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Letter to the Editor

X-ray luminosity and spiral fraction of nearby clusters of galaxies. Astrophysical consequences of an observational bias

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Abstract. The spiral fraction in nearby clusters ($z < 0.05$) has been underestimated in the past, and increasingly so with redshift. The tentative value of spiral fraction with zero bias is about 50-60%. Distant clusters ($z \sim 0.4$) such as 3C295, cl 0024+1645 and cl 0939+4713, which were claimed to have an "excess" of spiral galaxies $f_{sp} \sim 50\%$, have in fact a *normal* spiral fraction. Conversely, distant clusters such as cl 0016+16 and II Zw 1305.4+2941 which were claimed to have a "normal" spiral content $f_{sp} \sim 0-10\%$ have in reality a *low* spiral fraction.

The tight correlation between spiral fraction and X-ray luminosity previously found is the result of two observational biases, namely the apparent increase of X-ray luminosity with redshift, due to the Malmquist bias, and the simultaneous decrease of the observed spiral fraction. The interpretation that smaller (i.e. low X-ray luminosity) clusters have a high spiral fraction and that larger cluster have a low spiral fraction is thus no longer true. Consequently, galaxies do not have to change morphological type when clusters merge. This resolves the conflict between the observations and the necessity, if the correlation were real, of such a morphological evolution.

Key words: Galaxies: clustering – fundamental parameters – spiral – interactions – intergalactic medium; X-rays: general

1. Introduction

Several observations can be explained if one assumes that morphological evolution takes place in clusters. Galaxies in luminous X-ray clusters are predominantly Es and S0s (Melnick & Sargent 1977; Bahcall 1977; Edge & Steward 1991b) and the fraction of spiral galaxies is anticorrelated with the X-ray luminosity of the cluster (Bahcall 1977; Edge & Steward 1991b). The morphological composition of galaxies in clusters is a function of the redshift (Butcher-Oemler effect, Butcher & Oemler 1978a), of the local density (Hubble 1936; Dressler 1980) or of the distance from the cluster center (Sanromà & Salvador-Solé 1990; Whitmore, Gilmore & Jones 1993). Spirals in cluster are often anemic (van den Bergh 1976), their gas content is a decreasing function of the cluster radius (Giovanelli & Haynes 1985; Gavazzi 1988) and it is correlated with the X-ray luminosity of the cluster (Giovanelli & Haynes 1985).

All these observations have suggested that gas in galaxies can be removed by some process (ram pressure, evaporation, etc.) and that the morphological type can be altered by mergers, stripping and other mechanisms, allowing spirals to became S0s and Es (Gunn & Gott 1972; Edge & Steward 1991b; see also Sarazin 1986 or Whitmore 1989 for reviews).

Whatever the mechanism is that produces this morphological evolution, it must explain the fact that, compared to spirals, S0s have brighter and larger bulges (Dressler 1980), thicker disks (Burstein 1979), different colors (Sandage et al. 1970; Faber & Gallagher 1976) or equivalently a different stellar composition, as well as the fact that S0s exist in regions of low density (Dressler 1980) and in the field.

Similarly, it must take into account the fact that, compared to spirals, Es have a larger number of globular cluster per luminosity and of different metallicity (van den Bergh 1990 but see also Ashman & Zept 1992).

At present we are not able to find a mechanism able to modify all the different properties that characterise galaxies to transform them into galaxies of another Hubble type. It is thus not clear what physical mechanism is responsible for the morphological evolution (Whitmore 1989).

Despite these difficulties, two external properties of galaxies are well explained: merging can well reproduce the morphology-density and morphology-radius relations for ellipticals (Mamon 1992) and stripping can well reproduce the relation between X-ray luminosity and spiral fraction (Bahcall 1977). At the base of the two relations is the hypothesis that the morphological classification of galaxies is a well defined tool, insensitive (or sensitive in a controlled way) to subjective or other biases. Poulain, Nieto & Davoust (1992) have shown that the morphological discrimination between E and S0 is a difficult task, so that for Perseus and more distant clusters, from 30% to 60% of early-type galaxies are erroneously classified (see their Table 1 or Andreon 1993).

