Chemical evolution in the context of GALAH:
description of methods and preliminary results

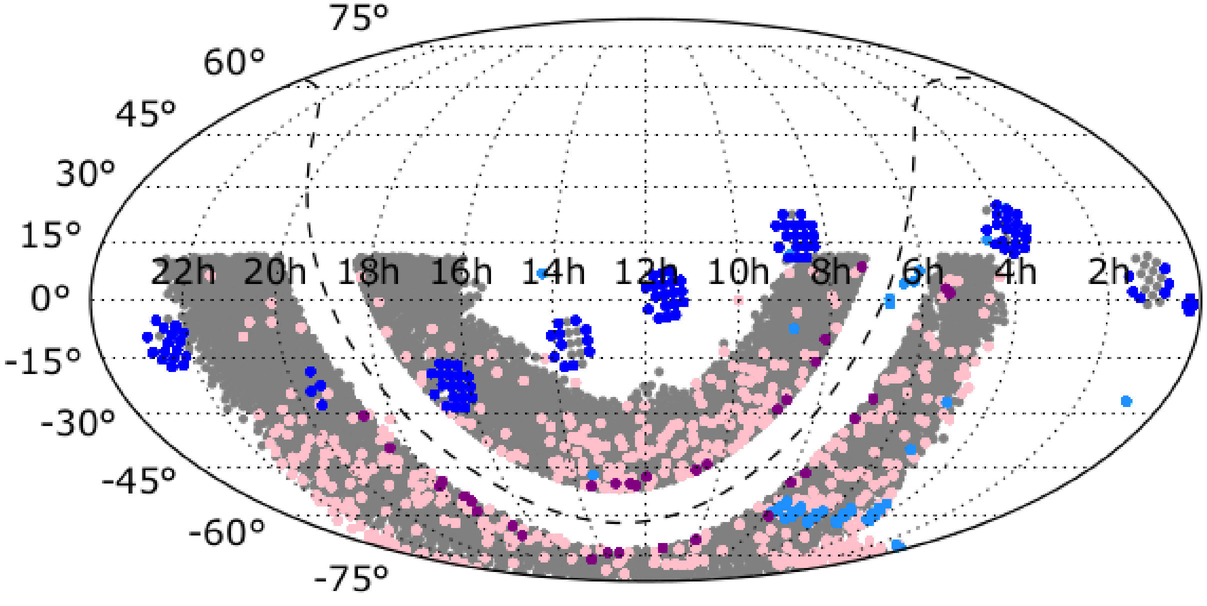
Jane Lin

Martin Asplund, Aaron Dotter
the GALAH Collaboration

The GALAH Survey

- 1 million stars spectroscopic survey of the Milky Way, primarily targeting the disk.
- Main goal is to use chemical tagging to reconstruct the formation and evolution of the Galaxy.
- Obtaining elemental abundances of 29 elements:

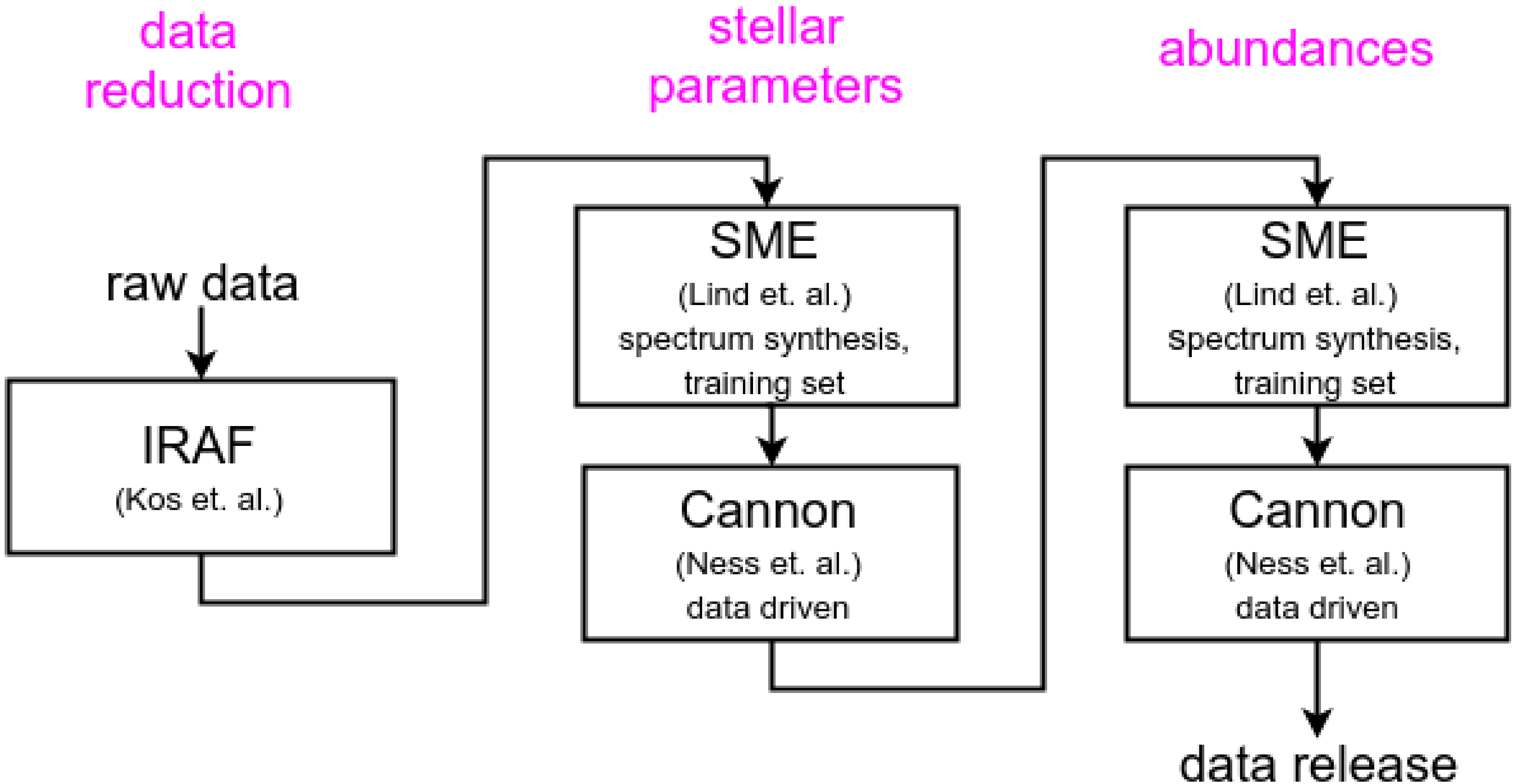
Light elements: Li, C, Alpha elements: O, Mg, Si, Ca, Ti Light odd-Z: Na, Al, K, Iron-peak: Sc, V, Cr, Mn, Fe, Ni, Co, Cu, Zn, s-process: Rb, Sr, Y, Zr, Ru, Ba, La, r-process: Ce, Nd, Eu



Survey progress as of Jan 2016.
Grey= unobserved fields
Pink=observed fields
Purple=Tycho-2 bright stars
blue=K2-HERMES
Cyan=pilot survey fields
Total= ~250k stars observed

Figure from Martell (2016).

Data flow in GALAH



Spectroscopy Made Easy (SME)

(Piskunov & Valenti (2016))

- Solving for: Teff, logg, [m/H], vsini, micro/macro turbulence, radial velocity (RV) and elemental abundances. Steps:

  1) Spectral masking- only informative regions are retained.

  2) Initial synthesis to determine RV and continuum.

  3) Solving for global stellar parameters (e.g. Teff, logg, [m/H])

  4) Solving for individual abundances, with fixed stellar parameters.

- NLTE correction in the form of departure coefficients.
- Sources of parameter uncertainties:

  1) Numerical errors in the solver (negligible)

  2) Measurement errors in observations (quality dependent)

  3) Physical errors from models (NLTE, poor atomic data etc...)

