Galactic Bulge: chemical evolution

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Presented at Stars without borders, Ljubljana, by Sofia Feltzing (Lund), June 2019

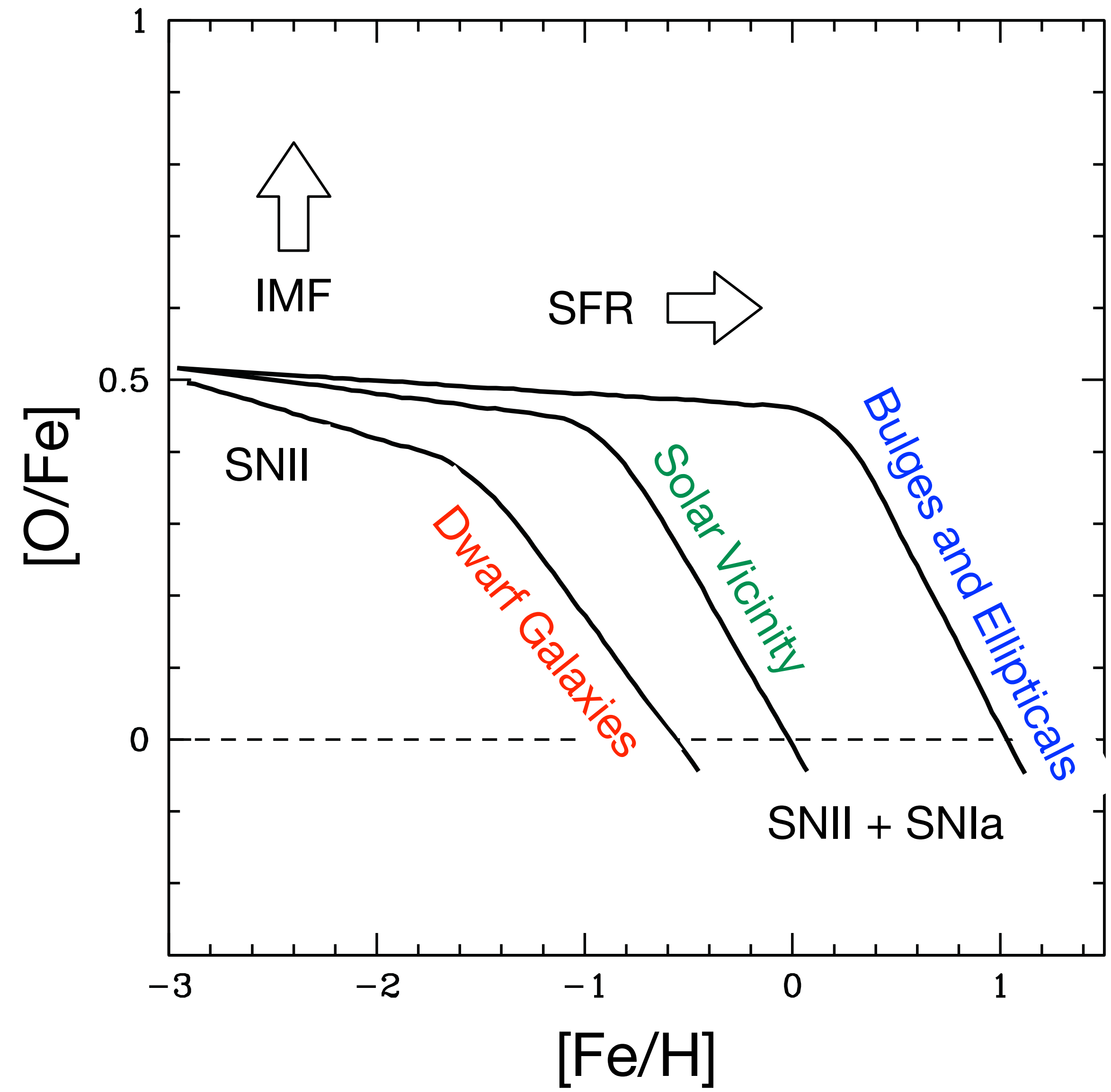
Setting the stage

- Primordial collapse where the Bulge and the thick disk form early on simultaneously (also referred to as the in situ scenario) via strong gas accretion.
- Bulge formation by hierarchical merging of subclumps, prior to the disk formation.
- Merging of early thick-disk subclumps, migrating to the center and forming the Bulge.
- Major merger hypothesis, where disk galaxies result from major mergers of gas-rich galaxies.
- Formation of the Bulge from the disk through a bar instability (secular evolution).
- Formation of a Bulge component triggered by the accretion of dwarf galaxies.

- The hope is that elemental abundances will help to differentiate between (at least some of) these scenarios
- Barbuy et al and McWilliam review the current status of observations and chemo/dynamical models

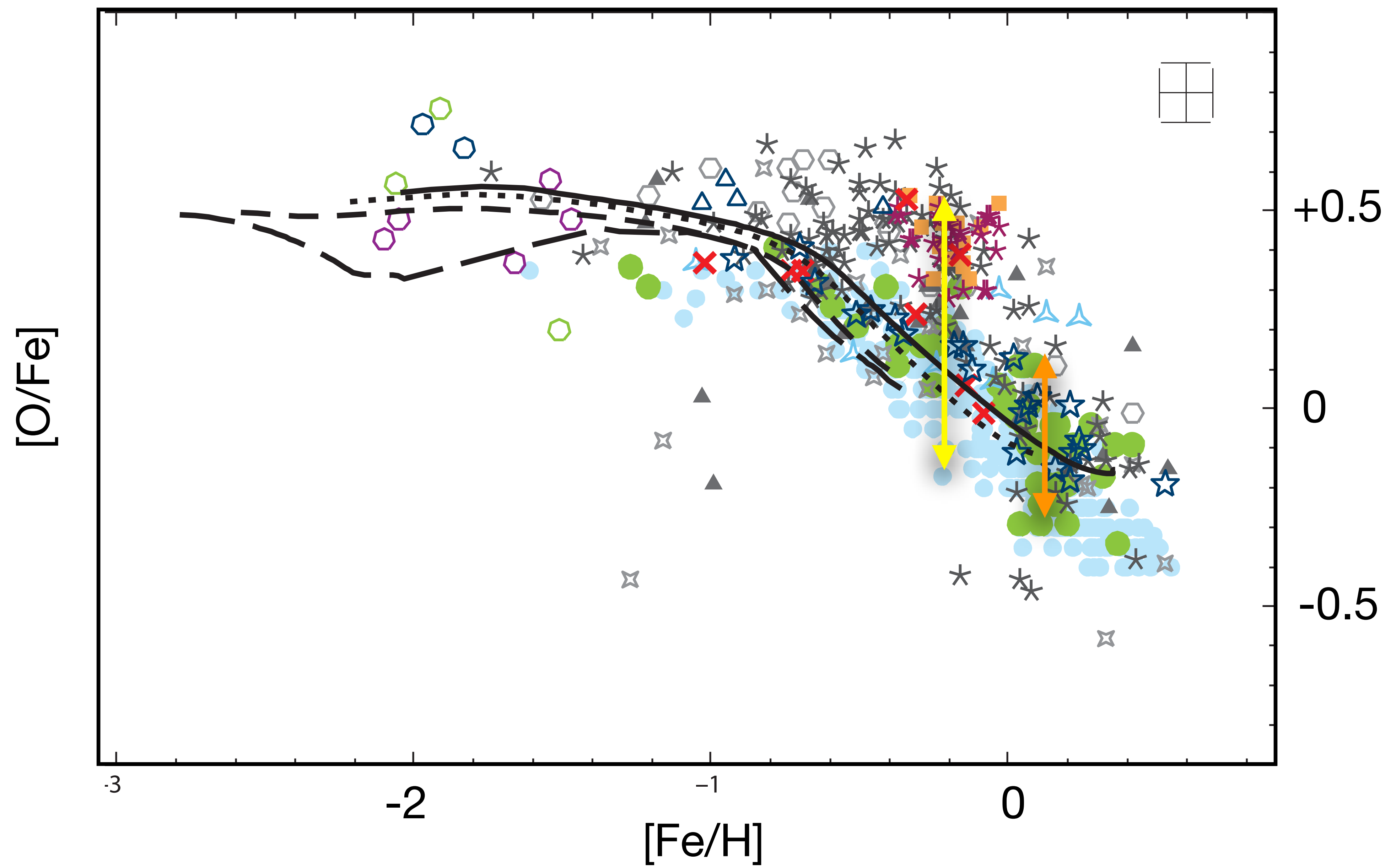
McWilliam 2016 PASA 33 e040
Barbuy, Chiappini, Gerhard 2018 ARA&A 56 223

