

Mg II 2800 Å EMISSION IN LATE TYPE STARS

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I. INTRODUCTION

Emission in Ca II H and K and the occurrence of He I 10830 Å and 5876 Å absorption in stars of spectral type G and later have been, until recently, the most compelling evidence for the existence of chromospheres in stars other than the sun. Ultraviolet observations of late-type stars are now beginning to extend the list of spectral features which have a direct bearing on our understanding of stellar chromospheres. Strong emission in the 2795, 2803 Å doublet of Mg II has been seen in the rocket spectrum of Arcturus with 7 Å resolution (Kondo 1972) and in OAO-2 scans of Arcturus and a number of other bright K and M stars at 25 Å resolution (Doherty 1971). Rottman et al. (1971) have detected Lyman alpha emission in Arcturus.

The largest body of data on ultraviolet spectra of late-type stars now available is the series of scans made with the long wavelength Spectrometer 1 on board OAO-2. Some features of selected scans from this series and estimates of Mg II emission fluxes were reported earlier (Doherty 1971). Since that time, the effects of sky background, scattered light and variable instrumental sensitivity have become better understood. Additional stars define more clearly the transition from Mg II 2800 Å absorption to emission with advancing spectral type, and additional scans of α Sco provide a better estimate of Mg II emission strength for this supergiant. For these reasons it is appropriate to re-examine the OAO results on Mg II emission here.

II. APPEARANCE OF THE SCANS

Characteristics of Spectrometer 1 and OAO-2 operation have been described by Code et al. (1970). The spectrometer is stepped at intervals of 20 \AA and has an exit slot 20 \AA wide.

Comparison of OAO-2 planetary scans with the solar spectrum indicates that the actual resolution is closer to 25 \AA (B. D. Savage, private communication).

Figure 1 shows averaged scans of three of the brightest K and M stars observed, α Boo (K2 III), α Tau (K5 III) and α Ori (M2 Iab). The dashed lines represent approximately the fluxes that would be observed if these stars radiated as black bodies at the temperatures (θ) indicated. For all of these stars the flux decreases rapidly toward shorter wavelengths and reaches the level of the sky background by about 2300 \AA . The radiation temperature, however, is fairly constant over a broad region of the spectrum of each star. Emission at 2800 \AA

