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DISCOVERY OF THREE NEW RS CANUM VENATICORUM–LIKE COUNTERPARTS TO *HEAO 1* X-RAY SOURCES

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ABSTRACT

We report the identification of three high galactic latitude X-ray sources, detected by the *HEAO 1* Scanning Modulation Collimator (MC) experiment, with the bright stars HD 113816, HD 146413 (=ADS 9982) and HD 39576. We have found all three stars to be chromospherically active by virtue of their Ca II emission strength. The latter two stars exhibit variable X-ray emission in the 1–13 keV energy range, while HD 113816 is a softer (0.9–2.5 keV) and steadier source, judging from our two observations. Our optical spectroscopic observations reveal small radial velocity variations over months for HD 113816 and insignificant variations for HD 146413. We interpret the former as indicating HD 113816 is a member of the long-period RS CVn–like class, and this is supported by its spectral classification of K2 IV–III. HD 39576 shows the weakest Ca II core emission, but its earlier spectral type (G1) implies a larger Ca II surface flux. The level of X-ray flux detected from these three stars is some one to two orders of magnitude higher than predicted empirically from the Ca II emission fluxes. We propose that the X-ray emission results from flarelike activity and interpret the variable and harder flux observed from two of the sources, HD 146413 and HD 39576, as evidence. HD 113816 distinguishes itself from the other two, as well as the majority of known X-ray flaring RS CVn binaries, by exhibiting softer X-ray emission. We show that it is very similar, both in optical and X-ray character, to the soft flaring RS CVn HD 155638, and we report for the first time the detection of this latter star as a *HEAO 1* MC source.

Subject headings: Ca II emission — stars: binaries — stars: individual — X-rays: binaries

I. INTRODUCTION

We are currently involved in a program to locate and study the optical counterparts of the weak, unidentified, hard X-ray sources observed by the Scanning Modulation Collimator (MC, or A3) experiment flown on *HEAO 1* (Gursky *et al.* 1978). The data base of *HEAO 1* represents the most recent, deepest, flux-limited all-sky survey of hard (1–13 keV) X-ray sources (see, for example, Wood *et al.* 1984), with the MC experiment capable of providing precise X-ray positions that frequently lead to the identification of the optical counterpart (Schwartz *et al.* 1981; Schwartz *et al.* 1985; Tuohy *et al.* 1985, 1986; Remillard *et al.* 1986).

Observations by *HEAO 1* established RS Canum Venaticorum binaries and related systems as X-ray sources (Walter, Charles, and Bowyer 1978; Walter *et al.* 1980). Subsequent observations by the *Einstein Observatory* (*HEAO 2*) resulted in detections of many more RS CVn systems (Walter and Bowyer 1981), as well as other classes of stars exhibiting chromospheric and coronal activity (e.g., W UMa and BY Dra systems). The *Einstein Observatory* also revealed that soft coronal X-ray emission was a ubiquitous feature of single stars over a wide range of spectral type and luminosity class (Vaiana *et al.* 1981).

The picture which has emerged is that any star of spectral type F–K may show solar-like activity to a greater or lesser degree depending upon the efficiency of the α-ω dynamo mechanism in producing magnetic flux loops. This efficiency is dependent chiefly upon the depth of the surface convective zone and the rotation period. The dynamo efficiency can be parameterized by the Rossby number, itself proportional to rotation period and inversely proportional to the convective turnover time scale, τ_c, of eddies at the base of the convective zone (see, for example, Maggio *et al.* 1986).

A 10^7 K corona, maintained by starspot and flare activity, was proposed by Walter *et al.* (1980) to be responsible for the soft X-ray flux in RS CVn systems. Spectra obtained with the Solid State Spectrometer (SSS) on the *Einstein Observatory* required at least a two-temperature fit (Swank *et al.* 1981). Using a coronal loop model, the authors showed that emission regions could be extensive enough for interaction to occur with the companion star and this picture is supported on theoretical grounds by Uchida and Sakurai (1983). Majer *et al.* (1986) also found two-temperature fits to be prevalent, based on *Einstein* Imaging Proportional Counter (IPC) data. While they concluded that plasma was present over a wide range of temperatures, any particular model fit simply reflects the temperatures characteristic of a particular instruments' own energy response.

Coronal activity, as measured by $L_x/L_{\rm bol}$, was shown in a series of papers (Walter and Bowyer 1981; Walter 1981, 1982; Ayres and Linsky 1980) to depend inversely on the rotation period of the star. Pallavicini *et al.* (1981) showed that L_x was correlated with $v \sin i$ for various types of stars, including multiple systems. As a *group*, the RS CVn binaries have the largest L_x values ($\sim 10^{30}$ to a few times 10^{31} ergs s^{-1}) and obey this relation, although the correlation *within* the group is poor. Indeed, Majer *et al.* (1986) clearly show that L_x is independent of period for RS CVn systems, and have argued, as have Rengarajan and Verma (1983), that the L_x/L_{bol}–period dependence is simply due to the variation of the radius of the active star, on which L_{bol} depends, with period. Shorter period systems must have smaller radii to avoid semidetached configurations and subsequent Roche lobe overflow.

Chromospheric activity in RS CVn stars (Hall 1976) and dMe flare stars (Bopp 1974) is also period dependent. Mewe, Schrijver, and Zwaan (1981) and Schrijver (1983) have shown that chromospheric activity, as measured by Ca II emission line fluxes, correlates with the quiescent soft X-ray flux. They have shown that single dwarfs and giants, RS CVn and spectroscopic binaries all obey this single relation, with the RS CVn systems being the most active.

A small number of RS CVn systems have also been observed as *hard* (2–10 keV), flaring, or transient X-ray sources (Charles 1983; Stern, Underwood, and Antiochos 1983). Garcia *et al.* (1980) first suggested that flares from RS CVn binaries were the sources of the common, fast transient X-ray sources seen at high galactic latitude (Pounds 1976). Flares observed from RS CVn binaries are highly energetic events with time scales ranging from hours to weeks (Linsky 1984). If we adopt a peak flare luminosity of 10^{32} ergs s^{-1} (Schwartz *et al.* 1981) and a nominal flux detection limit of 2×10^{-11} ergs cm^{-2} s^{-1}, typical of weak MC sources, then high galactic latitude flares should be detectable from RS CVn systems at distances up to ~ 200 pc. Taking a typical absolute magnitude of $2 < M_v < 4$ for the active G–K V–III component, we expect that such a flaring RS CVn, or related system, will be seen as a *HEAO 1* X-ray transient if it is brighter than $m_v \approx 9.5$.

In this paper we report the identification of three high-latitude *HEAO 1* MC X-ray sources with the chromospherically active RS CVn–like stars HD 113816, HD 146413, and HD 39576. In § II we present the X-ray data for these sources. Optical observations, including coudé spectroscopy and broad-band and narrow band photoelectric photometry, are summarized in § III. In § IV we discuss the implications of our data and compare them to other X-ray emitting RS CVn systems. We conclude with summary remarks in § V.

II. X-RAY OBSERVATIONS AND SOURCE IDENTIFICATIONS

The nonimaging MC experiment produced multiple positional error boxes or "diamonds" uniformly distributed over the 4° × 4° FWHM field of view of the experiment. These diamonds resulted from the beam pattern produced by the two sets of wire collimators, referred to in the rest of this paper as MC1 and MC2, which modulated the X-ray signal as the spacecraft rotated. The responses of these collimators were 30″ and 120″ FWHM and resulted in error diamonds of similar dimensions. As described in Remillard *et al.* (1986), the multiplicity of diamonds is substantially reduced by imposing other X-ray survey error boxes. The *HEAO 1* Large Area Sky Survey (hereafter "LASS") catalog (Wood *et al.* 1984) presents details of the 842 sources detected during the first complete celestial scan by *HEAO 1.* The source positions reported in the catalog in many cases reduce the number of viable error diamonds from several hundred to between 5 and 50. Since the MC experiment viewed sources contemporaneously with LASS, the latter has been utilized to enable weak MC data to be rebinned on LASS positions, thus allowing us to reliably use MC results as weak as 2.5 to 3 σ (Schwartz *et al.* 1985).

