Extremely Big Eyes on the Early Universe

9-13 September 2019

Rome

The effects of the ICM on gas, dust and star formation histories: lessons learned from integral-field spectroscopy at low redshift

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On behalf of the GASP team

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20 ANNI DI RICERCA SCIENTIFICA DI ECCELLENZA

GAS AND GALAXY EVOLUTION

The gas supply regulates the stellar histories of galaxies

- Several processes can affect the gas content:

  -- shock-heating of circumgalactic gas, that stops cooling in a DM halo

  -- galactic winds due to star formation or an active galactic nucleus

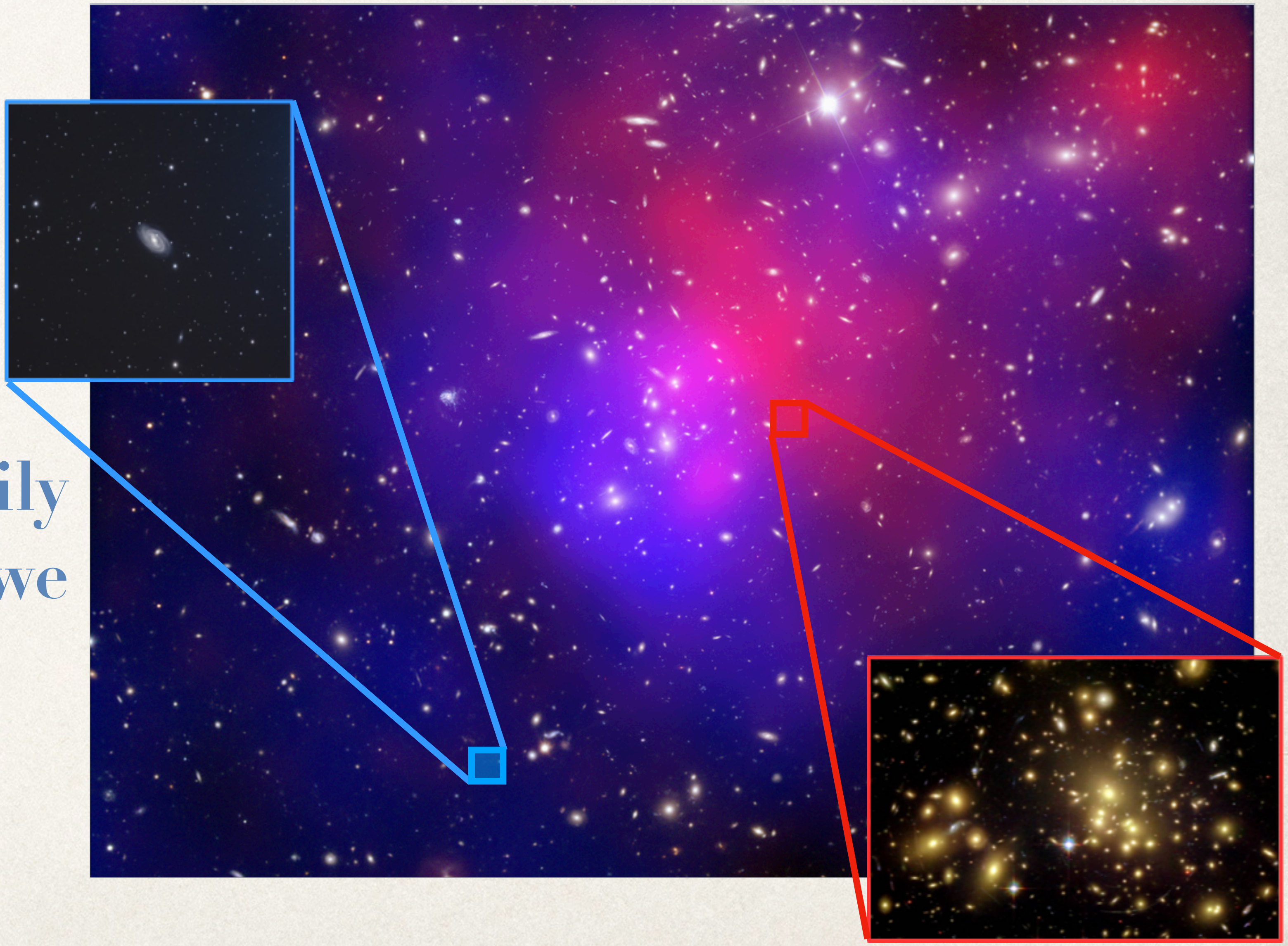
  -- affecting gas and stars: tidal interactions, mergers

  -- affecting only gas: *ram pressure stripping* and strangulation

- Gas removal processes can lead to the interruption of the star formation activity (quenching)

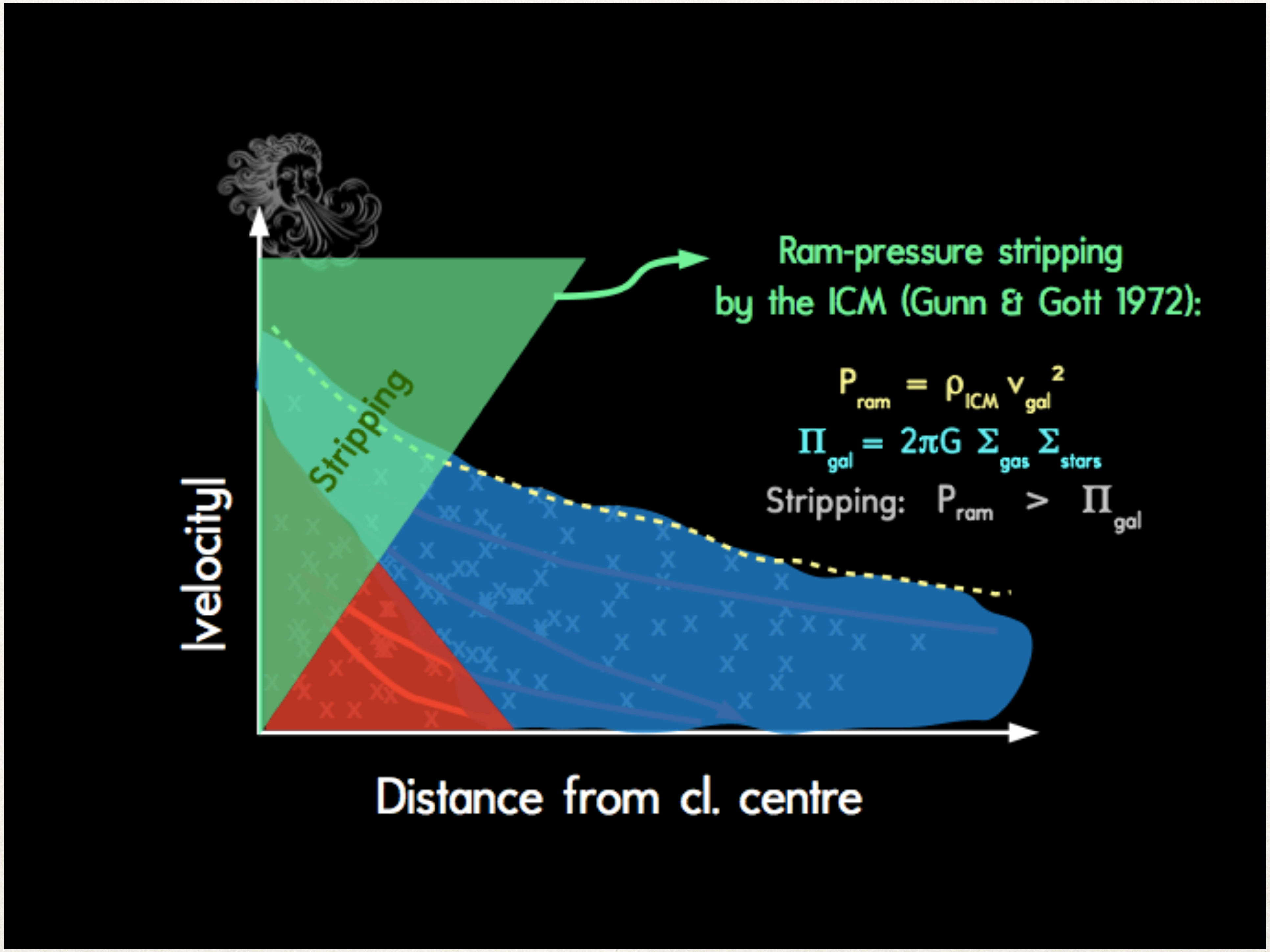
Galaxies and cosmic environment

- Galaxies can be found in different environments
- Galaxy properties change with environment (morphologies, SFR, stellar masses, gas content…)



A variation does not necessarily imply a causal relation – can we observe environmental processes while they act on galaxies?

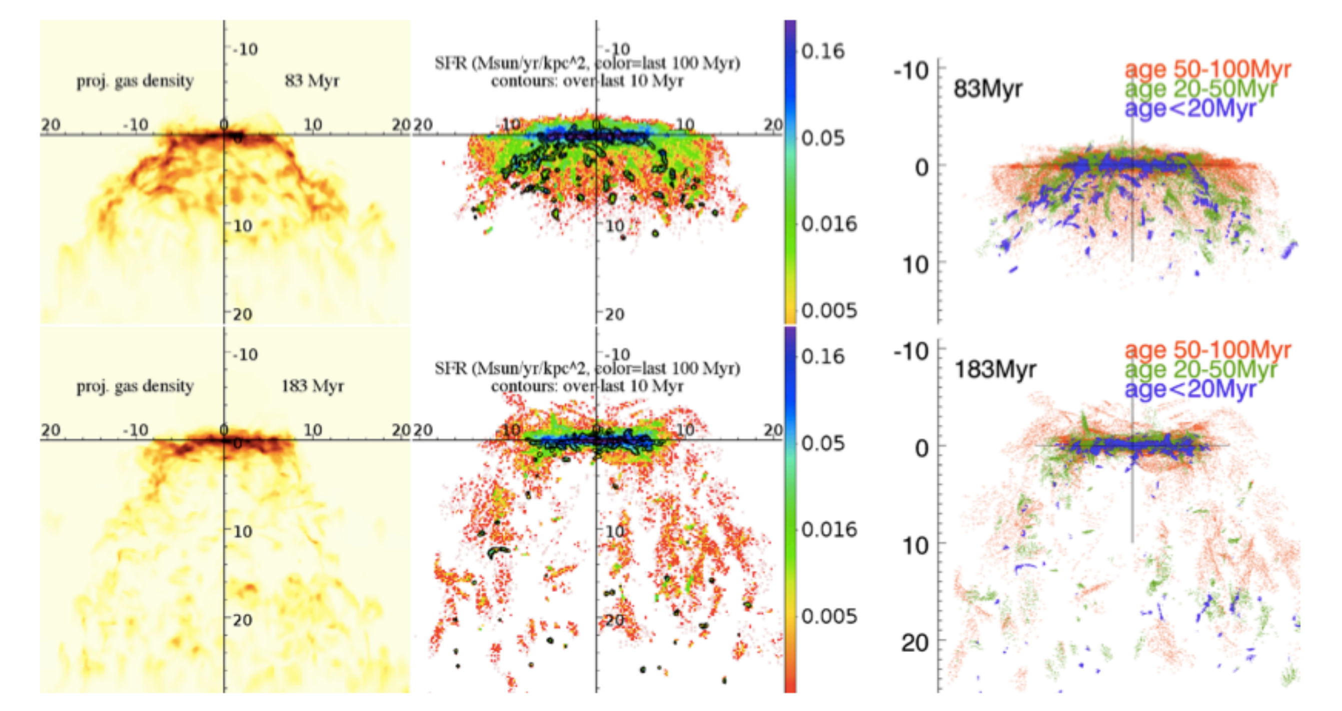
Ram-pressure stripping



Ram-pressure stripping in simulations

Consequences of stripping:

- Tails of gas emerge from the disk, new stars form in knots in the tails
- SF can be enhanced/suppressed
- Truncated disks (outside-in stripping)
- Disturbed gas kinematics



Roediger+ 2014

Roediger & Hensler 2005 - Kronberger et al. 2007-2008 - Roediger & Brügger 2008 - Kapferer et al. 2008-2009 - Jáchym et al. 2007-2009 - Tonnesen & Bryan 2008-2012 - Bekki 2009, 2014 - Bekki & Couch 2010 - Book & Benson 2010 - Steinhauser et al. 2012 - Roediger et al. 2014 - Bischko et al. 2015...

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

Gas Stripping Phenomena in Galaxies

- Where, why and how is gas removed from galaxies?
  - Is gas being removed?
  - By which physical process?
  - What is the amount and fraction of gas that is being removed?
- What are the effects of gas removal on the star formation activity and on galaxy quenching?
- What is the interplay between the gas physical conditions and the activity of the galaxy central black hole?
- What is the stellar and metallicity history of galaxies prior to and in absence of gas removal?
- What is the role of the environment?

