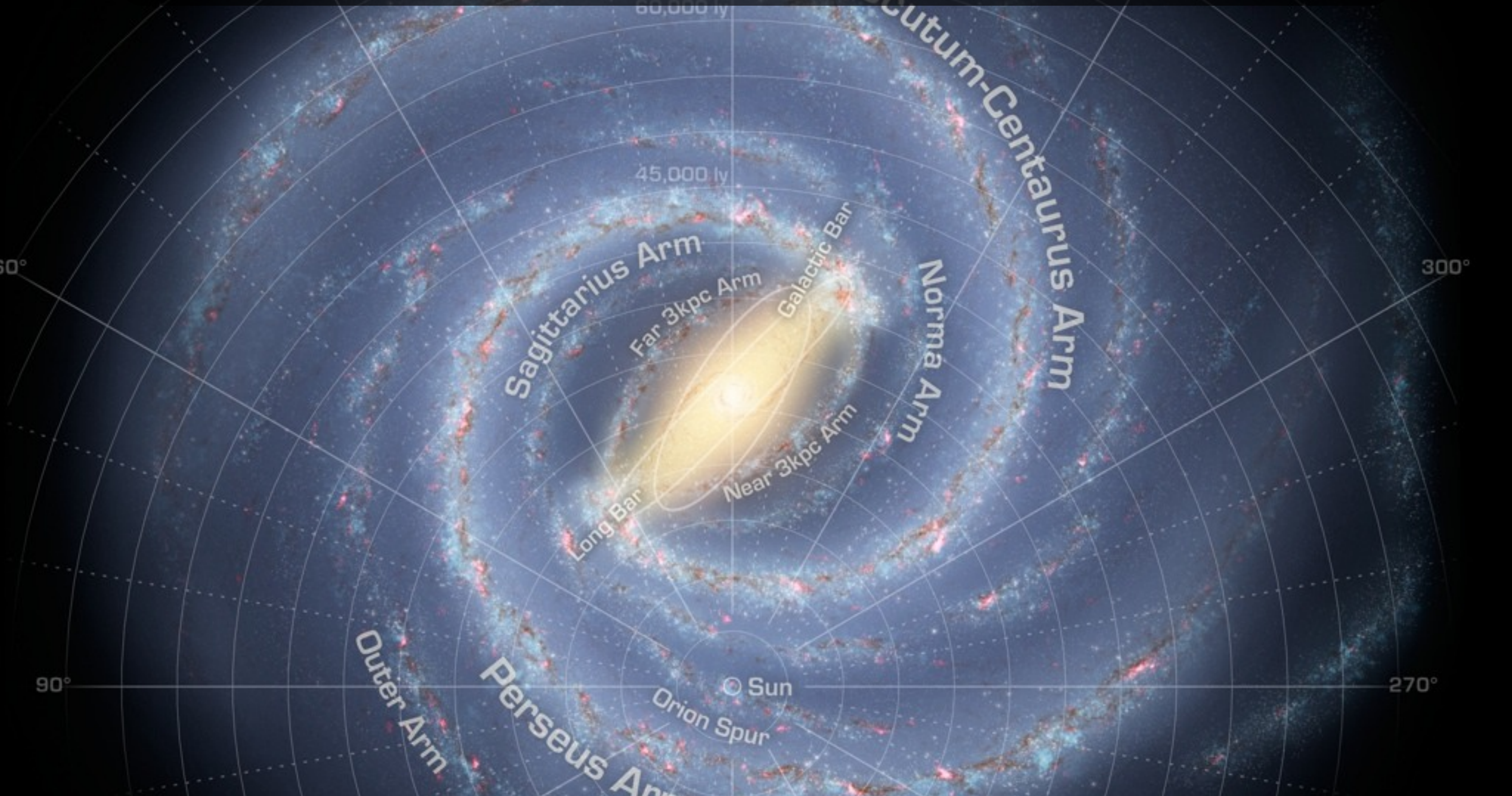
Galactic Chemical Evolution



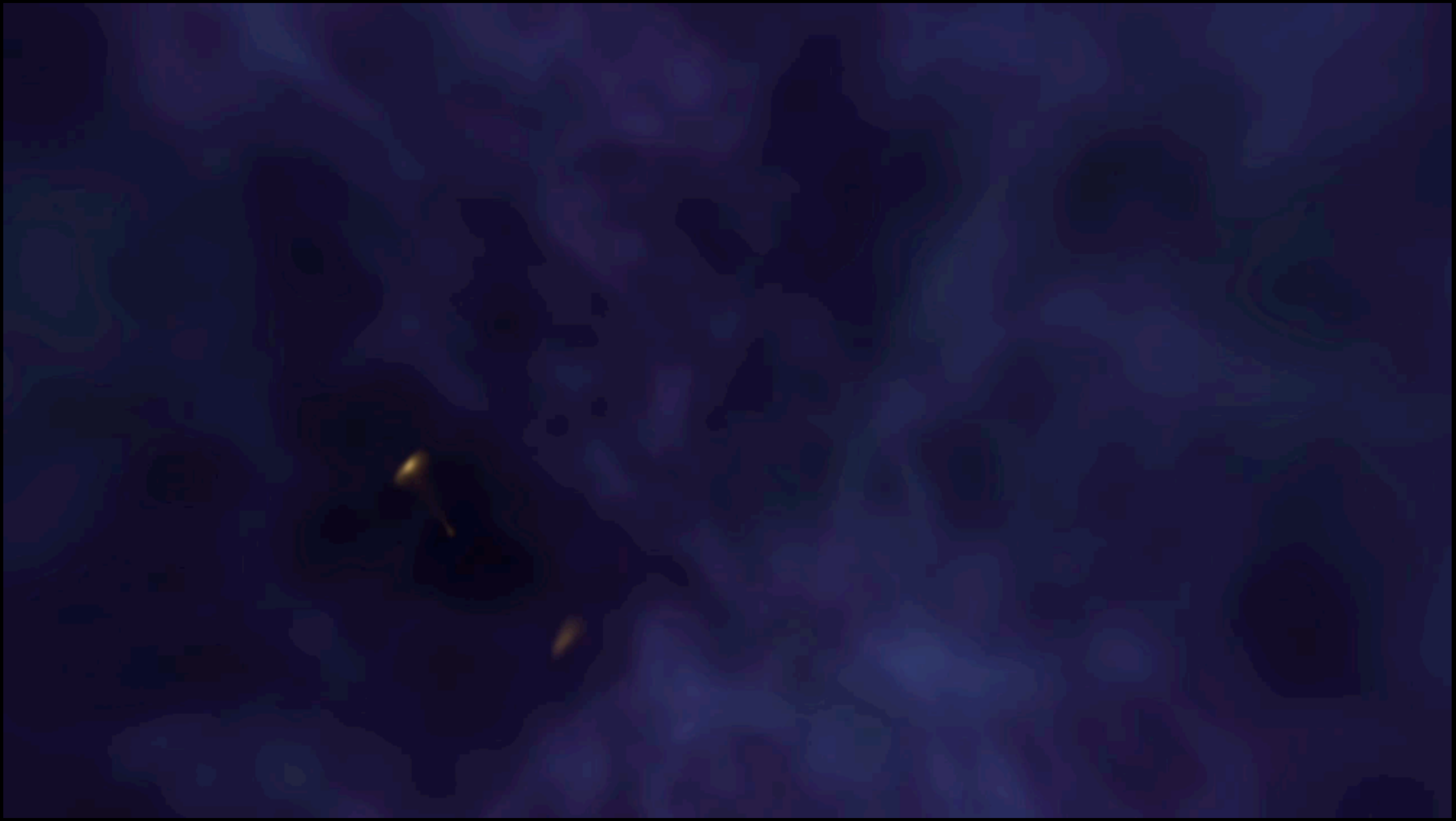
Brian O'Shea
Michigan State University

What kinds of questions do we want to address?

- Does the mass distribution of stellar populations change over time?
- What can we learn about the progenitor galaxies of the Milky Way (and the Milky Way's star formation history)?
- What is the site (or sites) of the r-process?
- What limits can we place on the Type Ia supernova rate?

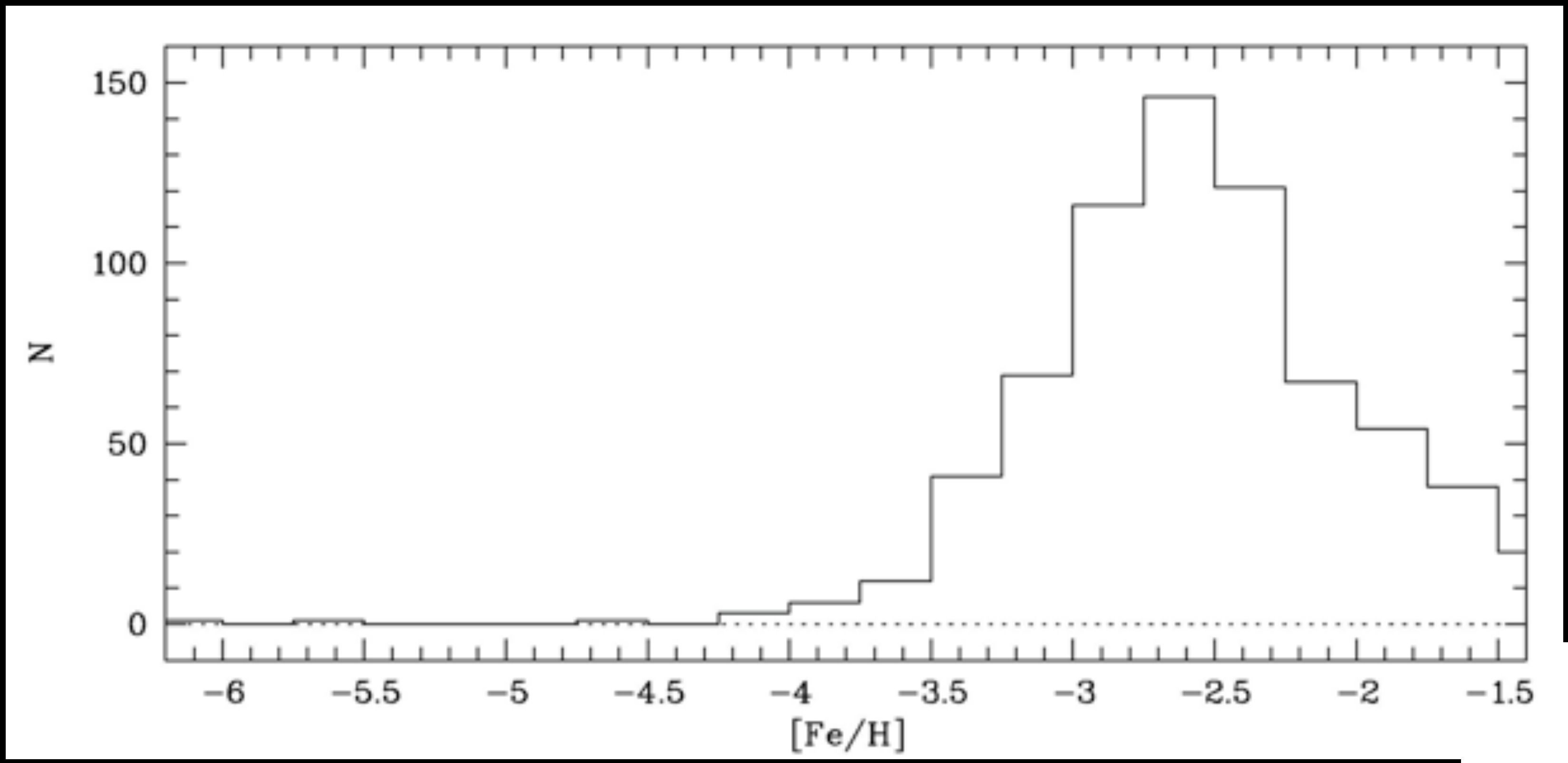
All done in the context of hierarchical structure formation!

