THE MOUNT WILSON PROGRAM FOR STELLAR ACTIVITY CYCLES

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ABSTRACT

The present review will focus upon the incidence, form, and characteristic timescale of long-term chromospheric variations that, from the work of O.C. Wilson and his successors, can be descerned in records of CaII H and K emission now extending over 16 years, and the relation, if any, between properties of activity cycles and stellar mass, age, and rate of rotation, in the light of current evidence.

INTRODUCTION

In 1966, O.C. Wilson began what became the first successful attempt to uncover and study, in other main sequence stars, chromospheric variations analogous to those observed in the course of the solar cycle.

This work has been continued and considerably expanded in scope by Wilson's successors since the completion of the first phase by Wilson himself (Wilson 1978). In fact, July 1982 marks the beginning of the third year in which the Mount Wilson 1.5m telescope has been dedicated almost exclusively and continuously to various aspects of this work, a level of effort which has been sustained in the form of a team project involving individuals associated with Mount Wilson, Sacramento Peak Observatory, The Harvard-Smithsonian Center for Astrophysics, and the Astronomical Institute at Utrecht.

The effort has paid off. Even in the past year, there have emerged a number of extremely interesting results (and perhaps an equal number of new questions) bearing upon the rotation rates of stars on the lower main sequence, and the rotation - activity connection. The results also bear to some extent upon the detailed surface properties of stars exhibiting chromospheric activity.

J. O. Stenflo (ed.), Solar and Magnetic Fields: Origins and Coronal Effects, 113–132.

At the risk of proceeding not entirely in a logical order (since the critical discussion of many of the things I just mentioned will follow in the review by Bob Noyes), I would like in the present discussion to focus upon the observed properties of activity cycles as they are found in stars, in the light of what has been accomplished in this field since the publication of Wilson's monumental original work.

OBSERVATIONAL APPROACH

The method of observation introduced by Wilson is based upon the fact that the chromospheric CaII H and K line emission flux varies in synchronism with other indices of the state of magnetic activity in the Sun.

The photoelectric spectrometer (Vaughan, Wilson and Preston 1978) currently in use to measure the calcium flux index in stars is different in detail but identical in principle to that used by Wilson. It has thus been possible to preserve continuity of measurement for over 15 years.

The CaII H and K line-core index is defined by the expression

$$S = k\ (N_H + N_K)\ /\ (N_V + N_R),$$

where _k_ is a normalizing factor derived from observations of standard stars to remove instrumental effects, and N_H, N_K, N_V, and N_R refer to the number of photon counts in two band 1Å wide centered at H and K and in two photospheric reference bands 20Å wide centered at 4001Å and 3901Å to the red and violet sides of the H-K region. In the present instrument the fluxes in these four bands are measured sequentially at a switching frequency of about 30 Hz with a single detector. The errors of measurement of S are close to those introduced by photon noise. The error is usually held to about 2 percent in the observations of Wilson's stars. To allow for wavelength shifts corresponding to a star's geocentric velocity a precomputed offset is introduced at the time of observation, centering the passbands on the H-K lines to within about 0.05Å. All of the investigations being pursued in the Mount Wilson stellar activity program are made in exactly this way.

THE STARS UNDER INVESTIGATION

Since we will be discussing Wilson's collection of stars in which chromospheric variations have been followed up to this point, it is appropriate to recall how these stars were selected.

In the first 1.5 years of Wilson's study, observation was concentrated on a rather large number of stars from the (never published) Strömgren-Perry catalog for which 10 Å/mm spectrograms had earlier been obtained. The results of this study were reported by Wilson (1968). Beginning in the fall of 1967 many of the S-P stars were deleted from the program; retained were those in which H-K emission has been seen in the spectrograms, as well as some in which emission might be weakly present and others with minimal H-K emission to serve as standards. Also in 1967 a number of late type (G2 - M0) main sequence stars were added. The ultimate collection thus consisted of about 90 stars ranging from early F to M0, selected on the basis of CaII emission to the representative (characteristically but not statistically) of the observed range in H-K flux along the lower main sequence.

One of the global attributes of this sample is that it shares the property found by Vaughan and Preston (1980) in a survey of a much larger and presumably unbiased sample of nearby stars, that F and G dwarfs in the Solar neighborhood are either roughly as active as the Sun, or about twice as active, as measured by the calcium emission index. As yet there is not satisfactory explanation for this dichotomy, which is illustrated in Figure 1.

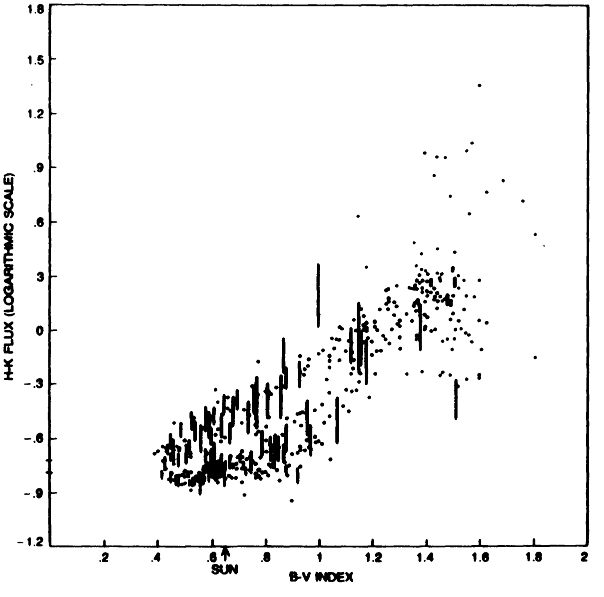

Fig.1: The log S,B-V diagram for stars in the solar neighborhood survey of Vaughan and Preston (1981) [points], and stars in the Wilson study of long-term chromospheric variations [bars indicate the range of their variations]. The plot reveals an apparent dichotomy in which H-K emission is either comparable to the Sun's, or about twice as great, in late F and G stars.

