THE ASTROPHYSICAL JOURNAL, 202: 733–740, 1975 December 15

ULTRAVIOLET OBSERVATIONS OF COOL STARS. IV. INTENSITIES OF LYMAN-α AND Mg II IN EPSILON PEGASI AND EPSILON ERIDANI, AND LINE WIDTH–LUMINOSITY CORRELATIONS

W. McCLINTOCK, R. C. HENRY,*† AND H. W. MOOS*
Physics Department, Johns Hopkins University

AND

J. L. LINSKY*‡
Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards, Boulder
Received 1975 April 11; revised 1975 June 2

ABSTRACT

The Princeton spectrometer on the *Copernicus* satellite has been used to confirm the existence of a line width–luminosity relation for the Lα and Mg II λ2800 chromospheric emission lines in K-type stars, by observation of a K2 dwarf (ϵ Eri) and of a K2 supergiant (ϵ Peg). Combined with previously reported observations of lines in three K giants (α Boo, α Tau, and β Gem), the data are consistent with an identical dependence of line-width on absolute visual magnitude for the Ca II K, Lα, and Mg II λ2795 lines. Surface fluxes of Lα, Mg II λ2800, and O V λ1218 (upper limit) for ϵ Eri, and of Mg II λ2800 for ϵ Peg are also compared with values reported previously for the three giant stars.

Subject headings: Ca II emission — emission-line stars — late-type stars — line profiles — spectra, ultraviolet

I. INTRODUCTION

Ultraviolet observations of three giant stars were reported in previous papers (Moos *et al.* 1974 [Paper I]; Gerola *et al.* 1974 [Paper II]; and McClintock *et al.* 1975 [Paper III]). Lines observed were the H I λ1215.6 resonance line (Lα); the Mg II $\lambda\lambda$2795.5, 2802.7 resonance lines; the O V λ1218 intercombination line (in β Gem); and upper limits on H I λ1025.7 (Lβ) and Si III λ1206 lines. This program is extended in the present paper to K-type stars of a much wider range of luminosity. Observations have been made of the Lα and Mg II λ2800 lines in the K dwarf ϵ Eri, and of the Mg II doublet in the K supergiant ϵ Peg. An upper limit is also given for the O V λ1218 line in ϵ Eri.

The five stars studied in this program all show Ca II λ3933 emission (Wilson and Bappu 1957), which is evidence for chromospheres in these stars. The stars β Gem, ϵ Eri, and ϵ Peg show He I λ10830 absorption (Vaughan and Zirin 1968); but only one (ϵ Peg) exhibits Hα emission (Kraft *et al.* 1964), which is rare in late-type stars.

II. OBSERVATIONS

Observations with the *Copernicus* spectrometer (Rogerson, Spitzer, *et al.* 1973) were made on 1973 December 12/13 for ϵ Eri and on 1974 October 12/13 for ϵ Peg, and included low-resolution (Copernicus U2 channel, ~0.25 Å) scans of H I λ1215 (Lα) in ϵ Eri and low-resolution (V2, ~0.51 Å) scans of the Mg II resonance doublet $\lambda\lambda$2797.5, 2802.7 in both ϵ Eri and ϵ Peg. Observing techniques and data reduction procedures are described in Paper III.

Table 1 summarizes the observational results for ϵ Eri and ϵ Peg, including estimates of stellar surface fluxes assuming angular diameters of 0".0026 and 0".0139, respectively, for the two stars. The angular diameter for ϵ Eri is the mean of that determined by Wesselink *et al.* (1972) and the angular diameter deduced from the radius of Gray (1968) and the parallax of Hoffleit (1964). The angular diameter of ϵ Peg is deduced from the $B - V$ color using the method of Wesselink (1969) and Wesselink *et al.* (1972).

During the Lα observations for ϵ Eri, the high-resolution far-ultraviolet detector was used as a real-time monitor of the particle background, a procedure which has proved very reliable in aiding removal of background from the low-resolution far-ultraviolet data. In Figure 1, the solid line is a histogrammed average of the 50 scans of ϵ Eri after background subtraction. One spectral step at line center was heavily contaminated by geocoronal Lα emission, and only an upper limit (estimated by comparing the average intensity of the 25 nighttime scans with that of the 25 daytime scans) is given. Wavelengths are vacuum values in the rest frame of the star. The baseline shown is the average (-0.07 ± 0.25 counts per 14 s per 0.19 Å) of 25 spectral steps away from line center. Error bars are $\pm 1\ \sigma$, where σ is the rms error in the

* Guest investigator with the Princeton University telescope on the *Copernicus* satellite, which is sponsored and operated by the National Aeronautics and Space Administration.

† Alfred P. Sloan Foundation Research Fellow.

‡ Staff member, Laboratory Astrophysics Division, National Bureau of Standards.