Building galaxies, one piece at a time



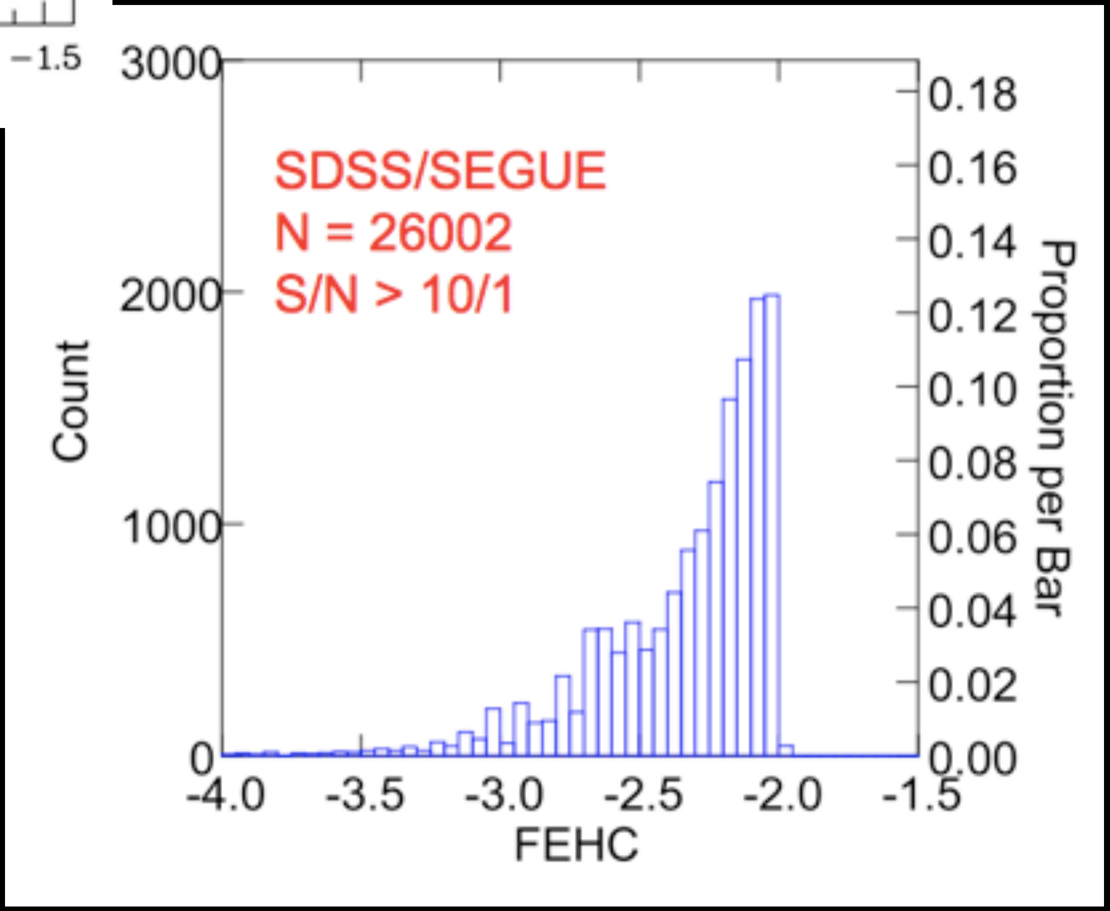
Observations

Focus on metal-poor stars

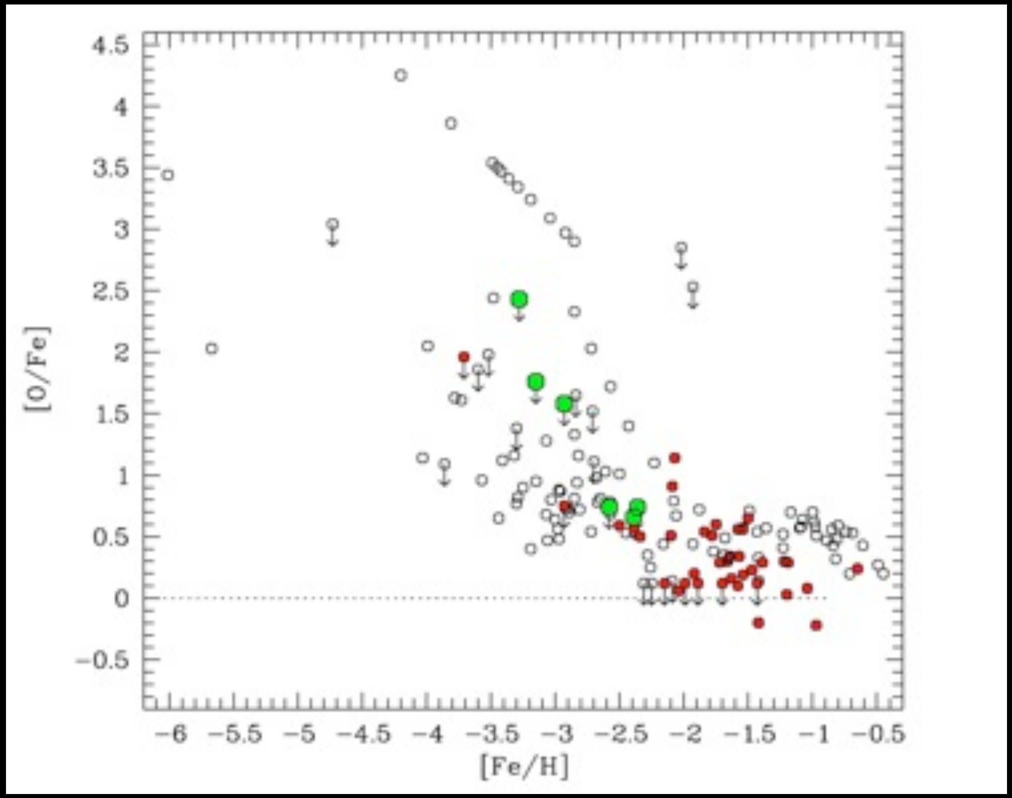


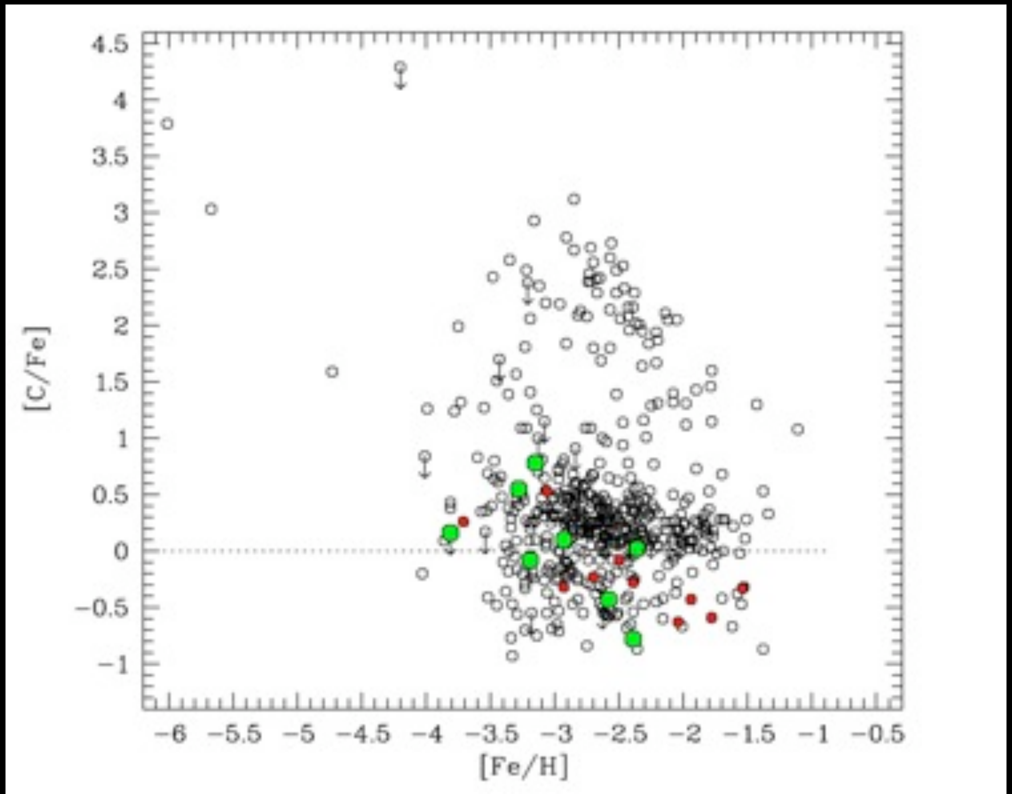
Below: subsample of SDSS/SEGUE (c/o Tim Beers) N ~ 26K

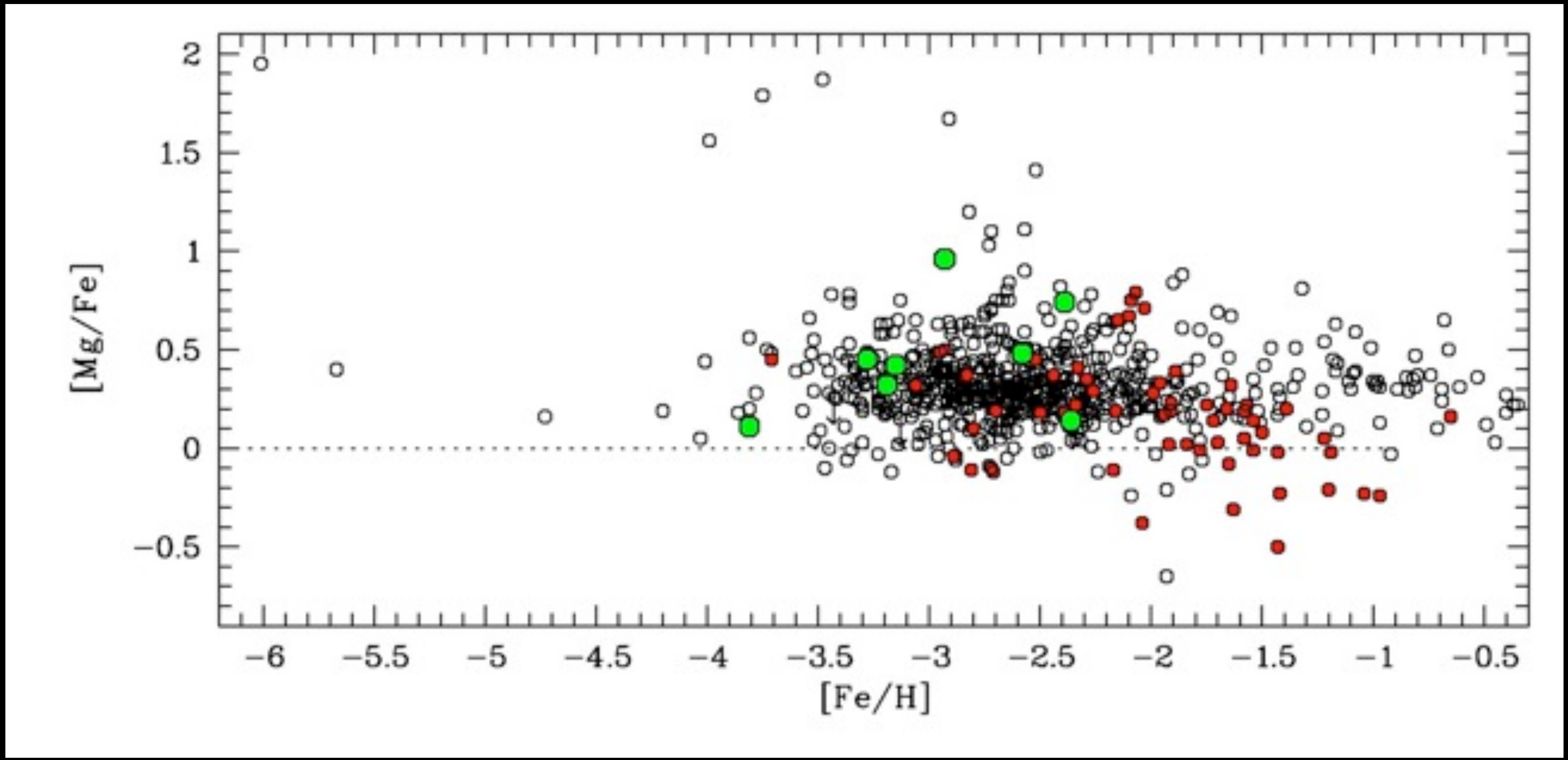
Above: Frebel et al. high-resolution sample (N~1000)



