X-682-77-93

PREPRINT

TMX- 71327

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(NASA-TM-X-71327) RADIO AND X-RAY VARIABILITY OF THE NUCLEUS OF CENTAURUS A (NGC 5128) (NASA) 12 p HC A02/MF A01 CSCL 03B
N77-26060
Unclas
G3/93 35257

APRIL 1977

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

RADIO AND X-RAY VARIABILITY OF THE NUCLEUS OF CENTAURUS A

(NGC 5128)*

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APRIL 1977

* Work supported in part by NASA Grant #NGL 21-002-033

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ABSTRACT

Centaurus A (NGC5128) has been observed by the authors at radio frequencies of 10.7, 31.4, 85.2, and 89 GHz and at X-ray energies greater than 20 keV. These observations, together with the results which have been reported by other workers, are interpreted in terms of models of the nucleus of this radio galaxy. The radio observations cover the period from 1973 through early 1977. The X-ray observations cover two 10-day intervals, one in July and August 1975 and the other in July and August 1976. The source exhibits significant variability in all the observed radio frequencies. The observed radio and X-ray intensities show some concurrent variations but do not track one another throughout the observations. A model of the source in which X-rays are produced by inverse Compton scattering of blackbody photons by relativistic electrons is proposed to explain these observations. The observed variations in the electromagnetic spectrum are shown to be consistent with adiabatic expansion of a trapped plasma in conjunction with turbulent accelerations of the relativistic electrons. Upper limits obtained with the model indicate that there may be sufficient energy available in the nucleus to form radio lobes with the same total energy as those already present.

I. INTRODUCTION

Centaurus A (NGC 5128) is a radio galaxy with an active nucleus that emits radiation over the entire electromagnetic spectrum. In the radio range, Cen A consists of two separate sets of radio lobes (Wade et al. 1971) centered on the nuclear component. The outer radio lobes are approximately 5 degrees apart and the inner lobes are separated by 3.5 arc minutes. Since the distance to Cen A is approximately 5 Mpc, the linear separations of the outer and inner lobes are 400 kpc and 5 kpc, respectively. Both sets of radio lobes lie along what appears to be the rotation axis of the galaxy, although some asymmetry is observed. The angular size of the nucleus is smaller than 10^{-3} arc seconds (Kellermann 1975). Kellerman (1974) also reported evidence for variability of the nucleus of Cen A at 9 GHz (3mm) on a timescale of days (see Figure 1). Fogarty and Schuch (1975) observed Cen A from April through December 1974 and found no significant variability at 22 GHz (13.5mm). Price and Stull (1973), and Stull and Price (1975) observed fluctuations in the 10.7 GHz (2.8 cm) flux of the nucleus of Cen A from 1973 to 1975 though no day-to-day variability was noticed during that observing period.

Optically, Cen A is an E0 type galaxy with an obscuring dust lane girdling the equator. A near infrared (< 1 micron) "hot spot" with an angular size of approximately 5 arc seconds (linear dimension of 120 pc) has been observed at the center of the galaxy by Kunkel and Bradt (1971). A source with an angular size of less than 7 arc seconds was also detected by Becklin et al. (1971) at 1.6 to 10 microns. They showed that the intensity of the radiation at 2.2 microns is more than 10 times the surface brightness of our galaxy. Kleinmann and Wright (1974) measured the flux from the nucleus at 10 microns in June 1973, two years after the Becklin observation, and found that the flux had decreased by a factor of three to 1.0 ± 0.1 Jy (1 Jy ≡ 10^{-23} ergs cm^{-2} s^{-1} Hz^{-1}). Grasdalen and Joyce (1976) observed the nucleus at 10μ in August 1975 and obtained the same intensity as that reported by Becklin et al. (1971). They further note that the significance of the previously reported decrease may have been overestimated due to a systematic error.

Cen A has been observed at X-ray wavelengths intermittently since 1971 (see Figures 2 and 3). These observations provide evidence for marked variability in the intensity and also suggest changes in the spectral index (see Figure 4). An increase of the X-ray flux in the energy range 2-60 keV over an interval of six days has been observed by Winkler and White (1975). The additional longer timescale variability is evident in Figure 2. At 100 keV, the photon flux is sufficiently low that day-to-day variations are difficult to measure and none has been observed, but a significant increase did occur in the interval between 1971 and 1973 at this energy. At γ-ray energies, an upper limit of 10^{-32} ergs cm^{-2} s^{-1} Hz^{-1} at approximately 250 Mev has been obtained by Fichtel et al. (1976). An integral flux of $(4.4 \pm 1) \times 10^{-11}$ photons cm^{-2} s^{-1} at energies greater than 3×10^{11} eV has been reported by Grindlay et al. (1975a).

In this paper, radio and X-ray data taken during 1975 and 1976 are presented, and these results are compared with the results previously obtained. The new data lead to a better understanding of the nature of the physical processes taking place in the nucleus of Cen A, and make clear the importance of additional systematic observations of this source over the broadest possible energy range.

II. RADIO OBSERVATIONS

The radio observations made by the authors are presented in this section in order of increasing frequency. All radio observations were centered on the nuclear component of Cen A and the contribution from the inner radio lobes is negligible at all frequencies. The observations of Cen A were particularly difficult because they were all made from sites in North America, where the source was never more than 15 degrees above the horizon.