TABLE 1

SUMMARY OF RESULTS

Parameter	ϵ Eri (K2 V)	ϵ Peg (K2 Ib)
Lα λ1215.7		
Number of spectral scans	50	...
Total dwell time per step (s)	700	...
Counts per 14 s (total line)	36.0 ± 3.6	...
Observed flux (photons cm^{-2} s^{-1})	0.75	...
Stellar surface flux* (10^3 ergs cm^{-2} s^{-1})	317	...
Full width at half-intensity (Å)	1.0 ± 0.1	...
Mg II $\lambda\lambda$2795.5, 2802.7		
Number of spectral scans	24	60
Total dwell time per step (s)	336	840
Counts per 14 s (total line):		
λ2795.5	1314 ± 256	2775 ± 644
λ2802.7	681 ± 166	2657 ± 594
Observed flux (photons cm^{-2} s^{-1}):		
λ2795.5	4.06	8.80
λ2802.7	2.11	8.43
Stellar surface flux* (10^3 ergs cm^{-2} s^{-1}):		
λ2795.5	727	55
λ2802.7	376	53
Full width at base (Å)		
λ2795.5	1.0 ± 0.3	3.4 ± 0.3

* No correction for interstellar absorption.

mean, estimated from the scatter of the 50 measurements at that wavelength. The nominal slit-width of the spectrometer is 0.185 Å at Lα, but the resolution of this histogrammed spectrum is 0.25 Å due to Doppler shifts caused by spacecraft orbital motion.

Low-resolution scans of the Mg II resonance lines were also obtained for ϵ Eri. Background was removed using the "standard table of backgrounds" described in Paper III which left a substantial average residual count-rate (1300 counts per 14 s). A large fraction of this is very likely a result of inadequacy of the standard table; however, detailed tests allow the possibility that some stellar signal (~200 counts per 14 s) is being detected. If so, this could be either stellar continuum at 2800 Å or scattered radiation from longer wavelengths.

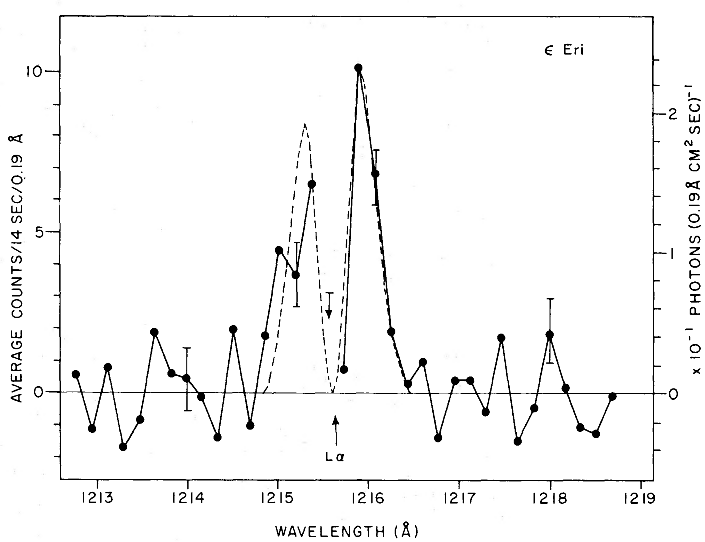

FIG. 1.—The observed Lα emission from the K2 dwarf ϵ Eri. Filled circles are the data points (0.173 Å apart). The left ordinate is the number average of photomultiplier pulses per 14 s per resolution element per scan, while the right-hand scale gives the absolute intensity. Error bars are ±1 σ. One spectral step, at line center (*horizontal line with arrow*), is an upper limit. The dashed line is a simple model, using an interstellar hydrogen density $\langle n_{\rm H\,I} \rangle = 0.05\ cm^{-3}$.

