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New measurements of rotation periods for Hyades stars, which were obtained from re-analysis of Mount Wilson Observatory CaII H-K emission flux measurements, are reported. The existence of systematic, color-dependent discrepancies between the measured rotation periods for Hyades stars and those predicted by the Rossby relation as originally calibrated by Noyes et al. (1984) has led to a re-examination of the form of the relationship between chromospheric emission, rotation, and color. Keywords;

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Stellar Activity and the Rotation of Hyades Stars

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We have obtained determinations of rotation periods for several main-sequence members of the Hyades cluster through re-analysis of Mount Wilson Observatory CaII H-K emission flux measurements. A discussion of our analysis procedure using Scargle's (1982) modified periodogram algorithm is provided by Radick *et al.* (1987). We summarize our results in Table 1. The entries in column 5 are rotation periods (P_N) predicted from B-V color indices and mean S-index values according to the prescription of Noyes *et al.* (1984). The measured periods (P_{obs}), along with their formal uncertainties, are listed in column 6. Three criteria for judging the reliability of each measurement appear in columns 7-9: (1) the amplitude signal-to-noise ratio (S/N) of the rotational modulation, (2) the false alarm probability (P_a) for the signal peak in the periodogram, and (3) an overall quality rating (A, B, or C), assigned according to the qualitative appearance and characteristics of the periodogram.

TABLE 1

Newly Derived Rotation Periods For Hyades Stars
From CaII H-K Observations

Star	Sp	B-V	S-index	P_N	P_{obs}	S/N	P_a	Quality	Season
VB36	F6V	0.441	0.210	2.61	2.71 ± 0.01	1.54	0.029	C	1981-82
VB81	F6V	0.470	0.230	3.17	2.20 ± 0.01	1.32	0.047	C	1982-83
VB57	F7V	0.491	0.242	3.65	2.68 ± 0.01	0.88	0.033	C	1982-83
VB77	F7V	0.502	0.261	3.46	2.43 ± 0.01	1.23	0.018	A	1982-83
VB31	G0V	0.566	0.291	5.15	5.43 ± 0.02	1.07	< 0.001	B	1983-84
VB58	G6V	0.680	0.384	6.56	6.08 ± 0.04	1.05	0.086	B	1982-83

Note: Data for VB31 previously reported by Radick *et al.* (1987).

The existence among Hyades stars of systematic, color-dependent discrepancies between measured and predicted rotation periods has already been noted by Radick *et al.* (1987). These discrepancies, which average 19% and occasionally approach 40%, are shown in Fig. 1a.

A-1 20

Another representation is shown in Fig. 1b, where normalized H-K emission (R'_{HK}) is plotted against Rossby number -- the rotation period scaled by the convective turnover time scale. The solid curve is the mean relation derived from data for 41 field stars by Noyes *et al.* (1984). There is a striking segregation of early G-type Hyades stars above this curve, and late G- and early K-type Hyades stars below it. The Hyades data is better represented by the dashed line, which flattens more strongly (i.e., saturated) toward higher activity. Indeed, a saturated relation is also qualitatively compatible with the original field star data.

The discrepancies can also be relieved by a modification to the shape of the scaling function ($\tau_c^{(2)}$), as shown in Fig. 1c. The solid curve is the mean relation obtained by Noyes *et al.* (1984). The dashed line, which

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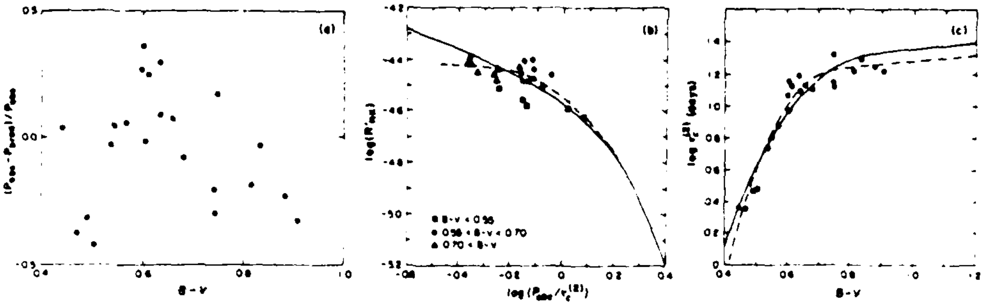

Figure 1.
(a) Fractional residuals (observed minus predicted period, scaled by observed period) for 22 Hyades stars
(b) Normalized CaII H-K emission as a f nction of Rossby number. The solid curve is the relation derived by Noyes *et al* (1984). The dashed line bette. represents the Hyades data.
(c) The scaling function $\tau_c^{(2)}(B-V)$, as derived by Noyes *et al.* (1984) (solid line), and as fitted to the Hyades data (dashed line)

rises more steeply, is a polynomial fitted to the Hyades data points. We note that recent theoretical calculations of the convective turnover time (Gilliland 1985, Rucinski and VandenBerg 1986) also predict this steeper rise.

