(NASA-CR-175572) A SURVEY OF Mg II h AND k EMISSION IN NEAR-SOLAR TYPE STARS (Wisconsin Univ.) 18 p HC A02/MF A01 CSCL 03A

N85-22269

G3/89 Unclas 19521

NSG 5242

SUMMARY

IUE measurements of Mg II h and k emission fluxes are presented for 30 F and G stars that are on or near the main sequence and compared with Wilson's measurements of the Ca II H and K fluxes in these stars. In contrast with previous studies of Mg II emission in stars of this type, the survey includes a large proportion of stars with very low chromospheric activity as well as 111 Tau, χ^1 Ori and other examples of strong chromospheric emission. Spectra are displayed for 12 stars with sufficiently strong emission to yield useful profile information.

Emission cores are present in all of the stars observed. A sharp lower limit to the flux in the cores of the k lines implies the existence of a minimum level of chromospheric activity in which the k line flux is a constant fraction of stellar luminosity. Reduction of Wilson's values to absolute fluxes produces a close correlation between Mg and Ca strength with possibly some dependence on color. For the most active stars, the Mg k and Ca fluxes are consistent with the presence of solar plage covering up to one half of the stellar surface. However, the ratio of k to h in these stars is much less than this simple interpretation predicts.

A Survey of Mg II h and k Emission in Near-Solar Type Stars

L. R. Doherty*

Astronomy Department, University of Wisconsin,
475 N. Charter St., Madison, WI 53706

---

*Guest observer with the _International Ultraviolet Explorer_ satellite.

I. INTRODUCTION

Olin Wilson's two major studies of Ca II H and K emission in field stars that are not very different from the sun (Wilson 1968, 1978) have established these facts: stars of near-solar type show a wide range of emission strength, the range of observed strength is greatest for the youngest stars, and variability, in patterns that suggest analogs of the solar activity cycle, is common. What produces these differences in emission among stars with similar basic structure (stars on the main sequence with T_{eff} between about 5600 and 6400 K) is not known with certainty. There is ample evidence that rotation is an important factor. Average Ca emission strength and rotational speed decrease steadily with age from the young Hyades stars to the field stars with ages near 10^{10} years (Kraft 1967; Skumanich 1972; Smith 1978, 1980).

Since most field F and G dwarfs have rotational speeds of $v \sin i < 6$ km s^{-1}, close to the limit of earlier measurement by line profile techniques, progress in this field depends on the analysis of very high resolution profiles which can yield errors of a few tenths km s^{-1} (Soderblom 1982) and on detection of periodic changes in Ca emission (Stimets & Giles 1980; Vaughan et al. 1981) or other chromospheric indicators such as He I 10830 (Smith 1980) and ultraviolet emission lines (Hallam & Wolff 1981). Meanwhile, single observations of chromospheric and transition-region lines in stars of near-solar type are desirable

to investigate structural differences. Does strong Ca emission indicate that a star has a large fraction of its surface covered with solar plage (Blanco, Catalano & Marilli 1976; Wolff, Heasley & Timothy 1983). This view would explain the correlations between the emission fluxes in the Mg II, O I, and Si II lines in G and K dwarfs which Ayres, Marstad and Linsky (1981) find. However, these authors report very different behavior for He II, higher transition region lines, and soft x-rays. Kelch et al. (1979) find that active chromospheres in dwarfs produce about the same level of Ca emission as solar plage, but their profile analysis does not support the simple picture that active solar and stellar regions are identical. Active regions on the sun have steeper temperature gradients than the average sun, but the derived stellar gradients are the same for both quiet and active stars and the gradient varies smoothly with effective temperature in a relation that includes the average sun. This analysis relies solely on observations of the K line for F and G stars. Two active K dwarfs, for which both K and Mg II k data are available, have temperature gradients well above the quiet star relation. Perhaps additional spectral data for the other stars will show that the models based on the K line alone do not determine the gradient accurately. On the other hand, the active regions in stars that are as cool as K0 may be significantly different than in the active F and early G stars.

In this paper I report on measurements of the strength of Mg II h and k in 30 stars of near-solar type. These stars were selected from the group for which Wilson (1968) obtained quantitative measurements of the flux in 1 Å bands centered on the H and K lines. Because these stars are even fainter at 2800 Å, the IUE observations were planned to yield integrated line fluxes of stars representing a wide range of Ca emission strength and age to give profiles for only a few of the brighter stars with strong emission. UV echelle spectra of three stars included here, α Com (F5 V), γ Ser (F6 V), and ι Vir (F7 IV), and also β Vir (F8 V) were obtained with BUSS (Kondo et al. 1979) and these spectra should yield h and k profiles with 0.1 Å resolution. IUE spectra have somewhat poorer resolution but can still provide good measures of V/R asymmetry and line widths. IUE profiles of h and k in near-solar type stars have been published for ζ Tuc (G2 V) (Pagel & Wilkins 1980), β Hyi (G2 IV) (Pagel & Wilkins 1980; Stencel et al. 1980) α Cen A (Ayres & Linsky 1980), the G0 V star HD 206860 (Blanco, Catalano & Marilli 1979) and for 15 other dwarfs in the range F5 to G6 (Garcia-Alegre, Ponz & Vazquez 1981). All stars in the last paper are included in the present study.

II. OBSERVATIONS

All of the spectra here were recorded with the LWR camera on IUE in the high dispersion mode, using the small (3 arcsec) aperture to achieve maximum spectral resolution. Data for this study consist of the flux numbers (FN) in the IUE extracted net spectrum. The FN provide only relative intensities. Variable light loss at the

small aperture makes it necessary to calibrate each observation separately. To do this I compared the average FN in 20 Å bands with OAO-2 fluxes for similar stars (Code & Meade 1979). These bands were chosen to correspond closely to the bands used in the OAO-2 spectrum scanner and also to fall near the centers of the echelle orders in the region 2900-3100 Å where the highest FN are recorded for cool stars. Linear relations between log flux and B-V served to interpolate fluxes separately for class IV and V stars.