Observations: Light elements







Plots from Frebel (2009)

Observations: Light elements

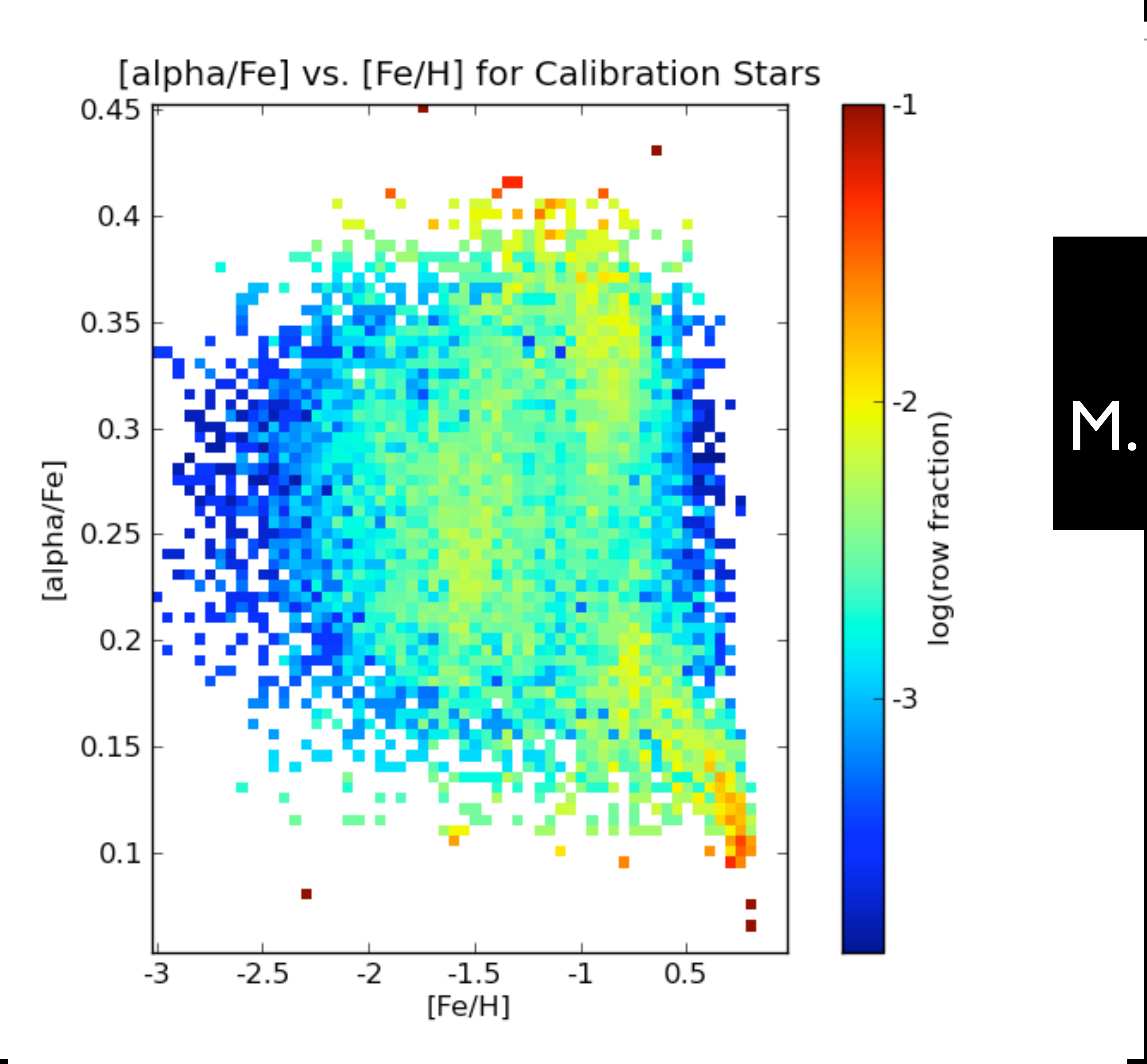
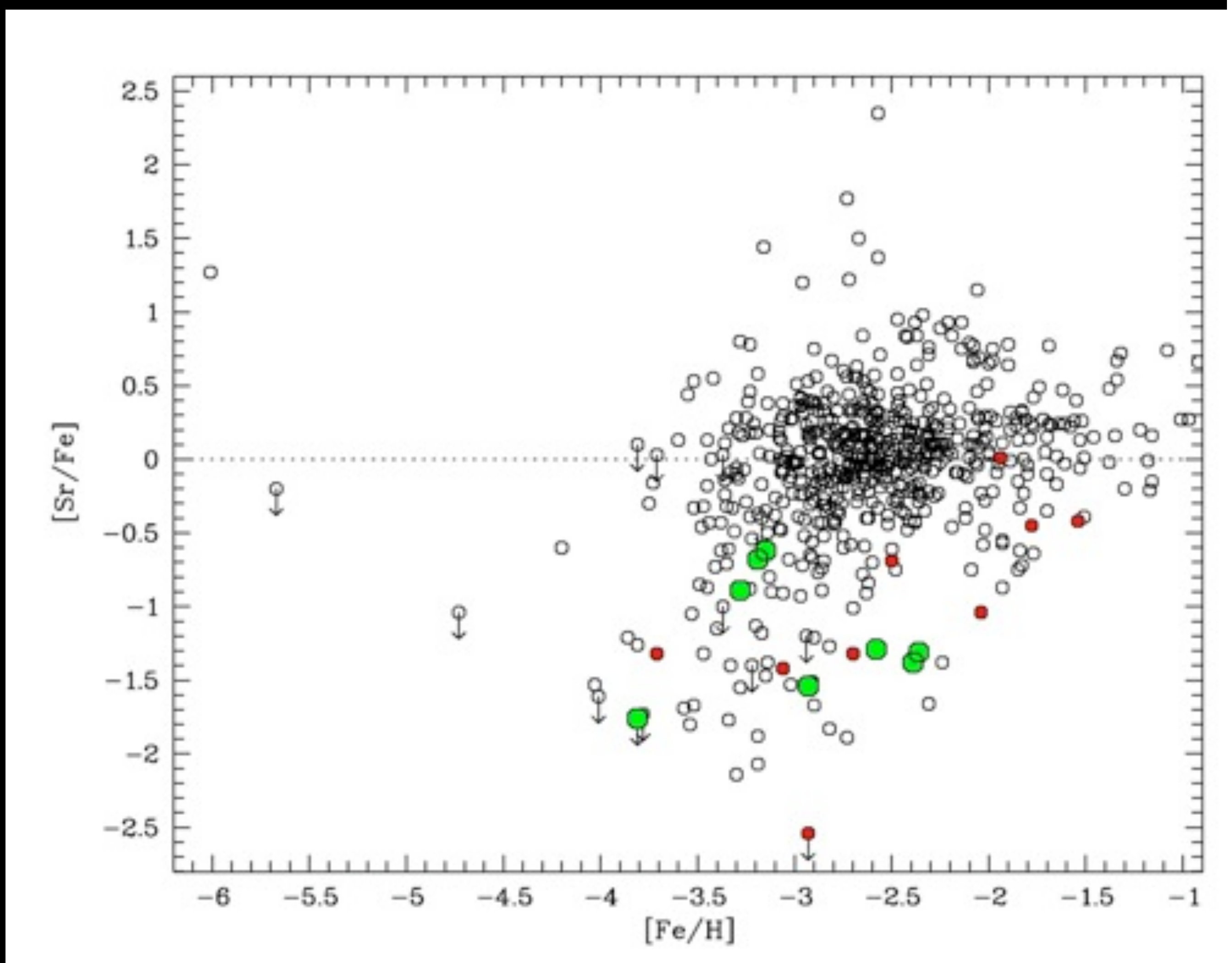
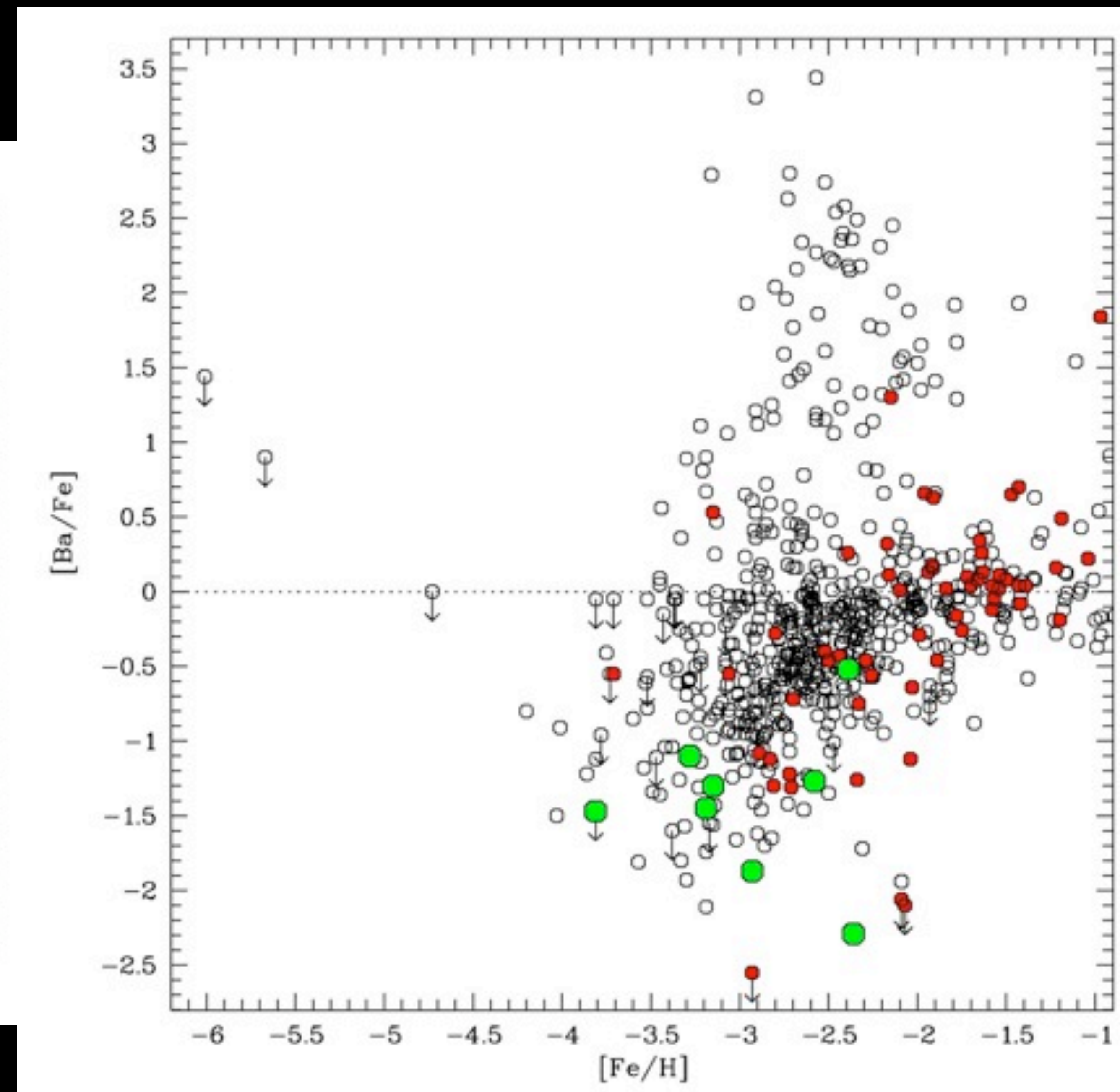


