THE CHEMICAL HISTORY OF STAR-FORMING GALAXIES IN NEARBY CLUSTERS

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Outline

I. Introduction: The evolution of cluster galaxies

II. Spatially resolved spectroscopy of star-forming galaxies in the Hercules cluster (Petropoulou et al. 2011, ApJ, 734, 32)

III. The star formation and chemical history in the Hercules Supercluster (Petropoulou et al, 2013, in prep.)

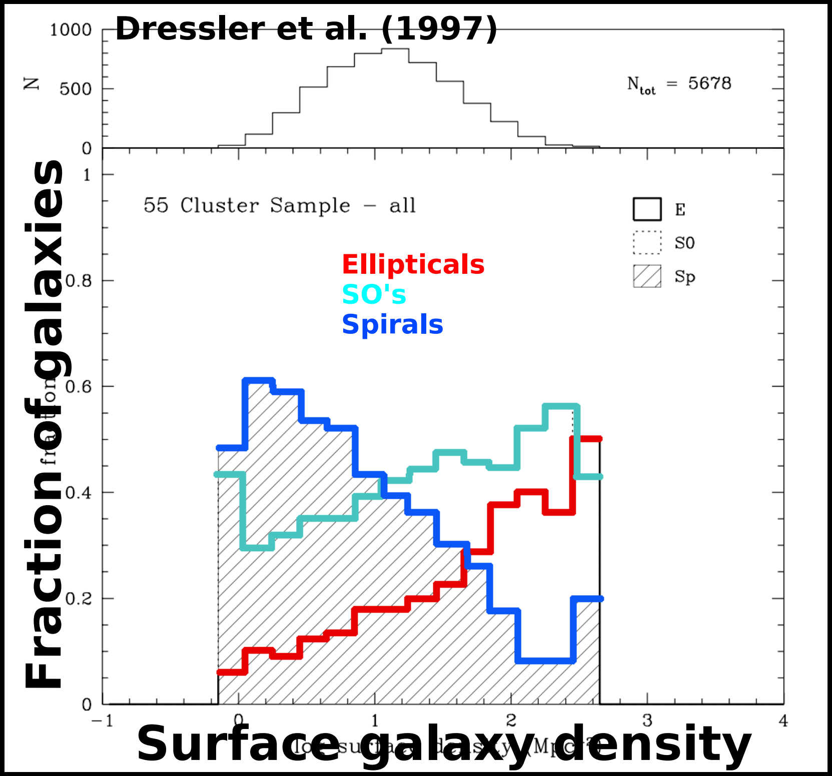
IV. The chemical enrichment of low-mass star-forming galaxies in Coma, A1367, A779, and A634 (Petropoulou et al. 2012, ApJ, 749, 133)

V. Discussion: clues on the underlying mechanisms driving the Mass-Metallicity Relation

VI. Current work

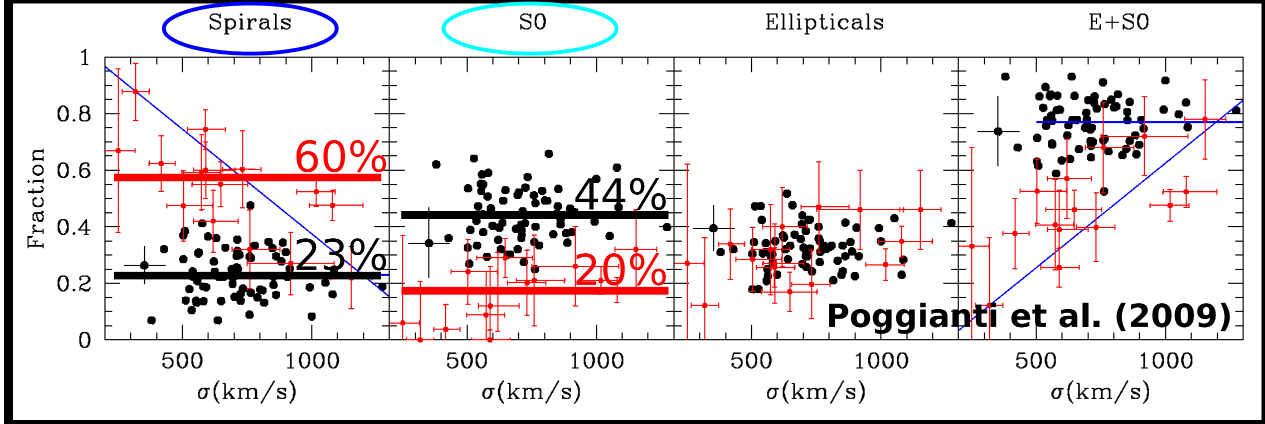
Galaxy evolution is connected with the environment

I. Morphology-density relation (Dressler 1980)



and morphological evolution

WINGS clusters: $0.04<z<0.07$, EdisCS clusters:$0.5<z<1.2$

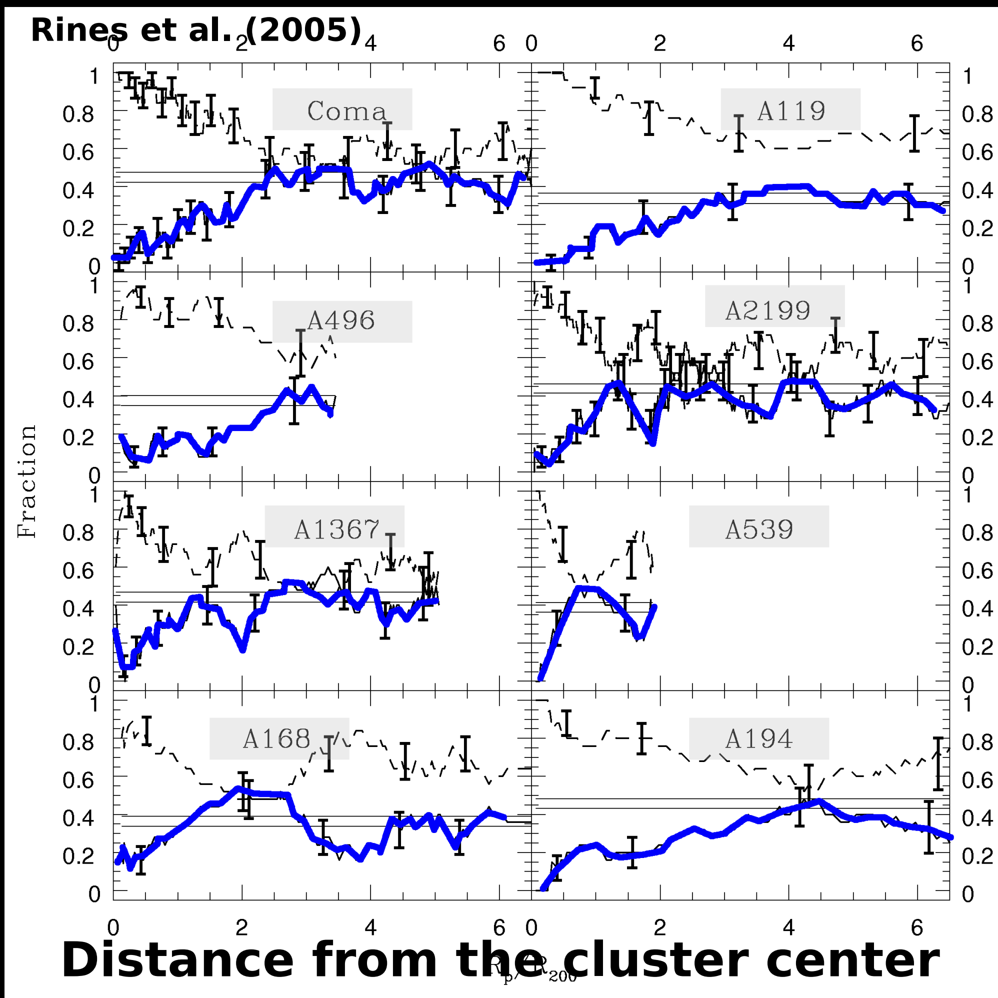


Butcher-Oemler effect: an increase with redshift in the fraction of blue star-forming galaxies seen in cluster cores between z=0.0-0.5 (Butcher & Oemler 1978,1984).

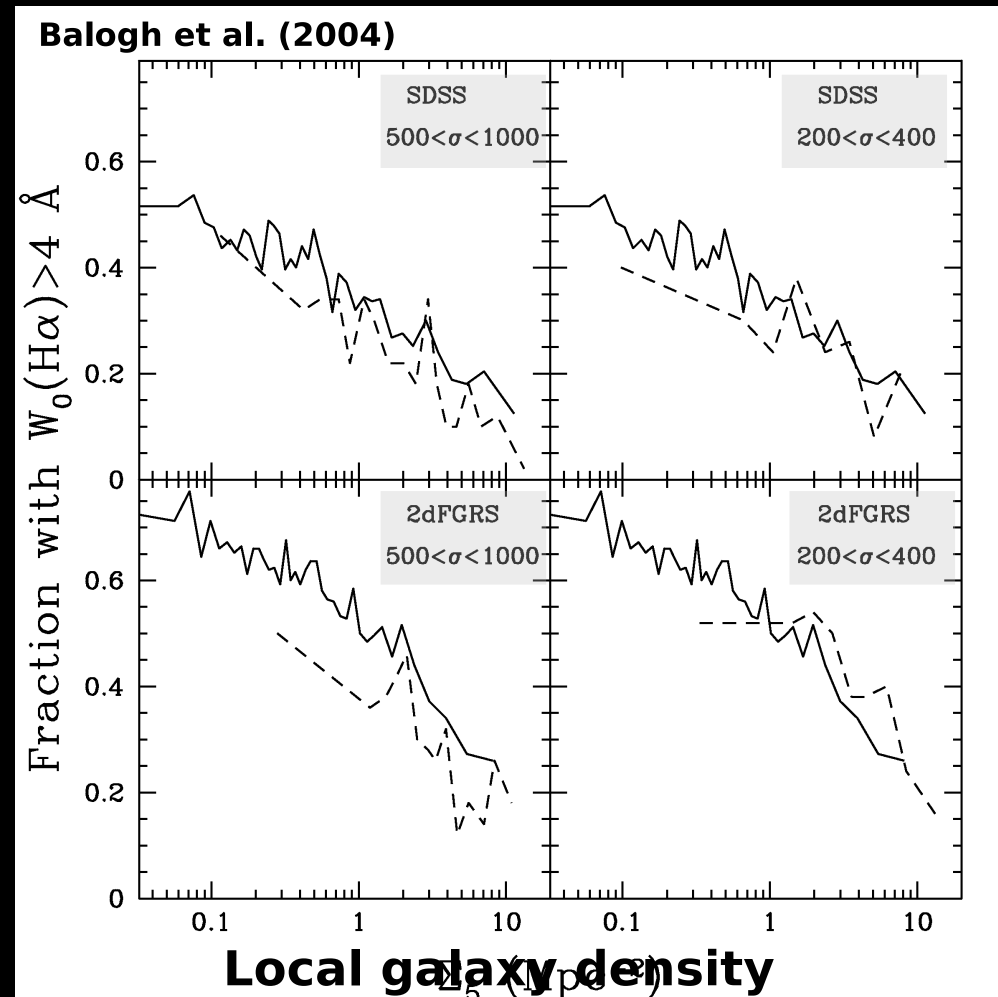
I. Introduction: the evolution of cluster galaxies

II. Star-formation-density relation

CAIRNS: z<0.05



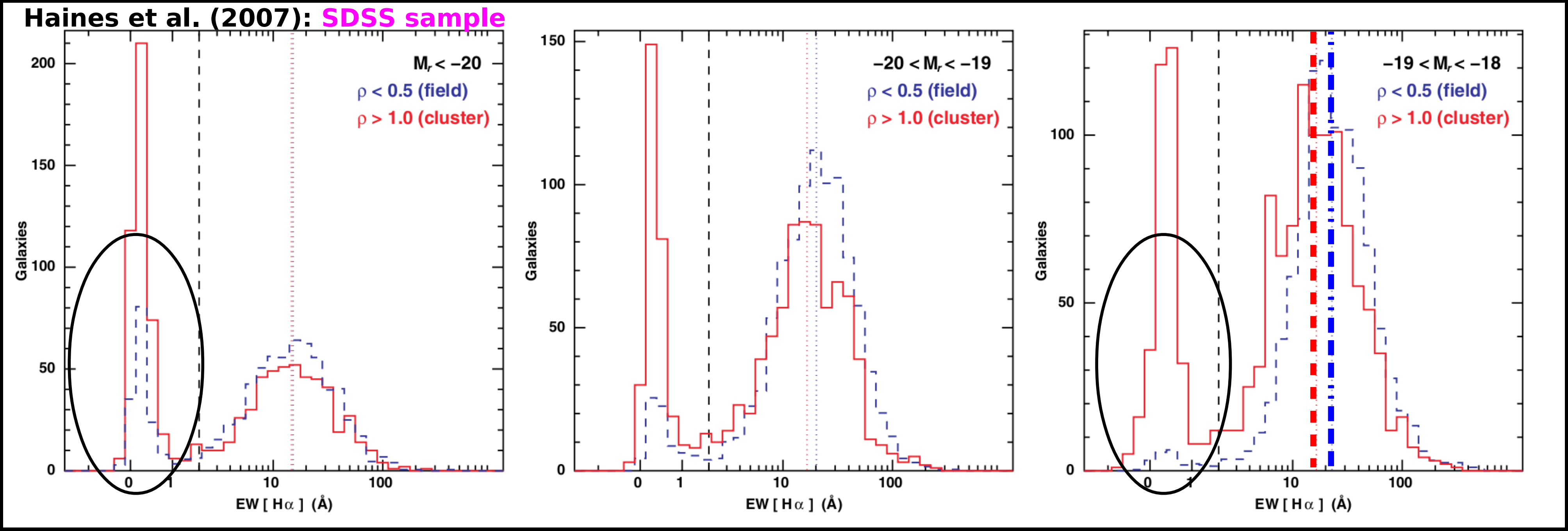
SDSS+2dF: 0.05<z<0.095

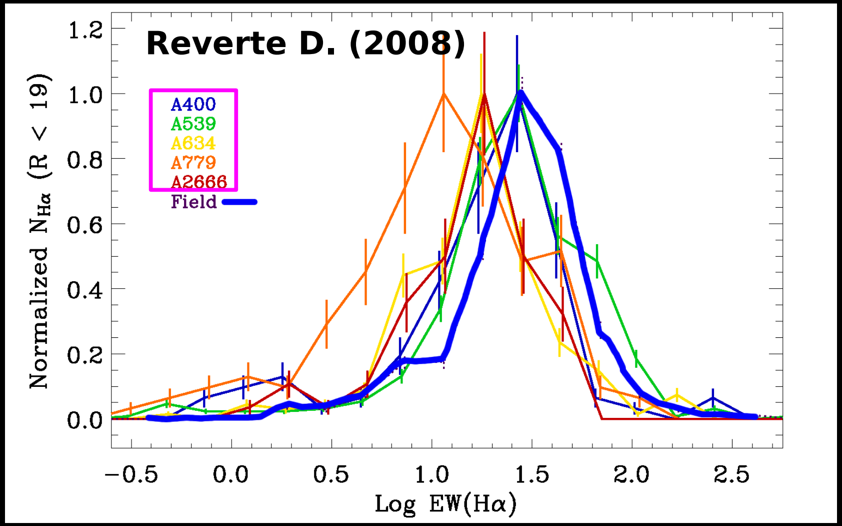


Are lower SFRs in clusters induced directly by environmental effects or result from the "secular" galaxy evolution?
If environmental effects suppress SF in clusters, which is the mechanism? (Time-scales are important!)

