STRIPPING GALAXIES OF THEIR GAS

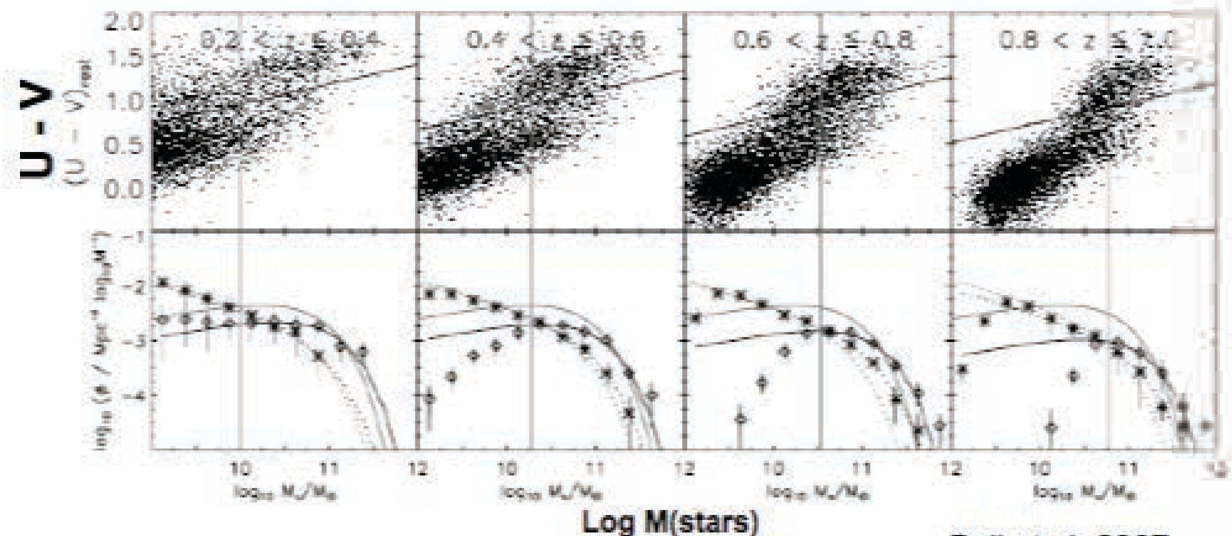
Bianca Poggianti

INAF-Astronomical Observatory of Padova

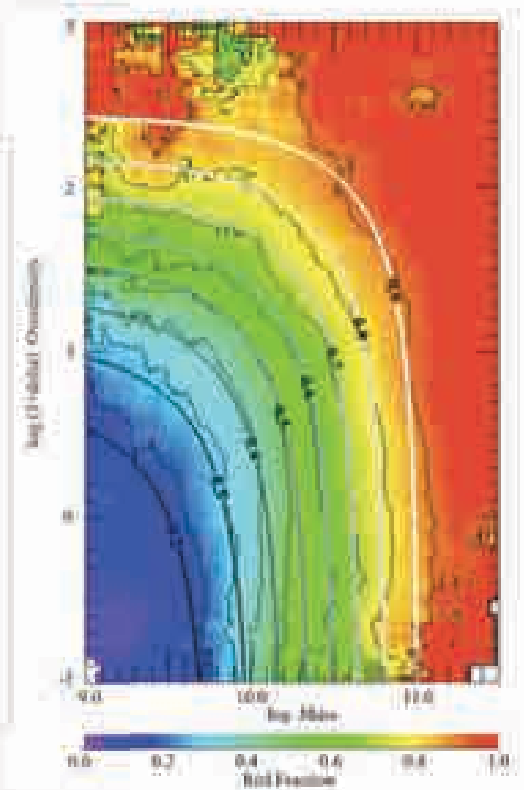
- Motivation: why is it important, what are we looking for
- An introduction to ”jellyfish galaxies”: some previously known cases
- Presentation of OMEGAWINGS survey
- Our jellyfish galaxies results

ONE OF THE MAJOR OPEN QUESTIONS IN THE FIELD OF GALAXY EVOLUTION

THE PHYSICAL DRIVER/S OF THE STAR FORMATION HISTORY, AND THE CAUSE OF GALAXY *QUENCHING*



Bell et al. 2007



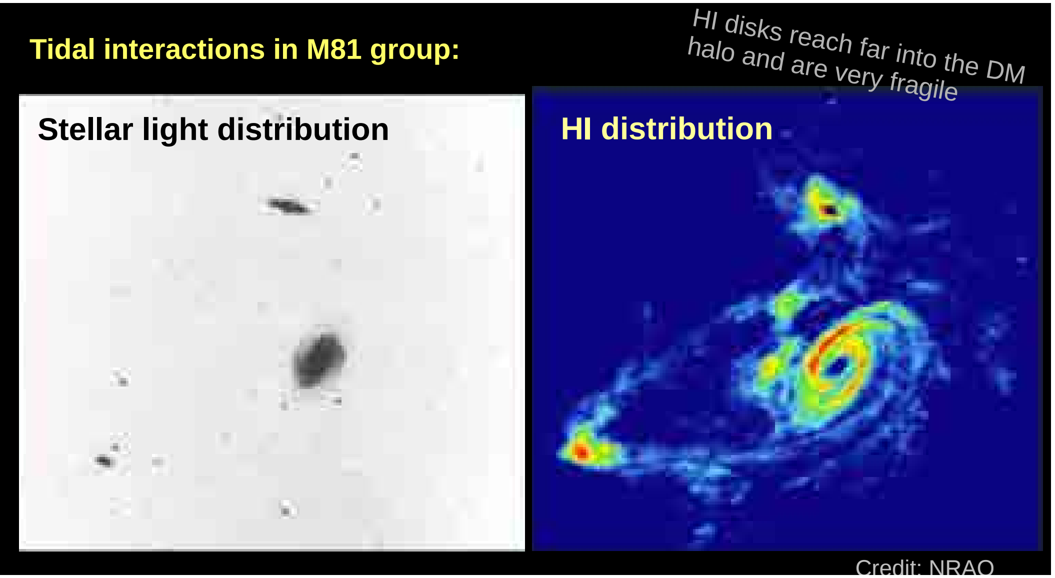
Peng+ 2010

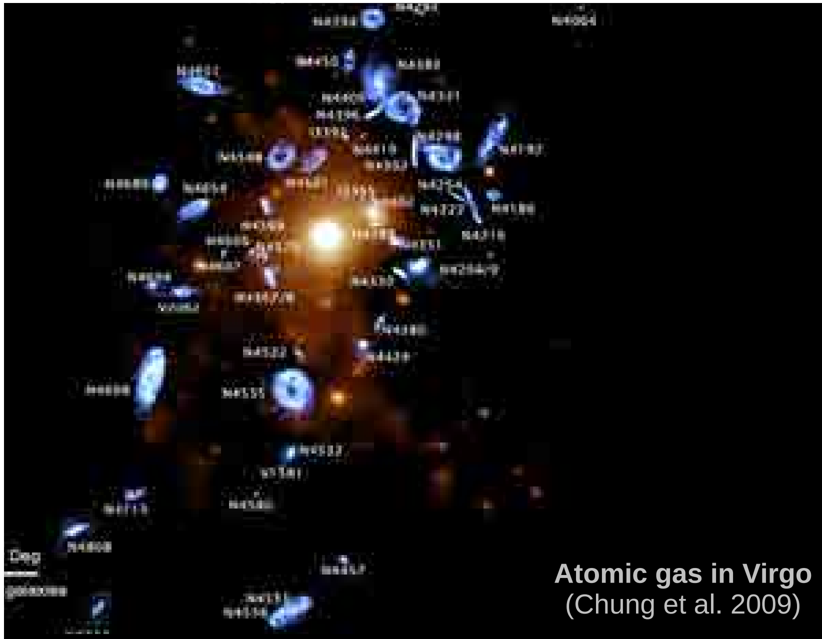
GAS AND GALAXY EVOLUTION

Fuel for star formation

Sensitive tracer of different environmental processes, such as ram pressure stripping and tidal interactions, but also harassment and eventual preprocessing in infalling groups

Observations have shown that the HI gas is disturbed and eventually truncated and exhausted in galaxies in low-z clusters





SOME ENVIRONMENTAL PHYSICAL MECHANISMS

- **Gas stripping** – Interactions galaxy-IGM (Gunn&Gott 1972, Quilis et al. 00, Vollmer et al. 99)

  ram pressure stripping, viscous stripping, thermal evaporation - FAST

  most efficient when IGM gas density and velocity are high

- Tidal forces – Cumulative effect of many weaker encounters - so called "**harassment**" (Richstone 1976, Moore et al. 1996)

  most efficient in clusters - especially on smaller galaxies

- **Mergers and strong galaxy-galaxy interactions**

(Toomre&Toomre 1972; Farouki&Shapiro 1981)

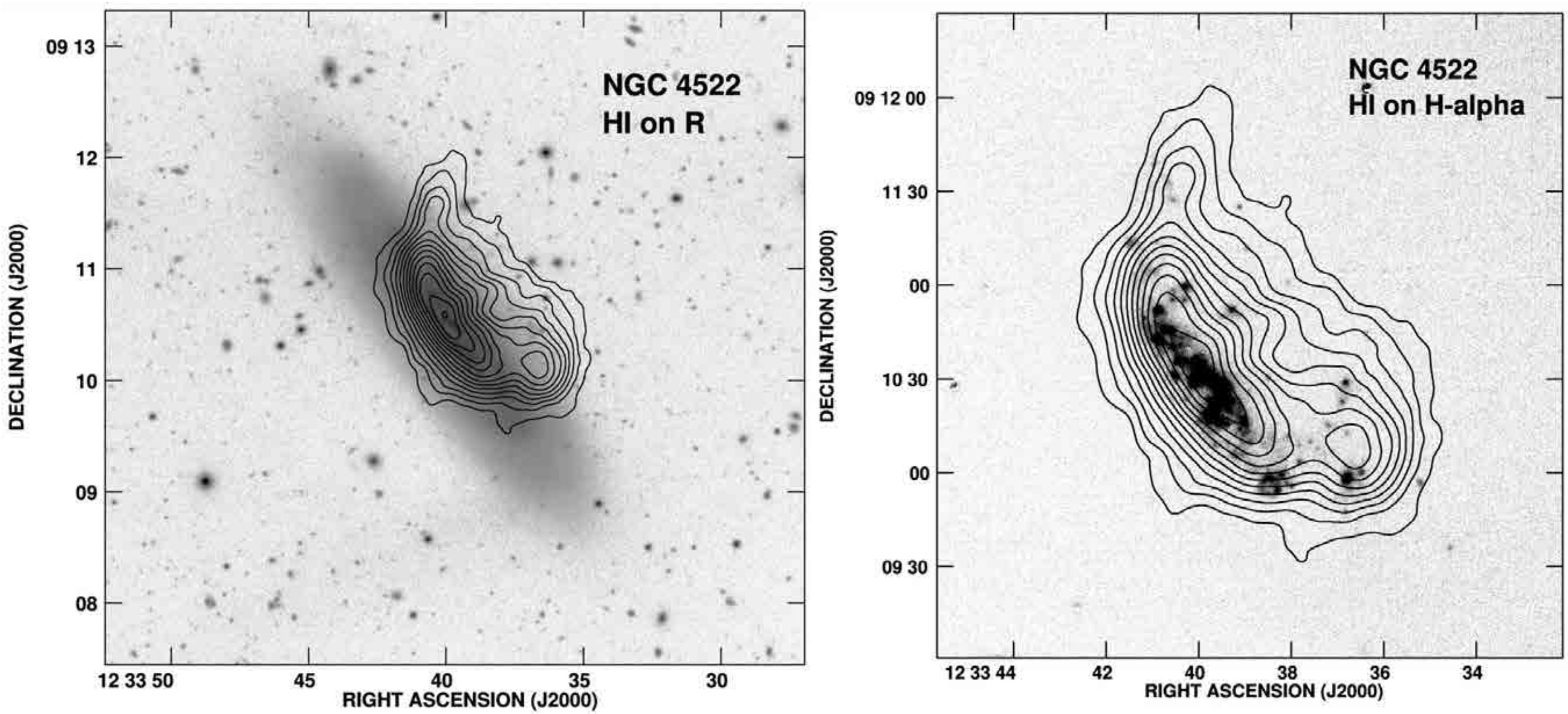
  most efficient when low relative velocities (groups)

- **Strangulation** (also known as starvation or suffocation)

(Larson, Tinsley & Caldwell 1980)

  loss of hot gas outer envelope affecting gas cooling - SLOW

Ongoing gas stripping caught in the act



Kenney, van Gorkom and Vollmer 2004, in the Virgo cluster

Ram P goes as ICM_density * v^2

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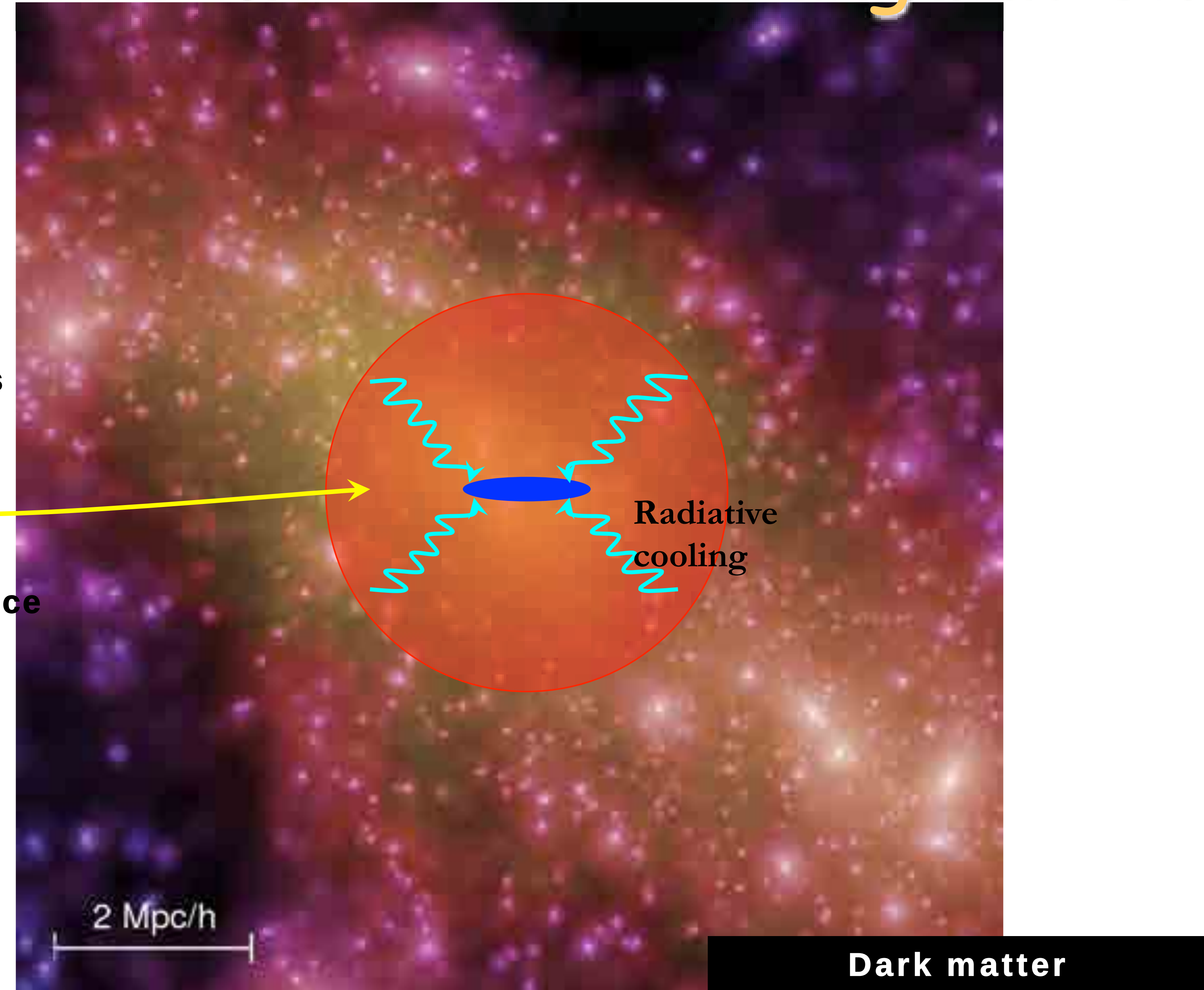
The halo model and strangulation

