AGE-ABUNDANCE TRENDS IN THE GALAH SURVEY

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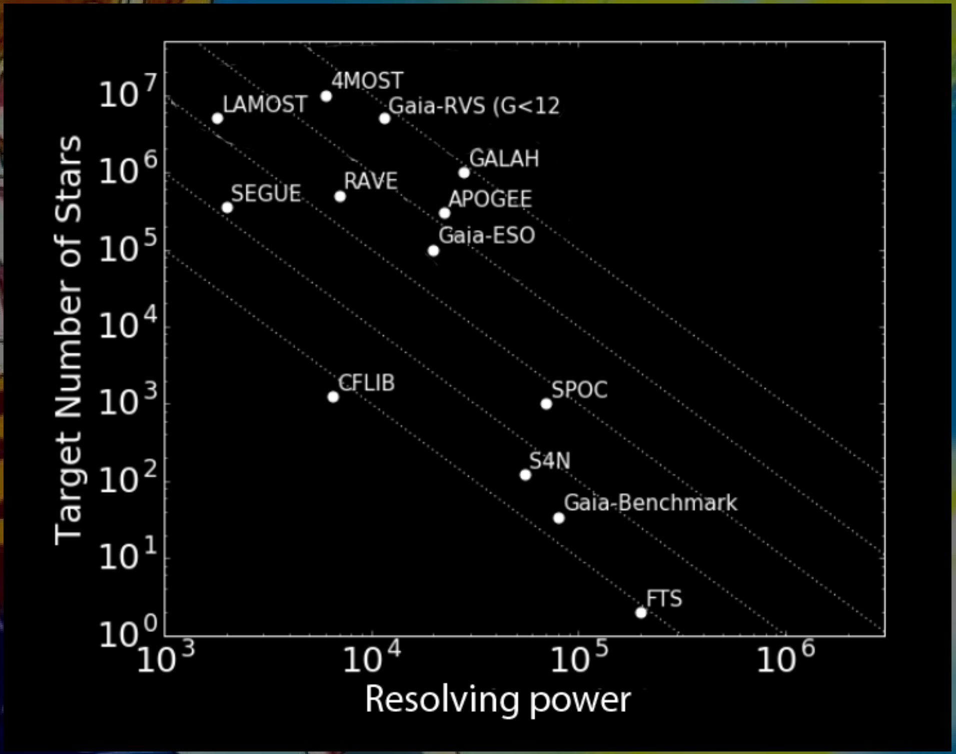
A revolution in galactic archaeology

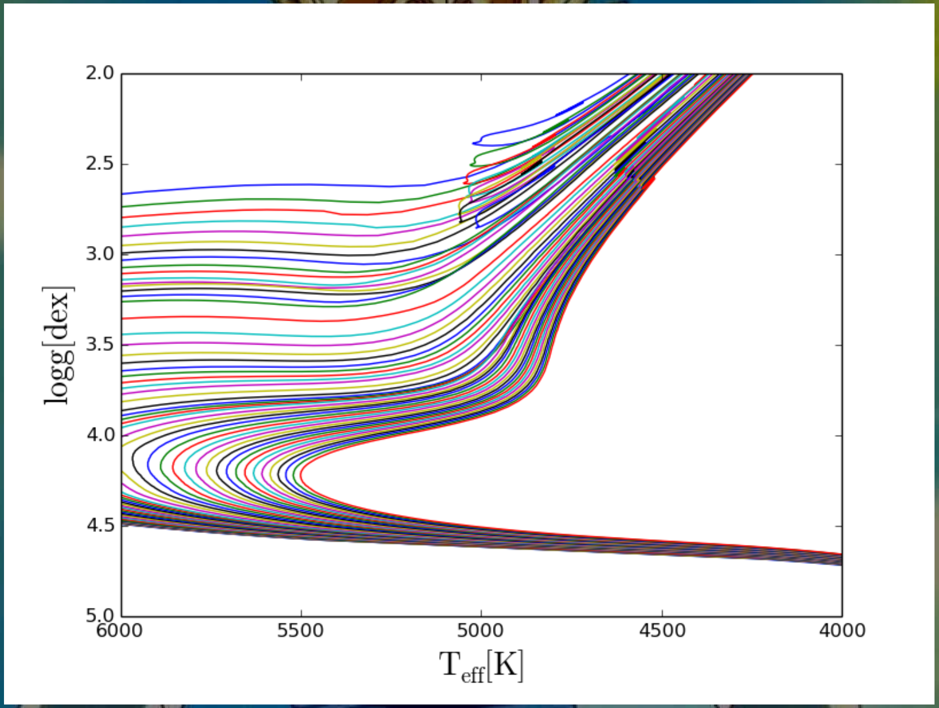
- Era of large scale surveys (>10e5 stars)
- Precise stellar parameters + abundances
- Gaia parallaxes and kinematics
- Probing chemical evolution at different metallicities & galactic locations



Ting+ (2017)

My Work

- Probing chemical evolution on a large scale using GALAH DR2 subgiants + isochrone ages (complementary to asteroseismic/CNO ages for giants)

