Microlensed dwarfs (and subgiants) in the Galactic bulge

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Artist's impression of the central bulge of the Milky Way
Credit: ESO/NASA/JPL-Caltech/M. Kornmesser/R. Hurt

Collaborators

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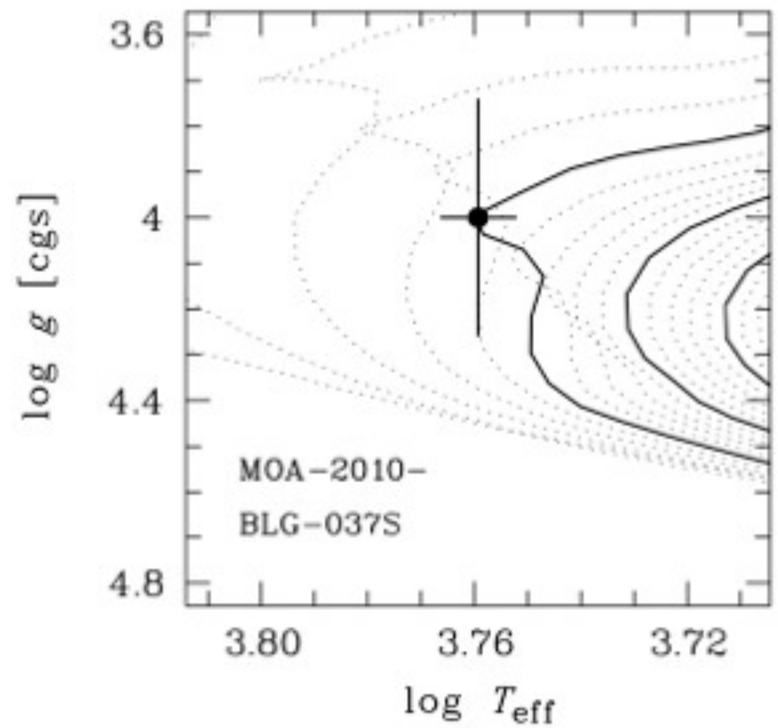
Why dwarfs and subgiants?

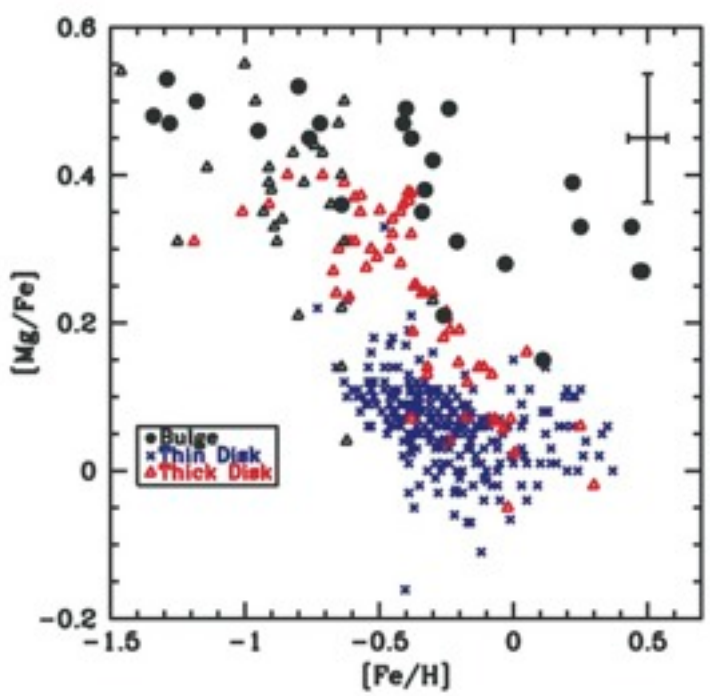
Commonly used in GCE studies: Edvardsson et al. (1993), Fuhrmann papers, Reddy papers, Bensby papers,.....and many more....

Reliable tracers of the chemical composition of the gas cloud they formed from: Long life times (>10 Gyr) and their atmospheres remain intact.

It is possible to estimate stellar ages of individual stars from isochrones

Studies showed that Bulge giants and nearby disk dwarf stars showed very different abundance trends.
Need to compare dwarfs with dwarfs...





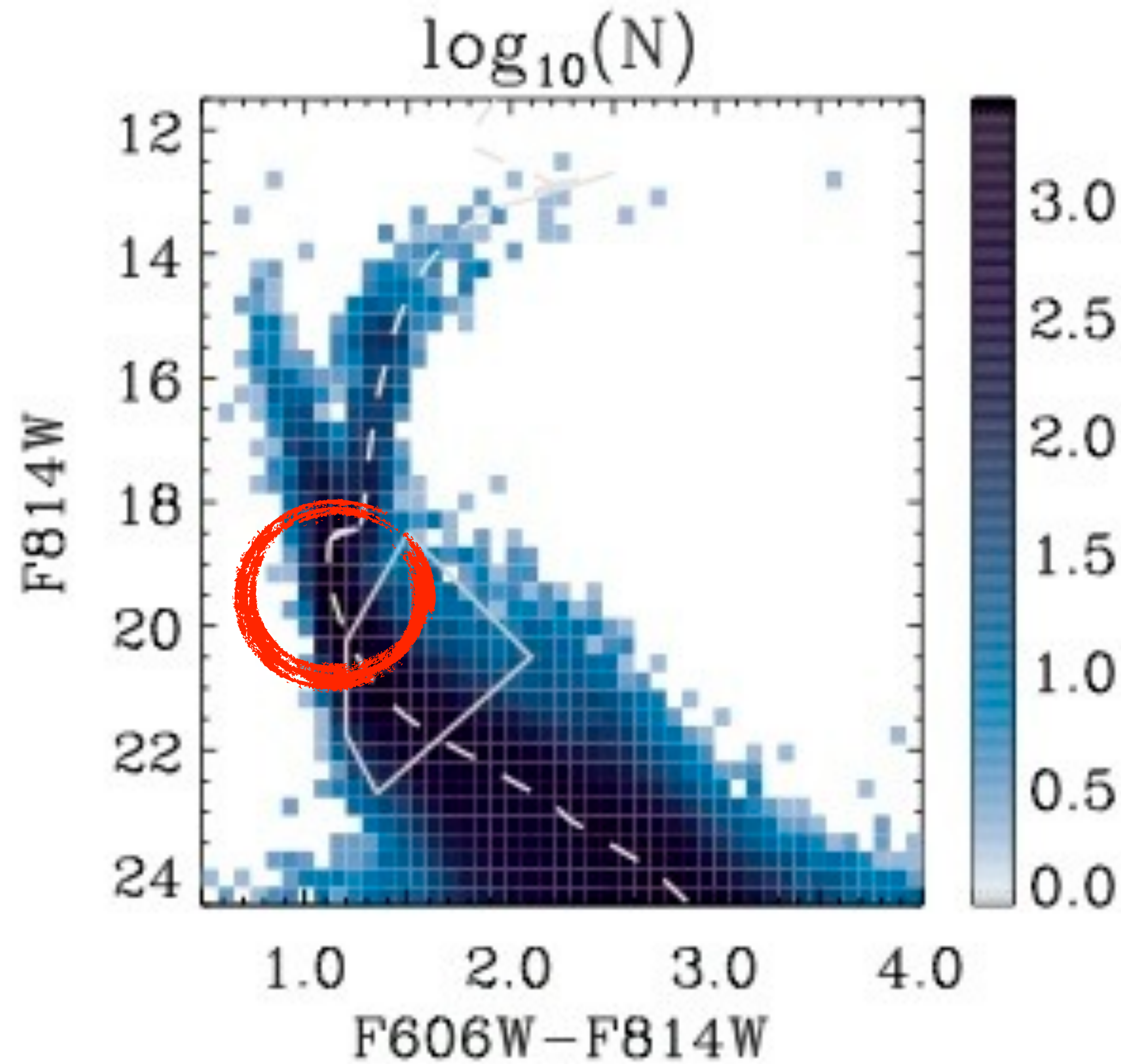
Fulbright et al. (2007)

Dwarf stars in the Galactic bulge are faint

Dwarf stars in the Galactic bulge have V~19-20,

An instrument such as UVES on VLT/UT2 would require around 50 hours to get a decent high-res spectrum (S/N>50, R>40000)

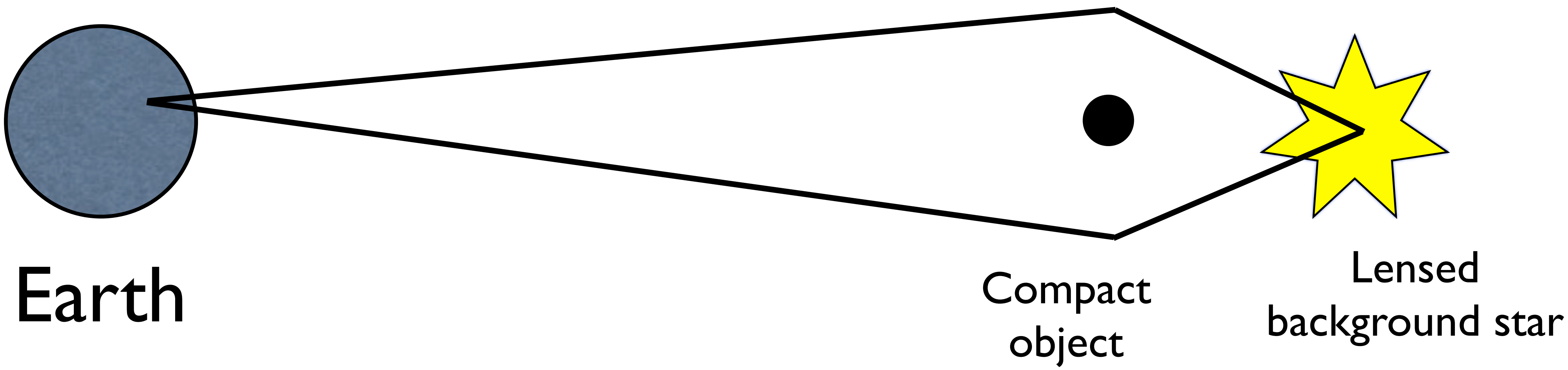
(might have problem with the TAC...)



Clarkson et al. (2008)

Microlensing

A star can brighten by factors of several hundreds during a microlensing event

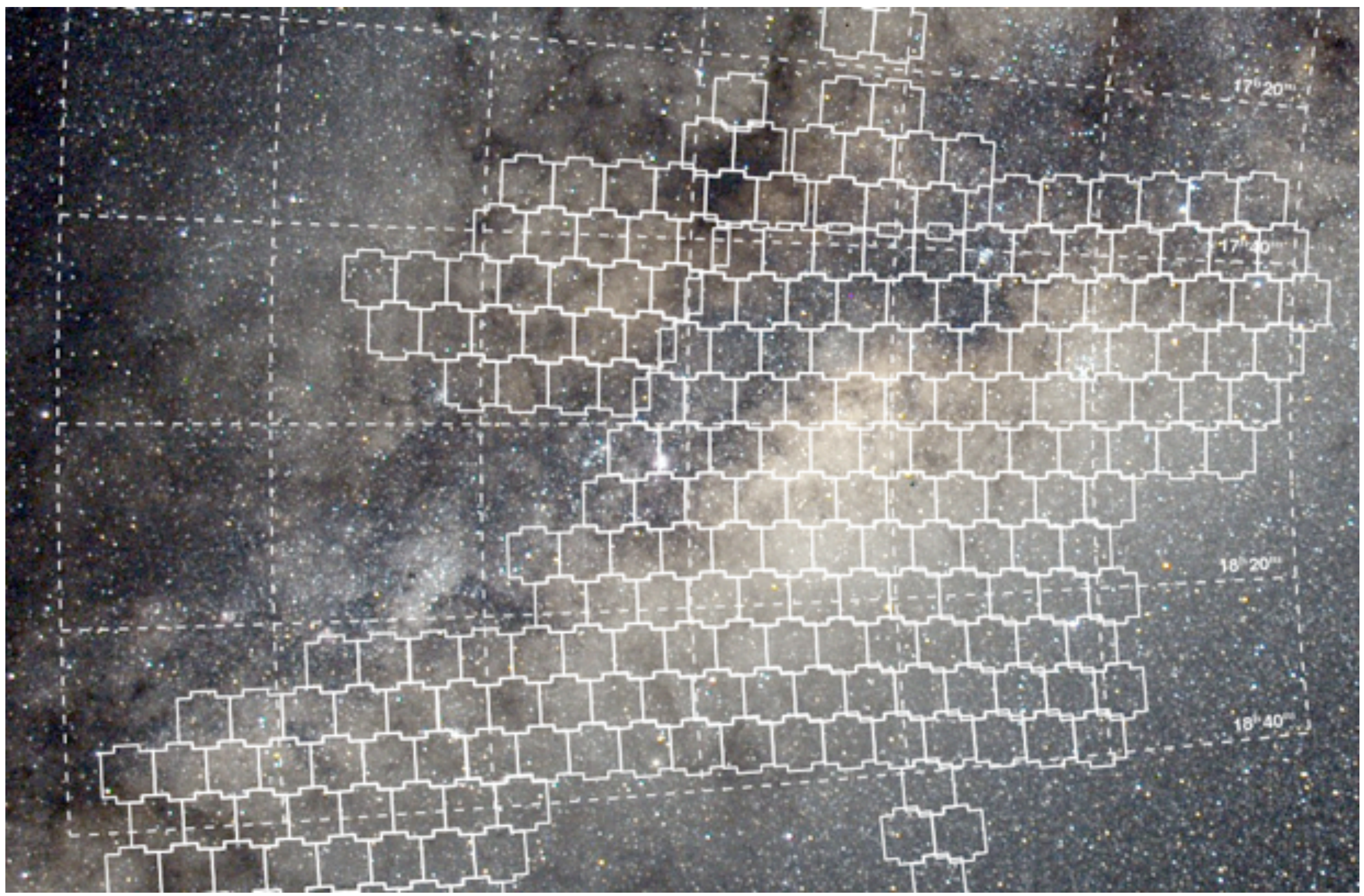


If the star reaches I~15 a 2 hour exposure with UVES gives S/N>50

OGLE and MOA

OGLE-IV on Las Campanas has so far detected 1818 microlensing events towards the Galactic bulge in 2013

