Metals and Evolution of SF Galaxies in different Environments

Jose M. Vilchez
IAA-CSIC

J. Iglesias-Páramo
V. Petropoulou
M. Mollá
S. Duarte Puertas
C. Kehrig
J.M. Solanes
R. Amorín
P. Papaderos
J.M. Gomes



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COSMIC METAL CONTENT

as a function of lookback time

&

ALSO structure
=> *environments of galaxies*

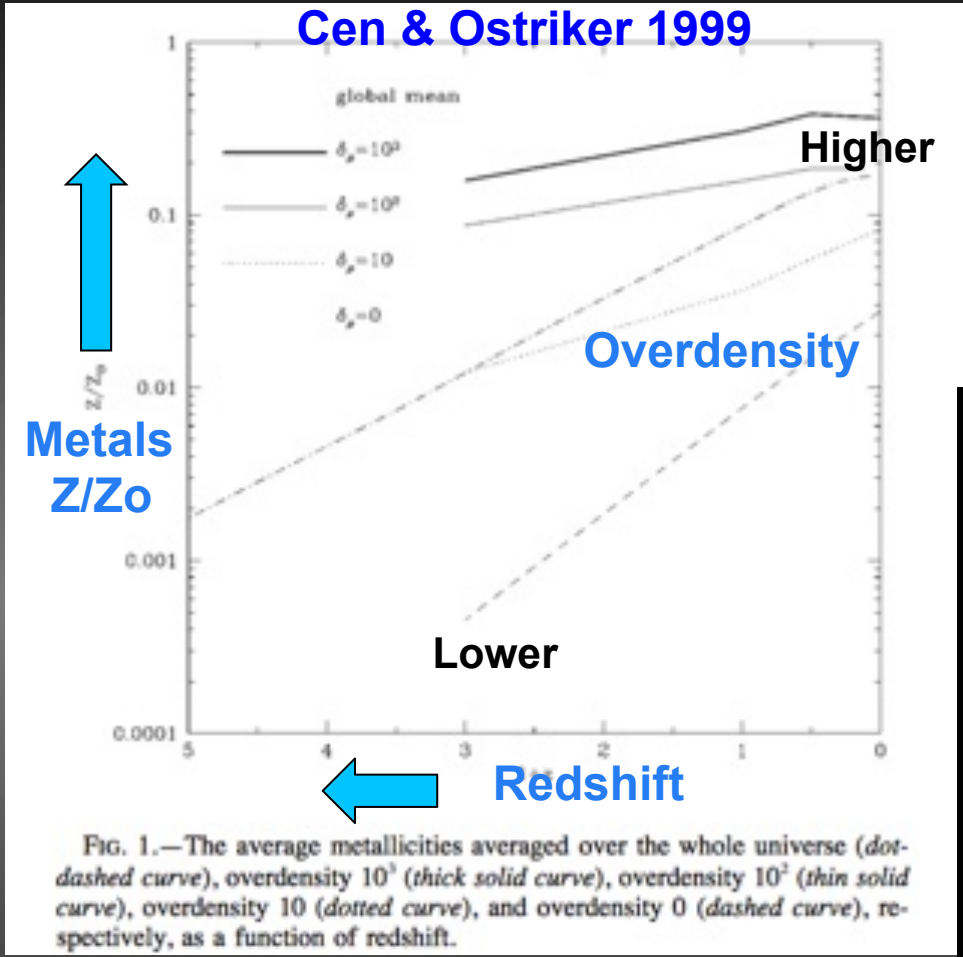
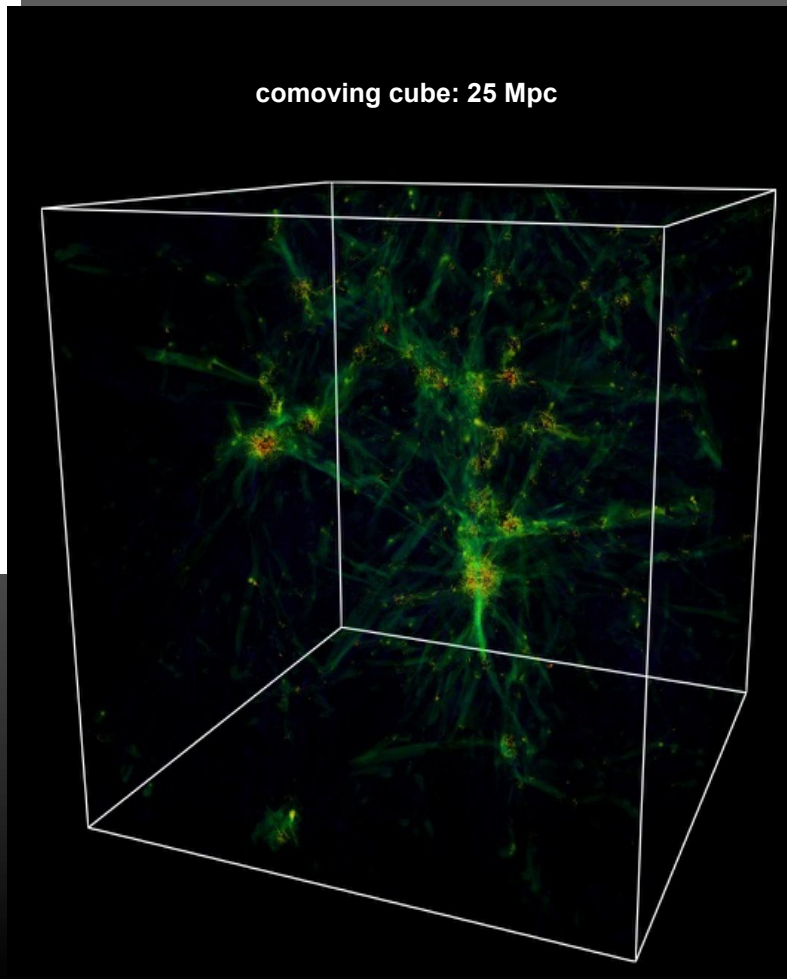
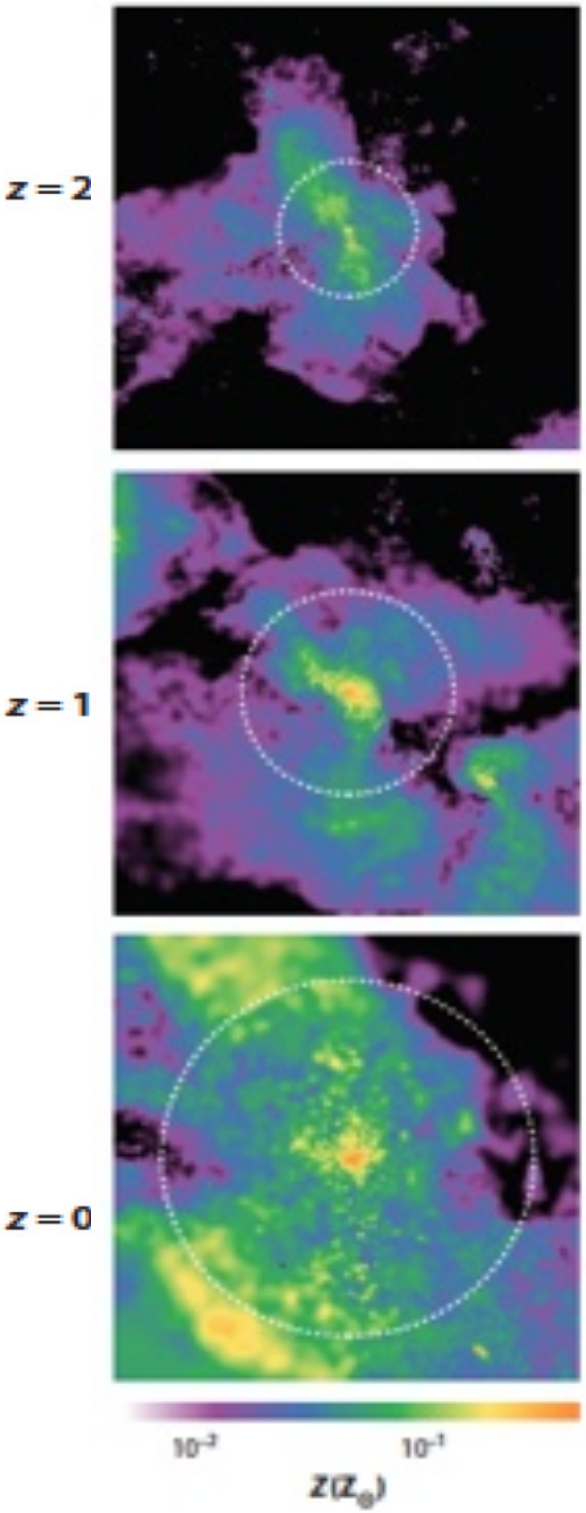


FIG. 1.—The average metallicities averaged over the whole universe (*dot-dashed curve*), overdensity 10^3 (*thick solid curve*), overdensity 10^2 (*thin solid curve*), overdensity 10 (*dotted curve*), and overdensity 0 (*dashed curve*), respectively, as a function of redshift.



