IUE OBSERVATIONS OF TWO LATE TYPE STARS BX MON (M4 + pec) AND TV GEM (M1 Iab)

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ABSTRACT

IUE observations of two late type stars BX Mon and TV Gem have been obtained that reveal the emission properties in the ultraviolet of sub-luminous companions. Analysis of the continuum emission observed from BX Mon suggests the companion is a middle A III star. High excitation emission lines observed between 1200 Å and 2000 Å (C IV, Si III], C III]) that generally do not typify emission observed in either late M type variables or A type stars are also detected. It is suggested that these strong high-excitation lines arise in a large volume of gas heated by non-radiation processes that could be the result of tidal interaction and mass exchange in the binary system. In contrast to stars such as BX Mon that are observed in the visible to have emission lines superimposed on the strong absorption of the M giant, the luminous M1 supergiant TV Gem shows unexpected intense UV continuum throughout the sensitivity range of IUE. The UV spectrum of TV Gem is characterized by intense continuum with broad absorption features detected in the short wavelength range. Our analysis shows that the companion could be a B9 or A1 III-IV star, although a fully self-consistent model including the observed color index has as yet not been fully developed. Alternate suggestions are presented for explaining the UV continuum in terms of an accretion disk in association with TV Gem.

INTRODUCTION

IUE observations of two late type giants BX Mon (M4 + pec) and TV Gem (M1 Iab) were obtained that reveal strong emission continuum. BX Mon was selected for IUE observations because earlier ground-based spectra obtained by Minkowski showed broad emission in Hβ, Hγ, and H: that are superimposed on a strong absorption spectrum[1]. As such, the visible spectrum suggests the presence of a hot companion that is not sufficiently luminous to dominate the integrated light of the binary system. Following the observations of Minkowski further work by other observers was not pursued, leaving only sparse references in the literature that collectively indicate this star could possibly be an intense source of ultraviolet emission, and possibly a symbiotic system. Our UV observations, however, indicate that the companion is most likely a middle A luminosity III-IV star. The general appearance of the UV spectrum from BX Mon is not representative of UV spectrum observed in classic symbiotics, which suggests that BX Mon most likely does not undergo tidal interaction or mass exchange with its companion to the same extent as currently envisaged for symbiotic stars. This follows because the ultraviolet spectrum in the long wavelength range (2000 Å to 3200 Å) is dominated by blackbody emission continuum that can be explained by an A main sequence star, and accordingly, does not typify the general models presently considered for symbiotic stars that have as companions white dwarfs or central stars of planetary nebulae. However, the high excitation lines in emission that are observed suggest a large volume of gas is present that is not heated by photo-excitation processes.

On the other hand, the detection of strong ultraviolet continuum from TV Gem is unexpected because earlier ground-based spectral classification observations suggest this star is only a normal M type supergiant [3,4]. Similarly, photometric observations of TV Gem[5,6] do not show a blue excess in the continuum, which is a result consistent with earlier spectral data obtained from ground-based observations.

Low dispersion UV spectra obtained in both short and long wavelength cameras show strong continuum throughout the IUE spectral range. The continuum is for the most part featureless with the exception of a number of broad absorption features in the short wavelength spectrum. These features might be identified with Si, Al and Fe absorption found in early B or A luminosity II-III stars[7]. However, a fully self-consistent model that explains our UV spectra and earlier ground-based photometric observations of TV Gem has as yet not been fully developed. We discuss the details concerning our observations and analysis of both stars in the sections that follow.

BX Mon: Observations and Analysis

Mayall[8] determined the intrinsic light period of BX Mon = H.V. 10446 of 1380 days; that designates this star as the longest recorded intrinsic variable. It is listed in the Catalogue of Emission Line Stars of Bidelman[1]. IUE observations of BX Mon were obtained on 31 August 1979 in low dispersion (~ 6 Å spectral resolution) using 60 minute exposures in both the short and long wavelength cameras and the large (10" x 20") entrance aperture of the IUE spectrometer. The FES white light monitor obtained a visual magnitude ~11, which places the luminosity of the primary star near maximum light at the time of these observations. The observed extremes in m_V are 11 to 13 magnitudes[8]. IUE spectra in high dispersion are not possible owing to the unreasonably long exposures required to achieve adequate signal-to-noise.