Galaxy evolution is connected with the environment

III. Star-formation activity of cluster galaxies



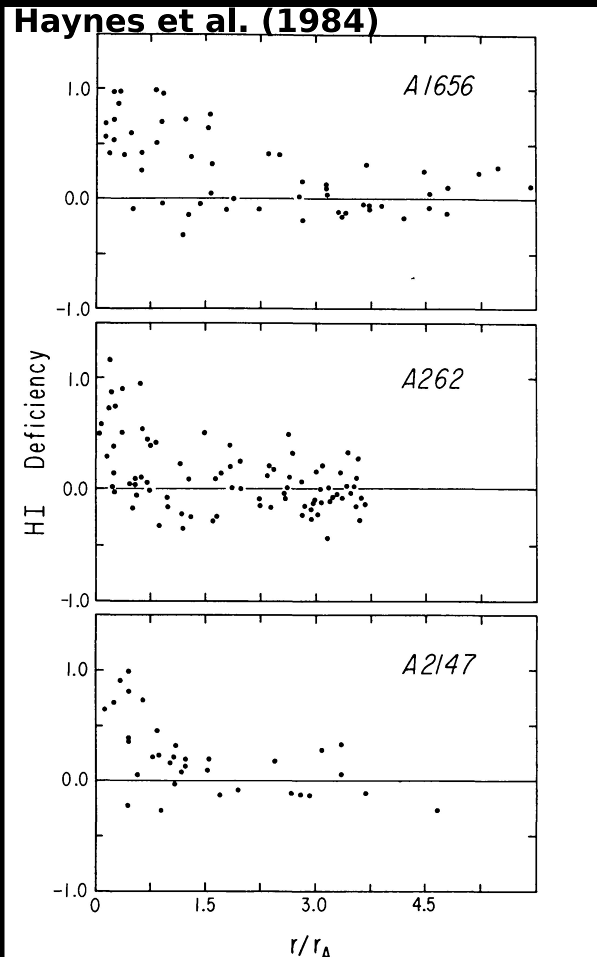


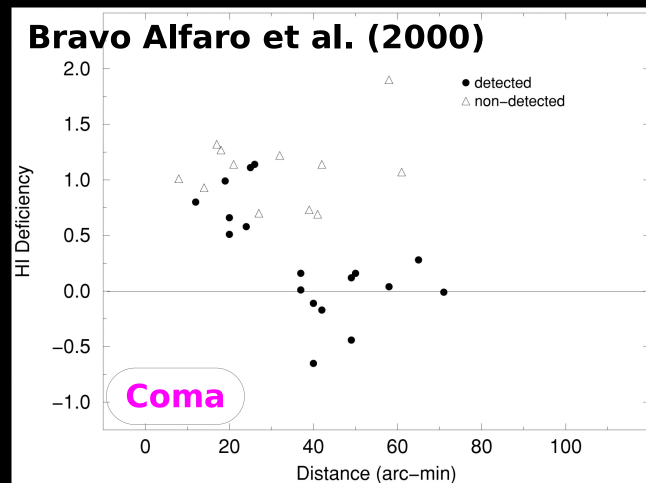
Simulations by Tonnesen et al. (2007): ram-pressure stripping the most common mechanism of gas removal

Poggianti et al. (2009): k+A galaxies preferentially located in clusters

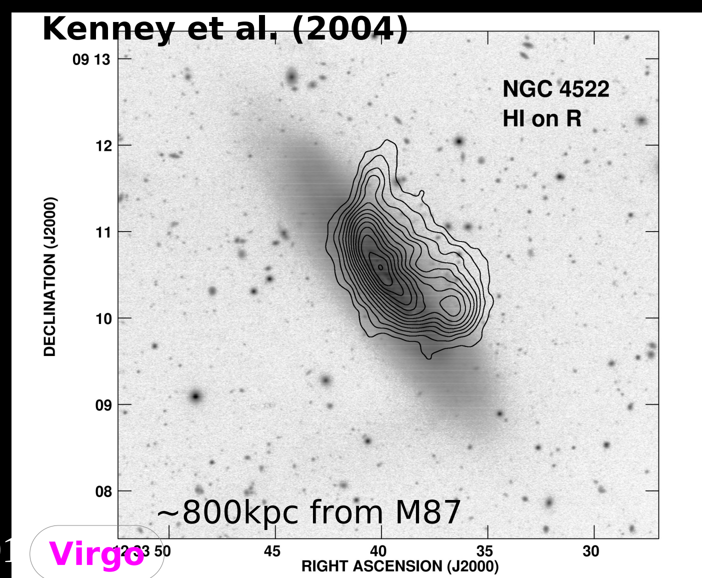
Galaxy evolution is connected with the environment

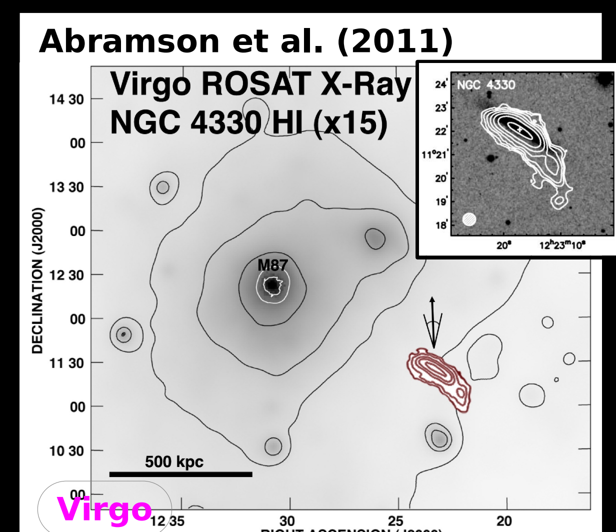
IV. Deficiency and disturbed morphologies of the atomic gas of cluster galaxies





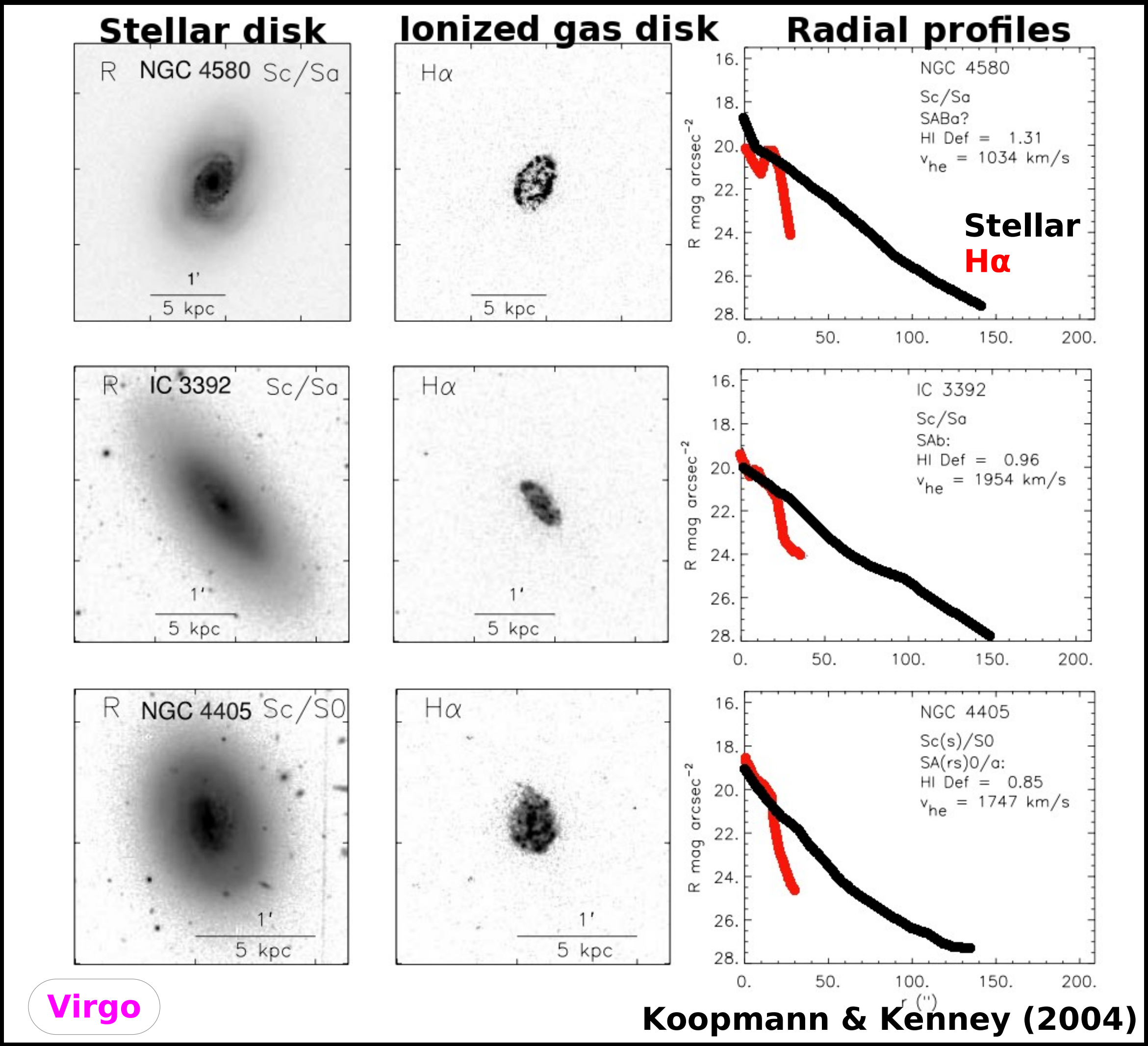
HI deficiency in Virgo spirals:
Chamaraux et al. (1980),
Cayatte et al. (1990)

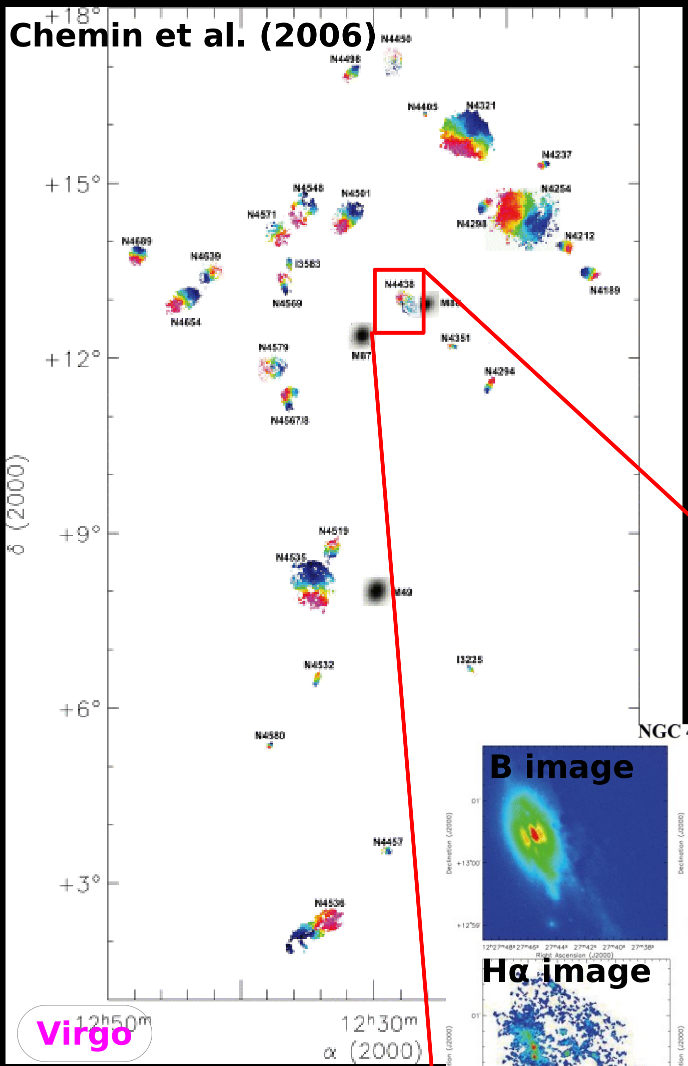


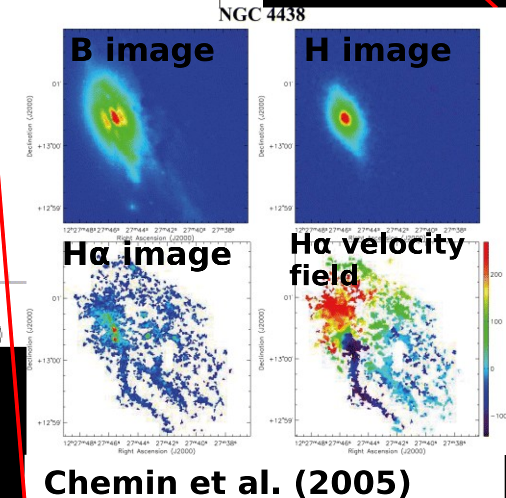


Galaxy evolution is connected with the environment

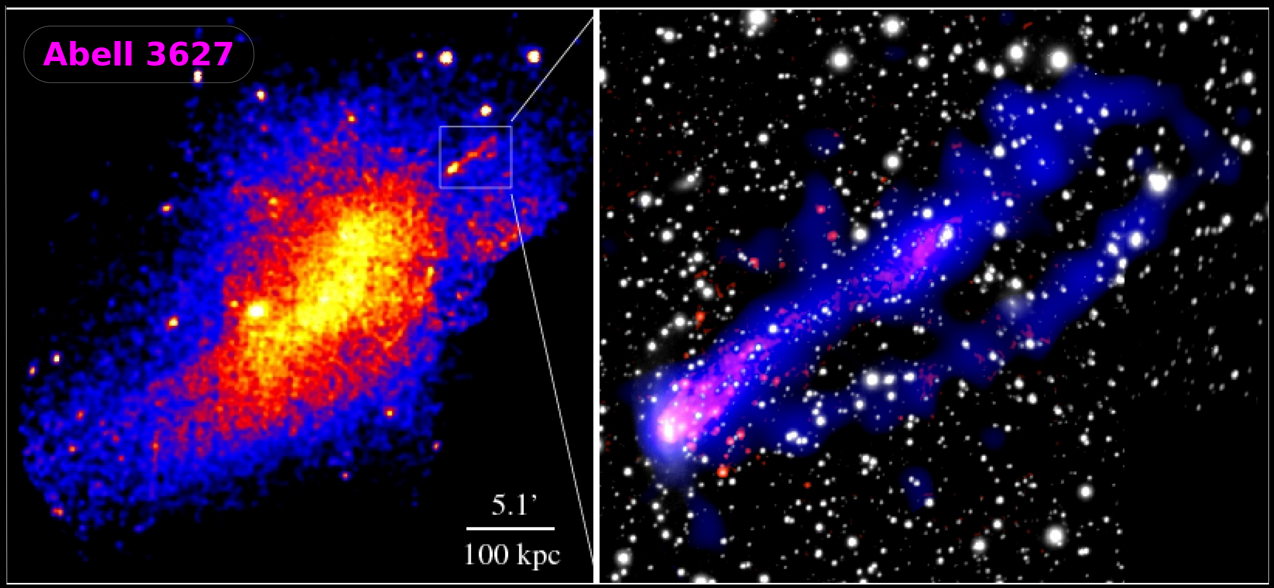
IV. Deficiency and disturbed morphologies of the ionized gas in cluster galaxies



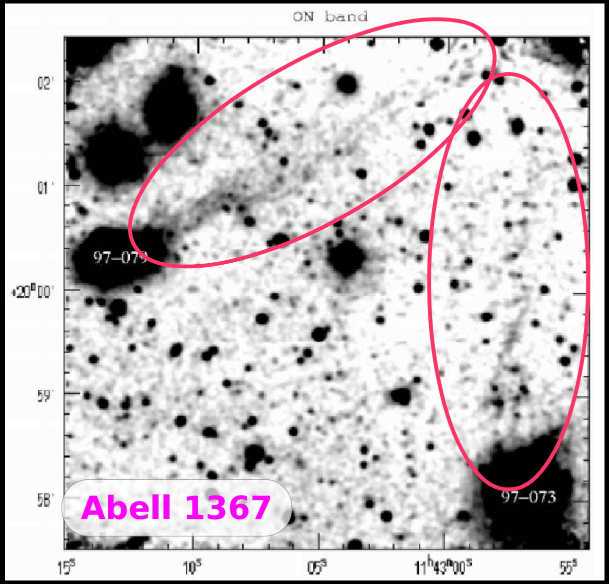




Ram-pressure stripping: caught in the act



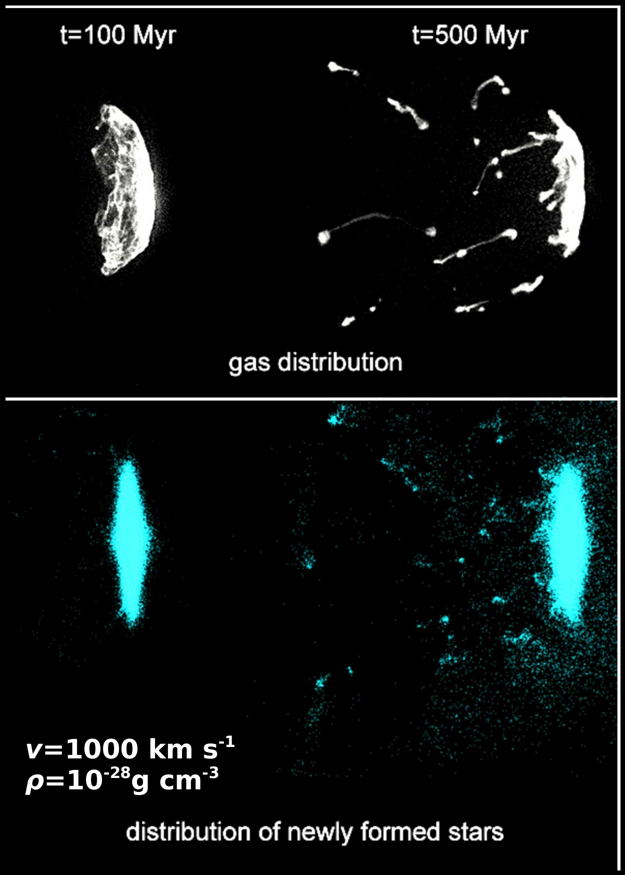
Sun et al. (2010):
XMM mosaic of A3627 (z=0.016)
Spectacular Xray(in blue) +Hα(in red) tails of ~80 kpc in the galaxy ESO137-001 ~280 kpc from the cl. center