Figure c/o
M. Derris (MSU)

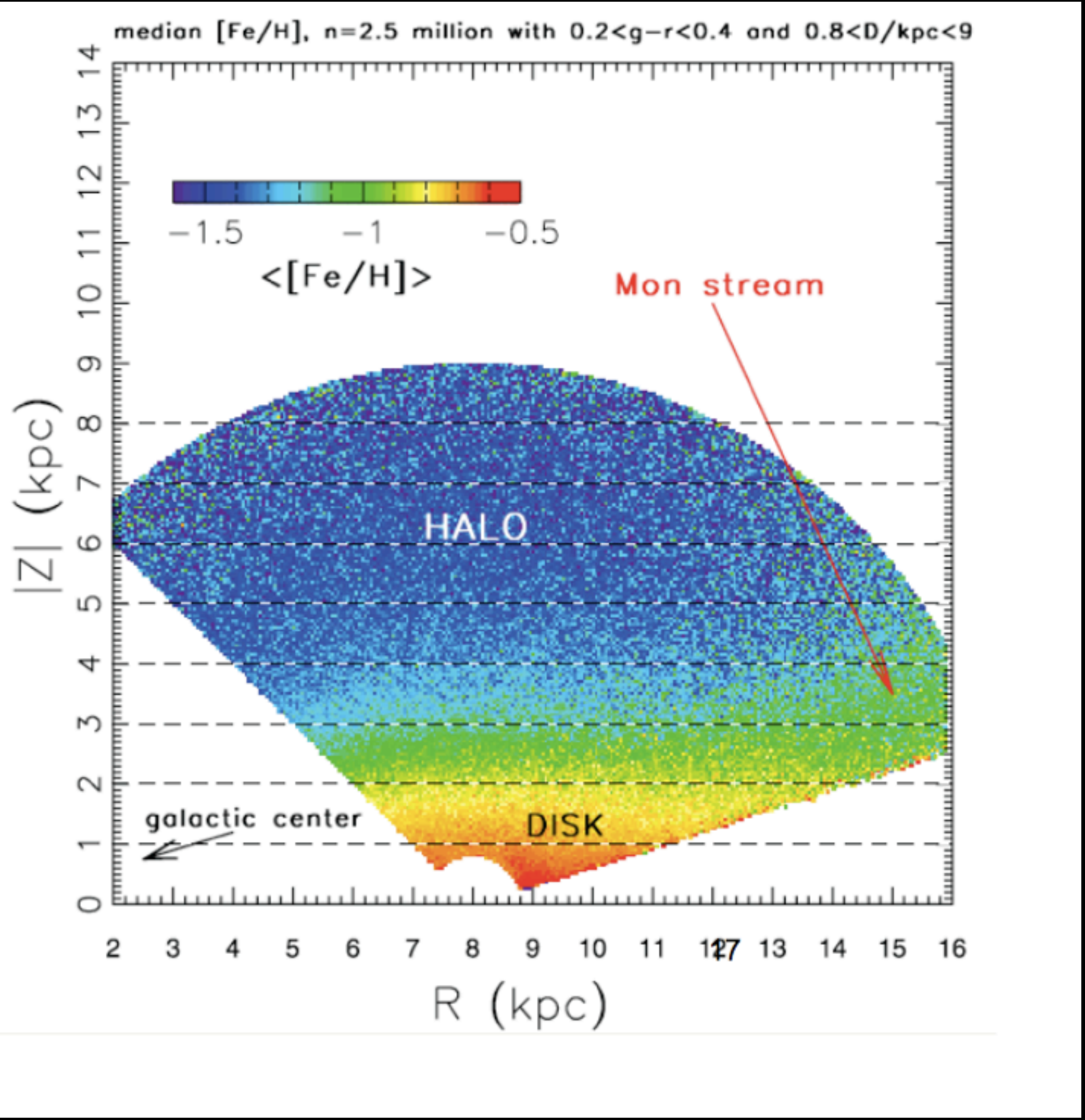
Plots from
Frebel (2009)

Observations: Heavy elements

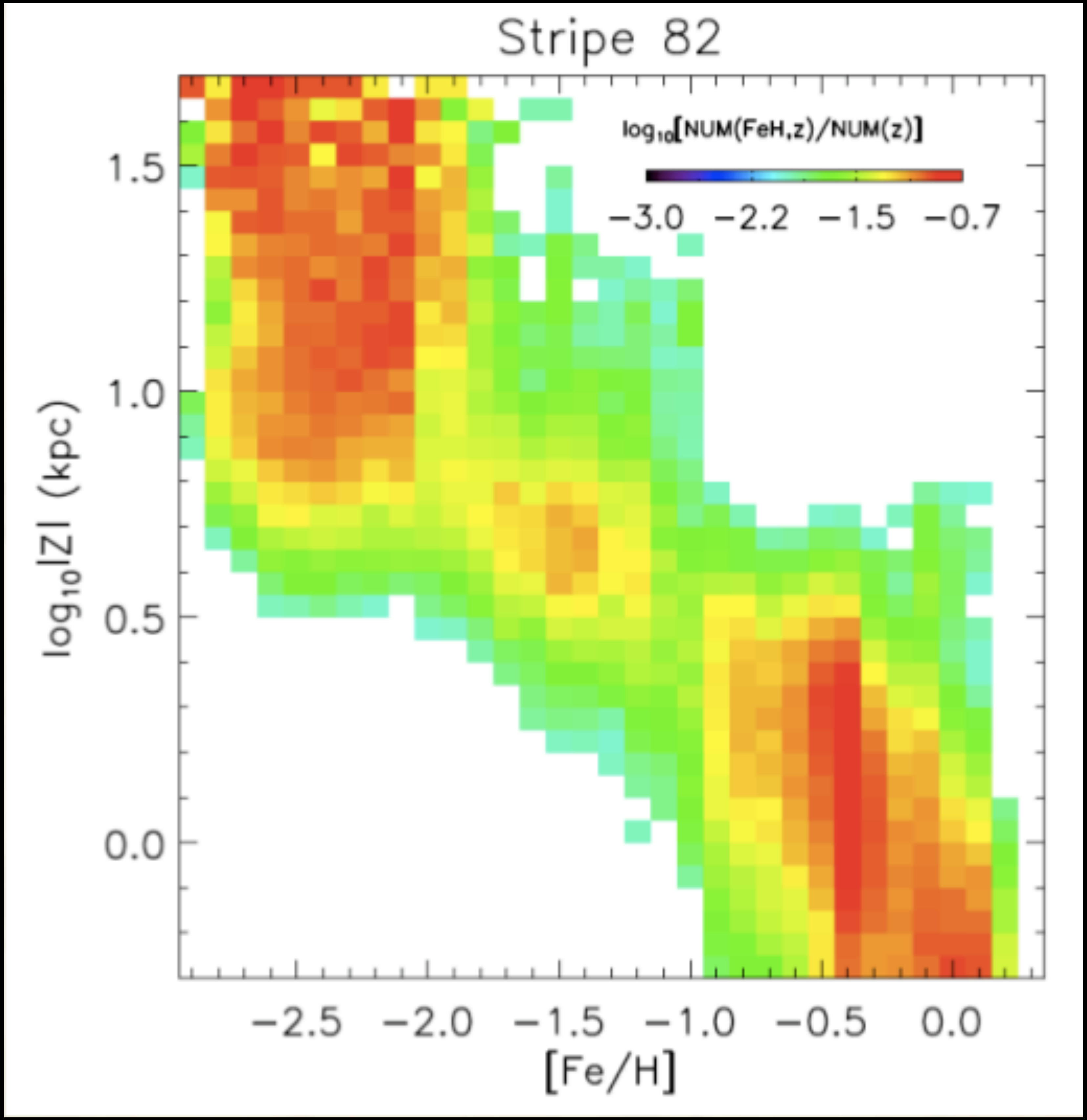




Plots from Frebel (2009)

