Data-driven ages for individual red giant stars

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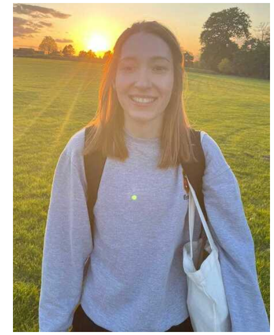

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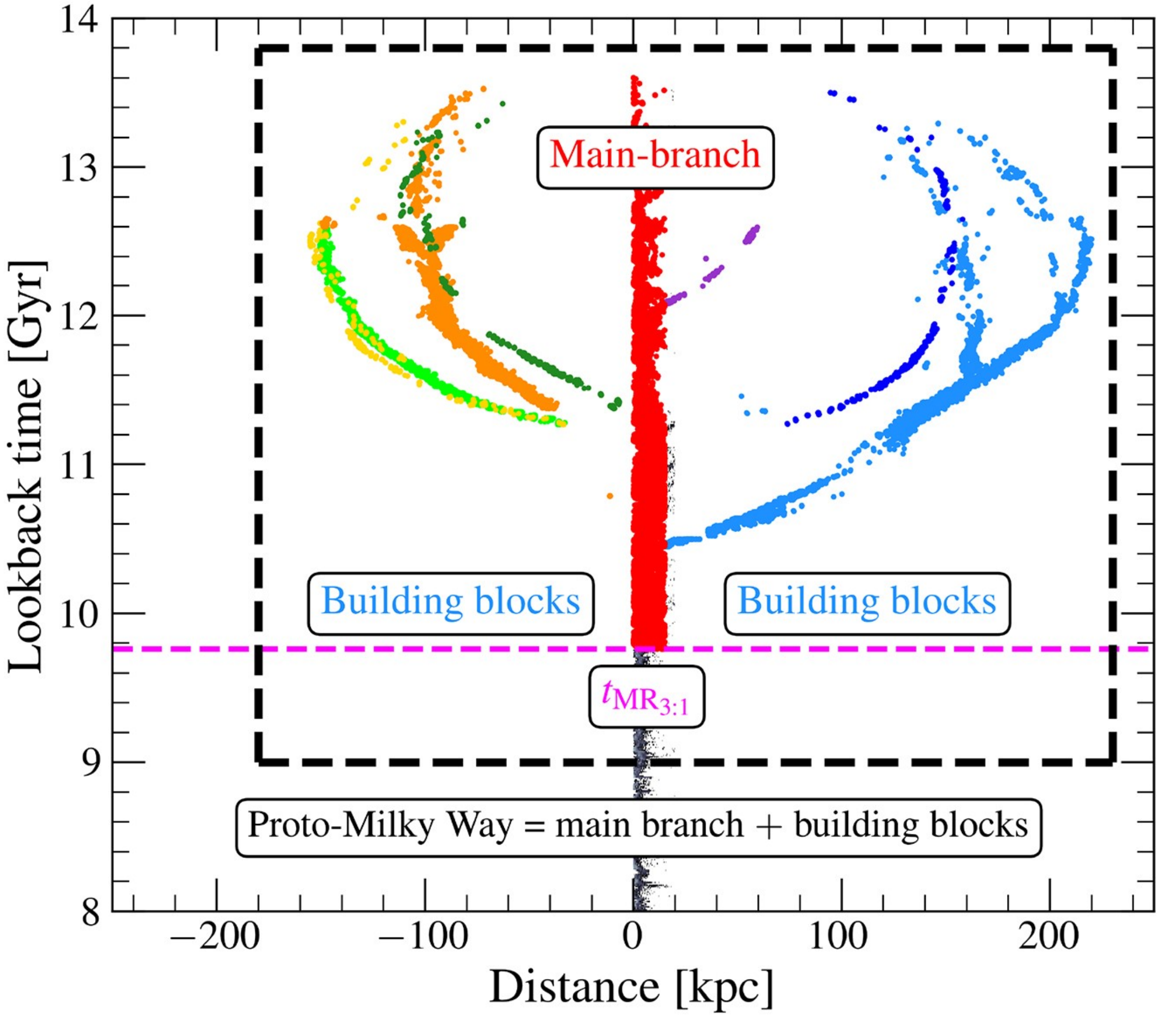
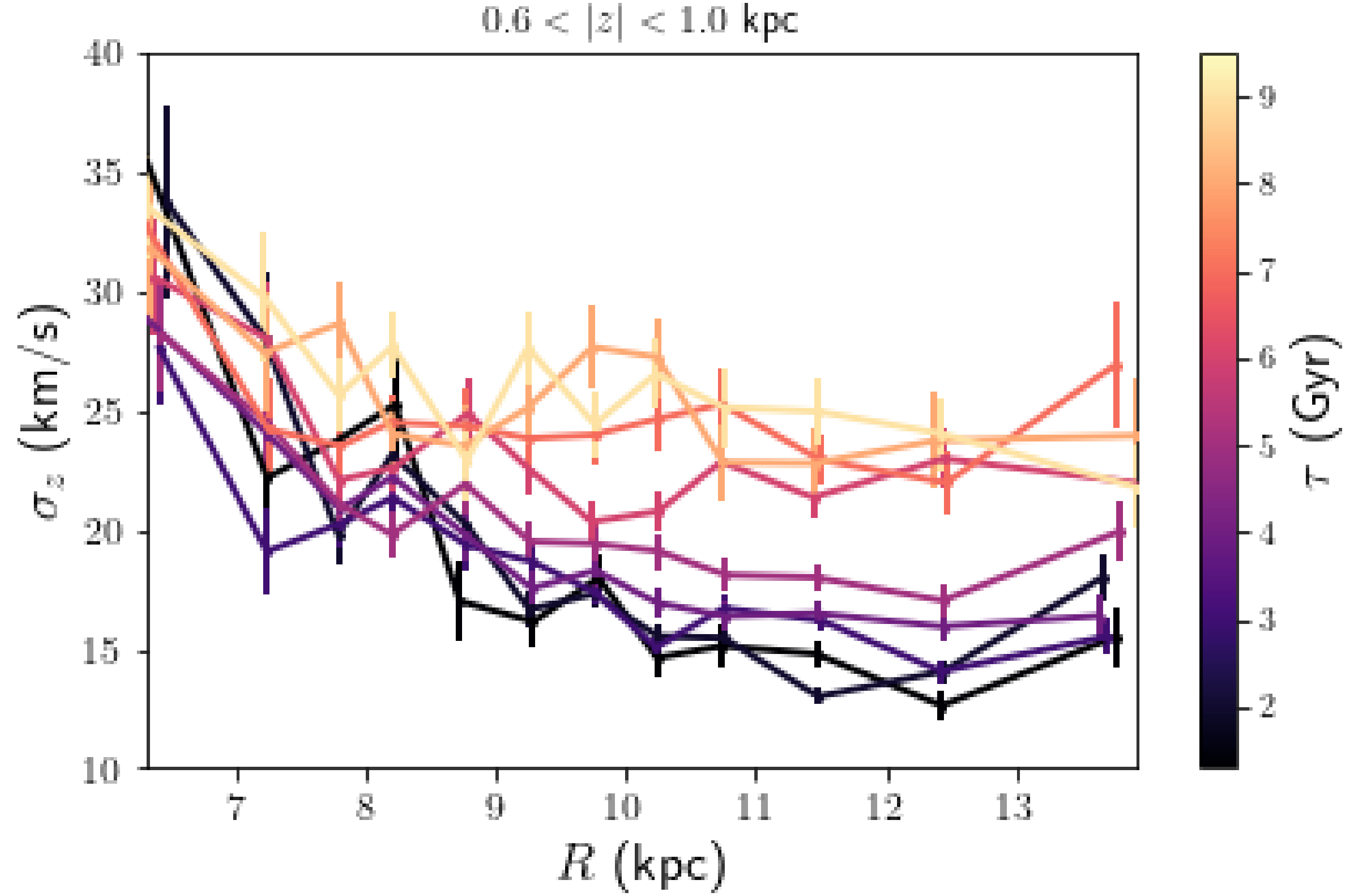
We've heard much about events in the Milky Way's past. To piece this into a tale, we need to be able to assign ages to stars



