1982

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Recommended Citation
Michalitsianos, A.G., Kafatos, M., Feibelman, W.A., Wallerstein, G. (1982) A Brightening of the Symbiotic Variable SY Muscae, *Astronomy and Astrophysics*, 109: 136-140.

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Comments
This article was originally published in *Astronomy and Astrophysics*, volume 109, in 1982.

1982A&A...109..136M

Astron. Astrophys. 109, 136–140 (1982)

ASTRONOMY AND ASTROPHYSICS

A Brightening of the Symbiotic Variable SY Muscae

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Received November 2, accepted December 17, 1981

Summary. The symbiotic variable SY Muscae has been observed with IUE in September 1980 and June 1981 and in the photographic region in May 1981. The entire ultraviolet spectrum brightened between September and June by about a factor of 5. The spectrum shows high excitation including emission from N v and high electron density, about $10^{10}\,cm^{-3}$ as determined from various line ratios in the ultraviolet. The optical spectrum is dominated by permitted lines; even [O III] is very weak again indicating high density in the ionized region. The increase in ultraviolet continuum and line emission may be due to enhanced mass transfer from the cool star whose period is 623 d and whose maximum was predicted to occur very close to the time of the June 1981 observations. Alternatively the hot star and much of the emitting gas could have been in eclipse in September 1980.

Key words: stars: binaries – stars: combination spectra – stars: mass loss – ultraviolett spectra

I. Introduction

The symbiotic star SY Mus has been rather neglected since its nature was recognized by Henize (1952) who found it to show permitted emission lines and [O III] 4363 A emission superimposed upon an M-type continuum. It had previously been known as a rather regular variable of period 623 d and an amplitude of a little more than one magnitude in the photographic region (Uitterdijk, 1934; Greenstein, 1937). We have observed it with the International Ultraviolet Explorer (IUE) as part of the Goddard group's survey of ultraviolet spectra of symbiotic stars. The optical spectra were obtained by Wallerstein whose attention to SY Mus was called by Stencel.

IUE spectra taken on 20 September 1980 and 11 June 1981 show that on the latter date the continuum had intensified by about a factor of 5 and that various emission lines had also increased by factors from 1.5 to 5 as compared with the first epoch of observation. According to the light curves of Greenstein and Uitterdijk extrapolated for 20 cycles the 1980 September observations were made during rising light and the 1981 June observations were taken very close to the center of the dip in the double maximum. The FES monitoring system on the IUE showed that the visual magnitude was approximately 10.7 in September 1980 and 10.4 in June 1981.

* Visiting observer, Cerro Tololo Inter American Observatory, Managed by the American Universities for Research in Astronomy, Inc. under contract with the National Science Foundation

II. Observations

a) Ultraviolet Spectra

Ultraviolet observations were obtained exclusively with the 10″ × 20″ entrance slit of the IUE spectrometer in both the low and high dispersion mode. The camera exposure times and image sequence numbers are shown in Table 1 for both observing epochs. High dispersion observations are not available for 20 September 1980. The IUE data tapes were analyzed using the data reduction routines in FORTH at NASA/GSFC on the PDP 11/40 computer (Fahey and Klinglesmith, 1979). Low resolution SWP and LWR spectra are shown together for both observing epochs in Fig. 1. The spectra are plotted in absolute intensity units against wavelength and have been calibrated using the corrected intensity transfer function adopted for IUE Echelle spectra (Cassatella et al., 1980). Note that the intensity scale differs between the two epochs. The spectra shown in Fig. 1 are also corrected for interstellar absorption since a value $E_{B-V}=0.3$ following the extinction curve of Savage and Mathis (1979) is just sufficient to remove the $\lesssim 2200$ A continuum dip. This value of extinction is in close agreement with Feast, Robertson and Catchpole (1977) who obtained an $E_{B-V}=0.23$ from the JHKL colors of the M giant in the system after adopting $M_V=-0.4$ for the absolute magnitude of the primary in their relationship for galactic absorption A_V.

b) Optical Spectrum

A sequence of four spectra differing by factors of three in exposure times (from 1 min to 30 min) were obtained on the night of 29 May 1981 (*UT*) with the 1-m CTIO Carnegie Image Tube Spectrograph. These optical observations coincide closely in time with our second series of spectra obtained on 11 June 1981 with IUE. The spectra were widened to 0.6 mm and covered the region from 3650 A to 5050 A at a dispersion of 60 A/mm.

