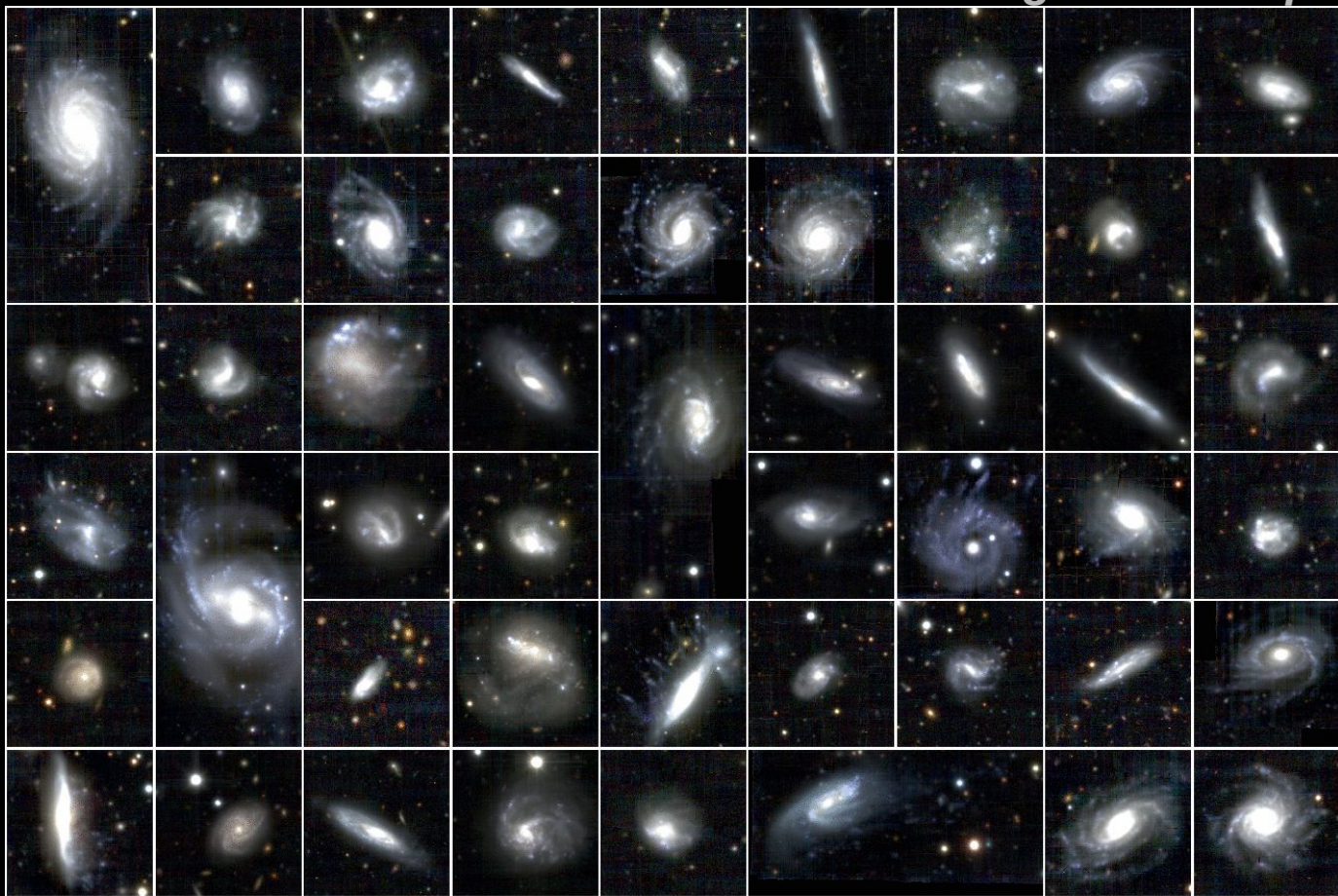


The GASP Large Programme with MUSE

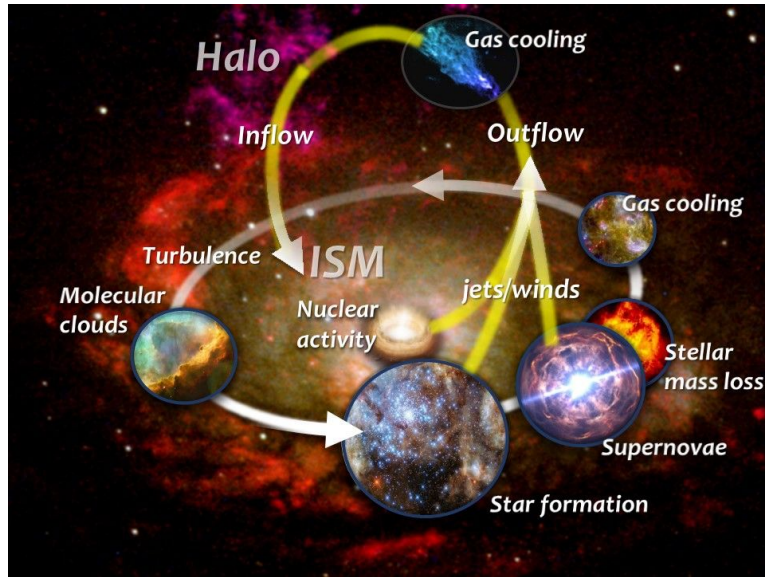
and its multi-wavelength follow ups



C. Bellhouse (ESO, Uni. Birmingham)
 D. Bettoni (INAF-OAPd)
 A. Cava (Obs. Geneve)
 W. Couch (AAO)
 M. D'Onofrio (UniPD)
 G. Fasano (INAF-OAPd)
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 P. Serra (INAF-OaCA)
 M. Ramatsoku (INAF-OaCA)
 M. Verheijen (Kapteyn, Groningen)
 T. Deb (Kapteyn, Groningen)
 K. George (India)
 M. Gitti (UniBo)
 A. Ignesti (UniBO)
 A. Wolter (INAF-Brera)

Marco Gullieuszik - INAF-OAPd

The gas cycle



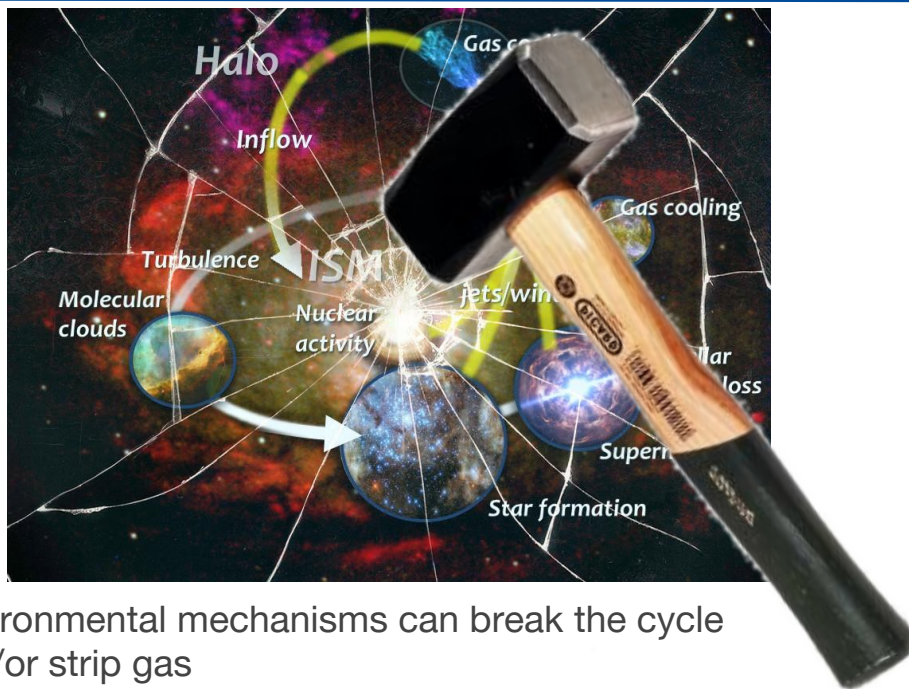
From http://www.spica-mission.org/science_galaxies.xhtml

