Some 1.7 g (specific area, 1.4 m^2/g) of $LaCoO_3$ (*2*) at room temperature (25°C) and at a flow rate of about one new volume of intercrystalline gas every second showed 4 percent reduction of butene-2 to *n*-butane with substantial isomerization. The feed gas was hydrogen with about 2 percent olefin (*cis*-2-butene) by volume. At 100°C the yield of *n*-butane was 22 percent at the same time there was essentially an equilibrium isomerization. At higher temperatures hydrogenolysis sets in. At 280°C and a contact time of about 1 second the yield was 31 mole percent methane, 8 percent ethane, 9 percent propane, 10 percent *n*-butane, 0.1 percent 1-butene, 4.6 percent *trans*-2-butene, and 9.4 percent *cis*-2-butene from a feed of approximately 2 percent *cis*-2-butene in H_2 at 1 atmosphere total pressure. Detailed data are given in Table 1. Some butadiene was formed above 200°C, and there were other products (still undetermined) above 230°C.

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3. Supported in part by the Air Force Office of Scientific Research under grant AF-AFOSR-1255-67 Mod. C and by NASA (grant NASA-05-007-003).

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X-rays from Centaurus A and the Far-Infrared Background Radiation

In a recent report Byram *et al.* (*1*) reported that they have detected x-rays from Centaurus A with an observed flux in the 1- to 10-kev region of $(4.3 \pm 1.6) \times 10^{-2}$ kev cm^{-2} sec^{-1}. By comparing this measurement with the x-ray flux that would result from Compton scattering of ambient photons by the radio-producing electrons in the nebula, Byram *et al.* (*1*) concluded that their x-ray measurement is below that predicted with the use of the far-infrared observations of Shivanandan *et al.* (*2*), Houck and Harwit (*3*), and Muehlner and Weiss (*4*), all of which indicate the existence of a diffuse background radiation substantially above 3°K in the submillimeter region. This conclusion, however, is based on a crude calculation which neglects the spectral characteristics of both the synchrotron and the Compton radiations and overestimates the x-ray output by up to an order of magnitude. Furthermore, an independent measurement by Bowyer *et al.* (*5*) indicates that the x-ray flux from Centaurus A in the 1- to 10-kev region is about 1.7×10^{-1} kev cm^{-2} sec^{-1}, that is, higher by a factor of 4 than that reported by Byram *et al.* (*1*). The inconsistency between the x-ray and far-infrared measurements is therefore open to serious question and should be considered in more detail.

I studied this problem by using a more complete treatment of synchrotron and Compton radiations. By taking into account the uncertainties in the physical parameters in the radiating region, I found that both measurements in the 1- to 10-kev region, as well as the upper limits on the hard x-ray flux from Centaurus A obtained by Haymes *et al.* (*6*), are consistent with the existence of a high metagalactic submillimeter background substantially above the 3°K background observed at submillimeter wavelengths.

If the electrons in the source region have a power law spectrum,

$$N(\gamma) = k\gamma^{-\Gamma} \text{ electrons (unit } \gamma)^{-1} \quad (1)$$

where γ is the electron Lorentz factor (E/mc^2), Γ is the spectral index, and k is a normalization constant, the synchrotron flux density at the earth (in watts per square meter per hertz) is given by (*7*)

$$F_s(\nu) = 1.35 \times 10^{-25} a(\Gamma) k R^{-2} B^{(\Gamma+1)/2} \times (4 \times 10^{-2})^{(\Gamma-1)/2} (10^8/\nu)^{(\Gamma-1)/2} \quad (2)$$

where B is the magnetic field of the source in gauss, R is the distance in centimeters, ν is the frequency in hertz, and $a(\Gamma)$ is a slowly varying function of Γ, with $a(\Gamma) \cong 0.1$ for $\Gamma \cong 2.5$.