Elemental abundances in the Galactic Bulge area



McWilliam 2016 PASA 33 e040 (adapted from Matteucci & Brocato 1990)

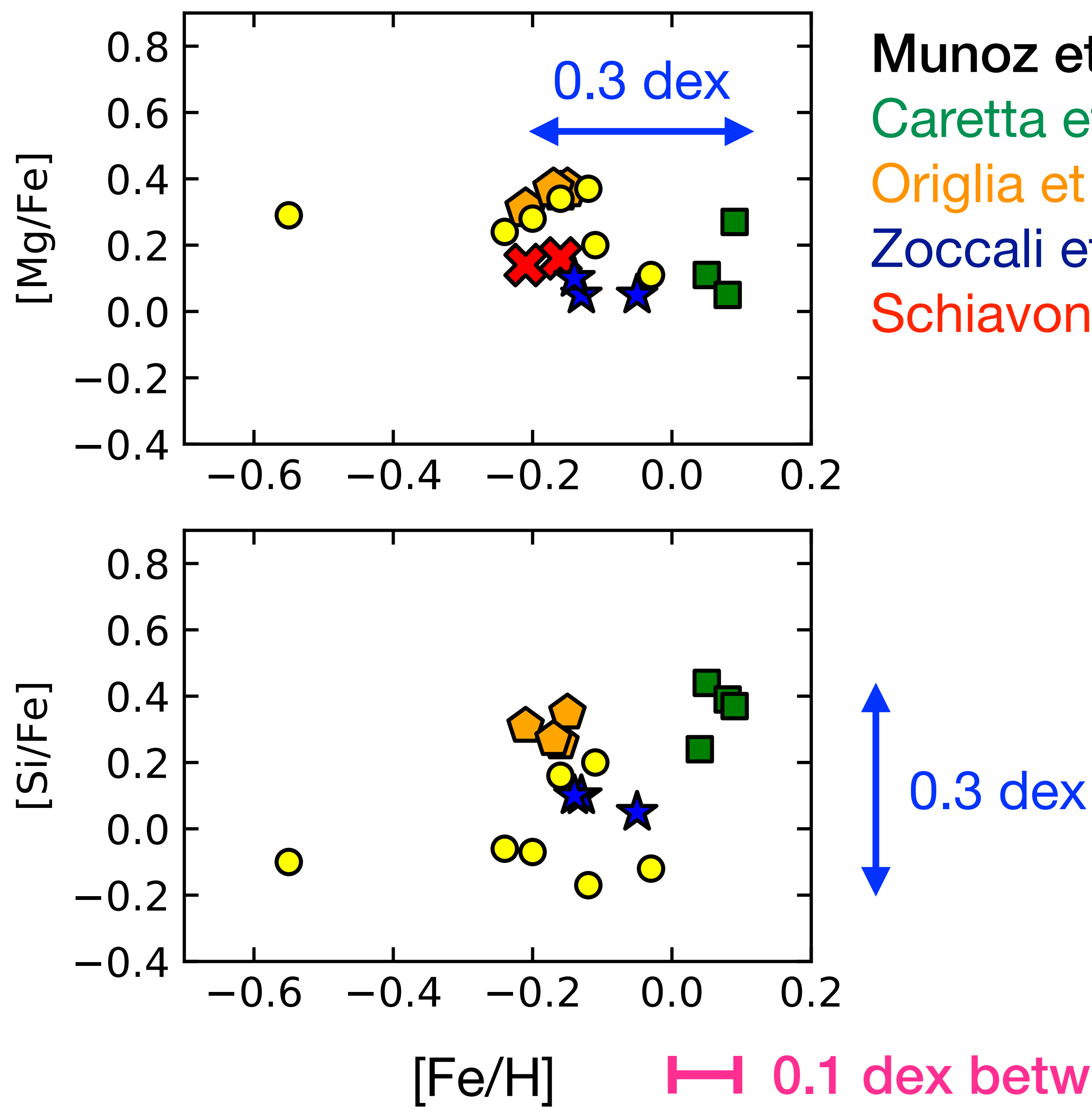
Elemental abundances in the Galactic Bulge area



Barbuy, Chiappini, Gerhard 2018 ARA&A 56 223

Giants are tricky

The example of NGC6528 – one of the most metal-rich globular clusters



Munoz et al 2018 A&A 620 A96
Caretta et al 2001 AJ 122 1469
Origlia et al. 2005 MNRAS 356 1276
Zoccali et al. 2004 A&A 423 507
Schiavon et al. 2017 MNRAS 466 1010

We all do our best but it remains difficult to get consistent results between studies