Both Mg II h and k appear in order 83 of the IUE spectrum. The h line also appears in order 82, but in both orders this line lies near the end of the order where the sensitivity is low. As a result, errors in background subtraction affect h more than k. As the observing schedule permitted, longer exposures (over 30 min) were made during the first shift when the radiation background was low. Even so, the k1 flux is typically only 10 per cent above the background and in some cases h1 is lost entirely. The IUE extraction procedure determined the background from a 15-pixel (1 Å at 2800 Å) running mean of the counts in the pixels midway between adjacent orders. Near 2800 Å the centers of the orders are separated by four times the full width at half maximum of the gaussian intensity distribution across the order. Because the Mg II absorption wings are deep, only the adjacent orders contribute to the interorder background, and typically we expect this contribution to be about 5 per cent of the total background. Calcomp plots of the gross spectrum show variations in the smoothed background that support this estimate. Contamination of the Mg profile must have the same spectral variation and, if the scattering remains gaussian at distances equal to the order of separation, then this contamination is only a little less than in the interorder background. Thus errors in background due to light scattering between orders largely cancel in the extraction. That other errors remain is shown in the discrepancies that often appear between the h absorption features measured in two orders. An extreme example is the profile for 99 Her, an F7 V star with weak emission. The FN from order 82 were reduced by 2000 to bring the profiles into close agreement before plotting in Figure 1. In view of zero-point errors of this size, net emission fluxes above an estimated absorption profile may be more reliable than total fluxes for weak lines. On the other hand, the noisy spectra lead to discrepancies in the net fluxes, in this example at least. Note the effect of the echelle blaze on the noise, as seen in the profiles of 10 Cnc (G2 IV) (Figure 1). Here the background error is wavelength-dependent. Occasionally, interference during data transmission to the ground produces a narrow rippled pattern ("microphonics") diagonally across the echelle image. When this happened, the pattern often (and irritatingly) fell across order 83 near the Mg lines. The photowrite image makes it possible to identify and disregard affected parts of the spectrum.

Measures of emission line flux for this survey have been obtained in two ways. The first is the mean peak flux defined arbitrarily as the mean flux in the central 1/3 Å of the profile. In the sun the separation of the emission peaks is 0.32 Å in k and 0.28 Å in h at the center of the disk (Kohl & Parkinson 1976). These values will increase slightly for the integrated disk. There is no indication from the stellar profiles with well-defined double peaks that the k2 spacing is different from that in the sun. This suggests that even in spectra where noise may distort the peak shape the mean peak flux defined above will remain a consistent measure of the region of the chromosphere that produces the central reversal.

The second method of flux measurement is intended to estimate the net flux in the emission core defined as the integral between k1 minima of the excess flux above the radiative equilibrium profile. The net flux is an important quantity in determining chromospheric cooling rates. Linsky & Ayres (1978) discuss the determination of the net flux for both Mg II k and Ca II K in the sun and find that the net k1 flux is only slightly less than the total flux ("k1 index"). Extrapolating the observed wing profile under the core is a poor approximation to the RE profile and underestimates the net flux. From their Figure 2 the error in the net flux appears to be about 20 per cent. The effects of extrapolation are much larger for the K line. For stars other than the sun it is not known whether the k1 index or a net flux based on extrapolation is, in principle, the better approximation to the true net flux. This will depend on how much the effects of upper photospheric heating on the wing profile change with effective temperature. So far such calculations have been made only for the K line (Kelch et al. 1979). Also, for weak emission, an error in the subtracted IUE background becomes magnified in the k1 index. Even if the RE fluxes were known from models, subtracting them from the observed k1 index would lead to greater error in the resulting net flux. For these reasons, the method adopted here is to measure the area in the emission core above a hand-drawn, extrapolated absorption profile. I will call this the apparent net flux. Whether or not this equals the true net flux, it is still a quantity that can be usefully compared with synthetic spectra.

Table 1 contains the observational data. Spectral types are taken from the Bright Star Catalog, 4th edition. Mean peak fluxes and apparent net fluxes are reduced to the values that would be observed at the earth if the stars had visual magnitude V = 5.0. In addition, the table lists two measures of the mean flux in the H and K lines of Ca II which will be useful for comparison with the Mg data. Wilson (1968) measured the ratios of the fluxes in 1 Å bands at the centers of H and K to the flux recorded in nearby 25 Å side bands. I have multiplied Wilson's values of $(F_H + F_K)/2$ by the factor DEX(-0.4(v-y)) to reduce these fluxes to a common visual magnitude. This method is satisfactory for the small range in color of the stars considered here. Wilson (1968) determined a lower envelope to the distribution of flux against color and subtracted these values from the observed fluxes to give net

fluxes. His method appears to yield net fluxes less than those expected from subtracting the RE profile and more than those based on an extrapolated wing profile. If, however, the upper photospheric heating is directly related to the chromospheric heating, then a measure such as Wilson's should vary monotonically with the chromospheric net flux and still serve as a useful index. Net fluxes from Wilson (1968), reduced as above to a common visual magnitude, are tabulated.

Spectra of 12 of the 30 stars observed here are shown in Figures 1 and 2. Radial velocity effects have been removed. Omitted are those spectra for which weak emission or high background noise or both prevents the extraction of useful profile information. No attempt is made here to obtain line widths. Pagel & Wilkins (1980) determined widths for h and k in a variety of stars by fitting the observed profiles with a theoretical profile based on a simple slab model of the chromosphere. Their method includes correction for instrumental broadening. However, since their model produces profiles without a central absorption feature, convolving these profiles with the instrumental profile may not increase the widths by the same amounts as it would for the actual profiles. This might explain why the two G2 stars in their sample have a derived FWHM (i.e., at half the maximum of the synthetic profile) of 0.63 Å. This corresponds to the limb spectrum of the sun (Kohl & Parkinson 1976) or to a strong plage (Lemaire & Skumanich 1973). More puzzling is the large k width that Ayres and Linsky (1980) observed in α Cen (G2 V). Their use of the large

IUE aperture should not have degraded the resolution enough to produce a width of 0.8 Å from a solar profile. Since the Ca II K emission core is about 10 per cent wider in α Cen than in the sun (Ayres & Linsky 1980), the difference in k widths is probably real. Yet these two stars are strikingly similar in gross structure and even rotation rates (Ayres & Linsky 1980; Boesgaard & Hagen 1974). All of the well-exposed k lines in the present study have FWHM = 0.7 Å, which should lead to intrinsic widths in agreement with Pagel & Wilkins (1980). In only one star, 99 Her (Figure 1) do the observations of k and of h in both orders agree on widths of 0.5 Å or less. If the actual lines are strongly asymmetric, it is possible that noise is responsible for the apparently narrow emission.