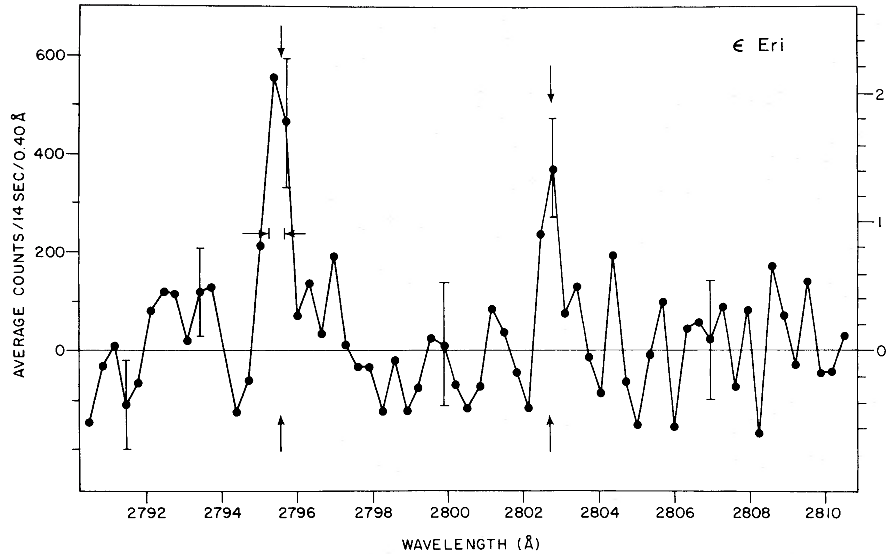

FIG. 2.—The observed Mg II resonance doublet emission from the K dwarf ϵ Eri. Axes and error bars are as in Fig. 1. Arrows mark the nominal line centers. Horizontal arrows give the estimated intrinsic half-width of the λ2795.5 feature, corrected for instrumental broadening.

Figure 2 is a histogrammed average of the 24 Mg II scans of ϵ Eri. The straight line, which was least-squares fitted to the residual background (excluding the two spectral regions with clear emission), establishes an arbitrary zero level.

Mg II data were also obtained for the K supergiant ϵ Peg. Each component was scanned separately. After backgrounds were subtracted using the "standard table," an average residual count-rate of 1275 counts per 14 s per spectral step remained. Figure 3 is a histogrammed average of the 60 scans. The straight line, drawn by eye, establishes an arbitrary zero level, estimated to be reliable to ± 50 counts per 14 s.

Error bars in Figures 2 and 3 are $\pm 1\ \sigma$ rms errors in the mean estimated from the scatter of the individual scans. The resolution of the data (~ 0.51 Å) is slightly less than the nominal value of the spectrometer exit slit-width (0.395 Å), due to Doppler shifts. Wavelengths are air values in the rest frame of the star.

The Lα data also set an upper limit on the flux of the forbidden O V λ1218 line. The utility of this line in searching for cool stellar coronae is discussed in

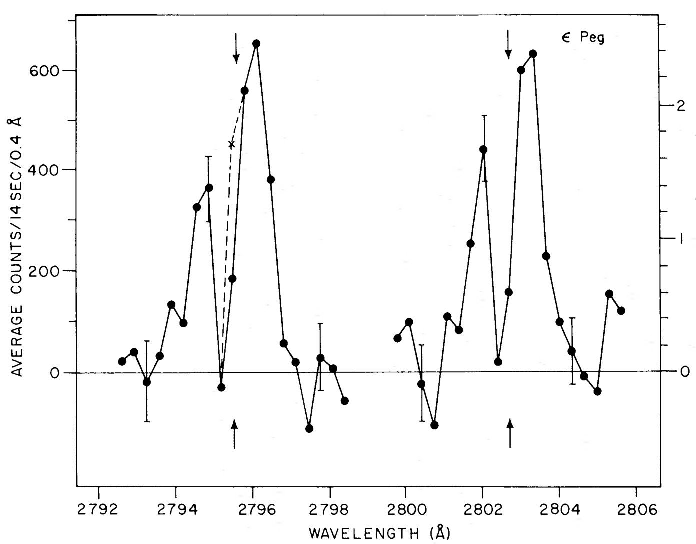

FIG. 3.—The Mg II emission profiles from the K2 supergiant ϵ Peg. Error bars and axes are as in Fig. 1. The dashed line shows the correction for interstellar absorption required, based on particular assumptions discussed in the text. This correction depends critically on the velocity assumed for the interstellar gas.

Papers II and III. Using a procedure described in Paper III, the 3 σ upper limit for ϵ Eri is found to be 6 counts per 14 s (or 0.13 photons $cm^{-2} s^{-1}$), corresponding to a stellar surface flux of 5.4×10^4 ergs $cm^{-2} s^{-1}$.

III. DISCUSSION

We interpret the observed profiles of the chromospheric emission lines, after allowing for the effects of interstellar absorption.

a) *Absorption by Interstellar Hydrogen*

The K dwarf ϵ Eri is only 3.3 pc distant. Application of simple models for the intrinsic line profile and for the interstellar hydrogen absorption, using methods described in Paper III, showed that the low-resolution Lα profile cannot be used to distinguish among values of $\langle n_{\rm H\,I} \rangle \leq 0.1$ cm^{-3} for the average local interstellar hydrogen density. The dashed line in Figure 1 is a model using $\langle n_{\rm H\,I} \rangle = 0.05$ cm^{-3}, a symmetric intrinsic stellar profile similar in shape to the solar Lα line but with the self-reversal removed, a half-width of 0.95 Å, and a velocity displacement of -0.04 Å (10 km s^{-1}) for the absorption relative to the stellar line center. This velocity displacement is consistent with the value of -0.05 Å estimated from the stellar radial velocity and local interstellar H I flow velocity (cf. Table 3 in Paper III). Obviously, no lower limit for $\langle n_{\rm H\,I} \rangle$ can be established by these models because the degree of intrinsic self-reversal present in the stellar profile cannot be confidently estimated.