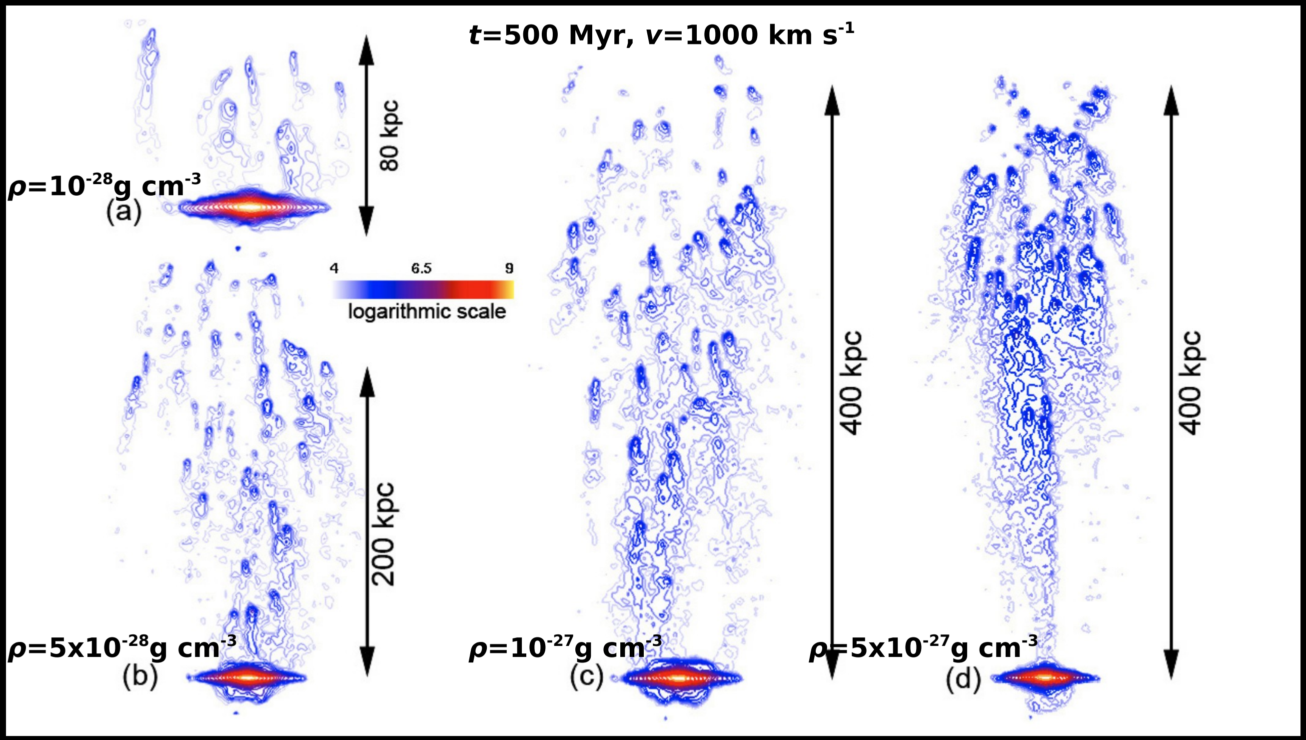
Gavazzi et al (2001):
75 kpc trails of ionized gas behind two Irr galaxies in A1367

Pressure-triggered star formation

N-body/hydrodynamic simulations



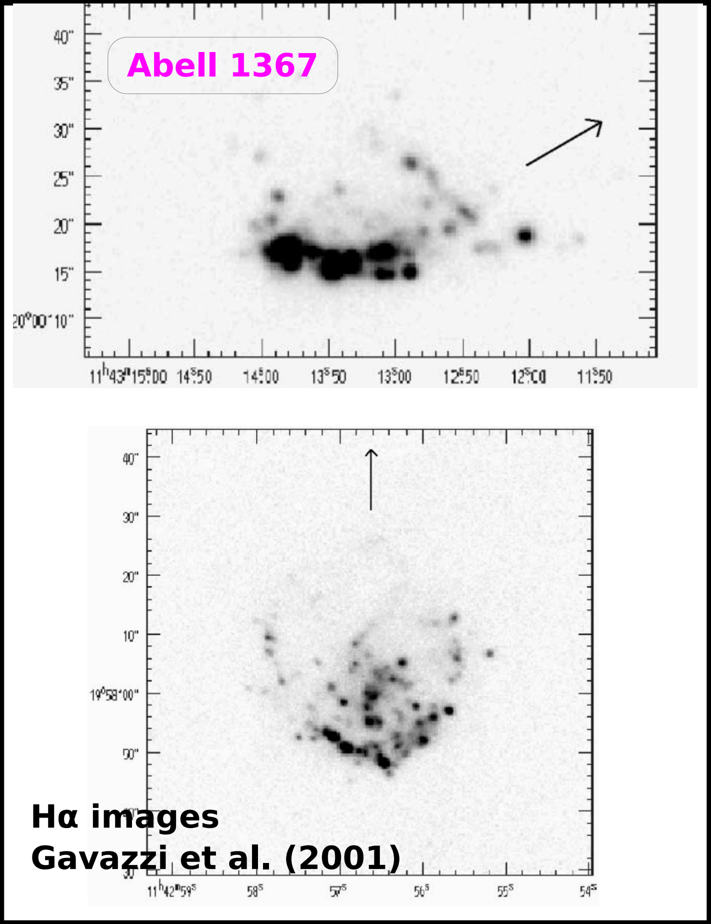
Kronberger et al. (2008):
SFR enhanced by a factor of 3
Star-formation mainly in the disk



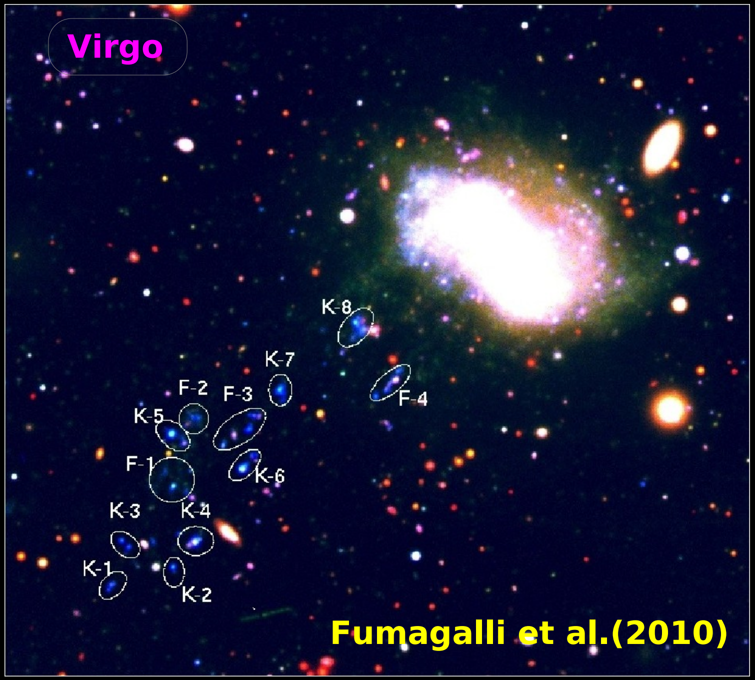
Kapferer et al. (2009):
95% of the star-formation occurs in the wake
The newly formed stars fall back to the disk

Pressure-triggered star formation

Observations



Hα images
Gavazzi et al. (2001)



Fumagalli et al.(2010)

Porter et al. (2008) and Mahajan et al. (2010) report a statistical enhancement of the SFR for dwarf galaxies entering the cluster environment through fillaments:

- ✔ pressure-triggered star formation... or...
- ✔ preprocesing in groups ...
- ✔ galaxy-galaxy harassment ...

Chemical history of cluster galaxies

Several cluster related environmental processes can affect the SFH and the gas exchange between the galaxy and its environment.

Could these processes alter the chemical evolution of cluster galaxies?

Studying the impact of the environment on galaxy metallicity can help understand the physical mechanisms driving galaxy formation and evolution

Our sample of clusters:

Cluster	A1656 (Coma)	A1367	A779	A634	A2151 (Hercules)	A2152	A2147
Mass (Mo)	1.2×10^{15}	8.1×10^{14}	4.8×10^{13}	7.1×10^{13}	6.1×10^{14}	5.5×10^{13}	2.9×10^{14}
L_X (erg s^{-1})	9.3×10^{43}	2.3×10^{43}	0.3×10^{43}	0.08×10^{43}	1.6×10^{43}	0.3×10^{43}	3.0×10^{43}
Distance	~100 Mpc	~100 Mpc	~100 Mpc	~100 Mpc	~160 Mpc	~160 Mpc	~160 Mpc

- ✗ New spatially resolved spectroscopy in a sample of star-forming galaxies in Hercules
- ✗ **781** low-mass star-forming galaxies (10^8-10^{10} Mo) with SDSS spectroscopy
- ✗ A selection of the most recent empirical calibrations to derive ISM chemical abundances

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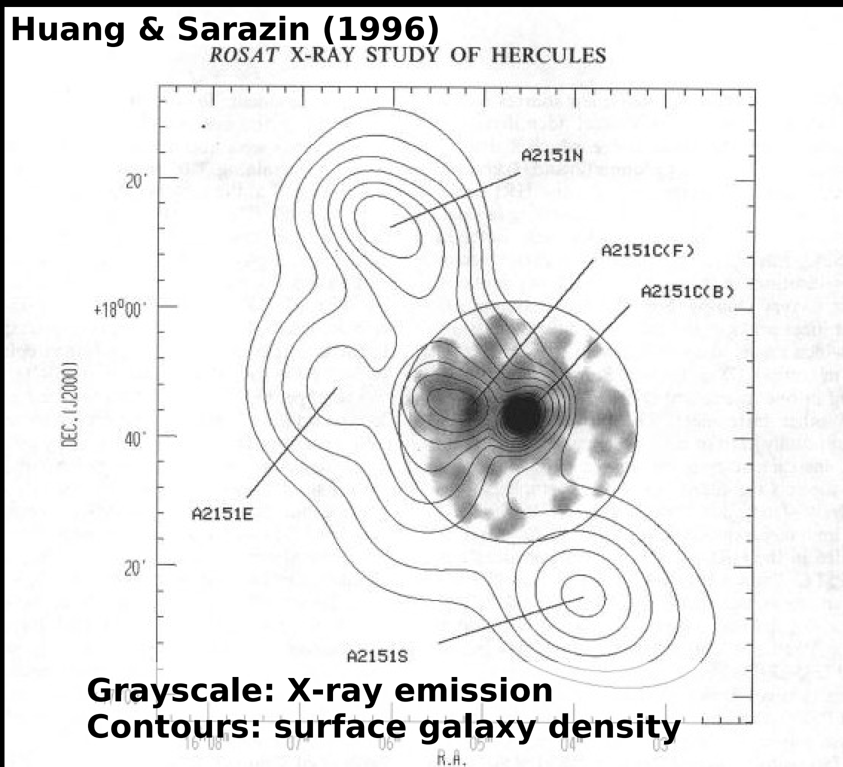
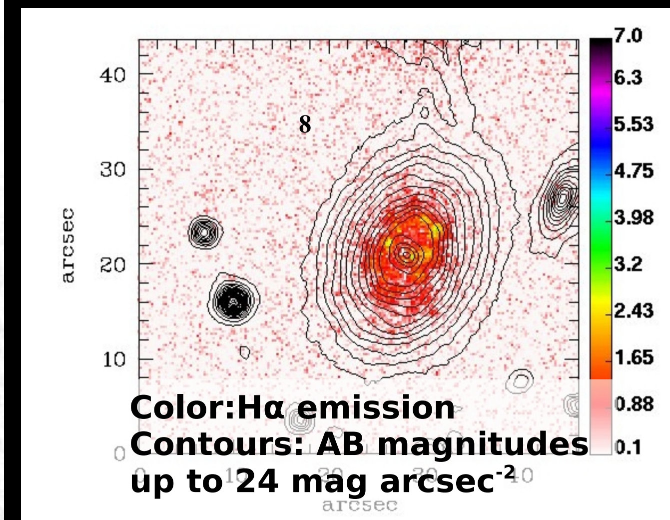
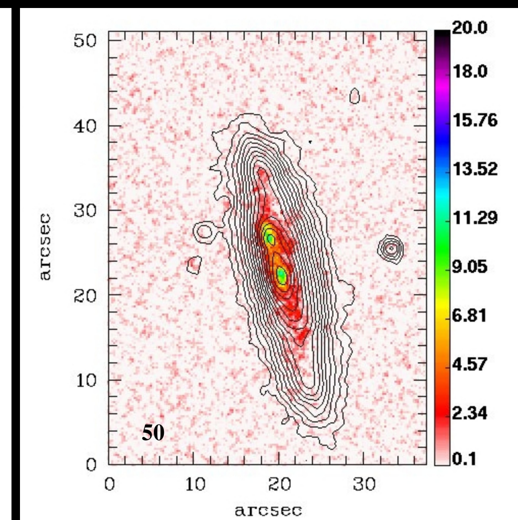
The Hercules cluster

α:16h05m15s **δ**: +17d44m55s **z**~0.036 **σ**$_v$~750km/s



Bird et al. (1995): The eastern and central subcluster have undergone recently a merger event

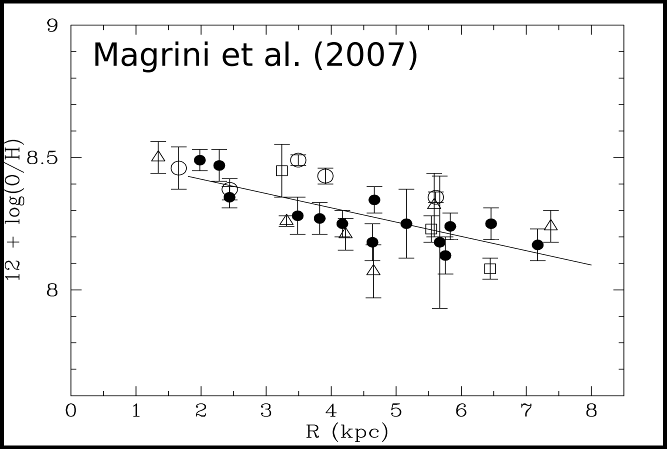


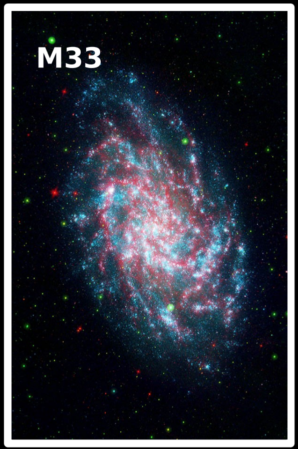


Cedres et al. (including Petropoulou V.) (2009):
Hα survey: ~40 SF galaxies ($-21<M_B<-16.5$) in Hercules central region ($R<R_{200}$)

Spectroscopic follow-up: 31 SF galaxies
15 luminous $M_B<-19$ and 16 dwarf/Irr $M_B>-19$

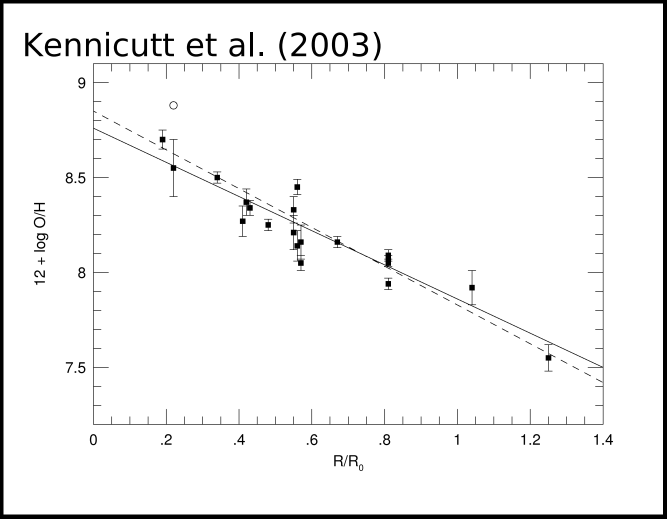
Abundance gradients

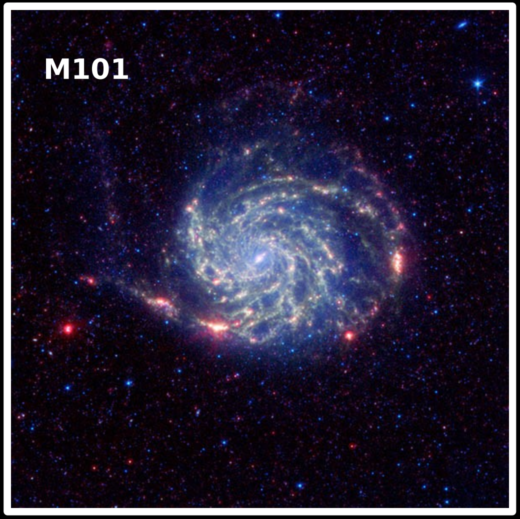




Galaxy metallicity?

