Reference Stars and Analysis Challenges for the Metal Poor Galaxy

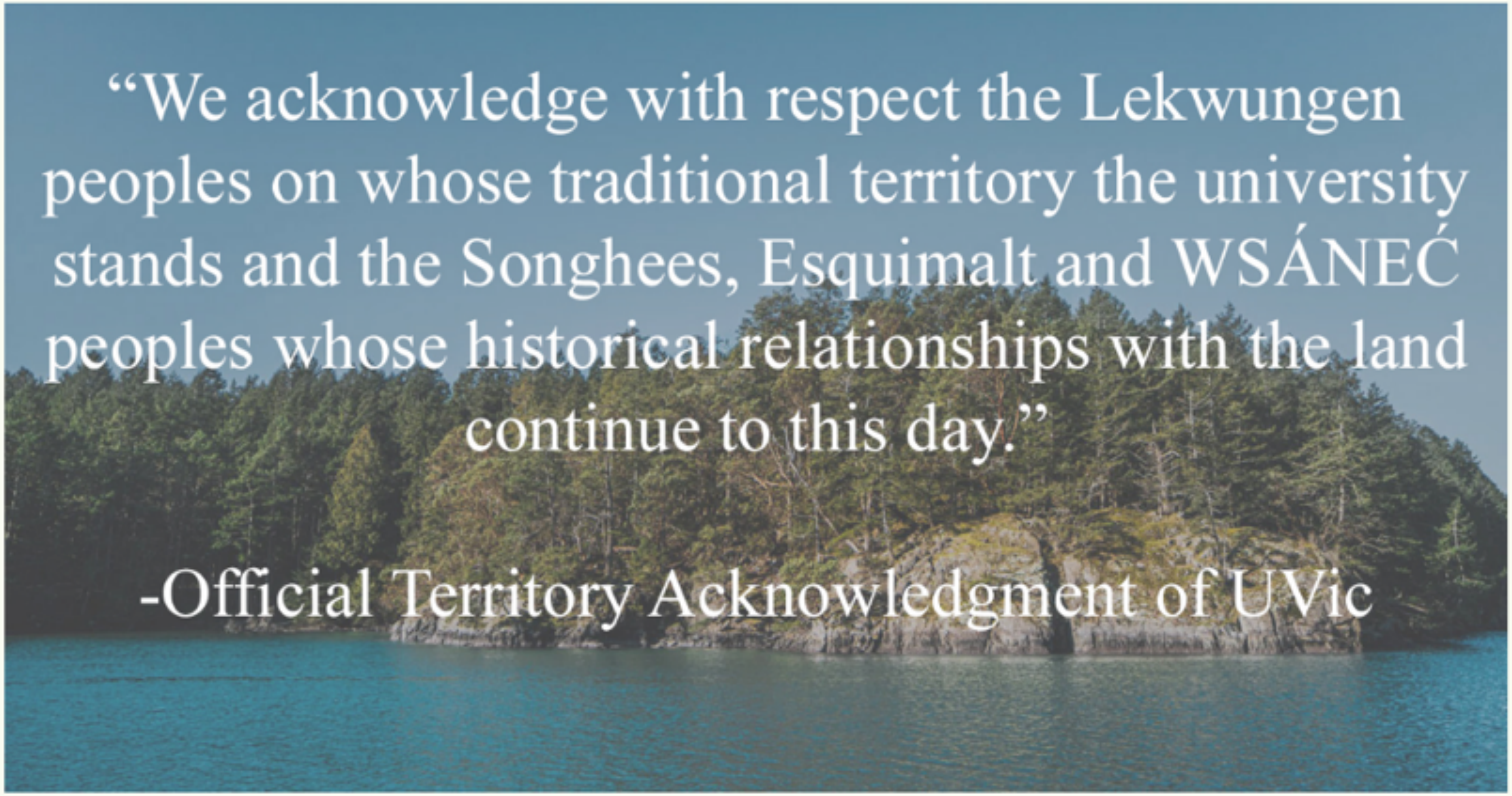
Kim Venn *(UVic)*

Federico Sestito, Spencer Bialek, Collin Kielty, Fletcher Waller, Julio Navarro (UVic),
Sebastien Fabbro, Alan McConnachie, Patrick Cote (NRC)

Else Starkenburg (Kapetyn), Kris Youakim (Lund), David Aguado (Cambridge)
Nicolas Martin, Rodrigo Ibata, Anke Arentsen, Guillaume Thomas (Strasbourg)
& the Pristine collaboration

UVic Astrophotography Club (French Beach, BC, 2017)

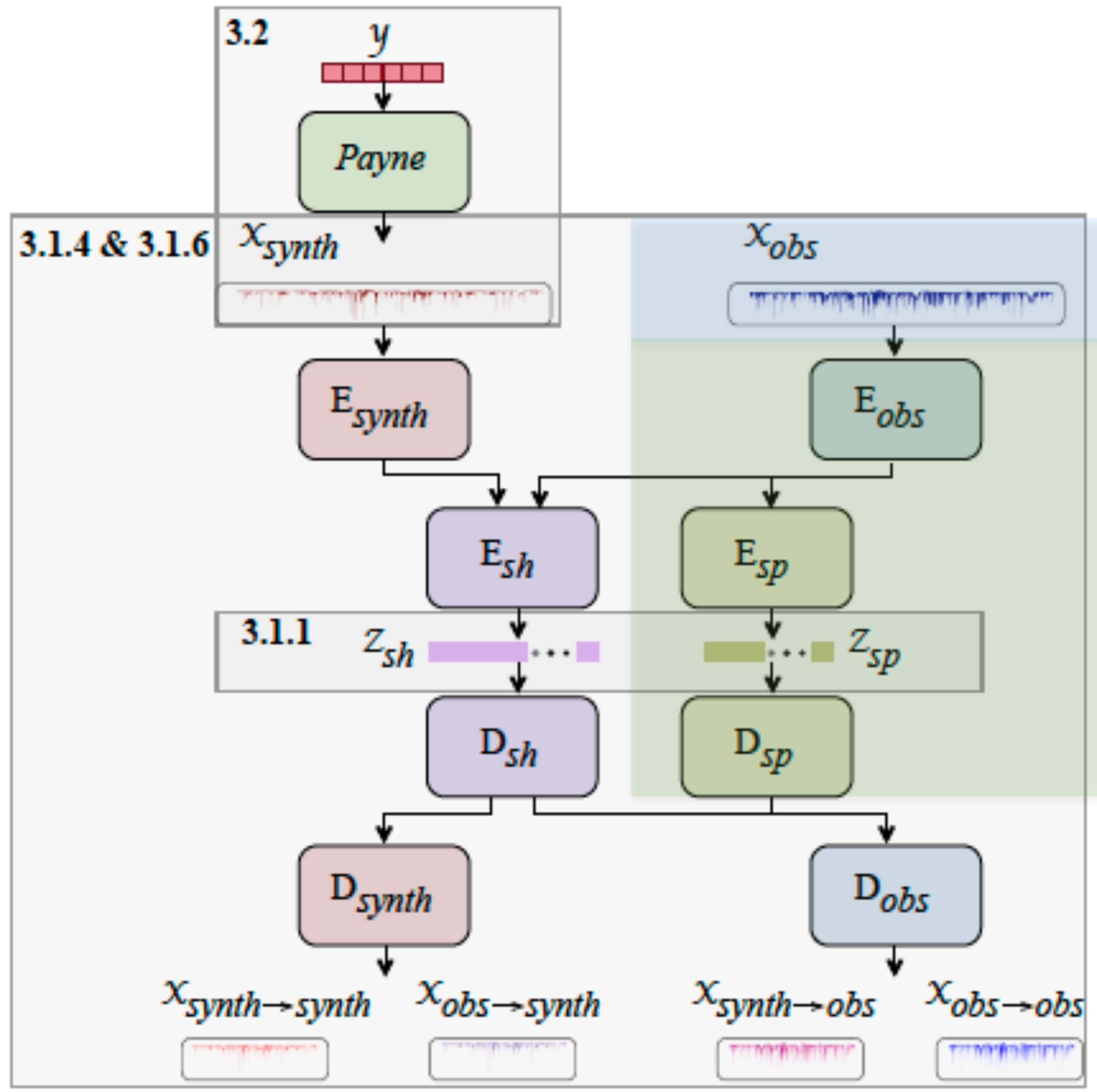
Lund : 14 Apr 2021



1. **Simplest acts of awareness and respect for the Indigenous peoples in our communities.**

2. **Action from the United Nations Declaration on the Rights of Indigenous People and the Canadian Truth & Reconciliation Commission 2015.**

Firstly*



Cycle-StarNet

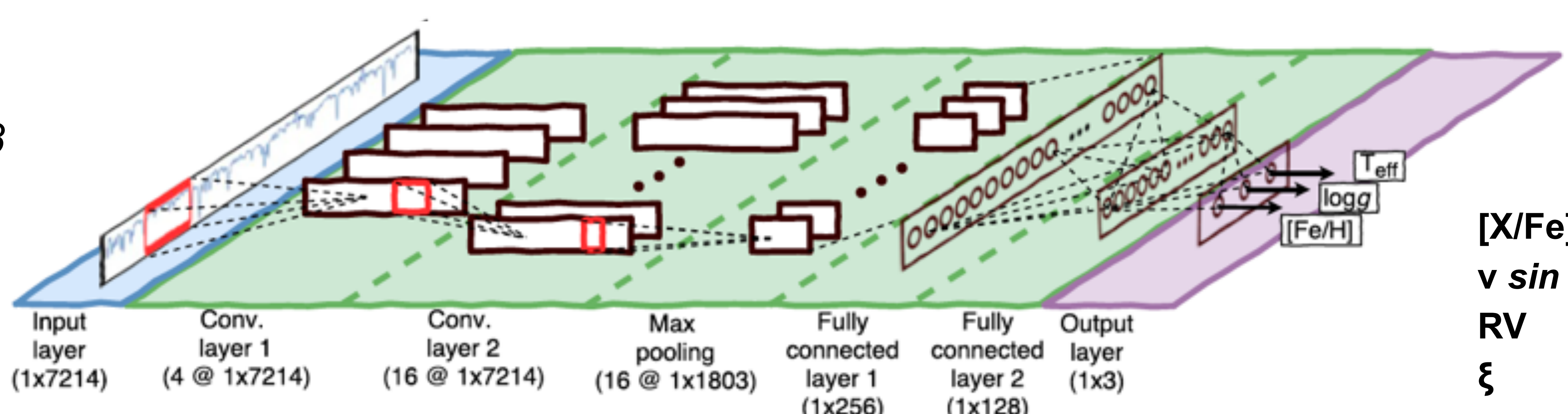
O'Briain et al. 2020

*(*YS Ting talk)*

StarNet

Fabbro et al. 2018

Bialek et al. 2020



<—— range of hyper parameters possible ——>

[X/Fe]
v *sin* i
RV
ξ
SNR

Secondly*

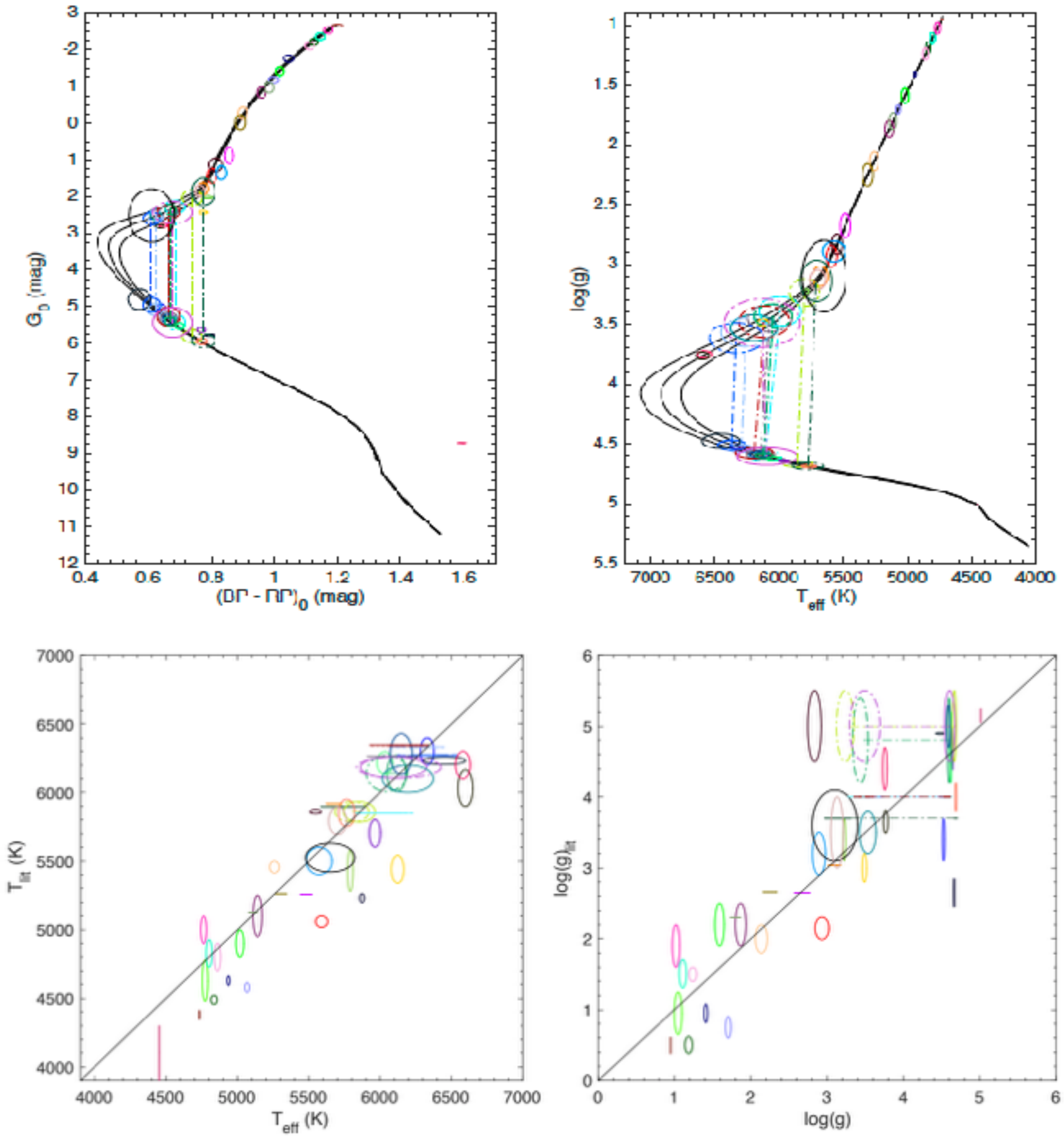
Challenges
in analyzing EMP stars, stellar parameters.