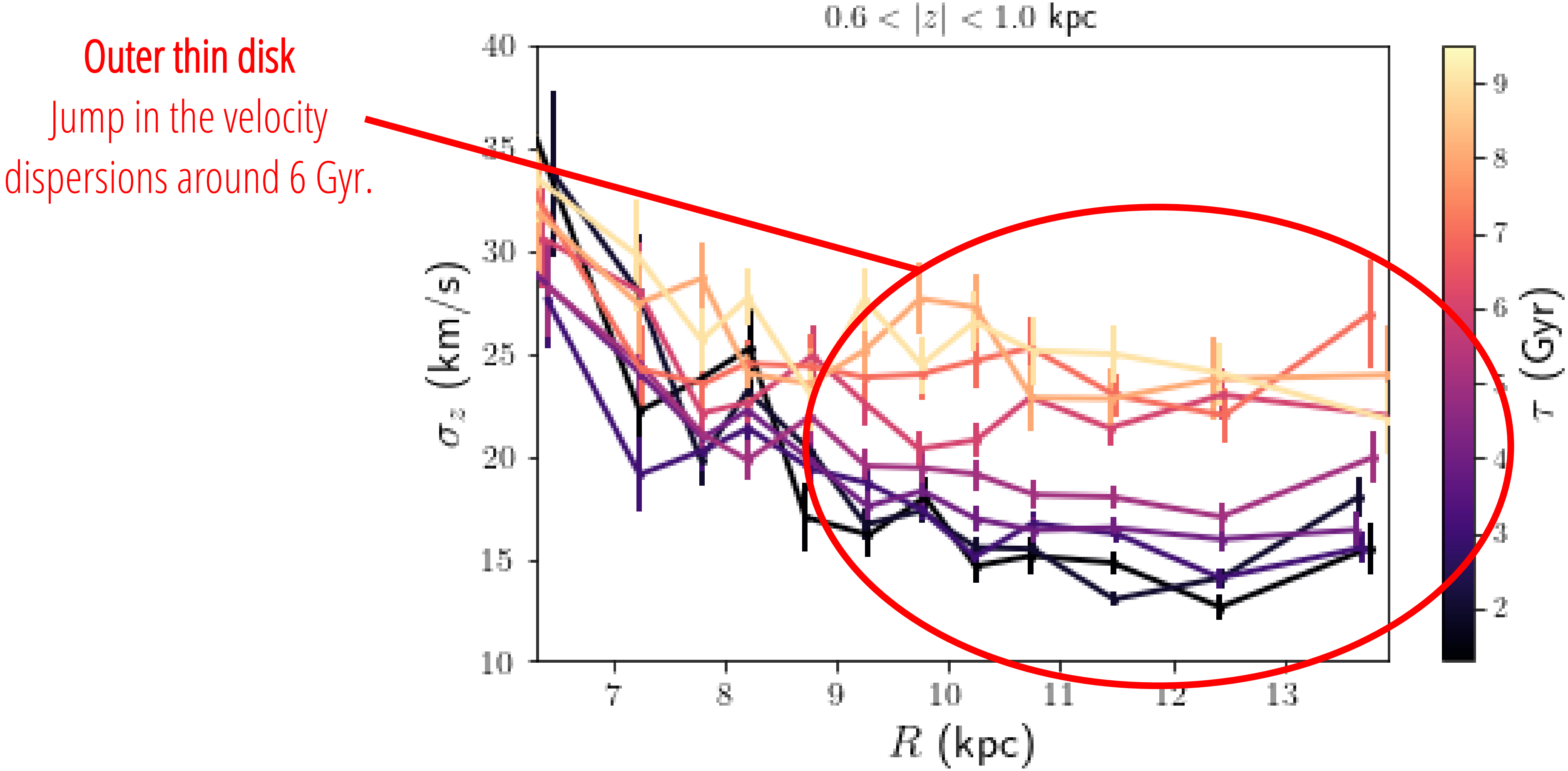
HORTA ET AL. (2024)

DAS, HUANG, CIUCA, AND FRAGKOUDI, 2024



Ages have helped reveal a complex age-velocity dispersion relation in the outer thin disc

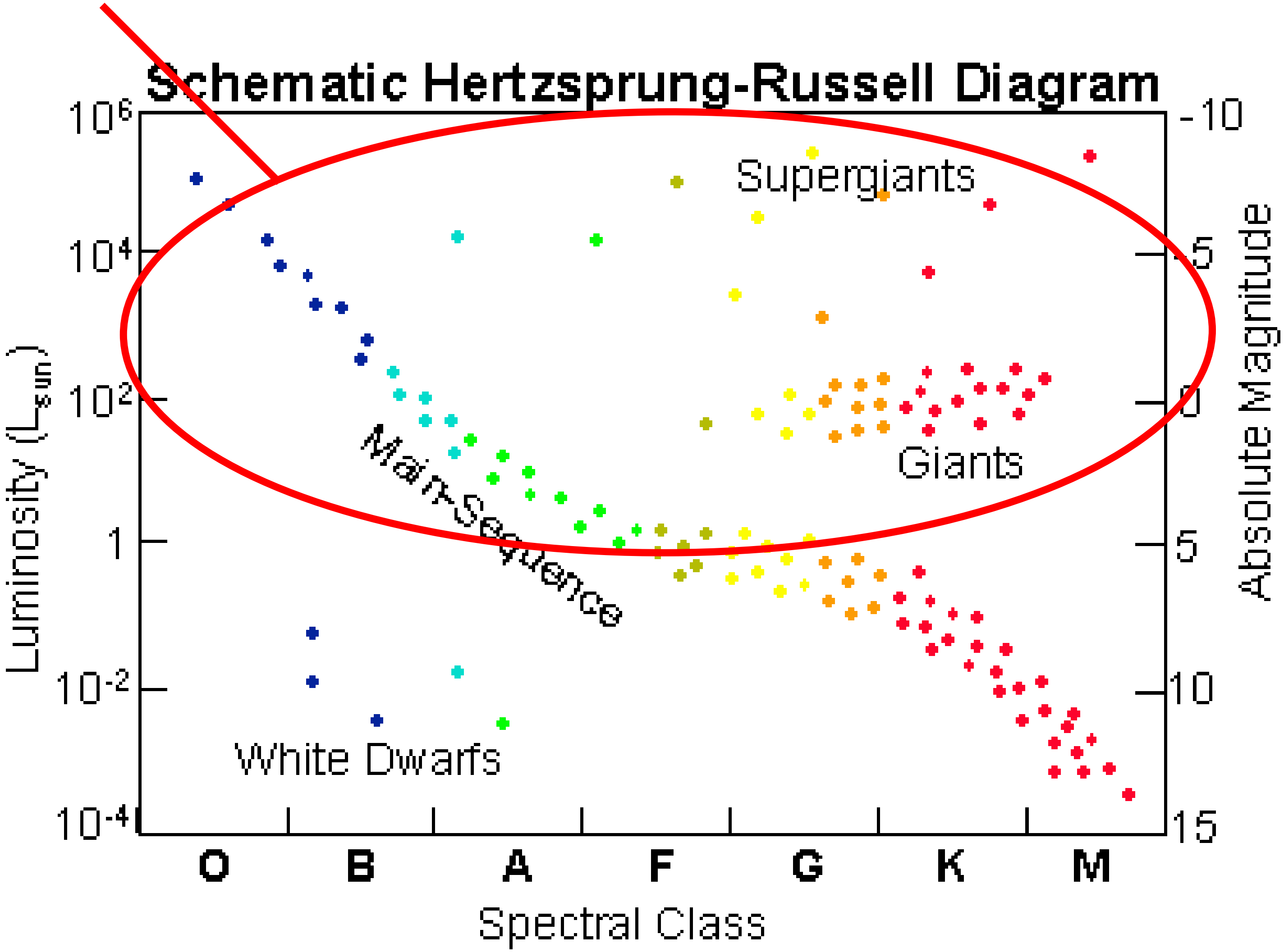
DAS, HUANG, CIUCA, AND FRAGKOUDI, 2024



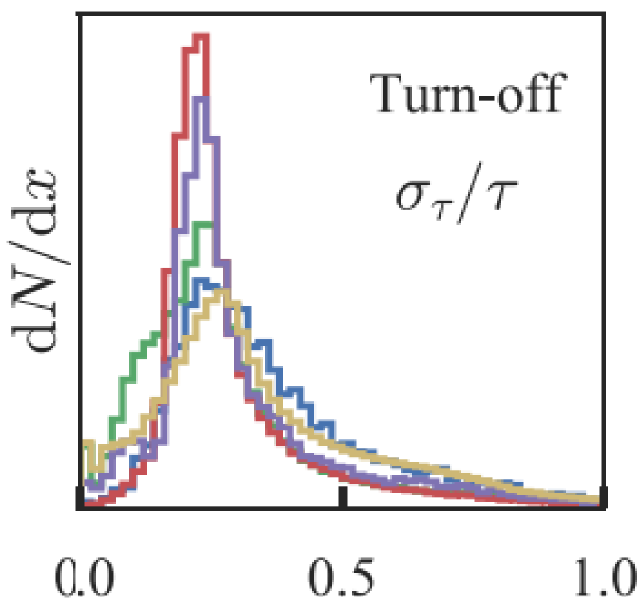
Ages have helped reveal a complex age-velocity dispersion relation in the outer thin disc