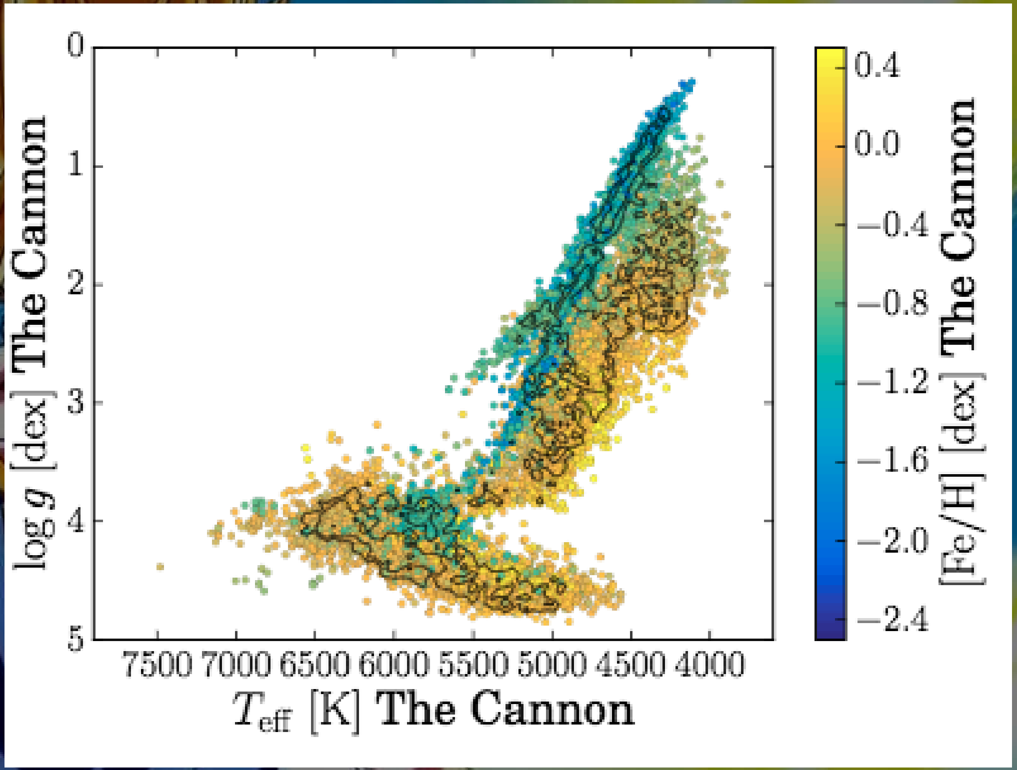


1) Global trends: age-metallicity relationship + MDF

2) Elemental trends: age-abundance relationships

GALAH DR2 DATA SET

- 342,682 stars
- Stellar parameters
- Gaia parallaxes
- 32 elemental abundances



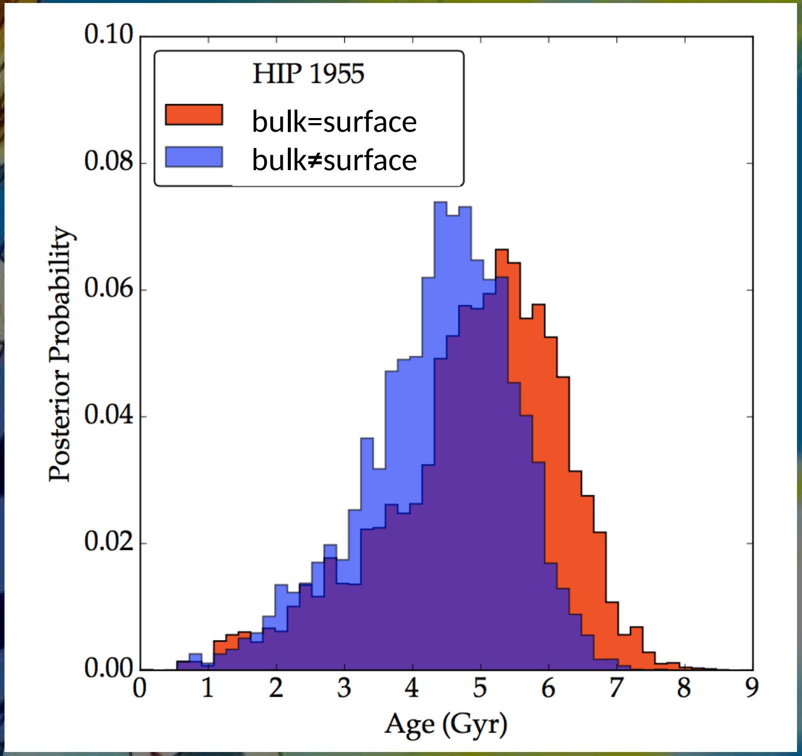
Buder+2018

Bulk vs Surface Metallicity

- MIST isochrones (Choi+2016) computed using atomic diffusion & extra mixing in surface layers in MESA models

  $[Fe/H]_{bulk}$ – time independent, initial composition of models

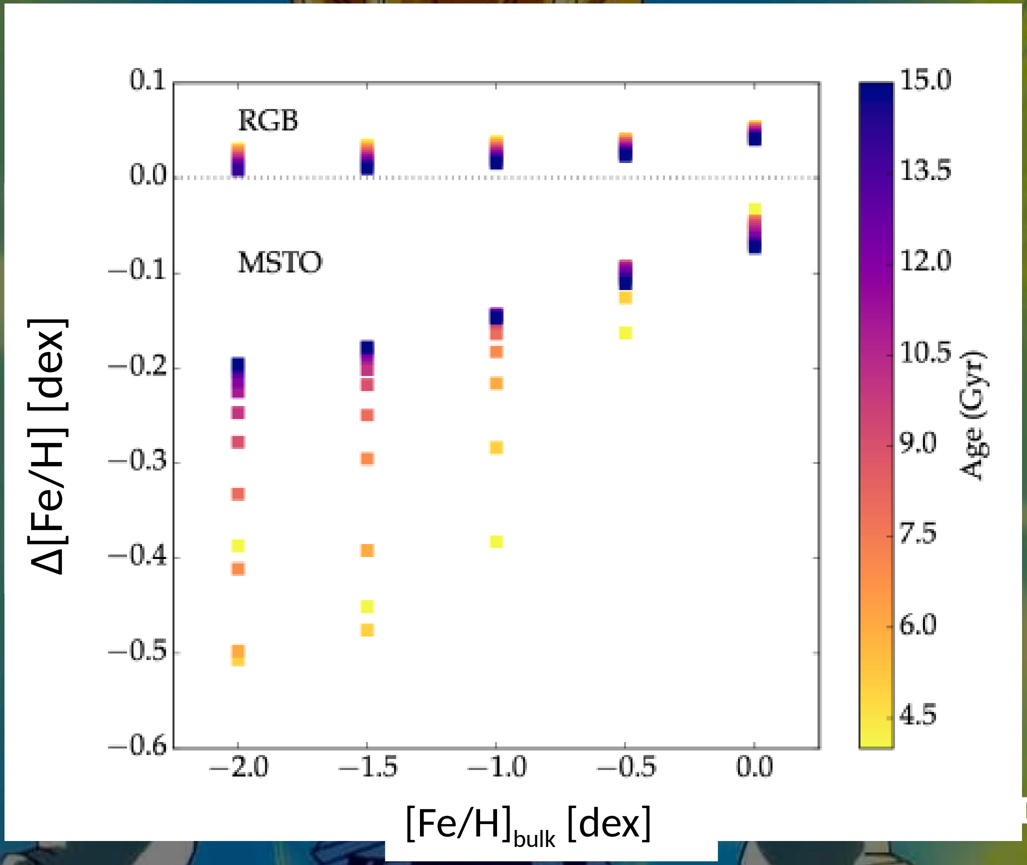
  $[Fe/H]_{surface}$ – time dependent, subject to mixing, diffusion and gravitational settling



Dotter+ (2017)

Bulk vs Surface Metallicity

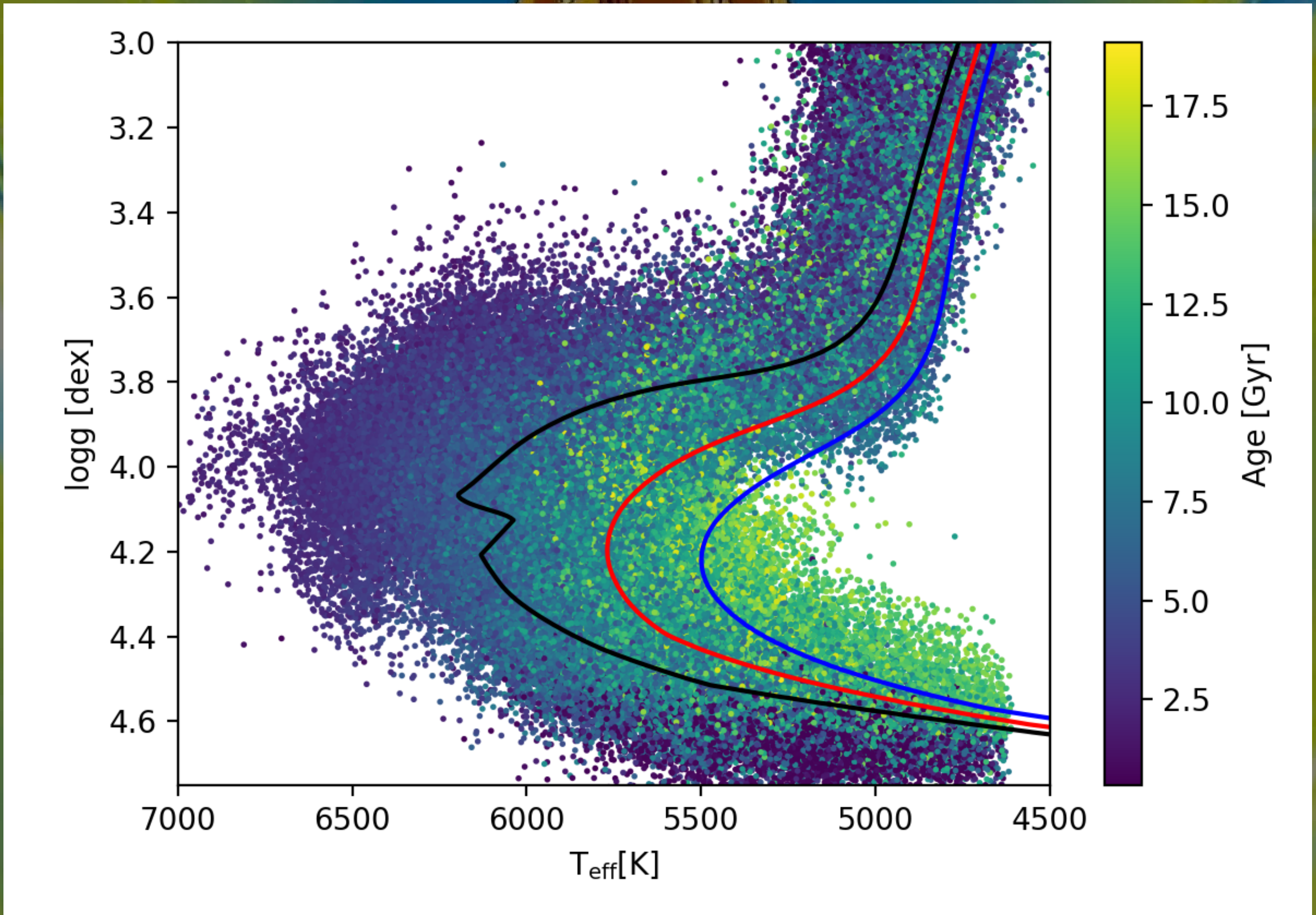
- Systematic age differences up to 20%



Dotter+ (2017)