In Sestito et al. (2019):

Gaia DR2 colours and parallaxes were used with isochrones **(*M Joyce talk)** and a Bayesian inference method for Teff and log in UMP stars.

Comparisons with the literature values showed

Δ Teff < 800 K
Δ log *g* < 1.0, or
< 2.0 dwarf/subgiant

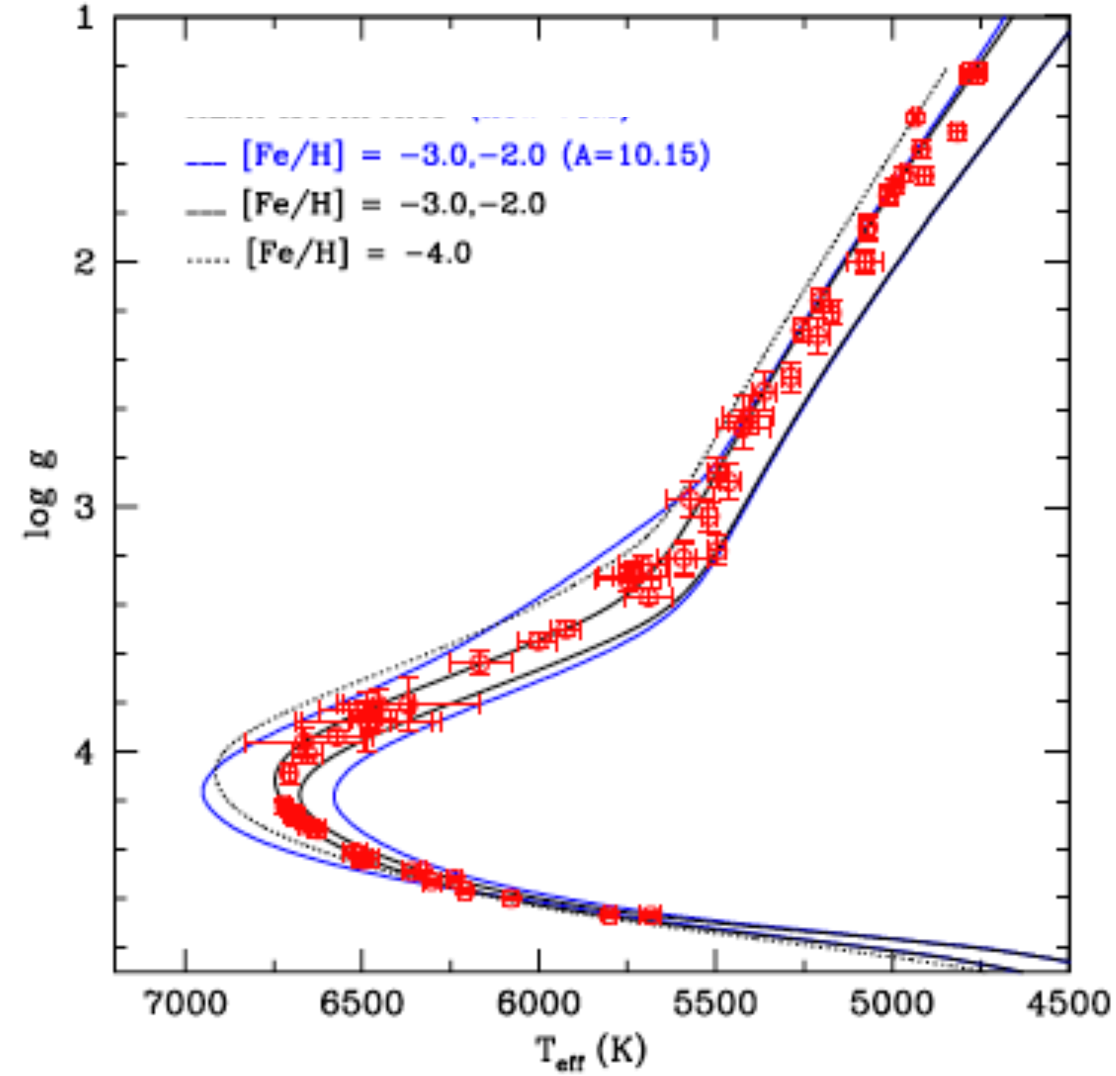


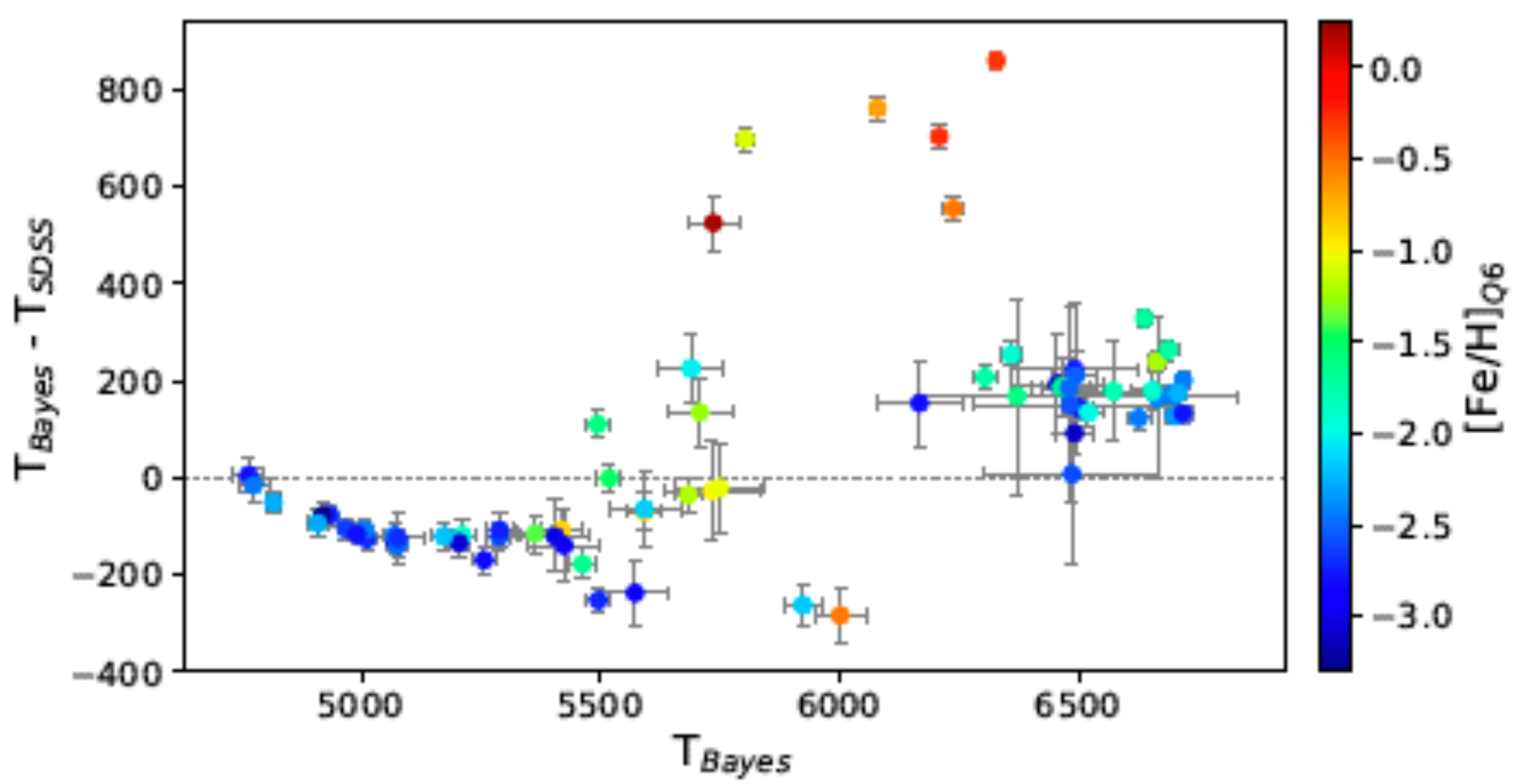
In Venn et al. (2020):

Used the Gaia DR2 colours and parallaxes for Bayesian inferred stellar parameters of newly discovered EMP stars from Pristine (CFHT ESPaDOnS).

Also found significant differences when compared to other methods (T_{SDSS} shown).

Δ Teff < 800 K (full sample)
< 300 K (EMP stars)





In Kielty et al. (2020, submitted):

Again, used the Gaia DR2 colours and parallaxes for Bayesian inferred stellar parameters of newly discovered EMP stars from Pristine (Gemini GRACES).

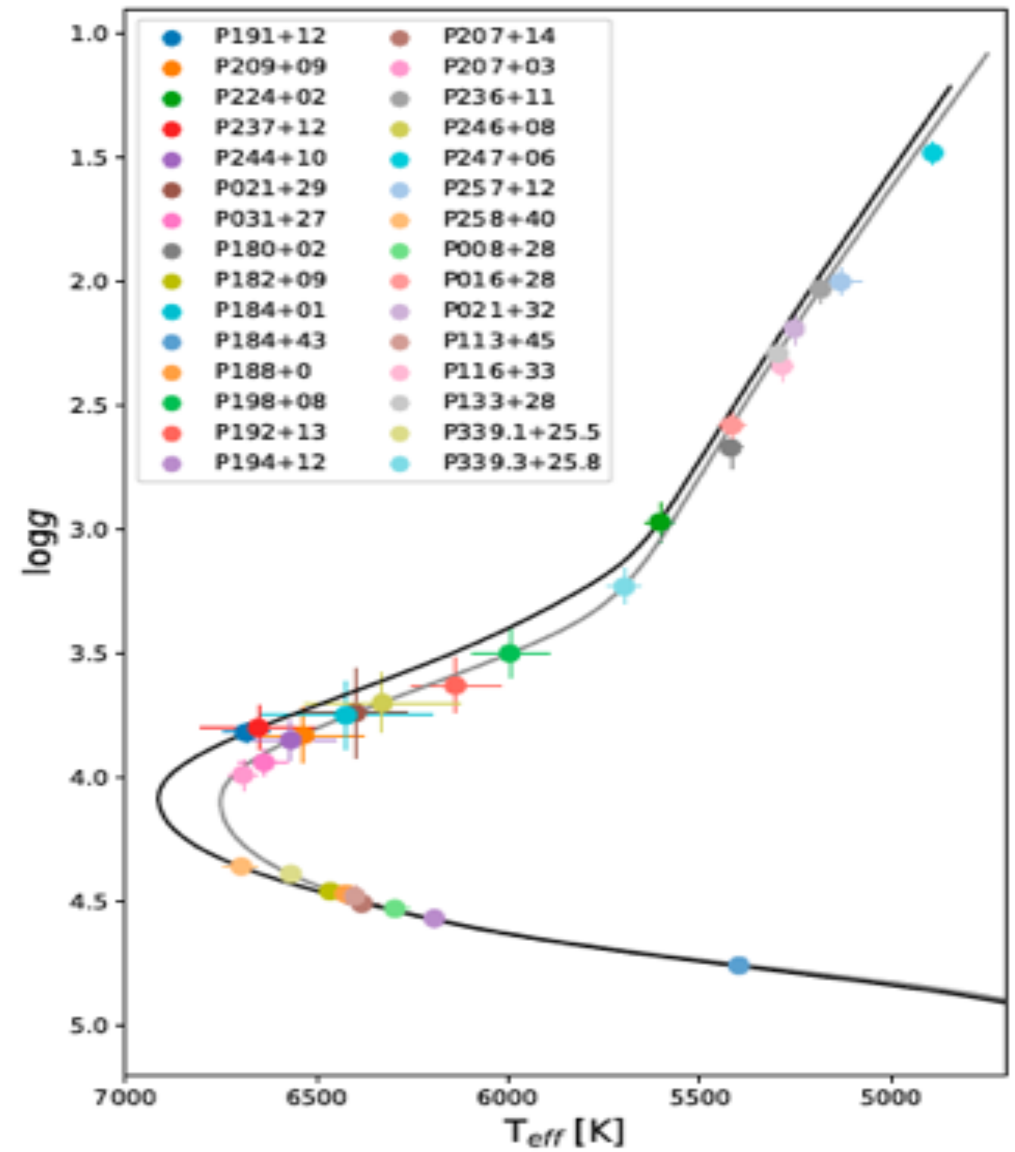
Full sample has [Fe/H] < -2.5, so Teff offsets not due to metallicity.