Perhaps, however, a broader re-evaluation of the form of the relationship between chromospheric activity, rotation, and color is warranted. There are now some 95 main-sequence stars, ranging in spectral type from F3 to M4, for which direct measurements of both CaII emission flux and rotation period are available. On the basis of this much larger sample, we find that Noyes' (1983) suggestion that activity is a separable function of rotation and color remains valid, i.e., that

$$log(R'_{HK}) = f(P) + g(B-V).$$

Note since, for main-sequence stars, normalized H-K emission ($log(R'_{HK})$), H-K surface flux density ($log(F'_{HK})$), and H-K luminosity ($log(L'_{HK})$) are all linked by additive functions of color, the existence and form of $f(P)$ are independent of the choice of units for measuring activity. In particular, we find that

$$f(P) = -0.80*log(P).$$

The quantity $log(R'_{HK}) - f(P)$ is plotted in Fig 2a. The rolloff toward the M-type stars ($B-V > 1.2$) may reflect a deficiency in chromospheric emission for these stars, as reported by Schrijver and Rutten (1987). The solid curve,

$$g(B-V) = -10.169 + 15.458(B-V) - 18.946(B-V)^2 - 8.909(B-V)^3 - 0.832(B-V)^5,$$

is a polynomial representation of the data.
The quantity $log(R'_{HK}) - g(B-V)$ is plotted in Fig 2b. The Hyades stars do not appear to deviate noticeably from the overall relations shown in Figs 2a and 2b. In Figs 3a-d, we separate the data of Fig 2b into four groups, corresponding roughly to F-, G-, K-, and M-type stars.

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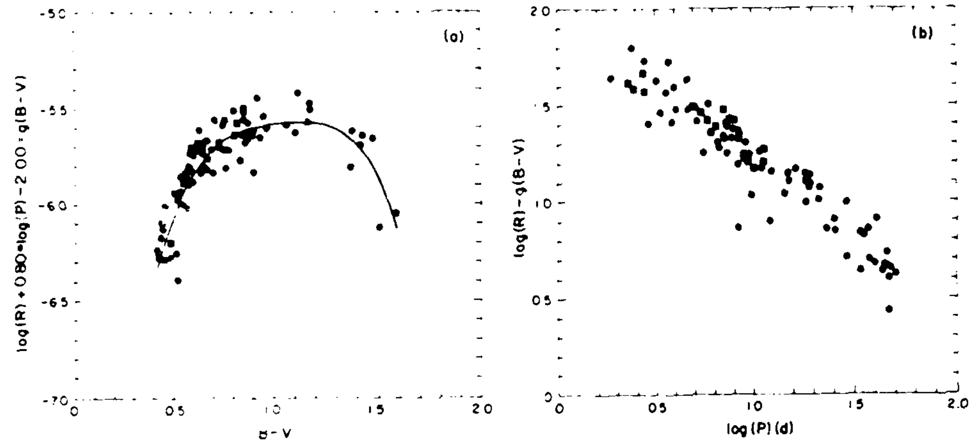

Figure 2

(a) The color-dependent function $g(B-V)$, as determined from field (circles) and Hyades (squares) star data.
(b) The rotation-dependent function $f(P)$, as determined from field (circles) and Hyades (squares) star data.

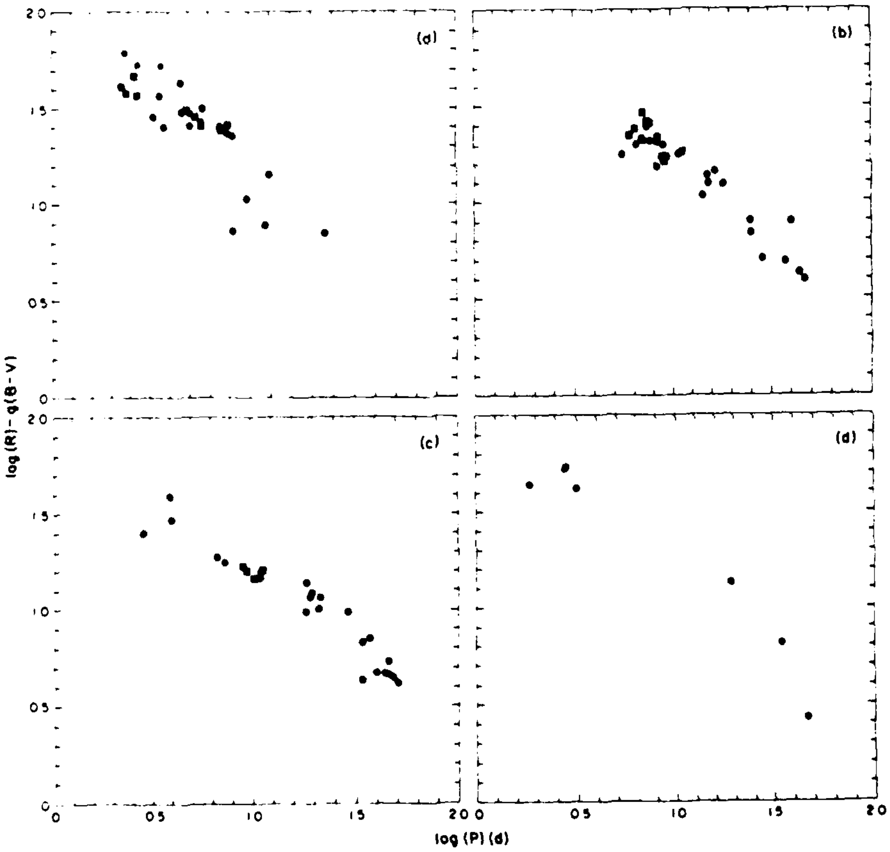

Figure 3

(a) $f(P)$ for $0.40 < B-V < 0.60$ (F-type stars); (b) $f(P)$ for $0.60 < B-V < 0.80$ (G-type stars); (c) $f(P)$ for $0.80 < B-V < 1.20$ (K-type stars), (d) $f(P)$ for $1.20 < B-V < 1.60$ (M-type stars). Field stars are represented by circles, Hyades stars by squares.