The Compton flux density (in kiloelectron volts per second per square centimeter per kiloelectron volt) from the same electron distribution is given by (*8*)

$$F_c(\epsilon) = 10^{-18} \rho k R^{-2} \times (4/3\epsilon_0)^{(\Gamma-3)/2} \epsilon^{-(\Gamma-1)/2} \quad (3)$$

where ρ is the ambient photon energy density in electron volts per cubic centimeter, and ε_0 and ε are the energies of the incident and scattered photons, respectively, in kiloelectron volts. By combining Eqs. 2 and 3, we get

$$F_c(\epsilon) = 7.5 \times 10^7 \rho F_s(10^8 \text{ hz}) \times (4 \times 10^{-2})^{-(\Gamma-1)/2} B^{-(\Gamma+1)/2} \times (4/3\epsilon_0)^{(\rho-3)/2} \epsilon^{-(\Gamma-1)/2} \quad (4)$$

Thus, the x-ray flux depends only on the measured radio flux and the magnetic field and photon energy density in the nebula, and is independent of the distance and the normalization of the radiating electron spectrum. For the parameters used by Byram *et al.* (*1*) [$\Gamma = 2.54$, $B = 4 \times 10^{-6}$ gauss, $\varepsilon_0 = 1.2 \times 10^{-3}$ ev (1 mm)] and $F_s(10^8$ hz$) = 7.6 \times 10^{-23}$ watt m^{-2} hz^{-1} (*7*), the integral of Eq. 4 from 1 to 10 kev yields

$$F_c(1 \text{ to } 10 \text{ kev}) = 0.015\, \rho \text{ kev sec}^{-1} \text{ cm}^{-2} \quad (5)$$

For $\rho = 0.25$ ev cm^{-3} and $R = 3.8$ megaparsecs, Eq. 5 yields an x-ray luminosity of 0.9×10^{40} erg sec^{-1}, which is a factor of 6 lower than that computed by Byram *et al.* for the same parameters (*1*). This discrepancy is the direct result of the neglect of the spectral distributions of the x-ray and radio emissions. The electrons used in the calculation of Byram *et al.* (*1*) correspond to the energy range ~0.25 to

Table 1. X-ray fluxes (in kiloelectron volts per square centimeter per second) from Centaurus A in the range from 1 to 10 kev.

B (gauss)	$\rho =$ 6 ev cm^{-3}	$\rho =$ 13 ev cm^{-3}
	Calculated x-ray flux	
4×10^{-6}	0.09	0.2
10^{-5}	0.02	0.04
	Observed x-ray flux	
Byram *et al.* (*1*)		0.043 ± 0.016
Bowyer *et al.* (*5*)		0.17

Table 2. Fluxes of hard x-rays from Centaurus A.

Energy interval (kev)	Calculated flux (photon cm^{-2} sec^{-1} kev^{-1})	Upper limits (*6*) (photon cm^{-2} sec^{-1} kev^{-1})
34– 60	7×10^{-5}	2.9×10^{-4}
60–100	2.8×10^{-5}	1.4×10^{-4}
100–250	7×10^{-6}	1.9×10^{-5}
250–567	1.6×10^{-6}	1.5×10^{-5}

12.5 Bev and will produce x-rays from several hundred electron volts to about 1 Mev. A monoenergetic approximation will therefore overestimate the x-ray output in any subinterval of this energy range.

The value of 4×10^{-6} gauss for the magnetic field in Centaurus A is based on equipartition between the energy densities in cosmic rays and magnetic fields in the nebula (*7*). The magnetic field, however, can have a significantly higher value, and a value of up to 10^{-5} gauss is consistent with polarization measurements of radio emission from Centaurus A (*9*).

In Table 1 I summarize the predicted low-energy x-ray fluxes and compare them with the available measurements. Even if the observations are considered as upper limits, for $B = 10^{-5}$ gauss both $\rho = 6$ ev cm^{-3} (*10*) and $\rho = 13$ ev cm^{-3} (*2*) are consistent with the x-ray measurements. If $B = 4 \times 10^{-6}$ gauss, the predicted x-ray fluxes are still consistent with the measurements of Bowyer *et al.* (*5*) but are somewhat larger than those of Byram *et al.* (*1*).

