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ULTRAVIOLET STUDIES OF NOVA-LIKE VARIABLES

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Final Report

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TABLE OF CONTENTS

I. Summary of Completed Research

Our investigations of UX Ursae Majoris-type nova-like variables and binaries with degenerate components in the far ultraviolet with the International Ultraviolet Explorer satellite have resulted in a total of five publications and papers. The list of papers are given in Section II and the copies of the papers are given in Section III.

The chief results of this research program are summarized as follows:

1) The discovery of hot, high velocity ($\sim$1000 km s^{-1})winds from the accretion disks of the nova-like stars

2) We affirm the presence of thick accretion disks centered on the degenerate components of the nova-like variables studied.

3) By fitting theoretical flukes computed by R.E. Williams for steady state accretion disks models, we determined that the accretion rates of $\dot{M} \gtrsim 10^{-9} M_\odot$/yr. These inferred accretion rates are higher than found for the dwarf novae in quiescence.

4) The steady state disk structure in a stable radiative state thus explains for the first time the "absence of outbursts" for the Nova-like stars.

II. Publications and Papers on Research Completed under
Grant NAG 5-205

The Nova-like Variable KQ Mon and the Nature of the UX Ursae
Majoris Stars in Advances in UV Astronomy: Four Years of
IUE Research, NASA Confer. Publ. 2238, p.460, 1982. E.M. Sion
and E.F. Guinan.

High Velocity Gas Outflow from the Nova-like Variable LSI
55^c-8. In Advances in UV Astronomy: Four Years of IUE
Research, NASA Confer. Publ. 2238, p. 465, 1982. E.F. Guinan
and E.M. Sion.

An Ultraviolet Investigation of the Unusual Eclipsing Binary
System FF Agr. in Advances in UV Astronomy: Four Years of
IUE Research, NASA Conf. Publ. 2238, p. 517.

The Hot DO White Dwarf HD 149499B: Einstein Redshift of a
DB Progenitor with Carbon Features. Astrophys. J. (Letters),
265, L87, 1983. E.M. Sion, E.F. Guinan and F. Wesemael.

KQ Mon and the Nature of the UX Ursae Majoris Nova-like Variables
in Cataclysmic Variables and Related Objects, eds. M. Livio
and G. Shaviv (Reidel: Dordrecht) 1983. E.M. Sion and E.F. Guinan.

Advances in Ultraviolet Astronomy:

Four Years of IUE Research

Yoji Kondo, Jaylee M. Mead,
and Robert D. Chapman, *Editors*
NASA Goddard Space Flight Center
Greenbelt, Maryland

THE NOVA-LIKE VARIABLE KQ MON AND THE FUTURE OF THE UX URSA MAJORIS STARS

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ABSTRACT

KQ Mon is a new UX UMa-type nova-like variable discovered by Howard Bond. Optical spectra taken by Bond in 1978 reveal very shallow Balmer absorption lines and He I (λ4471) absorption. Bond also did UBV and high speed photometry in 1978 and early 1981. There has been no evidence of orbital variations but the appearance of the optical spectrum and the presence of low amplitude flickering suggested a strong similarity to CD-42°14462 (=V3885 Sgr) and other members of the UX UMa class. KQ Mon was observed at low dispersion with the IUE satellite. Six spectra taken with the short wavelength prime (SWP) camera are dominated by strong broad absorption lines due to N V, O I, Si III, Si IV, C IV, He II, N IV, and Al III. There is little evidence of orbital phase modulation over the time baseline of our observations. Unlike UV observations of other UX UMa-type objects, KQ Mon exhibits no emission lines or P Cygni-type profiles and the velocity displacements appear to be smaller, suggesting the absence of a hot, high velocity wind characterizing other UX UMa stars. The relationship of KQ Mon to other UX UMa disk stars is discussed and a model is suggested to explain their observed properties and the lack of major outbursts.

INTRODUCTION

In a continuing investigation of the nature of nova-like variables, a new system, KQ Mon, recently discovered by H.E. Bond (1978) was added to our program of study with the International Ultraviolet Explorer Satellite. Bond's (1981) optical spectra revealed very shallow Balmer absorption lines and HeI (λ4471) absorption, while his UBV and high speed photometric observations in 1978 and again in early 1981 revealed no light variations due to possible orbital phase modulation nor was any brightness change expected given the absence of radial velocity variations in the optical spectra. However, Bond's high speed photometry revealed the presence of low amplitude flickering. This observation coupled with the appearance of the optical spectrum and its location near the old novae and white dwarfs in the two color diagram suggested a strong similarity of KQ Mon to the UX Ursa Majoris subset of the nova-like variables (Warner 1976). Analysis of our ultraviolet spectra confirm that KQ Mon shares the UV characteristics of the other UX Ursa Majoris stars.

OBSERVATIONS

KQ Mon has been observed at low dispersion with the IUE satellite on

December 5, 1981 and February 5, 1982. The instrumentation and spacecraft characteristics are described by Boggess et al (1978). We obtained four spectra with the short wavelength prime (SWP) camera, and four spectra with the long wavelength redundant (LWR) camera. The exposure times were 35 minutes and 40 minutes respectively, with the large and small aperture and two of the spectra were trailed.

Using the Fine Error Sensor (FES) photometer, visual magnitudes of +13.06 and +12.97 were obtained in December 1981 and February 1982 respectively while Bond obtained V=+13.06 in 1978, indicating that the light level appears reasonably constant. Broad band color indices for KQ Mon were measured by Bond (1982) to be B-V=+0.08, and U-B=-0.72. The U, B and V magnitudes were converted to absolute flux units using the absolute calibration of Hayes (1980). Since our data tapes from the February 1982 observing run were not available when we went to press, we cannot address here the question of whether line and continuum variations are present due to orbital phase modulation.

In figure 1 a single SWP spectrum typical of the others is shown together with labelled identification of the most important line features. The spectrum is dominated by strong broad absorption lines due to NV, OI + SiIII, SiIV, CIV, HeII and NIV. Possible Lya absorption is obscured by the strong geocoronal feature. The long wavelength (LWR) spectrum appears essentially featureless. No absorption dip is apparent at λ2200 indicating that interstellar reddening for KQ Mon is probably small. In figure 2 we plot the unreddened satellite continuum fluxes on a log F_λ vs. logλ ($\overset{\circ}{A}$) scale along with the broad band $\underline{U}$ $\underline{B}$ and $\underline{V}$ fluxes. On the same figure we show, for comparison, theoretical continuum fluxes from model steady state accretion disks calculated by Williams (1981b) assuming a disk inclination angle i=0 (pole-on). The models shown in figure 2 are normalized to the optical $\underline{B}$ band flux.

COMPARISON TO OTHER UX UMA STARS

The UV line spectrum of KQ Mon shows strong broad absorption lines of the resonance doublets and excited species but unlike other members of the UX UMa class (e.g. TT Ari LS I 55 8, V 3885 Sgr, RW Sex) they are not appreciably violet-displaced and P Cygni-type emission is entirely absent. Thus a hot wind from the disk driven by X-radiation from the inner disk may be weak or absent in KQ Mon. Moreover, the absorption lines of KQ Mon appear to be somewhat broader than those of LS I 55 8, V 3885 Sgr and RW Sex.

The estimates of mass loss rates due to wind outflow in the UX UMa stars give $\dot{M}_{wind} \simeq 10^{-2}$ to 10^{-4} $\dot{M}_{acc}$ where $\dot{M}_{acc}$ is the mass accretion rate (cf. Guinan and Sion 1982, Greenstein and Oke 1982). The weakness or absence of an outflowing wind in KQ Mon may be due either to (1) a somewhat lower $\dot{M}_{acc}$ than other UX UMa stars (2) accreting gas flowing above and/or below the disk plane or (3) a weak white dwarf magnetic field preventing disk gas from forming a high pressure zone at the equator which could drive the type of polar wind described by Greenstein and Oke (1982), also Witta (1982).

Like other UX UMa stars, the UV continuum is essentially flat from UV to the optical and can be fitted quite well with accretion disk fluxes (see fig. 2). Reddening corrections would shift the fluxes upward in figure 2 toward a higher accretion rate. The accretion rate of KQ Mon probably lies between $10^{-8} M_\odot$ yr^{-1} and $10^{-10} M_\odot$ yr-1.

NATURE OF THE UX URSA MAJORIS STARS

Given the high ionization states of the UV absorption lines and the evidence for mass outflow in most of the UX UMa stars, the following tentative interpretation of the UV line and continuum spectra is suggested based in part on the wind models of Cassinelli Olson and Stalio (1978 cf. section IV, Guinan and Sion .1982). If we assume the X-radiation in these systems emerge from the hot inner disk boundary layer region rather than say a "hot spot" at the disk edge it is likely that the UV resonance doublets such as N V (λ1240), C IV (λ1550) and Si IV (λ1396) arise in an outflowing wind. These high ionization features, seen in combination with a relatively "cool" integrated disk continuum, are similar to the UV spectra of O and B stars with outflowing winds (Cassinelli, Olson, and Stalio). A thin hot corona ($\sim 10^6$K) at the base of the flow in the boundary layer region provides the X UV photon source needed for the high ion states. The high ionization stages can be produced by the Auger mechanism, whereby two electrons are removed from C, N and O following K shell absorption of X-rays. Greenstein and Oke (1982) have independently proposed for RW Sex that an outflowing wind from the disk is driven by X-radiation, with the gas in conical geometry at the poles of the degenerate dwarf. They propose a broad cone while Guinan and Sion (1982) did not specify the geometry. In either case the outflowing gas is seen silhouetted against a luminous disk for a large range of orbital inclinations which explains the appearance of the blue-shifted absorption lines and P Cygni-type features observed in a number of UX UMa stars. It is likely that when the accretion rate $\dot{M}$ is high, X UV quanta do not penetrate to the disk edge because the accretion flow is optically thick to that flux region. When the disk luminosity declines (i.e. $\dot{M}$ decreases), it is predicted that mass loss should cease, the absorption lines formed in the wind should disappear, the continuum should fade and the UV line spectrum should go into emission with the high excitation UV emission lines originating in a "chromosphere" surrounding the inner disk region (cf. TT Ari; Krautter et al 1981). The site of this "chromosphere" is predicted to be the upper parts of the disk atmosphere more than one scale height from the central plane of the disk. When $\dot{M}$ again increases, the boundary layers' luminosity goes up and the UV spectrum again goes into absorption and an outflowing wind may again be driven.

