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DISCOVERY OF A NONSOLAR EXTREME-ULTRAVIOLET SOURCE

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ABSTRACT

We report the first observation of extreme-ultraviolet radiation from an extrasolar object. The data were obtained with a grazing-incidence telescope flown as part of the *Apollo-Soyuz* mission. The source is located in Coma Berenices, at $\alpha_{1950} = 13^h13^m$, $\delta_{1950} = +29°$. Positive detections have been made in the 170–620 Å, 114–150 Å, and 55–150 Å wavelength bands. The intensity is 4×10^{-9} ergs cm^{-2} s^{-1} in the 170–620 Å band. Possible identification with the hot white dwarf HZ 43 is discussed.

Subject headings: stars: individual — stars: white dwarf — X-rays: sources

I. INTRODUCTION

Astronomical observations in the extreme-ultraviolet (EUV) band, 100–1000 Å, are of profound significance for studies of stellar evolution, stellar atmospheres, and the interstellar medium. On theoretical grounds, the existence of stars producing predominantly ionizing ($\lambda < 912$) radiation has been postulated to explain the ionization state of the interstellar medium. Such stars might represent a very hot phase of stellar evolution (Hills 1972; Rose and Wentzel 1973). On observational grounds, effective surface temperatures greater than 20,000 K are found, for example, among O stars, among white dwarfs of classes DAn and DAwk, among the subdwarf OB stars (cf. Greenstein and Sargent 1974), and among the ultraviolet-excess objects observed from TD-1A by Carnochan *et al.* (1975). Recent spectroscopic studies of interstellar matter toward nearby stars (e.g., Rogerson *et al.* 1973; Bohlin 1975; Dupree 1975) indicate that, in many directions, neutral hydrogen concentrations are as low as 0.01–0.1 cm^{-3}. Thus, direct EUV observations of sufficiently hot stars should be possible to distances of 20 – 100 pc (Cruddace *et al.* 1974).

Preliminary surveys at EUV wavelengths have been carried out from sounding rockets, and set upper limits of the order of 10^{-7} ergs cm^{-2} s^{-1} for sources in limited regions of the sky (Riegler and Garmire 1974; Henry *et al.* 1975, 1976). However, significant constraints on stellar emission models would require improvements in sensitivity of perhaps two orders of magnitude.

The *Apollo-Soyuz* mission offered the opportunity to make extended observations of numerous candidate stars with an EUV telescope having the requisite sensitivity. Approximately 20 hours of observing time were obtained, in which data were taken on approximately 30 preselected stars, one planet, and the EUV background radiation. One target exhibited a particularly intense EUV flux and is described in this report. This object thus becomes the first nonsolar source to be detected in the EUV band.

II. INSTRUMENT DESCRIPTION

The *Apollo-Soyuz* extreme-ultraviolet telescope (Margon and Bowyer 1975) consisted of a 37 cm diameter grazing-incidence mirror assembly, a continually rotating (10 rpm) six-position filter wheel, and a pair of channel electron-multiplier photon detectors. An opaque position on the wheel permitted nearly continuous monitoring of detector background during the mission. The field of view of the instrument was circular, with selectable diameters of 2°.5 or 4°.3 FWHM, obtained by commanding either of the detectors into the focal position. The detector not at the focal position was monitored to further establish the stability of the background count rates. Count rates from both detectors were telemetered each 0.1 s, along with the filter wheel position and other auxiliary information.

The entire system was calibrated in the laboratory with collimated radiation at numerous wavelengths between 44 and 2650 Å. Absolute intensities were established with the use of NBS-calibrated vacuum-photodiode secondary standards above 200 Å and propane proportional counters below 200 Å. The various filters, in combination with the efficiency characteristics of the mirror assembly and detector, defined the wavelength bands summarized in Table 1. Columns (1) and (2) list the filters and their bandpasses at 10 percent peak transmission. In column (3) we give the energy-integrated effective area or "grasp" $G = \int A(E)dE$. Column (4) gives the effective energy $E_e = \int EA(E) dE/G$.