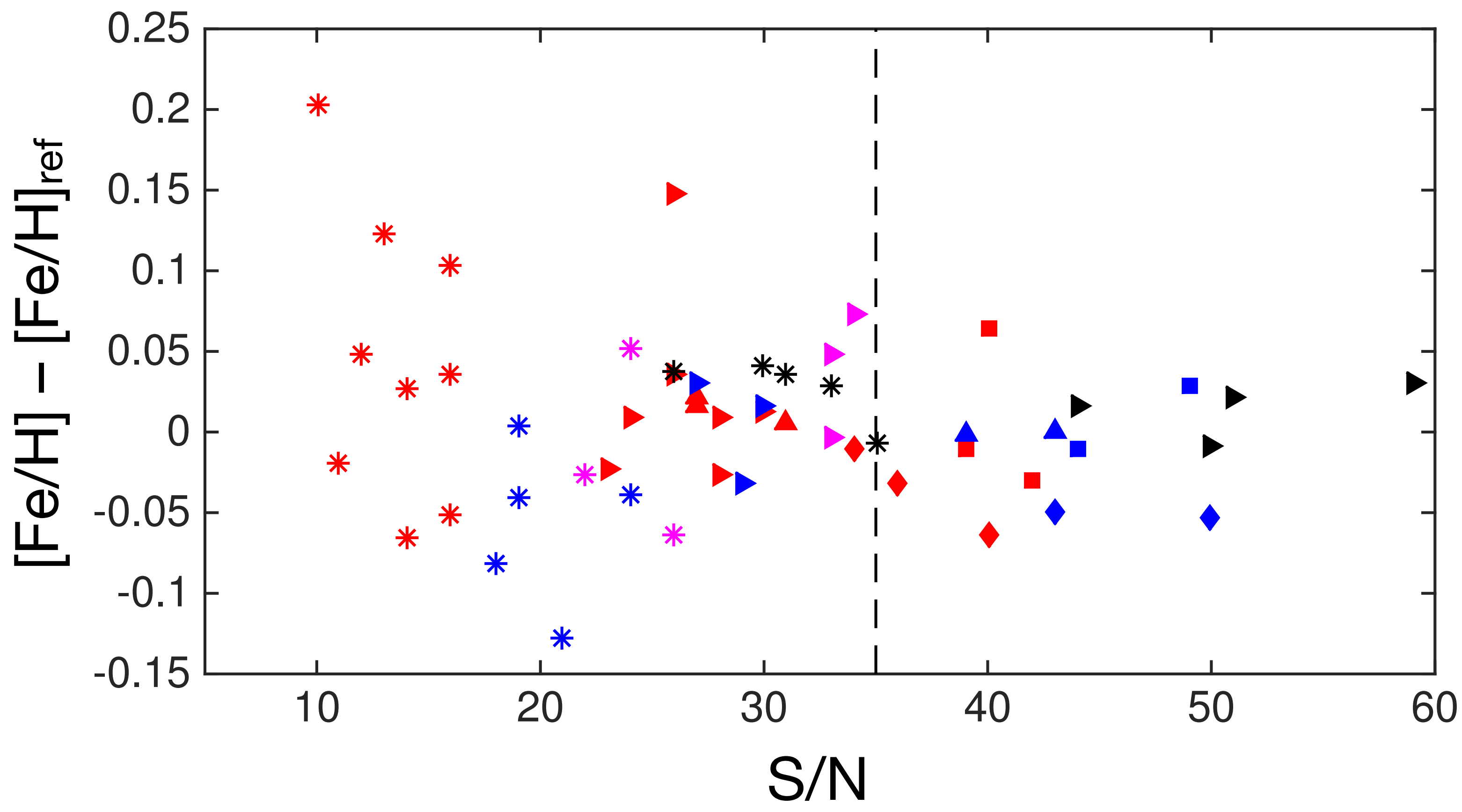
➡ Single "source" is your best option

0.1 dex between methods
Liu, Ruchti, Feltzing, Primas 2017 A&A 601 A31

SNR - so important

Red giant stars in NGC 6528 - each symbol is one star

One, Two, Three exposures combined



- How much of perceived scatter in elemental abundance trends is just low SNR results?

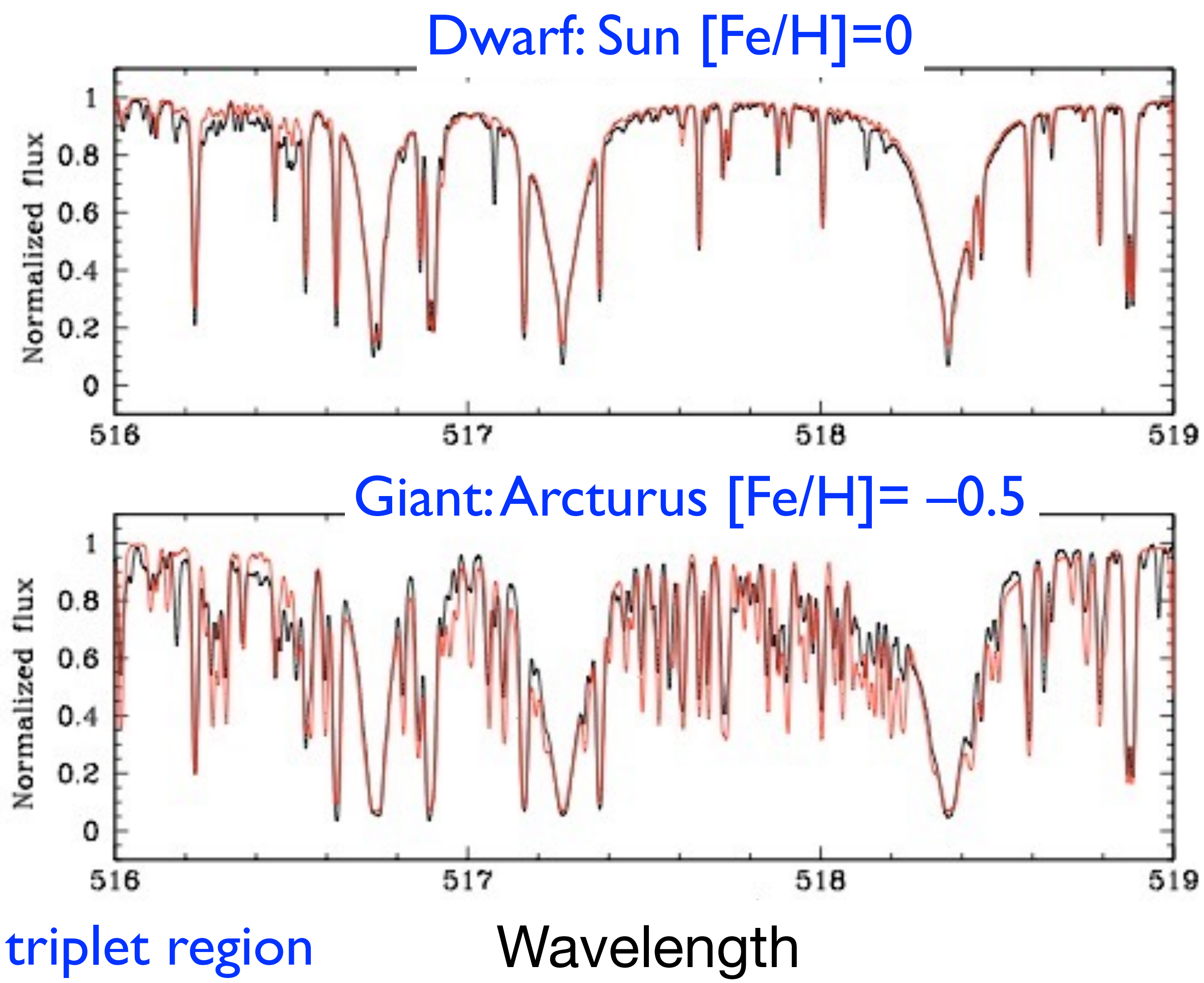
Liu, Ruchti, Feltzing, Primas 2017 A&A 601 A31

Two recent examples

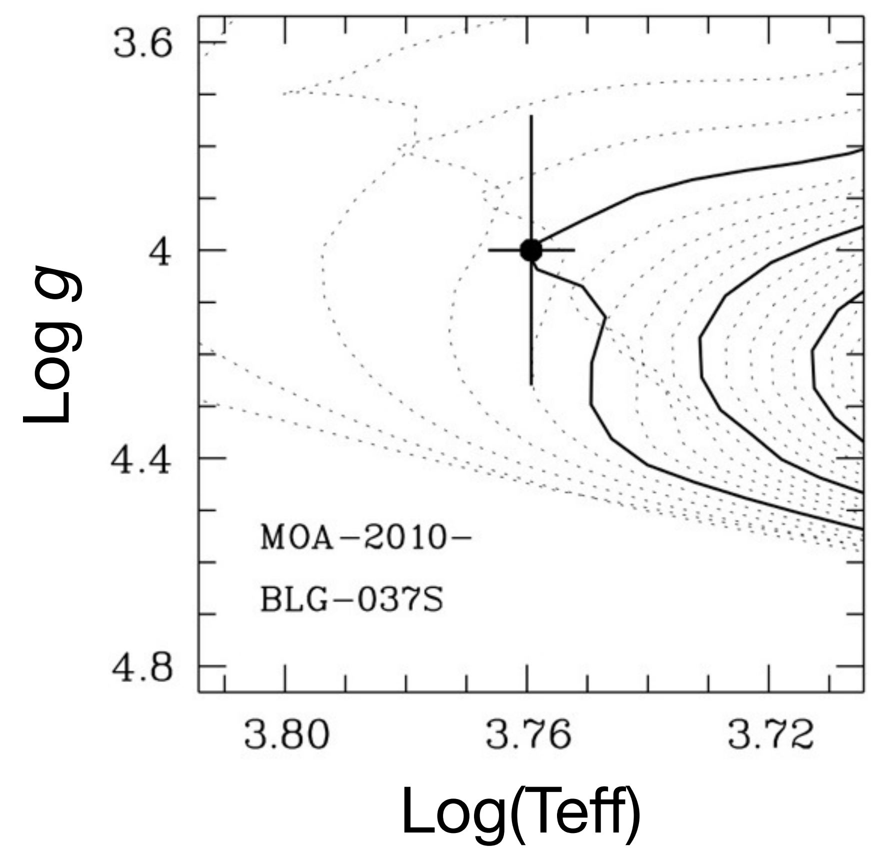
of self-consistent bulge chemical evolution studies

