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# DECAMETRIC RADIO IDENTIFICATION OF AN EXTRAGALACTIC X-RAY SOURCE

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## ABSTRACT

A radio source with an unusually high spectral index between 22 and 81.5 MHz is identified with the *Uhuru* X-ray source 2U 1706+78. It is probably associated with the cluster of galaxies Abell 2256. This identification provides further support for the inverse Compton model of X-ray emission by rich clusters of galaxies.

The *Uhuru* observers (Giacconi *et al.* 1971; Gursky *et al.* 1972) have recently suggested that there exists a class of extragalactic X-ray sources that is associated with rich clusters of galaxies. Bridle and Feldman (1972, henceforth referred to as Paper I) noted that several of the X-ray emitting clusters contain radio sources with unusually large linear extents and high spectral indices. They proposed that the X-ray emission arises from inverse Compton scattering of the 3° K background radiation by relativistic electrons that have escaped from radio galaxies within the clusters; a similar conclusion has been reached independently by Brecher and Burbidge (1972), and by Perola and Reinhardt (1972).

As radio sources with high spectral indices can be detected more readily at decametric wavelengths, we have searched a 22-MHz ($\lambda = 13.5$ m) sky survey for further radio identifications of *Uhuru* sources at $|b| > 10°$. The survey, which covers the area of sky between declinations $-31°$ and $+81°$, was made with the 22.25-MHz array (Costain, Lacey, and Roger 1969) at the Dominion Radio Astrophysical Observatory. A 22-MHz source was found close to the most probable position of the X-ray source 2U 1706+78. Sufficient data are available for this source to confirm that it is similar to the identifications discussed in Paper I. Only one further 22-MHz source that has not previously been suggested as a radio identification was found close to an *Uhuru* error field; although this source (PK 0255+13) has a spectrum resembling those shown in Paper I and lies near the rich cluster Abell 401, both the radio source and the cluster lie outside the *Uhuru* 90 percent positional confidence limits and are not discussed further here.

The radio source within the positional error field of 2U 1706+78 has a 22-MHz flux density of $95 \pm 30$ f.u.[1] on the scale of Roger, Bridle, and Costain (1972). The 22-MHz position agrees with that of NB 78.26, catalogued at 81.5 MHz by Branson (1967); the source also appears in the 38-MHz survey of Williams, Kenderdine, and Baldwin (1966), where it is designated as 1704+78.9. Figure 1*a* shows the position of NB 78.26, the most probable X-ray position and the optical center of the rich cluster of galaxies Abell 2256, within the *Uhuru* error field; the positions are listed in table 1. NB 78.26 lies only ~180 kpc from the center of Abell 2256 and satisfies the criterion established by Wills (1966) for a significant identification of the radio source with the cluster of galaxies. The iden-

[1] 1 f.u. = $10^{-26}$ W m$^{-2}$ Hz$^{-1}$.

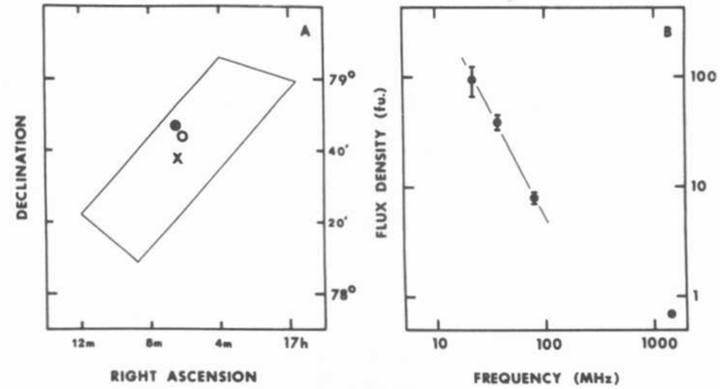


FIG. 1.—(*a*) (*left*) The positions of 2U 1706+78, NB 78.26, and Abell 2256, in 1950.0 coordinates. The box marks the 90 percent confidence limits of the X-ray position, and the X denotes the most probable location of the X-ray source. *Open circle*, the position of the radio source NB 78.26; *filled circle*, the position of the center of Abell 2256. (*b*) (*right*) The spectrum of the radio emission identified with 2U 1706+78. The line shows a least-squares fit to the data at 22.25, 38, and 81.5 MHz, giving a spectral index of 1.9. The uncertainty in the 1445-MHz flux density is indicated by the size of the dot.