I shall now consider the upper limits at higher energies. From Eq. 4, for $B = 4 \times 10^{-6}$ gauss, the photon flux is

$$\phi = 5 \times 10^{-3} \, \epsilon^{-1.77} \times \rho \text{ photon cm}^{-2} \text{ sec}^{-1} \text{ kev}^{-1} \quad (6)$$

In Table 2 the upper limits obtained by Haymes *et al.* (*6*) are compared with the predicted fluxes at several selected energies (47, 80, 175, and 408 kev), for $\rho = 13$ ev cm^{-3}. As can be seen, for the choice of parameters that produces the largest x-ray output, the calculated fluxes are all lower than the measured upper limits.

I conclude that all the available x-ray measurements are consistent with a metagalactic submillimeter background. Moreover, if the x-ray emission from Centaurus A is produced solely by Compton scattering in the nebula and if a magnetic field of 4×10^{-6} gauss (based on equipartition between the magnetic field and cosmic-ray energy densities for a proton-to-electron ratio of 100 to 1) is indeed a lower limit, a photon density of at least 2.5 ev cm^{-3} is required to account for the low-energy x-ray observations. It has recently been suggested (*11*) that the high submillimeter background results from the superposed contribution of powerful extragalactic infrared sources. It is clear that this suggestion is not ruled out by the available x-ray flux measurements of Centaurus A.

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In our report (*1*) we attributed the evidence of x-ray emission from Centaurus A to inverse Compton scattering of the cosmological background radiation in the extended radio clouds. Taking our marginal observation of x-rays as an upper limit, we concluded that the background temperature was closer to 3°K than to the 7° or 8°K (50 times higher energy density) indicated by infrared measurements.

Ramaty criticizes us on the following counts:

1) That the approximations that we used in predicting the flux from radio measurements lead to an error of a factor of 6 in the sense of overestimating the theoretical flux.

2) That Bowyer *et al.* (*2*) observed a flux from Centaurus A four times higher than our upper limit.

3) That our choice of equipartition magnetic field, 4×10^{-6} gauss, is not necessarily correct; he suggests that 10^{-5} gauss is equally plausible and cites observational evidence from Cooper *et al.* (*3*).

Our responses to these criticisms are as follows:

1) We agree that Ramaty's calculation of the inverse Compton flux is more precise than our approximation and accept his lower value.

2) Bowyer *et al.* identified the flux they observed with the region centered on the optical galaxy and without the inclusion of the emission peaks of the radio clouds. In effect, they claimed no evidence for inverse Compton x-rays from the extended radio sources. Our own observations showed no evidence (signal-to-noise ratio, $-0.8\ \sigma$) for emission from the southernmost radio cloud. The $\sim 3\ \sigma$ indication of x-ray emission from the northern cloud was weighted as much toward the optical galaxy as toward the center of the northern radio cloud. Since the radio emission is equally divided between the northern and southern clouds, the total lack of evidence for x-rays from the southern cloud could be used as an argument for substantially reducing our upper limit value of inverse Compton flux.

3) Cooper *et al.* observed the Faraday rotation produced by our own galactic halo on the radio flux from Centaurus A and concluded that the upper limit of the galactic magnetic field in our own galactic halo is about 10^{-5} gauss. Ramaty appears to have confused this observation as evidence for the magnetic field in Centaurus A. Cooper *et al.* further estimated that no more than 1/6 of the measured rotation could be attributed to the radio source itself. We believe that support for our choice of 4 microgauss for the equipartition magnetic field is indicated by the smoothness of the polarization distribution in Centaurus A. Other authors (*4*) have used field strengths as low as 10^{-6} gauss.

We believe that the evidence points toward a background temperature of 3°K rather than 8°K, but it is most important to improve the x-ray observation with sufficient sensitivity and resolution to distinguish clearly whether any x-ray emission originates in the extended radio clouds as distinct from the nuclear region.

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