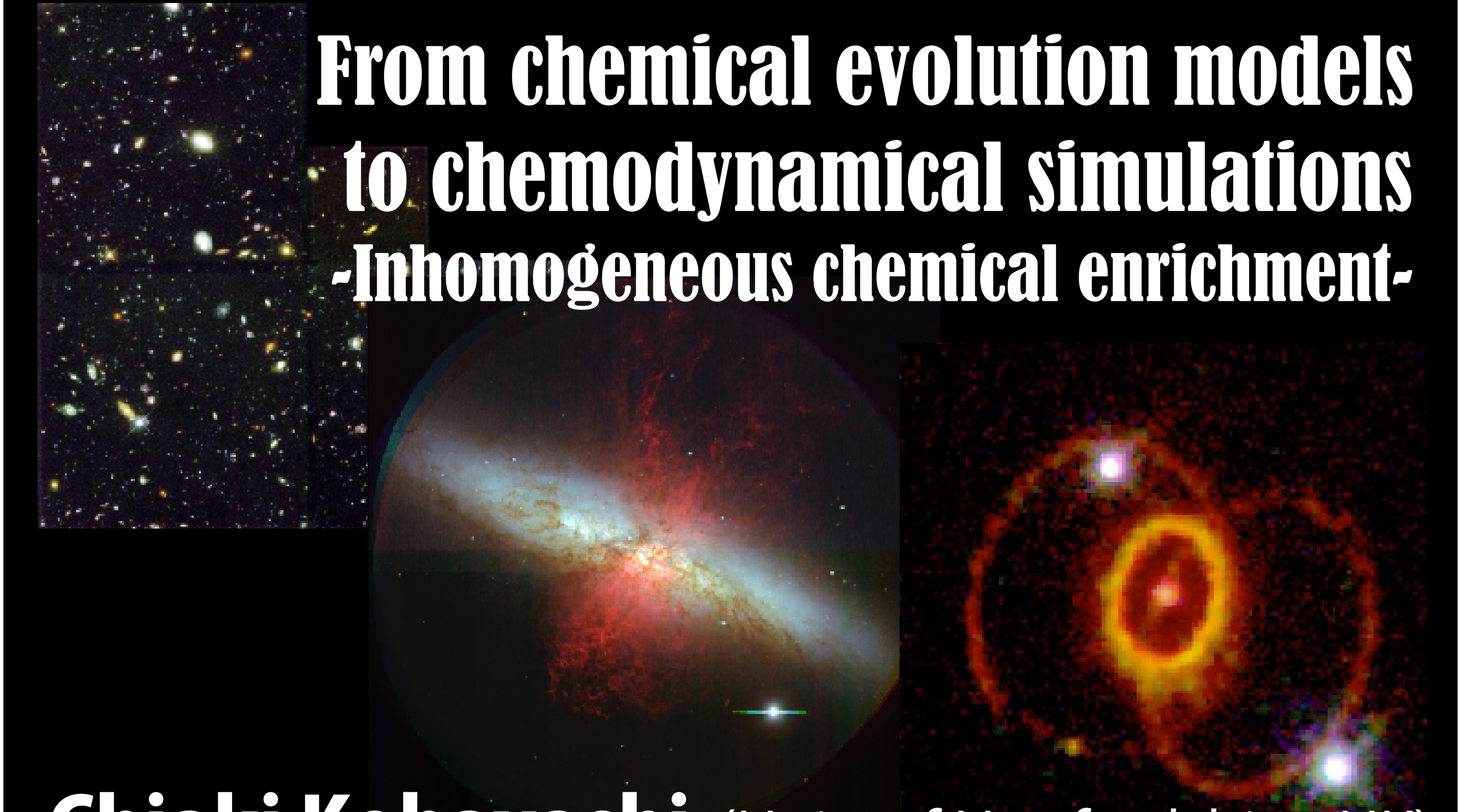
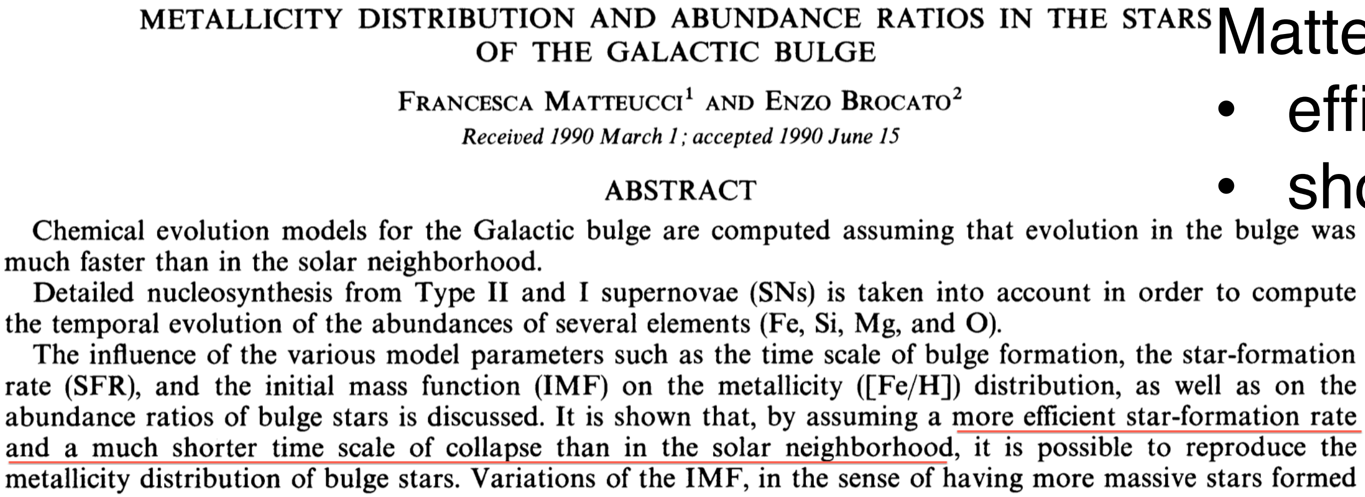
From chemical evolution models to chemodynamical simulations

-Inhomogeneous chemical enrichment-



Chiaki Kobayashi (Univ. of Hertfordshire, UK)

Thanks: This presentation file made on D. Yong's computer.



METALLICITY DISTRIBUTION AND ABUNDANCE RATIOS IN THE STARS OF THE GALACTIC BULGE

FRANCESCA MATTEUCCI[1] AND ENZO BROCATO[2]

Received 1990 March 1; accepted 1990 June 15

ABSTRACT

Chemical evolution models for the Galactic bulge are computed assuming that evolution in the bulge was much faster than in the solar neighborhood.

