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CYGNUS X-2: NEUTRON STAR OR DEGENERATE DWARF?

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ABSTRACT

Two conflicting models have been proposed for Cyg X-2: a degenerate dwarf model which predicts a distance of 250 ± 50 pc and a neutron star model which implies a distance of about 8000 pc. Based on a reddening study, we find that the distance to Cyg X-2 is greater than 1100 pc, which rules strongly against the degenerate dwarf model. Our conclusion is based on observations of the 2200 Å feature in the spectrum of Cyg X-2 made with the *International Ultraviolet Explorer* (*IUE*), and *UBV* and spectroscopic observations of 38 field stars. For the reddening of Cyg X-2 we find $E(B-V) = 0.40 \pm 0.07$ ($1\ \sigma$), which is consistent with the reddening to infinity in that direction inferred from radio data. Consequently, Cyg X-2 may be located in the halo at ~8 kpc as proposed in 1979 by Cowley, Crampton, and Hutchings.

Subject headings: stars: neutron — ultraviolet: spectra — X-rays: binaries

I. INTRODUCTION

Cameron and Mock (1967) were among the first to suggest that accretion onto a degenerate dwarf would produce a compact X-ray source and that this might be the correct model for Sco X-1 and a dozen other bright X-ray sources known at that time. Since 1967 this model has been developed in detail to explain, for example, the observed properties of Sco X-1 (Hoshi 1973; Aizu 1973) and the X-ray pulsations of Cen X-3 and Her X-1 (De Gregoria 1974; Yokoo and Hoshi 1974; for a review see Katz 1977, and Kylafis and Lamb 1982).

The degenerate dwarf model, however, contains a fatal flaw which was pointed out from the beginning: the maximum hard X-ray luminosity that can be produced is at most a few times 10^{36} ergs s^{-1} (Cameron and Mock 1967; Kylafis and Lamb 1982), whereas the luminosities of the bright sources[6] are typically 10^{36}–10^{38} ergs s^{-1} (see, e.g., Bradt and McClintock 1983). For this reason and others it is now widely agreed that the first-discovered (i.e., bright) X-ray binaries (including Sco X-1, Cen X-3, and Her X-1 mentioned above) contain accreting neutron stars or, in some cases, black holes. Nevertheless, because the distances to individual sources are often poorly known, it is possible that a few of them may be nearby, low-luminosity systems which contain degenerate dwarfs. As discussed below, Branduardi *et al.* (1980) present an interesting argument that Cyg X-2 is one such source. Cygnus X-2 was probably detected in the very first observations of X-ray astronomy in 1962 (see Giacconi *et al.* 1967*a*). It was the second compact X-ray source to be optically identified (Giacconi *et al.* 1967*b*). Shortly thereafter Kraft and Demoulin (1967) studied the optical counterpart and concluded that the star is of spectral type G, probably a subdwarf; they estimated its distance to be 500–700 pc. This view prevailed for a decade.

In 1979 Cowley, Crampton, and Hutchings (1979) discovered a 9.84 day spectroscopic orbital period which implies that the system is large with a binary separation $\sim 7\ R_\odot$ (see also Crampton and Cowley 1980). They deduced that the optical companion is a luminous F giant or subgiant which fills its Roche lobe and is located at a distance of ~8000 pc with a peak X-ray luminosity near the Eddington limit for a 1 $M_\odot$ object, $L_x = 1.2 \times 10^{38}$ ergs s^{-1} (see Bradt and McClintock 1983). The large luminosity rules out a degenerate dwarf and argues that the compact object is a neutron star (cf. Kylafis and Lamb 1982).

A conflicting model for Cyg X-2 was proposed by Branduardi *et al.* (1980) (also see Kylafis and Lamb 1982). Their X-ray observations of Cyg X-2 revealed a double-valued relationship between the X-ray intensity and the slope of the X-ray spectrum. Remarkably, the observations matched theoretical predictions which they had made earlier for spherical accretion onto a nonmagnetic degenerate dwarf. Moreover, Branduardi *et al.* argued that it is difficult to account for the observed behavior of Cyg X-2 in terms of accretion onto a neutron star. Their detailed model and observations imply that the compact X-ray source is a degenerate dwarf at a distance of 250 ± 50 pc with a luminosity $L_x = 7 \times 10^{34}$ ergs s^{-1}.

In this paper we present evidence that the distance to Cyg X-2 is greater than 1100 pc and is consistent with the value of ~8000 pc suggested by Cowley, Crampton, and Hutchings (1979). Therefore, our results rule strongly against the white dwarf model of Branduardi *et al.* (1980) and favor the conventional neutron star model.

II. OBSERVATIONS AND RESULTS

In 1980 we began a program to provide information on the distance to Cyg X-2. We determined the reddening of Cyg X-2 from observations of the strength of the 2200 Å interstellar absorption feature and determined the run of reddening with distance in the direction of Cyg X-2 from optical photometric and spectroscopic observations of nearby field stars.

a) IUE Data: The Reddening of Cygnus X-2

In 1980 April we observed Cyg X-2 with the *International Ultraviolet Explorer* (Boggess *et al.* 1978*a*, *b*). Three spectra

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[6] For example, those listed in the 4U X-ray catalog (Forman *et al.* 1978). This excludes cataclysmic variables, which are lower-luminosity X-ray sources (10^{31}–10^{35} ergs s^{-1}) that contain an accreting degenerate dwarf (see Kylafis and Lamb 1982).

