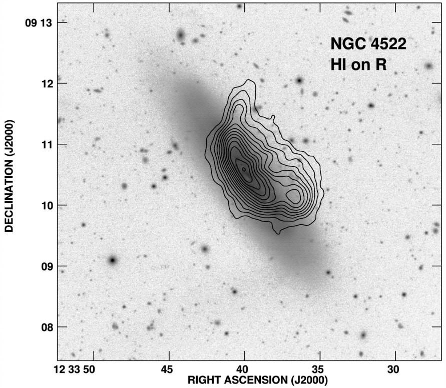
Ram-pressure stripping galaxies at different cosmic Ages: results from the GASP survey and future developments

Marco Gullieuszik

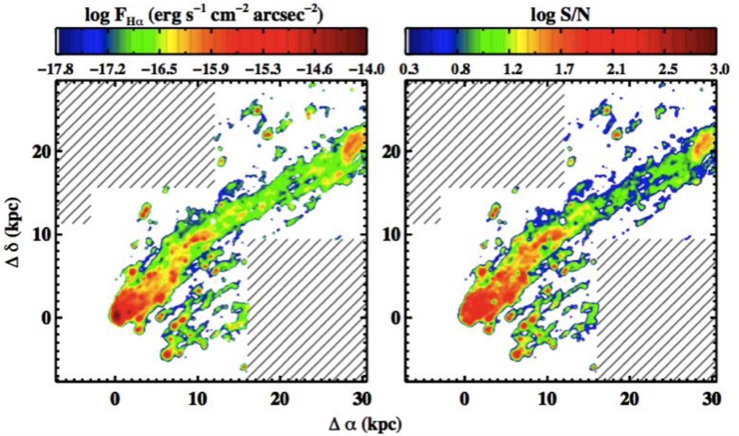
Ram-pressure stripping galaxies



Observational evidence for gas stripping in clusters from:

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

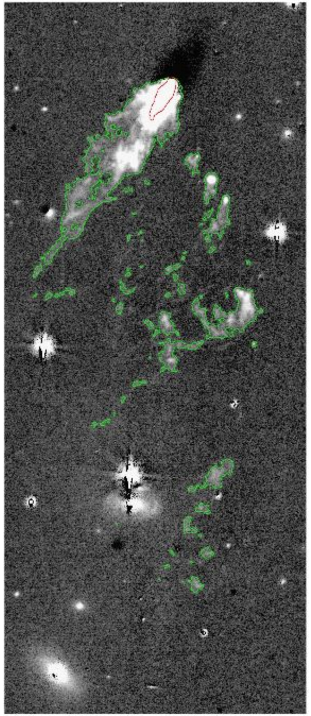
HI - Kenney+2004, Virgo cluster



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

First systematic searches for stripping candidates from optical images:

- Poggianti+2016 (low-z)
- McPartland+ 2016 (interm.-z)



Halpha imaging, Yagi+ 2010, 2017, Coma cluster

GASP - The Team

GAs Stripping Phenomena in galaxies

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

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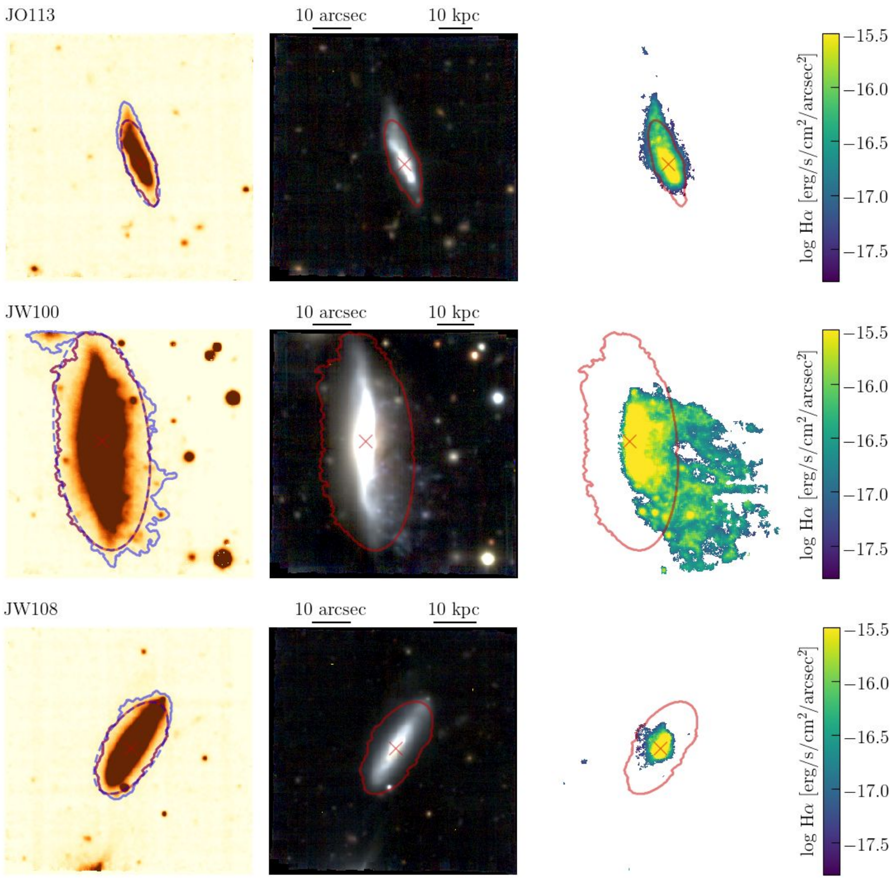
This project has received funding from the European Research Council (ERC) under the Horizon 2020 research and innovation programme (ERC Advanced Grant, grant agreement N. 833824)

GASP - The sample



114 galaxies at z~0.05

- 64 stripping candidates from Poggianti+2016
- 12 control sample cluster galaxies
- 38 galaxies in low-density environments

➔ Stellar mass: 10^{9} $10^{11.5}$ $M_{\odot}$

➔ Host halo mass: 10^{11} $10^{15.5}$ $M_{\odot}$
(field, filaments, groups, clusters)

➔ different stages of stripping to sample the whole stripping history

MUSE ESO Large Programme +

- ALMA/APEX (CO),
- JVLA/MeerKAT (HI),
- UVIT@ASTROSAT (UV)
- HST (UV - optical - Halpha NB)

