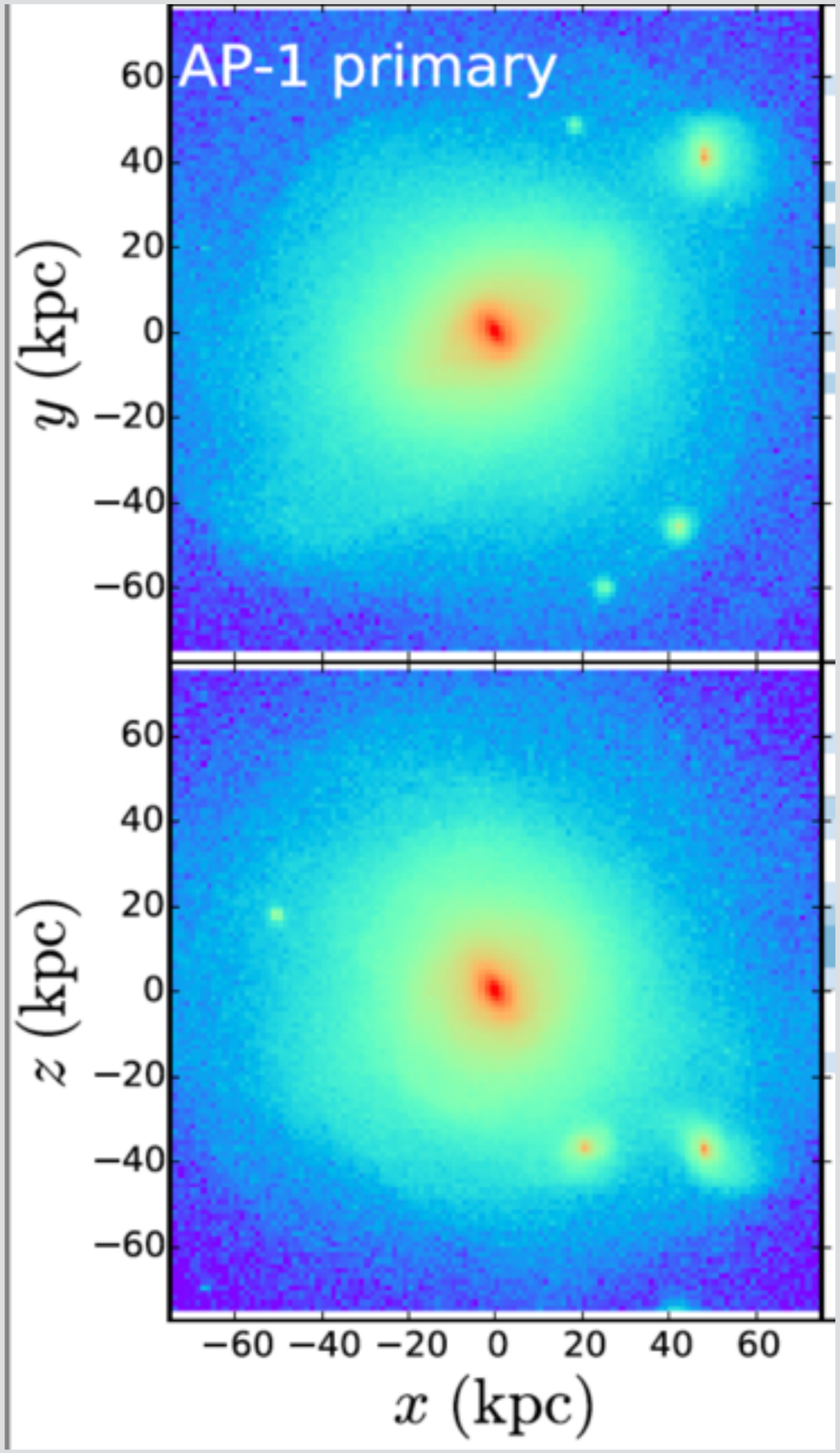
Spectroscopy of stars in the CFHT Pristine survey

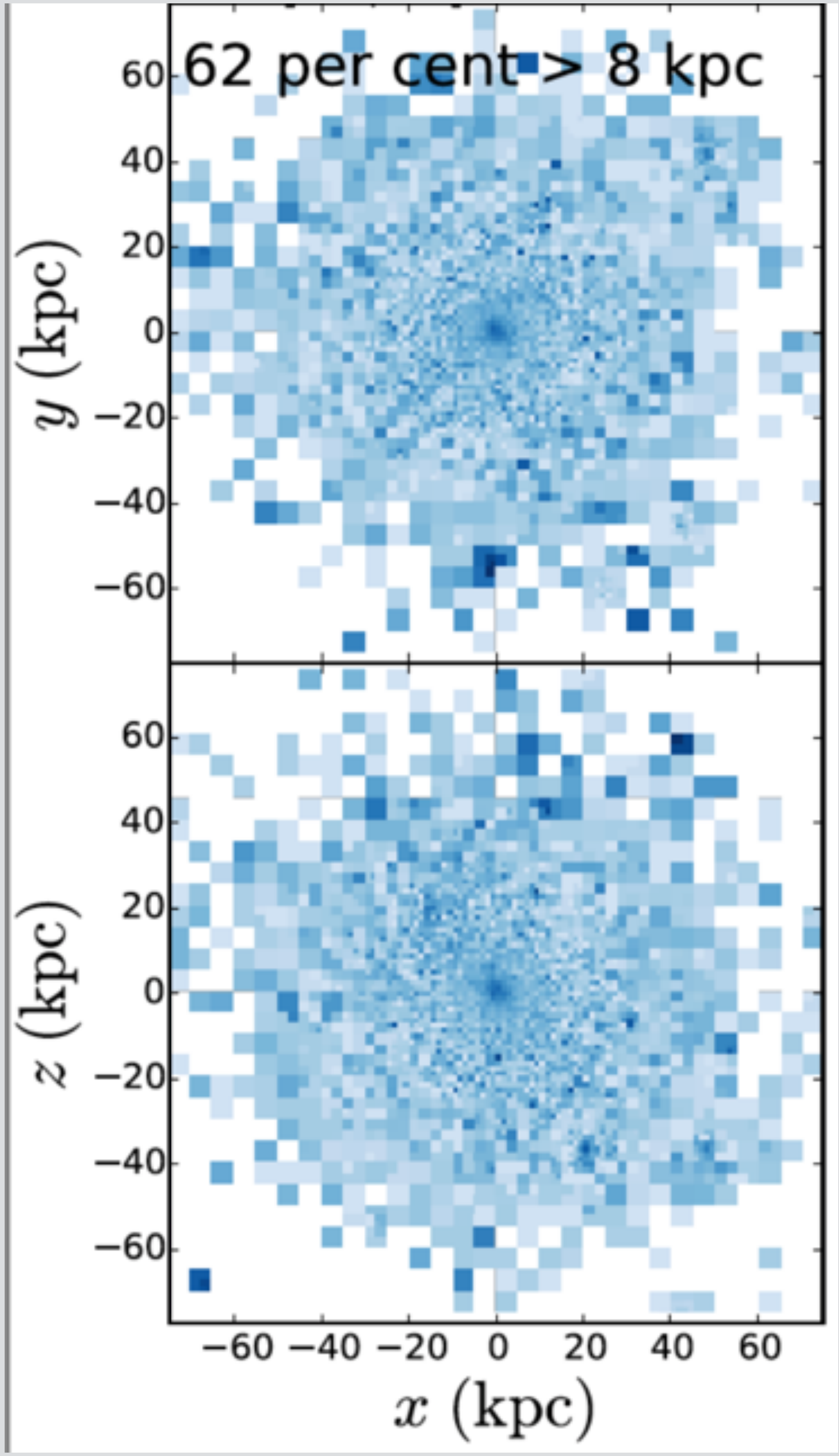
Kim Venn
Univ. of Victoria

PI: Else Starkenburg & Nicolas Martin. Co-Is: David Aguado, Carlos Allende Prieto, Edouard Bernard, Piercarlo Bonifacio, Elisabetta Caffau, Raymond Carlberg, Patrick Côté, Morgan Fouesneau, Patrick François, Jonay Gonzales Hernandez, Stephen Gwyn, Vanessa Hill, Rodrigo Ibata, Pascale Jablonka, Nicolas Longeard, Julio Navarro, Alan McConnachie, Ruben Sanchez-Janssen, Kim Venn, Kris Youakim e.g., Starkenburg et al. 2017



Analysis of the APOSTLE hydrodynamical simulations of Local Groups:

shows the location of stars, and lots of substructures e.g., Starkenburg et al. 2017



Further, examining the location of the oldest stars (<0.8 Gyr after Big Bang) shows lots in the outer parts of the Galaxy (>8 kpc).

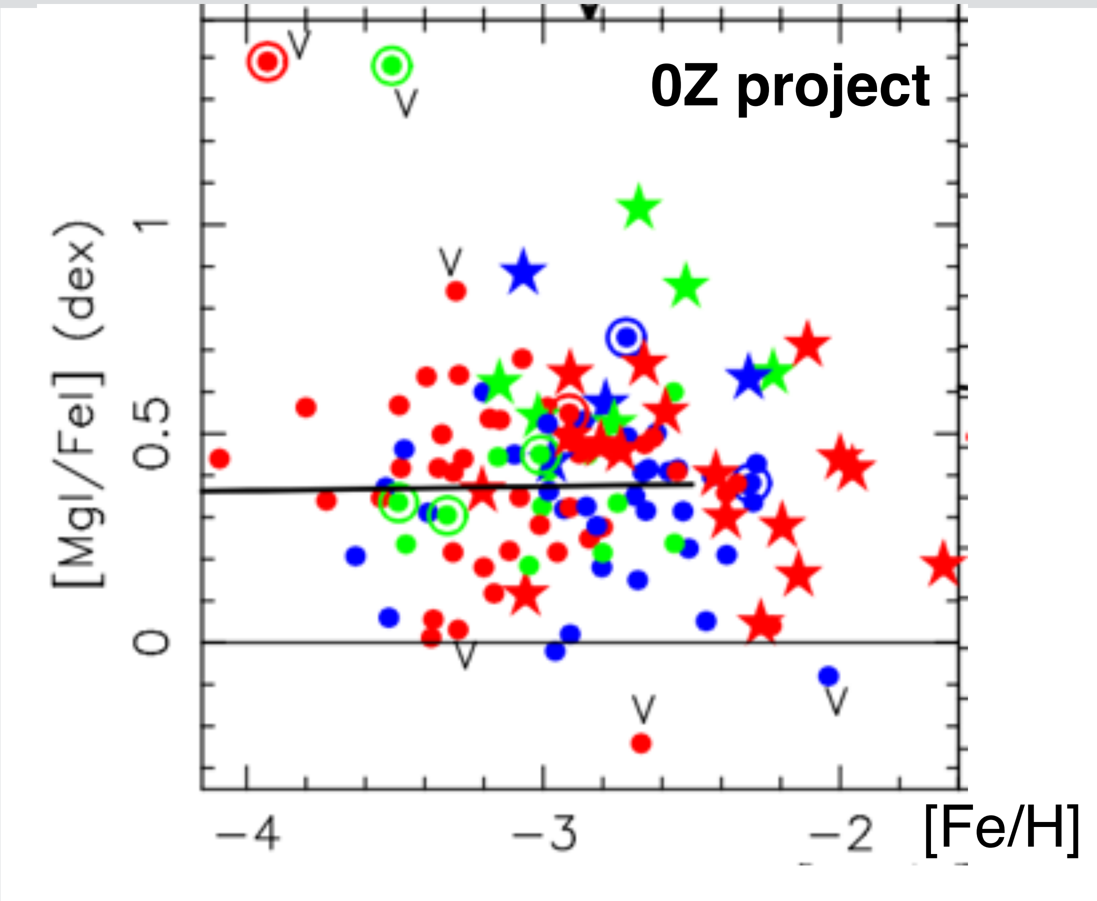
colour coded by % of old stars, which also have [Fe/H] < -2.5

Searching for Metal Poor Stars

HK and HES surveys

- Use prism techniques and HR spectra to study EMP stars.

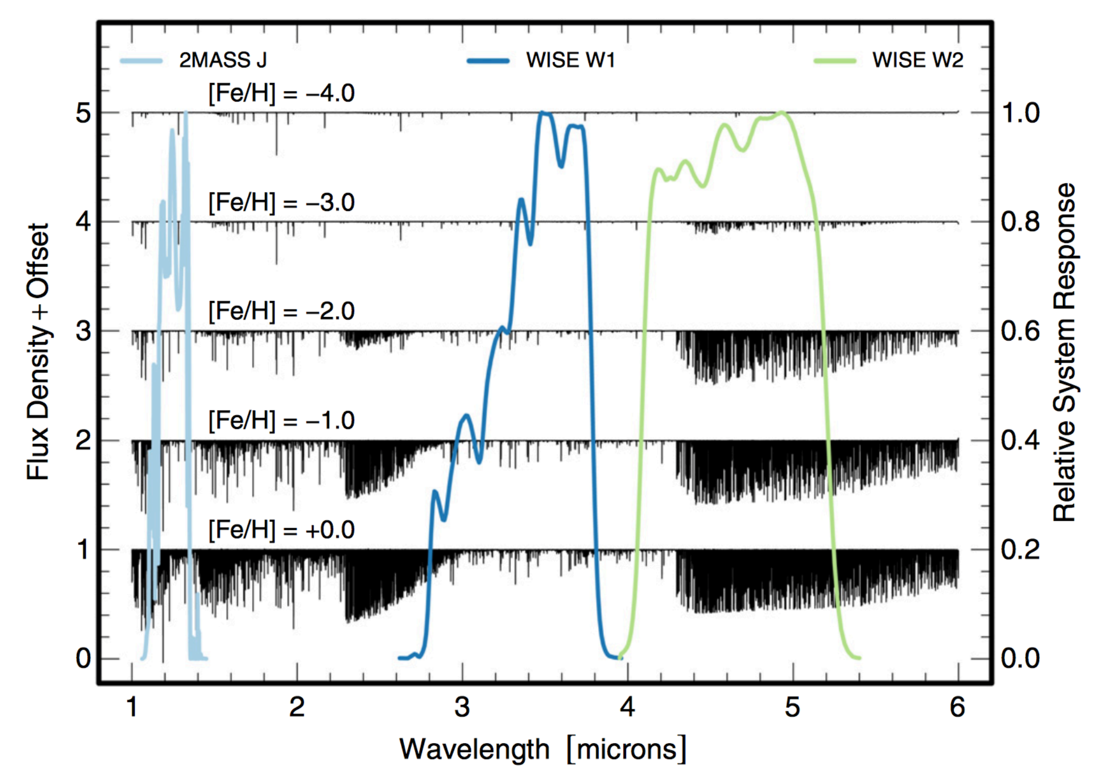
(e.g., Beers et al., 1985, Christlieb et al., 2002, Cohen et al. 2008, 2013)



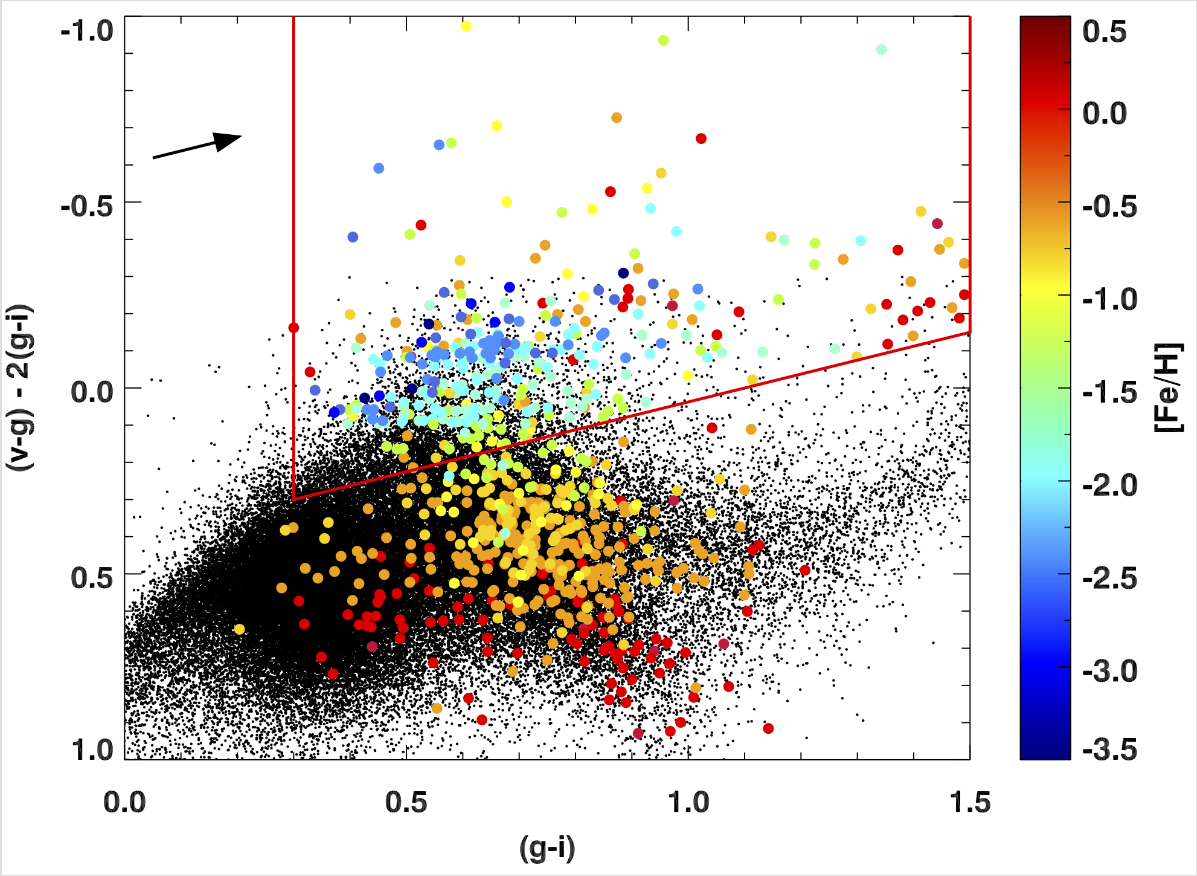
Use photometry

- Combination of bands all over the spectrum, including the WISE infrared bands for bright stars.

