ANALYSIS OF THE SYMBIOTIC STAR AG PEGASI

Charles D. Keyes and Mirek J. Plavec
Department of Astronomy, University of California, Los Angeles

ABSTRACT

High and low dispersion IUE data are analyzed in conjunction with coincident ground-based spectrophotometric scans and supplementary infrared photometry of the symbiotic object AG Pegasi. The IUE observations yield an improved value of E(B-V) = 0.12. The two stellar components are easily recognized in the spectra. The cool component may be an M1.7 III star and the hot component appears to have T_{eff} of approximately 30000 K. The emission lines observed in the ultraviolet indicate two or three distinct emitting regions. Nebular component ultraviolet intercombination lines suggest an electron density of several times 10^{10} cm^{-3}.

INTRODUCTION

AG Pegasi (HD 207757) is a well-known symbiotic star, although it does not display the irregular outbursts that are typical of most symbiotics. It brightened only once, over 100 years ago, and has been declining ever since. The important work of Hutchings, Cowley, and Redman (ref. 1) describes the spectral peculiarities and changes which have interested many ground-based investigators over the years. The first satellite ultraviolet observation, and first direct evidence of a hot star in the system, was the broad-band OAO-2 photometry of Gallagher et al (ref. 2).

AG Pegasi was observed with IUE in August and November, 1978 by MJP. Both high and low dispersion SWP images and only low dispersion LWR images were obtained. Coincident ground-based spectrum scans of high photometric accuracy were made in the 3200-7000 Å region with the Cassegrain Image Dissector Scanner (IDS) on the Lick 3-meter Shane telescope in August, 1978 by CDK. Figure 1 shows the combined observed spectrum of AG Peg. It is quite gratifying to note that the three IDS scans and two IUE images match extremely well with no artificial shifting imposed. It should also be noted that all SWP IUE images have been corrected for the image processing error originally present in the data.

We have re-evaluated the interstellar reddening of AG Peg with the extinction curve of Seaton (ref. 3) and found the color excess to be E(B-V) = 0.12 ± 0.03 from the 2200 Å extinction feature. The larger value of 0.2 obtained by Gallagher et al. is probably due to the very strong emission lines contaminating their broad-band photometry shortward of 2000 Å.

The observations show clearly the presence of both a hot and a cool component in the system. The IUE spectra are dominated by a

number of extremely strong emission lines and a bright continuum that rises steadily toward shorter wavelengths. The IDS spectra show that the decline of the ultraviolet continuum continues to approximately 4300 Å where the continuum begins a steady rise to the red.

THE COOL COMPONENT

Infrared photometry of AG Pegasi has been published by Szkody (ref. 4) and Swings and Allen (ref. 5). We have previously (ref. 6) obtained a value of $f_e = 5.5 \pm 0.8 \times 10^{-8}$ ergs-cm^{-2}sec^{-1} for the total observed continuous flux of the cool component (corrected for interstellar extinction). This result was based upon an integration of the published photometry and upon an independent extrapolation of our Lick spectrophotometry. Colors obtained from the Szkody magnitudes were also used to determine the spectral type of the cool component in the system of Lee (ref. 7). On the assumption that the luminosity class is III, the colors formally indicate a classification of M1.7 III. Comparison of our Lick scans with standard stars 104 Her (M1 III) and 2 Peg (M3 III) shows that AG Peg is intermediate between them and suggests that the cool component may be normal. The effective temperature, according to Lee, is 3570 K.

Consistently throughout this presentation we shall express the distance d in kpc and the stellar parameters in solar units. The general formula

$$R = 5.89 \times 10^{12} \ T^{-2} \ d \ f^{0.5} \qquad (1)$$

leads to the following relations for the cool component:

$$R_c = (108 \pm 9)d \qquad L_c = (1720 \pm 260)d^2 \qquad MBOL_c = (-3.3 \pm 0.2) + 5 \log d \qquad (2)$$

If the cool component really is luminosity class III, then using the calibration of Lee, $MBOL_c = -1.9$, R = 56 $R_\odot$, and d = 0.5 kpc. If the luminosity class is II, $MBOL_c = -3.8$, R = 134 $R_\odot$, and d = 1.24 kpc (z = 0.6 kpc below the galactic plane), and, even in this case, the star would be substantially smaller than its critical Roche lobe, estimated by Hutchings et al to be 285 $R_\odot$.