The primary role of the gas component in galaxy evolution:

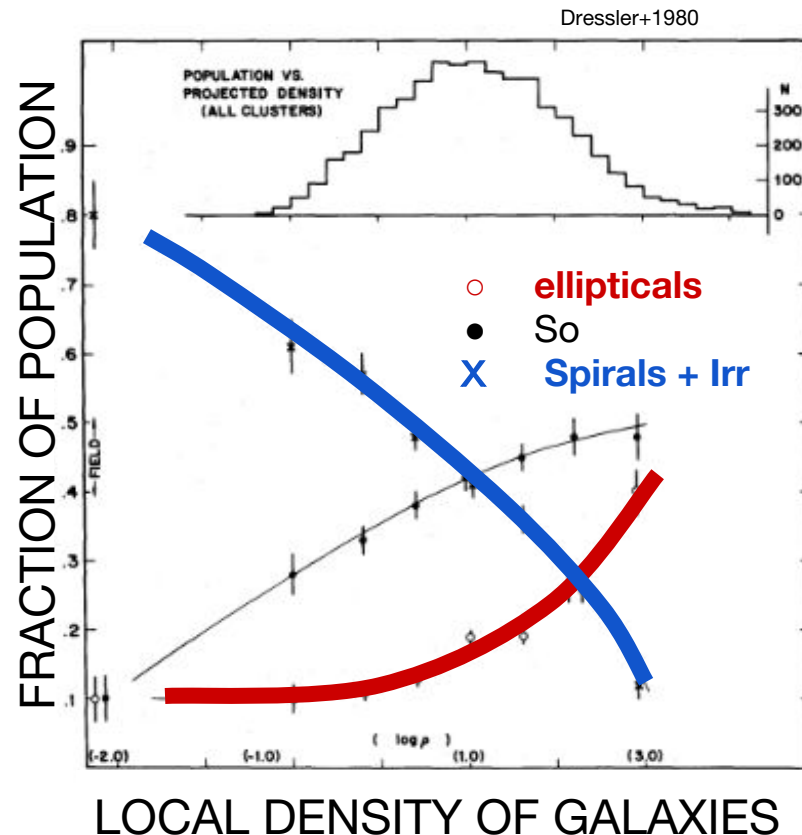
Isolated galaxies are self regulating systems

- + **gas replenishment**
- **consumption (stellar evolution)**
- **Ejection (SN/massive stars/AGN outflows)**

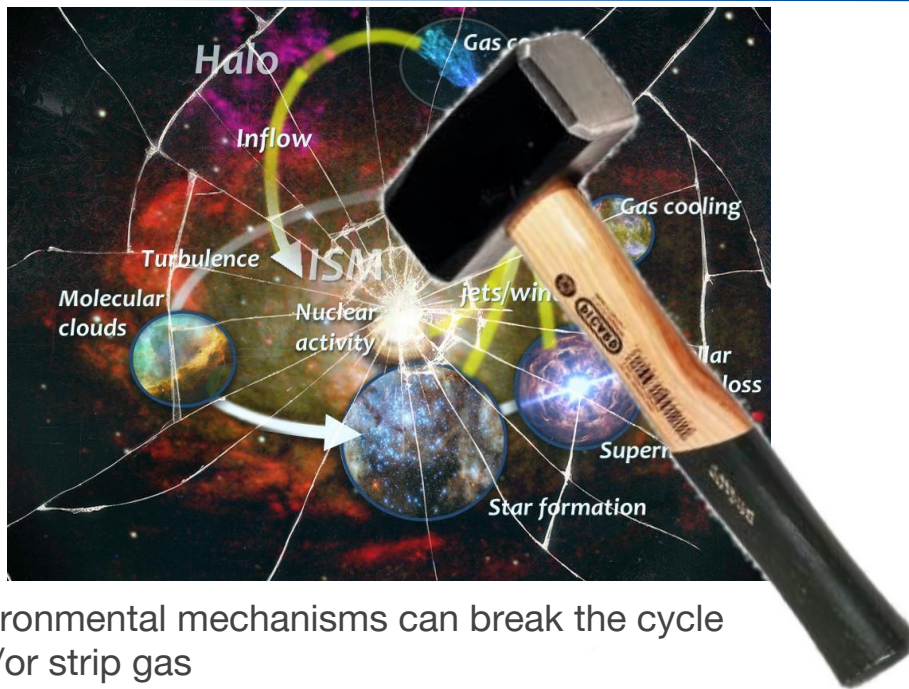
The gas cycle: environmental effects



Environmental mechanisms can break the cycle
and/or strip gas
> **environmental quenching of Star Formation**



The gas cycle: environmental effects



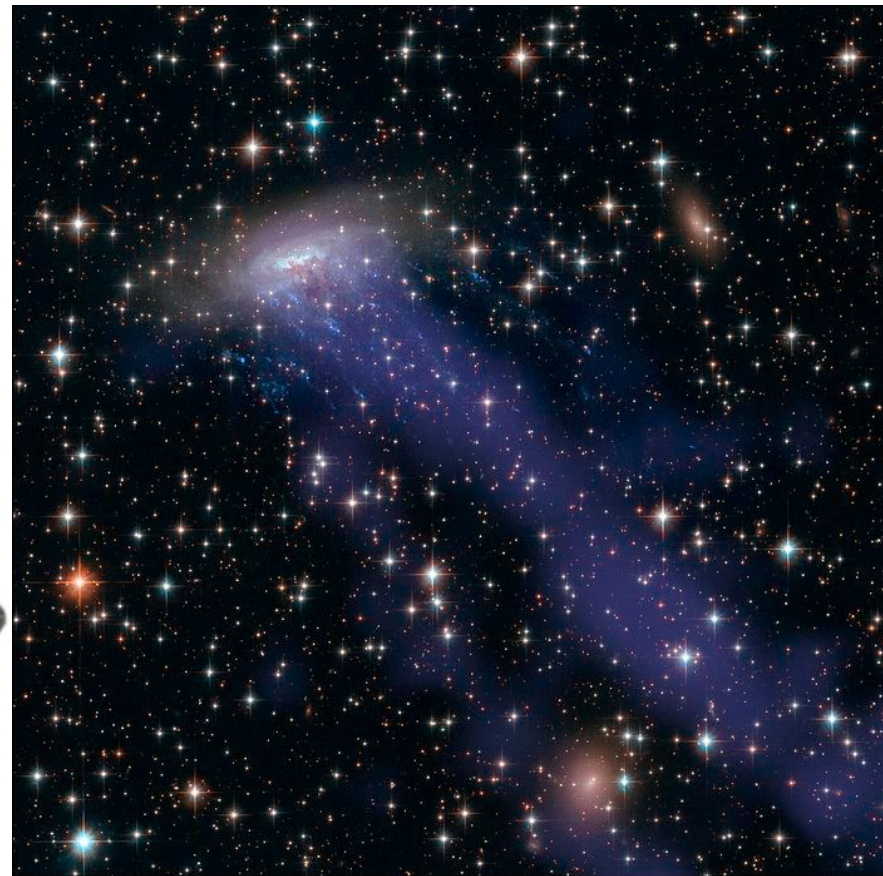
Environmental mechanisms can break the cycle
and/or strip gas

> ***environmental quenching of Star Formation***

Ram-pressure stripping

Interaction IntraCluster Medium - gas in the galaxy disc

the most efficient stripping mechanism in clusters



Gas Stripping Phenomena in galaxies

ESO Large Programme - PI Poggianti

120h with MUSE@VLT

94 Gas stripping candidates (clusters/groups/field)

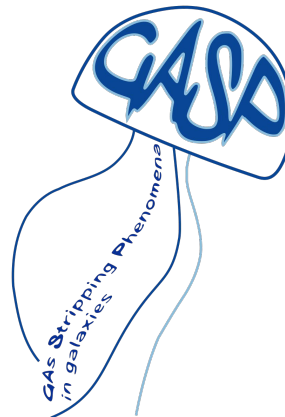
20 galaxies as control sample

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

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

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

- Galaxies in different **environments** (clusters, groups, field+control sample)
- Galaxies with different **masses** (from 10^9 to $10^{11.5} M_{\odot}$)
- Galaxies with different **stripping signatures**