simulated views (from EAGLE; adapted from Schaye et al. 2015 and Oppenheimer et al. 2016) of the CGM

single galaxy with $M_\star = 2.5 \times 10^{10}\ M_\odot$ at $z = 0$



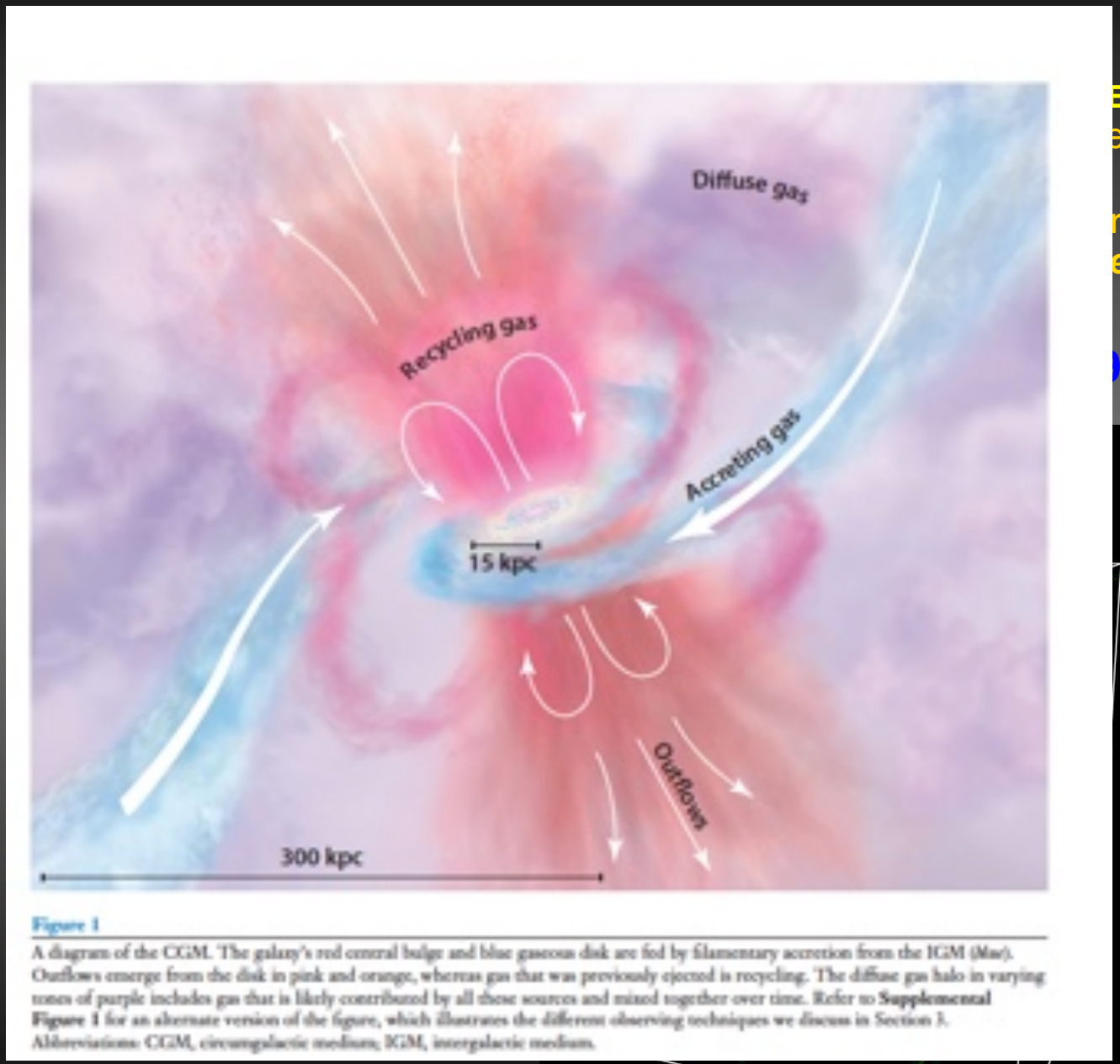


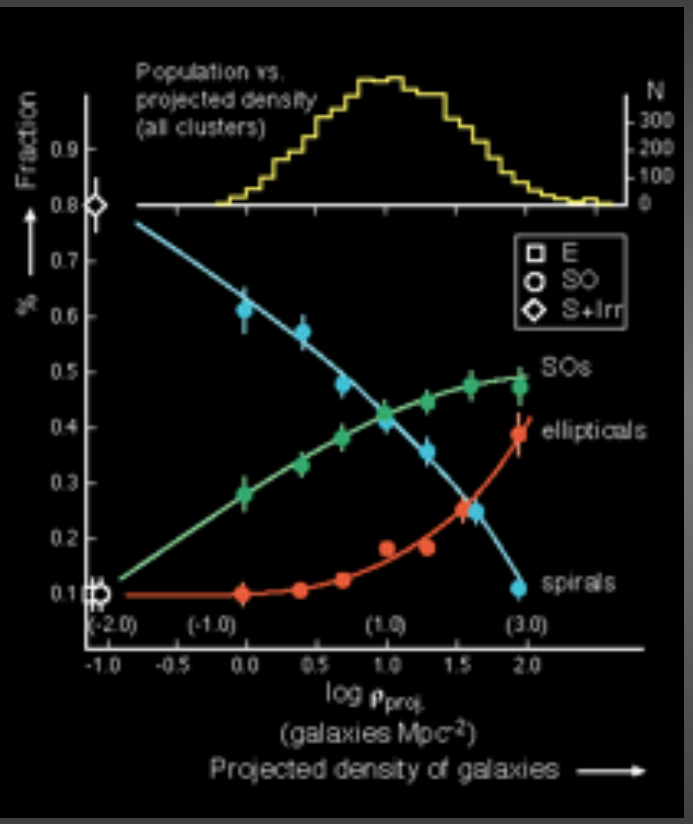
Figure 1

A diagram of the CGM. The galaxy's red central bulge and blue gaseous disk are fed by filamentary accretion from the IGM (*blue*). Outflows emerge from the disk in pink and orange, whereas gas that was previously ejected is recycling. The diffuse gas halo in varying tones of purple includes gas that is likely contributed by all these sources and mixed together over time. Refer to **Supplemental Figure 1** for an alternate version of the figure, which illustrates the different observing techniques we discuss in Section 3. Abbreviations: CGM, circumgalactic medium; IGM, intergalactic medium.

Morphology-density & SF-density Relations

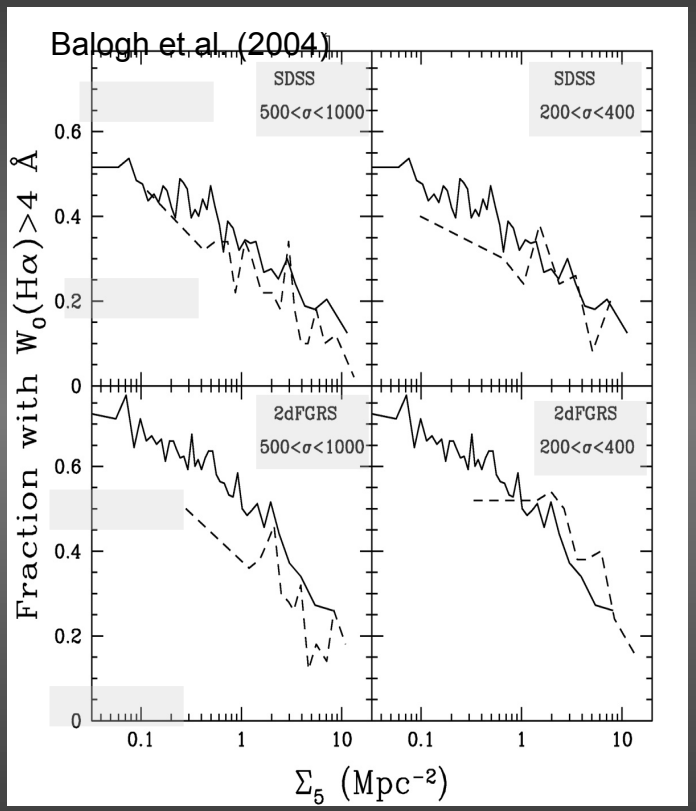
*Empirical laws in the **nearby** universe*

Dressler (1980)



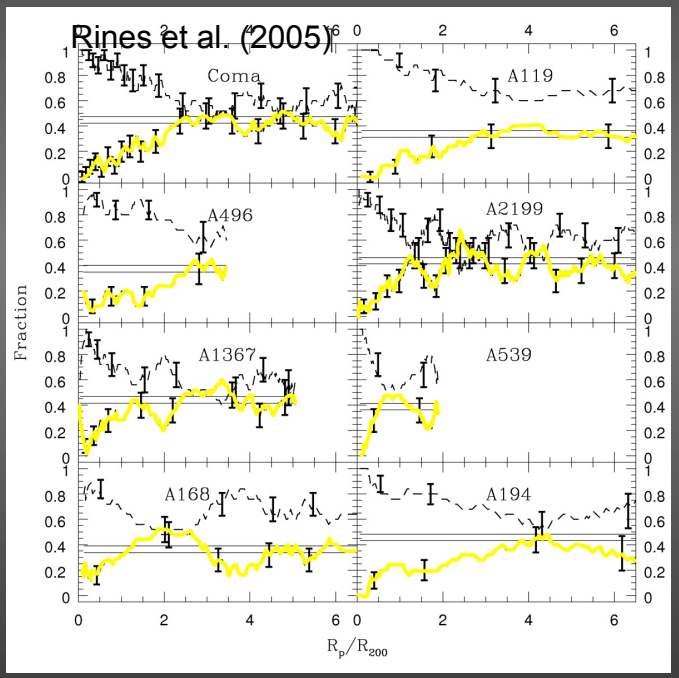
SDSS+2dF: 0.05<z<0.095

Balogh et al. (2004)