10.7 GHz (2.8 cm)

The Stanford University radio telescope (Bracewell *et al.*, 1973) is an East-West array of five 18 meter antennas with an E-W resolution of 17 arc seconds. Periodic measurements of the 10.7 GHz flux density of the central component of Cen A have been made (by WG and KP) since June 1973. Figure 1 summarizes previously reported measurements (Price and Stull, 1973) and gives new 1975 and 1976 data. All observations have been analyzed by the same method with 3C273 being used to provide an absolute flux calibration. Monthly 10.7 GHz flux density measurements of 3C273 were supplied by Dr. W. J. Medd and Dr. G. A. Harvey of the National Research Council of Canada. On each date, Cen A was observed within one hour of meridian transit, and 40 to 100 separate measurements of its flux density were taken. The uncertainties in Figure 1 are the standard deviation of the mean in these measurements. The theoretical noise level of the instrument for these observations is typically 0.12 Jy for the 1973 data and 0.03 Jy for the more recent data. The uncertainties in Figure 1 are larger than these values, probably because of refraction effects and uncertainty in amplitude calibration, both due to the low elevation of Cen A at Stanford. General trends can be seen quite clearly, such as the relatively rapid decline of the flux density from late July to early September in 1976. From a linear regression analysis during this period, we obtain a rate of change of flux density of the order of 0.2 Jy/day. Other fluctuations are of a similar magnitude.

31.4 GHz (9.5 mm) and 85.2 GHz (3 mm)

In early 1975, Cen A was added to a list of sources which are observed periodically (by WD and RH) at 31.4 and 85.2 GHz using the 11-meter antenna of the National Radio Astronomy Observatory at Kitt Peak. The observing procedures and equipment for the 31.4 GHz measurements have been described in detail by Dent and Hobbs (1973), and for 85.2 GHz by Hobbs and Dent (1977). Observations are made by a beam switching technique and are calibrated extensively to overcome errors due to pointing and antenna gain by frequent interlocking measurements of strong non-variable sources. The primary calibration source was the galactic source DR 21, with an assumed flux density of 18.35 Jy at 31.4 GHz and 16.9 Jy at 85.2 GHz, and an uncertainty of approximately 4% at each frequency.

Measurements of Cen A are particularly difficult: the observing window is 30 minutes maximum, and the measurements can be made only under ideal weather conditions. Atmospheric attenuation is determined by measuring the relative temperature (T_A) of the atmosphere at different elevations (θ) and obtaining a least-squares fit to the equation:

$$T_A(\theta) = 280\ \tau_o\ \mathrm{Csc}(\theta) + \mathrm{Constant}$$

where τ_o is the absorption of one air mass. The results of measurements during 1975 and 1976 are given in Table 1 and Figure 1. The uncertainty associated with the measurement is the standard deviation obtained from the set of antenna temperature measurements and does not include any contribution from the uncertainty in flux of the calibration source.

90 GHz (3.3mm)

Observations were made (by BU and EC) at 90 GHz with the NRAO 11-meter telescope at Kitt Peak. The receiver was a dual-channel, cooled mixer radiometer coupled to a 4.5-5.0 GHz cooled, parameteric IF amplifier. The double sideband system temperature was about 300K. The receiver was located at the Cassegrain (f/13.8) focus, and beam switching was accomplished by nutating the sub-reflector at 5 Hz. At 90 GHz the telescope half-power beamwidth was about 76 arc seconds and the dual beam separation was set to 4 arc minutes. The aperture efficiency at this wavelength was about 35%. The two receiver channels (which respond to orthogonal linear polarizations) were averaged to measure the total source flux density. Five-point observations were made to remove the effects of small telescope pointing errors, and measured signals have been corrected for atmospheric extinction. The absolute calibration scale was determined by nearly simultaneous observations of DR 21, which was assumed to have a flux density of 16.9 Jy ± 4% at 90 GHz (Ulich 1974). The uncertainties in each flux density measurement are due mainly to receiver noise and do not include the uncertainty in the absolute calibration.

III. X-RAY OBSERVATIONS

Cen A was observed with the high energy X-ray detector (BD, JB, CC, JD, KF, LO) on board OSO-8 during July and August of 1975 and 1976. The detector consists of actively shielded CsI(Na) crystals (Dennis et al. 1977) and is sensitive to X-rays in the range from 20 keV to 3 MeV. The observations were analyzed in the manner outlined by Dolan et al. (1977) to obtain the photon spectrum incident upon the detector. The derived intensities at 100 keV are shown in Figure 3 along with observations reported by other experimenters.

IV. DISCUSSION

The data presented in the previous section provide information on the variability of Cen A over an extremely wide range of frequencies. These observations together with other published results are consistent with a single injection of a cloud of relativistic electrons which evolves by adiabatic expansion and turbulent acceleration. The observed fluctuations in both the radio and the X-ray spectra imply that the energy emitted as electromagnetic radiation may not represent the total energy available in the nucleus. In the following sections, we discuss previously proposed models in which the radio radiation is produced by the synchrotron process and the X-rays are produced by inverse Compton scattering of the synchrotron photons. We propose a different model in which the X-rays are produced by inverse Compton scattering of photons with a blackbody distribution. This model is used to determine the magnetic field strength and the physical size of the emitting region, and the radiation temperature of the blackbody photon distribution in the nucleus. We then calculate upper limits on the energy in the nucleus and show that there may be sufficient energy available to form another pair of radio lobes.

A. Recapitulation of the Available Observations

The available radio and X-ray data have been accumulated from many observers and do not have uniform time coverage. However, it is interesting to note the concurrences and differences between the fluctuations at various frequencies which can be seen by examination of Figures 1, 2 and 3. The 10.7 GHz measurements show that the flux density increased by approximately a factor of 1.5 between September 1973 and March 1974. The flux went through an apparent minimum in July 1975, followed by a second increase in the fall of 1975 and subsequent decrease during the spring and summer of 1976. During this period there is evidence for day-to-day variability, which may confuse these long term trends. Kellermann's 1974 data at 31.5 and 89 GHz, coupled with the observations by the present authors at 31.4, 85.2 and 90 GHz show a similar pattern of temporal variability. The 2-6 keV X-ray flux observations can be interpreted as a single long term increase in 1972 and 1973 followed by a decrease in 1975 and 1976 (Sanford, et al., 1977) with short term variability (Winkler and White, 1975) superimposed on this general trend. The increase by a factor of 1.5 occurred approximately one year before the first observed increase in the 10.7 GHz flux. The X-ray intensity at 100 keV seems to have followed the same general trend as the 2-6 keV flux, although there is some evidence that the initial brightening at 100 keV may have taken place approximately six months before the increase at 2-6 keV. The magnitude of the total increase at 100 keV was also apparently a factor of 2 larger. The 2-6 keV flux density and the 100 keV intensity are shown for comparison in Figures 2 and 3, respectively.