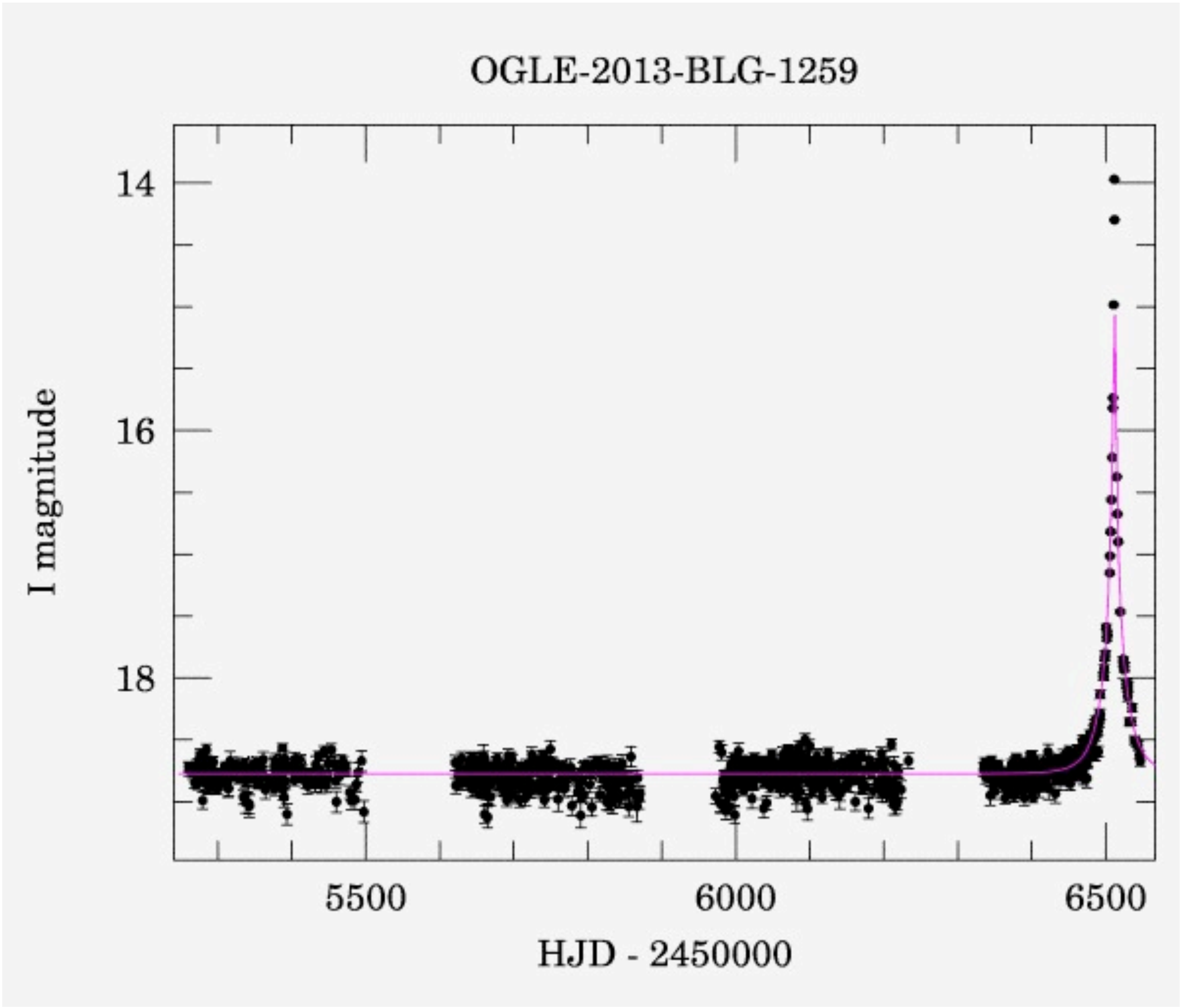
MOA in New Zealand has detected 635 microlensing events in 2013



Bulge fields currently monitored by OGLE-IV

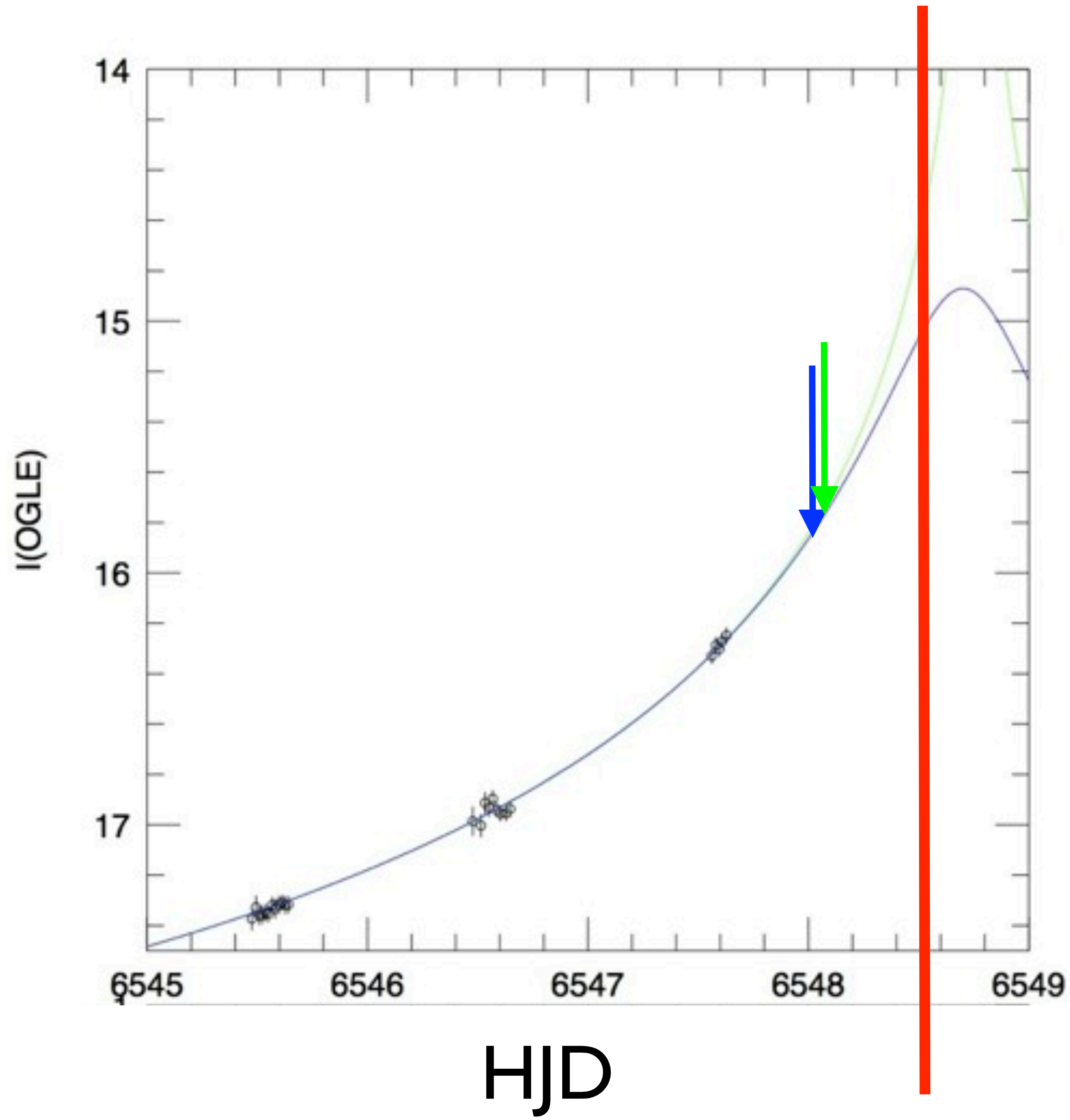
Microlensing

Amax ~ 100



ToO triggering

Latest event three days ago: OGLE-2013-BLG-1793



UT 13:17 (blue arrow)
Light curve prediction from Andy Gould

UT 13:46 (green arrow)
ToO trigger sent to Paranal

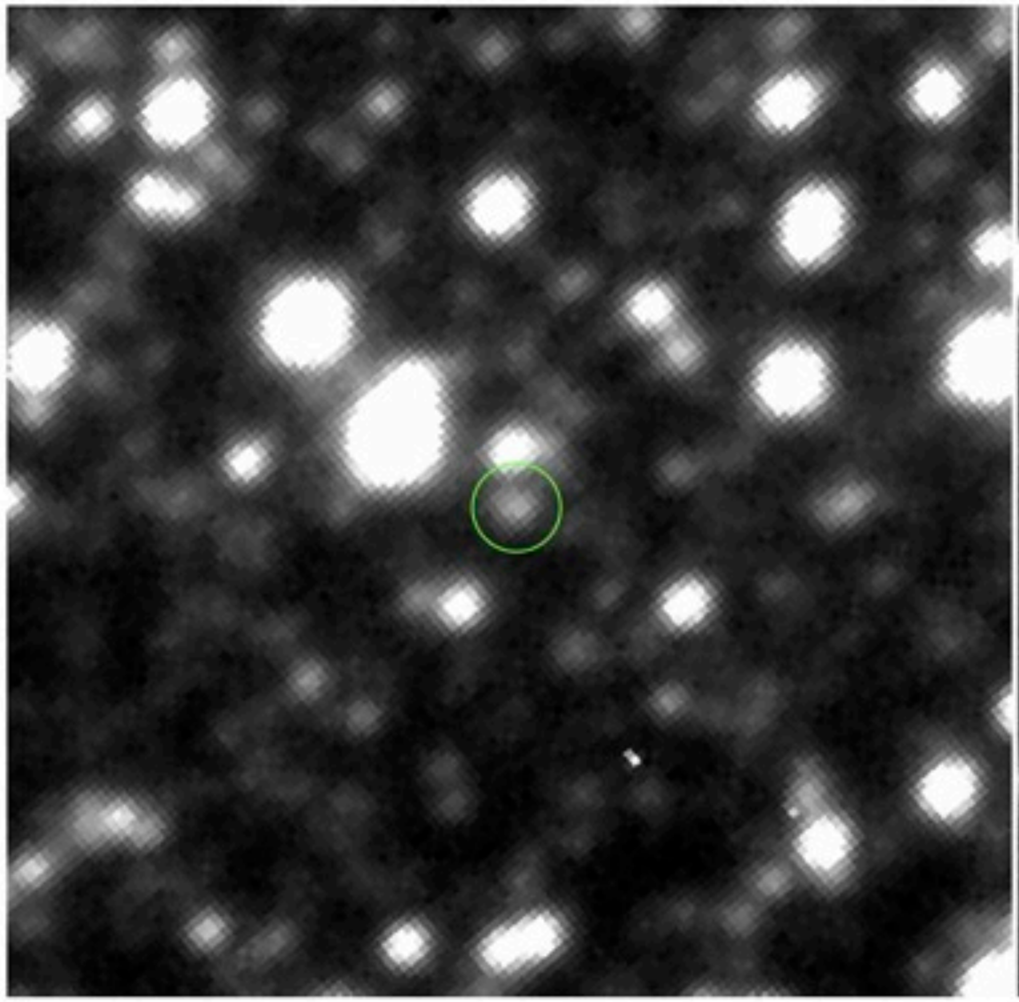
UT 01:00 (red line)
Observation with UVES at VLT starts, 2 hour exp. time

(The object peaked at I=13.8 at UT05:00 at airmass>5 .....)