https://doi.org/10.1017/S0074180900029788 Published online by Cambridge University Press

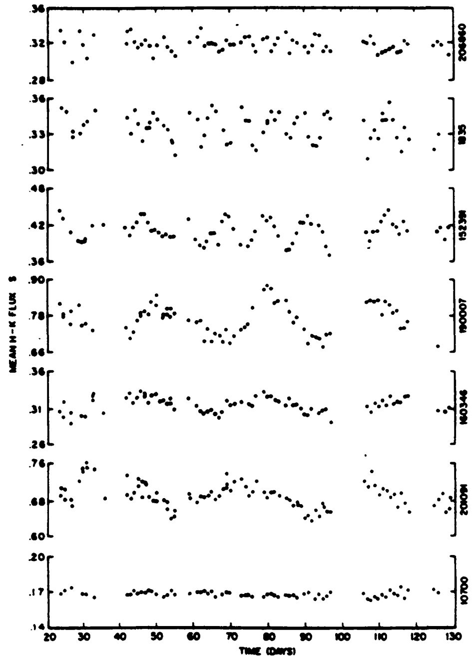

Fig. 2: Mean H-K fluxes vs. time for selected main sequence stars, illustrating the rotational modulation effect. From Vaughan, Baliunas, Middelkoop, Hartmann. Mihalas, Noyes and Preston (1981).

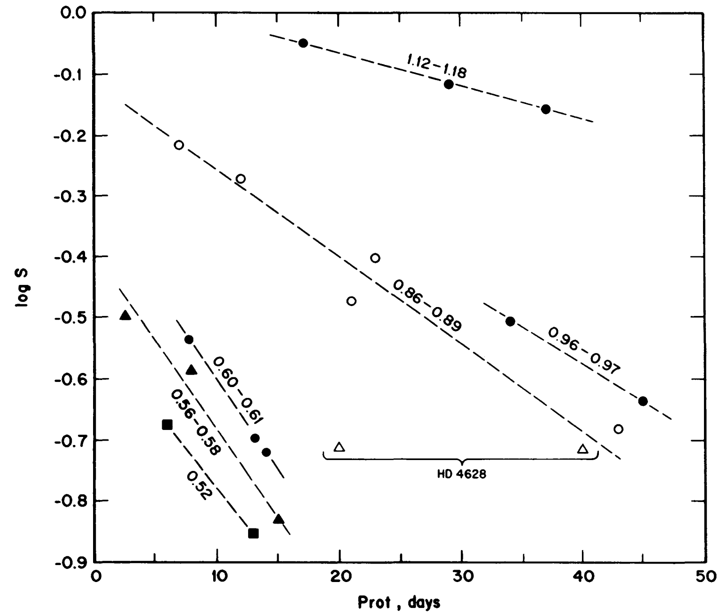

Fig. 3: Log S vs. period of rotation for stars in selected narrow intervals of B-V. For a given color, the points lie along well-defined sequences indicative of the rotation-activity relation. Recent observations have shown that HD 4628 rotates with a period of 36 days. From Vaughan, Baliunas, *et. al.*, 1981.

Furthermore, as was also noticed in 1979 (Vaughan 1980), cyclic variations closely resembling the solar cycle seem to be encountered most commonly (if not exclusively) among the less active stars.

CALCIUM EMISSION AS A TRACER AND PREDICTOR OF ROTATION

Perhaps the most recent major advance in the study of chromospheres has come about through the use of chromospheric active regions as rotation tracers, a possibility made evident by Wilson's earliest observations. In fact, Wilson's observations have been shown to contain significant rotational information (Stimets and Giles 1980; Noyes 1981).

The rotational modulation effect, illustrated in Figure 2 (taken from Vaughan, et.al 1981; see also Baliunas, et.al. 1983) actually leads to two methods for inferring the rate of stellar rotation, as will be discussed more fully by Noyes.

In the first method the rotational period is inferred by autocorrelation analysis (in many cases by inspection) of a time series of observations showing the rotational signature. LaBonte (1982) has shown in the case of the Sun that when the fundamental rotational modulation is present in a time series of disk-integrated surface magnetic flux measurements (an index proportional to Wilson's CAII index), the rotation period inferred corresponds to the solar rotation at the latitude of maximum magnetic activity.

The second method, calibrated by the first method but otherwise entirely independent of it, makes use of the relation illustrated in Figure 3 (from Vaughan, et.al. 1981), between the mean level of calcium emission and the rotation rate.

In HD 4628, one of the stars identified in Figure 3, autocorrelation analysis at first indicated a rotation period of about 20 days. However, the apparent flux-rotation relation would have been better satisfed if the period of rotation of this star were 40 days, and we suggested that the period found by autocorrelation analysis might be a harmonic of the true period of rotation. This has now been found to have been a correct prediction, on the basis of more recent observation (see Baliunas, et.al. 1983) in which a clear modulation emerged with, in fact, a period close to 36 days.

CURRENT OBSERVATIONAL RESULTS

Having indicated the direction in which the discussion will go, I would like now to focus attention upon the present state of affairs in the observational study of activity cycles, in the light of what has been learned up to this point.

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We can proceed by first examining a few up-to-date examples of the chromospheric variations thus far observed in main sequence stars. I have selected 9 examples (Fig. 4a-i) illustrating the variety of forms encountered; they are not meant to be statistically representative of the reppertoire found in nature.

HD 81809 exhibts a cyclic variation that would be hard to distinguish from the solar cycle in form, amplitude, noisiness, and the relative timescales of rise and decay of activity in the course of the cycle. Such a pronounced cycle is rarely seen except in main sequence stars that are of considerably later spectral type (cooler) than the Sun.

HD 160346 and HD 201091 (61 Cyg A) are examples of later-type stars that exhibit highly pronounced cycles. Parts of three successive cycles have been recorded for these stars. Note that certain differences can be seen between one maximum and the next, reminiscent of the irregularity of the solar cycle.