- But no alpha enhancement

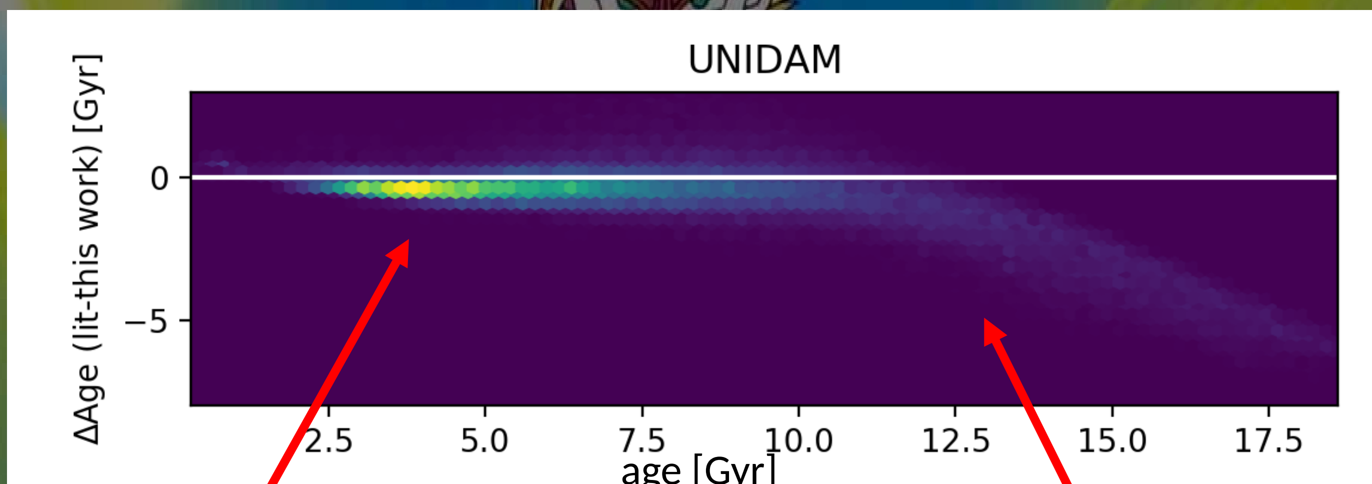
GALAH Results



- ~160,000 turn-off and subgiants + strict convergence criteria

Comparing to other ages

- UNIDAM (Mints & Hekker+2017)- alpha enhanced PARSEC isochrones



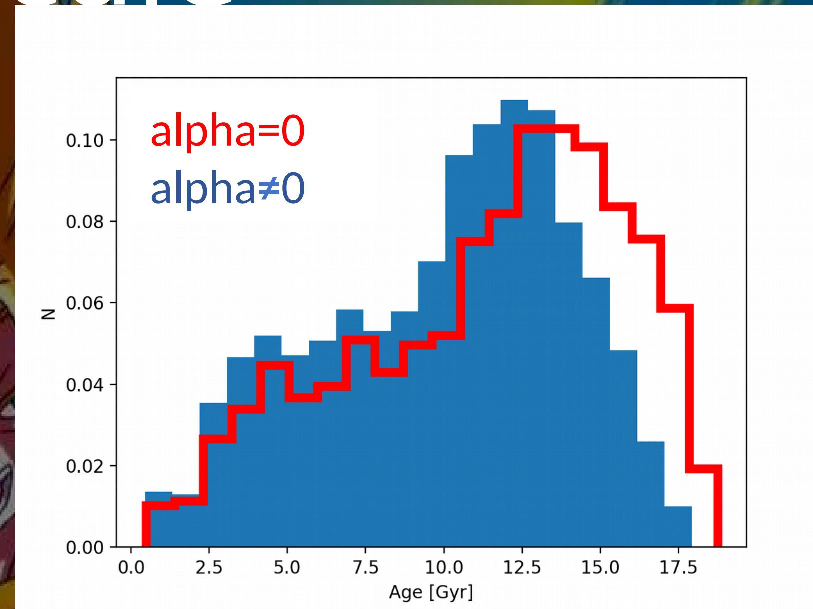
slight offset (<1Gyr) before 10Gyr, likely due to isochrone choices

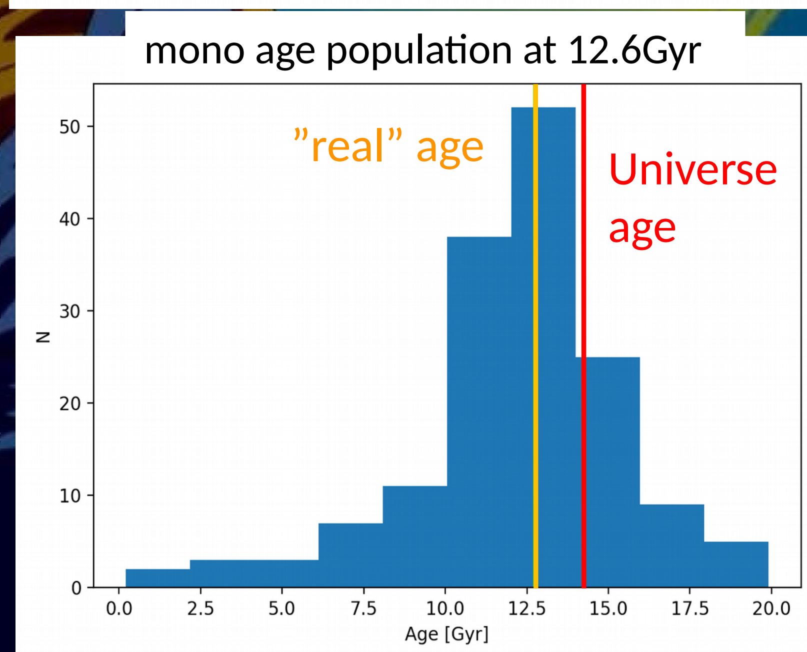
large offset after 10Gyr (PARSEC has a terminal age of ~14Gyr)

Extended age scale

1) Lack of alpha enhancement in MIST
2) Parameter uncertainties
3) MIST abundance scales:
   Asplund+09 vs
   Anders & Grevesse+89

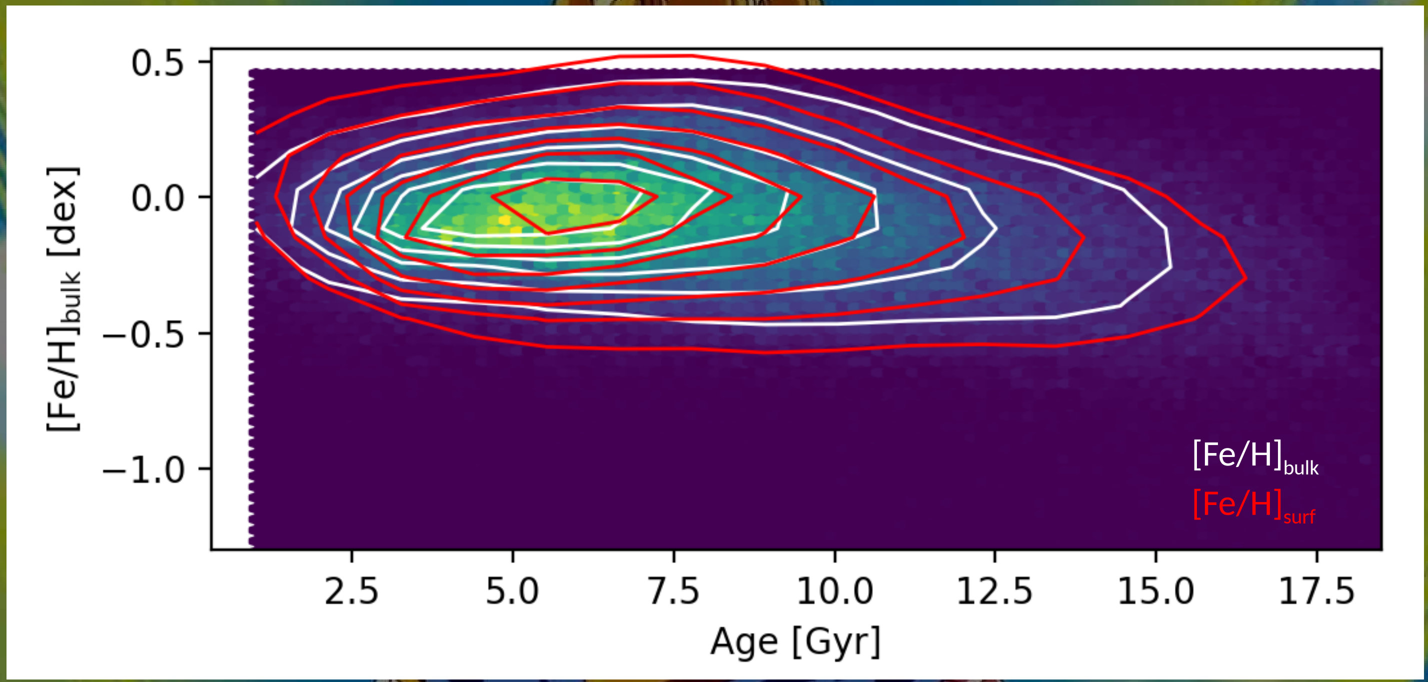
Everything is relative!





