GAMA: The Evolution of Spiral Galaxies in the Group Environment

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with

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Introduction

The initial supply of gas from which the stars of galaxies are formed must have been accreted from the intergalactic medium (IGM). Arguably this process of accretion of IGM gas by galaxies is amongst the most fundamental involved in the formation of baryonic structure and, barring major galaxy-galaxy interactions, will determine the evolutionary fate of a galaxy. Accordingly, it has been the focus of much theoretical work, with the currently widely accepted picture being that of a two step accretion; first from the IGM onto the host dark matter halo, forming a virialized intracluster medium (ICM) and then, via cooling, from the ICM into the ISM of the galaxy (Fig. 1, [1,2]).

The second step depends on the temperature of the ICM and its ability to cool, so that the efficiency of gas-fuelling is expected to decline with increasing halo mass. For low mass galaxies it is believed, that the accretion is balanced by self-regulated stellar feedback removing ISM from the galaxy, while for massive galaxies (which predominantly reside in massive halos) AGN feedback is thought to further suppress accretion leading to a maximum efficiency in ~10^{12} $M_\odot$ halos [3,4]. Indeed, as can be seen in Fig. 2, the ratio of stellar to dynamical mass for galaxy groups in the Galaxy And Mass Assembly (GAMA) survey[1][5] approaches the universal baryon mass fraction for low mass halos and declines with increasing halo mass.

Further complexity is added by the hierarchical merging of DM halos giving rise to galaxy groups. For satellite galaxies, i.e. those not at rest w.r.t. the center of mass of their group, their motion relative to the ICM introduces further processes, e.g. ram-pressure stripping which can affect the rate of accretion onto the galaxy. Indeed, until recently, it has generally been assumed that no gas-fueling takes place in satellite galaxies.

It is essential, however, to note that this scenario rests almost solely on theoretical considerations, with little in the way of direct empirical constraints with which to contrast its predictions.

We have used the GAMA survey, in particular the GALEX-GAMA UV data[2] and the galaxy group catalog G^3Cv1 [6] to, for the first time, derive direct quantitative empirical constraints on the process of gas-fueling as a function of environment.

