THE ASTROPHYSICAL JOURNAL, 163:L73–L77, 1971 January 15

EXCESS BACKGROUND RADIATION OF SOFT X-RAYS AT THE GALACTIC POLE AND PLANE

RICHARD C. HENRY
E. O. Hulburt Center for Space Research, and
The Johns Hopkins University, Baltimore, Maryland

AND

GILBERT FRITZ, JOHN F. MEEKINS, TALBOT CHUBB, AND H. FRIEDMAN
E. O. Hulburt Center for Space Research,
Naval Research Laboratory, Washington, D.C. 20390
Received 1970 November 14

ABSTRACT

A Teflon-windowed proportional counter has been used to measure a flux of 18 Å (0.68 keV) X-rays from regions near the North Galactic Pole. This flux is significantly in excess of what is predicted by extrapolation of the X-ray background spectrum between 2 and 10 keV, which was observed simultaneously by both a Teflon- and a Mylar-windowed counter. A possible source of this soft X-ray background is thermal emission from a dense intergalactic medium. The spectrum between 2 and 10 keV suggests that the break toward higher energies occurs closer to 10 keV than 40 keV. A flux of soft X-rays is also observed in the galactic plane near $l^{II} = 190°$. Unexplained line features at 6 and 7 keV are present in the data.

I. INTRODUCTION

We have previously reported (Henry *et al.* 1968, hereafter called Paper I) a simultaneous measurement of the background X-ray flux at high galactic latitudes at about 44 Å (0.27 keV) and between 1.5 and 8 keV. The energy intensity measured at 44 Å stood a factor of 5–35 (depending on the allowance for interstellar absorption) above the flux predicted by extrapolation from the higher energies. It appeared that an independent source was contributing at 44 Å. Thermal radiation from a hot intergalactic plasma was suggested as a possible explanation of our data, and we deduced that the density, if the gas is smoothly distributed, must be close to the so-called cosmological density required for closure of the Universe.

Serious doubt has been cast on the reality of the rise in the X-ray background at low energies for the following reasons: (1) the wide range of values of the 44 Å flux that has been reported (Bowyer, Field, and Mack 1968; Baxter, Wilson, and Green 1969*a*, *b*; Bunner *et al.* 1969; Shukla and Wilson 1970; and our present and earlier results); (2) the suggestion by Bowyer and Field (1969) that low-energy particles might simulate X-rays; and (3) the observation of such low-energy particles (Stevens and Garmire 1970). In addition, measurements at 44 Å are troubled by the question of the allowance to be made for interstellar absorption. Even if the 21-cm emission at the galactic pole correctly indicates the amount of material in that direction—a matter subject to some doubt (Carruthers 1970)—Bowyer and Field (1969) and Bunner *et al.* (1969) have pointed out that unevenness in the distribution of that material would lead to reduced X-ray attenuation.

In view of these difficulties at 44 Å, we have made a measurement of the background flux at 18 Å, where the interstellar absorption is substantially reduced. Our new observations, described below, appear to confirm the existence of an excess soft X-ray component.

II. NEW OBSERVATIONS

At 22:30 MST on 1969 March 13, an Aerobee rocket was launched at White Sands Missile Range. Two X-ray proportional counters, one with a Mylar window having transmission bands bordering on 44 Å (0.27 keV) and over the range 0.8–13 keV, and one with a Teflon window having transmission bands bordering on 18 Å (0.68 keV) and over 1.2–13 keV, scanned the galactic plane near $l^{II} = 190°$ and also near the North Galactic Pole. The data obtained will be discussed in detail elsewhere, but the key results are summarized here.

Figure 1 shows the spectrum accumulated with the Teflon-window counter during 81 seconds of observation near the galactic pole, expressed in counts (cm² sec sterad keV)$^{-1}$. A non–X-ray background of about 15 counts sec^{-1} over the energy range 0.4–10 keV, and independent of energy, has been subtracted. This rate was determined by observing the inside of a protective door covering the detector during the ascent of the rocket.