CAIRNS: z<0.05

Rines et al. (2005)



Local galaxy density

Distance to the cluster center

@ HIGH Z: CHANGE !! -> high SF associated to higher density of galaxies
Emission line Surveys (e.g Elbaz+ z ≥ 1: HIZELS Cochrane+ 2017; Sobral +)

SF in galaxies in dense environments

Environmental processes can affect the evolution of SF galaxies in clusters

I. **Galaxy-ICM interactions** ram-pressure stripping, thermal evaporation of the ISM, turbulent and viscous stripping of the ISM, pressure-triggered star-formation

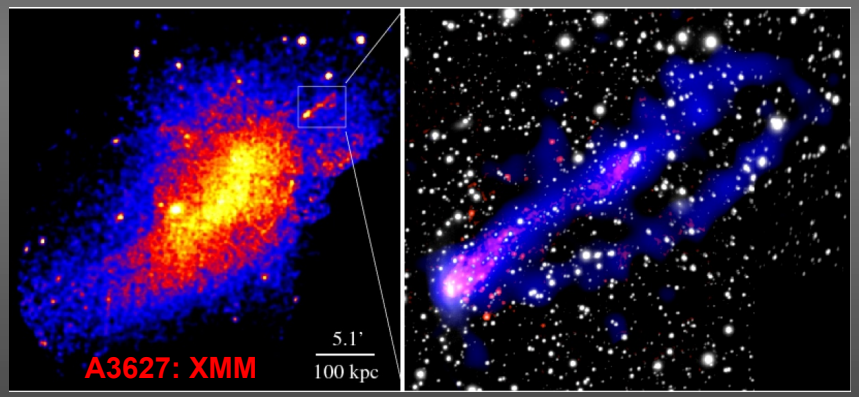
II. Galaxy-Cluster Gravitational Potential interactions tidal compression of galactic gas, tidal truncation of the outer regions of a galaxy (Inter-galactic light, PNs Virgo/Coma)

III. Galaxy-Galaxy interactions mergers (Tissera's models), harassment (Moore+)

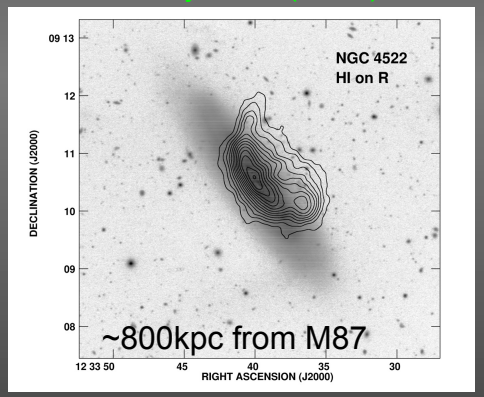
IV. Starvation/strangulation
halo gas reservoir lost. Larson (1980); Balogh (80); Peng et al (2015)

Ram-pressure stripping

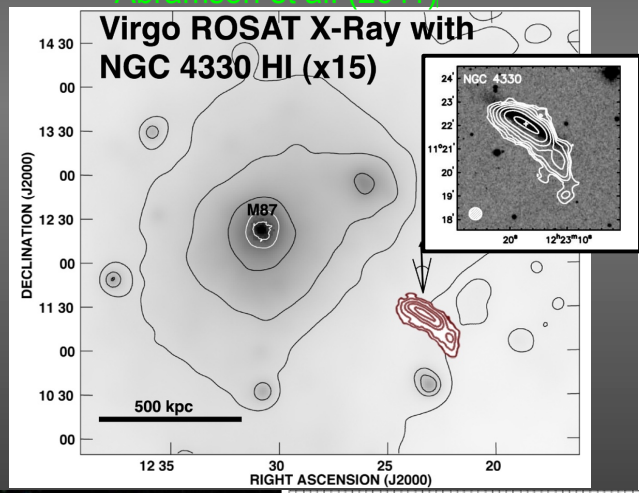
review in e.g. Treu+ 2003



Kenney et al. (2004)



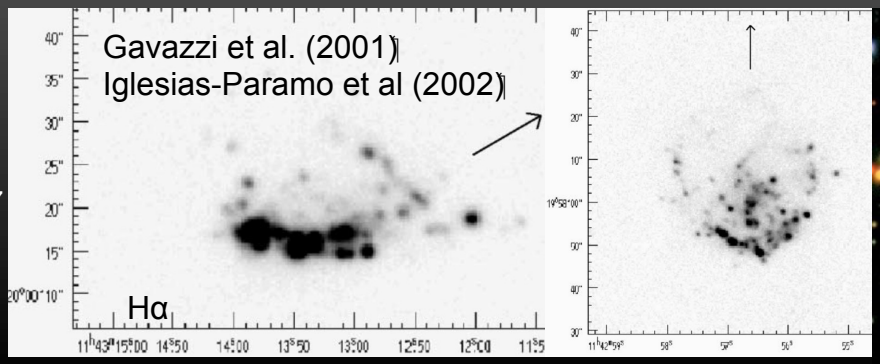
Abramson et al. (2011)

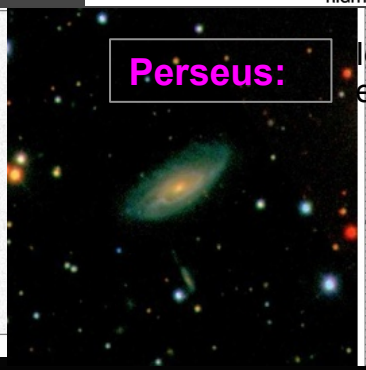


Sun et al. (2010)
XMM mosaic of A3627 one of the closest massive clusters (z=0.016)
Spectacular Xray(in blue)+Hα(in red) tail ~80 kpc in the galaxy ESO137-001
~280 kpc from the cluster center

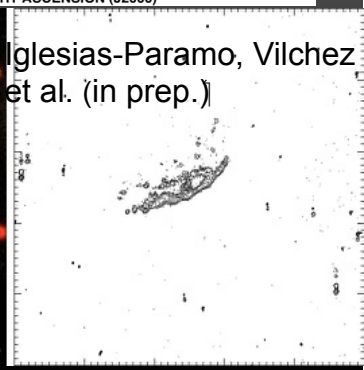
Also **Gavazzi et al (2001)**: 75 kpc trails of ionized gas behind two Irr galaxies in A1367
Gavazzi et al (2017).

Boselli and Gavazzi (PASP 2006)





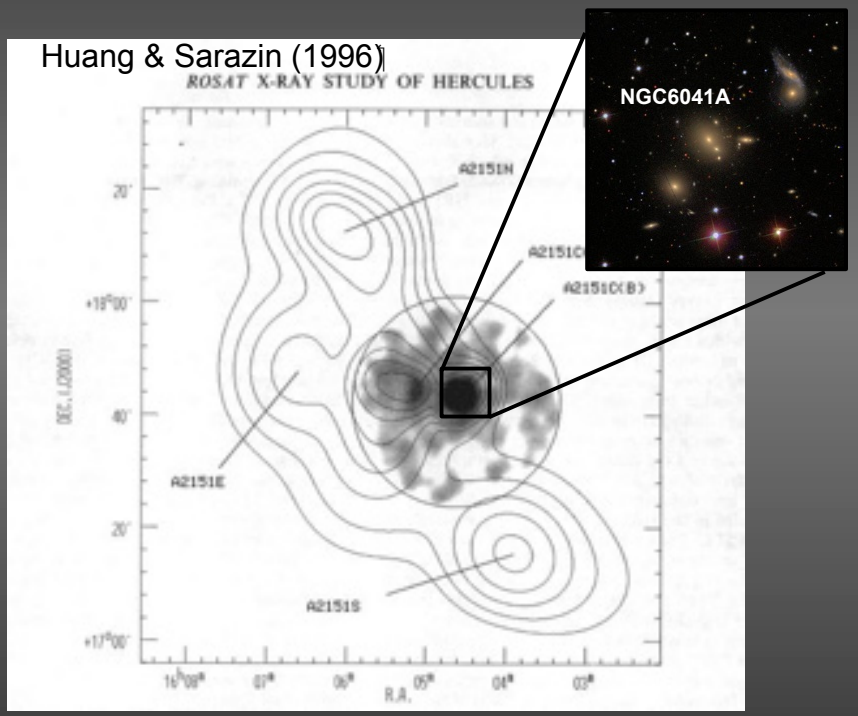
Iglesias-Paramo, Vilchez et al. (in prep.)

