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FAR-ULTRAVIOLET OBSERVATIONS OF MV LYRAE[1]

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ABSTRACT

MV Lyrae was observed in low state ($m_B \approx 18$) with the *International Ultraviolet Explorer* from 1200 to 3100 Å, on 1980 December 27. Weak emission and absorption features are apparent over a well defined continuum, the shape of which is close to, but appreciably flatter than, that given by a Rayleigh-Jeans law. The energy distribution obtained combining the ultraviolet observations with published optical and near infrared data, can be interpreted as a high-temperature blackbody ($T = 6$–7×10^4 K), with emitting area $A \approx 10^{18}$ cm^2, consistent with the whole surface of the white dwarf, plus the emission of a red dwarf companion. This model predicts negligible soft X-ray flux. Alternatively, a large portion of the ultraviolet emission could be ascribed to a hot spot ($T \approx 2 \times 10^5$ K, $A \approx 10^{16}$ cm^2), similarly to the cases of AM Her, SS Cyg, and U Gem, with a corresponding soft X-ray flux of the order of that observed in 1977 and in 1979.

Subject headings: stars: individual — ultraviolet: spectra — X-rays: binaries

I. INTRODUCTION

The variability of MV Lyrae was discovered by Parenago (1946) who found $m_{pg} = 10.3$–11.2. In the first optical spectra (McRae 1951, 1952; Greenstein 1952), only absorption lines were present. Broad hydrogen lines were observed in emission in 1953 by Greenstein (1954). At the same epoch, variability on a time scale of minutes was detected by Walker (1954). In 1966, hydrogen emission lines were observed to be narrow with rapid radial velocity variations of 40 km s^{-1} (Walker 1966) and a possible orbital period of $\sim$2 hr was suggested.

Recent spectral observations (Vojkhanskaya 1980) confirmed the existence of two different states: one characterized by the presence of emission lines, the other by a continuum with absorption features not always visible.

New interest in the source was caused by a substantial drop in brightness ($\Delta m \approx 5$ mag) which occurred in mid-1979 and lasted at least up to the end of 1980 (Romano and Rosino 1980; Wenzel 1980).

Spectroscopy of the source during the 1980 low state showed relatively narrow and persistent emission lines and enabled a determination of the orbital period $P = 0^{\mathrm{d}}.133$ (Schneider, Young, and Shectman 1981). Near-infrared observations by the same authors determined the spectral type of the companion star as M5 V, yielding a distance of 320 pc.

High-speed photometry by Robinson *et al.* (1981) in 1980 July showed that at minimum light, the rapid flickering which appears to be typical at maximum occurs only sporadically.

Soft X-ray ($\frac{1}{4}$ keV) emission from the source was detected in 1977 with the *HEAO 1* satellite by Mason, Kahn, and Bowyer (1979). At 2 keV a 2.5 σ detection with the same satellite is reported by Cordova, Jensen, and Nugent (1981). Measurements by Becker (1981) with the IPC on board the *Einstein* satellite in 1979 April and October show a substantial decrease (a factor of $\sim$2) in the X-ray flux presumably associated with the optical transition observed in 1979 August. Vojkhanskaya *et al.* (1978) reported the possible presence of circular polarization suggesting that the object is endowed with a strong magnetic field $B \approx 10^8 G$. This, however, was not confirmed by extended observations of Tapia (1981).

In this paper ultraviolet observations of the source in low state ($m_B \approx 18$), obtained with the *International Ultraviolet Explorer* (*IUE*), are presented. Their implications in establishing the nature of the system are examined.

II. OBSERVATIONS

MV Lyrae was observed with the *International Ultraviolet Explorer* (*IUE*) on 1980 December 27 at the ESA Satellite Tracking Station, Villafranca, Spain. The on-board Fine Error Sensor (FES) did not detect the source, which corresponds to an upper limit $m_B \gtrsim 14$. The source was acquired in the large aperture ($10'' \times 20''$) of the spectrometer by means of the blind offset technique with coordinates: R.A. (1950) = $19^{\mathrm{h}}05^{\mathrm{m}}44^{\mathrm{s}}.34$, decl. (1950) = $+43°56'20''.7$. The short (1200–1950 Å) and the long (1900–3100 Å) wavelength cameras (SWP and LWR, respectively) were exposed twice in sequence in the low-resolution mode ($\Delta\lambda \approx 6$ Å). A journal of observations is given in Table 1. The exposures cover different fractions of the orbital period, from one-fifth to four-fifths. No phasing of our observations is possible due to the insufficient precision of the ephemerides determined by Schneider *et al.*

