

AN ULTRASOFT X-RAY SOURCE IN COMA BERENICES

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ABSTRACT

We have observed an intense soft X-ray source with an extraordinary spectrum in Coma Berenices, 4° northeast of and unassociated with the Coma cluster of galaxies. Two spectra, obtained at different times in a sounding rocket flight, indicate that the source temperature in thermal models is less than 10^6 K; a power-law model requires photon power-law indices steeper than $n = -3$. The intensity in the 44–165 Å band is of the order of 5×10^{-10} ergs cm $^{-2}$ s $^{-1}$, but no flux is present at energies 0.3–2.1 keV to a limit of 1×10^{-10} ergs cm $^{-2}$ s $^{-1}$. The lack of bright stars or a supernova remnant in the error box implies that this may be a new class of soft X-ray sources.

Subject headings: stars: white dwarfs — X-rays: sources — X-rays: spectra

I. INTRODUCTION

On 1974 June 15 at 0515 UT, an X-ray astronomy payload designed primarily to study soft X-ray emission from clusters of galaxies was launched from White Sands Missile Range, New Mexico, aboard a Black Brant VC sounding rocket. A series of preprogrammed maneuvers was executed by an attitude control system aided by rate-integrating gyros; these observations included a 50 s duration scan across the Coma cluster of galaxies. During this maneuver an X-ray source with an unusual spectrum was observed in Coma Berenices, approximately 4° northeast of the Coma cluster. This source dominates the soft X-ray count rate in this region, and together with the clusters was the only statistically significant signal during the flight. This source was first reported by Hayakawa *et al.* (1975a) on the basis of data from a rocket flight several years ago. Subsequent additional preliminary reports on the source have also been made by Hearn and Richardson (1975), Clark (1975), Bowyer *et al.* (1975), Richardson *et al.* (1975), Hayakawa *et al.* (1975b). In this *Letter* we report the details of the position, intensity, and X-ray spectrum of this extraordinary object.

II. INSTRUMENTATION AND OBSERVATIONS

The data discussed here were obtained by a large area proportional counter filled with propane at 150 mm pressure, and equipped with a very thin ($70 \mu\text{g cm}^{-2}$) polypropylene window. This combination provides effective bandpasses ($>5\%$ response) in two regions, 5–39 Å and 44–165 Å. A magnetic broom surrounded the entrance aperture to reject electrons of energies up to 10 keV. Aluminum honeycomb was used to collimate the instrument into two disjoint circular fields, (hereafter referred to as A and B), each 3° diameter FWHM and separated from each other by 5°. The collimation

was such that half the counter anode wires viewed only field A, while the alternate half viewed only field B. For each detected pulse event, information on which anode set was triggered, together with anticoincidence flags and six bits of pulse height data, was telemetered to the ground. This arrangement effectively creates two separate detectors (which can observe source and background simultaneously) whose efficiency, gain, and energy resolution are known to be identical at all times. The effective areas of fields A and B are 249 and 166 cm 2 , respectively; there is a 10 percent uncertainty in the effective area calibration. The pulse height analyzer was calibrated in flight with radioactive sources at 1.48 and 0.28 keV on both the ascent and descent. The aspect of the detectors with respect to the celestial sphere was derived from photographs of the star field obtained with a 35-mm camera, and is known to $\pm 4'$ during periods of small maneuver rates. Data reported here were all obtained at altitudes above 150 km and at small zenith angle, so no atmospheric corrections are necessary.

The Coma cluster observation consisted of a rapid (5.5 s^{-1}) roll from an observation of α Boo (cf. Cruddace *et al.* 1975) to a point about 5° east of the center of the cluster, where the roll rate was damped, with motion stopping at a point 1° west of Coma. A slow (0.025 s^{-1}) scan was then performed back to the east across the cluster. The count rates in both fields of the detector in the 44–165 Å band during these maneuvers are shown in Figure 1. (The 5–39 Å data obtained on the Coma cluster have been discussed by Malina *et al.* 1974). At 148 s after launch, an obvious source is seen transiting through field A. Simultaneously, the roll rate begins to damp, and, at about 150 s, an equally obvious signal appears in field B. The fact that the two signals are recorded at different times in the two fields, but in the same physical counter volume, precludes a charged particle event; however, the time spacing of the events is entirely consistent with a point source transiting

