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

Bianca Poggianti

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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

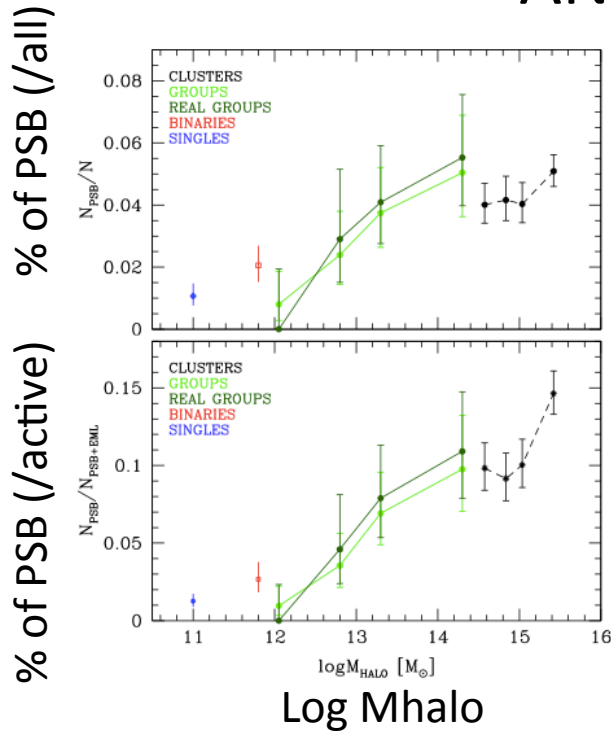


IN GALAXY CLUSTERS, BOTH FAST-QUENCHING AND SLOW-QUENCHING?

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

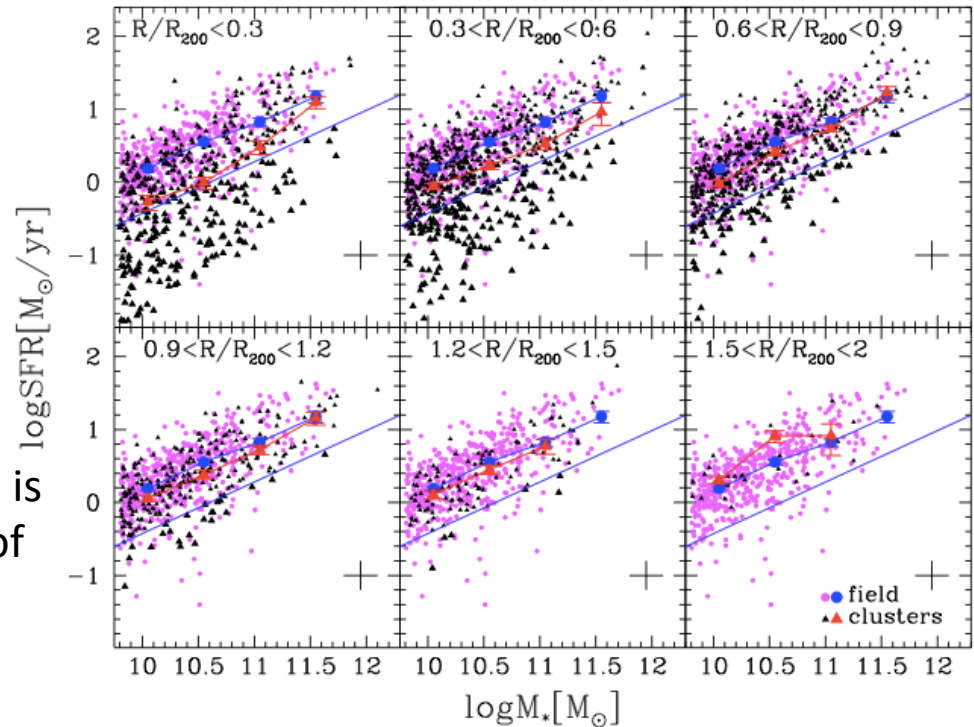
See also Wilkinson's talk

Paccagnella+ 2019



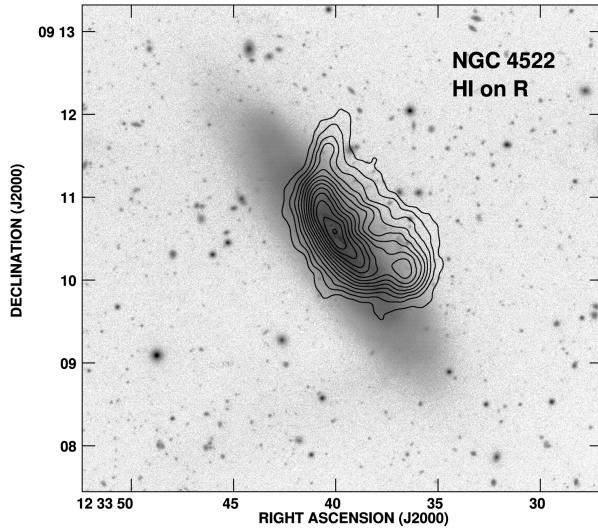
In clusters, the median SFR-mass relation is shifted to lower SFRs – large population of outliers below the main sequence within $0.6R_{200}$

Paccagnella+16, Vulcani+10



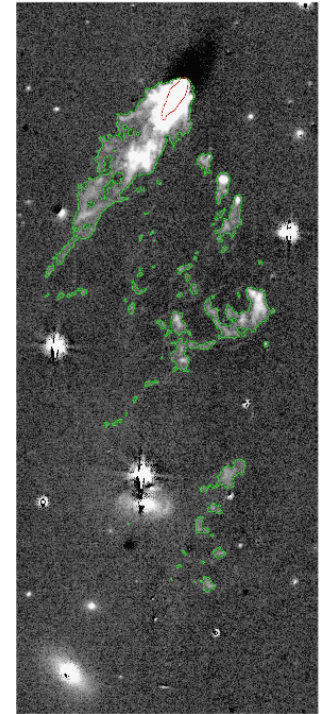
RAM PRESSURE STRIPPING

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 spectroscopy
.....and even optical images



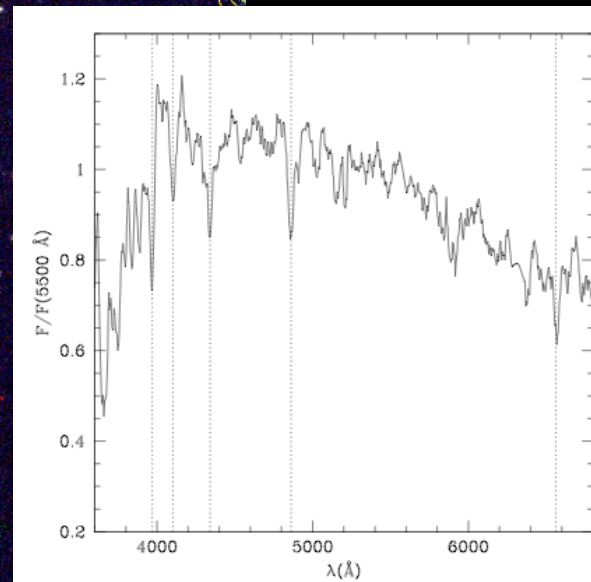
Halpha imaging, Yagi
+ 2010, 2017, Coma
cluster

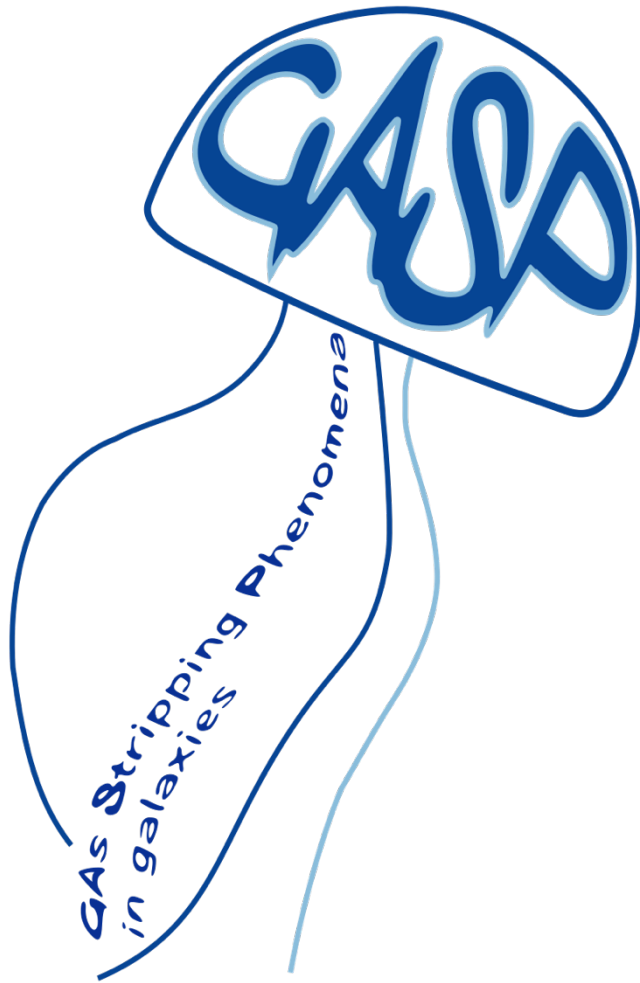
“JELLYFISH GALAXIES”:

“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





Gas Stripping Phenomena with MUSE

ESO Large Programme

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

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A. Omizzolo

M. Owers

R. Paladino

M. Radovich

M. Ramatsoku

P. Serra

S. Tonnesen

J. Van Gorkom

M. Verheijen

B. Vulcani

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?

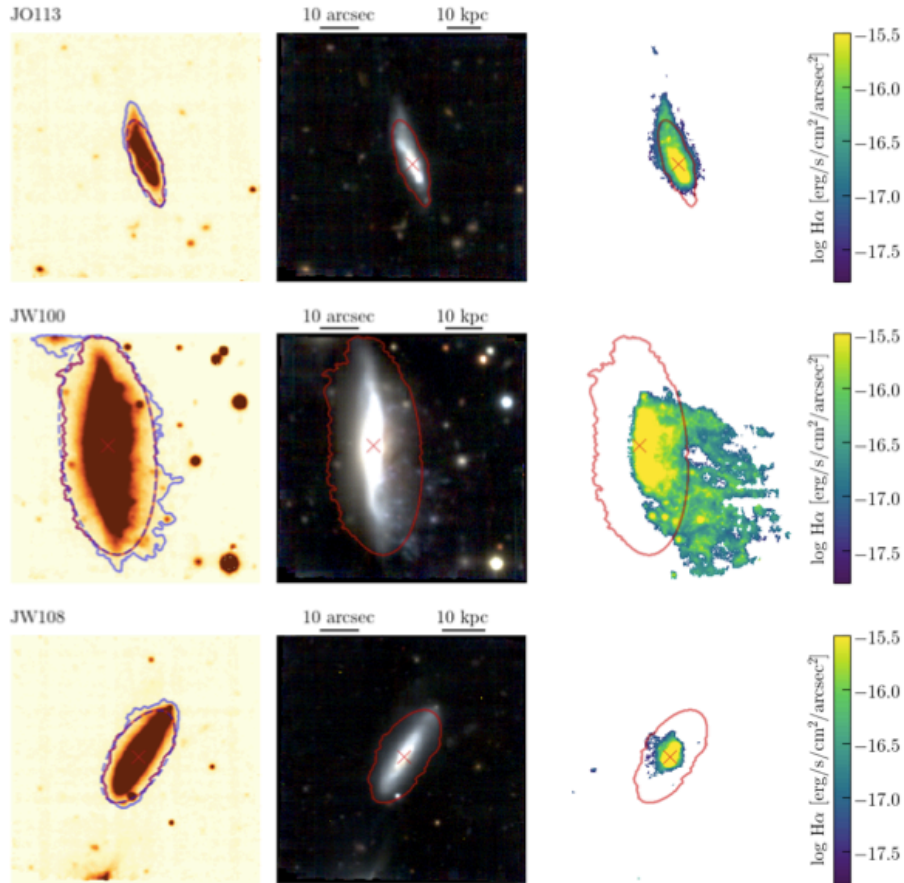
Selected to have unilateral debris/tails in optical images

