ULTRAVIOLET PROPERTIES OF THE SYMBIOTIC STARS

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1. Introductory Remarks

Prior to the launch of the IUE satellite in early 1978, the only symbiotic star previously detected in the ultraviolet by earlier UV satellites, such as the OAO-2, TD-1 and ANS experiments, was AG Pegasi = HD 207757 (Gallager et al. 1979). These broad-band observations indicated that the symbiotics as a class may show a significant ultraviolet flux and thus they became natural candidates for a survey with the IUE satellite. The following is an interim report on a survey of the symbiotics, both at low and, for AG Pegasi and CH Cygni, at high resolution.

Our IUE program began in June, 1979 and is continuing through 1981. The main thrust of the program has been to attempt to verify that the symbiotics are, for the most part, binary systems and form a natural extension of the short period cataclysmic variables. We hoped to accomplish this goal by directly observing the hot component in the UV, where it is uncontaminated by the flux of its giant companion.

Our early hope that the symbiotics would appear as UV "bright" objects has been realized. As a class, they display a diverse and complex spectrum in the UV, exhibiting both a rich emission-line spectrum, and on the deeper exposures, a definite continuum. We have obtained multiple low resolution spectra on a sample of twelve symbiotics, including the classical prototype Z And, BF Cyg, AX Per, and the eclipsing systems CI Cyg and AR Pav. High resolution spectra were taken on AG Peg around its orbital cycle to study both line profiles and radial velocity variations. Some early results of our survey were presented by Lambert et al. (1980); Sahade and Brandi (1980) discussed a similar survey, dividing the symbiotic stars into two broad groups based on the appearance of the UV emission-line spectra.

M. Friedjung and R. Viotti (eds.), The Nature of Symbiotic Stars, 103–113.

The following sections present a general discussion of the UV spectra of the symbiotics, including both the emission lines and the continua. As it is somewhat premature to draw general conclusions based on a small sample, the emphasis is biased towards a discussion of individual stars. AG Pegasi is used as an illustrative, albeit atypical, example.

2. The survey Selection

The observational sample for which we have extensive results consists of the brighter, and perhaps the more interesting, symbiotics. The sample forms a relatively homogeneous group, having been selected by the following criteria:

1. The stars were (originally) in a quiescent state, outside of eruption. However, during the course of the survey CH Cyg, AX Per and most spectacularly AG Dra have undergone eruptions;

2. the stars are classified as S type symbiotics (Allen 1978) showing relatively normal stellar-like infrared colors. Multiple infrared observations have established the lack of any significant variability;

3. the stars included the known eclipsing symbiotics, such as CI Cyg and AR Pav, and the only well established spectroscopic binary, AG Peg.

By observing the S type symbiotics, the interpretive aspect becomes more tractable since the variability of the late type component does not additionally confuse the question, as for the D type symbiotics. As importantly, the lack of any significant variability permitted the UV observations to be combined with ground based optical and infrared data with a degree of confidence.

3. Ultraviolet Spectra of the Symbiotics

Ultraviolet spectra have been obtained for the above sample, using the SWP and LWR cameras aboard the IUE satellite in both the low and high resolution modes. Particular attention has been paid to the known binary systems, either eclipsing or spectroscopic, to assure coverage around the orbital cycle and both outside and during eclipse.

a. Low resolution spectra

The low resolution ($\lambda = 6$ A) data show a rich and varied emission-line spectra for all of the stars in the sample with the exception of CH Cyg. The SWP bandpass includes the highest number of lines, dominated by NV (1239, 1243 A), CII (1335 A), SiIV 1394, 1403 A), NIV] (1486 A), CIV (1548, 1551 A), HeII (1640 A), OIII] (1666 A), NIII] (1749 A), SiIII] (1892 A), and CIII] (1909 A). The LWR bandpass also includes the CIII]

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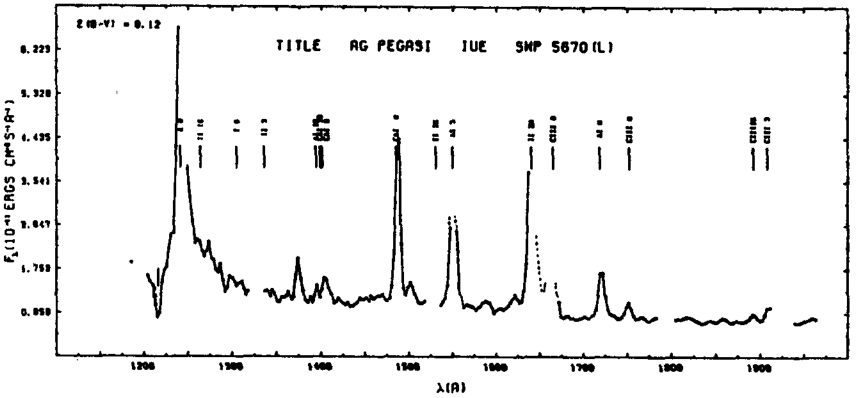

