X-RAY EMISSION AS EVIDENCE OF ACTIVITY IN OTHERWISE "NORMAL" GALAXIES

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ABSTRACT. The very large majority of the galaxies selected in X-ray surveys are active galaxies (e.g. narrow emission line galaxies, Seyfert galaxies etc.). There are however a few examples of normal galaxies, which are sometimes characterized by an X-ray luminosity in excess of what is expected on the basis of their optical appearance. A closer look at these galaxies may reveal the presence of a mini active nucleus or of other processes responsible for the powerful X-ray emission. Here we consider the normal galaxies selected in the Medium Sensitivity Survey and we discuss the properties of the most X-ray luminous one. We show that this object, which has an optical spectrum lacking any evidence of nuclear activity and which has a radio luminosity typical of early type galaxies, is indeed a peculiar galaxy surrounded by a hot (>2 keV) halo extending out to a radius of 300 kpc, implying a total mass of $\sim 3 \times 10^{13}\ M_\odot$.

1. INTRODUCTION

The Einstein Observatory Medium Sensitivity Survey (MSS) is a sample of X-ray sources serendipitously discovered in high galactic latitude observations obtained with the Imaging Proportional Counter (IPC) on board the Einstein Observatory (for a description of the survey see Maccacaro et al., 1982). The published sample consists of 112 sources. All of them have been spectroscopically identified (Stocke et al., 1983; Gioia et al., 1984), the largest constituents (50%) being Active Galactic Nuclei (AGN - Seyfert galaxies and quasars), followed by stars (25%), clusters of galaxies (16%), BL Lac objects (5%) and "normal" galaxies (3%).

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That Active Galactic Nuclei are, as a class, powerful X-ray emitters has been known for some time (see, among others, Elvis et al., 1978; Tananbaum et al., 1979; Kriss, Canizares and Ricker 1980; Maccacaro 1984) and it is therefore not surprising that in a survey based on X-ray selection this class of objects is very well represented. X-ray observations of known quasars and Seyfert galaxies and the study of X-ray discovered AGN indicate that their X-ray luminosity is in the range 10^{42} to 10^{47} ergs/s. (e.g. Zamorani et al., 1981; Gioia et al., this symposium). Non-active, normal galaxies, instead, are only weak X-ray emitters with integrated X-ray luminosity in the range 10^{39}-10^{41} ergs/s (Long and Van Speybroeck 1981).

The X-ray properties of normal galaxies have been extensively studied by several authors who have considered separately spiral systems, starburst nuclei, elliptical and S0 galaxies (see Fabbiano, 1986, for a recent and comprehensive review of their properties). The X-ray emission is the result of the integrated contribution of discrete sources (binary X-ray sources, supernova remnants etc.), of the thermal hot gas emission associated with star formation activity, and of the extended gaseous component associated with some elliptical galaxies.

In the published MSS sample three galaxies have been classified as normal. In this paper we shall focus our attention on one of these galaxies which, given its optical and radio properties, seems to be extremely overluminous in the X-ray band. A more detailed discussion of the properties of this object is given in Maccagni et al., 1987.

2. X-RAY SELECTED "NORMAL" GALAXIES

We fully concur with Prof. Ambartsumian who has pointed out in his welcoming address that 'we are unable today to give an exact scientific definition of the terms "the nucleus of a galaxy" or "the activity of the nucleus"'. In this paper, however, we frequently refer to "normal" and "active" galaxies. We would therefore like to introduce a working definition of "active" and "normal" galaxy. With "active" galaxy we refer to a galaxy for which there is reasonable evidence for nuclear non-thermal optical emission. With "normal" galaxy we refer to those galaxies in which the optical emission is clearly dominated by the integrated contribution of thermal stellar processes. Furthermore we believe that it is fair to say that a galaxy is to be considered "normal" until it is proven "active".

The three normal galaxies in the published MSS sample are: NGC 4156, NGC 4291 and MCG 00-04-077 which we shall refer to with its X-ray name 1E0116.3-0116.

NGC 4156 is a spiral galaxy whose X-ray luminosity is approximately 9×10^{41} ergs/s; the properties of this galaxy have been discussed in detail by Elvis et al., 1981. These authors noted the presence of weak emission lines (Hβ, O[III], Hα) in its spectrum and concluded

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that this galaxy has the weakest emission line fluxes of any previously reported galaxy with similar X-ray luminosity. A limit of 13% is obtained for the contribution of a possible non-thermal continuum to the V band flux. The Hβ/Lx ratio however is not inconsistent with previous results obtained from the analysis of weak Seyfert and "narrow emission line" galaxies. NGC 4156 is probably a normal galaxy hosting a very weak active nucleus.

The second galaxy is NGC 4291, an elliptical with a luminosity of 8×10^{40} ergs/s, consistent with being truly a normal galaxy.