(LSWR 7379, 7380 and 7393) were obtained with the long wavelength camera (1900–3200 Å) at a resolution of about 7 Å FWHM. The total exposure time was 13.4 hours. Cyg X-2 was centered in the large (10″ × 20″) aperture by making a precise offset from a bright, nearby field star. On three occasions we made long integrations with the FES star camera and verified that Cyg X-2 was, in fact, centered in the aperture to better than 1″.5.

The data were reduced using software developed by Snijders (1980*a*) which extracts a weak signal in the presence of a high background including bright spots produced by cosmic-ray events and camera blemishes. The standard VILSPA or NASA software is inadequate for the reduction of faint, low-resolution spectra and produces large photometric errors ($\gtrsim 2 \times 10^{-14}$ ergs cm^{-2} s^{-1} $Å^{-1}$) due to errors in the background evaluation (Snijders 1980*b*). Snijders's procedure reduces the fluctuations in the background by a factor of ~2–3. The extraction slit is always centered on the spectrum itself, which is not always the case in the standard reduction software. The data are transformed into absolute fluxes using a calibration based on the reduction of the *IUE* standard stars with Snijders's reduction procedures.

A sum of the three spectra is plotted at the top of Figure 1 and labeled $E(B-V) = 0$. The broad 2200 Å interstellar absorption feature, which depresses the continuum level by a factor of about 2, is apparent. As shown in Figure 1, we corrected our spectrum for various assumed amounts of reddening using the interstellar extinction data summarized by Seaton (1979). We fitted the corrected data sets to power law spectra ($F_\lambda \sim \lambda^n$) and computed χ^2 versus $E(B-V)$. The reddening which corresponds to the minimum χ^2 is the value we have adopted for Cyg X-2: $E(B-V) = 0.40 \pm 0.07$ mag (1 σ). We note that the value of the reddening derived by Chiappetti *et al.* (1981) [$0.4 < E(B-V) < 0.5$] is consistent with our determination; their result is based on an independent analysis of our data which they obtained from the *IUE* archives.

b) *Photometric Data*

We selected 24 stars within 30′ of Cyg X-2 using objective prism plates taken with the Case Western Schmidt and made available by Dr. Peter Pesch. The stars are identified in the photograph in Figure 2 (Plate 18), and denoted by filled circles in Figure 3*a*. Early-type stars (B and A) were favored over late-type stars in the selection because the former probe greater distances and because it is possible to determine their luminosity class with greater certainty. The photoelectric observations were done on 1980 June 11 and 12 UT with the 1.3 m McGraw-Hill telescope. We used an EMI 9789 photomultiplier tube and a filter set which closely matched the standard *UBV* system. The seeing was good ($\lesssim 2''$), and a 10″ aperture was used throughout the observations. Twenty-four *UBV* standard stars in Selected Areas 106, 109, and 111 (Landolt 1973) were observed. They spanned a wide range of colors and provided a set of linear transformations from instrumental units to *UBV* magnitudes. Some stars were observed only once a night, whereas others were observed as many as five times each night and used to derive values for the atmospheric extinction coefficients (see, e.g., Hardie 1962). The derived magnitudes and colors of the Cyg X-2 field stars are listed in Table 1. The errors are less than 0.015 mag based on the mean residuals computed for the standard stars. Photometric errors are a negligible source of uncertainty in this study.

In addition to the two dozen field stars discussed above, we included 14 stars which were part of an earlier reddening study of the Cyg X-2 field done by Cathey and Hayes (1968). The stars are listed in the second half of Table 1; the photometric data is from Cathey and Hayes (1968). As shown in Figure 3*a*, these stars are located 1°–2° from Cyg X-2.

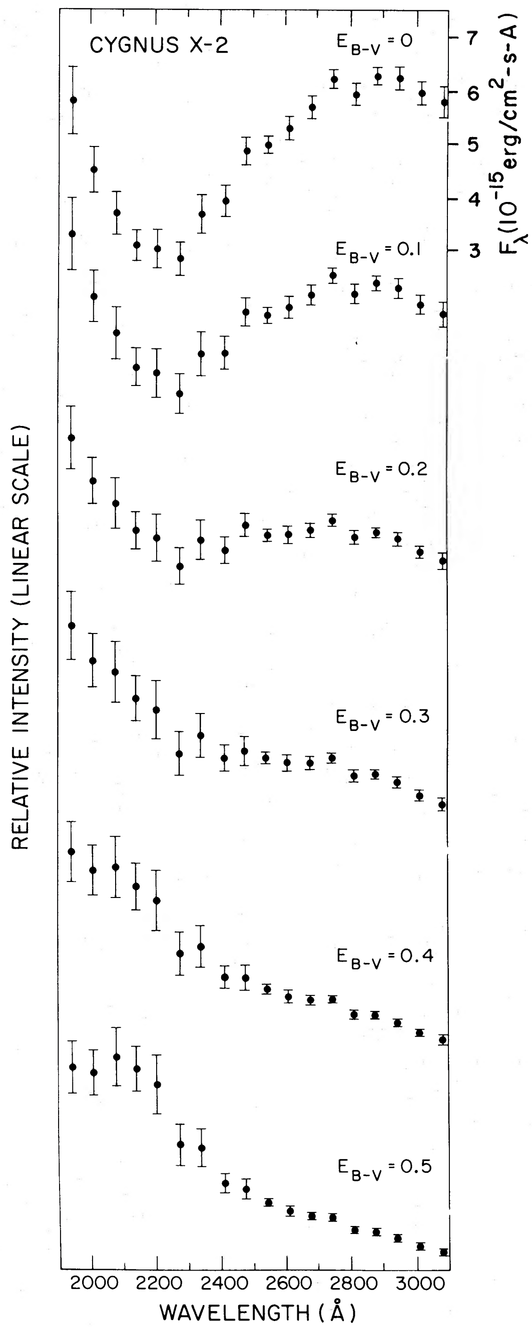

FIG. 1.—*Top trace*, *IUE* spectrum of Cyg X-2 with no correction for interstellar reddening. (Note the intensity scale on the right.) The broad interstellar absorption feature near 2200 Å is the dominant feature in the data. *Lower traces*, the data are shown corrected for increasing amounts of interstellar reddening. The 2200 Å feature is least apparent in the data set labeled $E(B-V) = 0.4$.