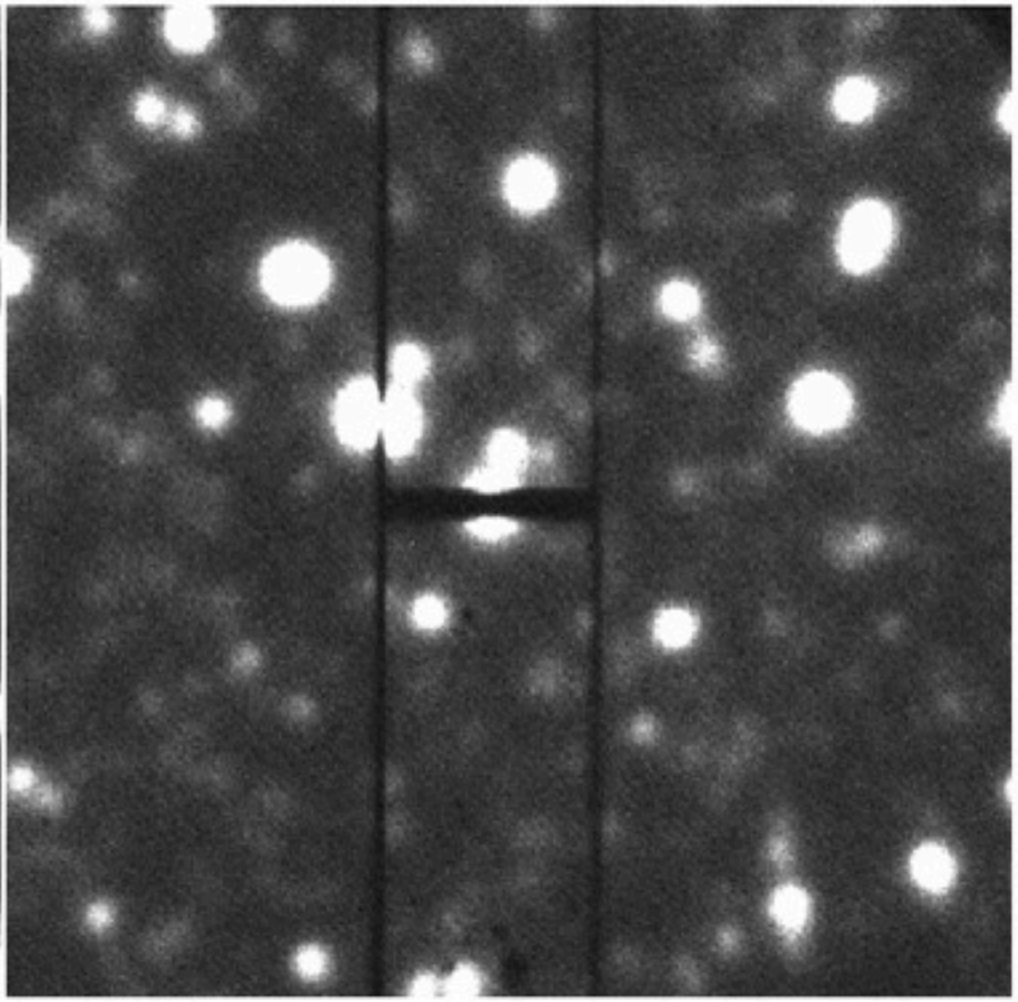
ToO program with UVES on VLT

OGLE-2013-BLG-1259

Image taken at CTIO on July 24 (12 days before UVES observations)



Slit viewer image with 1.0 x 8 arcsec slit covering the object during UVES observations on Aug 6



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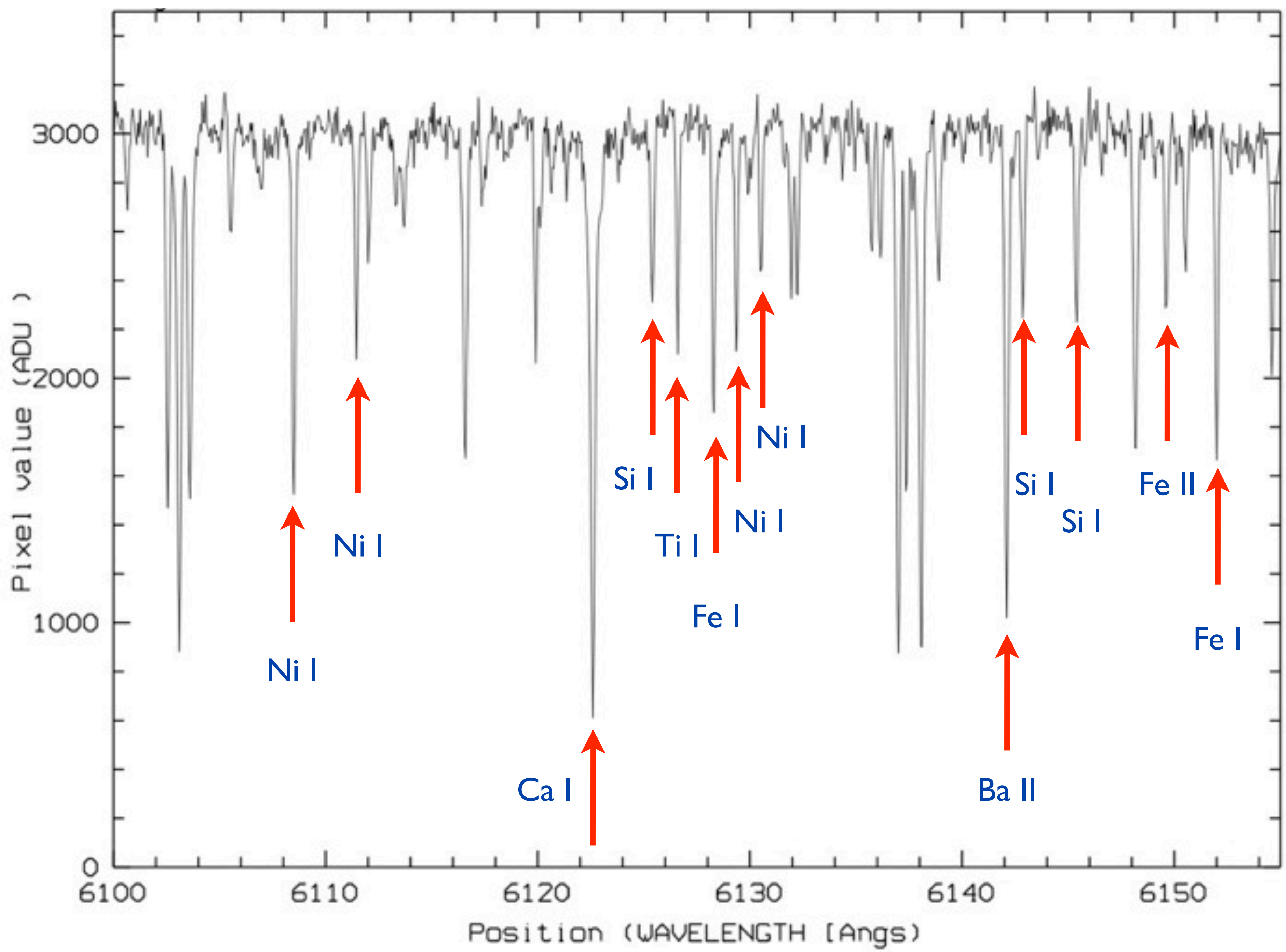


REDL + REDU
5700Å-9300Å

S/N =80-120
Teff = 5708 K
logg = 3.90
[Fe/H] = +0.33

Based on
90 FeI &
13 FeII lines

(The BLUE spectrum (3600-4800Å) is usually unusable due to the high extinction)

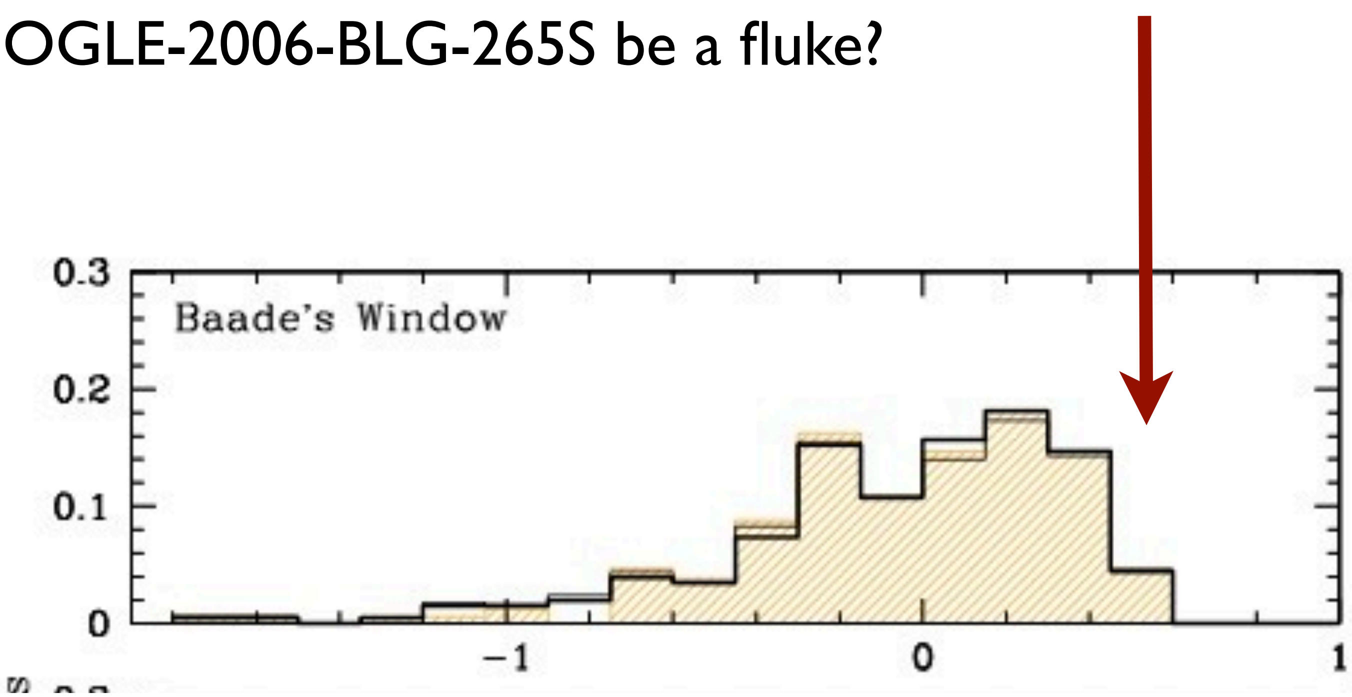
A short history of the microlensed MDF

#1 OGLE-2006-BLG-265S

Johnson et al., 2007, ApJ, 655, L36

- **[Fe/H]=+0.56** - most metal-rich dwarf star ever!
  more metal-rich than any of the giants stars studied in the Bulge
- Solar-type alpha-element abundances, i.e. [alpha/Fe]~0
  Possibly inconsistent with the high alpha abundances seen in giants, however, no giant as metal-rich

Could OGLE-2006-BLG-265S be a fluke?



Zoccali et al. (2008)
red giants in BW

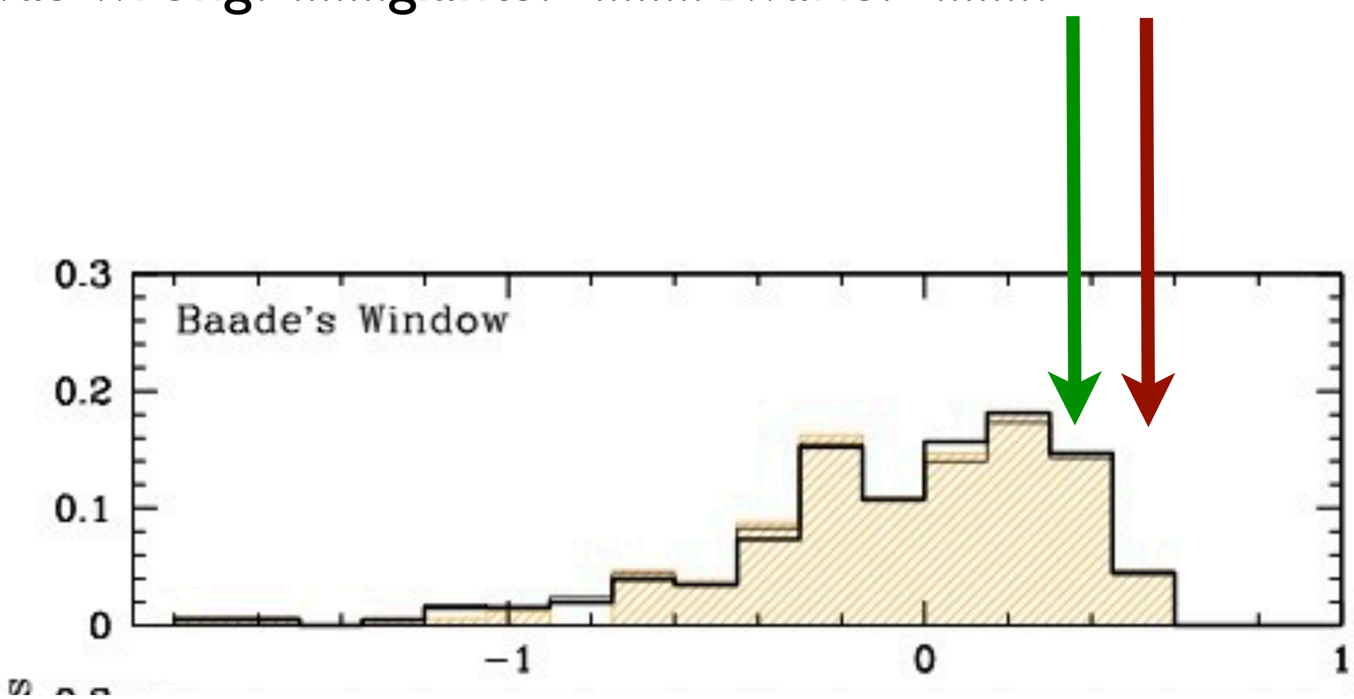
#2 MOA-2006-BLG-099S

Johnson et al., 2008, ApJ, 685, 508

- **[Fe/H]=+0.36** - more metal-rich than any M giant observed in the Bulge
- [alpha/Fe] similar to what is found in Bulge giants at same metallicity

At the very high end of the giant MDF!

what was wrong? ....giants? ....dwarfs? ....?