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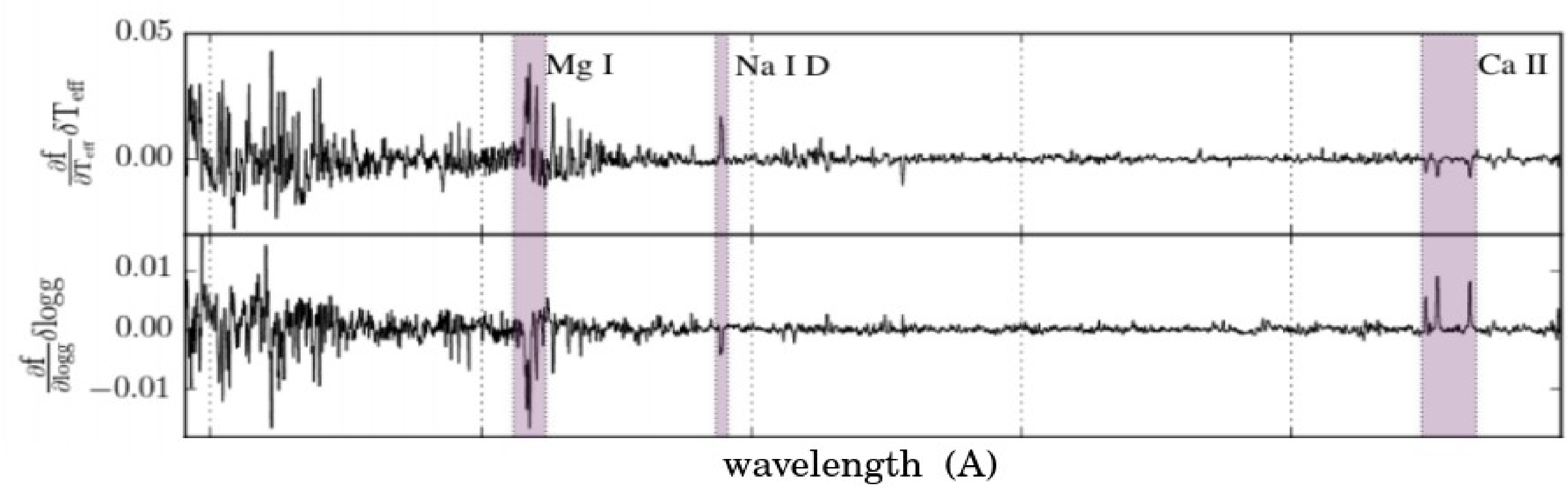
Main contributor to formal errors.
Actual errors likely underestimated!

The Cannon (Ness (2015))

- Data driven model using 'stellar labels' (e.g., stellar parameters):

  flux at a certain wavelength can be described as a smooth polynomial function of these labels.

- Two steps: training step to generate the functions and test step to transfer stellar labels to unknown spectra using generated functions.
- Model independent, relies on an externally robust set of training spectra.
- Quick convergence (<1 second/star compared to 15-30min/star using SME), ideal for large surveys.



Sensitivity of each pixel to stellar labels, as a function of wavelength. Major spectral features correspond to high sensitivity. Figure from Ho (2016).

SME→Cannon training set (stellar parameters)

- Training set of ~2000 stars, high SNR (>50/pixel), TGAS & asteroseismic logg. Good coverage of HR diagram.
- 6 labels from SME: Teff, logg, [α/Fe]*, vsini, microturbulence + extinction label from Majewski (2011) & 2MASS/WISE. (*solar scaled, weighted average of Mg, Si and Ti.)
- Lines used for stellar parameters (1D-NLTE (Lind 2012) for Fe, 1D-LTE for rest):

Species	Fe I	Fe II	Ti I	Ti II	Sc I	Sc II	Hα	Hβ
number	52	5	16	6	6	5	1	1

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1D-NLTE synthesis for more elements <3D> models to come!

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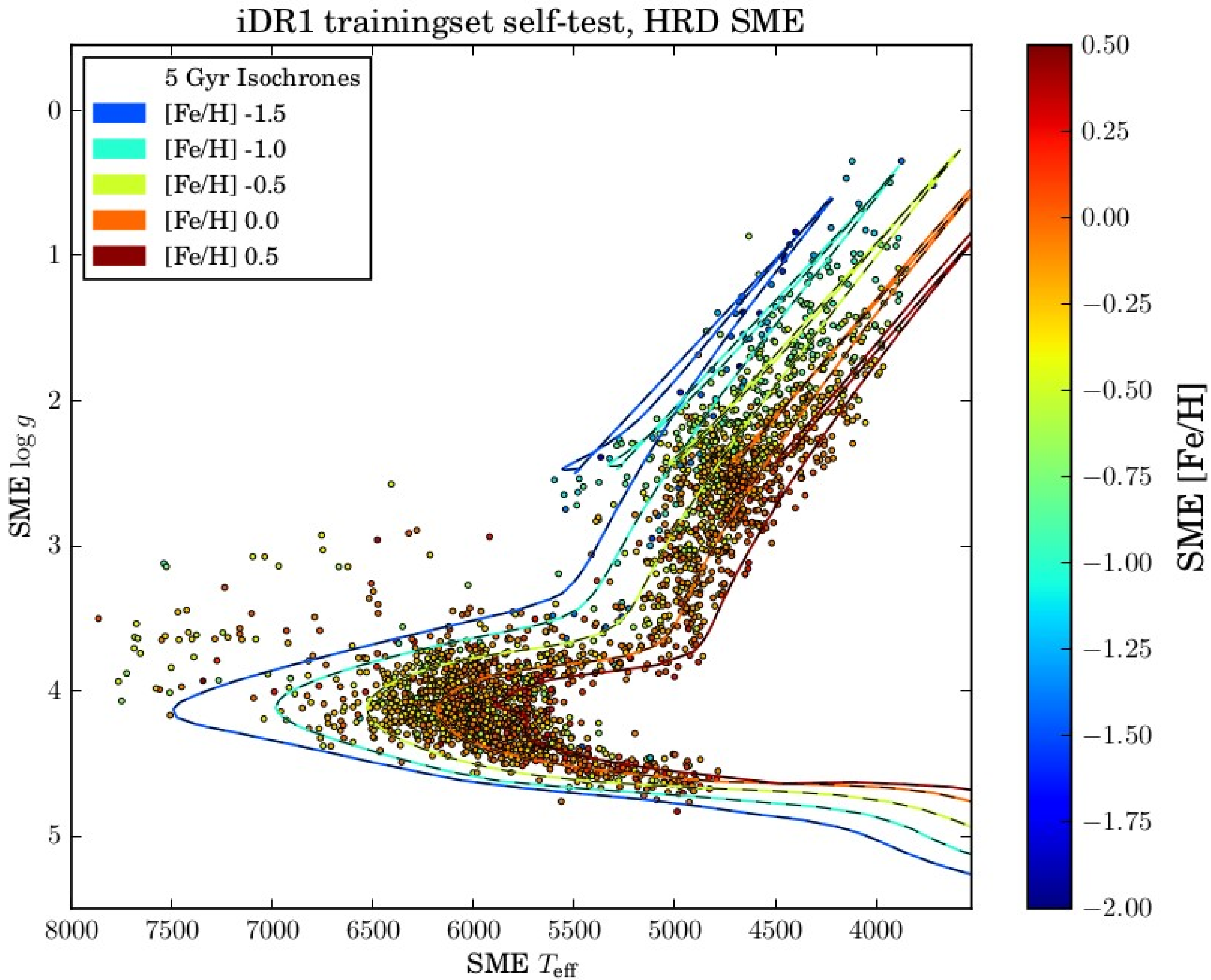
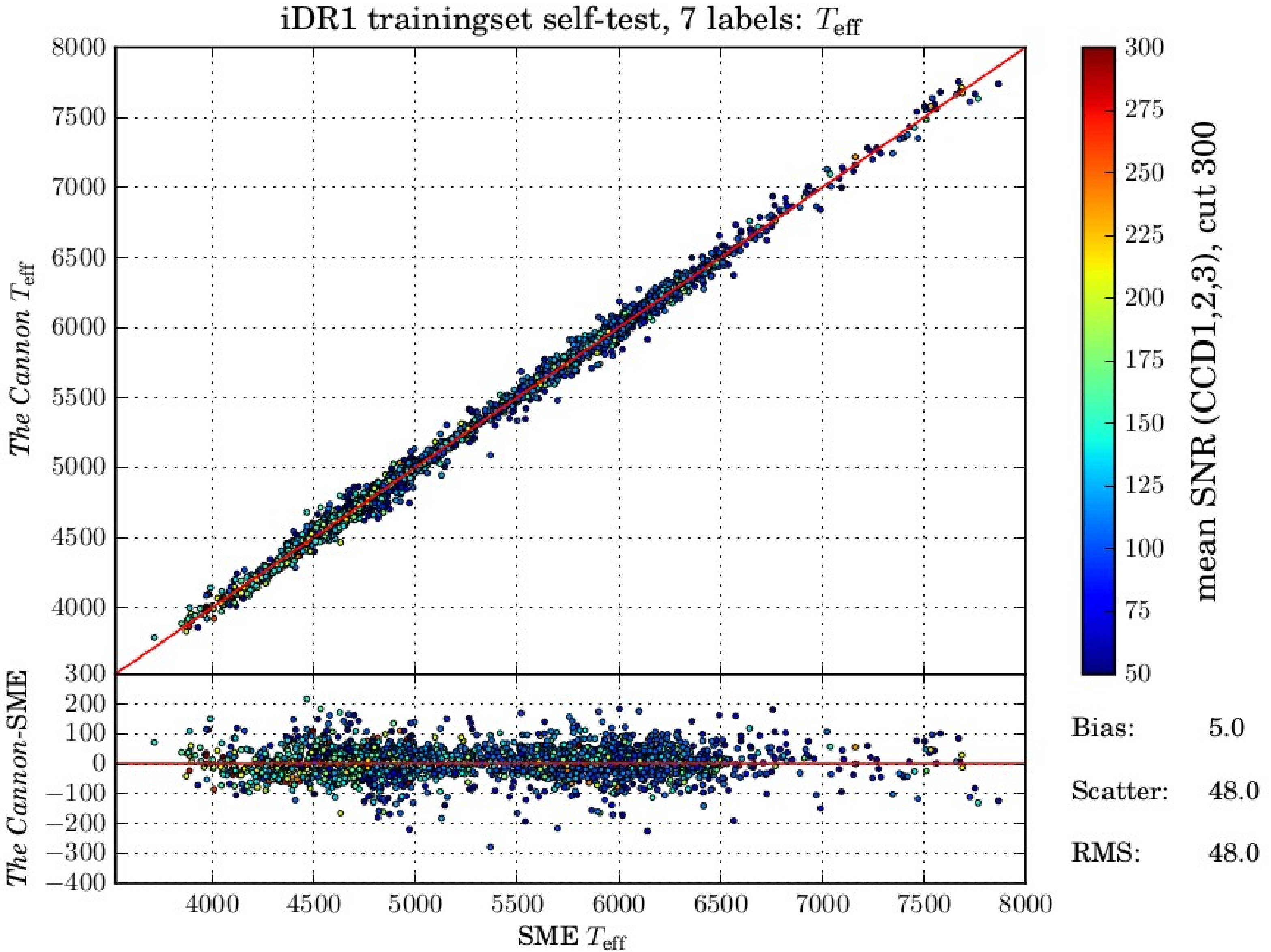


