# *EUVE* Spectrophotometry of QS Tel: The Second Pole Becomes Active

S. R. ROSEN,[1] J. P. D. MITTAZ,[2] D. A. H. BUCKLEY,[3]
A. LAYDEN,[4] C. McCAIN,[5]
J. P. OSBORNE,[1] AND M. G. WATSON[1]

[1]Department of Physics, University of Leicester, University Rd., Leicester, LE1 7RH, UK

[2]Mullard Space Science Laboratory, Holmbury St. Mary, Surrey, RH5 6NT, UK

[3]South African Astronomical Observatory, PO Box 9, Observatory 7935, South Africa

[4]Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile

[5]Mt. Stromlo and Siding Spring Observatories, Weston Creek, PO, ACT 2611, Australia

We present results of *EUVE* spectrophotometry of the EUV luminous polar, QS Tel (RE1938-461), together with contemporaneous optical photometry and spectroscopy. In marked contrast to the *ROSAT* survey observations, the *EUVE* light curve shows two flux maxima per orbital cycle, implying that both magnetic poles were active. A deep, narrow dip is observed during one of the two flux maxima, exhibiting a complex morphology which includes pronounced flickering behaviour. Although this feature is probably caused by stream occultation of the emission region, the apparent lack of spectral hardening at this time disfavours photoelectric absorption by cold gas as the dominant source of opacity. Whilst the overall *EUVE* spectrum can be characterized by a low temperature (~15eV) blackbody, implying a large soft/hard component flux ratio (~50), tentative evidence of an absorption edge from NeVI at 85A and lines due to NeVIII and NeVII at 98Å and 116Å respectively indicate that more sophisticated models must be employed. Quasi-simultaneous optical photometry shows a substantial change in the light curve over an interval of just 3 days and little evidence of correlated behaviour with the EUV flux. We consider the implications of these results on the accretion geometry and the structure of the accretion flow.

## 1. Introduction

QS Tel (RE1938-461) was the brightest of seven new polars (AM Her stars) discovered via the *ROSAT* WFC survey (Pounds et al. 1992). Polars are magnetic cataclysmic variables (CVs) comprising a low mass star donating material to a strongly magnetic ($B \sim 10^7$G), synchronously rotating white dwarf (see Cropper 1990 for an overview). On average, these seven new systems showed a larger EUV/optical flux ratio than previously known polars detected in the WFC survey (e.g., Watson et al. 1993) and it was suspected that they might also be characterized by large soft/hard X-ray flux ratios. Such EUV bright polars may improve our understanding of the homogeneity of the accretion flow and its interaction with the magnetosphere (e.g., mechanical heating of the white dwarf's atmosphere by dense filaments of material in the inflow has been advanced as a mechanism to explain systems with large EUV excesses—Frank, King & Lasota (1988) and references therein). Apart from its brightness, initial interest in QS Tel (Buckley et al. 1993) arose from both its orbital period of 2.33 hr, which places it inside the well known CV period gap, and its simple EUV bright-faint light curve which is symptomatic of a single, small, active pole which passes behind the limb of the white dwarf for a fraction of the rotation cycle. QS Tel has since been found to possess the largest magnetic field yet measured in a polar (Schwope et al. 1995).



*S. Bowyer and R. F. Malina (eds.), Astrophysics in the Extreme Ultraviolet,* 331–335.

## 2. Observations

Two *EUVE* observations of QS Tel were made starting on 1993 Aug 16 (~30 ks exposure) and on Oct 6 (~70 ks). The source was only significantly detected in the (70–200Å) short wavelength spectrometer (SWS) and Deep Survey (DS) instruments. Contemporaneous fast (10s) white light optical photometry was obtained from the SAAO on Aug 16. Further fast B band photometry from CTIO was secured on Aug 19/20, whilst time-resolved H$\alpha$ and H$\beta$ spectroscopy was obtained on the nights of Aug 17 and 18 with the 2.3m ANU telescope at the Siding Springs Observatory.

## 3. The *EUVE* Light Curves

The *EUVE* SWS and DS light curves of QS Tel were folded on the linear orbital ephemeris of Schwope et al. (1995) whose epoch (phase 0.0) is believed to correspond to inferior conjunction of the companion star. The *EUVE* data reveal two key properties (see Figure 1). Firstly, unlike the bright-faint morphology of the *ROSAT* WFC survey data, the *EUVE* light curve contains two prominent flux maxima per cycle, demonstrating that both magnetic poles were active at that time. This underlying modulation is accompanied by a hardening of the spectrum during the maxima. Secondly, a deep, narrow dip is evident (phase 0.97–1.10) during the maximum that corresponds most closely with that observed during the WFC survey.

The SWS and DS data show that the mean dip profile comprises a slow (~300s) ingress (phase 0.97–1.01), a broad minimum (phase 1.01–1.09) which appears to contain an interval of enhanced emission between phase 0.04 and 0.08, and a rapid egress (lasting <40s) at phase 1.10 (see Figure 1). Residual flux ($\geq$2%) is detected at all phases in the dip. However, exploiting the sensitivity of the DS instrument allowed us to examine the individual dips in greater detail. This revealed that the enhancement during dip minimum is in fact resolved into pronounced flaring activity. Flaring behaviour is also evident during dip ingress, partially explaining the wide range of ingress profiles observed. In contrast, the epochs of the six observed dip egresses differ by no more than 25s. By dividing the SWS data into two energy bands, we tested the data during the dip for evidence of spectral changes. Although we are hampered by the weak signal at this time, we find no convincing evidence of spectral hardening during dip ingress or dip minimum. Since we believe that the dip is caused by stream occultation of the white dwarf's emission site (see § 4), if we assume that the mid-dip flares are due to intrinsic fluctuations at the emission source, as viewed through the stream, the enhanced S/N available during such flares can be exploited to more sensitively test for hardness ratio changes. None are found, suggesting that photoelectric absorption in a cold, homogeneous medium is not the dominant absorbing mechanism.

