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A 6 SECOND PERIODIC X-RAY SOURCE IN CARINA

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ABSTRACT

A serendipitous source, 1E 1048.1 − 5937, was discovered during *Einstein* imaging observations of the Carina nebula. On 1979 July 13, this source had an intensity of 0.14 IPC counts s^{-1}, and the signal was 65% pulsed with a period of 6.44 s. An earlier observation failed to detect any source with strength greater than 1/10 the above signal. The source is therefore highly variable, perhaps transient. An *EXOSAT* observation of this source on 1985 June 20 confirmed the pulse period and refined the source position to an accuracy of 10″. On the basis of the position, we tentatively identify the source with a $V \approx 19$ optical counterpart. The X-ray spectrum is best fitted by a power law with photon index = 2.26 and a column density of $\sim 1.6 \times 10^{22}$ atoms cm^{-2}. The X-ray characteristics are consistent with an accretion-powered Be star binary.

Subject headings: stars: Be — stars: individual — X-rays: binaries — X-rays: sources

I. X-RAY OBSERVATIONS

a) Einstein Observatory

1E 1048.1 − 5937 is located outside the bright Carina nebula, ~40′ east of η Carinae. It can be seen in the X-ray map given by Seward and Chlebowski (1982). The observation consisted of two ~40 minute exposures separated by 11 hours. Average source intensity was about the same, and 6 s pulsations were clearly observed during each interval.

Figure 1 shows the pulse shape observed 1979 July 13. The source was moderately strong by *Einstein* standards but far below the threshold for *Uhuru*-type detectors. Background is included in Figure 1 and is 2.5 counts per bin, ~7% of the source strength. Although only 380 counts were recorded, the pulsation level was highly significant, with probability of being accidental less than 10^{-6}. The data given in Figure 1 were 63% pulsed, which, after background subtraction, gave a source pulsed fraction of 0.68 ± 0.07.

The X-ray spectrum was not well determined. The source was 25′ from the telescope axis and outside the "ribs" of the *Einstein* imaging proportional counter (IPC), a region where the detector gain was not well calibrated. The pulse height spectrum can be fitted with a variety of spectral shapes if the column density of absorbing material, N_H, is a free parameter. Assuming a thermal spectrum (exponential plus Gaunt factor), the data can be fitted with temperatures, kT, ranging from 0.6 to 4 keV, and with N_H between 3 and 15 × 10^{21} atoms cm^{-2}. The most likely values are $kT \approx 1$ keV and $N_H \approx 7 \times 10^{21}$ atoms cm^{-2}. Assuming a power law, the acceptable range of photon spectral index is $1.5 < \alpha < 4$ and $2 < N_H < 10 \times 10^{21}$ atom cm^{-2}. The calculated X-ray luminosity in the range 0.2–4 keV, L_x, is dependent on a large correction factor for absorption in intervening gas. Possible values range from 1.5 to 5×10^{34} ergs s^{-1} if the distance (see discussion) is 3 kpc.

After discovery of the pulsations, a search was made for other *Einstein* sightings. Only one other field was found which might contain the source: an IPC observation made 1978 December 22 contained the source position just at the edge of the field of view, 40′ from the telescope axis. This region is normally excluded from the IPC data area because non–X-ray background is high and the vignetting correction is large (~4). The source was not detected, and we can set an upper limit of 0.010 counts s^{-1} (corrected for background and vignetting). The source is, therefore, either transient or variable by at least a factor of 10.

b) EXOSAT

We performed an *EXOSAT* observation of this source lasting 6.5 hours on 1985 June 20. The source was detected in the Low Energy telescope (LE; effective energy range 0.02–2.5 keV; see de Korte *et al.* 1981 for details) with an intensity of $2.1 \pm 0.5 \times 10^{-3}$ counts s^{-1} (Smale *et al.* 1985). The significance of this detection is greater than 10 σ. Details and results from both the *Einstein* and *EXOSAT* observations are summarized in Table 1.