The third galaxy is MCG 00-04-077 = 1E0116.3-0116. Analysis of CCD images obtained with B, V, and R filters indicates that its brightness profile is very well fitted by the $r^{1/4}$ de Vaucouleurs' law. The fitted eccentricity is 0.62 and we have correspondingly classified this galaxy as E3 (see Maccagni et al., 1987).

3. 1E0116.3-0116

This galaxy has a visual magnitude of 15.6 (integrated over a 10" radius) and a central surface brightness of 15.3 V_{mag}/arcsec^2. At a redshift of 0.045 (H_o=50 Km/s/Mpc) its absolute magnitude is M = -21.6. The classification of this galaxy as "normal" is based on two optical spectra covering the range 4000 to 6600Å and 4700 to 7400Å which have been obtained at the Multiple Mirror Telescope. The latter spectrum extends far enough into the red to establish the absence of Hα in emission, and we can set a 3 σ upper limit on the equivalent width of Hα of W(Hα) < 2Å. We have observed this galaxy also at radio wavelengths. 1E0116.3-0116 is a weak radio source. It has been detected with the VLA as an unresolved source of 1.1 mJy (5 GHz) (Gioia et al., 1983). This yields a radio luminosity of 9.5×10^{28} ergs/s/Hz.

In the X-ray band (0.3-3.5 keV), however, this galaxy is radiating 1.1×10^{43} ergs/s. This X-ray luminosity is far in excess of the luminosity of normal galaxies and is more typical, given the optical magnitude, of the radio galaxies in the 3CR sample or of Seyfert nuclei.

It seems to us that the X-ray emission is indicating the presence of some process which is not evident from the information collected at either radio or optical wavelength.

If the X-ray emission is originated in the nuclear region of the galaxy through a non-thermal process, then we would be dealing with a new class of objects or, at least, a fairly different subpopulation of the complex family of active galaxies. If, on the other hand, the X-ray emission is due to a hot gaseous corona surrounding this galaxy we would be dealing with an unusually large and unexpected amount of gas.

These two different X-ray emission mechanisms have different signatures. Detection of X-ray variability, for instance, would imply a nuclear origin for the X-ray emission. The analysis of the X-ray energy spectrum would also provide a way to distinguish between non-thermal and thermal emission. It is unfortunate that the available X-ray data on this galaxy are too poor for a meaningful X-ray spectral analysis. A search for time variability is also prevented by the fact that 1E0116.3-0116 has been detected as a weak source in an observation lasting less than 2 hours. We can however analyze the angular distribution of the recorded X-ray counts to test whether the X-ray emission is extended. Figure 1 shows the X-ray isointensity contours for 1E0116.3-0116. The source appears clearly extended. To quantify its spatial extent we have compared the surface brightness profile (obtained from a determination of source net counts in circular annuli of increasing radius) with a simulated point source profile appropriate for the same instrumental gain, energy range and spectral type.

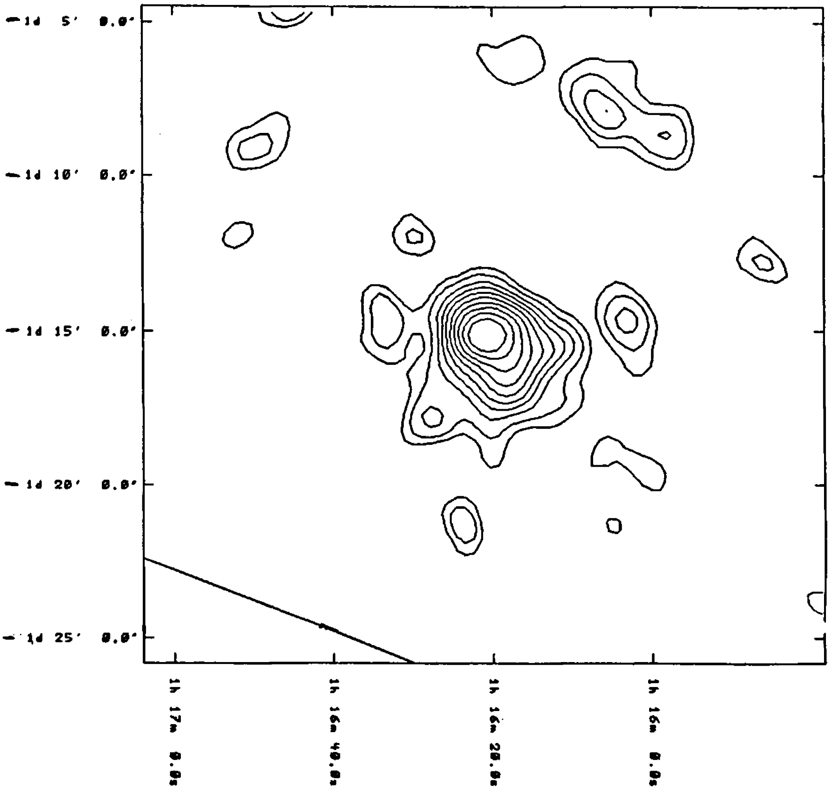

Figure 1. X-ray isointensity contours for the source 1E0116.3-0116.

