IUE OBSERVATIONS OF THE SYMBIOTIC STAR AG DRACONIS

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ABSTRACT

The extensive IUE observations of the symbiotic system AG Draconis along seventeen years have allowed the coverage of long periods of quiescence and of a number of different outbursts. This presents an unique opportunity to study the nature of the hot star as well as the physics of the accretion processes. The IUE data cover eleven orbital cycles of the system, and show that UV variations during quiescence are characterized by the modulation of the continuum and the emission lines along the 554 days orbital motion. During the IUE lifetime six outbursts were observed. These outbursts can be divided in two types according to its *"hardness"*, as derived from the behaviour of the UV continuum and emission lines. Simultaneous X–ray observations with EXOSAT and ROSAT point to a clear anticorrelation of optical/UV and X–ray fluxes during outburst.

Key words: Ultraviolet; Symbiotic Stars; AG Draconis.

1. INTRODUCTION

AG Draconis (BD+67 922) is the brightest symbiotic system in the UV and in X–rays. It is one of the most representative members of the symbiotic class, and presents remarkable characteristics, such as a large radial velocity (v_r=-148 km s^{-1}), high galactic latitude (b^{II}=+41°), and a cool component with an early spectral type (K) and a low metalicity ([Fe/H]=-1.3). AG Dra is a metal poor symbiotic binary in the galactic halo.

The hot component of the system is a white dwarf which during quiescence burns hydrogen on its surface at a rate of 3.2×10^{-8} $M_\odot$ yr^{-1} providing a luminosity of 2500 $L_\odot$ (for a distance of 2.5 kpc).

The optical light curve of AG Dra is characterized by extended *quiescence* periods (V=9.8–10), and erratic *active phases*, which occur every several years (Figure 1). During quiescence, there are small semirregular photometric variations (ΔV=0.1 mag) with pseudo–periods of 300-400 days. The U–band light curve displays variations with an amplitude of 1 magnitude and a period of 554 days (Meinunger (1979)), which has been associated with the orbital motion of the system, as confirmed by radial velocity measurements (Mikolajewska et al. 1995, Smith et al. 1996).

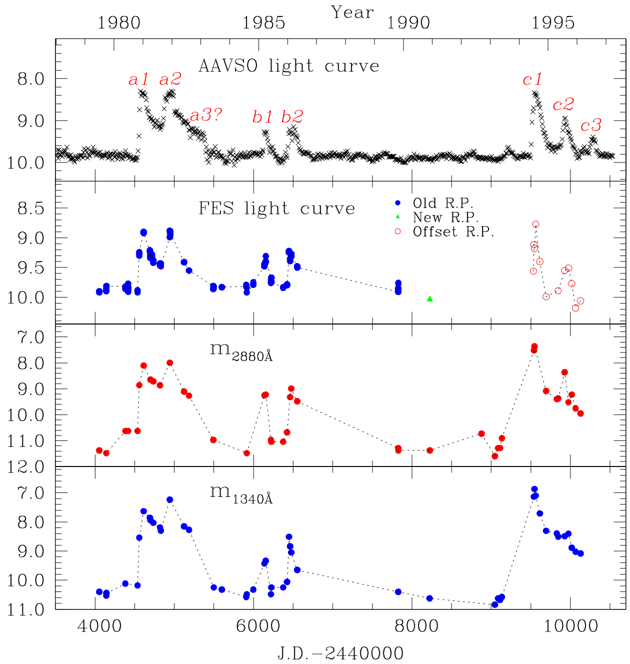

Figure 1. Visual and Ultraviolet light curves of AG Dra in the period 1979–1996. Shown are, from top to bottom: the AAVSO light curve (ten days means, Mattei (1997)), the FES light curve, and the near and far-UV light curves. The two latter are given in magnitudes, derived from the expression m_λ=-2.5 log (F_λ)-21.05. Both are corrected for a reddening of E(B-V)=0.06.

