THE DISTRIBUTION OF CHROMOSPHERIC EMISSION STRENGTHS AMONG RED DWARFS

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The survey of Vaughan and Preston (1980, hereafter VP) of Ca II emission among solar neighborhood stars has shown the distribution of chromospheric emission (CE) of these stars. For stars bluer than (B-V)= 1.50, it is possible to transform VP's equivalent width S into a relative flux by use of Middelkoop's (1982) formulae. This enables construction of a chromospheric color-magnitude diagram (illustrated in Soderblom 1982), which shows the same general features as VP's log S vs. (B-V) plot, except that the CE (as a fraction of the stellar luminosity) declines with mass due to the decline of the ZAMS rotational velocity with mass (Soderblom 1983).

The presence of a gap in this diagram is problematical because a number of effects can contribute to produce systematic trends (Soderblom 1983). What is of interest here is the distribution of CE's for K and M dwarfs, i.e., for (B-V)>1.0. The few K-M dwarfs that are extraordinarily strong Ca II emitters are BY Draconis variables or flare stars. The spread in CE for the rest is fairly small: 0.4 dex encompasses all the K-M dwarfs except for a few very weak emitters. As expected, halo population objects have weaker CE on the average than the disk stars do.

(B-V) is a poor temperature indicator for K-M stars. (V-R)'s would be superior but are unavailable for most of VP's stars. To examine the distribution of CE for K-M dwarfs, I have used (R-I) from Gliese (1969). Middelkoop's formulae are not appropriate for such cool stars, so Figure 1 shows log S vs. (R-I). The F and G stars in this diagram are compressed below (R-I)=0.40 ((B-V)$\lesssim$1.0). As before, there are BY Draconis and flare stars in the upper right corner. For (R-I)$\gtrsim$0.70 ($\simeq$dM2, (B-V)$\simeq$1.4), the distribution appears to turn over, so that the very weakest stars exhibit weak CE despite the apparent increase in CE that should result from weaker continua. This turnover may be caused in part by VP's continuum bands, which show unexpected behavior for (B-V)>1.0 (see Fig. 3 of VP). However, this would affect all stars redder than (R-I)=0.40.

The most probable cause of this turnover is the nature of the sample for very cool stars. As Upgren and Armandroff (1981) have shown, our

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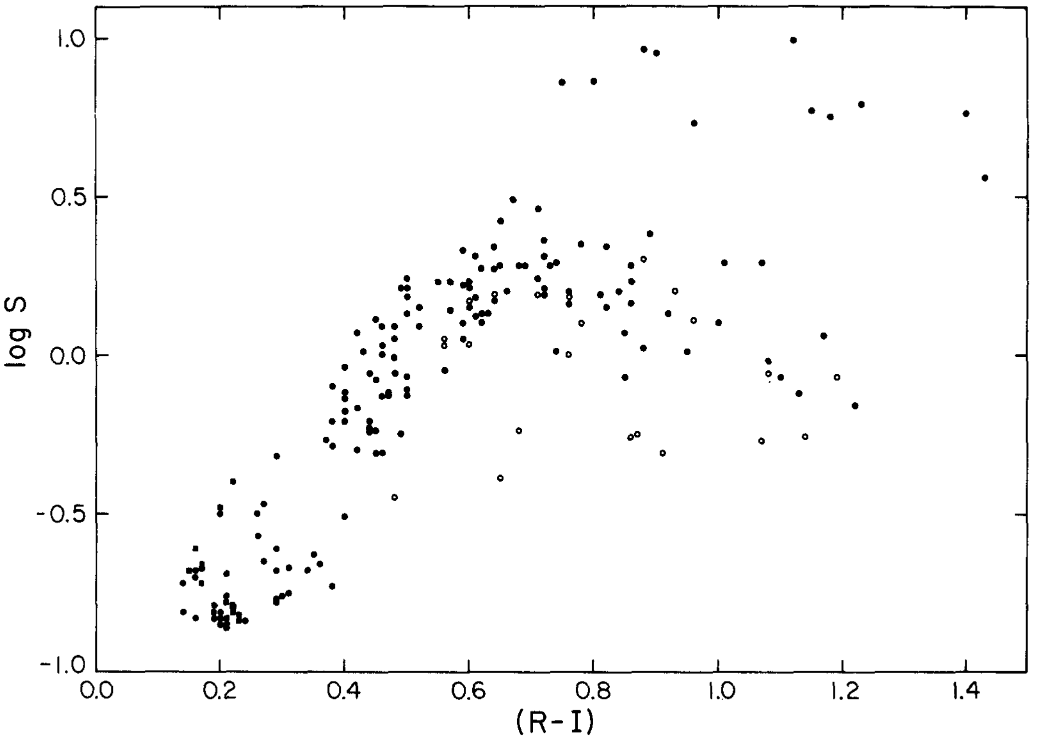

