SPECTRA OF SYMBIOTIC STARS

Hagai Netzer and Elia M. Leibowitz
Department of Physics and Astronomy and the Wise Observatory, Tel Aviv University

and Gary Ferland
Department of Physics, University of Kentucky, Lexington

ABSTRACT

We have observed Z And and other symbiotic stars at the Wise Observatory and have obtained absolute flux measurements of many emission lines. Preliminary analysis of the data shows that the line emitting gas is probably photoionized by a hot, $T_* \gtrsim 200,000$ ^oK continuum, which can explain the extremely strong HeII lines. The hydrogen Balmer line intensities are different from what is predicted by recombination theory and the optical depths in Hα and Hβ must be significant. Our photoionization model can be used to deduce the geometry, density and temperature of the line emitting gas, and the nature of the hot companion.

INTRODUCTION

Symbiotic stars, unlike other objects discussed at this meeting, have long orbital periods, of the order of 1000 days, and may not be associated with a compact object. Spectroscopic study of them is the most important tool for understanding the physical processes in their line emitting zone. In this paper we present preliminary results from an ongoing project at the Wise Observatory, Israel, to monitor such objects.

OBSERVATIONS

Spectrophotometric observations of several symbiotic stars were carried out with the Wise Observatory 1-m telescope during 1981 and 1982. The detector used is a 2x936 diode self-scanned Digicon. It enables absolute flux measurements with low to moderate (1-6Å) spectral resolution over a 3500Å wavelength range. The spectrum of Z And, shown in Fig. 1, is a typical example. This spectrum was obtained with a large entrance aperture, and the flux put on absolute scale by observations of spectrophotometric standards. The linearity and stability of the Digicon enables us to measure many weak emission lines, up to a level of about

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2 percent the intensity of Hβ. The real limitation in measuring such weak features is not the detector but the underlying continuum, with the strong molecular bands. We have therefore subtracted an M giant continuum prior to the measurement of line intensities.
The present work is concerned mainly with Z And and we defer discussion of other objects to a later date.

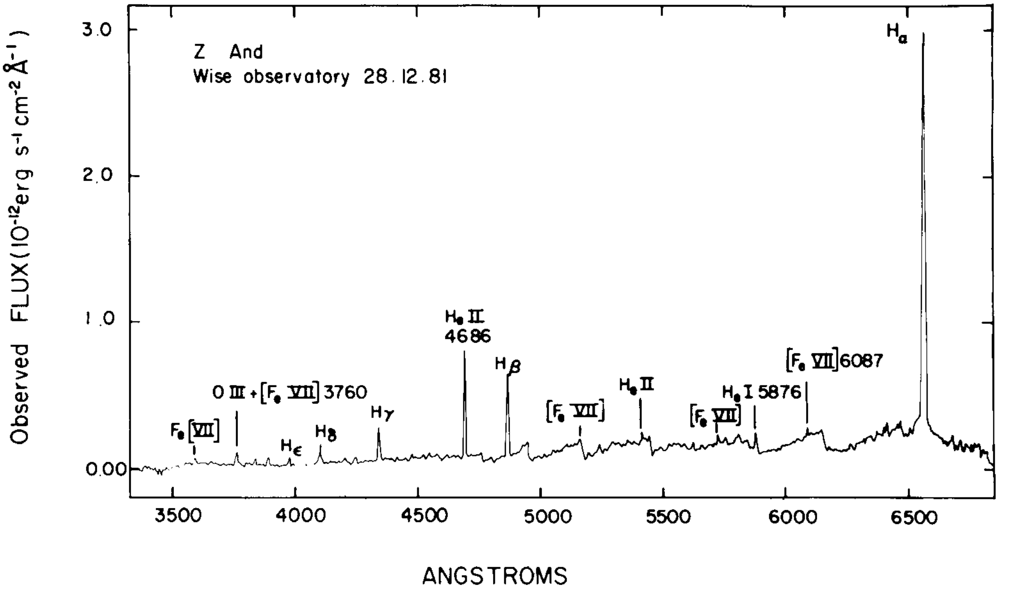

Figure 1. Digicon 110 Å/mm spectrum of Z And, obtained at the Wise Observatory in December 1981.