Why dwarf stars?

- Spectra are "easy" to analyse, at least easier than even moderately metal-poor giants.

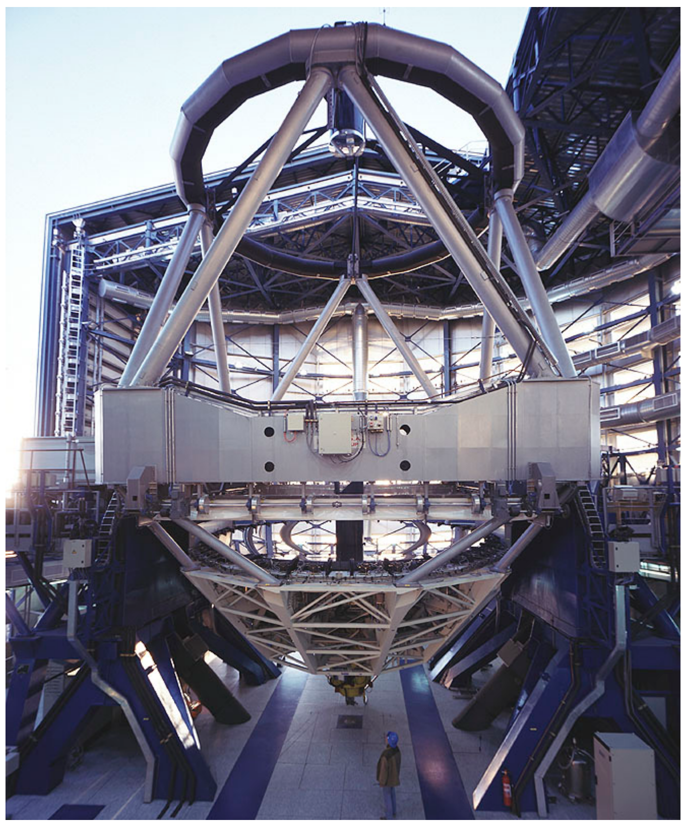


Mg triplet region



- Ages can be "easily" derived.

Target-of-Opportunity program on UVES/VLT
P82 – P94; PI: Feltzing
Keck and Magellan access through collaboration
$20 \leq A_{max} \leq 1000$

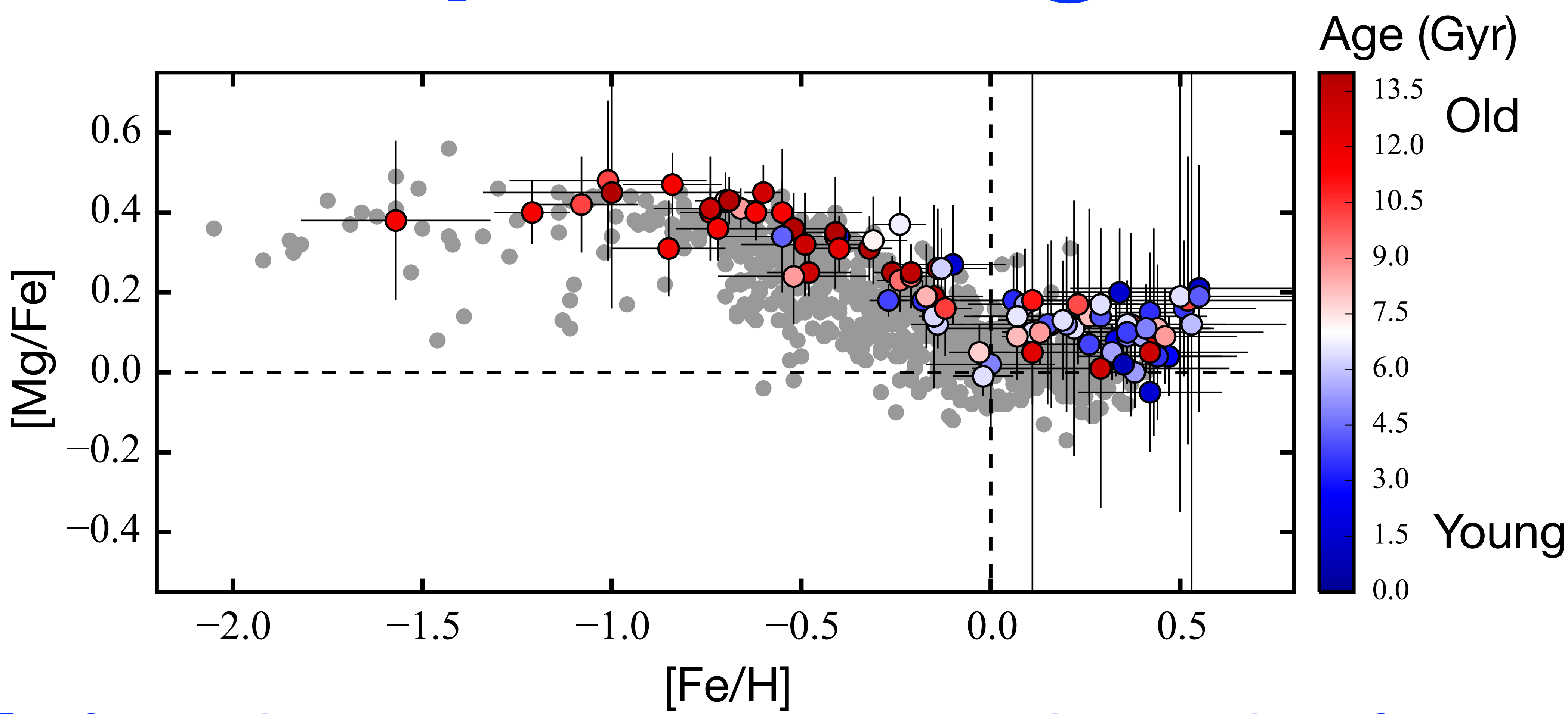


ToO program at VLT with UVES		
Period	Observed	Awarded
P82 (2008)	2	2
P83	7	8
P84	4	4
P85	10	10
P86	2	3
P87	10	10
P88	3	4
P89	15	15
P90	5	5
P91	15	15
P92	4	5
P93	8	8
P94 (2014)	5	5
Total:	**88**	**94**

Successful analyses	
Keck	6
Magellan	10
VLT	75
Total:	**91**

$V_{un\text{-}\mu}$ ~19-20

μ-lensing



- Self-consistent comparison between bulge dwarf stars and solar neighbourhood stars
- Bulge fits upper envelope of thick disk
- Careful studies of giants have shown the same