The pronounced peak in the observed spectrum near 0.6 keV (Fig. 1) is what would be expected from the known transmission properties of the Teflon window if the counts being recorded are really caused by X-rays entering the counter. Thus, this characteristic X-ray response pattern constitutes proof that the flux, even at as low an energy as 0.6 keV, is due to X-rays.

Theoretical X-ray spectra have been folded through the instrument sensitivity and resolution in a manner that has been previously described (Meekins *et al.* 1969). The curve in Figure 1 marked -1.4 is the X-ray background spectrum in the range 1.5–10 keV, $I = 12.6\,E^{-1.4}$ photons (cm² sec sterad keV)$^{-1}$, which we reported in Paper I. It fits the present data quite well above 2 keV, but a strong excess appears at lower energies and in particular at 18 Å. The curve labeled -2.0 is an attempt to fit the whole range of data with a single power law of that index. A slope even steeper than -2.0 would be required to obtain a fit at 18 Å, and this would worsen the fit above 3 keV. The energy

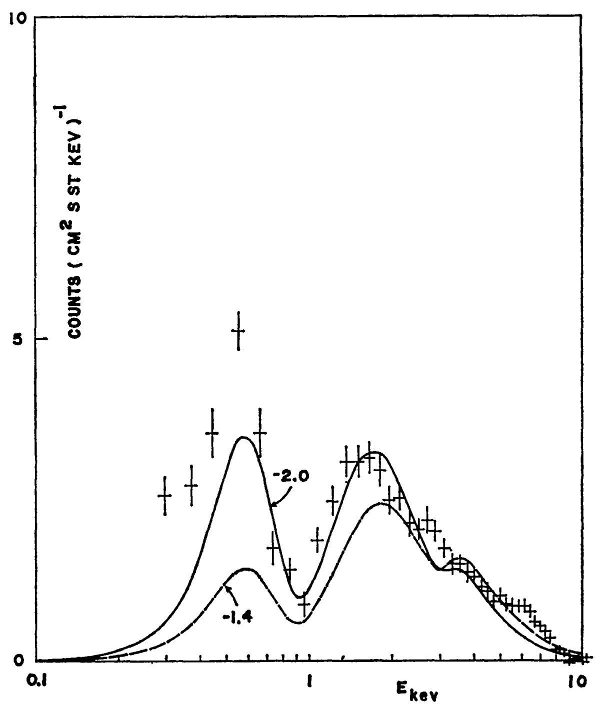

FIG. 1.—Response of a Teflon-windowed X-ray proportional counter pointed near the galactic pole. The pronounced peak in the data near 0.6 keV, where Teflon preferentially transmits X-rays, shows that a flux of genuine X-rays is actually being observed. The data above 2 keV fit a power-law spectrum of index -1.4, with a strong excess over such a power law at 18 Å (0.6 keV). An attempt to fit the entire range of data with a single power law of index -2.0 fails. The -2.0 curve is the lower curve above 3 keV. Vertical standard error bars are 2 σ in length.

calibration for the spectra was obtained in flight by using a ^{55}Fe source. A spectrum of the Crab Nebula taken before the background spectra suggests the possibility of a 5 percent increase in gain during the flight. This would improve the fit in the background spectrum for the -2.0 slope to some extent. However, no observer has reported the possibility of a slope even as steep as -2.0 in the range 2–8 keV. We conclude that a genuine excess of soft X-rays occurs at the galactic pole.

Of course, this analysis is based on the assumption that the background spectrum is a smoothly varying continuum. Our spectrum shows evidence for the presence of line features, discussed below; and if such features form a significant fraction of the total radiation, a detailed high-resolution study of the spectrum will eventually be necessary.

The Teflon detector gave comparable evidence for an 18 Å flux in the galactic plane $l^{\mathrm{II}} = 190°$, where extragalactic radiation at this wavelength would be completely removed by absorption in the interstellar gas.