That UX UMa stars may have higher accretion rates than other types of cataclysmic variables is indicated directly or indirectly by (1) derived accretion rates from continuum fits (e.g. RW Sex, Greenstein and Oke 1982; V 3885 Sgr, Guinan and Sion 1982; TT Ari, Krautter et al 1982), (2) the flat continuum of a luminous, thick disk dominating light from the UV through the optical and IR, (3) the low ratio of L_X/L_{opt} for those UX UMa stars observed with the Einstein satellite (Cordova Mason and Nelson 1981) and (4) the outflowing winds from accretion disks which may manifest a higher boundary layer

luminosity or _local_ super Eddington accretion. It is very likely that the accretion rate of UX UMa stars is higher than, for example, the dwarf novae during quiescence.

We suggest here that the higher accretion rates of UX UMa stars are responsible for their lack of major outbursts. The optical spectra of the UX UMa stars resemble the spectra of dwarf novae in outburst (e.g. Warner 1976) and the UV continuum distribution and line spectra of the UX UMa stars also resemble the UV spectra of dwarf novae in outburst (cf. Krautter _et al_, 1982). H.E. Bond (1978) described V 3885 Sgr as being in continuous outburst since at least 1899 with only very minor changes in brightness in the last eighty-three years. If the UX UMa stars are in a continuous outburst state, we are led to seek a cause of the extended outburst. There is excellent agreement between our observed fluxes and the disk continuum fluxes of Williams (1981b). Thus the disk physical parameters and accretion rates from Williams (1981a) model grid can be adopted with reasonable validity. The higher accretion rates of the UX UMa stars implies more massive thicker disks with a source of viscosity which allows gas to continually accrete onto the white dwarf photosphere. Vila (1982) has calculated steady disks with high mass fluxes which become convective in their central planes. In these models, convective instability increases as the mass accretion rate increases. We argue here that higher $\dot{M}$ in the UX UMa stars produces disk convection which allows gas to continually dump onto the degenerate dwarf with the release of gravitational potential energy. According to Starrfield (1982) a similar scenario based upon disk calculations in progress is proposed to explain dwarf novae outbursts as due to the transition from an optically thin to an optically thick disk with onset of convection. In summary, we propose that UX UMa stars have higher accretion rates than dwarf novae in quiescence and post-novae and thus are in an extended outburst state until accretion from the companion star ceases or declines to the point that steady disk structure with convection ends.

ACKNOWLEDGEMENTS

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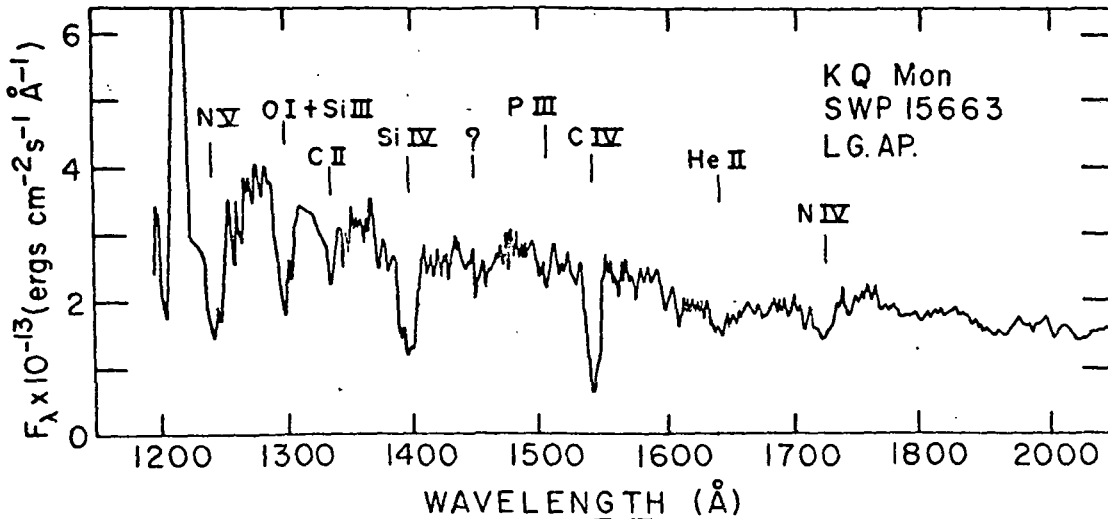
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Figure 1: Short Wavelength Prime (SWP) low dispersion IUE spectrum of
           KQ Mon. The strong off-scale emission line at λ1216 Å is
           geocoronal Lyman Alpha. Strong absorption features are
           identified.

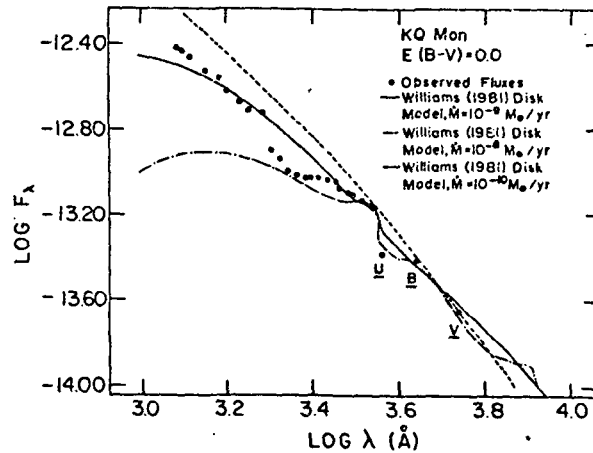Figure 2: Flux plot log F_λ versus log λ compared with three accretion disk
           models of Williams (1981b) normalized at the optical V band flux.
           Optical fluxes are labelled with corresponding bandpass
           designations and all continuum fluxes are unreddened.

HIGH VELOCITY GAS OUTFLOW FROM THE NOVA-LIKE VARIABLE LSI 55°-8

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INTRODUCTION

LSI 55°-8 ($\alpha = 00^h18^m10^s$; $\delta = +55°26'.1:1950$) was identified as a possible subluminous, blue object by Haug (1970) from its unusual UBV colors during the Hamburg-Case Survey of Luminous Stars (Hardorp et al. 1959). Palomar spectra of LSI 55°-8 obtained by Greenstein, Sargent and Haug (1970; hereafter GSH) show a blue, nearly smooth continuum with weak, broad Balmer absorption lines having weak emission cores; other weak, broad emission lines of He II $\lambda4686$ and C III $\lambda4647$ were also reported. From its spectrum and UBV measures (V=+12.79; B-V=+0.07; U-B=-0.79), GSH suspected the object of being an old nova or a cataclysmic variable. High speed photometry was carried out during 1977 by Africano and Quigley (1978), where they monitored the star on 7 nights for a total of 20 hours and found rapid, nonperiodic light variations of up to 0.4 mag. Rapid light variability (flickering) is a common photometric characteristic of many cataclysmic variables and nova-like variables (Robinson 1976) and is believed to be associated either with a hot spot at the impact region of the gas with the accretion disk, or with non-radial oscillations of the disk, driven in the boundary layer region (Hesser, Lasker and Osmer 1972). Since LSI 55°-8 is not known to have undergone a large change in brightness with time like the dwarf novae, Quigley and Africano classified it (correctly) as a nova-like variable. It is generally believed that nova-like variables are either (a) old novae that have undergone outbursts that were unrecorded or (b) dwarf novae that are in very extended high states similar to those observed for the Z Cam systems, but of much longer duration (Warner 1976).

THE OBSERVATIONS

LSI 55°-8 was observed with the IUE satellite on 1981, December 05 as part of a continuing ultraviolet study of nova-like variables. Five low dispersion (~6A) SWP spectra ($\lambda\lambda1175-1900$) and two LWR spectra ($\lambda\lambda2100-3100$) were obtained over a 4 hour time interval. In addition, the optical brightness of the star was monitored between the UV exposures using the Fine Error Sensor (FES) onboard the satellite. The FES counts were converted to V-magnitudes using the calibration of Holm and Crabb (1979). During the observing interval the range of visual magnitudes was between $+12^m63 \leq V(FES) \leq +12^m78$. These values are close to the value of V=+12.79, measured earlier by Haug, and the short-term variability in light is similar to that found previously by Africano and Quigley.

RESULTS

The far UV spectrum of LSI 55°-8 (SWP 15659S) is shown in Fig.1 where the data reduction was by the standard IUESIPS routines. The identified spectral features are shown in the figure and also

are listed in Table I along with the rest and measured wavelengths, the residual intensities, the line widths at half maximum, and the corresponding Doppler displacement velocities. The LWR spectra of the star are essentially featureless. The UV spectrum of LSI 55°-8 is strikingly similar to the nova-like binaries V3885 Sgr (Guinan and Sion 1982) and RW Sex (Greenstein and Oke 1982), which both show strong, blue-shifted absorption lines of such high temperature ions as C IV, NV, Si IV, and He II in their SWP spectra. As can be seen from the table, the high temperature ($\sim 10^5$K) ions of C III, C IV, He II, NV, and Si IV have relatively large negative Doppler shifts corresponding to radial velocities between -800km s^{-1} and -1400km s^{-1}. Much higher expansion velocities are associated with the broad absorption wings of the lines. The low temperature ($\sim 10^4$K) ions of H I (Lyα), O I, Si II, and Si I do not appear to show significant velocity displacements and probably originate from the outer accretion disk, with some contribution from the interstellar medium. In addition, the C IV ($\lambda 1549$) resonance doublet shows a variable P Cygni-type profile with a blue-shifted absorption component. The presence of this feature, along with the blueshifted absorption features of the high temperature ions, indicate the existence of outflowing hot plasma (i.e. a wind). Using the method of Castor, Lutz and Seaton (1981), an upper limit of the mass outflow rate can be made from the short wavelength edge of the C IV absorption which yields $\dot{M}_{max} \gtrsim 10^{-9} M_\odot$/yr. Fig. 2 shows a plot of the normalized C IV profile as a function of time. As shown in this figure, the C IV profile is variable with the largest changes occurring in the relative strength and shape of the emission component. These changes appear to be systematic and may be associated with the changing projection of the outflowing hot plasma against the disk as a function of orbital motion. We have found similar behaviour for the C IV feature of TT Ari, in which the profile appears to change with its orbital motion (Guinan and Sion 1981). Fig.3 shows the residual line intensities of a few of the stronger spectral features as a function of time; in addition to the C IV variations, it appears that strength of the He II ($\lambda 1640$) absorption feature is also time dependent. Although at low resolution it is difficult to be certain, it appears that the observed changes in the He II residual intensity are caused by broad emission filling in the bottom of the absorption feature. If this is the case, there appears to be correlation between the observed decrease in the C IV emission line strength with time and the decrease of the He II emission, inferred from the apparent strengthening of the He II absorption line feature with time.

