MIXING OF CHEMICAL ELEMENTS IN GALAXY FORMATION MODELS

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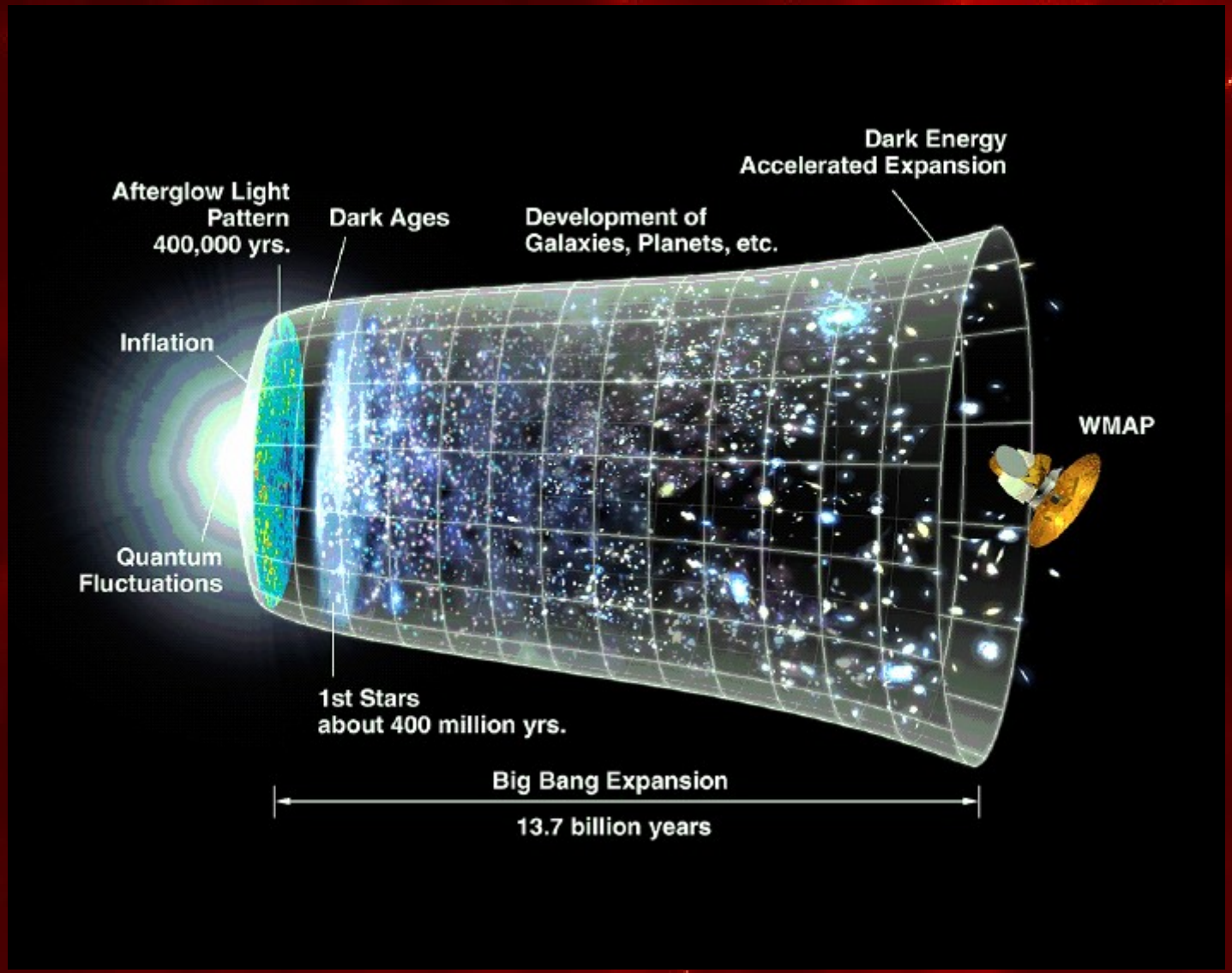
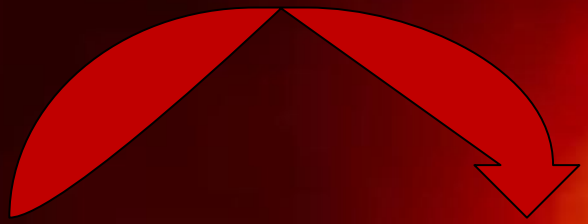

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

GALAXY FORMATION



Growth of the structure:
Collapse, infall and mergers

environmental effects:
starvation
strangulation, etc

Gas accretion, cooling and condens

star formation and stellar evolution

supernova feedback:
chemical + energy release

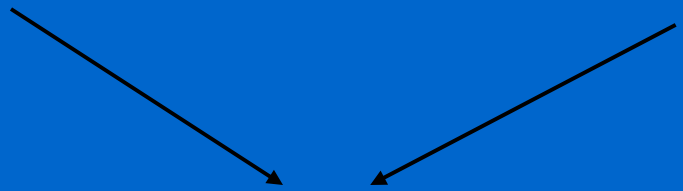
Supernova Feedback

CHEMICAL ENRICHMENT

- SN: Main source of heavy elements
- Change the cooling time

HYDRODYNAMICAL HEATING

- evaporates cold-dense gas
- galactic winds which can results in outflows or galactic fountains



- Regulates the star formation activity and enriches the ISM and IGM
- Affects the gas dynamics: disc formation

This might leave chemical fossils which can be used to track the formation history of a galaxy

CHEMICAL FEEDBACK

An incomplete list on chemical modeling in cosmological simulations:

- Raiteri et al. (1996; also Berczik 1999)→ SNII & SNIa; Fe & H
- Mosconi, Tissera, Lambas & Cora. (2001): SNII & SNIa, Eth.
- Lia, Portinari & Carraro (2002):detailed SE; diffusion
- Kawata & Gibson (2003): SNII, SNIa,IS; Eth +Ekin
- Springel & Hernquist (2003): Z + Twophases +Ekin
- Kobayashi (2004; et al. 2006):detailedSE; Eth +Ekin
- Scannapieco et al. (2005, 2006): SNII & SNIa + Multiphase+SNE
- Okamoto et al. 2006: SNII+SNIa+Twophases+Ekin
- Oppenhaimer & Dave (2006): SNII &SNIa + Twophases + Ekin
- Stinson et al. (2006): SNII&SNIa + cooling off
- Martinez-Serrano et al. (2008): detailedSE; diffusion
- Wiersma et al. (2009): detailedSE; smoothed metals+ Ekin

