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COMPARISON OF ACTIVITY CYCLES IN OLD AND YOUNG MAIN-SEQUENCE STARS

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Evidence cited indicates that solar-like activity cycles (smooth, undulating variations in chromospheric H-K emission flux, with a rapidly varying component that increases in amplitude in the maximum of the cycle) are characteristically found only in old stars, among the 91 main-sequence stars studied by Wilson (1978).

Key words: main-sequence stars—chromospheres—stellar ages

In the preceding paper (Vaughan and Preston 1980, hereafter referred to as Paper I), we presented results of an ongoing survey of chromospheric Ca II H and K line emission fluxes in 486 main-sequence F-G-K-M stars in the solar neighborhood, as defined by the Greenwich *Catalog of stars within twenty-five parsecs of the Sun* (Woolley et al. 1970). The observations, carried out with a four-channel spectrometer in a manner described by Vaughan, Preston, and Wilson (1978), yield the value of a flux index, S, which is essentially the equivalent width of the H2 and K2 emission components plus residual photospheric fluxes in the central 1 Å cores of H1 and K1. In Paper I we noted that in the log S,$(B-V)$ diagram, solar-neighborhood F and G stars are segregated into two distinct branches of respectively high and low H-K flux, separated by a "gap", or marked deficiency of stars at intermediate levels of H-K flux. This effect remains unexplained and subject to further investigation. In view of evidence that chromospheric activity is a declining function of age in main-sequence stars (Wilson 1963; Wilson and Skumanich 1964; Wilson and Woolley 1970; Skumanich 1972), and evidence discussed in Paper I, it is presumed that the more highly chromospherically active stars are young, perhaps comparable in age to the Hyades, while the less active stars have ages in excess of 10^9 y.

Figure 1 is a log S,$(B-V)$ diagram in which the 91 stars followed by Wilson from 1966 to 1977 (Wilson 1978) are plotted as vertical bars indicating the extremes of their H-K flux variations as measured, at approximately monthly intervals, over a span of about 11 years. Inspection of this diagram reveals that here too, the diagram has two branches, a fact noted briefly, but not illustrated, in Paper I.

Of the 91 stars shown here, 52 were not included in the solar-neighborhood sample investigated in Paper I; they comprise an independent sample. The other 39 stars were in both samples. Wilson selected these 91 stars to represent all levels of activity along the lower main sequence, but he did not intend them necessarily to be a statistically accurate sample of the actual stellar population. Were this the only sample available, the gap seen in it might be held suspect as a selection effect, perhaps introduced because the H-K fluxes of these stars were known and used in picking the sample. No such selection effect can be presumed to exist in the case of the Woolley Catalog stars, however. The evidence of the Wilson sample does not suggest that the gap, or bifurcation of the log S,$(B-V)$ diagram, will diminish as more stars are added to the survey, as planned. On the contrary, the gap appears to be seriously in need of an astrophysical explanation.

The bifurcation in the log S,$(B-V)$ domain into two "branches", even though we do not understand why this occurs, is of interest in connection with the search for possible systematic trends among the stellar activity cycles described by Wilson (1978). The purpose of this article is to show that a fundamental difference in behavior can, in fact, be discerned between the two branches (binned according to whether they fall above or below the solid line in Fig. 1).

The principal difference is that among stars of the lower branch, as one proceeds to examine later and later spectral types, the variation encountered always has the form of smooth, undulating cycles similar to the solar cycle; and in these cycles, the rapidly-varying component of the variation is almost always larger in the maximum of the cycle, as it is in the case of the sun. These statements do not describe the behavior one finds in stars of the upper branch; in these, chaotic behavior taking place over a considerable range of time scales seems characteristic, and well-defined sun-like cycles are the rare exception, if they occur at all. The difference just described can be examined by comparing Figures 2 and 3, in which Wilson's time-resolved H-K flux observations for stars in each branch separately are arranged in order of $(B-V)$ color index.

