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Coronal Temperatures of Unusually Active K-Dwarf Binary Systems
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Final Report

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1. Summary

We report the results of a ROSAT pointed study of 4 BY Dra systems. Good quality pulse-height spectra are available from all four systems. Except for a required interstellar absorption component in HD 319139, the four systems have remarkably similar X-ray spectra; the two systems BD +22°669 and BD +23°635 (Leiden 20) look virtually identical in X-rays. Analyis of the 4 X-ray spectra reveals that, in all cases, a single-temperature hot plasma (RS or Mewe) spectra is inadeqaute to fit the data, and two temperatures are required. We present examples of fitted pulse-height spectra and χ^2 contours in kT_1-kT_2 space.

2. Introduction

In an initial investigation of the Hyades cluster using ROSAT all-sky survey data (Stern *et al.* 1991a), we noticed that a group of stars of spectral type K (0.8<B-V<1.3) stood out as being brighter in L_x , in some cases by over an order of magnitude, compared to other Hyades members of similar color. The properties of these stars and associated ROSAT survey data are listed in Table 1.

Table 1: X-Ray Bright K dwarfs in the Hyades from the All-Sky Survey

Name	V	Sp. Type	Period(d.)	PSPC ct s^{-1}	Exp(sec)	L_x (10^{29} erg s^{-1})
BD +22°669	9.52	K1V+K5V	1.89	0.58	103.5	8.4
BD +23°635	9.38	K3V+K8V	2.39	0.53	404.1	7.7
VA 677	11.03	K + ?	1.5	0.23	392.4	3.4
L 30	10.00	K	?	0.18	312.7	2.6

The optical properties of these systems, and their unusually high X-ray luminosity, suggest that they are likely BY Draconis variables. In fact, BD+23°635 has been identified as such on the basis of chromospheric emission (Bopp, Africano, and Goodrich, 1986). The BY Draconis stars are a group of red (dKe–dMe) low-amplitude variables with photometric periods typically a few days, Ca II and often Hα emission, and unusually bright X-ray emission for their spectral type, with a typical $L_x \approx 5\times10^{29}$ erg s^{-1}

(Bopp and Fekel 1977, Caillault 1982). Most, but not all, are binaries in short period orbits, with rapid rotation the crucial factor in their high level of activity. A few are dMe flare stars (Bopp and Fekel 1977, Strassmeier *et al.* 1988). Because of the low level of optical variability, and intrinsic faintness, the confirmed BY Dra variables are mostly found at distances < 20-40 pc from the Sun.

Only a handful of BY Dra systems have been studied with even the modest spectral resolution of the *Einstein* IPC. Schmitt *et al.* (1990), in their sample of 130 IPC spectra, investigated the systems CC Eri, OU Gem, YY Gem, BY Dra, and the single flare star AU Mic. Since only 2 systems (CC Eri and OU Gem) were dK type, there was no way to separate spectral properties of traditional dMe "flare stars" from the earlier dK binaries. In addition, these two systems had less than 700 counts in their IPC spectra, resulting in poor constraints on model spectra.

Estimating coronal temperatures or temperature distributions in various classes of active cool stars has proven useful in identifying the presence of high temperature, "flare-like" plasma of $T>10^7$ K in the dMe stars. In contrast to this, most emission in main sequence F-G stars comes from $T<10^7$ K (Schmitt *et al.* 1990). There are more recent hints that this holds true even for stars of similar age: preliminary results from a spectral sample of Hyades G and M dwarfs (not including any of the stars in Table 1), obtained during a deep ROSAT PSPC exposure, show the same trend (Stern *et al.* 1991b; see Figure 2). We therefore proposed to conduct an X-ray spectral survey of 4 BY Dra systems.

3. Observations

The 4 BY Dra systems were observed by the ROSAT PSPC during the AO-3 observing cycle. In Table 2 we list the PSPC targets, their (optical) spectral properties, the observation dates (in 1993), and observing time (in ksec) for each target.