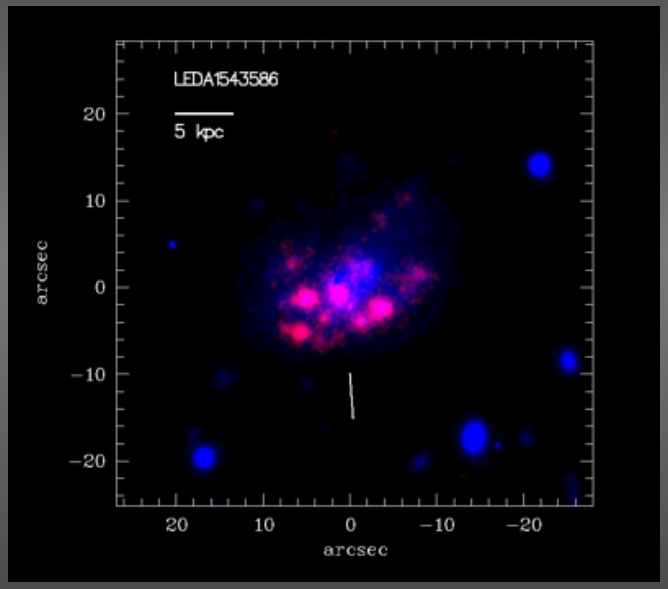


The Hercules cluster: *a benchmark*

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

Low-mass and low-metallicity galaxies show systematically $|\Delta V| > \sigma_V$ and disturbed Hα morphologies.





Red: Hα emission. Blue : r band image
(Petropoulou, Vilchez et al in prep.)

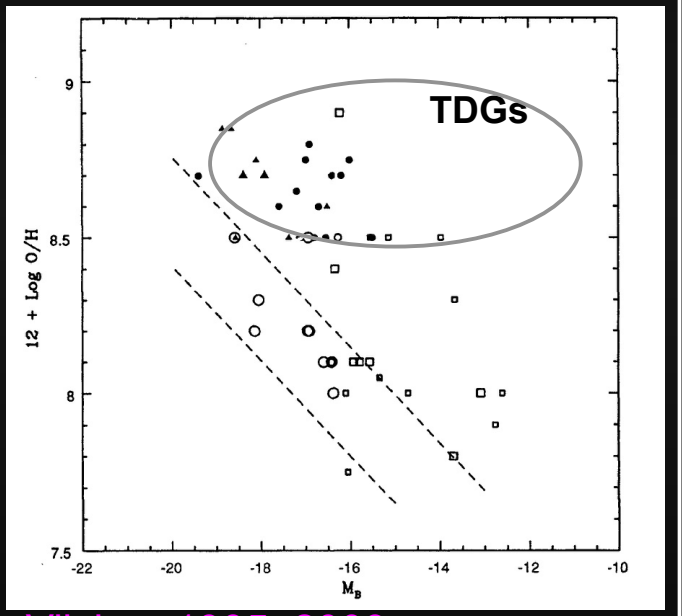
Bird et al. (1995): Central and eastern sub-clusters have recently undergone a merger event
Cedres et al. (2009): Hα survey: ~40 SF galaxies (-21<M_B<-16.5) in Hercules central region (<R_{200})
Petropoulou, Vilchez, Papaderos et al. (2011; HSC 2018 in prep): Spectroscopic follow-up of SF galaxies

Mass-SF-Environment: *galaxies in* ***clusters***

Environmental processes affect gas exchange with CG Medium/environment
=> effect on SFH & chemical evolution of cluster galaxies ??

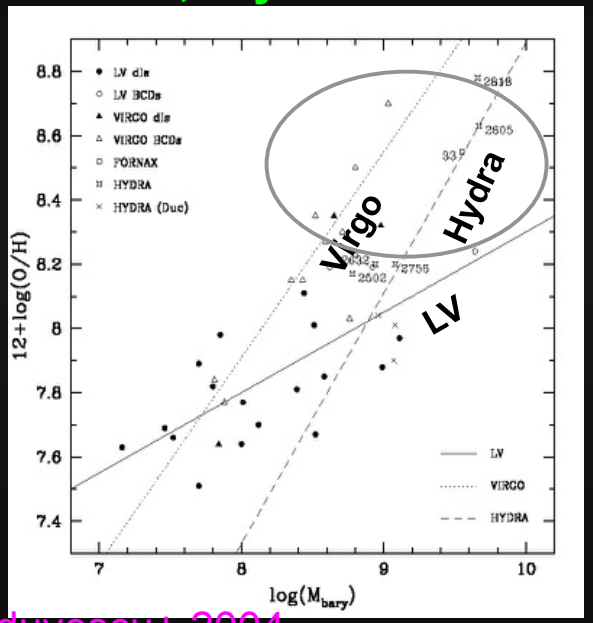
Can we see the imprint of cluster environment on metallicity ?

Virgo / Field



Vilchez 1995; 2003

Fornax, Hydra



Vaduvescu+ 2004
Vaduvescu,Kehrig,Vilchez+2011

Hercules

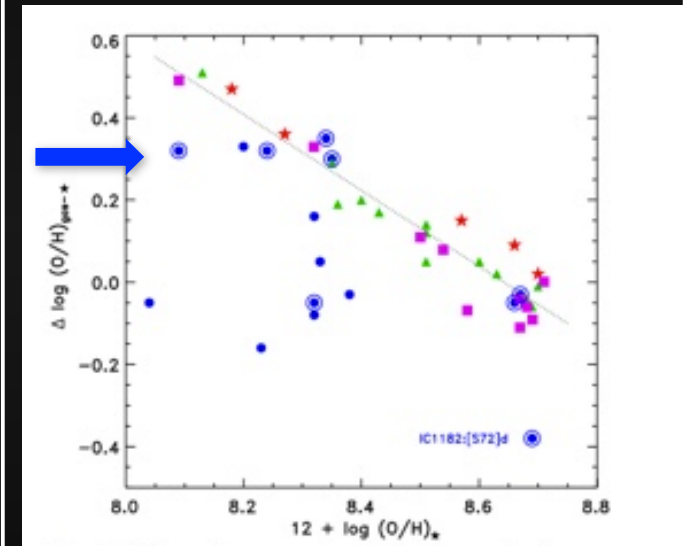


Figure 16. Difference between gas-phase and stellar oxygen abundances vs. stellar oxygen abundance 12+log(O/H), derived from the STARLIGHT mass-weighted stellar metallicity $Z_{\star,m}$ (colors and symbols as in Figure 11).

Petropoulou, Vilchez et al. 2011, 12
Petropoulou+ 2018 (HSC in prep)

Virgo / Field: Skillman et al 1996 ; Henry et al 1992, 94, 96; Telles & Terlevich 95; Hughes+ 2013
Spirals in Pegasus I: Robertson et al 2012

IMPORTANT: WORK EXPLORING M-Z(-SFR) VERSUS ENVIRONMENT

e.g. Mouhcine 2007; Cooper et al 2008; Ellison et al 2009; Petropoulou et al. 2011, 2012;
Hughes et al 2015; Pilyugin et al . 2017; Petropoulou et al. 2017 (Hercules Supercluster)

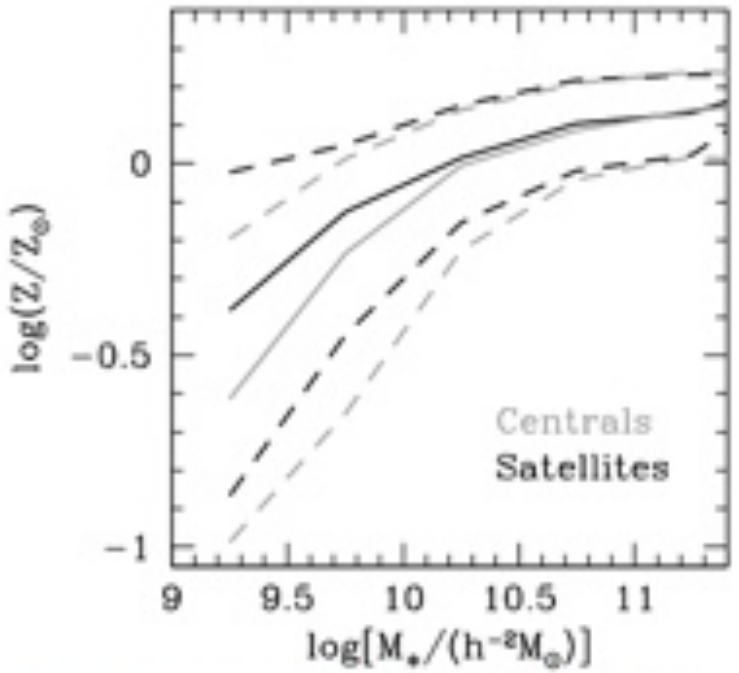


Fig. 3 The average stellar metallicity of centrals (grey solid line) and satellites (black solid line) as a function of their stellar mass. The dashed lines represent the 16th and 84th percentiles of the stellar metallicity distribution within each bin of stellar mass (Pasquali et al. 2010).

