14 April 2021

GALAXY EVOLUTION AND ENVIRONMENT

THE CLUSTER VIEW AT z<1

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European Research Council
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GASP
GAs Stripping Phenomena in galaxies

OSSERVATORIO ASTRONOMICO DI PADOVA
INAF ISTITUTO NAZIONALE DI ASTROFISICA

LARGE CLUSTER-DEDICATED SPECTROSCOPIC SURVEYS z=0-1

<u>MOS surveys</u>

MORPHS (A. Dressler)
CNOC (H. Yee)
EDisCS (S. White)
SpARCS (G. Wilson, A. Muzzin)
ICBS (A. Dressler)
WINGS+OMEGAWINGS (B. Poggianti)
LOCUSS(ACRES) (G. Smith)
GCLASS (G. Wilson, A. Muzzin)
CLASH-VLT (P. Rosati)
XXL (M. Pierre)
GOGREEN (M. Balogh)

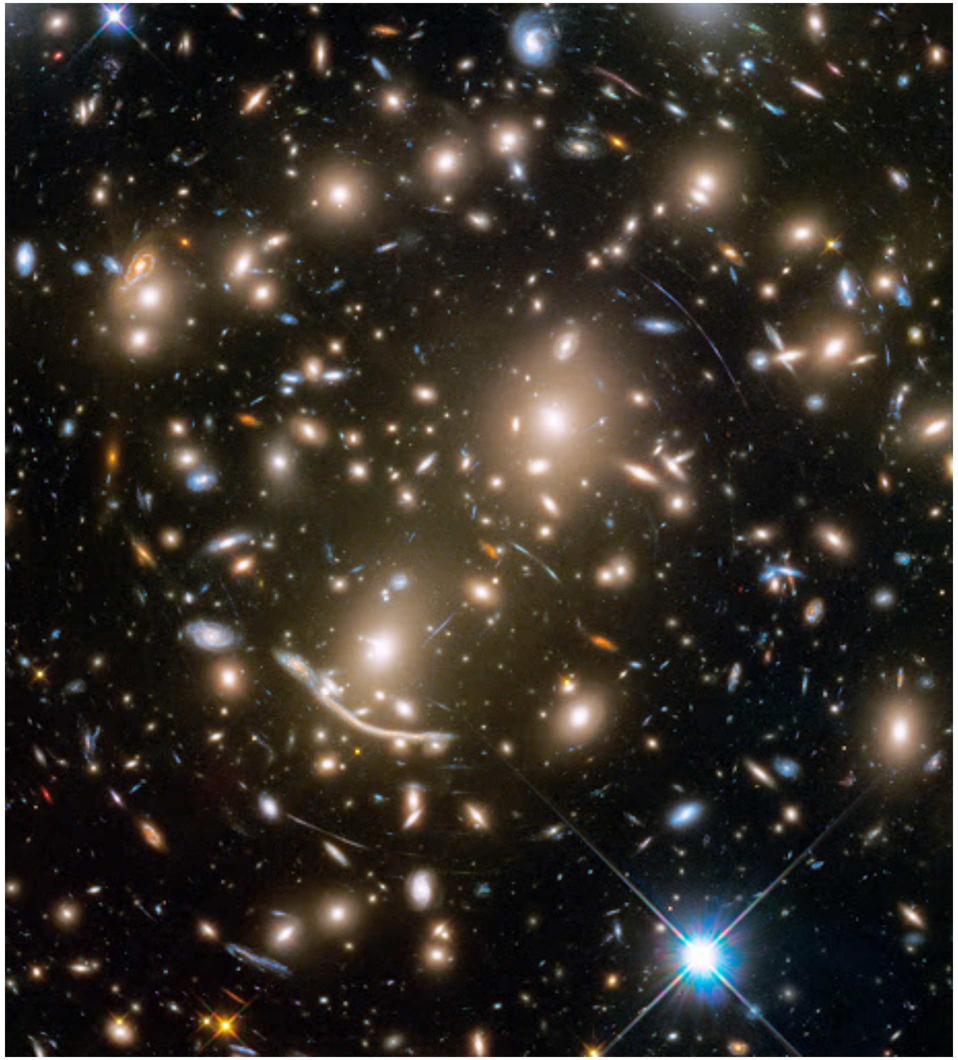
Spectroscopic campaigns of Coma, Virgo, Fornax….
STAGES (M. Gray)

<u>IFU surveys</u>

GASP (B. Poggianti)

MUSE Lensing Cluster GTO program+ (J. Richard)

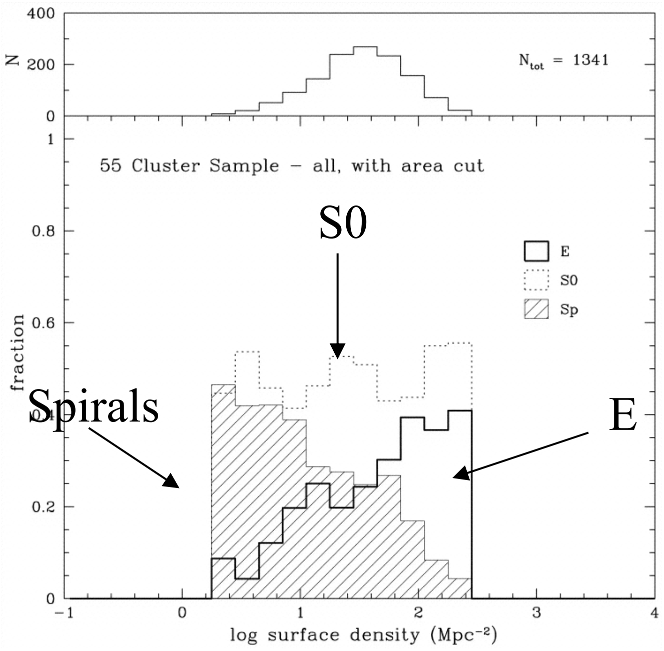
Fornax 3D (E. Iodice, M. Sarzi)



WITHOUT (?) SPECTROSCOPY

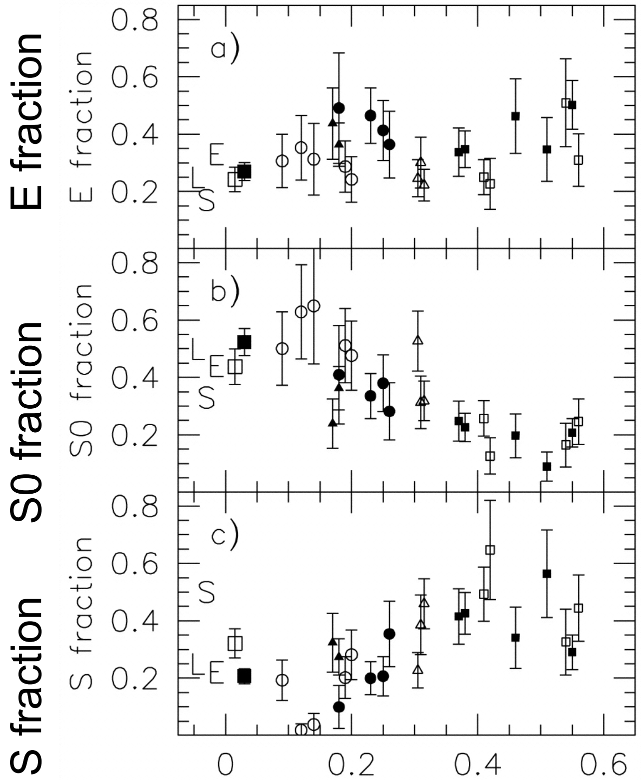
Almost all major results on galaxy evolution in clusters come from spectroscopy – with some notable exceptions – eg, the morphology-density relation and the evolution of spirals into S0 galaxies

Fraction of galaxies



Log projected surface density (Mpc^-2)