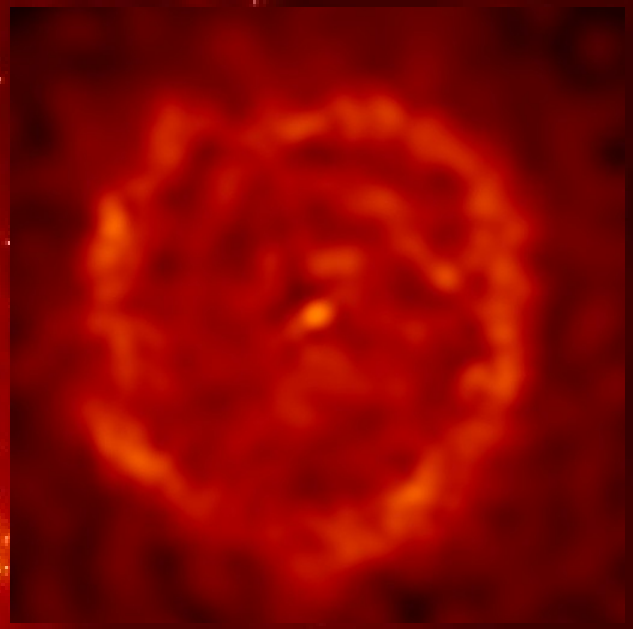
★ A GADGET-3 (Springel 2005) with:

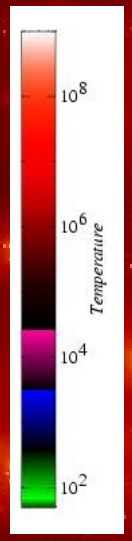
- ❖ Stochastic star formation (Springel & Hernquist 2002)
- ❖ Chemical enrichment from Type II and Ia Supernovae and metal-dependent cooling
- ❖ **Multiphase gas model: allows overlap of dense and diffuse gas**
- ❖ **Supernova feedback: distributes energy separately for cold and hot pre-defined phases (thermal feedback + reservoir for cold phases) within the context of the Multiphase gas model.**

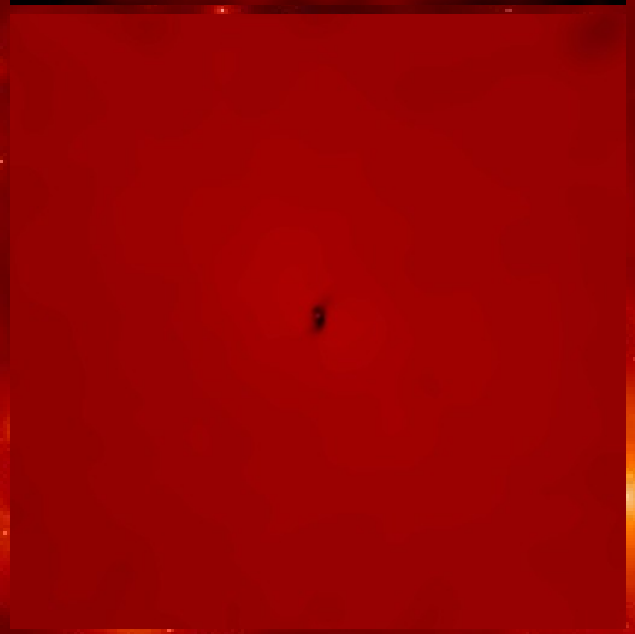
All this implemented without scale-dependent parameters ➔ well suited to run cosmological simulations where systems of different mass form simultaneously.

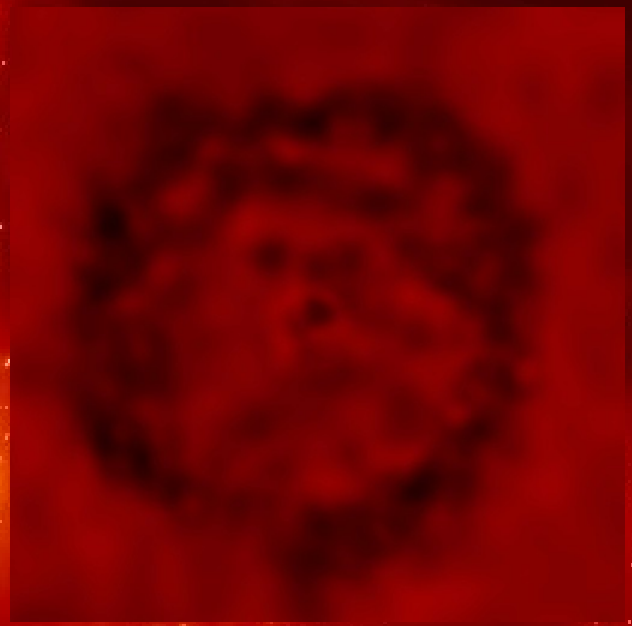
Scannapieco, Tissera, White & Springel 2005,2006,2008

