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LOW-ENERGY X-RAY OBSERVATIONS OF THE WOLF 630 SYSTEM

HUGH M. JOHNSON
Lockheed Missiles and Space Company
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ABSTRACT

The septuplet of M dwarfs is resolved into three components, Wolf 630ABab, Wolf 629ab, and VB 8AB, with the *EXOSAT* channel multiplier array (CMA). W630 and VB 8 have previously been observed with the *Einstein* high resolution imager (HRI) and W630 only with the *Einstein* imaging proportional counter (IPC) and solid state spectrometer (SSS). The ratio of CMA to HRI count rates for VB 8 can be produced with an isothermal plasma model temperature $T = (6.4^{+1.6}_{-0.9})$E5 K, which is exceptionally low in the known range of coronal temperatures. The count rate during 18,112 s of effective exposure with *EXOSAT* shows that VB 8 flared once in 0.05–2 keV flux. $T > 6.4$E5 K in a flaring state, coupled with $T < 6.4$E5 K in a quiescent state during the HRI observation, may also represent the data for VB 8. The results are of special interest for objects near the limit of the hydrogen-burning main sequence.

Subject headings: stars: flare — stars: individual (Wolf 630) — stars: visual multiples — stars: X-rays

I. INTRODUCTION

Wolf 630 (= V1054 Oph = Gliese 644 = HD 152751) is the brightest of three stars with common proper motion at a distance of 6.4 pc. They have been resolved into seven components as follows: W630AB is a close visual binary discovered by Kuiper (1934) with an orbit by Voûte (1946). The blended-image classification is dM3.5e (Joy and Abt 1974). W630 A or B is also a single-line spectroscopic binary (Joy 1947), and astrometry (Weis 1982) shows an anomalously high mass-luminosity ratio in B, which is probably the spectroscopic binary (Pettersen, Evans, and Coleman 1984). At least one of the stars in W630 flares optically (Eggen 1965) and also flares in the 0.2–4 keV range (Johnson 1981). The C and D nomenclature for the other visual components has been applied inconsistently in the literature, so they will be called W629 and VB 8. W629 is another single-line spectroscopic binary (Joy 1947), first classified sdM4 but reclassified dM 4 (Joy and Abt 1974). VB 8 (Van Biesbroeck 1961) is a pair of dwarfs near the limit of the hydrogen-burning main sequence (Nelson, Rappaport, and Joss 1985; D'Antona and Mazzitelli 1985). The brighter M7 V component (Probst and Liebert 1983) has a possibly substellar companion, VB 8B (Harrington, Kallarakal, and Dahn 1983; McCarthy, Probst, and Low 1985). A curious dwarf—subdwarf, young disk–old disk dichotomy between W630 and W629 is presented photometrically by Eggen (1978); taken by itself, W630 may be classified old disk kinematically but young disk according to coronal X-ray power and chromospheric activity (Johnson 1981, 1983*a*). A resolution of the discrepancy between age indicators has been suggested in terms of formation in high-velocity or intermediate-velocity interstellar clouds (Johnson 1983*b*).

II. PRE-*EXOSAT* X-RAY OBSERVATIONS

Several properties of this complex system have been determined from 1979 observations: W630 was observed by Johnson (1981) with the *Einstein* IPC (0.2–4 keV) and HRI (0.15–3 keV), and by Swank and Johnson (1982) with the SSS (0.5–4 keV). The $L_x = 1.2$E29 ergs s^{-1} is among the highest M-dwarf coronal luminosities measured with the IPC. The SSS defined the quiescent spectrum of W630 as a two-component thermal plasma with the dominant component at $T = (6.5 \pm 1.0)$E6 K and the much weaker component at $T > 1$E7 K. Fe underabundance (0.6 of solar) was indicated by lack of line emissions in the SSS spectrum. VB 8 was detected only with the HRI, which gave $L_x = 5$E26 ergs s^{-1}. The HRI production processing that is designed to analyze variability gives a probability of 0.71–0.83 for constant flux of W630, and a probability of 0.52–0.72 for constant flux of VB 8, but these statistical estimates are not very significant. W629 was not detected.

III. *EXOSAT* OBSERVATIONS

The telescope, described by de Korte *et al.* (1981), was directed to W630, with some decentering to acquire a guide star, and obtained an effective exposure of 18,112 s. The spectral range that is defined by the CMA with the thin Lexan filter is useful for a star as near as W630, where interstellar hydrogen column density is estimated to be $N_{\rm H} = 1$E18 cm^{-2} from the local neutral hydrogen density $n_{\rm H} = (5 \pm 1)$E-2 cm^{-3} (Weller and Meier 1981). For example, the deficiency of photons at 100 eV is only 5% according to the photoelectric cross sections (Morrison and McCammon 1983). The X-ray images in Figure 1 have coordinates that agree within $\pm 10''$ of the optical coordinates.