In the stars just discussed, there is high confidence in the reality of the observed cycles, and in the periods (or characteristic timescales) that might be assigned to them.

HD 120136 is a case in which I would say there is only fair confidence that a cycle is present, having a timescale of about 10 years, as judged in part from the variation on the amplitude of the seasonal scatter which in previous examples (and in the Sun) is largest at the peak of the cycle.

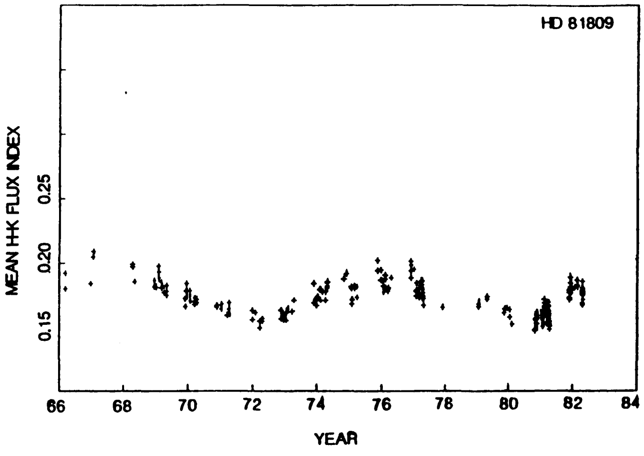

Fig. 4(a): H-K Flux records from Mt. Wilson project, 1966 to 1982.

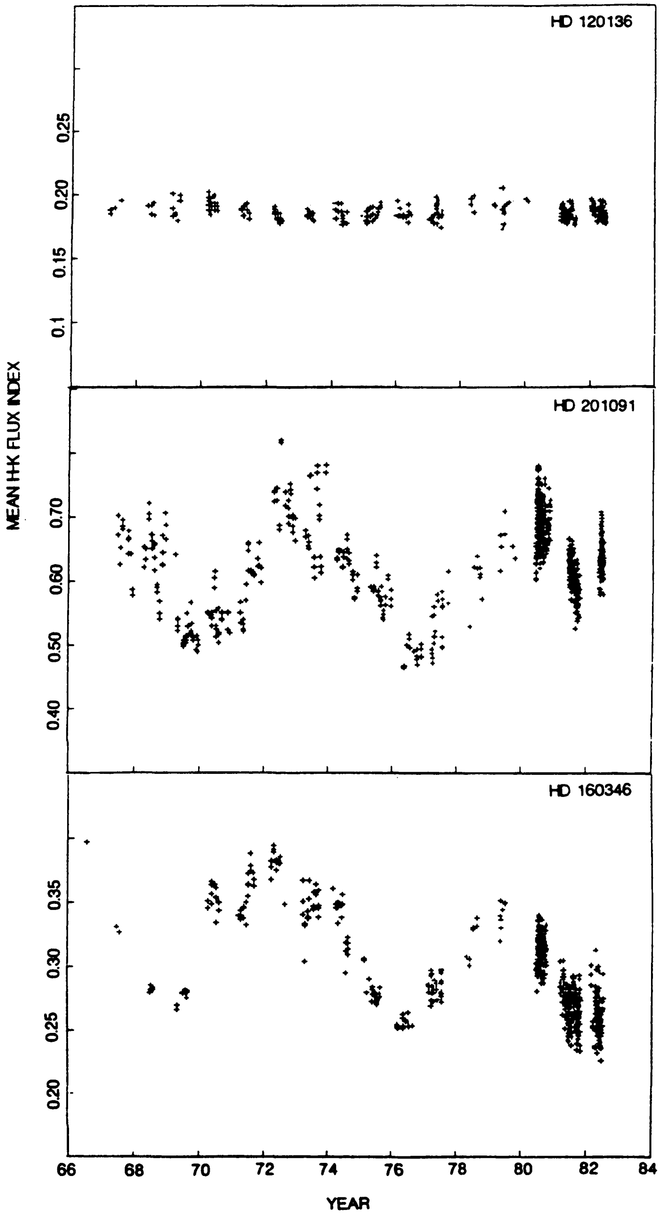

Fig. 4(b)-(d), continued.

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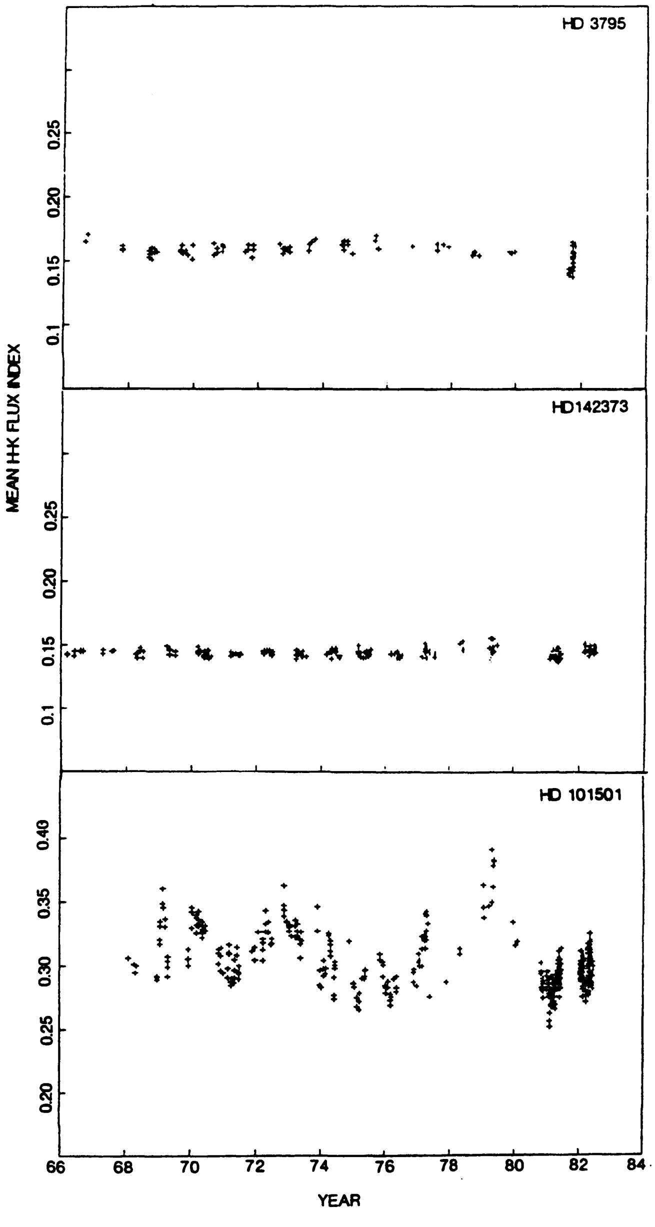

