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

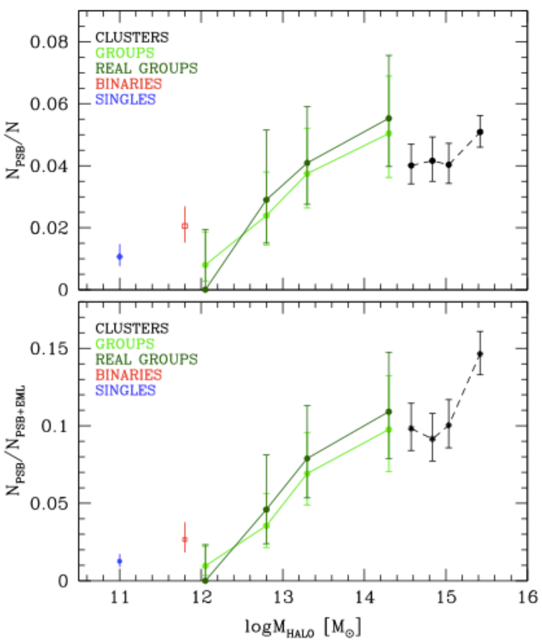
Bianca Poggianti
INAF-Astronomical Observatory of Padova

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?

% of PSB (/all)

% of PSB (/active)

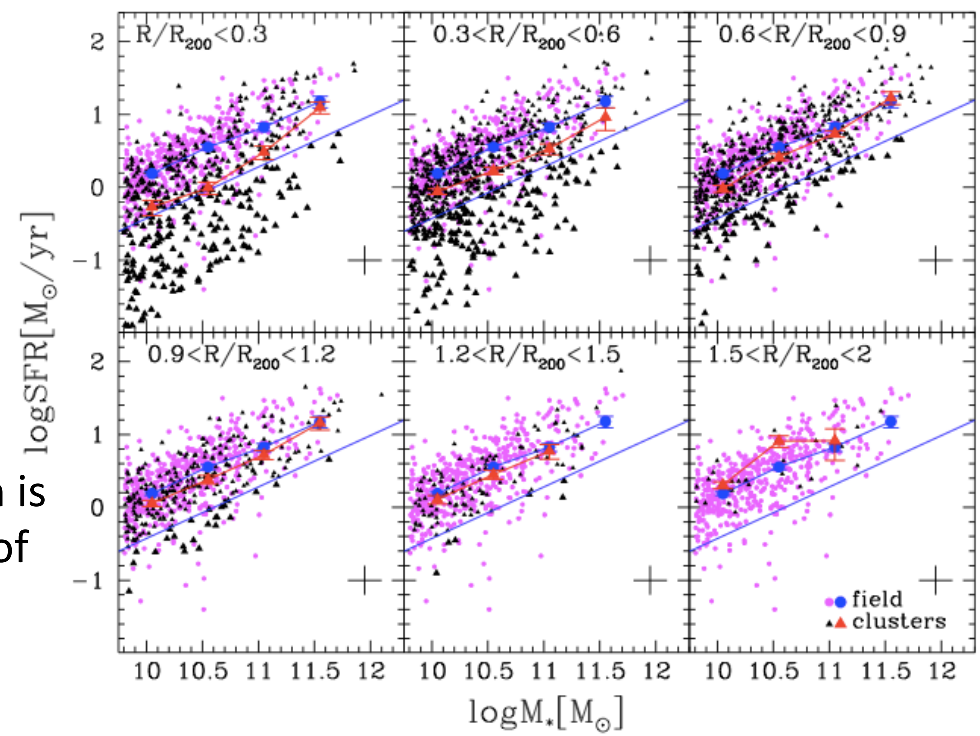


Log Mhalo

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

See also Wilkinson's talk

Paccagnella+ 2019

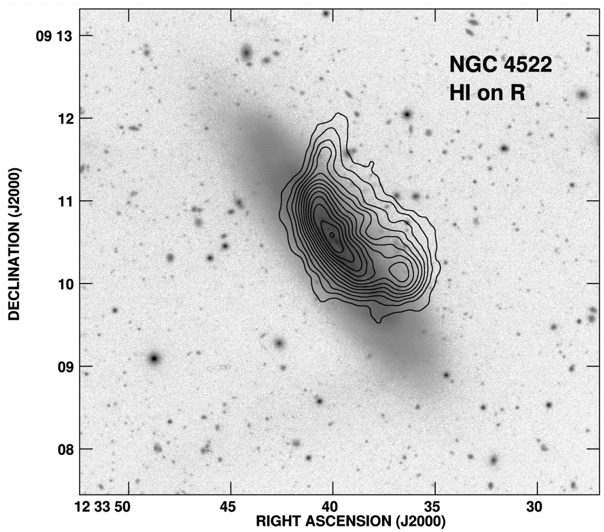


In clusters, the median SFR-mass relation is shifted to lower SFRs – large population of outliers below the main sequence within 0.6R200

Paccagnella+16, Vulcani+10

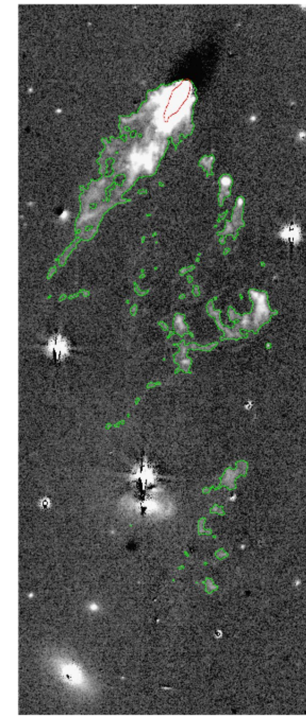
RAM PRESSURE STRIPPING

Observational evidence for gas stripping in clusters from:



HI - Kenney, van Gorkom and Vollmer 2004, Virgo cluster

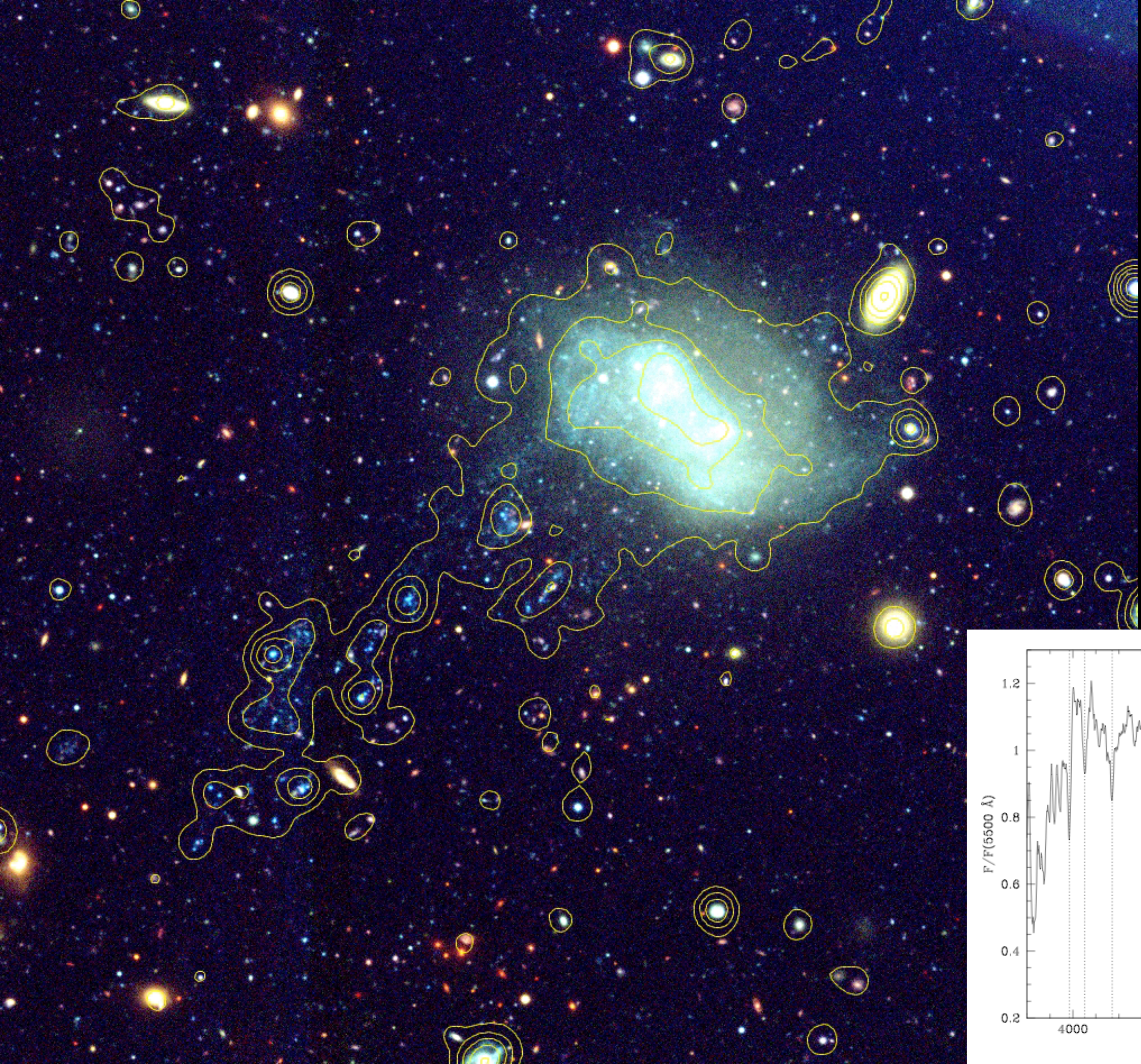
HI
UV imaging
H-alpha narrow band imaging
X-ray
IFU spectroscopy
……and even optical images



Halpha imaging, Yagi + 2010, 2017, Coma cluster

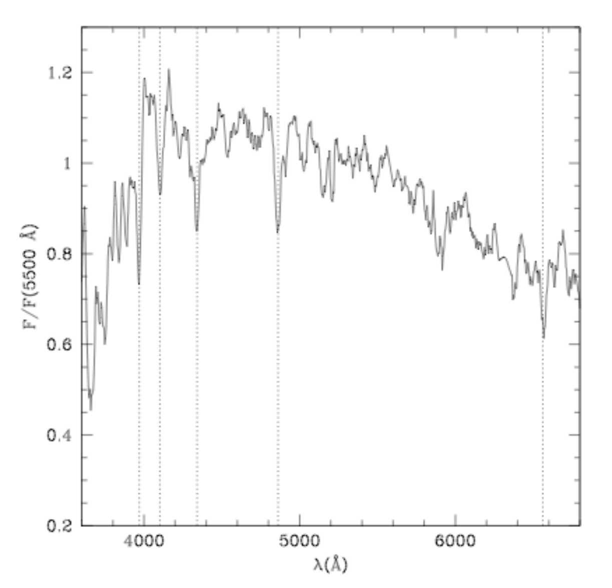
“JELLYFISH GALAXIES”:

“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



GASP

GAs Stripping Phenomena in galaxies

Gas Stripping Phenomena with MUSE

ESO Large Programme

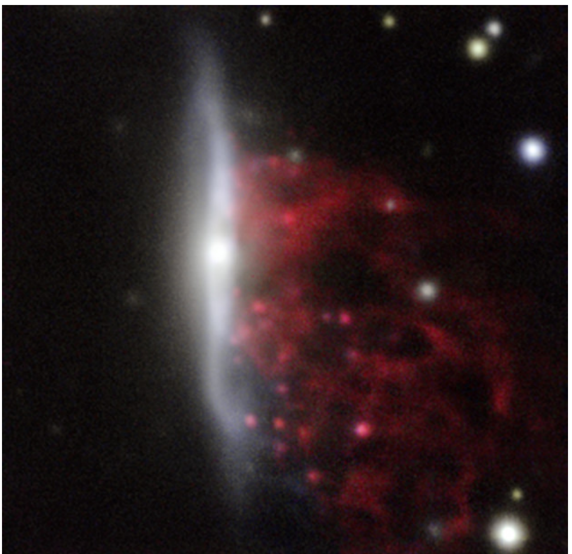
http://web.oapd.inaf.it/gasp/

PI B. M. Poggianti

C. Bellhouse
D. Bettoni
T. Deb
A. Biviano
W. Couch
G. Fasano
A. Franchetto
J. Fritz
K. George
M. Gullieuszik
G. Hau
Y. Jaffe'
S. McGee
A. Moretti
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



