THE ASTROPHYSICAL JOURNAL, **262**:675–681, 1982 November 15

ULTRAVIOLET EMISSION IN THE Mg II *h* AND *k* LINES IN Be STARS

FREDERICK C. BRUHWEILER
Astronomy Department, Computer Sciences Corporation
THOMAS H. MORGAN
Southwestern University
AND
KAREL A. VAN DER HUCHT
Space Research Laboratory of the Astronomical Institute at Utrecht
Received 1981 October 29; accepted 1982 April 8

ABSTRACT

Ultraviolet observations made by the Balloon-borne Ultraviolet Stellar Spectrometer (BUSS) of bright early Be stars reveal emission components to the Mg II doublet at 2800 Å. These profiles show central absorption features due to interstellar plus possible circumstellar contributions. These absorption features are bounded by emission lobes on either side. The emission components may in part be due to resonance scattering within the line profile, but there are definite contributions to the emission via a Bowen mechanism driven by Lyman β. Slight apparent shifts in the absorption components relative to the emission may indicate expansion ~ 5–10 km s^{-1} for the line-forming region giving rise to Mg II. If the material in the shell is accelerated by radiation pressure, comparisons of Mg II velocities with species of higher ionization suggest that the degree of ionization in the shell increases at larger distances from the star. This is not unlike the conditions observed in the stellar winds of O and B supergiants.

Subject headings: line formation — stars: Be — ultraviolet: spectra

I. INTRODUCTION

It is well known that chromospheric emission is observed in the ultraviolet resonance *h* and *k* lines of Mg II at 2800 Å in late-type stars. Recently, Slettebak and Snow (1978) and Marlborough, Snow, and Slettebak (1978), using the ultraviolet spectrometer aboard the *Copernicus* satellite, detected highly variable Mg II *h* and *k* emission in the Be star γ Cas (B0.5 IV). Since γ Cas is also an X-ray source, the variable emission was presumed to occur within a mass stream between the primary and a collapsed invisible companion. The actual physical process responsible for the Mg II emission was not discussed, but comparisons with emission from late-type stars were made. This leaves two basic questions. First, is the occurrence of Mg II emission unique to γ Cas, or does it occur in other Be and early type stars as well? Second, what is the physical process giving rise to the observed Mg II resonance emission?

In this paper, we present ultraviolet observations of the Mg II *h* and *k* lines of three early type Be stars, including γ Cas, acquired by the Ballon-borne Ultraviolet Stellar Spectrometer (BUSS). All three (ϕ Per, υ Cyg, and γ Cas) display emission at Mg II *h* and *k*. We show that a Bowen mechanism is responsible for the observed emission in these objects, and present other supporting evidence for this interpretation.

II. OBSERVATIONS

The spectral data were obtained with the JSC/SRL BUSS. The heart of this payload was an echelle spectrograph and a SEC vidicon attached to a 40 cm f/7.5 telescope. The instrument was controlled from the ground, and the spectral data were digitized and telemetered to the ground station located at the launch site near Palestine, Texas. The payload float altitude was 40 km from which most of the mid-UV spectral region was accessible. Forty-eight echelle orders, comprising a spectral range extending from 2000 to 3400 Å, were imaged on the 25 mm×25 mm vidicon target with a resolution of 0.1 Å (0.05 Å per pixel) in all orders. An oscillating mirror mechanically widened the spectra to nine pixels perpendicular to the axis of dispersion. Both the payload and its performance have been documented elsewhere (Kondo *et al.* 1979; de Jager *et al.* 1979). All three stars discussed here were observed during the night of 1976 September 16–17.

The relevant data including exact times of observation and exposure are presented in Table 1. All spectral data have been processed using a new intensity calibration scheme which represents an improvement over calibration techniques used previously to process BUSS data. The interorder signal has been smoothed and subtracted from the gross spectrum. The spectra of γ

TABLE 1

DATA ON OBSERVED STARS

Parameter	HR 264 (γ Cas)	HR 496 (φ Per)	HR 8146 (υ Cyg)
Spectral type and luminosity class	B0.5 IVe	B1 III–IV?pe	B2 Ve
m_v	2.65	4.03	4.45
Integration time (minutes) ..	1.5	7.0	10.0
JD 2,443,038+	0.768	0.745	0.788

NOTE.—The data on spectral types and luminosity classes come from Lesh (1968).

