Chemical Evolution Models of the Milky Way with Radial Migration

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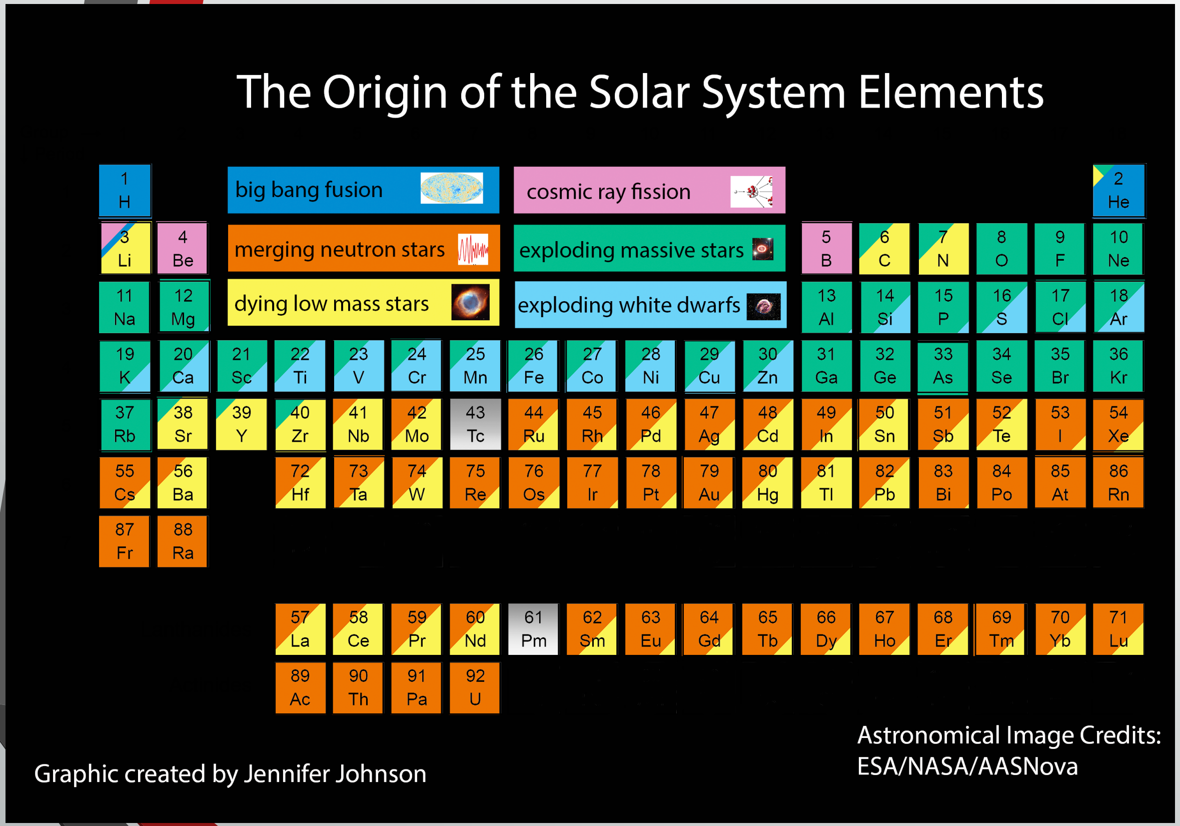
Galaxies Make Stars, Stars Make Metals



Present-day chemistry encodes information on the nuclear reactions that occurred over a galaxy's history (i.e. stars & supernovae)

Here: O & Fe

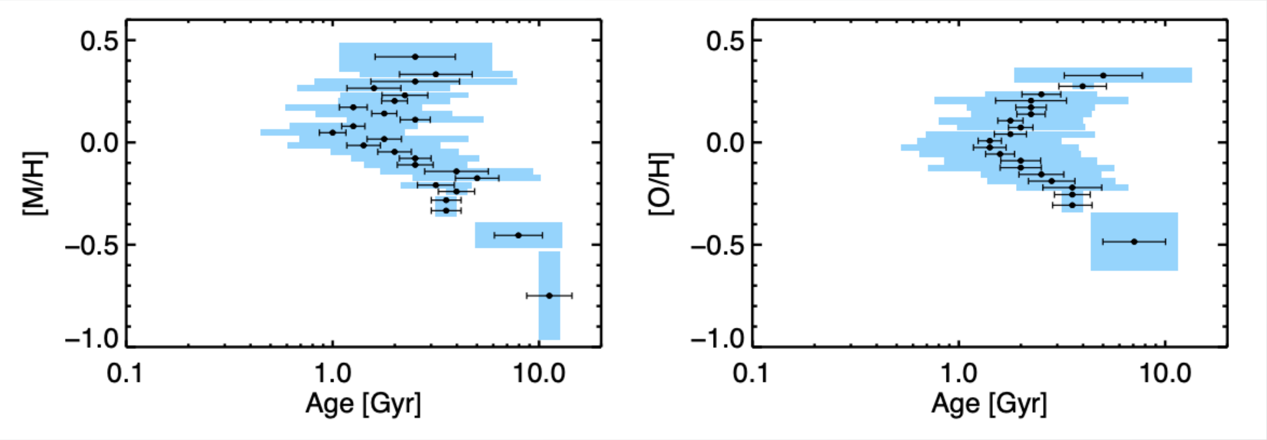
- Core Collapse Supernovae
- Type Ia Supernovae