B. Interpretation of the Radio and X-Ray Temporal Variations

The radio and X-ray spectra can be determined as a function of time from the data discussed in the previous section. The radio spectrum is consistent with a self-absorbed synchrotron source in which the 10.7 GHz flux density remains in the self-absorbed region, and the 30 to 90 GHz data lie along the power law portion. The power law index for the photon energy spectrum obtained in this way is approximately 0.6 in late 1975, and 0.4 in 1976. For the 1974 data, the spectral index is 0.5 if we use the low value of the 89 GHz data and 0.1 if we choose the high number (Kellermann 1974). The flux density in July 1976 has apparently decreased at all measured frequencies from the values measured during Dec. 1975. Between May and August 1976, the radio measurements at 10.7 GHz and 90 GHz show approximately the same rate of decline. These data demonstrate clearly that significant variability can arise over timescales that are on the order of a month. Daily variability is apparent in the 10.7 GHz data. Kaufmann et al. (1976) have observed the source at 22 GHz during 1974 and 1976 from the Southern Hemisphere. The flux reported and the day-to-day temporal variability are in general agreement with the synchrotron spectrum constructed from the data presented in this paper.

The X-ray power law spectral index as determined from the available data is shown as a function of time in Figure 4. In view of the importance of the possible temporal changes in this spectral index for models of Cen A, it is of interest to determine the probability that the observations do indicate a statistically significant variation. The hypothesis of a constant spectral index, α, is fit by the observations with a chi-squared value of 65.4 for 10 degrees of freedom. Thus, the probability that the fluctuations of the data are random variations from a constant α is less than 10^{-6}. The two data points reported by Mushotsky et al. (1976) are usually thought to be the most telling evidence for the variability of the spectral index. Even if we exclude these two data points, the remaining data indicate the observations of the spectral index have less than a 2% probability of being drawn from a constant value. We have neglected the influence of possible systematic errors in calculating these probabilities; the effect of these errors would be to lower the confidence levels in a varying spectral index which we have derived.

The radio radiation from the nucleus of Cen A is almost certainly produced by the synchrotron mechanism. It is probable that the X-ray radiation is produced by inverse Compton scattering of protons by the same relativistic electrons which produce the synchrotron radiation. Several such models are possible and will be described in detail in section C. However, several general comments can be made in view of the concurrent radio and X-ray observations discussed above.

The observed variations of the X-ray and radio radiation are consistent with the injection of a single burst of relativistic electrons in the galactic nucleus sometime during 1971 or early 1972. These electrons produce the synchrotron radio radiation and the inverse Compton X-ray spectrum. A delay between the rise in the X-ray flux and the 10.7 GHz flux density is to be expected because the electrons responsible for the burst are initially opaque to their own synchrotron radiation (van der Laan 1966), though transparent to X-rays. Such a delay cannot be confirmed due to the lack of data at 10.7 GHz prior to 1973. This interpretation of the data is, however, supported by the high flux values that were measured at 89 and 31.5 GHz during 1974 (Figure 1). The short term variability might not be expected with the van der Laan interpretation which invokes adiabatic expansion, but may be adequately explained by turbulence in the source (Pacholczyk and Scott 1976).

C. Discussion of Possible Models

The radio radiation from Cen A's nucleus is almost certainly synchrotron in nature. The X-ray radiation is most likely to be photons inverse Compton scattered by the relativistic synchrotron electrons. Previous models are based on the assumption that the photons are the synchrotron radiation itself, the so-called synchro-Compton models. If these models are correct, and the low energy cutoff in the radio data is caused by synchrotron self absorption, then both the magnetic field and the angular diameter of the source can be calculated from the measured synchrotron and inverse Compton fluxes (see e.g., Kellermann and Pauliny-Toth 1968). Grindlay (1975) has proposed such a model in which the high energy X-rays are produced as synchro-Compton radiation from the source responsible for the centimeter and millimeter radio data. In this model, the low energy X-rays are mainly the synchrotron emission from a second more extended radio source. Mushotzky (1977) has proposed a similar model which uses only one source of synchrotron and synchro-Compton radiation. This model accounts for the spectral variability of the X-rays by adiabatic expansion (after van der Laan 1966) and by synchrotron losses. Both of these theories require that the spectrum of the microwave source extend into the infrared. At present, the simultaneous observations in the radio and infrared which may corroborate this assumption are unavailable. Tucker et al. (1973) suggested that the X-ray radiation might be produced by inverse Compton scattering of infrared photons. This radiation is emitted by dust grains heated by electromagnetic radiation from the nonthermal source.

We propose here a model for the nucleus of Cen A in which X-rays are produced by inverse Compton scattering of a blackbody radiation field by the relativistic synchrotron electrons, where the blackbody photon distribution comes from stars in the nucleus. Such a thermal photon field is suggested by both the infrared measurements of Kunkel and Bradt (1971) and by the optical measurements of van den Bergh (1975). The angular diameter of 5 arc seconds and the temperature of 250K obtained for the infrared source can be used to place an upper limit on the energy in the relativistic electrons in the emitting region. The concentration of hot, blue stars in the vicinity of the nucleus suggested by van den Bergh(1975) implies a starlight photon field with a temperature of 10^4K. This blackbody photon distribution is used in calculating the magnetic field and the linear dimension of the source.