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European Research Council
Established by the European Commission

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

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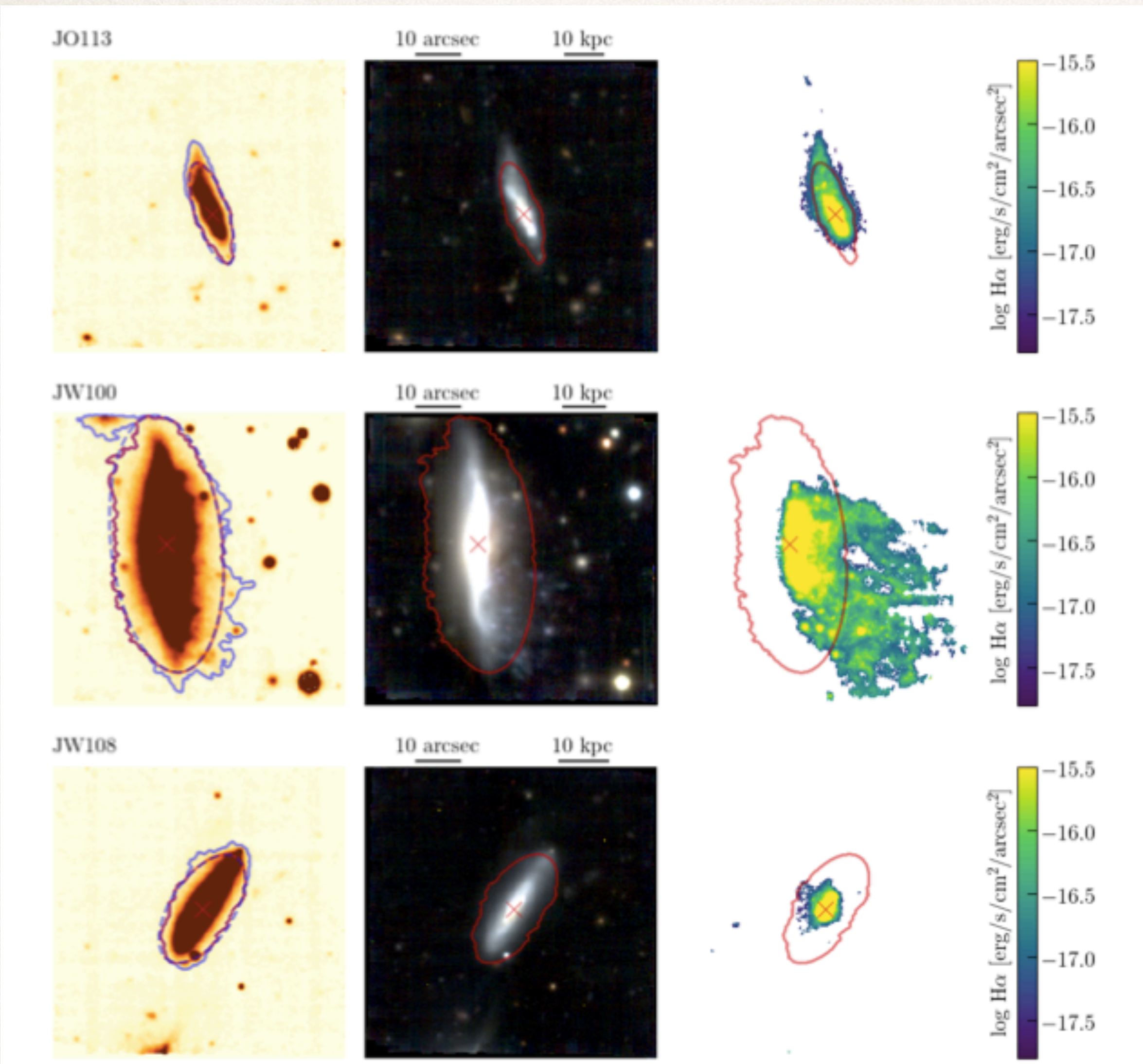
GASP multi-wavelength data

- OPTICAL: 120 hours on MUSE/VLT over 4 semesters + Xshooter
- SUB-MM: 77 hours on SHFI/APEX +22 hours on ALMA (CO)
- HI data: 100 hours on JVLA+13 hours on Meerkat
- UV: 104.4 ks on UVIT/Astrosat
- Magnetic fields: 50 hours on JVLA
- + X-ray Chandra archival data

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

GASP characteristics



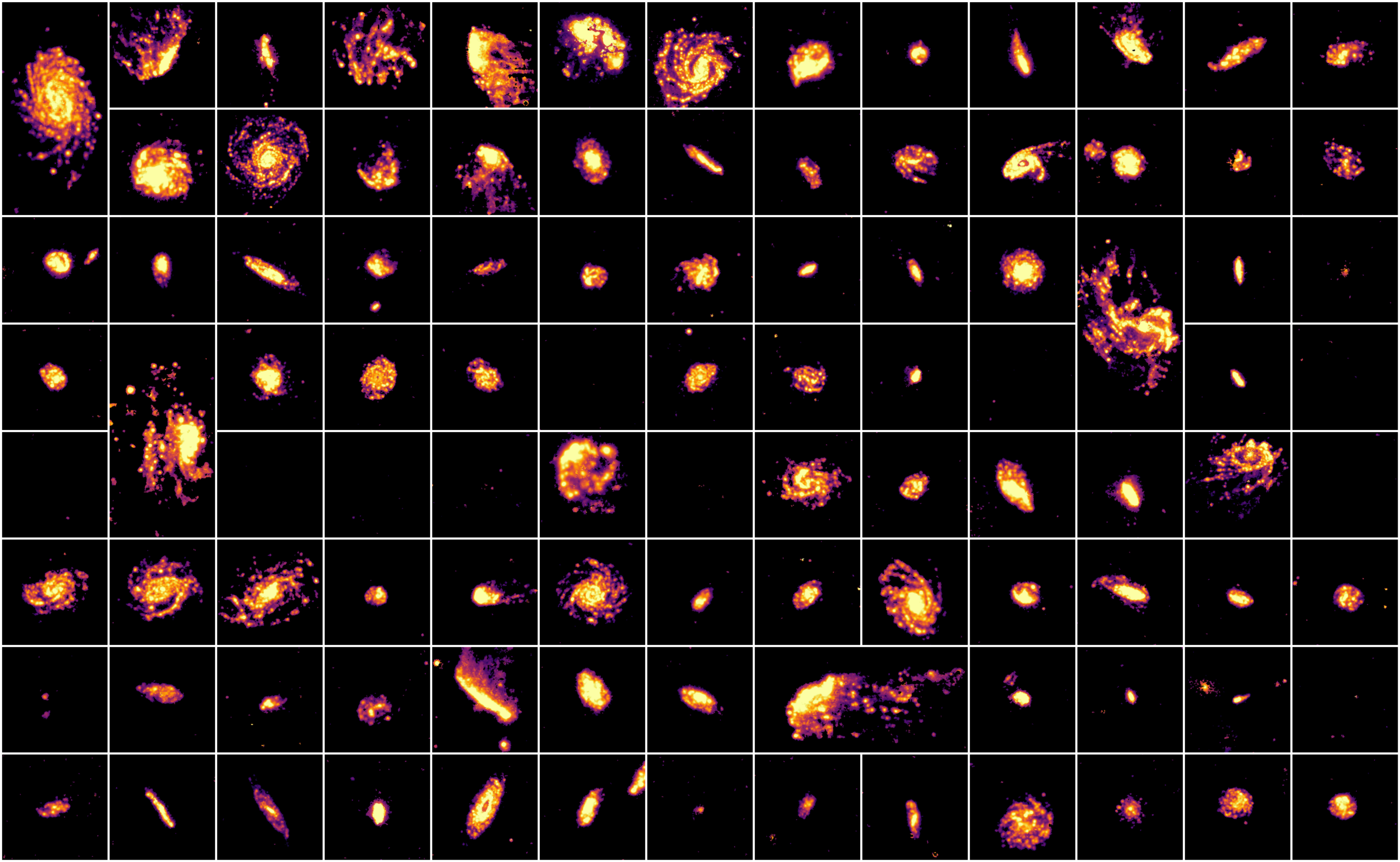
Poggianti+ 2017, Gullieuszik+ 2019

- 114 galaxies at z=0.04-0.07: 94 stripping candidates + 20 disk galaxies with no morphological anomalies.
- Area coverage: FOV(1'X1')=60X60kpc, 4-10 Re
- stellar masses in the range $10^{9.2}$-$10^{11.5}M_{\odot}$
- Halo masses in the range Host halo mass range 10^{11}-$10^{15.5}M_{\odot}$(field, groups, clusters)
- sample drawn from Poggianti et al. (2016), a catalog of jellyfish in WINGS/OMEGAWINGS (clusters) and PM2GC (general field)

MAIN FEATURES: galaxy area coverage, mass RANGE, environment

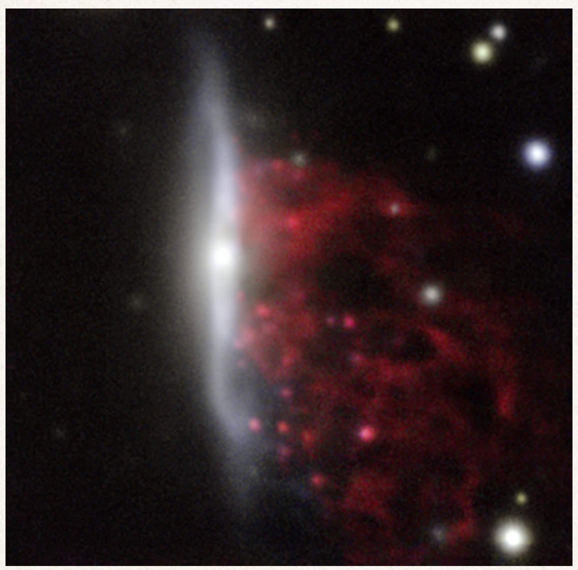
GASP - GAs Stripping Phenomena in galaxies with MUSE

2018 Marco Gullieuszik

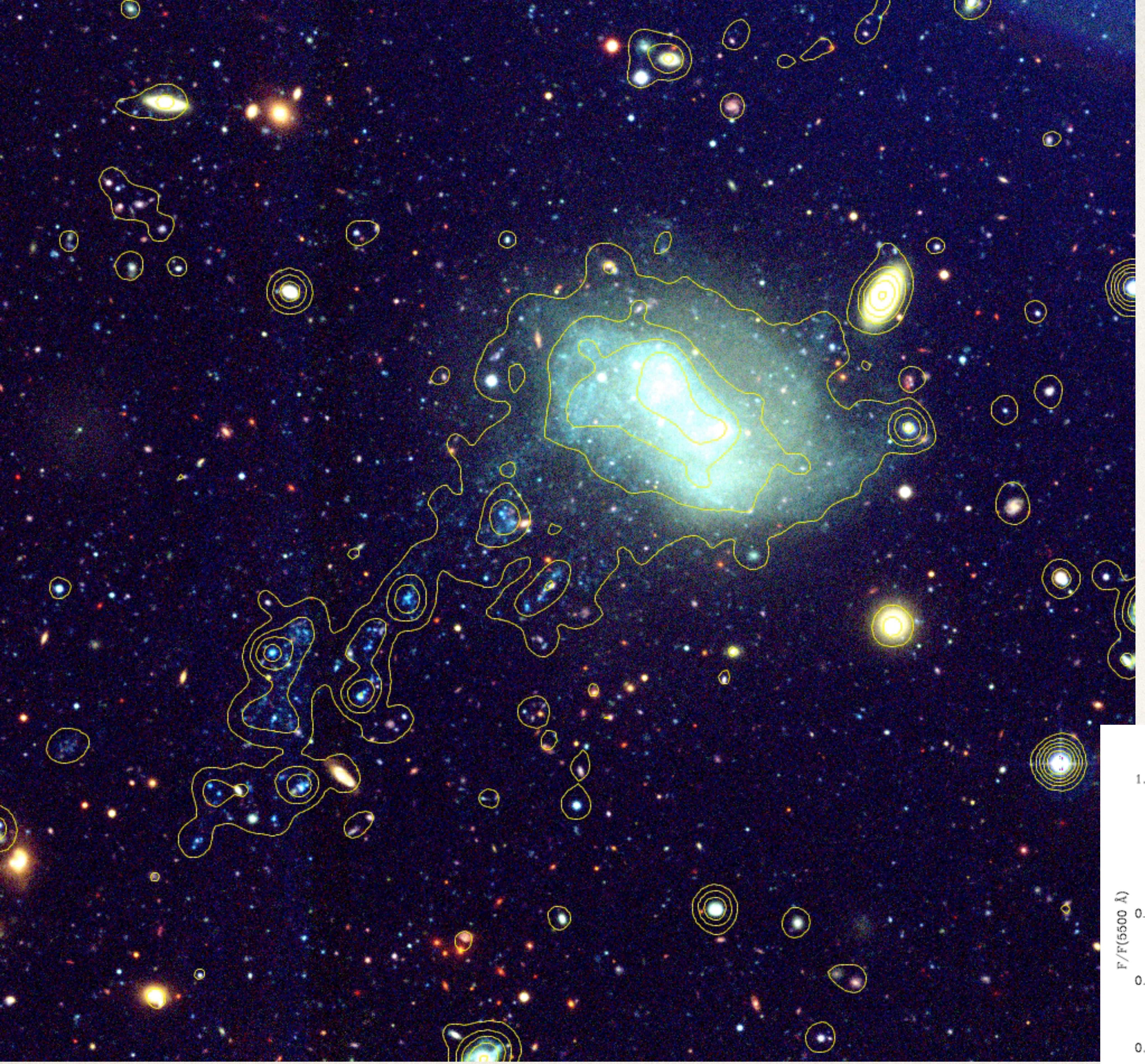


Jellyfish galaxies

"Galaxies with clearly distorted images with optical data resolving multiple filaments offset asymmetrically from the galaxy " (Smith+ 2010)

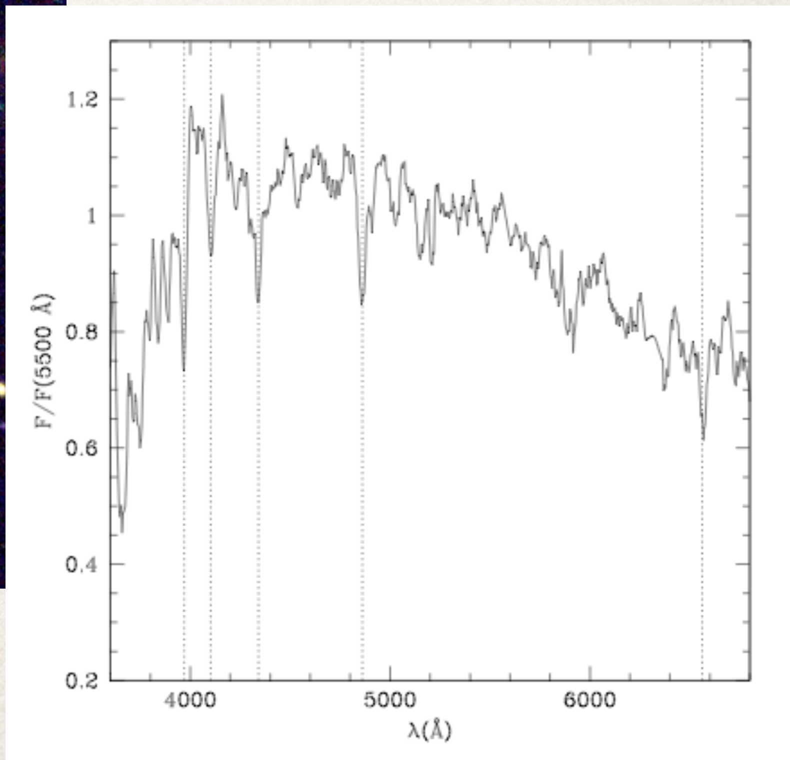


First systematic searches for stripping candidates from optical images: Poggianti+2016 (low-z) and McPartland+ 2016 (interm.-z)



