# Chemodynamical Simulation of the Milky Way Galaxy


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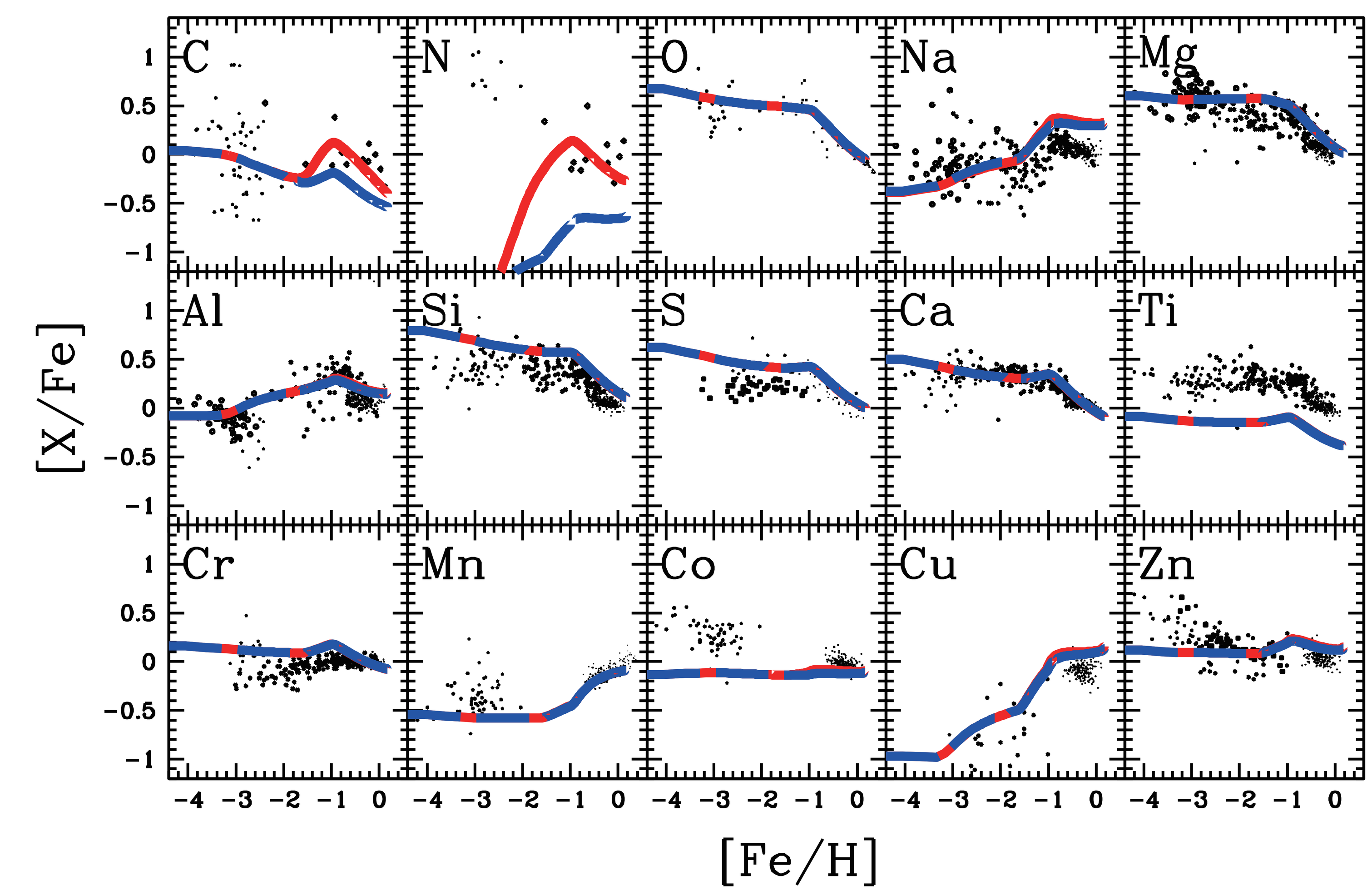
## 1. Abstract