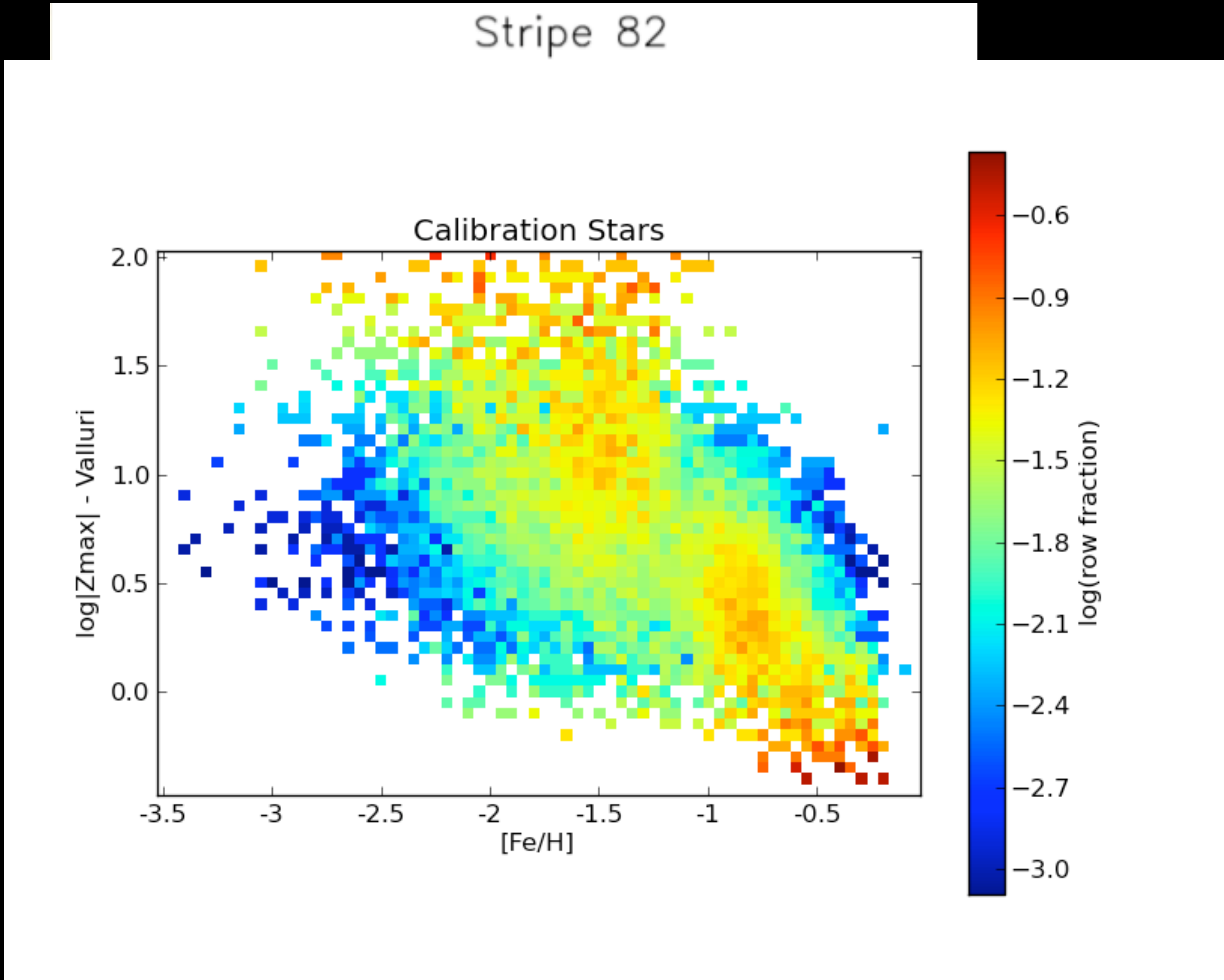


Ivezic et al. 2008



ugriz photometry, SDSS Stripe 82

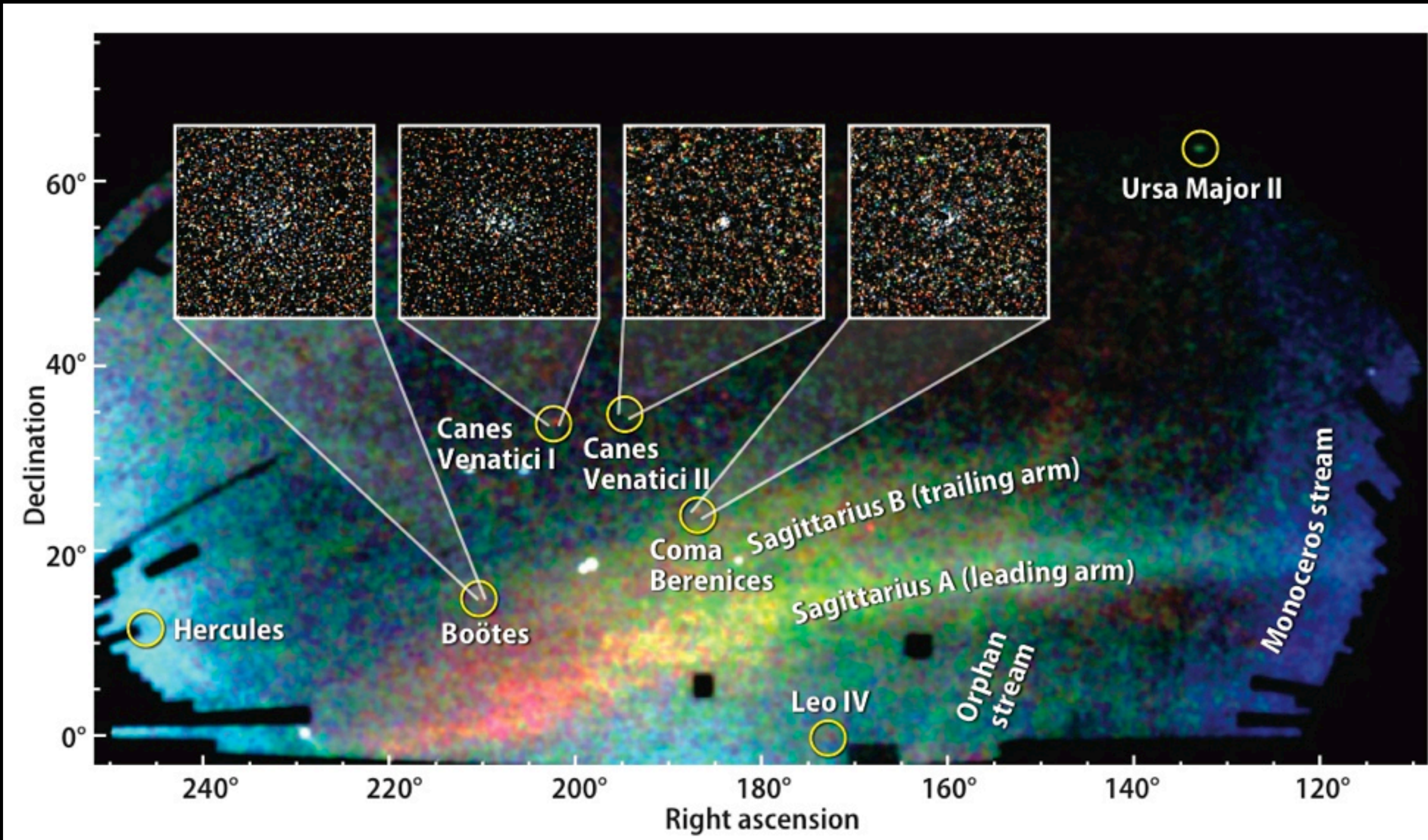
(also seen in dynamical evolution of stars: see talk by Monica Derris)



otometry,
Stripe 82

seen in
l evolution
of stars: see talk by
Monica Derris)

image c/o Vasily Belokurov, SDSS-IICollaboration



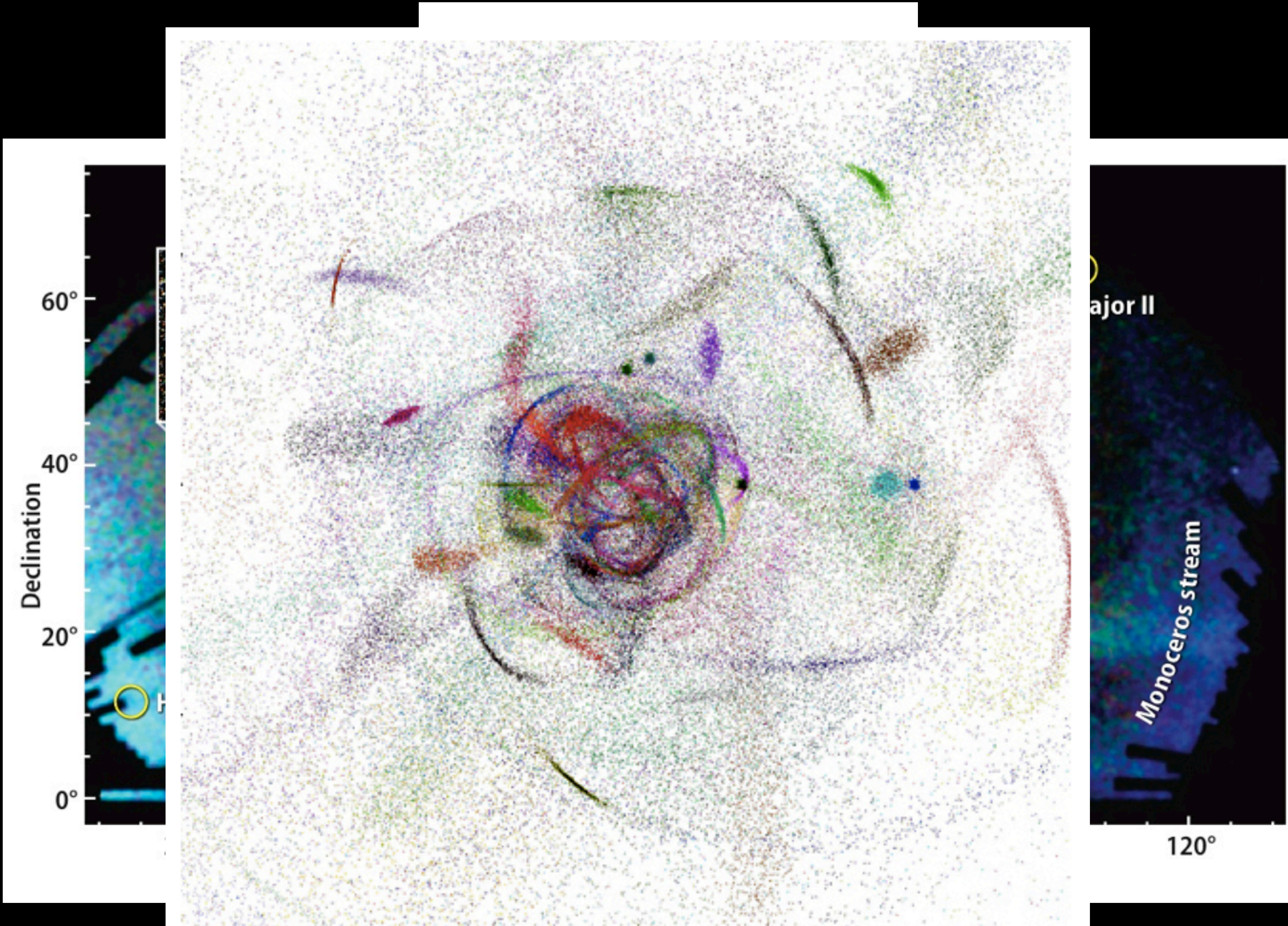


Image c/o Paul Harding, CWRU

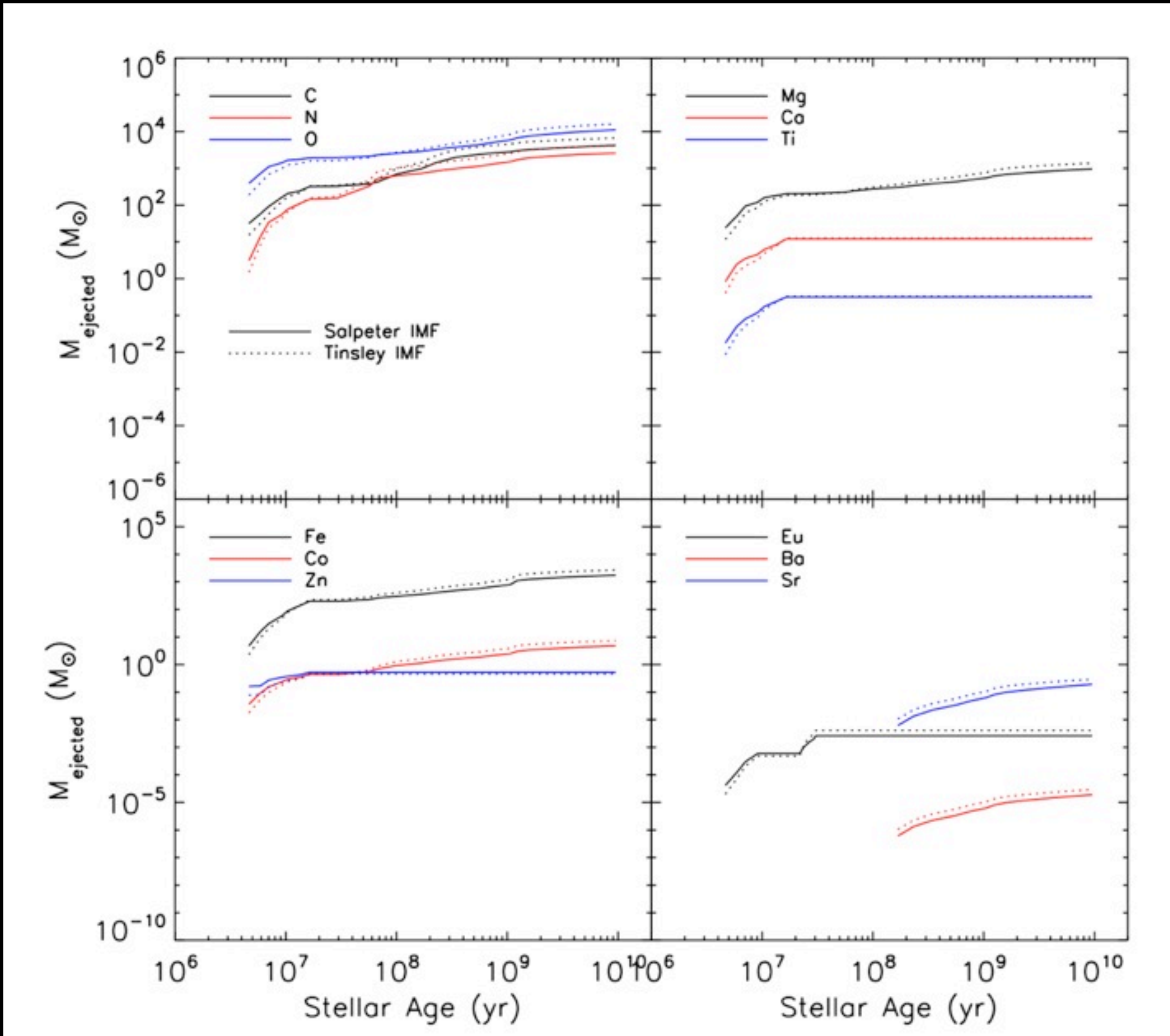
Current/near future stellar surveys

- SDSS+SEGUE-I and II: optical photometry of 200M+ stars, spectroscopy of ~500K (+ proper motions of ~10M) (already done)
- SDSS+APOGEE: near-IR spectroscopy of ~100K stars in bulge,halo, disk (get ~12 species) (2011-14)
- LAMOST: like SEGUE, but 5M stars (~2011-14)
- SkyMapper: photometry of entire southern sky (~5e9 stars) (~2014)
- GAIA: astrometry, low-res spectroscopy of ~1e9 stars (launch 2011-12, data 2013-16)
- LSST: 20K square degrees to m > 27 (billions...) (~2018+)

What are the basic ingredients for GCE models?