The optical emission is dominated by permitted lines; the forbidden lines present are very weak. Hydrogen recombination lines are seen down to H_{18}, and those of H II to λ 3813 A. Other features present are He I, N III, O III (one Bowen fluorescent line), Si II, Ca II, Fe II, and [Fe II]. The [Fe II] lines are very weak; [Ne III] and [O III] (4363 A only) may be present. The [O III] lines at λλ 4959, 5007 A, seen commonly in symbiotic stars, are not visible on our spectra, which reach the continuum on the longest exposure. Lines of Mg I 4571 A and Si λ 3905 A are also present in

Table 1. Observing program

Epoch	Camera/Seq. no.	Exposure (min)	Dispersion	m_V (IUE FES)
20 Sept. '80	SWP 10188	90	Low	10.7
	LWR 8855	60	Low	10.7
11 June '81	SWP 14236	240	High	10.4
	LWR 10828	50	Low	10.4
	SWP 14237	45	Low	10.4
	LWR 10829	65	High	10.4
	SWP 14238	10	Low	10.4
	LWR 10833	7	Low	10.4

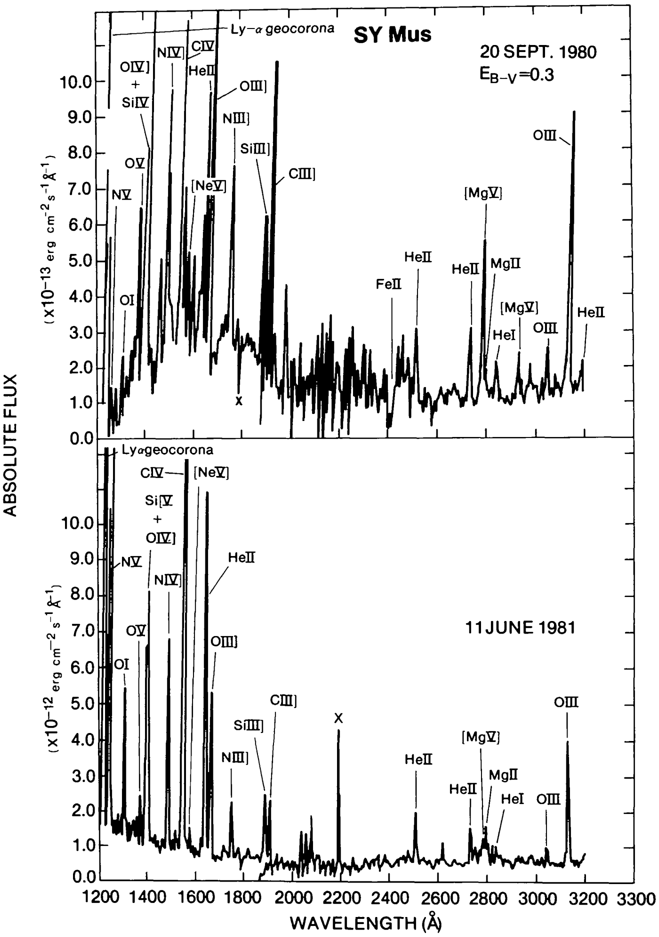

Fig. 1. Combined low resolution SWP and LWR exposures of SY Mus obtained with with IUE taken on 20 September 1980 and 11 June 1981. The intensity scale for the lower plot is ten times the scale of the upper plot