Hester+2010, Fumagalli+2011, Kenney+2014

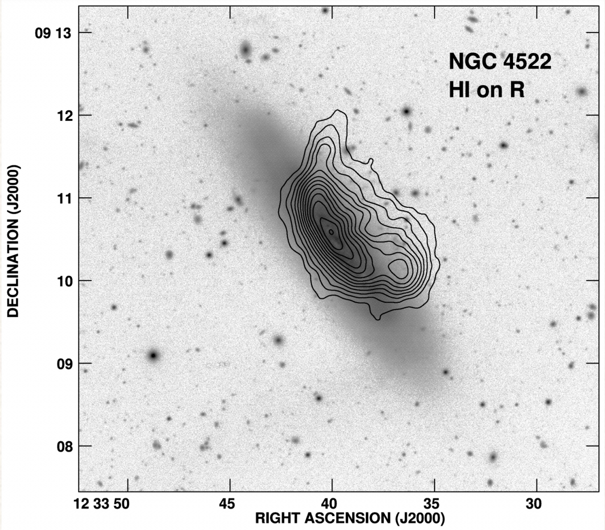
VCC121 (IC3418) in the Virgo cluster



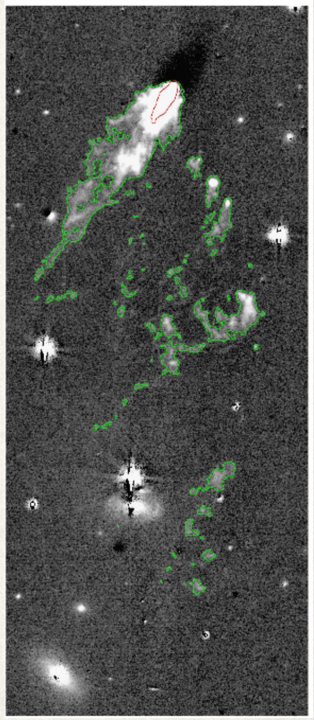
Tails

Observational evidence for gas stripping in clusters from:

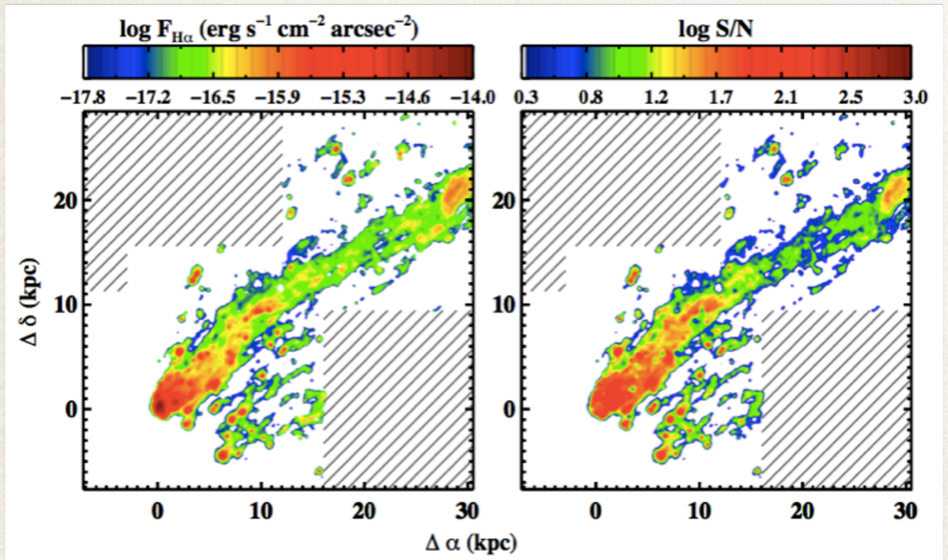
- HI
- H-alpha narrow band imaging
- X-ray
- IFU spectroscopy
- ……and even UV and optical images



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

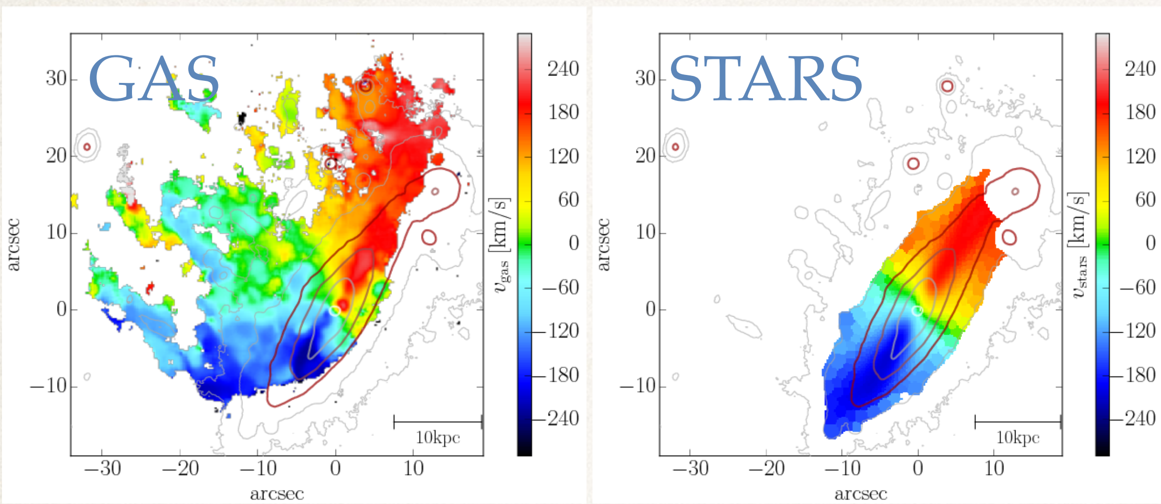


Halpha imaging, Yagi+ 2010, 2017, Coma cluster



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

Ram pressure stripping: Gas and Stellar kinematics

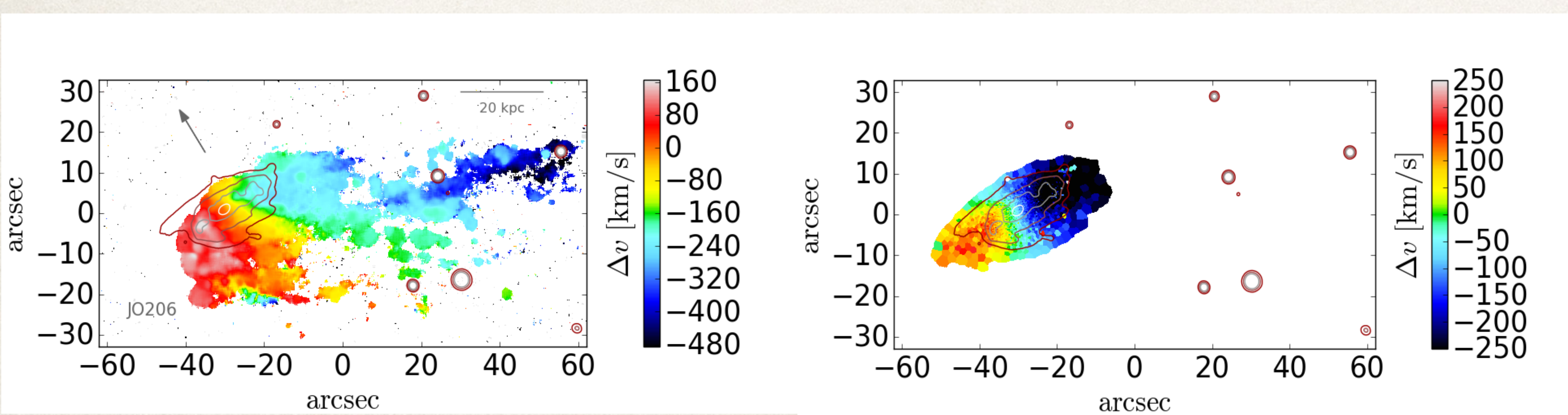


Gullieuszik+ 2017

The stellar component is not disturbed, regular stellar kinematics:

gas-only stripping

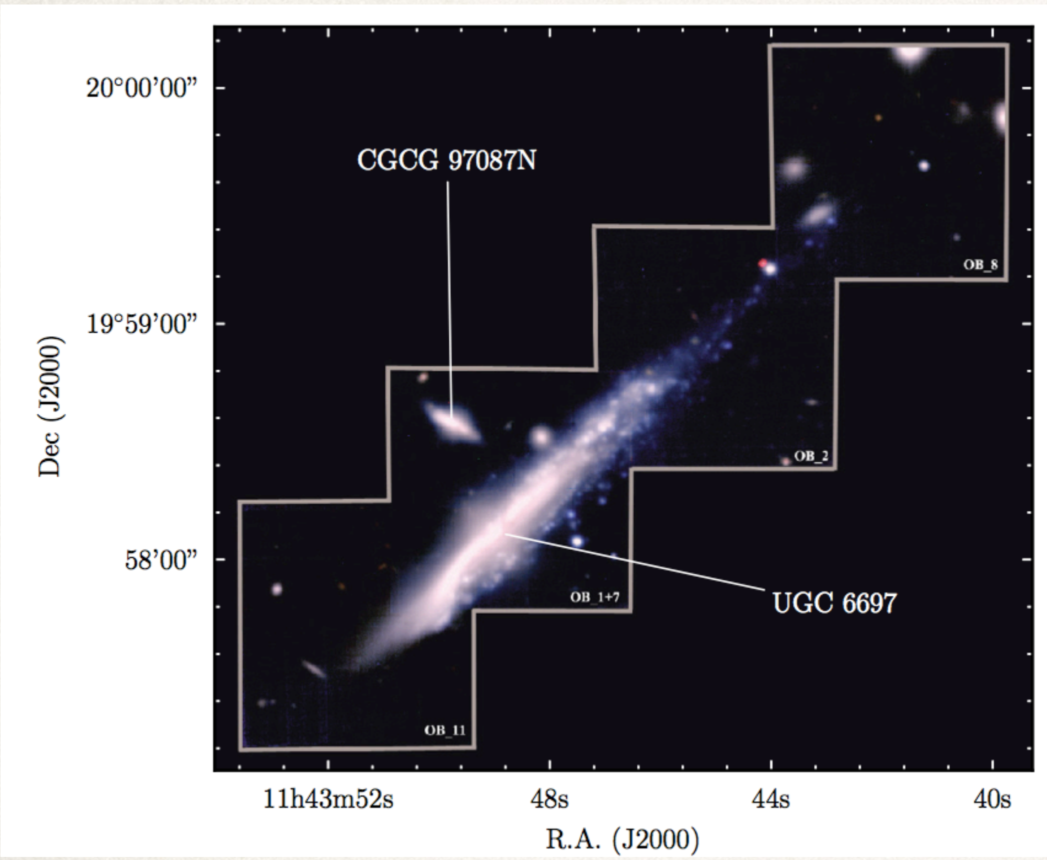
Stripped gas maintains coherent rotation for several kpc downstream



