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GAS, STAR FORMATION AND QUENCHING IN CLUSTERS (mostly) and GROUPS

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Galaxy evolution Star formation Enrichment with metals Gas in/outflows Gas and stellar kinematics Role of environment Quenching AGN triggering mechanisms, and feedback



IN GALAXY CLUSTERS, BOTH FAST-QUENCHING AND SLOW-QUENCHING?



Clusters are the realm of post-starburst galaxies (Dressler & Gunn 1982, Couch & Sharples 1987)

See also Wilkinson's talk

Paccagnella+ 2019



In clusters, the median SFR-mass relation is shifted to lower SFRs – large population of outliers below the main sequence within 0.6R200

Paccagnella+16, Vulcani+10

RAM PRESSURE STRIPPING

Observational evidence for gas stripping in clusters from:



HI - Kenney, van Gorkom and Vollmer 2004, Virgo cluster HI UV imaging H-alpha narrow band imaging X-ray IFU spectroscopyand even optical images



Halpha imaging, Yagi + 2010, 2017, Coma cluster

"JELLYFISH GALAXIES":

"Galaxies with clearly distorted images with optical data resolving multiple filaments offset asymmetrically from the galaxy" [Smith et al., 2010, UV asymmetry]



VCC121 (IC3418) in the Virgo cluster

> Hester+2010, Fumagalli +2011, Kenney +2014





GASP cluster parent sample from OMEGAWINGS survey= OmegaCAM@VST + AAOmega@AAT and GASP group/field sample from PM2GC survey, based on MGC



120h with MUSE@VLT (+ALMA+APEX+JVLA+UVIT) observations completed in 2018 94 gas stripping candidates (clusters/groups/field) 20 galaxies as control sample z=0.04-0.07

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

Selected to have unilateral debris/tails in optical images

Poggianti et al. (2017) ApJ, 844, 49



ESO PRESS RELEASE 1725

GASP CHARACTERISTICS



 SELECTION OF TARGETS: stripping candidates + control

All stripping stages, from prestripping (control), to stripping, poststripping all the way to fully-stripped post-starburst

- Area coverage FOV(1'X1')=60X60kpc, 4-10 Re
- Galaxy stellar mass range
 10^9 10^11.5
- Host halo mass range 10^11 - 10^15.5



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The stellar component is not disturbed, regular stellar kinematics: gas-only stripping Stripped gas maintains coherent rotation for several kpc downstream



RAM PRESSURE STRIPPING AFFECTING THE STAR FORMATION ACTIVITY OF GALAXIES:

Indirectly (through an AGN)

Directly: SF in tails SF in disks Quenching

AGN TRIGGERING MECHANISMS AND FEEDBACK: **RAM PRESSURE-AGN CONNECTION**

7 galaxies with H α tentacles longer than the diameter of the stellar disk and stellar masses 4 * 10¹⁰ - 3 * 10¹¹ Msun

5 AGN (Seyfert2) and 1 LINER

---- suggesting that ram-pressure stripping is triggering the AGN

ISM interacting with non-rotating ICM loses angular momentum

oblique shocks in a disk flared by magnetic field



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Ram-pressure feeding of supermassive black holes

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Poggianti+ 2017b

AGN TRIGGERING MECHANISMS AND FEEDBACK: AGN and their OUTFLOWS in JELLYFISH GALAXIES

1) Comparison with AGN, shock and HII models using combination of line ratios confirms AGN.

2) Nuclear iron coronal lines and extended (>10kpc) AGN-ionized regions in some of the galaxies.

3) AGN outflows in 4/6, extending out to 1.5-2.5kpc, with outflow velocities 250-550km/s





Radovich+ submitted

AGN FEEDBACK: STAR FORMATION QUENCHING IN THE CENTRAL REGION OF



A JELLYFISH GALAXY (MUSE+ALMA+UVIT)

A central 8kpc-long region depleted of molecular gas and of star formation (central UV hole) – this region is filled with gas ionized by the AGN



Å CO ALM7



George+ submitted

STAR FORMATION IN STRIPPED TAILS



IFU data allow us to assess gas ionization mechanism from multiple line ratios.

See also Fossati+ 2019.

SF evidence also from UV+Halpha (Boselli+ 2018, Abramson+ 2011), UV-only of post-SB (Hester+ 2010, Yoshida+ 2008), and UV-only or Halphaonly surveys (Smith+ 2010, Yagi and Gavazzi's works)



ESO137-001, Sun et al. 2010, Fumagalli+ 14, Fossati et al. 2016, in Abell 3627



SOS 114372, Merluzzi+2013, 2016, Shapley supercluster

STAR FORMATION IN THE TAILS?

Not always?