Table 2: PSPC Targets

Name	V	Sp. Type	Period(d.)	d(pc)	Obs. Start	Obs. End	Exp (ksec)
BD +22°669	9.52	K1V+K5V	1.89	45	24 Feb 15:43	4 Mar 22:08	4.1
BD +23°635	9.38	K3V+K8V	2.39	45	26 Feb 10:47	27 Feb 01:53	3.5
HD 319139	10.4	K5Ve	2.45	40	3 Apr 16:49	4 Apr 19:01	4.6
V775 Her	8.04	K05 + K5-M2V	2.88	24	8 Apr 05:01	8 Apr 05:44	2.1

4. Results

All four sources in Table 2 above were detected by the PSPC at approximately the expected count rates. In Table 3 below we list the results of running the EXSAS MLDETECT algorithm on each field.

Table 3: PSPC Results

Name	X-Ray Position						Δ pos.	ML	cts sec^{-1}
	h	m	s	°	′	″	″	ratio	(vig. cor.)
BD +22°669	4	18	10.6	+23	17	1	23.	15652.	0.71±0.01
BD +23°635	4	11	56.1	+23	38	8	9	12714.	0.67±0.01
HD 319139	18	14	10.9	-32	47	25	9	3509.	0.23±0.01
V775 Her	18	55	53.2	+23	33	29	13	26157.	1.9±0.03

The source spectra were also extracted with EXSAS, and the individual pulse-height channels were binned in each case to achieve ≈ 5:1 S/N ratio in each bin. Comparison of spectral fitting results with spectra of the same objects extracted using the PROS 34-channel scheme did not show significant differences in the fitted results. None of the sources was adequately modeled using a single-temperature Raymond-Smith (RS) or Mewe-Kaastra thermal plasma, so we proceeded by fitting the pulse-height spectra to two temperature models, with interstellar absorption included for two of the sources (HD 319139 and V 775 Her; the other two stars are in the Hyades cluster and show no evidence of absorption).

The results of the model fitting are given in Table 4 and in Figures 1 and 2. In the table we indicate the best fit temperatures and emission measures and the 90% confidence limits. Figure 1 shows the pulse-height spectra for each source along with the best-fit 2T (or abs + 2T) model. Figure 2 shows χ^2 contours in kT_1–kT_2 parameter space indicating the regions of valid 2-T models for each system.

Table 4: Model Fitting Results

Name	kT_1 keV	EM_1 $10^{52}cm^{-3}$	kT_2 keV	EM_2 $10^{52}cm^{-3}$	log N_H $10^{20}cm^{-2}$
BD +22°669	0.20±0.02	2.0±0.4	0.96±0.10	4.3±0.6	
BD +23°635	0.24±0.05	2.2±0.5	0.97±0.11	3.6±0.7	
HD 319139	0.30±0.15	1.1±0.3	1.16±0.6	2.4±0.5	2.5±1.0
V775 Her	0.18±0.02	2.2±0.3	0.91±0.05	3.4±0.3	0.2±0.2

5. Discussion

The most remarkable result of our spectral study is that the four objects studied are almost indistingushable in their intrinsic X-ray spectra, at least at the resolution of the ROSAT PSPC. Except for the differences in the *extrinsic* values of the insterstellar column density, each of the two components in the PHA spectra have best fit values which are within the 90% confidence limits of the corresponding two components in each others' spectrum. This may suggest that, for K dwarf BY Dra systems with short periods ($<$ 3 days) the stellar dynamo achieves a "saturated" state which produces coronae that are essentially indistinguishable from each other with the spectral resolution of ROSAT. It remains to be seen if such coronae, when studied with the higher spectral resolution of, say, the ASCA or even the AXAF-S satellites, will reveal subtle differences in their emission measure distributions.

6. Foreign Travel

One foreign trip was undertaken by the P.I. from 15 Mar to 24 June 1993 to during which time he performed analysis of the ROSAT PSPC data in collaboration with Dr. Jurgen Schmitt of the Max Planck Institut für Extraterrestriche Physik, Garching, Germany.

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Stern, R.A., Schmitt, J.H.M.M., Pye, J.P., Stauffer, J.R., and Simon, T., 1991b, B.A.A.S., 23, 1329.

Figure Captions

Figure 1. Pulse-height data and best fit models for: (a) BD +22°669 , (b) BD +23°635 , (c) HD 319139 , and (d) V775 Her.

Figure 2. χ^2 confidence contours in kT_1-kT_2 space for: (a) BD +22°669 , (b) BD +23°635 , (c) HD 319139 , and (d) V775 Her.