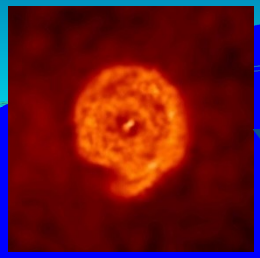
Milky Way Type galaxy: Multiphase ISM

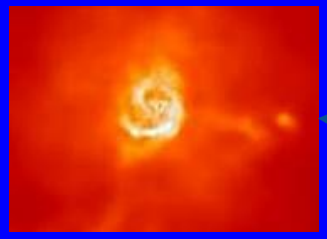


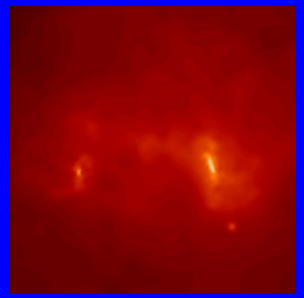


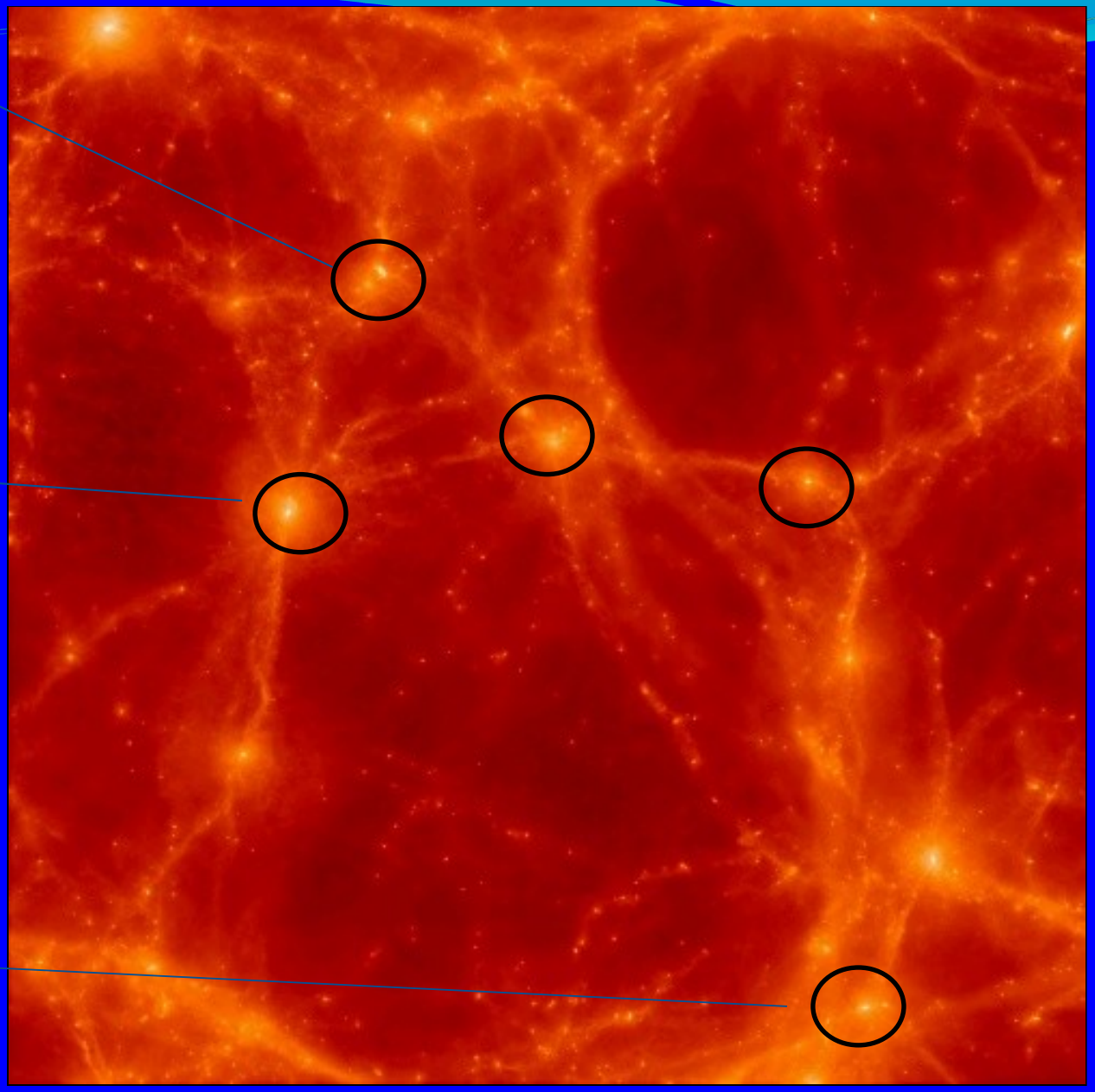












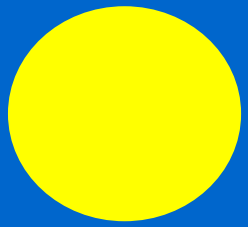
10 Mpc/h

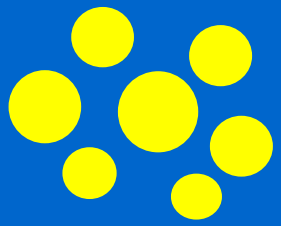
Patricia Tissera

CHEMICAL FEEDBACK

Mosconi, Tissera, Lambas & Cora 2001

Numerical space		Physical space	Need
Star particles	↔	Stellar populations	IMF: **SNe** **long-lived stars**





Type II Sne

- **M* > 8 Mo; typical life-times: ~ 10^6 yr**
- **Produce most O, Si, Ca, etc**

Type Ia Sne

- **Typical life-times: ~ Gyr**
- **Main source of iron (Fe)**

Chemical Yields

Intermediate mass stars (not included in our models)

CHEMICAL FEEDBACK

When SN explosions take place, they distribute metals according to the SPH technique. For a given chemical element x at a particle i,