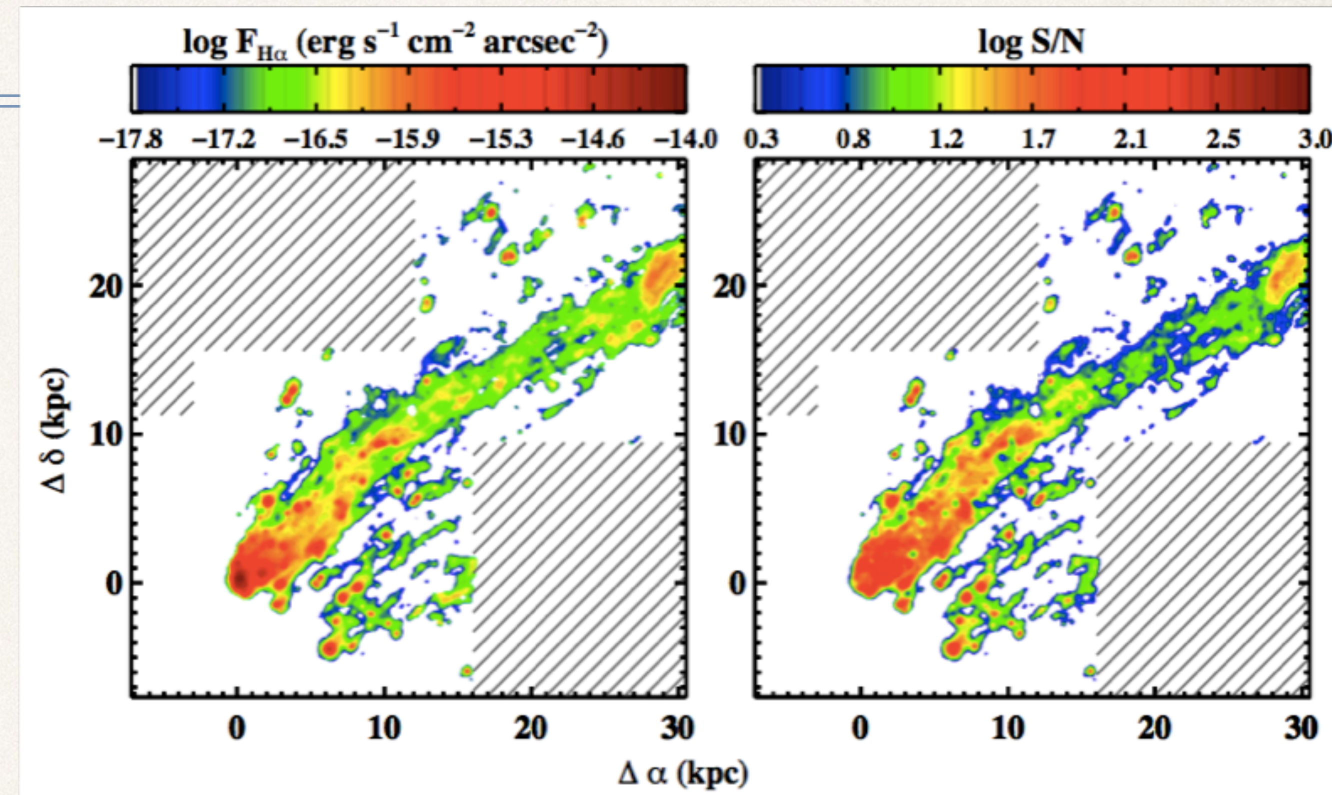
Poggianti+ 2017

See also e.g. Fumagalli+ 2014

Star Formation in Stripped tails

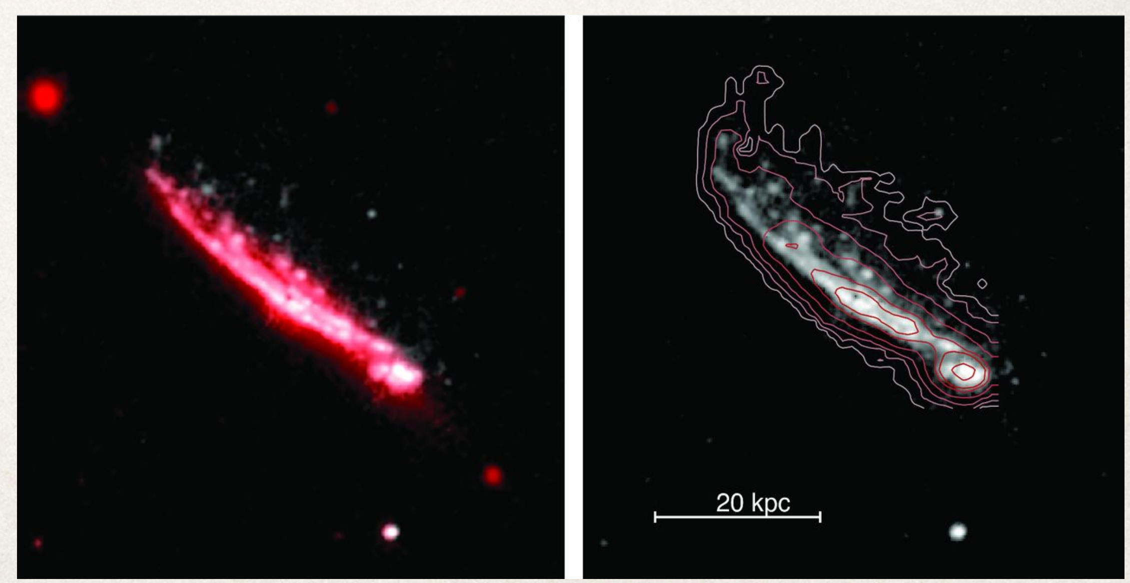


UGC6697, Consolandi et al. 2017, Abell 1367



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

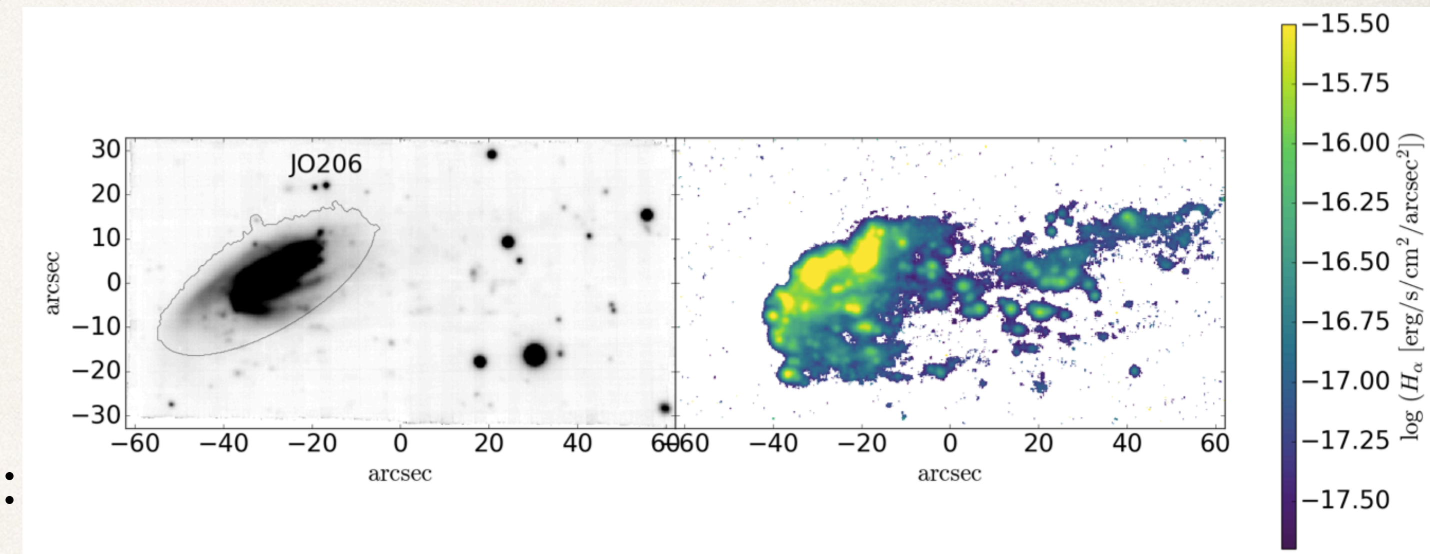
See also Fossati+ 2019

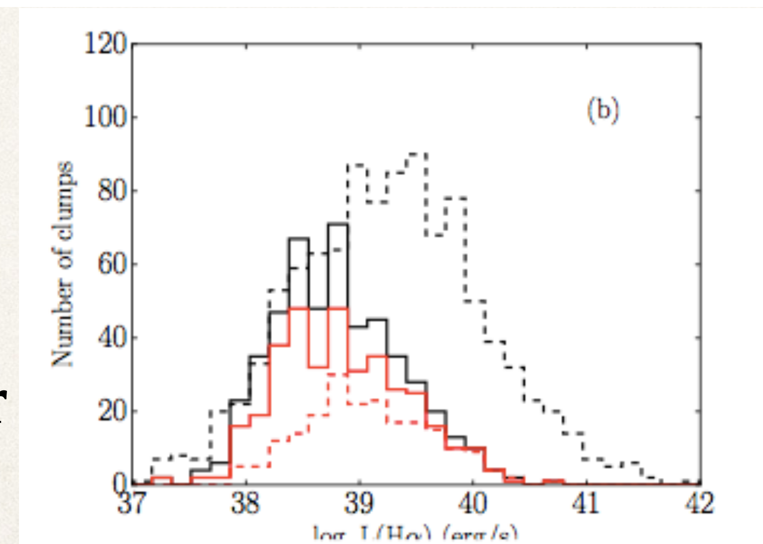
SF evidence also from UV+Halpha (Boselli+ 2018, Abramson+ 2011), UV-only of post-SB (Hester+ 2010, Yoshida+ 2008), and UV-only or Halpha-only surveys (Smith+ 2010, Yagi and Gavazzi's works)

Star Formation in Stripped tails

Galaxies with long extraplanar Halpha tails (20-100 kpc long):

- the dominant ionization mechanism of gas in the tails is photonization by young massive stars (MUSE BPT diagrams)
- 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 stellar mass of the clumps in the tails 3X10^6Msun





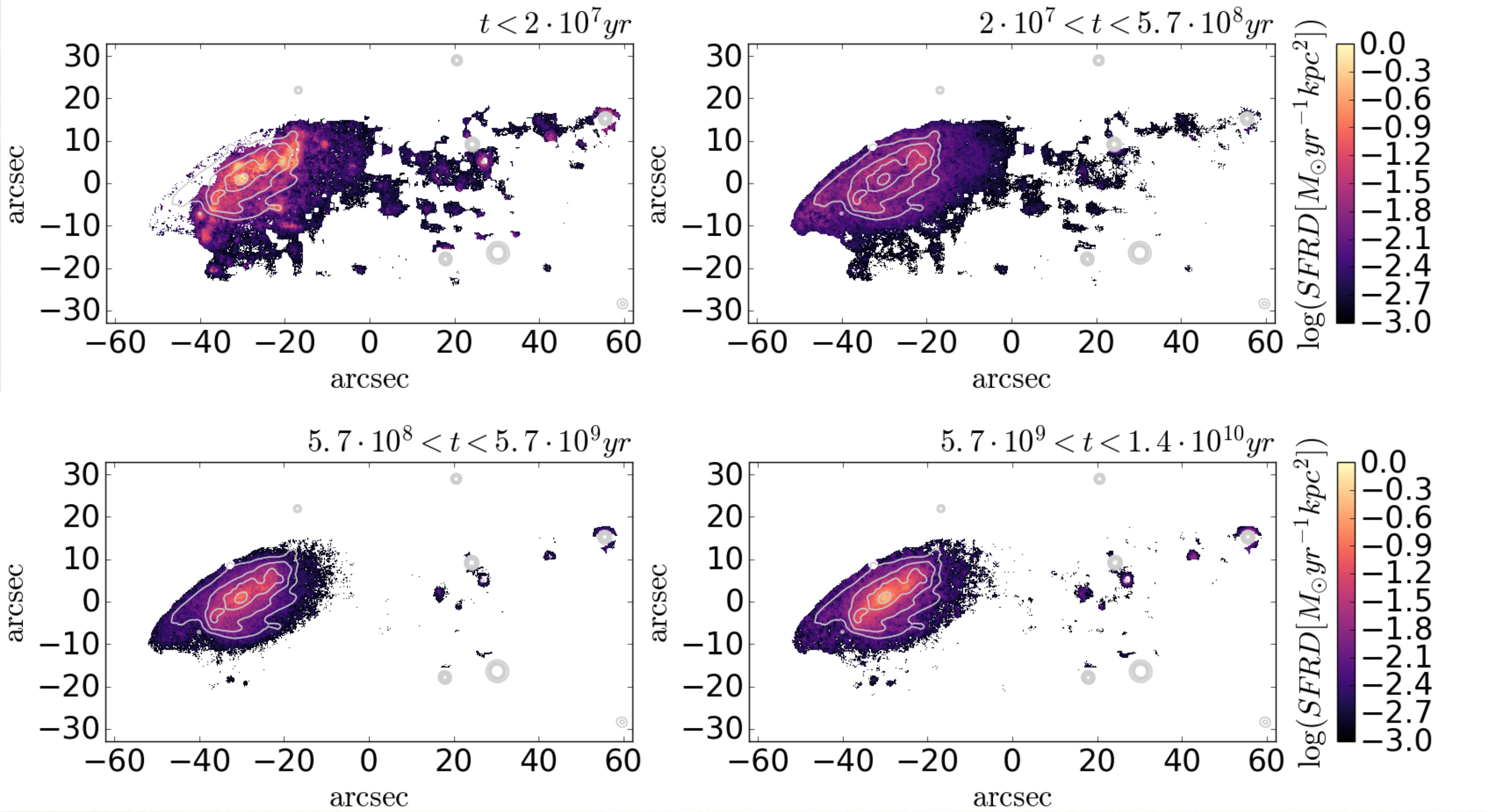
Log Halpha luminosity (erg/s)

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

Poggianti+ 2019

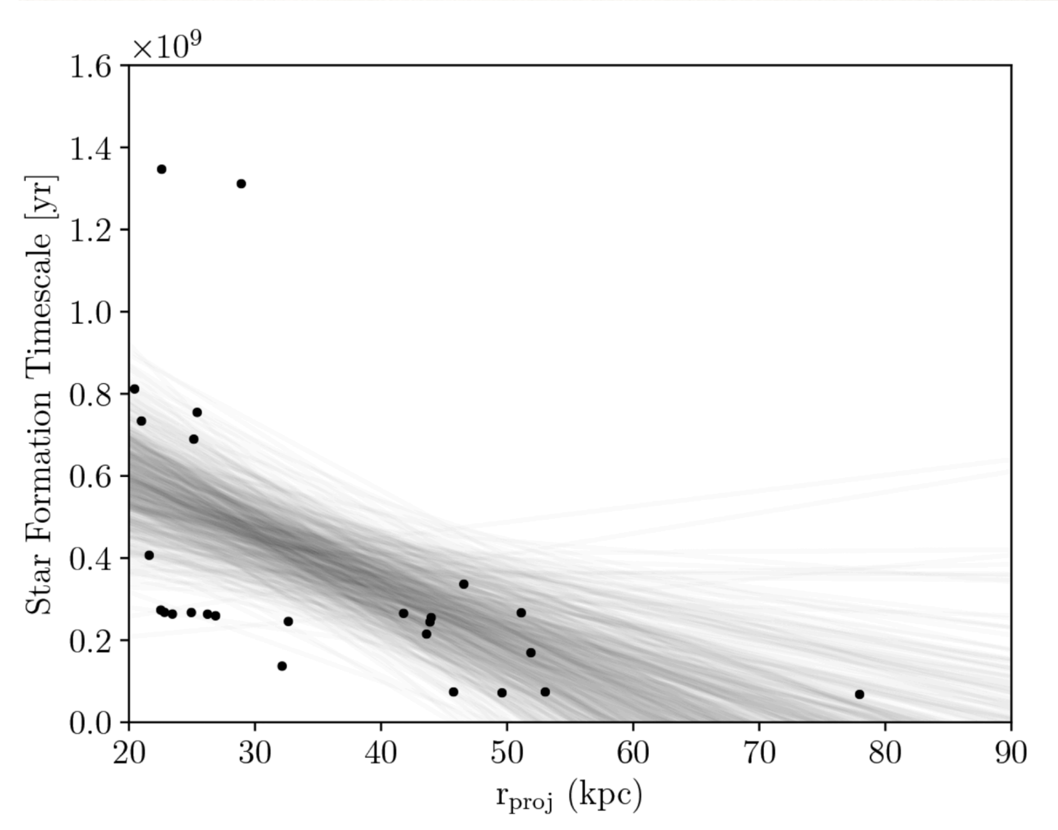
SFH in stripped tails

SINOPSIS (Fritz et al. 2007, 2011, 2017)



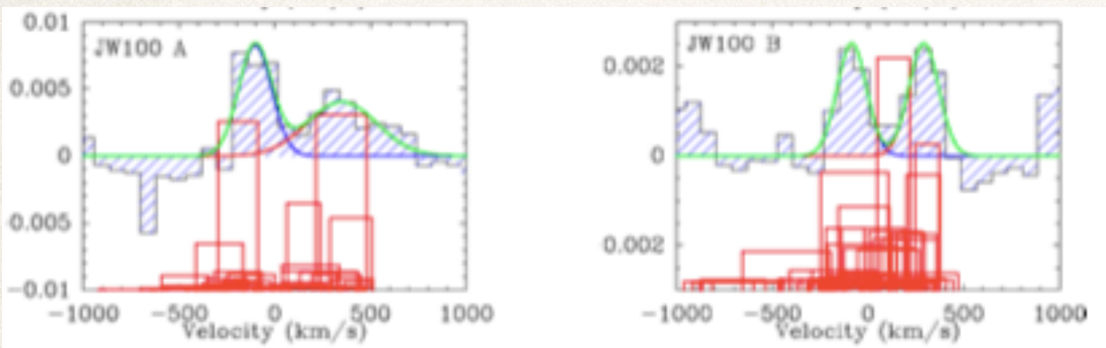
SF in the stripped gas was ignited sometime during the last ~ 5 × 10^{8}yr