Dressler 1980, as in Dressler+ 1997



redshift

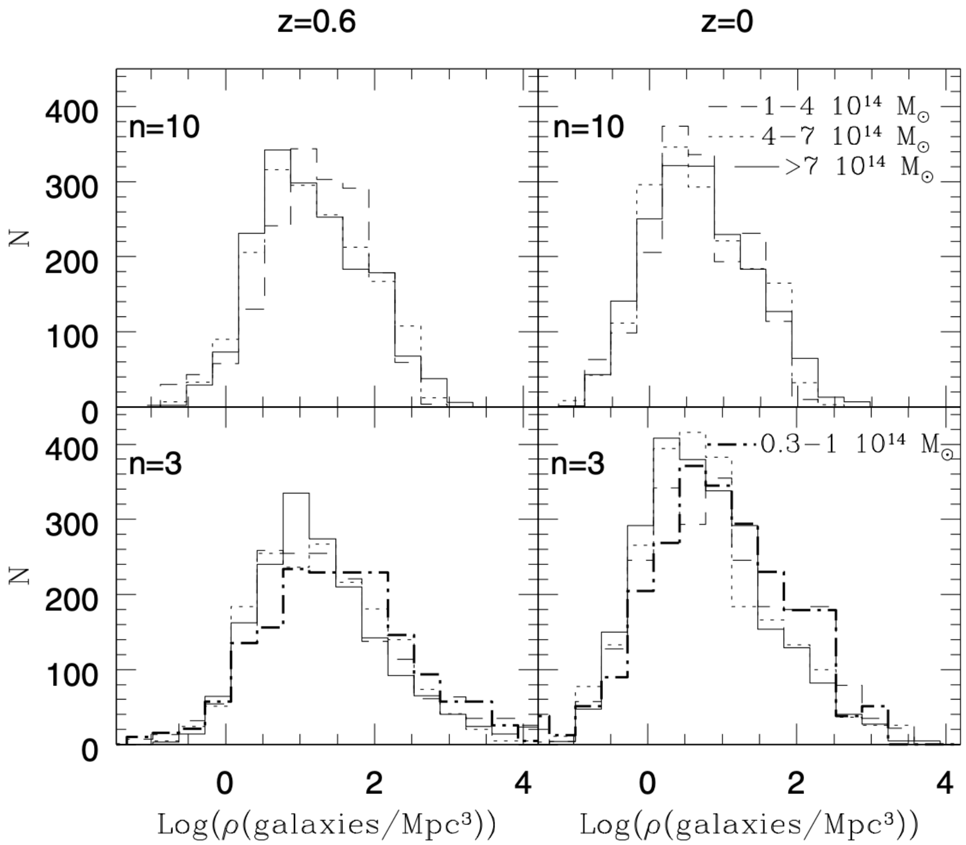
Fasano+ 2000

see also Dressler+ 1997, Postman+ 2005, Smith+ 2005, Desai+ 2009

CLUSTERS ≠ DENSITY

The distribution of galaxy number density conditions felt by galaxies in virialized systems does not depend on the halo mass at least over the range 3X10^13 – 10^15 - the intuitive belief that the most massive clusters are the densest environments is incorrect.

Careful when making statements about how galaxy properties depend on “environment”:
some properties depend more on local galaxy density,
others on “global environment” (clusters vs field, or halo mass).
(e.g. Ellison+ 2009)



Poggianti+ 2010

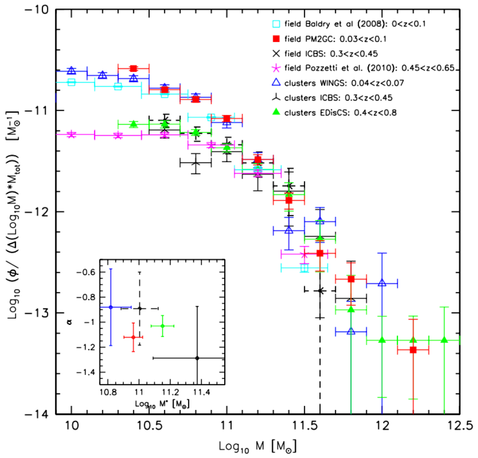
SOME FUN FACTS ABOUT CLUSTERS

- In clusters, we can study both the so called "environmental effects" (ram pressure stripping, strangulation, harassment etc) and….all the rest!
- Clusters are "cosmic accelerators"… accelerators of evolution
- Clusters are sites of "super-quenching": all quenching processes are efficient

STELLAR MASS ASSEMBLY

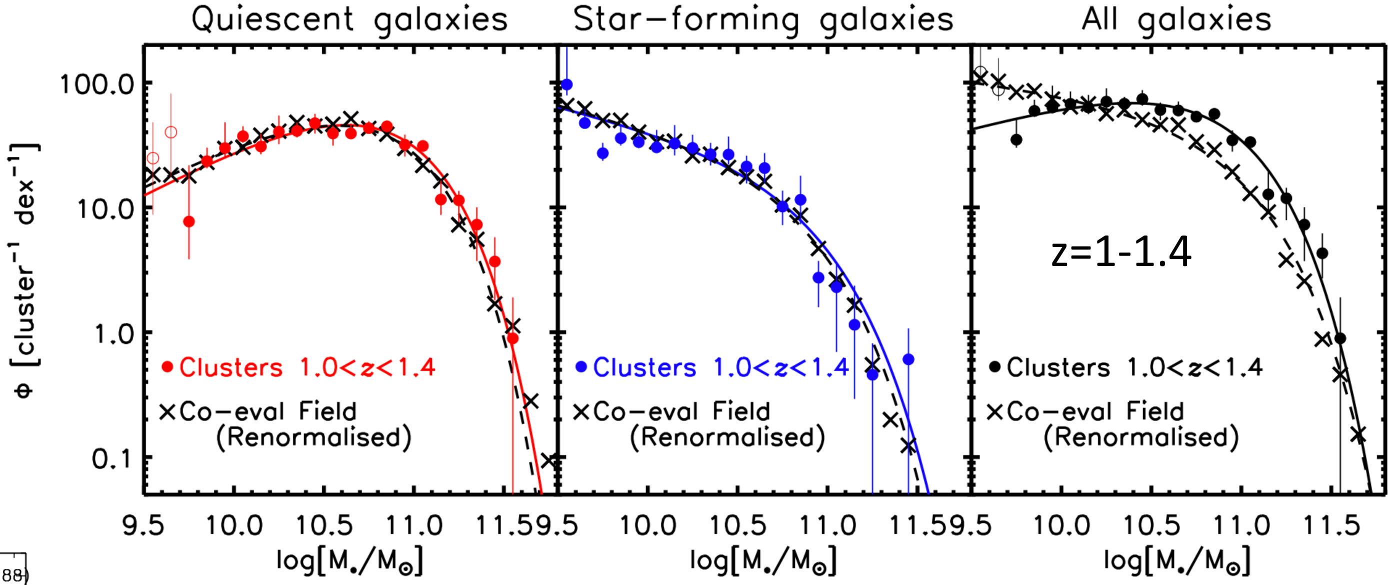
The dependence of the SMF on local density is well established (also at the high mass end)

z=0 & z=0.4-0.8



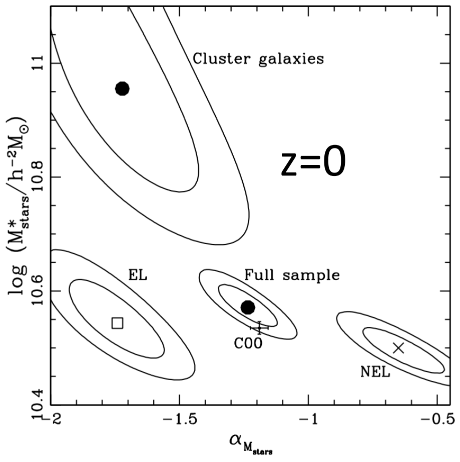
Vulcani+ 2013

The shape of the distribution of stellar masses above log~10.2 does not change significantly between clusters and field at intermediate and low-z

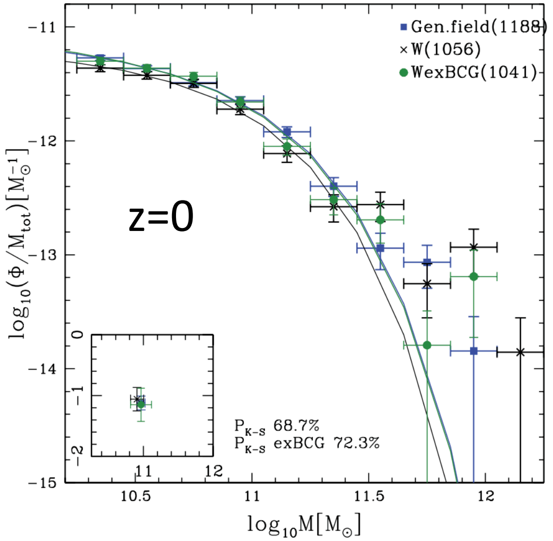


van der Burg+ 2020, see also Nantais+ 2016

Need to go at z~1.2 to start seeing differences?