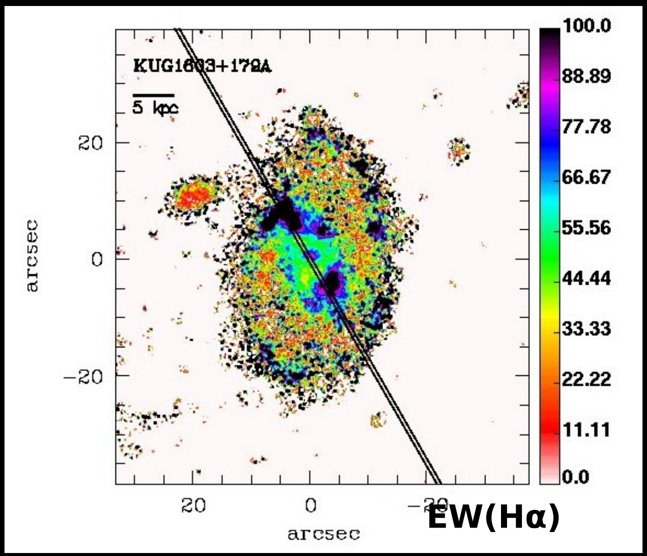
Yes... but where?

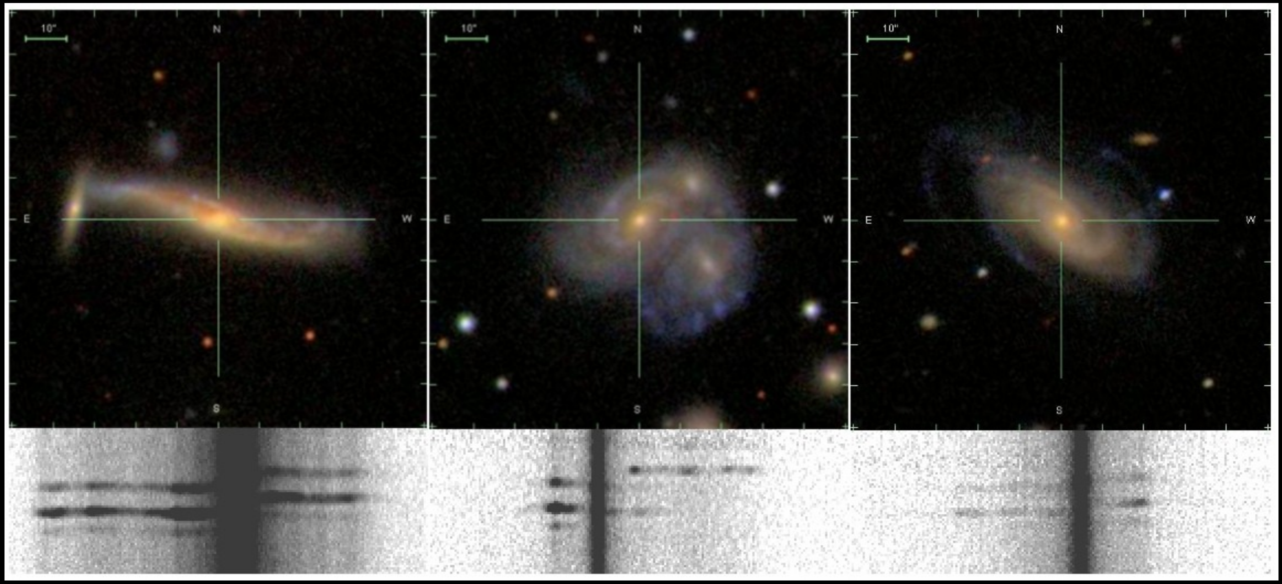




Local Universe galaxies show abundance gradients up to -1 dex (e.g. Pilyuginet al. 2004)
Moustakas & Kennicutt (2006): “Galaxy metallicity” at $0.4R_{25}$

Spectroscopic follow-up





✗ Spectroscopic data reduced using IRAF

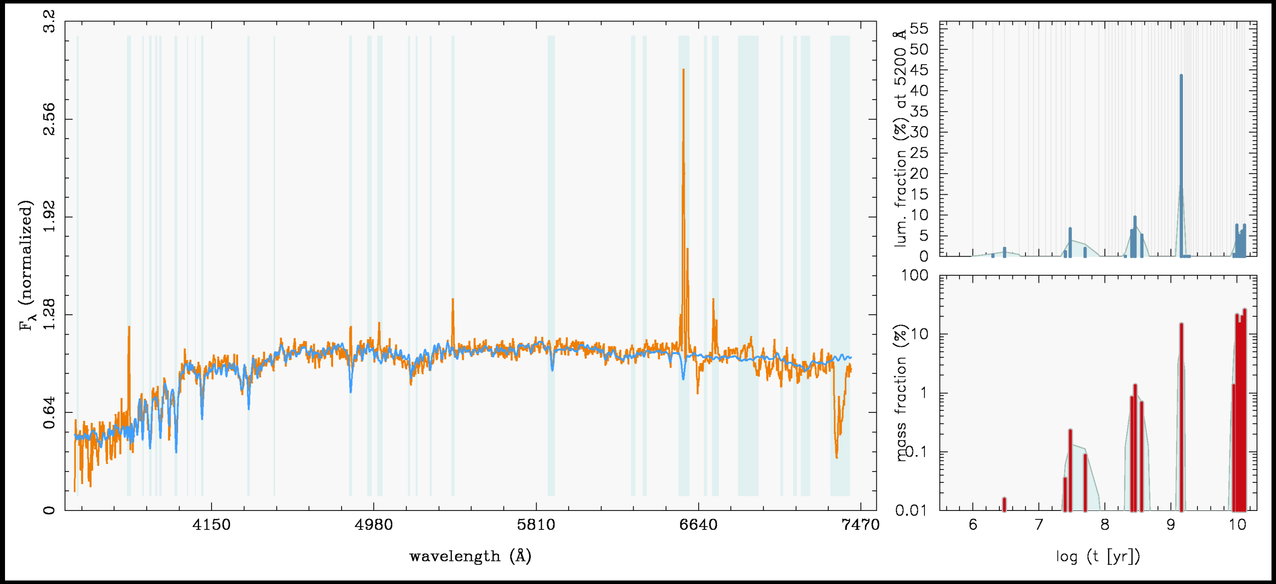
✗ For galaxies with rich spatial structure, the 2D spectra were split into 1D spectra corresponding to different galaxy regions

Spectral synthesis model fitting

STARLIGHT:
Bruzual & Charlot (2003) models
Metallicities: Zo/5, Zo/2.5, Zo
59 ages: 0.25-13 Myr

Stellar population properties:

Light-weighted stellar age $\tau_{*,L}$
Light-weighted stellar metallicity $Z_{*,L}$
Mass-weighted stellar age $\tau_{*,M}$
Mass-weighted stellar metallicity $Z_{*,M}$



We correct the emission-line spectra from stellar absorption

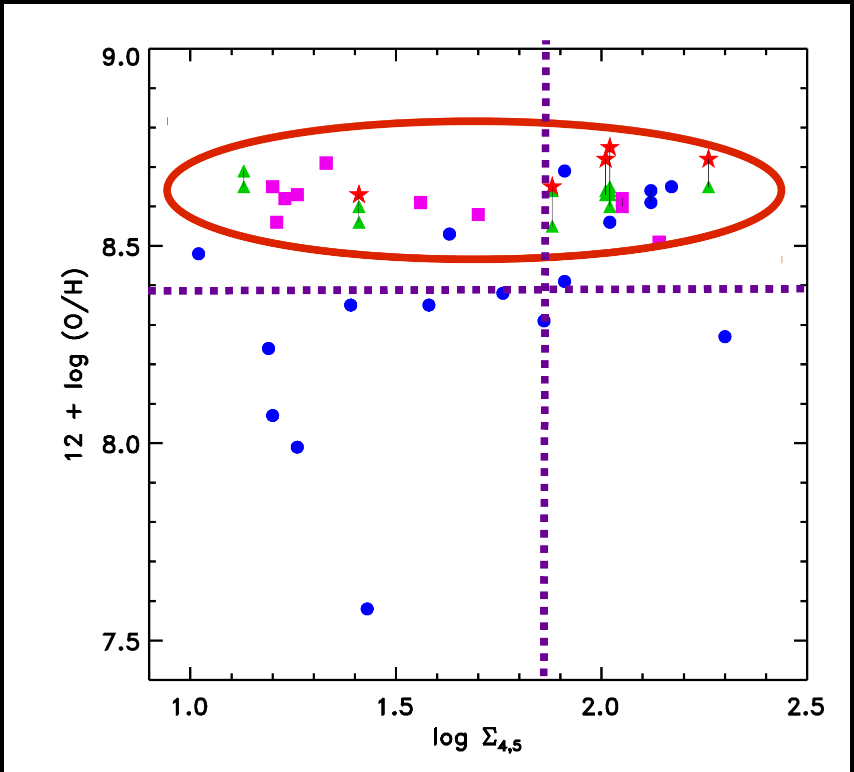
Abundance derivation

- ✗ We measure Balmer emission lines: Hα, Hβ, Hγ, Hδ (when possible) and collisionally excited lines: [OII]λ3727, [OIII]λ5007, [NII]λ6584, [SII]λλ6717,6731
- ✗ We compute the c(Hβ) and correct our spectra from extinction
- ✗ We derive chemical abundances (O/H and N/O) using the empirical calibrations of Pilyugin et al. (2010) and Perez-Montero & Contini (2009)

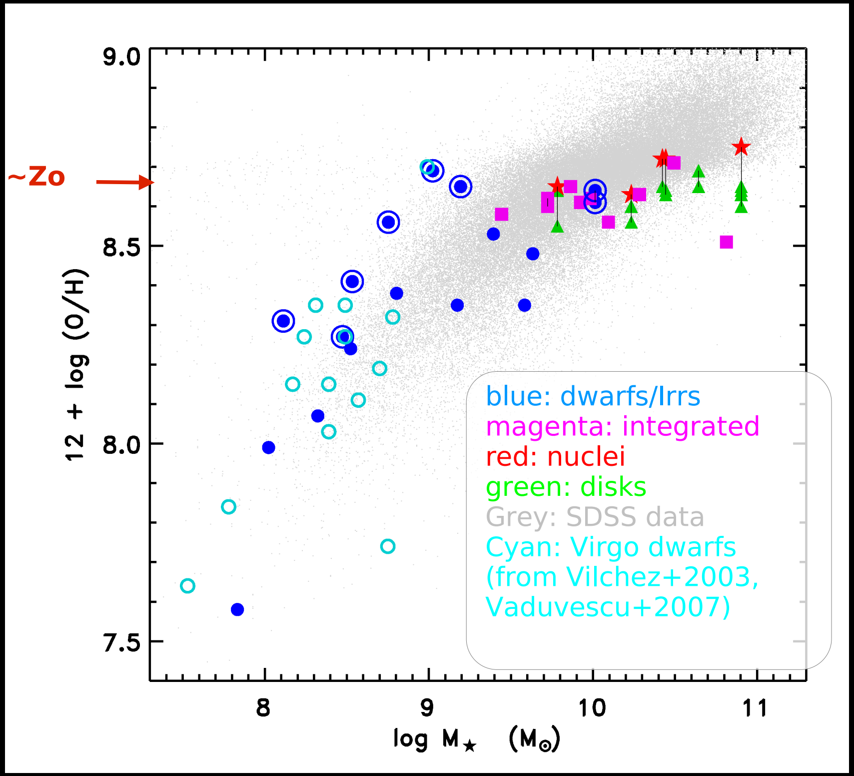
Pilyugin et al. (2010) present an empirical calibration (e.g. based on "direct" measurements of the O/H in local Universe H_{II} regions) and use R_{23}, R_2, R_3, N_2, S_2 with intrinsic error of 0.1 dex.

Perez-Montero & Contini (2009) give an empirical calibration based on the N2 parameter.

Fundamental relations vs Environment



$\Sigma_{4,5}$: the density to the average of the projected distances to the 4th and 5th nearest neighbors

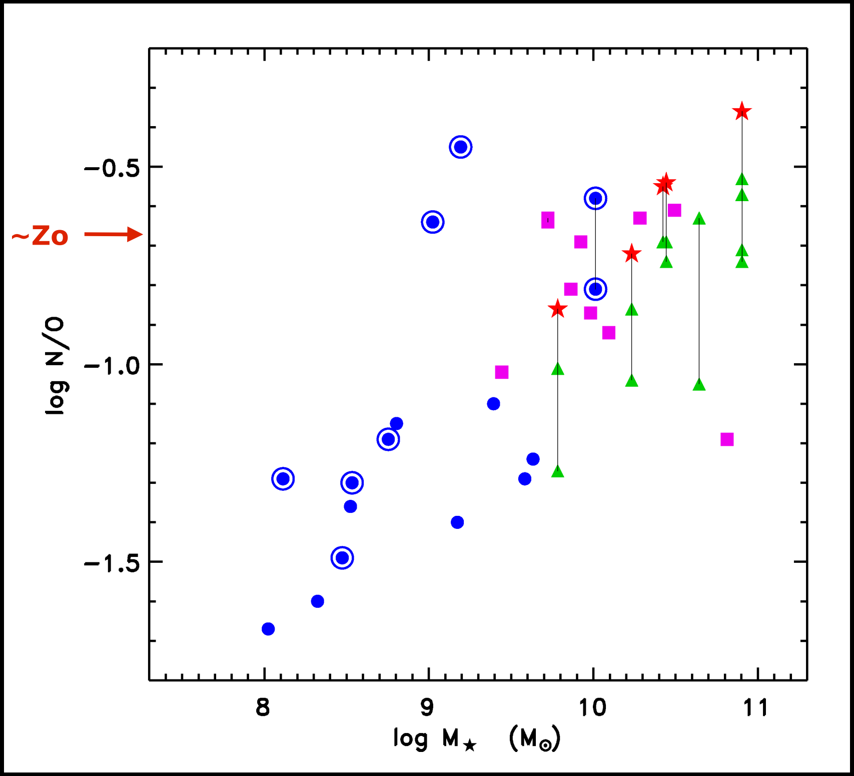


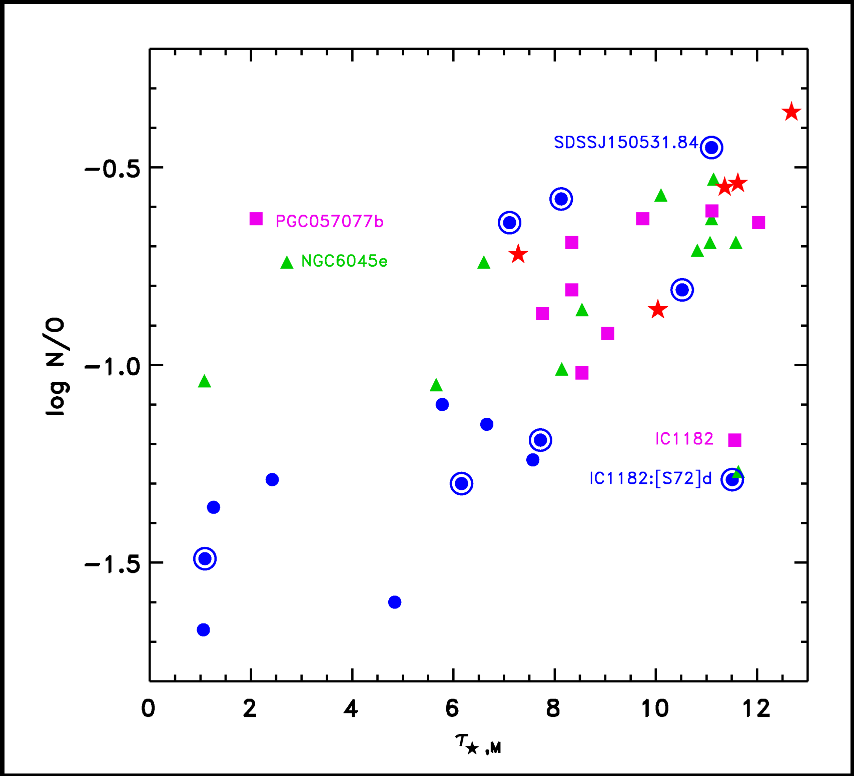
Stellar mass: kcorrect algorithm (Blanton & Roweis 2007), Chabrier (2003) IMF, Bruzual & Charlot (2003) stellar evolution