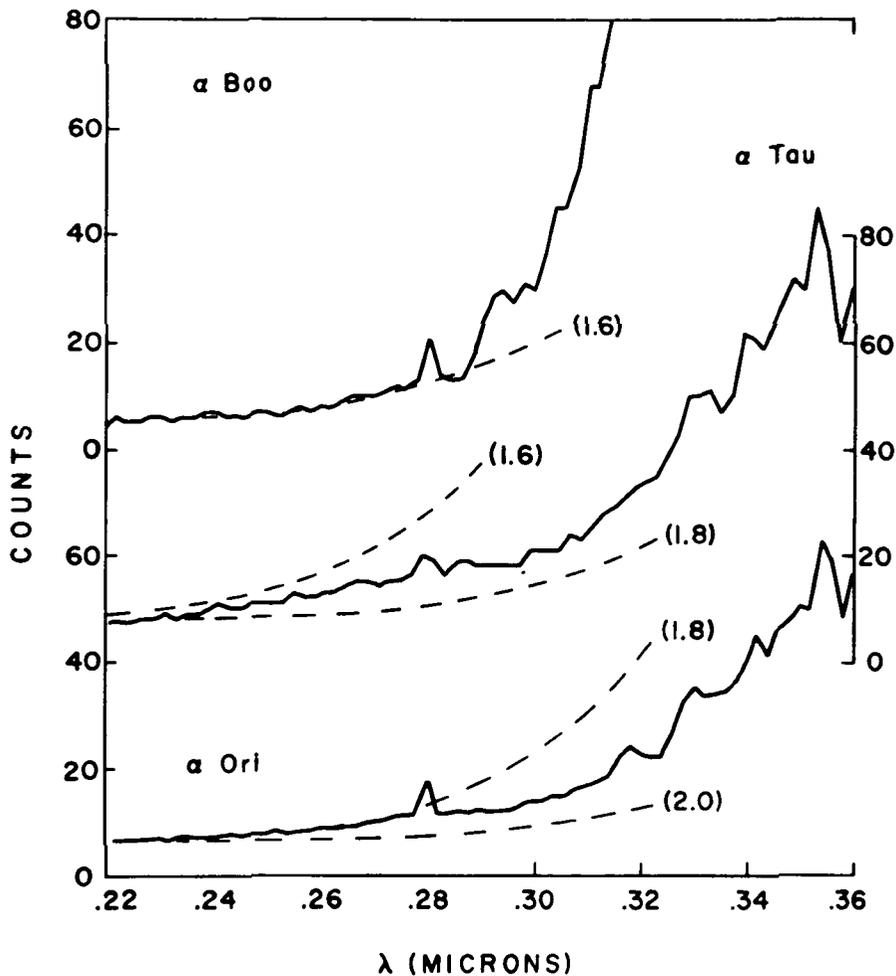


Figure 1.—Averaged OAO scans of α Boo (K2 III), α Tau (K5 III) and α Ori (M2 Iab). The dashed lines show black body fluxes for the temperatures (θ) indicated.

is a prominent feature of all of these scans. The peak near 3180 Å in α Ori is due to emission in a number of Fe II lines (Weymann 1962). No other emission features have been identified in these scans.

Figure 2 shows segments of scans of stars chosen to illustrate the transition from net absorption to emission at 2800 Å. Luminosity classes I, II and III are grouped separately. No wavelengths are indicated in Figure 2. Differences in wavelength registration up to 20 Å between scans are possible due to spacecraft pointing variations, and the scan segments have been plotted so that, numbering from the left, 2800 Å falls between channels 5 and 6. Each segment of 11 channels thus covers 220 Å centered on the Mg II doublet. The approximate level of the sky background is indicated by the short horizontal line next below each scan segment, except for α Sco, where the contribution of the B companion cannot be determined accurately. Pointing variations and therefore wavelength differences are usually quite small for scans made in the same orbit or in closely following orbits, where the same star-tracker configuration is employed. Thus two or more scans can often be averaged, and where this has been done, the number averaged for each segment in Figure 2 is given in parentheses. In the case of β Her and η Dra, both G8 III, the full scans were enough alike to warrant combining the segments for the two stars.

We look first at the qualitative differences in the scans. In β Her and η Dra, the 2800 Å region has three strong absorption features and strongly resembles the solar spectrum seen with the same resolution [see Doherty (1971) or the OAO scan of Mars in Wallace, Caldwell and Savage (1972)]. The flux drops steeply from 2900 Å to the 2852 Å line of Mg I, then falls even lower in the (unresolved) Mg II doublet. A third absorption feature near 2740 Å is due principally to Fe II. With advancing spectral type, the Mg II feature fills in, and is clearly in emission by K2. For class I supergiants, emission appears to dominate by late G. Although β Dra is an MK standard for class II, Kron (1958) lists this star as G2 Ib. The width of Ca II K (Wilson and Bappu 1957) and OAO-2 ultraviolet filter photometry (Doherty 1972) agree with the higher luminosity. Thus I have put β Dra in the class I sequence, where the absence of any Mg II line fits this sequence well. The appearance of Mg II in class II stars more nearly resembles that in class III than in I, and, as far as can be judged from the small number of stars, the transition from absorption to emission takes place at somewhat earlier spectral type than in class III.