The initial step in finding the *HEAO 1* MC optical counterparts has been to search on-line catalogs of many different classes of objects, all potential X-ray sources, for coincidence with X-ray error diamonds. Examples of such catalogs are the *General Catalogue of Variable Stars* (Kukarkin *et al.* 1969), *Catalogue of Emission Line Objects* (Wackerling 1970), and *Catalogue of Stars within 25 Parsecs of the Sun* (Woolley *et al.* 1970). Particular attention was also paid to off-line catalogs such as compilations of RS CVn systems (Hall 1981; Hall, Zeilik, and Nelson 1985) and cataloged emission line objects (Bidelman and MacConnell 1973; Houk and Cowley 1975; Houk 1978, 1982; Weiler and Stencel 1979; Hearnshaw 1979) for coincidences with MC and LASS positions. In most cases such searches have not produced a viable candidate. The next step in the identification procedure is to search for UV-excess objects on Schmidt plates of the X-ray fields (see Remillard *et al.* 1986 for a full description of this method). In parallel with the above, we also consider any bright stars ($m_v < 10$), usually SAO catalog objects, coincident with MC error diamonds. Early-type stars are observed for evidence of Be or shell star characteristics; such stars have been associated with X-ray sources when they are companions to neutron stars (Rappaport and van den Heuvel 1982). Stars of spectral type F–K were observed spectroscopically for signs of chromospheric activity, viz., Ca II emission. In each of the three cases reported in this paper, a cataloged SAO star was found within one of the ~ 2 arcmin^2 MC error diamonds. Subsequently, coudé spectroscopy revealed the chromospheric nature of these stars, which will be discussed in § III.

The three X-ray sources were observed by the *HEAO 1* instruments on two or three separate scans. Each scan lasted 4–7 days, and the scans of an individual source occurred every 6 months. The X-ray detections for each source are summarized below. The positions determined by the MC and LASS experiments are shown in Figures 1, 2, and 3 together with the proposed optical counterparts. We have estimated the 2–10 keV fluxes from the LASS catalog count rates using a conversion factor representative of RS CVn systems. Our conversion factor is reasonably close to the value used by Pravdo, White, and Giommi (1985) for coronal emission between 0.5 and 10 keV, but our value is 25% larger than that quoted by Wood *et al.* (1984) for a Crab-like spectrum. The MC detections in general are too near threshold to yield reliable flux estimates.

a) 1H 1303−047 (=HD 113816 = SAO 139157)

This source is listed in the LASS catalog as a detection in the first 6 months of the mission. The X-ray flux is 7.0×10^{-11} ergs cm^{-2} s^{-1} in the energy range 2–10 keV. The source was scanned twice by *HEAO 1* (1978 January 2–8 and 1978 July 3–9), and the MC result is most significant during the second observation. The MC error diamonds (see Fig. 1) were obtained from the energy channel with sensitivity in the range 0.9–2.5 keV, and the statistical significance of the detection is 2.7 σ in MC1 and 3.8 σ in MC2. The $V = 8.3$ mag star HD 113816, at $\alpha(1950) = 13^h03^m51^s$ and $\delta(1950) = -4°34'42''$, is within one of the error diamonds and exhibits very strong emission lines at Ca II H and K, as can be seen in Figure 4*a*.

b) H1613+075 (=HD 146413 = SAO 121460 = ADS 9982)

This source was not detected by either the LASS or MC during the first *HEAO 1* scan (1977 August 20–24). However,

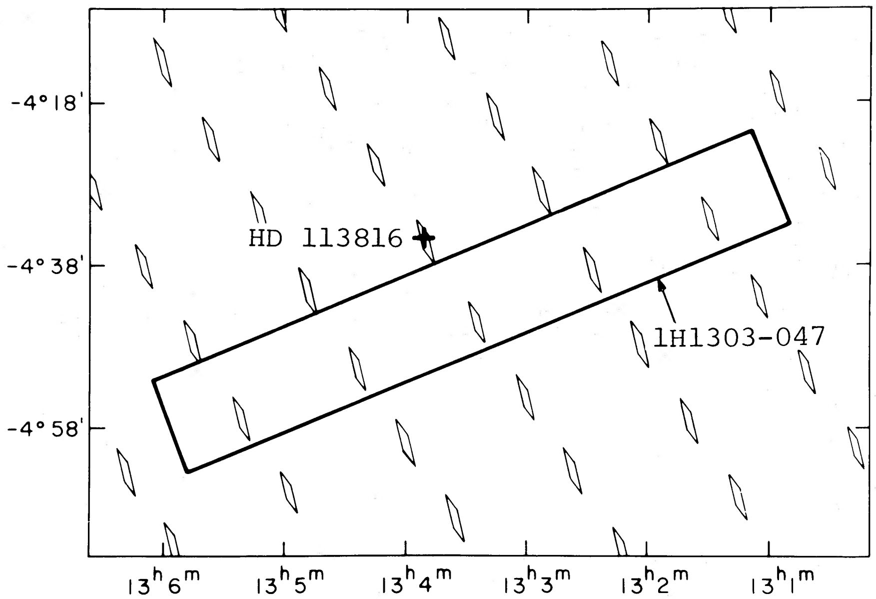

FIG. 1.—X-ray field for 1H 1303−047 showing the MC error diamonds and LASS error box. The $V = 8.3$ star HD 113816 lies at $\alpha(1950) = 13^h03^m51^s$, $\delta(1950) = -04°34'42''$.

in the sum of the second and third scans (1978 February 15–19 and 1978 August 20–23), the MC detected a source with a significance of 3.4 σ in MC1 and 4.3 σ in MC2 in the energy range 1–13 keV. The $V = 8.6$ mag star HD 146413 at $\alpha(1950) = 16^h13^m31^s$ and $\delta(1950) = -7°29'14''$, a visual binary (ADS 9982) with both of its components exhibiting Ca II H and K emission, was found within an MC error diamond. We have conducted our own analysis of LASS data in order to derive the line of position[1] shown in Figure 2*a* during the second 6 months' observation. The third LASS observation was not used as it was affected by detector malfunctions. Although the proposed optical counterpart is not within the 90% confidence limits of the detection, the positional deviation is not large enough to exclude the identification.

We show in Figure 2*b* error boxes pertaining to three soft (<1 keV) sources in the vicinity of H1673+075 detected by the *HEAO 1* A-2 (soft) experiment (Nugent *et al.* 1983). One has subsequently been identified as a Seyfert galaxy (E1615+061) with an unusually soft spectrum by Pravdo *et al.* (1981) using the IPC and High Resolution Imager (HRI) of the *Einstein Observatory*. Pravdo *et al.* (1981) report that *HEAO 1* detected the Seyfert during the first two 6 month scans, in contrast to our MC and LASS data for H1613+075, which are for the second and third scans. Further, we do not detect H1613+075 as a distinctly soft source in our 0.9–2.5 keV channel of the MC. Thus we conclude that there is no confusion of our source with E1615+061.

The variable nature of the MC source plus the presence of these nearby soft A-2 sources may account for the discrepancy of the LASS position. The X-ray flux during the second and third scans is approximately 3×10^{-11} ergs cm^{-2} s^{-1} in the range 2–10 keV.

[1] The line of position is orthogonal to the scan plane of the *HEAO 1* instruments and is derived from the time of central transit of the X-ray source through the field of view. It is always parallel with the longest dimension of the LASS error box.

c) 1H 0543−289 (=HD 39576 = SAO 170952)

The 2–10 keV flux determined for this source from the LASS catalog (Wood *et al.* 1984) is 2.6×10^{-11} ergs cm^{-2} s^{-1} during the first scan of the source (1977 September 16–23). The MC results are appreciably more significant, however, for the sum of the second and third scans (1978 March 13–20 and 1978 September 17–24), with statistical significances of 3.1 σ in MC1 and 4.0 σ in MC2 in the energy range 1–13 keV. A ninth magnitude G star with Ca II H and K emission, HD 39576, at $\alpha(1950) = 05^h50^m19^s$ and $\delta(1950) = -28°40'02''$, lies within an MC error diamond that is well outside the LASS error box, but not far from the LASS line of position. The MC and LASS positions are shown in Figure 3. We do not consider the deviation from the LASS box to invalidate our identification. Our experience with previous identifications of faint *HEAO 1* MC sources, plus identifications listed in the LASS catalog itself, have led us to conclude that the A-1 boxes are significantly underestimated. The RMS deviations in the positions of the identified sources, often confirmed by independent X-ray results (e.g., *EXOSAT*) typically require an increase of ~ 3.5 in the area of the "90% confidence" LASS boxes.