Cas, υ Cyg, and φ Per are shown in Figure 1, and in Figure 2 the spectra of these three stars divided in each case by the local continuum are shown together for comparison.

A brief observational history of each star, together with a review of our data for each, is given in what follows.

a) γ *Cassiopeiae*

The Be star γ Cas, being one of the brightest of the Be stars ($m_v = 2.65$), has also been the most extensively studied. UV observations indicate that the envelope surrounding the object is quite variable. A rocket spectrum of γ Cas (Bohlin 1970), showed P Cygni profiles for the C IV resonance lines at 1550 Å, while *Copernicus* data 5 years later failed to reveal P Cygni characteristics for these features (Snow and Marlborough 1976). The most dramatic spectral variability was found by Marlborough, Snow, and Slettebak (1978) and Slettebak and Snow (1978). In their data, the emission components of the Mg II resonance doublet may sometimes appear longward, and at other times shortward, of the reference interstellar Mg II absorption line. At yet other times, the emission is entirely absent. Further, they find evidence for rapid variations in the emission lines in time scales of 2–3 minutes. Certain scans of the 2802 Å region sometimes showed no detectable emission, while scans of the 2795 Å region acquired only a few minutes earlier revealed very strong emission. Although the 2802 Å line should be weaker, its intensity should not be weaker than half that of 2795 Å. If the emission were constant over the time of observation, the 2802 Å line would have been easily detected. Other data presented by Snow and Slettebak may indicate related profile variations; namely possible weak emission in the core of the Si IV resonance lines at 1400 Å and possible variable N V resonance absorption at 1240 Å. Yet the strongest evidence for spectral variations are the *V*/*R* variations and the long term and sometimes sudden variations in Mg II emission.

The BUSS data presented in Figure 1 for the region of the Mg II doublet show the sharp Mg II resonance absorption lines presumably interstellar in origin and weak, but definite, emission lobes. The latter is best seen in Figure 2. *Copernicus* observations by Slettebak and Snow made during 1976 October, 1 month after those acquired by BUSS, indicate also a weak longward emission component on the order of 6% of the continuum for the 2795.6 Å feature. However, because of the reported variability in the Mg II emission, the similarity between the strength and placement of emission in BUSS data and in *Copernicus* data may be fortuitous. Nonetheless, no photospheric absorption is detected in data obtained with these two spectrographs, either for the Mg II resonance transitions or for the Mg II ($3p$–$3d$) subordinate lines at 2790 and 2798 Å.

b) υ *Cygni*

This object, with a $v \sin i \leq 200$ km s^{-1}, was designated by Slettebak (1949) as a "pole-on" Be star. Visual data show that υ Cyg has strong structureless Hα emission with no central reversal (see, for example, Peters 1976). High dispersion spectrograms acquired by one of us (T. H. M.) in 1977 September also indicate structureless Hα emission. In addition, no strong shell lines are present in the visible spectrum of υ Cyg either in the BUSS data or in the visual spectrograms acquired in 1977 September. All of these observations support the interpretation of υ Cyg being viewed as a "pole-on" system with no visible shell lines originating from an equatorial disk. The ultraviolet data presented for υ Cyg in Figure 2 show, as in γ Cas, strong narrow absorption features presumably of predominant interstellar origins with wavelengths close to the rest wavelengths of the Mg II resonance doublet. Although the data are noisy, they clearly show asymmetric emission lobes (with peak intensity about 20% of the continuum) on both sides of the narrow central absorptions at 2795 and 2802 Å.

c) φ *Persei*

The shell star φ Per (B1 III–IV) with a large $v \sin i$ (400–450 km s^{-1}) is considered to be viewed as an "equator-on" system. In addition, this object is a spectroscopic binary with a period of 130 days with pronounced shell features both in the visual and in the UV. Emission in the Balmer series is quite strong, with strong central reversals (Poeckert and Marlborough 1979; Peters 1976). High dispersion spectrograms obtained at KPNO in 1977 September also show strong Hα emission with a sharp central self-absorption.

