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THE X-RAY EMITTING GALAXY CEN-A

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THE X-RAY EMITTING GALAXY CEN-A

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ABSTRACT

OSO-8 X-ray observations of Cen-A in 1975 and 1976 are reported. The source spectrum can be well fit in both years by a power law of number index 1.62 and absorption due to 1.3 x 10^{23} at/cm^2. The total flux varied by a factor 2 between 1975 and 1976. In 1976 there were ∿ 40% flux variations on a time scale of days. The 6.4 keV Fe fluorescent line and the 7.1 keV absorption edge were measured implying Fe/H ∿ 1.6 x 10^{-5}. Simultaneous radio measurements (Beall et al. 1977) show variation in phase with X-ray variability. Models considering radio, millimeter, IR and X-ray data show that all the data can be accounted for by a model in which the X-rays are due to a synchrotron self-Compton source embedded in a cold H_2 cloud.

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I. INTRODUCTION

NGC5128 was one of the first extragalactic objects to be identified as an X-ray source (Bowyer et al. 1970). Subsequent X-ray observations from 1970 to 1975 (Lampton et al. 1972; Tucker et al. 1973; Grindlay et al. 1975; Stark, Davison and Culhane 1976; Winkler and White 1975; Mushotzky et al. 1976) show this source to be variable in both intensity and spectral index.

Radio observations have revealed an extremely compact, variable source (Kellerman 1974). Infrared (Grasdalen and Joyce 1976), optical (Kunkel and Bradt 1971) and X-ray (Delvaille et al. 1977) observations have all identified a small component centered on this radio source.

In this paper we report X-ray observations of Cen-A in 1975 and 1976. The moderate resolution X-ray spectral data reported here allow us to determine for the first time the column density of Fe in an extragalactic object. In addition the broad bandwidth and high sensitivity of these observations together with simultaneous radio observations (Beall et al. 1977) and IR observations (Hildebrand et al. 1977) severely constrain models of the X-ray emitting and absorbing regions and allow us to develop a unified model of this X-ray source.

II. OBSERVATIONS

We report OSO-8 observations of Cen-A on days 208-217 in 1975 and days 211-221 in 1976. The detector is a multiwire proportional counter sensitive in the 2-60 keV range with a net area of 263 cm^2 and a 5.1° circular collimation. This detector has an energy resolution of $\sim$ 18%

at 6.7 keV and the data are transmitted in 63 quasilogarithmically spaced pulse height channels. For this observation channels above 8 keV have been grouped resulting in 25 energy channels. The mode of observation (Serlemitsos et al. 1976) enables us to obtain both source and background spectra every spacecraft revolution (∿ 10 sec). The data used in the analysis are free of confusion by any known X-ray sources. These data have been divided into 6 data sets of ∿ 3 days each with an exposure of $(3.7 - 7.5) \times 10^7$ cm^2 sec each.

III. DATA

A. Source Intensity

The X-ray flux from Cen-A decreased by a factor of two between our observations in 1975 and 1976. In addition the Cen-A flux was found to vary during each 10 day observation. In July-August 1975 the 2-60 keV intensity varied from $.106\pm.005$ cts/cm^2sec to $.141\pm.003$ cts/cm^2sec, corresponding to a variation in the 2-6 keV flux from $(3.22\pm.06) \times 10^{-10}$ ergs/cm^2sec to $(4.1\pm.09) \times 10^{-10}$ ergs/cm^2 sec. The dominant trend in 1975 is a secular <u>increase</u> of flux with time (Figure 1) with no significant day to day variability.

In July-August 1976 the 2-60 keV intensity varied from $.049\pm.003$ cts/cm^2sec to $.077\pm.003$ cts/cm^2sec. This corresponds to a variation in the 2-6 keV flux of from $(1.61\pm.009) \times 10^{-10}$ ergs/cm^2sec to $(2.25\pm0.09) \times 10^{-10}$ ergs/ cm^2 sec. There was no dominant trend in the 1976 data with both a decline and rise evident. The data show a ∿ 40% flux decrease from day 213 to day 216 and a 20% increase from day 216 till day 218. On day 213 there is a short, 1/3 day, 10% flux increase which is significant at the 1.5σ level. The variations during the two observations are not of the same total magnitude but represent similar percentage changes in flux.

B. Spectra

The data can, at all times in 1975 and 1976 (Figure 2, Table 1), be well fit by a power law with a photon index, $\alpha = 1.66 \pm 0.03$ with low energy absorption due to a column density of $N_H = (1.33 \pm 0.07) \times 10^{23}$ atm/cm^2.

In this analysis "cosmic" abundances (Withbroe 1971) of the heavy elements were used to determine the low energy turnover. Thermal bremsstrahlung models are unacceptable, giving significantly worse fits to our data with increases in χ^2 greater than 10 over the power law model, and with a χ^2/deg of freedom > 1.5.

When all our data are combined together the resulting spectrum can be well fit by a model containing both an emission line at 6.4 ± 0.1 keV and an Fe absorption edge at 7.1 ± 0.3 keV. The emission line has a measured width consistent with a narrow, unresolved line broadened by the detector response (Figure 4). The equivalent width of the emission line is 120 ± 35 eV (2σ errors). The absorption edge corresponds to $(1.9 \pm 0.7) \times 10^{-4}$ gms/cm^2 (2σ error) of Fe in the line of sight. With the introduction of the line and edge the best fit to the Cen-A spectrum has a photon spectral index $\alpha = 1.65 \pm .02$ and a column density $N_H = (1.314 \pm 0.036) \times 10^{23}$ atm/cm^2 with a χ^2 per degree of freedom of .958.

During the fluctuations in intensity there are <u>no</u> statistically significant changes in α or N_H nor is there a change in the equivalent width of the line or the depth of the edge from 1975 to 1976. However, 50% variation in line strength or depth of the edge between 1975 and 1976 cannot be ruled out at the 2σ confidence level. Fits to our data do not indicate any curvature or two component nature to the spectrum. Fits incorporating a 2 slope power law model (Grindlay et al. 1975) do not significantly reduce $\chi^2_{d\ o.f.}$ relative to single slope power law models.

