# OBSERVATIONS OF THREE RADIO GALAXIES WITH THE EINSTEIN X-RAY OBSERVATORY

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We would like to present early results from the EINSTEIN X-ray Observatory on three radio galaxies: Centaurus A, NGC 315 = DW0055+30, and Cygnus A = 3C405. We hope to demonstrate that imaging X-ray astronomy can provide important insights into the physics and environment of radio galaxies and their extended radio components.

NGC 5128, the parent galaxy of the double-double radio source Centaurus A, is the nearest radio galaxy, providing the best testing ground for high resolution X-ray studies. The X-ray morphology has proved to be rich and varied. We detect four distinct components to the X-ray emission: (1) the strong, compact nucleus detected by earlier satellites; (2) extended emission around the nucleus; (3) emission from the inner radio lobes; and (4) a unique X-ray jet between the nucleus and the NE radio lobe. A detailed presentation of these observations can be found in Schreier et al. (1979).

Figure 1 shows a contour map of our High Resolution Imager (HRI) image of the central region of Cen A. The strong source is coincident with the infrared nucleus to within a few arcseconds pointing uncertainty. An X-ray jet extending about 1 arcmin (2 kpc) from the nucleus pointed toward the NE radio lobe, which lies 3 to 5 arcmin from the nucleus, is clearly seen. The jet is closely aligned with faint blue optical filaments recently discovered by Dufour and van den Bergh (1978). We believe this jet of several times $10^{39}$ erg/sec in the 0.5 to 4 keV band - the first to be discovered in X-rays - suggests the presence of continuous flow of matter and energy from the nucleus to the radio lobe. We have constructed a model for the jet in which the emission is produced by thermal bremsstrahlung from a dense ($n \sim 1$ cm$^{-3}$), subrelativistic ($v \sim 10^3$ km/sec) beam ejected from the nucleus. The beam would then power the radio lobe. The total mass in the beam is about $10^6$ $M_\odot$ and the optical filaments would arise from cooled portions of the beam or by shock heating of pre-existing cold clouds. Our thermal model for the X-ray emission is not unique; X-ray synchrotron emission, for instance, cannot immediately be excluded.



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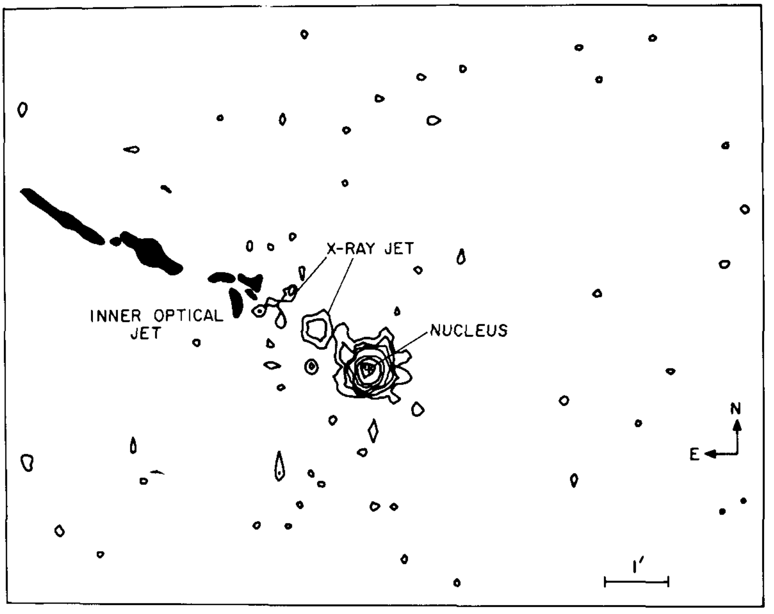


Figure 1: Isointensity contour map of the HRI image of Centaurus A. The X-ray jet to the northeast is clearly seen. The dark shapes to the northeast show the positions of diffuse features in the optical jet discovered by Dufour and van den Bergh (1978).

There is emission in excess of a point source extending at least 1 arcmin isotropically about the nucleus. We do not yet know if the isotropic component of about 2 x $10^{40}$ erg/sec is due to hot gas, stellar sources, or some other origin.

The same region observed with the Imaging Proportional Counter (IPC) onboard EINSTEIN shows excess emission 3 to 5 arcmin SW of the nucleus, associated with the inner radio lobe. Weaker emission is also present near the NE lobe. The brighter lobe emits 2 x $10^{39}$ erg/sec in the 0.3 to 3 keV band, consistent with inverse-Compton scattering off the microwave background if the mean magnetic field strength is 4 x $10^{-6}$ Gauss or less.

Turning to our next galaxy, NGC 315 is the next closest member of the class of giant radio galaxies after Cen A, with huge radio jets extending more than 20 arcmin on each side of the galaxy (Bridle et al. 1979). The IPC image exhibits a weak X-ray source at the position of the galaxy with a luminosity of 1 x $10^{42}$ erg/sec in the 0.5 to 3 keV band, comparable to the total emission from Cen A. There is no X-ray emission from or around the strong radio jets. The narrow collimation of the radio jets does thus not appear to be produced by pressure from an X-ray emitting ambient medium.

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There are two possible sources for the X-ray emission observed near the galaxy. First, it may be associated with the compact radio source at the nucleus, as is the case for most of the X-ray emission from Cen A. The lack of optical emission lines or evidence for hot gas suggests that the underlying engine does not involve "thermal" processes (e.g., accretion discs), but rather non-thermal processes like the self-synchrotron-Compton mechanism. On the other hand, the observed X-rays may be generated in a diffuse hot gas 2 arcmin in size, as has been invoked by Fanti et al. (1976) to explain an apparent steepening in the radio spectrum of the inner jet. This explanation, however, implies that NGC 315 has produced or accreted $10^{10}$ $M_{\odot}$ of gas, which would be highly unusual.

Finally we come to Cygnus A, which has been associated with the X-ray source 1957+40 for several years. Earlier satellites have shown that at least some of the emission is extended, but could not accurately determine the relative contributions of emission from the nucleus, the radio lobes, and gas associated with the cluster surrounding the galaxy (see Fabbiano et al. 1979). The EINSTEIN HRI image of Cygnus A shows the emission is extended and spherically symmetric, centered on the cD galaxy. We therefore believe the circumgalactic medium is the origin of the X-ray emission. There is no excess emission at the galaxy nucleus and the two radio lobes 1 arcmin away.

We can place a limit of $1 \times 10^{42}$ erg/sec on the contribution of a point source at the center of the galaxy ($10^{43}$ erg/sec is possible if the spectrum is strongly cutoff due to intrinsic absorption). Recall, in comparison, that the nucleus of Cyg A emits on the order of $10^{45}$ erg/sec of radiation in each of the radio, infrared, and optical bands. The X-ray limit is an order of magnitude below the self-synchrotron-Compton emission predicted in models of Kafatos (1978). The absence of emission from the radio lobes is in reasonable agreement with radio estimates of an equipartition magnetic field on the order of $10^{-4}$ Gauss (Hargrave and Ryle, 1976). Spectroscopically Cyg A is a "narrow line radio galaxy" resembling Seyfert II galaxies, which are relatively faint in X-rays. The lack of a strong nuclear X-ray source may thus suggest that the radio and X-ray properties are not strongly correlated.

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