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



ESO
PRESS
RELEASE
1725

GASP CHARACTERISTICS



- SELECTION OF TARGETS: stripping candidates + control

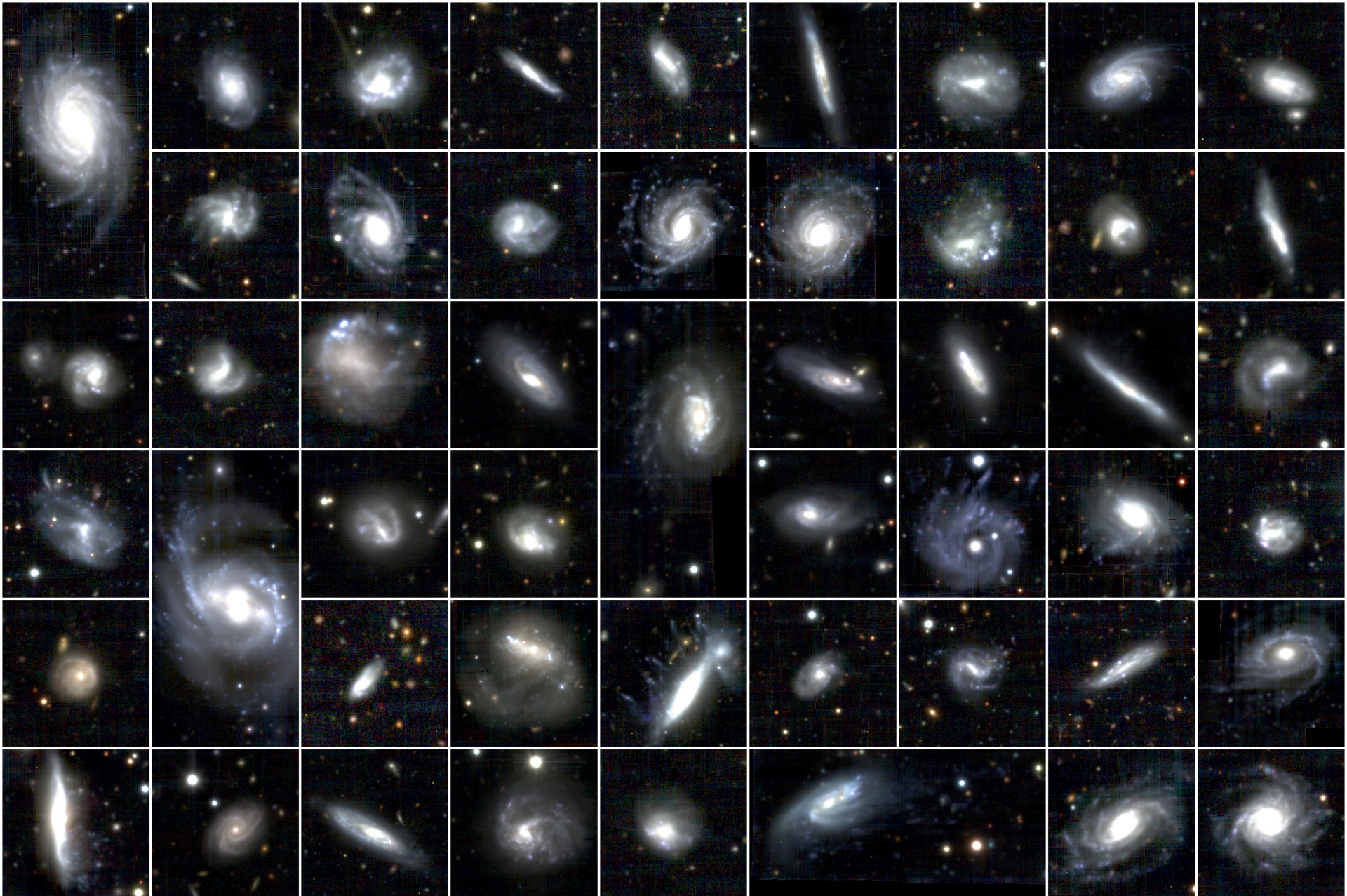
All stripping stages, from pre-stripping (control), to stripping, post-stripping all the way to fully-stripped post-starburst

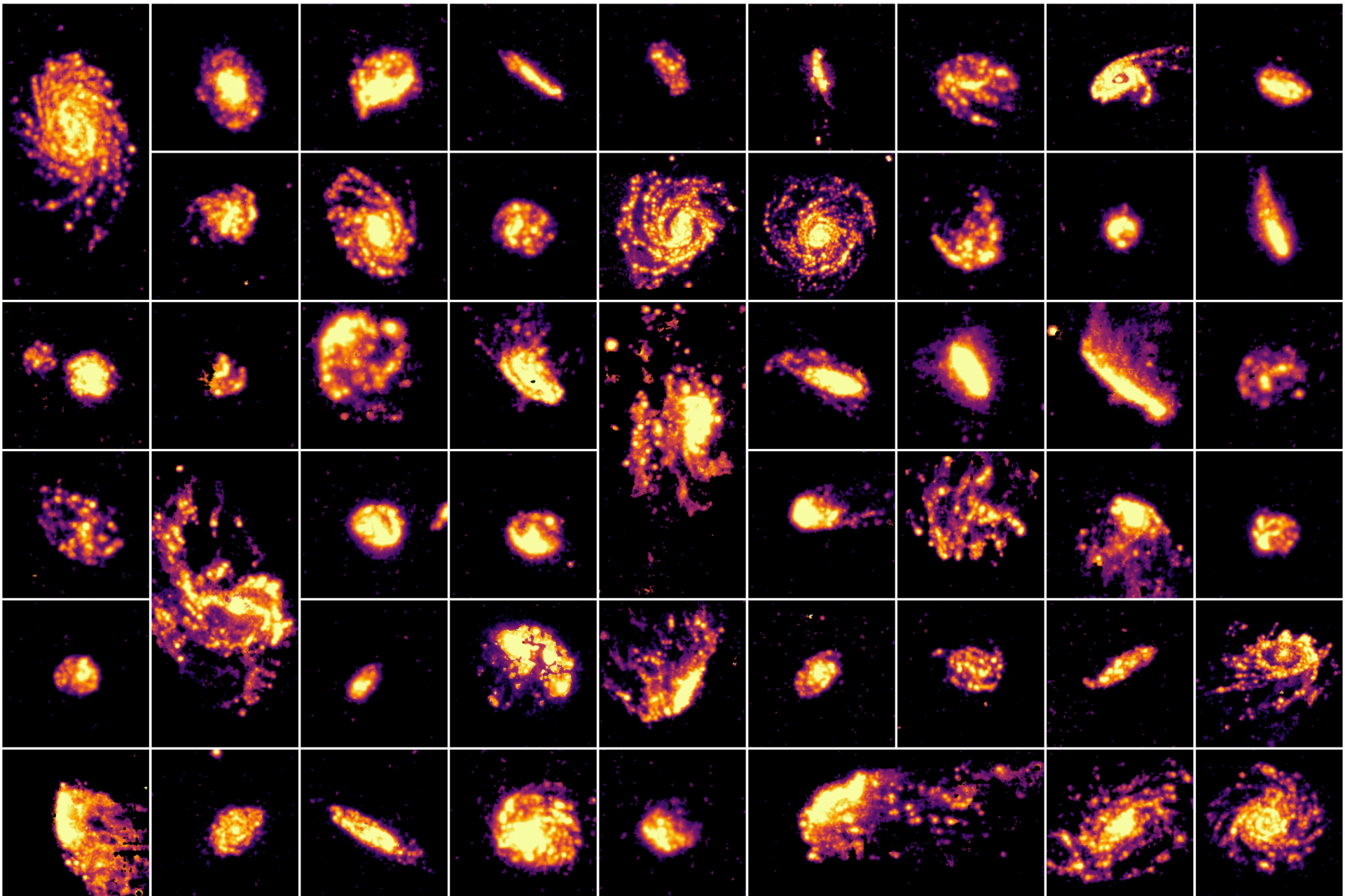
- Area coverage
FOV(1'X1')=60X60kpc, 4-10 Re

- Galaxy stellar mass range
 $10^9 - 10^{11.5}$

- Host halo mass range
 $10^{11} - 10^{15.5}$



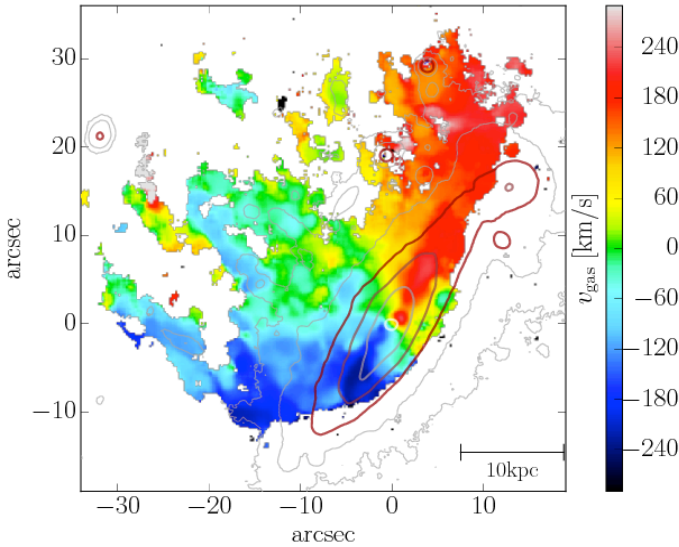




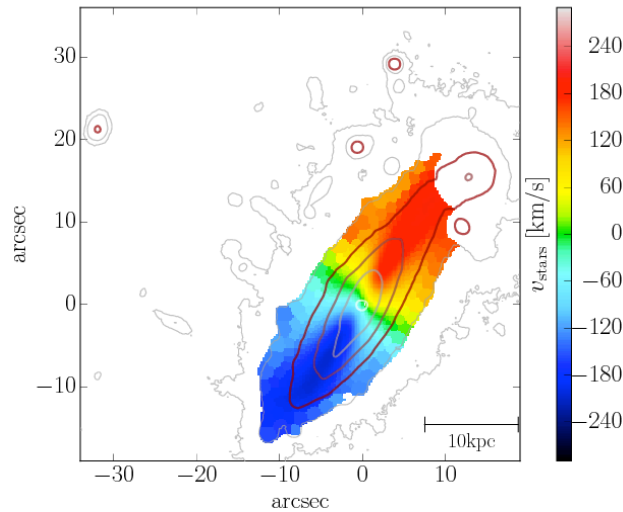
GAS and STELLAR KINEMATICS



GAS

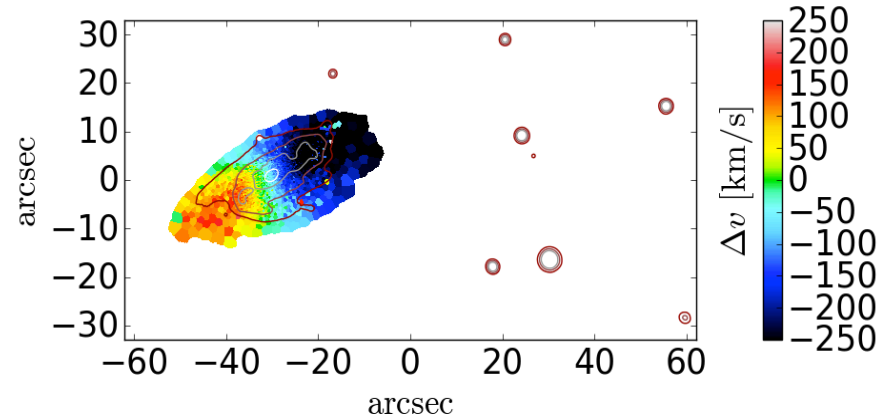
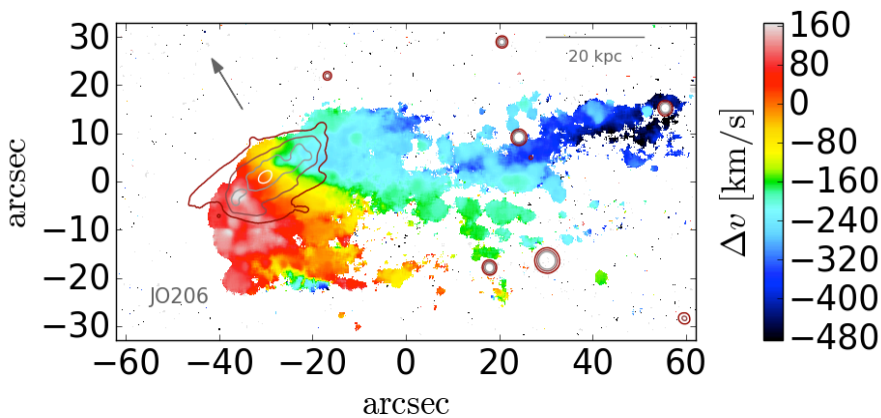


