Chromospheric Ca II H and K Emission Among Subdwarfs

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ABSTRACT

Echelle spectra have been obtained of the Ca II H and K lines for a sample of metal-poor subdwarf stars as well as for a number of nearby Population I dwarfs selected from among those included in the Mount Wilson HK survey. The main conclusion of this paper is that Ca II H- and K-line emission does occur among subdwarfs. It is particularly notable among those subdwarfs with colours of $B - V \geq 0.75$; all such stars observed exhibit chromospheric emission, although emission is observed among some subdwarfs bluer than this colour. The Ca II K emission profile in most subdwarfs exhibits an asymmetry of $V/R > 1$, similar to that seen in the integrated light of the solar disk. Two quantitative indicators of the contrast between the peaks in the emission profile and the neighbouring photospheric line profile are introduced. Measurements of these indicators show that the level of Ca II emission among the subdwarfs is similar to that among low-activity Population I dwarfs.

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1. Introduction

Chromospheric activity among main-sequence stars is well known to be a decreasing function of age. The fluxes in the chromospheric emission features formed in the cores of the Ca II H and K lines show a decrease with age among stars younger than 4.5 Gyr (Skumanich 1972). Within most main-sequence stars chromospheric heating is thought to be governed by the activity of an interior magnetic dynamo, the strength of which depends on the stellar rotation rate. As main-sequence stars age they spin down, with a consequent decrease in dynamo activity and chromospheric heating (Hartmann & Noyes 1987).

The dynamo model has met with considerable success in describing the evolution of chromospheric activity among main-sequence stars. However, much of the data published to date on chromospheric activity among dwarf stars of spectral types F-G-K pertains to stars younger than ~5 Gyr. Such is true, for example, of the studies by Skumanich (1972) and Simon, Herbig, & Boesgaard (1985). By comparison, there is much less spectroscopy available pertaining to chromospheric activity among older dwarfs, particularly halo subdwarfs. Consequently, little is known about the evolution of chromospheric activity among the oldest main-sequence stars in the Galaxy. To study the low levels of activity expected among such stars, we have carried out a spectroscopic study of the Ca II H and K lines for a sample of low-metallicity subdwarfs. Metal-poor subdwarfs which are members of the Galactic halo are amongst the oldest stars in the Galaxy. They are useful for studying chromospheric activity at great ages.

The observations of Ca II H and K line emission among subdwarfs reported in this paper complement the HST GHRS observations of Mg II lines among metal-poor solar-like stars by Peterson & Schrijver (1997).

2. Observations

High-resolution spectra of both the Ca II H and K lines were obtained for a sample of subdwarfs using the Hamilton echelle spectrograph and the Lick Observatory 3-m Shane telescope at Mount Hamilton. A TI 800×800 CCD was used as the detector. Data were obtained during a number of observing runs: one night in May 1991, one night in September 1991, 3 nights in September 1994, 2 in November 1994, and 2 nights in each of April and June 1995. Observations of many of the stars took the form of several consecutive exposures of 2700 sec duration each. Total integration times per star typically ranged from 5400 sec to 10,800 sec. Calibration exposures obtained during the observing runs included exposures of a ThAr lamp to be used for wavelength calibration of the data, and exposures of a quartz lamp to be used as flat-field frames. Most of the data were reduced using standard IRAF packages, with the exception that the scattered-light background was subtracted using the algorithms described by Churchill & Allen (1995). The spectra that were obtained in 1991 for HD 25329, HD 103095, HD 157948, and HD 188510, were reduced with the VISTA package.