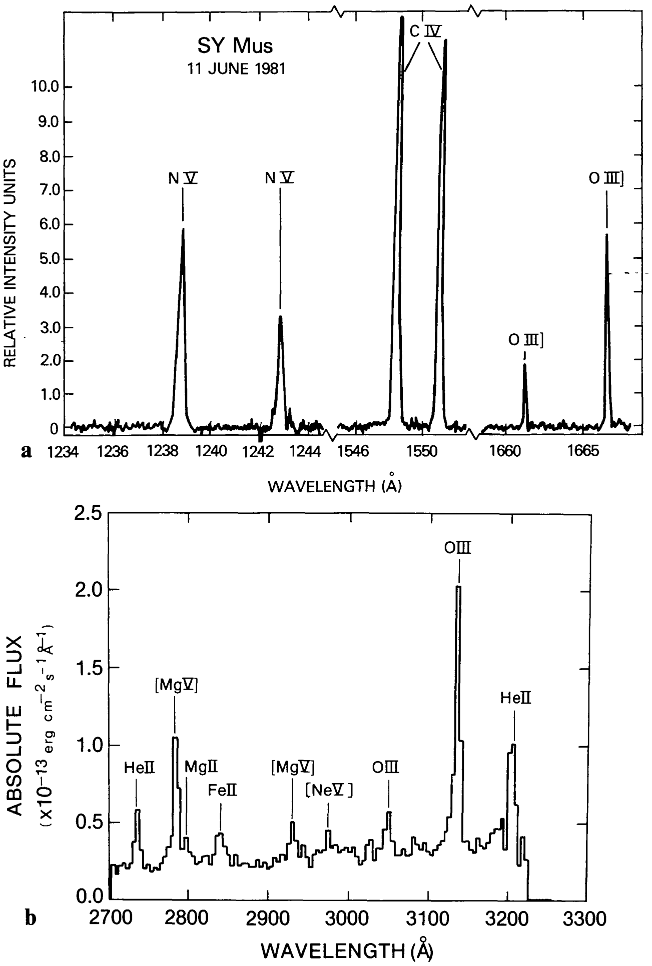

Fig. 2. a The spectrum of SY Mus on 11 June 1981 at high dispersion with IUE showing characteristic emission line profiles for high excitation species of N v, C iv, and O iii]. **b** Expanded wavelength scale of a low resolution IUE spectrum obtained on 20 September 1980 with IUE showing the presence of several forbidden lines [Mg v] and [Ne v] as well as He ii, Mg ii and the Bowen florescence excited lines of O iii

emission. They may come from the atmosphere of the cool star whose presence is clearly indicated by TiO absorption. These lines are frequently seen in the spectra of long period variables; however they may be excited by a different mechanism in symbiotics than in long period variables.

Clearly the emission spectrum is that of a high density gas of moderate excitation. There is no evidence for a stellar eruption in the form of displaced absorption lines. A similar spectrum with only permitted lines, except for λ4363 A was reported by Henize (1952). Our preliminary radial velocity with respect to the sun is $+9\,\mathrm{km\,s^{-1}}$. No correction for telescope position has been made because an insufficient number of standards have been measured to date. A correction as large as $20\,\mathrm{km\,s^{-1}}$ may have to be applied to the velocity quoted above. At our resolution, about 1.5 A which

Table 2. Absolute emission line flux

		- 20 Sept. 1980 -		- 11 June 1981 -	
Ion	λ(A) Laboratory @	λ(A) IUE	Flux #*	λ(A) IUE	Flux #*
N V	1238.8, 1242.8	1236.4	1.013	1239.2	1.602
O I	{1302.2, 1304.9, 1360.0	1301.6	0.169	1303.2	2.150
C II	1335.7			1335.6	0.074 ?
O V	1371.3	1366.2	0.256	1370.6	0.735
Si IV	1393.8	1392.6	0.100	1393.0	1.412
O IV]	{1397.2, 1399.8, 1401.2	1398.2	1.548	1402.2	3.871
N IV]	1486.5	1483.0	0.672	1487.2	3.429
C IV	1548.2, 1550.8	1545.2	*	1547.8	1.432
[Ne V]	1574.9	1570.8	2.560	1573.6	0.318
		1591.6	0.232		
He II	1640.4	1637.2	*	1639.4	1.446
O III	1660.8, 1666.2	1662.2	0.979	1666.8	4.082
N IV]	1718.6			1716.8	0.284
N III]	{1746.8, 1748.6 1749.7, 1752.2 1754.0	1748.6	0.570	1750.4	1.366
		1775.8	0.081	1776.4	0.185
Si II	1816.9			1818.2	0.214
Si III]	1892.0	1888.2	0.440	1892.9	1.505
C III]	1908.7, 1906.7	1907.6	0.687	1909.2	1.209
Fe II (148)	2444.5	2444.0	0.009		
Fe II (148)	2465.2	2462.5	0.006	2462.2	0.338
Fe II (243)	2484.2	2484.2	0.004	2482.6	0.353
He II	2511.2	2512.4	0.205	2509.2	1.045
He II	2733.3	2737.4	0.287	2736.9	1.492
Fe II (62)	2743.2			2744.4	0.215
[Mg V]	2783.2	2785.2	0.675	2783.6	0.459
Mg II h&k	2795.5,2802.7	2799.8	0.037	2799.4	2.291
He I	2829.1	2825.8	0.005	**	**
Fe II (399)	2845.5	2844.4	0.207	**	**
Fe II (391)	2865.5	2862.8			
[Mg V]	2928.7	2932.8	0.215		
[Ne V] ?	2973.4	2975.0	0.005		
O III	3023.5	3028.6	0.108	3023.8	0.314
O III	3047.1	3051.2	0.198	3047.0	0.494
O III	3132.9	3134.6	*	3132.7	4.306
He II	3203.1	3204.8	*	3204.8	1.467

