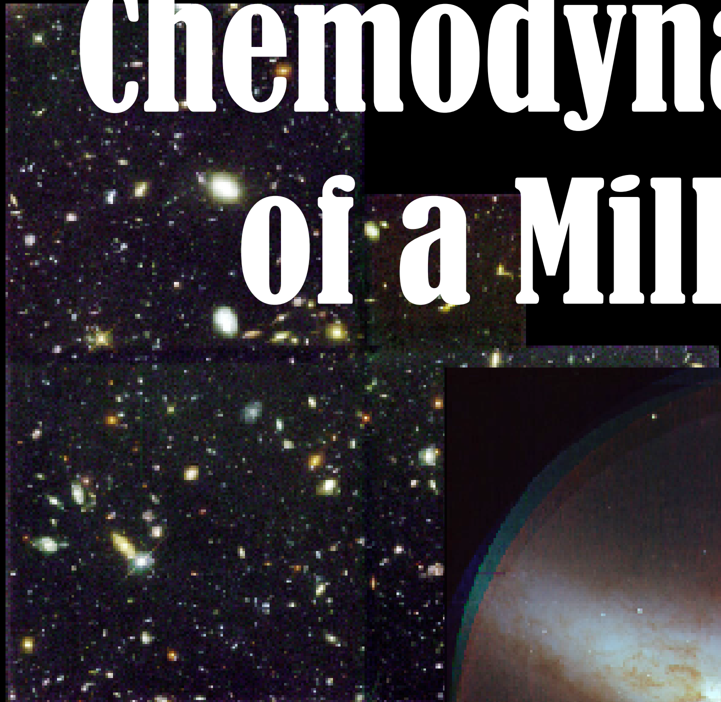
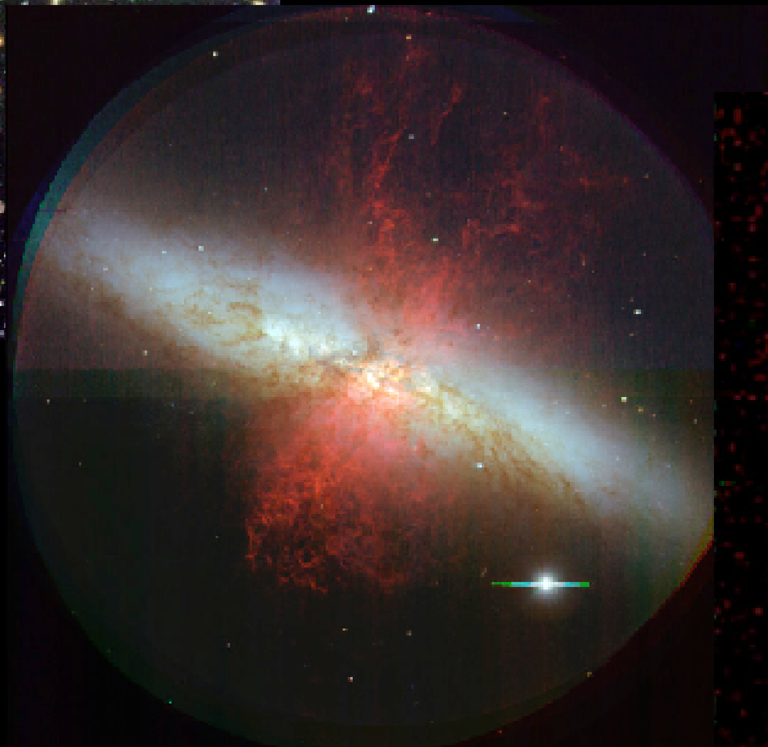
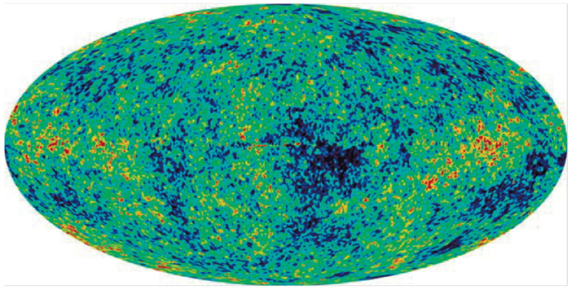
Chemodynamical Simulations of a Milky Way type galaxy

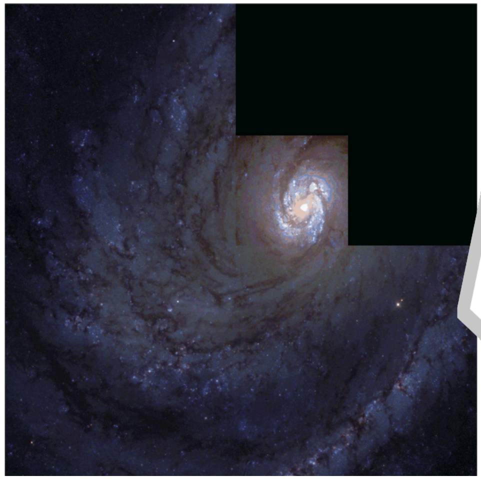


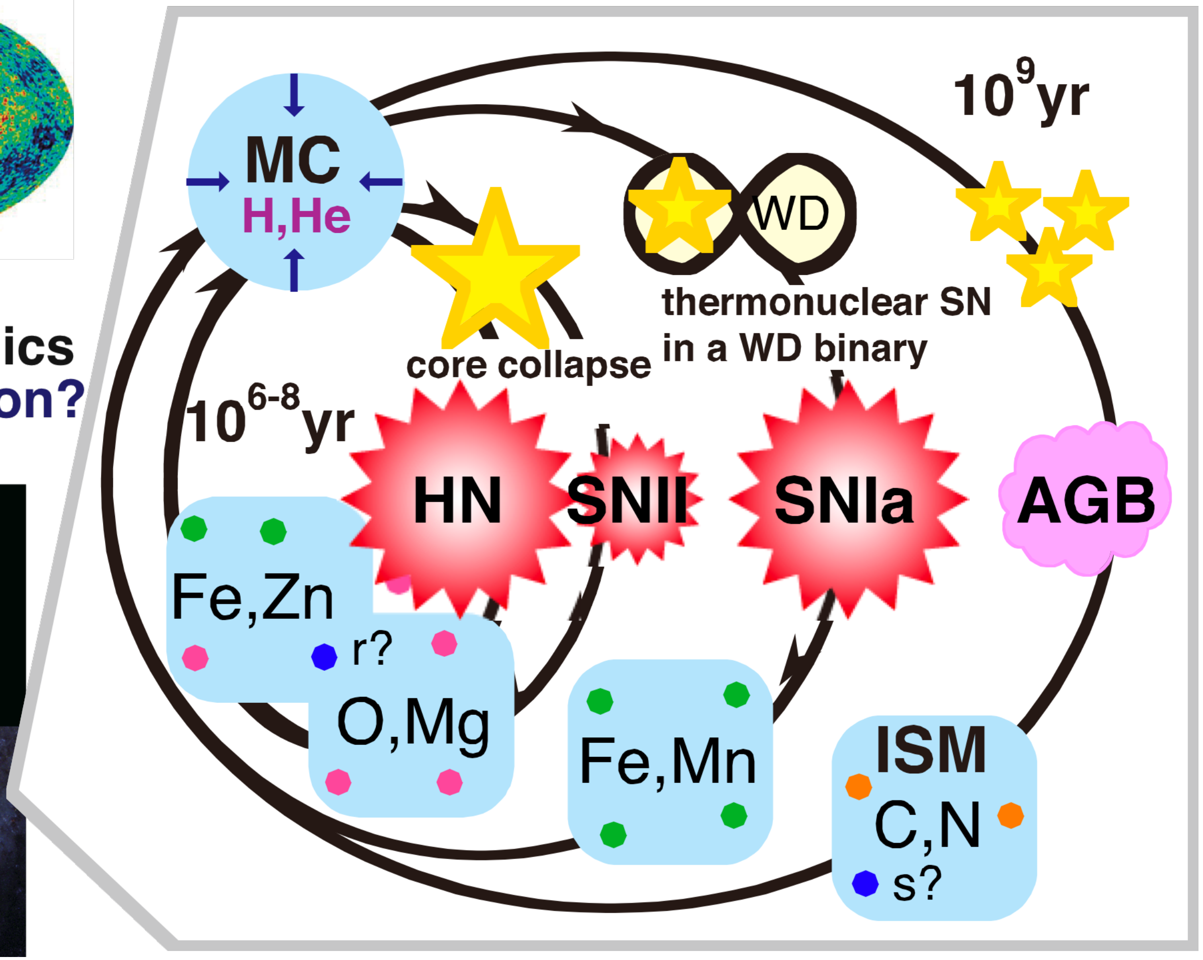


Chiaki Kobayashi
(Australian National University)

