Chemical evolution in hierarchical clustering scenarios

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Cosmological simulations have evolved greatly in recent years, with improved description of:

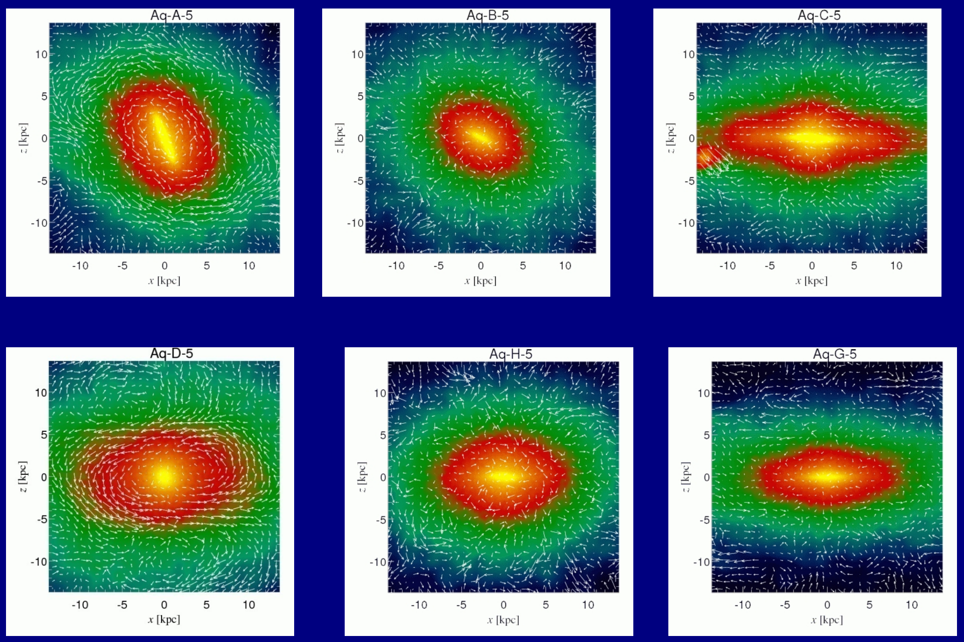
Cooling, star formation , black hole formation, and SN and AGN feedback, etc.

Most aspects of baryonic physics are still described by sub-grid models.

There is still much to be understood before being able to have a consistent picture of galaxy formation.

Confronting simulations with observations is a key route for this purpose: Chemical patterns can be powerful tools for advancing in this task.

Aquarius galaxies



- 8 galazy-sized haloes of approx 10^{12} Mo (Springel et al. 2008) selected from a Σ-CDM cosmological volume of 100 Mpc/h box , with mild isolation criterion.
- The final systems have ~ a millons particles.
- Run with GADGET-3 including our multiphase, SN feedback and chemical models.

Do they reproduce general chemical trends observed in spiral galaxies?

Which chemical patterns are common to all of them?

Which chemical trends can be related to their different assembly histories?

Main Features of the Numerical Code

An extended version of GADGET-3 (Springel 2005) with:

❖ Stochastic star formation (Springel & Hernquist 2002)

❖ Chemical enrichment from Type II and Ia Supernovae and metal dependent cooling (Mosconi et al. 2001).

❖ Multiphase gas model: allows overlap of dense and diffuse gas, decoupling gas clouds with different entropies, on particle-particle basis.

❖ Self-regulated Thermal Supernova feedback: distributes energy separately for cold and hot pre-defined phases. For the cold phase, thermal energy is stored in a reservoir and ejected when enough energy has been accumulated so that the heated particles will reach an entropy (and consequently cooling time) similar to that of their hot neighbours.

❖ SN feedback is able to drive mass-loaded winds with strength that 'naturally' adapts to the potential well of galaxies without the need to introduce mass-dependent parameters.

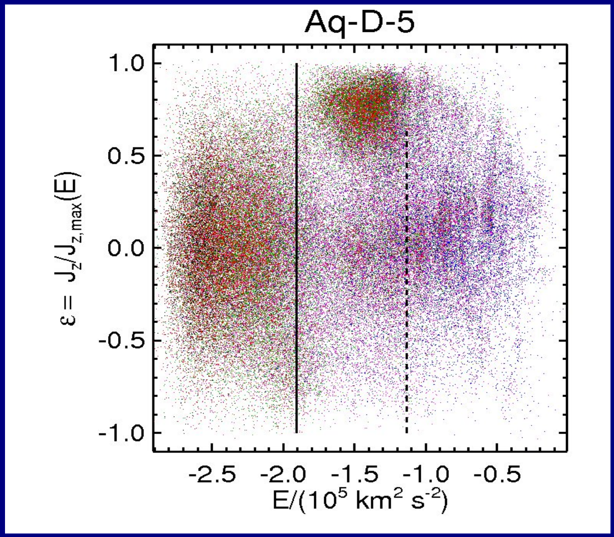
Scannapieco, Tissera, White & Springel 2005,2006,2008

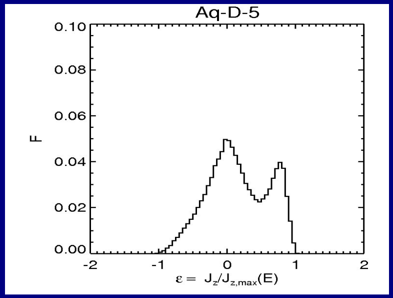
Aquarius haloes

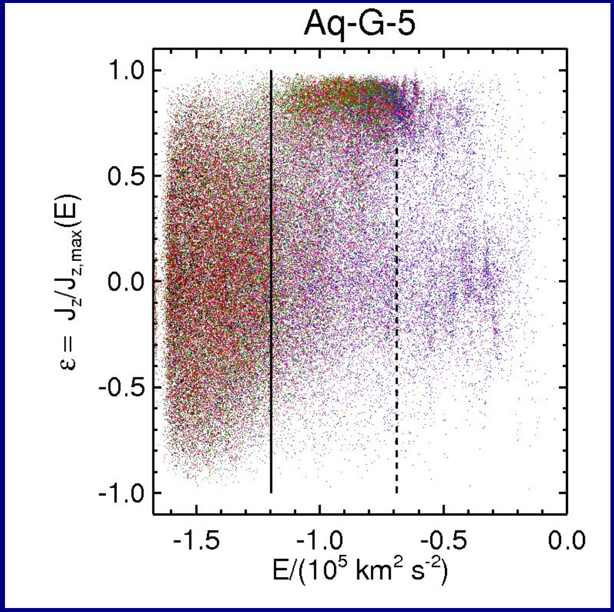
- 8 galazy-sized haloes of approx 10^{12} M_{o} (Springel et al. 2008) selected from a Σ-CDM cosmological volume of 100 Mpc/h box , with mild isolation criterion.
- The final systems have ~ a millons particles.
- Run with GADGET-3 including our multiphase, SN feedback and chemical models.

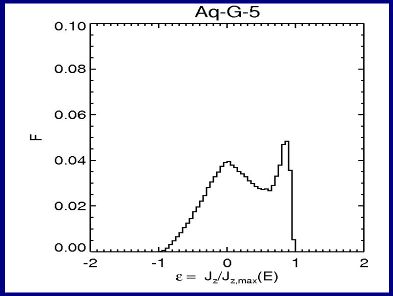
The spheroidal and surviving disc components show general dynamical properties consistent with observed spiral galaxies
(Scannapieco et al. 2008, 2010, 2011).

Different dynamical components





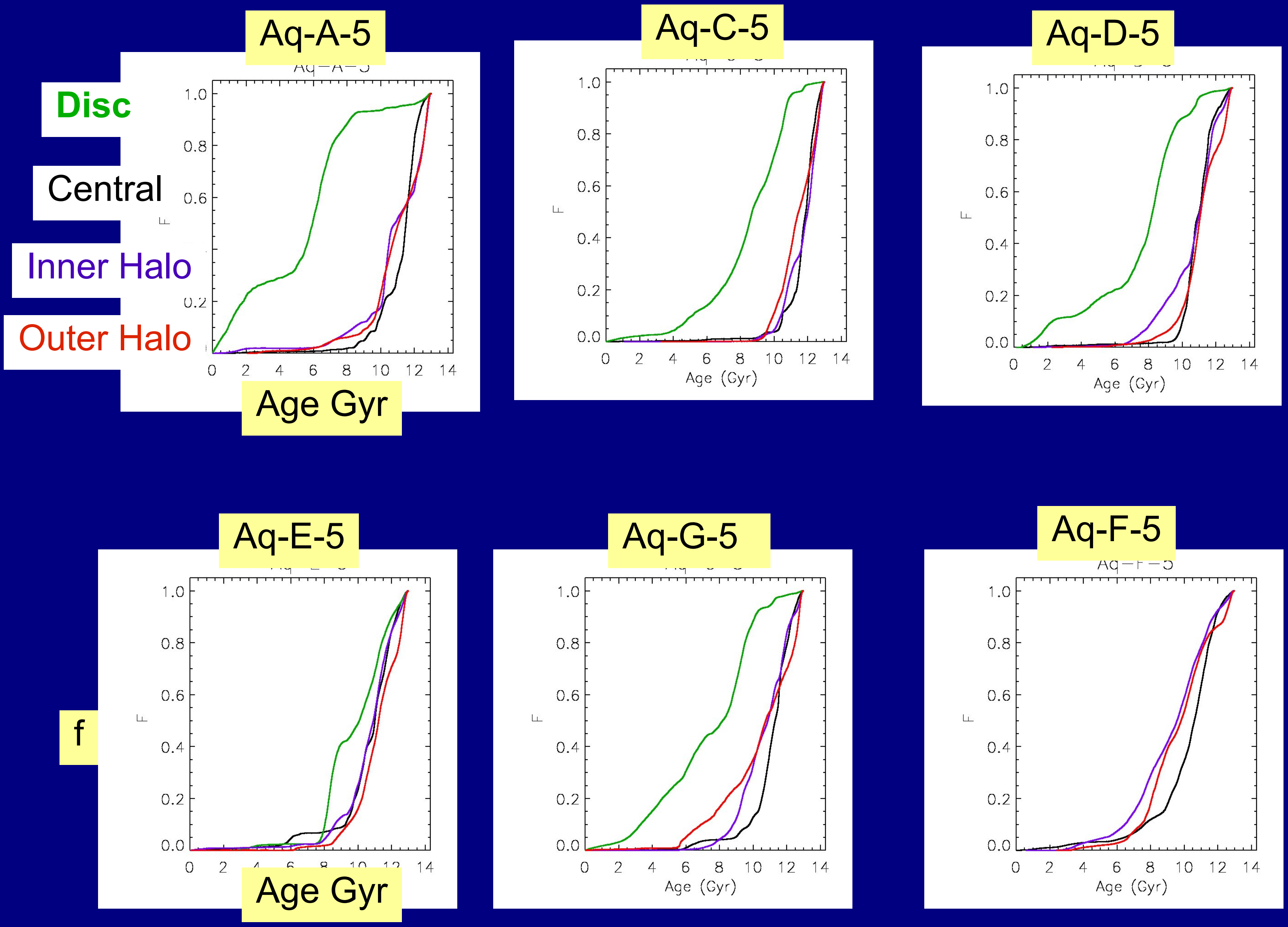


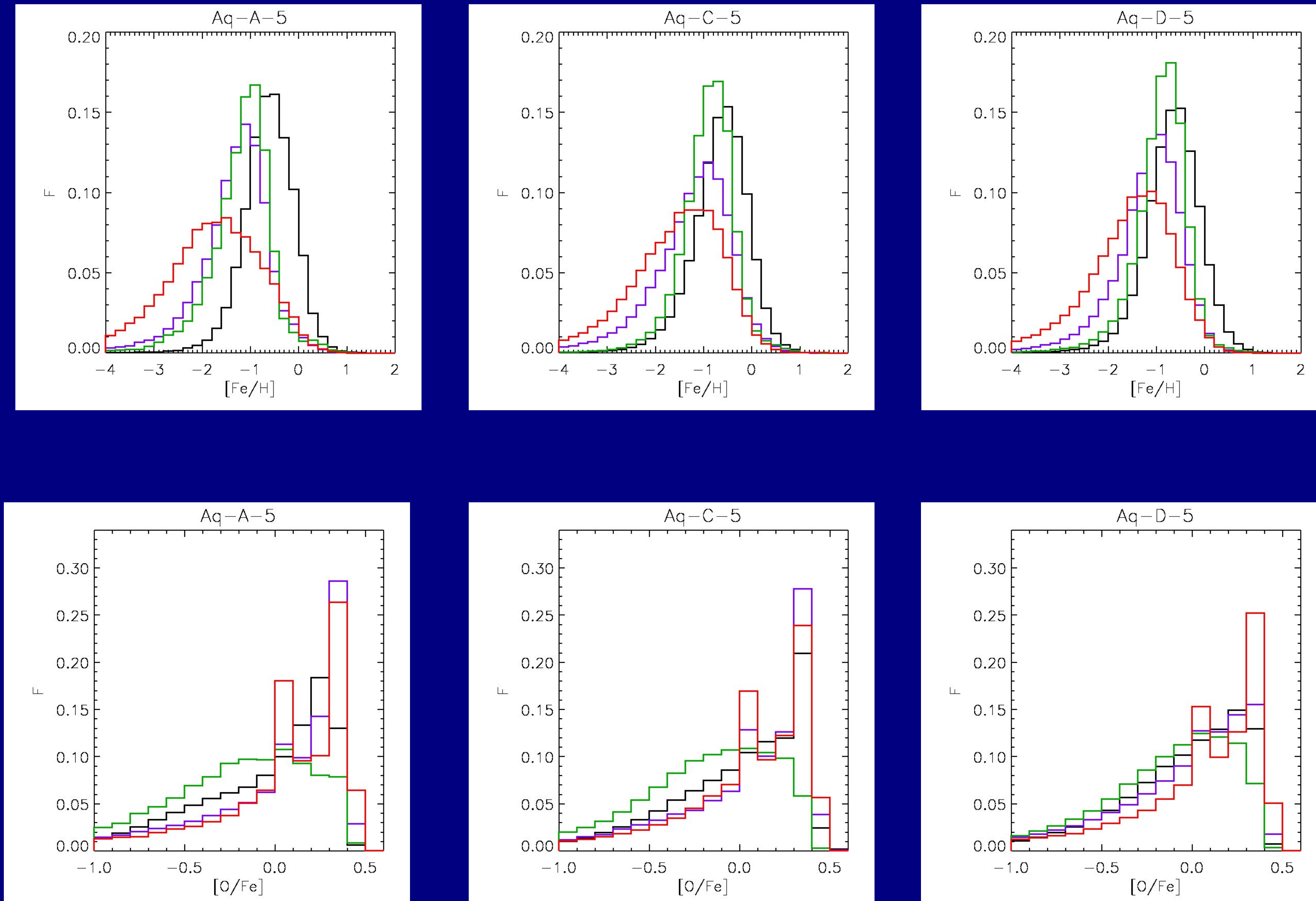


Red-Black: high [Fe/H]

Blue-Magenta: low [Fe/H]

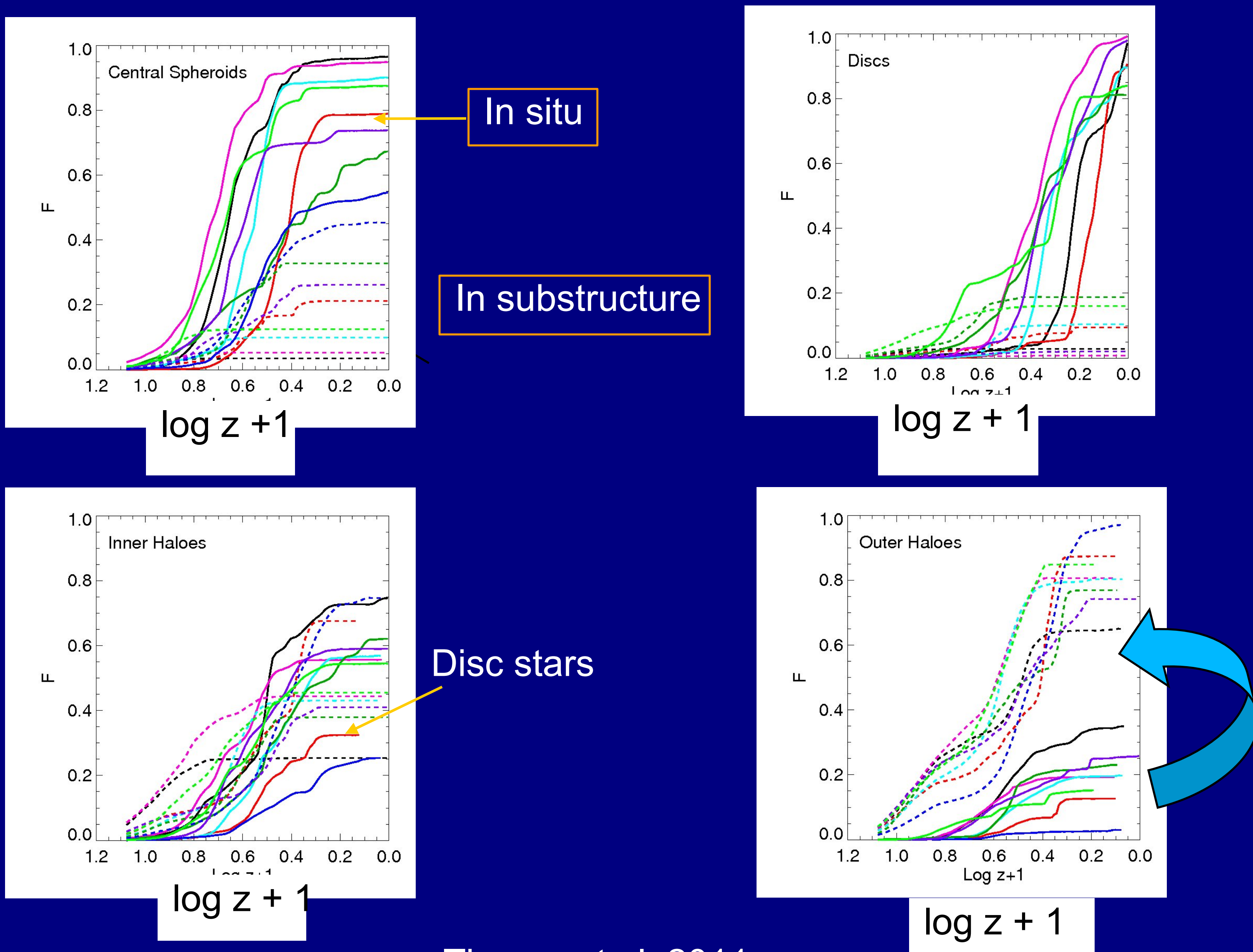
Star formation histories of each component