Figure 2 shows, respectively, the temporal behavior of the exposure efficiency, the source count rates of VB 8 and W630, and their background count rates multiplied by an areal factor of 7.266. Although exposure efficiency is variable, it does not account for all variability of source count rates. An apparent flare in the count rate for VB 8 to a peak of ~7 counts per 32 s starts at UT 06:12 and lasts ~10 minutes with an above-average count rate for the following 40 minutes. This flare episode may account for all the counts in the average count rate of 0.25 counts per 32 s during the effective exposure. VB 8 is not a cataloged optical flare star, and the indication of X-ray flare activity is especially noteworthy if VB 8A as well as VB 8B has failed to establish main-sequence hydrogen burning, as Nelson, Rappaport, and Joss (1985) have suggested.

Table 1 lists the new *EXOSAT* data. Source counts for W630 and VB 8 were made in the radius of 64″ around the

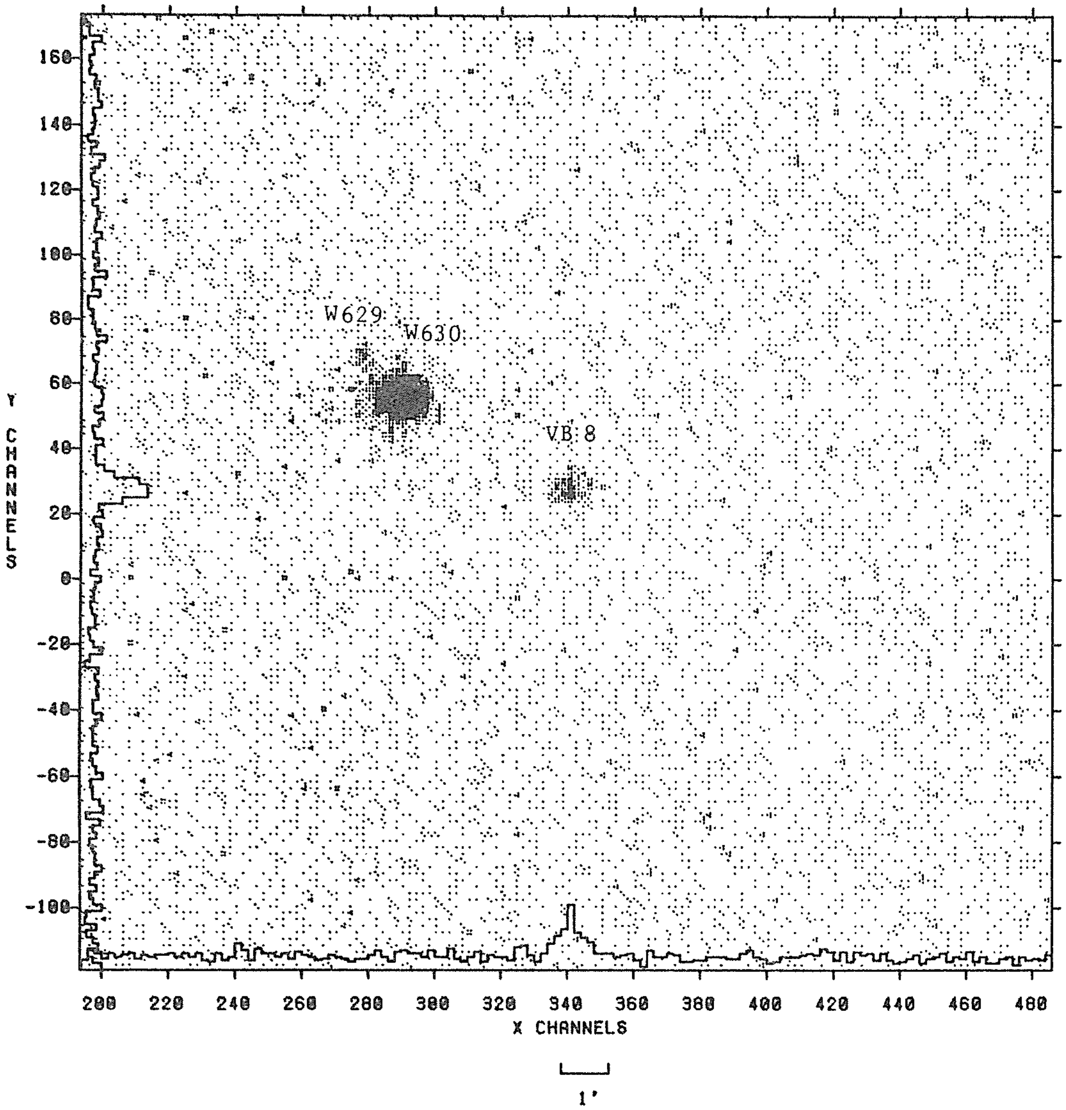

FIG. 1.—Full-resolution image of the Wolf 630 system made with the *EXOSAT* low-energy telescope. North is 174° from the positive X-axis. The histograms show the relative count rates in strips of X and Y channels that include the image of VB 8.

images, and background counts in an annulus from 64″ to 184″; but the image of W629 required source counts in a radius of 21″ so as not to encompass the image of W630, and the background count rate of W630 in the reduced area was applied to W629. Table 1 also lists HRI data specially reprocessed with global background instead of DETECT background, which is too high for W629 and VB 8 in proximity to W630 (cf. *Einstein Observatory Revised User's Manual* 1984).