There is ample evidence for mass outflow in φ Per since the C IV and Si IV resonance transitions in φ Per have been reported (Snow and Marlborough 1976) to display asymmetric shortward shifted absorption profiles. BUSS data acquired during the same exposure as

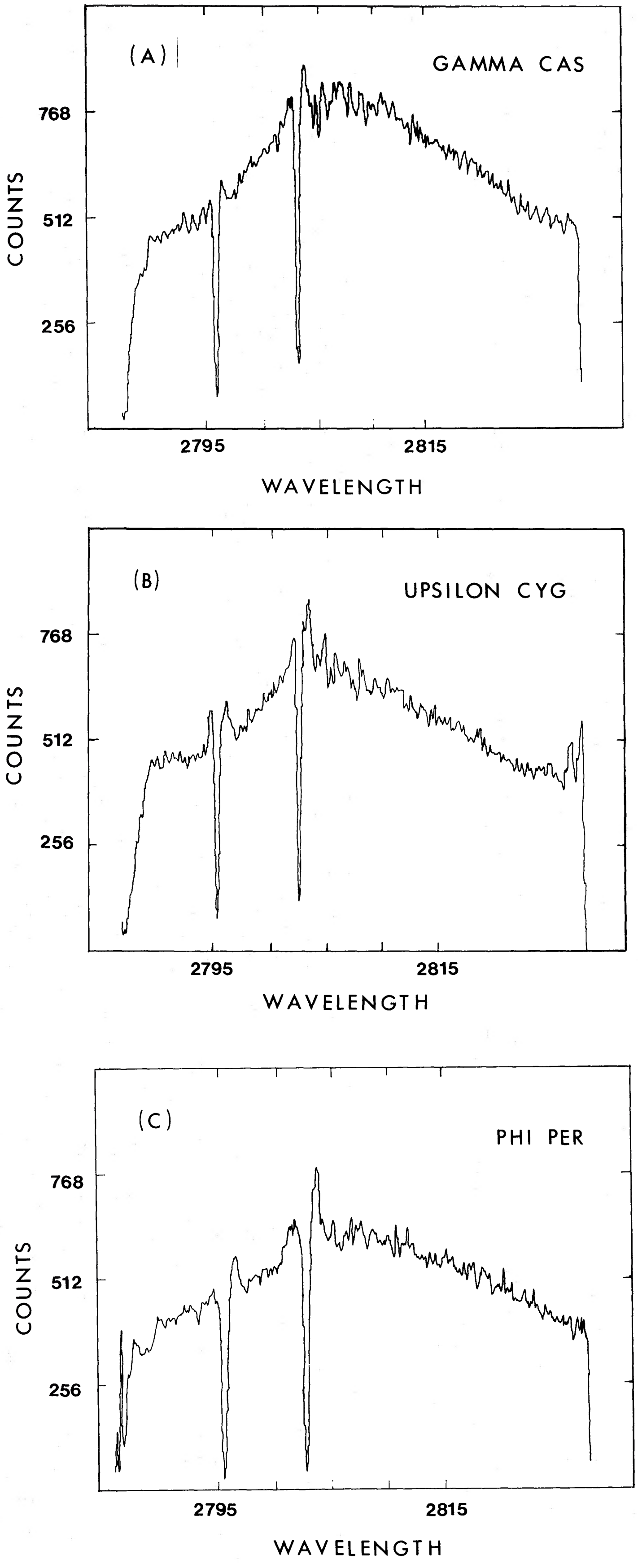

FIG. 1.—Relative intensities, with echelle order function contained of the three stars (*a*) γ Cas, (*b*) υ Cyg, and (*c*) ϕ Per, for the order containing the Mg II resonance doublet.

