Observational Cosmology Journal Club

May 8, 2017, Taira Oogi

[1] Phase-space analysis in the group and cluster environment: time since infall and tidal mass loss
Jinsu Rhee et al.; arXiv:1704.04243

[2] Galaxy Zoo: The interplay of quenching mechanisms in the group environment
R. J. Smethurst et al.; arXiv:1704.06269

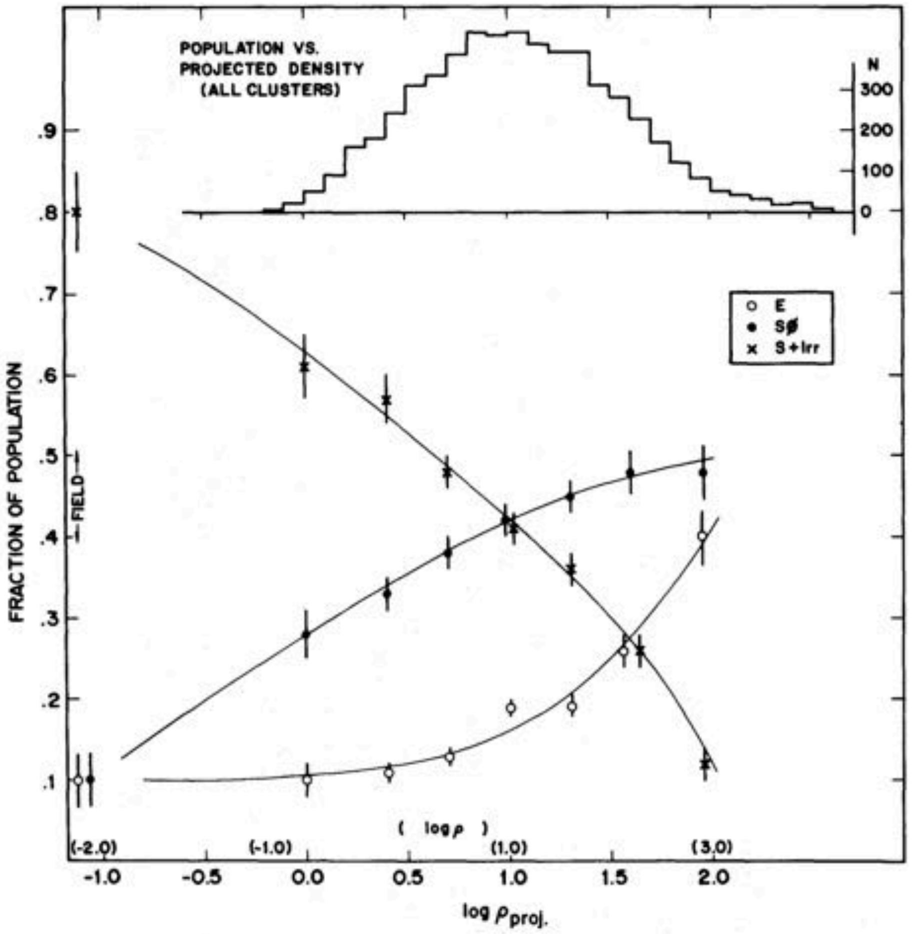
[3] Discovery of ram-pressure stripped gas around an elliptical galaxy in Abell 2670
Yun-Kyeong Sheen et al.; arXiv:1704.05173

[1] Phase-space analysis in the group and cluster environment

Morphology-density relation

- Different types of galaxies prefer different environments (the morphology-density relation).
- One possibility is that environmental mechanisms may be preferentially acting in higher density environments, halting star formation and/or transforming galaxies morphologically.
- The correlation may be due to a superposition of other possible quenching mechanisms each of which depend on internal factors.
- Questions
    - How does the environment influence the detailed morphological structures of a galaxy?
    - Is quenching that is directly caused by the environment occurring in galaxy groups?

Dressler 1980



[1] Phase-space analysis in the group and cluster environment

This study

- Focus on the Harassment (tidal mass loss)
- They examine how a galaxy's location in phase-space can provide valuable information on both time since infall and tidal mass loss.
- Specifically, they quantify what the location of galaxies in phase-space can tell us about the time since the galaxy fell into the cluster, and the amount of tidal mass loss they have suffered.

Gnedin 2003

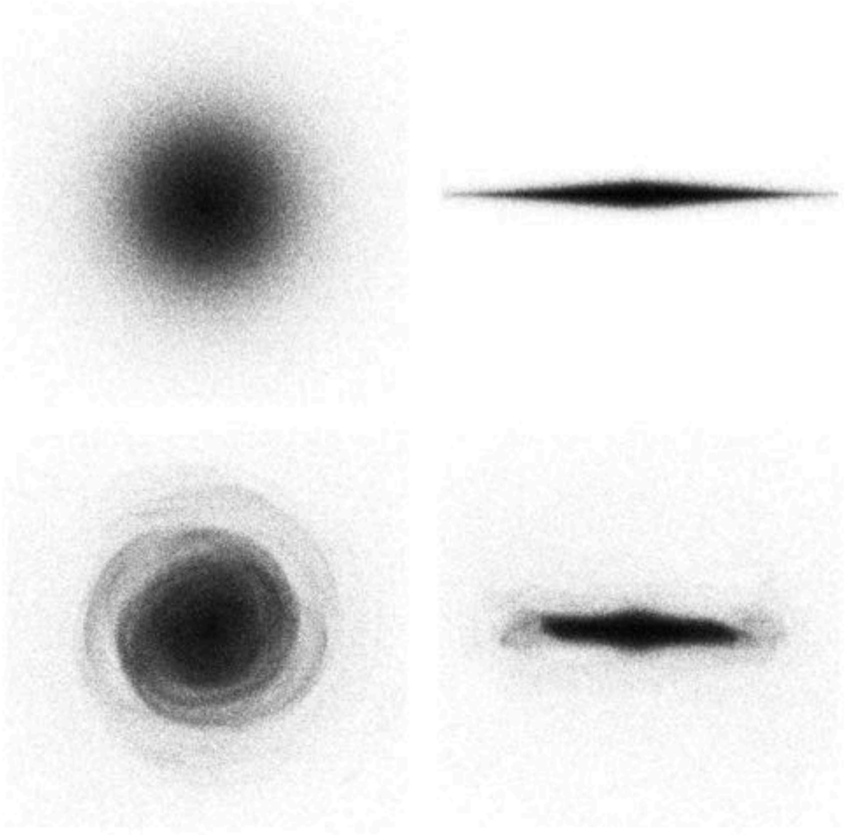


FIG. 2.—*Top panels*: Initial conditions for large disk galaxies (face-on and edge-on views; only stellar particles are shown). *Bottom panels*: Final configuration of galaxy L1.