The short wavelength spectral range exhibits both continuum and line emission. Between 1200 Å and 2000 Å the spectrum is characterized by O I (1302 Å), C IV (1548, Å 1550 Å), Si III] (1892 Å) and C III] (1906 Å) emission (Figure 1). The absolute line fluxes measured for the strongest emission lines are shown in Table 1, and were obtained using the data reduction routines in FORTH developed by Drs. Klinglesmith and Fahey at NASA/GSFC. The long wavelength spectral range (2000 Å to 32000 Å) is generally dominated by the continuum of the hot companion. The absorption feature at 2800 Å due to Mg II (2800 Å) is found typically in 8000 K to 10,000 K A type main sequence stars[12].

The continuum of the hot companion in the long wavelength range was found to be best approximated by line blanketed continuum models that correspond to A type luminosity class III stars around 9000 K[9]. As such, we adopt an A4 or A5 III star as the companion to BX Mon. From the observed continuum distribution with blanketing, we deduce an $E_{B-V} \sim +0.25$ for the interstellar absorption[11]. A lower limit of distance can be approximated if we suppose that the A type companion has a visual magnitude sufficiently less than the primary at minimum so that it does not dominate the integrated light of the system. Accordingly, as an upper limit we assume $m_V \gtrsim 14$, whose corresponding absolute magnitude M_V from Allen (ref. 12) is $M_V = +2.5$, appropriate for an A4 type III star. A lower limit of distance $d \sim 1400$ pc is obtained assuming these conditions.

The high-excitation lines emission observed in the 1200 Å and 2000 Å range are, however, more difficult to explain in terms of emission from either an M4 or A main sequence star. It is unlikely that the high excitation line emission such as C IV (1548 Å, 1550 Å) is explained by a late A type star because the appearance of such lines is inconsistent with UV spectra of A1 V to A7 IV-V stars obtained by OAO-2[12]. Analysis of Ca II K line core emission in A1 V to A7 IV-V stars suggests also that chromospheric emission is minimal for these spectral types[13]. Chromospheric emission from the cool M4 giant atmosphere is also unlikely because IUE spectra obtained of late type M variables and Mira variables and even M supergiants suggest only a warm chromosphere ($T_{chromosphere} \sim 10,000$ K) is present[14, 15]; that is not sufficiently ionizing to produce the observed line emission.

It is likely that mass loss commonly associated with late type M stars[16] forms a circumstellar shell around the binary system. Photoexcitation and recombination processes are not appropriate here for exciting circumstellar material because middle A type main sequence stars cannot provide sufficient UV ionizing photons in the circumstellar envelope volume ($r \gtrsim 10^{15}$ cm) to explain the observed excitation. As such, invoking a form of mechanical heating through shock waves, tidal interaction or possibly strong stellar magnetic fields provides speculative ideas for model development. More spectra in the visual, UV are required to develop a general model that encompasses all aspects of emission from this interesting object.

UV Observations of TV Gen = HD42475

IUE observations of TV Gem were obtained in low dispersion using 10 minute exposures in both short and long wavelength cameras on November 25, 1979. Observations were repeated in the same manner on January 16, 1980, with essentially similar results. The spectrum is characterized by strong continuum that is devoid of emission lines but which has broad absorption features in the short wavelength spectral range (Figure 2). The absorptions features observed are centered at 1400 Å, 1540 Å, 1604 Å. The low resolution of ~6 Å makes precise identification of these absorption features difficult. The feature centered around 1400 Å is possibly explained by the presence of Si IV lines that appear blended in low dispersion spectra. Si IV 1400 Å absorption would typify middle B type main sequence stars[17] as we have found by examining low resolution spectra from OAO-2 of early standard stars. The features identified in Figure 2 persist even if the spectra from different observing dates are averaged together, supporting the view that these features are real and not detector noise.

Broad features, centered at 1540 Å and 1604 Å, that are $\Delta\lambda \sim 40$ Å and $\Delta\lambda \sim 20$ Å in width, respectively, are also observed. The feature at 1604 Å is possibly explained as Fe III (1601 Å, 1611 Å, UV118) or Al III (1600 - 1612 Å) observed in early O and B stars. Generally, B5 to B7 V stars exhibit weak absorption due to Si IV and C IV[17]. As seen here the features at 1400 Å and 1604 Å would be consistent with this interpretation. However, the feature at 1540 Å cannot be attributed to C IV because its measured wavelength (even in low resolution) is too far removed from the rest wavelengths of the resonance doublets (1548 Å, 1550 Å). It could, however, be possibly attributed to Fe III.