Galactic Archaeology



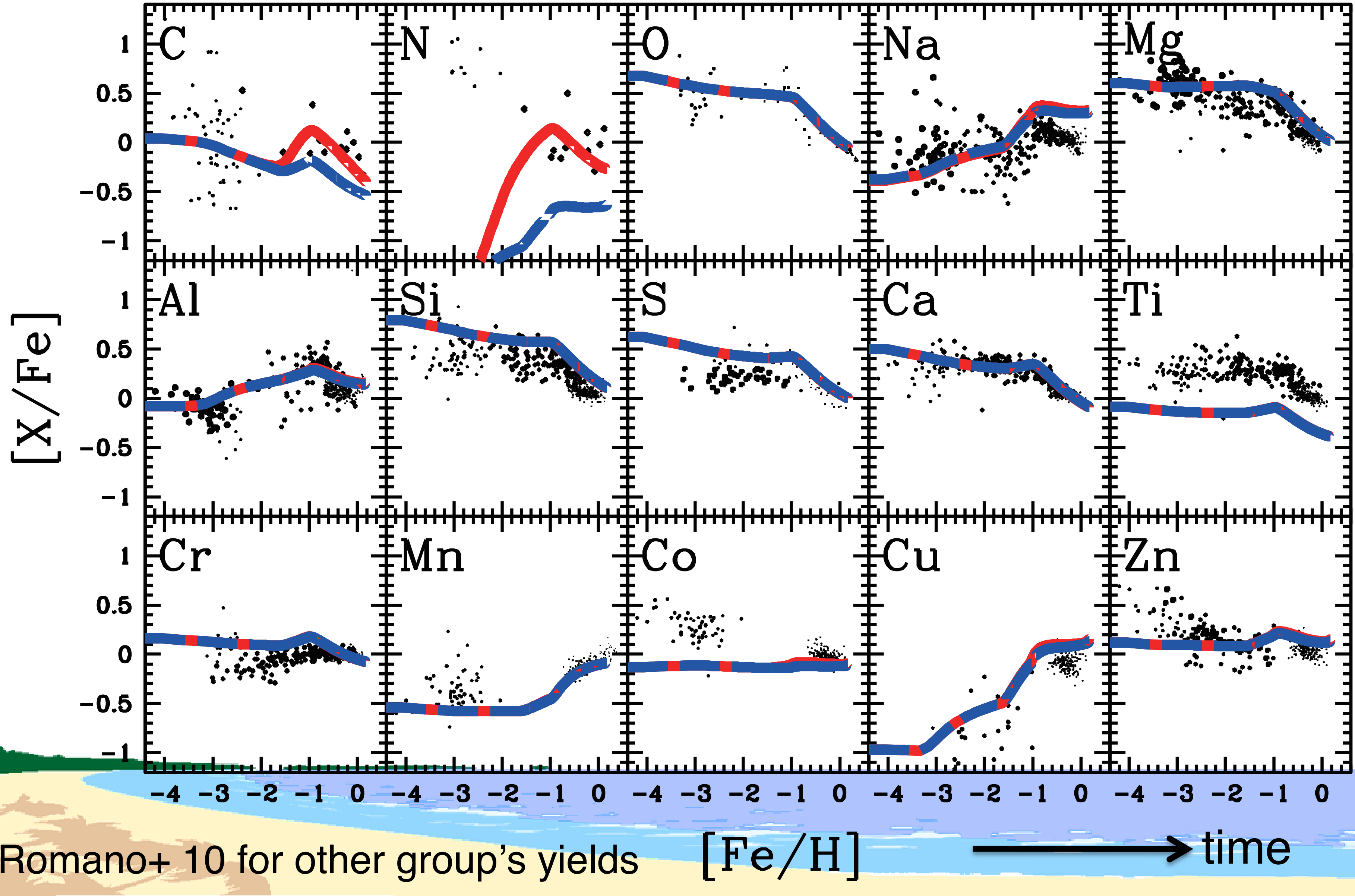




- [Fe/H] and [X/Fe] evolve in a galaxy: stars are fossils that record the formation history of the galaxy

Nucleosynthesis Yields

SN+HN (CK+ 06); SN+HN+AGB (CK, Karakas, Umeda 2011, MNRAS)



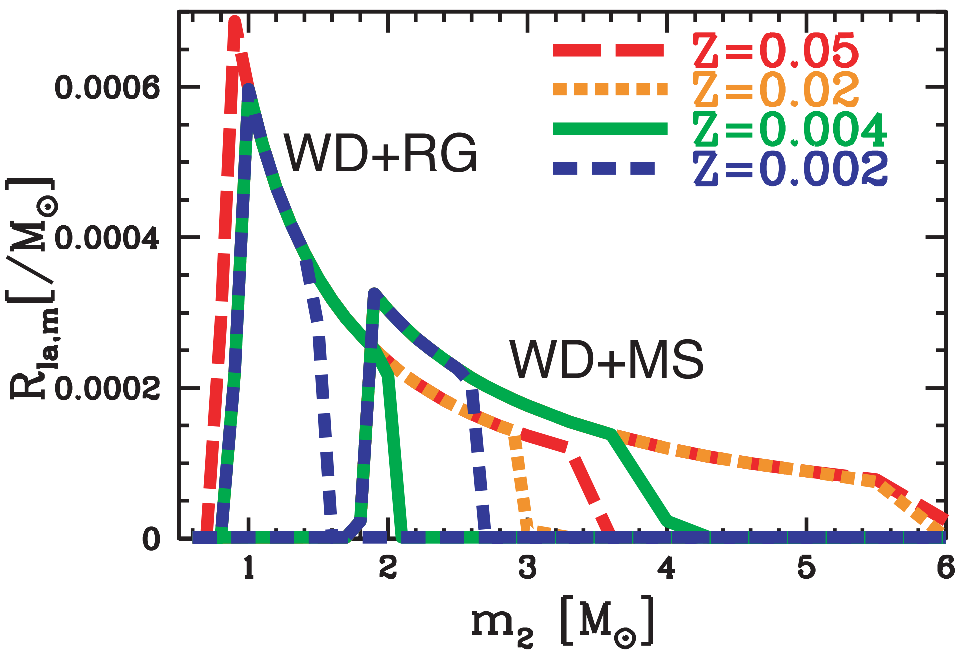
Romano+ 10 for other group's yields

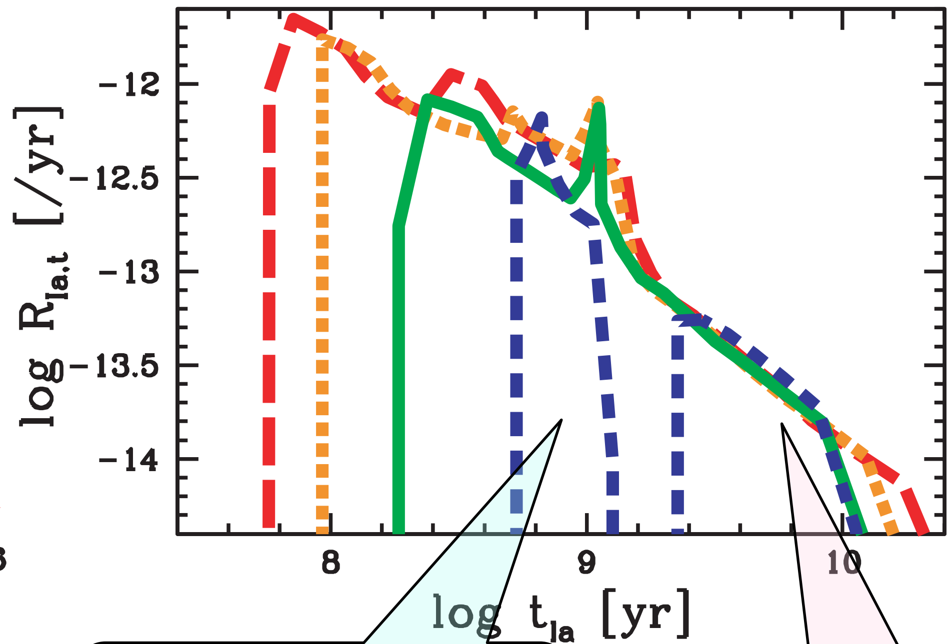
Type Ia Supernova Rate

- Single Degenerate Scenario; SNIa Lifetime ~ lifetime of companion star
- Companion mass ranges from binary calculation (Hachisu, Kato, Nomoto)

$$\mathcal{R}_{\rm Ia} = b \int_{\max[m_{1{\rm p},\ell},\, m_t]}^{m_{1{\rm p},u}} \frac{1}{m}\phi(m)\,{\rm d}m \int_{\max[m_{1{\rm d},\ell},\, m_t]}^{m_{1{\rm d},u}} \frac{1}{m}\phi_{\rm d}(m)\,{\rm d}m.$$

primary WD — secondary star



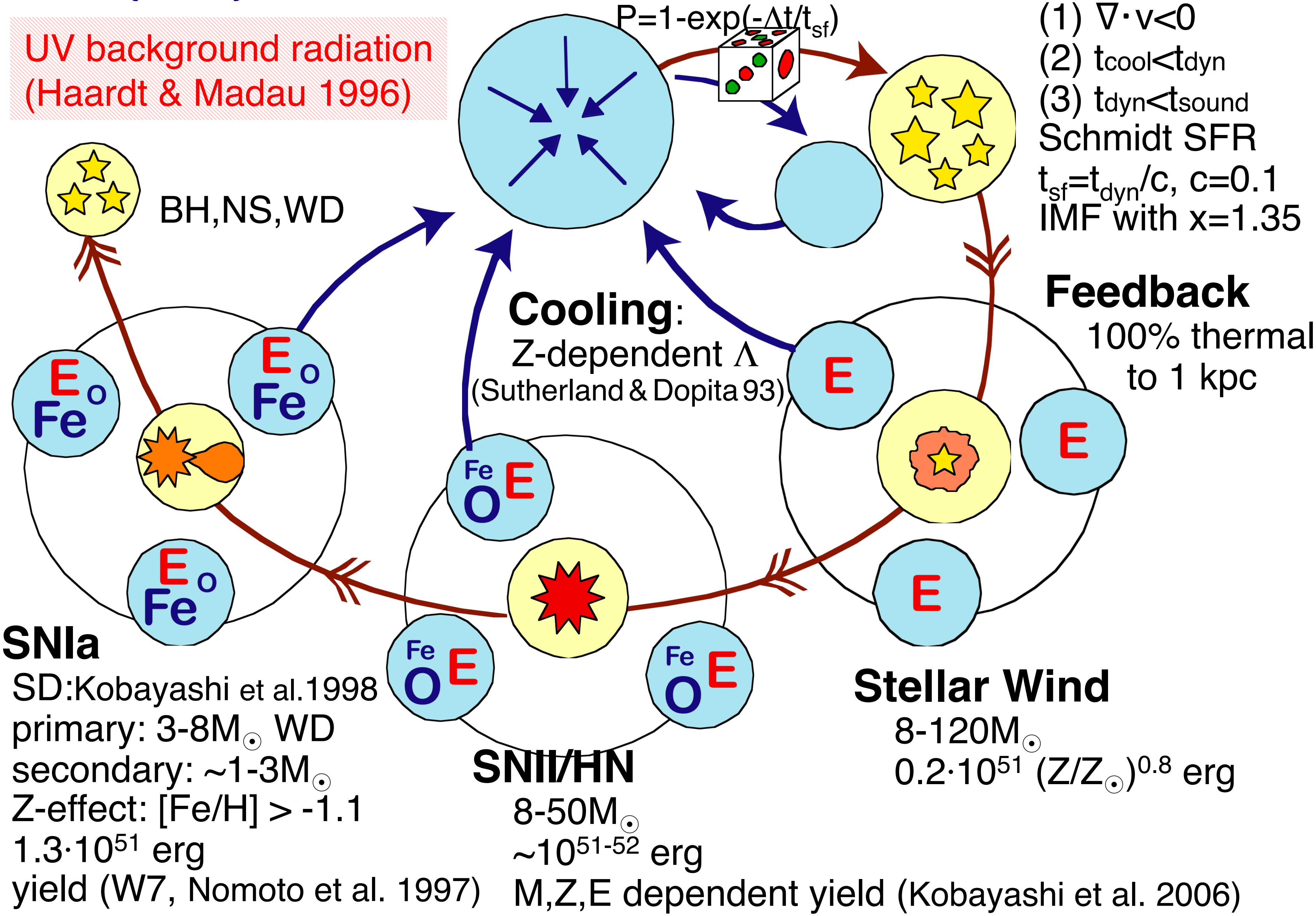


MS, 0.1-1Gyr
in spirals or high-z

RG, 1-20Gyr
in ellipticals

CK et al. (1998); CK & Nomoto (2009)
Greggio 05; Matteucci+ 06 for other SNIa models