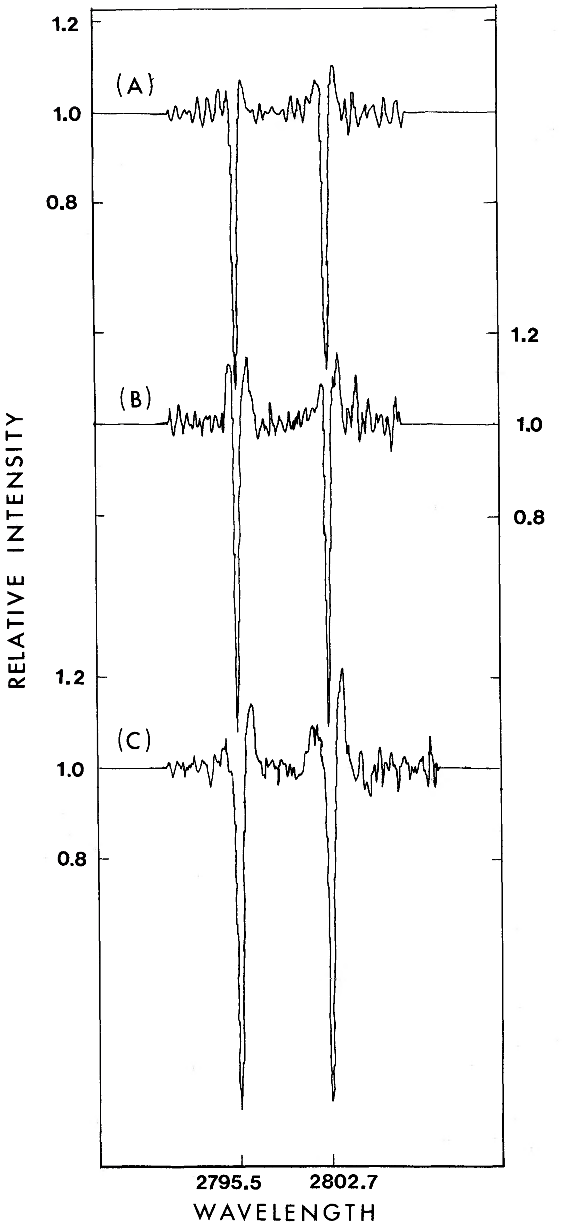

FIG. 2.—Relative intensities with echelle order function removed of the three stars (*a*) γ Cas, (*b*) υ Cyg, and (*c*) ϕ Per, in the neighborhood of the Mg II doublet.

the data presented here show shortward-shifted absorption features identified as the three transitions of the Fe III UV 48 multiplet at 2070 Å as reported previously (Bruhweiler, Morgan, and van der Hucht 1978). These transitions are not resonance lines, but arise from a metastable state 5 eV above ground. These profiles indicate outflow velocities up to 350 km s^{-1}. From these features, Bruhweiler, Morgan, and van der Hucht derived the column density to be $N(\mathrm{H}) = 1.43 \times 10^{19}$ cm^{-2} along the line of sight with a corresponding mass outflow estimate of 5×10^{-11} $M_\odot$ yr^{-1}.

The Mg II resonance doublet profiles as observed by BUSS are presented in Figure 2. The emission is very strong (peak above 20%). As in the cases of γ Cas and υ Cyg, strong central absorption features appear with no discernible wavelength shifts with respect to rest wavelengths. Nonetheless, the widths of these central absorptions, though not evident in the illustrations presented here, are broader than those for γ Cas and υ Cyg.

III. THE ORIGIN OF THE Mg II PROFILES

The appearance of the resonance Mg II emission features with central reversals in the Be stars as displayed in Figure 2 is reminiscent of the Hα profiles in many Be stars, in which Hα emission clearly indicates a true net emission process resulting from the recombination of hydrogen.

At least part of the observed absorption is expected to be interstellar in origin. Although no measurable velocity shifts are apparent, Figures 1 and 2 suggest that the Mg II absorption is shifted with respect to the emission, for each star, by 5–10 km s^{-1}. Therefore, some contribution to the central absorptions from a slowly expanding circumstellar shell seems likely.

However, since the Mg II features are resonance transitions, it might be argued that there is no real net emission in these Mg II features and the observed emission lobes are formed entirely by redistributing or scattering photons within the line profile as is the case in resonance line profiles of O and B supergiants. For the case of a spherically symmetric envelope where thermalization by electrons is negligible, the emission flux in the profile is expected to equal that missing due to the absorption component. However, neither of these conditions is found in the circumstellar material around Be stars.

If the generally accepted equatorial disk models are correct for Be stars (see Poeckert and Marlborough 1978, for example), resonance radiation would be preferentially scattered out of the plane of the disk. This would result in enhanced or a total net emission in Mg II when viewed at angles near the pole. Conversely, a total net absorption would be seen when viewed at angles near the equator.