Fig. 4(e)-(g), continued.

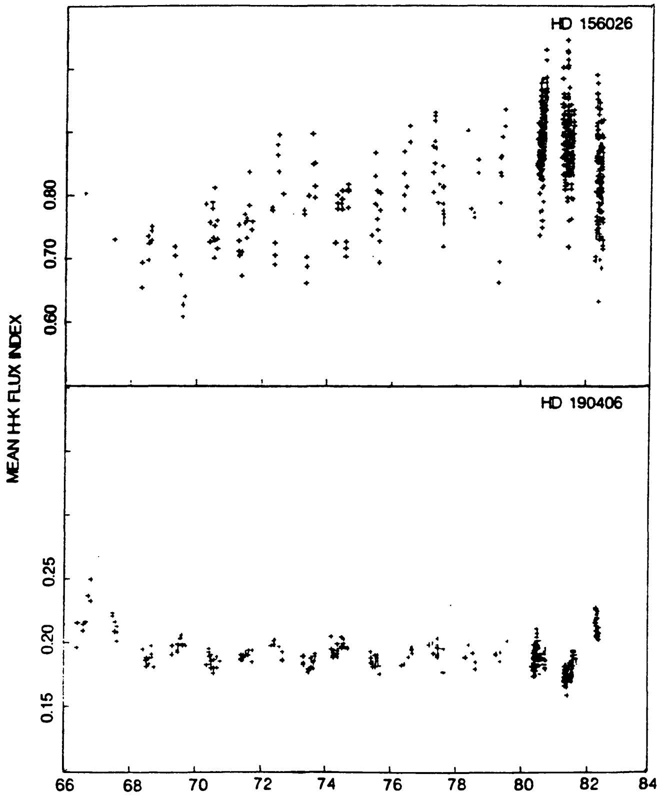

Fig. 4(h)-(i), continued.

HD 3795, with only 4.5% standard deviation in H-K index, is a case in which confidence in the existence of a cycle is low, but not zero. In comparison with HD 142373, the quietest standard with s.d. =2%, HD 3795 seems to be not quite flat; it could be varying on a timescale of about 12 years, or longer. It is likely that all stars, even the standards, show some real change.

There are variations in some stars that suggest limited resemblance, if any, to the solar cycle. HD 10151 is one of several stars in which large changes occur in the course of time, but the variation appears to be entirely chaotic. The solar cycle as we know it is irregular, but not random.

HD 156026 has increased steadily in mean flux during the entire interval of observation and its nearly uniform seasonal scatter is the largest of any star in Wilson's collection. The gradual rise in mean flux could be part of a cycle whose timescale exceeds 16 years. It may be that HD 190406 is a case of a very short cycle of perhaps 2.6 years. In what follows I have not taken it to be such. At a later time perhaps this will have to be reconsidered.

WHICH STARS ARE CYCLIC?

From examination of the entire collection of observations I have listed in Table 1 those stars for which I think a characteristic timetable of solar-cycle-like chromospheric variation might plausibly be assigned for comparison with other stellar parameters. In most respects, this list is in accord with lists independently drawn up by Wilson and by Noyes from the same set of material, although there are some differences arising out of the subjectiveness of the criteria one uses to decide whether to include weakly or perhaps irregularly varying stars.

In the resulting collection of 27 cyclic or possibly cyclic stars, there is high confidence ("H") in the reality of the cycle in 15 of them, fair confidence ("F") in eight, and low confidence ("L") in five.

TABLE 1

27 STARS THAT SEEM TO HAVE ACTIVITY CYCLES SIMILAR TO THE SOLAR CYCLE*

HD	B-V	S_{min}	S_{max}	P_{rot} (d)	P'_{rot} (d)	T_{cyc} (y)	H	F	L	COMMENTS
SUN	.66	.165	.21	25.5	25.4	8-12	✓			
3651	.85	.16	.24	-	39.9	10	✓			
3795	.73	.14	.17	-	29.8	≥12		✓		Weak
4628	.88	.18	.30	38	36.0	8-9	✓			
10476	.84	.16	.26	-	34.6	10	✓			
12235	.62	.15	.18	-	21.4	10		✓		
16160	.97	.20	.28	45	44.8	11-12	✓			
26965	.82	.18	.25	30:	33.4	10	✓			61 Cyg B Type
32147	1.07	.24	.39	-	48.1	9-10	✓			
81809	.64	.15	.21	-	22.3	9	✓			
100180	.57	.15	.18	-	18.3	>12		✓		
103095	.75	.16	.21	-	30.6	6-7	✓			
160346	.96	.24	.39	33.5	36.4	7-8	✓			
161239	.65	.13	.16	-	29.0	>12	✓			Weak
166620	.87	.18	.25	42	38.1	14?	✓			
182572	.78	.14	.18	-	36.3	≥12		✓		
201091	1.19	.46	.80	38	41.0	7	✓			
201092	1.38	.70	1.30	48	48.0	11-12	✓			t(rise)> t(decay)
219834	.79	.14	.18	30:	28.7	10		✓		Weak
120136	.48	.175	.21	-	8.3	10		✓		Weak
115404	.93	.45	.63	17-20	17.7	≥12			✓	61 Cyg B Type?
131156	.76	.38	.55	6.5	7.2	13?			✓	61 Cyg B Type?
149661	.81	.30	.49	21.3	17.6	>11?			✓	
155886	.86	.30	.51	20.3		>13?		✓		
152391	.76	.33	.48	11.1	10.3	≥12	✓			
165341	.88	.28	.55	20	19.7	≥12		✓		t(rise)<< t(decay)
190007	1.12	.58	.98	29	28.0	11?			✓	