AG Draconis has been observed with IUE since April 1979 until January 1996. During this period it has undergone six light maxima (or ***outbursts***) in November 1980 and December 1981 (*a1, a2*), March 1985 and January 1986 (*b1, b2*) and June 1994 and July 1995 (*c1,c2*). Further minor outbursts took place in June 1996 (*c3*) and May–June 1997. The long duration of the first active phase might be attributed to a third outburst (*a3*) around January 1983. A description of the behaviour of the system in the period 1979–1983 can be found in Viotti et al. (1983) and Viotti et al. (1984).

The 1985-86 outbursts were observed by EXOSAT (Viotti et al. 1995). AG Draconis started to be regularly moni-

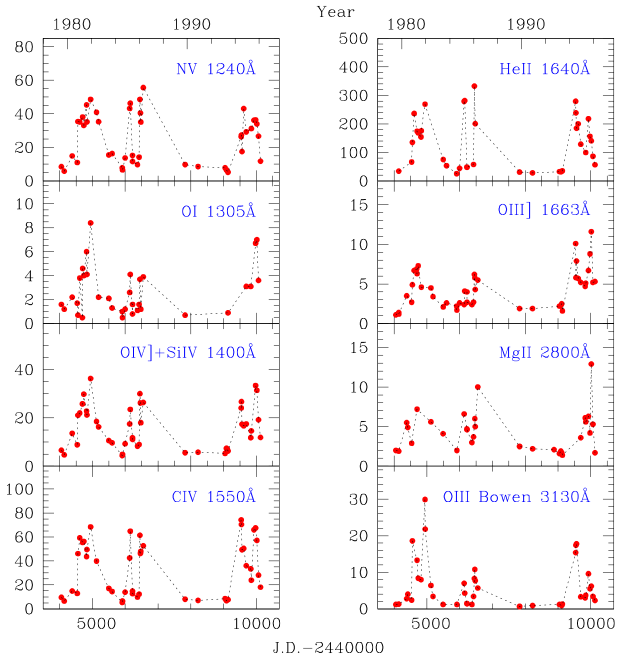

Figure 2. Evolution of the most representative UV emission lines. Fluxes are given in units of 10^{-12} erg cm^{-2} s^{-1}, and corrected for a reddening of E(B-V)=0.06.

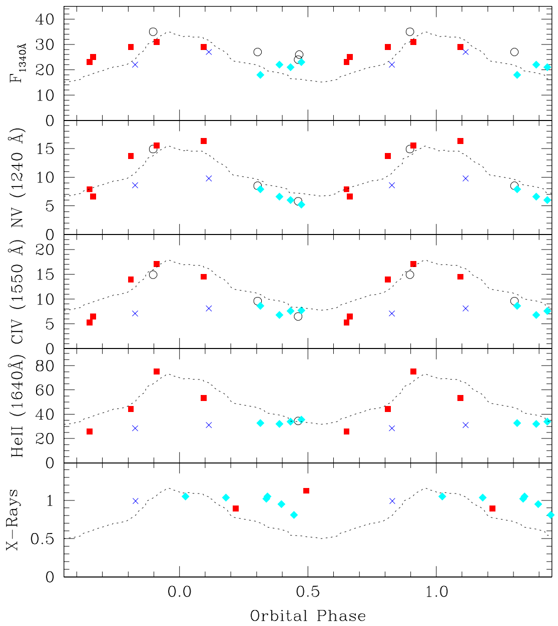

Figure 3. Orbital variations of the far UV continuum, representative emission lines and the X–ray flux of AG Dra during quiescence. Different symbols correspond to different epochs: open circles: June 1979 - October 1980, squares: June 1983-October 1984, crosses: October 1989-November 1990, and diamonds: September 1992-May 1993. Units are 10^{-14} erg cm^{-2} s^{-1} Å^{-1} for the continuum and 10^{-12} erg cm^{-2} s^{-1} for the lines. Both are corrected for a reddening of E(B-V)=0.06. X–rays are given in counts s^{-1} and are normalized to the average value during quiescence. Overplotted is the smoothed u light curve of Kahler (1987).

tored with ROSAT in 1990, and has been continuously observed since the onset of the 1994 activity phase (Greiner et al. 1997).

Figure 1 and 2 show the light curves of two UV continuum bands and of some representative emission lines obtained during the 17 years of IUE observations.