Simple calculations also show that collisional processes cannot be ignored in the Mg II resonance profiles. Using the star ϕ Per as an example, we adopted the physical parameters for its shell as derived by Gehrz, Hackwell, and James (1974). We further adopt an expected range of ionization and assumed a purely Gaussian profile with a total broadening of 20 km s^{-1}, and then calculated the mean scattering path lengths of photons in the line center of the Mg II λ2795 photons. Using the approximation of van Regemorter (1962) for the ratio of collisional to radiative de-excitations, the thermalization lengths of these λ2795 photons were derived by the random walk method. These lengths were found to be 2×10^9 cm and 2×10^{10} cm for cosmic

1982ApJ...262..675B

abundances and ionization fractions (Mg II/Mg) of 0.1 and 0.01, respectively. Because of its smaller oscillator strength, the 2802 Å photons have larger thermalization lengths than the 2795 Å photons by a factor of 2. If we take the physical dimensions of the disk model of Poeckert and Marlborough (1978) as a guide, then the thermalization length at line center, 2×10^{10} cm, which may be an upper limit, is comparable but still less than the thickness of the circumstellar disk, and an order of magnitude less than the radial extent of the circumstellar disk. Even though photons will be redistributed to wavelengths away from line center where thermalization lengths are longer, thermalization by electrons will still be very effective in destroying the scattered photons and the observed emission.

These two effects make it difficult to explain any observed Mg II emission in systems that are observed "equator-on." For example, the high $v \sin i$ (450 km s^{-1}) and the presence of shell lines in ϕ Per indicate we are viewing this system "equator-on." Yet, this system reveals very strong emission relative to the central absorption which may be predominantly of interstellar origin. It seems impossible that pure scattering, at least in ϕ Per, can account for the strength of the observed Mg II emission lobes. It is necessary, therefore, to find a physical mechanism responsible for this emission.

It has been proposed that many Be stars are actually binaries with late-type companions, and, of course, chromospheric Mg II emission is observed in late-type stars. Unlike the situation here, the emission in late-type stars is seen against a weak continuum. If late-type companions were responsible for Mg II emission in spectra of Be stars, the late-type companion would also certainly dominate the spectrum at visual wavelengths (cf. Parsons 1981), which is not the case here. One also may rule out that the Mg II is produced in a chromosphere of the central Be star, since any visible Be star chromosphere would have a temperature above the local continuum of the Be star ($T_e \geq 20{,}000$ K) thereby producing an ionization equilibrium much too high for Mg II to be present.

We maintain that the observed Mg II resonance line emission is due to a Bowen mechanism. This Bowen mechanism is made possible by the juxtaposition of Lyβ λ1025.7 and Mg II λ1026.0 (Bowen 1947). This mechanism is driven by a strong Lyβ emission in stars, which overpopulates the $2P^o(5p)$ level of Mg II (see Fig. 3), and the resulting electron cascade leads to the observed emission in the Mg II resonance lines. This cascade takes place by two separate channels. One channel for this cascade is $5p \rightarrow 3d$(λλ3848, 3850), $3d \rightarrow 3p$(λλ2798, 2790), and $3p \rightarrow 3s$(λλ2795, 2802). The other channel is $5p \rightarrow 4s$(λλ3616, 3615), $4s \rightarrow 3p$(λλ2936, 2928), and again $3p \rightarrow 3s$(λλ2795, 2802). Since the transition probabilities, though uncertain, are larger for the $5p \rightarrow 3d$ transition than for the $5p \rightarrow 4s$ (Wiese, Smith, and Glennon 1966), higher downward radiative rates would be found in transitions of $5p \rightarrow 3d$ than of $5p \rightarrow 4s$. Without competition from other collisional or radiative rates, emission would be expected in all transitions that participate in the cascade. Electron scattering may also easily "smear-out" any weak emission (see § IV).