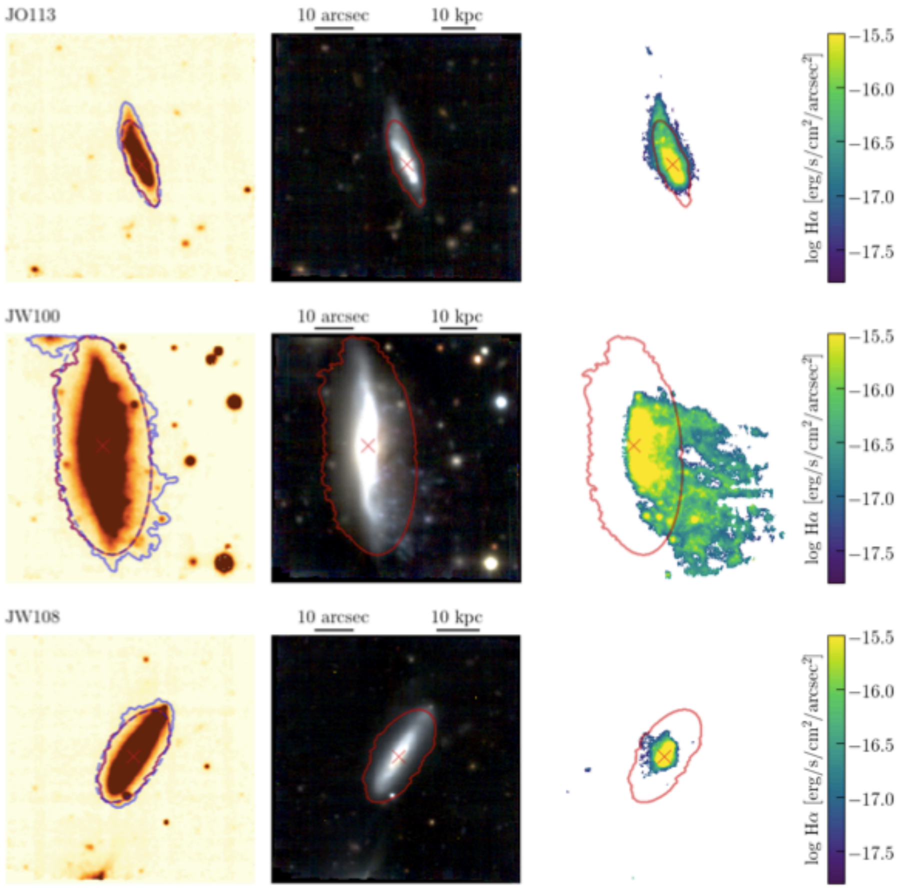
where, how, why is gas removed from galaxies?
what is the effect on the galaxy SFH?

Selected to have unilateral debris/tails in optical images

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

ESO
PRESS
RELEASE
1725

GASP CHARACTERISTICS



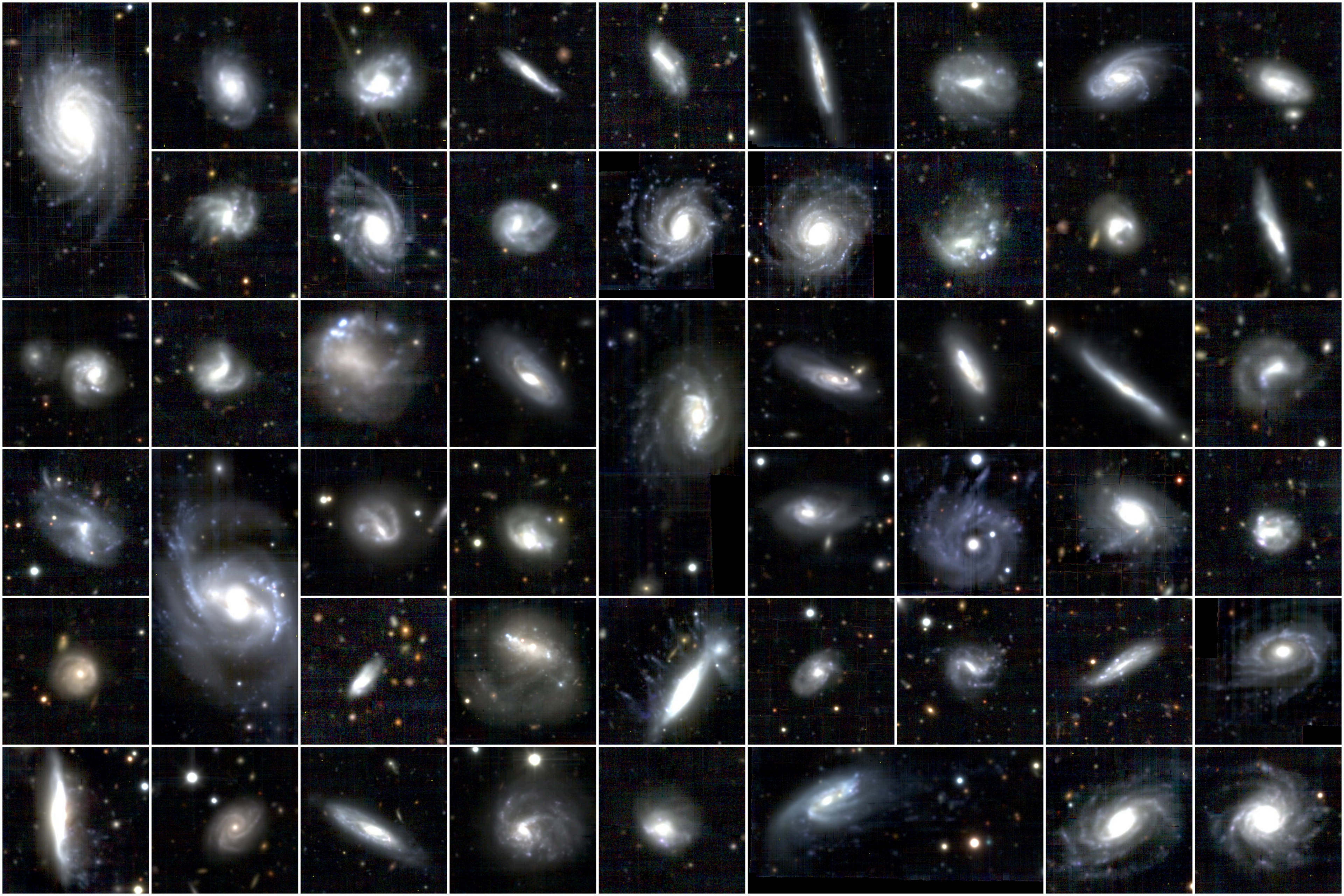
- SELECTION OF TARGETS: stripping candidates + control

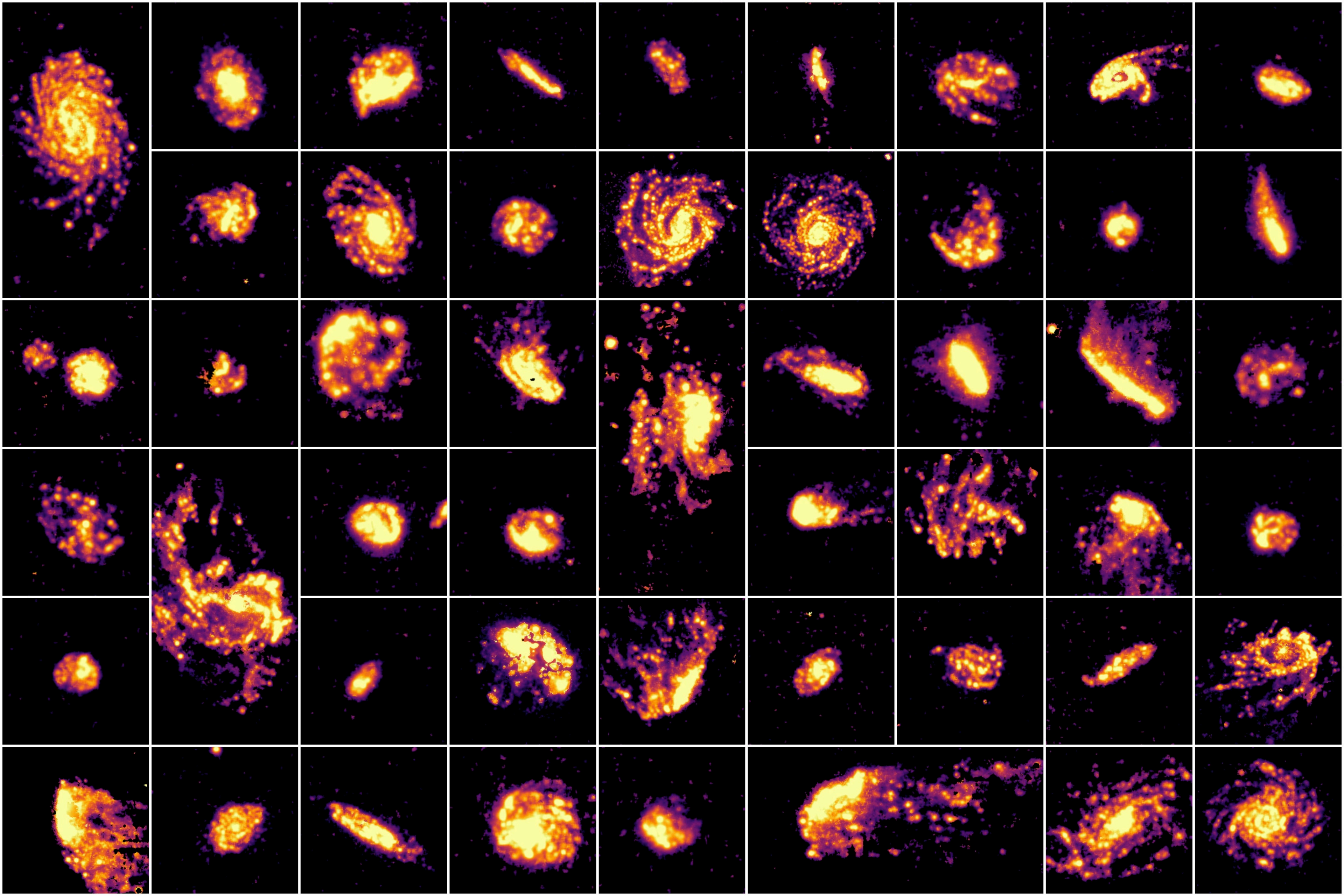
All stripping stages, from pre-stripping (control), to stripping, post-stripping all the way to fully-stripped post-starburst