Disc Bulge Inner Halo Outer Halo

Fraction of stellar mass formed in the progenitor and in substructures



Tissera et al. 2011

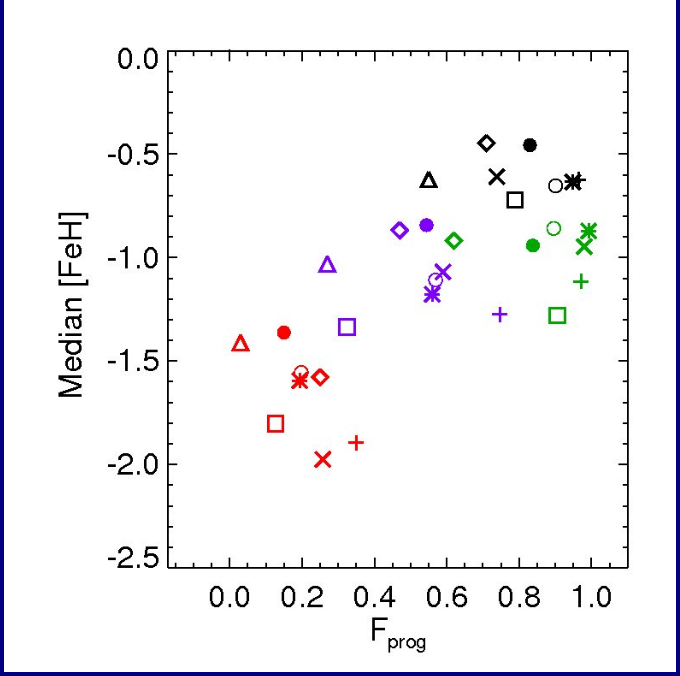
Chemical abundances and history of assembly

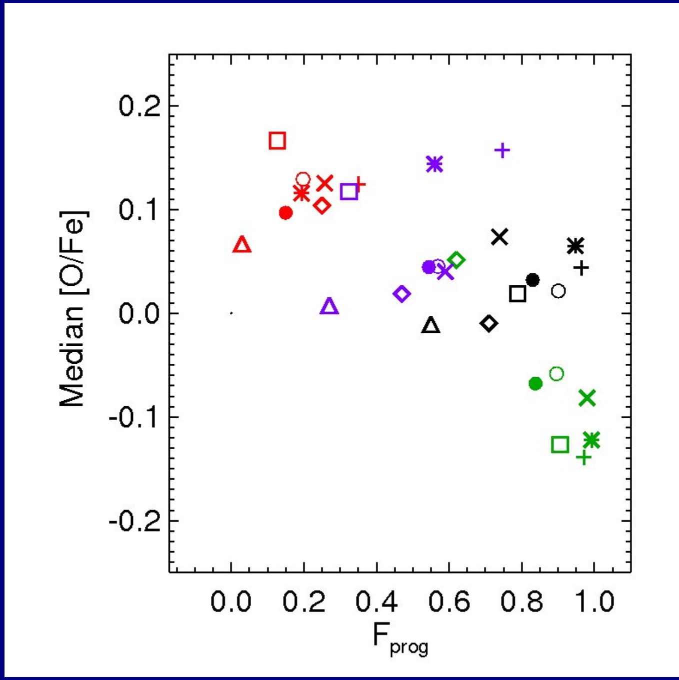
Disc

Bulge

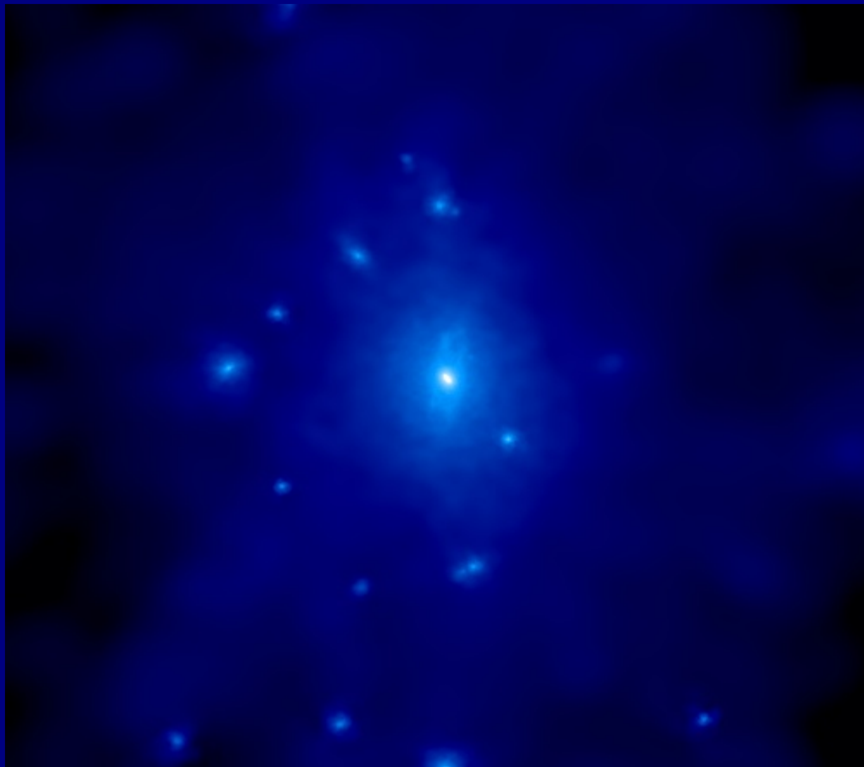
Inner Halo

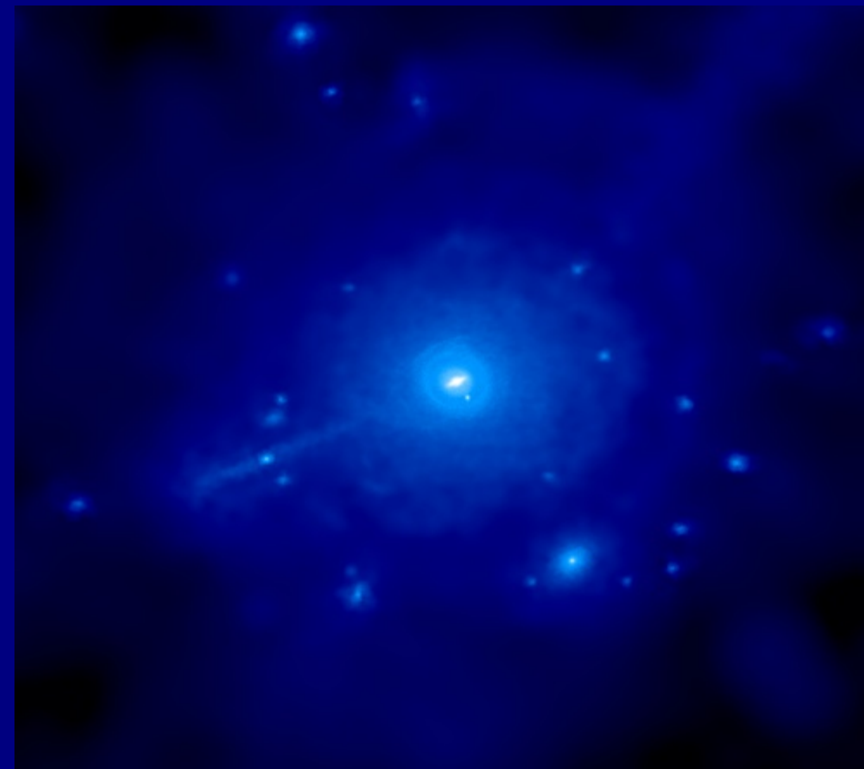
Outer Halo

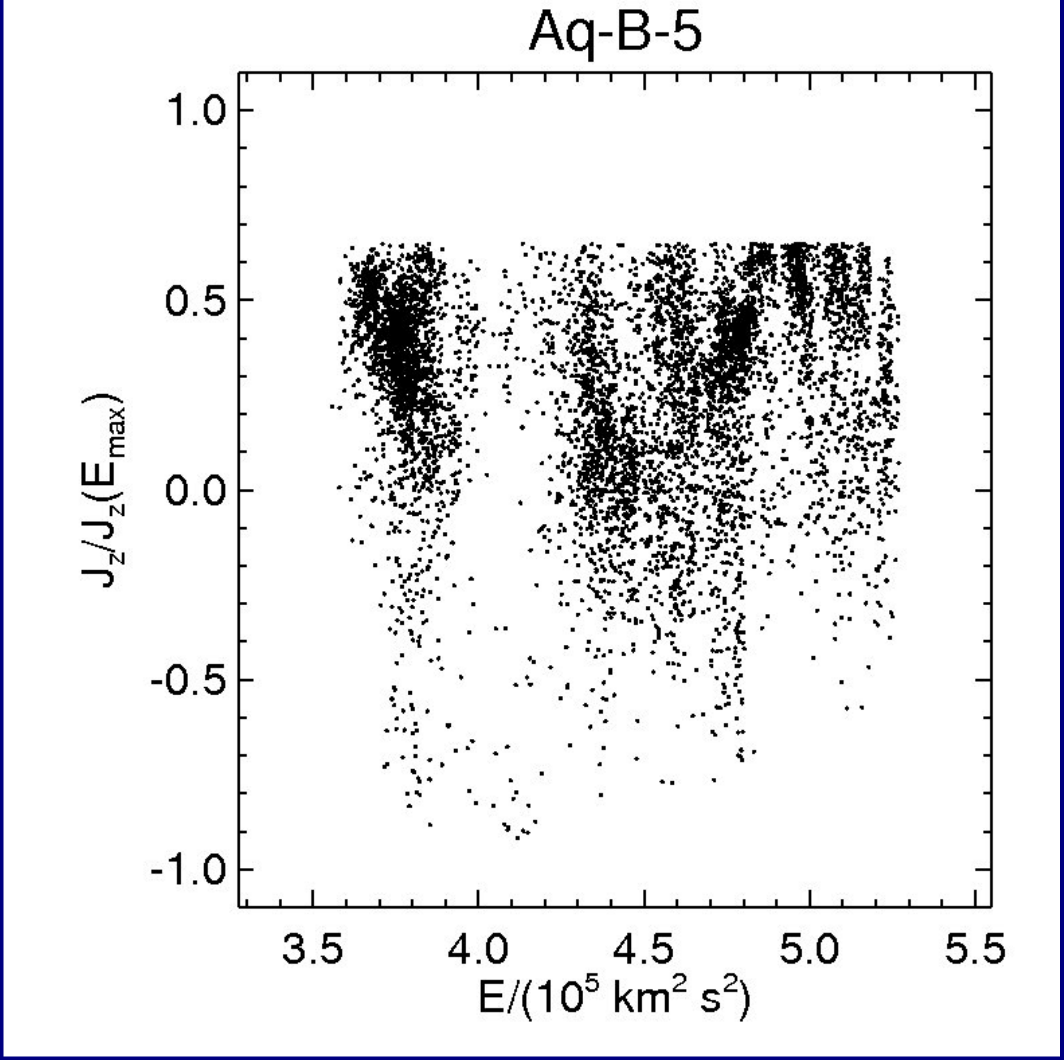




F_{prog}= stellar mass fraction formed in situ



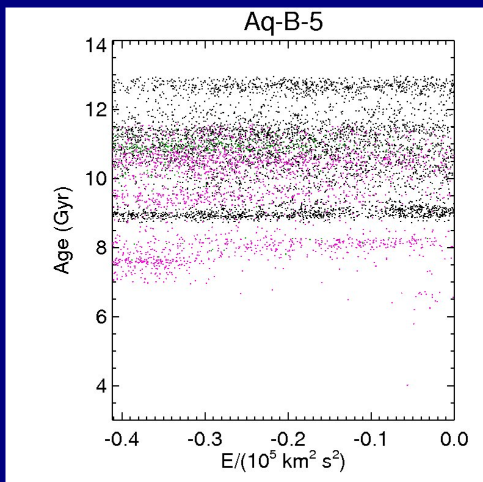


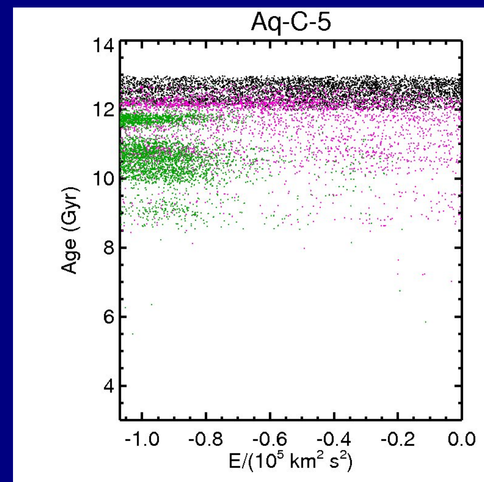


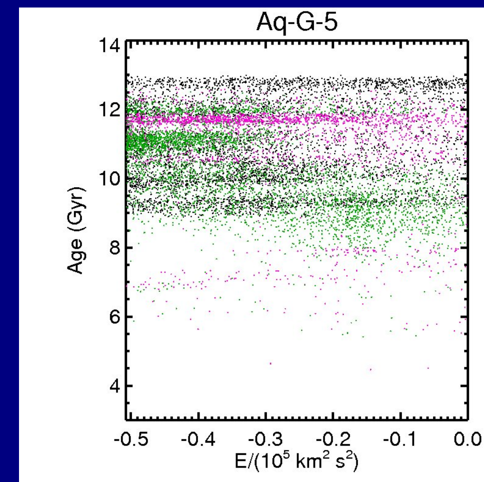
Most of stars are formed in substructures which can be difficult to pick up if they formed within available timesteps

Stellar haloes are found to be built by accreted stars:

debris and 'endo-debris' and disc heated stars which are located only in the inner haloes





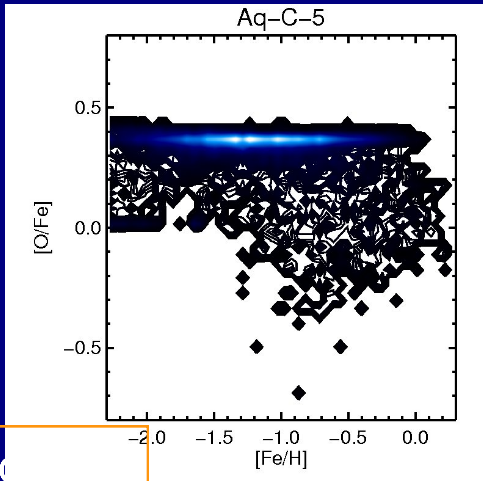


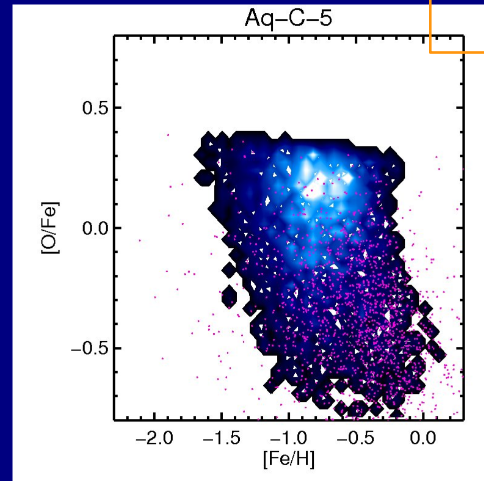
Debris stars cover the whole range of binding energy and tend to be the oldest stars.

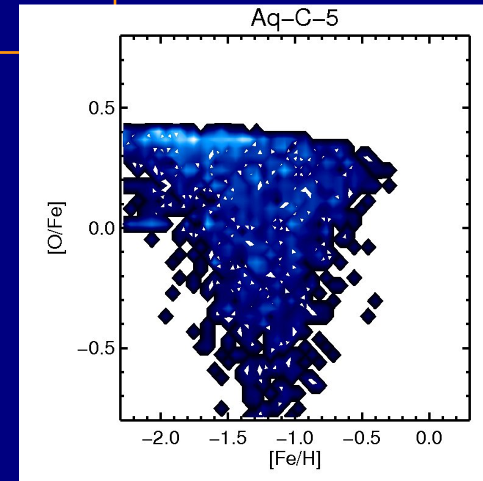
Haloes might have different episodes of disc heating. The oldest ones might not have kinematical signal.

