I. INTRODUCTION

The optical spectrum of EG Andromedae (HD 4174) was noted by Wilson (1950) to consist of a normal M2 giant upon which were superposed the emission lines of [O iii], [Ne iii], and the Balmer series. The ultraviolet spectrum is rich in emission lines as well as Hz. Accurate cross-correlation absorption-line velocities determined from Ti i, Ca i, and Fe i features convincingly demonstrate that EG And is a single-lined spectroscopic binary. The velocity curve suggests that the photometric ephemeris reported by Smith in 1980 should be revised by a redefinition of zero phase by about 0.08 of a period. The primary of the system may be similar to the central star of a planetary nebula embedded in a dense nebula ($R \approx 2 R_\odot$, $n_e = 1.6 \times 10^9$ cm$^{-3}$) with a mild stellar wind ($v \approx 74$ km s$^{-1}$). The behavior of the emission lines is interpreted to indicate that the primary and its surrounding nebula suffer a partial eclipse by the cool giant secondary.

Subject headings: stars: combination spectra — stars: emission-line — stars: individual — ultraviolet: spectra

II. OBSERVATIONS

a) Ultraviolet

Two high-dispersion spectra of EG And were obtained with the IUE SWP camera (1150–2000 Å) using the large entrance aperture (Boggess et al. 1978). The first spectrum was obtained at Hz minimum (SWP 15271, phase 0.6) and the other near maximum (SWP 20269, phase 0.91). Both exposures were deep, 360 and 355 minutes, respectively, in order to bring out the wings of the brighter emission lines and to detect the fainter features. The cores of the brighter lines such as C iv and O iii are consequently saturated.

The spectra were extracted using the standard IUE reduction routines (Cassatella Ponz, and Selvelli 1981). The phase 0.6 spectrum obtained on 1981 October 15/16 appears to be less noisy than the phase 0.91 spectrum of 1983 June 20. The former was processed with the old high-dispersion reduction routines (Cassatella Ponz, and Selvelli 1981). The spectrum is sampled is doubled in the new software which results in an apparent increase in the resolution. Spectra reduced with the old routines appear to be smoothed. The new
software also corrects the wavelength scale for the motion of Earth and the IUE satellite.

The resolution of the spectra is about 0.13 Å or 25 km s\(^{-1}\) at 1550 Å. The internal consistency of the wavelength calibration is about 2 km s\(^{-1}\) (Thompson, Turnrose, and Bohlin 1981).

b) H\(\alpha\) Observations

Eight H\(\alpha\) profiles of EG And were obtained between 1979 August and 1982 August. The Washburn Observatory echelle spectrograph (Schröder and Anderson 1971) attached to the 91 cm telescope at Pine Bluff was used. The spectra were recorded with the Wisconsin intensified Reticon system (McNall and Nordsieck 1976). The data collection and reduction techniques have been described in detail by Anderson, Oliversen, and Nordsieck (1980, hereafter Paper I). These spectra are slit limited so that an absolute flux scale cannot be established, nor can the flux level of a given profile be directly compared to that of another. However, the internal intensity calibration is linear over a dynamic range of 10^7 compared to that of another. However, the internal intensity calibration is linear over a dynamic range of 10^7. Furthermore only the central thousand diodes (out of 1872 per array), corresponding to 35 Å, are used in these studies. This avoids nonlinearities associated with pin-cushion distortion in the electrostatic intensifier and flexure, both magnetic and mechanical, which can give rise to flat-field errors at the ends of the arrays.

The resolution (FWHM) of the H\(\alpha\) profiles is 0.3 Å or 14 km s\(^{-1}\). The wavelength calibration of the Washburn echelle/Reticon spectra is established by means of observations of a thorium-argon hollow cathode source which is mounted on an optical bench which swings into the telescope beam above the Cassegrain light baffle. Its position roughly 2 m above the telescope's focal plane make it very easy to register it accurately on the optical axis. Scans of the hollow cathode are done both immediately before and after each stellar observation, with the telescope pointed at the object in question. In the reduction process, the “before” and “after” object comparison spectra are averaged, and a cubic polynomial is fitted to the centroids of seven lines which are detected at high signal-to-noise ratio in the H\(\alpha\) order. The typical residuals in the fit are of the order of 0.5 pixels which is 0.018 km s\(^{-1}\) rms. Observations of IAU radial velocity standards (Pearce 1955) have been made to check for systematic errors and show agreement at the ± 3 km s\(^{-1}\) level.