In order to quantify the strength of the Ca II K emission line relative to the photospheric profile, two parameters have been measured from spectra obtained in either the 1994 or 1995 observing runs. The first of these compares the intensity in the two K-line emission peaks to the photospheric profile on both sides of this emission:

$$K = \frac{I_{P1} + I_{P2}}{I_{B1} + I_{B2}}$$

where $I_{P1}$ and $I_{P2}$ denote the recorded counts in the blueward and redward peaks respectively of the K-line emission profile, while $I_{B1}$ and $I_{B2}$ denote the counts in the local minima where the blueward and redward wings of the emission profile intersect the photospheric profile. The definitions of $I_{B1}$, $I_{B2}$, $I_{P1}$, and $I_{P2}$ are illustrated in Figure 1. In some cases where emission is seen more distinctly in the blueward component of the emission profile, and only weakly or not at all in the red component, the parameter $K_\nu = I_{P1}/I_{B1}$ was measured. Stars which show either no emission, or inflections in the core without local emission maxima, are assigned the designation $K_\nu \leq 1$. Such stars may still have chromospheres as indicated by the model Ca II K line spectra of Oranje (1983); small amounts of network and/or plage emission can be present on the surface of a solar-like dwarf without producing distinct emission peaks in the line core. In the case where $I_{B1} = I_{B2}$, then $K = 0.5(K_\nu + I_{P2}/I_{B1})$: if the blueward emission peak is stronger than the redward peak then $I_{P2} < I_{P1}$ and $K < K_\nu$.

Two samples of stars were observed in this program: (i) a sample of metal-poor subdwarfs chosen from the lists of Carney & Latham (1987) and Laird, Carney, & Latham (1988), and (ii) a num-
Table 2 indicates whether any Ca II emission lines were apparent in the Mount Hamilton spectra. In some cases it is difficult to decide whether a star exhibits very weak emission or no emission; such cases are designated with a semi-colon in column 6. In most cases the H and K emission lines exhibit the same asymmetry; in such cases the \( V/R \) asymmetry is indicated in column 7. In a few cases where the asymmetry of these two emission lines differ, a remark is given in the footnotes, which also contain other miscellaneous comments on the character of the emission. The values of the parameters \( K \) and \( K_v \) are also listed in Table 2.

3. Discussion of the Spectra

Representative spectra of both the Mount Wilson stars and the subdwarfs observed are shown in Figures 2–9. The wavelength scale in these figures is the rest frame of the ThAr lamp used to obtain the wavelength calibration. Of the stars observed from the Mount Wilson survey, two of them, HD 78366 and HD 101501, are classified by Noyes et al. (1984) as very active dwarfs. The spectra of these two stars are shown in Figures 2a and 2b. Although both stars exhibit H and K line emission asymmetries of \( V/R > 1 \), this asymmetry is not very pronounced; both the \( R \) peaks are very strong and only slightly weaker than the \( V \) peaks. The other stars observed from the Mount Wilson survey are classified as relatively low-activity stars. Spectra for two such stars, HD 115617 and HD 141004, are shown in Figures 3a and 3b. The differences in Ca II H and K emission line strengths between the stars in Figures 2 and 3 are readily apparent. The star HD 190406 has weak emission with a \( V/R \) asymmetry only slightly greater than unity, as shown in Figure 4a. Most of the stars listed in Table 1 exhibit a Ca II emission line asymmetry of \( V/R > 1 \), the same as for the integrated solar disk (White & Livingston 1981) and many other dwarf stars (cf. Linsky et al. 1979; Basri & Linsky 1979). The only star observed from the Mount Wilson survey that exhibits a clear asymmetry of \( V/R < 1 \) is HD 176051. The spectrum of this star is shown in Figure 4b.

Among some of the bluer stars (\( B - V < 0.6 \))
that were observed from the Mount Wilson survey the spectra do not exhibit a clear double-peaked K-line emission profile, but instead show slight inflections or irregularities in slope near the core of the dominant absorption profile. An example of such a star is HD 159332, the spectrum of which is shown in Figure 5a. In the spectra of such stars there are no local maxima due to emission within ±1 Å of the K line core. Another example of this phenomenon is HD 184499. In the spectrum of this star, shown in Figure 5b, the H line exhibits weak emission, whereas the K line core exhibits an inflection in slope, becoming steeper near the core. The lack of discernible emission features in the H and K lines of Population I dwarfs with spectral types as early as mid-F to early-F has been attributed by Oranje & Zwaan (1985) to the ionisation of Ca II to within their atmospheres.