INNER HALO

Disc heated stars

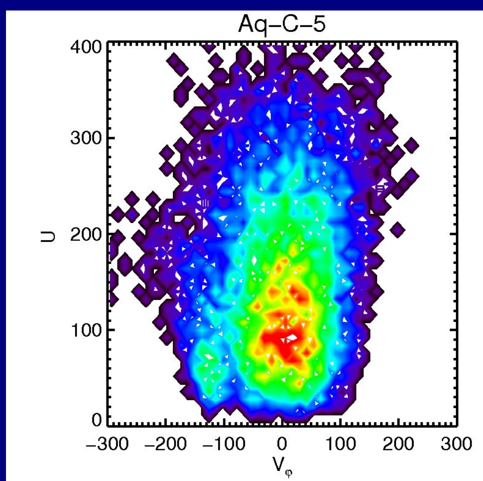




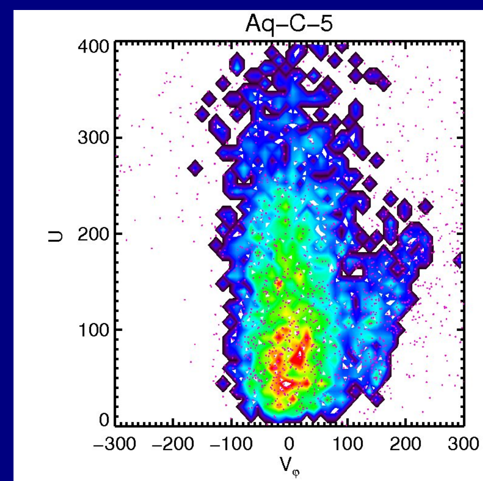


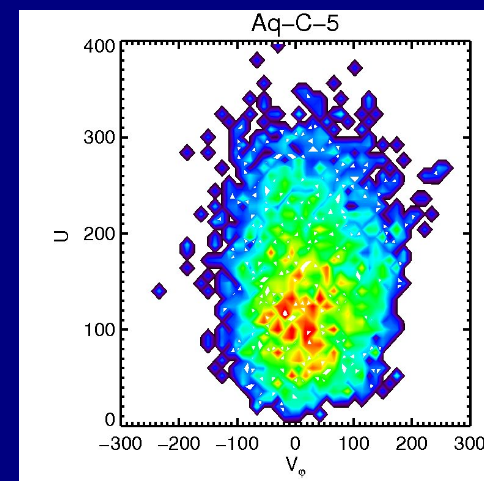
Accreted

Toomre%s diagram



Toomre%s diagram



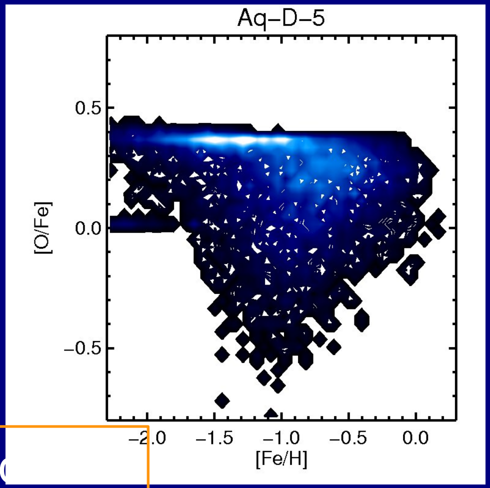


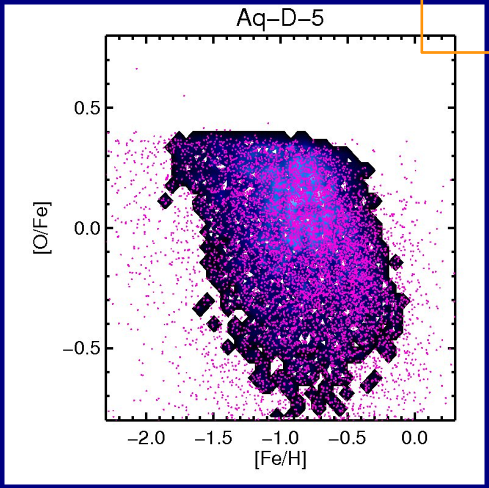
Aq-C-5:
86% accreted stars
14% disc heated stars

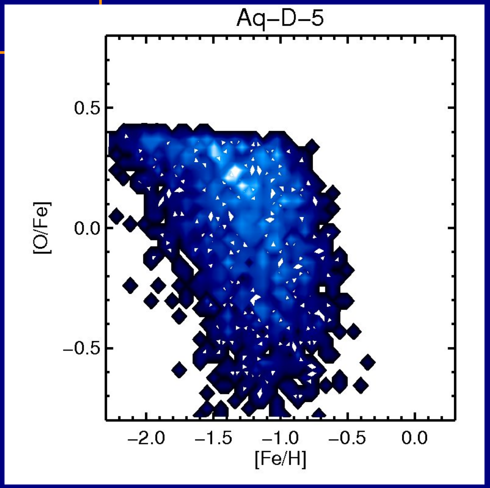
Magenta: 8<age <10 Gyr

INNER HALO

Disc heated stars

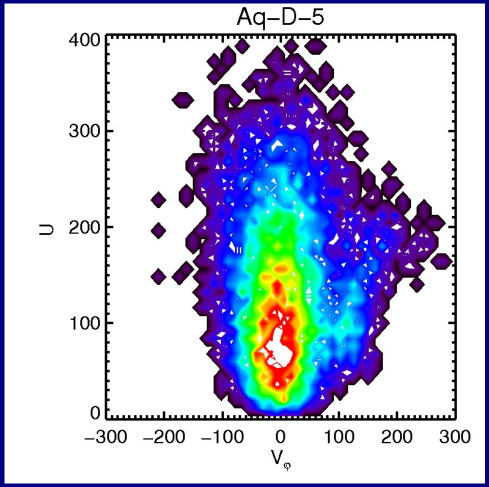




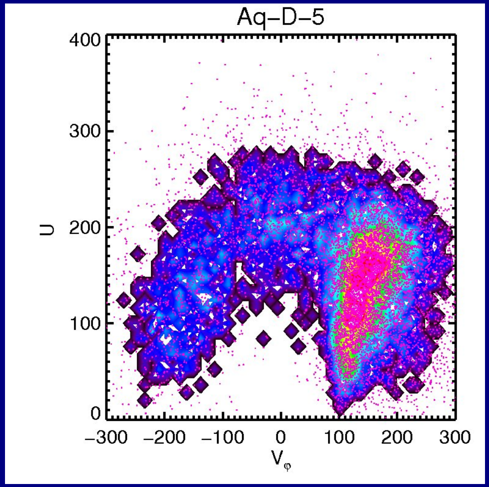


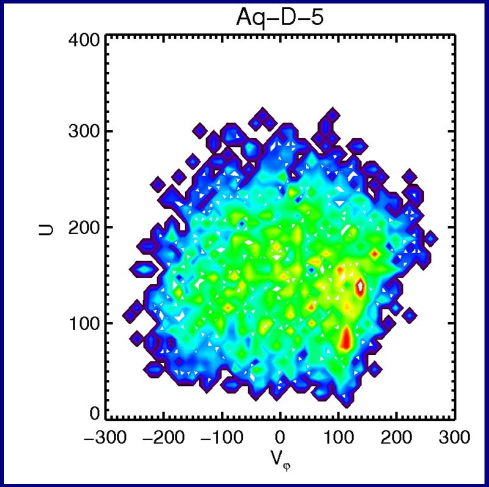
Accreted

Toomre's diagram



Toomre's diagram

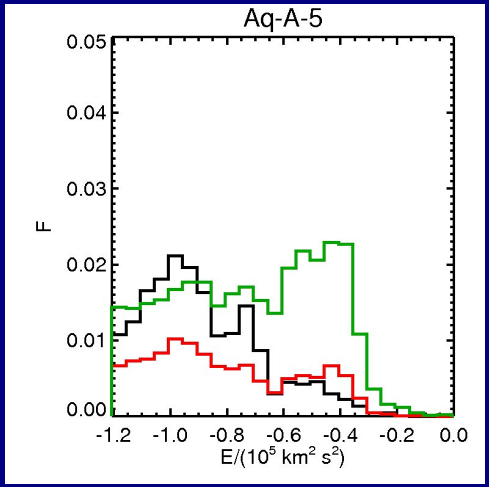


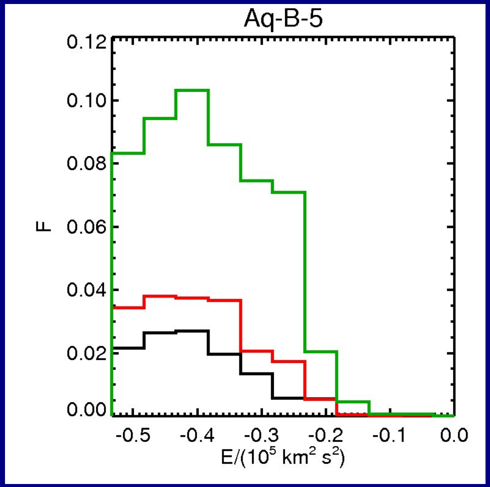


Aq-D-5:
72% accreted stars
28% disc heated stars

Magenta: 8<age <10 Gyr

Abundance gradients in the outer haloes

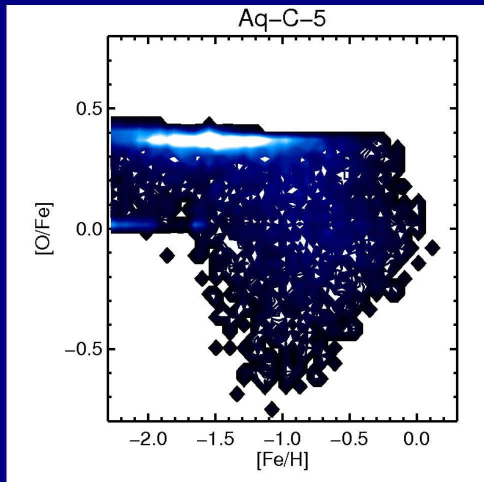


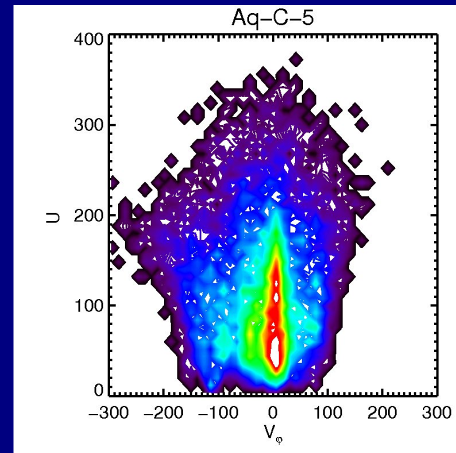


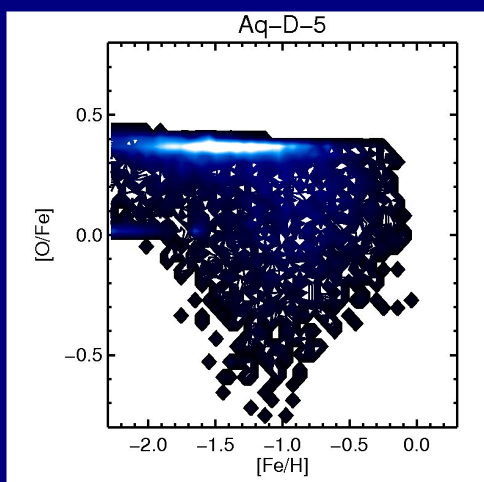
[Fe/H] > -1 black
-1.5<[Fe/H]<-1 red
[Fe/H] < -1.5 green

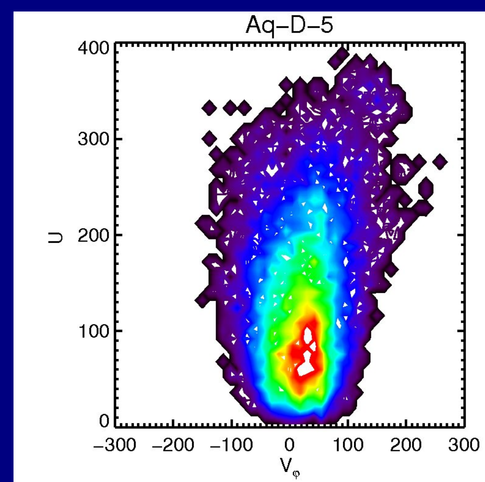
Metallicity gradients in the outer haloes: 0 to ~ -0.01

Gradients are determined by the contributions of more massive satellites

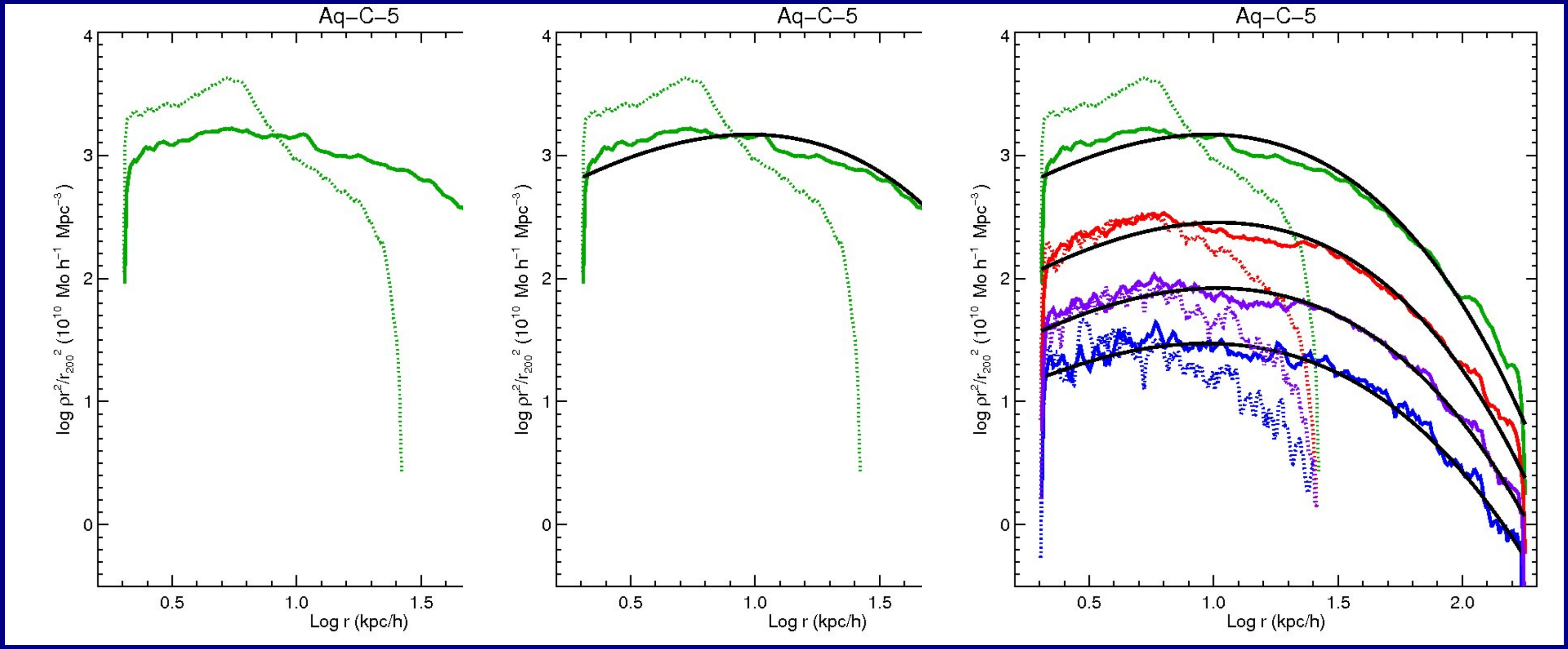

Aq–C–5
[O/Fe]
0.5
0.0
–0.5
–2.0
–1.5
–1.0
–0.5
0.0
[Fe/H]

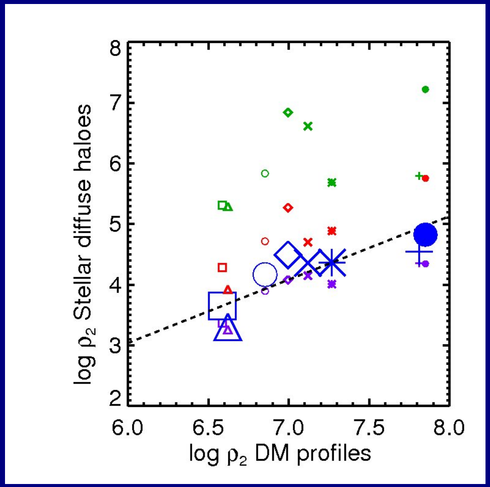

Aq–C–5
400
300
200
100
0
U
–300
–200
–100
0
100
200
300
V_φ

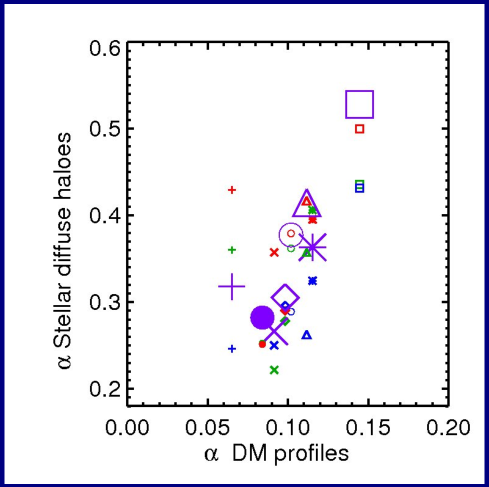

Aq–D–5
[O/Fe]
0.5
0.0
–0.5
–2.0
–1.5
–1.0
–0.5
0.0
[Fe/H]

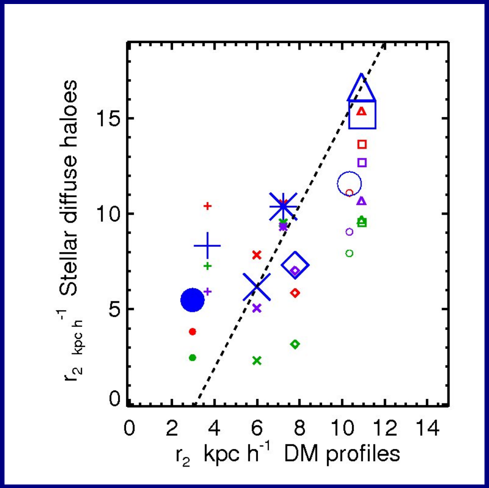

Aq–D–5
400
300
200
100
0
U
–300
–200
–100
0
100
200
300
V_φ

Density profiles of the stellar diffuse haloes.