We present chemodynamical simulations of a Milky Way-type galaxy using a self-consistent hydrodynamical code that includes star formation, Type II and Ia supernova feedback, and chemical enrichment from λCDM initial conditions.
In the simulated galaxy, the kinematical and chemical properties of the bulge, disk, and halo are consistent with the observations. **The bulge** formed from the assembly of subgalaxies at z>3, and has higher [α/Fe] ratios because of the small contribution from Type Ia Supernovae. **The disk** formed with a constant star formation over 13 Gyr, and shows a decreasing trend of [α/Fe] and increasing trends of [(Na,Al,Cu,Mn)/Fe] against [Fe/H]. However, **the thick disk** stars tend to have higher [α/Fe] and lower [Mn/Fe] than thin disk stars because of the short formation timescale (3-4Gyr). The low [α/Fe] and low [Mn/Fe] in dwarf Spheroidal galaxies (**dSphs**) is consistent with the yields of low-mass core-collapse supernovae (*Kobayashi & Nakasato 2011, ApJ, 729, 16*).
The star formation history of galaxies is imprinted in the elemental abundances of stellar populations (**Galactic Archaeology**), and the formation scenario can be tested with the comparison with a large homogeneous sample of observations such as HERMES.
This approach can be used for galaxies in general. The observed elemental abundances of the C-rich Damped Lyman α (**DLA**) system (Cooke et al. 2011) is in excellent agreement with the nucleosynthesis yields of faint core-collapse supernovae of primordial stars.
This suggests that chemical enrichment by the first stars in the first galaxies is driven by core-collapse supernovae from ~20-50 M$_\odot$ stars *(Kobayashi et al. 2011, ApJL, 730, L14)*.


## 2. Nucleosynthesis Yields

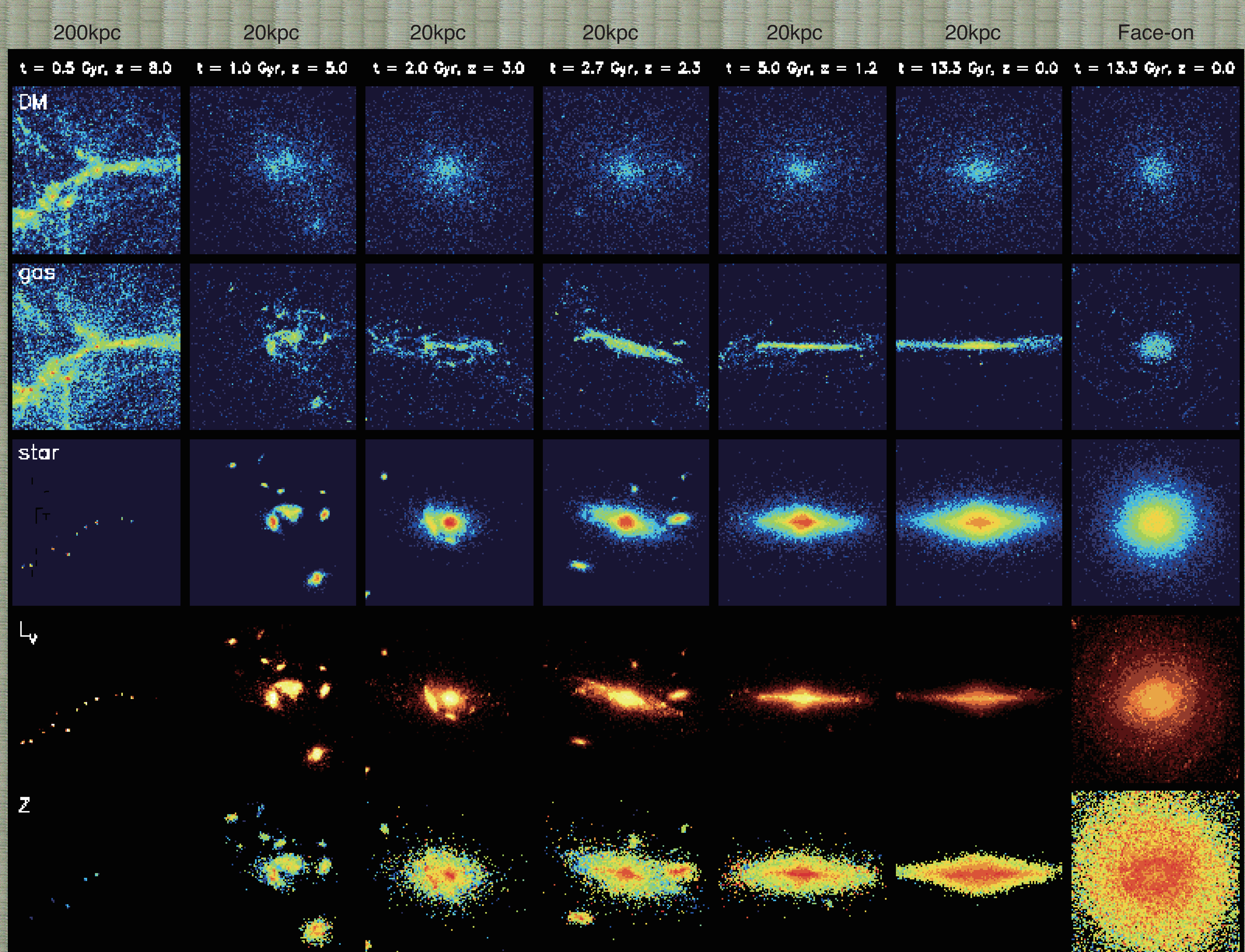
Evolutions of elemental abundance ratios [X/Fe] against [Fe/H] for **the one-zone model** with our yields of core-collapse supernovae (dashed line, Kobayashi et al. 2006), and with AGB stars (solid lines, Kobayashi, Karakas & Umeda 2011, MNRAS, 414, 3231).
The dots are observational data of stars in the solar neighborhood.