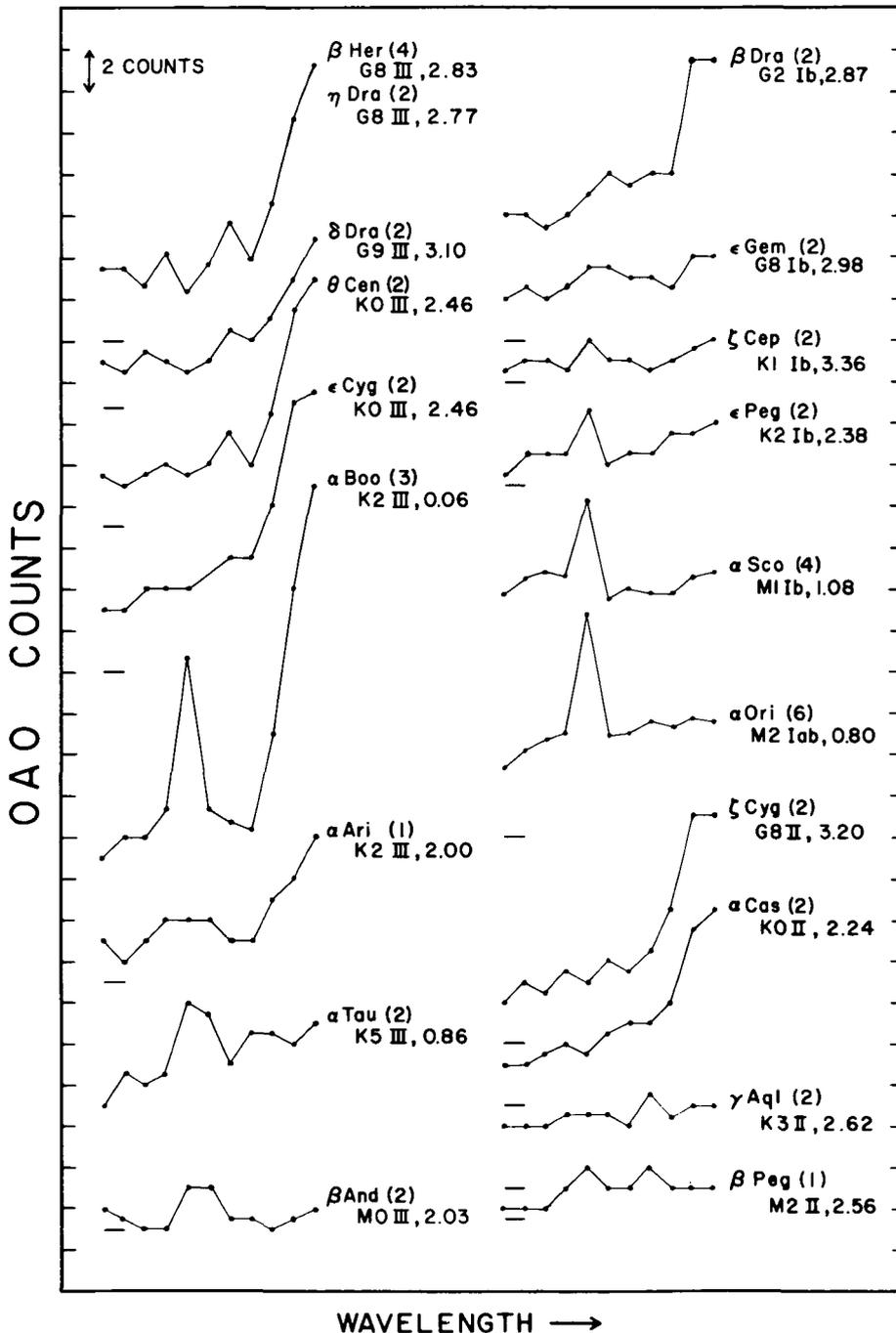


Figure 2.—Averaged OAO scan segments for the region of the Mg II doublet. Each segment covers 220 Å of the spectrum. Numbering from the left, 2800 Å falls between channel 5 and 6. The horizontal line next below each scan shows the level of the sky background. Spectral type, visual magnitude, and number of scans averaged (in parentheses) are given for each star.

III. Mg II EMISSION FLUXES

It is difficult to measure the Mg II emission flux accurately. The strength of the underlying absorption feature is not known but must be significant for many of these stars. No separate measurement of the background of sky plus dark counts is made, and this background must be estimated from the counts at the short wavelength end of the scan, where the contribution from the star is normally negligible. Unfortunately, not all scans cover the full range of the spectrometer. Variation in dark counts during a scan due to the earth's radiation belt can also introduce errors in the estimated background. Only the best scans were selected for Figure 2, and the background indicated for each segment is probably good to one count. Another difficulty in determining Mg II fluxes is the variation in wavelength registration. For some stars, notably α Ori, all the emission appears to fall within a single channel. Mg II H and K are separated by only 7 Å, and if we suppose the widths of the stellar emission cores have the same relation to the width of Ca II K as we observe in the sun, then we can expect one channel to contain all the Mg II emission if this channel is centered between the H and K components. For α Tau and β And, however, the emission is divided equally between two channels. The best interpretation of the α Tau and β And scans would appear to be that these scans are shifted in wavelength by about one-half channel relative to α Ori, rather than that extremely broad Mg II emission cores exist in some stars. Other lines in the scans of α Tau have profiles consistent with a wavelength shift of this amount.