* Compiled July 1982

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For the stars in Table 1, the distribution of H-K flux as a function of B-V is plotted in Figure 5, in which the amplitude of flux variation of each star is shown by a vertical bar. The bar is solid for "H-rated" stars, and dashed otherwise. All but one of the stars rated "H" lie in the lower portion of the diagram which includes the Sun. Conversely all but one of the stars rated "L" lie in the upper branch of the same diagram in which the level of activity tends to be twice the Sun's. This is the dichotomy mentioned earlier. It is convenient to preserve the distinction in listing separately, in the upper and lower sections of the Table, the stars belonging to the two categories.

As can be seen in Table 1, cycle timescales estimated for stars in the upper branch are for the most part lower limits of around 12 years, possibly of significance, but uncertain at best.

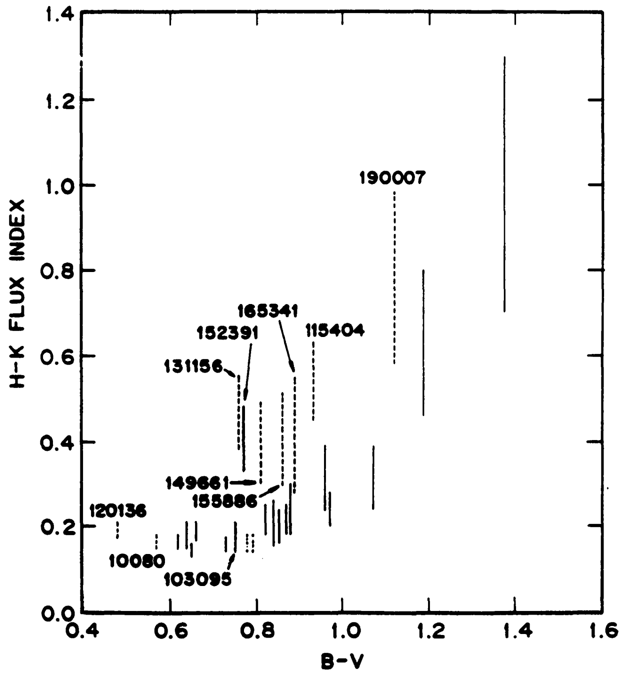

Fig. 5: The S, B-V diagram for stars listed in Table 1. Solid bars indicate the range of variation in stars considered with high confidence to have a cycle. Dashed bars indicate the range of variation in stars whose variations might, with fair or low confidence, be considered as cyclic. Compare Fig. 1.

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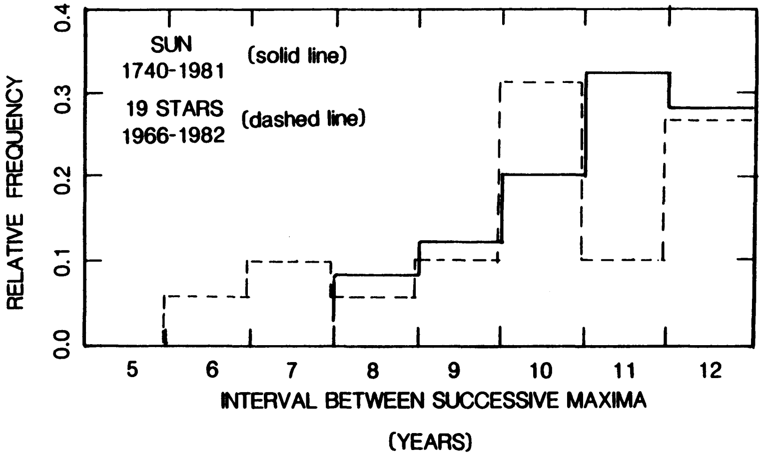

Fig. 6: Histogram of the intervals in years between successive sunspot maxima after 1740 [solid line, after Waldmeier], compared with histogram of the same parameter for 19 stars in which analogous variations are seen.

For stars in the lower branch, the estimated cycle timescales have a mean value of 10 y ± 1.9 y (s.d.). As shown in Figure 6, the cycle periods of these solar-branch stars exhibit a frequency distribution somewhat resembling the distribution of the intervals of time between successive solar mixima as given, from records long maintained at the Swiss Federal Observatory here in Zurich, by Waldmeier(1961; 1976). Stellar activity cycles are found, however, that are definitely shorter in duration than any so far seen in the Sun. It is of interst, therefore, to explore the question of whether individual deviations from the mean cycle period are in any way correlated with other parameters that might be considered, such as stellar mass or rate of rotation, or both.

As can be seen in Figure 7, if there is any correlation between cycle timescale and stellar color index (mass), it is not particularly striking.

THE ROTATION PERIODS OF CYCLIC AND POSSIBLY CYCLIC STARS

As mentioned earlier, there are two methods whereby the rotation period of a star can be inferred from observations of its calcium emission index. Thus, by means of autocorrelation analysis, values of P_{rot} have been determined for 16 of the stars listed in Table 1. In 10 others, rotation periods could not be inferred by this method, presumably because sufficient modulation is not present in the data so far collected.