We can compare our results for the Mount Wilson stars with synthetic Ca II K line spectra computed by Oranje (1983). Using a mean plage emission profile derived for the Sun, Oranje (1983) computed model Ca II K-line-core profiles for dwarf stars of similar colour to the Sun and a range of fluxes in the K line core. For dwarfs with K line emission fluxes comparable to those exhibited by the Sun during the solar cycle, Oranje’s model profiles would show emission peaks in the K line core with an asymmetry of $V/R > 1$. This is consistent with the behaviour seen among many of the lower-activity dwarfs in our Mount Wilson sample. For solar-colour dwarfs with fluxes in the K line core lower than occurs at any time during the solar cycle, distinct emission peaks are not seen in Oranje’s models. Instead they exhibit inflections or small changes in slope near the line core. Such a circumstance is exhibited by HD 184499 (spectral type G0V). For a star such as this Oranje presumes that the surface magnetic flux arises only from a magnetic network and not from plages. Oranje’s models with the highest K-line-core fluxes have pronounced emission profiles with $V/R < 1$. By contrast, the two stars from our Mount Wilson sample with the greatest core fluxes, HD 78366 and HD 101501, show emission profiles that are nearly symmetrical. Oranje’s models indicate that the $V/R$ asymmetry of the K line emission profile will change from $> 1$ to $< 1$ with increasing amounts of plage emission. It is therefore likely that the plage coverage in the models could be made to reproduce the near-symmetry of the profiles of HD 78366 and HD 101501. Such models would have slightly lower activity levels than Oranje’s highest-activity models.

All of the metal-poor dwarfs and subdwarfs having colours of $B - V \geq 0.70$ in the sample exhibit Ca II H and/or K emission. The spectra of four of these stars are shown in Figures 6 a–d. Both the H and K lines of HD 78050, for example (Figure 6c), reveal a clear chromospheric emission core in which the violet emission peak is slightly stronger than the redward peak. An asymmetry of $V/R > 1$ is typical of most subdwarfs that show Ca II emission. Among those showing emission is HD 103095 (= Groombridge 1830), which is one of the few subdwarfs that were included in the Mount Wilson HK survey; it was found from that survey to show an activity cycle in H and K emission of period 7.3 yr (Balunis et al. 1995).

Unlike stars such as HD 78050, which has a colour of $B - V = 0.80$ and shows distinct Ca II H and K emission reversals, a number of the stars in the program have colours similar to, or bluer than, the Sun, and one (HD 20507) is as blue as $B - V = 0.45$. The chromospheric K-line emission for such subdwarfs is often extremely weak, and for many of the subdwarfs bluer than $B - V = 0.65$ emission has not been conclusively detected. Since the identification or non-detection of emission for some stars might be considered subjective, particularly for instances of weak emission, plots of the spectra of three of these subdwarfs are given in Figures 7 a–c.

Among stars from Table 2 bluer than $B - V = 0.70$, HD 153344 with a colour of $B - V = 0.67$ exhibits a clear emission feature in the Ca II K line. However the metallicity of this star is [Fe/H] = −0.3, and as such it is possibly a Galactic disk dwarf and not a Population II object. The bluest subdwarf found to exhibit Ca II emission is HD 134169 with a colour of $B - V = 0.55$. This subdwarf is comparable in colour to the bluest dwarfs from Table 1 that exhibit a K-line emission peak (as opposed to an inflection near the K line core). The spectrum of this star is shown in Figure 8. Although there are no clear emission peaks in the core of the H line, there is a weak emission peak to the violet side of the K-line core.

One star from Table 2 that shows unusual emission profiles is HD 224087, the spectrum of which is shown in Figure 9. Emission is clearly seen in both the H and K lines, but the emission profiles, although asymmetric, are single-peaked rather than double-peaked. Carney & Latham (1987) find this star to be a “near-certain” binary on the basis of radial velocity variability. It is possible that the peculiar activity of this
star is related to it's binarity.