CK(04): GRAPE-SPH +

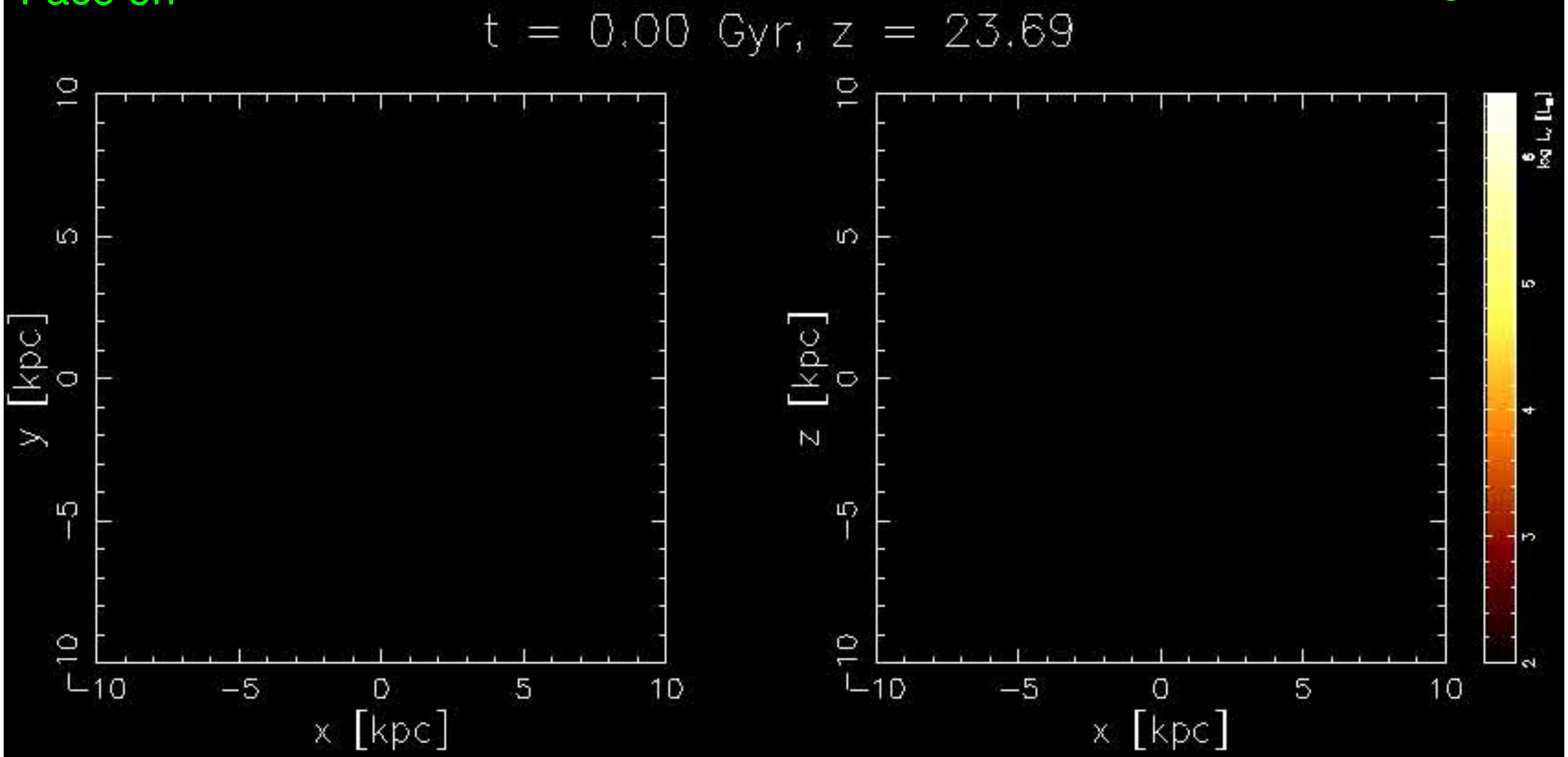


The Milky Way Galaxy

Initial Condition: λCDM fluctuated sphere with λ~0.1, r~3Mpc,
M_{tot}~10^{12} $M_\odot$, N_{tot}~120.000, M_{gas}~10^6 $M_\odot$, M_{DM}~10^7 $M_\odot$
(CK & Nakasato 2011, ApJ, 729, 16)

