NASA

Technical Memorandum 83947

Einstein Solid State Spectrometer Observation of the Peculiar Red Dwarf Wolf 630 AB

Jean H. Swank and Hugh M. Johnson

JUNE 1982

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

EINSTEIN SOLID STATE SPECTROMETER OBSERVATION OF THE PECULIAR RED DWARF WOLF 630 AB

Jean H. Swank
Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

and

Hugh M. Johnson[1]
Lockheed Missiles and Space Company
Palo Alto, California 94304

ABSTRACT

Wolf 630 AB is a double and perhaps triple star with a predominant dM 3.5e spectrum. It is one of the relatively strong red dwarf X-ray sources. The 0.5-4 keV spectral data for a steady, non-flaring flux are interpreted in terms of emission from thin thermal plasma with a dominant temperature of ~ 6.5×10^6 K. Both in temperature and average surface flux the quiescent corona is similar to that of the low temperature component found for RS Canum Venaticorum binaries. There is an indication of additional emission above 10^7 K, but the ratio of high to low temperature

[1]Guest Observer with the Einstein Observatory

emission is smaller than for typical RS CVn systems. The Solid State Spectrometer observed the spectrum of only one other red dwarf, AD Leo, which is very similar to that observed for Wolf 630 AB.

I. INTRODUCTION

Wolf 630 AB = Gliese 644 AB = V1054 Oph = HD 152751 is a close visual binary in a larger multiple system. Joy and Abt (1974) classify the blended double image (separation 0.2") as dM3.5e. Broadband photometry to a wavelength of 3.4 μm discloses no peculiarities and leads to the mean values T_{eff} = 3400K, L = 9.1 (±0.6) x 10^{31} ergs s^{-1}, and R = 3.1 (±0.5) x 10^5 km (Pettersen 1980). However, Joy (1947) attributed radial velocity variations in Wolf 630 AB to a spectroscopic binary, and Johnson (1981) noticed that the deviant velocities occurred in a fairly narrow range of phase in Voute's (1946) visual orbit (period 1.715 years, the shortest known). Several series of astrometric plates, as discussed most recently by Weis (1982), lead to a peculiar binary in which the fractional mass of the less luminous component B is 0.671 ± 0.056 of the total mass of 0.84 (±0.10) $M_{\odot}$. The quiescent V magnitudes of the components differ no more than 0.25 mag, and it is not known which component flares or whether each is capable of flaring. According to Weis (1982) component A is the more nearly normal and component B is underluminous for its mass by two or three magnitudes. The possibility that component B is itself binary remains to be tested. A white dwarf or subdwarf component which is as massive as the red dwarf of component B but which contributes little to the integrated V magnitude might provide the required astrometric mass in component B and the spectroscopic orbital velocities that are sometimes unexpectedly large in the integrated light of the normal red dwarfs.

II. OBSERVATIONS

After Wolf 630 AB was discovered to be a relatively strong X-ray source in IPC and HRI Einstein samples of nearby red dwarfs (Johnson 1981) it was specially scheduled for a Solid State Spectrometer (SSS) observation. The exposure of 9.2 x 10^3 s began 1979 September 4 at $0^h.5$ UT. The SSS is described by Joyce et al. (1978). The HRI detected Wolf 630 C at 7.1 x 10^{-14} ergs cm^{-2} s^{-1}, < 1/2% of the flux from Wolf 630 AB, and did not detect Wolf 630 D at that level, so that although the 6'diameter SSS field of view included Wolf 630 D, and Wolf 630 C, at 3' 41" from Wolf 630 AB, was very close to the edge of the nominal field, their contribution to the spectrum should have been negligable.