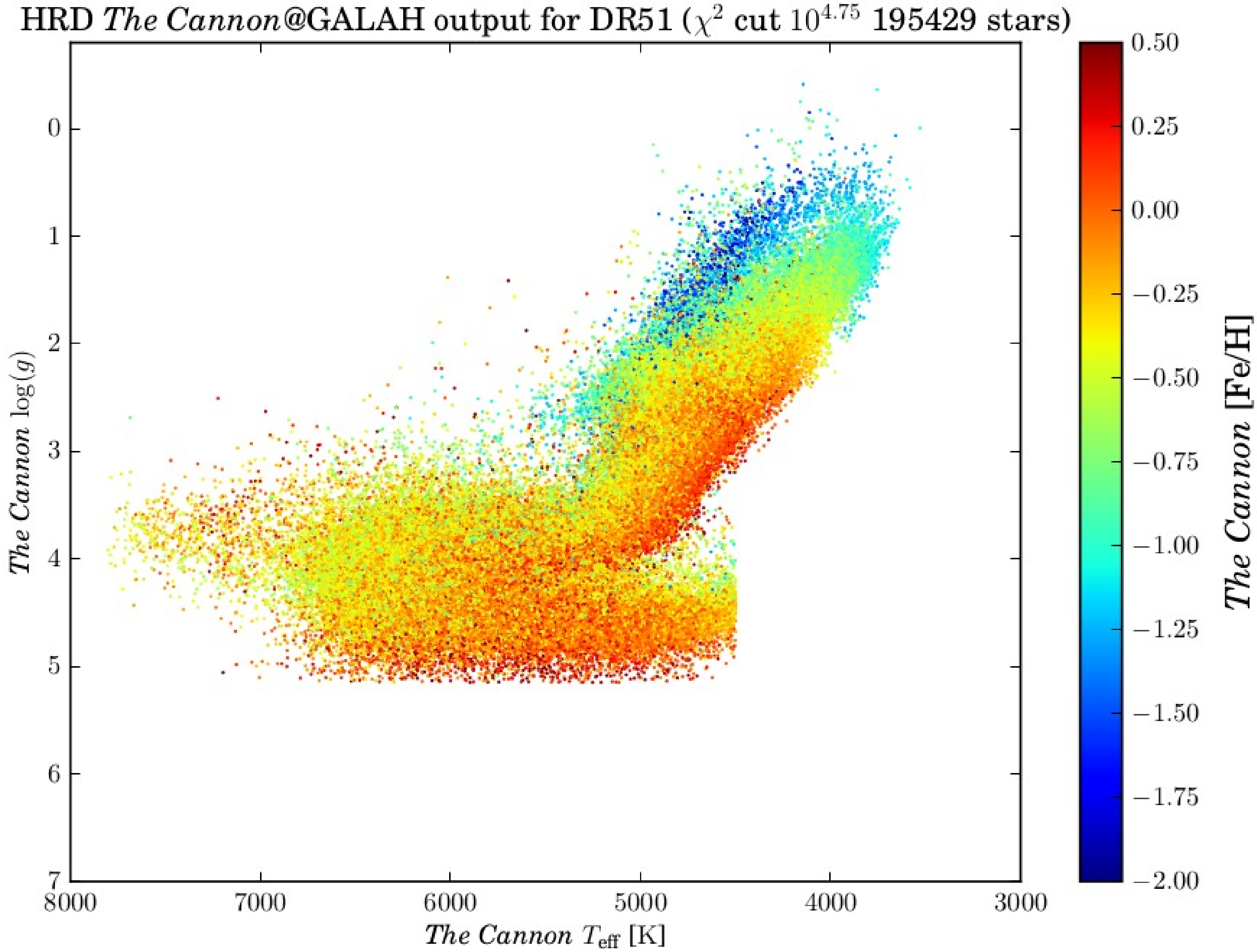
HR diagram of the Cannon training set.

- Constant logg offset of 0.145dex was present for both the giant branch and MS dwarfs when compared to K2/isochrones.
- Manually corrected before the Cannon analysis.
- Potential telluric correction issues in data reduction.

Cannon self-test, Teff



Cannon HR diagram, ~200k stars



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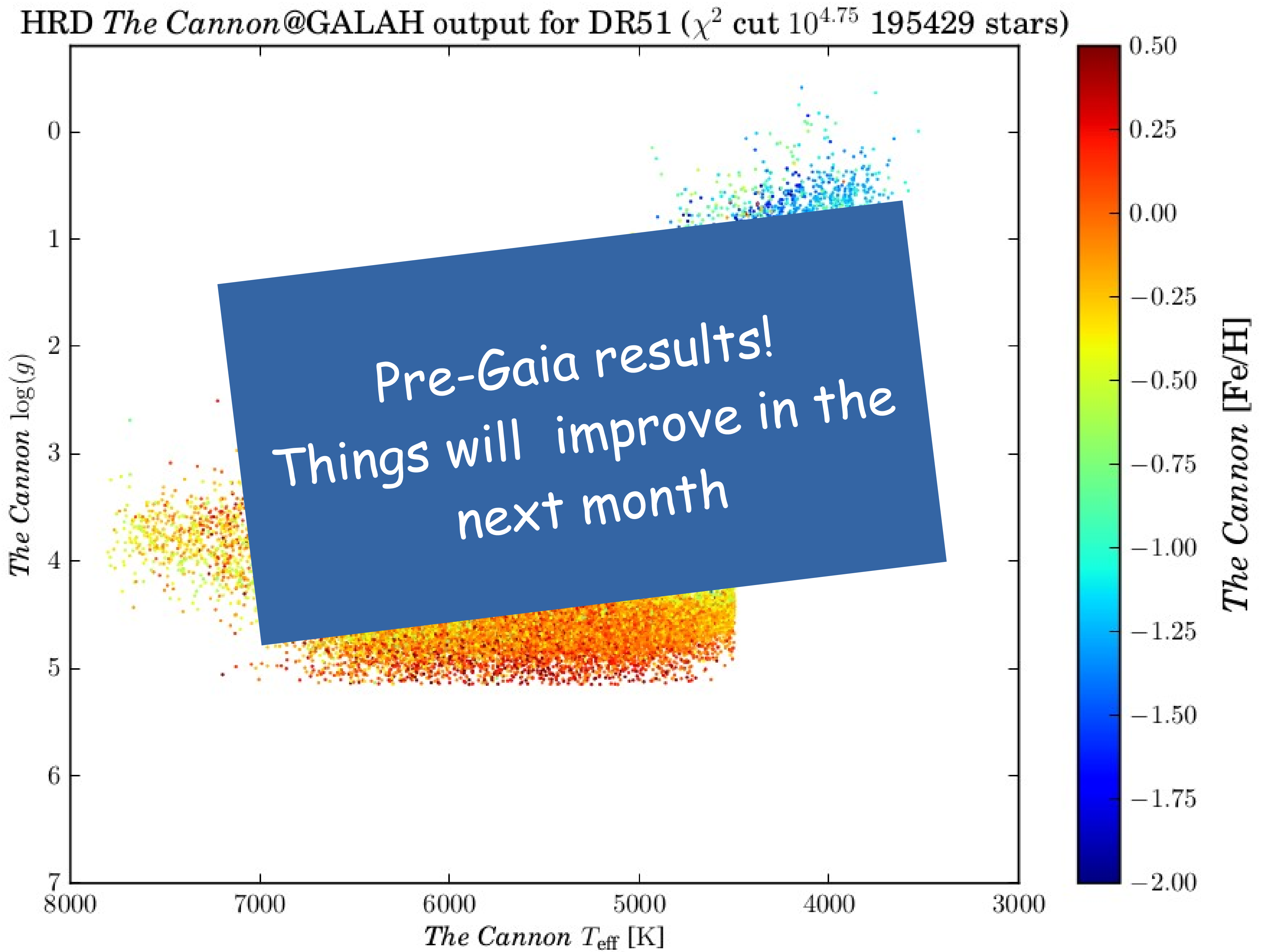
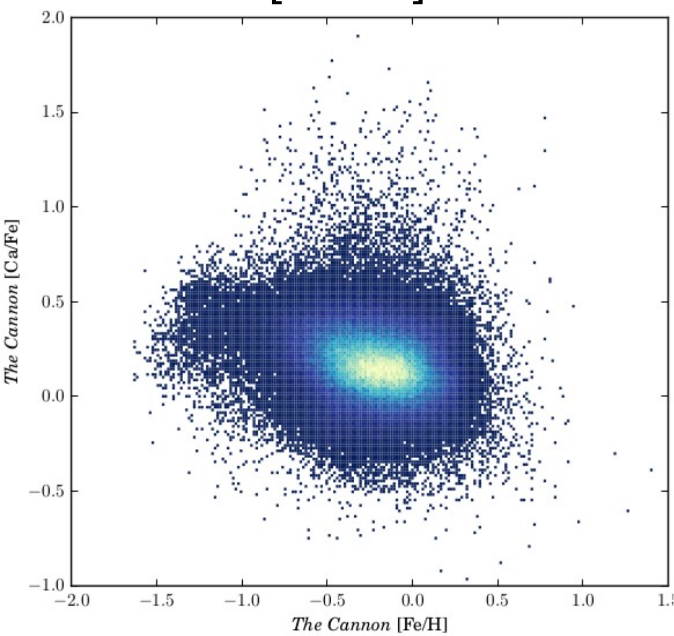