The successful launch of the *Apollo* spacecraft on 1975 July 15 achieved a 215 km altitude, 51° inclination orbit. The EUVT alignment was verified to an accuracy of 0°.3 by a raster scan of the stars ι and κ Aquilae. During the entire mission the instrument performed flawlessly: the background count rates remained low and reproducible, while quick-look data showed no degradation in sensitivity.

TABLE 1

EUV PHOTOMETRIC DATA

INSTRUMENT CHARACTERISTICS				OBSERVATIONS	DERIVED FLUXES		
						Corrected for Atmosphere	
Filter Material (1)	Bandpass (2)	Grasp cm²eV (3)	E_e eV (4)	(source count rate* counts s⁻¹) (5)	Raw ph(cm² s eV)⁻¹ (6)	ph(cm² s eV)⁻¹ (7)	mfu (8)
Parylene..........	83–225 eV (55–150 Å)	590	142	22±1	0.037	0.039	3.7
Beryllium.........	83–109 eV (114–150 Å)	60	100	8±0.5	0.13	0.15	9.9
Aluminum.........	20–73 eV (170–620 Å)	270	46	160±3	0.59	1.0	30
Tin..............	16–25 eV (500–780 Å)	108	21	<50	<0.46	<1.2	<17
BaF_2..............	8.0–9.2 eV (1350–1540 Å)	0.47	9	<25	<53	<53	<325

* Errors quoted are ± 1 σ statistical errors.

III. DATA AND ANALYSIS

As part of the planned observing schedule, the ultrasoft X-ray source in Coma Berenices (Hayakawa *et al.* 1975*a*, *b;* Hearn and Richardson 1975; Margon *et al.* 1976) was observed for 7 minutes starting at 22^h26^m UT, 1975 July 22. After taking background data for 1 minute, a 3° spacecraft roll maneuver brought the center of the instrument line of sight to a point 1° north of the intended target. Thus the target was just at the edge of the instrument's 2° field of view. Several roll and pitch scans of about 0°5 then occurred, moving the field of view off and on the source. Finally, additional sky background data were taken 3° off the target.

During these maneuvers, obvious increases and decreases in the detector count rates were immediately recognized. A plot of the count rate versus time is shown in Figure 1 for the 55–150, 114–150, 170–620, 500–780, and 1350–1540 Å bands, with each point representing the average count rate over a 0.8 s time interval. Also shown in the count rate in the opaque filter position, which indicates that the observed instrumental background remained steady at 0.6 counts s^{-1}.

A crude estimate of the spectral energy distribution of this object can be made by dividing the observed count rate in each band by the appropriate energy-integrated effective area. Such an estimate is exact for continua having constant photon fluxes per unit frequency. In Table 1, we list the observed background-subtracted count rates for the Coma source (col. [5]) and the estimated continuum fluxes, both raw (col. [6]) and corrected for atmospheric attenuation at E_e (col. [7]) based on the CIRA 1965 Model 2 reference atmosphere, appropriate for the observing conditions. The spectral energy fluxes in units of 10^{-26} ergs cm^{-2} s^{-1} Hz^{-1} (=mfu) are listed in column (8). The total energy flux in the 170–620 Å band is approximately 4×10^{-9} ergs cm^{-2} s^{-1}.

We have plotted these intensities as a function of wavelength in Figure 2. Also shown is the 44–165 Å detection and 1 keV upper limit reported by Margon *et al.* (1976); the data appear compatible and support the identification of the EUV object with the Coma soft X-ray source. It is clear from this figure that the spectrum peaks in the EUV band, in the vicinity of 300 Å.

A more precise description of the spectrum can be provided by using the observed count rates to constrain parameters of emission models. For these calculations, we have chosen simple continuum models without lines, whose photon number per unit energy functions have the following forms: power law, $N(E) = AE^n \exp(-N_H\sigma)$; exponential, $N(E) = AE^{-1}\exp(-E/kT)\exp(-N_H\sigma)$; blackbody, $N(E) = AE^2[\exp(E/kT) - 1]^{-1}\exp(-N_H\sigma)$. In each case, the energy-dependent attenuation cross section per hydrogen atom, σ, has been taken from Cruddace *et al.* (1974) with normal abundances, no ionization, and no molecular hydrogen.