STARS



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)

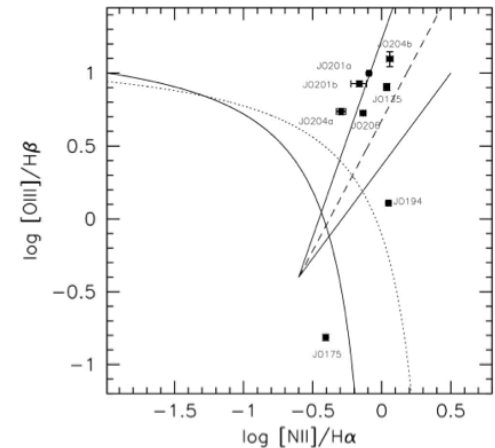
Directly: SF in tails
SF in disks
Quenching

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 $4 * 10^{10} - 3 * 10^{11} M_{\text{sun}}$

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

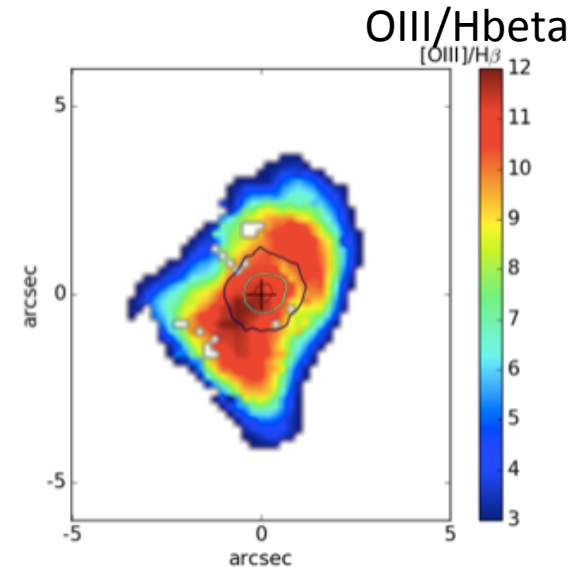
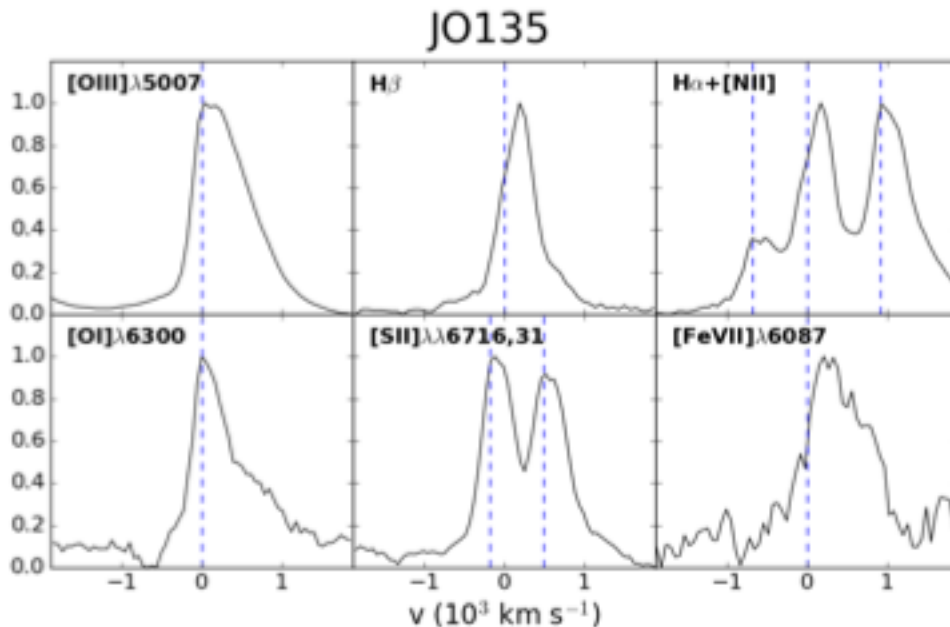
Poggianti+ 2017b

The image shows a screenshot of the Nature journal website. At the top, the 'nature' logo is displayed with the tagline 'International weekly journal of science'. Below the logo is a navigation bar with links for Home, News & Comment, Research, Careers & Jobs, Current Issue, Archive, Audio & Video, and For Authors. A secondary navigation bar shows 'Archive', 'Volume 548', 'Issue 7667', 'Letters', and 'Article'. The main content area features the article title 'Ram-pressure feeding of supermassive black holes' under the 'NATURE | LETTER' section. The authors listed are Bianca M. Poggianti, Yara L. Jaffé, Alessia Moretti, Marco Gullieuszik, Mario Radovich, Stephanie Tonnesen, Jacopo Fritz, Daniela Bettoni, Benedetta Vulcani, Giovanni Fasano, Callum Bellhouse, George Hau & Alessandro Omizzolo. Below the authors are links for 'Affiliations', 'Contributions', and 'Corresponding author'. At the bottom, the publication details are given: 'Nature 548, 304–309 (17 August 2017) | doi:10.1038/nature23462' and 'Received 26 April 2017 | Accepted 21 June 2017 | Published online 16 August 2017'.

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



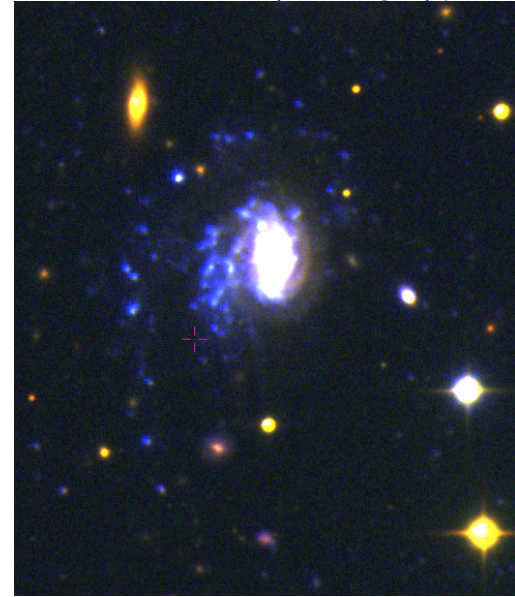
Radovich+ submitted



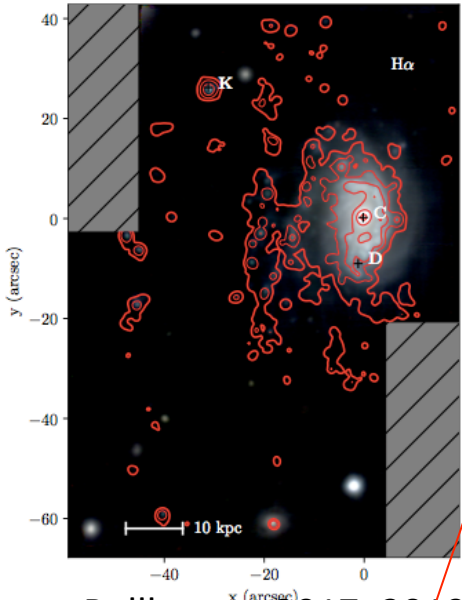
AGN FEEDBACK:

STAR FORMATION QUENCHING IN THE CENTRAL REGION OF A JELLYFISH GALAXY (MUSE+ALMA+UVIT)

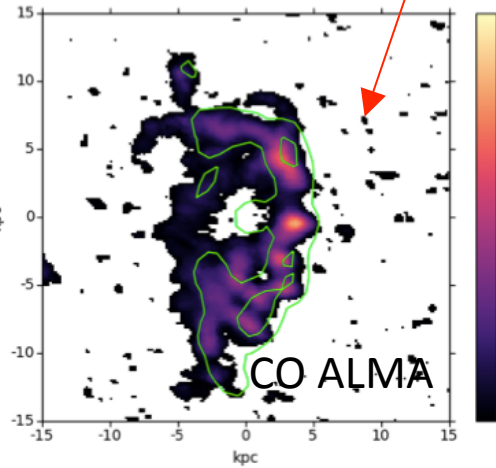
A central 8kpc-long region depleted of molecular gas and of star formation (central UV hole) – this region is filled with gas ionized by the AGN