It is relevant to note here that the radio and X-ray flux densities do not track one another throughout the plotted interval. The 2-6 keV flux apparently does not share the fluctuation that occurs at 10.7 and 31.4 GHz from July 1975 to July 1976, but continues to decline. The 100 keV intensity decreases during this period by a factor of approximately 3. This lack of concurrent variability between the radio and x-ray data can be interpreted within the blackbody-Compton model as being the result of an expanding cloud of relativistic synchrotron electrons leaving the region in which the energy density of the blackbody photons is high. In such a case, the synchrotron emission may stay constant or even increase as the X-ray flux decreases. It is also possible that some part of the decrease in the 2-6 keV flux is caused by increased absorption of the low energy X-rays by an ionized intervening medium that is beginning to recombine. Such an intervening medium is suggested by Davison et al. (1975) and Serlemitsos et al. (1975) who observe X-ray absorption consistent with 1.6×10^{23} atoms of hydrogen cm^{-2} along the line of sight. Van den Bergh (1975) notes that these observations are consistent with optical data which suggest an extinction of 100 magnitudes. An initial burst of X-ray radiation associated with the injection of relativistic electrons might ionize the intervening medium. If the decrease in the 2-6 keV flux during 1975 were due solely to recombination, the value implied for the density of hydrogen atoms is 10^4 cm^{-3}. Using the X-ray absorption, and Kunkel and Bradt's hot spot as a linear dimension, the density of hydrogen atoms becomes 10^3 cm^{-3}. The values are not inconsistent. However, increased absorption does not account for the decrease in the 100 keV data.

D. Consequences of the Blackbody-Compton Model

We assume that the ambient radiation field in the nucleus is principally that of a blackbody. The cloud of relativistic synchrotron electrons, the magnetic field, and the blackbody photon field may not be distributed uniformly throughout the nucleus. If the relativistic electrons, the blackbody photons, and the magnetic field occupy the same region of space, then we can calculate the relationship between the magnetic field and the photon temperature in the source from the ratio of the X-ray flux density, $F(\nu_c)$, to the synchrotron flux density, $F(\nu_s)$. The frequencies are chosen such that ν_s and ν_c are in the power law (unabsorbed) portions of the radio and X-ray spectra, respectively.

We also assume that the relativistic electrons have a power law spectrum of the form $N(\gamma) \propto \gamma^{-n}$, where $N(\gamma)$ is the electron number density in electrons cm^{-3} at a particular value of γ, the ratio of an electron's total energy to its rest mass energy $(m_e c^2)$, and n is the index of the electron number spectrum. With these assumptions the ratio of the fluxes is given by combining equations 4-53 and 4-54 of Tucker (1976) as:

$$\frac{F(\nu_c)}{F(\nu_s)} = 2.47 \times 10^{-19} \; (5.25 \times 10^3)^q \; \frac{b(n)}{a(n)} \; T^{3+q} \; B^{-(q+1)} \left(\frac{\nu_c}{\nu_s}\right)^{-q} \qquad (1)$$

where B is the magnetic field in gauss; a(n) and b(n) are determined from the synchrotron spectrum and depend only on the electron power law index, n; T is the temperature of the blackbody photon distribution in degrees K; and q is the spectral index of the X-ray energy spectrum [q=(n-1)/2]. We choose $\nu_c = 2.4 \times 10^{19}$ Hz(100 keV) and $\nu_s = 5 \times 10^{10}$ Hz. Substituting these values and q = 0.5 obtained from the observations into Equation 1 yields:

$$\frac{F(\nu_c)}{F(\nu_s)} = 2.88 \times 10^{-19} \; T^{3.5} \; B^{-1.5}. \qquad (2)$$

In the 1974 observations, the ratio of $F(\nu_c)/F(\nu_s)$ at the chosen frequencies was found to be 10^{-7}. Thus, from Equation 2

$$T^{3.5} \; B^{-1.5} = 1.6 \times 10^{12}. \qquad (3)$$

A plausible value for the temperature of the blackbody photons is 10^4K, since the nucleus must contain stars as well as a non-thermal energy source. Substituting this value into equation 3 gives B = 3.4 gauss. This is considerably larger than a typical galactic magnetic field, which is on the order of microgauss, but may be reasonable for the emitting region.

For a self-absorbed synchrotron source, the relationship between the magnetic field, B, in gauss, the angular size, θ, in arc seconds, and the maximum synchrotron flux $F(\nu_m)$ in Jy is:

$$B = 2.2 \times 10^7 \, F(\nu_m)^{-2} \cdot \nu_m^{\,5} \cdot \theta^4 \qquad (4)$$

where ν_m is the frequency in GHz at the maximum flux density (Slish 1963 and Williams 1963). For B = 3.4 gauss, and the frequency at which the observed radio flux density is maximum, $\nu_m \approx 25$ GHz, we obtain from Equation 4, $\theta = 1.5 \times 10^{-3}$ arc seconds. This corresponds to a linear diameter of 50 light days. If we choose $T = 10^3$K, then the values of B and θ are 1.6×10^{-2} gauss and 4×10^{-4} arc seconds (10 light days), respectively.

E. An Upper Limit for the Energy Contained in Relativistic Electrons in the Nucleus of Cen A.

The change in the X-ray spectral index as a function of time, if it is real, has important physical consequences. The apparent tendency of the spectral index to harden with time during the initial X-ray brightening indicates that particle acceleration may be taking place. Particle acceleration is also suggested by the fluctuations of the radio spectrum throughout the observing period. This evidence for continuing particle acceleration suggests that only a small fraction of the total energy in the nucleus of Cen A is emitted in the form of X-ray and radio radiation, the remaining being contained in kinetic energy of the ejecta, thermal energy, magnetic field energy, etc. It follows that the energy release now taking place in the nucleus of Cen A may be sufficient to lead to the eventual formation of a pair of radio lobes similar to those that are already present. We pursue this line of reasoning in some detail.