In this letter we concentrate on the spiral fraction and on the X-ray luminosity of nearby clusters, with particular attention to clusters used to establish the relation between spiral fraction and X-ray luminosity.

2. The spiral fraction of nearby clusters

Figure 1 shows the relation between the apparent spiral fraction of the cluster and its redshift. The data are taken from Bahcall (1977) and Dressler (1980). The same data were used

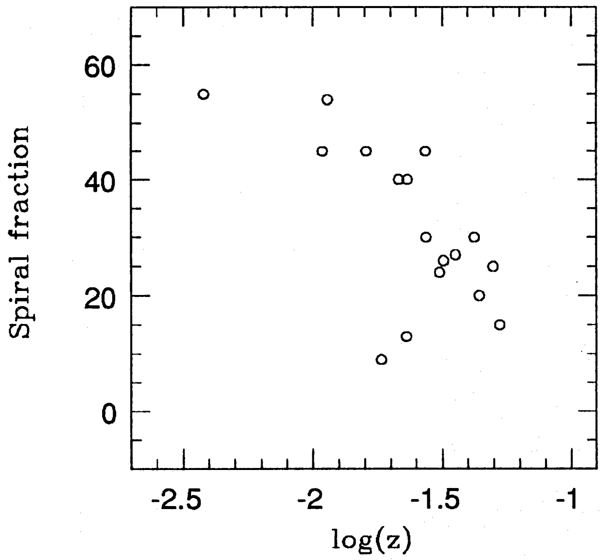

Fig. 1. Spiral fraction of observed clusters vs redshift. Note that $\log(z) = -1$ means $z = 0.1$

by Bahcall (1977) and Edge & Steward (1991b) to establish the anticorrelation between spiral fraction and X-ray luminosity of clusters.

It is astonishing that the apparent spiral fraction is a strong function of redshift since it diminishes by a factor of about 4 from $z \sim 0$ to $z = 0.05$. We note that this factor is as large as the original excess of blue galaxies detected in the cluster 3C295 (Butcher & Oemler 1978a).

The two points off the correlation are Perseus and Coma, two clusters which have a low spiral fraction for their redshift.

There are two possible explanations for the observed dependence of spiral fraction on redshift:

i)the effect is real, so that the spiral fraction is a strong function of redshift, and consequently of cluster age,

ii)the effect is the result of an observational bias, which arises because the difficulty of correctly classifying spiral galaxies increases with redshift.

The first explanation requires that the process altering the galaxy morphology takes place in less than 5 % of the Hubble time (less than 10^9 years if $H_0 = 50$ km s^{-1} Mpc^{-1}) since we detect differences in a very small range of redshift. In this case all observable galaxy characteristics must obviously change in this short time. But we have no evidence that, for example, the stellar composition of galaxies, and consequently their spectrum and colors, have changed in the last 10^9 years as required by this scenario.

The difficulties of a morphological evolution scenario have already been pointed out by Dressler (1980), Sarazin (1986), and van den Bergh (1990); they can be made even worse here by the necessity that the evolution take place rapidly.

Again, in order to observe the correlation between spiral fraction and redshift, all clusters must have formed simultaneously and from very similar initial conditions, otherwise all clusters at a given redshift would not have the same age (or the same dynamical age), and, consequently, the correlation would not be observable. It is difficult to understand how this could happen, in particular in a scenario of hierarchical cluster formation. Furthermore clusters show diverse appearances both in the optical and in the X-ray (Abell 1958; Bautz & Morgan 1970; Jones & Forman 1984) that are difficult to understand if all clusters have the same dynamical age.

A strong and rapid evolution is thus clearly excluded.

The second explanation for the anticorrelation between spiral fraction and redshift means that a large part of real spiral galaxies have not been classified correctly.

First of all, we note that Bahcall (1977) already claimed that at $z = 0.05$ the "galaxies are too faint to classify (them) accurately and a systematic effect could be introduced". This means, by continuity, that already at a lower redshift the classification begins to be uncorrect.

Second, high resolution data of galaxies in the inner region of Perseus (Poulain, Nieto & Davoust 1992) show that the spiral fraction of galaxies is at least 20 % (lower limit) and probably of the order of 30 % (Andreon 1993). Considering that the spiral fraction is a rising function of the cluster radius, that the data only concern the inner region of the cluster, and that the classification criteria used are tighter than the expert observer ones (only galaxies showing arms are classified spirals so that real spiral edge-on galaxies remain unclassified), the spiral fraction determination of expert observers can be underestimated by at least a factor 3 in the Perseus cluster.