2. THE QUIESCENCE

To study the behaviour of the system during quiescence we have selected IUE spectra taken at minimum visual flux (V $\geq$ 9.7). In Figure 3 we show the quiescence points folded with the orbital period of 554 days. Overplotted as a dotted line is shown the *u* Strömgren average light curve given by Kahler (1987), which cover three consecutive cycles in the period 1976–1980. Some features show a large modulation during the orbital motion (e.g. the NV 1240Å resonance line). Other lines such as CIV 1550Å and HeII 1640Å show a less pronounced minimum near phase 0.5. Intercombination lines are less modulated. Contrary to expected, the far UV flux – thought to be mainly due to the continuum of the hot star – is little modulated, while the variations of the near UV continuum are larger.

X–ray observations near phase 0.5 made by EXOSAT (November 1985) and ROSAT (May 1993) showed no occultation in 1985, and a possible partial occultation in 1993 (see the bottom panel of Figure 3).

In order to quantify the degree of attenuation of each feature along the orbit, we have averaged the points in the phase ranges 0.25–0.75 (Flux$_{min}$) and 0.75–0.25 (Flux$_{max}$). The results are shown in Table 1.

The pronounced modulation shown by some of the lines (e.g. NV) indicate that they are partly eclipsed during the orbital motion. The shape of the light curve suggests that they are formed in an extended area, and that the size of the occulting region is larger than the K star.

3. THE ACTIVE PHASES

AG Draconis has undergone three active phases during the period 1979–1996. Each of them had at least two optical maxima. Figure 4 shows the behaviour of the UV and optical continua, the NV 1240Å and HeII 1640Å lines and the X–rays during the different outbursts. During the two major active periods (1980–81 and 1994–95) the increase in the UV continuum was much larger than in the visible. On the other hand, the behaviour of far UV and optical continua was similar during the weaker outbursts of 1985–86. The 1985 and 1995 outbursts went nearly unnoticed in the far UV. The time to return to minimum seems to be related to the strength of the outburst. The 1980 outburst had not completely finished when the 1981 activity phase started. On the contrary, the system returned to quiescence between the two weaker 1985–86 maxima.