Hot baryons

~10^6 K for galaxies, hence invisible



FROM BLUE STAR-FORMING TO RED PASSIVE: GALAXIES IN TRANSITION IN DIFFERENT ENVIRONMENTS

Benedetta Vulcani[1], Bianca M. Poggianti[2], Jacopo Fritz[3], Giovanni Fasano[2], Alessia Moretti[2, 4], Rosa Calvi[4], and Angela Paccagnella[4]

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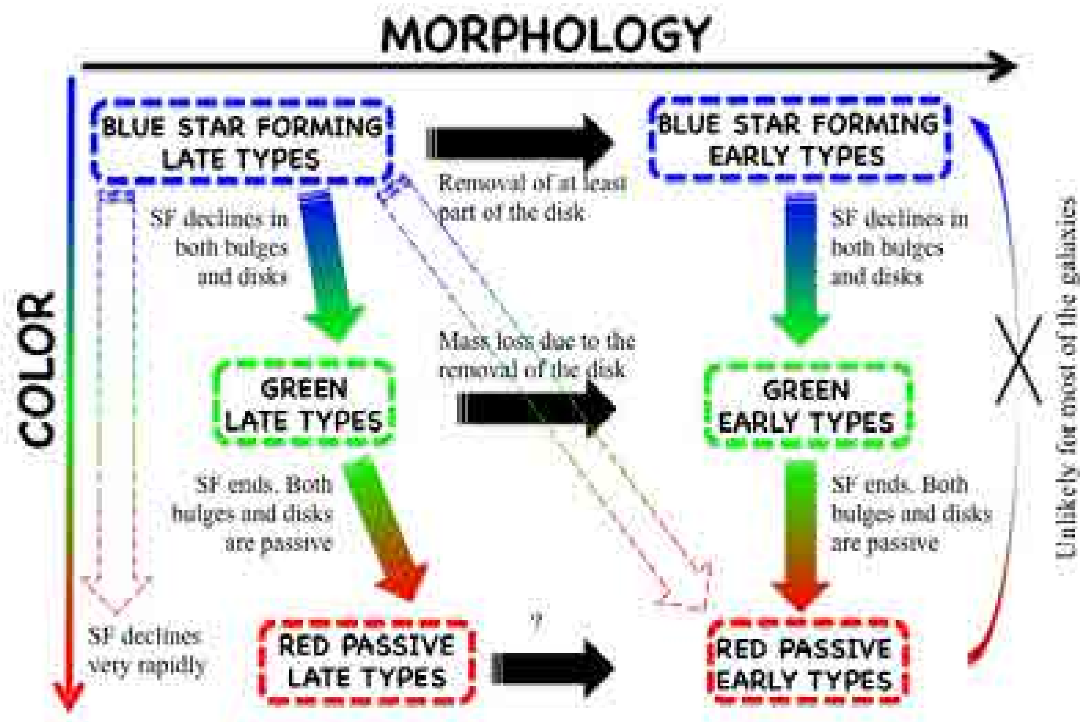
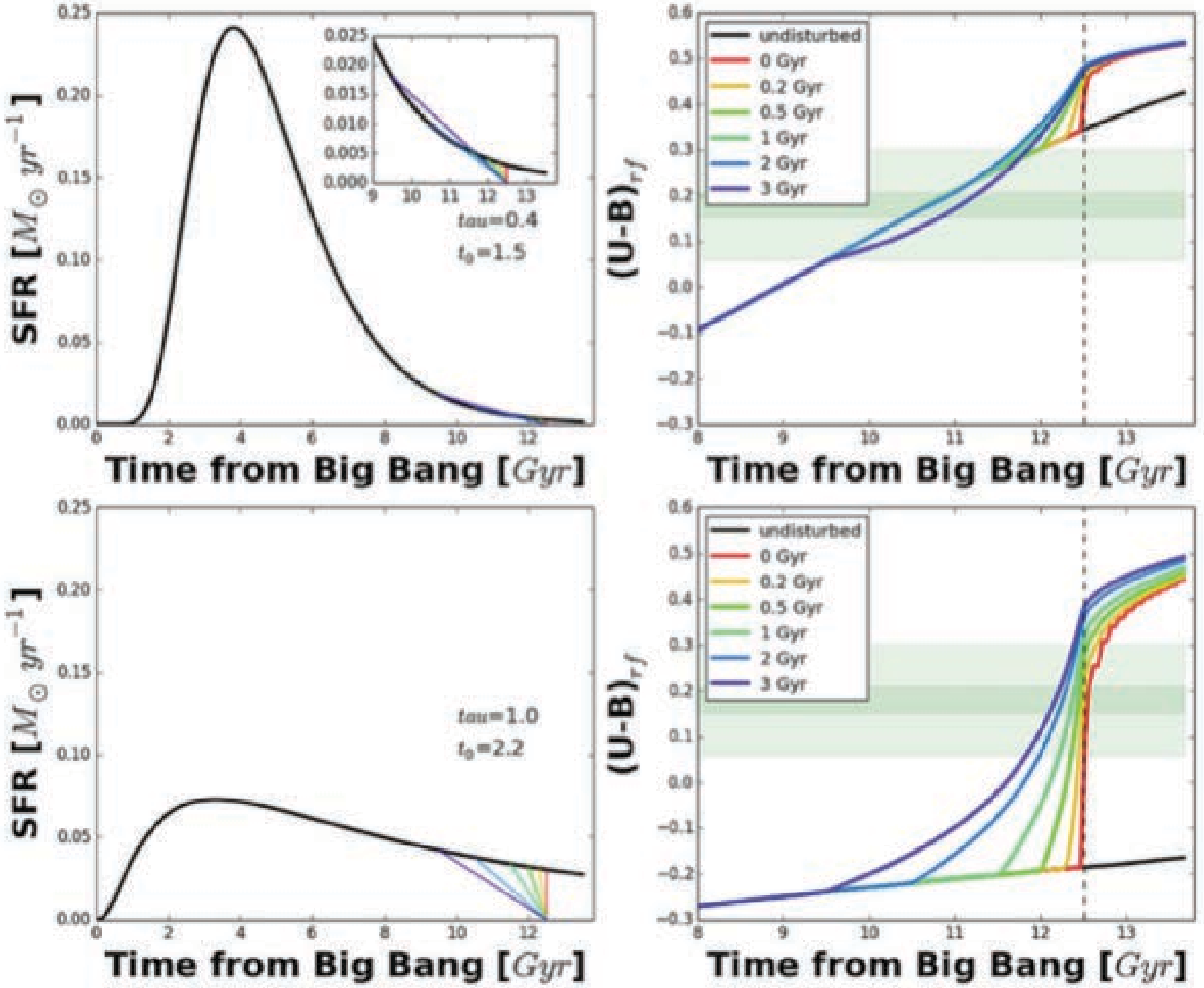
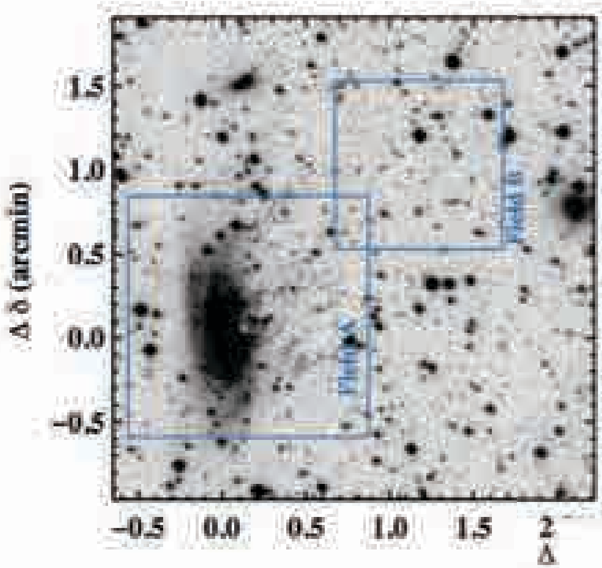