Since the Perseus cluster is one of the nearest clusters and since morphological classification is increasingly difficult with distance, we can estimate that the spiral fraction in clusters more distant than Perseus determined by expert observers from visual classification can be underestimated by at least the same amount.

The Malmquist bias present in the same redshift range ($0 < z < 0.05$) as the clusters considered here for the luminosity index Λ_c (Tammann 1987), a morphological parameter tied to the Hubble type (de Vaucouleur 1979), clearly confirms that the detection of the arms become more and more difficult as the redshift increases and independently confirms the dependence found between observed spiral fraction and redshift.

An independent and direct confirmation of this bias could be obtained by imaging galaxies in this redshift range with the Hubble Space Telescope or a high resolution camera with a tip-tilt corrector.

From Fig. 1 we note that the extrapolated spiral fraction at redshift 0, or at bias 0, i. e. where the morphological misclassification is lowest, is about 50-60 %. This means that the spiral fraction of nearby clusters is of this order. This value of the spiral fraction makes the spiral composition of clusters more like the one in the field than previously estimated.

The analysis of the spectra and/or of the colors of distant clusters ($z \sim 0.4$) shows that in some of them the fraction of galaxies having the spectrum or the color of spiral galaxies is large and about 30-50 %, (Butcher & Oemler 1978a; 1984a,b). The quoted value is well above the claimed "normal" spiral fraction quoted for nearby clusters ($\sim$ 10%, Butcher & Oemler 1978b). This excess of spiral galaxies in distant clusters has been discussed and/or questioned for a long time (De Gioia-Eastwood, Grasdalen 1980; Dressler & Gunn 1982; Dressler 1984; Dressler et al. 1985,). Hubble Space Telescope images of distant clusters have unequivocally confirmed the original value of the spiral fraction (Dressler 1993; Maran & Kinney 1993).

Taking into account this new estimate of the spiral fraction in nearby clusters, no excess of spiral galaxies is present in distant clusters such as 3C295, cl 0024+1645 (Butcher & Oemler

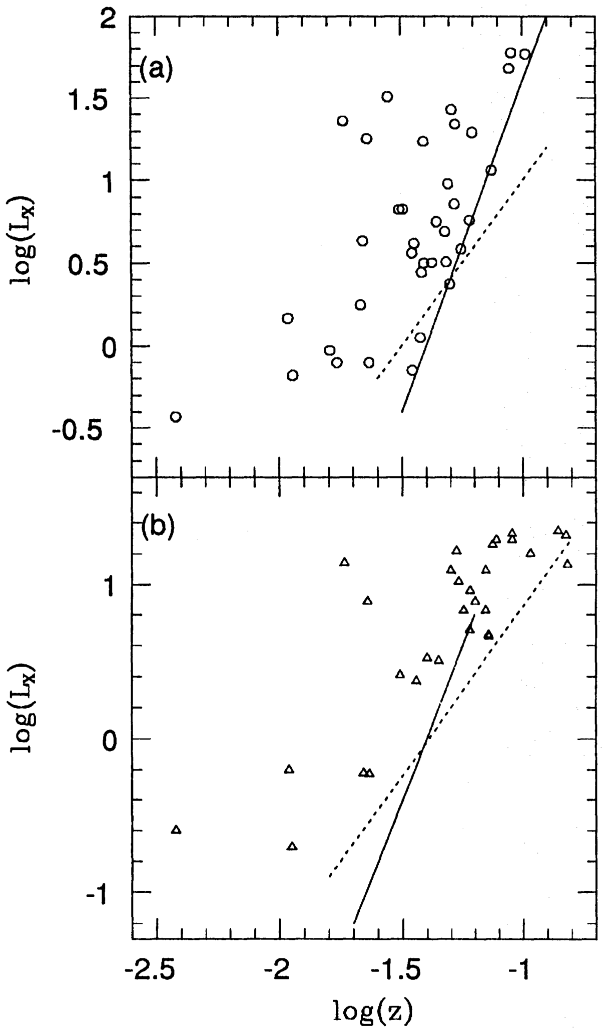

Fig. 2. Plot of X-ray luminosity as a function of redshift for clusters observed by *Exosat* (a) and by *Ariel 5* (b). Luminosities are expressed in units of 10^{44} erg s^{-1}. The solid and dashed lines mark the slope of a surface brightness and flux limited sample respectively