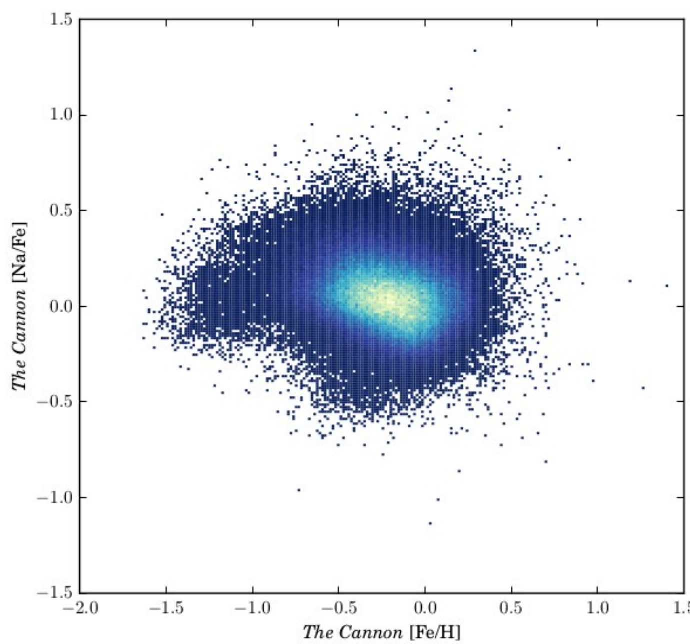
SME→Cannon training set (abundances)

- Training set of ~8500 stars with K2 logg and SNR>50/pixel.
- Abundances of 13 elements (Na, Mg, Al, Si, K, Ca, Sc, Ti, Cr, Fe, Ni, Cu, Ba), with additional Teff, logg, [Fe/H], E(B-V) labels.

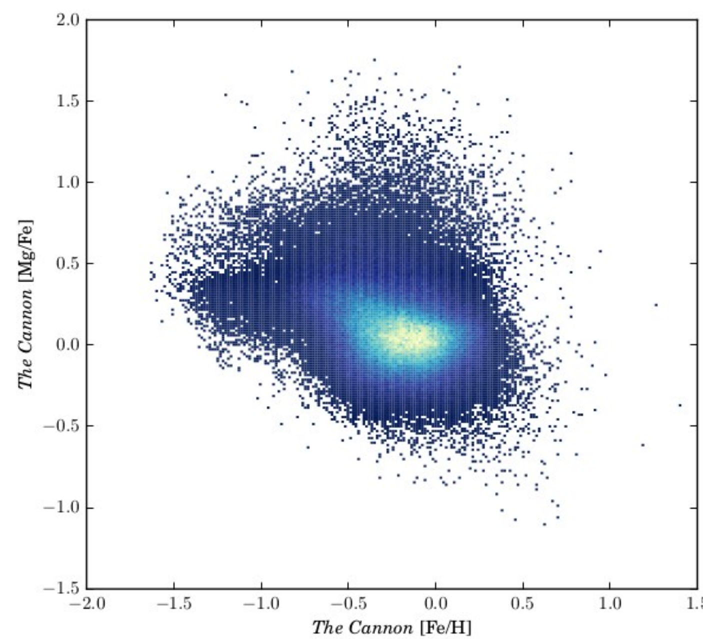
[Ca/Fe]



[Na/Fe]



[Mg/Fe]



Cannon [Fe/H] (colour map=counts)

Bayesian isochrone fitting

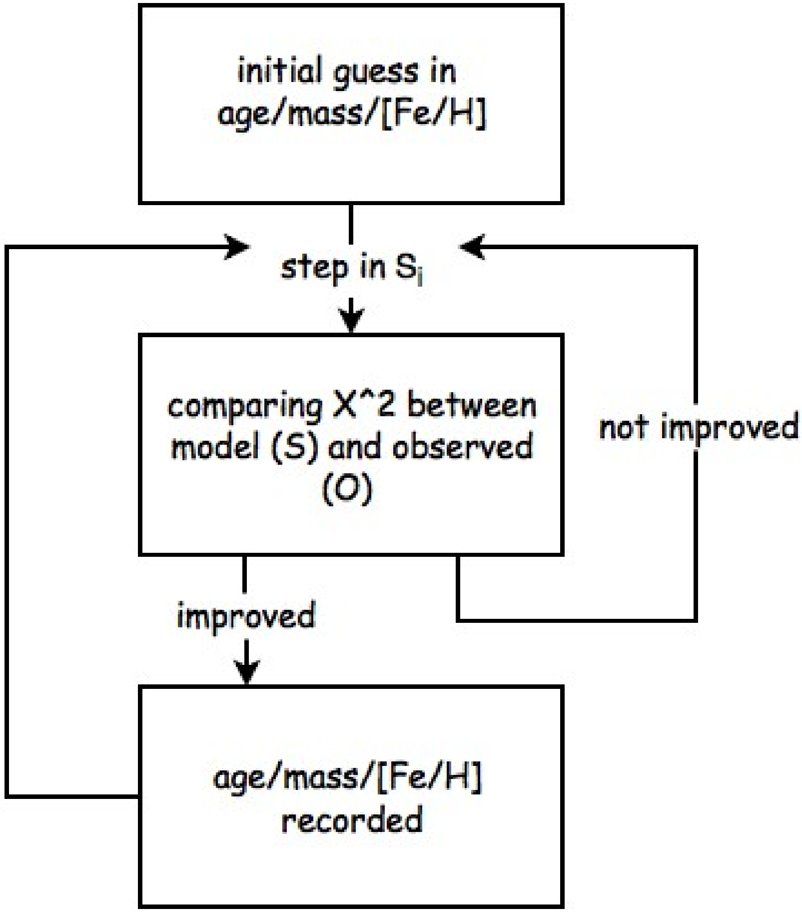
- The posterior probability p1 can be written as:

$$p_1(M, \tau, [Fe/H]|O_i) = p_0 L/N$$

$$L = \frac{1}{\sqrt{(2\pi)^k|\Sigma_i|}}\exp\Big(-\frac{1}{2}(O_i - S_i)^T\Sigma_i^{-1}(O_i - S_i)\Big)$$

