AGN feedback and the colour evolution of local galaxies

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Abstract

Effects of AGN feedback on galaxy star formation histories in groups and clusters, as traced by optical colours, are considered. Kinetic feedback from powerful lobe-dominated radio sources suppresses star formation in galaxies near the AGN host. No such suppression is observed around core-dominated, weaker radio sources. Despite being rare, powerful AGN have profound long-term effects on galaxy star formation histories. Clusters with no currently detectable radio emission carry an imprint of past AGN activity.

Motivation

Feedback from Active Galactic Nuclei (AGN) is required to explain the galaxy stellar mass function and star formation histories (e.g. Croton et al. 2006; Shabala & Alexander 2009). The power and frequency of AGN outbursts is intimately linked to black hole environment (Shabala et al. 2008; Best et al. 2005), and it is unclear whether mechanical or radiative processes drive the feedback. Powerful, rare AGN outbursts associated with lobe-dominated (Fanaroff-Riley (FR) Type 2) radio sources and their more frequent, less energetic, core-dominated (FR-1) counterparts can both in principle play important roles in regulating the star formation history of galaxies.

We compare the effects of both types of radio sources on galaxies near the AGN host by looking at galaxy colours. Photometry is used to reconstruct star formation histories (e.g. Kaviraj 2009; Kaviraj et al. 2011), and thus quantify the effects of feedback from different types of AGN on star formation.

Sample construction

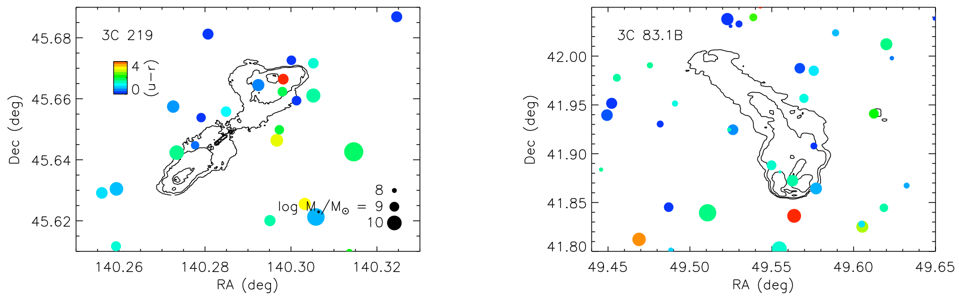
We construct samples of galaxies associated with Fanaroff-Riley Type 1 (core-dominated) and 2 (lobe-dominated) radio AGN.

1. Radio sources

Radio AGN with spectroscopic redshifts < 0.2 were selected from the 3CRR, NVSS and FIRST surveys. The sample spans a large range of sizes (few kpc to Mpc) and radio source ages (few to few hundred Myrs).

2. Galaxies

SDSS was mined for galaxies within radius 1.5 x R_{major} of the AGN host, where R_{major} is the angular size of the radio source. Objects with photometric redshifts matching the AGN host redshift were retained for analysis. Photometric redshift selection enables us to study AGN effects on the smallest galaxies with shallow potential wells- precisely the objects in which gas is expected to be affected by kinetic and radiative AGN feedback.



Galaxies near FR-2 (*left*) and FR-1 (*right*) radio sources. Symbol sizes are indicative of galaxy stellar mass, while symbol colours denote *(u-r)* photometric colours.

3. Projection effects

For each radio source, galaxies were split into three groups:

i) Galaxies lying outside the radio source contours. There are definitely not affected by the passage of the expanding radio source.
ii) Galaxies lying within the innermost part of radio source contours. For lobe-dominated FR-2s these were galaxies within the radius defined by the minor axis of the radio source. For core-dominated FR-1s the radius was taken as half the outermost contour. Such samples are unlikely to be affected significantly by projection effects (see Shabala, Kaviraj & Silk 2011), and thus represent galaxies genuinely overrun by radio sources.
iii) Galaxies within the radio source contours, but outside the inner region. Some of these will be genuinely overrun by radio sources, others will falsely appear to be associated with radio sources due to projection effects.

The analysis below compares the colours of innermost (i.e. 'definitely overrun') and outer ('definitely unaffected') groups.