III. OPTICAL OBSERVATIONS

a) Spectroscopic Survey

Spectra were obtained in the Ca II H and K region for all candidate stars using the coudé spectrograph on the Mount Stromlo Observatory 1.88 m telescope. A typical wavelength interval of $\lambda\lambda$3900–4090 was achieved using the third order of a 600 lines mm^{-1} grating, blazed at λ12,000 in the first order. A blue BG12 filter was employed to remove the overlapping second order spectrum. The detector was a two-dimensional photon counting array (PCA; Stapinski, Rodgers, and Ellis 1981) consisting of a CCD intensified by two microchannel plates (MCP) coupled to a phosphor. The structure of the MCPs is a hexagonal array of 12 μm diameter "pores" of 15 μm separation. A typical photon event at the phosphor has a spatial FWHM of ~ 60 μm. This event is detected by a Fair-

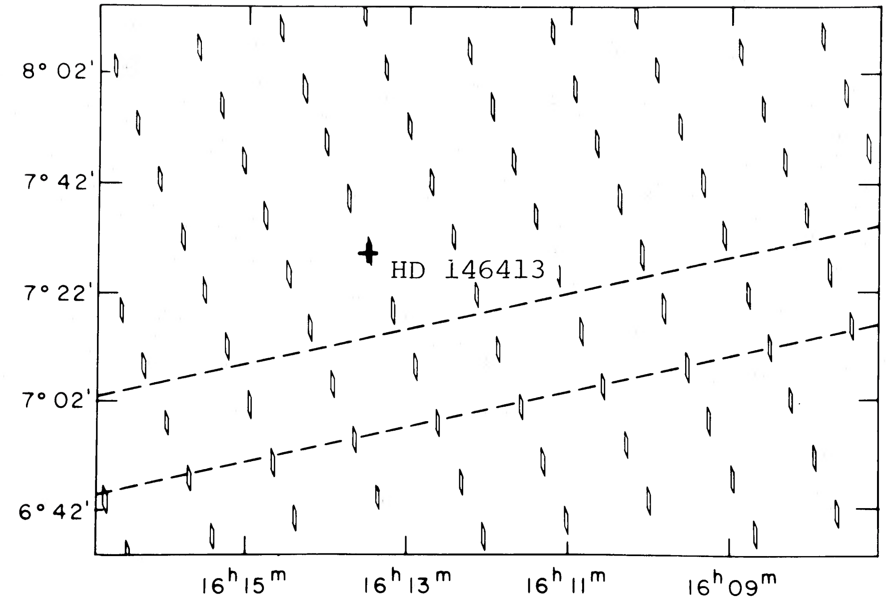

FIG. 2*a*

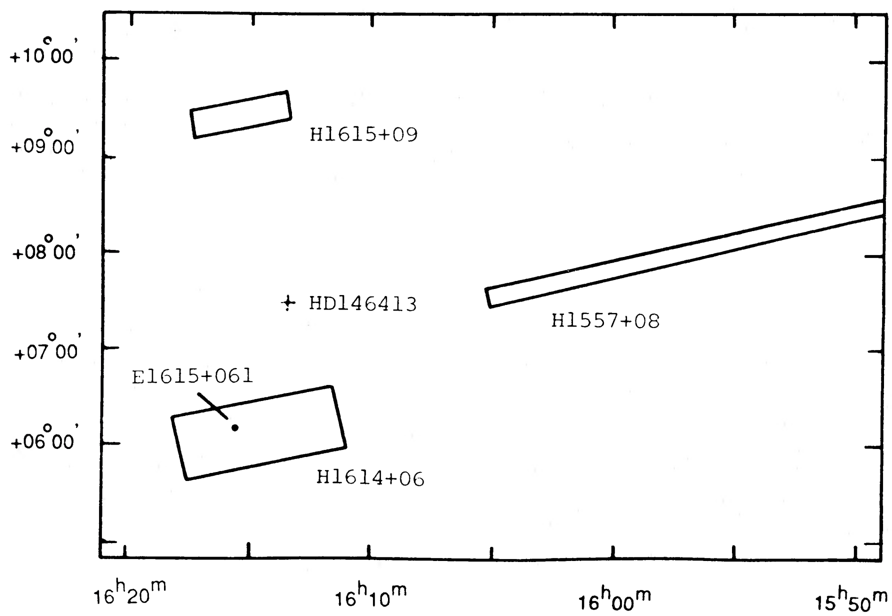

FIG. 2*b*

FIG. 2.—(*a*) X-ray field for H1613+075 showing the MC error diamonds and our determination of the LASS box from the second 6 month scan (*dashed*). The $V = 8.7$ visual binary HD 146413 (ADS 9982) lies at $\alpha(1950) = 16^h13^m31^s$, $\delta(1950) = +07°29'14''$. (*b*) A wider view of the region near H1613+075 including three soft (<1 keV) *HEAO* A-2 sources (Nugent *et al.* 1983). H1614+06 has been identified with a Seyfert galaxy E1615+061 (Pravdo *et al.* 1981).

child 222 CCD which consists of a 380 × 244 array of 30 μm × 36 μm photosites. An individual event is centered to within half a photosite, thus resulting in an effective array with 760 pixels in the dispersion direction, each of 15 μm width. At a typical reciprocal dispersion of 16.7 Å mm^{-1}, this implies ~0.25 Å pixel^{-1} or ~18.7 km s^{-1} pixel^{-1} in the region of interest. Taking 2 pixels as a theoretical resolution limit (=0.5 Å) results in a minimum slit width of ~505 μm. For our observations we employed slit widths between 550 and 650 μm, depending upon the seeing, which corresponded to projected widths of 1''.8–2''.3. The best achievable resolution thus varied from 0.55 to 0.65 Å, or 41 to 49 km s^{-1}. Gaussian FWHMs of representative unblended and unsaturated arc lines were typically ~45 km s^{-1}.

Out of a total of 19 bright F–K stars satisfying our selection criteria (viz., $m_v \leq 9$–10, spectral type F–K, positional coincidence with MC error diamonds), the three noted above showed clear evidence of chromospheric activity in every spectrum we obtained. Representative summed spectra of these stars are shown in Figure 4. We have adopted the Ca II emission classification scheme of Hearnshaw (1979) in an attempt to relate these stars to other known or suspected RS CVn systems. As Hearnshaw's classification scheme is based on lower resolution spectra (60 Å mm^{-1}) than our data, we have

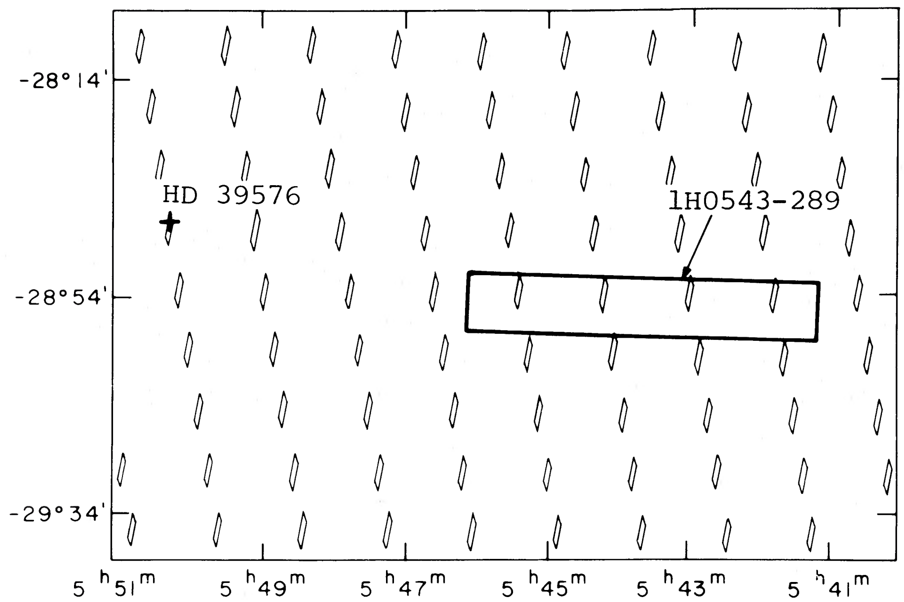

FIG. 3.—X-ray field for 1H 0543−289 showing the MC error diamonds and LASS error box. The $V = 9.05$ star HD 39576 lies at $\alpha(1950) = 05^h50^m19^s$, $\delta(1950) = -28°40'02''$.

first convolved our spectra with an appropriate Gaussian (FWHM ≈ 2.4 Å) before classifying the emission strength. We estimate the average emission strength of HD 113816, HD 146413, and HD 39576 as Class A, C, and D, respectively. We further note that the emission strength of HD 146413 varies at least over one class and that our data obtained in good seeing reveals that both components of this visual binary (ADS 9982) exhibit Ca II emission.