Typically, the h and k lines in dwarfs are asymmetric, with V/R > 1. For three of the stars in Figures 1 and 2, V/R < 1. They are β Com, β CVn, and 111 Tau. An unusual (possibly unique) situation occurs in 70 Vir where V/R > 1 for h but V/R < 1 for the k line. This is difficult to understand physically, since the absorption coefficients differ by a factor of two only, and the lines must be formed in nearly identical strata. Ordinarily, I would blame this result on noise in the data, but the profiles shown in Garcia-Alegre et al. (1981) agree qualitatively with the V/R asymmetries found here for all of their stars, including 70 Vir!

III. DISCUSSION

Wilson (1968) looked for correlations of mean Ca flux with color (b-y), metallicity (Δ m1) and age (Δ c1). For stars with b-y > 0.300, the range in which strong emission appears, there is a steady increase in the maximum flux observed with increasing b-y. If these fluxes are adjusted to represent a fraction of the total stellar (bolometric) flux, the fluxes for the coolest stars (b-y = .410) are reduced by 40 per cent relative to those with b-y = .300, and it is reasonable to assert that the maximum Ca flux is a constant fraction of the luminosity in this color range. The net flux expressed as a fraction of the luminosity still increases by a factor of two, a trend which is confirmed by the more detailed measurements and analysis of Linsky et al. (1979) for three very active chromosphere stars in this color range and is seen also in the Hyades (Blanco et al. 1976). A result that only the extensive data of Wilson (1968) (and similar measurements by Vaughan and Preston) show is that the majority of F and G field dwarfs has very weak emission and for these stars the fraction of the star's luminosity that appears in Ca emission declines with increasing b-y (Hartmann et al. 1984).

We expect the strengths of the h and k lines to follow, at least qualitatively, differences in Ca strength from star to star. The cosmic abundances and ionization energies of these ions dictate that their resonance lines will be formed in almost the same atmospheric strata. For solar models, the Mg and Ca emission indices respond to changes in the structure of the lower chromosphere. However, the Mg lines are more sensitive due to their greater opacities (see e.g., Ayres & Linsky (1976) and references there). Figure 3 plots the Mg II k peak flux (Table 1) against b-y. As expected, the figure resembles Figure 1 in Wilson (1968). An interesting feature of Figure 3 is the flat lower boundary of the flux distribution. This suggests that the Mg flux cannot fall below a certain fraction of the visual flux. Since the radiative equilibrium (absorption) profile of a line in the ultraviolet must decline relative to the visual for cooler stars, the constancy of the k flux implies that stars in this color range have k emission cores. There is a minimum chromosphere.

Figure 4 compares the k fluxes with the Ca fluxes of Table 1. It is possible that temporal variations account for much of the scatter. Wilson (1978) and Baliunas et al. (1983) typically find 10 per cent variability in Ca strength in the F and G stars. Rotational modulation produces 25 per cent variation in Mg in the G0 star HD 206860 (Blanco et al. 1979), 12 per cent in 111 Tau and a Cen A (Hallam & Wolff 1981) but none in χ^1 Ori (Boesgaard & Simon 1984). Despite any such effects, there remains some indication that the ratio k/Ca depends on color. To see this, we first group the observations according to flux level to eliminate the dependence of k/Ca on flux. As Figure 5 shows, stars with emission comparable to or less than the sun's have slightly larger ratios on the average for larger b-y. Stars with intermediate and strong emission display very definite changes with color. Thus it is possible that for stars of a given color there is a unique relation between k and Ca flux, which we would expect if chromospheric structure depends on only one additional parameter (most likely rotation).

In view of Figure 5 we do not expect the Mg data to yield correlations between chromospheric emission and metallicity or age not already found by Wilson (1968) for a much larger number of stars. His Figure 3b, which plots Ca flux against Δ c1, deserves comment, however. He argues that "if two or three points are ignored" the figure shows that evolving stars pass through a minimum level of chromospheric activity while on the main sequence and that the emission again rises beyond about Δ c1 = 0.14. I have made a similar plot using reduced values of Wilson's data with the Ca flux now normalized to the bolometric flux of each star. This is shown in Figure 6. There is no evidence for an upturn in average flux with advancing age. Instead, Figure 6 shows that both the range of Ca flux and the average flux decrease steadily with age. In contrast to the peak k flux we discussed above, the ratio of net k flux to net Ca flux does not steadily increase with emission strength. Its behavior is shown in Figure 7, which can be understood as follows: because the k1 intensity is very small, net k fluxes measured here approximate closely the excess chromospheric radiative loss rates in the k line (Linsky & Ayres 1978). For the Ca lines, the net fluxes give excess radiative rates only if the minimum fluxes which Wilson (1968) adopted correspond to RE profiles, that is to lines in stars with no chromospheres (and no upper photospheric heating either, since Wilson's 1 Å band exceeds the K1 width). Using Wilson's (1978) K flux for the sun and comparing the observed and RE profiles given by Linsky & Ayres (1979) show that Wilson's (1968) adopted minimum for stars with the color of the sun is about 30 per cent higher than the RE value, which means that the net K flux underestimates the excess radiative loss rate in the solar K line by a factor of 1.8. This factor will decrease for active stars and increase for stars near the minimum. Figure 7, then, suggests that the ratio of excess chromospheric loss in K to excess loss in 1 Å bands centered on the H and K lines decreases steadily with lower levels of net flux. To confirm such a trend and to separate the contributions of chromospheric and upper photospheric losses in the K line will require observation and analysis of weak Ca stars similar to the work of Kelch et al. (1979) and Linsky et al. (1979) for the active dwarfs.

We now turn to the observations of Mg II h. Figure 8 plots the ratio of the peak k flux to the flux in h. Poorer quality data (marked with a colon in Table 1) are omitted from this figure. If h is available in both orders, the mean is used. Inspection of the Skylab profiles (Doschek & Feldman 1977) shows that the peak flux ratio has a minimum value of about 1.25, for the interior of a supergranulation cell, increases to about 1.35 near the quiet solar limb, and reaches values of 1.5 or more in active regions. Although this trend is qualitatively the same found by Lemaire & Skumanich (1973), their values are systematically lower, with the ratio for the average cell only about 1.1. The profiles of Kohl & Parkinson (1976) give 1.15 for the center of the quiet disk.

