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EXOSAT OBSERVATIONS OF THE RAPIDLY ROTATING FLARE STAR GLIESE 890

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ABSTRACT

We present the first X-ray observations of the late-type dwarf flare star Gliese 890 using the low-energy (LE) and the medium energy (ME) detectors of the *EXOSAT Observatory.* A steady X-ray emission, most probably of coronal origin, is detected. No flaring activity is observed in our X-ray observations. We have carried out a combined spectral fit to the LE and ME data and derived an X-ray plasma temperature of 1.4 ± 0.3 keV and the equivalent hydrogen column density of $(7.5 \pm 4.7) \times 10^{19}$ cm^{-2} using the plasma emission models given by Raymond and Smith. The X-ray luminosity in the 0.1–4.0 keV energy band is 4.1×10^{29} ergs s^{-1}. The X-ray luminosity and the temperature are typical of a slowly rotating dMe type flare star and do not show any effect of the fast rotation, possibly suggesting a saturation effect of the dynamo action. It appears unlikely that a hot white dwarf companion is hibernating in orbit around Gl 890.

Subject headings: stars: flare — stars: individual (Gliese 890) — stars: late-type — stars: X-rays

I. INTRODUCTION

The late-type star Gliese 890 (= BD −16°6218) is a rapidly rotating spotted star with an equatorial rotational velocity of about 70 km s^{-1} (Young, Skumanich, and Harlan 1984). A photometric period of 0.4311 days has also been observed in Gl 890 (Young *et al.* 1984; Pettersen *et al.* 1987; Bopp *et al.* 1988). The spectral type of Gl 890 has been estimated by Pettersen *et al.* (1987) to be dM1.5e and the spectroscopic parallax to be 0$''$.05 (distance 20 pc). The average *V* magnitude always lies within 0.05 mag of 10.85, while the photometric amplitude can vary between a few hundredths of a magnitude and 0.15 mag. Similarly, the $(B-V)$ colors cluster around 1.43, with a scatter of only a few hundredths of magnitude, with the exception of the value obtained by Pettersen *et al.*, which may be affected by flares (see Bopp *et al.* 1988). The relatively small excursion in the *V* and $(B-V)$ values is explained by invoking long-lived spots near the poles of the star. The optical and UV spectroscopic results of Young *et al.* (1986) also argue for the existence of such spots. Flaring activity from Gl 890 has been observed with a high-speed photometer (Pettersen *et al.* 1987), and an Hα flare has also been reported (Herbst and Layden 1987). Intense radio emission has been seen recently from this source (Slee *et al.* 1988).

One of the most intriguing features of Gl 890 is its fast rotation. The observed optical and UV properties of Gliese 890 are, however, consistent with a slowly rotating dMe type flare star. Hence, it is very interesting to examine the coronal X-ray emission of Gliese 890. The star was observed using the *EXOSAT* (*European X-ray Astronomy Satellite*) *Observatory* in 1985. We have obtained and analyzed the X-ray data from the *EXOSAT* archives. Here we present the details of the observations and the results of our analysis.

II. OBSERVATIONS AND ANALYSIS

The X-ray observations were performed in 1985 November 16, using both the medium-energy (ME) detectors and the low-energy (LE) telescope having a channel multiplier array (CMA) as the detector. The details of the instruments used are given by Turner, Smith, and Zimmermann (1981) for the ME detectors and by de Korte *et al.* (1981) for the LE+CMA. The particulars of the observations are given in Table 1. The LE data were obtained with two filters namely, Lexan 3000 (3LX) and aluminum/parylene (Al/P) (see White and Peacock 1988 for filter efficiencies). The ME data analyzed were acquired from seven of the eight argon-filled detectors, as the detector number 3 was off throughout the observations. These observations were carried out by first pointing the first four detectors (viz., detectors 1, 2, 3, and 4 collectively known as the "half 1" detectors) at the source while the other four detectors (viz., 5, 6, 7, and 8 collectively known as the "half 2" detectors) monitored the background. The roles of the two halves were exchanged later on, and the observations continued.