Since the second of our two IUE spectra postdates our last optical observation by nearly a full period of the object, any inferences made on the basis of profile morphology assume that the profiles repeat from one cycle to the next. This assumption is justified as illustrated by our own data as well as by other published data. Smith (1980) published three of his 23 H\(\alpha\) spectrograms from the 1976-1979 observing seasons (phases 0.40, 0.70, an 0.85) and Slovak (1982a, b) displayed higher resolution photoelectric spectra for phases 0.73 and 0.29.

The combined photographic and photoelectric H\(\alpha\) data base spans a total of 2087 days or 4.4 periods of 470 days. From observations taken at equivalent phases in different cycles, the H\(\alpha\) profile is seen to repeat its appearance quite faithfully. For instance, the uppermost profiles in Figure 4, taken two cycles apart but at essentially the same phase (0.23 and 0.24) are nearly identical. Similarly the profiles at phases 0.60 and 0.65, taken one cycle apart, match closely. Finally, the photoelectric Reticon spectrum of Slovak (1982a) shows close qualitative agreement with the spectrogram in Smith (1980) obtained during the same cycle (phases 0.73 and 0.70, respectively).

III. Results

a) Ultraviolet

The emission-line fluxes and peak radial velocities for the more obvious features are listed in Table 1. The laboratory wavelengths were obtained from a similar listing for V1016 Cyg given by Nussbaum and Schild (1981). All lines which were saturated or very weak are noted in the table. Note also that C IV has not been included in Table 1 and will be discussed separately below. In general the emission-line fluxes are weaker at phase 0.6 than at 0.91, and several features, most notably O I, O IV, and He II, disappear altogether.

The average heliocentric emission-line radial velocity, based on line centroids, was — 96 ± 9 km s\(^{-1}\) at phase 0.91. This error is an upper limit to the internal consistency of the velocity measurements. All weak, saturated or obviously peculiar features (e.g., He II and C IV) were excluded in the average. At phase 0.6 the similarly averaged heliocentric velocity was — 91 ± 7 km s\(^{-1}\).

Figure 1 shows the C IV λ1548–1550 Å doublet. At phase 0.91 the profile is distinctly P Cygni in form. The center of the absorption or reversal portion of the feature is at — 168 km s\(^{-1}\). An interstellar line at a velocity of —12 km s\(^{-1}\) can be seen on the red wing of the λ1548 component. The corresponding feature at λ1550 is apparent on the photowrite but is somewhat masked by noise in the extraction shown in Figure 1. At phase 0.6 the broad blue wing of the profile is missing and the red wing is weakened. The velocities and full widths at half-maximum of the main emission peaks are similar at the two phases.

Figure 2 shows the He II 1640 Å line. At phase 0.91, the full width at the base of the profile is 960 km s\(^{-1}\), and the FWHM is 180 km s\(^{-1}\). An emission spike at λ1640.8 can be seen on the long-wavelength wing of the He II. The feature appears to be real, rather than a blemish such as a particle hit, and is probably [O I] which has a laboratory wavelength of 1641.3 Å. This identification is further substantiated by the presence of other O I lines. At phase 0.6, the He II and [O I] lines are completely missing. At phase 0.91 both Si IV and O IV are clearly present (Fig. 3), but at phase 0.6, O IV disappears while Si IV remains roughly constant.

b) H\(\alpha\)

Figure 4 illustrates the variations in the H\(\alpha\) profile of EG And. In the vicinity of phase 0.6 the profile shows weak emission both blueward and redward of an absorption line which goes well below the continuum of the cool giant. At other phases, the hydrogen line is completely in emission with an asymmetric profile in which the blue wing is broader than the red wing. This morphology is typical of many symbiotics (Oliversen and Anderson 1982).