(x 10^{-12} erg cm^{-2} s^{-1} A^{-1})

** telemetry

* emission line fluxes not corrected for reddening

@ from Kelly and Palumbo (1973)

* saturated

corresponds to about 100 km s^{-1}, we do not see any asymmetry in the optical emission lines, nor are there any significant velocity differences from one ion to another.

Figure 1 illustrates the dramatic changes that the UV spectrum of SY Mus has undergone over a time span of approximately nine months. The combined SWP and LWR spectra for both observing epochs are corrected for interstellar extinction for an $E_{B-V}=0.3$, where the enhanced noise level of the continuum at wavelengths 2000 A $\lesssim \lambda \lesssim$ 3200 A on 20 September 1980 reflects the low observed flux. Of interest in SWP 10188 are possible continuum absorption features in the red wings of O IV] 1397, 1399, 1401 A, and O III] 1660, 1666 Å. Figure 2a shows several

Table 3. Emission lines identified in high resolution

Ion	λ(A) IUE	λ(A) Laboratory#
N V	1238.9	1238.8
	1242.9	1242.8
O I	1304.9	1304.8
	1306.1	1306.0
S IV	1393.8	1393.7
O IV]	1399.8	1399.7
O IV]	1401.2	1401.1
Si IV	1402.8	1402.7
O IV]	1404.8	1404.8
S IV]	1406.1	1406.0
O IV]	1407.4	1407.3
N IV]	1482.9	1483.3
	1486.6	1486.4
C IV	1548.3	1548.1
	1550.7	1550.9
He II	1640.4	1640.3
O III]	1660.9	1660.8
	1666.2	1666.1
N III]	1748.7	1748.6
	1749.7	1749.6
	1752.3	1752.1
	1754.0	1753.9
Si II	1817.0	1816.9
Si III]	1892.1	1892.0
C III]	1908.9	1908.7
He II ?	2251.8	2252.6
[Mg V]	2783.1	2783.1
Mg II	2796.0	2795.5
	2803.1	2802.6
O III	2836.5	2836.3
[Mg V]	2928.8	2928.7
O III	3047.4	3047.1
	3122.4	3121.7
	3133.1	3132.8
He II	3207.6	3203.1

@high resolution data available for 11 June 1981 only

#from Kelly and Palumbo (1973)

lines in this spectral region at high dispersion. The lines are very sharp and indicate that their intrinsic width is less than the instrumental width of about 30 km s^{-1}. A number of unidentified emission lines were observed at λλ 1455.0, 1591.4 and 1621.9 A. The slightly broadened blue wing of O IV] seen in September may be attributed to a blend of Si IV λλ 1393, 1401 A that increased in strength on 11 June 1981, and was clearly resolved from the O IV] lines even in low resolution on this date. Similarly, the O III line at λ 3133 A has an extended blue wing that is attributed in low resolution to a blend with O III λ 3121.7 A.

Table 2 summarizes emission lines identified in low spectral resolution with corresponding absolute intensities from IUE for both observing epochs. In Table 3 emission lines identified from high dispersion spectra are shown from data acquired on the second observing epoch. A comparison of absolute intensities between the first and second observing epochs can not be made for C IV λλ 1548, 1550 A owing to detector saturation and satellite telemetry problems.