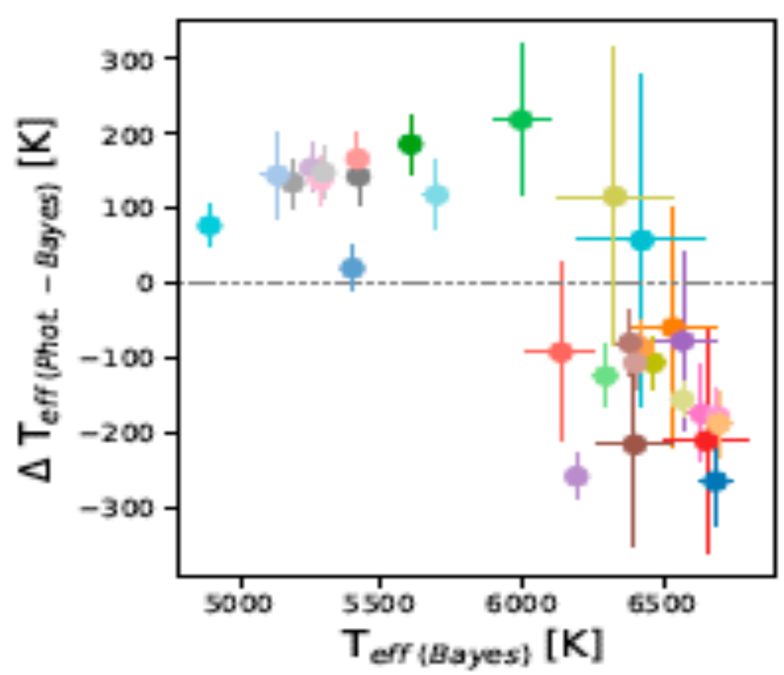
Again, offsets from other methods:

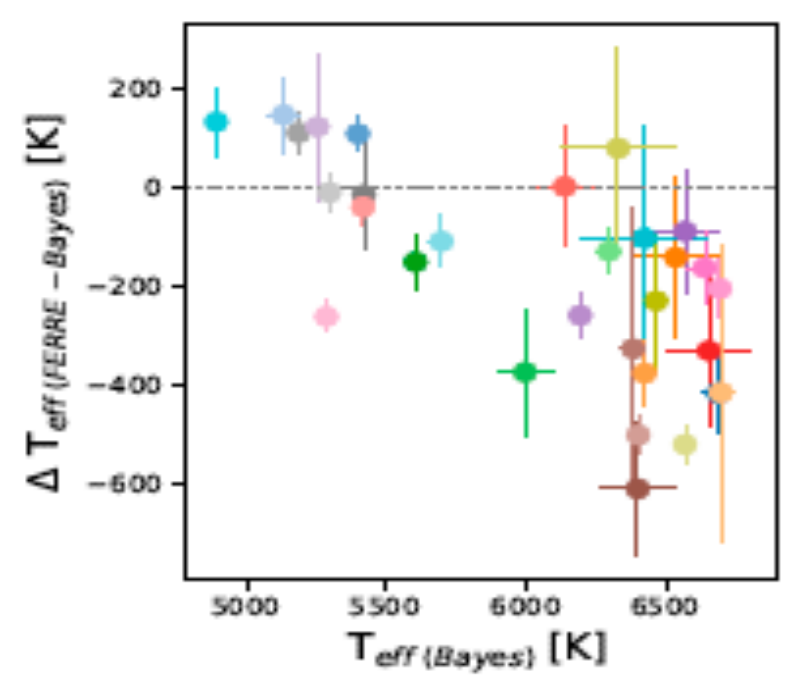
Δ Teff < 300 K (photom)

Δ Teff < 600 K (FERRE)

These Teff differences would require big changes in log g on those isochrones!

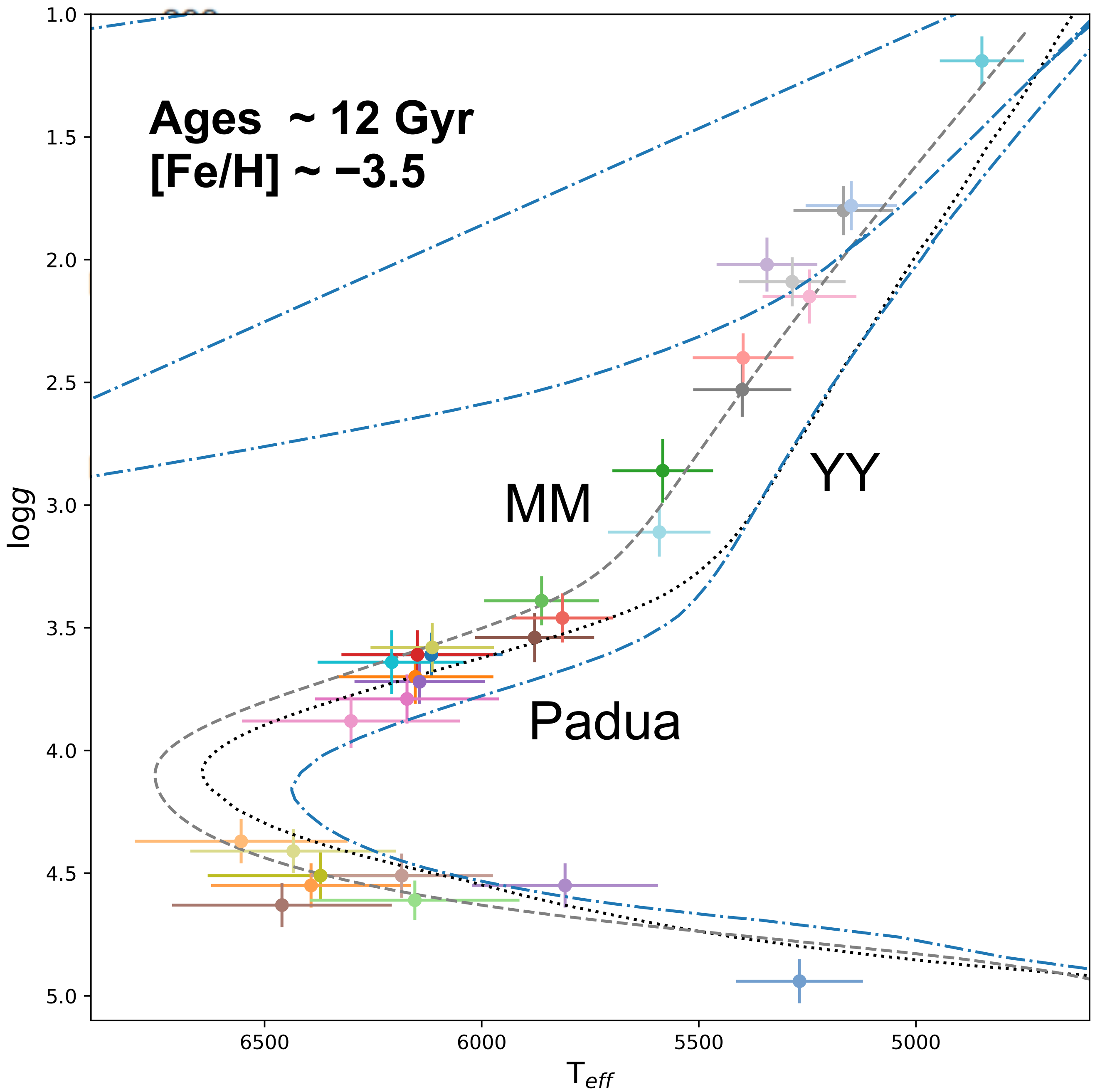






In Kielty et al. (2020, revised):

We can see the isochrones for EMP stars are not consistent between different models.
We are adopting a different approach now (data points)…



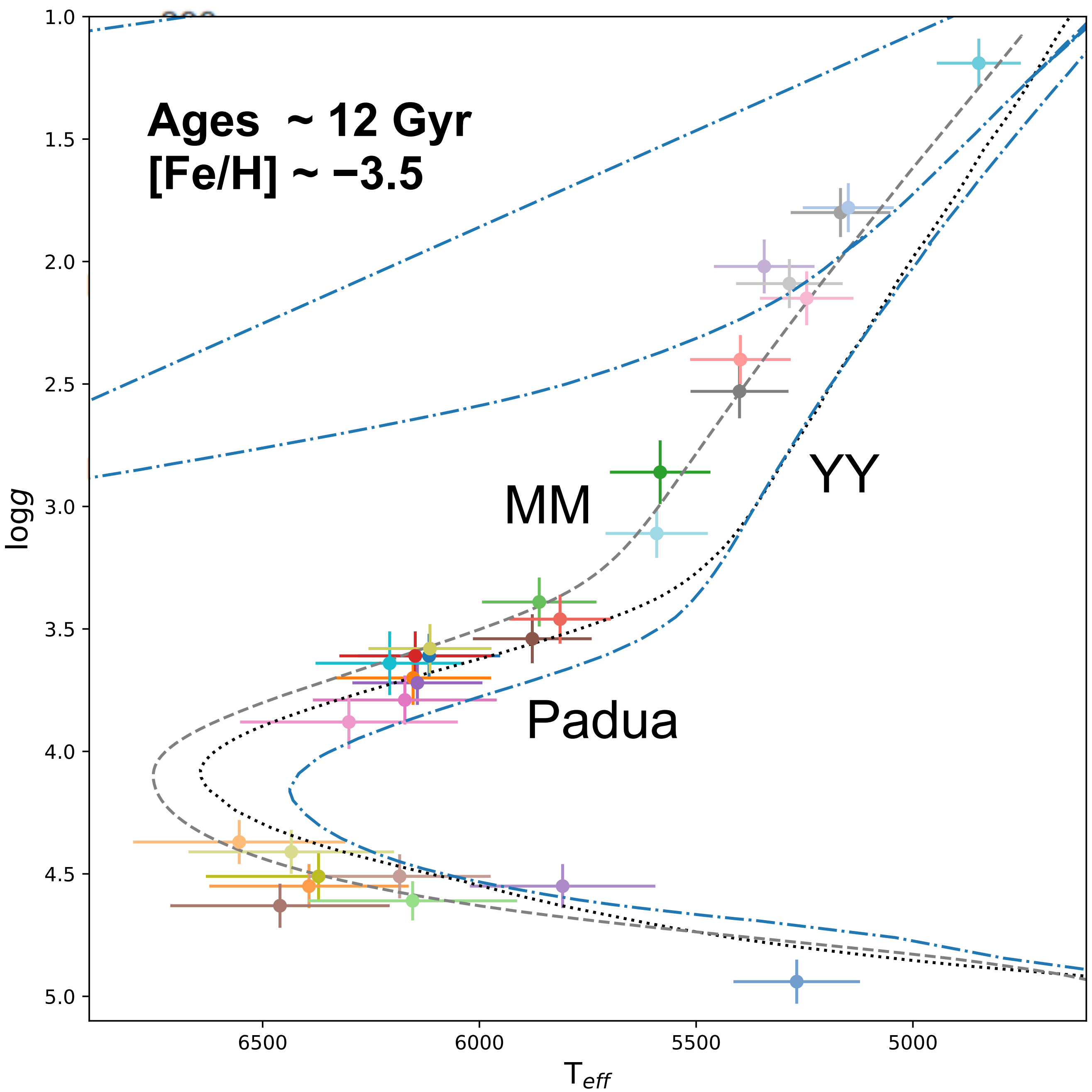
Can these be improved through calibrations of field EMP stars?

