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OPTICAL IDENTIFICATION OF H0123+075 AND 4U 1137−65: HARD X-RAY EMISSION FROM RS CANUM VENATICORUM SYSTEMS

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ABSTRACT

We identify the X-ray transient H0123+075 with HD 8357, and the *Uhuru* source 4U 1137−65 with HD 101379. The identifications are based on precise positions obtained with the *HEAO 1* scanning modulation collimator. Optical studies of both stars indicate they are members of the RS CVn class. This doubles the number of RS CVn–type systems first detected in hard ($\gtrsim$2 keV) X-rays to a total of four. We discuss solar analogies in RS CVn behavior and note that RS CVn systems could be responsible for a significant fraction of observed high–galactic-latitude X-ray transients.
Subject headings: stars: chromospheres — stars: coronae — stars: variables — X-rays: sources

I. INTRODUCTION

RS CVn binaries and similar systems (e.g., VW Cep: Carroll *et al.* 1980; and σ Cor Bor: Agrawal, Riegler, and Garmire 1980) have recently been established as an important class of soft X-ray sources (Walter *et al.* 1980). Although 15 identifications have been suggested to date, only two of these were detected at X-ray energies above 2 keV. The *Ariel 5* source 2A 1052+606 (Cooke *et al.* 1978, preprint version) was precisely located with the *HEAO 1* scanning modulation collimator (MC) (Schwartz *et al.* 1979) and was identified with BD +61°1211, which was subsequently determined to be an RS CVn system (Crampton, Dobias, and Margon 1979). HR 1099 was observed with *Copernicus* during a simultaneous X-ray and radio flare (White, Sanford, and Weiler 1978) and may be associated with the bright transient 4U 0336+01 at galactic latitude $b = -41°$, which lasted 1 week (Forman *et al.* 1978).

We report here precise positions, obtained with the *HEAO 1* MC, for two other sources which we identify with probable RS CVn systems. One is the variable source H0123+075 (Marshall *et al.* 1979): the 7th magnitude star HD 8357 falls in one of 22 allowed error regions, and we have obtained several spectra which show that it is likely to be an RS CVn or related system. The other is 4U 1137−65: the 5.7 mag star HD 101379 falls within our unique precise position and is considered a probable RS CVn system (Weiler and Stencel 1979). These results indicate that variable hard X-ray emission may be a common feature of RS CVn or related systems. The rapid flaring observed from two of these four systems and the high space density of RS CVn binaries ($\sim 10^{-5}$ pc^{-3} including non-eclipsing systems; Hall 1976; Walter, Charles, and Bowyer 1978) raise the possibility that such systems may account for a large number of the short-duration transient sources reported at high galactic latitudes.

II. H0123+075 = HD 8357 = SAO 109841

a) X-Ray Observations

The source H0123+075 was discovered with the *HEAO 1* A-2 experiment and was reported to be variable (Marshall *et al.* 1979). We have binned the MC data about the centroid of the A-2 error box (for a description of the instrument and data analysis technique, see Schwartz *et al.* 1978; Gursky *et al.* 1978) and detect the source at more than $\sim$15 μJy[1] during the interval 0900–2300 UT on 1978 January 13. A flare to 75 μJy was detected at 1112:09 UT. The postmaximum decline was not observed because of a pointed observation carried out between 1405 and 1721 UT. At its peak brightness the source is detected at 7 σ in the 1–5.5 keV energy band, and at 2.5 σ in the 5.5–13.5 keV band. However, the data are not of sufficient statistical significance to estimate spectral parameters.

Based on six scans taken while the source was at its brightest, we have obtained a set of 22 error regions, each of area 2.2 arcmin^2, which are consistent with the *HEAO 1* A-2 position and the *HEAO 1* Large Area Sky

[1] For an assumed thermal bremsstrahlung spectrum with kT = 3 keV, and no low-energy cutoff, a flux of 1.0×10^{-11} ergs cm^{-2} s^{-1} between 2 and 6 keV corresponds to a flux density of 1 μJy at 3.2 keV; 1 μJy $\equiv 0.242 \times 10^{-11}$ ergs cm^{-2} s^{-1} keV^{-1}.

