X. ... AND THE REST (SYMBIOTICS, SUPERGIANTS, PLANETARIES, POPULATION II SYSTEMS)

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THE SYMBIOTIC BINARY SYSTEM AG PEGASI

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ABSTRACT

A complete coverage of the spectrum of AG Peg has been obtained between wavelengths 1200 - 7000 A by us, and can be supplemented by IR photometric observations by others. Our IUE observations yield a lower value of E(B-V), about 0.12. The two stellar components are easily recognized, but their characteristics are still rather uncertain.

The cool component may be a normal M1.7 III giant, but the temperature and luminosity of the hot star remain largely indeterminate. Firstly, there are no good models for a hot subdwarf, and secondly, it is difficult to determine the relative contribution of the star itself and the surrounding hydrogen cloud.

The emission lines observed in the UV have double or triple structure, indicating two or three distinct emitting regions.

INTRODUCTION

AG Pegasi is a prominent representative of the symbiotic stars, although it lacks one typical characteristic, namely persistent flare activity. It brightened only once, about 100 years ago, and has been on the decline all the time since. It is probably an extremely slow nova. Its smaller-scale light fluctuations, and in particular its spectrum peculiarities and variations have over the years attracted the attention of many investigators, notably of Merrill, Boyarchuk, Hutchings and Redman, Cowley and Stencel. References to their work can be found in the important paper by Hutchings, Cowley, and Redman (1975), which concluded the period during which no direct evidence existed for the presence of a hot component, although the binary nature of the object was no longer in doubt.

A new era started when observations in the satellite ultraviolet brought about direct evidence for the presence of a hot star. Gallagher et al. (1979) discussed broad-band photometry from the OAO-2 satellite. They concluded that the hot component is a very luminous UV source with

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a luminosity probably lying between 1000 $L_{\odot}$ (if the cool component is a normal M3 III star) and 8100 $L_{\odot}$ (if the cool component fills its critical Roche lobe). They preferred the higher luminosity as it can better explain the nova-like eruption.

AG Pegasi has been studied at UCLA for several years as part of CDK's thesis on symbiotic stars. Our contribution to be discussed here consists of scans obtained with the 120-inch Shane telescope of Lick Observatory, and of MJP's IUE scans made with low and high dispersions in 1978.

We re-examined the interstellar reddening of AG Peg and found the color excess to be most likely E(B-V) = 0.12 ± 0.03, from the 2200 A extinction bump. The higher value of 0.2 obtained by Gallagher et al. is probably due to emisssion lines contaminating the broad-band OAO-2 photometry. With the adopted color excess, we derived the overall energy distribution between 1200 and 7000 A shown in Fig. 1. The photometric accuracy of the Lick IDS scanner is well known. It is very gratifying to see that the three scans made with three different grating settings, and the two scans with the two IUE cameras match very satisfactorily: no arbitrary shifts were made.

THE COOL COMPONENT

For both components, the scans cover only a small fraction of their total luminosities. There appears to be less ambiguity in the case of the cool component. Infrared photometry of AG Peg was published by Szkody (1977) and Swings and Allen (1972). Their excellent mutual agreement suggests that there probably has been little variability in the IR. An independent estimate of the total flux from the cool component was based on our Lick spectrophotometric data from the interval 4260 - 6800 A. The scanner data from the interval 3200 - 4260 A cannot be used, since it contains an unknown admixture of the radiation of the hot component and/or b-f and f-f hydrogen continuum. The two estimates give for the total observed flux (corrected for interstellar extinction) a value $f_c = 5.5 \times 10^{-8}$ erg/cm^2/s, with a 15% estimated uncertainty.

The colors obtained from Szkody's magnitudes were used to determine the spectral type of the cool star, using Lee's (1970) calibration. Assuming that the luminosity class is III, we find an encouraging agreement of four different estimates, and adopt the mean, M1.7 III. Comparison of our scans with two standards, 104 Her (M1 III) and 26 Peg (M3 III) indeed places AG Peg in between them, and suggests that the cool component may be normal, contrary to some previous conclusions presumably affected by the transition region shortwards of about 4200 A. The effective temperature of M1.7 III in Lee's calibration is 3570 K. We will consistently express the distance d in kpc and the stellar parameters in solar units. Then the general formula

$$R = 5.89 \times 10^{12} \quad T^{-2} \quad d \quad f^{1/2} \tag{1}$$

leads to the following equations for the cool component:

$$R_c = 108 \quad d \quad , \quad L_c = 1720 \quad d^2 \quad , \quad M_c = -3.3 - 5 \log d \quad . \tag{2}$$

If the cool star is really M1.7 III, then $d = 0.5$ kpc and $R_c = 56\ R_\odot$. Luminosity class II giants are 1.9 mag brighter, so the radius would be 134 $R_\odot$ and $d = 1.24$ kpc ($z = 0.6$ kpc below the galactic plane). Even in this case, the star would be substantially smaller than its critical Roche lobe, estimated to be 285 $R_\odot$ after Hutchings, Cowley, and Redman (1975).