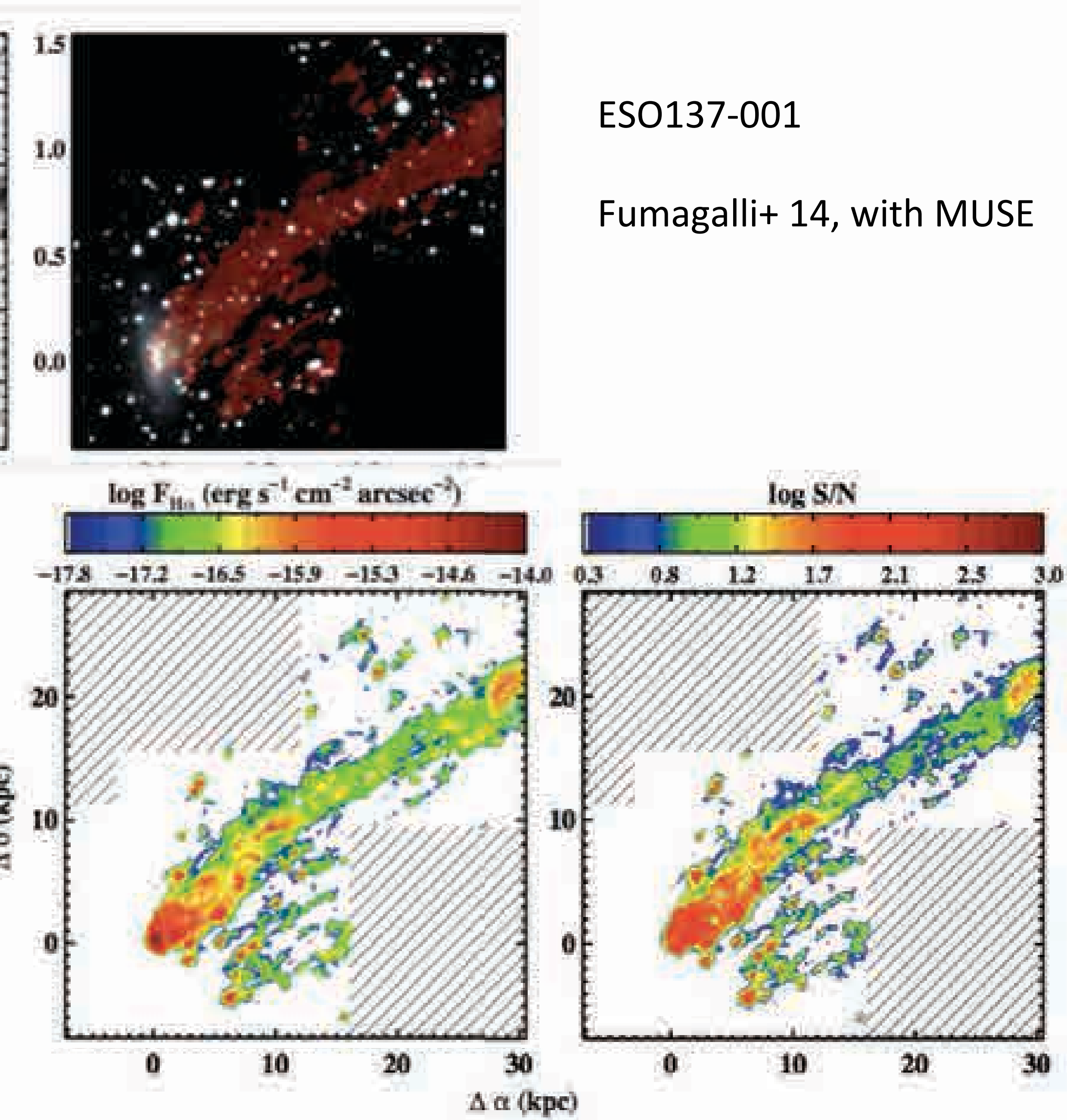
Vulcani+ 2015



Vulcani+ 2015

Jellyfish galaxies



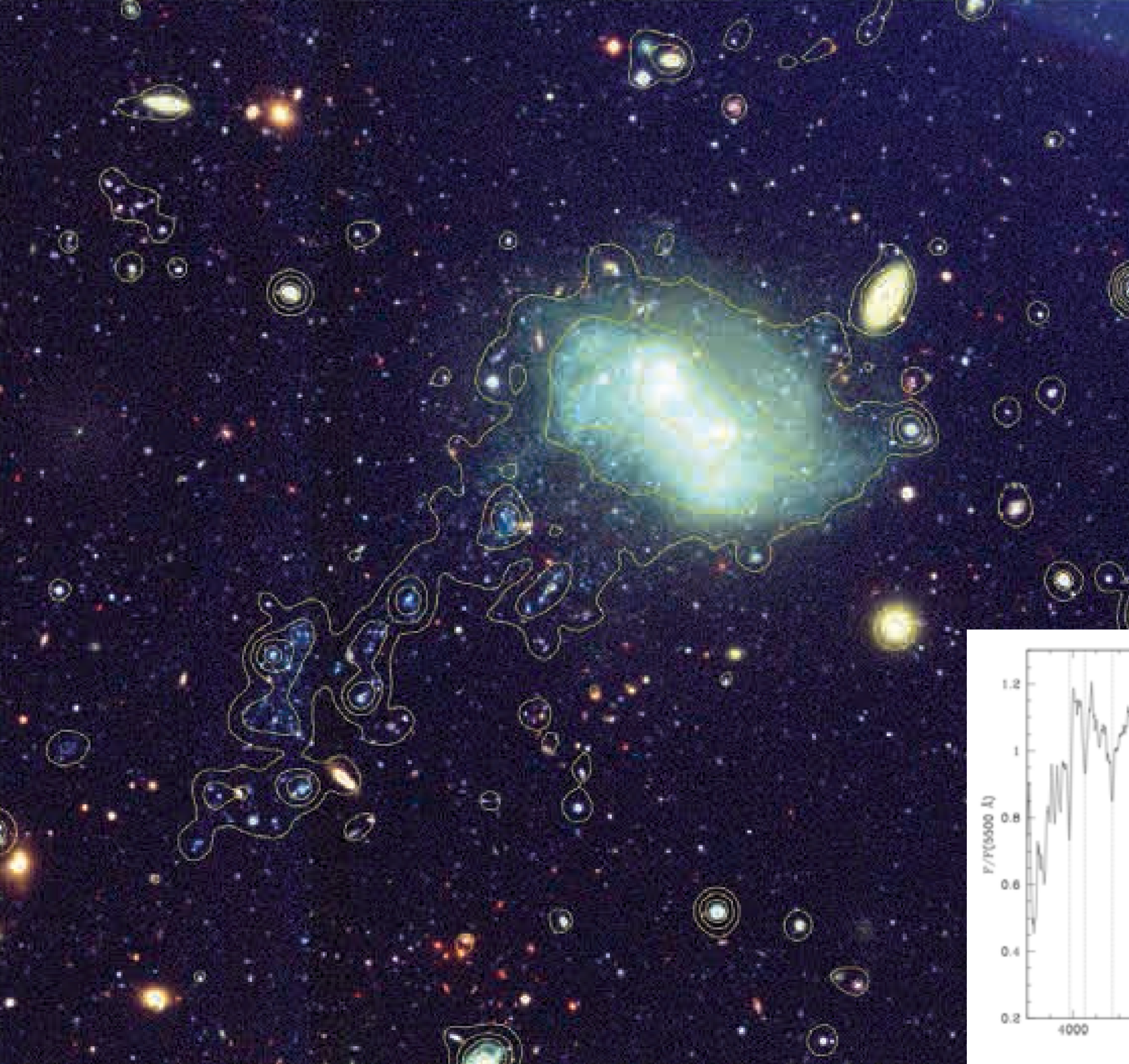


ESO137-001

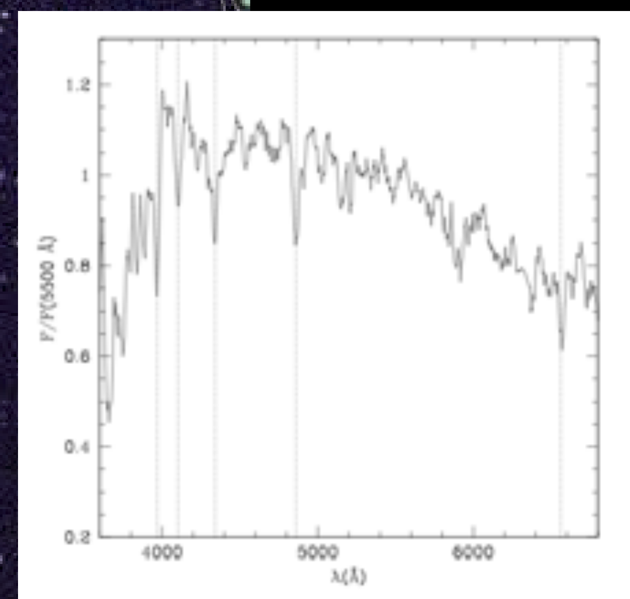
Fumagalli+ 14, with MUSE

ACS F475 in 10^15
Msun cluster at z=0.016

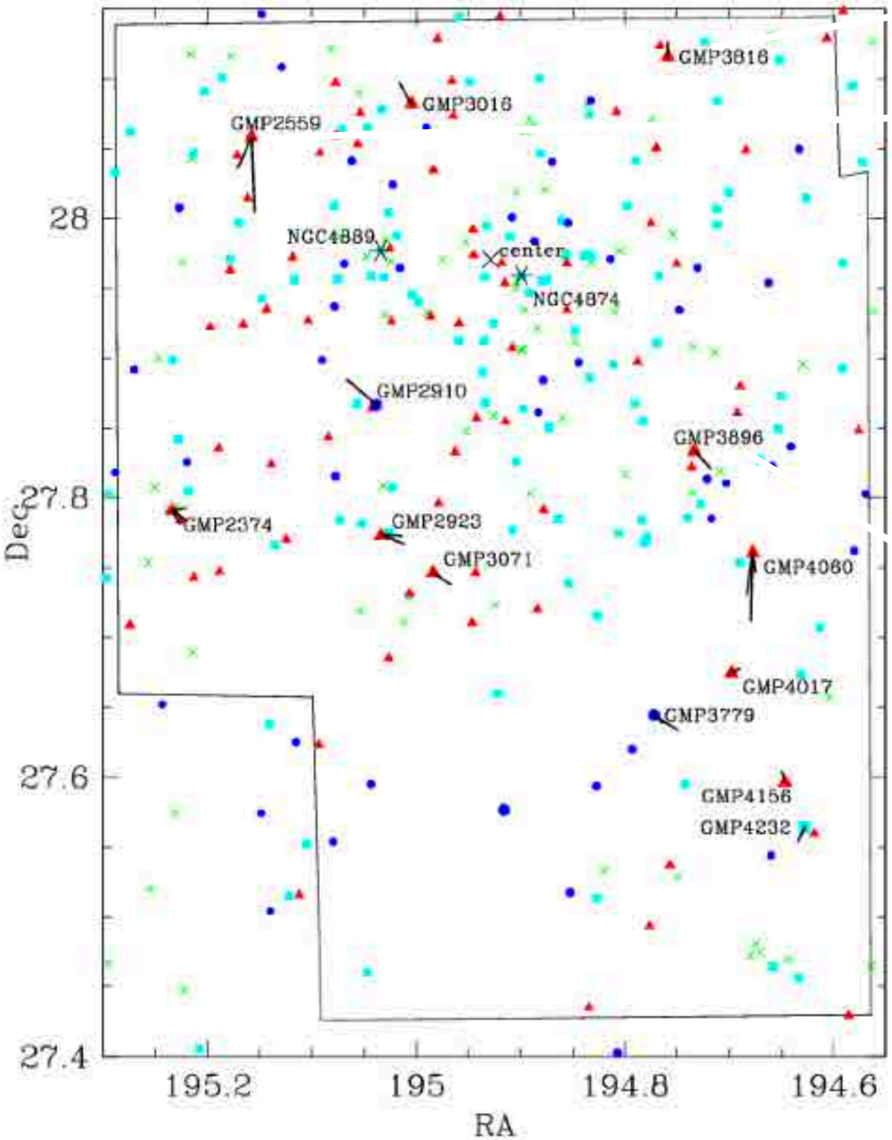
VCC1217
in the Virgo
cluster

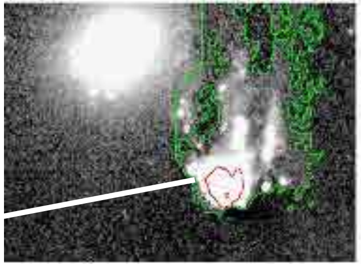


Fumagalli+11
Hester+10

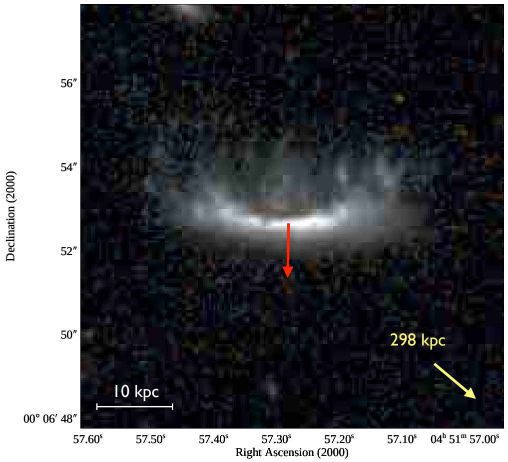


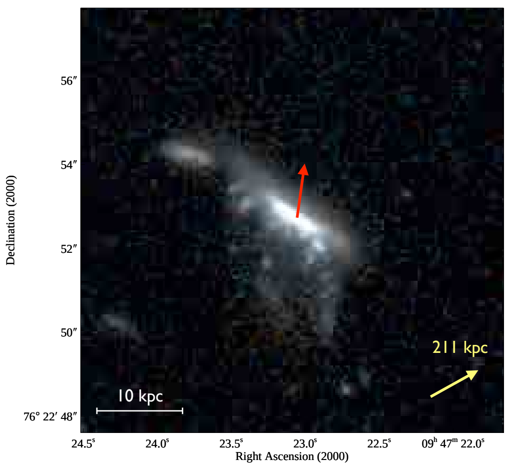
Coma Subaru (Yagi+ 10)





6 examples from Ebeling+ 2014 in X-ray clusters at z=0.3-0.4





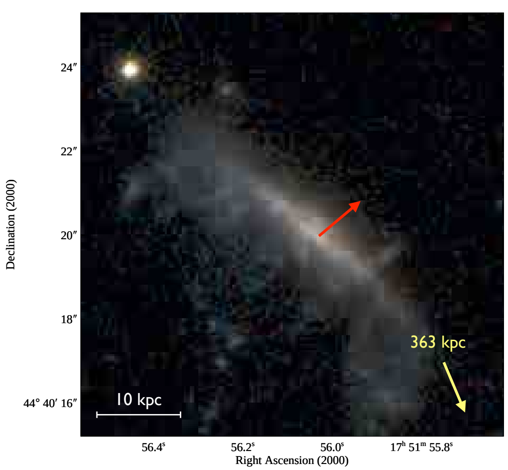
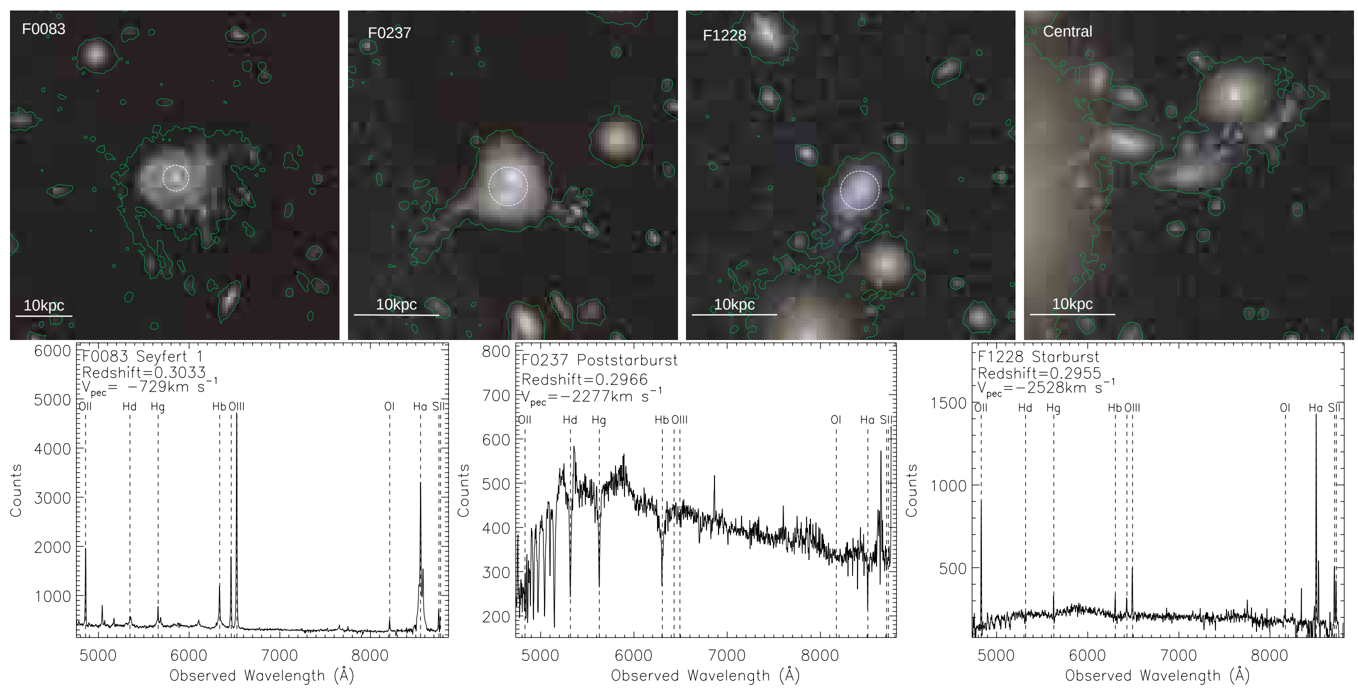


Figure 1. *HST* images of extreme cases of ram-pressure stripping in galaxy clusters at $z > 0.2$. From left to right: galaxy C153 in A2125 at $z = 0.20$ (WFPC2, F606W+F814W, Owen et al. 2006); galaxy 234144–260358 in A2667 at $z = 0.23$ (ACS, F450W+F606W+F814W, Cortese et al. 2007); galaxy F0083 in A2744 at $z = 0.31$ (ACS, F435W+F606W+F814W, Owers et al. 2012).



4 galaxies in the merging cluster Abell 2744
Owers+ 12

WIde-field Nearby Galaxy-cluster Survey

(WINGS) and its extension (OMEGAWINGS)

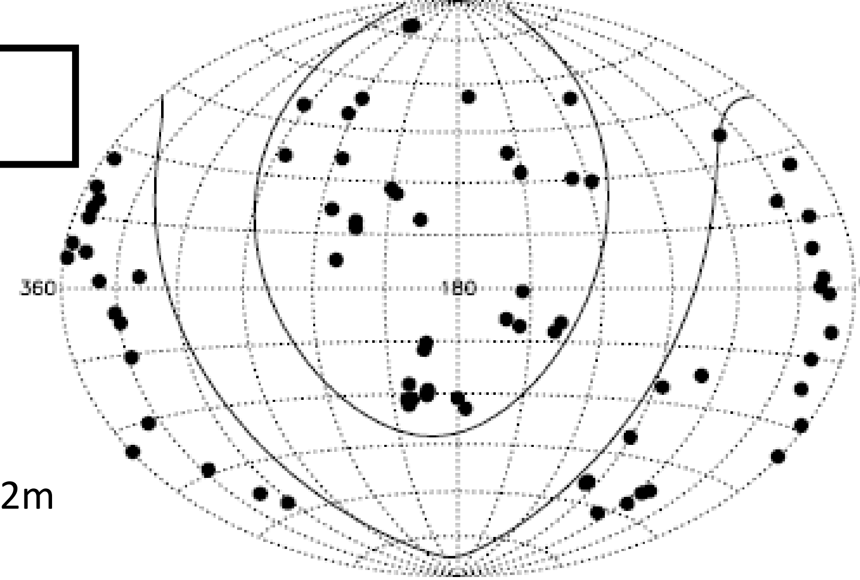
A wide-field survey of 77 X-ray selected clusters at z=0.04-0.07

Daniela Bettoni
Mauro D'Onofrio
Giovanni Fasano (co-PI)
Alessandro Omizzolo
Bianca M. Poggianti (PI)

Antonio Cava
Jacopo Fritz
Tiziano Valentinuzzi
Jesus Varela
Alessia Moretti
Benedetta Vulcani
Marco Guilleuszik
Angela Paccagnella
Valentina Guglielmo

Alan Dressler
Warrick Couch
Per Kjaergaard
Mariano Moles

THE WINGS DATASET



Sigma=500-1200+km/s, Log L_X=43.3-44.7 erg/s

B and V deep photometry with WFC/INT and WFC/2.2m on 34'X34'

FOV 1.2-2.7Mpc, res. 0.7-1.6kpc, M_V~-13
400.000 gal phot., 40.000 surf.phot + morph

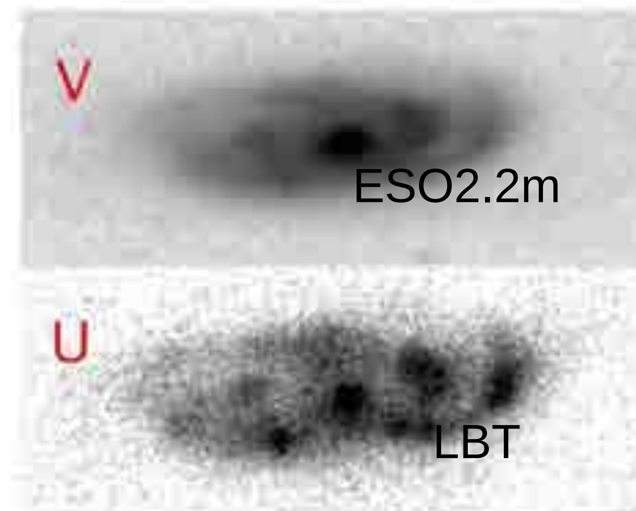
Optical fibre spectroscopy with 2dF/AAT and WYFFOS/WHT

48 clusters, 6500 spectra, 100-200 galaxies/cluster, down to M_V~-17

Near-IR deep photometry, J and K with WFC/UKIRT

36 clusters – galaxy masses, SED + struct.props

Some U-band with INT, LBT & Bok



Reaching out to 0.6 virial radii for most clusters

VST PROGRAM(S)

u (1hr), V and B (25min each) on a 1deg sq. with Omegacam/VST: 60hrs + 50hrs GTO Omegacam and VST

B and V completed (periods 88 to 93): 45 clusters – data reduced in Padova with a modified version of ALAMBIC

u-band ongoing – data reduced in Naples by VST data center (Aniello Grado and c.)

