EINSTEIN AND IUE OBSERVATIONS OF NEARBY RED DWARFS

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ABSTRACT

This paper summarizes data for 40 representative nearby stars from one guest observer's coordinated programs with the Einstein observatory or IUE observatory. The coronal X-ray, chromospheric ultraviolet, and auxiliary optical properties of sets of these stars are tabulated or illustrated in several ways. Factors of stellar duplicity are shown to be quite prevalent in presenting the observations. The most luminous X-ray dwarfs below the Sun are strongly prone to binary status. X-ray luminosity, and the ratio of chromospheric flux to X-ray flux, are dependent on photospheric radius. A very long period BY Draconis variable of type dM6e (HH And) is a detected X-ray source, and some presumably quite old (halo) stars are detected.

1. INTRODUCTION

As a sequel to an analysis of the nature of the unidentified high-latitude X-ray sources that were cataloged by early 1978 (Johnson 1978) I proposed an Einstein guest-observer program to detect a representative sample from the 100 stars within 6.5 pc, listed by Allen (1973). This sample was extended in 1979, and in 1980 some spectroscopic binaries within 25 pc were added to the total. Activity such as flaring was a neutral factor in the composition, and there is actually some bias against flare stars in the sample because flare stars had been evidently preferred as the prior HEAO-B Consortium selections of late dwarfs (cf. Giacconi et al. 1978).

Johnson (1981) produced Einstein guest observer data for 16 nearby-star IPC targets (several of which are unresolved binaries) and for five HRI images from the same sample. This paper extends earlier Einstein guest observer data of stars nearer than 25 pc by 15 more IPC targets, several of which are again known or suspected binaries that the IPC does not resolve. HRI data for three IPC targets, as reprocessed in 1982, now resolve two of the close binaries and pinpoint one component

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of each of them. In order to provide ultraviolet spectral information along with the X-ray data for the IPC targets, IUE observations were made in 1981 of 13 of the targets from the total of 29 candidates. Woolley 319A was also observed with the IUE but not with Einstein. A log of the IUE data sorted by right ascension is included in IUE NASA Newsletter, No. 18 (1982). For the sake of a unified nomenclature the primary identifications of stars here will be according to the catalog of Woolley et al. (1970) where coordinates and many other data may be found. Other observers, notably Weidemann et al. (1980) and Linsky et al. (1982), have independently obtained IUE spectra of four more stars in the present Einstein sample (Woolley 15A, 144, 440, and 820B).

Because red dwarfs are the most numerous species of stars, they are naturally represented most often in the above programs; and because red dwarfs are prototypes for activity such as flaring and the BY Draconis syndrome, active stars are found in these programs. However, other stars are needed and included for comparative purposes. Several known or suspected but unclassified binary companions are also present.

2. TABULATIONS OF DATA

Table I requires the following explanation. V and M_V are from Woolley et al. (1970), and $M_{bol} = M_V + BC$, where the bolometric correction BC is the function of MK spectral type according to Johnson (1966). The column of spectral type is the miscellaneous compilation in Woolley et al. (1970). The dM(e) types are updated by some MK types according to Wing and Dean's (1982) 8-color photometric classification in the next column, or (in parentheses) according to Wing and Yorka's (1979) tables of correspondence with MK types. The dK types are updated from Buscombe (1977). One can still find a little disagreement among recent classifications. For example, Boeshaar (1978) and Keenan and McNeil (1976) call Kapteyn's star a subdwarf, and the latter classify TZ Ari M5-V. Wing's system is used in this paper also as needed for dM stars from Johnson (1981). The column of Binary Characteristics refers only to spectroscopic binaries, SB, all of them single-line, followed by the range of velocity (km s^{-1}), and the number of measured radial velocities, RV, compiled from the literature. It should be noted that the designation SB based on as few as 2 RV depends on the judgment of spectroscopists who know their equipment and measures. There are outstanding puzzles with some of the stars, e.g. Woolley 905 for which Abt (1973) lists five 1939-44 plates with successive RV = +24.0, -16.4, -70.1, -96.1 and -67.2 km s^{-1} from the Mt. Wilson files. But Abt (1982) has found no publication other than Joy (1947), who gave a mean RV = -81 $\pm$ 2.5 kms^{-1} from three (of the same?) plates, and Wilson (1953) who also lists -81 km s^{-1} from four plates! The Table I range is for the five plates, and the designation SB is questioned only because of the foregoing history.