1) GALAH age-metallicity & MDF

GALAH Age-Metallicity



- Scatters in AMR: intrinsic & observational
- Flat, with large scatter in [Fe/H] for ages <12 Gyr, downward trend for the oldest stars
  e.g.,
  Casagrande+ (2011), Bergemann+ (2014), Edvardsson+ (1993), Feltzing+ (2001)…

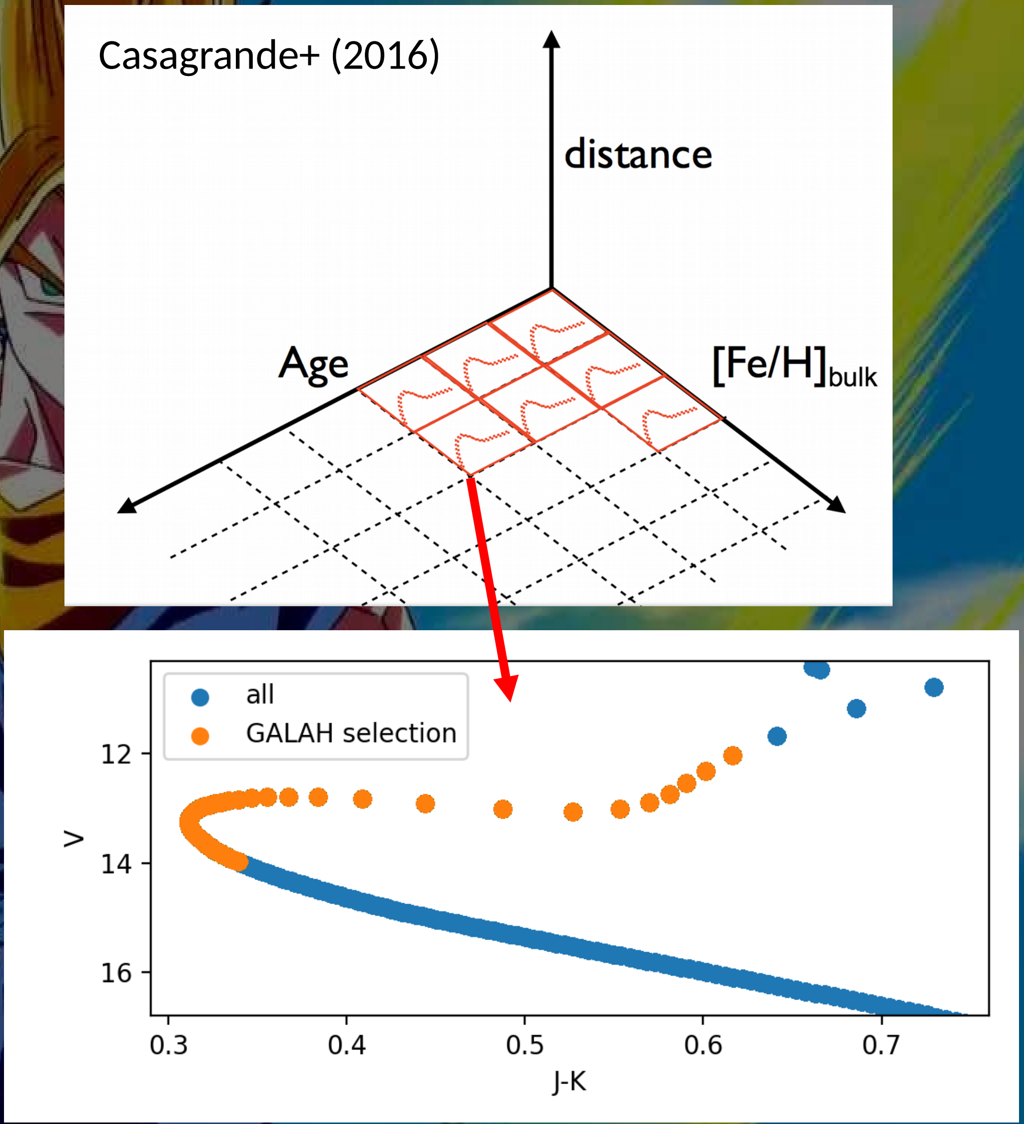
Target selection effects

- Populate the grid with Kroupa IMF+MIST isochrone
- Apply GALAH colour selection function
- Observing probability:

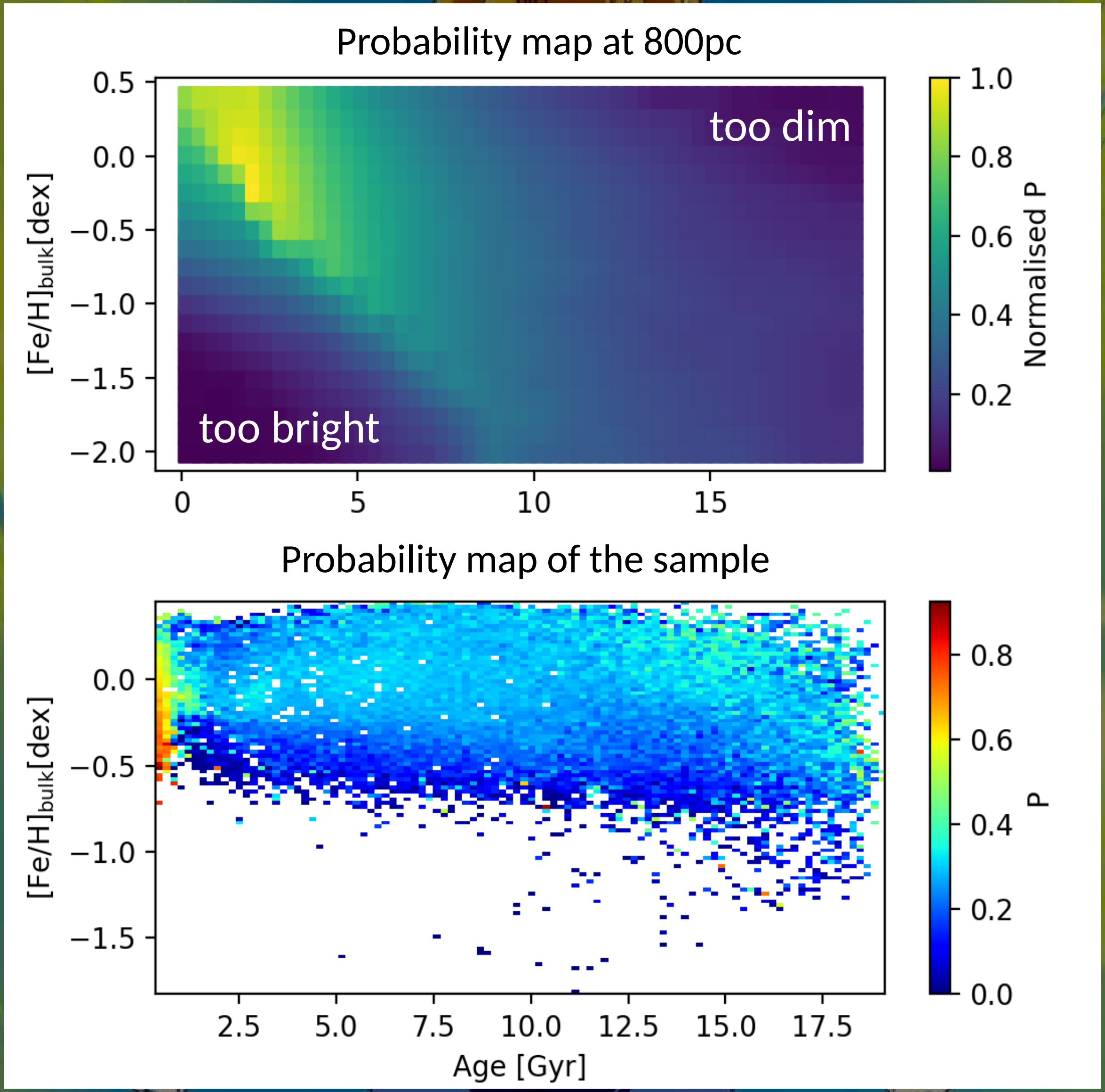
$$P\{\text{age}, [Fe/H]_{bulk}, \text{distance}\} = \frac{N^*_{in}}{N^*_{all}}$$