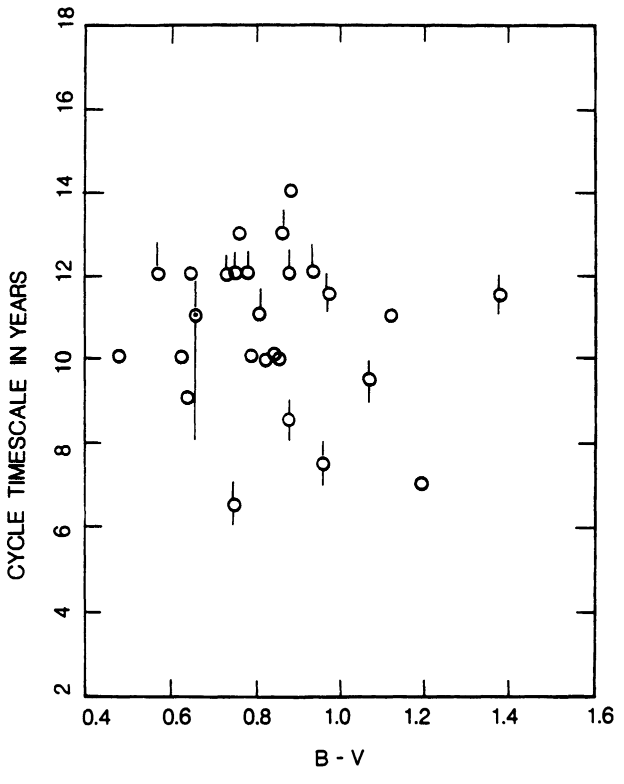

Fig. 7: The cycle timescale in years vs. B-V for the 27 stars in Table 1. The solar cycle timescale (sun symbol) varies from about 8-12 years. Some stars are found to have a shorter timescale, but there is no clear correlation of this parameter with B-V.

By appealing to the rotation-activity relation, however, it is possible to supply predicted values of the missing rotational periods for those cases in which these are not yet known by a more direct method. .

Vaughan, et.al. (1981) gave a tentative calibration of the activity-rotation relation, of the form

$$S = 0.78 \exp(-P_{rot}/30), \quad 0.86 \leq B-V \leq 0.89$$

but this applies only to a narrow interval of color index. To gain wider applicability it is necessary to calibrate also the color dependence of the relation. Recently Noyes and I, working partly together and partly independently, have followed two different approaches in attempting to arrive at such a more general calibration. One approach, which I pursued, but will mention only briefly, was simply to fit to the observations an empirical expression of the form

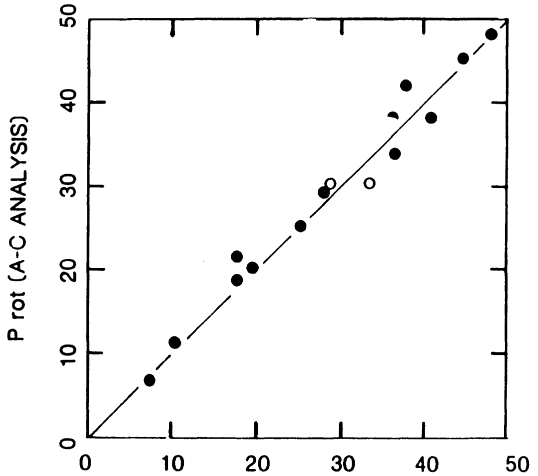

Fig. 8: Periods of stellar rotation inferred from autocorrelation analysis of H-K flux variations compared with periods of rotation as predicted from the activity-rotation relation.

$$\log S = \underline{a} + \underline{b}\, P_{rot}$$

in which a and b are assumed to be linear functions of B-V.

The result, solved for P_{rot}, is the expression

$$P_{rot} = \frac{\log S + 0.63 - 0.59 \quad (B\text{-}V)}{0.0.48 \quad (B\text{-}V) \quad - 0.056}$$

This expression actually reproduces the observed value of P_{rot} fairly well, but only in the range $0.54 \lesssim B\text{-}V \lesssim 0.89$

The second and much better approach followed recently by Noyes is based upon the use of Middelkoop's (1982) calibration of S in absolute flux units. Leaving further discussion of the approach to Noyes, therefore, I have adopted, in Column (6) of the Table, his predicted rotation periods, given to me, in fact, over the telephone. I believe Noyes regards these as preliminary, but most likely not far from the final values based on present data.

The likely validity of this procedure is evident when one compares those cases in which P_{rot} has both been inferred from A-C analysis and predicted from the rotation-activity relation. As shown in Figure 8, the resulting periods are in remarkably good agreement over the full range in period of rotation and spectral type exhibited by the stars under discussion.

COMPARISON OF CYCLE TIMESCALE, ROTATION RATE, AND COLOR

For the first time, it becomes possible to examine, more or less directly from observation, the possible connection between cyclic behaviour and the rate of stellar rotation. This we shall do by means of a series of four diagrams. The discussion should be considered preliminary, as mentioned earlier, being the result of work still in progress.

To proceed, it is expedient first to examine the variation of P_{rot} with B-V, as is done in Figure 9. Filled symbols identify stars whose periods of rotation were found by A-C analysis; open symbols identify stars whose rate of rotation was predicted by the use of the Noyes-Middelkoop calibration. Also circles identify stars whose periods of rotation were found by A-C analysis; open symbols identify stars whose rate of rotation was predicted by the use of the Noyes-Middelkoop calibration. Also circles identify stars that lie in the lower (solar) branch of the flux-color-diagram, and triangles identify stars in the upper (Hyades-like) branch. The dichotomy in H-K emission is not apparent in stars as red as 61 Cyg A and B.