Ram pressure at play: stellar vs gas kinematics

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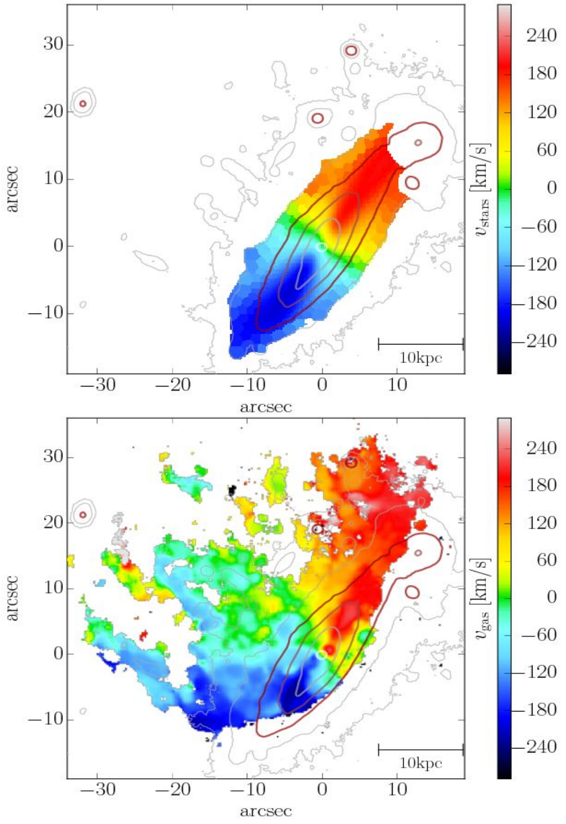
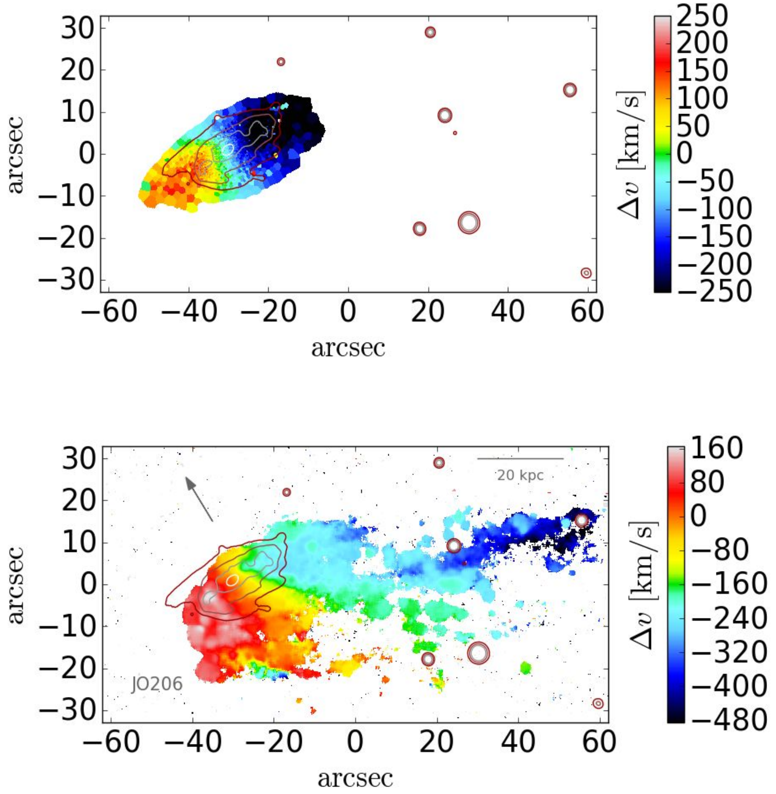


Gullieuszik+ 2017



Poggianti+ 2017

Regular stellar disc kinematics

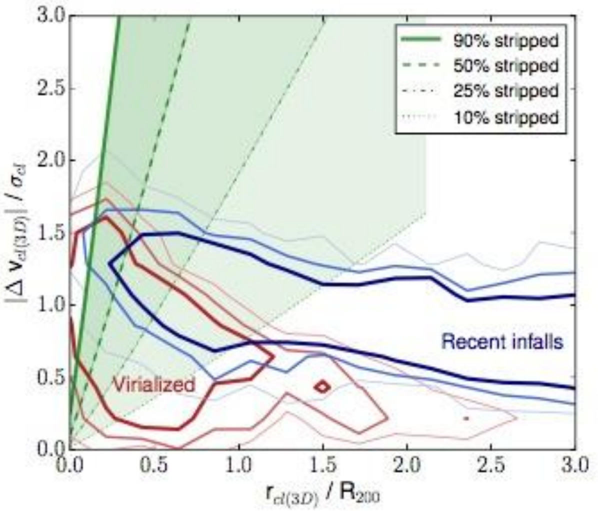
Stripped gas maintains coherent rotation for several kpc downstream

> galaxies are moving at high speed in the ICM

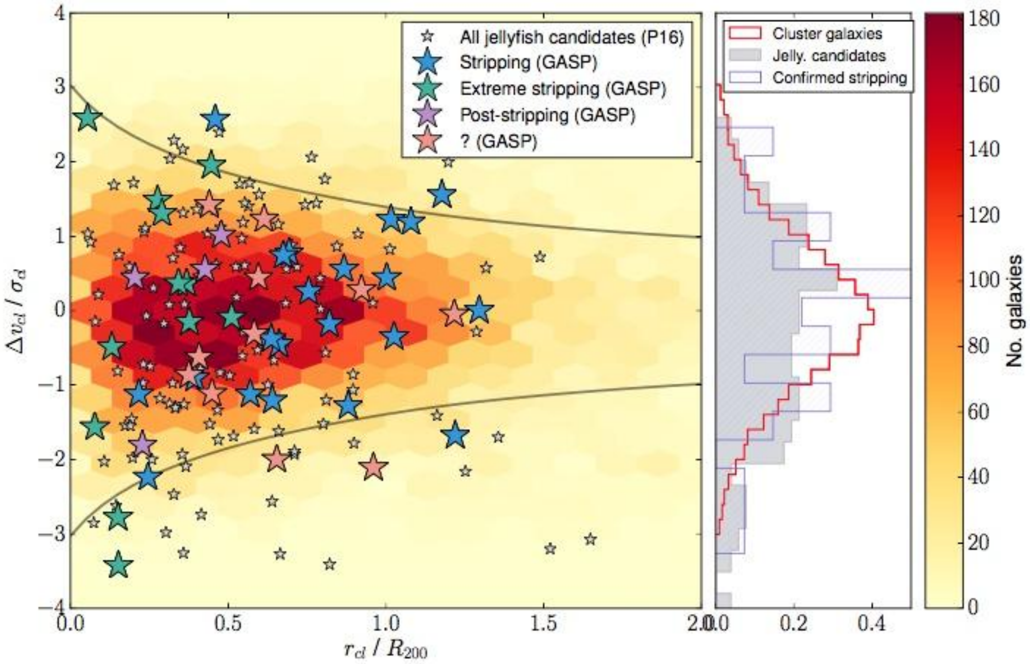
see also
Fumagalli+2014;
Fossati+2016
Consolandi+2017