$$Mx_i = \sum_j m_j/\rho_j \, Mx_i \;\; W(r_{ij},h_{ij})$$

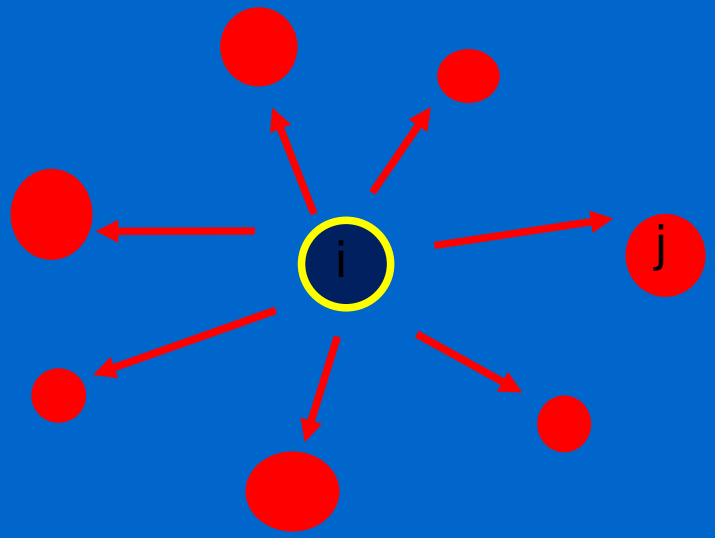
Each neigbhour will receive

$$Mx_j = m_j/\rho_j \, Mx_i \;\; W(r_{ij},h_{ij})$$

Metal mixing at small scales

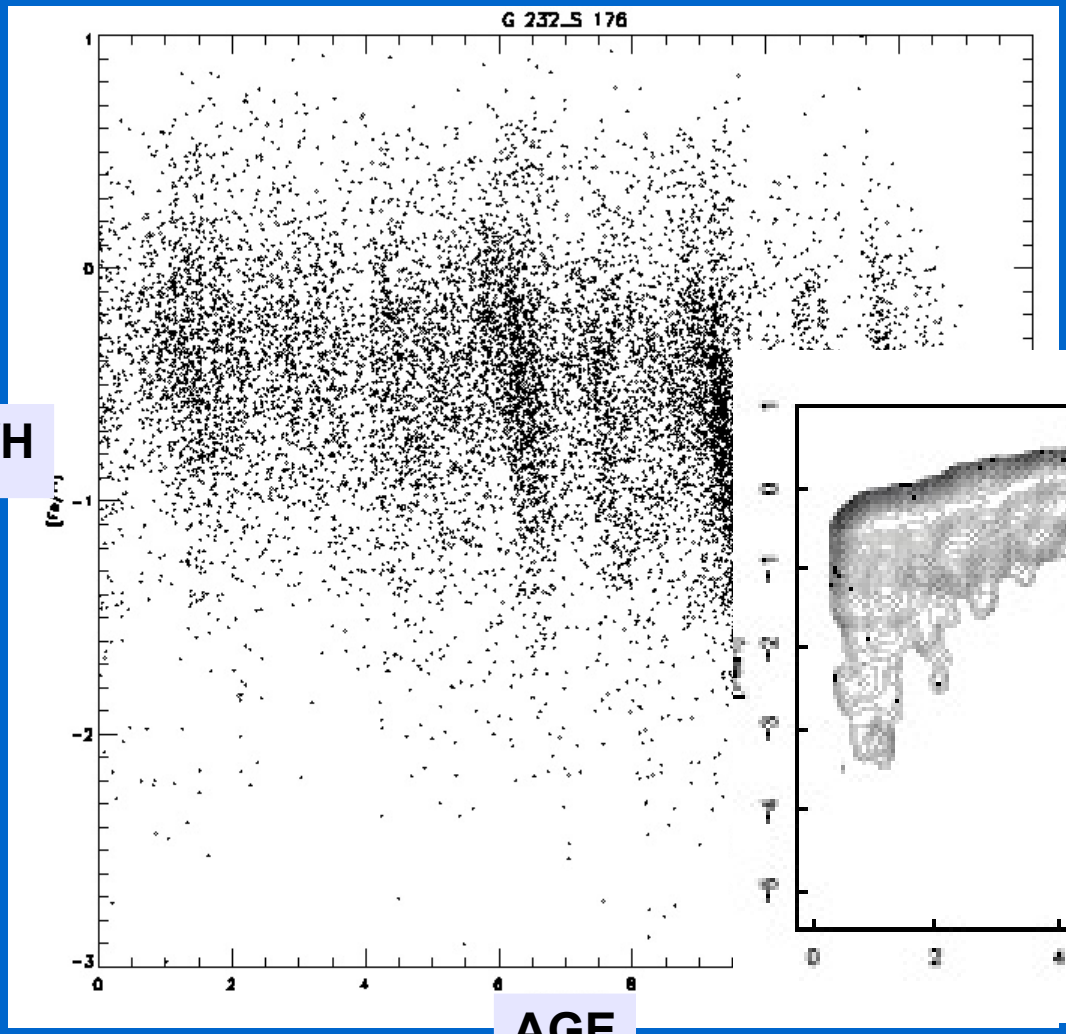
Exploding star particle

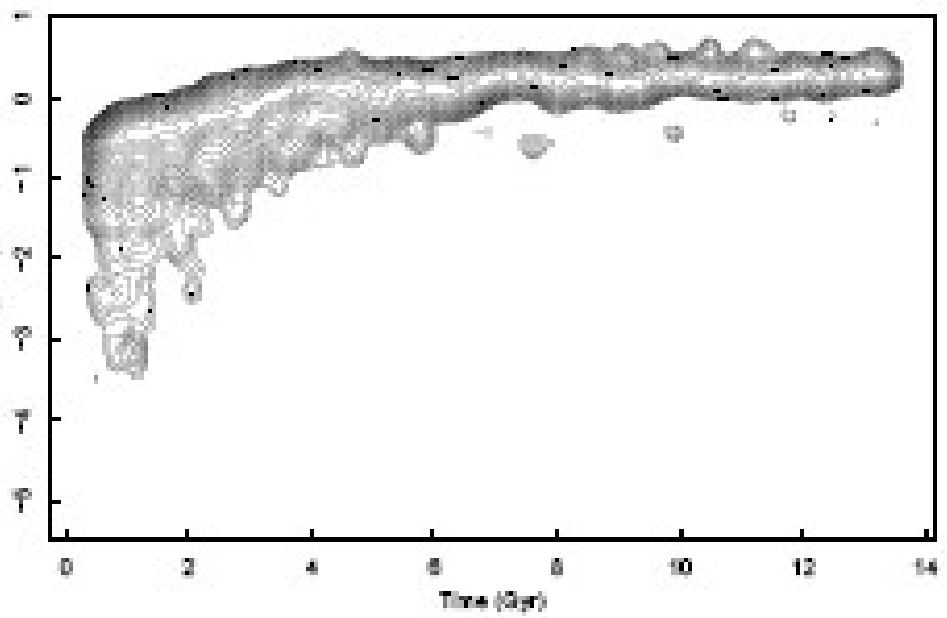
Gaseous neighbours



Mosconi, Tissera, Lambas & Cora 2001

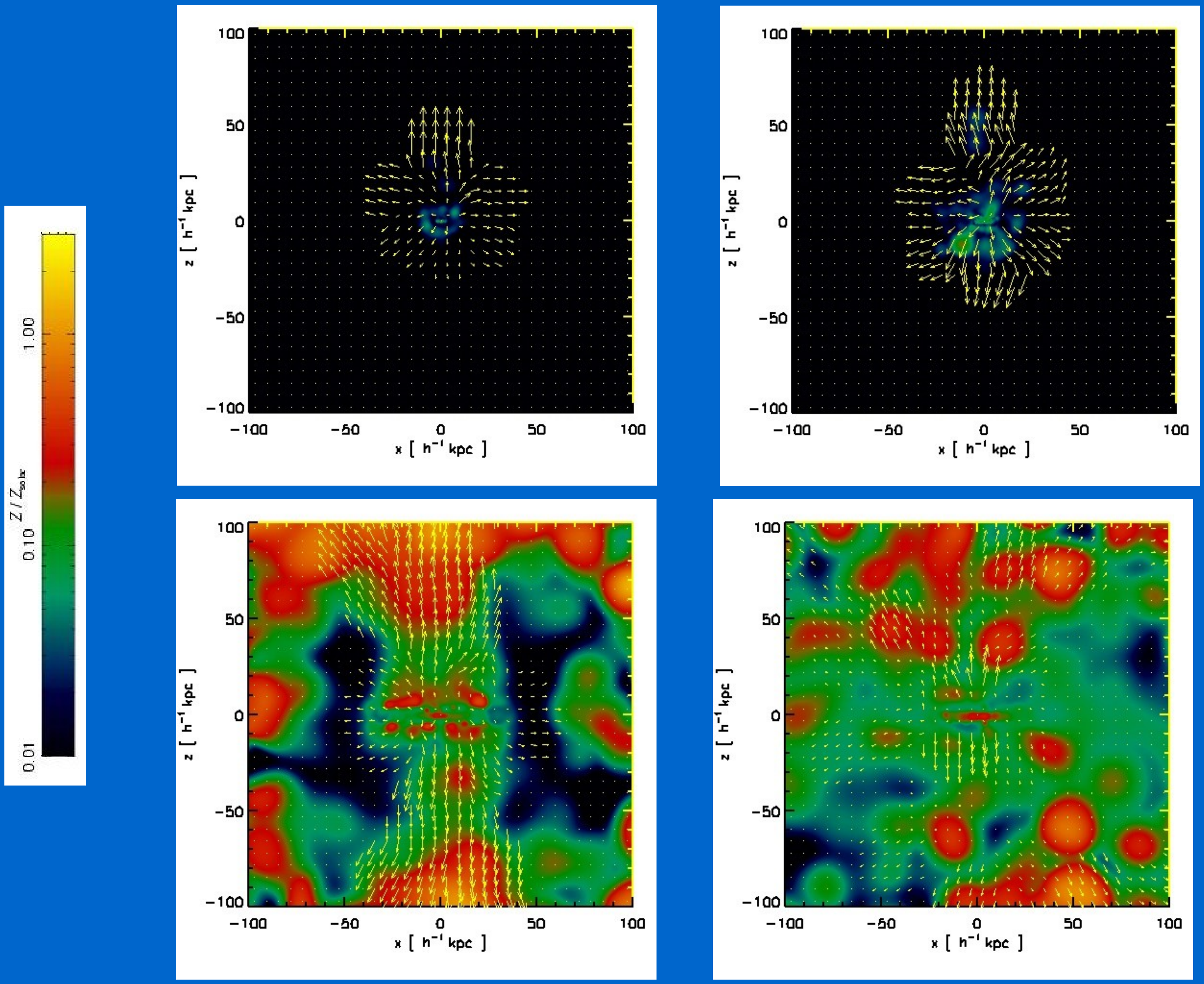
DIFFUSION





Martinez-Serrano et al. 2008

Mixing by Galactic outflows



Scannapieco et al. 2006

Aquarius haloes

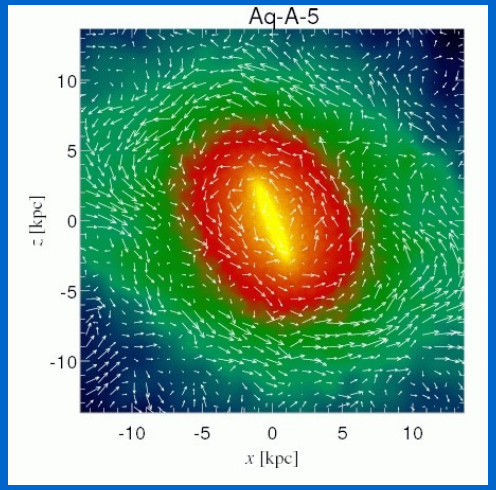