O/H for luminous galaxies does not show dependance on local density
Pilyugin et al. (2002): abundance properties of Virgo and field bright spirals should not vary

Chemically evolved dwarf/irregular galaxies populating the highest local densities, are located in the upper part of the mass-metallicity relation

N/O vs mass and stellar age



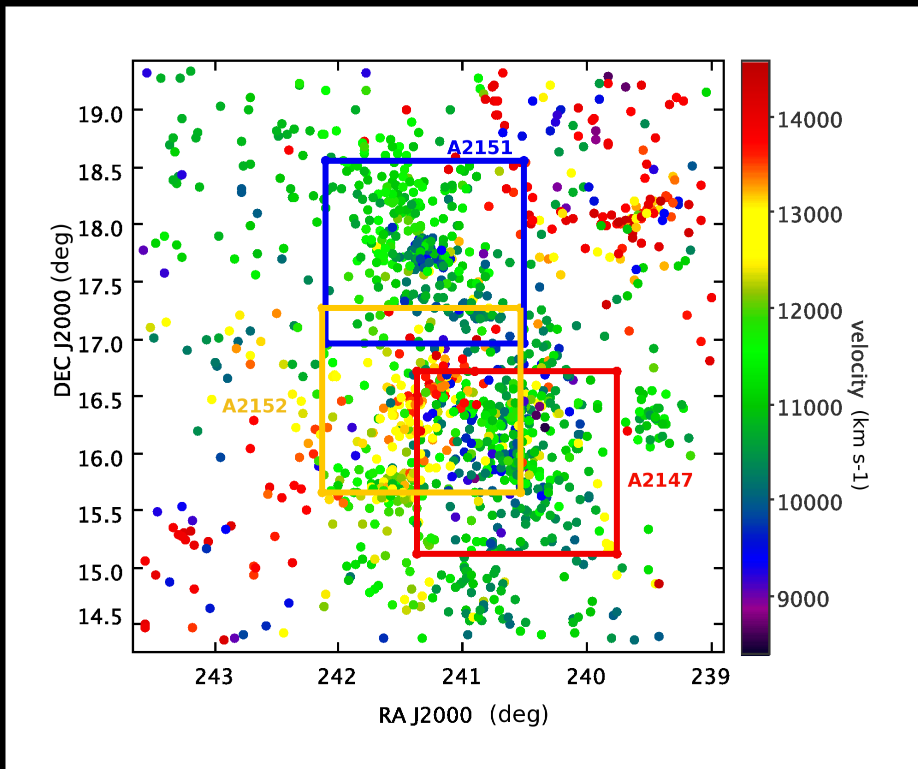


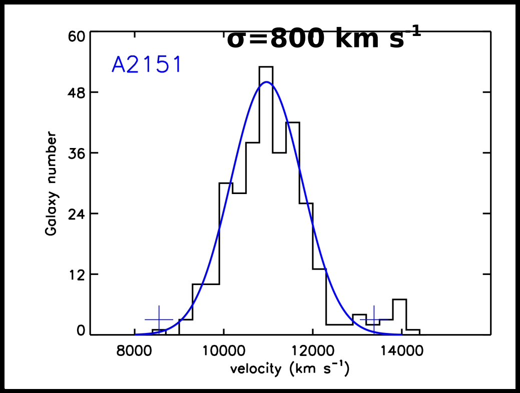
Shallow O/H abundance gradients & significant N/O spatial variation: sign of nuclear gas inflow? (*see Vollmer et al. 2001*)

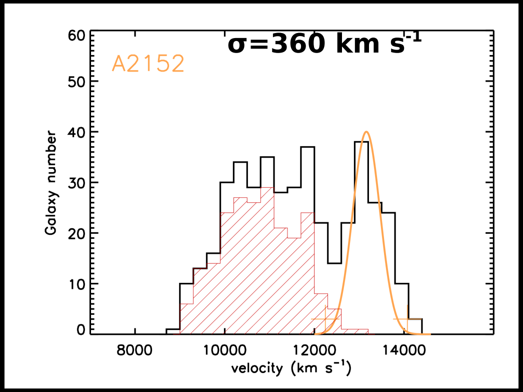
The N/O (of the ionized gas) shows a clear positive trend with the stellar age, derived by spectral fitting

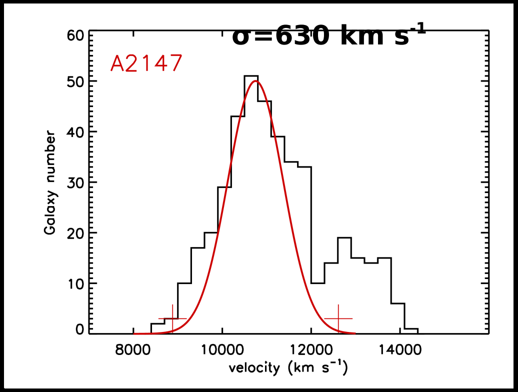
The large-scale structure of the HSC

~1400 galaxies with SDSS spectroscopy in an area of 13x14 Mpc^2







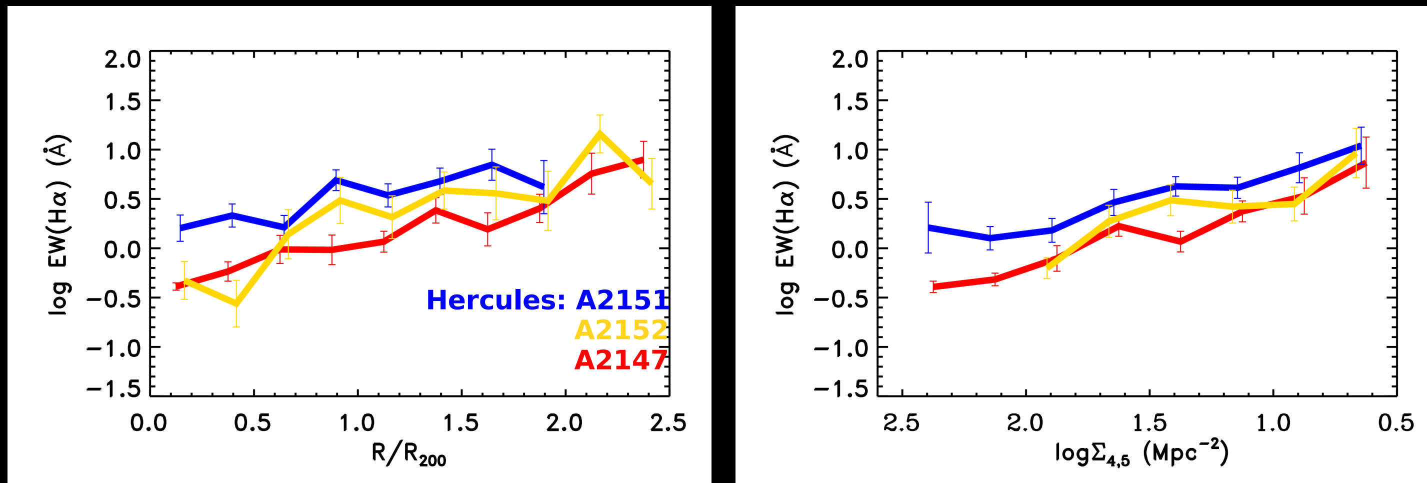


In the central region ($R<R_{200}$) of A2151 (A2152, A2147)
50% (33%, 24%) of the galaxies are star-forming
and 71% (50%, 32%) of the low-mass galaxies are star-forming

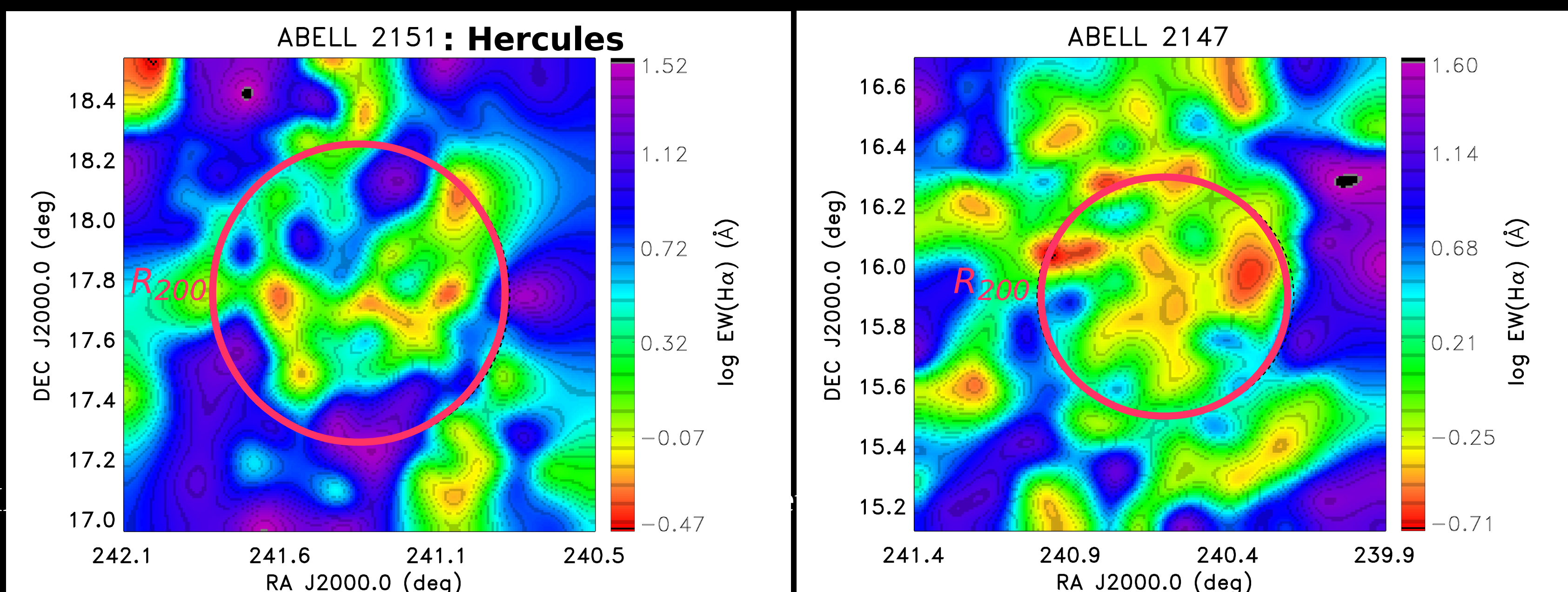
Poggianti et al (2006): increasing fractions of passive galaxies with increasing cluster mass

Star-formation activity at large-scale

The star-formation-density relation in A2151, A2152, A2147



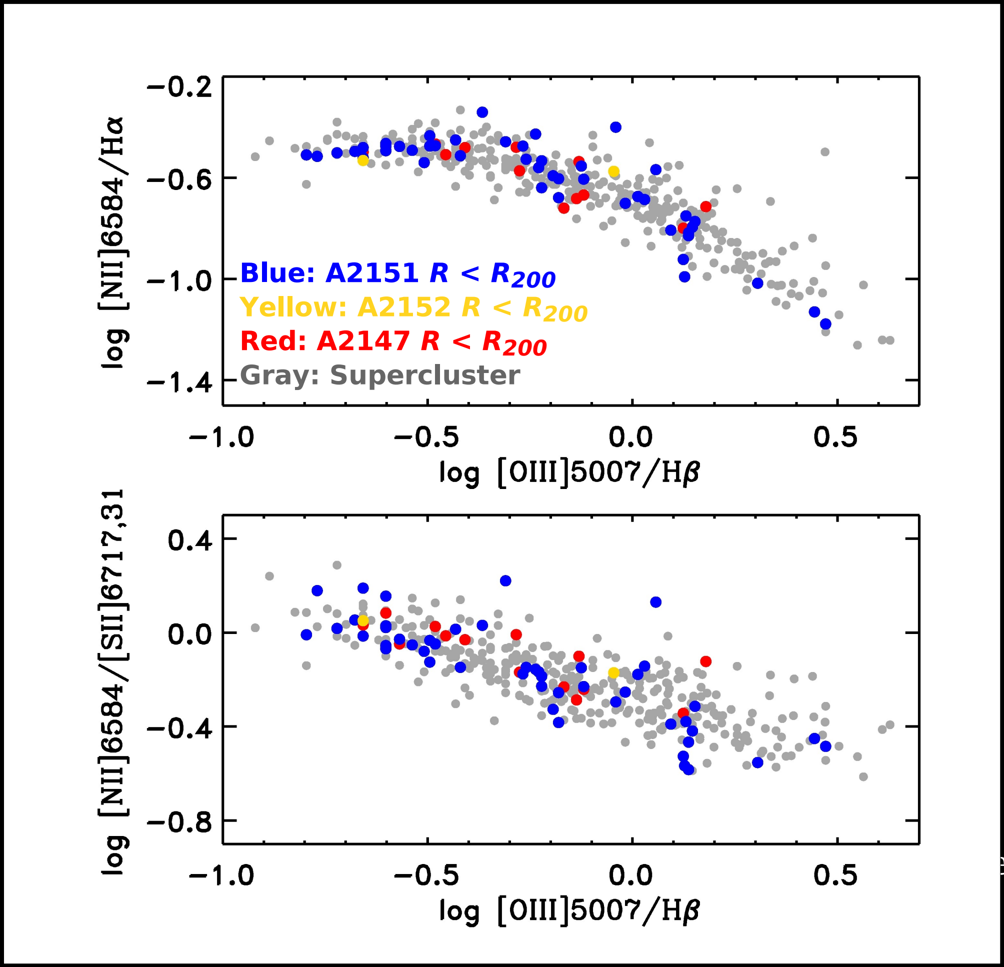
Filaments of star-forming galaxies entering A2151 and A2147