The data reduction and analysis were performed using the XANADU (X-ray Analysis and Data Utilization) software package. We detected only one X-ray source within 1° of the center of the LE field of view. In Figure 1 we show the smoothed images of the flare star obtained using the two filters. The images are consistent with that of a point source. The dot shows the optical position of Gl 890, which is about 22$''$ away from the best-fit X-ray position. The optical position is taken from Gliese (1969) which is correct to about 8$''$. The accuracy of source location with *EXOSAT* is in the range of 4$''$–15$''$ (see Gronenschild 1985). We have examined the Palomar Sky Survey prints for objects near Gl 890 and find no candidates within 64$''$ of Gl 890. We, therefore, believe that the identification of the X-ray source with Gl 890 is secure. The background-subtracted count rates corrected for vignetting, telemetry dead time, and the sum-signal distribution are shown in Table 1. The background was obtained from a region adjacent to the position of the source and also from an annular box surrounding the source. No significant variation was observed in the intensity of the source down to a time scale of 400 s, using the 3LX data with the most significant detection.

For the analysis of the ME data, we used the background obtained from the same detectors while offset for subtraction, using the "swap" technique (Smith 1984). The subtracted counts were further corrected by using the accumulated "difference" spectra—difference in the background spectra acquired while in the offset position and aligned position, resulting due to changed environment and shielding. The "difference" spectra used were provided in the ME calibration

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TABLE 1

LOG OF OBSERVATIONS AND COUNT RATES

Serial Number	Instrument	Filter	Start of Observation (1985 Nov 16 UT)	End of Observation (1985 Nov 16 UT)	Duration (s)	Corrected Count Rate[a]
1	CMA	Lexan 3000	02 00:02	02 52:02	11112	3.47 ± 0.38
2	CMA	Lexan 3000	04 16:50	06 18:34		
3	CMA	Lexan 3000	06 18:50	06 28:18		
4	CMA	Al/P	02 56:02	04 13:30	4648	1.33 ± 0.49
5	ME ("half 1")[b]	...	01 6:26	04 03:14	10608	1.22 ± 0.84
6	ME ("half 2")	...	04 12:50	06 18:34	7544	1.98 ± 0.52
7	ME ("half 2")[c]	...	07 16:02	09 00:02	6240	...

[a] Units: 10^{-4} counts cm^{-2} s^{-1}.

[b] Detector 3 is off. The "On-Source" half-array is indicated.

[c] Variable background.

file and obtained close to the actual observation time of the source. The count rates obtained are listed in Table 1. The source is very weak in the ME with only "half 2" detectors providing a significant detection in one observation. In the second observation with the "half 2" detectors the background was found to vary during the observation making the subtraction procedure unreliable; thus, no estimate is obtained from this observation. The observation with the "half 1" detectors but using only detectors 1, 2, and 4 gave detection with poorer significance but consistent with the source counts obtained from "half 2." The higher background in these detectors—about 25% more than in the "half 2" detectors—and the smaller effective area due to the nonavailability of one detector resulted in the reduced sensitivity of the "half 1" array and therefore in the poorer significance of the detection.

The information obtained from the LE using two filters and the ME detectors can be used to provide a spectral estimation. We used the Raymond-Smith plasma emission models (Raymond and Smith 1977; Raymond 1986) and the interstellar absorption cross sections given by Morrison and McCammon (1983) to estimate the spectral parameters of the X-ray emission from Gl 890. We assumed normal solar abundances for all the elements in the plasma. In Figure 2 we show the pulse height spectrum and the best-fit model. The ME data used and shown in Figure 2 are from the "half 2" detectors. The best-fit model ($\chi^2 = 5.9$ for 10 degrees of freedom) gave a temperature of 1.4 ± 0.3 keV and the absorption parameter, i.e., equivalent column density due to interstellar hydrogen ($N_{\rm H}$), as $(7.5 \pm 4.7) \times 10^{19}$ atoms cm^{-2}. The 0.1–4 keV intensity is 8.6×10^{-12} ergs cm^{-2} s^{-1}. The ME "half 1" data gave identical parameters but with larger errors. The adopted method of applying the "difference" corrections to the half-ME arrays does not always yield a reliable background subtracted spectra (see Yaqoob, Warwick, and Pounds 1989); therefore, we also obtained the spectral data from those ME detectors that were in the "corner" configuration (viz., detectors 1, 4, 5, and 8) and immune from such corrections. The analysis of the spectral data thus obtained gave estimates of the spectral parameters that were identical to the ones quoted above.