IV. DISCUSSION

A. Intensity Variations

A compilation of prior observations (Sanford 1976, Beall et al. 1977) indicates that Cen-A has varied in X-ray intensity by at least a factor of 5 from 1971-1976, with Winkler and White (1975) reporting a factor of two increase in ∿ 6 days in 1973. Our data confirm the existence of variations on long and short time scales and indicate that the flux can decrease as well as increase on short time scales. Our 1975 results agree, within the errors, with the Copernicus flux (Stark et al. 1975) observed on day 210 of $(2.9 \pm 0.5) \times 10^{-10}$ ergs/cm^2 sec in the 2-6 keV band.

Simultaneous 10.7 GHz measurements in 1976 (Beall et al. 1977), Figure 1, indicate that the radio and X-ray flux probably vary in phase. However the X-ray flux varied by ∿ 40% while the 10.7 GHz flux varied by ∿ 18% over days 212-217. The observation of flux changes on a time scale of days implies, for a single emitting region, a small ($R \sim ct$) size of ∿ 3 light days. If the "flare" on day 213 is a real and not a statistical fluctuation then structure in the emitting region may exist on a scale of $<$ 1/2 light day. The existence of a short time scale flux decrease implies the existence of loss mechanisms that can operate on this timescale. The total energy emitted in the 4-60 keV bands was $L_x \sim 1.29 \times 10^{43}$ ergs/sec in July-August 1975 and $L_x \sim 6.92 \times 10^{42}$ ergs/sec in July-August 1976 assuming a distance of 5 Mpc to Cen-A (Burbidge and Burbidge 1959).

The model implications of such intensity variations will be discussed in Section V.

B. Spectra

1. Spectral Index

Our data, as well as those of Stark et al. (1976) provide strong evidence for non-thermal rather than thermal models for this source. We will therefore restrict our discussion solely to such models.

Our observation of a constant spectral index while the flux changes by factors of 2 indicates the existence of both gain and loss mechanisms that are independent of spectral index. This result is slightly discordant with the best fit of $\alpha = 1.79 \pm .02$ for the source in January 1975 reported by Stark et al. (1976). During 1976 (Beall et al. 1977, Kaufmann et al. 1977) the radio spectral energy index from 22 to 90 GHz was $\alpha \approx .63$ with a best fit of $F_\nu \cong 6.4 \times 10^{-16} \nu^{-.63}$ cgs units. We note that the X-ray and radio spectral indices are, within errors, identical. Millimeter data taken a month earlier (Hildebrand et al. 1977) indicate that this power law may extend to 270 GHz. This similarity in spectral index between the radio and X-ray, unless fortuitous, can be considered as a strong constraint on any emission mechanism. The non-observation of any spectral curvature over the 4-60 keV range places strong constraints on two component models of X-ray emission. In particular the model proposed by Grindlay et al. (1976) of fluctuations in two separate components to fit the spectral index and intensity fluctuations does not fit our data. Similarly, the model proposed by Mushotzky (1977) would require modification in order that no spectral curvature would be observed over this energy range.

2. Low Energy Absorption

All data presented in this paper are consistent with no variation in absorbing column density. Our value of N_H is in good agreement with that derived by Stark et al. of $N_H = (1.35 \pm .02) \times 10^{23}$ and is marginally consistent with the results of Tucker et al. 1973, $N_H = (9 \pm 3) \times 10^{22}$ and Davison et al. 1975, $N_H = (1.6 \pm .3) \times 10^{23}$ at/cm^2.

In principle, optical and infrared extinction measurements, HI absorption and emission data, 100μ and 1 mm emission fluxes, and X-ray low energy turnover data can all be combined to determine the amount of gas in a line of sight to the nucleus of Cen-A. In this section we shall attempt to fit all the available data with a model in which the same volume of gas and dust accounts for all the relevent data.

Optical observations of a dark central dust lane in Cen-A are an indication of a large amount of dust and gas, highly unusual in a giant elliptical galaxy. Van den Bergh (1976) has observed that the visual extinction, A_v, varies between 1.5 - 6.1 mag in the dark lane depending on the position. Using the calibration of A_v to equivalent hydrogen column density, N_H, derived from observations in our galaxy (Gorenstein 1975, Ryter, Cesarsky and Audouze 1975), this extinction implies $N_H \lesssim 1.6 \times 10^{22}$ at/ cm^2 due to material in the dust lane. Thus, most of the observed X-ray absorption cannot be due to average absorption in the dust lane.

HI observations (Wright 1973, Roberts 1970) indicate that the neutral hydrogen column density is $\lesssim 1.5 \times 10^{21}$ at/cm^2. They further indicate that significant column densities of HI do not exist in small scale ($\lesssim$ 5.6′) structures. Thus most of the X-ray absorption cannot be due to either average global HI material across the face of Cen-A or to patchy "local" HI clouds. The combination of optical and HI observations thus lead us to a model in which most of the X-ray absorption is due to material associated with H_2 and is located in a small scale structure around the nucleus. In this model one expects the infrared flux from 2-1000μ to be thermal emission from cold dust which is admixed with the H_2 similar to the H_2 clouds in our galaxy. Rickard et al. (1977) have observed large, dense H_2 clouds in M82 and NGC253. The 2-1000μ spectra of these galaxies (Elias et al. 1977) shows a spectrum indicative of emission by cold $T \sim 40^{\circ}K$ dust. We feel that the 2-12μ data of Grasdalen and Joyce (1976) combined with the 100μ data of Harper (1977) and the 1mm data of Hildebrand et al. (1977) (Fig. 3) indicate a similar spectrum in Cen-A.

This reinterpretation of the 2-12μ data is supported by the lack of variability in the near IR flux and the good agreement of the Cen-A spectrum with the models of Leung (1976). One thus expects that the column density of gas inferred from the near IR and millimeter data should be consistent with the X-ray absorption column density.

Using an extrapolation of the non-thermal radio continuum to 1mm allows us to estimate that $\sim$ 4 Jy is due to emission from cold dust. If the effective temperature at this wavelength is $\sim 25\text{-}40^{\circ}K$ and the dust is optically thin at 1mm then $\sim (7.5\text{-}6) \times 10^{-4}$ gm/cm^2 of dust is implied.

If the dust to gas ratio is 1/300 (Gillett et al. 1975) the 1 mm data indicate $N_{H_2} \sim (1.4 - 1.1) \times 10^{23}$ at/cm^2.