THE HOT COMPONENT

The total continuum flux (corrected for extinction) between 1200 and 3200 Å is $f_h = 1.26 \times 10^{-8}$ erg-cm^{-2}sec^{-1}. (The emission lines, incidentally, contribute an additional 27 percent.) This observed continuum is most likely a combination of a true stellar continuum and the continuous radiation of a nebular H II region.

The hot component spectrum is clearly contaminated by that of the cool component longward of 4300 Å. We have attempted to remove the cool component contamination by subtracting a scan of the M1 III standard 2 Peg from AG Peg in the 3400-5500 Å region. The scans were normalized and were virtually identical in the 5300-5500 Å interval where the hot component contributes negligibly to AG Peg. Figure 2 shows the resultant

energy distribution of the hot component plus hydrogen nebula compared with the Kurucz (ref. 8) model atmosphere energy distributions that provide the two best fits. By fitting the energy distributions we determine from (1)

$$T = 25000 \quad R_h = 1.34\ d \quad L_h = 635\ d^2 \quad MBOL_h = -1.94 - 5 \log d \quad (3)$$

$$T = 30000 \quad R_h = 1.0\ d \quad L_h = 730\ d^2 \quad MBOL_h = -2.40 - 5 \log d \quad (4).$$

For the surface gravitational acceleration we get

$$\log g = 4.4 - 2 \log d \quad\quad\quad (5)$$

if we assume the hot object mass is not too different from one solar mass (ref. 1). A subdwarf is indicated, despite the model log g. Indeed, the Wolf-Rayet character of some of the ultraviolet emission features (see next section) implies a wind blowing outward from the hot component and that some sort of extended region of line formation must exist. Moreover, model atmosphere calculations of hot stars with extended atmospheres have shown that the resultant energy distributions tend to resemble those of cooler, less extended atmospheres (ref. 9). Therefore, it would be quite surprising if a standard, plane-parallel, LTE, high surface gravity, normal composition atmosphere represented well this subdwarf.

Note that there is a modest flux excess in the 3000-4000 Å region that grows more pronounced as models hotter than 30000 K are tried. This excess is doubtlessly due in part to continuous Balmer emission, the overlapping of high Balmer lines, and perhaps free-free emission. We are currently attempting to adequately combine emission from a hydrogen nebula with individual stellar models in the hope of producing a better fit.

As a result of the Wolf-Rayet character of some lines, we also compared the ultraviolet energy distribution of AG Peg with the TD-1 observations of several Wolf-Rayet stars by Willis and Wilson (ref. 10) in the 1350-2550 Å region. Their one WN5 (HD 50896) and one of two WN6 (HD 192163) stars displayed continua clearly steeper than that of AG Peg. The remaining WN6 star (HD 191765), for which Willis and Wilson find a surprisingly similar temperature to HD 192163, provided a better, though not perfect, match in this spectral region. Willis and Wilson determined a Zanstra temperature, based upon the 1640 Å He II equivalent width and a grid of Kurucz model atmospheres, of 29200 K for HD 191765. Using the tabulations of Willis and Wilson we determine the He II 1640 Zanstra temperature for AG Peg to be 31900 K. We should note that the 1640 equivalent width in AG Peg is considerably stronger than that of either WN6 star in the Willis and Wilson sample.

THE EMISSION LINES

Emissions of N V, C IV, Si IV, and lower ions of these elements are present in the IUE spectra. No O IV is seen, although the O III 1663 Å doublet and several of the Bowen flourescent lines are visible.

A quite well-developed recombination spectrum of He II is also present. The high dispersion IUE spectra show that the line profiles are quite complex and that many lines have two or three components.

One component comes from a highly ionized region near the hot object and shows broad P Cygni profiles of a Wolf-Rayet character. The N V resonance doublet at 1239 and 1242 Å and the permitted N IV 1718 line show this structure. The N IV] intercombination line at 1486 Å (Fig. 3) displays both the broad Wolf-Rayet structure and a sharp, nebular component (FWHM = 0.3 Å) which apparently is formed in a more distant, quiescent region.