The Binary Characteristics of Table I are compiled to emphasize that the red dwarfs may often be close binaries and this may distort many of the conclusions that might be made of them were they all single

Table I. Some Optical Properties of the Extended Sample

Woolley	Other Name	Sp. Type	Other Datum	V	M_V	M_{bol}	Binary Characteristics
9066	TZ Ari	dM5e	M4.5 V	12.28V	13.92V	11.4V	1 RV
191	Kapteyn	MO V	MO.O(V)	8.85	10.89	9.8	non-SB(8), 10 RV
206	V998 Ori	dM4e	(M3.5 V)	11.50V	10.73V	8.6V	SB(43), 3 RV
293	EG 56	DF		14.5	15.7		0 RV
319A	$+10^{\circ}1857$	dM1	(MO.O V)	9.68	8.71	7.6	prob.SB(16),3 RV
334	$-8^{\circ}2582$	dMO	(K5.0 V)	9.51	9.1	8.0	prob.SB(13),3 RV
402	Wolf 358	dM5	M3.8 V	11.66	12.42	9.9	SB(34), 3 RV
440	L145-141	DA	C_2 band	11.48	13.05		0 RV
447	FI Vir	dM5	M4.1 V	11.10	13.49	11.0	non-SB(10), 7 RV
9400A	SV101251	dK8	V=1.5	9.77	8.3	7.3	prob.SB(11),7 RV
576	$+6^{\circ}2986$	K5	KO V;MO V	9.87	8.7	8.2	prob.SB(35),5 RV
628	$-12^{\circ}4523$	dM4	M3.5 V	10.12	12.10	9.9	SB(25), 6 RV
9566	HD149162	dK1	KO V	9.3	7.4	7.2	SB(37), 5 RV
861	Wolf1037	sdK6		14.19	13.0	12.3	SB(37), 2 RV
866	L789-6	dM6e	M5.5 V	12.18	14.60	11.8	0 RV
905	HH And	dM6e	M5.1:V	12.29V	14.80V	12.0V	?(120), 5 RV

stars or binaries with defined orbits. Even Woolley 144 (ϵ Eri) with many RV measures, and a range of only 1.9 km s^{-1} among the observatory means, has been published as a close binary in speckle interferometry (Blazit et al. 1977). An M3 V companion can fit into the interferometric, photometric, and astrometric data; but the RV data may be satisfied only with an orbit of low inclination.

Table II gives $R/R_{\odot}$ and T_{eff} according to Pettersen (1980) or an interpolation of his data plotted as functions of $M_V \geq +9$. Allen's (1973) functions of $M_V < +9$ extend the table up the main sequence. White dwarf R, T_{eff} are from Shipman (1979). Luminosity is estimated as $L(R, T_{eff})$ and again as $L(M_{bol})$ for comparison. The galactic orbit eccentricity e and the space velocity $|(U^2 + V^2 + W^2)^{1/2}|$ from Woolley et al. (1970) provide a basis for estimating the population or age group of each star as young (Y) or old (O) in the absence of other previously published designations, chiefly Veeder's (1974) or Mould and Hyland's (1976). The respective designations for Woolley 447 differ as shown.

Table III compiles the available BY Draconis period or the consistent equatorial rotation information. For Woolley 71 (τ Cet) only $v_e \sin i = 2.4$ km s^{-1} is known. For Woolley 15B an incomplete photometric cycle was published under the name CQ And (misprinted for GQ And) and questioned as rotationally dependent because all other stars accepted as members of a BY Draconis class by Bopp and Espenak (1977) had periods of less than five days. Woolley 905 is designated HH And and classified as a BY Draconis type variable of 120-day period in Kukarkin et al. (1976), so it raises strong questions about the definition of the