If stars with strong emission have high proportions of solar plage, then we would expect the ratio of the k to h peak flux to increase with flux level. No h trend is evident in Figure 8, which instead suggests that the k/h ratio is constant or decreases slightly. The ratio of apparent net flux, which does not depend on the background subtraction procedure, behaves in the same way. One star, 71 Ori, has a ratio of net flux near 2.1 on two good spectra. If this is real, it indicates that the region of core formation is optically thin. However, other stars with the same color, expected to have the same underlying absorption line, have the same ratio of peak flux as 71 Ori.

It is instructive to compare these results with the variation of K/H in the sun and stars. According to Shine & Linsky (1972), the ratio of the core intensity (in 1 Å bands) increases in plages by about 10 per cent over that in the quiet sun. This agrees well with the difference in ratios that Wilson (1978) finds for very active stars and those with activity levels near the sun's. If we look only at the integrated intensities above the quiet solar profiles, that is the net plage emission, the K/H ratio is about 1.2. Again, this value agrees well with the ratio of net fluxes obtained by Wilson (1968) for active stars. We may conclude that while the observed K/H ratio in active stars is consistent with a large contribution from solar-type plage, the k/h ratio is not.

In Figure 4 the three most active Ca stars have Ca fluxes twice the solar value, while their k fluxes are about 4 times greater than in the sun. Kelch & Linsky (1978), using the Skylab profiles of Doschek and Feldman (1977), found that in several active regions the k1 index increased by a factor of 7 over its value for the quiet sun. As seen on Ca patrol plates with a fixed bandpass of 0.51 Å the increase in K emission in these regions was little more than a factor of two. Such plates underestimate the change in the K1 index. From photoelectric observations of the K line in plages, Shine & Linsky (1972) found K1 widths close to 1 Å. Their values of the integrated intensities in this band above the quiet profile for three plages indicate that the K1 index increased by an average factor of 5. If active chromospheres in other stars consist of varying mixtures of quiet and plage regions like the sun's then the observed ratio of the k1 to the K1 index ought to lie between 1.0 and 1.4 times the solar value. This is not the case for the cool dwarfs ϵ Eri and 70 Oph A, in which this ratio is less than the solar value despite the larger flux in emission (Kelch 1978). From the point of view of the present study, the quantity of interest in comparing plage and quiet regions is the increase that would be seen in a 1 Å band as employed by Wilson. The data of Shine & Linsky (1972) point to an increase of a factor of 3 in this case. Because the Mg absorption profile is very weak we can suppose that the peak k fluxes of Figure 4 are proportional to the k1 index, with the result that the three stars with the strongest emission have exactly the fluxes expected for stars half covered with solar plage. Since the k/h ratio for these stars has not increased (see Figure 8), a different chromospheric structure (temperature and density profile) presumably exists, but is one

that can mimic the Mg/Ca ratio of solar plage. It is clear that stars with <u>weaker</u> emission than the quiet sun also require some change in structure (rather than a simple absence of plage).

IV. CONCLUSIONS

Emission fluxes in the Mg II k line in a sample of 30 field stars of near-solar type correlate closely with Ca II H and K fluxes measured by Wilson (1968) when all fluxes are normalized to a common visual stellar magnitude, which, for the narrow range of spectral types considered, is equivalent to normalization to a common bolometric flux. Thus it appears possible to characterize the range of chromospheric activity in F and G dwarfs by a single sequence of chromospheric structural changes. A variety of evidence (the most recent in Baliunas et al. 1983) points to rotation as the dominating factor in producing such a sequence.

Despite the almost certain presence of scatter in the correlation of Mg and Ca emission strength due to rotational modulation, there is an indication that the correlation depends on color. If this is true, it strengthens the view that a single parameter (e.g., rotation) determines the amount of chromospheric activity in stars of otherwise similar structure.

Because Mg emission cores stand in much greater contrast to the line wings than is the case for Ca, the present survey provides an opportunity to search for very low levels of activity among those stars which lie on Wilson's (1968) lower limit of Ca flux. Surprisingly, all stars in the survey have definite reversals in the Mg k core and, moreover, there is a sharply defined minimum in the k flux which is the same fraction of the bolometric flux, independent of color. Thus it appears that, in this range of stellar type, chromospheric heating does not fall below some minimum fraction of the star's luminosity in the region where the Mg line cores are formed.

It is possible to explain the observed Mg k and Ca fluxes in the stars that are more active than the sun in terms of large areas of solar-type plage. However, the ratio of Mg k to h flux in the active stars is less than or equal to the ratio found for the stars with weak chromospheres (and the quiet sun), unlike active areas on the sun, supporting the view that increased activity represents a change in low chromospheric structure as well as in that of the transition region (Ayres, Harstad & Linsky 1981).

ACKNOWLEDGEMENTS

I thank the IUE staff for their assistance during my visits to GSFC and Marilyn Meade, in Madison, for extracting data from the IUE Guest Observer tapes in the form most convenient for my purposes.

REFERENCES

Ayres, T. R. & Linsky, J. L., 1976. Astrophys. J., 205, 874.

Ayres, T. R. & Linsky, J. L., 1980. Astrophys. J., 235,76.

Ayres, T. R., Harstad, N. C. & Linsky, J. L., 1981. Astrophys. J., 247, 545.

Baliunas, S. L., Vaughan, A. H., Hartmann, L., Middelkoop, F., Mihalas, D., Noyes, R. W., Preston, G. W., Frazer, J. & Lanning, H., 1983. Astrophys. J., 275, 752.

Blanco, C., Catalano, S. & Marilli, E., 1976. Astr. Astrophys., 48, 19.

Blanco, C., Catalano, S. & Marilli, E., 1979. Nature, 280, 661.

Boesgaard, A. M. & Hagen, W., 1974. Astrophys. J., 189, 85.

Boesgaard, A. M. & Simon, T., 1984. Astrophys. J., 277, 241.

Code, A. D. & Meade, M., 1979. Astrophys. J. Suppl., 39, 195.