Phase space analysis

GASP **jellyfish galaxies are first infallers**, and the more extreme are close to the cluster center and have higher velocities (i.e. suffer more intense stripping)

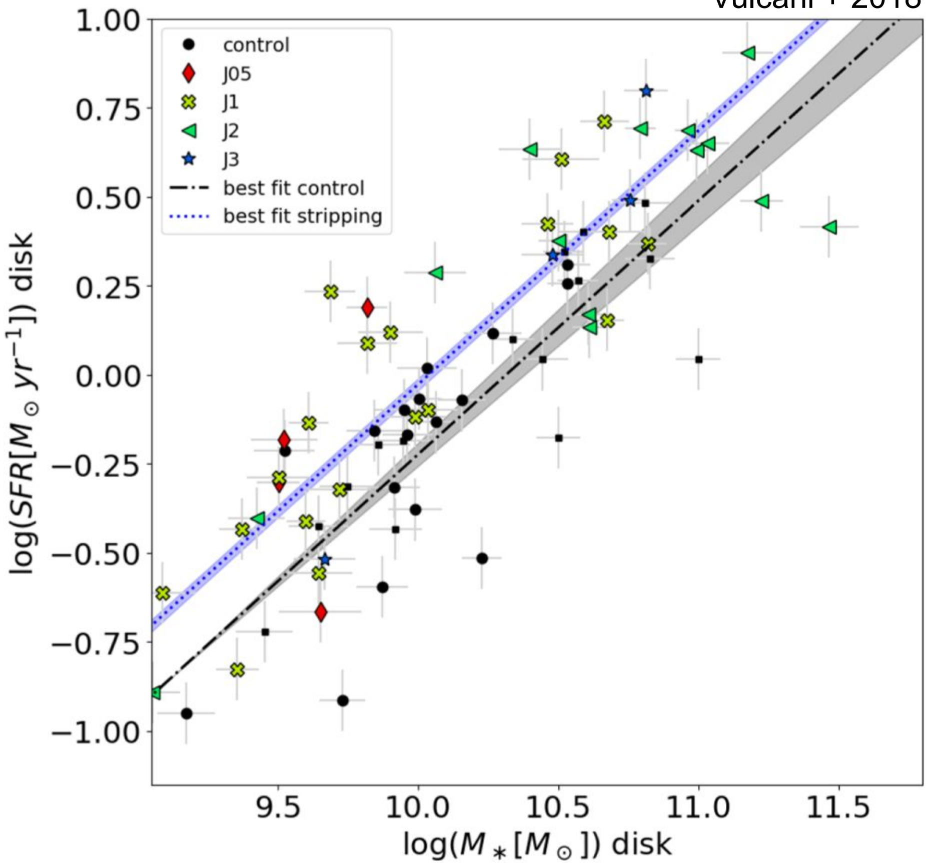


Jaffe' et al., 2018



Enhanced global SFR

Vulcani + 2018



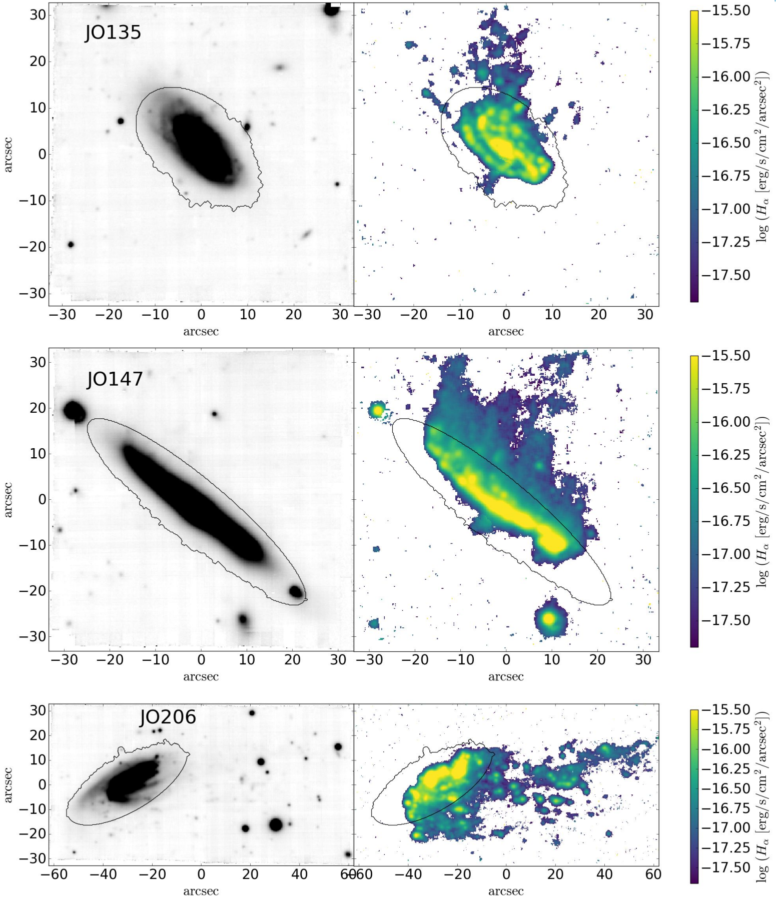
Galaxies undergoing stripping show a systematic enhancement of the *disk* SFR at fixed disk galaxy stellar mass (0.2dex)

in agreement with results from individual objects (Crowl et al. 2006; Merluzzi et al. 2013; Kenney et al. 2014)

