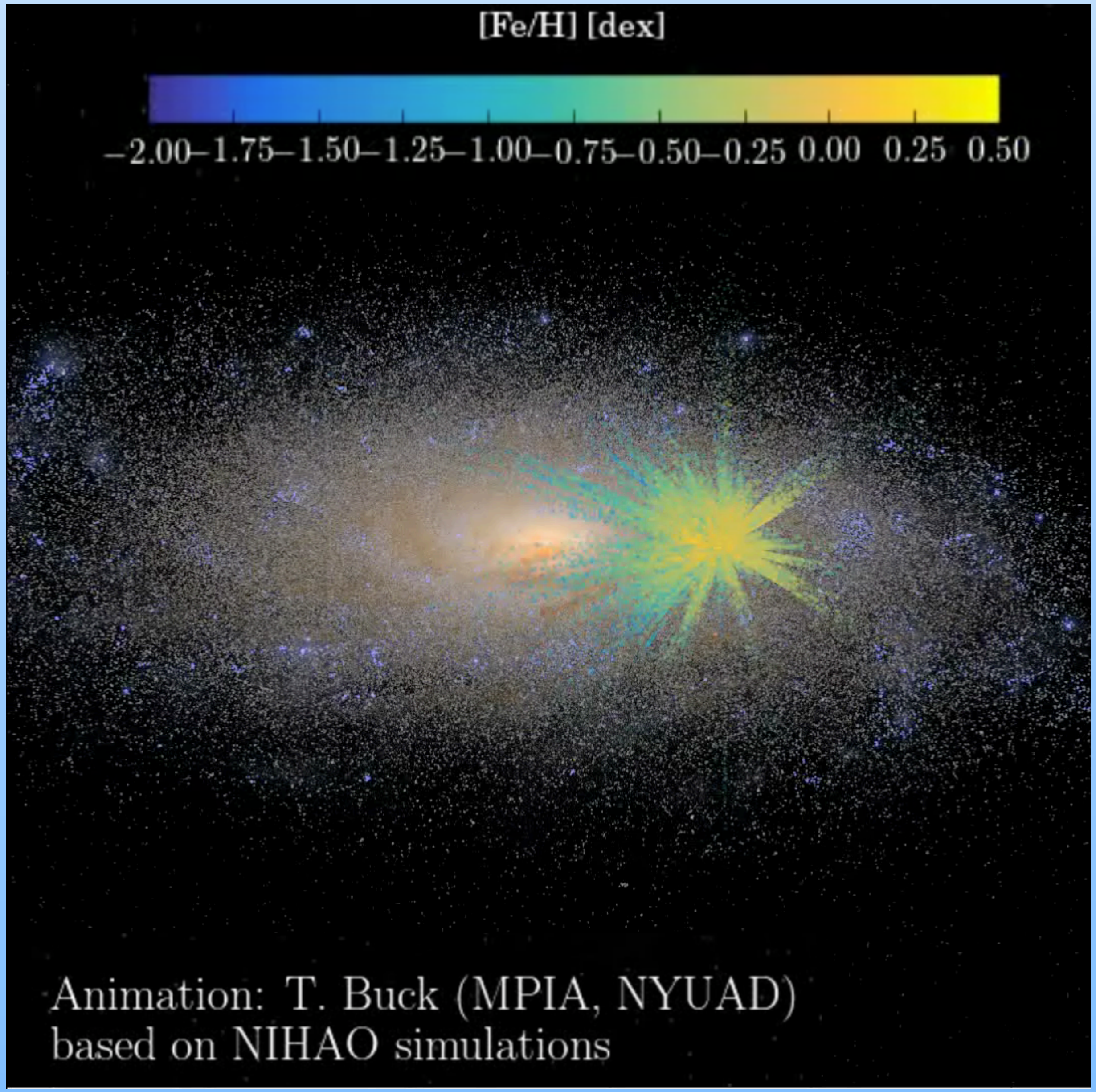
The GALAH Survey and Gaia

- A melting pot of chemo-dynamics -

Sven Buder (MPIA Heidelberg) & the GALAH Survey team



The astrometric revolution

Spectral type

Absolute magnitude

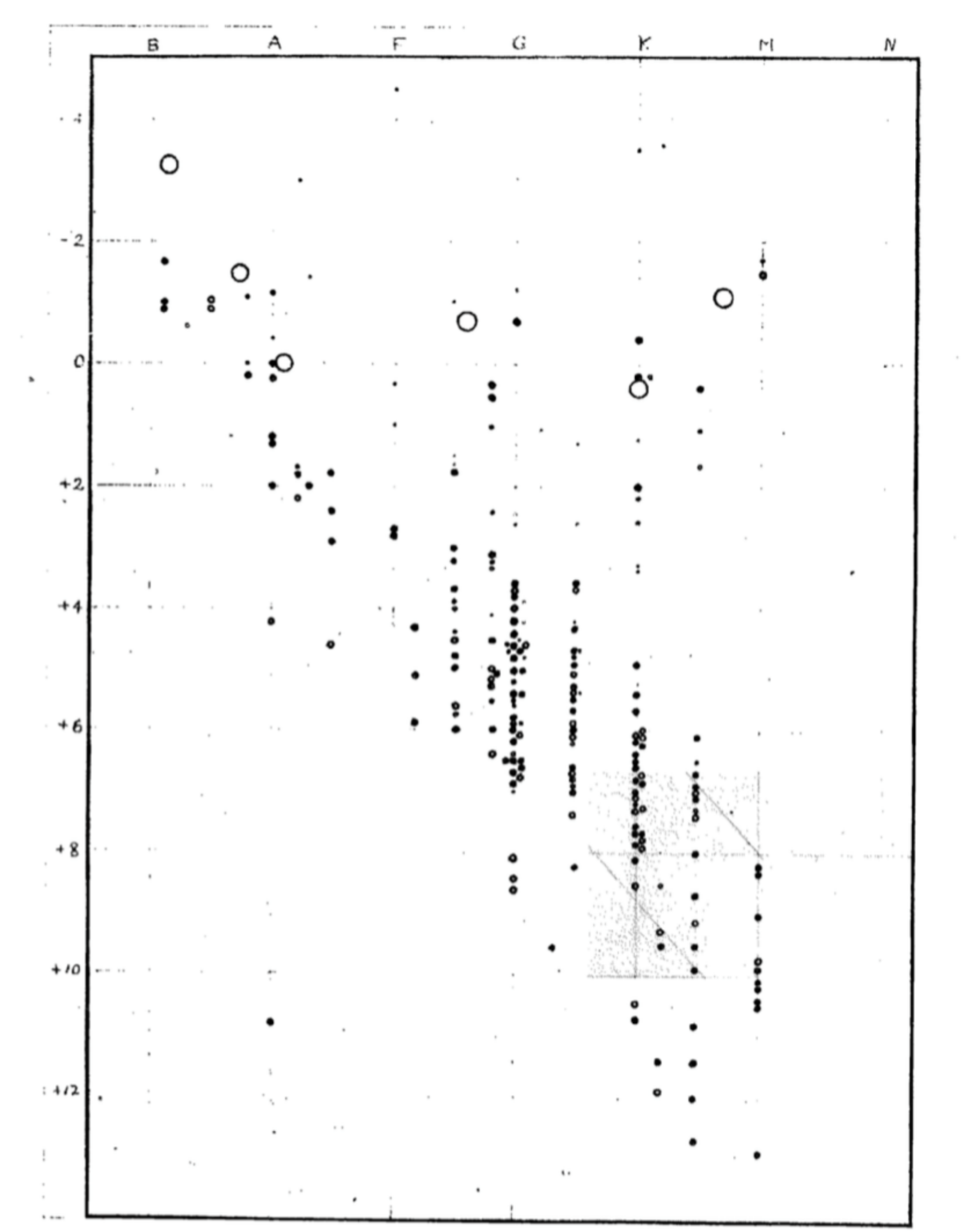


Figure 1.

Russell (1914): Popular Astronomy, 22:275

Figure 1 [...] The spectral class appears as the horizontal coördinate, while the vertical one is the absolute magnitude [...]. The larger dots denote stars for which the computed probable **error of the parallax is less than 42 per cent** of the parallax itself [...]. This is a fairly tolerant criterion for a **"good parallax"**.

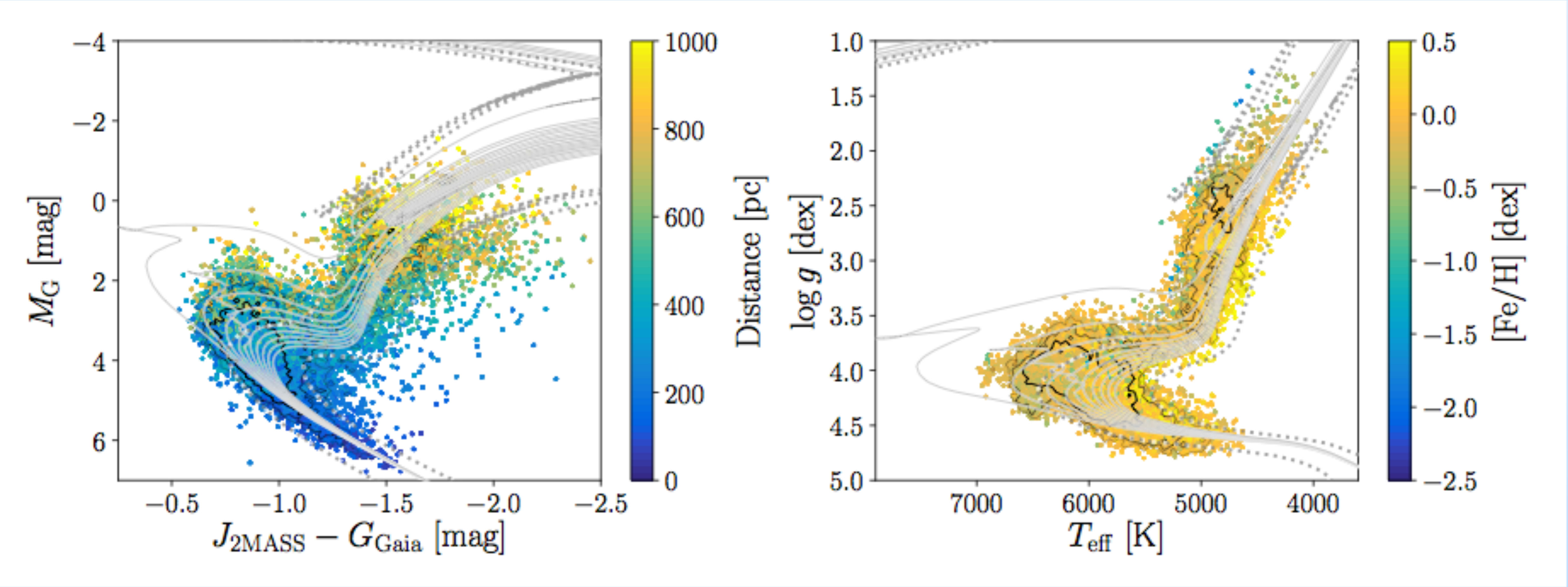
TABLE V

Mean Absolute Magnitudes

Spectrum	Stars of Measured Parallax				Stars in Clusters			
	No.	Abs. Mag.	Formula	O—C	No.	Abs. Mag.	Formula	O—C
B2	...	...	...	...	21	—1.2	—1.1	—0.1
B8	...	...	...	...	8	+0.3	+0.2	+0.1
A0	6	+1.4	+1.4	0.0	13	0.5	0.6	—0.1
A4	7	2.5	2.3	+0.2	26	1.7	1.5	+0.2
F0	...	...	...	...	15	2.4	2.7	—0.3
F1	5	4.2	3.7	+0.5	...	...	...	...
F3	...	...	...	...	7	3.3	3.3	0.0
F5	9	4.3	4.5	—0.2	...	...	...	...
F8	8	5.1	5.2	—0.1	5	4.2	4.4	—0.2
G0	29	5.7	5.6	+0.1	18	5.0	4.8	+0.2
G5	19	5.7	6.6	—0.9	9	5.1	5.8	—0.7
K0	28	7.1	7.7	—0.6	9	6.4	6.9	—0.5
K4	19	9.2	8.6	+0.6	7	+7.0	+7.7	(—0.7)
Ma	10	+9.9	+9.8	+0.1	...	...	...	...

PHOTOMETRY VS. SPECTROSCOPY?

HRD	Spectral type	M_V / Luminosity (class)
CMD	Color	Magnitude
Kiel	Temperature	Surface gravity



$$\log\left(\frac{\mathcal{M}}{\mathcal{M}_\odot}\right) - \log\left(\frac{L_{\mathrm{bol}}}{L_{\mathrm{bol},\odot}}\right) + 4\cdot\log\left(\frac{T_{\mathrm{eff}}}{T_{\mathrm{eff},\odot}}\right) + \log g_\odot = \log g$$

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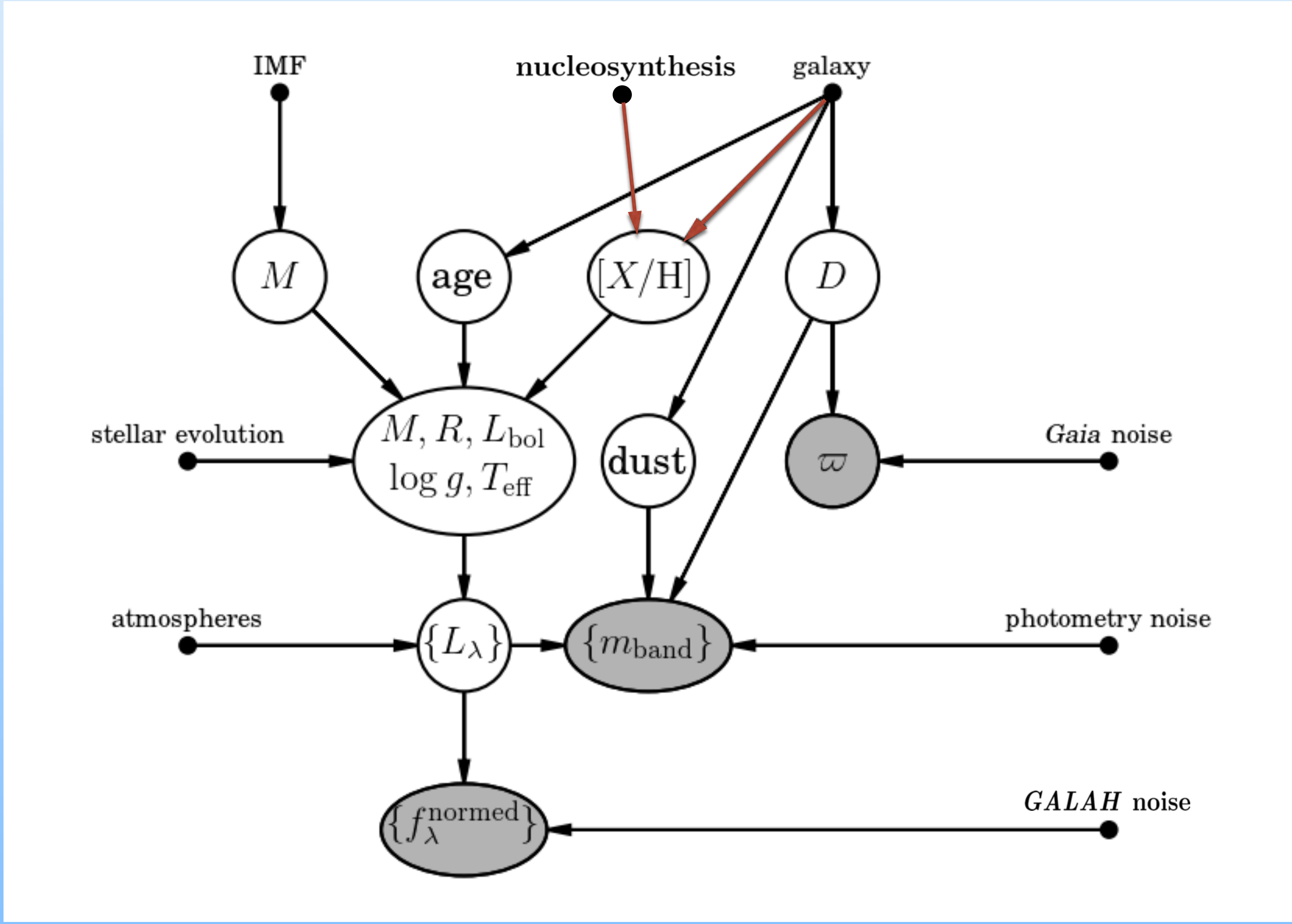
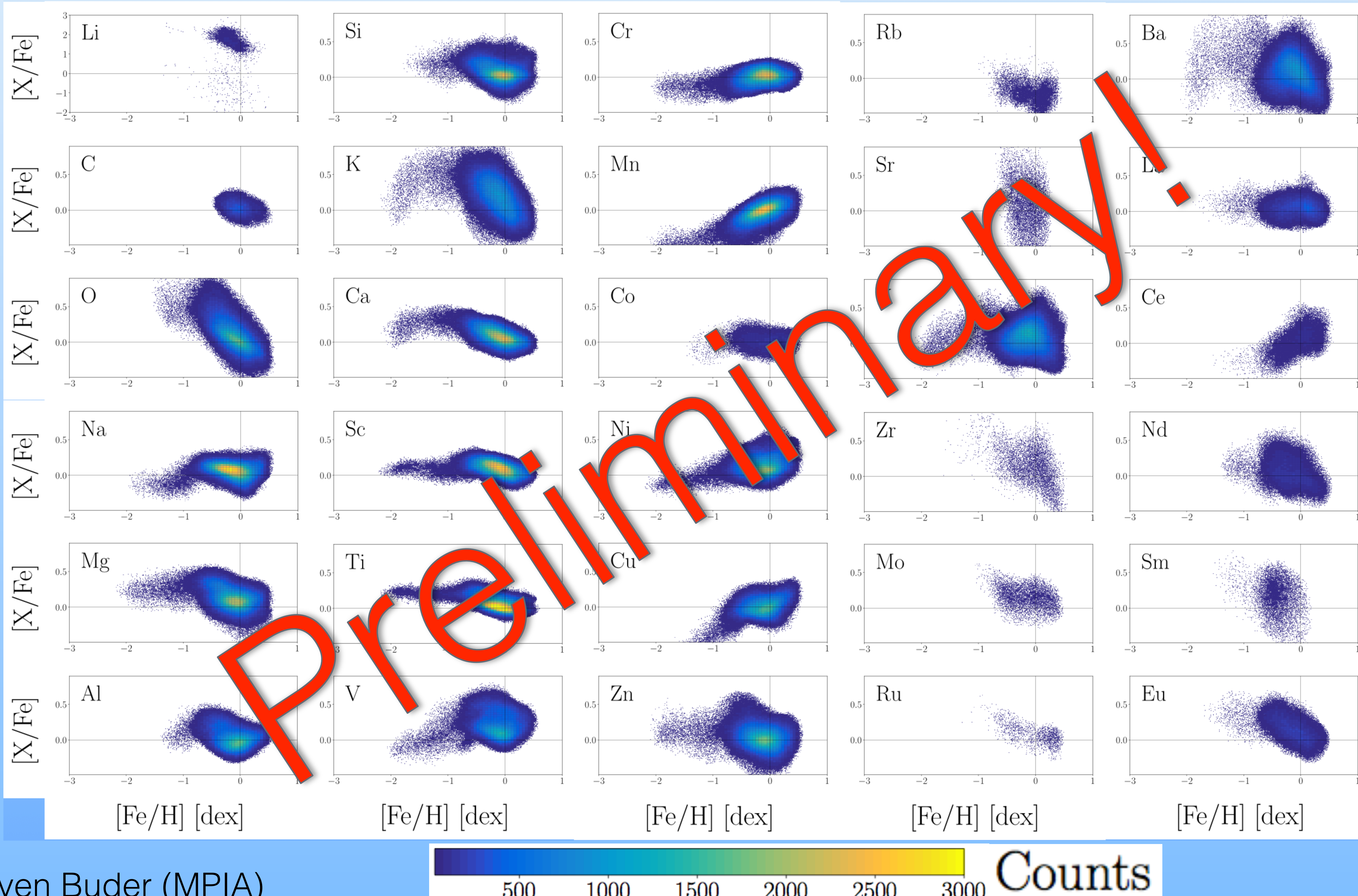
IT'S ALL CONNECTED!



Rix, Hogg, Buder and others

[X/H] or [X/Fe] as Stellar DNA?