Doschek, G. A. & Feldman, U., 1977. Astrophys. J. Suppl., 35, 471.

Garcia-Alegre, M. C., Ponz, J. D. & Vazquez, M., 1981. Astr. Astrophys., 96, 17.

Hallam, K. L. & Wolff, C. L., 1981. Astrophys. J. Lett., 248, L73.

Hartmann, L., Soderblom, D. R., Noyes, R. W., Burnham, N. & Vaughan, A. H., 1984. Astrophys. J., 276, 254.

Kelch, W. L., 1978. Astrophys. J., 222, 931.

Kelch, W. L., Linsky, J. L. & Worden, S. P., 1979. Astrophys. J., 229, 700.

Kohl, J. L. & Parkinson, W. H., 1976. Astrophys. J., 205, 599.

Kondo, Y., de Jager, C., Hoekstra, R., van der Hucht, K. A., Kamperman, T. M., Lamers, H. J. G. L. M., Modisette, J. L. & Morgan, T. H., 1979. Astrophys. J., 230, 526.

Kraft, R. P., 1967. Astrophys. J., 150, 551.

Lemaire, P. & Skumanich, A., 1973. Astr. Astrophys., 22, 61.

Linsky, J. L. & Ayres, T. R., 1978. Astrophys. J., 220, 619.

Linsky, J. L., Worden, S. P., McClintock, W. & Robertson, R. H., Astrophys. J. Suppl., 41, 47.

Pagel, B. E. J. & Wilkins, D. R., 1980. preprint.

Skumanich, A., 1972. Astrophys. J., 171, 565.

Smith, M., 1978. Astrophys. J., 224, 584.

Smith, M., 1980. Publ. astr. Soc. Pacific., 91, 737.

Stencel, R. E., Mullan, D. J., Linsky, J. L., Basri, G. S. & Worden, S. P., 1980. Astrophys. J. Suppl., 44, 383.

Stimets, R. W. & Giles, R. H., 1980. Astrophys. J. Lett., 242, L37.

Soderblom, D. R., 1982. Astrophys. J., 263, 239.

Vaughan, A. H. & Preston, G. W., 1980. Publ. astr. Soc. Pacific, 92, 235.

Vaughan, A. H., Baliunas, S. L., Middelkoop, F., Hartmann, L. W., Mihalas, D., Noyes, R. W. & Preston, G. W., 1981. Astrophys. J., 250, 276.

Wilson, O. C., 1968. Astrophys. J., 153, 221.

Wilson, O. C., 1978. Astrophys. J., 226, 379.

Wolff, S. C., Heasley, J. N. & Timothy, J. C., 1983. Publ. astr. Soc. Pacific, 95, 1025.

FIGURE CAPTIONS

Figure 1 – IUE spectra of Mg II h and k in selected stars. Ordinates are marked in intervals of 10^4 IUE flux numbers (FN). For 99 Her, the FN for order 82 were reduced by 2000 before plotting. Absolute fluxes for these stars are given in Table 1.

Figure 2 – IUE spectra of Mg II h and k in the survey stars with strongest emission. Ordinates are marked in units of 2×10^3 FN. Absolute fluxes are given in Table 1.

Figure 3 – Mg II k mean peak flux (see Table 1 and text) plotted against color for survey stars (circles) and the sun (+).

Figure 4 – A comparison of k mean peak fluxes with Wilson's (1968) mean Ca II H and K fluxes reduced to a common visual magnitude (see Table 1 and text).

Figure 5 – Ratio of k to Ca flux plotted against color. Stars are separated according to k flux level: triangles, $f_k > 100$; open circles, $f_k > 40$; filled circles, $f_k < 40$.

Figure 6 – Wilson's (1968) Ca fluxes reduced to a common bolometric magnitude and plotted against the age parameter $\Delta c1$.

Figure 7 - Ratio of net k to net Ca flux (see Table 1 and text) plotted against net k flux.

Figure 8 - Ratio of mean peak k to mean peak h flux plotted against k flux.

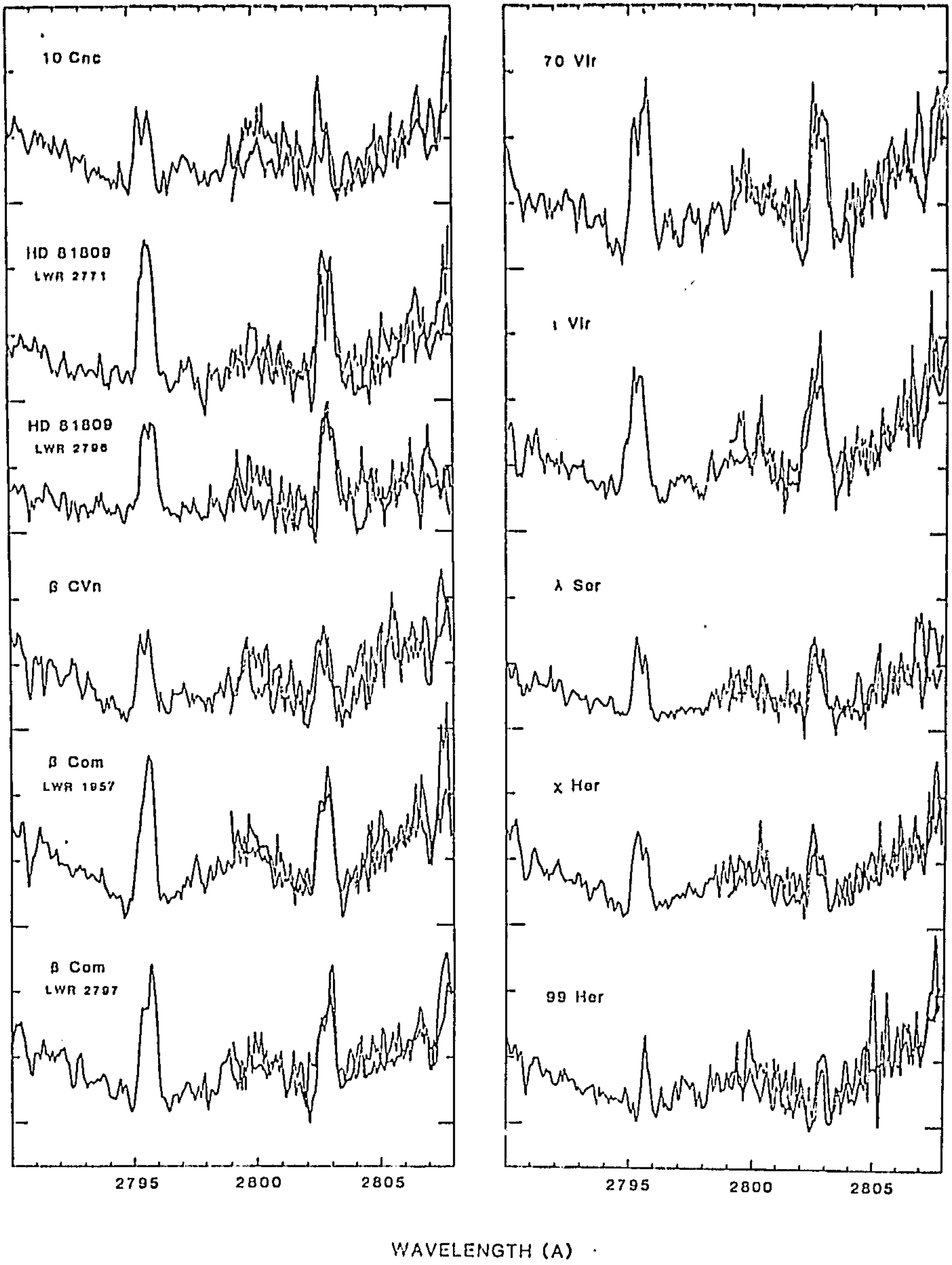
10 Cnc
HD 81809
LWR 2771
HD 81809
LWR 2796
β CVn
β Com
LWR 1957
β Com
LWR 2797
70 Vir
ι Vir
λ Sgr
χ Her
99 Her
2795
2800
2805
2795
2800
2805
WAVELENGTH (A)