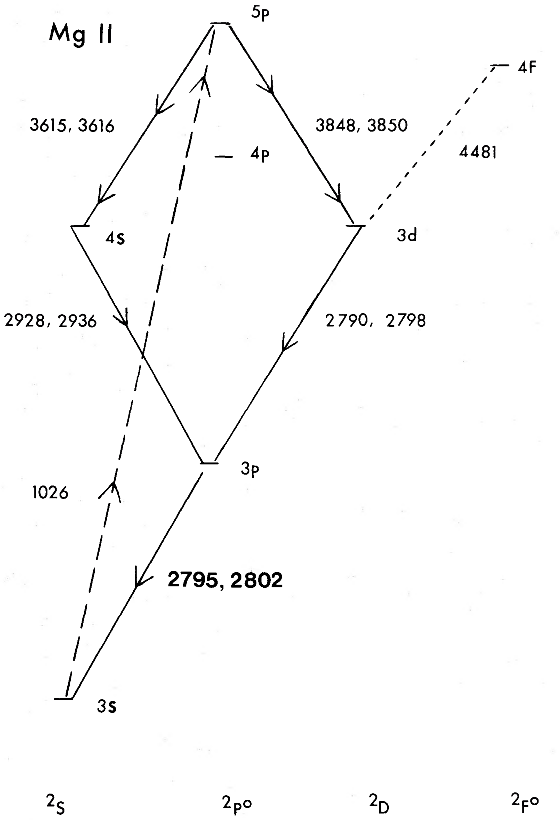

FIG. 3.—Partial Grotrian diagram of Mg II showing relevant transitions for the Bowen mechanism discussed in the text.

The net emission in the resonance lines would be stronger than in the other transitions primarily due to the funneling of both cascade channels into the $3p$ level. It is also not clear what the competition of other collisional and radiative rates has on the population of the levels. However, the oscillator strengths of the resonance lines (λλ2795, 2802), and the lines λ2798, λ2790, and also λ4481 are large. Therefore the normal collisional and radiative rates must be considered even at low densities. The net effect of these rates could be to partially nullify or compete with the Bowen mechanism. However, the actual effects are difficult to estimate without detailed calculations.

The expected equivalent widths of the ultraviolet stellar Mg II features can be taken from the LTE and non-LTE calculations of Mihalas (1972). These calculations were quite successful in reproducing the observed anomalous equivalent widths of Mg II λ4481 ($3d$–$4f$) as observed in early B and O stars without resorting to magnesium overabundances or large values of microturbulance. Both the LTE and non-LTE calculations, which neglect the presence of a Bowen mechanism and match the observed Mg II λ4481, indicate that the Mg II subordinate lines at 2790 Å and 2798 Å are strongly in absorption in the spectral range (B0–B2) of main sequence stars. They predict equivalent widths of 150–210 mÅ, with the non-LTE models providing larger equivalent widths than the LTE models. Since Be stars have gravities comparable to those of main sequence stars, lines of comparable strength should be seen in their spectra. Although stellar rotation may wash out these features in Be stars, they are predicted to be fairly strong lines and should be detectable here.

We have made an effort to examine Be star spectra for other evidence for the Bowen mechanism operating in other Mg II transitions. In the data presented here (Figs. 1 and 2), the $3d \rightarrow 3p$ lines at λλ2790,2798 are noticeable by their absence in the spectra of all three Be stars. Also, the $5p \rightarrow 3d$ lines at λλ3848,3850 are not seen in the visual high-dispersion spectrograms acquired in 1978 by one of us (T. H. M.). Whether these lines have been filled in by emission can not at present be ascertained.

Indirect proof of a Bowen mechanism operative in Mg II comes from the ion O I. Spectroscopic results presented by Peters (1976) indicate moderately strong O I λ8846 emission in υ Cyg with stronger emission in ϕ Per, the two stars showing strong Mg II emission studied here. The O I λ8446 emission has been shown to be due to a Bowen mechanism pumped by Lyβ. Electrons are pumped in the multiplets $\lambda 1025(2^{3P}{-}3^3D^o) \rightarrow \lambda 11237(3^3D^o{-}3^{3P}) \rightarrow \lambda 8446(3^{3P}{-}3^3S^o) \rightarrow \lambda 1302(3^3S^o{-}2^3P)$. The presence of λ8446 emission in these stars provides strong evidence for pumping via a Bowen mechanism in Mg II.

IV. CONCLUSIONS

Of the three early-type Be stars observed by BUSS VII plus χ Oph in BUSS IX, the spectra all displayed emission in the Mg II *h* and *k* lines. All of this suggests that Mg II emission is a normal phenomenon in Be stars of earlier spectral type which also show Balmer emission. The presence of strong Balmer and O I λ8446 emission along with Mg II *h* and *k* emission points toward a Bowen mechanism driven by Lyβ as being responsible for both the Mg II and O I emission.