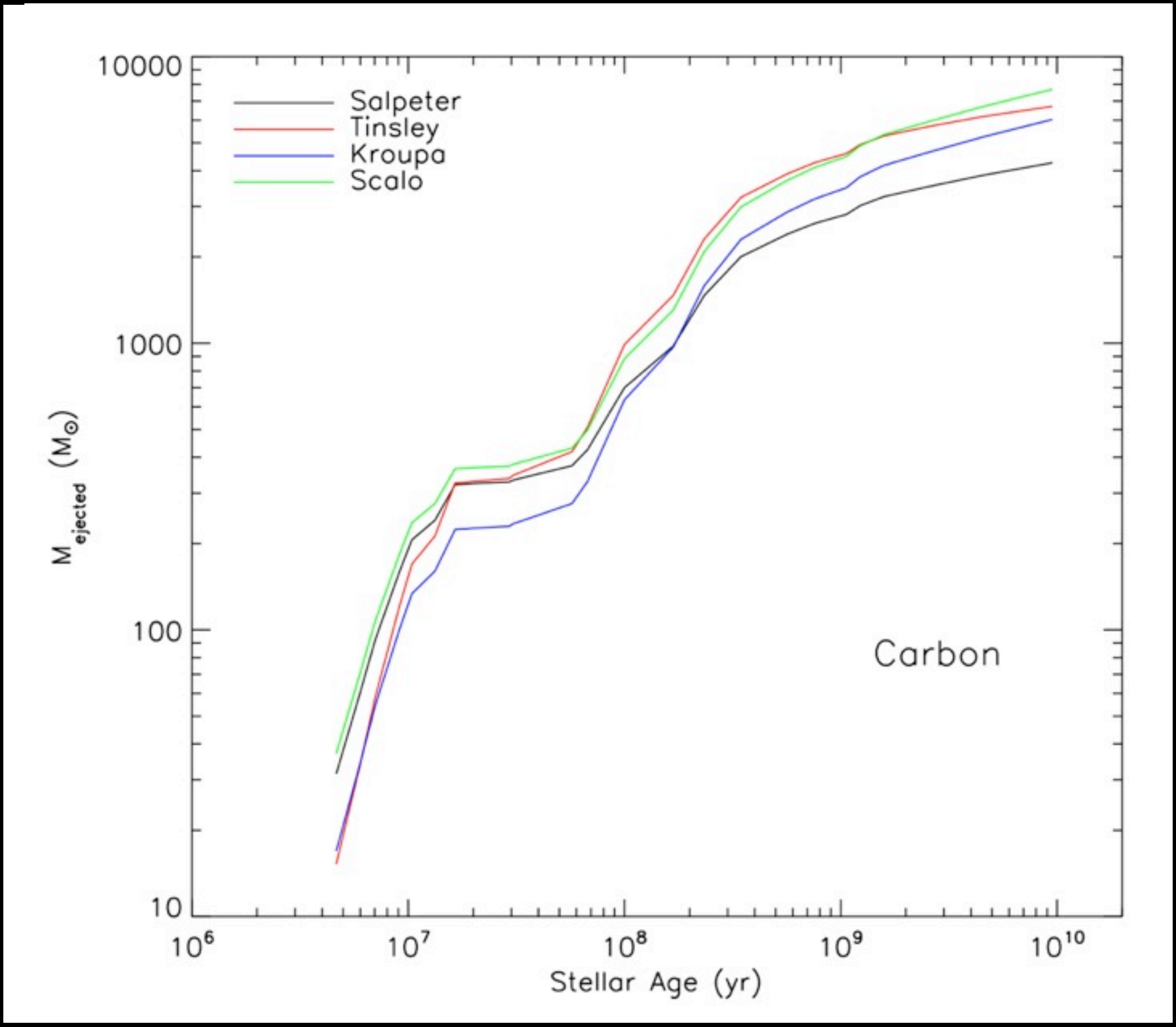
- Gas reservoir(s)
- Mass function for forming stars (IMF; may vary with time)
- Nucleosynthetic outputs from stars (Type Ia, Type II, AGB, stellar winds, ...)
- Assumptions about how gas is exchanged between stars and gas

Nucleosynthetic outputs: one example



Model created by Carolyn Peruta - see her talk later this morning

Nucleosynthetic outputs: one example



Model created by Carolyn Peruta - see her talk later this morning

What kinds of GCE models are currently used?

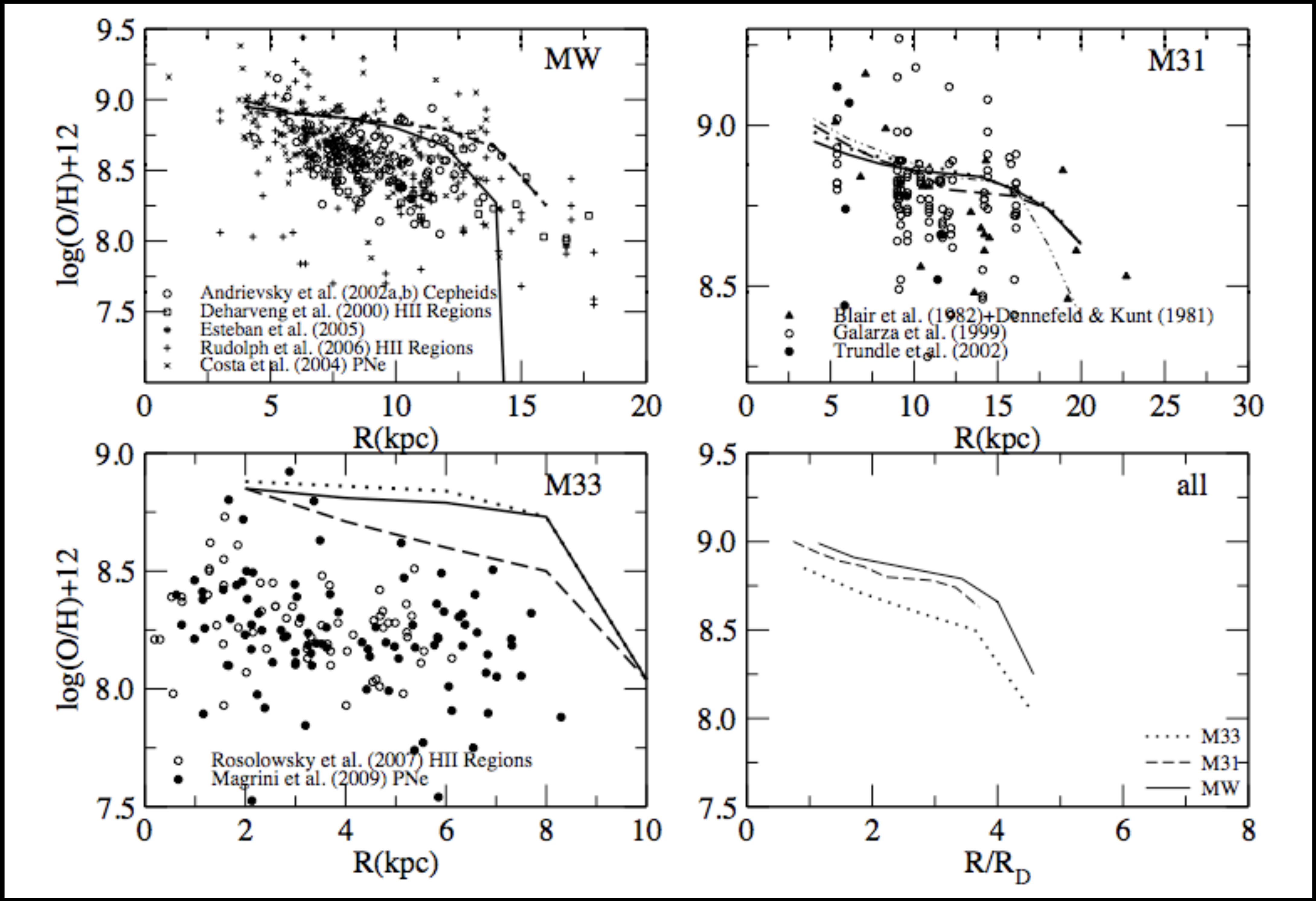
Analytic models

- One to few zones; study mass budgets in gas, stars, various elements
- Simple set of PDEs with yields as inputs (inflow/ outflow from reservoir as needed)
- Pros: simple math, parameterizations; easy to understand results; good for 'bulk' chemical evolution (Type Ia/II or r/s balance on galaxy scales)
- Cons: poor 'spatial resolution', not easy to include hierarchical galaxy formation, not really stochastic