III. RESULTS AND DISCUSSION

The X-ray luminosity (L_x) of Gl 890, as estimated from the spectral fit to the data, is 4.1×10^{29} ergs s^{-1} in the 0.1–4.0 keV band. Using the cooling curves given by Raymond, Cox, and

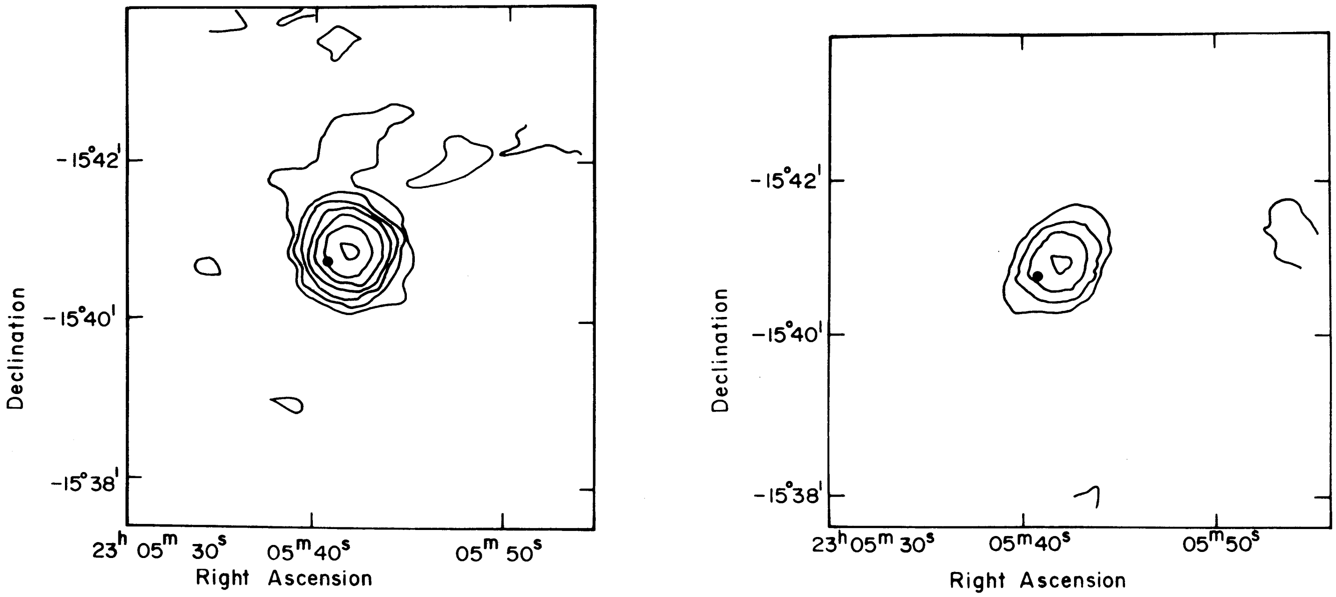

FIG. 1a

FIG. 1b

FIG. 1.—(*a*) The smoothed X-ray image of Gl 890 obtained from the *EXOSAT* LE detector with the Lexan 3000 filter. The contour levels are at 2.8, 4.0, 5.7, 8.3, 12.0, 17.3, 25.0 counts per pixel. The optical position of Gliese 890 is marked as a dot. (*b*) The smoothed X-ray image obtained from the *EXOSAT* LE detector with the Al/P filter. The contour levels are at 1.5, 2.2, 3.1, 4.5 counts per pixel. The optical position of Gliese 890 is marked as a dot.

