Research Note

X-ray observations of radio-jet galaxies

G. K. Miley¹, C. Norman¹⁻², J. Silk³, and G. Fabbiano⁴

1 Sterrewacht Leiden, Huygens Laboratorium, Wassenaarseweg 78, NL-2300 RA Leiden, The Netherlands
2 Institute of Astronomy, Madingley Road, Cambridge, CB3 0HA, United Kingdom
3 Astronomy Department, University of California, Berkeley, CA 93720, USA
4 Center for Astrophysics, Cambridge, MA 02138, USA

Received December 6, 1982; accepted February 20, 1983

Summary. The possibility that the morphology of radio-galaxy jets may be influenced by interaction with X-ray emitting gaseous halos prompted us to observe several “jet” galaxies with the Einstein Observatory. These observations carried out with the IPC had a high detection rate (5 out of the 6 radio galaxies observed). The X-ray data for these objects are presented. The X-ray luminosities lie between \( \sim 10^{45} \) and \( \sim 10^{46} \) erg s\(^{-1}\). The X-ray emission was found to be extended for the two galaxies with the most counts, 3C130 and 3C449. Three of the detected galaxies are known to be associated with clusters and we suggest that 3C130 may also be associated with a cluster.

Key words: radio jets – X-rays

Introduction

As discussed by Norman and Silk (1979), the existence of circumgalactic gaseous halos would have important implications for the confinement and evolution of radio sources. Extended radio sources have sizes typically \( \sim 100 \) kpc, i.e. comparable with the sizes inferred for the halo. Most of the radio emissions would therefore lie inside and possibly be confined by the halo. In several radio galaxies the detailed radio morphologies indicate interaction of the radio emitting relativistic plasma with a hot gas. This is particularly true in the case of radio jets (e.g. van Breugel and Miley, 1977; Miley, 1980; Bridle, 1981) whose widening or bending could well be caused by the interaction with a gaseous halo or with a hot intracluster medium. It was known that optical counterparts of a few radio jets existed (Butcher et al., 1979) and an extrapolation of the radio optical spectra suggested that in some cases the jets themselves might be detectable in the X-rays.

With the object of studying such effects we selected all 19 radio galaxies known (in February 1979) to have jets as interesting objects to study with the Einstein X-ray telescope. Our original aim was to search for X-ray emission with the Image Proportional Counter (IPC) and to study morphology of selected detected X-ray source with the higher resolution High Resolution Imager (HRI) in an attempt to relate the X-ray and radio structures. Because several objects were included in overlapping programs, and due to the untimely demise of the satellite, we obtained observations of only six such radio galaxies with the IPC and the planned HRI observations were not carried out. Here we present the results obtained.

Results

The Einstein Observatory and its associated instrumentation is described in Giacconi et al. (1979). The data were obtained during 1979 and 1980. The analysis was confined to the energy range 1 to 3 keV to avoid contamination by a flight calibration source at higher energies and the enhanced soft X-ray background at low energies.

The results are summarized in Table 1. There are those give the name of the radio galaxy, its visual magnitude and redshift (Burbidge and Crowne, 1979), the total observing time, the X-ray position, and the positional offset of the X-ray position from the position of the optical nucleus or radio core. Subsequent rows give respectively the number of counts, the assumed \( \text{H} \text{i} \) column density taken from Heiles (1975), the X-ray flux and X-ray luminosity obtained in the 1⁻3 keV region. The bottom row gives the resulting values of \( n_{\text{core}} \) \( \Gamma_{\text{core}} \) where \( n_{\text{core}} \) the electron density and \( \Gamma_{\text{core}} \) the volume of the core and a temperature corresponding to 1⁻3 keV has been assumed. These latter quantities were taken from a 4' diameter region surrounding the X-ray centre, except for 3C130 whose X-ray emission appears slightly extended and for which a 10' diameter region was also measured. The X-ray luminosities were calculated assuming a power-law X-ray spectrum with a photon number index of 1.5 after correcting the observed fluxes for absorption in the galaxy. Due to its low galactic latitude this correction for 3C130 is very uncertain. The last column gives the linear size corresponding to the 1' IPC beam at the distance of the galaxy. For B0844 + 31 and 3C402 the count rate was too low to make any estimate of angular extent. We can quantify the angular extent of 3C130 and 3C449 by using the test of Henry et al. (1979; see also Fabbiano et al., 1982).

The full width-half-maximum diameters of circular gaussian functions fitted to the brightness distributions are 2.3⁻0.4 and 2.0 \( \pm 0.5 \) for 3C130 and 3C449 respectively. Figure 1 is a contour representation of the observed (smoothed) brightness distribution of 3C130 and 3C449.

The X-ray luminosities are typical of clusters (cf. Jones et al., 1979) and of active galaxies (Lawrence and Elvis, 1981; Fabbiano et al., 1982). Of our objects, only B0844 + 31 and 3C277.3 are