(Schlaufman & Casey 2014, Casey & Schlaufman 2015)

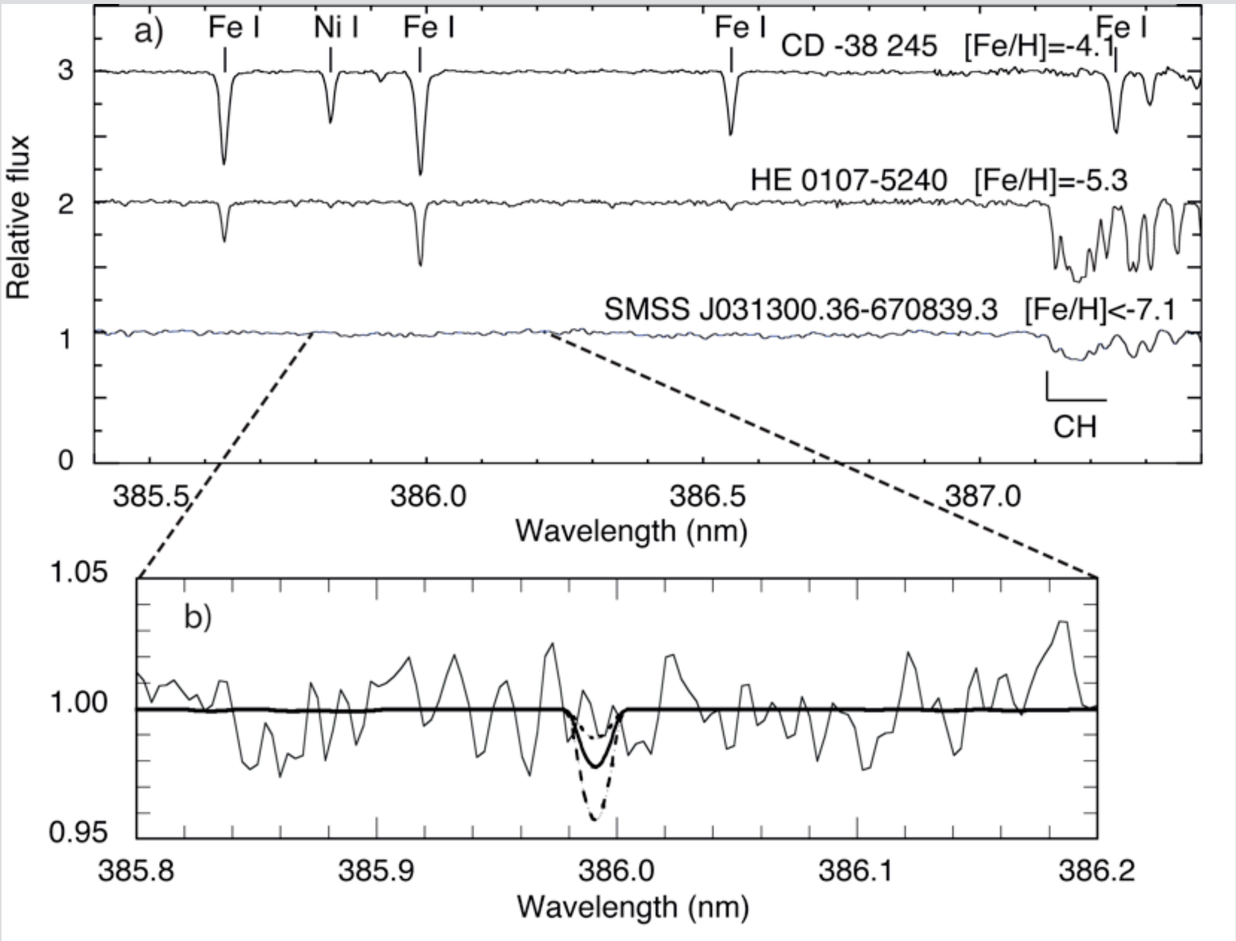


The Ca H&K surveys



Southern Hemisphere – *Skymapper*

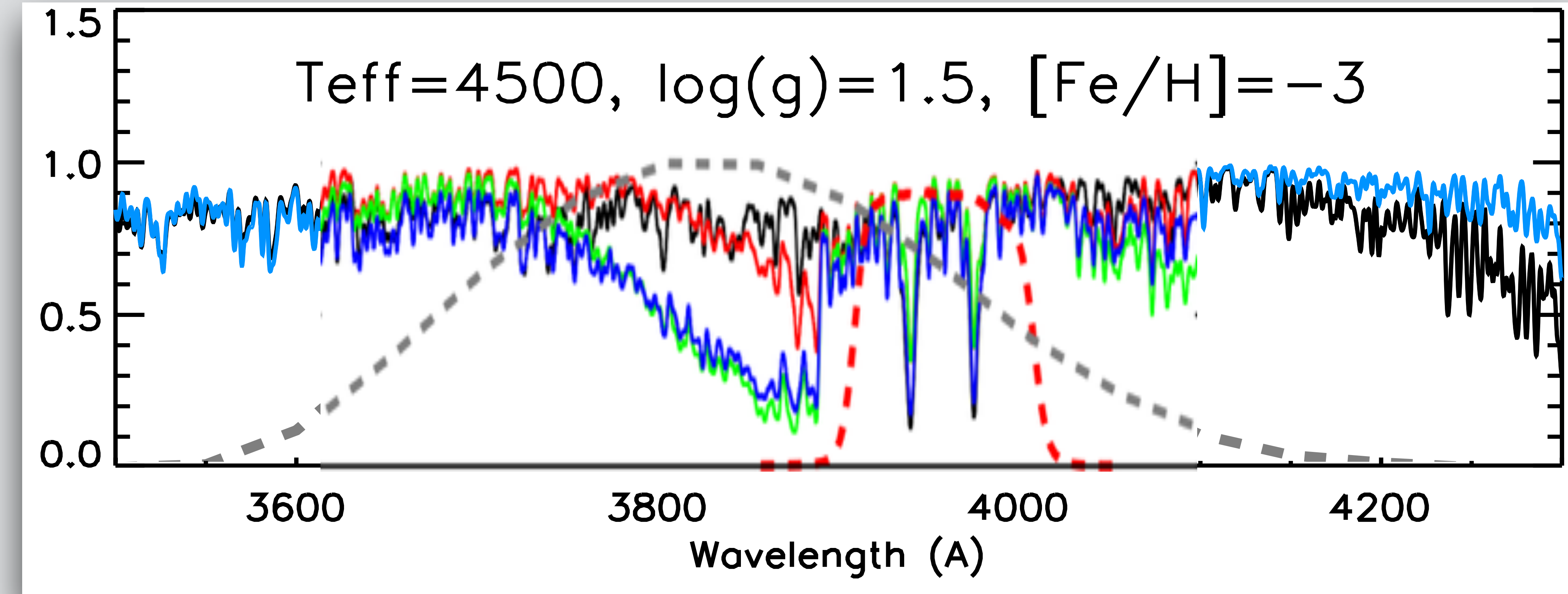
- 20,000 deg^2
- with ugriz filters
- Search for metal-poor stars, including in the Bulge (*Howes et al. 2015*)