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

- Galaxy stellar mass range 10^9 – 10^11.5

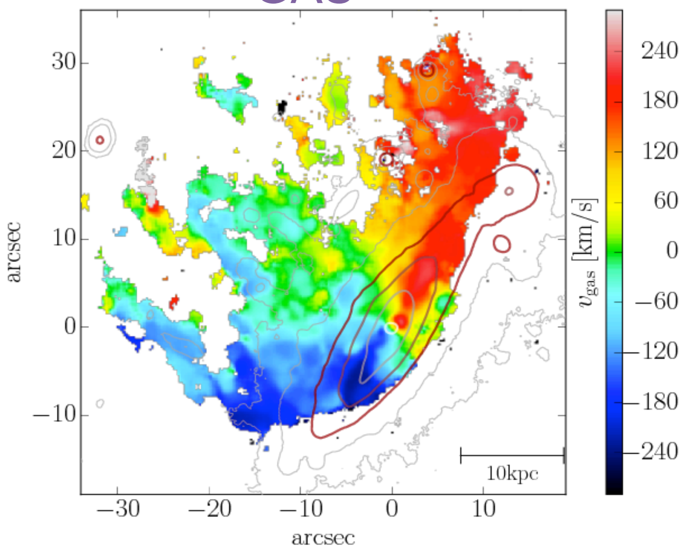
- Host halo mass range 10^11 - 10^15.5



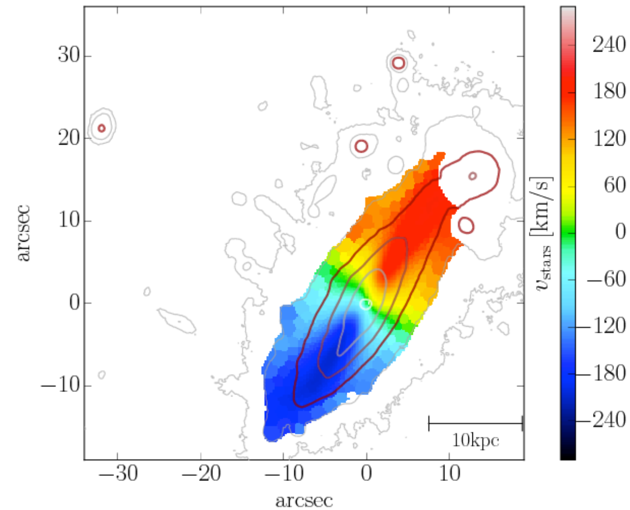


GAS and STELLAR KINEMATICS

GAS

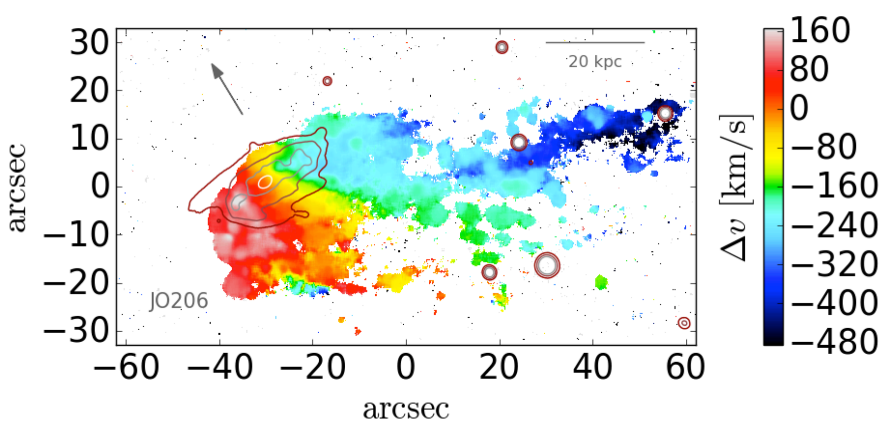


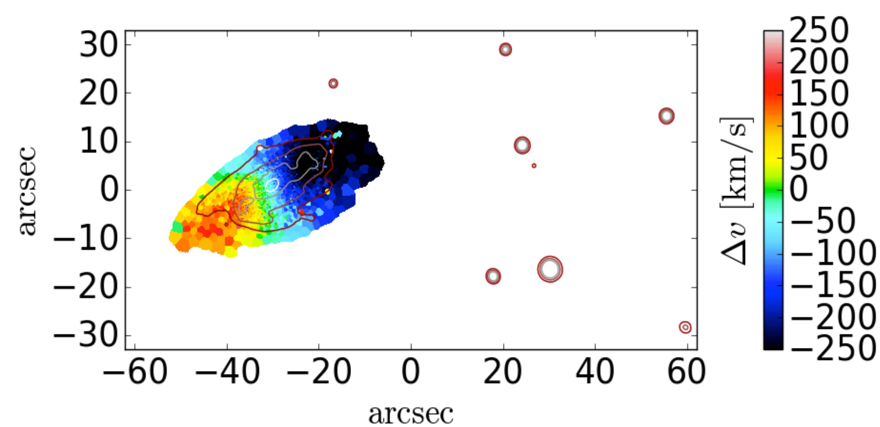
STARS



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:

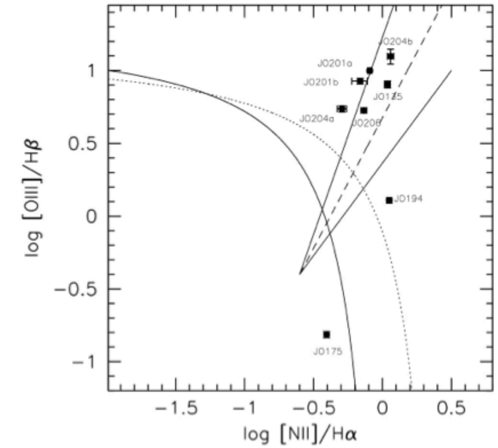
Indirectly (through an AGN)

Directly: SF in tails
SF in disks
Quenching

AGN TRIGGERING MECHANISMS AND FEEDBACK:

RAM PRESSURE-AGN CONNECTION

7 galaxies with Hα tentacles longer than the diameter of the stellar disk and stellar masses $4 * 10^{10}$ - $3 * 10^{11}$ 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

Poggianti+ 2017b

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Archive > Volume 548 > Issue 7667 > Letters > Article

NATURE | LETTER

日本語要約

Ram-pressure feeding of supermassive black holes

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

Affiliations | Contributions | Corresponding author

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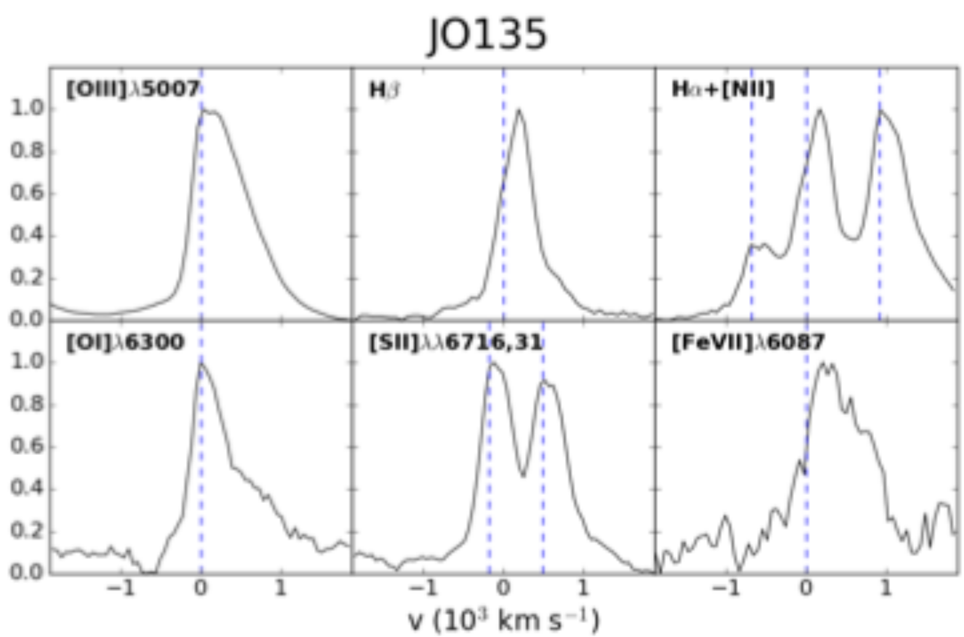
AGN TRIGGERING MECHANISMS AND FEEDBACK:
AGN and their OUTFLOWS in JELLYFISH GALAXIES

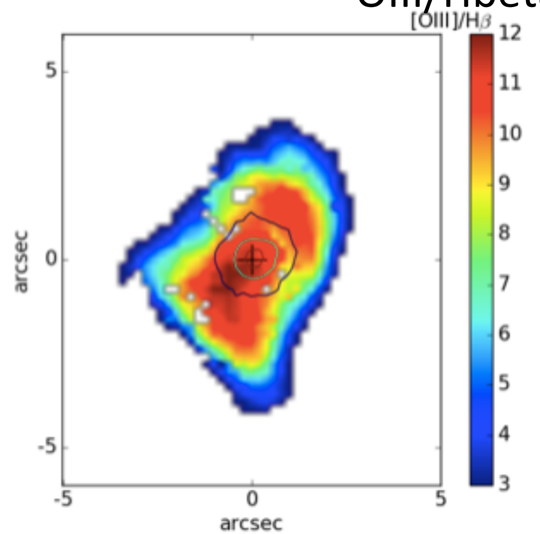
1) Comparison with AGN, shock and HII models using combination of line ratios confirms AGN.

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



OIII/Hbeta

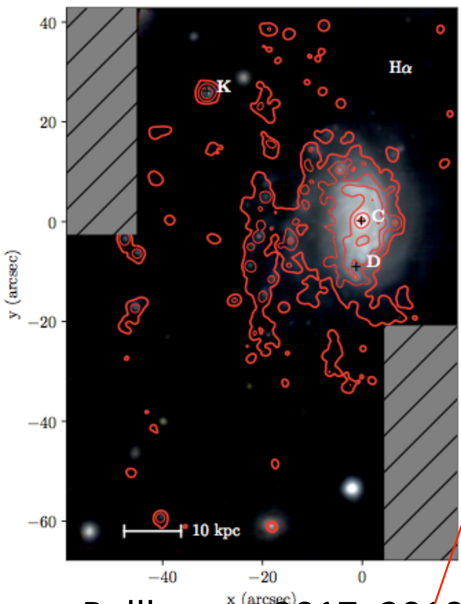


Radovich+ submitted

AGN FEEDBACK:

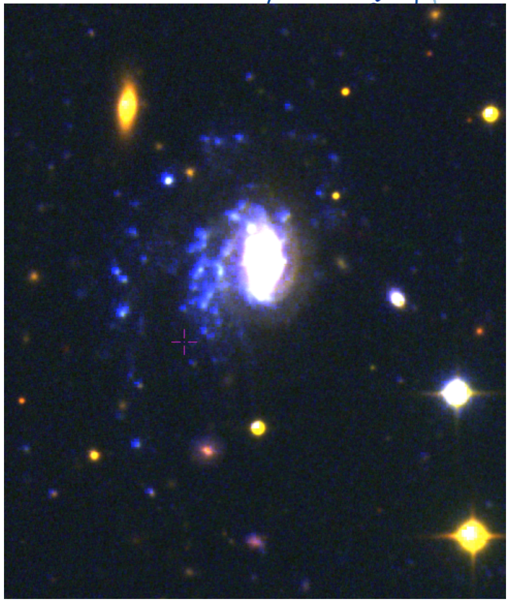
STAR FORMATION QUENCHING IN THE CENTRAL REGION OF A JELLYFISH GALAXY

(MUSE+ALMA+UVIT)