Great asset: out to 2.5 virial radii

Photometry, but also detailed morphologies, structural parameters, color maps etc

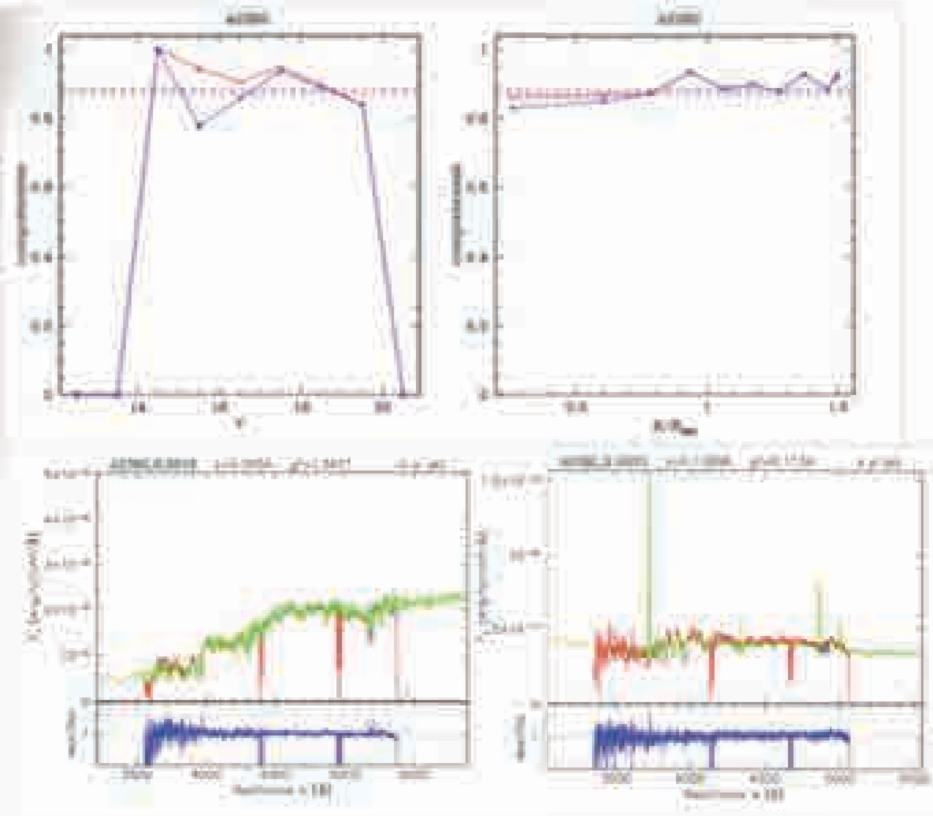
Gullieuszik+ 2015

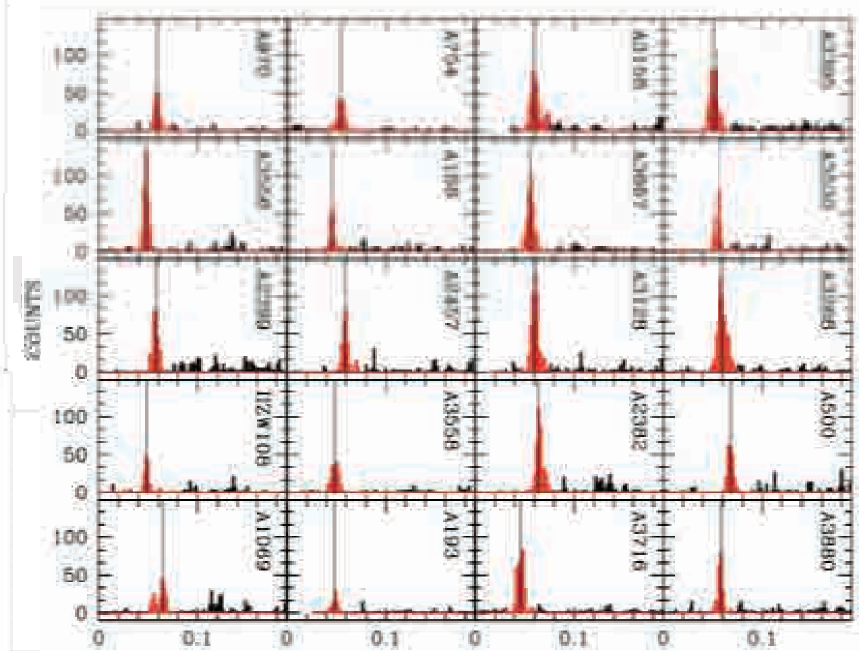
AAOMEGA SPECTRA

AAOmega/AAT spectroscopic follow-up of clusters observed with VST – > 90% spectr. completeness to V=20, 30k spectra

Ongoing -

18 nights allocated so far (~25-27 clusters), need other 9 to complete the programme





Large effort: 114 telescope nights, 29 refereed pubs so far, all wide-field – ALL PUBLIC on VO as soon as published (Moretti+ 2014)

WFC/INT, WFC/ESO2.2, WYFFOS/WHT, 2dF/AAT, WFCAM/UKIRT, 90prime/Bok, LBC/LBT, Omegacam/VST, AAOMEGA/AAT,GMOS/Gemini, VIMOS/VLT, X-Shooter/VLT, MUSE/VLT

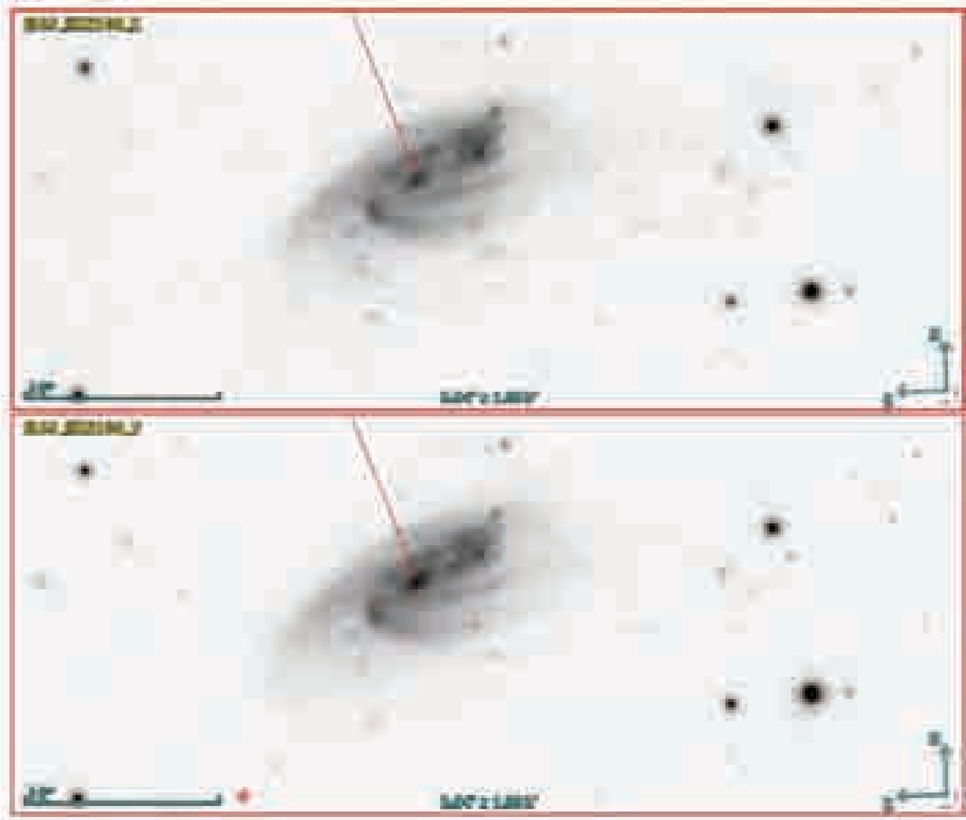
A VISUAL SEARCH

Two of us (BP & GF), independently inspected the B-band OMEGACAM images (if seeing > 1.3”, V-band)

Assign a “jellyfish class” from 5 (very strong) to 1 (very weak) – possible tidal cases identified, mergers excluded – class is likely combination of stripping phase and orientation

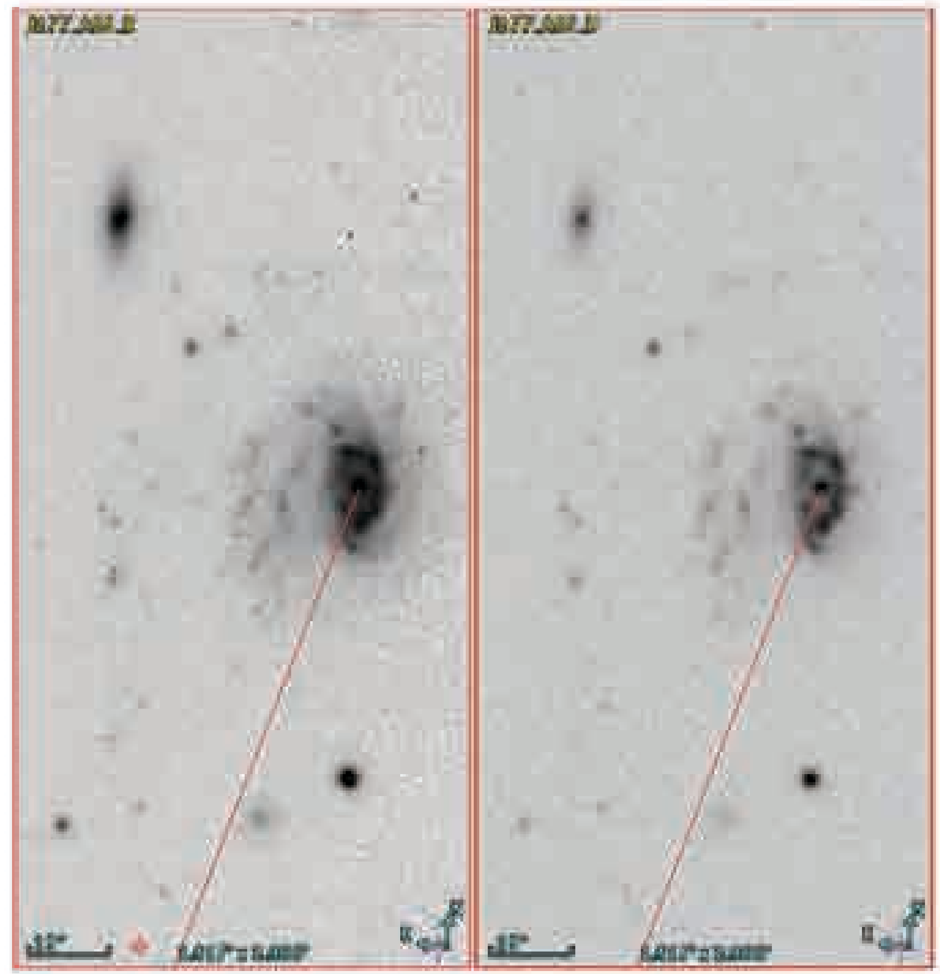
A range of “morphological patterns” (proper jellyfishes, handlebars, croissants, comets etc…)

JELLYFISH GALAXIES IN WINGS CLUSTERS



The WINGS group, Poggianti+ in prep.

JELLYFISH GALAXIES IN WINGS CLUSTERS



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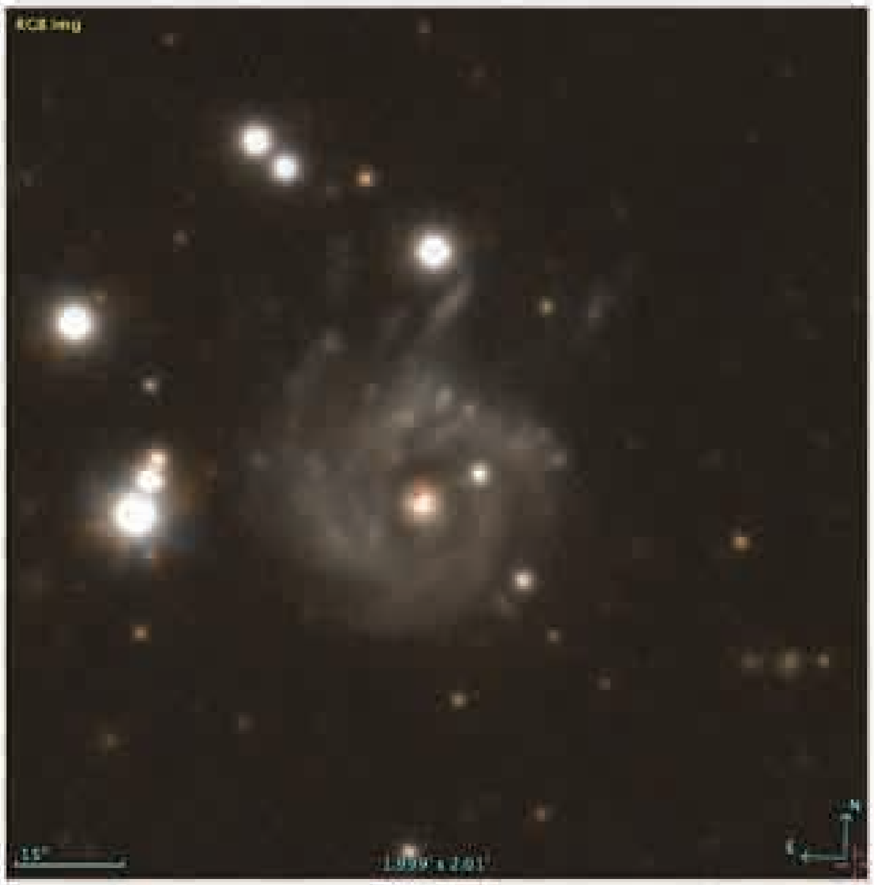

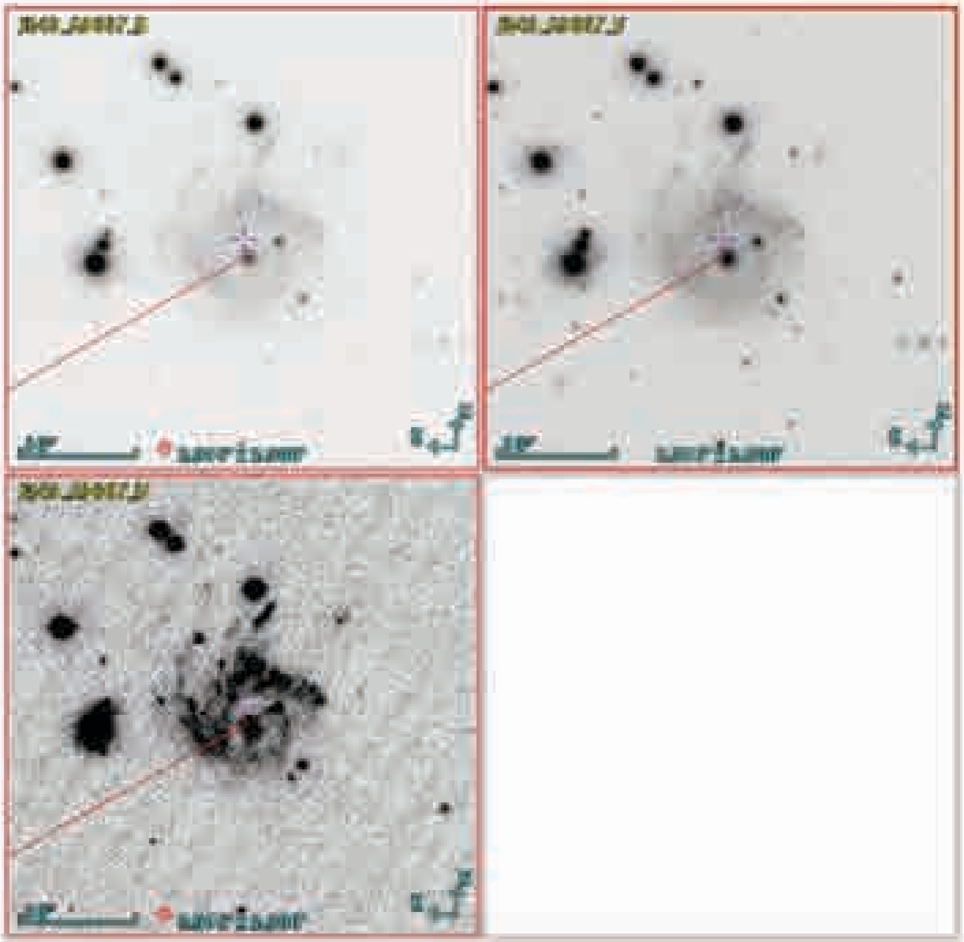

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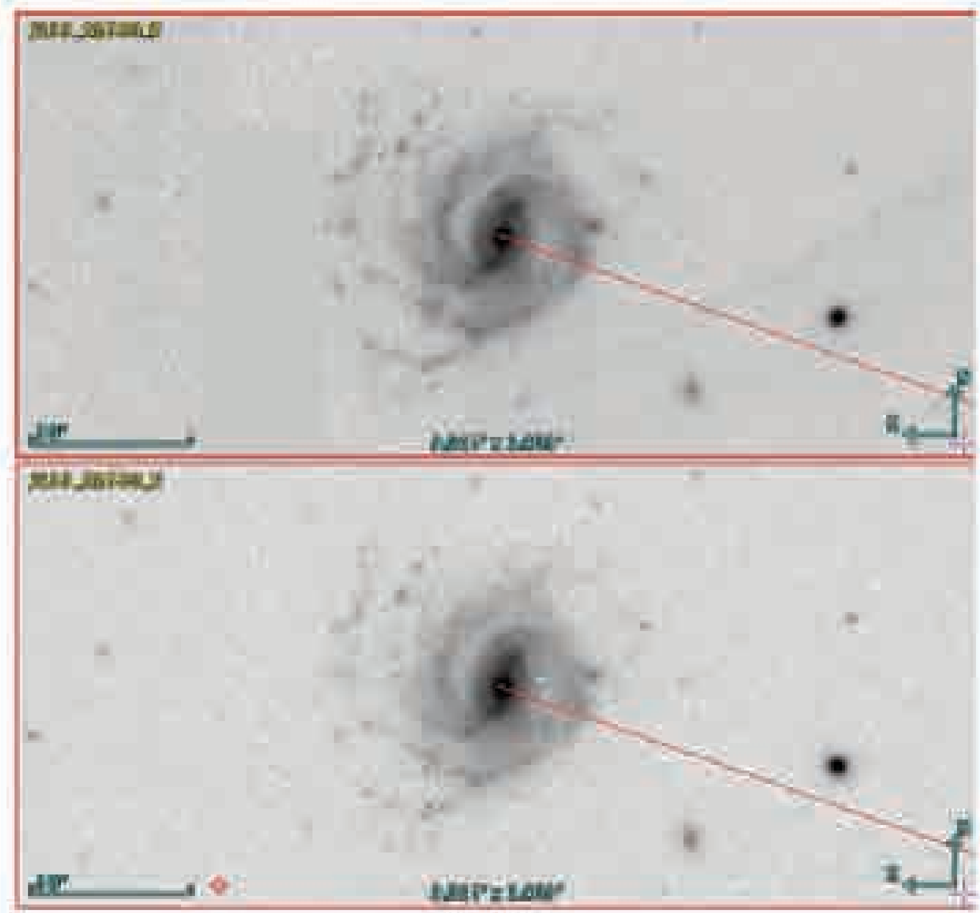