As can be seen in Figure 9, there appears to be two entirely distinct sequences, one containing all but one of the circles, the other all of the triangles and in addition 61 Cyg A and B. Evidently

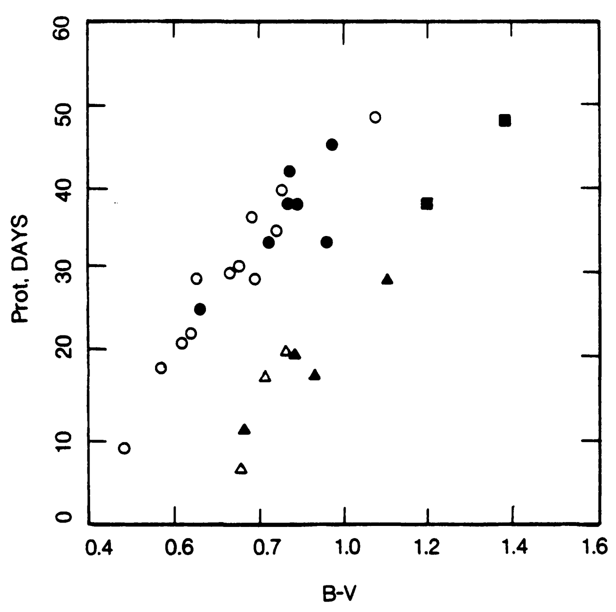

Fig. 9: Period of rotation vs B-V for the stars listed in Table 1. Filled symbols denote stars whose P_{rot} is known from A-C analysis. Circles represent stars belonging to the solar sequence in Fig. 1.

this diagram reflects the dichotomy encountered previously. However, here it appears also in the distribution of rates of rotation in the limited sample of stars collected for the study of cyclic behavior. This seems to me to be a surprising result that should be investigated on the basis of an unbiased and larger sample.

One way to look for a relation between cycle period, rotation rate, and color is to plot the ratio of two of the variables against the third. In this case the dimensionless ratio T_{cyc}/P_{rot} (the number of rotations per cycle) would seem plausibly to be a physically significant choice. A plot of this parameter against B-V is shown in Figure 10. Circles and triangles have the same meaning as earlier. As a result of the small dispersion in the cycle timescales and the tight correlation (existing in the present possibly biased sample) between rotation rate and B-V, the points (especially the circles) lie along sequences in this diagram. The variation in the parameter T_{cyc}/P_{rot} over a factor of about five is contributed primarily (indeed, as will be seen, entirely) by the color-dependence of the period of rotation. Is there, then, any causal relationship between T_{cyc} and the color (or mass) of a star exhibiting a cycle ?

To find out, we may plot, as a function of color, the difference between T_{cyc}/P_{rot} (using observed values of the cycle timescale) and (using the mean value T_{cyc} = 10 y) the ratio T_{cyc}/P_{rot}, and examine

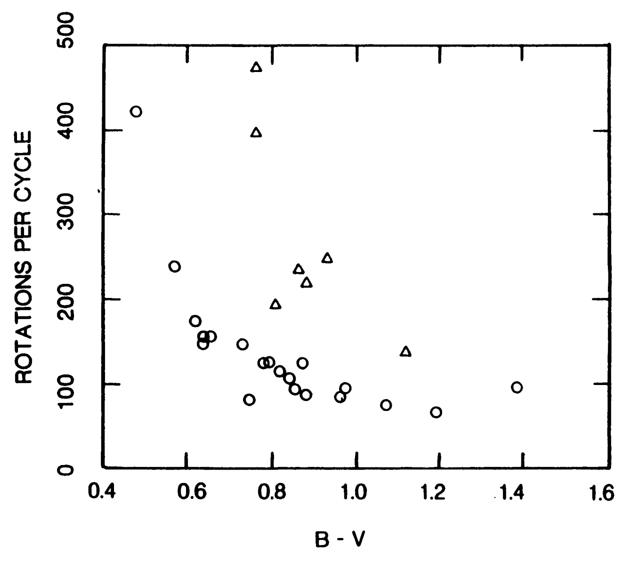

Fig. 10: The ratio of cycle timescale to rotation period (rotations per cycle) vs. B-V for stars in Table 1. Circles depict stars in the solar sequence of H-K flux vs. B-V. Triangles depict stars in the active (Hyades-like) sequence.

the resulting diagram for systematic trends. Such a diagram is given in Figure 11. It seems that no systematic variation of the deviation from the mean cycle timescale as a function of B-V is evident.

Finally, in Figure 12, a similar procedure serves to test whether there is systematic variation of the deviation of T_{cyc} from the mean as a function of rate of rotation. The plot is again restricted to solar-branch stars. Except for the fact already noted by Vaughan et.al (1981) that cycles seem to occur only when P_{rot} exceeds about 20 days (or equivalently B-V exceeds about 0.6 as seen in Figure 9.) there is no evidence that deviations of individual cycle timescales from the mean value depends systematically upon the rate of stellar rotation.

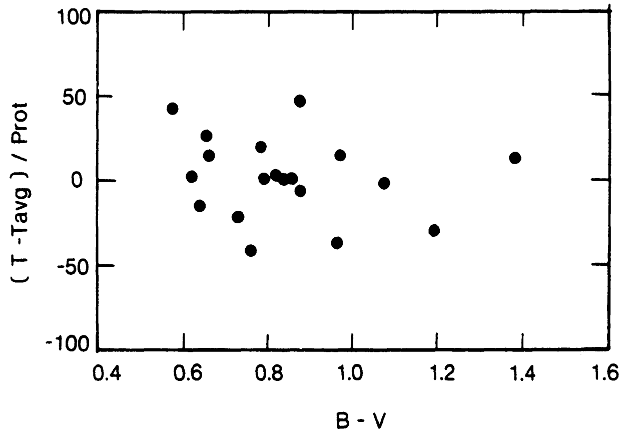

Fig. 11: Deviation from the mean cycle timescale (T_{avg} = 10 y) divided by P_{rot}, plotted as a function of B-V.