The 2-12μ data can also be used to derive a dust column density by measuring the depth of the 10μ absorption feature. However, as Jones et al. (1977) point out radiative transfer effects are important at this wavelength. The net effect of such effects is to make the measured 10μ optical depth and angular size smaller than the "true" values. Using the measured value of $\tau_{10\mu} \approx 0.9 \pm 0.2$ from Grasdalen and Joyce, a ratio of $A_V/\tau_{10\mu} \sim 16.7$ from Gillette et al. and a ratio of 1.4 for the true to measured A_ν for $\tau_{10\mu} \sim .6$ from Jones et al. we derive a "true" $A_V \sim 36 \pm 8$ mag. Using the N_H vs. A_V relationship of Gorenstein this implies $N_H \sim (8 \pm 2) \times 10^{22}$ at/cm^2. Scaling to the model calculations of Jones et al. gives us a dust column density of $\sim 3 \times 10^{-4}$ gm/cm^2 of silicate material and a "true" size to the 2-10μ IR source of ∿ 250 pc. Given the errors and the model fits required we feel that the measured N_H from the X-ray, 1mm and 2-12μ data are in good agreement. If, as these data indicate, most of the gas in Cen-A is in the form of H_2, then, because the X-ray cross section of H_2 is greater than that due to H atoms alone (Brown and Gould 1967), the column density of hydrogen inferred from X-ray data should be lowered by 10-20% so that $N_{H_2} \approx (1.1 - 1.2) \times 10^{23}$ at/cm^2. The CO upper limit of Rickard et al. (1977) is consistent with this column density of H_2.

Following Tucker et al. (1973) we can examine if the cold, H_2, dusty circum-nuclear material can exist near the X-ray source. The X-ray emission will excite an HII region of size $r_\star \sim 3 \times 10^{21} (L_{41}/n)^{1/2}$ cm, with X-ray luminosity in units of 10^{41} ergs/sec. Our data set the 2-6 keV input flux at L_{41} (2-6) keV $\simeq$ 9 in 1975. For $N_H = 1.3 \times 10^{23}$ we derive $n \sim 300$ cm^{-3} and $r_* \sim 170$pc. For grains with an emissivity $\sim .01$ the size of the cold dust emitting region is $r \sim 170$ pc, if it is homogenous and spherical. We thus are in close balance between the size of the cold absorbing region and the size of the X-ray produced HII region. More detailed models are required to decide the geometry of the region around the nucleus.

3. Fe Line Emission and Fe Abundance

The presence of an Fe edge at 7.1 keV and an Fe emission line at 6.4 keV in the Cen-A spectrum provide strong evidence for absorption and emission by cold ($T < 2.5 \times 10^{6}$ °K) iron. The expected ratio of Fe 6.4 fluorescent line emission/Fe K edge absorption is .309 (Fink et al. 1966) for cold Fe with a spherical geometry. Our measurement of this ratio is .29 ± .09, a good fit to this simple model.

If we use a column density of 1.3×10^{23} atm/cm^2 of hydrogen then $\mathrm{Fe/H} = (1.6 \pm 0.5) \times 10^{-5}$ ($[\mathrm{Fe/H}] = -4.79$). The standard "cosmic" values (Trimble 1975) range from 2.4×10^{-5} for the solar photosphere to 3.3×10^{-5} for the solar corona. If we use the column density of H_2, which is $\sim$ 15% lower, $\mathrm{Fe/H} \sim 1.9 \times 10^{-5}$. Thus there exists a weak indication of Fe "underabundance" in Cen-A by perhaps as much as 2.5.

In "normal" giant ellipticals the color and line strengths in the integrated stellar colors are consistent with Fe/H at twice the solar abundance (van den Bergh 1975). However this may not be true for Cen-A, as van den Bergh (1976) has indicated that an anomalously large amount of the integrated star light from Cen-A is emitted by metal poor stars. The anomalous low column density of Fe can not be interpreted as an ionization effect. Only very high resolution measurements of the Fe line and edge energies can determine if the gas is truly cold with $T < 1 \times 10^{6} {}^{o}K$. Low energy high resolution measurements of S and Si emission lines can in principle help resolve the ionization state of the absorbing gas in Cen-A. Since we have only truly measured the Fe/CNO ratio and not Fe/H, it is also possible that the CNO group are over-abundant by ∿ 2 while Fe has a normal cosmic abundance. This would be more consistent with optical metalicity measurements (Faber 1973). The most recent determinations of solar O abundance (Parkinson 1977) would require a factor of 4 overabundance.

In principle if the Fe fluorescent line emitting region is far from the continuum X-ray source the variation in the absolute strength of the 6.4 keV line should be delayed with respect to the variation in the strength of the continuum. This effect has been observed in the emission line spectra of QSO's and Seyferts. Our data on the strength of the 6.4 keV line in 1975 vs. that in 1976 are not of sufficient quality to constrain the size of the Fe line emitting region. In our model of the absorption line region in Cen-A there should be a phase lag on the order of years between changes in the continuum and line, with the equivalent width of the line increasing during short scale flux decreases in the continuum.

V. X-RAY EMISSION MODEL

We believe that the observation of similar X-ray and radio spectral indices combined with the probable correlation in 1976 of radio and X-ray flux variation is a strong argument for models in which these are related. The synchrotron-self-Compton model (SSC) is such a mechanism. In this mechanism, the X-rays are produced by Compton scattering of the lower energy synchrotron photons off the radiating population of relativistic electrons. Because this mechanism must <u>always</u> be present at some level we feel that the simplest model is one in which the single component SSC process can account for all the observed X-ray behavior. Observations at other epochs may require an additional contribution (Beall and Rose 1977) from thermal-Compton X-rays. A 2 component SSC model has been proposed by Grindlay (1975) for Cen-A. A model similar to the one we develop here has been proposed by Mushotzky (1976).