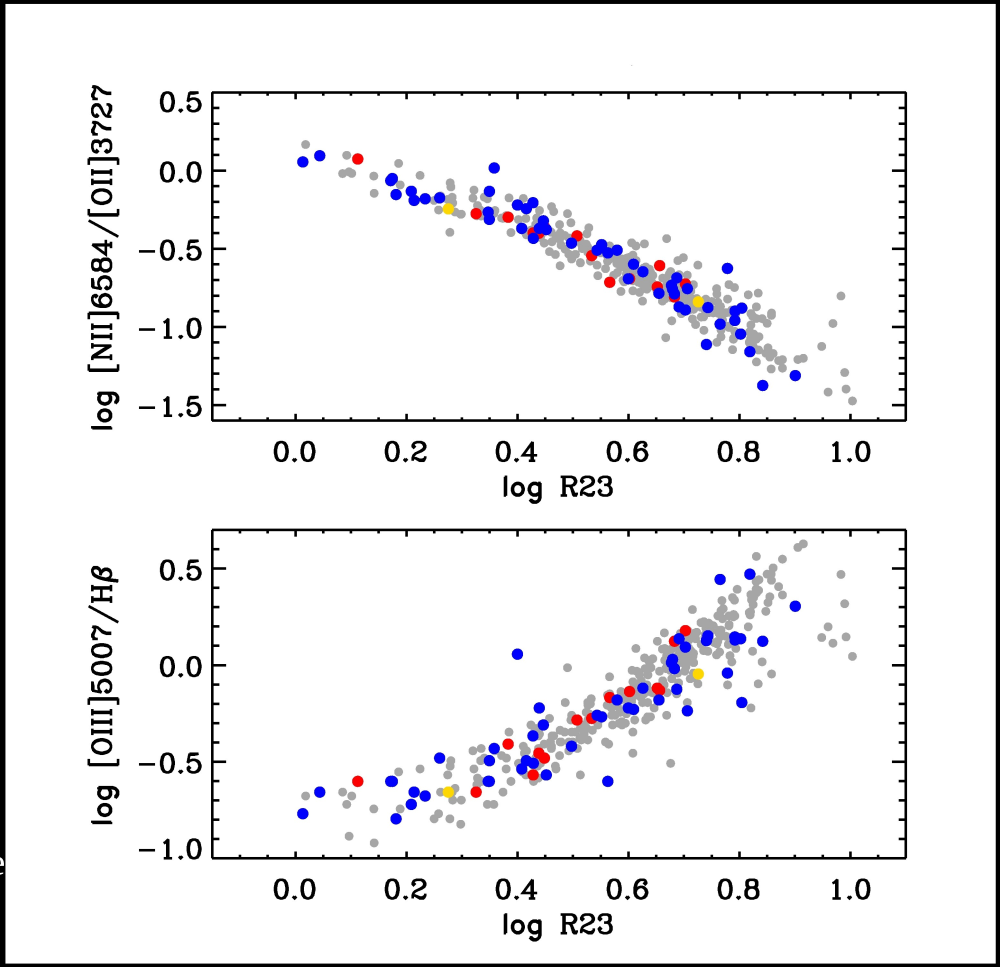


Spectroscopic properties vs environment

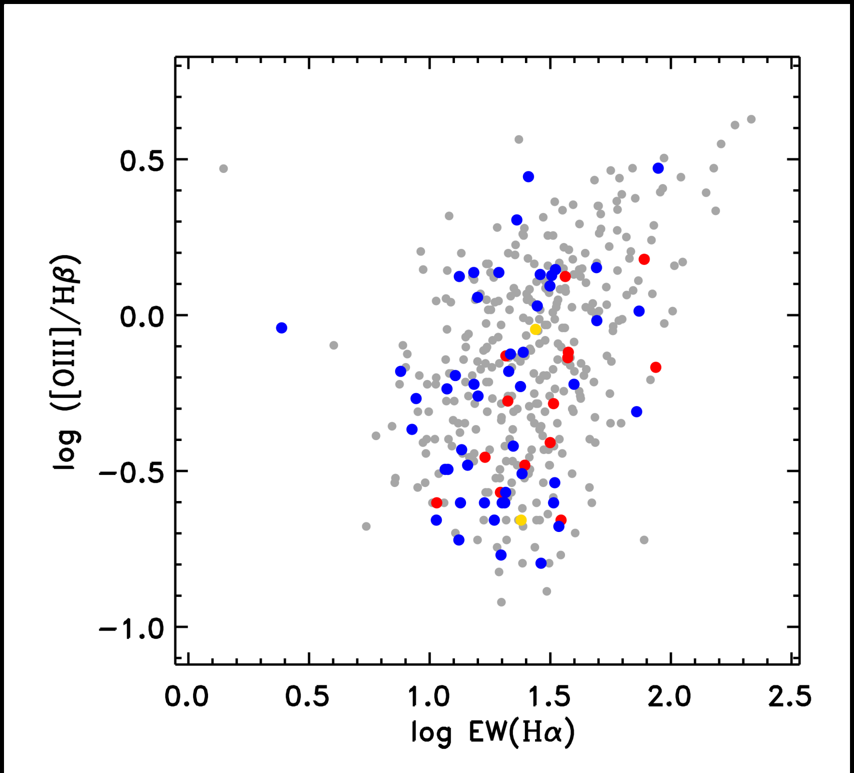
SDSS DR8 spectroscopy: corrected for stellar continuum

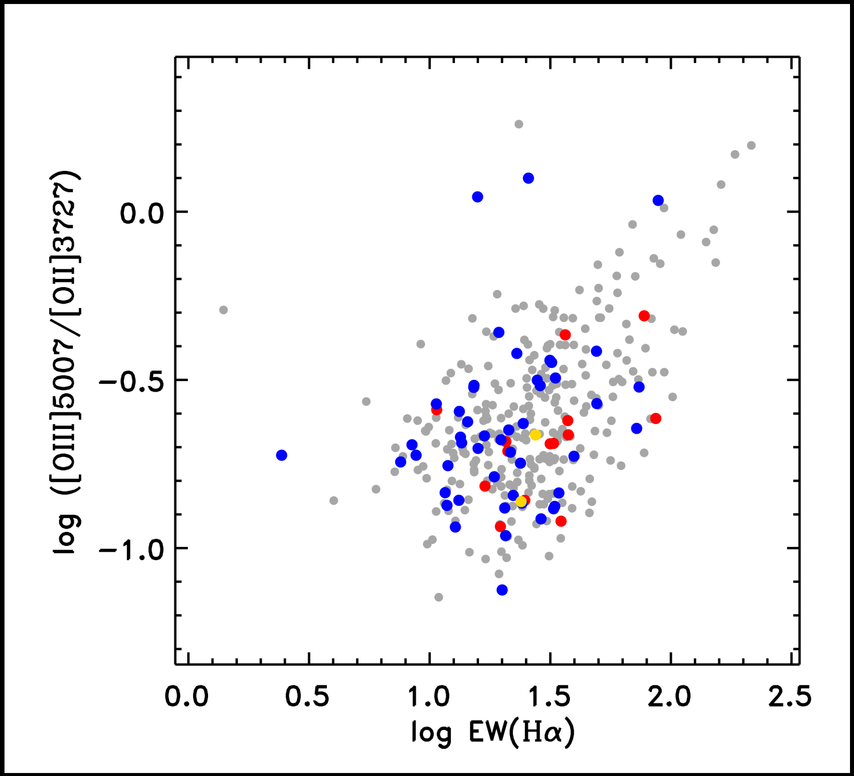
- ✗ We select 385 low-mass galaxies (log *M/Mo* < 10) + S/N criterion
- ✗ We derive the c(Hβ) and correct the emission lines for extinction





Spectroscopic properties vs environment





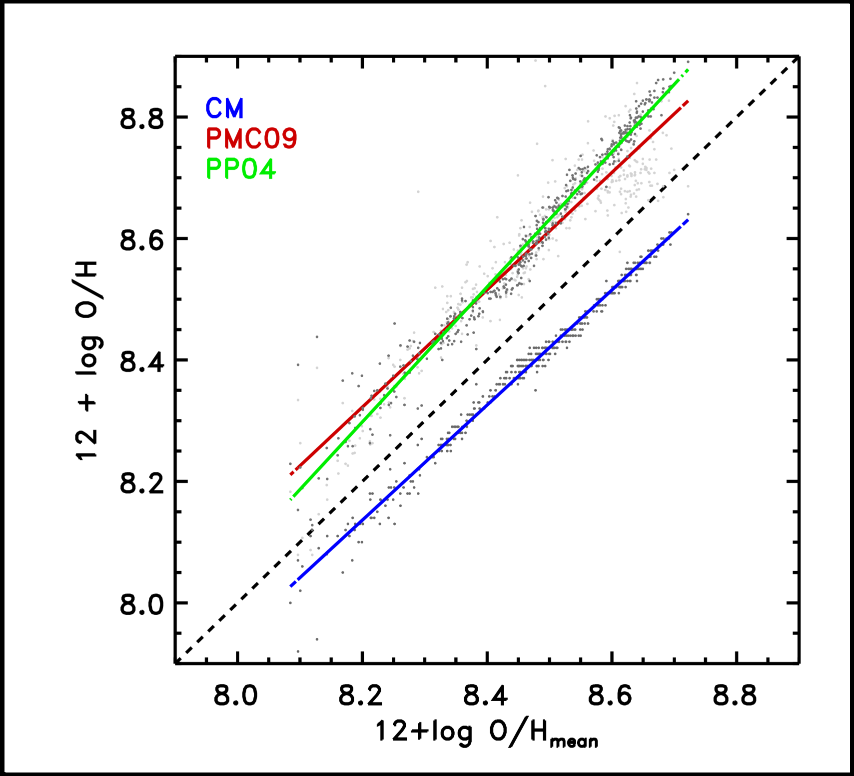
The emission line ratios of our sample of low-mass star-forming galaxies in the Hercules Supercluster lie in the range of values of normal star-forming galaxies independently of cluster membership

Abundance derivation

Empirical calibrations used:

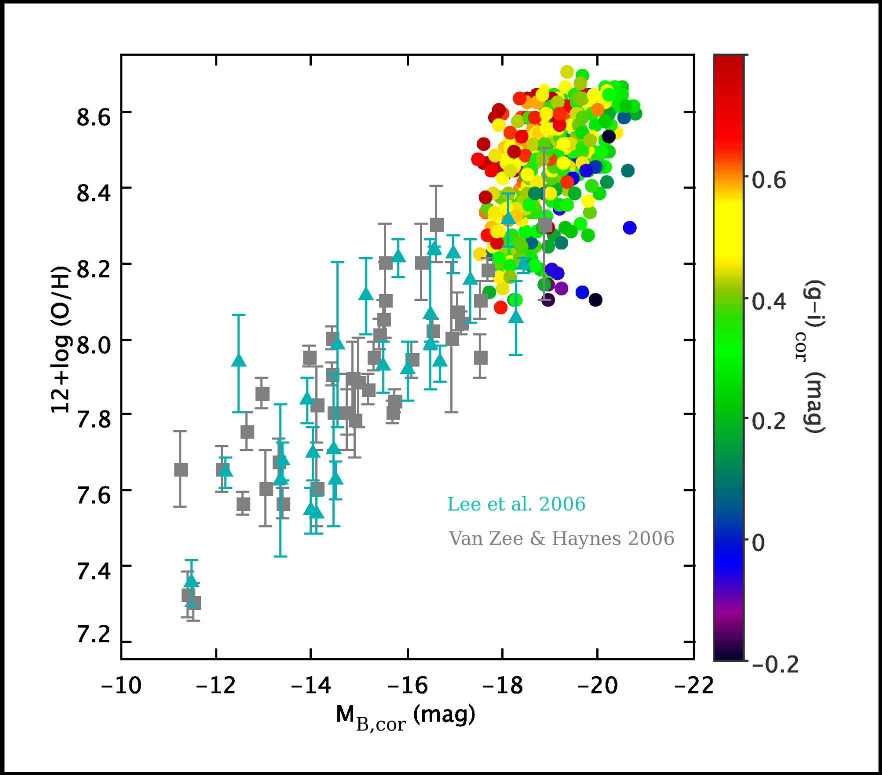
- Pilyugin et al. (2012) "C-method" using
  R_{23}, R_2, R_3, N_2, S_2
  intrinsic error: 0.1 dex
- Perez-Montero & Contini (2009)
  N2 parameter calibration
  intrinsic rms error: 0.3 dex
- Pettini & Pagel (2004)
  O3N2 parameter calibration
  intrinsic error: 0.14 dex

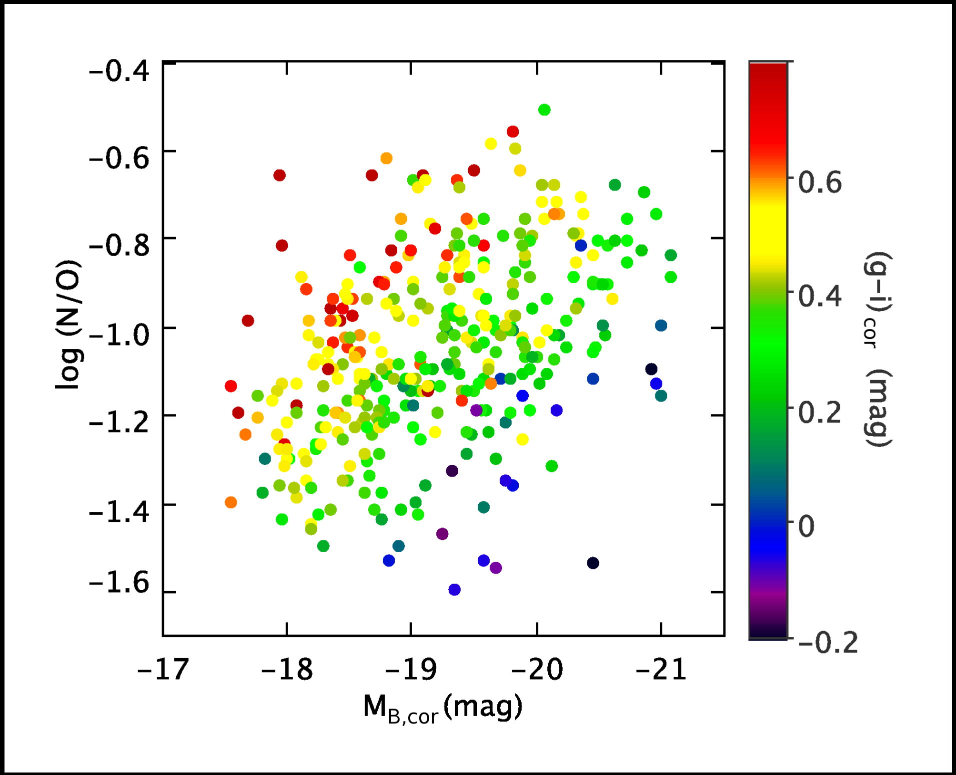
✗ We adopt the mean value weighted to the intrinsic error of the calibration



Luminosity-Metallicity relation

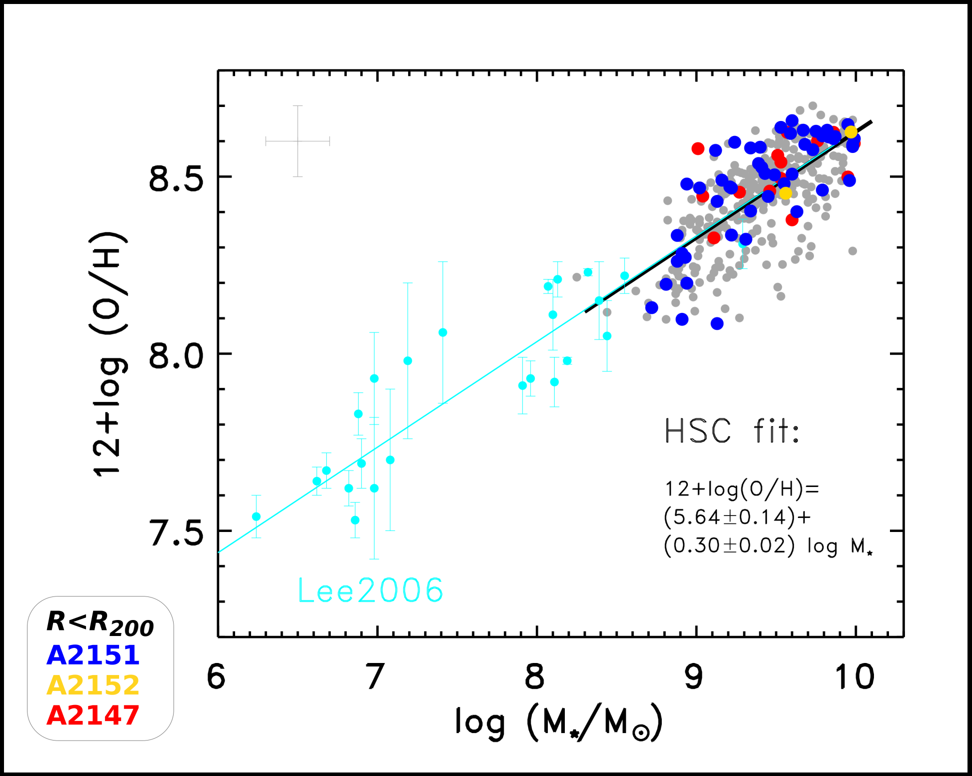
- ✗ We derive M_B from SDSS *g* magnitude and we correct for extiction using the c(Hβ) we derived from the Balmer emission lines