- Populate the grid with Kroupa IMF+MIST isochrone
- Apply GALAH colour selection function
- Observing probability:

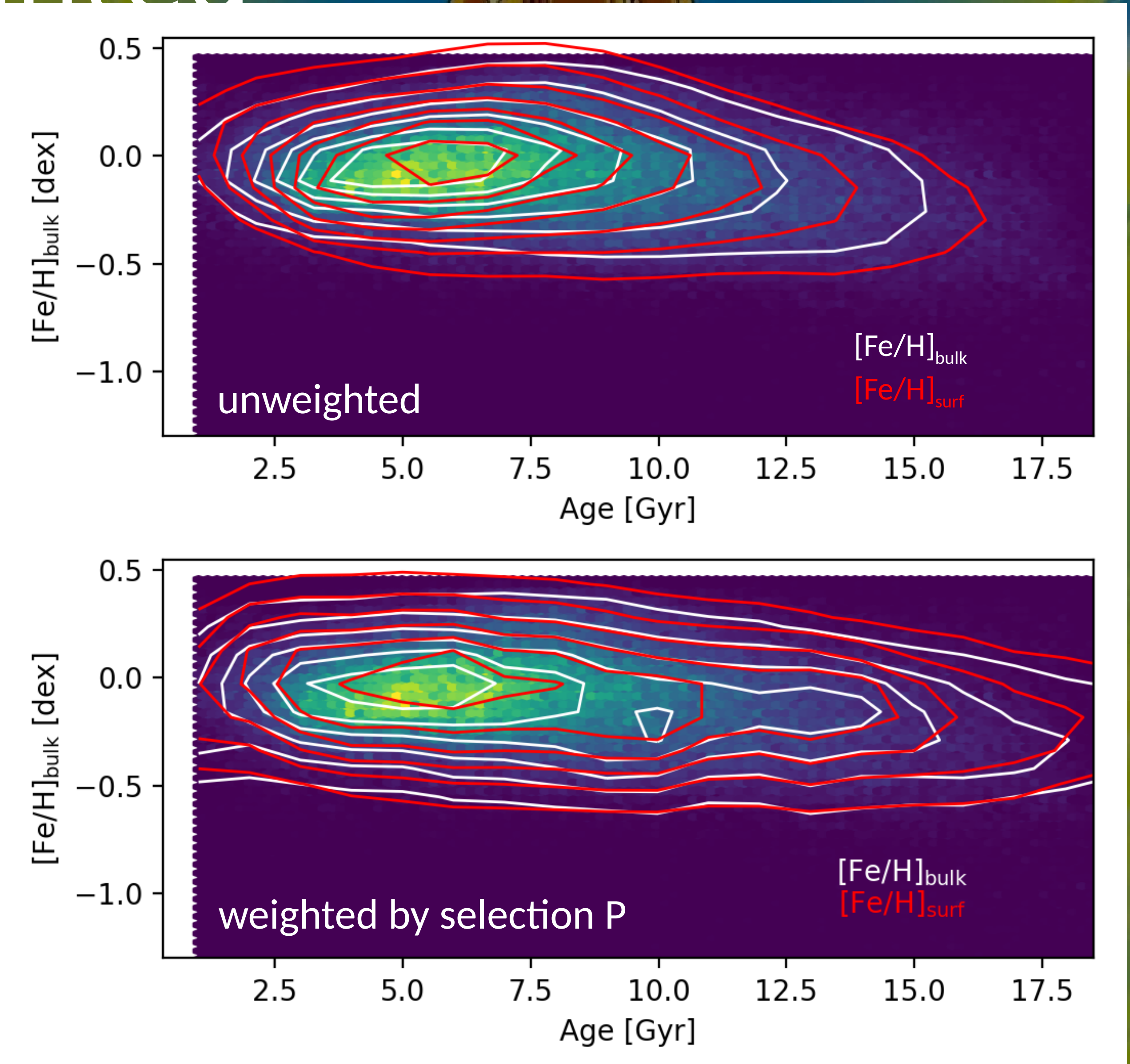
P{age, [Fe/H]$_{bulk}$, distance}



Target selection effects

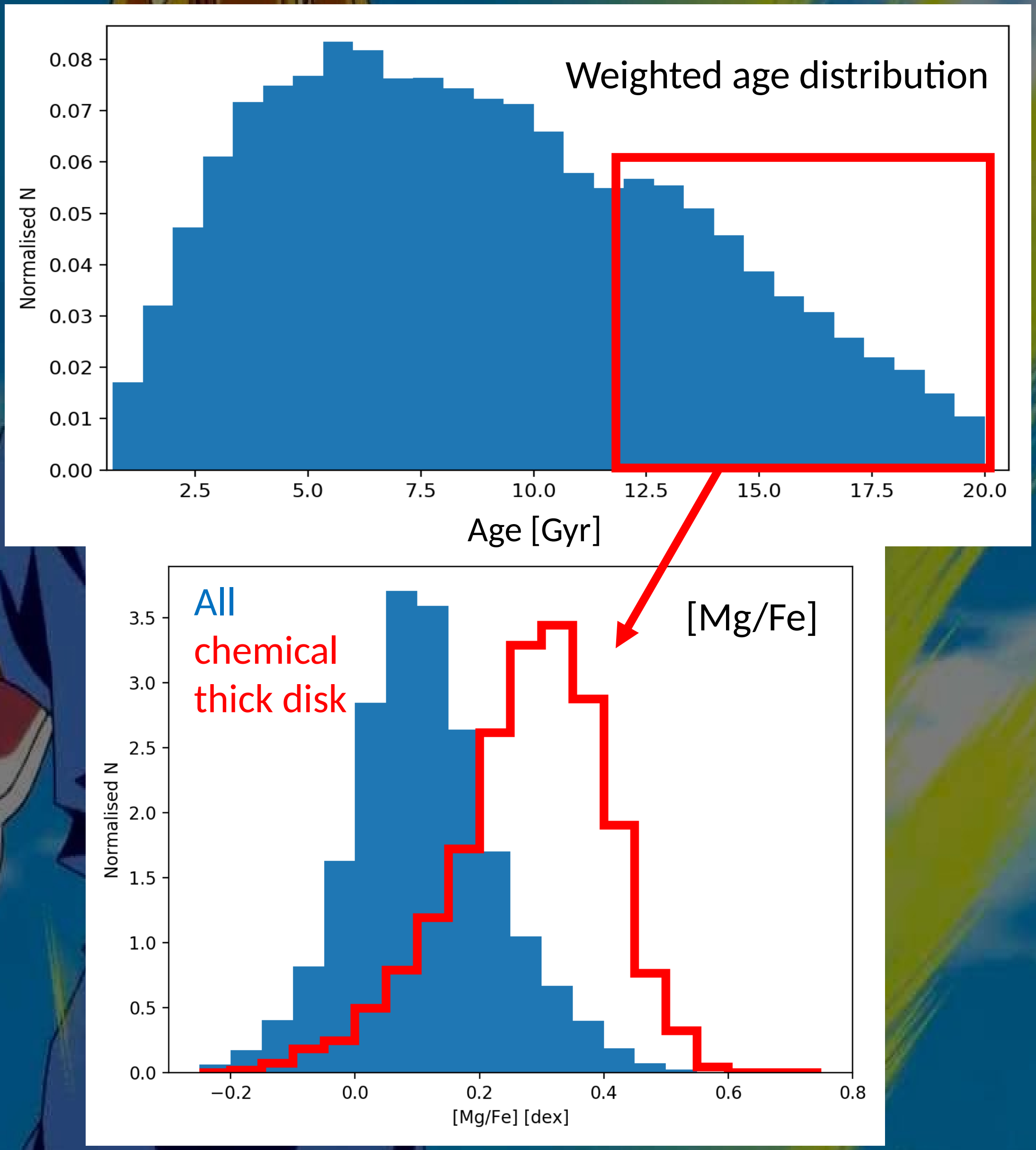


GALAH Age-Metallicity: weighted



GALAH Age-Metallicity

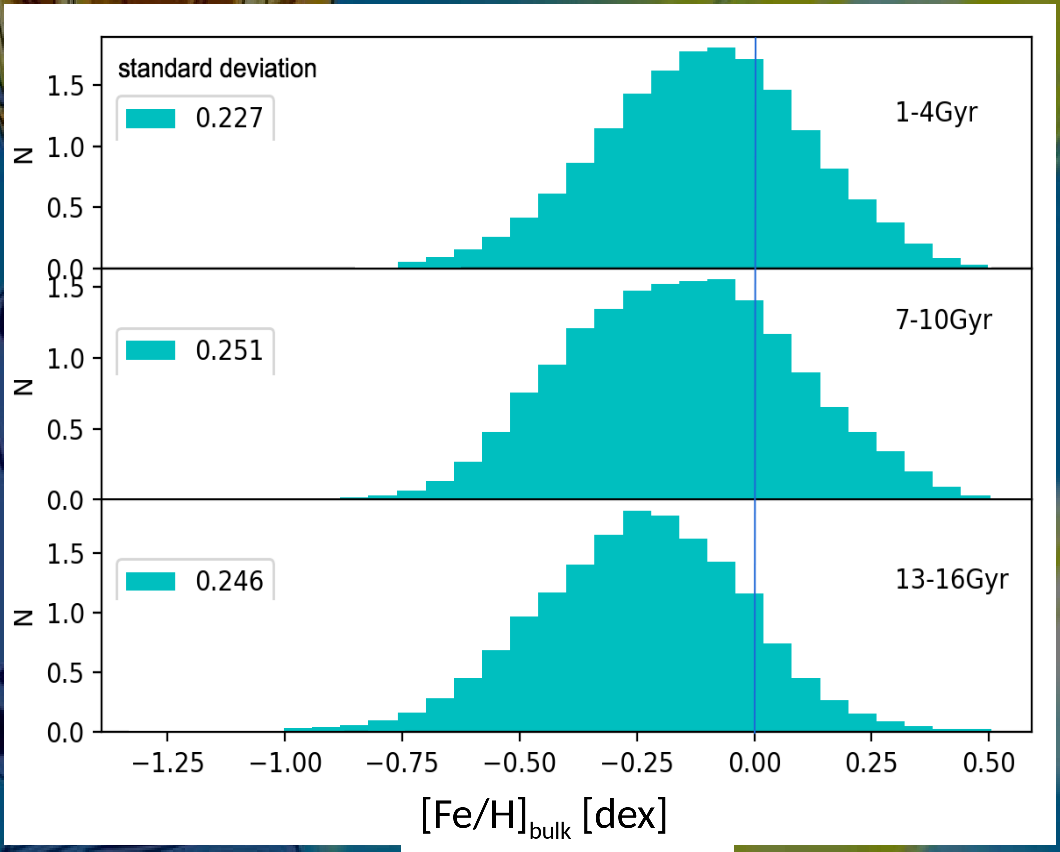
- Quenching of star formation between chemical thick and thin disks?
  e.g.,
  Fuhrmann+(1998),
  Haywood+(2016)
- Observed in smaller samples
  e.g.,
  Casagrande+(2016),
  Rendel+ (in prep)



GALAH MDF

- MDF spread increases for young age bins ✉ radial migration
  (e.g., Schonrich & Binney+ 2009)