Table 1 quotes the W630 dominant plasma temperature T measured with the SSS. This value of T was used in one of a series of isothermal plasma models (Raymond and Smith 1977) updated by Raymond (1986), with absorption by interstellar $N_{\rm H} = 1{\rm E}18\ {\rm cm}^{-2}$, and folded through the response functions of the *EXOSAT* and *Einstein* instruments. In accordance with the SSS result, a low Fe abundance (0.6 of solar) is put into the models. The model ratio of CMA to HRI count rates for W630 at $T = 6.5{\rm E}6$ K exceeds the observed ratio by 12%. The difference of ratios may be a result of change of X-ray flux between dates of the observations. The difference of ratios could be reduced by assuming a slightly higher T in the model; higher $N_{\rm H}$ would also work, but the relative telescope efficiencies may not be known to better accuracy than the accuracy of these parameters.

The observed ratio of CMA to HRI count rates for VB 8 (increased by 12% in accordance with the preceding remarks) generally yields two values of model T(HRI) for any value of model T(CMA), but the assumption of equal T for the two observations has the single solution, $T = 6.4{\rm E}5$ K, as given with errors in Table 1. The quantity T should be higher in a flaring state than in a quiescent state, so that the flare observed with the CMA should make $T({\rm CMA}) > T({\rm HRI})$, which acceptably leaves the lower value of a quiescent $T({\rm HRI}) < 6.4{\rm E}5$ K. The observations interpreted with the models thus lead to $T \leq 6.4{\rm E}5$ K for the quiescent corona of VB 8, and $T \geq 6.4{\rm E}5$ K for its flaring state, where $T \approx 6.4{\rm E}5$ holds if the corona was equally active during both the HRI and the CMA observations.

Tabulated emission measure for the dominant coronal plasma of W630 is from Swank and Johnson (1982), and emission measure for VB 8 is from the HRI functions illustrated by