We also paid particular attention to the luminosity discriminant line Sr II λ4077. The MK classification uses the strength of this line with respect to the neighboring Fe I lines (λ4045, λ4063, and λ4071) to infer luminosities for F–K stars. For HD 146413 and HD 39576, a dwarf classification is consistent with our measurements, while for HD 113816, the increased strength of the Sr II feature indicates a somewhat higher luminosity, IV–III.

b) Radial Velocity Study

A radial velocity study of each star was initiated upon discovery of chromospheric activity. Coudé data were obtained, as described in the previous section, from 1984 January to 1985 January and were wavelength-calibrated using Fe-Ar arc spectra taken before each stellar exposure. Individual spectra of the stars had typical signal-to-noise ratios of 10–50, except for the 1984 July data for HD 113816 and HD 146413, which had a decreased signal to noise of ∼2 due to bright Moon conditions. Two cross correlation methods (Simkin 1974; Tonry and Davis 1979) were used to determine radial velocity variations for the three stars over the spectral region λλ3900–4030. The difference in the two methods basically resides in the determination of the position of the cross-correlation function (CCF), by either finding its maximum or fitting a parabola. The templates used in the stellar cross-correlations were high signal-to-noise spectra of the radial velocity standards BS 4546 (HD 102964), α TrA (HD 150798) and β Lep (HD 36079). Before the cross-correlations were performed, each spectrum was Fourier-transformed and filtered in frequency space to remove both the high-frequency noise component plus the lowest frequencies responsible for continuum variations and broad spectral features. The resultant back-transformed data thus consisted of sharp features and a flat continuum. Heliocentric corrections were applied to all the data. The two cross-correlation methods gave virtually identical results, well within the errors. The same cross-correlation techniques applied to all the wavelength-calibrated arc data resulted in a standard deviation of 2 km s^{-1}. The radial velocity standards, cross-correlated among themselves, gave velocities to within ∼2–3 km s^{-1} of their published values. The velocities of the program stars using different templates were also found to agree within the same limits. The individual errors derived using the cross correlation techniques are typically ∼4 km s^{-1} or 0.2 pixels. These errors represent how well the normalized CCF can be centered, and as such depend on the extent to which the CCF peak is smeared, for whatever reason. The errors quoted are probably overly conservative, particularly when we consider the velocity agreements outlined above. We note that the best result achieved with the Mount Stromlo system is ±0.1 pixels. This limit is set at present by the systematic errors in the event centering algorithm of the PCA itself. The requirements of filtering the higher frequency coherent noise associated with this effect probably degrades the final accuracy to which stellar spectral features can be centered and hence effectively broadens the CCF.

In Table 1 we present the radial velocity data for all three stars. A discussion of these data is deferred until later (§ IV*c*).

c) Photometry

Broad-band photoelectric photometry was conducted on all three stars for the purposes of obtaining colors. The 0.76 m folded Cassegrain telescope at Mount Stromlo Observatory and the 1.0 m Cassegrain at Siding Spring Observatory were employed with a single-channel and dual-channel photometer, respectively. Measurements were made in the $UBVR_cI_c$ (Cousins 1976) system using an RCA C31034R GaAs photomultiplier on the 0.76 m and a Hamamatsu R934-02 and identical RCA GaAs photomultiplier on the 1.0 m telescope.

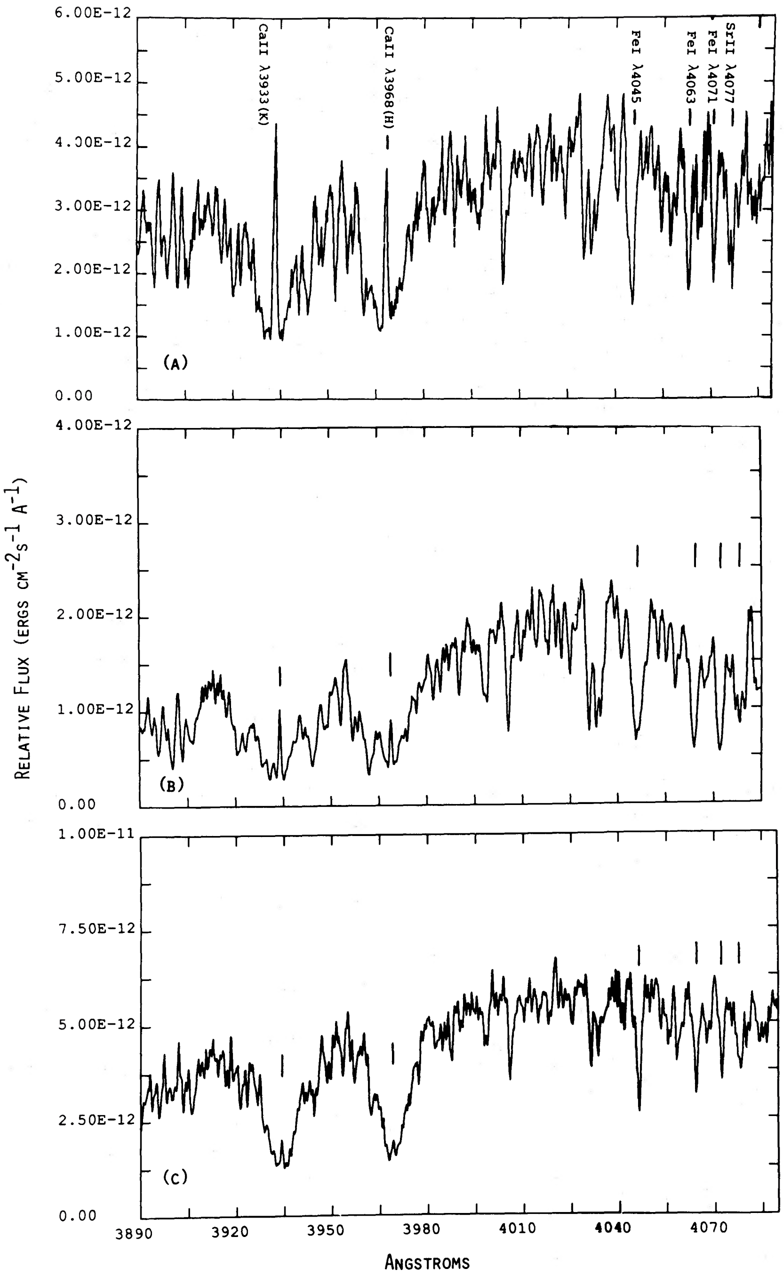

FIG. 4.—Representative coudé spectra in the region of Ca II H and K for the three proposed optical counterparts (*a*) HD 113816, (*b*) HD 146413, and (*c*) HD 39576.

Conversion from the instrumental to standard system was achieved by observing *E*-region (Cousins 1973, 1976; Graham 1982) and equatorial (Landolt 1983) standard stars. We have adopted Taylor's (1986) conversion formulae to derive the $V-R$ and $V-I$ indices in the Johnson (1966) system. Later in this paper we use the $(V-R)_J$ index in the Barnes-Evans relationship to determine the stellar angular diameters. The effective temperatures of the stars have been estimated from Cousins's $(V-R)_c$ index using Bessell's (1970) calibration. The results are very close to the values derived following Johnson (1979).

Subsequent to our broad-band photometry, intermediate band colors in the DDO system (see, for example, McClure 1979) were obtained at Siding Spring Observatory using the 2.3 m telescope and employing a GaAs Hamamatsu R934-02 photomultiplier. The results from this work have enabled us to determine luminosity classes for each of the stars.

The galactic latitudes of the three stars ($b \approx +58°$, $+39°$, and $-24°$, respectively, for HD 113816, HD 146413, and HD 39576) means that the reddening will be quite low, and from Burstein and Heiles (1982) we estimate upper limits to $E(B-V)$ of 0.03, 0.04, and 0.03, respectively.

We have plotted the DDO colors of our three stars on to McClure and Forrester's (1981) two-color diagrams. For HD 113816, the position is in the region of class IV and III stars. This is consistent with its place in Fekel, Moffett, and Henry's (1986) $V-R$ versus $B-V$ diagram, where it lies with other chromospherically active giants which are all systematically