THE HOT COMPONENT

The observed (and corrected for extinction) flux between 1200 and 3260 A is $f'_h = 1.26\times10^{-8}$ erg cm^{-2} s^{-1} . (Emission lines in the same region contribute an additional 3.45×10^{-9} erg cm^{-2} s^{-1}, i.e. 27% on top of the observed continuum). The observed continuum is most likely a blend of a true stellar continuum and continuous radiation of a hydrogen nebula.

Two extreme cases can be considered. In the first alternative, the radiation contaminating the flux from the cool star around 4000 A (in fact, with traces going up to 5200 A) is attributed mainly to the hot star directly. In this case, the whole observed "hot" continuum between 1200 A and 5000 A can be reasonably well fitted by a Kurucz model with $T_{eff} = 25{,}000$ or 30,000 K. Only a relatively weak b-f contribution shortward of the Balmer limit is needed in this case. For $T = 30{,}000$ K we then get from (1):

$$R_h = 1.03 \quad d \quad , \quad L_h = 773\ d^2 \quad , \quad M_h = -2.46 - 5 \log d \quad . \tag{3}$$

Also, for the surface gravitational acceleration we get

$$\log g = 4.4 - 2 \log \quad d \ , \tag{4}$$

so that the good fit found for $\log g = 4.5$ is not inconsistent with the rest of the data, if we assume that the mass of the hot star will not be much different from one solar mass. However, the fact that $T_{eff} = 25{,}000$ K and $\log g = 3.0$ gives an even better fit casts doubts on the procedure. It would indeed be surprising if a standard plane-parallel LTE and normal-composition atmosphere represented well the hot subdwarf. The most seriuos argument against this fit is, of course, that the star must radiate enough photons capable of ionizing He II, since the He II recombination spectrum is strong.

In the second extreme alternative, we may assume that the contaminating radiation around 4000 A is all due to a hydrogen cloud. This implies a much higher temperature for the central star, but enables us to avoid assigning high luminosity to it, because we may assume that the star's flux falls off very rapidly already in the far UV and becomes negligible longward of, say, 2000 A. Then the observed (corrected) flux from the star is only 8.8×10^{-9} erg cm^{-2} s^{-1}. Assume, quite tentatively, that the star's temperature is 10^5 K and that it is nearly represented by a black body. Then the total flux is $f_h = 1.6\times10^{-7}$ erg cm^{-2} s^{-1} and we have, in analogy to (3),

$$R_h = 0.24 \text{ d} \quad , \quad L_h = 5000 \text{ d}^2 \quad , \quad M_h = -4.5 - 5 \log \text{d} \quad . \qquad (4)$$

In principle, an analysis of the strength of the He II lines, combined with properly matching the two components (stellar and nebular) of the continuum, should determine the star's parameters. Although we are trying hard, we are not sure that the solution will be well determined. There are no good models of hot subdwarfs that would reliably give the number of photons emitted shortward of 227 A (Bohlin, Harrington and Stecher, 1978), and the continuum fitting will be largely arbitrary since the stellar continuum will probably not be adequately modelled.

THE EMISSION LINES

Besides a well-developed recombination spectrum of He II, the UV spectrum of AG Pegasi shows a number of strong emission lines such as N V, C IV, Si IV, and lower ions of these elements. The high-dispersion IUE spectra show that the line profiles are quite complex: we can distinguish two or three components in most lines.

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 lines at 1239 and 1242 A and the permitted N IV 1718 line show this structure. The N IV] intercombination line at 1486 A (Fig. 2) displays both the broad Wolf-Rayet structure and a sharp nebular component (FWHM = 0.3 A) which is apparently formed in a more distant, quiescent region.

All the other intercombination lines, C III] 1909 A, Si III] at 1892 A, and the N III] λ 1750 group, display only the sharp, nebular component. The resonance doublet of C IV at 1548 and 1550 A (Fig. 3) shows the nebular emission component and several narrow, blue-shifted absorptions superposed on a broad λ 1550 emission. The 1548 A component is quite weak, probably due to a broad P Cygni absorption component of the 1550 line.

The presence of C III] 1909 A, the absence of C III] 1906 A, and evaluation of critical densities for collisional de-excitation of the relevant energy levels establishes a density range between 10^7 and 10^9 cm^{-3} for the nebular emitting region. Maximum densities implied by the other intercombination lines are all less than 10^{11} cm^{-3} .