4. Emission Profile Parameters

The largest set of measurements of Ca II emission line strengths in the literature is that resulting from the Mount Wilson program (Vaughan & Preston 1980; Duncan et al. 1991). The S index compares the combined flux in the H and K emission lines with the flux in comparison bands at 3900 Å and 4000 Å. Such an index is not well suited to measurement from Hamilton echelle spectra since the four wavelength regions used to obtain the index are all located in different echelle orders. However, Figure 10, which shows a plot of both K and $K_v$ versus S for the Mount Wilson survey stars from Table 1 with discernible emission, indicates that there is a relationship between the Hamilton-echelle indices and S, although this latter index does exhibit an intrinsic spread among stars for which K and $K_v$ are close to unity. Although the errors in our values of K and $K_v$ are difficult to assess, since we have few measurements of stars observed on different nights, Figure 10 does illustrate that the accuracy is sufficient to distinguish between stars of high and low activity levels, which is the main purpose for which we wish to use these measurements.

Comparisons between the Ca II K-line emission strengths of the Mount Wilson stars from Table 1 and the subdwarfs from Table 2 are shown in Figure 11, in which both S (upper panel) and $K_v$ (lower panel) are plotted against $B - V$. In the upper panel, the one subdwarf shown (as an open circle) is HD 103095 (= Groombridge 1830); the point plotted is an average of the largest and smallest values of S listed by Duncan et al. (1991). Also shown in the upper panel are the mean locii for Population I dwarfs having weak Ca II emission (solid line) and strong emission (dashed line). These locii have been determined by eye from Figure 1 of Noyes et al. (1984), in which a bimodal distribution in S is apparent among F and G dwarfs in the Mount Wilson program. The level of emission in Groombridge 1830 is comparable to that in relatively low-activity Population I dwarfs.

In the lower panel of Figure 11 $K_v$ is plotted versus $B - V$ for stars in Tables 1 (filled circles) and 2 (open symbols) with discernible emission. The two high-activity stars, HD 78366 and HD 101501, fall in a region of the figure that is well separated from both the low-activity Population I stars and the subdwarfs. The subdwarfs define a relatively tight sequence that overlaps the data for the low-activity dwarfs sampled from the Mount Wilson survey. As would be expected on the basis of their old age, the subdwarfs appear to be low-activity stars. Both HD 153344 and HD 221613, which on the basis of their metallicities are probably disk dwarfs rather than subdwarfs, also lie along the low-activity sequence in Figure 11.

In Figure 11 both the S and $K_v$ indices show a strong $B - V$ colour dependence. The sequence defined by the subdwarfs in the lower panel of Figure 11 rises with increasing $B - V$ colour. The S index among low-activity Population I dwarfs behaves in the same way (see e.g., Noyes et al. 1984). In the case of the S index this colour dependence is due to the reduction with decreasing effective temperature of the flux in the reference passbands (Middelkoop 1981). The $K_v$ index is presumably also responding in the same way; for a given intensity $I_{F1}$, the index will increase with increasing $B - V$ due to the systematic reduction in the comparison intensity $I_{B1}$.

5. Conclusions

The main conclusion of this paper is that Population II subdwarfs do have chromospheres, i.e., their outer atmospheres are heated by some form of non-radiative process. In terms of the contrast of the peaks in the K-line emission profile relative to the neighbouring absorption profile, and the preponderance of an asymmetry of $V/R > 1$, the subdwarfs appear similar to low-activity dwarfs sampled from the Mount Wilson survey. These observations are consistent with data on the Mg II lines of metal-poor solar-type stars reported by Peterson & Schrijver (1997).

The origin of an asymmetry of $V/R > 1$ among both dwarfs and subdwarfs is not well understood. As Linsky (1980) has pointed out such an asymmetry can be produced by downward motions in the region of formation of the central $K_3$ absorption feature, or by upwards motions in the $K_2$ formation region if there are no systematic motions in the region of $K_3$ formation (see Ayres & Linsky 1975 for the definitions of this terminology). Presumably the reason for the $V/R > 1$ asymmetry among the subdwarfs is the same as for the Population I dwarfs, including the Sun. However, the origin of this asymmetry even for the best studied case of the Sun is still not completely clear. This subject has been reviewed by Linsky (1980), Cramp (1983), and Rutten & Uitenbroek (1991). The consensus seems to be that the
asymmetry is associated with upwards propagating gravity or acoustic waves (see, e.g., Carlsson & Stein 1992, 1997).