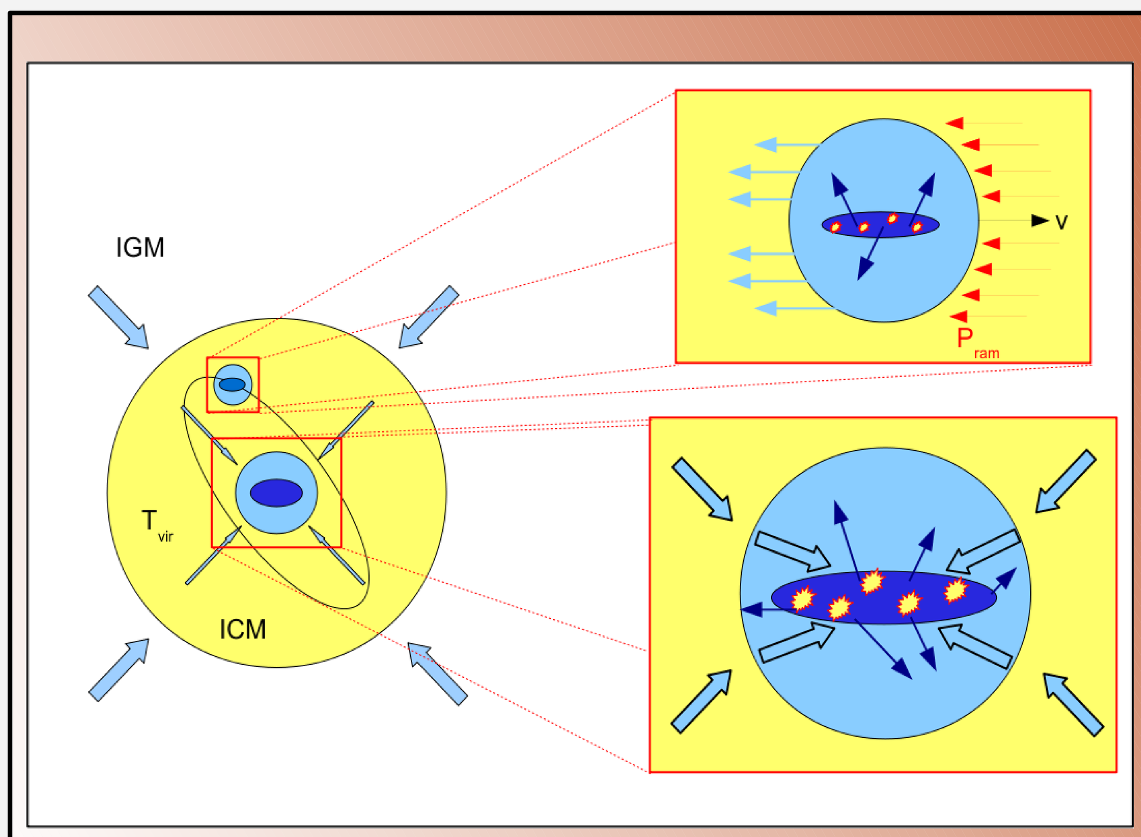

Fig. 1

Schematic representation of theoretically expected gas-fueling cycle. Material is accreted from the IGM, virialized, cools (at a rate related to the mass of the halo), and is accreted into ISM. ISM is removed by self-regulated SF feedback. In the case of satellite galaxies, ISM and cooling ICM already bound to the galaxy (light blue) can be removed due to the motion of the galaxy through the ICM, e.g. via ram-pressure stripping.

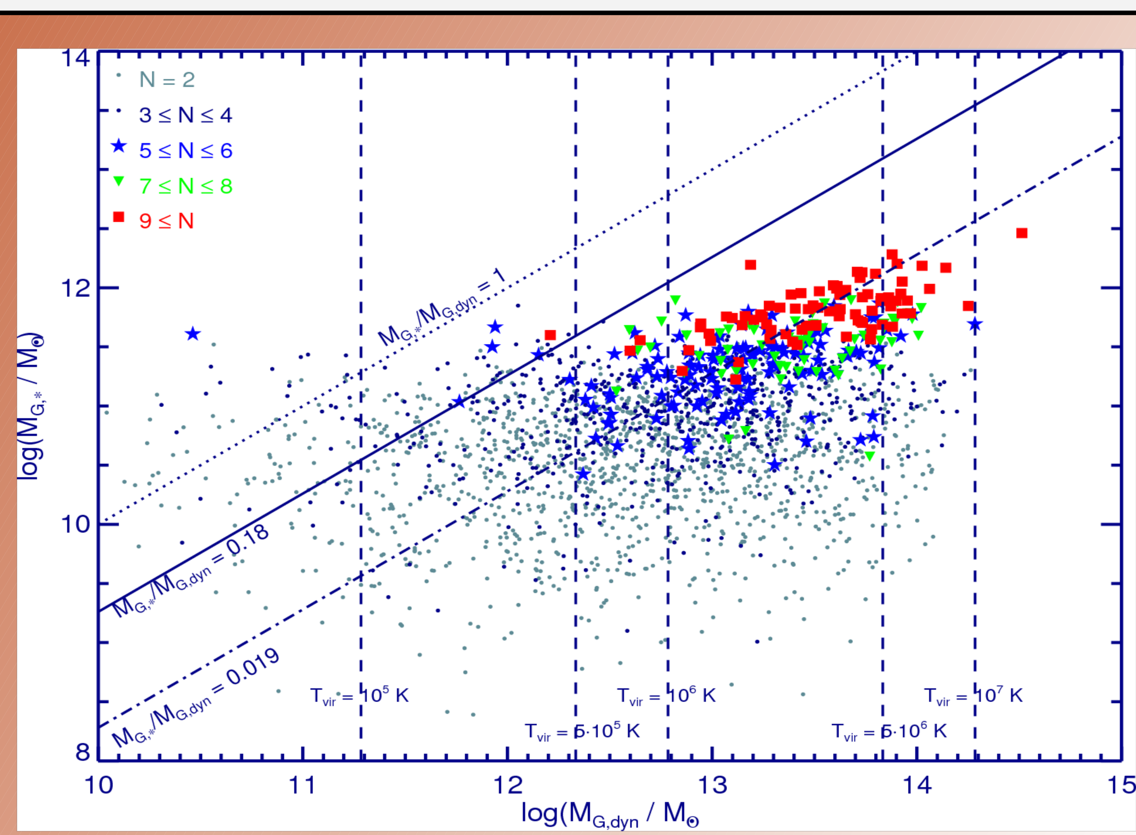

Fig. 2

Total stellar mass as a function of dynamical mass for GAMA groups color coded according to number of members N. The mass fraction in stars approaches the expected baryonic mass fraction in low mass groups and is lower in more massive groups and clusters.