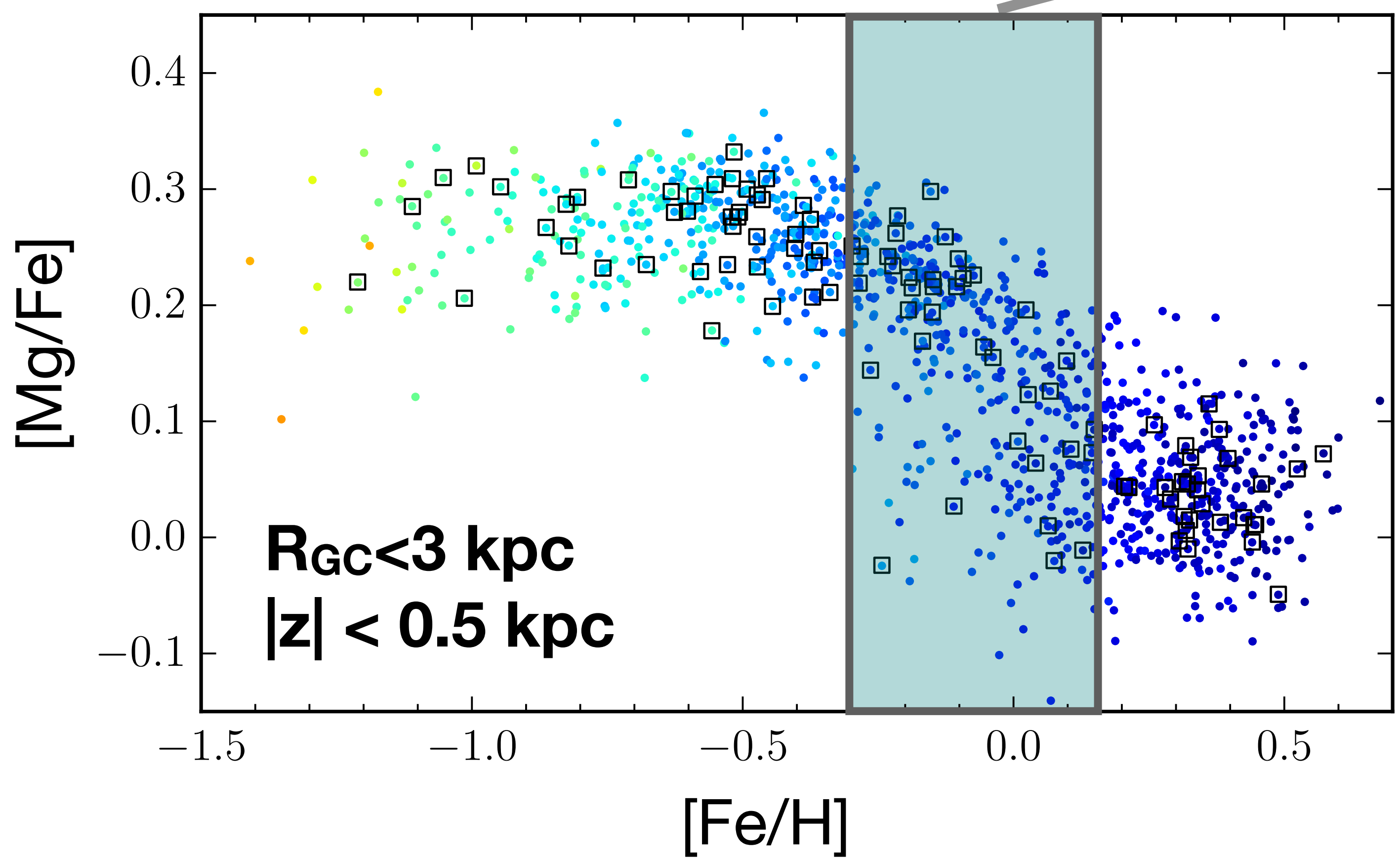
Bensby et al. 2017 A&A <u>605</u> A89 **e.g. Jönsson et al. 2017 A&A <u>598</u> A101**

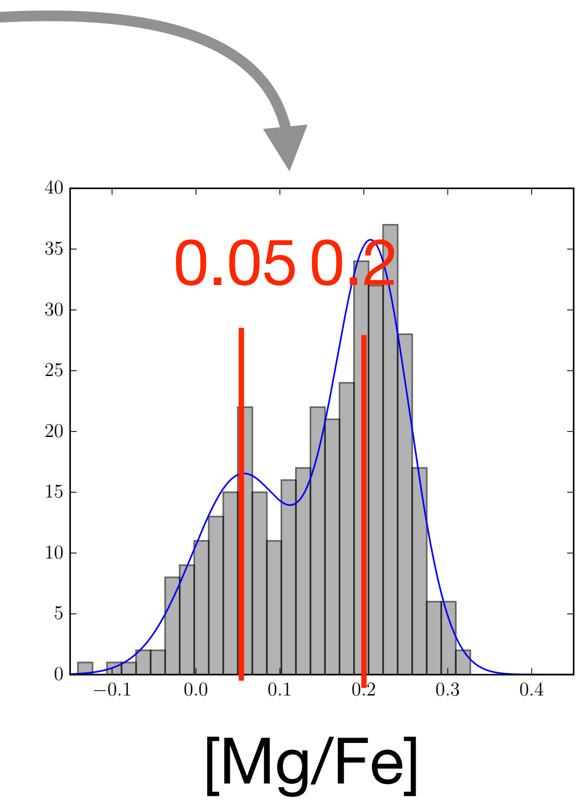
Giants from APOGEE

NIR spectra

Two bulge sequences?