In addition to the uncertainty in the origin of the $V/R$ asymmetry, the Ca II K-line emission observations do not permit a determination of whether the chromospheric activity of the subdwarfs is being modulated by a magnetic dynamo, as for the Sun, or whether it is produced by a process which is active even in the absence of such a dynamo. Statistical analyses of the chromospheric emission line fluxes of late-type Population I stars have been used to argue that the emission can be divided into two components (Schrijver 1987a,b, 1995): a “magnetic dynamo” component which correlates with stellar rotation rate and decreases with age, and a rotation-independent “basal” component. The magnetic dynamo component is important for stars like the Sun, and is particularly strong in late-type dwarfs younger than 1 Gyr. The basal component is thought to reflect the contribution of acoustic heating to the maintenance of a chromosphere (Schrijver 1987b; Cuntz, Rammacher, & Ulmschneider 1994).

Whether the chromospheres of subdwarfs are “basal chromospheres” or are maintained by a magnetic dynamo is not clear from the Ca II K line observations. The finding by Baliunas et al. (1995) that the subdwarf HD 103095 exhibits an activity cycle of period 7.3 years in the Ca II H and K emission lines, suggests an analogy with the solar cycle, implying that the subdwarfs have chromospheres whose long-term behaviour is dominated by a magnetic dynamo.

The similarity in Ca II K-line emission strength among the subdwarfs and the lowest-activity stars sampled from the Mount Wilson survey seems consistent with the spectroscopy of main-sequence stars in the old open clusters NGC 188 and M67 by Barry, Cromwell, & Hegge (1984) which suggests that the rate of decline of the fluxes in the Ca II H and K line cores flattens out after $\sim 3$ Gyr. These observations, and those noted in the previous paragraph, would be consistent with a scenario in which the magnetic dynamo ceases to decline significantly in activity once main-sequence stars reach an age of around 5 Gyr. There could be two reasons for this. Either the dynamo reaches a true minimum level, as in the turbulent magnetic field scenario of Durney, De Young, & Roxburgh (1993), or else the rate of spin down of dwarfs and subdwarfs older than 5 Gyr becomes very slow.

The alternative to these dynamo scenario is that chromospheres among stars older than 5 Gyr are largely maintained by an age-invariant basal heating mechanism, and that activity produced by an age-dependent magnetic dynamo has dropped to a low level by comparison. In sufficiently old main-sequence subdwarf stars the dynamo might be relatively inactive and acoustic heating may become the dominant mechanism for maintaining a “basal chromosphere.” This is the scenario proposed by Peterson & Schrijver (1997) on the basis of similarities observed between the Mg II emission line profiles of metal-poor solar-type stars and solar quiet regions. In this respect it is perhaps relevant to note that the most extreme $V/R > 1$ Ca II K line asymmetry in the integrated spectrum of the solar disk occurs around the times of solar minimum (White & Livingston 1981).

The type of observation that may differentiate between these scenarios is a search for soft x-ray emission among subdwarfs. If subdwarfs are found to have solar-like coronae, with soft x-ray properties consistent with temperatures of 1-2$\times 10^6$ K, then the case for dynamo-maintained chromospheres and coronae would be strengthened.