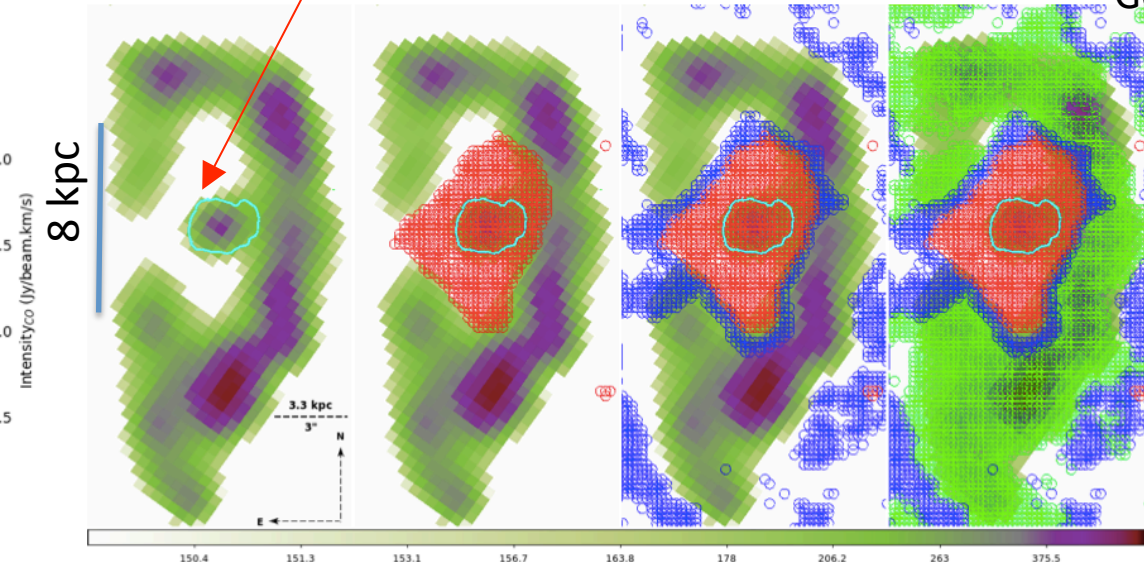
George+ 2018



Bellhouse+2017, 2019

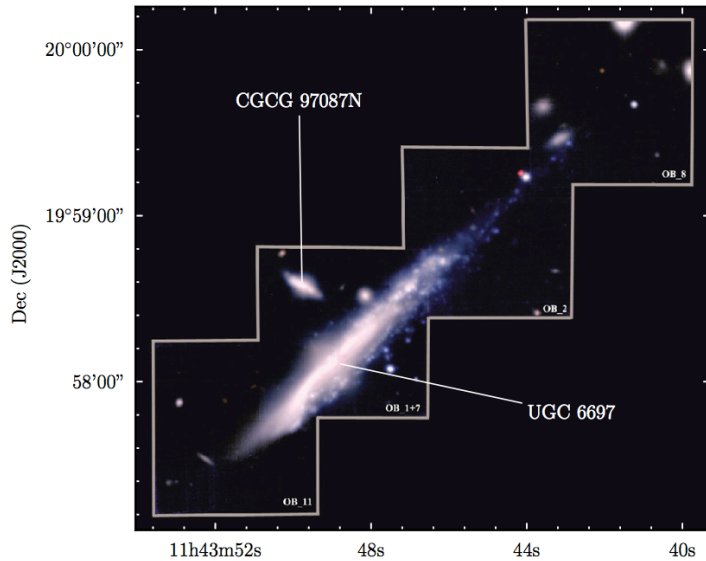


CO ALMA



George+ submitted

STAR FORMATION IN STRIPPED TAILS

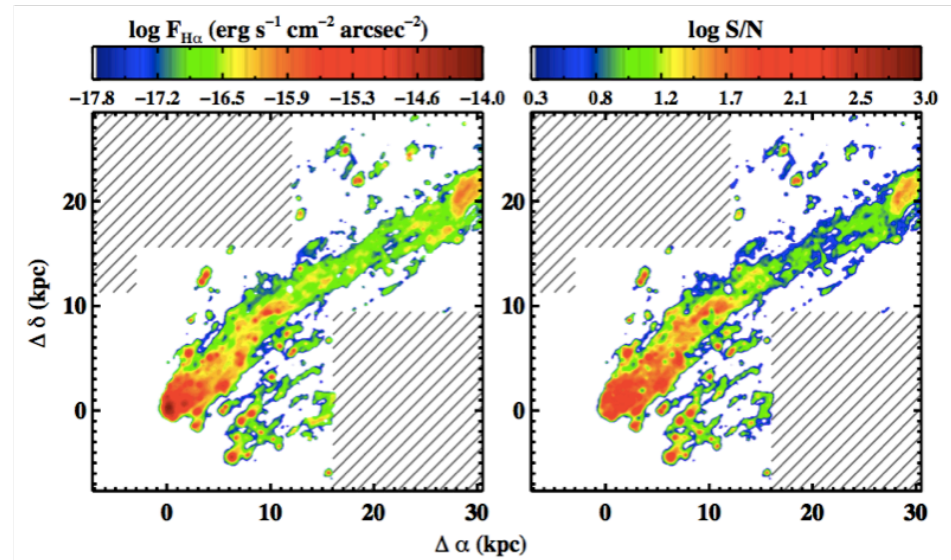


UGC6697, Consolandi et al. 2017, Abell 1367

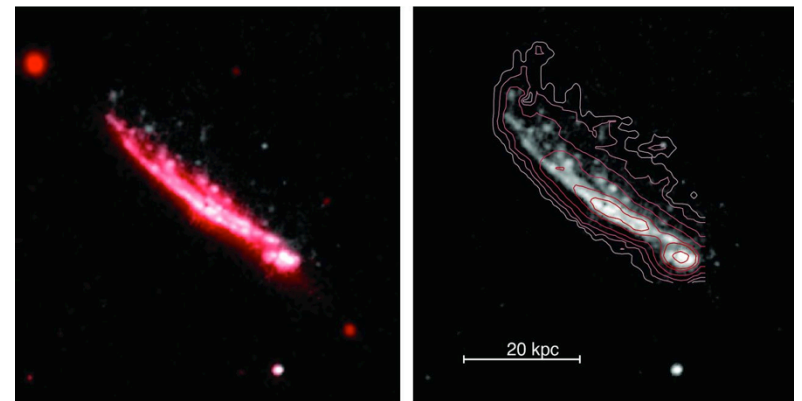
IFU data allow us to assess gas ionization mechanism from multiple line ratios.

See also Fossati+ 2019.

SF evidence also from UV+H α (Boselli+ 2018, Abramson+ 2011), UV-only of post-SB (Hester+ 2010, Yoshida+ 2008), and UV-only or H α -only 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



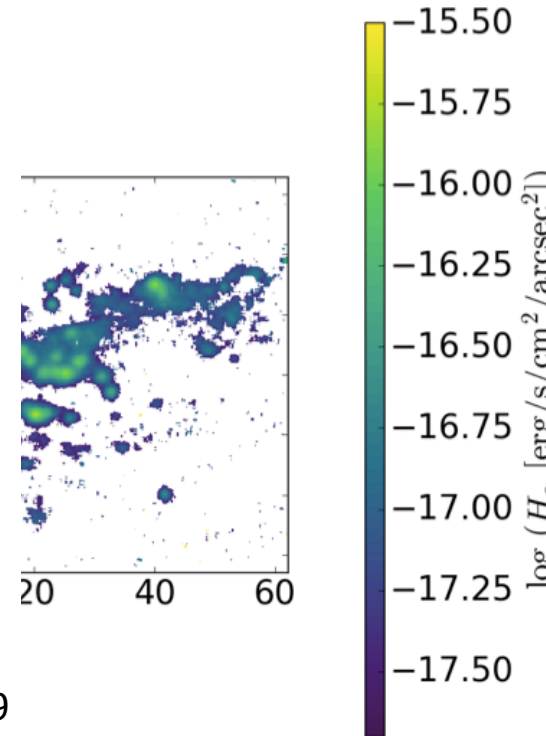
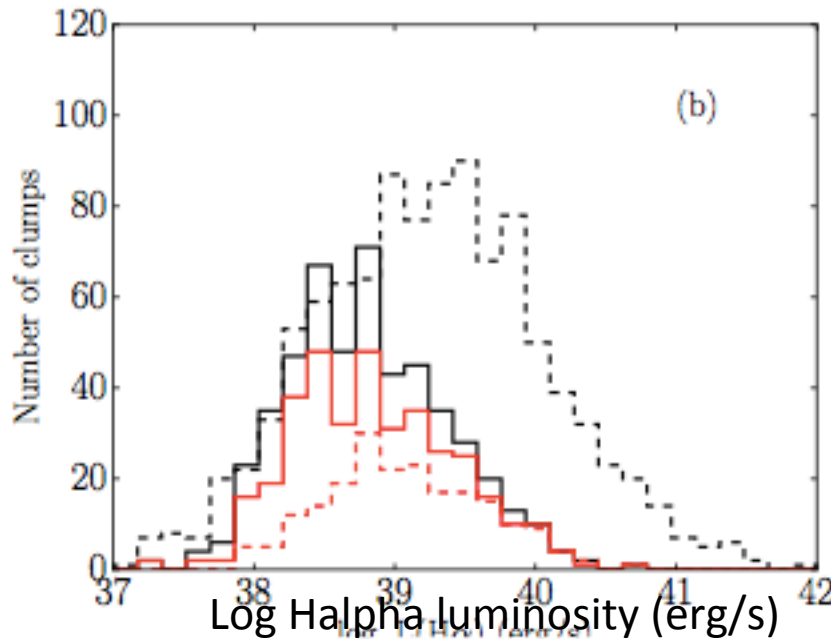
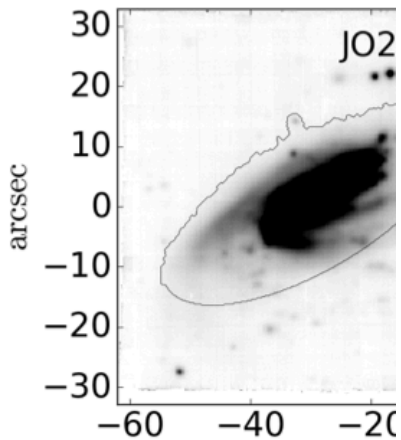
STAR FORMATION IN THE TAILS

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



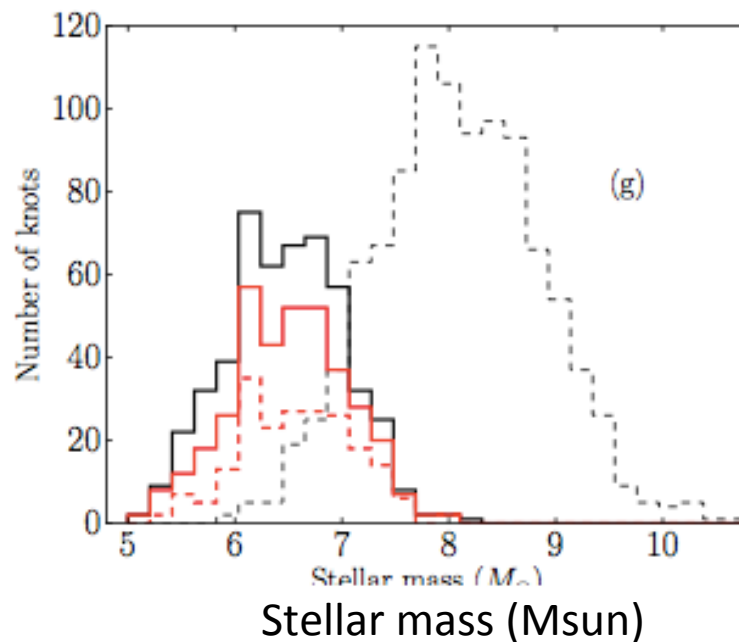
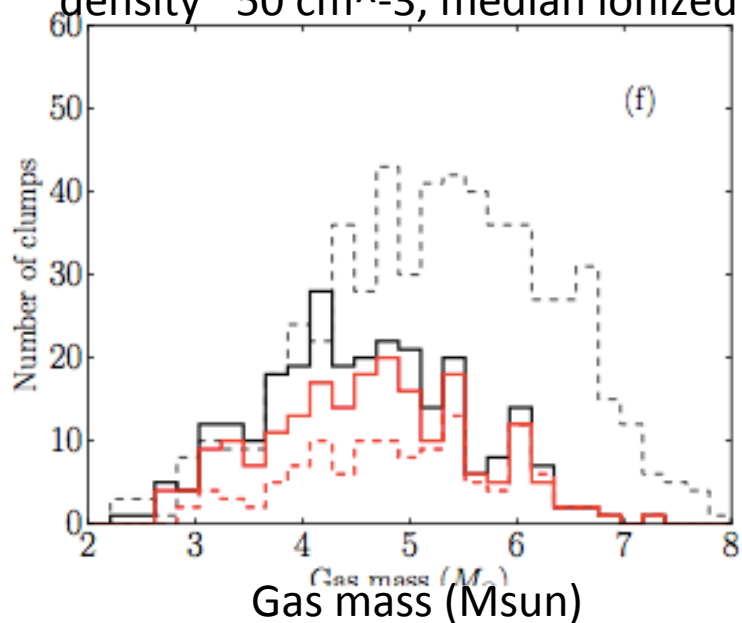
The SF takes place in H α bright, dynamically cold (median $\sigma=27$ km/s) **star-forming clumps forming in-situ in the tails.**

Clump H α luminosities typical of “giant HII regions” (eg Carina Nebula) and “supergiant HII regions” (eg 30Dor in LMC). Median 5×10^{38} erg/s.





Gas densities and (ionized) gas masses of clumps quite high. Median gas density $\sim 50 \text{ cm}^{-3}$, median ionized gas mass $4 \times 10^4 M_{\odot}$.



Median stellar mass $3 \times 10^6 M_{\odot}$

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

SF in stripped tails contributes to ICL !

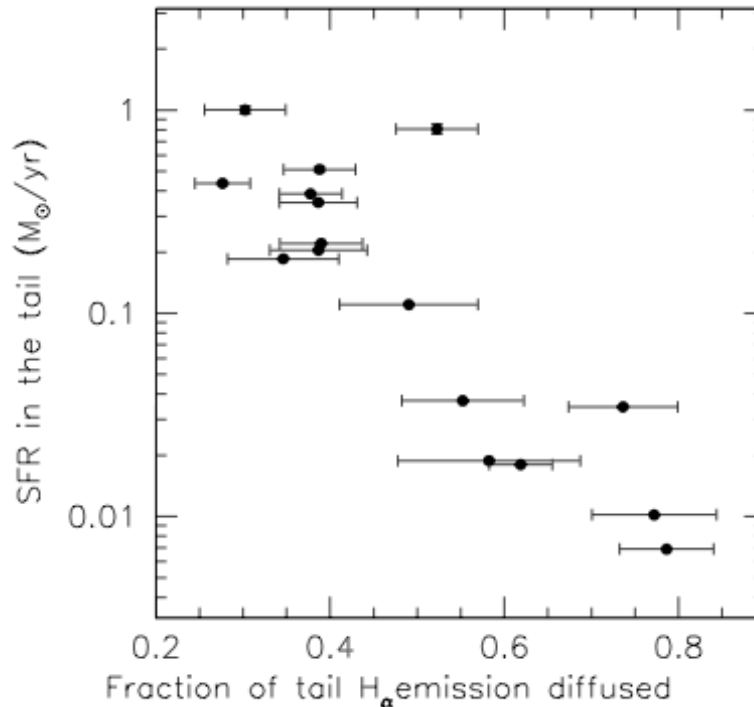
DIFFUSE H α EMISSION (DIG)



In tails, 50% of emission is H α clumps and 50% is DIG.