The count rate in the Medium Energy experiment (Turner, Smith, and Zimmermann 1981) was a steady 2 counts s^{-1} throughout the observation in the 2–10 keV energy range. This observation enables us to confirm the presence of X-ray pulsations, at a period of 6.4407 ± 0.0009 s, slower by 0.003 s than the value derived from the *Einstein* observation but not of high enough precision to definitely indicate a period shift. The best fit to the ME X-ray spectrum is a power law with photon index 2.26 (see Fig. 2), with a χ^2 for the fit of 19.85 for 19 degrees of freedom. The hydrogen column density is poorly defined by the ME data alone; however, by including the count rate for the LE, we derive $N_H = 1.6 \pm 0.3 \times 10^{22}$ atoms cm^{-2}. The flux in the 2–10 keV range is 2.2×10^{-11} ergs cm^{-2} s^{-1}. Assuming this same spectrum was valid at the time of the *Einstein* observation, we calculate that the source was a factor of 1.4 more luminous at the time of the *EXOSAT* observation.

II. SEARCH FOR OPTICAL COUNTERPART

Figure 3 (Plate 12) shows the optical field with a 2′ diameter circle centered on the IPC location. This is the nominal 90% confidence region. The *EXOSAT* 20″ diameter circle is also displayed and is consistent with the *Einstein* position.

A search was made for optical transients on ~200 blue plates in the Harvard Collection. Faintest objects on the best