Balogh+ 2001

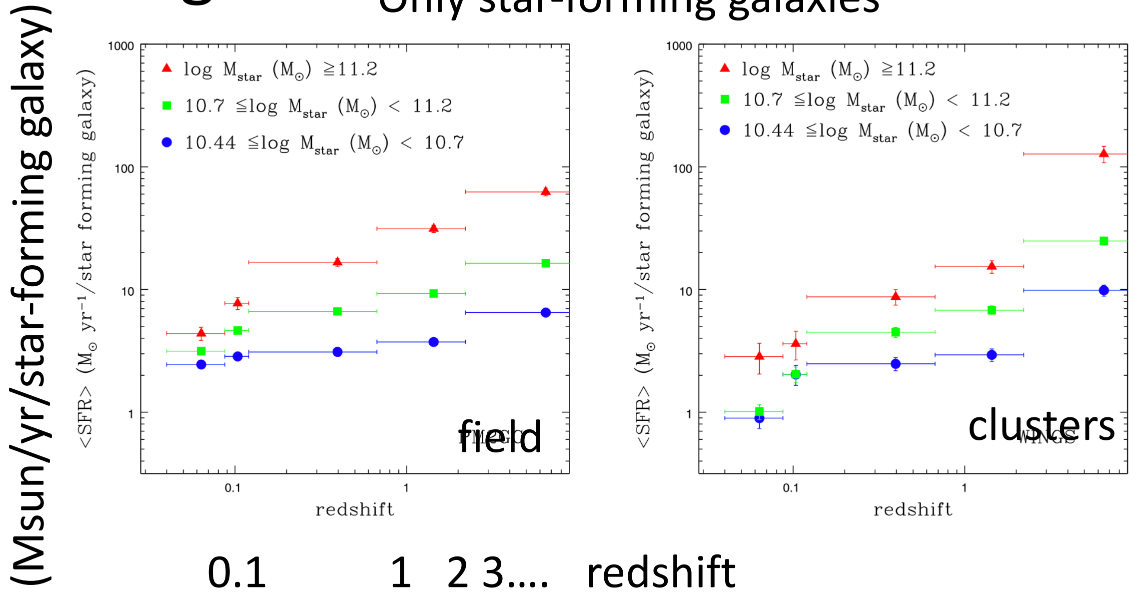


Calvi+ 2013

STAR FORMATION HISTORY
from full spectral fitting

The average star formation history of a galaxy changes with galaxy mass, and at a given mass changes from clusters to field: the decline is steeper in clusters –also for still star-forming galaxies today (and does not depend on galaxy morphology – ask me if interested)

Only star-forming galaxies



Guglielmo+ 2015 (SINOPSIS code, Fritz+)

The decline of the cosmic SFRD is due to:

1. The quenching of a fraction of galaxies
2. The decline with time of the SFR of star-forming galaxies

Between z~1.5 and z=0:

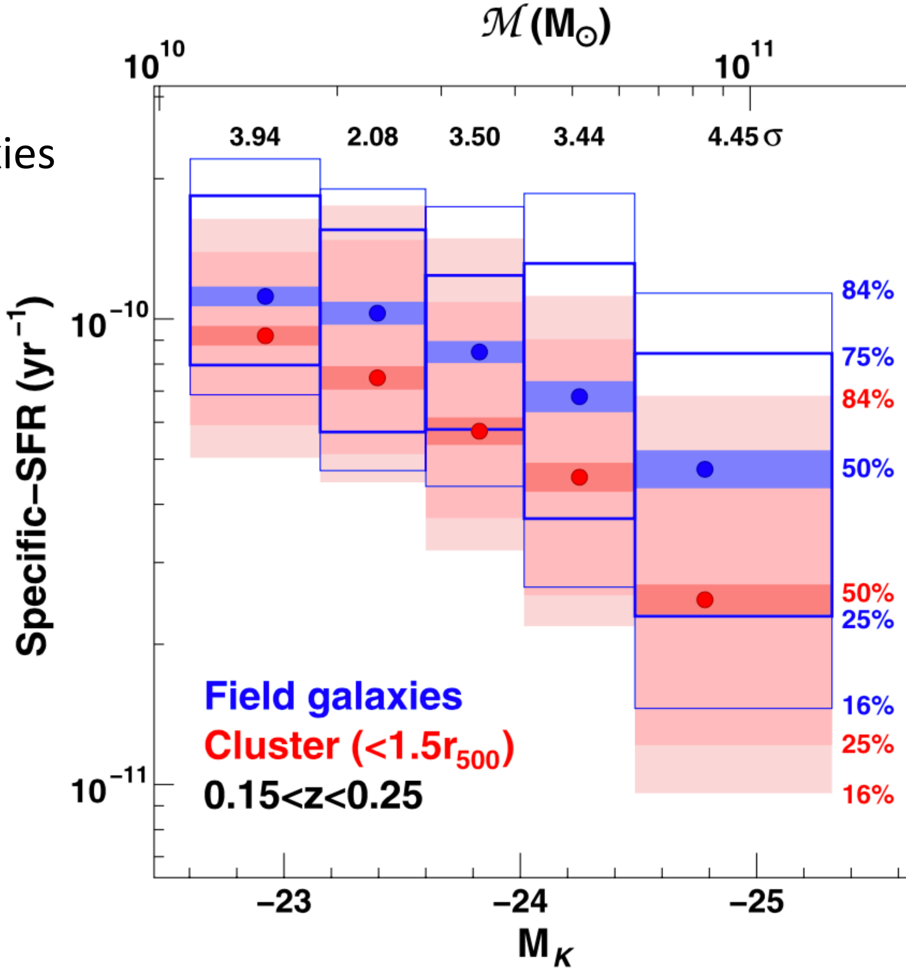
In the general field, the relative contribution of 1. and 2. is ~50%

For galaxies in clusters today, the contribution of 1. and 2. is 75% and 25%, respectively

STAR FORMATION
SLOW QUENCHING IN CLUSTERS

A significant population of slowly-quenching (>1 Gyr) galaxies in clusters

Star-forming galaxies



Haines+ 2013, LOCUSS

The SFR-mass relation in clusters ≠ from the field: a population of star-forming outliers below the main sequence – both at intermediate (Vulcani+ 2010) and low-z (Paccagnella+ 2016) (not at z~1.6? Nantais+ 2020) – the population of outliers varies with host halo mass also in the group regime (Wang+ 2018 GAMA)

This is a population of slowly-quenching galaxies

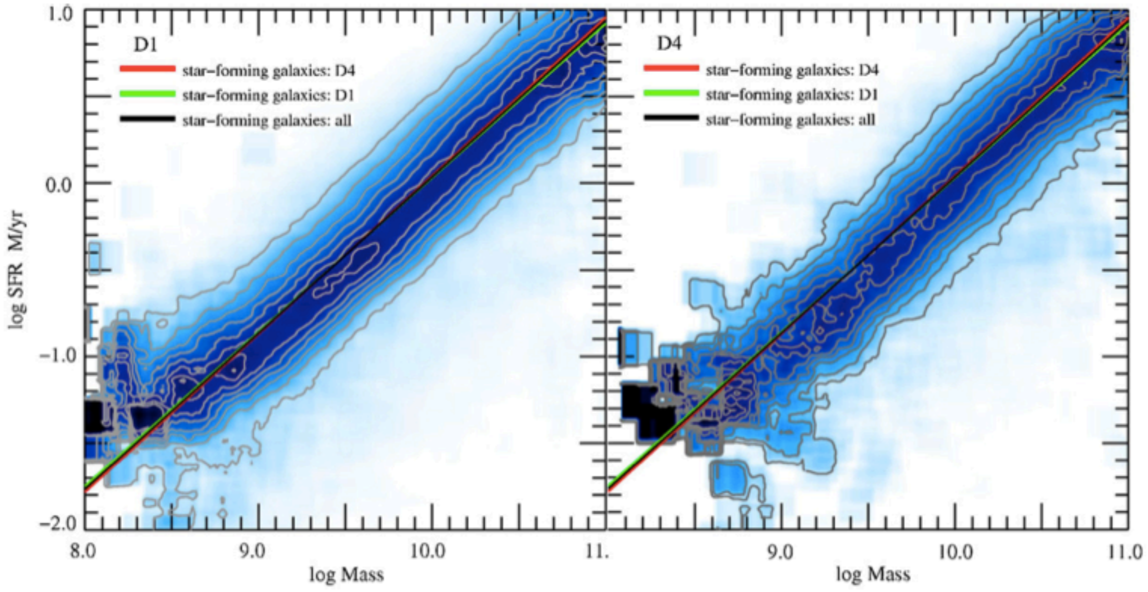
Their fraction relative to star-forming galaxies is high in the central regions of clusters – no galaxy-mass dependence