AAO and Magellan/MIKE spectra

- Found [Fe/H] < –7 star! *(Keller et al. 2014)*

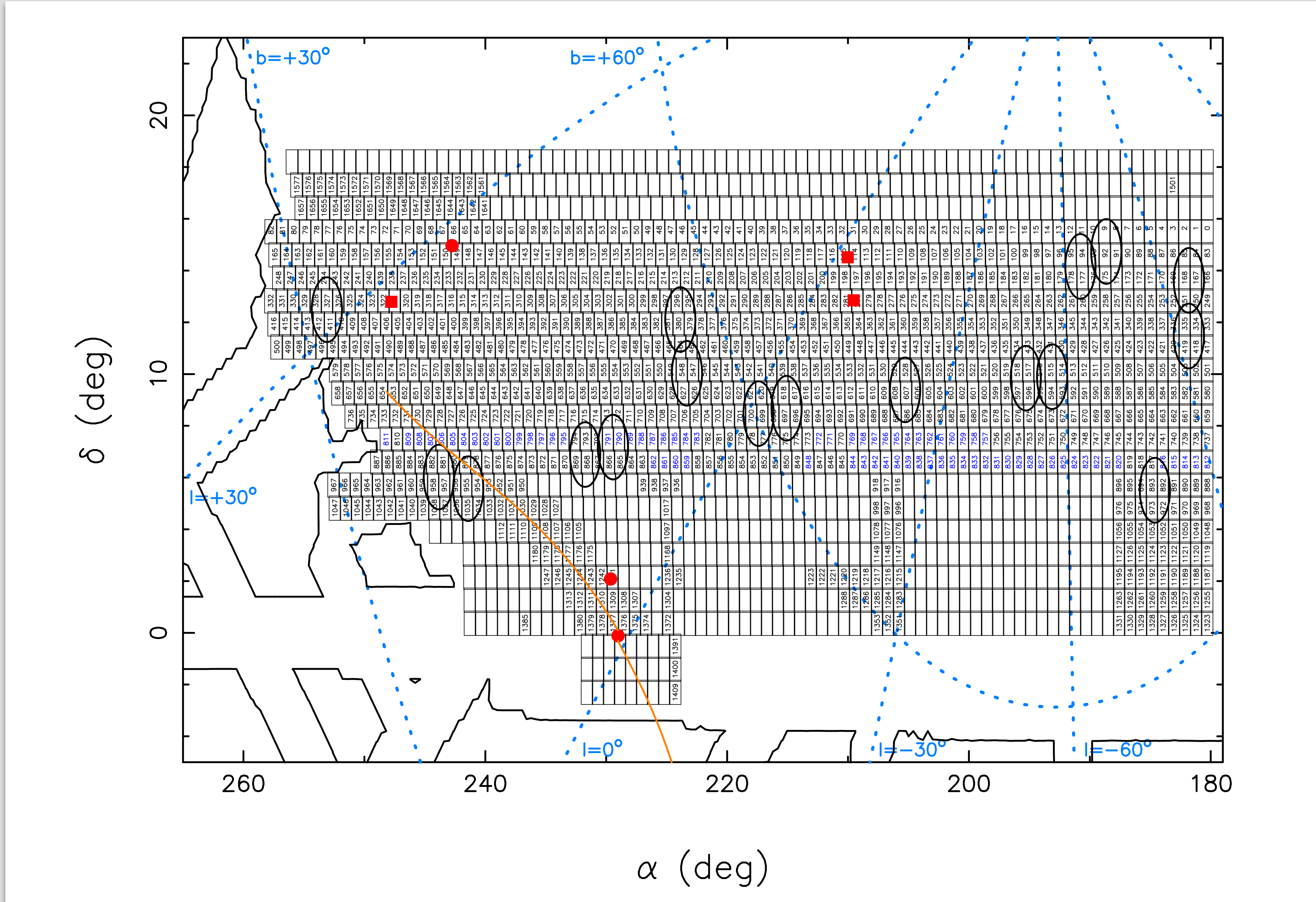
New Ca H&K filter at CFHT



[C/Fe] = +2 [C+O/Fe] = +2 [C+N+O/Fe] = +2

Pristine filter is more narrow than Skymapper filter, and less biased by Carbon

The Pristine CFHT Ca H&K survey



Starkenburg et al. 2017

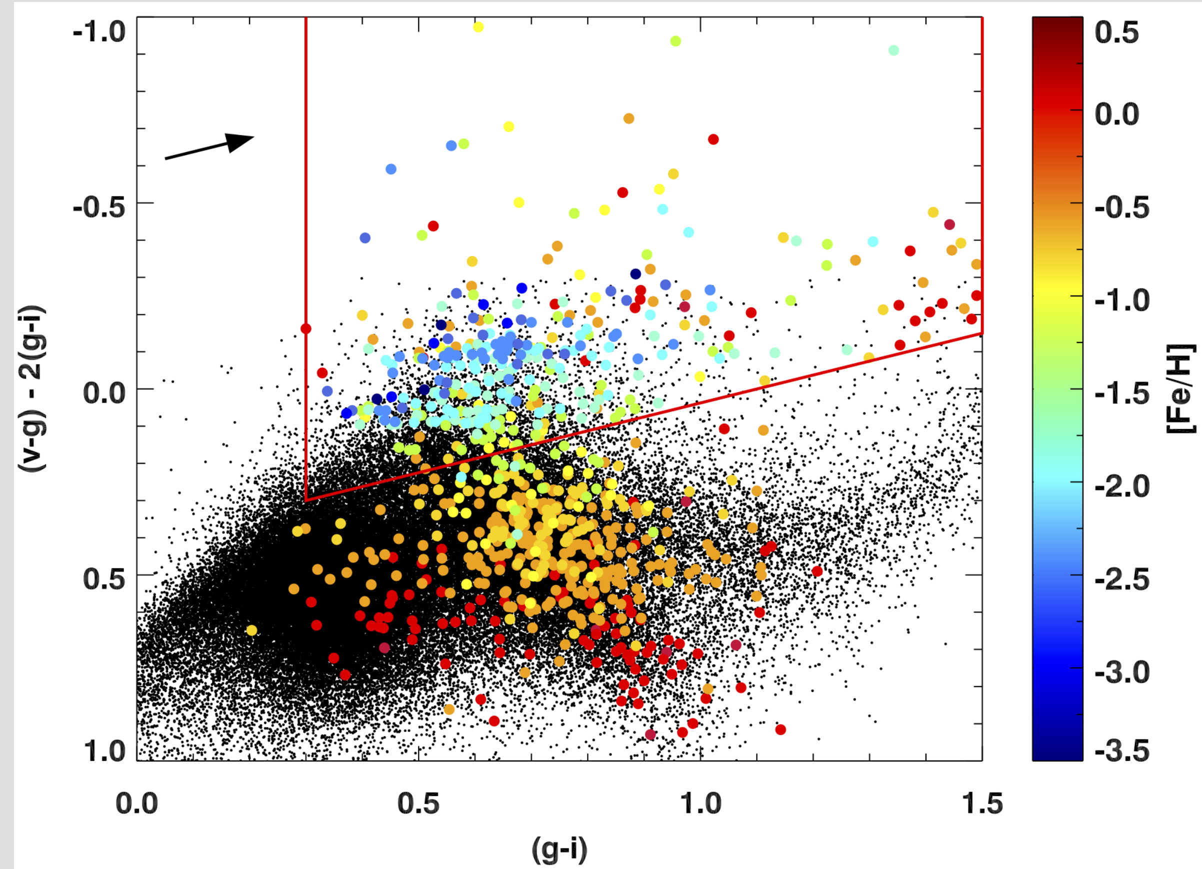
The Ca H&K surveys

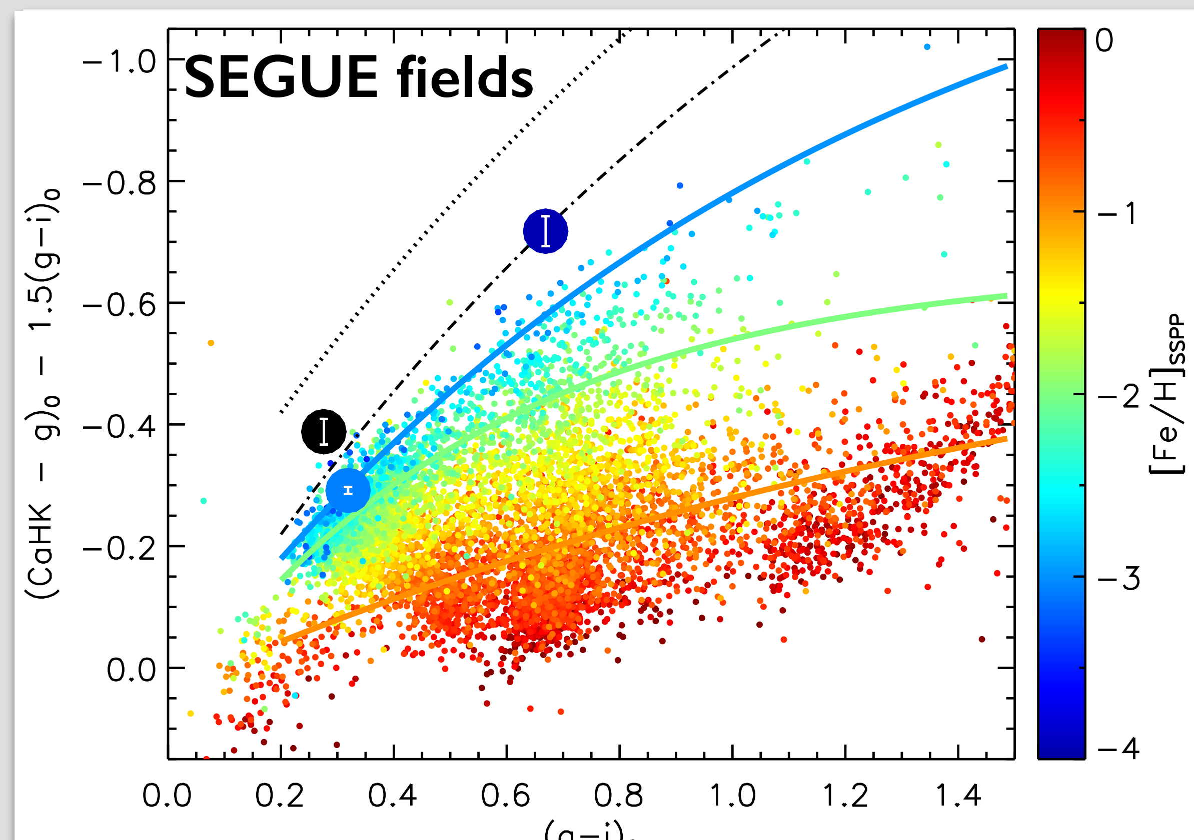
Southern Hemisphere – *Skymapper*

- All 20,000 deg^2, can reach the bulge with *ugriz* filters
- Found [Fe/H] < –7 star!

Northern Hemisphere – *Pristine*

- ~1,000 deg^2 (→ 3,000 deg^2), with PanStarrs *gri* photometry
- SDSS-SEGUE metallicities
- Cleaned of contaminants





Starkenburg et al. 2017; Youakim et al. 2017

Pristine: Medium Resolution Spectroscopy

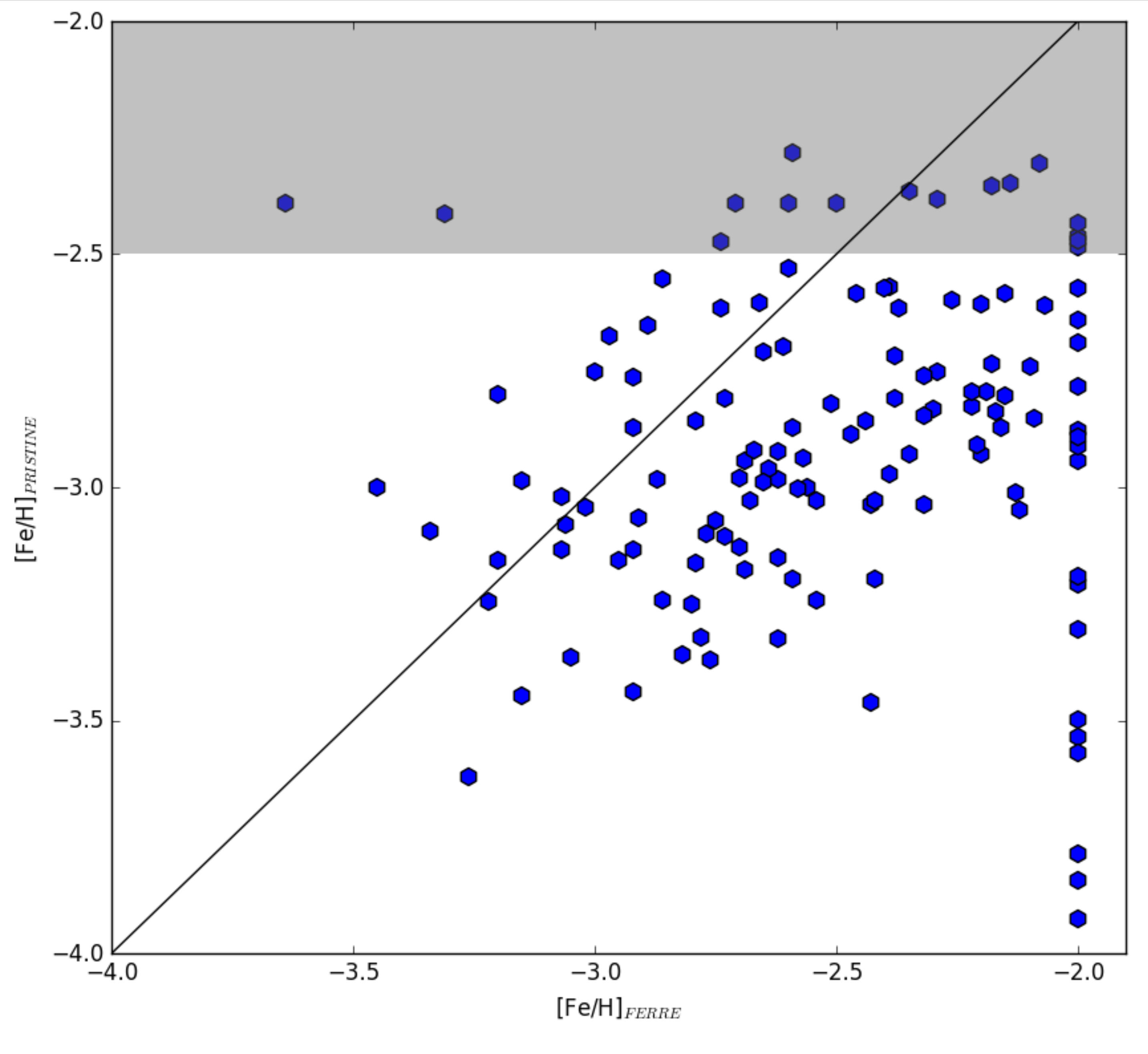
- 15 < V < 17
- ~200 stars with R~2500
- FERRE spectral fitting to CaH&K, G-band, Mgb …

When selecting $[Fe/H]_{PRISTINE} < -3$ (out of 62 stars) :

18% have [Fe/H] < -3.0

40% have [Fe/H] < -2.5

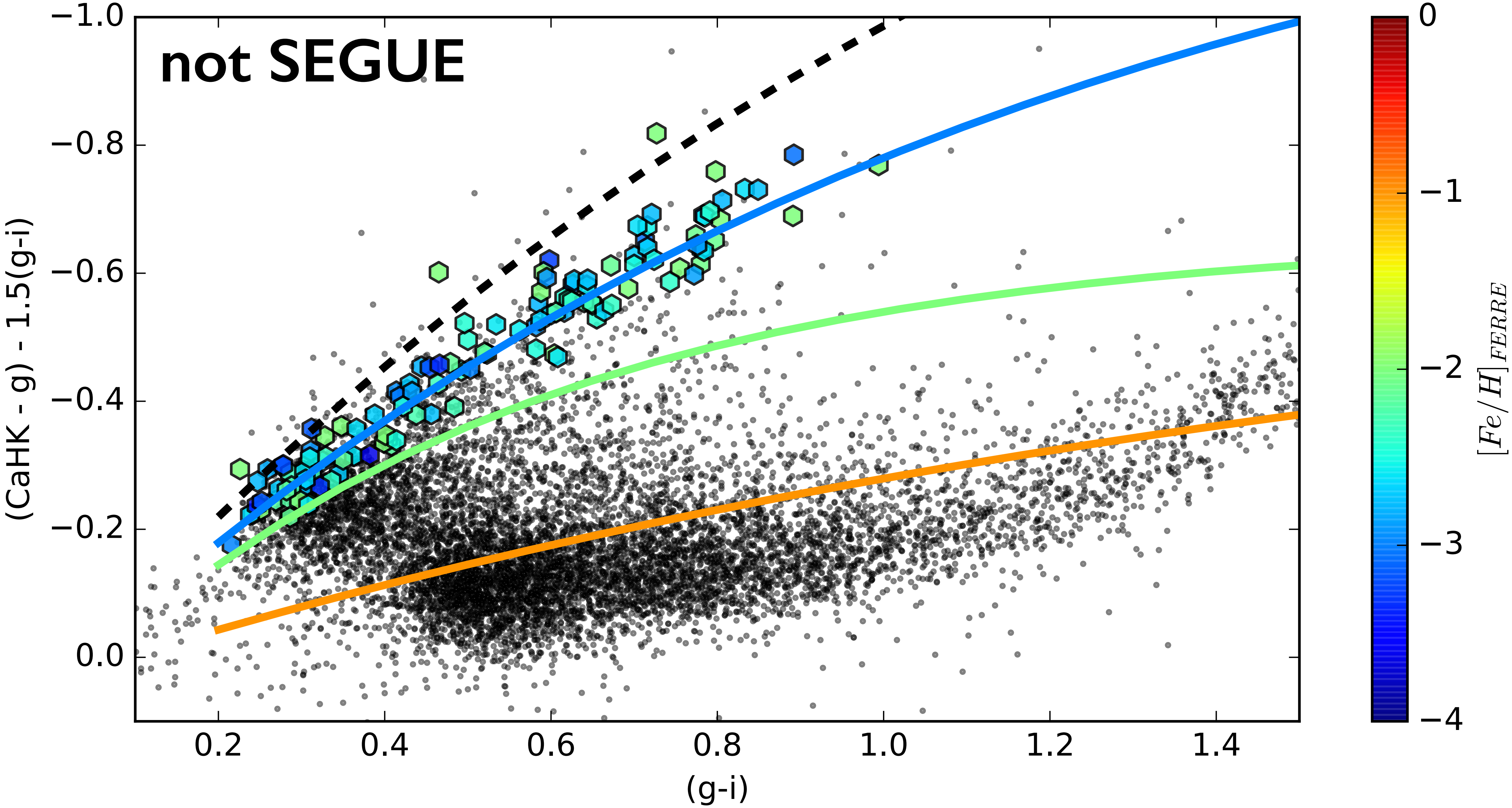
10% have [Fe/H] < -2.0



Youakim et al. 2017

Pristine: Medium Resolution Spectroscopy

~18% with [Fe/H] < -3, and ~70% with [Fe/H] < -2



Youakim et al. 2017

Pristine: High Resolution Spectroscopy

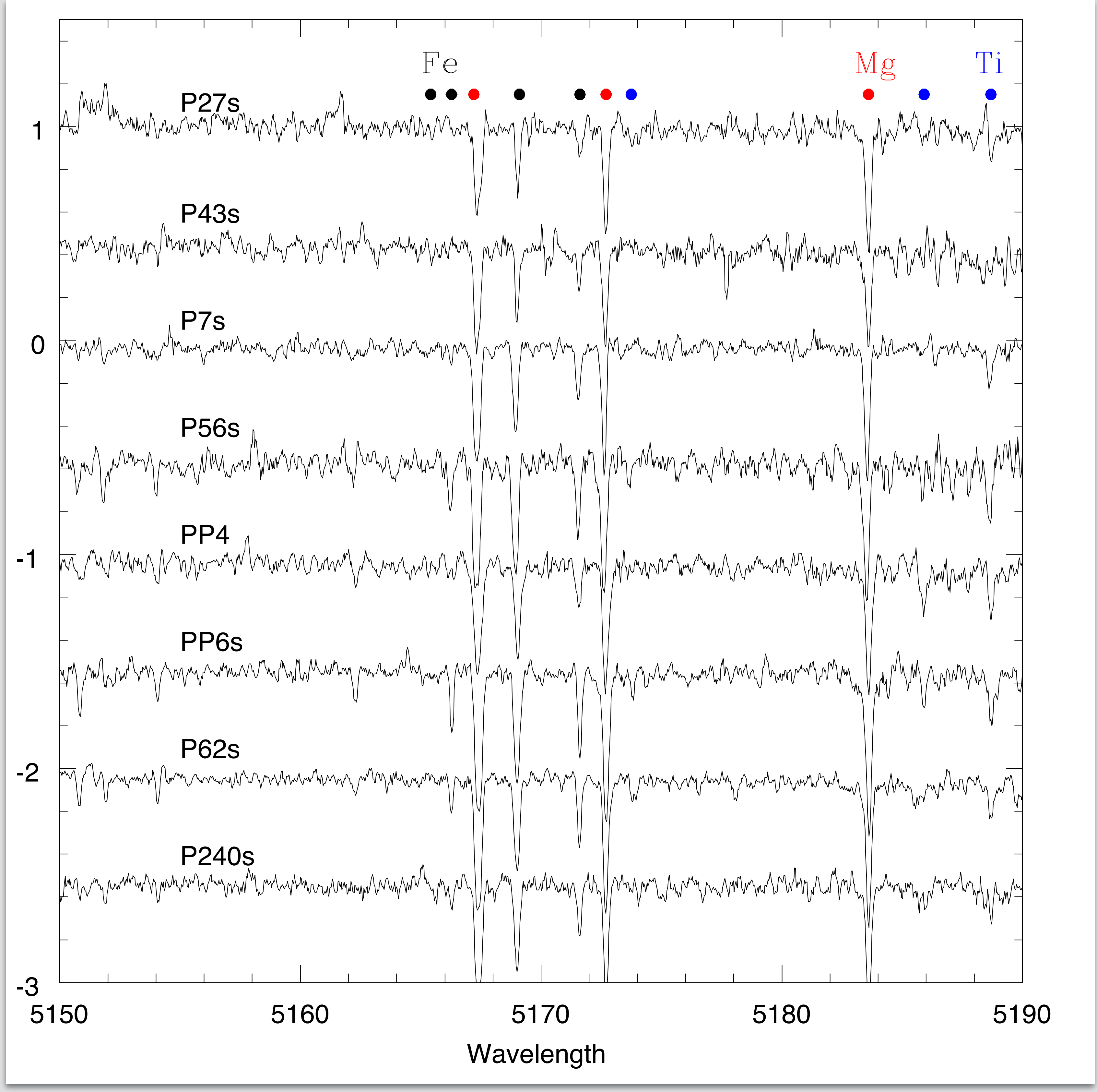
In 2015-2016:

>50 stars with V<15 estimated from Pristine with [Fe/H] < -2.5

R ~65,000 from CFHT/ ESPaDOns

4000 - 9000 A

~14 new EMP stars



Venn & Pristine (in prep)

Pristine: High Resolution Spectroscopy

~60 stars with R ~65,000 from CFHT/ESPaDOns

- Photometric/spectroscopic/isochrone stellar parameters
- Marcs (Osmarcs) model atmospheres
- Line-by-line analysis (not a lot of lines!), LTE
- MOOG (EQW & Syntheses)

Difficulties in

- securing spectroscopic parameters (especially giants vs dwarfs)
- NLTE effects on spectral parameters (especially Teff)
- SNR~30 only.