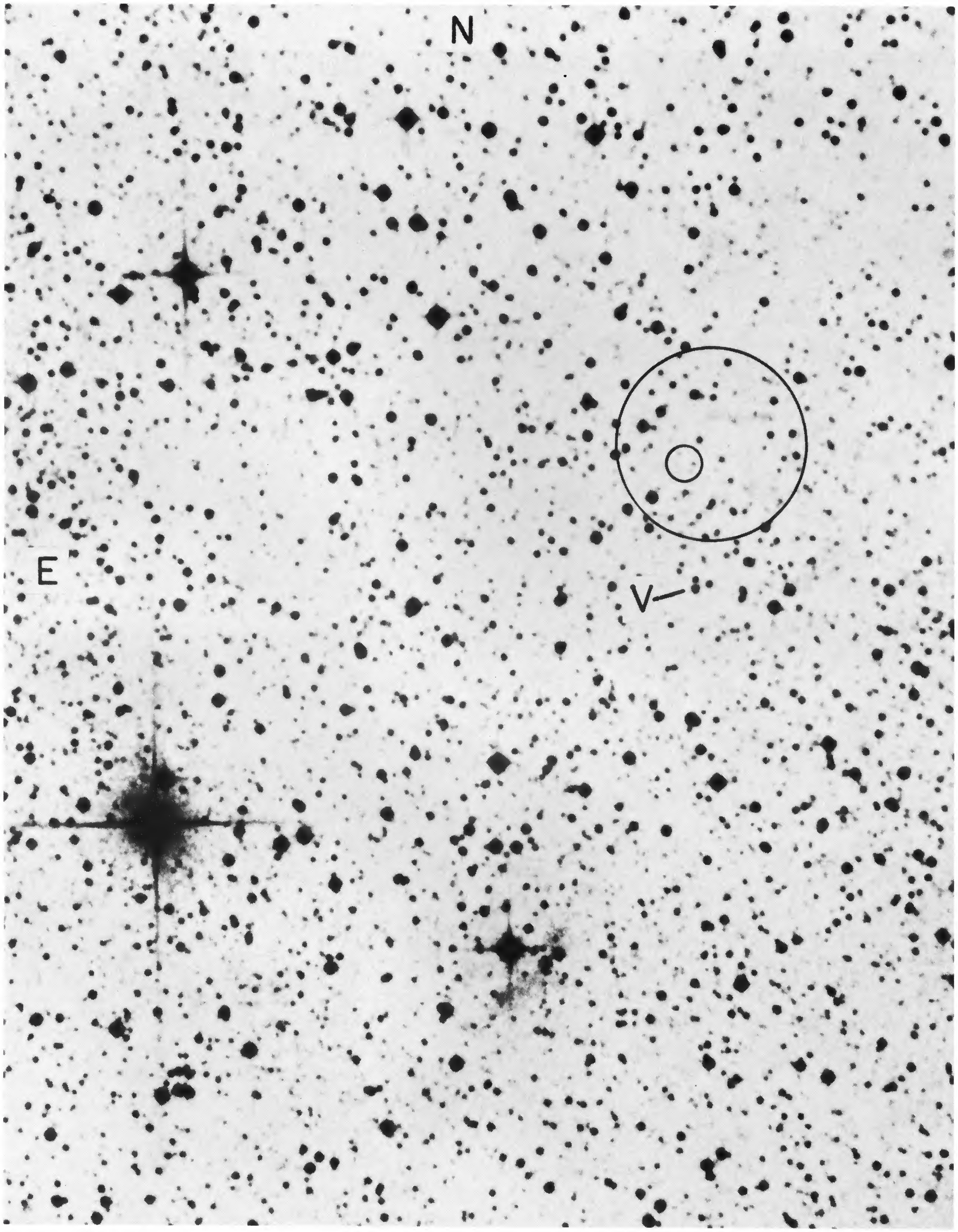

FIG. 3.—Portion of *ESO* blue survey plate with *Einstein Observatory* 2′ diameter circle and the *EXOSAT* 20″ diameter circle showing the most probable location of 1E 1048.1 − 5937. " V " is the location of the variable discussed in the text.

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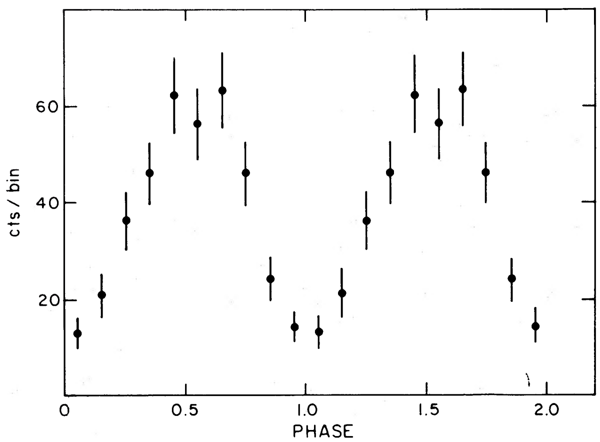

FIG. 1.—X-ray intensity vs. phase of 1E 1048.1 − 5937, assuming a period of 6.4377 s. Data are from the *Einstein* observation and are repeated to cover two cycles. Error bars show 1 σ counting statistics.

TABLE 1

SOURCE CHARACTERISTICS

Characteristic	*Einstein Observatory*	*EXOSAT*
Position (1950)	R.A. $10^h48^m8\overset{s}{.}0$ Decl. $-59°37'21\overset{''}{.}0$	$10^h48^m10\overset{s}{.}05$ $-59°37'24\overset{''}{.}9$
Error radius	60″	10″
Counting rate (counts s^{-1})	0.14 ± 0.01 (IPC)	$2.1 \pm 0.5 \times 10^{-3}$ (LE)
Energy flux ergs cm^{-2} s^{-1} [a]	4×10^{-12} (0.2–4 keV)	2.2×10^{-11} (2–10 keV)
L_x [b] ergs s^{-1}	$2\text{–}5 \times 10^{34}$ (0.2–4 keV)	2×10^{34} (2–10 keV)
Period	$6\overset{s}{.}4377 \pm 0\overset{s}{.}0010$	$6\overset{s}{.}4407 \pm 0\overset{s}{.}0009$
Epoch[c]	1979 July 13.219 JD 2,444,068.719	1985 June 20.112 JD 2,446,236.612

[a] Measured at detector.
[b] Distance = 3 kpc.
[c] Start of observation.

plates had $m_{pg} \approx 16$. One plate (not one of the best) taken 1979 May 24, 50 days previous to the X-ray observation, shows a possible 14 mag transient close to the X-ray source. This object can be identified with one of the group of three stars, labeled "V" in Figure 3. However, the *EXOSAT* position excludes any of these stars from further consideration as the pulsar's counterpart.