TABLE 1

RADIAL VELOCITY MEASUREMENTS

Date	M.J.D.	V (km s^{-1})
HD 113816		
1984 Jan 21	45720.4811	13.1 ± 3.3
	45720.6898	11.6 ± 3.5
1984 Jan 22	45721.7173	10.7 ± 3.1
1984 Mar 27	45786.6788	17.5 ± 3.7
1984 Mar 28	45787.7016	12.8 ± 3.7
1984 Apr 24	45814.6730	14.3 ± 3.5
1984 Apr 25	45815.6974	19.1 ± 3.7
1984 Jul 6	45887.4324	14.9 ± 4.2
	45887.4568	16.7 ± 4.5
1984 Jul 8	45889.3776	18.0 ± 4.0
1984 Aug 7	45919.3933	22.6 ± 4.2
1984 Aug 8	45920.3870	36.9 ± 4.9
	45920.4094	35.1 ± 4.3
1985 Jan 8	46073.7366	19.9 ± 4.2
1985 Jan 9	46074.7289	18.7 ± 3.8
HD 146413		
1984 Mar 27	45786.7977	−2.2 ± 3.5
1984 Apr 24	45814.7744	−4.7 ± 3.6
1984 Apr 25	45815.6314	4.8 ± 3.6
	45815.6633	2.6 ± 3.6
1984 Jul 6	45887.4973	2.8 ± 3.9
	45887.5211	3.0 ± 4.2
	45887.5523	4.1 ± 4.1
1984 Jul 8	45889.4187	1.4 ± 3.6
	45889.4503	0.3 ± 4.0
1984 Aug 7	45919.4404	2.6 ± 3.8
	45919.4587	−0.9 ± 3.8
	45919.4775	−0.6 ± 4.1
1984 Aug 8	45920.4262	4.9 ± 4.1
	45920.4389	8.0 ± 4.5
HD 39576		
1984 Nov 28	46032.7239	30.4 ± 3.4
1985 Jan 8	46073.5234	25.9 ± 3.0
	46073.5543	27.8 ± 3.9
1985 Jan 9	46074.6901	12.9 ± 3.3

redder in $V-R$ than the field giants. We have therefore classified HD 113816 as K2 IV–III. For HD 146413 and HD 39576, the DDO colors imply a class V for both, although less well defined for the latter where class IV may also be admissable. Combined *BVRI* and DDO colors for these stars are consistent with the K5 V and G1 V spectral classifications found in the literature. In Table 2 we present the results for all three stars and include values found in the literature.

d) Ca II H *and* K *Emission Fluxes*

As pointed out in the Introduction, Ca II emission fluxes are a useful chromospheric activity diagnostic. To make use of empirically determined relationships between these fluxes and such quantities as soft X-ray flux and X-ray emission measure, we have used a number of high-quality spectra to measure the Ca II fluxes. These spectra were calibrated to an absolute flux scale by using observations of secondary flux standards (Oke and Gunn 1983) observed under identical conditions and similar airmasses during the same night. A mean extinction was applied and gross pixel-to-pixel variations were removed, if present, before calibration using a long-exposure flat field.

We have measured the total flux in the interval between H_1 and K_1 minima as in Linsky *et al.* (1979). A Gaussian fitting algorithm was also employed to determine wavelengths, fluxes, and equivalent widths of the Ca II emission and absorption features. The emission fluxes in this latter method are therefore defined in a similar manner to Blanco *et al.* (1974) and Blanco, Catalano, and Marilli (1976). Results from both methods are given in Table 3. We note that for HD 39576, the weakness of the emission cores results in larger statistical errors when fitting a Gaussian.

The fluxes at Earth thus measured (f) are converted to stellar surface fluxes (F) by employing the Barnes-Evans relationship between angular diameter and apparent brightness and color of the star (Barnes and Evans 1976; Barnes, Evans, and Parsons 1976). We have:

$$\log \phi \text{ (milliarcsec)} = 0.4874 - 0.2V_0 + 0.858(V-R)_J \quad [0.0 < (V-R)_J) < 1.26] \quad (1)$$

and

$$F = f(d/R)^2 = f(4.125 \times 10^8/\phi)^2 , \quad (2)$$

TABLE 2

PHOTOMETRIC DATA

Star	Broad-Band *UBVRI*: V	$B-V$	$V-R_c$	$V-I_c$	$V-R_J$[a]	$V-I_J$[a]	Narrow-Band DDO: 45–48	42–45	41–42	38–42	SP Class	References
HD 113816	8.27	1.15	0.65	1.22	0.93	1.57	1.217	0.983	0.171	−0.362	K2 III–IV	1
	8.4	1.2	...	...	...	...	...	...	...	...	K0[b]	2
HD 146413 (ADS 9982)	8.41	1.18	0.75	1.34	1.08	1.72	1.120	1.257	−0.099	−0.362	K5 V	1
	8.74	1.10	...	...	...	...	...	...	...	...	K5[b]	3
A	9.30	1.05	...	...	...	...	...	...	...	...	K3 V[b,c]	3
B	9.72	1.15	...	...	...	...	...	...	...	...	K5 V[b,c]	3
HD 39576	9.05	0.60	0.32	0.64	0.48	0.82	0.994	0.630	0.017	−0.788	G1 V	1
	9.1	0.7	...	...	...	...	...	...	...	...	G1 V[d]	2

[a] The $V-R_J$ and $V-I_J$ indices are calculated using Taylor's 1986 calibration.
[b] From Ochsenbien *et al.* 1981.
[c] From Edwards 1976.
[d] From Houk 1972.
REFERENCES.—(1) This study. (2) CSI Catalogue (Ochsenbien *et al.* 1981). (3) Eggen 1965.

where ϕ is the stellar angular diameter in milliarcseconds, V_0 is the apparent visual magnitude corrected for extinction, F is the absolute surface flux, f is the apparent flux at Earth, d is the distance to the star, and R is the radius. For the moment we assume that the active component contributes most of the flux, and therefore adopt this single star relation. Corrections for interstellar extinction are considered to be negligible for the high latitude presumed dwarf stars HD 146413 and HD 39576 and no more than 0.1 mag for HD 113816 (see § IV*d*). Finally we follow the techniques used by Linsky *et al.* (1979) and correct the inferred surface fluxes by subtracting the value of surface flux predicted by a radiative equilibrium model atmosphere. This correction is derived from the observed $(V-R)_J$ used with Figure 3 of Linsky *et al.* (1979). These final corrected fluxes, $F'(\mathrm{H}) + F'(\mathrm{K})$, represent the net radiative losses, or cooling rates, in the chromosphere due to Ca II H and K. We normalize these losses to the total surface flux of the star, $\sigma T_{\mathrm{eff}}^4$, thus arriving at the activity parameter, R_{HK}:

$$R_{\mathrm{HK}} = [F'(\mathrm{H}) + F'(\mathrm{K})]/\sigma T_{\mathrm{eff}}^4 . \quad (3)$$

For each star, the measured flux and derived surface flux estimates are included in Table 3. We emphasize that our flux estimates are necessarily crude in comparison to spectrophotometry and estimate errors of $< \pm 0.2$ dex in $\log (f_{\mathrm{H}} + f_{\mathrm{K}})$, a result comparable to Bopp's (1983) Ca II surface flux estimates for 19 RS CVn binaries. He maintained that fluxes could be estimated to $\pm 50\%$ from tracings of medium-resolution (13 Å mm^{-1}) spectra on photographic plates. Since the logarithm of the flux is the quantity frequently related to other activity parameters, such large errors in flux are not so deleterious.

IV. DISCUSSION

a) The Optical Identifications

We first address the strength of our optical identifications. To date we have investigated ~ 100 MC fields accessible from Mount Stromlo. For each field we scrutinize ~ 50 MC error diamonds which are 2–4 arcmin^2 in size. The total area is therefore ≤ 5.5 deg^2. What we must consider is the number of stars exhibiting Ca II emission at moderate resolution expected to be seen in this area, and hence the probability of a chance positional coincidence.

The total number of F–K stars at $\delta < -26°$ listed in the three volumes of the Michigan Spectral Catalog (Houk and Cowley 1975; Houk 1978, 1982) as exhibiting Ca II H and K emission is 57, or $\sim 5 \times 10^{-3}$ stars deg^{-2}. We note that $\sim 75\%$ of these stars appear in either Bidelman and MacConnell's (1973) or Weiler and Stencel's (1979) lists. The expectation number n, for the total area under study is therefore ~ 0.06 resulting in a probability of $\sim 3\%$ for a false identification for the three stars. This argument is really only applicable for chromospherically active stars with Ca II emission strong enough to be seen on the Michigan prism plates. We consider that at least HD 113816 (emission class A) would have detectable emission. If we consider RS CVn systems only, then adopting a space density of $\sim 10^{-5}$ systems pc^{-3} (e.g., Walter, Charles, and Bowyer 1978) results in a total surface density of RS CVn stars brighter than $m_v \approx 10$ of 7.7×10^{-3} systems deg^{-2}. Therefore the probability of an RS CVn system falling in a diamond by chance is also $\sim 5\%$. We conclude that the proposed optical identifications are very likely on statistical grounds. We note also that our identifications are supported by the optical and X-ray properties, and that no other viable optical counterparts were forthcoming following searches of individual diamonds for faint ($V < 18$ mag) UV excess objects.

b) Binarity

What is immediately obvious from the radial velocity results (Table 1) is the low-amplitude velocity variations seen in HD 113816 and HD 146413 over a long time base.