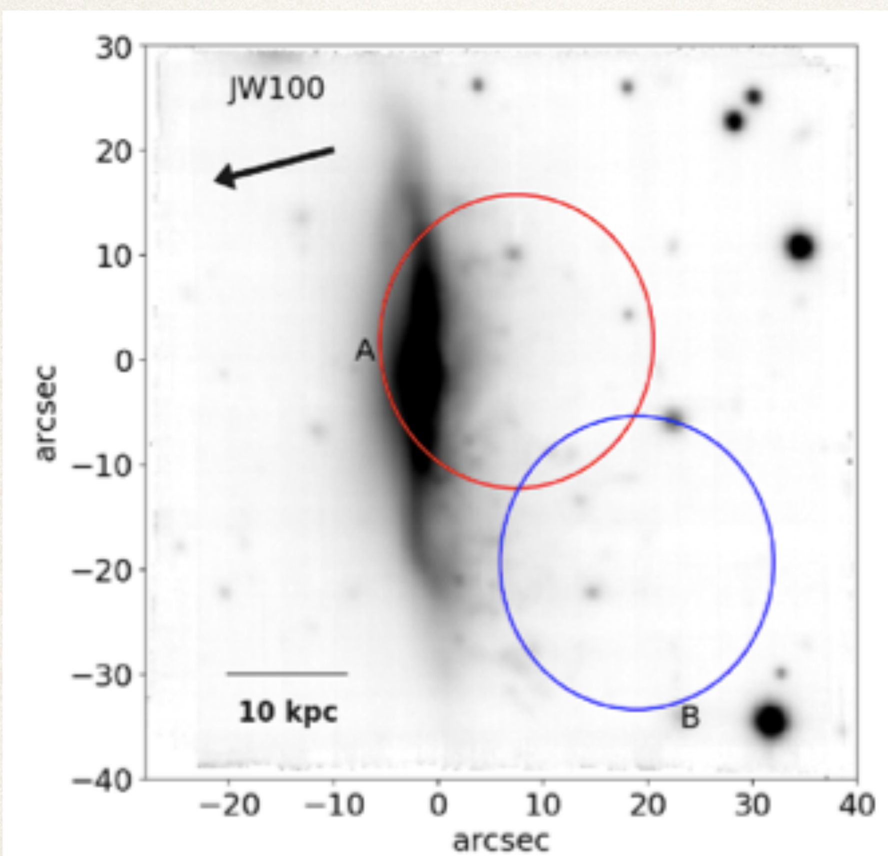
Poggianti+ 2017, Bellhouse+ 2019



As knots collapse out of the stripped gas as it moves away from the galaxy, older knots collapsed earlier when the stripped gas was closer to the disc

Molecular gas in the tails: single dish studies





Moretti+ 2018

Large molecular gas masses (CO) in the tails, and in the disks

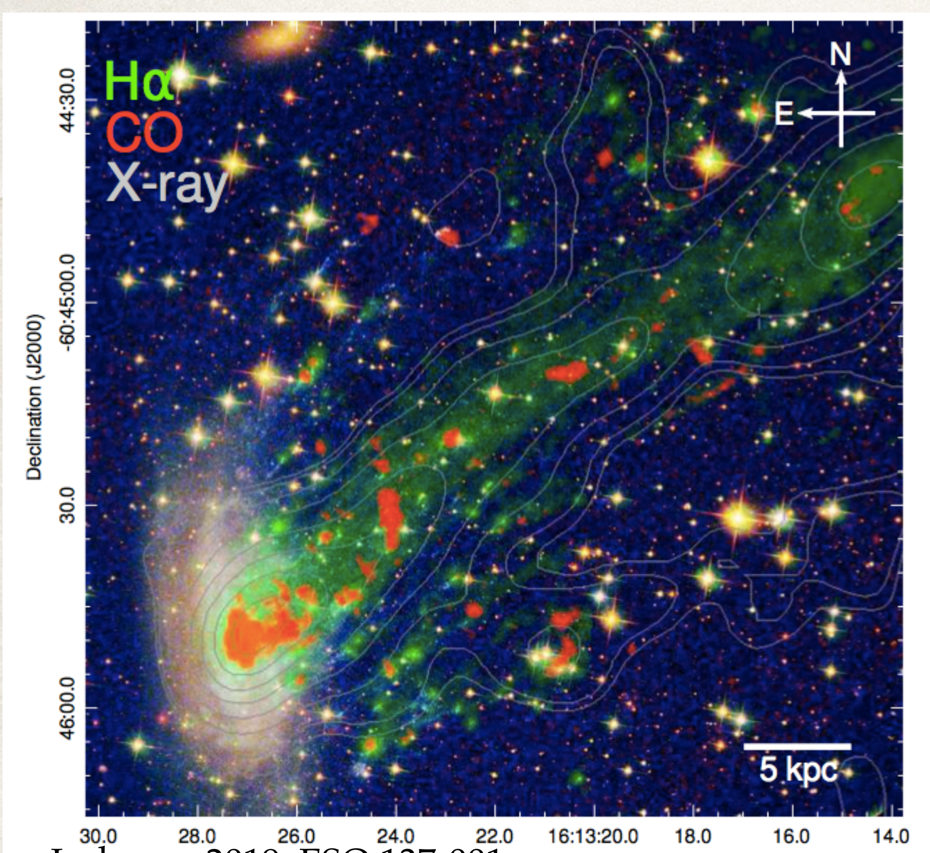
Until recently, 8 galaxies detected (large beam, low spatial resolution)

Jachym+ 2014, 2017, Verdugo+ 2015, Lee+ 2018, Moretti+2018

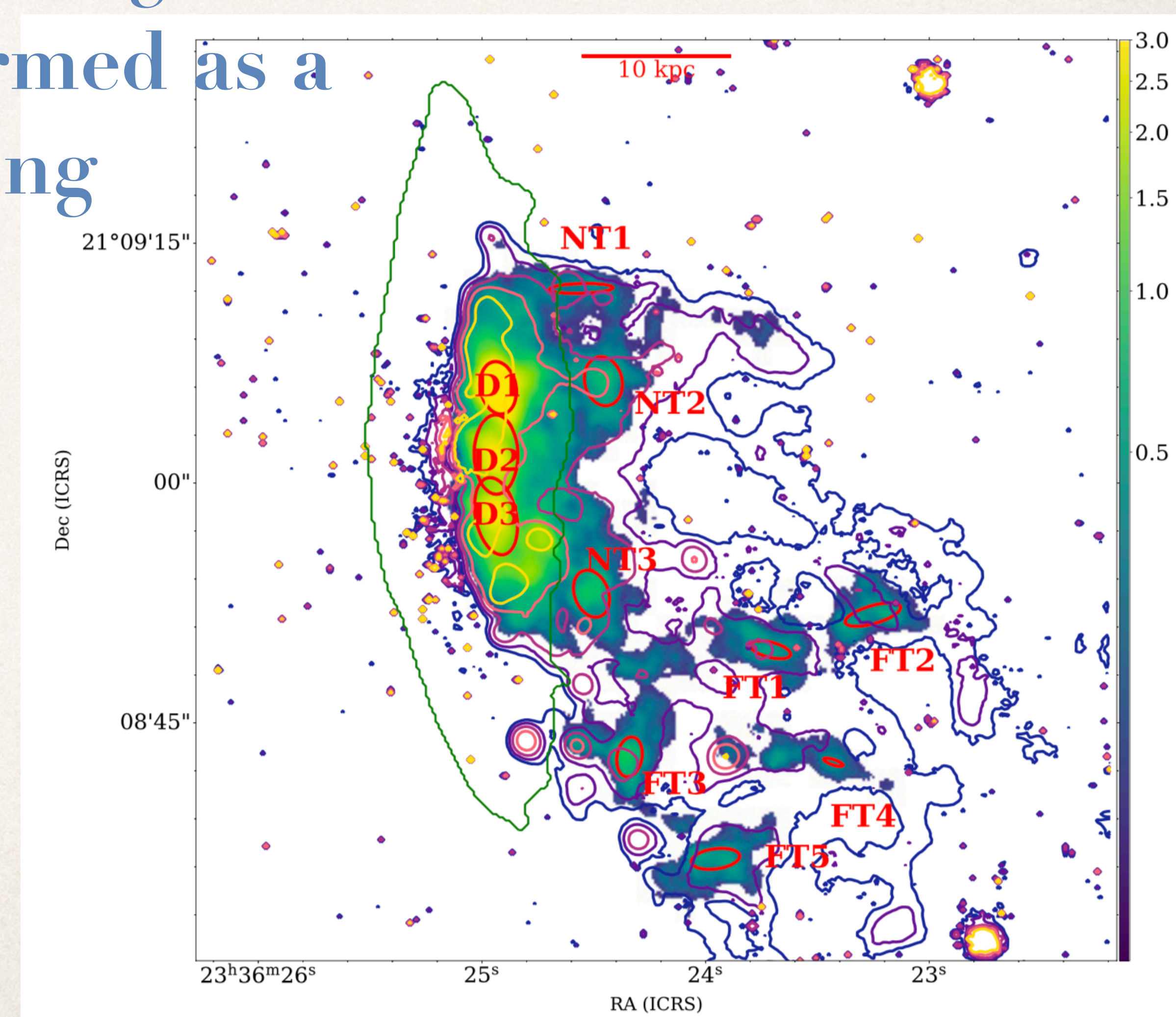
Molecular gas in the tails: an ALMA view

Individual CO clumps can be studied: from 10^6 to 10^9 Msun clumps
In the tail, molecular gas much more diffuse (larger scales)
Molecular gas formed in the tails (close to the disk can be stripped gas)

JW100 is extremely rich in molecular gas, suggesting that part of it is newly formed as a consequence of the gas stripping

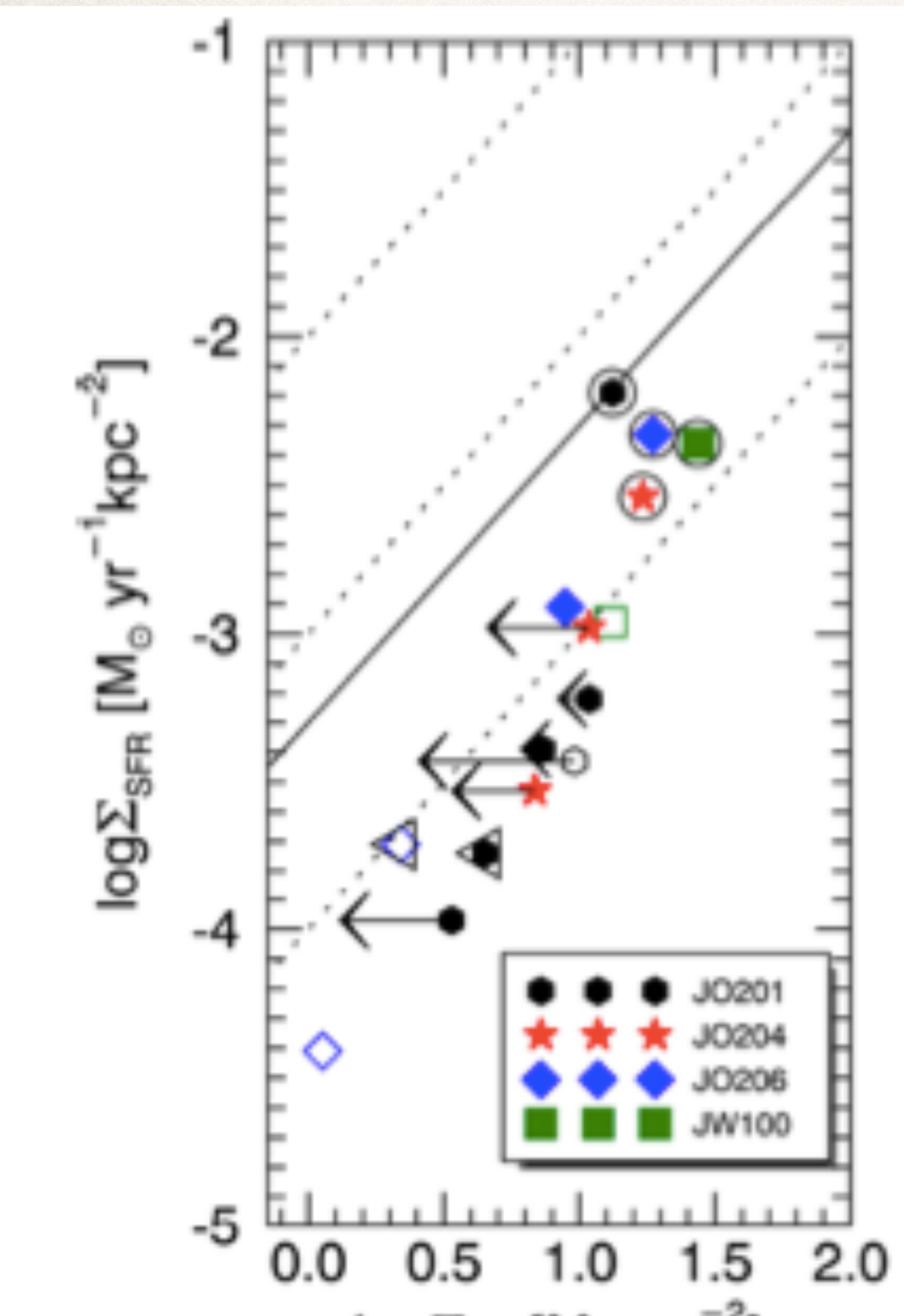


Jachym+ 2019 ESO 137-001



Moretti+ 2019 in prep.

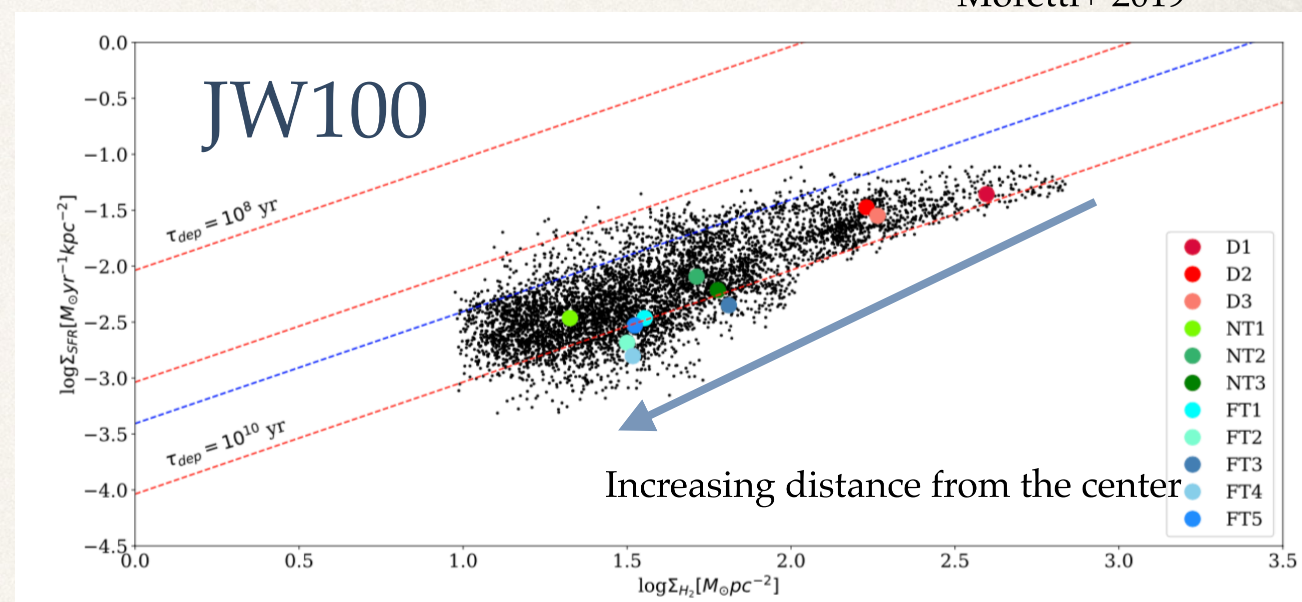
Star Formation Efficiency



Moretti+ 2018

Overall, lower than in spiral disks
Lower in tails than in jellyfish disks

Moretti+ 2019



clear gradient in the depletion time: most of the molecular gas in the tail will not be used to fuel the SF, but will ultimately join the ICM