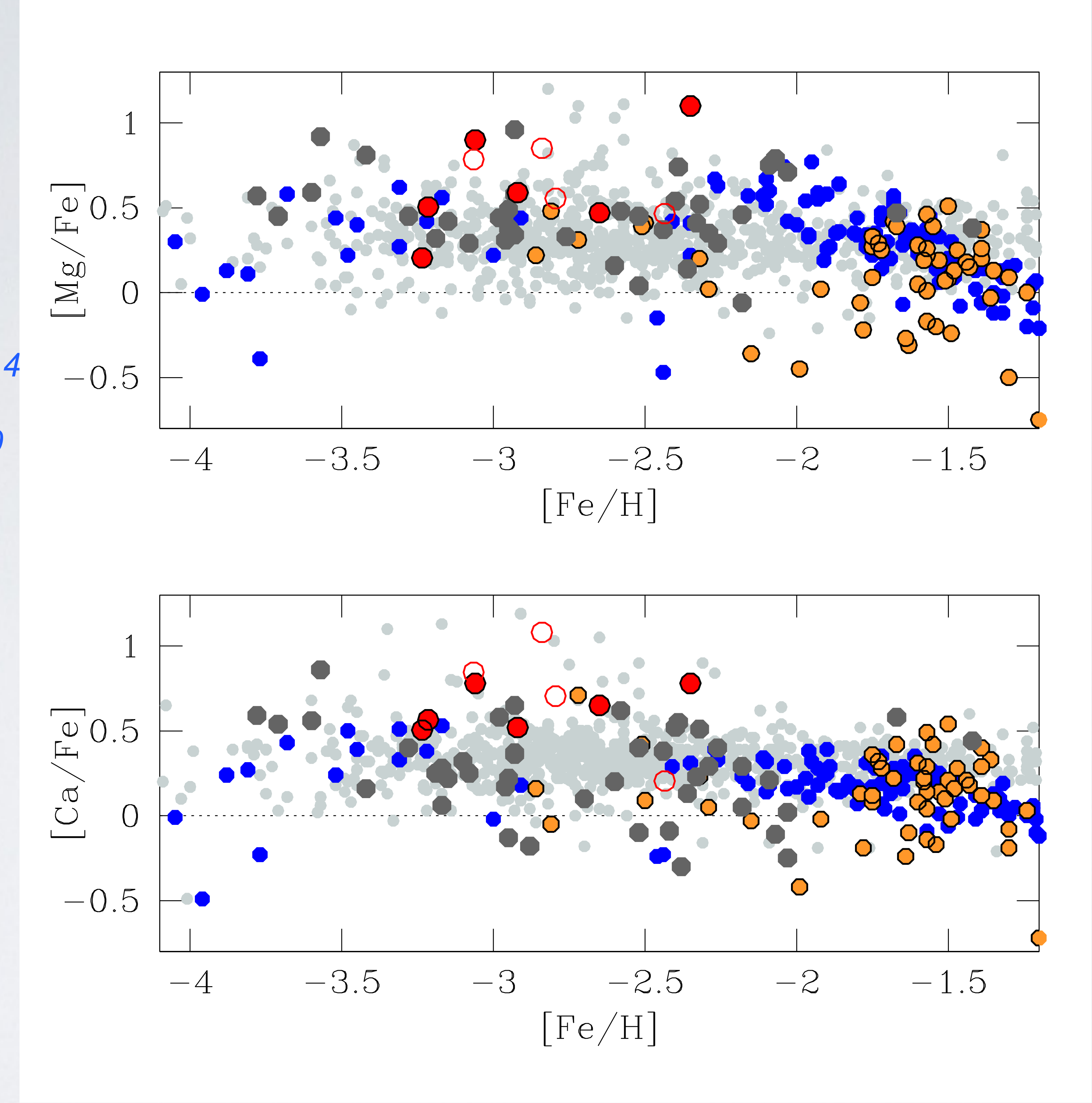
PRISTINE

SCULPTOR

Skuladottir et al. 2016
Jablonka et al. 2015
Simon et al. 2015
Starkenburg et al. 2014
Hill et al. 2010
Tafelmeyer et al. 2010
Frebel et al. 2010
Letarte et al. 2010
Giesler et al. 2005
Shetrone et al. 2003

CARINA

Norris et al. 2017
Venn et al. 2012
Lemasle et al. 2012
Koch et al. 2008
Shetrone et al. 2003



UFDs

Venn et al. 2017
Roederer et al. 2016, 2014
Ji et al. 2016,
Francois et al. 2015
Ishigaki et al. 2014
Frebel et al. 2014, 2010
Koch et al. 2013, 2014
Simon et al. 2010
Aden et al 2010
Norris et al. 2010
Feltzing et al. 2009
Cohen & Huang 2009

MWG

Roederer et al. 2014
Aoki et al. 2013
Cohen et al. 2013
Yong et al. 2013
Frebel et al. 2010
Reddy et al. 2006
Venn et al. 2004

~20 % of full sample (55) do have [Fe/H] < -2.5 **

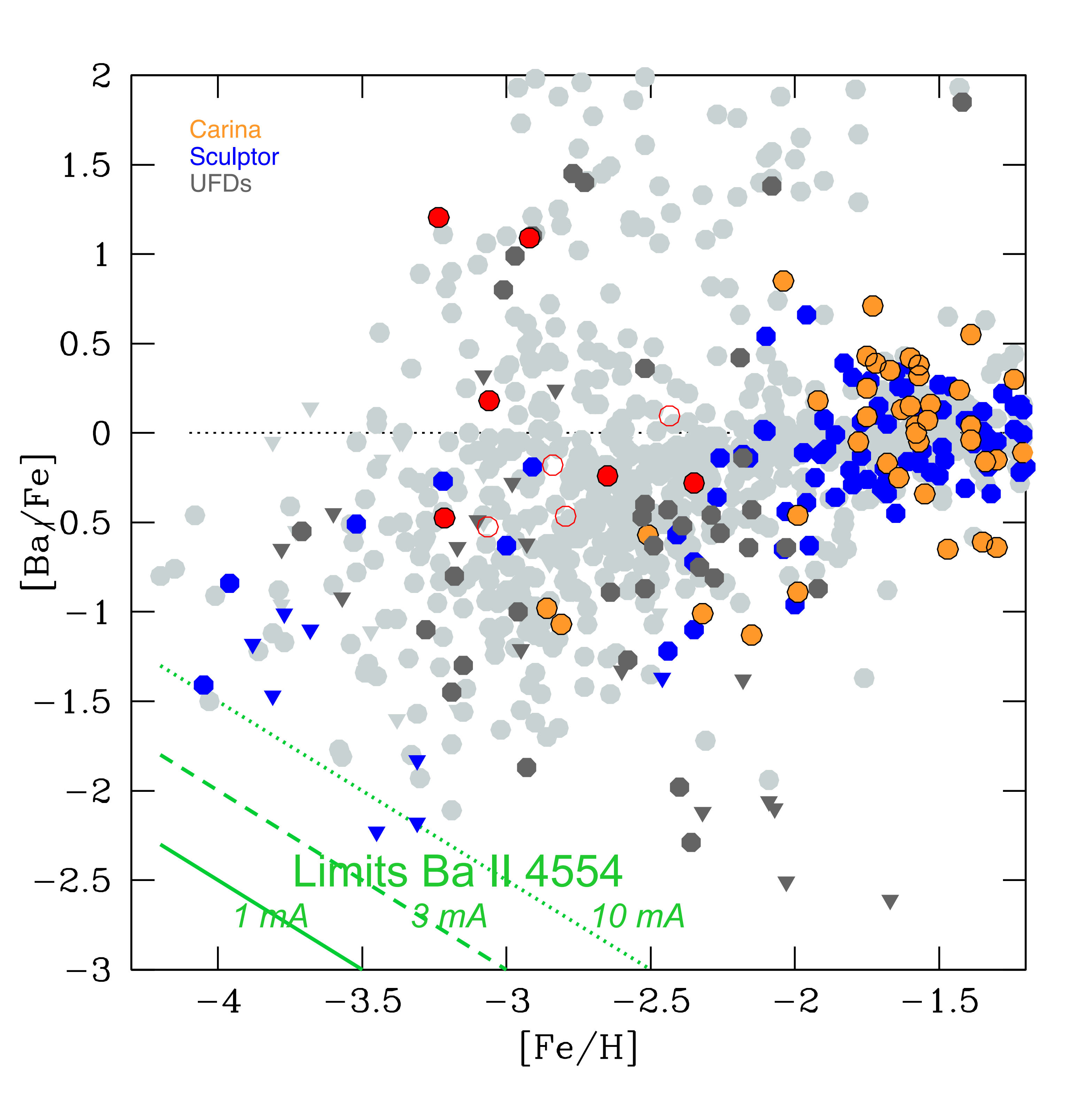
PRISTINE

SCULPTOR

Skuladottir et al. 2016
Jablonka et al. 2015
Simon et al. 2015
Starkenburg et al. 2014
Hill et al. 2010
Tafelmeyer et al. 2010
Frebel et al. 2010
Letarte et al. 2010
Giesler et al. 2005
Shetrone et al. 2003

CARINA

Norris et al. 2017
Venn et al. 2012
Lemasle et al. 2012
Koch et al. 2008
Shetrone et al. 2003



UFDs

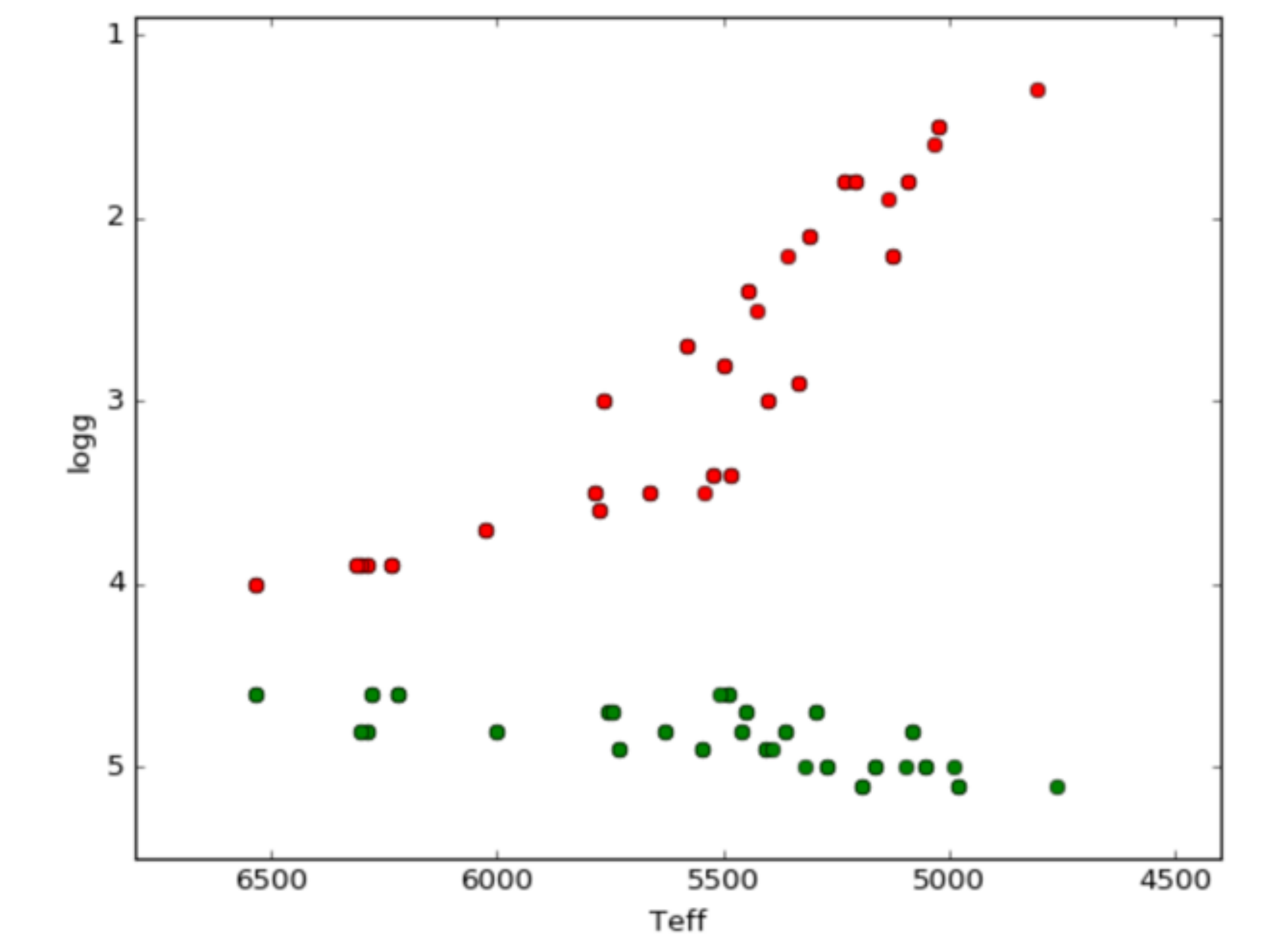
Venn et al. 2017
Roederer et al. 2016, 2014
Ji et al. 2016,
Francois et al. 2015
Ishigaki et al. 2014
Frebel et al. 2014, 2010
Koch et al. 2013, 2014
Simon et al. 2010
Aden et al 2010
Norris et al. 2010
Feltzing et al. 2009
Cohen & Huang 2009

MWG

Roederer et al. 2014
Aoki et al. 2013
Cohen et al. 2013
Yong et al. 2013
Frebel et al. 2010
Reddy et al. 2006
Venn et al. 2004

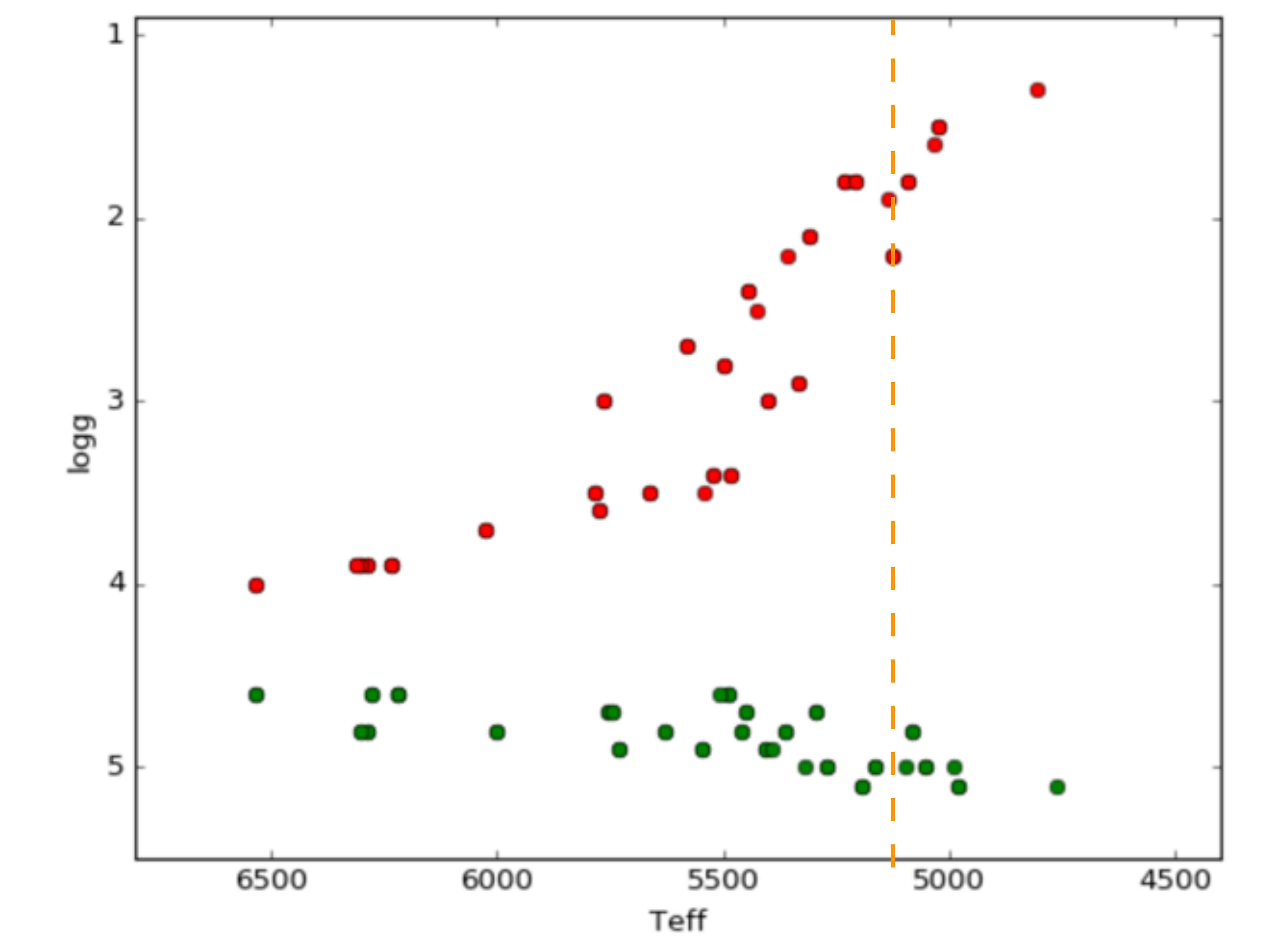
When SNR low for EMP stars then Gravity can be tough