We shall follow the terminology of Jones, O'Dell and Stein (1974) in this SSC analysis and the reader is referred to that paper for details. The radio data imply a turnover frequency of $\nu_A \approx 18$ GH$_Z$ (Figure 3) ratio of radio, F_{ν_R}, to X-ray, F_{ν_X}, flux of $E_\nu^{sc} \sim .14$ and a flux at the turnover frequency $F_{\nu_A} \sim 24$ Jy. As Jones et al. (1974) have shown such data determine the angular size, θ_s, and the magnetic field B in the source with:

$$\theta(\mathrm{ms}) \cong .427 * 4.49^{\left[2(2\alpha - 1)\right]/(3+2\alpha)}$$

$$\left\{ \left[\frac{1}{i_{ao}} \left(\frac{F_{\nu_A}}{\mathrm{f.u}}\right) \left(\frac{\nu_A}{\mathrm{GHz}}\right)^{-5/2} \right]^{1+\alpha} * \qquad (1)$$

$$\left[e_{ao} \log \Lambda \left(\frac{E_\nu^{sc}}{100\%}\right)^{-1} \left(\frac{F_{\nu R}}{\mathrm{f.u.}}\right)\left(\frac{\nu}{\mathrm{GHz}}\right)^{\alpha} \right]^{\frac{1}{2}} \right\}^{1/(3+2\alpha)}$$

Using $\alpha = .62$ and $\log \Lambda = 1$, we derive a visible source radius of $\theta_s =$ .24 ms which at a distance of 5 Mpc is $r \sim 6.8$ light days. If we define a measure of flux variability $t_\nu = \bar{F}_\nu|\Delta t/\Delta F_\nu|$ then for a spherical optically thick synchrotron source expanding at a velocity β_o the relation $r_s = 3\,\beta_o\,ct_v$ holds (van der Laan 1966). For Cen-A in July-August 1976 the data give $t_v \sim 10$ and this implies, if we set $r_s = r_\theta$, that $\beta_o \sim .22$, a non-relativistic expansion velocity. The derived magnetic field is $B \gtrsim 7.5 \times 10^{-2}/\sin \phi_o$, where ϕ_o is the pitch angle of the electrons. The lifetime of the electrons against synchrotron losses at ν_A is $t_{1/2} \sim 10$ $(\sin \phi_o)^2$ years and the synchrotron loss frequency, $\nu_L \sim 8 \times 10^{11}\,(\sin \phi_o)^{+3}$ t^{-2} Hz for injection t years ago. For this model ν_L is in the millimeter region and would be unobservable. The Compton lifetime is $t_{1/2} \gtrsim .1$ year at ν_n considering just the photon field due to the radio component. In a SSC model the X-ray spectrum should exhibit a curvature if the radio flux has a break (Mushotzky 1976). In the model parameters for Cen-A in 1976 this curvature should be evident only above 150 keV.

Because the synchrotron and Compton loss times are long compared to the observed X-ray and radio flux decreases and since the X-ray spectrum is constant we shall attribute the short time scale flux decreases to adiabatic expansion. In the following discussion the superscript "o" refers to the state before expansion and the "prime" to after expansion.

If the monitored radio frequency is close to the radio turnover frequency, ν_A, then the ratio of the observed radio flux after expansion by an amount $\rho = r'/r_o$ is

$$(F'_{\nu_R}/F^o_{\nu_R}) \cong \rho^{-5(1+\alpha)/(5/2+\alpha)} \qquad (2)$$

Using the 10.7 GHz data of Beall et al. between days 214 and 217 of 1976 we find $(F'_{\nu_R}/F^o_{\nu_R}) \sim .825$ and $\rho \sim 1.08$. The X-ray flux varies as

$$(F'_{\nu_x}/F^o_{\nu_x}) \sim (F'_{\nu_R}/F^o_{\nu_R}) \; (F'_{\nu_A} \nu'^{\alpha}/F^o_{\nu_A} \nu_A^{o\alpha})^{(3+2\alpha)}$$

$$(\nu_A/\nu_A^o)^{-\xi} \; (\theta'_s/\theta^o_s)^{-2(3+2\alpha)} \qquad (3)$$

where for $\alpha = .62$

$$\text{(a)} \quad F'_{\nu_A} \approx F^o_{\nu_A} \; \rho^{-2.58}$$

$$\text{(b)} \quad \nu'_A = \nu^o_A \; \rho^{-2.065} \qquad (4)$$

$$\text{(c)} \quad \xi = 9.92$$

Inserting the known values of ν_A and F_{ν_A} on day 214 (Figure 3) we calculate that $(F'_{\nu_x}/F^o_{\nu_x}) \sim .62$. The observed ratio is $\sim .69$. This excellent agreement provides evidence not only for adiabatic expansion but also for the SSC model. If we assume an initial size $r^o_s \sim 6.8$ light days then expansion by 1.08 in $\sim$ 3 days implies a source expansion velocity of $\beta_o \sim .18$ for a spherically symmetric expanding source. This velocity agrees quite well with that derived above from variability time arguements.

We note that if the monitoring radio frequency $\nu_{obs} << \nu_A$, that variations in $F_{\nu_{obs}}$ should be anti-correlated with changes in the X-ray luminosity. We thus predict that at some times, if the SSC model is correct, the X-ray and 10.7 GHz radio fluxes will vary out of phase. The lack of simultaneous multi-frequency data in 1975 does not permit us to determine if the 1975-1976 flux decrease was due to adiabatic expansion. However, if the source expansion velocity was constant during this epoch at $\beta \sim .2$ we would have expected $\rho \sim 9.7$ and that there would be no observable X-ray or radio flux in 1976. Thus combination of 1975 and 1976 data indicates reinjection or reacceleration of particles and/or time dependent expansion. If we assume that the radio turnover frequency and spectral index in 1975 were the same as in July 1976, we derive source parameters of $\theta_s \sim .26$ ms and $B \gtrsim 5.4 \times 10^{-2}$ gauss.

The X-ray flux increase seen over days 218-220 1976 could be due to reinjection or reacceleration of relativistic particles. We would require the new particles to have approximately the same spectral index as those emitting before the event. If we fix ν_A and α and only allow F_{ν_A} to vary the X-ray data imply a 5% change in the radio flux. Unfortunately, simultaneous 10.7 GHz data are not available.

VI. CONCLUSIONS

The combined radio, infrared and X-ray data allow one to construct a coherent complete model for Cen-A, for the 1976 epoch. The X-ray and radio spectral index and intensity variability correlations give strong evidence for a single component synchrotron self-Compton model of X-ray production. In this model adiabatic expansion and reinjection/reacceleration provide the mechanism for variability. No relativistic effects are required, nor is a 2 component source model.

The millimeter, 100μ, 10μ and X-ray data are consistent with the X-ray absorption occurring in a cold dusty H_2 region located around the nucleus. The total IR spectrum is due to emission of cold dust in a model similar to that proposed by Jones et al. for NGC 1068. The 10μ IR data are not consistent with an extrapolation of the non-thermal radio flux into the IR.

