CAPELLA REVISITED

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ABSTRACT. I summarize the highlights of two IUE programs to study the active chromosphere binary, Capella (α Aurigae A: G6 III + F9 III).

INTRODUCTION. One of the more puzzling stellar systems in the solar neighborhood is the spectroscopic binary Capella (d ≈ 13 pc). Both components are nearly identical in mass, temperature, luminosity and age, but visible and ultraviolet spectra of the pair are remarkably different. For example, the optical spectrum of the primary is sharp-lined while that of the secondary is diffuse and difficult to identify (Wright 1954), aside from an unusually strong Li I λ6708 absorption (Wallerstein 1966). In the ultraviolet, on the other hand, the chromospheric emission spectrum of the secondary is quite prominent, while that of the primary star is difficult to detect (Ayres and Linsky 1980).

Iben (1965) offered a solution to the lithium richness and spectral diffuseness of the secondary spectrum. He proposed that the primary is a slowly rotating post helium flash giant, while the secondary is crossing the Hertzsprung gap for the first time. Accordingly, the F giant is still shedding the angular momentum inherited from its rapidly rotating early-type progenitor, and still burning off its surface primordial lithium by deep mixing. The enhanced ultraviolet emission of the Capella secondary likely also can be traced to its recent incursion into the yellow giant region. In particular, stellar chromospheres and coronae are thought to derive from magnetic activity (Vaiana and Rosner 1978), and fast rotating convective stars likely manufacture more magnetic flux than slow rotators (Parker 1970).

From the standpoints of stellar evolution, the origin of magnetic activity, and the development of chromospheres and coronae, the Capella system clearly provides an important prototype. Here, I present the highlights of two studies of Capella undertaken during the third and fourth years of IUE. The first program consists of high dispersion spectroscopy at critical phases of the Capella orbit, and will be published in more detail elsewhere (Ayres, Schiffer and Linsky 1982). The second program is a two month monitoring effort to search for ultraviolet modulations induced by the rotation of magnetic active regions onto and off of the visible hemisphere of the Capella secondary.

OBSERVATIONS. In the study of Capella at critical orbital phases, entire NASA #2 shifts were devoted to sequential exposures alternating between the long wavelength and short wavelength echelettes, with typical exposure times of 1 minute and 30 minutes, respectively. The multiple exposures improve S/N by co-addition, provide an empirical assessment of spectrum reproducibility, and can reveal short term (±hours) fluctuations in emission line strengths. In the rotational modulation program, 10 NASA #2 shifts were split into 22 observing opportunities, each typically consisting of four echelette exposures: 2 LWRs of 1 minute and 2 SWPs, one of 10 minutes and the other of up to 60 minutes. A description of the high dispersion reduction procedures and the results of
an echelle mode calibration study undertaken during the monitoring effort can be found in Ayres (1982a).

For this presentation, I analyzed in detail the fluxes of three features—the C IV λ1548, 1551 doublet, Si II λ1808 and Mg II λ2796—from both programs. I normalized the Si II and Mg II line emission to "continuum" fluxes measured in bands well separated from the line cores to minimize systematic errors owing to mispositioning of the target in the large slot and the thermal sensitivity of the image converters. I corrected the raw wavelength scales provided by the IUE SIPS for the telluric component, the radial velocity of Capella, and a temperature dependent term having a slope of 5.2 km s\(^{-1}\)C\(^{-1}\) for LWR and 2.4 km s\(^{-1}\)C\(^{-1}\) for SWP, with a zero offset of 13 km s\(^{-1}\) for THDA(LWR) = 13\(^\circ\)C and THDA(SWP) = 8\(^\circ\)C (see Ayres 1982b). Finally, I adjusted the C IV absolute fluxes by 0.8% C\(^{-1}\) x [THDA - 8\(^\circ\)C] (Bohlin et al. 1980).

ANALYSIS. Figure 1 depicts profiles of C IV λ1548, Si II λ1808 and Mg II λ2796 from the monitoring program. The ordinate of the figure is a relative intensity scale with the Mg II feature reduced by a factor of 25. For each profile set, the horizontal line denotes the zero intensity level which is displaced upwards in proportion to the temporal separation between observing opportunities. Orbital phases are from the Heintz (1975) ephemeris. For reference, at the phase 0.75 quadrature, the primary and secondary are at -27 km s\(^{-1}\) and +27 km s\(^{-1}\), respectively; at the phase 0.25 quadrature, the component radial velocities are reversed; while at the phase 0 conjunction the giants have the same radial velocity and the spectrum is single lined.