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The result is shown in Figure 2. The Kolmogorov-Smirnov test indicates that the two distributions are significantly different.

We have fitted the radial surface brightness profile with an expression of the type:

$$S(r) = S(o) \times (1+(r/a)^2)^{-n}$$

which, under the hypothesis that the X-ray emitting gas is in hydrostatic equilibrium, allows us to derive the gravitating mass as a function of the radius r (Fabricant, Lecar and Gorenstein 1980).

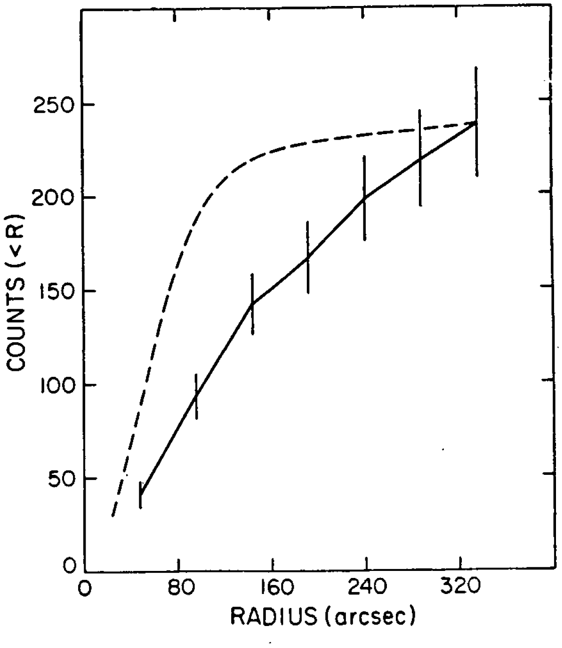

Figure 2.
Radial distribution of the X-ray counts of 1E0116.3-0116 (solid line) compared with the radial distribution of a simulated point-like source (adapted from Maccagni et al. 1987).

Core radii between 1'.2 and 1'.6 and indices n between 1.7 and 1.2 well represent the data. Assuming that the temperature of the X-ray emitting gas is of the order of 2 keV (the measured IPC pulse height distribution is incompatible with temperatures below 2 keV, but no meaningful upper limits can be obtained) and that no temperature gradient is present, we can calculate the total mass of the galaxy, i.e. the mass inside r_{max}= 4 arcmin. We obtain 3-4 x 10^{13} $M_{\odot}$, a value very similar to the mass of M87 measured by Fabricant and Gorenstein (1983).

4. CONCLUSIONS

When studied at optical or radio wavelengths, 1E0116.3-0116 is a normal galaxy. At X-ray wavelengths, however, 1E0116.3-0116 is a

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peculiar galaxy characterized by a luminosity of 10^{43} erg/cm^2/s (0.3-3.5 keV) due to a hot gaseous halo extending out to a radius of ~ 300 kpc. We have shown that a total binding mass of a few 10^{13} $M_\odot$ is implied by the X-ray emitting gas. We do not yet know whether galaxies of this kind are extremely rare or whether they account for a non negligible fraction of normal elliptical galaxies. 1E0116.3-0116 is the only such case found in the published Medium Sensitivity Survey which covers only 90 square degrees of sky.

A major effort to extend the Medium Sensitivity Survey is presently under way (see paper by Gioia et al. at this symposium), 780 square degrees of sky have been studied, and 836 serendipitous X-ray sources have been found. Upon completion of the optical identification program (that has so far yielded more than 400 identifications) we should be able to assess the frequency of this phenomenon which has important implications for the mass-to-light ratio in galaxies and for their formation and evolution process. Apparently these galaxies can be revealed only through their X-ray emission.

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DISCUSSION

HECKMAN: What is the cooling time for the X-ray emitting gas in the galaxy you discussed with spatially extended emission?

MACCACARO: We do not have a firm determination of the temperature of the X-ray emitting gas. The X-ray surface brightness distribution is also affected by uncertainties due to the limited X-ray statistics. As a consequence of this we cannot, at present, determine whether the cooling time is significantly shorter than the Hubble time.

TOVMASSIAN: What can you say about radio emission of normal galaxies with X-ray emission. Do they have radio emission as well?

MACCACARO: E0116-0116 is a very weak radio source, it has been detected with the VLA as 1.1mJy radio source at 6cm. NGC 4291 has not been detected (upper limit 1.2mJy) nor we have detected NGC 4156 (v.l. $\simeq$ 1mJy). These are the radio data we have on the "normal" galaxies selected from the Einstein Medium Survey.

CANNON: In the case of E0116-0116, how confident can you be that all the X-ray emission comes from the optical galaxy and not from some other background object (e.g. quasar or active galaxy)?

MACCACARO: Inspection of the POSS plates shows no other plausible candidate for the identification of the X-ray source. Furthermore, the fact that the X-ray emission is extended is a very strong supporting evidence for the identification of this source with the galaxy.