Smith (1980) found changes in the H\(\alpha\) equivalent width, radial velocity, and profile which correlated with the 470 day photometric period. The minimum equivalent width and maximum redshift of the emission coincided with phase 0.6. The velocities he measured were of the marginally resolved H\(\alpha\) emission peak. Because his spectra were of low signal-to-noise ratio and limited dynamic range, he was unable to measure absorption-line velocities. The difficulty in interpreting symbiotic emission-line velocity variations is considerable (cf.
TABLE 1
IUE Observed Emission-Line Intensities

<table>
<thead>
<tr>
<th>λLAB (Å)</th>
<th>ION</th>
<th>λobs (Å)</th>
<th>(V^a) (km s(^{-1}))</th>
<th>F(^b)</th>
<th>λLAB (Å)</th>
<th>ION</th>
<th>λobs (Å)</th>
<th>(V^a) (km s(^{-1}))</th>
<th>F(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1302.2...</td>
<td>O i</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1303.9...</td>
<td>O i</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1393.8...</td>
<td>Si iv</td>
<td>1393.4</td>
<td>-95</td>
<td>3.8</td>
<td>1401.2...</td>
<td>O iv</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1404.8...</td>
<td>O iv</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1486.5...</td>
<td>N iv</td>
<td>1486.1</td>
<td>-84</td>
<td>1.2</td>
</tr>
<tr>
<td>1641.3...</td>
<td>O i</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1660.8...</td>
<td>O iii</td>
<td>1660.3</td>
<td>-85</td>
<td>1.3</td>
</tr>
<tr>
<td>1746.8...</td>
<td>N iii</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1782.2...</td>
<td>N iii</td>
<td>1751.6</td>
<td>-101</td>
<td>0.34</td>
</tr>
<tr>
<td>1808.0...</td>
<td>Si ii</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1814.7...</td>
<td>Ne iii</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1854.7...</td>
<td>Al iii</td>
<td>1854.1</td>
<td>-91</td>
<td>0.31 w</td>
<td>1862.8...</td>
<td>Al iii</td>
<td>1862.2</td>
<td>-91</td>
<td>0.19 w</td>
</tr>
<tr>
<td>1906.7...</td>
<td>C iii</td>
<td>1905.7</td>
<td>-155</td>
<td>1.0 o</td>
<td>1908.7...</td>
<td>C iii</td>
<td>1908.1</td>
<td>sat</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Notes.—o: C iii line falls between two orders and cannot be reliably measured.
w: Weak line (typical error: \(\pm 0.1 \times 10^{-12}\) ergs cm\(^{-2}\) s\(^{-1}\)). sat: saturated line.
a SWP 15271 and SWP 20269: Heliocentric radial velocity.
b Units: 10\(^{-12}\) ergs cm\(^{-2}\) s\(^{-1}\).

Fig. 1.—Comparison of C iv profiles for SWP 20269 (phase 0.91) and SWP 15271 (phase 0.60). The zero level for SWP 20269 has been displaced vertically in the plot by an additional unit of \(2 \times 10^{-11}\) ergs cm\(^{-2}\) s\(^{-1}\) Å\(^{-1}\). Note that the broad blueshifted wings are missing during minimum (phase 0.60).
Fig. 2.—Comparison of the He ii profiles for SWP 20269 and for SWP 15271. The zero level for SWP 20269 has been displaced vertically in the plot by $2 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$. The broad He ii emission is completely absent during Hα minimum. The emission feature on the long-wavelength wing of He ii is probably [O i] λ1641.3 Å.

Fig. 3.—Comparison of the Si iv and O iv multiplets for SWP 20269 and 15271. The zero level for SWP 20269 has been displaced upward by $1.5 \times 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$. At phase 0.91 both Si iv and O iv are clearly present, while at phase 0.60 only the Si iv line was observed.
Fig. 4.—Hz profiles of EG And obtained with the Wisconsin Echelle Spectrograph and Intensified Reticon system between 1979 August and 1982 August. Absorption lines from the red giant atmosphere can also be seen in the plots. The Julian Date minus 2,440,000 of each spectrum is indicated at the right, and the phase according to Smith (1980) is given on the left. The spectra are normalized so that the average continuum level is one ordinate unit above zero intensity; successive spectra are displaced in intensity by one unit. The five absorption lines from which the radial velocities were determined, are indicated by numbers 1 to 5 and are, respectively Ti i 6554.23, Ti i 6556.07, Fe i 6569.22, Ca i 6572.78, and Fe i 6575.02.