C. Bellhouse (ESO, Uni. Birmingham)

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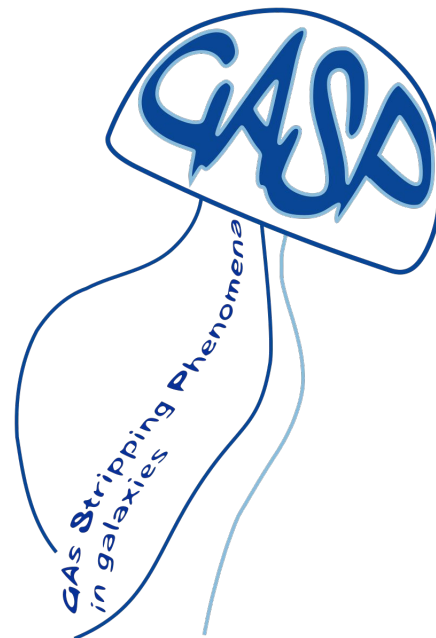
A. Wolter (INAF-Brera)

→ Observations completed: April 2018

→ Phase 3 data available (for 50% galaxies) with

- * datacubes
- * emission line flux maps
- * velocity maps
- * Star Formation History maps in 4 age bins, ages, stellar masses
- * integrated spectrum

→ DR2 (all galaxies): April 2019



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News and Updates > First data release of the deep 3D cubes plus ancillary maps and 1D spectra from the Large Programme 'Dissecting GAs Stripping Phenomena in galaxies (GASP)' 15 Jan 2018

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First data release of the deep 3D cubes plus ancillary maps and 1D spectra from the Large Programme 'Dissecting GAs Stripping Phenomena in galaxies (GASP)'

Published: 26 Oct 2017

The ESO Large Program 'Dissecting GAs Stripping Phenomena in galaxies' (<http://web.oapd.inaf.it/gasp/>, PI: B.Poggianti) is now releasing deep MUSE 3D cubes observed in wide field mode and natural seeing plus ancillary products from all the observations taken during the first three semesters of the program (P96, P97 and P98).

The scientific goal of the large programme is to study galaxies at $z = 0.04-0.07$ in different environments. The first half of the final sample (57/114) is now released. For each target galaxy, the released data products are the reduced and combined MUSE 3D data cubes that can be queried and downloaded using the [Phase 3 query form](#). The 3D data cubes come together with an associated extracted 1D spectrum and associated maps of the emission-line fluxes for the Halpha and Hbeta emission, the Halpha 2D line-of-sight velocity field, the average star formation rate in four age bins, as well as luminosity-weighted stellar age and stellar mass density maps.

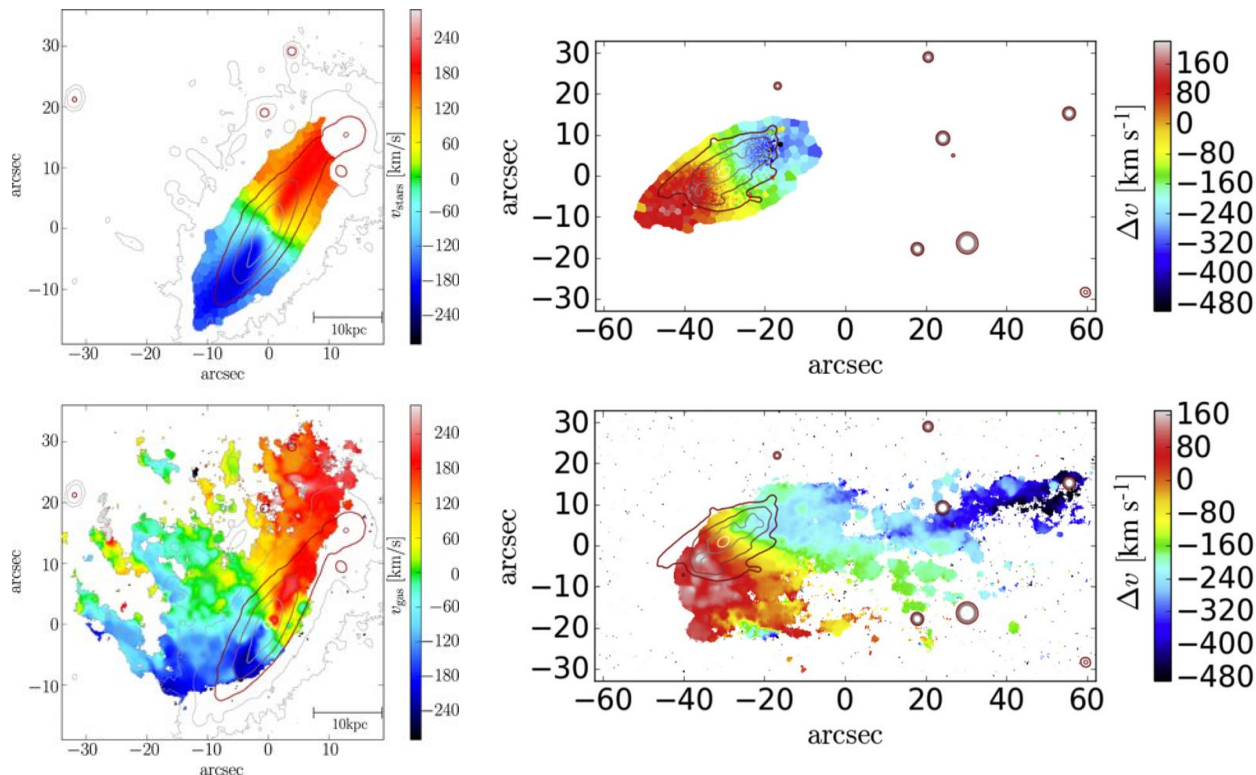
The released data come with a detailed description of the Large Program and a comprehensive data documentation [here](#).

Last Update: 27.10.17 © ESO

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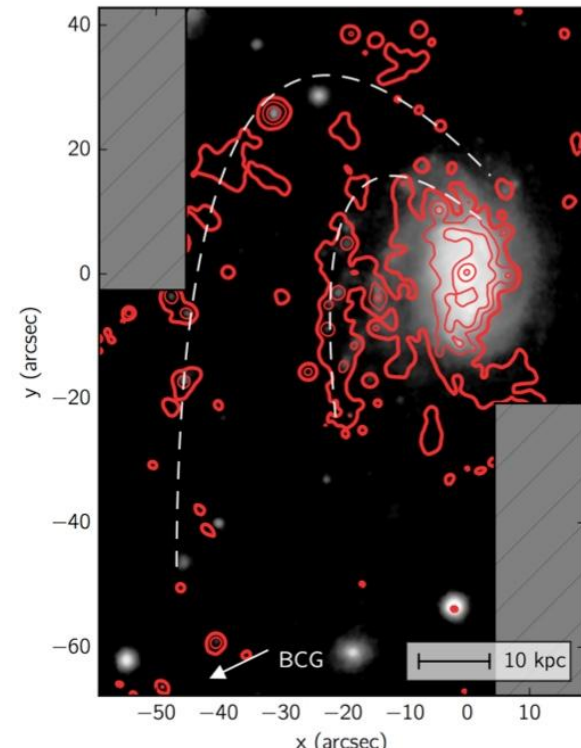
1. **GASP. I. Gas stripping phenomena in galaxies with MUSE**
Poggianti et al. (2017a), ApJ 844, 48
2. **GASP. II. A MUSE view of extreme ram-pressure stripping along the line of sight: kinematics of the jellyfish galaxy JO201**
Bellhouse et al. (2017), ApJ 844, 49
3. **GASP. III. JO36: a case of multiple environmental effects at play?**
Fritz et al. (2017), ApJ 848, 132
4. **GASP. IV. A Muse View of Extreme Ram-pressure Stripping in the Plane of the Sky: The Case of Jellyfish Galaxy JO204**
Gullieuszik et al. (2017), ApJ 846, 27
5. **GASP. V. Ram-pressure stripping of a ring Hoag's-like galaxy in a massive cluster**
Moretti et al. (2018), MNRAS, 475, 4055
6. **Ram-pressure feeding of supermassive black holes**
Poggianti et al. (2017b), Nature, 548, 304
7. **GASP. VII. Signs of gas inflow onto a lopsided galaxy**
Vulcani et al. (2018a), ApJ 852, 94
8. **GASP. VIII. Capturing the birth of a Tidal Dwarf Galaxy in a merging system at $z \sim 0.05$**
Vulcani et al. (2017), ApJ 850, 163
9. **GASP IX. Jellyfish galaxies in phase-space: an orbital study of intense ram-pressure stripping in clusters**
Jaffé et al. (2018), MNRAS 476, 4753
10. **GASP. X: APEX detection of molecular gas in the tails and in the disks of ram-pressure stripped galaxies**
Moretti et al. (2018), MNRAS 480, 2508
11. **UVIT view of ram-pressure stripping in action: Star formation in the stripped gas of the GASP jellyfish galaxy JO201 in Abell 85**
George et al. (2018), MNRAS 479, 4126
12. **GASP. XII. The variety of physical processes occurring in a single galaxy group in formation**
Vulcani et al. (2018b), MNRAS, 480, 3152
13. **GASP. XIII. Star formation in gas outside galaxies**
Poggianti et al. (2019), MNRAS, 482, 4466P
14. **Enhanced star formation in both disks and ram pressure stripped tails of GASP jellyfish galaxies**
Vulcani et al. (2018c), ApJ, 866L, 25

