IUE OBSERVATIONS OF THE CHROMOSPHERIC ACTIVITY-AGE RELATION IN YOUNG SOLAR-TYPE STARS

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INTRODUCTION

The difficulties of measuring magnetic fields in late-type stars other than the sun are well known, as one is reminded by other contributions to these Proceedings. This Symposium nevertheless comes at a very opportune time, as we are now at the point where we can begin to explore the relationship of stellar magnetism to flare activity and quiescent cool star chromospheres, transition regions (TRs), and coronae.

Except for the synoptic observations of the chromospheric Ca II H-K lines by Wilson (1978), in which he sought evidence for magnetic activity cycles, there is still scant data on stellar activity, especially at UV and X-ray wavelengths where 10^5 K TRs and 10^6 - 10^7 K coronae are expected to radiate. This paper presents new UV data, obtained with the IUE spacecraft, for a dozen solar-type stars in the field. The stars are of spectral type F6 V - G1 V; on the basis of their high Li content, they range in age from 0.1 to 2.8 Gyr (Duncan 1981). Our purpose is to study the evolution of TR and chromospheric emission with stellar age, and also the surface distribution of magnetically active regions as revealed by rotational modulation of UV emission line fluxes.

OBSERVATIONS

Low resolution (~6 Å) spectra from 1200-1950 Å were obtained with the SWP camera of IUE. We have measured the strengths of chromospheric and TR emission features (mostly unresolved blends) of O I, C I, C II, C IV, Si IV, N V, and He II. The bright continuum at $\lambda > 1750$ Å is generally overexposed in our deep exposures, saturating the Si II, Si III, and C III features. Echelle spectra of the Mg II lines at 2800 Å (resolution 220 mÅ) were obtained for all but one star with the LWR camera. A dozen exposures of χ^1 Ori, covering three rotational cycles, were made with both cameras in order to assess the effects of surface activity (Boesgaard and Simon 1982).

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CORRELATIONS: ACTIVITY AND AGE

We find that the hottest TR lines are more strongly enhanced above quiet sun fluxes in the young stars than are the lines formed in the low chromosphere, and thus the high temperature lines follow a steeper relation between emission strength and age than do the chromospheric lines. As representative of 10^5 K plasma, the observed C IV 1549 Å strengths are shown in Figure 1. The line fluxes are normalized to the apparent stellar bolometric luminosity, and the symbols are keyed to stellar rotational velocities from Soderblom (1980) or Kraft (1967). Normalized fluxes are also given for T Tauri variables (Imhoff and Giampapa 1982), corrected for UV extinction, for stars in the Hyades cluster (Zolcinski et al. 1982), and for the active and quiet sun. A power law, flux $\propto$ Age$^{-0.8}$, fits the C IV data reasonably well, despite some significant deviations. The range of variation observed for χ^1 Ori (at 0.6 Gyr), denoted by a shaded box in Figure 1, presumably gives a fair indication of the scatter in C IV brightness expected as stellar active regions or bright supergranulation network rotate on and off the visible stellar disk.