Although LSI 55°-8 is not definitely known to be a binary system, it has most of the characteristics (both spectral and photometric) exhibited by the nova-like, UX UMa-type variables, as well as with the dwarf novae in outburst or standstill. These systems are believed to be very short period, close binaries involved in active mass transfer and mass loss via Roche lobe overflow of gas from a low mass, cool star onto a white dwarf (Robinson 1976). An accretion disk is formed around the white dwarf compon-

ent as a result of the mass transfer mechanism and is predicted
by Herter et al. (1979) to dominate the luminosity of the system
at all but long wavelengths. Using the interstellar extinction
law of Nandy et al. (1975), the data was de-reddened after several
trials until no perceptable 'dip' (under-corrected for inter-
stellar extinction) or 'hump' (overcorrected interstellar extinct-
ion) appeared at $\lambda 2200$. A value of $E_{B-V}=0.30$ was adopted and the
observations were corrected for interstellar extinction and appear
in Fig. 4 as log F_{ν} vs. log ν. Various steady state, accretion disk
model fluxes were tried (Herter et al.(1979); Pacharintanakul and
Katz (1980); Williams(1981))with the model fluxes of Williams
yielding the best fit to observations. As shown in the figure,
the steady-state accretion disk of Williams with accretion rate of
$\dot{M}\sim 10^{-7} M_{\odot}$/yr.and i=0 fits the data very well. The disk model fluxes
of Herter et al. and Pacharintanakul and Katz produce higher
than observed fluxes in the far UV relative to the optical wave-
length fluxes. Unfortunately the Williams' fluxes are available
only for the case in which the disk is seen face-on (i=0). The
effect of viewing the disk at higher inclination has been invest-
igated by Herter et al., and produces a decrease in the far UV
flux relative to optical wavelengths, as the outer, cooler portion
of the disk beginsto dominate the observed radiation. From the
appearance of its optical and UV spectrum (especially the presence
of the blueshifted absorption features of the highly ionized
species and C IV P Cygni-type profile), and the lack of signific-
ant periodic light variations, it appears that LSI 55-8 is being
viewed at a low inclination (i$\sim$50°). The high accretion rate of
$\dot{M}\sim 10^{-7} M_{\odot}$/yr, inferred from fitting the Williams disk model fluxes
to our data, would appear to support the hypothesis that LSI 55-8
and related nova-like systems are in a state of prolonged outburst.

A ground-based radial velocity study of the star is needed to
confirm the binary nature of the object and to determine its
orbital period. The spectral changes observed in our study indic-
ate a period $3^h<P<7^h$. We plan to publish a more thorough invest-
igation of this interesting star in the near future. We wish at
this time to thank Dr. Howard Bond for supplying us with an iden-
tification chart, and also to thank Dr. Robert Williams for send-
ing unpublished theoretical disk model fluxes.

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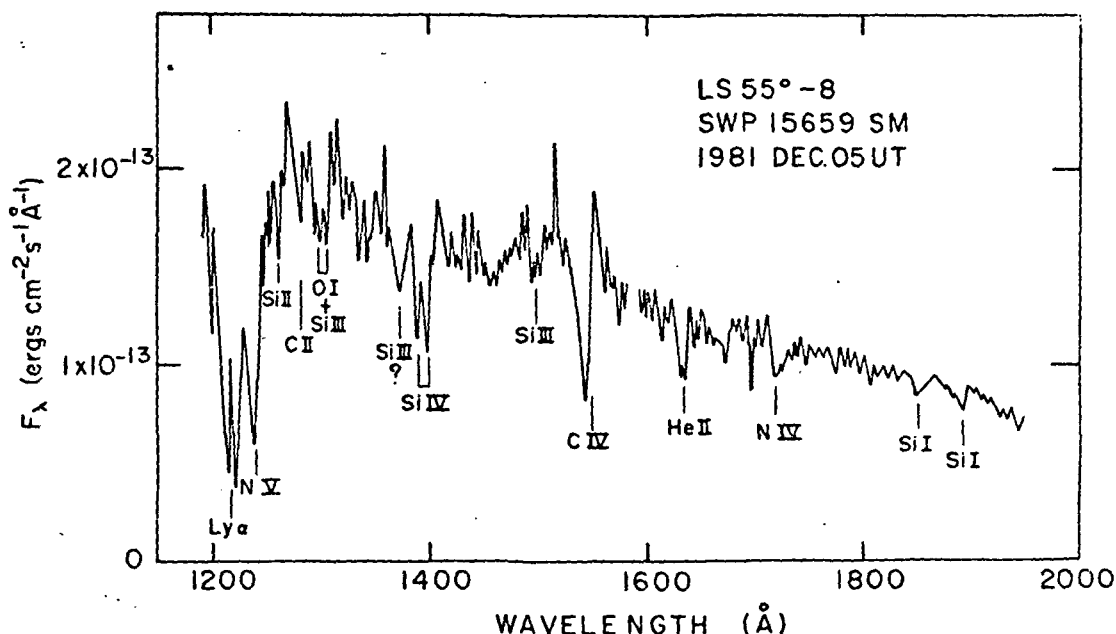Williams, R.E. 1981, unpublished models.

Fig. 1. The SWP 15659 (small aperture) spectrum of LSI 55°-8 with the stronger spectral features identified.

TABLE 1

Measurements of Some of the
Stronger Spectral Features
of LS55 -8 (on SWP 15659S)

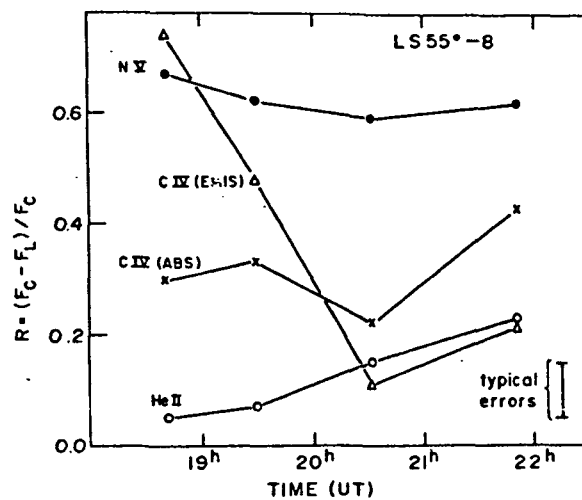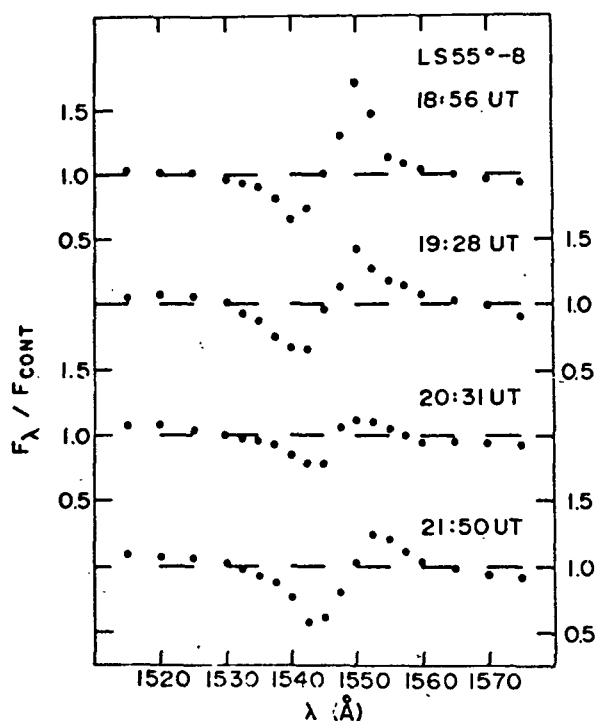| ION	$\lambda_0(\text{Å})$	$\lambda_{OBS}(\text{Å})$	$(F_C-F_L)/F_C$	$\lambda_W(\text{Å})$	$V_r(\text{KMS}^{-1})$
CIII	1175.67*	1170	0.49	6	-1445
HI(Ly)	1215.67	1216	0.82	24	+81
HeII	1215.17				
NV	1240.15*	1237	0.77	11	-760
SIII	1262.6*	1263	0.17	5:	+100
OI+SiIII	1303*	1302	0.21	14:	-230
SiIV	1393.73	1390	0.28	6	-800
SiIV	1402.73	1399	0.32	7	-800
CIV	1549.05*	1542	0.44	10	-1365
		1553	-0.28	8	+785
HeII	1640.47	1633	0.23	10	-1365
SII	1852.5*	1853	-0.10	9	+80
SII	1893.25*	1893	0.12:	10	+120

Fig. 3. The observed residual intensities of C IV (absorption and emission components), He II(λ1640), and N V(λ1240) as a function of time.