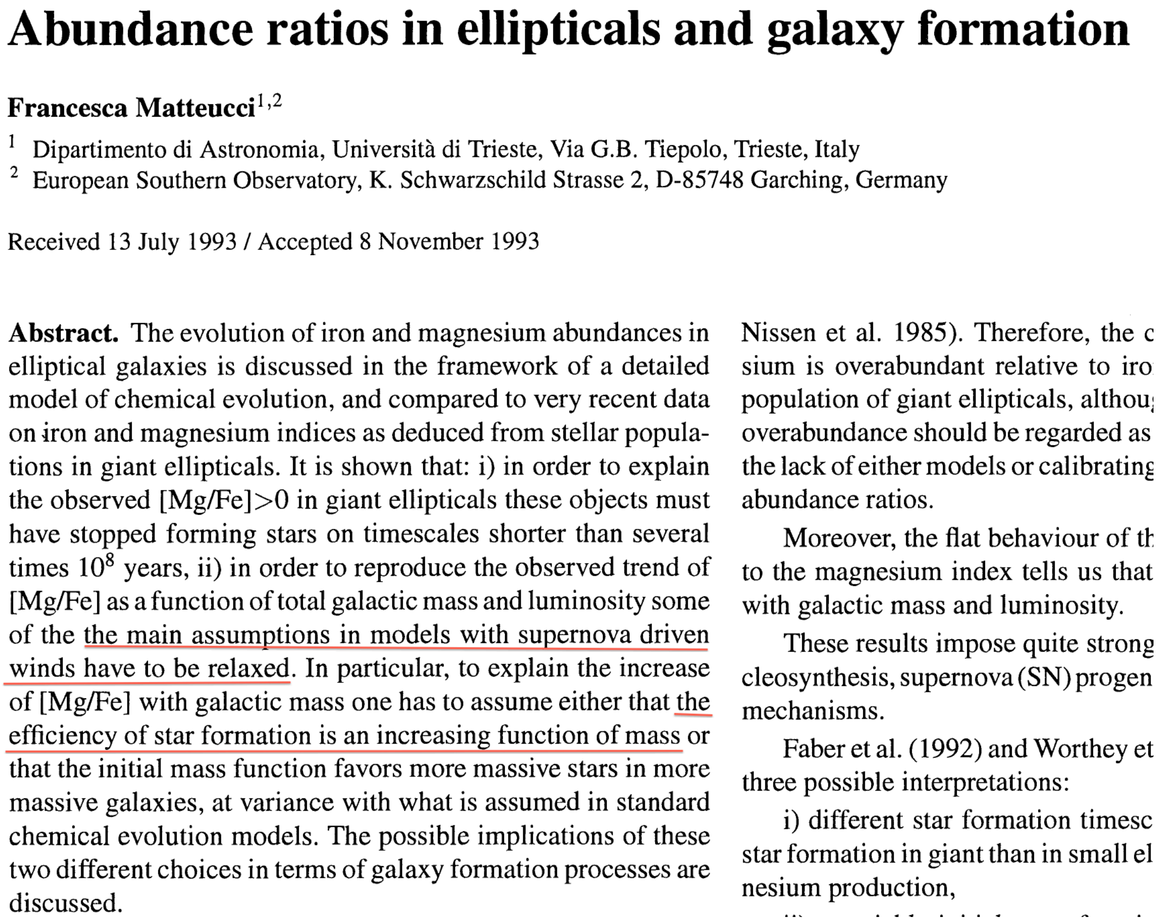
Detailed nucleosynthesis from Type II and I supernovae (SNs) is taken into account in order to compute the temporal evolution of the abundances of several elements (Fe, Si, Mg, and O).

The influence of the various model parameters such as the time scale of bulge formation, the star-formation rate (SFR), and the initial mass function (IMF) on the metallicity ([Fe/H]) distribution, as well as on the abundance ratios of bulge stars is discussed. It is shown that, by assuming a more efficient star-formation rate and a much shorter time scale of collapse than in the solar neighborhood, it is possible to reproduce the metallicity distribution of bulge stars. Variations of the IMF, in the sense of having more massive stars formed
in the bulge than in the region of the solar vicinity impro
cerns the position of the metallicity peak. However, given
observation relative to the IMF, no firm conclusions are all

Finally, we demonstrate that, due only to the faster evol
borhood and irrespective of the chosen IMF, the [O, Mg, S
different from those found for stars in the solar vicinity,
abundant ($\simeq +0.5$ dex) with respect to iron in stars with
result applies also to elliptical galaxies and its importance
ratios observed in halo and disk stars in the solar vicinity i

Matteucci & Brocato 90

- efficient SFR
- shorter timescale



Abundance ratios in ellipticals and galaxy formation

Francesca Matteucci[1,2]

[1] Dipartimento di Astronomia, Università di Trieste, Via G.B. Tiepolo, Trieste, Italy
[2] European Southern Observatory, K. Schwarzschild Strasse 2, D-85748 Garching, Germany

Received 13 July 1993 / Accepted 8 November 1993

Abstract. The evolution of iron and magnesium abundances in elliptical galaxies is discussed in the framework of a detailed model of chemical evolution, and compared to very recent data on iron and magnesium indices as deduced from stellar populations in giant ellipticals. It is shown that: i) in order to explain the observed [Mg/Fe]>0 in giant ellipticals these objects must have stopped forming stars on timescales shorter than several times 10^8 years, ii) in order to reproduce the observed trend of [Mg/Fe] as a function of total galactic mass and luminosity some of the the main assumptions in models with supernova driven winds have to be relaxed. In particular, to explain the increase of [Mg/Fe] with galactic mass one has to assume either that the efficiency of star formation is an increasing function of mass or that the initial mass function favors more massive stars in more massive galaxies, at variance with what is assumed in standard chemical evolution models. The possible implications of these two different choices in terms of galaxy formation processes are discussed.

Nissen et al. 1985). Therefore, the c
sium is overabundant relative to iro
population of giant ellipticals, althou
overabundance should be regarded as
the lack of either models or calibrating
abundance ratios.

Moreover, the flat behaviour of th
to the magnesium index tells us that
with galactic mass and luminosity.

These results impose quite strong
cleosynthesis, supernova (SN) progen
mechanisms.

Faber et al. (1992) and Worthey et
three possible interpretations:

i) different star formation timesc
star formation in giant than in small el
nesium production,

Matteucci 94

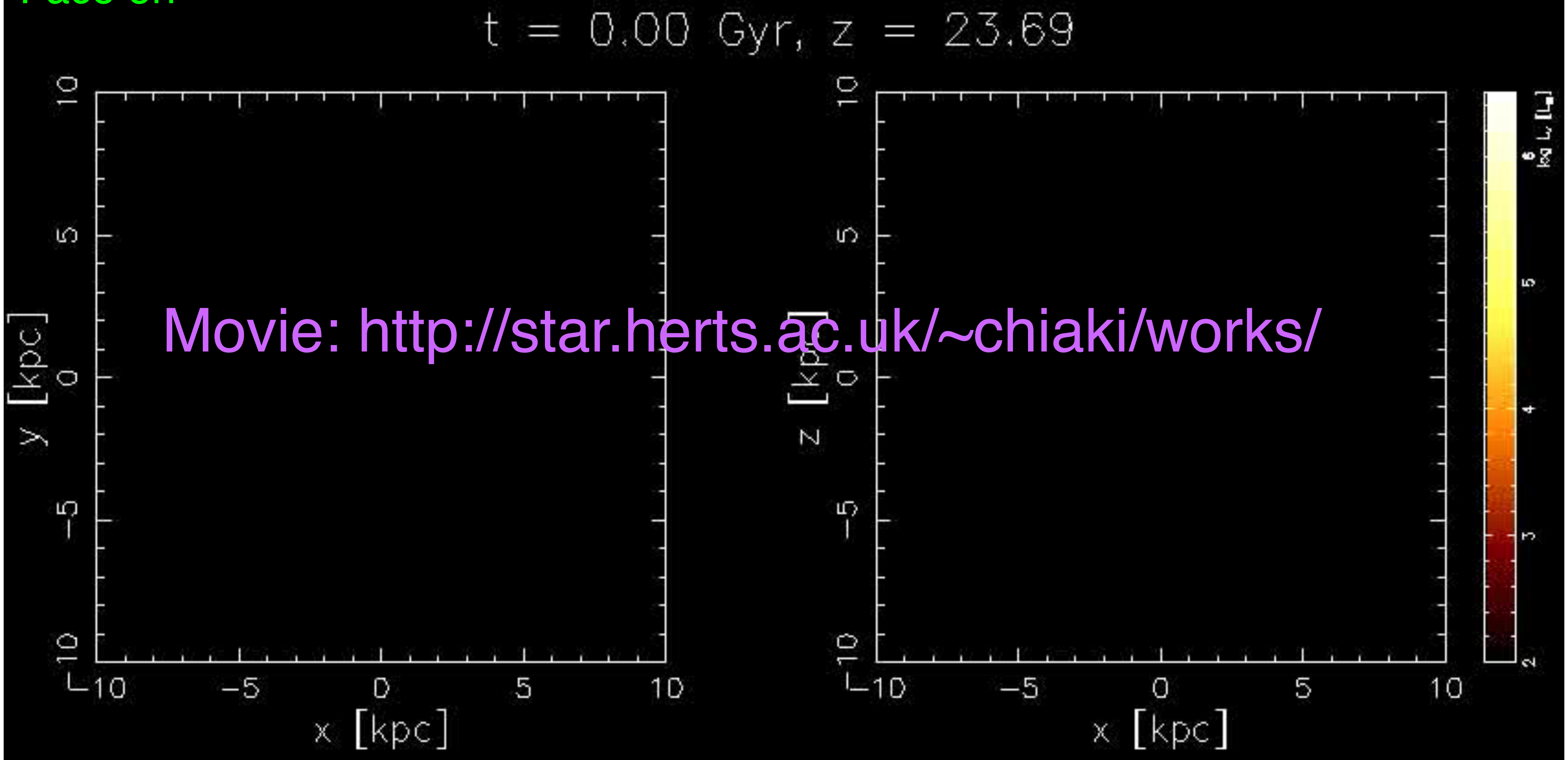
- inverse galactic winds
- increasing SF efficiency