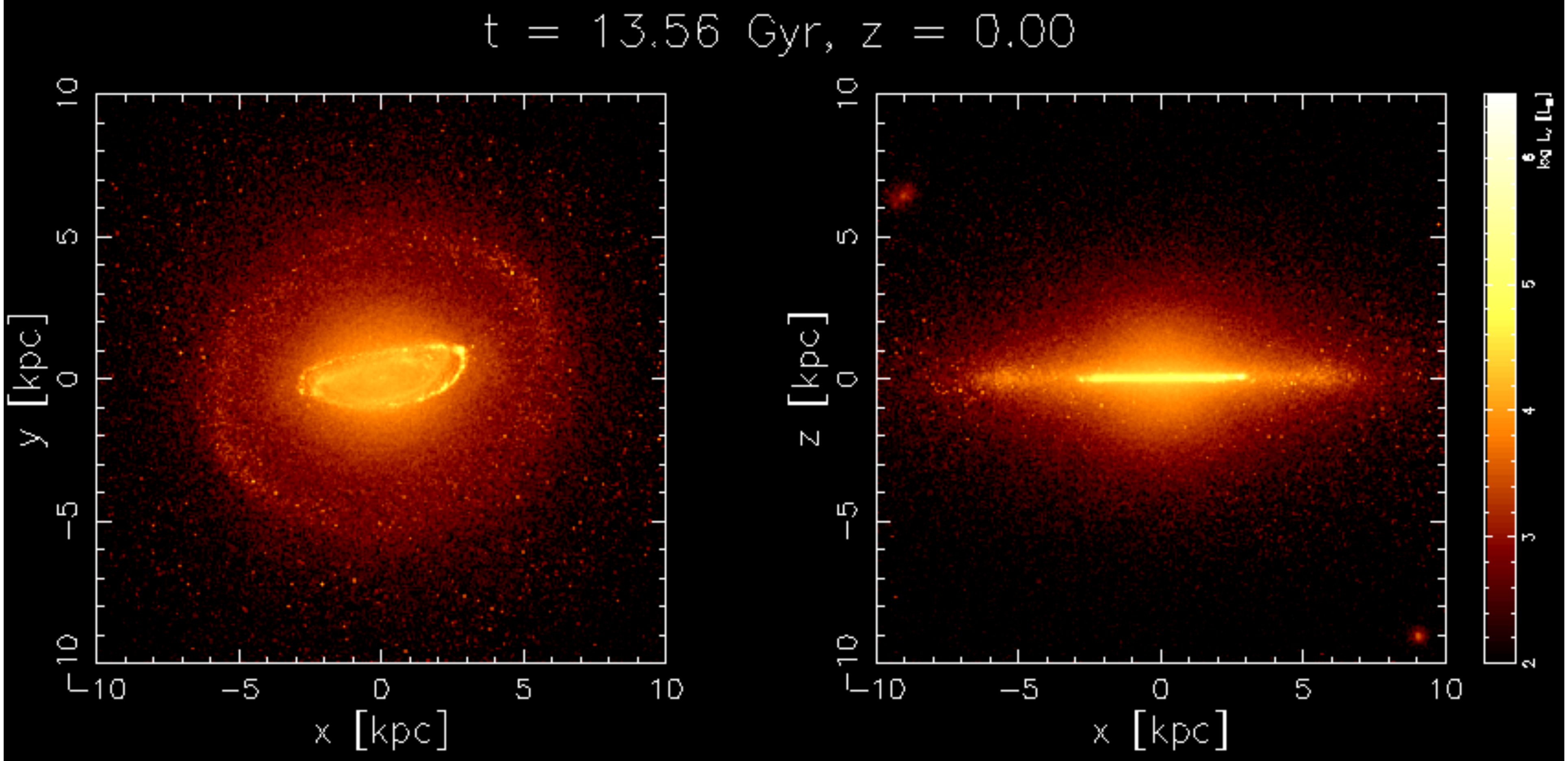
Face on

Edge on



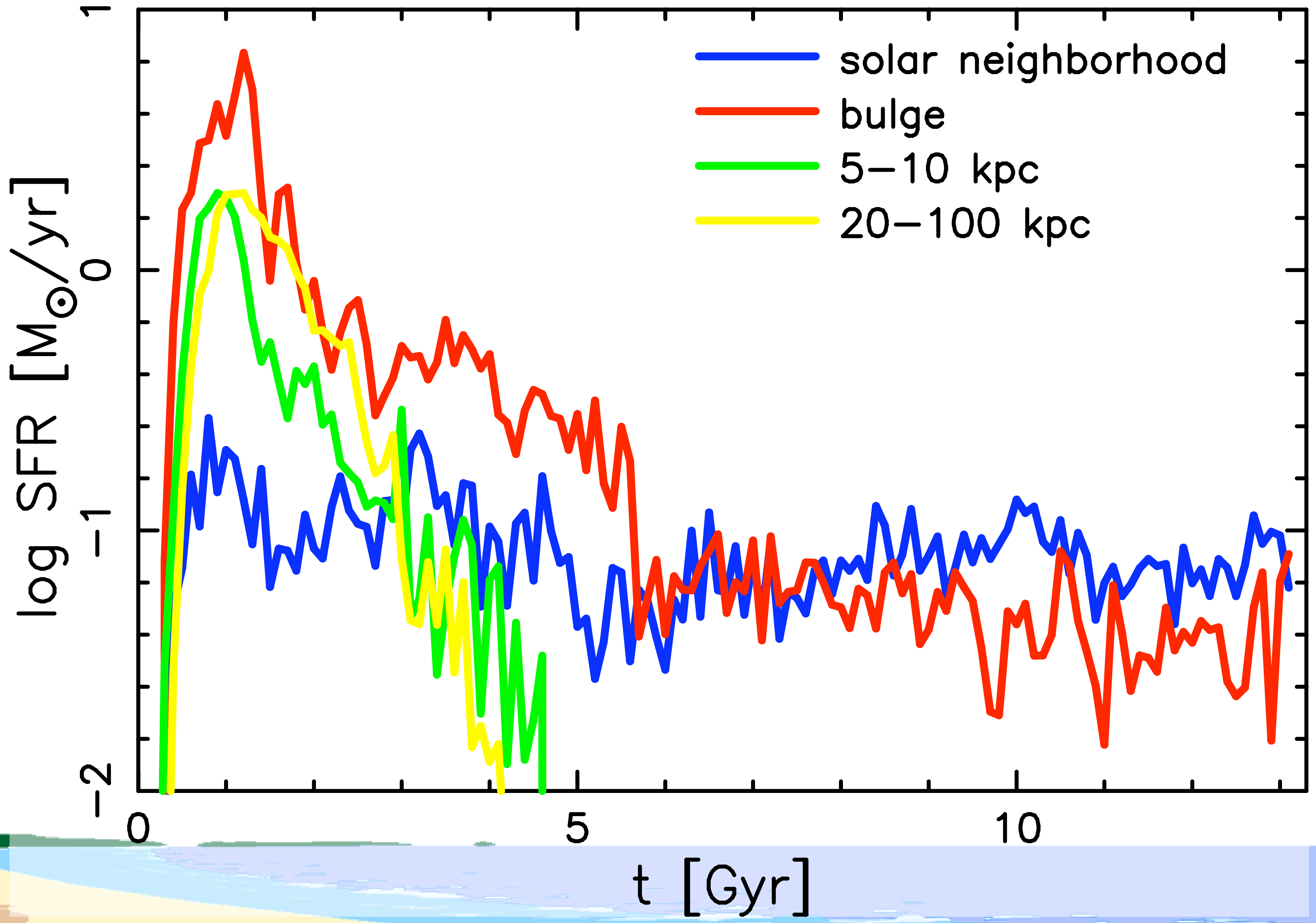
Aquarius IC

- Code: Gadget-3 + SF+FB+CE (CK, Springel, White 07)
- Aq-5-C (M_{gas}~10^5 $M_\odot$), merger @ z=0.5…..

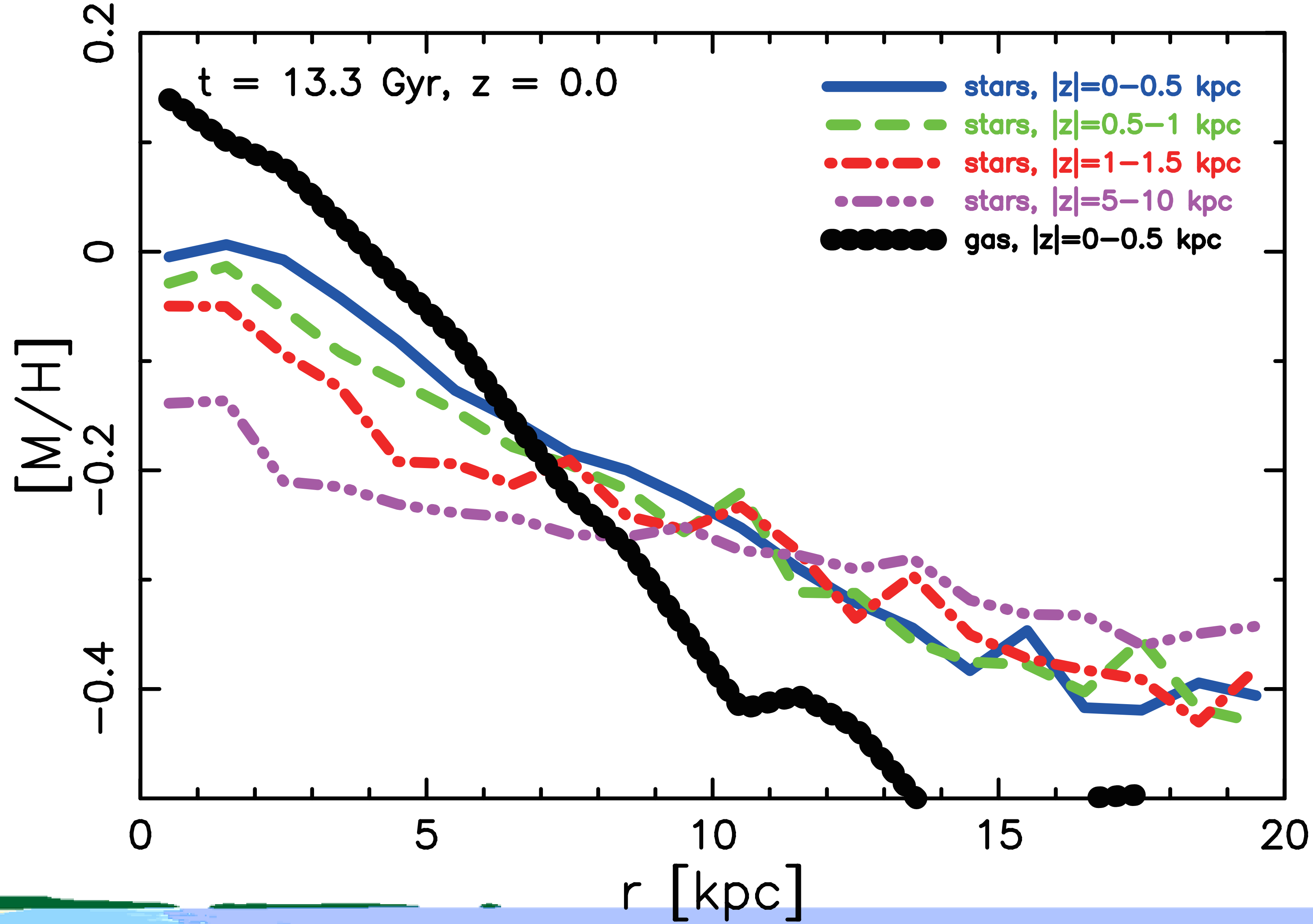


Star Formation Rate

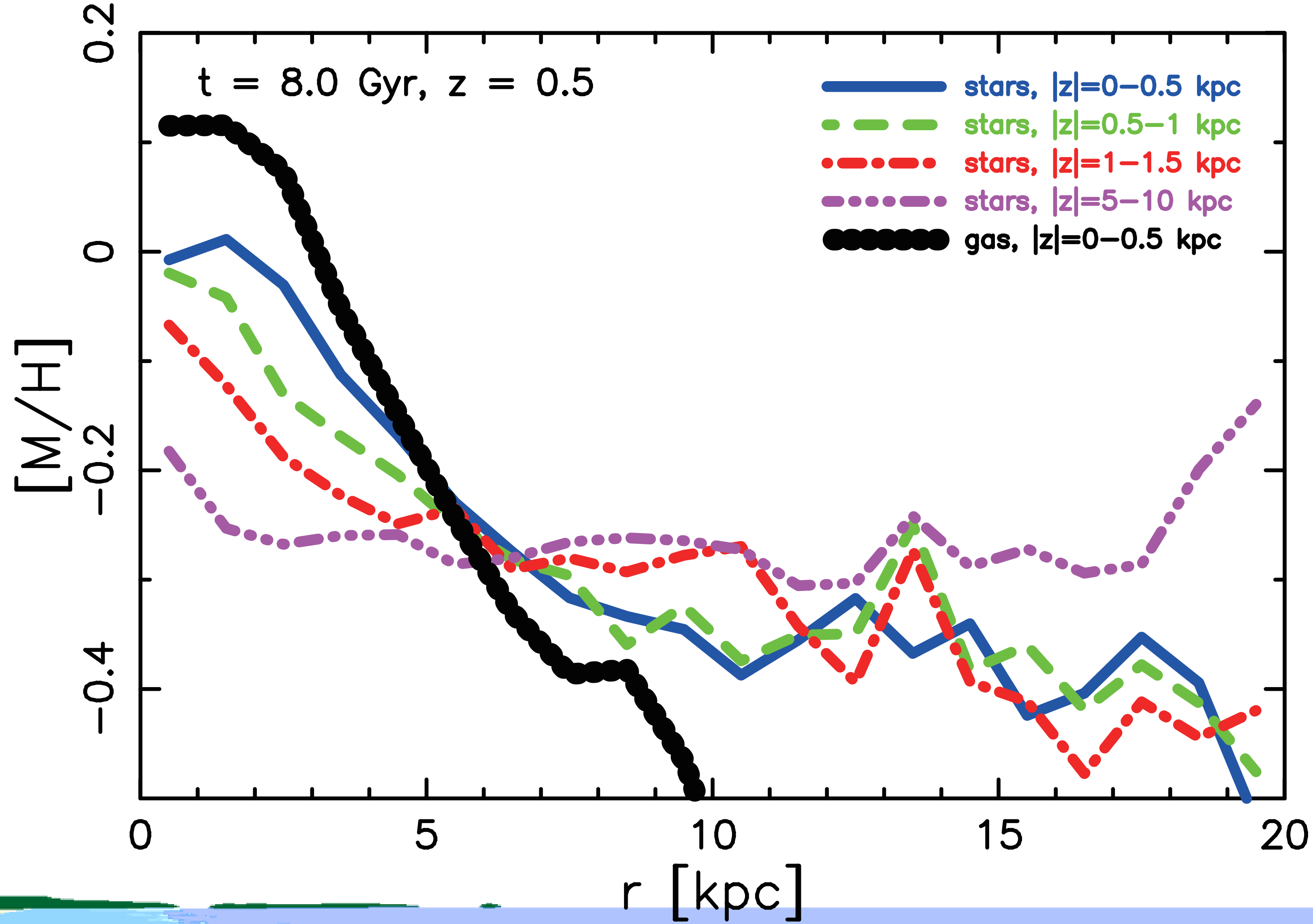
Bulge r<1, Solar Neighborhood: 7.5<r<8.5,|z|<0.5 kpc