Figure: Johnson (2019), Science, 363, 474

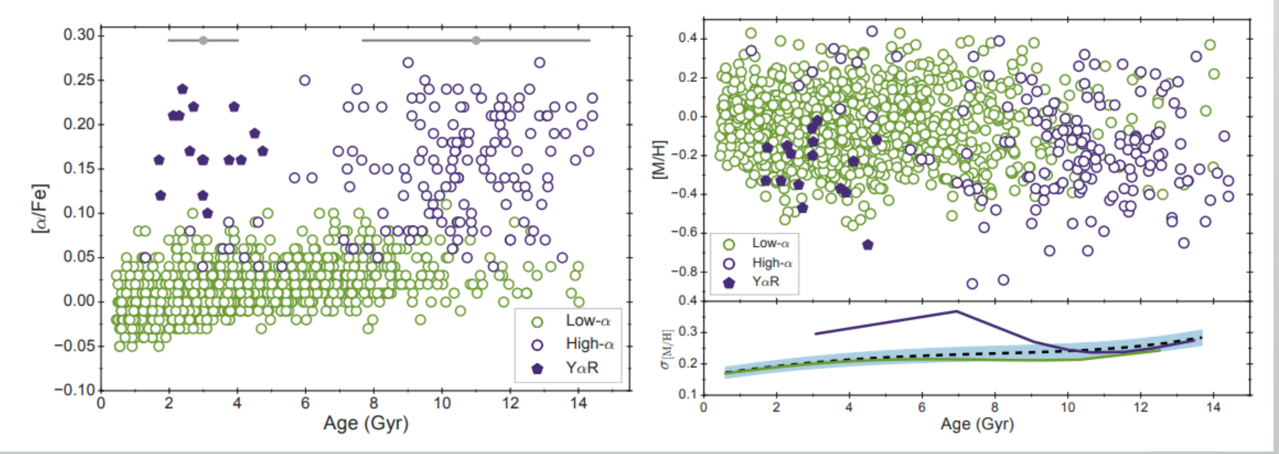
Motivation: The Observed Data

The Age-Metallicity Relation

- Highest-Z stars in solar annulus statistically older than solar-Z stars



- Population of young, alpha-rich stars w/asteroseismic ages



Top: Feuillet et al. (2018) Fig. 3; Bottom: Silva-Aguirre et al. (2018) Fig. 10

Motivation: The Observed Data

Bimodality in [α/Fe] vs. [Fe/H] – most apparent ~5-9 kpc