Forbidden Mg V identified at λλ 2783.2, 2929.1 A on 20 September 1980 (Fig. 2b) declined in absolute intensity and relative to Mg II at λλ 2795, 2802 A (Table 2). It is difficult at this stage to determine if in fact the absolute flux has decreased in forbidden lines because the intensity estimated for any given emission line depends on what one perceives the continuum level to be. If formed in a region very far removed from the continuum regions, [Mg V] may appear weaker simply for reasons of contrast, because the general level of the continuum in the LWR wavelength range has increased almost by one order of magnitude. For the same considerations [Ne V] λ 2973 A appears to have vanished on 11 June 1981. However, an absence of strong forbidden line emission during the enhanced phase of UV emission could in fact reflect a higher electron densities, i.e. $n_e > 10^6$ cm^{-3}, which is substantiated by high dispersion spectra of the C III] intercombination lines which show $I(\lambda 1906.7\ \mathrm{A})/I(\lambda 1908.7\ \mathrm{A}) \ll 1$. Absence of [O III] λλ 2322, 4959, 5007 A further suggests high electron densities as does the $I(2322\ \mathrm{A})/I((1661\ \mathrm{A}) + I(1667\ \mathrm{A})) \ll 1$ ratio which suggests $n_e \gtrsim 10^9$ cm^{-3} (Nussbaumer and Storey, 1981). Using the O IV] λλ 1404.8 A/1401.2 A and the 1407 A/1401.2 A ratios, as well as the N III] λλ 1754 A/1749.8 A and the λλ 1752 A/1749.8 A ratios we also find $n_e \sim 3\ 10^{10}$ cm^{-3}.

III. Discussion

The distance to SY Mus was obtained from the value of interstellar extinction obtained from the UV continuum dip at $\lambda \lesssim 2200$ A, an absolute magnitude for the primary $M_V = -0.4$ (Feast et al., 1977), and apparent magnitude $m_V = 10.7$ from the IUE-FES monitor for 20 September 1980. The continuum distribution on 11 June 1981 in the $2000\ \mathrm{A} \lesssim \lambda \lesssim 3200$ A wavelength range can be fitted with a blackbody curve appropriate to a $T_{eff} = 40{,}000$ K star. Thus, if we consider the absolute UV continuum flux level $F_{\lambda 1400} \sim 10^{-12}$ erg cm^{-2} s^{-1} A^{-1} for a $T_{eff} = 40{,}000$ K star, we obtain the following parameters for the secondary: $L = 90\ L_\odot$, $R = 0.2\ R_\odot$ and $m_V = 13.6$. Similarly, if $T_{eff} = 10^5$ K, then $L = 530\ L_\odot$, $R = 0.08\ R_\odot$ and $m_V = 14.4$. The relative magnitude differences between primary and secondary respectively are $\Delta m_V = 2.9$ and 3.7. Therefore, the primary dominates emission at optical wavelengths, but by virtue of its effective temperature makes essentially no contribution in the near or far UV. These stellar parameters place the secondary in a region of the H-R Diagram occupied by central stars of planetary nebulae. The parameters for such subdwarfs are consistent with those derived by Kafatos et al. (1980) for the companion in the symbiotic star RW Hya, and by Altamore et al. (1981) for Z And. We have considered stars as hot as 10^5 K in order to explain the presence of high ionization potential lines of He II and N V. A star of T_{eff}

$=40{,}000$ K does not produce a sufficient number of ionizing photons to explain the presence of such lines. We thus favor models of symbiotic stars which include hot sub-dwarfs with $T_{\rm eff} > 65{,}000$ K. On the other hand if the highest excitation lines are excited mechanically (i.e. by shocks) we cannot use them to limit the temperature of the hot star.

The UV continuum distribution observed on 20 September 1981 is complex and difficult to interpret. Michalitsianos et al. (1982) have suggested that it might explained by a combination of continua in which nebular recombination emission dominates the 2000 Å to 3200 Å range. The 1200 Å to 2000 Å wavelength range might be ascribed to line-blanketed continuum emission from an object whose luminosity and surface effective temperature is appropriate to an early A type star. Theoretical models of Kurucz (1979) for early A for B type stars, however, do not provide a good fit to the data. Therefore, the nature of the UV continuum distribution of SY Muscae prior to its enhanced emission phase remains obscure for the present.