[1] Phase-space analysis in the group and cluster environment

- Cosmological hydrodynamic zoom-in simulations using the adaptive mesh refinement code RAMSES.
  - 15 high density regions (clusters)
  - The baryon prescriptions were applied in the Horizon-AGN simulation.

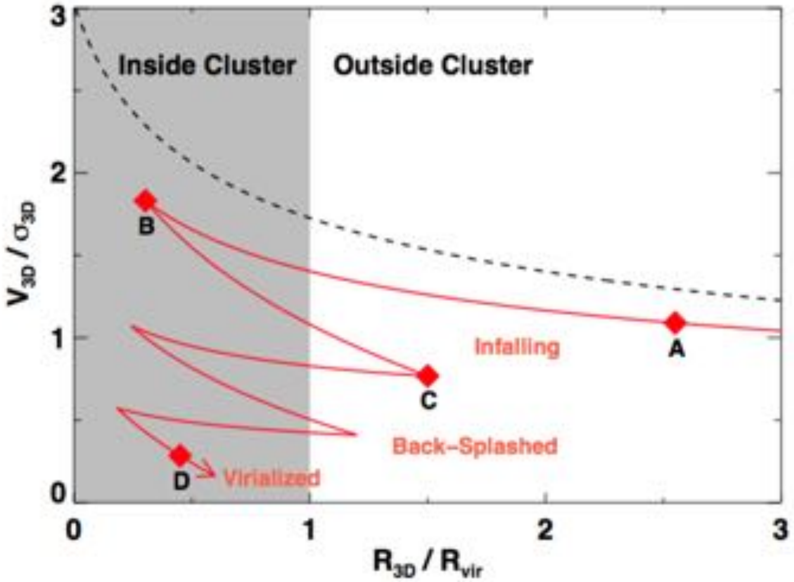


FIG. 1.— Toy schematic of a galaxy's trajectory after inalling into the cluster, shown using normalized orbital velocity, and normalized clustocentric radius. The red solid line is the trajectory of the galaxy up until $z = 0$. The black-dashed line is the escape velocity curve of the cluster, calculated as described in the text. Initially the galaxy is found in the 'infalling' region (between A and B). After first pericenter, it approaches apocenter at C. If the apocenter is beyond the cluster virial radius, then the galaxy is found in the 'back-splash' region. Between C and D, the object settles into the lower-left hand corner of the diagram, known as the 'virialized region'.

$$f_{\rm ML} = 1 - \frac{M_{\rm now}}{M_{\rm peak}} \qquad (5)$$

where $M_{\rm now}$ is the final mass (at z=0) and $M_{\rm peak}$ is the maximum mass in the mass evolution history of a subhalo.

$$f_{\rm ML} = f_{\rm int} + f_{\rm ext} \qquad (6)$$

where $f_{\rm ext}$ is the fractional tidal mass loss that occurred before entering the cluster virial radius (i.e. externally),

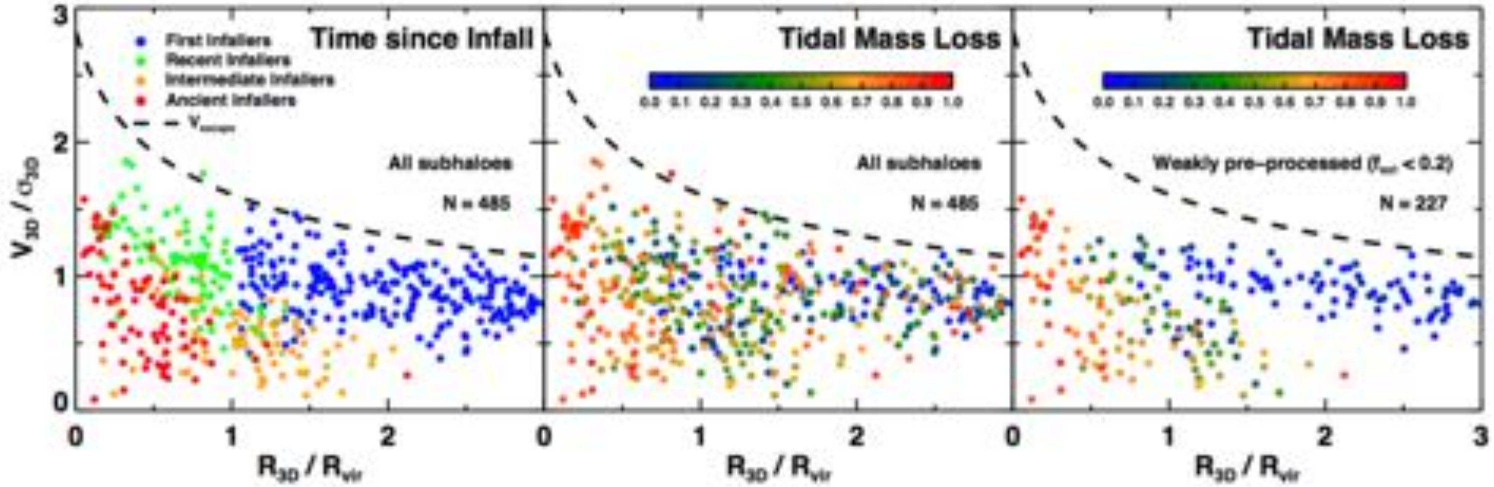


FIG. 2.— Phase-space diagrams of a single massive cluster, Cluster C3 ($\sim 2.3 \times 10^{14} M_\odot$). The black-dashed line is the escape velocity curve. In the left panel, symbol color indicates time since the galaxy fell into the cluster, binned into 4 time bins (First Infallers, Recent Infallers, Intermediate Infallers and Ancient Infallers, for detail see text), where color indicates the time bin (see legend). Galaxies in each time bin tend to occupy fairly distinct regions in the phase-space diagram. In the middle and right panel, color indicates the fraction of the total halo mass that has been tidally stripped. Blue colors indicate weak tidal mass loss, and red colors indicate very strong tidal mass loss (see color bar). The left and middle panel include all the galaxies of the cluster. The right panel contains a subsample of the galaxies, which have suffered low mass loss external to the cluster ($f_{\rm ext}$<0.2). With the exclusion of pre-processed galaxies, the plot of time since infall (left panel) and the tidal mass loss (right panel) share a resemblance.