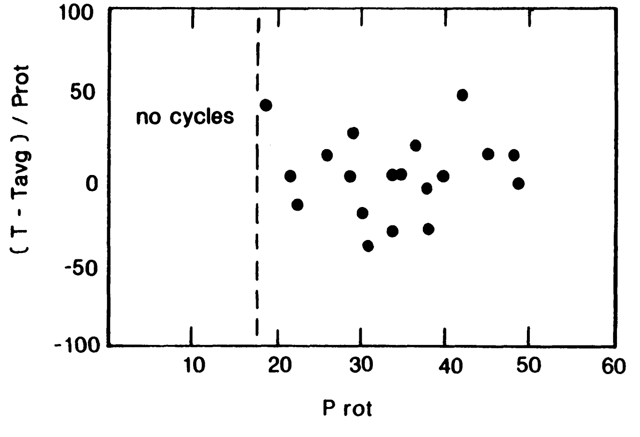

Fig. 12: Deviation of the mean cycle timescale (T_{avg} = 10 y) divided by P_{rot}, plotted as a function of P_{rot}.

CONCLUDING REMARKS

As mentioned earlier, these are preliminary results, but they confirm what previously has been suspected from comparison of the distribution of activity cycle periods in stars with irregularities in the solar cycle timescale.

Whether or not a solar-type cycle exists seems to depend upon the period of rotation, but if such a cycle exists, its period does not seem to depend upon the parameters we are currently considering.

Can it be that the stellar-mass dependence of T_{cyc}/P_{rot} (the "windup ratio" of an activity cycle), so beautifully illustrated on Figure 10, is entirely coincidental and of no causal significance? The observations do not by any means serve to disprove that the cycle is casually related to stellar mass or rotation; neither, it seems, do they suggest any direct or simple causal connection of these parameters with the details of the process once the cycle becomes established.

In any case, it would appear that if a theoretical model is constructed in which T_{cyc} is affected by the value of the rotation rate as a parameter, this effect must be compensated as a function of some other parameter related to stellar mass.

It seems likely that significant further progress might come about if it should become possible in some way to measure the magnitude of differential rotation in a star, upon which any dynamo process depends perhaps more directly than upon rotation itself. The observational difficulties involved seem very substantial at this point, but it must be remembered that the whole effort has only just begun.

In the meantime, important questions remain to be explored such as the question of the significance of the dichotomy in F-G dwarfs and the related question of the age dependence of calcium emission and rotation both in dwarfs and (as investigators from the Utrecht group have begun to explore) in evolved stars. Thus, it is worth mentioning that in preparation for studies that will take place beginning this Fall, the H-K spectrometer is about to be modified with installation of a new chopper wheel to allow measurement of H&K simultaneously, thus gaining factor of two improvements in throughput for observations of faint Hyades and Pleiades cluster stars. At the same time a new exit mask will provide both 1 Å and 2 Å bandwidths at H and K, the latter being designed for the study of chromospheric emission in giants.

ACKNOWLEDGEMENTS

The Mount Wilson program is supported in part by a grant from the National Science Foundation to the Carnegie Institution of Washington, with additional support coming from NASA (1975) and currently from the Smithsonian Astrophysical Observatory. My participation in this Symposium was sponsored by Perkin-Elmer. Most of the observations in the course of the past year were made by Dr. Douglas K. Duncan (Research Associate, MWO), James Frazer, Howard H. Lanning, and Laura A Woodard (MWO), Tony Misch (SAO-MWO), and Dr. Sallie L. Baliunas (CFA). I am continually grateful to these individuals and the many others whose enthusiastic cooperation has made a large undertaking possible and fruitful.

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DISCUSSION

SODERBLOM: Of the stars you have shown us, I would pick HD 142373 as the one star most like the sun in terms of mass, age, rotational velocity, etc., yet this star shows no apparent variations. How would the sun appear if observed in the same way as your stars? Would its 11-yr cycle be obvious?

VAUGHAN: Of all 91 stars in Wilson's collection, I think that HD 81809 most resembles the sun in its variation of H-K emission and mean H-K flux. Yes, the sun's cycle would be obvious.

SODERBLOM: Do you feel that the lack of apparent cyclic variations in stars above the "gap" is due to the greater noise in the observations? In other words, if you observe these stars long enough, might you see the cycles?

VAUGHAN: I mentioned in a *Publ.Astron.Soc.Pacific* article (1980) that another decade of observations will be required to decide whether these stars are periodic (or have an underlying periodic component). That may be an optimistic statement.

SEVERNY: The presented paper represents an example of a unique, long-term investigation, and we should congratulate the Mt. Wilson observers for such a large amount of efficient work.

I think it would be interesting to complement this investigation with simultaneous estimates of the brightness of the stars, which might be obtained from other sources, e.g. from surveys. Do you have some simultaneous data on the fluctuations of brightness (m_{ph} or m_V)? Have you been monitoring the brightness?

VAUGHAN: Thank you. Our instrument (the H-K photometer) is not equipped for magnitude measurements. In the case of λ And, Baliunas has shown that H-K flux is anti-correlated with photospheric brightness, using data from the Mt. Wilson survey and from Ed Guinan.

WALTER: You mentioned an anti-correlation between stellar brightness and Ca II index in λ And. Is the chromosphere getting brighter, or is it constant while the photosphere is getting fainter?

VAUGHAN: Ed Guinan's photometry showed 20–30% change in the V and U bands, while the H-K emission varied in the opposite direction by a much larger factor. This must mean that the chromosphere actually brightened.

GOLUB: Both in the solar case and for the stars in your survey there is interest in learning about the polar fields. I would like to know whether there are any stars for which you have Ca data, and which you think are being observed pole on.

VAUGHAN: One suspect is HD 10700, which is remarkably constant in H-K emission, but whose emission level ($S \approx 0.17$) is well above that of Wilson's standards. More generally, I suppose stars for which we fail to see rotational modulation might be candidates, especially if the activity level is not minimal, and lack of modulation has characterized the star for a long period of time. As observations continue, cases may turn up in which one can believe computed values of sin i from spectroscopic and Ca II observations.

FOING: What stellar parameters distinguish the cyclic from the non-cyclic stars?

VAUGHAN: The stars showing cycles lie (with some possible exceptions) in the lower half of the H-K flux vs. $B - V$ diagram, and are slow rotators ($P_{rot} > 20$ days).