1960s-present

Example: chemical evolution of spiral disks

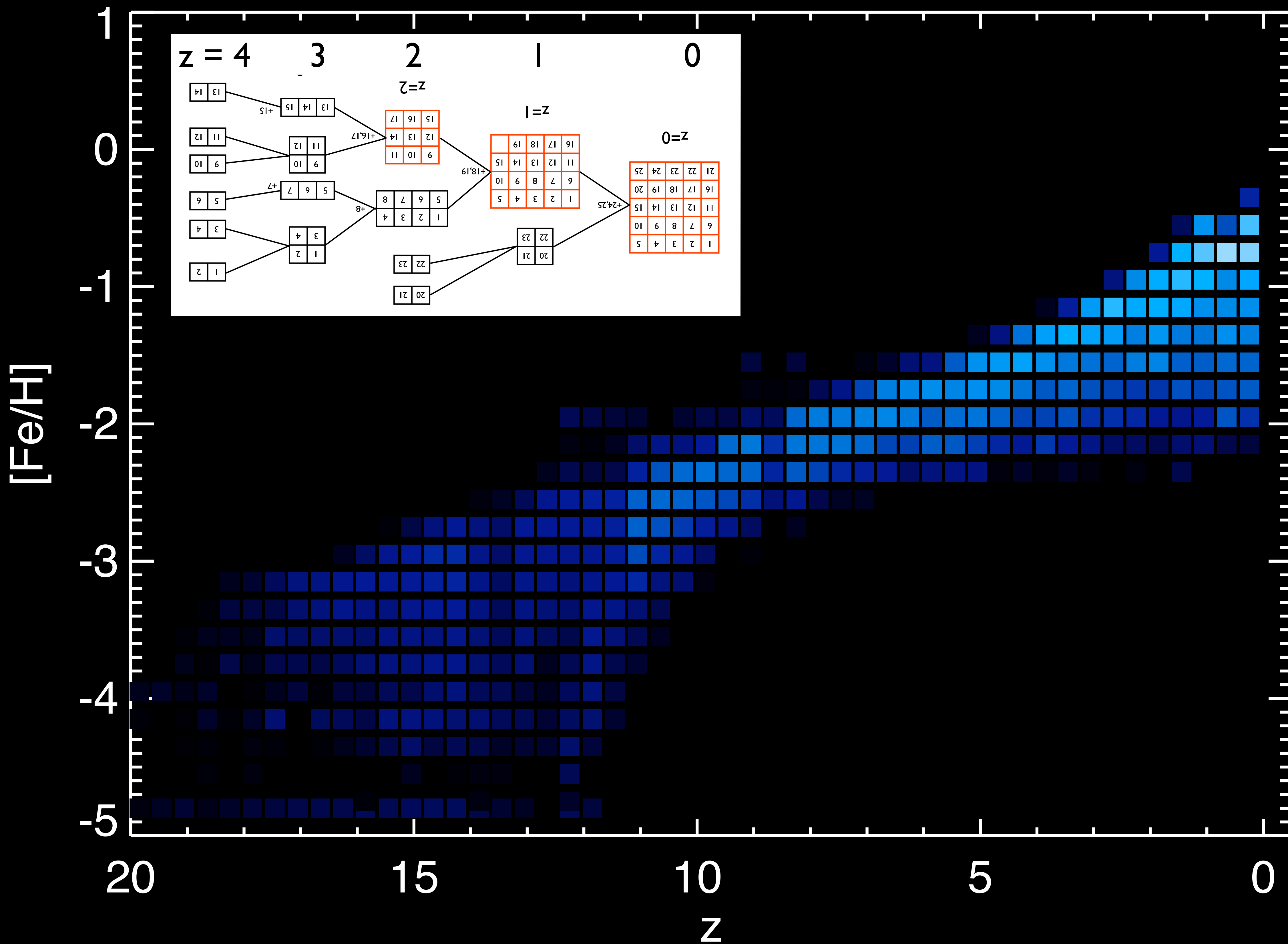
Macon-Uchida et al. 2010, A&A, 520, 35



Semi-analytic models

- Take into account hierarchical structure formation via EPS formalism or N-body simulations, "painting" GCE on top of merger tree
- Pros: simple math, parameterizations; incorporates structure formation; relatively cheap to run (can do parameter studies)
- Cons: poor resolution, gas dynamics not explicitly included (causing proliferation of parameters)