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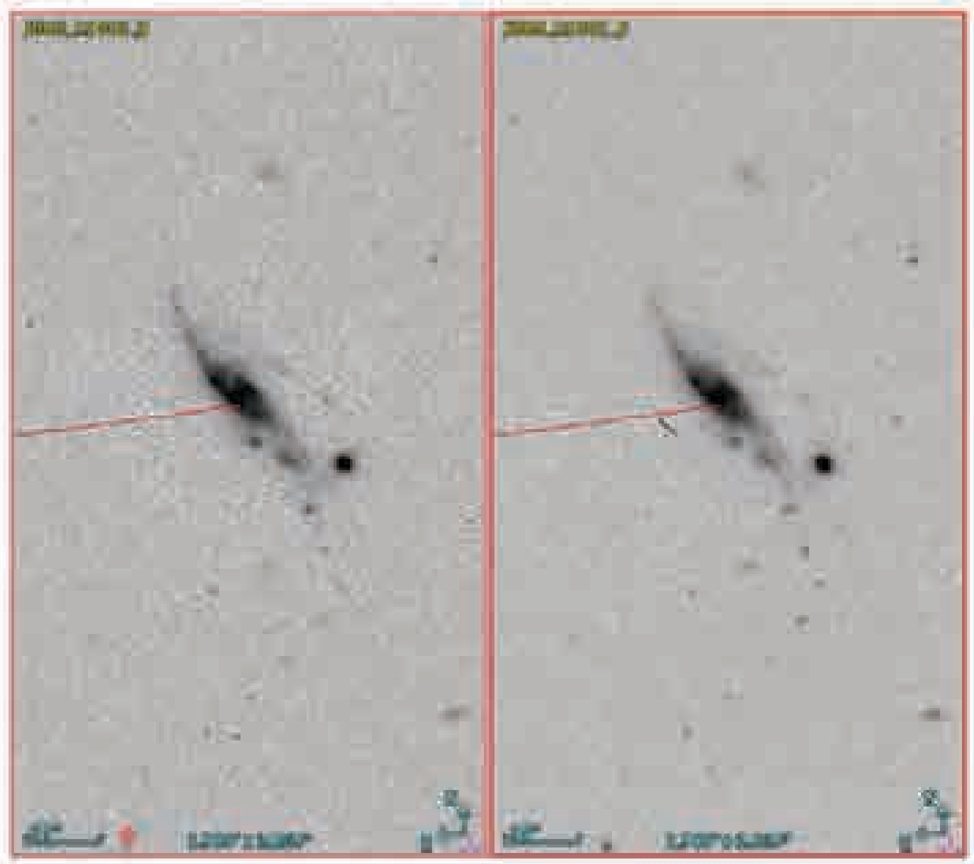

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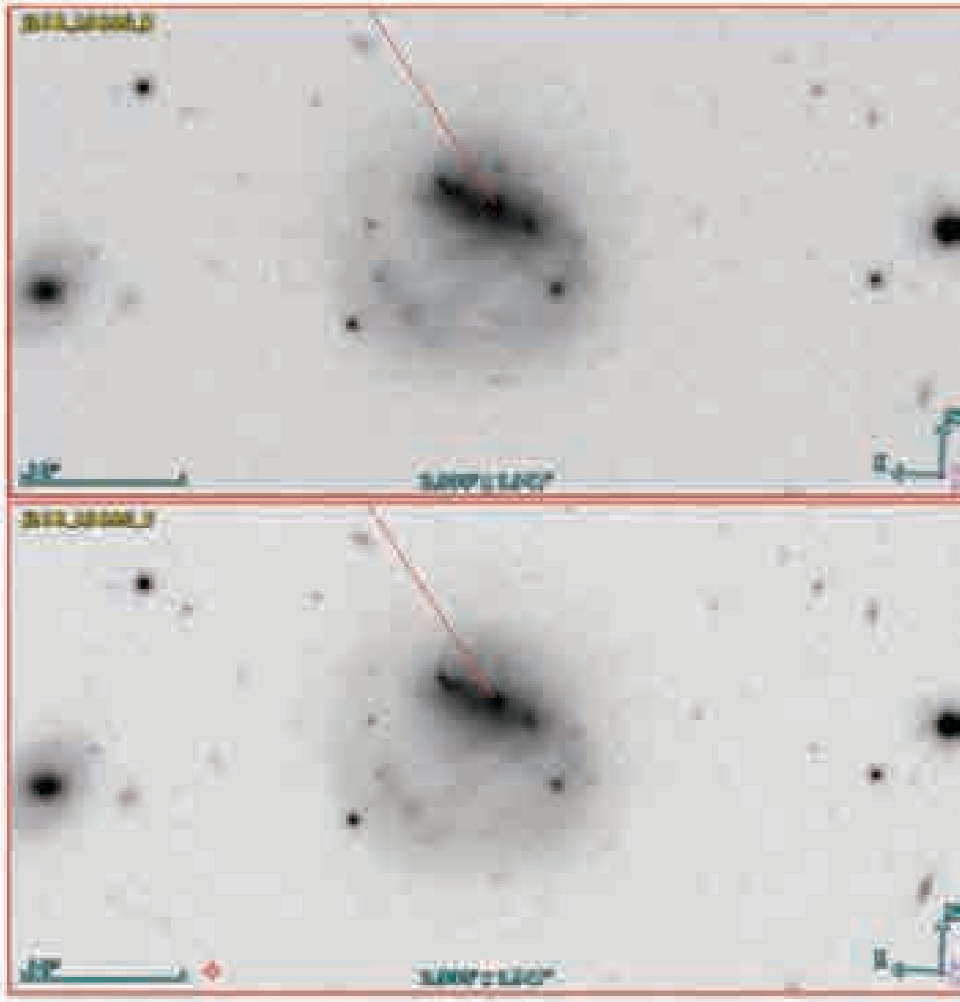

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JELLYFISH GALAXIES IN WINGS CLUSTERS

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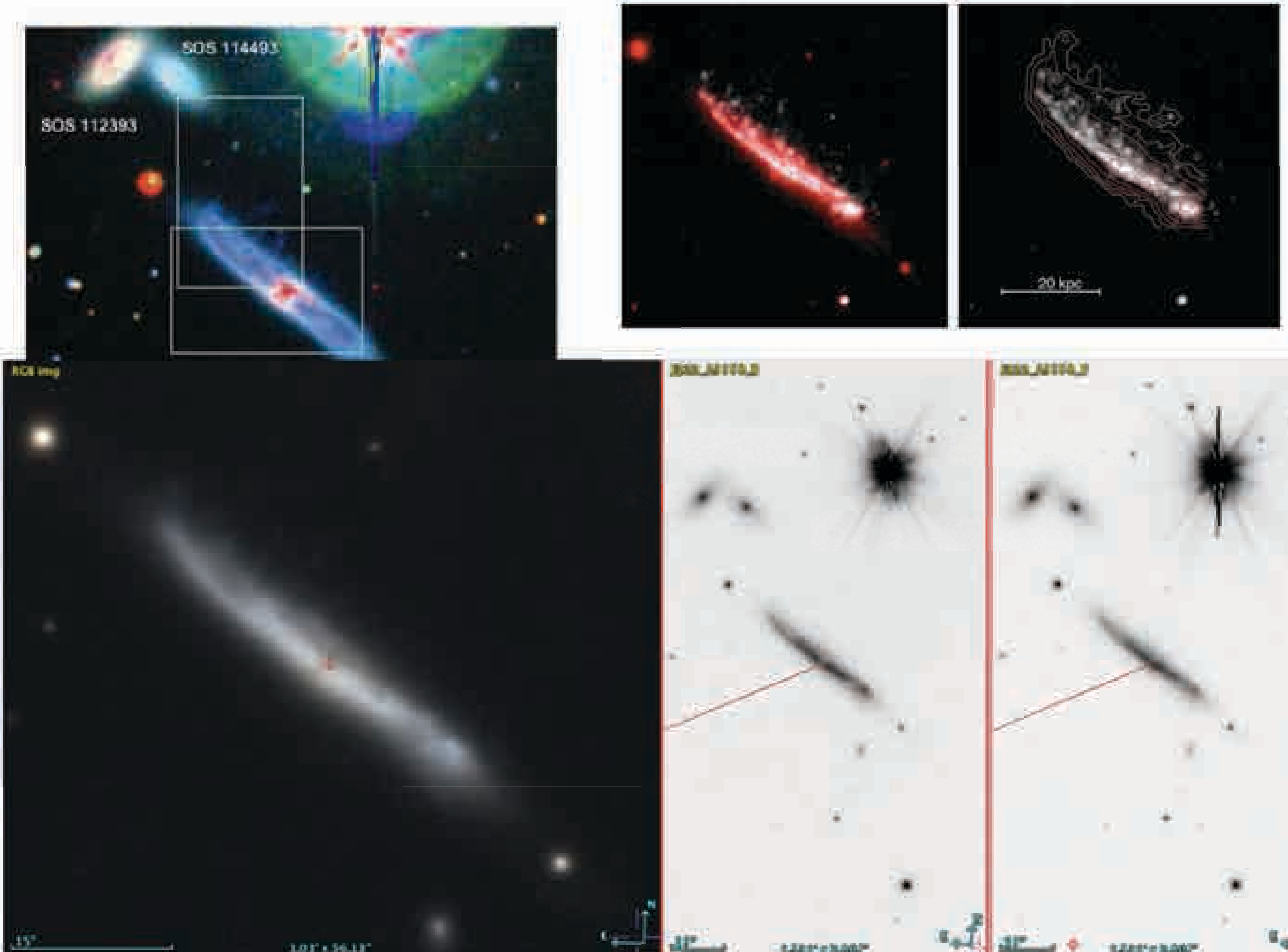
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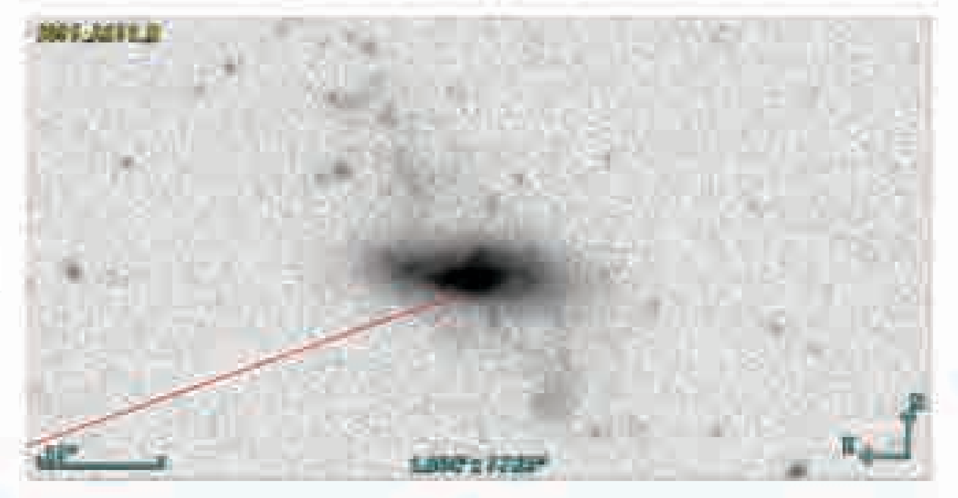
JELLYFISH GALAXIES IN WINGS CLUSTERS



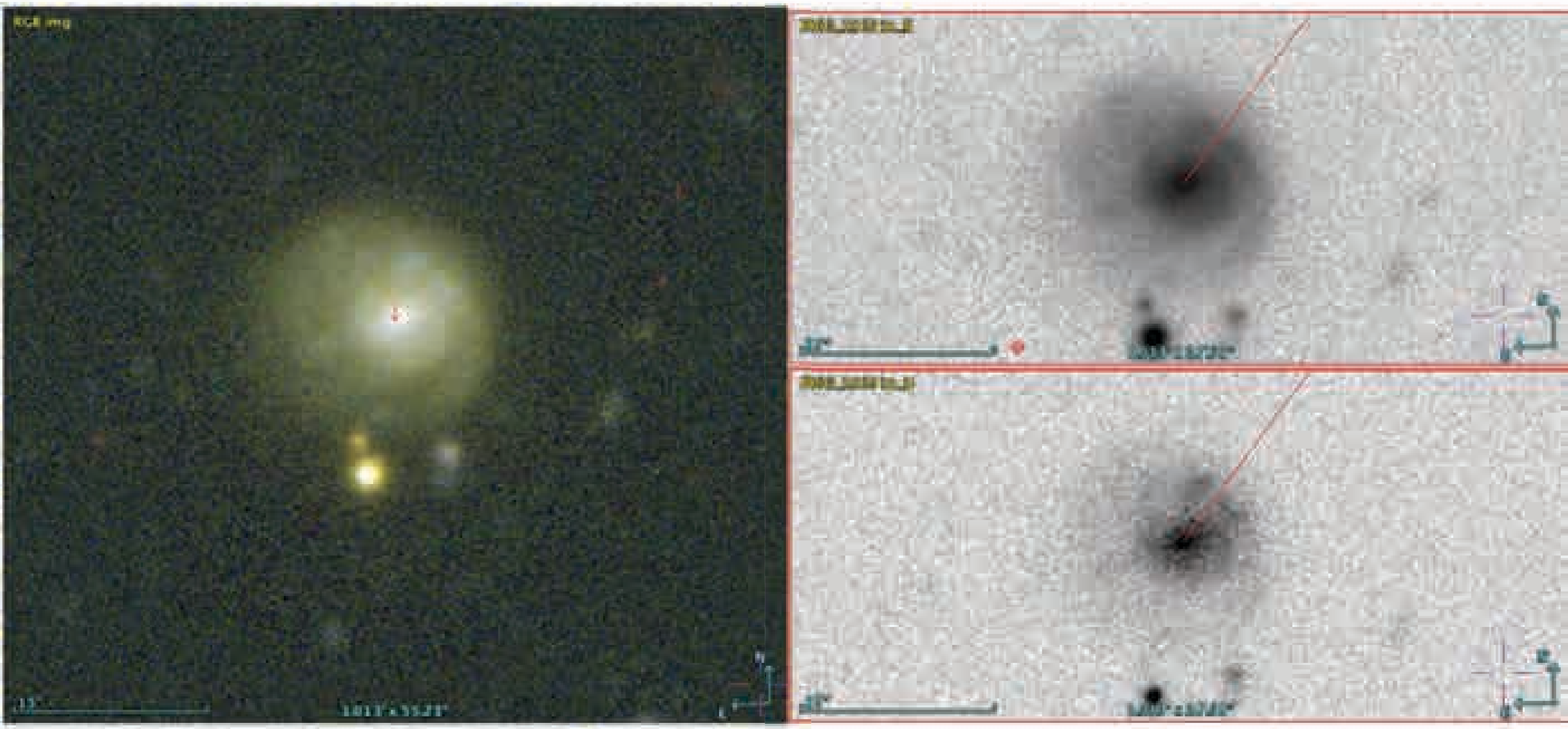
241 jellyfishes in the field of 41 clusters
of which 165 with redshift
of which 115 members

91 with spectrophotometric modeling

9%	have emission lines +strong Balmer abs.	(e(a))
16%	have very strong emission lines	(e(b))
64%	have spectra “typical” of local spirals	(e(c))
5%	have passive abs. line spectra	(k)
6%	have post-starburst spectra	(k+a)

The WINGS group, Poggianti+ in prep.