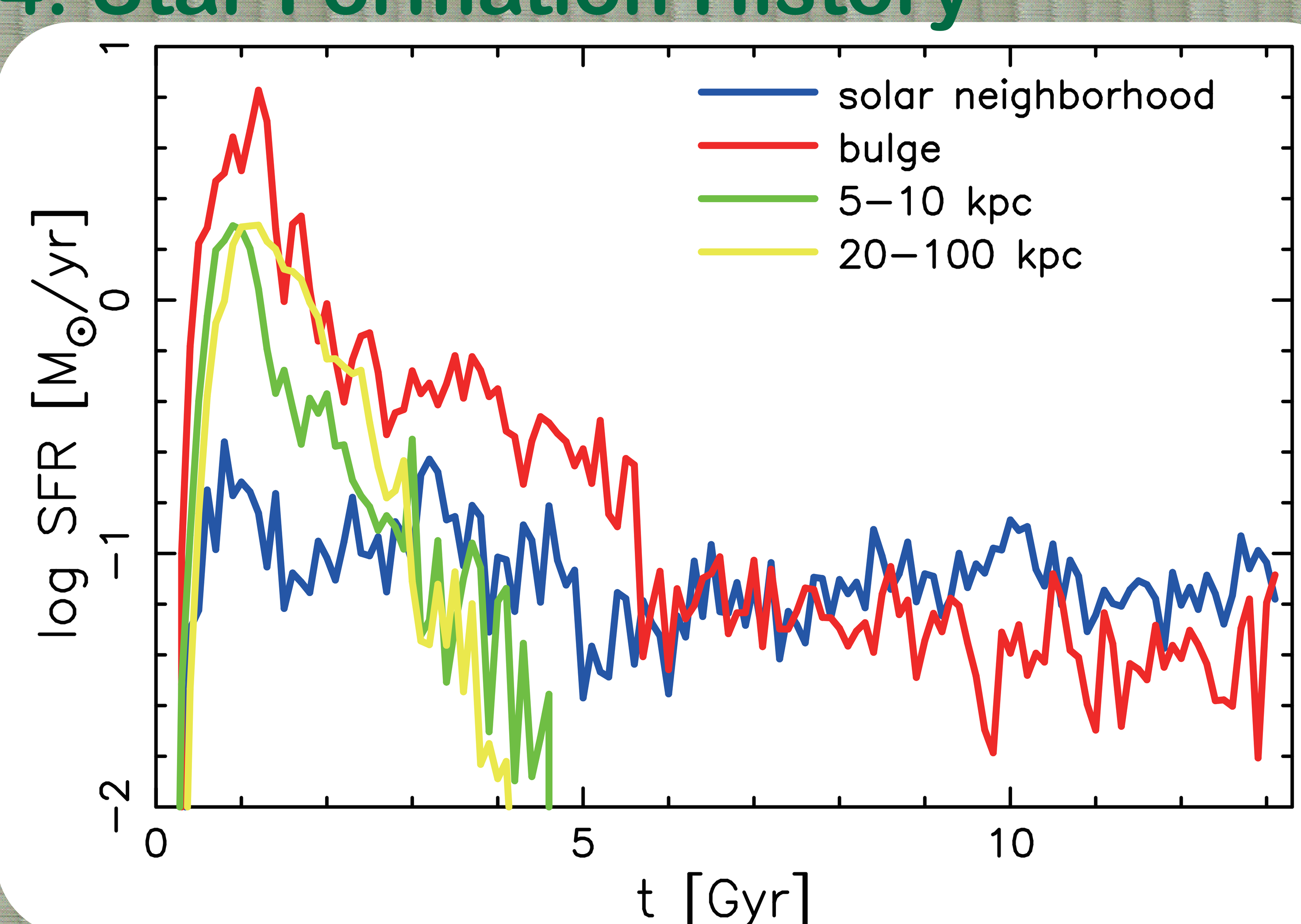

A large contribution of **hypernovae** ($E_{51}$>10, M>20M$_\odot$) is required from the observed abundance of Zn, i.e., [Zn/Fe]~0 (Kobayashi et al. 2006). Our **SN Ia progenitor model** (Kobayashi & Nomoto 2009) is based on the single degenerate scenario with the