[1] Phase-space analysis in the group and cluster environment

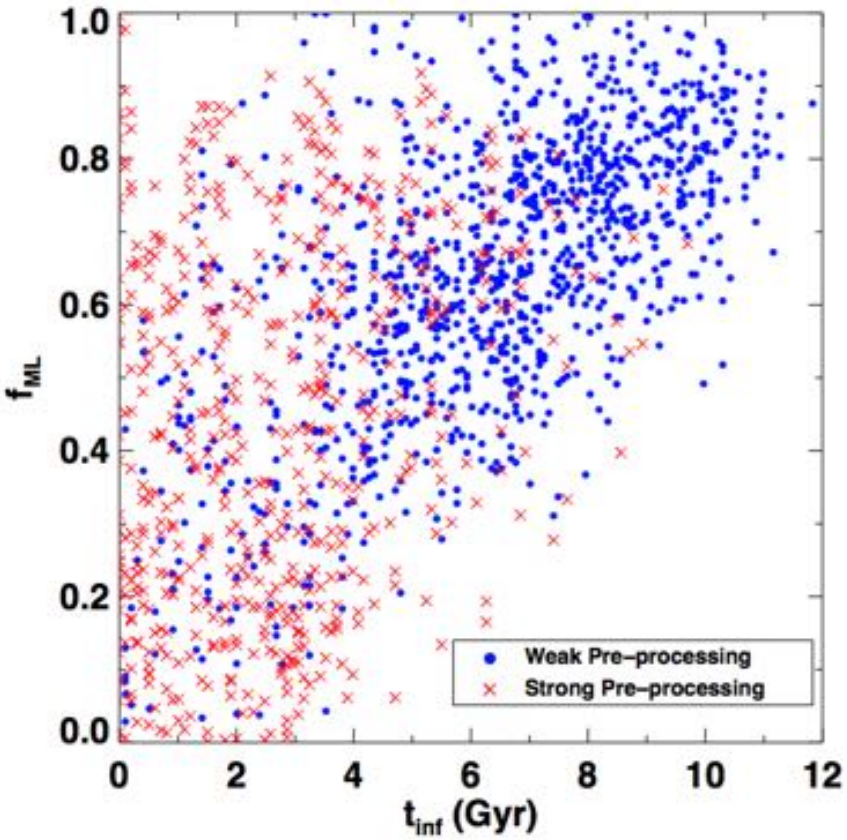
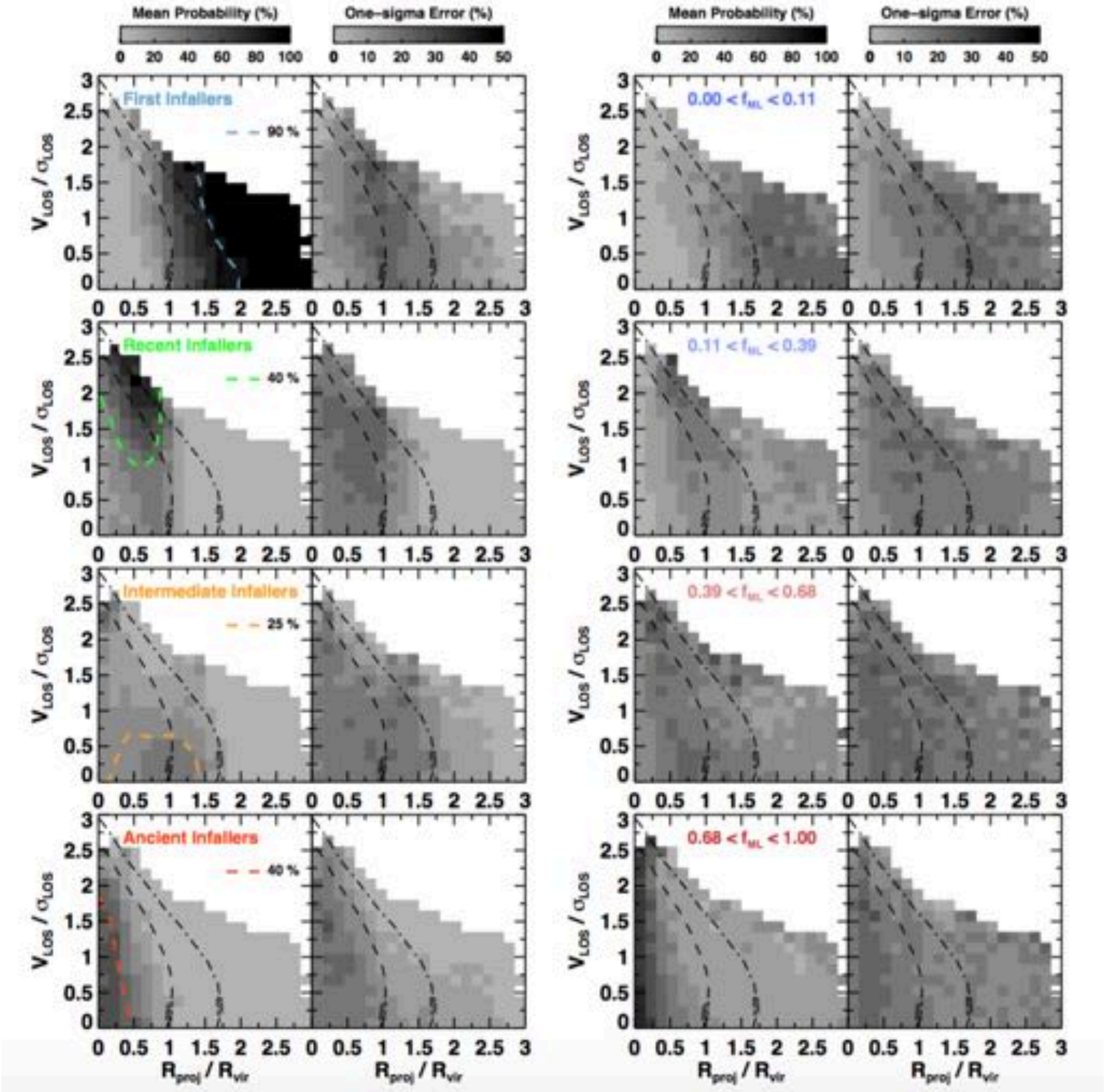


FIG. 3.— The correlation between fractional tidal mass loss $f_{\rm ML}$ and time since infall into the cluster $t_{\rm inf}$. Data points are galaxies from all of the clusters in our sample. We make two subsamples based on the strength of pre-processing they experience. The weakly pre-processed sample lose less than 20% of their total mass loss before entering the cluster (dark blue filled circles). The strongly pre-processed subsample lose more than 80% of their total mass loss before entering the cluster (red crosses). In the absence of pre-processing effects, a clear linear trend between time since infall and mass loss is seen.