- Gravities from isochrones : Dartmouth [Fe/H] = -3, age =10 Gyr
- then dwarf/giant discrimination difficult,
- even Balmer lines & CaT/MgB line wings degenerate ΔT & Δlogg



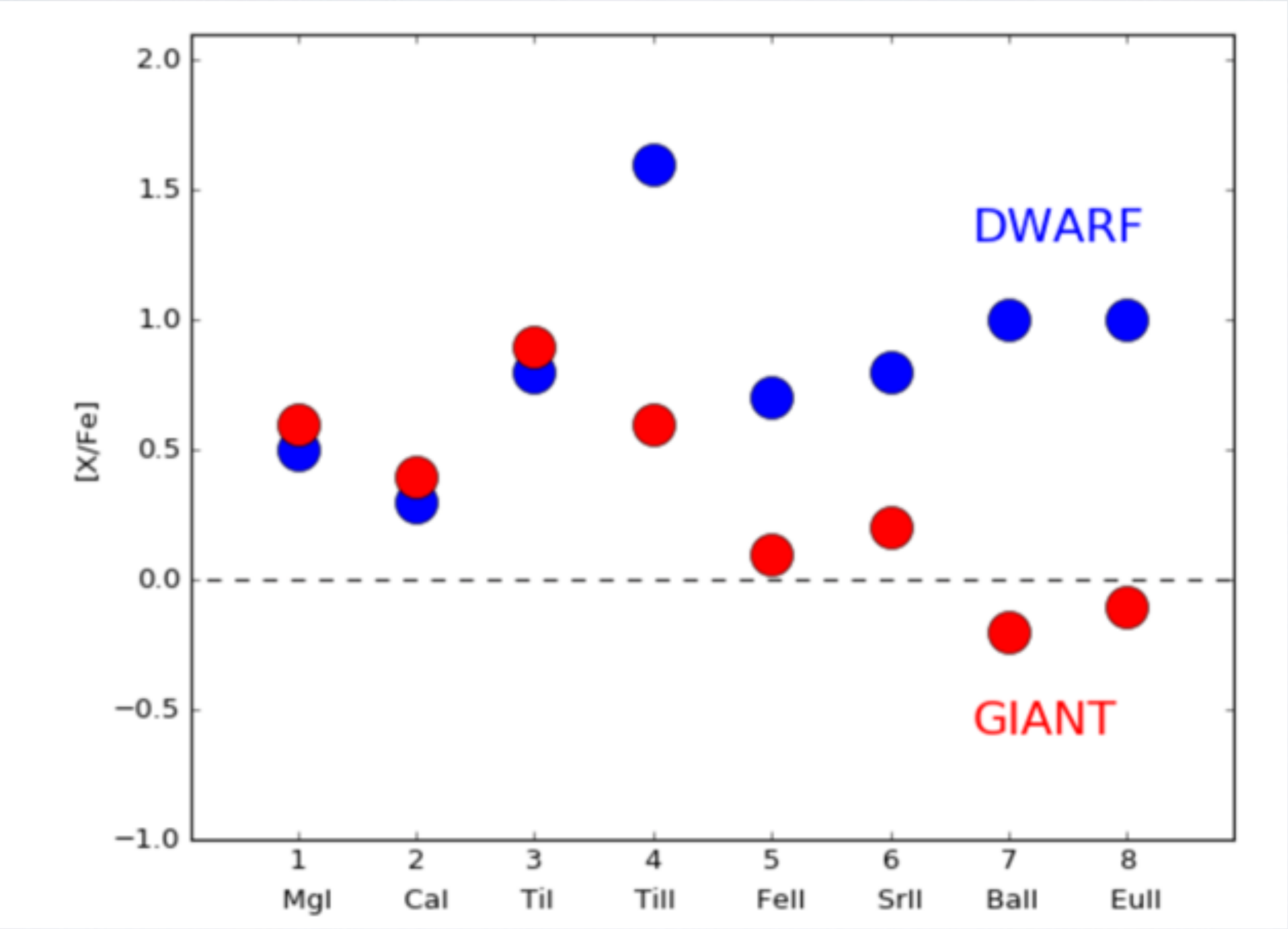
When SNR low for EMP stars then Gravity can be tough

- Gravities from isochrones : Dartmouth [Fe/H] = -3, age =10 Gyr
- then dwarf/giant discrimination difficult,
- even Balmer lines & CaT/MgB line wings degenerate ΔT & Δlogg



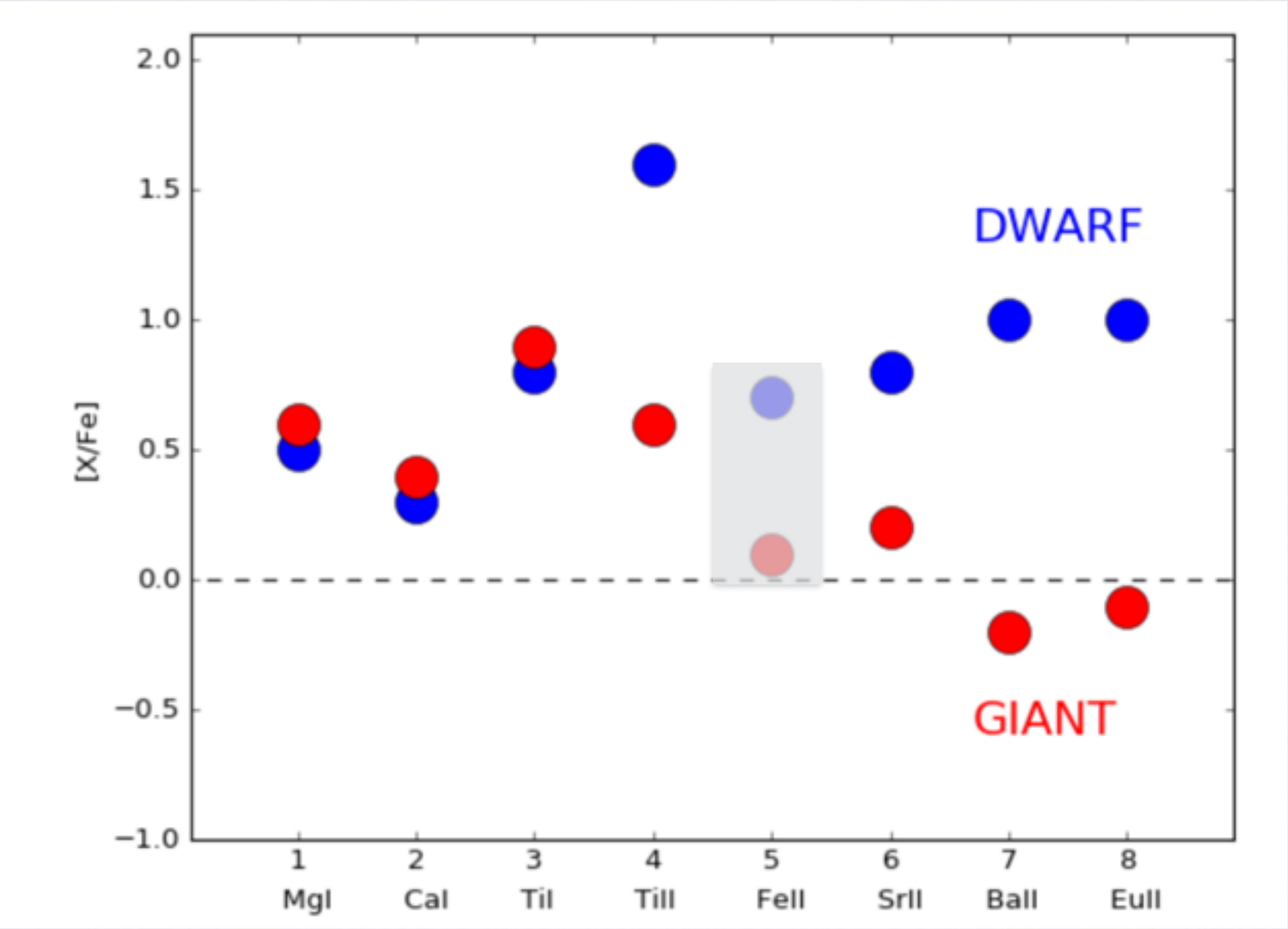
Example: one object with T~5000 K

- MgI, CaI, TiI, FeI are not sensitive to logg
- but TiII, FeII, SrII, BaII, EuII are sensitive
- EMP with low SNR mean no/poor FeII



Example: one object with T~5000 K

- MgI, CaI, TiI, FeI are not sensitive to logg
- but TiII, FeII, SrII, BaII, EuII are sensitive
- EMP with low SNR mean no/poor FeII



The dwarf solution could resemble an r-rich star (other than Ti II)

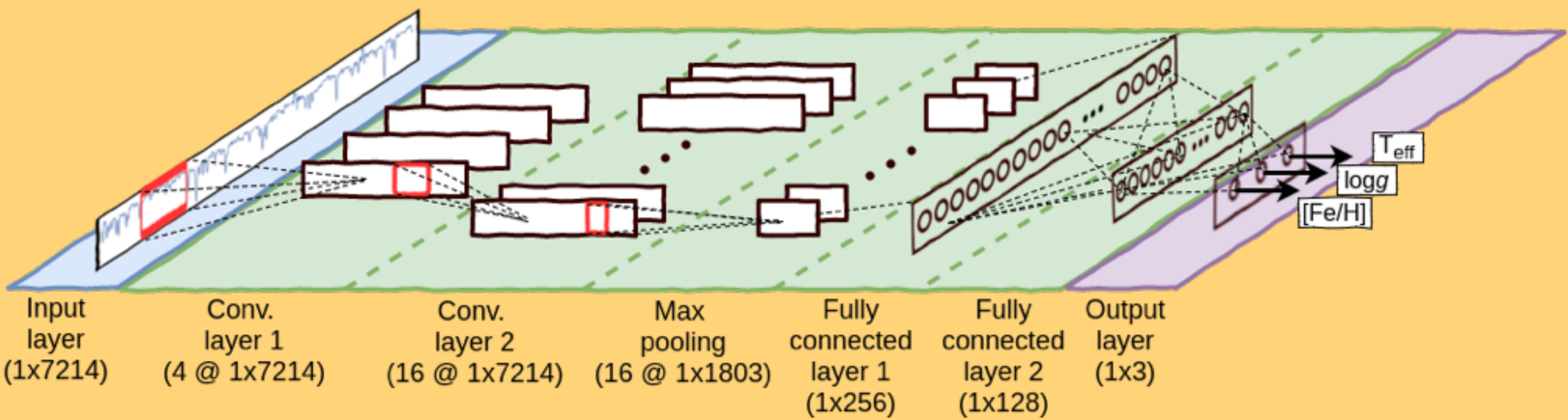
Initial Analyses - *Easy*
Detailed Analyses - TIME CONSUMING!!

Started looking for ways to automate the analysis of these & future Espadons and other spectral surveys

1. FERRE	not blue enough to use as in our INT diagnostic analyis
2. the Cannon	not enough Espadons data for the training set
3. other PCA etc analyses	not publicly available

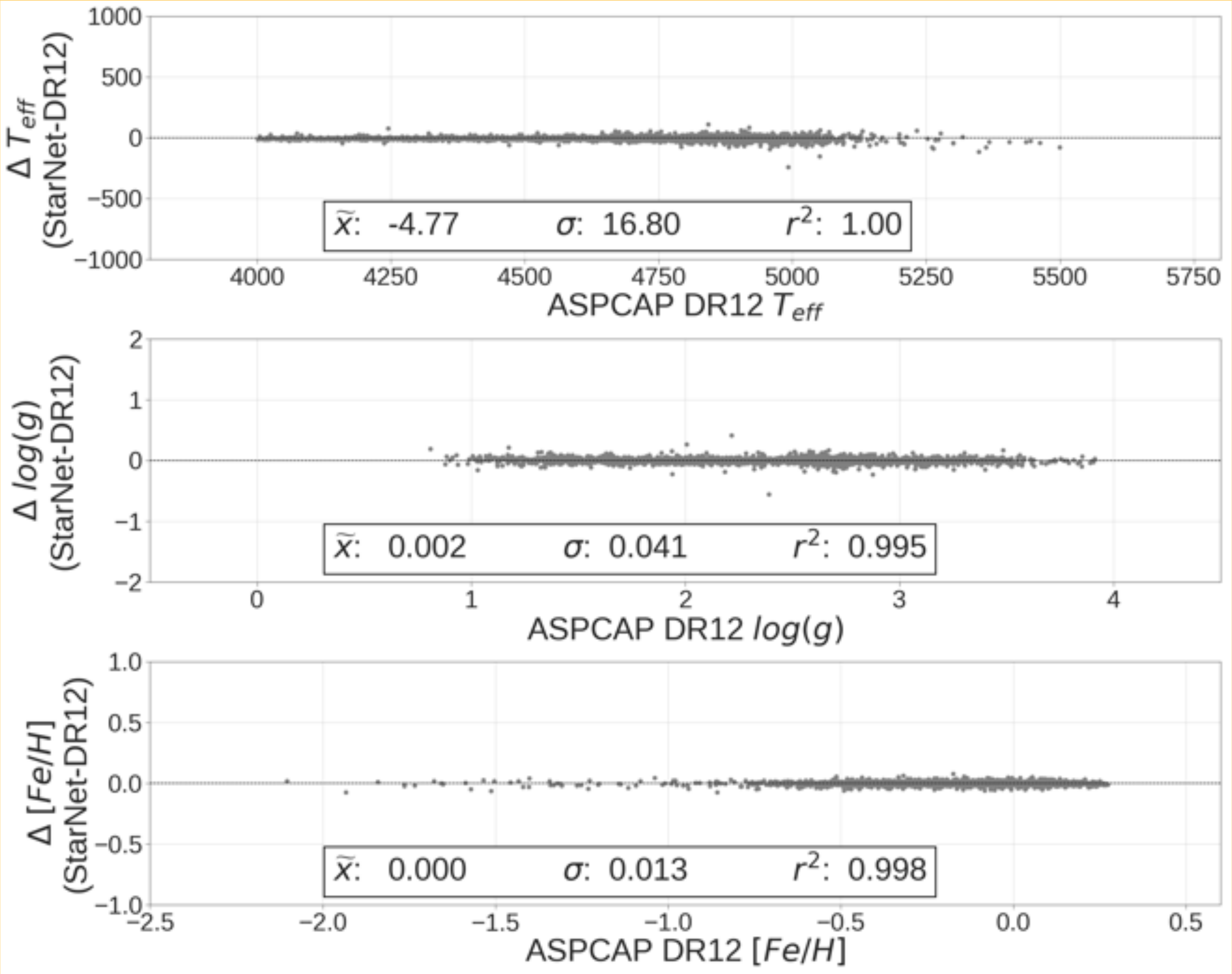
Deep Learning with Neural Networks

An NN consists of a collection of interconnected nodes arranged in layers: an input layer, a number of hidden layers, and an output layer (i.e. the predictions). The hidden layers are able to form non-linear and weighted combinations of the input, to produce the output labels.



StarNet architecture is a Convolutional Neural Network (CNN) composed of fully connected layers that apply weights to each input value, through a series of filters convolved across the length of the input vector.