DISCUSSION

Our spectrum of Z And and the recent IUE data of Altamore et al. (1981) show lines of low (e.g. OI 1304), moderated (e.g. CIII] 1909) and very high excitation (e.g. [FeVII] lines). Such a large range in excitation is usually a result of photoionization by a hot continuum, and we shall assume therefore that this process is indeed the main source for ionizing and exciting the line emitting gas. We investigate the consequences of a simple model where a hot central source (hot blue companion? disc around a compact source?) illuminates some gas around it, causing heating and ionization. The line emitting gas can be anything from a skin of an accretion disc to expanding gas shell or even the atmosphere of the M star. The model is spherically symmetric so all the gas is at the same distance from the ionizing source. We assume a black body ionizing continuum and attempt to deduce its temperature from comparison of the model calculations with the observations. This simplified picture does not intend to represent a full realistic model for the system, but has some general consequences regarding some of the more important physical processes.

The spectral analysis of Z And shows:

a. [FeVII] (Nussbaumer and Storey 1982), CIII] and NIII] (Altamore et al. 1981) lines indicating $10^8 \leq N_e \leq 10^{11}$ cm^{-3} and $T_e \sim 2$ -$3x10^4$ ^oK in the line emitting gas

b. extremely strong HeII lines, in particular, HeII 4686 which is stronger than Hβ

c. very small reddening, $E_{B-V} < 0.3$

d. Balmer decrement very different from that predicted by radiative recombination theory

Point b above is most interesting, and typical also for other symbiotic stars. Possible explanations for it include:

(i) Very Hot Ionizing Source: The HeII 4686/Hβ line ratio reflects mainly the relative number of ionizing photons below and above 4 Ryd. (most photons with $h\nu > 4$ Ryd. will be absorbed by He^+). Large relative abundances of helium cannot therefore be the explanation for the abnormal line ratio (see for example Williams 1971). A high ionization temperature is needed, of at least 150,000 ^oK and possibly even 200,000 ^oK or more.

(ii) Density Bounded Emission Line Clouds: Photons with energy larger than 4 Ryd. are absorbed by He^+ ions close to the inner illuminated surface of the cloud. Softer photons, that ionized hydrogen, are absorbed deeper inside. Density bounded situations, in comparison with radiation bounded cases, would favour the excitation of HeII 4686 over that of Hβ.

(iii) Optically Thick Hydrogen Balmer Lines: The strong HeII 4686/Hβ may in fact be the result of a relatively weak Hβ, rather than a very strong HeII 4686. The observed Hα/Hβ ratio in Z And is about 6, and is much larger than the recombination case B value of 2.8. The reddening deduced from other lines is too small to explain this and also there is no single E_{B-V} that can explain both Hα/Hβ and Hγ/Hβ. One must look therefore for other processes that affect the hydrogen spectrum.

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Study of Balmer decrement in Quasars and Seyfert galaxies shows that self-absorption in the Balmer lines must be common and important (Netzer 1975). The result of this is a steep Balmer decrement, quite similar to the one seen in Z And. The optical depth in the Balmer lines depends on the incidence flux of ionizing photons, and can be calculated once this is known (Ferland and Netzer 1979). We have calculated $\tau(H\alpha)$ for our best fit photoionization model and found it to be much larger than 1. Strengthening this conclusion are the observed strong OI lines at 8446 and 1304Å. These lines are excited by OI fluorescence with $L\beta$ and are further enhanced if $\tau(H\alpha)$ is larger than 1. Their unusual strength in the spectrum of Z And is another indication of considerable optical depth in the Balmer lines.