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Mon. Not. R. Astron. Soc. **407,** 937–954 (2010) doi:10.1111/j.1365-2966.2010.17074.x

Ages and metallicities of central and satellite galaxies: implications for galaxy formation and evolution

Anna Pasquali,[1⋆] Anna Gallazzi,[1] Fabio Fontanot,[1,2] Frank C. van den Bosch,[3] Gabriella De Lucia,[2] H. J. Mo[4] and Xiaohu Yang[5]

High

Cluster Mass

Low

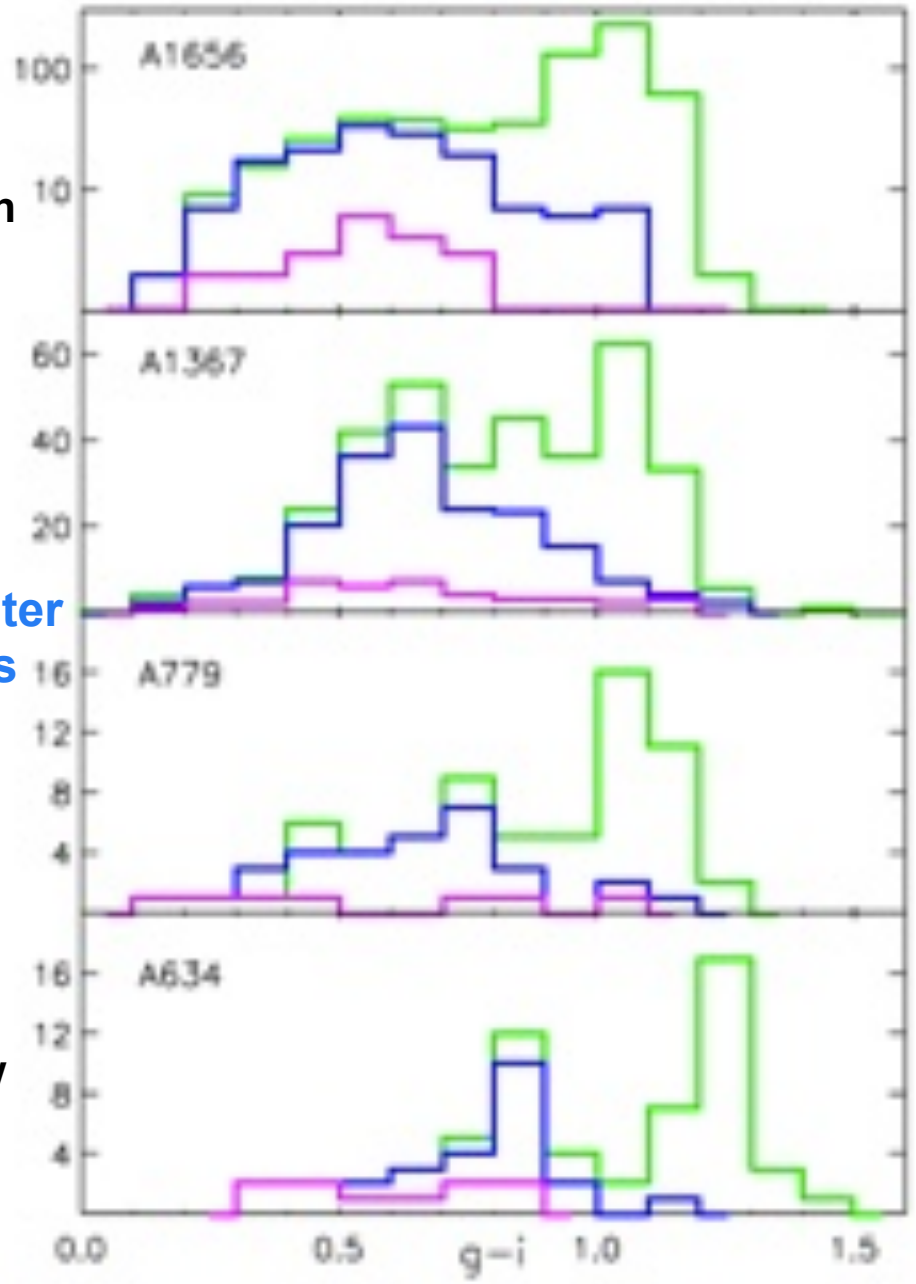
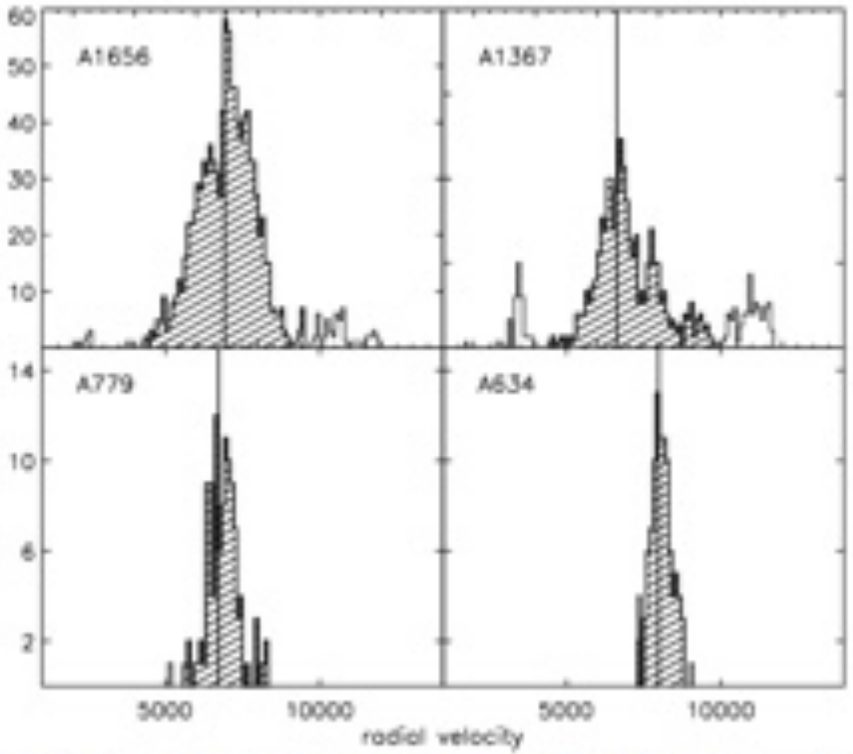


Figure 2. Color $g-i$ histogram of dwarf galaxies (green line), SF dwarf galaxies (blue line), and SF dwarf galaxies to $R \leq R_{200}$ (magenta line) for our clusters' sample. Logarithmic scale is used for A1656. No correction has been performed for the galactic extinction, and the shift observed for A634 toward redder colors is consistent with the slightly higher galactic extinction suffered by this cluster.

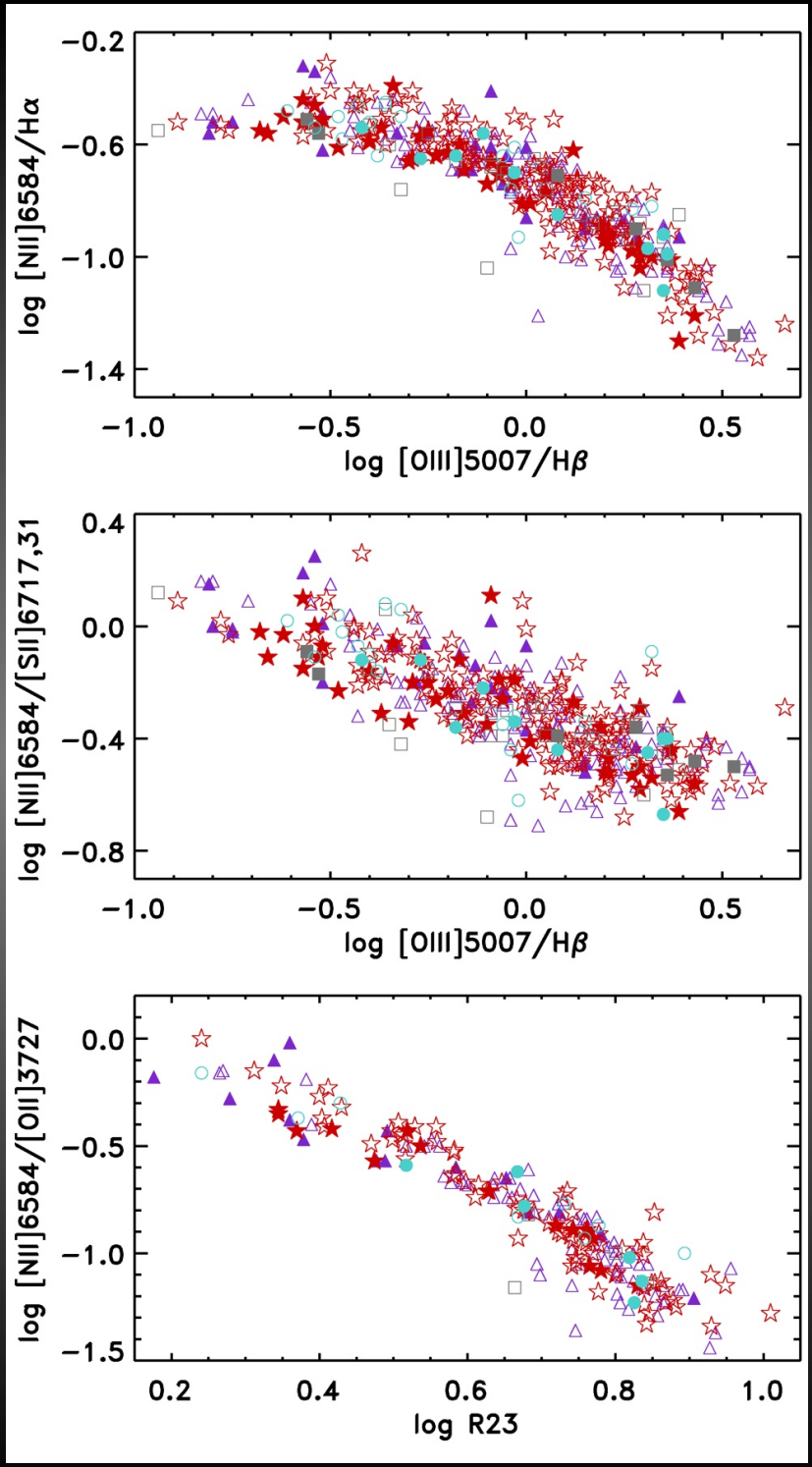


y histogram for all galaxies with SDSS-DR8 spectroscopic data within $3R_{200}$ from the center of each cluster. The velocit nts the mean cluster radial velocity as given in NED (Coma: $cz = 6930$ km s^{-1}; A1367: $cz = 6600$ km s^{-1}; A779: ed region indicates the adopted velocity range at $\pm 3\sigma_v$ around the mean cluster velocity.