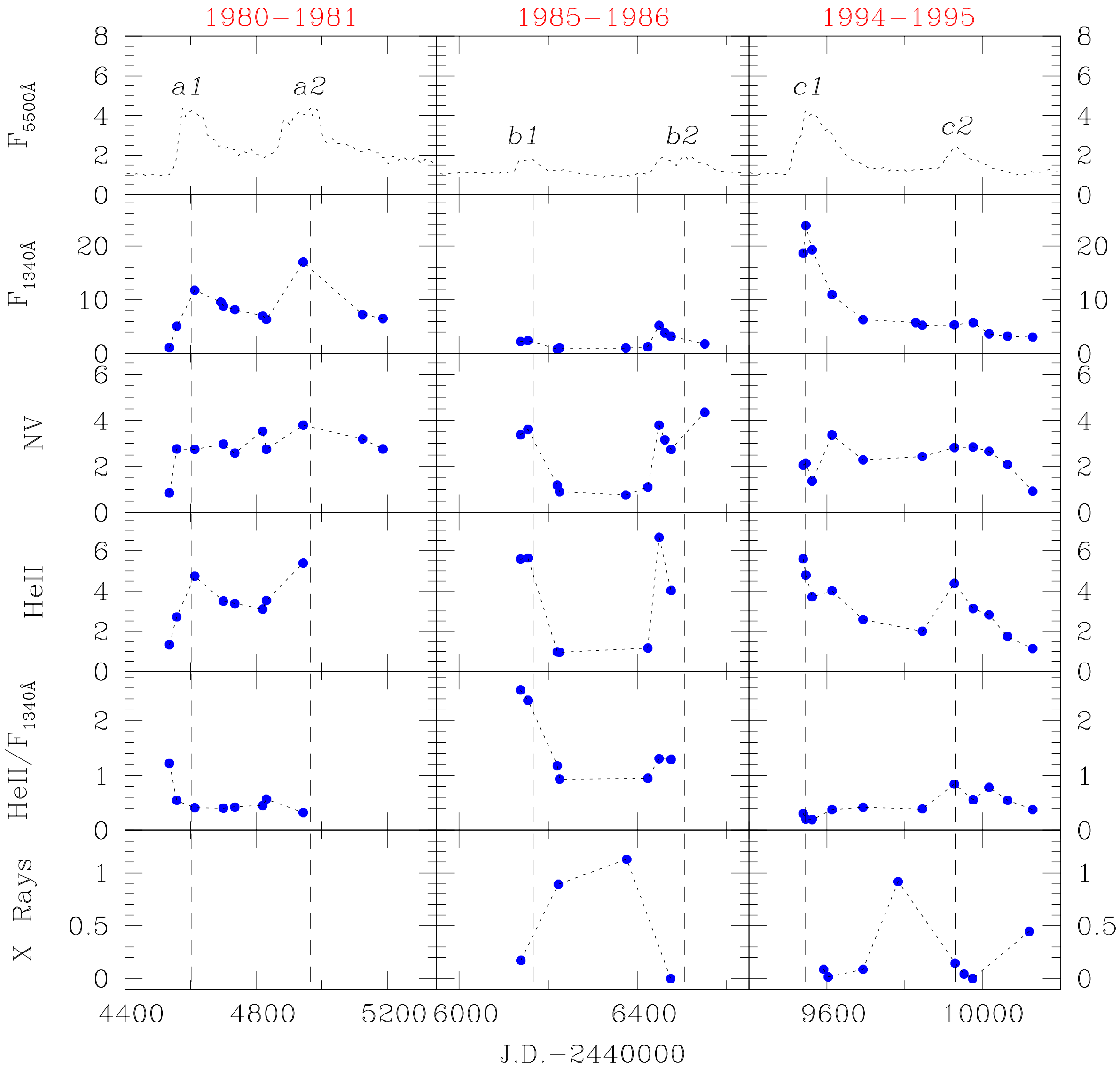

Figure 4. The different activity phases of AG Draconis. Shown are the visual, far-UV and X-ray fluxes, the NV 1240Å and HeII 1640Å lines, and the ratio of the HeII line to the far-UV continuum. Vertical lines mark the times of optical maxima. All values are normalized to the average quiescence value.

Table 1. UV orbital modulation during quiescence

	$Flux_{max}/Flux_{min}$
u band Flux	2.35±0.34
NV 1240 Å	1.88±0.27
CIV 1550 Å	1.73±0.31
OI 1305 Å	1.67±0.59
HeII 1640 Å	1.54±0.30
F_{cont}(2880 Å)	1.47±0.28
OIII] 1663 Å	1.39±0.27
F_{cont}(1340 Å)	1.26±0.12

Although the 1985–86 outbursts were weak both in the visible and in far UV, the UV emission lines reached intensities comparable to the much stronger 1980–81 and 1994-95 outbursts. The ratio HeII(1640Å)/F(1340Å) was much higher than in quiescence, specially at the time of the *"b1"* maximum, while in the other events this ratio was below the average quiescence value (Figure 4). If the variation of this ratio is taken as a measurement of the changes in temperature of the hot source during outburst, the different outbursts can be divided into "cool" (*a1, a2, c1, c2*) and "hot"(*b1, b2*).

X–ray observations of the last two active phases have been performed by EXOSAT and ROSAT, respectively. In 1985–86 X-rays decreased at the time of the optical/UV maxima, and increased in the period between them (Viotti et al. 1995). ROSAT observed AG Draconis in quiescence in the period 1990–1993, during which the flux was nearly constant. At the beginning of the 1994 outburst the X–ray flux decreased by more than a factor 100 respect to the average quiescence value. In the period between the two optical maxima *c1* and *c2* it nearly went back to the quiescence value to decrease again in coincidence with the second optical outburst (Greiner et al. 1997).