Our data can be satisfactorily fitted by any of these trial spectra, provided that the free parameters are appropriately chosen. In Figure 3 we show our derived parameter constraints for these models. In each case, contours are drawn at the $\chi^2_{min} + 6.25$ level, appropriate for 90 percent statistical confidence with three free parameters (Lampton, Margon, and Bowyer 1976). These constraints are compatible with, but much stricter than, the parameter regions derived from the soft X-ray rocket data obtained by Margon *et al.* (1976.)

IV. POSITION AND POSSIBLE IDENTIFICATION

Positional information on this source can be derived from the fact that, as the spacecraft pointing varies, the count rates are occasionally interrupted. The *Apollo* spacecraft aspect is measured by an inertial guidance system and telemetered each 2 seconds. This has been combined with our inflight data on the EUVT alignment to obtain four independent position zones for the source. These define a common region shown in Figure 4 (Plate L4).

The SAS-C observations have given a positional error box for the soft X-ray source; this is compatible with our EUV position and is also shown in Figure 4. It is highly likely that one object is responsible for the soft X-ray and EUV emission. It has been suggested

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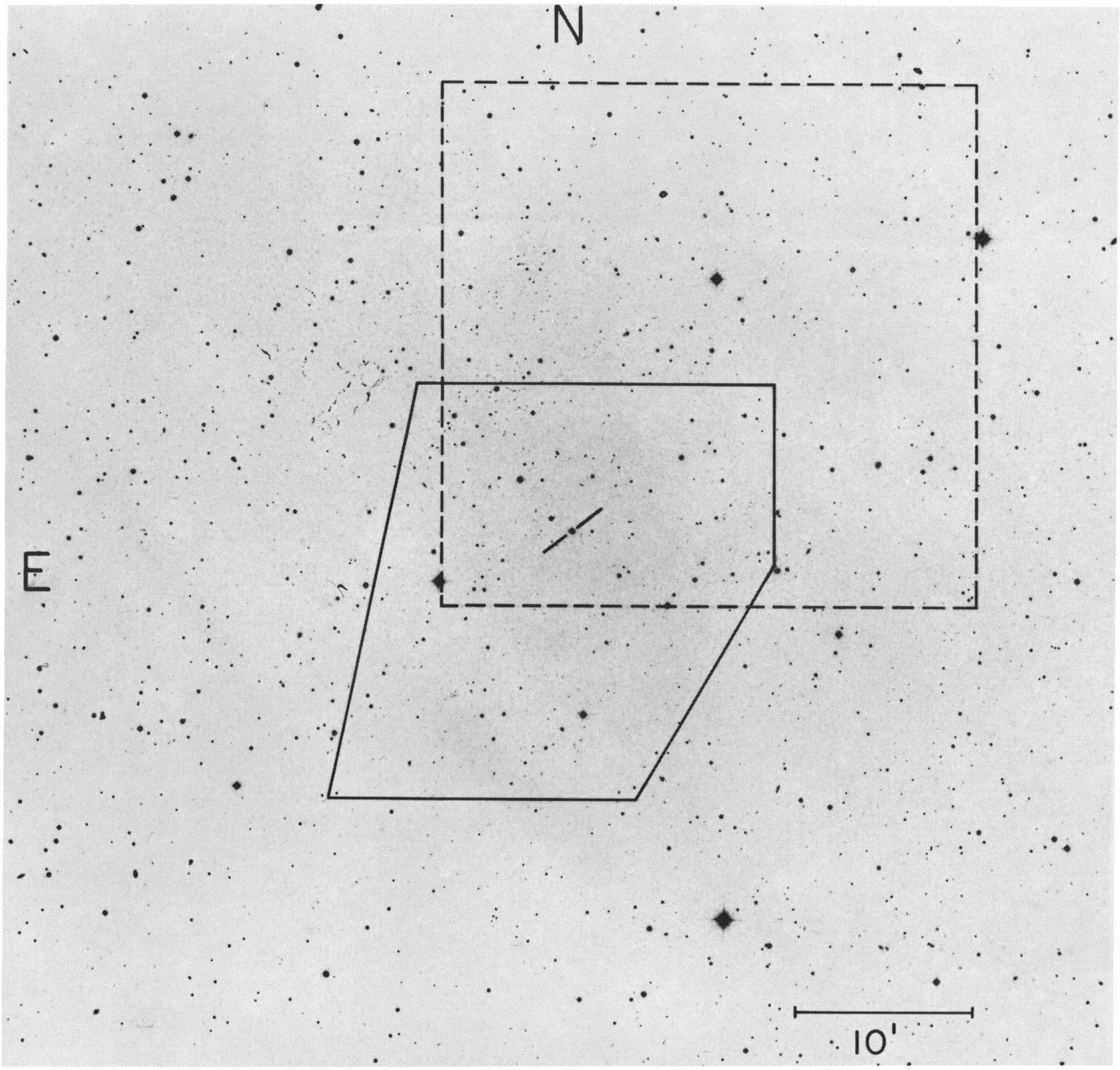