Figure 1 shows the SSS spectral data, fitted using models calculated by Raymond and Smith (1977,1979) of line and continuum emission from isothermal plasmas in collisional equilibrium. For an isothermal plasma with abundances fixed to be solar, a χ^2 of 101 for 27 degrees of freedom suggests that a more complex model is needed. Considerable improvement (χ^2 = 47) is obtained with the abundance of Fe reduced to 1/2 of solar, although the fit still corresponds to a confidence level of less than 1%. Spectra of RS CVn systems can be fitted with a bimodal distribution of emission measure with temperature, and an acceptable fit for Wolf 630 AB is obtained for a model consisting of two plasmas, as shown in Figure 1. An underabundance of Fe (0.6 of solar) is still preferred (χ^2 = 31 versus 39 for solar). The fit parameters kT and the observed emission measure ($\int dV\, n_e^2$), along with the implied flux, are given in Table 1 for both components. The cooler component, (at ~ 6.5 x 10^6 K) should have ~ 25% as much flux below 0.5 keV as above. The hotter component implies 10% or more as much flux above 4 keV as below. The SSS would not have been sensitive to emission at temperatures below ~ 2 x 10^6 K, at which there could be as large an emission measure as at the detected temperatures.

In the two temperature model the best fit high temperature emission measure and luminosity are ~ 1/3 those of the lower temperature plasma. In the case of the RS CVn systems this ratio was of order 1, except for Capella and σ CrB, for which it was ~ 0.1 (Swank et al. 1981b, Holt et al. 1979; Agrawal, Riegler and White 1981). In the spectra of both Capella and σ CrB the relatively isolated emission lines of Mg and Si at ~ 1.3 and 1.8 keV are obvious. The equivalent widths are not diluted by much high temperature continuum. These lines are not obvious to the eye in data for the other RS CVn sources we observed. (For given abundances any high temperature contribution is constrained by the observed equivalent widths as well as by the shape of the composite continuum.)

The low temperatures for Capella and σ CrB are below 6 x 10^6 K, in a range where Fe XVIII and Fe XVIII lines dominate at 0.7-0.8 keV. For Wolf 630 AB these lines do not stand out above the other, unresolved, line contributions below 1 keV. Neither does the Fe XX transition at 1 keV which dominates in the models for temperatures around 7 x 10^6 K and can be seen in the spectra of UX Ari, for example (Swank et al. 1981b, Swank and White 1980). The preference for a lowered abundance of Fe in the fits to the Wolf 630 AB data reflects the lack of structure in the 0.7-1 keV range. A distribution of temperatures in the range 6-7 x 10^6 K could smooth the spectrum. But there are also uncertainties in the atomic physics of the models to which these Fe L-shell lines are sensitive.

The high temperature component is not well constrained. We cannot say that the distribution is bimodal in having emission at widely separated temperatures and significant upper limits on emission at a temperature in between, as we could for the RS CVn systems (Swank and White 1980). Figure 1 shows 90% confidence contours for each component allowing the other to vary. (The projections of these contours give the errors quoted on kT and EM.) We do not know of course the relative contributions of the stellar components A and B, and within the 90% confidence limits are fits with all contributions below 10^7 K.

Although Wolf 630 AB flares in X-rays as well as in the visible (Johnson 1981), no flares were observed during the SSS observation. The luminosity we see is only 1/2 of the luminosity estimated by Johnson (1981) for an HRI observation and the approximately equal luminosity corresponding to the lowest count rates seen in the IPC observation which detected a flare. For the temperatures and emission measures derived for the SSS data, Cash, Charles and Johnson (1981) predict about 1/2 the HRI count rate Johnson observed. If the quiescent level is not itself variable, this difference implies significant emission at the lower temperatures to which the SSS is insensitive.