Cowley and Stencel 1973). We have therefore concentrated on extracting accurate absorption-line velocities from our data.

In the Washburn Observatory Reticon spectra, which are of both high signal-to-noise ratio and cover a large dynamic range, not only is the very strong hydrogen emission-line measured without saturation, but also the continuum and the absorption lines are well detected. The problem is then to extract from these data information about the radial velocity variations of the red giant component of the system independent of the vicissitudes of the emission-line emitting region. To this end we have proceeded as described below.

We have applied the cross-correlation velocity technique of Simkin (1974) to measure the relative velocity shifts of the red giant absorption spectrum. In order to ensure that the strong emission line does not dominate the solution and to ensure that the emission line suppression technique does not introduce spurious results, we have used two different emission-line deletion techniques. The first method was simply to replace the portion of the spectrum containing the emission feature with a smooth interpolation between regions of roughly 1 Å width on each side of and well beyond the emission line. This very smooth, noise-free section of the spectrum might itself dominate the cross-correlation. To check this possibility, the continuum regions to the left and to the right of Hz were treated as independent spectra of abbreviated length. All three sets of spectra were then masked in preparation for fast Fourier trans-
formation according to the prescription of Brault and White (1971) wherein the mean of each spectrum is subtracted from it and a cosine bell function applied to each end so that it blends smoothly into the new zero mean level. All spectra were subjected to a standard fast Fourier transform algorithm. The transform of the spectrum at phase 0.65 (JD 2,444,916) was chosen as a standard because of its high signal-to-noise continuum. The product of each transform and the complex conjugate of the standard spectrum was formed and the result transformed back to the data domain yielding the cross-correlation function of each spectrum with the standard. The peak of each cross-correlation function was located both by maximum value and zero derivative searches. The peak then represents the shift of each spectrum relative to the standard spectrum. All three sets of spectra gave results in good agreement with one another (0.7 km s\(^{-1}\) rms) verifying that the derived shifts are not an artifact of the suppression method. The results of the analysis are plotted as the solid points in Figure 5.

The cross-correlation method has the disadvantage that it does not provide the actual heliocentric velocities. Therefore, we have also measured the velocities in the more traditional way of fitting a Gaussian profile to the cores of identified, unblended lines. The five lines identified in Figure 4 were so measured in each of the spectra. The heliocentric velocity of the spectrum used as the reference spectrum in the cross-correlation analysis was $-91.2$ km s\(^{-1}\). The value was added to the differential velocities used in the cross-correlation analysis, and the results of both techniques are listed in Table 2.

The emission-line velocities of Smith (1980) place the velocity minimum (maximum redshift) near the phase of the $u$ band photometric minimum of Kaler and Hickey (1983), a result which would be incompatible with an eclipse model. In contrast, Figure 5 clearly shows that the cool component passes through the systemic velocity toward positive values at about the time of the photometric minimum. In order to refine this picture we performed a nonlinear least squares fit of a function of the form:

$$V = \gamma - K \sin 2\pi(\phi - \phi_0) ,$$

where $\gamma$ is the systemic velocity, $K$, the velocity amplitude; and $\phi_0$, an adjustment to the definition of zero phase. A more general orbital solution was deemed unjustified because of the paucity of data and the fact that relatively close, evolved systems of this sort are very likely well circularized. We have also implicitly accepted the 470 day period. This analysis was applied to both the cross-correlation and the profile fit data, and the results are summarized in Table 3. The $\chi^2$ for the cross-correlation data is far superior to that of the profile fit solution. This is to be expected since the cross-correlation technique utilizes the entire spectrum and does not presume a particular shape for the line profiles. For these reasons in the discussion which follows we adopt the results of the cross-correlation analysis.

IV. DISCUSSION

The Washburn Observatory Reticon data clearly establish that EG And, like AG Peg (Hutchings, Cowley, and Redman 1975), is a spectroscopic binary in the classic sense. Furthermore, with the slight revision in the phasing suggested above, the picture is entirely consistent with the hypothesis that the photometric and spectroscopic variations are the result of a partial occultation, by the giant, of a hot component and its environs.