We are confident of the reality of the larger velocities measured for HD 113816 on 1984 August 8. On that date we also observed the RS CVn binary HD 5303 (Collier, Hearnshaw, and Austin 1981). Our cross-correlation results for this system were reduced in a similar manner and showed a double-peaked CCF consistent with the star's double-lined spectroscopic binary classification. The velocity shifts of the dominant peak, corresponding to the cooler component responsible for the Ca II emission, were phased according to the ephemeris given by Collier, Hearnshaw, and Austin (1981) in their note in proof. These heliocentrically corrected velocities were found to superpose *exactly* on their radial velocity curve for HD 5303.

The data for HD 146413 are consistent with a constant velocity. The velocities appear normally distributed with a mean value of ~ 2 km s^{-1} and a standard deviation of ~ 3 km s^{-1}. Our mean velocity is some 5 km s^{-1} less than the systemic velocity quoted in Abt and Biggs (1972) of 7 km s^{-1}. Woolley and Symms (1937) have published an orbit for HD 146413 (ADS 9982 = Σ2026) with the following parameters: $P = 680$ yr, $a = 3\farcs04$, and $i = \pm 131°$. The system has a high proper motion, with the following values found in the literature: =G017−008, $\mu = 0\farcs53$, P.A. = 155° in the Lowell Proper Motion Catalog (Jenkins 1952, 1963); =LFT 1260 = LHS 3172, $\mu = 0\farcs500$, P.A. = 160°.8 in Luyten (1955, 1979). The variability of Ca II line strengths in HD 146413 previously noted may arise from spectral contamination by the fainter visual component (B) during deterioration in seeing.

We initially pursue the hypothesis that these stars are RS CVn binaries. Following Hearnshaw (1979), we estimate the

TABLE 3

Ca II EMISSION-LINE FLUXES AND CHROMOSPHERIC ACTIVITY INDICATORS

Star	$\log T_{\mathrm{eff}}$[a]	ϕ[b] (mas)	$f_{\mathrm{H1}} + f_{\mathrm{K1}}$[c] (ergs cm^{-2} s^{-1})	$F_{\mathrm{H1}} + F_{\mathrm{K1}}$ (ergs cm^{-2} s^{-1})	$F_{\mathrm{H1}}' + F_{\mathrm{K1}}'$ (ergs cm^{-2} s^{-1})	$\log R_{\mathrm{HK}}$	f_{K}[d] (ergs cm^{-2} s^{-1})	W_{K} (Å)
HD 113816	3.64	0.25	5.03×10^{-12}	1.40×10^{7}	1.39×10^{7}	−3.17	1.40×10^{-12}	1.57
HD 146413	3.65	0.46	1.39×10^{-12}	1.10×10^{6}	1.08×10^{6}	−4.23	4.9×10^{-13}	0.49
HD 39576...........	3.77	0.12	2.42×10^{-12}	2.72×10^{7}	2.62×10^{7}	−3.42	$\sim 3 \times 10^{-13}$	~0.2

[a] From Bessell's 1979 calibration.
[b] From Barnes-Evans relation.
[c] As in Linsky *et al.* 1979.
[d] Similar to definition as in Blanco *et al.* 1974, 1976.

probability that the semivelocity amplitude, K, of a randomly chosen RS CVn of total mass M_T and orbital period P is less than K_0 km s^{-1}. The following expression (Hearnshaw 1979) is used:

$$P(K < K_0) = 1 - \left\{1 - \left[\frac{K_0(P/M_T)^{1/3}}{106.4}\right]\right\}^{1/2} . \quad (4)$$

If we adopt $K_0 \approx 15$ km s^{-1}, a value consistent with our data for HD 113816, then for a typical RS CVn system of mass ratio near unity with a total mass 2.4 $M_\odot$ and period ≤ 14 days, the probability of finding such a system with $K \leq 15$ km s^{-1}, i.e., very low orbital inclination ($i \approx 0°$), would be ~ 0.1, i.e., low. If HD 113816 and HD 146413 are indeed classical RS CVn binaries, then we conclude they are probably of long orbital period and possibly low orbital inclination. For HD 39576, the four velocities are insufficient to put limits on K but do suggest variability.

We can compare our value of ≤ 15 km s^{-1} with the results of Collier-Cameron, Lloyd-Evans, and Balona's (1986) systematic survey of Ca II emission line objects found by Bidelman and MacConnell (1973). Out of a total of 55 stars exhibiting Ca II emission, 37 were binaries of which 11 show semiamplitude variations < 15 km s^{-1}. Young and Koniges (1977) studied Ca II H and K emission in spectroscopic binaries and found that for periods < 100 days, 59% of all binaries showed Ca II emission, while it was virtually absent for longer period systems. The strongest emission objects were either subgiants or giants with ~ 20 day periods or main-sequence stars with periods < 5 days. They interpreted these results to imply that tidal coupling, and therefore chromospheric activity, is enhanced in stars with large ratios of star radius to Roche lobe radius; if this ratio drops to 15%, Ca II emission is virtually absent. The most active stars are subgiant components of RS CVn binaries with periods < 20 days, a consequence of tidally induced orbital-rotational synchronism (Zahn 1977).

Our data for HD 113816 and HD 146413 do not conclusively establish these systems as RS CVn binaries; however, if they are they must belong to the long period group, i.e., $P > 20$ days. An alternative binary model may involve extreme mass ratio systems where the observed velocities are small. Such a model has been developed (e.g., Walter and Basri 1981) for the extremely chromospherically active FK Comae systems (Bopp and Stencel 1981). This possibility is investigated in § IV*f*.

Single star classifications are not inconsistent with Collier-Cameron, Lloyd-Evans, and Balona's (1986) discovery that $\sim 30\%$ of the Bidelman and MacConnell (1973) Ca II sample are *single* RS CVn–like objects with photometrically determined rotation periods in excess of 10 days. The rotation rates and velocity dispersions about the LSR of these stars are consistent with them having evolved from rapidly rotating late-A to early-F stars.

We have investigated rotation in all three stars by examining the broadening of the normalized CCFs discussed in § III*b*. One of our radial velocity standards, β Lep, has a published $v \sin i$ of 11 km s^{-1}. We have measured the FWHM of this standard and our three stars with identical resolution. The observed broadening of the CCFs were quadratically corrected using the β Lep data resulting in the following $v \sin i$ estimates of 30, 40, and 65 km s^{-1} respectively for HD 113816, HD 146413, and HD 39576. Errors are likely to be $\leq \pm 10$ km s^{-1}. Results obtained for the active FK Comae star HD 32918 (Collier 1982) using this method were in agreement with its listed $v \sin i$, within errors.

c) Ca II *Emission*

The level of Ca II emission seen in our three stars is similar to that observed by Bopp (1983) in his survey of RS CVn systems. We note that for HD 113816, the star we observe with the strongest core emission, only three of Bopp's sample, HD 86590 (K0 V), HR 8703 (K1 IV–III), and HR 6469 (F8), have larger surface fluxes. The visual binary, HD 146413, is not alone in having both visual components exhibiting Ca II emission. Hall, Zeilik, and Nelson's (1985) catalog lists 12 of the 84 RS CVn systems as visual binaries of which one (Capella) is listed as exhibiting Ca II emission in both components. Despite apparently weak emission cores, HD 39576 would appear to have the largest Ca II surface fluxes. This is not so unusual when we consider that its earlier spectral type (G1) leads to a greater photospheric contribution in the blue. If this star is indeed an RS CVn system, then the presence of a presumably earlier spectral type companion (F–G) will further dilute the contrast of the emission against the surrounding continuum and may explain the observed filling-in of the Ca II absorption lines, which are shallower than stars we have observed of similar spectral type. A comparison of our stars with Linsky *et al.*'s survey, covering a wide range of spectral type and luminosity class (Linsky *et al.* 1979; Kelch, Linsky, and Worden 1979), shows them to be very active indeed. They all lie above the mean active chromosphere relation in the normalized Ca II chromospheric loss–temperature ($R_{\rm HK} - \log T_{\rm eff}$) plane.

d) *Predicted Soft X-Ray Activity*

Mewe, Schrijver, and Zwaan (1981) and Schrijver (1983, 1985) have shown that a reasonably tight correlation exists among stars over a wide range of effective temperature and luminosity, between the Ca II H and K surface flux and the soft X-ray surface flux. Their data are based on narrow-band measurements of Ca II H and K fluxes (Wilson 1978; Vaughan and Preston 1980; Middelkoop 1982; Rutten 1984) using the Mount Wilson H and K photometer (Vaughan, Preston, and Wilson 1978) and 0.15–4 keV IPC or HRI fluxes. They define an *excess* Ca II flux, $\Delta F_{\rm H+K}$, defined as the difference between the measured flux and some lower limit dependent upon luminosity and color. This minimal flux has been interpreted as originating in quiet nonmagnetic Ca II networks (Mewe, Schrijver, and Zwaan 1981) and therefore is unassociated with any X-ray emitting coronal loops.