III. CONCLUSION

Einstein IPC observations have established that dM and especially dMe stars commonly have X-ray luminosities in the range 10^{26}-10^{29} ergs s^{-1} (e.g. Johnson 1981; Vaiana et al. 1981) and Johnson's observations identified Wolf 630 AB as having a relatively high level of quiescent emission. Even if the two members contribute equally, at least one is near the maximum of the range observed. For a bolometric luminosity of 9 x 10^{31} ergs s^{-1} and X-ray luminosity of 2 x 10^{28} ergs s^{-1} per component, the minimum 0.5-4.0 keV luminosity, which appears quiescent, corresponds to L_x/L_{Bol} = 2 x 10^{-4}. Widely different types of stars have the same ratio L_x/L_{Bol}: the flare star Proxima Cen (Haisch and Linsky 1980), which has a quiescent X-ray luminosity 13 times smaller than the mean of Wolf 630 A and B, and a typical RS CVn binary containing a G or K subgiant (Walter and Bowyer 1980) with X-ray luminosity 100 times larger.

The SSS data show that the spectrum of Wolf 630 AB during a time of apparent quiescence is dominated by that of plasma of the same temperature as the lower temperature of RS CVn binaries (~ 6.5 x 10^6 K). This is nearly twice as hot as the 3.5 x 10^6 K estimated by Haisch and Linsky (1980) for the quiescent Proxima Cen, which is already as hot as active regions on the sun (Vaiana and Rosner 1978).

A higher temperature component is indicated and it could be as hot as the ~ 40 x 10^6 K emission from the RS CVns, although it would be less important relative to the lower temperature emission than in those systems. For them the evidence for the high temperature emission was compelling. For Wolf 630 AB the spectrum is definitely harder than the emission from Raymond-Smith models of plasma with temperatures ~ 6.5 x 10^6 K and near solar abundances. But a relatively broad distribution of emission measure around the low temperature best fit, in the range 0.5-1.0 keV, also gives a fit within the 90% confidence limits.

The SSS observed the spectrum of only one other star of similar type. The spectrum of AD Leo is very similar to that observed for Wolf 630 AB (Swank et al. 1981a), and is fitted with a similar mix of emission at ~ 7 x 10^6 K and 40 x 10^6 K, suggesting that the type of spectrum is common to the dMe stars with high X-ray luminosity.

The coronae of active red dwarfs and RS CVn stars may differ in the proportion of a very soft component, ~ 10^6 K. Comparison of the IPC and HRI with the SSS results suggests such a component for Wolf 630 AB, although there could be slow variability of the "quiescent" corona of dMe stars, as there is of the magnitude of some (Bopp and Espenak 1977). For the RS CVn stars (for which X-ray variability on time scales of a day does occur) the same comparison has not been made. However, Cash et al. (1978) restricted such a contribution for Capella to contribute little to its total X-ray luminosity.

For reasonable values of pressure, the temperatures and the emission measures for the low temperature components of the RS CVn spectra implied coronae rather extended compared with typical solar values and the high temperature plasma so extended as to suggest interaction with the binary companion (Swank et al. 1981b). In contrast, the quiescent flux from Proxima Cen (Haisch and Linsky 1980) is consistent with solar sized magnetic loops of 3.5 x 10^6 K plasma covering only part of the stellar surface. If the corona is assumed to be made up of magnetic structures satisfying a scaling law like that of Rosner, Tucker and Vaiana (1978), the dominant temperature we observed for Wolf 630 AB requires pressures higher by a factor of 6 than those required for Proxima Cen for the same loop lengths (10 and 100 dynes cm^{-2} for 10^{10} and 10^9 cm loops). The scaling law implies the same pressure-length relationship as obtained for low temperature components of RS CVn coronae, since the temperatures are about the same.

The surface flux and the scale height of the corona implied by the X-ray emission measure depend on the radius assumed for the source. A red dwarf of 0.27 M_0 (Weis 1982) should have a radius of ~ 0.29 R_0 rather than the 0.4 R_0 implied by the photospheric temperature and luminosity (Pettersen 1980), assuming equal contributions from A and B. The surface flux, even with the uncertainty in radius, is $\gtrsim$ 4 x 10^6 ergs $cm^{-2}s^{-1}$, as great as that of solar active regions (Vaiana and Rosner 1978), like that of typical RS CVn low temperature components (Swank and White 1980) and about 4 times that of Proxima Cen (Haisch and Linsky 1980) and the quiet Sun. Thus the mean surface flux as well as the dominant temperature are similar to those of the RS CVn low temperature components. If we divide the emission measure between Wolf 630 A and B and use the smaller radius, loops of ~ 1.6 x 10^{10} cm would cover the surface at ~ 6 dynes cm^{-2}. This calculation gives loop lengths of the same order for the low temperature coronae of the RS CVn systems. For a red dwarf however the same length represents a 10 times higher fraction of the stellar radius.