c) *Spectroscopic Data*

We made spectrophotometric observations of the 38 stars (discussed above) in the field of Cyg X-2 on the nights of 1981

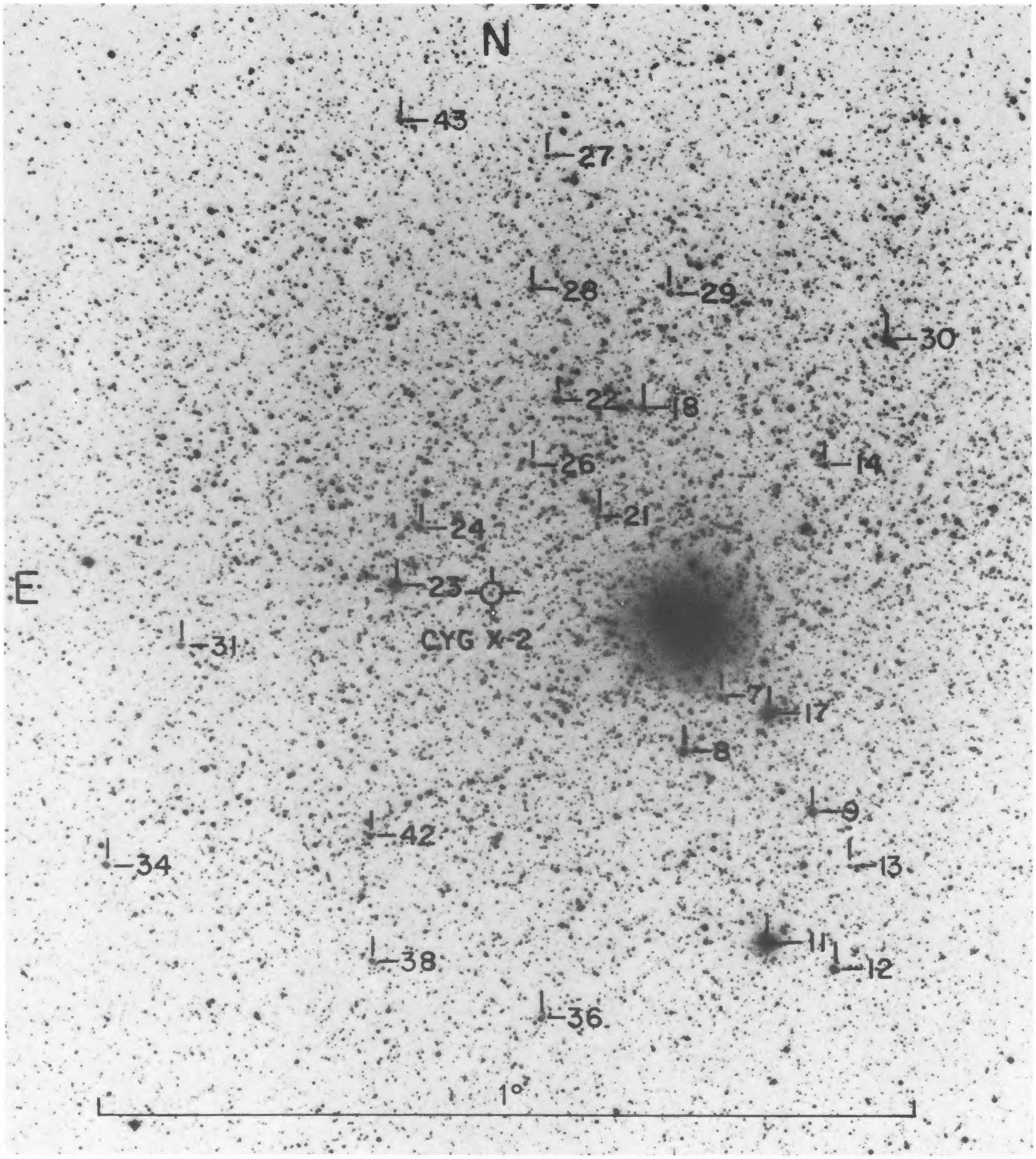

FIG. 2.—Finding chart showing the locations of the 24 field stars selected for the Cyg X-2 reddening study (see § II*b*). (Reproduced from the Palomar Observatory Sky Atlas, blue print).