The X-ray data give the determination of Fe abundance in a giant elliptical galaxy. The observed strength of the 6.4 keV fluorescent Fe line agrees with the expected strength based on the depth of the observed 7.1 keV K edge. The inferred abundance of Fe, $\left[\mathrm{Fe/H}\right] = -4.79$ is slightly below the cosmic value. Since X-ray measurements really refer to Fe/CNO the total N_H is not well determined by X-ray data alone.

The combination of a moderate energy resolution X-ray detector with simultaneous radio and IR observations have allowed the construction of a consistent model for this complicated and peculiar galaxy. We strongly suggest that similar observations of other compact extragalactic X-ray sources be performed.

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TABLE I. PHOTON SPECTRA PARAMETERS WITH NO Fe LINE

Date Of Year	α	N_H (x 10^{23})	A	χ^2/d o.f.
208-211,1975	1.70±.03	1.386±.054	$.363^{+.024}_{-.029}$	.825
211-214,1975	1.635±.04	1.26±.090	$.367^{+.035}_{-.045}$	.735
214-217,1975	1.685±.04	1.296±.063	$.417^{+.036}_{-.029}$	1.39
211-214,1976	1.66±.03	1.35±.054	$.228^{+.015}_{-.014}$	1.52
214-218.4,1976	1.67±.04	1.44±.041	$.185^{+.012}_{-.019}$	.855
218.4-221.5,1976	1.64±.03	1.296±.072	$.192^{+.017}_{-.016}$	1.29

For fit of form

$$\frac{dN}{dE} = (A \pm \Delta A) \exp\left(-(N_H \pm \Delta N_H)\sigma\right) E^{-(\alpha \pm \Delta\alpha)} \text{ ph/cm}^2 \text{ sec keV}$$

For all the data equally weighted

α = 1.665 ± .025

N_H = (1.337 ± .066) x 10^{23}

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FIGURE CAPTIONS

Figure 1 The 2-60 keV flux from Cen-A binned in 15,000 sec. intervals. This data has been corrected for source aspect. The days refer to day numbers of 1975 and 1976 respectively. The 10.7 GHz radio data for 1976 (Beall et al. 1977) is super-imposed on the X-ray data, as diamonds, and is referenced to the right hand scale.

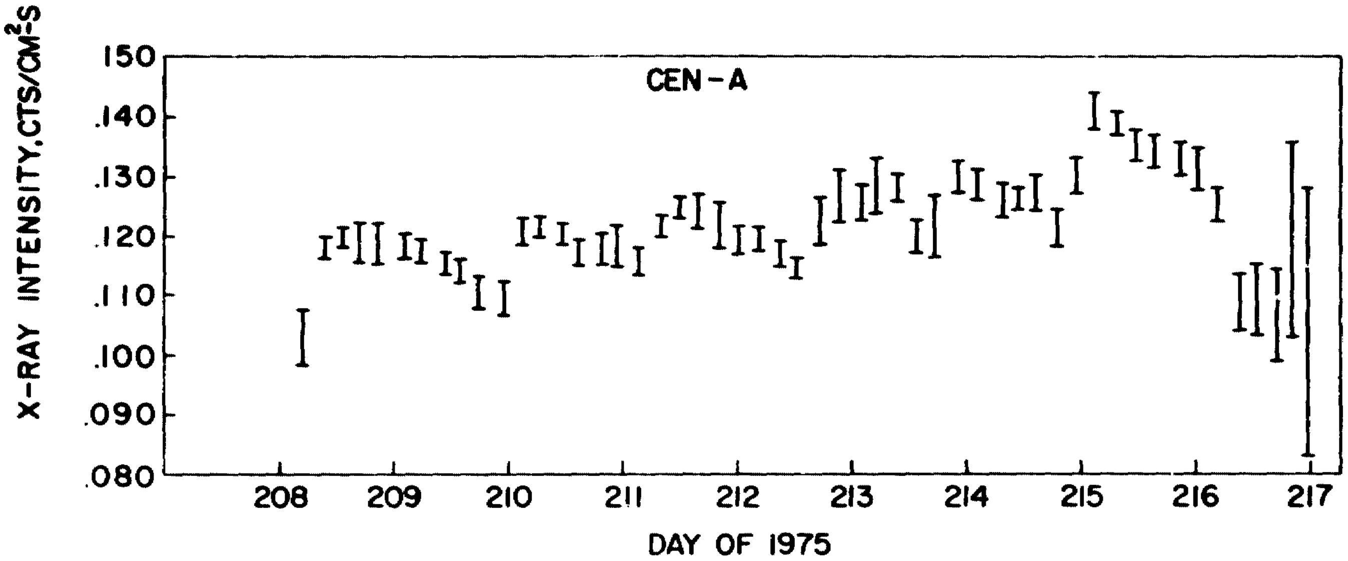
Figure 2a. Continuum X-ray spectra of Cen-A in ph/cm^2 sec keV. The upper points are 1975 data and lower 1976 data--there has been no shift in the zero points.