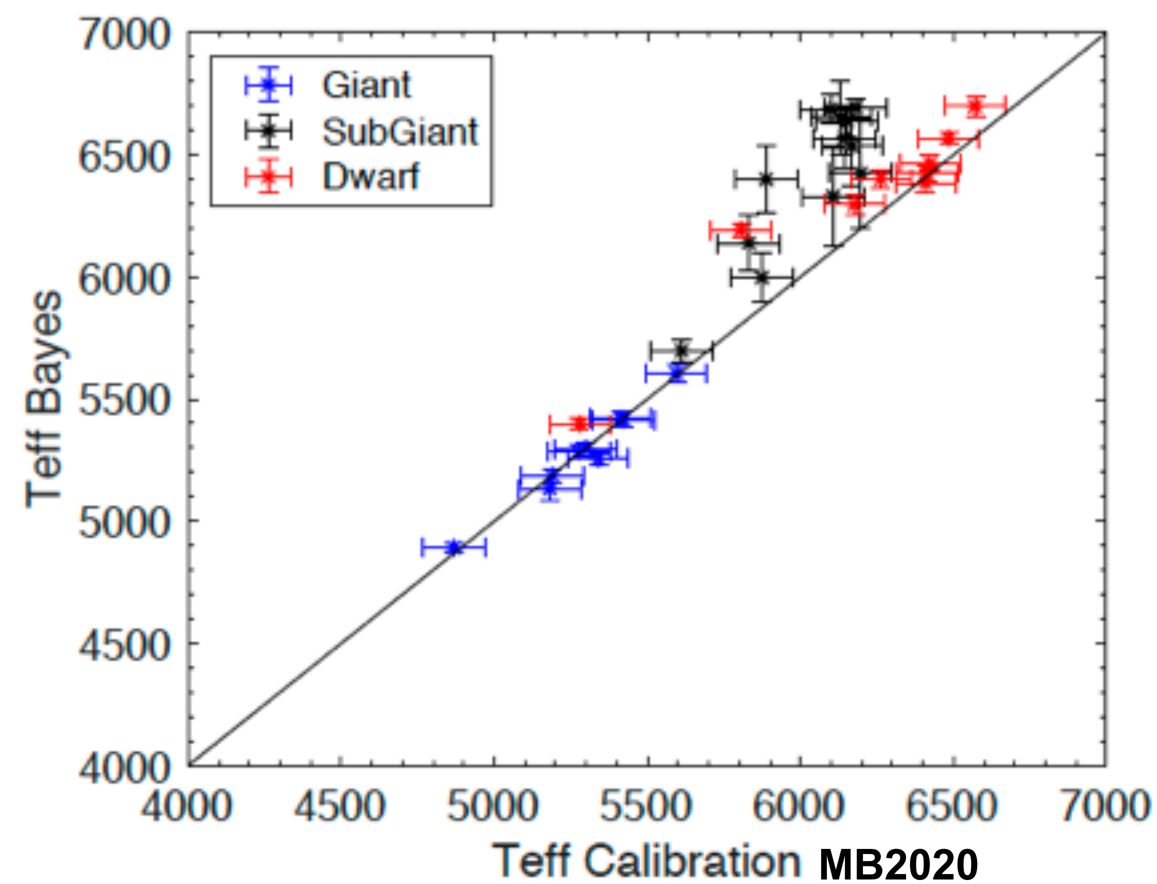
In Kielty et al. (2020, revised):

We can see the isochrones for EMP stars are not consistent between different models.
We are adopting a different approach now …

Mucchiarelli & Bellazzini (2020) T-colour calibration for Gaia colours*

$$5040/T_{eff} = b_0 + b_1(BP-RP) + b_2(BP-RP)^2 + b_3[Fe/H] + b_4[Fe/H]^2 + b_5[Fe/H](BP-RP)$$





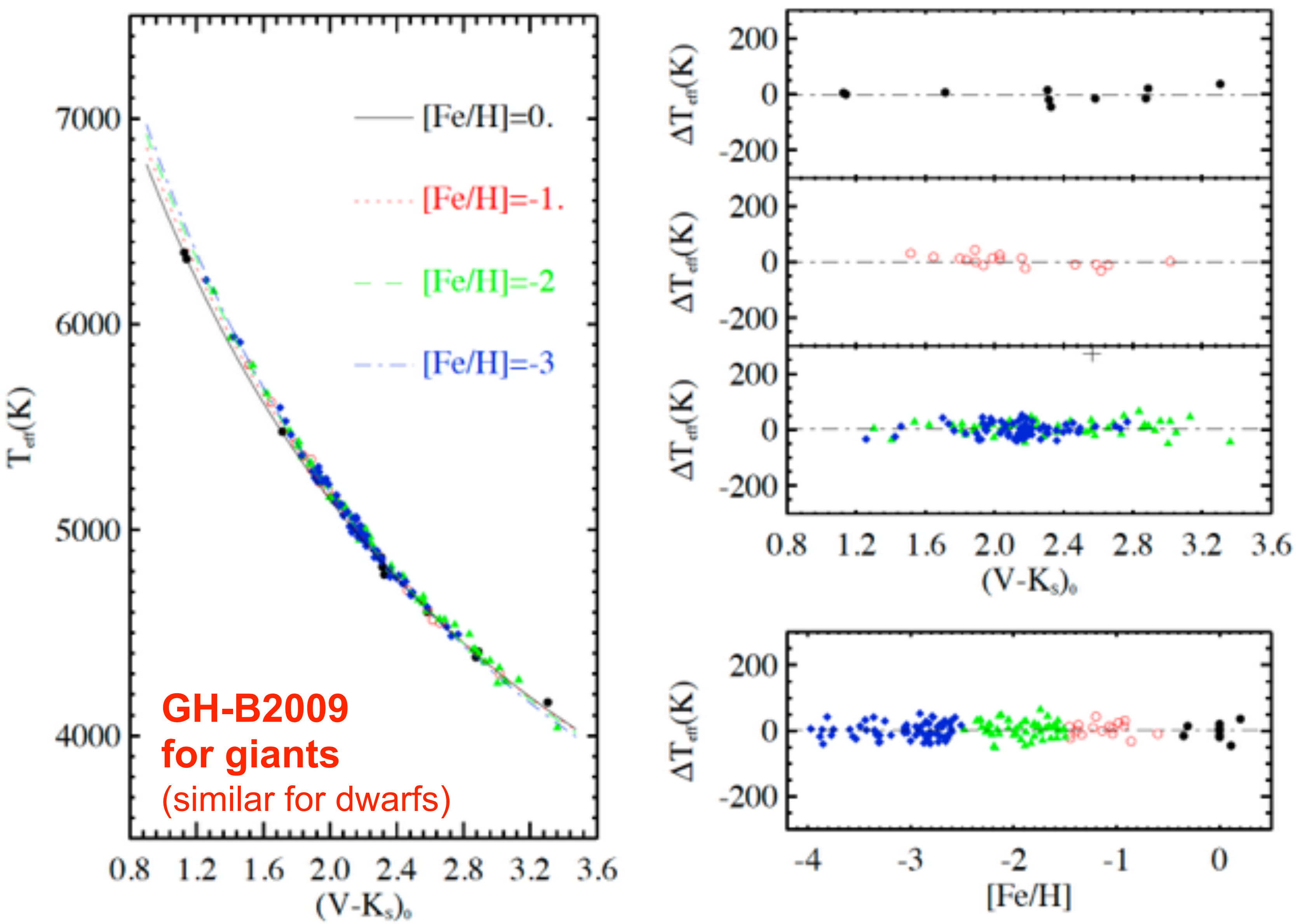
Calculations by Federico Sestito

Mucchiarelli & Bellazzini 2020

Update for Gaia colours from Gonzalez-Hernandez & Bonifacio (2009) IRFM, who calibrated T's based on 2MASS and UBV colours over a wide range of stellar properties, including EMPs.

Mucchiarelli & Bellazzini (2020) T-colour calibration for Gaia colours*

$$5040/T_{eff} = b_0 + b_1(BP-RP) + b_2(BP-RP)^2 + b_3[Fe/H] + b_4[Fe/H]^2 + b_5[Fe/H](BP-RP)$$



Casagrande et al. 2021

Also update for Gaia colours from Casagrande et al. (2010) IRFM, who calibrated T's based on 2MASS and UBV colours over a less wide range of stellar properties (few EMPs).

Mucchiarelli & Bellazzini (2020) T-colour calibration for Gaia colours*

$$5040/\mathrm{Teff} = b_0 + b_1(\mathrm{BP-RP}) + b_2(\mathrm{BP-RP})^2 + b_3[\mathrm{Fe/H}] + b_4[\mathrm{Fe/H}]^2 + b_5[\mathrm{Fe/H}](\mathrm{BP-RP})$$

Casagrande et al. (2021) T-colour calibration for Gaia colours*

$$T_{\mathrm{eff}} = a_0 + a_1 X + a_2 X^2 + a_3 X^3 + a_4 X^5 + a_5 \log(g) + a_6 \log(g)\, X + a_7 \log(g)\, X^2 + a_8 \log(g)\, X^3 + a_9 \log(g)\, X^5 + a_{10}[\mathrm{Fe/H}] + a_{11}[\mathrm{Fe/H}]\, X + a_{12}[\mathrm{Fe/H}]\, X^2 + a_{13}[\mathrm{Fe/H}]\, X^3 + a_{14}[\mathrm{Fe/H}] \log(g)\, X$$