The stars HD 201091 and HD 201092 (61 Cygni A and B), here binned with the upper branch because they lie mostly above the arbitrary dividing line in Figure 1,

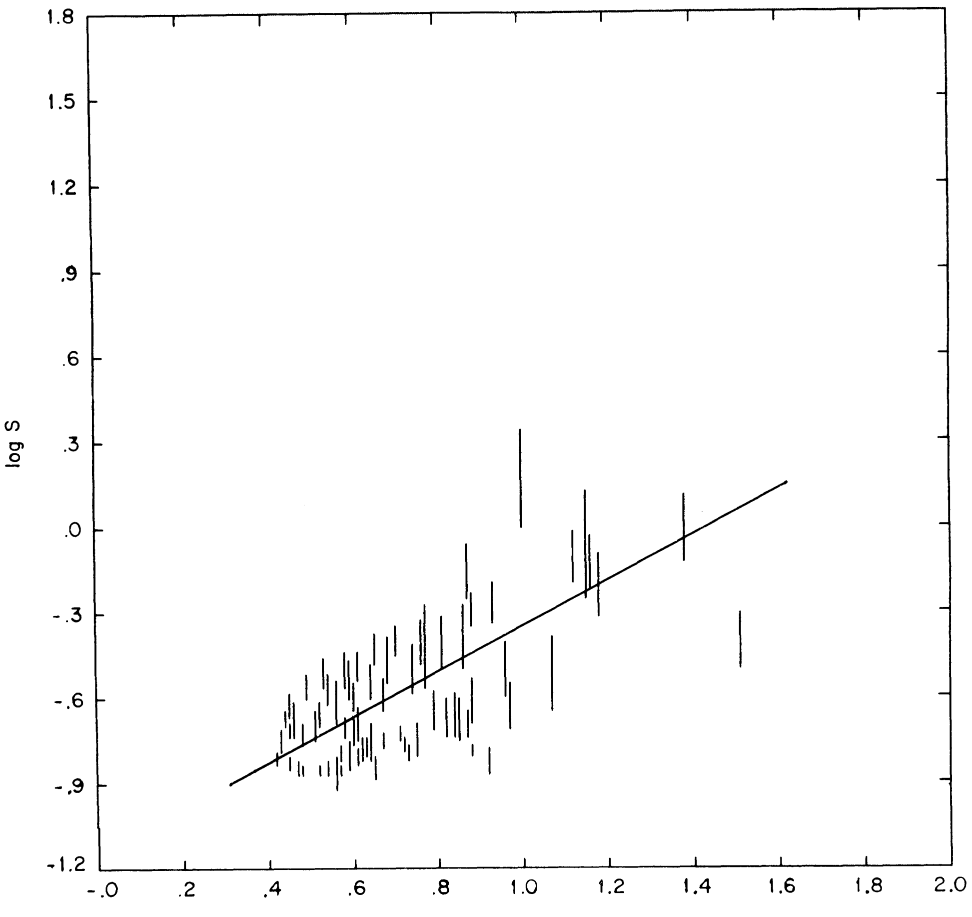

FIG. 1—The log S,$(B-V)$ diagram for 91 stars whose time variations were followed by Wilson (1978). Each star is represented by a vertical bar extending over the maximum range of its variation from 1966 to 1977. A solid line defines the manner in which stars were binned into an upper and lower branch of respectively young and old stars, as discussed in the text.

appear to be exceptions to the rule that sun-like behavior is not found in the upper branch. However, the space velocity of this pair (over 100 km s^{-1}) suggests that 61 Cyg A and B are quite old, hence perhaps properly belonging to the lower branch, in which their observed cyclic behavior is not exceptional. The bifurcation in the log S,$(B-V)$ diagram, in fact, ceases to be particularly apparent among stars cooler than K1 or K2.

The sun's mean H-K flux and its range of variation as inferred from lunar measurements by Wilson (1978) place it among the lower branch of chromospherically less-active stars, at $(B-V) \sim 0.66$. HD 81809 is the only star earlier on the main sequence than the sun known to have a prominent cycle, although in many earlier stars (for example HD 187013 and HD 89744), the short-term "noise" component of H-K flux variation appears to grow larger and smaller in amplitude on a solar-cycle-like time scale. The majority of lower-branch (i.e., old) stars redder than HD 103095 (Groombridge 1830, $(B-V) \sim 0.75$) show prominent solar-like behavior, on a time scale that seems to be independent of spectral type among these stars.

In contrast, the behavior of young- or upper-branch stars is characterized by the occurrence of variability on a 1–2 year time scale (as in HD 76151), abrupt increases in flux followed by slow decline (as in HD 78366), and larger excursions in mean flux which, as in HD 101501, are perhaps more suggestive of a stochastic process than a periodic one. Whether these longer-term variations in young stars are actually perodic or not is a question whose answer will require at least another decade of observation.