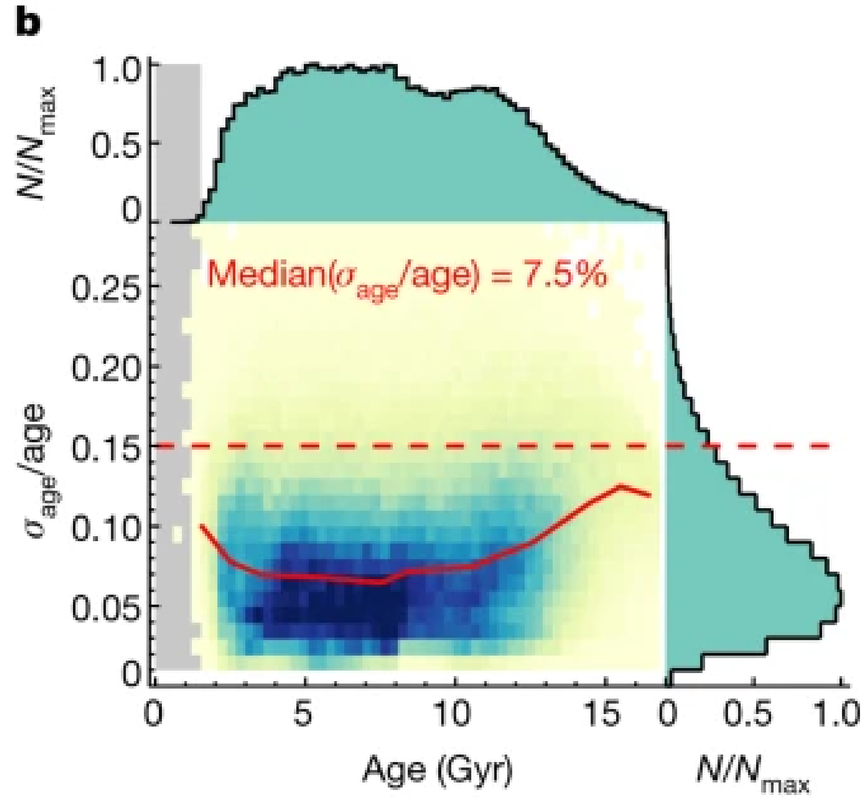
Luminous stars probe a large volume and can be observed at different ages

Luminous stars (main sequence turn offs, subgiants, giants)



Isochrone ages using photometry, spectroscopy and parallaxes for sub-giants and MSTO stars are relatively precise



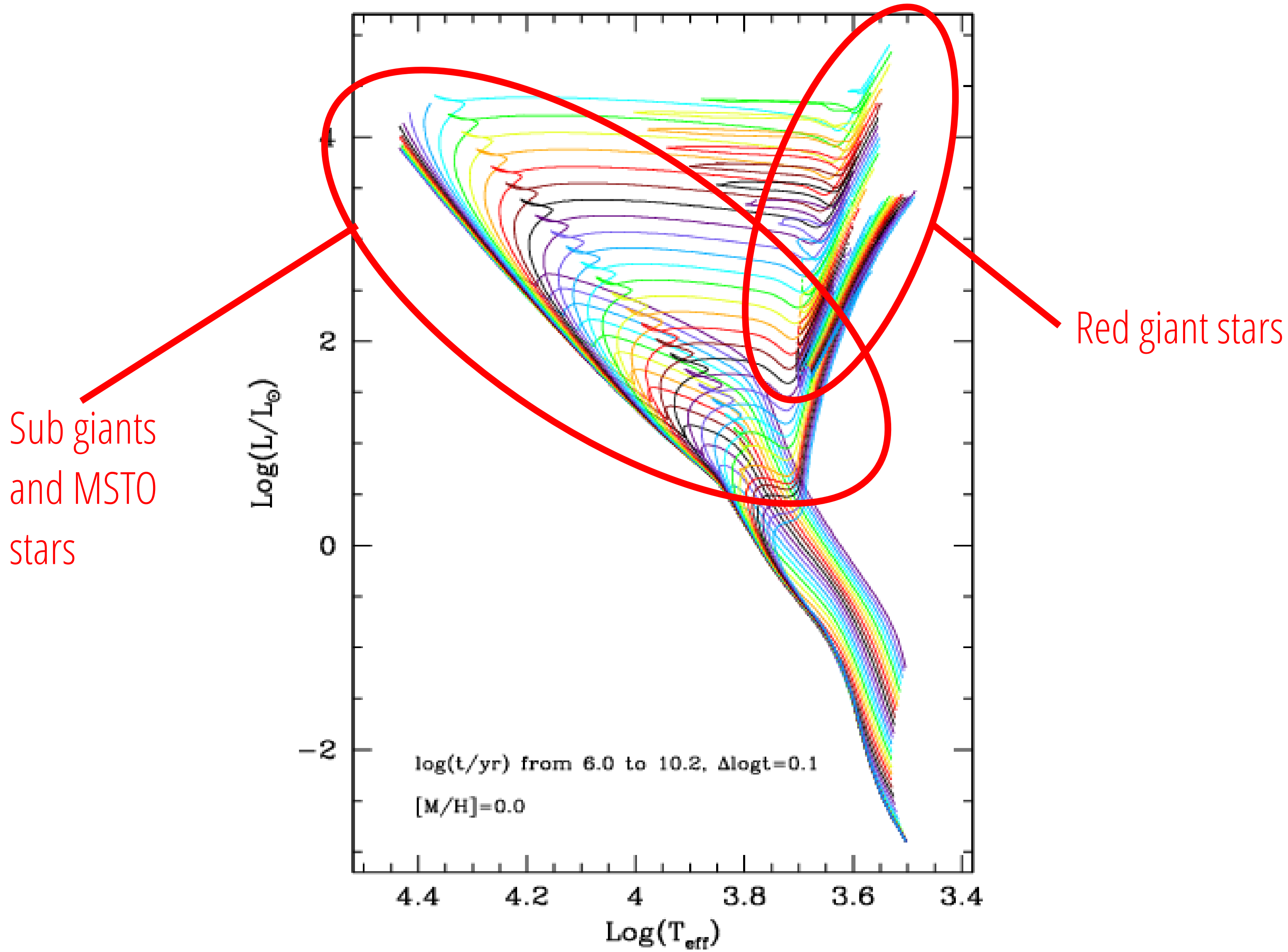


~25% ERROR FOR MSTO STARS IN APOGEE, (SANDERS & DAS, 2018)

~7.5% ERROR FOR SUB-GIANTS IN LAMOST (XIANG & RIX 2022)