Survey (LASS) line of position. The brightest star in any of these is HD 8357 (Fig. 1, Pl. L4), listed in the *Henry Draper Catalog* as type G5, $m_{pg} = 7.3$. No optical variability has been reported in the *General Catalog of Variable Stars* (Kukarkin *et al.* 1970). At a galactic latitude of $b = -54°$, the probability that a star brighter than 8th magnitude would fall in any of the allowed error regions is 5×10^{-3} (Allen 1973).

Snyder *et al.* (1979) have noted the presence of UV Psc, a previously known RS CVn binary, in their allowed location uncertainty for H0123+075. Our multiple positions rigorously exclude this star as the source of the 1978 January 13 X-ray flare.

b) Optical Observations

Spectra of HD 8357 were obtained in the Ca II K (λ3934) region to assess the chromospheric emission and the possibility of duplicity. Spectrograms (cf. Fig. 2*a*) of ~30 Å surrounding the Ca II K emission core were obtained at a resolution of 0.04 Å with the echelle spectrograph and intensified reticon detector on the 1.5 m reflector at Mount Hopkins Observatory.

The RS CVn binaries are portrayed as systems with extensive chromospheric and coronal activity from a cool, luminous component near spectral type K0 IV, and a hotter companion, near F–G V (Hall 1976). In HD 8357, the Ca II K emission is remarkably strong relative to the nearby photospheric flux and is similar to that observed in other RS CVn systems. The three echellograms, obtained over 1 month, show no detectable variation in the relative flux of the K-emission core.

To search for a secondary star, we calculated the cross-correlation functions (cf. Tonry and Davis 1979) of the photospheric spectra of HD 8357 with α Boo (K2 III), a single, sharp-lined template whose spectrum is shown in Figure 2*a*. In order that only the absorption lines contribute to the correlation function, the emission core was excised from each of the spectra. The cross-correlation functions (Fig. 2*b*) show two significant peaks, indicating two late-type stellar spectra at radial-velocity separations varying between 20 and 45 km s^{-1}. For comparison, we show the autocorrelation function of the spectrum of α Boo, which shows that the double peaks calculated from the spectra of HD 8357 are not intrinsic to the pattern of photospheric lines in the spectrum of α Boo. The recurrence of the phase in spectra 1 and 3 (Fig. 2*b*) indicates an orbital period of less than 1 month. However, the orbital motion of ~20 km s^{-1} over 2 days in spectra 2 and 3 (Fig. 2*b*) suggests a shorter period. The centroid of the Ca II K core is comoving with the brighter peak of the correlation function. Further, at a radical velocity separation of ~40 km s^{-1}, there is no broadening of the K-core