The secondary is quite prominent in the Mg II k line, which is formed at about 6000 K in the stellar chromosphere. The weaker primary star contribution can be seen clearly near the quadratures, although the interstellar feature at -8 km s\(^{-1}\) obscures it somewhat near the phase 0 conjunction. The primary probably accounts for no more than 30% of the total Mg II emission. The secondary also is prominent in Si II λ1808, which is formed at about 10\(^4\) K in the upper chromosphere. A moderate (<30%) contribution by the primary is indicated by the increase in FWHM from the conjunction towards
either quadrature. Note that the Si II emission envelope is symmetric about zero velocity (vertical line) near the conjunction. In C IV λ1548, formed at about 10⁵ K, the influence of the secondary is dominant, and the contribution of the primary is difficult to assess. The line width and profile shape do not change as dramatically as those of the lower excitation features, and the C IV emission appears to shift bodily from one quadrature to the other. The primary contribution is no more than 10%. Finally, near the conjunction, when the spectrum is single lined, C IV λ1548 appears to be redshifted relative to Si II λ1808 by roughly 10 km s⁻¹, reminiscent of the downflows observed over solar magnetic active regions in high excitation lines (Athay 1981). A similar redshift phenomenon has been reported by Stencel et al. (1982), who analyzed a long SWP echelle exposure of the early G supergiant β Draconis.

Figure 2 summarizes the results of the timing program, including fluxes from the critical orbital phase study. The line fluxes or flux ratios are normalized to the mean value for the 1981.19-1981.33 period (stippled box). The error bars on the values from the critical orbital phase study (1980 through early 1981) refer to the dispersion of the individual fluxes from the mean of the multiple exposure sequences. I adopt that dispersion to characterize the error associated with single flux measurements, as well as an upper limit on short term fluctuations of the Capella emission. The vertical extent of the stippled box represents the dispersion of the individual fluxes of the timing sequence about the mean value. Statistically significant modulations appear in each diagnostic, particularly Mg II for which the S/N is quite good. The major fluctuations are compatible with a rotation period of ≈10 days, consistent with the v sin i ≈ 30 km s⁻¹ derived from the width of Li I λ6708 (Ayres and Linsky 1980). Despite the existence of fluctuations in all three diagnostics, the most remarkable result of the timing study is the steadiness of the Capella ultraviolet emission. In particular, the system has exhibited a dispersion in its ultraviolet line output of only ±6% (1σ) in C IV and ±3% (1σ) in Si II λ1808 and Mg II λ2796 over the 1980-1981 period.

DISCUSSION. The observations of Capella at critical orbital phases confirm that the fast rotating secondary star is responsible for the bulk of the ultraviolet line emission from the system, particularly in the high excitation C IV doublet. The emission dichotomy between the otherwise similar giants implies that the spindown of single stars evolving across the Hertzsprung gap
must be very rapid, particularly if both the Capella giants are in their first
crossing as suggested by Boesgaard (1971). Accordingly, the majority of the
single yellow giants, which are post helium flash, should be slow rotators
and comparatively inactive like the Capella primary (cf., Simon, Linsky, and
Stencel 1982). Only the relatively rare first crossers should be fast rotators
with active chromospheres and coronae like the Capella secondary.

Finally, the ultraviolet steadiness of the Capella secondary is remarkable
in light of the large fluctuations typical of active dwarf stars (Hallam and
Wolff 1981) and the K subgiant components of tidally synchronized RS CVn-type
binaries (Simon and Linsky 1980). Among these cooler stars, factor of 2
fluctuations in C IV are not uncommon (Boesgaard and Simon 1981; Ayres
and Linsky 1982). The steadiness of the Capella secondary suggests a nearly homogeneously organized unordered surface magnetic field. In contrast, the emitting regions on the cooler stars appear to be spatially concentrated. For example, the starspots of the RS CVn subgiants are large enough to produce optical
photometric modulations (Hall 1978). Small decaying spots which are dark in
Mg II may well be responsible for the quasi-periodic dips in the Capella timing
record. If so, the spots probably are located in the northern hemisphere of
the secondary since the dips are comparatively narrow (Note: i = 135°).
Nevertheless, the Capella secondary must be covered almost uniformly with bright
regions analogous to solar plages in order to produce the steady emission
behavior. I speculate that the shallowness of the F giant convective envelope is
responsible for the lack of large scale spatial structure in its surface
magnetic active regions. Only when the convective envelope becomes deep can
dynamo action (Parker 1970) impress the large scale spatial coherence on the
subsurface field required to produce large "spotted" areas on the stellar
disk.

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