4. CONCLUSIONS

The steady and intense UV and X–ray emission in AG Draconis during quiescence indicate the presence of an effective physical process, most probably accretion of the K giant wind onto the surface of the hot companion. The absence of eclipses in the far UV puts a limit to the orbital inclination, while the partial eclipse of the NV line should be due either to asymmetry in the N^{+4} emission region, or to its extension being larger than that of the source of the far UV continuum. This seems to suggest that the red giant is filling (or nearly filling) its Roche lobe (Greiner et al. 1997). In this model X-rays originate from the white dwarf surface (kT≈14.5 eV, $L_x \approx 2{\times}10^3$ $L_\odot$).

If this were the case, we should have expected an increase in the X–ray flux in occasion of the outburst, which is generally attributed to an increase in the mass accretion rate. The most surprising result, which has been observed in all the outbursts so far detected in X–rays, has been the deep decrease (and nearly disappearance) of the X–ray flux, in full anticorrelation with the optical and UV fluxes (see Figure 5). We suggest that during outburst the photosphere of the accreting hot star expands up to twice its quiescence radius. Consequently its surface temperature decreases and the maximum of the emission moves from soft X–rays to EUV, where it would be substantially absorbed by the interstellar hydrogen.

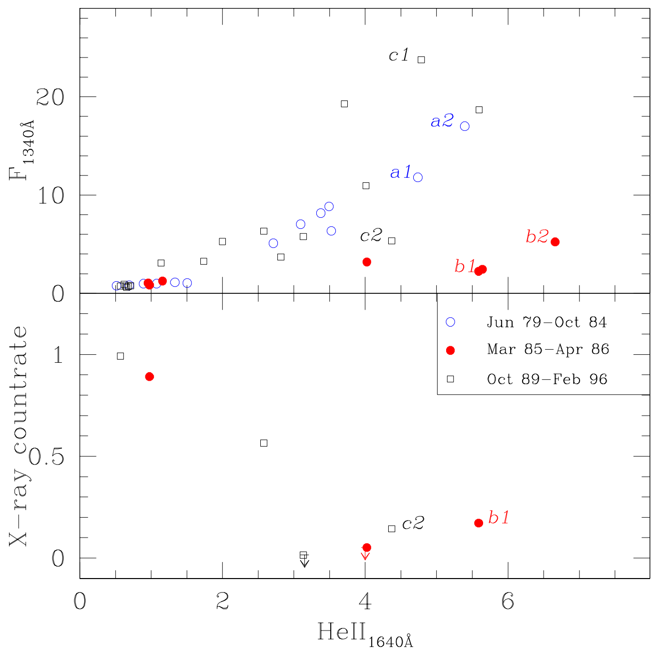

Figure 5. Relation between the X–ray flux, the far UV continuum and the HeII 1640Å line intensity. Different epochs are represented by different symbols. All measurements have been normalized to the quiescent values (i.e. on both plots quiescence is at (1,1)). The points corresponding to the peaks of the optical outbursts have been labeled according to Figure 1.

Two more optical outbursts occurred after the IUE switch-off, in 1996 and 1997. This phase is currently being monitored with ROSAT-HRI, and photometrically and spectroscopically from ground based telescopes.

REFERENCES

Greiner, J., Bickert, K., Luthardt, R., Viotti, R., Altamore, A., González-Riestra, R., Stencel, R.E. 1997, A&A 322, 576

Kahler, J.B. 1987, AJ 94, 437

Mattei, J. 1997, private communication

Meinunger, L. 1979, IBVS No. 1611

Mikolajewska, J., Kenyon, S.J., Mikolajewski, M., García, M., Polidan, R. 1995, AJ 109, 1289

Smith, V.V., Cunha, K., Jorissen, A., Boffin, H.M.J. 1996, A&A 315, 179

Viotti,, R., Ricciardi, O., Ponz, D., Giangrande, A., Friedjung, M., Cassatella, A., Baratta, G.B., Altamore, A. 1983, A&A 119, 285

Viotti, R., Altamore, A., Baratta, G.B., Cassatella, A., Friedjung, M., 1984, ApJ 283, 226

Viotti, R., Giommi, P., Friedjung, M., Altamore, A. 1995, in "Cataclysmic Variables", ed. A. Bianchini, M. Della Valle, M. Orio, Kluwer, p. 195