This holds also on ~1kpc scales, as shown by spatially resolved SMR-M relation (Vulcani+2020 submitted)

SF in gas outside RPS galaxies

- Galaxies with long extraplanar Hα tails (20-100 kpc long)
- The gas in the tail is ionized by photo-ionization by young massive stars
- The SF take place in bright, dynamically cold (σ=27 km/s) Hα clumps forming in situ in the tails
- The luminosity of Hα clumps is typical of giant (Carina Nebula) and supergiant (30Dor) HII regions
- The median stellar mass in the clump is $3x10^6$ $M_\odot$



Poggianti + 2019

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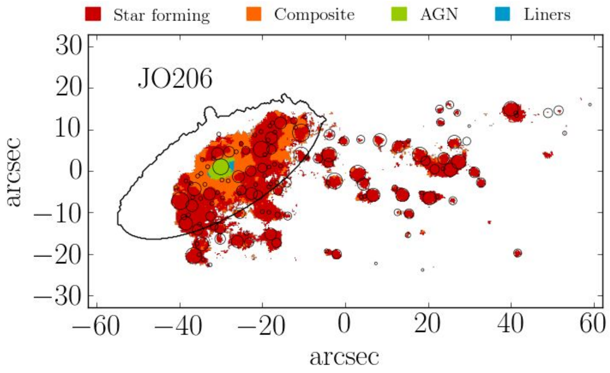

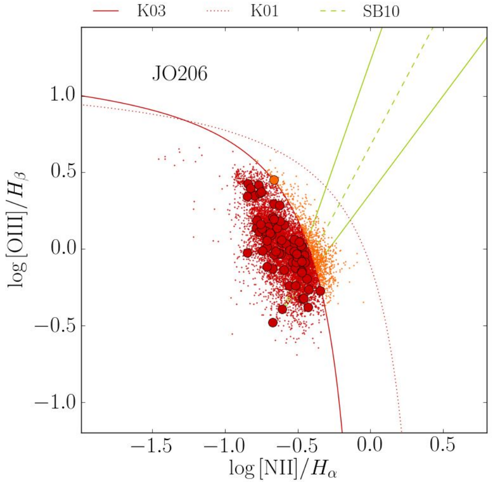

Poggianti + 2019

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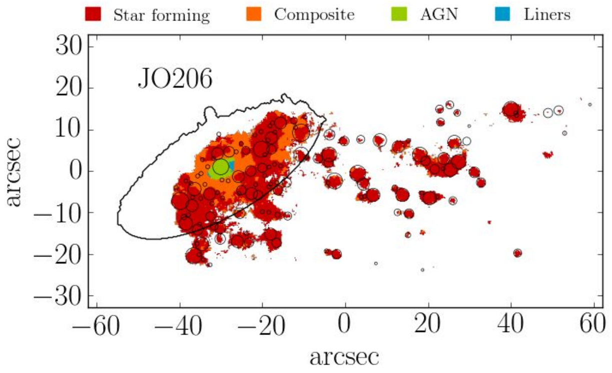

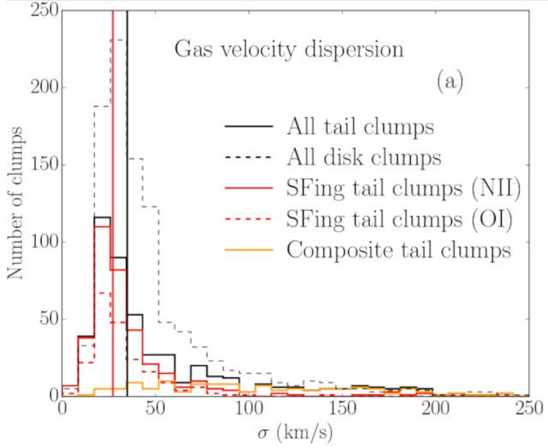

Poggianti + 2019

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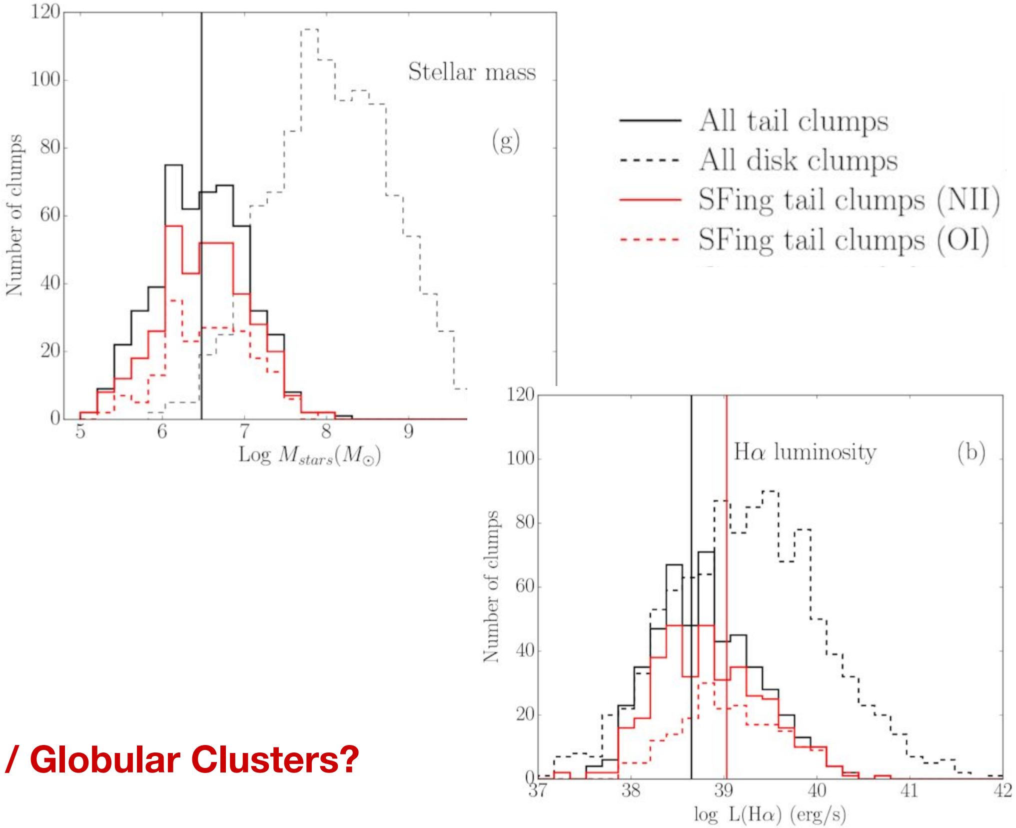
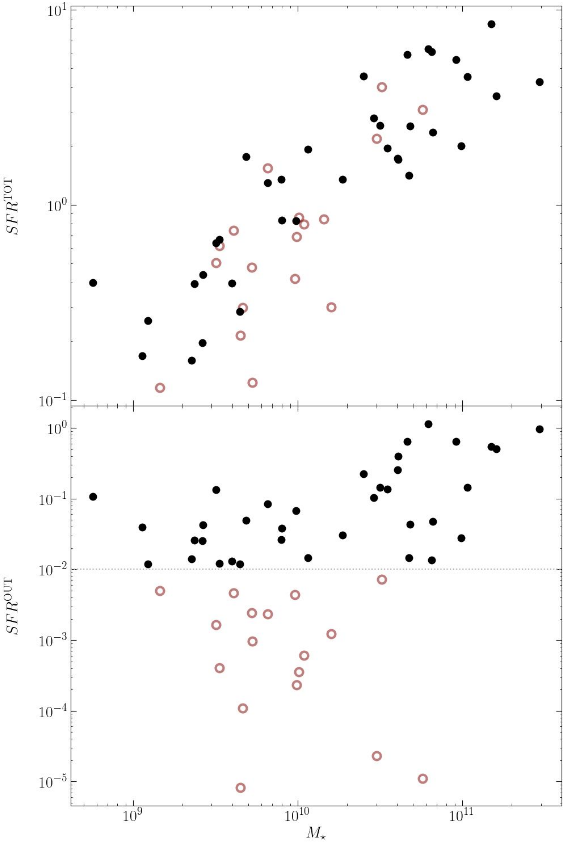