Metallicity Gradients @ z=0

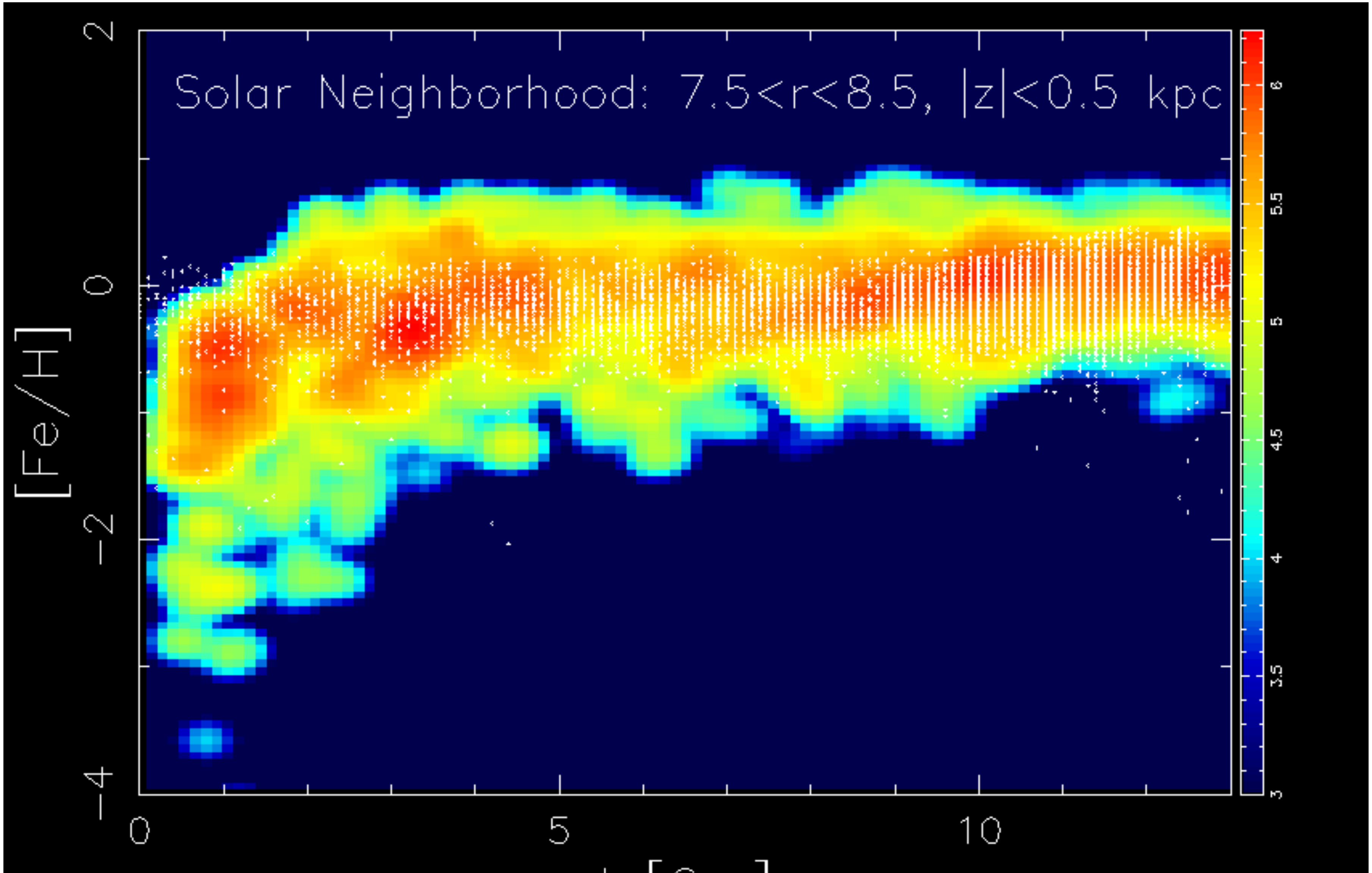


Metallicity Gradients @ z=0.5



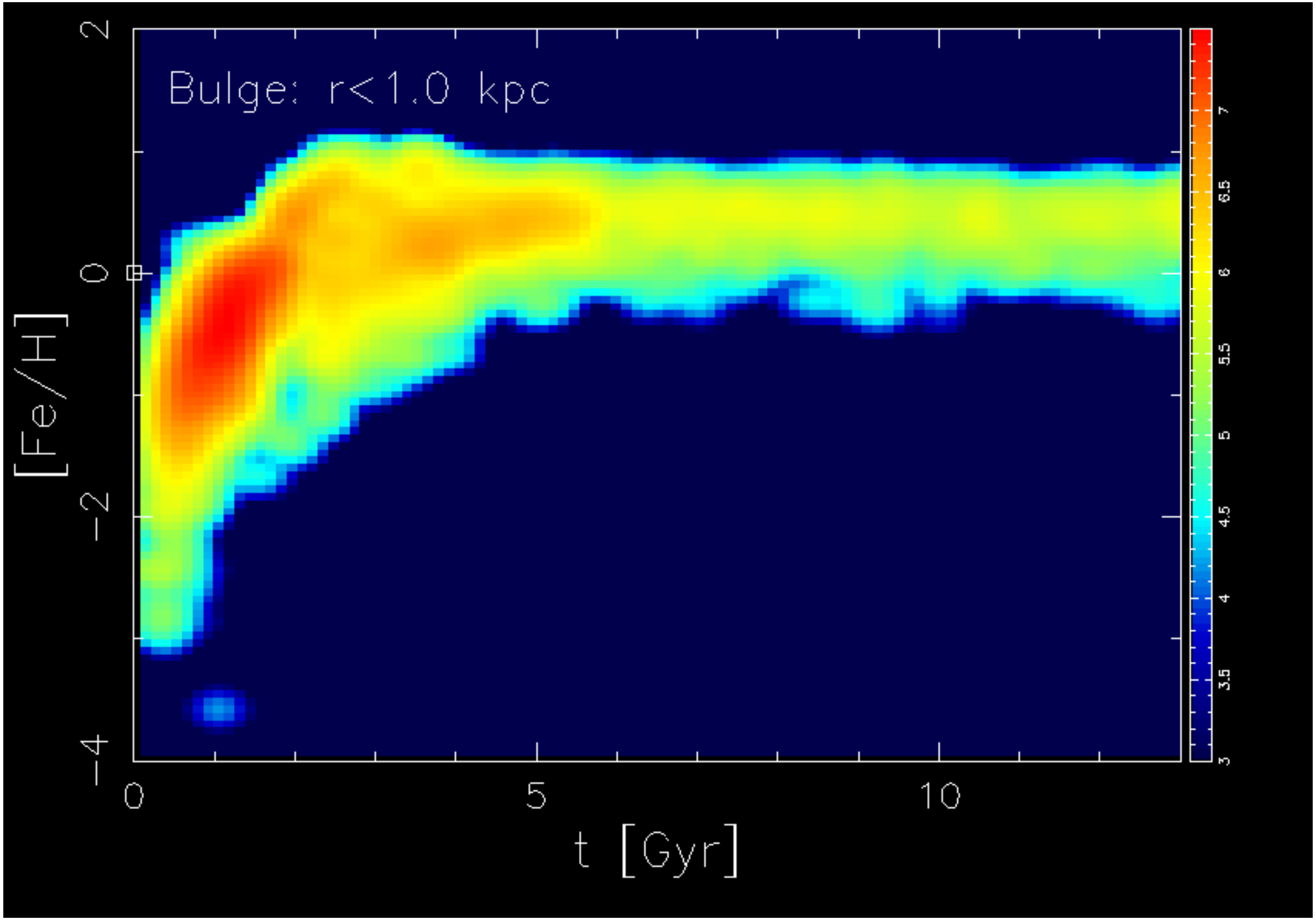
- Consistent with lensed spiral galaxies @ z=1.5 (Yuan et al. 2011)

Age-Metallicity Relation

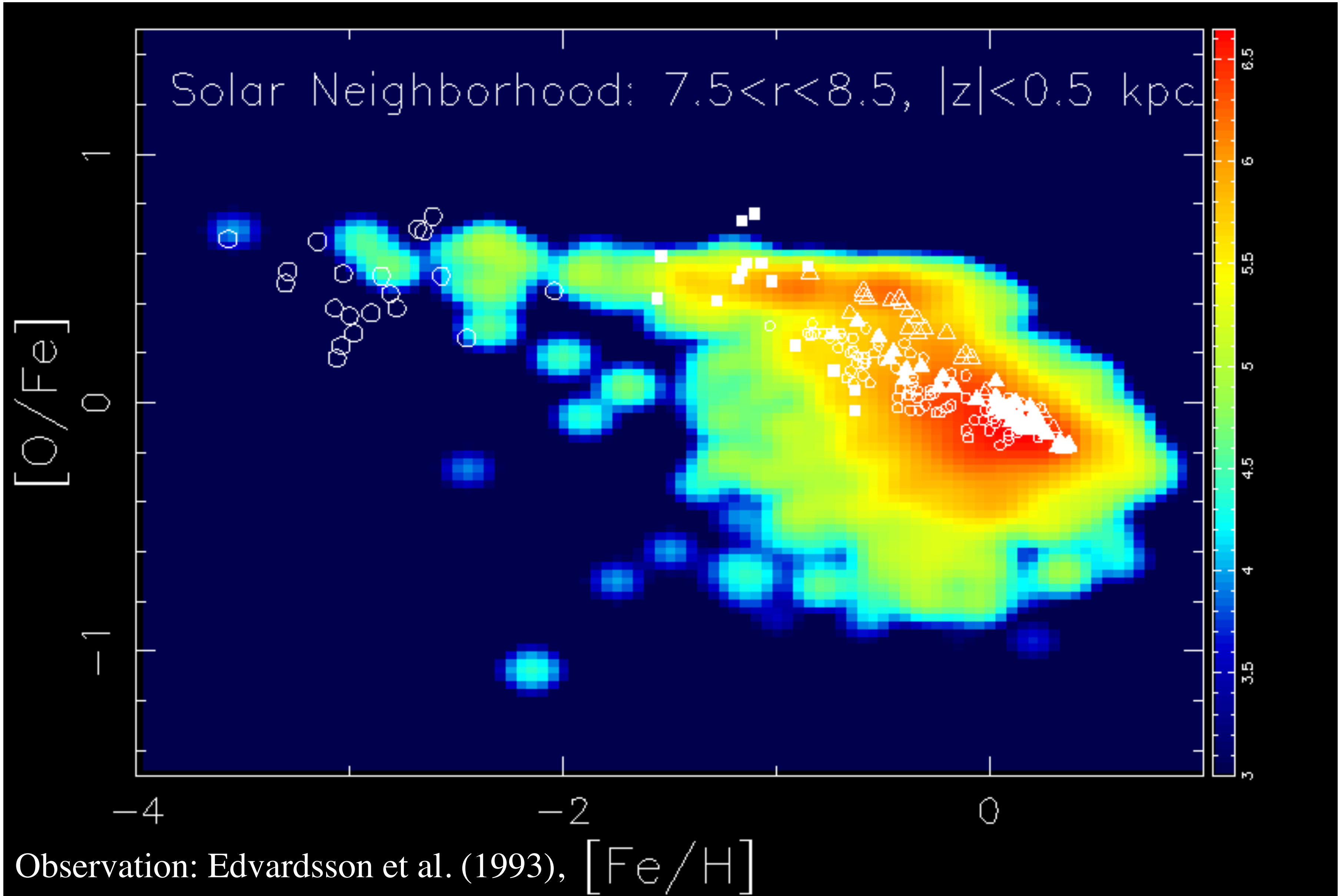


Observation: Holmberg et al. (2007)