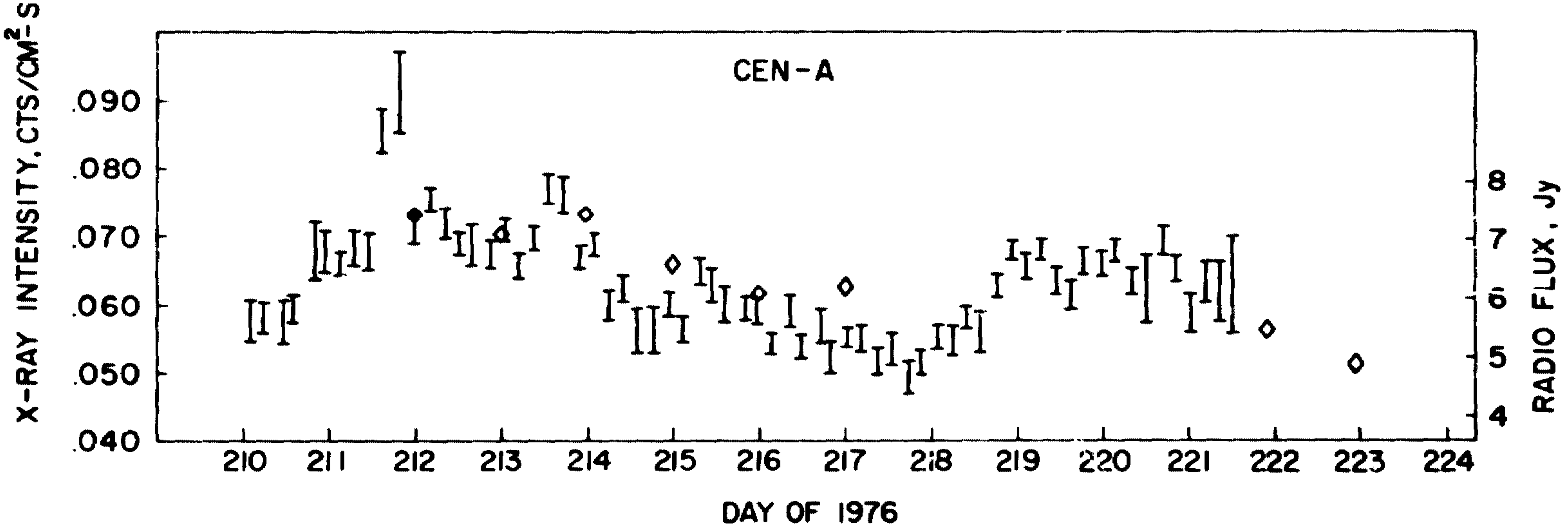
Figure 2b. The fit to the data on days 216-219 in 1976, including a power law, low energy absorption and a line at 6.4 keV. The dotted line is the fit folded back through the detector response, the points are pulse height counts/keV.

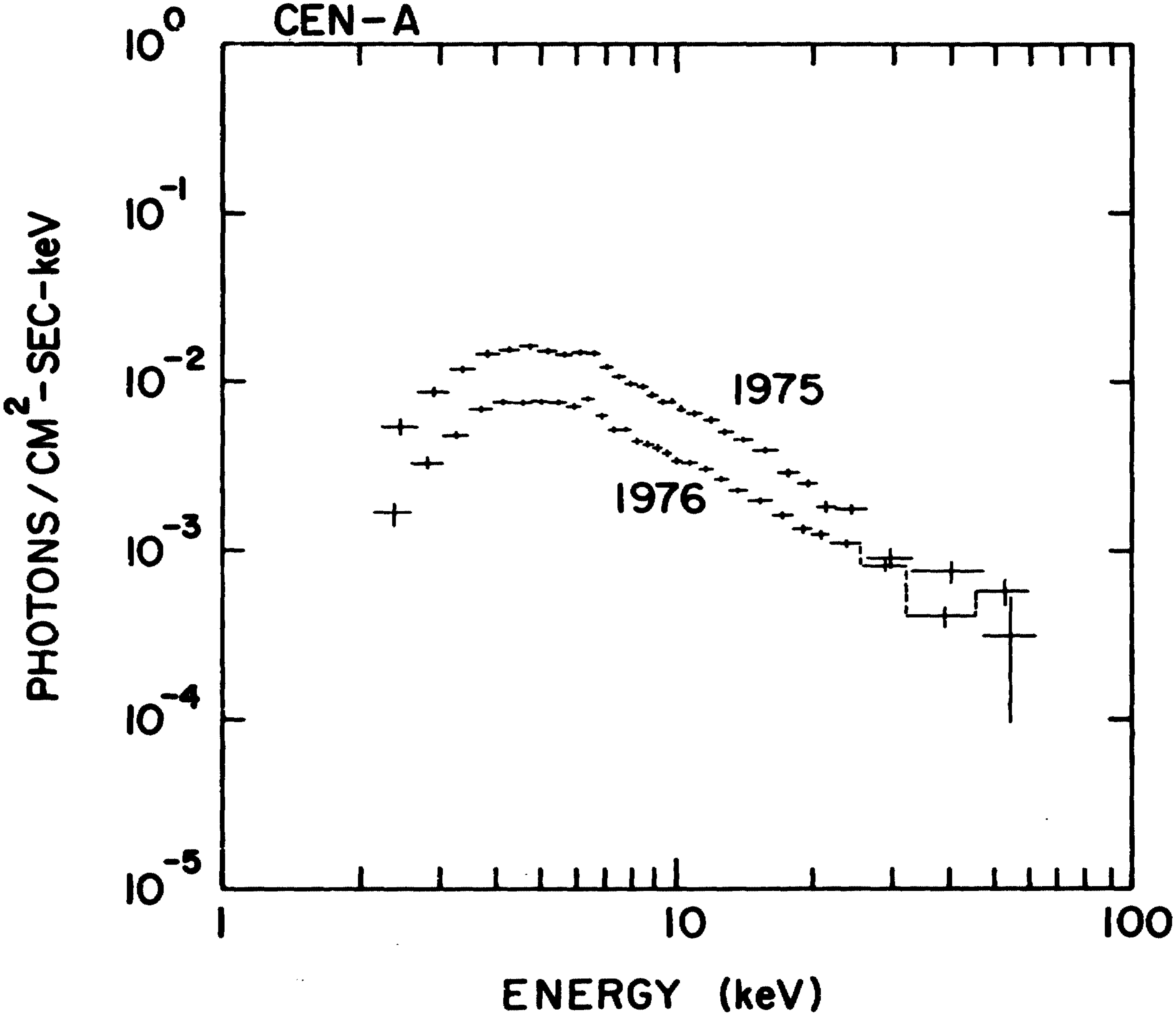
Figure 3. The composite spectrum of Cen-A in July 1976. The 10.7 GHz (V), 31.4 (DH), 90 GHz (CU) data are from Beall et al. (1977). The 2, 10.7 GHz points are from day 212 and 217, 1976. The 31.4 GHz is from day 154, 1976 and the 90 GHz data from day 212, 1976. The 22 GHz data, K, is from Kaufmann et al. (1977) from day 212, 1976. The 1 mm data, H1, is from Hildebrand (1977) taken in June 1976 and the 100μ, Hz, data from Harper (1977) and is from 1976. The 2-11μ data, circles, is from Grasdalen and Joyce (1976) with the filled circles uncorrected and the open circles corrected for reddening. The optical data, diamonds, is from Kunkel