Figure 1. Low resolution SWP spectrum of AG Pegasi.

feature, in addition to various HeI lines and the MgII doublet (2796, 2802 A). Thus, the lines present span a wide range in excitation, and represent both resonance and intercombination transitions.

Sequential SWP and LWR spectra are shown for AG Peg in Figures 1 and 2, respectively. Gaps in the data arise from reseaux features falling on the spectral order; dashed lines indicate saturated portions. The data have been de-reddened using a value of E(B-V) = 0.12, determined from the existence of the 2200 A feature in the LWR spectrum. While atypical because of the line breadth as compared to most symbiotics, the spectra show the impressive diversity of emission features.

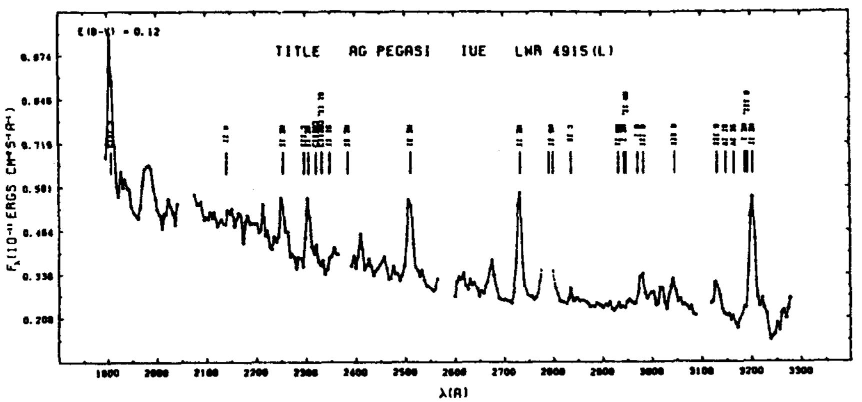

Figure 2. Low resolution LWR spectrum of AG Pegasi.

While the line ratios differ from star to star, several general comments can be made. CIV invariably appears as the strongest feature, followed closely by HeII. In AG Peg, the nitrogen lines (NV and NIV]) are also exceptionally strong. The intensity ratios are orbitally modulated

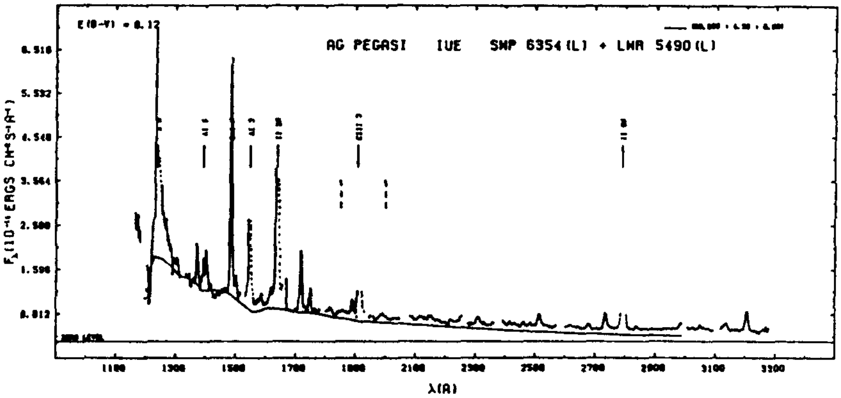

Figure 3. Combined low resolution spectra for AG Pegasi.

an effect which is most clearly seen in the eclipsing systems. In AG Peg, the MgII lines weaken and strengthen around the orbit, in a similar fashion to the behaviour of the MII lines in the optical (Hutchings, Cowley and Redman 1975). The HeII/NIII] and CIV/NIII] ratios in AR Pav decrease remarkably upon ingress to eclipse, reminiscent of the HeII/[OIII] ratio in the optical (Thackeray and Hutchings 1974).