FIG. 4.—Positional error box for the EUV source derived from the present data (*solid line*). The dotted line gives the soft X-ray position derived by SAS-C (Hearn and Richardson 1975; Richardson *et al.* 1975). The white dwarf HZ 43 is marked. Enlargement is from the blue Sky Survey plate (© National Geographic Society–Palomar Observatory Sky Survey; reproduced by permission of the Hale Observatories).

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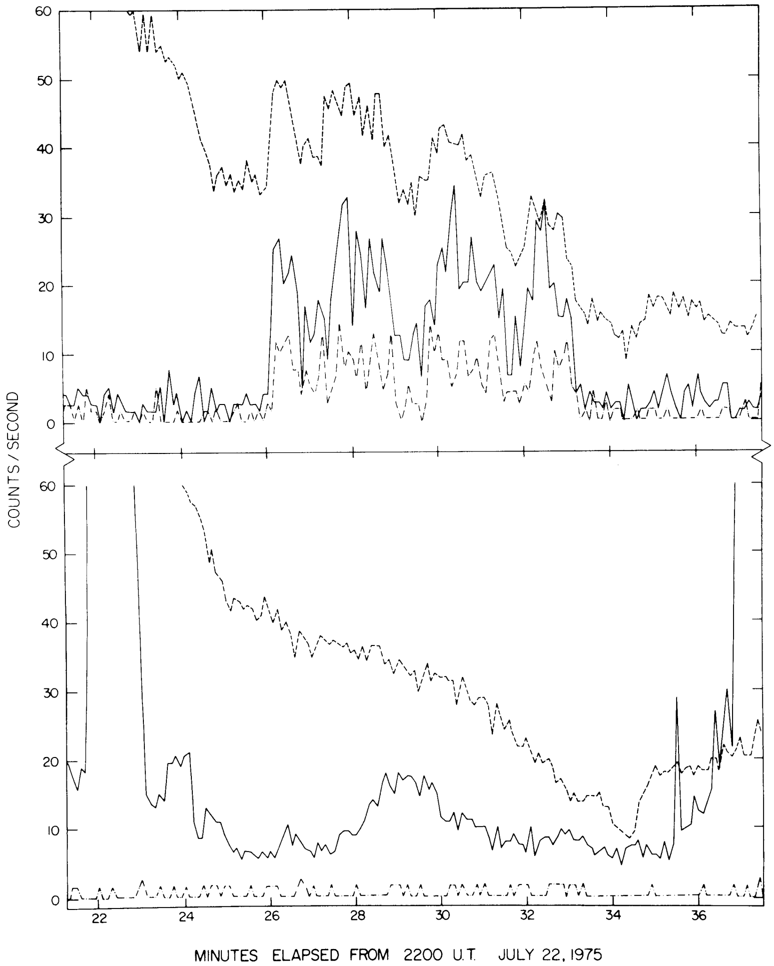

FIG. 1.—*Top panel*, count rates versus time in wavelength bands defined by filters of aluminum (*broken line*, counts divided by 15); parylene (*solid line*); beryllium (*dot-dash line*). *Lower panel*, same as above for tin (*broken line*, counts divided by 30); barium fluoride (*solid line*, counts divided by 10); opaque shutter (*dot-dash line*). The trends in the aluminum and tin bandpasses are due to the spatial variations in the geocoronal foreground radiation; this behavior was repeatable on numerous orbits. The barium fluoride count rates are dominated by the occasional observations of known blue stars.