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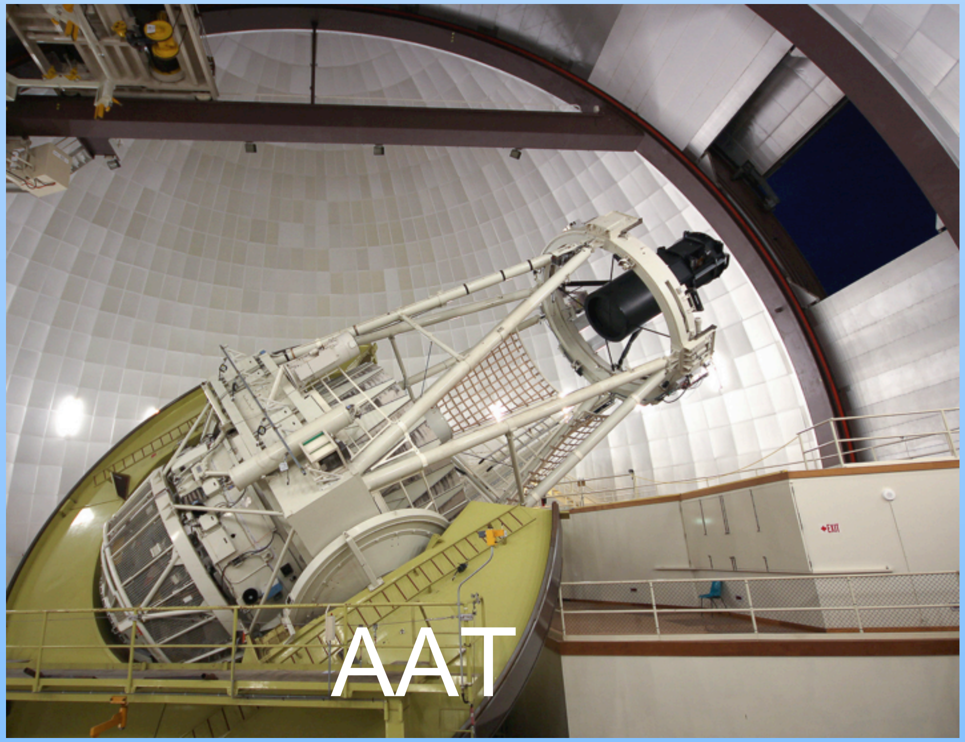
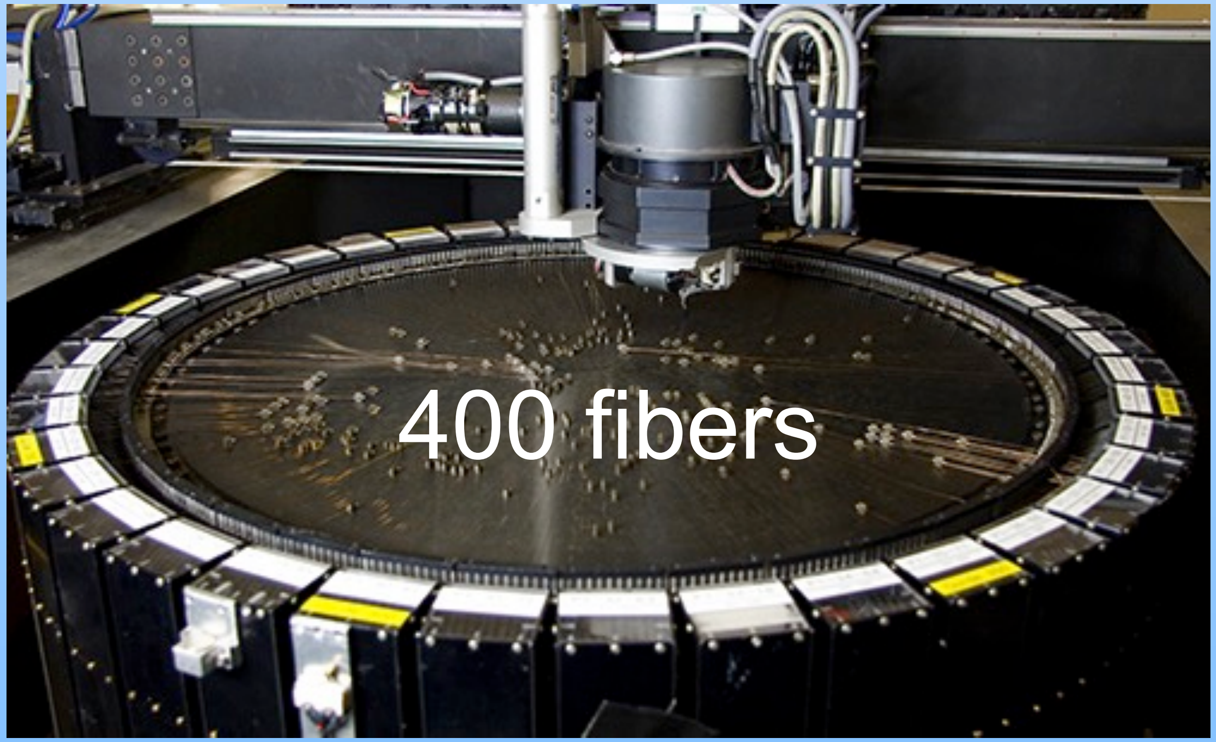
Part I: GALAH

- Distribution function of stellar properties (chemical composition, age, position, orbits)
- Chemical tagging (with 30 [X/Fe] as stellar DNA)
- Improve understanding of stellar physics/evolution

Selection	within magnitude limits	**R**	28000 (2dF HERMES)
Size	560k (aim: ≳ 1.0 Mio)	**λ**	~1000 Å (VIS incl. Hα,Hβ)





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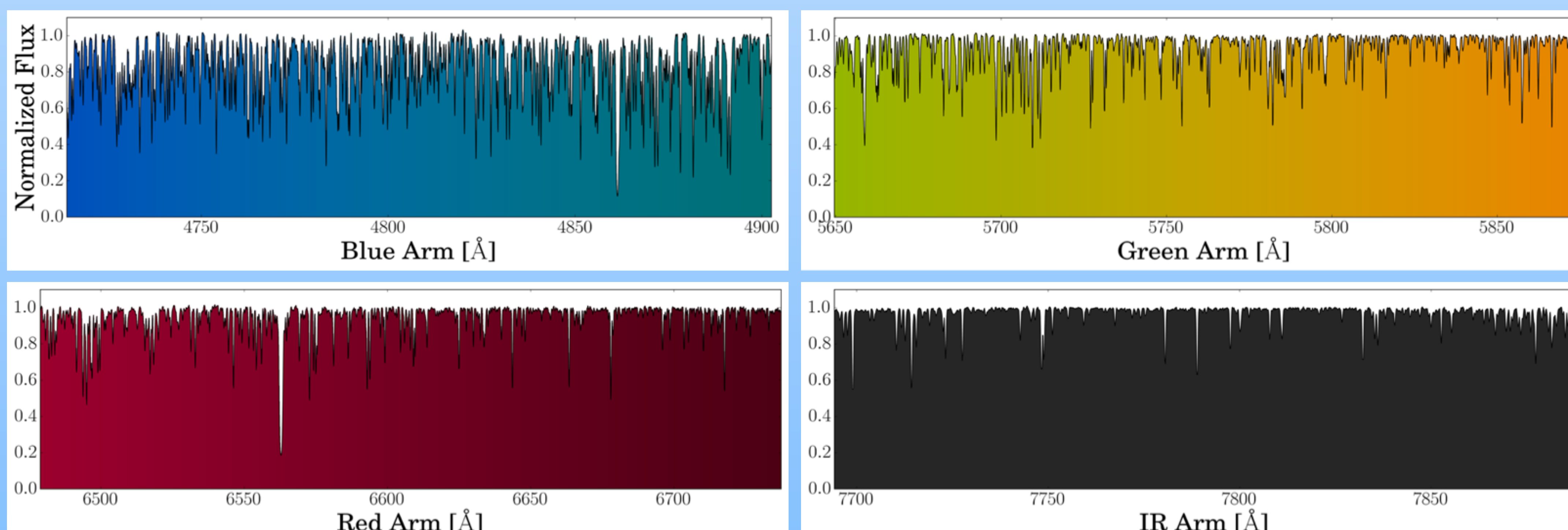
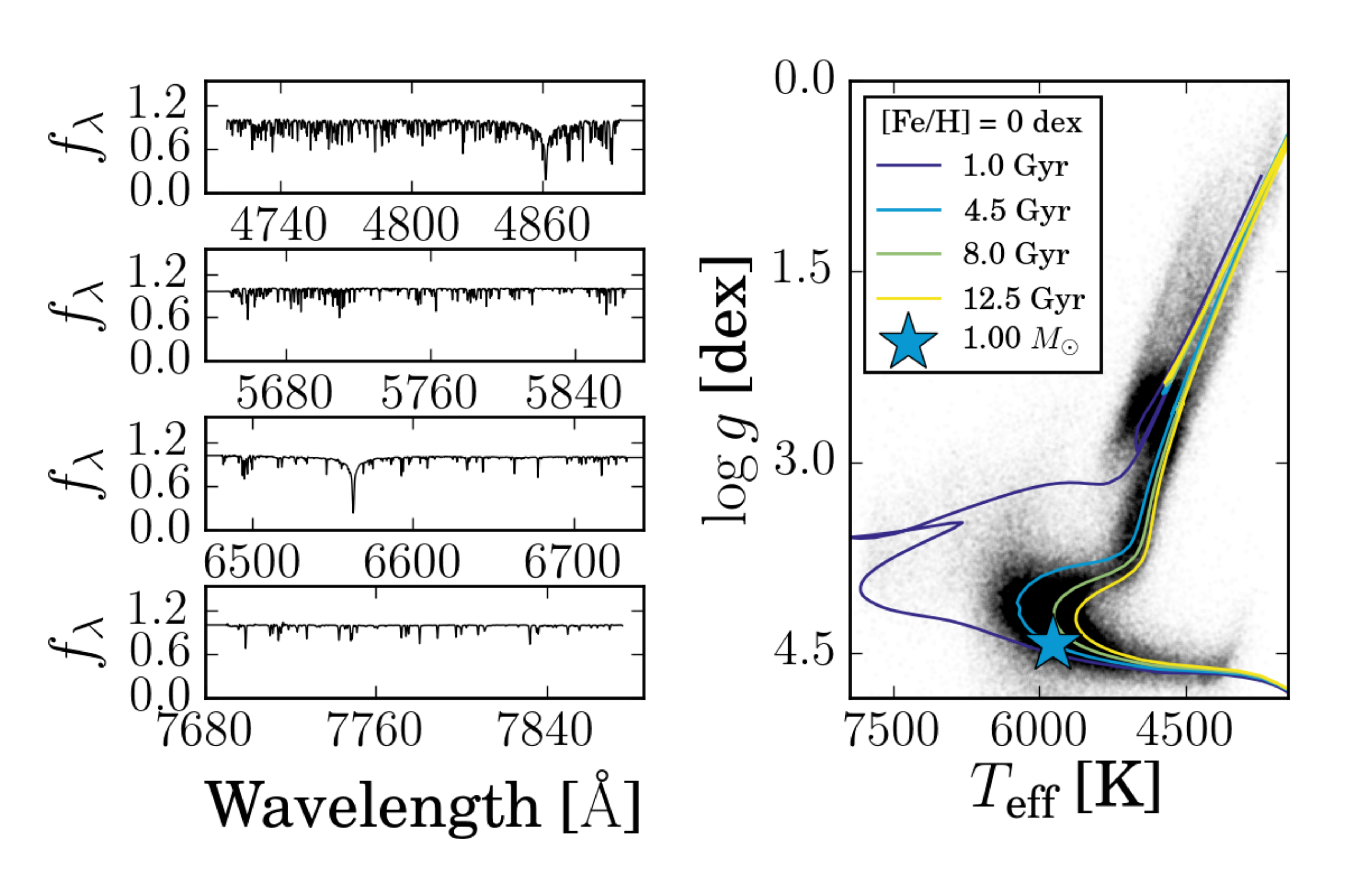


Up to 10^6 spectra



hot(ter) stars (v_{sini}), FGK dwarfs + giants , cool dwarfs (TiO!), pre-MS stars, emission stars, binaries, …
+ bad spectra

HOW TO ANALYSE 10^6 SPECTRA?

Problem 1: Computational costs

Stellar physics-driven data analysis takes ~ 1h per star
(on-the-fly syntheses of spectra/spectral lines from MARCS models)

Problem 2: High precision needed

List of numerous, unblended, well-defined lines (best: whole spectrum)

Solution:

Combine physics-driven analysis for small representative set with data-driven analysis on whole sample:

Spectroscopy Made Easy (SME) by Piskunov & Valenti (2017)

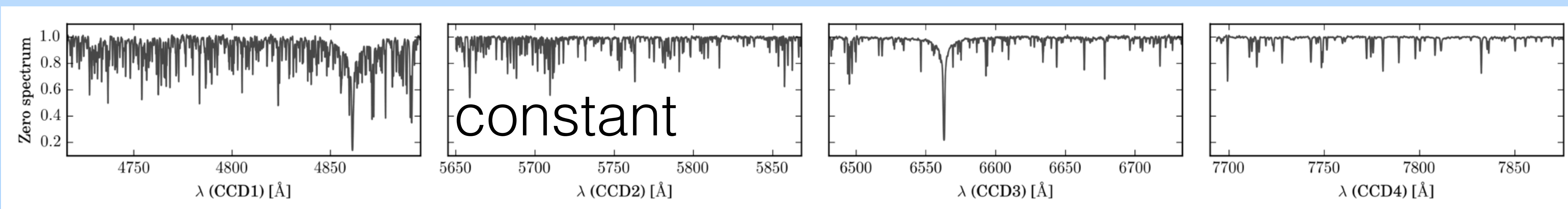
+

The Cannon by Ness et al. (2015)

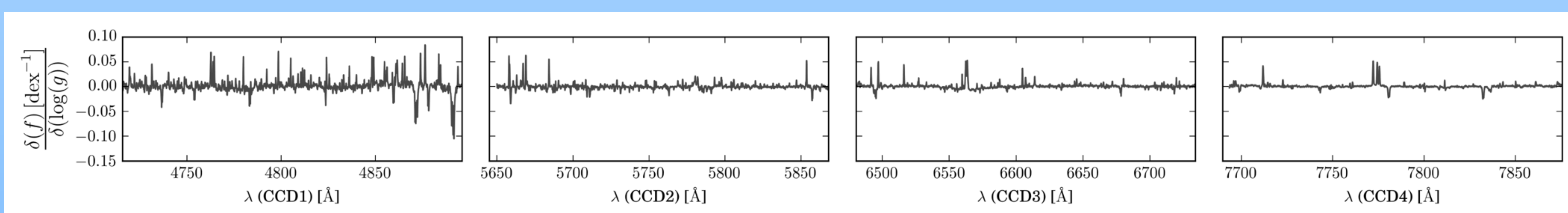
The Cannon (Ness et al. 2015)

Use linear algebra (e.g. quadratic model) to construct spectra from stellar labels (T_{eff}, log g, [Fe/H], …)

$$f_{n,\lambda} = \Theta_\lambda^T \cdot l_n + \text{noise}$$



linear coefficient for logg:



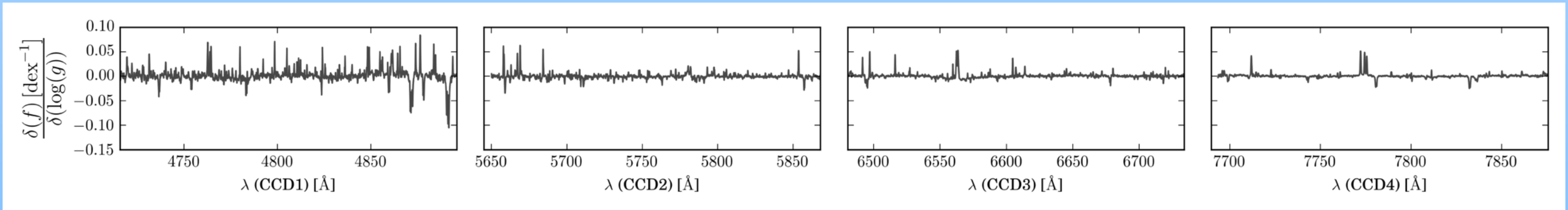
The Cannon (Ness et al. 2015)

Use linear algebra (e.g. quadratic model) to construct spectra from stellar labels (T_{eff}, log g, [Fe/H], …)

$$f_{n,\lambda} = \Theta_\lambda^T \cdot l_n + \text{noise}$$

many properties can be used as a label:
… , v_{mic}, v_{sini}, [X/Fe], age, mass, E(B-V), A_K, BVRIJHK, …

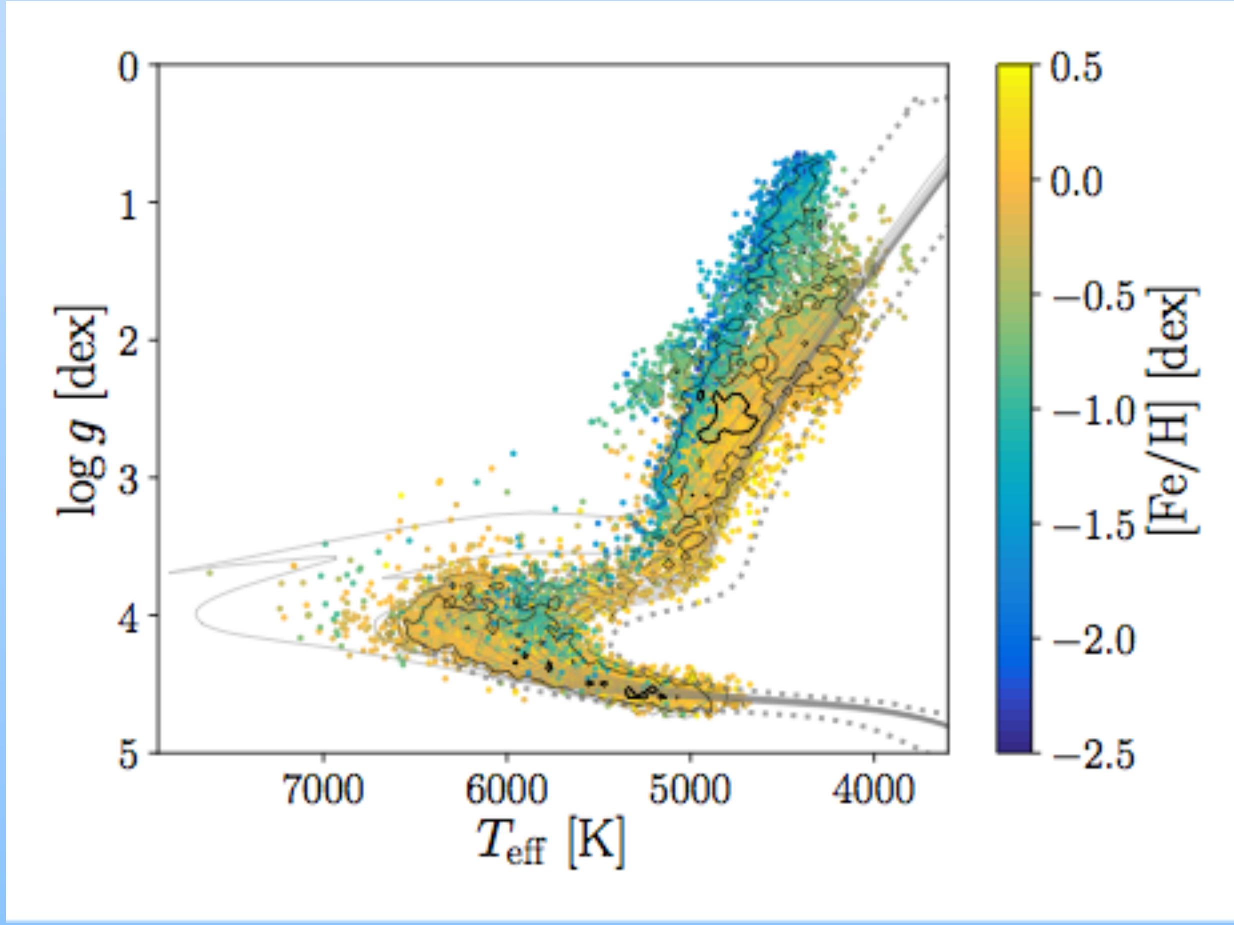
linear coefficient for logg:



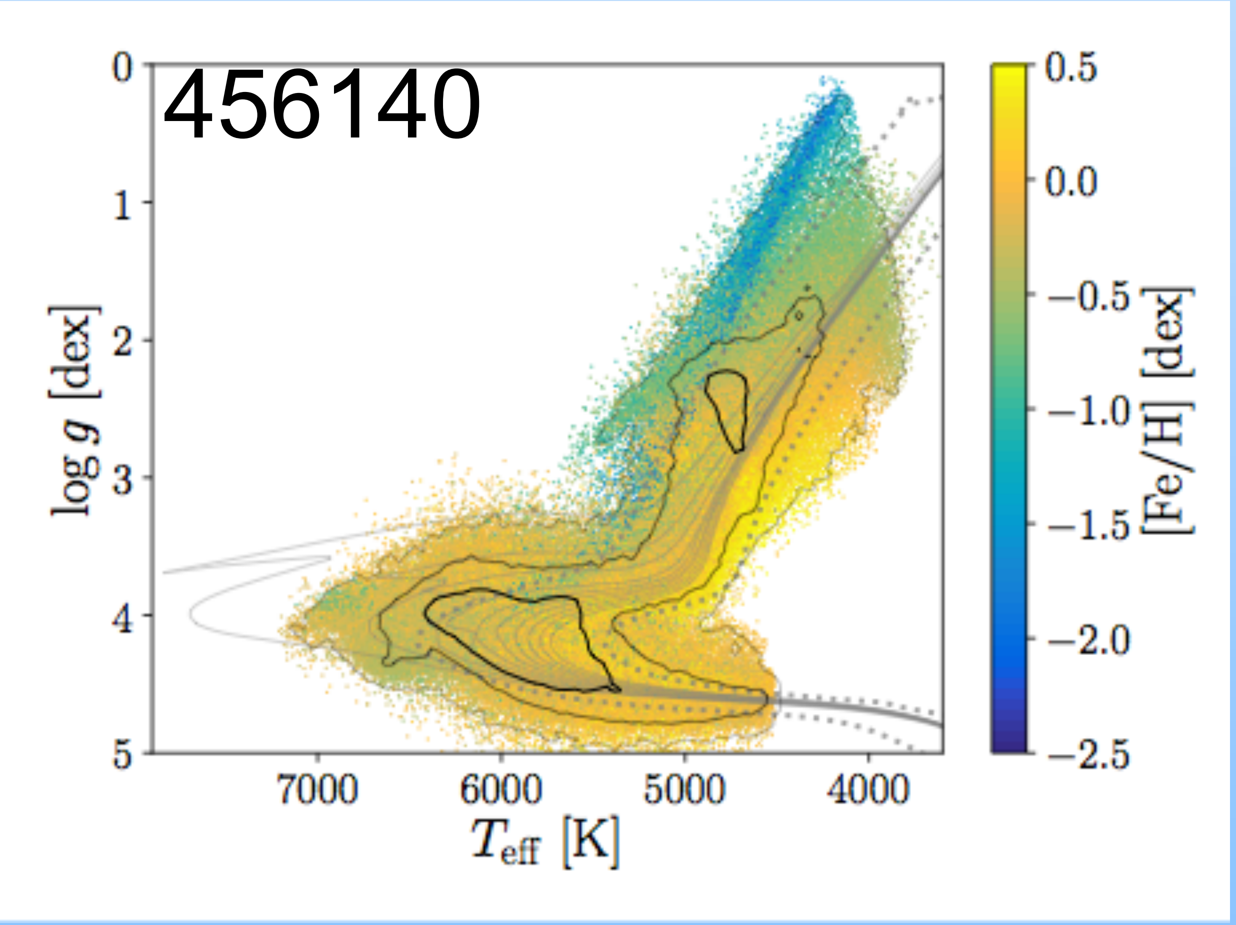
The Cannon (Ness et al. 2015)

(e.g. quadratic model) to construct spectra from stellar labels (Tef

$$\mathrm{f}_{n,\lambda} = \Theta_\lambda^T \cdot l_n + \mathrm{noise}$$



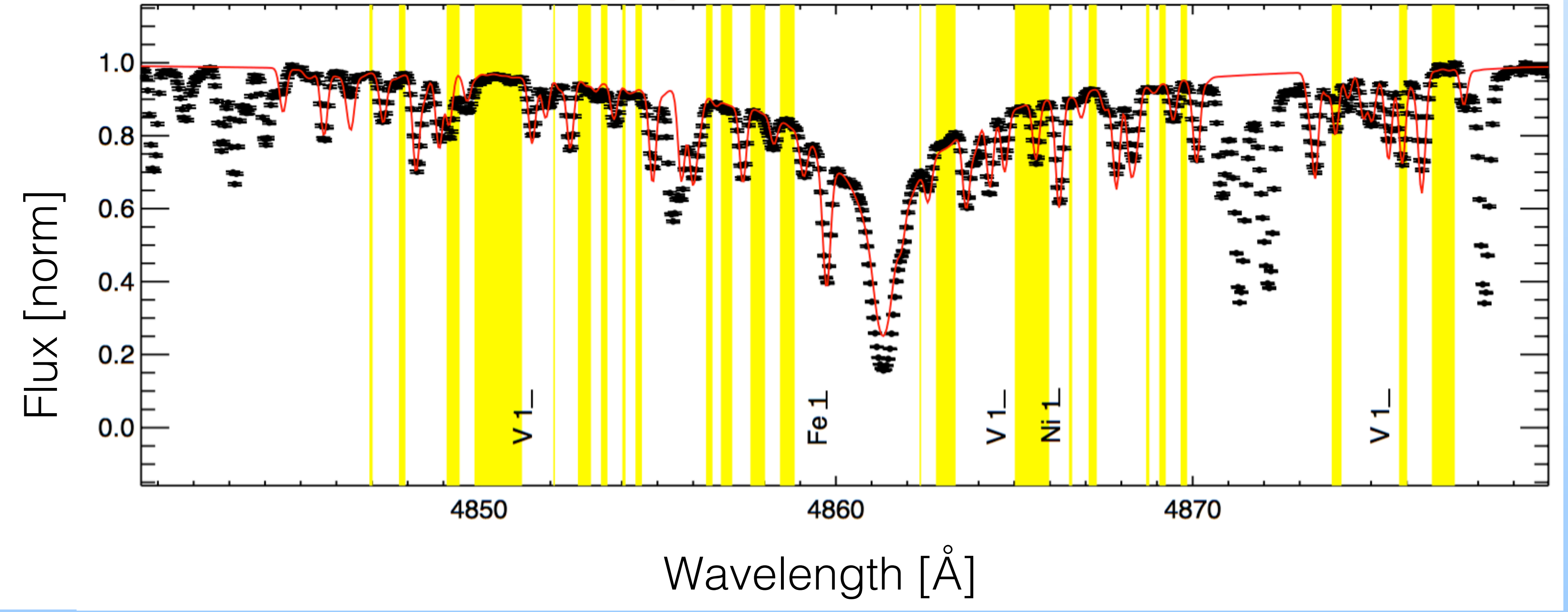
l_n fixed, train Θ_λ



Θ_λ fixed, optimise l_n in 0.1s

WE NEED GOOD TRAINING LABELS!

Spectroscopy Made Easy (more than 200 users)
(Valenti & Piskunov 1996, Piskunov & Valenti 2017)



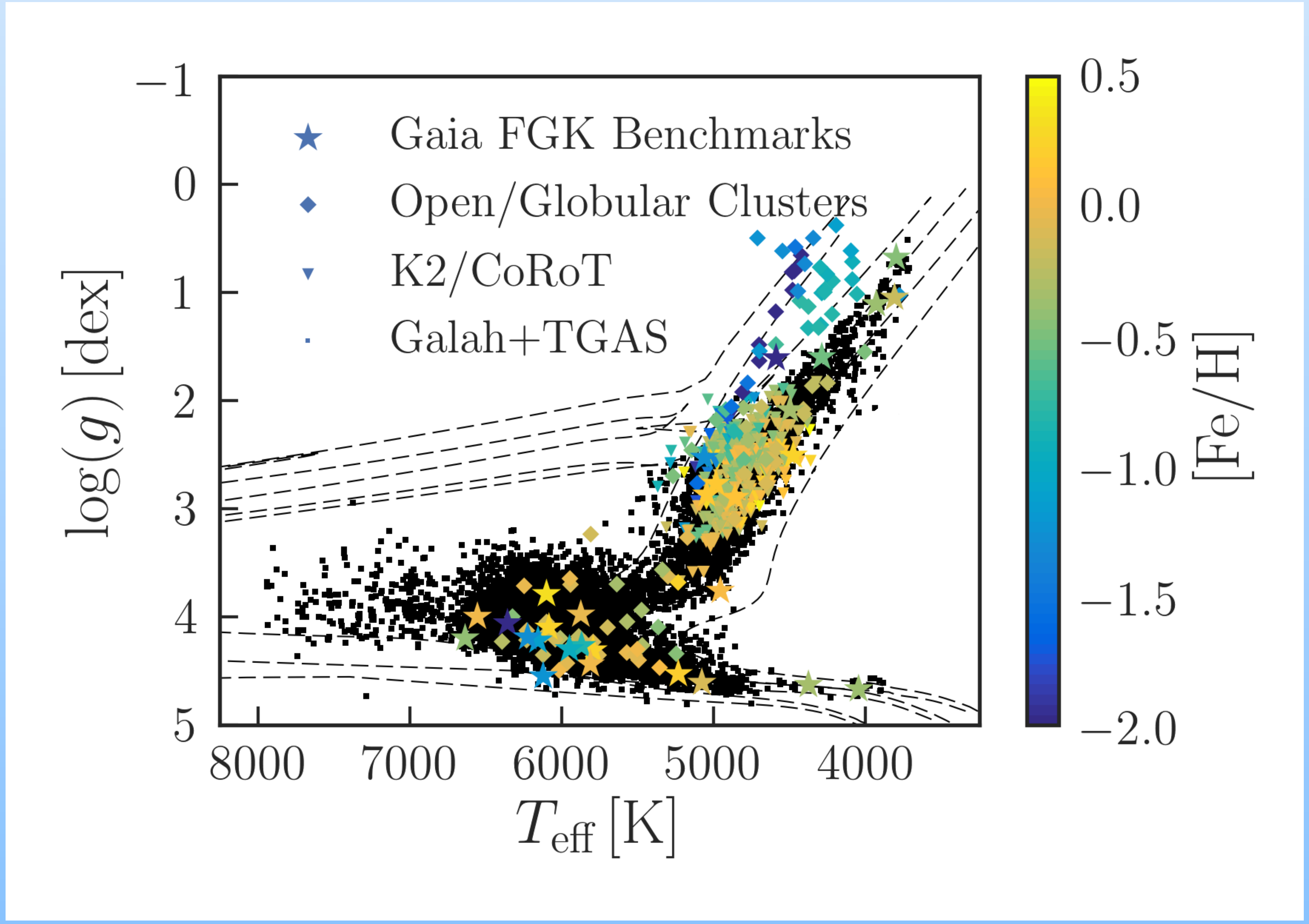
Spectrum synthesis based on atmosphere models incl. non-LTE
(molecular+ionisation equilibrium, continuous+line opacities, radiative transfer)

χ^2 **optimisation** with Levenburg-Marquardt algorithm in IDL wrapper

Stellar parameters: T_{eff}, $\log g$, [Fe/H], $v_{\sin i}$, v_{mic}
with fixed stellar parameters: element abundances **A(X) / [X/H] / [X/Fe]**

Stellar labels? Stellar parameters

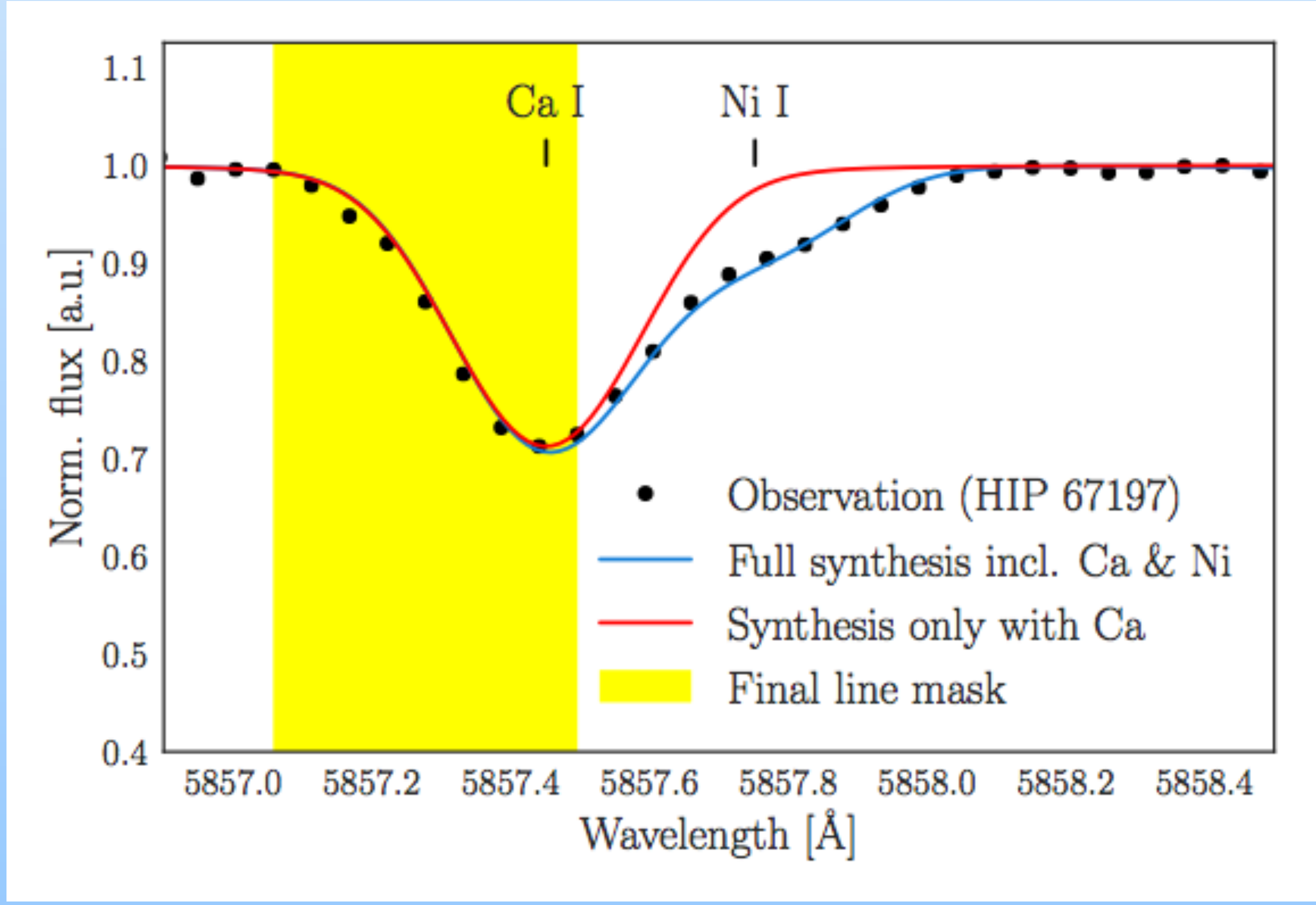
validation/calibration with non-spectroscopic information



Soon: TESS, e.g. TESS-HERMES by Sharma, Stello, Buder et al. (accepted)

STELLAR LABELS? ABUNDANCES

What influences abundance measurements?
GBS paper V: Jofré, Heiter, …, Buder, … (2017)



Continuum placement

Broadening parameters

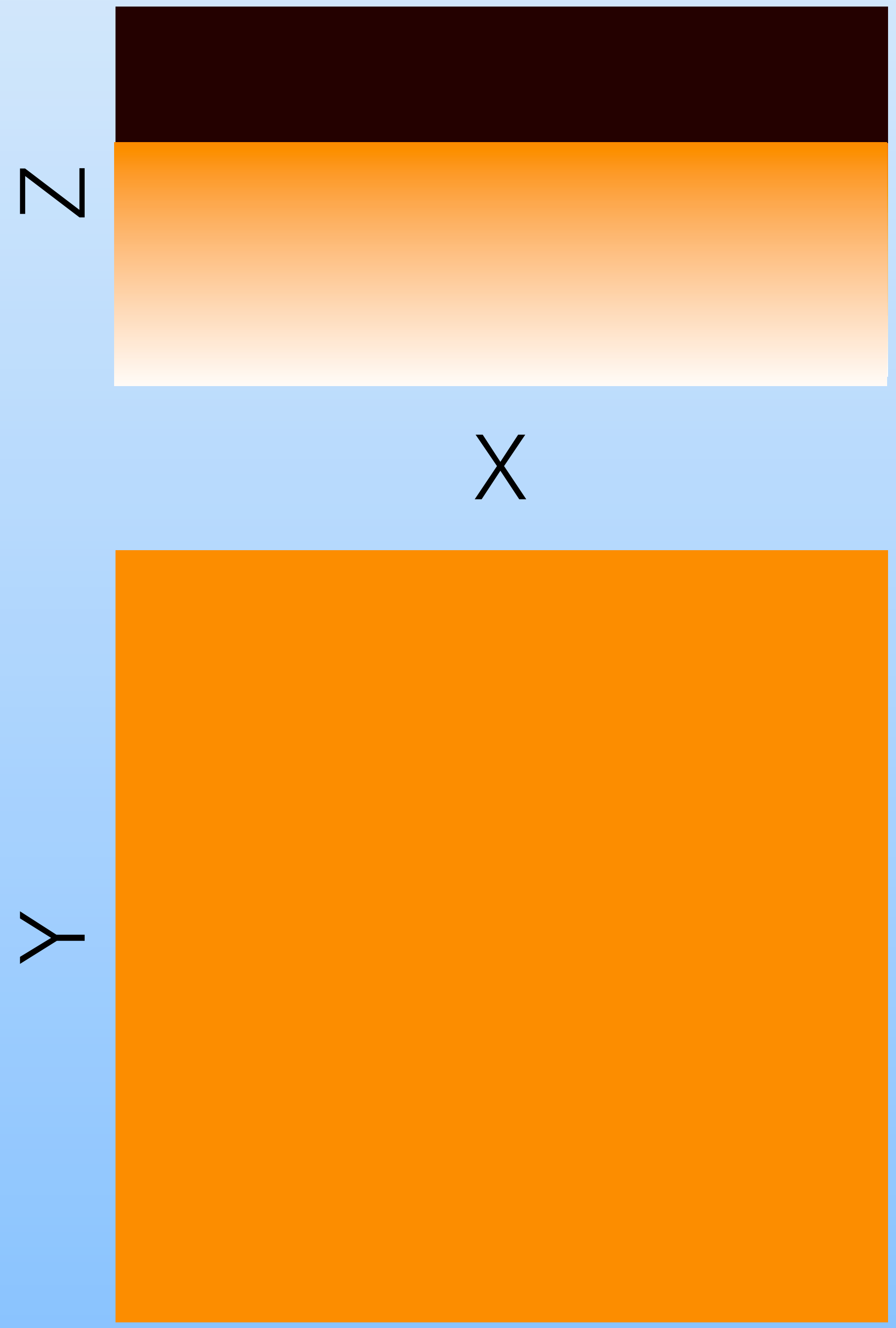
Instrumental characteristics

Line data (λ, f-value)

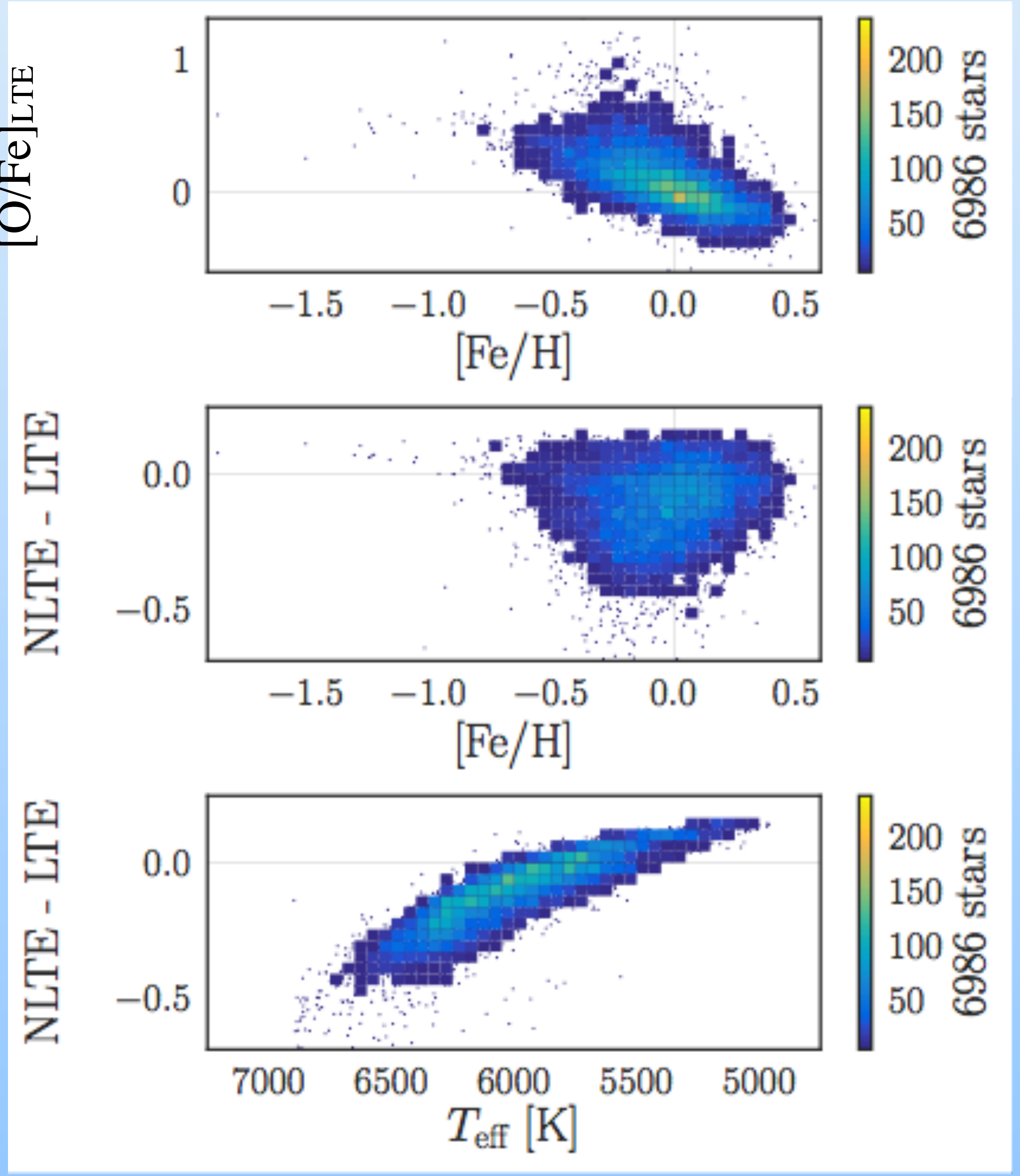
Blends

Telluric / sky lines

STELLAR LABELS? 1D LTE?