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REFERENCES

Ayres, T. R., Linsky, J. L., 1975, ApJ, 200, 660
Balimbas, S. L., et al., 1995, ApJ, 438, 269
Barry, D. C., Cromwell, R. H., Hegge, R. H., 1984, ApJ, 277, L65
Basri, G. S., Linsky, J. L., 1979, ApJ, 234, 1023
Carlsson, M., Stein, R. F., 1992, ApJ, 397, L59
Carlsson, M., Stein, R. F., 1997, ApJ, 481, 500
Carney, B. W., 1979, ApJ, 233, 211
Carney, B. W., Latham, D. W., 1987, AJ, 93, 116
Churchill, C. W., Allen, S. L., 1995, PASP, 107, 193
Cram, L. E., 1983, PASA, 5, 152
Cuntz, M., Rammacher, W., Ulmschneider, P., 1994, ApJ, 432, 690
Duncan, D. K., et al., 1991, ApJS, 76, 383
Durney, B. R., De Young, D. S., Roxburgh, I. W., 1993, Sol. Phys., 145, 207
Giclas, H. L., Burnham, R., Jr., Thomas, N. G., 1971, Lowell Proper Motion Survey, Northern Hemisphere (Lowell Observatory, Flagstaff)
Hartmann, L. W., Noyes, R. W., 1987, ARAA, 25, 271
Laird, J. B., Carney, B. W., Latham, D. W., 1988, AJ, 95, 1843
Linsky, J. L., 1980, ARAA, 18, 439
Linsky, J. L., Worden, S. P., McClintock, W., Robertson, R. M., 1979, ApJS, 41, 47
Middelkoop, F. 1981, A&A, 101, 295
Noyes, R. W., Hartmann, L. W., Baliunas, S. L., Duncan, D. K., Vaughan, A. H., 1984, ApJ, 279, 763
Oranje, B. J. 1983, A&A, 124, 43
Oranje, B. J., Zwaan, C., 1985, A&A, 147, 265
Peterson, R. C., Schrijver, C. J., 1997, ApJ, 480, L47
Rutten, R. J., Uitenbroek, H. 1991, Sol. Phys., 134, 15
Schrijver, C. J., 1987a, A&A, 172, 111
Schrijver, C. J., 1987b, in Cool Stars, Stellar Systems, and the Sun, eds. J. L. Linsky & R. E. Stencel (Berlin: Springer-Verlag), p. 135
Schrijver, C., 1995, A&AR, 6, 181
Simon, T., Herbig, G. H., Boesgaard, A. M., 1985, ApJ, 293, 551
Skumanich, A., 1972, ApJ, 171, 565
White, O. R., Livingston, W. C., 1981, ApJ, 249, 798
Wilson, O. C., 1976, ApJ, 205, 823
Vaughan, A. H., Preston, G. W., 1980, PASP, 92, 385

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Table 1: K Emission Line Properties of Mount Wilson Survey Stars

| Name    | V    | B − V | SpT | S     | Emission | V/R | K   | K_v |
|---------|------|-------|-----|-------|----------|-----|-----|-----|
| HD 13421 | 5.63 | 0.56  | G0IV | 0.130 | yes^f    | > 1 | ...| ≤ 1^g |
| HD 78366 | 5.93 | 0.60  | F9V  | 0.240 | yes^d    | > 1 | 1.99 | 2.02 |
| HD 101501 | 5.33 | 0.72  | G8V  | 0.310 | yes^d    | > 1 | 2.60 | 2.74 |
| HD 115617 | 4.74 | 0.71  | G6V  | 0.160 | yes       | > 1 | 1.13 | 1.16 |
| HD 136202 | 5.06 | 0.54  | F8III-IV | 0.140 | infl^b  | ≈ 1 | ...| ≤ 1^g |
| HD 141004 | 4.43 | 0.60  | G0V  | 0.160 | yes       | > 1 | 1.09 | 1.17 |
| HD 142373 | 4.62 | 0.56  | F8V  | 0.142 | yes       | > 1 | ...| 1.06 |
| HD 159332 | 5.64 | 0.48  | F6V  | 0.145 | infl^a   | > 1 | ...| ≤ 1^g |
| HD 176051 | 5.22 | 0.59  | F9V  | 0.180 | yes       | < 1 | 1.12 | 1.09 |
| HD 184499 | 6.63^c | 0.60^c | G0V^c | 0.145^c | Kn,Hy^c | > 1 | ...| ≤ 1^g |
| HD 187013 | 4.99 | 0.47  | F7V  | 0.150 | infl^a   | > 1 | ...| ≤ 1^g |
| HD 187691 | 5.11 | 0.55  | F8V  | 0.150 | Kn,Hy^c | > 1 | ...| ≤ 1^g |
| HD 190406 | 5.80 | 0.61  | G1V  | 0.190 | yes       | ≥ 1 | 1.17 | 1.19 |
| HD 207978 | 5.53 | 0.42  | F6IV-V | 0.155 | no        | ...| ...| ...|