By deliberately saturating the emission lines, the underlying continuum can be detected. Two deeply exposed spectra of AG Peg have been combined in Figure 3 to show the ultraviolet continuum. In the SWP bandpass the continuum is well represented by a Kurucz (1979) stellar model atmosphere with T_e = 30,000 K and log g = 4.50. However, longward of 1900 A, the observations deviate significantly from the model, showing an excess flux presumably arising from Balmer continuum emission.

The UV continua of Z And and BF Cyg are also well represented by stellar model atmospheres, giving confidence to the interpretation of these stars as binary systems. However, in the eclipsing systems CI Cyg and AR Pav, the hot component is obscured by the large optical depth in the accretion "shell" which surrounds the stars. The continuum appears rather flat (f_λ = constant).

b. High resolution spectra

For two of the brightest symbiotics (AG Peg and CH Cyg) we have obtained a series of high resolution spectra, primarily in the SWP bandpass. Representative line profiles for AG Peg are shown in Figure 4.

A remarkable diversity of the line profiles is evident, again somewhat unrepresentative of the typical symbiotic. The breadth of the lines gives a Wolf-Rayet appearence to the features, indicative of a strong stel

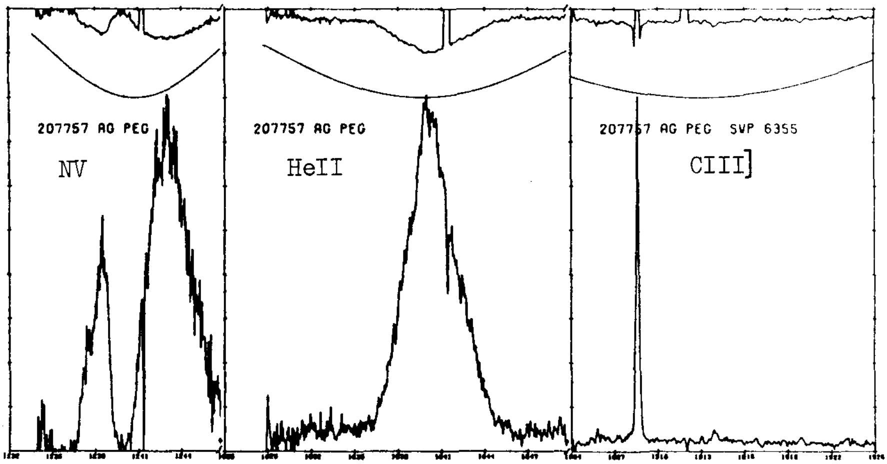

Figure 4. High resolution IUE profiles for AG Pegasi.

lar wind. The UV resonance doublet shows a classical P Cygni profile, whereas the HeII line is quite symmetric nimicking the HeII (4686 A) feature. The narrow CIII] is more characteristic of a true nebular emission line. The stratification of the emission line region is thus clearly evident.

CH Cyg shows a strong OI line at 1300 A in the SWP high resolution spectra, in addition to a castellated MgII feature in the LWR data. Each component of the MgII doublet shows the same structure, and Wing and Carpenter (1980) argue that the two absorption components are due to interstellar absorption and circumstellar absorption, respectively. Excluding the interstellar contribution to the profile, the MgII profile resembles the H_α emission line (Anderson, Oliversen, and Nordsiek 1980).

4. Combined Ultraviolet and Ground-based Data

While awaiting the absolute flux calibration for the IUE high resolution spectra, our analysis has concentrated on the continuum distribution derived from the low resolution data. By combining the IUE results with ground-based optical and infrared fluxes, we have derived absolute energy distribution for our sample, covering the range from 1200 A to 34,000 A. We have calculated mean fluxes across various bandpassas selected to avoid the emission lines, and thus the flux distributions truly represent the continuum.

Low resolution UV spectra have been combined with optical data of similar resolution, obtained with a Cassegrain Digicon Spettrograph (CDS) at the McDonald Observatory, and are shown for AG Pegasi in Figure 5. A partial identification of line features is given longward of 2200 A; notable