The total stellar Lα surface flux required to reproduce the observations critically depends on the chosen value of $\langle n_{\rm H\,I} \rangle$. For example, $\langle n_{\rm H\,I} \rangle = 0.01$ cm^{-3}, 0.05 cm^{-3}, 0.10 cm^{-3} give relative stellar surface fluxes for ϵ Eri deduced from the above model (which has no self-absorption in the intrinsic profile) of 1.00, 1.25, and 1.58, respectively. Similar corrections are required for other stars. Therefore, in order to allow more meaningful intercomparison with the fluxes of the three stars of Paper III, relative corrections for the interstellar absorption were computed for all four stars using the above range of values for $\langle n_{\rm H\,I} \rangle$ and the intrinsic line profiles, with overall shapes similar to the solar Lα profile and half-widths equal to the values given in Table 1 and Table 3 of Paper III. The amount of self-absorption for the intrinsic stellar profiles is not known. However, upper limits to the flux correction due to a particular value of $\langle n_{\rm H\,I} \rangle$ can be set by assuming that there is no intrinsic self-reversal and, therefore, the observed central reversal is due *entirely* to interstellar absorption. In this case, the interstellar hydrogen also depresses the peaks of the emission line; and, for increasing values of $\langle n_{\rm H\,I} \rangle$, larger values of the total intrinsic stellar surface flux are required to reproduce the observed profile, although the shape of the absorption core changes only slightly (see Fig. 5 of Paper III and note that to reproduce the observed profile the height of the intrinsic profile must be increased for increasing values of $\langle n_{\rm H\,I} \rangle$). A lower limit to the flux correction for the assumed value of $\langle n_{\rm H\,I} \rangle$ can be set by assuming that the observed reversal at line center is due entirely to self-absorption in an optically thick chromosphere. In this case, interstellar absorption still causes the peaks of the emission line to be depressed even though there is essentially no interstellar contribution to the core of the line.

Although the predicted total Lα surface flux from each star increases for increasing $\langle n_{\rm H\,I} \rangle$, the relative fluxes among the various stars are less sensitive to changes in $\langle n_{\rm H\,I} \rangle$. Relatively narrow lines are more affected by interstellar absorption, so for ϵ Eri and β Gem the correction factor leads to a more substantial increase in the estimated surface flux than is the case for α Tau and α Boo. The results given in Table 2 are intended as a guide for interpreting the absolute values of ultraviolet emission fluxes for the four stars.

b) *Absorption by Interstellar Magnesium*

Calculations based on the same assumptions that were made in Paper III suggest that, compared with the statistical errors inherent in the observation, interstellar absorption has a negligible effect on the observed total emission rate and line profiles for the Mg II lines of the nearby dwarf ϵ Eri. In particular, measurements by Rogerson, York, *et al.* (1973) for α Leo ($d = 22$ pc) indicate that the average local space density of Mg II is $\langle n_{\rm Mg\,II} \rangle = 5 \times 10^{-8}$ cm^{-3}. Thus, for ϵ Eri ($d = 3.3$ pc), the column density of Mg II is $N(\rm Mg\,II) = 5.08 \times 10^{11}$ cm^{-2}, which corresponds to an unsaturated interstellar line with an equivalent width of $W = 4.35 \times 10^{-14} N(\rm Mg\,II) = 0.02$ Å. Since the resolution of the observation is 0.51 Å, interstellar absorption can cause at most a 6 percent decrease in a single spectral step, which is small compared with the size of the statistical errors of the observation.

The distance to ϵ Peg (250 pc) is sufficiently large that interstellar Mg II absorption may have an appreciable effect on the observed profile. Unfortunately, few measurements of interstellar element abundances have been made in the direction of ϵ Peg ($l^{\rm II} = 65°$, $b^{\rm II} = -31°$), so it is difficult to confidently estimate a range of values for the column density of Mg II. However, since the optical depth at line center has the high value $\tau_0 \approx 350$ for an assumed value of $\langle n_{\rm H\,I+H_2} \rangle = 0.5$ cm^{-3} (and for Mg II depleted relative to "cosmic" abundance by a factor of 10, following Rogerson, York, *et al.* 1973; Morton *et al.* 1973; and Morton 1974), the equivalent width changes by only 20 percent for an order-of-magnitude change in the column density. Measurements by Hobbs (1969) of interstellar sodium absorption in π Aqr ($l^{\rm II} = 66°$, $b^{\rm II} = -45°$, and $d = 370$ pc), as well as observations of 21-cm emission by Goldstein and MacDonald (1969) in the direction of HD 206540 ($l^{\rm II} = 66°$, $b^{\rm II} = -31°$) indicate that interstellar clouds in the direction of ϵ Peg have heliocentric velocities V_c in the range -15 km $s^{-1} \leq V_c \leq -10$ km s^{-1}. The dashed line in Figure 3 shows the correction to the λ2795.5 component that is required under the assumption that $\tau_0 = 350$, $\langle n_{\rm H\,I} + n_{\rm H_2} \rangle = 0.5$ cm^{-3}, the dispersion velocity along the line of sight is 7 km s^{-1}, and the average heliocentric velocity of clouds in the line of sight is -13 km s^{-1}. (For the sake of clarity, no correction has been applied to the λ2802.7 profile.) The details of the correction depend critically upon the last number. For example, if V_c is -30 km s^{-1} instead of -13 km s^{-1}, the deep absorption component that is seen one spectral step from line center could be entirely explained in terms of interstellar Mg II absorption. However, it was noted in Paper III that Mg II interstellar absorption cannot explain the asymmetry observed in the α Boo and α Tau emission profiles, as their distance is much smaller than that for ϵ Peg.