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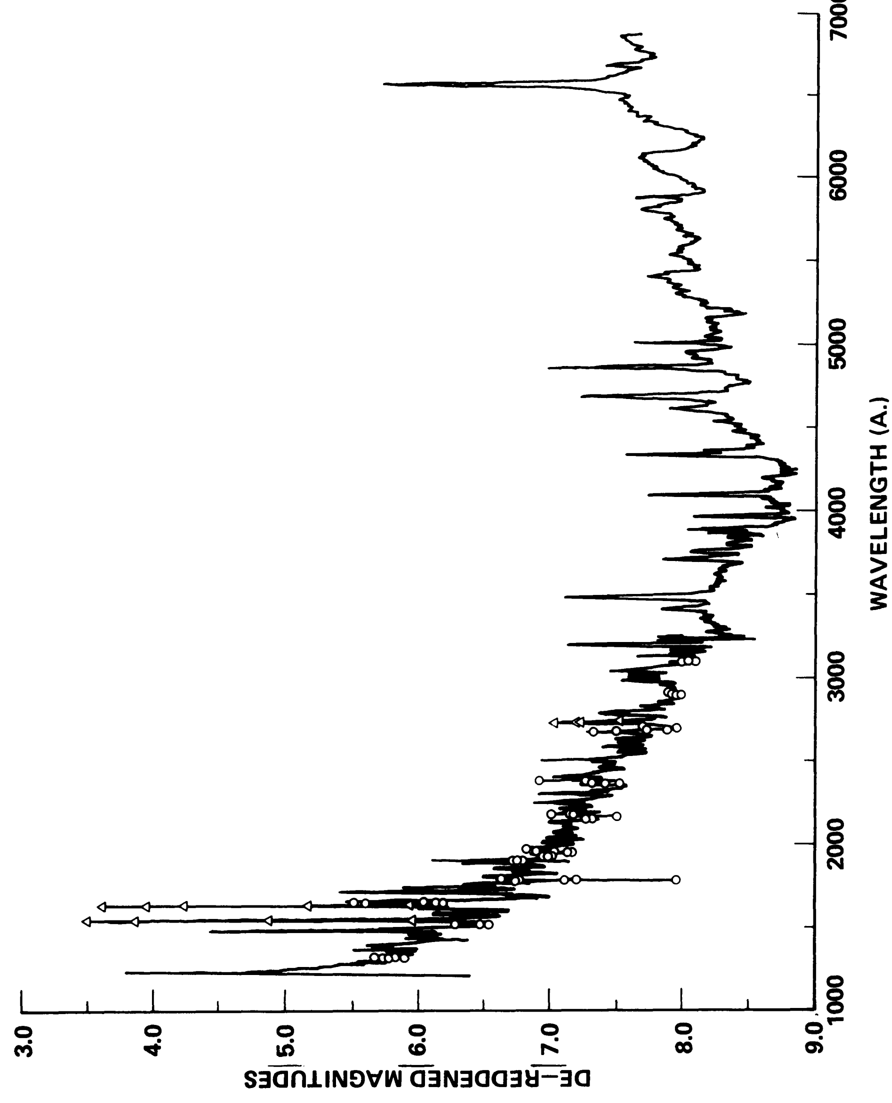

Fig. 1: Spectrum of AG Pegasi, 1200-7000 A.
Circles mark reseau contamination, triangles are saturated pixels.

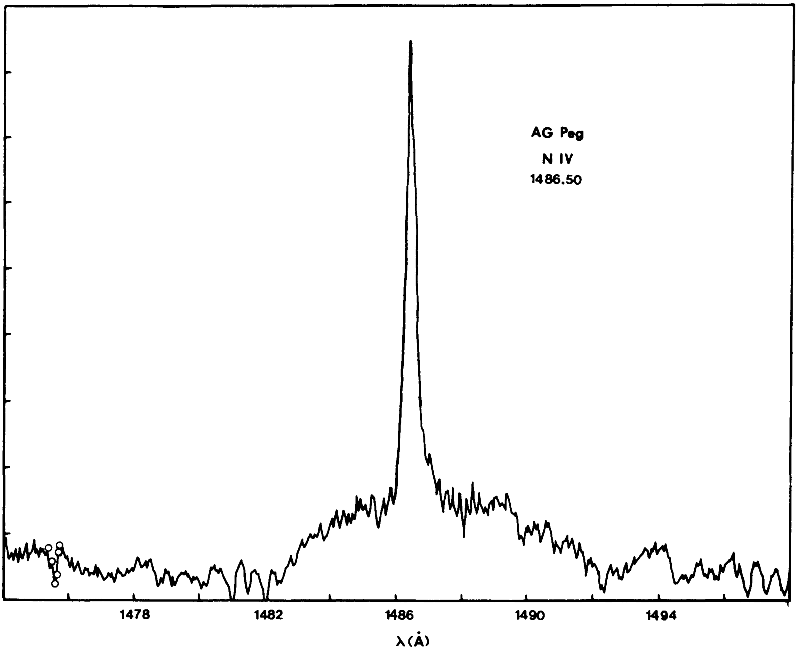

Fig. 2: The N IV] line in AG Peg.