The energy density of the relativistic electrons, ϵ_e, can be expressed as (Tucker 1976)

$$\epsilon_e = \bar{\gamma} \, m_e c^2 \, N_e \qquad (5)$$

where $\bar{\gamma} m_e c^2$ is the "average" total electron energy and N_e is the average density of the electrons in some emitting region. N_e may be expressed as

$$N_e = \int_{\gamma_0}^{\gamma_1} N(\gamma)\, d\gamma \tag{6}$$

for the power law distribution of electrons, $N(\gamma) = A\,\gamma^{-n}$, between values of γ from γ_0 to γ_1. Assuming that the power law portion of the synchrotron spectrum extends from 25 to 90 GHz, γ_0 and γ_1 are approximately 10^3 and 10^4, respectively, the exact values depending on the magnetic field (Ginzberg and Syrovatskii 1965). The flux density of the inverse Compton X-ray radiation, $F(\nu_c)$ in Jy, caused by inverse Compton radiation from a blackbody photon field can be expressed as (Tucker 1976):

$$F(\nu_c) = \frac{L(\nu_c)}{4\pi D^2} = \frac{4.2 \times 10^{-40}\, R^3}{3D^2}\, A T^{3+q}\, b(n) \left(\frac{2.1 \times 10^{10}}{\nu}\right)^q \tag{7}$$

where D is the distance to Cen A in cm (1.55×10^{25} cm = 5 Mpc), R is the radius of the emitting region in cm, and $L(\nu_c)$ in ergs s^{-1} Hz^{-1} is the luminosity at a frequency ν_c. The X-ray and radio spectra are consistent with n=2 (q=0.5), which gives b(2)=5.25.

The blackbody-Compton radiation mechanism is relatively sensitive to the effective temperature of the blackbody photons. By choosing a lower limit for the temperature, we can find an upper limit to the total energy in the relativistic electrons. The 250K value obtained for the infrared source is certainly a lower limit for the effective temperature. Substituting T=250K and R=5 light days, into Equation 7, we find that the normalization constant A becomes 1.7×10^9 cm^{-3} corresponding to an electron density, N_e, of 7×10^5 electrons cm^{-3} for the observed value of $F(\nu_c)$. Substituting this value into Equation 5 yields $\epsilon_e = 6 \times 10^3$ erg cm^{-3} as a maximum energy density for the relativistic particles.

For T=10^3 and 10^4K, ϵ_e becomes 2 and 10^{-4} ergs cm^{-3}, respectively. If the emitting region is the only region in the nucleus that contains these relativistic particles, then the maximum energy of the source for the observed outburst is 6 x 10^{51} ergs. This is comparable to the energy release in a supernova.

It is possible, however, that the radiation we see may come from regions of enhanced magnetic field strength or blackbody photon energy density, or both. If this is true, there may be non-emitting regions within the nucleus that contain energetic particles. We can calculate an upper limit for the total energy in relativistic electrons in the nucleus by assuming that the electron energy density throughout the nucleus is the same as that calculated for the emitting region. Using a blackbody photon temperature of 10^3K and the infrared nuclear dimension of 120 pc we obtain 5 x 10^{61} ergs as the maximum energy of the relativistic electrons in the nucleus. For a 10^4K blackbody photon temperature the maximum energy is 5 x 10^{57} ergs. These energies are sufficient to form a pair of radio lobes similar to the two sets already present.

IV. CONCLUSIONS

The radio observations from the nucleus of Cen A can be used to construct a self-absorbed synchrotron spectrum which varies in time in a way strongly reminiscent of turbulent accelerations and adiabatic expansions of a cloud of relativistic electrons with an ambient magnetic field. The fluctuations in the radio and X-ray observations do not track one another throughout the observations, but separate after a time in a way which suggests a blackbody-Compton mechanism where inverse Compton scattering of a blackbody photon distribution produces the observed X-rays. The X-ray intensity predicted by this mechanism decreases as the relativistic electron cloud expands to regions of lower blackbody photon energy density. Upper limits on the energy in the recent outburst are of the same order of magnitude as the energy release in supernovae explosions. Finally, upper limits for the energy in relativistic particles in the entire nucleus indicate that there may be sufficient energy to form another pair of radio lobes.

It is clear that continued VLBI measurements of the nucleus of Cen A as well as additional simultaneous measurements of its radio, infrared, and X-ray spectra over a long period are needed to confirm or refute our limited understanding of this source.

ACKNOWLEDGMENTS

We thank Pierre Kaufmann for helpful discussions of the data. We also thank Pierre Kaufmann, E. Scalise, Jr., J. C. Raffaelli, and P. Marques des Santos for allowing us to use their observations at 22 GHz prior to publication. We acknowledge the efforts of the people who made the X-ray observations possible: the personnel in the Laboratory for Solar Physics and Astrophysics, OSO-8 Project Scientist, Roger Thomas, in particular. We thank the personnel of Comtech, Inc., E. Cutler and W. Kennard in particular, for assistance with the data analysis. We thank Bee Nolan and Anne Thompson for assistance in typing, and Mrs. Mary Dobbins for moral support.