- 8 galazy-sized haloes of 10^{12} M_o (Springel et al. 2008) selected from a Λ-CDM cosmological volume of 100 Mpc/h box , with mild isolation criterion.
- ICs have been modified to include baryons.
- approx half a millons particle per specie.
- Run with GADGET-3 including chemical evolution.

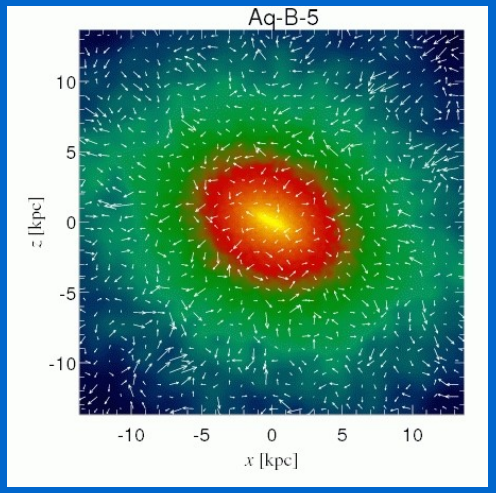
Can these simulations reproduce general trends?

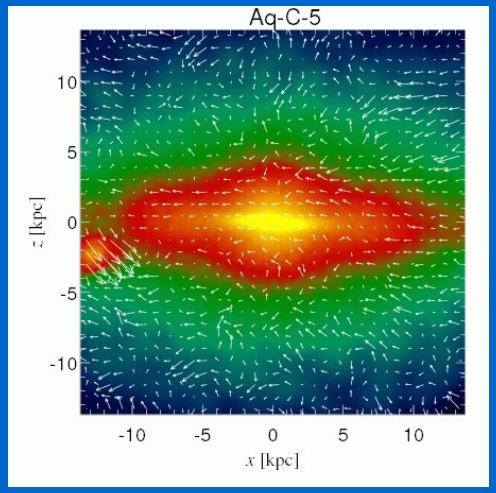
Can we link the chemical properties to their histories of assembly?

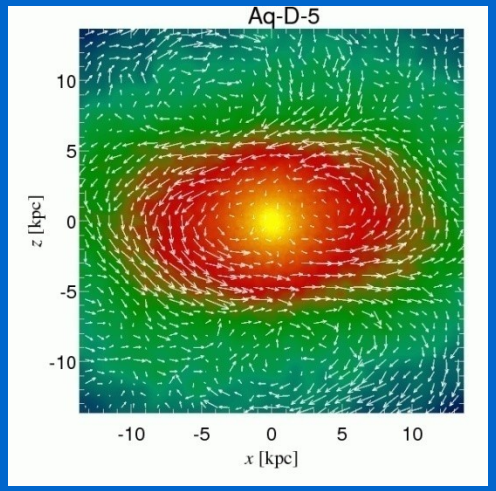
Tissera, White & Scannapieco in preparation