[1] Phase-space analysis in the group and cluster environment

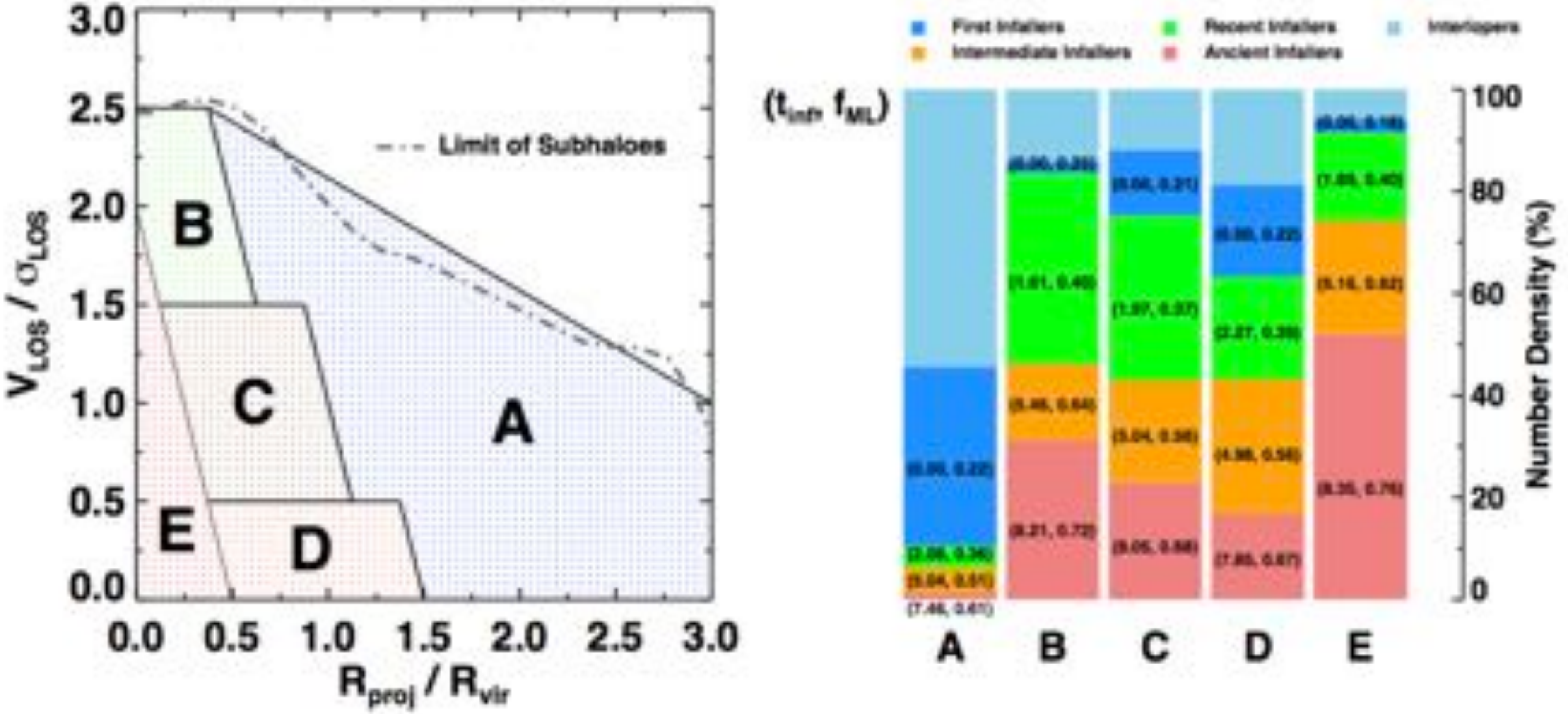


FIG. 6.— Left panel: A projected phase-space diagram, split up into distinct regions (labelled A-E). Regions are chosen to try to maximize the fraction of a particular time since infall population. The grey-dashed line indicates the limit of subhaloes after 1000 random rotations. Right panel: Information about each region. In each bar graph, colors indicate the corresponding time since infall group (see legend), and vertical height of the color bar indicates the fraction of the total galaxies in that region. The numbers in brackets indicate the mean time since infall, and mean tidal mass loss fraction in that bar, respectively.

[2] The interplay of quenching mechanisms in the group environment

Motivation

- Question: Is quenching that is directly caused by the environment occurring in galaxy groups?
- In order to isolate the cause of the density-morphology and density-SFR correlations, they need to observe how morphology and galaxy quenching timescales change in dense environments with different properties in comparison to the field.

This study

- They construct a sample of both group and field galaxies and use a Bayesian inference method to determine the quenching time and rate describing a simple exponentially declining SFH for a galaxy given its optical and NUV colours.
- They also investigate the morphological structures as a function of the group-centric radius.