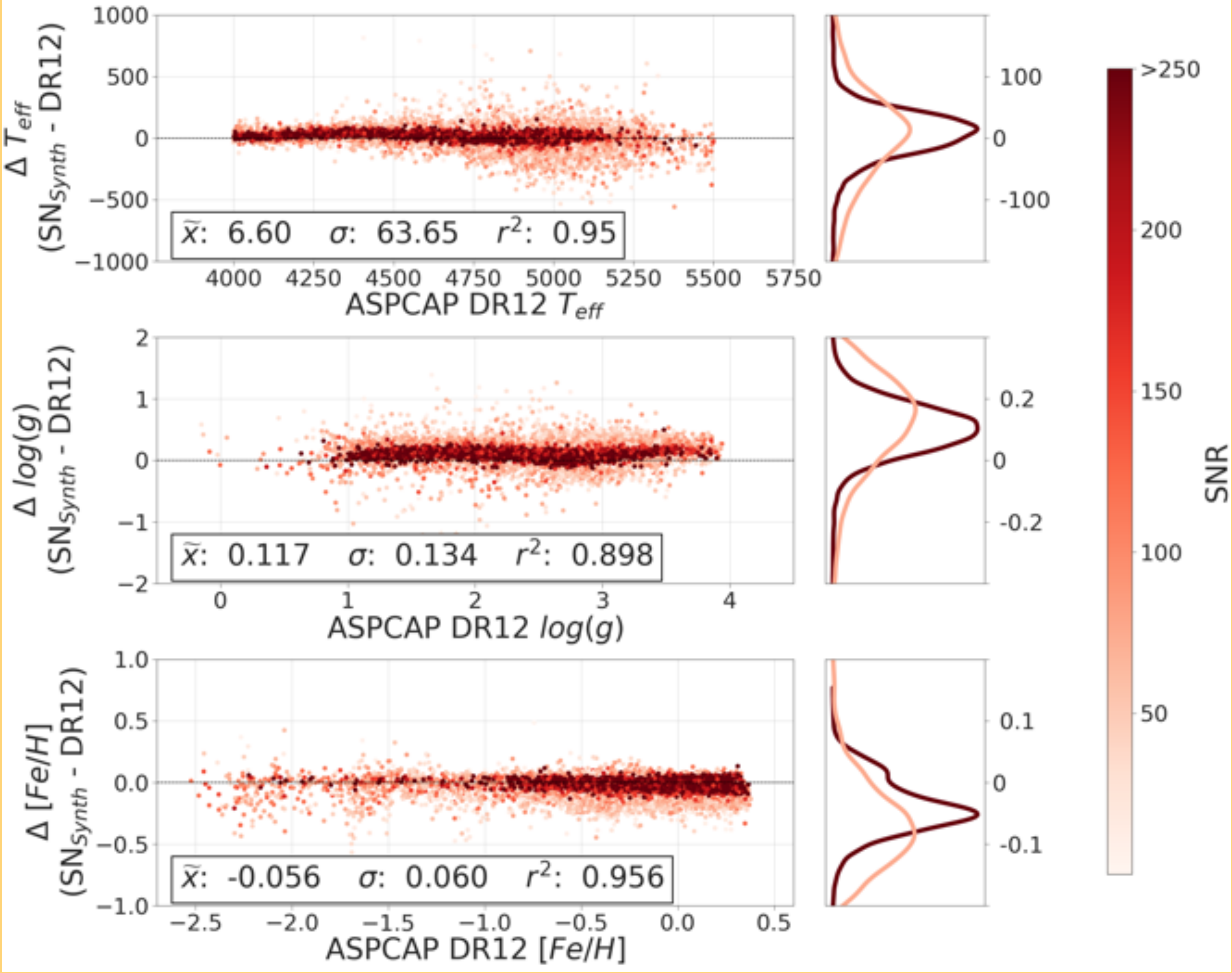
Train & Test with APOGEE data



Trained on 41000 predictions individual visit spectra from the ASPCAP DR12 with NO_PERSISTENCE and S/N > 200.

Tested on 2780 combined spectra of different stars with S/N > 200

Train StarNet on Synthetic Spectra

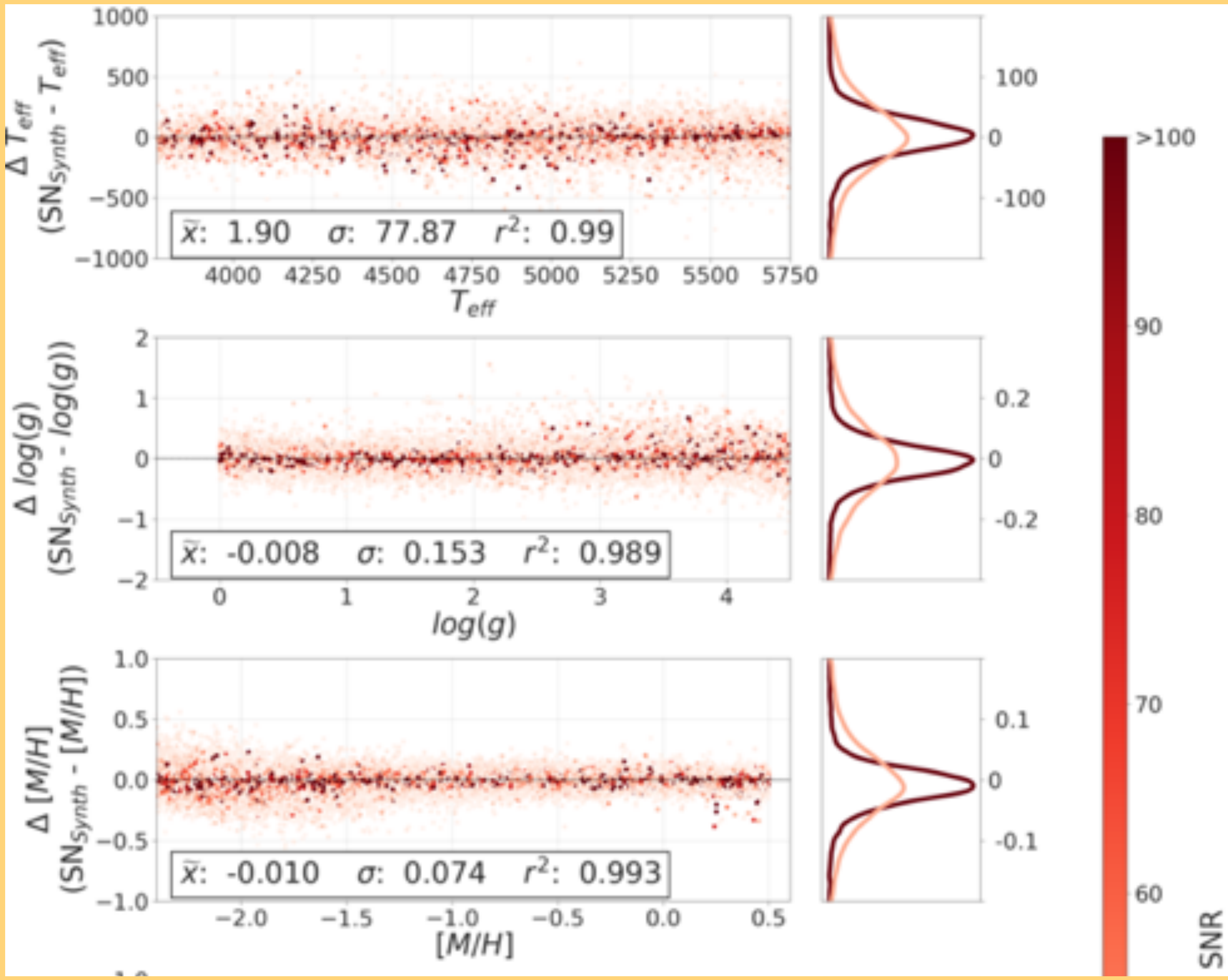


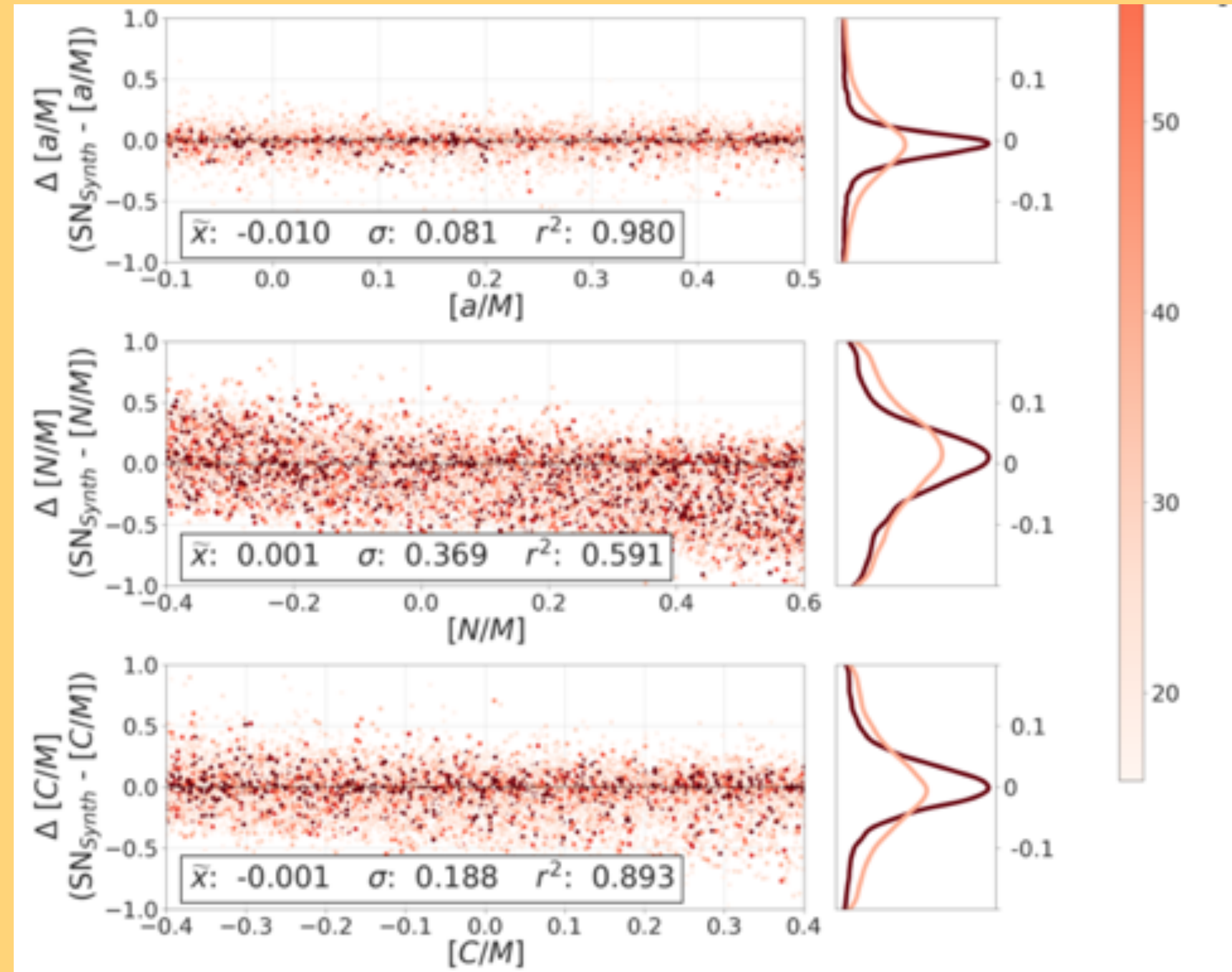
StarNet was trained on 224000 synthetic spectra randomly sampled from the full ASSET synthetic grid (e.g., 3500 - 8000K in Teff, 0 - 5 in logg, etc…)

Test set of 21787 combined APOGEE spectra without flags.

Train & Test StarNet on Synthetic Spectra

Fabbro, Bialek, O'Briain, Venn, Kielty, Jahandar, Monty (2017) in prep





StarNet trained on 6 labels.

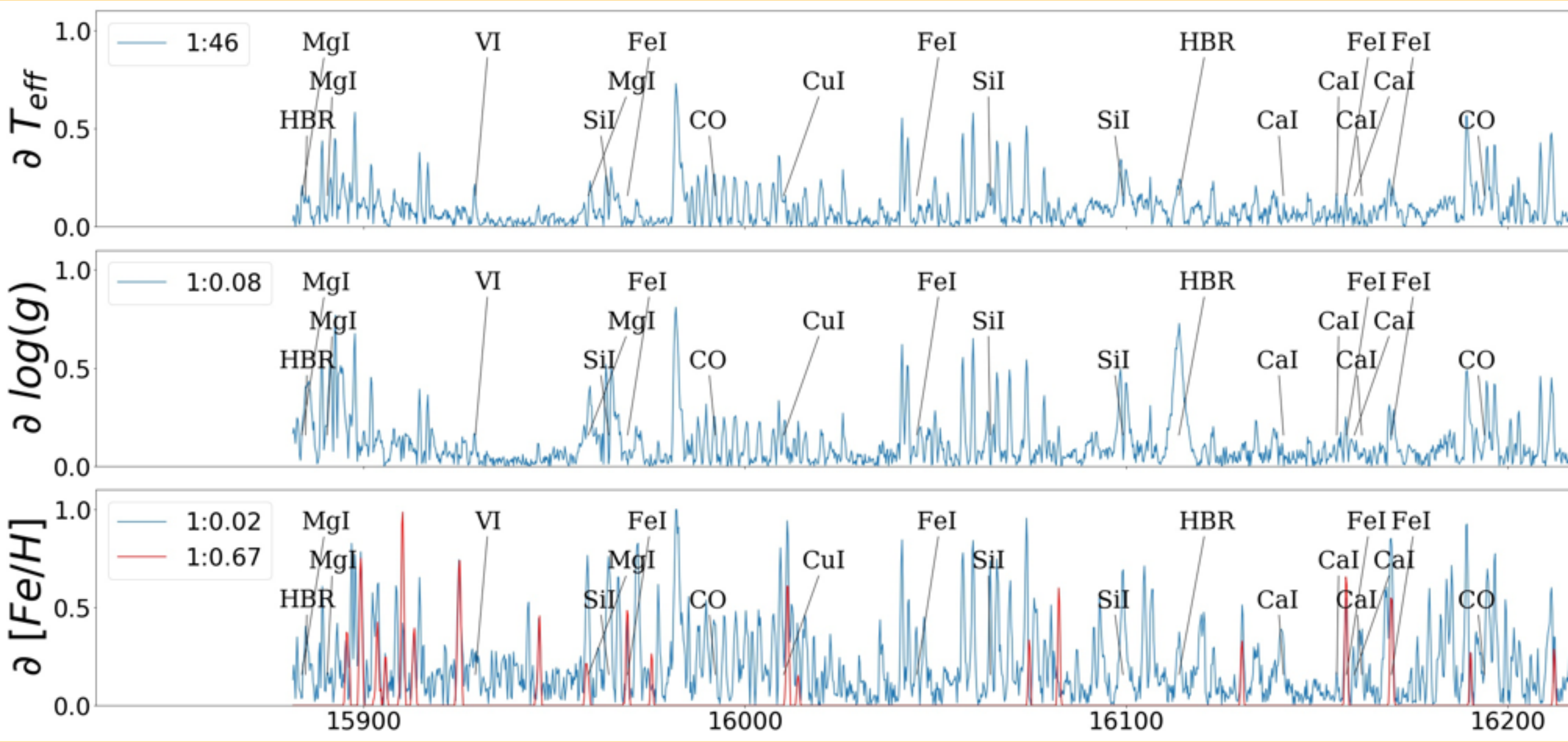
Dispersions similar in Teff, logg, [M/H],

very small in [alpha/M]

very large in [C/M] and [N/M]

Partial Derivatives

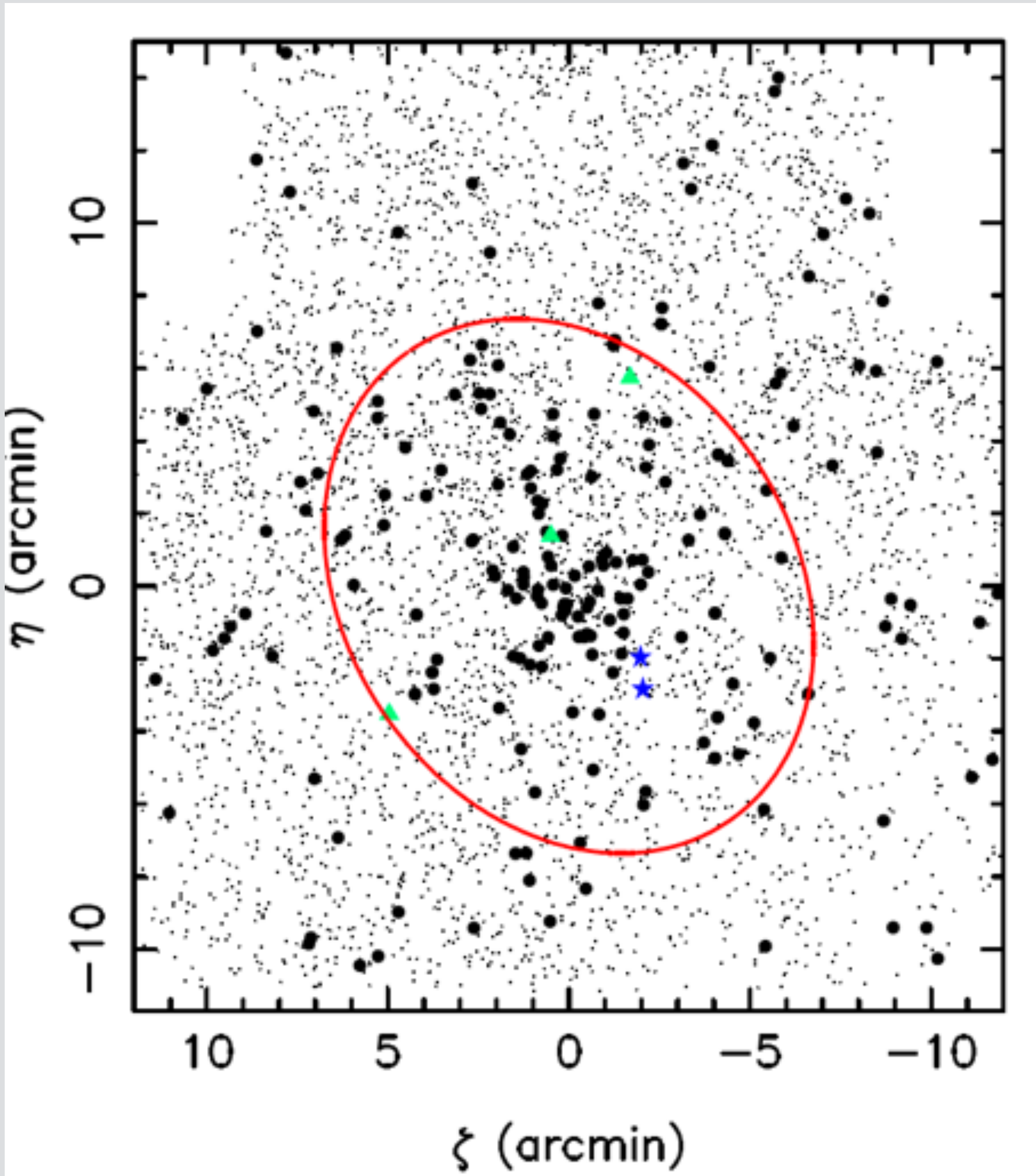
Fabbro, Bialek, O'Briain, Venn, Kielty, Jahandar, Monty (2017) in prep