Age-Metallicity Relation

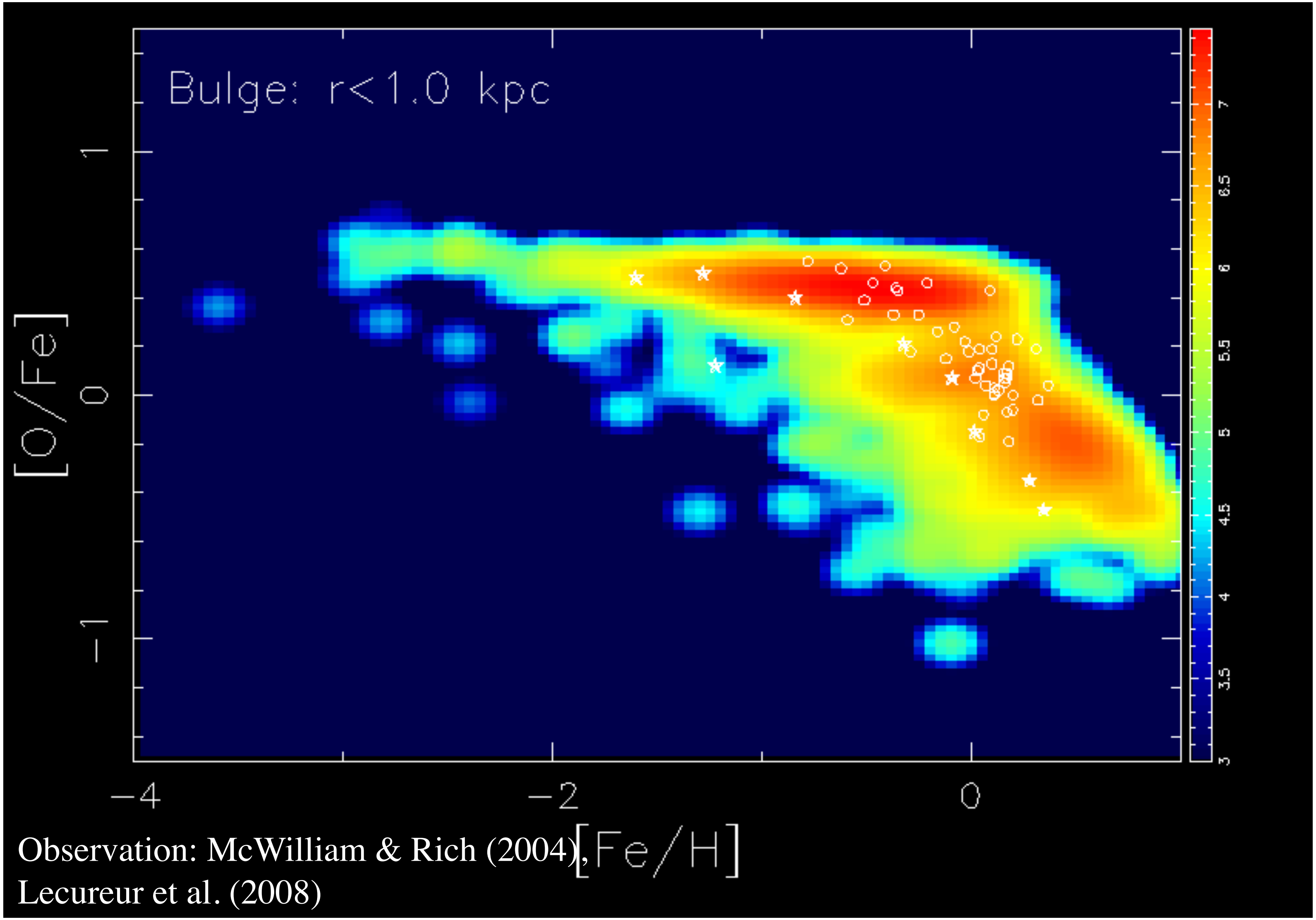


[O/Fe]-[Fe/H] Relation



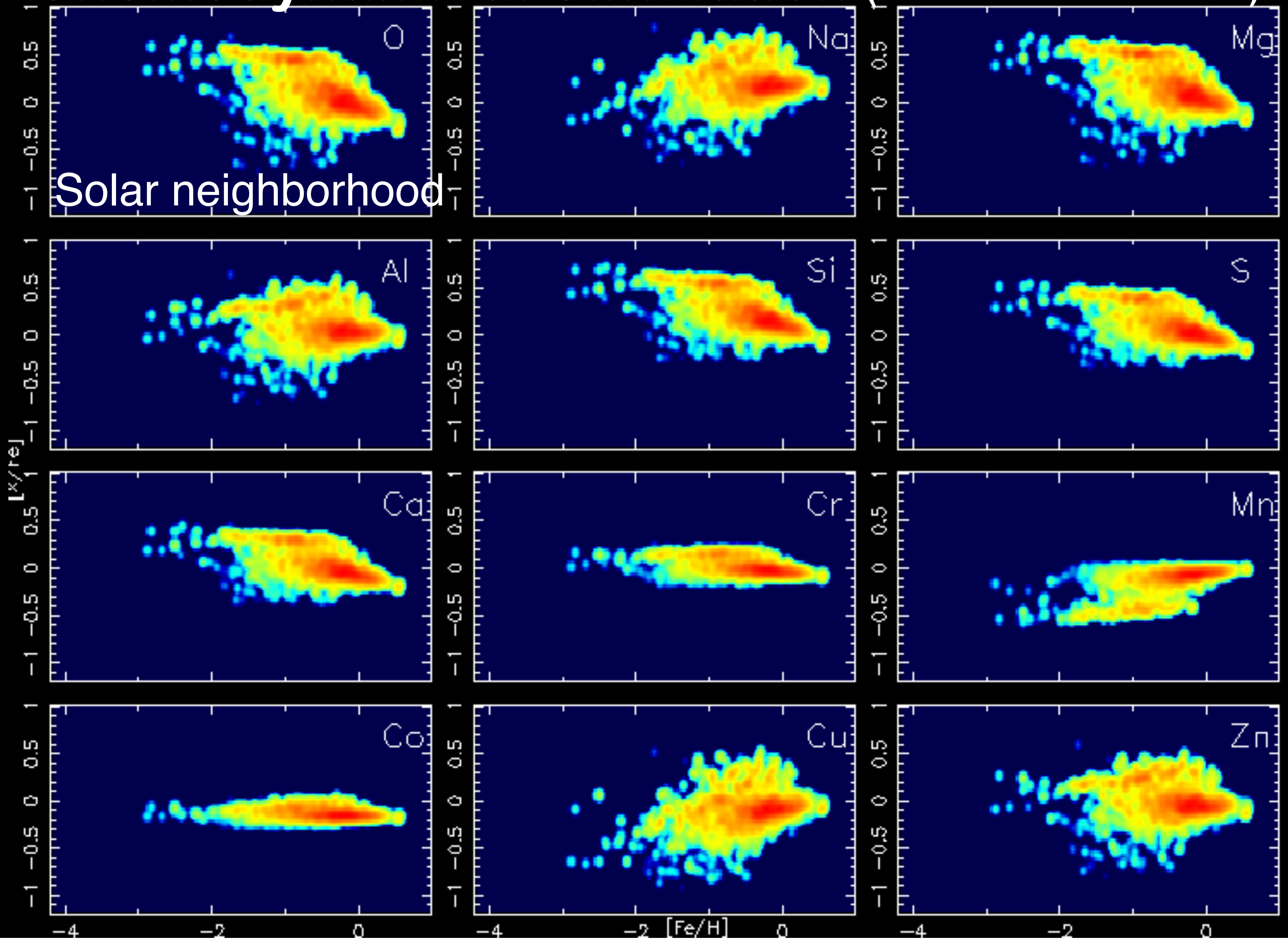
Observation: Edvardsson et al. (1993),
Bensby et al. (2004), Gratton et al. (2003), Cayrel et al. (2004)

