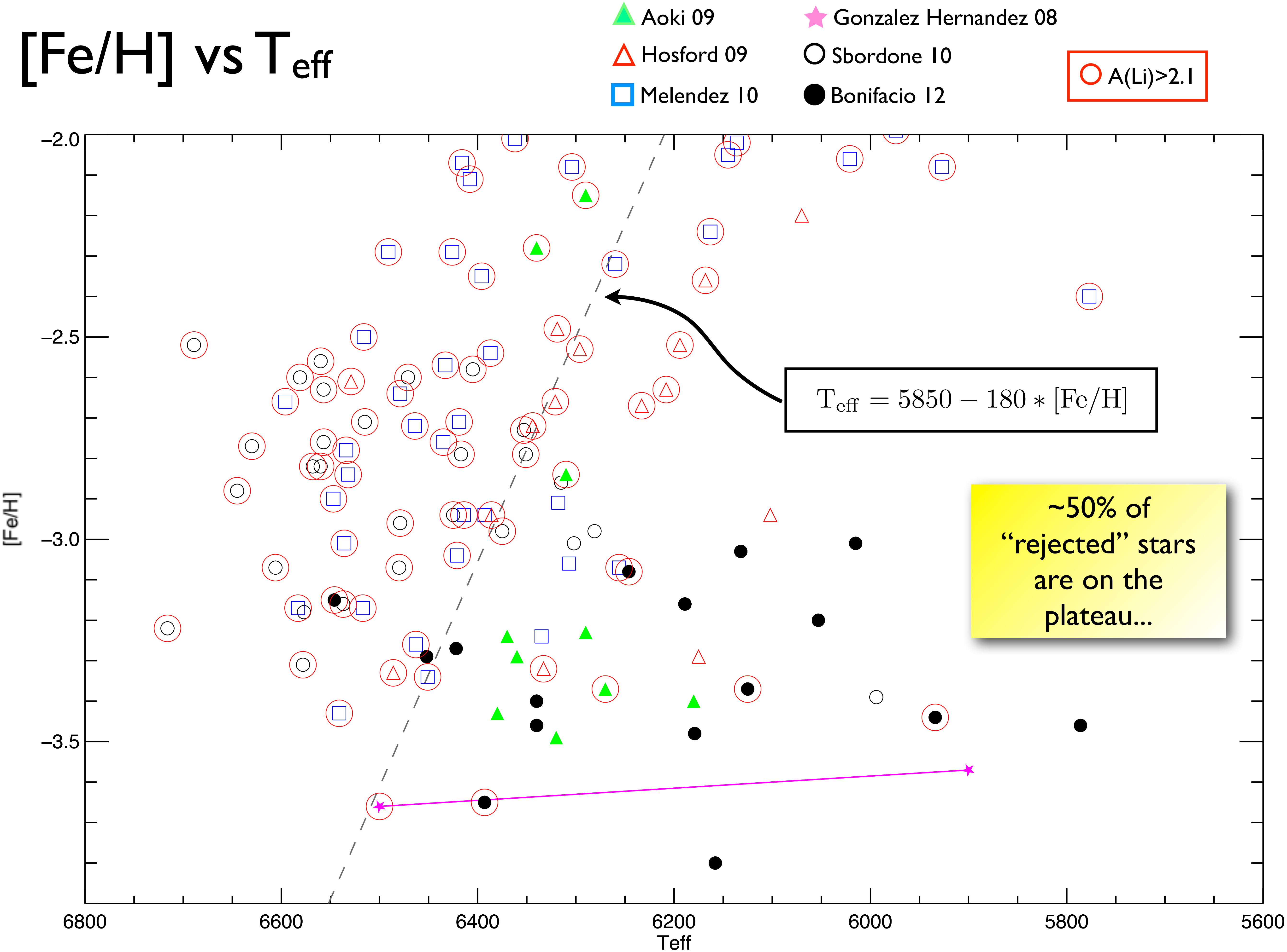
Bonifacio 12
A(Li)>2.1
$T_{eff} = 5850 - 180 * [Fe/H]$
−2.0
−2.5
−3.0
−3.5
[Fe/H]
6800
6600
6400
6200
6000
5800
5600
Teff

[Fe/H] vs T_{eff}



Aoki 09
Hosford 09
Melendez 10
Gonzalez Hernandez 08
Sbordone 10
Bonifacio 12
A(Li)>2.1
$T_{eff} = 5850 - 180 * [Fe/H]$
~50% of "rejected" stars are on the plateau...
[Fe/H]
Teff
−2.0
−2.5
−3.0
−3.5
6800
6600
6400
6200
6000
5800
5600