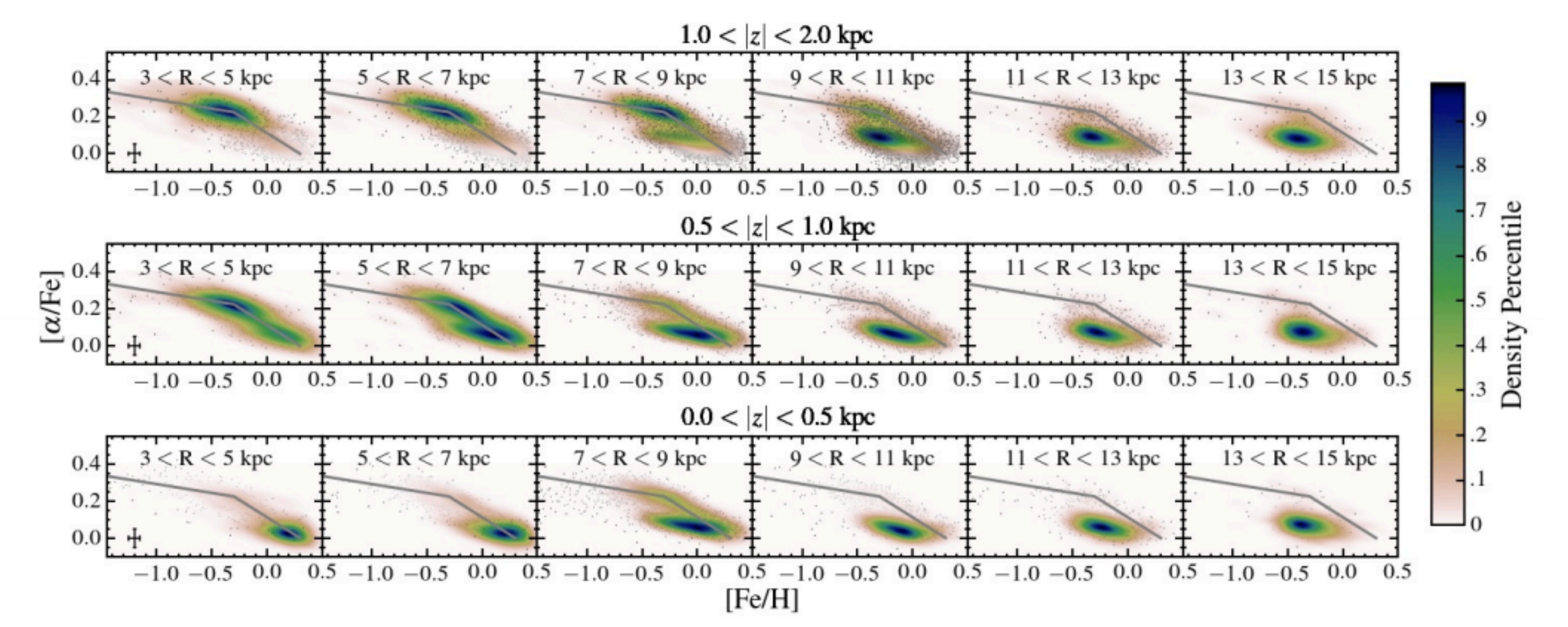
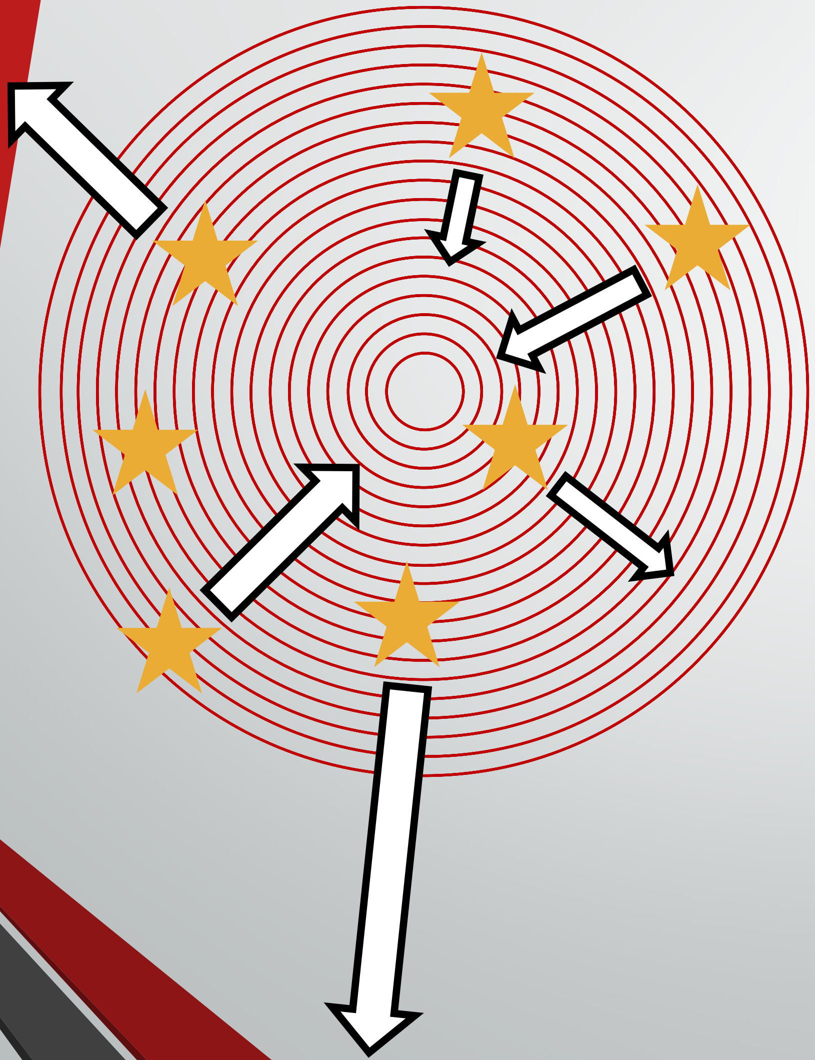


Figure: Hayden et al. (2015), Fig. 4

Multizone + Hydro = Hybrid Model



Disk described as 250 pc annuli extending from R = 0 to 30 kpc

Star particles form and gas evolves in a given annulus according to conventional *one-zone* models of chemical evolution

Stars migrate between zones according to an *analog* from hydro simulation w/similar formation radius and time