formation of UltraCompact Dwarf Galaxies / Globular Clusters?

Poggianti + 2019

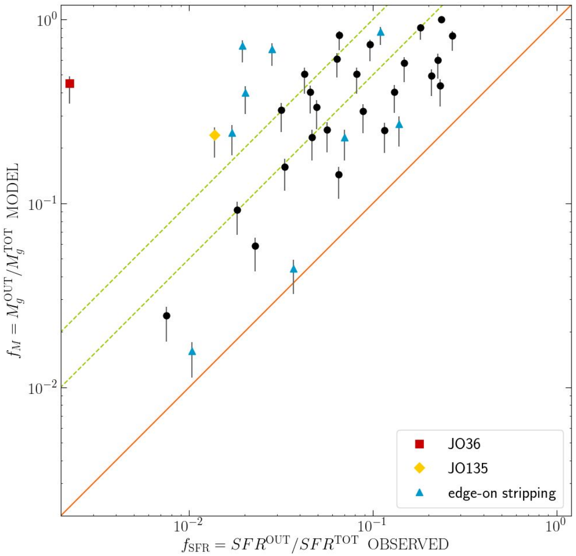
What does the SFR in the tail depends upon?

Gullieuszik+2020



galaxy mass - cluster mass - velocity in the ICM - clustercentric distance

The interplay between all the parameters involved is complex: There is not a single, dominant one in shaping the amount of SFR observed in the tails



Observed fraction of SFR that is "out" follows the fraction of gas mass that is expected to be stripped according to the Gunn&Gott formulation

$$\frac{M^{\rm OUT}}{M^{\rm TOT}} \sim 5\frac{SFR^{\rm OUT}}{SFR^{\rm TOT}}$$

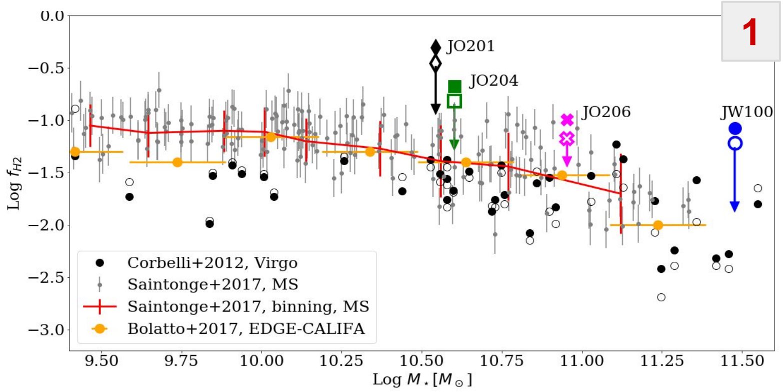
$$\frac{SFR^{\rm OUT}}{M^{\rm TOT}} \sim 5\frac{M^{\rm OUT}}{SFR^{\rm TOT}}$$

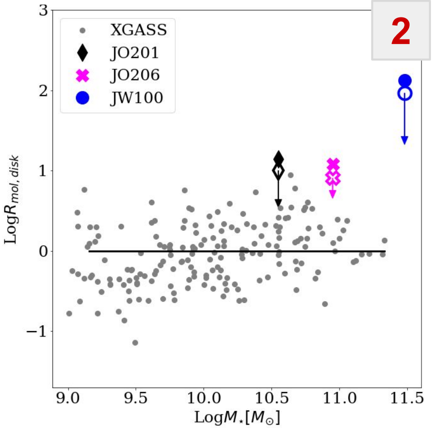
SF efficiency in the tails: a factor ~5 lower than in the disc?

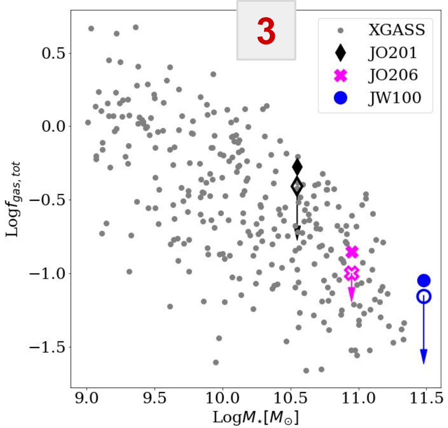
ALMA (CO) results seems to confirm this idea

Neutral and molecular gas

Moretti+ 2020b, Poster n.747







1. Ratio of molecular gas mass over galaxy stellar mass 4-5 times higher than in normal galaxies

2. The ratio of molecular gas mass over neutral gas mass in the disk is 4-100 times higher than in normal galaxies
(see also Ramatsoku+2019,2020; Deb+2020)

3. 3. The total (molecular+neutral) gas mass is similar to normal galaxies of similar stellar mass

Very efficient conversion of neutral gas in molecular gas in jellyfish galaxies

long molecular gas depletion times (several Gyr) corresponding to generally very low star formation efficiencies.