The total stellar surface flux that is deduced from the observations also depends on V_c. With $V_c = -13$ km s^{-1}, the corrected flux = 1.1 times the uncorrected flux; while if the reversal is entirely due to interstellar absorption ($V_c = -30$ km s^{-1}), the factor is 1.35. Three-color measurements of this star (Blanco *et al.* 1970) indicate that it is unreddened; and, therefore, no appreciable correction for extinction by dust is required.

Similar pronounced reversals were reported by Kondo *et al.* (1972) for the Mg II components in α Ori ($l^{II} = 200°$, $b^{II} = -9°$, $d = 160$ pc). It appears possible that at least part of the observed reversal is due to absorption by interstellar Mg II. Although many measurements of interstellar absorption have been made in the general direction of α Ori, most of the stars observed lie at distances greater than 450 pc; and there is no knowledge as to which absorption components observed in the spectra of these stars are due to material between α Ori and the Earth. Nonetheless, a first approximation to the effect of interstellar absorption in α Ori can be made based upon these measurements. Heliocentric velocities of 27 km s^{-1} $\geq V_c \geq$ 23 km s^{-1} for the interstellar clouds in the direction of α Ori inferred from sodium measurements (Hobbs 1969) are consistent with the observed slight blueshift in the Mg II absorption-center with respect to the stellar Mg II emission profile. Furthermore, the measurement by Morton *et al.* (1973) of an average column density of 8.2×10^{12} cm^3 pc^{-1} in the direction of λ Ori A ($l^{II} = 195°$, $b^{II} = -12°$, $d = 611$ pc) implies an optical depth $\tau_0 \approx 350$ (and therefore an equivalent width $W \approx 0.4$ Å) for Mg II λ2795.5, which is also consistent with the observed stellar profile. Thus, the reversals may have a substantial contribution from interstellar absorption. However, a marked feature of the Mg II profiles is the great difference in shape in each of the two components. This, of course, is not explained by saturated absorption profiles due to interstellar matter.

c) *Chromosphere of* ϵ *Eri*

The absolute line intensities given in Table 1 are based on values of the spectrometer sensitivity taken from Paper III, and the angular diameters described above. Within the calibration error of the spectrometer (a factor of 2) the uncorrected stellar surface fluxes are close to the solar values taken from Table 2

TABLE 2

INTERCOMPARISON OF STELLAR SURFACE FLUXES AND FLUX RATIOS

	α TAURI (K5 III) 5/6 Feb.	α TAURI (K5 III) 17/18 Oct.	ϵ PEGASI (K2 Ib) 12/13 Oct.	α BOOTIS (K2 III p) 19/20 May	ϵ ERI (K2 V) 12/13 Dec.	β GEM (K O III) 16/17 Oct.	SUN (G2 V)
Surface Flux (10^3 ergs cm^{-2} s^{-1}) (uncorrected for interstellar absorption)							
Mg II	68.6	48.1	108	192	1103	106	1200
O V	...	[1.53]	...	[2.0]	[54]	7.5	0.3
Lα	17.6	17.4	...	32.1	317	19.2	249 ± 37.0
Surface Flux (10^3 ergs cm^{-2} s^{-1}) (corrected for interstellar H I absorption)							
$n_H = 0.01$ cm^{-3}:							
Lower limit	18.2	18.0	...	33.7	345.5	21.4	
Upper limit	21.8	27.6		39.5	445.4	26.1	
Lα $n_H = 0.05$ cm^{-3}:							
Lower limit	21.2	20.9	...	39.1	421.9	27.9	
Upper limit	30.0	29.7		49.7	556.4	36.9	
$n_H = 0.10$ cm^{-3}:							
Lower limit	24.6	24.4	...	45.2	506.4	39.5	
Upper limit	38.1	37.7		60.2	704.9	57.4	
Flux Ratios (uncorrected for interstellar absorption)							
Lα/Mg II	0.26	0.36	...	0.17	0.28	0.18	0.21
Mg II/(Mg II ϵ Eri)	0.062	0.044	0.097	0.17	1	0.10	1.09
Lα/(Lα ϵ Eri)	0.056	0.055	...	0.10	1	0.061	0.79