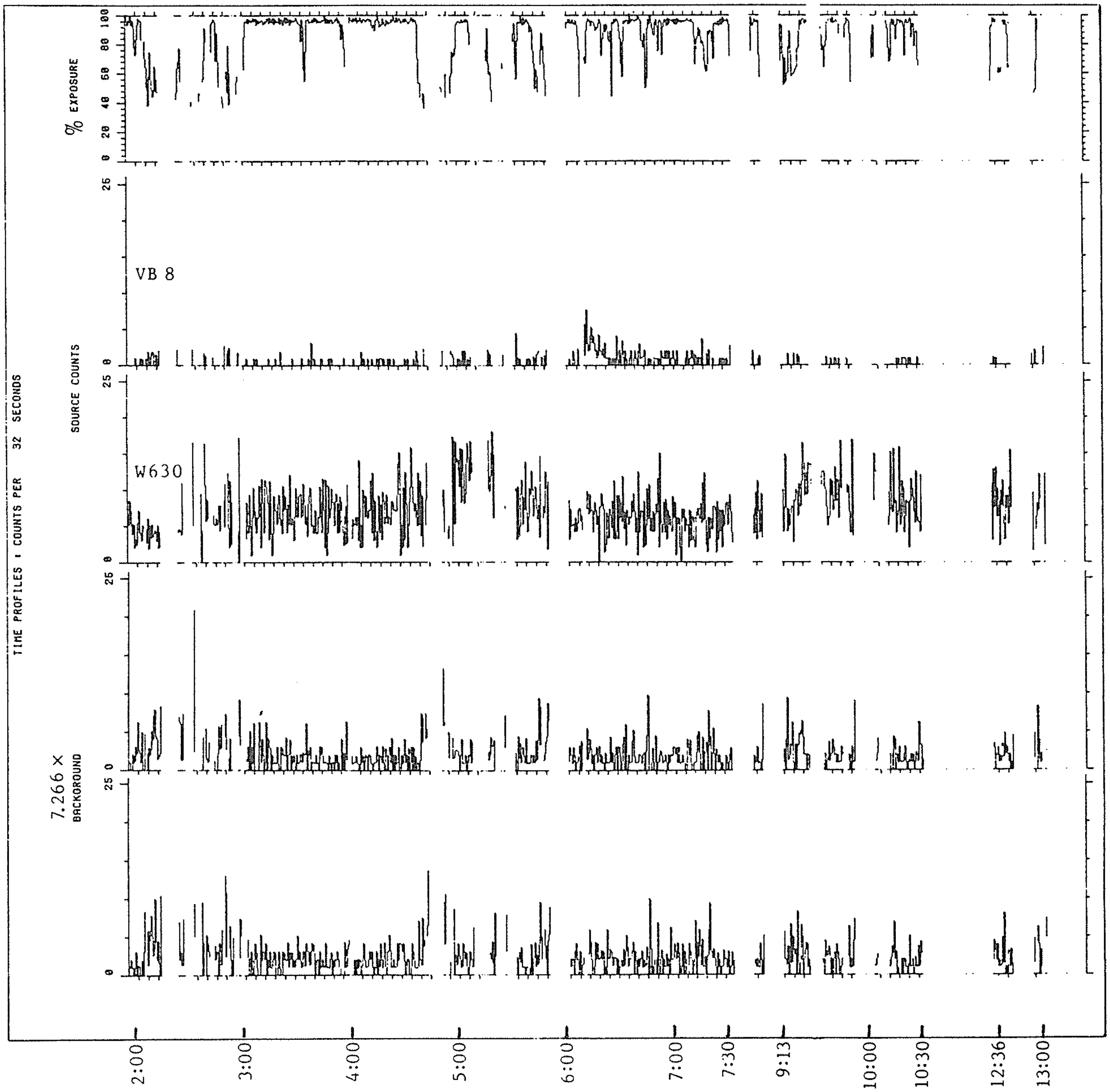

FIG. 2.—*Top to bottom*: percent of exposure with the *EXOSAT* low-energy telescope, VB 8 source counts per 32 s, W630 source counts per 32 s, VB 8 background counts per 32 s in an annular area 7.266 times source area, and W630 background counts per 32 s in a similar area, on 1985 March 8 from 2:00 to 13:00 UT (with time gaps from 7:30 to 9:13 and from 10:30 to 12:36 UT). The fine ticks are separated 320 s.

Cash, Charles, and Johnson (1980). Table 1 concludes with cited mass M and photospheric radius R, corresponding log g, and pressure scale height $H(T)$. Two estimates of the mass of VB 8A are quoted; they imply quite different ages, respectively 1.68E9 yr and 1.9E8 yr (Nelson, Rappaport, and Joss 1985). The contribution of VB 8B to X-ray flux may not be negligible. The observed CMA count rate for W629 stands alone in Table 1 except for the mass estimate provided by the referee.

IV. CONCLUSION

The basic result is the low coronal T for any relatively quiescent state of VB 8. In comparison, coronal $T \geq 6.3\text{E}6$ K (i.e., one to two orders of magnitude higher) for a sample of 12 M dwarfs (Golub 1983). A fully convective dwarf near the limit of the hydrogen-burning main sequence, or a pair of them (Nelson, Rappaport, and Joss 1985), is shown to be capable of X-ray coronal activity. The observations also show that the three visually resolved components of the septuplet system differ very widely in X-ray characteristics. The new data do not resolve the question of the age of the W630 system. The very low L_x of W629 suggests old age according to current ideas, just as the high L_x of W630 has previously suggested youth; unresolved multiplicity in each X-ray object hinders interpretation. Flaring in VB 8 may suggest youth, but low coronal T may be theoretically correlated with low L_x, hence old age (cf. Golub 1983).

Other objects that may be substellar, e.g. VB 10 = V1298 Aql = +4°4048, should be considered as viable candidates for further X-ray observations.