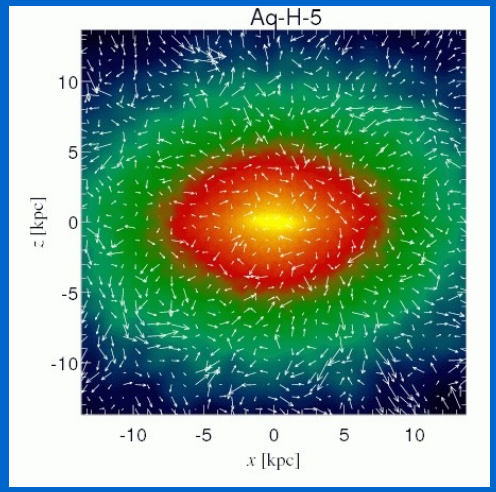
Aquarius galaxies

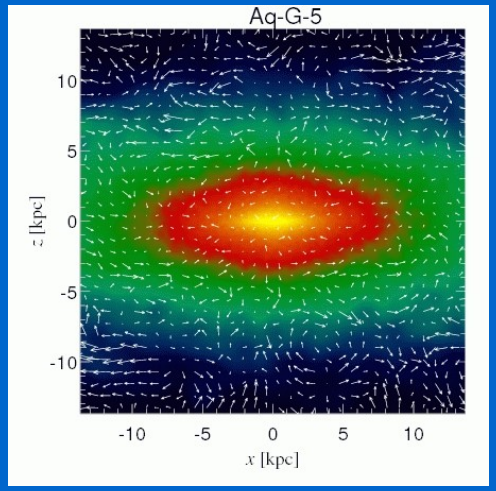




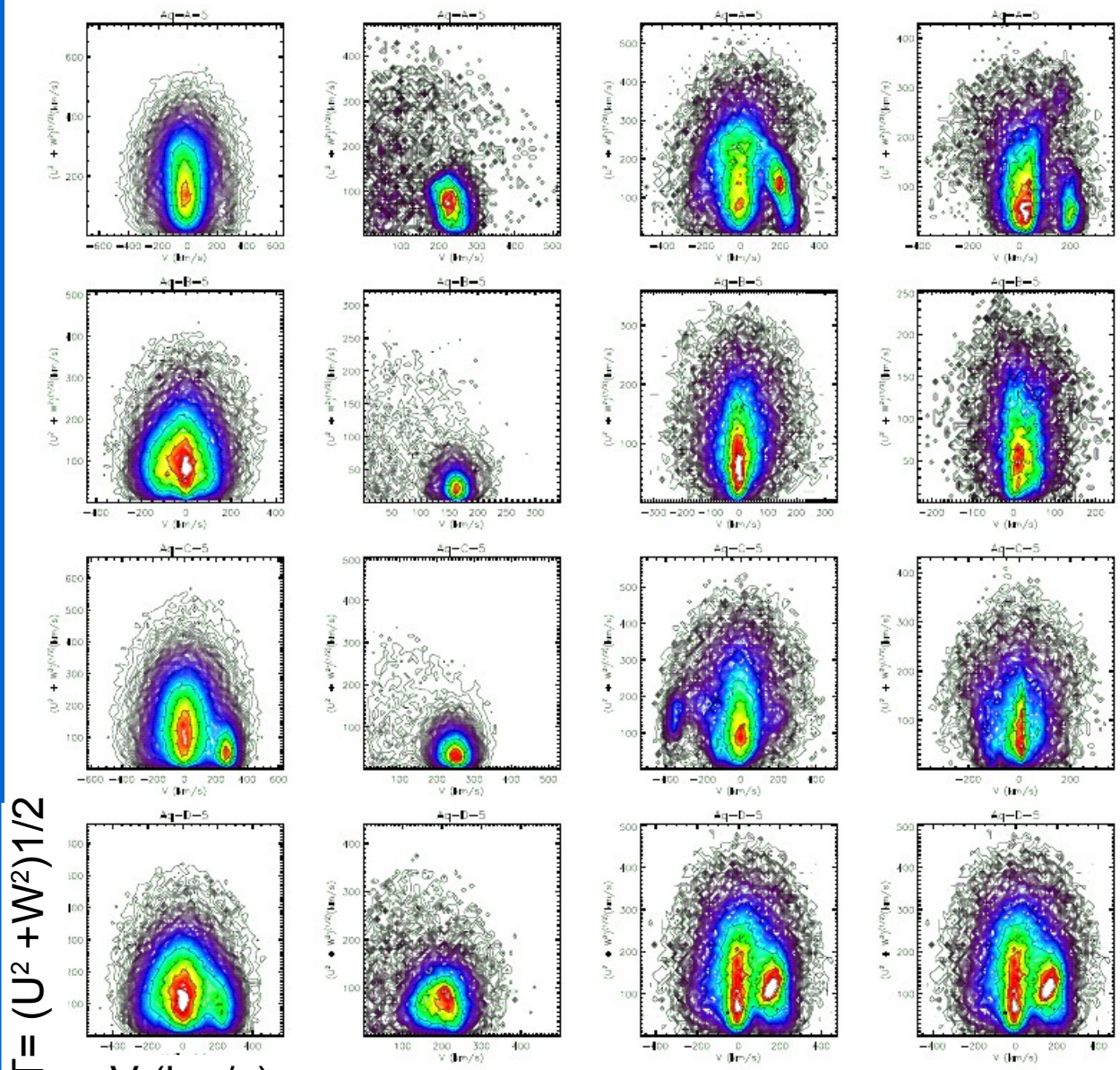








Scannapieco, White, Springel & Tissera 2008



Toomre's diagram

Star formation histories of each component

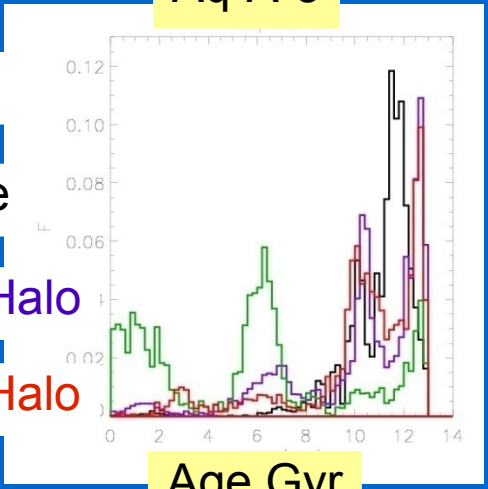
Disc

Bulge

Inner Halo

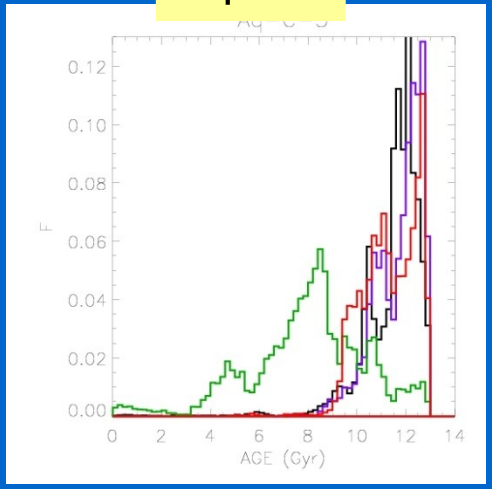
Outer Halo

Aq-A-5

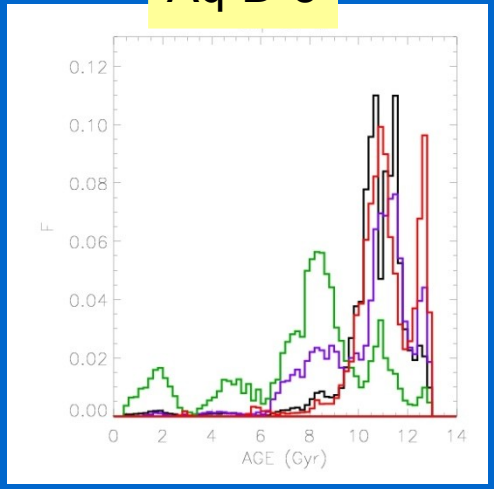