NOTE.—The values in brackets are upper limits.

of Paper III (see Table 2) indicating that ϵ Eri has a well-developed chromosphere. The uncorrected Lα surface flux reported in Table 1 is an order of magnitude larger than values reported in Paper III for the K giants α Tau, α Boo, and β Gem, while the Mg II surface flux from ϵ Eri is a factor of 5 greater than that inferred for any other K-type star observed with *Copernicus*. For the purpose of intercomparison, ratios of fluxes of the five K-type stars are given in Table 2, uncorrected for interstellar absorption. The only flux ratio that varies substantially with change in the assumed value of local $\langle n_{\mathrm{H\,I}} \rangle$ is Mg II/Lα for each star. The ratio (Mg II ϵ Peg)/(Mg II ϵ Eri) may be low by a factor 1.35 (see § III*b*).

An interesting feature of the ϵ Eri Mg II flux is the ratio of k/h (i.e., λ2795.5/λ2802.7). For an optically thick resonance doublet formed in a chromosphere where the temperature increases with height, the more opaque component is expected to be brighter; but only *slightly* brighter (Linsky 1970). For example, the ratio of k emission to h emission is 1.18 in the Sun. Although the data are quite noisy, the Mg II k/h emission ratio (1.9 ± 0.6) may violate the rule. If so, this would suggest that Mg II in ϵ Eri may be optically thin and/or formed in a different manner than in the solar chromosphere. Thus, though the total surface fluxes indicate a similarity with the solar chromosphere, this should be treated with caution.

d) Chromosphere of ϵ Peg

If the correction for interstellar absorption shown in Figure 3 is appropriate, the blueshifted (-34 km s^{-1}) central absorption in the Mg II profiles of ϵ Peg may be related to the asymmetries observed in other spectral regions. Wilson (1957) reported that the self-reversal in the Ca II λ3933 emission feature was blueshifted by -34 km s^{-1}. Furthermore, ϵ Peg exhibits blueshifted (-44 km s^{-1}) absorption in the He I λ10830 line (Vaughan and Zirin 1968) and blueshifted emission in Hα (Kraft *et al.* 1964). The velocity of recession from the star is considerably less than the surface escape velocity (80 km s^{-1}), indicating either that these phenomena occur in material that is two or more radii above the stellar surface or that a stellar wind is present with a velocity that increases outward as the density decreases. Similar asymmetries are also observed in the Mg II and Lα profiles in α Boo, and to a lesser degree in α Tau (Paper I and Paper III), but not in the Ca II λ3933 emission feature (Wilson and Bappu 1957) of either star. Asymmetric profiles for both Mg II components for α Tau have been observed by Kondo *et al.* (1975). However, they also report asymmetry for only the λ2795.5 line of ϵ Peg. They interpret the difference in k and h profiles as indicating the presence of a circumstellar shell. A similar interpretation has also been proposed to explain the struc-