Milky Way-type 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

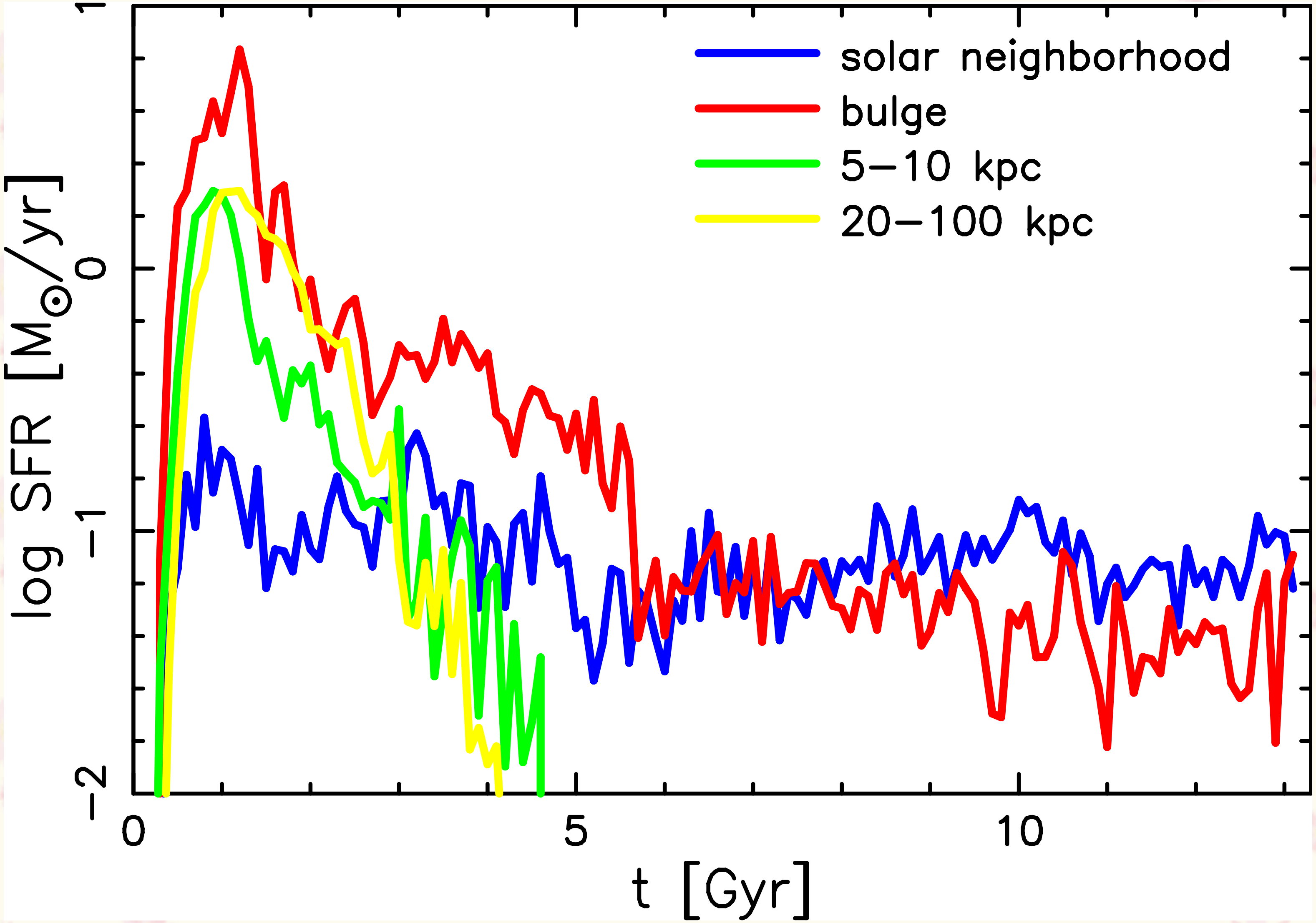
Edge on



Movie: http://star.herts.ac.uk/~chiaki/works/

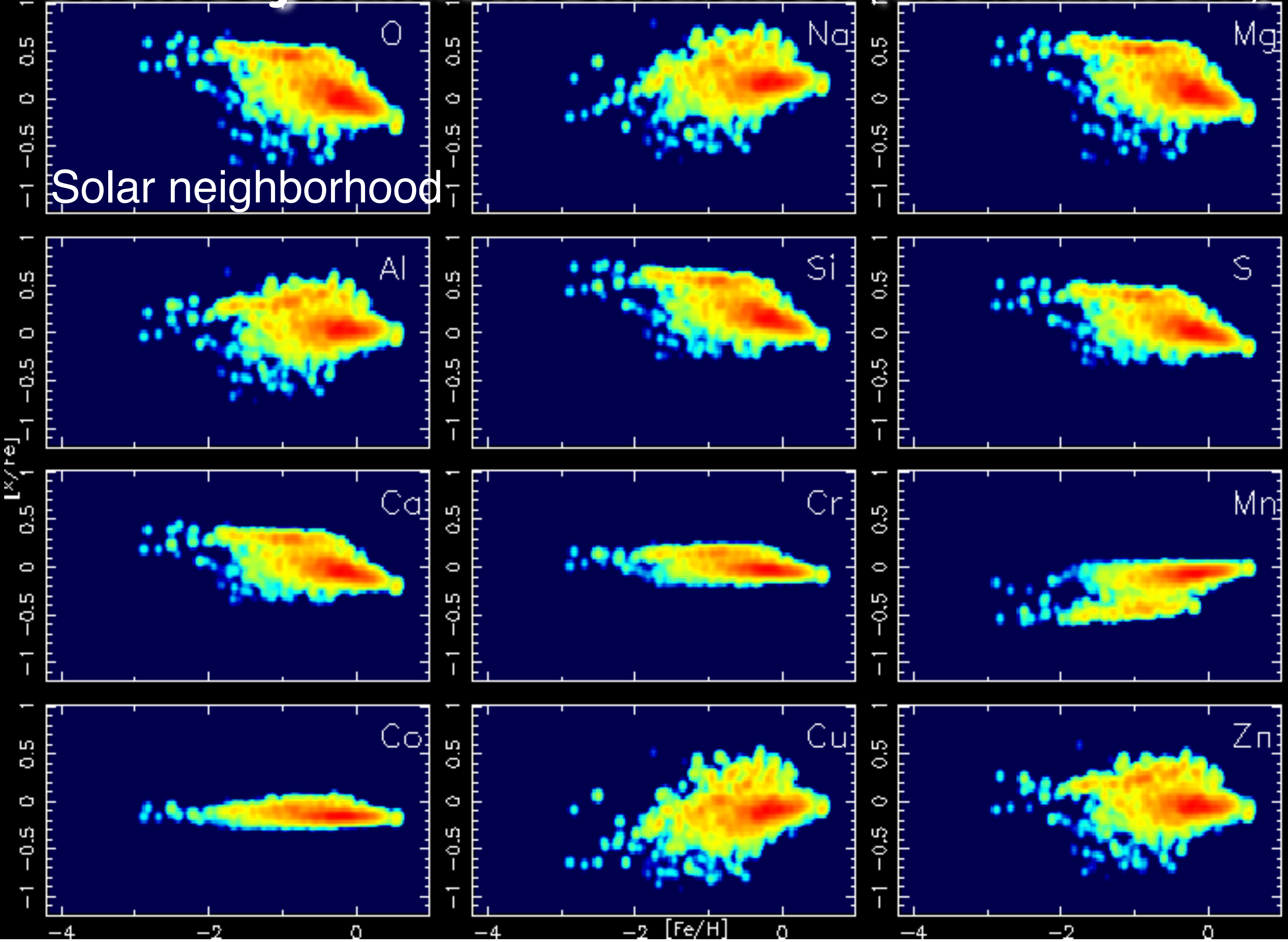
Star Formation History depends on environment