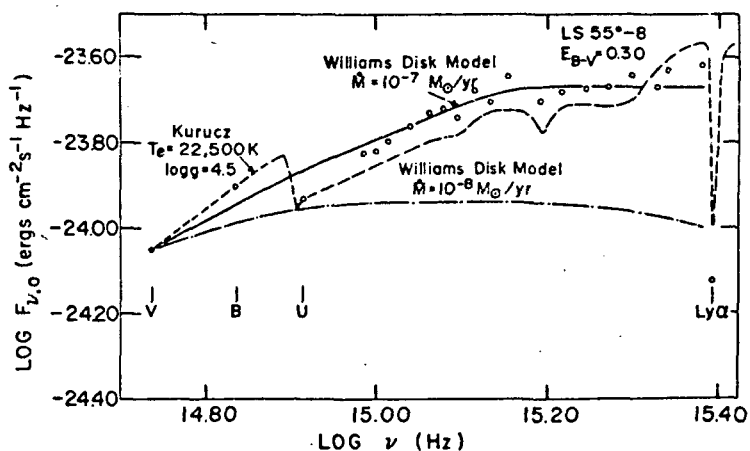Fig. 2. The variation of the normalized C IV (λ1549) profiles of LSI 55°-8 with time.

Fig. 4. The de-reddened continuum fluxes of LSI 55°-8 plotted along with the Williams' (1981) accretion disk fluxes. The stellar fluxes for T_{eff} = 22,500°K; log g=4.5 from Kurucz (1979) are also plotted for comparison. All of the model fluxes have been normalized to the observed flux near λ5500. (i.e. log F_{ν}=14.74).

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AN ULTRAVIOLET INVESTIGATION OF THE UNUSUAL ECLIPSING BINARY SYSTEM FF AQR

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INTRODUCTION

FF Aqr (BD-3°5357) is an eclipsing binary which consists of a G8 III-IV star and a subdwarf in a $9^d.2$ orbit. IUE and optical observations of such a system provide a unique opportunity to extract information about the temperature, gravity and composition of the subdwarf as well as about the chromosphere of its giant companion, which is known to have strong Ca II H+K emission and may resemble members of the RS CVn group. A series of 7 low-dispersion IUE exposures in both wavelength regions was obtained on Dec. 6, 1981 during the eclipse of the subdwarf, during egress, and out of eclipse. In Fig. 1 these observations and the binary phase at which they were made are shown on a schematic representation of the V-band light curve obtained in 1975 by Dworetsky et al. (1977). The depth in V is 0.15 mag. The circles are IUE V- magnitudes from FES measures obtained during the observing run. They indicate an eclipse depth some 0.05 mag. lower than expected, possibly due to difficulties with the color term in the FES calibration. In our calculations we assumed the eclipse depths of Dworetsky et al. in U, B and V.

THE SUBDWARF COMPONENT

The smoothed continuum flux of the spectrum LWR 12086 (large aperture) taken during total eclipse was subtracted from the out-of eclipse spectrum LWR 12088 (large aperture) to yield the UV continuum flux longward of 1900 Å for the subdwarf alone. For the shortwave region, spectrum SWP 15662 yields the subdwarf flux directly since the continuum is essentially zero in the spectrum SWP 15660 taken in eclipse. The calibrated flux from these large-aperture exposures is shown in Fig. 2, and includes the Lyα line. The UV flux was de-reddened adopting $E_{B-V} = 0.10$, and the interstellar extinction law of Nandy et al. 1975, which is sufficient to fill in the shallow interstellar extinction feature near 2200Å. In principle log g and T_{eff} can now be determined. However suitable model atmospheres for subdwarfs are not readily available. We used the model atmospheres of Kurucz (1979) for stars of solar abundance, and the pure hydrogen models of Wesemael et al. (1979) for high gravity stars. Fits using both models are shown in Fig. 2. The Kurucz model provides a better fit to the UV continuum and the optical U, B, V fluxes, while the Wesemael model gives a much better fit to the Lyα line, and permits a more accurate determination of log g. A temperature near 35,000°K and log g ∿ 6.0 are suggested. For $E_{B-V} = 0.10$ the intrinsic color of the giant component is $(B-V)_o = +1.00$ which corresponds to a spectral type near G8 III and T = 4800°K, hence $m_{bol} = +9.17$. A distance of 320 pc and a radius of 6.1 $R_\odot$ is consistent with the analysis of Dworetsky et al. and with an absolute magnitude $M_{bol} \sim +1.60$ derived from our own analysis of λ And, which is also a G8 III-IV star, but of known distance (Dorren and Guinan 1982). Masses of 0.5 $M_\odot$ and 2.0 $M_\odot$ for the subdwarf and giant respectively are consistent with the mass function of f(m) = 0.0188 and the inclination of 81° which, following

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Dworetsky et al., we adopt. The eclipse duration implies that for i = 81°, R_{sd} = 0.1 $R_{\odot}$ and log g $\sim$ 6.1.

The subdwarf spectrum is shown in Fig. 3 for the short wavelength region, with the identification of the prominent absorption lines. It shows strong C II as well as C IV and Si IV. Note that He II λ1640 is relatively weak. Its presence is, however, confirmed by our other spectra. Its weakness can be understood as either representing a low surface abundance due to diffusion or as due to the lower effective temperature range of the subdwarf (35,000K $\leq T_e \leq$ 40,000) especially in view of the absence of the middle ultraviolet He II (3 → n) series in the LWR spectrum. Thus it is expected that HeII (λ4686) would be weak in the optical spectrum and the classification would probably be sdOB. Unfortunately the cool component dominates the light at optical wavelengths making a direct measurement of the He II λ4686 feature difficult. On a log g/log T_{eff} plot (Fig. 4, from Hunger and Kudritzki, 1981) the subdwarf in FF Aqr appears to the right of the subdwarf group. The approximate boundary between sdB and sdO subdwarfs lies at log $T_e \sim 4.6$. In the same figure we show for comparison a downward extension to higher gravity and temperature of the Strittmatter and Norris (1971) boundary between the domain of radiation pressure driven mass loss and surface diffusion. Stars to the right of the dashed boundary should generally be weak helium line/metal deficient objects due to downward diffusion. Neglecting the possible effects of accretion, the observed strength of the helium and metal lines in the subdwarf in FF Aquarii may shed light on the evolutionary status of the hot subdwarfs and in particular the possibility of an sdO/sdB evolutionary transition.

THE COOL COMPONENT

The SWP spectrum of the G8 star is shown in Fig. 5 in which the emission lines are identified. The spectrum is generally similar to that of λ And (Baliunas and Dupree 1982) with the hot transition region lines of NV, C IV and C II prominent and with weaker Si IV and He II as is found in stars with active chromospheres. In fig. 6 the ratio of line fluxes at Earth to apparent bolometric luminosity (Ayres et al. 1981) are plotted against the same ratio for Mg II (from LWR 12086) and compared with the fluxes from the most active RS CVn stars HR 1099 and UX Ari, with the similar giant component of the RS CVn system λ And, and with the unusual rapidly rotating G - giant FK Comae and another member of this interesting small group, HD 199178 (Bopp and Stencel 1981). Relative to Mg II, the star has greater emission in the hot lines in particular than the active RS CVn stars. We note that the observed distortions of the light curve (Dworetsky et al.) may be due to surface activity on the G star (spots?) rather than the reflection effect which should be negligible for this system.

In a separate paper we hope to analyze the subdwarf with more suitable model atmospheres and investigate its evolutionary status. Our own optical photometry from 1977-1978 will also be analyzed to obtain tighter constraints on the parameters of this important system.

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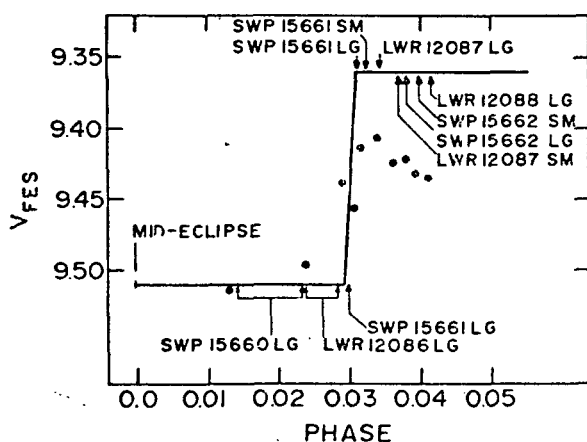Wesemael, F., Auer, L.H., Van Horn, H.M. and Savedoff, M.P., 1980, Ap. J. Suppl. 43, 159.

Fig.1-Orbital phase of the IUE exposures shown on a schematic light curve. The circles are the FES V-magnitudes.
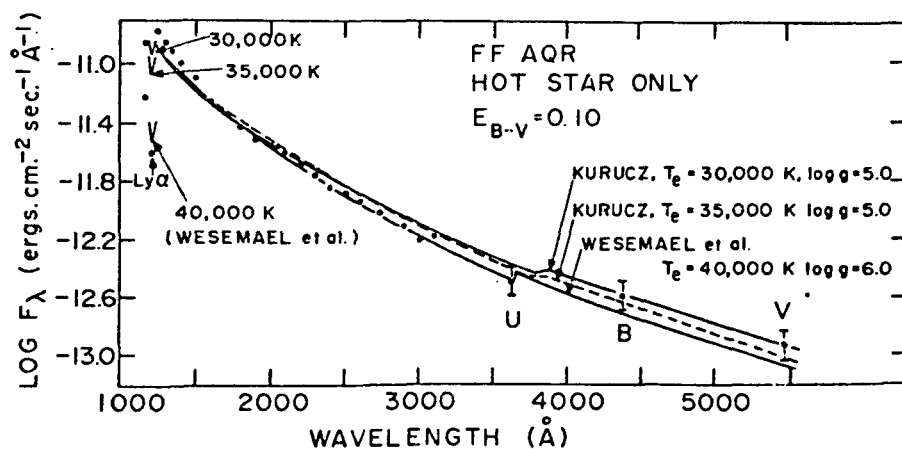