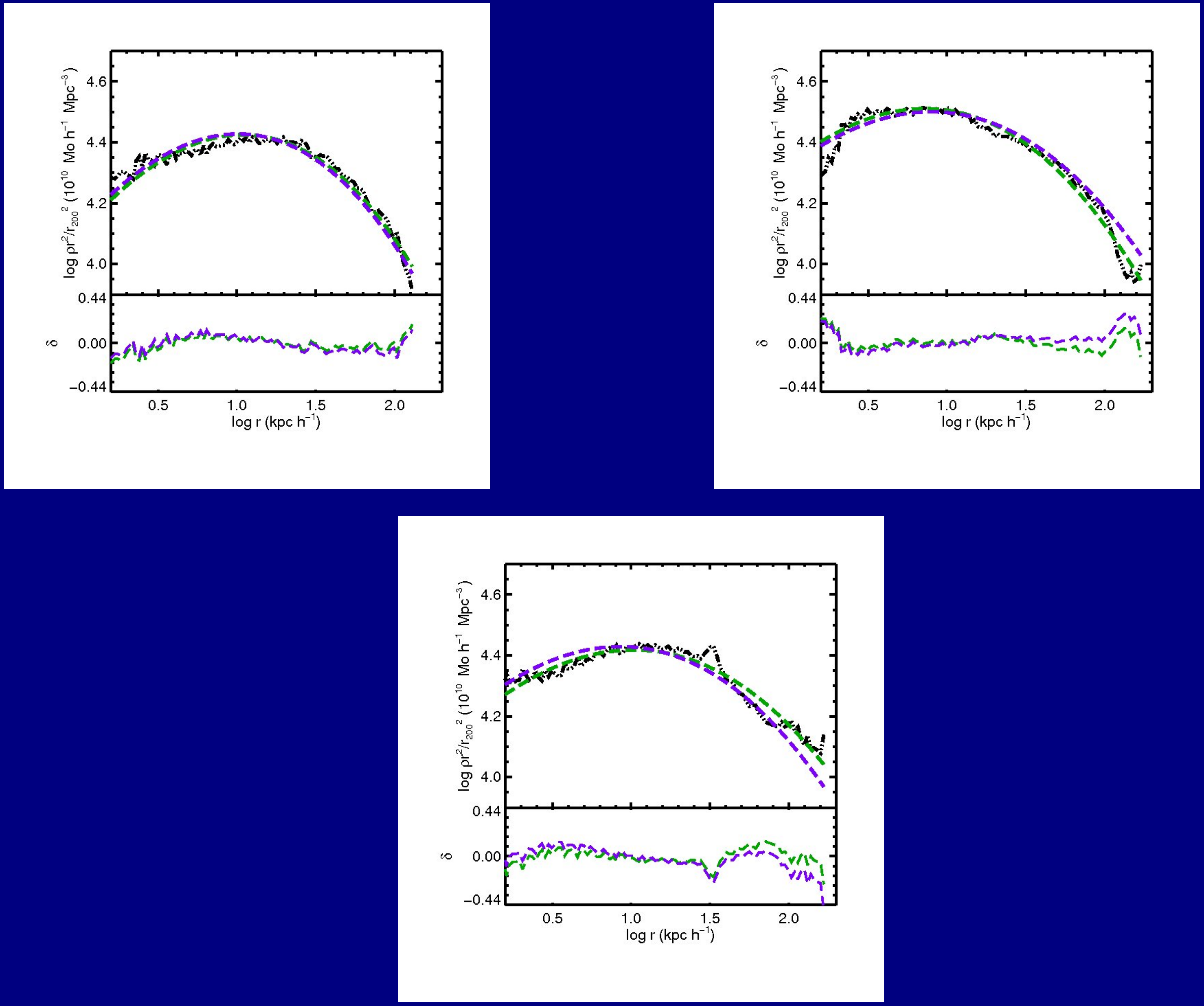



log ρ2 Stellar diffuse haloes
log ρ2 DM profiles

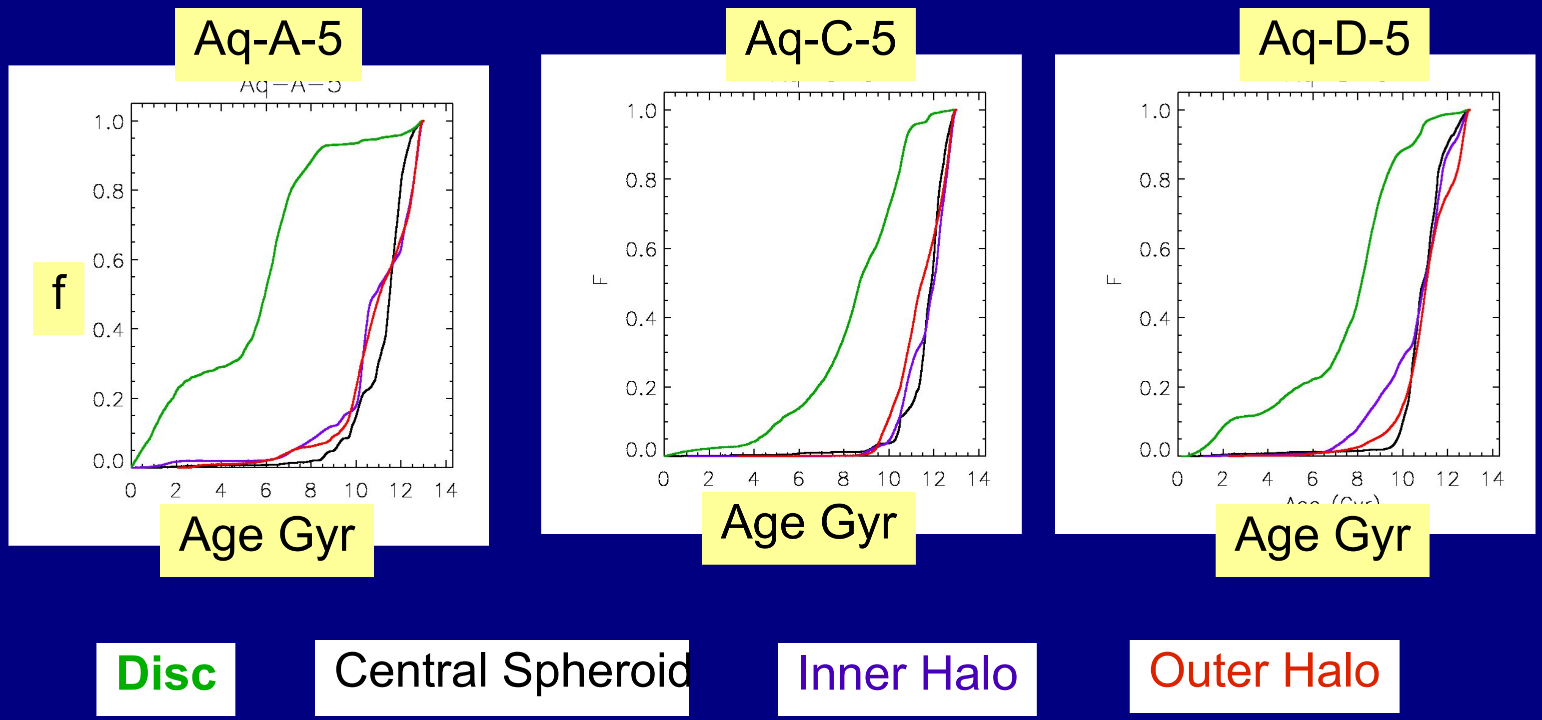

α Stellar diffuse haloes
α DM profiles


r2 kpc h-1 Stellar diffuse haloes
r2 kpc h-1 DM profiles

Predicted dark matter profiles from the parameters of the stellar halo profiles.

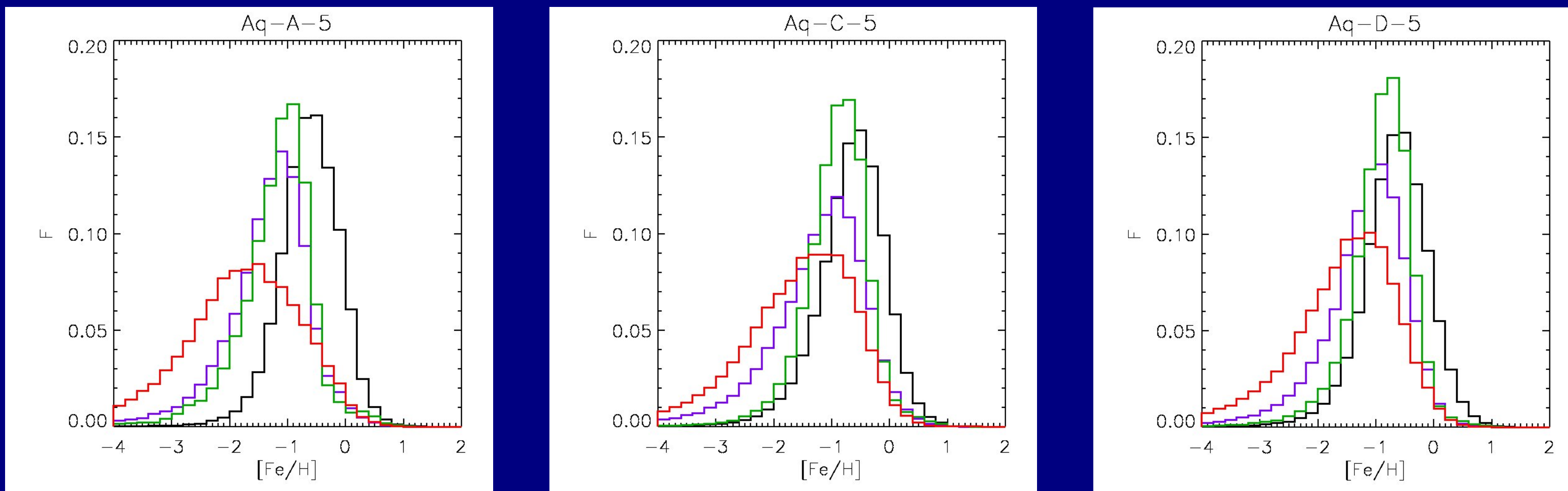


Star formation histories



Star formation histories of central spheroids, inner and outer haloes are very similar.

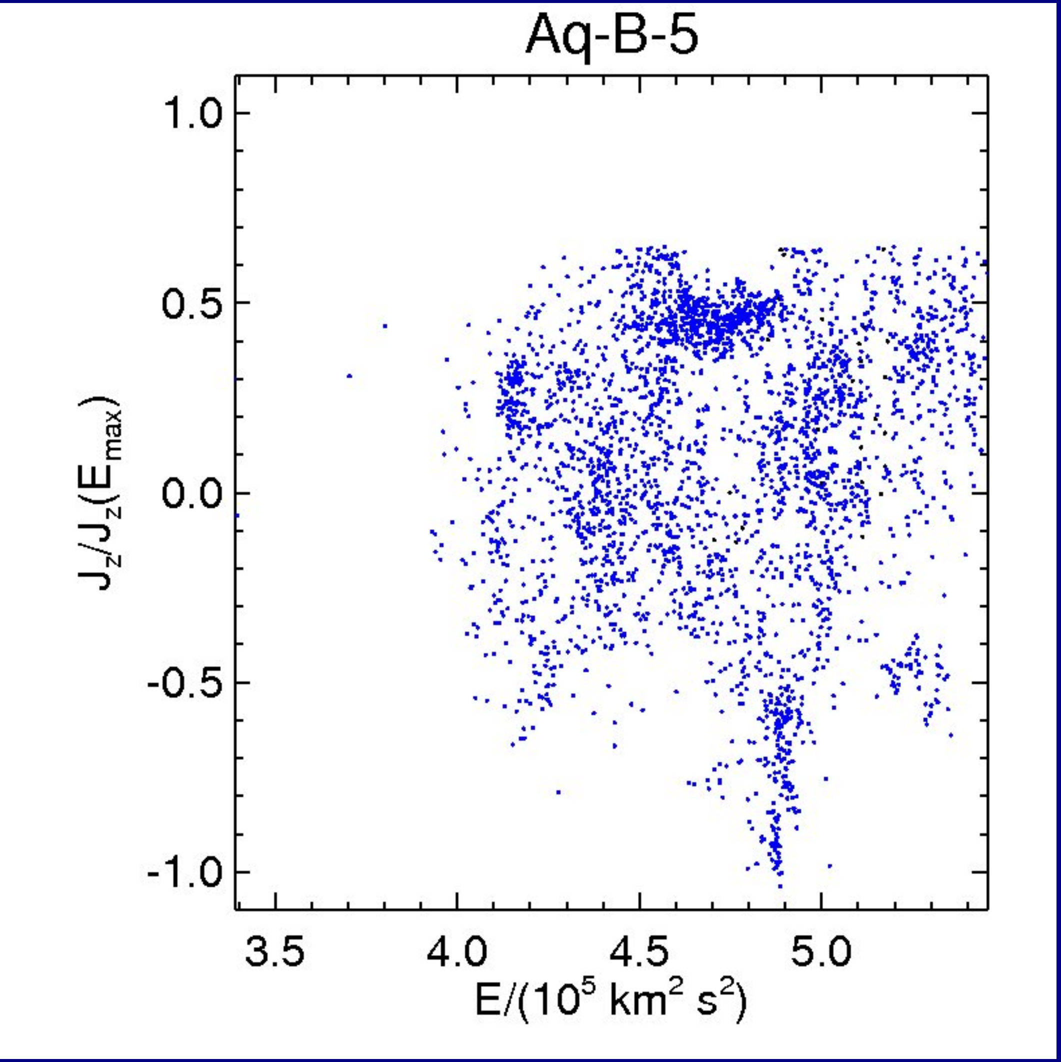
Chemical abundances



Disc Bulge Inner Halo Outer Halo

But not the chemical properties: the potential well and their histories
Of assembly are different.

Binding energy for stars in the smooth component of the outer halo



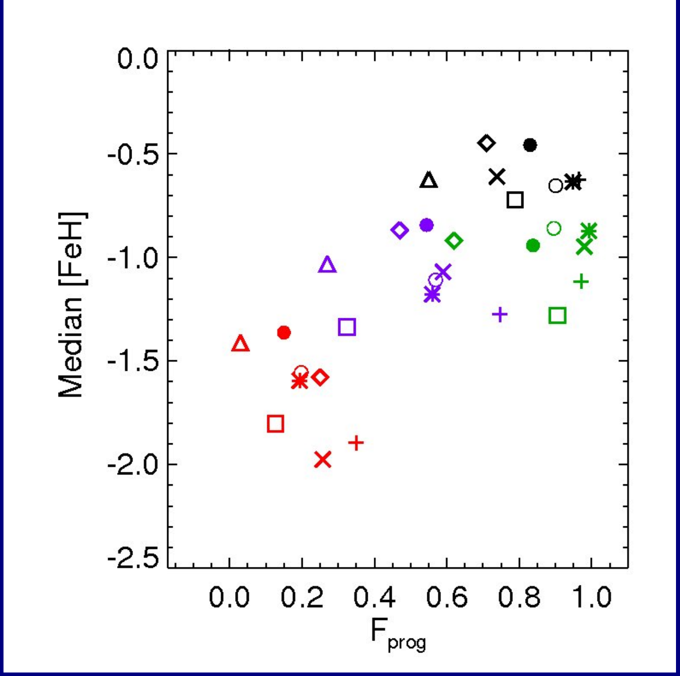
Chemical abundances and history of assembly