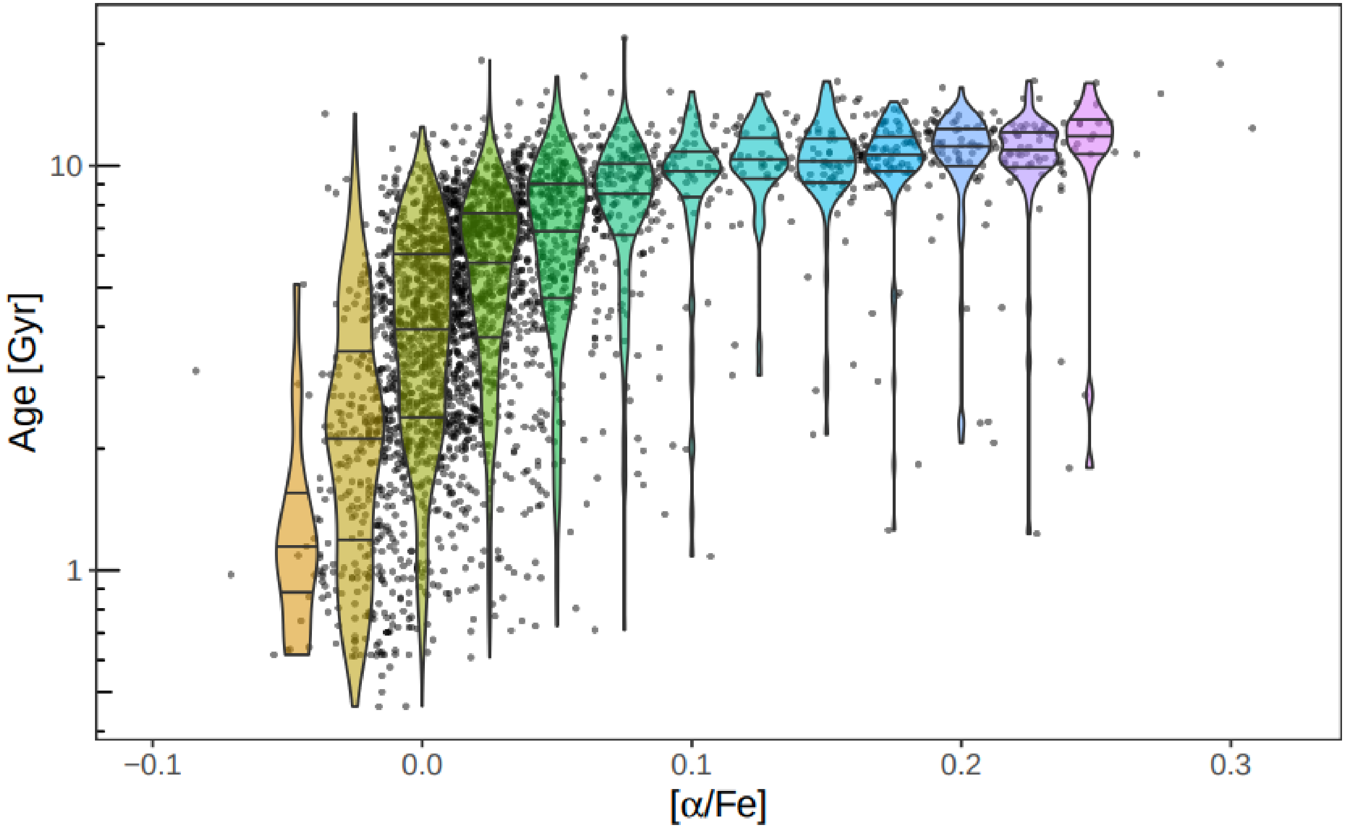
See also e.g. Mints & Hekker (2018), Quieroz et al. (2018), Sharma et al. (2018), Zhang et al. (2021),Nepal et al. (2024)

Stellar isochrones do not separate as well for red giants



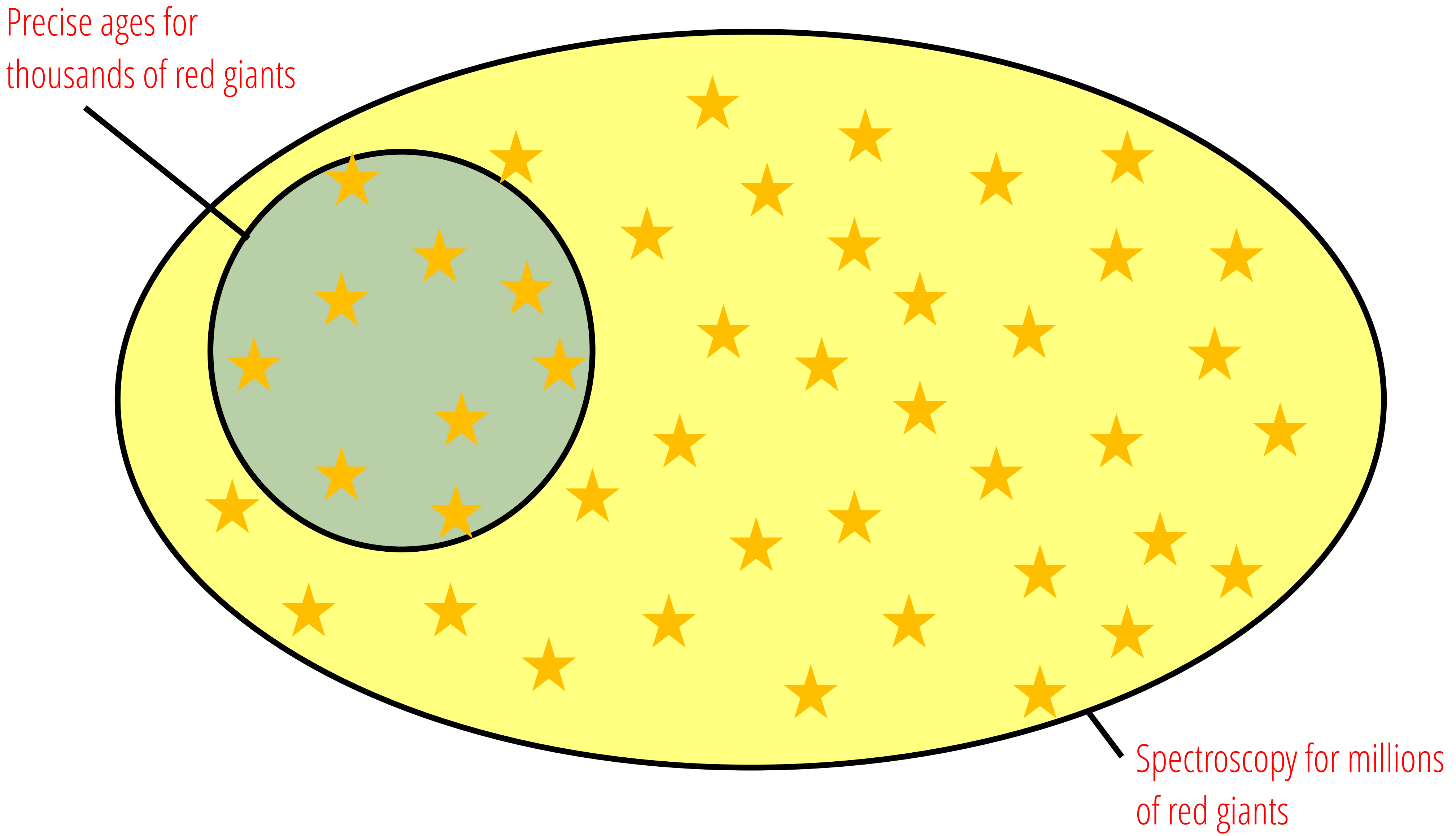
We can get precise ages for red giant stars but for a smaller number of stars through asteroseismology

~23% ERROR FOR RED GIANTS IN KEPLER-APOGEE STARS (MIGLIO ET AL. 2021)



See also e.g. Pinsonneault et al. (2014), Vrard et al. (2016), Pinsonneault et al. (2018), Warfield et al. (2024)

Data-driven methods enable us to map precise red giant ages to a large number of red giants