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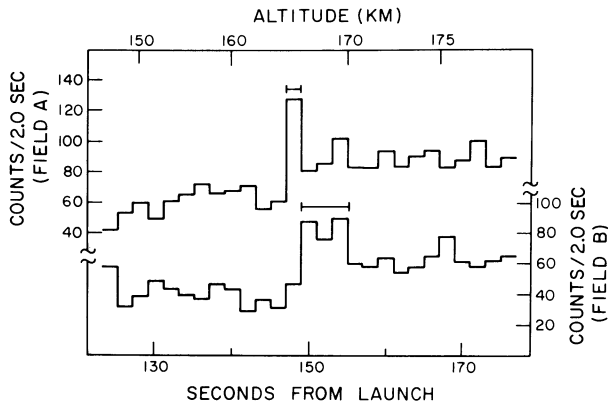


FIG. 1.—Count rates versus time in the 44–165 Å band for the two detector fields of view. *Upper panel*, field A; *lower panel*, field B. Field A has 50% greater collecting area than B, causing the differing background rates during the time interval 125–145 s. The field B data remain slightly above background after the source transit because the source remains in the edge of the field of view. *Bars*, sections of data used to examine source spectra.

through the two fields which are offset by 5° . Likewise, the duration and shapes of the transits are consistent with a point source of soft X-rays; the broadened peak in field B is due to the decrease in maneuver rate during the observation.

Because the fields of view were moving rapidly at this time, we have taken especial care to obtain background data from the immediate source vicinity. Background data for field A were extracted from times 145.5–147.0 and 148.7–150.2 s after launch, and yielded a value for the background count rate of 38.4 ± 3.5 counts s^{-1} ; the background data in field B come from 140.9–148.0 s, and have the value 17.5 ± 1.6 counts s^{-1} . The difference in these rates is due to both the difference in effective areas and orientation of the two fields of view. The source data were obtained from times 147.0–148.7 s for field A, and 148.0–155.2 s in field B; the count rates were 68.7 ± 6.4 and 39.9 ± 2.4 counts s^{-1} , respectively. If we include the statistical uncertainties in both the source and background count rates, we calculate that the observed excesses in fields A and B are significant at the 4.2σ and 7.8σ levels, respectively. As will be discussed below, the intensities and spectra derived from the independent photon sets in the two fields agree. The spectra are not compatible with the known detector response to ultraviolet radiation, nor are there any bright blue stars or near the fields of view at these times. Therefore, we conclude with high confidence that we have detected an intense celestial source of soft X-rays.

III. ANALYSIS

The high and changing maneuver rates during this observation, coupled with the relatively large fields of view, make it difficult for us to assign a precise position for this X-ray source. However, the data yield a good line of position in one dimension, oriented NE–SW. Our error box for the position is a rectangle with corners located at $\alpha(1950) = 13^h04^m$, $\delta = 25^\circ$; $\alpha = 12^h58^m$,

$\delta = 26^\circ$; $\alpha = 13^h08^m$, $\delta = 31^\circ$; and $\alpha = 13^h14^m$, $\delta = 30^\circ.5$. This location is well removed from the Coma cluster, and our data are certainly not positionally confused with that known X-ray source.

Almost precisely 1 year after our observation, the MIT experiment aboard SAS-C observed an intense soft source (which they designate MX 1313 + 29) in the same region of sky, according to the preliminary report of Hearn and Richardson (1975). The position error box given by these workers is considerably smaller than ours, and intersects our box near the northeast corner. The unusual spectra and comparably large fluxes seen in both experiments make it highly probable that the sources are identical. Because sources near the edge of our field of view require a nontrivial intensity correction, we have chosen to proceed on this assumption and correct our observed fluxes using the most probable MIT position. An intensity appropriate to the center of our error box would be a factor of 3.0 less than the values reported here.