Fig.2-UV and optical fluxes for the hot subdwarf, assuming E_{B-V} = 0.10. Kurucz and Wesemael et al. fits are shown.
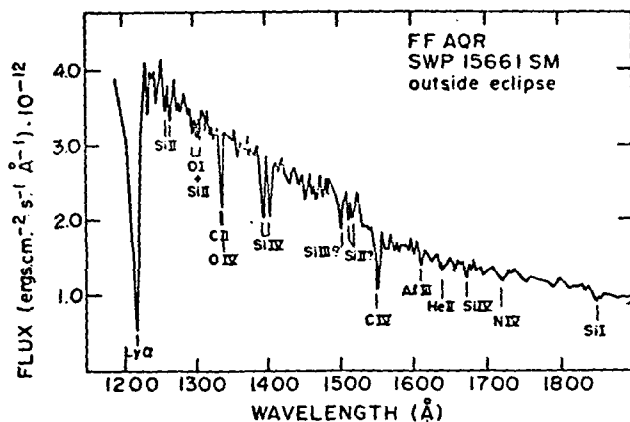
Fig.3-The subdwarf UV spectrum from 1200-1900 Å with prominent absorption lines identified.
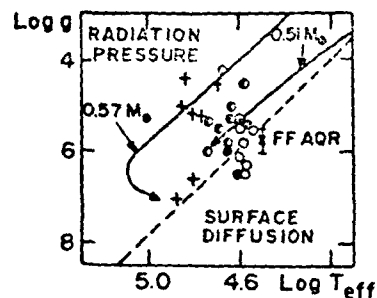

Fig.4-Position of the subdwarf on a log g / log T_{eff} plot. Evolutionary tracks for 0.51 and 0.57 $M_\odot$ stars are shown. The dashed line is discussed in the text. The positions of sdOB stars (o), extreme He-rich (•) and intermediate He-rich stars (⊙), and central stars of planetary nebulae (+) are shown. (From Hunger and Kudritzki 1981).
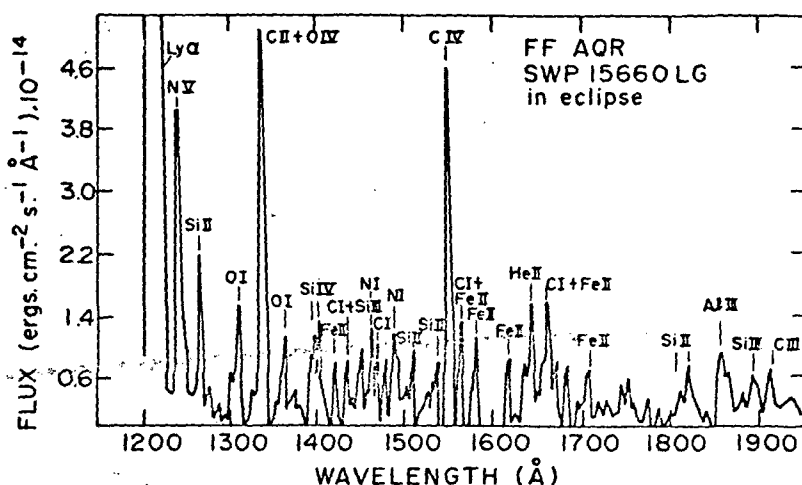

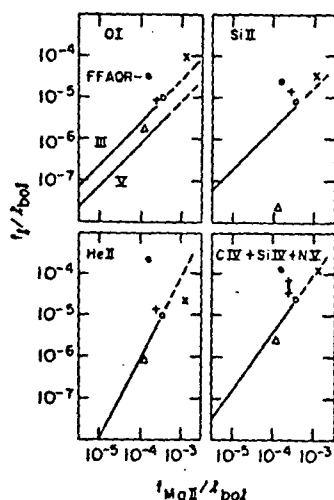Fig.5-The spectrum of the G8 III-IV component with prominent emission lines identified.

Fig.6-Correlation diagrams for chromospheric and transition region fluxes for late-type giants and dwarfs (solid lines: Ayres et al. 1981). The cool star in FF Aqr (•) compared with FK Com (x), HD 199178 (+), the mean of HR 1099 and UX Ari (o), and λ And (Δ) (Bopp and Stencel 1981).

THE HOT DO WHITE DWARF HD 149499 B: EINSTEIN REDSHIFT OF A DB PROGENITOR WITH CARBON FEATURES

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ABSTRACT

High-resolution *IUE* spectra of the hot DO white dwarf HD 149499B have been analyzed. The mass of the white dwarf needed to fit our measured gravitational redshift is $0.5 \pm 0.1 \, M_{\odot}$ for a degenerate core composed of carbon based upon using a nonzero temperature mass-radius relation. The resonance doublet of C IV ($\lambda 1550$) appears to be photospheric in origin, and two possible explanations for the presence of carbon in a hot DO white dwarf are discussed. The relationship of HD 149499B and other DO white dwarfs to the DB white dwarfs is also considered.

Subject headings: stars: atmospheres — stars: white dwarfs

I. INTRODUCTION

The DO white dwarfs have long been thought to be the immediate, hot, helium-rich progenitors of the chemically pure DB white dwarfs, although, for the derived abundances of DO stars, dilution or expulsion of remaining hydrogen may be still required (see Sion, Guinan, and Wesemael 1982). It now appears that there are three distinctly different classes of DO white dwarfs Wesemael *et al.* 1983). Members of the hottest temperature class ($T_e \geq 80,000$ K) have ultraviolet photospheric metal lines not unlike the hottest subdwarf O stars; an intermediate temperature class of DO stars ($T_e \sim 70,000-80,000$ K) exhibits photospheric metals with only He II in the optical, and a "cooler" type ($T_e \sim 50,000-60,000$ K) like HZ 21, Lanning 14, and HD 149499 B, exhibits no positively detected photospheric metal lines from low-dispersion *International Ultraviolet Explorer* (*IUE*) spectra.

High-dispersion *IUE* spectra can provide crucial information on the nature of the hot DO stars by revealing weak photospheric features, narrow, non–local thermodynamic equilibrium (non–LTE) line cores, and evidence for mass outflow and circumstellar gas. HD 149499 B is one of a handful of hot degenerates bright enough to be observed at high resolution with the *IUE* spacecraft. High-resolution spectra of HD 149499 B were obtained by us in 1979 August. The detailed line profile data from these spectra, along with low-dispersion UV line profiles, *IUE*, *Voyager 2*, and optical continuum fluxes, were used to do a detailed spectrophotometric analysis (Sion, Guinan, and Wesemael 1982, hereafter SGW). However, over a dozen positively identified weak line features in the high-resolution spectrum of HD 149499 B are definitely interstellar in origin. The local interstellar medium in the directions of HD 149499

B and three other white dwarfs has been thoroughly investigated by Bruhweiler and Kondo (1981, 1982) who analyzed the interstellar absorption lines in high-resolution *IUE* spectra.

In the present work, we analyze weak noninterstellar line features (C IV $\lambda 1549$ and He II $\lambda 1640$) first reported by Sion and Guinan (1982), who presented a preliminary gravitational redshift determination. These features were detected only at high resolution and shed further light on the nature of the DO stars. Our objectives in this *Letter* are to (1) analyze the C IV ($\lambda 1549$) resonance doublet as a test of the effect of radiative accelerations on diffusion time scales as well as theoretical predictions based upon diffusion theory, (2) explore the possible evolutionary implications of having carbon features in the spectrum of a hot DO white dwarf, and (3) determine an Einstein gravitational redshift for the hot white dwarf using the core of the He II ($\lambda 1640$) absorption feature and a K0 V companion of known radial velocity. To our knowledge, HD 149499 B is the hottest white dwarf for which a gravitational redshift has been determined and thus makes possible the first direct test, for a non-DA white dwarf, of the effect of nonzero temperature on the mass-radius relation for a completely degenerate configuration.

In § II we present our high-resolution observations and discuss the accuracy of our *IUE* wavelength scale: in § III we describe the Einstein redshift determination and discuss its implications; in § IV we discuss evolutionary implications of the C IV absorption features, and in § V we summarize our conclusions.

II. HIGH-RESOLUTION SPECTRUM

Observations of HD 149499 B were obtained on 1979 August 24 with the high-resolution echelle mode of the

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IUE. A detailed description of the spacecraft instrumentation is found in Boggess *et al.* (1978). Two images were obtained with the large aperture, one with the short-wavelength prime camera (SWP 6272) having an exposure time of 90 minutes and one with the long-wavelength redundant camera (LWR 5442) having an exposure time of 75 minutes.

The data reduction for our spectra was carried out at the *IUE* data reduction facility at the Goddard Space Flight Center. The data were corrected for echelle ripple and background as provided by the *IUE* Observatory. Wavelength corrections are also required for effects of thermal and temporal variations on the SWP camera. The resulting wavelength calibration yields an absolute wavelength scale accurate to approximately 3 km s^{-1} (see Bruhweiler and Kondo 1982). A check on our measured wavelengths was made through comparison with those measured by Bruhweiler and Kondo (1982) for several interstellar lines in the spectrum of HD 149499 B. In seven out of eight lowly ionized interstellar features across the SWP region measured by ourselves and Bruhweiler and Kondo (1982), agreement was exact to a hundredth of an angstrom. An independent check on our measured wavelengths was made by comparison with measurements of Dupree and Raymond (1982) for the C IV (λ1549) features and the He II (λ1640) absorption core in their four SWP spectra of HD 149499 B. Again, agreement with our measurements was excellent.