NGC 4569 in Virgo Boselli et al. 2016



STAR FORMATION IN THE TAILS

16 galaxies with long extraplanar Halpha tails (20-100 kpc long): the dominant ionization mechanism of gas in the tails (between 65% and 95%) is photonization by young massive stars.

The SF takes place in Halpha bright, dynamically cold (median σ =27 km/s) starforming clumps forming in-situ in the tails.

Clump Halpha luminosities typical of "giant HII regions" (eg Carina Nebula) and "supergiant HII regions" (eg 30Dor in LMC). Median 5X 10^38 erg/s.



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Median stellar mass 3X10^6Msun

Fate of these stellar clumps unknown: Are we witnessing the formation of UltraCompact Dwarf Galaxies / Globular Clusters?

SF in stripped tails contributes to ICL !

DIFFUSE Halpha EMISSION (DIG)

In tails, 50% of emission is Halpha clumps and 50% is DIG. From BPT, also the DIG in the tails is mostly due to photoionization by young massive stars (>80% in most galaxies, but a few exceptions), but also "LINERlike" emission component from [OI] line: thermal heating from ICM?



Diffuse emission due to lower luminosity HII regions, or to photon leakage from SFing clumps? Average escape fraction is 18% (ranging between 6% and 46%)



The SFR in the tails is typically a few percent (2-5%), and up to 20%, of the total SFR.

Poggianti+ 2019

STAR FORMATION AND ITS RELATION WITH GAS: MOLECULAR GAS

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Large molecular gas masses in the tails, and in the disks – 8 galaxies published so far with low spatial resolution, large beam



In the disk of 4 GASP galaxies (APEX), molecolar gas mass ~ 10% of stellar mass as in normal spirals – all the molecular gas in the tails is extra! (relevant for Kodama's, Noble's and Dannerbauer's high-z results)

Jachym+ 2014, 2017, Verdugo+ 2015, Lee+ 2018 and 4 galaxies in Moretti+ 2018

STAR FORMATION AND ITS RELATION WITH GAS: STAR FORMATION EFFICIENCY



Region A Region B Region C Region D

Region E Region F

Region G Region H

Region I

3.0

HI GAS

Generally, HI tails are present in jellyfish galaxies with Halpha tails – but HI and Halpha can be very different....





JVLA C-array



Ramatsoku+ 2019

Ramatsoku+ in prep.

Deb, Verheijen+ in prep.



Ramatsoku+ 2019, and in prep.

HI already depleted (for galaxy mass and surface brightness) – excess of SF for the HI content



(enhanced) STAR FORMATION IN THE DISK



Galaxies undergoing stripping show a systematic enhancement of the *disk* SFR at fixed disk galaxy stellar mass (0.2dex) == RPS can moderately enhance the SFR in the disk before quenching

Vulcani+ 2018c

QUENCHING: POST-STARBURST SIGNATURES





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Gullieuszik+ 2017

QUENCHING: POST-STARBURST SIGNATURES



In SAMI, 17 galaxies in clusters: a mix of local post-starburst (with SF in their centers) and global ones

All within 0.6R200, outside-in quenching in galaxies at first infall

Owers+ 2019

Post-SB much more common in clusters than in lower density regions



POST-STARBURST SIGNATURES: NO (ionized) GAS and NO SF LEFT

Oh, yes!





Can ram pressure halt the SF completely?



Post-starburst spirals, with strong Balmer absorption throughout the disk – SF quenching outside-in – typically located between 0.5 and 1 r200

Santorelli 2018, Vulcani+ in prep.





JELLYFISH GALAXIES ON FIRST INFALL AND RADIAL ORBITS

ENRICHMENT WITH METALS



Metallicity gradients in disks and tails – for both control galaxies and jellyfish galaxies



Franchetto+ in prep.

Bellhouse+ 2019



ENVIRONMENT outside clusters: GROUPS and ISOLATED GALAXIES





Evidence for gas accretion in an isolated spiral

Vulcani+ 2018a



A galaxy group with multiple processes at work:

ram pressure, strangulation, merger...and cosmic web?

Vulcani+ 2018b

CONCLUSIONS



- With IFS we are studying the ionized gas and stellar content of galaxies undergoing gas removal and normal galaxies in clusters, groups and the field
- Ram pressure-AGN connection in clusters
- Star formation takes place in stripped tails: the star formation process in such extreme environments is characterized by massive, luminous star-forming clumps whose physical properties seem to follow scaling relations similar to clumps in disks
- Multi-wavelength observations are starting to unveil the connection between the various gas phases (molecular, neutral, ionized gas) and the star formation (activity and quenching)
- In groups and low mass haloes, a variety of physical processes that can be studied with IFS: ram pressure, strangulation, mergers, cosmic web and gas accretion