STAR FORMATION
SFR-Mass relation

Results shown in the previous slide seem at odd with some SDSS results

1. The SFR-mass relation is tight, there are no significant outliers below it, hence the transition from star-forming to passive must be very fast

2. The SFR-mass relation does not depend on “environment”



…but this is local density

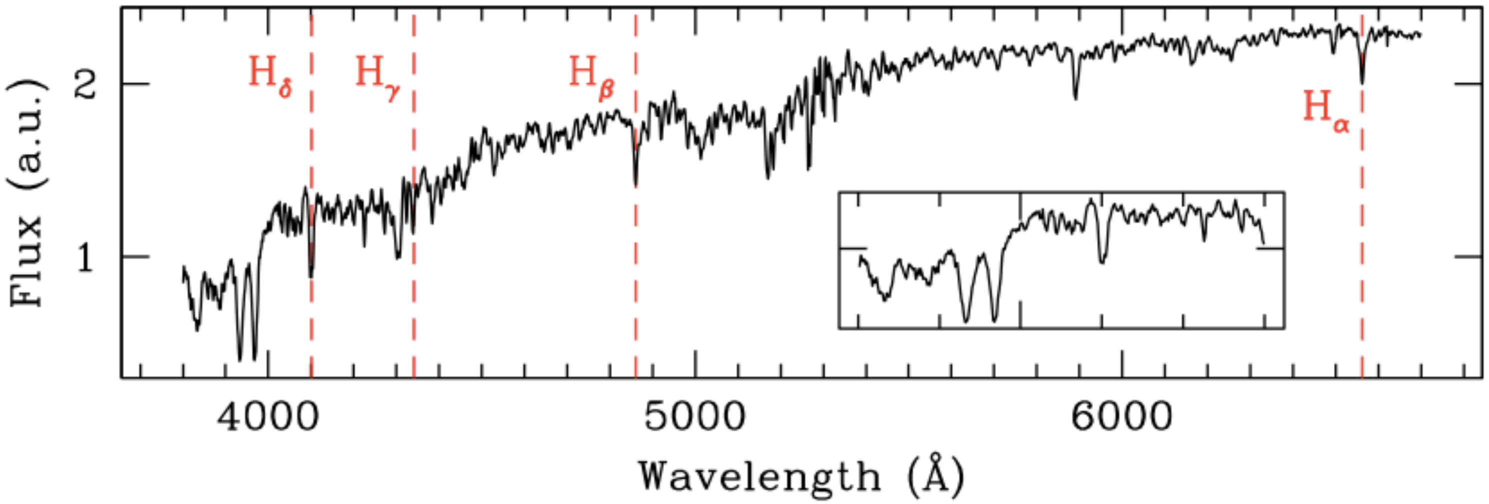
Peng+ 2010

STAR FORMATION
FAST QUENCHING IN CLUSTERS

k+a (E+A, Post-StarBurst (PSB)…)

Arguably, the most evident and robust examples of galaxies that have recently been quenched (Dressler & Gunn 1982)

SF shut-off during the last Gyr, on a short timescale (<~10^8 yr)



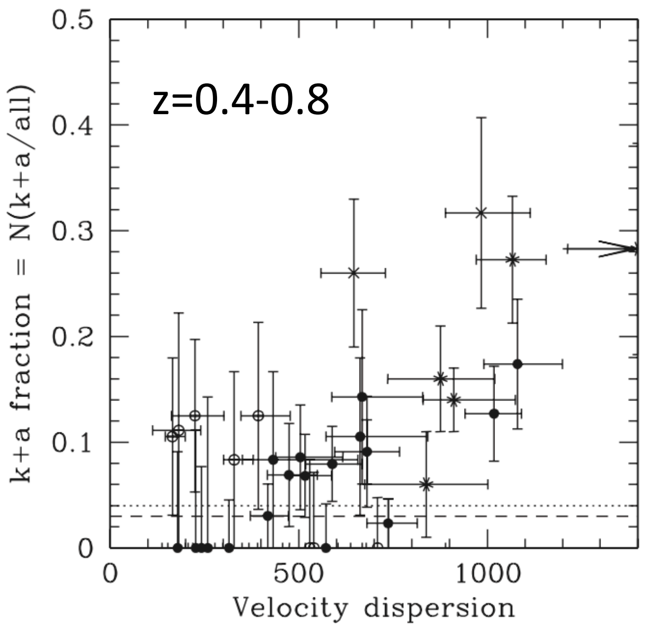
k+a (E+A, Post-StarBurst (PSB)…)

K+a spectra proportionally much more common in clusters than in the field – at all redshifts

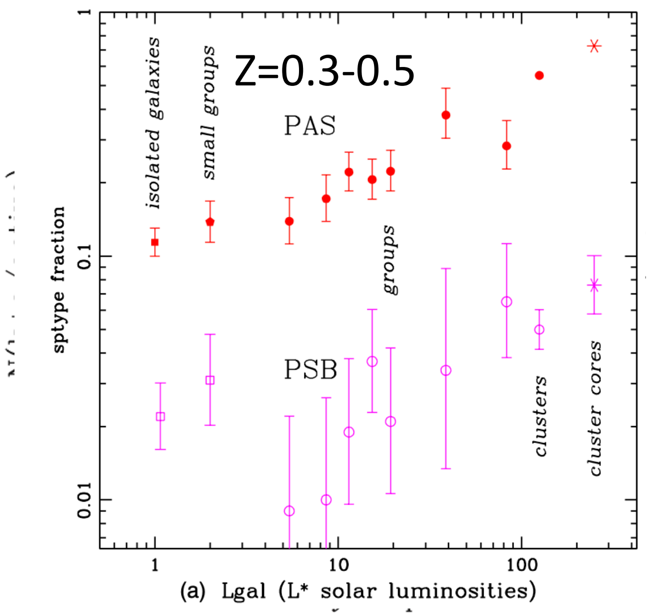
K+a phenomenon related to ram pressure stripping in clusters (int. and low-z), and often to mergers in the field (low-z)

To keep in mind: different processes can give origin to similar spectra

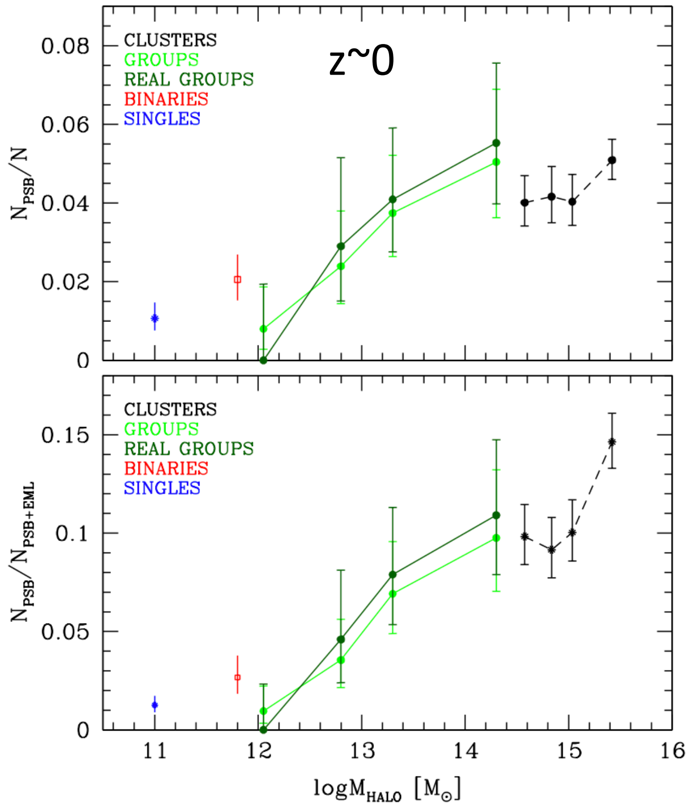
(At high-z, PSB spectra in galaxies that have just stopped their first and major SF episode – massive quiescent galaxies at z~3 are PSBs))



