STELLAR ACTIVITY AND CALCIUM EMISSION VARIABILITY

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ABSTRACT. Time series analysis of fluctuations of Ca II H and K chromospheric emission has provided us with much information concerning stellar activity. On all timescales, events which parallel solar behavior can be observed: activity cycles, on timescales of years; rotation of stars and evolution of active areas on timescales of days to weeks; flare-like phenomena on timescales as short as minutes.

We expect that the analogues of solar activity exist on other stars. By studying stellar counterparts to solar activity, we can hope to investigate the physical parameters which are thought to influence chromospheric and coronal activity. The stellar surfaces are usually spatially unresolvable; it is thus difficult to measure directly either small-scale surface inhomogeneities or the associated magnetic fields expected from spatially restricted areas.

On the Sun, however, areas with strong surface magnetic fields show intense chromospheric Ca II H and K emission (Babcock and Babcock 1955; Skumanich et al. 1975). Although indirect, the Ca II H and K features are good indicators of stellar magnetic activity. A major advantage of the Ca II features is their accessibility to ground-based observatories. Long-term synoptic programs are in progress to monitor stellar chromospheric activity, and this paper will highlight ongoing work at Mt. Wilson. Monitoring variations of Ca II H and K chromospheric emission over different timescales can reveal different physical phenomena: (1) Long-term (years) variations corresponding to stellar activity cycles; (2) intermediate term (days-months) variations indicating rotation or evolution of stellar active areas; (3) short-term (minutes-hours) variations resulting from impulsive and flare-like phenomena.

LONG-TERM BEHAVIOR

In contrast to small luminosity fluctuations in visible light, the sunspot number cycle is prominently marked in disk-integrated Ca II H and K emission which can vary by as much as 40% from solar maximum to minimum (Sheeley 1967; White and Livingston 1978). In a decade-long survey, Wilson (1978) monitored calcium emission from nearly 100 cool dwarf stars at the Mt. Wilson

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100" telescope. Wilson (1978) showed that many of the dwarfs in the spectrum type range F-G-K-early M undergo long-term variations. A statistical summary of Wilson's findings is: 40% show smooth fluctuations which appear to be cyclic with periods of 5-10 years or slightly longer. 40% show erratic variations which do not appear to be cyclic over the decade observed. The remainder show little, if any, observable fluctuations.

Since 1978 Wilson's work has been extended at Mt. Wilson on the 60" telescope after the construction of a dedicated frequency-chopping spectrophotometer (Vaughan et al. 1979). The continuation of Wilson's work on activity cycles is important for a number of reasons: First, it is necessary to build up the statistics of the phenomena. In many stars we've seen only one "cycle." Other stars have shown only secular changes which imply periods longer than a decade. Second, it is of interest to define the properties of an average cycle. For different epochs, the solar cycles can be dissimilar--for example, in the extreme case, compare the present-day solar cycle to the Maunder minimum (Eddy 1976). Third, it is possible to explore other stars such as giants, which may allow us to inject the controlled parameter of evolution into the question of activity cycles. Fourth, Vaughan (1980) analyzed the Wilson (1978) survey of dwarfs with activity cycles in the context of the solar neighborhood survey (Vaughan and Preston 1980). There may be a distinction between the morphology of activity cycles for the weak and strong emission-line stars. The old, chromospherically less active stars tend to show a smooth, long-term variation reminiscent of the Sun's activity cycle while the young, active stars show erratic fluctuations, qualitatively different than those observed in the old stars. This dichotomy in cycle behavior has prompted theoretical work in dynamo behavior (Durney et al. 1981; Knobloch et al. 1981).

INTERMEDIATE TIMESCALE VARIATIONS

Wilson (1978) himself suggested that the "scatter" on a timescale of days to weeks contained in the long-term data trains could be caused by the rotation of long-lived active regions through our line of sight. A concerted effort to monitor intensively these dwarfs nightly bore out this speculation. An important point is that the rotation period is measured directly, rather than the projected rotational velocity. The classical method of determining rotational velocity in late-type stars is notoriously difficult: First, the Doppler line broadening is usually extremely small, and second, the inclination of the stellar rotation axis must be known. Some results of the Vaughan et al. (1981) and Baliunas et al. (1982) quantitative measures of stellar rotation can be summarized:

(1) Although previously known from statistical studies of projected rotational velocity in open-cluster dwarfs, (Kraft 1967; Skumanich 1972), we confirm that rotation slows with decreasing Ca II emission strength.