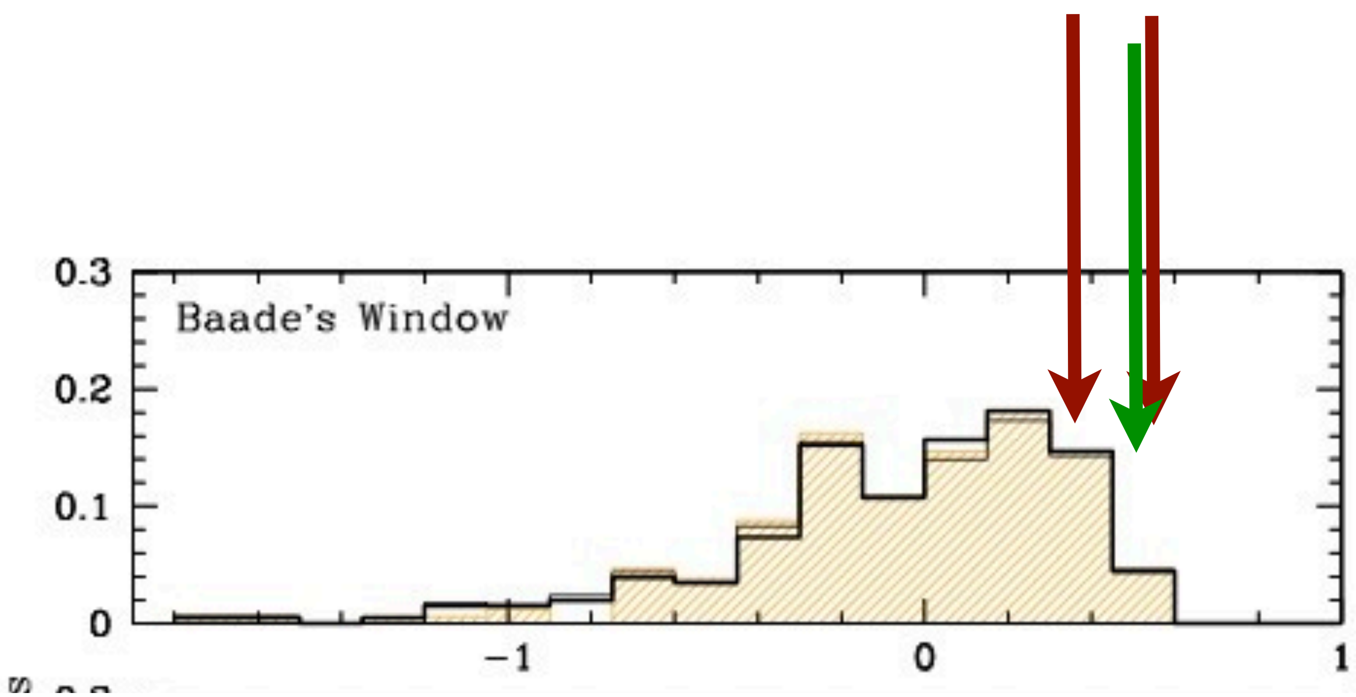
Zoccali et al. (2008) red giants in BW

#3 OGLE-2007-BLG-349S

Cohen et al., 2008, ApJ, 682, 1029

- **[Fe/H]=+0.51**
- No enhancement in any of the alpha-elements
- Suggests that the Bulge is much more metal-rich than previously thought!

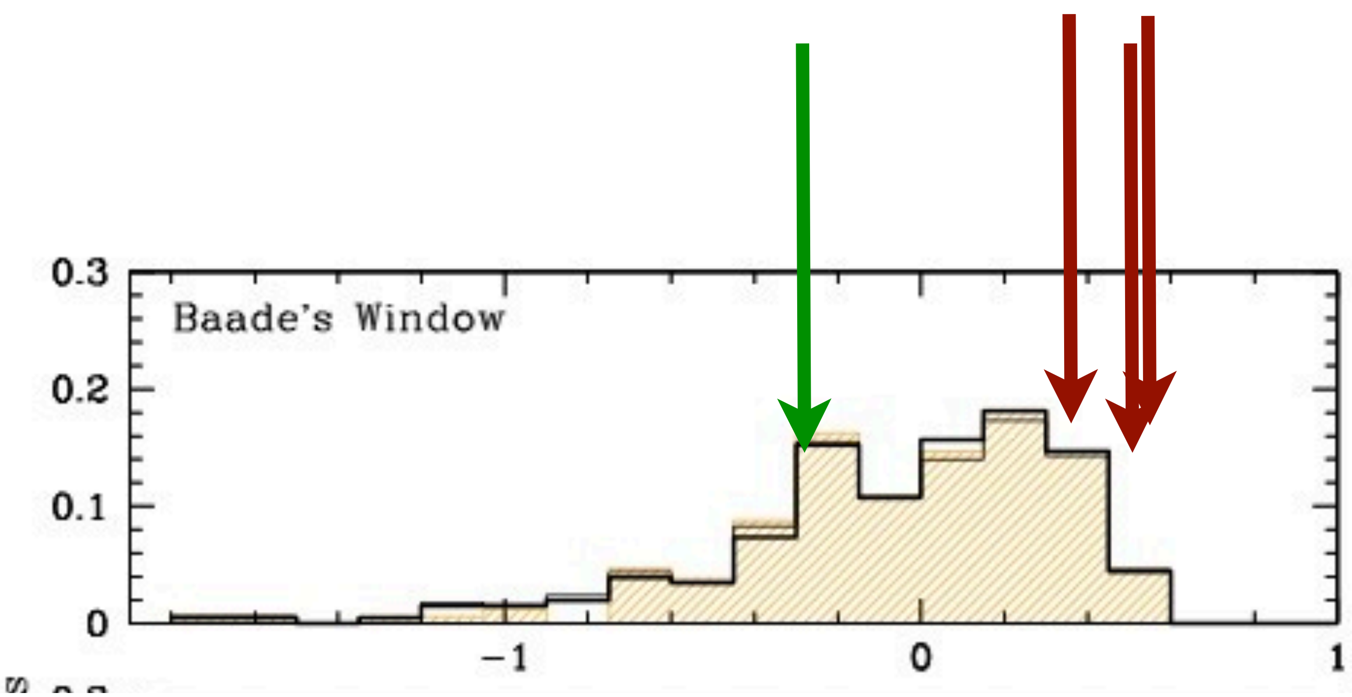
Zoccali et al. (2008)
red giants in BW



#4 OGLE-2008-BLG-209S

Bensby et al., 2009, A&A, 499,737

- **[Fe/H]=-0.33**
- Look, there are metal-poor microlensed dwarf stars in the bulge! (even though this was a sub-giant).
- [alpha/Fe] similar to what was found in Bulge giants and nearby thick disk stars at the same metallicity

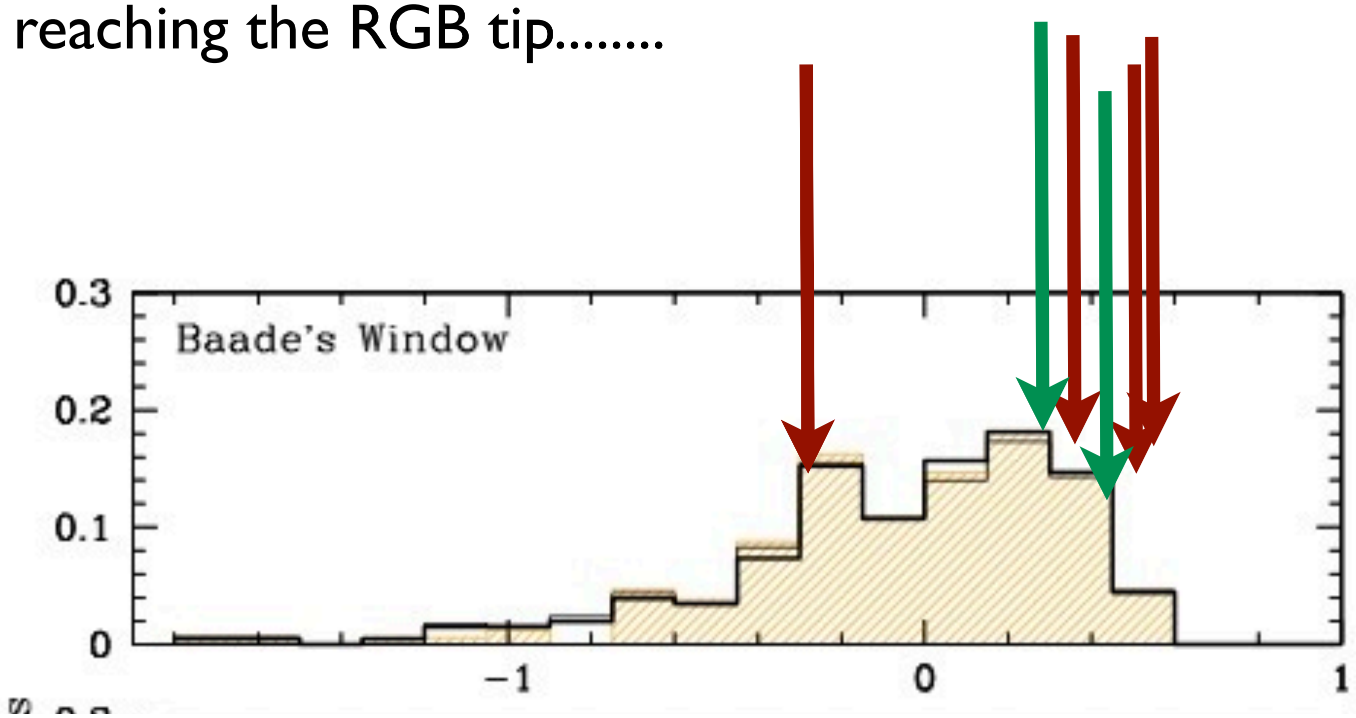


Zoccali et al. (2008) red giants in BW

#5-6 OGLE-2008-BLG-310S & -311S

Cohen et al., 2009, ApJ, 609, 66

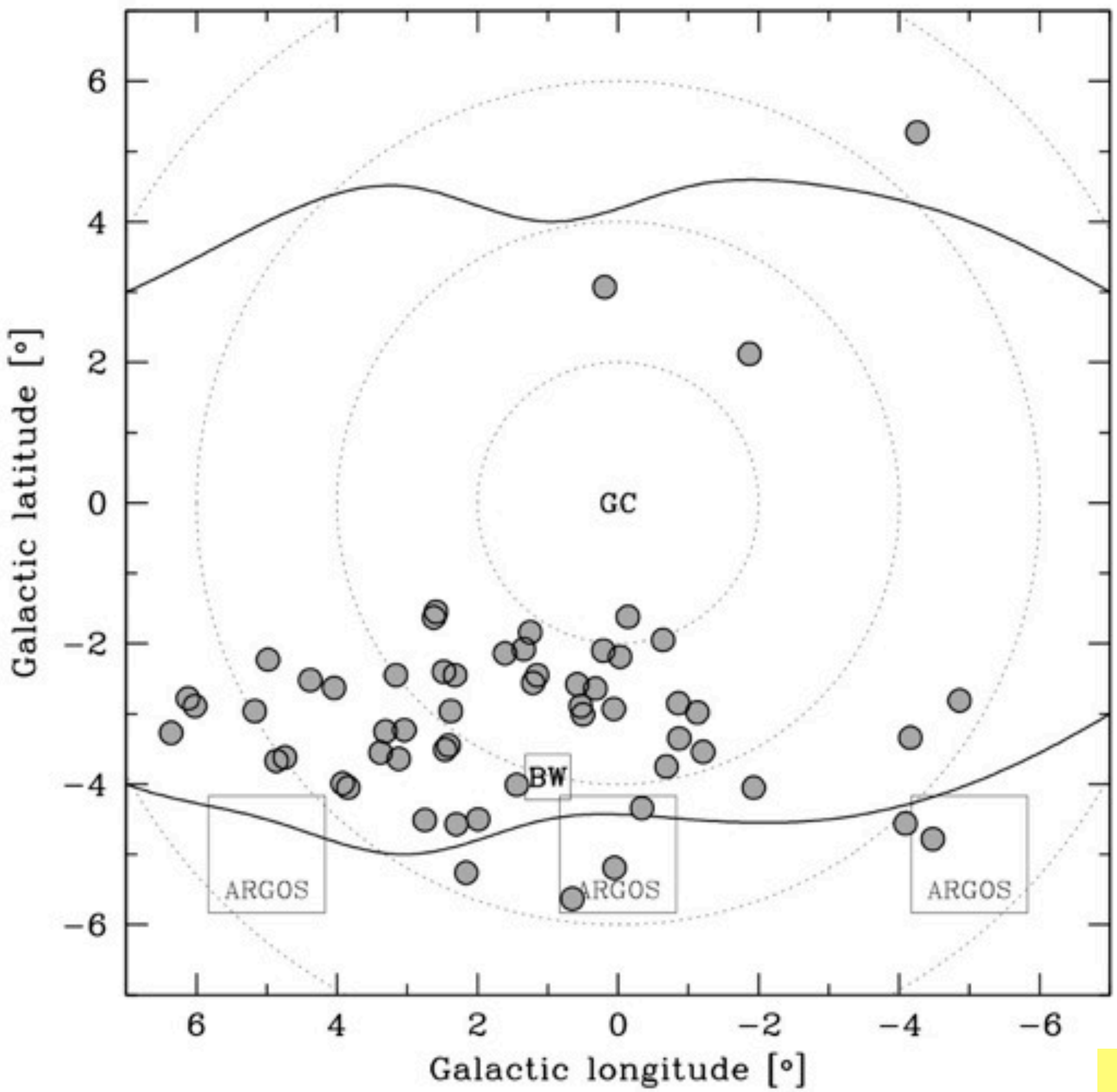
- **[Fe/H]=+0.41 and +0.26**
- 40000 random draws of 6 stars from the Zoccali et al. (2008) sample of 500 giants and in only 0.4% of the cases the drawn sample is as metal-rich as the sample of 6 microlensed bulge dwarfs
- Advocates for a very metal-rich MDF for the Bulge and that the most luminous metal-rich giants are missing as they lose their entire atmosphere before reaching the RGB tip........



