INFALLING STARBURST GALAXIES ON THE OUTSKIRTS OF CLUSTERS

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Galaxy clusters are assembled by the infall of galaxies along large-scale filaments. These filaments can provide the right environment for the gas-rich galaxies to interact with one another just before they encounter the hot intra-cluster gas of the galaxy cluster into which they are falling (Porter & Raychaudhury 2007, Porter et al. 2008). Recently several studies (e.g. Gavazzi et al. 2003, Moran et al. 2005, Marcillac et al. 2006) have discovered spectacular starburst galaxies near the boundaries of rich clusters, indicating a connection between galaxy evolution and the transformation of galaxies on the filaments. Most of these clusters are at high redshift and the starburst galaxies are dwarfs, generally occurring in small groups or pairs.

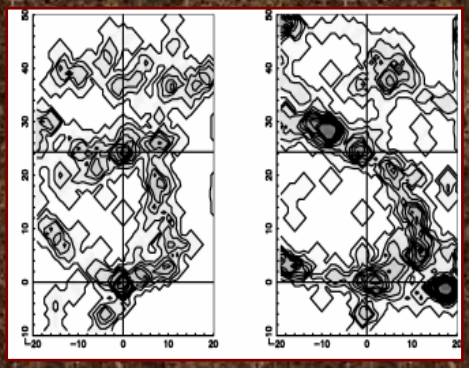

Figure 1 : An example of a typical filament in our sample. The two panels show smoothed galaxy ($M_r \leq -20.5$) density distribution along two planes on which the 3-d distribution is projected (see Pimbblet et al. 2004 for details). Based on these projections galaxy filaments can be classified into *straight, warped, sheet & irregular*. In this example we see a 'warped' filament, i.e. a distribution which is twisted around the inter-cluster axes in both projections.

Using the integrated star formation rates (SFRs) and specific star formation rates (SSFRs) estimated by Brinchmann et al. (2004) from the data provided by SDSS[1] DR4, we define 'starburst' galaxies as those with $M_r \leq -20.5$, SFR > 10 $M_\odot$ yr^{-1}, log SFR/M* > -10 yr^{-1} & non-AGN on the basis of emission-line ratios. We find 46 Abell clusters ($z \leq 0.15$) with at least one such starburst galaxy within 3 h_{70}^{-1} Mpc from the cluster centre. We compare the SFRs in these clusters to a control sample of 61 similar clusters.

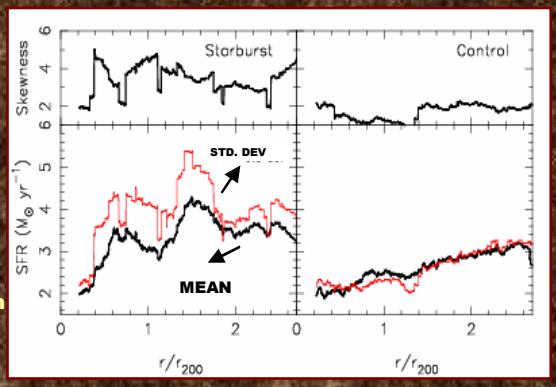

Figure 2: The mean SFR of the clusters (*black*) with at least one starburst galaxy on the outskirts (*left panel; Starburst clusters*) as a function of (scaled) cluster-centric distance compared to a similar sample of 'control' clusters (*right panel*). In *red* is plotted the standard deviation of the same. It is intriguing that despite the expected decline in the mean SFR towards the centre of the cluster, the mean SFR profile is very different for the two samples.

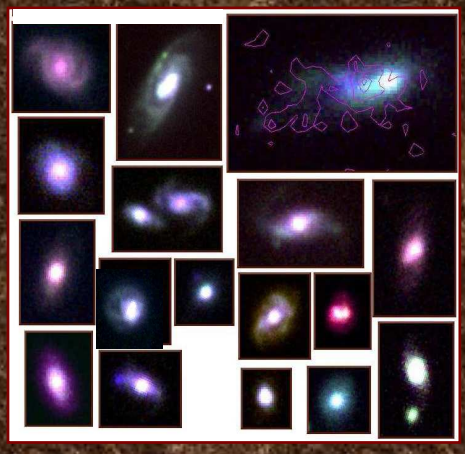

Figure 3: True colour (*gri*) SDSS images of some of the infalling starburst galaxies on the outskirts (1-2 r_{200}) of the clusters. Overlaid on one of the galaxies are the unsmoothed UV contours from SWIFT.