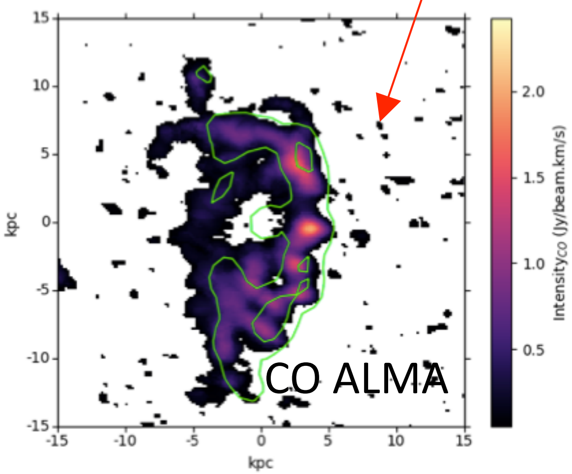


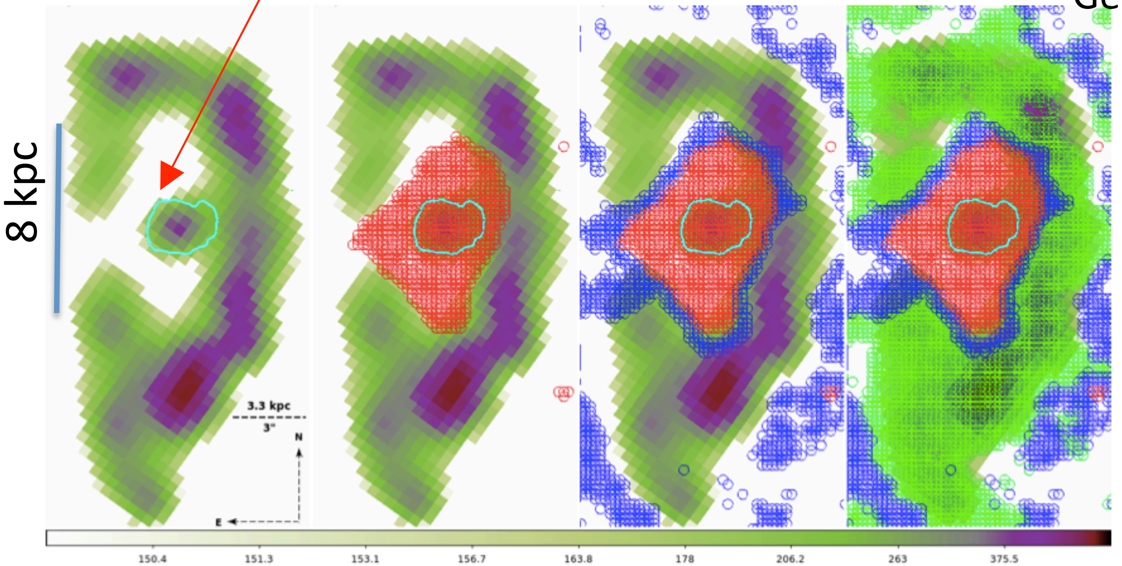
Bellhouse+2017, 2019

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



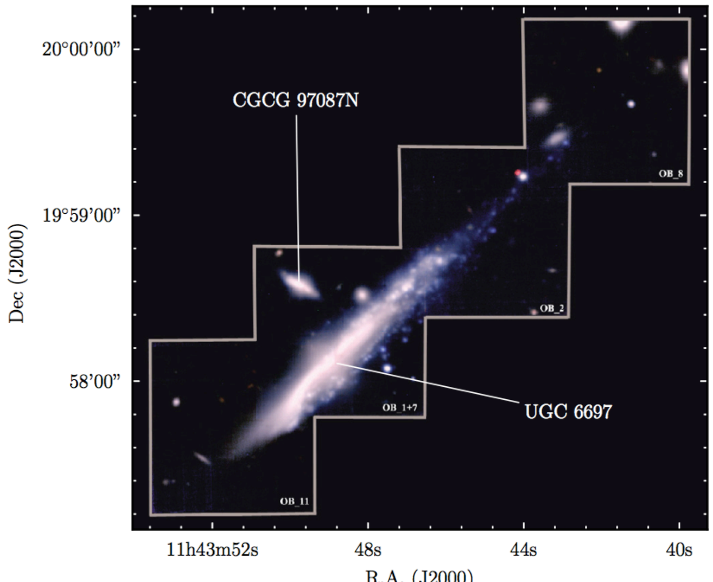
George+ 2018



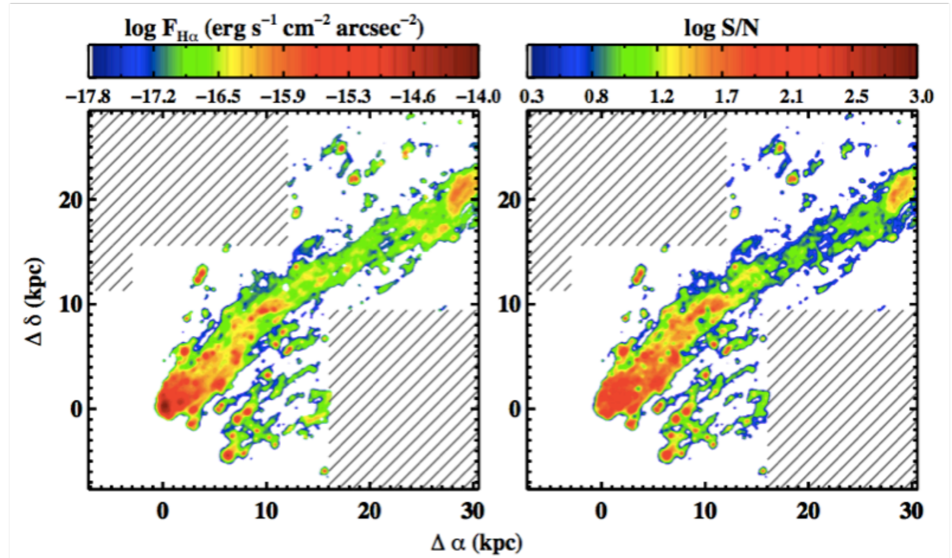


George+ submitted

STAR FORMATION IN STRIPPED TAILS

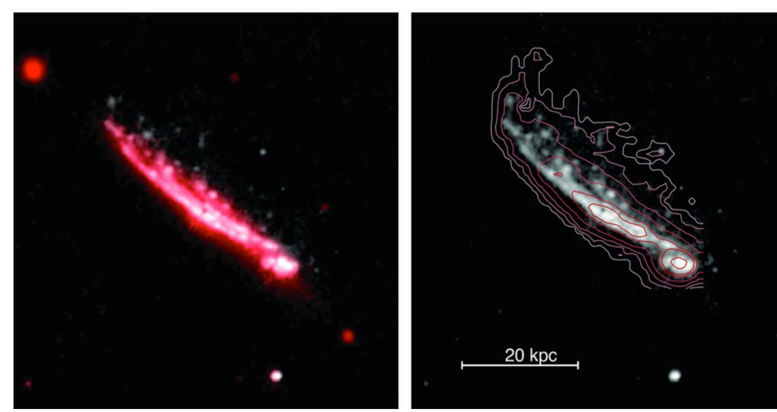


UGC6697, Consolandi et al. 2017, Abell 1367



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

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



SOS 114372, Merluzzi+2013, 2016, Shapley supercluster

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 Halpha-only surveys (Smith+ 2010, Yagi and Gavazzi's works)

STAR FORMATION IN THE TAILS?

[Not always?]

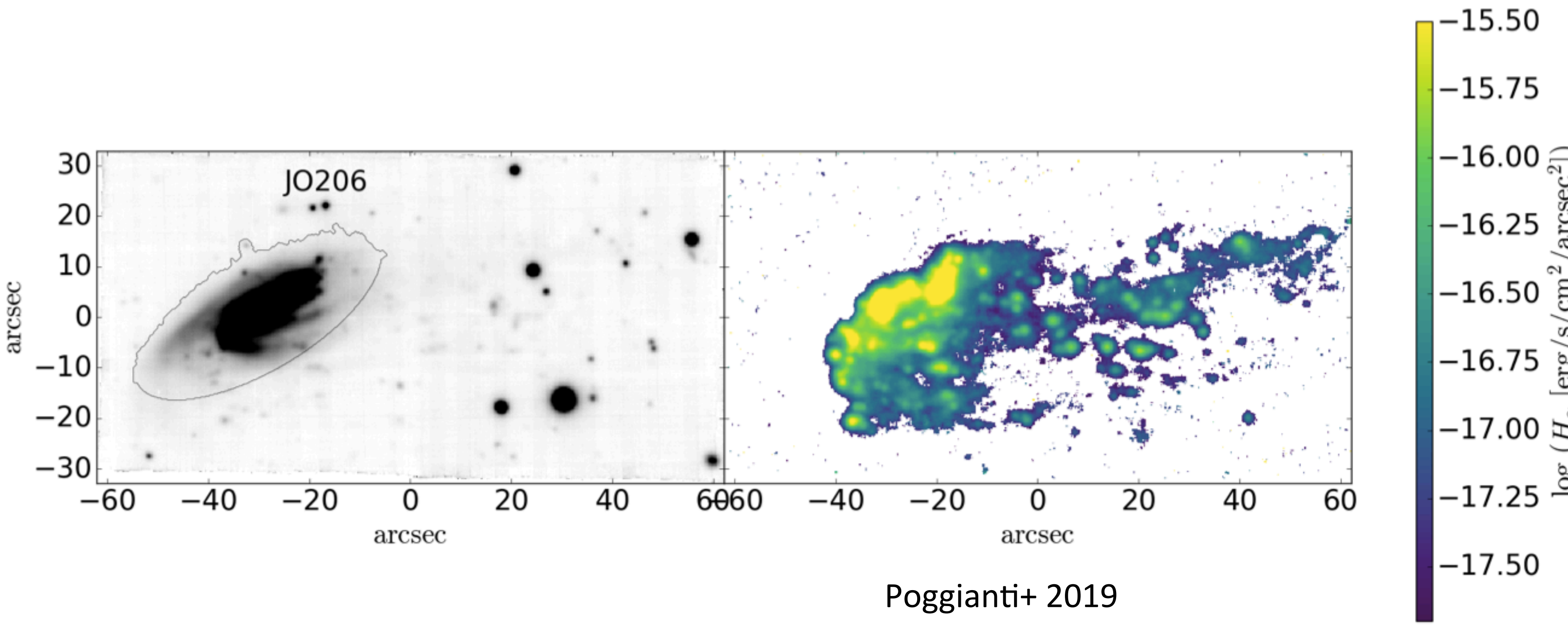
NGC 4569 in Virgo
Boselli et al. 2016

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) star-forming 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.



Poggianti+ 2019

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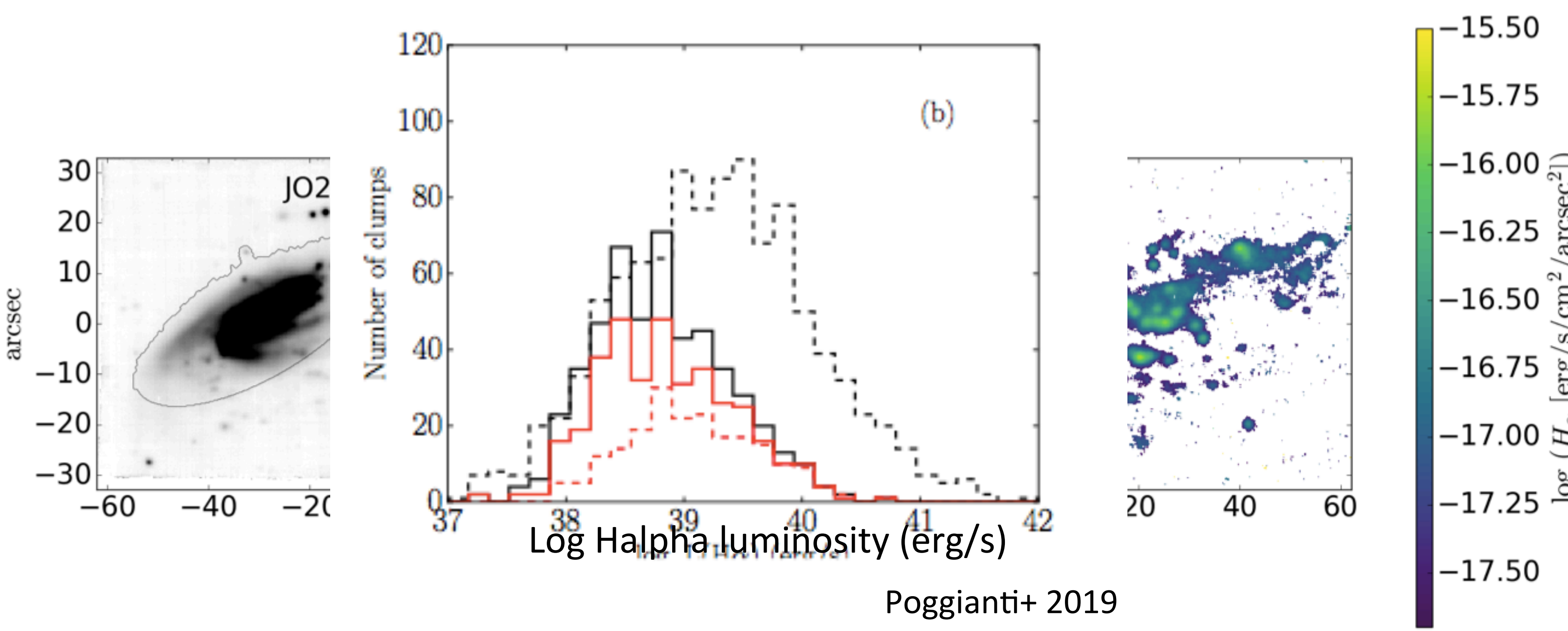
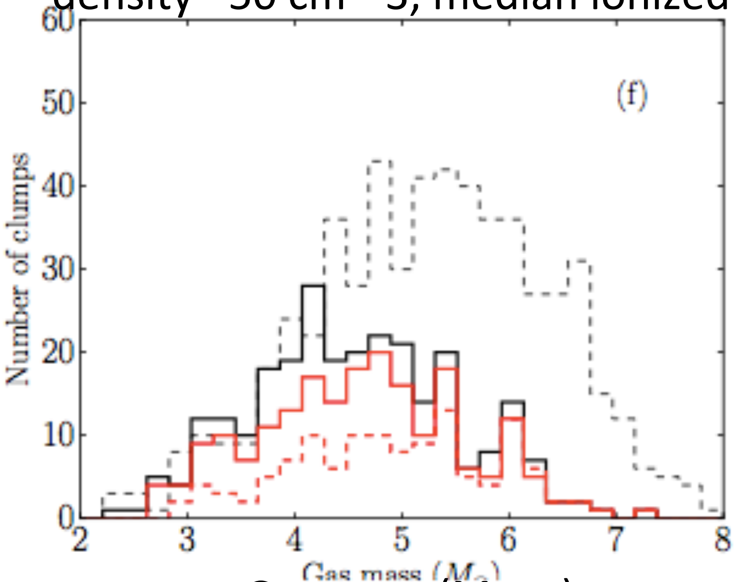
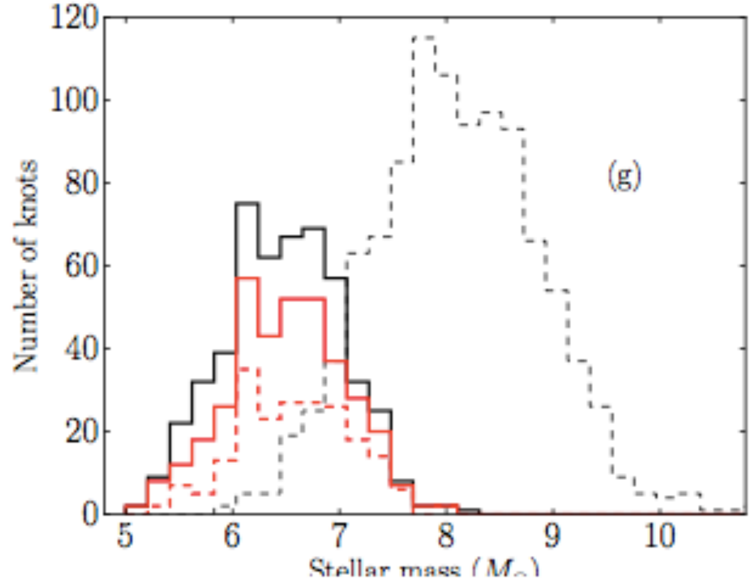


Poggianti+ 2019

Gas densities and (ionized) gas masses of clumps quite high. Median gas density ~50 cm^-3, median ionized gas mass 4X10^4 Msun.