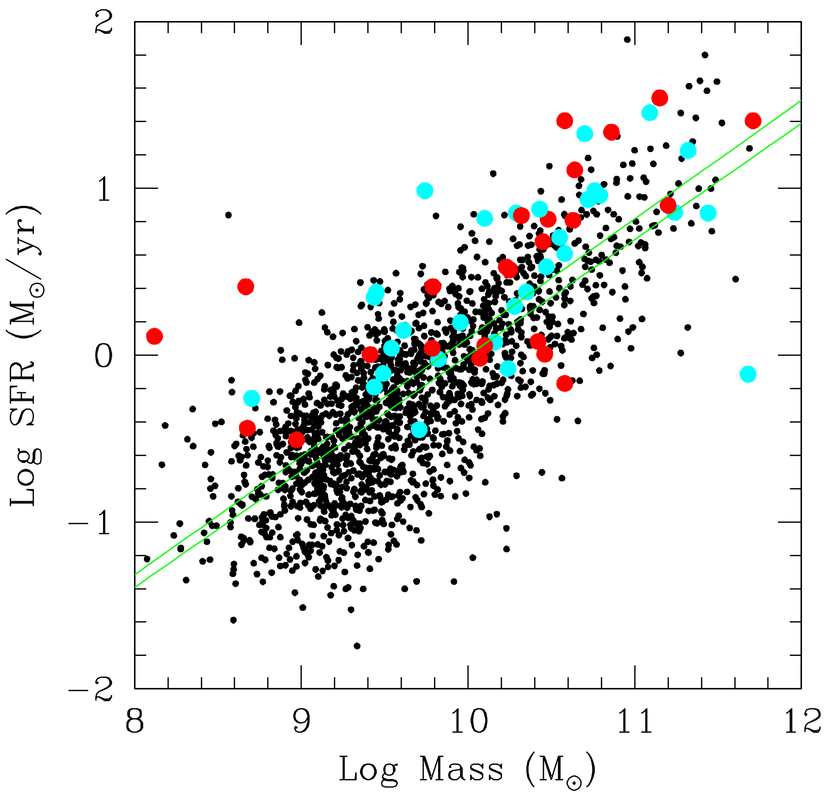
A POST-STARBURST JELLYFISH

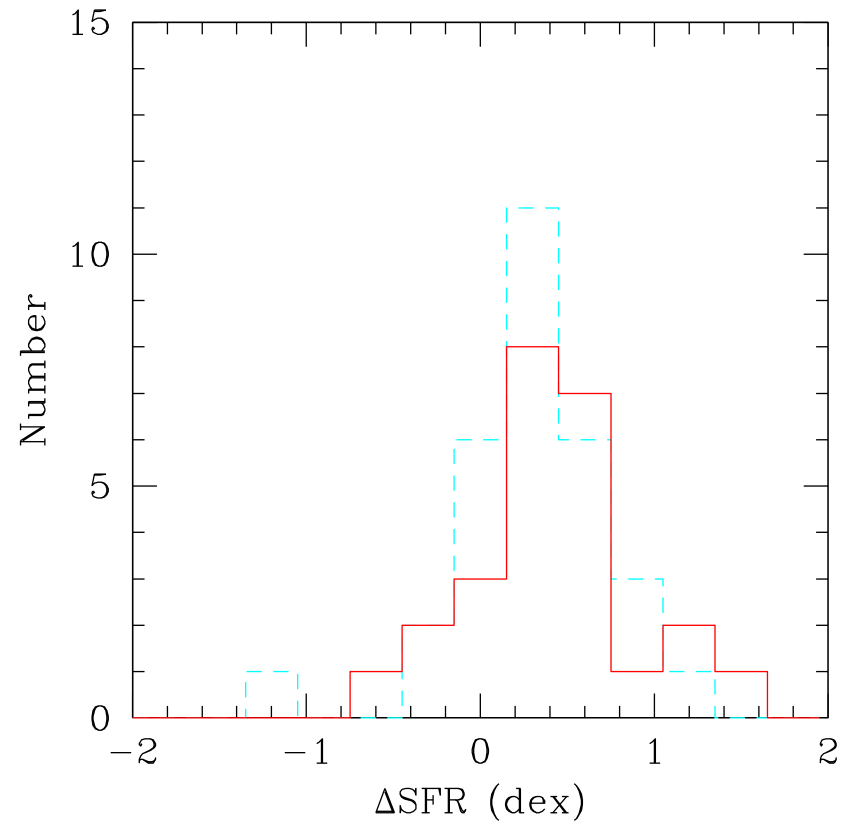


Post-SB are usually 1 and 2

The WINGS group, Poggianti+ in prep.

JELLYFISH GALAXIES IN WINGS CLUSTERS

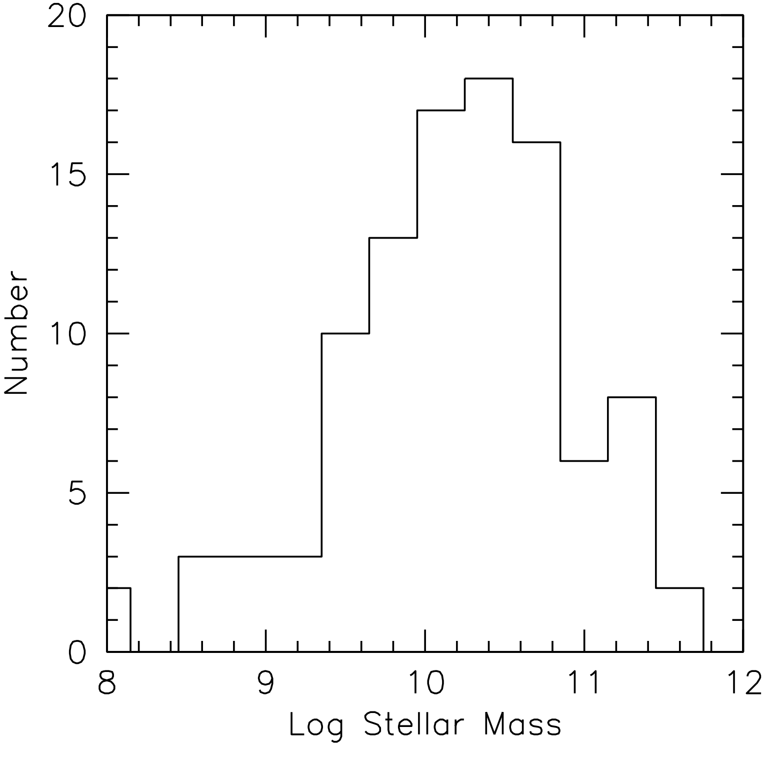


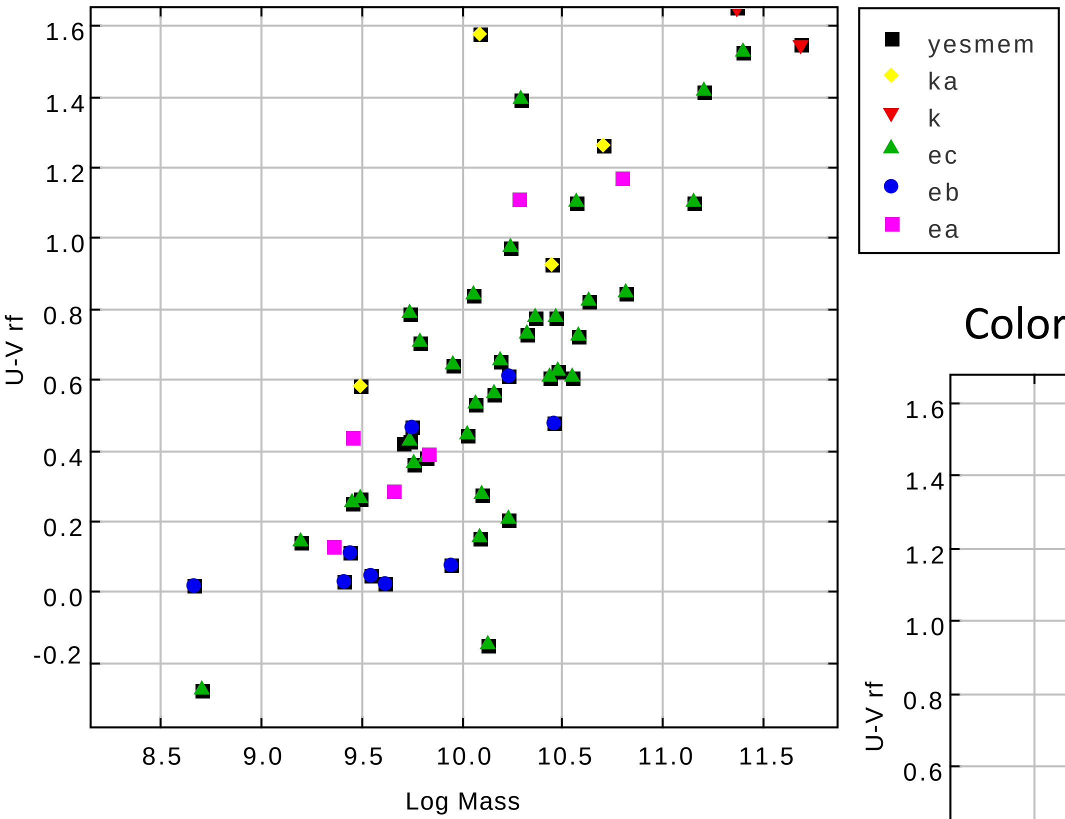


Compared to other field(cluster) galaxies, jellyfishes have a SF enhancement of a factor 1.3-1.8 / 1.7-2.3 (classes 12-345)

The WINGS group, Poggianti+ in prep.