Send offprint requests to: G. K. Miley
Table 1. Results of IPC observations

<table>
<thead>
<tr>
<th>Object</th>
<th>3C 130</th>
<th>B0844+31 (IC 2402)</th>
<th>3C 277.3 (Coma A)</th>
<th>PKS 1601+173 (NGC 6034)</th>
<th>3C 402</th>
<th>3C 449</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual magnitude</td>
<td>16.5 ± 1.0</td>
<td>13.5</td>
<td>15.9</td>
<td>13.5</td>
<td>(i) 14</td>
<td>(i) 14</td>
</tr>
<tr>
<td>Redshift</td>
<td>0.1090</td>
<td>0.0675</td>
<td>0.0857</td>
<td>0.03407</td>
<td>0.0297</td>
<td>0.0171</td>
</tr>
<tr>
<td>Observing time (10^6 sec)</td>
<td>2.46</td>
<td>2.09</td>
<td>3.10</td>
<td>1.58</td>
<td>3.29</td>
<td>2.21</td>
</tr>
<tr>
<td>X-ray RA Position (1950)</td>
<td>04 48 59.73</td>
<td>08 44 48.82</td>
<td></td>
<td>16 01 18.60</td>
<td>19 40 24.74</td>
<td>22 29 07.7</td>
</tr>
<tr>
<td>DEC</td>
<td>+51 59 46.1</td>
<td>+31 57 48.1</td>
<td></td>
<td>+17 20 36.8</td>
<td>+50 29 35.0</td>
<td>+39 06 10.4</td>
</tr>
<tr>
<td>Offset RA</td>
<td>+26</td>
<td>-71</td>
<td></td>
<td>+52</td>
<td>(i) +28</td>
<td>0</td>
</tr>
<tr>
<td>Offset (arc sec) DEC</td>
<td>-10</td>
<td>-21</td>
<td></td>
<td>+39</td>
<td>(i) - 9</td>
<td>(i) - 75</td>
</tr>
<tr>
<td>Counts (1–3 keV)</td>
<td>126 ± 15 (4′)</td>
<td>27.7 ± 8.5</td>
<td>26.0</td>
<td>18.3 ± 7.0</td>
<td>40.7 ± 13.3</td>
<td>86.2 ± 13.7</td>
</tr>
<tr>
<td>(central 4′)</td>
<td>306 ± 31 (10″)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumed HI Col. Density (cm^{-2})</td>
<td>28 x 10^{20}</td>
<td>3.9 x 10^{20}</td>
<td>3.3 x 10^{20}</td>
<td>3.9 x 10^{20}</td>
<td>13 x 10^{20}</td>
<td>12 x 10^{20}</td>
</tr>
<tr>
<td>Flux (erg cm^{-2} s^{-1})</td>
<td>1.5 x 10^{-13} (4′)</td>
<td>3.6 x 10^{-13} (10″)</td>
<td>3.6 x 10^{-13} (4′)</td>
<td>3.3 x 10^{-13} (10″)</td>
<td>4.1 x 10^{-13}</td>
<td>1.2 x 10^{-12}</td>
</tr>
<tr>
<td>Luminosity (erg s^{-1})</td>
<td>2.0 x 10^{44} (4′)</td>
<td>5.0 x 10^{44} (10″)</td>
<td>7.7 x 10^{42} (4′)</td>
<td>6.0 x 10^{43} (10″)</td>
<td>1.7 x 10^{42}</td>
<td>1.6 x 10^{42}</td>
</tr>
<tr>
<td>IPC 1′ Beam (kpc)</td>
<td>190</td>
<td>118</td>
<td>150</td>
<td>59</td>
<td>43</td>
<td>24</td>
</tr>
<tr>
<td>$r_{core}$ (cm/kpc)</td>
<td>&lt; 5 x 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 3</td>
<td>&lt; 1</td>
<td>&lt; 2</td>
</tr>
</tbody>
</table>

1 Uncertain because 3C 130 is in galactic plane
2 Assumed Hubble Constant is $H_0 = 50$ km s^{-1} Mpc^{-1}
3 Pair of radio galaxies (i) and (ii)

relative isolated. PKS 1601+173 is in Abell 2151, 3C402 and 3C449 are located in Zwicky clusters and any cluster surrounding 3C130 would be obscured. So it is likely that, in some cases associated clusters will contribute to our observed X-ray luminosities. Particularly for 3C130, the high X-ray luminosity and large extent suggests the presence of a cluster. Further evidence for the existence of a cluster in this case comes from the radio morphologies. Apart from 3C130 itself there are two other radio sources in the vicinity (within 40′ or 8 Mpc) which also have narrow, edge-darkened double structures. All three doubles have approximately the same orientation (Jügers, in preparation). For an isothermal sphere of temperature $T$ with core radius $r_{core}$ and X-ray...
luminosity $L_\star$, the pressure at radius $r$ is
\[ P(r) = 10^{-11} \left(100 \text{ kpc/r}_{\text{core}}\right)^{1.5 \cdot \left(L_\star/10^{44} \text{ erg s}^{-1}\right)^{0.5}} \cdot \left(T/10^7 \text{ K}\right)^{0.75} \left(V_{\text{core}}/r\right)^2 \text{ dyne cm}^{-2} \]
where which assuming linear sizes as observed for 3C130 and 3C402 would in global terms be sufficient to confine the radio sources. However, since the radio and X-ray data have such different angular resolution this conclusion should be treated with caution.

Despite the relatively short integration time of $\sim 2000$ s per source, we detected X-ray emission from 5 of the 6 galaxies observed. An enlarged sample obtained by combining our data with those of other workers will enable some statistical questions to be investigated (Fabbiano et al., 1982). In particular it is interesting to know how the X-ray fluxes and luminosities depend on various salient radio and optical properties of the galaxies, such as radio core and jet fluxes, radio spectra, and galaxy magnitudes. Such information may reveal whether the X-ray emission comes from a circumgalactic halo, from the jets themselves, or whether it emanates from a compact nuclear core. We had hoped that our HRI observations would have settled the origin of the emission and that the parameters derived for X-ray halos would place further important constants on the environment of the jets. These unresolved questions will now be pursued using the EXOSAT satellite.

Acknowledgement. We thank the staff of the Center for Astrophysics for advice on reducing the data. JS acknowledges support from NASA Grant and GKM acknowledges partial support from NATO Grant 1828.

References