The two strongest features in the SWP spectrum are the stellar absorption features due to Lyα + He II (λ1216) and He II (λ1640). Unlike the low-dispersion spectrum of HD 149499 B, the high-dispersion spectrum reveals a very sharp He II (λ1640) core, which is briefly discussed in SGW, and a strong, sharp resonance doublet of C IV (λ1550). In Figure 1 the sharp He II line core is shown, and in Figure 2 we display the C IV resonance doublet. For comparison, three N I lines which are typical of the interstellar features in the spectrum of HD 149499 B are shown in Figure 3. The observed low-dispersion He II (λ1640) profile has an equivalent width of 4–5 Å (see SGW, Fig. 3), and the expanded wavelength scale of the He II region in the high-resolution spectrum shown in Figure 1 reveals the sharp core but not the entire profile whose wings extend far beyond the scale of Figure 1. The identifications and wavelength displacements of the interstellar lines in the UV spectrum of HD 149499 B are tabulated by Bruhweiler and Kondo (1982) and are not repeated here. However, in the region of Mg II ($\lambda\lambda$2795, 2802), the LWR spectrum is extremely noisy, making it difficult to measure $\Delta\lambda$ for the absorption components, which we interpret as interstellar. However, our LWR spectrum reveals emission components of Mg II whose displacements indicate they arise from the K0 V star HD 149499 A which is the cool component of the visual pair, at a present separation of approximately 1".5.
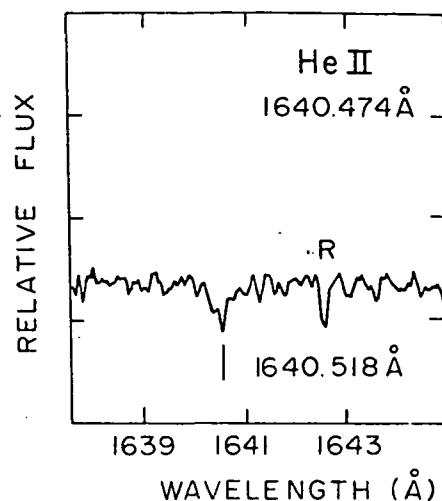

Fig. 1.—*IUE* high-resolution line fluxes for He II (λ1640). The data displayed are from SWP 6272 and reveal the sharp line core. The rest wavelength is shown to the upper right. The feature just longward of λ1642 is a reseau mark.

The sharp core of the He II (λ1640) was measured on the single high-resolution spectrum of SGW and three high-resolution exposures obtained by Dupree and Raymond (1982). In each case, the line center was defined to be the deepest part of the line. The average displacement was found to be $\Delta\lambda = +0.05 \pm 0.02$, considerably redshifted relative to the lowly ionized interstellar features. The longward component (λ1550.774) of the C IV (λ1550) resonance doublet, whose displacement is less affected by interstellar contribution, yielded $\Delta\lambda = +0.06 \pm 0.02$ for the four combined spectra. Each
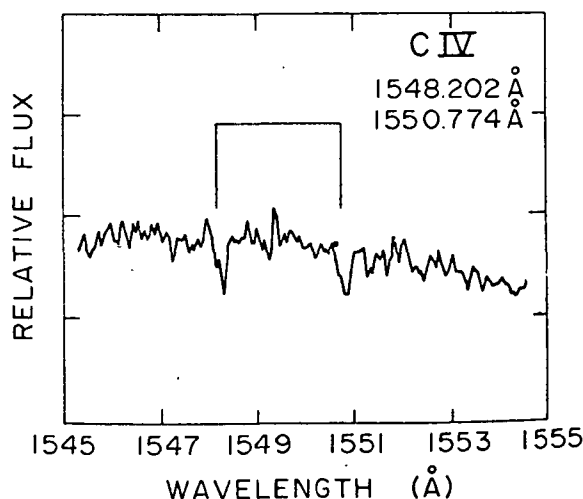

Fig. 2.—The *IUE* spectral region covering C IV from SWP 6272. The two components have slightly different measured wavelength displacements, and the rest wavelengths are shown to the upper right.
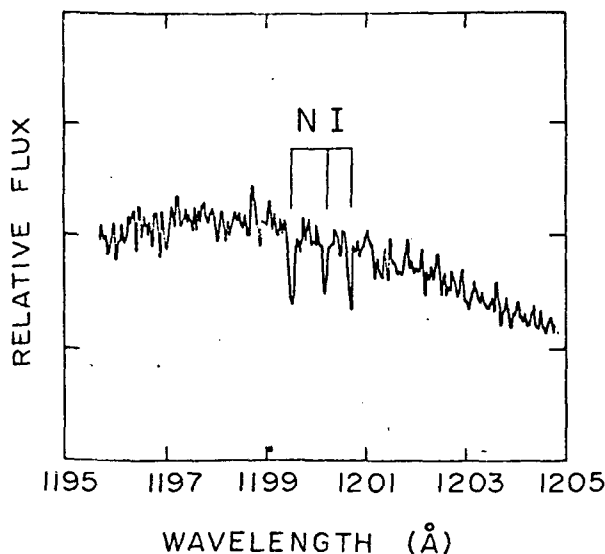
FIG. 3.—*IUE* data showing three N I lines typical of the sharp interstellar features in the spectrum of HD 149499 B.

component of C IV has an equivalent width of ~ 80 mÅ and is redshifted relative to the interstellar features.

We feel that the C IV absorption in the spectrum of HD 149499 B is most likely photospheric rather than interstellar in origin. A photospheric origin is supported by (*a*) C IV having the same wavelength displacement as He II (λ1640), (*b*) the apparent absence or extreme weakness of N V (λ1240) and Si IV (λ1400) to the limit of 20 mÅ which would be present if the C IV were interstellar, (*c*) the likelihood that C IV ions would be supported by differential radiation pressure force at the effective temperature (~ 55,000 K) of HD 149499 B (Fontaine and Michaud 1979; Vauclair, Vauclair, and Greenstein 1979), and (*d*) the presence of C IV in the low-dispersion *IUE* spectra of at least four hotter DO stars (Wesemael *et al.* 1983). We return to points (*c*) and (*d*) in § IV.

III. GRAVITATIONAL REDSHIFT DETERMINATION

Correcting for the motion of the Earth and the *IUE* spacecraft (+23 km s^{-1}), the displacement of the He II core yields $V_r = -14.2 \pm 2.8$ km s^{-1} for the heliocentric radial velocity of HD 149499 B. Wegner (1978) measured the heliocentric radial velocity of the K0 V component (HD 149499 A) to be -31 ± 3 km s^{-1} from the Na D and Ca I lines. His measurement was made from a red spectrum using a coudé spectrograph with a plate factor of 13.6 Å mm^{-1}. The errors in Wegner's radial velocity measurement and our *IUE* measurements are roughly comparable. Using $V_r = -31$ km s^{-1} and our heliocentric radial velocity for the white dwarf yields a velocity displacement due to the Einstein redshift of $+17 \pm 5$ km s^{-1}. This value is well below the mean

gravitational redshift (+45 km s^{-1}) of DA stars determined by Greenstein *et al.* (1977) but is consistent with, for example, the redshift of 40 Eri B (Wegner 1980) and corresponds to a 0.4–0.5 $M_\odot$ white dwarf composed of carbon based upon the zero-temperature mass-radius and mass-gravity relations of Hamada and Salpeter (1961). Moreover, the relatively low mass (~ 0.45 $M_\odot$) needed to fit our gravitational redshift is not inconsistent with the lower mean mass (0.44 $\pm$ 0.01 $M_\odot$) derived by Koester, Schulz, and Wegner (1981) from fitting colors and equivalent widths of DB stars. However, such masses are uncomfortably small if they correspond to white dwarfs with cores composed of carbon since they are not much larger than the minimum mass for helium burning.

In interpreting our gravitational redshift, one should be cautioned about effects which would tend to yield a lower redshift value. At a surface temperature of 55,000–60,000 K, the radius of HD 149499 B could be larger than that of a completely degenerate, zero-temperature configuration as in Hamada and Salpeter (1961). However, according to the latest evolutionary models by Winget, Lamb, and Van Horn (1983), using state-of-the-art envelope physics for a cooling carbon white dwarf, release of gravitational energy and the radius correction due to nonzero temperature for a star which has cooled to the temperature of HD 149499 B is too small ($\leq$ 25% radius increase; see below) to make a significant difference. If the sharp core of He II (λ1640) forms significantly higher in the atmosphere than in the wings, a lower gravitational redshift derived from this line would result. Although one cannot completely rule out this possibility, it is difficult to understand how helium could be supported at a significant fraction of the stellar radius above the photosphere. We prefer to interpret the sharp core as being due to non–LTE effects (see SGW).

If our gravitational redshift is compared to a mass-radius relation defined by the models of Winget, Lamb, and Van Horn (1983), the implied mass is between 0.5 $M_\odot$ and 0.6 $M_\odot$, a value higher than that implied using the Hamada-Salpeter (1961) relation. Moreover, the higher implied mass agrees with the radius determination reported in SGW based upon the photometric parallax and temperature determination for HD 149499 B. The recent trigonometric parallax by Ianna, Rohde, and Newell (1982) agrees very closely with the distance used in SGW (34 pc vs. 36 pc) yielding a radius very close to that reported in SGW. Unfortunately, the comparison of our radius with the Winget *et al.* models is possible only for 0.6 $M_\odot$ until other models become available. For temperatures between 50,000 and 70,000 K, the radius increase over the zero temperature value is 25% or less for a pure carbon model and for a ^{12}C core with a helium layer of 10^{-6} stellar masses and hydrogen layer of 10^{-10} stellar masses.

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IV. IMPLICATIONS OF IONIZED CARBON FEATURES

The presence of carbon in the photosphere of HD 149499 B suggests two interesting possibilities. The first one involves the net downward diffusion velocity for a helium-rich white dwarf which depends upon the competition between the downward acceleration due to gravitational plus thermal diffusion g_{GT} and the radiative acceleration g_{rad}. Vauclair, Vauclair, and Greenstein (1979) have shown that, in helium-rich envelopes, radiative accelerations are larger due to the larger broadening of the lines, whereas saturation effects prevent an enhancement of CNO ions for hydrogen envelopes. For a helium-rich white dwarf with $M = 0.5$ $M_\odot$ and $T_e = 55,000$ K as in HD 149499 B, $\log g_{rad} > \log g_{GT}$ for temperatures greater than $\log T = 4.75$ which corresponds to a mass fraction $\Delta M/M \sim 5 \times 10^{-16}$ at $\tau = 1$. Thus, the presence of photospheric carbon in observable amounts in HD 149499 B would appear to confirm the predictions of diffusion theory. However, it should be noted that the theory is still beset with uncertainties in the proper treatment of diffusion at small optical depth. The absence or extreme weakness of observable nitrogen in HD 149499 B would suggest that since g_{rad} is greater on nitrogen than carbon in a helium-rich white dwarf, the nitrogen may have left HD 149499 B earlier in the form of a wind driven by selective radiation pressure.