Ram pressure stripping is at play



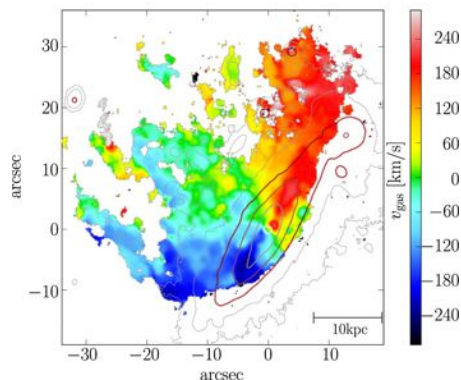
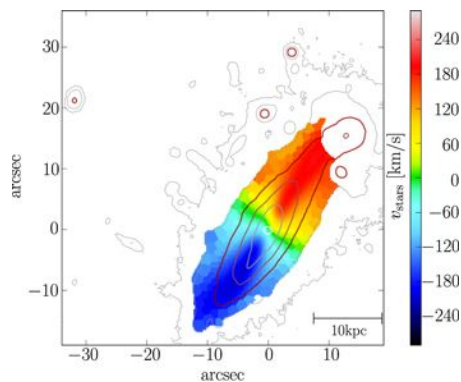
Gullieuszik et al., 2017

Poggianti et al., 2017

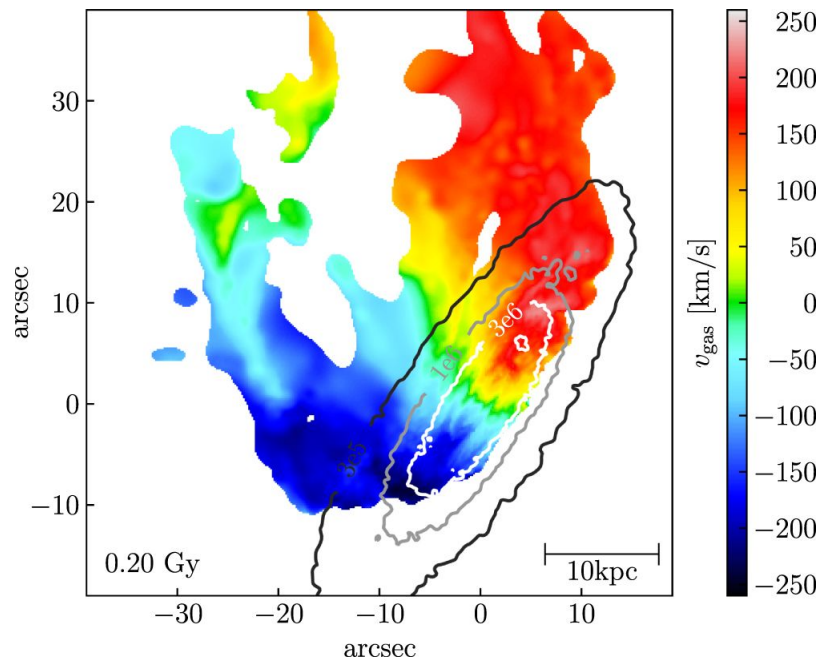


Bellhouse et al., 2017

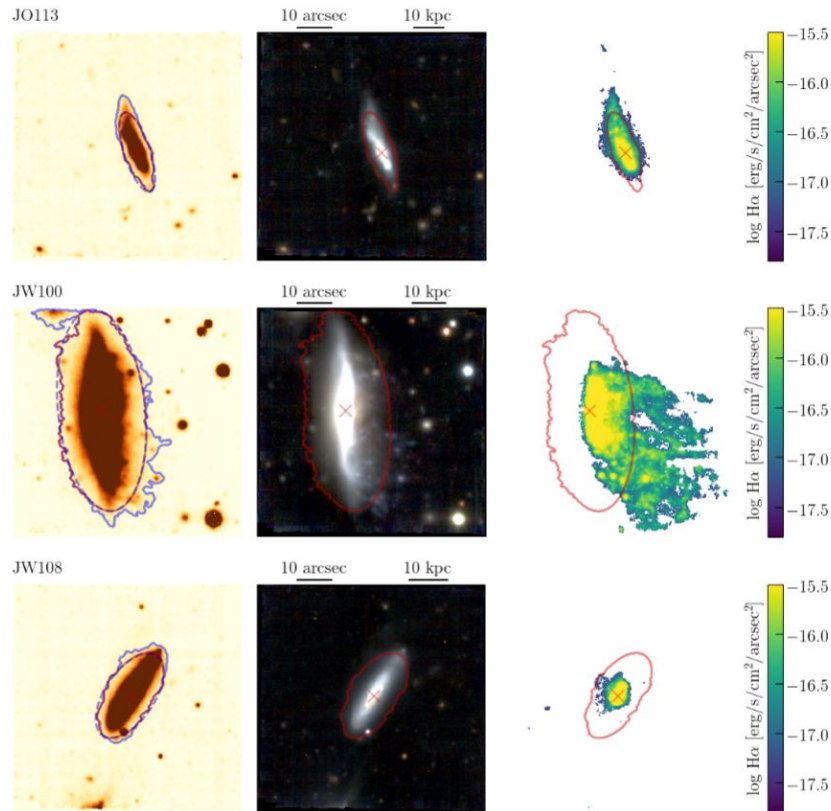
Ram pressure stripping is at play



Gullieuszik et al., 2017

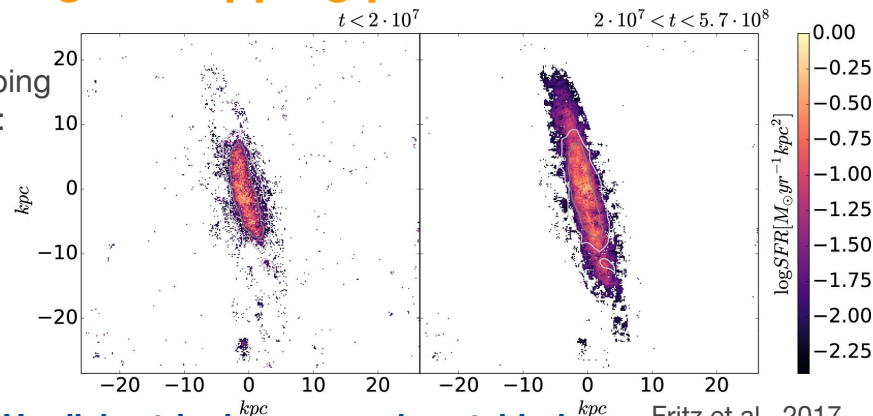


+
**Hydrodynamical
N-body Simulations**



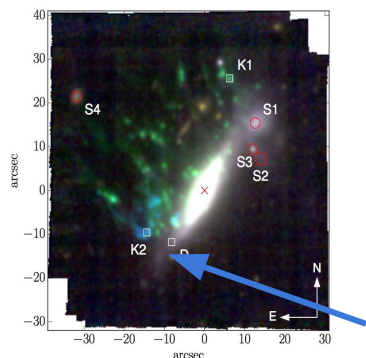
Different gas stripping phases are revealed