The "mass function" for single line spectroscopic binaries is

$$f(M_1, M_2, \dot{i}) = K^2 P/2\pi G$$

where $y$ is the systemic velocity, $K$, the velocity amplitude; and $\phi_0$, an adjustment to the definition of zero phase. A more general orbital solution was deemed unjustified because of the paucity of data and the fact that relatively close, evolved systems of this sort are very likely well circularized. We have also implicitly accepted the 470 day period. This analysis was applied to both the cross-correlation and the profile fit data, and the results are summarized in Table 3. The $\chi^2$ for the cross-correlation data is far superior to that of the profile fit solution. This is to be expected since the cross-correlation technique utilizes the entire spectrum and does not presume a particular shape for the line profiles. For these reasons in the discussion which follows we adopt the results of the cross-correlation analysis.

IV. DISCUSSION

The Washburn Observatory Reticon data clearly establish that EG And, like AG Peg (Hutchings, Cowley, and Redman 1975), is a spectroscopic binary in the classic sense. Furthermore, with the slight revision in the phasing suggested above, the picture is entirely consistent with the hypothesis that the photometric and spectroscopic variations are the result of a partial occultation, by the giant, of a hot component and its environs.

The "mass function" for single line spectroscopic binaries is

$$f(M_1, M_2, \dot{i}) = K^2 P/2\pi G$$

where $y$ is the systemic velocity, $K$, the velocity amplitude; and $\phi_0$, an adjustment to the definition of zero phase. A more general orbital solution was deemed unjustified because of the paucity of data and the fact that relatively close, evolved systems of this sort are very likely well circularized. We have also implicitly accepted the 470 day period. This analysis was applied to both the cross-correlation and the profile fit data, and the results are summarized in Table 3. The $\chi^2$ for the cross-correlation data is far superior to that of the profile fit solution. This is to be expected since the cross-correlation technique utilizes the entire spectrum and does not presume a particular shape for the line profiles. For these reasons in the discussion which follows we adopt the results of the cross-correlation analysis.

IV. DISCUSSION

The Washburn Observatory Reticon data clearly establish that EG And, like AG Peg (Hutchings, Cowley, and Redman 1975), is a spectroscopic binary in the classic sense. Furthermore, with the slight revision in the phasing suggested above, the picture is entirely consistent with the hypothesis that the photometric and spectroscopic variations are the result of a partial occultation, by the giant, of a hot component and its environs.

The "mass function" for single line spectroscopic binaries is

$$f(M_1, M_2, \dot{i}) = K^2 P/2\pi G$$

where $y$ is the systemic velocity, $K$, the velocity amplitude; and $\phi_0$, an adjustment to the definition of zero phase. A more general orbital solution was deemed unjustified because of the paucity of data and the fact that relatively close, evolved systems of this sort are very likely well circularized. We have also implicitly accepted the 470 day period. This analysis was applied to both the cross-correlation and the profile fit data, and the results are summarized in Table 3. The $\chi^2$ for the cross-correlation data is far superior to that of the profile fit solution. This is to be expected since the cross-correlation technique utilizes the entire spectrum and does not presume a particular shape for the line profiles. For these reasons in the discussion which follows we adopt the results of the cross-correlation analysis.

IV. DISCUSSION

The Washburn Observatory Reticon data clearly establish that EG And, like AG Peg (Hutchings, Cowley, and Redman 1975), is a spectroscopic binary in the classic sense. Furthermore, with the slight revision in the phasing suggested above, the picture is entirely consistent with the hypothesis that the photometric and spectroscopic variations are the result of a partial occultation, by the giant, of a hot component and its environs.

The "mass function" for single line spectroscopic binaries is

$$f(M_1, M_2, \dot{i}) = K^2 P/2\pi G$$

where $y$ is the systemic velocity, $K$, the velocity amplitude; and $\phi_0$, an adjustment to the definition of zero phase. A more general orbital solution was deemed unjustified because of the paucity of data and the fact that relatively close, evolved systems of this sort are very likely well circularized. We have also implicitly accepted the 470 day period. This analysis was applied to both the cross-correlation and the profile fit data, and the results are summarized in Table 3. The $\chi^2$ for the cross-correlation data is far superior to that of the profile fit solution. This is to be expected since the cross-correlation technique utilizes the entire spectrum and does not presume a particular shape for the line profiles. For these reasons in the discussion which follows we adopt the results of the cross-correlation analysis.