The relative intensities of the Mg II *h* and *k* emission does imply partial thermalization of these features. The relative strength of the longward and shortward emission lobes in each Mg II emission profile in all three Be stars indicate a small negative velocity shift of the central narrow absorption with respect to the emission upon which it is superposed. The origin of the narrow absorption is due to interstellar and possibly circumstellar contributions.

It is easly shown that in the shells of Be stars Lyβ radiation is rapidly converted within a short pathlength into Hα plus photons in the $2^2S{-}1^2S$ continuum (Osterbrock 1974). Then, if the Mg II emission is due to a Bowen mechanism, it must originate almost exclusively within the same physical region as does the hydrogen recombination spectrum. The comparable widths of the Balmer and Mg II emission support this. The average of the half widths $\frac{1}{2}(\Delta\lambda)_E$ of Hβ and Hγ in the three stars discussed here (Slettebak 1976) yields 155 km s^{-1} comparing favorably with the 125 km s^{-1} found for the Mg II emission.

The Mg II transition at λ1026.0, unlike the O I transition at λ1025.7, does not closely coincide with the center of Lyβ. The separation between Mg II and Lyβ corresponds to 100 km s^{-1}, rather more than the hydrogen thermal velocity which is 13 km s^{-1} at 20,000 K. Although the flux in broad wings of a strong Lyβ emission or even a strong local continuum might be sufficient to drive the Bowen mechanism in Mg II, other means of broadening or redistributing Lyβ emission, so that the emission overlaps more with Mg II, are very important and might well govern the effectiveness of the Bowen process.

Poeckert and Marlborough (1979) have shown that the electron scattering optical depths must be substantial ($\tau_{\rm es} \gtrsim 0.1$) in Be star shells and produce observable broadening to the Balmer emission. However, the destruction path length of Lyβ photons, unlike Balmer photons and Mg II 2800 Å photons, is extremely short compared to the mean free path for electron scattering —it is at least several orders of magnitude smaller even under the most favorable of conditions. Although electron scattering may be effective in broadening the observed Mg II emission (or any transitions with sufficiently long thermalization lengths), it seems unlikely that it is important in broadening Lyβ emission.

Either turbulence or a steep velocity gradient might increase the amount of overlap of Lyβ with Mg II λ1026.0. Both possibilities, in addition, would also increase the destruction or thermalization lengths of Lyβ and Mg II at 2800 Å and lead to stronger observable Mg II emission. In this regard, turbulence in the Be shells on the order of 100 km s^{-1} has been suggested previously (Marlborough and Snow 1980; Marlborough, Snow, and Slettebak 1978).

In the case of γ Cas, variations in the Mg II profiles (Marlborough, Snow, and Slettebak 1978) have been linked previously to similar variations in Hβ during the period partially covering the ultraviolet Mg II observations. However, the relative strengths of the violet and red components (the V/R ratio) of the double-peaked Hβ emission (mean values of the peaks were at -77 and 109 km s^{-1}) varied significantly over a 3.4 year cycle. As noted by Marlborough, Snow, and Slettebak, the V/R variations in Mg II mimic those in Hβ as presented by Cowley, Rogers, and Hutchings. Also, there is some hint that variations of the Mg II emission at short time scales (approx. minutes) are correlated with those of the Balmer lines (Slettebak and Snow 1978). However, few data exist, and any linkage of these two short-period phenomena still must remain tentative.

The apparent displaced central absorptions relative to the Mg II emission might be interpreted as evidence for a slow expansion of the order of 5–10 km s^{-1}. Since the BUSS exposure of ϕ Per also shows asymmetric absorptions of the Fe III UV 48 multiplet displaying expansion velocities of -350 km s^{-1}, one consistent interpretation is that the Mg II emission originates in a region typified by low ionization and low expansion velocities while the regions farther away from the star in which the Fe III is found exhibit higher expansion velocities seen in the resonance lines of C IV and Si IV in the far-UV.

If turbulence or a velocity gradient governs the Bowen mechanism and is ultimately responsible for the strength of Mg II emission, then we are led to expect some correlation in the widths of Balmer emission and the strength of Mg II emission. Of course, the Mg II emission is also a function of hydrogen emission strength, making such effects difficult to disentangle. Simultaneous ultraviolet and visual monitoring of the Mg II 2800 Å region and the Balmer lines may eventually resolve this question.