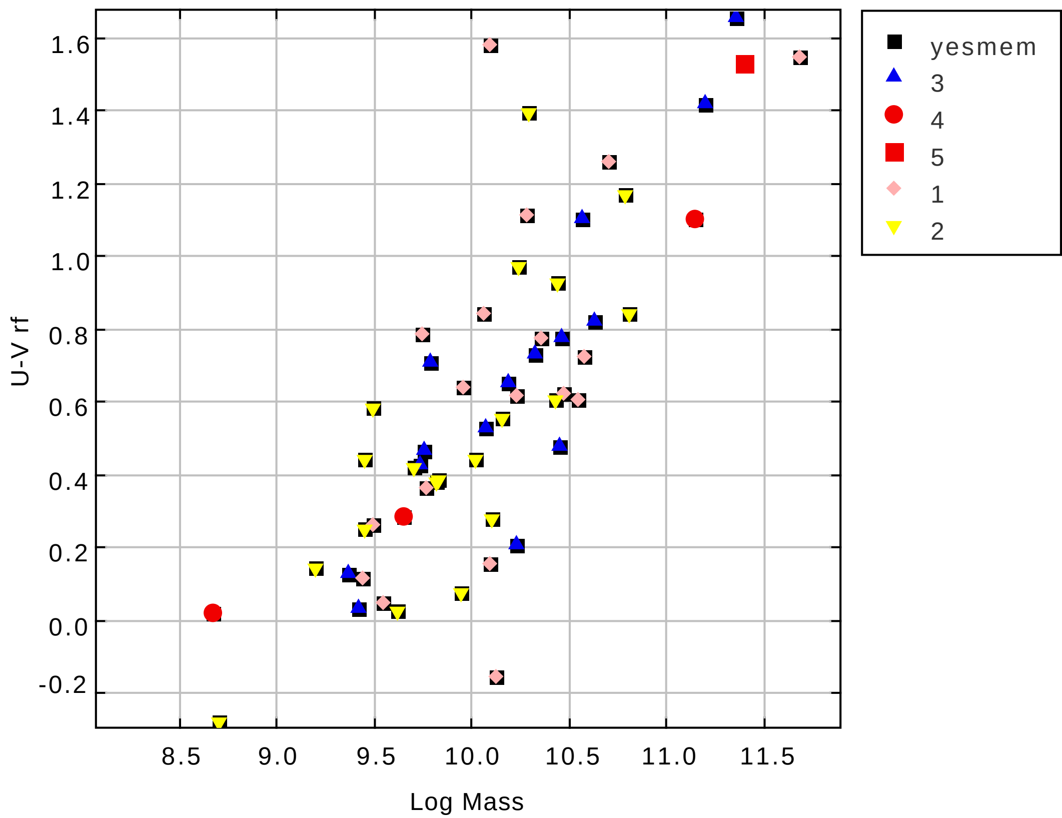
MASS DISTRIBUTION



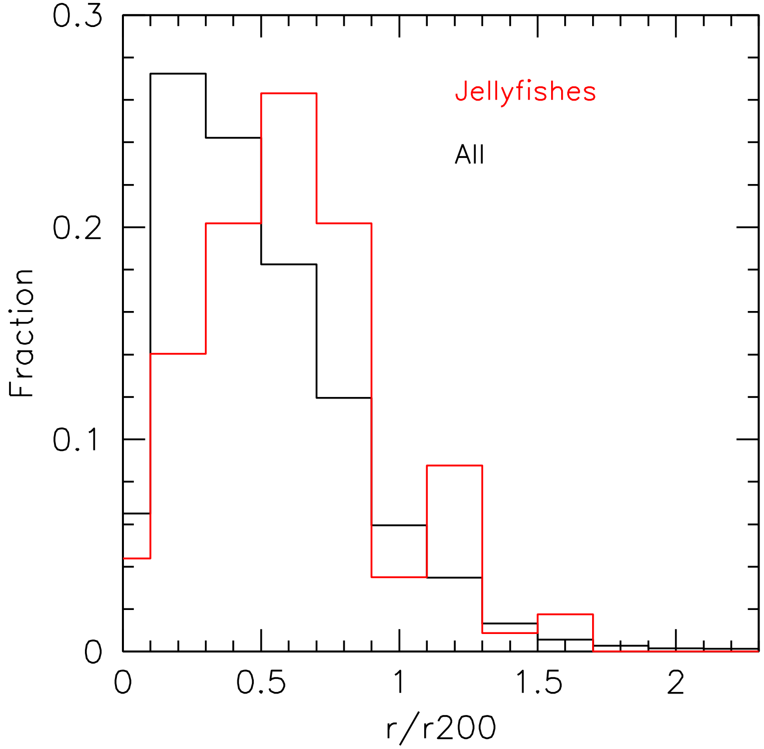


Color-mass diagram and spectral types

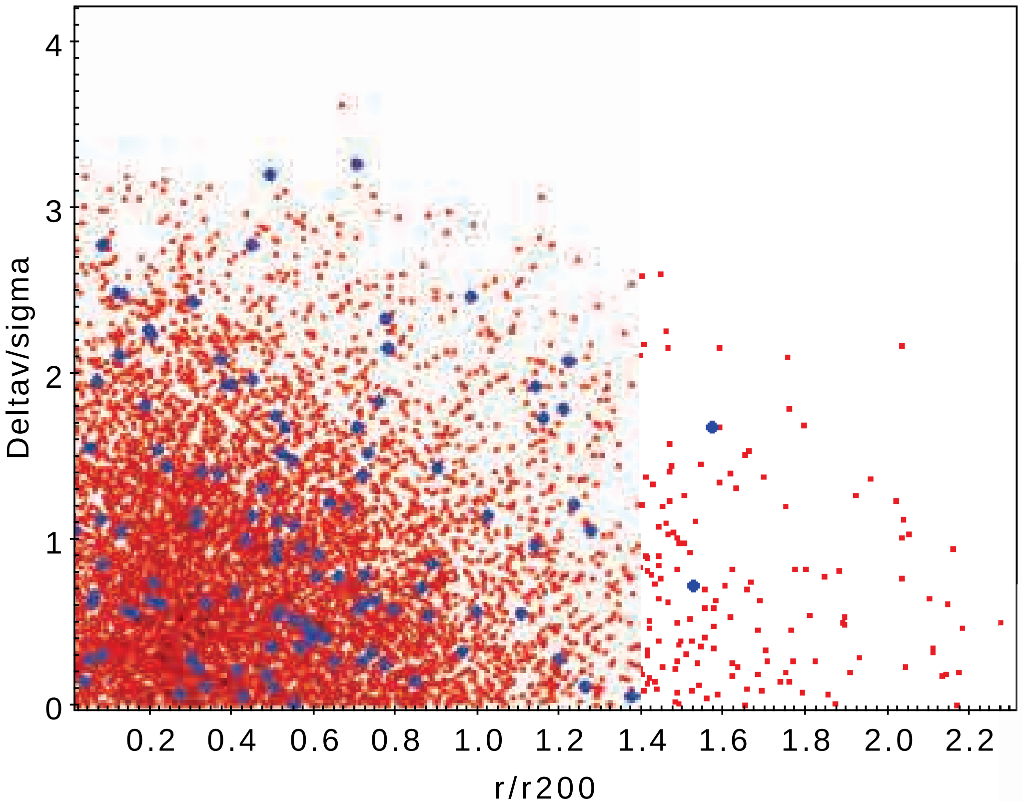
Color-mass diagram and jellyfish class



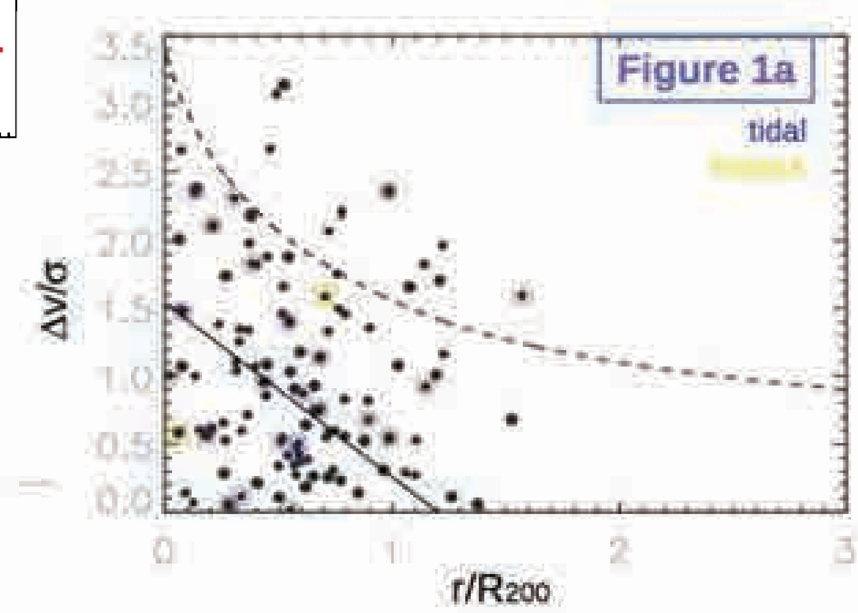
CLUSTERCENTRIC DISTANCE

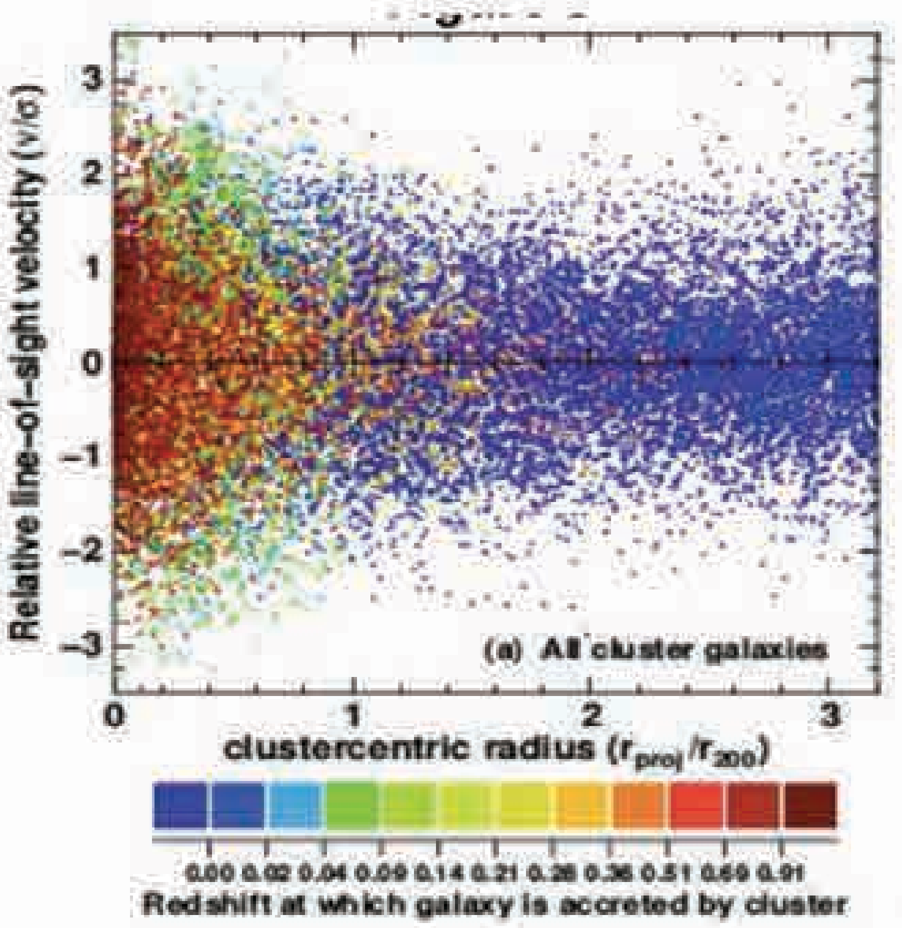


PHASE-SPACE DIAGRAM: GALAXY ORBITAL HISTORIES

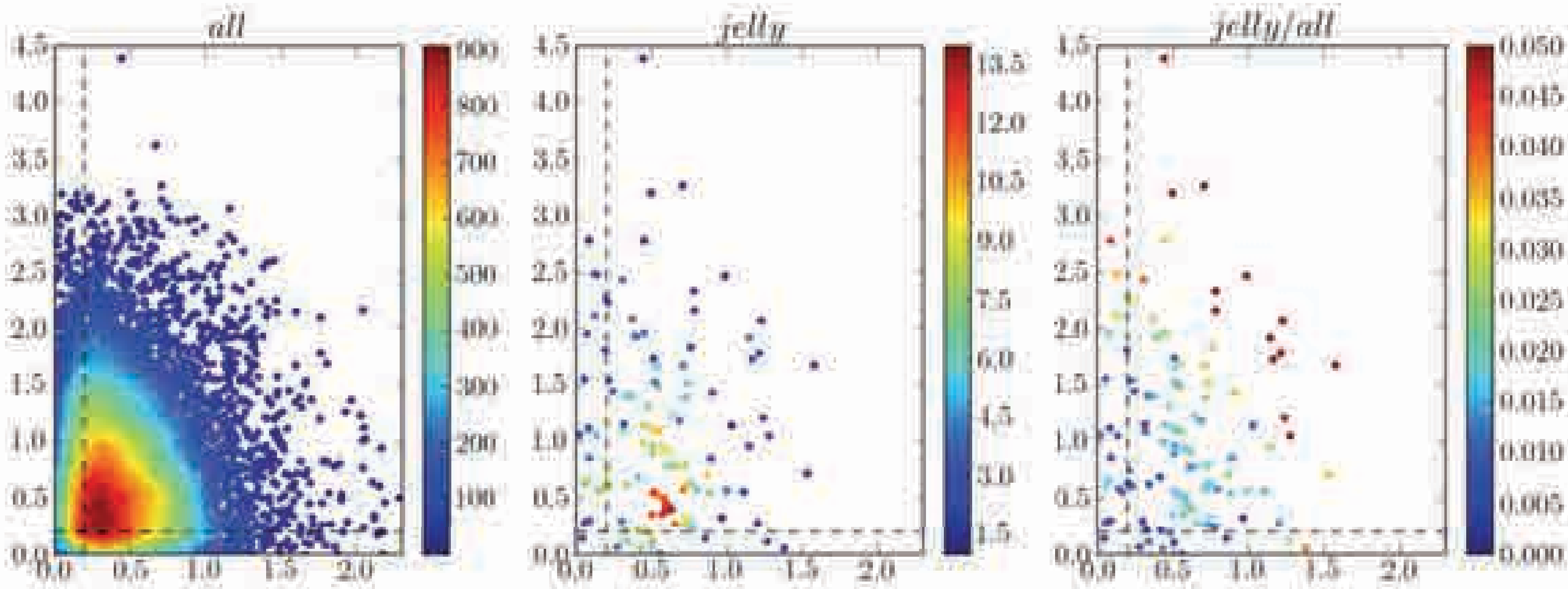


Projected distance from cluster center normalized by R200 vs the peculiar line-of- sight velocity of each galaxy with respect to the cluster recessional velocity normalized by sigma



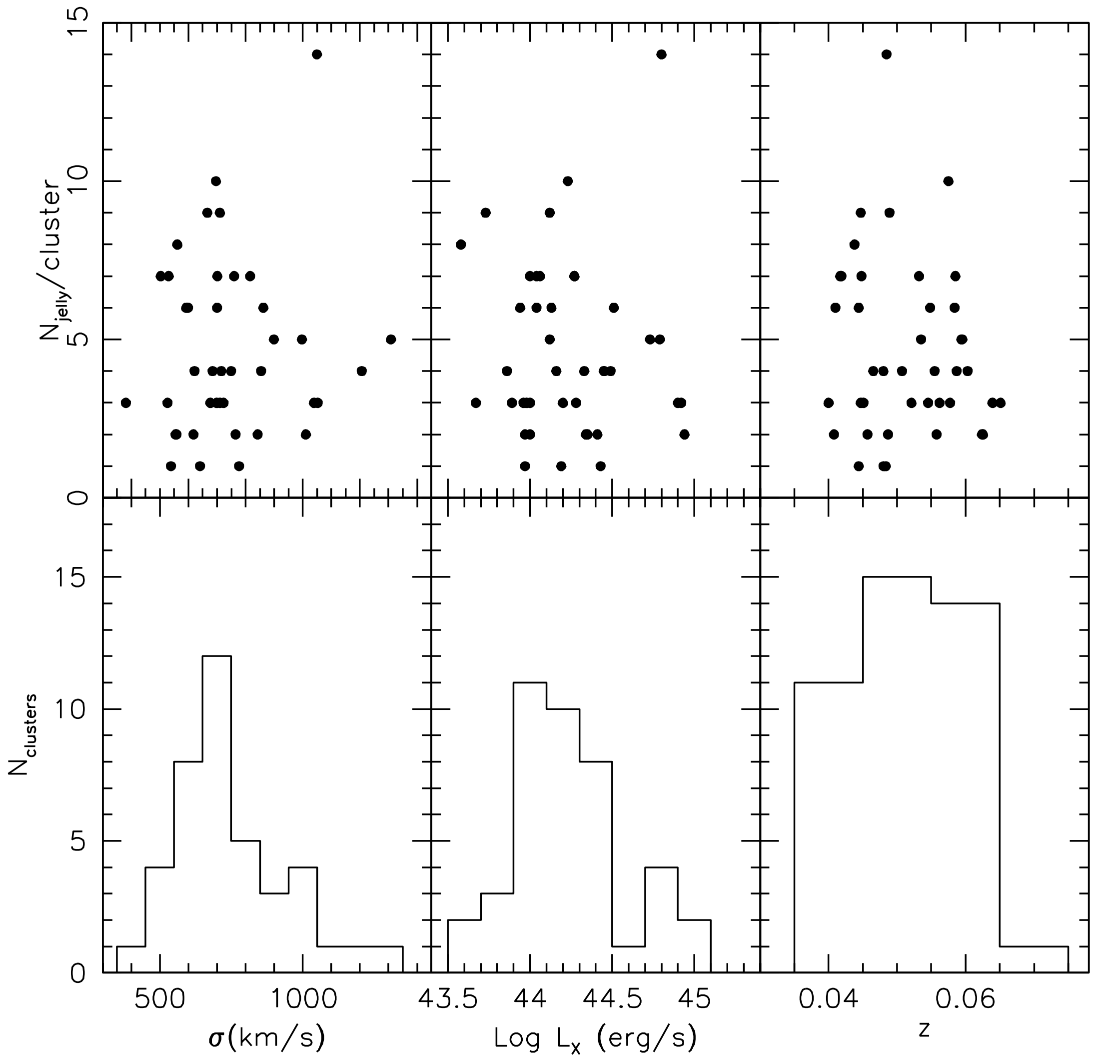


Haines+ in prep.



$$P_{ram} = \rho_{ICM} v_{gal}^2$$

$$\rho_{ICM}(r_{3D}) = \rho_0 \left[1 + \left(\frac{r_{3D}}{R_c}\right)^2\right]^{-3\beta/2}$$



Independence from global cluster properties

41 clusters, of which 7 in Shapley (17% of total)

N_j == Number of jellyfishes that are member (1) or could be members (no redshift, -1)

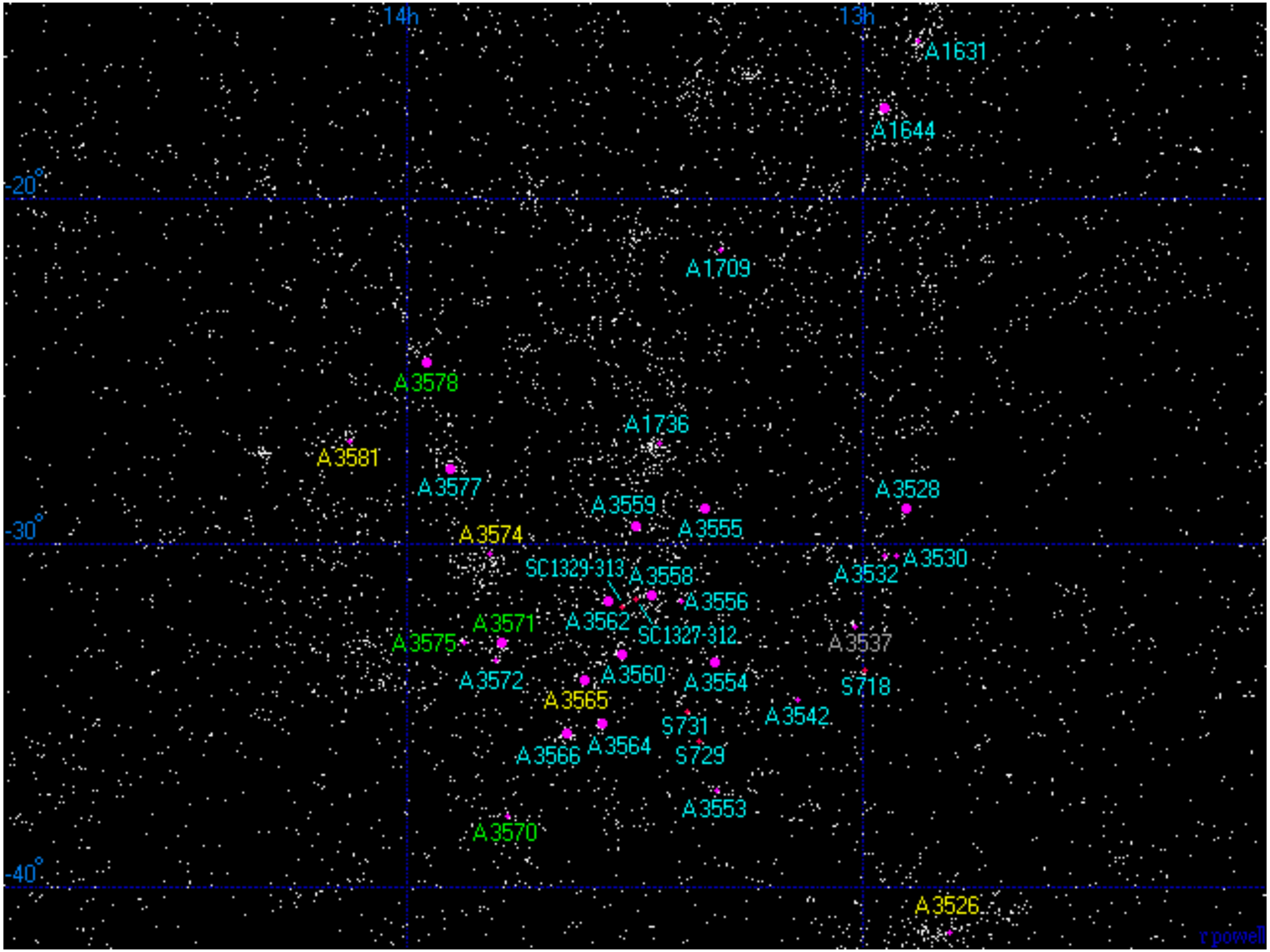
Tot N_j == 190

average number of potential jelly per cluster = 4.6

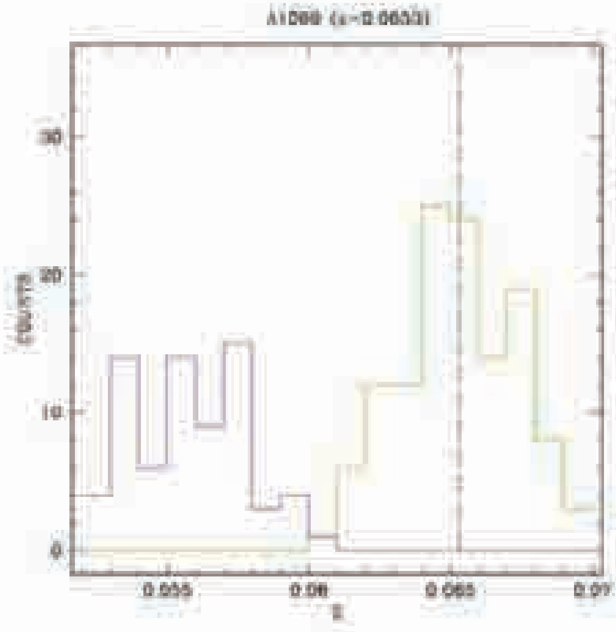
43 = N_j in Shapley clusters, == 23% del totale