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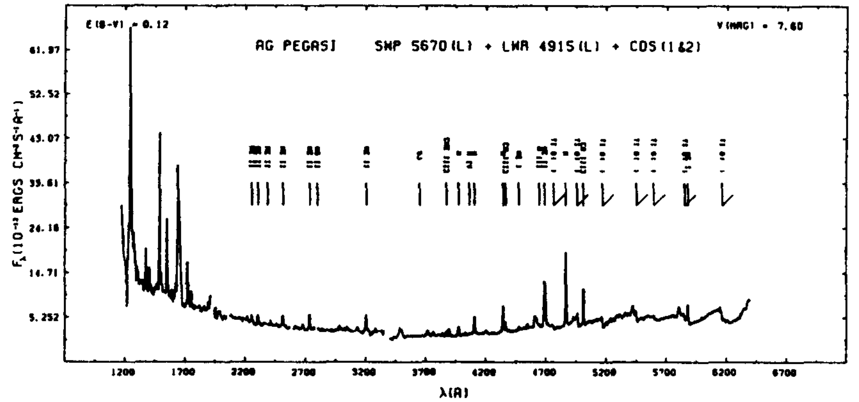

Figure 5. Combined IUE and optical spectra for AG Pegasi.

are the HeII emission lines juxtaposed across the continuum containing TiO bandheads, arising from the α and γ series.

Using broad-band Johnson JKL fluxes, which appear uncontamined by emission, the absolute energy distribution displayed in Figure 6 was derived for AG Peg. In this figure, the Johnson U and B fluxes are shown, clearly demonstrating the contamination of the emission lines and indicating the danger of estimating the properties of the hot component from the (U-B) - (B-V) color diagram. The bandpasses of the filters are indicated by the horizontal bars central on individual data points.

The data in Figure 6 are shown on a magnitude scale, where the fluxes have been converted to the same energy scale as the Johnson V magnitudes. The energy distribution is compared to a composite stellar distribution, comprised of an O9"V" star (V = 11.0) and an M3III star (V = 8.40). The composite curve is derived using the intrinsic Johnson UBVRIJKL colors in addition to UV colors determined from the OAO-2, TD-1, and ANS satellites (Parsons 1981). The intrinsic distributions are scaled to the observations upon specifying the V magnitude of the individual components and a value for the reddening. Good agreement with the observations is obtained except in the region where the nebula most strongly contributes (see figure 3), confirming the analysis of Gallagher et al. (1979).

5. Concluding Observations

The IUE observations of the symbiotic stars have revealed ultraviolet properties which rival diversity of the optical features. Nonetheless, the UV data have for the first time permitted the hot component to be studied relatively uncontaminated by the giant companion, which dominates the optical regime. The UV observations provide convincing evidence that

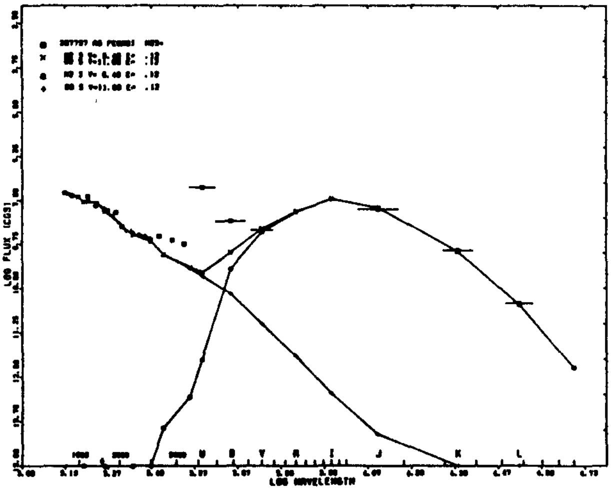

Figure 6. Absolute energy distribution for AG Pegasi.

indeed many of the symbiotics have hot stellar companions, imbedded in the enshrouding nebula or accretion "shell" fromed from the wind arising off of one or possibly both of the components. Another possibly impulsive, as opposed to steady-state, contributor to the nebula could come during the eruptive periods. The large range in excitation and density of the symbiotic nebulae can be understood by a combination of such processes.

Much remains to be done in the ultraviolet, as the initial observations have only really served to point the direction future research should take. Of immediate interest is the study of an eruptive symbiotic, such as AG Dra, to define the active, as opposed to quiescent, properties. Hopefully, such observations would lead to an understanding of the source of the symbiotic eruptions, currently believed to be a mass-transfer "burst" (Bath 1981). The final goal which should motivate any program, observational or theoretical, is to place the symbiotics in a stellar evolutionary sequence so that their progenitors, as well as their progeny, may be clearly identified.

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REFERENCES

Allen, D.A.: 1979, in F.M. Bateson, J. Smak, and I.H. Urch (eds.), "Changing Trends in Variable Star Research", IAU Colloquium No.46, University of Waikoto, Hamilton, New Zealand, p.125.