FIGURE 1

TABLE 1

OBSERVATIONS

HD	Name	Spectrum	b-y	LWR	IUE Exposure (min)	Peak Flux* (10^{-13} ergs cm^{-2} s^{-1} Å^{-1})			Apparent Net Flux† (10^{-13} ergs cm^{-2} s^{-1})			Ca Flux‡	
						k	h(83)	h(82)	k	h(83)	h(82)	Total	Net
7439...	37 Cet	F5 V	290	2803	20	34:	34:	34:	---	---	---	776	---
18256...	46 Ari	F6 V	308	1935	45	50	42	42	32	23	---	824	203
19994...	94 Cet	F8 V	362	2774	45	43	19:	19:	---	---	---	669	120
32923...	104 Tau	G4 V	415	2772	50	31	26	---	18	18	14	584	85
33256...	68 Eri	F2 V	300	2773	35	34	34:	---	---	---	---	732	---
34411...	λ Aur	G2 IV-V	389	2818	40	33	27	33	15	10	8	601	81
35296...	111 Tau	F8 V	348	1936	50	155	143	159	106	85	95	1284	786
				2820	50	135	137	140	97	61	75		
39587...	χ^1 Ori	G0 V	380	2768	30	178	171	171	99	91	85	1217	764
43042...	71 Ori	F6 V	293	2769	45	47	44	47	29	11	16	790	---
				2819	37	44	32:	29	33	17:	15		
48682...	56 Aur	G0 V	357	2775	50	45	16	24	21	8:	---	668	108
				2817	50	46	51:	41	24	12	29		
67228...	10 Cnc	G IV	408	2770	75	27	18	31	18	8	13	565	61
				2816	75	24:	32	38	17:	15	18		
81809...		G2 V	418	2771	70	54	39	51	35	26	30	727	241
				2796	70	45	49	49	29	29	28		
95128...	47 UMa	G0 V	392	2776	50	36	48	31	20	21	14	593	74
109358...	β CVn	G0 V	385	2777	27	39	33	40	21	18	18	644	112
114378...	α Com	F5 V	304	1943	18	98	69	101	57	26	59	1129	543
114710...	β Com	G0 V	372	1957	25	69	59	68	41	29	16	810	292
				2797	25	65	55	65	43	28	31		
115383...	59 Vir	G0 V	376	1944	60	139	147	178	126	85	120	1277	824
117176...	70 Vir	G2.5 V	452	1945	110	31	28	29	20	15	17	507	54
124570...	14 Boo	F6 IV	343	1959	60	38	19:	19:	17	---	---	579	---
124850...	ι Vir	F6 III	341	1946	21	62	58	67	36	34	34	939	381
136202...	5 Ser	F8 III-IV	352	1947	45	31	63:	43	15	---	18	617	40
141004...	λ Ser	G0 V	385	1960	25	45	43	49	25	17	28	665	145
142373...	χ Her	F8 V	381	1956	30	28	21	29	17	7	18	594	33
142860...	γ Ser	F6 V	320	1961	13	37	31	23	16	13	---	724	104
143761...	ρ CrB	G2 V	394	2798	65	35	28	31	23	10:	13	583	53
157214...	72 Her	G0 V	409	2799	65	50	29	56	31	17	22	594	81
165908...	99 Her	F7 V	361	2800	40	39	29	41	14	8	13	651	68
187013...	17 Cyg	F7 V	316	2802	32	33	22	11	---	---	---	682	54
187691...	ο Aql	F8 V	356	2801	45	27	38	27	15	15	12	623	58
216385...	σ Peg	F7 IV	321	1934	30	25:	35	19:	15	12	---	651	21

* flux average over the central 0.3 Å of the emission core, reduced to visual magnitude V = 5.

† core flux above the extrapolated wing profile, reduced to V = 5.

‡ Wilson's (1968) values of 1/2 ($F_H + F_K$) and 1/2 ($\Delta F_H + F_K$), resp., adjusted to a visual reference band.