The spectra have been reduced with the procedure developed at the European Southern Observatory, using

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TABLE 1

JOURNAL OF OBSERVATIONS AND INTEGRAL FLUXES OF MV LYRAE

Image No.	Exposure Time (min)	Epoch of Observation (1980 Dec UT)	Integral Fluxes (10^{-11} ergs cm^{-2} s^{-1}) 1230–1900 Å	1900–2500 Å	2500–3100 Å
SWP 10905	40	27.4785	1.17	...	...
LWR 9589	60	27.5089	...	0.38	0.19
SWP 10906	150	27.5547	1.26	...	...
LWR 9590	118	27.6598	...	0.40	0.19

the calibration curve by Bohlin *et al.* (1980). The integral fluxes in selected wavelength intervals (see Table 2) do not vary significantly between different exposures, and the matching between fluxes in the two wavelength ranges is satisfactory, yielding no evidence of variability of the continuum within our observations. Figure 1 shows the spectra obtained combining each short wavelength spectrum with the long wavelength one taken immediately afterwards. Spectra SWP 10905 and LWR 9581 are somewhat underexposed.

The line spectrum exhibits weak absorption and emission features; they have been checked against defects of the cameras and ion events by inspection of the line-by-line extracted spectrum. A list of the features we consider real, also on the grounds of their appearance in both our exposures, is given in Table 2. Some of them are unusual and because of their weakness and the low resolution of the spectra, their identification is uncertain. Some variability is apparent in the line spectrum. In spectrum SWP 10905, covering one-fifth of the orbital

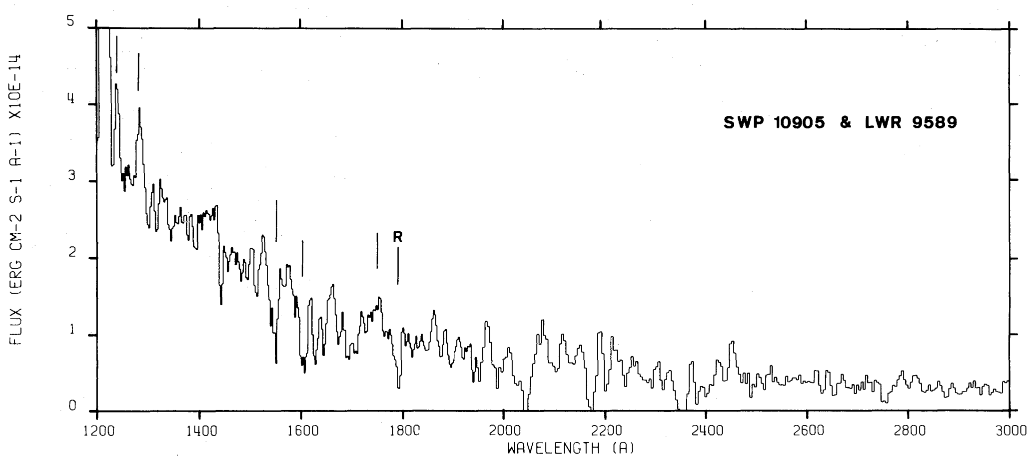

FIG. 1*a*

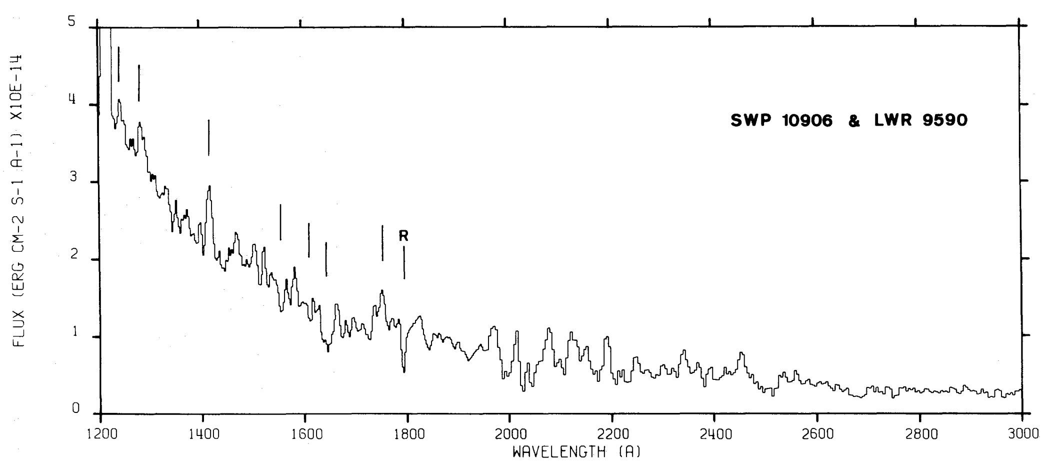

FIG. 1*b*

FIG. 1.—UV spectra of MV Lyrae in low state, obtained combining exposures in the short wavelength (SWP) and in the long wavelength (LWR) cameras (see text). Vertical bars indicate the features listed in Table 2. Reseau marks are labeled with "R."