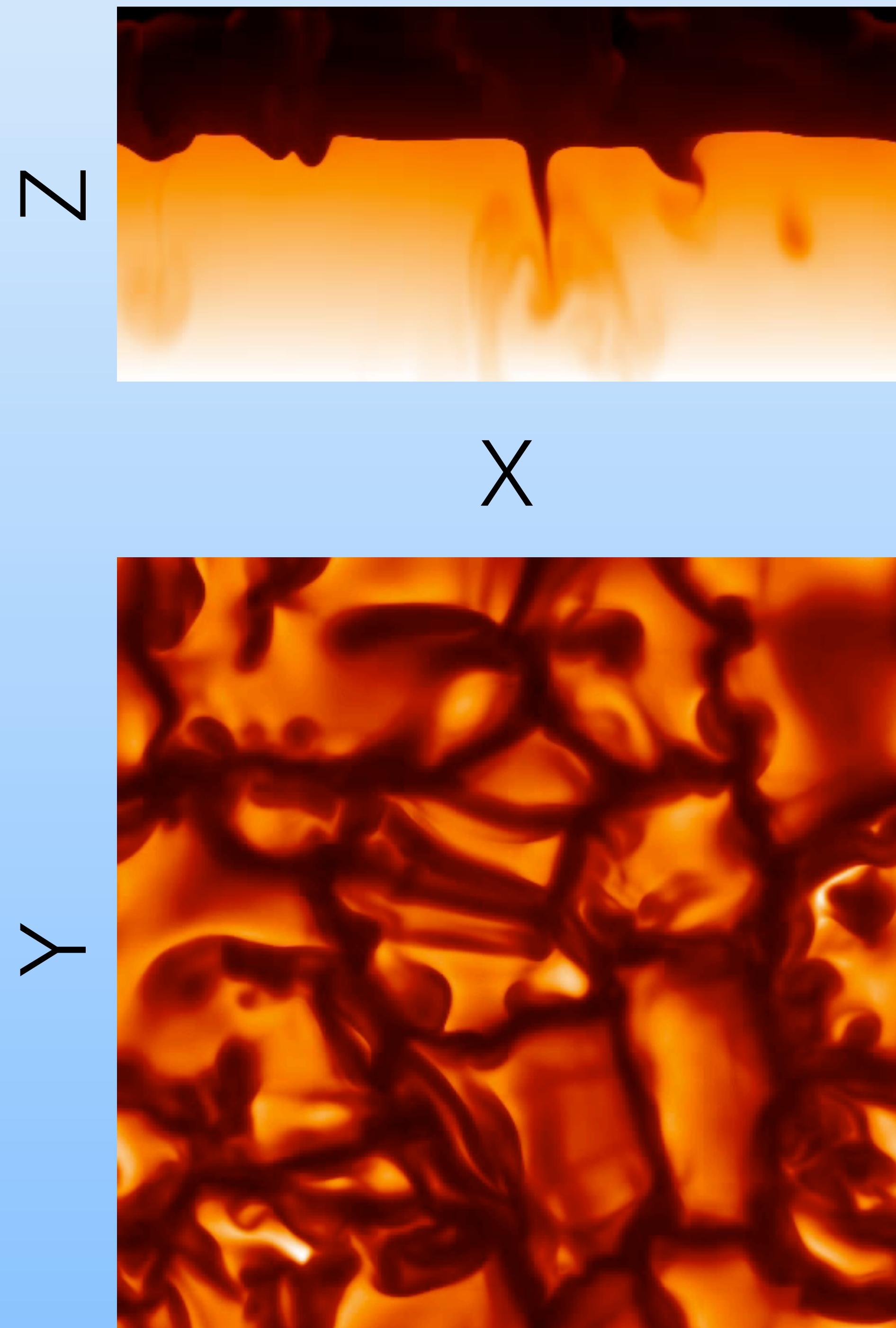
Work by Collet, Magic, Asplund, and others



OI 777 NLTE corrections by A. Amarsi

GALAH: still 1D, but already NLTE for Li, O, Na, Mg, Al, Si, Fe

STELLAR LABELS? 3D NON-LTE!



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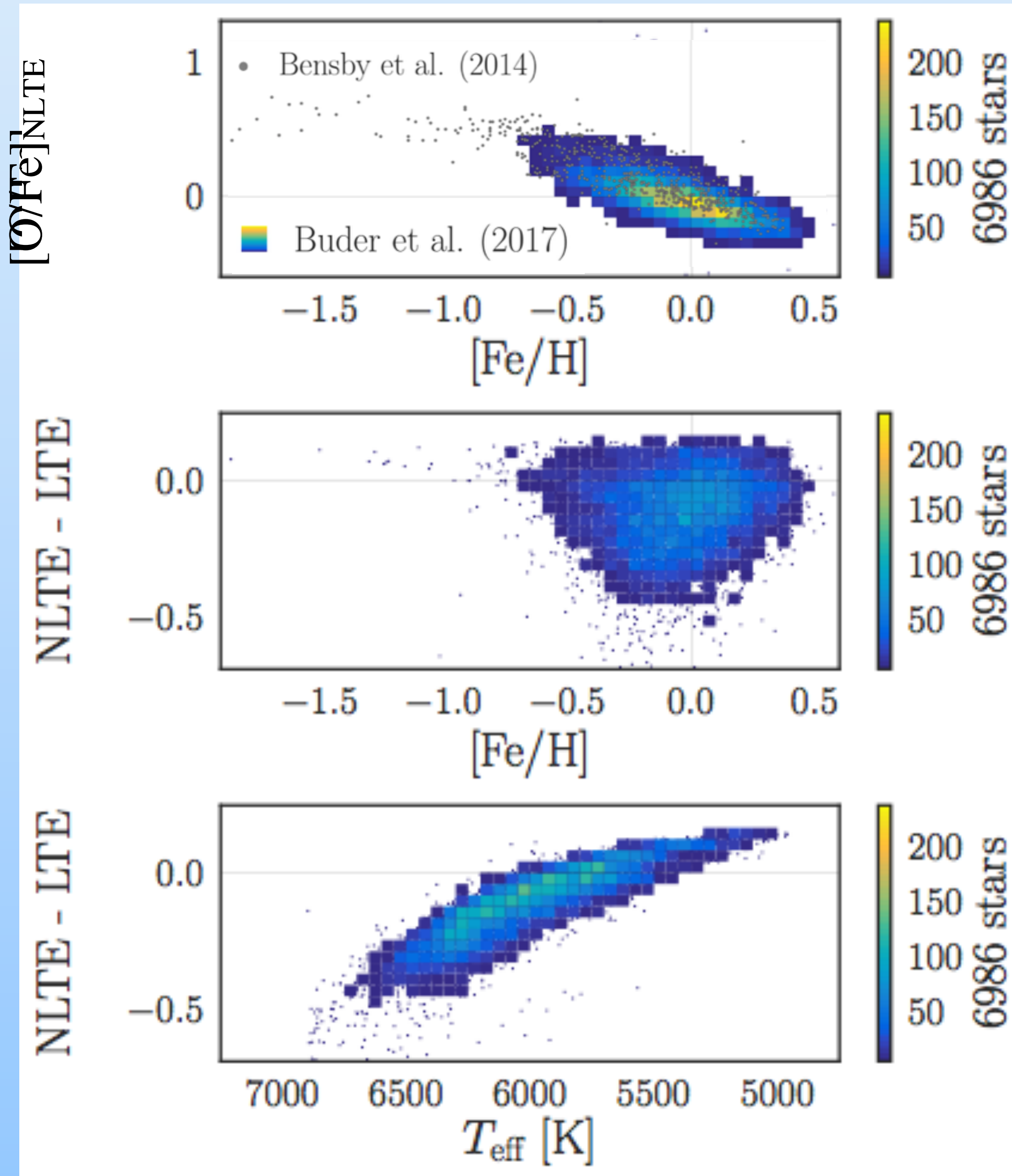

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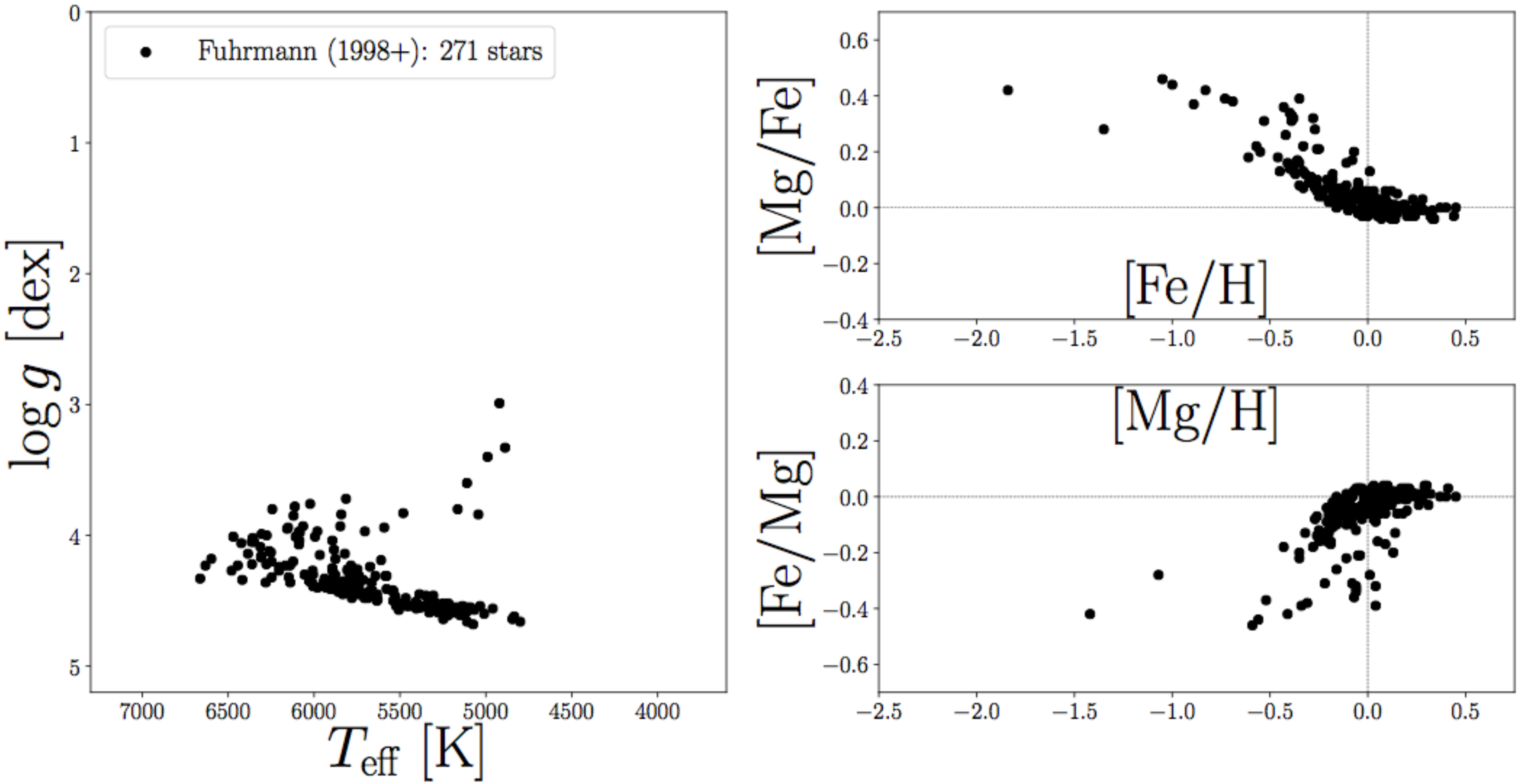
A NEW HORIZON FOR GALACTIC ARCHAEOLOGY



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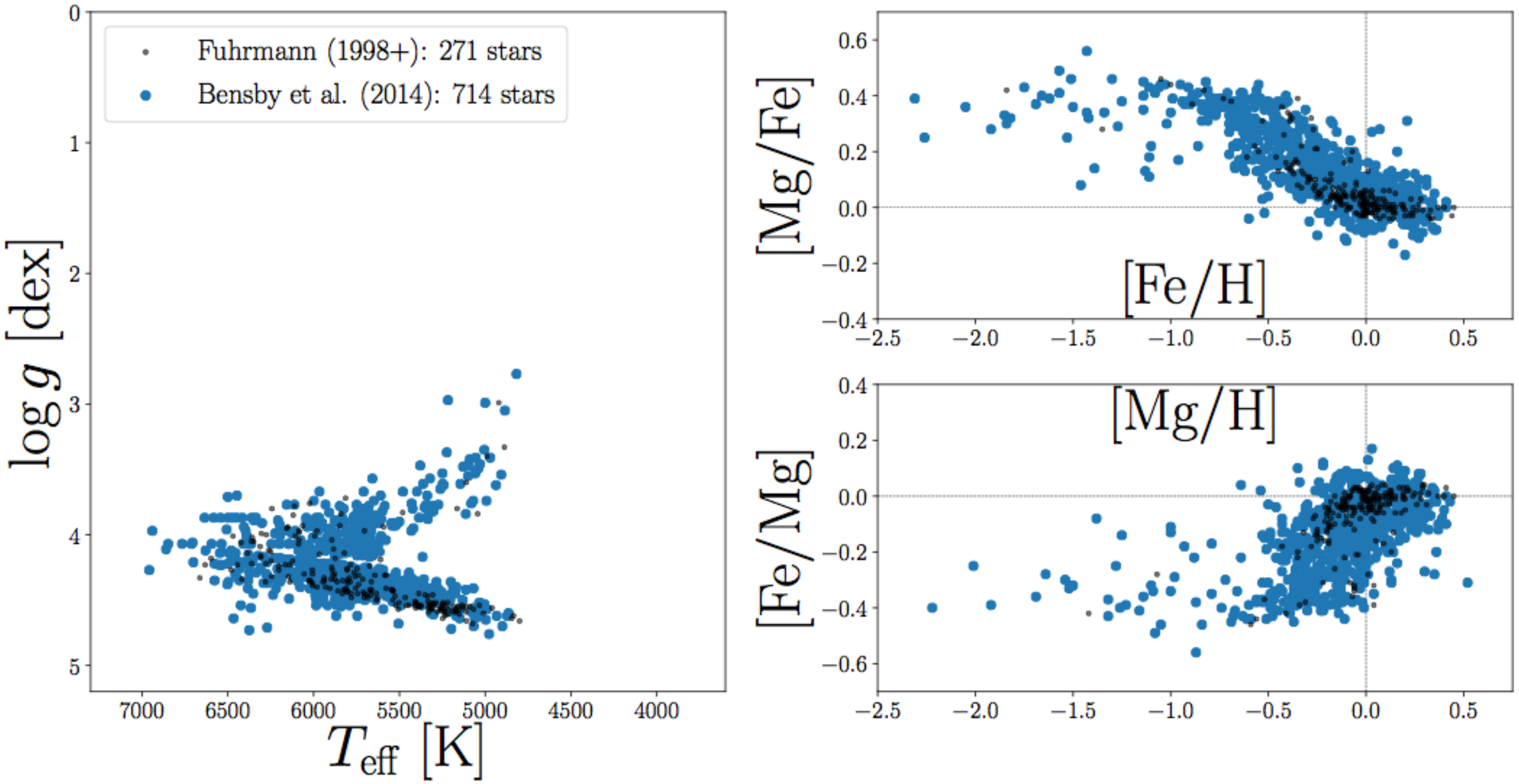
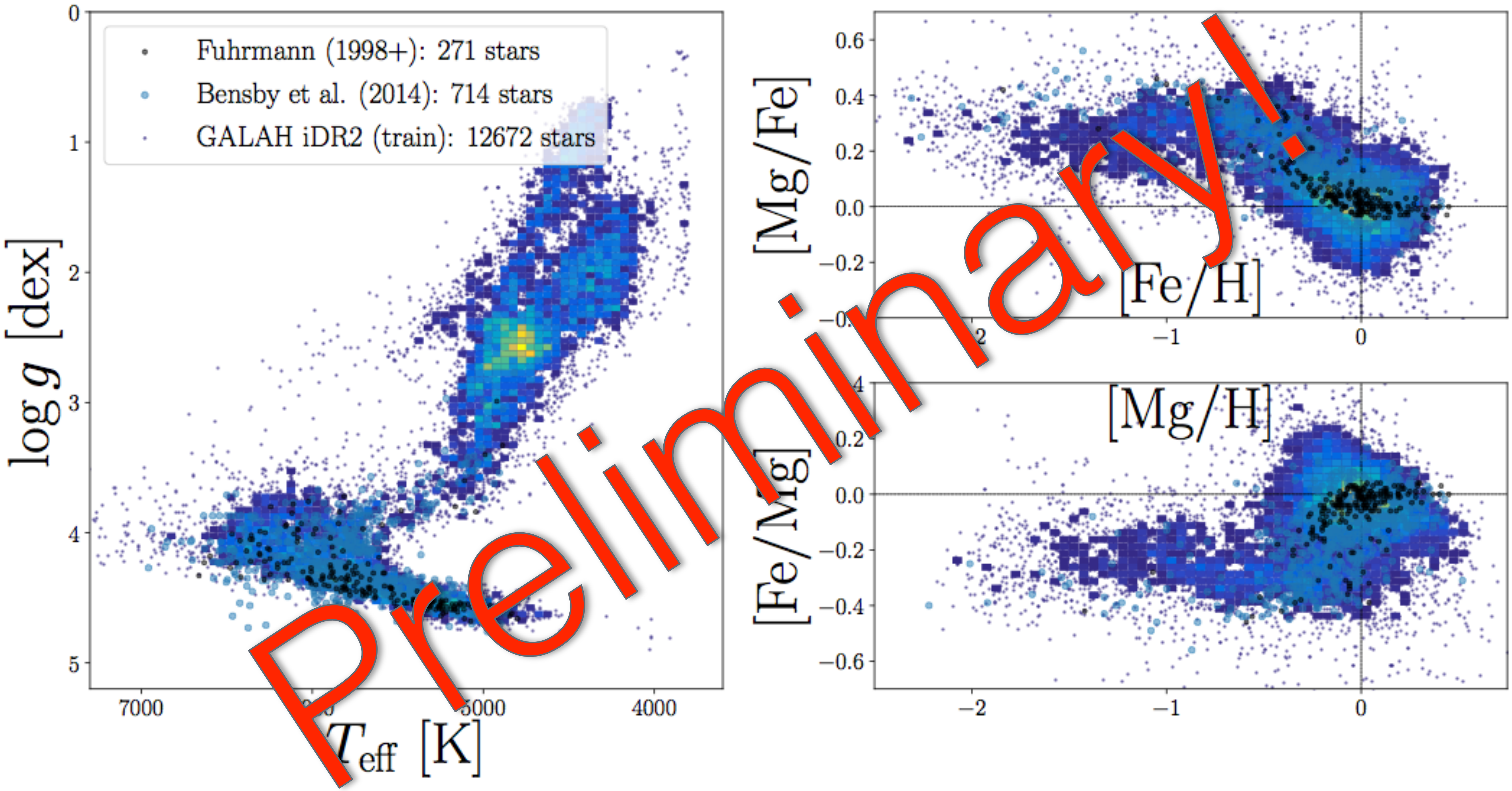