Age Gyr

Aq-C-5

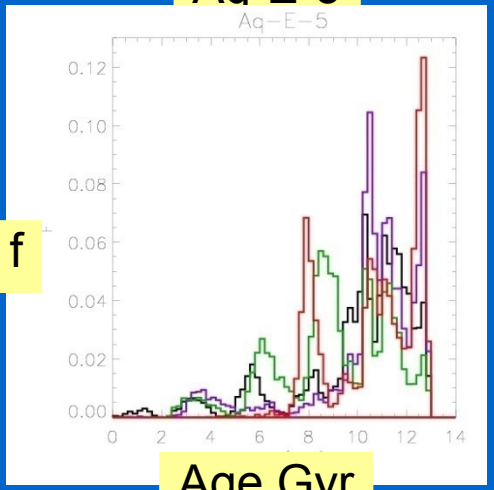


Aq-D-5



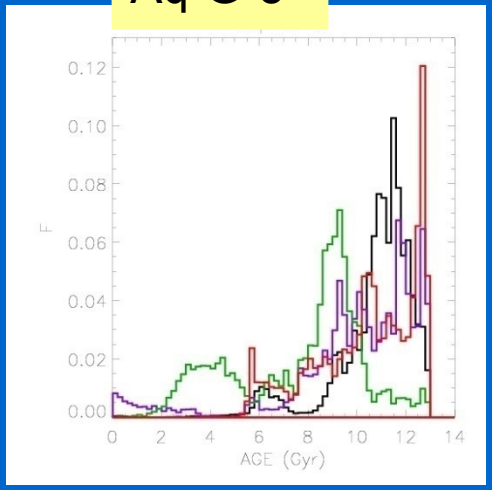
Aq-E-5

f

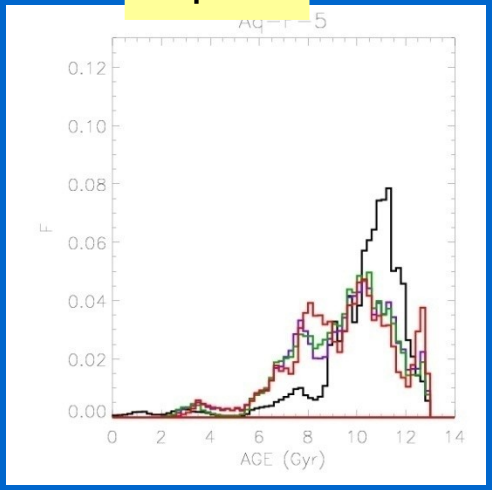


Age Gyr

Aq-G-5



Aq-F-5



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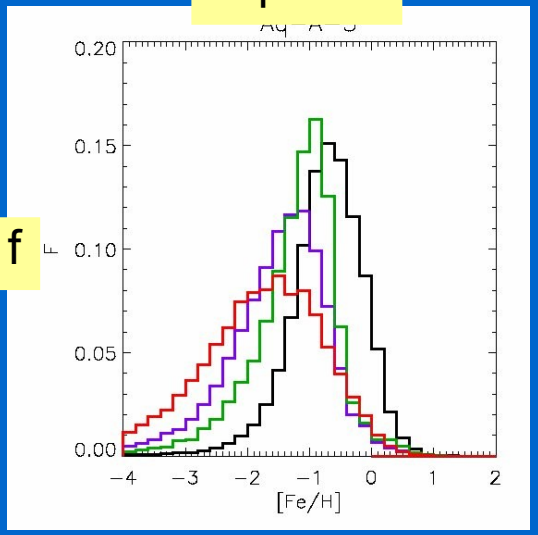

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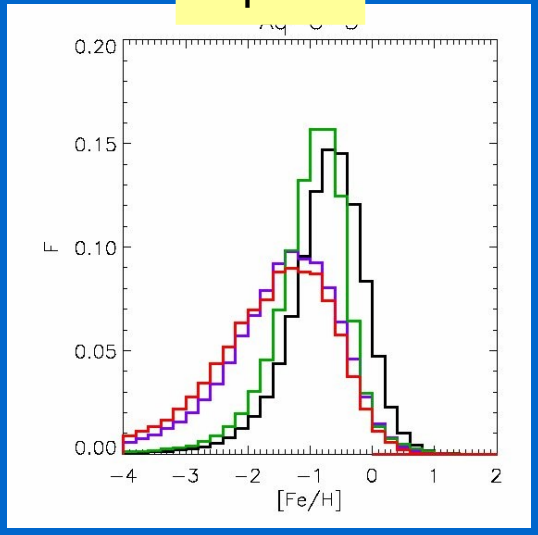
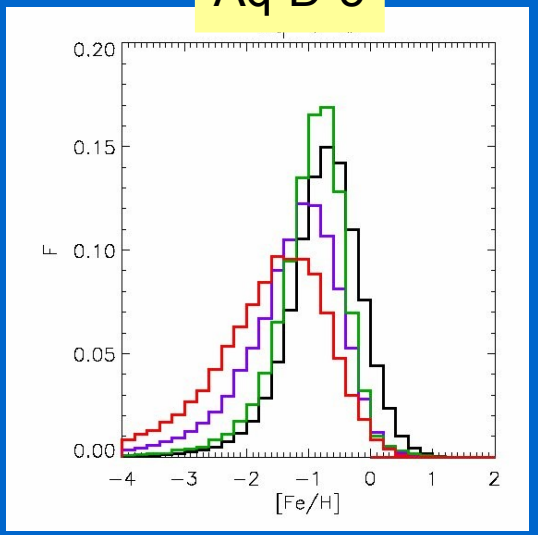