The signal-to-noise ratio and the resolution of the *International Ultraviolet Explorer* (*IUE*) do not match those of BUSS, thus making the weak Mg II emission described here more difficult to detect with that instrument. However, further observations in the near-UV and far-UV might provide more information on the physical conditions in the circumstellar envelopes of Be and shell stars.

Even though we can not say anything definite about the short time variability in γ Cas, we have found Mg II emission to be a common occurrence in Be stars.

The success of the BUSS payload was due in large measure to the engineering excellence of the binational engineering team which developed and flew the payload. The authors feel deeply indebted both to the Dutch engineering group headed by Dr. Theo Kamperman of the Space Research Laboratory (Utrecht) and to the American engineers led by Mr. C. W. Wells of Lockheed Electronics Corporation (Houston). The efforts of these two and their co-workers helped make the BUSS program a model for international cooperative efforts.

REFERENCES

Bohlin, R. C. 1970, *Ap. J.*, **162**, 571.
Bowen, I. S. 1947, *Pub. A.S.P.*, **59**, 196.
Bruhweiler, F. C., Morgan, T. H., and van der Hucht, K. A. 1978, *Ap. J.* (*Letters*), **225**, L71.
Cowley, A. P., Rogers, L., and Hutchings, S. B. 1976, *Pub. A.S.P.*, **88**, 911.
de Jager, C., Kondo, Y., Hoekstra, R., van der Hucht, K. A., Kamperman, T. M., Lamers, H. J. G. L. M., Modisette, J. L., and Morgan, T. H. 1979, *Ap. J.*, **230**, 534.
Gehrz, R. D., Hackwell, J. A., and James, T. W. 1974, *Ap. J.*, **191**, 675.
Kondo, Y., de Jager, C., Hoekstra, R., van der Hucht, K. A., Kamperman, T. M., Lamers, H. J. G. L. M., Modisette, J. L., and Morgan, T. H. 1979, *Ap. J.*, **230**, 226.
Lesh, J. R. 1968, *Ap. J. Suppl.*, **17**, 371.
Marlborough, J. M., and Snow, T. P. 1980, *Ap. J.*, **235**, 85.
Marlborough, J. M., Snow, T. P., and Slettebak, A. 1978, *Ap. J.*, **224**, 152.
Mihalas, D. 1972, *Ap. J.*, **177**, 115.
Osterbrock, D. E. 1974, *Astrophysics of Gaseous Nebulae* (San Francisco: Freeman).
Parsons, S. 1981, *Ap. J.*, **245**, 201.
Peters, G. J. 1976, in *IAU Symposium 70, Be Stars and Shell Stars*, ed. A. Slettebak (Dordrecht: Reidel), p. 209.
Poeckert, R., and Marlborough, J. M. 1978, *Ap. J.*, **220**, 940.
______. 1979, *Ap. J.*, **233**, 259.
Schild, R. E. 1976 in *IAU Symposium 70, Be Stars and Shell Stars*, ed. A. Slettebak (Dordrecht: Reidel), p. 107.
Slettebak, A. 1949, *Ap. J.*, **110**, 498.
______. 1976, in *IAU Symposium 70, Be Stars and Shell Stars*, ed. A. Slettebak (Dordrecht: Reidel), p. 123.
Slettebak, A., and Snow, T. P. 1978, *Ap. J.* (*Letters*), **244**, L127.
Snow, T. P., and Marlborough, J. M. 1976, *Ap. J.* (*Letters*), **203**, L87.
van Regemorter, H. 1962, *Ap. J.*, **136**, 906.
Wiese, W. L., Smith, M. W., and Glennon, B. M. 1966, *Atomic Transition Probabilites* (Washington: Government Printing Office).

FREDERICK C. BRUHWEILER: Code 685, CSC, Goddard Space Flight Center, Greenbelt, MD 20771

THOMAS H. MORGAN: Department of Physics, Southwestern University, Georgetown, TX 78626

KAREL A. VAN DER HUCHT: Space Research Laboratory of the Astronomical Institutes of the Netherlands, 21 Beneluxlaan, Utrecht, The Netherlands