IV. DISCUSSION

The Washburn Observatory Reticon data clearly establish that EG And, like AG Peg (Hutchings, Cowley, and Redman 1975), is a spectroscopic binary in the classic sense. Furthermore, with the slight revision in the phasing suggested above, the picture is entirely consistent with the hypothesis that the photometric and spectroscopic variations are the result of a partial occultation, by the giant, of a hot component and its environs.

The "mass function" for single line spectroscopic binaries is

$$f(M_1, M_2, \dot{i}) = K^2 P/2\pi G$$

where $y$ is the systemic velocity, $K$, the velocity amplitude; and $\phi_0$, an adjustment to the definition of zero phase. A more general orbital solution was deemed unjustified because of the paucity of data and the fact that relatively close, evolved systems of this sort are very likely well circularized. We have also implicitly accepted the 470 day period. This analysis was applied to both the cross-correlation and the profile fit data, and the results are summarized in Table 3. The $\chi^2$ for the cross-correlation data is far superior to that of the profile fit solution. This is to be expected since the cross-correlation technique utilizes the entire spectrum and does not presume a particular shape for the line profiles. For these reasons in the discussion which follows we adopt the results of the cross-correlation analysis.

IV. DISCUSSION

The Washburn Observatory Reticon data clearly establish that EG And, like AG Peg (Hutchings, Cowley, and Redman 1975), is a spectroscopic binary in the classic sense. Furthermore, with the slight revision in the phasing suggested above, the picture is entirely consistent with the hypothesis that the photometric and spectroscopic variations are the result of a partial occultation, by the giant, of a hot component and its environs.

The "mass function" for single line spectroscopic binaries is

$$f(M_1, M_2, \dot{i}) = K^2 P/2\pi G$$

where $y$ is the systemic velocity, $K$, the velocity amplitude; and $\phi_0$, an adjustment to the definition of zero phase. A more general orbital solution was deemed unjustified because of the paucity of data and the fact that relatively close, evolved systems of this sort are very likely well circularized. We have also implicitly accepted the 470 day period. This analysis was applied to both the cross-correlation and the profile fit data, and the results are summarized in Table 3. The $\chi^2$ for the cross-correlation data is far superior to that of the profile fit solution. This is to be expected since the cross-correlation technique utilizes the entire spectrum and does not presume a particular shape for the line profiles. For these reasons in the discussion which follows we adopt the results of the cross-correlation analysis.

IV. DISCUSSION

The Washburn Observatory Reticon data clearly establish that EG And, like AG Peg (Hutchings, Cowley, and Redman 1975), is a spectroscopic binary in the classic sense. Furthermore, with the slight revision in the phasing suggested above, the picture is entirely consistent with the hypothesis that the photometric and spectroscopic variations are the result of a partial occultation, by the giant, of a hot component and its environs.

The "mass function" for single line spectroscopic binaries is

$$f(M_1, M_2, \dot{i}) = K^2 P/2\pi G$$

where $y$ is the systemic velocity, $K$, the velocity amplitude; and $\phi_0$, an adjustment to the definition of zero phase. A more general orbital solution was deemed unjustified because of the paucity of data and the fact that relatively close, evolved systems of this sort are very likely well circularized. We have also implicitly accepted the 470 day period. This analysis was applied to both the cross-correlation and the profile fit data, and the results are summarized in Table 3. The $\chi^2$ for the cross-correlation data is far superior to that of the profile fit solution. This is to be expected since the cross-correlation technique utilizes the entire spectrum and does not presume a particular shape for the line profiles. For these reasons in the discussion which follows we adopt the results of the cross-correlation analysis.
or:

\[ f(M_1, M_2, i) = M_2 \sin^3 i (1 + R)^{-2}, \quad (4) \]

where \( R \) is the ratio of the mass of the primary, the cool giant in this case, to that of the secondary, \( R = M_1/M_2 \). Substituting the assumed period, 470 days, and the value of the primary cross-correlation velocity amplitude from Table 3, we find:

\[ f(M_1, M_2, i) = 3.2 \times 10^{-2} M_0. \quad (5) \]