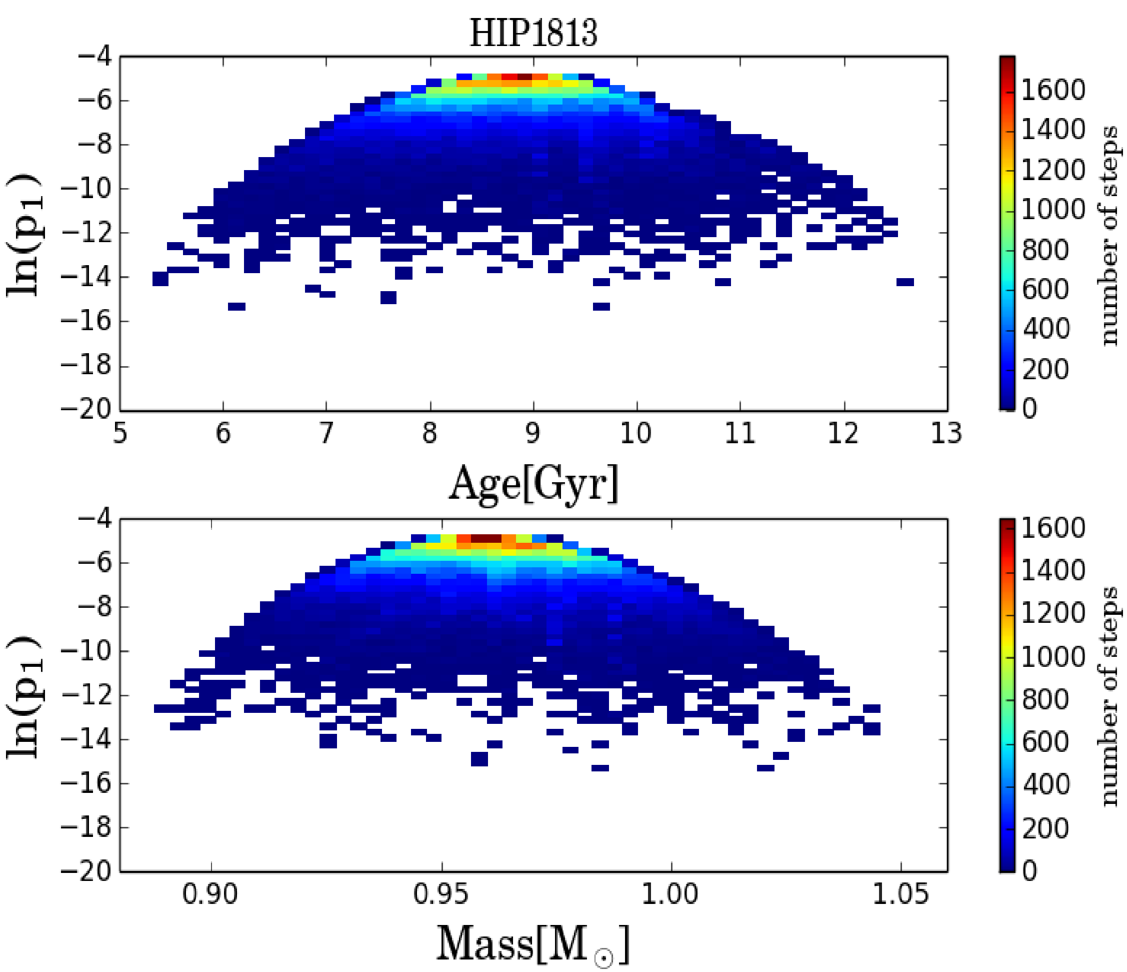
where M=mass, τ=age, Oi=observables, p0= prior, L=likelihood, N=normalisation constant, Si=model parameters

- Flat prior in age (0-14Gyr), Salpeter IMF for mass.
- Posterior sampled using MCMC (Foreman-Mackey (2013)), with multiple walkers (100+)



Decision tree of a MCMC walker. The walker will only construct the chain when χ2 has improved compared to the previous step.

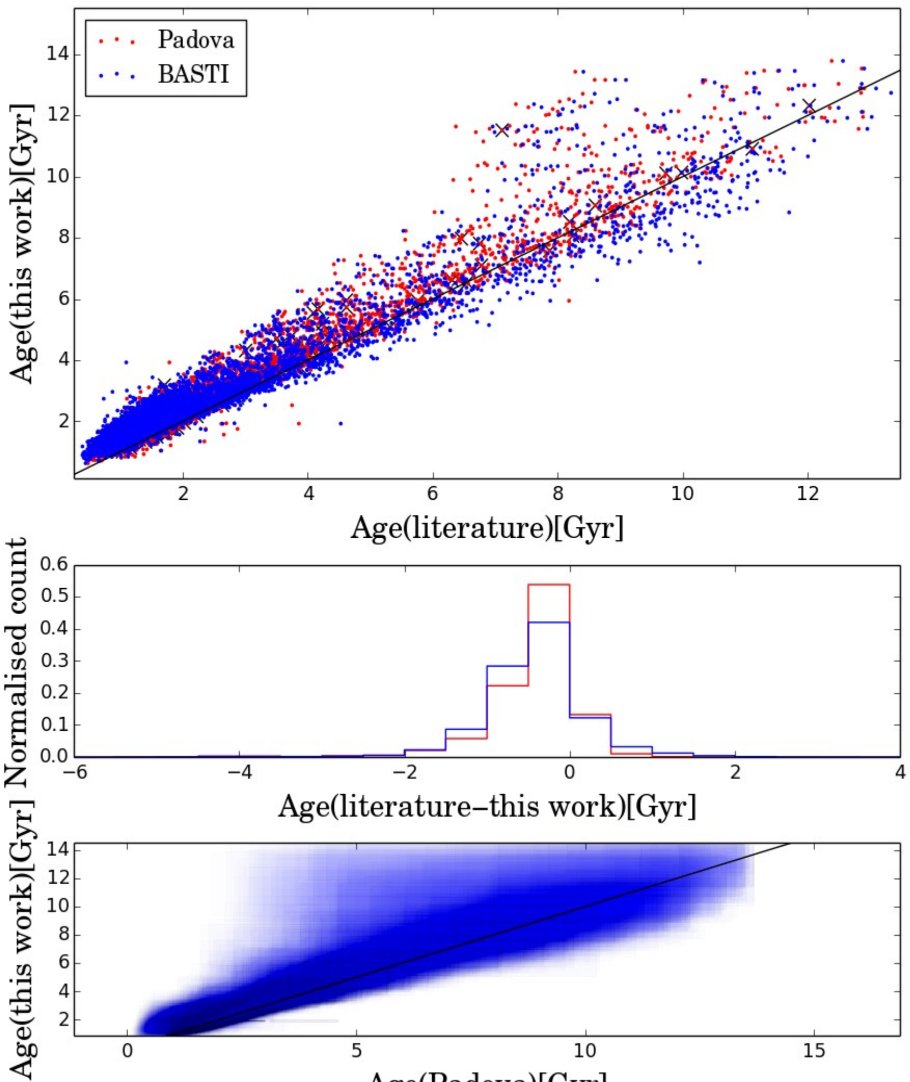
	Observable	Method
GALAH	$T_{\rm eff}$	spectroscopy, photometry
	logg	spectroscopy, asteroseismology
	[Fe/H], [α/Fe]	spectroscopy
Parallax from Gaia	M_K	apparent magnitude and parallax
K2	ν_{max}	asteroseismology
	$\Delta\nu$	asteroseismology



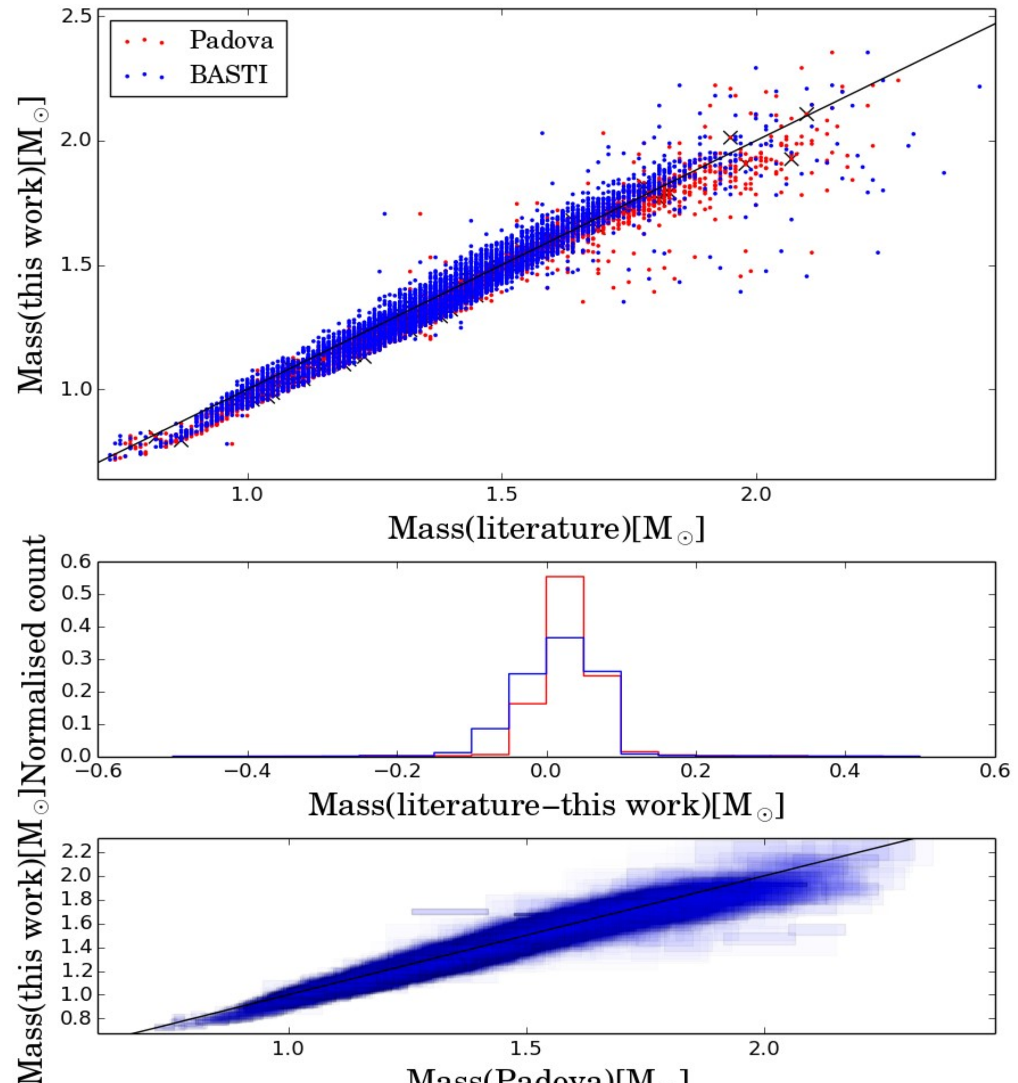
- Isochrone sets from Dartmouth Stellar Evolution Database (Dotter 2008)
- Returns full distributions in mass, age and [Fe/H], and all model parameters (Teff, logg, [Fe/H], Mk)