Considering the thermal spectrum of temperatures observed in the coronae of other stars and the level of surface flux there is no need for Wolf 630 B to be a short period binary in which accretion onto a compact object is occurring. If a white dwarf is hidden in the system the closest companion does not fill the Roche lobe. There could still be a tidal interaction giving rise to enhanced activity in Wolf 630 B. However no close companion has been suspected for AD Leo.

Rotation has been suggested as the key element giving rise to the BY Draconis "syndrome" (Bopp and Fekel 1977), flaring activity (Bopp and Espenak 1977) and high X-ray to bolometric luminosity ratios (e.g. Pallavicini et al. 1982 and references therein), whether the rotation is that of a single or a binary star. The rotation rates are not known for either component of Wolf 630 AB or for AD Leo. The AB orbit of Wolf 630 is seen nearly face on (Voute 1946), so that if other angular momenta are aligned, rotational broadening and variability due to spot rotation will be hard to detect. Bopp and Espenak (1977) found none for AD Leo, so that if rotation is necessary for enhanced X-ray emitting coronae, we may be looking close to the axis of rotation in that case too. It is notable that whatever the Wolf 630 AB system harbors, the temperatures and optical luminosity of AD Leo obtained by Pettersen (1980) are the same as for the mean Wolf 630 AB component.

In the quiescent solar corona, temperatures of X-ray emitting gas cluster around a few x 10^6 K, despite a range of loop sizes. It has been suggested that at 2-3 x 10^6 K there must be a stable balance between heating and cooling (Linsky 1982). With the Sun as an example, it should not be surprising that SSS observations find that stellar coronae can be described by a dominant characteristic temperature (Wolf 630 AB and AD Leo) or a simple two temperature model (RS CVn stars), even when the temperatures are significantly different from the characteristic solar temperature. Because the temperatures characterize non-flaring coronae, presumably they also represent a stable balance point. Temperatures around 6.5×10^6 K are characteristic of stars so different as K subgiants and dwarf flare stars, so that the balance must be insensitive to many stellar parameters. It is interesting that the average surface fluxes at this temperature are also similar for stars differing in radii by a factor of 10, although as far as is known yet the hot structures could cover only small fractions of the stars. The image of the star covered with active regions like those on the Sun has seemed apt because the fluxes are similar. A missing ingredient in the description, however, is the reason why the temperatures are hotter than those of most solar active regions.

Our analysis depends on the work at GSFC of many of our colleagues and J.H.S. thanks especially S.S. Holt for stimulating discussions. H.M.J.'s part of this work was initiated under contract NAS8-33332 with NASA in 1979, and completed under the Lockheed Independent Research Program. We are indebted to the Center for Astrophysics Einstein group, especially Dr. Fred Seward, for much assistance there.

REFERENCES

Agrawal, P.C., Riegler, G.R. and White, N.E. 1981, M.N.R.A.S. 196, 73p.

Ayres, T.R., and Linsky, J.L. 1980, Ap. J. 241, 279.

Bopp, B.W., and Espenak, F. 1977, A.J. 82, 916.

Bopp, B.W., and Fekel, Jr., F. 1977, A.J. 82, 490.

Cash, W., Bowyer, S., Charles, P.A., Lampton, M., Garmire, G. and Riegler, G. 1978, Ap. J. (Letters) 223, L21.

Haisch, B.M., and Linsky, J.L. 1980, Ap. J. (Letters) 236, L33.