The experiment at 44 Å was less successful. No peak in the counting rate was observed centered on 0.27 keV. Postflight laboratory tests revealed significant ultraviolet sensitivity of the detector just below, but not at, the 0.27-keV peak. Therefore, we cannot have the confidence regarding our 44 Å measurement that the data permit at 18 Å.

III. SOFT X-RAY SPECTRA: POLE AND PLANE

In Figure 2, the observed data points from the two counters are plotted against the spectra of those source models found to be most consistent with the data. In both the Galaxy and pole spectra, data from the Mylar counter are represented by crosses and those from the Teflon counter by crosses with dots. The lowest-energy Teflon point is the 18 Å point.

In the pole spectrum, the data points lie close to the curve labeled P, which represents an intensity

$$I = 12.6\,E^{-1.4} + \frac{175}{E}\exp\left(-\frac{11.6}{4.5}E\right)\ \text{photons (cm}^2\ \text{sec sterad keV)}^{-1}\,, \qquad (1)$$

where E is in keV—that is, a power law which dominates at higher energies, and a thermal component which dominates at lower energies. This curve falls somewhat below the data, whereas adding a thermal component of 3×10^6 ° K instead of 4.5×10^6 ° produces a curve that exceeds the data somewhat; the two curves suggest the range of temperature that the data will tolerate. However, we cannot distinguish between an added thermal component and a change in index from -1.4 to about -2.5 below 1.8 keV.

In Paper I we suggested that the excess soft component might have a temperature $\sim 1 \times 10^6$ ° K, and the curve in Figure 2 labeled 1968 shows such a component added to the higher-energy power law. It does not describe the excess flux that appears near 1 keV, an energy region that we did not observe in 1968. Curve C represents the power-law spectrum alone, and the difference between it and curve P shows the amount of the excess flux. Curve B is the spectrum reported by Bunner *et al.* (1969). For each curve, except B, we have assumed interstellar absorption corresponding to a density of 0.55 H atoms cm^{-3}, a value suggested by observation of absorption of X-rays from the Crab Nebula (Fritz *et al.* 1971), a galactic half-thickness of 150 pc, and the cosmic abundances used by Brown and Gould (1970).

The higher temperature found in the present investigation and in that of Bunner *et al.* (1969), if attributed to intergalactic gas, requires that the density be somewhat reduced, but no more than the uncertainty in the flux measurement. This result, combined with uncertainties in the heating history of the assumed gas and its unknown degree of clumpiness in intergalactic space, does not justify estimating the intergalactic gas density any closer than the range 10^{-6} to 10^{-5} cm^{-3} if the radiation we observe is actually due to bremsstrahlung from such gas. The high temperature suggests that the radiation is not due to emission from a galactic halo, for Spitzer (1956) has shown that so hot a halo would not be gravitationally bound to the Galaxy.