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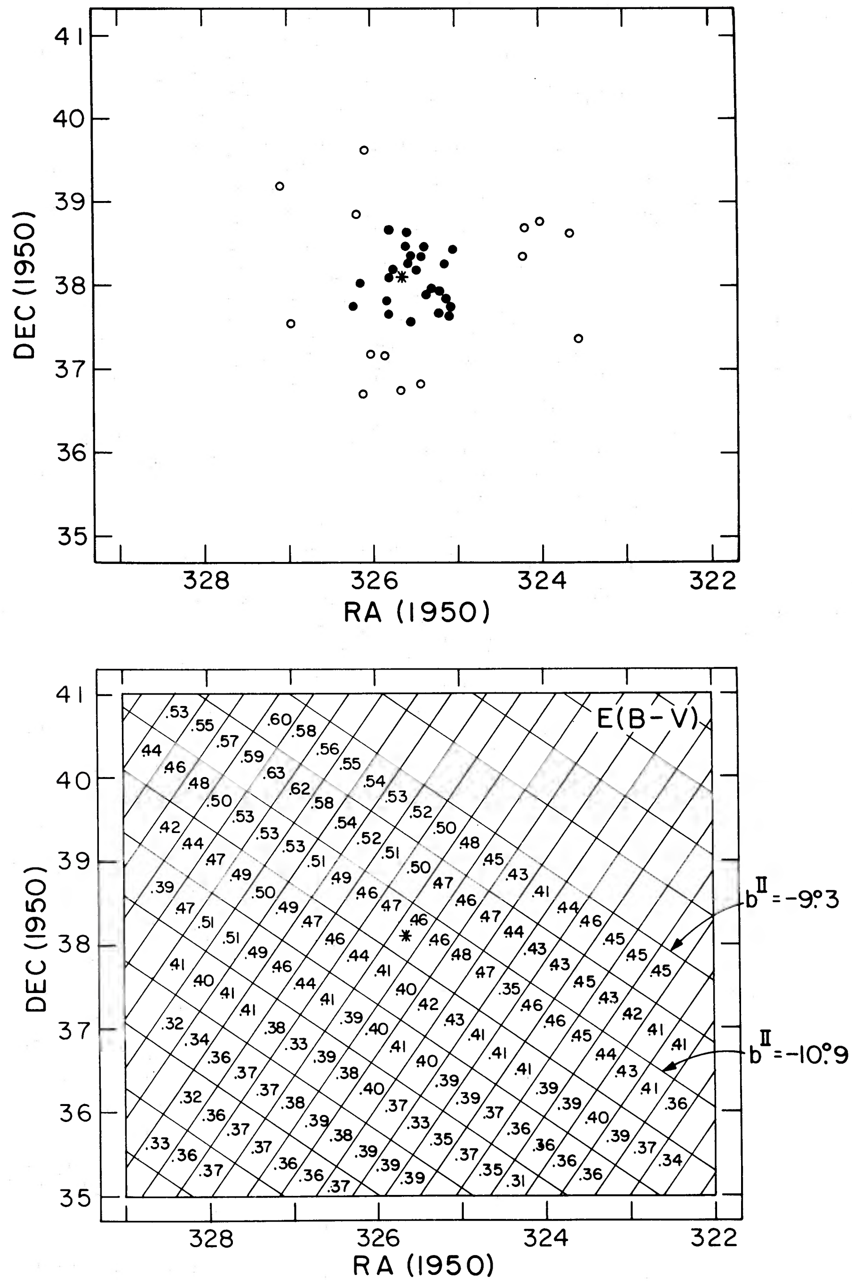

FIG. 3.—(*a*) (*top*) The locations of the field stars used to determine reddening. The filled circles correspond to the 24 field stars which are labeled on the photograph in Fig. 2 and listed in the top half of Table 1. The open circles are 14 field stars initially used by Cathey and Hayes (1968). The location of Cyg X-2 is marked by an asterisk. (*b*) (*bottom*) The average reddening to infinity in 0°3 × 0°6 sky cells in the vicinity of Cyg X-2 inferred from 21 cm H I data. The scale is the same as in Fig. 3*a*; Cyg X-2 is located at the center and marked by an asterisk. The upper right portion of the map is blank because the high-latitude H I survey we used does not contain data for $|b^{II}| \lesssim 9°$.

September 7–15 UT using the 1.3 m McGraw-Hill telescope and the Mark II spectrometer. The Mark II is a 2048 channel photon-counting spectrometer which contains an intensified Reticon detector (Shectman and Hiltner 1976). We used a 600 line mm^{-1} grating in second order which gave a resolution of 2.2 Å FWHM (~0.52 Å per channel) and a wavelength coverage of 3800–4600 Å. The resolution and passband were chosen to match the values which are typically used in two-dimensional MK classification of photographic spectra (Morgan and Keenan 1973). A comparison sequence of MK spectral types was established for this configuration of the Mark II spectrometer by observing 72 stars which have been classified on the MK system by others (Johnson and Morgan 1953; Abt *et al.* 1968; Morgan and Keenan 1973; Buscombe 1977; Morgan, Abt, and Tapscott 1978). About half of the MK standards were observed with the Cyg X-2 field stars in 1981 September. The other half were observed in an earlier observing run in 1981 July with precisely the same instrumentation and observing setup.

A 2″ × 10″ slit was used for the observations of all program stars and standard stars. The sky count rate, which was a small fraction ($\lesssim$30% and typically ~5%) of the total count rate,