A new horizon for Galactic Archaeology



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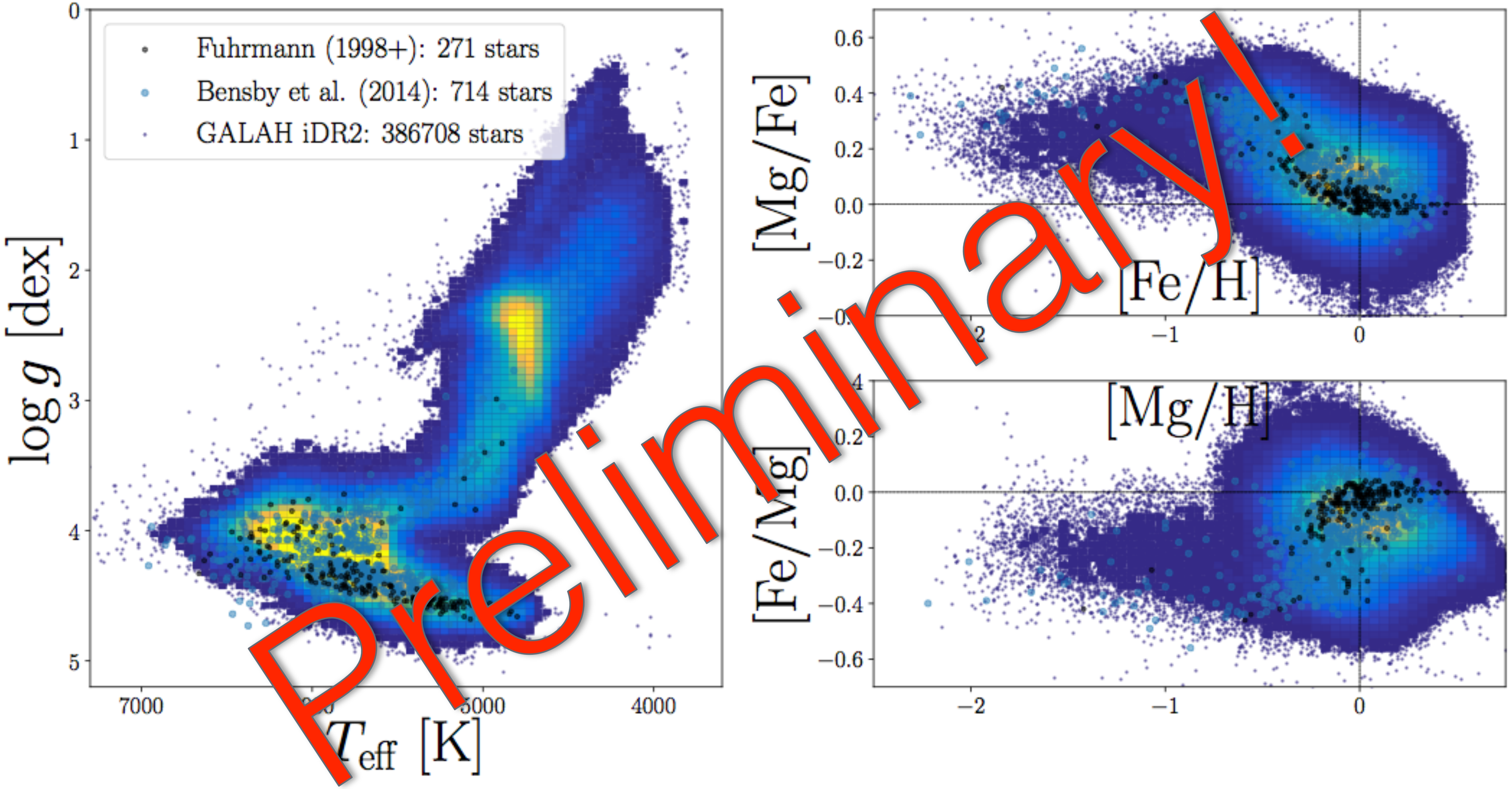
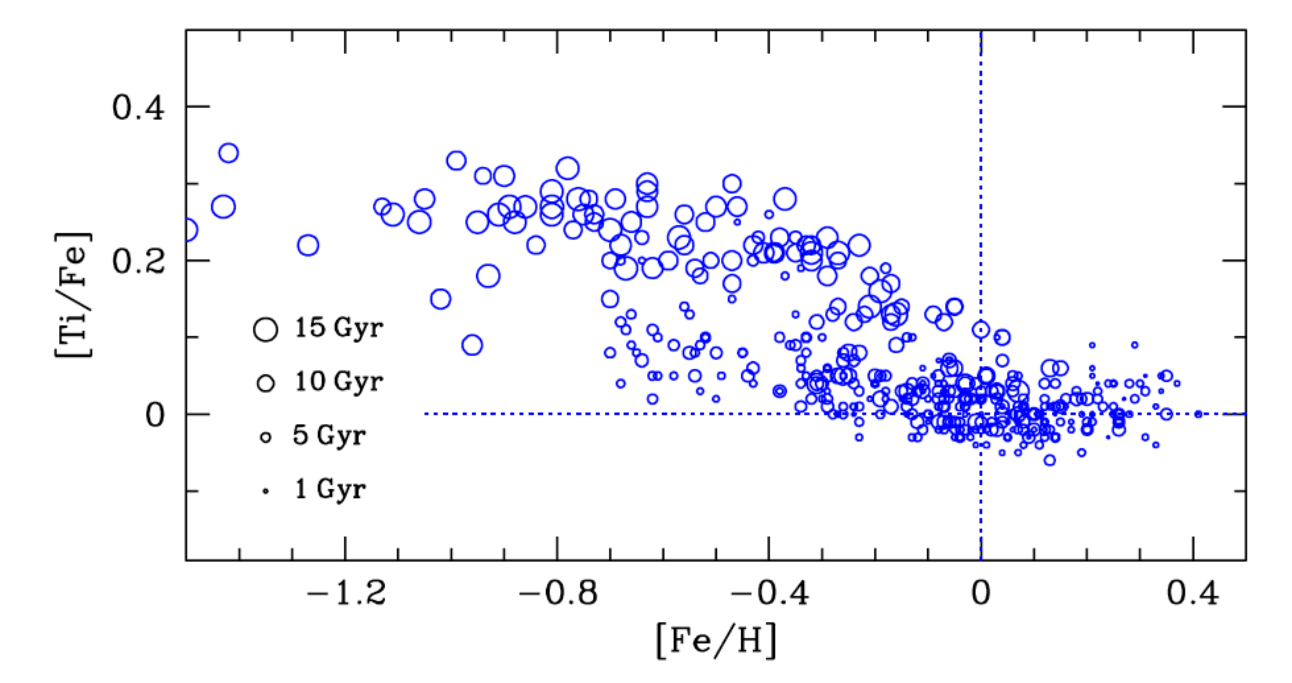


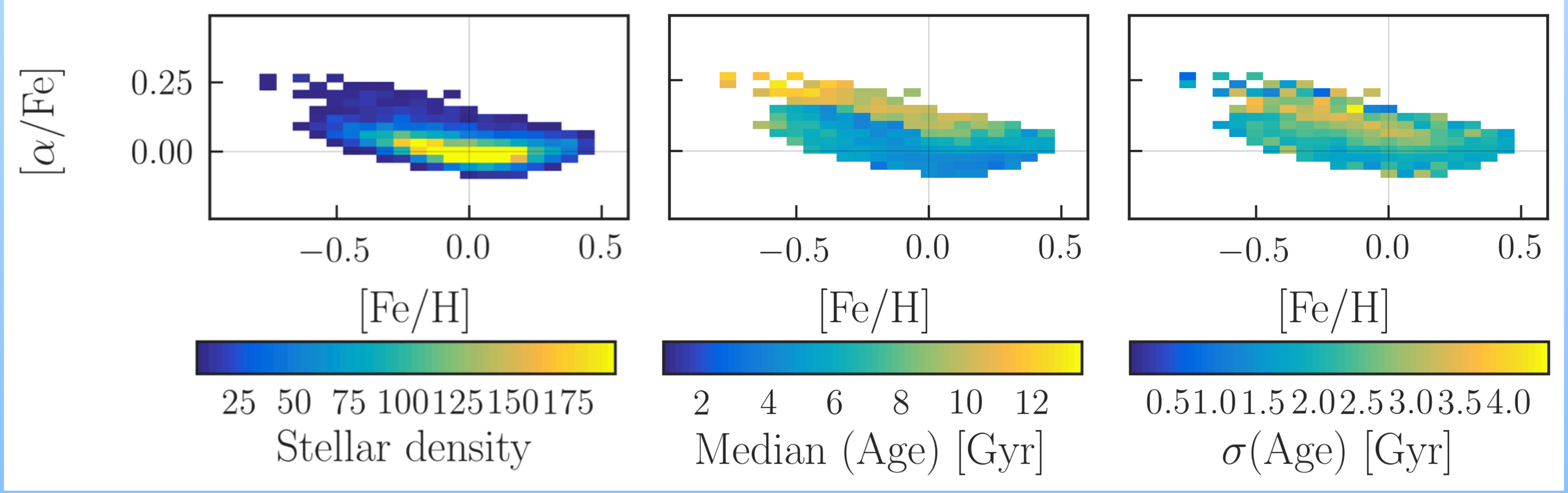
AGE TRENDS IN THE SOLAR NEIGHBORHOOD

Thick disk
α-enhanced
old (> 8 Gyr)



Thin disk
α-poor
young (< 8 Gyr)

Bensby et al. (2014) - 714 dwarfs



Buder et al. (in prep.), ages with ELLI code from Lin et al. (subm.)

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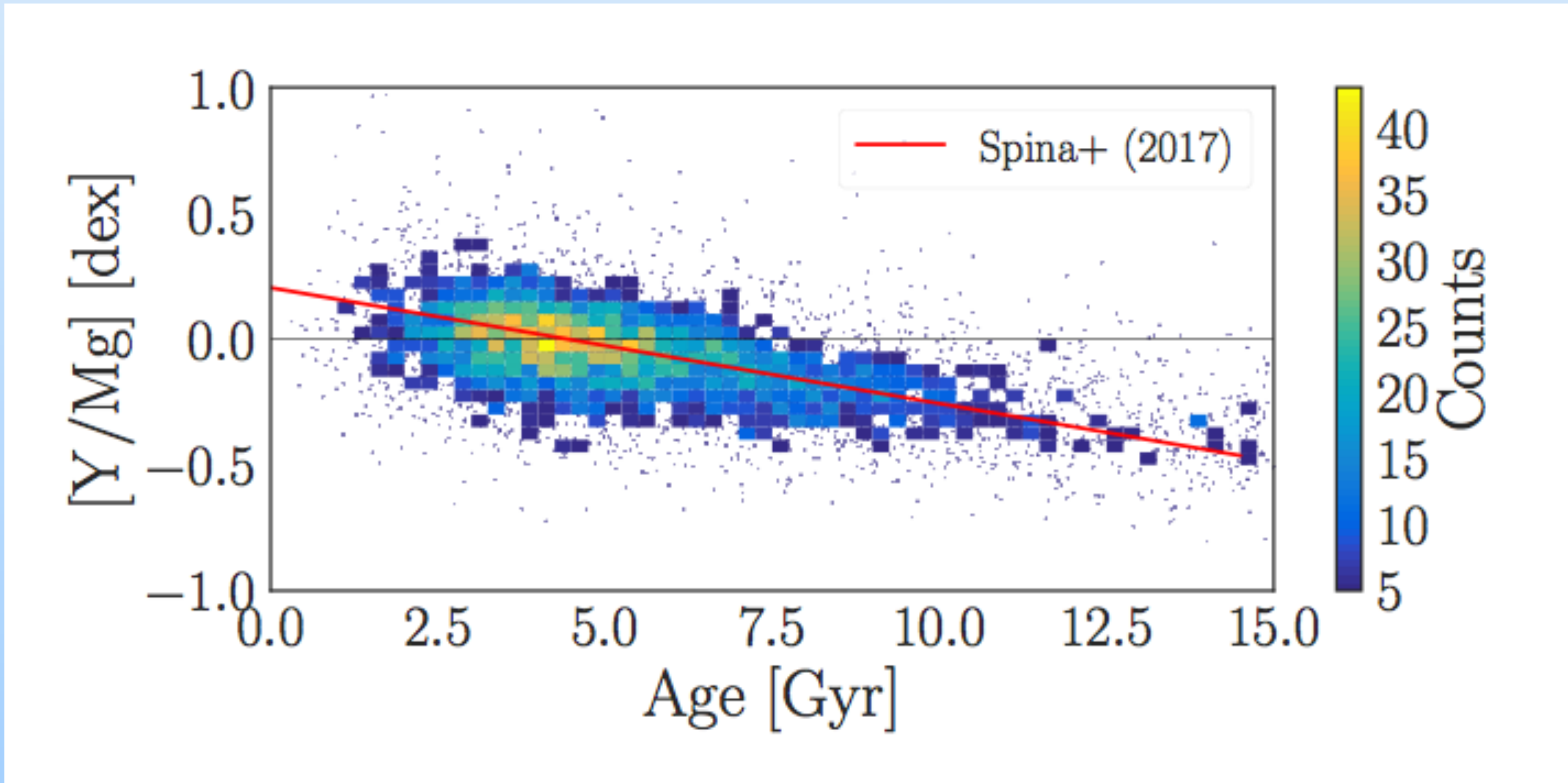
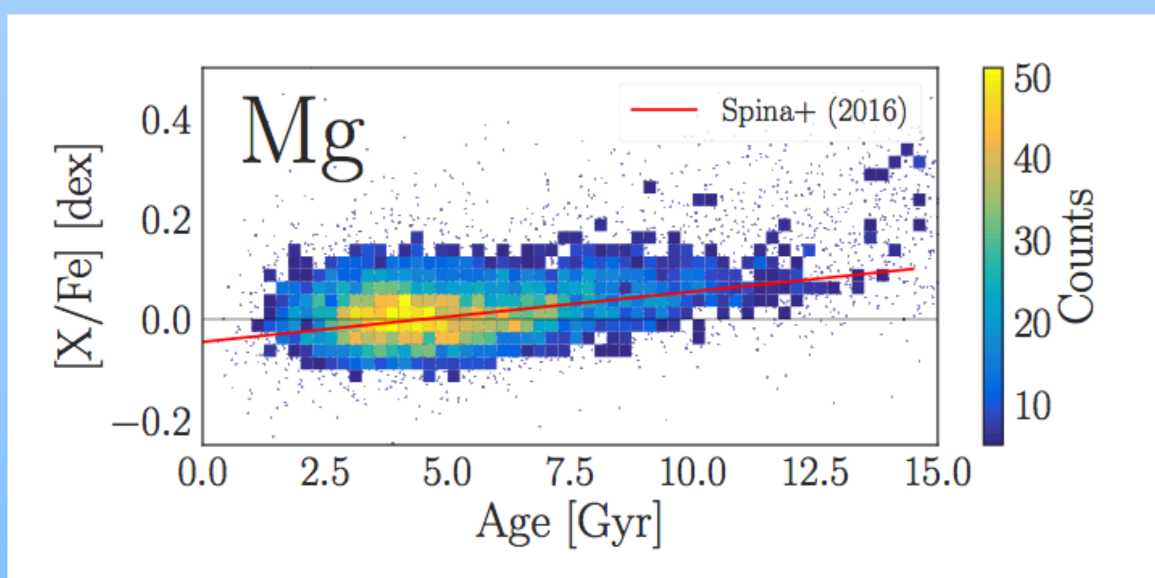
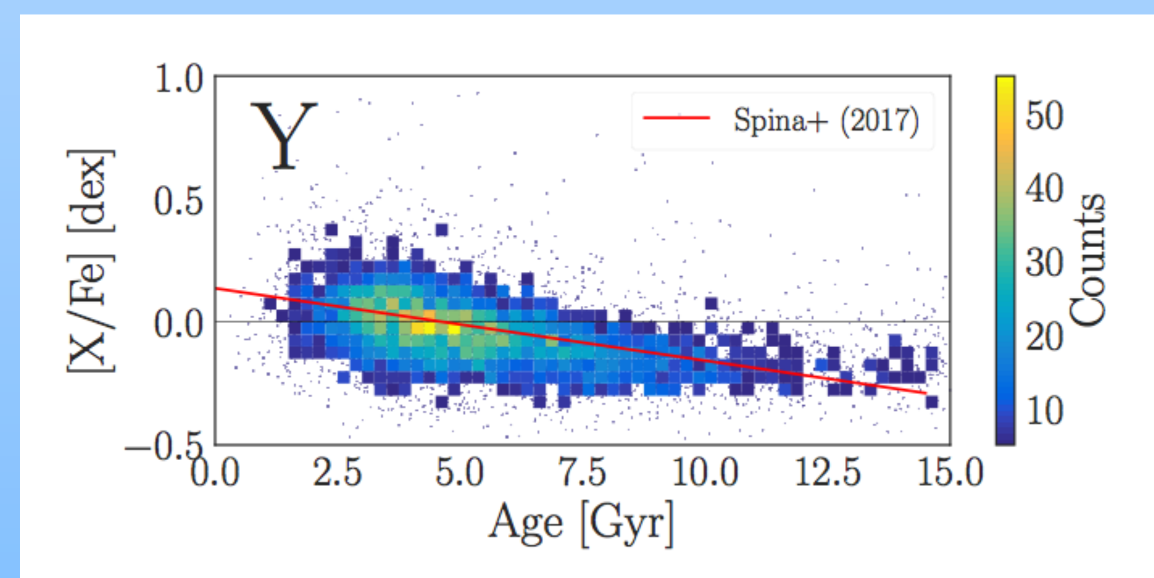
AGE TRENDS IN THE SOLAR NEIGHBORHOOD

Buder et al. (in prep) ~8000 Galah+TGAS dwarfs (with preliminary age estimates)