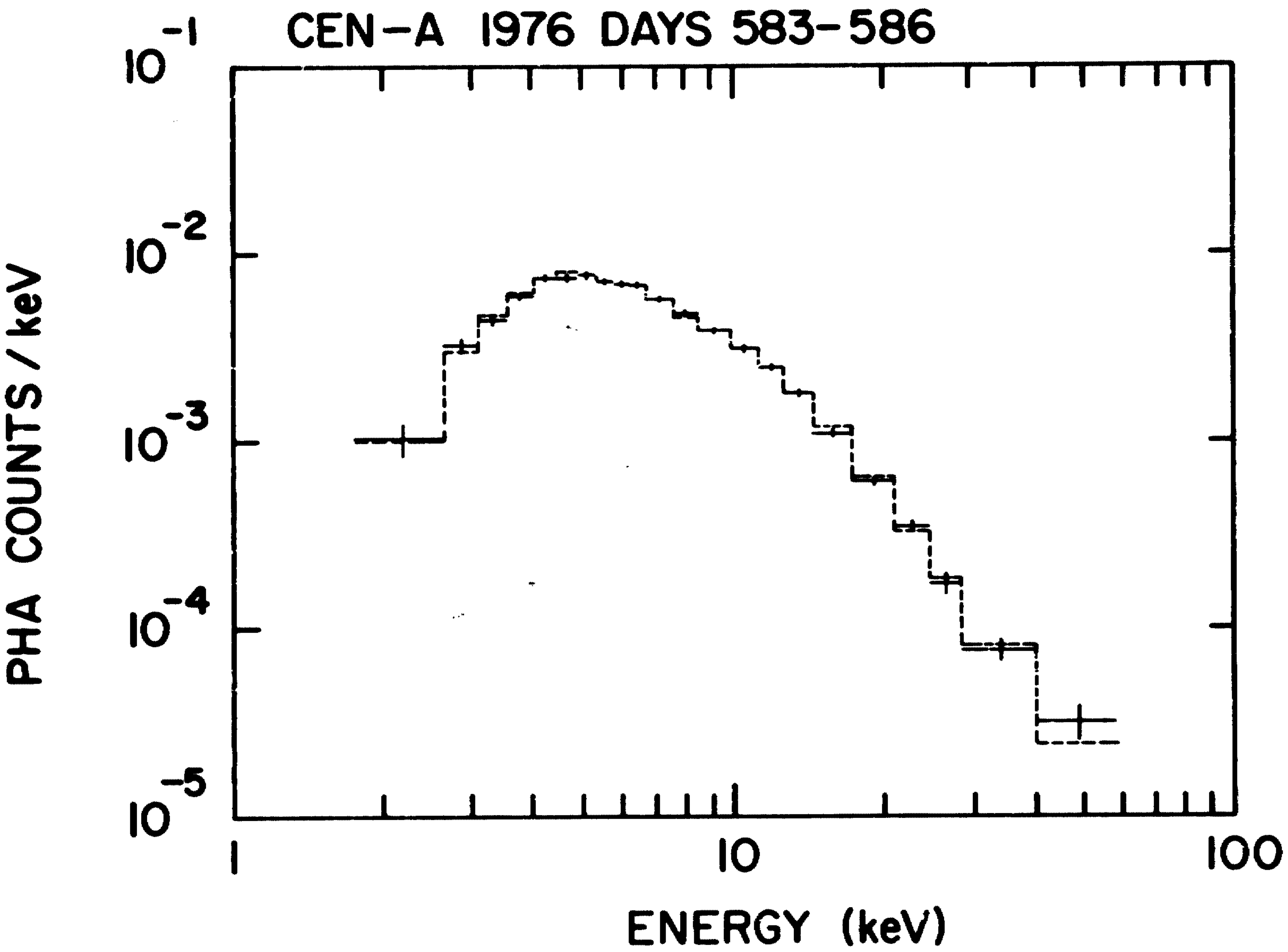
and Bradt (1971). The X-ray data is from days 211-214, 1976. The dotted line through the IR data flux is a model fit from Leung (1976) and is normalized at 100μ.

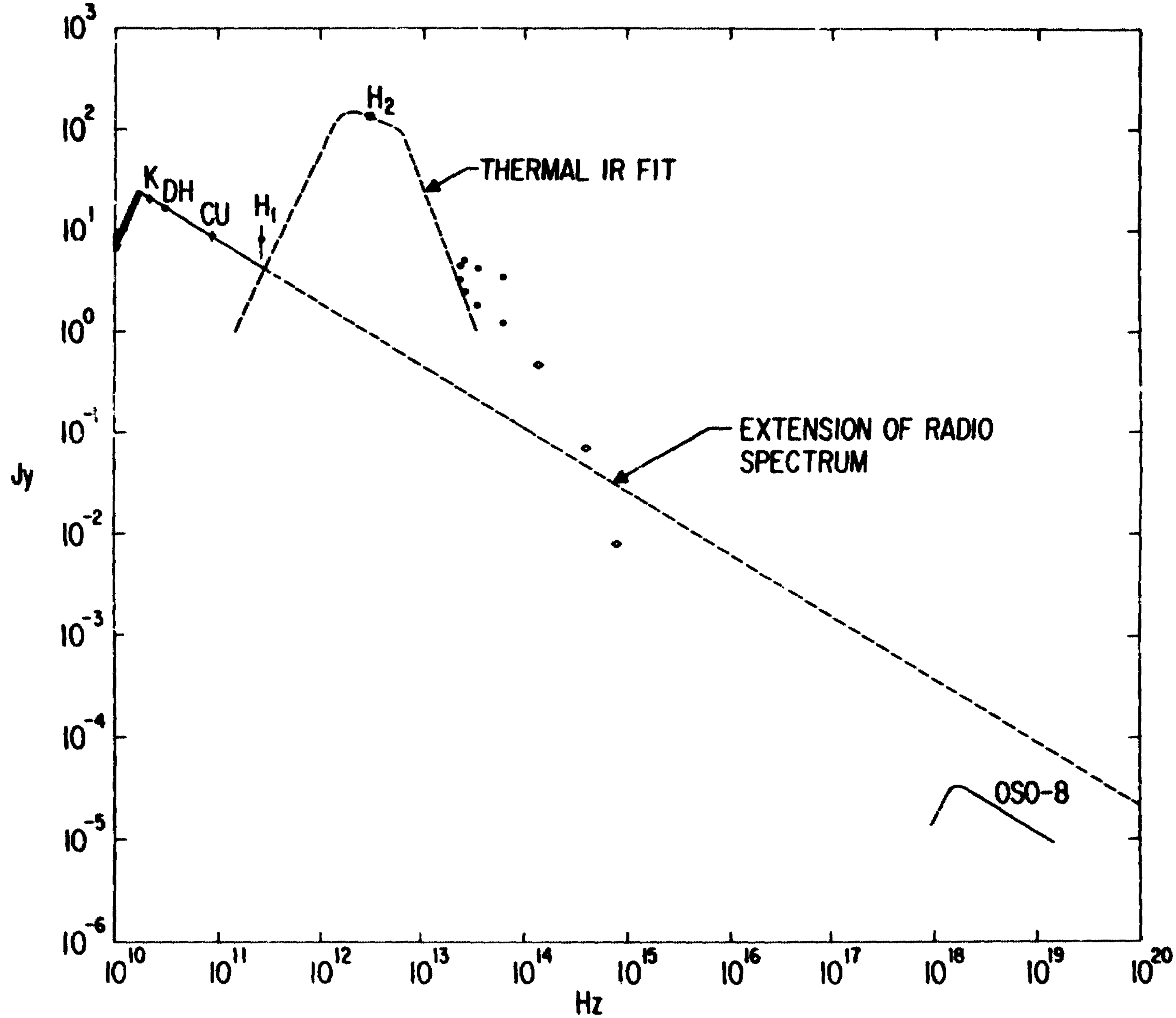
Figure 4. The residual counts above the best fit power law for the composite 1975-1976 Cen-A spectrum in the 5-11 keV range. Note the line at ∿ 6.4 and edge feature at ∿ 7.1 keV, indicated by arrows.