In the case of old stars, it can be inferred from the sun that the observed H-K flux and its variation arise mostly from calcium plages associated with magnetically active regions, which grow to cover up to a third of the solar disk at the maximum of the cycle. The relative importance of other contributors to the observed emission may be different in the case of young stars, or the excitation mechanism may be of a different kind than the sun's, but observational evidence does not suffice as yet to decide the reason for the absence of solar-like cycles in these

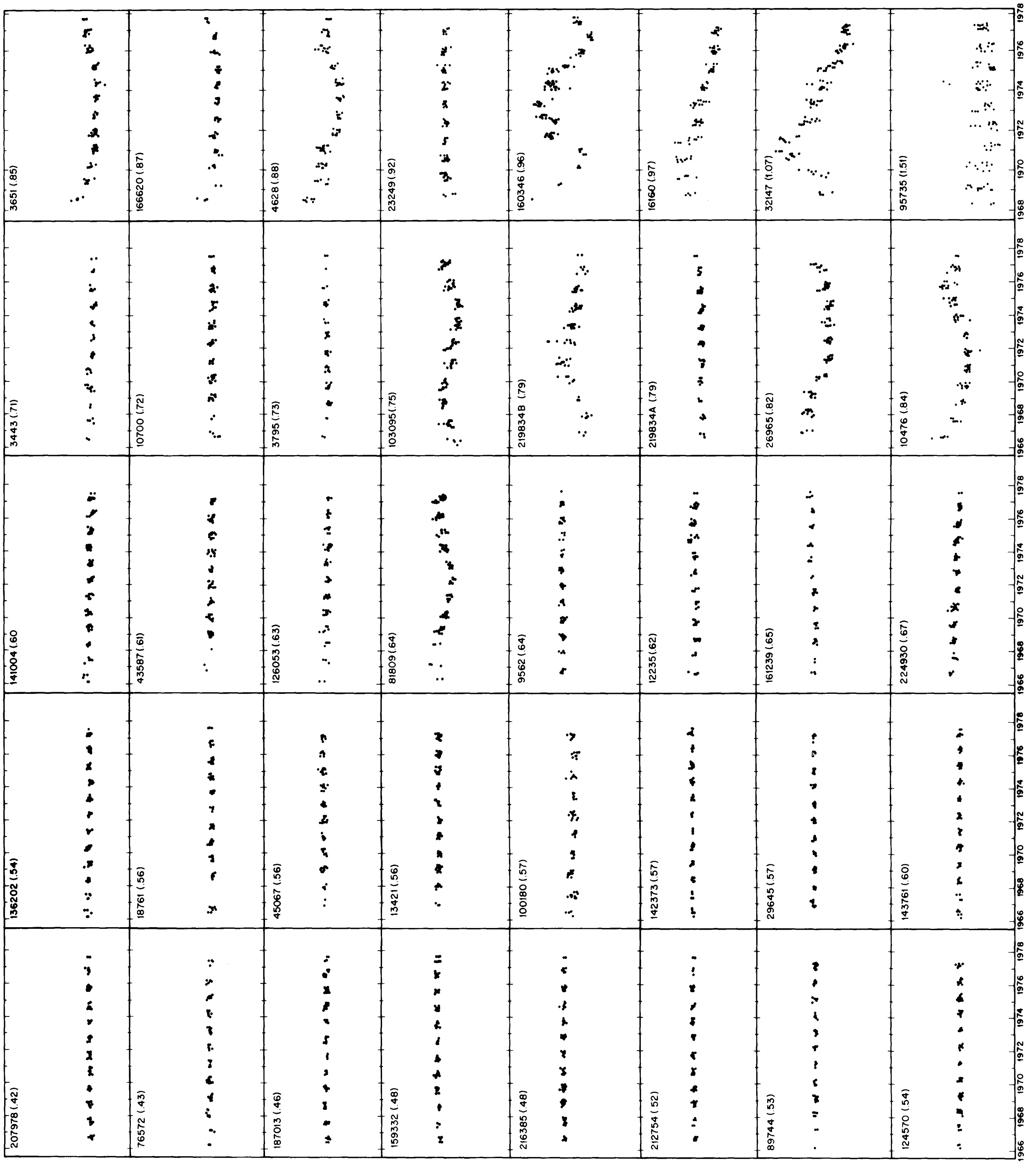

FIG. 2—Wilson's observations of H-K flux variations in old stars, identified as defined in Figure 1, and arranged in order of increasing $(B-V)$ color index.