Star Formation in Stripped tails

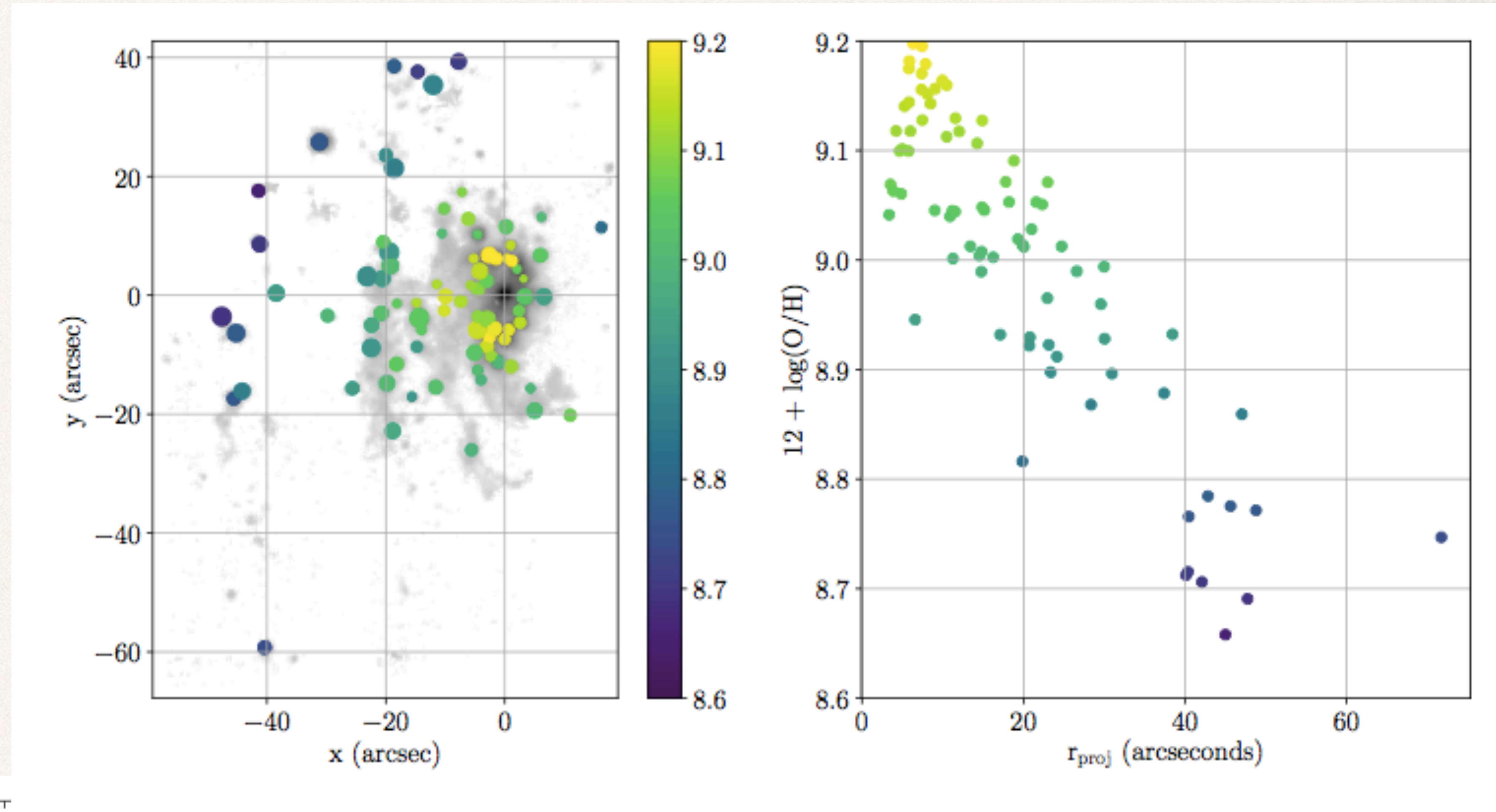
Not always?

NGC 4569 in Virgo
Boselli et al. 2016

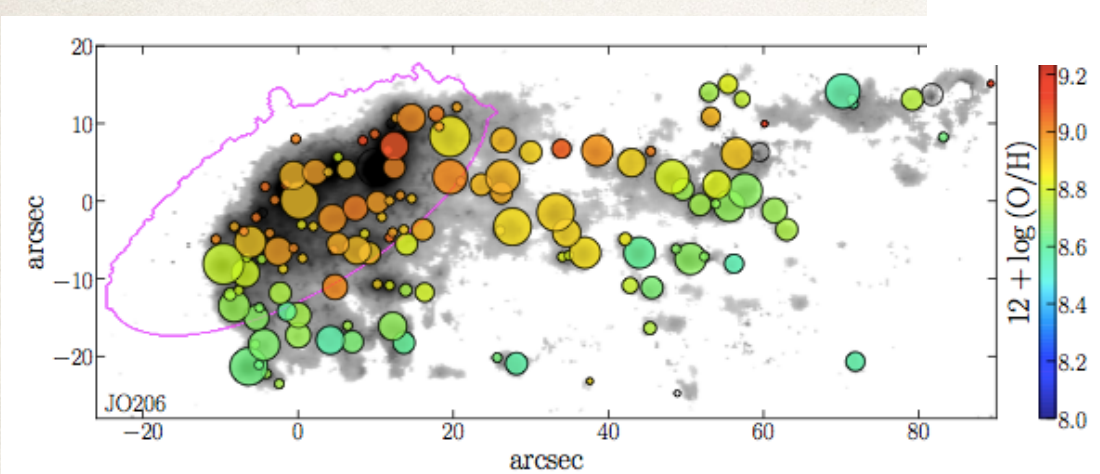
Gas metallicity gradients

Gas metallicity gradients in disks and tails

Is it driven by disk gradients+ outside-in stripping, or influenced by mixing with intracluster medium?



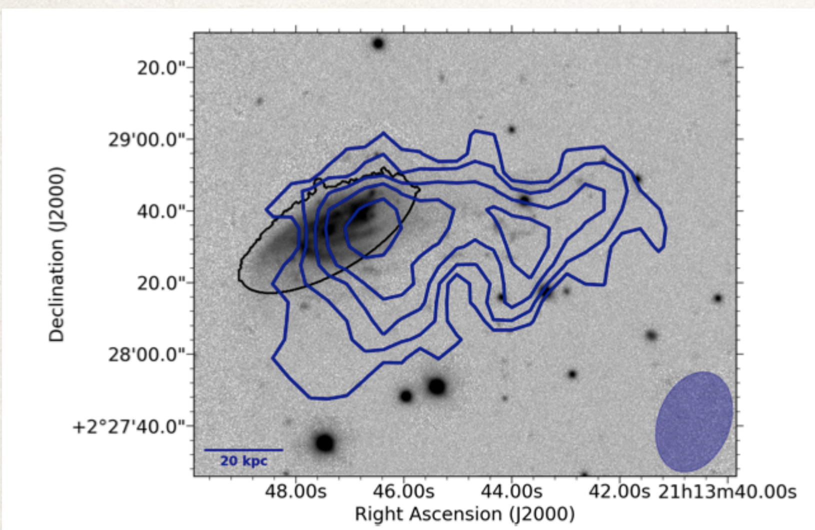
Bellhouse+ 2019

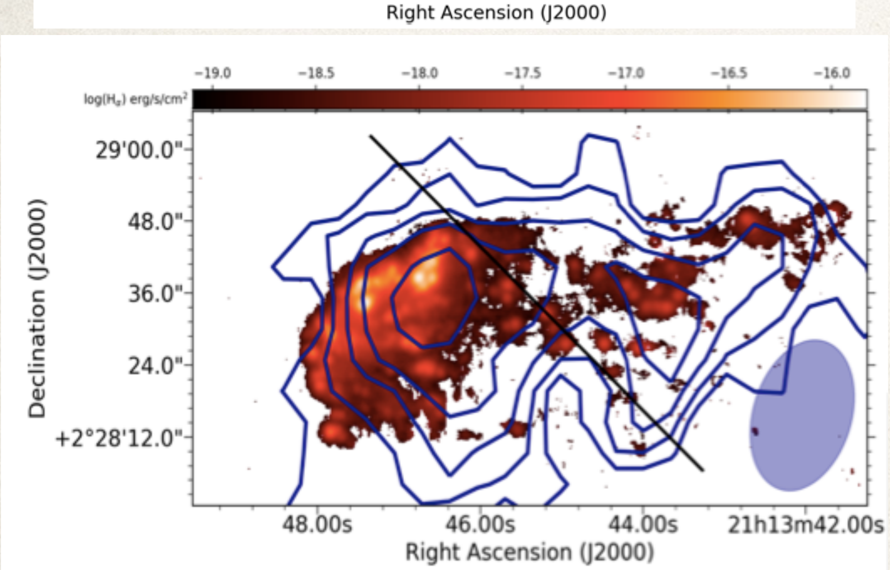


Franchetto+ in prep.

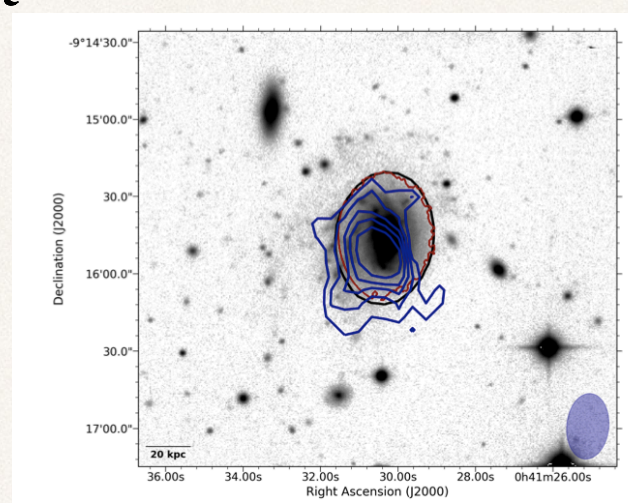
HI gas

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

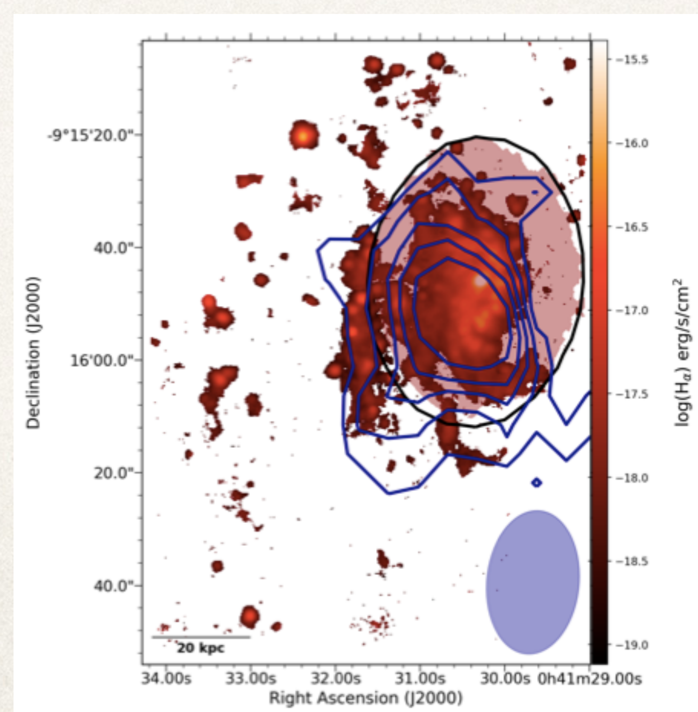




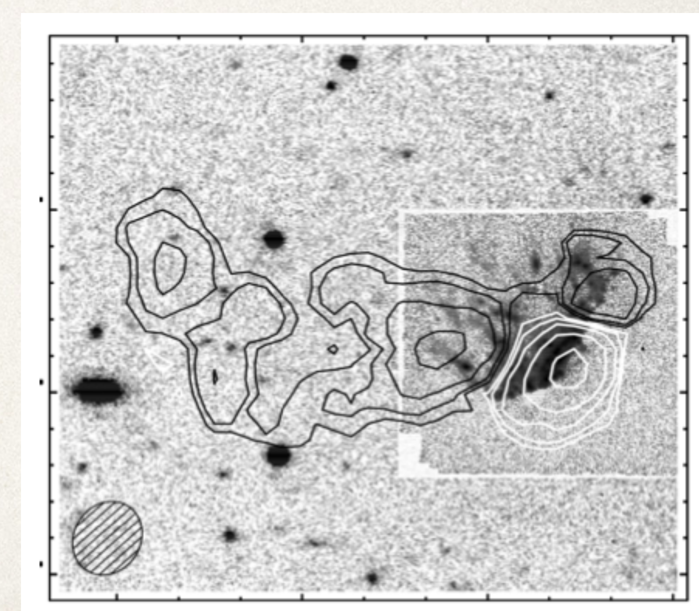
Ramatsoku+ 2019



JVLA C-array



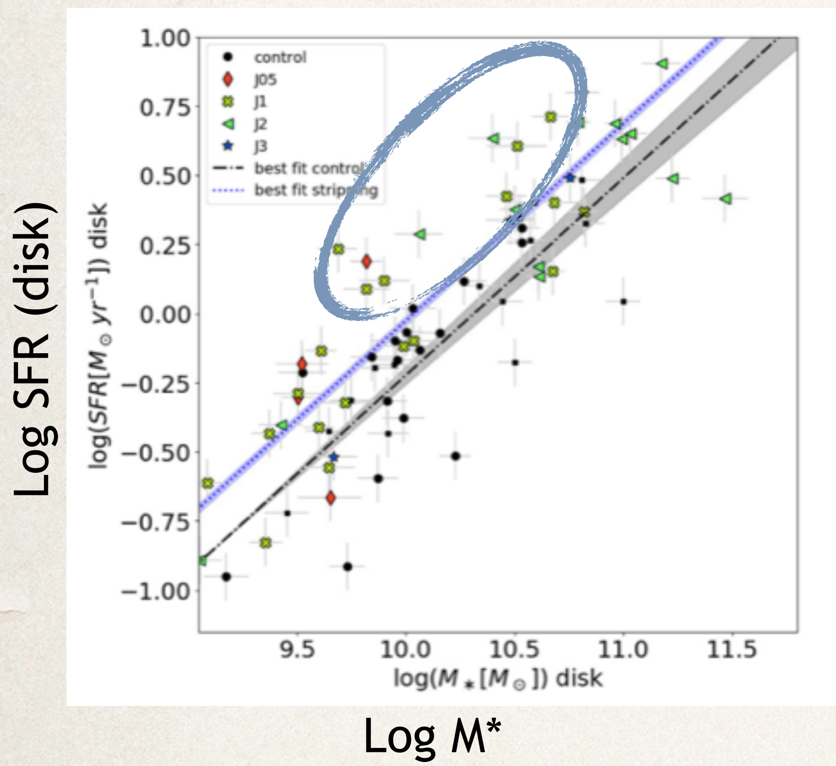
Ramatsoku+ in prep.