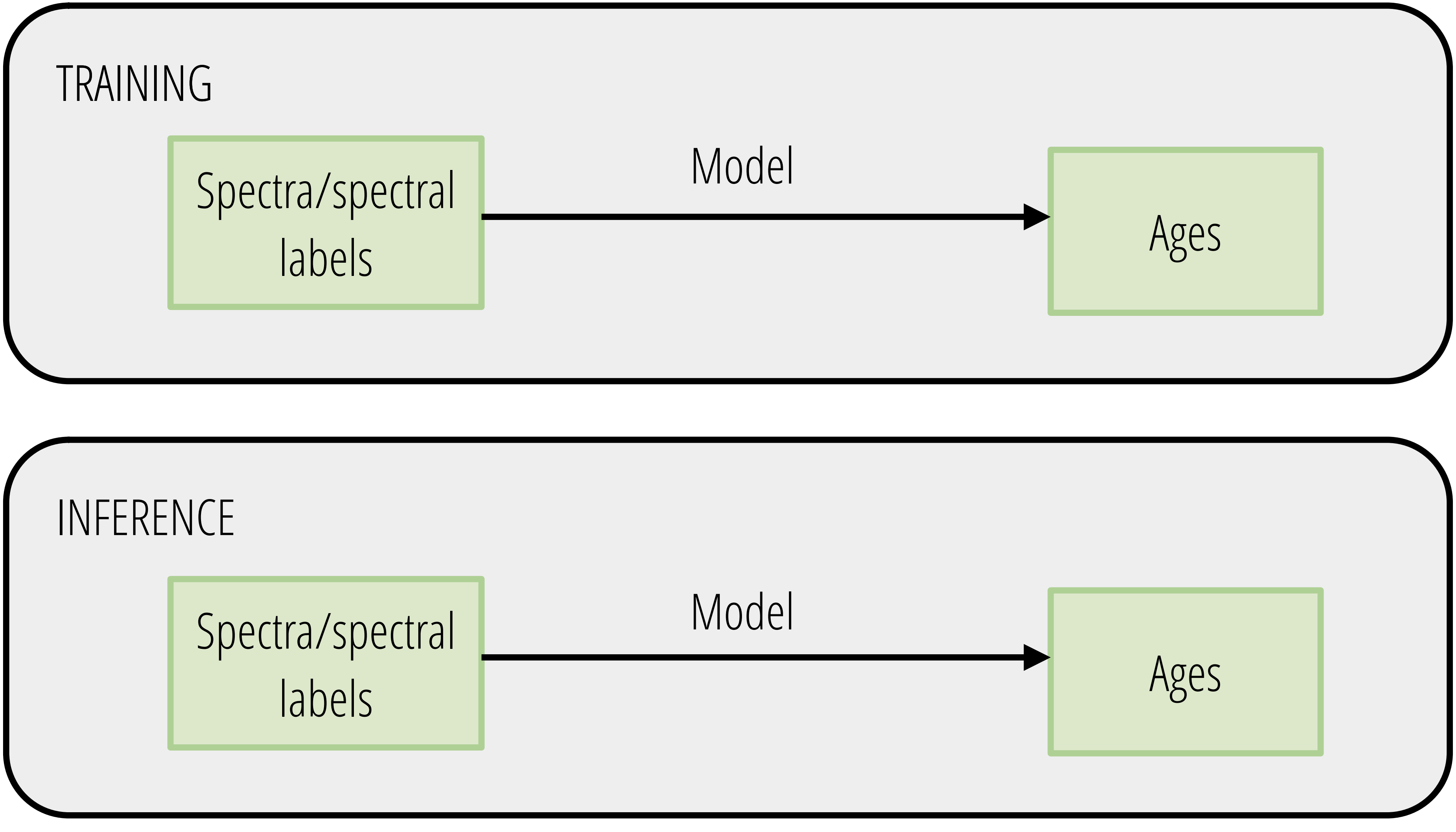


To do this we look for sections of spectra or spectral labels that correlate with age

From spectra, we measure:

- **Surface gravity, effective temperature, metallicity, and intensities at different wavelengths (i.e. apparent magnitudes and colours)**. These variables encode age information as a result of STELLAR EVOLUTION.
- **Chemical abundance ratios**. These variables correlate with age as a result of CHEMICAL EVOLUTION e.g. [Y/Mg] and [C/N] (see e.g. Nissen 2016, Martig, M et al. 2016, Skúladóttir 2019, Delgado Mena et al., 2019, Hayden et al., 2022)

A data-driven method consists of two key phases: training and inference



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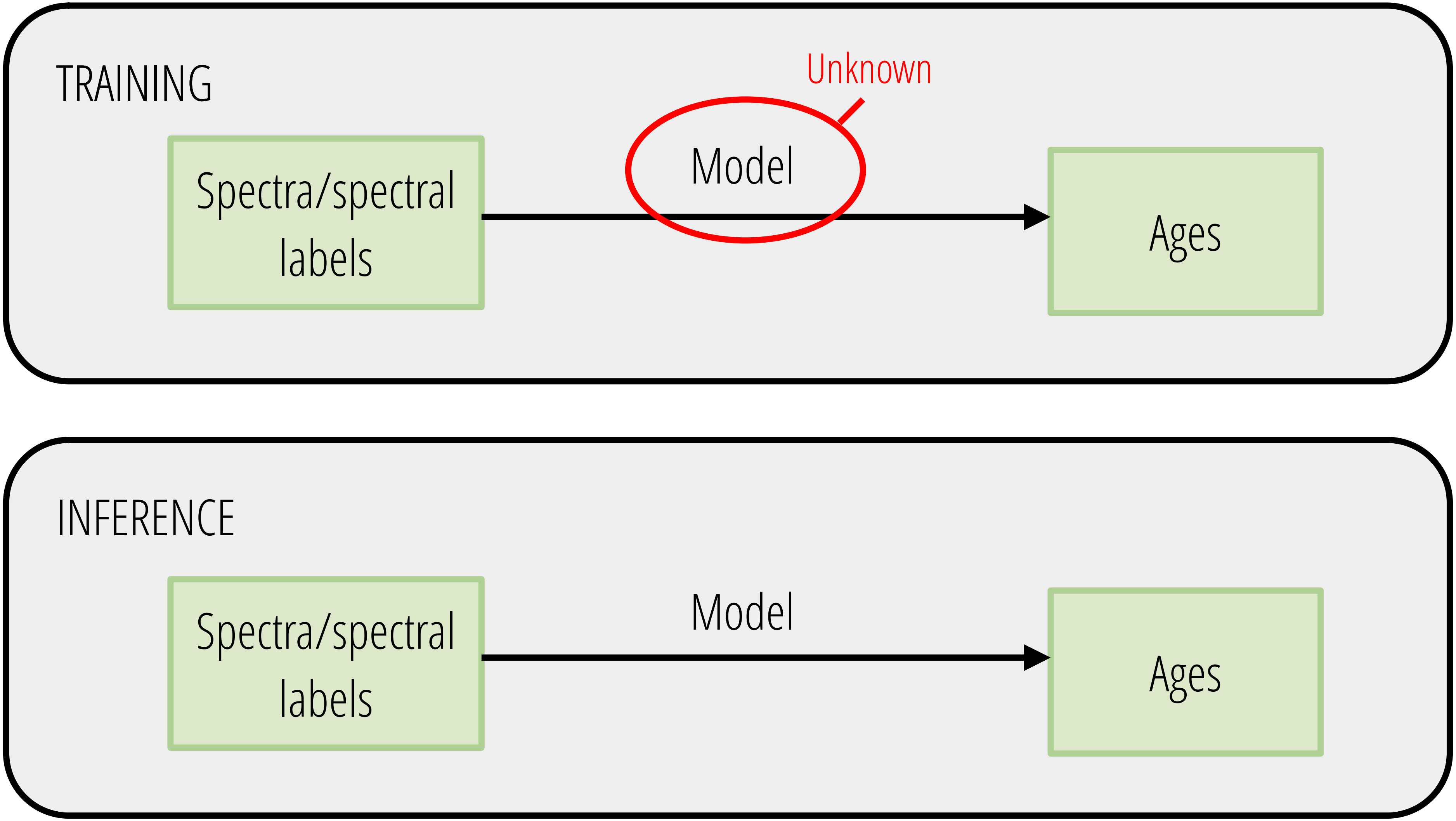