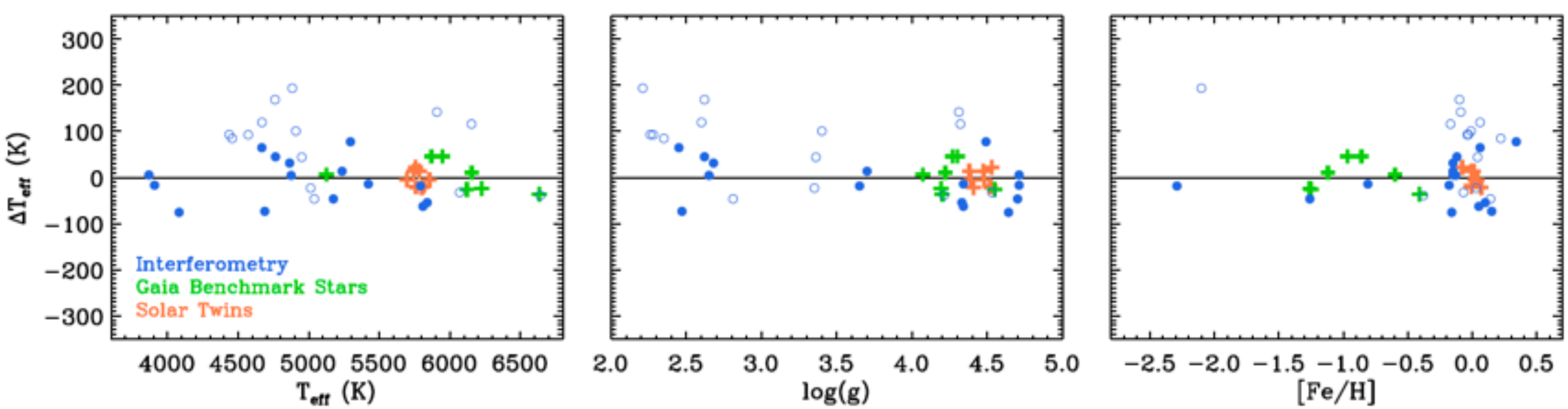
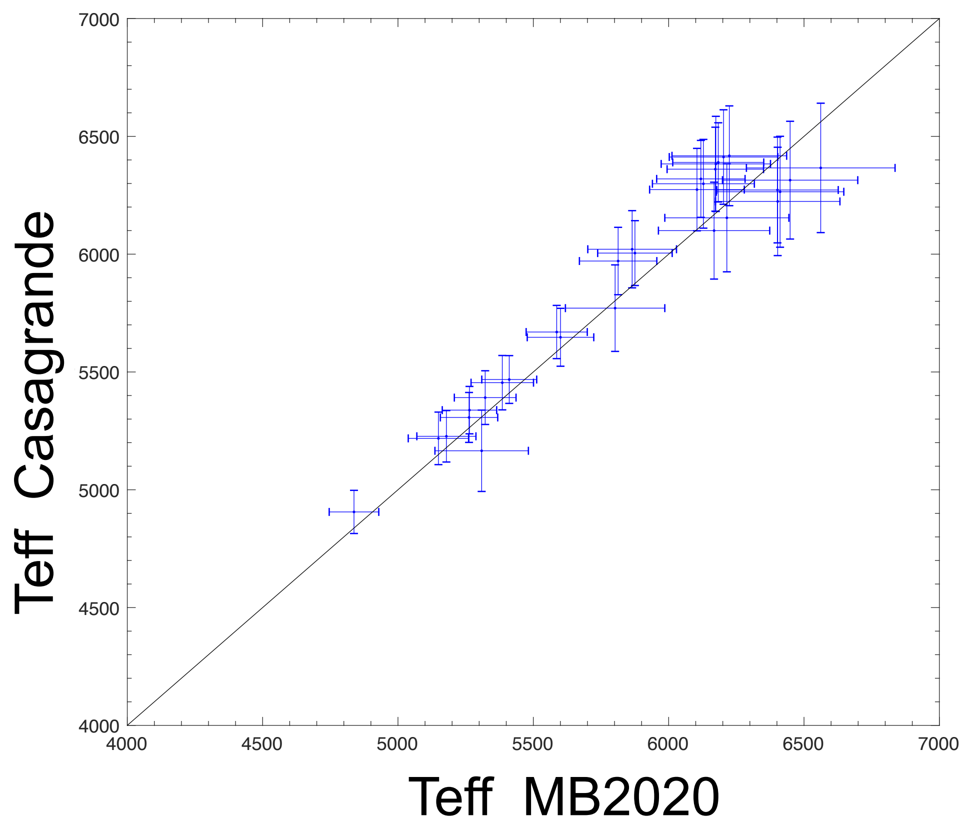
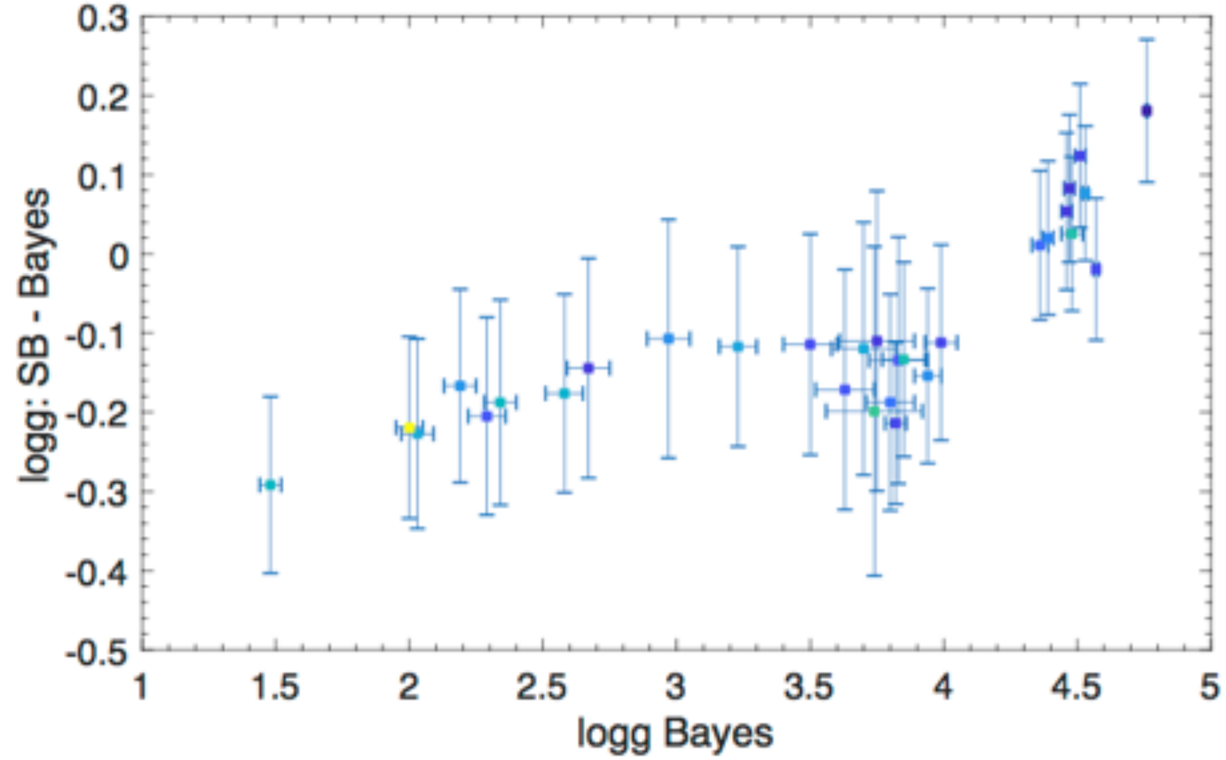


Figure 6. Comparison between T_{eff} derived using our $(BP-RP)_0$ relation and those available (ours−literature) for solar twins (orange), Gaia Benchmark Stars (blue) and interferometry (green). Filled and open circles indicate interferometric T_{eff} better than 1 and 2 percent, respectively.

Sestito et al. 2021 in prep

Comparison of Gaia colour T's for the Pristine-GRACES sample in Kielty et al. (2020, revised),
i.e., Casagrande et al. 2021 vs Mucchiarelli & Bellazzini 2020 (LEFT)
and gravities from Stefan-Boltzmann law



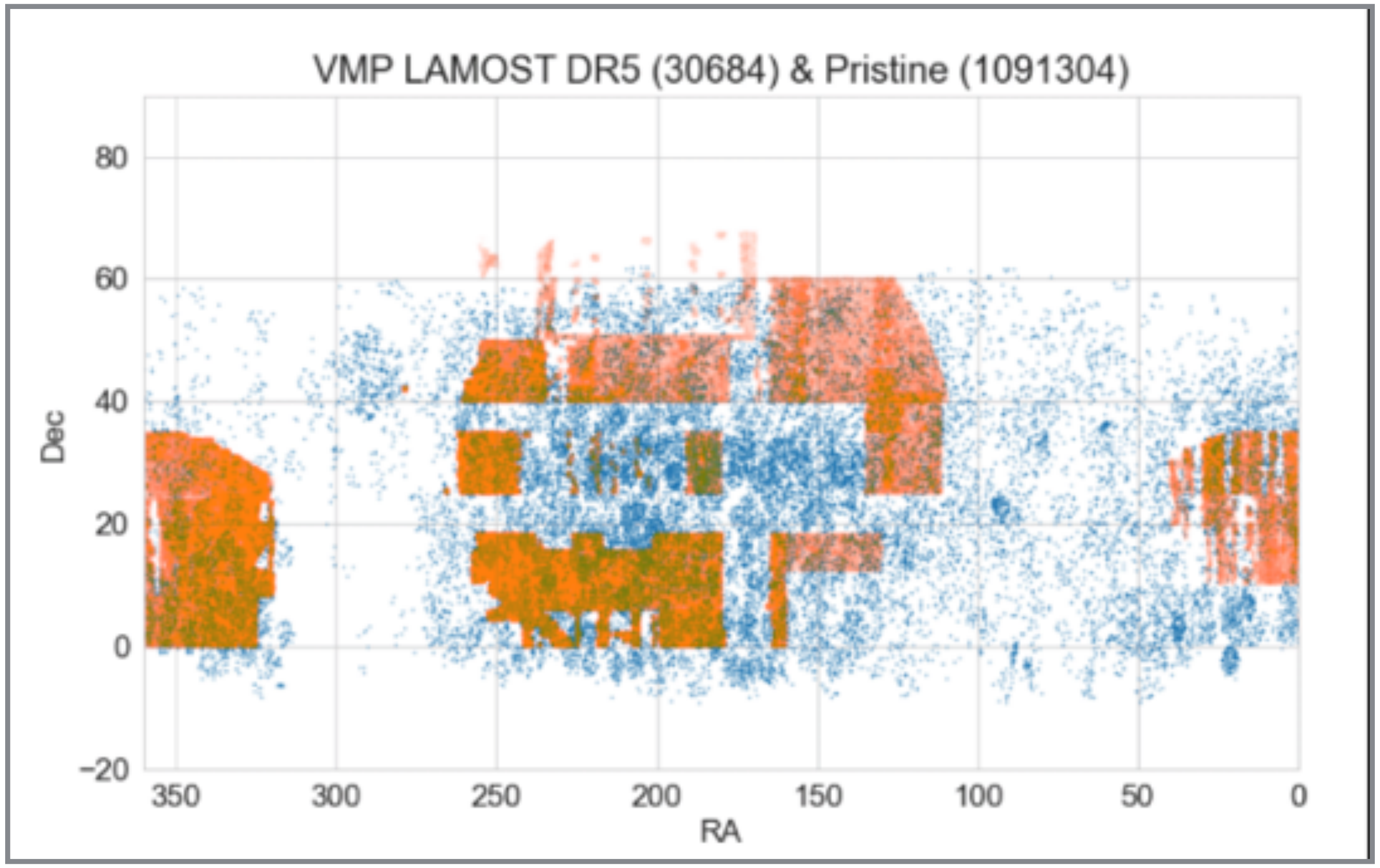


We do use [Fe/H] from Pristine as a first estimate, folding errors into the T uncertainties.

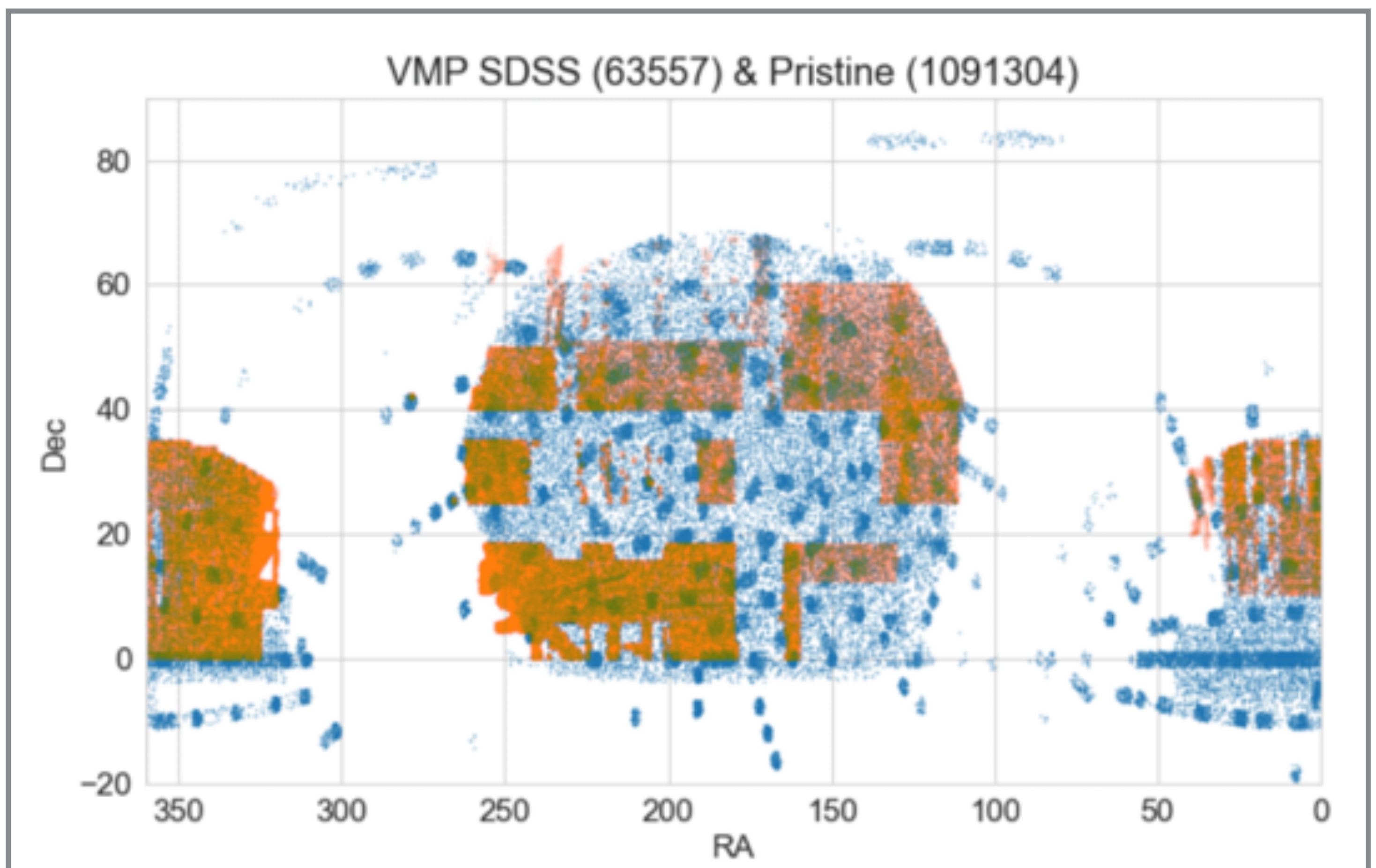
Log *g* using Stefan-Boltzmann law, uses Teff from MB2020, and flat M distribution (0.5 to 1.0 M⊙).

Thus, Teff and log g from only Gaia colours and parallax (L), metallicity, and extinction.

Can apply to the whole Pristine sample.