TABLE 2

Emission (e) and Absorption (a) Features of MV Lyrae at Minimum in the Ultraviolet

Proposed Identifications	λ obs (Å)	
	Image SWP 10905	Image SWP 10906
Geocoronal Lyα	e 1216	e 1214
N I (1243)/N V (1240)? ...	e 1239	e 1242
Not identified	e 1283	e 1280
Not identified	...	e 1415
C IV (1550)?	a 1551	a 1555
Fe II (1608)	a 1606	a 1609
He II (1640)	...	a 1640
N III (1750)?	e 1754	e 1752
Reseau mark	1792	1798

period, both the emission and the absorption features appear more conspicuous than in spectrum SWP 10906 which covers four-fifths of it. The variation could be ascribed to phase modulation, but our data are insufficient to verify this possibility.

From the absence of any noticeable extinction dip at 2200 Å an upper limit to $A_v \lesssim 0.15$ is inferred. This is consistent with the estimated distance of 320 pc and with the total hydrogen column density of 6.7×10^{20} cm^{-2} derived from radio measurements (Heiles 1975). Therefore, no reddening correction is applied to the data.

The shape of the continuum is close to, but appreciably flatter than, a Rayleigh-Jeans ($F_\lambda \propto \lambda^{-4}$) distribution and is consistent with a blackbody of temperature $T = 6$–7×10^4 K.

III. DISCUSSION

The photometry of Romano and Rosino (1981, private communication) suggests that MV Lyrae has been continuously in low state since 1979 August. In particular, three observations spaced during 1980 December yielded $m_B = 18 \pm 0.3$, consistent with the 1980 May–August observations by Schneider *et al.*, and with the spectrophotometric data of Robinson *et al.* (1981) taken in 1980 July. Although sporadic increases of brightness can occur, as for example in 1980 September (Robinson *et al.* 1981), it seems reasonable to combine the ultraviolet data with the optical and near-infrared photometry obtained when the source was in low state (Fig. 2).

An acceptable fit to the observed energy distribution from 1200 to 10000 Å is given by the superposition of two blackbody components (see Fig. 2). The low-temperature blackbody represents the red dwarf secondary ($R = 0.26\ R_\odot$, $T = 3000$ K). The high-temperature component corresponds to $T = 6.5 \times 10^4$ K with total luminosity $L_t \approx 1.5 \times 10^{33}$ ergs s^{-1}. The area of the emitting region turns out to be $A \approx 1.5 \times 10^{18}$ cm^2, comparable to the surface of a white dwarf.