Zoccali et al. (2008) red giants in BW

This is when our ToO program with UVES/VLT starts

Position on the sky

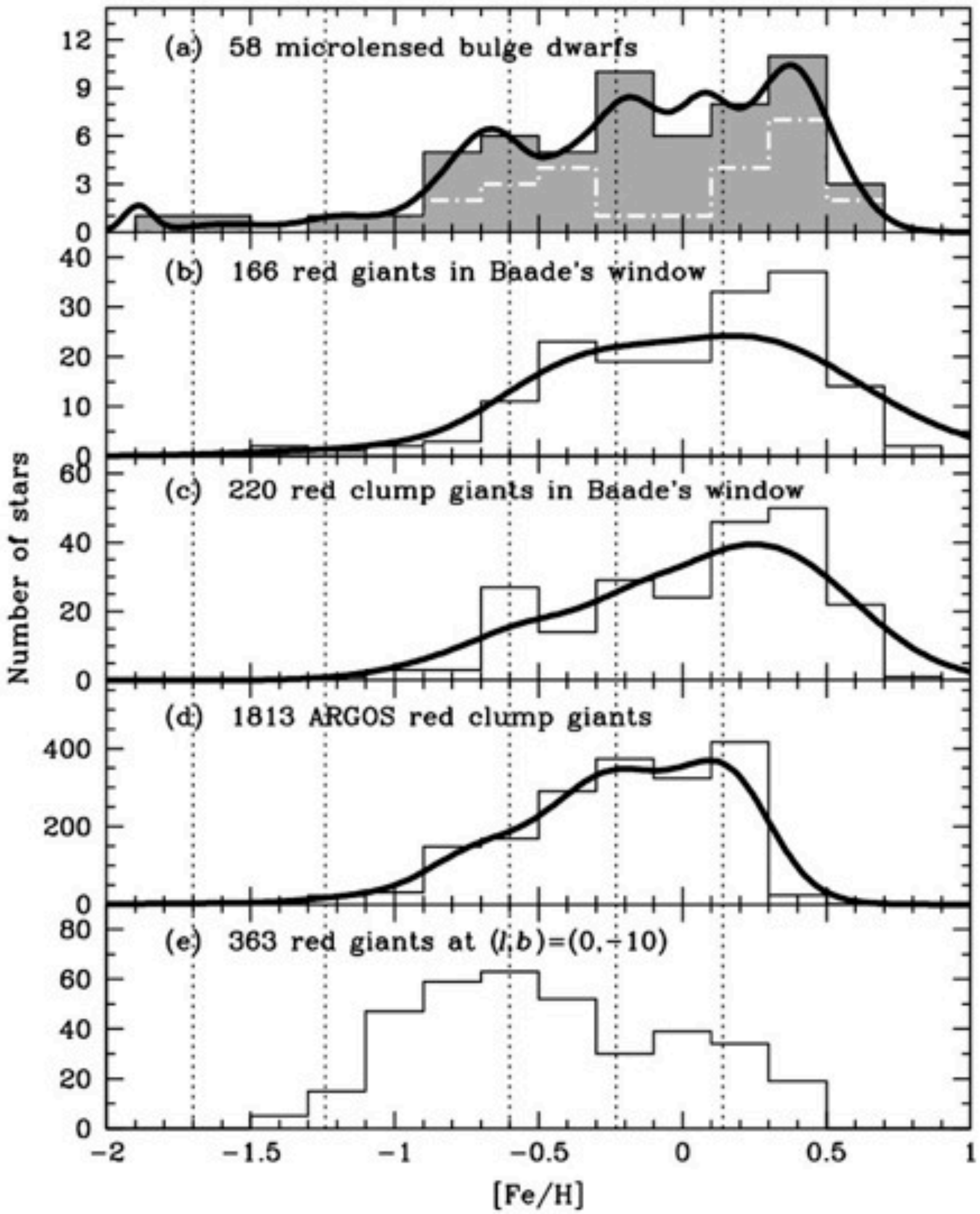


Positions reflect the areas that are currently being moniteroed by MOA and OGLE

Distributed 2-5 degrees below the plane (or ~150-750 pc below the plane, assuming a distance of 8 kpc to the GC)

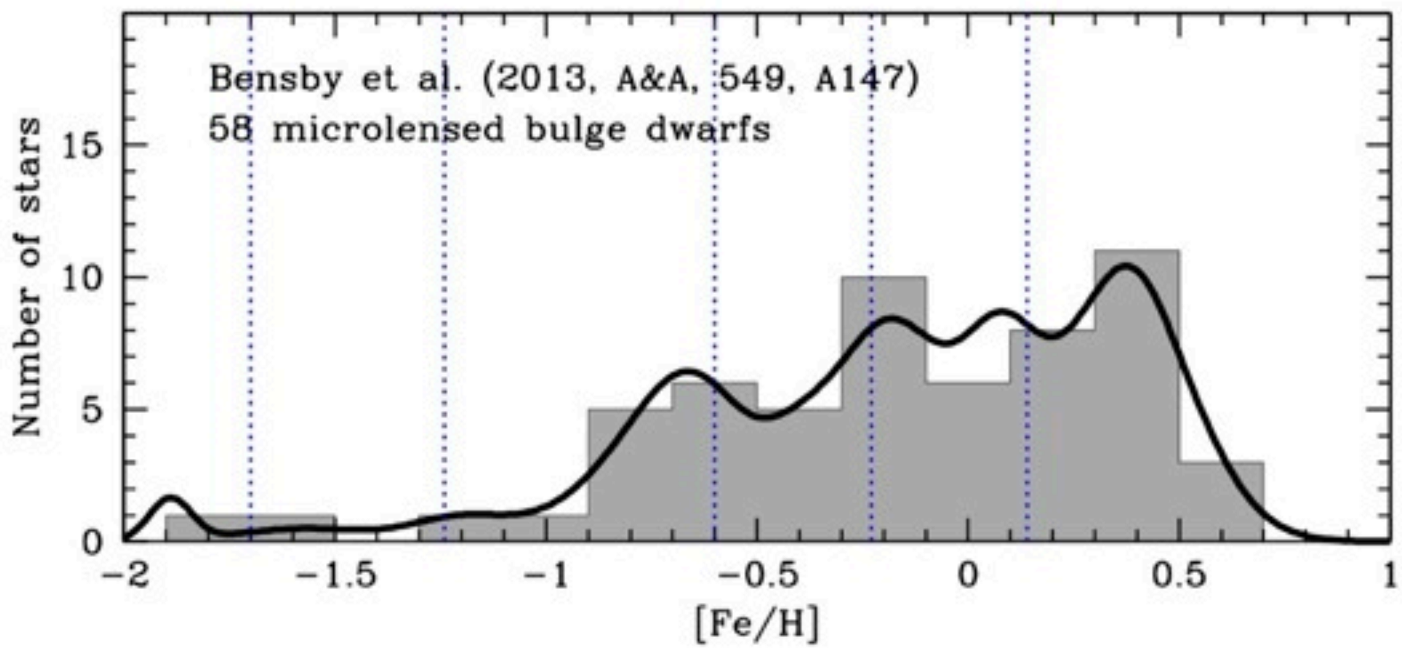
58 bulge dwarfs from Bensby et al. (2013, A&A, 549, A147)

MDF - comparison to other studies



		glat
58 bulge dwarfs from Bensby et al. (2013, A&A, 549, A147)		-2 - -5
166 red giants in BW from Hill et al. (2011)		-4
220 red clump giants in BW from Hill et al. (2011)		-4
1813 red clump giants from Ness et al. (2012)		-5
363 red giants from Uttenthaler et al. (2012)		-10

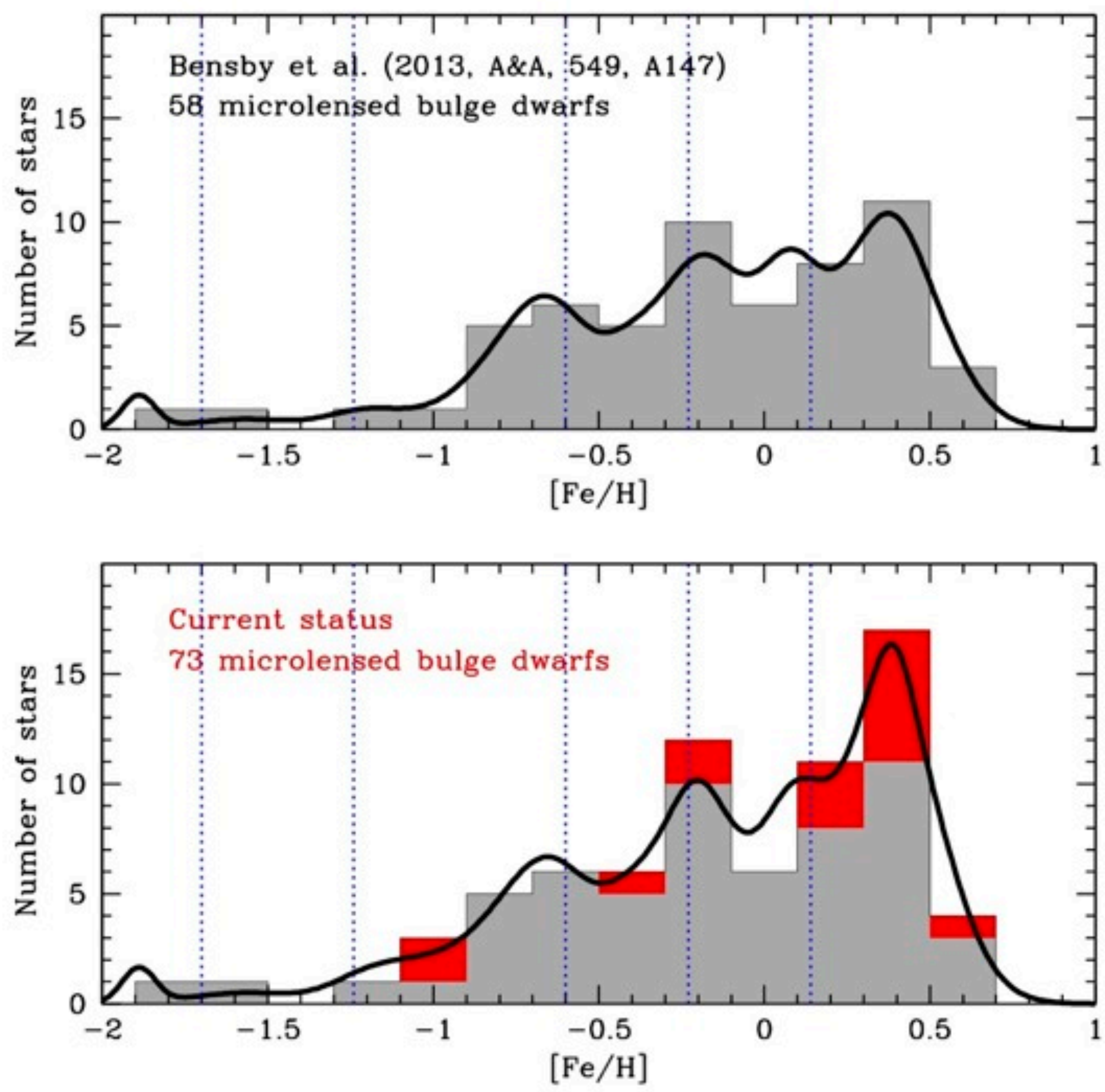
The peaks from ARGOS



The peaks in the generalised dwarf MDF coincide well with the peaks from the ARGOS study.