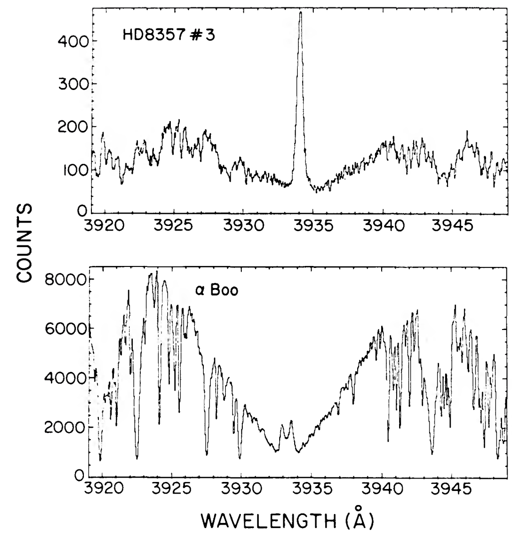

Fig. 2*a*

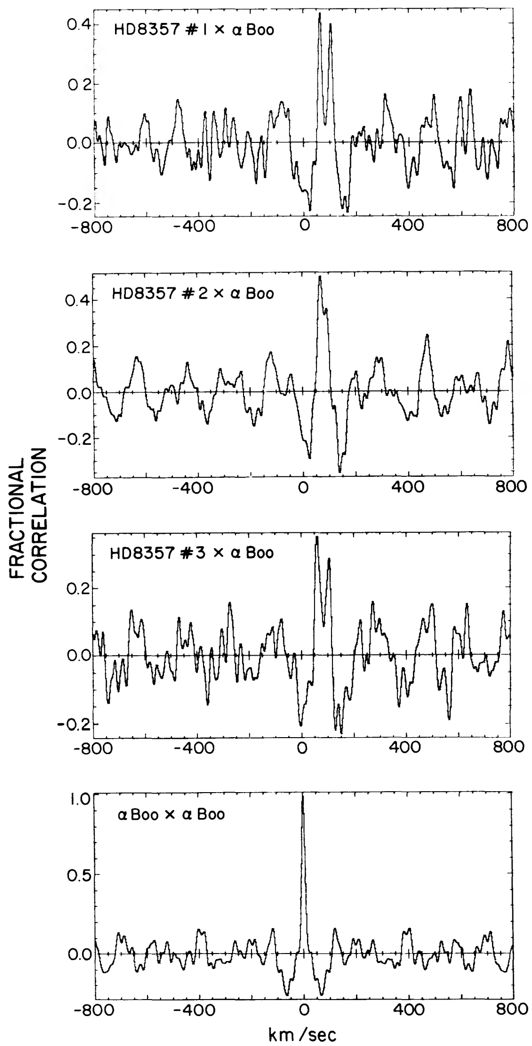

Fig. 2*b*

Fig. 2.—(*a*) Ca II K (λ3933) spectra taken with the echelle and intensified reticon on the 1.5 m reflector at Mount Hopkins. The resolution is 0.04 Å. (*b*) Cross-correlation functions of α Boo with HD 8357 as observed (1) on 1979 Dec. 9—10 minute exposure, $\Delta v = 40$ km s^{-1}; (2) on 1980 Jan. 2—60 minute exposure, $\Delta v = 22$ km s^{-1}; (3) on 1980 Jan. 4—60 minute exposure, $\Delta v = 45$ km s^{-1}. At bottom is the autocorrelation of an 8 minute exposure of α Boo.

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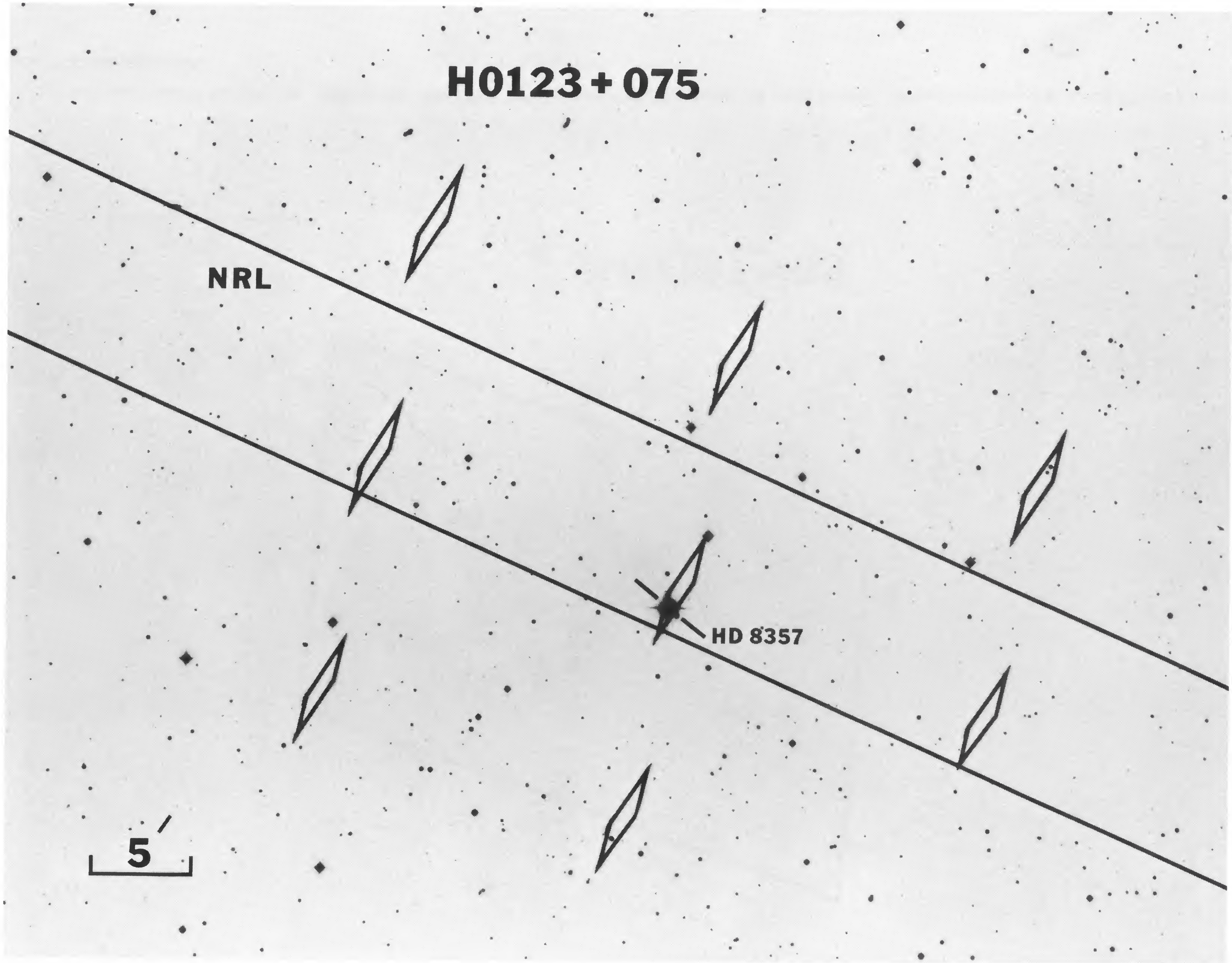