Holt, S.S., White, N.E., Becker, R.H., Boldt, E.A., and Mushotzky, R.F., Serlemitsos, P.J. and Smith, B.W. 1980, Ap. J. (Letters) 234, L65.

Johnson, H.M. 1979, Bull. A.A.S. 11, 775.

Johnson, H.M. 1981, Ap. J. 243, 234.

Joy, A.H. 1947, Ap. J. 105, 96.

Joy, A.H., and Abt, H.A. 1974, Ap. J. Suppl. 28, 1.

Joyce, R.M., Becker, R.H., Birsa, F.B., Holt, S.S., and Noordzy, M.P. 1978, IEEE Trans. Nucl. Sci. 25, 453.

Linsky, J.L. 1982, in X-Ray Astronomy in the 1980's, Proceedings of the Goddard Symposium on X-Ray Astronomy and Spectroscopy, in press.

Pettersen, B.R. 1980, Astr. Ap. 82, 53.

Raymond, J.C., and Smith, B.W. 1977, Ap. J. Suppl 35, 419.

- - - - - 1979, private communication.

Rosner, R., Tucker, W.H., and Vaiana, G.S. 1978, Ap. J. 220, 643.

Swank, J.H., and White, N.E. 1980, Smithsonian Astrophysical Observatory Special Report, No. 389, 47.

Swank, J.H., Boldt, E.A., Holt, S.S., Marshall, F.E., and Tsikoudi, V. 1981a, Bull. Am. Phys. Soc. 26, 570.

Swank, J.H., White, N.E., Holt, S.S., and Becker, R.H. 1981b, Ap. J. 246, 208.

Vaiana, G.S. and Rosner, R. 1978, Ann. Rev. Astr. Ap. 16, 393.

Vaiana, G.S. et al. 1981, Ap. J. 245, 163.

Voute, J. 1946, Riverview College Obs. Pub. 2, 43.

Walter, F.M., and Bowyer, S. 1981, Ap. J. 245, 671.

Weis, E.W. 1982, Astron. J. 87, 152.

Woolley, R., Epps, E.A., Penston, M.J., and Pocock, S.B. 1970, Roy. Obs. Ann., No. 5.

FIGURE CAPTION

Figure 1. Pulse height spectrum of Wolf 630 AB. The histogram shows the SSS response to the best fit model of a two temperature plasma (abundance of Fe 1.9×10^{-5} or 60% of solar) for kT_L = 0.55 keV and kT_H = 6 keV. Insert shows 2 parameter 90% confidence contours for temperature T and emission measure EM for the low (L) and high (H) temperature components.

TABLE 1. PARAMETERS OF TWO COMPONENT SPECTRAL FITS

Component	kT(keV)	logT(K)	EM(10^{51}cm^{-3})	Flux*(10^{-11}ergs cm^{-2}s^{-1})	L(10^{28} ergs s^{-1})$^{+}$
L	$0.54^{+0.08}_{-0.09}$	6.81±0.07	1.8±0.7	0.6±0.25	3.0±1.2
H	> 0.7	> 6.9	$0.66^{+1.2}_{-0.5}$	0.19±0.17	0.88±.78
TOTAL					3.9±0.4