Poggianti+ 2009, EDisCS



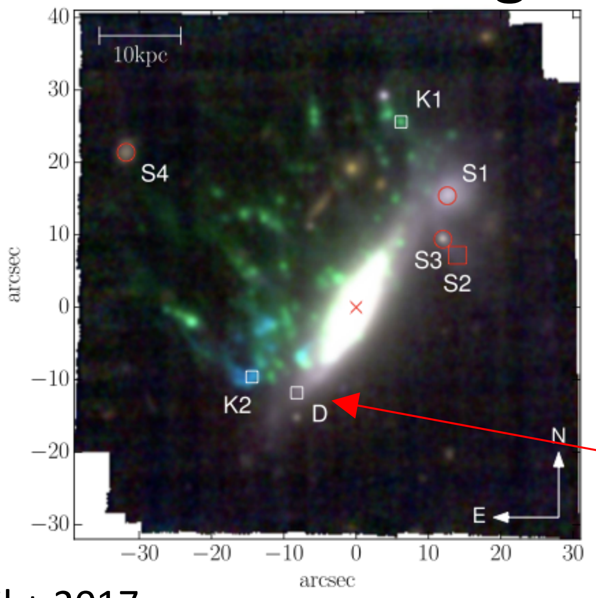
Dressler+ 2013, ICBS



Paccagnella+ 2019, WINGS+PM2GC(MGC)

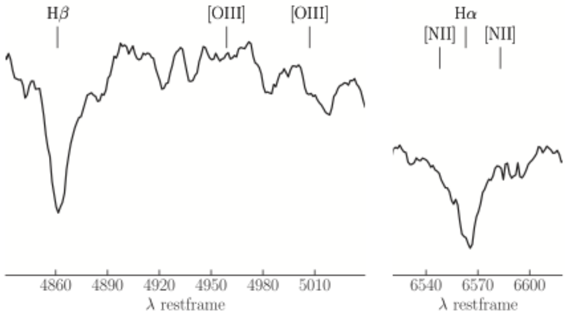
STAR FORMATION

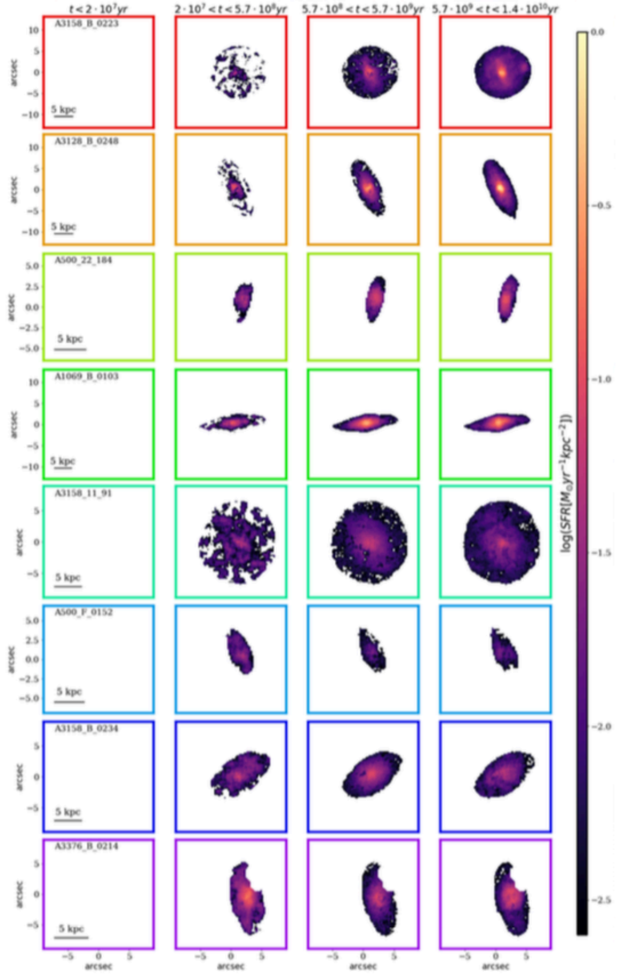
Integral-field studies see the formation of k+a galaxies while it is happening



Gullieuszik+ 2017

"Local post-starburst" signature:
outer regions of disks recently stripped





Post-starburst spirals, with strong Balmer absorption and no emission lines – outside-in quenching

typically located between 0.5 and 1 cluster virial radii (r200)

Vulcani et al. 2020 GASP, see also Owers+ 2019 SAMI

STAR FORMATION
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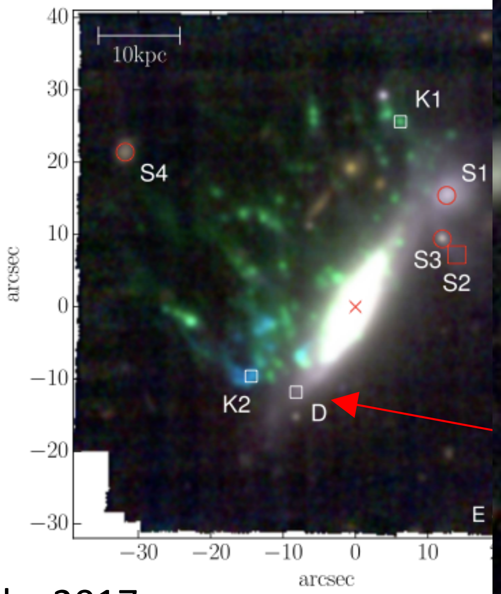

Gullieuszik+ 2017

d

Post-starbur
emission lin

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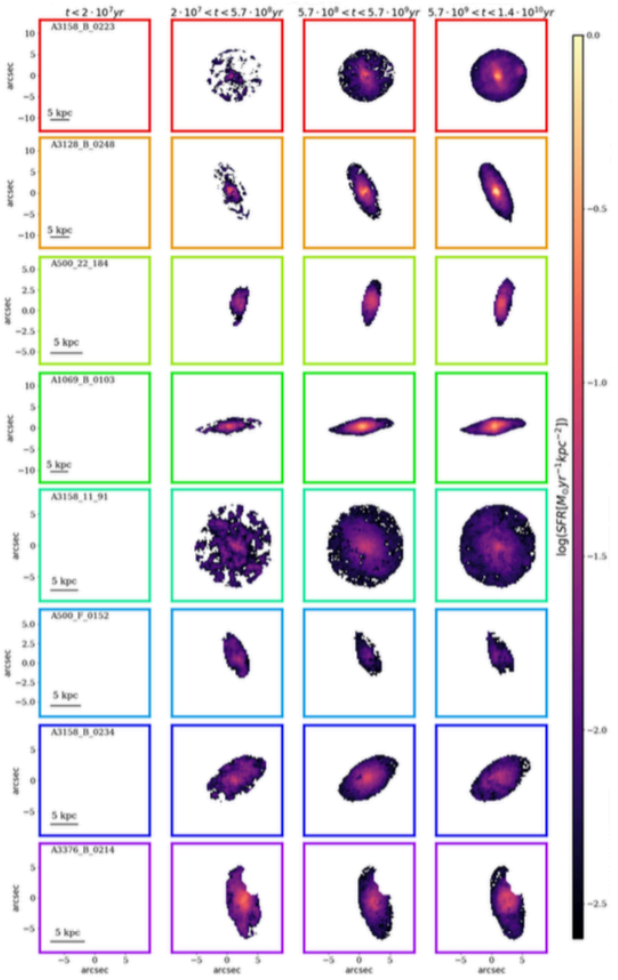