Photo-excitation of a circumstellar nebula is likely to be the dominant mechanism that gives rise to the observed high excitation line emission. The line profiles in low dispersion on 20 September 1980, as well as low and high dispersion on 11 June 1981 do not exhibit anomalous structure. There is no evidence for either P-Cygni type profiles or line broadening that might suggest large scale motions. Instead, all of the emission lines appear rather narrow consistent with photo-excitation of a relatively quiescent gas. High dispersion IUE spectra of RW Hya also suggest similar properties as that found here for SY Mus (cf. Kafatos et al., 1980). In contrast, the peculiar emission star RX Pup (Kafatos et al., 1982) exhibits complex emission line structure in C IV λ1548, 1550 A, and split line profiles apparent in Si III] λ1892.0 A, He II λ1640.4 A and in a number of other high excitation emission lines. This suggests complex kinematic motion in this system, i.e. streamers, mass transfer and possibly an accretion disc.

The overall increase in the UV emission in SY Mus is best described as an enhancement of quiescent emission rather than an outburst or eruption. The cause of this increase will remain obscure until frequent coverage in both the optical and ultraviolet permit a detailed description of all the phenomena as they evolve. A variable mass-loss rate from the cool star can cause a variable accretion rate onto the hot star of a binary. The resulting change in effective temperature and radius of the hot star whose luminosity is likely to be enhanced by accretion heating will have strong effects on the state of ionization of the nebula. The high density of the ionized part of the nebula will cause its state of ionization and electron temperature to respond rapidly to changes in the ultraviolet flux. Perhaps the regular pulsation of the *M* star as shown by the constant period of 623 d effects its mass-loss and hence the accretion onto the hot star. If that is true the ultraviolet spectrum may also vary with a period of 623 d, perhaps in phase with the cool star.

An entirely different explanation of the brightening of both the UV continuum and the lines is the possibility that the hot source in SY Mus was in eclipse in September 1980 and had emerged by June 1981. Once again only a substantial number of additional observations will show if this may be correct.

Acknowledgements. G. Wallerstein is pleased to thank *JILA* and its Chairman, R. McCray, for hospitality and computer time. We wish to thank Dr. J.P. Swings for useful comments for improving the text.

References

Altamore, A., Baratta, G.B., Cassetella, A., Friedjung, M., Giangrande, A., Ricciardi, O., Viotti, R.: 1981, *Astrophys. J.* **245**, 630
Cassetella, A., Holm, A., Ponz, D., Schiffer, F.H.: 1980, IUE *Newsletter* **8**, 1
Fahey, R.P., Klinglesmith, D.A.: 1979, IUE *Forth spectral analysis user's guide*, NASA Tech. Note *X*-685-79-29
Feast, M.W., Robertson, B.S.C., Catchpole, R.M.: 1977, *Monthly Notices Roy. Astron. Soc.* **179**, 499
Greenstein, N.K.: 1937, *Bull. of Harvard College* **906**, 3
Henize, K.G.: 1952, *Astrophys. J.* **115**, 133
Kafatos, M., Michalitsianos, A.G., Hobbs, R.W.: 1980, *Astrophys. J.* **240**, 114
Kafatos, M., Michalitsianos, A.G., Feibelman, W.A.: 1982, *Astrophys. J.* (in press)
Kelly, R.L., Palumbo, L.J.: 1973, N.R.L. Report No. 7599
Kurucz, R.L.: 1979, *Astrophys. J. Suppl.* **40**, 1
Michalitsianos, A.G., Kafatos, M., Feibelman, W.A., Hobbs, R.W.: 1982, *Astrophys. J.* **253**
Nussbaumer, H., Storey, P.J.: 1981, *Astron. Astrophys.* (in press)
Savage, B.D., Mathis, J.S.: 1979, *Ann. Rev. Astron. Astrophys.* **17**, 73
Uitterdijk, J.: 1934, *Bull. Amer. Inst. Neth.* **7**, 177

Note added in proof: According to visual estimates by members of the Variable Star section of the Royal Astronomical Society of New Zealand kindly supplied by Frank M. Bateson, SY Mus reached minimum in November 1980, was rising during May–June 1981 and was near maximum in November 1981.