Table II. Properties of the Entire Sample

Woolley	$R/R_{\odot}$	T_{eff} (100K)	L(R,T) (ergs s^{-1})	$L(M_{bol})$ (ergs s^{-1})	Galactic Orbit e	Space Velocity (km s^{-1})	Age Group
15A	0.41	35	8.7(31)	1.1(32)	0.12	51	OD
15B	0.19	32	1.3(31)	1.9(31)			
71	0.87	51	1.8(33)	1.6(33)	0.22	37	?
9066	0.19	31	1.2(31)	8.3(30)		53	?
139	0.91	54	2.4(33)	2.3(33)	0.36	127	OD
144	0.83	48	1.3(33)	1.3(33)	0.09	22	Y
191	0.43	33	7.6(31)	3.6(31)		293	halo
206	0.44	33	7.9(31)	1.1(32)	0.007	25	Y
213	0.23	32	1.9(31)	2.1(31)	0.36	126	halo
9193	0.012	44	2.0(29)				?
293							?
319A	0.65	38	3.0(32)	2.8(32)	0.19	54	O
334	0.61	37	2.4(32)	1.9(32)	0.08	39	Y
402	0.30	32	3.3(31)	3.3(31)	0.10	40	YD
412A	0.49	34	1.1(32)	1.2(32)	0.36	130	OD
412B	0.13	29	4.1(30)	1.5(30)			
440	0.010	95	3.1(30)				?
445	0.24	33	2.4(31)	2.5(31)	0.27	121	halo
447	0.21	31	1.4(31)	1.2(31)	0.09	26	YD,OD
9400A	0.67	41	4.4(32)	3.6(32)	0.10	52	O
9400B	0.56	36	1.8(32)				
576	0.65	38	3.0(32)	1.6(32)	0.24	93	O
628	0.33	32	3.9(31)	3.3(31)	0.04	26	YD
9566	0.73	41	5.2(32)	4.0(32)	0.22	75	O
643	0.22	32	1.8(31)	1.6(31)	0.13	41	OD
644A	0.45	34	9.3(31)	9.1(31)			
644B	0.45	34	9.3(31)	1.0(32)	0.13	41	OD
644C	0.13	25	2.3(30)	1.0(30)			
702A	0.89	52	2.0(33)	2.1(33)	0.07	29	Y
702B	0.73	41	5.2(32)	5.3(32)			
780	1.01	58	4.0(33)	4.0(33)	0.11	49	OD
783A	0.79	45	8.8(32)	1.0(33)	0.33	138	halo
783B	0.28	31	2.5(31)	2.5(31)			
820A	0.72	41	5.1(32)	4.8(32)	0.28	105	OD
820B	0.67	39	3.6(32)	2.8(32)			
860A	0.35	32	4.4(31)	4.0(31)	0.11	32	OD
860B	0.24	31	1.8(31)	1.2(31)			
861	0.21	32	1.6(31)	3.6(30)	0.54	209	halo
866	0.25	30	1.7(31)	5.8(30)	0.19	79	OD
905	0.16	30	7.2(30)	4.8(30)	0.29	84	OD

type. Kron (1950) reported the 120-day period of Ross 248 (another name

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Table III. Period and Equatorial Rotation Velocity

Woolley	Period (days)	v_e (km s^{-1})	References
15B	> 7	< 1.4	Bopp and Espenak (1977)
71	≤ 19	≥ 2.4	Soderblom (1981)
144	12	3.5	Hallam and Wolff (1981)
702A	20	2.3	Stimets and Giles (1980)
820A	35	1.0	Hallam and Wolff (1981)
820B	45	0.7	Hallam and Wolff (1981)
905	120	0.07	Kron (1950)

for Woolley 905) from the unpublished light curve observed by Gordon and Kron (1982), and noted that the shape of the light curve simulates the secondary variation of YY Gem (Kron 1952). He concluded that the Ross 248 amplitude of 0.06 magnitude originates in the same way, by the rotation of the star, in this case with a long period.

Table IV gives the new X-ray IPC data derived and arranged as for the earlier observations (Johnson 1981).

Table IV. X-Ray Properties of the Extended IPC Sample

Woolley	$\alpha(1950+\mu_\alpha \Delta T)$	O-C (s)	$\delta(1950+\mu_\delta \Delta T)$	O-C (")	F_x (ergs $cm^{-2}s^{-1}$)	L_x (ergs s^{-1})
9066	$01^h57^m30^s.3$	-0.5	+12°49′11"	-26	1.5(-12)	4.0(27)
191	05 10 00.3	...	-45 02 46	...	< 1.9(-13)	< 3.5(26)
206	05 29 29.6	+0.2	+09 47 11	-10	4.8(-12)	1.2(29)
293	07 52 15.7	...	-67 38 44	...	< 8.9(-14)	< 3.6(26)
334	09 04 19.0	+0.8	-08 36 22	-36	2.6(-13)	4.4(27)
402	10 48 17.3	...	+07 04 39	...	< 1.4(-13)	< 8.3(26)
440	11 43 10.7	...	-64 33 40	...	< 1.5(-13)	< 4.2(26)
447	11 45 10.3	-2.4	+01 05 21	-02	3.2(-13)	4.2(26)
9400AB	12 13 25.6	...	+05 55 05	...	< 1.4(-13)	< 6.5(27)
576	15 02 25.7	+2.8	+05 50 12	-03	1.7(-13)	6.3(27)
628	16 27 30.8	...	-12 32 53	...	< 1.5(-13)	< 2.9(26)
9566	16 30 21.9	-0.1	+03 21 05	+20	1.5(-12)	1.1(29)
861	22 26 17.0	...	+05 33 16	...	< 2.1(-13)	< 7.8(27)
866	22 35 49.9	-0.6	-15 34 21	-43	8.0(-13)	1.0(27)
905	23 39 27.3	-2.0	+43 54 23	-23	1.5(-13)	1.8(26)