metallicity effect (Kobayashi et al. 1998), which causes the knee in the [(α,Mn,Zn)/Fe]-[Fe/H] relations.

## 3. GRAPE-SPH Simulation

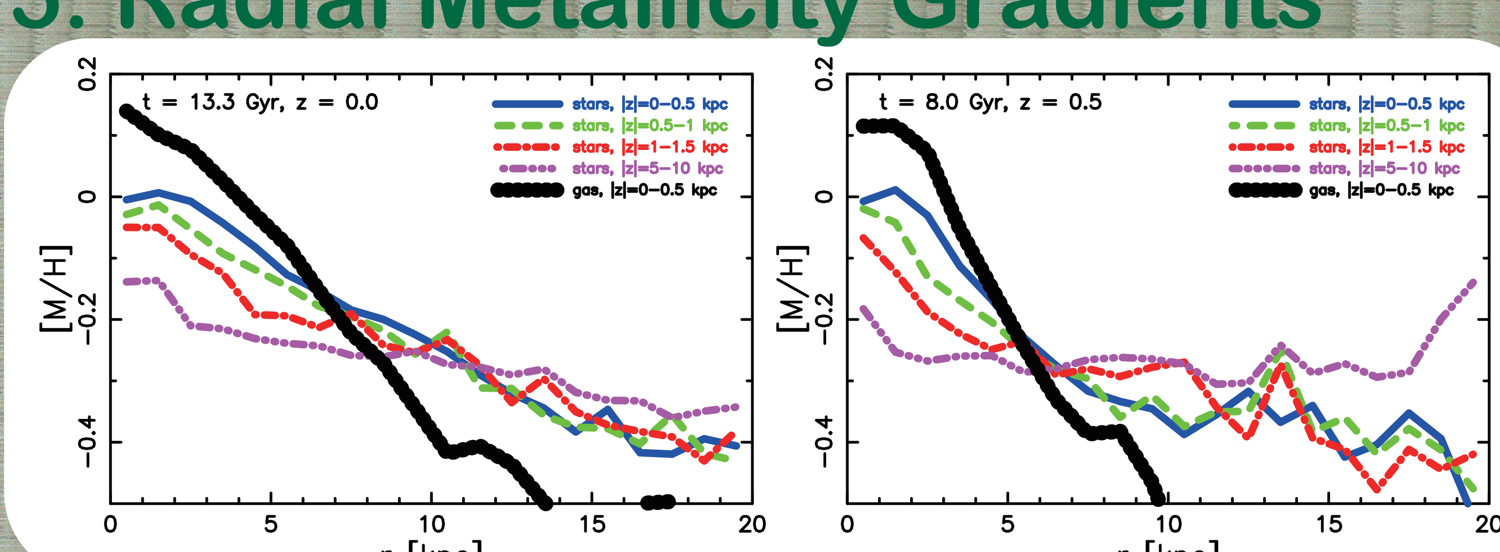
**Time evolution of our simulated Milky Way-type galaxy**
for dark matter, gas, stellar mass, V-band luminosity, and stellar metallicity.