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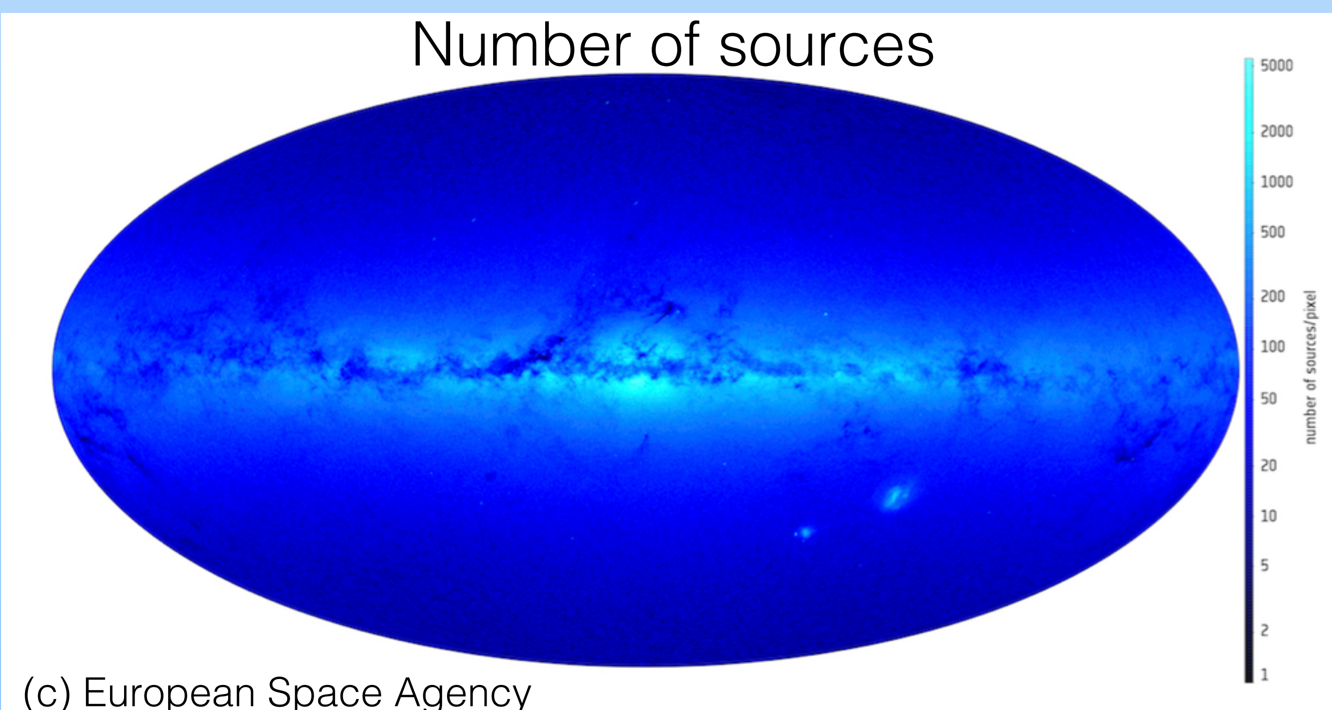
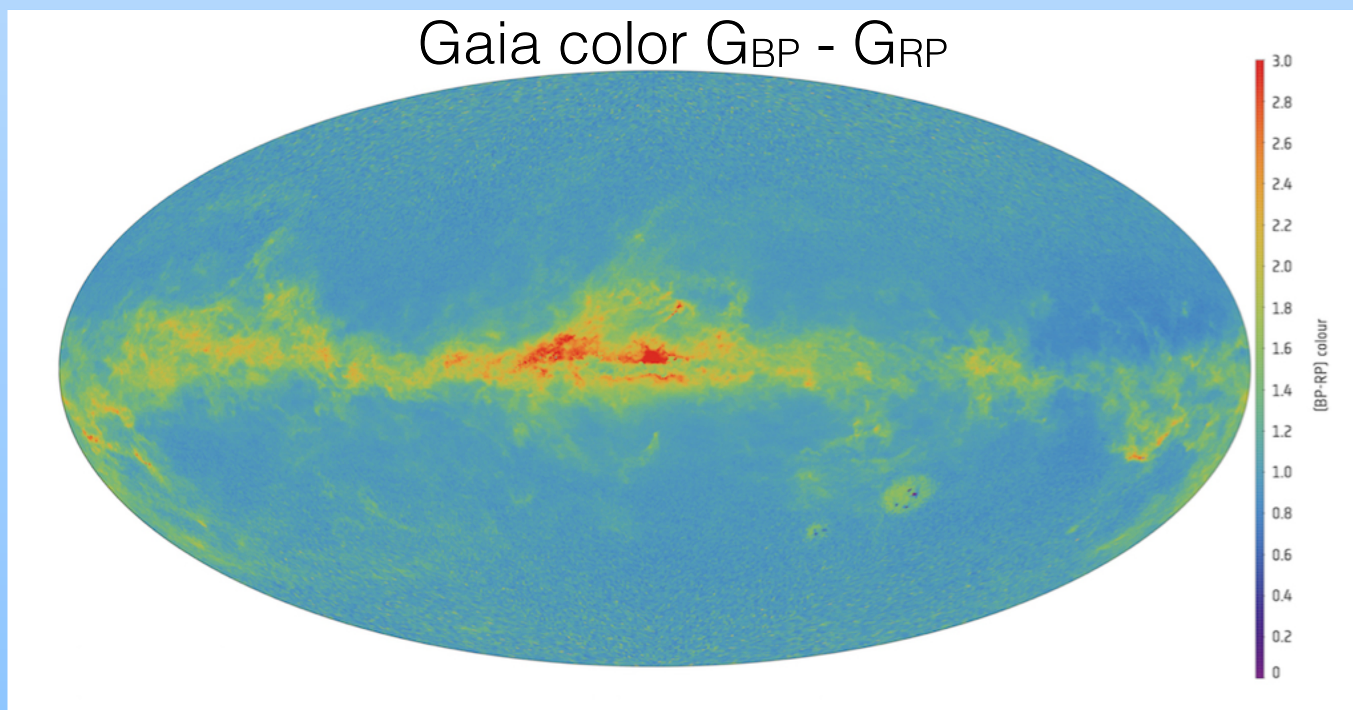
Part 2: Gaia (DR2*)

*based on press releases on esa.int

5D	> 10^9 sources
2D	Sources w/ ϖ+μ
RV	G_{RVS} < 12 mag

Photometry	G, G_{BP} and G_{RP}
T_{eff} / A_G	G < 17 mag





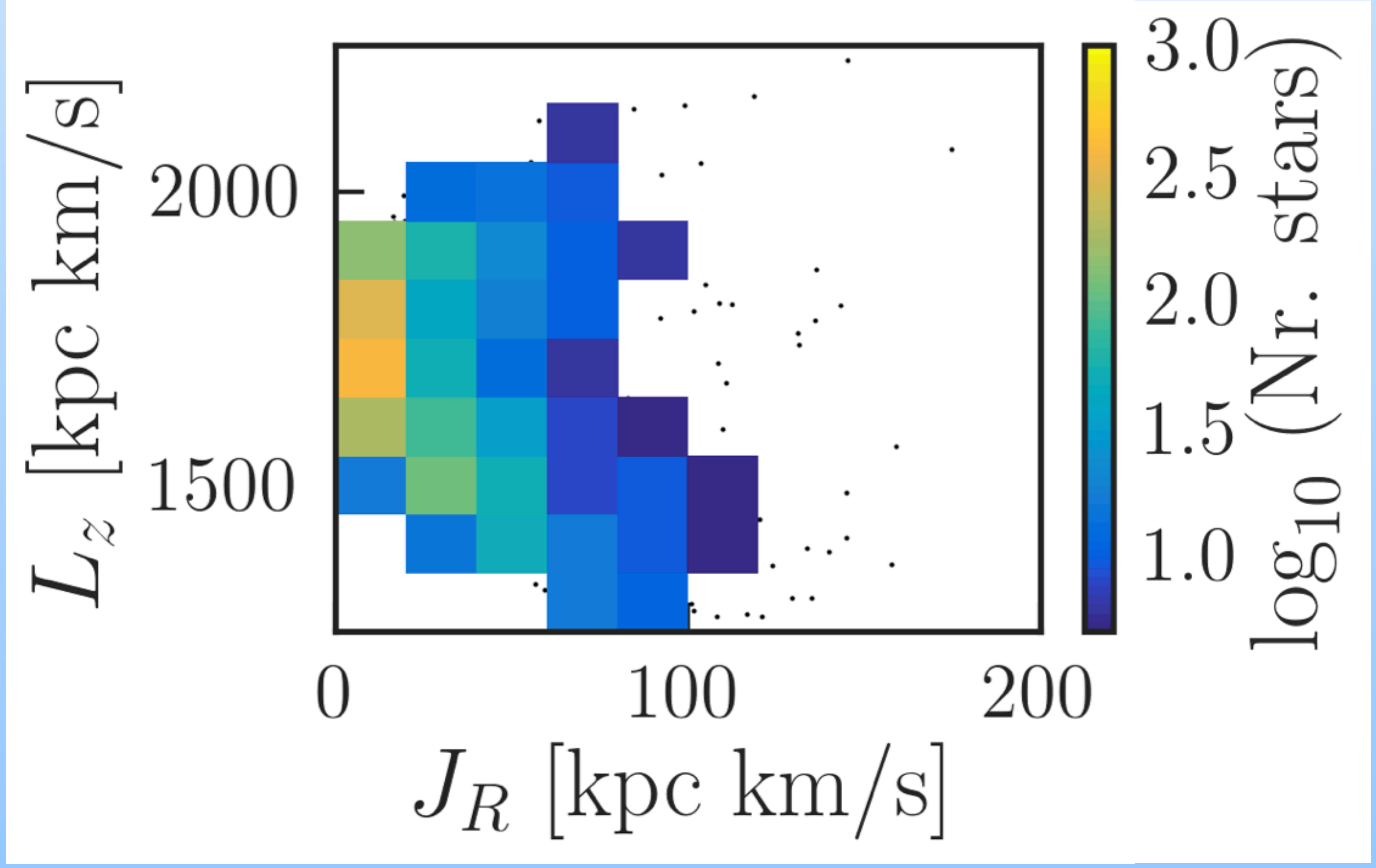
DYNAMICS / KINEMATICS IN THE GAIA ERA

RA,Dec,Distance $\quad pm_{RA}, pm_{Dec}, v_{rad}$

$$\Rightarrow R,\ \varphi,\ z,\ J_R,\ J_\varphi(\equiv L_Z),\ J_Z$$

Integrals of motion, *galpy* by Bovy (2015)

~ ‘mean radius’



~ ‘eccentricity’

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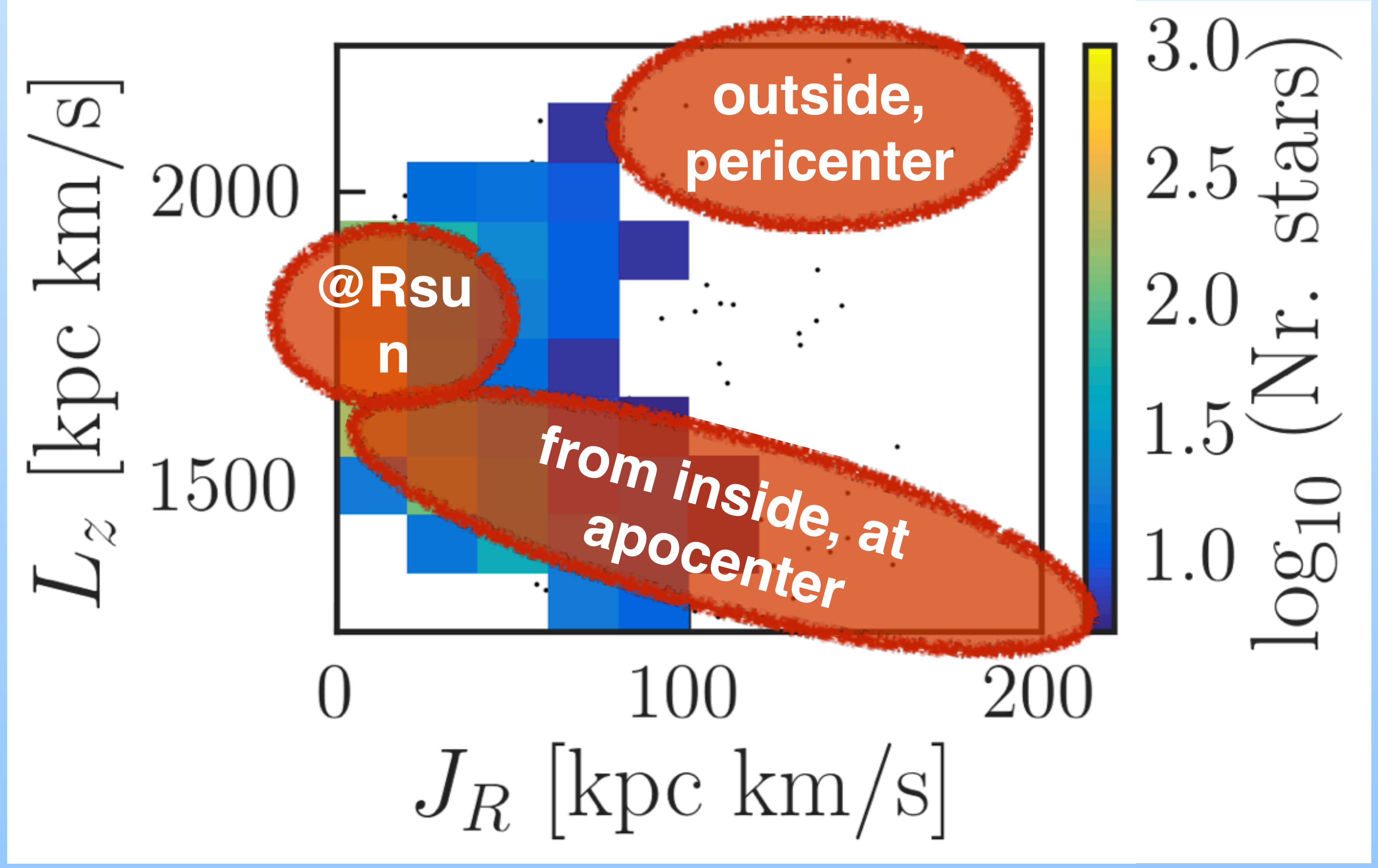
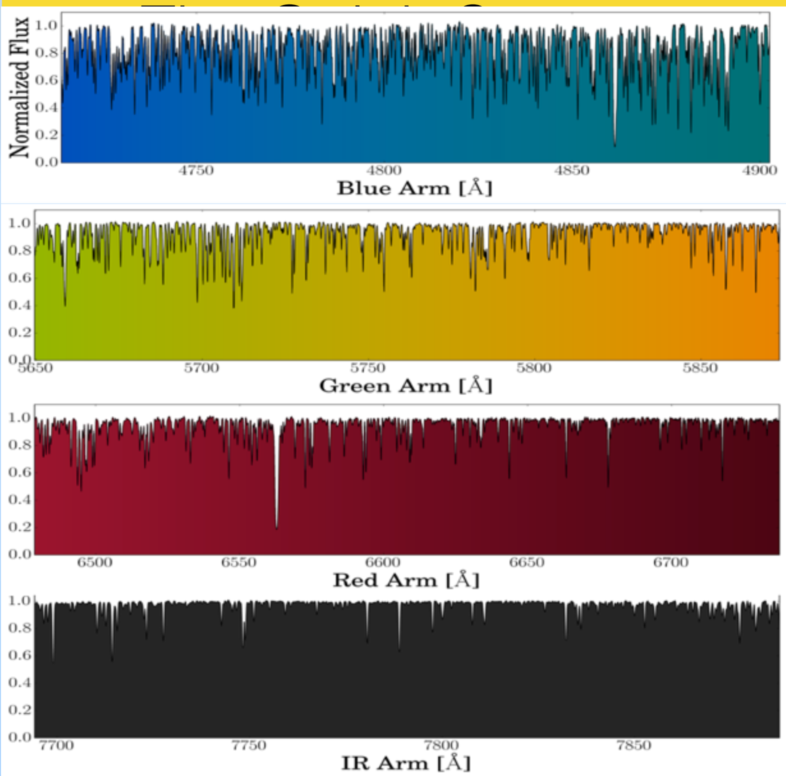


~ 'eccentricity'

Good distances: dwarfs within 1 kpc (Gaia DR1 TGAS) or RC

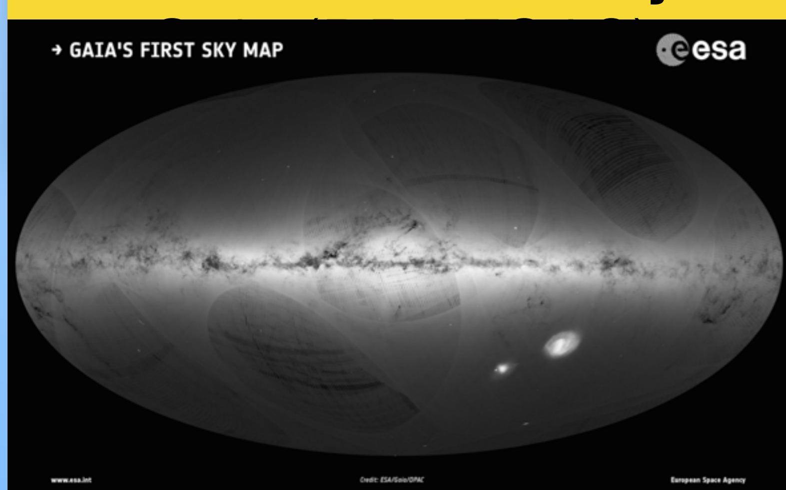
PART 3: GALAH AND GAIA

Spectroscopy



+

Astro-/Photometry



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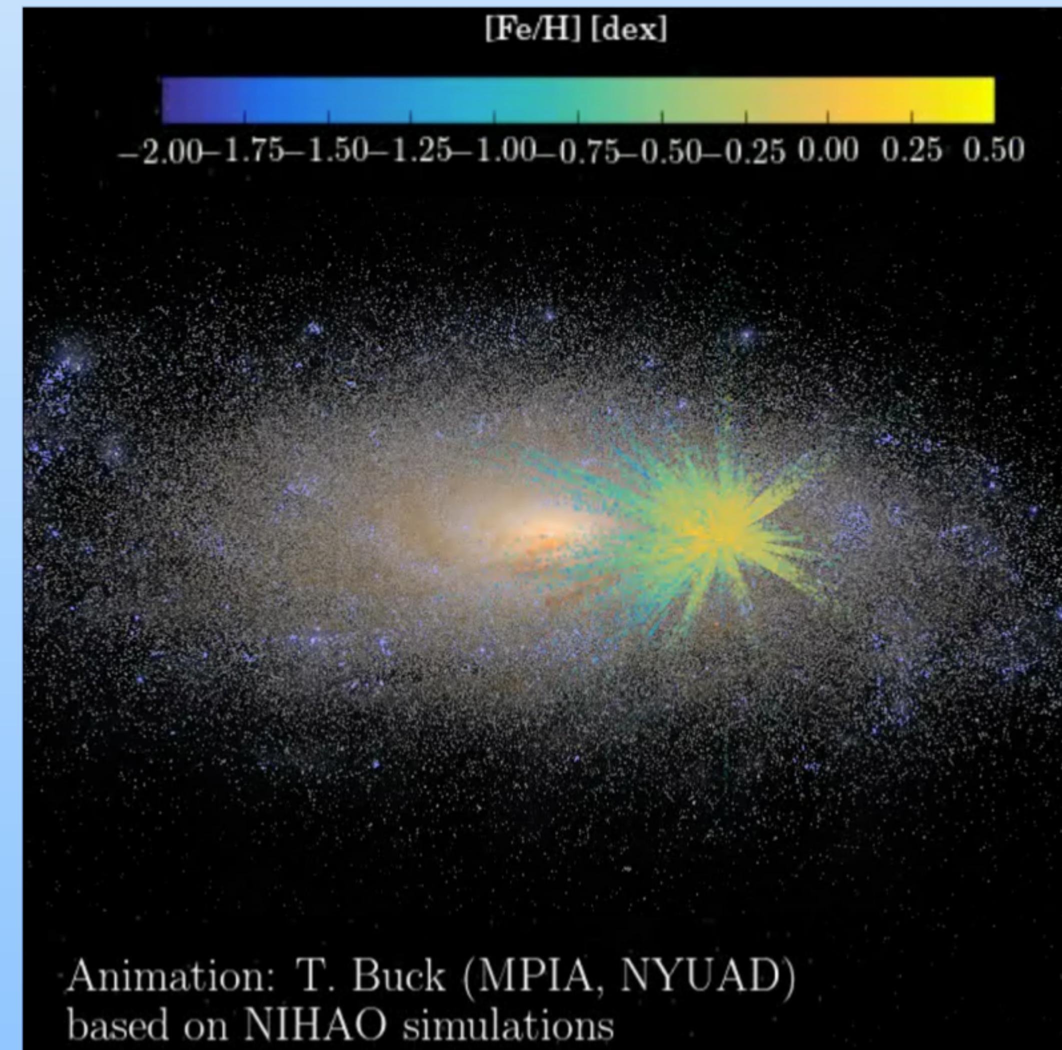