Table V gives the reprocessed X-ray HRI data also as arranged for the original HRI observations (Johnson 1981) except that net counts per star are tabulated rather than F_x (thus without intervention of a con-

Table V. Reprocessed HRI X-Ray Data

Woolley	$\alpha(1950)+\mu_\alpha\Delta T$	O–C (s)	$\delta(1950)+\mu_\delta\Delta T$	O–C (")	Net Counts (10^3 s)$^{-1}$	Exp. (s)
644A 644B	$16^h52^m46^s.87$	+0.17±0.03	− 8°15′08″.2	+0.2±0.5	648±26	4158
702A	18 02 56.12	+0.12±0.03	+ 2 30 02.1	−1.9±0.5	193±14	8912
702B	18 02 56.05	+0.19±0.03	+ 2 30 03.9	−3.7±0.5	< 5.3	
783A	20 07 56.13	+0.08±0.17	−36 14 29.3	+0.2±2.0	5.0±2.2	5031
783B	20 07 56.58	−0.37±0.17	−36 14 33.0	+3.9±2.0	< 3.8	

version factor). The 1950 SAO catalog coordinates are supplemented with binary orbit information for the comparison O–C of Einstein observed coordinates with the calculated coordinates. The HRI reduction program provides error estimates for the observed coordinates which are quoted after O–C. It is not known how much of the larger values of O–C depends on SAO errors. Except for Woolley 644AB, which is still blended with 0″.2 separation, it is possible to decide that component A of each binary provides the X-ray flux. Errors in the original 1979 HRI data were too large to prefer any binary component over the other. Net counts for Woolley 702B and 783B are estimated as upper limits from the background counts data. These HRI ratios A:B of X-ray flux will be applied to the IPC estimates of F_x and L_x in Johnson (1981) for the following discussion. HRI reduction includes an examination of the time stream of data for variability in these images, but no evidence was found for it. The last column of Table V (Exp.) reports the total time in the reprocessed image.

Tables VI and VII summarize new IUE measures of the flux density of detected line emissions, and also a sample of continuum averaged at λ2660 around λλ2640–2680. The low resolution blends several doublets for which mean laboratory wavelength is listed. However, the Mg II emission doublet is partially resolved in Woolley 412A, 820A, 866, and 860AB; and it appears serrated at the peak in Woolley 576 and asymmetric in Woolley 9066. Mg II in Woolley 9566 is in very slight emission on noisy continuum, and in Woolley 783A the profile shows slight emission within shallow absorption. Geocoronal Lyα is blended with each stellar Lyα, which is seen as a pointlike image within the larger geocoronal image on the IUE Photowrite representations of Woolley 644AB, 783A, 820A, and 860AB. The stellar Lyα image is not seen in Woolley 191. The stars for which only Mg II and continuum λ2660 are listed were not exposed in the IUE short wavelength camera. Mg I 2852 is a very deep absorption feature in Woolley 9566, and there is also a large and broad but unidentified emission between Mg II 2799 and Mg I 2852 that peaks at λ2822. This emission does not appear to be an artifact, but it is definitely out of the ordinary when compared with the earlier spectrum of the Sun or the spectra later than K1 V in this collection.

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Table VI. Flux Density of Line Emissions (ergs cm^{-2} s^{-1}) and of λ2660 Continuum (ergs cm^{-2} s^{-1} $Å^{-1}$)

Sp.	Woolley 9066	Woolley 191	Woolley 644AB	Woolley 783A	Woolley 820A	Woolley 860AB
H I 1216		8.7(-12)	1.3-1.4(-11)	1.6(-11)	Saturated	1.1(-11)
N V 1241			2.9-3.2(-13)		5.6(-14)	
O I 1304			4.2-10 (-14)		8.8(-14)	
C II 1335			1.4-2.6(-13)		1.0(-13)	
Si IV 1394			5.2-19 (-14)			
Si IV 1403			1.0(-13)			
C IV 1549			3.4-11 (-13)		1.2(-13)	
He II 1640			1.4-3.6(-13)		9.9(-14)	
C I 1657			9.1-14 (-14)		1.0(-13)	
Al II 1671					3.0(-14)	
Si II 1808			3.9-9.0(-14)	3.3(-14)	1.3(-13)	
Si II 1817			9.1-12 (-14)	8.3(-14)	2.0(-13)	
Fe II 2585 -2631			1.2(-12)			
Mg II 2799	1.5(-13)	4.2(-14)	3.1(-12)	1.8(-12)	1.8(-11)	4.0-4.6(-13)
Continuum	nil	1.3(-15)	8.3(-15)	9.0(-13)	1.3(-13)	3.3(-15)