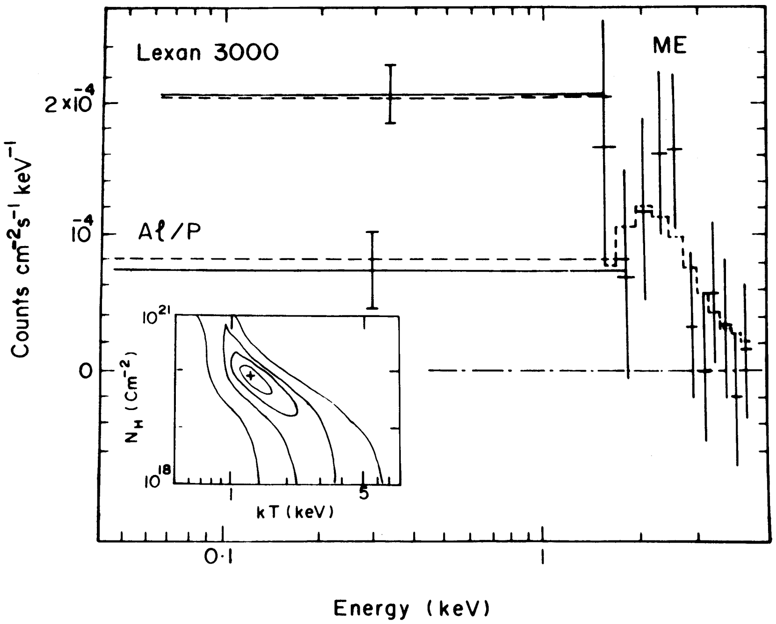

FIG. 2.—The observed count rate spectra of Gl 890 obtained using the LE Lexan 3000 filter, the LE Al/P filter, and the ME "half 2" detectors of the *EXOSAT* Observatory. The best-fit spectrum using the Raymond-Smith plasma emission model ($kT = 1.36$ keV and $N_H = 7.5 \times 10^{19}$ cm^{-2}) is shown as a dotted line. The zero level is shown as a dash-dotted line. The χ^2 contours are shown in the inset at levels of $\chi^2_{\rm min}$ plus 1, 2.71, 4.61, and 9.21, for the two interesting parameters kT and N_H.

Smith (1976), the emission measure is calculated to be 1.4×10^{52} cm^{-3}. There was no indication of any flaring activity in the 3LX data (the source is too weak in the Al and ME data for variability studies), and hence the flux observed can be treated as the quiescent state emission of the source. The ME data used for the combined spectral fit are contemporanous to the 3LX observation, and hence the X-ray parameters obtained are treated as the quiescent state coronal plasma parameters of the source.

It has been suggested that flare stars also have two temperature coronae (Agrawal, Rao, and Sreekantan 1986) as seen in the RS CVn binaries (Swank *et al.* 1981). The flare star Wolf 630 was observed using the SSS on board the *Einstein Observatory* (Swank and Johnson 1982) and the X-ray data were fitted with a model having two temperature components. Count rate ratios obtained using different filters with the *EXOSAT* LE detectors have shown that the coronal temperatures of flare stars lie either in the range 0.3–0.5 keV or in the range 1.1–1.4 keV (Pallavicini *et al.* 1988). The X-ray data on Gl 890 do not indicate any lower temperature component. A search for a lower temperature component gave negative results, and the data are insufficient to make any quantitative statements. There are indications that the coronal temperature increases with later spectral types (Schrijver, Mewe, and Walter 1984). The temperature obtained for Gl 890 (1.3 keV) agrees with the high-temperature solution obtained for the flare stars by Pallavicini *et al.* (1988) and also with the coronal temperature (1.4–1.8 keV) measured in the rapidly rotating K dwarf AB Dor (Collier-Cameron *et al.* 1988). For nearby late-type stars, it is generally assumed that the N_H values are negligible (see, e.g., Collier-Cameron *et al.* 1988). Following Paresce (1984) who obtained a local volume density of 0.07 cm^{-3} (with a large scatter), we expect a column density of 4×10^{18} cm^{-2} in the line of sight to Gl 890. Our search through the literature failed to find a measurement of N_H in the general direction of and near Gl 890. We would, however, like to point out that the 90% confidence contours (i.e., $\chi^2 + 4.61$ for two parameters of interest) for the column density as shown in Figure 2 enclose the expected value.