Observations that were kindly made available to us by Dr. J.B. Oke using the multi-channel scanner of the 200-inch telescope confirms the existence of large excess continuum in the near UV between 3500 Å and 3200 Å. The visible spectrum is characterized by normal M1 or M0 type I supergiant emission in which TiO bands dominate the absorption. Early spectral classification work has classified TV Gem as a normal M1 supergiant. Emission in the hydrogen lines, ionized and neutral species are not observed [22], although this star is noteworthy for having particularly weak Ca II H and K emission[22].

Comparing the general properties of the UV continuum in the short wavelength range with OAO-2 spectra of standard early type stars, we find that the continuum might be explained if the companion is a B9 - A1 (III-IV) star. An O or B supergiant is immediately ruled out because such a star would be sufficiently luminous that earlier spectral classification observations [20, 21] would have detected its presence. On the other extreme, a bright white dwarf or central star of a planetary nebula is also ruled out because the expected UV continuum flux based on stellar parameters[12] would be $\sim 10^2$ times less than observed for a star at 1400 pc.

Based on the adopted distance to TV Gem, a B9 III-IV star would have an apparent magnitude uncorrected for absorption $m_V = 10.35$ (absorption corrected $m_V = 9.15$), and corresponding absolute magnitude $M_V = -2.8$ and bolometric magnitude $M_{bol} = 3.4$. Similarly, an A1 III - IV type would have $m_V = 9.8$ uncorrected for absorption (absorption corrected $m_V =$ -2.8) and $M_{bol} = -3.1$.

If we postulate the existence of a B9 or A1 III - IV type star the difference in apparent magnitude between the two stars is 2 to 3 magnitudes. Although the M1 supergiant is brighter than a B9 or A1 star by approximately 3 magnitudes, one would expect that some level of flux contribution to the photometric color of the M1 be made by an early companion, especially in the blue band. For TV Gem B-V = +2.30 [23] and B-V = +2.25[24], that is consistent with typical photometric colors of normal M1 supergiants. For comparison an M1 supergiant similar to TV Gem such as α Sco (M1 Iab + B), but known to have an early companion, has a B-V = +1.82 [24]. The difference in magnitudes between primary and secondary in α Sco is $\Delta M \sim 4$. Accordingly, the B-V color index of TV Gem does not indicate an abnormally high level of blue continuum but in fact suggests a color typical of only a cool star, even though the estimated magnitude difference between primary and secondary is $\Delta M \sim 3$. The B-V in TV Gem should in fact be even smaller than that measured for α Sco on the basis of this analysis.

An observational test to determine if in fact an early companion is associated with TV Gem would consist of a UBV monitoring program. TV Gem has a variable designation SRc and as such has irregular excursions in luminosity that occur on timescales of 182 days. If the companion is assumed to have constant brightness, the B-V color index of TV Gem should become smaller as the M supergiant approaches minimum light. If a correlation is established between color and brightness in the manner described here, this would argue in favor of the presence of an early companion star.

An alternative explanation of our IUE data might be found if we consider the presence of a high energy source in close proximity to the extended envelope of the M1 supergiant. If $F\lambda \alpha \lambda^{\circ}$ or even $F\lambda \alpha \lambda^{-1}$, then $F_{\nu} \alpha \nu^{-2}$. This frequency dependence is similar to the properties of the high energy spectrum in soft X-rays observed in well known X-ray sources. Emission from an accretion disc onto a compact object may thus explain the strong UV continuum. This interpretation immediately explains the general absence of blue excess in the spectrum of TV Gem and an absence of strong or weak emission lines. As such, an accretion disk could form from the material exchanged from the extended envelope of the primary that falls on a condensed object that would heat infalling material to temperatures in the 10^6 K range. Observations in the visual, UV and X-rays are required to further discern the properties of the companion to TV Gem.