Galaxy Sample:

4 nearby clusters

SF Dwarfs



ALL galaxies cover the whole range in excitation conditions independent of their exact location in the cluster (i.e. within or outside the Virial radius of each cluster)
Idem. Id. for other galaxy properties

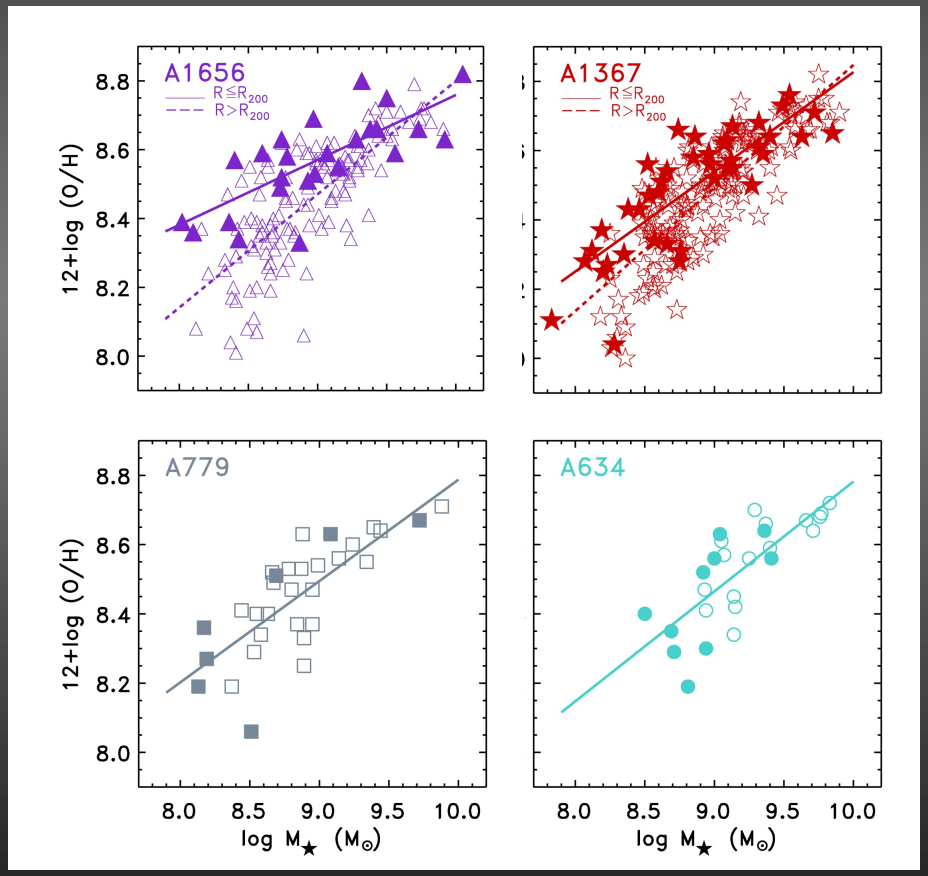
Cluster core: filled symbols

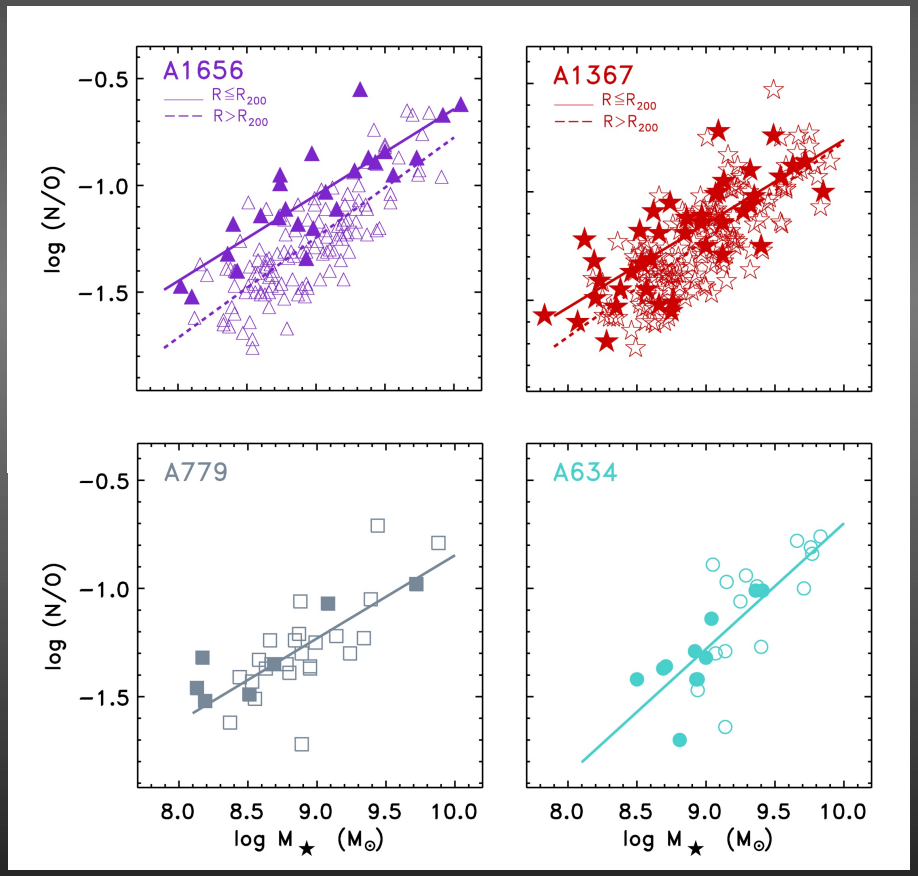
SF Dwarf galaxies in 4 nearby clusters:

Coma, A1367, A779 & A634

Cluster sample: **mass range: 10^{13} - 10^{15}** M_o , Distance ~100 Mpc

Spectroscopic data: SDSS **corrected for underlying stellar continuum**





Cluster mass … matters

Petropoulou et al 2012, 2018 HSC (in prep)

GAS METALLICITY MZR IN GALAXIES OF CLASH CLUSTERS AT *z* ~0.35
ENVIRONMENTAL IMPACT ON GALAXY CHEM. EVOLUTION

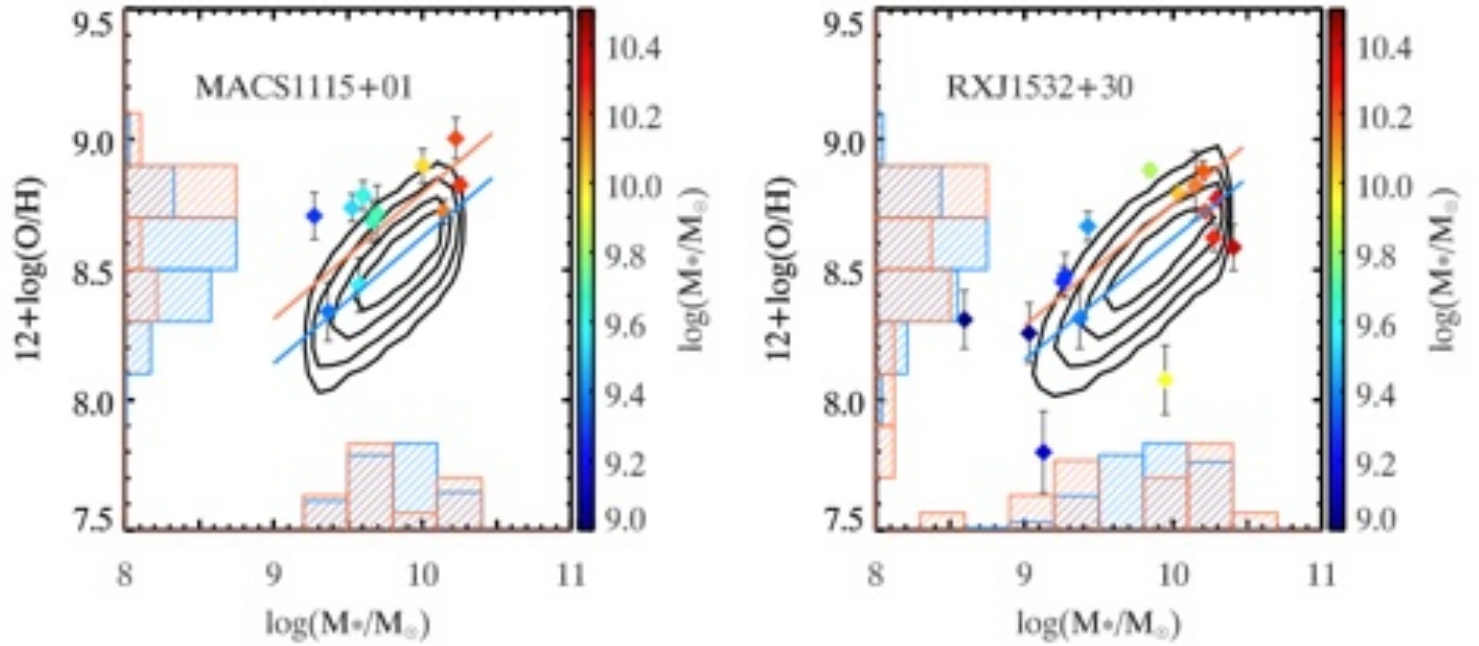


Figure 6. MZR for cluster members. Left panel: MACS J1115+01; right panel: RX J1532+30. The MZR for the local comparison sample is represented as the contours (25%, 50%, 70%, and 90%) in each panel. The red and blue curves represent the best linear fit of the MZR to cluster and SDSS data, respectively. The red and blue histograms in each panel represent the mass and metallicity distribution of the cluster members and SDSS control sample, respectively. The metallicity distributions for MACS J1115+01 and the local comparison sample are clearly different.