Middelkoop (1982) and Rutten (1984) have compared Linsky *et al.*'s (1979) fluxes with those determined by the previous authors using the Mount Wilson system on an overlapping sample of stars. Rutten obtains the following relation between the two systems:

$$F_{\rm H} + F_{\rm K}(\text{Mewe, arbitrary units}) = 1.19 \times 10^{-6}[F_{\rm H1} + F_{\rm K1}]$$
$$(\text{Linsky, ergs cm}^{-2}\ \text{s}^{-1}) . \quad (5)$$

We have used this relation to convert our fluxes, measured in a manner similar to Linsky *et al.*, into the arbitrary units used by Mewe, Schrijver, and Zwaan (1981) based on the Mount Wilson system. The excess flux $\Delta F_{\rm HK}$ was then derived by subtracting the minimum flux obtained using Rutten's (1984) surface flux-$(B-V)$ diagrams.

Schrijver (1983) employed a common factor analysis to show that the relation between F_x and $\Delta F_{\rm HK}$ was independent of stellar radius or mass and could be described as

$$F_x = 3.4 \times 10^5 \Delta F_{\rm HK}{}^{1.67} . \quad (6)$$

From our derived values of ΔF_{HK} we use the above relation to predict the level of soft X-ray flux. We have converted the surface flux thus obtained to a flux measured at Earth using equation (2). This flux in the 0.15–4 keV band is then converted into a 2–10 keV flux, corresponding to the LASS instrument. We have achieved this by adopting a thermal spectrum with a temperature characteristic of an RS CVn corona. Majer *et al.* (1986) fitted single-component thermal spectra to 24 RS CVn systems, obtaining temperatures in the range $\sim 8 \times 10^6$ to $\sim 6 \times 10^7$ K. We have therefore adopted these two extremes plus a mean temperature of $\sim 2 \times 10^7$ K to investigate the range of 2–10 keV fluxes permissible. A value of $N_H \leq 10^{19}$ H cm^{-2} was used for the class V (therefore closer) stars HD 146413 and HD 39576, consistent with that implied from the assumed H density (Paresce 1984) and distances derived in § IV*e*. For HD 113816, we have used Savage and Mathis's (1979) relation $N_H = 4.4 \times 10^8 E(B-V)$ and obtain a value of $N_H \leq 1.4 \times 10^{20}$ H cm^{-2}, adopting the upper limit of $E(B-V) \approx 0.03$.

Following Schrijver (1983) and Majer *et al.* (1986), we determine the *specific* emission measure, ζ:

$$\zeta = \epsilon/4\pi R^2 = \int n_e{}^2 dv/4\pi R^2 = F_x/E(T)\,, \quad (7)$$

where $E(T)$ is the cooling rate, or emissivity, of the plasma. We have derived a mean value of 1.7×10^{-23} ergs cm^3 s^{-1} for $E(T)$ in the 0.15–4.5 keV band from Majer *et al.* (1986) and the cooling curves of Raymond, Cox, and Smith (1976) and have found that it is a slowly varying function of coronal temperature. Thus an incorrectly assumed temperature hardly affects the derived specific emission measure.

In Table 4 are the predicted X-ray fluxes, the excess Ca II fluxes and other relevant data. It is clear from these results that the level of soft X-ray surface flux predicted from the strength of the Ca II emission is one to two orders of magnitude lower than that measured. The only star that lies many sigma above Schrijver, Mewe, and Walter's (1984) log F_x − log ΔF_{HK} fit is the strong Ca II RS CVn system, II Peg. Schwartz *et al.* (1981) have identified this highly variable star (Marstad *et al.* 1982) as a *HEAO 1* transient X-ray source, one of the six hard X-ray variable systems discussed by Charles (1983), known at that time. The specific emission measures for our three stars are indicative of high activity when compared to Schrijver, Mewe, and Walter's (1984) stars. For example, the least active of our stars, HD 146413, has a ζ comparable to RS CVn, SZ Psc, and II Peg. Such large ζ values are characteristic of higher temperature coronae.

e) Luminosities

Distance estimates have been made for all three stars based on the standard relation

$$V - M_v = 5 \log d - 5 + A_v\,. \quad (8)$$

In the case of HD 113816, we have used James's (1974) tables of M_v given for various combinations of the DDO colors $C_0(45–48)$ and $C_0(42–45)$ to derive an absolute visual magnitude for HD 113816. We have adopted the corrections subsequently suggested by Janes (1979) and have corrected for a reddening of $E(B-V) \approx 0.03$. The result is $M_v = 2.1$, and assuming a standard conversion of $A_v = 3.3E(B-V)$ (Allen 1973), we derive a distance of ~ 165 pc. For HD 146413 and HD 39576, distances are determined in a similar manner, with M_v derived from Allen (1973) based on our spectral classifications (Table 2). Assuming a class V for both stars gives distances of ~ 30 and ~ 85 pc, respectively, and if we accept the possibility of a class IV for HD 39576, then a distance of ~ 162 pc is implied.

The published dynamical parallax for HD 146413 is 0".036 (Jeffers, van den Bos, and Greeby 1963), in close agreement with the spectroscopic (Abt and Biggs 1972) and photometric (Eggen 1965) parallaxes and consistent with the rough determination above. We have therefore adopted a distance of 28 pc for HD 146413.

We have calculated the luminosities in the 2–10 keV band from the observed LASS fluxes and our distance estimates. Bolometric luminosities were derived from the M_v values and bolometric corrections from Allen (1973). The L_x/L_{bol} values are all characteristic of high activity and compare with the most active short-period RS CVn systems (Walter and Bowyer 1981).

Finally we estimate the stars' radii from the distance and ϕ and derive the emission measures, ϵ, using equation (7). In Table 5 we present all of the above information.

f) Flares: Comparison to Other Systems

In § IV*d* we have argued that the observed X-ray fluxes are higher than predicted solely on the basis of chromospheric activity, as indicated by the Ca II emission. In an effort to understand these observations, we discuss below several systems which we consider to be similar.

All of the six variable hard X-ray emitting RS CVn systems discussed by Charles (1983) have L_x values in the range $\sim 4 \times 10^{31}$ to $\sim 8 \times 10^{33}$ ergs s^{-1}. Several of these stars have been observed to flare at X-ray wavelengths, with decay time scales typically much longer than the classical dMe flare stars,

TABLE 4

X-RAY FLUXES AND SPECIFIC EMISSION MEASURES

		Predicted from Ca II Emission				Measured	
			f_x(2–10 keV) (ergs cm^{-2} s^{-1})				
Star	ΔF_{HK}	f_x(0.15–4 keV) (ergs cm^{-2} s^{-1})	Low T	Mean T	High T	f_x(2–10 keV) (ergs cm^{-2} s^{-1})	ζ (cm^{-5})
HD 113816	16.6	1.3×10^{-11}	5×10^{-13}	2.8×10^{-12}	7.2×10^{-12}	7×10^{-11}	3×10^{31}
HD 146413	1.0	1×10^{-12}	5×10^{-14}	2.5×10^{-13}	6.5×10^{-13}	3×10^{-11}	4×10^{30}
HD 39576	30.2	1.1×10^{-11}	5×10^{-13}	2.7×10^{-12}	7.0×10^{-12}	2.6×10^{-11}	7×10^{31}

NOTE.—The low, mean, and high T referred to are the three temperature regimes used to convert from hard to soft X-ray bands and correspond to $\sim 8 \times 10^6$, $\sim 2 \times 10^7$, and $\sim 6 \times 10^7$ K, respectively (see text).

of the order $\sim 10^4$ s (Stern 1984). One well observed dMe system is Proxima Centauri, where an increase in soft emission and hard X-ray "bursts" are observed during flares (Haisch 1983). Pye and McHardy (1980) have reported a flare from σ Gem detectable for ~ 8 hr while HR 1099 has been associated with the bright transient 4U 0336+01, which has been known to last for ~ 1 wk.

One well-studied system is H0123+075, identified by Garcia *et al.* (1980) as the $V = 7.28$ RS CVn, HD 8357. This source was observed by three of the *HEAO 1* instruments; LASS (A-1), MC (A-3) and A-2 (soft) during 1978 January. Over the interval January 9 to January 15, two flares were detected, separated by ~ 2.5 days, with fluxes of $\sim 1.2 \times 10^{-10}$ and $\sim 6.8 \times 10^{-10}$ ergs cm^{-2} s^{-1} in the LASS 0.5–20 keV band (Ambruster, Snyder, and Wood 1984). Garcia *et al.* (1980) saw the second flare reported by Ambruster *et al.* as a 7 σ detection in the 0.9–5.5 keV band and 2.5 σ in the 5.5–13.3 keV band. Furthermore, the source was detected above the quiescent level for a period of ~ 14 hr at a flux $> 3.6 \times 10^{-11}$ ergs cm^{-2} s^{-1}.