All the other intercombination lines, C III] 1909 Å, Si III] 1892 Å, and the N III] 1750 Å group, display only the sharp, nebular component. The resonance doublet of C IV at 1548 and 1550 Å (Fig. 4) shows the nebular emission component and several narrow, blue-shifted absorptions superposed on a broad 1550 emission. The 1548 component is quite weak, probably due to a broad P Cygni absorption of the 1550 line.

An analysis of the line strengths of the N III] 1750 multiplet indicates that the electron density in the N III] region must be between 1×10^{10} cm^{-3} and 5×10^{10} cm^{-3}. The presence of the C III] 1909 Å line, the absence of C III 1906 Å, and evaluation of critical densities for collisional de-excitation of the relevant energy levels are consistent with this result. Maximum densities implied by the other intercombination lines are also all less than approximately 10^{11}.

COMMENTS

The symbiotic stars are a group of objects where, in spite of considerable effort, non-controversial models were not possible before the advent of IUE (and perhaps not after). In the optical spectrum, a late type continuum is observed on which are superposed emission lines (H, He I, He II, C III, N III, and some forbidden lines), which require a radiation source much hotter than the K or M type giant whose absorption spectrum is visible. Single- and binary-star models were proposed, and both may have some validity, since the group may very well be heterogeneous. An inspection of Fig. 1 shows why the dilemma was practically unsolvable without ultraviolet spectroscopy. In the optical region, the hot component is virtually unobservable, having a much smaller radiating surface. In fact, the small "ultraviolet excess" and "absorption line veiling" contaminating the late-type spectrum shortward of about 5000 Å seems to be due to free-free and bound-free radiation of hydrogen, naturally excited by the hot component, but testifying only indirectly to its presence. For AG Peg, we find the radius of the hot subdwarf on the order of 1 R$_\odot$, effective temperature probably about 30000 K, while the mass may be 1 - 2 M$_\odot$. The profiles of the emission lines are composite, and the broadest components suggest a similarity between the hot star and the WR nuclei of planetary nebulae. In the past century, the outflow of mass from AG Peg had the character of an extremely slow nova. The red giant component

is probably not merely a passive companion; more likely, it triggered the activity and is the ultimate source of much of the material. Yet it appears now to be much smaller than its Roche limit – a rather vexing dilemma.

One of the current problems is the actual temperature of the hot component. Michalitsianos et al. (ref. 11) believe that the hot component temperature in RW Hydrae must be above 10^5 K, and explain that the continuum longward of about 2000 Å is due to a hydrogen cloud. Since AG Pegasi closely resembles the Wolf-Rayet spectra for which Willis and Wilson postulate temperatures only on the order of 30000 K, we think that such a temperature is sufficient to explain both the ultraviolet continuum and the strength of the He II lines, and that the hydrogen cloud contributes only modestly in the vicinity of the Balmer jump in AG Pegasi.