Table 1
X-Ray and Optically Derived Properties of Galaxy Cluster Sample

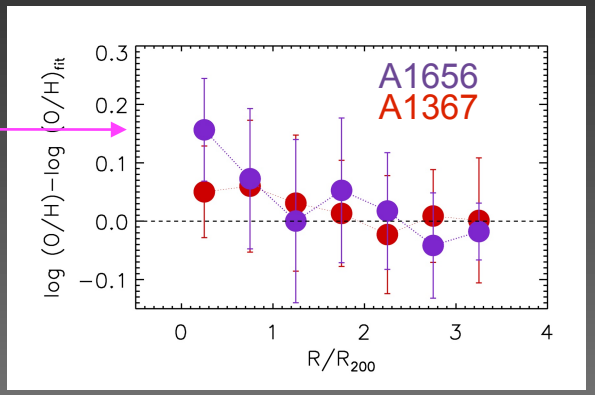
Cluster	z^a	kT^b (keV)	$L_{Bol}{}^b$ (10^{44} erg s^{-1})	$r_{vir}{}^c$ (Mpc/h)	$M_{vir}{}^c$ (10^{15} $M_\odot/h$)	$c_{vir}{}^c$
MACS J1115+0129	0.352	8.0 ± 0.4	21.1 ± 0.4	1.78	1.13 ± 0.10	2.9 ± 0.9
RX J1532+3021	0.362	5.5 ± 0.4	20.5 ± 0.9	1.47	0.64 ± 0.09	3.8 ± 1.7

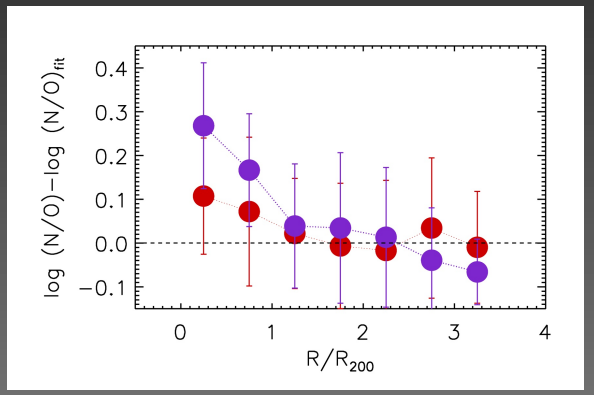
Notes.
[a] Redshift derived from SDSS spectra of central BCG.
[b] kT is the temperature, and L_{Bol} is the total luminosity derived from the X-ray data (Postman et al. 2012).
[c] r_{vir} is the virial radius, M_{vir} is the total halo mass at the virial radius, and c_{vir} is the concentration parameter at the virial radius of strong- and weak-lensing observations (Merten et al. 2015).
[d] σ_{cl} is the radial velocity dispersion from our observations, and M_{vel} is the halo mass estimated from the velocity dispersion.

Cluster membership or local density?

Distance from the cluster center

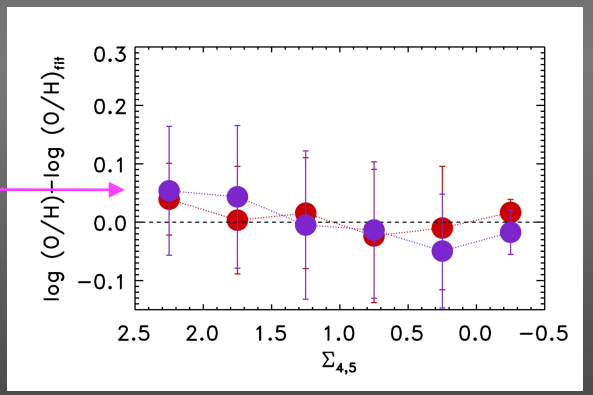
~0.15 dex

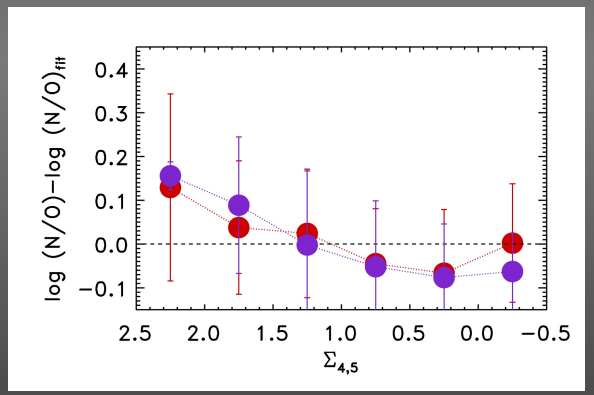




~0.3 dex

~0.05 dex

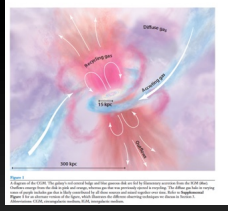


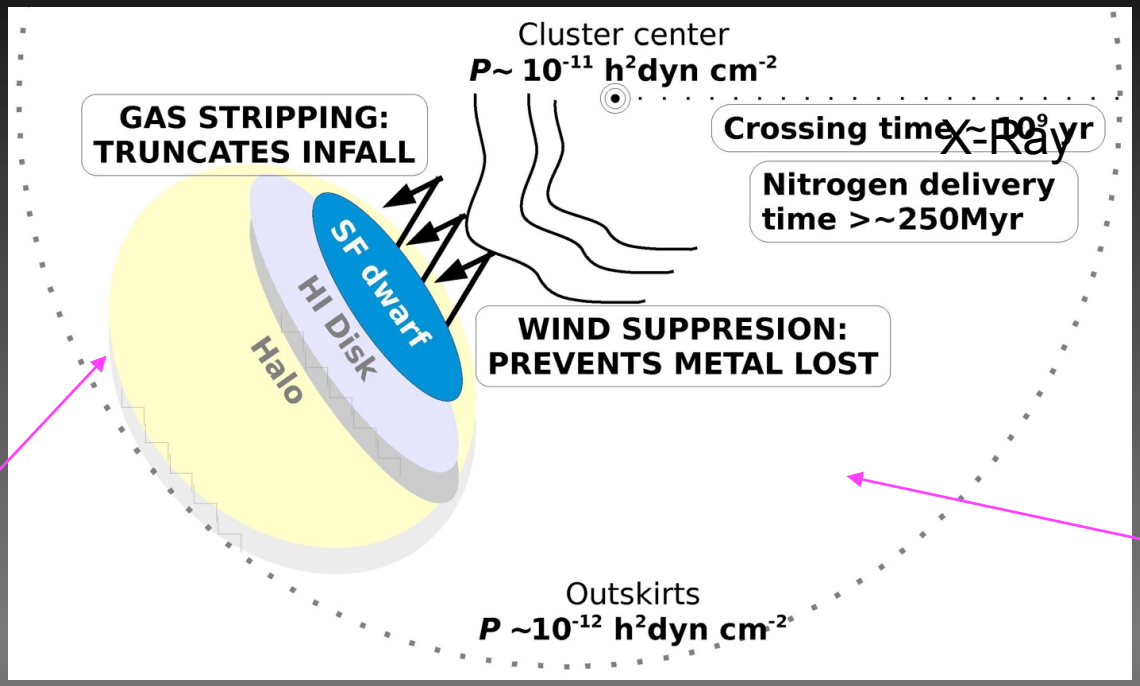


Local galaxy density

Left: The difference of the derived 12+log(O/H) of each galaxy with the $12+\log(O/H)_{fit}$ given by the bisector linear fit, as a function of the cluster centric radial distance (Up) and the local galaxy density (Down). Right: the same for N/O

A proposed scenario





Enhanced metallicity could be produced by a combination of effects: the gal. wind suppresion and reaccretion, due to pressure confinement by the ICM, plus truncation of gas reservoir infall by RPS.
SF (RP stripped) dwarfs & satellite galaxies (Petropoulou+ 2011, 12, 18; Pasquali+ 2010, 12; Gupta+ 2017) => **metallicity enhancement**

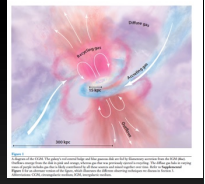
Consistent with model predictions: Dave et al. (2011), Finlantor & Dave (2008) parametric models

Bahe et al (2017); EAGLE sim: i) stripping of metal poor gas & ii) suppression metal poor inflow + recycling.