Comparison with GCS
(Casagrande (2011))

This work

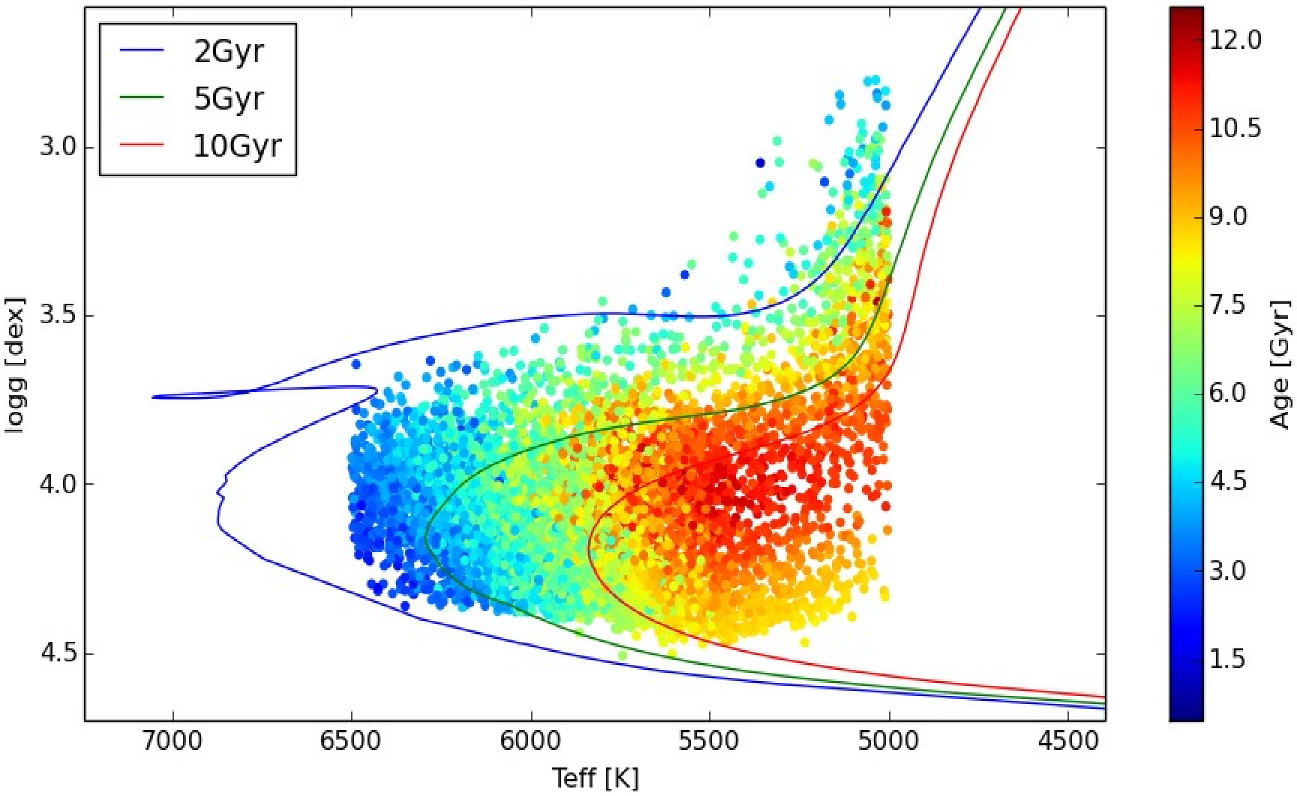


Age (GCS)
(mean difference 0.45Gyr)



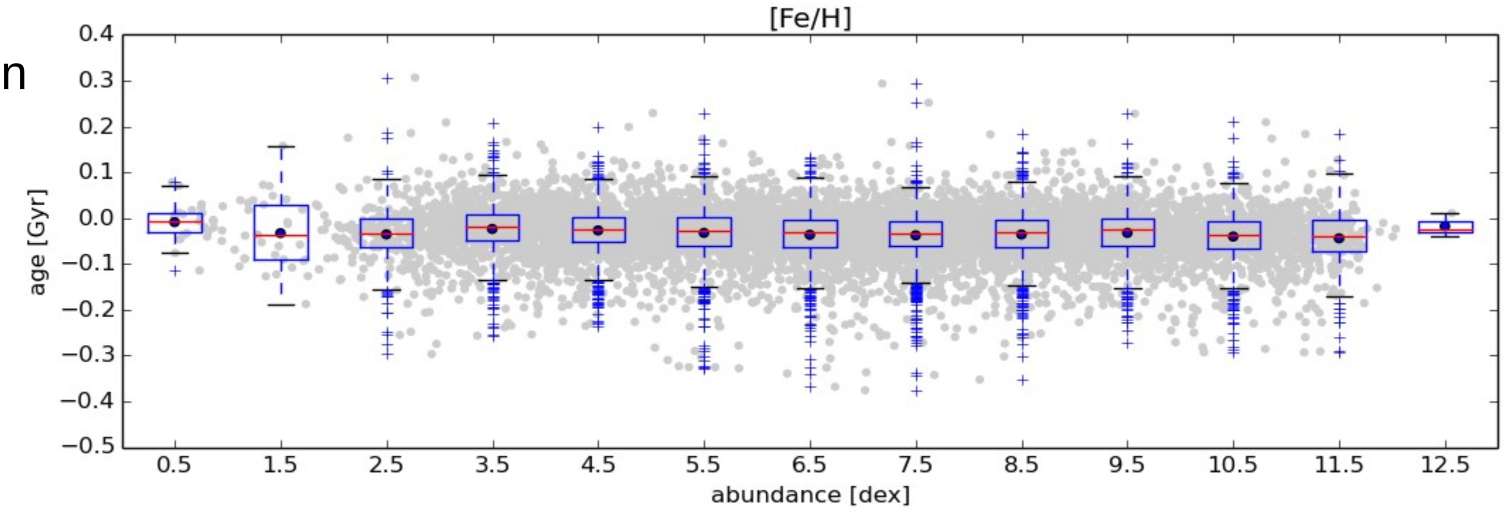
Mass (GCS)