- Sub-solar MDF peaks- sample contains a range of |z|
- But plateaus in older bins ✉ lack of a radial metallicity gradient in the thick disk?
  (e.g., Hayden+2015, Delgado Mena+2019)

MDF weighted by selection P



2) GALAH age-abundance trends

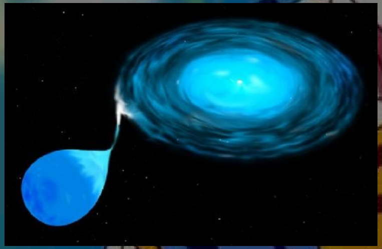
GALAH abundance-age trends

- Different elements are produced in different nucleosynthesis sites, with different production time-scales

SNe II

Alpha elements
e.g., O, Mg, Si, S, Ca, Ti

SNe Ia



Iron peak elements
e.g., Cr, Mn, Co, Ni

Low mass stars

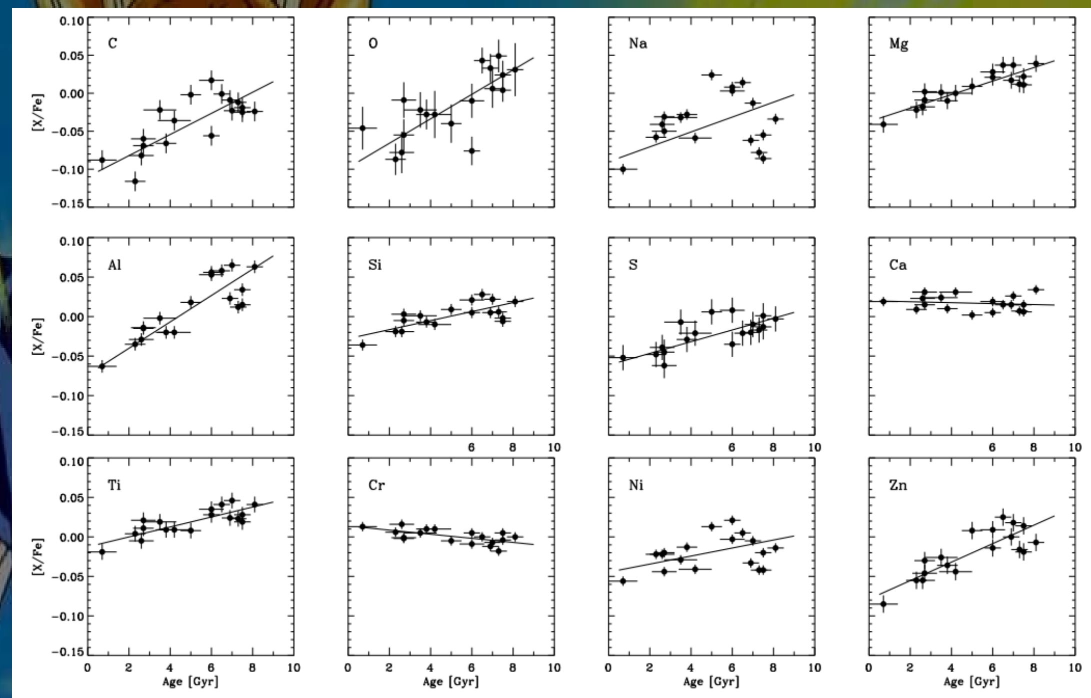
s-process elements
e.g., Rb, Sr, Y, Zr, Ru, Ba, La

Neutron star mergers?