Vertical dotted lines mark the peaks identified by Ness et al. (2012)

Current status of microlensed dwarf MDF

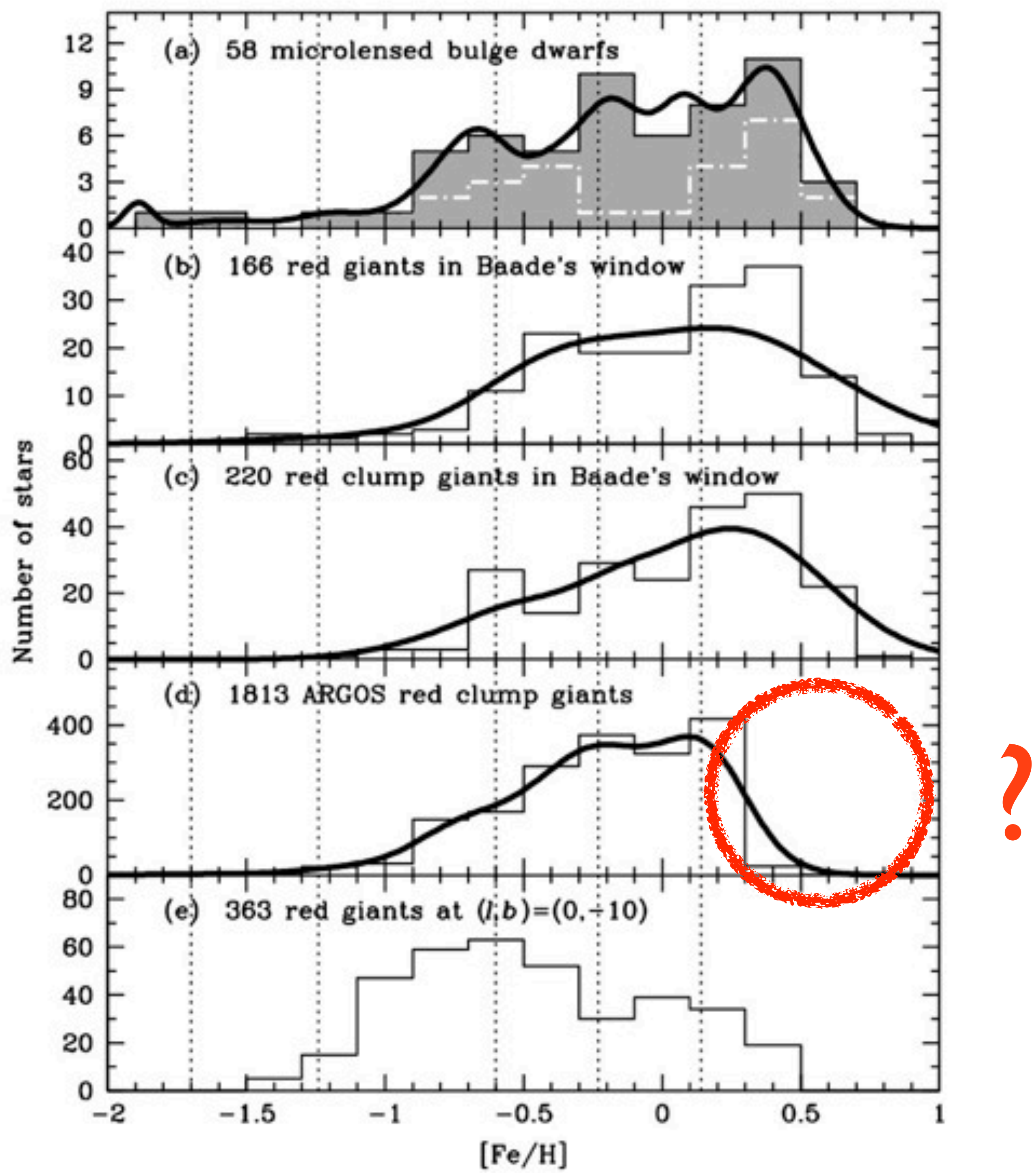


15 more targets have so far been observed in 2013.

...and so far, the peaks seem to persist, or even become more well-defined.......

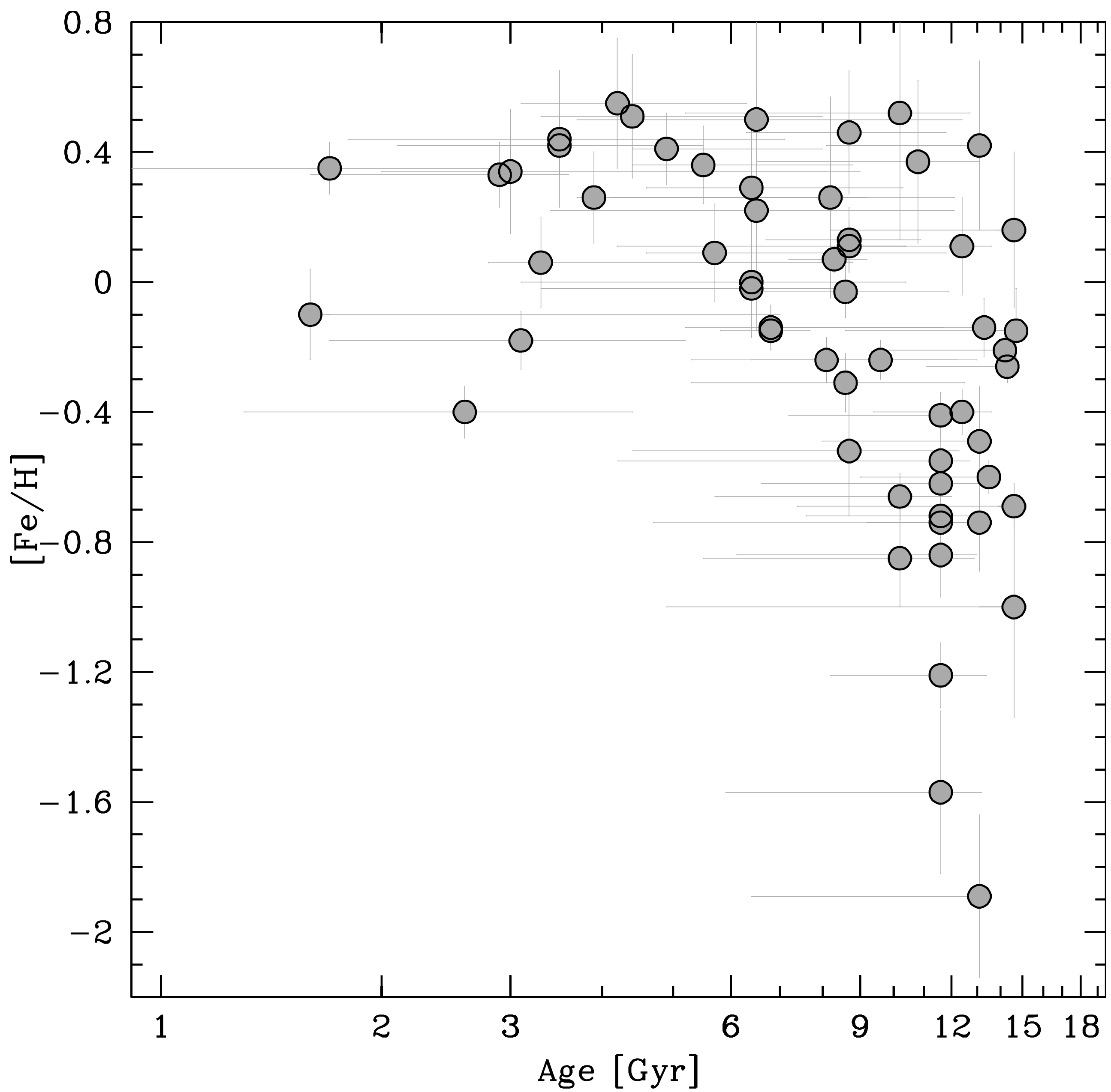
Vertical dotted lines mark the peaks identified by Ness et al. (2012)

But where are the metal-rich stars in the ARGOS data?



Ages

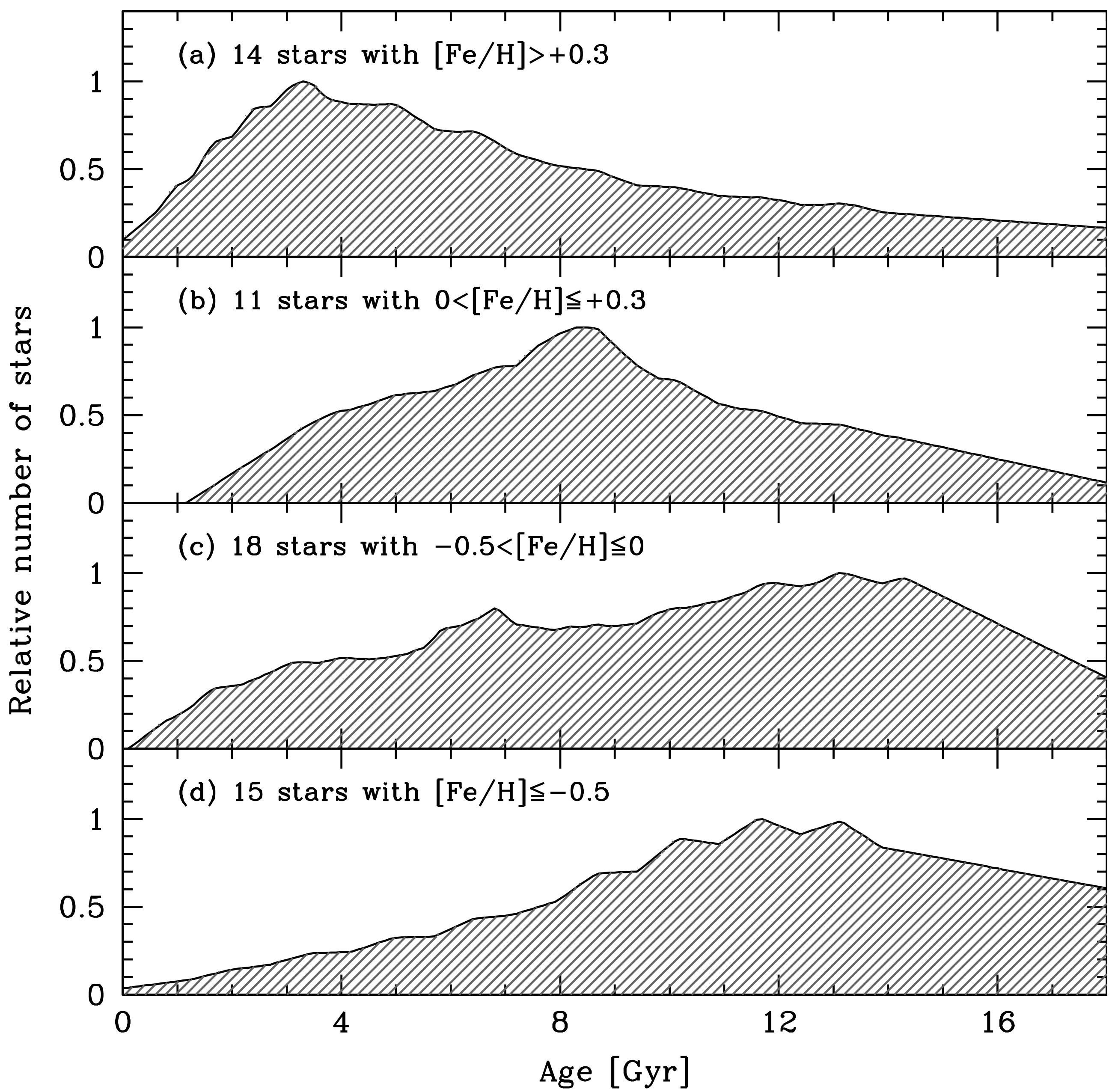
A significant fraction of younger stars



58 bulge dwarfs from Bensby et al. (2013, A&A, 549, A147)

Ages

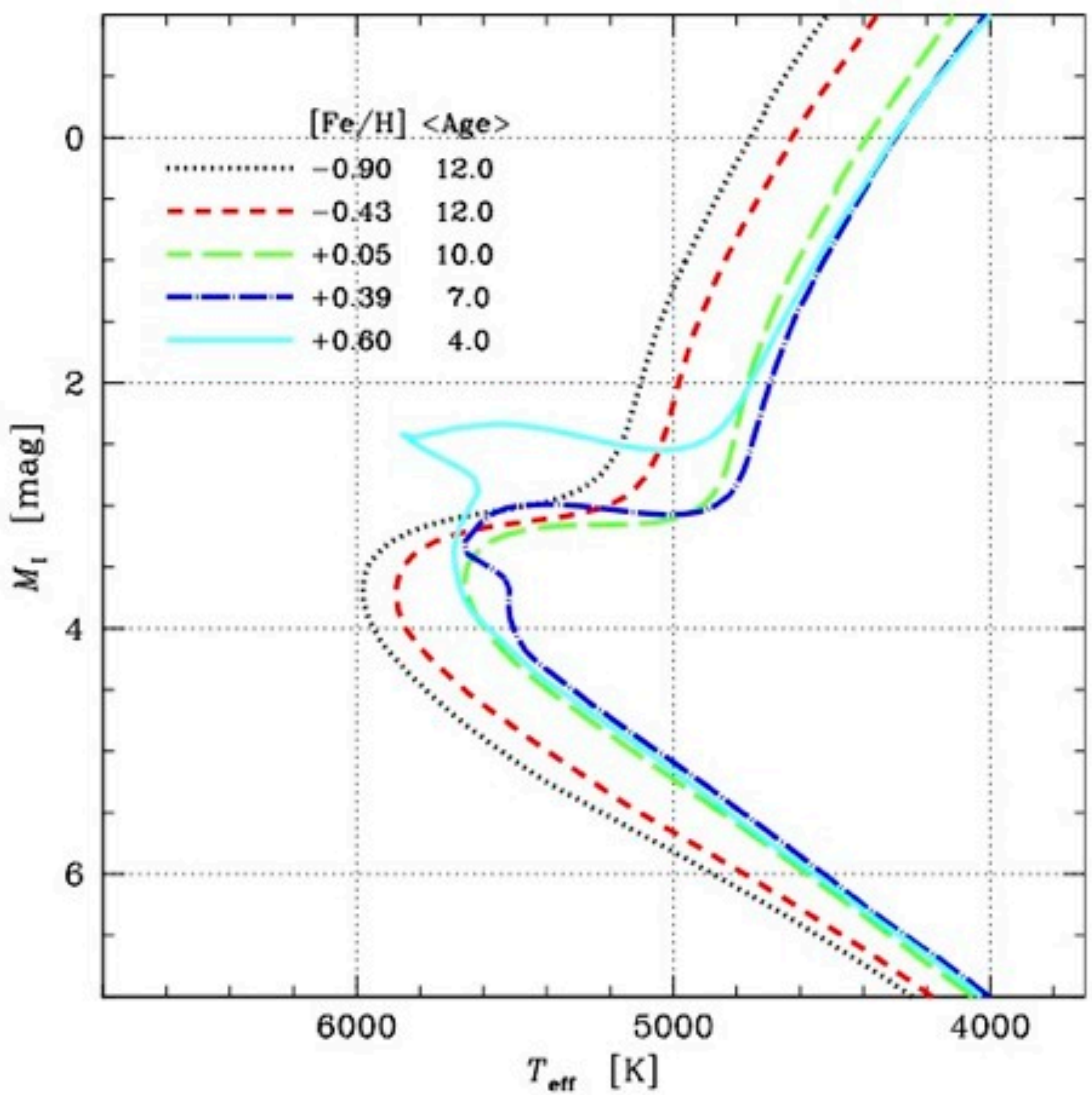
Summing up the individual age probability distributions in different [Fe/H] bins