FIG. 1.—Finding chart for H0123+075. The A-1 LASS line of position and the *HEAO 1* MC error diamonds are superposed on a Palomar Sky Survey red plate. Not seen are the 18 additional MC error diamonds in the intersection of the A-1 and A-2 error boxes. UV Psc is an RS CVn variable in the western corner of the A-1 error box, but it is well outside any MC error diamonds.

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emission, which would be apparent if the stellar companion contributed significantly to the emission. Thus, the bright chromospheric emission is dominated by one stellar component which also shows stronger photospheric lines in this spectral region.

From the measured width of the Ca II K emission core, the Wilson-Bappu relationship (Engvold and Rygh 1978) yields a luminosity class of III for the primary. The sharpness of the photospheric features rules out a subgiant whose spectral features have been substantially broadened by rotation. However, strong chromospheric emission can also widen the emission core, as in the case of λ And (Baliunas and Dupree 1979). As a result, the luminosity class can be overestimated from the Wilson-Bappu relationship. Thus, HD 8357 may well be a subgiant. From the range of spectroscopic parallax corresponding to luminosity classes IV-III, we calculate a range of X-ray luminosity 4×10^{32} to 3×10^{33} ergs s^{-1}. These values are comparable to the X-ray luminosity (2–6 keV) of HR 1099 during the flare observed with *Uhuru* and to the maximum luminosity of 2A 1052+606.

III. 4U 1137−65 = HD 101379 = SAO 251522

4U 1137−65 was reported as a 9 UFU[2] source with a positional uncertainty of 0.031 deg^2 in the *Fourth* Uhuru *Catalog* (Forman *et al.* 1978). Data from scans of this source which took place on 1978 January 30 and July 31–August 3 have been superposed. Detections at significance levels of 4.2 σ and 3.2 σ were obtained with MC 1 (30″ FWHM) and MC 2 (120″ FWHM), respectively, corresponding to an average flux density of 5 μJy (2–6 keV). Although the MC intensity is nearly a factor of 3 below that measured with *Uhuru*, this cannot be taken as firm evidence for a long-term variability due to the presence of nearby bright sources.

Only one of the multiple MC error regions, with an area of 2.4 $arcmin^2$, is consistent with the *Uhuru* position. The brightest star in the MC error region is HD 101379, $m_v = 5.1$ (Fig. 3, Pl. L5), classified by Weiler and Stencel (1979) as a very likely RS CVn system on the basis of Ca II H and K emission and its known variability (Houk and Cowley 1975). Recent observations show radial velocity shifts in the emission lines which vary on the time scale of approximately 1 day (Stacy, Stencel, and Weiler 1980).

Based on the expected absolute magnitude $M_v = 0.7$ of a G5/8 III star, we estimate a distance of 75 pc and infer an average X-ray luminosity of 3×10^{31} ergs s^{-1} (2–6 keV) during our observation.