[O/Fe]-[Fe/H] Relation

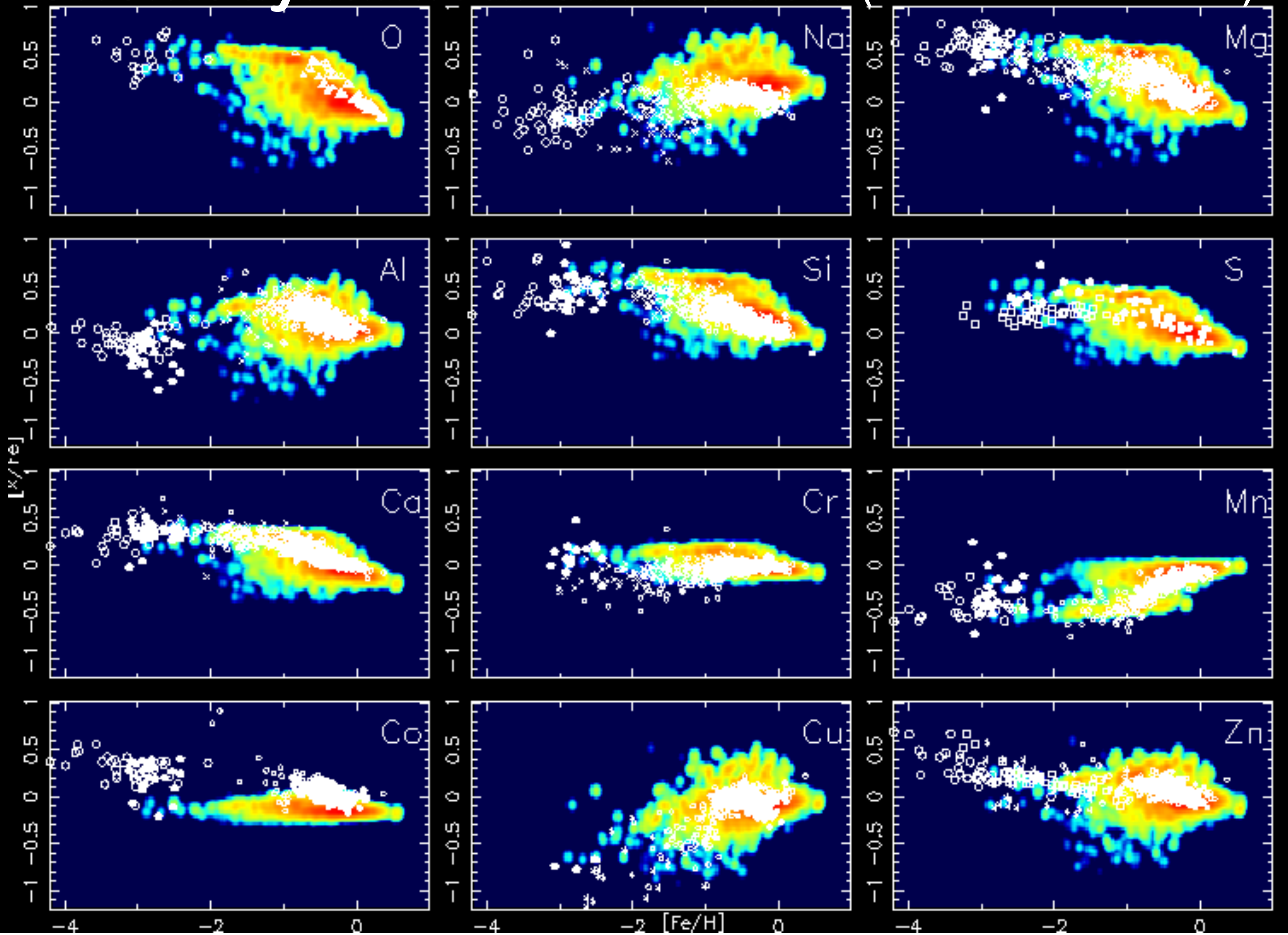


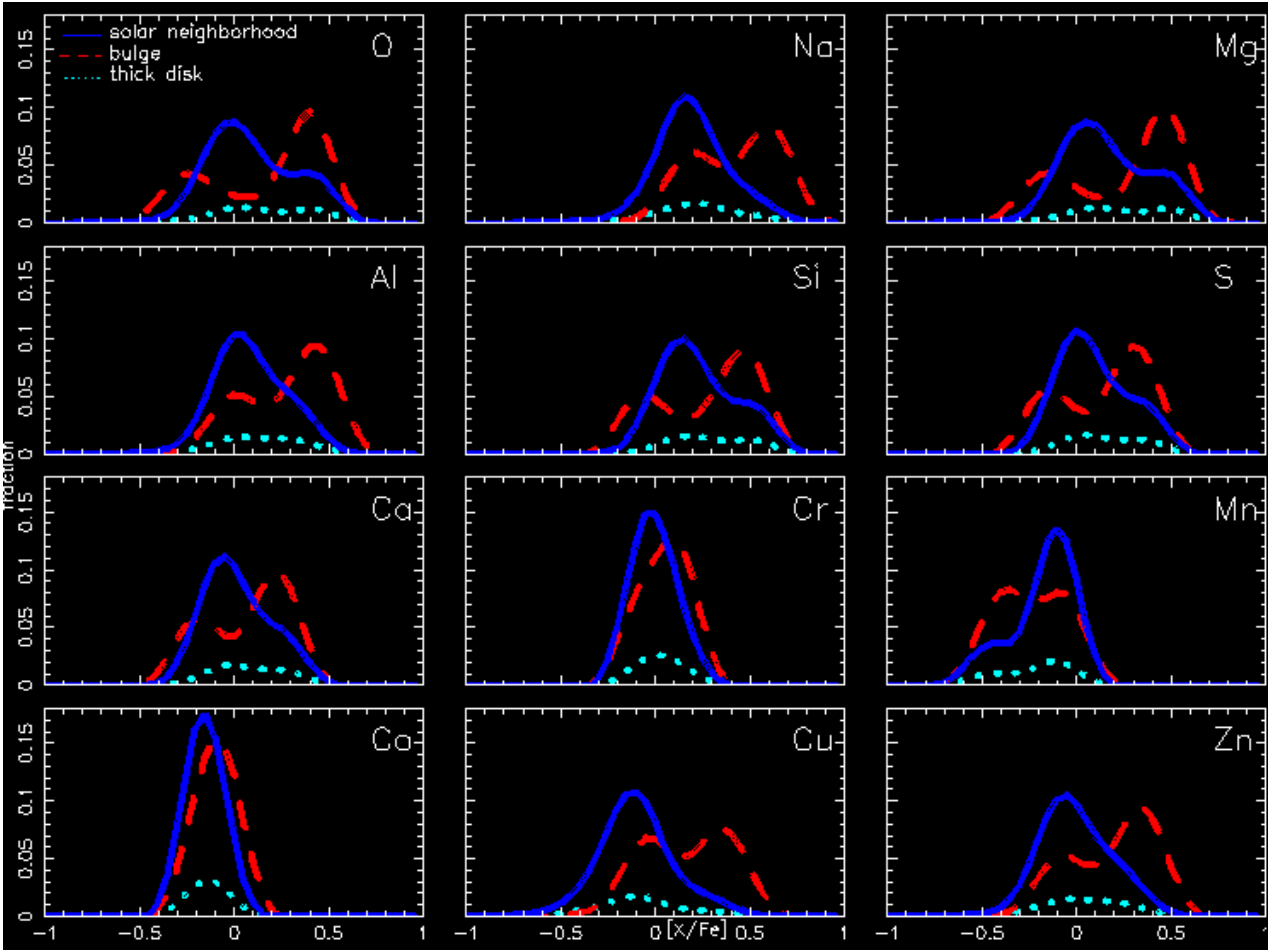
Observation: McWilliam & Rich (2004),
Lecureur et al. (2008)

Chemodynamical Simulation (CK & Nakasato 2011)



Chemodynamical Simulation (CK & Nakasato 2011)

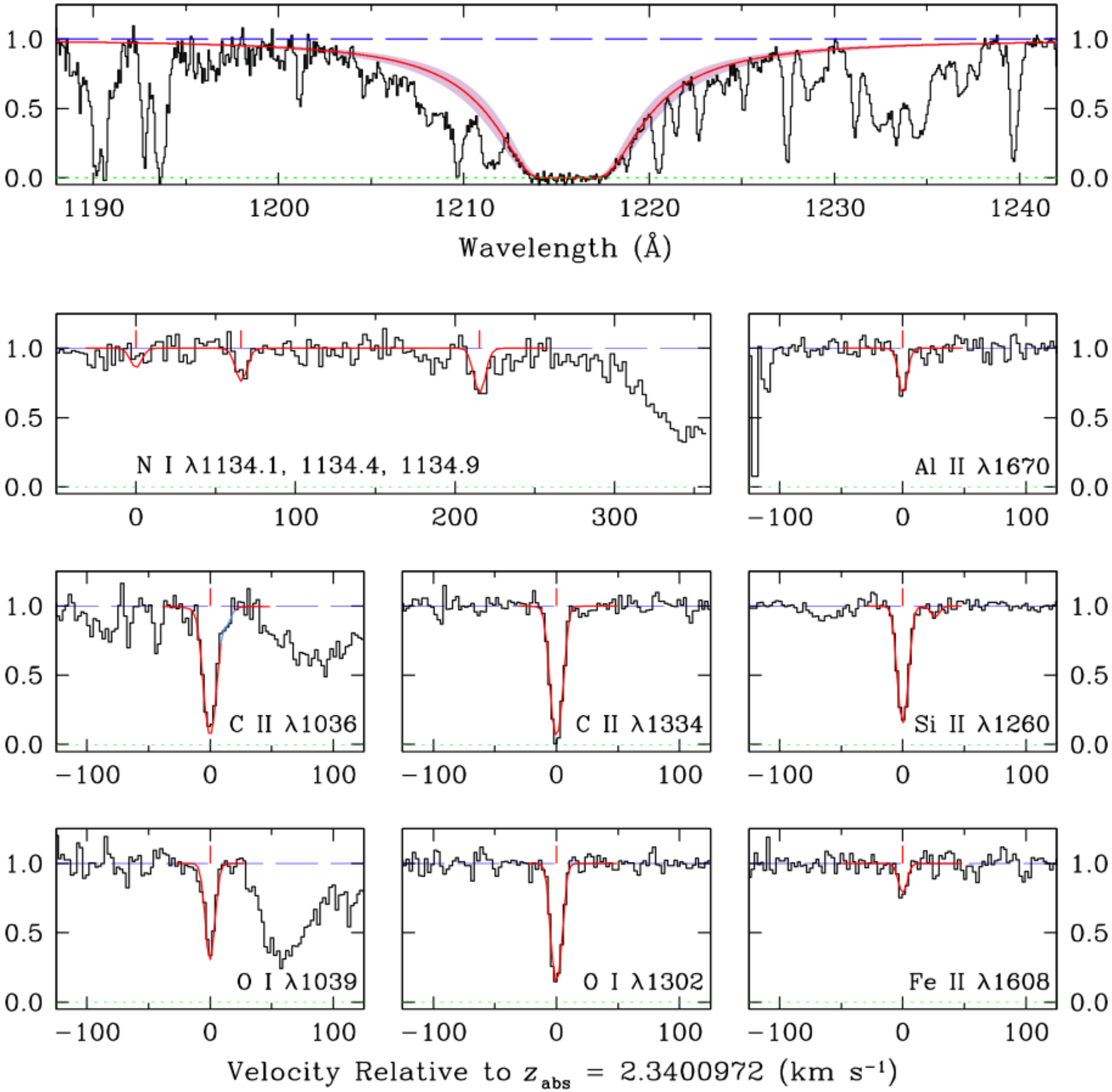




solar neighborhood
bulge
thick disk
O
Na
Mg
Al
Si
S
Ca
Cr
Mn
Co
Cu
Zn
fraction
[X/Fe]
0
0.05
0.1
0.15
−1
−0.5
0
0.5
1

Is this universal?