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

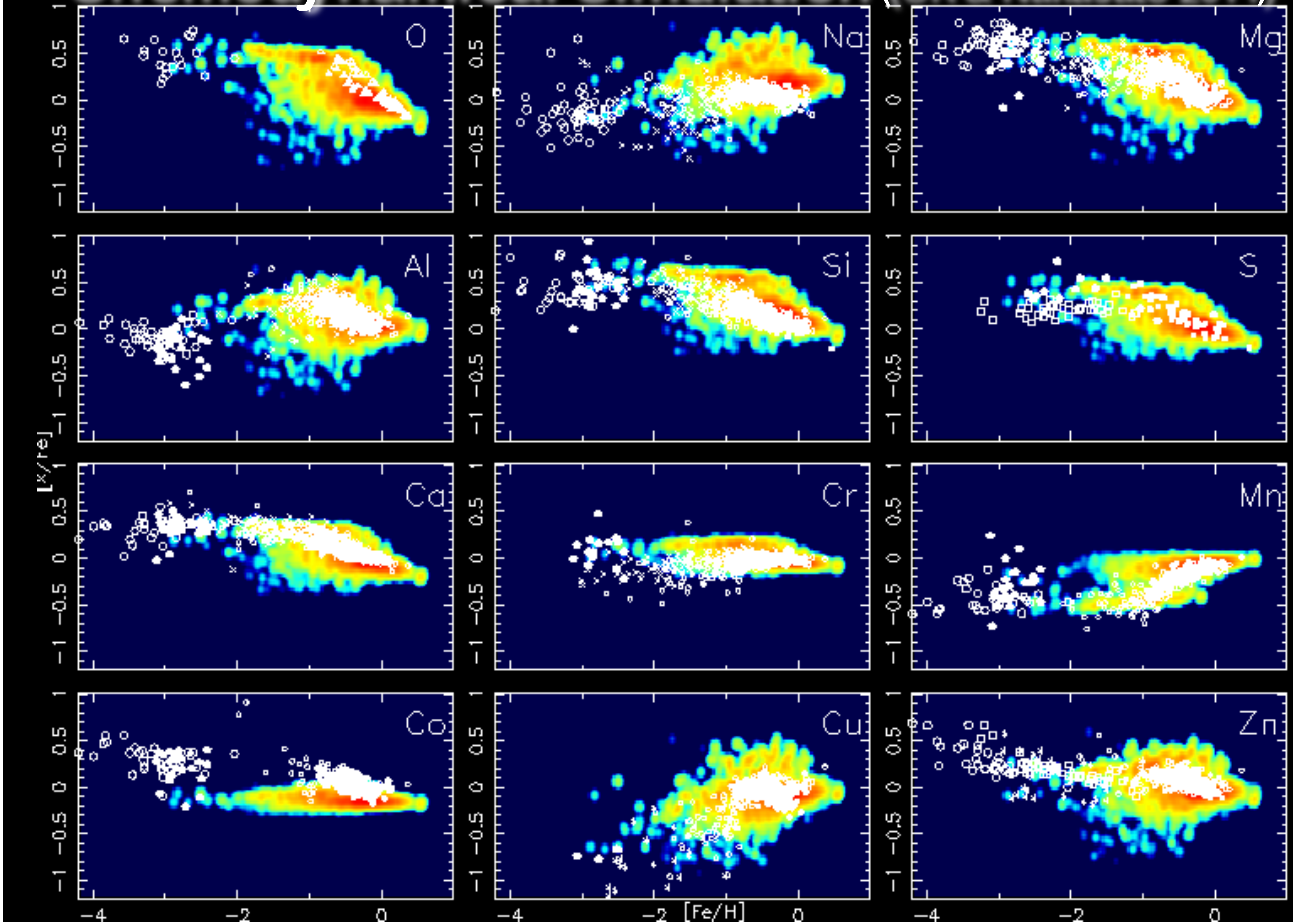


CK & Nakasato 2011

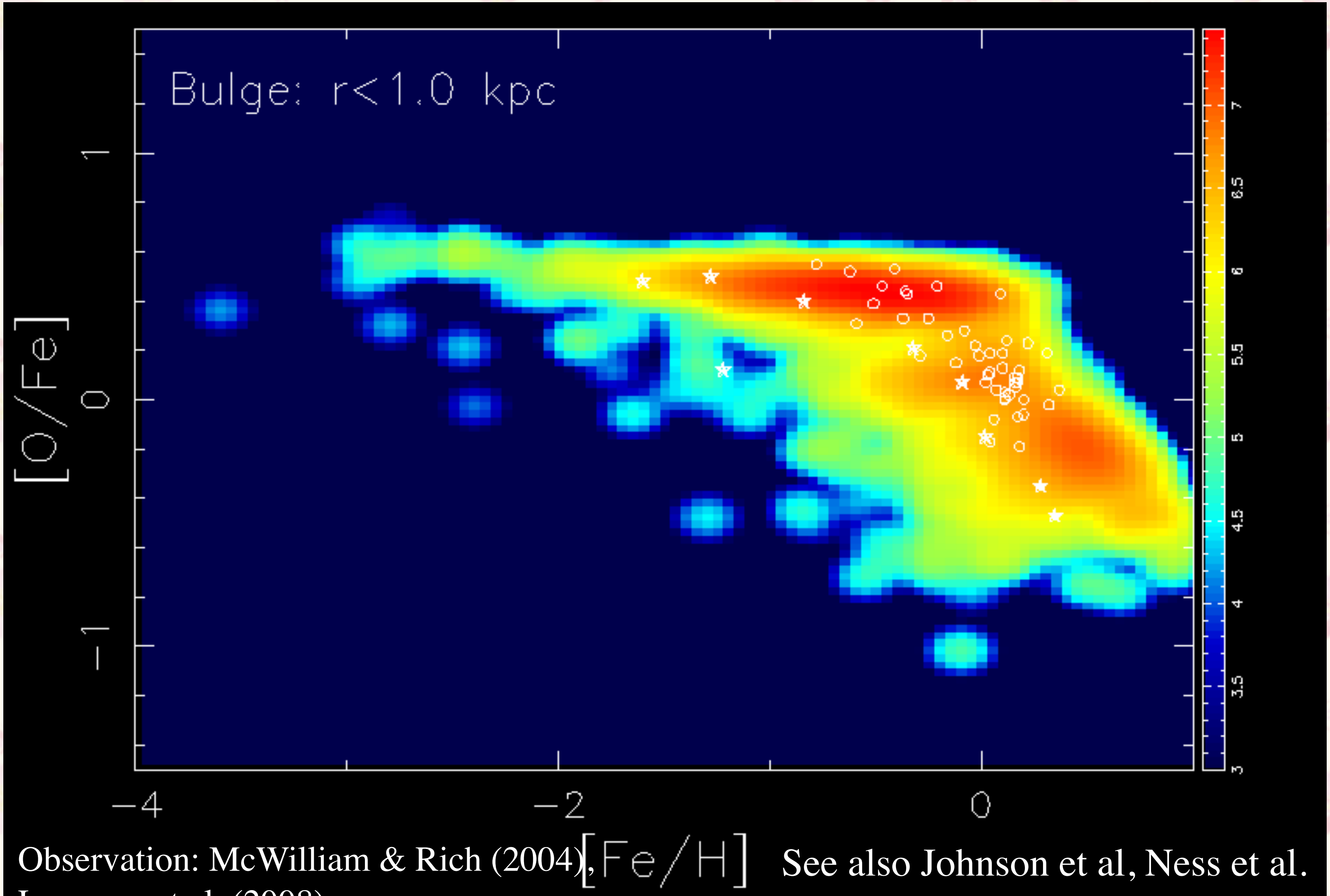
Chemodynamical Simulation (CK & Nakasato 2011)