IV. DISCUSSION

a) Solar Analogies in RS CVn Behavior

The origin of soft X-ray emission from RS CVn binaries is thought to be due to a corona of temperature $\sim 10^7$ K, maintained by intense starspot and related flarelike activity (Walter, Charles, and Bowyer 1978). The nature of the hard (and rapidly variable in two of the four identified systems) X-ray emission is not well understood. Although we do not measure an X-ray spectrum for HD 8357, we can infer an effective temperature of more than 3×10^7 K to produce the observed 2.5–5.5 keV X-ray emission; and therefore can infer an X-ray free-free emission measure of order 10^{56} cm^{-3}. (We do not expect significant line emission in our 2.5–5.5 keV channel.) At this higher temperature, models directly scaled from solar analogies (Walter *et al.* 1980) cannot produce the observed emission measure within the presumed dimensions of the binary system.

b) Origin of High-Galactic-Latitude Fast Transients

We note that the rapid variations observed in two of the four identified systems may be closely related to the nature of the fast, high-galactic-latitude X-ray transients reported by a number of observers (Cooke 1976; Rappaport *et al.* 1976; Schrijver *et al.* 1978). It has been estimated that about 100 transients which give a flux greater than 10 UFU occur per year (Ricketts, Cooke, and Pye 1978, reported by Pounds 1978). For a peak flare luminosity L_x, flare recurrence rate R, and space density ρ of the flaring systems, the expected number of transient events per year which produce a flux greater than f *Uhuru* counts s^{-1} is:

$$N(>f) = 16\left(\frac{L_x}{5 \times 10^{32}\ \text{ergs s}^{-1}}\right)^{3/2}\left(\frac{f}{10\ \text{UFU}}\right)^{-3/2} \times \left(\frac{\rho}{10^{-5}\ \text{pc}^{-3}}\right)\left(\frac{R}{10^{-1}\ \text{yr}^{-1}}\right)\ \text{yr}^{-1}\,, \quad (1)$$

where we have scaled the parameters by plausible values. Flares can be detected to a maximum distance of:

$$D = 155\left(\frac{L_x}{5 \times 10^{32}\ \text{ergs s}^{-1}}\right)^{1/2}\left(\frac{f}{10\ \text{UFU}}\right)^{-1/2}\ \text{pc}\,, \quad (2)$$

which is comparable to the 110 pc scale height (Hall 1976) of RS CVn systems. Thus the distribution of such events should be nearly independent of galactic latitude. This explanation predicts that some of the high-latitude transients should be recurrent and that the number of transients increase more slowly than $f^{-3/2}$ for $f \leq 10$ UFU. Although several other kinds of systems may demonstrate fast-transient behavior, it is possible that RS CVn systems may account for a significant number of the observed events.

Since stars of type F–K were considered unlikely candidates for X-ray source counterparts, RS CVn systems are likely to have been overlooked in past searches of fast-transient error regions. For this reason we have searched the error regions of published high-galactic-latitude ($|b| > 10°$) transients for bright ($m_v \lesssim 8.25$) stars of types F–K. We have limited our search to boxes less than ~ 2 deg^2 in size. The surface density of such stars is nearly isotropic in galactic latitude at $|b| > 10°$ and has a value of ~ 0.77 deg^2 (Shapley and Cannon 1924). In the five error regions searched, 3.2 such stars are expected by chance, and six are seen (Table 1). The Poisson probability of finding more than five stars is 10%. Optical studies of these stars

[2] 1 UFU = 1.7×10^{-11} ergs cm^{-2} s^{-1} (2–6 keV); ~ 1.6 μJy at 3.6 keV, for an assumed Crab-like spectrum.