Table VII. Flux Density of Mg II 2799 Line Emissions and of λ2660 Continuum as in Table VI

Woolley	319AB	412A	9400AB	576	628	9566	866
MgII 2799	5.1(-14)	1.9(-13)	5.8(-13)	2.0(-13)	1.4(-13)	9(-14):	2.4(-13)
Continuum	6.4(-16)	2.1(-15)	3.7(-15)	2.0(-15)	8.3(-16)	3.8(-14)	5.6(-16)

3. CORRELATIONS OF DATA

Figure 1 plots log L_x vs. log $R/R_\odot$. Photospheric radius R is one of the fundamental stellar parameters and is directly involved in coronal emission measure for scale. If the coronal radii of stars below the Sun were proportional to R while all other factors of emission remained the same, $L_x \propto R^3$ should appear. The large dispersion of data in L_x shows that other factors perturb but they do not rule out this simple geometry. Relatively little is known about red dwarf coronal temperatures among the other factors. An unexpected discovery from the only Einstein Solid State Spectrometer observations of red dwarfs, AD Leo (Swank et al. 1981) and Wolf 630AB (Swank and Johnson 1982), was the latter's quiescent dominant temperature of about 6.5 x 10^6 K and an indication of additional emission above 10^7 K. This is strongly reminiscent of the RS Canum Venaticorum class of coronal properties. Wolf 630AB, which appears in Table II as Woolley 644A and 644B, is a peculiar multiple star of which component B is probably a spectroscopic binary.

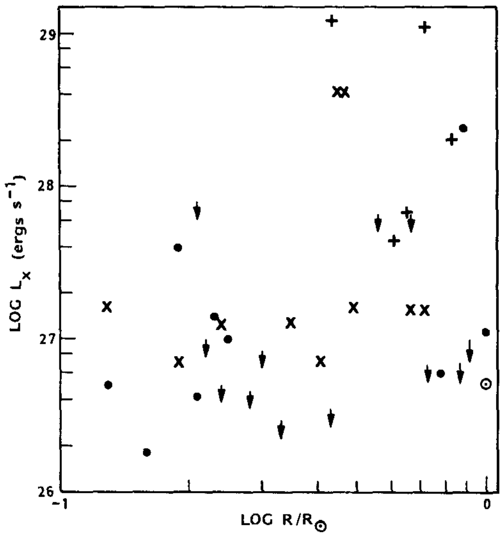

Figure 1: Dependence of L_x on $R/R_\odot$. The symbol "•" plots a star that is a resolved member of a binary or a star that is not known to be a binary; "x" plots a member of a blended binary with half of total L_x, so that some of the symbols may be upper limits and some of them may be plotted at half of true L_x; "+" plots a primary member of a candidate binary for which the secondary is not plotted because neither its spectrum nor its magnitude is known; and "↓" plots the upper limit of an IPC-undetected star. The average Sun (⊙) is from Pallavicini et al. (1981).

Stellar duplicity may be an important factor in L_x. All but three stars in Figure 1 with $L_x > 10^{27}$ ergs s^{-1} are members of visual, interferometric, or suspected spectroscopic binaries. One of these three, Woolley 9066 (TZ Ari), has only one published radial velocity so it is untested. Another, Woolley 213 (Ross 47), is listed by Abt (1970) with four Mt. Wilson velocities (+80.6, +112.3, +104.1, and +98.0 km s^{-1}). They do not exclude the star as a potential spectroscopic binary. The third star, Woolley 780 (δ Pav) is the only one of the three in question that is fairly certainly established as a single star, with $L_x = 1.1 \times 10^{27}$ ergs s^{-1}. Although the stars that are binaries may often be close binaries, Woolley 702A (70 Oph A) is the most probable example of a luminous X-ray dwarf that is not a close binary. Batten and van Dessel (1976) found marginal evidence for a short-period variation in the radial velocities of 70 Oph A, but later observations do not support it (Batten 1982).