Solar neighborhood

Chemodynamical Simulation (CK & Nakasato 2011)



Bulge – old, metal-rich, α-enhanced

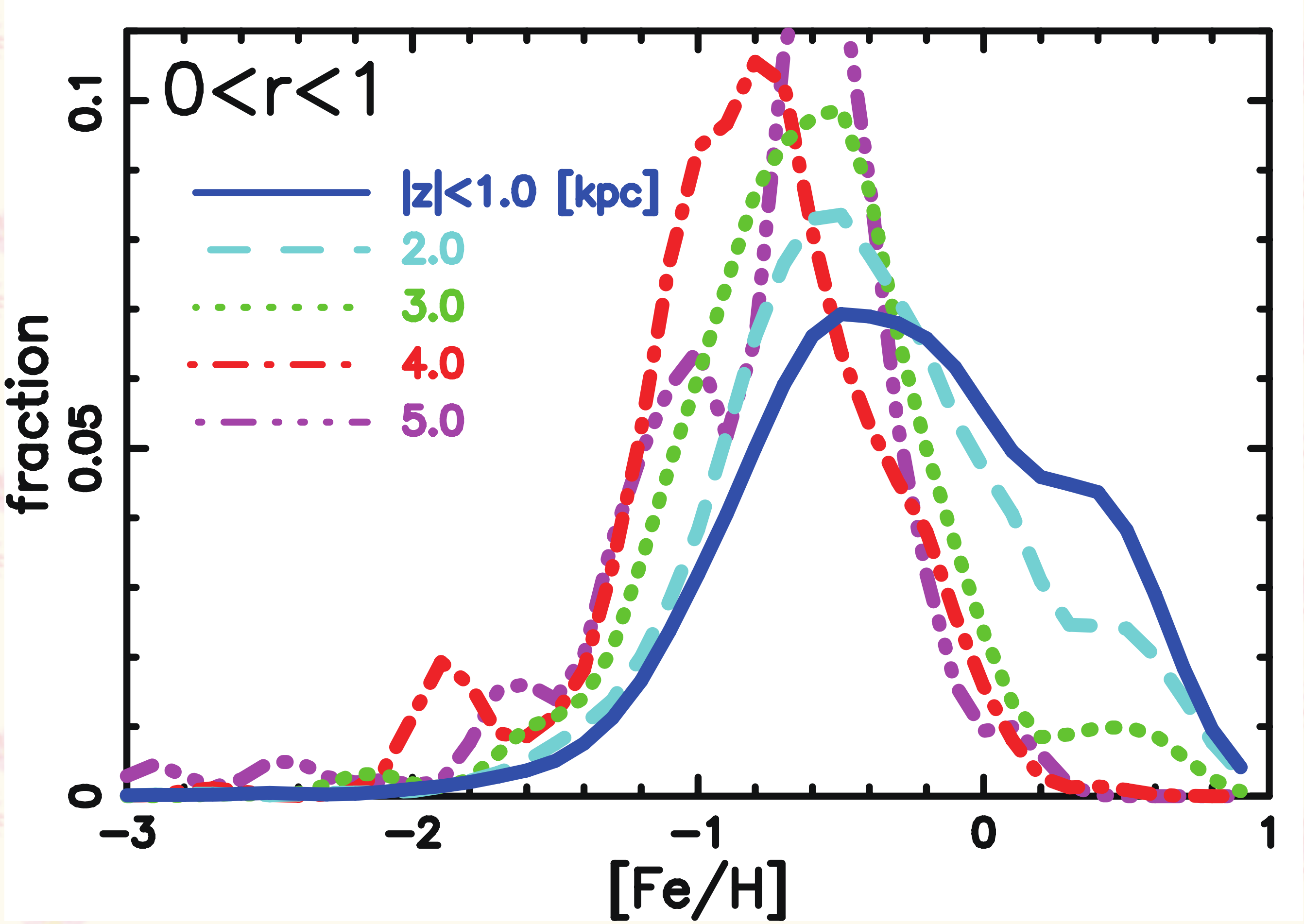


Observation: McWilliam & Rich (2004), Lecureur et al. (2008)

See also Johnson et al, Ness et al.