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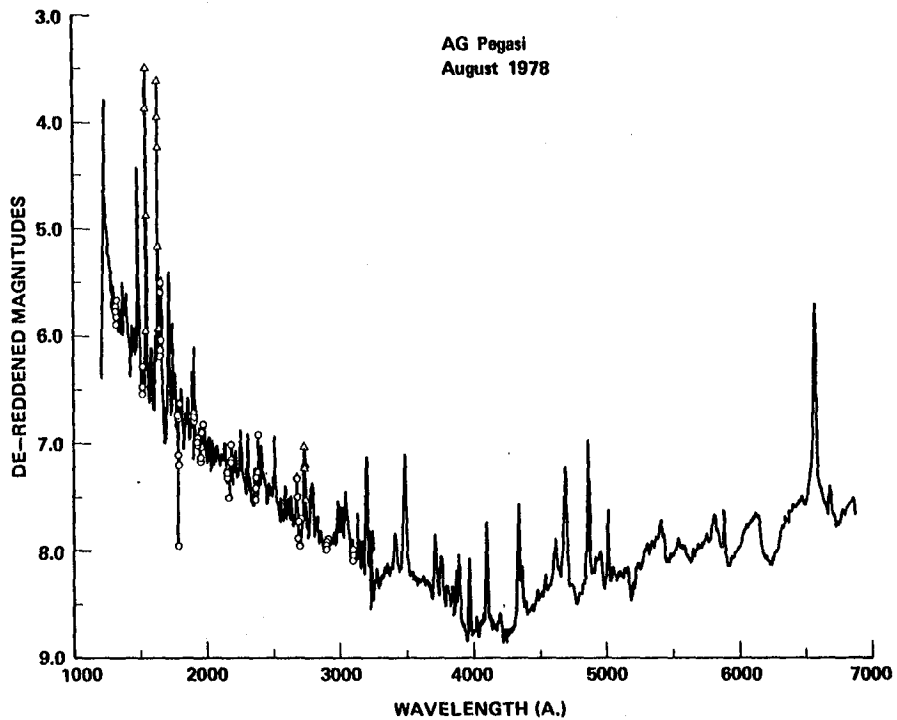
Fig. 1.: Spectrum of AG Pegasi, 1200-7000 Å. Circles mark reseau contamination, triangles are saturated pixels.
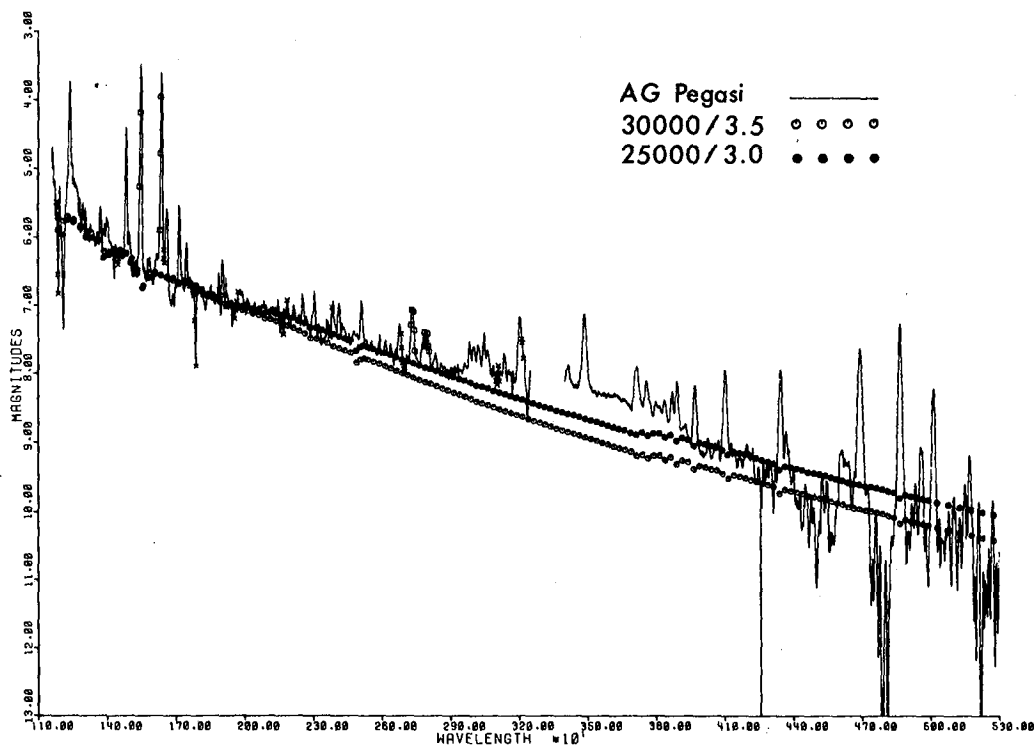