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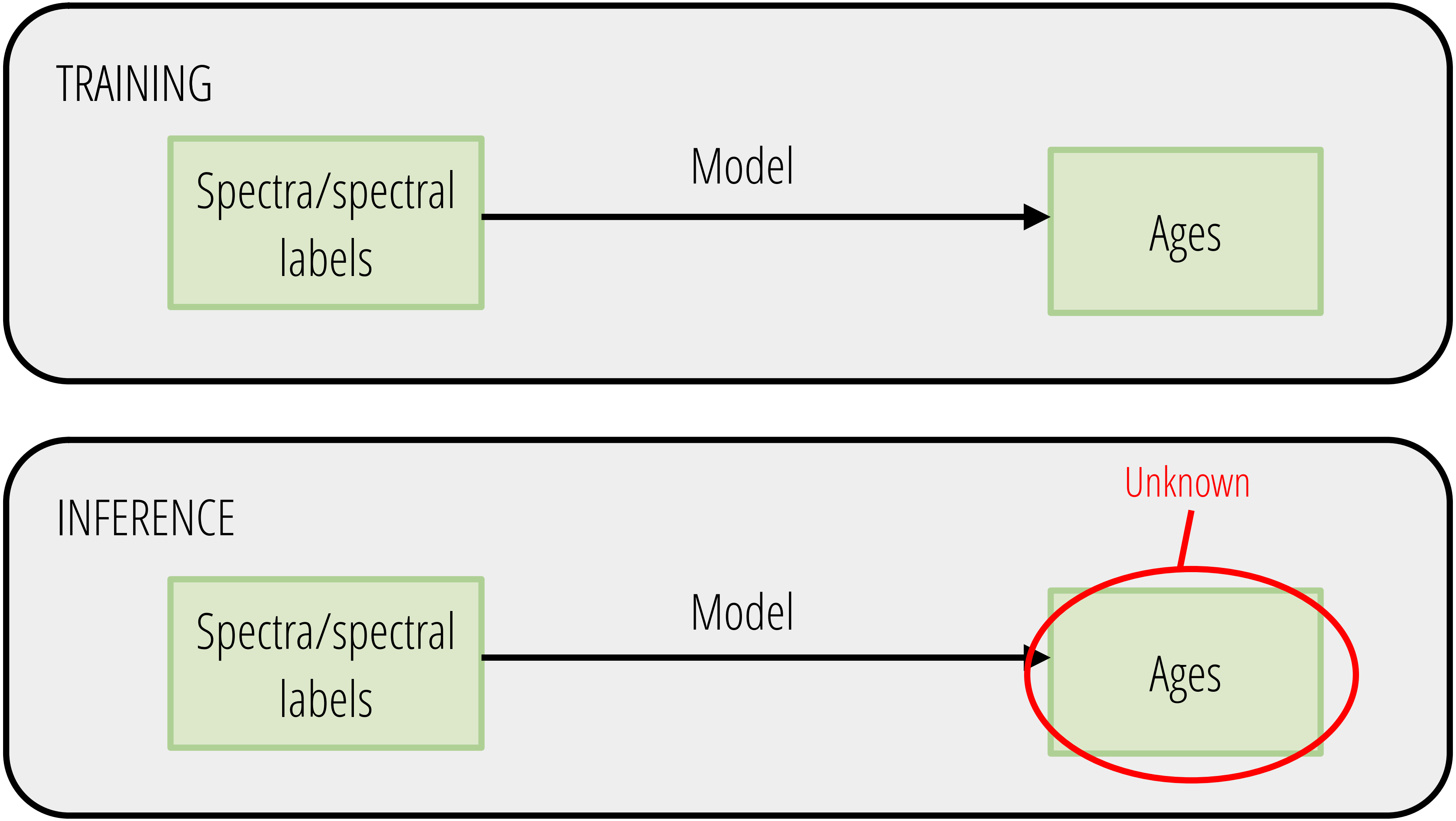
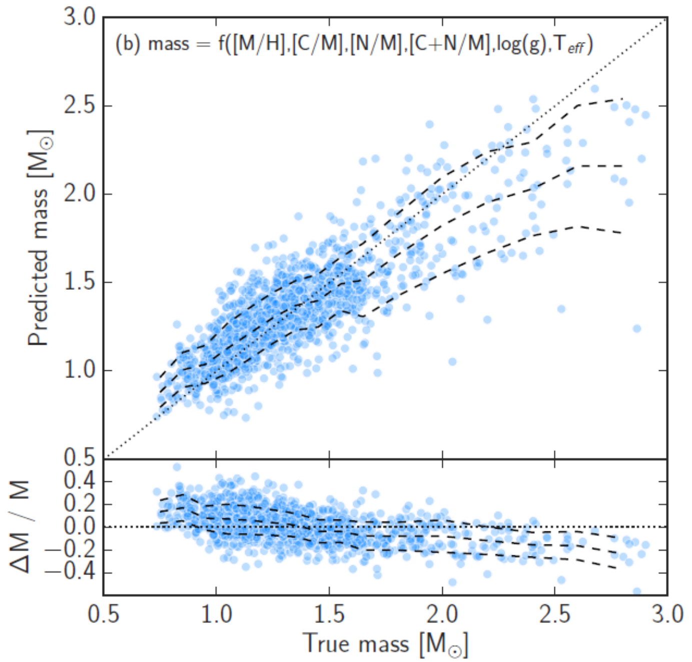


There has been a proliferation of data-driven methods for learning red giant ages

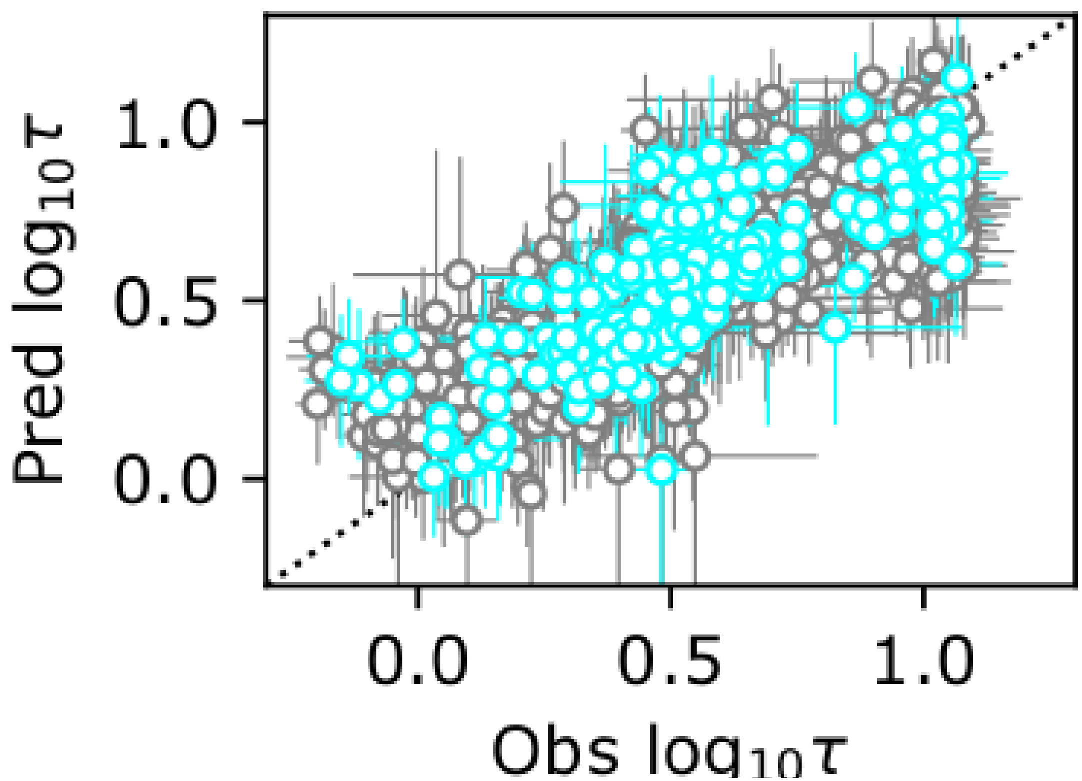
Paper	Spectra/spectral labels	Model	Mass/Ages
Martig et al. (2016)	APOGEE spectral labels	Linear polynomial	Kepler (scaling relations)
Ness et al. (2016) [The Cannon]	APOGEE spectra	Quadratic polynomial	Kepler (scaling relations)
Das & Sanders (2018)	APOGEE spectral labels	One hidden layer feed-forward neural network	Kepler from Vrard et al. (2016)
Ciucă et al. (2021)	APOGEE spectral labels	Two hidden layer feed-forward neural network	Kepler from Miglio et al. (2021)
Wang et al. (2023)	LAMOST spectra	One hidden layer feed-forward neural network	Kepler from Vrard et al. (2016)

See also e.g. Hayden et al. (2022), Moya et al. (2022), Zhang et al. (2024 – see SPT talk!)