---

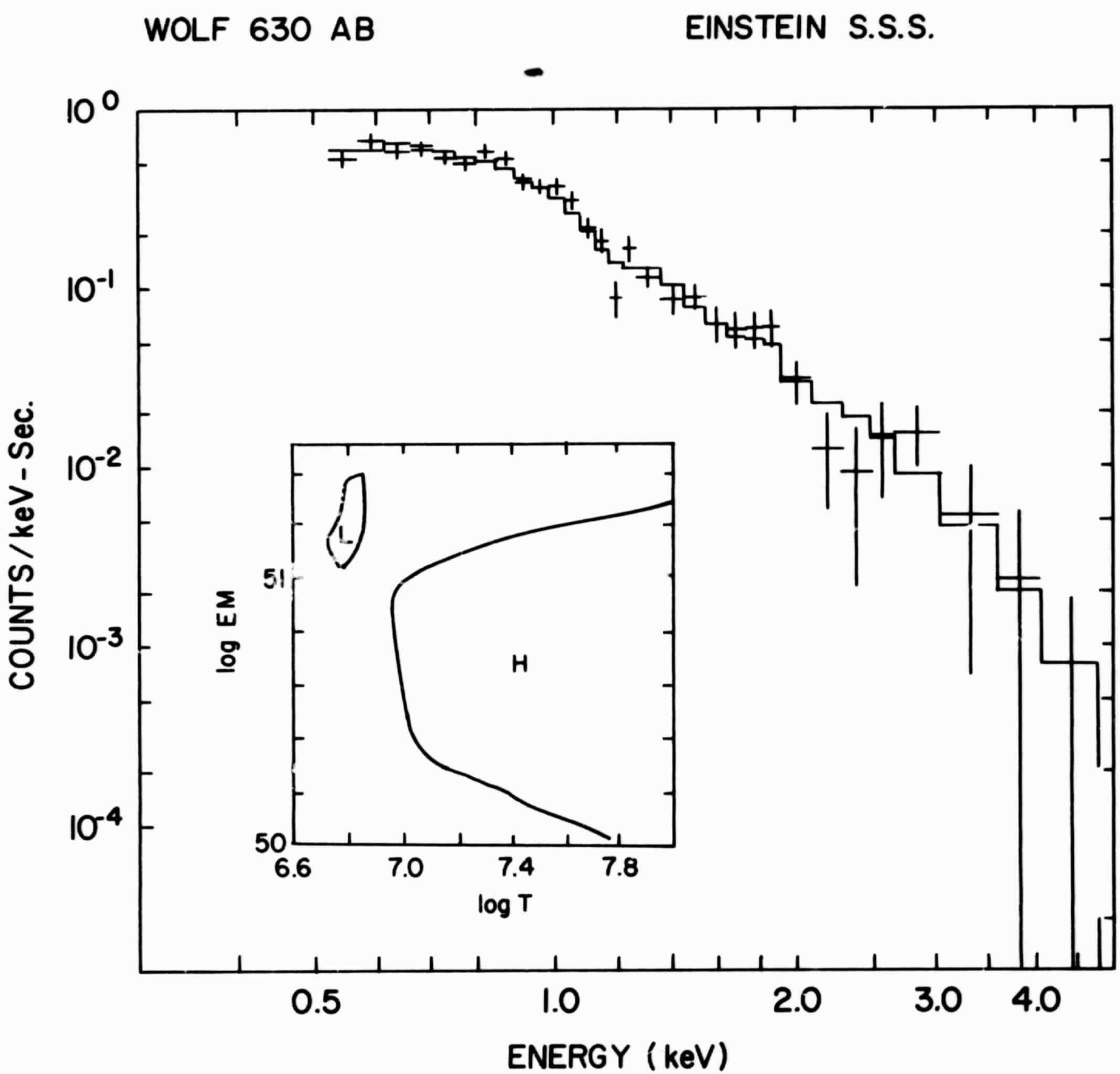
* 0.5 - 4 keV flux

+ 0.5 - 4 keV luminosity at a distance of 6.2 pc (Woolley et al. 1970).

Address of Authors

JEAN H. SWANK, Code 661, Laboratory for High Energy Astrophysics, NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771

HUGH M. JOHNSON, Dept. 52-12, Bldg. 255, Lockheed Missiles & Space Co., Inc. 3170 Porter Drive, Palo Alto, California 94304.



WOLF 630 AB
EINSTEIN S.S.S.
COUNTS/keV-Sec.
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0.5
1.0
2.0
3.0
4.0
ENERGY (keV)
log EM
51
50
6.6
7.0
7.4
7.8
log T
L
H