[2] The interplay of quenching mechanisms in the group environment

Galaxy Zoo 2 project

- Images from SDSS DR7
- Berlind et al. (2006) group catalog

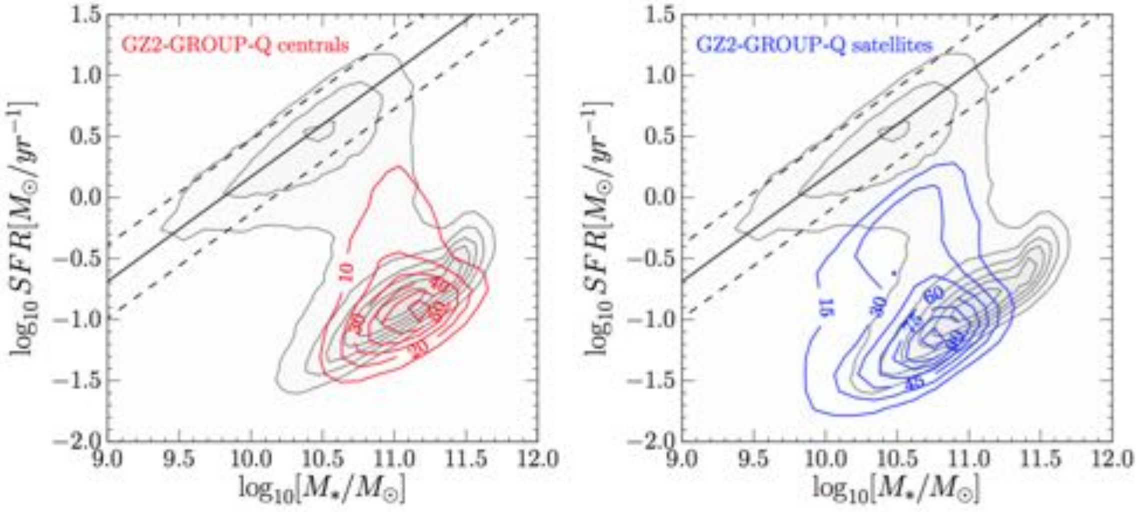


Figure 1. The stellar mass-SFR plane showing central (left; red contours) and satellite (right; blue contours) galaxies in the GZ2-GROUP-Q sample, selected to be 1σ below the SFS. In both panels the entire SDSS sample from the MPA-JHU catalogue is shown by the grey contours. The definition of the SFS from Peng et al. (2010) at $\bar{z} = 0.053$ (solid line, the mean redshift of the GZ2-GROUP-Q sample) with $\pm 1\sigma$ (dashed lines) is shown.

- Star formation history
  - STARPY code allows the user to derive the quenching star formation history of a single galaxy through a Bayesian Markov Chain Monte Carlo method.

Input: u-r color, NUV-u color, redshift

Star formation history:

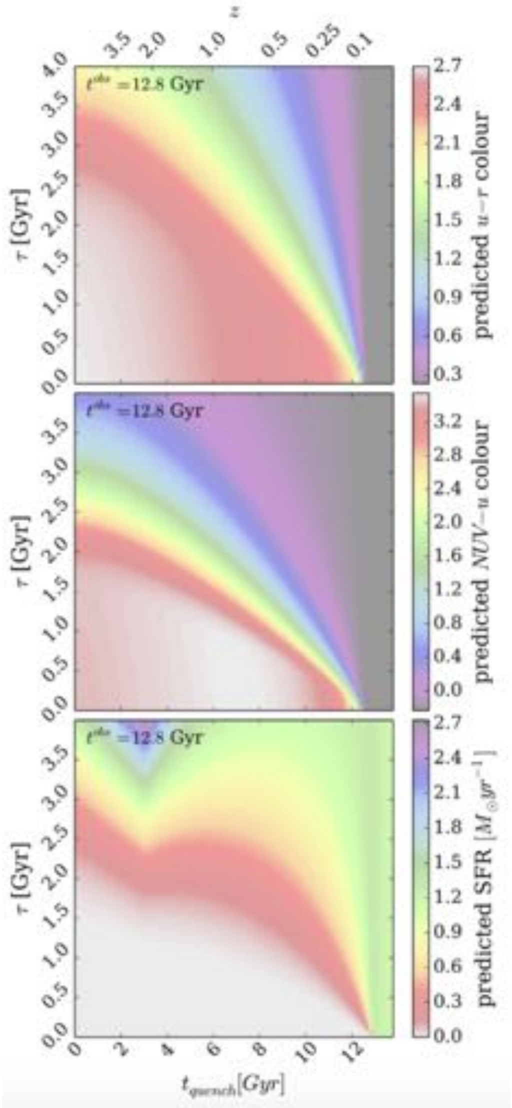
$$SFR = \begin{cases} i_{sfr}(t_q) & \text{if } t < t_q \\ i_{sfr}(t_q) \times exp\left(\frac{-(t-t_q)}{\tau}\right) & \text{if } t > t_q \end{cases} \quad (4)$$