The other possibility emerges from consideration of dredge-up processes that occur before ejection of a planetary nebula and the possible linkage of these processes with the origin of the and DB white dwarf spectral sequences. Iben (1976) shown that, for stars larger than 3 $M_\odot$, inward penetration by envelope convection lifts away nitrogen created from carbon in the CNO shell source during the first ascent of the giant branch and lifts away more nitrogen as well as helium from the helium zone surrounding the inert $^{12}C - ^{16}O$ core during the second ascent of the giant branch. Recent evolutionary model calculations by Iben et al. (1983) show that some planetary nebula central stars, cooling in the range from 10 to 100 $L_\odot$, can undergo a late helium-shell flash and retrace their evolutionary path back to the red giant domain as the final thermal pulse causes the core to brighten. Preliminary results indicate that a substantial number of planetary nuclei may undergo the final thermal pulse (Kaler 1982), although dependence upon interior parameters is still unclear.

Models such as these (1) may explain the phenomenon of Abell 30 and Abell 78 (Iben et al. 1983), large high-excitation planetary nebulae that exhibit zones of nearly pure helium near their cores, and (2) may be relevant to the origin of DB white dwarfs. If we suppose that HD 149499 B is a true hot progenitor of DB stars

from single star evolution, the presence of carbon and absence of nitrogen may be an artifact of pre-white dwarf evolution and a common characteristic of DB progenitors. This suggestion is strengthened by statistical arguments that the C_2 white dwarfs are cooled DB stars (Sion, Fragola, and O'Donnell 1979) and by the recent detection by Wegner (1980) of neutral helium in the optical spectra of two C_2 stars. In addition, neutral atomic carbon lines have been detected in several DC white dwarfs known to be helium dominated, in other words, cooled DB stars. It should be noted, however, that carbon in the photosphere of a hot DO star could be explained by mechanisms other than the two we have discussed above. Recently, for example, Wesemael and Truran (1982) have discussed the accretion of grains by slowly rotating, weakly magnetic, helium-rich white dwarfs as a means of explaining metal features in the spectra of objects much cooler than HD 149499 B.

V. SUMMARY OF CONCLUSIONS

From high-resolution *IUE* spectra of the hot DO white dwarf HD 149499 B, we have used the sharp, non–LTE He II line core to derive a gravitational redshift which, within the observational uncertainties, is fitted by a carbon core with a mass of 0.5 ± 0.1 $M_\odot$. If this star is a true DB white dwarf progenitor, the low mass is not inconsistent with generally lower masses of DB stars derived from model atmosphere fits by the Kiel group in particular.

We argue that the C IV resonance doublet detected in our high-resolution *IUE* spectrum is photospheric in origin. We suggest that its presence can be attributed to differential radiation pressure force on carbon ions, or an enhanced carbon abundance due to dredge-up processes, or a late shell flash during the pre–white dwarf evolutionary phase, or to all three.

Theoretical C IV line profiles are needed in order to place limits on the carbon abundance in HD 149499 B and other hot helium-rich degenerates. This would enable us to make a study of the carbon abundances that are present in the hottest DO stars down to the coolest DB stars as a function of radiative acceleration and gravitational thermal diffusion time scales.

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KING: Since you have such large line opacities wouldn't it be the
case that your ratios will be affected by the deviation from spherical
symmetry, so that if it is the secondary, as it moves around, your pre-
dicted ratios should change.

METZGER: Yes, definitely, if you talk about Balmer decrement, my
prediction is that it should change.

SHAVIV: Is the continuum between the lines real continuum or
noise?

METZGER: First, you have seen the M giant which was very strong
and that was subtracted by another M giant.

SHAVIV: Do you then have an estimate for the relative energy in
all the lines and the continuum.

METZGER: Yes, I do, this comes from other people's observations
with the IUE, this relates to my answer about the covering factor
much of the source is covered by clouds)

KQ MON AND THE NATURE OF THE UX URSA MAJORIS NOVA-LIKE VARIABLES

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ABSTRACT

KQ Mon, a new UX UMa type nova-like variable discovered by
H.E. Bond, exhibits optical spectra, UBV and high speed photometric
characteristics strongly similar to other members of the UX Ursa
Majoris subset. However its ultraviolet spectra when compared with
other UX UMa stars shed considerable light on the nature of these
objects. Its spectrum is dominated by strong broad highly ionized
absorption lines including the NV, SiIV and CIV UV resonance doublets.
No emission lines or P Cygni type features are evident and the velocity
displacements are smaller suggesting the absence of a not high velocity
wind characterizing other UX UMa stars. A physical interpretation of
the UV absorption spectra and optical spectra and their observed
temporal variations is presented. Based upon (1) high mass accretion
rates derived by fitting the observations with theoretical continuum
fluxes from steady accretion disk models by R.E. Williams, (2) the
presence of outflowing winds with the determination of corresponding
mass loss rates and properties of the theoretical wind models by
Cassinelli, Olson and Stalio, and (3) new time independent steady state
disk structure computations, a model is suggested to explain the
observed properties of the UX UMa stars and their lack of major outbursts.

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1. INTRODUCTION

The UX Ursa Majoris stars form a group of nova-like variables
with common photometric and spectroscopic properties. The optical
characteristics of these objects are thoroughly described by Warner
(1976). They appear to be related to the cataclysmic variables but
are not known to have undergone major outbursts such as those observed
for dwarf novae, recurrent novae, classical novae, or symbiotic
variables. In order to understand the still uncertain evolutionary
connection between the UX UMa stars, the old novae, the dwarf novae in
the outburst or extended high states and other cataclysmic variables
as well as the physics of steady state disks, it is fundamentally

important to know why any outburst behavior is absent in these stars. Critical new information about the UX UMa stars has recently become available from x-ray observations with the Einstein satellite (cf. Cordova, Mason and Nelson 1981) and ultraviolet spectroscopy with the International Ultraviolet Explorer satellite (cf. Greenstein and Oke 1982, Holm, Danek and Schiffer 1982, Guinan and Sion 1982a, 1982b, Sion and Guinan 1982, Wargau et al 1982). A new object, KQ Mon, has been added to our program of study with the IUE satellite. In this paper we discuss its relationship to the other UX UMa stars and suggest a model to explain their observed properties and absence of major outbursts.

2. OBSERVATIONS OF KQ MON

Bond's (1981) optical spectra of KQ Mon revealed very shallow Balmer absorption lines and HeI (λ4471) absorption, while his UBV and high speed photometric observations in 1978 and again in early 1981 revealed no light variations due to possible orbital phase modulation nor was an appreciable brightness change expected given the absence of radial velocity variations in the optical spectra. However, Bond's high speed photometry revealed the presence of low amplitude flickering that when coupled with the appearance of the optical spectrum and KQ Mon's location near the old novae and white dwarfs in the two color diagram, suggested a strong similarity to the UX Ursa Majoris subset of the nova-like variables (Warner 1976).

KQ Mon was observed at low dispersion with the IUE satellite on December 5, 1981 and February 5, 1982. The instrumentation and spacecraft characteristics are described by Boggess et al. (1978). Four spectra with the short wavelength prime (SWP) camera, and four spectra with the long wavelength redundant (LWR) camera were obtained. The exposure times were 35 minutes and 40 minutes respectively, with the large and small aperture and two of the spectra were trailed.

Using the Fine Error Sensor (FES) photometer, visual magnitudes of +13.06 and +12.97 were obtained in December 1981 and February 1982 respectively while Bond obtained V=+13.06 in 1978, indicating that the light level appears reasonably constant. Broad band color indices for KQ Mon were measured by Bond (1982) to be B-V=+0.08, and U-B=-0.72. The U, B and V magnitudes were converted to absolute flux units using the absolute calibration of Hayes (1980).

In figure 1 a single SWP spectrum typical of the others is shown together with labeled identification of the strongest line features. The spectrum is dominated by strong broad absorption lines due to NV, OI + SiII, SiIV, CIV, HeII and NIV. Possible Lyα absorption is obscured by the strong geocoronal feature. The long wavelength (LWR) spectrum appears essentially featureless. The data was de-reddened using the interstellar extinction law of Nandy et al. (1975) and a value of E(B-V)=0.03 was adopted. In figure 2 we plot the de-reddened

satellite continuum fluxes on a log F_λ vs. log $\lambda(\text{Å})$ scale along with the broad band U, B and V fluxes. On the same figure we show, for comparison, theoretical continuum fluxes from model steady state accretion disks calculated by Williams (1981b) assuming a disk inclination angle i=0 (pole-on). The models shown in figure 2 are normalized to the optical V band flux.

3. COMPARISON TO OTHER UX UMA STARS

The UV line spectrum of KQ Mon shows strong broad absorption lines of the resonance doublets and excited species but unlike other members of the UX UMa class (e.g. TT Ari in its high state, LS I 55 8, V 3885 Sgr, RW Sex, UX UMa) they are not appreciably violet-displaced and P Cygni-type emission is entirely absent. Thus a hot wind from the disk driven by X-radiation from the inner disk may be weak or absent in KQ Mon. Moreover, the absorption lines of LS I 55 8, V 3885 Sgr and RW Sex. The ginally broader than those of the CIV, NV and SiIV absorption features show strengths and shapes of the CIV, NV and SiIV absorption features show significant variations as a function of time over the longest time baseline of our observations, 130 minutes. Similar line variations were found in other low inclination UX UMa stars (e.g. LS I 55 8, TT Ari, RW Sex) and may arise due to the changing aspect of gas observed against the disk at different orbital phases or possibly may result from disk asymmetry.

The estimates of mass loss rates due to wind outflow in the UX UMa stars give $\dot{M}_{wind} \sim 10^{-2}$ to $10^{-4}\,\dot{M}_{acc}$ when $\dot{M}_{acc}$ is the mass accretion rate (cf. Guinan and Sion 1982a, 1982b, Greenstein and Oke 1982). The weakness or absence of an outflowing wind in KQ Mon may be due to (1) a somewhat lower (sub-critical?) $\dot{M}_{acc}$ than other UX UMa stars (2) accreting gas flowing above and/or below the disk plane (3) a weak white dwarf magnetic field preventing disk gas from forming a high pressure zone at the equator which could drive the type of polar wind described by Greenstein and Oke (1982) or (4) a nearly pole-on disk with conical outflow of hot gas in a narrow cone angle.

