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ON THE OPTICAL IDENTIFICATION OF CYGNUS X-1

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ABSTRACT

We believe that the bright star at the location of the radio source near Cyg X-1 may not be associated with the X-ray source because its distance is greater than the upper limit for the distance to Cyg X-1, and because its spectrum and energy distribution are those of a normal B0 supergiant, with no peculiarities seen. Analysis of presently incomplete data suggests possible peculiarity of a very red faint star, which is the only other object in the radio error box brighter than $V \sim 19$. Available data indicate that Cyg X-1, whether or not it is the radio source, must be intrinsically several magnitudes fainter than, or have much redder colors than, either Sco X-1 or Cyg X-2.

Recent X-ray observations (referenced in the legend to Fig. 1 [Pl. L2]) have improved the position of Cyg X-1 to within about 1 arc min (Fig. 1). Additional measurements at the University of Tokyo (Miyamoto *et al.* 1971) are not shown, but are consistent with these. Also, a radio source has been discovered by Hjellming and Wade (1971) and independently by Braes and Miley (1971) near the bright star (BD+34°3815 = HDE 226868) within the intersection of the AS&E and MIT error boxes (inset of Fig. 1). Hjellming and Wade's measurements show that this source increased in brightness by at least 3 times between measurements 7 weeks apart. The fact that the X-ray source is also known to be variable on this time scale further suggests that the radio and X-ray sources may be the same. If so, then the position of Cyg X-1 is known to better than 10 arc sec.

Many observers have noted that BD+34°3815 lies within the radio error box, and have suggested that it may be associated with the X-ray source. We believe that this is not so clear, for the following reasons.

An upper limit of 0.8–1.0 kpc to the X-ray source has been given by Gursky *et al.* (1971), based on a measurement of the low-energy X-ray cutoff and an estimate of the hydrogen path length from 21-cm radio data. The star BD+34°3815, however, has been studied by several observers, including ourselves, and placed at a distance greater than 2 kpc on the usual assumptions of spectral type and three-color photometry. Hiltner (1956) gives $V = 8.89$, $B - V = +0.85$, $U - B = -0.24$, a polarization of 0.108 mag, and a spectral type of B0 Ib. Our data obtained with the 100-inch nebular spectrograph and the 200-inch multichannel spectrophotometer agree with Hiltner's and show nothing peculiar over the spectral range 3300–11,000 Å. The UBV data give $A_v = 3.3$ mag. The same value is obtained from our scanner data when combined with the spectral type and the normal law of interstellar reddening (Whitford 1958). Furthermore, the fact that the ratio of polarization to absorption for this star ($p/A_v = 0.03$) is consistent