GALAH HR diagram & age-metallicity

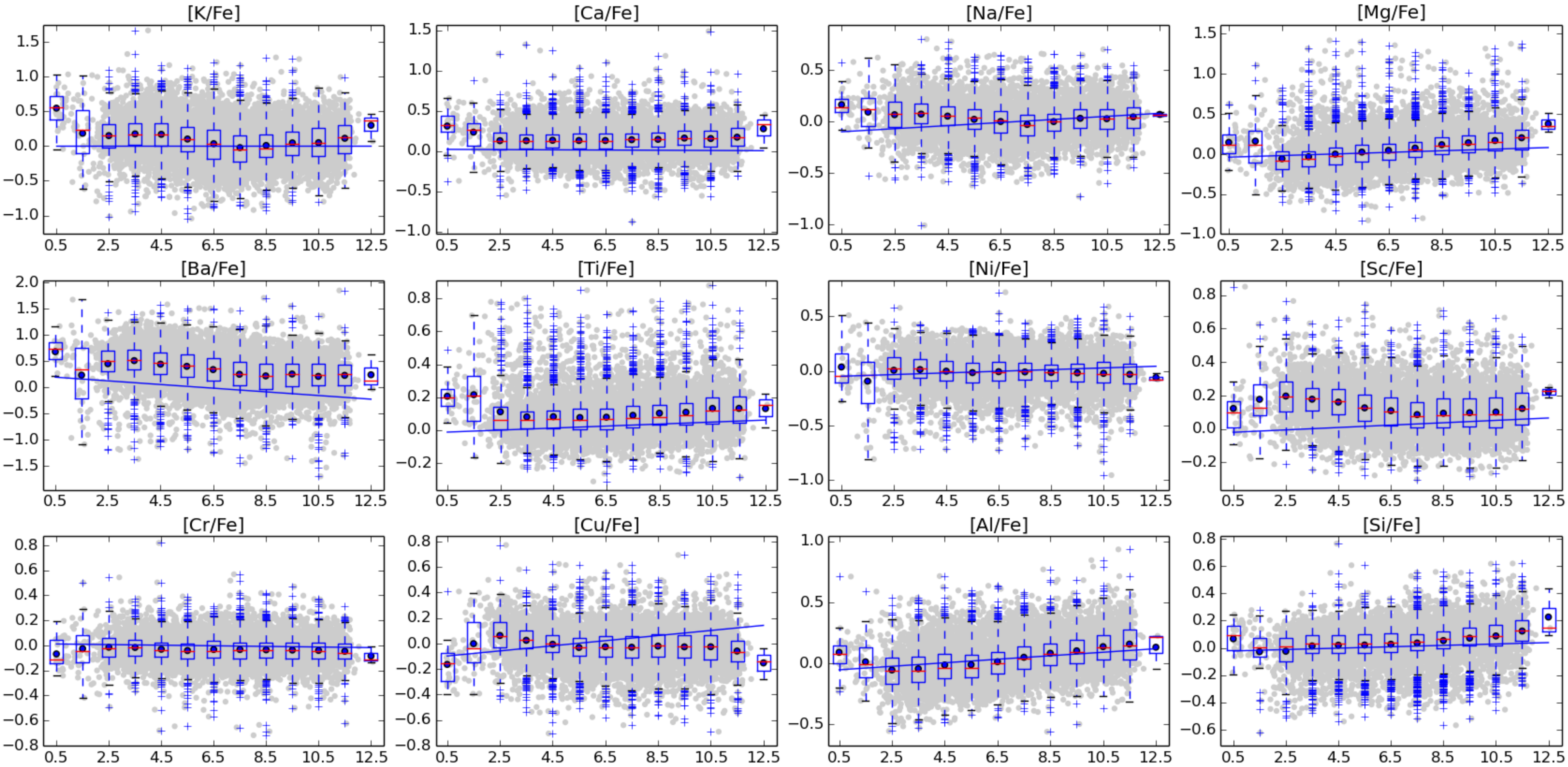


HR diagram of ~9000 Cannon stars colour coded in age. Only stars with bad MCMC chains are cut from the sample.

Age-metallicity relation for the sample.
Flat in the solar neighbourhood



[X/Fe] v Age
(complementing high precision studies of solar twins)



Age (Gyr) (linear fit from Spina (2016))

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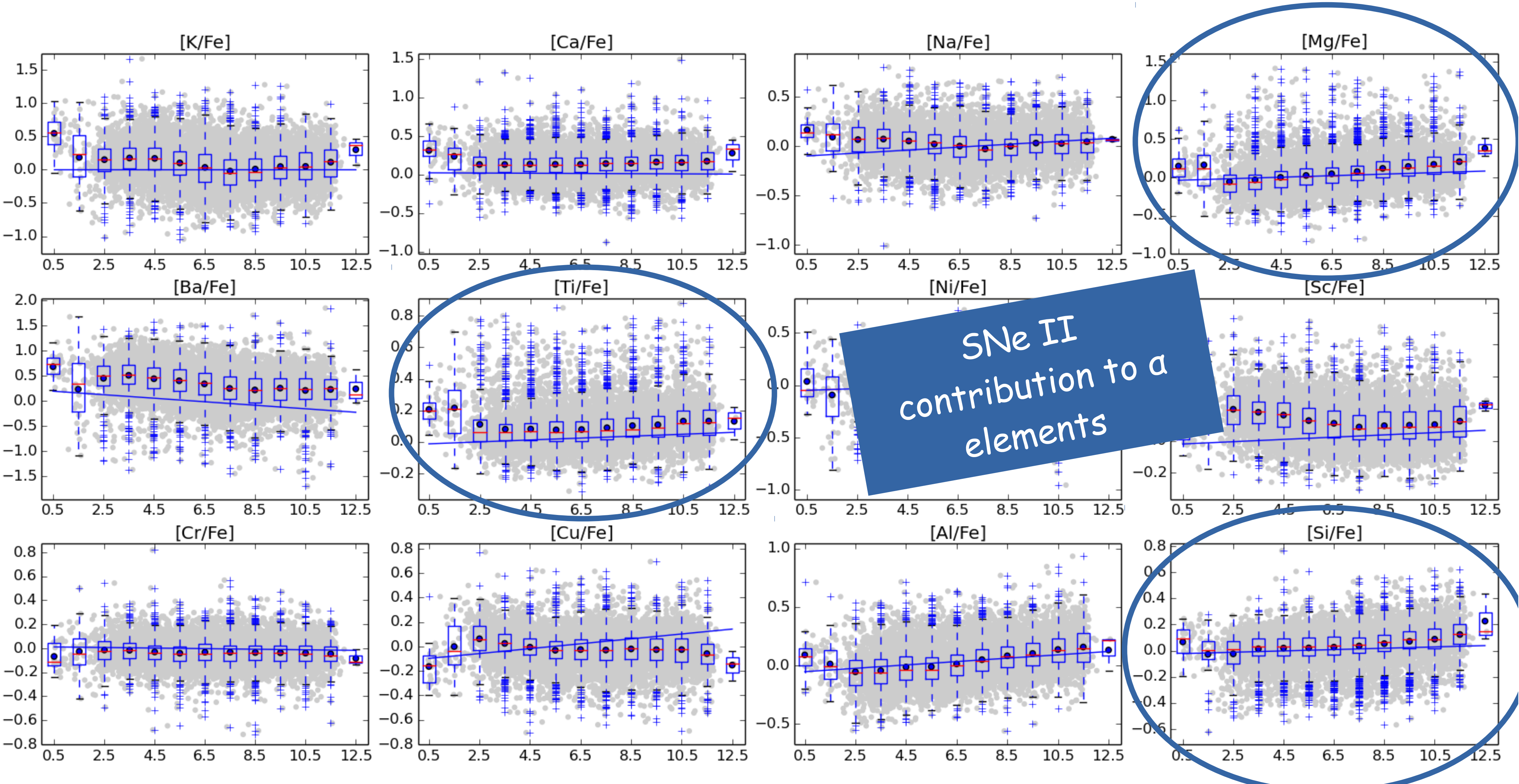

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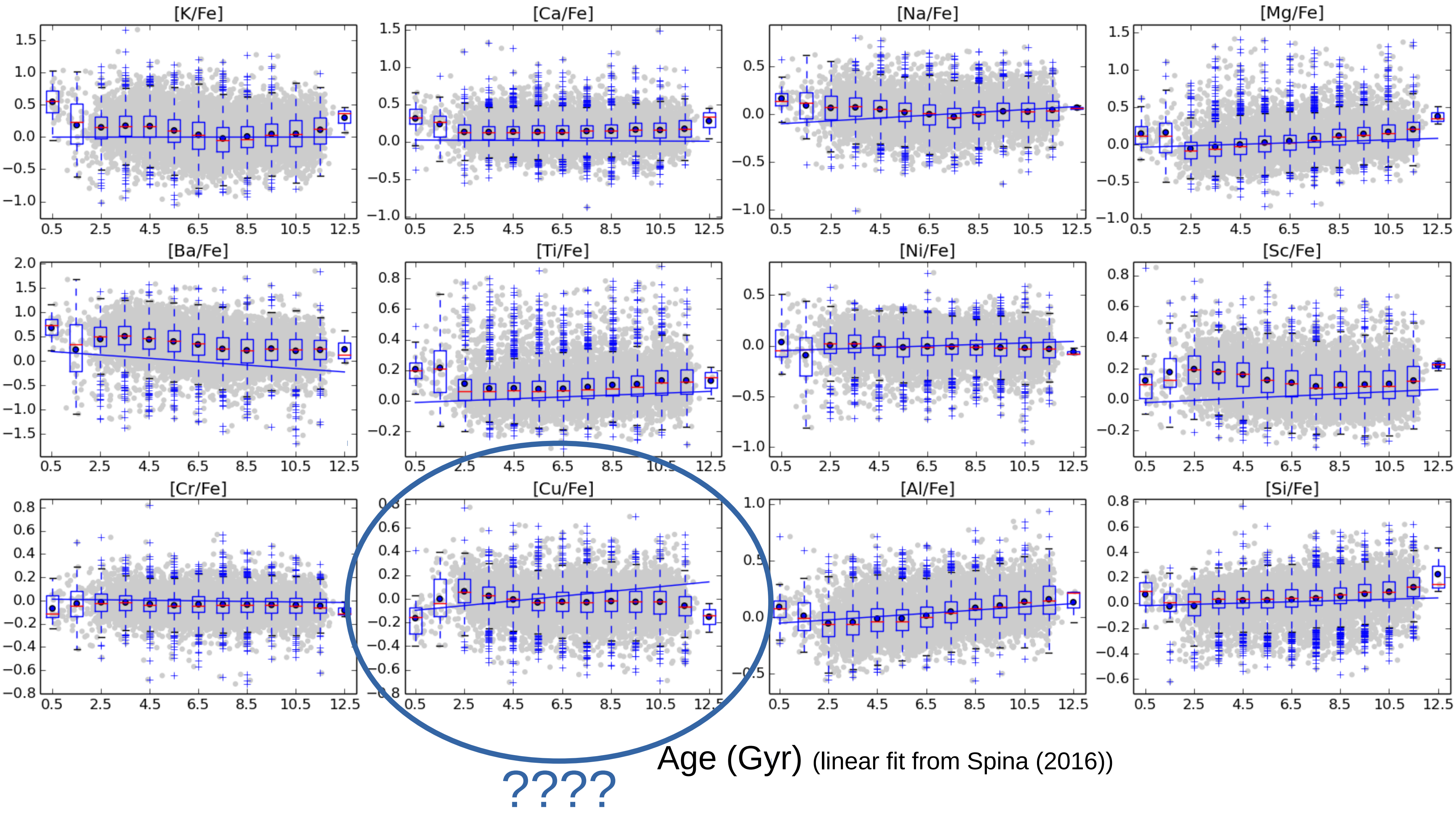

Fresh off the press TGAS results!!!