R_{GC}<3 kpc and |z| < 0.5 kpc



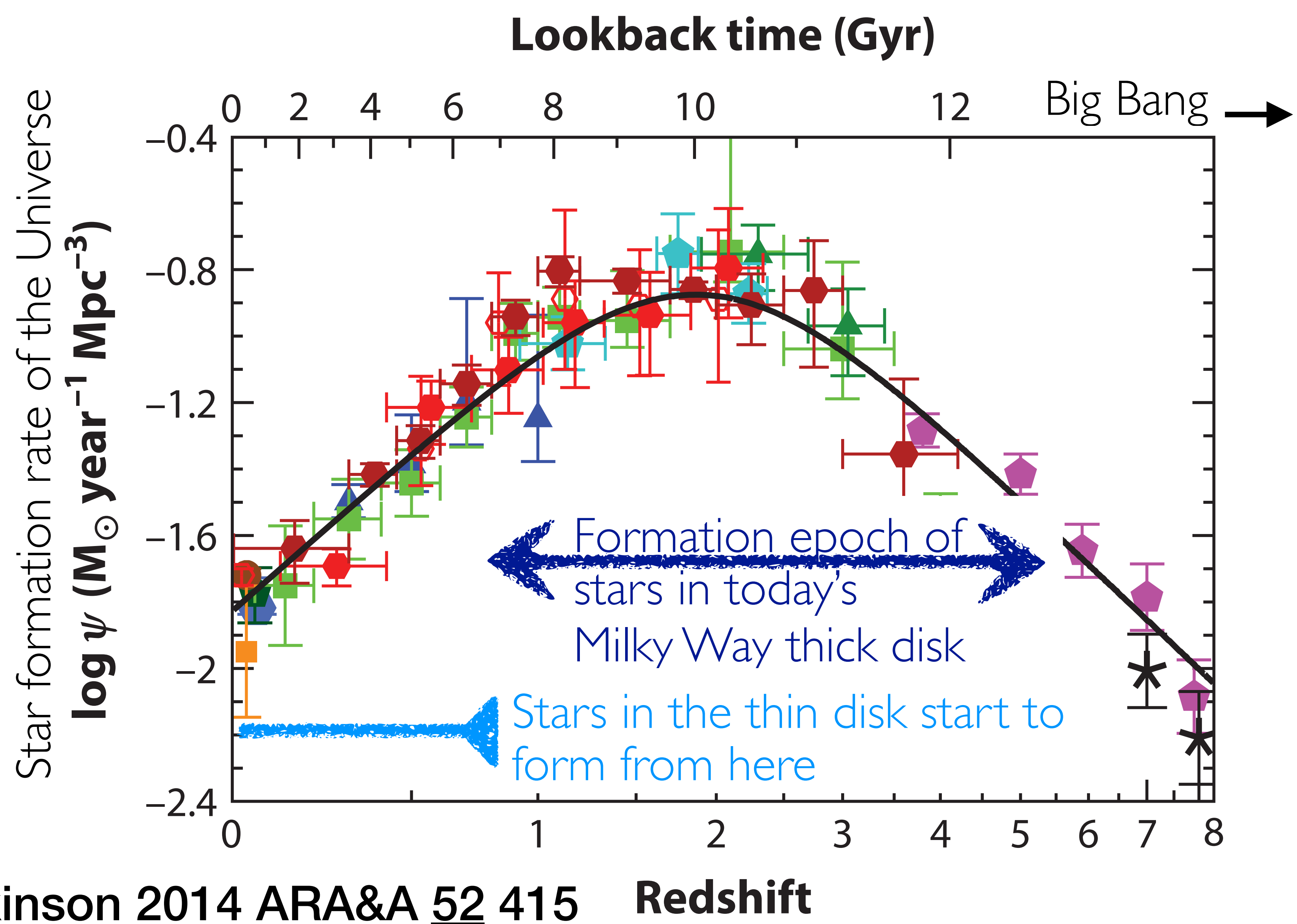


- High-alpha as expected
- Second sequence - p.m. indicate associated with bar
- Different ages? Compare μ-lensed stars (?)

Rojas-Arriagada et al 2019 arXiv:1905.01364

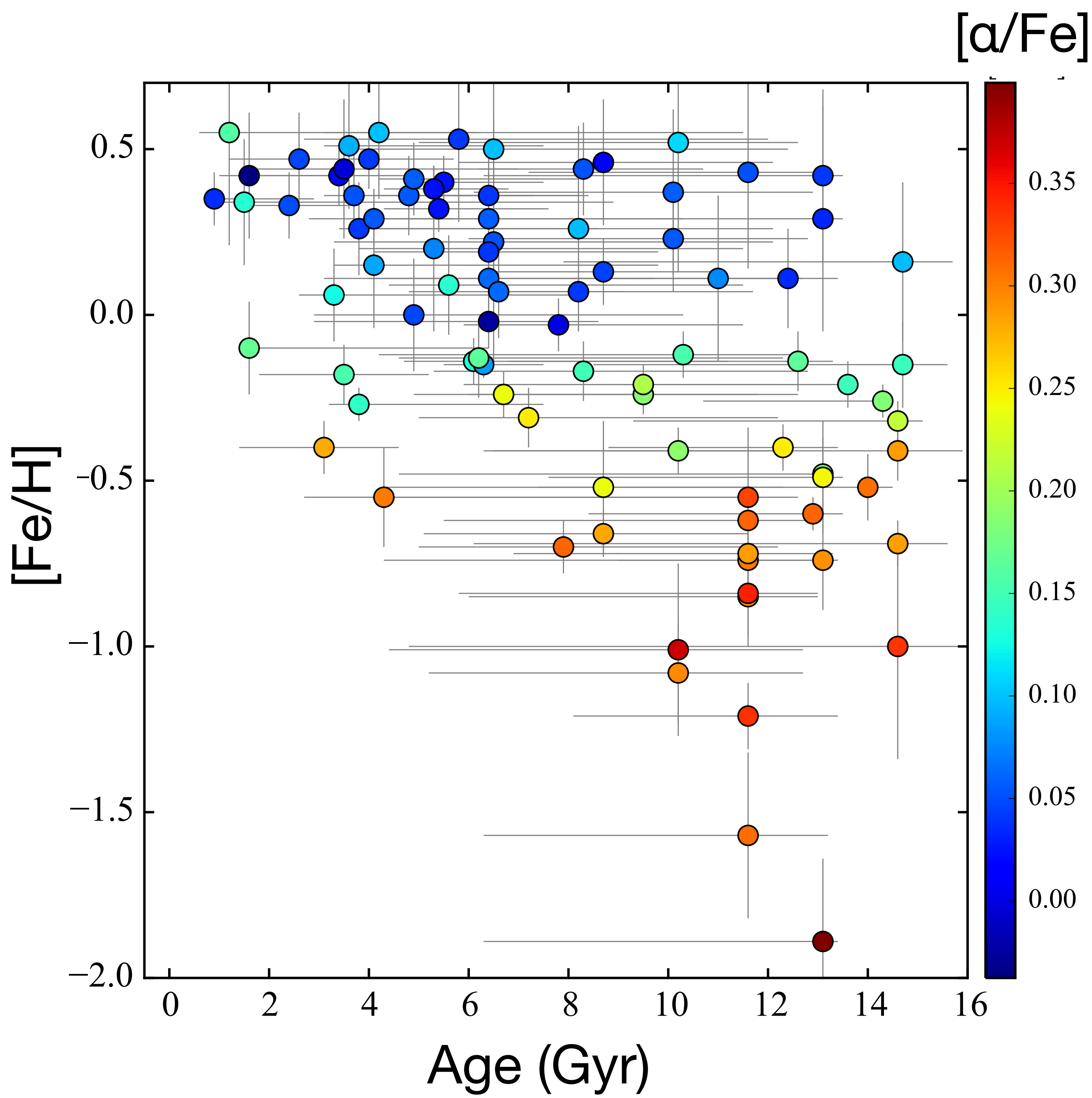
When do bulge stars form?

When do bulge stars form?



Madau & Dickinson 2014 ARA&A 52 415
Bensby et al. 2014 A&A 562 A71
Barbuy, Chiappini, Gerhard 2018 ARA&A 56 223