TABLE 1

DATA FOR FIELD STARS

Star or BD No.	V	$B-V$	$U-B$	MK Type[a]	M_v	$(B-V)_0$	$E(B-V)$	D(pc)
7	11.20	0.45	0.16	F0	2.70	0.29	0.16	396
8	10.26	0.10	−0.16	B8	0.00	−0.12	0.22	815
9	9.84	0.21	0.04	A5	2.10	0.15	0.06	323
11	7.45	0.25	0.15	A6	2.25	0.17	0.08	97
12	10.01	0.07	−0.11	B8.5	0.25	−0.10	0.17	697
13	12.45	0.32	0.17	A4	1.95	0.12	0.20	938
14	11.42	0.34	0.18	A5	2.10	0.15	0.19	553
17	8.19	0.61	0.00	G2	4.80	0.62	−0.01	48
18	10.96	0.53	−0.02	F7	4.00	0.49	0.04	232
21	12.69	0.23	0.17	A0	1.00	−0.02	0.25	1507
22	11.14	0.38	0.25	A7	2.40	0.19	0.19	423
23	8.80	0.41	0.01	F2	3.10	0.35	0.06	126
24	10.33	0.54	0.08	F8	4.20	0.52	0.02	163
26	11.78	0.31	0.23	A4	1.95	0.12	0.19	699
27	12.10	0.48	0.28	A9	2.60	0.26	0.22	574
28	11.77	0.49	0.16	F1	2.90	0.32	0.17	463
29	11.58	0.40	0.13	F1	2.90	0.32	0.08	484
30	9.13	0.52	0.06	F4.5	3.52	0.41	0.11	113
31	10.58	0.68	0.18	F9 IV	2.90	0.55	0.13	284
34	10.25	0.13	−0.10	B8.5	0.25	−0.10	0.23	713
36	11.27	0.17	0.13	A0	1.00	−0.02	0.19	856
38	11.06	0.44	−0.01	F3	3.27	0.37	0.07	326
42	11.04	0.42	0.01	F2	3.10	0.35	0.07	349
43	10.82	0.43	0.03	F2	3.10	0.35	0.08	311
38°4564	8.93	0.09	−0.39	B4	−1.35	−0.20	0.29	742
37°4383	9.63	0.19	0.14	A4	1.95	0.12	0.07	310
36°4674	8.52	−0.06	−0.39	B8	0.00	−0.12	0.06	463
36°4675	8.42	0.00	−0.28	B8	0.00	−0.12	0.12	405
38°4603	10.56	0.20	−0.05	B8.5 III	−0.70	−0.10	0.30	1148
37°4438	8.54	0.11	0.05	A1	1.30	0.01	0.10	242
38°4618	7.74	0.23	0.13	A5	2.10	0.15	0.08	119
36°4669	9.16	0.04	−0.03	B9	0.50	−0.08	0.12	452
39°4667	8.27	0.05	−0.07	B8.5	0.25	−0.10	0.15	322
38°4553	9.76	0.13	0.10	A0	1.00	−0.02	0.15	453
38°4561	8.84	0.20	0.15	A1 III	0.50	0.01	0.19	352
36°4677	9.34	0.19	0.15	A4	1.95	0.12	0.07	271
38°4613	10.11	0.27	0.10	A4	1.95	0.12	0.15	344
36°4664	9.49	0.26	0.13	A6	2.25	0.17	0.09	246

[a] Luminosity class V unless otherwise noted.

was subtracted from the data. The peak of the continuum was exposed to a fixed level of about 1500 counts per channel, which required about 20 min of observing time for a star of 10th mag. The data were flux calibrated (Oke 1974) and smoothed with a Gaussian filter which was slightly narrower than the instrumental resolution. Representative spectra of three Cyg X-2 field stars are shown in Figure 4.

We used the spectra of the 72 standard stars to classify the 38 program stars on the MK system. We made extensive use of the standard temperature and luminosity indicators (Keenan 1963; Abt *et al.* 1968; Morgan, Abt, and Tapscott 1978). The spectral classifications we assigned are given in Table 1; the corresponding absolute magnitudes and intrinsic colors are also given in Table 1 and are based on the tabulation of Deutschman, Davis, and Schild (1976).

d) The run of Reddening with Distance

The reddening and the distances of the field stars are given in the last two columns of Table 1. The reddening is the difference between the observed value of $B-V$ and the mean value for the spectral type, and the distance is given by $d(\mathrm{pc}) = 10^{0.2(V-A_v-M_v+5)}$, with $A_v = 3.2E(B-V)$ (cf. Seaton 1979). As shown in Figure 5, we find a roughly linear relationship between reddening and distance out to the most distant field stars which we observed ($d \approx 1000$ pc and $E(B-V) \approx 0.3$). Based on 21 cm H I observations, the reddening to infinity is ~ 0.45 (see § II*e*).

We note that a conflicting result was reported earlier by Cathey and Hayes (1968) who found that the reddening levels off at $E(B-V) = 0.22$. The limitations of their study which led to this conclusion include their reliance on spectral types from the *Henry Draper Catalogue* and *Atlas Borealis*, and the use of only 17 stars spread over a 5° diameter field (cf. Fig. 3*b*; § II*e*).

e) Reddening Inferred from 21 cm H I *Data*

In order to examine the reddening to infinity in various directions near Cyg X-2, we used a magnetic tape copy of the 21 cm radio data of Heiles and Habing (1974). We integrated the line profiles over velocity and converted the antenna temperatures to column densities and to reddening using the relationships given in Heiles, Stark, and Kulkarni (1981). The derived reddening averaged over 0°.3 × 0°.6 cells is shown in Figure 3*b*. The variability in $E(B-V)$ between adjacent cells is

