ACTIVITY CORRELATIONS IN CLOSE BINARY SYSTEMS

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The best way to learn about the detailed physical conditions associated with stellar activity is to construct detailed self-consistent model stellar atmospheres based on the wide range of diagnostics now available. A quicker rough analysis of the activity can be accomplished by studying the interrelations of the various diagnostics. Tight correlations between diagnostics suggest physical association, and the power law indices of the correlation can help to elucidate the general physical relation the diagnostics have with each other. Our aim in this study was to observe with the IUE satellite a homogeneous sample of stars for which there is extensive coronal data. The X-ray studies of close binaries by Walter and Bowyer (1981) and Walter (1982) provided such a sample; these stars are also accessible to the IUE because of their tendency to strong activity. Because of intrinsic stellar variability, this type of study is best carried out when all diagnostics are measured simultaneously. We have come fairly close to this ideal; only the coronal data is non-contemporaneous for most of the sample. Our reduction of the IUE data is quite similar to that of Ayres, Marstad and Linsky (1981, hereafter AML) and we have used essentially the same diagnostics.

In order to study the relations among the diagnostics we have constructed correlation plots in which the normalized flux in each diagnostic is plotted in a log-log plane against various canonical diagnostics, normalized to the bolometric flux measured at the earth (corrected for inactive components in the binary system). Thus we are studying a measure of the activity per unit surface area, free of errors in the stellar radius or distance. We chose three canonical diagnostics for which to make the correlations: MgII for the chromosphere, CIV for the transition region, and X-rays for the corona. In order to make a good quantitative assessment of the correlations and their significance, we have employed a numerical least-squares linear fitting program which minimizes the perpendicular distance to the data points from the fitted line. We have examined the relations both for the binary sample as a whole, which includes active K and G subgiant RS CVn stars and G main sequence components, and for the K subgiants separately. These latter

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comprise an active subclass for which the fuadamental stellar parameters are very similar and which have all just evolved off the main sequence. Due to tidal synchronization with their companions, these stars tend to have much higher rotational velocities than their field counterparts, which may account for their increased activity (see also Basri, Laurent and Walter 1982, hereafter BLW).

Our results for diagnostics compared to MgII correspond to the data presented in AML; we also see fairly good correlations between most of the diagnostics (see Table 1). The fits are uniformly much poorer for the full sample of stars than for the K subgiants. Examination of the data in detail reveals that the different subgroups of stars tend to have different general levels of activity. The full sample slopes are therefore somewhat misleading, so we concentrate on the results for the K star subgroups. For these, our correlation lines lie above the ALM lines and are steeper. The less active binaries show intermediate behavior. Thus it appears that not only do higher temperature lines increase more rapidly with activity, but the amount of increase itself also becomes greater with increasing activity. The lines fall into three classes of behavior: OI (with large scatter), CI and NV with slope $\sim$ 2.0, HeII, SiII, CII, CIV with slopes 2.5-3.0, and SiIV and X-rays with slopes $>$ 4.0. The formal errors in our slope determinations are less than 0.1. Note the puzzling behavior of NV, which should be formed at 10^5 K and might be expected to behave most like a coronal line.

The slopes of the relations are naturally much shallower when viewed relative to the transition region line CIV (see Table 1). In fact most of the lines have unit slope relative to this line for the K subgiants, and generally display the smallest scatter about the correlation line. Some of the relations are quite tight even with the full sample of stars, particularly CII. A lot of the other diagnostics behave as though they were also formed in the transition region for the K subgiants, including CI, OI, SiII, HeII, CII, and NV (with larger scatter). Only MgII shows significantly less than unit slope, while SiIV and X-rays show increasingly greater slope; these relations all have larger scatter. The different groupings relative to MgII may therefore partly just reflect the greater physical disconnection of this diagnostic in both temperature and optical thickness from the other lines, and partly the greater sensitivity of steeper slopes to small fluctuations in the data.