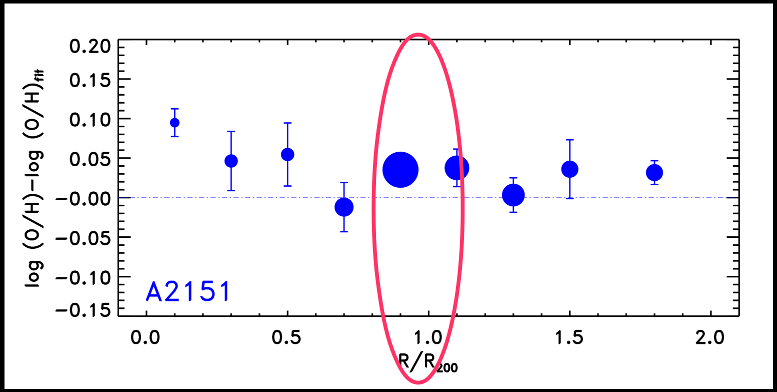


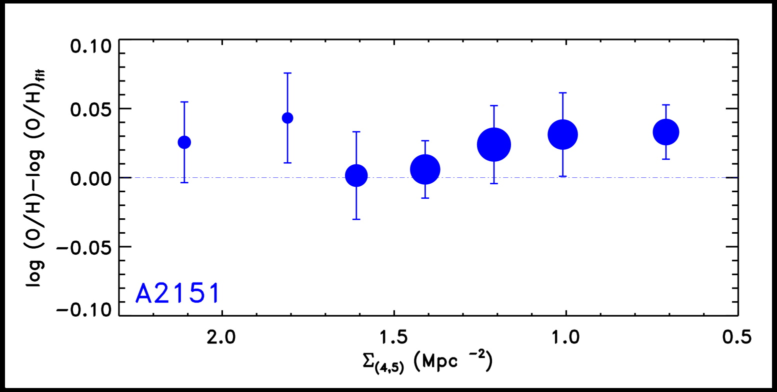


The dispersion of the luminosity-metallicity relation is intrinsically linked to galaxy color evolution

Mass-Metallicity relation







SDSS DR8 mass estimates derived from spectral fitting (Kauffmann et al. 2003)

MZR slope: 0.3 in agreement with Lee at al. (2003) and the predictions of state-of-the-art hydrodynamic simulations

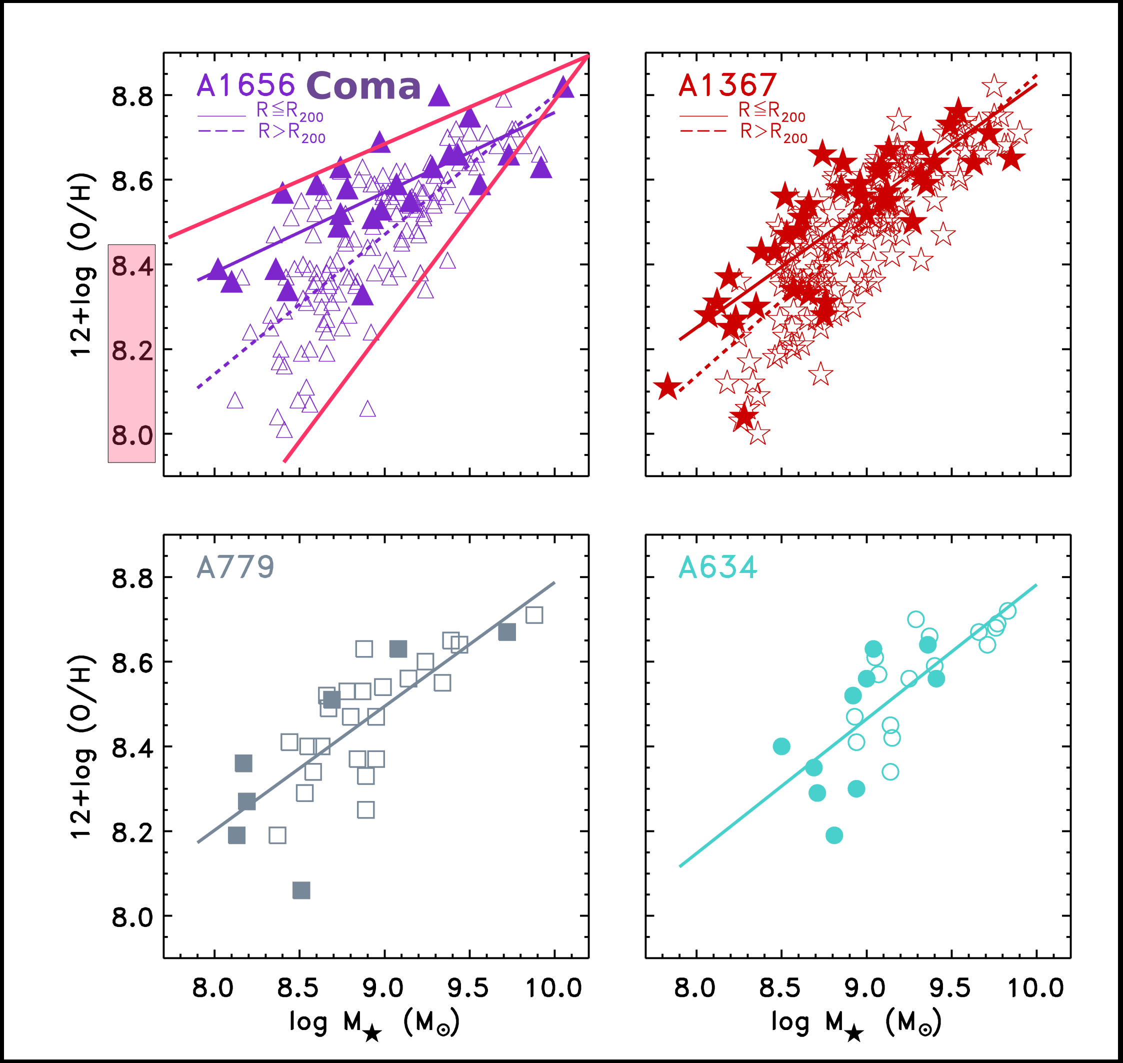
Low-mass star-forming galaxies in 4 nearby clusters

- ✗ Clusters: Coma, A1367, A779, A634 (M =10^{13}-10^{15} Mo, z~0.02)
- ✗ Galaxies: low-mass (M =10^{8}-10^{10} Mo) star-forming
- ✗ Data: SDSS DR8 spectroscopy of 396 galaxies in a region of $3R_{200}$ radius around each cluster

SDSS DR8 spectroscopy: corrected for stellar continuum

- ✗ We derive c(Hβ) and correct emission lines for extinction
- ✗ We check spectroscopic properties: independent of cluster environment
- ✗ We derive chemical abundances (O/H and N/O) using N2 calibrations of Perez-Montero & Contini (2009) and O3N2 calibration of Pettini & Pagel (2004) (lack of [OII]λ3727 for part of our sample of galaxies)

Mass-Metallicity relation



SDSS DR8 mass estimates derived from spectral fitting (Kauffmann et al. 2003)

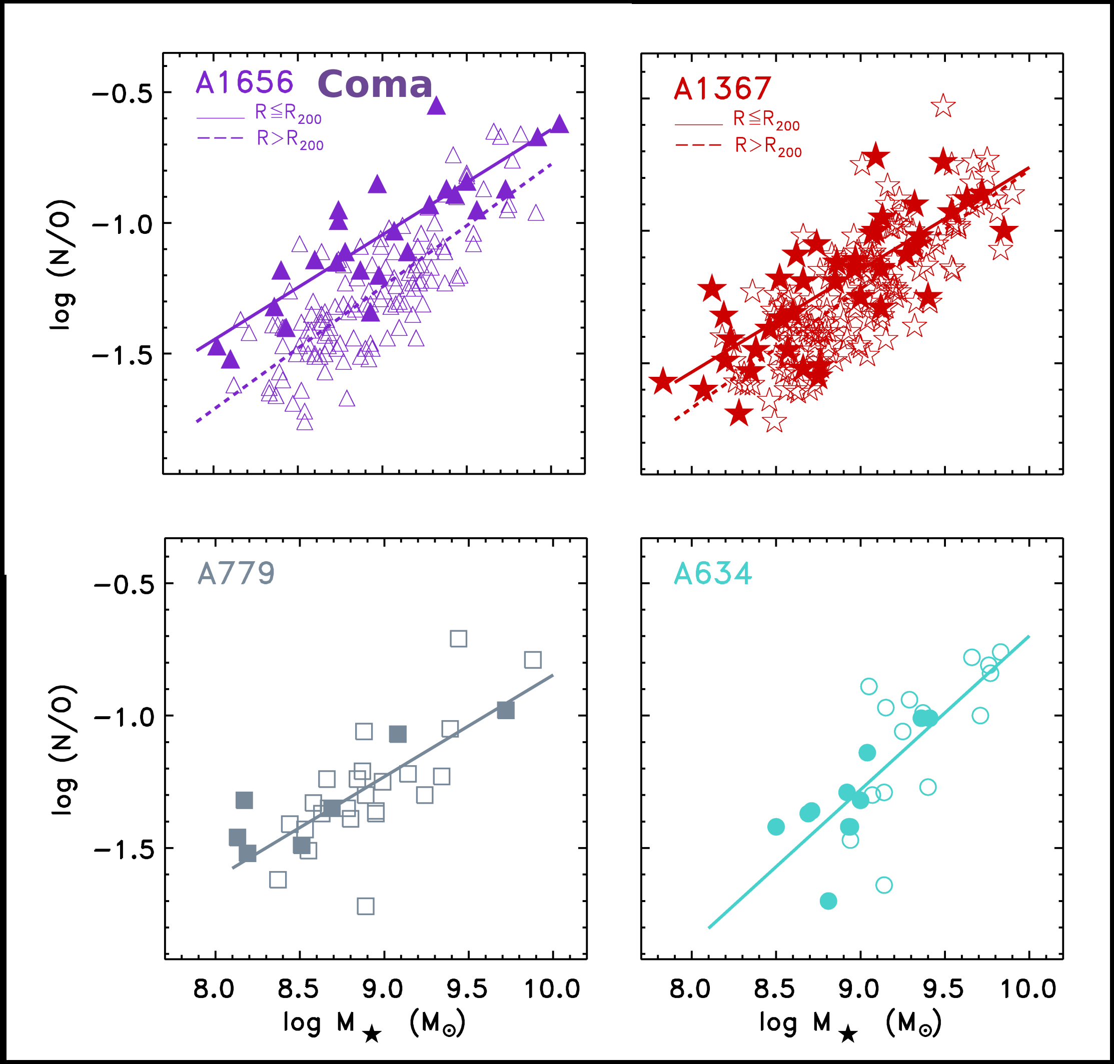
Slope of the MZR

	Coma	A1367	A779	A634
inside R_{200}:	0.19±0.03	0.28±0.03		
all:	0.30±0.02	0.33±0.02	0.29±0.04	0.32±0.05

MZR slope: 0.3 in agreement with Lee at al. (2003) and the predictions of state-of-the-art hydrodynamic simulations

The mass matters

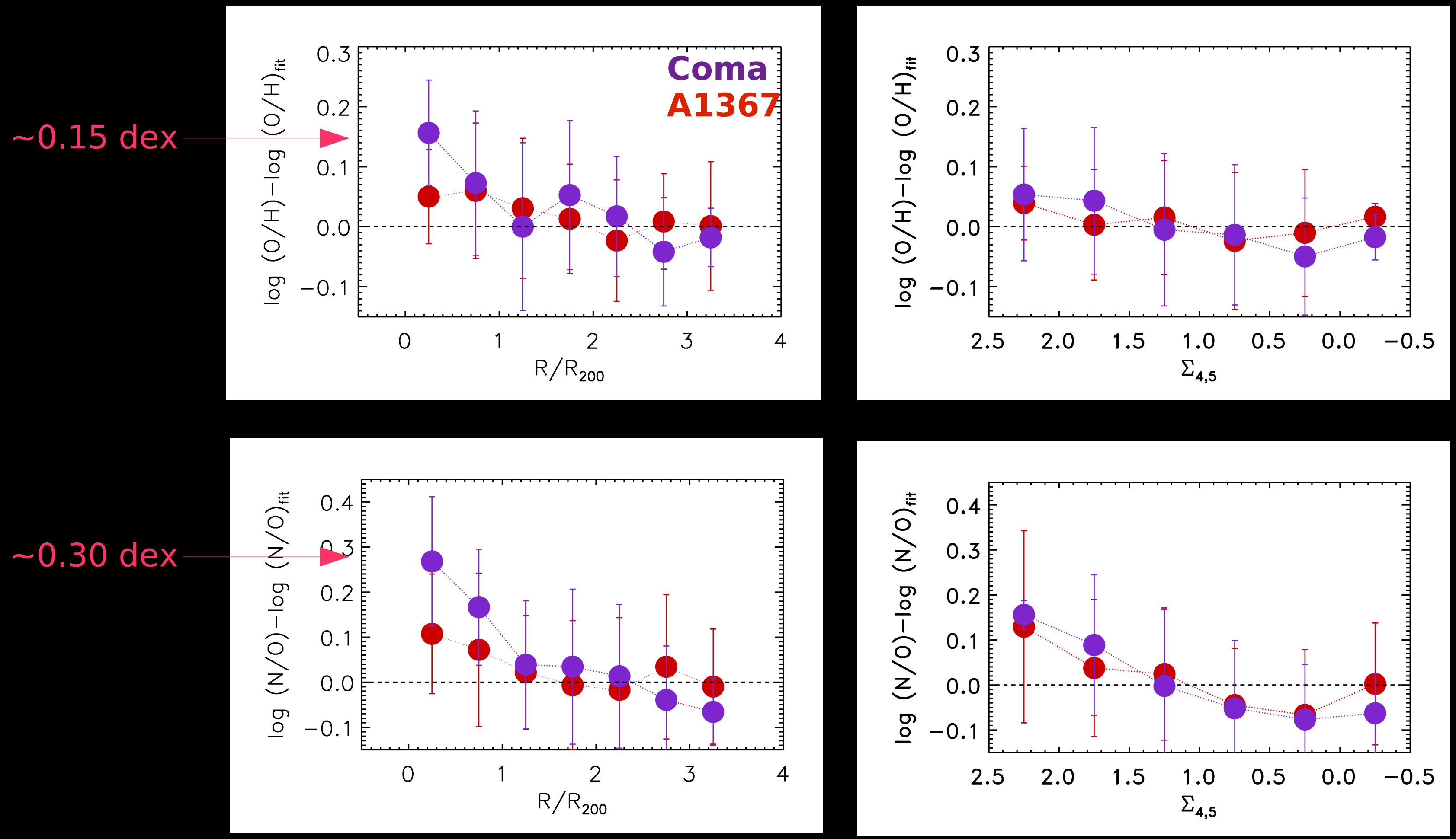
N/O versus mass



Oxygen is released after ~10 Myr
Nitrogen is released after >250 Myr

This chemical "clock" indicates that whatever mechanism affects Coma low-mass galaxies should be acting at least during 10^8 yr

Cluster membership or local density?