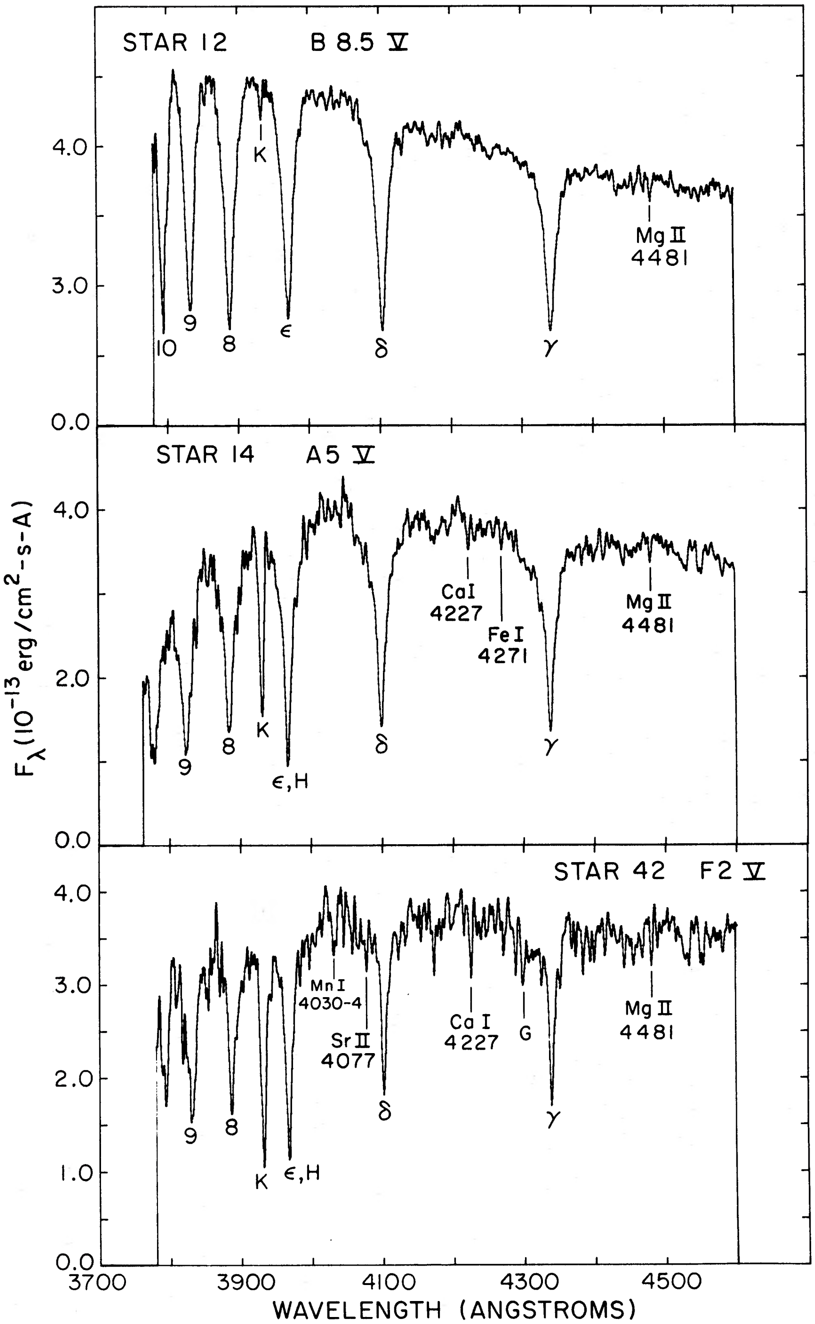

FIG. 4.—Representative spectra of three field stars obtained with the Mark II spectrometer. Spectrophotometric data were obtained for a total of 38 field stars and 72 MK standard stars.

relatively small ($\lesssim 10\%$), and may be due to the statistical fluctuations in the relatively small number (~ 10–20) of interstellar clouds expected in each $0\overset{\circ}{.}3 \times 0\overset{\circ}{.}6$ beam (McKee and Ostriker 1977). As expected, there is a large systematic increase in $E(B-V)$ with decreasing galactic latitude (Fig. 3*b*).

From these radio data we draw two conclusions. First, an estimate of the reddening to infinity in the direction of Cyg X-2 is $E(B-V) \approx 0.45$. Second, on an angular scale of $\sim 0\overset{\circ}{.}5$ the reddening to infinity is uniform within $\sim 20\%$ for the two dozen nearby field stars we selected (Fig. 3, *filled circles*). For the more distant stars (Fig. 3, *open circles*) the uniformity is $\sim 30\%$. For the $5°$ diameter field used by Cathey and Hayes (1968) the reddening to infinity varies by $\sim 50\%$.

III. DISCUSSION

A good correlation has been established between the strength of the 2200 Å feature and $E(B-V)$ (e.g., Danks 1980 and references therein). This relationship holds even in dark clouds, which strongly suggests that the carrier of the feature is a common substance which is well mixed in the interstellar

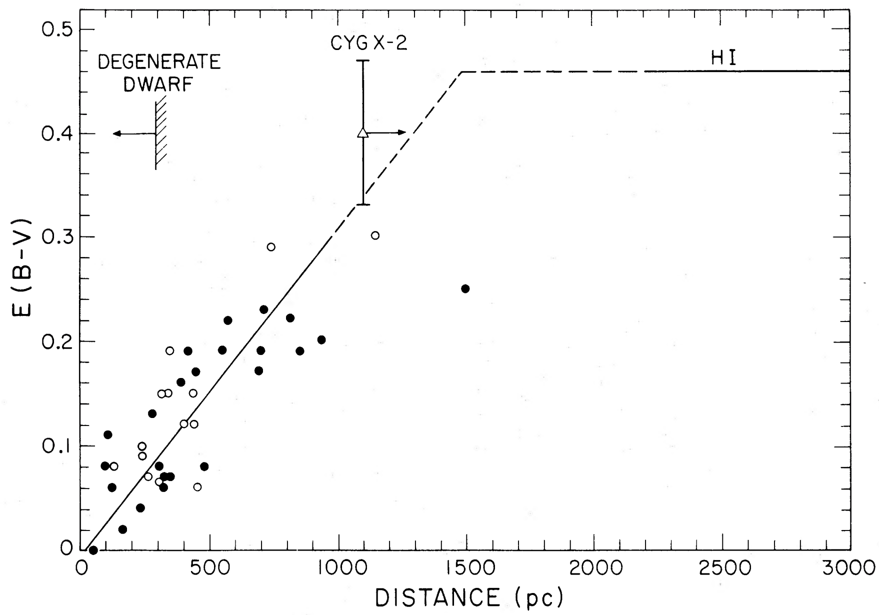

FIG. 5.—Reddening versus distance in the field of Cyg X-2. The filled circles are data for the field stars located within 0°.5 of Cyg X-2; the open circles are for more distant field stars (see Fig. 3*a*). The sloping line is a linear least squares fit to all the field star data. The horizontal line labeled "N_{HI}" is the reddening at infinity derived from 21 cm H I data. The observed reddening of Cyg X-2 is indicated (1 σ uncertainty) and corresponds to a distance $d > 1100$ pc. This rules strongly against the degenerate dwarf model (Branduardi *et al.* 1980) which predicts $d < 300$ pc.