TABLE 1

RADIO, OPTICAL, AND X-RAY PARAMETERS OF 2U 1706+78

A. POSITIONS

| Source | $\alpha$(1950.0) | $\delta$(1950.0) |
|---|---|---|
| X-ray | $17^h06^m.4$ | $78°38'$ |
| 22-MHz radio | $17^h06^m \pm 2^m$ | $78°.8 \pm 0°.4$ |
| 81.5-MHz radio | $17^h06^m10^s \pm 20^s$ | $78°44' \pm 1'$ |
| Abell 2256 | $17^h06^m.5$ | $78°47'$ |

B. RADIO SOURCE

| Frequency (MHz) | Flux Density (f.u.)* |
|---|---|
| 22.25 | 95 ± 30 |
| 38 | 39 ± 6 |
| 81.5 | 8 ± 1 |
| 1445 | 0.70 ± 0.06 |
| 22–81.5 MHz spectral index | 1.9 ± 0.2 |

C. OPTICAL CLUSTER

Abell distance group 3 (~200 Mpc)
Abell richness class 2

D. LUMINOSITIES†

| | |
|---|---|
| Extrapolated 10 MHz monochromatic power | $2 \times 10^{27}$ W Hz$^{-1}$ |
| 1.6–10-keV luminosity | $2.5 \times 10^{44}$ ergs s$^{-1}$ |

* Adjusted to flux-density scale of Roger *et al.* (1972).
† For comparison with those given in Paper I.

tification of the X-ray source with Abell 2256 was first suggested by Giacconi *et al.* (1971); the good agreement between the radio, optical, and X-ray positions strongly supports this identification.

The linear extent of the decametric radio source is unknown as it is not appreciably resolved at any of the three radio frequencies at which it has been observed. At the $\sim$200 Mpc distance[2] of Abell 2256 it could, however, have a linear diameter of $\sim$350 kpc, comparable to the diameters of the radio sources discussed in Paper I, while remaining unresolved in Branson's 81.5-MHz observations. The spectral index of the radio source between 22 and 81.5 MHz has the unusually high value of $1.9 \pm 0.2$. The spectrum is shown in figure 1*b*, which includes the 1445-MHz flux density determined interferometrically by Fomalont and Rogstad (1966); this flux density lies considerably above any plausible extrapolation from the low-frequency measurements and may refer to a different spectral component, such as those seen in the spectra of the sources considered in Paper I. The radio and X-ray properties are given in table 1; the extrapolated monochromatic power at 10 MHz (computed for comparison with those given in Paper I) exceeds that of the Coma cluster source by a factor of $\sim$10, while the soft X-ray luminosity exceeds that of the Coma cluster by a factor of $\sim$2. The X-ray luminosity can be accounted for by inverse Compton scattering of the microwave background by relativistic (GeV) electrons if the magnetic field strength in the radio source is $\lesssim 2 \times 10^{-7}$ gauss, a plausible upper limit for an intracluster magnetic field. It is therefore possible that this source is the most powerful example currently known of an X-ray source produced in this way.

Six rich clusters of galaxies are now known to contain radio sources[3] that fall within the 90 percent positional confidence limits of *Uhuru* sources at $|b| > 10°$. It is of considerable interest that in all of these clusters one component of the radio source has an unusually high spectral index. The six are Abell 347, Abell 426 (the Perseus cluster), Abell 1367, the Virgo cluster, Abell 1656 (the Coma cluster), and Abell 2256 (the cluster discussed here). We conclude that the most convincing identifications of *Uhuru* objects with radio sources in rich clusters of galaxies contain components with unusually high spectral indices. This strongly suggests a causal relationship between these phenomena, such as that provided by the inverse Compton model (Paper I). It should be noted that the scale of the X-ray sources varies from that of the radio halo of M87 to that of the galaxy distribution in the Coma cluster.

The presently available data do not *preclude* interpreting the soft X-ray emission of the clusters as bremsstrahlung from hot intracluster gas; more must be known of the X-ray properties of the sources before this interpretation can be distinguished from the inverse Compton model. If the latter is correct, the hard X-ray intensity of these sources should be proportional to $E^{-\alpha}$, where $\alpha$ is the radio spectral index and $E$ the photon energy. The X-ray sources should also be of approximately the same angular extent as the low-frequency radio sources.

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[2] For $H = 100$ km sec$^{-1}$ Mpc$^{-1}$.

[3] Giacconi *et al.* indicate that the position of 2U 0410+10 is near those of both the rich cluster Abell 478 and the N galaxy 3C 109, which might therefore be an alternative identification. The proximity of 3C 109 makes the detection of a 22-MHz source near Abell 478 difficult.

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