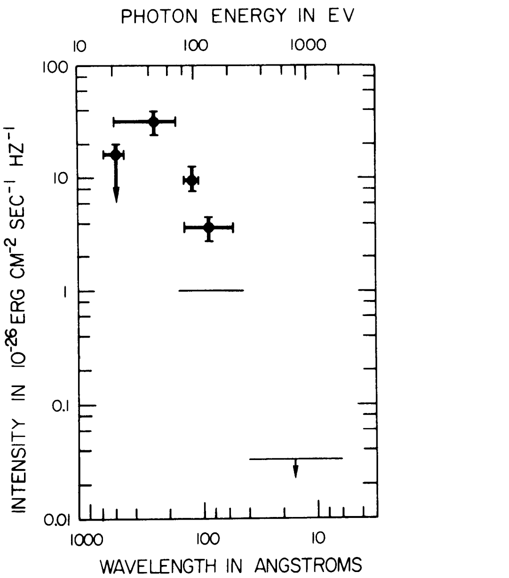

FIG. 2.—*Heavy points*, spectral intensities derived from the present data, background subtracted and corrected to the top of the atmosphere. Horizontal bars give bandpasses at 10% level; vertical bars show combined statistical and instrumental errors. Also shown (*light lines*) are the soft X-ray rocket data of Margon *et al.* (1976); the uncertainties in those intensities are dominated by the assumed spectral shape, as discussed in that reference.

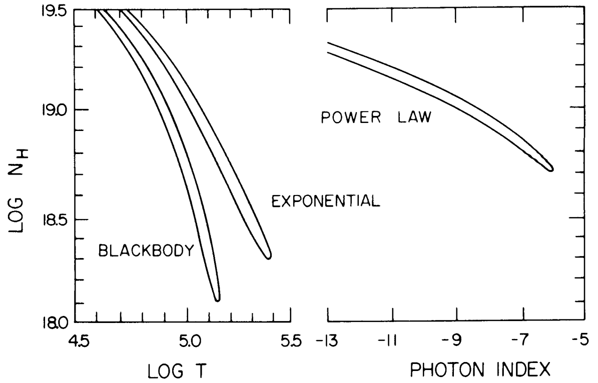

FIG. 3.—Contours of constant χ^2 for fits to blackbody, exponential, and power-law spectra. Each contour has been drawn at the $\chi^2_{min} + 6.25$ level, appropriate for 90% statistical confidence for fits with three adjustable parameters.

(Hearn and Richardson 1975) that the soft X-ray object is the hot white dwarf HZ 43 at $\alpha_{1950} = 13^h14^m\!.0$, $\delta_{1950} = +29° 22'$; the EUV position is compatible with this suggestion.

If this identification is correct, it is of interest to determine whether any of the simple spectra fitted here are compatible with the UBV magnitudes listed for HZ 43 (Eggen and Greenstein 1965): viz., $V = 12.86$, $B = 12.76$, $U = 11.62$. The power-law and exponential spectra would, if extended to visible wavelengths, give magnitudes much redder and brighter than observed. However, the blackbody spectra would be compatible at $T \approx 110{,}000$ K. Shipman (1972) has given an effective temperature of $T = 50{,}000 \pm 5000$ K for HZ 43, based on multichannel photoelectric data. However, we do not regard these data as incompatible with the temperature we suggest, since in this regime, the slope of the blackbody continuum in the optical band is extremely insensitive to temperature.

If our simple model with $T = 110{,}000$ K is appropriate, then the stellar radius is 7800 $(D/100 \text{ pc})$ km and the corresponding luminosity is 17 $(D/100 \text{ pc})^2 L_\odot$, in reasonable agreement with white dwarf models. The corresponding density of interstellar hydrogen is 0.014 $(D/100 \text{ pc})^{-1} \text{ cm}^{-3}$. Although our data do not uniquely require a blackbody stellar spectrum, we note that, with this explanation and identification, HZ 43 has the highest temperature of any known white dwarf.

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