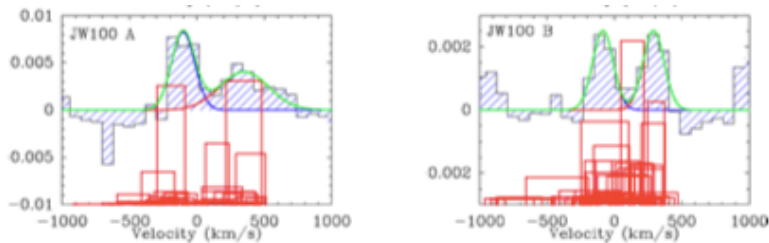
From BPT, also the DIG in the tails is mostly due to **photoionization by young massive stars** (>80% in most galaxies, but a few exceptions), but also “LINER-like” emission component from [O I] line: thermal heating from ICM?

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%)

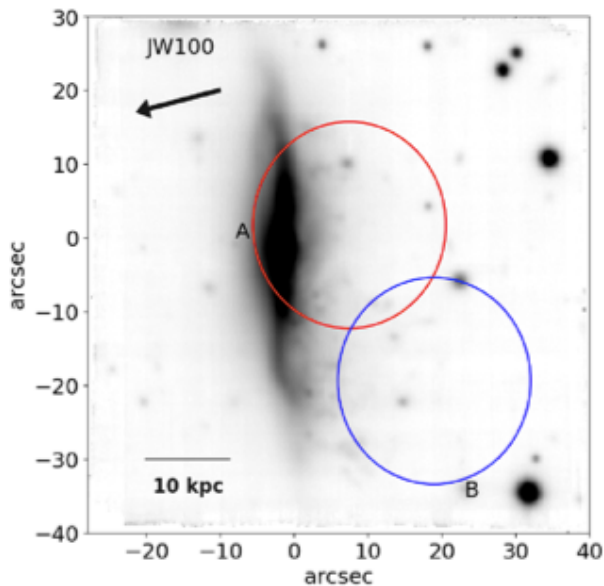


The SFR in the tails is typically a few percent (2-5%), and up to 20%, of the total SFR.

STAR FORMATION AND ITS RELATION WITH GAS: MOLECULAR GAS



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), molecular gas mass $\sim 10\%$ 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



NOW ALMA!!

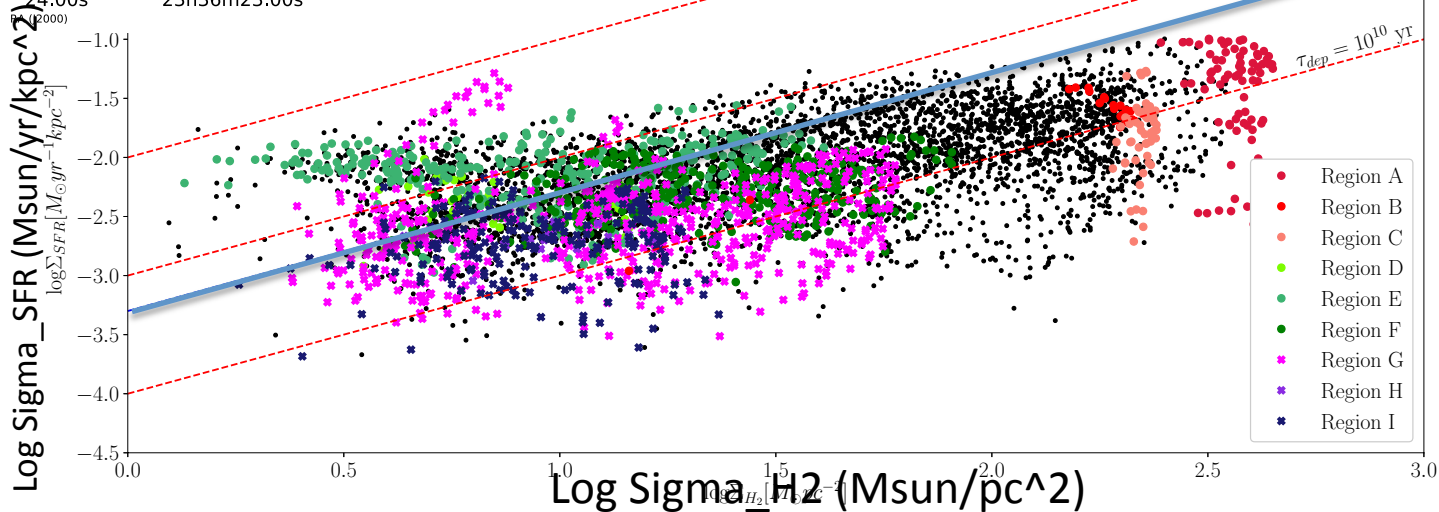
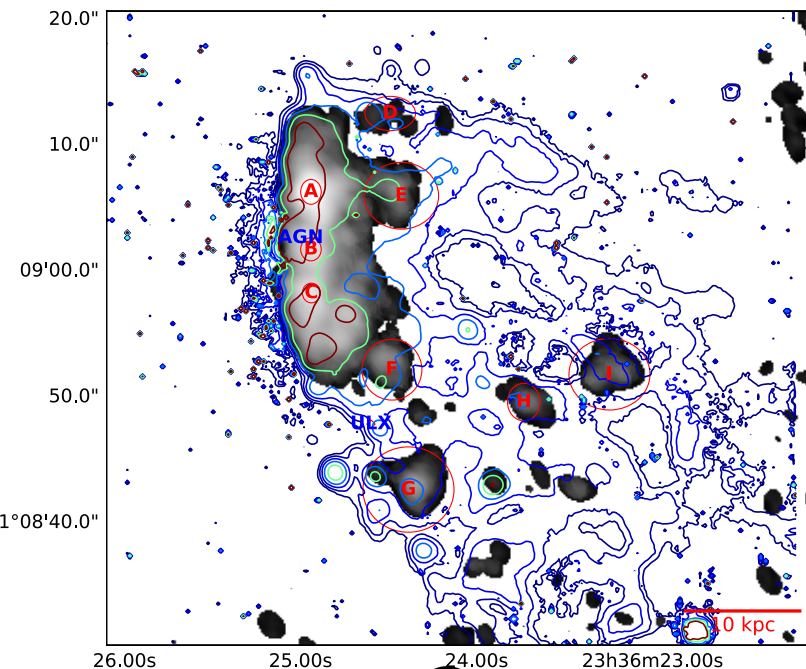
Individual CO clumps can be studied.

Large amounts of CO up to 35kpc from galaxy center: 5×10^7 to 8×10^8 Msun.

In the tail, mol. gas much more diffuse (larger scales)

Star formation efficiency/Kennicutt-Schmidt:

SF regions from SII line

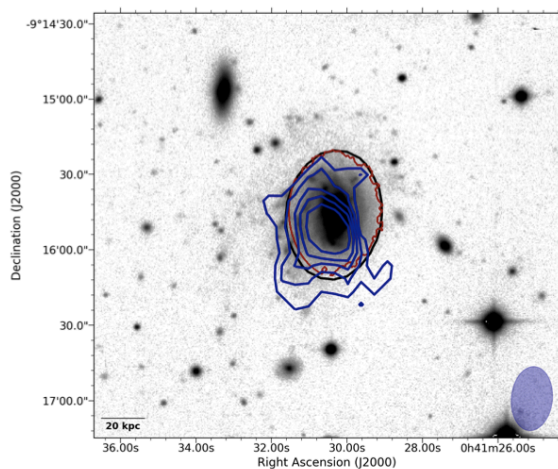
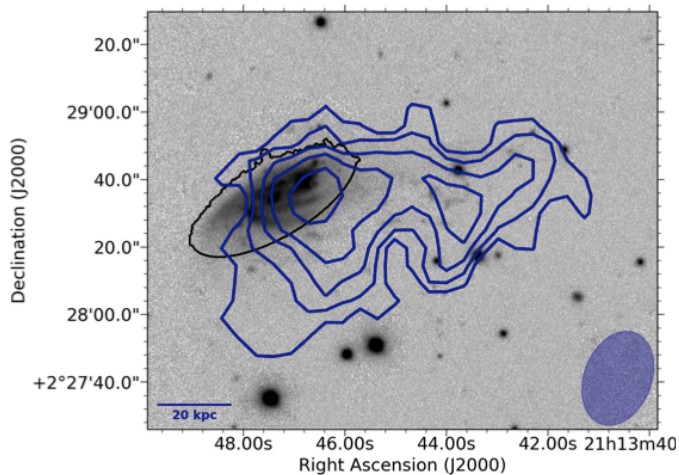


Moretti+ in prep.

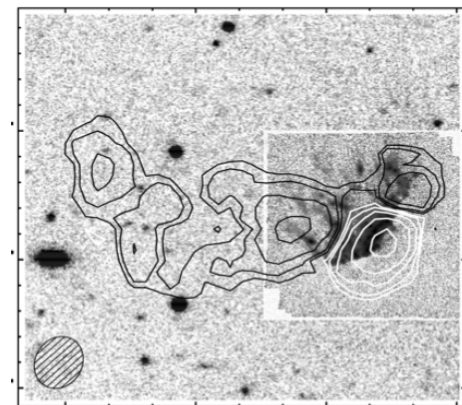
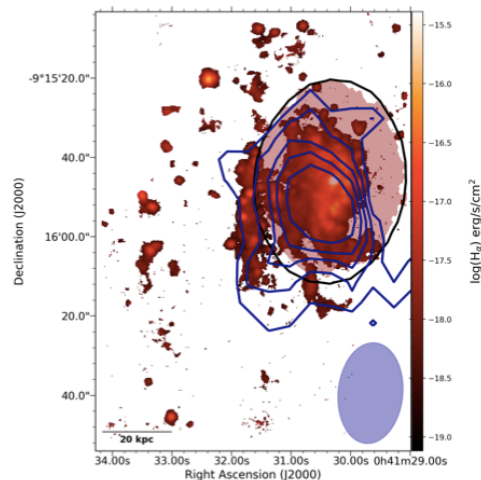
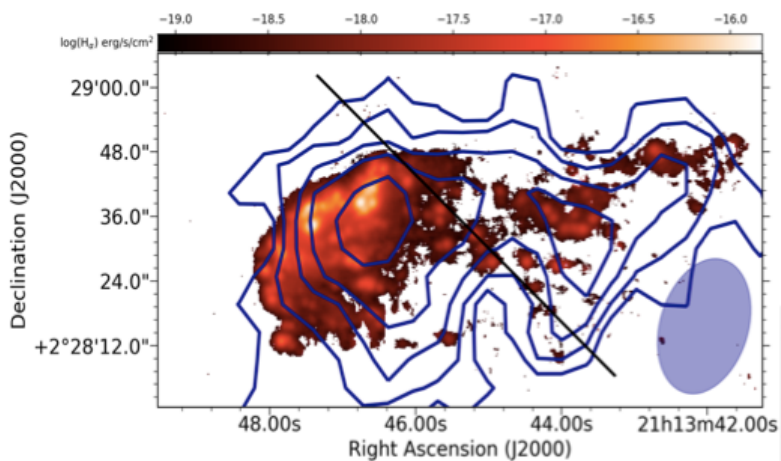
HI GAS