ORIGINAL PAGE IS
OF POOR QUALITY

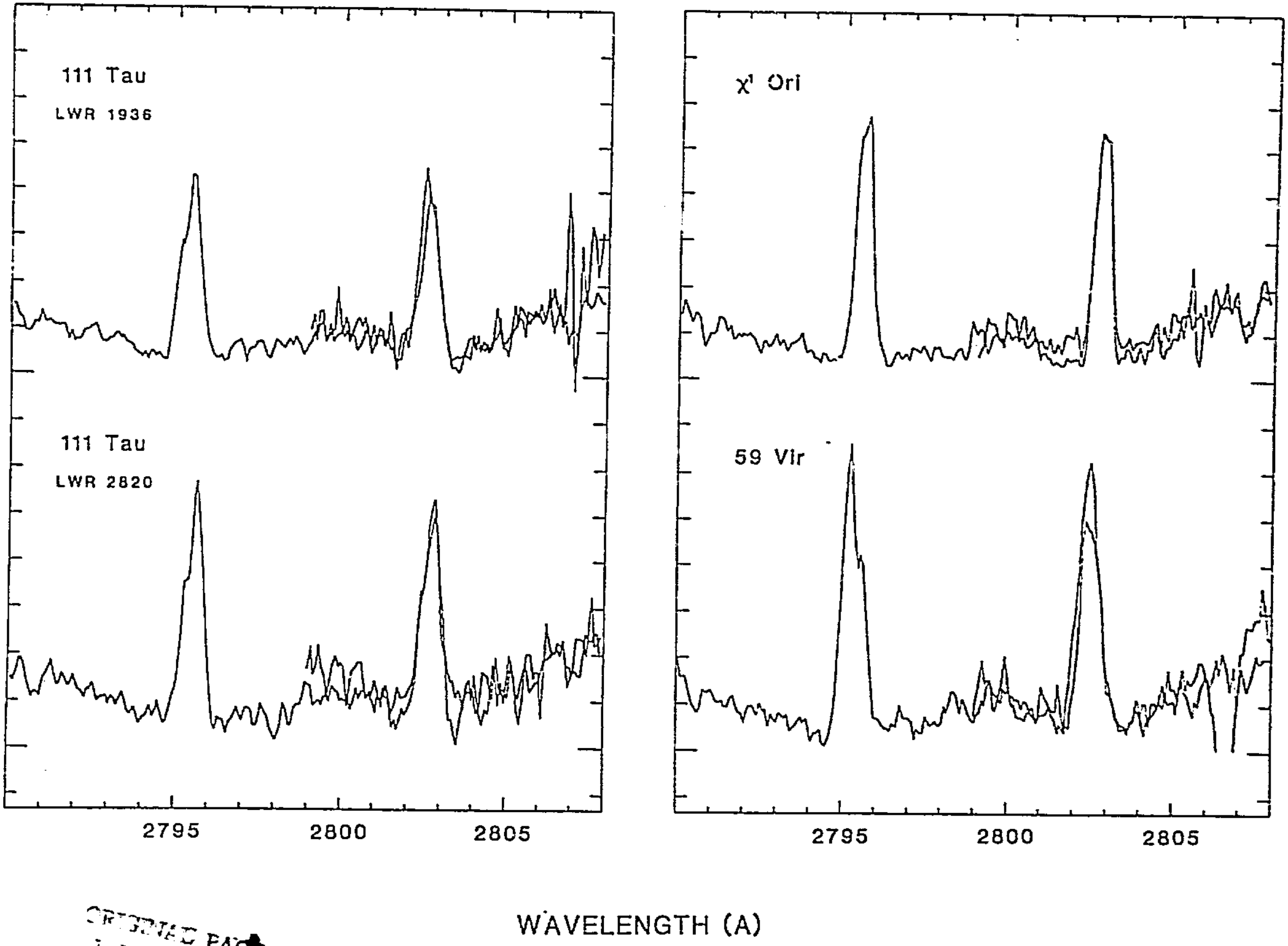
111 Tau
LWR 1936
111 Tau
LWR 2820
χ' Ori
59 Vir
2795
2800
2805
2795
2800
2805
WAVELENGTH (A)