Parameters

t_q: quenching onset time

τ: quenching timescale

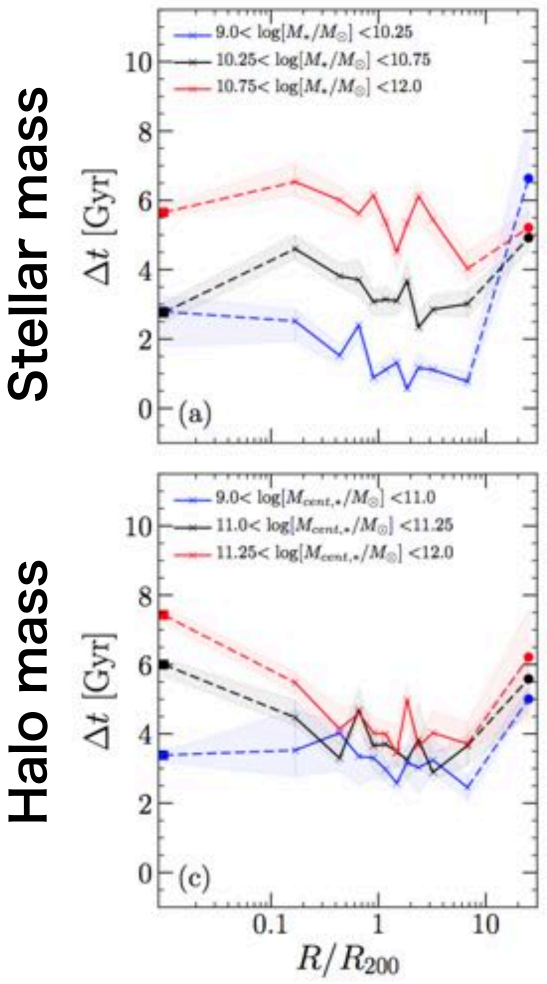
Smethurst et al. 2015

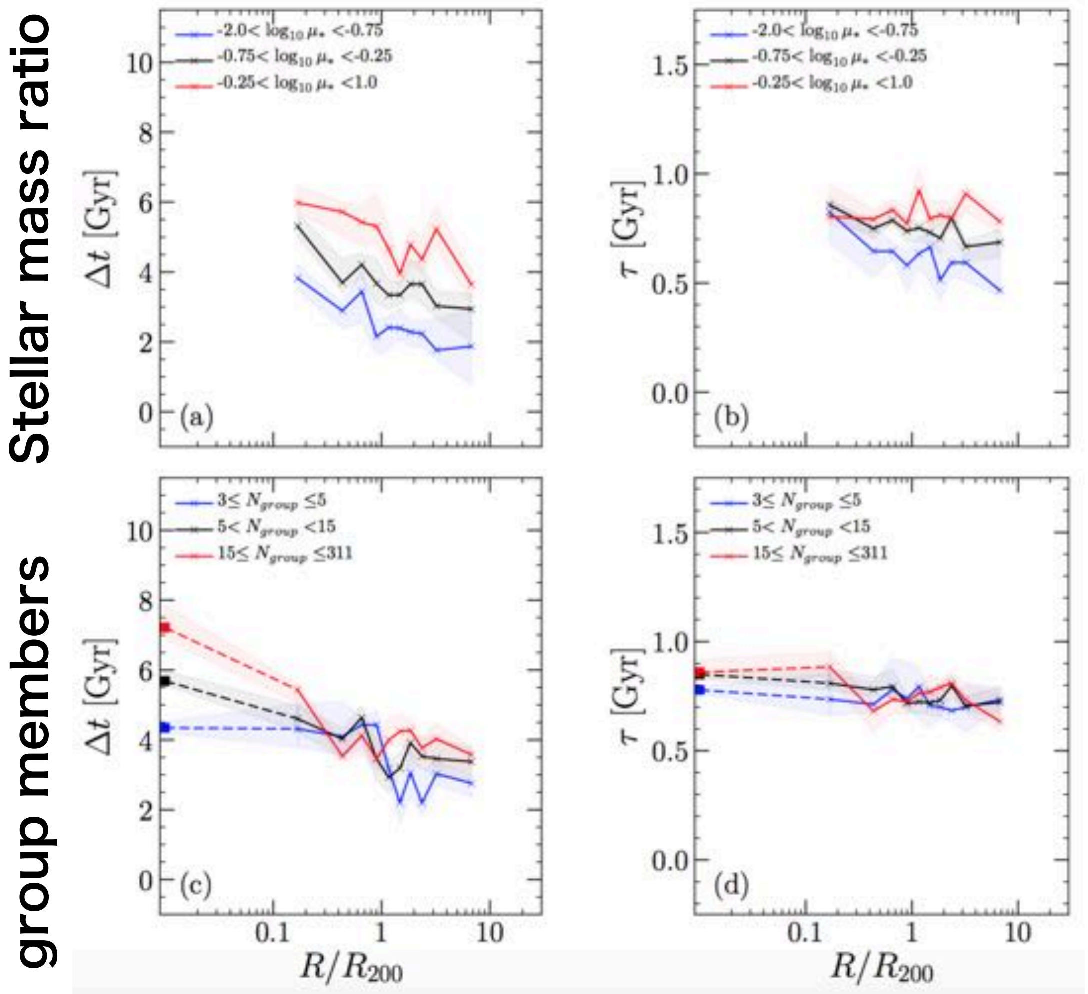


[2] The interplay of quenching mechanisms in the group environment

$\Delta t = t^{\mathrm{obs}} - t_q$: time since quenching onset

- Short quenching timescale and efficient quenching for low stellar mass galaxies
- The halo mass does not affect quenching.