medium and very resistant to modification by the environment (Wu, Gilra, and van Duinen 1980). There is, however, a considerable spread in the extinction curves of individual stars as shown by a study of 1367 stars observed by *ANS* (Meyer and Savage 1981). Thirteen of these stars, which were judged to have the most anomalous ultraviolet extinction, were observed with *IUE* by Massa, Savage, and Fitzpatrick (1983). They found that the extinction curve for HD 37367 (which is located in a field with no obvious dark clouds or nebulosity) gave the lowest predicted values for $E(B-V)$. If we had applied the curve for HD 37367 to our Cyg X-2 data, we would have found $E(B-V) \approx 0.26$ instead of $E(B-V) = 0.40 \pm 0.07$ (see § IIa). Clearly, variations in the extinction curves of individual stars are potentially an important source of uncertainty in the derived value of the reddening. Nevertheless, even if the reddening of Cyg X-2 were as low as 0.26 (and allowing for a statistical uncertainty of approximately 0.07), our basic conclusion would be unchanged: the degenerate dwarf model proposed by Branduardi *et al.* (1980) is ruled out because the distance to Cyg X-2 exceeds 300 pc (see Fig. 5). Moreover, it is very unlikely that the reddening of Cyg X-2 is this low because the extinction curve for HD 37367 is an extreme example selected from a study of 1367 stars.

We also note that a few stellar systems (e.g., cool giant stars and some novae and planetary nebulae) are surrounded by dust shells and consequently are intrinsically reddened; it appears very unlikely that Cyg X-2 is such a system. We conclude that the observed reddening of Cyg X-2 is interstellar and a reliable distance indicator.

Our results are summarized in Figure 5. The distance to Cyg X-2 is greater than 1100 pc for an uncertainty in $E(B-V)$ of 1 σ and greater than 800 pc for an uncertainty of 2 σ. This result rules out the degenerate dwarf model proposed by Branduardi *et al.* (1980)[7] which predicts $d = 250 \pm 50$ pc. Another way of arriving at this conclusion is the following. At a distance of 300 pc, the maximum allowed by the degenerate dwarf model, the reddening is $E(B-V) \approx 0.1$ (Fig. 5). The *IUE* spectrum of Cyg X-2 corrected for $E(B-V) = 0.1$ (Fig. 1), however, contains a strong interstellar absorption feature at 2200 Å; therefore, Cyg X-2 is significantly more distant than allowed by the degenerate dwarf model.

The reddening of Cyg X-2 derived from *IUE* observations is in agreement with the reddening to infinity inferred from 21 cm H I data. Our results, therefore, are consistent with a neutron star binary at a distance of $\sim$8000 pc as proposed by Cowley, Crampton, and Hutchings (1979). In this model, Cyg X-2 lies far beyond the galactic dust layer (see Fig. 5) and $\sim$1.5 kpc above the plane, and is presumably a halo-population object (see Cowley, Crampton, and Hutchings 1979).

Our lower limit on the distance to Cyg X-2 rules out the degenerate dwarf model of Branduardi *et al.* (1980). Moreover, several other lines of evidence also rule against this model. The optical observations of Cyg X-2 (Cowley, Crampton, and Hutchings 1979; see § I) imply an X-ray luminosity far in excess of those allowed for any degenerate dwarf. Maraschi, Tanzi, and Treves (1980) showed that the observed UV and optical intensities of Cyg X-2 and the model of Branduardi *et al.* imply that the optical companion underfills its Roche lobe. If so, it is very difficult to explain the large mass transfer required to power

[7] It also militates against *all* degenerate dwarf models for Cyg X-2. For a wide class of models, Kylafis and Lamb (1982) find a maximum X-ray luminosity of 2.2×10^{36} ergs s^{-1}; they conclude that this is close to the maximum luminosity for any degenerate dwarf model. At this limiting luminosity, the maximum intensity (Bradt and McClintock 1983) observed for Cyg X-2 corresponds to an upper limit on the distance of $D < 1100$ pc, whereas we find $D > 1100$ pc (1 σ).

the X-ray source. Pravdo (1983) has studied the low and medium energy (0.4–18 keV) X-ray spectrum of Cyg X-2 and concluded that it is inconsistent with the degenerate dwarf spectra computed by Branduardi *et al.* Also, Ross and Fabian (1980) argue that Branduardi *et al.*'s neglect of the effects of photoelectric absorption on the emergent X-ray spectrum invalidates their model.

Finally, we note that the greatest success of the degenerate dwarf model, its ability to account for the double-valued relationship between X-ray intensity and the shape of the X-ray spectrum in Cyg X-2 (see Section I), has been undermined by recent observations. This behavior has been observed in other sources (e.g., GX 5–1; Oda 1983) which are almost certainly neutron star binaries (e.g., see Webbink, Rappaport, and Savonije 1983); apparently it is not a unique signature of a degenerate dwarf as suggested by Branduardi *et al.* (1980).