r-process elements
e.g., Ce, Nd, Eu

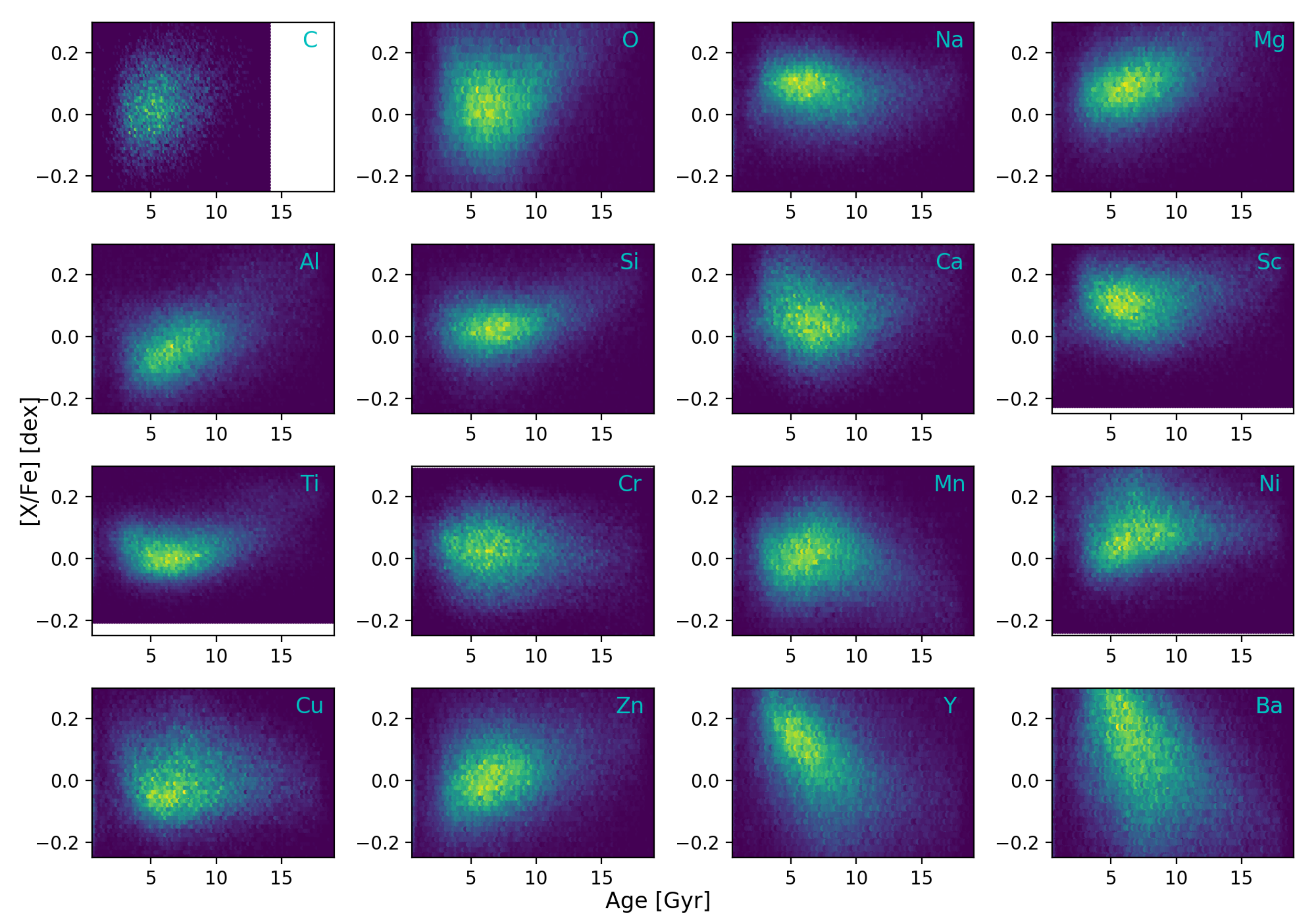
High precision samples

- Recent studies with high precision and multiple elements
  e.g.
  Adibekyan+ (2012),
  Nissen+ (2015),
  Bedell+ (2018),
  Spina+ (2016)….
- Behaviours at larger samples? – perfect for GALAH subgiants!



Nissen (2015)

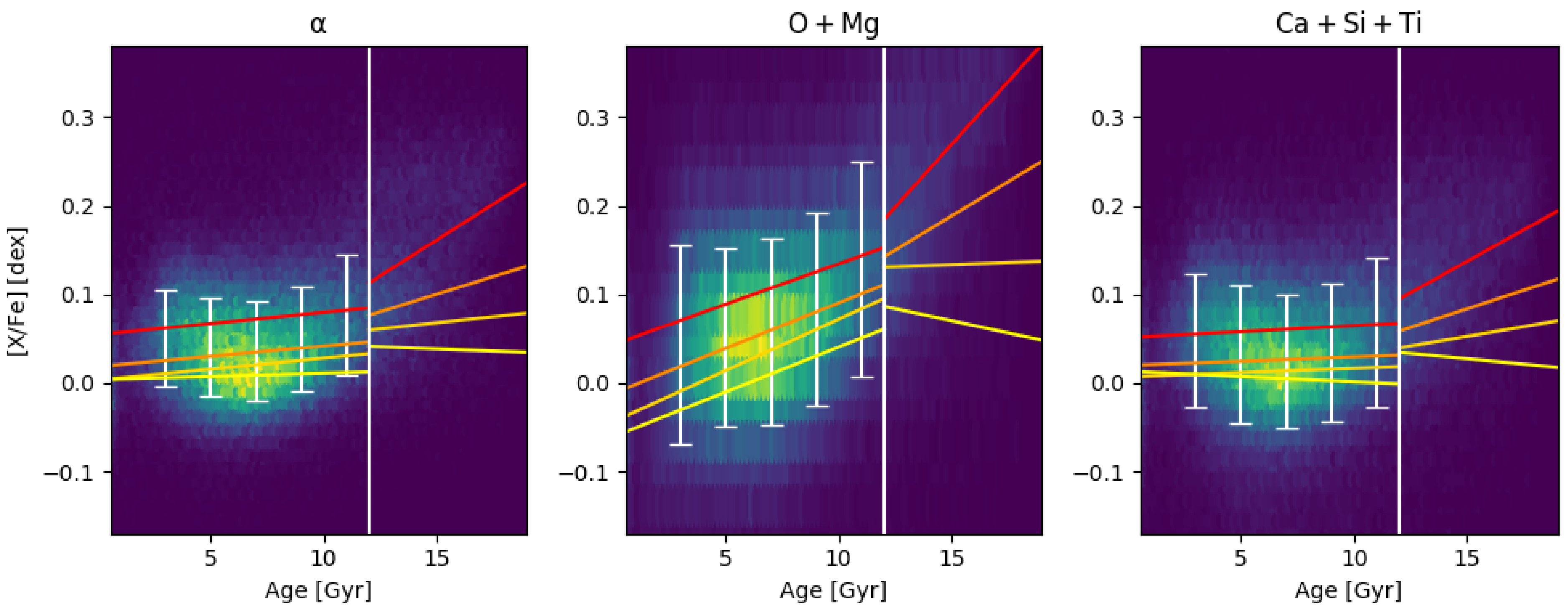
Abundance vs age trends



At least 20,000 measurements per element

Alpha elements

Weighted by selection P, $[Fe/H]_{bulk}$ bins: [-0.5 - 0.1], [-0.1 - 0], [0 - 0.1], [0.1 - 0.5]

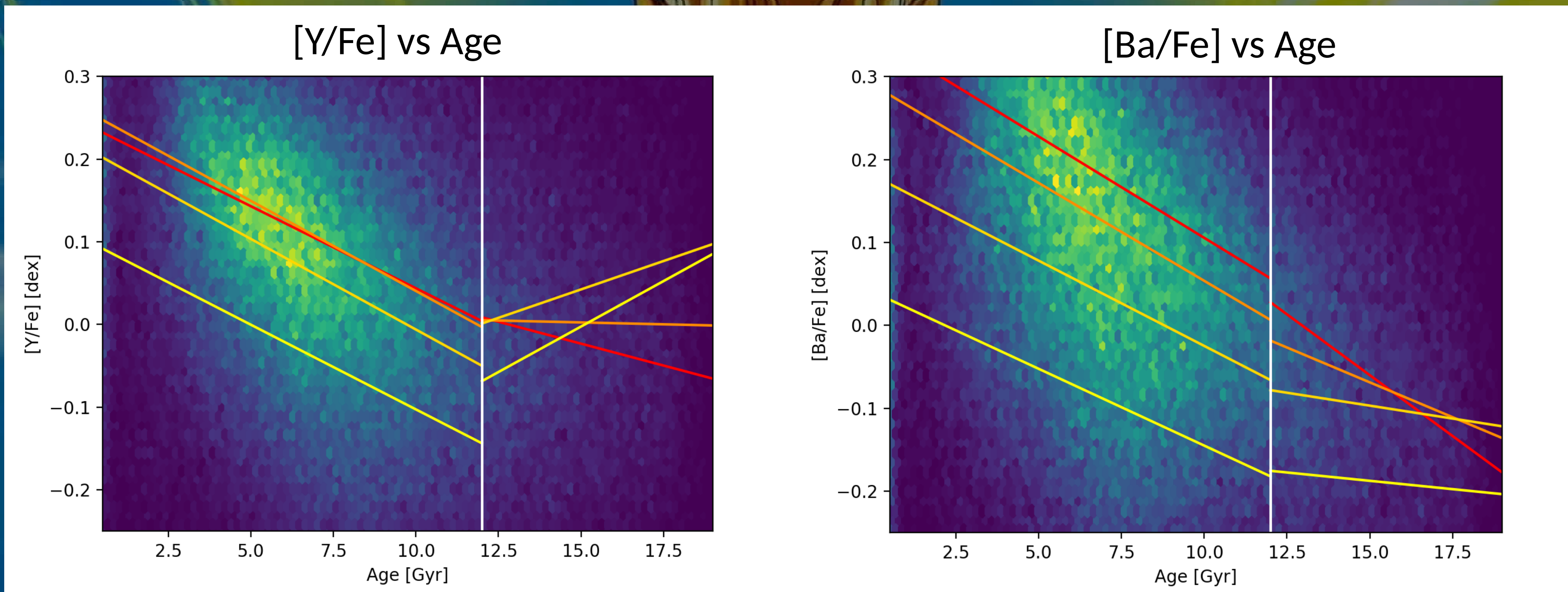


SNe II & SNe Ia interplay

Hydrostatic: steepest slope in the thin disk ✉ O & Mg have largest SNe II contribution