Method

An investigation of the environmental dependence of gas-fueling must probe the halo mass scale of ≲10^{13} $M_\odot$ where the maximum efficiency of gas-fueling is expected. However, a direct measurement of halos in this mass range on an object-by-object basis is only possible using velocity dispersion measurements of galaxy groups and even this has only now become possible with the GAMA galaxy group catalog ([6] , Fig. 3). Furthermore, direct measurements of the ISM of large samples of galaxies in groups are not yet available. Therefore, we make use of the star formation rate as a tracer of the ISM content, assuming that the probability of a unit mass of ISM being converted into stars per unit time is only a function of galaxian properties.

In order to be able to adopt this approach one must take care to isolate the effect of the galaxy-ICM interaction from other potential effects on the SFR. To do this we:

- Restrict ourselves to spiral galaxies using the method of Grootes et al. [7]
- Exclude galaxies which are interacting or may have recently interacted
- Control for possible dependencies on galaxian properties by considering the specific SFR – stellar mass relation (SSFR-M_*)
- Use space-borne NUV observations with radiative transfer based attenuation corrections [8,9] to determine the total SFR, resulting in a highly accurate tracer which is sensitive to SFR changes on timescales shorter than the typical free- fall timescale (1 Gyr)

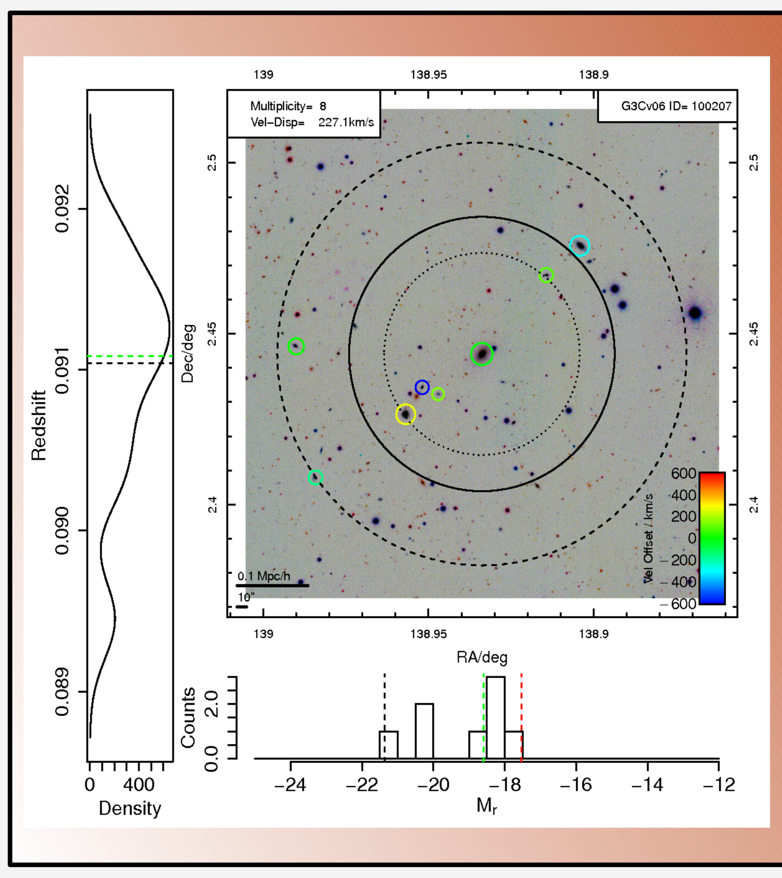

Fig. 3

A GAMA group with 8 spectroscopically determined member galaxies. The location in z and M_r of the BCG and the median group value are shown as blue and green dashed lines, while a red dashed line indicates the apparent magnitude limit of the survey [6]. The dynamical mass can be estimated from the velocity dispersion and the projected radius.