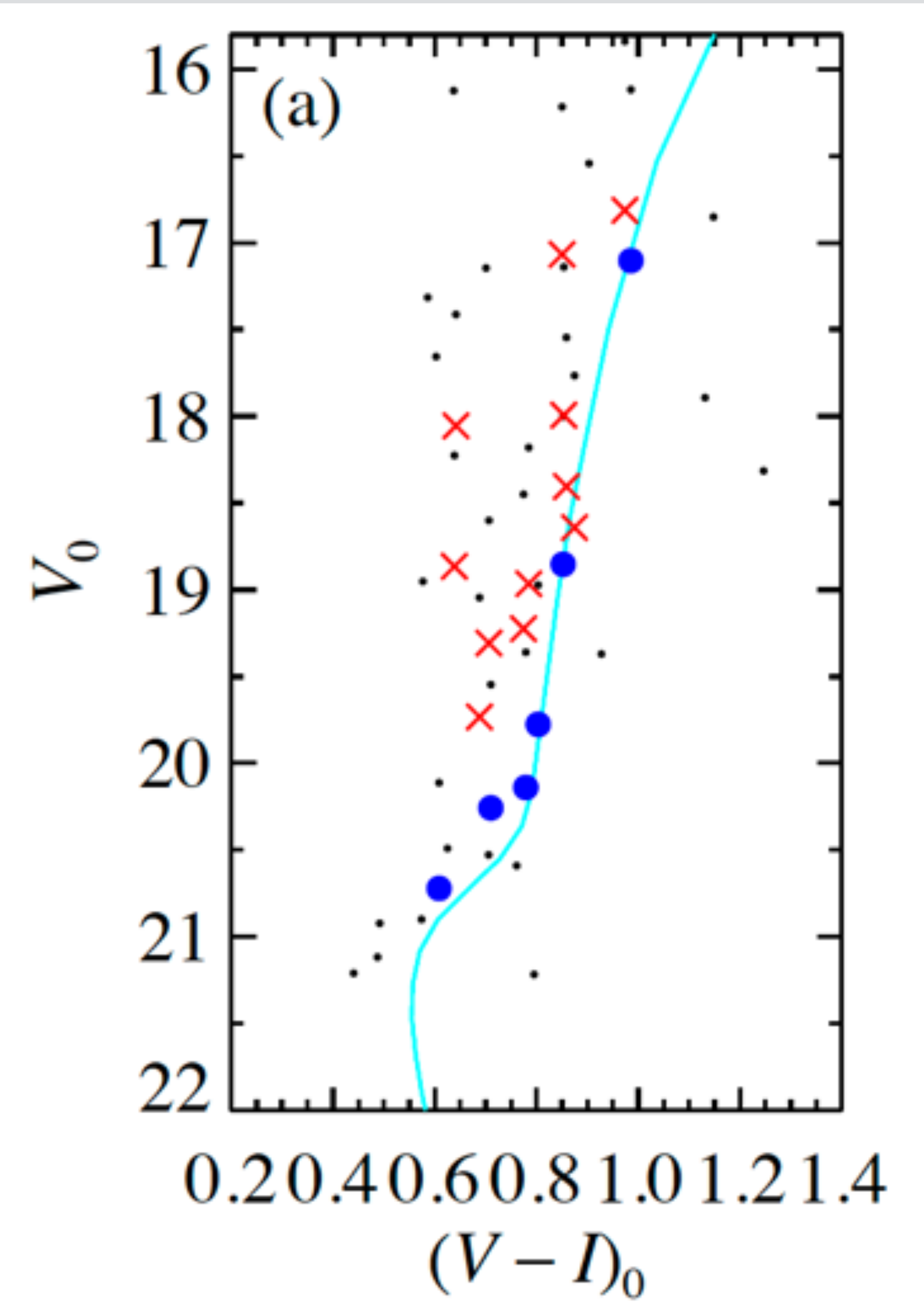


[Fe/H] derivatives are over-plotted with Ferre windows

Lines labelled from the APOGEE linelist

Example of the power of Pristine: dwarf galaxy Tri II

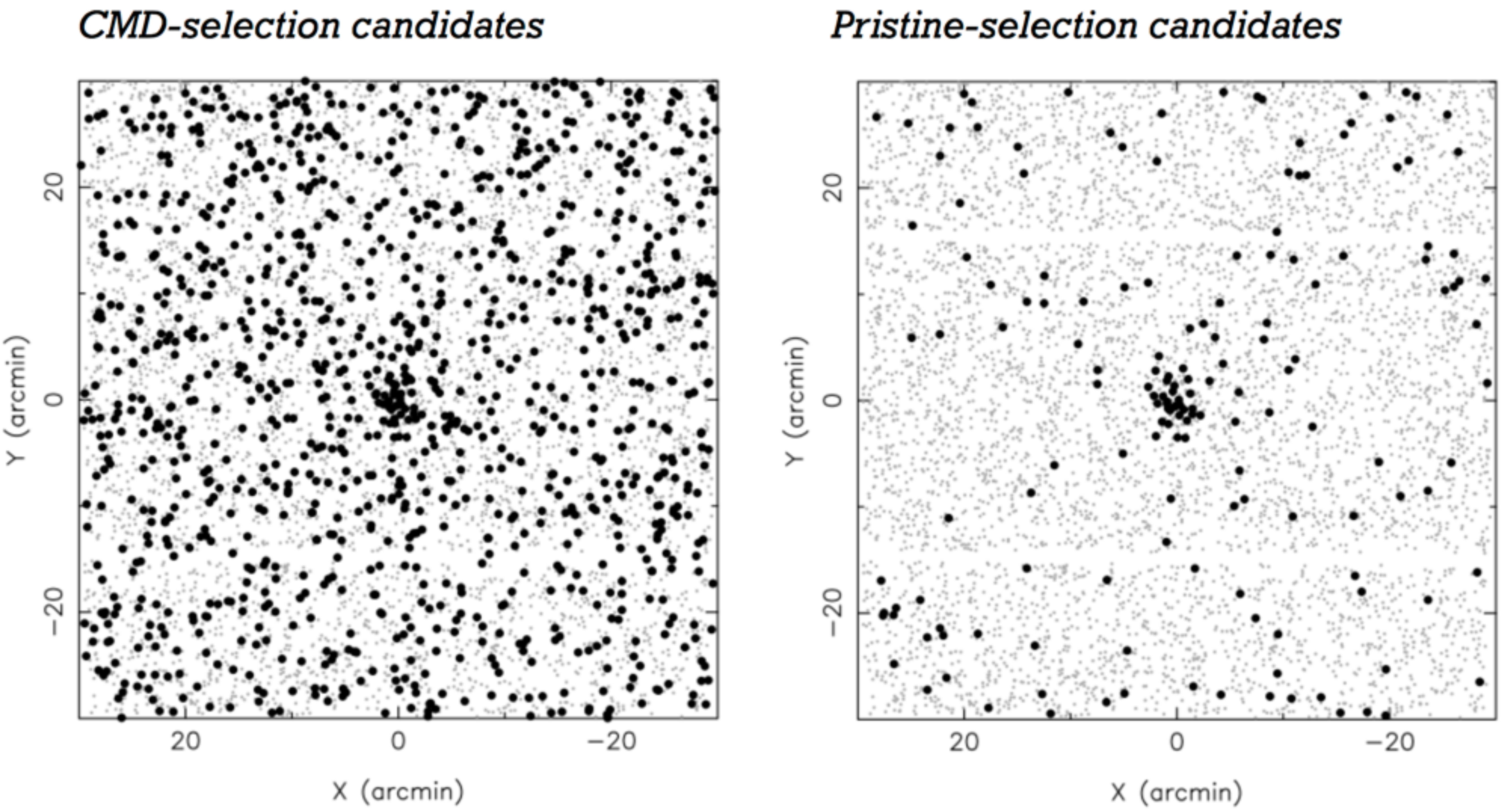




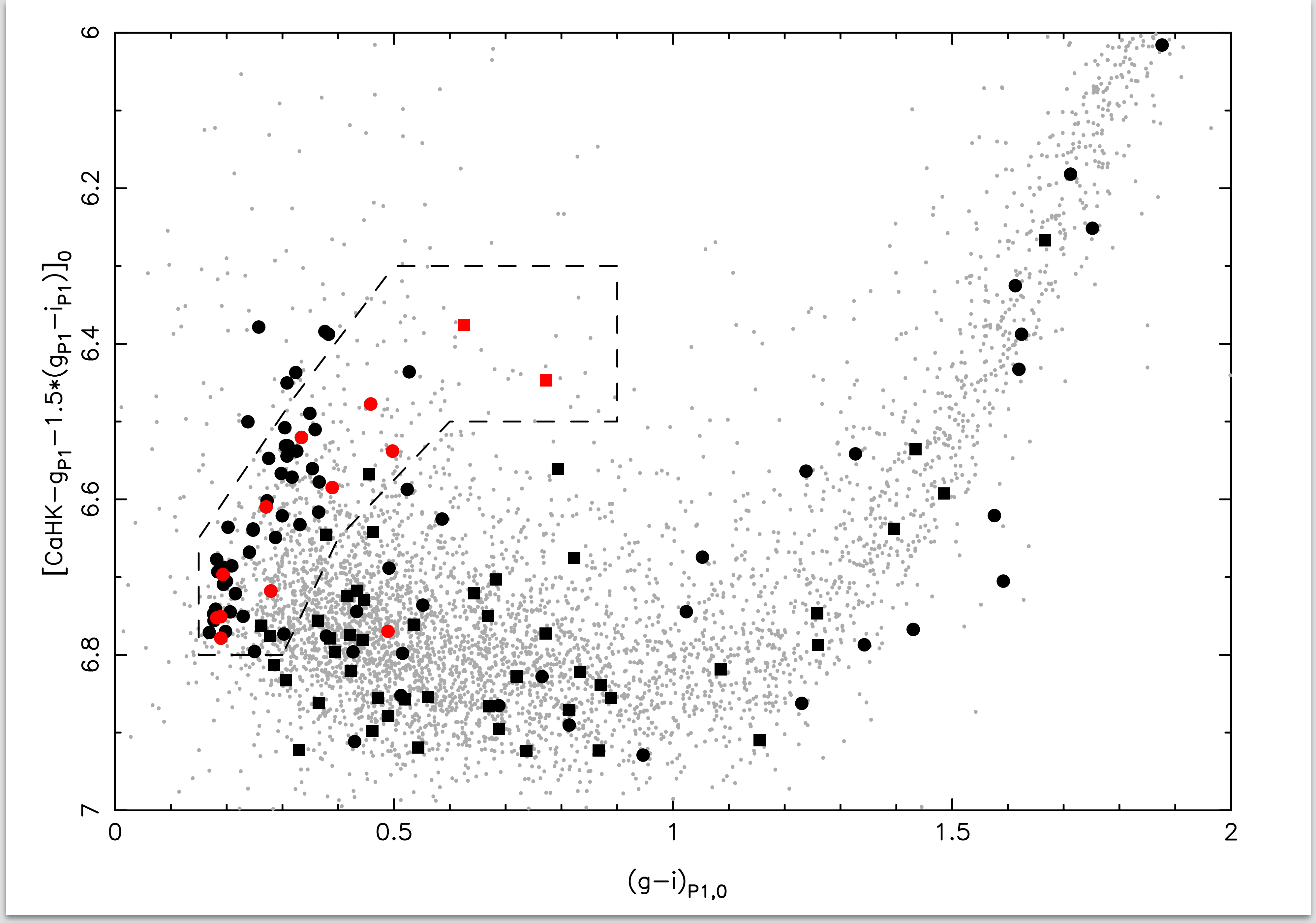
Laevens et al. 2015, Martin et al. 2015
from Pan-STARRS

Martin et al. 2015 &
Kirby et al. 2015
CaT RV selected

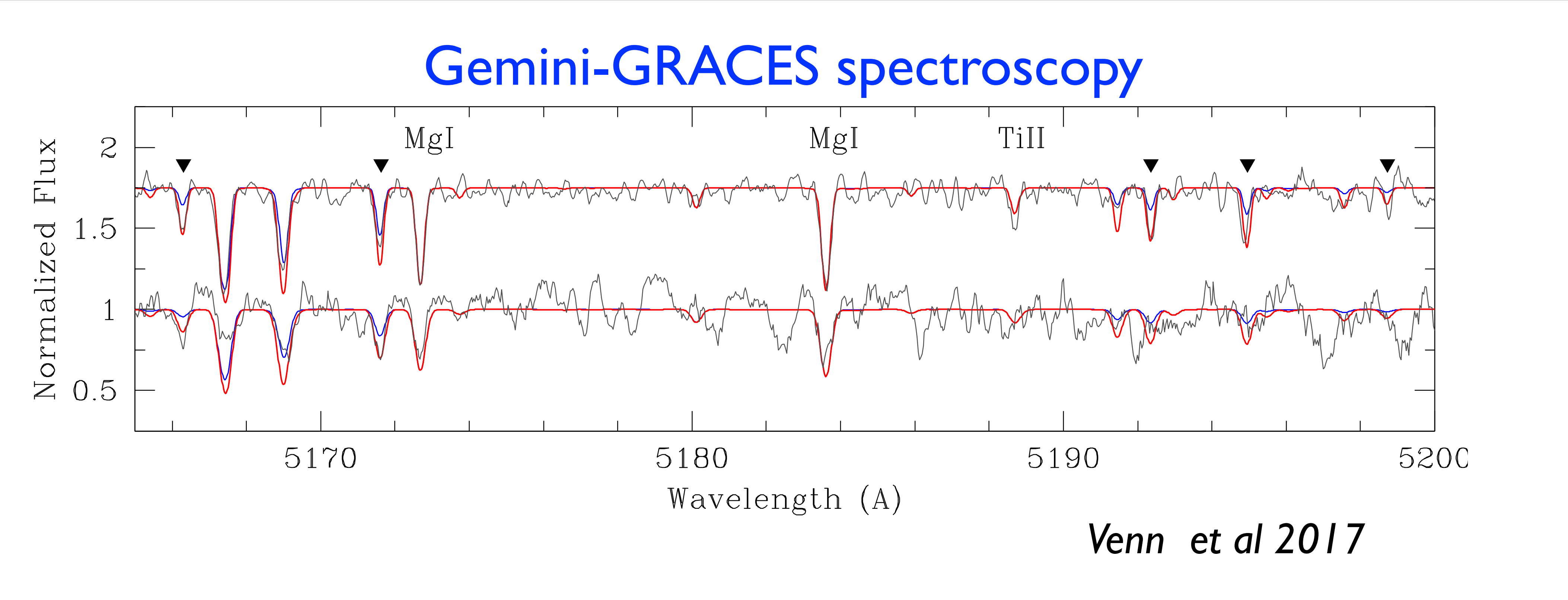
Triangulum II : PanSTARRS vs Pristine candidates