Figure 1. The logarithm of *S*, Vaughan and Preston's (1980) equivalent width of the Ca II H and K emission reversals, against (R-I) (in the Kron system) from Gliese (1969). The squares below (R-I)=0.30 are Johnson colors transformed to the Kron system. Open circles denote old disk and halo objects ($|W+10|>30$ km s^{-1} or $(U^2+V^2)^{1/2}>65$ km s^{-1}).

knowledge of the stellar composition of the solar neighborhood is complete only to about (B-V)=1.40 (M_V=+9), i.e., (R-I)=0.70. Stars cooler than this tend to be selected on the basis of unusual spectra in objective prism surveys (the BY Dra and flare stars) or because of large proper motions. This latter group tends to be much older than the disk stars. Our knowledge of young to intermediate age stars is poor for low masses.

This conclusion is reinforced by considering the space motions of the stars in Figure 1. If the very active stars are excluded (those with log S>0.50), the 47 stars with (R-I)≥0.70 have W_{rms}=25 km s^{-1}, while W_{rms}=16 km s^{-1} for the 43 stars with 0.50≤(R-I)<0.70. This latter velocity is typical of the disk population, but 25 km s^{-1} is appropriate to very old stars (Wielen 1974). Thus a more complete knowledge of K-M dwarfs in the solar neighborhood should turn up stars of moderate CE at all colors.

As Noyes (1983) has shown, the correlation between rotation period and CE is very tight for late-type dwarfs. BY Draconis stars have rota-

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tion periods of 2 to 10 days. The longest rotation period found by Baliunas *et al.* (1983) is 48 days for 61 Cygni B (K7V, (R-I)=0.60, log S=+0.04). The presence of stars as much as 0.4 dex below this suggests that their rotation periods may be as long as 120 days. However, Noyes' relation works for the mean chromospheric emission. These very cool stars are faint, and so knowledge of their CE variability is lacking. Among the most active stars, the average CE observed tends to be near the high end of the overall range of CE for the star, suggesting that one is unlikely to observe a star in a quiet state. Because the CE of halo stars is very weak, detection of their rotation periods will be difficult. An additional complication is that the low metal abundance of halo stars may systematically change the level of CE appropriate to a given rotation period.

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DISCUSSION

Giampapa: It is important to consider the nature of the chromospheres in these stars. It may well be that the selection effects you mentioned play a role but when you get to the very cool stars,as Linsky has pointed out,Ca II is not the dominant emitter. In fact, the energy in the Balmer lines becomes more important than Ca II. What one would like to do would be to replot your diagram taking into account all of the important emitters. As a second more minor point I should point out that dMe stars are found among both younger and older (kinematically) populations.

Soderblom: Yes, certainly Ca II is only one element in what is going on in these stars' chromospheres. This has the benefit of being a large survey, however. As regards the distribution of dMe stars what you say is also true. What I do not know is the frequency of flaring among stars of different ages. For instance, if you look at kinematically old stars what fraction are you likely to find in flare.

Vaiana: Is this sample volume complete so as to speak?

Soderblom: The stars are taken from the Gliese and Wooley et al catalogues. These catalogues are definitely not complete. Upgren and Armandroff recently concluded that the sample was representative although not complete to (B-V)=1.4. What they did was to examine those stars which lay in the Northern hemisphere and delete known binaries or those with radial velocity variations.

Anon: Can you say something about the gap?

Soderblom: The reason I do not think the gap is real is the following. Firstly I added about 40 stars to the original Vaughan-Preston sample and at least 6 lie in the so-called gap. The second reason is as follows. The upper branch of the area around the gap is about where one finds stars of the age of the Hyades. Now the difference in chromospheric emission between Hyades stars and the Sun is about 0.5 dex in good agreement with what you would expect on the basis of a $t^{-\frac{1}{2}}$ dependence and the relative ages of the Hyades and the Sun. Consider now the difference between the Pleiades and the Hyades. The Pleiades are an order of magnitude older than the Hyades. So on the basis of the above argument one would expect a further 0.5 dex in the chromospheric emission. This is not observed. Instead they are above the Hyades by about 0.1 dex. What is being seen is some kind of saturation phenomenon. From rotational velocity measurements it appears that it too begins to saturate and so the proportionality between the two is maintained. This effect will appear to make a concentration of stars just above where the gap is supposed to be. So there is no physical significance in the gap.