Vertical gradient in Bulge MDF

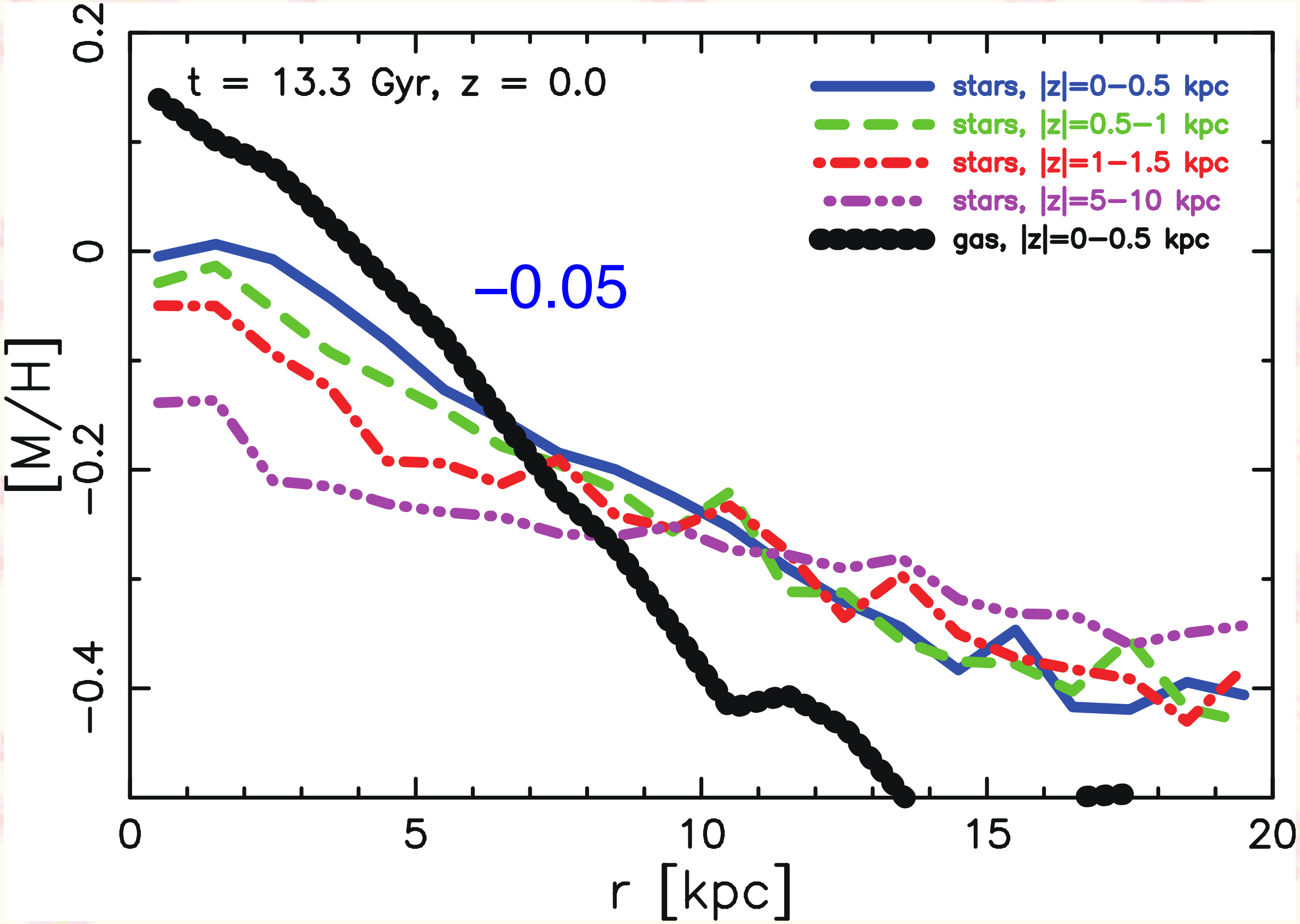
- The number of metal-rich (low [α/Fe]) stars decreases & metal-poor stars increase at higher latitudes (Zoccali+ 08; Bensby+ 11; Hill+ 11; Uttenthaler+ 12)



CK 2013

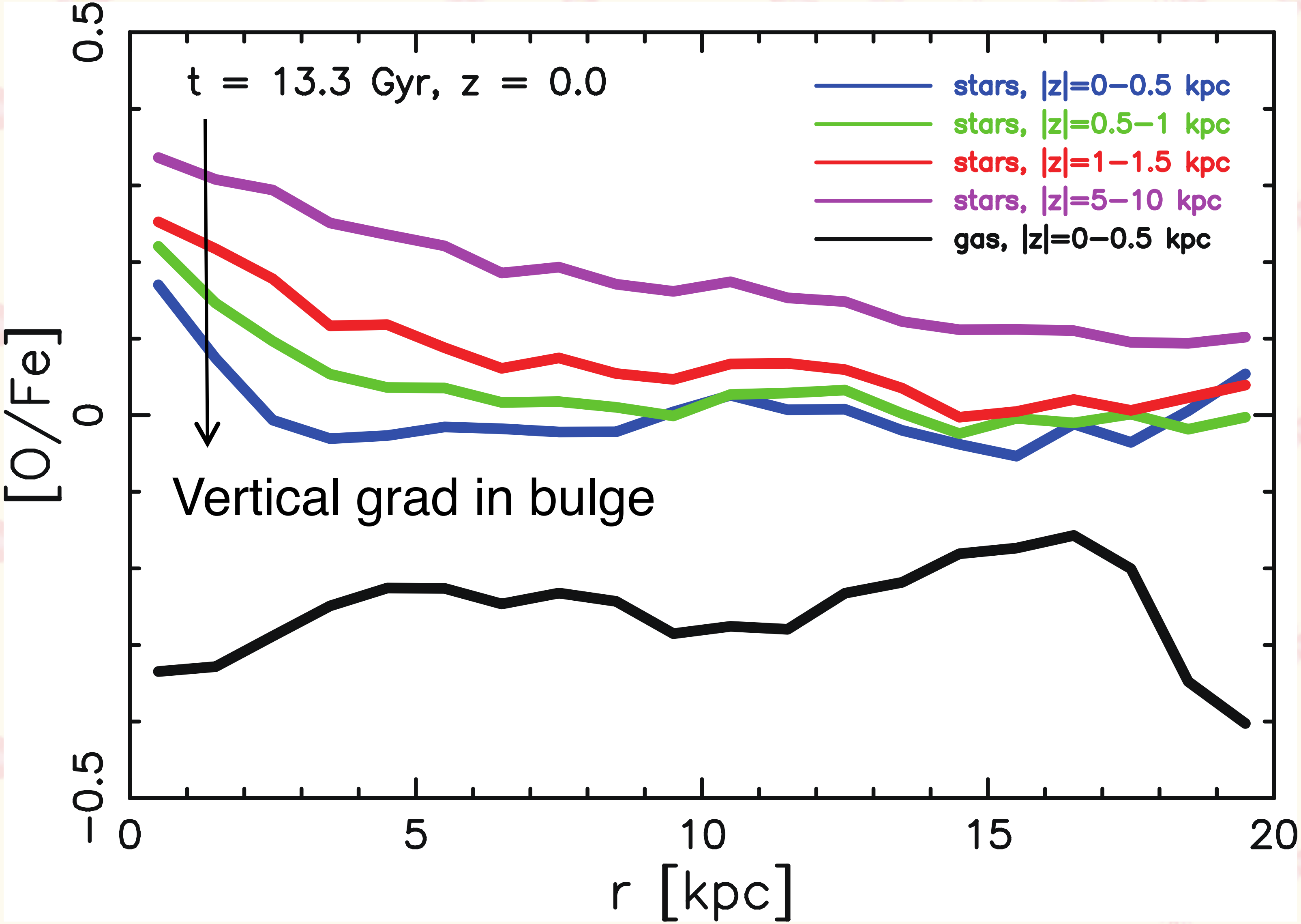
Disk – inside-out formation

- Metallicity Gradients: flatter at higher lzl (Cheng et al. 12), steeper at higher z (Jones et al. 10; Yuan et al. 11).



CK & Nakasato 2011

No [α/Fe] Gradients in disks



CK 2013

Inhomogeneous chemical enrichment

Variation for **in situ** component

I. Local variation in SF, inflow, outflow, and metal flows.
II. Heavy elements are distributed via SWs SNe, and the elemental abundance ratios depend on M,Z,E etc.
III. The ISM may be mixed before the next star formation by other effects e.g., diffusion and turbulence.