The already mentioned (§ IV*d*) active star II Peg has been identified as the counterpart to A0000+28 by Schwartz *et al.* (1981) based on a *HEAO 1* LASS and MC observation. This $V = 7.2$ RS CVn was observed by LASS in the first scan and detected in MC2 only, at 3.8 σ in the hardest (5.5–13.3 keV) energy channel. The authors deduce a hard source spectrum of $kT > 7$ keV (i.e., $T \approx 10^8$ K). Stern, Underwood, and Antiochos (1983) report that the $V = 8.34$ RS CVn HD 27130 flared during *Einstein Observatory* IPC and MPC observations to ~ 35 times the quiescent X-ray flux, peaking at $\sim 4 \times 10^{-11}$ ergs cm^{-2} s^{-1}. They also observed a hardening of the spectrum, with a flare temperature of $10^{7.5}$ to 10^8 K implied by the MPC 1–10 keV data.

Finally we discuss the very soft X-ray source, H1708+49, observed by *HEAO 1* A-2 (soft) and subsequently identified by Stern *et al.* (1981), using the *Einstein Observatory*, with HD 155638, later classified as an RS CVn binary. The A-2 observation showed the source to be very soft, being detectable only in the 0.16–0.4 keV LED at a flux of $\sim 2 \times 10^{-11}$ ergs cm^{-2} s^{-1}, with a temperature $\leq 10^{6.8}$ K. This implies a 2–10 keV flux of 5×10^{-12} ergs cm^{-2} s^{-1}, assuming a one-temperature model and negligible absorption as would be expected for this close ($d < 120$ pc), high-latitude ($b \approx +36°$) star. We report here that the *HEAO 1* MC experiment also detects HD 155638 during the first two all-sky scans. HD 155638 appears only in the two softer energy channels (0.5–5.5 keV) while a second source, Arp 102B, is detected weakly during all three scans, but only in the hardest (5.5–13.3 keV) channel and is also observed by the IPC at a flux level of 2.2×10^{-12} ergs cm^{-2} s^{-1}. The LASS catalog lists a source 1H 1712+490, which although positionally coincident with HD 155638 and H1708+49, is identified with the galaxy cluster Abell 2251. We consider this identification unlikely given its large distance ($z \approx 0.2$) and poor richness class (1), as reported by Johnson *et al.* (1983). Taking into account the above facts, we argue that the LASS flux is almost entirely due to HD 155638. Indeed we find that the MC data for the first scan (i.e., contemporaneous with the LASS observation) is dominated by HD 155638, particularly at softer energies where LASS was more sensitive. The LASS count rate for 1H 1712+490 corresponds to a 2–10 keV flux of 1–2 $\times 10^{-11}$ ergs cm^{-2} s^{-1}, well above the extrapolated A-2 2–10 keV upper limit ($< 5 \times 10^{-12}$ ergs cm^{-2} s^{-1}). This indicates the presence of a harder temperature component than the $T \leq 10^{6.8}$ K plasma. *HEAO 1* observed the source to be 5–10 times brighter than the *Einstein* IPC, which recorded a moderately hard source with a 0.4–4.5 keV flux of 5.6×10^{-12} ergs cm^{-2} s^{-1}. Furthermore, the *HEAO 1* A-2 experiment detected an additional soft component. We interpret these results as evidence for soft flares in HD 155638. We further claim that the IPC flux is consistent with the predicted quiescent flux based on the strength of the Ca II emission.

The flare model developed by Uchida and Sakurai (1983) has high-temperature plasma confined to magnetic flux tubes connecting the two stars of an RS CVn binary. Energetic flares result upon magnetic reconnection. Flares of such large spatial extent are supported by Hα and VLBI microwave observations (Linsky 1984). At this point it is worth mentioning the extremely active, fast rotating FK Comae stars. Bedford, Elliot, and Eyles (1985) point out that four of the five FK Com stars known at the time had been observed at X-ray wavelengths and found to be X-ray emitters. The system they discuss, HD 32918, was observed by them with *EXOSAT* from which they determine a coronal temperature of 1.2×10^7 K. Fortuitously, an *EXOSAT* observation of another source by us had HD 32918 in the field of view of the LE imaging instrument; however, we did not detect HD 32918 during the 10^4 s exposure, implying a 3 σ upper limit 0.1–2 keV flux of 3.7×10^{-11} ergs cm^{-2} s^{-1}. Flares at Hα have been observed by Ramsey and Nations (1981) in FK Comae itself. It remains to be seen whether single star models for FK Com stars can accomodate flaring phenomena. The recent *EXOSAT* observation by Landini *et al.* (1986) of an X-ray flare from the presumed single chromospherically active star π^1 UMa, although of lower energy, is the first such flare to be seen from a single star.

The X-ray properties of two of the sources we observed, H1613+075 and 1H 0543−289, can be summarized as follows: (1) hard sources, seen in all three channels of the MC (0.9–2.5, 2.5–5.5, and 5.5–13.3 keV); (2) variable by factors of at least 3 times. For 1H 1303−047, we list its pertinent properties

TABLE 5

DISTANCES AND LUMINOSITIES

Star	d (pc)	M_v	B.C.[a]	M_{bol}	L_x(2–10 keV) (ergs s^{-1})	L_x/L_{bol}	R ($R_\odot$)	ϵ (cm^{-3})
HD 113816	165	2.06 (IV–III)	−0.70	1.4	2.29×10^{32}	2.75×10^{-3}	5.47	5.5×10^{55}
HD 146413	28	7.3 (V)	−0.65	6.7	2.80×10^{30}	4.44×10^{-3}	1.39	4.7×10^{53}
HD 39576	85[b]	4.5 (V)	−0.02	4.5	2.24×10^{31}	4.55×10^{-3}	1.12	5.4×10^{54}
	162[c]	3.0 (IV)	−0.03	3.0	8.13×10^{31}	1.14×10^{-3}	2.12	1.9×10^{55}

[a] From Allen 1973.
[b] Distance assuming a V class.
[c] Distance assuming a IV class.

as (1) a softer source seen only in the 0.9–2.5 keV channel of the MC, but also in the LASS 2–10 keV band, and (2) possibly variable, brighter in the second scan.

We see from the above comparisons that the properties of two of our sources are entirely consistent with hard recurrent flaring RS CVn systems. The softer source 1H 1303−047 has properties similar to H1708+49, which we have established is a soft flaring source. Their presumed optical counterparts (HD 113816; K2 IV–III and HD 155638; G8–9 V–IV, respectively) are also very similar. Presumably a softer source temperature must characterize these flares.

The *HEAO 1* observing windows for the three sources were 7, 4, and 8 days each scan (i.e., every 6 months) respectively for 1H 1303−047, H1613+075, and 1H 0543−289. If we assume the quiescent X-ray emission flux, as predicted by the Ca II flux, is below the detection threshold of the MC experiment, then if the origin of the observed X-rays is flare activity, constraints can be made on the flare frequency. A minimum duty cycle of ~ 0.14 flares day^{-1} is implied for 1H 1303−047 and 1H 0543−289, while for H1613+075 it is ~ 0.25 flares day^{-1}, assuming flare time scales $\geq 10^4$ s. In practice, for a significant MC detection in the observing window, a higher frequency would probably be necessary. The flare frequencies required are in fact observed in RS CVn binaries. Variations in the total flare energy and decay time scales will also determine detectability of flares.

V. SUMMARY REMARKS

We have argued that the three *HEAO 1* MC sources reported in this paper are all chromospherically active stars with Ca II emission strengths comparable to the most active stars known, namely the RS CVn binaries. However, the chromospheric activity of the optical counterparts is insufficient to explain the level of X-ray flux observed based only on the empirical relations between Ca II and X-ray fluxes. Our X-ray observations can be explained in terms of a recurrent flare model. The optical and X-ray properties of known flaring RS CVn and related systems are similar to those of the three sources and their optical counterparts discussed in this paper. Although we have not conclusively established binarity in these stars, at least two, HD 113816 and HD 39576, show evidence suggesting it.

The rotation period of these stars, probably the single most important parameter, remains to be established. Future photometric monitoring of these stars to investigate the so-called photometric wave attributed to starspots is clearly important in determining this parameter. Radio observations would also be invaluable for investigating the flaring phenomena and, of course, future X-ray observations. High-resolution échelle spectroscopy is currently underway to determine more precisely $v \sin i$ and to investigate the nature of the Hα line.

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