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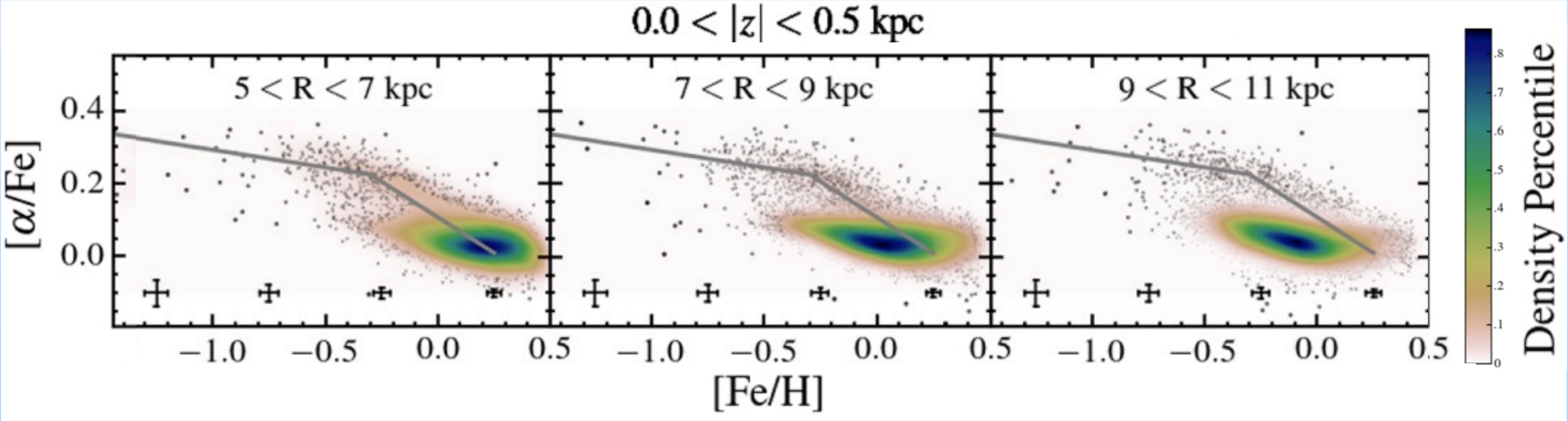
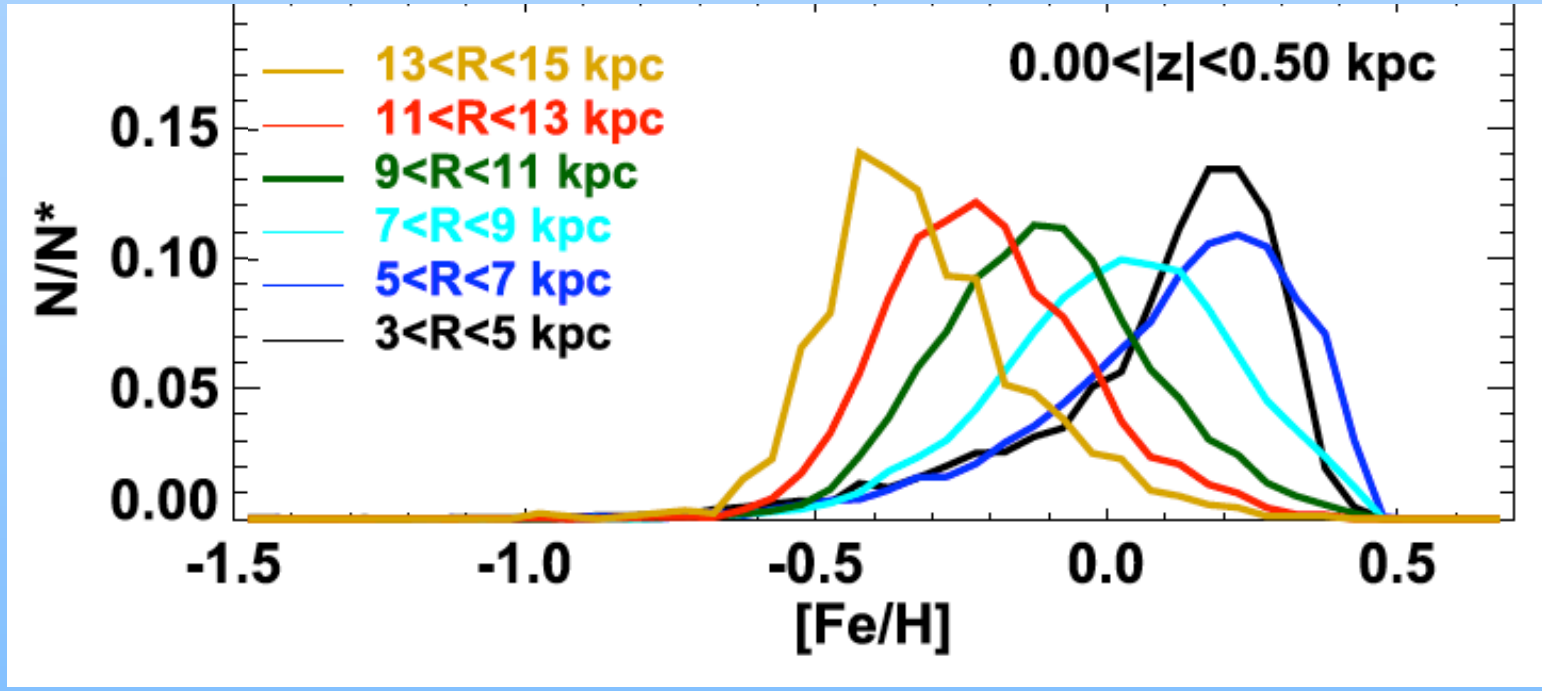
THINK/LOOK OUT OF THE BOX

Hayden et al. (2015) with APOGEE DR12

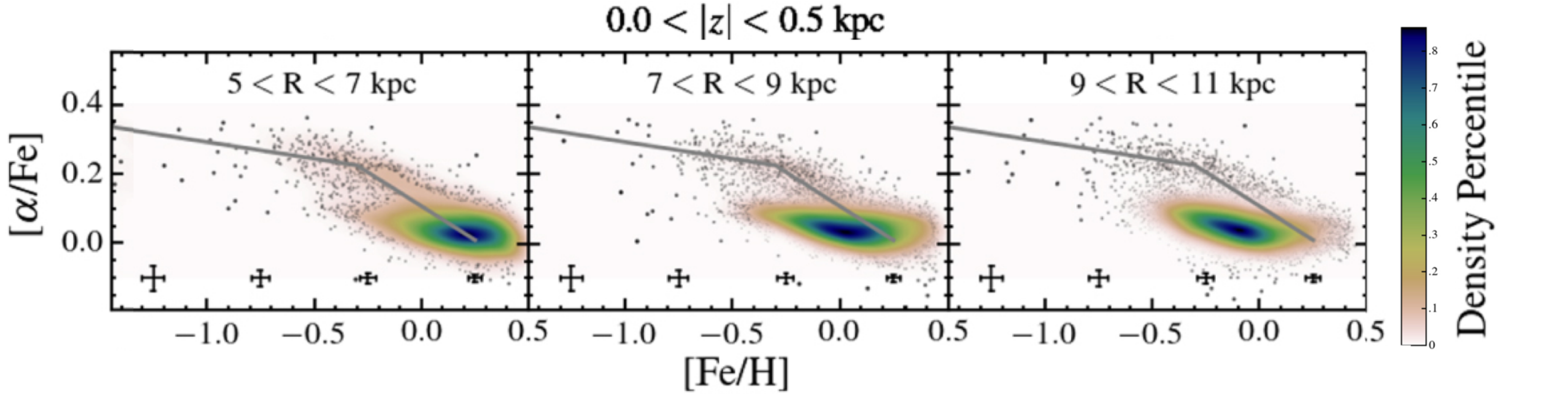


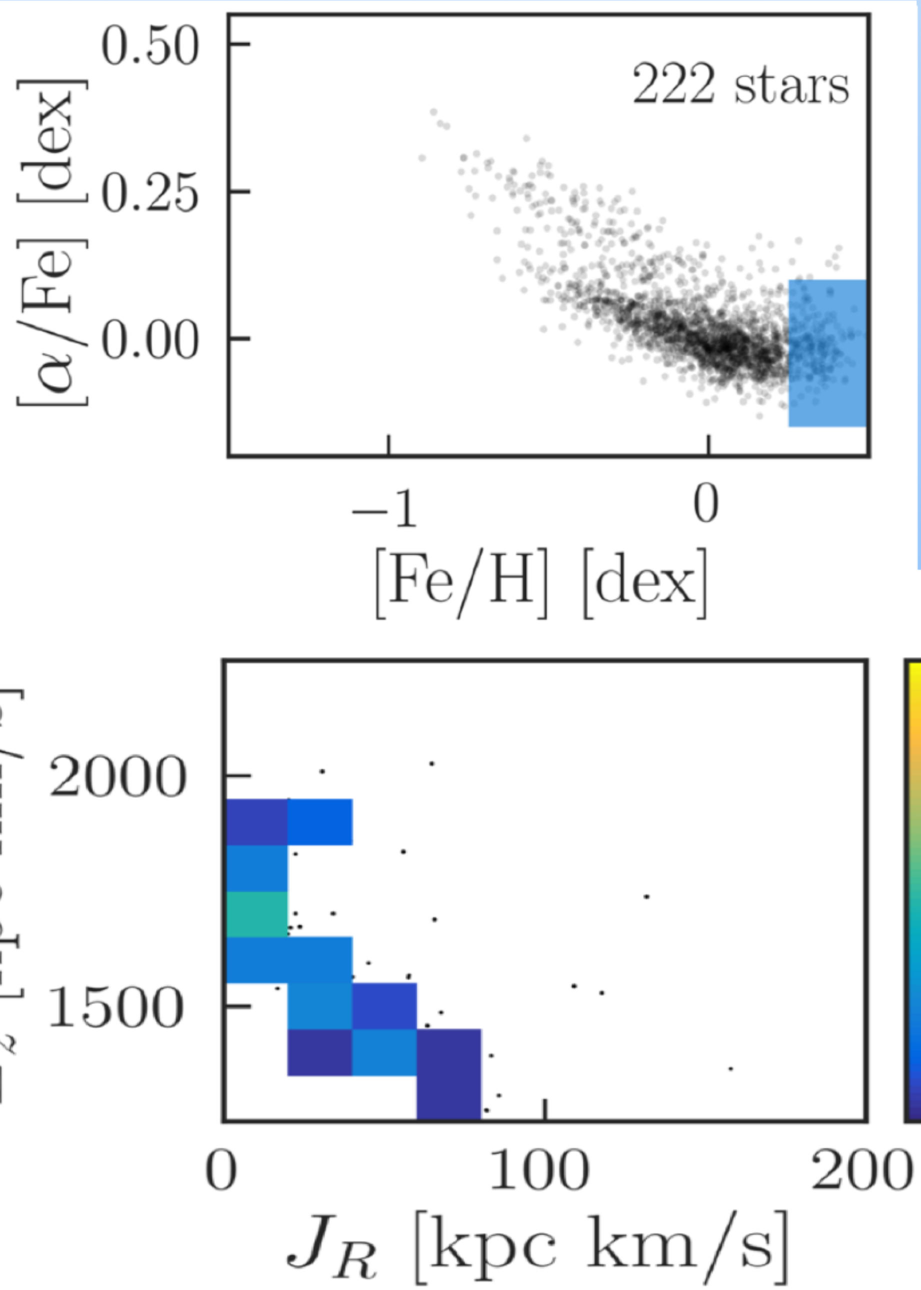
Radial gradient and skewed MDF close to plane



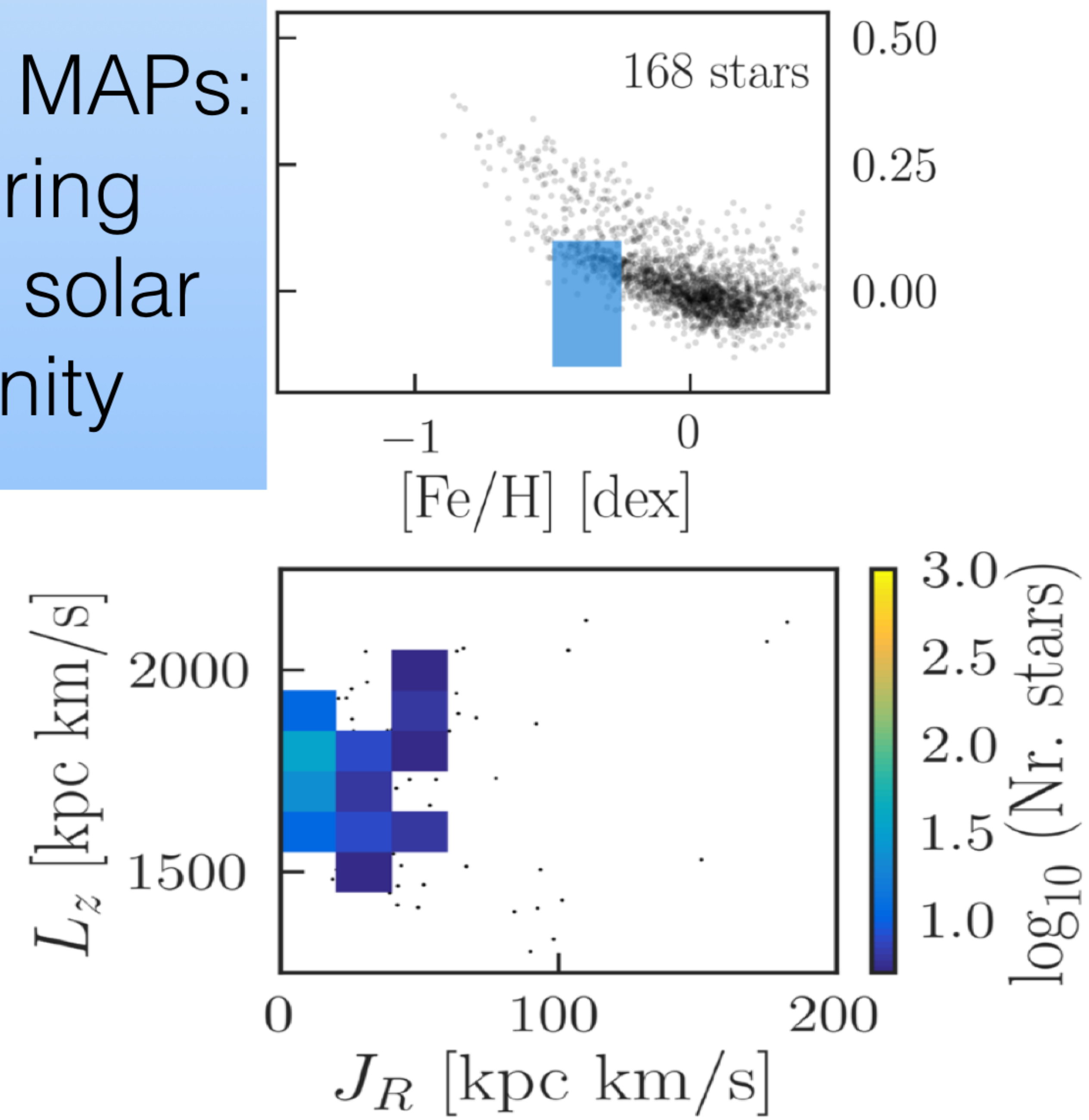
Radial migration and/or blurring?

APOGEE





Galah MAPs: Blurring in the solar vicinity



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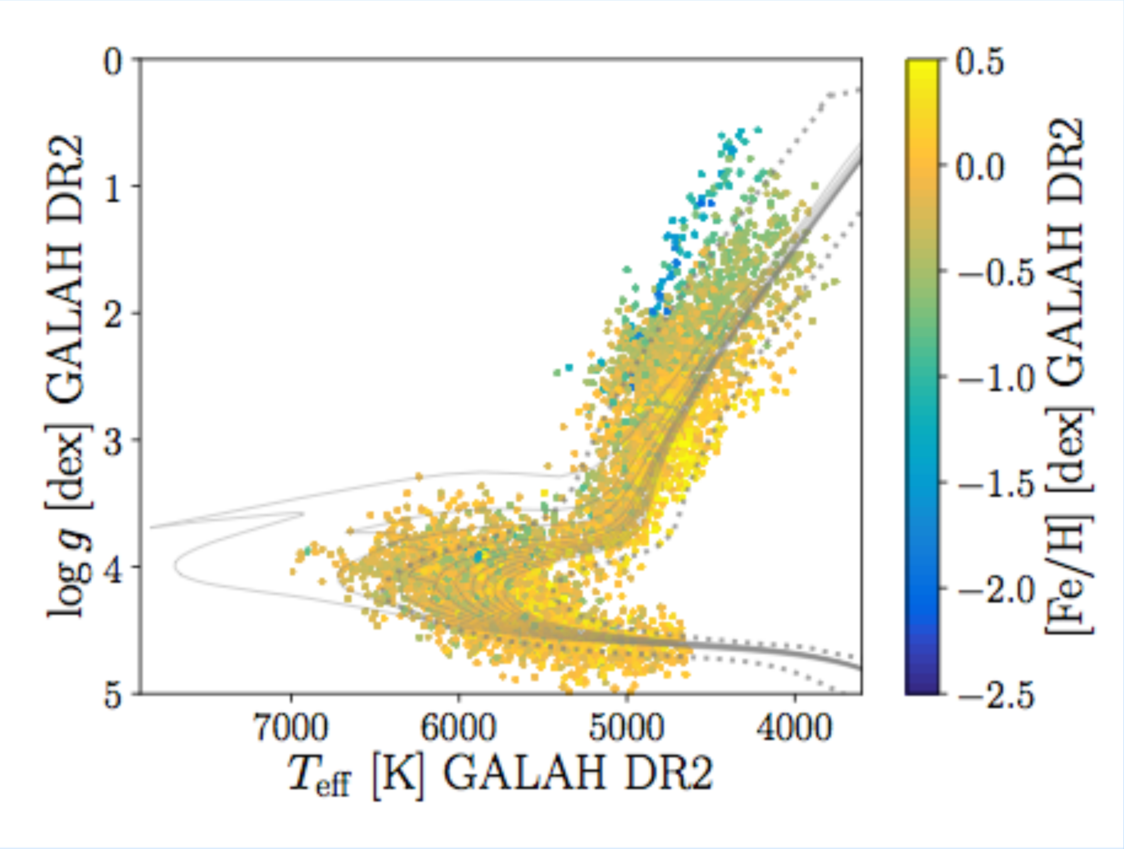
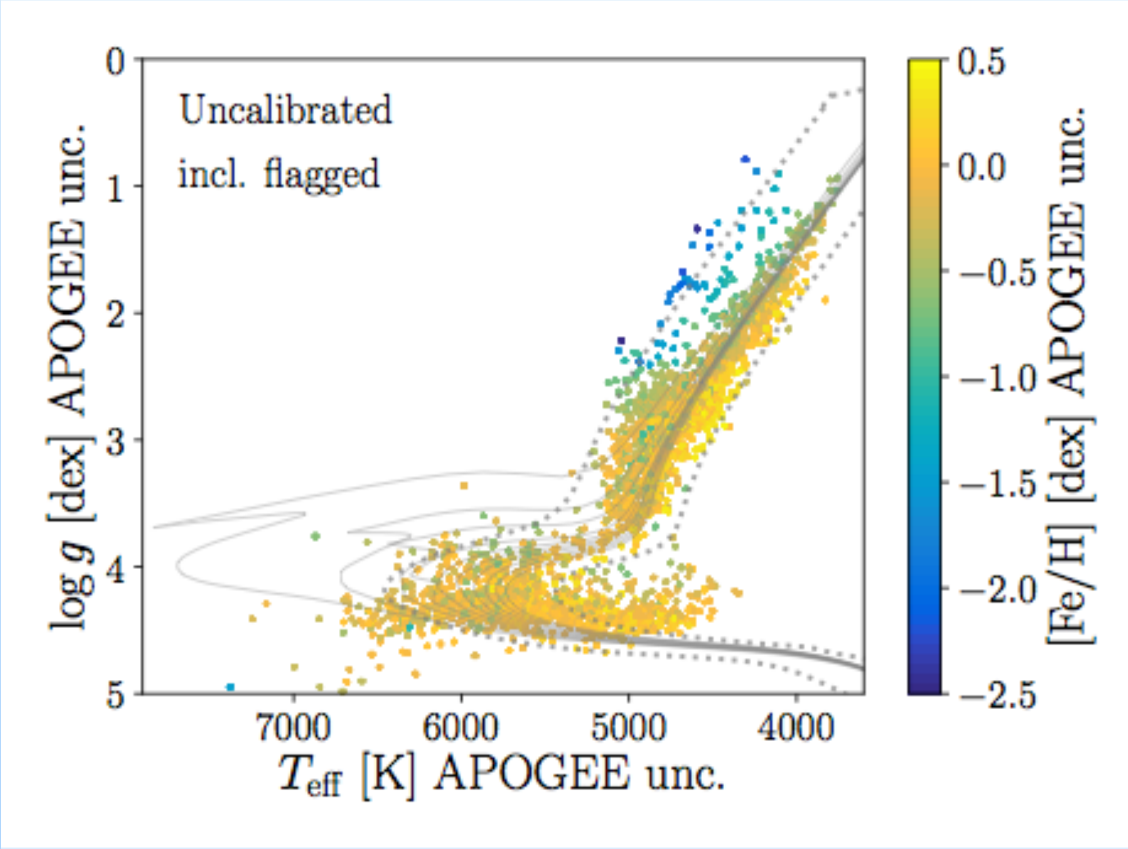
OUTLOOK: CONSISTENCY IN THE GAIA ERA