Results

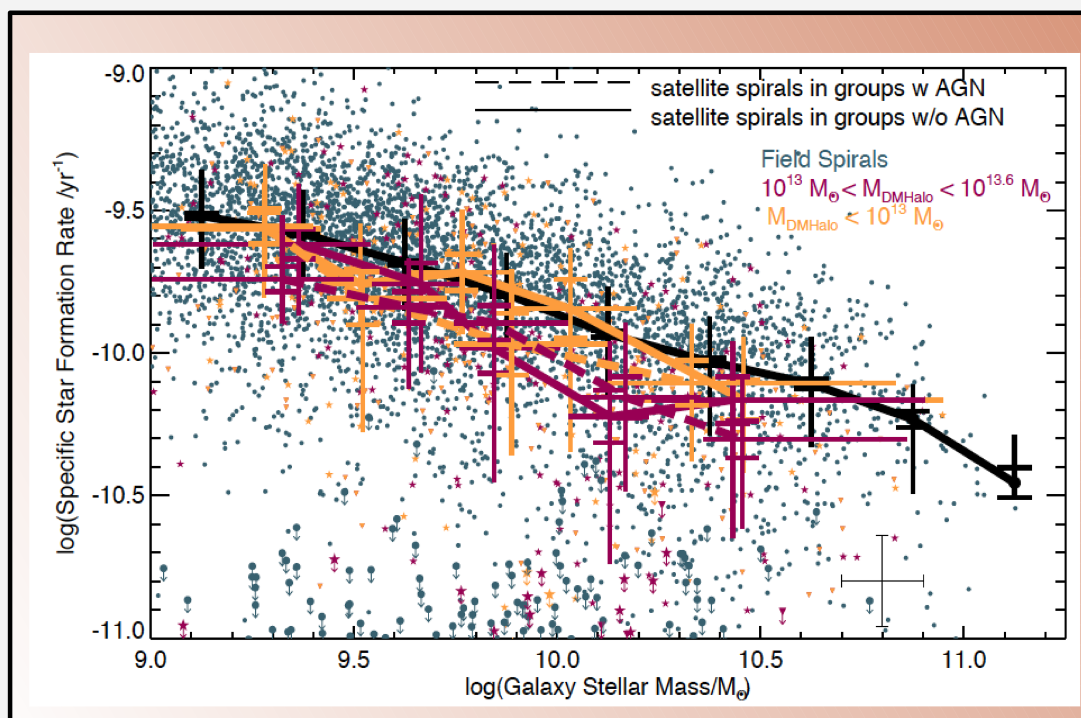

Fig. 4:

SSFR vs. stellar mass for satellite spiral galaxies in GAMA groups of low (orange) and intermediate (magenta) mass. The median relation for isolated field spirals is shown in black. The relations for AGN hosting groups are shown as dashed lines, while those for non-AGN-hosting groups are shown as solid lines. The individual galaxies in each class are shown as stars and inverted triangles, respectively.

Contrary to expectations, the SSFR-M_* for group spiral galaxies is only slightly suppressed w.r.t. the relation for isolated field galaxies. Furthermore, the relation displays no clear dependence on the mass of the group dark matter halo (Figs. 4 & 5). In fact, a detailed investigation of the offset in SSFR for group satellite spirals w.r.t. the median SSFR-M_* for field spirals shows that the dominant fraction of the group satellite spirals, rather than being quenched, is forming stars at the rate of the field, with the shift in the median resulting from a small population of severely quenched spirals (histograms in Fig. 5).

In contrast to this surprisingly uniform behavior, our results indicate that the presence of an AGN in the group strongly affects the gas-fueling and star-formation of non-AGN-host spiral group galaxies. (Fig. 5). However, this effect is only visible in massive DM Halos (M_{DMH} > $10^{13.6}$ $M_\odot$).

This represents the first direct confirmation of an AGN feedback mechanism operating directly through the ICM to quench star-formation. Remarkably however, this AGN feedback mechanism is able to affect other group galaxies, quenching star-formation in non-AGN-host group satellite spiral galaxies. Hitherto this type of effect has been largely ignored, with AGN feedback considered only in the context of the host galaxy.

Overall, the surprising new results obtained using the unique multi-wavelength database of the GAMA survey and the precision radiative transfer techniques [8,9] indicate that there is much to be done to understand the processes governing gas-fueling, and underscore the importance of empirical references in this endeavor.