Very metal-poor DLA



SDSS + follow-up (Cooke, Pettini et al. 2011)

z=2.3400972

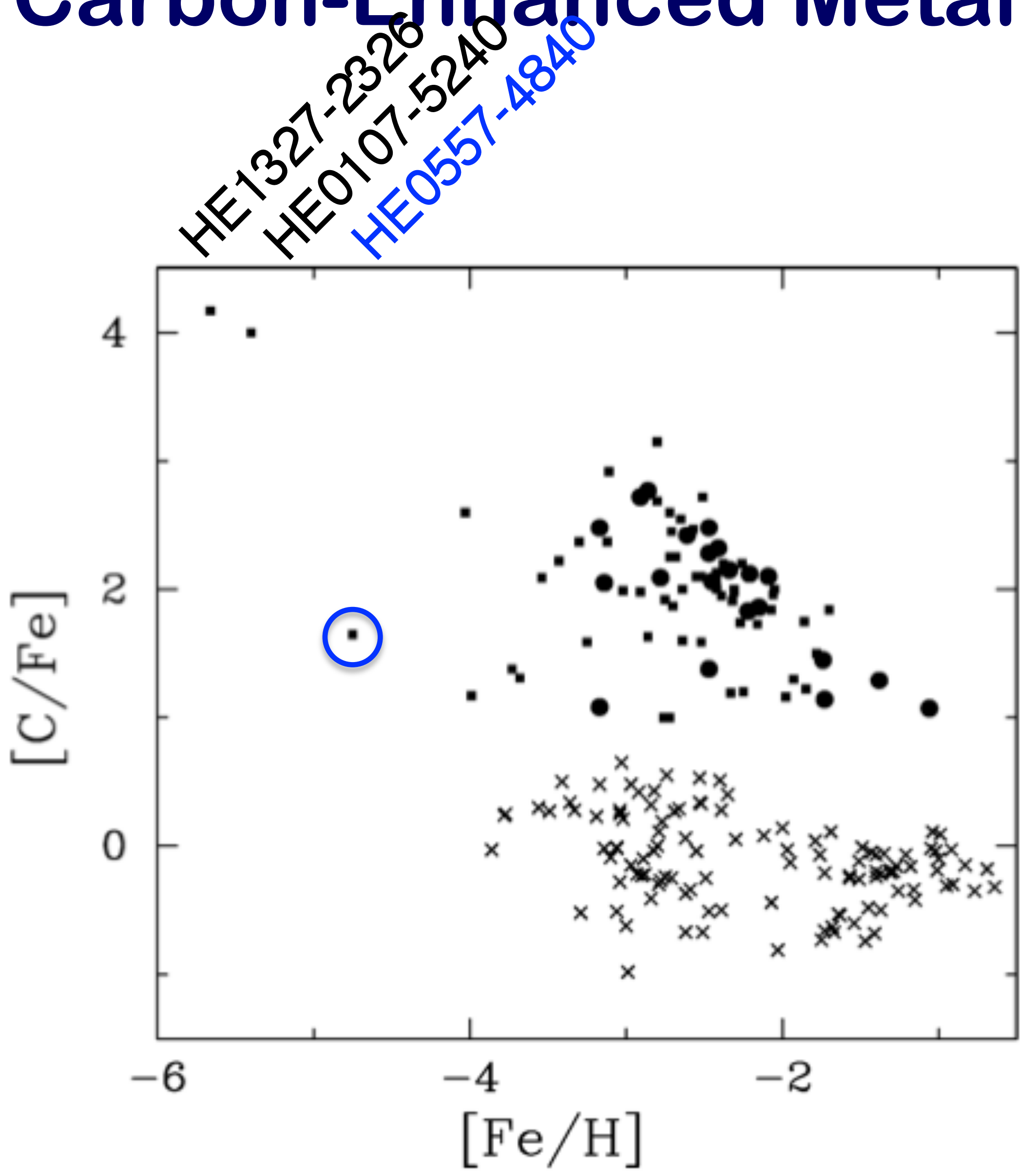
log N(HI)=20.55

[Fe/H]= –3

[C/Fe]= +1.55

Element	$\log (X/H)^{a}_{\odot}$	$[X/H]^{b}_{DLA}$
C	−3.61	−1.47
N	−4.22	−2.82
O	−3.34	−2.25
Al	−5.57	−3.25
Si	−4.49	−2.65
S	−4.85	$\leqslant -2.58$
Fe	−4.55	−3.02

Carbon-Enhanced Metal Poor (CEMP) Stars

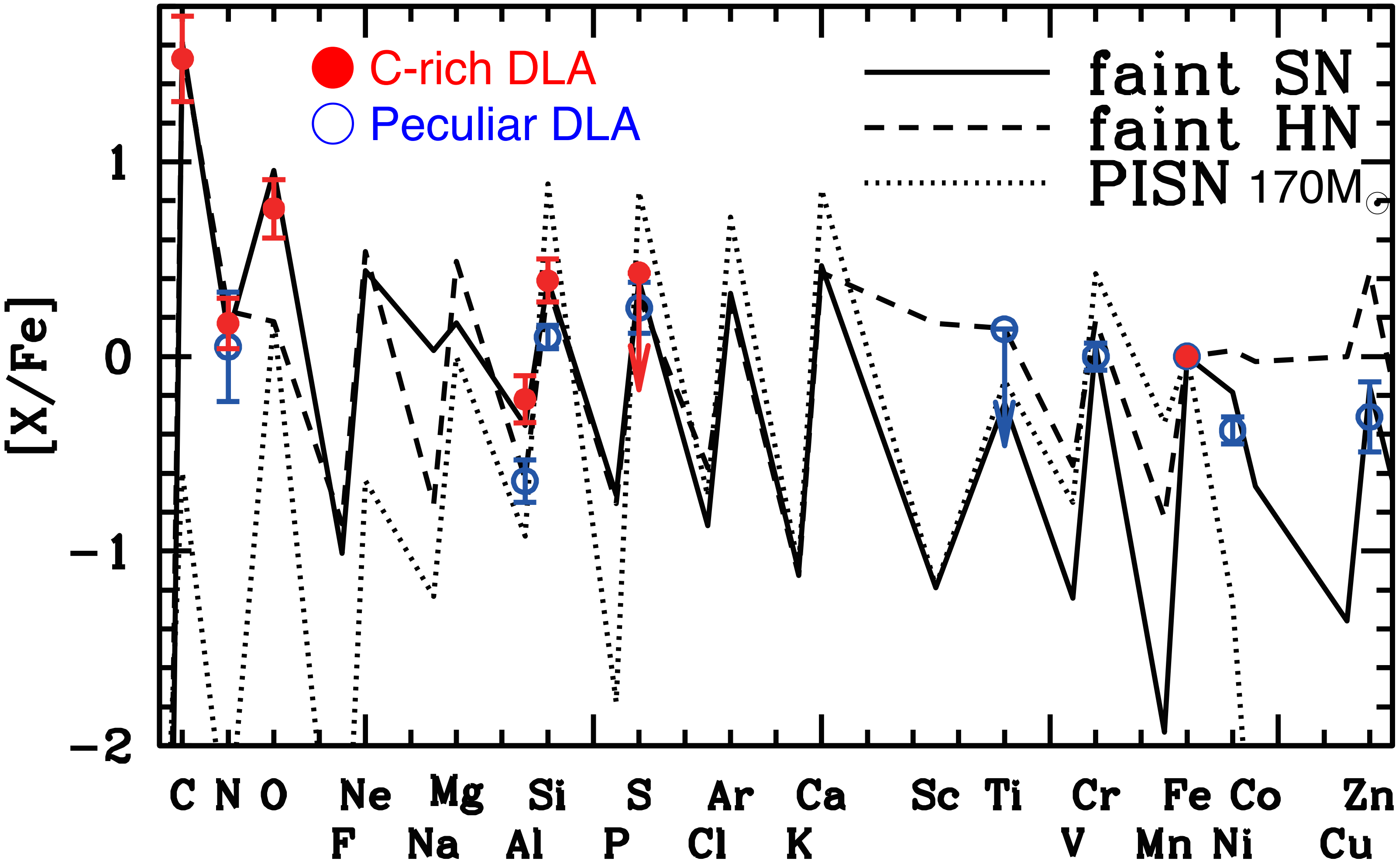


- Mass transfer from AGB star [redacted]ns (Suda et a[redacted]aro et al. 08; Izz[redacted]
  - bu[redacted]?
- Mass loss from rotating massive star (Meynet, Ekstroem & Maeder 2006)
  - [N/C]>0, high He. Fe-peak?
- Core-collapse supernova forming a blackhole (Umeda & Nomoto 2003; Iwamoto et al. 2005; Tominaga et al. 2007)
- Inter[redacted]n (Yoshii 19[redacted]3; but Frebe[redacted]2009)

10 – 25% of stars with [Fe/H] < –2 (Aoki 2010)

C-rich DLA vs SN models ($25M_\odot$,Z=0)

CK, Tominaga, Nomoto 2011, ApJL, 730, 14



— M_{in}–M_{out} = 1.76–6.14$M_\odot$, f = 0.008, M(^{56}Ni) = 0.0018$M_\odot$, M_{BH}=6.1$M_\odot$

-- -- M_{in}–M_{out} = 2.20–6.30$M_\odot$, f = 0.004, M(^{56}Ni) = 0.0014$M_\odot$, M_{BH}=6.1$M_\odot$

Conclusions

- At Z>0, the observed elemental abundances are well reproduced with chemodynamical simulations of a MW-type galaxy including "normal" SN, HN(E>10^{51}erg,M>20$M_\odot$), SNIa(Z), and AGB.
- In CDM picture, without major merger @ z<2
  - "Classical" **bulge** formed by assembly at z>2, have old age(>10 Gyr (80%)), high [α/Fe], high [(Na,Al,Cu)/Fe], low [Mn/Fe]
  - **Disk** formed inside-out with continuous SF, have radial/vertical metallicity gradients, younger age (<8 Gyr (50%)), lower [α/Fe]
  - Half of **thick disk** stars have formed in merging subgalaxies, have high [α/Fe], but [(Na,Al,Cu)/Fe]~0, low [Mn/Fe]

  can be tested with RAVE, SEGUE, HERMES@AAT(2012), APOGEE, ngCFHT(2020).
- The observed abundance pattern of the very metal-poor C-rich DLA @ [Fe/H]= –3 suggests that chemical enrichment by the first stars is driven not by PISN (170-300$M_\odot$ stars) but by core-collapse SNe (~20–50$M_\odot$ stars). – consistent with recent simulations of primordial SF (e.g., Greif et al. 11).
- Do not have to change IMF, except for dSphs (very low SF system?)