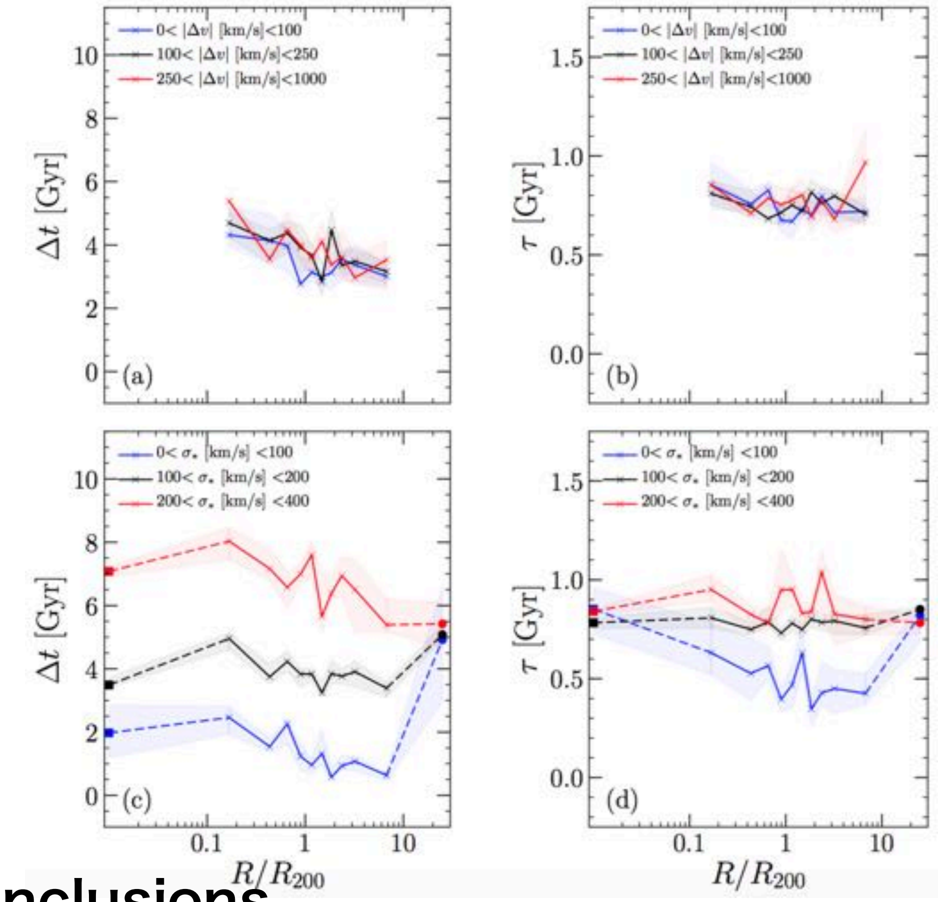


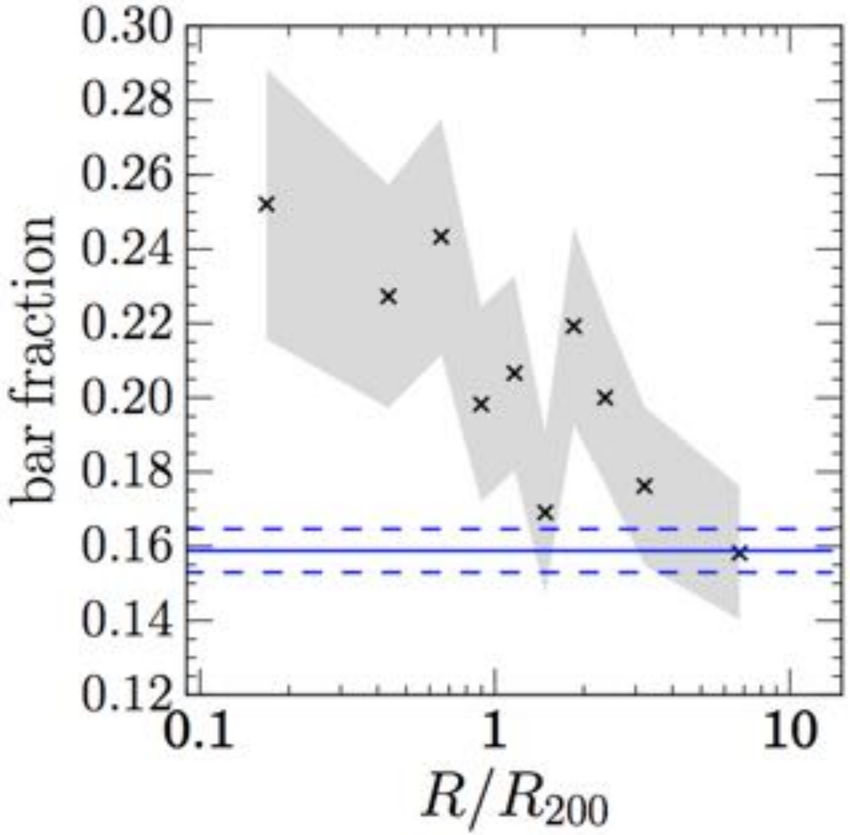
[2] The interplay of quenching mechanisms in the group environment

- The quenching mechanism is not correlated with the velocity at which satellites move through the dense environment.

Relative velocity

Stellar velocity dispersion





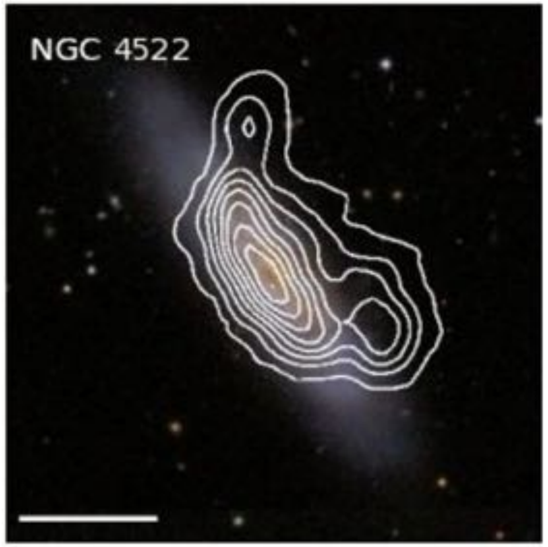
- **Conclusions**
  - Ram pressure stripping is not the main cause of quenching in the group environments.
  - An interplay of mergers, mass & morphological quenching and environment driven quenching mechanisms dependent on the group potential drive galaxy evolution in group.

[3] Discovery of ram-pressure stripped gas around an elliptical galaxy

Motivation

- Observation of HI gas stripping (e.g. Haynes et al. 1984)
- Recent progress: IFU (Integral Field Unit) studies are able to reveal the gas that is stripped and ionized and also provide the kinematical and physical properties of the ionized gas as well as the stars (e.g. Fumagalli et al. 2014)
- Stars are often formed in the stripped gas (e.g. Kenny & Koopmann 1999; Smith et al. 2010)
- The most striking examples: Jellyfish galaxies (Fumagalli et al. 2014)
- How effective is the ram pressure stripping?
  - a amount of stripped molecular, neutral and ionized gas
  - star formation during the stripping

Chung et al. 2009

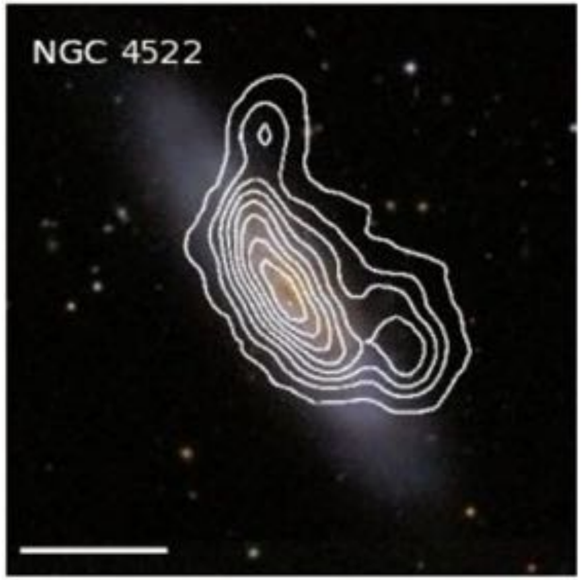


[3] Discovery of ram-pressure stripped gas around an elliptical galaxy

This study

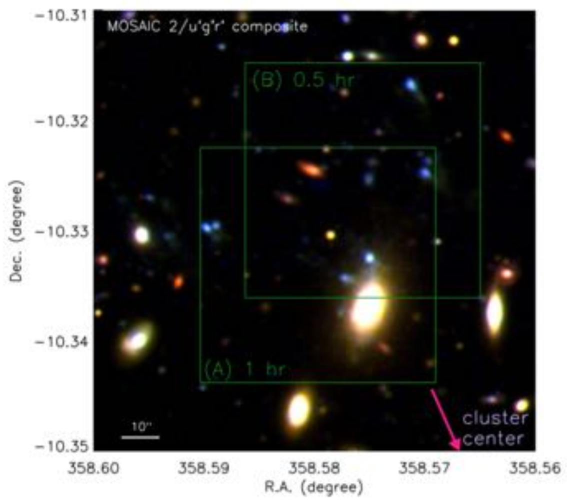
- They conducted IFU (Integral Field Unit) spectroscopic observations of a cluster galaxy using MUSE (Multi Unit Spectroscopic Explorer) on VLT (Very Large Telescope) to show the Halpha map and gas/stellar kinematics.
- They discover an elliptical galaxy that suffers from ram-pressure stripping for the first time.
- It is a post-merger elliptical galaxy.