Post-stripping signatures:

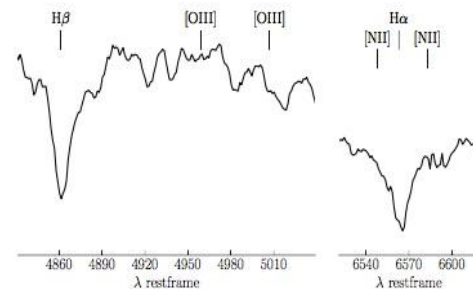


Truncated H α disk: stripping proceeds outside-in

Fritz et al., 2017



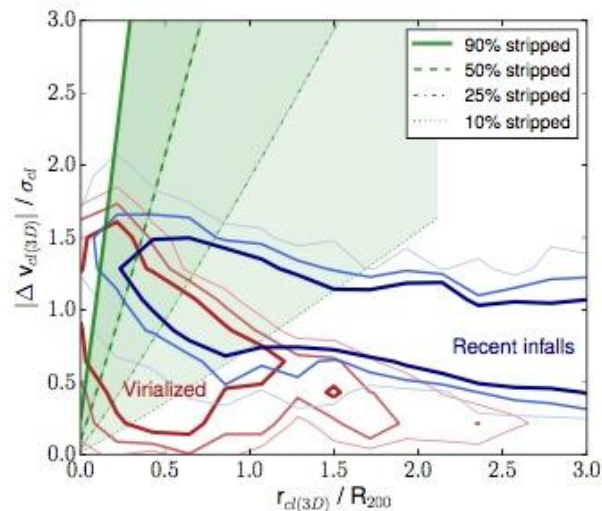
k+a spectrum



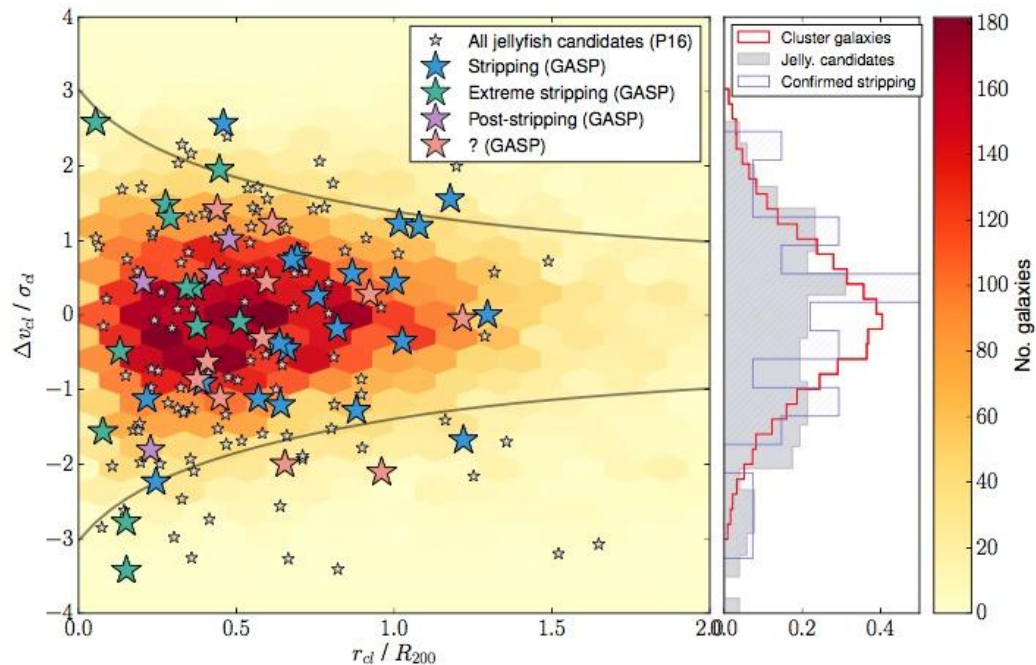
Gullieuszik et al., in prep

Gullieuszik et al., 2017

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



RPS - AGN connection

→ selecting (observed) JF:
H α tails as long as the stellar disk diameter

[masses between $4e10$ and $3e11$]

5/7 galaxies with emission line ratios typical of AGN
in the center and in an extended region of ~ 10 kpc.

only 3% of EL galaxies in WINGS clusters show AGNs)

AGN confirmed by Xray emission (Chandra)

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Letter

Ram-pressure feeding of supermassive black holes

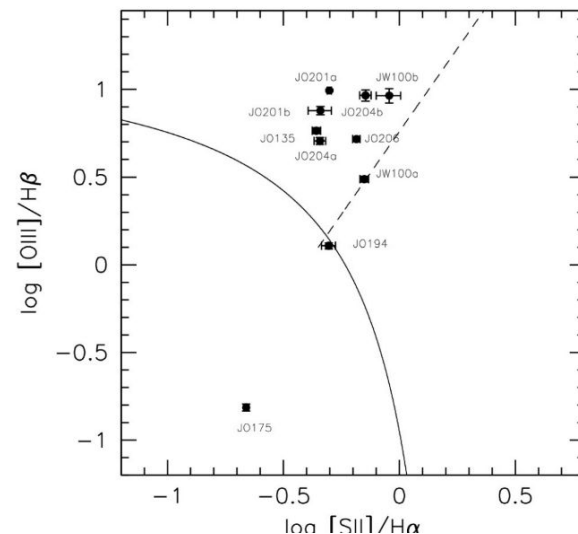
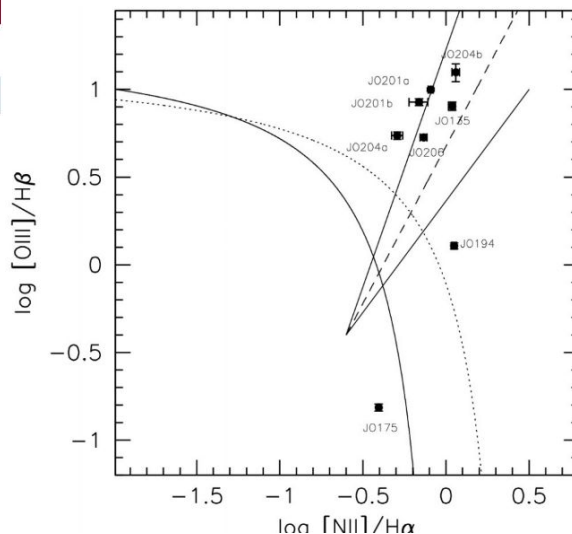
Bianca M. Poggianti, Yara L. Jaffé, Alessia Moretti, Marco Gullieuszk, Mario Radovich, Stephanie Tonnesen, Jacopo Fritz, Daniela Bettoni, Benedetta Vulcani, Giovanni Fasano, Callum Bellhouse, George Hau & Alessandro Omizzolo