TABLE 1

EXOSAT AND *Einstein* DATA AND RESULTS

BLENDED COMPONENTS	SOURCE COUNTS PER 10^3 s		ISOTHERMAL PLASMA T (K)	EMISSION MEASURE (cm^{-3})	M ($M_\odot$)	R ($R_\odot$)	log g (cm s^{-2})	H ($R_\odot$)
	CMA	HRI						
W630ABab	223 ± 3.6	644 ± 14	(6.5 ± 1.0)E6[a]	(1.8 ± 0.7)E51[a]	2.8E-1[b]	3.7E-1[c]	4.75	2.3E-1
VB 8AB	7.7 ± 1.0	5.8 ± 1.7	$(6.4^{+1.6}_{-0.9})$E5[d]	$(6.3^{+3.7}_{-2.3})$E49[e]	8.0E-2[f]	7.6E-2[f]	5.58	3.3E-3
					4.5E-2[g]	9.4E-2[f]	5.14	9.2E-3
W629ab	1.5 ± 0.4	...	...	...	1.4E-1[h]	...	...	...

[a] SSS result for dominant, cooler component of the coronae in blended triplet.

[b] Weis 1982, mean of triple components.

[c] Pettersen *et al.* 1984, mean of triple components.

[d] Discussed in the text; errors relate only to errors on count rate.

[e] Based on HRI count rate and error, parallax, and T (cf. Cash *et al.* 1980).

[f] Nelson *et al.* 1985, component A.

[g] Harrington *et al.* 1983, component A.

[h] Each component, assumed equal, according to the referee's use of the $M-L$ relation of Smith 1983 with log $L/L_\odot = -2.304$ from Reid and Gilmore 1984 corrected by -0.300 for duplicity.

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REFERENCES

Cash, W., Charles, P., and Johnson, H. M. 1980, *Ap. J.* (*Letters*), **239**, L23.
D'Antona, F., and Mazzitelli, I. 1985, *Ap. J.*, **296**, 502.
de Korte, P. A. J., *et al.* 1981, *Space Sci. Rev.*, **30**, 495.
Eggen, O. J. 1965, *Observatory*, **85**, 152.
———. 1978, *Ap. J.*, 226, 405.
Golub, L. 1983, in *IAU Colloquium 71, Activity in Red Dwarf Stars*, ed. M. Rodonò and P. B. Byrne (Dordrecht: Reidel), p. 83.
Harrington, R. S., Kallarakal, V. V., and Dahn, C. C. 1983, *A.J.*, **88**, 1038.
Johnson, H. M. 1981, *Ap. J.*, **243**, 234.
———. 1983*a*, in *IAU Colloquium 71, Activity in Red Dwarf Stars*, ed. M. Rodonò and P. B. Byrne (Dordrecht: Reidel), p. 109.
———. 1983*b*, *Ap. J.*, **273**, 702.
Joy, A. H. 1947, *Ap. J.*, **105**, 96.
Joy, A. H., and Abt, H. A. 1974, *Ap. J. Suppl.*, **28**, 1.
Kuiper, G. P. 1934, *Pub. A.S.P.*, **46**, 235.
McCarthy, Jr., D. W., Probst, R. G., and Low, F. J. 1985, *Ap. J.* (*Letters*), **290**, L9.
Morrison, R., and McCammon, D. 1983, *Ap. J.*, **270**, 119.
Nelson, L. A., Rappaport, S. A., and Joss, P. C. 1985, *Nature*, **316**, 42.
Pettersen, B. R., Evans, D. S., and Coleman, L. A. 1984, *Ap. J.*, **282**, 214.
Probst, R. G., and Liebert, J. 1983, *Ap. J.*, **274**, 245.
Raymond, J. C. 1986, private communication.
Raymond, J. C., and Smith, B. W. 1977, *Ap. J. Suppl.*, **35**, 419.
Reid, N., and Gilmore, G. 1984, *M.N.R.A.S.*, **206**, 19.
Smith, R. C. 1983, *Observatory*, **103**, 29.
Swank, J. H., and Johnson, H. M. 1982, *Ap. J.* (*Letters*), **259**, L67.
Van Biesbroeck, G. 1961, *A.J.*, **66**, 528.
Voûte, J. 1946, *Riverview College Obs. Pub.*, **2**, 43.
Weis, E. W. 1982, *A.J.*, **87**, 152.
Weller, C. S., and Meier, R. R. 1981, *Ap. J.*, **246**, 386.

HUGH M. JOHNSON: 1017 Newell Road, Palo Alto, CA 94303