In the plot of SFR in galaxies as a function of (scaled) radius from the centre of their nearest cluster (Fig. 2, left panel), the high standard deviation, along with positive skewness, around 1-2 r_{200}, shows that in clusters where starburst galaxies occur, they are found preferentially in the infall regions. Most of these galaxies show evidence of disturbed morphology and nuclear starbursts (Fig. 3) and of episodic star formation in their history (as evident from the EW(Hδ) and the 4000 Å break, Fig. 4). These findings suggest tidal interactions with close neighbours.

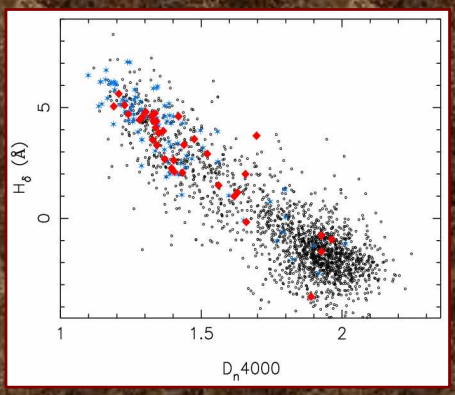

Figure 4: The EW(Hδ) and 4000 Å break, for all galaxies found within $3r_{200}$ of the centres of our clusters, are found to be correlated (black dots). The infalling extreme starburst galaxies between 1-2 r_{200} (red squares; SFR ≥ 10 $M_\odot$ yr^{-1} & log SFR/M* ≥ -10 yr^{-1}) and those with moderate star formation (blue stars; SFR ≥ 1 $M_\odot$ yr^{-1} & log SFR/M* ≥ -10 yr^{-1}) follow the relation, though with a smaller range for the parameters. Galaxies with small Dn4000 and large EW(Hδ) are likely to have experienced a burst of star formation in the recent past (~1-2 Gyrs, see e.g. Kauffman et al. 2003).

Our results suggest the enhanced occurrence of starburst galaxies are on the periphery of the more massive clusters. This is consistent with the results from simulations and observations which show that more massive clusters are likely to be fed by more filaments (Colberg 2005, Pimbblet 2004). A cluster with a deeper potential well will attract more galaxies, thereby increasing the galaxy density at the periphery, which in turn would increase the probability of galaxy-galaxy interactions, leading to bursts of star formation in the infalling galaxies.

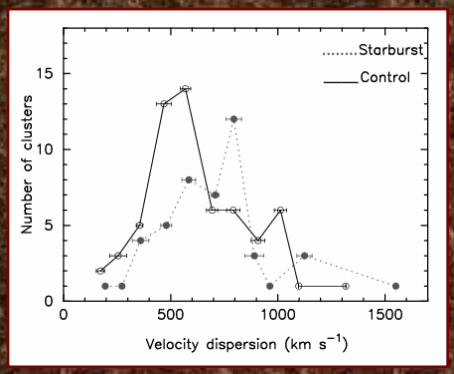

Figure 5: Distribution of velocity dispersions for clusters in the control sample (*solid*) and those with at least one starburst galaxy on their periphery (*dotted*). This shows that on an average, the clusters with at least one starburst galaxy on their boundary are more massive than the control clusters. It is also noticeable that our cluster sample encompasses a wide range of objects from group-like structures to massive clusters.

RESULTS: 1. Galaxies being assembled into clusters via large-scale filaments are likely to experience tidal interactions from other galaxies populating the cluster outskirts. These high speed encounters or 'galaxy-galaxy harassment' play a crucial role in galaxy evolution on filaments.

2. The observed starburst galaxies show evidence of ongoing star formation for the last ~1-2 Gyr (Fig. 4) and indications of interactions with other galaxies (Fig. 3).

3. Starburst galaxies are more frequently seen to be associated with (just outside their virial radii) of more massive clusters (Figs. 2 & 5). The acceleration provided to the galaxies by the cluster's potential enhances the galaxy density on the cluster periphery, thereby increasing the probability of galaxy-galaxy interactions amongst the infalling galaxies.

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