VMP LAMOST DR5 (30684) & Pristine (1091304)
Dec
RA
80
60
40
20
0
−20
350
300
250
200
150
100
50
0

Zhen Yuan

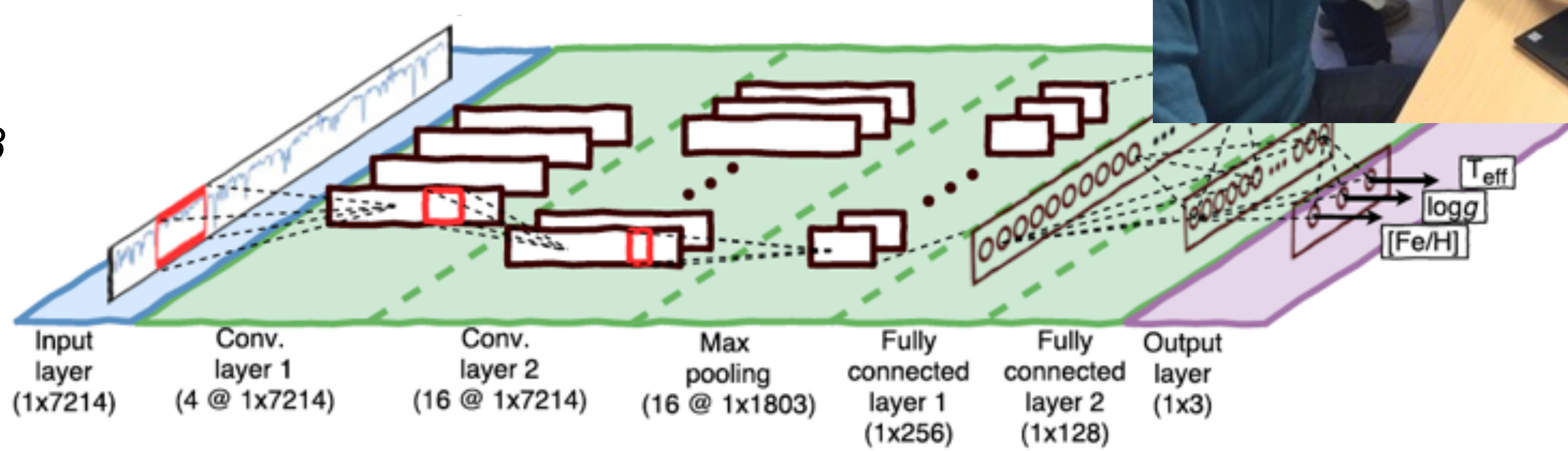

VMP SDSS (63557) & Pristine (1091304)
Dec
RA
80
60
40
20
0
−20
350
300
250
200
150
100
50
0

Instead of colour calibrations, also common to use spectral template fitting for stellar parameters

How do we calibrate these for precision results?

StarNet

Fabbro et al. 2018
Bialek et al. 2020



<—— range of hyper parameters possible ——>

[X/Fe]
v *sin* i
RV
ξ
SNR

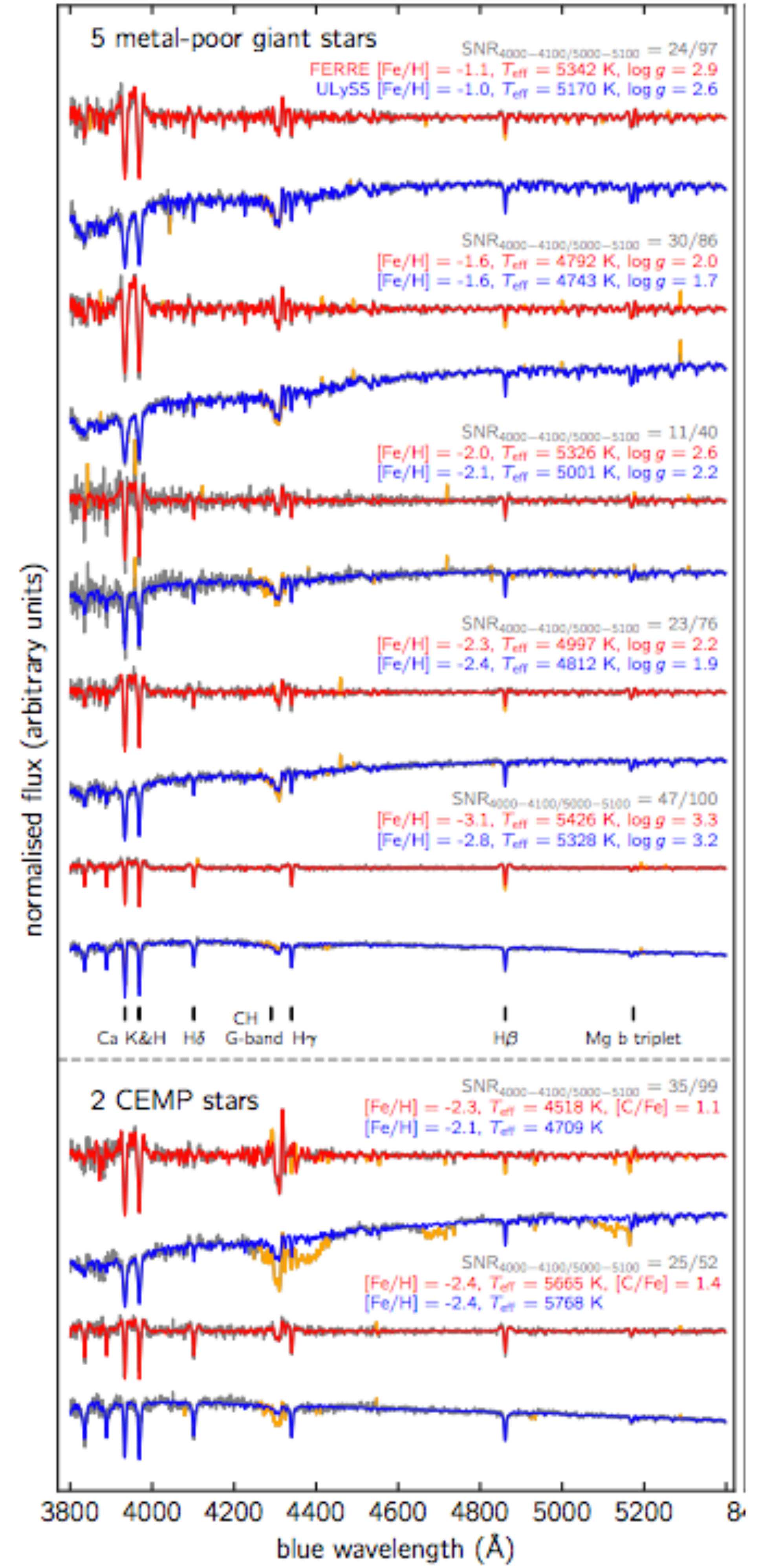
There has been a lot of work on spectral template fitting - I'm just going to discuss a few examples:

Arentsen et al. 2020 has been following-up on metal-poor candidates from the Pristine survey of the inner galaxy (PIGS).

She has collected spectra from AAT for ~12,000 targets at resolution R~2000.

Analysis uses two spectral template fitting programs, (some differences, e.g., continuum normalization)

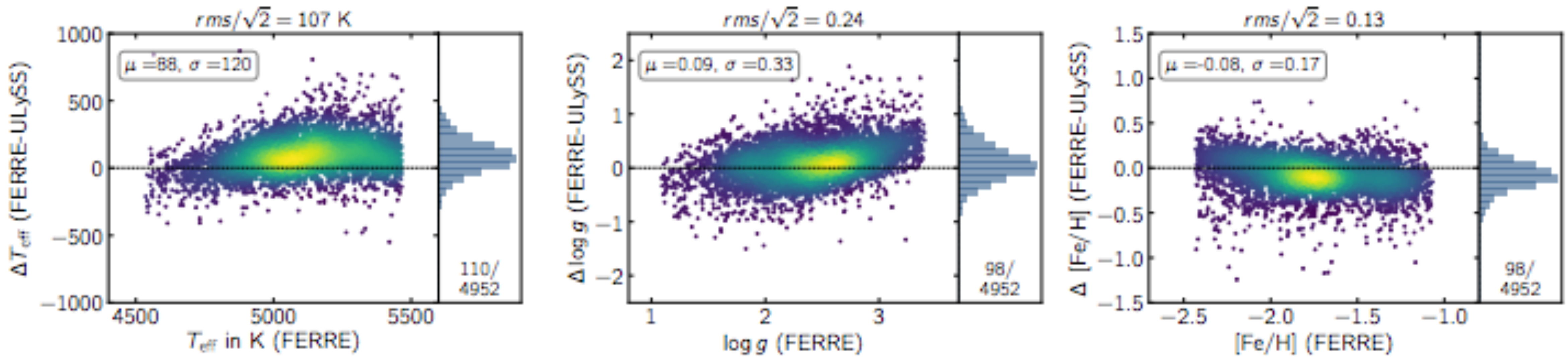
FERRE - synthetic grid of model atmospheres
ULYSSE - empirical stellar spectra (MILES)



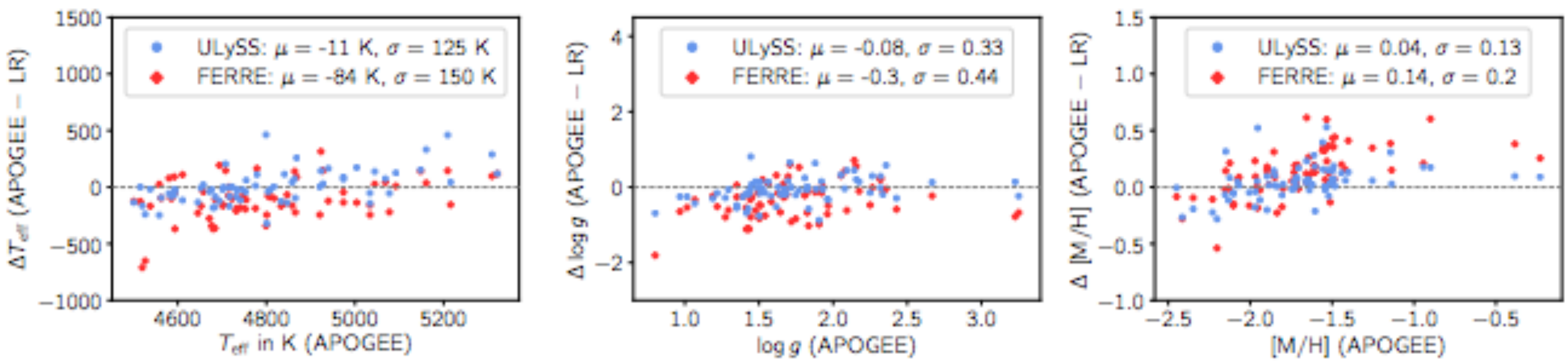
This is one approach to examining the synthetic gap, another is Cycle-StarNet (***YS Ting's talk**)

In Arentsen et al. (2020):

Incorporate differences between FERRE & ULySS as part of the errors analysis

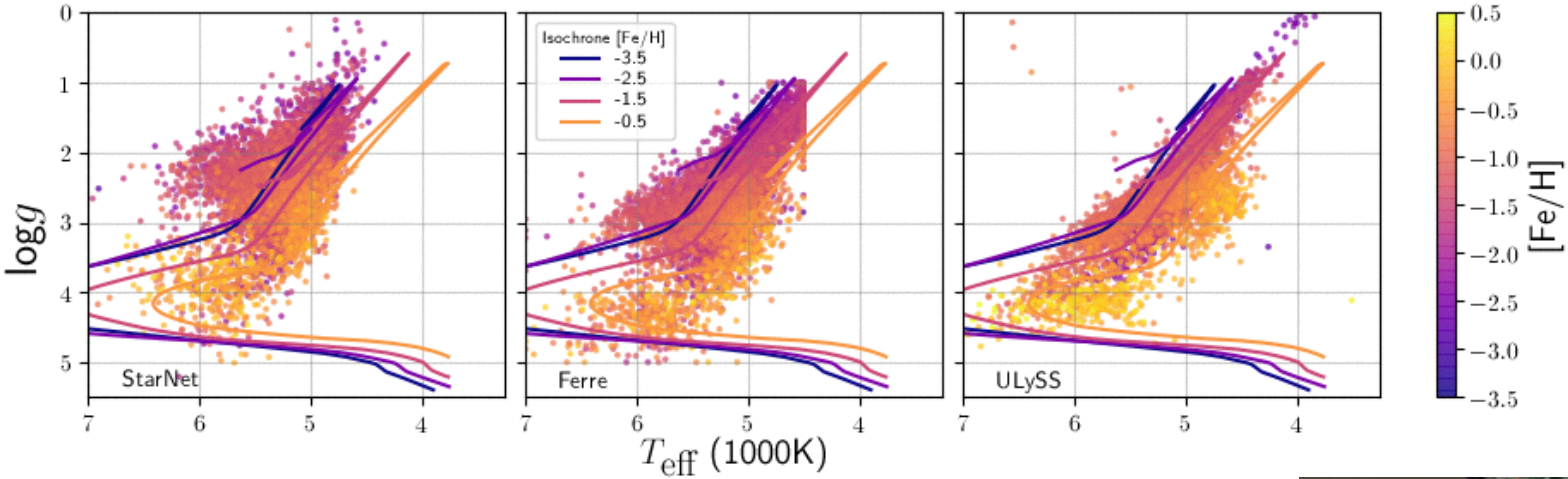


Compare individual stars in APOGEE (HRS) to also assess errors analysis in LRS



Additionally, Spencer Bialek has been examining PIGS spectra via StarNet.