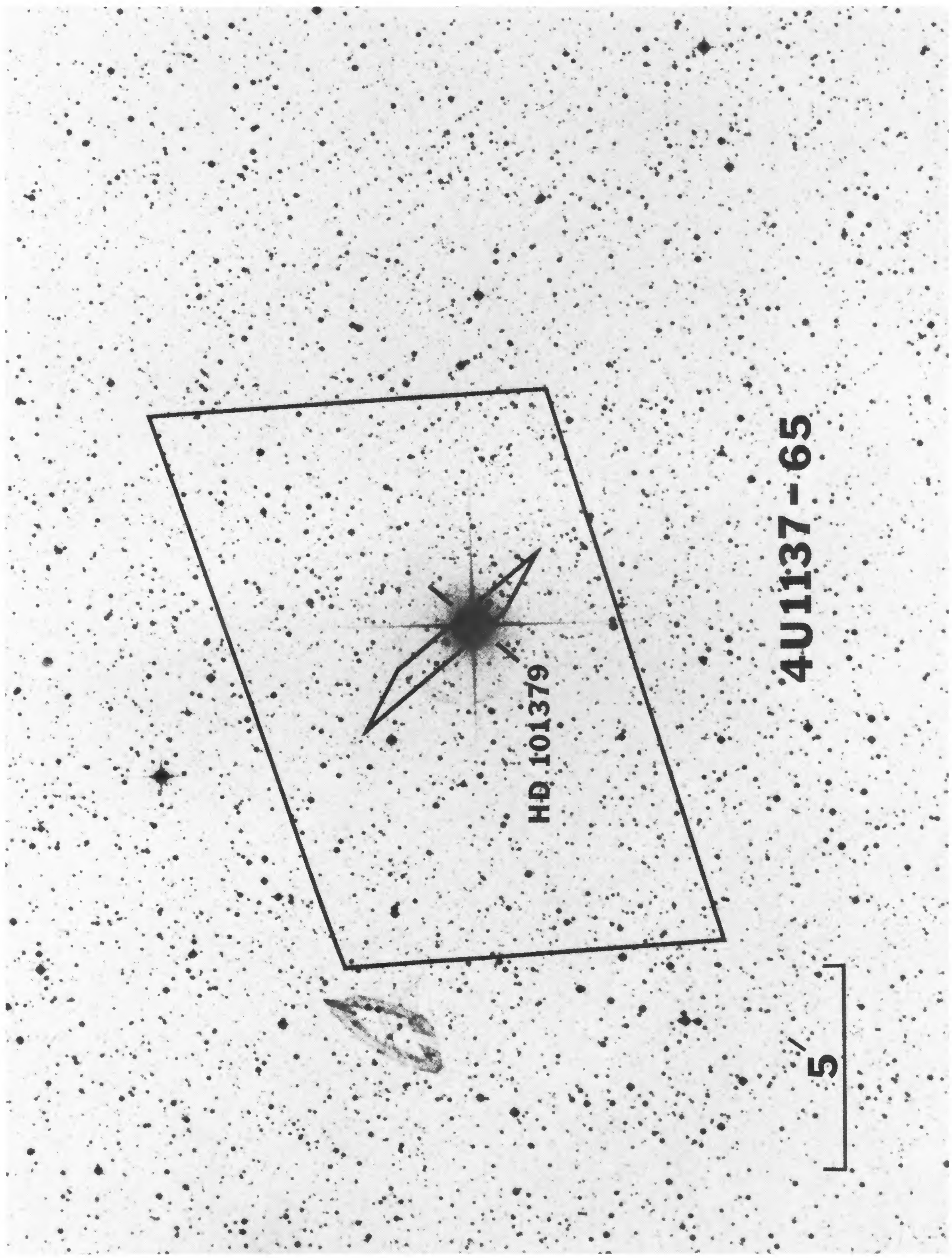

FIG. 3.—Finding chart for 4U 1137−65 = HD 101379. The *Uhuru* error box and the single allowed MC error diamond within it are superposed on the ESO Sky Survey plate.

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TABLE 1

BRIGHT F, G, AND K STARS IN OR NEAR X-RAY TRANSIENT ERROR BOXES ($\Delta\Omega \leq 2$ deg^2)

X-Ray Source	Star(s)[a] in Box	Star(s) near Box
ANS 0208+07[b].......	HD 13177, m_v = 8.8/K0	DMA 6−328, m_v=8.7/F5
		HD 13178, m_v=8.7/F5
A0352−40[c]..........	HD 25038, m_v = 6.9/K0	...
4U 1535−29[d]........	HD 142217, m_v = 8.2/F5	...
	HD 137798, m_v = 7.5/F8	
MX 2348−64[e]........	HD 222820, m_v = 5.7/K5	...
	m_{pg}=6.9/K2 II/III[f]	
	HD 222830, m_v = 6.9/K5	
	m_{pg}=8.0/K1/2 III[f]	
	HD 222781, m_v = 8.6/G5	
	m_{pg}=9.6/K2 III[f]	
4U 2358+21[d]........	HD 224657, m_v = 8.2/F0	HD 224671, m_v=8.8/F0

[a] Magnitude and spectral type from SAO star catalog, except as noted.
[b] Schrijver *et al.* 1978.
[c] Cooke 1976.
[d] Forman *et al.* 1978.
[e] Rappaport *et al.* 1976.
[f] Houk and Cowley 1975.

are needed to search for Ca II emission or evidence of a photometric wave, to determine if any of them are related to the RS CVn–type systems.