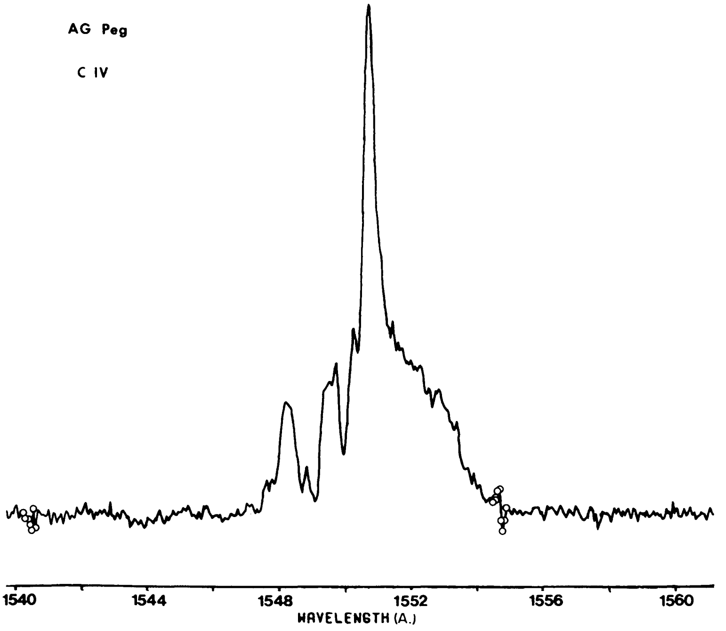

Fig. 3: The C IV resonance doublet in AG Pegasi.

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A FEW COMMENTS -- RATHER THAN A CONCLUSION

The cool star appears to be much smaller than its Roche lobe. Indeed, Hutchings, Cowley, and Redman (1975) postulate a stream flowing from the hot star towards the cool component. Yet the M star must play (or have played) an important role in the system, and probably was the ultimate source of the material that triggered the nova-like outburst about a century ago. One can obtain an M giant in a long-period binary system by letting a K giant lose mass via Roche lobe overflow (Plavec, Ulrich, and Polidan, 1973). However, such a mass transfer is almost inevitably catastrophic as it comes from a deep convective envelope, and would probably give the system a quite different character. Mass loss via a strong stellar wind is more likely for the M star.

The M star is probably more massive than the hot component, which appears to be more advanced in evolution. This indicates that we may be witnessing the second mass transfer phase. In the first phase, which could have been a case B, the initially more massive star lost most of its mass and was transformed into a helium star located now not far from the white dwarf region.

Although the low log g we have found for the hot star is probably quite spurious, the object may be extended. It is in the related star AR Pavonis (Thackeray and Hutchings 1974). Since AG Peg behaves like an extremely slow nova, Bath's model of an effective photosphere formed in an optically thick wind (Bath, 1978) may well apply.

A number of binary systems do not meet all criteria for being called symbiotic, but bear distinct resemblance to them and must be considered as possibly related to the symbiotics. AR Pavonis is a bona-fide symbiotic star, but may also be classified as a long-period Algol. It is in turn similar to RX Cas, a member of the "W Serpentis group" described by Plavec at this Symposium. Those stars display strong emission lines of C IV, N V, Si IV etc., apparently formed by collisions in a stellar wind. This strongly suggests that the emission lines observed in AG Peg may in part be formed in a similar regime.

REFERENCES

Bath, G.T.: 1978, Mon. Not. R.A.S. 182, 35.
Bohlin, R.C., Harrington, J.P., and Stecher, T.P.: 1978, Ap. J. 219, 575.
Gallagher, J.S., Holm, A.V., Anderson, C.M., and Webbink, R.F.: 1979, Astrophys. J. 229, 994.
Hutchings, J.B., Cowley, A.P., and Redman, R.O.: 1975, Ap. J. 201, 404.
Lee, T.A.: 1970, Ap. J. 162, 217.
Plavec, M., Ulrich, R.K., and Polidan, R.S.: 1974, Pub. A.S.P. 85, 769.
Swings, J.-P. and Allen, D.A.: 1972, Pub. Astr. Soc. Pacif. 84, 523.

Szkody, P.: 1977, Astrophys. J. 211, 432
Thackeray, A.D. and Hutchings, J.B.: 1974, Mon. Not. R.A.S. 167, 319.

DISCUSSION FOLLOWING KEYES AND PLAVEC

Guinan: Has AG Pegasi been detected as an X-ray source with the Einstein telescope? The strength of some of the emission features would indicate that it would have a substantial X-ray luminosity.

Keyes: To my knowledge, AG Pegasi has not been detected by X-ray detectors prior to Einstein. I do not know if it has been observed with Einstein.

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