Nice thing about synthetic grids is they can always be expanded and augmented.
Here, StarNet uses the 1DNLTE grid generated from MPIA NLTE website.



These early results are not great, yet. Initial tests have been with a small training grid, but the results are already encouraging for LR, broad wavelength (blue) spectra.

Could be applied to WEAVE-LR, or Gaia-RV survey

Builds from **Bialek et al. 2020** examination of synthetic grids with StarNet.

AMBRE

Pheonix

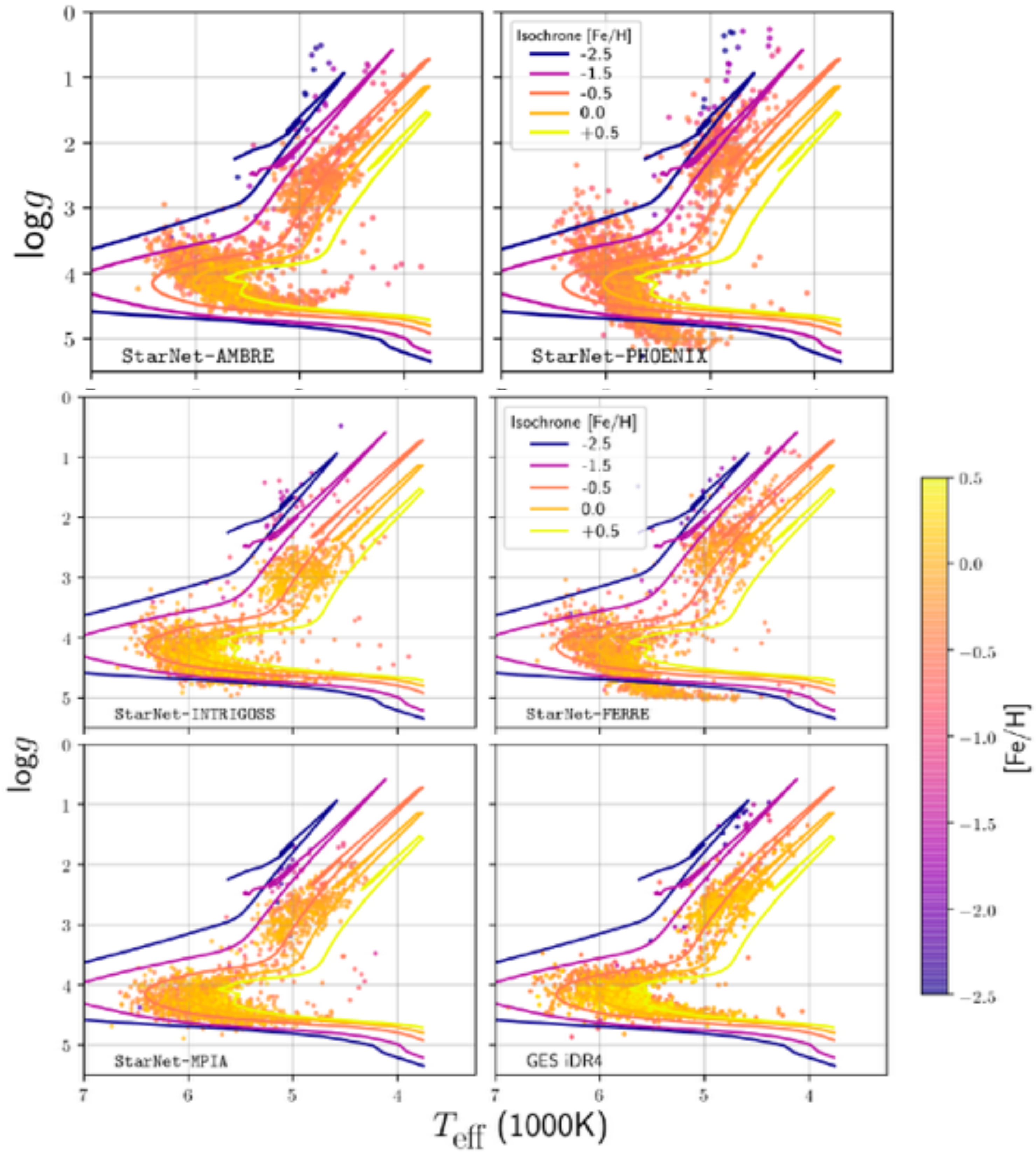
INTRIGOSS

FERRE

MPIA 1DNLTE

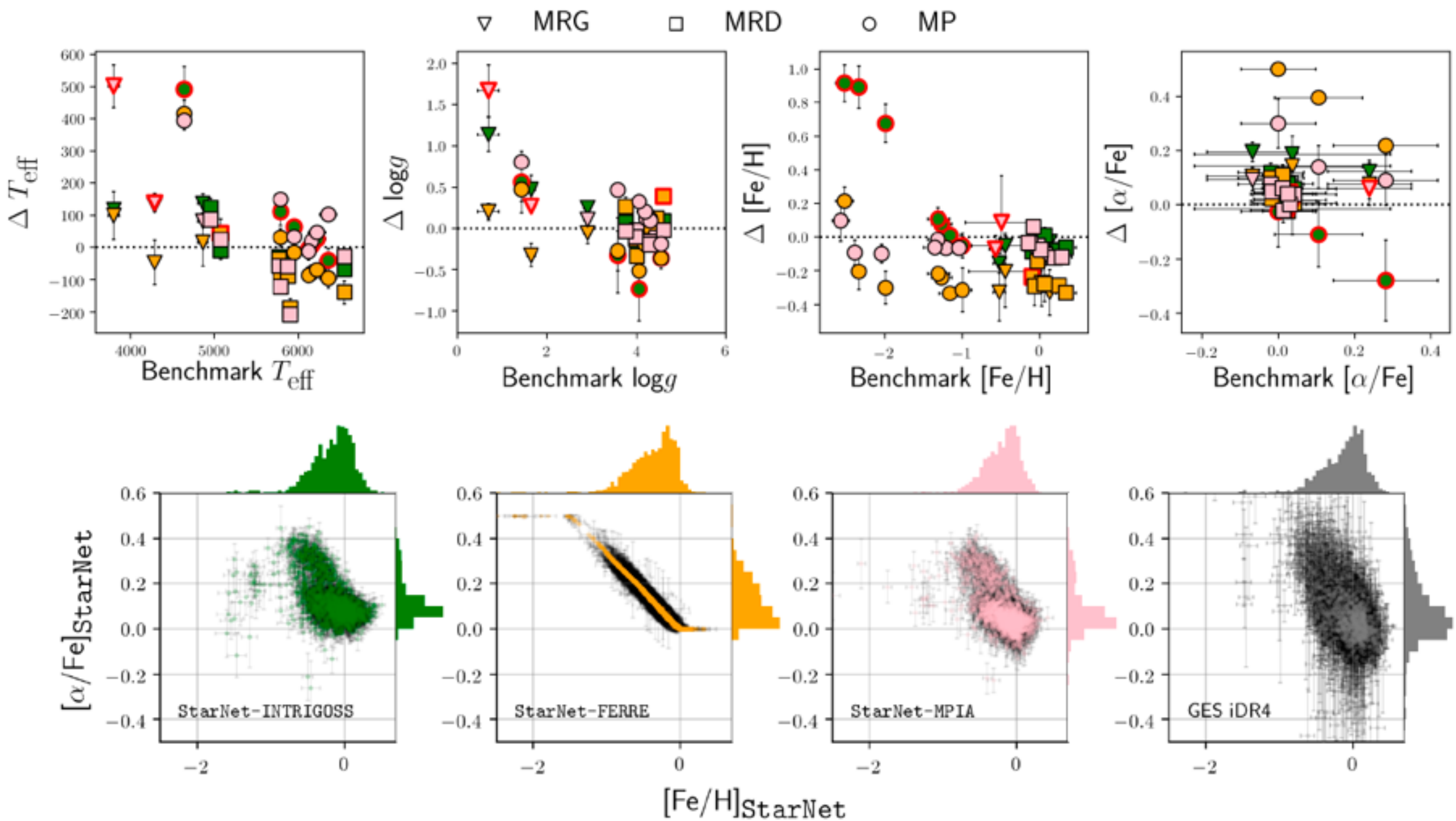
Comparing results from applications to the Gaia-ESO spectra (U520 data),

shows the semi-empirical INTRIGOSS and 1DNLTE MPIA grids recover iDR4 best.



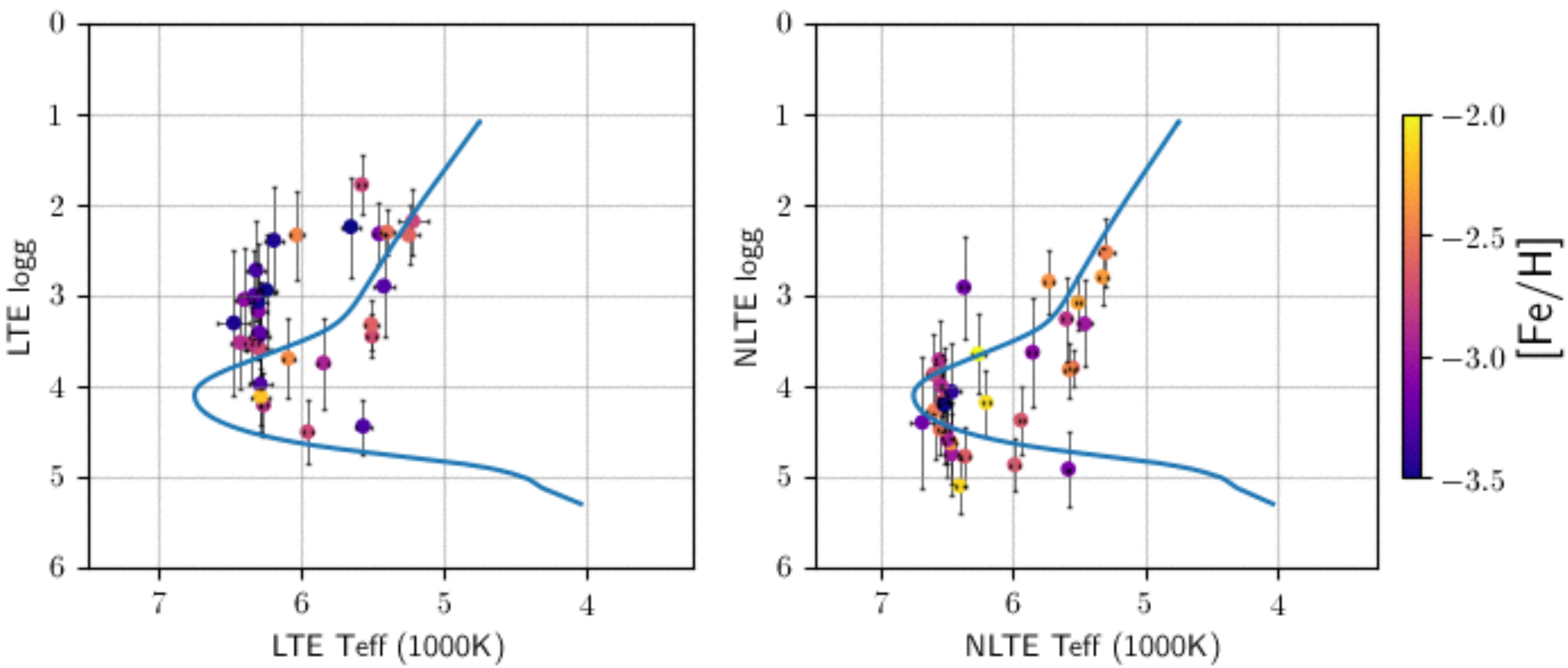
Bialek et al. (2020) also compared to GES benchmark stars specifically,

So long as stars were within the training grid boundaries, results we quite good.
(with the exception of [alpha/Fe] from our FERRE grid)