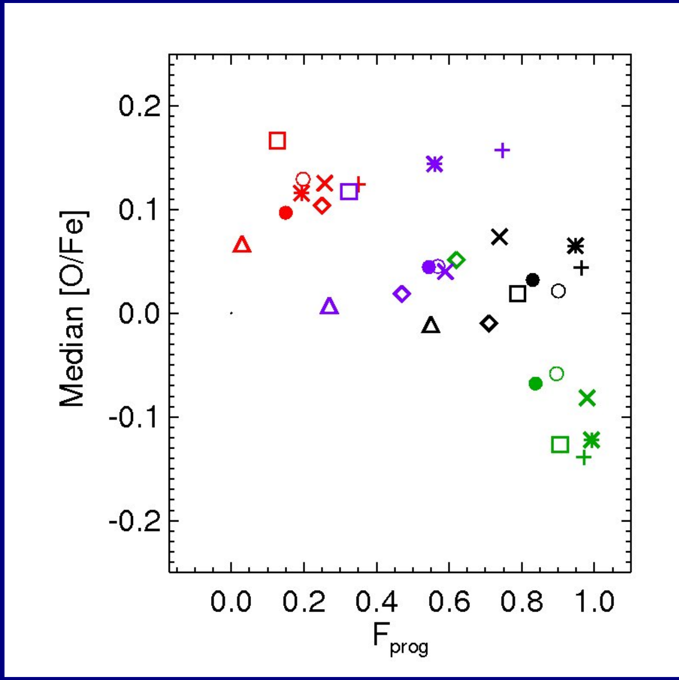
Disc

Bulge

Inner Halo

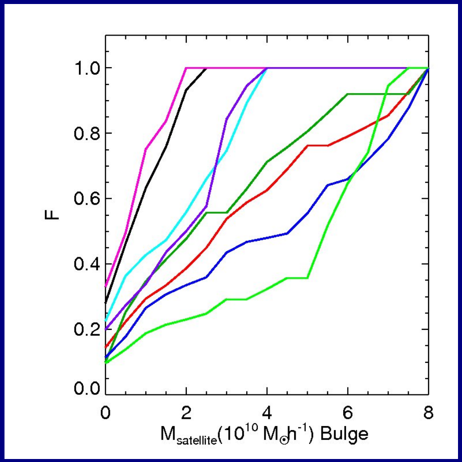
Outer Halo

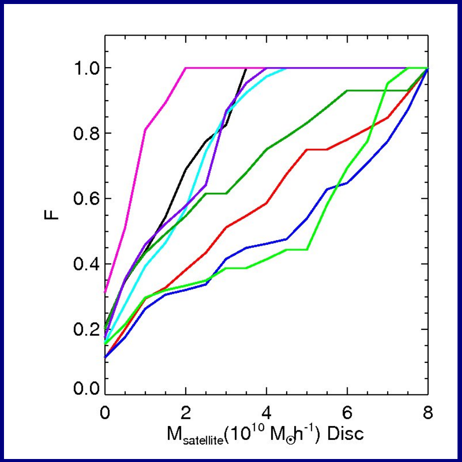


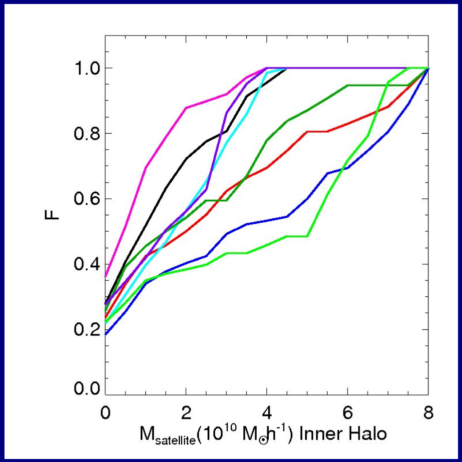


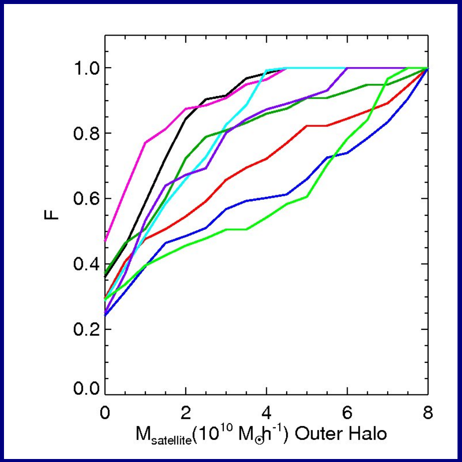
F_{prog}= stellar mass fraction formed in situ

Fraction of stars formed in satellites more massive than M_{stars}

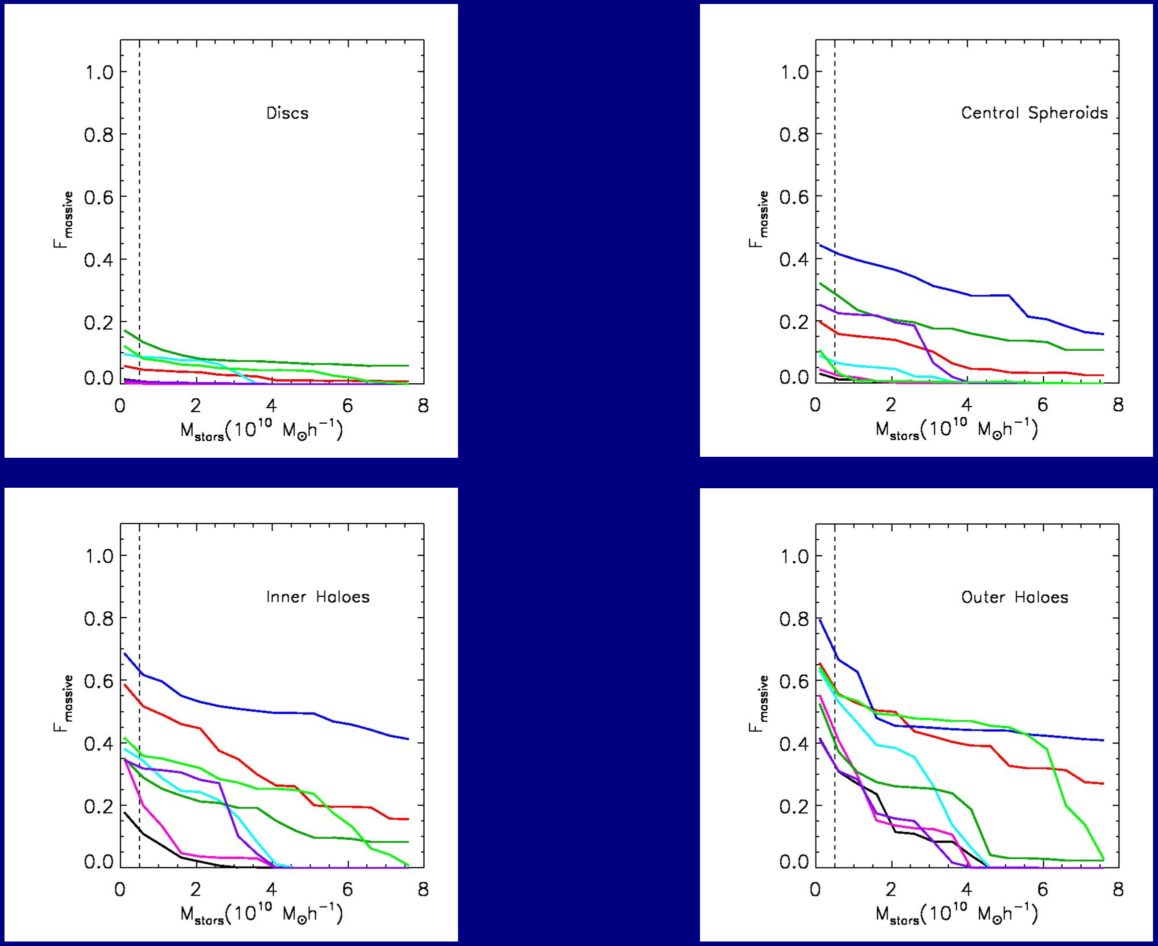




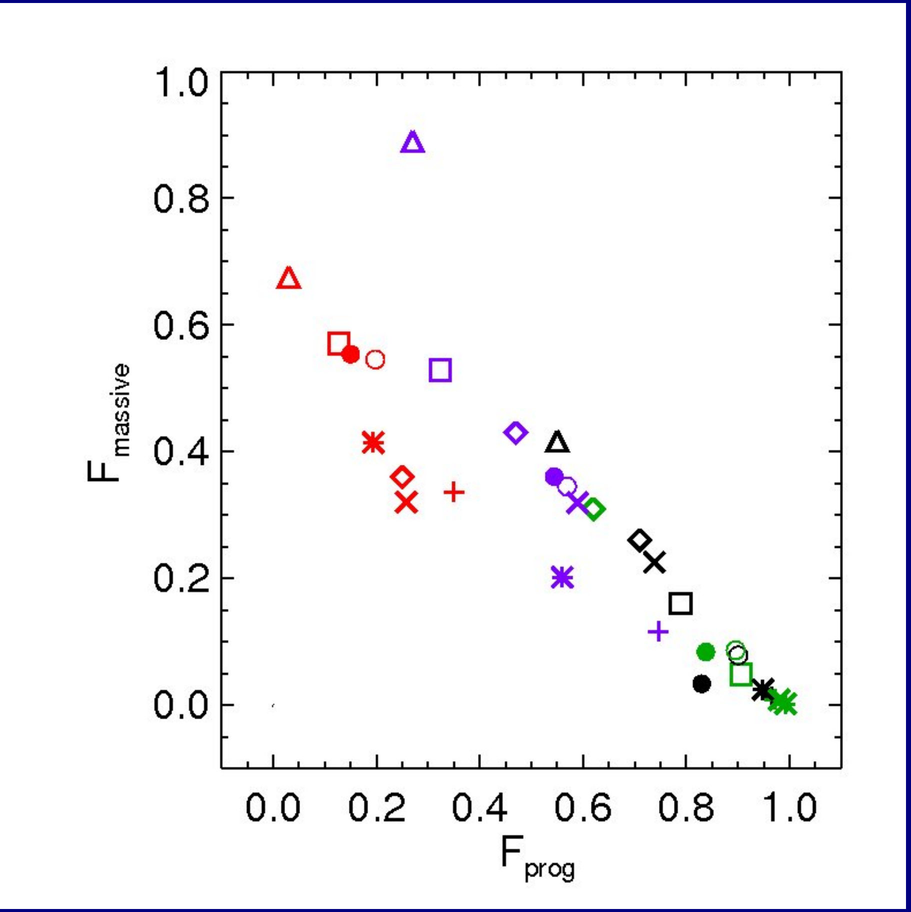


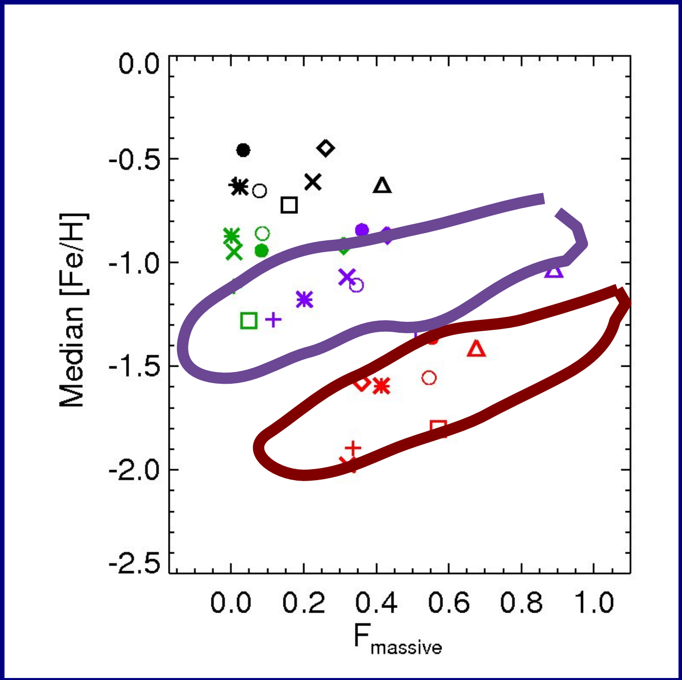


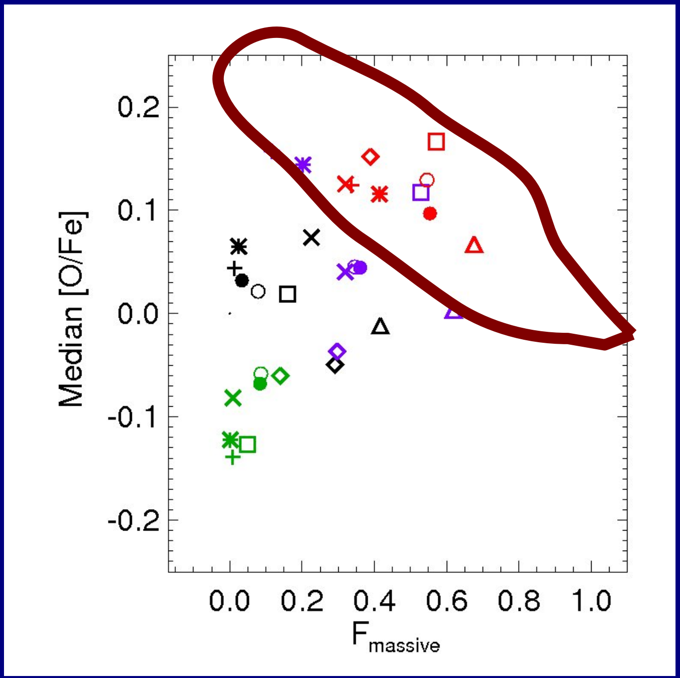
Fraction of stars formed in satellites more massive than M_{stars}



There is a correlation between the fraction of stellar mass formed in situ and the fraction of stellar mass formed in massive satellites ($M_{star} > 0.5\ 10^{10}$ Mo/h).





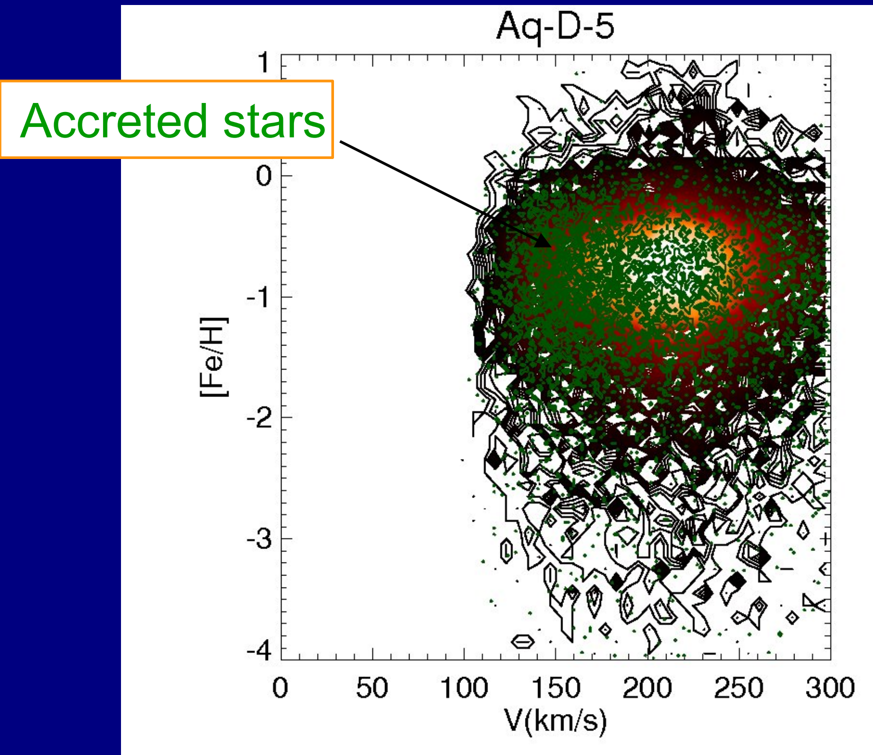


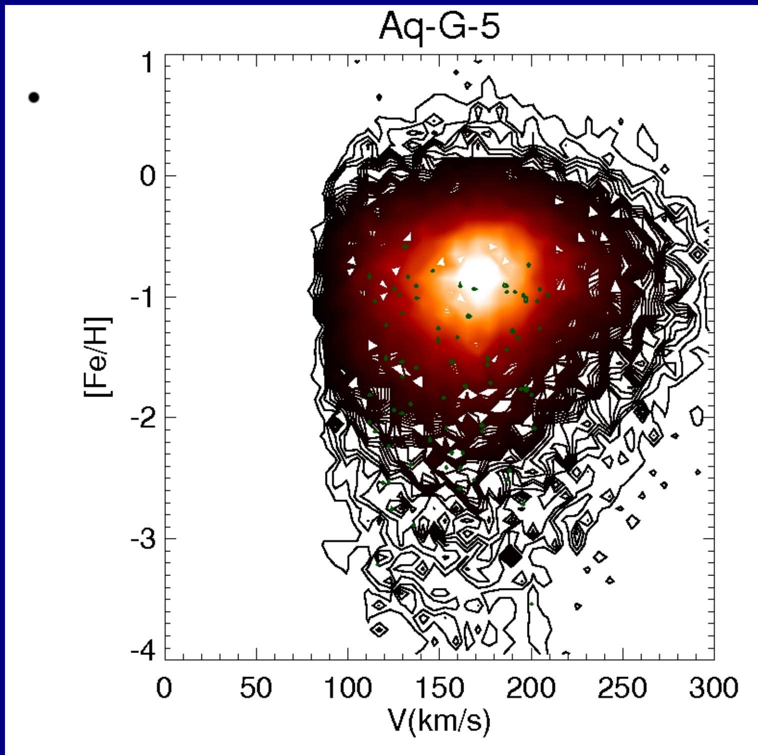
The level of enrichment of stars in the haloes tends to correlates with the fraction of mass formed in massive satellites:

the larger this fraction, the higher the median abundance of the haloes

Stars in the smooth stellar component accreted from satellites show larger e-enhancement than in situ ones.