Nature **548**, 304–309 (17 August 2017)
doi:10.1038/nature23462
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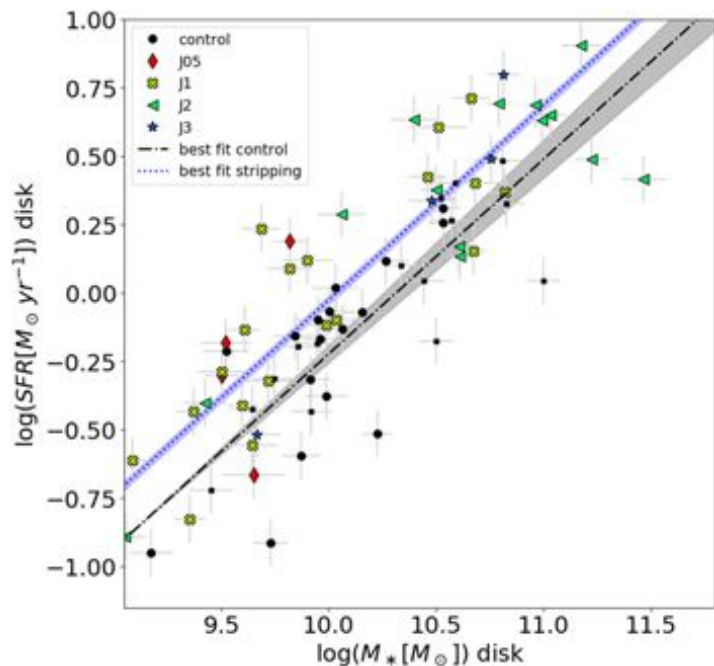
Received: 26 April 2017
Accepted: 21 June 2017
Published online: 16 August 2017

Galaxies and clusters Interstellar medium

Poggianti et al., 2017



Enhanced SFR in the disk galaxies undergoing ram-pressure stripping

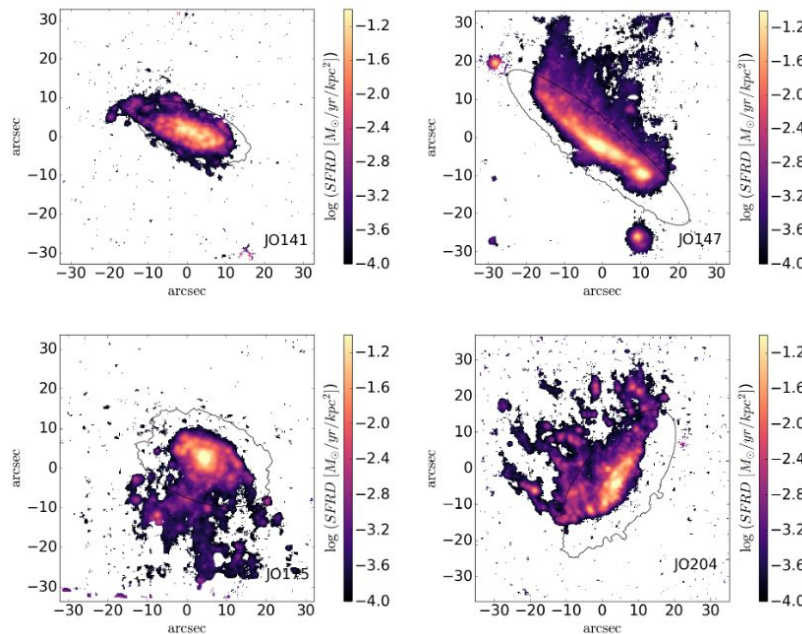


Vulcani et al., 2018

In situ star formation in the tails of all GASP galaxies

The tail clumps follow scaling relations similar to disk clumps.

Their stellar masses are comparable to Ultra Compact Dwarfs and Globular Clusters.



Poggianti et al. 2019

Molecular gas

→ CO gas with **APEX** (33+44 hrs) for 5 galaxies to detect molecular hydrogen in the galaxies and in the tails: is the molecular gas stripped as well or is it formed in situ? How much molecular gas is present in the tails and left in the main body? [molecular gas is present both in the disk and in the tails, with different velocities, **Moretti et al., 2018b**]

→ **ALMA** observations [4 targets, 22 hrs, 1mJy RMS, all with AGN, in different clusters. 1 kpc resolution would allow to resolve the knots as in GASP. CO21 and CO10. **Moretti et al., in prep.**]

Cold gas

→ Deep HI observations of 15 JF in 5 clusters with **JVLA** (100 hrs, 15 kpc resolution)[mainly to study the interplay of the different gas phases, but also to correlate HI deficiency to the JF appearance and to discover interactions, if any. **Ramatsoku et al., in prep.; Deb et al., in prep.**]

Magnetic field

→ 50 h JVLA S-band observation of JO206. Observations will be likely completed in ~weeks

Ongoing star formation

→ Ultraviolet view of RPS in action with **UVIT**/Astrosat (24.4 ks) [**George et al., 2018**]

→ **Chandra** observations [14 galaxies with masses $>2e10$ and JClass ≥ 3 , 10-60 ks each, 560 ks in total, 11 already show X-ray emission. To detect AGN signatures, shock fronts, ULXs]

CO

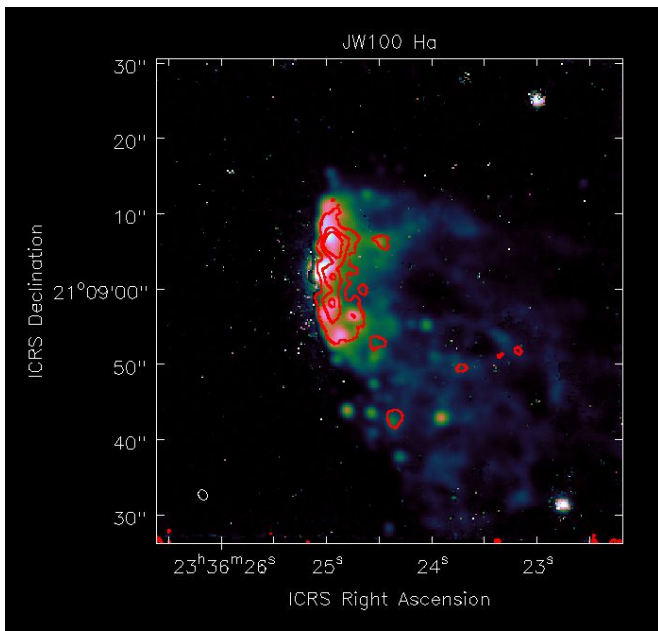
HI

B

UV

X

GASP follow-up programmes: ALMA



Red contours are CO21
from ALMA cycle
5(ACA+12m) at

0.3, 1.5 and 2.7
Jy/beam.km/s

Beam size = 1.4" x 1.1"

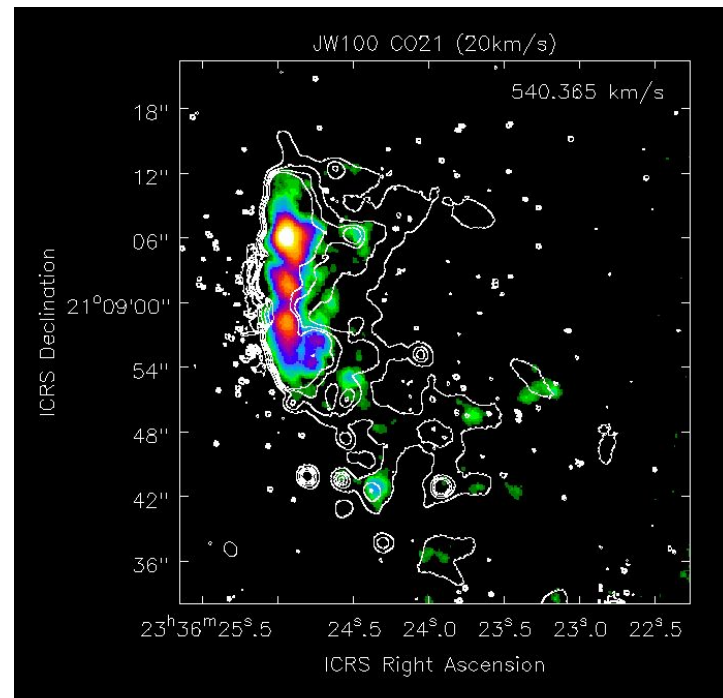
RMS (1 σ) = 1mJy/beam

CO(2-1) and H α not
always coincident:
different stages of
SF?