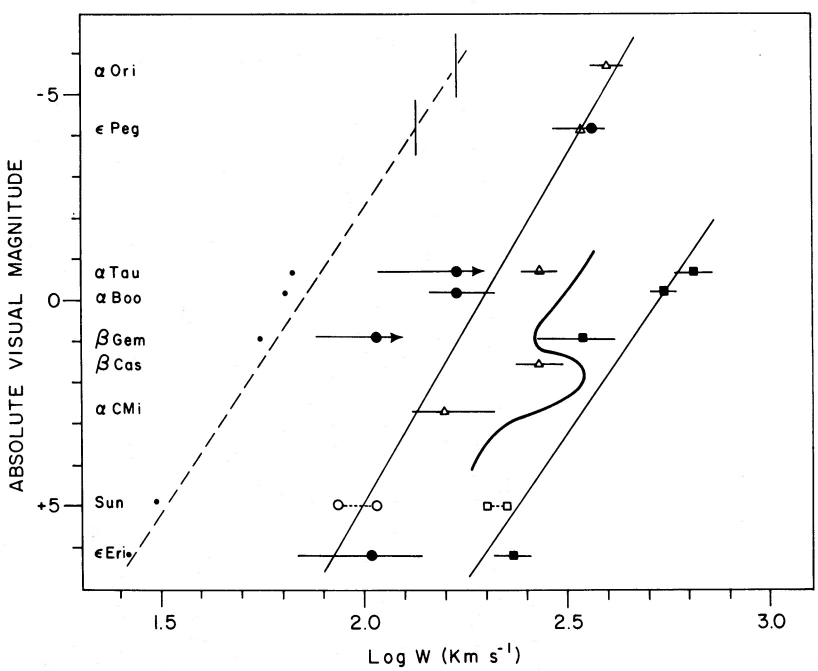

FIG. 4.—The relation between the width of chromospheric emission lines, and stellar luminosity. The ordinate is the absolute visual magnitude. The abscissa is log W measured in km s^{-1}. Squares represent Lα (full half-widths), and circles represent Mg II (full widths measured at the base). Two points, due to noisy data, have no upper limit on their width. Triangles are Mg II measurements reported by Kondo *et al.* (1972). Errors are shown as horizontal lines. Filled dots are data for Ca II widths (Wilson and Bappu 1957). The dashed line is the relation reported by Wilson (1959) for the Ca II K line. For two stars (*vertical lines*) the absolute magnitudes were computed from the Ca II widths. The curved line separates the Mg II data from the Lα data. Open circles and open squares are solar values.

ture of the Mg II profiles in α Ori (Modisette *et al.* 1973) as caused by Fe I λ2795 absorption in a cool shell.

The present data for ϵ Peg clearly indicate asymmetric profiles for both k and h, suggesting that this phenomenon arises from physical conditions in the emitting region itself rather than as absorption or scattering in a shell. The resolution of the present data is not good enough to provide detailed information on the shapes of the Mg II profiles for ϵ Eri, and within experimental error the Lα data present no evidence for asymmetry.

e) *The Line Width–Luminosity Relation*

Table 1 includes estimates of the full width at the base for the Mg II λ2795.5 profile and the full width at half-intensity for the Lα profile, both corrected for instrumental broadening. It was noted in Paper III that the line widths for both Mg II and Lα appear to be correlated with absolute visual magnitude in a similar fashion to the relation found by Wilson and Bappu (1957) for Ca II.

Figure 4 shows a plot of log W versus absolute visual magnitude for Lα, Mg II, and Ca K. For Lα (*filled squares*), W is the full width at half-intensity measured in km s^{-1}. Values for W have been computed from data taken from Table 1 of this paper and Table 2 of Paper III. Two values for the solar Lα half-width (0.80 Å from Bruner and Rense 1967 and 0.90 Å from Tousey 1967) are shown in the figure as open squares connected by a dotted line. Absolute visual magnitudes are taken from Allen (1973) unless otherwise noted. The relation

$$M_V = (40.2 \pm 4.5) - (14.7 \pm 1.6) \log W_{\mathrm{L}\alpha} \quad (1)$$

results from a least-squares fit to the Lα data.

The values for the full width at the base of the Mg II λ2795.5, measured in km s^{-1}, are also plotted in Figure 4 (*filled circles*). Two values for the solar Mg II width (0.89 Å from Lemaire and Skumanich 1973 and 0.97 Å from Tousey *et al.* 1974) are shown as open circles connected by a dotted line. Triangles are Mg II measurements taken from Kondo *et al.* (1972), (1975) which are not corrected for instrumental broadening. Absolute visual magnitudes for α Ori and ϵ Peg were computed from their Ca II K line widths (Wilson and Bappu 1957). The relation

$$M_V = (39.1 \pm 3.5) - (17.2 \pm 1.5) \log W_{\mathrm{Mg\,II}} \quad (2)$$

is the result of a least squares fit to the Mg II data, excluding β Gem for which the width is extremely uncertain, and excluding β Cas for which emission is stated by Kondo *et al.* (1972) to be somewhat uncertain. A similar relation has been obtained by Kondo *et al.* (1975). For comparison, the relation found by Wilson and Bappu (1957), and Wilson (1959), for the K line of calcium,

$$M_V = 27.59 - 14.94 \log W_{\mathrm{Ca\,K}}\,, \quad (3)$$

is also shown (*dashed line*).

Considering the quality of the data, as measured by the formal errors of the slopes in relations (1) and (2), it seems possible that the line-width–luminosity relation has the same slope in all three cases. Clearly, it would be valuable to obtain additional data over a larger range of absolute visual magnitude, especially in the case of Lα, to test this hypothesis.

The physical basis underlying such width-luminosity relations has been a matter of dispute for nearly 20 years as a result of confusion as to the precise width measured and the nature of the line profile (Doppler core or damping wing) at which the width is measured.

From the traditional point of view, the existence of a general width-luminosity relation may be interpreted in terms of "turbulent velocities" in a very simple way. Lines formed higher in the chromosphere are expected to show slightly larger widths than those formed at lower heights due to an increase of "turbulence" with height. Thus measurement of widths of three different lines gives an indication of the dispersion of turbulence present in any one star and the general correlation is "turbulent velocity" versus luminosity. However, this analysis is oversimplified because no account of the variation in chromospheric structure from star to star is involved. More detailed approaches to understanding general width-luminosity relations are being developed. Ayres *et al.* (1975) have recently shown that high-resolution observations of the Ca II K_1 and Mg II k_1 lines are consistent with a width-luminosity relationship involving $\Delta\lambda_{\mathrm{K}_1}$ and $\Delta\lambda_{k_1}$ with approximately the same functional relationship as equation (3). Since the K_1 and k_1 features are in the damping wings of the lines, Ayres *et al.* are able to derive theoretically the relationship in equation (3) independent of any considerations of "turbulent velocities" and show that $\Delta\lambda_{k_1}$ should exhibit the same slope. In this paper we show that $W_{\mathrm{Mg\,II}} = \Delta\lambda_{k_1}$ has a very similar slope to $W_{\mathrm{Ca\,K}}$, confirming the theoretical analysis. What remains to be shown, however, is why $W_{\mathrm{L}\alpha}$ obeys a similar width-luminosity relation.