Deb, Verheijen+ in prep.

General trends

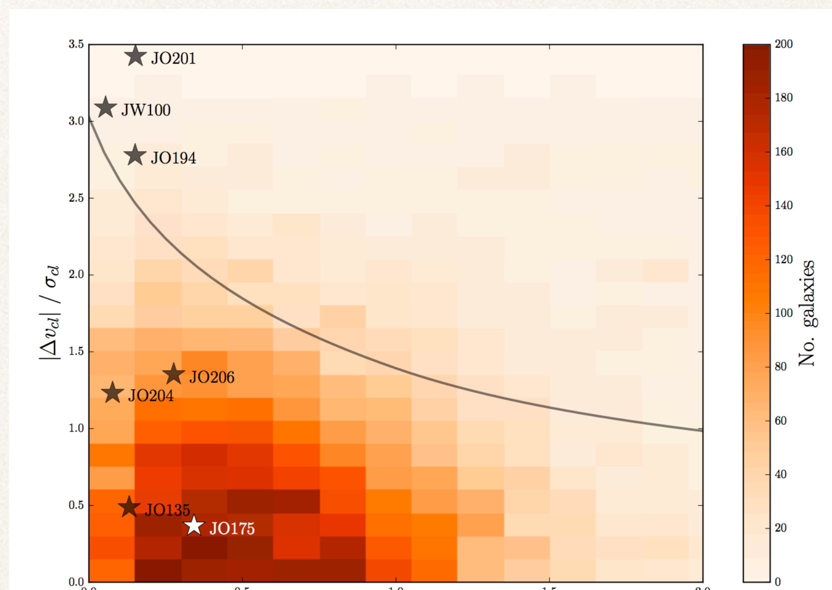
ENHANCED GLOBAL STAR FORMATION



RPS can moderately enhance the SFR in the disk before quenching

Vulcani+2018

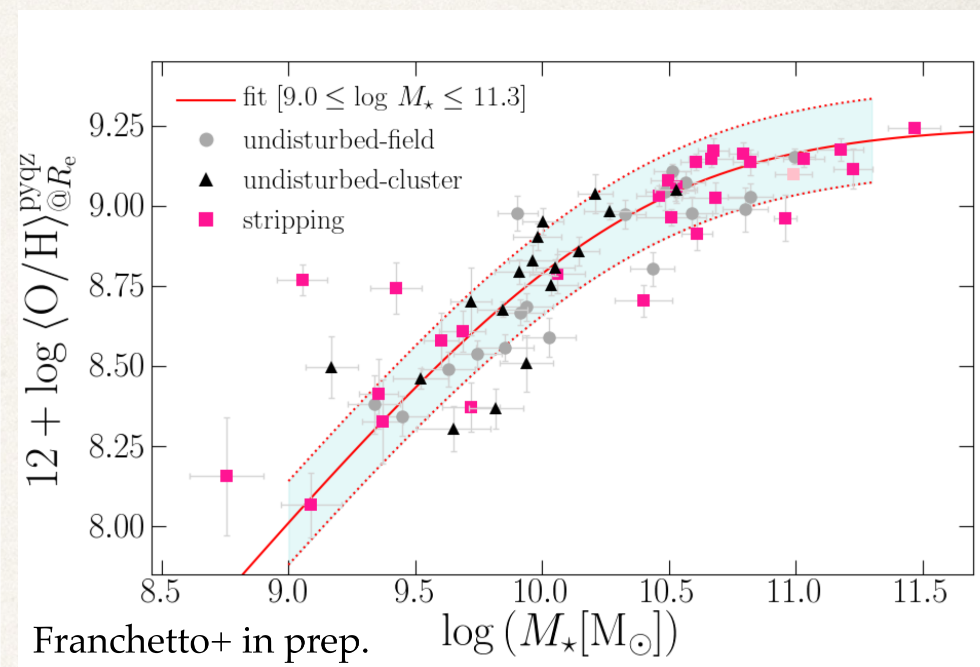
most extreme jellyfish galaxies host an AGN: RPS triggers AGN activity



Poggianti+2017

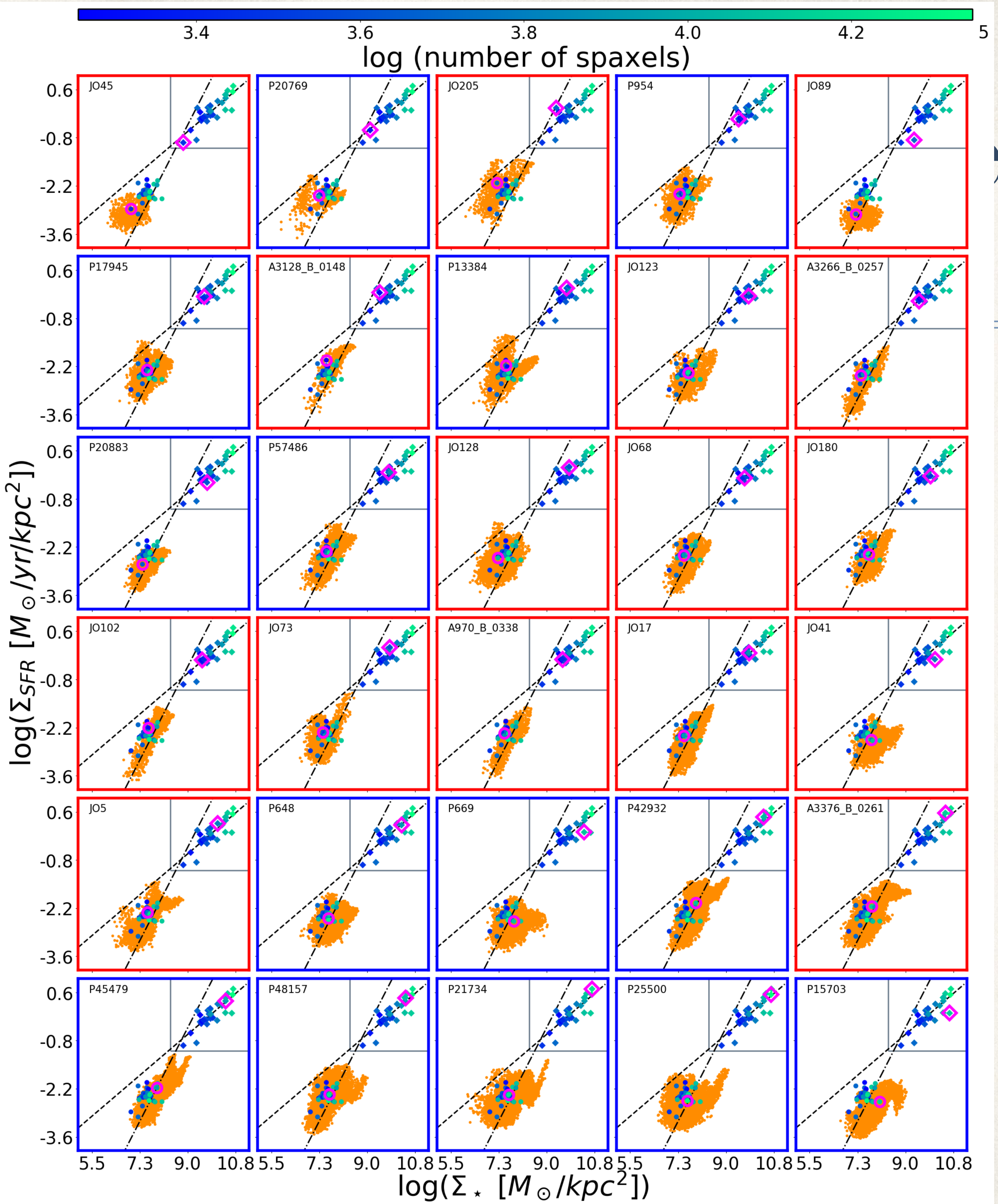
RAM PRESSURE-AGN CONNECTION

GLOBAL METALLICITY



Franchetto+ in prep.

No signs of enhancement/ suppression of metallicity at the effective radius for RPS galaxies



ends

SPATIALLY RESOLVED SFR-MASS

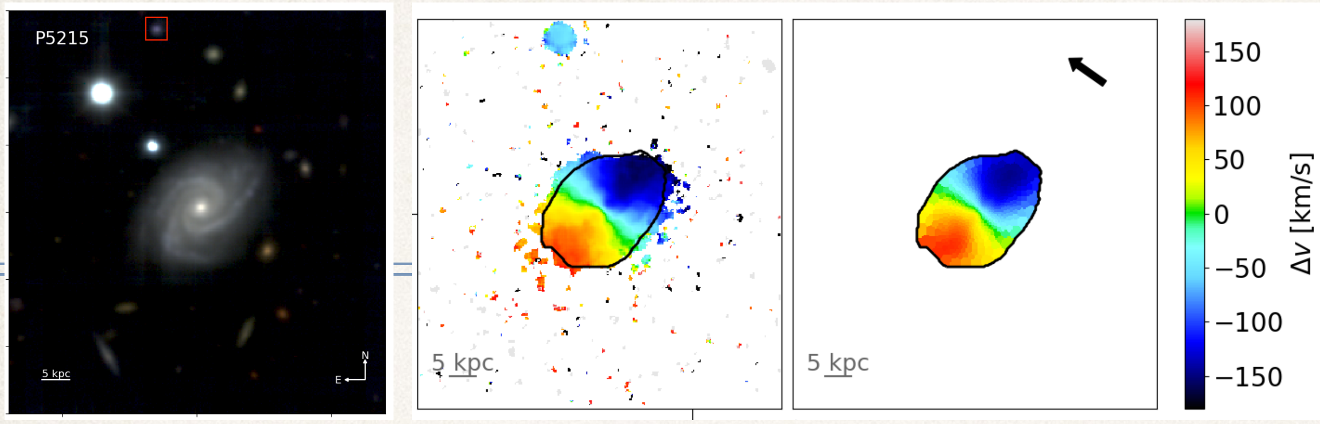
for undisturbed galaxies

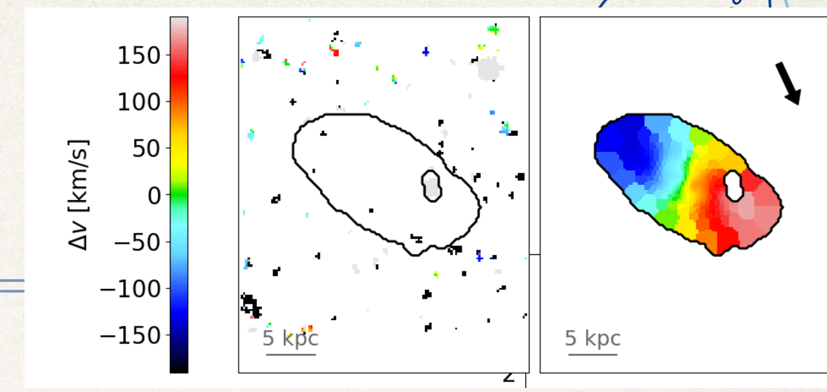
- Each object spans a distinct locus on the Σ_{SFR}-Σ_* plane
- Variety of relations:
  - Elongated
  - No clear sequence
  - Multisequences
  - Bend at high Σ_*
  - Flatten at high Σ_*
- Spaxels in the external regions are characterised by systematic lower Σ_* values