It has been observed that the X-ray luminosity bears a constant ratio to the bolometric luminosity ($L_{\rm bol}$) for the flare stars and the regular period RS CVn binaries (Agrawal, Rao, and Sreekantan 1986). The $L_x/L_{\rm bol}$ value for Gl 890 is $10^{-2.7}$, which is about 0.5 dex more than the average value obtained by Agrawal, Rao, and Sreekantan (1986), but is consistent with the values obtained for the early-type flare stars. The ratio of chromospheric line luminosity to L_x is also observed to be a constant for the flare stars. From the Mg II line luminosity ($L_{\rm Mg\,II}$) of Gl 890 (Doyle 1987) $L_{\rm Mg\,II}/L_x$ is calculated to be $10^{-1.2}$, which compares well with the average value of $10^{-0.9}$ obtained for the other flare stars (Agrawal, Rao, and Sreekantan 1986).

The coronal X-ray properties of Gl 890 are very similar to that of slowly rotating flare stars. For example, the flare star AU Mic has physical properties similar to that of Gl 890 but a very slow rotation velocity (about 6 km s^{-1}). AU Mic has an $L_x/L_{\rm bol}$ value of $10^{-2.6}$ and $L_{\rm Mg\,II}/L_x$ value of $10^{-1.0}$, close to the values measured for Gl 890 (Agrawal, Rao, and Sreekantan 1986 and references therein). This suggests that the coronal activity of flare stars does not increase monotonically with the rotation velocity, but reaches a "saturation level" at fast rotation. It has been shown that single late-type stars show a maximum value of $L_x/L_{\rm bol}$ (about 10^{-3}) for a Rossby number less than 0.5 (Vilhu and Walter 1987), and the $L_x/L_{\rm bol}$ value of Gl 890 (Rossby number about 0.02; Doyle 1987) is consistent with this suggestion.

The high rotation velocity of Gl 890 (about 70 km s^{-1}) is in contradiction with its old age as apparent from the space velocity and the nondetection of light elements. Several evolutionary scenarios have been sketched for Gl 890 (Pettersen *et* *al.* 1987) to account for its rapid rotation and old age. It has been pointed out that a faint star in a highly eccentric binary orbit can spin up Gl 890 by the strong tidal forces near the periastron. The high eccentricity of the orbit can be retained by pseudosynchronization. The main difficulty in such a scenario is that the two stars spiral in and get destroyed in a short time (about 10^8 yr) due to magnetic braking. We consider below a scenario in which a faint degenerate star can remain as a binary companion to Gl 890 for a long time.

The space density of the cataclysmic variables found in the Galactic surveys is about two orders of magnitude less than that deduced from the nova theory and the eruption frequency of novae in M31 (Patterson 1984). To account for this discrepancy, it has been postulated that novae remain in a hibernating state for about 10^3–10^6 yr (Shara *et al.* 1986), and they would be extremely difficult to distinguish photometrically from the field G, K, or M dwarfs since the underlying white dwarfs are very faint. The nearest ones should be about 20 pc away. The properties of the main-sequence companion of a hibernating nova are therefore very similar to that of Gl 890. The lack of detection of any radial velocity variation in Gl 890 can be explained if the hibernating novae also acquire eccentricity during the nova outburst. The X-ray observations can, however, limit the properties of a possible white dwarf companion of Gl 890. In the *EXOSAT* survey of white dwarfs (Paerels and Heise 1989), 13 hot DA white dwarfs were detected to be emitting soft X-rays, for which such physical parameters as distance and temperature are known. These white dwarfs have count rates of $>2 \times 10^{-3}$ counts cm^{-2} s^{-1} and $>3.7 \times 10^{-4}$ counts cm^{-2} s^{-1} in the Lexan 3000 and Al/P filters of LE, respectively, normalized to a distance of 20 pc. It is also found that the soft X-ray flux increases monotonically with the surface temperature of the white dwarf. The observed count rates of Gl 890 are much lower than the above values (see Table 1) and hence any white dwarf companion of Gl 890 must be considerably cooler than the white dwarfs in the *EXOSAT* survey, i.e., cooler than about 30,000 K. A study of UV spectra of Gl 890 would be very useful to constrain the properties of any white dwarf companion of Gl 890.

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