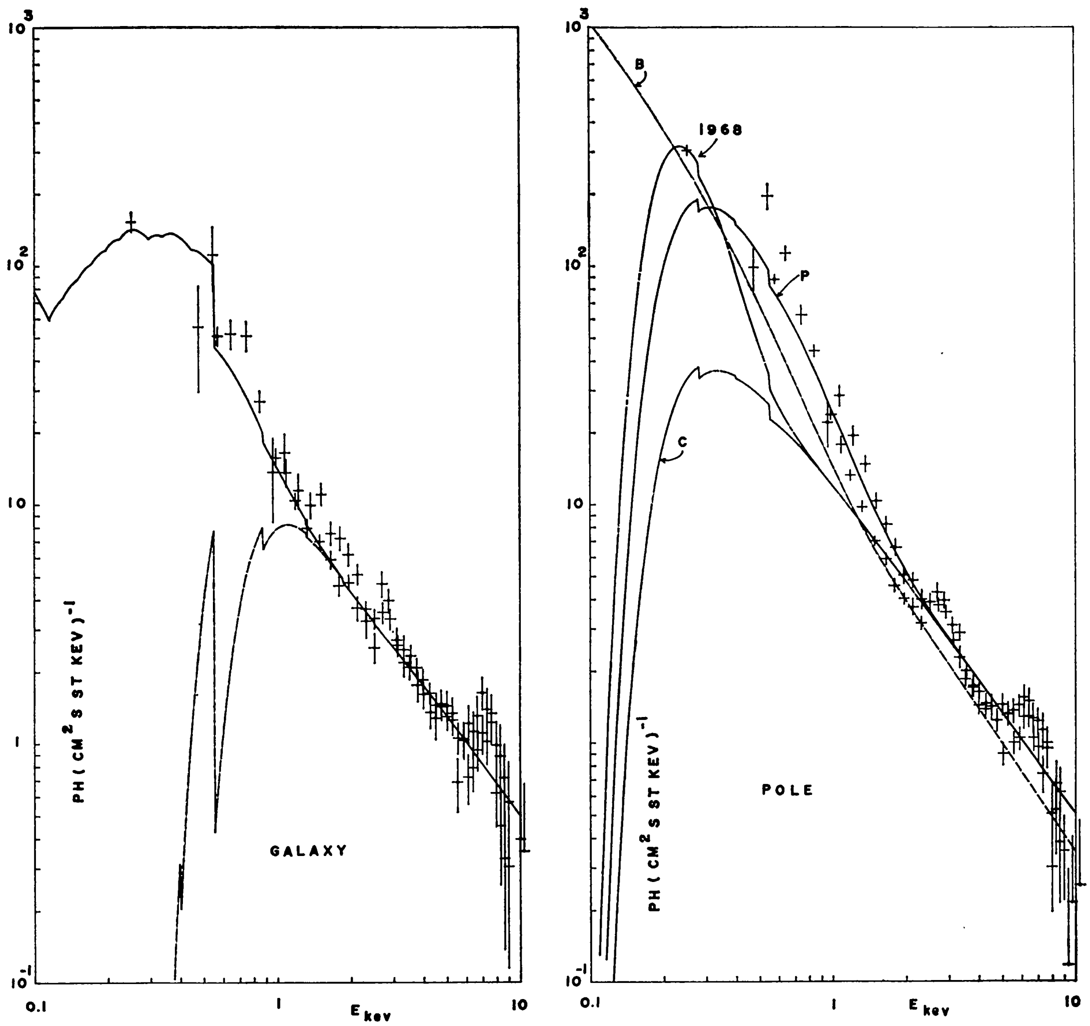

FIG. 2.—The X-ray spectra observed at the galactic pole and in the galactic plane. Curve P at the pole is a sum of a power law and a thermal component at 4.5×10^6 ° K that fits the data fairly well. The effect of absorption by interstellar gas (0.55 atoms cm^{-3}, 150 pc) is included. In Paper I we suggested a lower temperature source (e.g., curve 1968). Curve B is the observation of Bunner *et al.* (1969), and curve C is the curve P without the addition of the thermal component. The Galaxy data represent attenuated extragalactic radiation plus a thermal component at 2×10^6 ° K in the galactic plane; the lower curve is the intensity expected without this added component.

For the galactic plane, the data points are placed relative to the spectrum of a source model consisting of attenuated extragalactic radiation (derived from the spectrum labeled P) plus smoothly distributed galactic thermal emission at 2×10^6 ° K, partly absorbed by the interstellar gas. A galactic half-thickness of about 150 pc can be deduced for this emission from our data, which involved a scan over about 10° of latitude. In taking interstellar absorption into account, a smooth distribution at a density of 0.55 cm^{-3} was assumed, and material was taken to extend 3500 pc toward the anticenter. The spectral data probably exclude a power-law ("synchrotron") origin for this radiation, and we suggest that it may be due to many sources similar to Vul XR-1, reported in Paper I. The lower Galaxy curve shows the spectrum expected in the absence of any galactic emission.