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



JVLA C-array

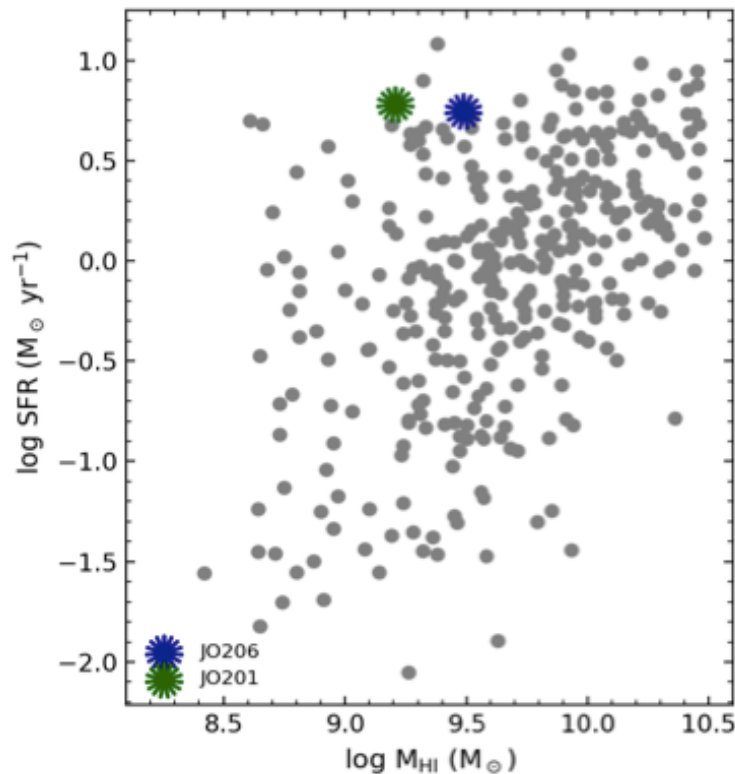
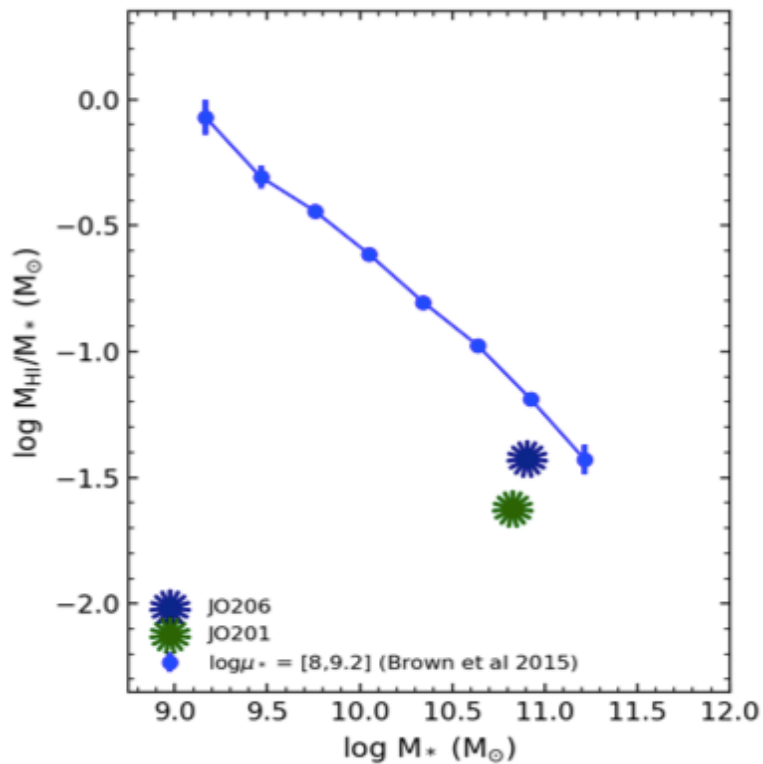


Ramatsoku+ 2019

Ramatsoku+ in prep.

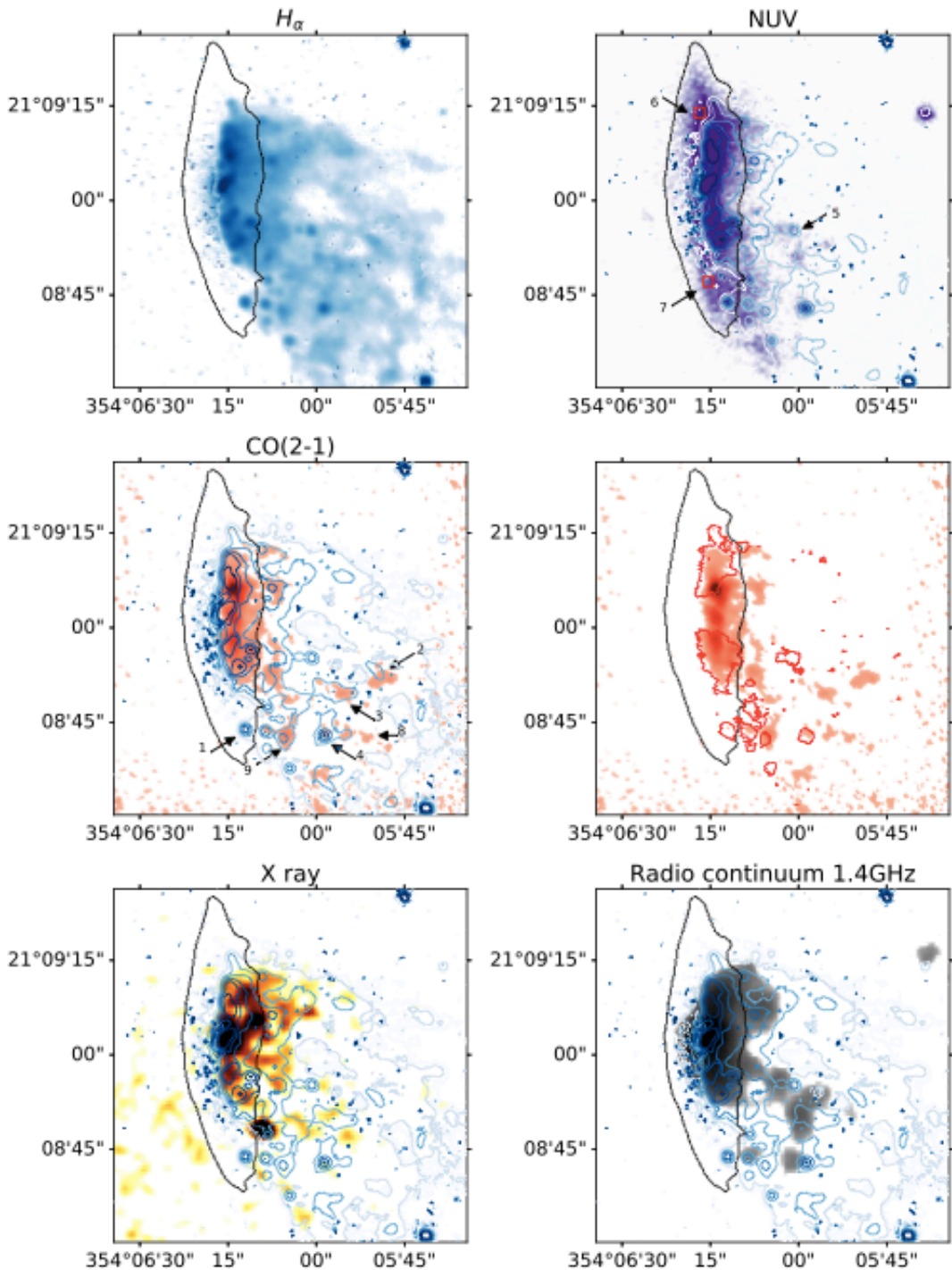
Deb, Verheijen+ in prep.

HI GAS

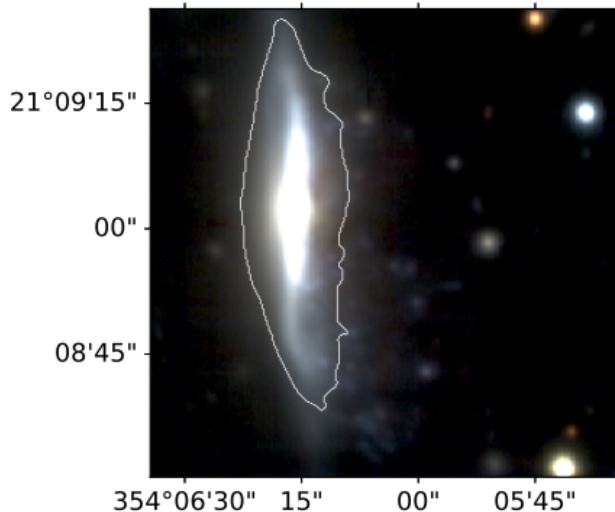


Ramatsoku+ 2019, and in prep.

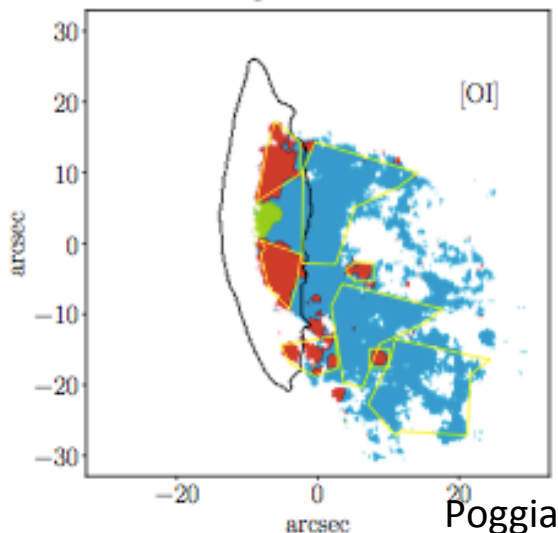
HI already depleted (for galaxy mass and surface brightness) – excess of SF for the HI content



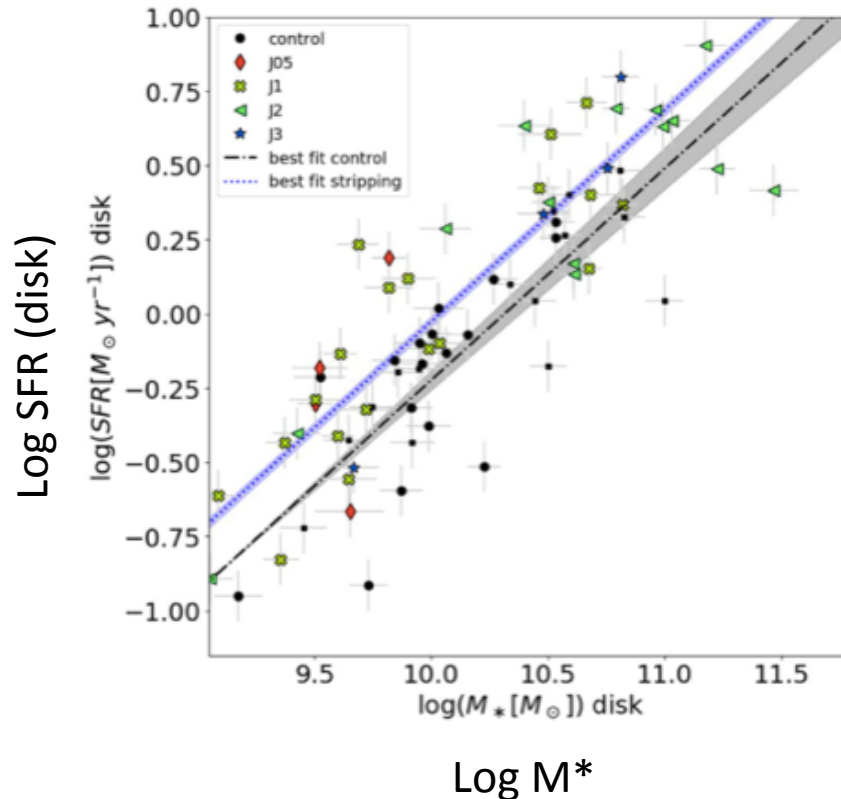
Multi-wavelengths tails: an astrophysical laboratory