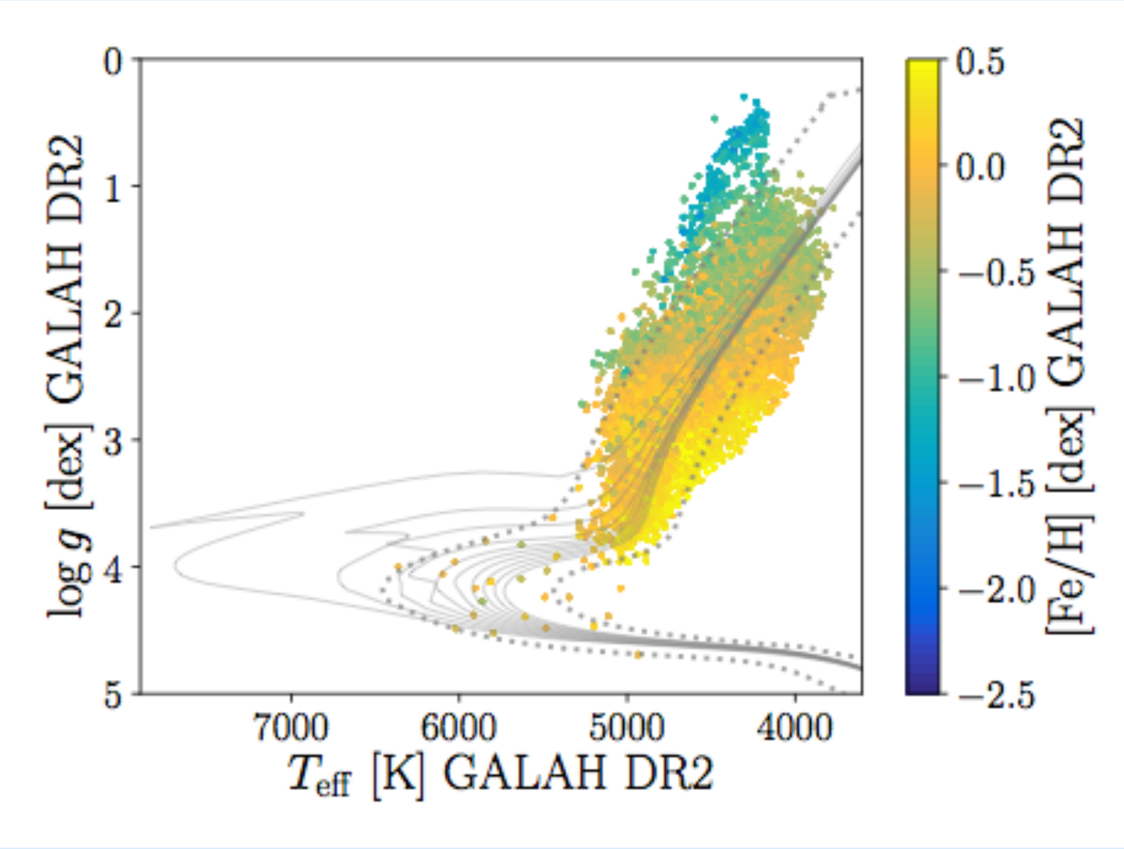
Survey overlap allows symbioses:

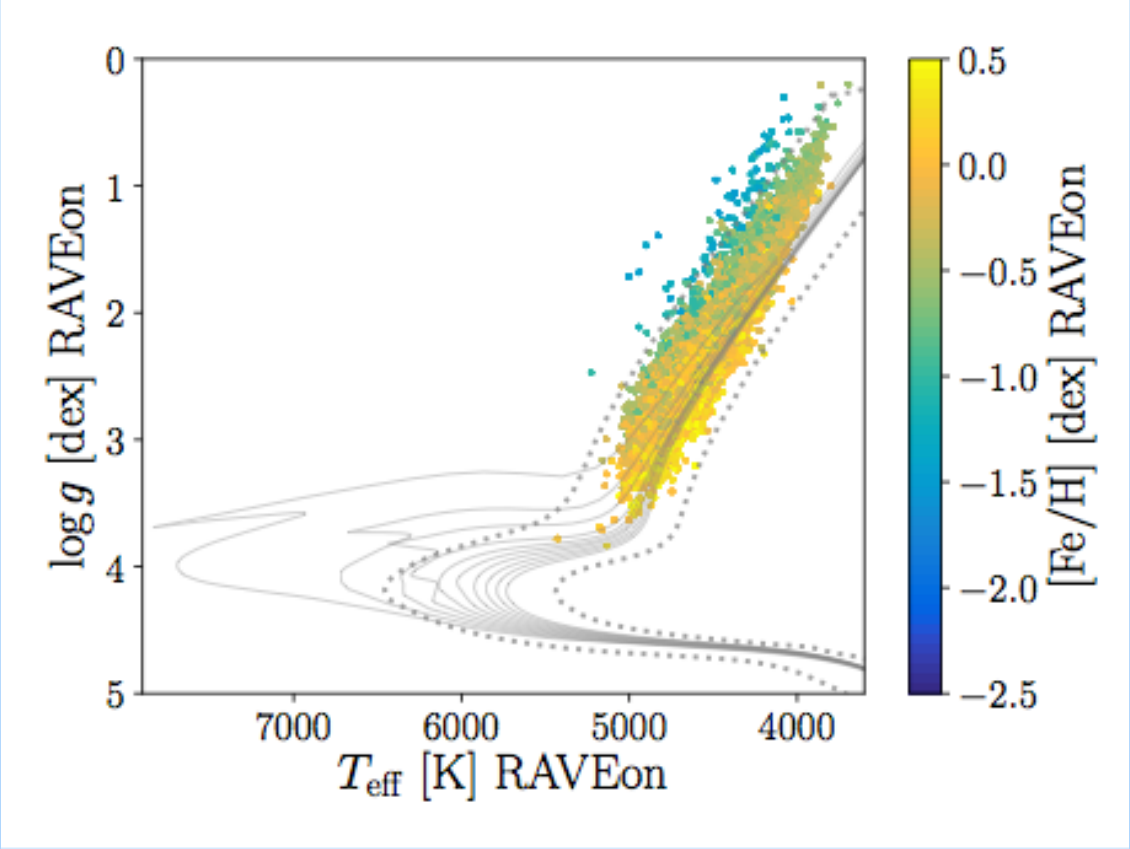
1) Consistency regarding accuracy and abundances

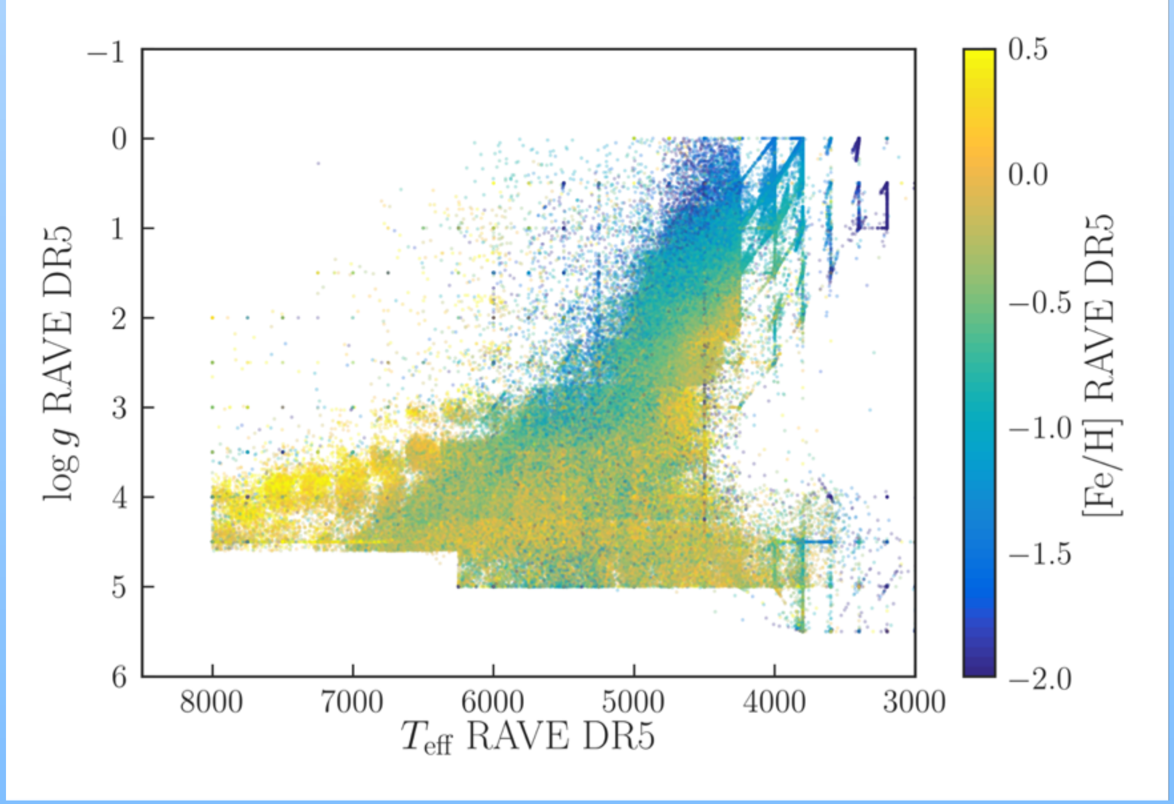
2) Line identification / expand (e.g. GALAH -> APOGEE)

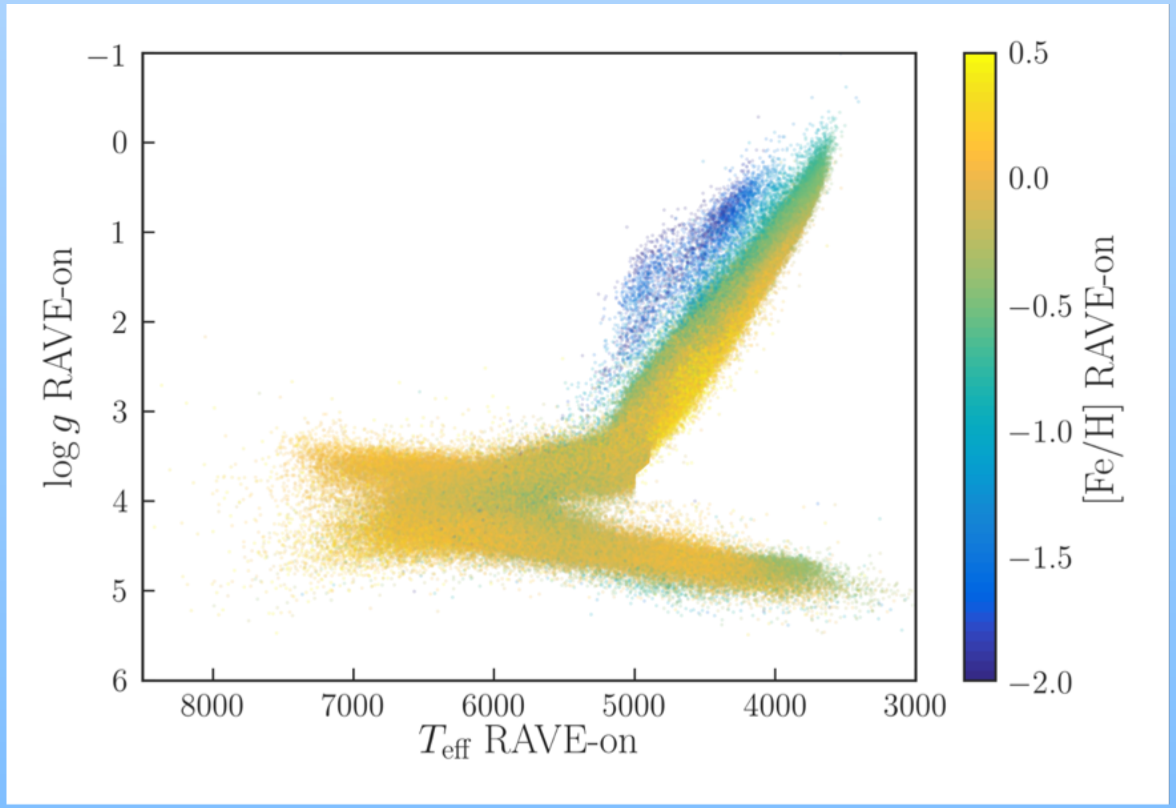
3) Label transfer via *The Cannon* *APOGEE -> RAVE (Casey et al. 2016)*

OUTLOOK: CONSISTENCY IN THE GAIA ERA









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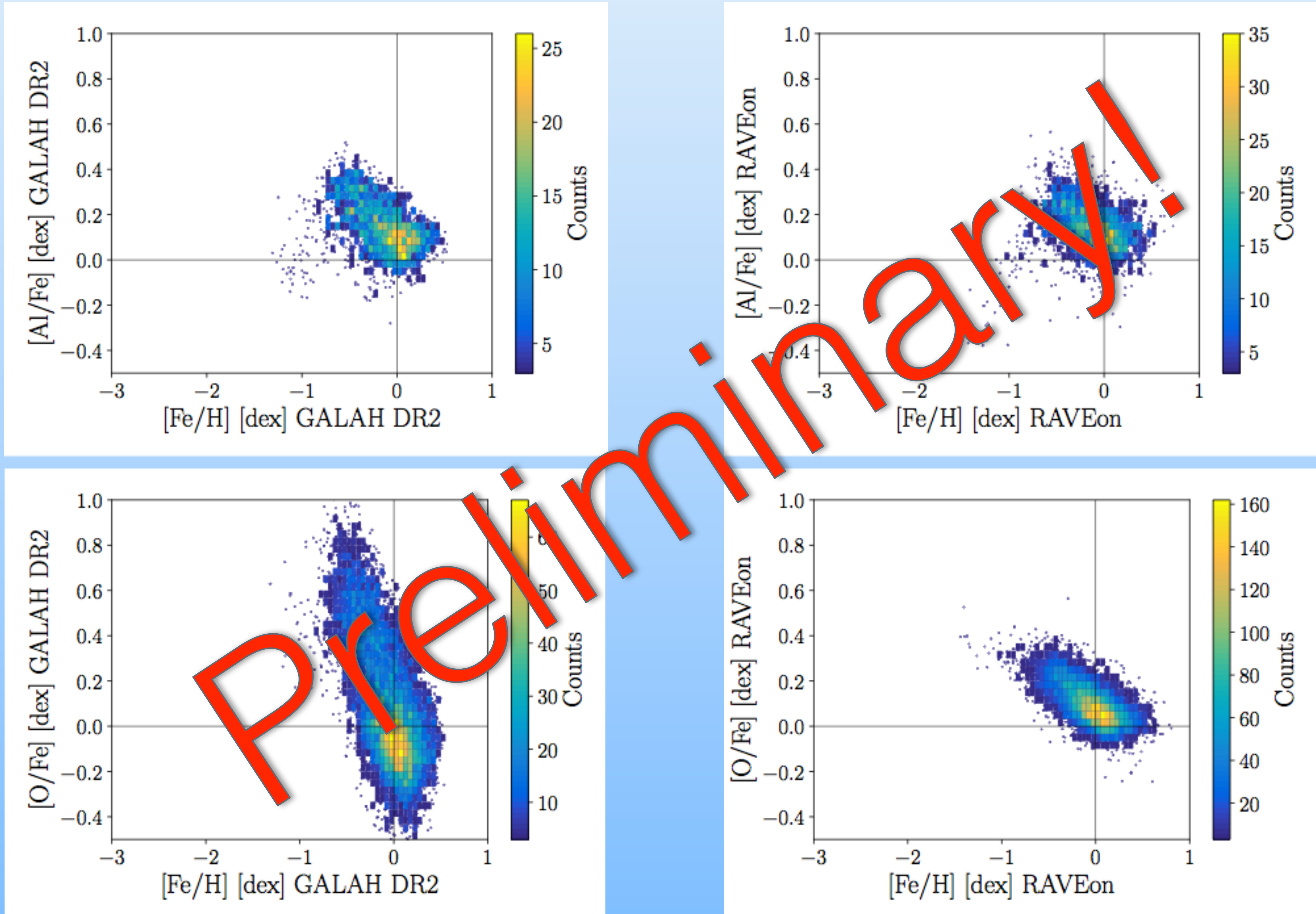
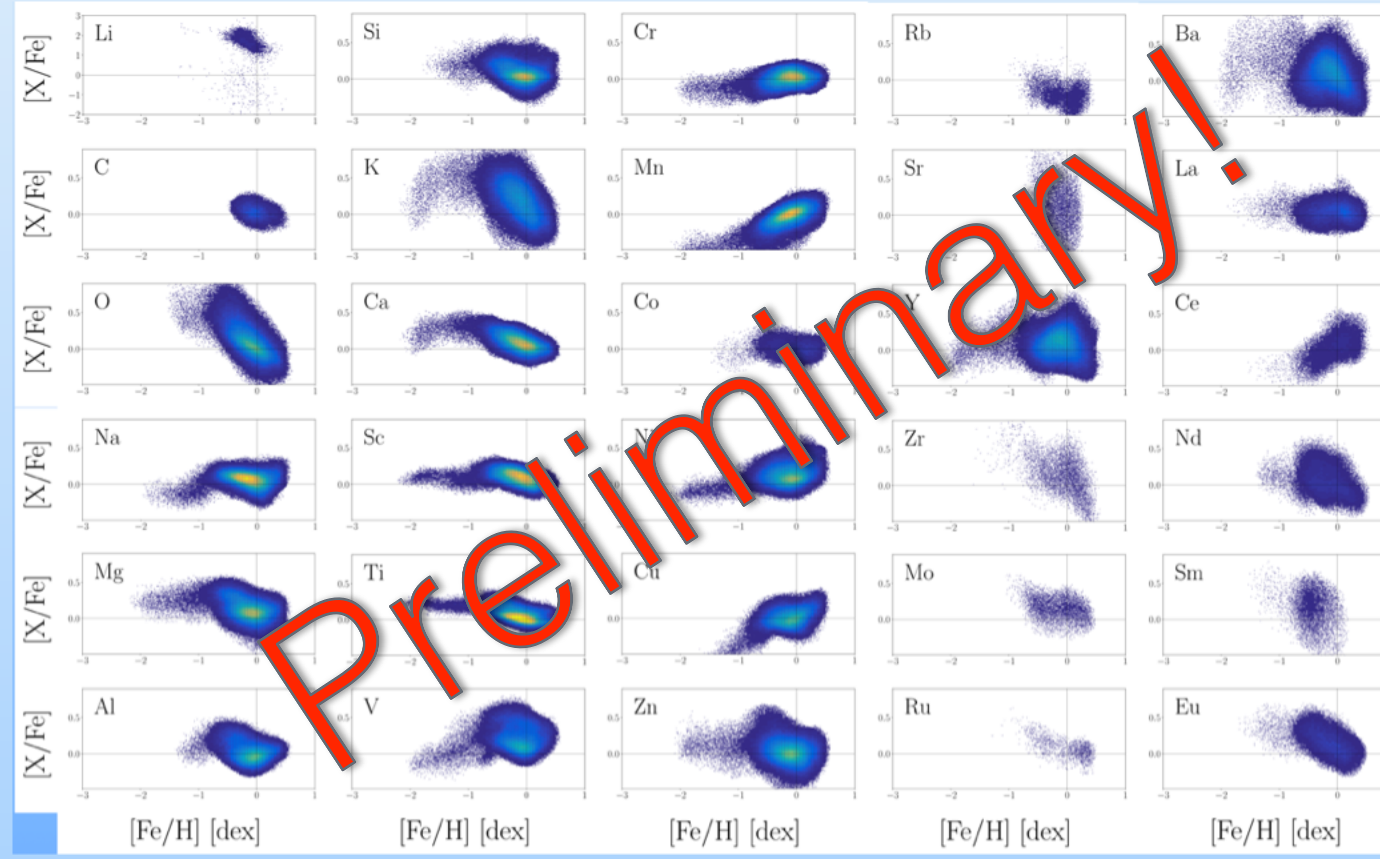


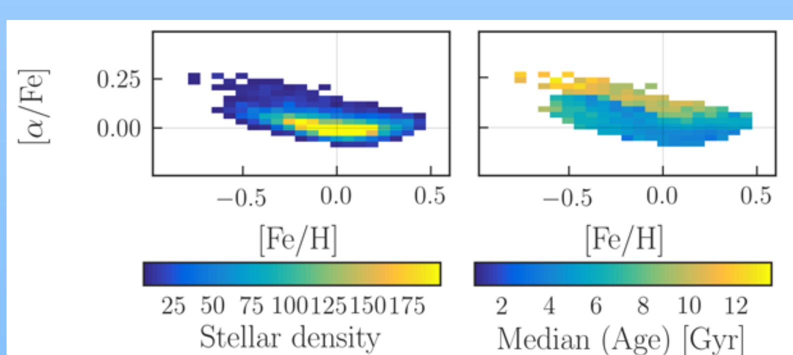
GALAH & GAIA

1) GALAH
will deliver up to 30 chemical elements with the aim to perform chemical tagging (for 1 Mio. ★)

2) Gaia
will deliver dynamical information (-> radial migration, blurring) and allows improved age estimation

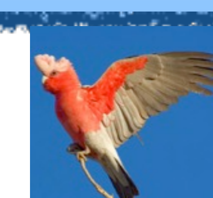


3) GALAH DR2 (Buder et al., in prep.) and Gaia DR2 will provide a melting pot of chemo-dynamics in April 2018



[X/Fe]
+ages
+dynamics

@astro_sven
@galahsurvey



Sven Buder (MPIA)