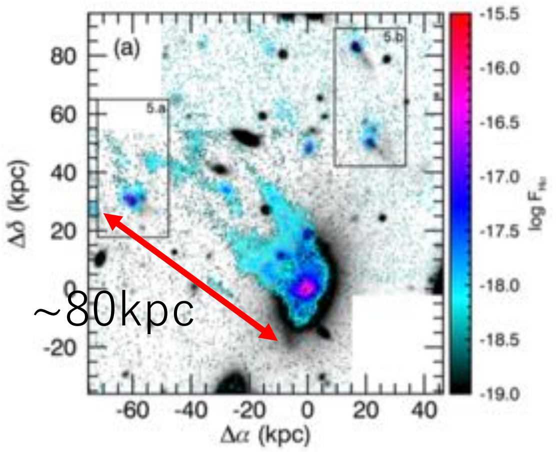
Chung et al. 2009



[3] Discovery of ram-pressure stripped gas around an elliptical galaxy

Results





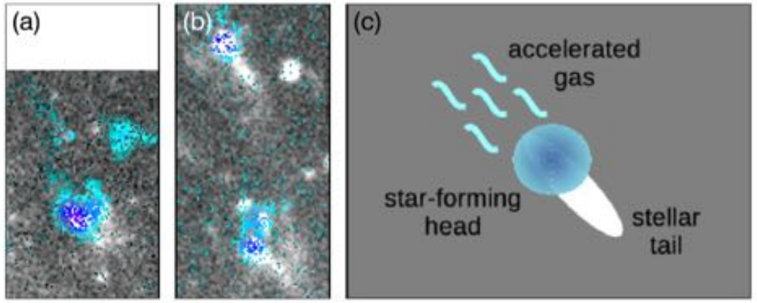
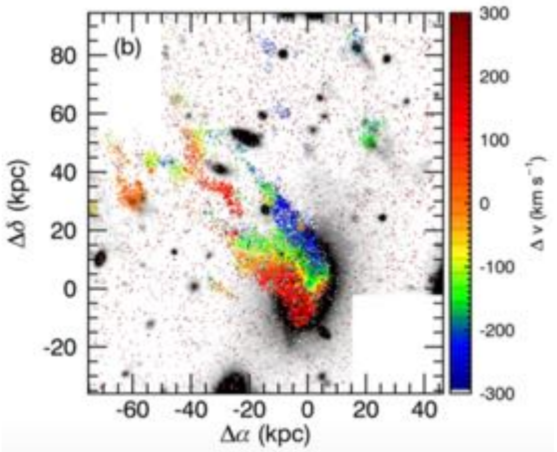


Figure 5. (a) and (b) Zoom-in images of some of the star-forming blobs, with the Hα flux map is superimposed over the deep r'-band image, (c) a schematic view of the blobs.



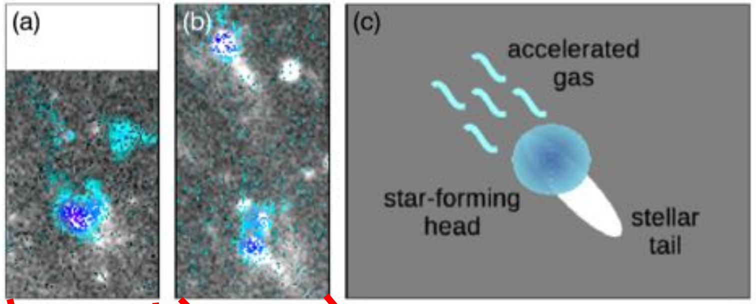
- Structure
  - Stellar system
    - Old stellar population, elliptical morphology, no rotation
  - Long tails
  - Blobs
  - Central star-forming gas disk

- Halpha blobs are associated with the blue optical blobs.
- Halpha gas disk (rotation)
- Rotation in the stripped gas as well as the gas disk.

[3] Discovery of ram-pressure stripped gas around an elliptical galaxy

Results

- A segregation under the ram-pressure stripping, with streams of ionized gas blowing downwind from the blob and streams of stars pointing upwind.
- The origin of the gas
  - A likely scenario is that a wet merger occurred.
- The origin of the star-forming blobs
  - The blobs are forming from the ram-pressure-stripped gas itself.
  - The blobs are tidal dwarf galaxies formed during the wet merger.



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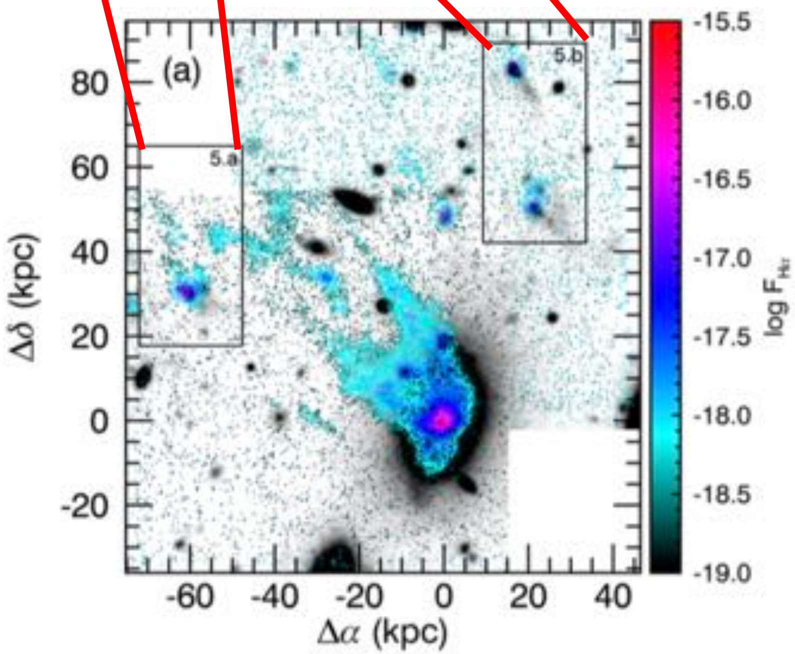

The clearest optical stellar tail so far.

Discussion

- Arguments
  - The gas was most likely acquired during a past wet merger
  - The star-forming blobs are also remnants of the merger
  - The one-sided tails and tadpole morphology of the blobs suggest that the system is undergoing ram pressure from the ICM.