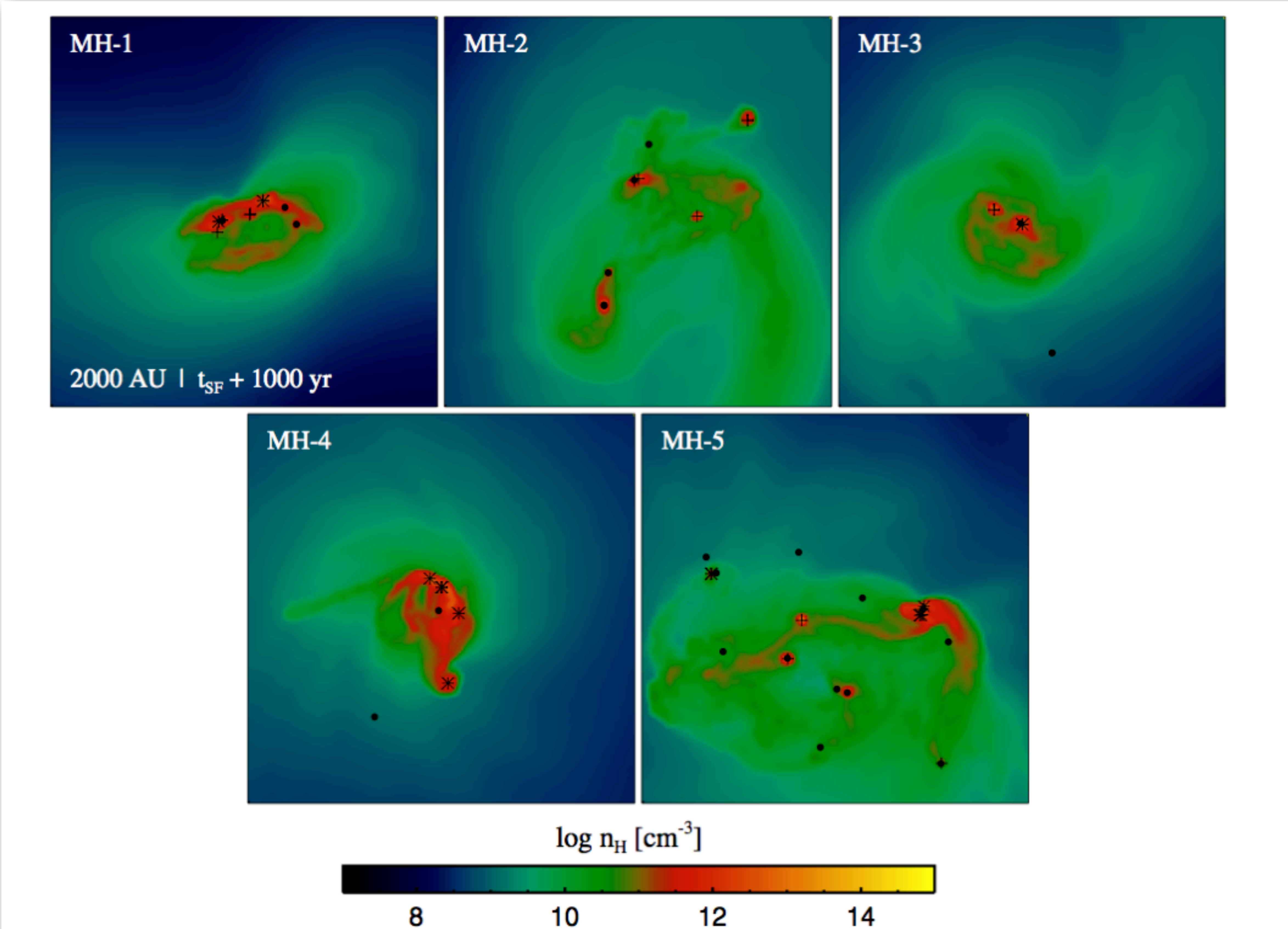
Conclusions...

... or rather , questions.

- The new SDSS sample confirms previous results: the Spite plateau is disrupted below [Fe/H]~-2.8
- Some cool stars, however, stay on the plateau even below [Fe/H]=-3.5
- First "real" HMP star appears quite ordinary chemically... but it has no detectable Lithium. And yet its structure should resemble a [Fe/H]=-3 <u>way</u> more than a [Fe/H]=-2 resembles a [Fe/H]=-1. What gives?
- Diffusion should be there. Depletion seem to favor cooler stars... but none of those seem to work alone. What are we missing?

Is it the way they are born?

Greif et al., 2011, ApJ, 737, 75



Interesting times ahead...

- The TOPoS (Turn Off Primordial Stars) ESO large program will observe ~100 candidate EMP-HMP TO stars extracted from SDSS... we badly need statistics at low metallicity.
- The Gaia ESO survey has begun! ~10^4 F-G local field dwarf will be observed with UVES...
- ... only very few will be very metal poor, but we will have a much less biased statistics of the Spite plateau, and of the high-metallicity Li behavior.