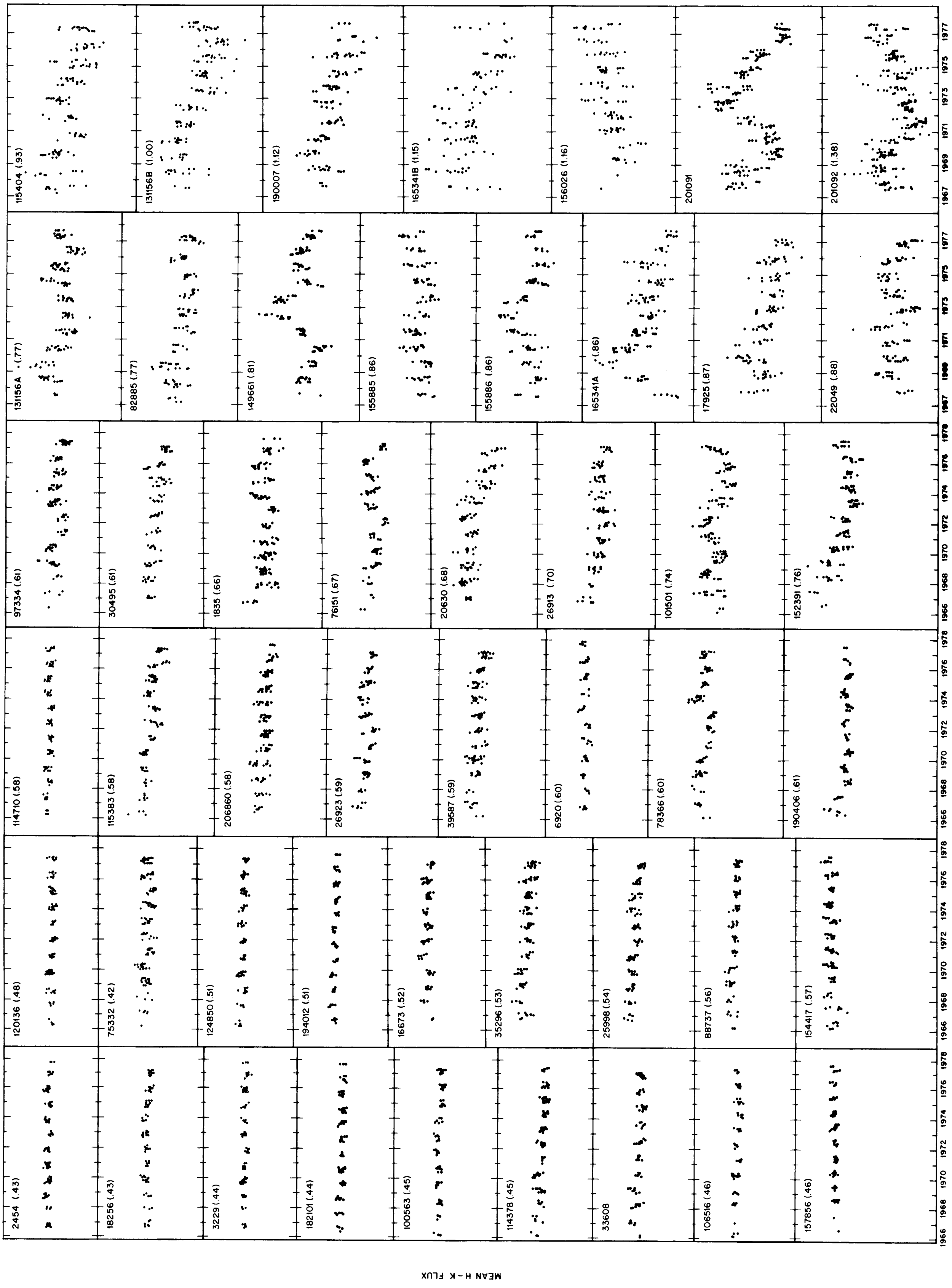

FIG. 3—Same as Figure 1 but illustrating Wilson's observations of young stars, identified as those on the upper branch of Figure 1.

young stars.

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