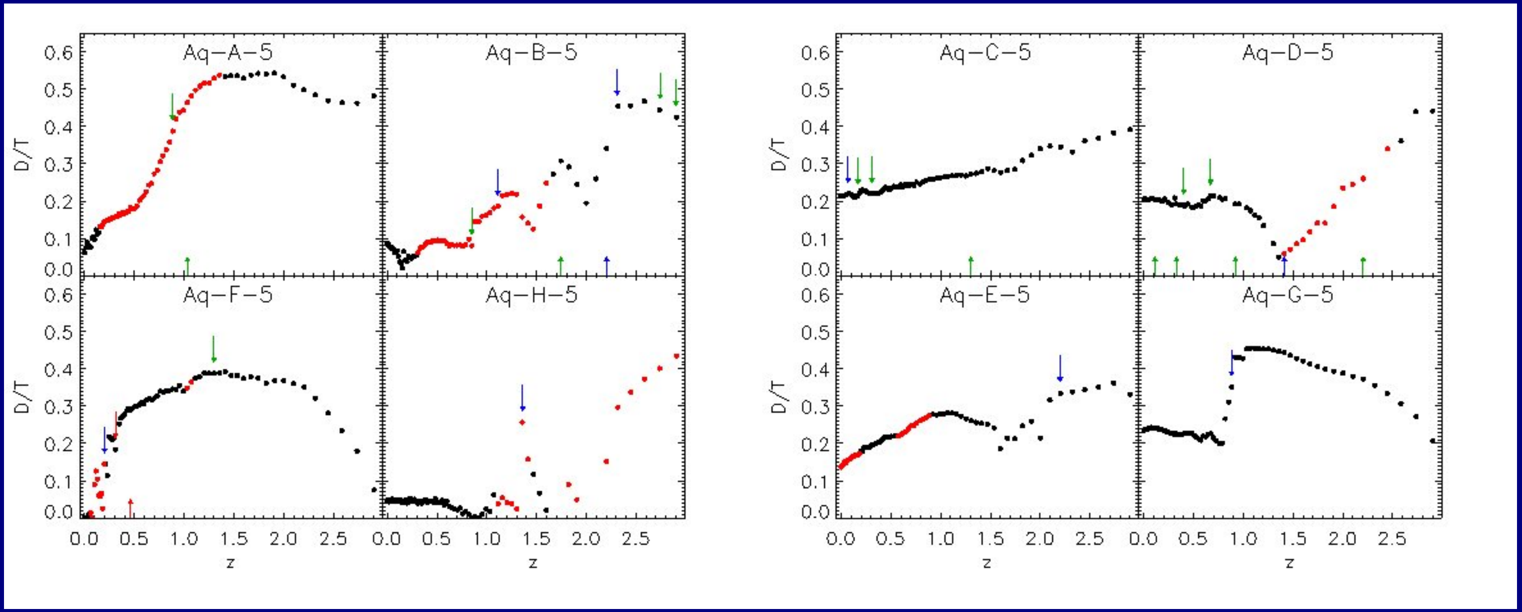
DISC COMPONENT





	[Fe/H]	[Fe/H]sat	[O/Fe]	[O/Fe]sat	Age	Age_sat	σ/vtan	σ/vtan
Aq-D	-0.86	-0.97	-0.096	0.19	7.99	10.91	0.68	0.77
Aq-G	-0.94	-1.75	- 0.09	0.08	8.06	12.22	0.62	0.71
						(Gyr)		

Minor mergers and interactions can be correlated with distruction of the disc components



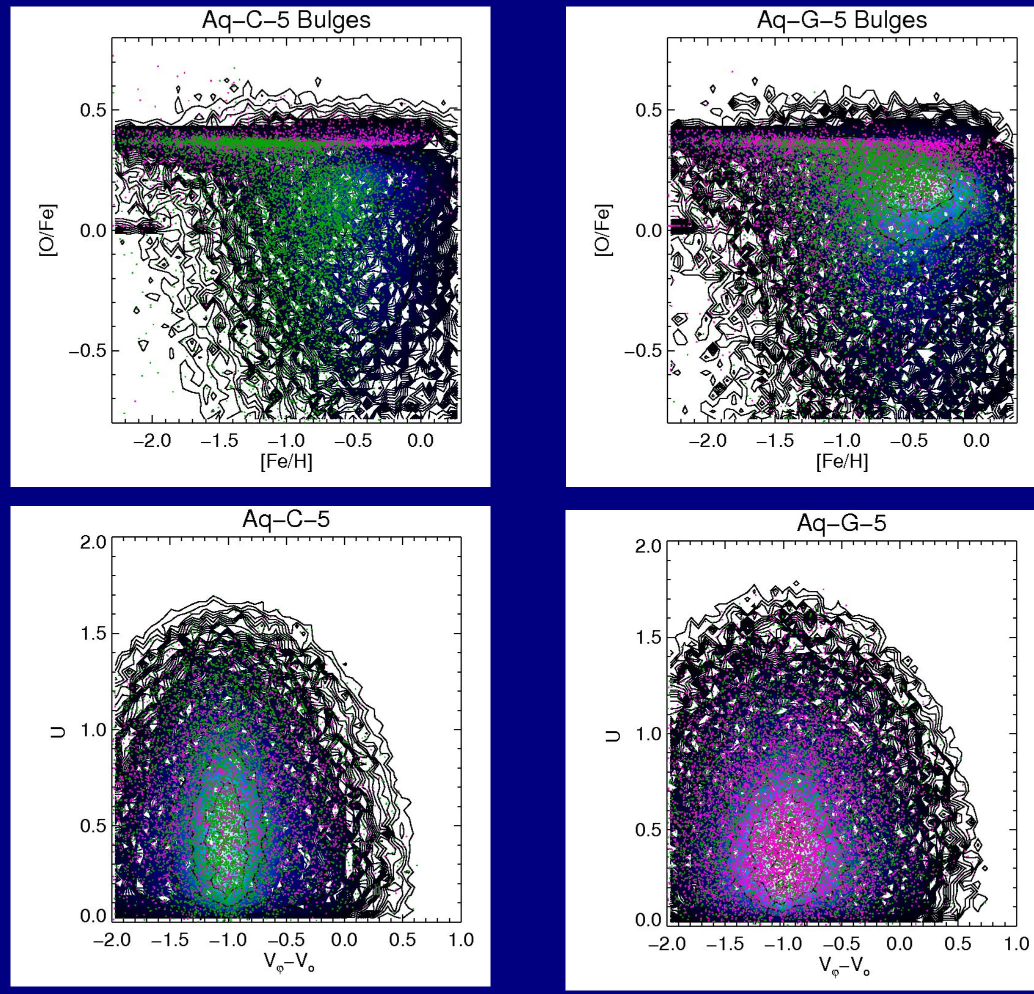
Scannapieco, Tissera, White, Springel 2009

CENTRAL SPHEROIDS or ‰Bulges‰

Map: In situ stars

Green: Disc stars

Magenta: Accreted stars



Aq-C-5: 95% in situ
Aq-G-5: 74% in situ

Stars coming from the disc tend to be low Alpha enriched with respect to accreted stars

And they might show larger dispersion.

Simulating major massive mergers: chemical evolut

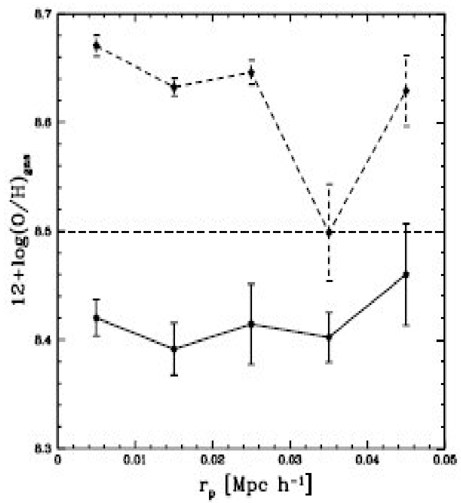
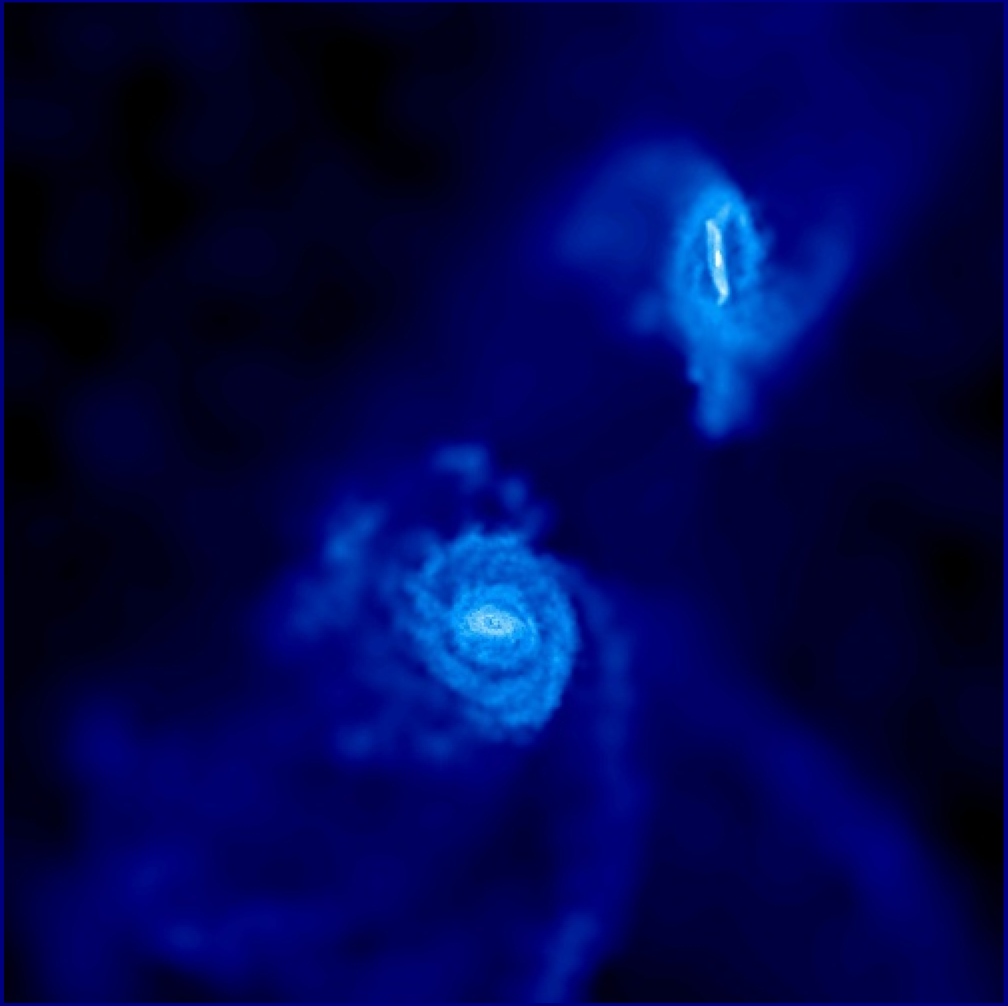


Fig. 9. Mean O/H abundances of the interstellar medium in galaxies in pairs estimated within 0.5 r_{opt} (solid line) and 2 r_{opt} (dashed line) as a function of relative separation. The horizontal line represents the mean O/H abundance for the control sample.

g. Barnes & Hernquist 1996, etc),

nd new ones (e.g. Perez et al. 2006,

Major massive mergers: chemical evolution



Wet mergers 25% and 50% gas in the discs .

Initially, gas component has a metallicity gradient consistent con local galaxies and high redshift galaxies, respectively.

We required the abundance of the gas component to be consistent with the MZR at z=0 and z~2.

We tried different orbital parameters and different combinations of SN feedback.

Perez, Michel-Dansac & Tissera 2011

How chemical elements were tredistributedudu

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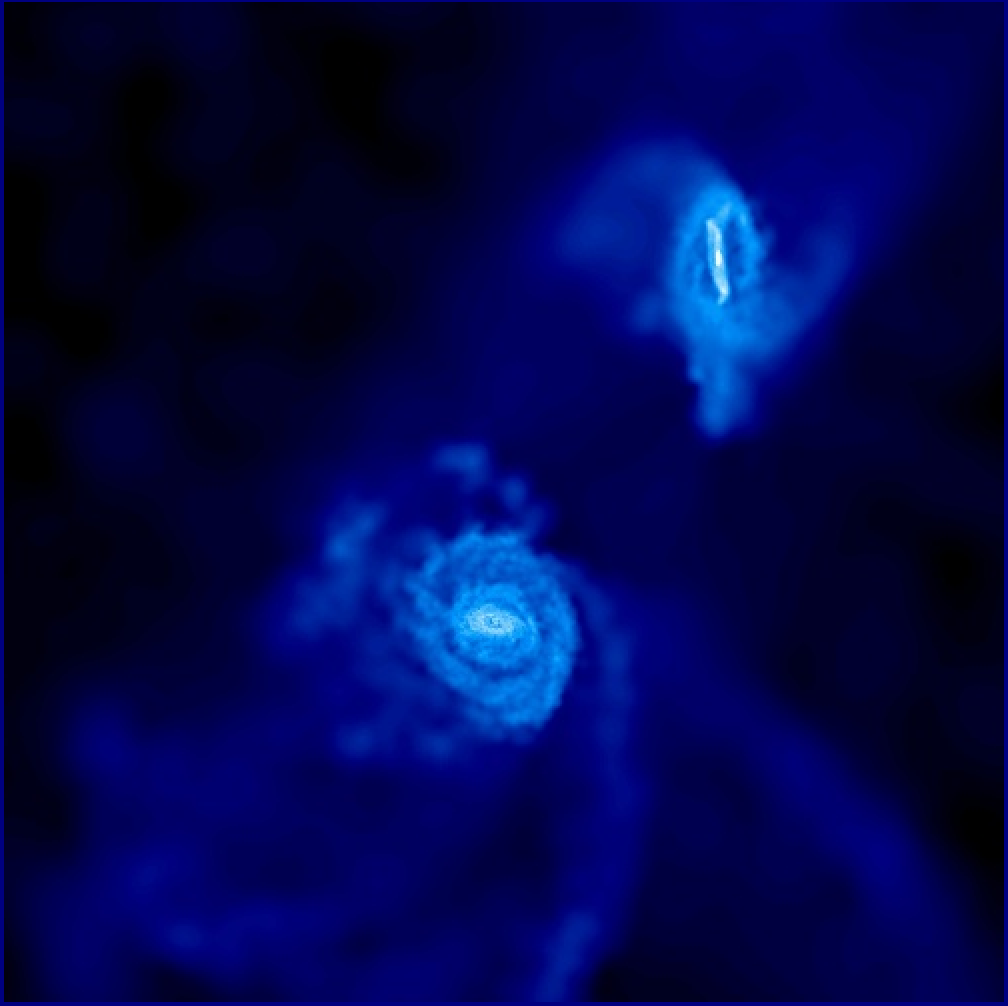
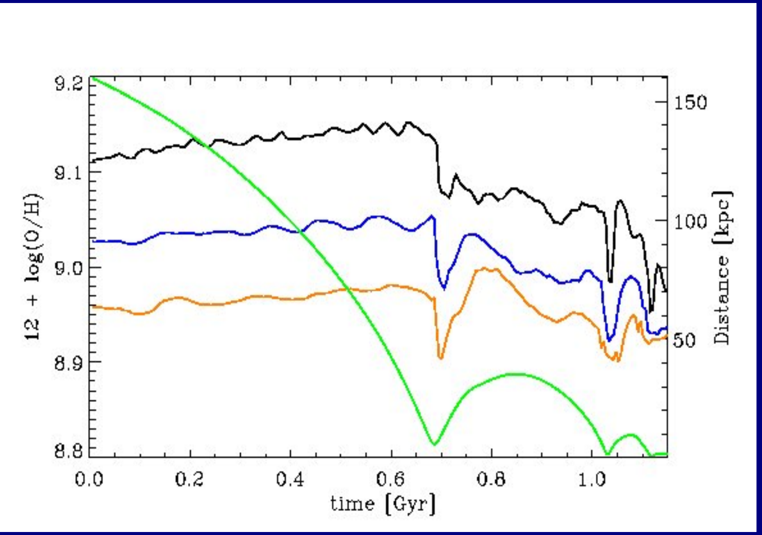
Major massive mergers: chemical evolution





Perez, Michel-Dansac & Tissera 2011

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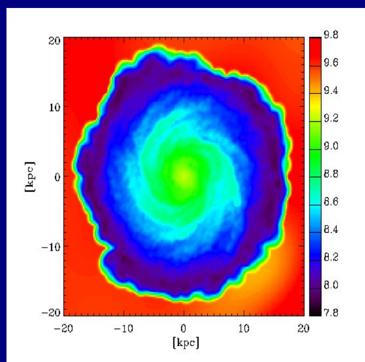
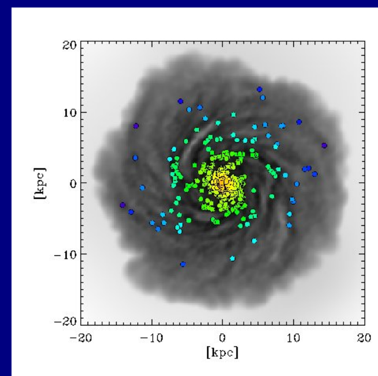
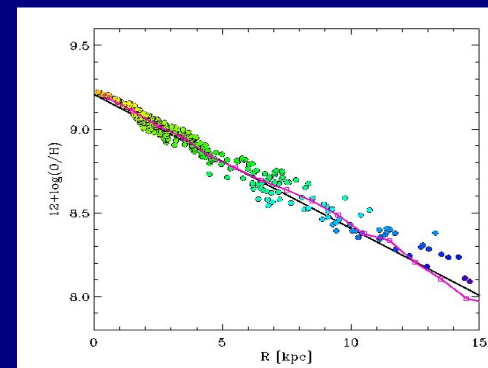
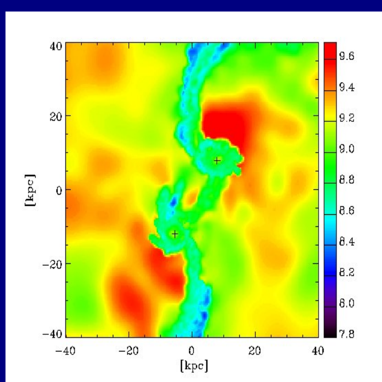
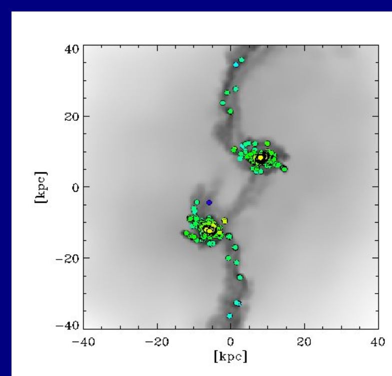
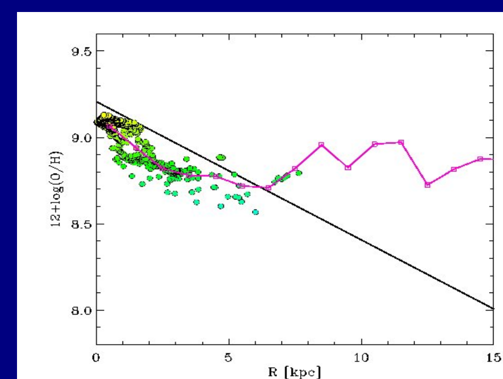