PLATE L2

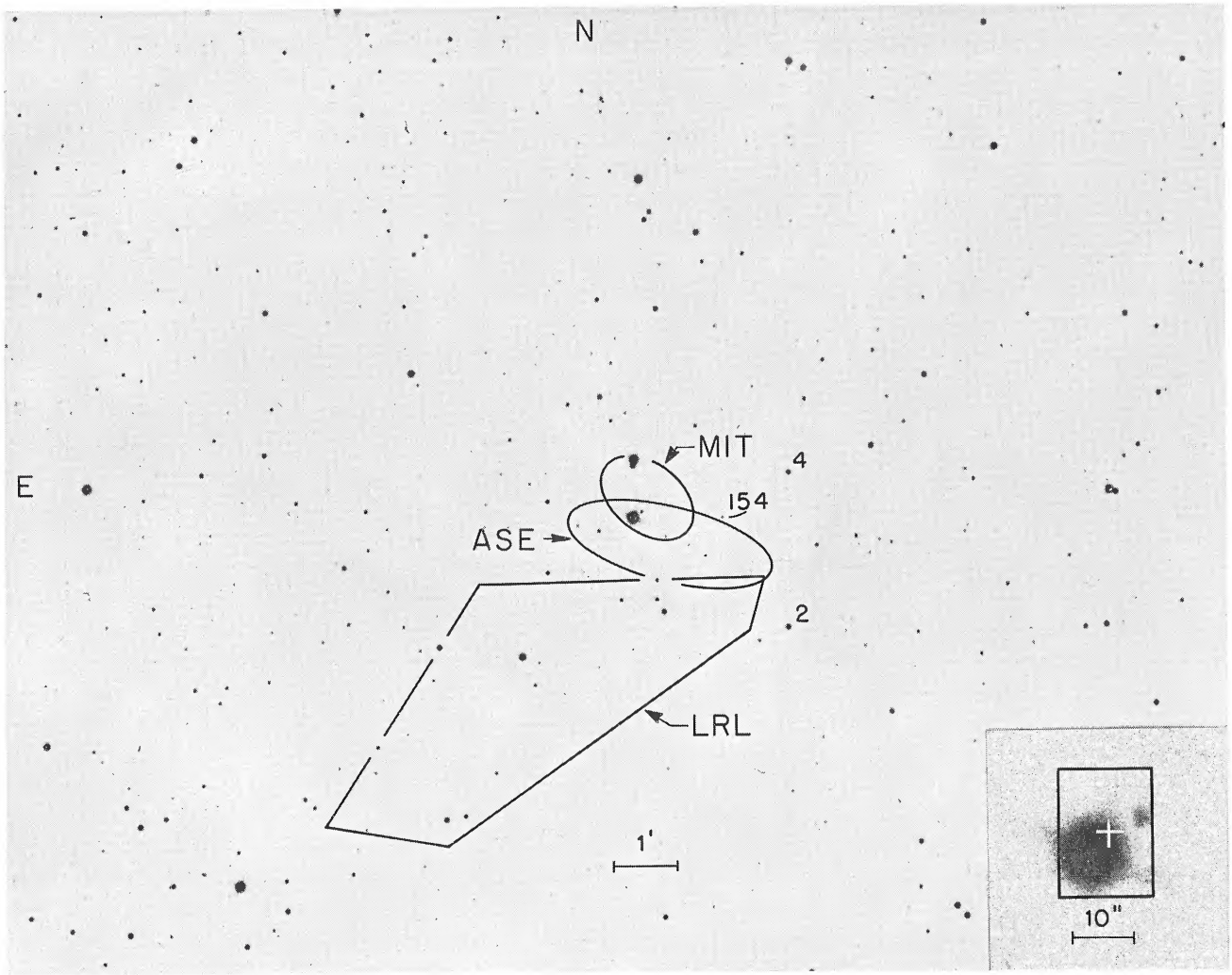

FIG. 1.—A 16′ × 19′ field, from a yellow plate taken with the Mount Wilson 100-inch, centered on Cyg X-1. *Error boxes*, X-ray positions determined by groups at American Science and Engineering (an improvement of the position reported by Tananbaum *et al.* 1971), MIT (Rappaport, Zaumen, and Doxsey 1971) and Lawrence Radiation Laboratory (Toor *et al.* 1971). The inset in the southwest corner is an enlargement of the vicinity of the bright star (BD+34°3815) within the intersection of the AS&E and MIT error boxes, and shows the position uncertainty (3 σ) of the variable radio source discovered by Hjellming and Wade (1971). Three stars from a more extensive photoelectric sequence are marked and have the following values: No. 2, $V = 12.98, B - V = +0.49, U - B = +0.06$; No. 4, $V = 13.62, B - V = +0.75, U - B = +0.24$; No. 154, $V = 15.59, B - V = +0.85, U - B = +0.29$.

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with well-known data in this region gives additional confidence in the absorption value. The resulting distance of the star is twice the upper limit of 1 kpc for the X-ray source. The uncertainty of the X-ray limit is appreciable, but Kerr (private communication) estimates the accuracy as better than 50–60 percent and considers an error of a factor of 2 to be unlikely.

Additional weaker evidence against an association of the star and the X-ray source is the absence of rapid variability of the star. The X-ray emission from Cyg X-1 is known to be variable by up to a factor of 2 on time scales from 50 ms to 5 s (Oda *et al.*1971; Holt *et al.* 1971; Rappaport, Doxsey, and Zaumen 1971). We have examined a number of stars in the field for variability (not necessarily periodic) on time scales from 10 ms to 10 s. No variations greater than those due to counting statistics were seen in BD+34° 3815, with a limit of 0.6 percent for a 1-s time scale. For longer or shorter time scales, this limit scales as $t^{-1/2}$.

Elimination of BD+34°3815 as a candidate would set a number of constraints on the optical identification of the source. One possibility is that the source is masked by the BD star, but either the alignment in this case would have to be nearly exact or the object would have to be fainter than $V \approx 18$, since visual observations at the 200-inch in good seeing show no companion other than a 15.2-mag red star about 9″ to the northwest. This object is of interest because it also lies within the radio error box (see inset of Fig. 1). Our investigation of this star is not complete, but preliminary data are sufficiently interesting to merit comment. We have a low-resolution (160 Å) spectral scan which agrees with published scans of M dwarfs (Willstrop 1964) from 4550 to 6500 Å, and with a 2600° blackbody from 6000 to 10,000 Å which is also reasonably consistent with M dwarf models. However, for $\lambda < 4550$ Å the scan shows an appreciable ultraviolet excess: the equivalent $U - B$ is approximately -0.4 mag, compared with $U - B \gtrsim +1$ for M dwarfs. But this result is not consistent with 100-inch plates taken 3 days earlier. The star is not seen on either blue or ultraviolet plates, although a nearby photoelectrically measured star which is about the same brightness in B and 0.7 mag fainter in U (No. 154 of Fig. 1) is seen on both plates. Taken at face value, the data would indicate that there is a very blue component associated with the red star, which varied by at least 1 mag in U and less than 0.1 mag in V in 3 days. However, we cannot yet rule out the likelihood that the scan may be contaminated by the nearby BD star, which is only 9″ away and 6.5 mag brighter in the ultraviolet end of the spectrum.

The search for rapid variability of the red star shows a limit of less than 2.5 percent on a time scale of 1 s.

Until the ambiguity in the red-star data is resolved, nothing definitive can be said about the optical identification, but it already seems clear that the X-ray source is optically unlike the two previous identifications, Sco X-1 and Cyg X-2.

Even if the radio source and X-ray source are not the same, three-color photographic photometry of 400 stars and two-color (B and UV) 48-inch plates show no ultraviolet-bright objects over the entire field shown in Figure 1, to a limit of $B \gtrsim 18$. Furthermore, objects in this region at the distance of the X-ray source cannot be extremely reddened, because our investigation of absorption in the field indicates no more than 2 mag of visual absorption at 1.5 kpc (the X-ray limit of Gursky *et al.*, including a 50 percent uncertainty).

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