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TABLE I

RADIO FLUX DENSITY OF THE NUCLEUS OF CENTAURUS A

Date	S (Jy)	Standard Deviation (Jy)
	10.7 GHz	
07-11-73	5.97	.41
07-12-73	5.53	.37
07-13-73	6.17	.29
07-14-73	6.00	.25
07-15-73	5.72	.26
07-18-73	6.32	.24
08-08-73	4.00	.19
05-23-74	8.38	.13
01-21-75	8.02	.11
01-22-75	7.58	.11
06-25-75	7.85	.14
07-23-75	6.05	.18
01-18-76	9.48	.15
05-31-76	8.28	.09
07-14-76	6.63	.11
07-21-76	7.60	.11
07-30-76	7.44	.11
07-31-76	7.12	.08
08-01-76	7.47	.12
08-02-76	6.60	.19
08-03-76	6.17	.11
08-04-76	6.25	.17
08-05-76	6.25	.20
08-09-76	5.49	.14
08-10-76	4.88	.20
09-01-76	5.92	.12
09-02-76	5.29	.19
	31.4 GHz	
05-21-75	17.09	.35
10-07-75	19.52	.47
12-08-75	20.52	.39
03-09-76	17.68	.25
06-02-76	16.29	.26
	85.2 GHz	
12-08-75	11.72	.50
	90 GHz	
05-17-76	10.5	.3
07-30,31-76	8.6	.7
08-29-76	8.9	.7
11-20-76	9.5	.6
02-15-77	9.4	.2

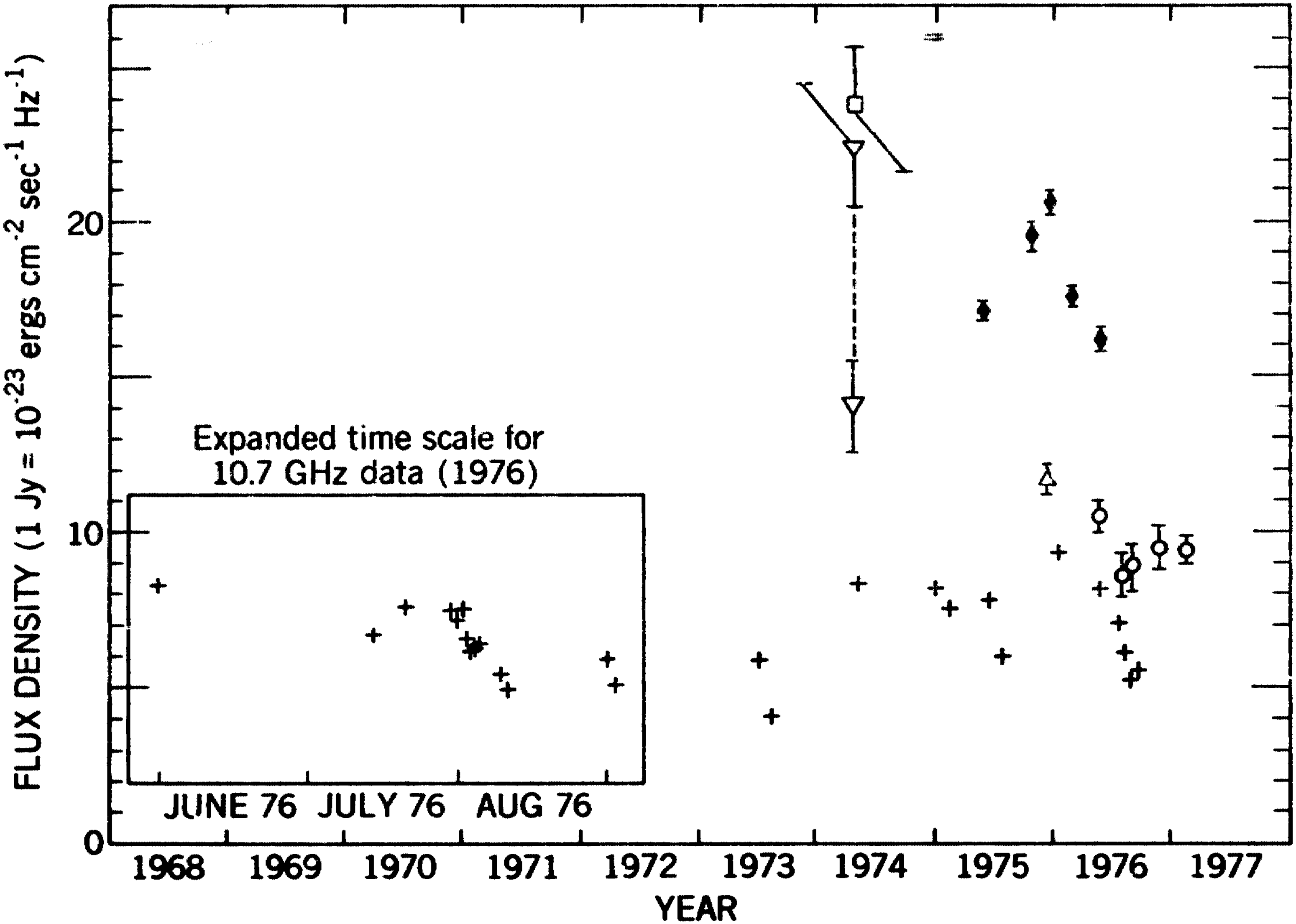
FIGURE CAPTIONS

Figure 1. Radio emission from the nucleus of Cen A.

Figure 2. History of Cen A 2-6 keV X-ray flux.