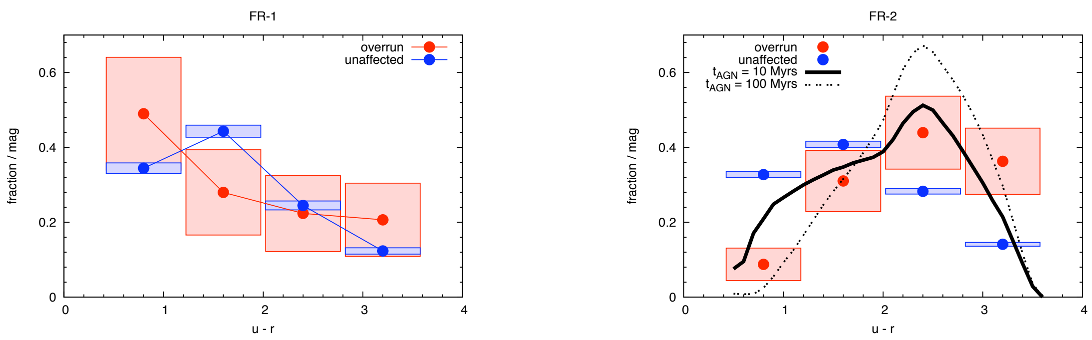
4. Mass corrections

Massive galaxies are known to be preferentially redder. We correct for the differing mass distributions in our samples in two ways. First, we exclude all galaxies outside the 10^{8} - 10^{10} $M_{\odot}$ mass range. Secondly, we weigh the counts of overrun (innermost) galaxies to match the mass distribution of unaffected ones.

	Radio sources	Overrun galaxies	Unaffected galaxies	Mixed galaxies
FR-1	21	27	2149	36
FR-2	71	58	6678	318

Galaxy colours

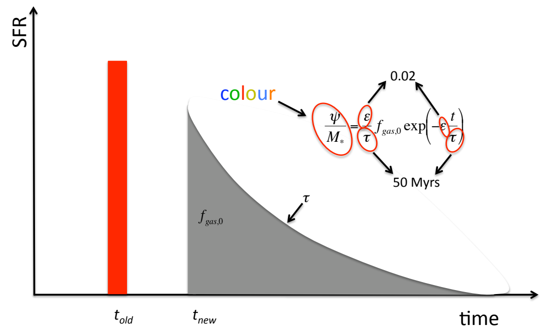
Galaxies overrun by powerful FR-2 radio sources show redder colours than unaffected galaxies around the same radio AGN. No such difference is seen in galaxies around core-dominated FR-1 radio sources. Thus, it looks like shock heating from supersonically expanding FR-2s suppresses gas cooling and star formation. On the other hand, radiative heating and mixing of radio plasma with group/cluster gas does not suppress star formation around FR-1 radio sources.



Colours of galaxies overrun by FR-2 radio sources are well explained by truncation of star formation 10-100 Myrs ago. This is consistent with the median radio source age of 44 Myrs in our sample, and provides **strong evidence** that AGN-triggered shocks suppress star formation in galaxies near the AGN host.

Model colours

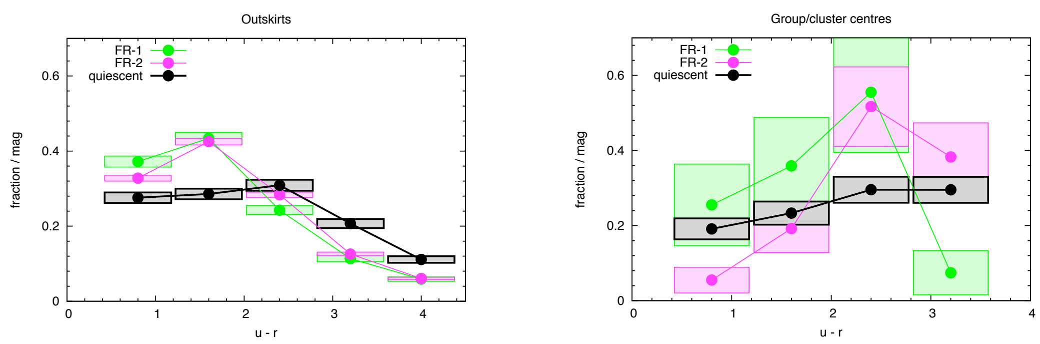
We test whether observed galaxy colours are consistent with truncation of star formation by a shock associated with an expanding FR-2 radio source. Star formation in local galaxies is well described by a superposition of an old instantaneous burst of star formation and a recent burst described by the Schmidt-Kennicutt law (e.g. Kaviraj 2009). Parameters for star formation efficiency and old burst ages were adopted from Kaviraj et al. (2011) and Kaviraj (2009). Galaxy colours predicted by population synthesis models (Bruzual & Charlot 2003) then contain information on the time at which the recent burst of star formation was truncated.