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REFERENCES

Agrawal, P. C., Riegler, G. R., and Garmire, G. P. 1980 *M.N.R.A.S.*, **190**, 853.
Allen, C. W. 1973, *Astrophysical Quantities* (3d ed.; London: Athlone Press), p. 243.
Baliunas, S. L., and Dupree, A. K. 1979, *Ap. J.*, **227**, 870.
Carroll, R. W., *et al.* 1980, *Ap. J.* (*Letters*), **235**, L77.
Crampton, D., Dobias, J., and Margon, B. 1979, *Ap. J.*, **234**, 993.
Cooke, B. A. 1976, *Nature*, **261**, 564.
Cooke, B. A., *et al.* 1978, *M.N.R.A.S.*, **182**, 489.
Engvold, P., and Rygh, B. O. 1978, *Astr. Ap.*, **70**, 399.
Forman, W., Jones, C., Cominsky, L., Julien, P., Murray, S., Peters, G., Tananbaum, H., and Giacconi, R. 1978, *Ap. J. Suppl.*, **38**, 357.
Gursky, H., *et al.* 1978, *Ap. J.*, **223**, 973.
Hall, D. S. 1976, *IAU Colloquium 29*, ed. W. S. Fitch (Dordrecht: Reidel), p. 287.
———. 1978, *A.J.*, **83**, 1469.
Houk, N., and Cowley, A. P. 1975, *University of Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars*, Vol. 1 (Ann Arbor: Department of Astronomy, University of Michigan).
Kukarkin, B. V., *et al.* 1970, *General Catalog of Variable Stars* (3d ed.; Moscow: Academy of Sciences).
Marshall, F. E., Boldt, E. A., Holt, S. S., Mushotzky, R. F., Pravdo, S. H., Rothschild, R. E., and Serlemitsos, P. J. 1979, *Ap. J. Suppl.*, **40**, 657.
Pounds, K. 1978, reported at HEAD/AAS Meeting on X-Ray and Gamma-Ray Astronomy, La Jolla, California, September 14.
Rappaport, S., Buff, J., Clark, G., Lewin, W. H. G., Matilsky, T., and McClintock, J. 1976, *Ap. J.* (*Letters*), **206**, L139.
Ricketts, M., Cooke, B. A., and Pye, J. P. 1978, *Bull. AAS*, **10**, 516.
Schrijver, J., Brinkman, A. C., Heise, J., den Boggende, A. J. F., Gronenschild, E., Mewe, R., Grindlay, J. E., and Parsignault, D. R. 1978, *Astr. Ap.*, **69**, 1.
Schwartz, D. A., Bradt, H., Briel, U., Doxsey, R., Fabbiano, G., Griffiths, R. E., Johnston, M. D., and Margon, B. 1979, *A.J.*, **84**, 1560.
Schwartz, D. A., Schwarz, J., Gursky, H., Bradt, H., and Doxsey, R. E. 1978, *Proc. AIAA 16th Aerospace Conference*, Vol. **78**, No. 34.
Shapley, H., and Cannon, A. J. 1924, *Proc. Am. Acad. Arts Sci.*, **59**, 215.
Snyder, W. A., Share, G., Meekins, J. F., Wood, K., Yentis, D., Kinzer, R., Evans, W. D., Byram, E. T., Chubb, T. A., and Friedman, H. 1979, *Bull. AAS*, **11**, 782.
Stacy, J. G., Stencel, R. E., and Weiler, E. J. 1980, *A.J.*, submitted.
Tonry, J., and Davis, M. 1979, *A.J.*, **84**, 1511.
Walter, F., Charles, P., and Bowyer, S. 1978, *Ap. J.* (*Letters*), **225**, L119.
Walter, F. M., Cash, W., Charles, P. A., and Bowyer, C. S. 1980, *Ap. J.*, **236**, 212.
Weiler, E. J., and Stencel, R. E. 1979, *A.J.*, **84**, 1372.
White, N. E., Sanford, P. W., and Weiler, E. J. 1978, *Nature*, **274**, 569.

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