Figure 2 shows a decline of L_x with v_e, the equatorial velocity of rotation. Most of the stars are above or to the left of Pallavicini et al.'s (1981) least-squares fit to partly different data, $L_x = 1.4 \times 10^{27}$ $(v_e \sin i)^2$, and that relation is an upper envelope for v_e dependence.

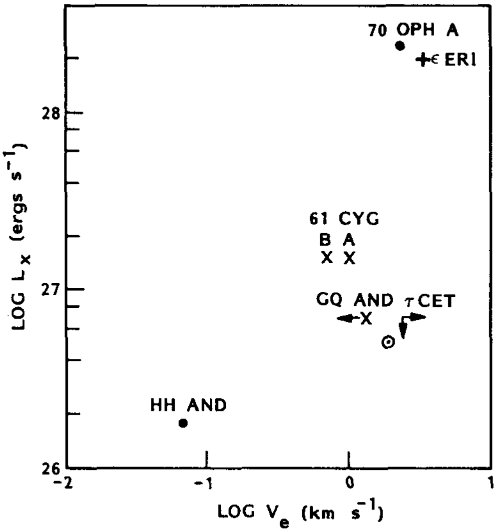

Figure 2: Dependence of L_x on v_e, the equatorial velocity of rotation. Plot symbols are the same as in Figure 1. The upper limit on v_e for GQ And results from a lower limit on observed light-curve period. The lower limit on v_e for τ Cet results from a $v_e \sin i$ observation.

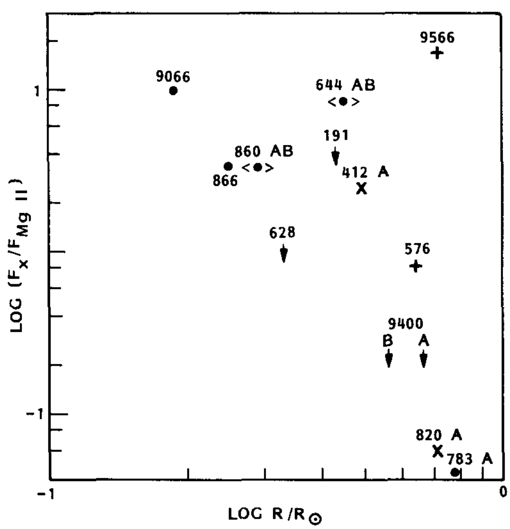

Figure 3: Dependence of the ratio $F_x/F_{Mg\ II}$ (coronal flux in the IPC band to chromospheric flux in the Mg II doublet line) on $R/R_\odot$. Plot symbols are the same as in Figure 1 except that "<>" brackets appear for binaries that are blended in both IUE and *Einstein* images.

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HH And is the most important plot in Figure 2 since it extends the range of v_e over an order of magnitude below previous investigations, and its inferred rotational velocity is only one or two percent as large as that of YZ CMi, a dM4.5e star that is probably single and young. Bopp and Espenak (1977) have maintained that all dMe stars (such as HH And) are subject to BY Draconis variability, but Bopp et al. (1981) clearly would not expect to encounter BY Draconis variability in dMe stars with $v_e < 3$ km s^{-1}. The Hα region of the HH And (Ross 248) spectrum is complex (Worden et al. 1981). The star may be completely convective and it obviously deserves much further investigation of photometric variability, rotation period, and the nature of its radial velocity range. The generation of magnetic flux and the related structure of spots in such convective stars has been only briefly discussed theoretically (e.g. Galloway and Weiss 1981; Durney and Robinson 1982). If the 120-day period in the light curve of HH And is truly rotational and not the growth and decay of a polar spot such as Mullan (1974) first supposed for convective dwarfs, or the integrated secular display of many spots, then rapid rotation is not an essential for the BY Draconis syndrome.

Figure 3 shows the relation of coronal flux to a representative measure of chromospheric flux. Coronal flux rises very rapidly with respect to chromospheric flux as radius shrinks in the progression down the main sequence from the Sun, with Woolley 9566 the exception to the rule. If the optically fainter spectroscopic binary component of Woolley 9566 provides dominant F_x and $F_{Mg\ II}$ in the system, the plot might be moved to smaller radius and so to better agreement with the other stars. Unfortunately the measure of the ratio of fluxes for Woolley 9566 is also the least certain of the plots.