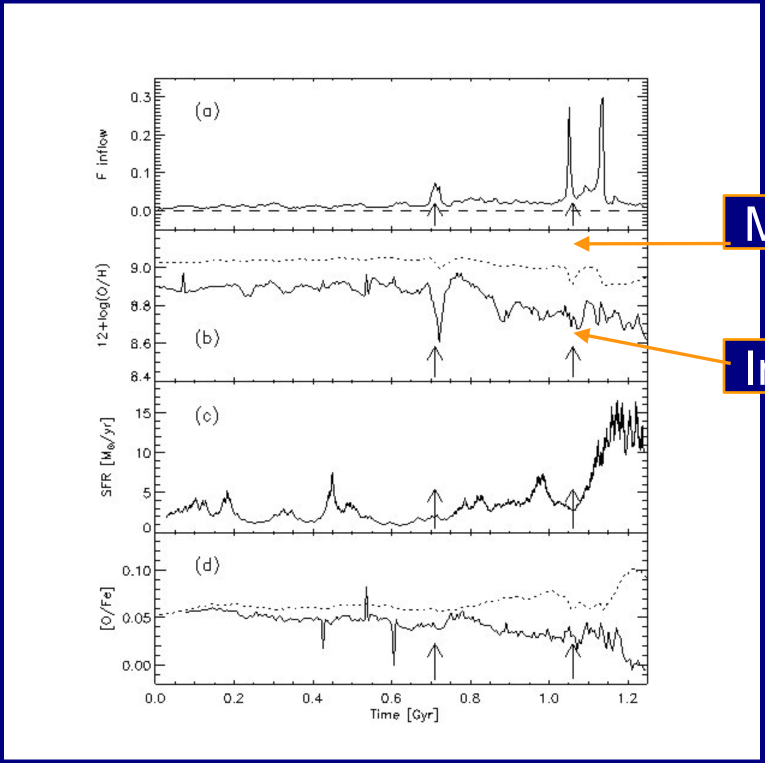


O/H maps

SF sites

O/H profiles

Poor gas merger

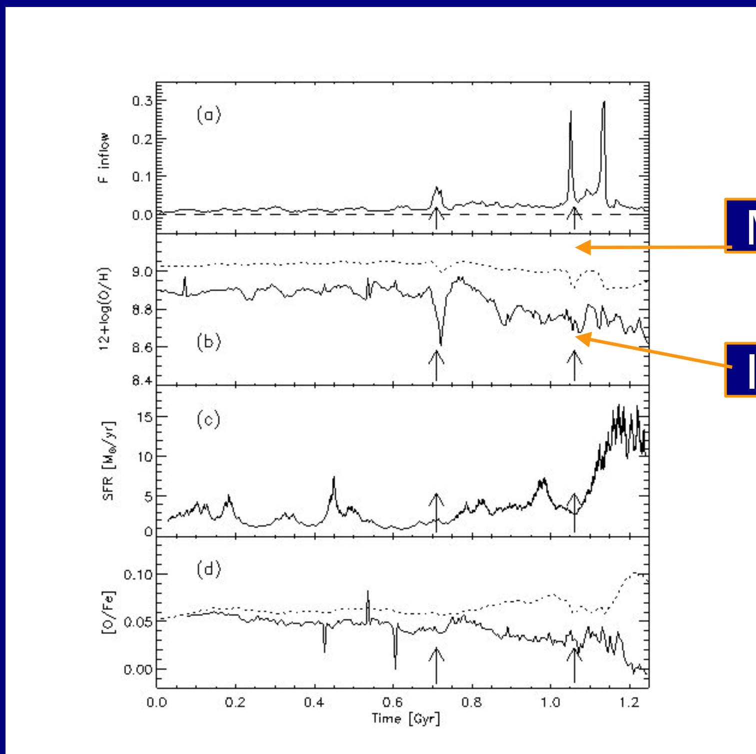


Mean gas Z

Infalling gas

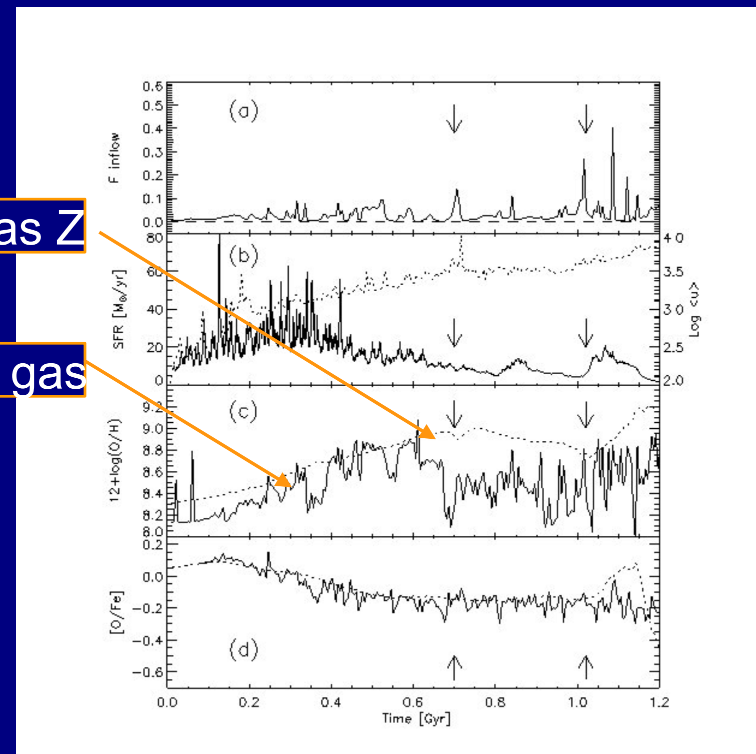
Poor gas merger

Rich gas merger

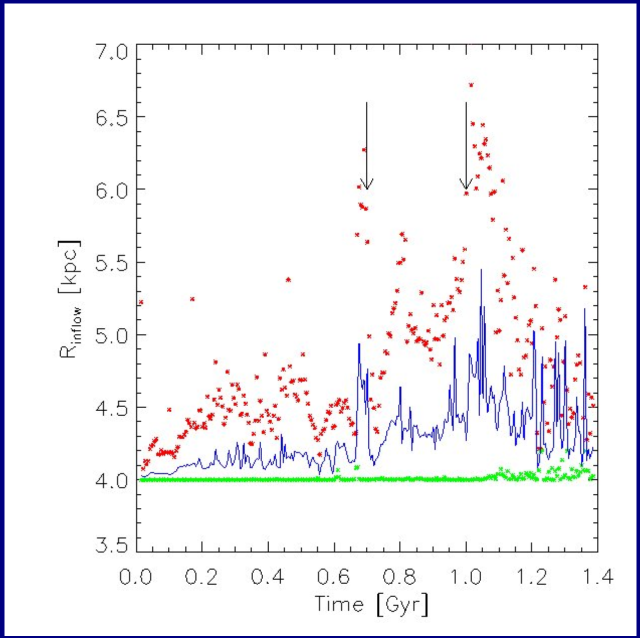


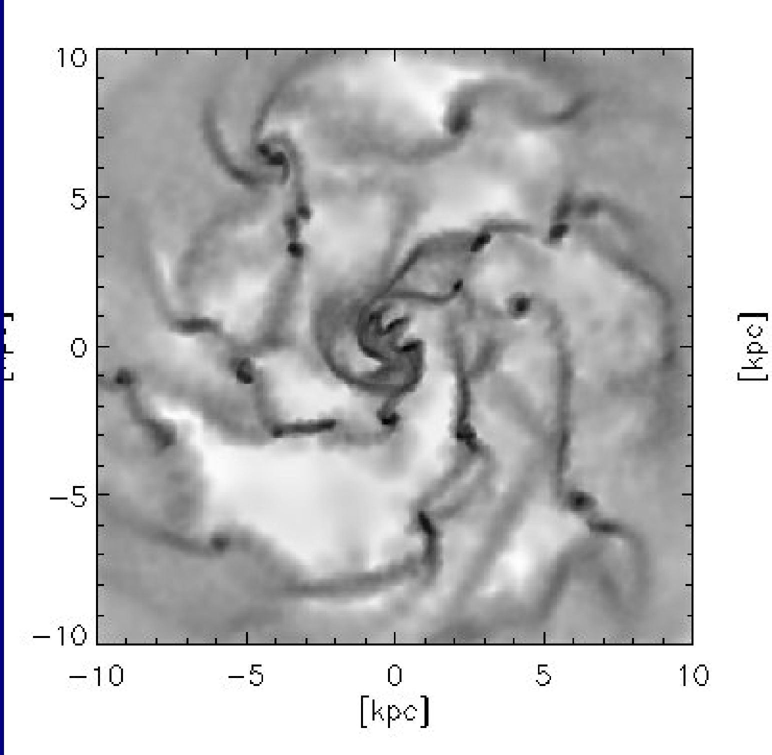
Mean gas Z

Infalling gas



Gas inflows in the very wet merger:





Perez et al. In preparation

Summary

- Tiny, minor and major mergers contribute to the formation of galaxies in a HCS.

- Their importance depende on the dynamical component: bulge, disc or halo

- Chemical features can be linked to the history of assembly: merger frequency,
- potential well of merging systems.

- Central spheroids formed mainly in situ: old stellar populations, [α-Fe] enriched ,
- higher O/H abundances. Some contribution from accreted stars (few percentage up t
- ~15 %), Contributions for disc stars vary around 35%, they tend to be θ-enriched.

- Stellar field haloes show a dual history of formation (e.g.Zolotov et al. 2009; Font et al. 2011).
- Outer Haloes formed by contribution from substructure; Inner haloes have larger
- Fraction of in situ formed stars dominated by disc heated ones. Debris stars tend to
- be old with lower level of enrichment and high [θ-Fe] . The median abundances correlate
- with the fraction of stars formed in massive satellites: the assembly history leaves its imprint.

- The disc component formed mainly in situ and in several starbursts resulting in a
- population with lower [O/Fe] content. There could be contribution from satellites (~15%; e.g
- Abadi et al. 2003). These stars are older, θ-enhanced and high velocity dispersion
- than those stars formed in situ. Simulated gradients are consistent with observations.

- Massive mergers can trigger strong inflows transporting low metallicity material inward.
- Lower metallicity in the central regions can indicate a time close to the pericenter but new
- SF will inject new material deluting the effects.

Summary

- Central spheroids formed mainly in situ: old stellar populations, [α-Fe] enriched ,
- higher O/H abundances. Some contribution from accreted stars (few percentage up to ~15
- Contributions for disc stars vary around 35%, these stars are old but they can be θ-enriche

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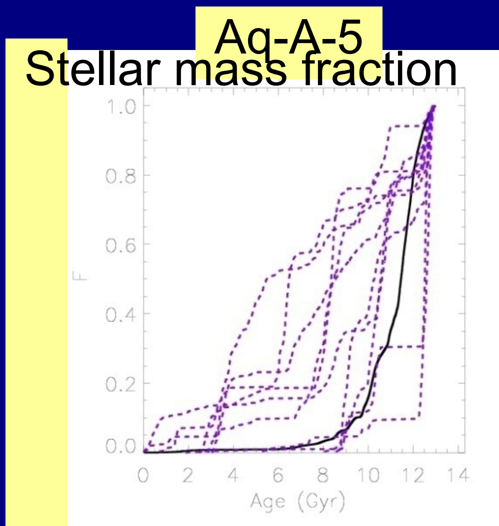
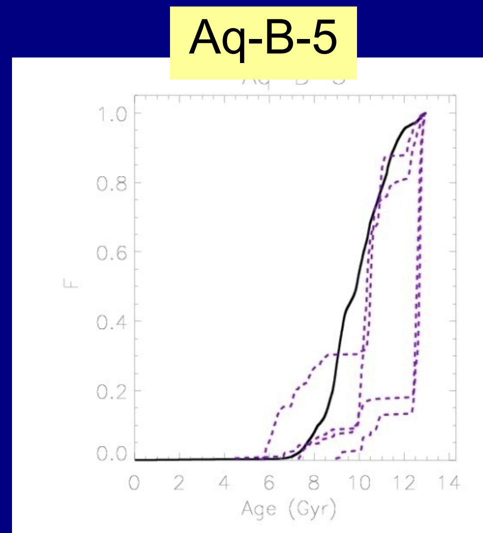
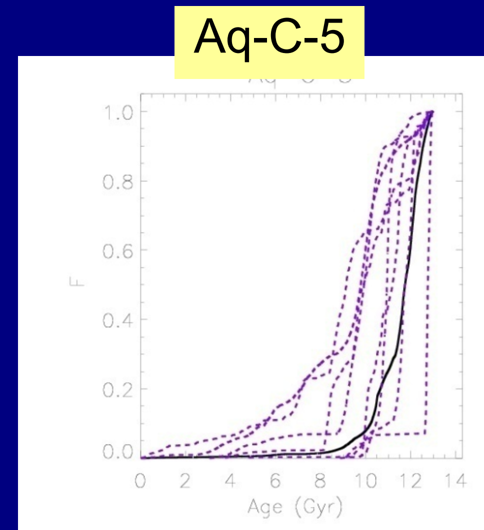
- Massive mergers can trigger strong inflows transporting material inward: metallicity depend
- FALTA

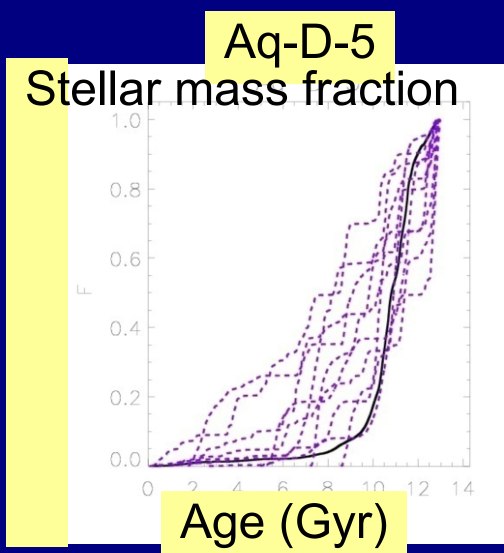
- Hierarchical clustering can produce general chemical patterns similar to
- observed ones.

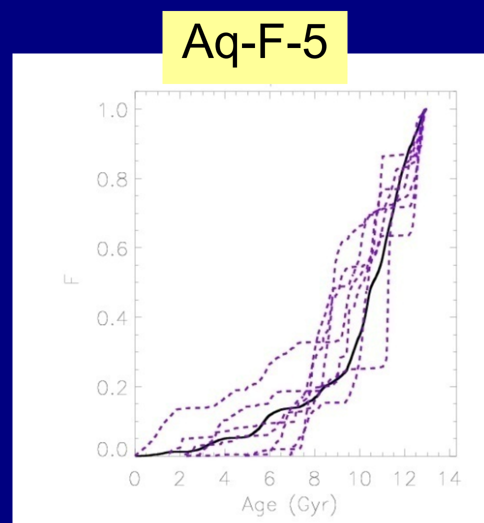
The satellite systems: star formation histories