CEN-A
X-RAY INTENSITY, CTS/CM^2-S
150
.140
.130
.120
.110
.100
.090
.080
208
209
210
211
212
213
214
215
216
217
DAY OF 1975

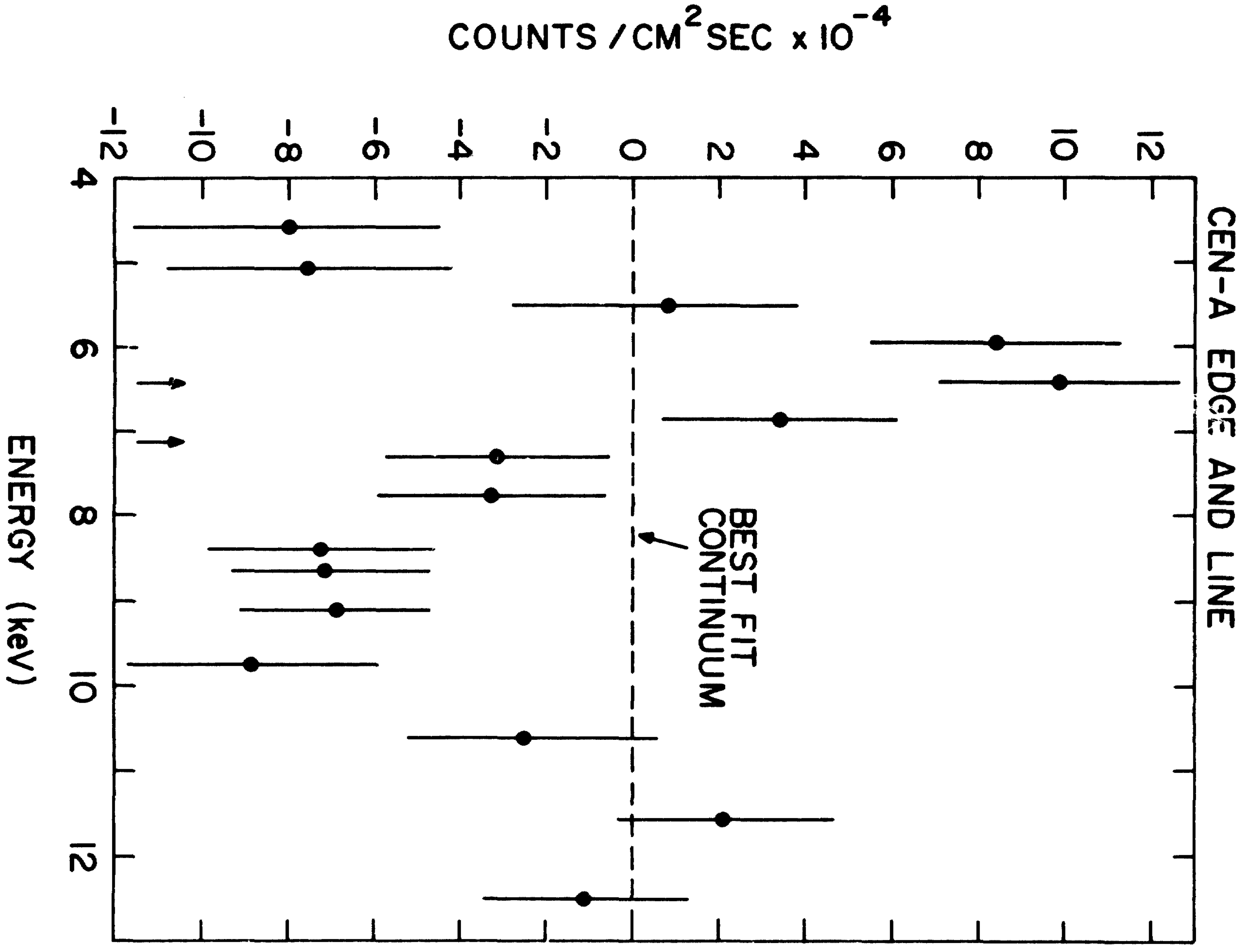

CEN-A
X-RAY INTENSITY, CTS/CM^2-S
.090
.080
.070
.060
.050
.040
RADIO FLUX, Jy
8
7
6
5
4
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
DAY OF 1976


CEN-A
PHOTONS / CM^2-SEC-keV
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1975
1976
1
10
100
ENERGY (keV)


CEN-A 1976 DAYS 583-586
PHA COUNTS / keV
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
ENERGY (keV)
1
10
100



Jy
Hz
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^10
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
K
DH
CU
H1
H2
THERMAL IR FIT
EXTENSION OF RADIO SPECTRUM
OSO-8


CEN-A EDGE AND LINE
COUNTS / CM^2 SEC x 10^{-4}
ENERGY (keV)
BEST FIT CONTINUUM
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
4
6
8
10
12