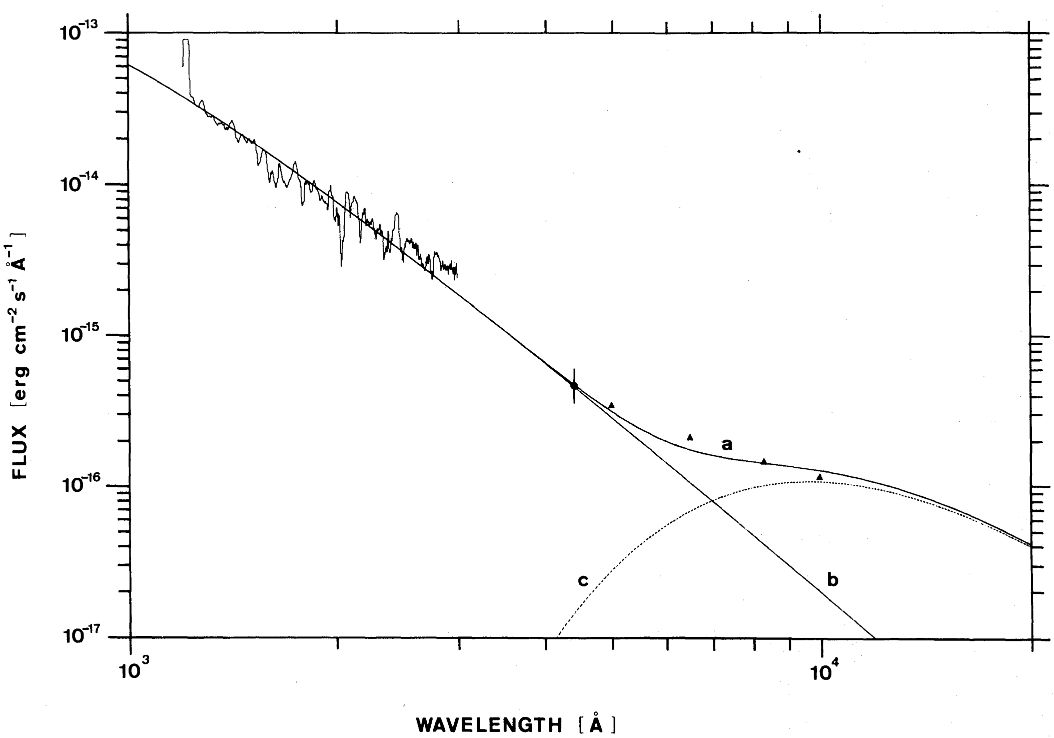

Fig. 2.—Energy distribution of MV Lyrae in low state. The ultraviolet spectrum is obtained averaging the observations presented in this paper. The filled circle represents the B magnitude by Romano and Rosino 1981; filled triangles represent the photometry by Schneider *et al.* 1981. Curve a is the sum of curves b and c. Curve b is a high-temperature blackbody distribution ($T = 6.5 \times 10^4$ K, $A = 10^{18}$ cm^2), and curve c is a low-temperature blackbody distribution accounting for the M5 V secondary ($T = 3 \times 10^3$ K, $R = 0.26\ R_\odot$).

The derived blackbody temperature is similar to that proposed for HZ 43, one of the hottest white dwarfs known (Heise and Huizenga 1980; Greenstein and Oke 1979).

The intensity of the geocoronal Lyα in our large-aperture observations prevents the detection of intrinsic Lyα absorptions comparable to that observed in HZ 43 (Greenstein and Oke 1979). However, we can exclude huge Lyα absorptions as observed in lower-temperature white dwarfs ($T \lesssim 20{,}000$ K).

The above interpretation of the continuum as due to a hot white dwarf is consistent with the suggestion by Robinson *et al.* (1981) that mass transfer ceases in the low state. The luminosity of a residual accretion disk should be small with respect to the total luminosity of the system, though it may be of importance in the blue region of the spectrum. The disk should also be responsible for the observed UV lines. In this picture the predicted soft X-ray flux from MV Lyrae in the low state is $F_{(0.25\ \mathrm{keV})} = 3 \times 10^{-15}$ ergs cm^{-2} s^{-1} Å^{-1}. This value is derived by scaling the observational results on HZ 43. Different He abundance and/or stratification may affect this estimate.

The soft X-ray flux of MV Lyrae measured in 1977 October and in 1979 April ($m_v \approx 12.6$) was a factor of 30 larger. This reduces to a factor ~ 10 in 1979 October ($m_v \approx 14.3$).

If the X-ray flux in the low state ($m_B \approx 18$) were found to be substantially higher than estimated for a hot white dwarf, a different deconvolution of the UV data, analogous to the cases of other cataclysmic variables (Fabbiano *et al.* 1981), should be considered.

Instead of fitting a single blackbody to the 1000–3000 Å range, the short wavelength part of the UV spectrum could be attributed to the Rayleigh-Jeans tail of a hotter blackbody ($T \approx 10^5$ K) and a larger contribution of a residual disk with $T \approx 3 \times 10^4$ K could explain the flatter spectrum in the 2000–3000 Å range. Assuming an X-ray flux similar to that observed by Mason (1979), one would derive for the hot blackbody the following parameters: $T = 2 \times 10^5$ K, $A = 10^{16}$ cm^2, $L = 5 \times 10^{34}$ ergs s^{-1}, consistent with those of other cataclysmic variables (Fabbiano *et al.* 1981).

In conclusion the continuum emission from 1200 to 10,000 Å of MV Lyrae in low state can be accounted for by a hot white dwarf ($T = 6 \times 10^4$ K) with a red dwarf companion, with negligible X-ray emission. Alternatively, the ultraviolet emission could be due to a hot spot ($kT \approx 20$ eV), accounting also for the soft X-ray emission. In either case, the existence of a residual accretion disk is suggested by the presence of absorption features in the spectrum; however, it gives a minor contribution to the total emission. In the first case, the mass transfer should be absent in the low state; in the second, it may still be present at a lower rate with the bulk of the energy being radiated as soft X-rays.

Simultaneous observations in soft X-rays and in the ultraviolet are essential in order to discriminate between the two models.

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