The X-ray relations show the most scatter; enough to make them unreliable as predictors of activity. This may reflect intrinsic stellar variability coupled with non-similtaneity of the X-ray data, and the fact that the corona is more sensitive to changes in activity levels than the cooler diagnostics. The most interesting aspect of these relations is that the line which shows most nearly unit slope is SiIV (not either HeII or NV). This is consistent with our other results and those of BLW that SiIV has the behavior most like coronal, and NV actually looks almost like a chromospheric line. Hartmann, Dupree, and Raymond (1980) have proposed that earlier studies of the formation of

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the HeII line at λ1640 which suggested a strong dependence on coronal X-ray fluxes are corroborated by a linear dependence of HeII and X-rays in their data. We find in fact that the slope of the K star relation is about 2/3 (slightly more for the full sample), but there is a very definite connection with X-rays in the sense that this relation shows much lower scatter than for any other diagnostic.

We have not yet carried out a detailed analysis to explain our results, so we offer here only a few possibilities. The behavior of the diagnostics would best be explained by an increasingly greater pressure at the transition region (and thus also in the corona) with increasing activity. One might expect something like a P^2 dependence of diagnostics in this regions but not the mid-chromosphere due to both the increasing populations of ions and increasing collisional excitation of the resonance lines. As the transition region moves low enough, even low ionization stages like CI and SiII are able to form in the lower transition region where collisional excitation is increasingly important. In the less active single stars some of these lines are more chromospheric, leading to the ALM results. Studies of the period-activity relations for these close binaries (BLW) leads to the suggestion that increasing total magnetic flux may largely be responsible for the increasing activity. The additional sensitivity of the hottest diagnostics to activity may derive from a more purely magnetic dependence of the heating and temperature in the corona compared to the chromosphere.

Table 1: Activity Correlations

	vs. MgII/ℓ_{bol}		vs. CIV/ℓ_{bol}	
	Slope	$\chi^2[\langle\sigma\rangle\sim .17]$	Slope	$\chi^2[\langle\sigma\rangle\sim .17]$
MgII 13(23)[1]	-	-	.4(.6)	1.2(1.9)
OI 12(24)	1.9(1.4)	.9(1.0)	.9(.7)	.5(1.2)
CI 10(21)	2.0(1.4)	.4(1.3)	.9(.8)	.4(1.6)
SiII 12(15)	2.9(2.1)	.9(2.0)	.9(.7)	.5(1.2)
HeII 11(20)	2.6(2.0)	.6(.8)	.9(1.2)	.5(1.3)
CII 12(25)	3.0(1.75)	.7(1.3)	1.0(.9)	.7(.6)
CIV 13(23)	2.8(1.7)	.7(1.6)	-	-
SiIV 11(19)	4.3(2.6)	.4(1.6)	1.25(1.1)	.8(1.5)
NV 11(20)	2.3(1.8)	.4(.1)	1.0(1.0)	2.0(2.6)
X-ray 17(30)	4.8(2.7)	.6(1.2)	1.5(1.6)	.95(.7)

[1]number of stars used: K RSCVn (all binaries)

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DISCUSSION

Walter: Is not surprising that you get such a tight correlation for He since the observations are non-contemporaneous and it varies all over the place by factors of up to an order of magnitude?

Basri: That's true. In fact I find the tightness of many of these relations surprising. Even when the data is non-simultaneous the correlations are better than you might expect.

Dupree: Do we actually know how much the X ray flux varies in RS CVn stars?

Basri: Yes, the X ray flux in a few of them has been observed to vary by as much as 0.5 dex and also flares have been seen. The rotation-activity correlations in fact show a scatter of about ± 0.3 dex. So from that alone one would expect them to be variable.

Bromage: I notice that there are no error bars on any of your points. Have you worked out correlation coefficients allowing for these errors and if so does the He II relation still appear tighter than the others?

Basri: We have done a fairly careful error analysis of this data. The table in fact gives both standard deviations and chi-squared values. I should also mention that the fits are not standard least squares fits in that the X and Y axes are dependent variables. We allow for errors in both quantities and we fit the points perpendicular to the line. These are the chi squares which result from that procedure. The measurement and intrinsic errors are reflected in the standard deviation. The standard error is in the log.

Bromage; So these are maximum likelihood fits. Are they straight line fits?

Basri: Yes. They are all straight line fits. Given the number of stars observed a more complicated fit is not warranted. The best case is C II vs C IV where the scatter is surprisingly low. So I believe that these relationship are physically significant and it is up to us to figure how these translate into the physics of the stellar atmosphere.

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