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Table 1

ABSOLUTE LINE INTENSITIES

($\times 10^{-13}$ ergs cm^{-2} s^{-1})

Ion	Laboratory λ(A)	BX Mon
N V	1239, 1243	0.6
O I+Si II	1302, 1309	1.8
O V	1371	0.1
Si IV + O IV]	1394, 1401 1403, 1407	0.2
N IV]	1487	
C IV	1548, 1550	1.2
[Ne IV]	1575	0.2
He II	1640	0.7
O III]	1661, 1666	0.7
N III]	1749, 1750, 1752, 1754	1.1
Si III]	1892	0.5
C III]	1907, 1909	0.5

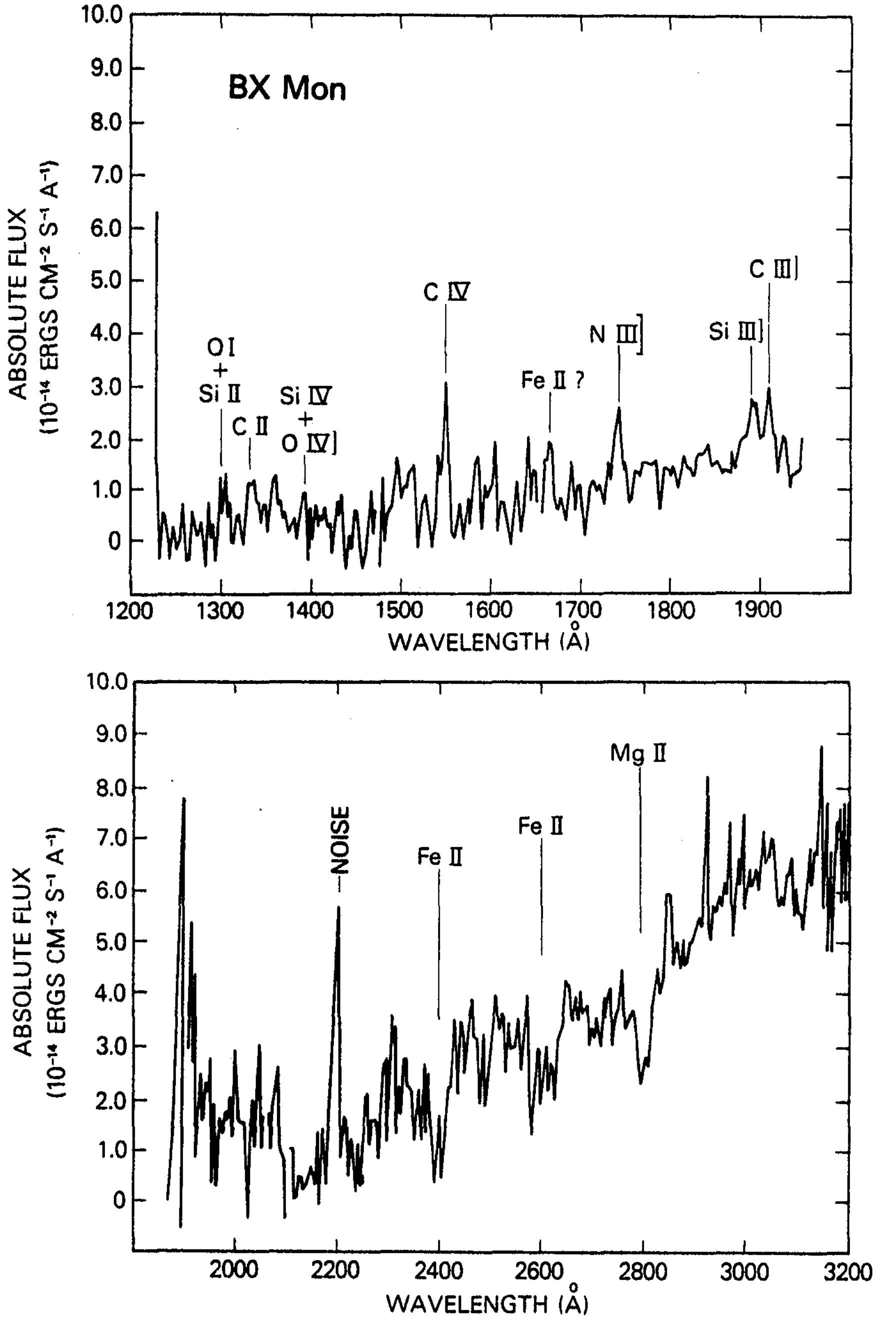

Figure 1
IUE low dispersion spectrum of BX Mon obtained using the 10" x 20" entrance aperture. Exposures of 60 minutes were used in both long and short wavelength cameras. Continuum and absorption features in the LWR range are explained by a middle A main sequence star. High excitation emission lines dominate the short wavelength range.