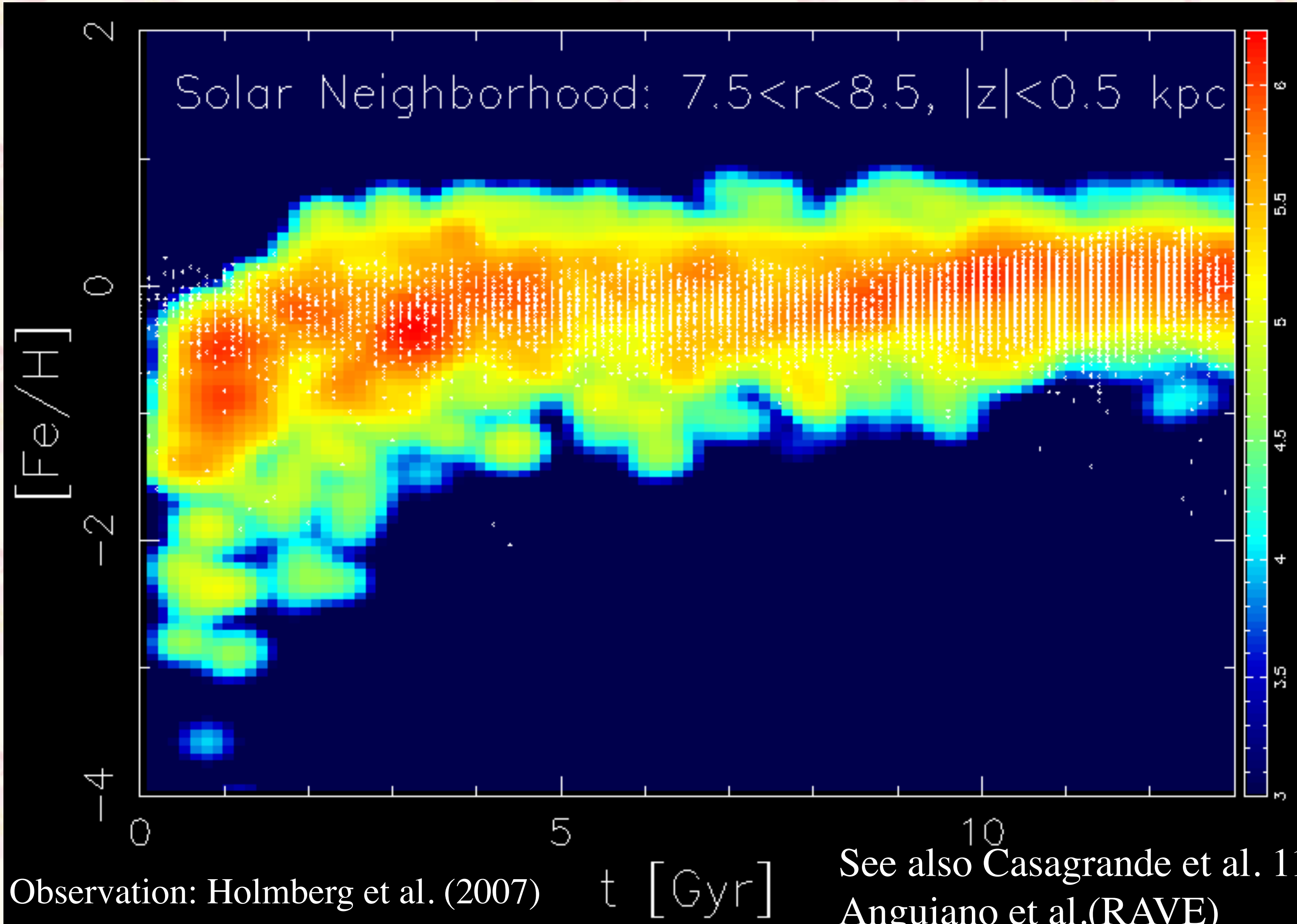
Additional effects

IV. Mixing of stars due to dynamical effects (**migration**, **accretion** of merging satellites).

Therefore

1. No strong Age-Metallicity Relation.
2. Most metal-poor stars ≠ Oldest stars
3. Long-lifetime sources (e.g., AGB) can contribute at low metallicities.

Age-Metallicity Relation

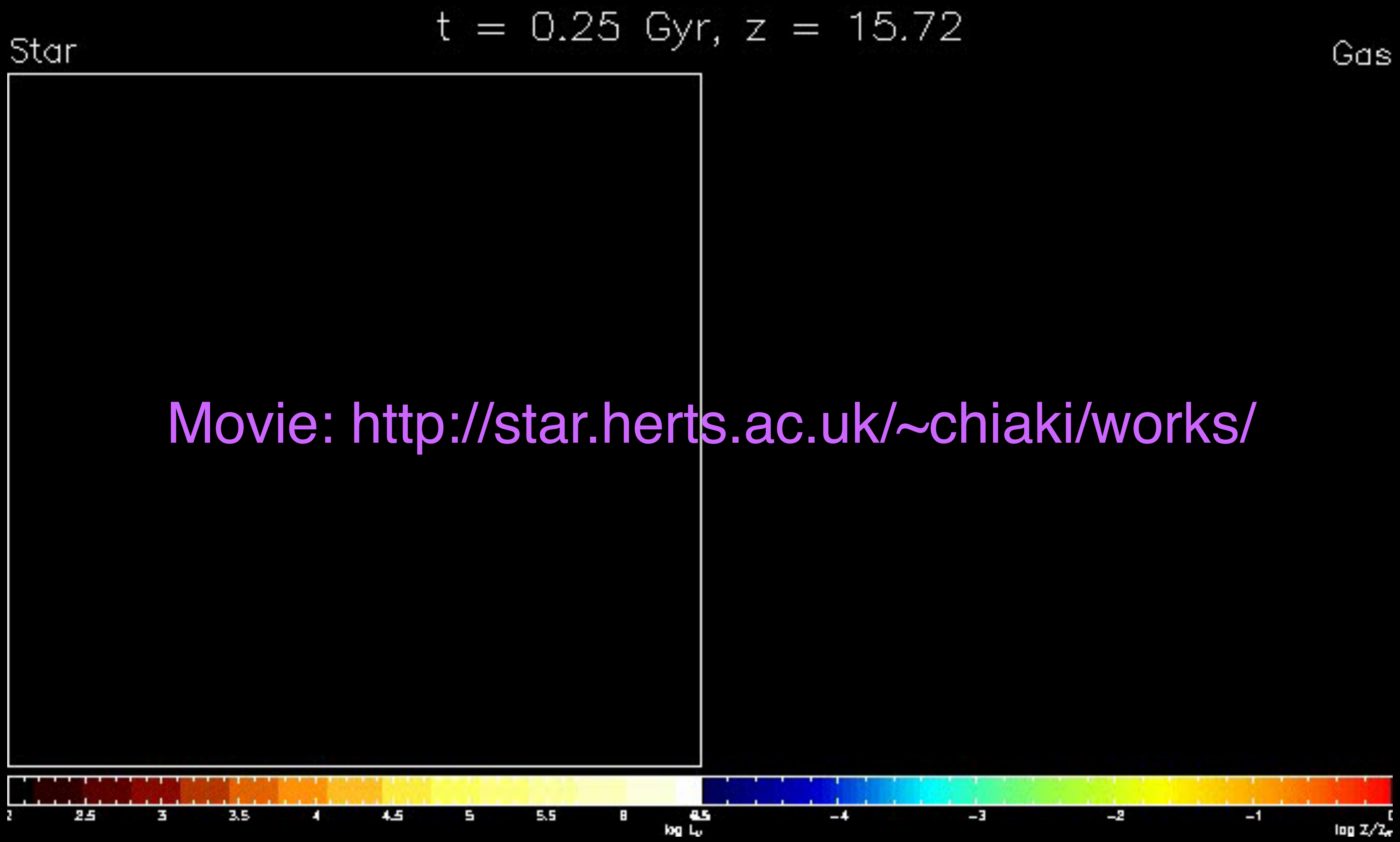


Observation: Holmberg et al. (2007)

See also Casagrande et al. 11;
Anguiano et al.(RAVE)