4. X-RAY FLARING BEHAVIOR

The IPC counts of the detected stars in Table IV were analyzed by standard Einstein computer programs for variability. Only one of them,

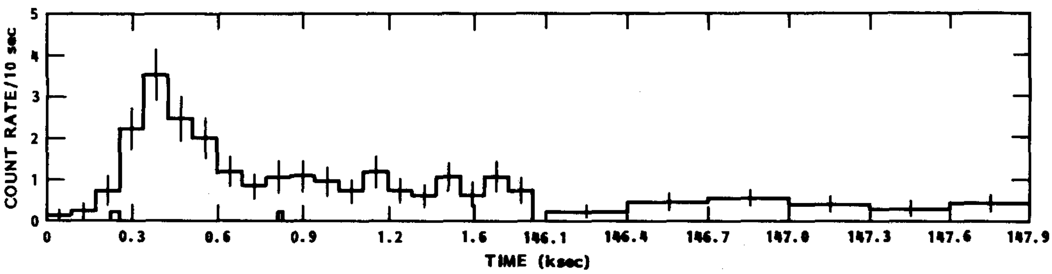

Figure 4: Two major sections of the IPC count rates for TZ Ari. Small cells near zero level mark interruptions in the data stream, for which a computer program has corrected the count rates. Time begins 1980 July 14 at UT 07:38:09.

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TZ Ari (i.e. Woolley 9066) exhibited an X-ray flare, while the others remained constant within statistical errors during periods of 1277 s to 4738 s in the integrated image.

Figure 4 shows the X-ray light curve of TZ Ari in two sections 1.7 days apart. The apparent flare duration at half peak level above postflare level is about 4 minutes, and the postflare level continued to decline for 1.7 days. Haisch (1983) reviews the behavior of several stellar X-ray flare events.

Figure 5 shows the results of an Einstein IPC spectral analysis for Wolf 630AB, divided into preflare and flare sections of the light curve (Johnson 1979, 1981). These may be compared with each other and with the Einstein Solid State Spectrometer (SSS) analysis for a quiescent period (Swank and Johnson 1982). Although Raymond thermal spectral fits were also made to the IPC data, their χ^2 values were not so good as the values of 12.7 and 6.7, respectively achieved for preflare and flare sections fitted to exponential spectra (with gaunt factor) over IPC spectral energy bins 4-12 (i.e. 0.5-4.8 keV). These spectra suggest that the temperature approximately doubled from preflare to flare, and that preflare temperature on this model is higher than the low-temperature component (kT = 0.54 keV) of the two-temperature model derived from the SSS observation. The observed total flux density in the 0.5-4 keV spectral range of the SSS observation was 7.9×10^{-12} ergs cm^{-2} s^{-1} as compared with the IPC results of 7.3×10^{-12} ergs cm^{-2} s^{-1} during preflare state and 1.8×10^{-11} ergs cm^{-2} s^{-1} during flare.

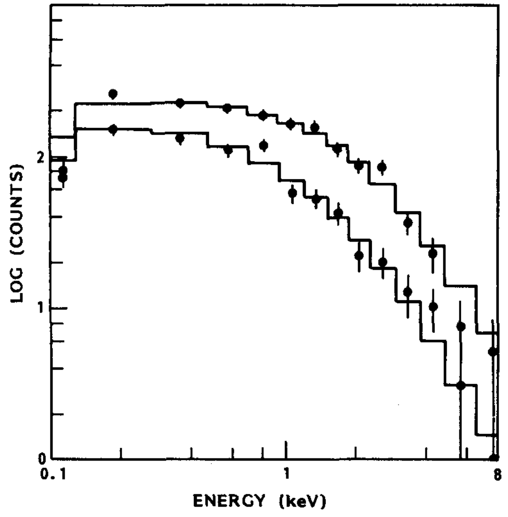

Figure 5: Observed preflare (lower) and flare (upper) spectra of Wolf 630AB fitted to exponential spectra (with gaunt factor) of kT = 1.25 keV and kT = 2.75 keV, respectively. The fits are at minimum χ^2 values. Preflare counts include the first 1.2 ksec of the IPC light curve.

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5. CONCLUSIONS

Stellar X-ray astronomy first utilized close binary systems with a compact component and its deep potential well to explain a class of bright galactic sources. Then around 1980 binaries were rejected in favor of unexpectedly energetic coronae to explain another larger class of weaker galactic sources. Each new dwarf-star X-ray source since 1979 has been almost exclusively relegated to one or the other class. Yet the abundance of binary stars suggests that caution is in order and that stellar duplicity may be a factor in the coronal X-ray stars. Stellar duplicity as a factor in red dwarf chromospheric activity has long been suspected (cf. Greenstein and Wilson 1969; Abt 1978). It is fairly clear that the factor of duplicity has not been observationally or theoretically investigated very much for the coronal class.

