THE SOLAR STELLAR CONNECTION IN THE FAR ULTRAVIOLET

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1.0 Introduction

We compare the far-ultraviolet "activity" of solar type stars, as measured with the IUE, to that of the Sun, as measured by the Solar Irradiance Monitor of the Solar Mesosphere Explorer (Rottman et al., 1982, Geophys. Res. Letters, 9, 587). The goal of our study is to explore the relationships between the "ultraviolet activity" at different levels of the atmospheres of solar type stars, after the manner of Ayres, Marstad and Linsky (1981, Ap. J. 247, 545). In particular, we have produced diagrams that depict correlations of fluxes of ultraviolet emission lines formed at different temperatures in the stellar outer atmosphere. Secondary goals are to establish, quantitatively, the strength of the solar ultraviolet activity within the class of solar-type stars, and to examine the amplitudes of rotational modulations of the solar emission lines during the declining portion of the current sunspot cycle.

A unique aspect of our study is that the spectral resolution of the SME instrument (7.5 Å) compares very favorably with that of the low dispersion mode of the IUE (5 Å). Furthermore, the SME instrument measures the full-disk solar irradiance, analogous to the spatially unresolved spectra of stars obtained by the IUE. Accordingly, the solar and stellar data can be reduced in a nearly identical fashion, thereby minimizing systematic errors that otherwise might be a concern.

2.0 Observations

The lines chosen for the present study were C IV (λ1550), C II (λ1335), C I (λ1657) and O I (λ1305). C IV is formed in the transition zone at 10^5 K; C II is formed in the high chromosphere at about 3 x 10^4 K; and the multiplets of neutral oxygen and carbon are formed deep in the chromosphere at 6,000 K.

Data for main sequence solar type stars, ranging in spectral type from F8 through G5, were obtained from the IUE archives at the Colorado RMAF. In some cases, several spectra of a given star were available, and were treated individually in the subsequent analysis.

The solar data set consisted of weekly averages of SME irradiance spectra taken over an 11 month period in 1982. The absolute flux scale of the SME spectra is maintained by periodic flights of calibration rockets.

3.0 Data Reduction

Owing to the large amounts of stellar (and solar) data to be analyzed, and our concerns of operator biases in interactive fitting procedures, we developed an automatic numerical algorithm to find, and measure, the reference emission lines in each spectrum.

Since the important C IV and C I features are located on top of a significant photospheric continuum in solar-type stars, we required a systematic technique to determine the appropriate continuum shape for each spectrum. First, the spectrum is smoothed by a median filter, and one pass of a running mean. Next, a "clipped" spectrum is created by taking the minimum of the smoothed spectrum or the original spectrum point-by-point, thereby effectively eliminating sharp emission structure. Last, the clipped spectrum is smoothed further by an additional pass of a running mean to provide an approximate continuum
background. This approach is straightforward to implement in an automatic algorithm, and has the important advantage that the continuum fit is systematically applied to all spectra without an operator bias.

Once the continuum level was determined, and subtracted from the spectrum, the automatic procedure identified the reference lines and measured their fluxes by means of a least-squares Gaussian fitting procedure. The results of the measurement procedure were stored in a disk file for later processing. Measurement errors were determined for the line fluxes according to the RMS deviation of the observed profile from the fitted Gaussian and the semi-empirical relations given by Landman, Roussel-Dupre and Tanigawa (1982, Ap. J., 261, 732). In this regard, the solar and stellar data were treated somewhat differently, since the former is governed by photon statistics, while the latter is dominated by readout noise and particle radiation fogging.

4.0 Results

Figure 1 illustrates sample spectra of the Sun and two nearby solar type stars: χ¹ Orionis and α Centauri A. The stellar spectra shown are composites of up to ten individual IUE spectra. The solar spectrum is an average of the entire set of SME data for the 11 months of 1982. The three spectra are qualitatively similar, although it is clear that χ¹ Ori is an order of magnitude more "active" than the Sun or α Cen A.

Figure 2 depicts the weekly averaged fluxes of several important solar lines over the course of 1982. Note that a pronounced rotational modulation is seen in all of the lines during the latter half of the year, but almost no modulation is apparent during the first half. The onset of the prominent modulation coincided with the development of a major active region on one hemisphere of the Sun near the middle of 1982 which persisted for many rotations. The modulation of over 25% seen in the second half of the year in H I Lyα is consistent with that observed in other solar-type dwarfs by Hallam and Wolff (1981, Ap. J. [Letters], 248, L73.)

Finally, we present diagrams comparing the normalized fluxes (i.e. \( f_l / f_{bol} \), where \( f_{bol} \) is the bolometric flux of the star) of different line pairs for the Sun and our sample of solar-type stars. Figure 3 illustrates C IV versus C II; Figure 4, C IV versus C I; and Figure 5, C I versus O I. For both the stellar data and the solar data, power laws were fitted to the observed normalized fluxes and plotted. The solar data covers a smaller range than the stellar data, but the slopes of the power laws appear to agree reasonably well within the uncertainties of the fits.

5.0 Discussion

The steepest power law slopes are for the correlation of the highest excitation line (C IV) against the lowest excitation line (C I). An analogous behavior was seen in the study by Ayres, Marstad and Linsky between the combined flux of N V + C IV + Si IV and the chromospheric species Mg II. This behavior was interpreted to indicate that the heating rates of the chromosphere and transition zone are strongly related, but are not identical functions of increasing activity. Furthermore, the C IV-C II flux correlation exhibits a unit power law slope in both the solar and stellar data, indicating a one-to-one correspondence between the fluxes formed at somewhat different temperatures in the transition zone, and suggesting a unity of the heating rates above about 3x10^4 K. However, the fact that the C I-O I correlations do not exhibit a one-to-one correspondence in either the stars or the Sun is somewhat of a mystery, but perhaps is related to the partial production of oxygen triplet emission by Lyβ pumping.
For the future, we hope to use these correlations and measurements of apparent Lyα emission from G-type dwarfs in the solar neighborhood to probe the abundance of neutral hydrogen in the local interstellar medium.

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Figure 1.
Sample spectra taken by the IUE for two solar-type stars, and by the SME for the Sun.

Figure 2.
Weekly averaged fluxes for several lines in the Sun during 1982.
Solar-type stars (IUE)

Figure 3.

Sun (SME)

Figure 4.

Figure 5.