Connecting to other galaxies…

Cosmological Simulations



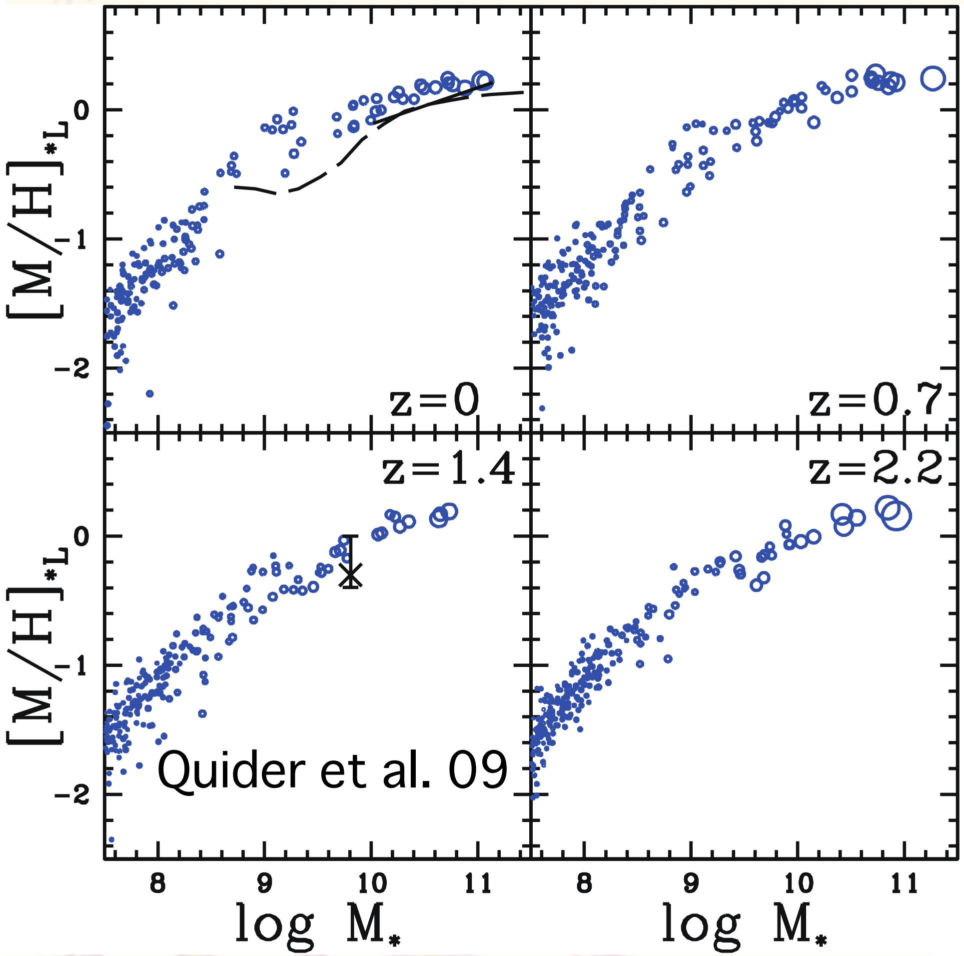
Movie: http://star.herts.ac.uk/~chiaki/works/

Stellar Luminosity Gas Metallicity

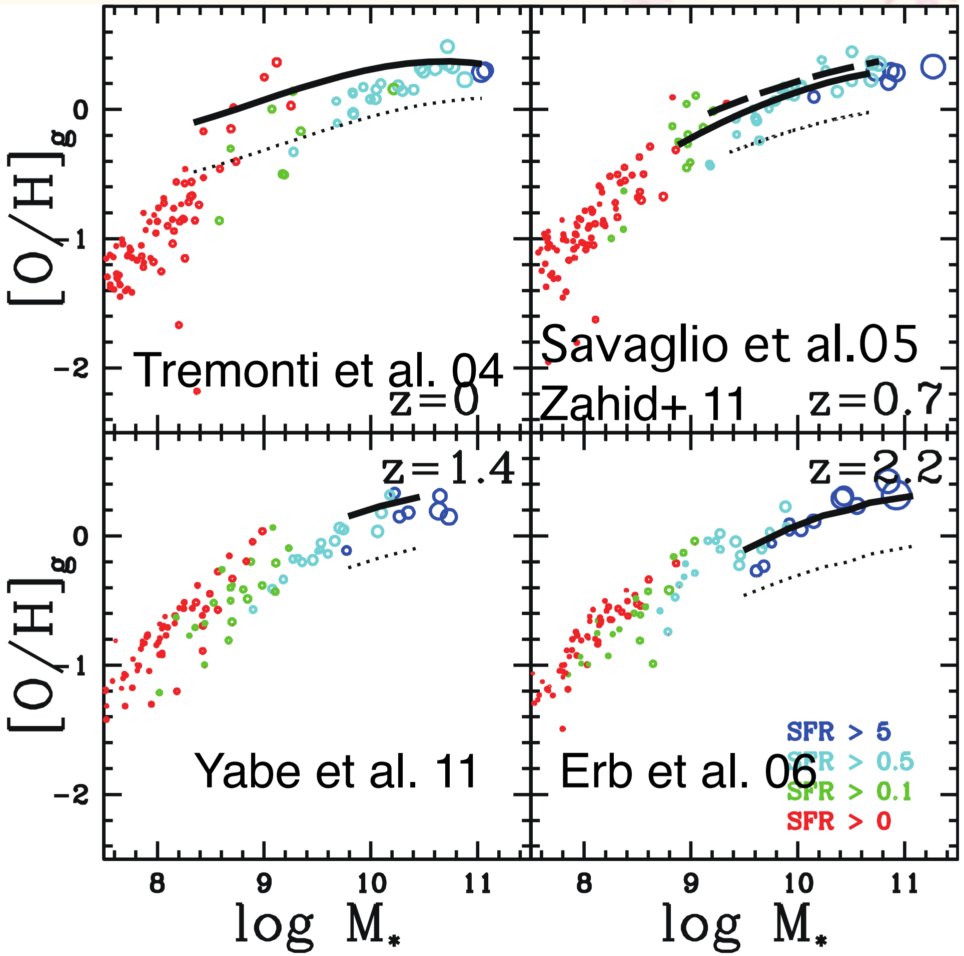
10Mpc; $N \sim 2 \times 128^3$; $m_{gas} \sim 10^7 M_\odot$; $H_0=70$, $\Omega_m=0.3$, $\Omega_\lambda=0.7$, $\Omega_b=0.04$, $n=1$, $\sigma_8=0.9$

Mass-Metallicity relations (without AGN)

Stellar Population r<10kpc



Gas emission weighted, r<10kpc



—— Es, center (Bender et al. 93)

— — SDSS (Gallazzi et al. 05)

—— R23 & O23 method

········ N2 method

CK+07; CK 13 with WMAP-7 cosmology

Summary+

In λCDM based chemo-hydro-dynamical simulations, chemical enrichment takes place **inhomogeneously**,

- **Disk**

  Inside-out. Z radial & vertical gradients exist, but **no [α/Fe] radial gradient**. Z radial gradient is steeper at higher-z (up to z~2).

- **Bulge**
  - Assembly at high-z. Mostly old, metal-rich, high [α/Fe], low [**Mn**/Fe], high [(**Na,Al,Cu,Zn**)/Fe]. **Z & [α/Fe] vertical gradients** exist**.**
  - Bar may form later (Scannapieco & Athanassoula 12), which will show boxy and cylindrical rotation.
- **Thick disk**
  - Half of stars have formed in merging subgalaxies.
- **Ellipticals**
  - Successive merging of gas-rich galaxies at high-z. Stars are old**. Z gradients** exist, the slope depends on the merging history.
  - Mass-metallicity relations originated from mass-dependent galactic winds. The [α/Fe] problem may be solved with AGN feedback.

Chemical evolution (namely elemental abundances and their gradients) are the key to understand galaxy formation & evolution.