Gas mass (Msun)



Stellar mass (Msun)

Median stellar mass 3X10^6Msun

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

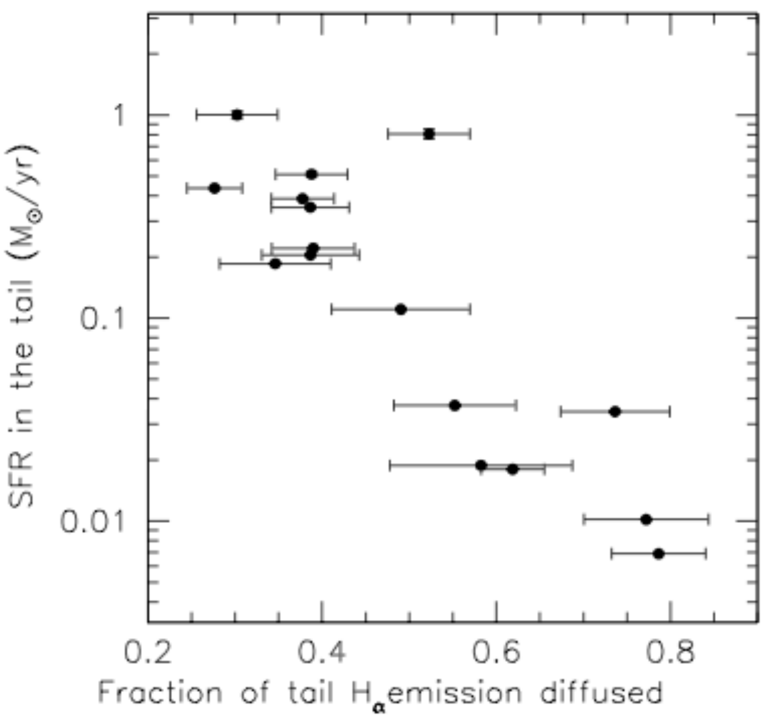
SF in stripped tails contributes to ICL !

Poggianti+ 2019

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 "LINER-like" emission component from [OI] line: thermal heating from ICM?

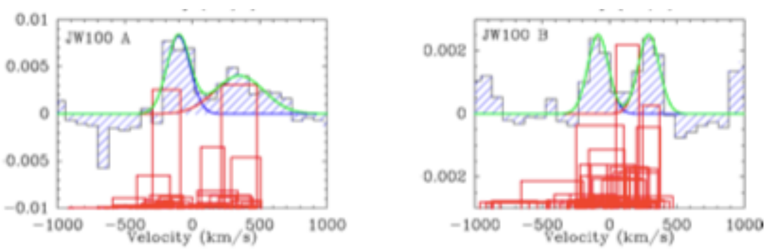
Diffuse emission due to lower luminosity HII regions, or to photon leakage from SFing clumps? Average escape fraction is 18% (ranging between 6% and 46%)



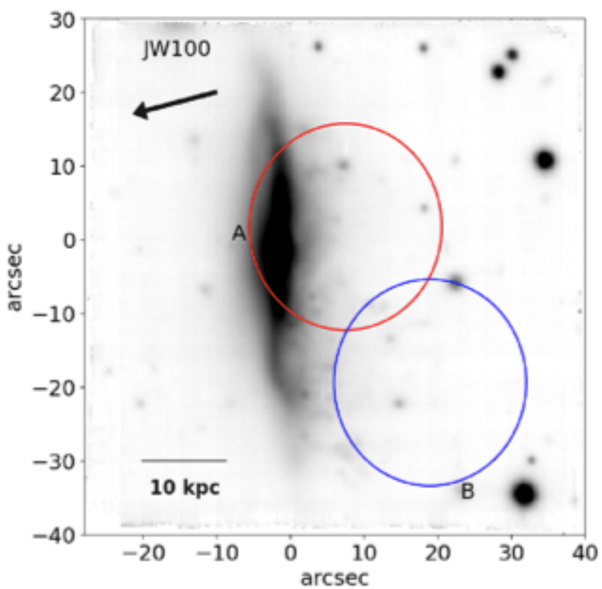
The SFR in the tails is typically a few percent (2-5%), and up to 20%, of the total SFR.

Poggianti+ 2019

STAR FORMATION AND ITS RELATION WITH GAS:
MOLECULAR GAS



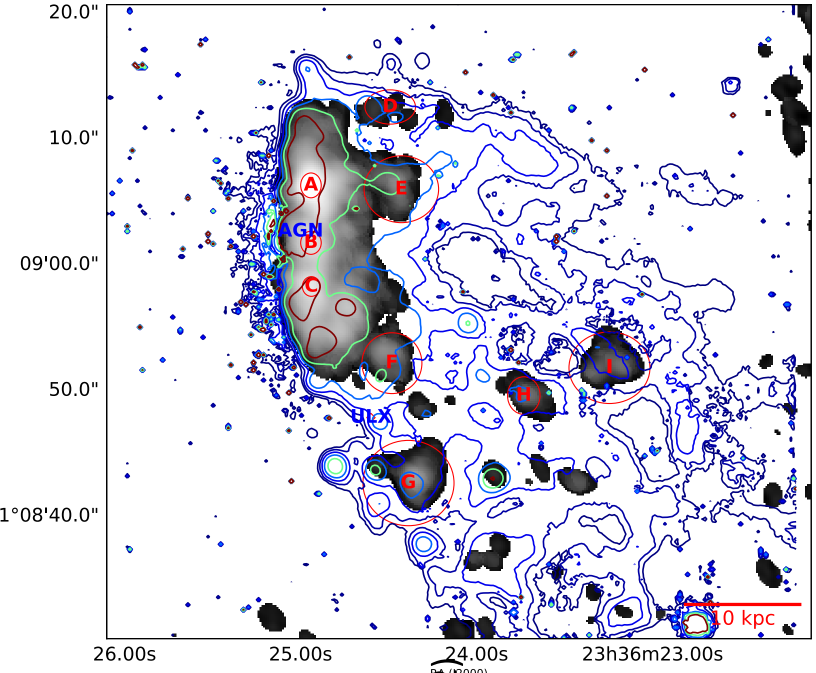
Large molecular gas masses in the tails, and in the disks – 8 galaxies published so far with low spatial resolution, large beam



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

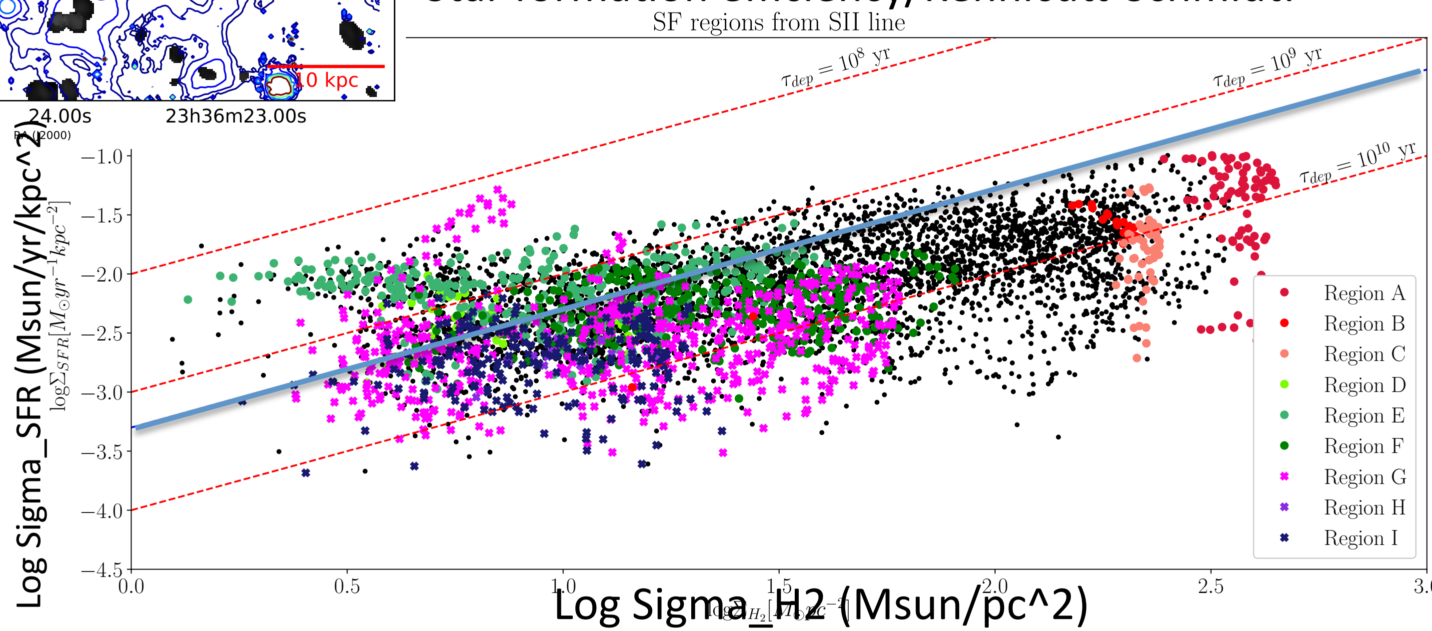


NOW ALMA!!

Individual CO clumps can be studied.

Large amounts of CO up to 35kpc from galaxy center: 5X10^7 to 8X10^8 Msun.
In the tail, mol. gas much more diffuse (larger scales)

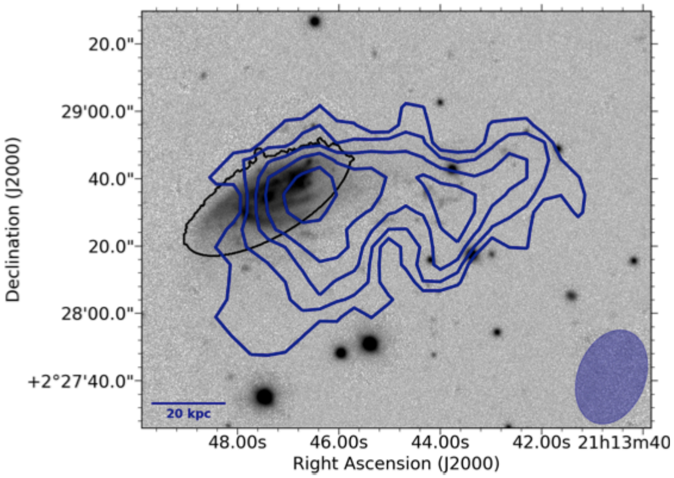
Star formation efficiency/Kennicutt-Schmidt:

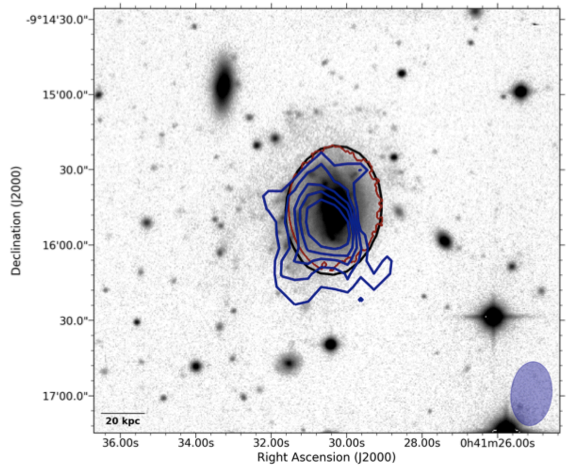


Moretti+ in prep.