Pre-TGAS

TGAS

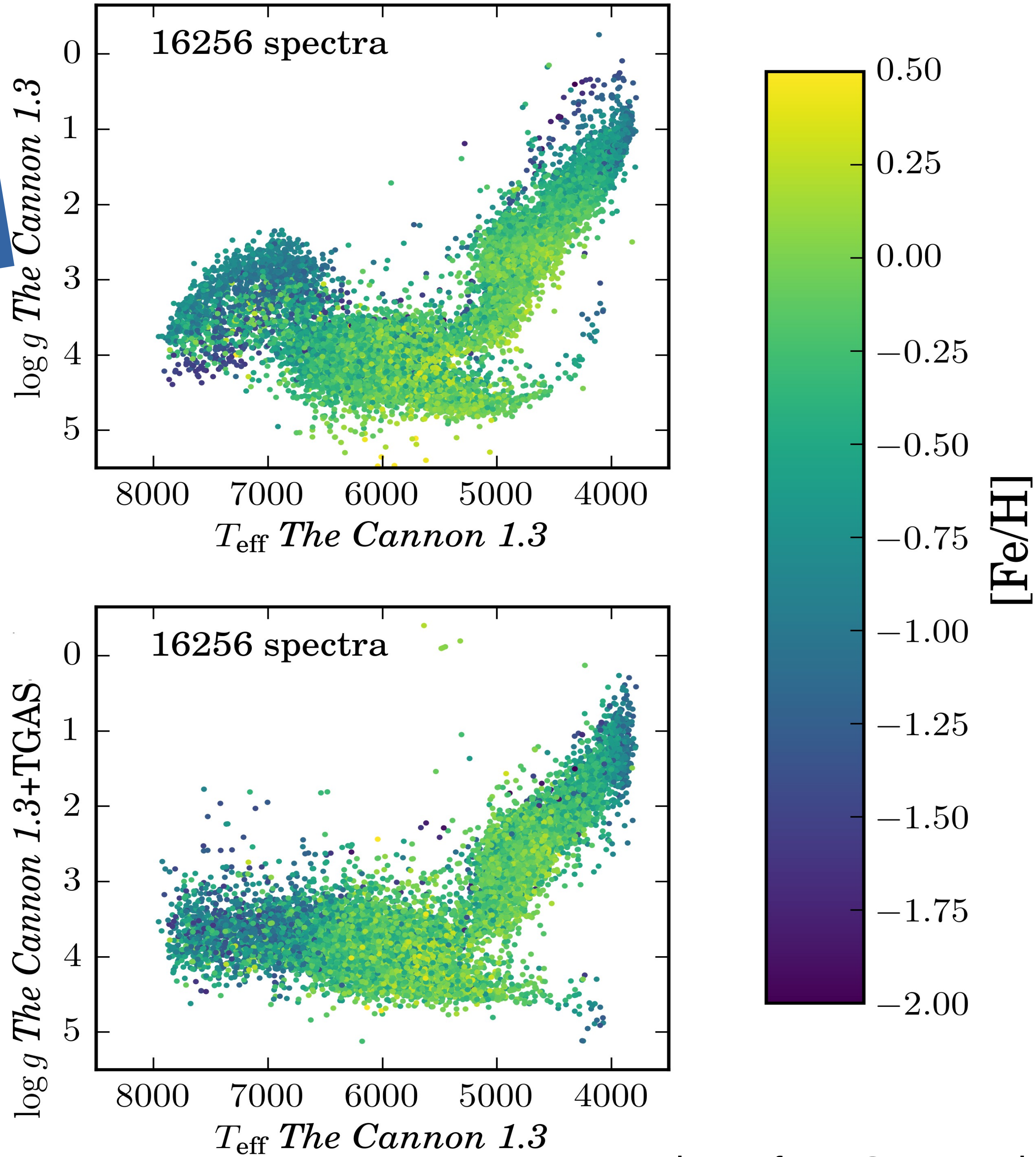

Figure from Sven Buder

Fresh off the press TGAS resu

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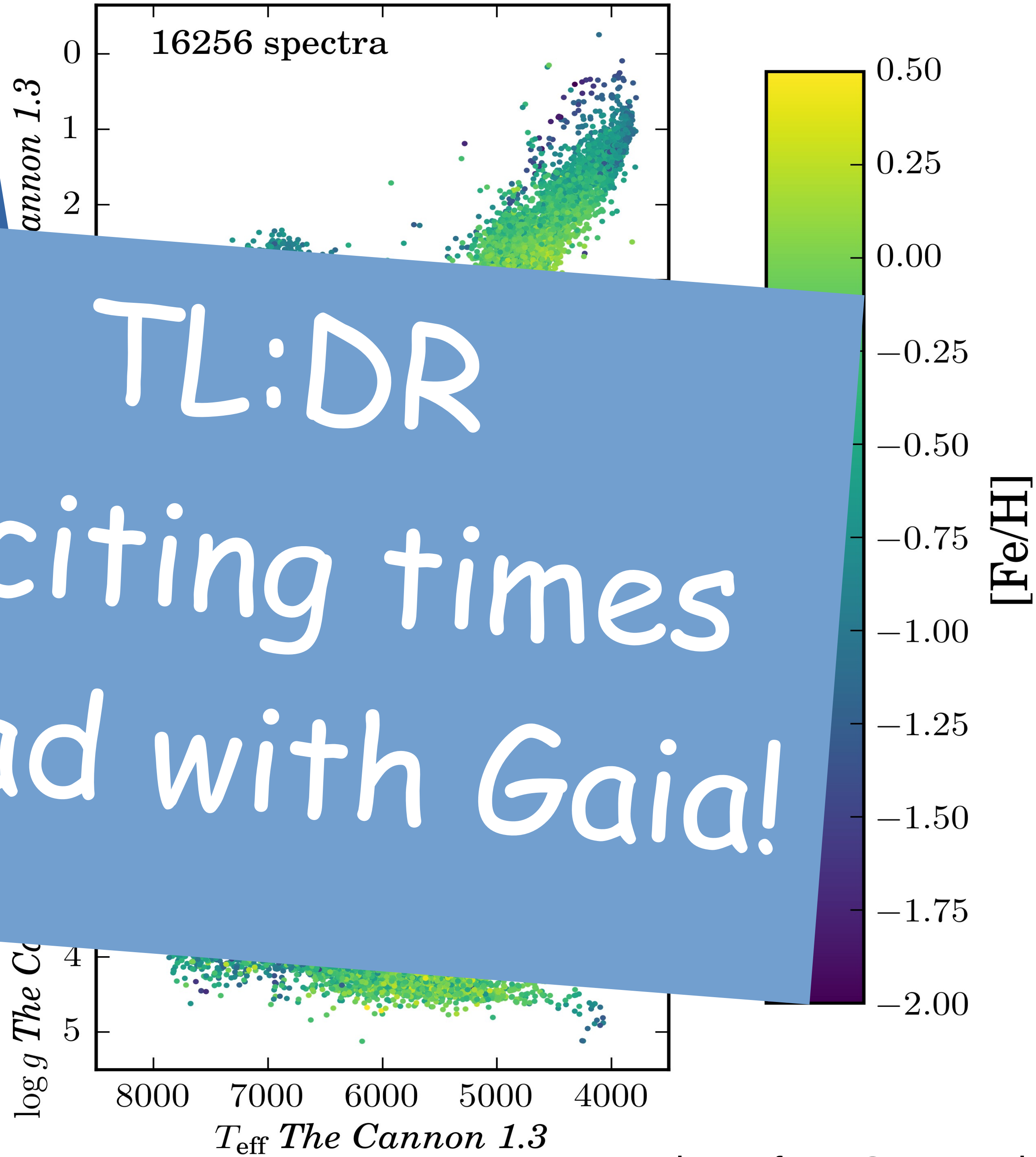

TL:DR
Exciting times ahead with Gaia!

Figure from Sven Buder