Fig. 2.: Spectrum of hot component and hydrogen nebula only compared with best two Kurucz atmosphere fits for AG Peg.
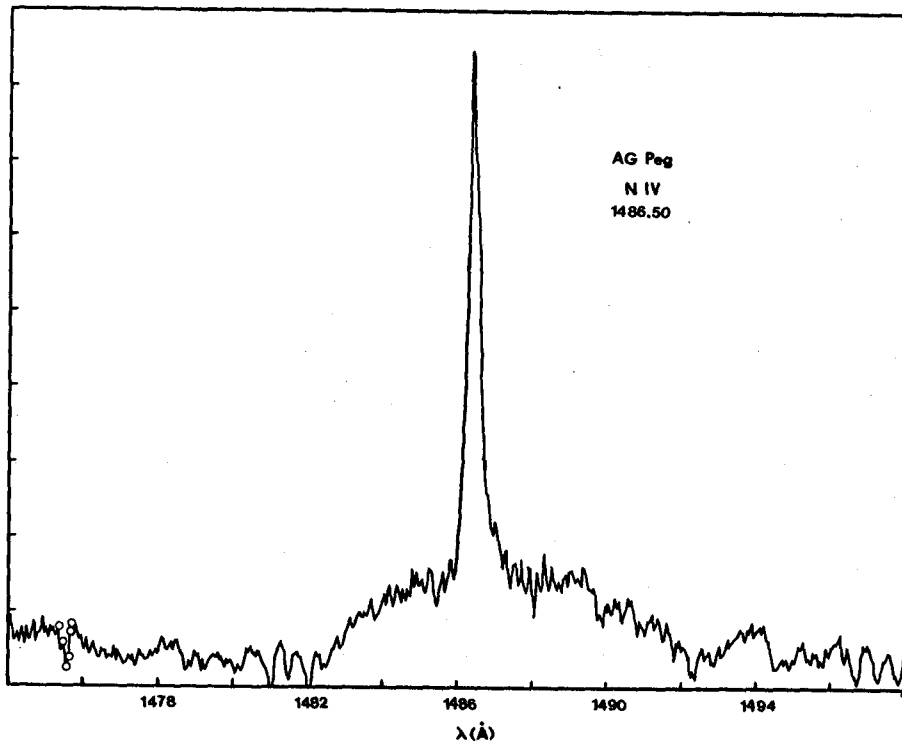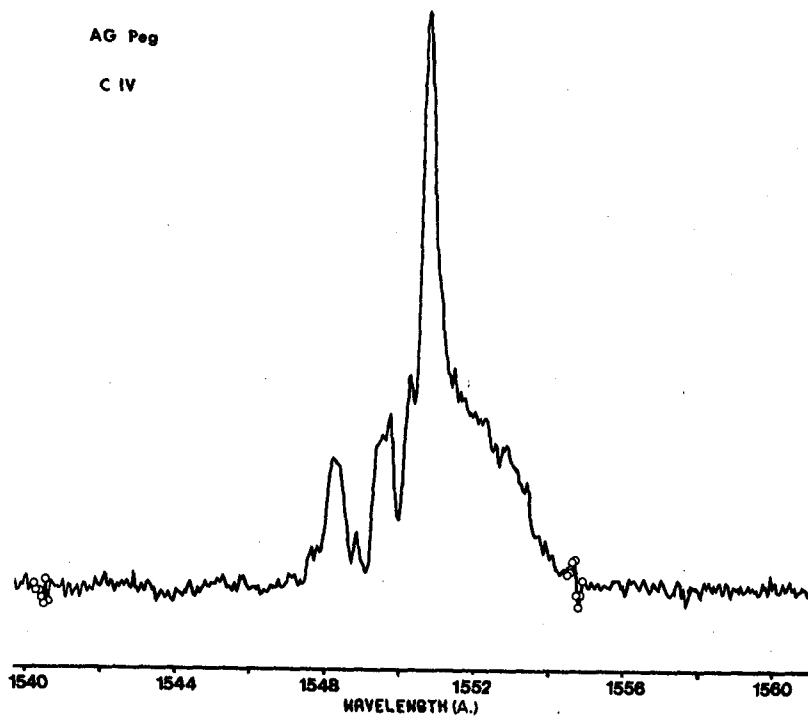
Fig. 3.:   The N IV] 1486 line in AG Pegasi.

Fig. 4.:   The C IV 1548, 1550 resonance doublet in AG Pegasi.

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