The mechanisms by which duplicity may be important include, again, Roche-lobe overflow or stellar wind to a companion, but not necessarily a very compact companion, interacting coronae of non-synchronous binaries, and tides. The fence that has been erected several times recently in the HR diagram to separate stars having weak or strong stellar winds, e.g. by Ayres et al. (1981), runs out between MK luminosity classes III and IV and leaves the question of red dwarf winds on open range. However, Durney and Leibacher (1973) and Coleman and Worden (1976) have discussed red dwarf winds positively, and Siscoe and Heinemann (1973) have foreseen colliding binary-system winds. There are still almost no quantitative coronal or wind studies dedicated to interacting red dwarf pairs, or a red dwarf with a partially degenerate companion, or a red dwarf with a compact companion so disposed as to be only an inefficient mass gainer and relatively weak X-ray producer. Rappaport et al. (1982) have started in this direction. Systems such as V471 Tau and PG 1413+01 (van Buren et al. 1980) may represent the inefficient kind of red-dwarf, white-dwarf pair with low L_x. Such studies might be applicable to many stars in this paper. Tidal effects on RS Canum Venaticorum behavior have been investigated (De Campli and Baliunas 1979; Scharlemann 1982). A corresponding approach to red dwarf binaries might be made. Once the possible binary interactions have been theoretically explored, X-ray astronomy may contribute much more to binary-star statistics as well as to astrophysics.

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DISCUSSION

Giampapa: I notice from your graph of L_X against MgII flux that these two are comparable in magnitude. Would it be true to say then that if one sums together the Mg flux, the Ca flux, the Balmer and transition region fluxes that these would exceed by perhaps an order of magnitude the coronal X-ray flux?

Johnson: Yes, it seems possible that is true.

Vaiana: The influence of the binary nature on the emission process appears crucial. Would you like to comment on whether this effect might be through higher induced rotation or otherwise e.g. through some kind of physical connection between the two stars? I ask this because on some Einstein images of well-separated binaries both stars are seen in emission.

Johnson: My comment would be that among the RSCVn stars, for instance, duplicity would seem to be a necessary condition. Yet in many of them the stars would not appear sufficiently close for one to directly influence the other. While I realize that enforced synchronism may lead to rapid rotation and thence to activity by mechanism described by others at this meeting, there are active binaries among the non-synchronous rotators. It is possible that the coronae or winds of these stars could interact and produce extra heating. I would say that the field of double star effects has yet to be explored in X-ray astronomy in any depth.

Linsky: There are two important observations which theoreticians need to explain and they are these. Firstly, the energy losses from the chromosphere of the quiet Sun exceed by two orders of magnitude those from the transition region and corona. On the other hand in the dMe stars the coronal X-ray loss, omitting any flows or heat conduction losses, already exceeds radiative losses in their chromospheres and transition regions. So there is a huge difference in the energy balance in the solar atmosphere and the dMe atmosphere in the sense that the Sun's outer atmosphere radiates predominantly in the cromosphere while in terms of energy the corona is irrelevant. Whereas in the dMe stars the corona is dominant and it could even be that the energy radiated by the chromosphere is a result of back-heating from the corona, an idea promoted by Cram. Could you comment on that?

Johnson: I am not a theoretician so I don't aim to comment.

Walter: I would like to make a comment on your comment on rapid rotation vis-a-vis RSCVn stars. RSCVn's are by definition binaries whereas in the dMe stars and stars like ξ Boo we are seeing the same kind of effects in single stars as long as they are rapidly rotating. So it appears that

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the effect of stellar duplicity is to keep a star rotating fast longer. I have a poster paper on X-ray and IUE observations of AR Lac through eclipse whereby we measure the size of the coronae. They are comparable in size to the solar corona. They are not big enough to interact with one another except perhaps during the large and peculiar flares that one sees on the RSCVn's. These flares have no solar analogues. The RSCVn coronae are small and solar-like and I would presume that you are seeing the same kind of thing in stars like Wolf 630 and the other dMe stars.

Johnson: Wolf 630 is a very complex system and I'm not sure how analogous it is to an RSCVn. Would you say that Capella is rapidly rotating because it is a binary?

Walter: No! Capella is rapidly rotating because it was a rapidly rotating A star which is evolving off the main sequence and there, duplicity doesn't matter. A star like ξ Boo is not rotating rapidly because of duplicity but because it is young. So rapid rotation is important in these objects and not membership of a binary.

Johnson: What you are saying is that rapid rotation has been proved to be important and not proved that duplicity is not important.

Walter: If you pick two stars with the same rotation rate, one in a close binary and one not, they are identical.