H α image + CO contours

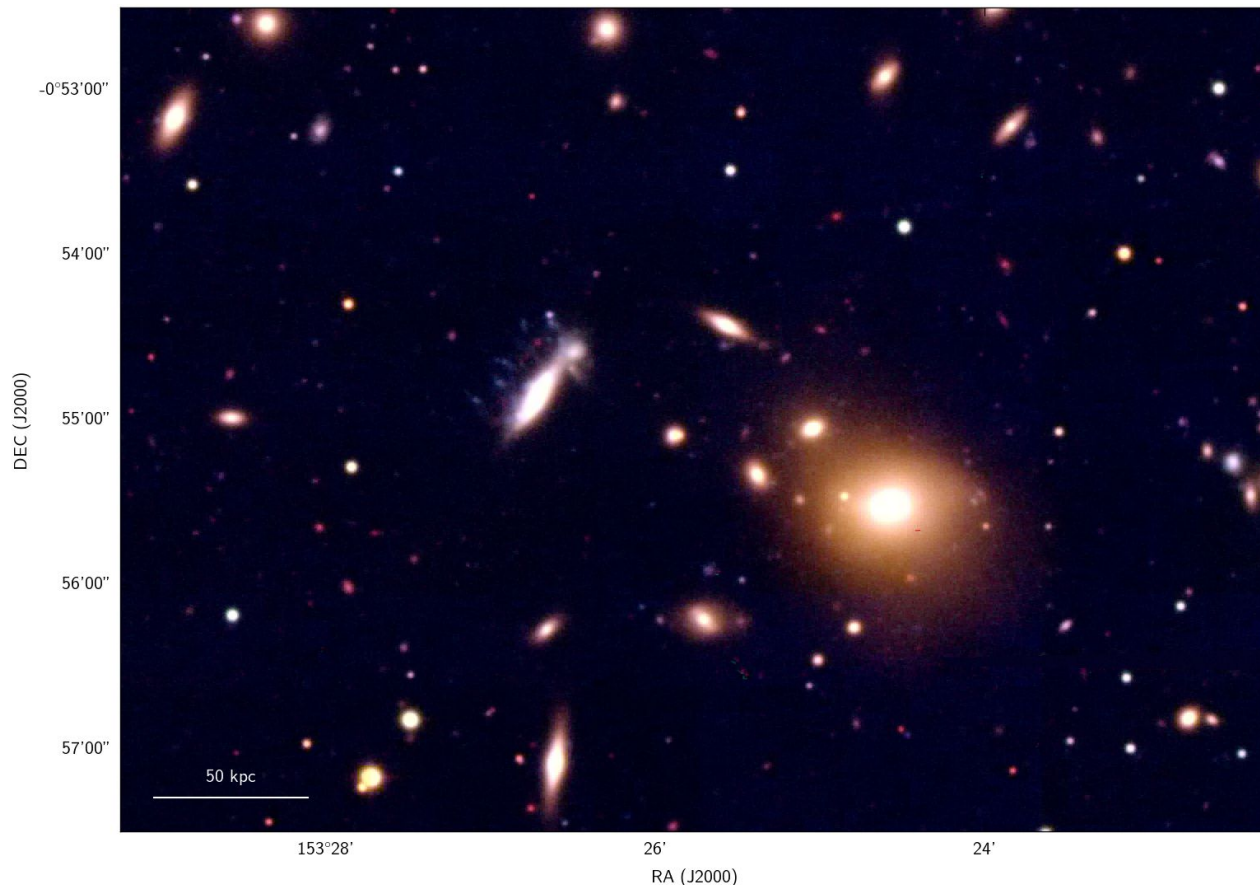
MUSE RGB image



CO image + H α contours

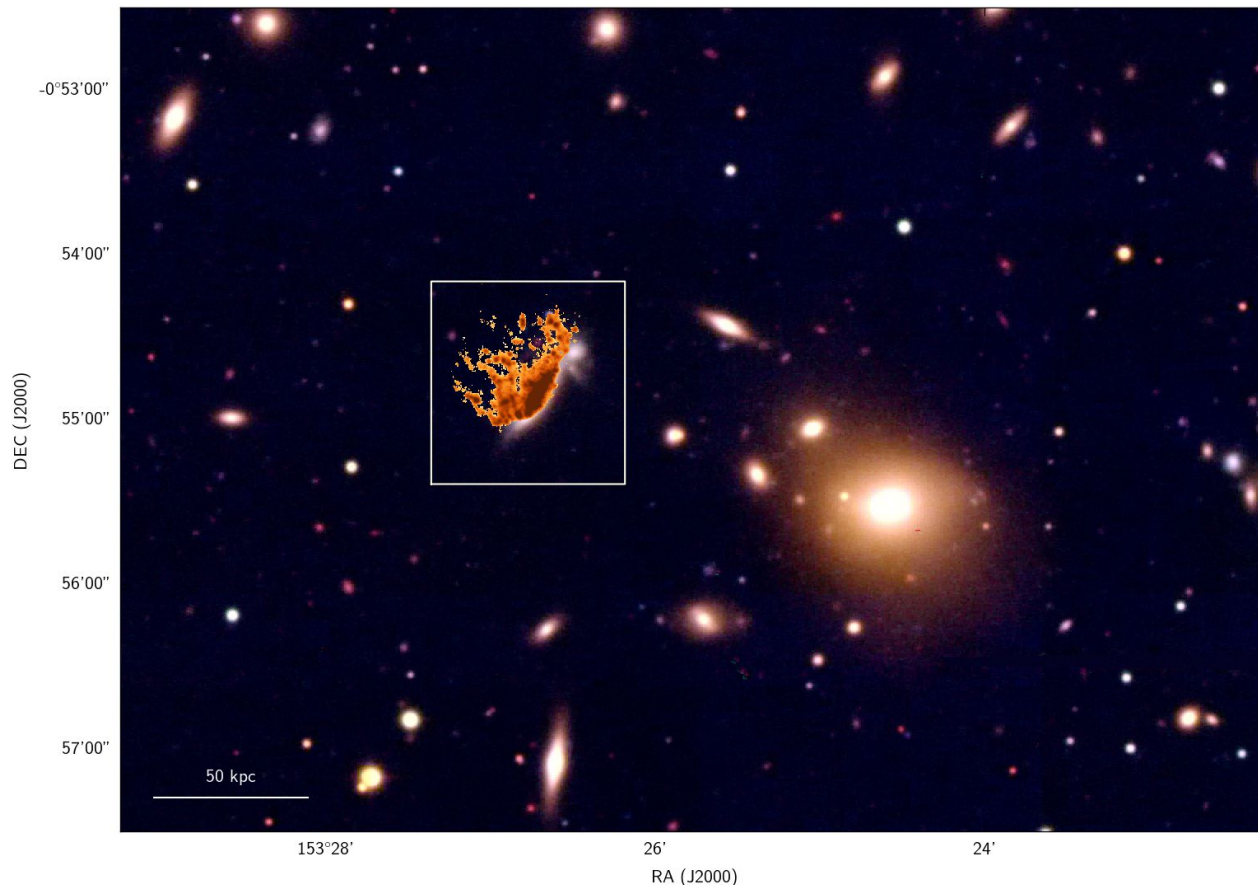
Moretti et al., in prep.