Anderson, C.M., Oliversen, N.A., and Nordsieck, K.H.: 1980, Astrophys. J. 242, 188.

Bath, G.T.: 1981, in R.E. Stencel (ed.), "North American Workshop on Sym biotic Satrs", JILA, Boulder, p.20 (abstract).

Gallagher, J.S., Holm, A.V., Anderson, C.M., and Webbink, R.F.: 1979, Astrophys. J. 229, 994.

Hutchings, A.D., Cowley, A.P., and Redman, R.O.: 1975, Astrophys. J. 201, 404.

Kurucz, R.L.: 1979, Astrophys. J. Suppl. 40, 1.

Lambert, D.L., Slovak, M.H., Shields, G.A., and Ferland, G.J.: 1980, in "The Universe at Ultraviolet Wavelengths", NASA, Greenbelt, p.461.

Parsons, S.B.: 1981, submitted to Astrophys. J.

Sahade, J., and Brandi, E.: 1980, in"The Universe at Ultraviolet Wavelen gths", NASA, Greenbelt, p.451.

Thackeray, A.D., and Hutchings, J.B.: 1974, Mon. Not. Roy. astr. Soc. 167, 319.

Wing, R.F., and Carpenter, K.G.: 1980, in "The Universe at Ultraviolet Wavelengths", NASA, Greenbelt, p.341.

DISCUSSION ON UV PROPERTIES

Keyes: The Zanstra temperatures derived from HeII 1640 for several objects, notably AG Peg, AG Dra, and RW Hya, are in the range 80000K - 120000K, which are considerably hotter than the Kurucz models used in your synthesis. In view of the fact that the IUE spectral range is on the Rayleigh-Jeans tail for such temperatures, have you attempted any fitting with black-body or model distributions hotter than 50000K?

Slovak: At this stage in the analysis, I have only used stellar models which are currently available. The Kurucz models, of course, only go up to T_{eff}= 50000K. My comparison is more of an indication that a simplistic comparison. Using a composite distribution of two stars alone is not sufficent to explain those symbiotics where the nebular contribution is significant. Good fits are derived for Z And and BF Cyg, but I cannot claim these are unique.

Kafatos: We have attempted similar fits for a few symbiotics (e.g. YY Her, SY Mus, etc.) and we find that they are not fitted well by a

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Kurucz model. The UV lines are very important because they show that the ionizing photons come from a ~100000K hot subdwarf or a ~100000K boundary layer. The continuum above ~2000 A is most probably nebular and therefore it is highly suspect to just fit the far UV continuum (between 1200 and ~1800 A).

Slovak: UV lines are indeed better indicators of UV radiation. What we may be seeing in the UV continuum is reprocessed radiation e.g. through an accretion disk.

Viotti: Dr. Cassatella at VILSPA did a lot of careful fitting of the UV continua of symbiotic stars. In the case of Z And (and of other stars, see e.g. the figure on page 9 of this book) the slope of the continuum in the far UV is close to Rayleigh-Jeans one, and has been fitted with a 100000K black-body. The difference between the observed continuum and the black-body one is easily fitted by a 15000K nebular (= ff + bf + 2 photons) continuum.

Slovak: The continuum fitting using non-stellar contributions in addition to the Rayleigh-Jeans tail of a hot star with T_{eff} 100000K, does indeed provide a better fit to the observed continua. The two photon contribution, however, is bound to be small at the densities considered in typical symbiotic nebulae.

Houziaux: I would like to ask Viotti: (i) one may wonder it is legitimate to just add or subtract continuum fluxes; (ii) how such temperatures (100000K) compare with Zanstra temperatures (from HeII lines e.g.).

Viotti: (i) Yes, as far as we assume that they originate in two separate regions. (ii) In AG Dra the hot continuum and HeII temperatures are nearly the same and may suggest a common origin.

Kafatos: I would like to go back to a point raised by Dr. Plavec about the importance of symbiotics where the hot source of the UV continuum is directly seen. In at least RW Hya, SY Mus and AG Peg this continuum comes from the Rayleigh-Jeans tail of hot subdwarfs with $T_{eff} \gtrsim 40000$K.

Plavec: A temperature of ~40000K is still low to explain the HeII emission.

Kafatos: That is correct, but since this is a lower limit one does much better than the Kurucz models in explaining both the far UV continuum and the ionizing radiation needed to explain the UV lines.