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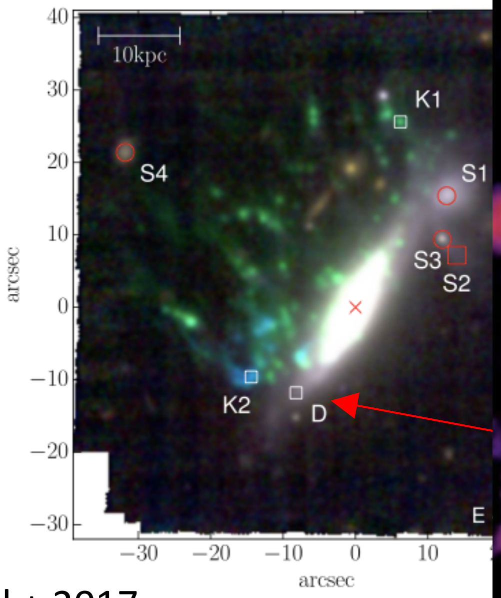

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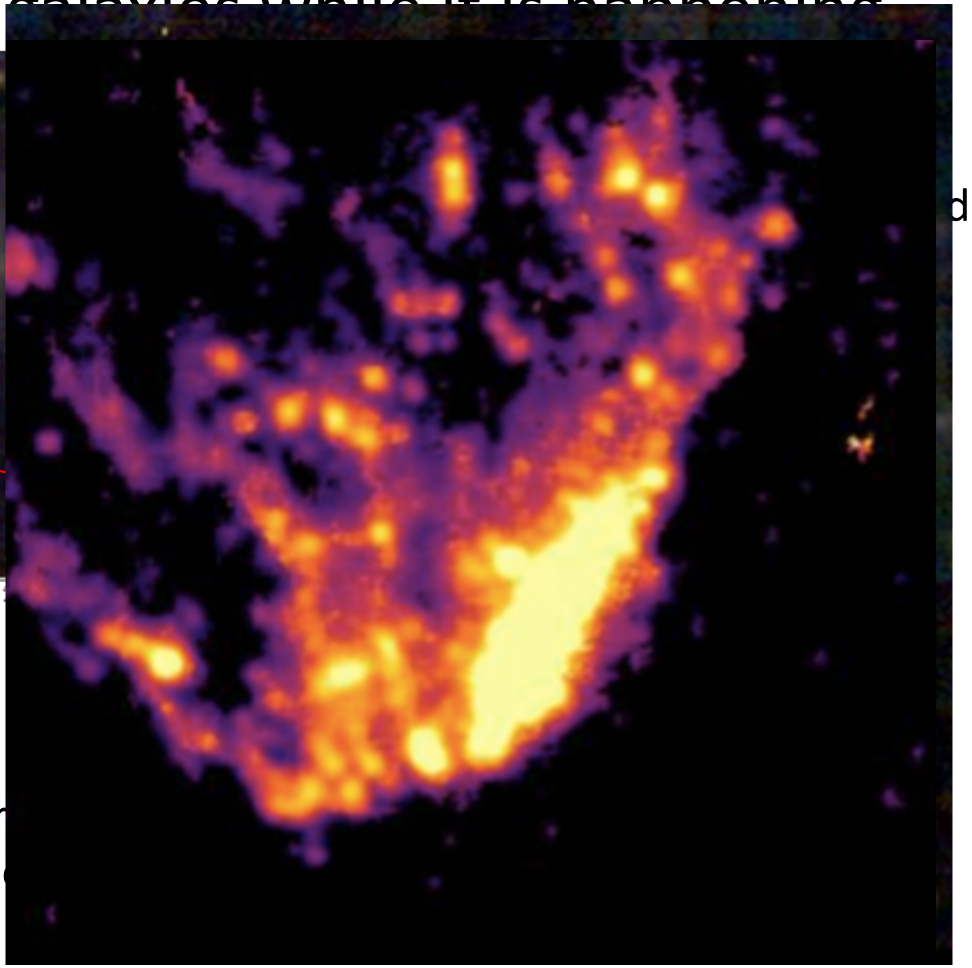

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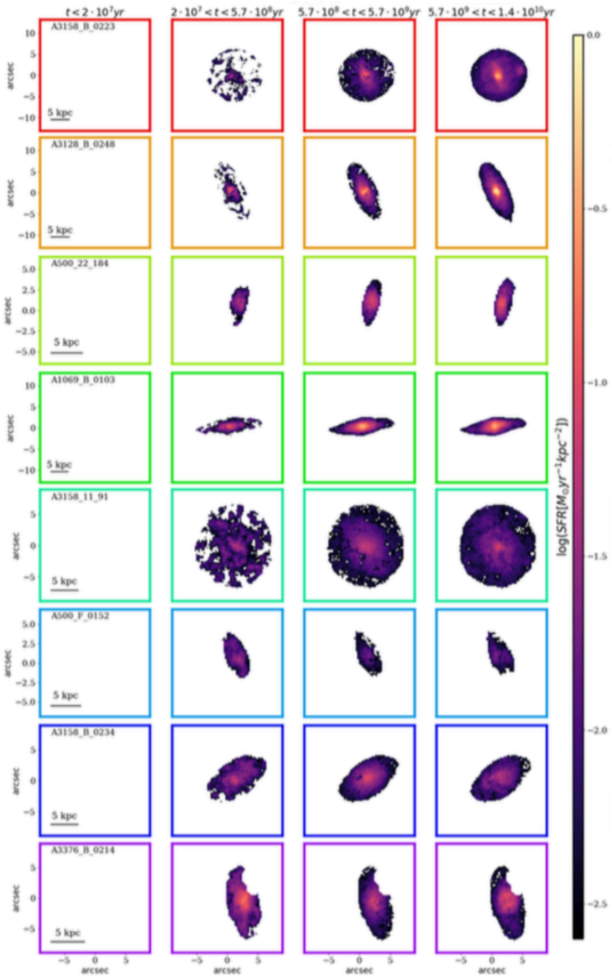

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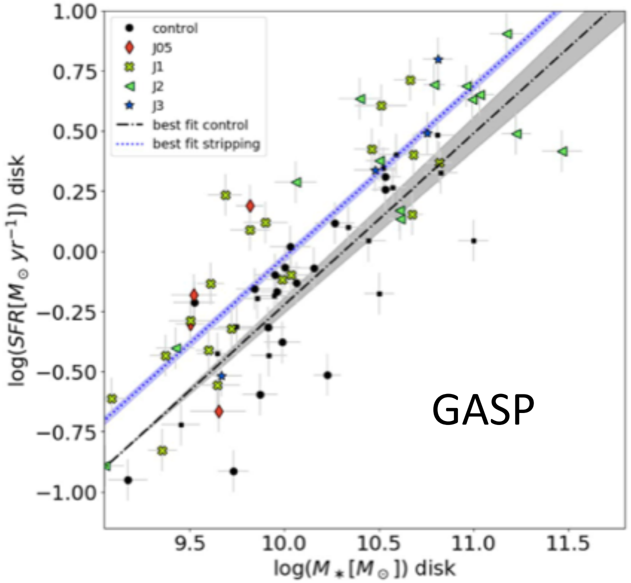
STAR FORMATION
Quenching timescales

So, both slowly quenching and fast quenching galaxies in clusters: different mechanisms?