Kenyon's (1983) ultraviolet color-color diagnostic indicates that the hot object in the EG And system is similar to the central star of a planetary nebula. As a working hypothesis we take this to mean a secondary mass on the order of 0.7 \( M_0 \). We can then solve the second of the two expressions for the mass function for the inclination as a function of the mass ratio. In addition we can, from elementary geometric considerations, determine the separation of the two objects and the minimum radius which the cool giant must have in order to eclipse the secondary. The results of these computations are plotted in Figure 6. From this figure it is apparent that if the size of the cool component is around 100 \( R_0 \), in reasonable agreement with the value of Kenyon and Gallagher (1983), then the mass ratio must be about 3.5. This in turn implies a current mass for the primary of 2.5 and the system as a whole a mass of 3.2 solar masses.

The critical radius for Roche lobe overflow is given by Paczyński's (1971) formula:

\[ r_{\text{crit}} = a (0.38 + 0.2 \log R). \quad (6) \]

For a mass ratio, \( R = 3.5 \), this yields \( r_{\text{crit}} = 0.49a \). If \( a \) is about 1.7 AU this corresponds to 180 \( R_0 \) which is substantially larger than the estimated radius for the cool component of the EG And, and it does not overflow its Roche lobe.

The system can now be imagined to have begun as a pair of stars each of about 1.6 solar masses, one slightly more massive than the other. As the initially more massive star evolved ahead of the other star out to the giant branch, it deposited its envelope on the former secondary, leaving behind the hot component now seen and accelerating the evolution of the star we now see as a giant.

If the mass of the hot object is currently less than the 0.7 \( M_0 \) assumed in the above example, then the mass ratio and the total system mass, or alternatively the necessary inclination, are decreased. This in turn reduces the mass that the initially more massive star must have had and so makes its age greater. The EG And system has been identified as a high-velocity star (Eggen 1964) and thus appears old. The mass of 1.6 \( M_0 \) suggested above is compatible with membership in such a population.

The ultraviolet emission lines provide additional information on the characteristics of the system. The presence of the broad \( \text{He} \, \alpha \) and \( \text{C} \, \alpha \) emission components argues in favor of the existence of a rapidly rotating disk surrounding the hot component. To first approximation, the circular velocity of a classic accretion disk is comparable to the velocity of escape from the hot component. The line width can thus be used to constrain the size of the hot component. Adopting the mass of 0.7 \( M_0 \) used above and radii of 0.01 \( R_0 \), 0.1 \( R_0 \), and 1 \( R_0 \) for white dwarfs, sub dwarfs, and main-sequence stars, respectively, the expected velocities, \((2GM_{\text{hot}}/R_{\text{hot}})^{1/2}\), are 5160, 1630, and 520 km s\(^{-1}\), respectively. The base width of \( \text{He} \, \alpha \) at 61640 is 960 km s\(^{-1}\) which is clearly incompatible with a white dwarf. However, either a main-sequence star or an object similar to the central star of a planetary nebula as suggested by Kenyon (1983) can be accommodated. On the other hand, the disk could not be as opaque nor as luminous as the accretion disks of classic cataclysmic or X-ray binaries lest it be detected by Kenyon's UV color-color diagnostic.

Nussbaumer and Storey (1982) have shown that the \( \text{O} \, IV \) multiplet ratio is relatively insensitive to electron temperature and can thus be used to determine the nebular density. Our observations of \( \text{O} \, IV \) out of the eclipse (phase 0.91) yield a ratio \( I(\lambda 1404.8)/I(\lambda 1401.2) \) of 0.41 which implies \( N_e = 1.6 \times 10^9 \) cm\(^{-3}\). Since the \( \text{O} \, IV \) lines completely disappear during the eclipse, we may take this density to be characteristic of the nebula in the immediate vicinity of the hot component. In what follows we will also use this for the hydrogen density, \( N \).