^a K_v profile shows an inflection near the core but no emission peak having a local maximum.

^b Both K and H profiles show an inflection near the core (although the inflection in the H line is less obvious), but no emission peaks.

^c Emission in H line, but K line shows only an inflection in the core.

^d Very strong emission.

^e Photometry and spectral type from Hipparcos Input Catalogue. The value of S is an average of the largest and smallest values tabulated by Duncan et al. (1991).

^f Weak emission in violet wing (K_2v) of the K_2 line. Possible H_2v emission, but very weak.

^g K line profile shows either no emission or an inflection near the line core without a clear emission peak.
Table 2: K Emission Line Properties of Metal-Poor Dwarfs

| Name      | G     | V     | B − V | [Fe/H] | Emission | V/R | K     | K_v |
|-----------|-------|-------|-------|--------|----------|-----|-------|-----|
| HD 4906   | G32-53| 8.76  | 0.76  | −1.1   | yes      | ≥ 1 | 1.26  | 1.31|
| BD +29 366| G74-5 | 8.76  | 0.58  | −1.1   | infl_c   | > 1 | ...   | ... |
| BD −1 306 | ...   | 9.08  | 0.58  | −1.0   | no       | ... | ≤ 1   | 1.1 |
| HD 14056  | G4-10 | 9.05  | 0.62  | −0.8   | infl_c   | > 1 | ...   | ≤ 1 |
| HD 20039  | G221-7| 8.89  | 0.75  | −1.2   | yes      | > 1 | 1.35  | ... |
| HD 20507  | G245-73| 6.93 | 0.45  | −1.0   | no       | ... | ≤ 1   | ... |
| HD 25329  | ...   | 8.51  | 0.87  | −1.5   | yes      | ≈ 1 | ...   | ... |
| BD +37 1458| ...  | 8.92  | 0.60  | −2.4   | no       | ... | ≤ 1   | 1.1 |
| HD 64606  | G112-54| 7.43 | 0.73  | −0.9   | yes_c   | > 1 | 1.22  | 1.25|
| HD 78050  | G9-47 | 7.68  | 0.80  | −1.9   | yes      | > 1 | 1.52  | 1.60|
| HD 103095 | ...   | 6.44  | 0.75  | −1.2   | yes      | > 1 | ...   | ... |
| HD 103912 | G122-57| 8.36 | 0.86  | −1.7   | yes      | ≥ 1 | 2.04  | 1.86|
| HD 134169 | ...   | 7.68  | 0.55  | −1.6   | yes_c   | > 1 | ...   | 1.06|
| HD 153344 | G226-36| 7.07 | 0.67  | −0.3   | yes      | > 1 | 1.05  | 1.08|
| HD 157948 | G182-7| 8.10  | 0.76  | −1.3   | yes      | > 1 | ...   | ... |
| BD +23 3130| G170-47| 8.95 | 0.64  | −2.9   | no       | ... | ≤ 1   | ... |
| HD 188510 | ...   | 8.83  | 0.59  | −1.6   | no       | ... | ≤ 1   | ... |
| HD 194598 | ...   | 8.35  | 0.49  | −1.3   | no       | ... | ≤ 1   | ... |
| HD 198300 | G230-49| 8.51 | 0.59  | −0.9   | yes_c   | ... | ...   | ... |
| HD 200580 | G25-15| 7.34  | 0.54  | −1.0   | no       | ... | ≤ 1   | ... |
| HD 201891 | ...   | 7.37  | 0.51  | −1.1   | no       | ... | ≤ 1   | ... |
| HD 221613 | G171-3| 7.14  | 0.58  | −0.6   | Ky,Hn_c | < 1 | 1.05  | 1.01|
| HD 224087 | G129-42| 8.94 | 0.81  | −0.7   | yes      | > 1 | ...   | ... |