(2) No good correlation exists between rotation period and activity cycle period. A weak threshold effect is apparent, though: stars whose rotation periods are longer than 20 days show morphologically solar-like activity cycles. This finding is consistent with the Vaughan (1980) result that old, relatively inactive stars show long-term fluctuations

similar to those of the Sun. The older stars happen to be the slower rotators, as earlier pointed out from the open cluster studies.

(3) The success rate for determining rotation in the chromospherically more active stars can be over 80%--much higher than for the older stars. This surprising result may be due to two effects:

a) The weak emission-line stars may show changes which are below our experimental sensitivity to such variations, and produce a lower success rate than for the active stars.

b) The lifetime of active regions or active longitudes may be longer in the young stars as compared to the old. As Noyes (1981) has found, the lifetimes of these inhomogeneities may be years.

(4) For a limited range in spectral type, the lengthening of rotation period with decreasing chromospheric emission strength is smooth between strong and weak emission line stars. This evidence is contrary to a discontinuous slaving of rotation as a star ages, an explanation proposed for the lack of intermediate emission-strength stars in the Vaughan and Preston (1980) solar neighborhood survey.

SHORT-TERM VARIATIONS

Flux variations on timescales of minutes to hours in the solar-type dwarfs are also evident from the long- and intermediate-data sets described above. Both Middelkoop et al. (1981) and Baliunas et al. (1981) described short-term changes for some of the Wilson dwarfs. For HD 22049 (K2V) (Baliunas et al. 1981), 5-10% fluctuations in the emission, which may be akin to flare events, are observed. Not only are brightenings present on a timescale of minutes, but "fadings" of the emission are also seen, especially in Middelkoop et al. (1981, Fig. 3).

The energetics of these flare-like events in chromospheric emission observed in HD 22049 and other G-K stars is similar to those seen in flare stars and large solar flares (Baliunas et al. 1981). It is the poor contrast of the emission variations relative to the nearby, bright photospheric continua in these solar-type dwarfs which masks our impression of flare activity as compared to the dwarf M stars.

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DISCUSSION

Worden: Regarding your flares, we had some data on ξ Boo A in the U band, which is one of the active stars you have been looking at. We did a Fourier analysis on it and find evidence that there are solar-flare-type events buried in that continuum.

Baliunas: That is very interesting since yours are continuum measurements.

Worden: The light curve looks flat but one can see from the frequency spectrum that it is not just scintillation noise.

Mullan: This matter of the microflares is a very important aspect of your work. Where does one draw the dividing line between stars which are really quiescent and flaring stars? The question has not been addressed here as to how one evaluates what fraction of star's light is coming out in flares This of course is bound up with how much energy is in the microflares. So I think this is a very important point that micro-flares are difficult to see because of the contrast problem.

Belvedere: During your talk you said many times that your results were important for dynamo theory. I would like to know in which sense they are important.

Baliunas: The dichotomy in the activity curves between the old and young stars has spurred a lot of work as to how one can produce long-term cycles which show such a spread in behaviour.

Vaiana: With regard to short-term variability or microflaring we should recall the statement made after Torres paper (by van Leeuwen) that an upper limit of order one thousandth of a magnitude could be placed on variations in the later-type stars. This contrasts with the short-term variability reported here in stars of spectral type G or earlier. In X-rays we find short-terms variability 20-60% in all of the stars for which we have adequate sensitivity. So it may be that for M stars the photosphere does not change more than two thousandth of a magnitude but for G and K stars one has variability such as Worden was reporting.

Baliunas: Well, we have not made continuous measurements.

Evans: You had a diagramme showing the variation in magnitude of a star consequent upon the presence of a spot and its rotation. Part of the curve was level and part showed an oscillation. You explained this in terms of a beat phenomenon. Have you considered the possibility of a spot migrating from a polar region where it would always be in view to a lower latitude where it will be alternately visible or not.

Baliunas: That might also be a reasonable explanation.

van Leeuwen: The variation for the K-stars which we have observed are also very small. But for AU Mic the amplitudes of the flares are not visible at all in Walraven V and B but are very large in L, U and W. We do not see these variations in the visual.

Kodaira: I have been monitoring the Hβ emission of γγGem for 5 years and have found a double wave variation and sometimes a cut off wave. So I would like to ask whether you have found a similar effect in your observations of emission lines or evidence of a migration of the emission-line region?

Baliunas: HD46282 is an interesting example. In our first year of observation we deduced a period of 19 days but later one of the active regions disappeared and the true period turned out to be twice 19 days. So we do see evolution in the light curve.