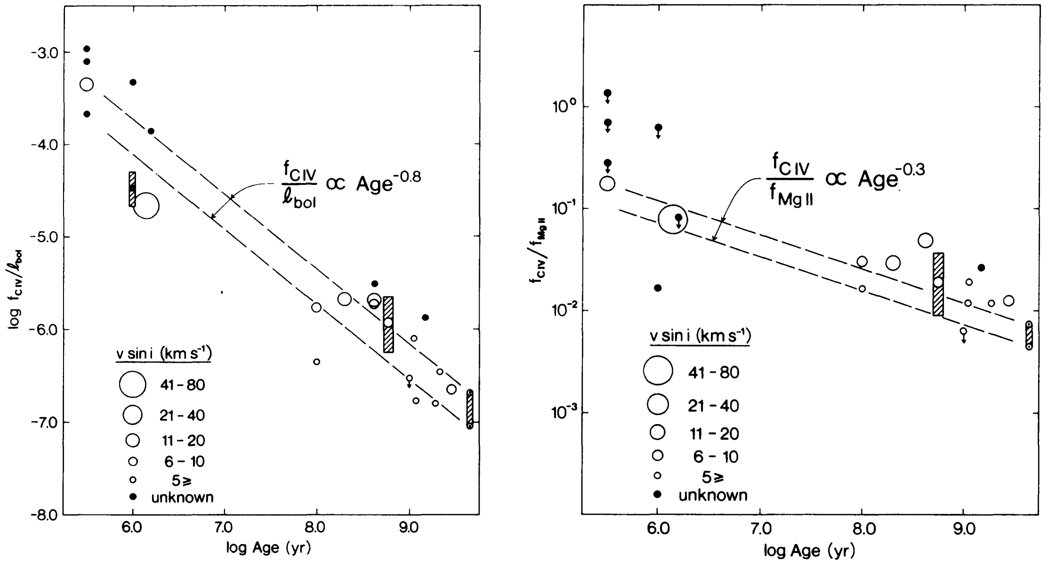

Figure 1 (left). Normalized flux of C IV 1549 Å. The range in line flux observed for RW Aur, χ^1 Ori, and the sun are shown.

Figure 2 (right). Ratio of C IV 1549 Å flux to the Mg II 2800 Å emission line flux.

UV emission lines of lower excitation (e.g., C II 1335 Å) follow similar power-law relations with shallower slopes. The chromospheric Mg II lines decline in strength with the square root of stellar age, a result given previously by Skumanich (1972) for the Ca II H-K reversals and axial rotation. The oldest stars in our sample tend to have both the weakest C IV and weakest Mg II emission. The $f_{C\ IV}/f_{Mg\ II}$ ratio, which measures the relative amounts of 10^5 K and chromospheric material, is correlated with age as shown in Figure 2: the younger the star, the larger the differential emission measure at high temperature, although the observational scatter is considerable. The scatter may be related to the fact that, in contrast to the large variation in the TR emission of χ^1 Ori, we found little variation in simultaneous observations of the chromospheric Mg II lines, with no more than a 13% range in average Mg flux over a year.

DISCUSSION

Our IUE observations indicate that emission fluxes of high temperature lines in the UV, and consequently the outer atmosphere heating and cooling rates, are correlated with the ages of solar-type stars. Stars one-tenth the age of the sun have emission measures in 10^5 K plasma an order of magnitude greater than the solar TR. This trend extends to the very young T Tau stars, although Hartmann et al. (1982) believe that their UV emission may arise from strong stellar winds. Among the young stars we find a greater enhancement of the emission strengths of high temperature lines (C IV, Si IV, N V) than those of low temperature lines (Si II, C I, Mg II).

Because a similar trend is present in UV spectra of solar active regions, and because high dispersion IUE spectra of active dwarf stars (including χ^1 Ori) show no opacity broadening by comparison with old solar-type stars like α Cen A, Ayres et al. (1982) conclude that magnetic structures on quiet and active dwarfs must be similar. They attribute differences in activity levels among dwarf stars to changes in the fraction of surface occupied by magnetic regions, e.g., plages. There are several difficulties with this model. First, in UV observations of the sun there is no difference in TR line widths between supergranulation cell interiors and boundaries (Feldman et al. 1976), coronal holes and the quiet sun (Doschek et al. 1981), or active regions and the quiet sun (Feldman and Doschek 1978). Furthermore, the Mg emission reversal, although more intense in solar active regions, is not perceptibly broader than quiet sun profiles from the chromospheric network or supergranulation cell interiors (Lemaire and Skumanich 1973). Second, the C IV surface flux of young field stars is ~20 times brighter than the quiet sun C IV emission. Since the contrast between active and quiet regions of the sun is a factor of 5-10 (Cook et al. 1980), the greater emission of young stars is difficult to explain by a larger coverage of solar plage, as suggested by Ayres et al. (1982), except possibly with filling factors very near to unity. But high values are precluded by the large rotational variations seen among the youngest stars. The surface fluxes of the T Tau stars, three orders of magnitude larger than the sun's, are impossible to understand with this kind of model. A more compact supergranulation network can't account for the enhanced C IV among young stars, especially the T Tauris, Since the solar TR lines are only 3-5 times brighter in the network than in cell interiors and the area coverage of the quiet sun network is ~40% (Reeves 1976). Therefore, a decided change in the temperature-pressure structure of young star atmospheres seems inescapable, and a change in the dimensions of their supergranulation patterns seems likely as well.

Although an enhanced network, varying in cell size across the stellar disk, is our preferred model for the UV activity-age correlations found here, intense active regions with lifetimes of a year or more may exist. We note however that brightness variations at the Mg II k_1 feature and the nearby continuum were not observed for χ^1 Ori, nor was any variation observed in the continuum below 2000 Å, as is found in the brightest solar plages (Cook et al. 1980).

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