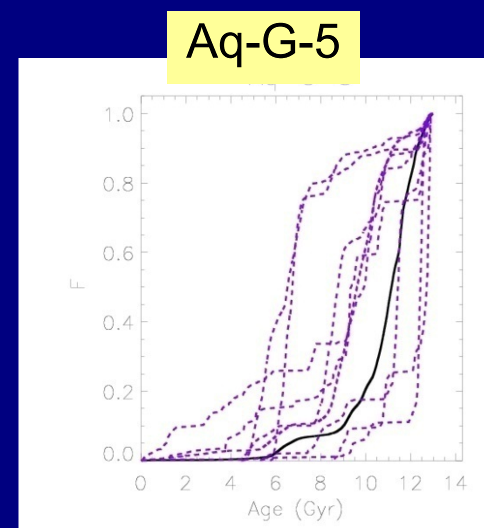




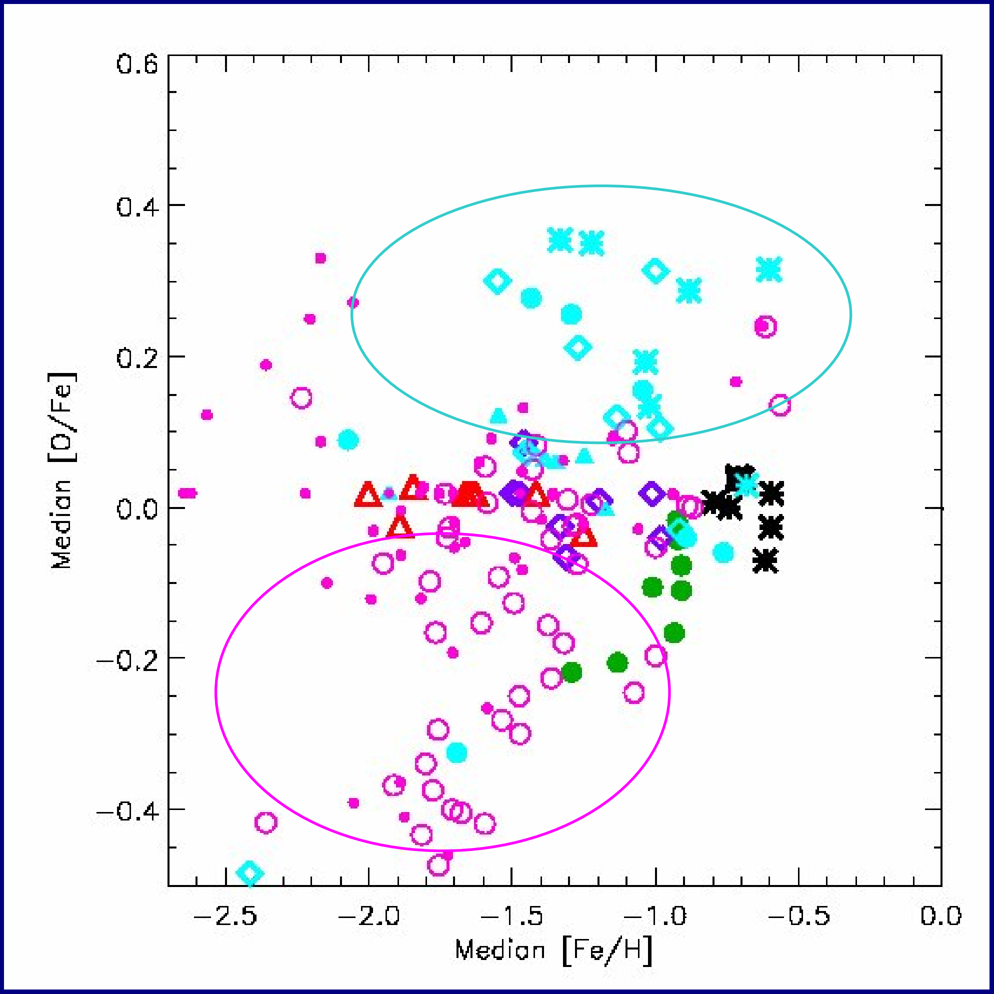








The satellite systems: chemical properties

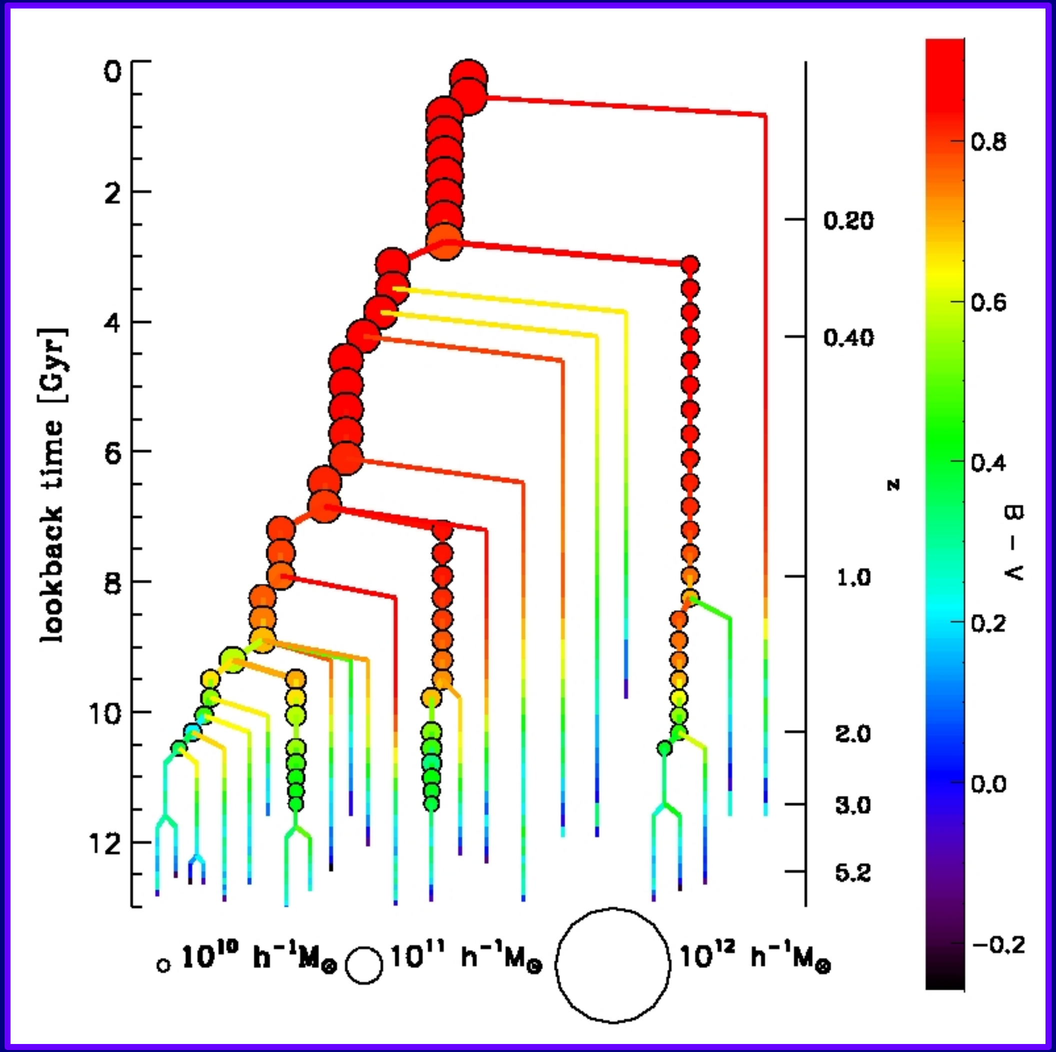


Chemical properties of the satellites which contribute to the formation of the main galaxies are different from those of the surviving satellites.

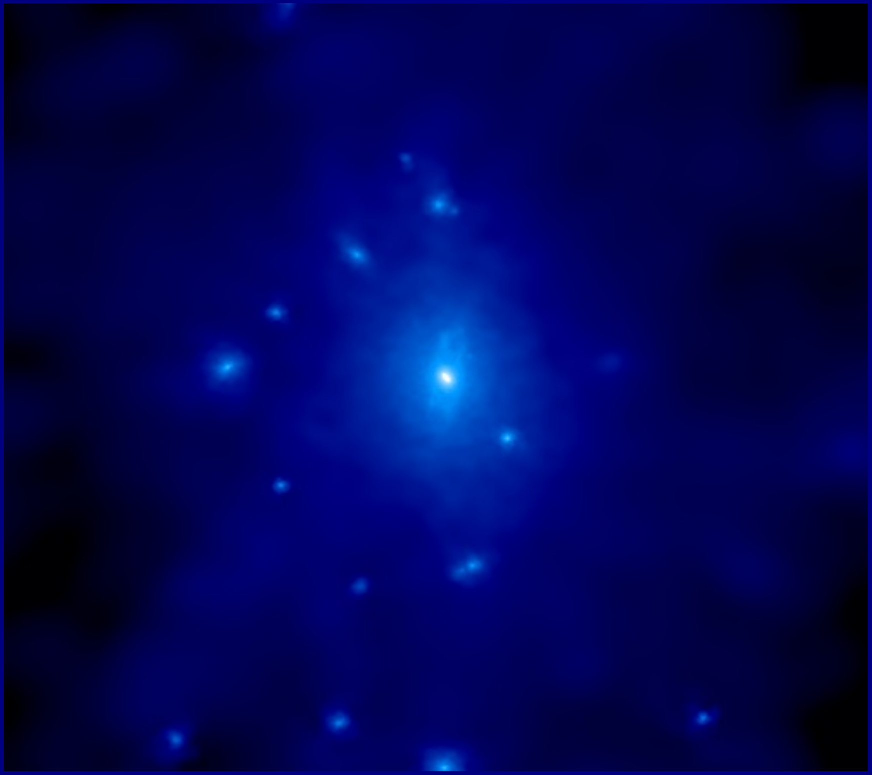
Stripped stars

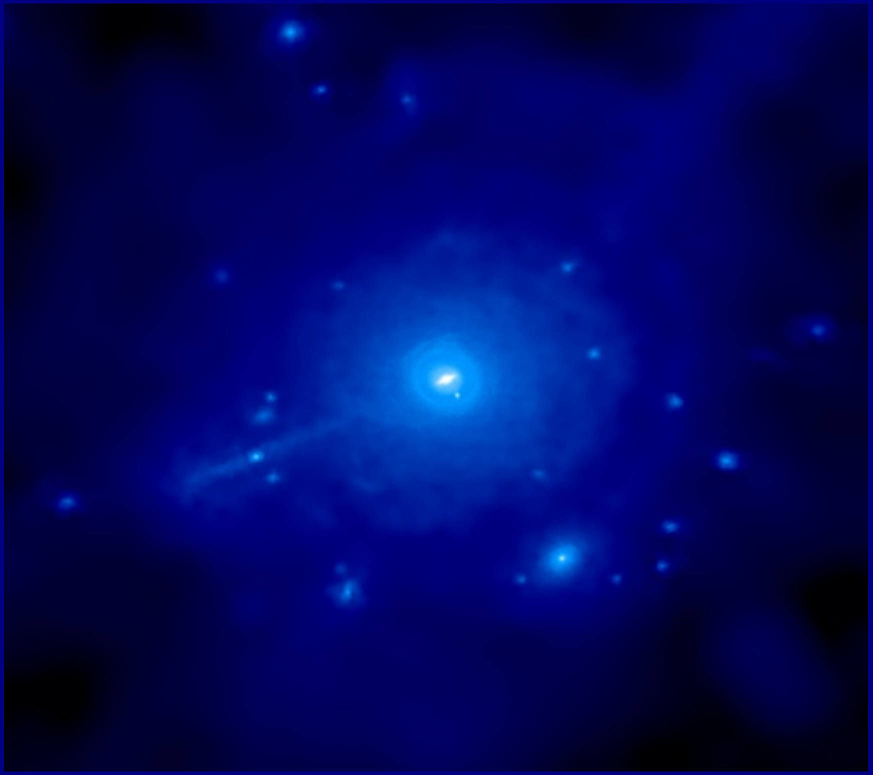
Star in surviving satellites

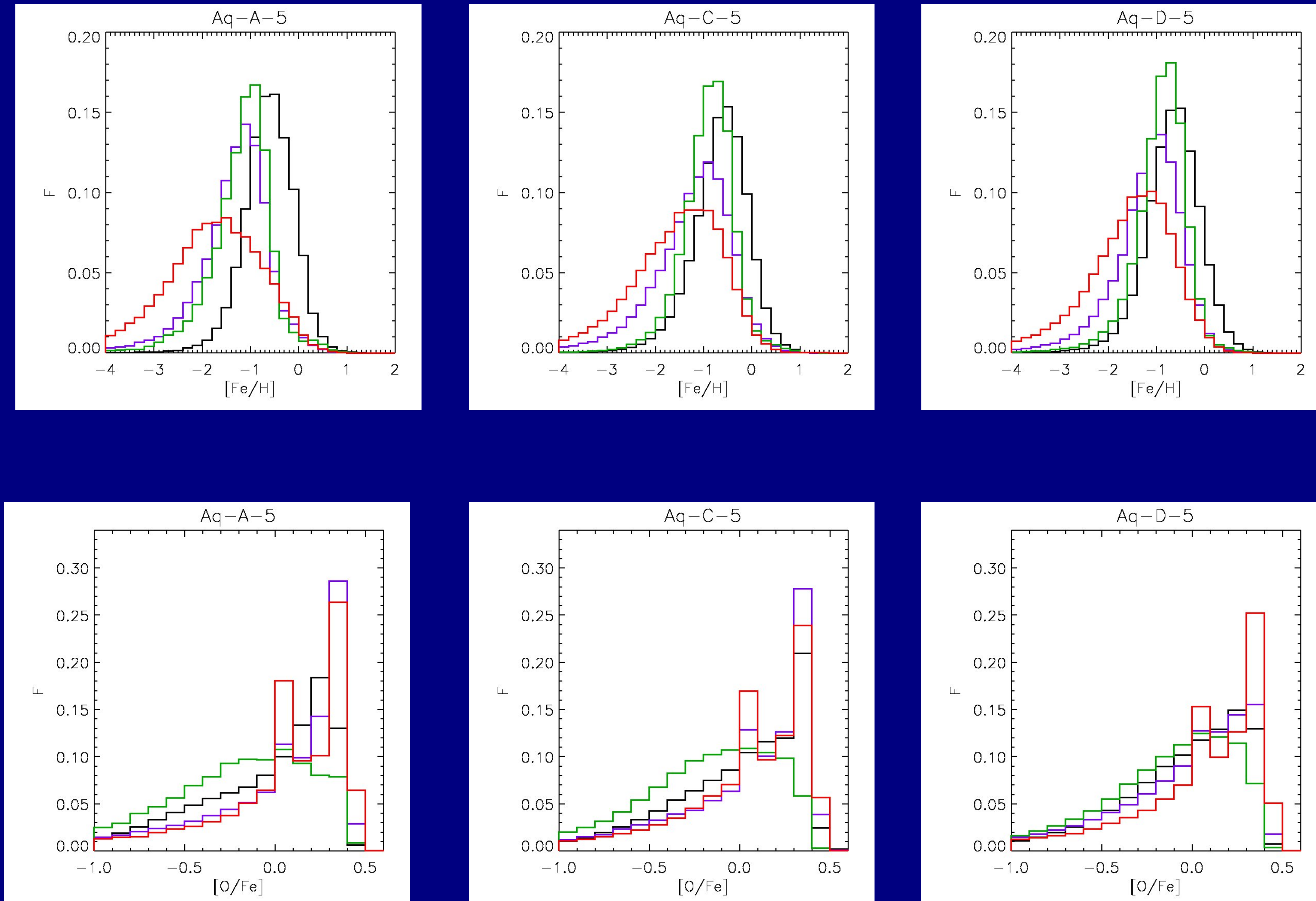
The hierarchical building up of the structure



Can the chemical properties of satellites galaxies be reproduced in Hierrachical scenarios?

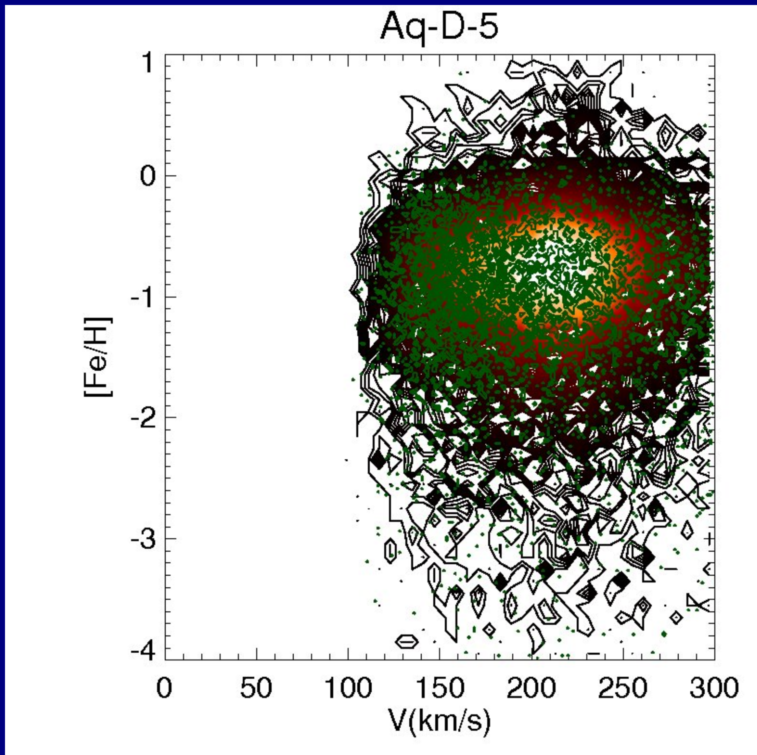


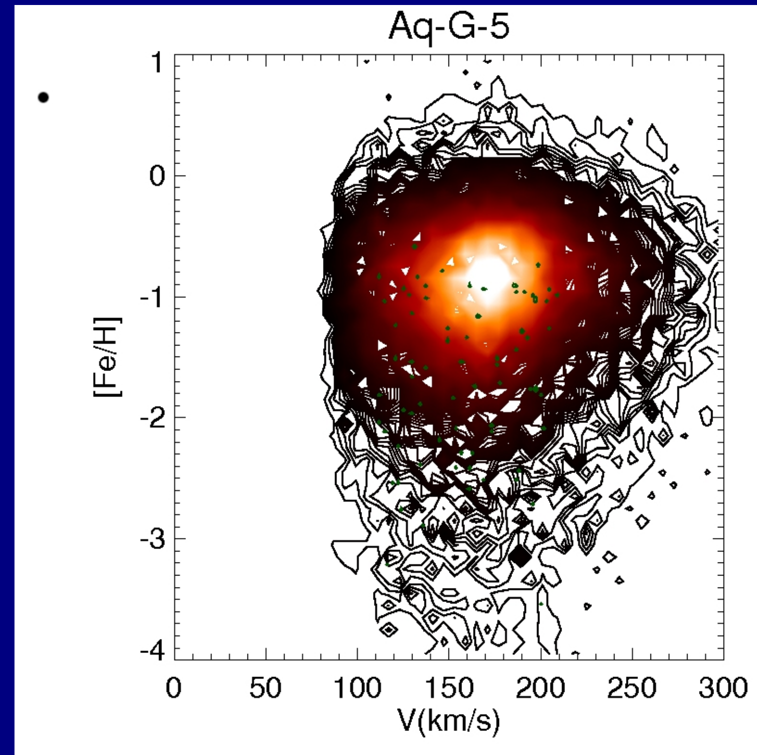




Disc Bulge Inner Halo Outer Halo

DISC COMPONENT





	[Fe/H]	[Fe/H]sat	[O/Fe]	[O/Fe]sat	Age	Age_sat	σ/vtan	σ/vtan
Aq-D	-0.86	-0.97	-0.096	0.19	7.99	10.91	0.68	0.77
Aq-G	-0.94	-1.75	- 0.09	0.08	8.06	12.22	0.62	0.71
						(Gyr)		