We are grateful to Dr. H. Spinrad and Dr. D. C. Morton for giving us access to their Mg II data for ϵ Eri; and to Dr. D. York, Dr. T. Snow, Dr. J. Drake, and Dr. W. Upson for their courteous help in working with *Copernicus*. This work was supported by grants from the National Aeronautics and Space Administration.

REFERENCES

Allen, C. W. 1973, *Astrophysical Quantities* (London: Athlone Press).
Ayres, T. R., Linsky, J. L., and Shine, R. A. 1975, *Ap. J.* (*Letters*), **195**, L121.
Blanco, V. M., Demers, S., Douglass, G. G., and FitzGerald, M. P. 1970, *Publ. U.S. Naval Obs.*, *2d Ser.*, **21**, 1.
Bruner, E. C., Jr., and Rense, W. A. 1969, *Ap. J.*, **157**, 417.
Gerola, H., Linsky, J. L., Shine, R., McClintock, W., Henry, R. C., and Moos, H. W. 1974, *Ap. J.* (*Letters*), **193**, L107 (Paper II).
Goldstein, S. J., Jr., and MacDonald, D. D. 1969, *Ap. J.*, **157**, 153.
Gray, D. F. 1968, *A.J.*, **73**, 769.
Hobbs, L. M. 1969, *Ap. J.*, **157**, 135.

Hoffleit, D. 1964, *Catalogue of Bright Stars* (New Haven: Yale University Press).
Kondo, Y., Giuli, R. T., Modisette, J. L., and Rydgren, A. E. 1972, *Ap. J.*, **176**, 153.
Kondo, Y., Morgan, T. H., and Modisette, J. L. 1975, *Ap. J.* (*Letters*), **196**, L125.
Kraft, R. P., Preston, G. W., and Wolf, S. C. 1964, *Ap. J.*, **140**, 135.
Lemaire, P., and Skumanich, A. 1973, *Astr. and Ap.*, **22**, 62.
Linsky, J. L. 1970, *Solar Phys.*, **11**, 355.
McClintock, W., Linsky, J., Henry, R. C., Moos, H. W., Gerola, H., and Shine, R. 1975, *Ap. J.* (in press) (Paper III).
Modisette, J. L., Nicholas, R. E., and Kondo, Y. 1973, *Ap. J.*, **186**, 219.
Moos, H. W., Linsky, J. L., Henry, R. C., and McClintock, W. 1974, *Ap. J.* (*Letters*), **188**, L93 (Paper I).
Morton, D. C. 1974, *Ap. J.* (*Letters*), **193**, L35.
Morton, D. C., Drake, J. F., Jenkins, E. B., Rogerson, J. B., Spitzer, L., and York, D. G. 1973, *Ap. J.* (*Letters*), **181**, L103.
Rogerson, J. B., Spitzer, L., Drake, J. F., Dressler, K., Jenkins, E. B., Morton, D. C., and York, D. G. 1973, *Ap. J.* (*Letters*), **181**, L97.
Rogerson, J. B., York, D. G., Drake, J. F., Jenkins, E. B., Morton, D. C., and Spitzer, L. 1973, *Ap. J.* (*Letters*), **181**, L110.
Tousey, R. 1967, *Ap. J.*, **149**, 239.
Tousey, R., Milone, E. F., Purcell, J. D., Schneider, W., and Tilford, S. G. 1974, *An Atlas of the Solar Ultraviolet Spectrum between 2296 and 2992 Å* (NRL Report No. 7788).
Vaughan, A. H., and Zirin, H. 1968, *Ap. J.*, **152**, 123.
Wesselink, A. J. 1969, *M.N.R.A.S.*, **144**, 297.
Wesselink, A. J., Paranya, K., and DeVorkin, K. 1972, *Astr. and Ap. Suppl.*, **7**, 257.
Wilson, O. C. 1959, *Ap. J.*, **130**, 499.
Wilson, O. C., and Bappu, M. K. V. 1957, *Ap. J.*, **125**, 661.

R. C. Henry, W. McClintock, and H. W. Moos: Department of Physics, The Johns Hopkins University, Baltimore, MD 21218

J. L. Linsky: Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, CO 80302