58 bulge dwarfs from Bensby et al. (2013, A&A, 549, A147)

Ages

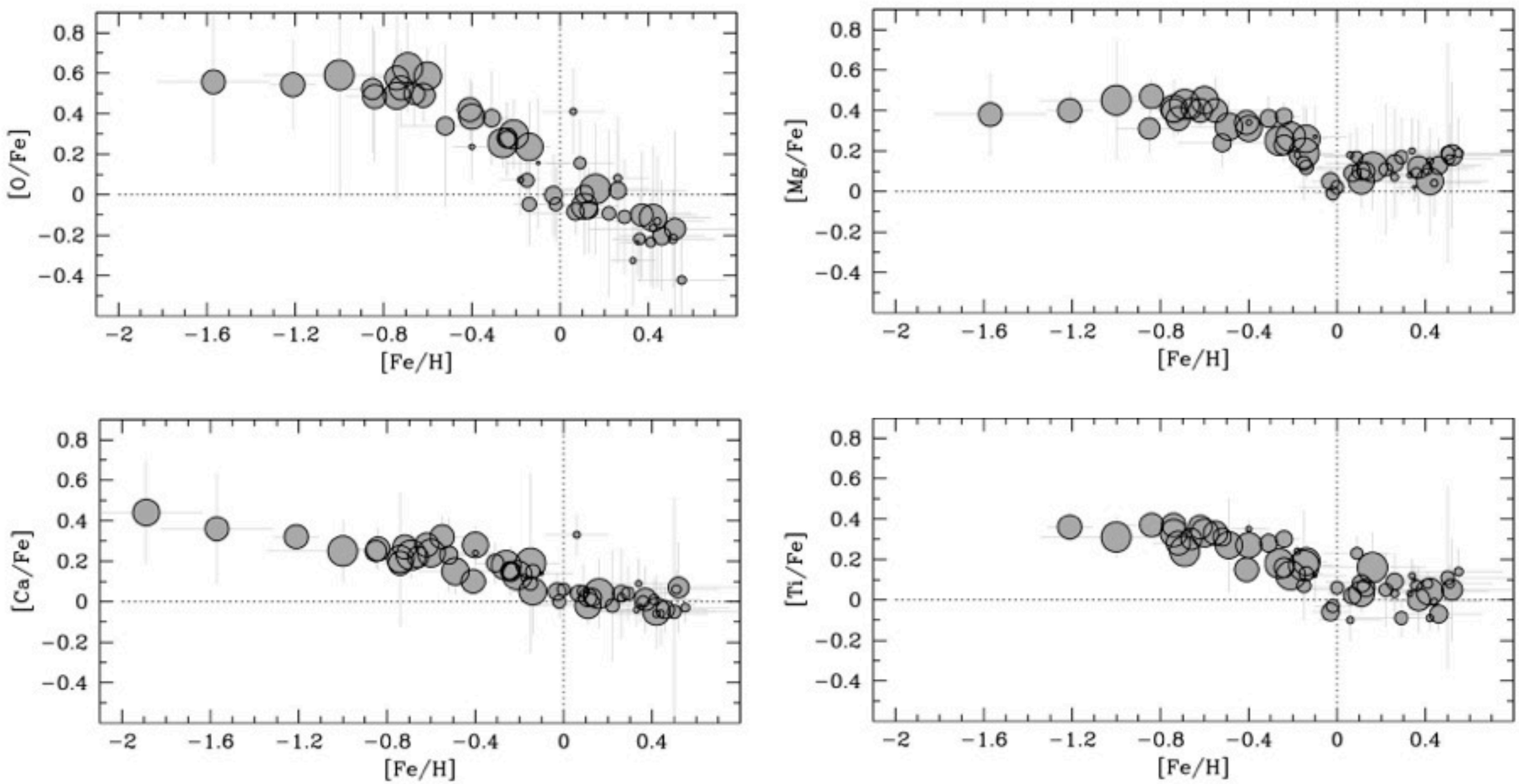
Young and metal-rich stars occupy the same region in the HR diagram as old and metal-poor stars



An apparent old turn-off

Bensby et al. (2013, A&A, 549, A147)

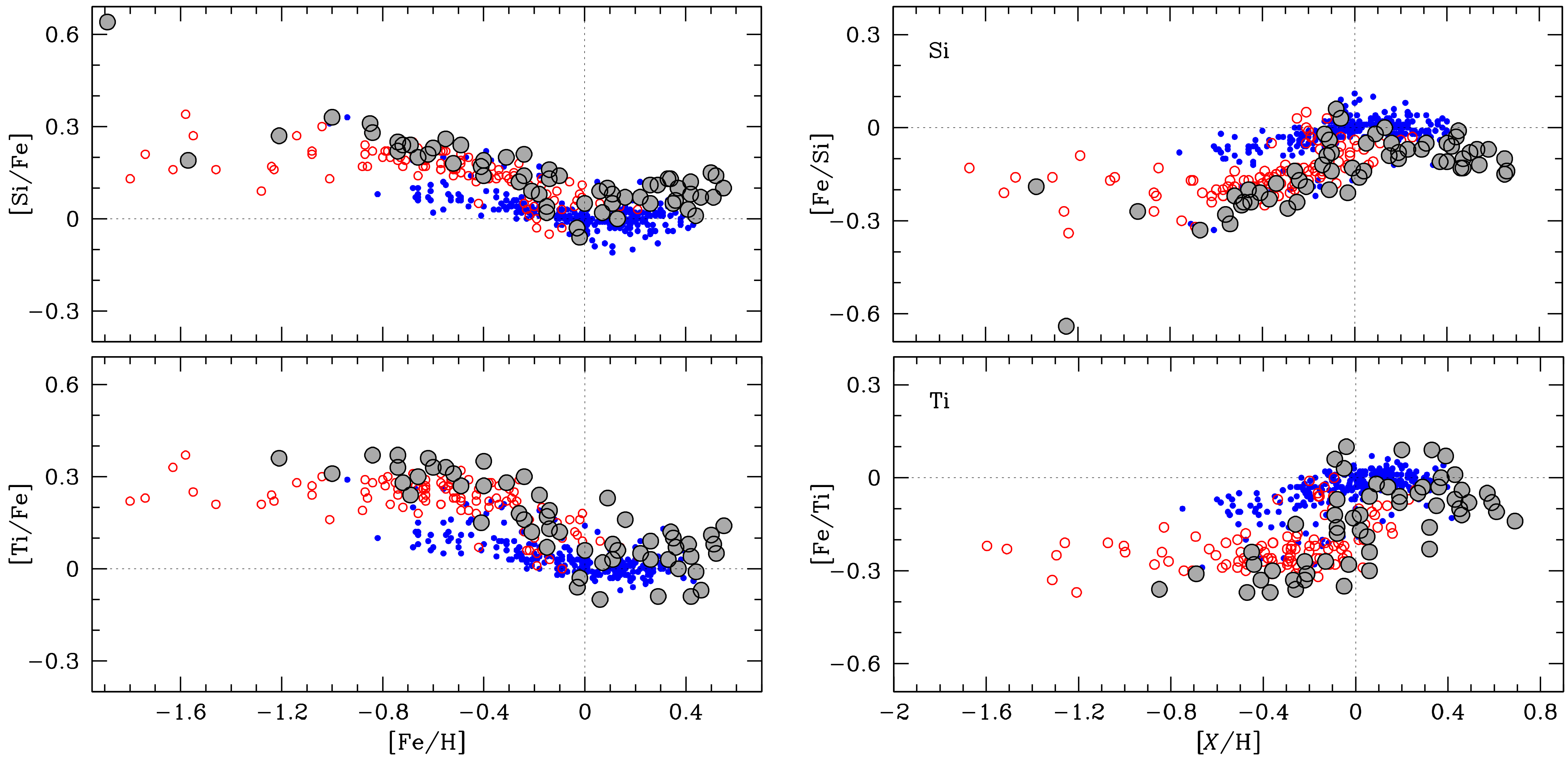
Abundance trends



58 bulge dwarfs from
Bensby et al. (2013, A&A, 549, A147)

Abundance trends

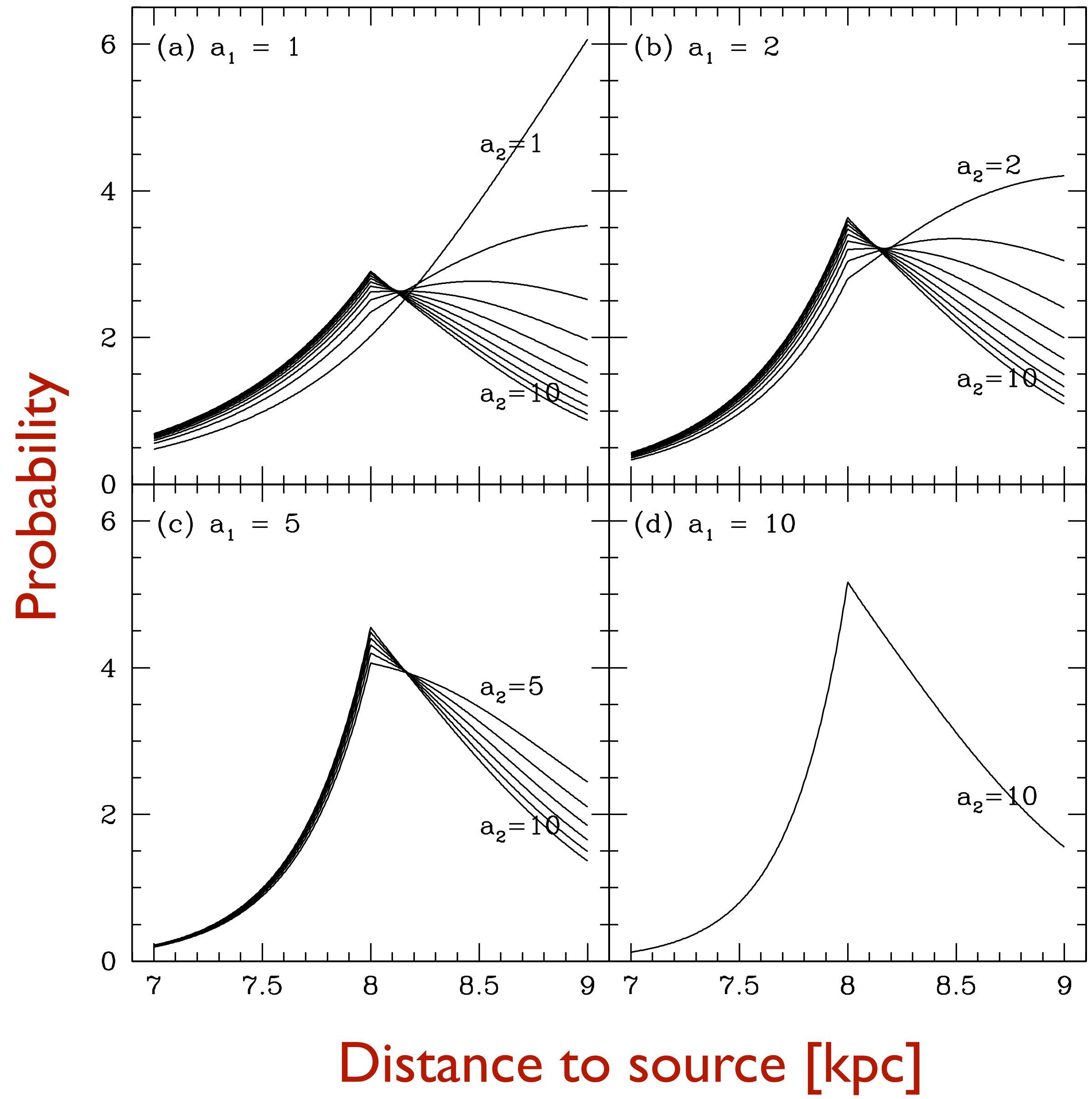
Red=nearby thick disk, Blue=nearby thin disk



Maybe slightly faster enrichment than the nearby thick disk....

58 bulge dwarfs from Bensby et al. (2013, A&A, 549, A147)

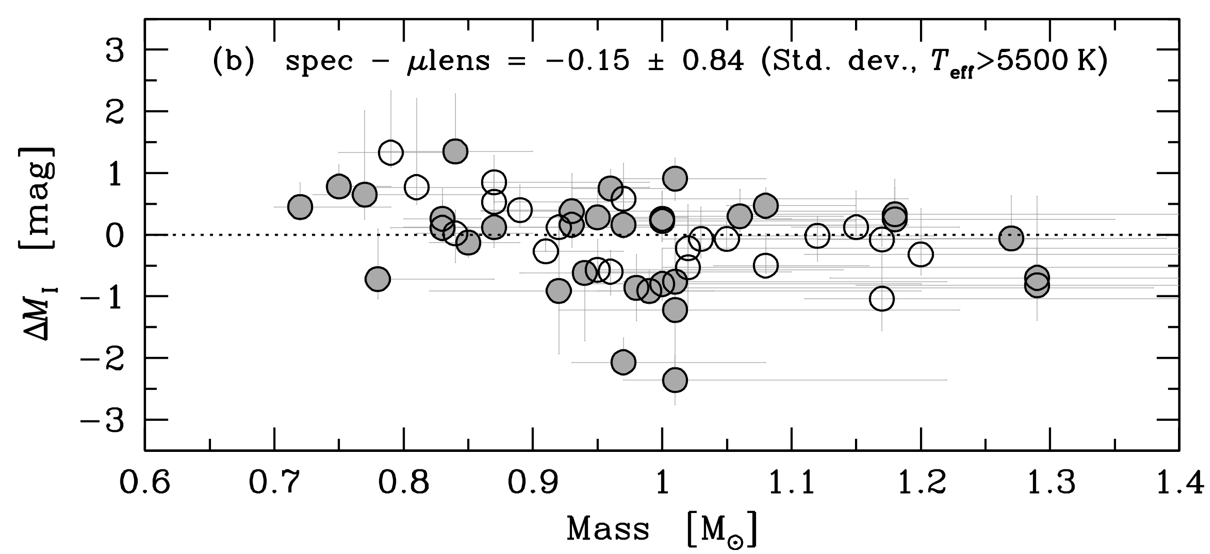
Are the microlensed dwarfs in the bulge?