Open questions

When can tails at different wavelengths be observed?

ionized gas, HI, CO, X-ray, radio continuum

How can we reach a complete census of ram pressure stripping?

Is SF a universal process? How does star formation efficiency depends on local conditions?

HST observations (resolution ~70pc) can help

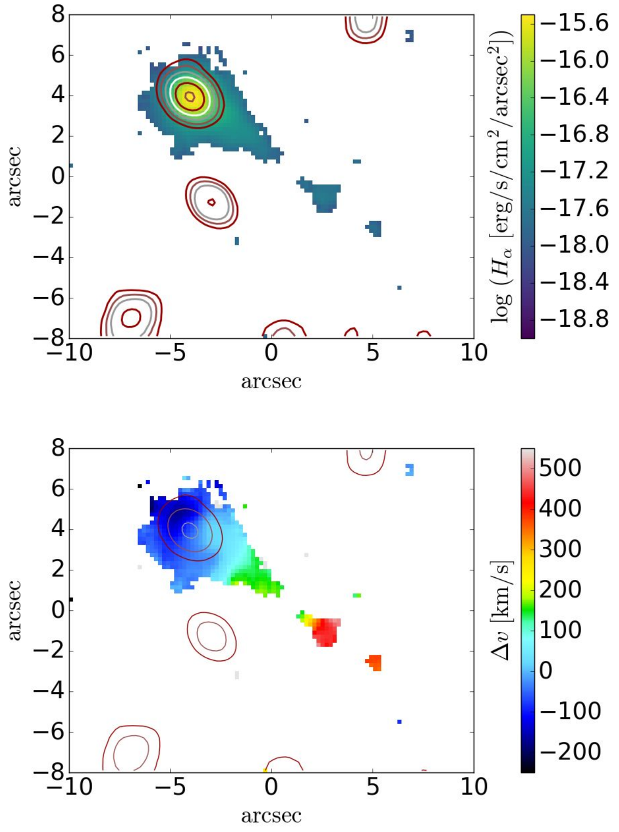
How does ram pressure trigger the AGN?

Inside and outside clusters, what is the role of ram pressure stripping for the evolution of the overall galaxy population? What about other mechanisms?

What is the nature and fate of the extraplanar star-forming clumps?
What is the contribution to the intracluster light and the intracluster medium?
What is the nature of the diffuse emission?
…

How does all this evolve with cosmic time?
at z~1: peak of cosmic SF; higher infalling rate

Ongoing work: RPS at intermediate z



Collaboration GASP team – MUSE GTO team (PI Richard)

See talk J.Richard S4c-n.220

Goal: study the process of ram pressure stripping and the quenching in galaxies in intermediate-redshift clusters (z=0.3-0.7)

Large sample of "Jellyfish galaxies" (with long ionized gas tails) and stripped galaxies identified in the MUSE+HST data: 55 cluster galaxies so far

The MUSE data provides:

- Emission-line maps
- Gas and stellar kinematics
- Dust extinction maps
- Ionization mechanism maps
- Gas metallicity maps
- Stellar populations and star formation histories

Future perspectives with MAVIS

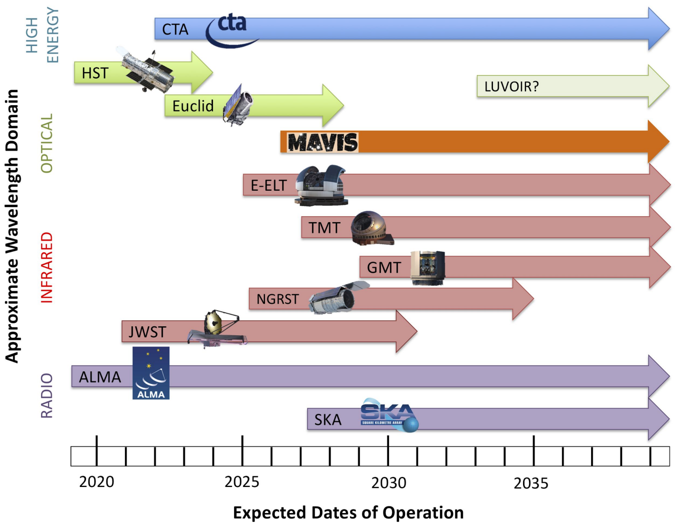
MCAO **A**ssisted **V**isible **I**mager and **S**pectrograph @ VLT
sharper than JWST, deeper than HST

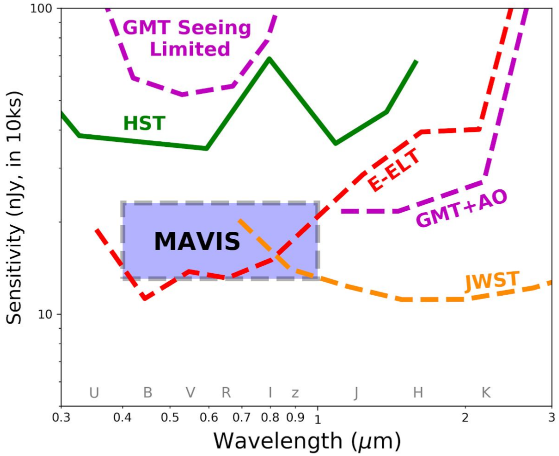
sky coverage: 50% at galactic pole

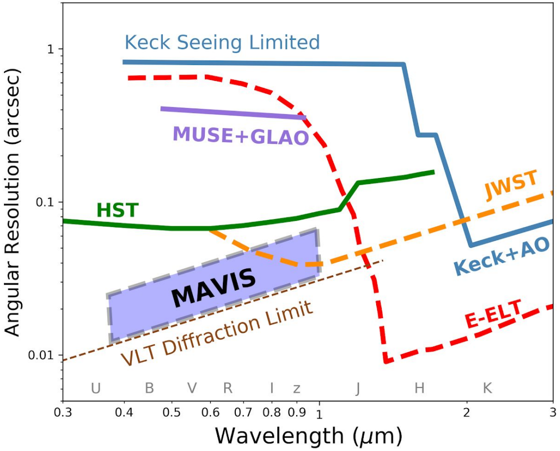
Imager: 30”x30” arcsec (7.4 mas/pixels)