We have used our pulse height data to derive information on the energy spectrum of the source. These data, consisting of 1.7 s from field A and 7.2 s from field B, are plotted separately in Figure 2. Several interesting features are immediately apparent. Four channels in each field separately detected the source at many standard deviations above background. There is no detection in the first channel ($E < 50$ eV) where the counter is known to respond to ultraviolet radiation. The spectra in the two fields are derived at different flight times from different data sets, and yet are consistent. The spectra are extraordinarily soft, with no positive detections of flux occurring at $E > 300$ eV ($\lambda < 41$ Å). Our upper limit on harder flux in the 0.3–2.1 keV band is 2.3×10^{-2} counts $cm^{-2} s^{-1} keV^{-1}$ at the 3σ level, equivalent to 1×10^{-10} ergs $cm^{-2} s^{-1}$. Thus the kilovolt X-ray flux is negligible, explaining why this

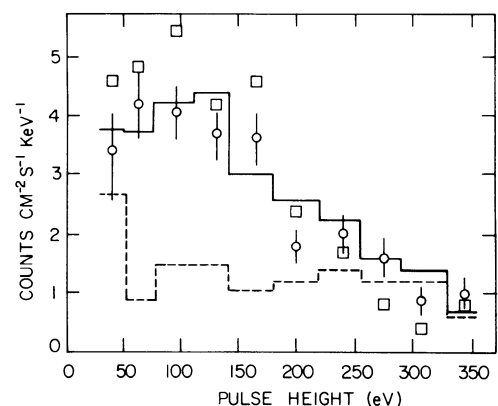


FIG. 2.—Pulse height spectra of the source in the two fields of view. *Circles*, field B; *squares*, field A. Error bars for field B are $\pm 1\sigma$ statistical errors. The uncertainties in field A have been omitted for clarity but are roughly twice those of field B. The data consist of 1.7 s from A centered at 150 s after launch, and 7.2 s from B centered at 152 s. *Broken line*, pulse height spectrum of the background. *Solid line*, a theoretical model spectrum, consisting of a blackbody of $T = 250,000$ K attenuated by absorption of column density $N_H = 5 \times 10^{18} cm^{-2}$, and added to the background.

source has not been previously detected in hard X-ray surveys.

We have compared the observed pulse height spectra with those convolved from three trial functions: a blackbody model, a power law, and a simple exponential using techniques described by Cruddace *et al.* (1972). The spectra were also subjected to varying amounts of photoelectric absorption, using the ultrasoft X-ray cross sections of Cruddace *et al.* (1974). The energy resolution of gas proportional counters in this wavelength regime is poor (in our case measured as 60% at 0.28 keV), so this analysis does not yield a single-valued function of photon flux versus energy within the 50–300 eV band; the inferred fluxes at a given energy are quite spectrum-dependent. However, our very stringent limits in the $E > 300$ eV region severely limit the inferred overall spectral slope, constraining all the spectra to be steeper than certain cutoff values. Similarly, our large number of counts separated into four wavelength channels in the 50–300 eV band do constrain the spectra to be flatter than certain limits, to avoid causing more counts than observed in the lowest channels. Thus although we cannot display a unique deconvolved plot of the energy dependence of the incident flux within our wavelength band, we can provide useful constraints on the overall spectral shape.

These data appear in Figure 3, where we plot contours of constant χ^2 in parameter space for each of the three models, using the technique described by Margon *et al.* (1975). The contours shown are $\chi^2_{\min} + 6.25$, which provides a 90 percent confidence region in these three-parameter fits; i.e., the plotted regions will (on statistical grounds) enclose the true parameter values 9 times in 10. In all three models there are parameter adjustments available which yield satisfactory fits, i.e., $\chi^2 \approx 1$ per degree of freedom. The fact that all simple models satisfactorily describe the data is due in part to the poor energy resolution of the detector at these ultrasoft wavelengths. The contours for data from the field A and field B detectors intersect for each model, providing quantitative confirmation of the qualitative impression of similar spectra in Figure 2. Field B contours are smaller than those of field A because there are 3 times as many counts available for analysis. It is clear that the source is cooler than 10⁶ K for the blackbody and exponential models, or steeper than -3 in the power-law model. This is to our knowledge the softest spectrum ever reported for a celestial X-ray source. Further, at least for the majority of the models, the

bulk of the flux emerges at wavelengths even longer than our 165 Å cutoff; this source appears to be radiating primarily in the extreme-ultraviolet.