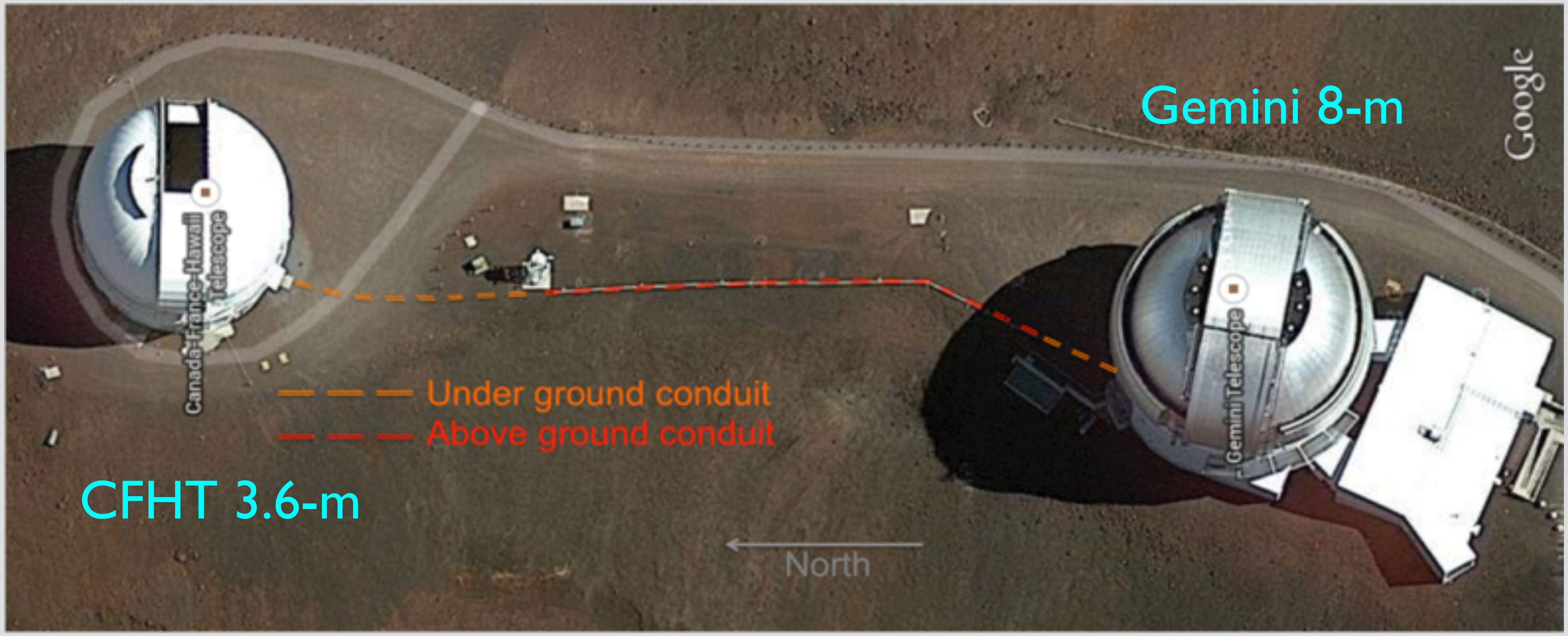


Tri II : PanSTARRS vs Pristine candidates

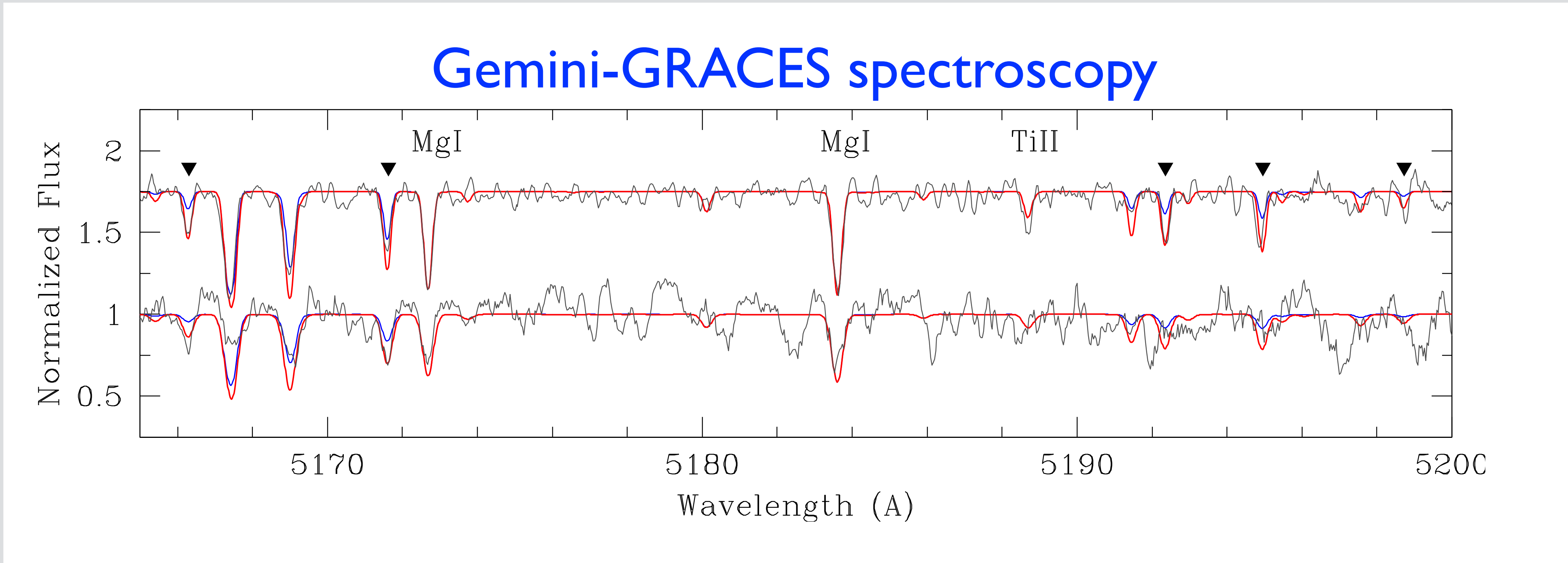


Triangulum II - high res spectroscopy

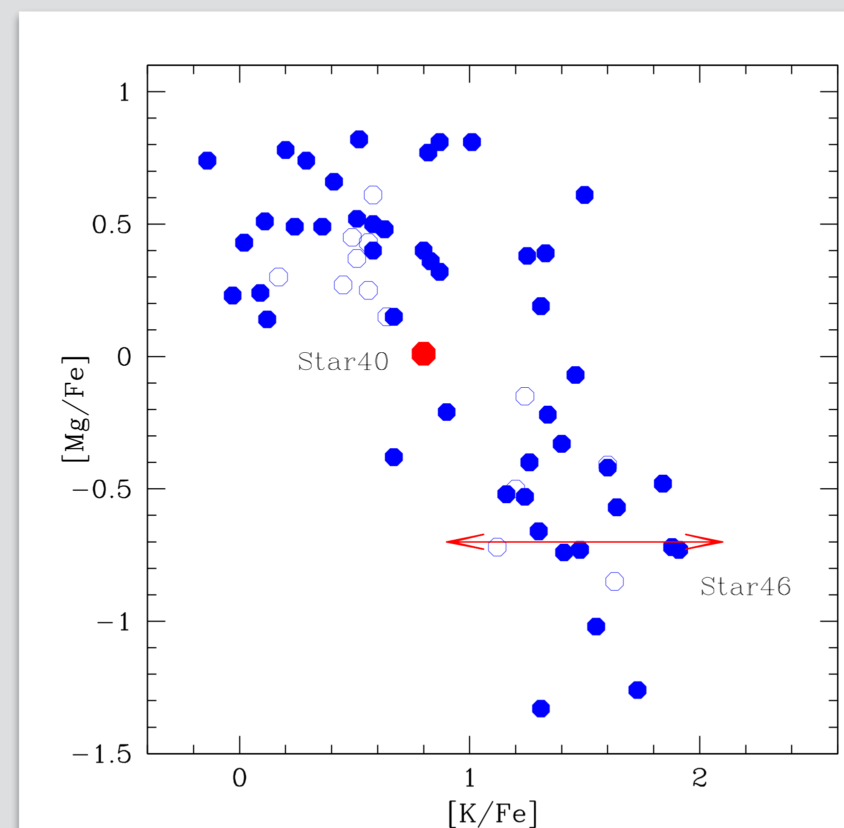




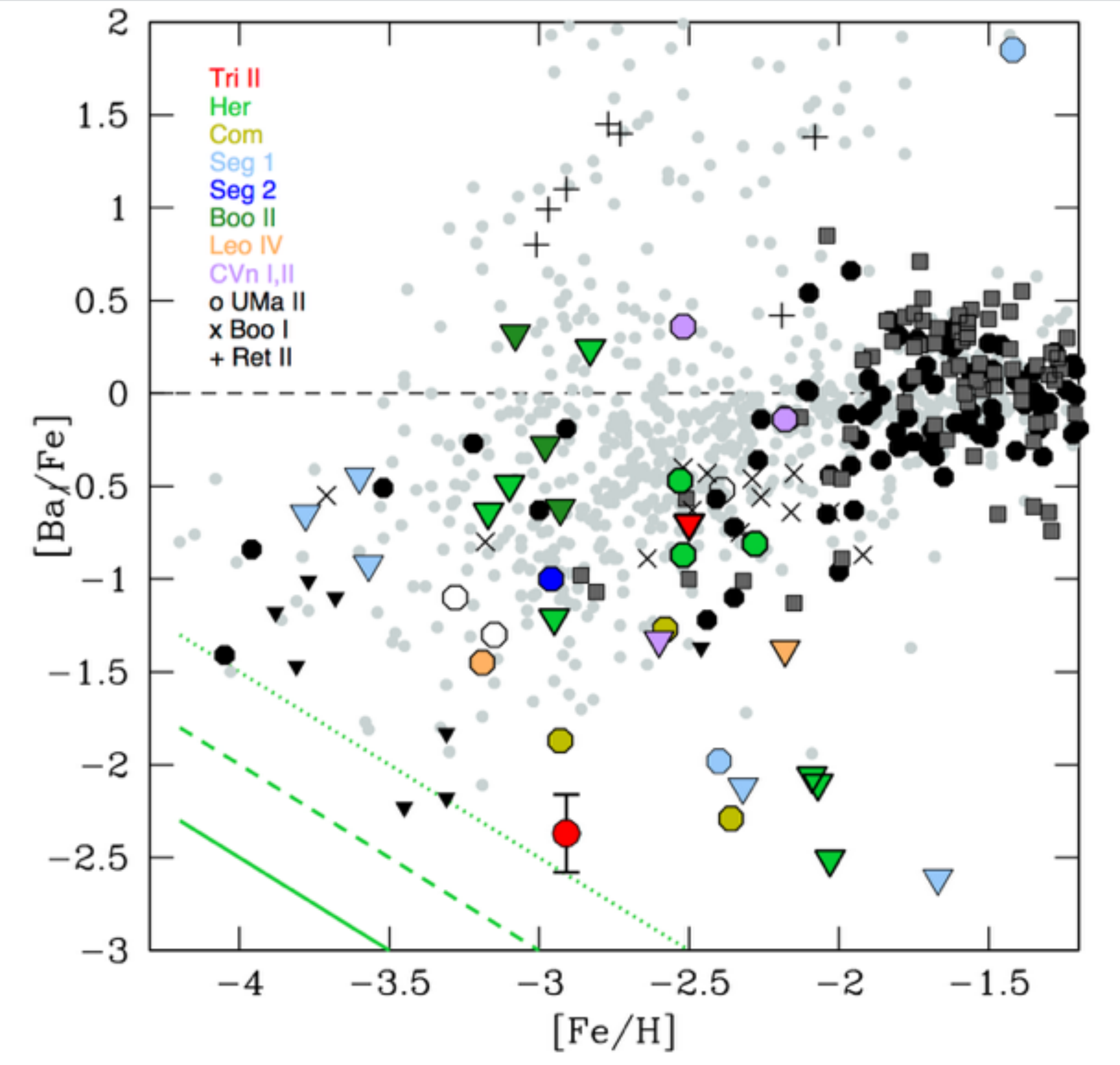
Triangulum II - high res spectroscopy (Mg, K)



Tri II shows the K-Mg anti-correlation (Venn et al. 2017), similar to that in NGC 2419 found by Mucciarelli et al. (2012) and Cohen & Kirby (2012).

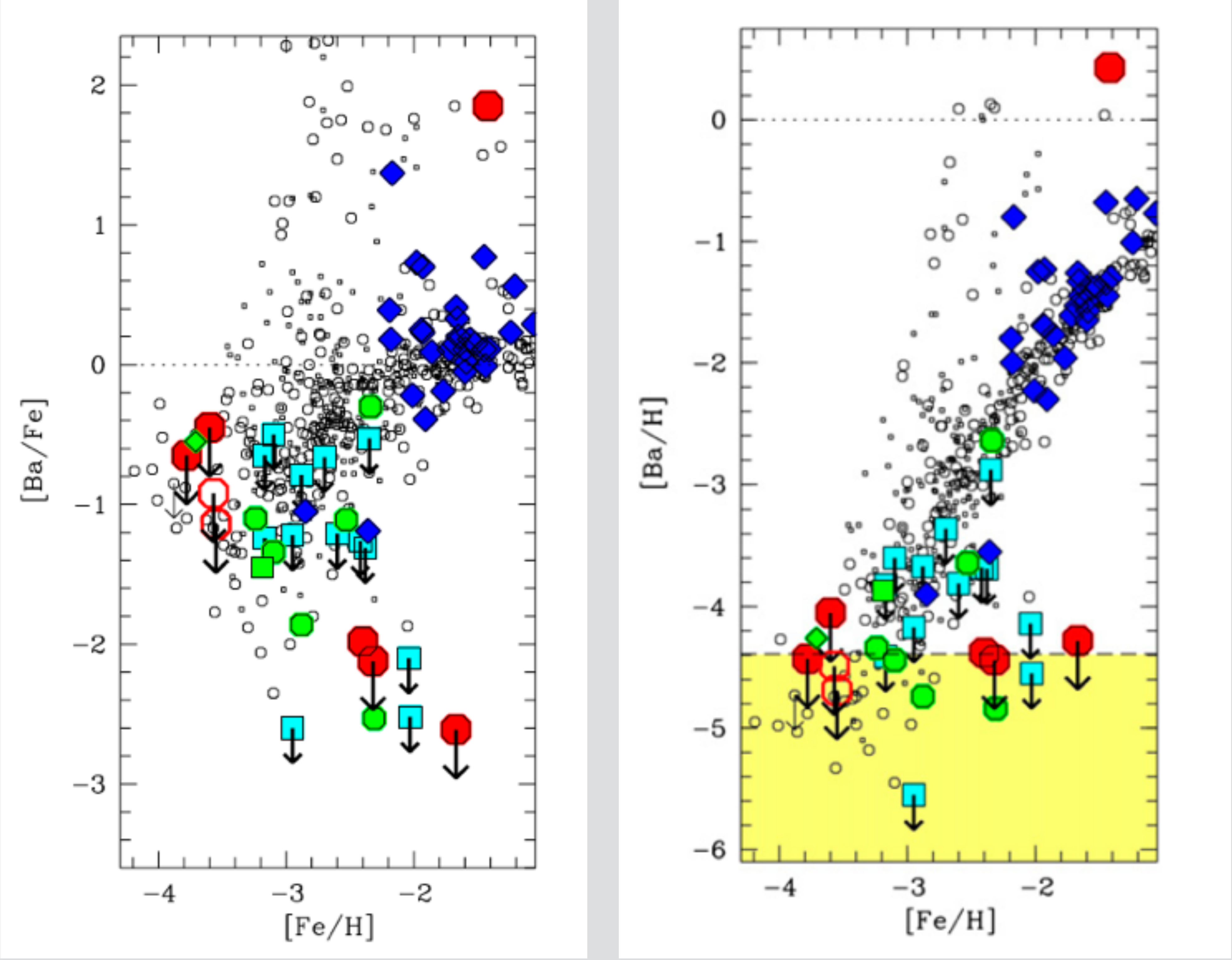


Triangulum II - high res spectroscopy (Ba)



Venn et al 2017; Kirby et al. 2017

Triangulum II is like Segue I and other UFDs, with low [Ba/Fe] at higher [Fe/H]



Frebel et al 2014

Goals for Pristine-HRS

1. Find & analyse old, metal-poor stars + StarNet for HRS
   - stellar nucleosynthesis and yields (improved atomic data!?)
   - early star formation & stellar populations

2. Metallicity decomposition of the Milky Way
   - structure as f([Fe/H]) → hierarchical accretion
   - added dimension to deconstruct MW, even in Gaia era

3. Independent study of faint dwarf galaxies
   - weeding out foreground contamination
   - efficiently building larger samples of spectroscopic member
   - chemical evolution modelling

+ see Ani Chiti's paper on Tuc II