µ-lensed ages



Bensby et al. 2017 A&A 605 A89 but see Renzini et al. 2018 ApJ 863 16

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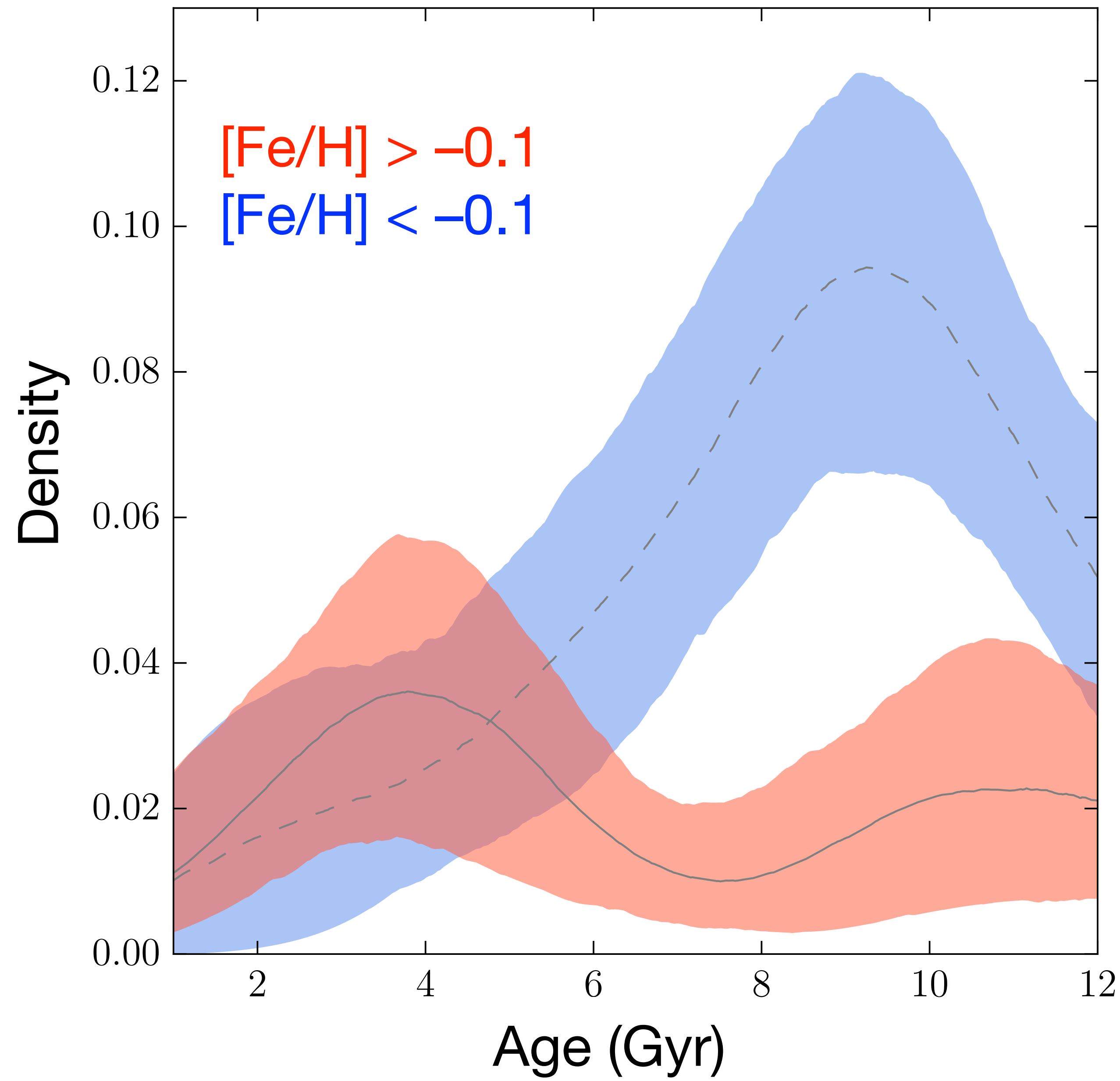
C/N ages for APOGEE



74 stars in Baade's window

C/N-ages might be underestimated for old stars

Schultheis et al. 2017 A&A 600 A14

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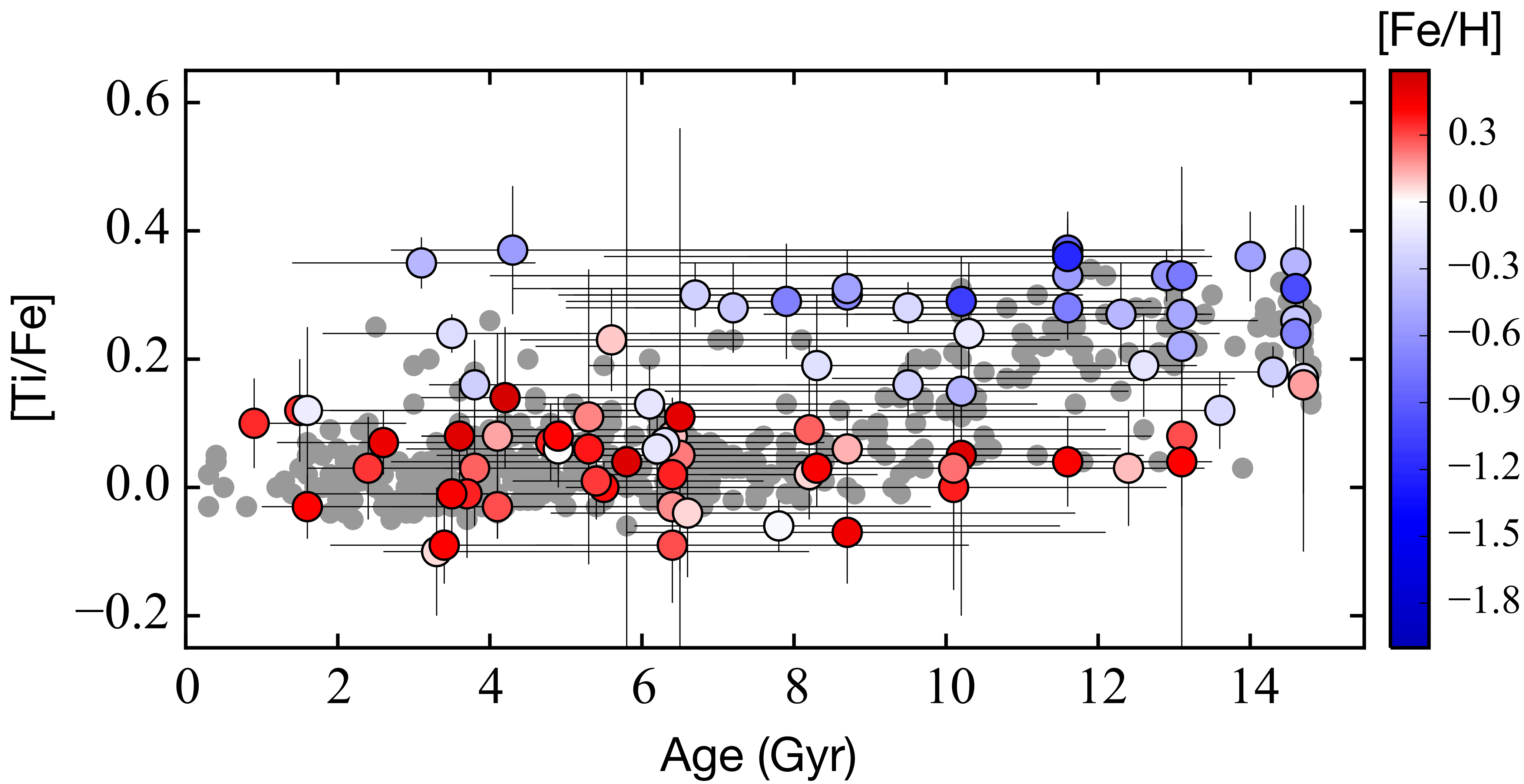
μ-lensed ages