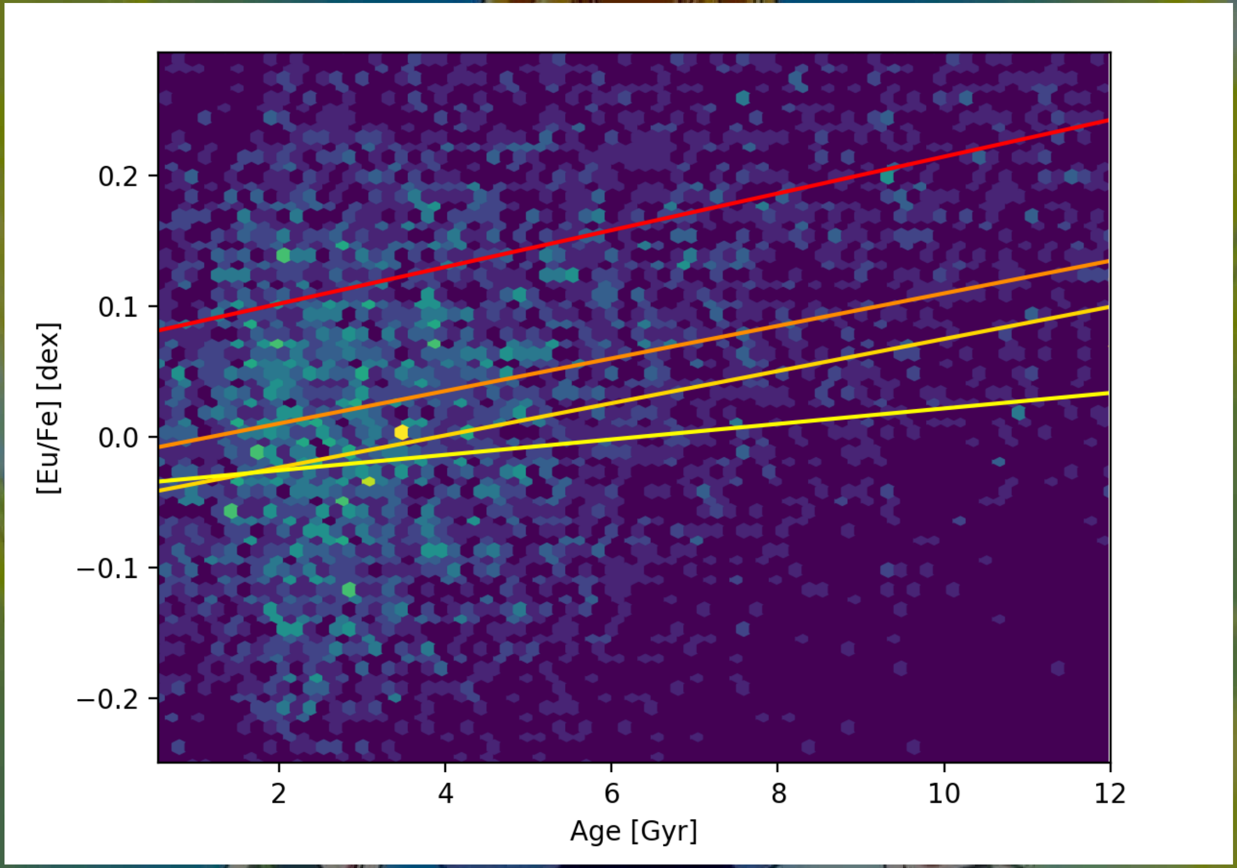
Explosive: flatter slope in the thin disk ✉ Ca, Si and Ti are alpha elements with non SNe II sources

s-Process elements



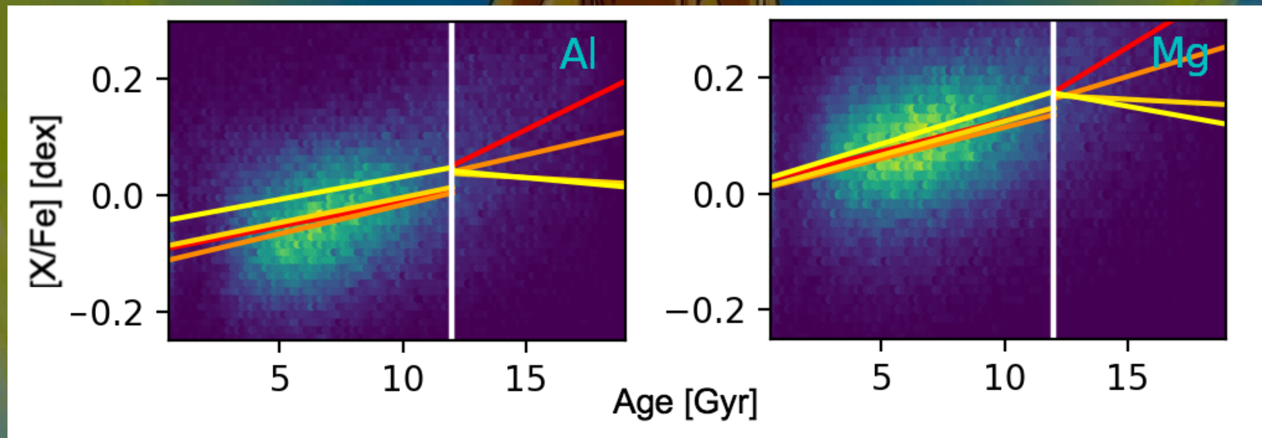
- s-process elements Y & Ba, abundance ratio increases in the thin disk- time delay from AGB stars

[Eu/Fe] vs age

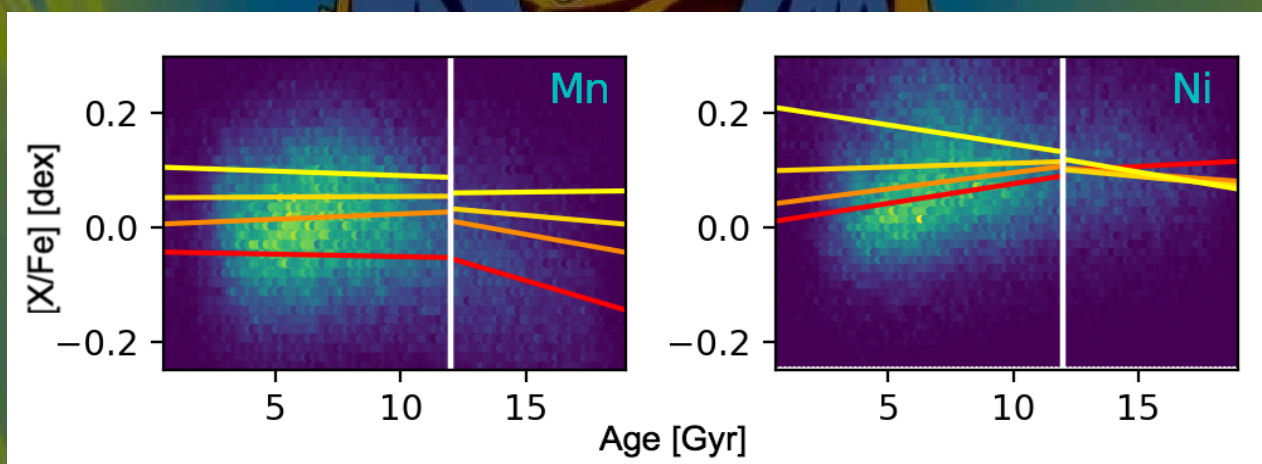


- r-process element Eu shows no time delay in the thin disk, possible non-neutron merger contribution? ✉ Need DR3

Chemical clock candidates



- Similar & tight relationship to age across all [Fe/H] bins ✉ good chemical clock candidates



- Flat slope & diverging [Fe/H] gradients ✉ poor chemical clock candidates

Summary

- Possible signature of the chemical thick disk in age distribution
- Abundance-age trends agree well with smaller, high precision studies (e.g., Bedell+2018, Delgado Mena+2019)
- Non neutron merger production for r-process elements