Vulcani+ 2019b

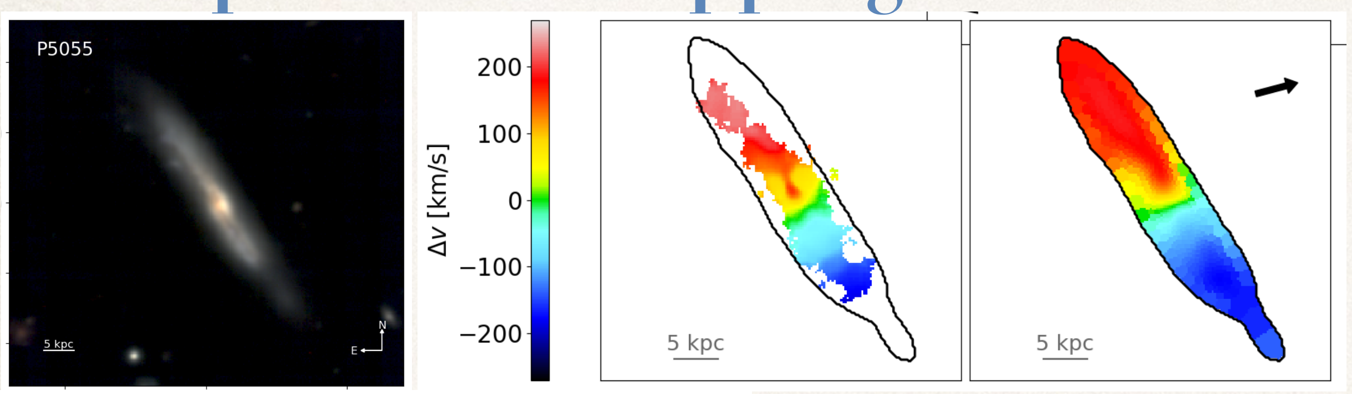
Vulcani+18b

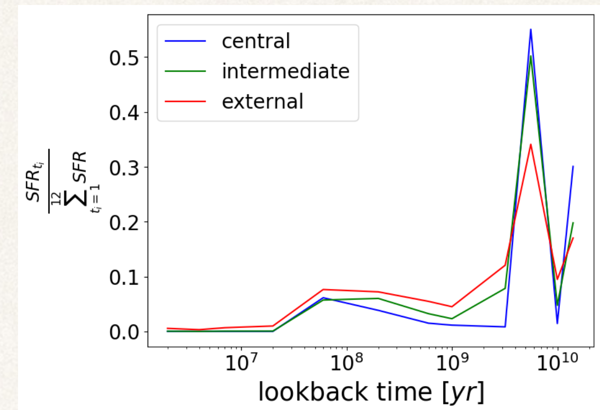
Galaxies in groups

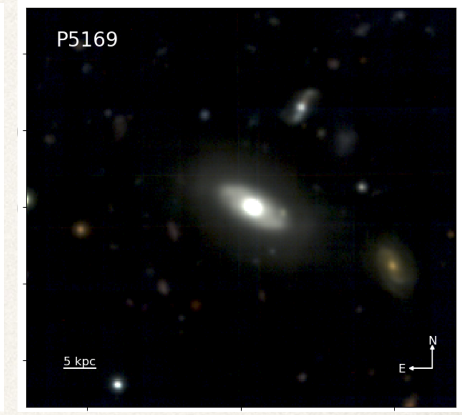




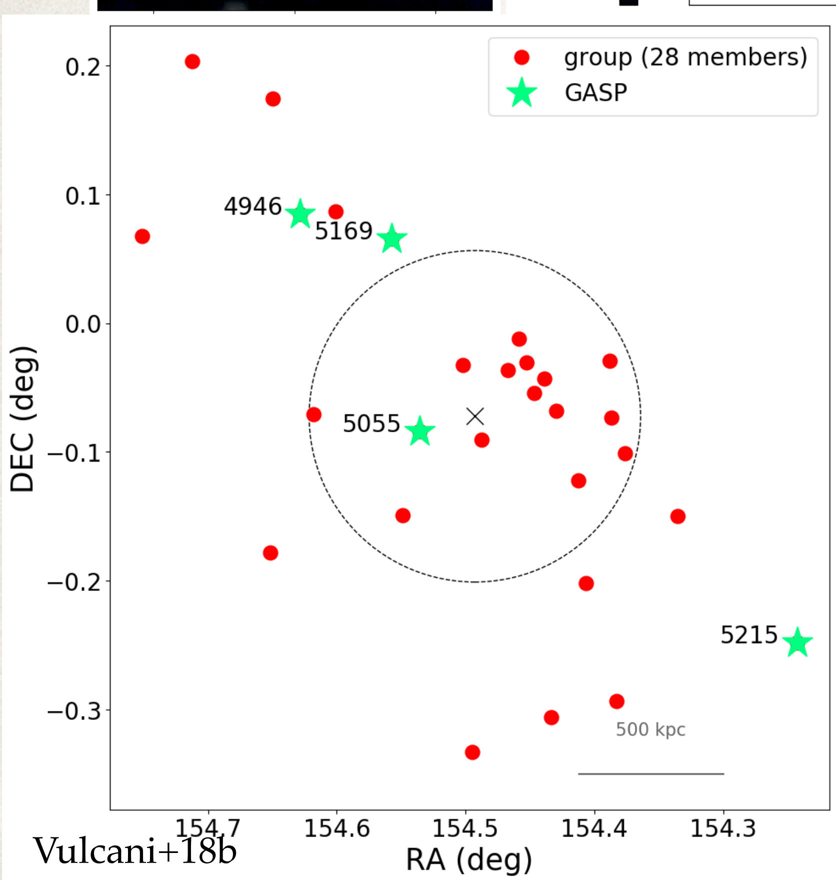
Ram pressure stripping



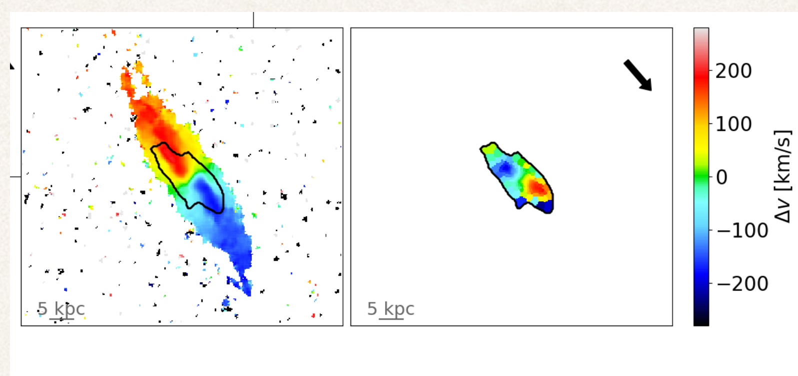




Strangulation

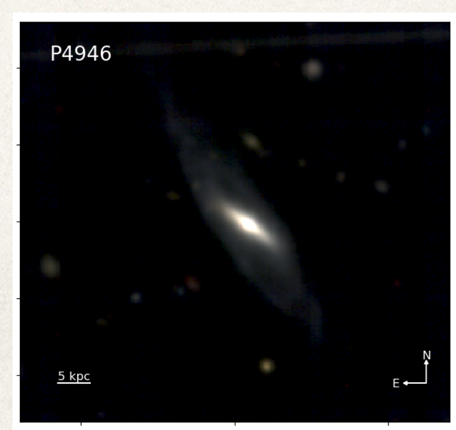


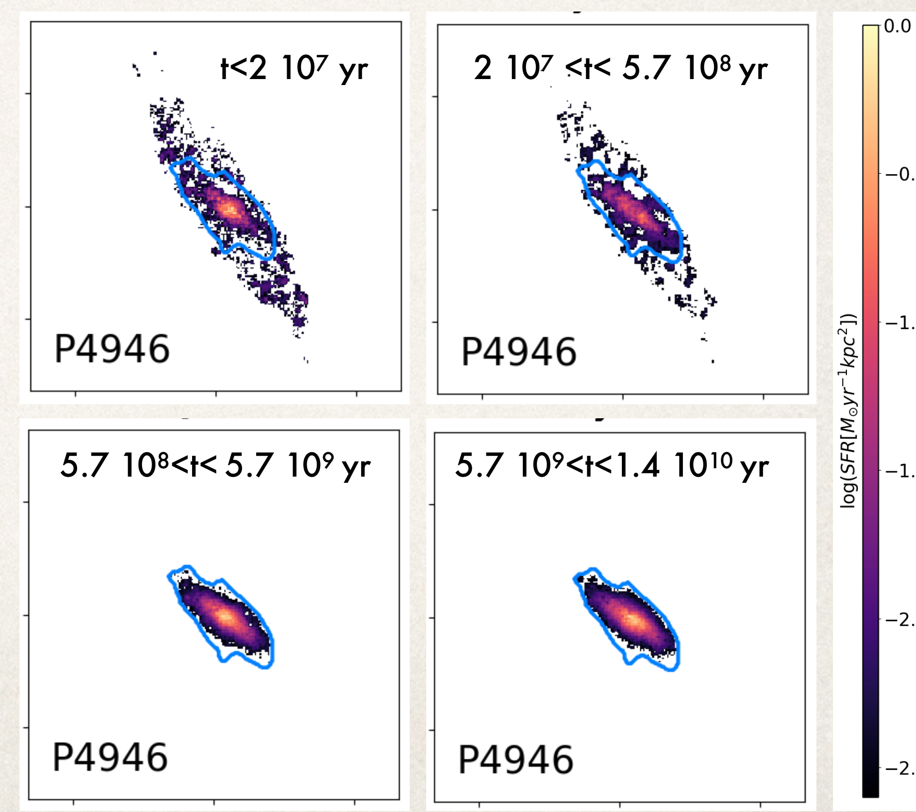
Vulcani+18b



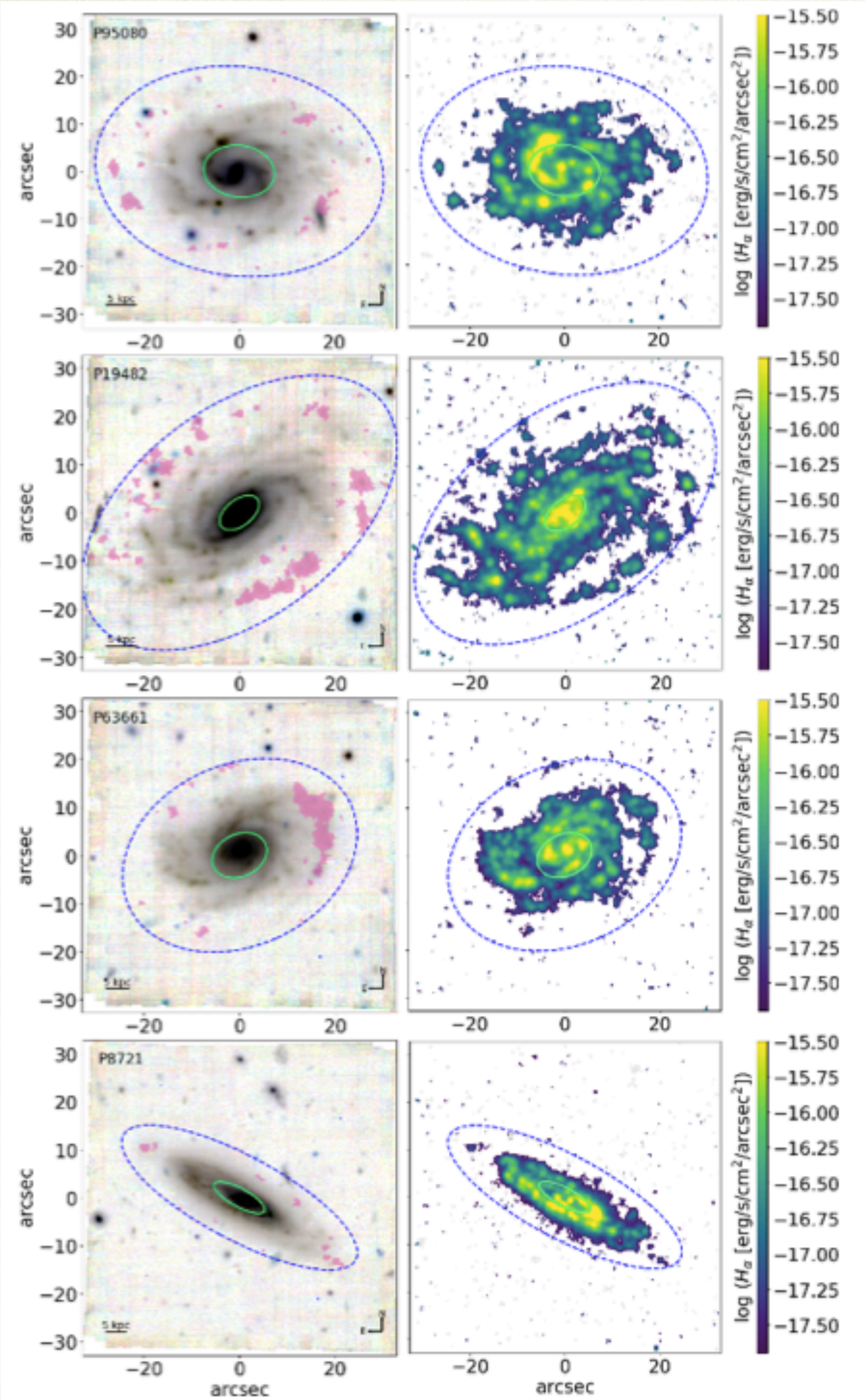
Gas accretion

see also Vulcani+18a





Galaxies in filaments



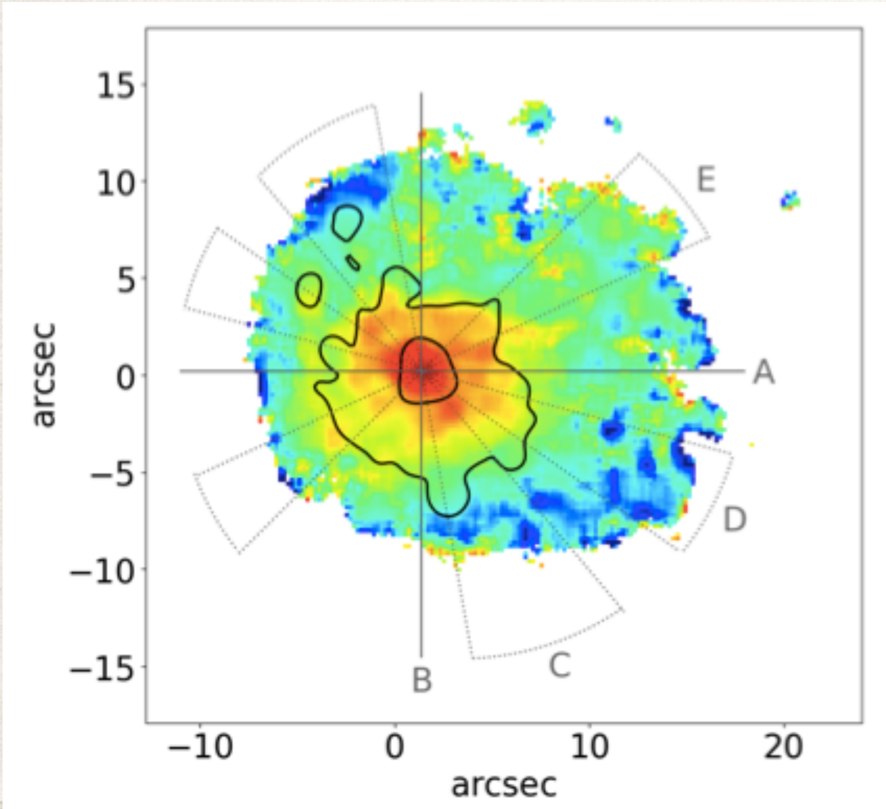
Peculiar (tattered) Halpha distribution:

Halpha clouds beyond 4 galaxy effective radii

“Cosmic web enhancement”? Galaxies passing through or flowing within filaments having an increase of SF in the densest regions of the circumgalactic gas?

Vulcani+ 2019a

Isolated galaxies



Evidence for gas accretion in an isolated, lopsided spiral from:

-- stellar ages

-- gas kinematics

-- gas metallicity distribution

Inflow of gas probably proceeding from the southwest

Vulcani+ 2018a

Open Questions

- *How can stars form in such a harsh environment? What are the conditions in the star forming clumps?*

  —> High resolution imaging of star forming galaxies at low- and intermediate redshifts (e.g. MAVIS@VLT, MICADO@ELT)

- *Is there warm molecular gas in the tails?*

  —> High spectral and spatial resolution of the ionized tail in the IR (MIRI@JWST)

- *Is the ram pressure an efficient quenching mechanism at intermediate redshift?What is the role of ram pressure for the evolution of galaxies in clusters, and is this role enhanced at intermediate redshifts with respect to the local Universe?*

  —> Deep high resolution imaging to detected stripped candidates at higher redshift (e.g. MICADO@ELT) and IFU in IR with large FoV to characterise the ionised gas (e.g. MAVIS@VLT)

Radisson Blu Saga Hotel, Reykjavik, Iceland
2020, April 20-24

UNIVERSITY OF ICELAND

THE UNIVERSITY OF KANSAS

INAF ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

SOC

Katey Alatalo
Gabriella De Lucia
Shy Genel
Yara Jaffé
Adam Muzzin (co-Chair)
Elke Roediger
Gregory Rudnick (co-Chair)
Stephanie Tonnesen
Remco van der Burg
Benedetta Vulcani (co-Chair)

LOC

Gunnlaugur Bjornsson
Adam Muzzin
Joakim Rosdahl
Gregory Rudnick
Benedetta Vulcani
Jesus Zavala Franco (Chair)

Invited Speakers

Stefano Borgani
Alyson Brooks
Matteo Fossati
Anthony Gonzalez
Bianca Maria Poggianti
Elke Roediger
Aaron Romanowsky (TBC)
Christy Tremonti
Pieter van Dokkum (TBC)
Tracy Webb
Vivienne Wild
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