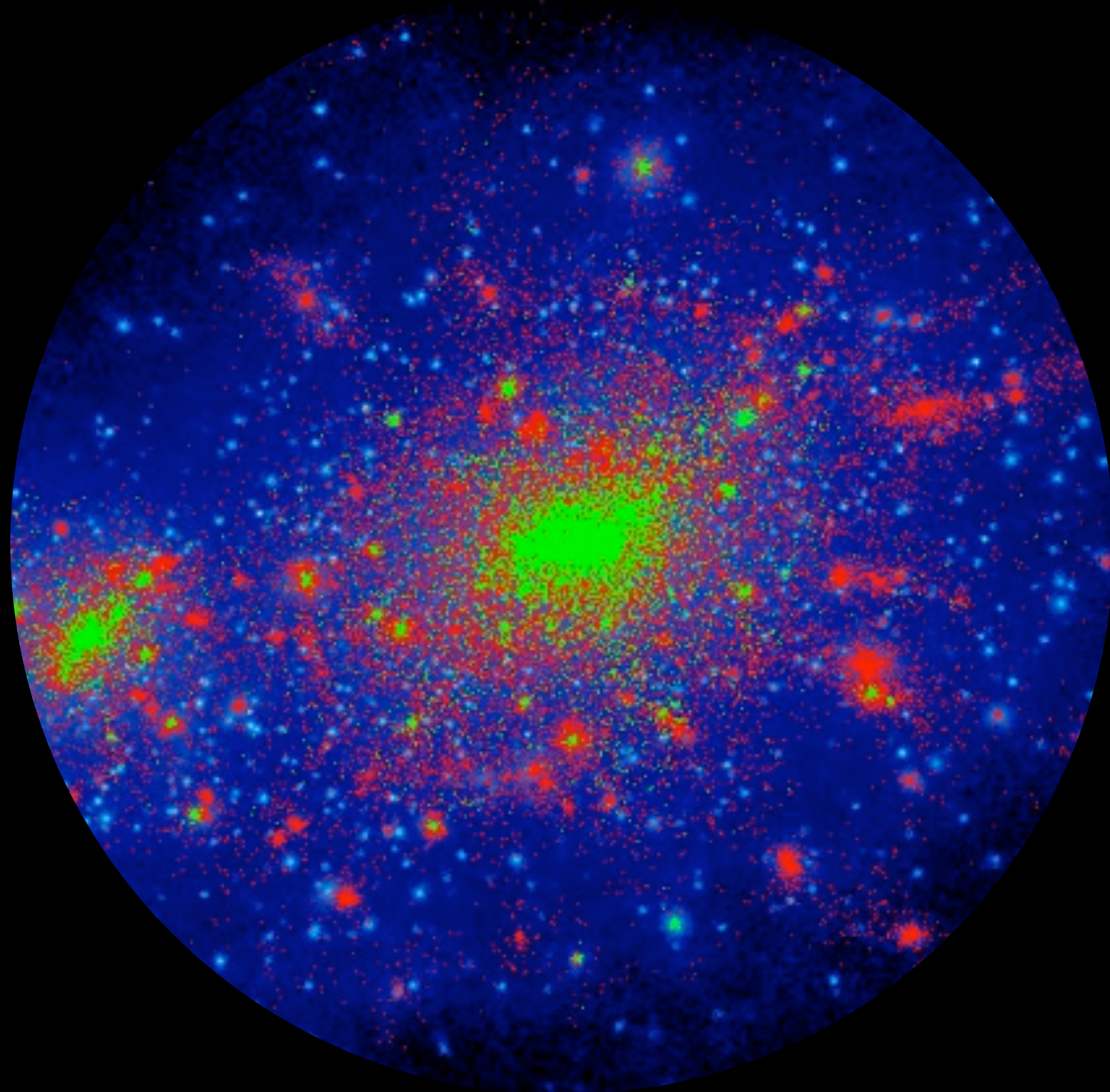
Early 2000s-present



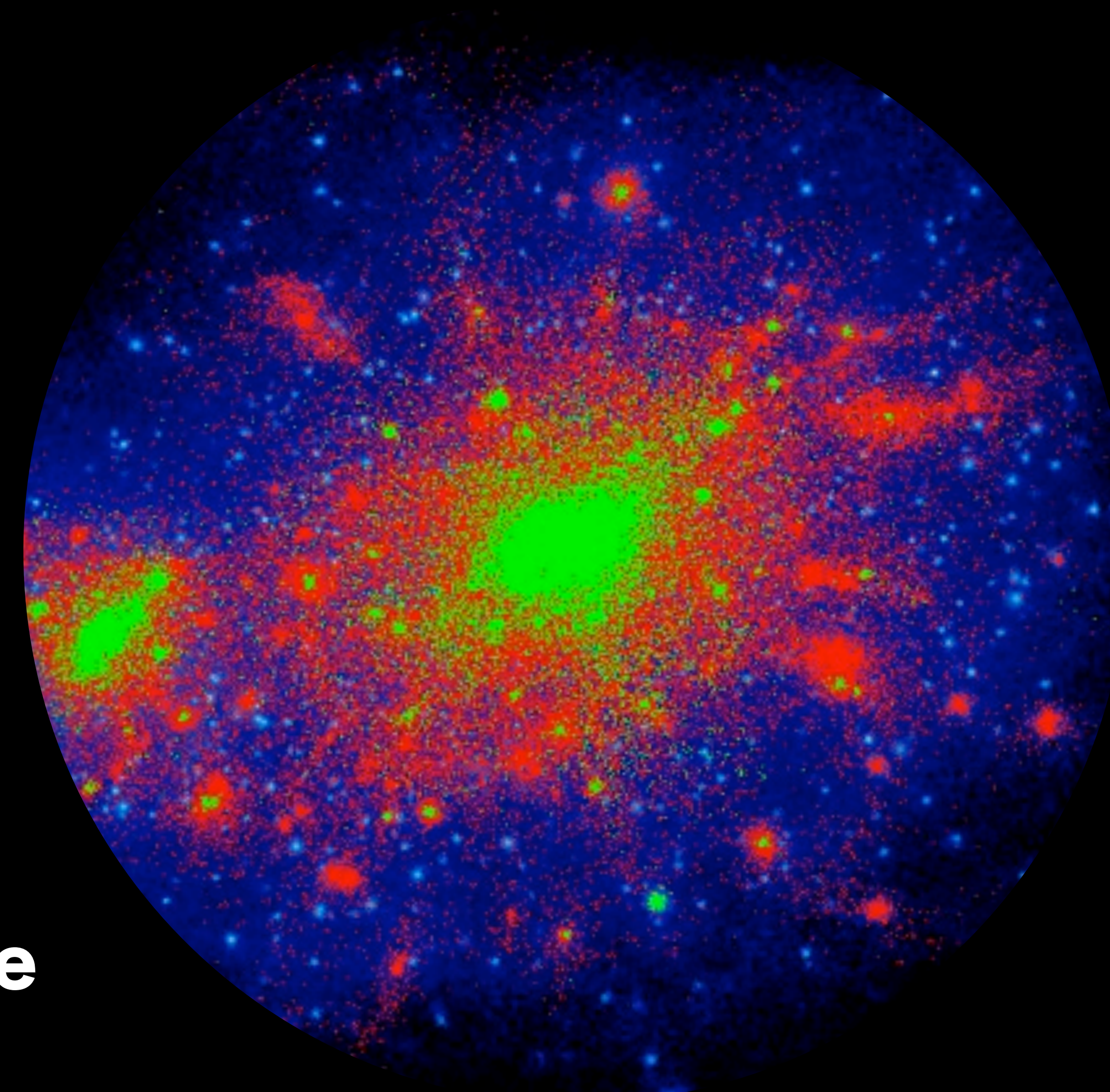
Tumlinson 2010, ApJ, 708, 1398

stars formed z > 10

stars formed at all z



[Fe/H] < -3.5

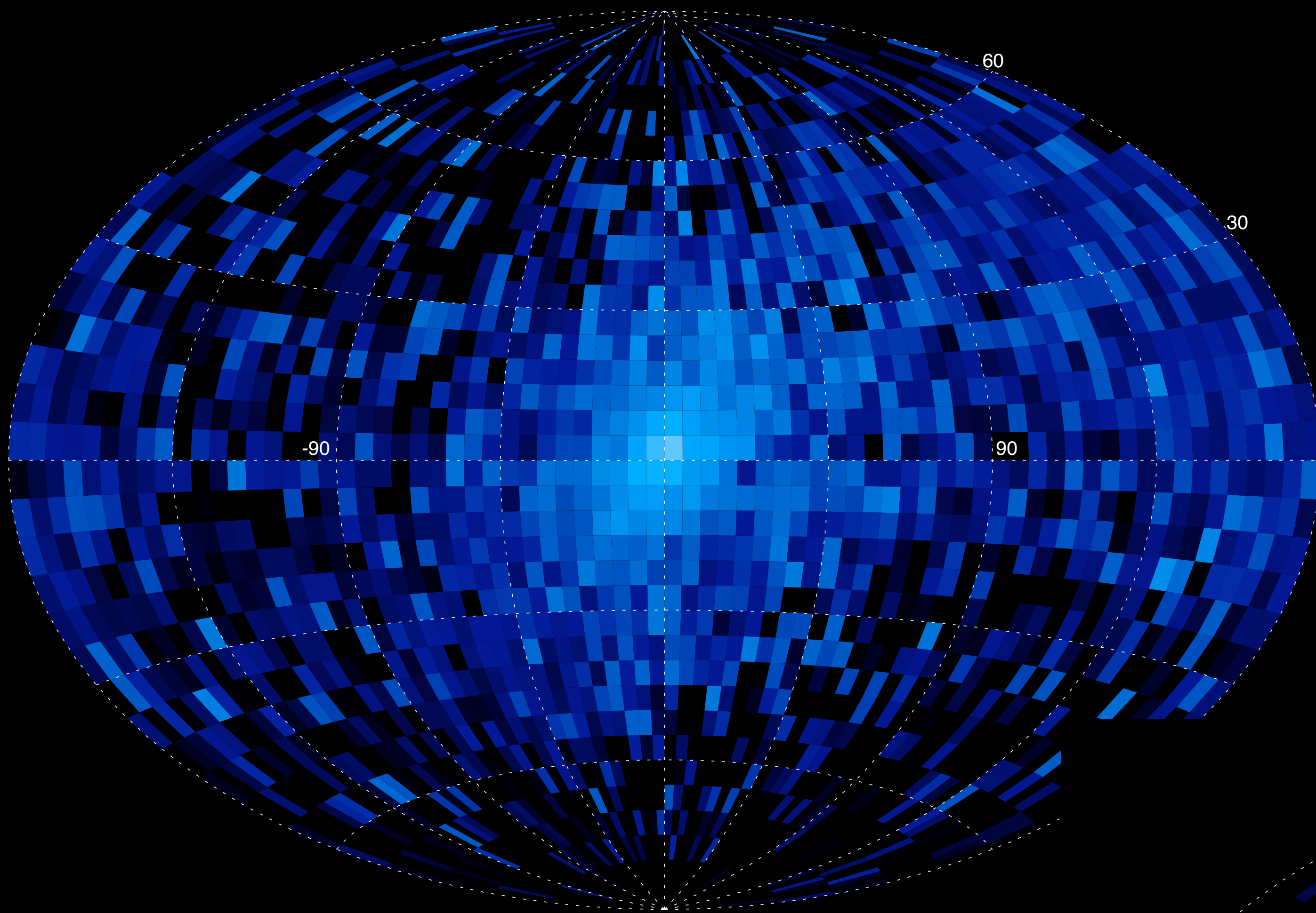


[Fe/H] < -2.0

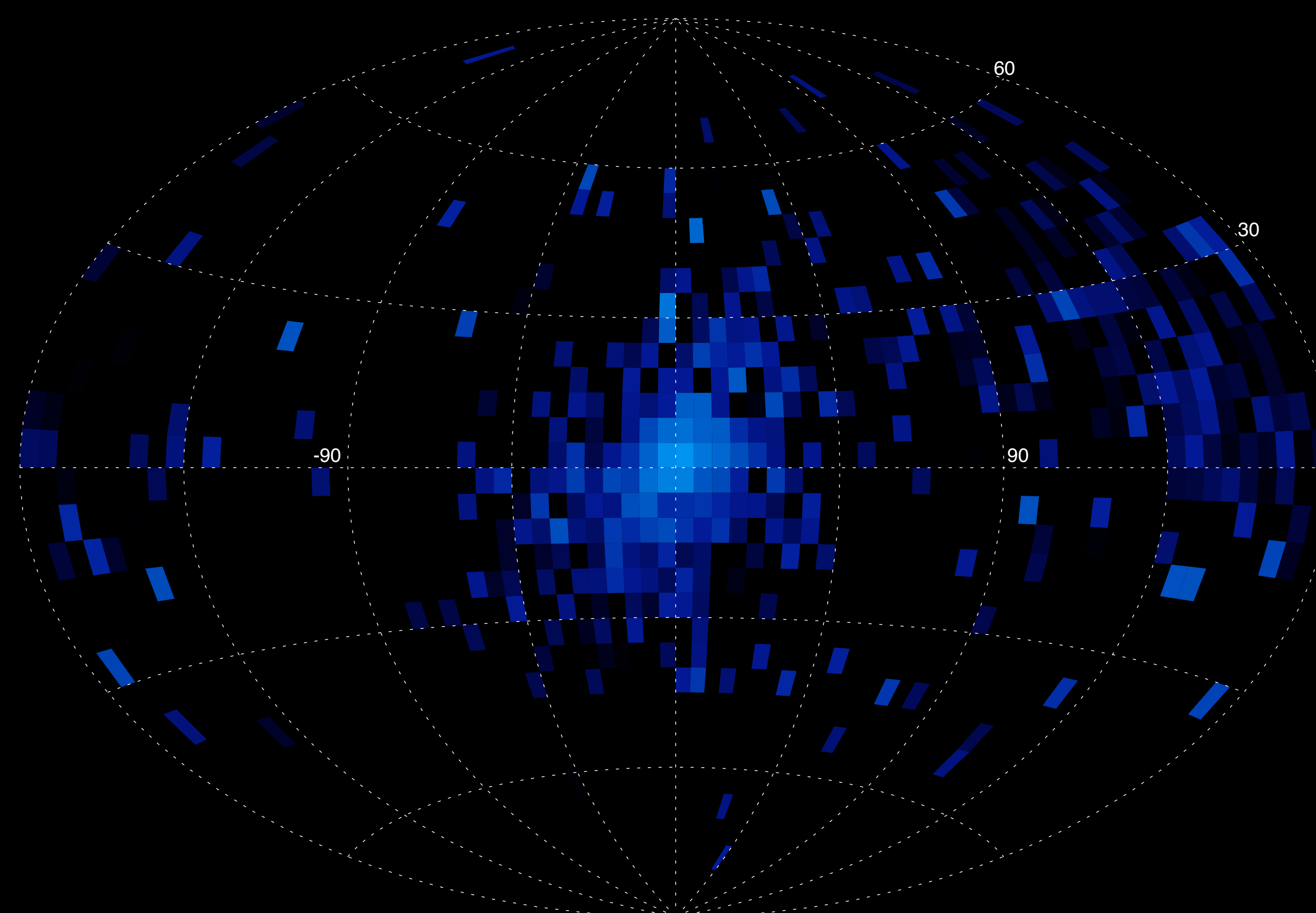
Chronologically older stars are more centrally concentrated.

Tumlinson 2010, ApJ, 708, 1398

All Stars with [Fe/H] < -3



All Stars with [Fe/H] < -3
from z > 15



The most ancient stars are “in the bulge” but not “of the bulge”.

Tumlinson 2010, ApJ, 708, 1398

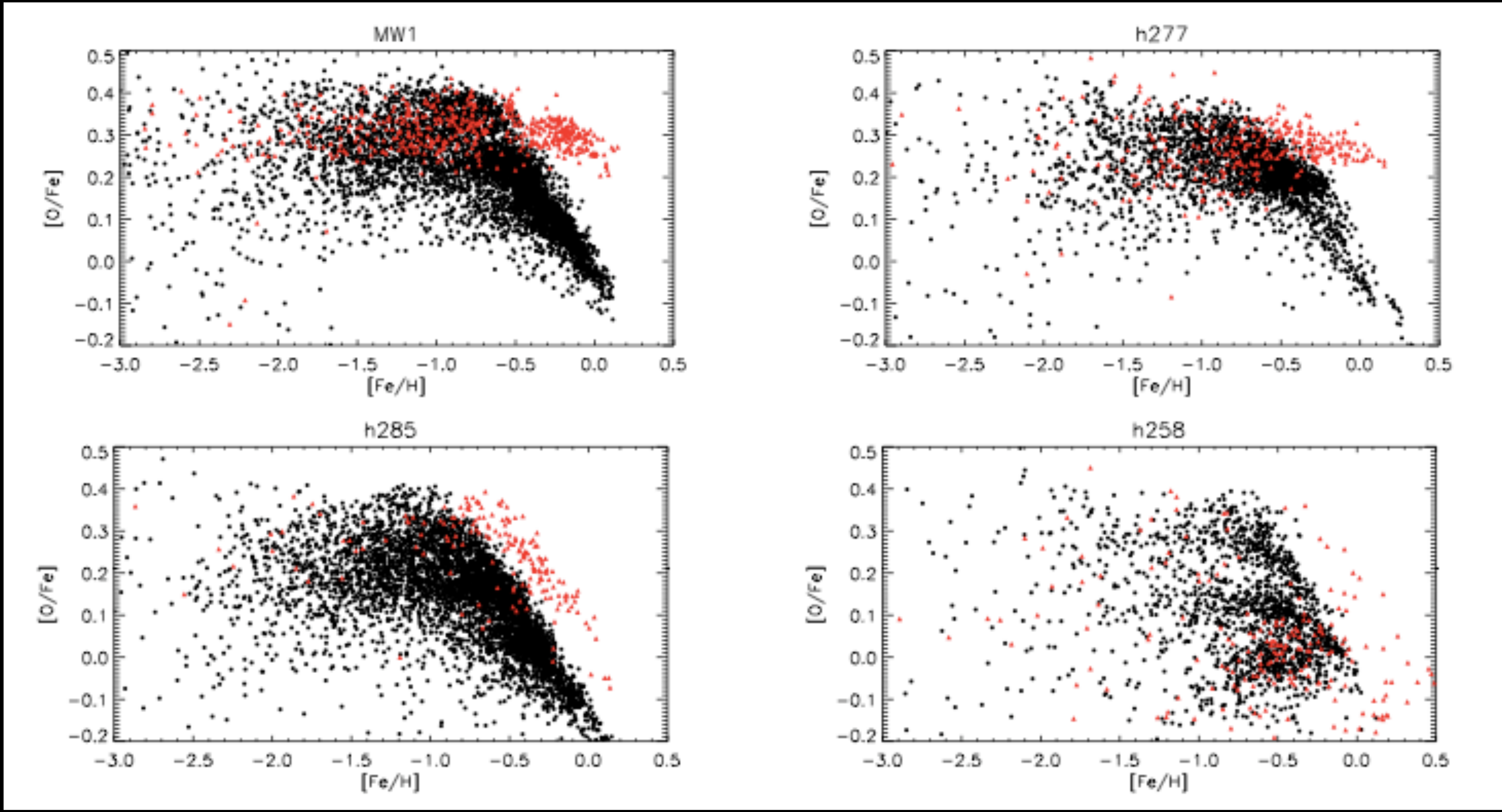
Numerical simulations

- Cosmological simulations of galaxy formation that explicitly include multiple chemical tracer fields in both gas and stars
- Pros: best spatial resolution, fully consistent with structure formation, most self-consistent treatment
- Cons: very, very expensive, still contain some subgrid physics (primarily related to star formation)

This is just starting: see Peruta talk later today

Example: simulation of stellar halo formation

Zolotov et al. 2010, ApJ, 721, 738



Red: stars formed in situ. Black: accreted stars.

Critical needs

- Stellar evolution models (including binary and explosive nucleosynthesis) over a large and regular grid of masses and metallicities (not just solar and primordial!)
- Deeper understanding of which results from stellar evolution calculations are the most/least reliable
- Statistical tools to compare theoretical models to observational data sets
- Close collaboration with observational colleagues to understand limitations of observational data

Summary/outlook

- One can use GCE models to constrain the evolution and IMF of stellar populations, nucleosynthetic sites, and MW progenitor galaxies
- We currently have a wealth of observational data on abundances/kinematics of metal-poor stars (with lots more on the way!)
- GCE models that wish to address modern observational data need to take into account hierarchical structure formation as well as detailed outputs of stellar evolution calculations!