## 4. Star Formation History

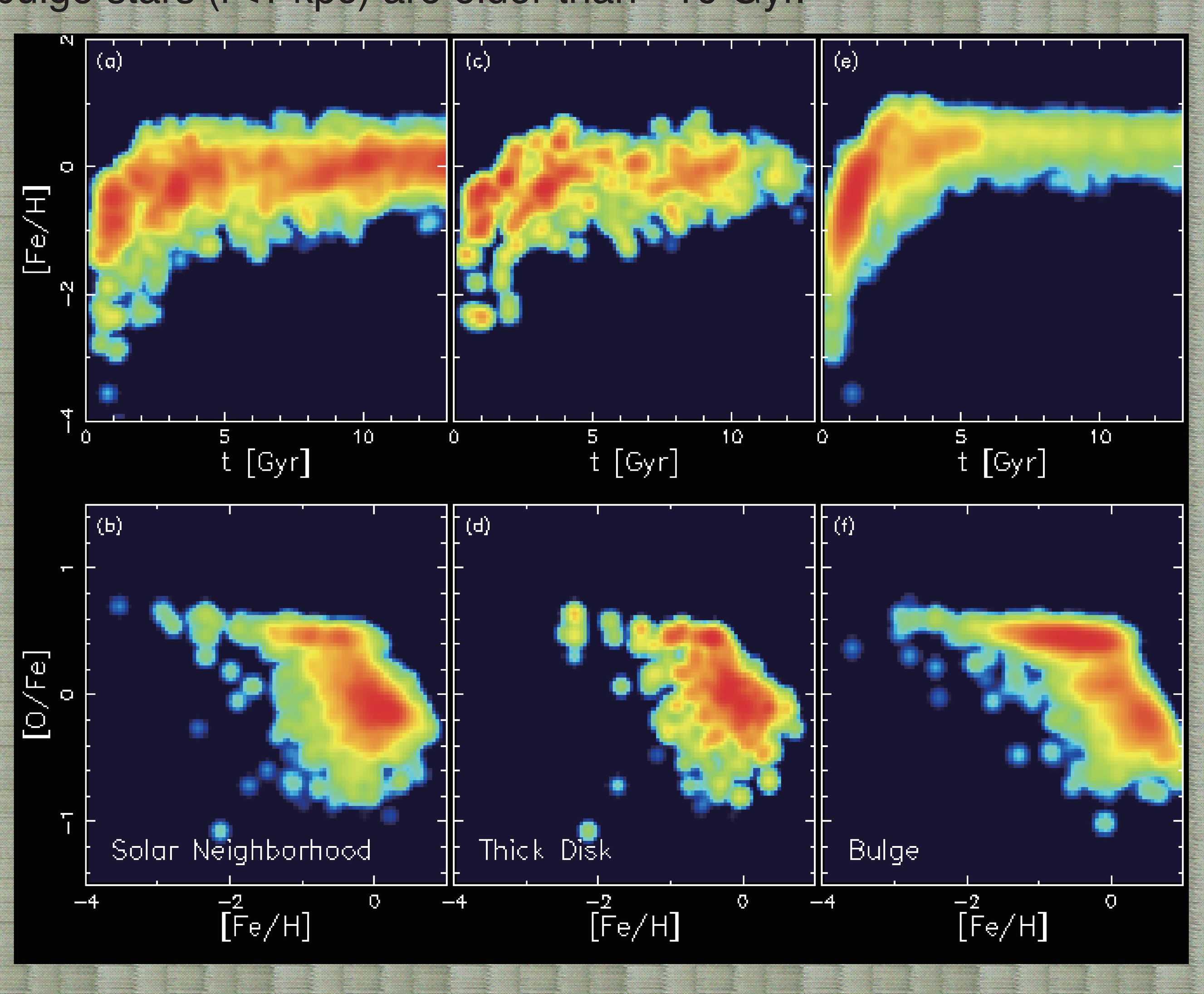



## 5. Radial Metallicity Gradients

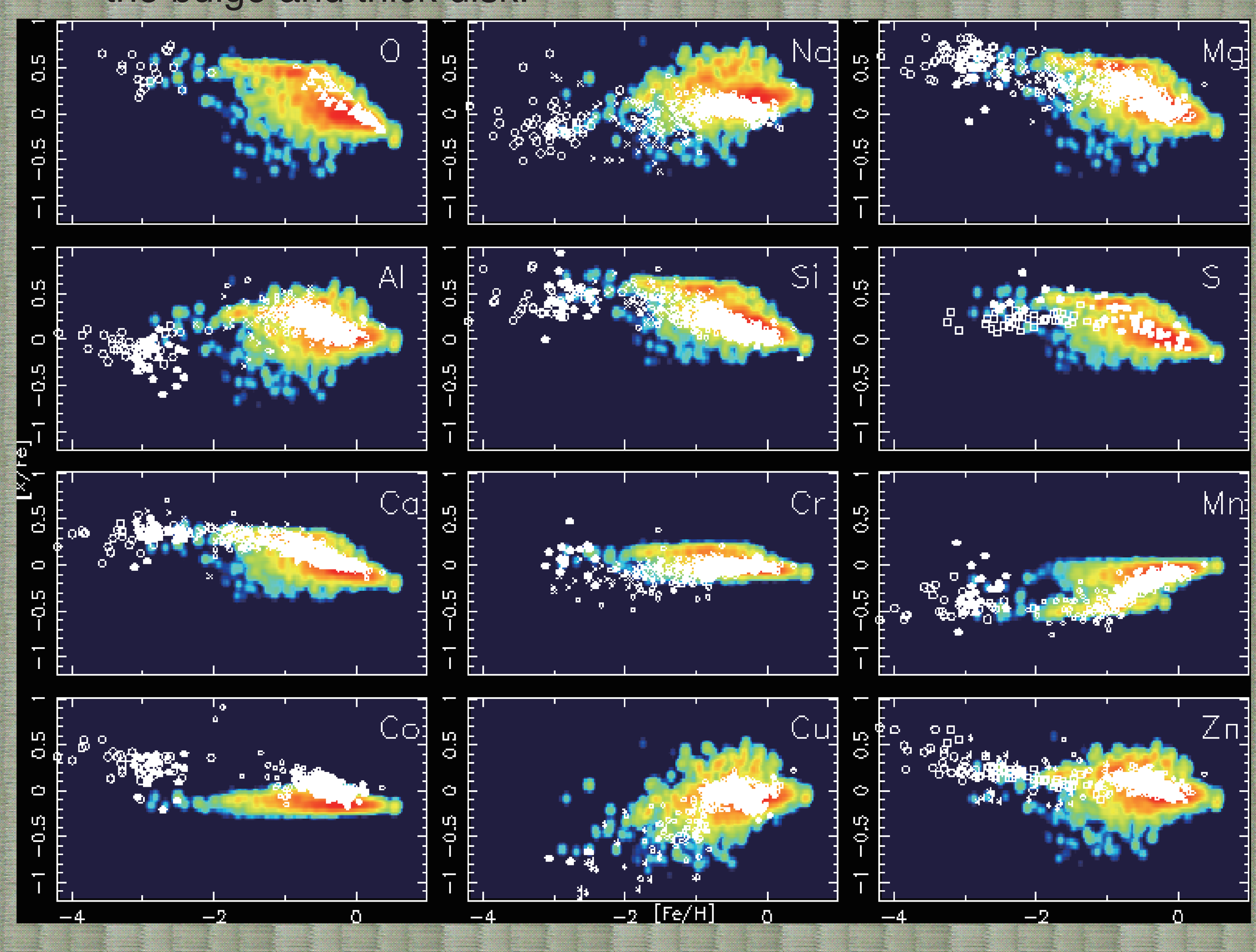



## 6. Elemental Abundances

**Age-Metallicity relations and [α/Fe]-[Fe/H] relations:**
(a,b) In the solar neighborhood (r=7.5-8.5 kpc, |z|<0.5 kpc), 50% of the disk stars are younger than ~8 Gyr. (c,d) When we define thick disk stars from the kinematics using the Toomre diagram, 70% of thick disk stars are older than ~8 Gyr. (e,f) 80% of the bulge stars (r<1 kpc) are older than ~10 Gyr.




**[X/Fe]-[Fe/H] diagrams from O to Zn:**
Frequency distribution of stars in the solar neighborhood. Color contours are for our simulation, where red is for the highest frequency. White dots show observational data from various literatures. See Kobayashi & Nakasato (2011) for the bulge and thick disk.




**The C-rich DLA @z=2.34, [Fe/H]=-3.04:**
Elemental abundance pattern of the metal-poor C-rich DLA (filled circles) and peculiar DLA (open circles). The solid and short-dashed lines show the nucleosynthesis yields of faint core-collapse supernovae from 25M$_\odot$ stars with Z=0, including an efficient mixing fallback to form a ~6M$_\odot$ blackhole. The dotted line is for pair-instability supernovae (PISN) from 170M$_\odot$ stars, which have too small [C/Fe] and too large [(Si,S)/Fe]. The observed DLA abundance is very similar to those of EMP stars including the ultra metal-poor star HE0557-4840 (Norris et al. 2007).