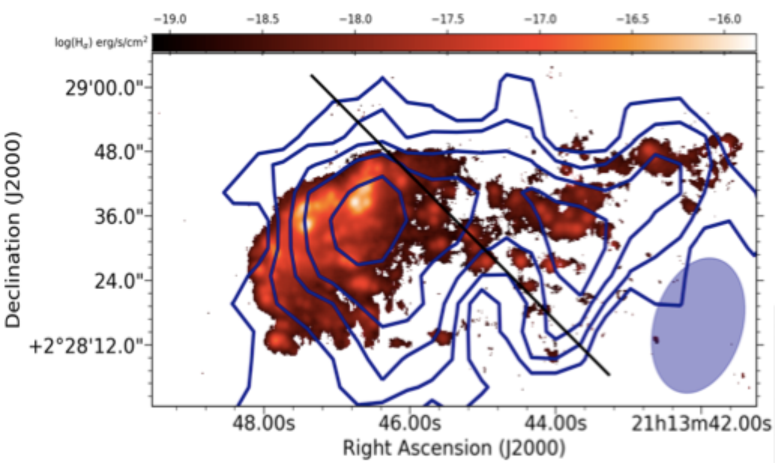
HI GAS

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

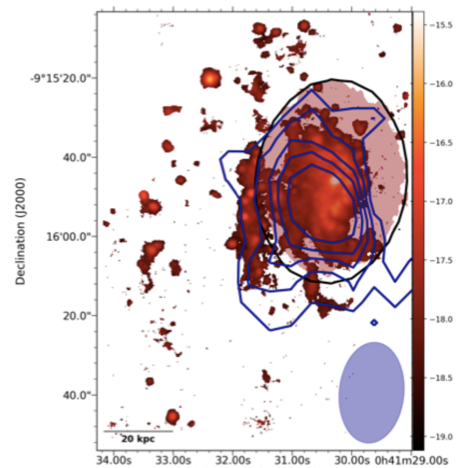




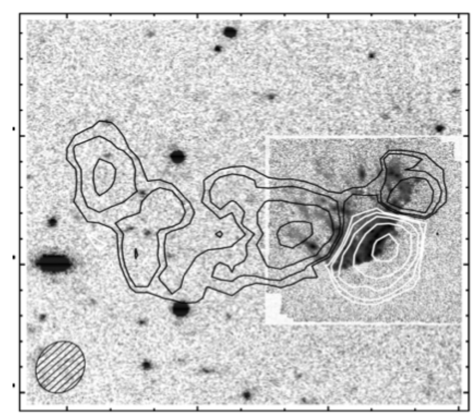
JVLA C-array



Ramatsoku+ 2019

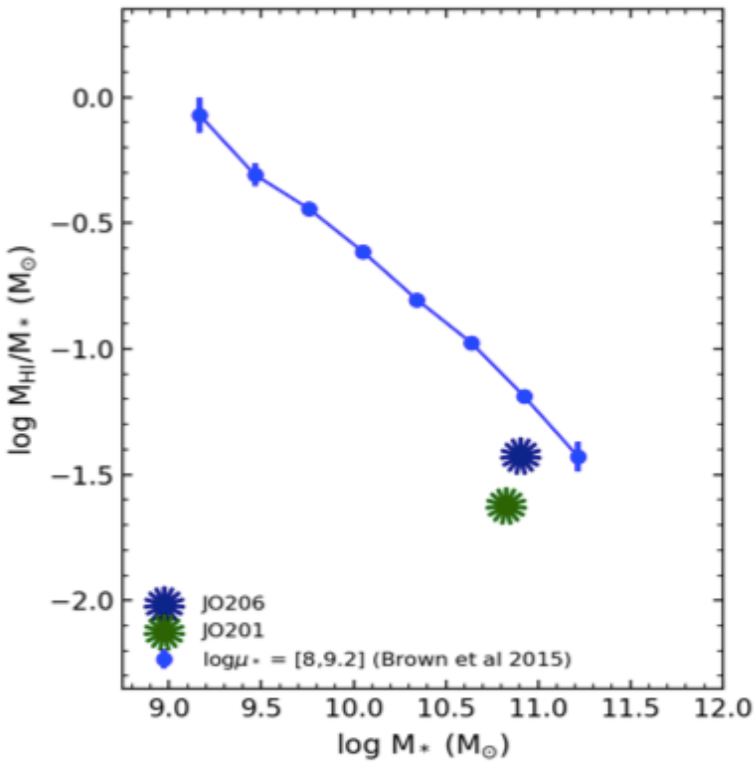


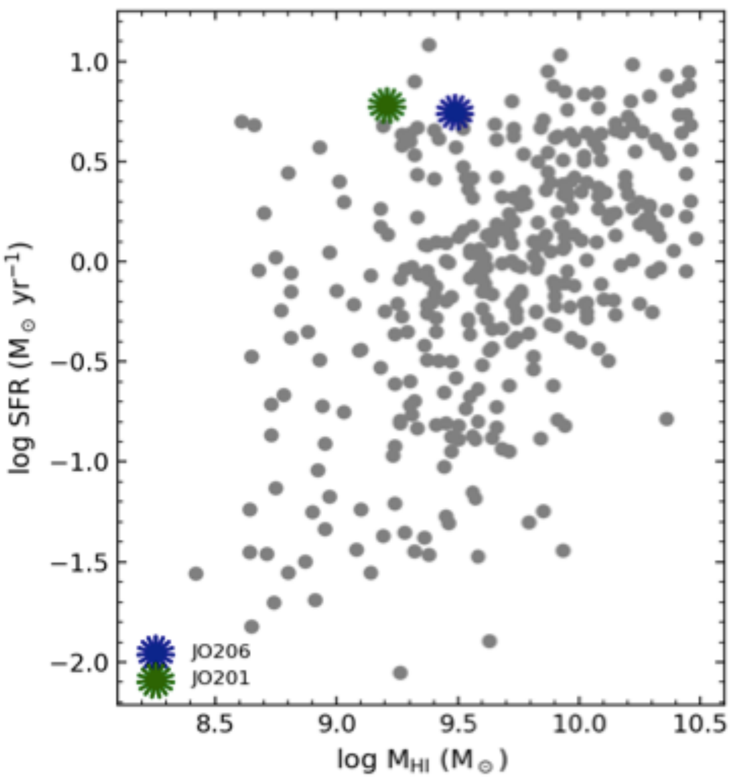
Ramatsoku+ in prep.



Deb, Verheijen+ in prep.

HI GAS

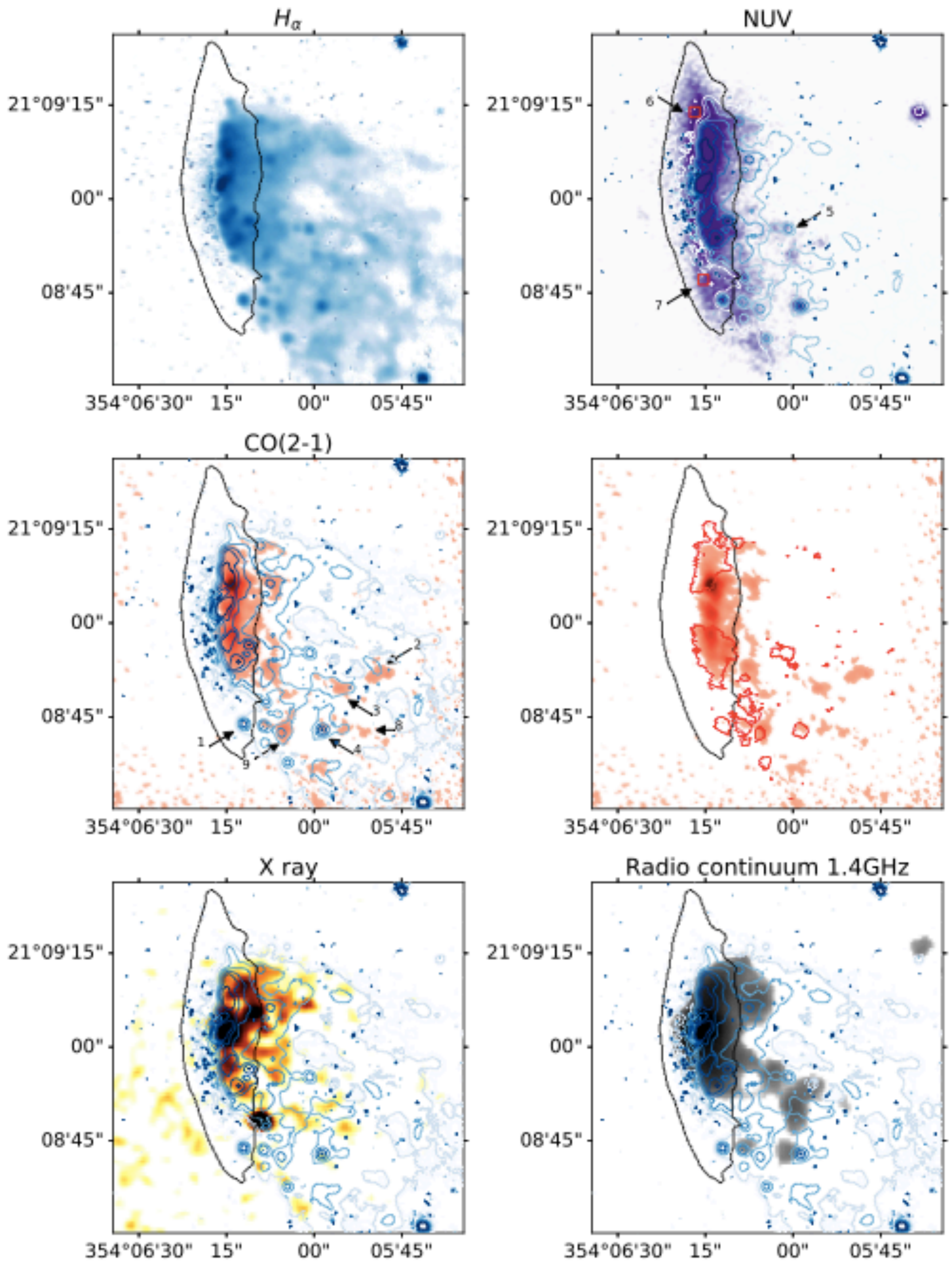


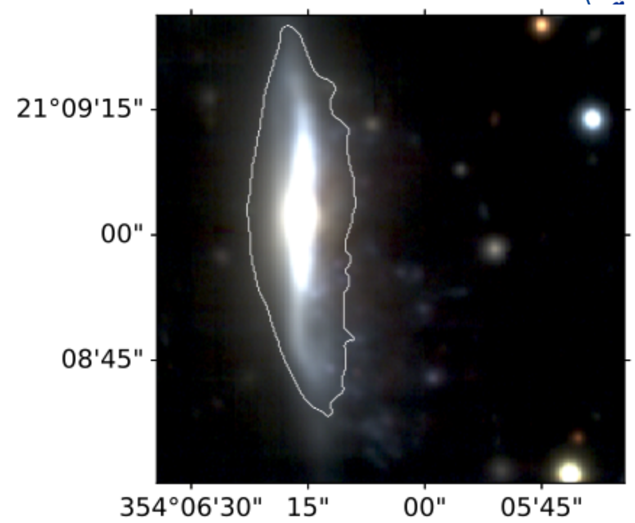


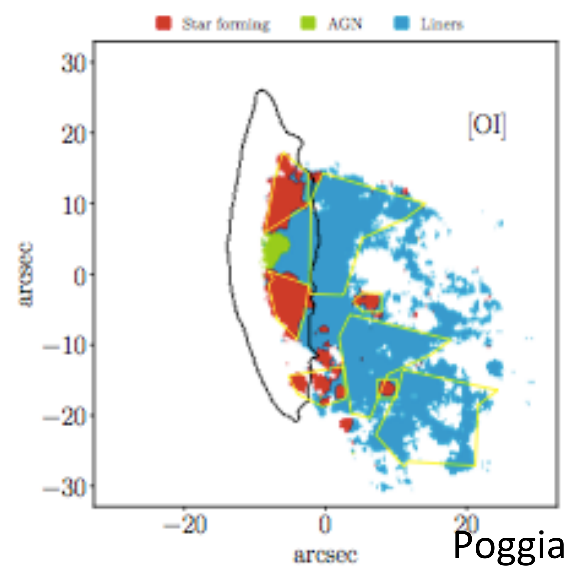
Ramatsoku+ 2019, and in prep.