GASP follow-up programmes: JVLA



u+B+V OmegaCAM@VST
Gullieuszik+2015

GASP follow-up programmes: JVLA



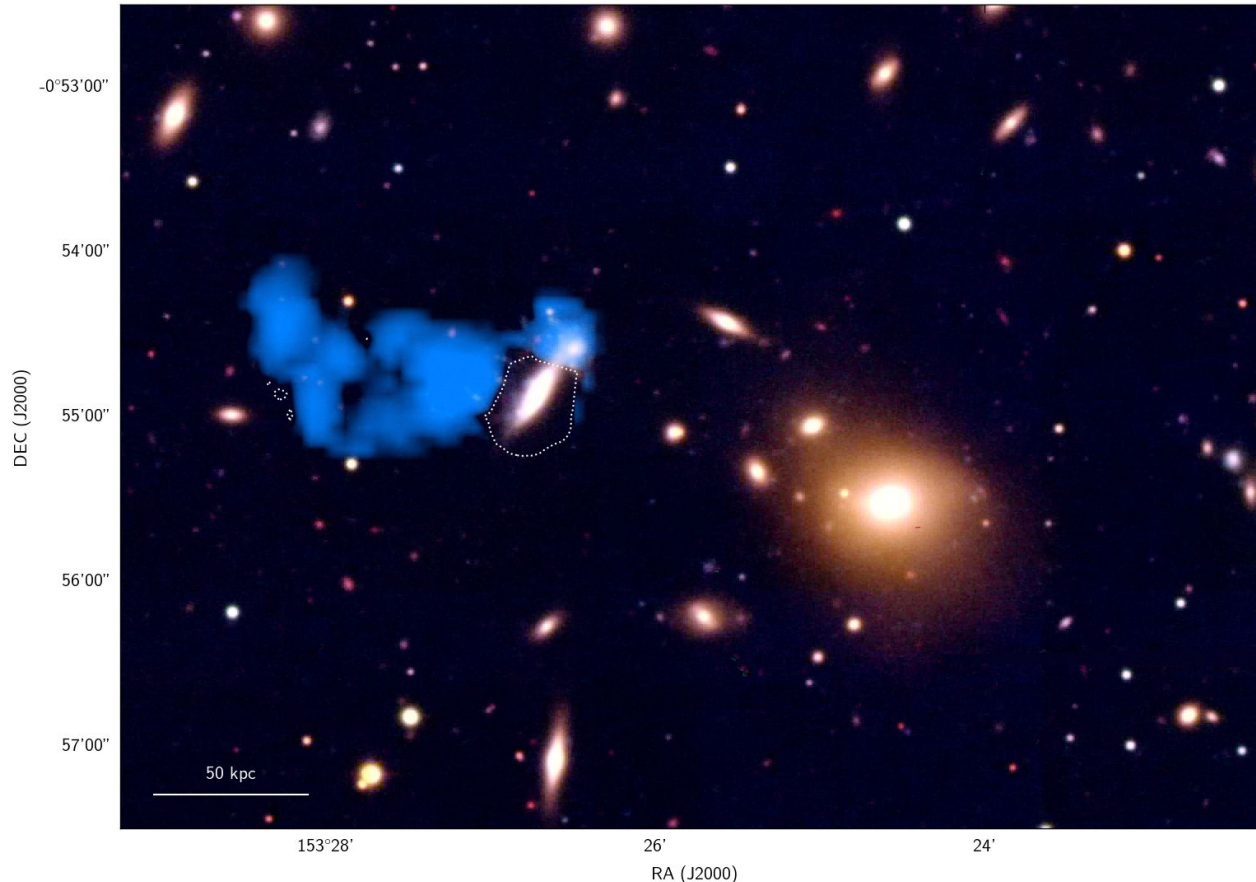
u+B+V OmegaCAM@VST

Gullieuszik+2015

Halpha MUSE@VLT

Gullieuszik+2017

GASP follow-up programmes: JVLA



u+B+V OmegaCAM@VST
Gullieuszik+2015

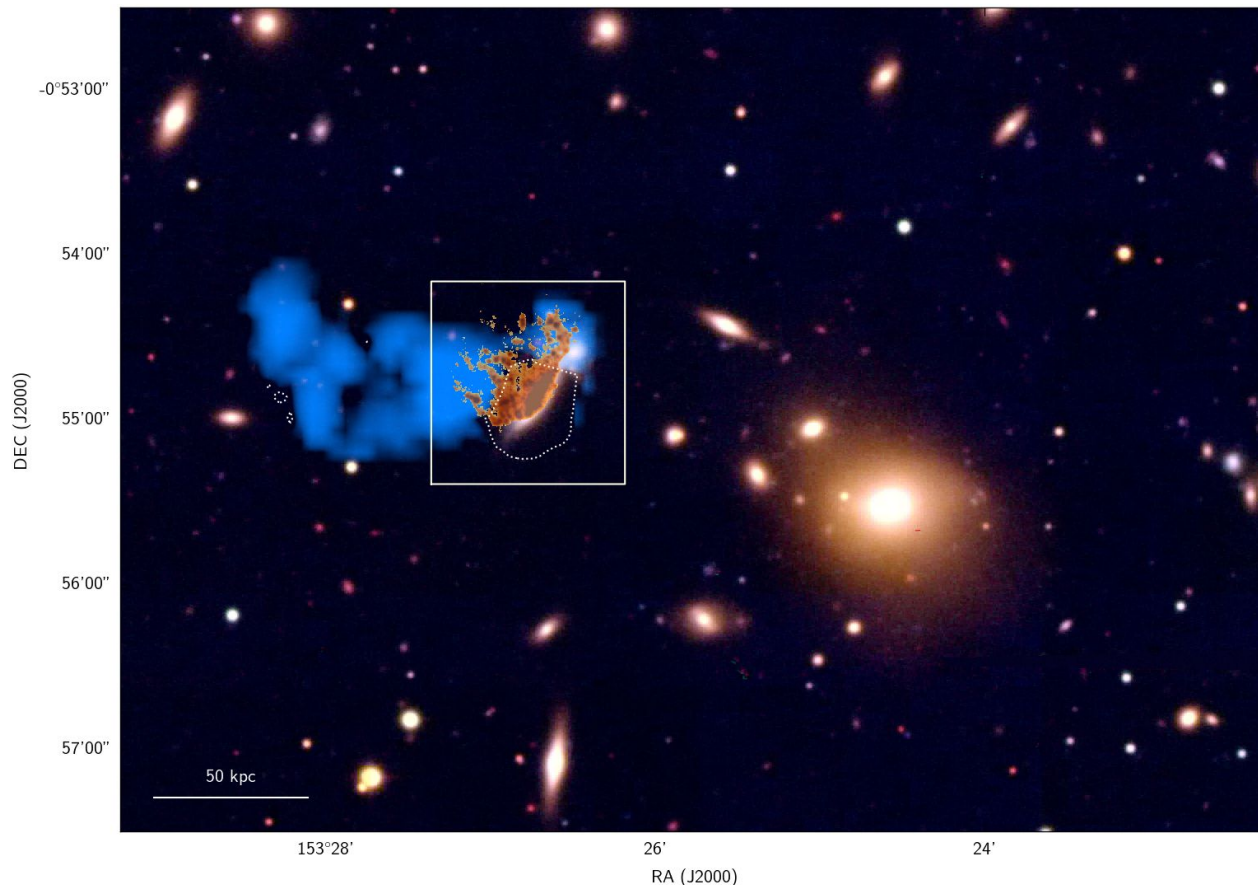
Halpha MUSE@VLT
Gullieuszik+2017

HI JVLA
Deb+ in prep.

90 kpc long HI tail ($1.3 \times 10^9 M_{\odot}$)

HI in absorption against the central
continuum source (AGN+SF)

GASP follow-up programmes: JVLA



u+B+V OmegaCAM@VST

Gullieuszik+2015

Halpha MUSE@VLT

Gullieuszik+2017

HI JVLA

Deb+ in prep.

WEAVE

- Galaxy cluster survey
- Stellar Populations at intermediate redshifts Survey (StePS)

JWST

Distribution of H₂ in the disc and tails of GASP galaxies

Science cases for:

MICADO/MAORY @ E-ELT

- Probing the assembly of high redshift early-type galaxies
- The star formation history of galaxies at the peak of their compactness

MAVIS @ VLT

- Mass growth and size evolution of early type galaxies
- **Dissecting the morphological evolution through the cosmic time and environment**
- **Ram-pressure stripping in intermediate-z clusters**
- **Variation of Star-forming clumps properties with redshift and environment**

Thank you

Background image:
Abell 85 (and JO201)
BV : WFI@ESO2.2m
NUV : UVIT-ASTROSAT
Radio-continuum : JVL