During the past 15 years, the degenerate dwarf model has been invoked to explain the properties of a number of bright X-ray binaries including Sco X-1, Cen X-3, Her X-1, and Vela X-1 (see Katz 1977), and most recently Cyg X-2. In each case the model has been discredited.

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REFERENCES

Abt, H. A., Meinel, A. B., Morgan, W. W., and Tapscott, J. W. 1968, *An Atlas of Low-Dispersion Grating Stellar Spectra.*
Aizu, K. 1973, *Progr. Theoret. Phys.*, **49**, 1184.
Boggess, A., *et al.* 1978*a*, *Nature*, **275**, 372.
Boggess, A., *et al.* 1978*b*, *Nature*, **275**, 377.
Bradt, H. V. D., and McClintock, J. E. 1983, *Ann. Rev. Astr. Ap.*, **21**, 13.
Branduardi, G., Kylafis, N. D., Lamb, D. Q., and Mason, K. O. 1980, *Ap. J. (Letters)*, **235**, L153.
Buscombe, W. 1977, *MK Spectral Classifications* (Third General Catalog) (Evanston: Northwestern University).
Cameron, A. G. W., and Mock, M. 1967, *Nature*, **215**, 464.
Cathey, L. R., and Hayes, J. E. 1968, *Ap. J. (Letters)*, **151**, L89.
Chiappetti, L., Maraschi, L., Tanzi, E. G., and Treves, A. 1981, *Space Sci. Rev.*, **30**, 287.
Cowley, A. P., Crampton, D., and Hutchings, J. B. 1979, *Ap. J.*, **231**, 539.
Crampton, D., and Cowley, A. P. 1980, *Pub. A.S.P.*, **92**, 147.
Danks, A. C. 1980, *Pub. A.S.P.*, **92**, 52.
De Gregoria, A. J. 1974, *Ap. J.*, **189**, 555.
Deutschman, W. A., Davis, R. J., and Schild, R. E. 1976, *Ap. J. Suppl.*, **30**, 97.
Forman, W., Jones, C., Cominsky, L., Julien, P., Murray, S., Peters, G., Tananbaum, H., and Giacconi, R. 1978, *Ap. J. Suppl.*, **38**, 357.
Giacconi, R., Gorenstein, P., Gursky, H., and Waters, J. R. 1967*a*, *Ap. J. (Letters)*, **148**, L119.
Giacconi, R., Gorenstein, P., Gursky, H., Usher, P., Waters, J., Sandage, A., Osmer, P., and Peach, J. 1967*b*, *Ap. J. (Letters)*, **148**, L129.
Hardie, R. H. 1962, in *Astronomical Techniques*, ed. W. A. Hiltner (Chicago: University of Chicago Press), p. 178.
Heiles, C., and Habing, H. J. 1974, *Astr. Ap. Suppl.*, **14**, 1.
Heiles, C., Stark, A. A., and Kulkarni, S. 1981, *Ap. J. (Letters)*, **247**, L73.
Hoshi, R. 1973, *Progr. Theoret. Phys.*, **49**, 776.
Johnson, H. L., and Morgan, W. W. 1953, *Ap. J.*, **117**, 313.
Katz, J. I. 1977, *Ap. J.*, **215**, 265.
Keenan, P. C. 1963, in *Basic Astronomical Data*, ed. K. A. Strand (Chicago: University of Chicago Press), p. 78.
Kraft, R. P., and Demoulin, M. 1967, *Ap. J. (Letters)*, **150**, L183.
Kylafis, N. D., and Lamb, D. Q. 1982, *Ap. J. Suppl.*, **48**, 239.
Landolt, A. V. 1973, *Ap. J.*, **78**, 959.
Maraschi, L., Tanzi, E. G., and Treves, A. 1980, *Ap. J. (Letters)*, **241**, L23.
Massa, D., Savage, B. D., and Fitzpatrick, E. L. 1983, *Ap. J.*, **266**, 662.
Meyer, D. M., and Savage, B. D. 1981, *Ap. J.*, **248**, 545.
McKee, C. F., and Ostriker, J. P. 1977, *Ap. J.*, **218**, 148.
Morgan, W. W., Abt, H. A., and Tapscott, J. W. 1978, *Revised MK Spectral Atlas for Stars Earlier than the Sun.*
Morgan, W. W., and Keenan, P. C. 1973, *Ann. Rev. Astr. Ap.*, **11**, 29.
Oda, M. 1983, paper presented at the Summer Workshop on γ-Ray and X-Ray Transients held in Santa Cruz, California.
Oke, J. B. 1974, *Ap. J. Suppl.*, **27**, 21.
Pravdo, S. H. 1983, *Ap. J.*, **270**, 239.
Ross, R. R., and Fabian, A. C. 1980, *M.N.R.A.S.*, **193**, 1P.
Seaton, M. J. 1979, *M.N.R.A.S.*, **187**, 73P.
Shectman, S., and Hiltner, W. A. 1976, *Pub. A.S.P.*, **88**, 960.
Snijders, M. A. J. 1980*a*, *SRC IUE Newsletter*, No. 5.
———. 1980*b*, *Proc. Second European IUE Conference*, Tubingen, Germany (ESA SP-157), p. lxxi.
Webbink, R. F., Rappaport, S., and Savonije, G. J. 1983, *Ap. J.*, **270**, 678.
Wu, C.-C., Gilra, D. P., and van Duinen, R. J. 1980, *Ap. J.*, **241**, 173.
Yokoo, H., and Hoshi, R. 1974, *Progr. Theoret. Phys.*, **51**, 418.

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