Recent theoretical calculations of the distance to microlensed sources, assuming a constant disc density and an exponential bulge, show that the distance to the sources is strongly peaked in the Bulge, with the probability of having D < 7 kpc very small (Kane & Sahu 2006)

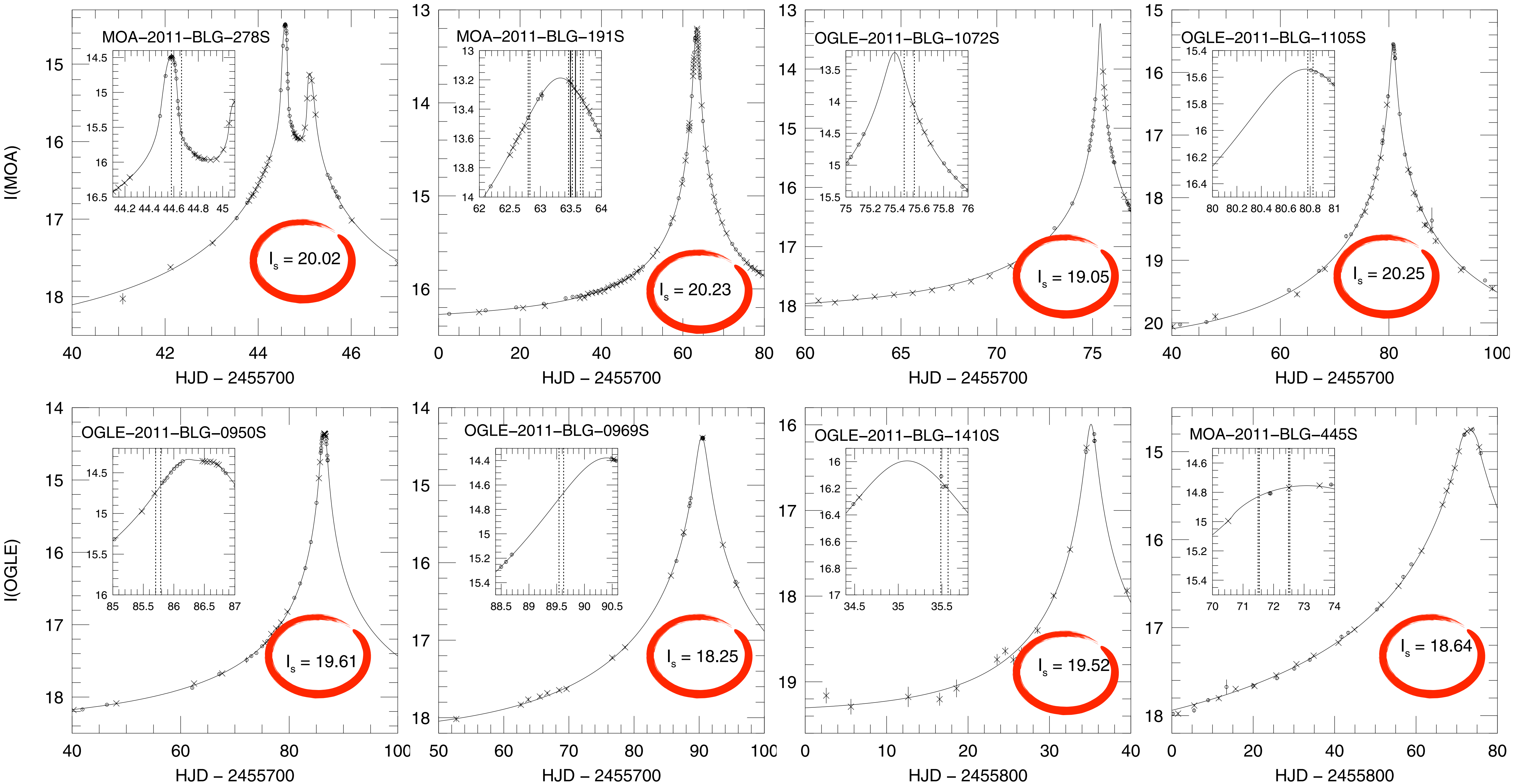
The ratio of the stellar number density at the central part of the bulge to the stellar density in the near side of the bulge is a_1, and to the far side of the bulge is a_2.

Comparing spectroscopic absolute magnitudes with microlensing absolute magnitudes compare well and are consistent with uncertainties in the spectroscopic log g



Are the microlensed dwarfs in the bulge?

Un-lensed magnitudes: I=18-20



Chemical evolution in the Universe: the next 30 years, Castiglione della Pescaia, September 17, 2013

Are the spectra affected by the microlensing event?

Dark limbening effects: the surface of the star is differentially magnified

"Finite source effects can be important in observations of gravitational microlensing of stars. Near caustic crossings, for example, some parts of the source star will be more highly magnified than other parts. The spectrum of the star is then no longer the same as when it is unmagnified, and measurements of the atmospheric parameters and abundances will be affected.....We find that ignoring the finite source effects for the more extreme case results in errors in Teff < 45 K, in log g of <0.1 dex, and in ξ of <0.1 km s −1 . In total, changes in equivalent widths lead to small changes in atmospheric parameters and changes in abundances of <0.06 dex, with changes in [Fe i/H] of <0.03 dex. For the case with a larger source-lens separation, the error in [Fe i/H] is < 0.01 dex."

Johnson et al (2011).

What is the Galactic bulge?

Cylindrical rotation (BRAVA survey) => none, or very small contribution of a classical bulge component

+

Ages and abundances a mixture of what is seen in other Galactic components

+

Multiple components seen in MDF

=>

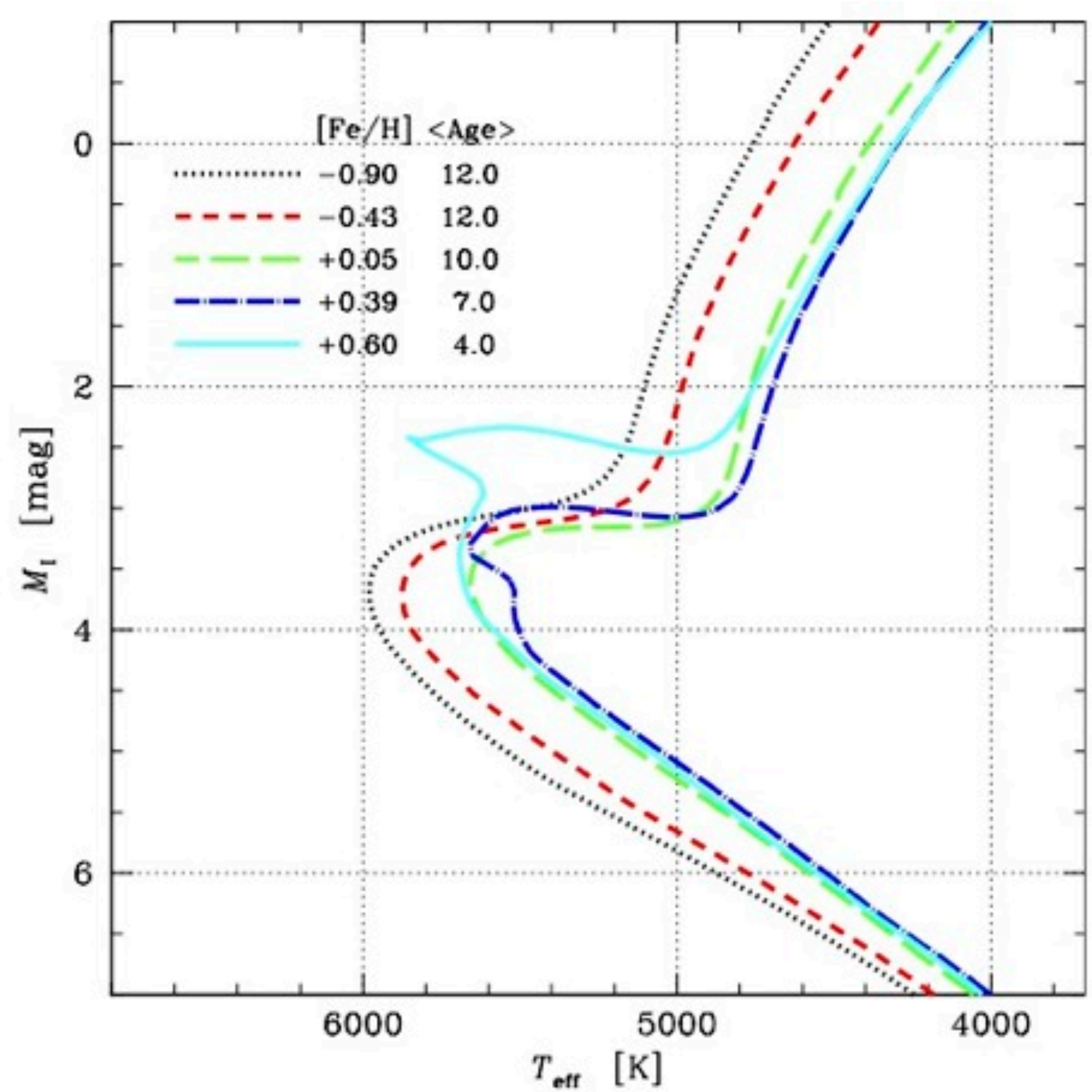
Maybe the bulge should be viewed as a "region" of the Milky Way rather than a "stellar population".

i.e.

The bulge region is a conglomerate of the Galactic stellar populations residing in the inner parts of the Galaxy.

Other issues....

The observing strategy, which is to trigger on events expected to be brighter than about I=15, makes the sample slightly biased toward young and metal-rich stars. The bias is not strong enough to account for all metal-rich and young stars (see discussion in Bensby et al. 2013 for further details)



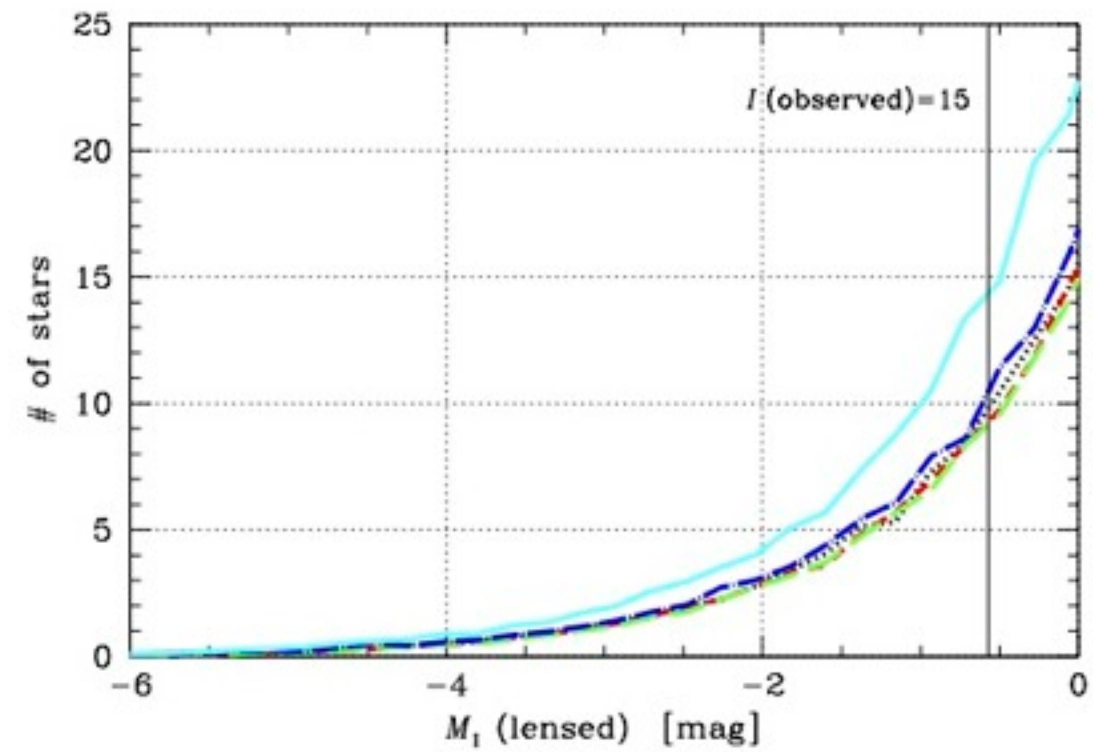


Fig. 23. Number of stars along the isochrones shown in Fig. 21, but now with microlensing of the sample included.