IV. SPECTRA ABOVE 2 keV

Above 2 keV, interstellar attenuation is expected to be negligible and the X-ray spectra should be virtually identical between pole and plane. However, a very slight but statistically significant excess was observed in the plane, in agreement with Cooke, Griffiths, and Pounds (1969).

As in Paper I, we obtain a shallower slope and higher intensity for the background at 2–8 keV than do most other observers. As we pointed out in Paper I, extrapolation of our data to higher energies places the break in the slope of the X-ray background spectrum at about 10 keV rather than at the often accepted value of 40 keV. From a compilation of recent observations by Silk (1970) we judge that the break appears to be near 17 keV.

An apparently monochromatic feature occurs in our spectra (Figures 1 and 2) at 7 keV in the Galaxy spectrum and 6 keV in the pole spectrum. The feature appears in both counters at the same energy for a given position on the sky. It is about 1.5 keV wide in every case, as would be expected for a line-emission source, given the known resolution of our counter. It does not appear in the spectrum of the Crab Nebula measured on the same flight, and is not due to a feature in the subtracted non–X-ray background spectrum. It is statistically significant in each counter on each target. There are therefore strong grounds for accepting it as a real feature of the X-ray spectrum incident on our detectors. The statistics of most previously published observations were generally insufficient to reveal such a line in the background spectrum. An exception is Ducros *et al.* (1970), who report a similar feature—but at 5 keV—in both the background and the Crab.

There appears to be no acceptable explanation for this line feature in our spectrum. The similar strength of the line in the galactic plane and pole indicates that it is not a feature associated with normal galaxies, for in that case a pole-to-plane ratio similar to that of starlight would be expected. If it is radiation from unusual galaxies or intergalactic space, it should not appear at 7 keV when our own (normal) Galaxy is observed and at a different (6 keV) energy at high latitudes. A cosmic origin would also, because of the redshift, produce a *step* rather than an apparently redshifted ($z = 0.14$) line in the spectrum, unless a specific object were being observed. Thus, the observation is a most puzzling one.

The E. O. Hulburt Center for Space Research is partially supported by the National Aeronautics and Space Administration. One of us (R. C. H.) received support from a National Science Foundation grant.

REFERENCES

Baxter, A. J., Wilson, B. G., and Green, D. W. 1969*a*, *Ap. J.* (*Letters*), **155**, L145.
———. 1969*b*, *Canadian J. Phys.*, **47**, 2651.
Bowyer, C. S., and Field, G. B. 1969, *Nature*, **223**, 573.
Bowyer, C. S., Field, G. B., and Mack, J. E. 1968, *Nature*, **217**, 32.
Brown, R. L., and Gould, R. J. 1970, preprint.
Bunner, A. N., Coleman, P. C., Kraushaar, W. L., McCammon, D., Palmieri, T. M., Shilepsky, A., and Ulmer, T. M. 1969, *Nature*, **223**, 1222.
Carruthers, G. R. 1970, *Space Sci. Rev.*, **10**, 459.
Cooke, B. A., Griffiths, R. E., and Pounds, K. A. 1969, *Nature*, **224**, 134.
Ducros, G., Ducros, R., Rocchia, R., and Tarrius, A. 1970, preprint.
Fritz, G., Henry, R. C., Meekins, J. F., Chubb, T. A., and Friedman, H. 1971, submitted to *Ap. J.*
Henry, R. C., Fritz, G., Meekins, J. F., Friedman, H., and Byram, E. T. 1968, *Ap. J.* (*Letters*), **153**, L11.
Meekins, J. F., Henry, R. C., Fritz, G., Friedman, H., and Byram, E. T. 1969, *Ap. J.*, **157**, 197.
Shukla, P. G., and Wilson, B. G., preprint 1970.
Silk, J. 1970, preprint.
Spitzer, L. 1956, *Ap. J.*, **124**, 20.
Stevens, J., and Garmire, G. 1970, paper presented at spring meeting, American Physical Society, Washington, D.C., April 30.