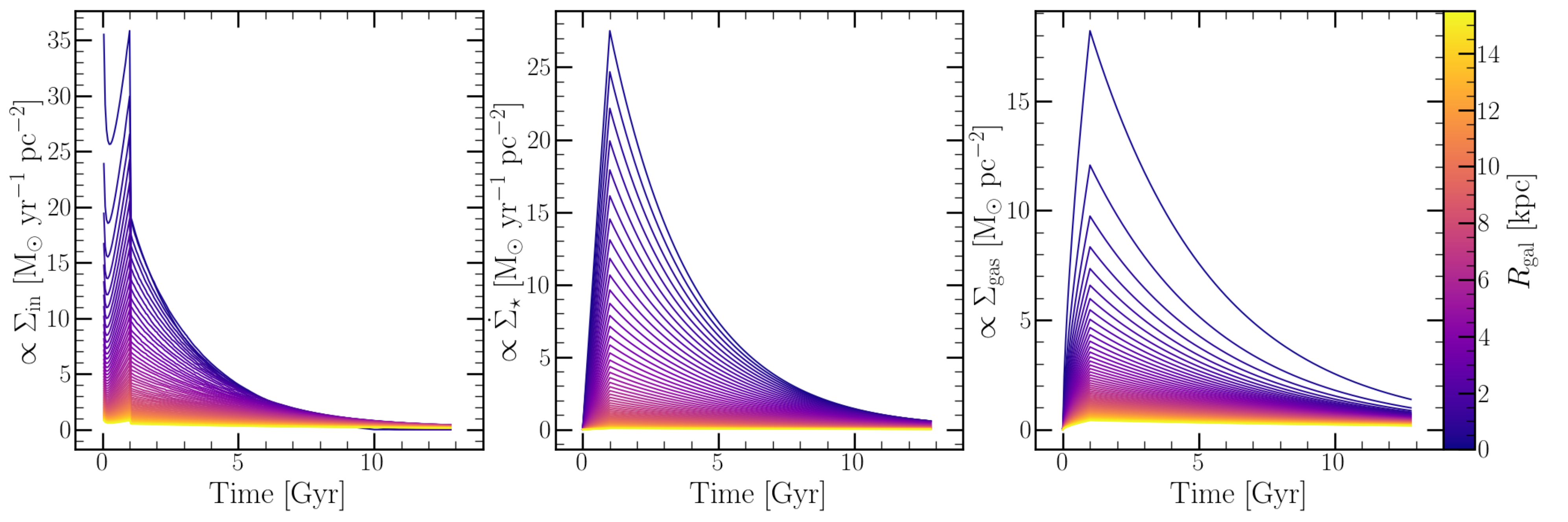
Note: There are no gas flows

Impose Inside-Out Growth

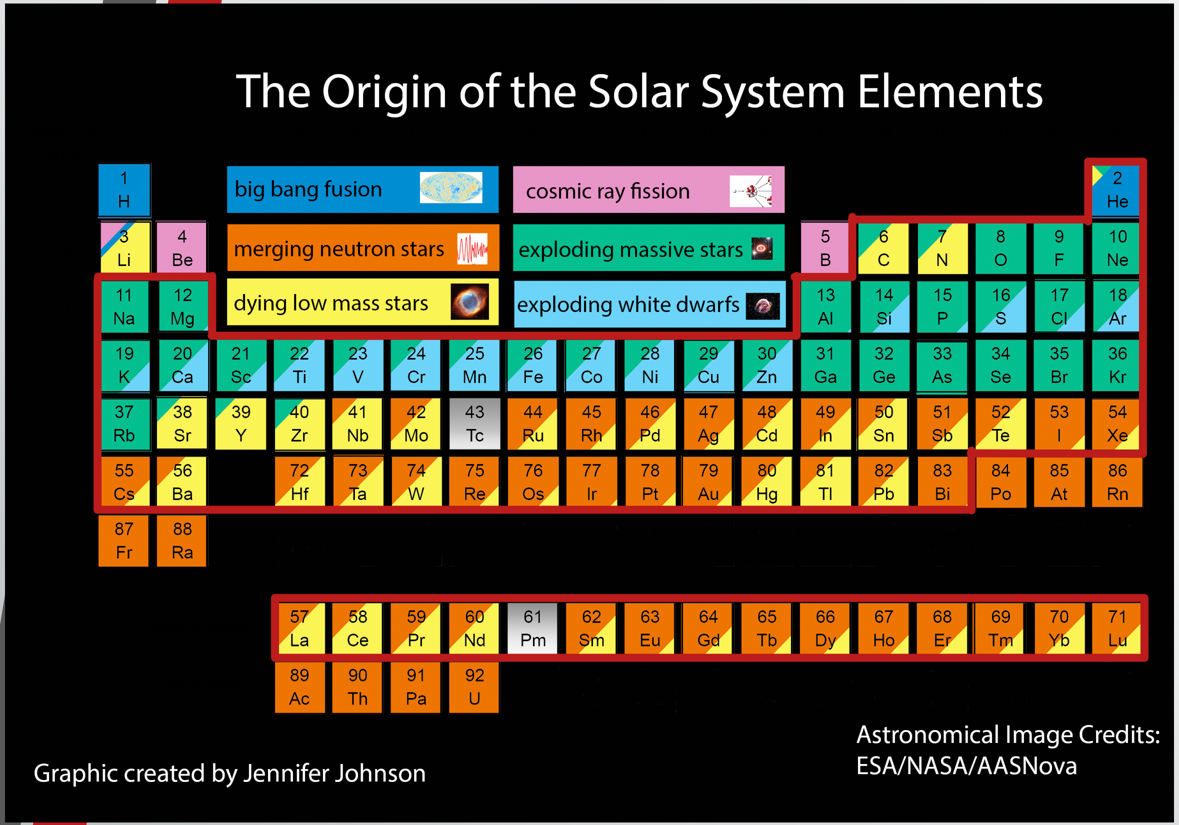
"Linear-then-Exponential" star formation history at each radius

Kennicutt-Schmidt scaling describes scaling of star formation rate with surface density of gas