Michalitsianos: A number of objects observed with IUE appear to outwardly resemble an early type star in terms of effective temperature and luminosity. As such a compact object through accretion may superficially resemble an early main sequence star, but if compared to model

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atmospheres do not fit theoretical expectation. What UV and optical tools exist by which we can differentiate an early main sequence star from an object with an accretion shell?

Slovak: High resolution IUE (and other ultraviolet spacecrafts, i. e. Space Telescope) observations of various line profiles would prove invaluable. Detailed studies of line profile (as opposed to continua) would give such fundamental parameters as log g, Doppler broadening, rotational broadening, etc. permitteing a distinction between stellar models and accretion disks.

Nussbaumer: In V1016 Cyg we have reproduced the observed IUE ultraviolet continuum with a combination of a 160000K black-body star, and a recombination and two-photon continuum from a $T_e \sim 15000K$ gas, rather similar to the drawing shown by Viotti for Z And. The hot star continuum dominates for $\lambda < 1600$ A.

Slovak: I have no IUE observations of V1016 Cyg myself, so I cannot comment on the ultraviolet continuum. Your results are encouraging for a binary interpretation of this system; the contribution of the hot gas is clearly an important component.

Kwok: How can we be sure of the relative contributions to the infrared colors from (i) the photosphere, (ii) ff and bf continua, and (iii) dust emission?

Slovak: I attempted to simplify the interpretive aspect by showing distributions for Allen's S type symbiotics. These stars are characterized by non-variable, stellar-like infrared continua. The infrared flux appears to arise entirely from the photosphere of the late type component with possibly some small contribution from the ff + bf emission in the nebula.

Keyes: If indeed the cool component's IR photometry is reasonably constant as is the case for several S type symbiotics in Slovak's sample, then we probably do not see much of a contribution of ff radiation radiation in the IR. This is because our observations with IUE and the Lick image tube scanner from 1200 to 8000 A show that the Balmer continuum level (3200-3600A) plus Balmer emission features can vary by as much as 0.3 magnitudes during periods of relative quiescence for objects such as AG Peg, while the available IR photometry for that star does not show corresponding large variations.

Slovak: Yes, the ff plus fb continuum falls steeply in the Johnson JHKL bandpasses.

Cassatella: I do not expect that it will be possible in the case of all symbiotic stars to see the presence of the hot stellar component in the UV. This is for example the case for o Ceti (M giant plus probably a white dwarf) whose UV spectrum only shows Balmer free-free and free-bound emission.

Slovak: The IUE observations indeed show that in many of the symbiotics, the hot stellar component is hidden by the nebular material, which reprocesses the radiation field of the hot component ($T_{eff} \sim 100000$K using the HeII 1640 A line to derive a Zanstra temperature) and the UV continua appear cooler ($T_{eff} \sim 10$–30000K) and non stellar.

Viotti: Dr. Ricciardi of our Institute has compared the intensities of the UV emission lines of the symbiotic stars observed at high resolution. Figure 1 shows the line intensities in V1016 Cyg, Z And, and AG Dra as compared to those in RR Tel. This kind of comparison may allow to make hypothesis on the structure of the emitting envelopes and to select among the possible models. Evident in the figure is that three stars, V1016 Cyg, Z And and RR Tel, have quite similar UV spectra, in spite of the fact that different models have been proposed by Nussbaumer and Schild (1981), Altamore et al. (1981) and Penston et al. (1981) for the three stars. On the contrary, the figure seems to suggest that the physical conditions of the emitting regions should be almost the same. In the case of AG Dra it is clear that the HeII recombination lines are about one order of magnitude stronger with respect to the other lines than those in RR Tel, probably as the result of a larger density of ionizing radiation.

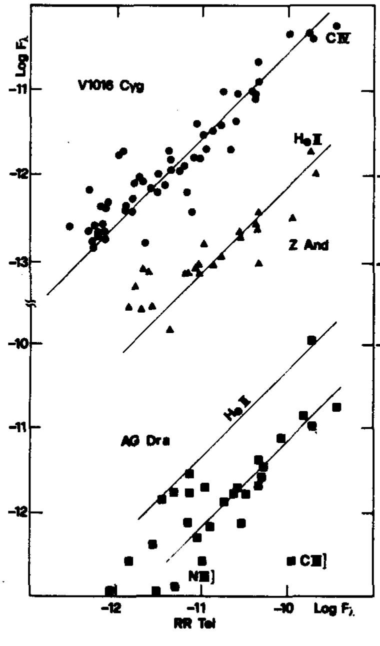

Figure 1.

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