Spencer Bialek now using StarNet + MPIA 1DNLTE for GRACES

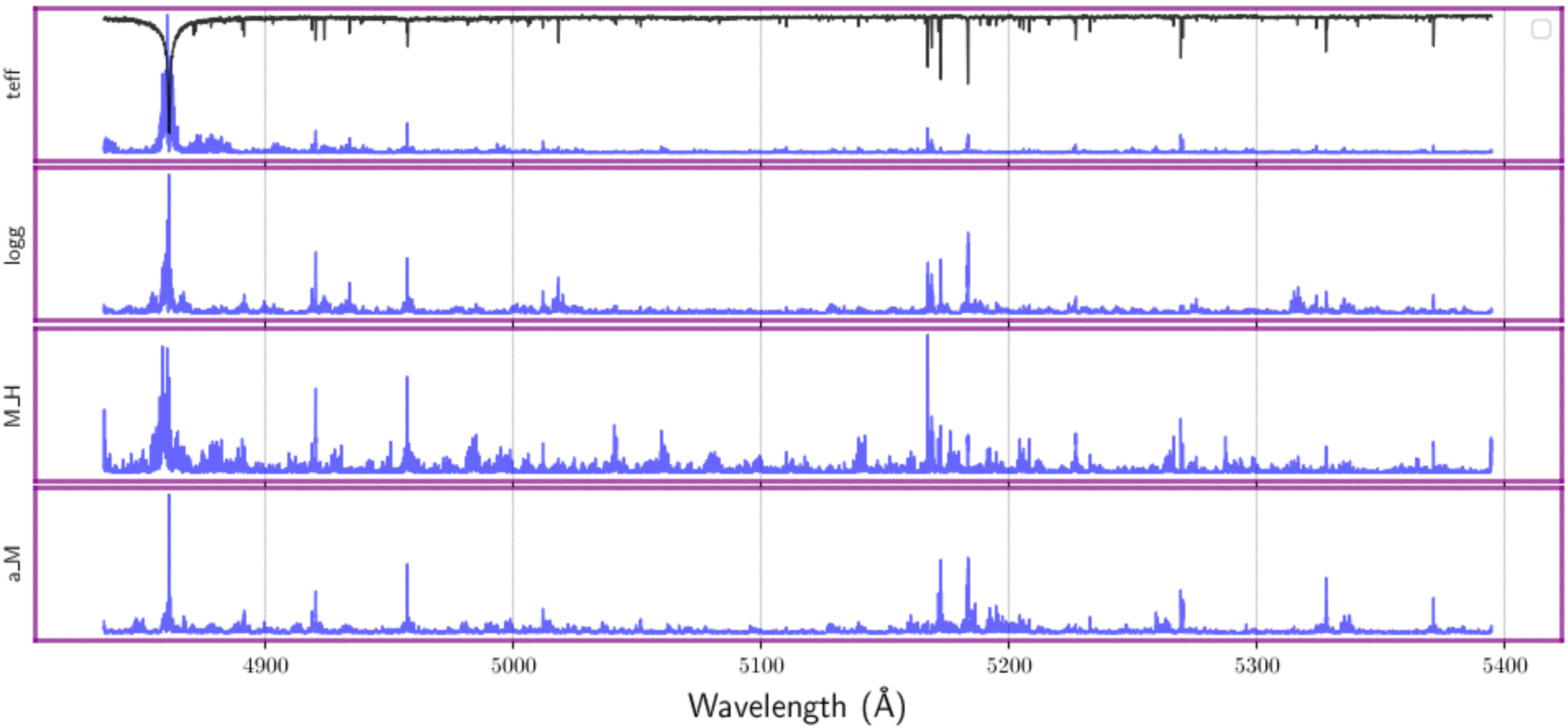
High resolution spectra (R~65,000), Kielty et al. 2020 sample of EMP stars.
Still early days, small training grid, but the 1DNLTE grid better matched to old isochrone.
We have not compared to MB2020 Teffs yet.



Could be applied to WEAVE-HR (4MOST, PSF)

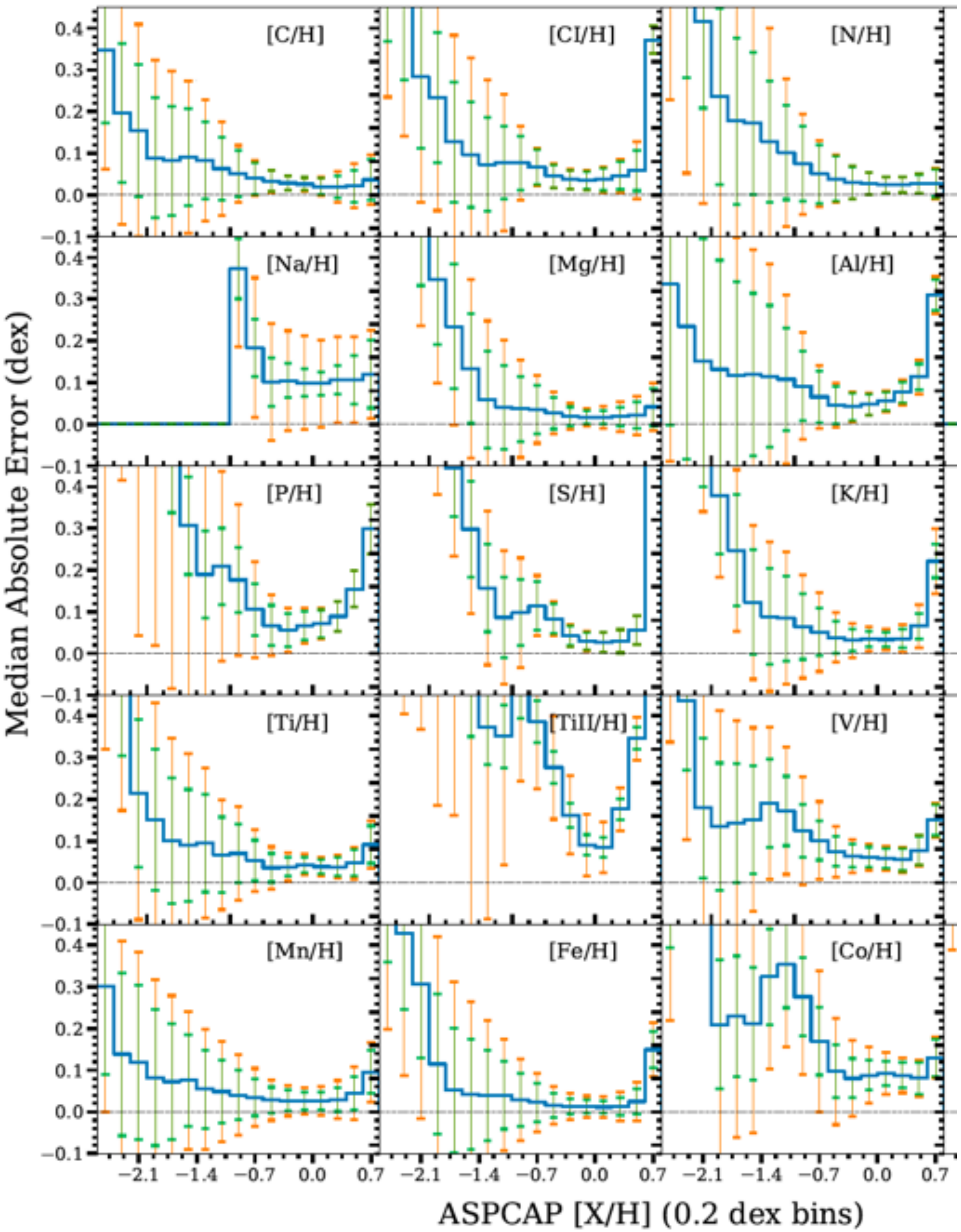
One concern with these GRACES spectra are the Balmer lines

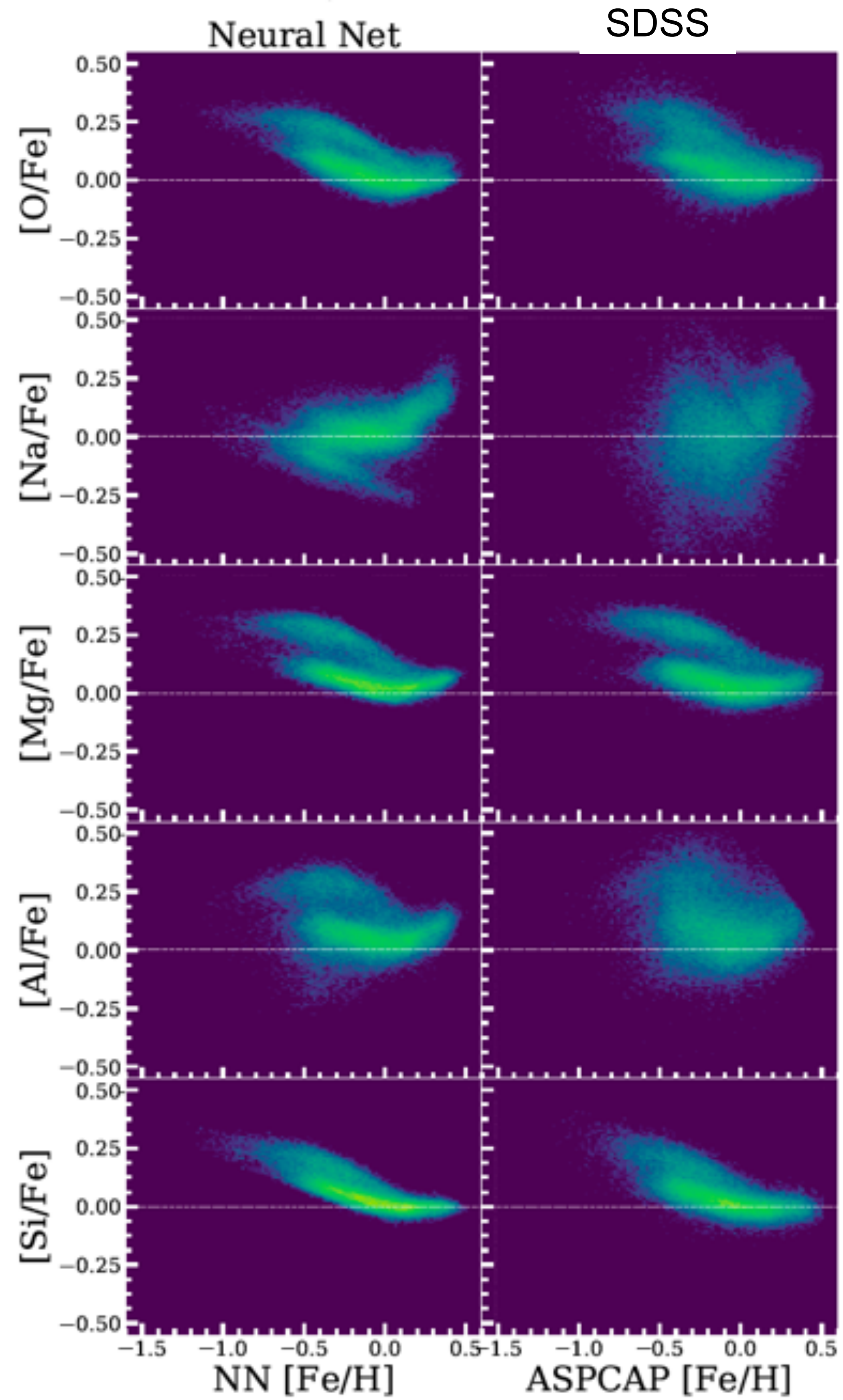
StarNet-MPIA 1DNLTE Teffs (too) strongly weighted by H-beta (~only)
Yes, cross-dispersed echelle means wings are in different orders.
More difficult to correct/normalize across orders as a Cassegrain optical fibre, not in a survey.



This is only the Gaia-ESO survey U520 spectral region. Fortunately, GRACES is wider.

Leung & Bovy 2019 developed a *data driven StarNet application with FERRE windows (=Astro-NN) applied to APOGEE DR14*





StarNet has been used in both data-driven and synthetic modes, and been applied successfully to both LR and HR spectra;

APOGEE	Fabbro et al. 2018
APOGEE (AstroNN)	Leung & Bovy 2019
LAMOST	Zhang et al. 2019, Xiang et al. 2021
Gaia-ESO	Bialek et al. 2020
Sitelle	Rhea et al. 2021

StarNet has now been used in both data-driven and synthetic modes, and been applied successfully to both LR and HR spectra;

APOGEE	Fabbro et al. 2018
APOGEE (AstroNN)	Leung & Bovy 2019
LAMOST	Zhang et al. 2019, Xiang et al. 2021
Gaia-ESO	Bialek et al. 2020
Sitelle	Rhea et al. 2021

The data driven modes require a priori data products

- ASPCAP, LAMOST, RAVE

The synthetic modes require synthetic grids

- MPIA 1DNLTE, INTRIGOSS, FERRE, etc.

and both require benchmark reference stars!

- Sun, Arcturus, Vega are not enough
- APOGEE, Gaia-ESO, (GALAH) data catalogues
- need more very metal-poor stars
- also spectroscopic binaries, rapid rotators, chemically peculiar stars, r-rich stars, CEMP, alpha-challenged, etc.

Upcoming spectroscopic surveys expected to map EMP stars

LR: PIGS, Gaia-RV, WEAVE-LR (SDSS-V, PFS)
HR: WEAVE-HR, GHOST (4MOST)

So we really need new and more benchmark reference stars!