^a Both K_2 and H_2 profiles show an inflection near the core but no emission peak having a local maximum.
^b Inflection in violet side of the core of the K line.
^c Noisy spectrum.
^d Emission is very weak.
^e Two spectra were obtained; in April 1995 the spectra show a nearly symmetric K_2 emission feature with the violet wing having only a slightly-higher peak than the red wing (Figure 5d), while in June 1995 a clearer asymmetry of V/R > 1 was exhibited.
^f Emission in core of the K line, but not the H line. The quoted V/R refers to the K line.
^g Emission profile shows an asymmetric emission peak, but does not exhibit a central K_3 absorption feature.
^h Values of K and K_v derived from the April 1995 spectrum.
^i Inflection or no emission in core.
Fig. 1.— The parameters used to calculate the emission-profile indices $K$ and $K_v$ are defined in this figure. The spectrum shown is that of HD 78366. The wavelength scale corresponds to the rest frame of the ThAr lamp used in wavelength calibrating the spectrum.
Fig. 2.— Spectra of the Ca ii H and K lines for the dwarfs HD 78366 (panel a) and HD 101501 (panel b). These stars show very strong H and K emission lines as well as the largest values of $S$, $K$, $K_\nu$ among the stars in Table 1.
Fig. 3.— Spectra of the Ca ii H and K lines for two low-activity dwarfs from the Mount Wilson survey: HD 115617 (panel a) and HD 141004 (panel b).
Fig. 4.— Spectra of the Ca ii H and K lines for the dwarfs HD 190406 (panel a), for which $V/R$ is only slightly greater than unity (as illustrated best by the H$_2$ line), and HD 176051 (panel b), which unlike the other stars from Table 1 exhibits an asymmetry of $V/R < 1$. 
Fig. 5.— Spectra of two dwarfs from the Mount Wilson survey that exhibit inflections in the slope of the H and/or K lines near the line center. Panel (a) shows a case of inflections in both line cores, whereas HD 184499 exhibits this phenomenon in the K line only.
Fig. 6.— Spectra of the Ca II H and K lines for the subdwarfs HD 4906 (G32-53; panel a), HD 64606 (G112-54; panel b), HD 78050 (G9-47; panel c), and HD 103912 (G122-57; panel d). These stars have colours of $B - V \geq 0.70$, and all show emission in at least one of the line cores.
Fig. 7.— Spectra of the Ca II H and K lines for three subdwarfs which do not show emission in the line cores: BD +37 1458 (panel a), HD 194598 (panel b), and HD 200580 [= G25-15] (panel c).
Fig. 8.— Spectra of the Ca II H and K lines of the subdwarf HD 134169.

Fig. 9.— Spectra of the Ca II H and K lines of HD 224087.
Fig. 10.— The two echelle-based Ca II K-line parameters $K$ and $K_v$ are shown plotted versus the Mount Wilson $S$ index for stars from Table 1. Only stars with $K_v > 1$ are shown; these stars have distinct emission maxima in the profile of the K-line core.
Fig. 11.— (Upper panel.) The S index for stars from Table 1 (filled circles) and HD 103095 (open circle) is shown plotted versus $B - V$. This figure indicates that the subdwarf HD 103095 (Groombridge 1830) has Ca II H and K emission lines comparable in strength to those of low-activity Population I dwarfs. The solid and dashed lines represent eye estimates of the mean loci for the low-activity and high-activity dwarfs respectively from Noyes et al. (1984; see their Figure 1). (Lower panel.) The $K_v$ parameter is plotted versus $B - V$ colour for Mount-Wilson-survey dwarfs from Table 1 (filled circles) and subdwarfs from Table 2 (open symbols). Only stars with $K_v > 1$ are plotted.