Genel (2016); ILLUSTRIS sim.: Metallicity-environment density correlation expected
(1/3) satellites dwarfs have lower SFR and older ages in dense environments,
(2/3) a higher concentration of the star-forming disks of satellite galaxies =>
bias SFR-weighted metallicities towards their inner, more metal-rich gal. parts (e.g. Gupta et al. 2017)

Opposite extreme: *truly isolated galaxies*

Chemical evolution in CIG 512



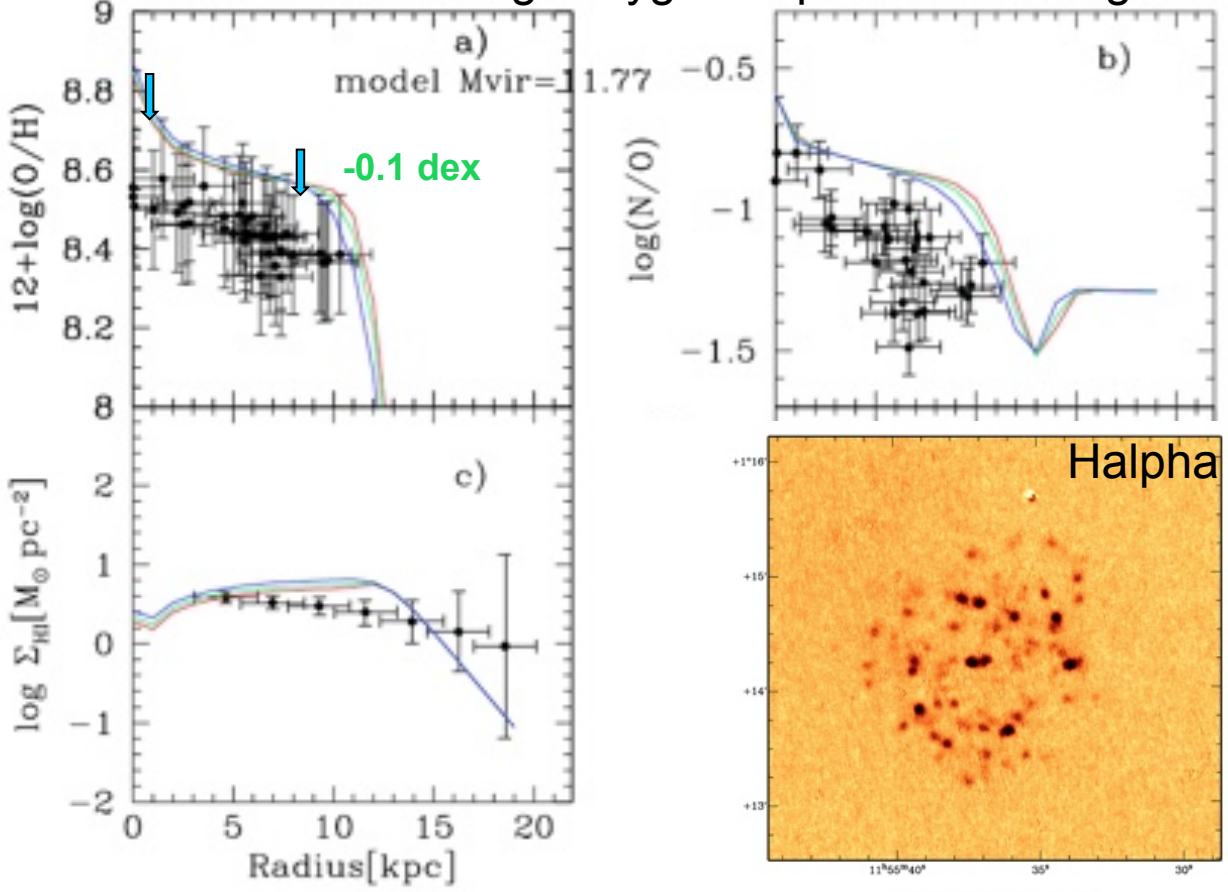


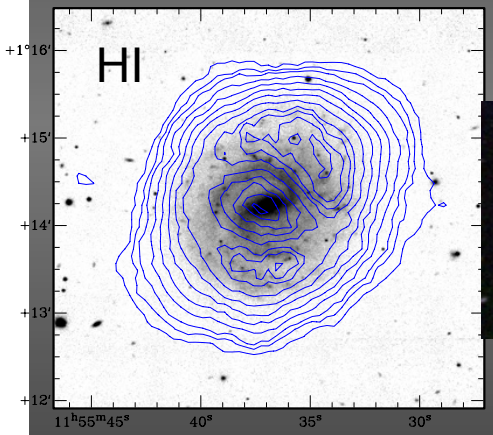
AMIGA Isolated Gals. Sample

F_tidal < 1/1000 fo its Mass
R_25 = 9.8 kpc (MW R_25 ≈ 10 kpc)

Distance = 31.9 Mpc
log LB [Lsol] = 9.40
log(LFIR) = 8.88
log(LK) = 9.86
Log(MHI) = 9.62
log(MH2) = 8.24 (extrapol.)

O/H Model - 0.1 dex of avg. Oxygen depletion in dust grains







MWG-type
Chem Evolution Model
=> low eficiency suggested
Missing Oxygen ?
- **Observed O/H lower**
- **0.2 dex + 0.1 dex depletion**
- **Observed N/O steeper**

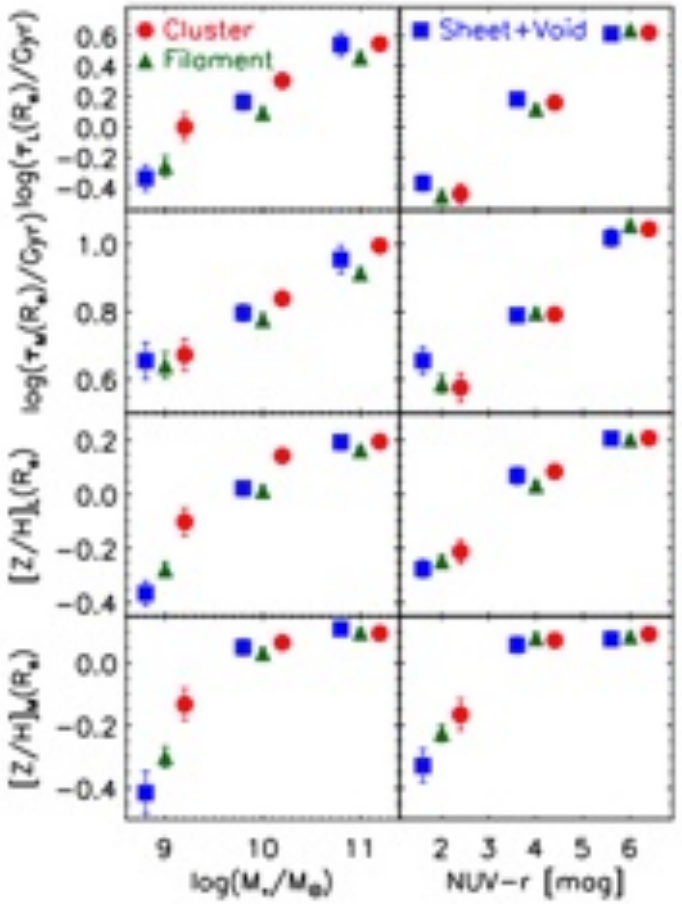


Figure 14. Median values of fitted age and metallicity at the effective radius R_e in each mass (left-hand panels) and $NUV - r$ colour (right-hand panels) bin. Symbols are the same as Fig. 11.

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MNRAS 465, 4572–4588 (2017) doi:10.1093/mnras/stw3030
Advance Access publication 2016 November 23

SDSS-IV MaNGA: environmental dependence of stellar age and metallicity gradients in nearby galaxies

Zheng Zheng,[1]★ Huiyuan Wang,[2] Junqiang Ge,[1] Shude Mao,[1,3,4] Cheng Li,[3,5]

Take-home message: Metals - SF - Environment

I.- M-Z versus *general SDSS galaxy field* <=> Moderate to small absolute effect (≈ 0.15 dex) on **the average M-Z locus** *(beware of SDSS general spec target bias)*

II.- Environmental effects

***a) Dense regions-clusters*: M-Z outliers (≥ 0.3 dex)** e.g. Tidal Dwarfs; ***Preprocessing* SF infalling** galaxies / satellites / **RPS SFGs** (Massive clusters) **metal enriched** w.r.t. centrals or the avg M-Z @Mass.

Observed facts expected/predicted from/in Cos.Hydro. simulations (EAGLE; IllUSTRIS).

b) Very low density - pure isolation: *chem evol. models* favouring a slow (secular) SFR & chemical evolution. Leading to the under-solar metallicity and N/O ratios found.

Homework:

c) *Turnover mass* in the **M-Z** "universal" parameterization: proposed **anti-correlation with local galaxy density must be explored** (Wu+ 2017; also de Rossi+ 2017).

Take-home message: Metals - SF - Environment

Caveats:

→Highest galaxy density (**clusters cores**) **in fact not well sampled within SDSS when using spectroscopic targets => need** to perform a complete exploration making use of new larger field IFS, e.g. SITELLE @CFHT MUSE @VLT.

→Explore possible **evolutionary effects @different gal. density/locations** using **FADO** code tools (@voids/walls/filaments/groups/clusters)


¡Gracias *Estallidos*!