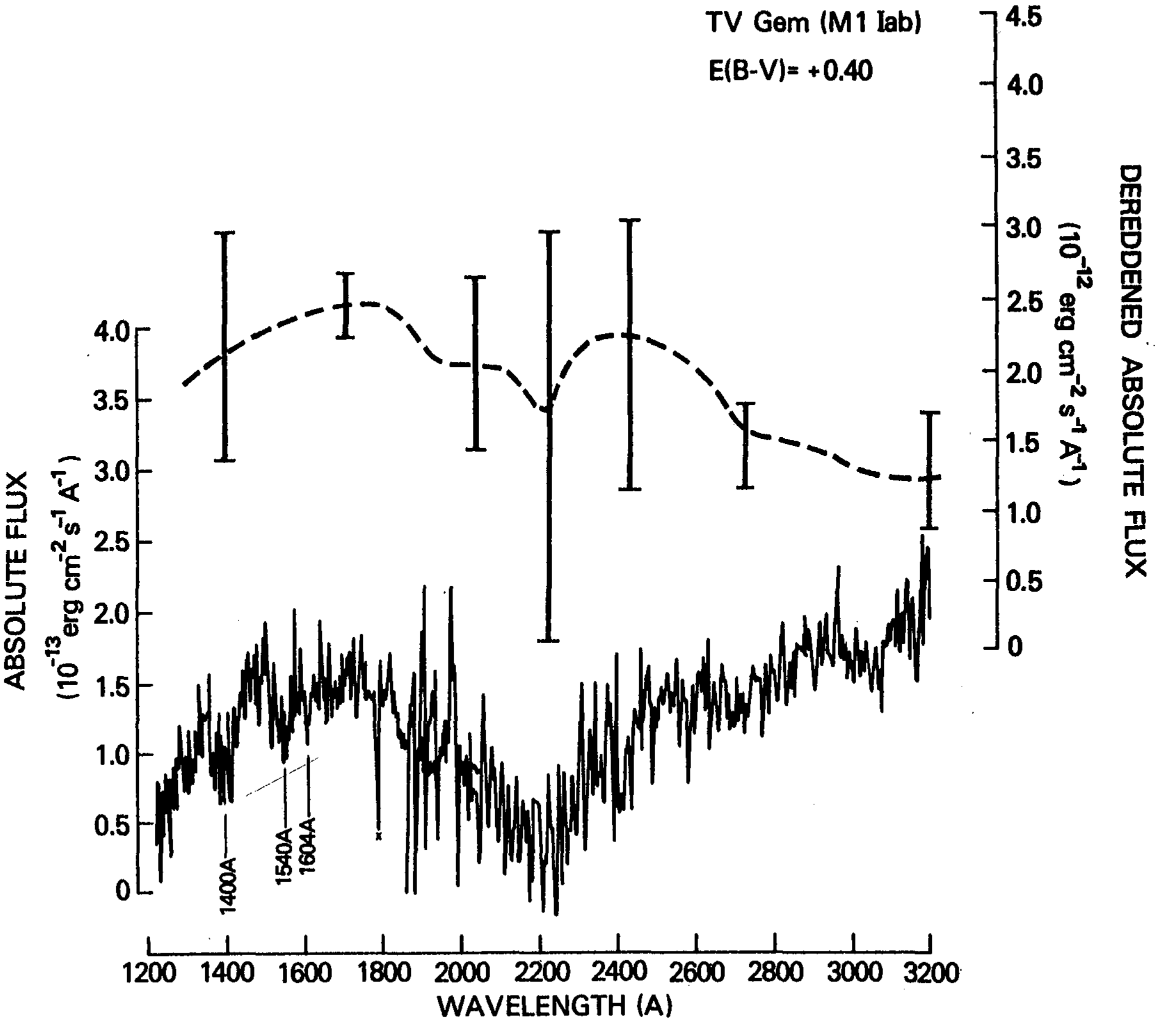

Figure 2
UV spectrum of TV Gem between 1200Å and 3200Å obtained in low dispersion using 10 minute exposures. Continuum dereddened (dashed line) by applying an E_{B-V} = +0.40 to the observed continuum. The error bars denote the uncertainty of the dereddened continuum if we consider the extreme uncertainty of the measured continuum level.