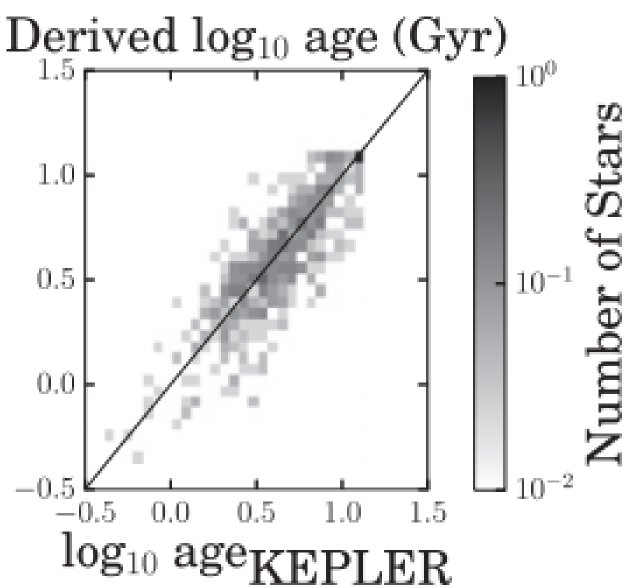
MARTIG ET AL. 2016 (40% AGE ERROR)



Red giant age precision has improved with time



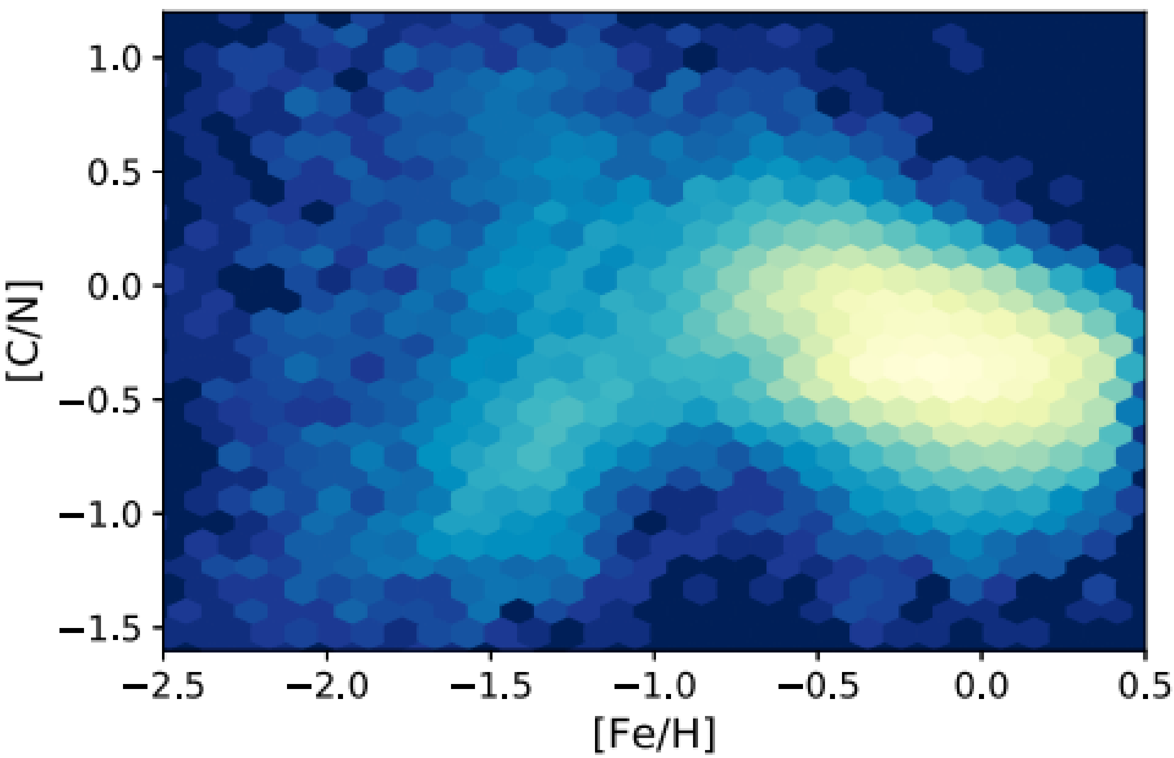
DAS & SANDERS, 2019 (16% AGE ERROR FOR APOGEE STARS)



NESS ET AL. 2016 (40% AGE ERROR)

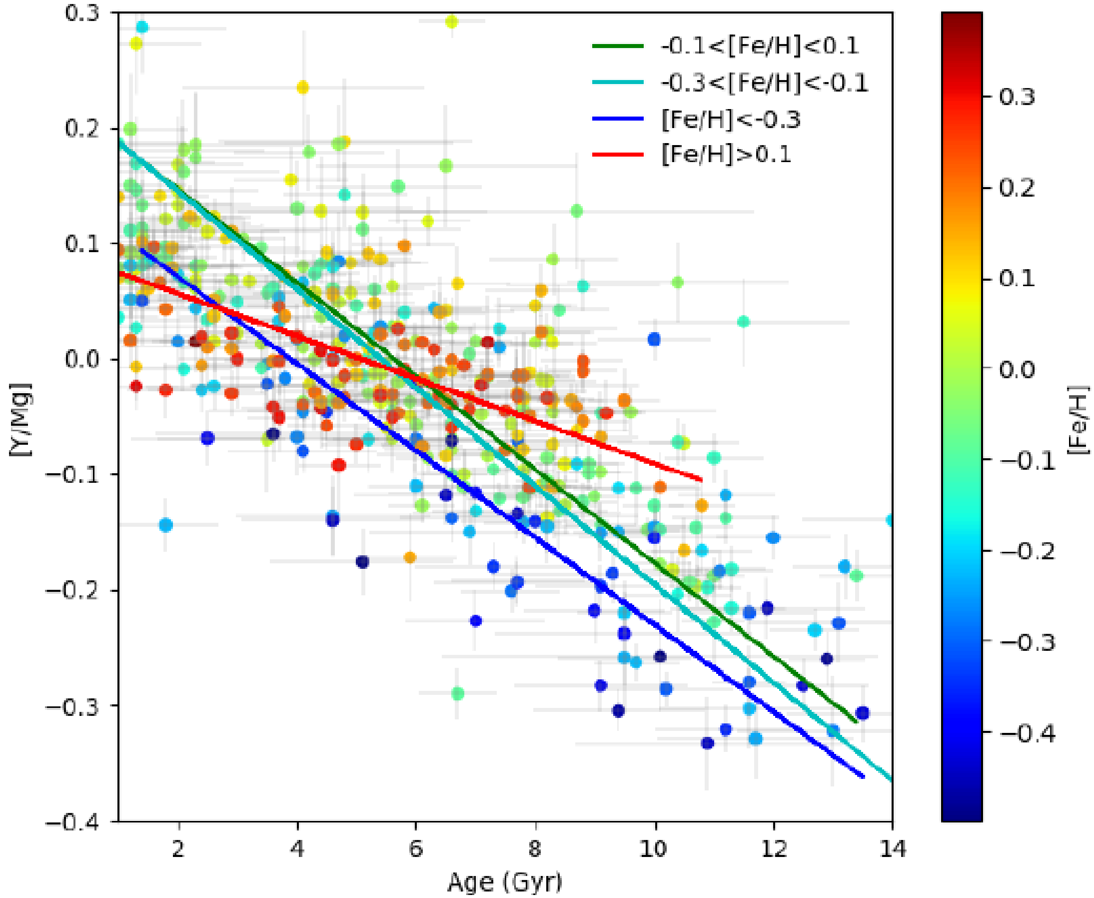
Problems with data-driven ages: the metal-poor end

DAS, HAWKINS, & JOFRE, 2020



- [C/N] relation with age breaks down because of efficient thermohaline mixing in metal-poor stars may lead to a large spread in [C/N] at low metallicities. See Spoo, Tayar et al. 2022.
- Inhomogeneities in interstellar medium (ISM) also become increasingly important at low metallicities.
- Fewer asteroseismological ages and can't really extrapolate data-driven models. See Montalban, J et al. (2020).