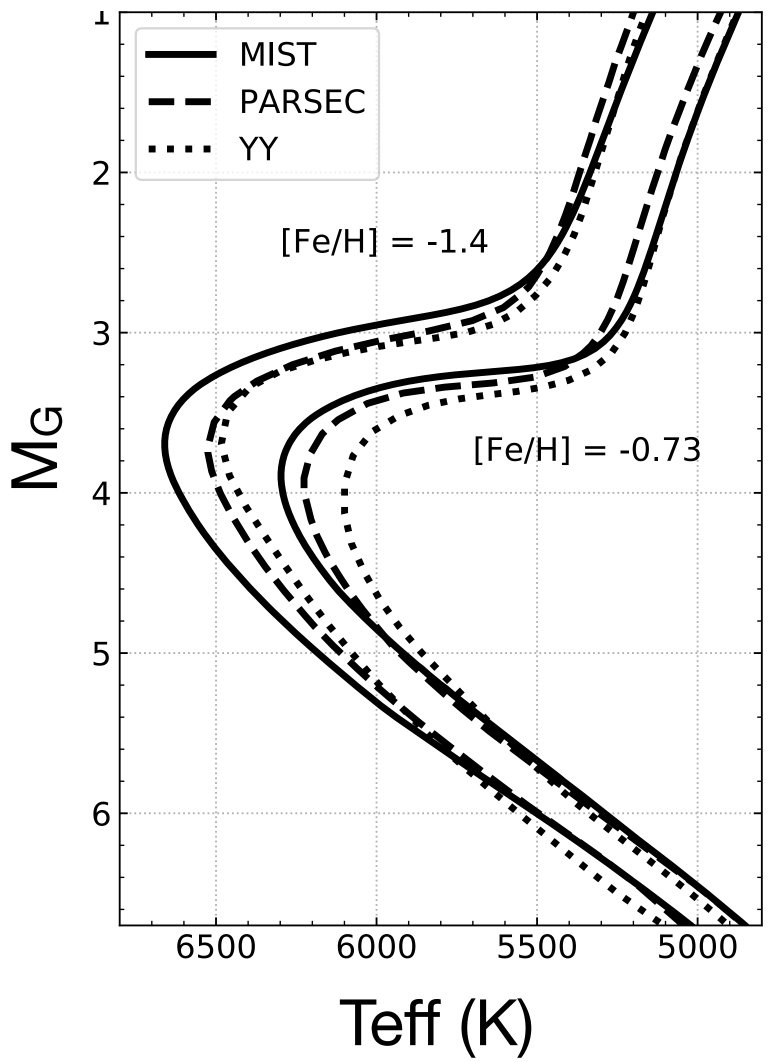
- Consistent with local results – some young stars could be blue stragglers, but not all young stars are blue stragglers

Chiappini et al 2015 A&A 576 L12, Martig et al 2015 MNRAS 451 2230
But see Jofré et al 2016 A&A 595 A60

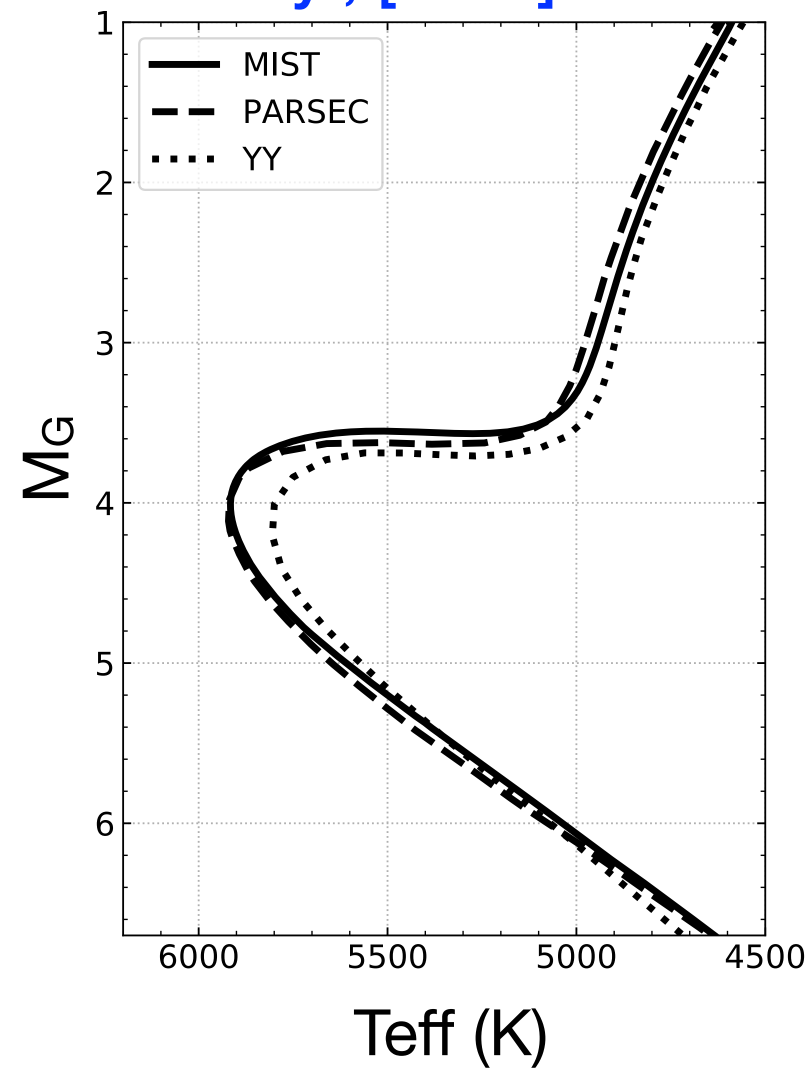
Bensby et al. 2017 A&A 605 A89

Check the models

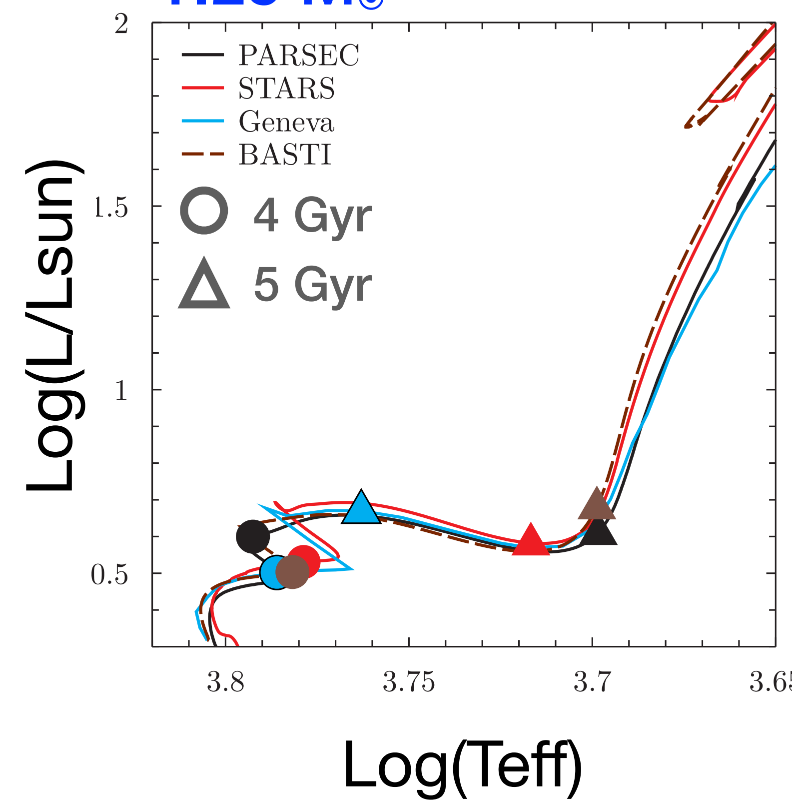
10 Gyr, [Fe/H]=-1.4, -0.73



10 Gyr, [Fe/H]=-0.2



1.25 $M_\odot$



- How well do we understand stellar evolution? Should we not spend more effort on this

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Summary

- Much progress in the observational picture - but we need to remain observant to not over interpret the data (ie interpreting the noise as signal)
- Compare only elemental abundance trends of same type of stars
- Avoid low SNR
- Gaia has already started to change also this field future releases will add much more
- Upcoming surveys such as APOGEE-S and 4MOST will add further depth to the study of the Bulge region