FIGURE 2

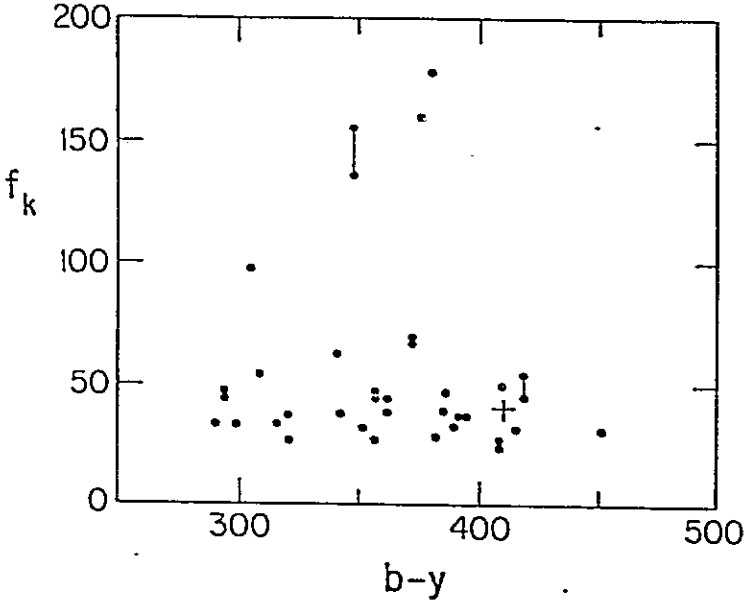

FIGURE 3

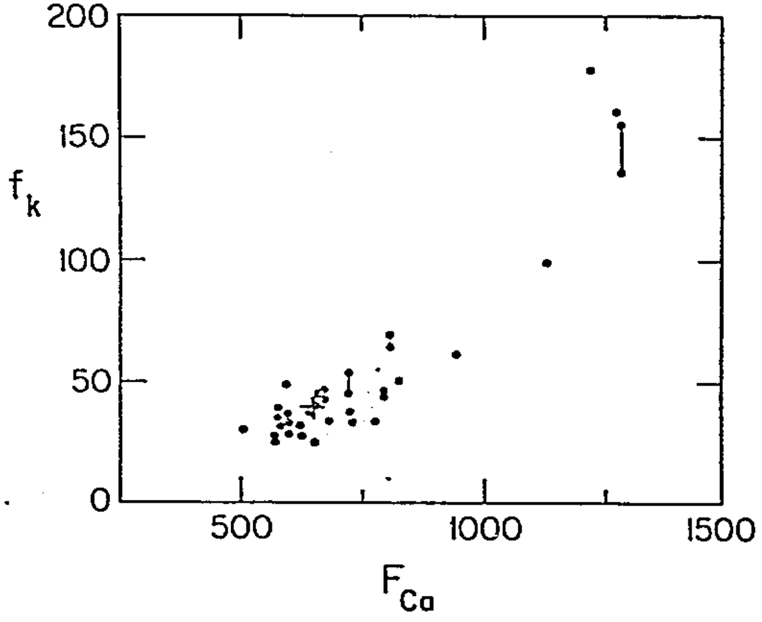

FIGURE 4

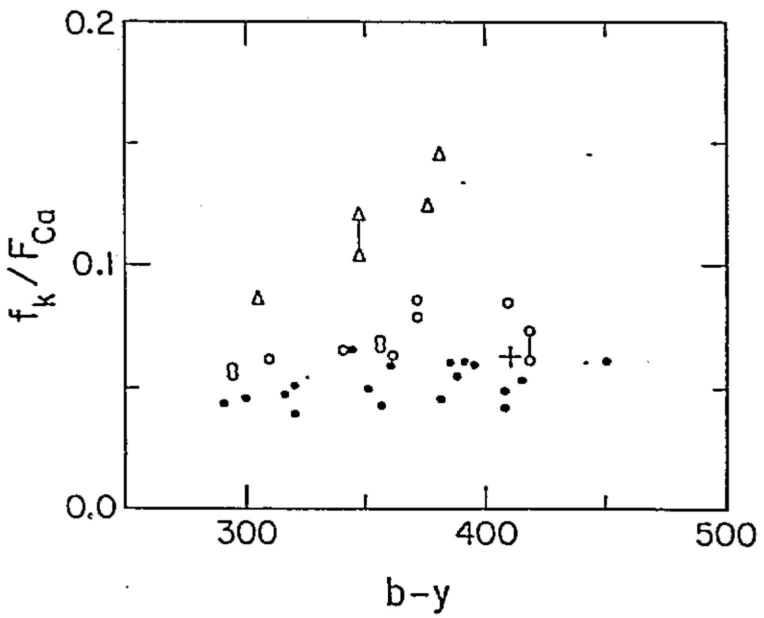

FIGURE 5

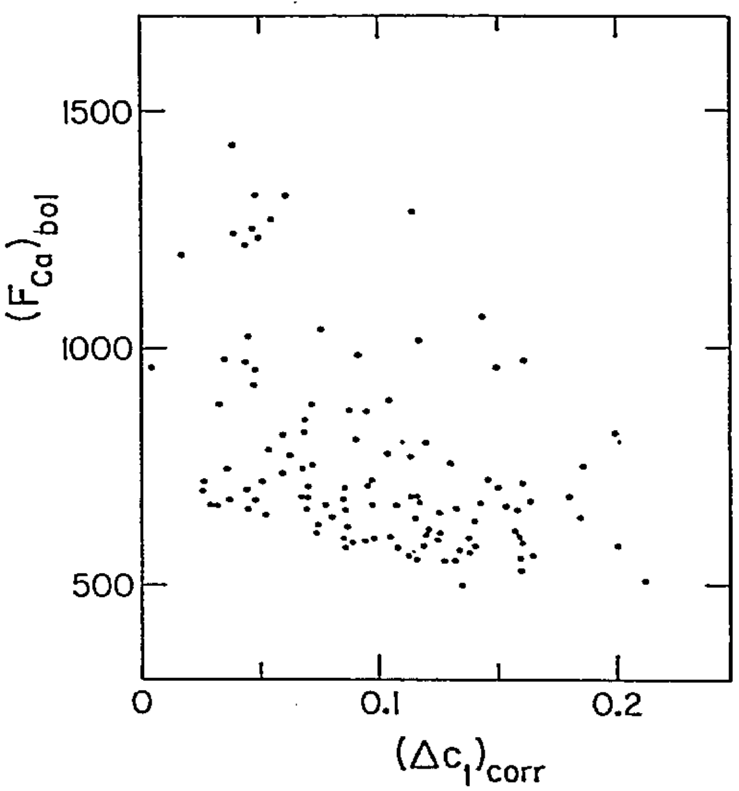

FIGURE 6

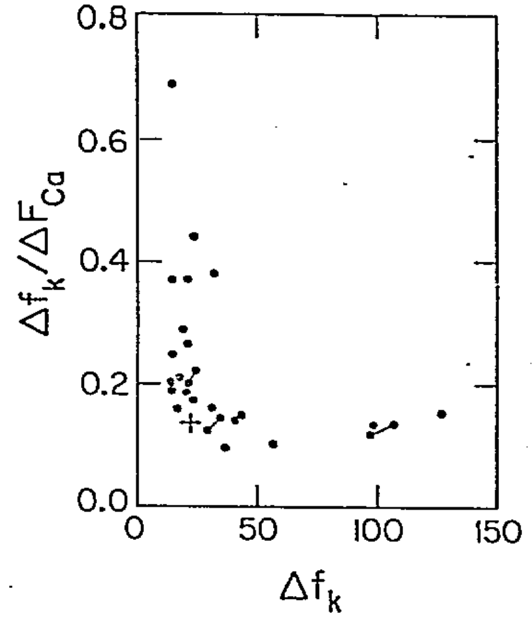

FIGURE 7

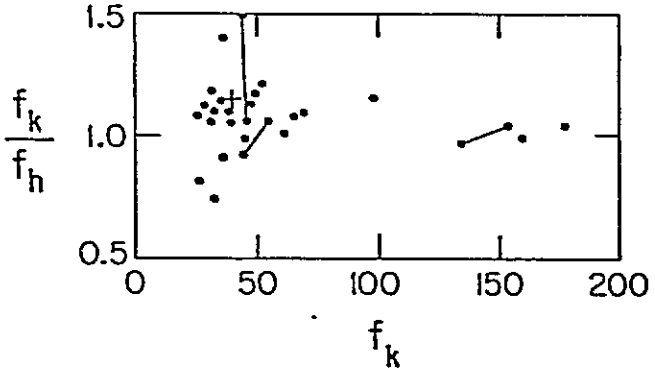

FIGURE 8