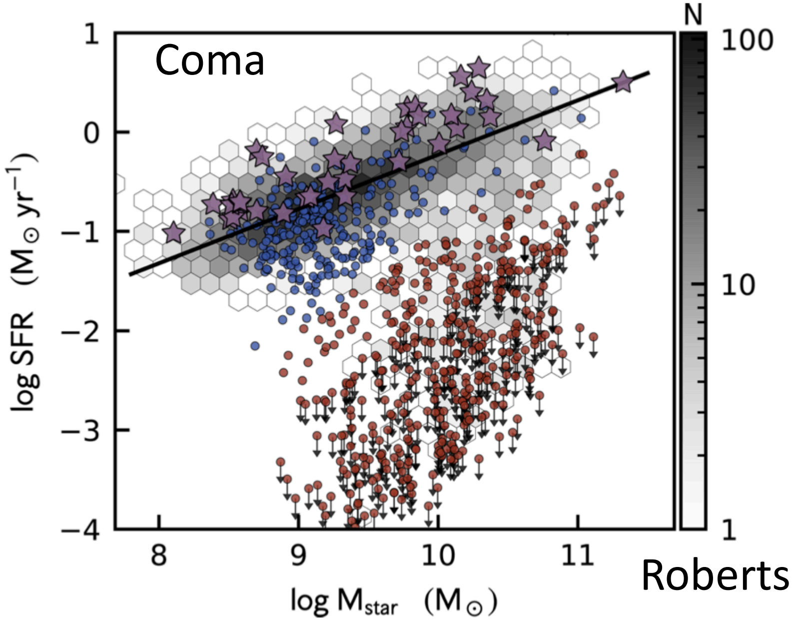
Is there overlap between k+a's, SFR-mass outliers and galaxies with "tails" (RPS)?
Nope:

Not necessarily -
The power of spatially resolved studies!

-- by selection, k+a's are non-star-forming
-- RPS galaxies are on or above (0.2dex excess) the SFR-mass relation
-- SFR-mass outliers are not, by definition



Vulcani+ 2018



Roberts & Parker 2020

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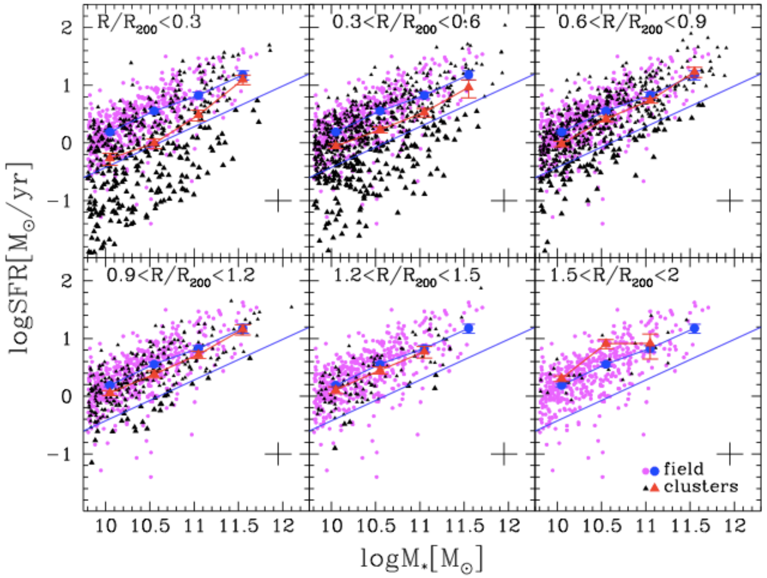
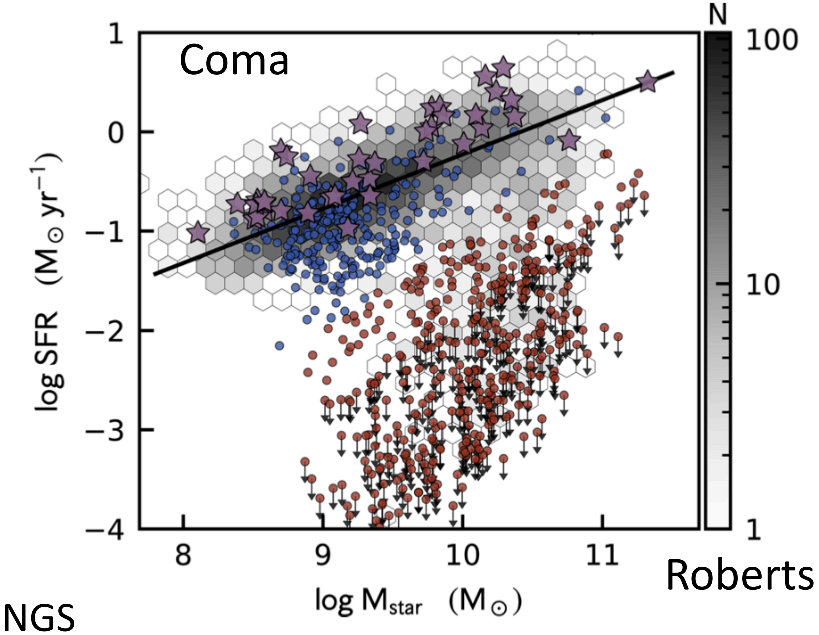
Vulcani+



Paccagnella+ 2016 - WINGS



Roberts & Parker 2020

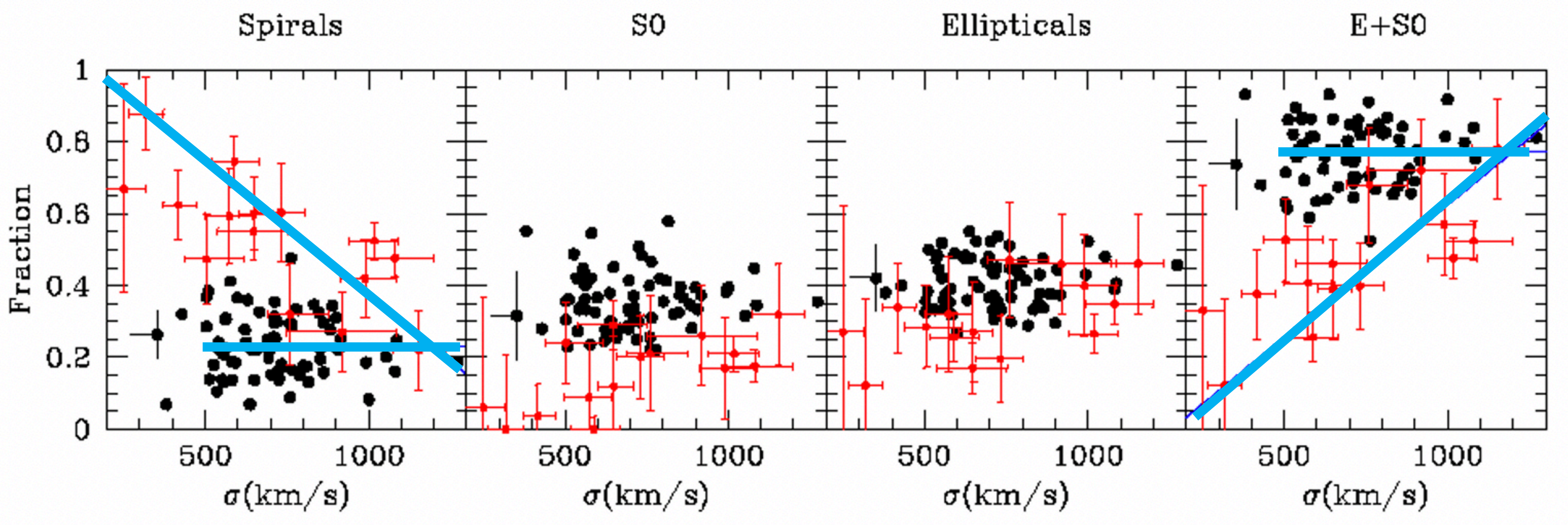
CORRESPONDANCE BETWEEN QUENCHING OF STAR FORMATION AND MORPHOLOGICAL EVOLUTION

Red: z=0.4-0.8

Black z=0

Light blue: star-forming fraction

Evolution of the star-forming fraction compared with the evolution of the morphological fractions



Cluster velocity dispersion (halo mass ~ sigma^3)

Poggianti+ 2009, EDisCS+WINGS

Gas Stripping Phenomena in galaxies

PI Bianca Poggianti

MUSE ESO Large Programme + ALMA/APEX (CO), JVLA/MeerKAT/ATCA (HI), UVIT@ASTROSAT (UV), HST, X-Shooter

where, how, why is gas removed from galaxies?
what is the effect on the galaxy SFH?