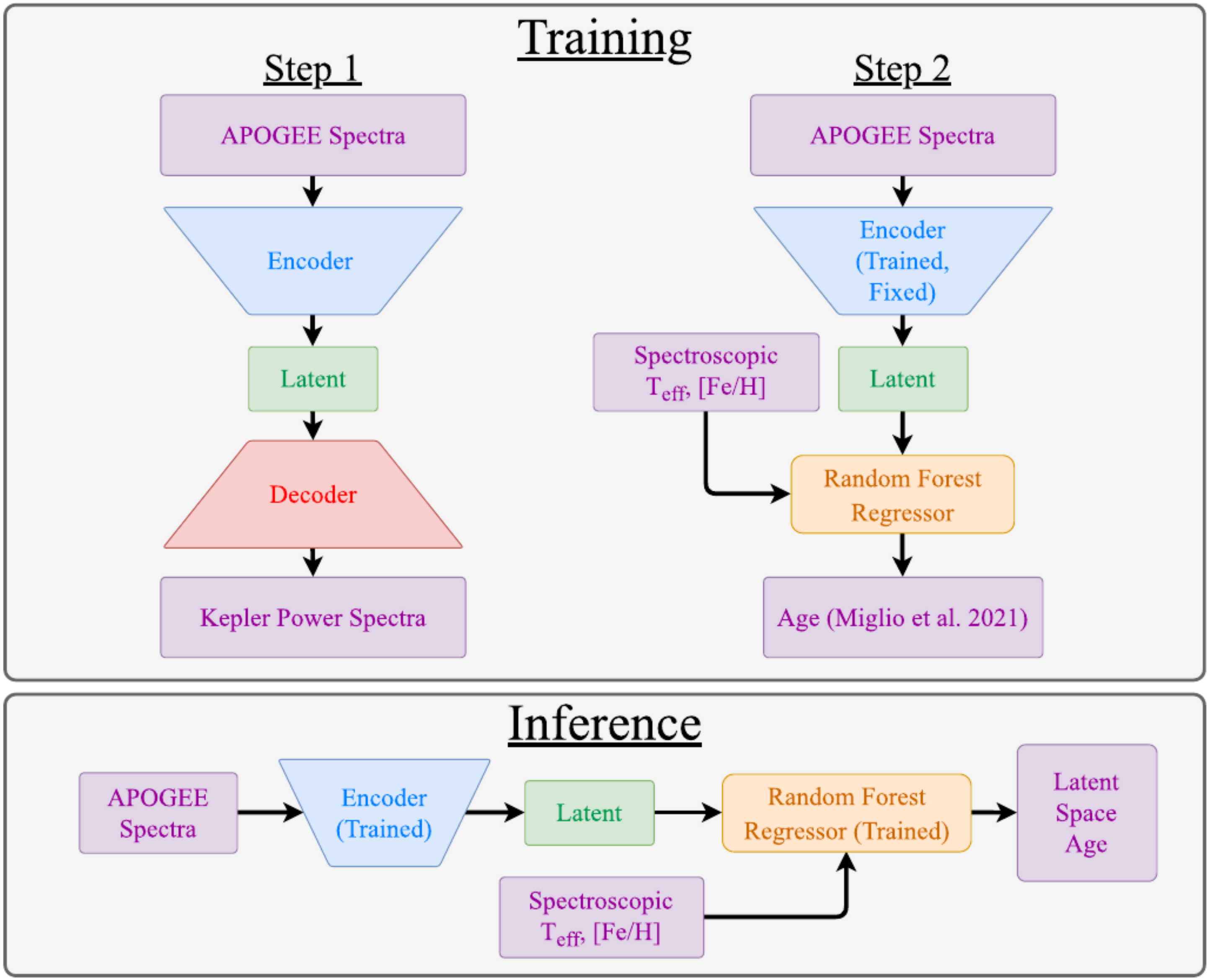
Problems with data-driven ages: Galactic chemical evolution



CASALI ET AL. (2020)

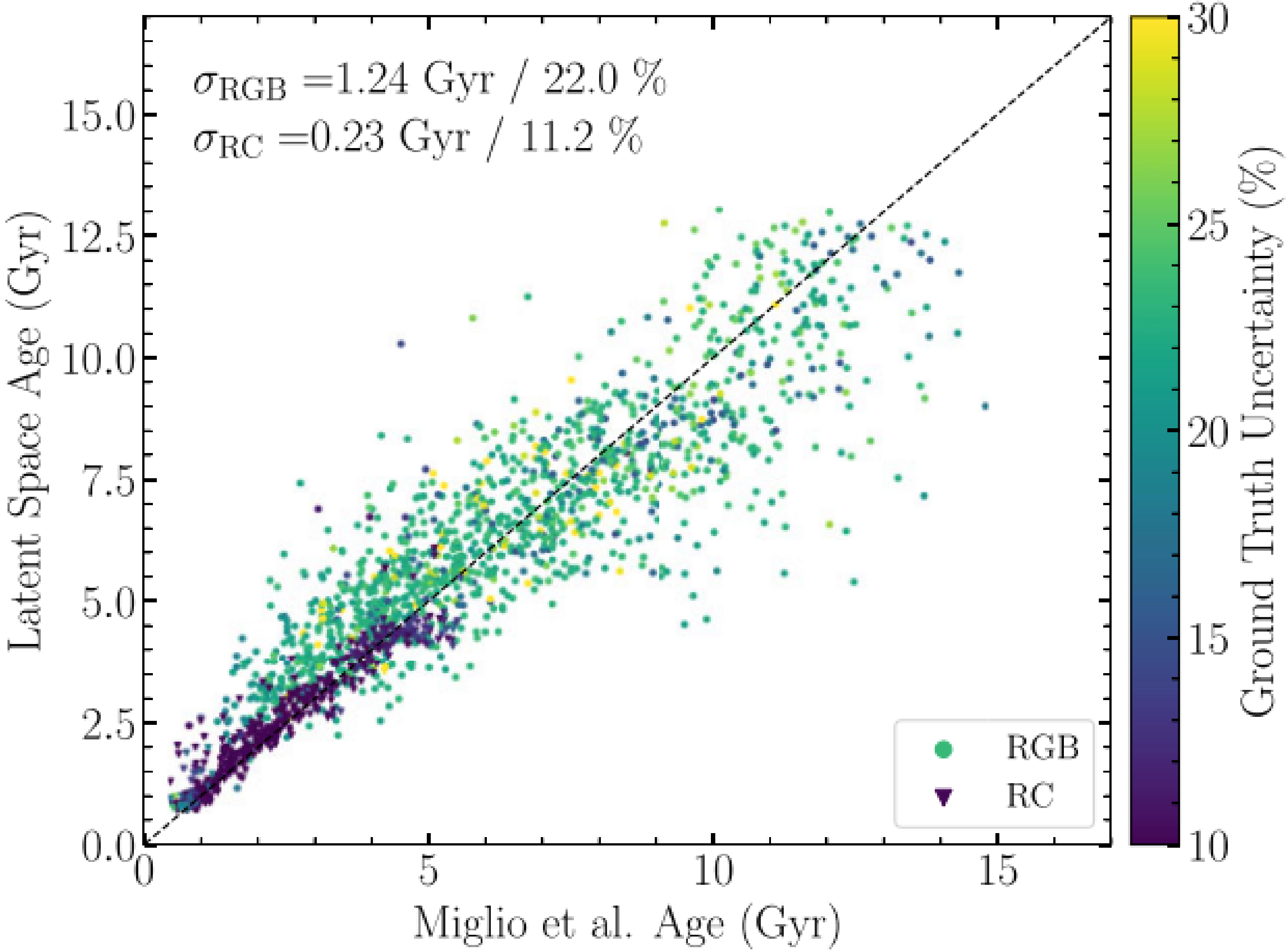
Rate of chemical evolution depends on Galactic location => non-universal relations between chemical clocks and age (e.g. Casali et al. 2020, Viscasillas Vázquez, C et al. 2022)

Adding a variational encoder-decoder to transform the APOGEE spectra can remove these correlations



LEUNG, BOVY, MACKERETH & MIGLIO, 2024

They are able to recover the Miglio et al. (2021) sample with similar age uncertainties (~23%)



LEUNG, BOVY, MACKERETH & MIGLIO, 2024

We should soon be able to get precise ages for many millions of red giants

- The Milky Way Mapper is observing (SDSS-V) for 4-5 million stars, some fraction of which will have APOGEE spectra => there will be even more spectra for red giants!
- In terms of asteroseismology, it would be interesting to know how K2 and TESS could help (their exposure time is less though).
- Would also be cool to explore the possibility of applying variational encoders-decoders that transform spectra with no overlap with Kepler (e.g. GALAH) to APOGEE spectra (where there is an overlap of 5000 to 10000 stars depending on the exact cuts) to get more precise ages for red giants in other surveys.