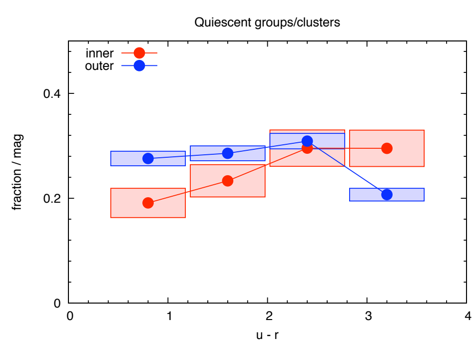


Importance of catastrophic feedback

Powerful FR-2 radio sources are much more rare than the less powerful FR-1s, roughly by a factor of 100 (Shabala et al. 2008). However, by sweeping gas out of the potential well, FR-2s can suppress star formation in group/cluster galaxies on timescales comparable with the dynamical timescale of ~ 1 Gyr. FR-1 feedback, on the other hand, can only suppress star formation in AGN hosts on the galaxy cooling timescale of 10-100 Myrs.

Long-term effects of radio source feedback can be considered by looking at clusters with no presently detectable AGN emission. A sample of local quiescent clusters was constructed from Dunn & Fabian 2008; Dunn et al. 2005. These clusters were split up into regions mimicking the radial distribution of galaxies in the inner and outer regions of groups/clusters with FR-2 radio sources. The resulting samples were again mass corrected.





Quiescent galaxies nearer to cluster centres are redder than those on the outskirts, even after mass corrections (*above*).

The outer regions of clusters with no detectable radio emission are significantly redder than similar regions in clusters hosting radio sources (*above left*). Thus, something is stopping star formation in quiescent clusters.

We suggest that past FR-2 outbursts are the culprit. Radio sources will become undetectable in surveys such as FIRST and NVSS after only a few hundred Myrs (Shabala, Kaviraj & Silk 2011), long before the ejected gas can return to the cluster. This keeps galaxies on cluster outskirts red.

Clusters showing detectable radio emission, on the other hand, must have had enough gas to fuel the latest burst of AGN activity, and thus galaxies on the periphery of such clusters will typically appear bluer.

This picture is confirmed by the colours in cluster centres (*above right*). Clusters hosting FR-1 radio sources are quite blue, pointing to ample supply of cold gas. Both quiescent and FR-2 host clusters are much redder, due to star formation quenching from a previous (in case of quiescent clusters) or new (for FR-2 hosts) AGN outbursts.

In this scenario, cD galaxies hosting radio sources are expected to have undergone recent star formation, and thus should appear bluer than cD galaxies in quiescent clusters.

Conclusions

Rare, powerful lobe-dominated (FR-2) radio sources profoundly affect group/cluster galaxies outside AGN hosts, regulating star formation on Gyr timescales. Less powerful FR-1 sources can only regulate star formation in the host galaxy, and on much shorter timescales. Both mechanisms therefore play key roles in galaxy evolution, through the clean-up and maintenance mode respectively.

	Frequency of occurrence	Trigger	Galaxies affected	Feedback timescale	Regulates SF?	Regulates cold gas content?	Mode
FR-1	Frequent	Hot gas cooling	Host only	t_{cool} (<100 Myrs)	Yes	No	Maintenance
FR-2	Rare	Mergers + cooling	Host + neighbours	t_{return} (>1 Gyr)	Yes	Yes	Clean-up

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