Yields stellar surface density that declines exponentially w/radius



Versatile Integrator for Chemical Evolution



vice 1.1.0

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pip install vice
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VICE

Python package designed to handle highly complex chemical evolution models

Multizone features in development; will be released with upcoming papers – used for simulating this model

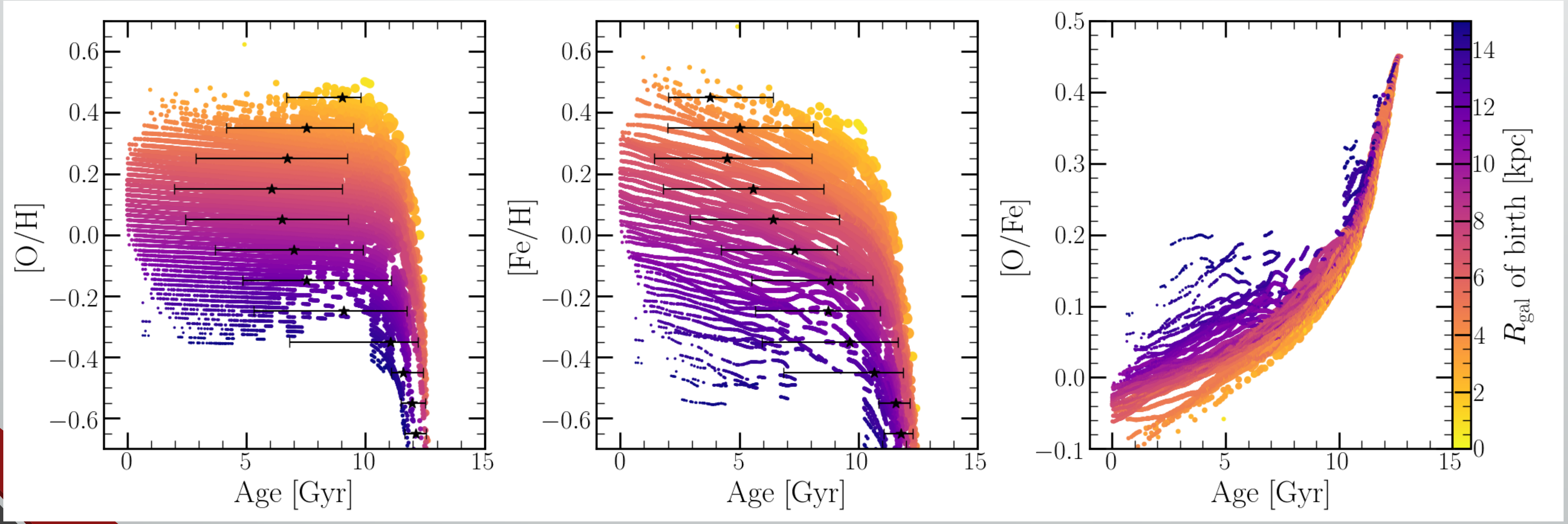
Nucleosynthetic yield tables included; users can construct their own for use in simulation regardless of previous yield studies

The Age-Metallicity Relation

All star particles with final radius in solar annulus (7 – 9 kpc)