A common property of nebulae with $\tau(H\alpha) > 1$ is an $H\beta$ weaker by a factor of ~ 2 than predicted by recombination theory. This helps to explain the anomalous HeII 4686/$H\beta$ in Z And. Another prediction, yet to be checked observationally, are changes of $H\alpha/H\beta$ and $H\gamma/H\beta$ intensity ratios, following variations of the ionizing continuum.

To summarize, our model and analysis indicate physical conditions in the emission line gas around Z And that are very different from those in low density nebulae. Line transfer effects are probably important and the gas may be density bounded. A very high ionization temperature continuum, possibly of $T_* > 200,000\ ^{o}K$ is also indicated. This puts severe limitations on models of symbiotic stars involving discs around main-sequence stars. Obviously much more work is still needed, especially if discs are present, and disc-type continuum, rather than a simple black body is causing the ionization. We are attempting to incorporate these modifications into our model, so that a better fit with the observation is achieved.

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DISCUSSION FOLLOWING H. NETZER'S TALK

BATH: I would just like to make the comment that by taking a single temperature source you have immediately taken a source which is not the expected source in symbiotic stars, in the sense that, most of us now believe that accretion is important and if disks are formed, then you have a temperature distribution over them which in main sequence accretion goes from 3000°K to 10^{5}°K and with white dwarf accretion it can go to 10^{6}°K, before it becomes super Eddington. Therefore you've got to worry in your photoionization balance calculations about a variation in the temperature of the exciting source and I wonder how much that will effect the conclusions that you make about the properties of the emission line region.

NETZER: I certainly agree with you. We are definitely going to put there something which is similar to the models that you have predicted. The main thing is that you need a very hot component there, you must have something there which is as hot or maybe hotter than $2x10^{5}$°K.

FRIEDJUNG: Just two or three little points: firstly there are some problems about the energy distribution of symbiotics that are not properly understood, we need high resolution IUE observation. Secondly, there is good reason to suppose in many symbiotic stars that a lot of the emission lines are formed in the winds from the red component, there are some indications for a radial velocity shift in the UV. Finally, I think that the physics of line excitation is more complicated, photoionization obviously does occur, there may be some regions with high electron temperature.

WILLIAMS: Why couldn't all of this be happening in the chromosphere of the secondary star?

NETZER: That is fine with me, I can tell you roughly what is the distance between the photoionizing source and the cloud and that is about the right distance, also I can tell you that the covering factor of the system is much smaller than one.

WILLIAMS: So you don't have to postulate the existence of clouds.

NETZER: No, this was just for illustration.

ROBINSON: Is it your impression looking at published spectra by other people that they will need higher temperatures for their central sources or lower than Z And, in particular, can you see if you will ever need temperature more like 10^{6} rather than a few times 10^{5}?

NETZER: I have seen at least two or three others with very strong He II lines, so for them it will be just the same, there may be some others which have weaker lines, but $2x10^{5}$°K is a lower limit for some of them.

LIVIO: You have actually stated a lower limit of $2x10^{5}$°K, if you could say that you can fit the observations better with 10^{6}°K this may mean that you need a compact object in there, while if you can do it with 10^{5}°K you may not need it.

NETZER: My impression is that you cannot do it with 10^{6}°K black body, you will need a disk component, which will contribute at softer energies, so if you take just a black body at 10^{6}°K, the answer is no, but that is not a good approximation anyhow.

KING: Since you have such large line opacities wouldn't it be the case that your ratios will be affected by the deviation from spherical symmetry, so that if it is the secondary, as it moves around, your predicted ratios should change.

NETZER: Yes, definitely, if you talk about Balmer decrement, my prediction is that it should change.

SHAVIV: Is the continuum between the lines real continuum or noise?

NETZER: First, you have seen the M giant which was very strong and that was subtracted by another M giant.

SHAVIV: Do you then have an estimate for the relative energy in all the lines and the continuum.

NETZER: Yes, I do, this comes from other people's observations with the IUE, this relates to my answer about the covering factor (how much of the source is covered by clouds) and this is a very small number of the order of 10%.