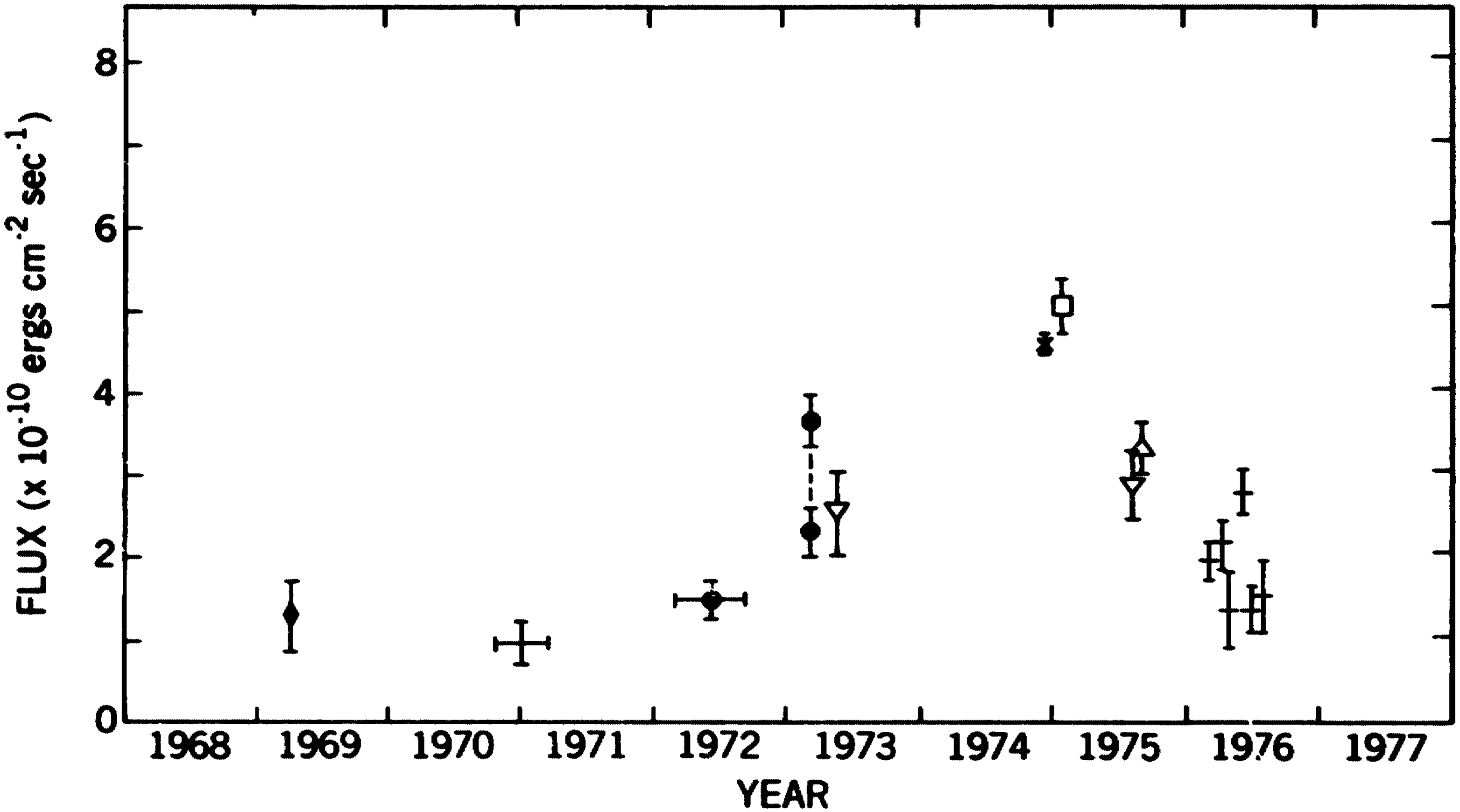
Figure 3. History of Cen A 100 keV X-ray intensity.

Figure 4. History of Cen A X-ray power law spectral index.



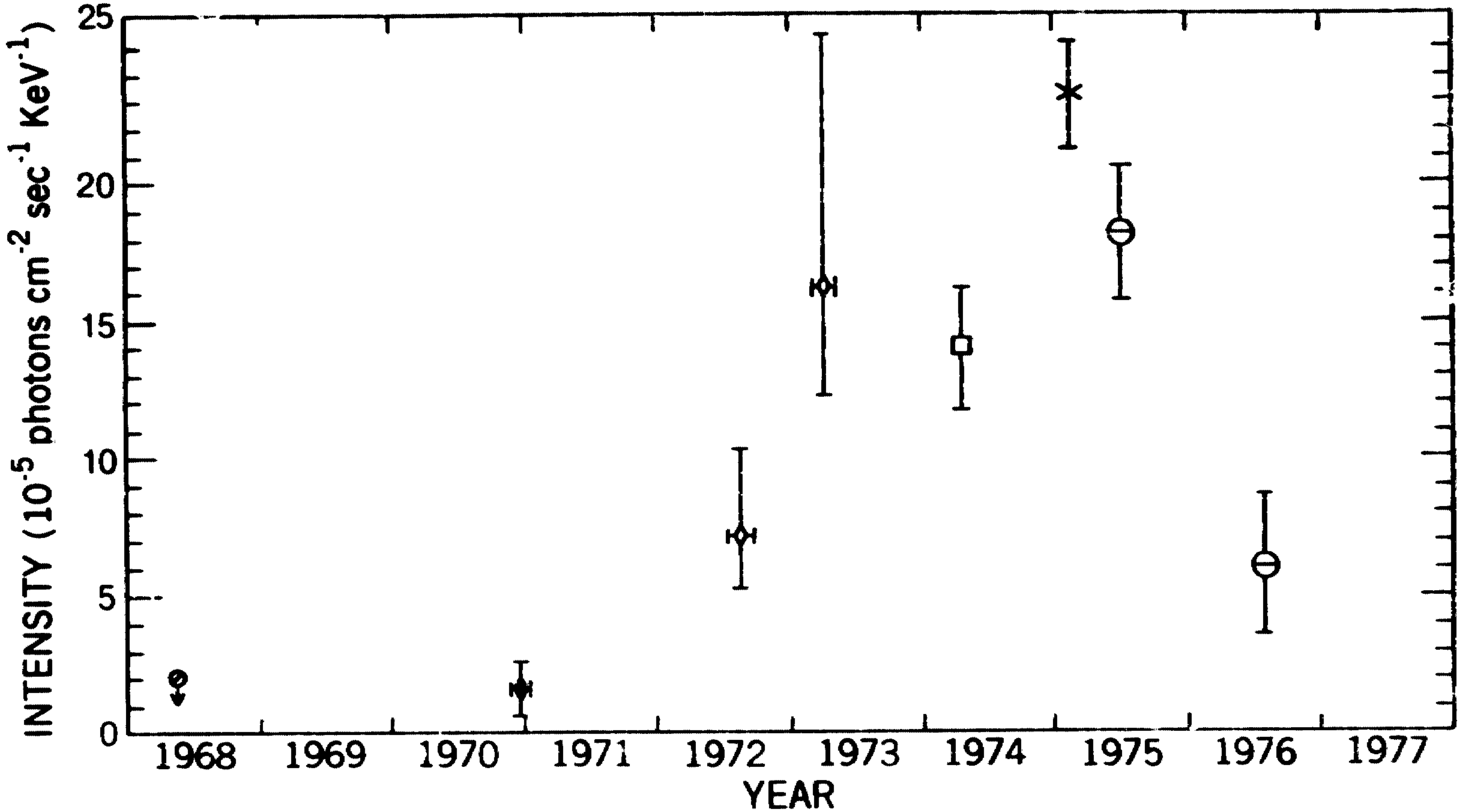
Graf and Price (10.7 GHz) = +; Dent and Hobbs (31.4 GHz) = ♦, (85.2 GHz) = Δ;
Kellermann (31.5 GHz) = □, (89 GHz) = ▽; Conklin and Ulich (90 GHz) = ○.