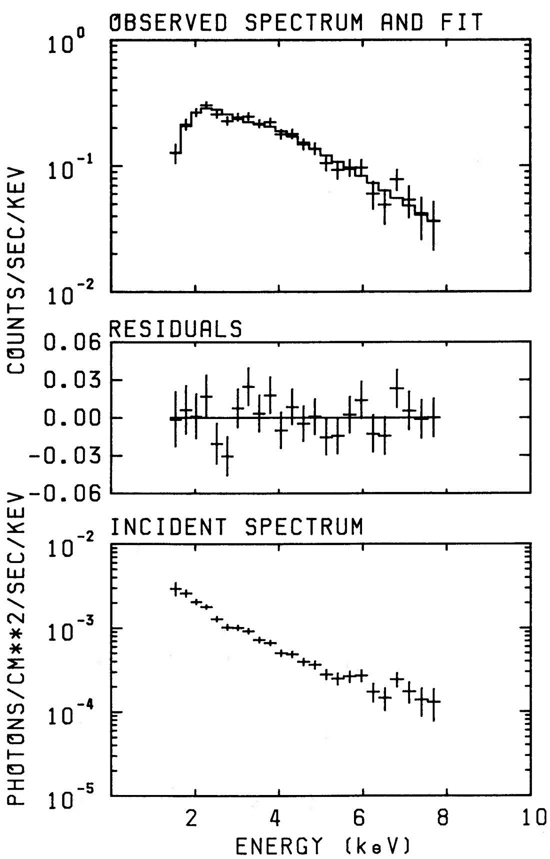

FIG. 2.—*EXOSAT* ME (1.5–8 keV) spectrum of 1E 1048.1 − 5937 showing the best fit power-law spectrum ($\alpha = 2.26$, $N_H = 1.6 \times 10^{22}$ cm^{-2}) and residuals.

Examination of SRC IIIa-J and ESO blue plates reveals that the brightest star in the *EXOSAT* error circle has magnitude $V = \sim 19$. A CCD frame of the field obtained using the 1 m telescope at the South African Astronomical Observatory by G. Efstathiou and S. Maddox on 1985 July 21, shows no obvious differences in the magnitude of the candidate star from its apparent magnitude in the plate cataloges. The high degree of obscuration measured by the *EXOSAT* implies a visual extinction of $A_v \approx 8$ mag (Ryter, Cesàrsky, and Andouze 1975).

III. DISCUSSION

The short period requires that the source be a rotating neutron star, probably accretion powered, although we have no direct evidence that it is a member of a binary system. The change in period measured in the two observations is about as expected from Doppler shifts in a binary orbit. More observations, however, are needed to confirm this. The low luminosity and high variability are characteristic of systems containing Be stars (Rappaport and van den Heuvel 1982).

The high column density measured by the *EXOSAT* LE suggests that there is a contribution to the obscuration from the Carina nebula. This places a lower limit on the distance to the source of 2.8 kpc. At this distance the derived 2–10 keV luminosity is $\sim 2 \times 10^{34}$ ergs s^{-1}. Assuming the source is within the Galaxy ($d < 20$ kpc) places an upper limit upon the luminosity of 10^{36} ergs s^{-1}. The extinction corrected visual magnitude of $V \approx 11$ implies $M_v = -1.2$ at the minimum distance of 2.8 kpc and -5.5 at the maximum. This suggests an early B spectral classification of luminosity class III–V, supporting our interpretation of 1E 1048.1 − 5937 as a Be type system.

An empirical relationship between the pulse period and orbital period (Corbet 1984) predicts that the period of 1E 1048.1 − 5937 is in the range 12–50 days. The Be star binaries with closest pulsation periods are 4U 0115+63 (3.6 s), with orbital period 24 days, and 2S 1553 − 542 (9.3 s), with orbital period 31 days. The most likely orbital period for 1E 1048.1 − 5937 is therefore ~28 days. X-ray observations are consistent with the source being transient and of duration similar to the brighter X-ray transients. This source, however, was not detected in the *Uhuru*, *Ariel 5*, or *HEAO 1* all-sky surveys, so, if it is transient, we suspect either it is not very bright at maximum or the recurrence interval is much longer than the above prediction.

We note in passing that this source is within the 1°3 error radius of the high energy γ-ray source 2CG 288−00 (Bignami and Hermsen 1983).

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