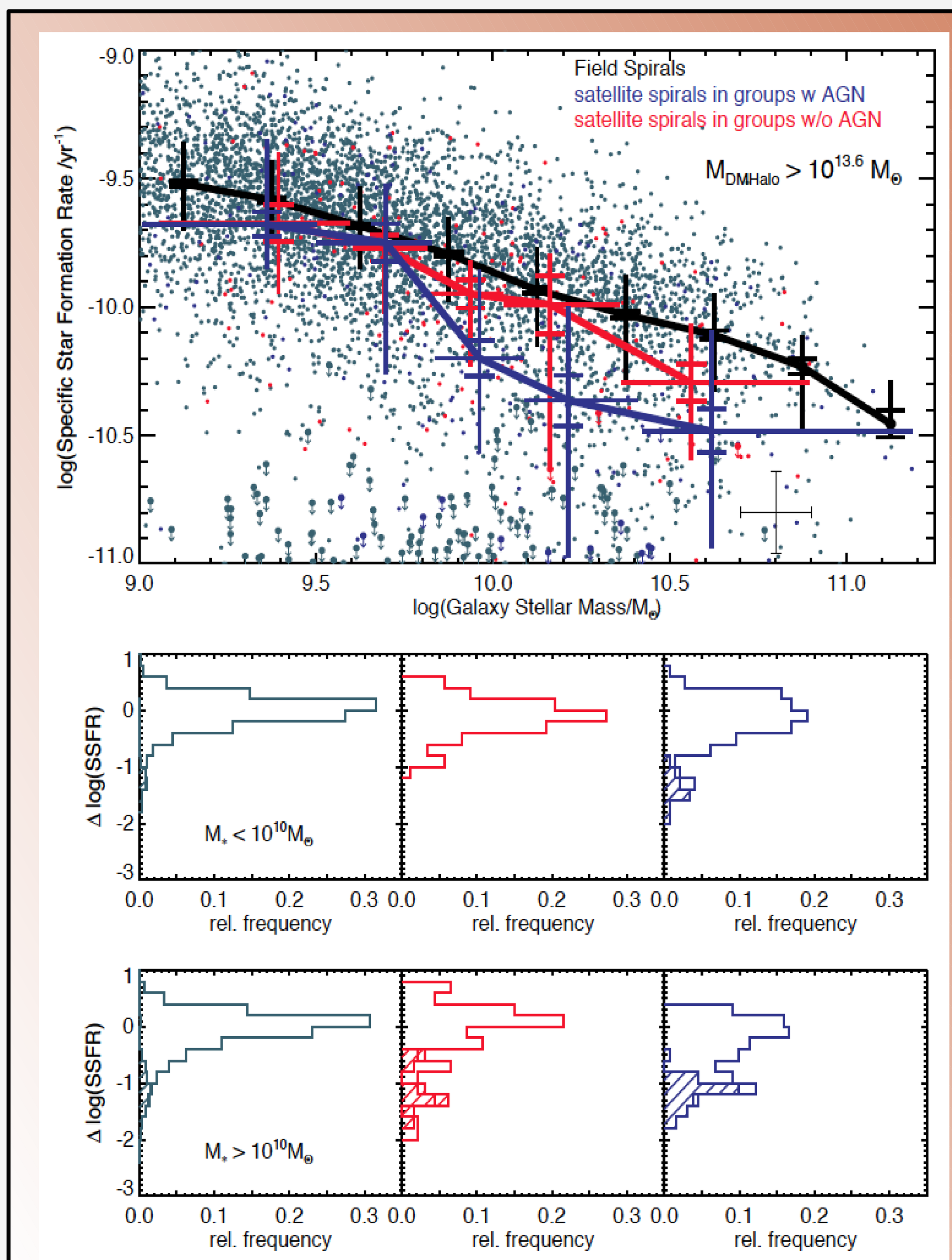

Fig. 5:

SSFR vs. stellar mass for satellite spiral galaxies in high mass GAMA galaxy groups with M_{DMH} > $10^{13.6}$ $M_\odot$, separated according to AGN-hosting (blue) and non-AGN-hosting (red) groups. The histograms show the distributions of the offset in SSFR from the median relation for field spirals (upper limits are hashed). A population of strongly quenched massive galaxies appears in AGN hosting groups and is absent in groups not hosting an AGN.

References

[1] White & Rees, 1972, MNRAS, 183, 341
[2] Mo, Mao, & White, 1998, MNRAS 295, 319
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[4] Croton et al., 2006, MNRAS, 365, 11
[5] Driver et al., 2011, MNRAS, 413, 971
[6] Robotham et al., 2011, MNRAS, 416, 2640
[7] Grootes et al., 2014, MNRAS, 437, 3883
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[9] Grootes et al., 2013, ApJ, 766, 59

[1] GAMA is a joint European-Australasian project based around a spectroscopic campaign us- ing the Anglo-Australian Telescope. The GAMA input catalogue is based on data taken from the Sloan Digital Sky Survey and the UKIRT Infrared Deep Sky Survey. Complementary imaging of the GAMA regions is being obtained by a number of independent survey programs including GALEX MIS, VST KIDS, VISTA VIKING, WISE, Herschel-ATLAS, GMRT, and ASKAP providing UV to radio coverage. GAMA is funded by the STFC (UK) , the ARC (Australia), the AAO, and the participating institutions. The GAMA website is: http://www.gama-survey.org.

[2] GALEX (Galaxy Evolution Explorer) is a NASA Small Explorer, launched in April 2003. We gratefully acknowledge NASA's support for construction, operation, and science analysis for the GALEX mission, developed in cooperation with the Centre National d'Etudes Spatiales (CNES) of France and the Korean Ministry of Science and Technology.