The observed chemical enhancement in O/H and N/O of Coma low-mass star-forming galaxies correlates principally with clustercentric distance

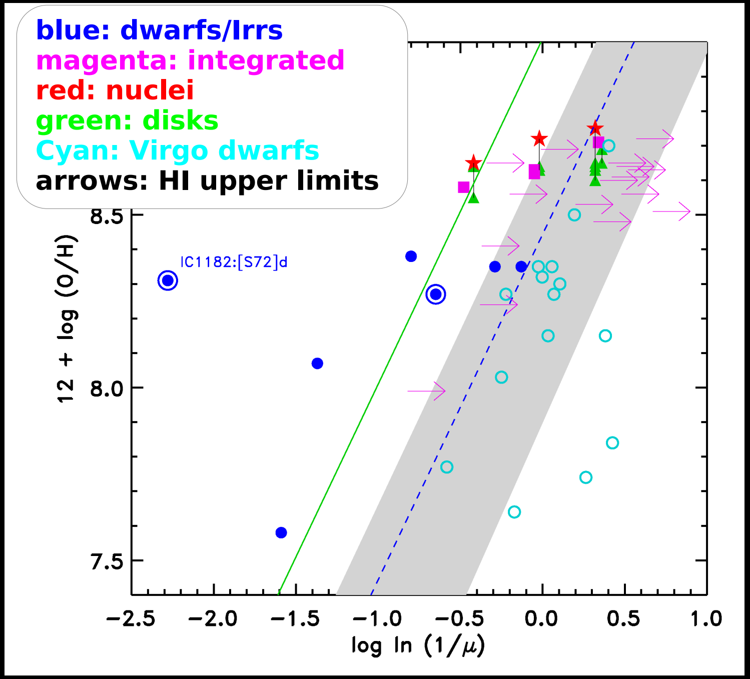
The Closed-Box Model

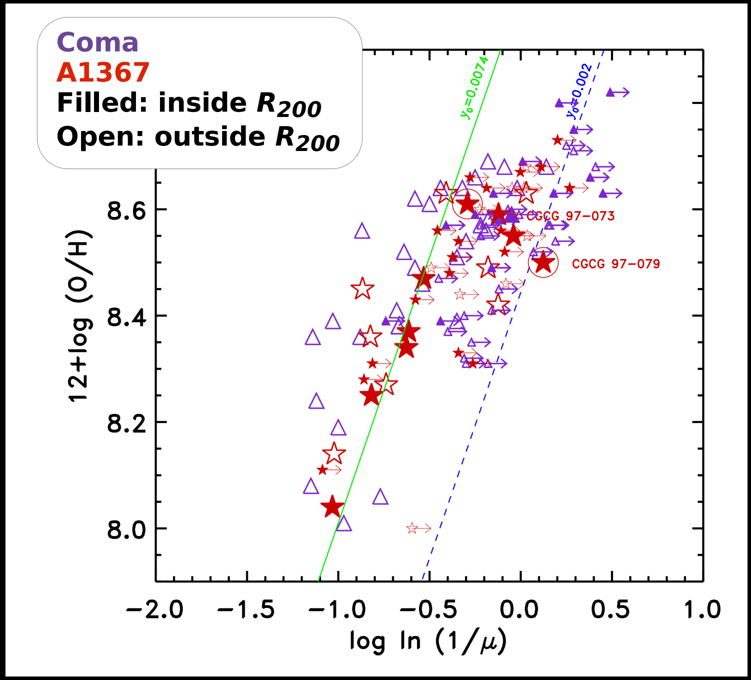
i. initially there is gas with no stars and no metals, ii. constant stellar IMF, iii. instantaneous mixing

Z=y ln(1/μ) where Z is the mass fraction of metals and $\mu=M_{gas}/(M_{gas}+M_{stars})$

HI data:

Dickey (1997): Hercules
Haynes et al. (2011): Coma
Cortese et al. (2008): A1367



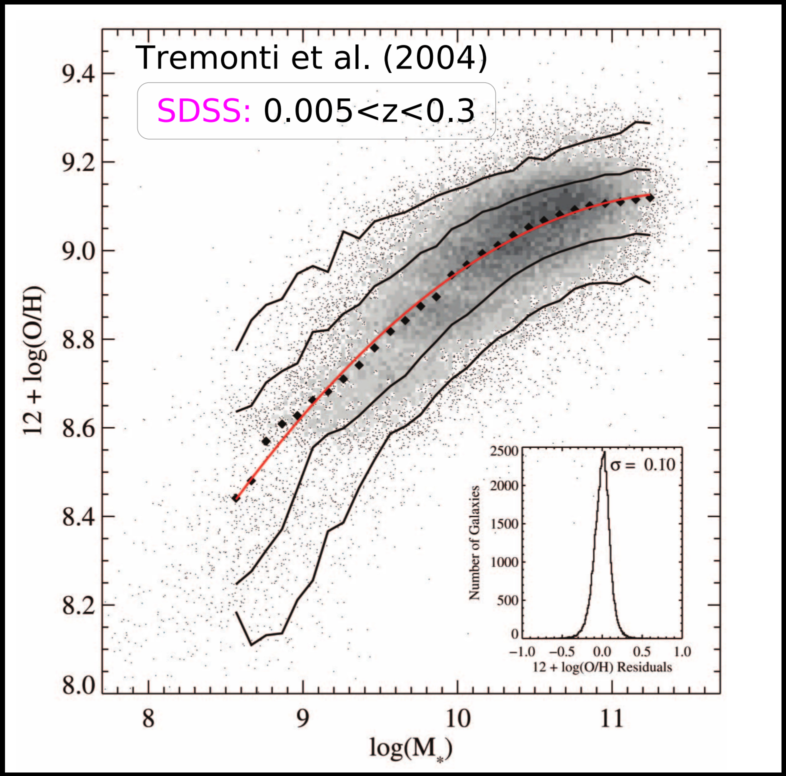


Green line: model yield (Meynet & Maeder 2002)
Blue line (van Zee & Haynes 2006) } effective yield for field dwarf galaxies
Grey strip (Lee et al. 2003)

Most cluster-core galaxies have suffered an important reduction of their HI mass
Galaxies in the core of A1367 and Hercules that follow the closed box model: “newcomers” to the cluster

The Mass-Metallicity Relation

- Metallicity is strongly correlated with galaxy luminosity: Lequeux et al. (1979)
- Mass-metallicity relation holds for $M=10^6$-10^{11} *Mo* e.g. Lee et al. (2006), Tremonti et al. (2004)
- and up to *z*~4 e.g. Savaglio et al (2005), Shapley et al (2005), Erb et al. (2006), Lamareille et al (2009)



Which is the physical mechanism underlying the MZR?

Ejection of metal-enriched gas by galactic outflows
(Larson 1974, De Lucia et al. 2004)

Variation of the IMF with mass (Koppen et al. 2007)

"Downsizing" (Brooks et al. 2007, Calura et al. 2009)

Inflows (smooth or via satellites)
(Dalcanton et al 2007, Dave et al. 2010)

The Mass-Metallicity Relation

N-body/Hydrodynamic simulations:

the equilibrium model & momentum driven winds

Finlator & Dave (2008), Dave et al (2011)

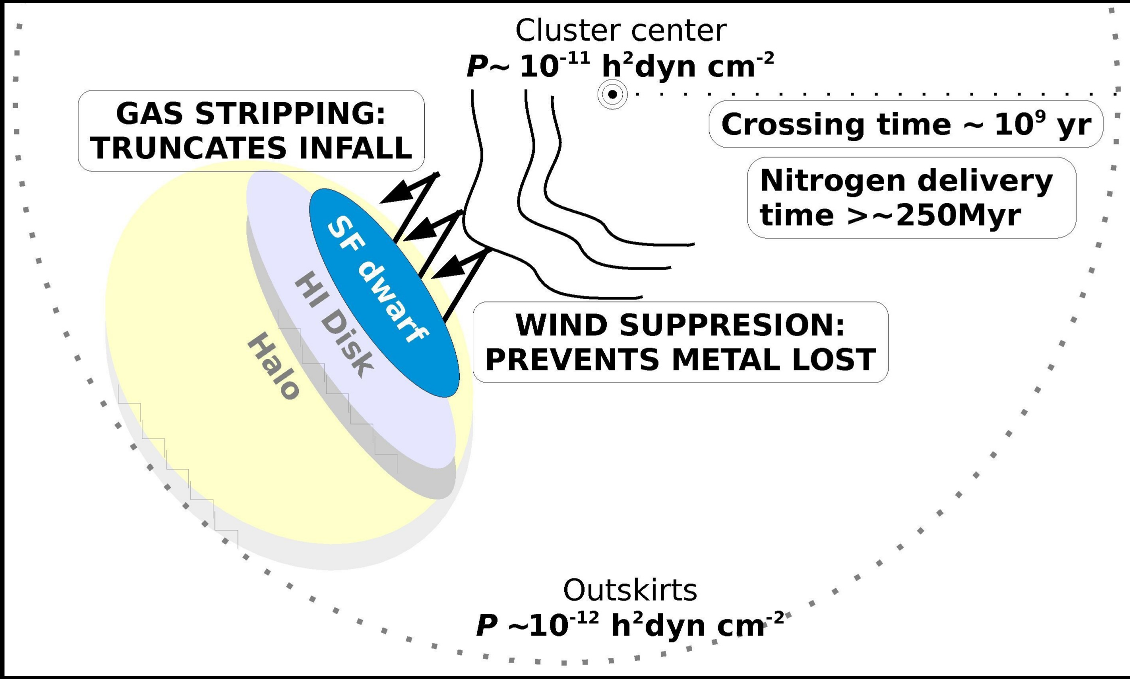
Gas chemical abundance Z — BALANCE: Inflows, Outflows, Gas consumption (by star formation)

Inflows / Outflows } ► mass outflow rate $\eta \propto v^{-1} \propto M^{-1/3}$

So: $Z \propto \eta^{-1} \propto M^{1/3}$, for $M < 10^{10.5}$ *Mo*

Model input	effect	mechanism	clusters	groups
inflows	accretion rate curtailed due to gas lost	Ram-pressure stripping	✓	—
		starvation, tidal interactions	✓	✓
	Preventive feedback due to enhanced SF			
outflows	Wind recycling due to pressure confinement	Hydrodynamic models predict wind suppression in clusters	✓	—
SFR	Temporaly enhanced	Pressure-triguered SF	✓	—
		galaxy-galaxy interactions	✓	✓

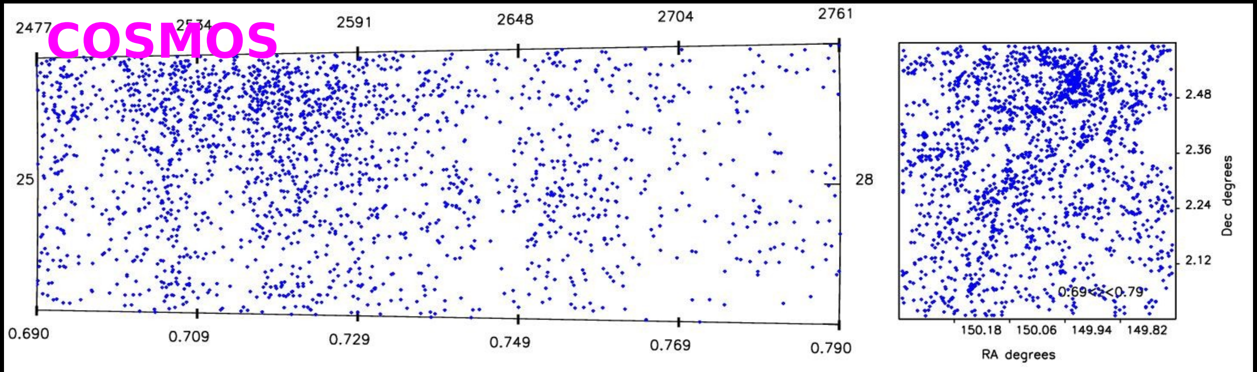
The proposed scenario

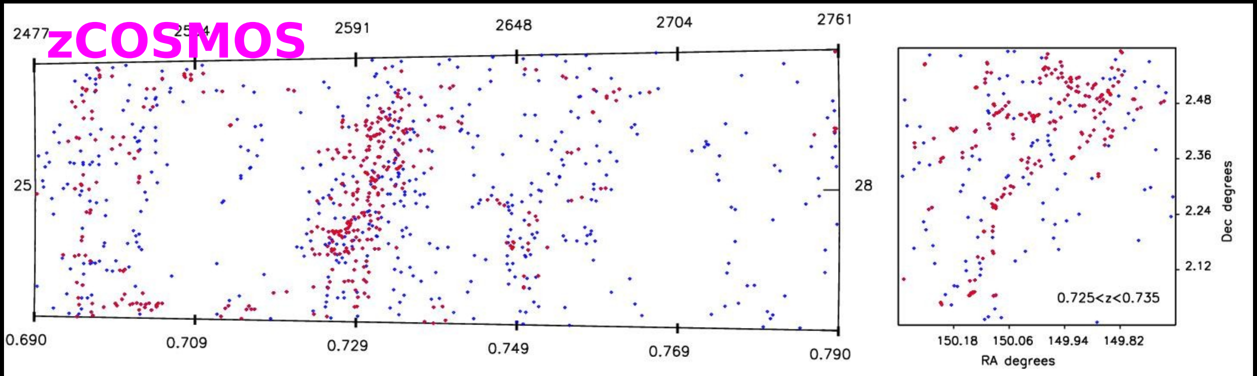


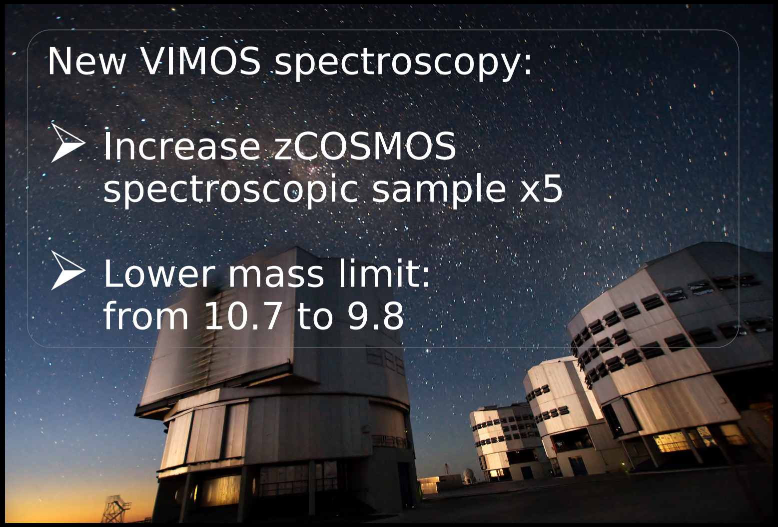
The enhanced metal enrichment could be produced by the combination of effects such as wind reaccretion, due to pressure confinement by the ICM, truncation of gas infall, as a result of RPS, and accelarated SFR due to pressure-triggered star formation

Searching the environmental impact has been an indirect way to tackle the question of the underlying physical process driving galaxy chemical evolution

The COSMOS structure at z=0.73: exploring the onset of enviroment-driven trends



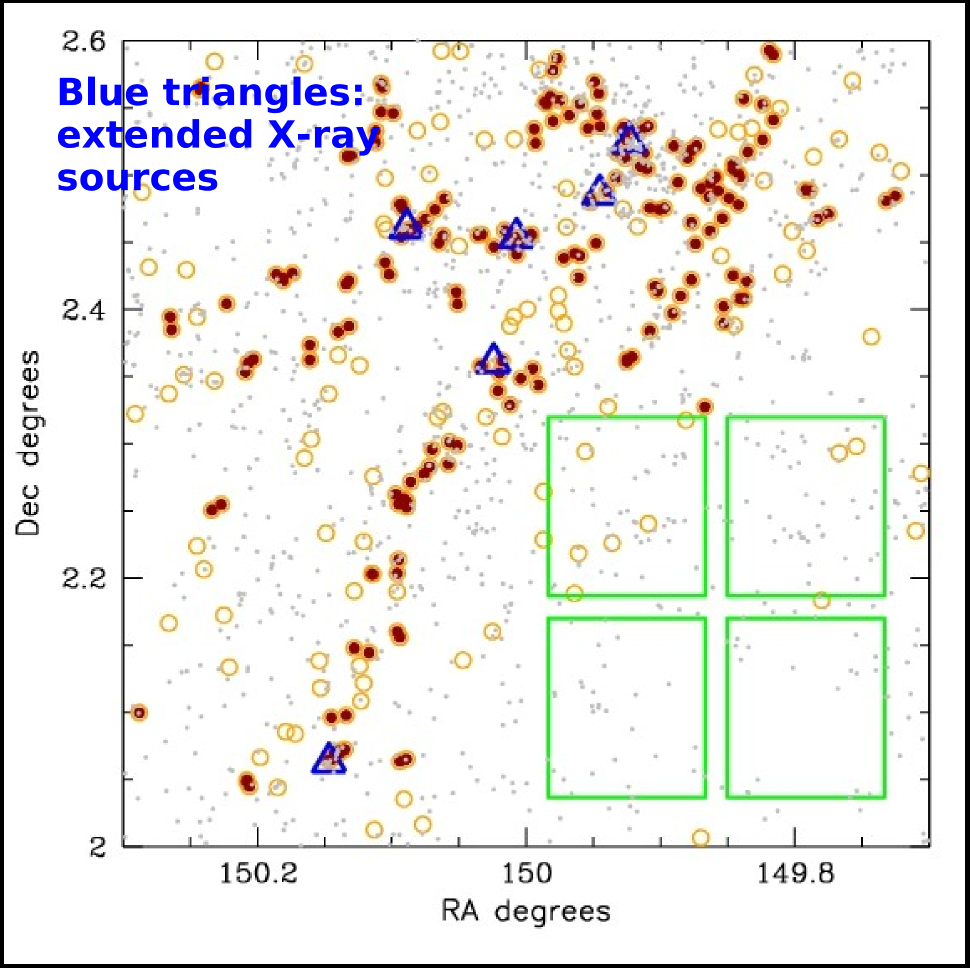




New VIMOS spectroscopy:

- Increase zCOSMOS spectroscopic sample x5
- Lower mass limit: from 10.7 to 9.8

The COSMOS structure at z=0.73: exploring the onset of enviroment-driven trends



Scientific goals:

- Map the large-scale structure
- Study galaxy properties as a function of the environment:
  SFR, metallicities, masses (in combination with the multiwavelength COSMOS photometry) etc...

Thank you!