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

Multi-wavelengths tails: an astrophysical laboratory



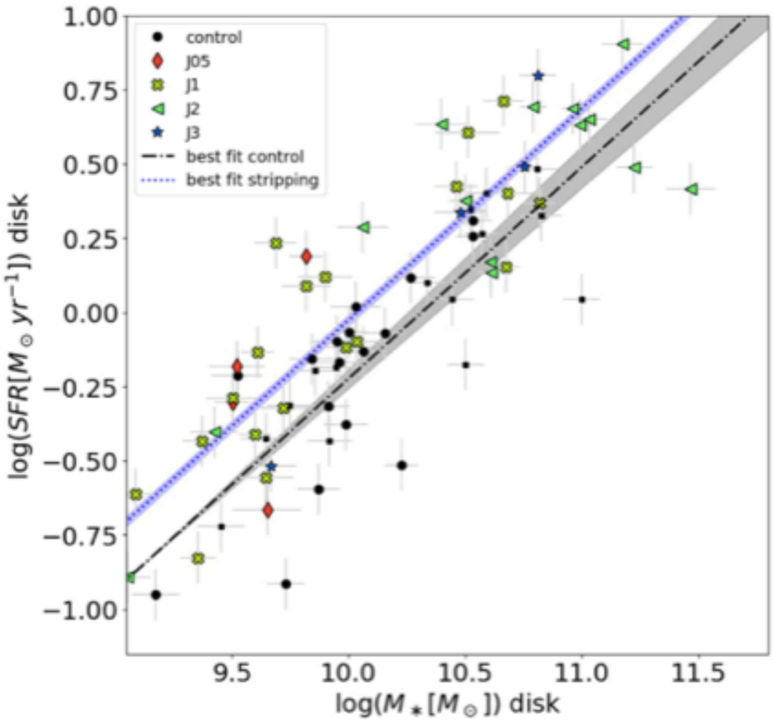




Poggianti+ in prep

(enhanced) STAR FORMATION IN THE DISK

Log SFR (disk)

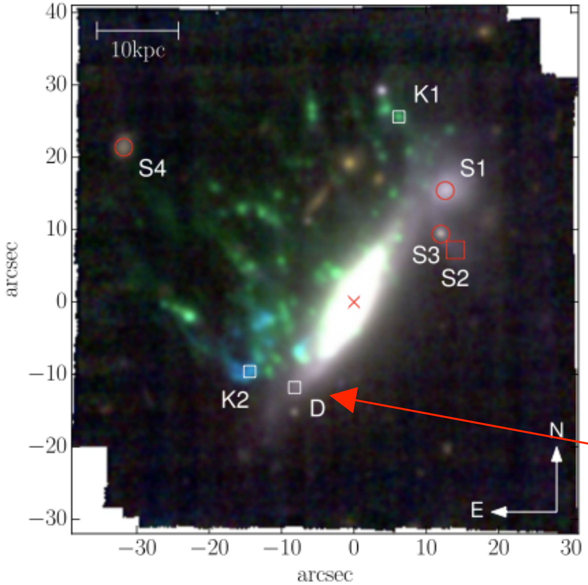


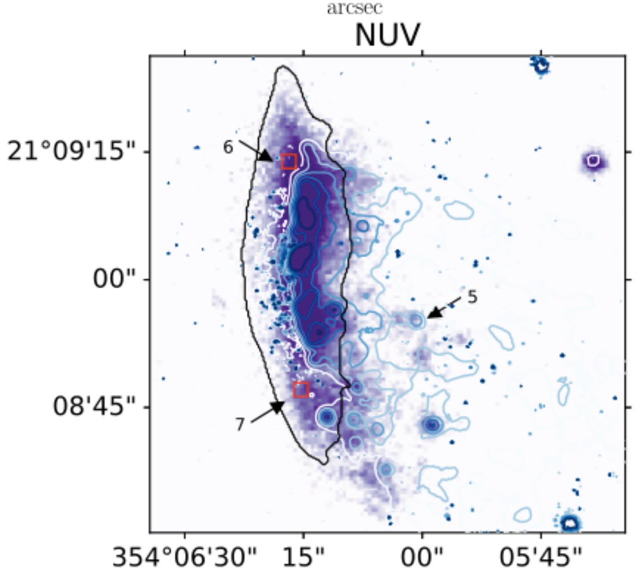
Log M*

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

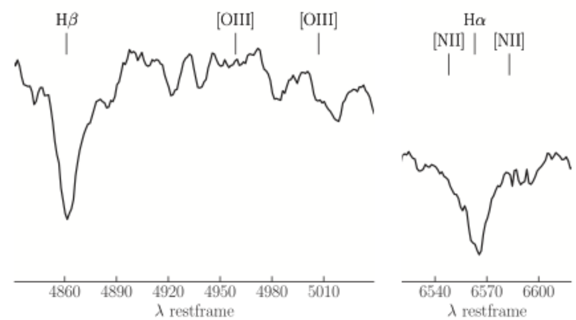
Vulcani+ 2018c

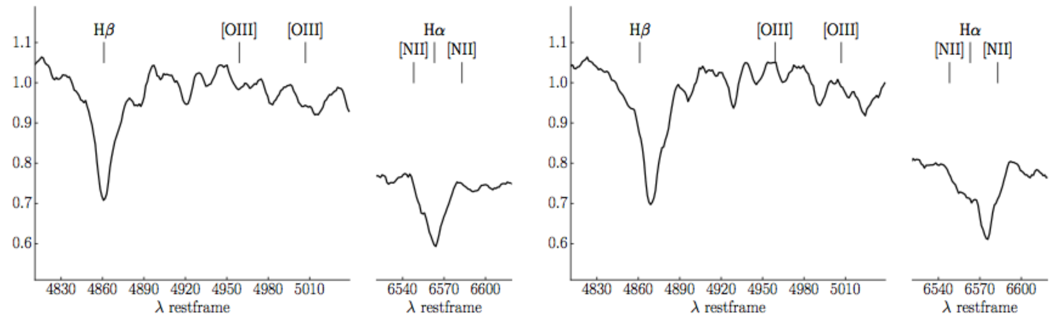
QUENCHING:
POST-STARBURST SIGNATURES





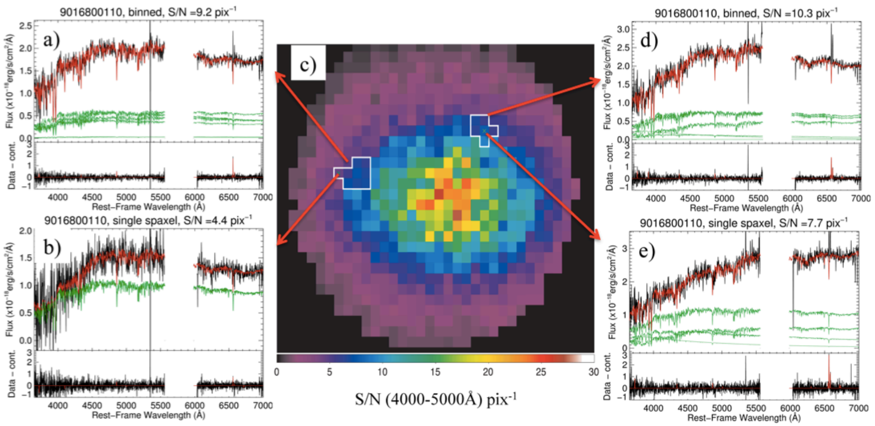
"Local post-starburst" signature: outer regions of disks undergoing stripping





Gullieuszik+ 2017

QUENCHING:
POST-STARBURST SIGNATURES

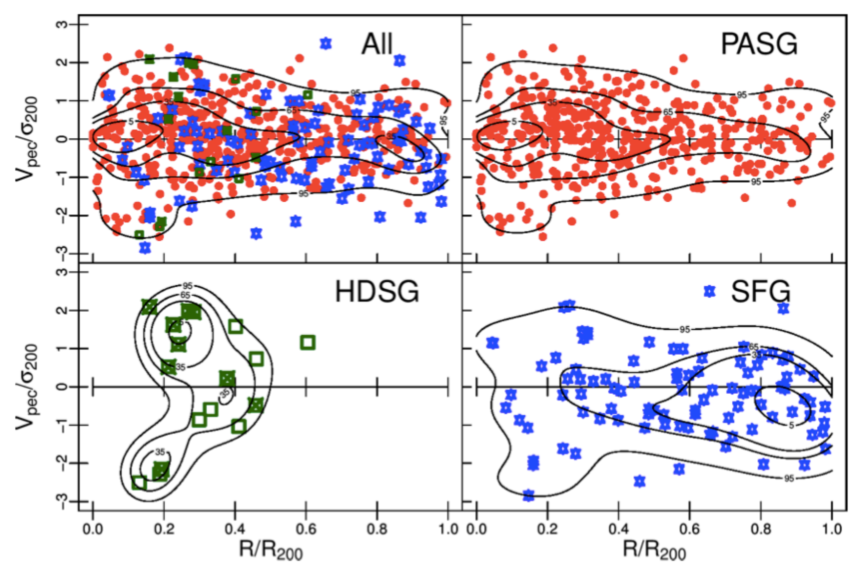


In SAMI, 17 galaxies in clusters: a mix of local post-starburst (with SF in their centers) and global ones

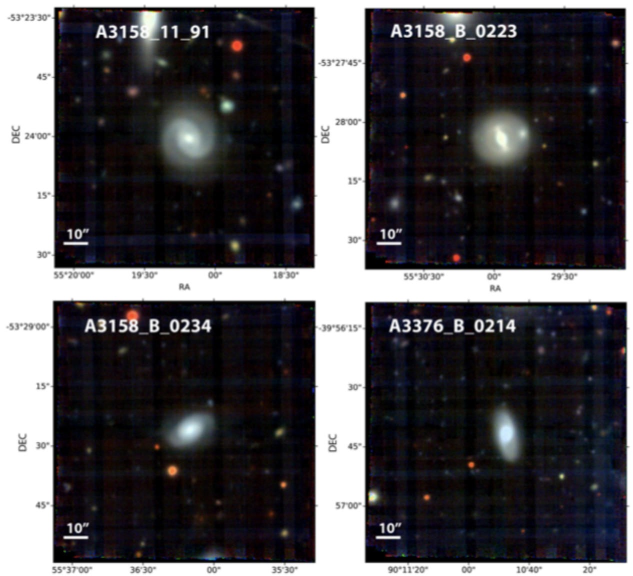
All within 0.6R200, outside-in quenching in galaxies at first infall

Owers+ 2019

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

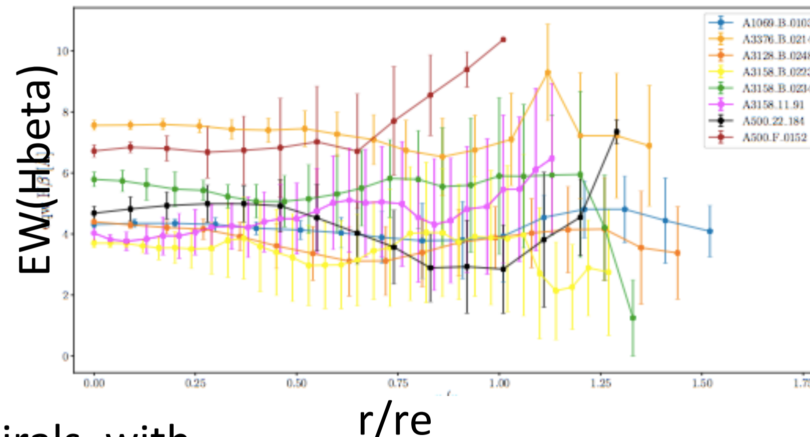


POST-STARBURST SIGNATURES: NO (ionized) GAS and NO SF LEFT

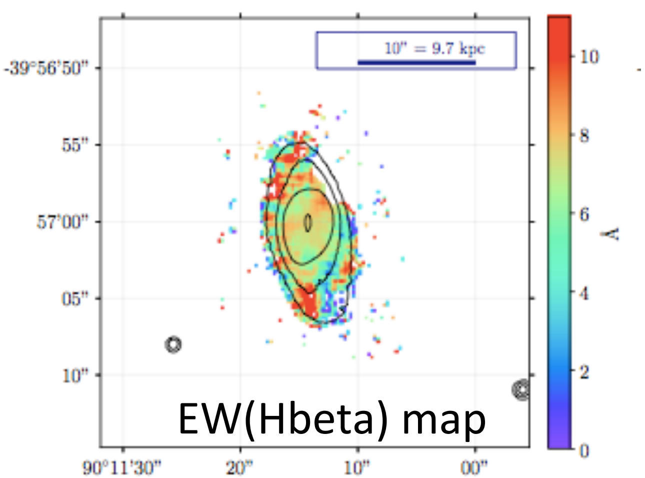


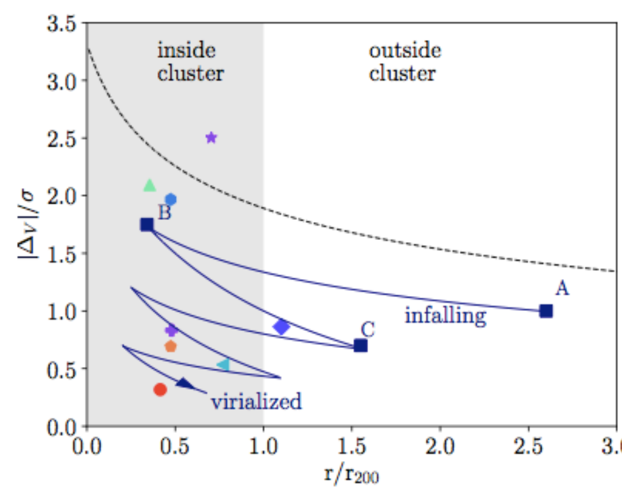
Can ram pressure halt the SF completely?