■ Star forming ■ AGN ■ Liners

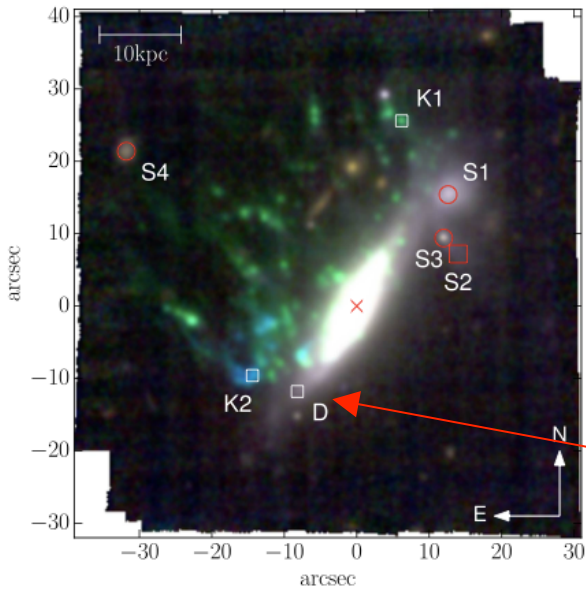


(enhanced) STAR FORMATION IN THE DISK

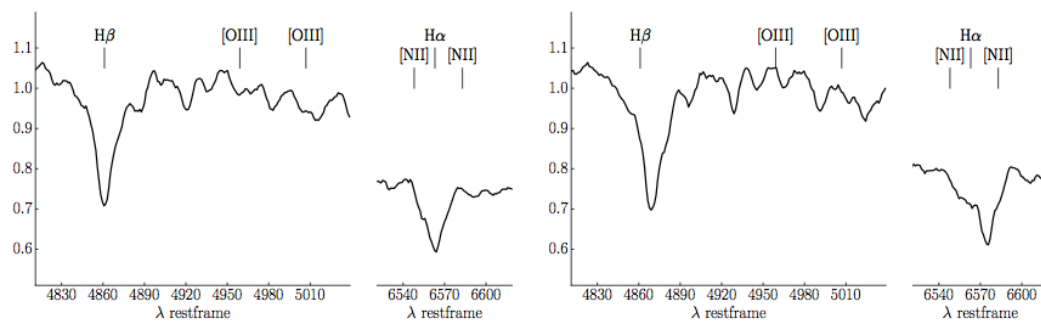
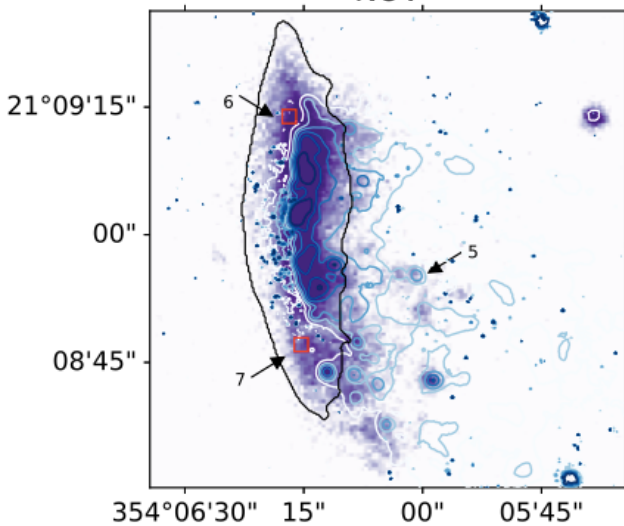
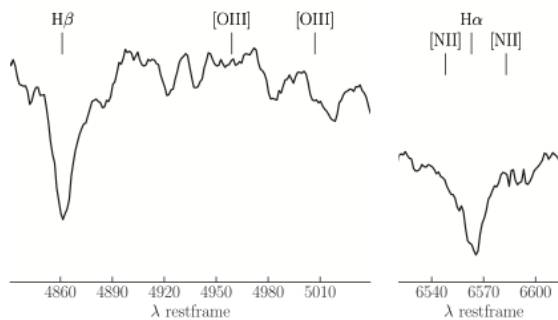


Galaxies undergoing stripping show a systematic **enhancement of the *disk* SFR at fixed disk galaxy stellar mass** (0.2dex) == RPS can moderately enhance the SFR in the disk before quenching

QUENCHING: POST-STARBURST SIGNATURES

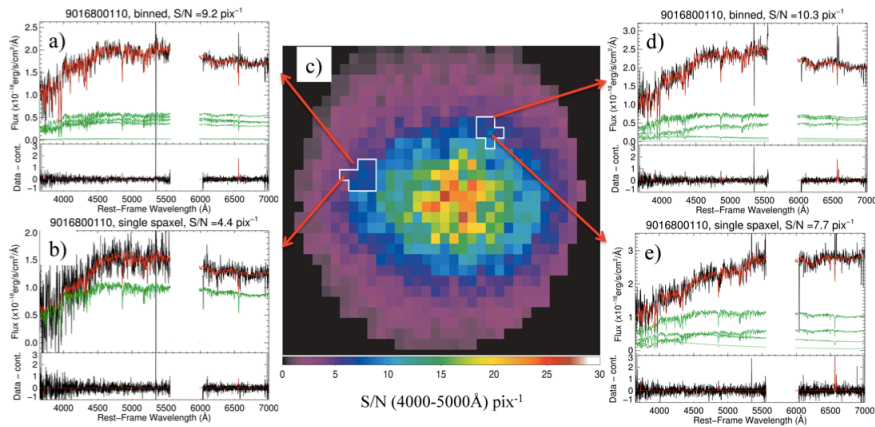


“Local post-starburst” signature:
outer regions of disks undergoing
stripping



Gullieszik+ 2017

QUENCHING: POST-STARBURST SIGNATURES

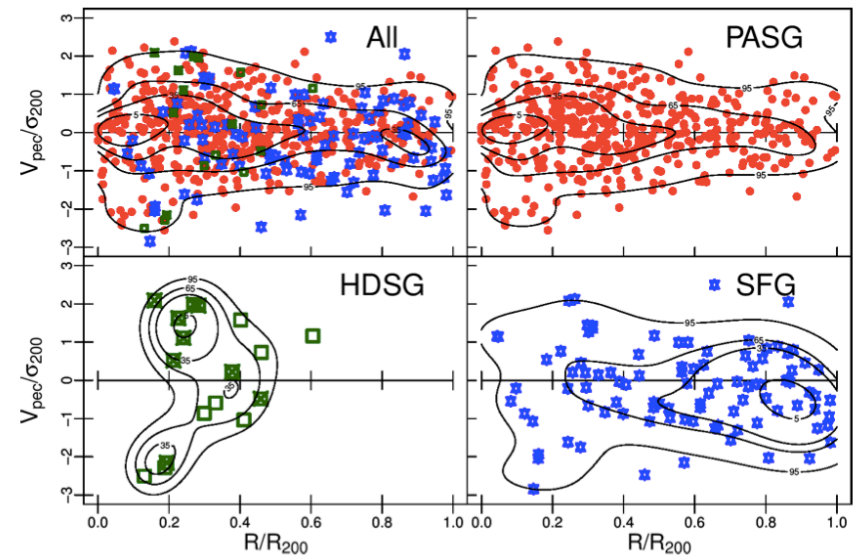


In SAMI, 17 galaxies in clusters: a mix of local post-starburst (with SF in their centers) and global ones

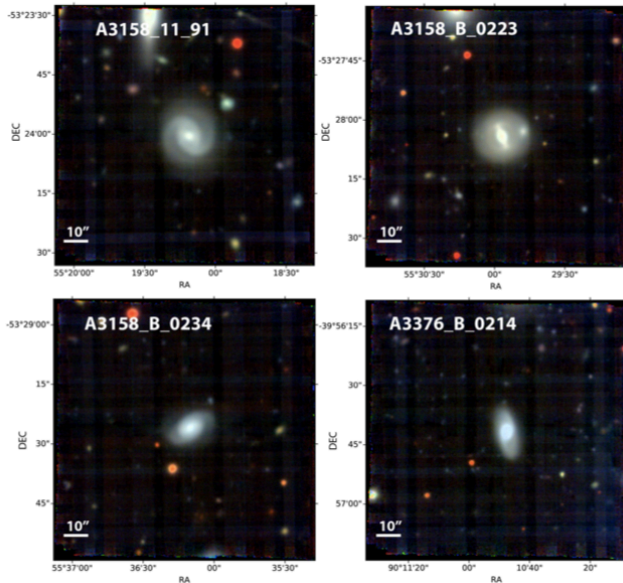
All within $0.6R_{200}$, outside-in quenching in galaxies at first infall

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

Owers+ 2019

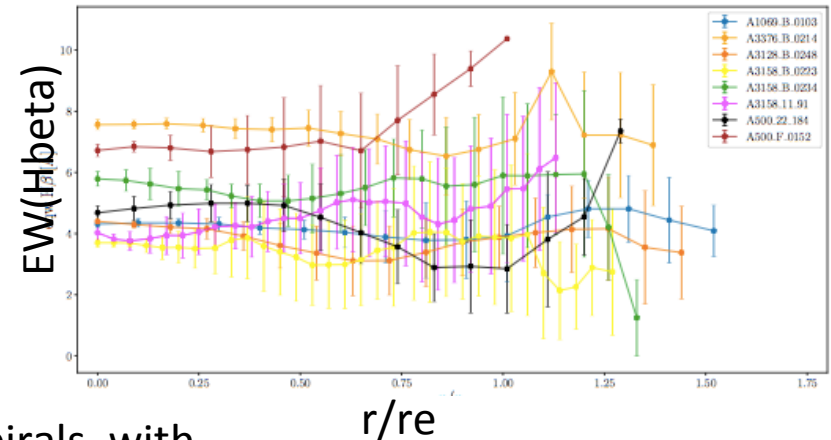


POST-STARBURST SIGNATURES: NO (ionized) GAS and NO SF LEFT

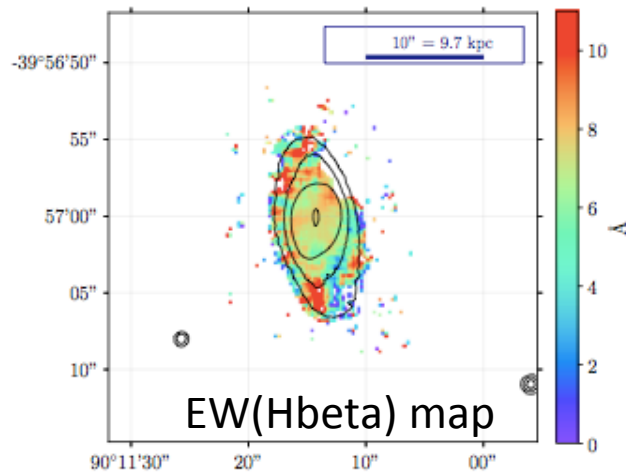
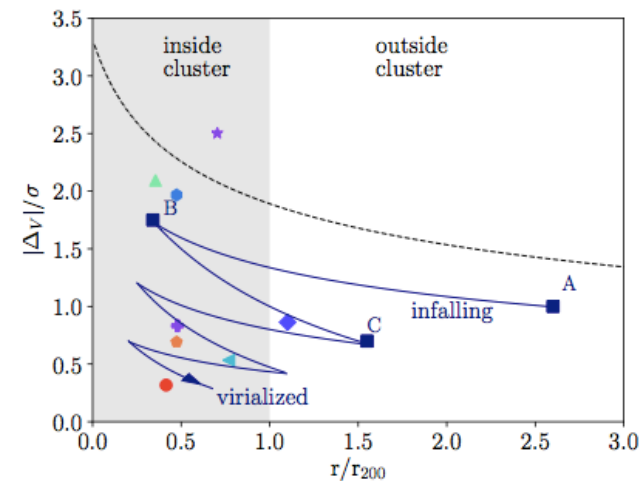


Can ram pressure halt the SF completely?

Oh, yes!



Post-starburst spirals, with strong Balmer absorption throughout the disk – SF quenching outside-in – typically located between 0.5 and 1 r_{200}

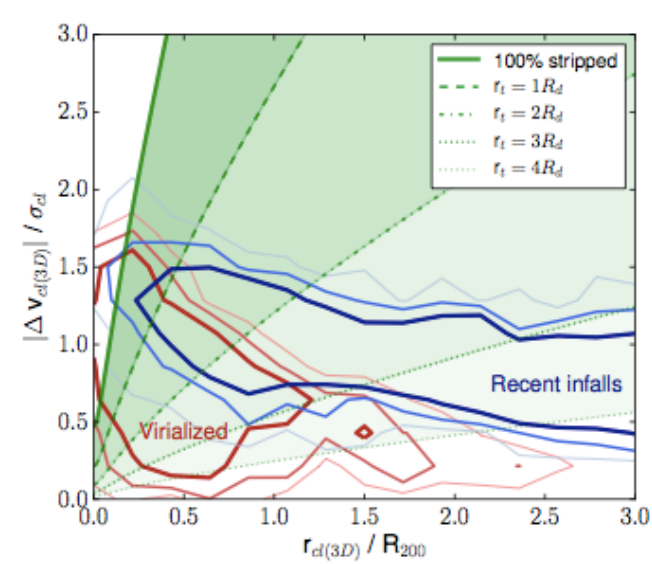


Santorelli 2018, Vulcani+ in prep.