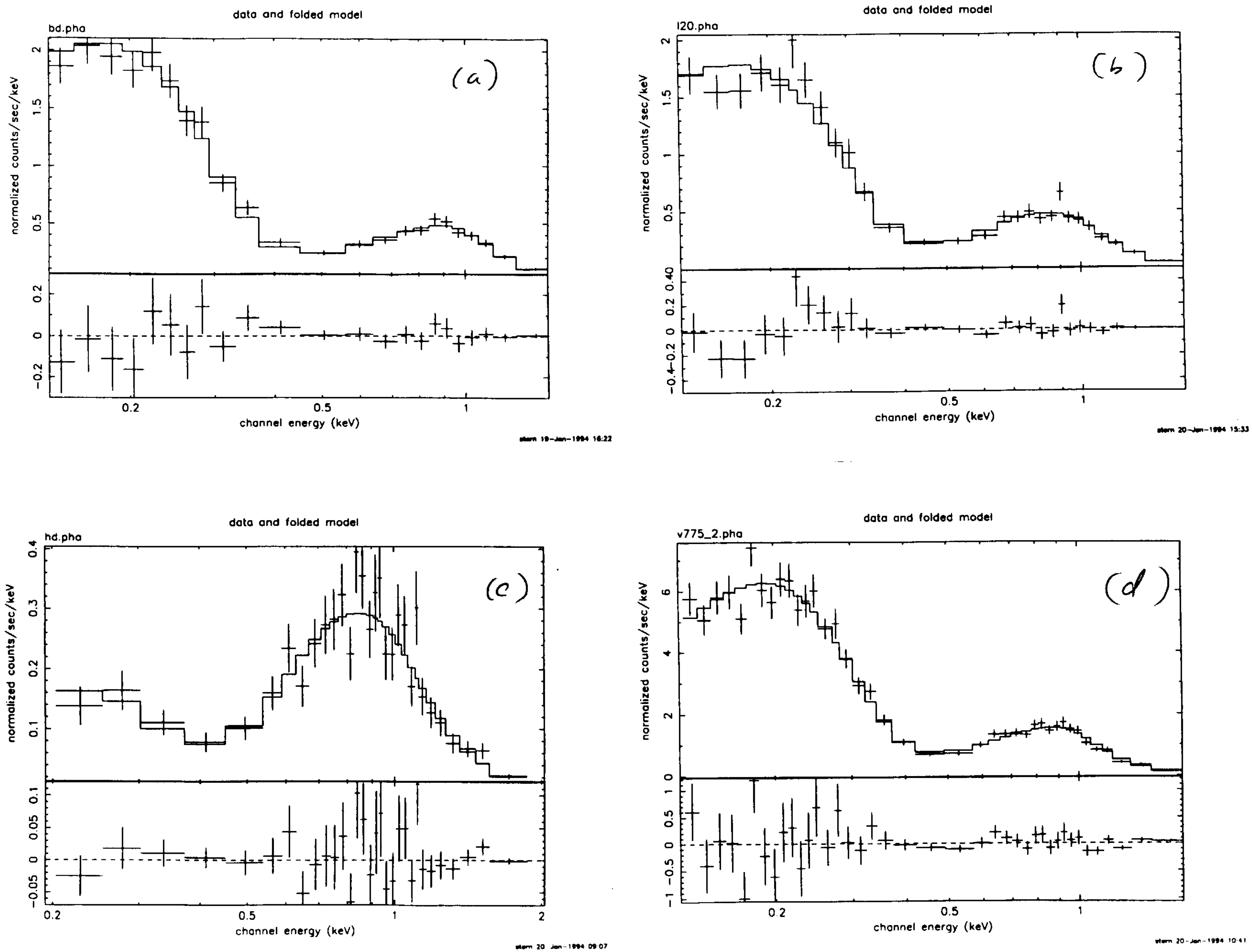
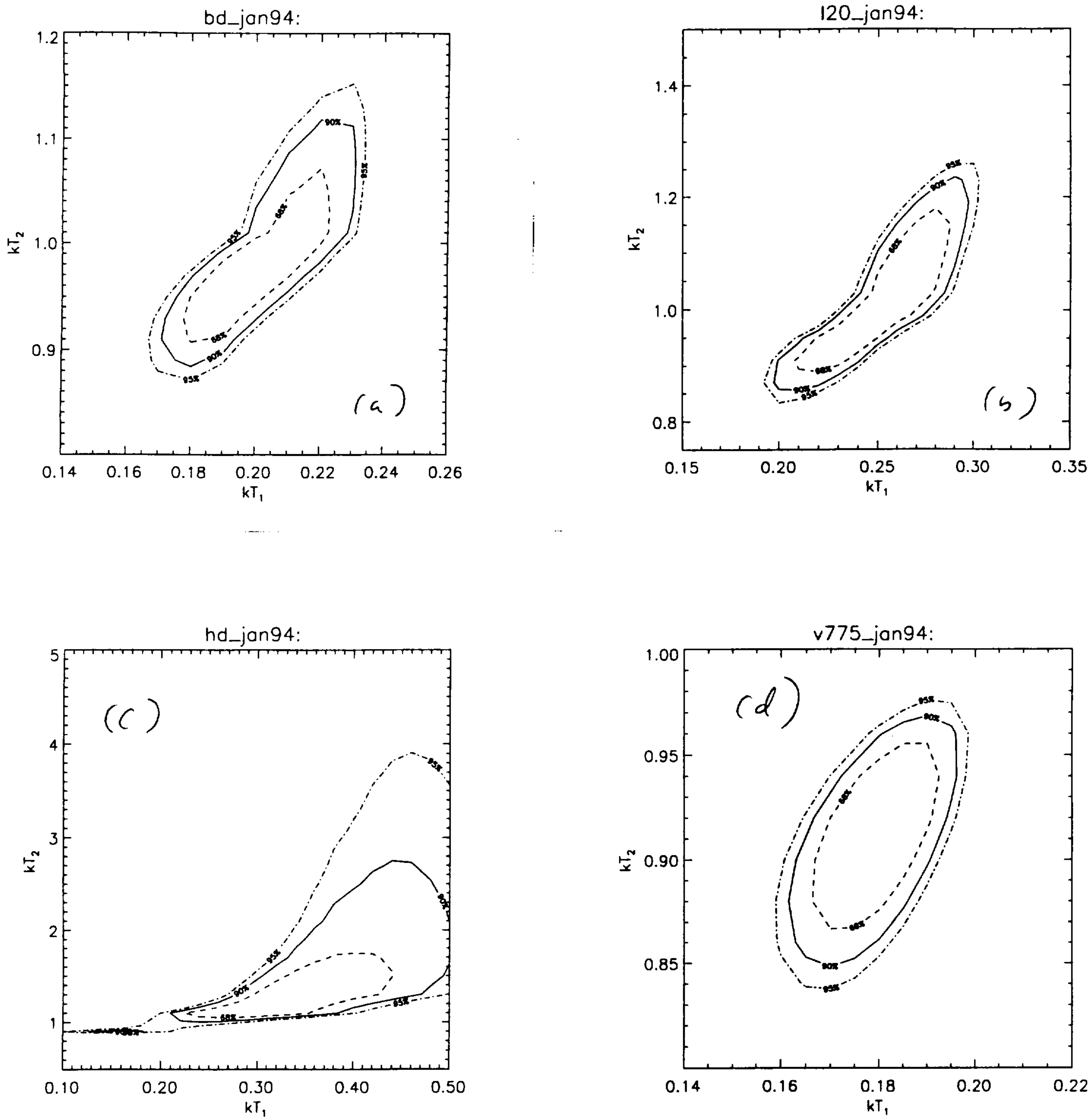

data and folded model
bd.pha
(a)
normalized counts/sec/keV
channel energy (keV)
stern 19-Jan-1994 16:22
data and folded model
120.pha
(b)
normalized counts/sec/keV
channel energy (keV)
stern 20-Jan-1994 15:33
data and folded model
hd.pha
(c)
normalized counts/sec/keV
channel energy (keV)
stern 20 Jan-1994 09:07
data and folded model
v775_2.pha
(d)
normalized counts/sec/keV
channel energy (keV)
stern 20-Jan-1994 10:41

FIGURE 1



bd_jan94:
I20_jan94:
hd_jan94:
v775_jan94:
kT2
kT1
(a)
(b)
(c)
(d)
68%
90%
95%
0.14 0.16 0.18 0.20 0.22 0.24 0.26
0.9 1.0 1.1 1.2
0.15 0.20 0.25 0.30 0.35
0.8 1.0 1.2 1.4
0.10 0.20 0.30 0.40 0.50
1 2 3 4 5
0.14 0.16 0.18 0.20 0.22
0.85 0.90 0.95 1.00

FIGURE 2

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