Table 1 gives estimated maximum values for the number of Mg II emission counts in the stars of Figure 2. These values are based on the following assumptions: 1) the underlying absorption profile has the same shape and equivalent width as in the sun, 2) 2800 Å falls either at the center or at the edge of the spectrometer slit, and 3) H and K have equal fluxes, with widths much less than 25 Å. For α Sco the underlying absorption line is taken to be that of a B5 star. For stars with 2800 Å flux greater than the nearby apparent continuum we can determine minimum emission counts, and these are given in Table 1 for eight stars.

Spectrometer 1 sensitivity varied by ± 30 percent over intervals of a few days, but no variation is detectable within single scans. To adjust the counts for any star to a standard sensitivity, multiply the counts by the factor f listed in Table 1. This correction factor is determined from a comparison of the 3370 Å narrow-band filter magnitudes of Johnson, Mitchell and Latham (1967) with the scan amplitude in this region after subtraction of the background. The 3370 Å magni-

Table 1

| HR | Name | Mg II OAO Counts | | f | IW (Ca II K) |
|------|----------------|------------------|-----|------|-----------------|
| | | Max | Min | | |
| 168 | α Cas | 2 | | 1.1 | |
| 337 | β And | 4 | 3 | 1.4 | 0.56 |
| 617 | α Ari | 2 | | 1.0 | 0.48 |
| 1231 | γ Eri | 2 | | >1.0 | |
| 1457 | α Tau | 10 | 5 | 0.7 | 1.29 |
| 2061 | α Ori | 8 | 6 | 0.7 | 2.23 |
| 2473 | ϵ Gem | 3 | 1.5 | 0.9 | 0.40 |
| 5288 | θ Cen | 1 | | 1.5 | |
| 5340 | α Boo | 12 | 8 | 1.0 | 2.96 |
| 5563 | β UMi | 1 | | 1.0 | 0.44 |
| 6132 | η Dra | 1 | | 1.1 | 0.36 |
| 6134 | α Sco | 6 | 4 | | 1.85 |
| 6148 | β Her | 1 | | 1.3 | 0.28 |
| 6536 | β Dra | 4 | | 1.4 | 1.32 |
| 7310 | δ Dra | 1 | | 1.0 | |
| 7525 | γ Aql | 2 | | 1.0 | 0.30 |
| 7949 | ϵ Cyg | 3 | | 0.9 | 0.43 |
| 8115 | ζ Cyg | 2 | | 0.9 | 0.15 |
| 8308 | ϵ Peg | 3 | 2 | 1.0 | 0.86 |
| 8465 | ζ Cep | 1.5 | 0.5 | >1.0 | 0.24 |
| 8775 | β Peg | 2 | | | 0.46 |

tude of θ Cen was estimated. For faint stars with few 3370 Å counts above sky and for the composite α Sco spectrum, a limiting value of f or no value is tabulated. For the remaining stars, f is known to within about ± 10 percent. α Boo is arbitrarily taken as the standard (f = 1). A preliminary calibration of the absolute response of the spectrometer at 2800 Å based on scans of solar-type stars yields the value 4.6×10^{-11} ergs cm⁻² sec⁻¹ per adjusted OAO count.