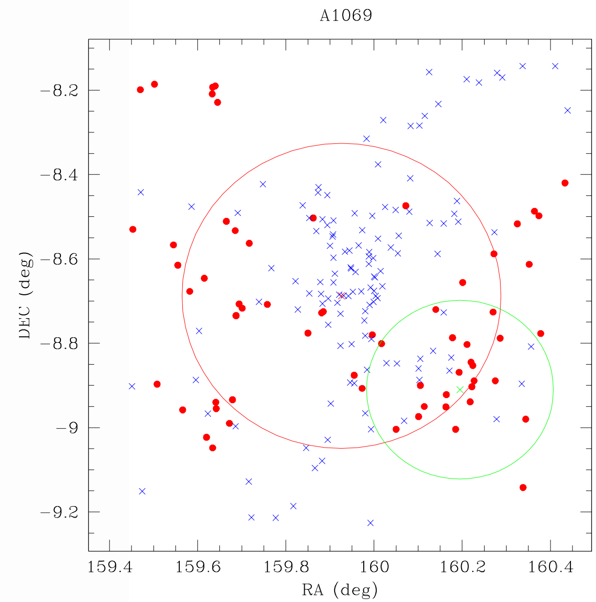
average number of jelly in Shapley clusters = 6.1 ("jelly excess")

SHAPLEY SUPERCLUSTER



JELLYFISHES IN GROUPS??





Paccagnella, PhD Thesis

A1069_2   372+-84 km/s

Where are the 50 “non cluster members located”?

7 for sure in structures along the line of sight

others too little information to say

Padova-Millennium Galaxy and Group Catalogue (PM2GC)

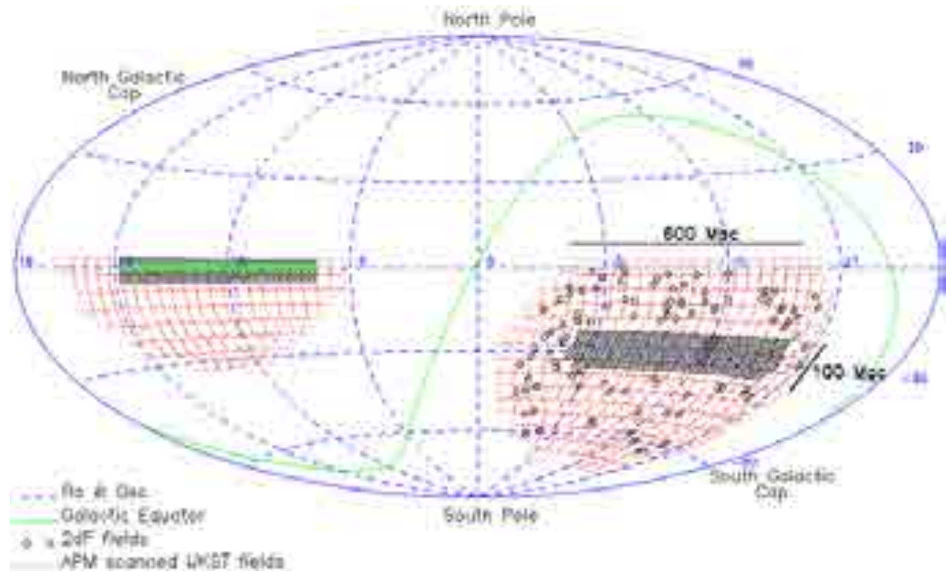
Rosa Calvi + WINGS collaborators

A general field galaxy sample at z=0.04-0.1

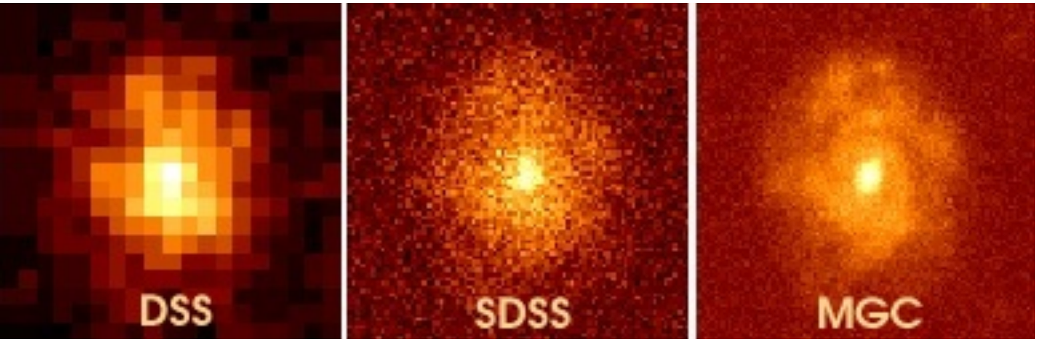
Based on the Millennium Galaxy Catalogue (PI Simon Driver, Liske et al. 2003), a 38 deg^2 equatorial survey

B-band imaging with WFC/INT

AAT/2dF redshift survey combined with 2dFGRS and SDSS: spectroscopic completeness in the area 96% to B=20



Padova-Millennium Galaxy and Group Catalogue (PM2GC)



ADVANTAGES compared to SDSS:

Better imaging quality

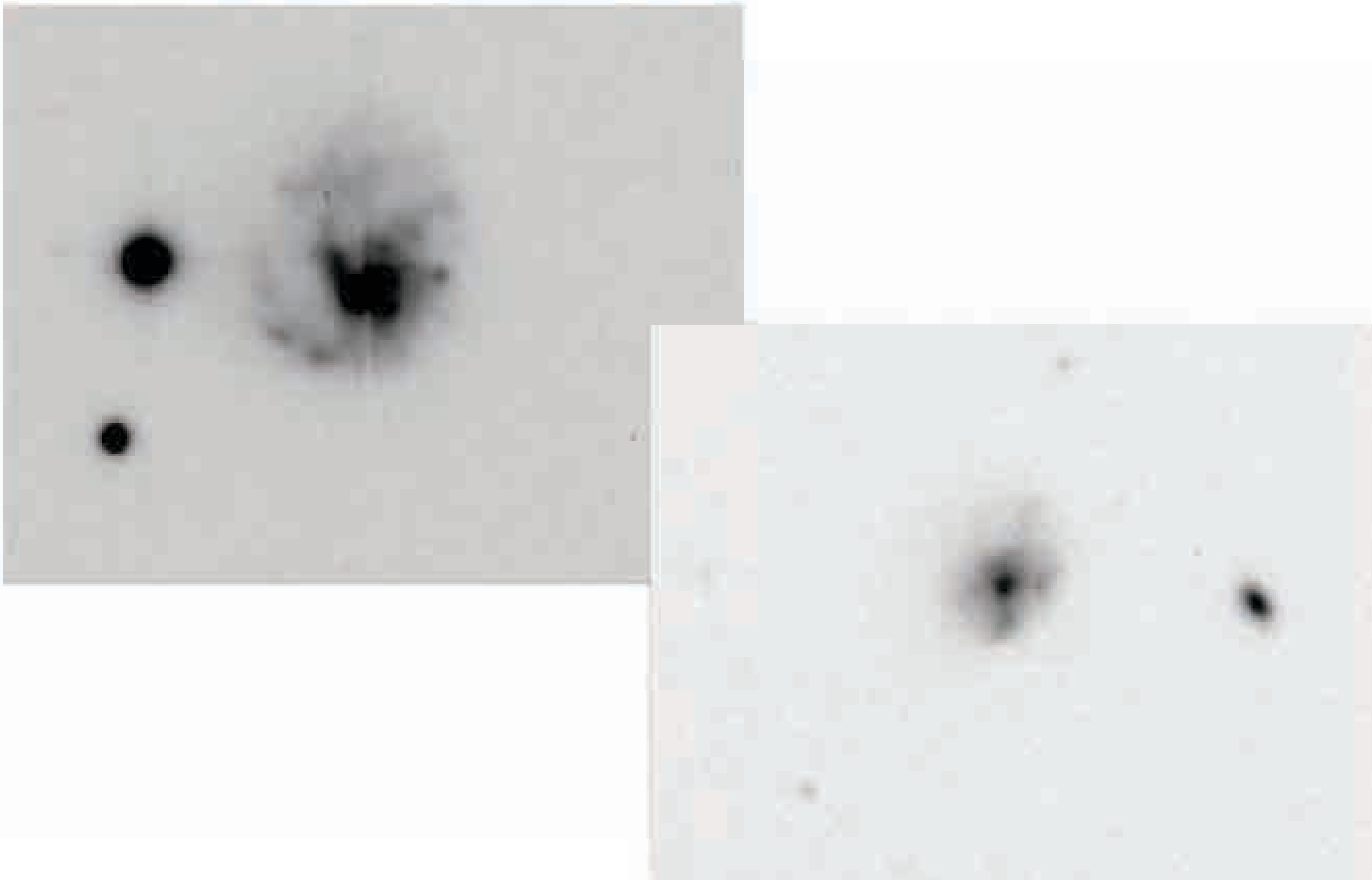
Spectroscopic completeness (14% of all, 27% of our compacts missing in SDSS)

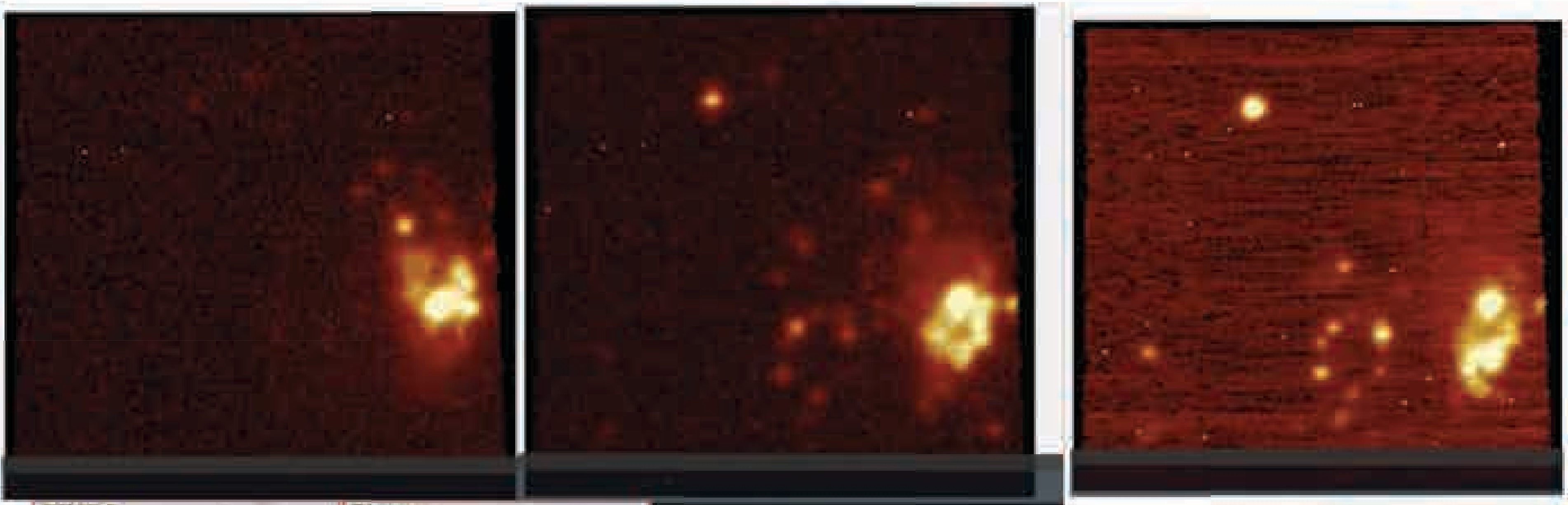
Group catalogue (groups, binaries and singles) and environment characterization (FOF algorithm)

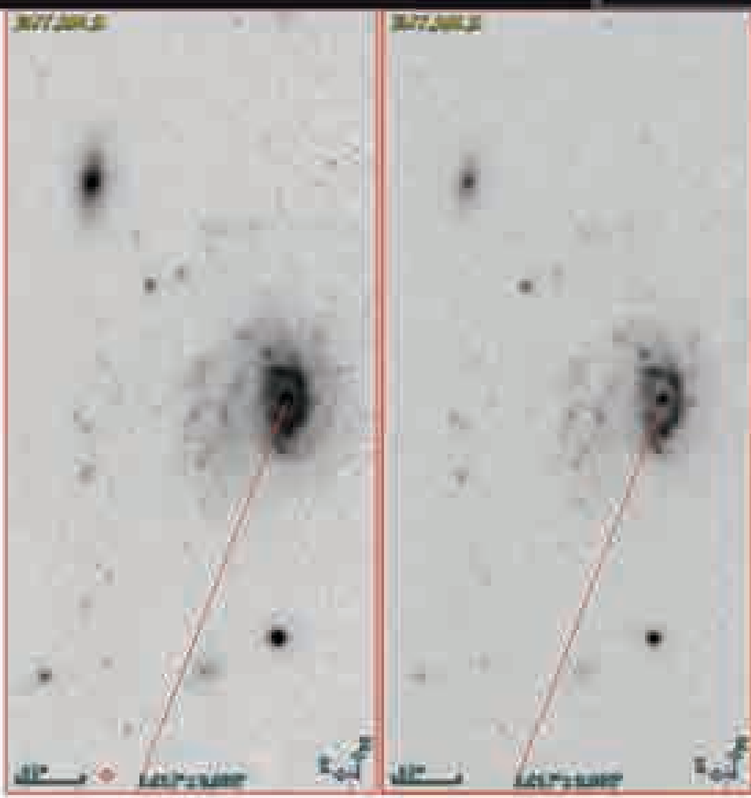
- Galaxy morphologies
- Galaxy stellar masses
- SFHs and stellar populations from spectral analysis

Calvi et al. 2011, 2012, 2013

JELLYFISHES IN THE FIELD?







MUSE DATA

In collaboration with Yara Jaffe’ and Yun-Kyeong Sheen

SUMMARY

Jellyfish galaxies are unmistakable signatures of gas stripping (most probably ram pressure stripping)

They are a wide spread phenomenon in clusters of all masses, weaker cases may be present in groups

The gas in the tentacles forms new stars, which are added to the intracluster light – When jellyfishes are optically recognizable, the majority are in a phase of enhanced star formation

Hints that their most favourable conditions are in complex structures, like cluster mergers, where X-ray shocks are found

There is now a large sample of jellyfishes in low-z clusters, for follow-up studies

To do next:

Position wrt. Chandra maps
Galaxy color maps (uBV) to see spatial distribution of star formation
IFU data (MUSE + KOALA?)
Investigate group jellyfishes