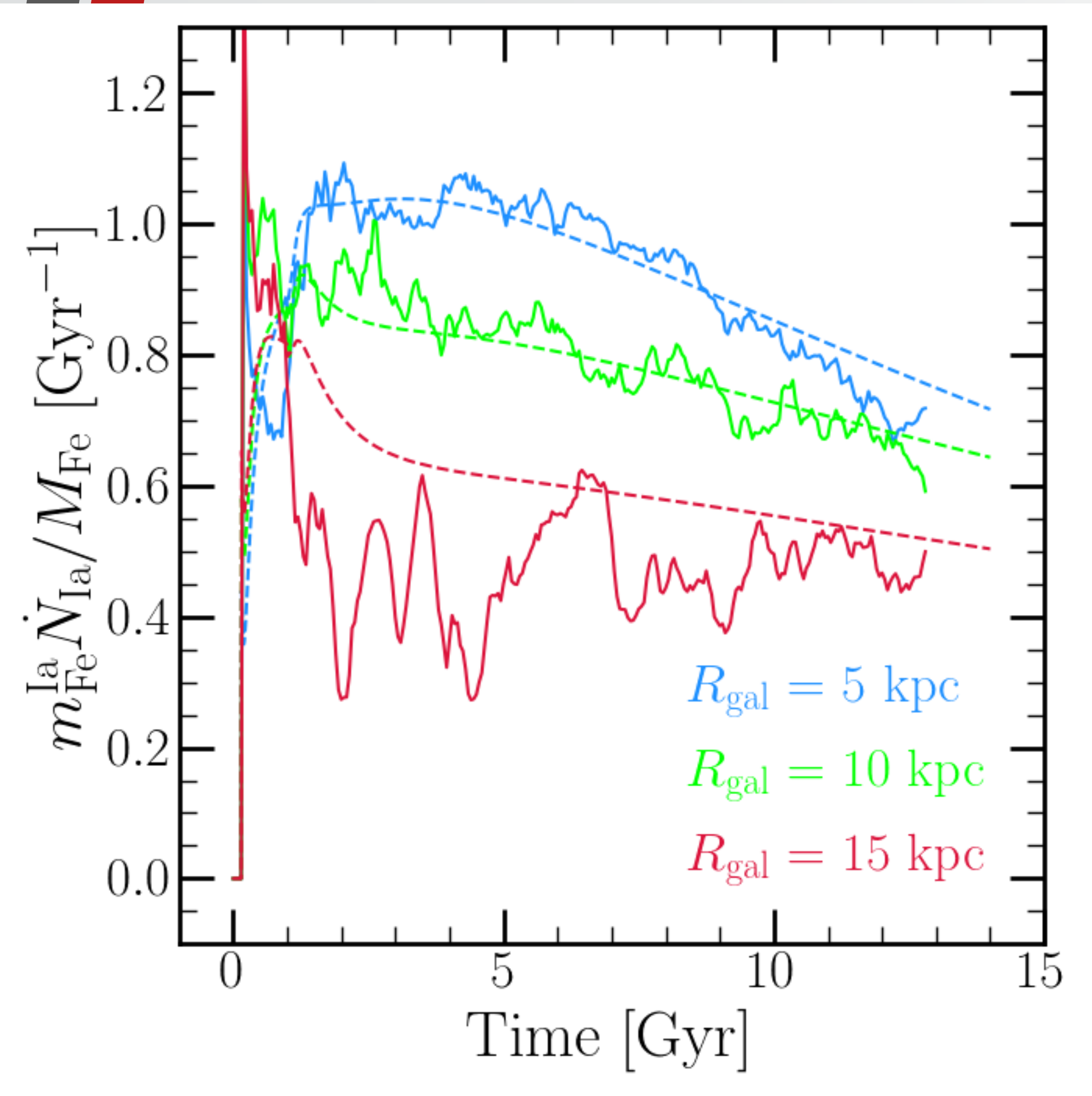
Predict O-rich stars to be statistically older than solar-O stars, but not for Fe

Population of young, high [O/Fe] stars from large radii



Observational References: Feuillet et al. (2018, 2019); Silva Aguirre et al. (2018); Martig et al. (2016)