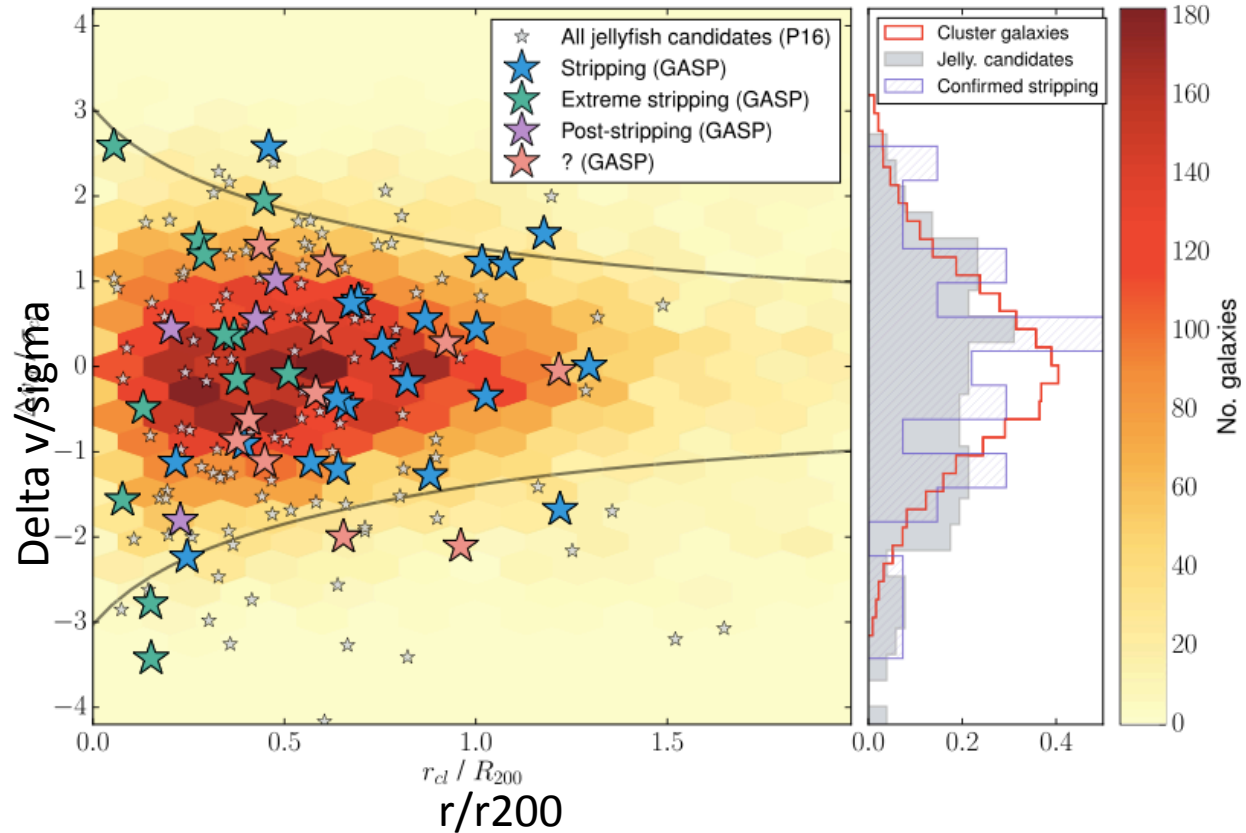
JELLYFISH GALAXIES ON FIRST INFALL AND RADIAL ORBITS



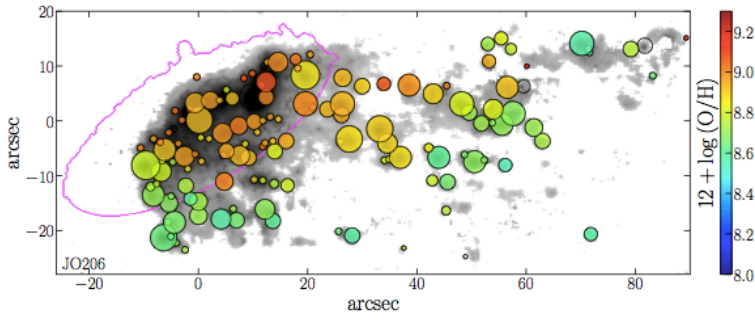
Those with the longest tails have very high peculiar velocities and small projected cluster-centric radii



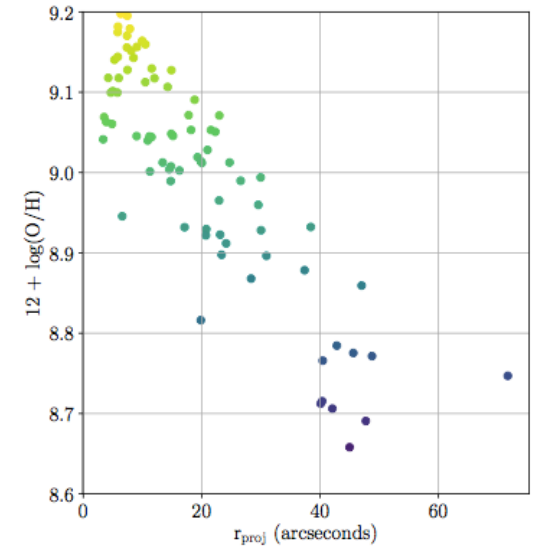
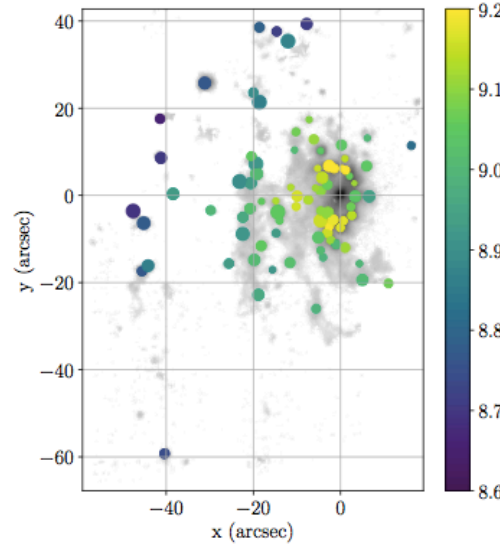
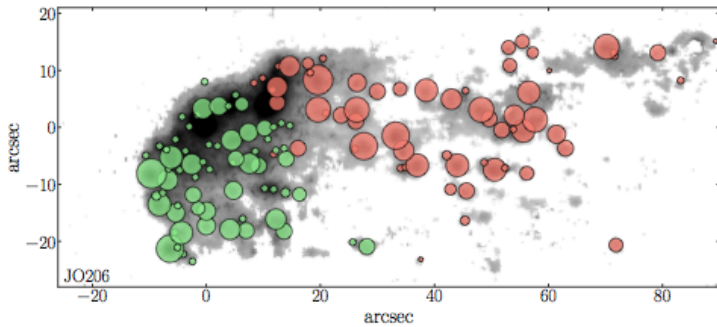
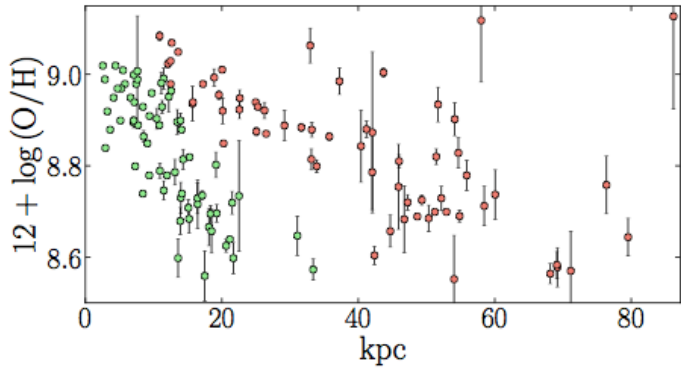
Jaffe'+ 2018



ENRICHMENT WITH METALS



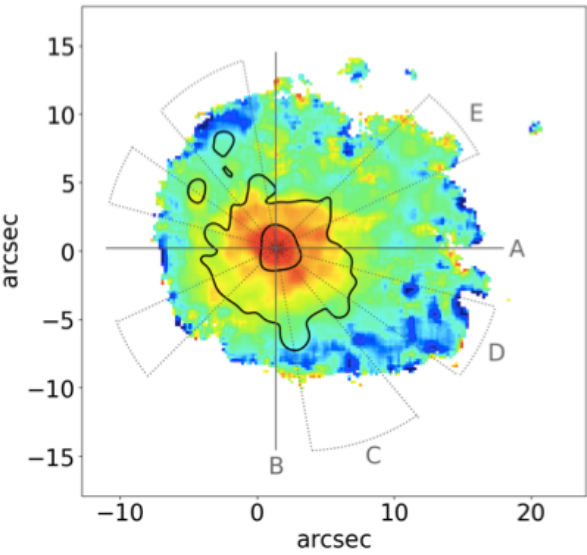
Metallicity gradients in disks and tails
– for both control galaxies and
jellyfish galaxies



Franchetto+ in prep.

Bellhouse+ 2019

ENVIRONMENT outside clusters: GROUPS and ISOLATED GALAXIES



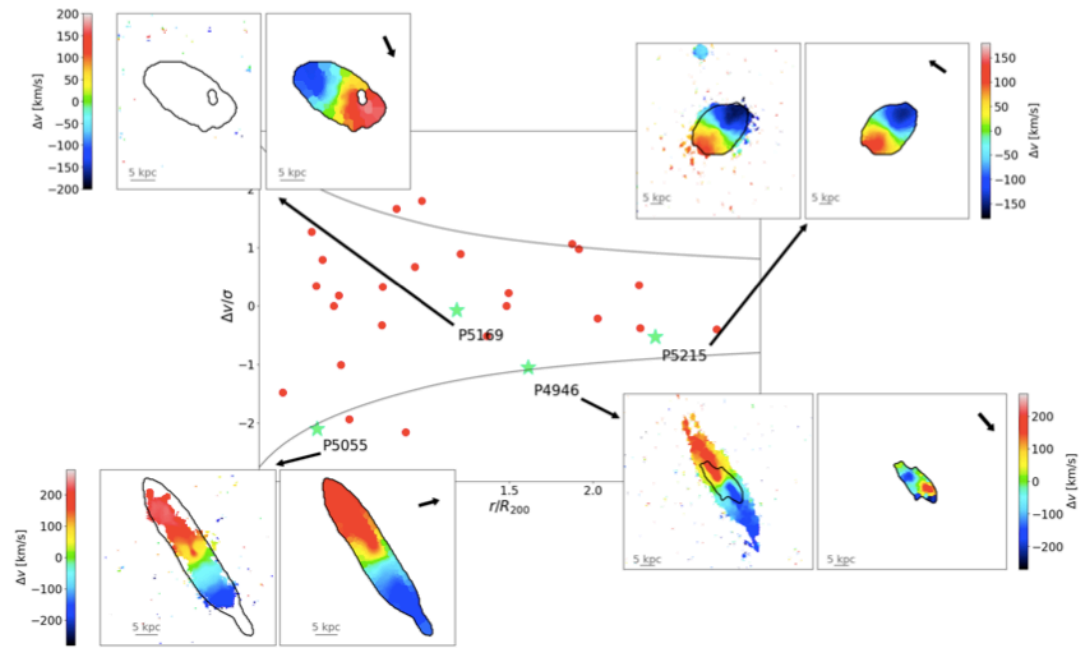
Evidence for gas accretion in an isolated spiral

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