---

**Fig. 6**—The inclination (\( \dot{\iota} \)), separation (\( a \)), and minimum red giant radius \( (R_a(\text{min})) \) as a function of mass ratio as determined from mass function implied by the fit shown in Fig. 5. A secondary mass of 0.7 has been assumed. The inclination scale in degrees is at the right, while the dimensional quantities are given in units of 100 solar radii by the scale on the left.
The He II emission-line flux can be used to estimate the size of the nebula. The flux emitted by a spherical nebula is given by:

$$dF = 0.33h
\nu r J N^2 A \xi,$$

where \(d\) is the distance; \(r\), the nebular radius; \(f\), the filling factor; \(A\), the helium abundance by number (0.1); and \(\xi\), the recombination coefficient. The recombination coefficient is not very sensitive to temperature, and the presence of the multiply ionized helium and carbon suggest a fairly high value. Thus from Osterbrock (1974) for helium at a temperature of \(2 \times 10^4\) K we use \(\xi = 3.3 \times 10^{-12}\) cm\(^3\) s\(^{-1}\). On the basis of infrared photometry, Kenyon and Gallagher (1983) determined a distance of 630 pc for EG And. Since the disappearance of the line is complete, the radius of the red giant represents an upper limit to the nebular radius. Using the radius of 120 R\(_{\odot}\) suggested by Kenyon and Gallagher, the filling factor is 0.026. If the nebular line is complete, the radius of the red giant represents an upper limit to the nebular radius. Using the radius of 120 R\(_{\odot}\) and the filling factor 0.026 if the nebula were uniform \((f = 1.0)\) then the implied nebular radius is 3.6 R\(_{\odot}\). Clearly the complete occultation of the He II region can be accomplished without requiring the inclination to be inordinately close to 90°.

The P Cygni profile of the C IV \(\lambda\lambda 1548-1550\) lines indicates that there is an outflowing wind in the system. The difference of the system velocity from the central reversal velocity gives a measure of the wind velocity. The central reversal occurs at a velocity of \(-168\) km s\(^{-1}\) while the optical data indicate a systemic velocity of \(-94\) km s\(^{-1}\). The velocity of the wind is thus 74 km s\(^{-1}\). This velocity is a factor of 3-4 times larger than the wind velocities seen in late-type giants (Reimers 1975) which do not in general show C IV P Cygni profiles (Ayres et al. 1982). Furthermore the P Cygni feature disappears during the occultation of the hot component. These two facts suggest that this mild wind is associated with the hot component.

The reason that the hydrogen emission-line velocities appeared to be inconsistent with an eclipse model is now apparent. At the time of the eclipse, enough of the nebula is hidden so that the photospheric absorption line of the red giant begins to dominate the profile. All that is left to appear as emission are the remnant wings, the measurement of which give extreme velocities rather than the systemic velocity as would be expected. Furthermore, the curious effect of an "eclipse" centered at phase 0.6 rather than 0.5 is resolved. Smith (1980) defined zero phase by means of the maximum Hz equivalent width. However, whenever the hot component and the nebula surrounding it are out of eclipse variations in the strength of the Hz feature are dominated by intrinsic fluctuations, and it is not a sensitive means of defining a phase zero. The optical velocity curve indicates that the zero phase should be retarded by 0.08 in phase or 37.6 days.

V. SUMMARY

The combination of the ultraviolet modeling of Kenyon (1983) and the clear detection of the orbital motion of the cool giant from the absorption lines, firmly establish EG And as a system similar to the classic symbiotic binary AG Peg. We suggest that a new ephememeris for EG And can be defined with its zero phase at JD 2,444,650. The system suffers an eclipse which occults not only the hot stellar component but also the inner dense nebula from which come the emission lines of He II and C IV. The hot component is probably an object like the central star of a planetary nebula, while the occulted nebula has a radius on the order of 2 R\(_{\odot}\). A wind flows out from the system at about 75 km s\(^{-1}\) and from the difference in the morphology of the C IV line in and out of the eclipse the source of the wind is most probably the hot component.

The authors wish to thank Drs. J. S. Mathis and S. M. Simkin for useful discussions. We also thank Scott Kenyon for making available in advance of publication his extremely useful "Collected History of the Symbiotic Stars" which was an appendix to his landmark thesis. N. A. O. and R. E. S. acknowledge the support of NASA in part through grant NASS-25774. The use of the IUE Regional Data Analysis Facility is also gratefully acknowledged.

The processing of the optical data was done at the Midwestern Astronomical Data Reduction and Analysis Facility (MADRAF) which was created through NSF grants AST 79-00894, 80-11445, and 81-21099.

REFERENCES

Pearce, J. A. 1955, IAU Trans., 9, 441.