Variability in the SN Ia Rate

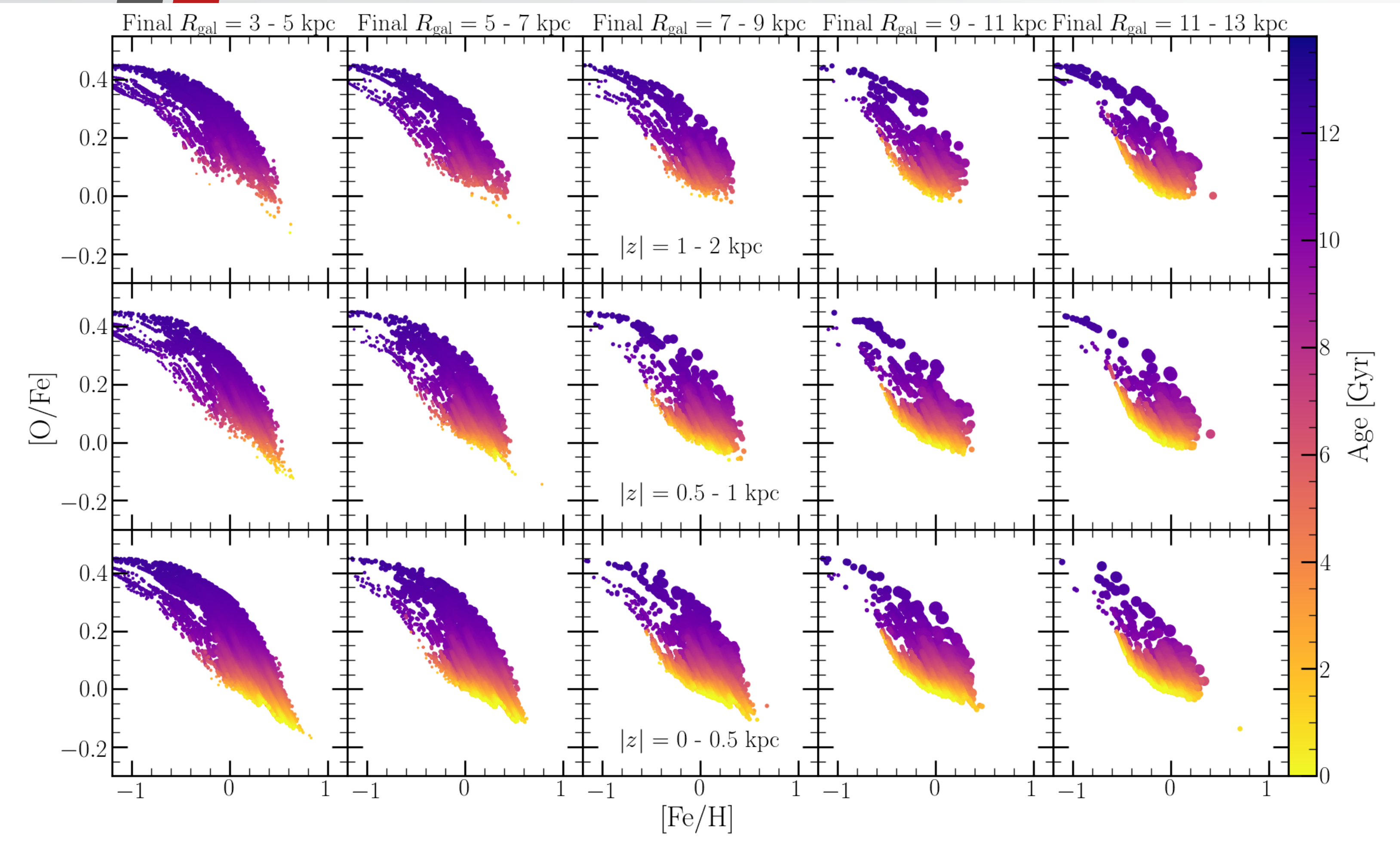


A star migrating one way is not necessarily balanced by another moving the other way *when weighted by their SN Ia rates*

At large radii: SN Ia rate considerably lower than expected given the star formation history for large portions of simulation

Population of stars that aren't alpha-enhanced but iron-poor

[α/Fe] vs. [Fe/H]



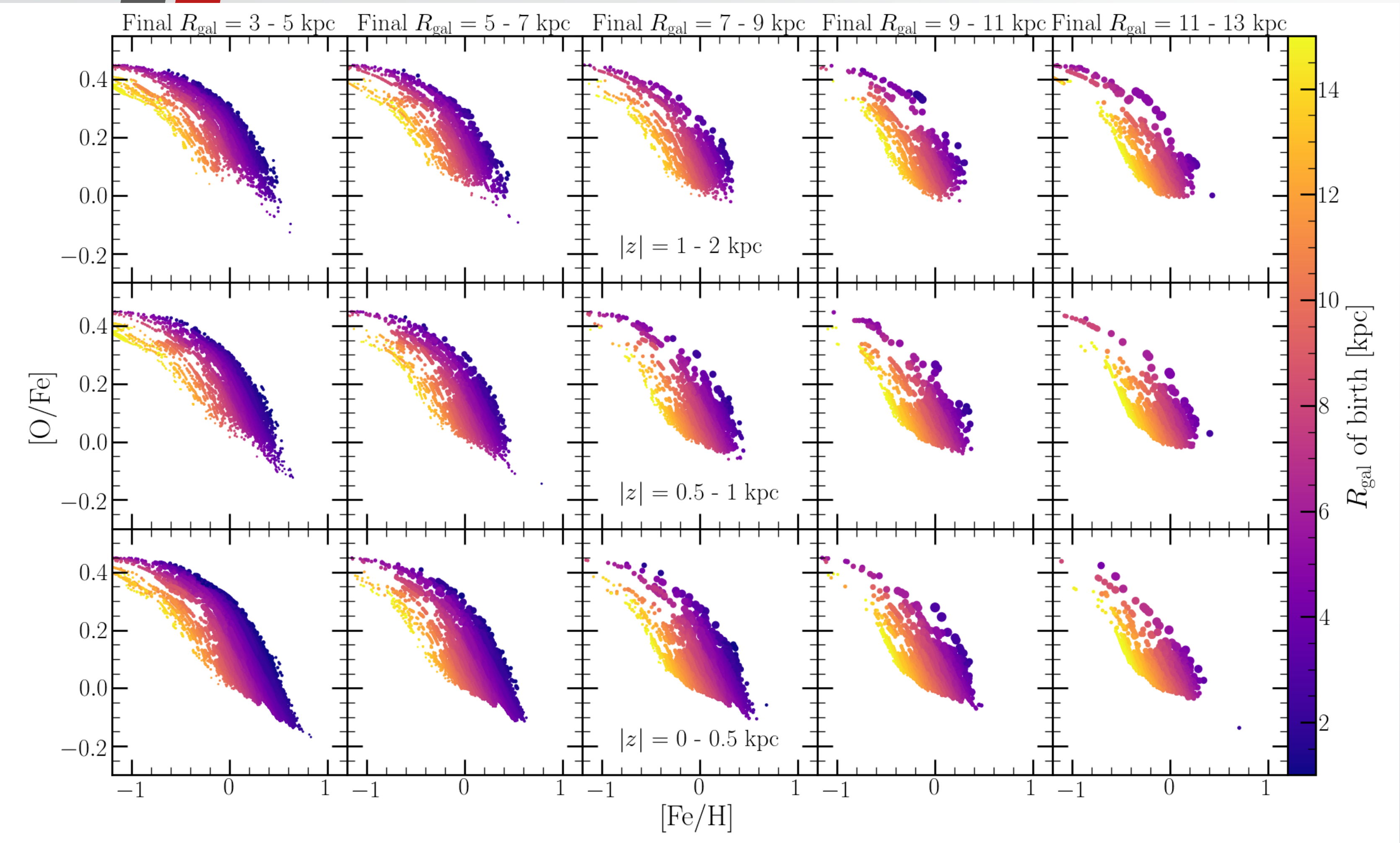
Evolution of low-alpha sequence with radius well reproduced