Oh, yes!



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

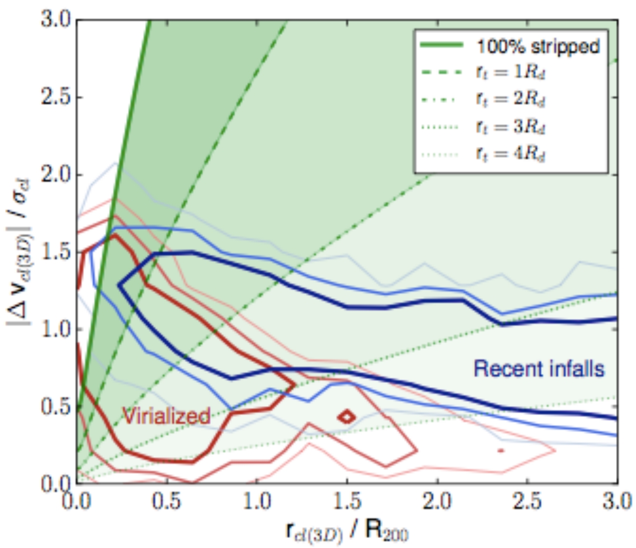




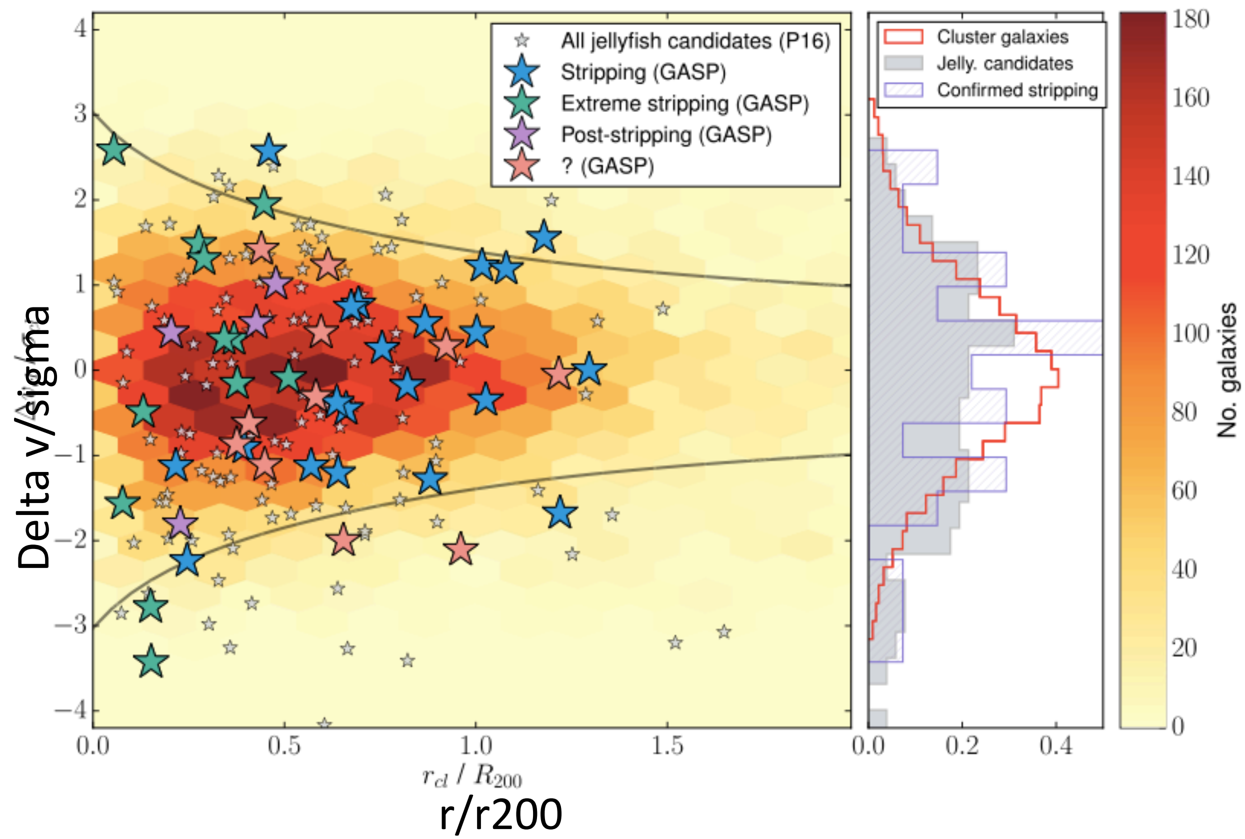
Santorelli 2018, Vulcani+ in prep.

JELLYFISH GALAXIES ON FIRST INFALL AND RADIAL ORBITS

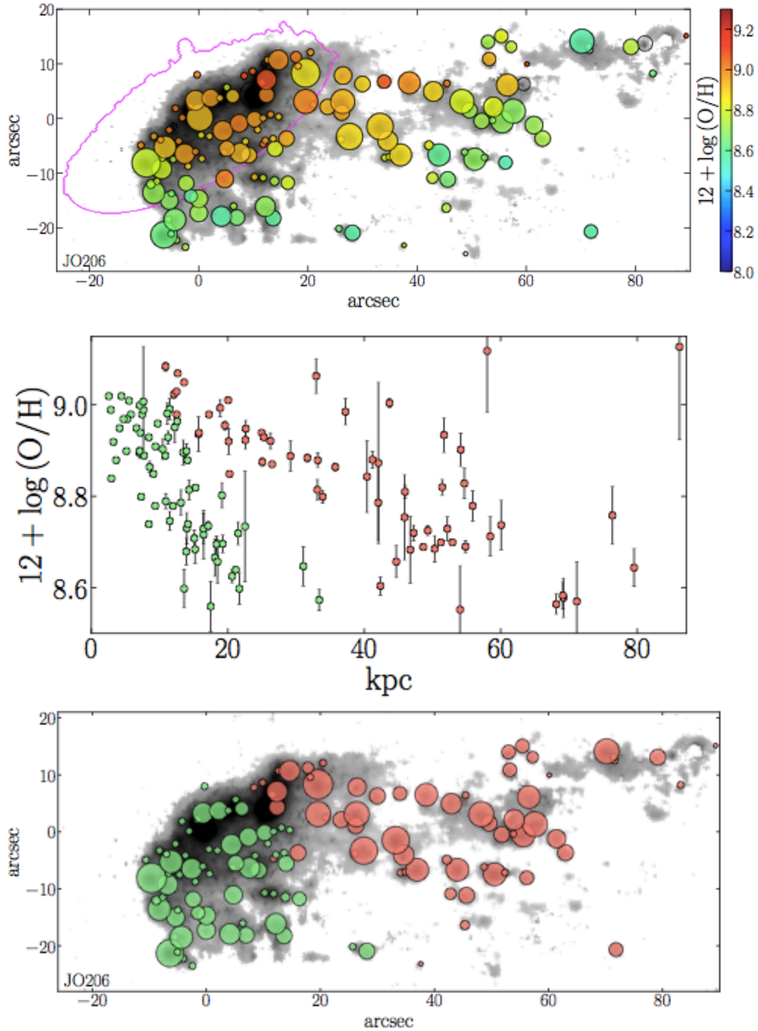
Those with the longest tails have very high peculiar velocities and small projected cluster-centric radii



Jaffe'+ 2018

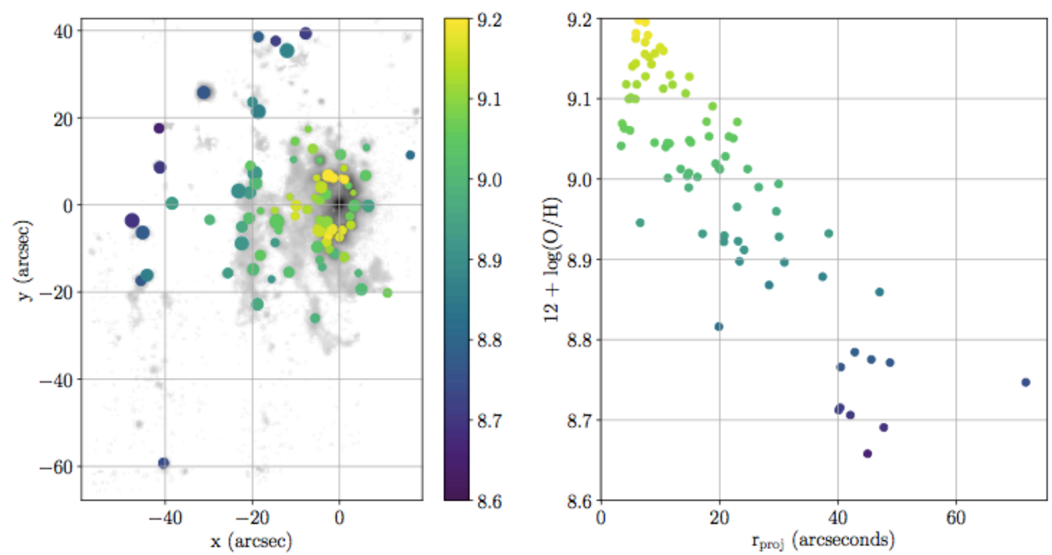


ENRICHMENT WITH METALS



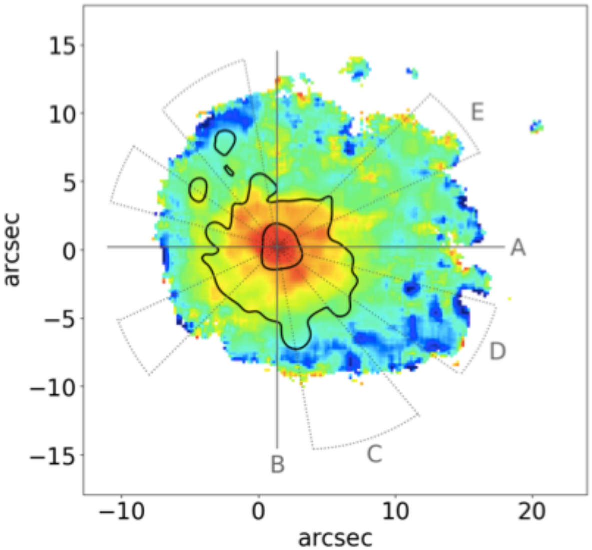
Franchetto+ in prep.

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



Bellhouse+ 2019

ENVIRONMENT outside clusters: GROUPS and ISOLATED GALAXIES

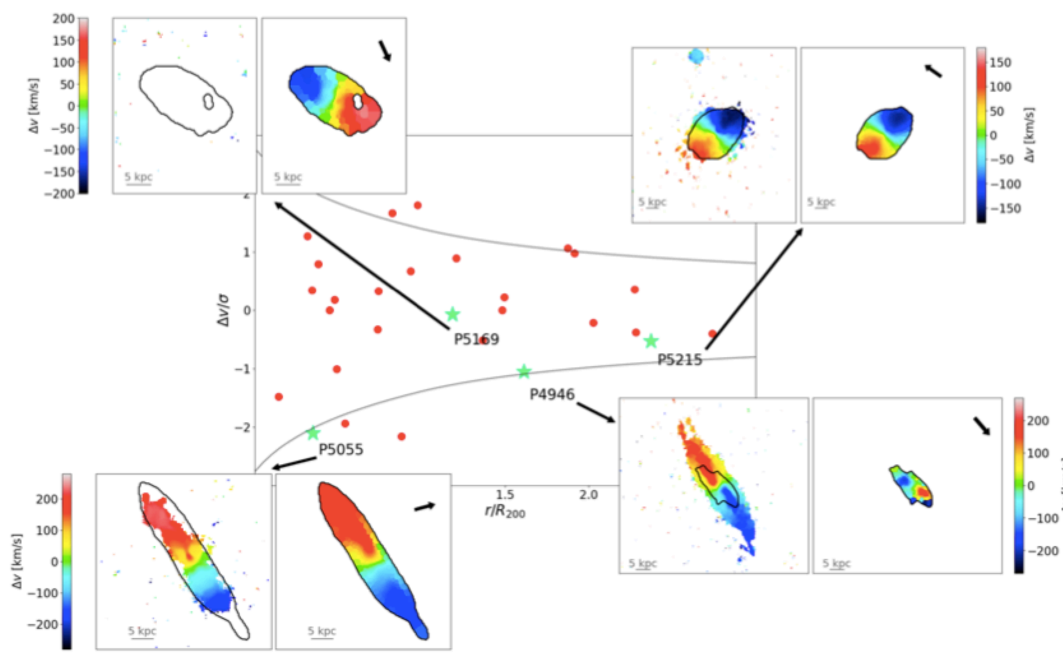


Evidence for gas accretion in an isolated spiral

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