Like other UX UMa stars, the UV continuum is essentially flat from the UV to the optical and can be fitted quite well with accretion disk fluxes. The disk model fits in figure 2 clearly indicate an accretion rate near $10^{-8}\,M_\odot yr^{-1}$ for KQ Mon.

4. NATURE OF THE UX URSA MAJORIS STARS

Given the high ionization states of the UV absorption lines and the evidence for mass outflow in most of the UX UMa stars, the following tentative interpretation of the UV line and continuum spectra is suggested based in part on the wind models of Cassinelli Olson and Stalio (1978 cf. section IV, Guinan and Sion 1982). If we assume the X-radiation in these systems emerges from the hot inner disk boundary

layer region rather than say a "hot spot" at the disk edge (because the disk is too luminous relative to a hot spot) it is likely that the UV resonance doublets such as N v (λ1240), C iv (λ1550) and Si IV (λ1396) arise in an outflowing wind. These high ionization features, seen in combination with a relatively "cool" integrated disk continuum, are similar to the UV spectra of O and B stars with outflowing winds (Cassinelli, Olson and Stalio 1978). A thin hot corona (~10^{6}K) at the base of the flow in the boundary layer region provides the X UV photon source needed for the high ion states. The high ionization stages can be produced by the Auger mechanism, whereby two electrons are removed from C, N and O following K shell absorption of x-rays. Greenstein and Oke (1982) have independently proposed for RW Sex than an outflowing wind from the disk is driven by X-radiation, with the gas in conical geometry at the poles of the degenerate dwarf. They propose a broad cone while Guinan and Sion (1982) did not specify the geometry for V 3885 Sgr. It should be noted that for values of the viscosity parameter α between 0.0 and 1 (Bath and Pringle 1981) derived for dwarf novae in outburst, a wind outflow geometry other than spherical would constrain the UX UMa systems to have magnetic fields (Wiita 1982). Indeed one of the UX UMa stars, TT Ari, appears to be an "intermediate polar" (Warner 1982) with a magnetic field strength lower than that associated with the AM Her objects and magnetic white dwarfs but strong enough to funnel a radial accretion flow. In either case the outflowing gas is seen silhouetted against a luminous disk for a large range of orbital inclinations which explains the appearance of the blue-shifted absorption lines and P Cygni-type features observed in a number of UX UMa stars. It is likely that when the accretion rate Ṁ is high, X UV quanta do not penetrate to the disk edge because the accretion flow is optically thick to that flux region. When the disk luminosity declines (i.e. Ṁ decreases), it is predicted that mass loss should cease, the absorption lines formed in the wind should disappear, the continuum should fade and the UV line spectrum should go into emission with the high excitation (barely displaced) UV emission lines originating in a "chromosphere" surrounding the inner disk region (cf. TT Ari in its low state; Wargan et al. 1982). The site of this "chromosphere" is predicted to be the upper parts of the disk atmosphere more than one scale height from the central plane of the disk. When Ṁ again increases, the boundary layers' luminosity goes up and the UV spectrum again goes into absorption and an outflowing wind may again be driven.

That UX UMa stars may have higher accretion rates than other types of cataclysmic variables is indicated directly or indirectly by (1) derived accretion rates from continuum fits (e.g. RW Sex, Greenstein and Oke 1982; V 3885 Sgr, Guinan and Sion 1982a; LS I 55 8, Guinan and Sion 1982b; KQ Mon, Sion and Guinan 1982; Wargau et al.1982; (2) the flat continuum of a luminous, thick disk dominating the light from the UV through the optical and IR, (3) the low ratio of L_x/L_{opt} for those UX UMa stars observed with the Einstein satellite (Cordova Mason and Nelson 1981) and (4) the outflowing winds from accretion disks which may manifest a higher boundary layer luminosity or local super Eddington accretion.

We contend here that the accretion rates of the UX UMa stars are higher than, for example, the dwarf novae during quiescence and that the higher accretion rates of the UX UMa stars are responsible for their lack of major outbursts. Based upon the excellent agreement between our observed fluxes and the theoretical disk continuum fluxes of Williams (1981b), steady accretion rates $\geq 10^{-8}$ M☉yr^{-1} are implied for the UX Ursa Majoris stars. A higher mass accretion rate implies more massive thicker disks with some mechanism or viscosity source which allows continuous accretion onto the white dwarf thus keeping the system in continuous "outburst" (or extended high state). Time independent steady state disk models with the central plane convection occurring for the high accretion rates associated with the UX UMa stars, have been calculated by Vila (1982). Here central plane convection would be an effective viscosity source allowing accretion onto the white dwarf. however, recent steady disk models by Meyer and Meyer-Hofmeister (1981) have stable radiative structure for $\dot{M}_{acc} \geq 10^{-9.5}$M☉yr^{-1}. Since the accretion rates of the UX UMa stars seem to be well above this value, steady state radiative disk structure can be maintained as long as Ṁ remains high enough for the disk to be in a stable radiative state. Thus these models lead us to suggest that the UX UMa stars possess steady state equilibrium disks due to their high mass accretion rates which would explain the absence of "outbursts." A stable steady state disk may also provide a natural explanation for the observed winds in RW Sex, LS I 55 8, V 3885 Sgr and UX UMa. If the accretion flow is high enough to be super-critical, the wind outflow may result from the response of the disk to re-establish a steady state accretion flow. In this case, KQ Mon may lack an outflowing wind because the accretion flow is just sub-critical. On the other hand, the accretion rate derived for RW Sex by Greenstein and Oke (1982) is super-Eddington for a 1M☉ white dwarf.

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Figure 1: Short Wavelength Prime (SWP) low dispersion IUE spectrum of KQ Mon. The strong off-scale emission line at λ1216 is geocoronal Lyman Alpha. The stronger absorption features are identified.
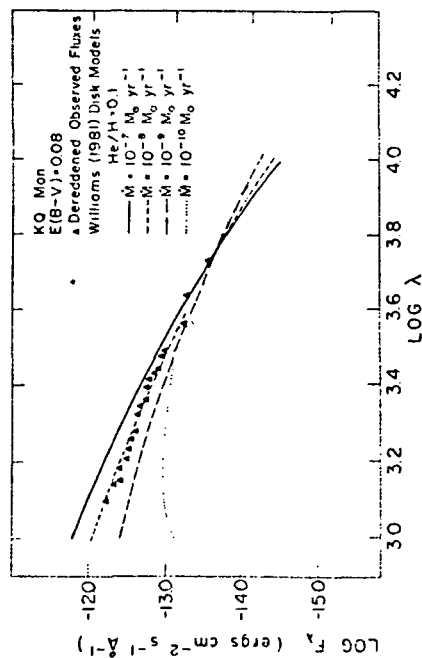

Figure 2: The de-reddened continuum fluxes of KQ Mon, log F_λ, versus log λ, compared with three solar composition accretion disk models of Williams (1981b) normalized at the optical V band flux. Optical fluxes are labeled with corresponding bandpass designations.

DISCUSSION FOLLOWING E. SION'S TALK

WARNER: The wind that you see, is the velocity greater than the escape velocity from the system?

SION: The wind velocities in all but one case are less than the escape velocity from the surface of the white dwarf. In the case of RO-7507 terminal velocities that exceed the escape velocity from a white dwarf are indicated.

WARNER: I am interested in escape from the system, I just wonder whether it is a method of losing angular momentum from the system, from the binary, that is.

SION: We haven't checked that yet.

WARNER: A bit of historical accuracy, the idea that UX Ursa Majoris systems, as they are now called, are systems in permanent outbursts, really goes back to Bob Kraft in about 1965 or so.

ROBINSON: Is there any correlation of the strength of the P Cygni profile with orbital inclination? That is to say, have you looked at UX Ursa Majoris, which has a very high inclination and does it show the P Cygni profiles, evidence of a wind and so forth?

SION: Yes, there is a correlation, the deeper the absorption trough the more nearly pole-on seems to be the system and in UX Ursa Majoris those same absorption features are gone, it is mostly emission in the UV, because you are looking at the gas above, you are seeing the disk edge on.

FRIEDJUNG: First, a reply to Robinson, there is a recent preprint by Cordova and Mason where they say there is a correlation between the intensity of the P Cygni component and the inclination. A second thing, I would like to say about the wind, these winds from accretion disks may not be quite as unusual as they first appear, they may resemble very much winds from normal hot stars and may be something completely different from the winds you get from novae during outburst. An approximate calculation I did, using the most recent form for radiation pressure in the lines, by Abbot, and applying it to the old nova HR Del predicted the mass loss rate to within a factor of two. My impression is that these winds may be driven just by the radiation pressure in the lines as in certain theories for hot star winds.

SION: This is precisely my interpretation.

MEYER: I want just to clarify what continuous outburst means, in view of the model that has been suggested by different people and also by us, it would just be the stationary disk, which is not modulated by the nonstationary flows in convective regions. So you don't need a special process to dump matter on the star, but rather you get rid, with your high mass flow rates, of the modulation process.

SION: In TT Ari the disk goes away or seems to shrink and then the luminosity goes down and then goes back up again.

MEYER: As long as you are above the critical mass accretion rate, of course you can have such variations. I would like to add that the velocities in your P Cygni profiles would probably give you information about the distance from the white dwarf from which the main bulk of this flow originates.

WILLIAMS: I was going to say that the fact that the velocities of outflow deduced from the resonance lines, are less than the escape velocity from the surface, requires that the mass loss is coming from further out, from the accretion disk. This is consistent with Friedjung's point that you would in fact expect mass loss from accretion disks, particularly in systems where you have heating of the disk by X-rays. One further point, N IV absorption that you identified, I think in KQ Mon that line is forbidden, it is very difficult to get it in absorption, I think you should recheck the identification of that, I think it may be a silicon line.

KING: I would like to support Williams' point. We had some UV spectra of UX UMa and we found that the C IV line was not eclipsed, when the system was eclipsed, which means this region of gas is very large, it must be as big as the shadow the secondary casts.