RESULTS OF AN IUE PROGRAM OF MONITORING THE ULTRAVIOLET EMISSION LINE FLUXES OF FOUR BINARY SYSTEMS: HR 1099, II PEG, AR Lac, AND BY Dra

N. Marstad, J. L. Linsky, and T. Simon
Joint Institute for Laboratory Astrophysics, National Bureau of Standards and University of Colorado, Boulder, Colorado 80309

M. Rodono, C. Blanco, S. Catalano, and E. Marilli
Osservatorio Astrofisico, Catania, Italy

and

A. D. Andrews, C. J. Butler, and P. B. Byrne
Armagh Observatory, Armagh, Northern Ireland

ABSTRACT

We present a preliminary report on a collaborative program to obtain IUE spectra and optical photometry and spectra of three RS CVn-type binaries (HR 1099, II Peg, and AR Lac) and the prototype BY Dra system. We monitored these systems for at least one orbital phase, and detected periodic variations in emission line flux from II Peg and HR 1099, indicative of rotational modulation of an active region on these stars. For II Peg the active region is in phase with photometric minimum as expected, but for HR 1099 ultraviolet emission maximum occurs at the time of photometric maximum.

I. INTRODUCTION

RS CVn-type binary systems are generally detached systems of 1–14 day periods that rotate synchronously due to tidal forces and generally consist of a KO IV primary (typically the active star) and a G5 V secondary. Hall (1976) has reviewed the properties of these systems. The most striking peculiarity of RS CVn binary systems (Hall 1980; Rodono 1980) — a migrating quasi-sinusoidal distortion in the light curve — was discovered in RS CVn itself by Catalano and Rodono (1967). Among the different models that have been proposed, the spot model (Hall 1972; Eaton and Hall 1979) appears to be the most successful: the outside of eclipse sinusoidal variation being attributed to rotational modulation of an uneven distribution of photospheric spots.

During the last several years, observers have used IUE to study a number of these systems. These programs include: (1) a study of the nonsynchronous Capella system (G6 III+F9 III) by Ayres and Linsky (1980), (2) a study of HR 1099 (KO IV+G5 IV) by Ayres and Linsky (1982), (3) a model chromosphere and transition region computed by Simon and Linsky (1980) that matches IUE spectra of HR 1099 and UX Ari, and (4) a study of λ And (G8 III–IV+) by Baliunas and Dupree (1982) indicating that chromospheric and transition region emission lines are brighter at photometric minimum for this system.

Wide-band photometric monitoring of BY Draconis stars has led to the widely accepted theory that the nearly sinusoidal light variations, with periods of a few days, are also due to large, dark spotted regions whose visibility is modulated by the stellar rotation. The BY Dra systems are typically binary,

*Staff Member, Quantum Physics Division, National Bureau of Standards.
consisting of early M or late K-type dwarf stars with periods of a few days, but Bopp (1979) has shown that not all BY Draconis stars are binaries as EQ Vir (K7 Ve) appears to be single. Thus the spots and flares, and by implication strong magnetic fields, are not a direct consequence of duplicity, but rather of efficient dynamo processes in stars that are rapid rotators (due to tidally-induced synchronism or young age). Linsky et al. (1982) have discussed IUE observations of EQ Vir and AU Mic.

II. OBSERVING PROGRAM

In the Sun there is an excellent correlation of strong magnetic fields with bright emission in lines formed in the chromosphere, transition region, and corona. Plage regions generally overlie spots on the Sun, but the area of plages is several times the spot area. This is likely due to the spreading out of field lines above the photosphere. If, as expected, photometric wave and other phenomena, which Kunkel (1975) collectively referred to as the "BY Draconis syndrome," are magnetic in character, then we predict that the emission lines formed in the chromosphere and transition region should undergo cyclic changes anticorrelated with the photometric variability. To test this hypothesis and to obtain spectra of plage and quiescent regions separately for modeling purposes, we monitored three RS CVn-type binaries (HR 1099, II Peg, and AR Lac) and the prototype BY Dra binary system with IUE on 1–7 October 1981. These stars were observed by IUE 4–9 times each at regular intervals throughout their 2.0–6.7 day periods, together with ground-based photometry and radio observations. Each IUE observation consisted of several low dispersion SWP spectra and several high dispersion LWR spectra.

We found essentially no line flux variations for AR Lac above the noise. BY Dra does show variations in the C IV and C II lines up to 50%, but no evidence for dependence on phase. By contrast, II Peg shows two distinct spectra (see Figs. 1 and 2) — a quiescent spectrum between phases 0.95 and 0.35, and

![Composite IUE spectra](image)

Fig. 1. Composite IUE spectra when the plage is present (sum of three spectra) and when the plage is not present (sum of five spectra).
Fig. 2. Observed flux in the Mg II λ2800, C IV λ1550, He II λ1640, C II λ1335, Si II λ1812, O I λ1304, and Si IV λ1400 features as a function of phase using the parameters $t_0 = 2442316.29$ and $P = 6.69296$ days. Also given are the FES visual magnitudes obtained simultaneously with the IUE spectra.

an active region spectrum between phases 0.40 and 0.90. The active region spectrum shows transition region emission lines a factor of 5 enhanced and chromospheric emission lines a factor of 2 enhanced compared to the quiescent spectrum. The active region appears centered on photometric minimum as determined using FES photometry and thus overlies dark star spots.

Our nine observations of HR 1099 show enhanced emission centered on phase 0.7 and a flare at phase 0.74. Flux enhancements near phase 0.7 and in the flare are also larger for transition region lines than for chromospheric lines. Observations during the second and third cycle are consistent with observations at similar phases during the first cycle. HR 1099 now exhibits a changing and complex photometric curve, but minimum now occurs at phase 0.20, out of phase with the ultraviolet emission line maximum.
III. DISCUSSION

This is only a preliminary discussion of a large data set that will be useful for many purposes, but several trends in the data appear very interesting. First, II Peg clearly shows the correlation of maximum chromospheric and transition region emission with photometric minimum, indicating as expected that stellar plages overlie star spots. Since the plage appears for 0.50 in phase, we are likely seeing the rotational modulation of a plage that is not very extensive in longitude. Second, the increasing enhancement of line flux with increasing temperature of formation is a phenomenon generally seen in solar plages and indicates that as the nonradiative heating rate increases in closed magnetic flux tubes, an increasingly large proportion of this heating goes into high temperature regions. Third, HR 1099 does not show a correlation of emission line maximum with photometric minimum either due to the presently complex photometric curve indicating spots on both hemispheres or the occurrence of a flare. Finally, the repeatability of ultraviolet emission line fluxes over three cycles indicates that the plages do not change appreciably on a time scale of one rotation.

We acknowledge the support of NASA through grant NAG5-82 to the University of Colorado, and thank the staffs of the IUE Observatory at Goddard and Vilsapa for assistance in the acquisition and reduction of these data.

REFERENCES

Hall, D. S. 1972, P.A.S.P., 84, 323.
Rodonò, M. 1980, in Binary Stars, Maratea (Italy), in press.