FIGURE 1



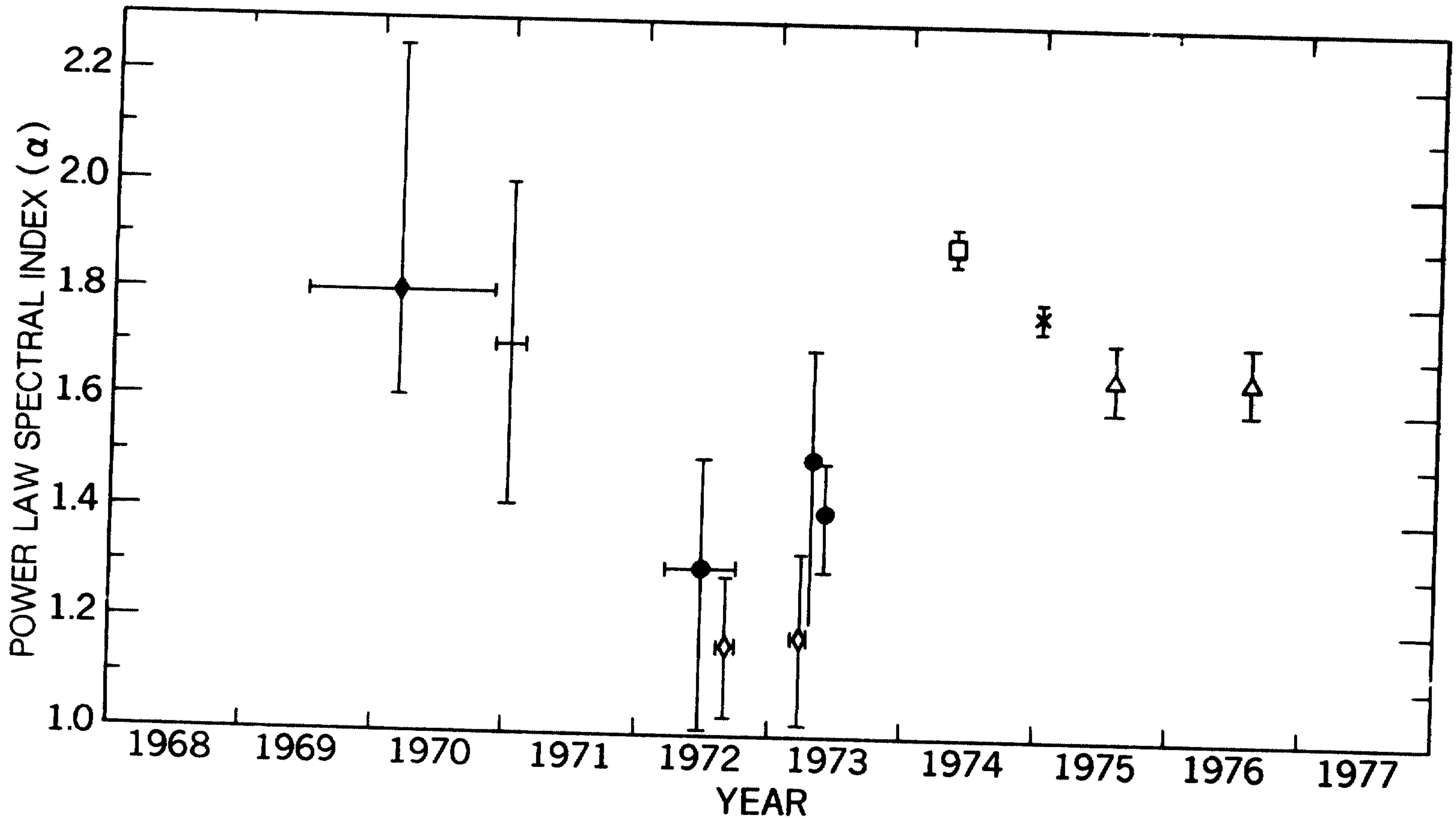
Lampton et al. (Rocket) = ; Tucker et al. (Uhuru) = ; Winkler and White (OSO-7/MIT) = ; Davison et al., Stark et al. = ; Stark et al. (Ariel V) = ; Grindlay et al. (ANS) = ; Stark et al. (Copernicus) = ; Serlemitsos et al. (OSO-8) = ; Sanford (Copernicus) = .

FIGURE 2



Haymes et al. (Balloon) = ; Lampton et al. (Balloon) = ; Mushotzky et al. (OSO - 7) = ;
Hall et al. (Balloon) = ; Stark et al. (Ariel V, Extrapolation) = ; Dennis et al. (OSO - 8) = .

FIGURE 3



Lampton et al. = ◆; Tucker et al. = ┼; Winkler and White = ●; Mushotzky et al. = ◇; Hall et al. = □; Stark et al. = ×; Mushotzky and Serlemitsos = △.

FIGURE 4

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