Aq-D-5



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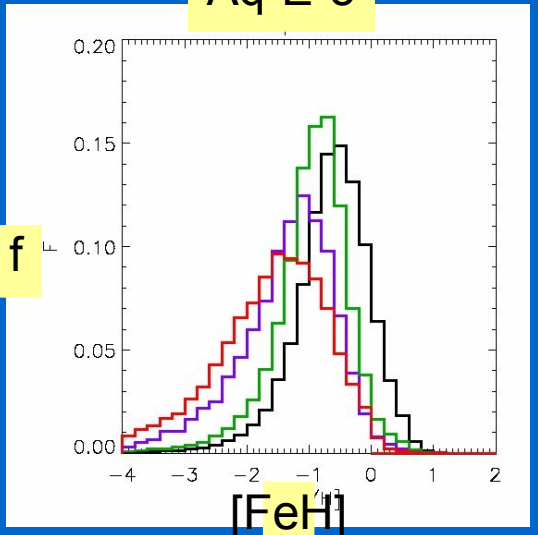

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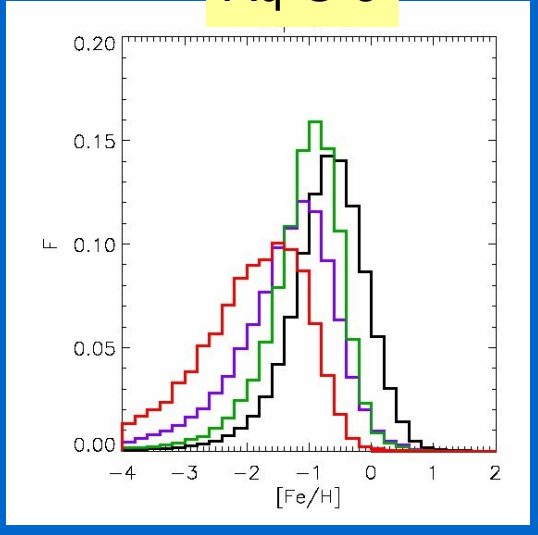
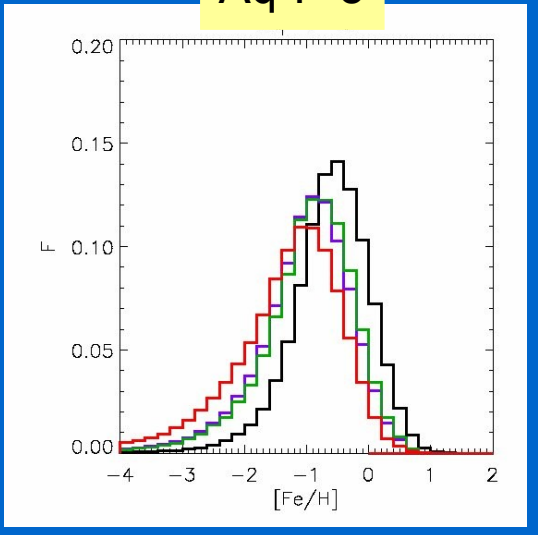
[FeH]

Aq-G-5



Aq-F-5



Disc

Bulge

Inner Halo

Outer Halo

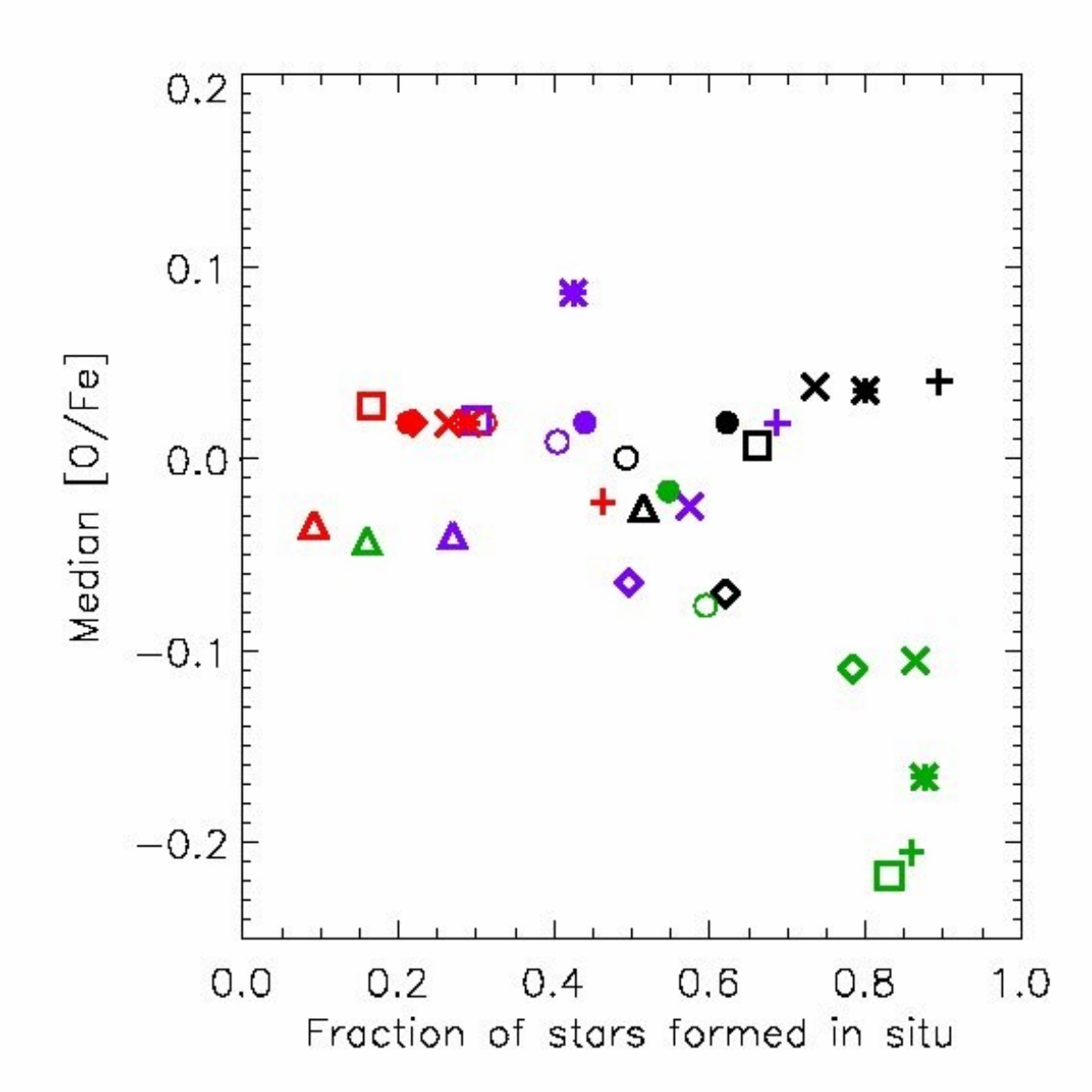
Median alfa-enhancement for each component

Disc

Bulge

Inner Halo

Outer Halo



Project: Metal mixing in the ISM and IGM

Red → high metallicity