1978a) and cl 0939 +4713 (Dressler 1993), thus resolving the problem of finding a physical mechanism able to produce the morphological evolution needed if the old determination of the spiral fraction is retained (for a review of such problems see e.g. Sarazin 1986 and Dressler 1984). Conversely, distant clusters such as cl 0016+16 and II Zw 1305.4+2941 (Koo 1981; Koo et al. 1988) claimed to have a normal spiral content $f_{sp} \sim 0-10\%$ have in reality a *low* spiral fraction.

3. The X-ray luminosity of clusters

The X-ray luminosity of the clusters observed by *Exosat* and *Ariel 5* is plotted in Fig. 2a,b as a function of their redshift. The data are taken from Edge & Steward (1991a) and McHardy (1978). Two features are evident: the mean luminosity of the clusters rises with redshift, and, conversely, the region of distant clusters of low and normal luminosity, is not populated. At $z > 0.05$ ($\log(z) > -1.3$), not only clusters of normal X-ray luminosity but also high X-ray luminosity clusters ($L > 3*10^{44}$ erg s^{-1}) are not detected.

These two features are the fingerprints of the Malmquist bias, from which follows that only clusters of improbably high X-ray luminosity, not representative of the population of all clusters at that redshift, will be detected at $z > 0.05$.

In an expanding universe the surface brightness is proportional to $(1+z)^4$ and the luminosity is proportional to the mean surface brightness. For these reasons, the locus of the clusters having the same mean surface brightness is a line in the plane $\log(L) - \log(z)$ with a slope of 4. This apparent surface brightness limit is plotted in Fig. 1a and 1b (solid line), together with the apparent luminosity limit (dashed line) which has a slope of 2.

The lower envelope of the *Exosat* data has the same slope as the apparent-surface brightness limit, whereas the agreement with the apparent-luminosity limit is clearly unsatisfactory. On the contrary, the lower envelope of *Ariel 5* data has a slope which matches better the apparent-luminosity limit than the apparent-surface brightness limit. This means that at $z > 0.05$ the clusters detected by *Exosat* are essentially of high mean surface brightness whereas the ones detected by *Ariel 5* are preferably of high luminosity.

Because these X-ray observations are flux- or brightness-limited, they must be used with particular caution.

4. Spiral fraction vs X-ray luminosity

Edge & Steward (1992b) found a tight anticorrelation between spiral fraction and X-ray luminosity (their Fig. 7) confirming earlier results by Bahcall (1977). Edge & Steward's interpretation of this tight anticorrelation in a hierarchical cluster formation scenario is that, when small clusters merge to form larger clusters, the spiral fraction decreases, i.e. the galaxies that were spirals rapidly have to change into another Hubble type.

In Bahcall's interpretation, spiral galaxies are stripped in clusters by the ram pressure of the hot intracluster gas. The higher the luminosity, the higher the quantity of gas in the cluster and consequently the stronger the effect of ram pressure. This interpretation is supported by her analytical treatment of the stripping mechanism that predicts the observed anticorrelation.

In Sect. 3 we have shown that the samples of nearby clusters detected by *Exosat* and by *Ariel 5* are not representative of all clusters in the same redshift range, so any claim coming from the analysis of the sample used by Edge & Steward and Bahcall is not a general statement but is only tied to the sample utilized.

Our analysis of the data also shows that the apparent correlation between spiral fraction and X-ray luminosity is caused by two observational biases, precisely, the increase of the X-ray luminosity with redshift and the simultaneous decrease of the spiral fraction. The fact that this anticorrelation no longer holds has two important consequences. The claim that smaller (i.e. low X-ray luminosity) clusters have a high spiral fraction whereas larger cluster have low spiral fraction is no longer true (obviously this do not mean that the reverse correlation is true). And galaxies do not have to change morphological type when clusters merge, a requirement that was contrary to observational evidence.

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