IFU:

- **Fine** Sampling: 20-25mas spaxels, 2.5” x 3.6” FoV
- **Coarse** Sampling: 40-50mas spaxels, 5” x 7.2” FoV





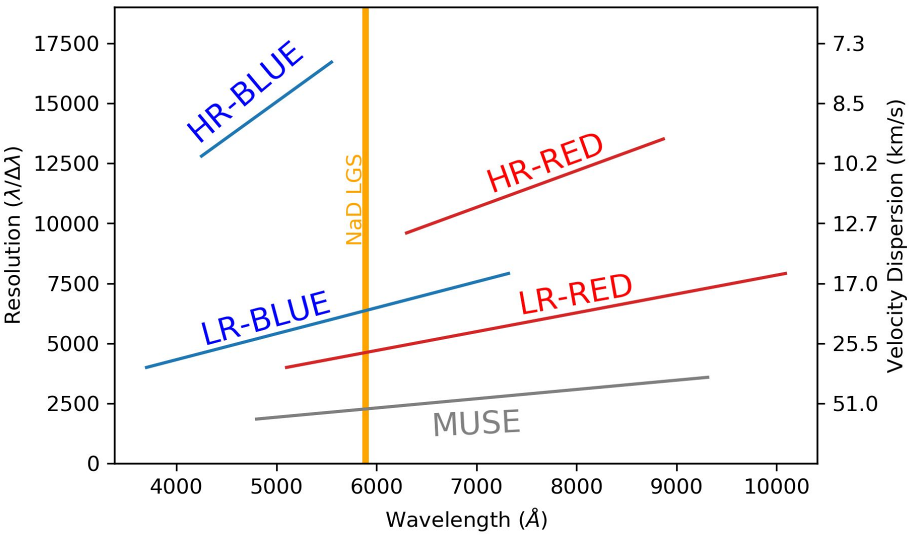


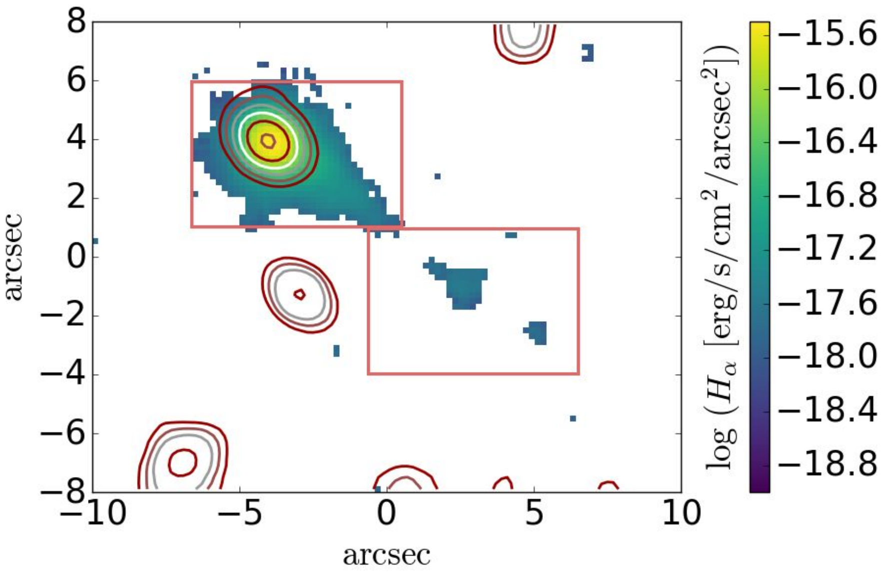
www.mavis-ao.org

PI :Francois Rigaut
Inst. Scientists: Richard McDermid & Giovanni Cresci

Phase A review ongoing
first light ~2026

Future perspectives with MAVIS





MAVIS IFU can map OII, H β and OIII for a significant sample of galaxies preselected from e.g. McPartland+2016 (z=0.4), RELICS survey (z=0.2-1), ESO VLT CLASH (z=0.2-0.5)

2 pointings at z~1, 1 pointings at z~0.4, w. IFU in coarse sampling mode 5”x7.2”;
spatial resolution better than GASP @z=0.05! 50 mas -> 400pc @z=1

Conclusions

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Jellyfish galaxies, and galaxies undergoing stripping in general, are an excellent opportunity to study a plethora of physical processes, testing our knowledge of such processes under extreme environmental conditions

Ram-pressure is the dominant stripping mechanism in the vast majority of GASP cluster galaxies

Star formation: enhanced in the disks, and in-situ also in tails

The observed SFR in the tails can be reproduced using Gunn&Gott prescriptions

Multi-phase gas in disks and tails:

excess of molecular gas, likely efficient conversion of HI into H2

star formation efficiency unusually high for HI, unusually low for H2

other slides

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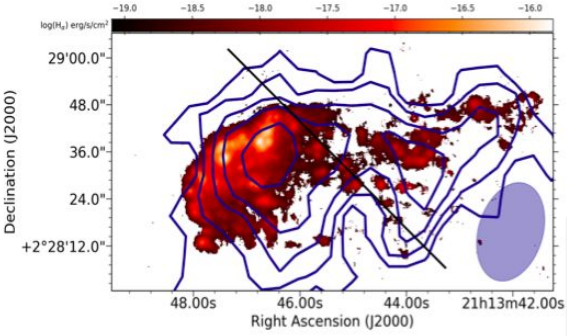
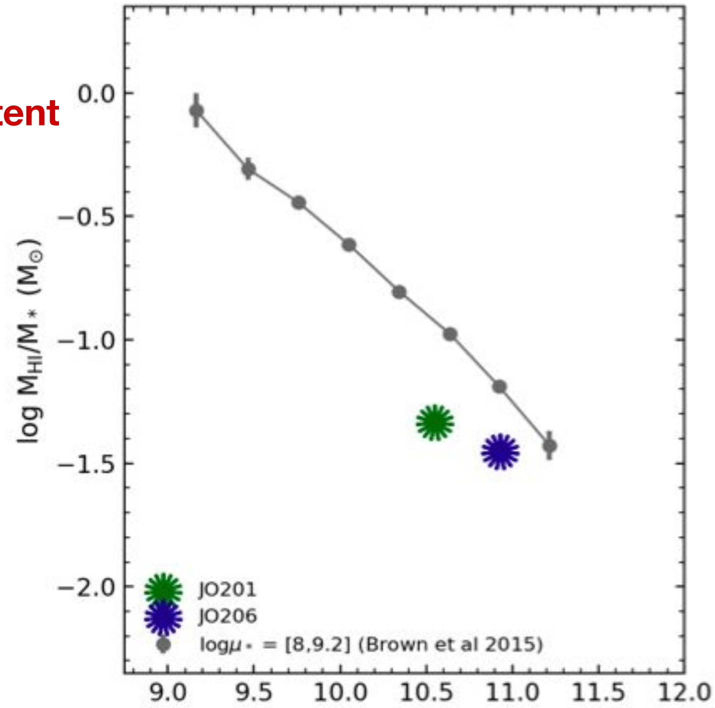
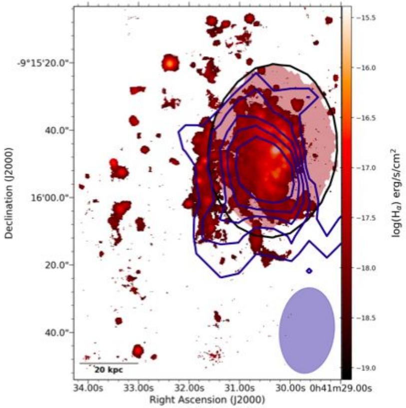
Neutral gas: JVLA

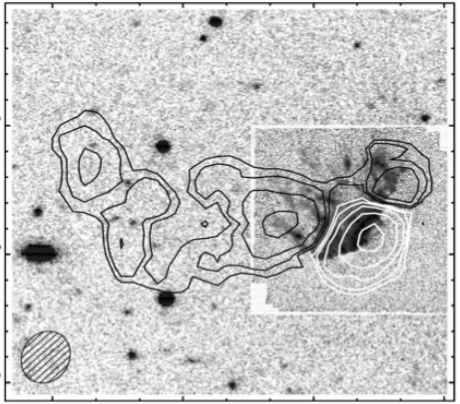
Generally, HI tails present in galaxies with Hα tails – but HI and Hα tail morphologies can be very different



- **Slightly HI-deficient**
- **SF excess for their HI content both globally and locally**





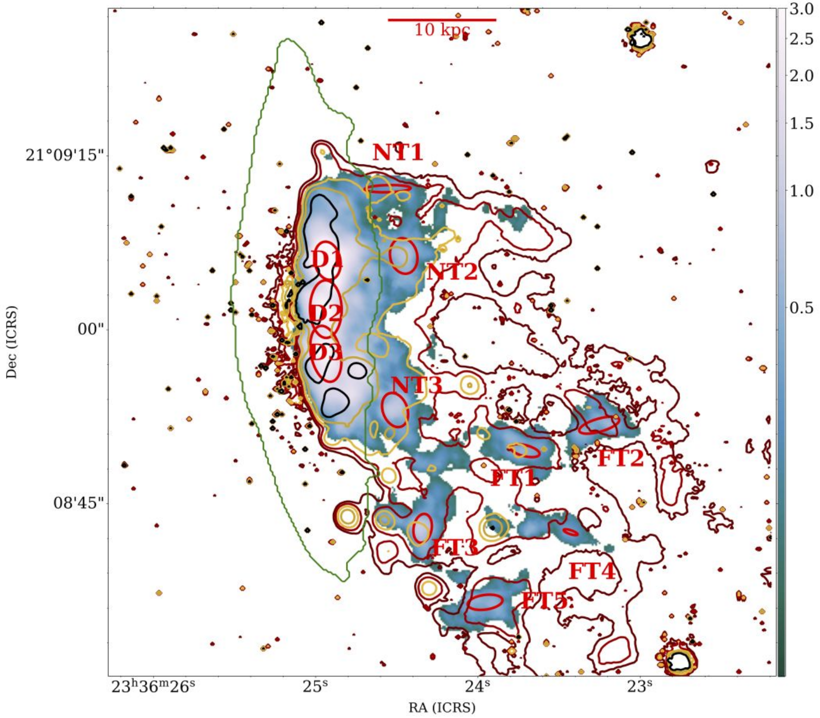


Ramatsoku+ 2019,2020; Deb+2020

log M* (M⊙)

Molecular gas in the disc: ALMA

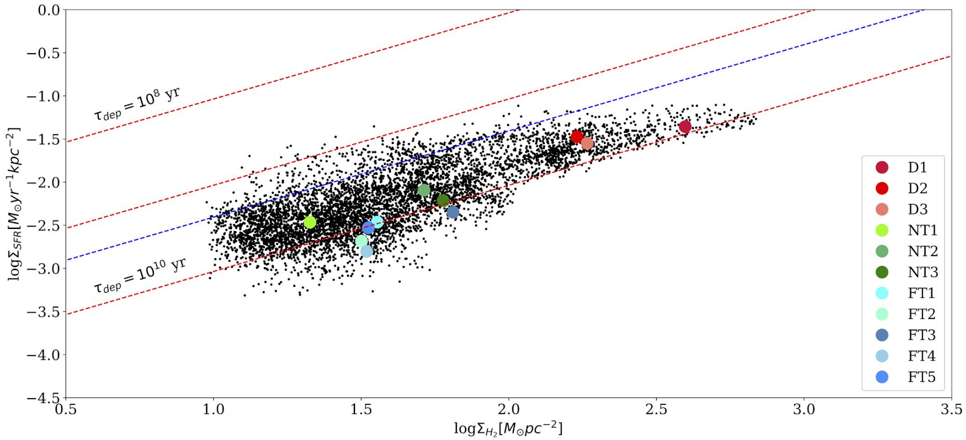
Moretti+ 2020a



CO(2-1) emission + Hα contours

Individual CO clumps can be studied: from 10^7 to 10^9 $M_\odot$ clumps.
In the tail, molecular gas much more diffuse (larger scales)

Molecular gas formed in the tails
> close to the disk it can be stripped gas



SFR density vs molecular mass density in the **D**isk; **N**ear **T**ail; **F**ar **T**ail

Star Formation efficiency lower than “normal” galaxies
SFE is lower in tails than in jellyfish disks.