Too many low-alpha stars at high |z|

Youngest stars form at lower left envelope of distribution

Observational Reference: Hayden et al. (2015)

[α/Fe] vs. [Fe/H]



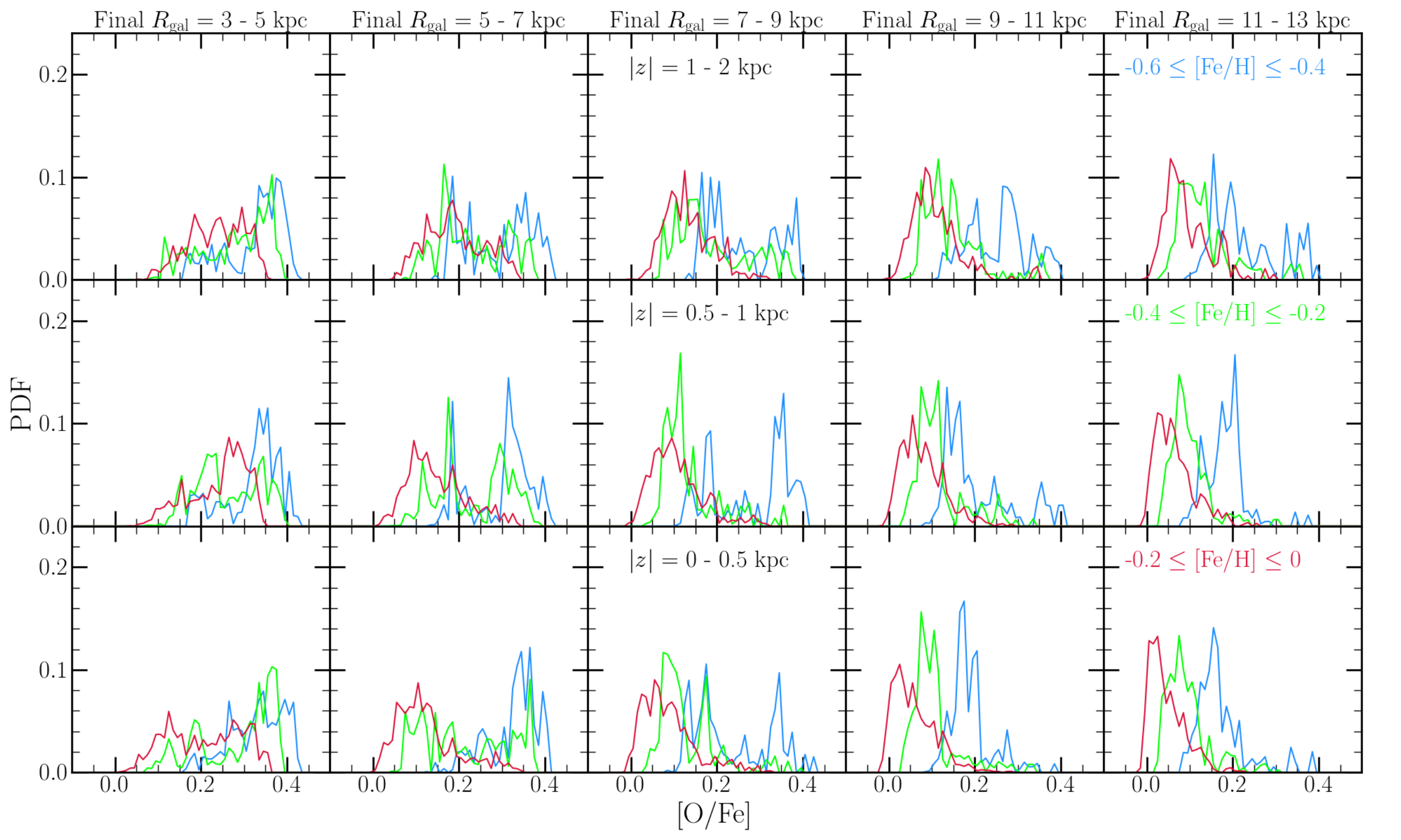
Evolution of low-alpha sequence with radius well reproduced

Too many low-alpha stars at high |z|

Width of low-alpha sequence arises from migration

Observational Reference: Hayden et al. (2015)

[O/Fe] Distributions at Constant [Fe/H]



Shift to low [O/Fe] with increasing radius as they should

Two populations most apparent between 5 and 9 kpc

Not exactly like Milky Way, but a bimodality nonetheless

Observational Reference: Hayden et al. (2015)

Conclusions

- Radial migration can produce an old, high [O/H] population of stars in solar neighborhood – interestingly not seen for [Fe/H]
- Young, iron-poor stars arise due to the impact of radial migration on the SN Ia rate at different radii
- A bimodality in [O/Fe] at constant [Fe/H] can arise from migration
  - Could however be shaped by merger events, starbursts, etc.
  - Number of low-alpha stars at high $|z|$ overpredicted
- VICE is publicly available and open-source!