In Figure 2 we have also shown with the solid line one of the blackbody models from Figure 3 which fit the data. This particular parameter set was selected for illustrative purposes only, to demonstrate that simple models are consistent with the observations. All the parameters enclosed by the Figure 3 contours provide acceptable fits, and should be regarded jointly as the experimental results.

Our spectra require that the equivalent column density of neutral hydrogen in the line of sight be $N_H \leq 10^{20}$ cm⁻². Since the total column density in this direction is $\sim 2 \times 10^{20}$ cm⁻² (Heiles 1975; Tolbert 1971), it seems probable that this source is galactic.

The steepness of the spectra requires that our best estimate of the integrated flux incident at Earth be somewhat model-dependent. The following values for the 44–165 Å intensity are typical of those derived for well-fit models for field B in Figure 3, assuming $N_H = 10^{19}$ cm⁻²: power law (index = -5), 5.0×10^{-10} ergs cm⁻² s⁻¹; blackbody ($T = 200,000$ K), 1.8×10^{-10} ergs cm⁻² s⁻¹; exponential ($T = 300,000$ K), 5.0×10^{-10} ergs cm⁻² s⁻¹. For comparison, a typical field A power-law fit (index = -7 , $N_H = 10^{19}$ cm⁻²) yields 4.8×10^{-10} ergs cm⁻² s⁻¹, in excellent agreement with field B. The quoted intensities must of course be corrected for energy-dependent absorption if they are to be converted to a luminosity at a given distance. The differences in these model-dependent intensities are the dominant uncertainty in quoting an observed flux for this source; the formal statistical uncertainties in the intensity are quite small ($\pm 15\%$).

Hearn and Richardson (1975) suggest the hot white dwarf HZ 43 as a candidate for the optical counterpart of this source. The distance of this star is of the order of 100 pc (Eggen and Greenstein 1965; Greenstein and Sargent 1974), and this is not in conflict with our upper limit on interstellar photoelectric absorption if $n_H \leq 0.3$ cm⁻³. Oke and Shipman (1971) and Shipman (1972) have given a blackbody temperature $T = 50,000$ K for HZ 43 based on the continuum slope in the visible; a temperature $51,000 < T < 140,000$ K is indicated by ANS far-ultraviolet observations (Wu *et al.* 1975; Wesselius 1975). Although our data do not uniquely require blackbody spectra, it is of interest to ask whether these spectra are compatible with the current

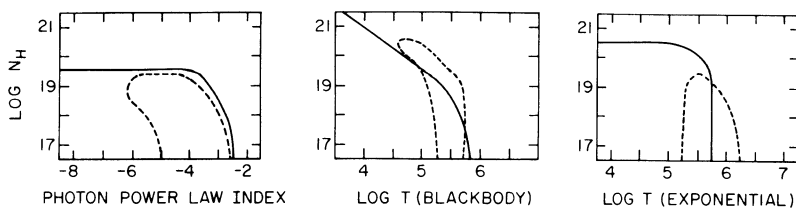


FIG. 3.—Contours of constant χ^2 for models fit to the pulse height data in Fig. 2. Solid lines, field A data; broken lines, field B data. The contours shown are $\chi^2_{\min} + 6.25$, which provide a 90% confidence volume for these three parameter fits. The spectral forms tested were: power law, $F(E) = cE^{-n} \exp[-N_H \sigma(E)]$; blackbody, $F(E) = cE^2 [\exp(E/kT) - 1]^{-1} \exp[-N_H \sigma(E)]$; exponential, $F(E) = cE^{-1} \exp(-E/kT) \exp[-N_H \sigma(E)]$.

results. If we adopt $d = 100$ pc, $R_* = 0.01 R_\odot$, and $N_H \leq 10^{20} \text{ cm}^{-2}$, we find fluxes consistent with our soft X-ray data for blackbody temperatures in the range $50,000 < T < 250,000$ K. The correct selection of a spectral shape and a detailed model for the emission must of course await data over a broader wavelength range.

The fact that this soft X-ray source has been observed by three independent groups over a period of several years makes it unlikely the source is transient, although

Hayakawa *et al.* (1975b) have suggested possible variability. The very soft spectrum and the lack of bright stars or supernova remnants in the error box indicate that this object is fundamentally different from previously observed sources.

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