114 galaxies at z=0.04-0.07, with masses 10^9-10^11.5 Msun, in clusters, groups, filaments and isolated

Selected to have unilateral debris/tails in B-band images + control sample

Spatial resolution ~1kpc (seeing)
Sky coverage out to 7 Re on average

http://web.oapd.inaf.it/gasp/

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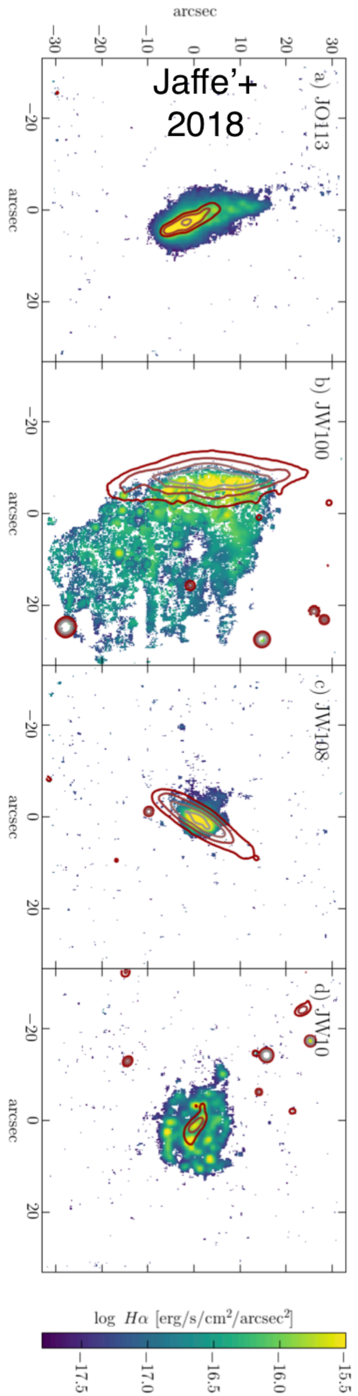
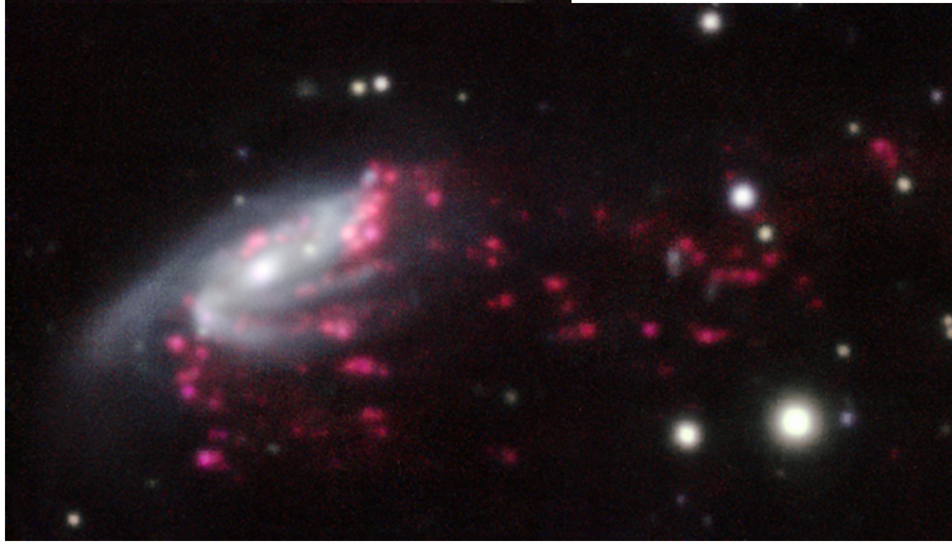


The key is the relation *SF-gas*

While multi-wavelength data in addition to optical spectroscopy is needed to probe HI (Ramatsoku+ 2019, 2020, Deb+ 2020) or molecular gas (Moretti+ 2018, 2020a,b), IFS can tell us (almost) everything about both ionized gas and stars.

From MOS to IFU: from a description of populations, to understanding the physics of processes at work.

Ram pressure stripping is the dominant mechanism today for turning star-forming galaxies falling into clusters into passive systems. MUSE has been unveiling how.



For how MUSE data can help study also other mechanisms (strangulation, accretion, cosmic web enhancement/stripping…), see Vulcani+ 2021 (and poster) and refs therein, and George+ 2019

Talks and posters from: Bellhouse (live talk on 13/4, unwinding spiral arms), Mingozzi (link AGN-RPS, outflows), Vulcani (groups, filaments, isolated galaxies), Gullieuszik (stars forming in the tails of stripped gas), Tomicic (diffuse ionized gas).

IF YOU WANT TO HEAR ABOUT GAS METALLICITIES ASK ME DURING QUESTIONS

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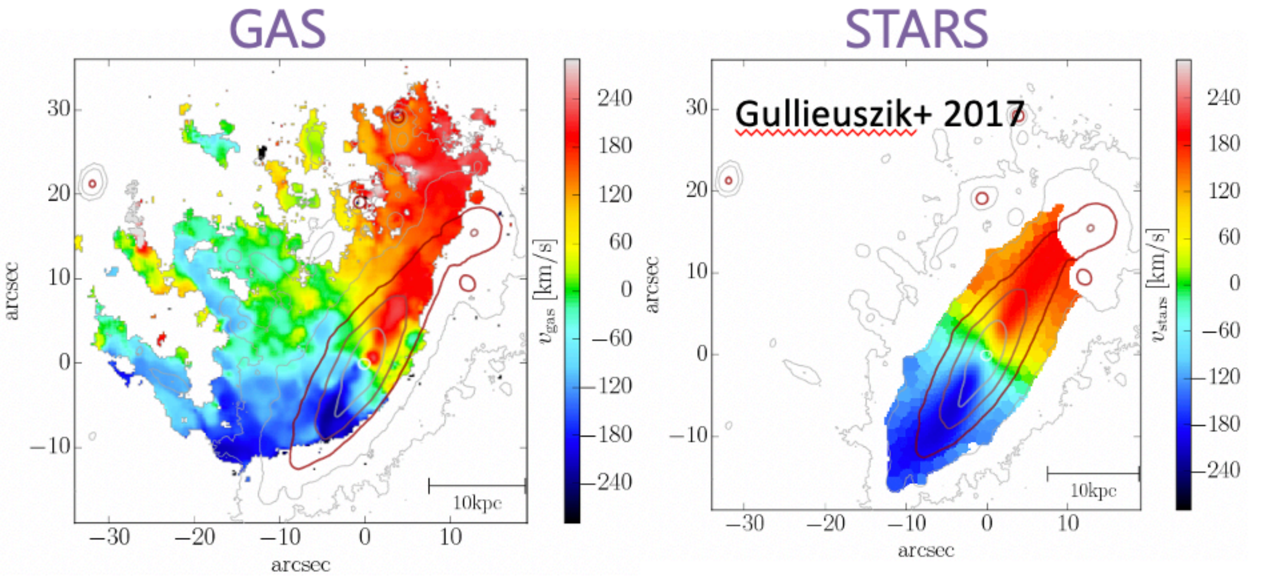

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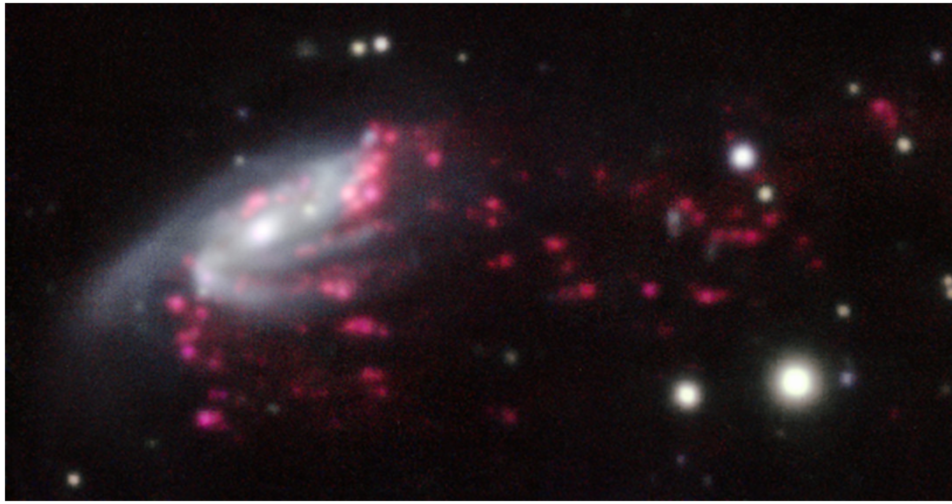

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