IV. COMPARISON OF Mg II AND Ca II EMISSION

To what extent the regions that form the Ca II and Mg II H and K lines in stars resemble the solar chromosphere is still largely conjecture. Athay and Skumanich (1968a) have investigated the formation of Ca II emission in a sequence of idealized stellar chromospheres. There is no similar treatment for Mg II. It is known that Mg II and Ca II brightness variations are directly correlated on the solar disk (Fredga 1969). The

eight stars in Table 1 for which maximum and minimum counts are available provide the opportunity to compare Mg and Ca fluxes for a variety of stars that are all quite different from the sun and have a wide range of T_{eff} and gravity. As a measure of total Ca II emission flux at the earth we will take the quantity IW , where I is a measure of the peak flux in the K line and W is the width (km/sec) measured by Wilson and Bappu (1957). Their eye estimates of emission intensity relative to the nearby continuum have been calibrated by Liller (1968). Call this relative intensity I' and define I by the equation

$$I = I'F$$

where F is the continuum flux. To the accuracy required here we may compute F from

$$m = -2.5 \log F$$

where m is the apparent magnitude of the star in the 4000 Å filter of Johnson, Mitchell and Latham (1967). IW can be evaluated for most of the stars in Table 1.

Adjusted Mg II counts are plotted against IW in Figure 3, with the maximum and minimum Mg II values connected by verti-

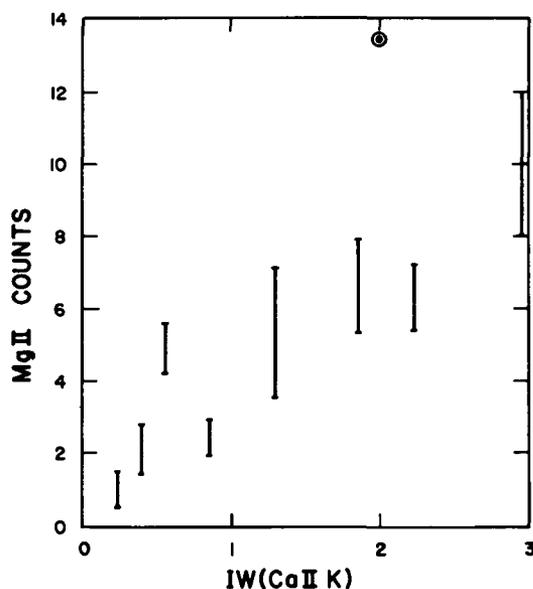


Figure 3.—Mg II 2800 Å emission flux (OAO counts) vs. IW , an approximate measure of Ca II K emission flux. The Mg II counts have been adjusted to a common spectrometer sensitivity (except α Sco), and for α Ori and α Sco the counts have been corrected for differential reddening.

cal bars. Counts for α Ori and α Sco have been increased by 0.3 mag to correct for differential interstellar reddening between 3933 Å and 2800 Å. With the exception of β And the stars in Figure 3 have the same ratios of line strengths within the uncertainties of observation. Unfortunately the uncertainties are rather large. If the underlying absorption features in these stars are actually much weaker than in the sun, then the lower limits in Figure 3 are closer to the true Mg II emission counts. These lower limits determine a single value of Mg II/IW to somewhat better accuracy. In this case Mg II/IW \sim 2.8. The remaining stars in Table 1 for which Ca II K data are available are at least consistent with this value.

Some stellar Ca II K profiles have been observed to change with time (Liller 1968), but there is no evidence for peak intensity differences greater than a few percent. No variations have been detected in the OAO Mg II data. The assumption that each of the two channels showing emission in β And and α Tau measures one component may be wrong. If the resolution is in fact greater than 20 Å and the emission cores in these stars are wide enough, then the number of counts in Table 1 can be too large. How much error this introduces depends on the details of the instrumental and stellar line profiles, which we do not know. It is difficult to reduce the emission by more than about 30 percent by this means alone. However, if the background at 3370 Å in β And is 2 counts lower than the 5 counts assumed in getting the tabulated spectrometer sensitivity, then Mg II for β And could be reduced in total by a factor of 2.

The solar symbol in Figure 3 shows the position the sun would have with $V = 0$. Solar Mg II counts are estimated from the profiles shown in Athay and Skumanich (1968b) and refer to a moderate level of solar activity. IW is calculated for the quiet sun (Smith 1960). On the basis of Sheeley's (1967) results we may expect IW to increase no more than a factor of 1.4 at solar maximum, so that the sun apparently lies somewhat above the run of stellar points. Considering that the emission line data for the sun and stars depend on different types of measurement, however, we cannot rule out the possibility that all of the stars in Figure 3, including the sun, have nearly the same value of the ratio Mg II/IW.

This research was supported by NASA NAS 5-1348.

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