The mean *EUVE* spectrum of QS Tel has been fit with simple blackbody models. The best fit yields a temperature of 15 eV and a column of $4.4 \times 10^{19}$ cm$^{-2}$. Taken at face value, the data imply a bolometric flux for the EUV/soft X-ray spectral component of about $10^{-9}$ ergs s$^{-1}$ cm$^{-2}$. A simple scaling of the estimated hard component flux deduced from an earlier *ROSAT* pointed observation then suggests that the soft/hard component flux ratio may be as high as ~50 although the lack of *ROSAT/EUVE* simultaneity and the weak constraints on the hard component spectrum mean that this ratio is somewhat uncertain. However, the *EUVE* spectrum (see Figure 2) shows tentative evidence of an absorption edge at 85Å, probably due to NeVI and possible absorption lines at 98Å and 116Å, perhaps due to NeVIII and NeVII respectively. Confirmation of the presence of these and perhaps other absorption features, probably achievable via

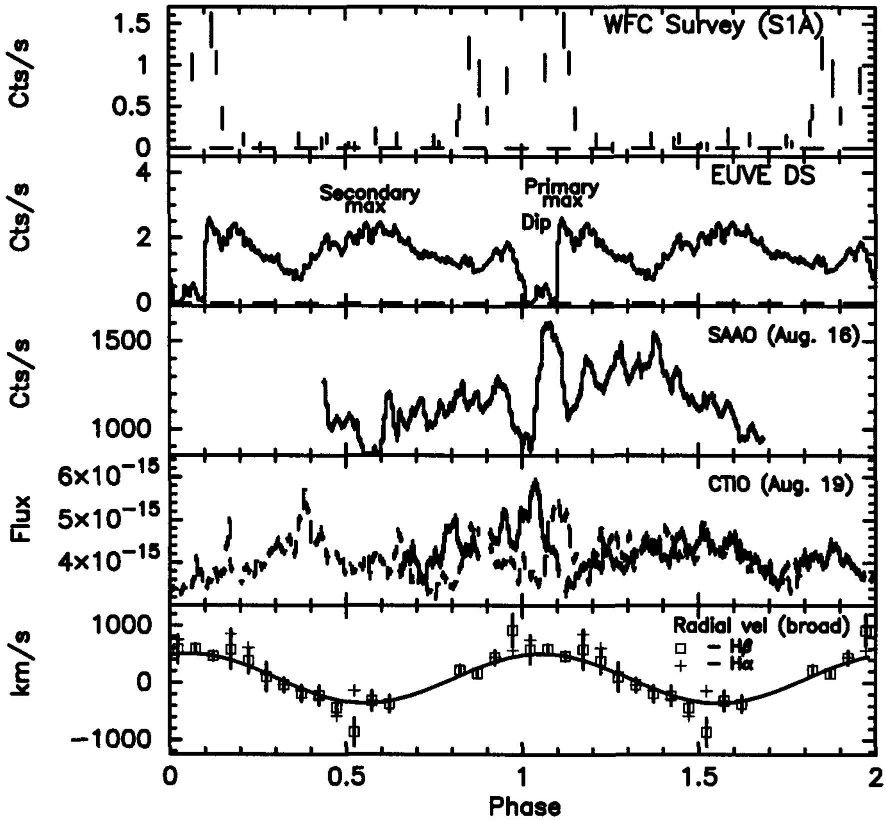


FIGURE 1. From top to bottom: The simple, single pole orbital light curve of QS Tel observed during the *ROSAT* WFC survey: the *EUVE* DS light curve showing the double-peaked (two pole mode) morphology: the SAAO optical light curve: the CTIO photometry, split into two sections and overlayed (solid and dashed lines): the radial velocity motion of the broad component of the optical emission lines (squares = H$\beta$, crosses = H$\alpha$) which reaches maximum redshift near the epoch of the EUV dip. Two cycles are shown for clarity except for the SAAO data where the full dataset is displayed unfolded and the CTIO data where two sections of a continuous timeseries are plotted, overlayed

further, higher quality, dithered mode *EUVE* observations, will confirm the need for more sophisticated modelling of the spectrum, an aspect currently being pursued.

## 4. Optical Results

The SAAO photometry of QS Tel taken quasi-simultaneously with the first *EUVE* run shows a complex orbital light curve (figure 1). Given that the EUV and optical fluxes likely arise in distinct emission regions, subject to physically and geometrically different orbital effects, it is perhaps not unsurprising that the EUV and optical light curves are essentially uncorrelated. A possible, shallow optical counterpart to the EUV dip might be present although assessment of its intrinsic depth may be affected by a

https://doi.org/10.1017/S0252921100036186 Published online by Cambridge University Press

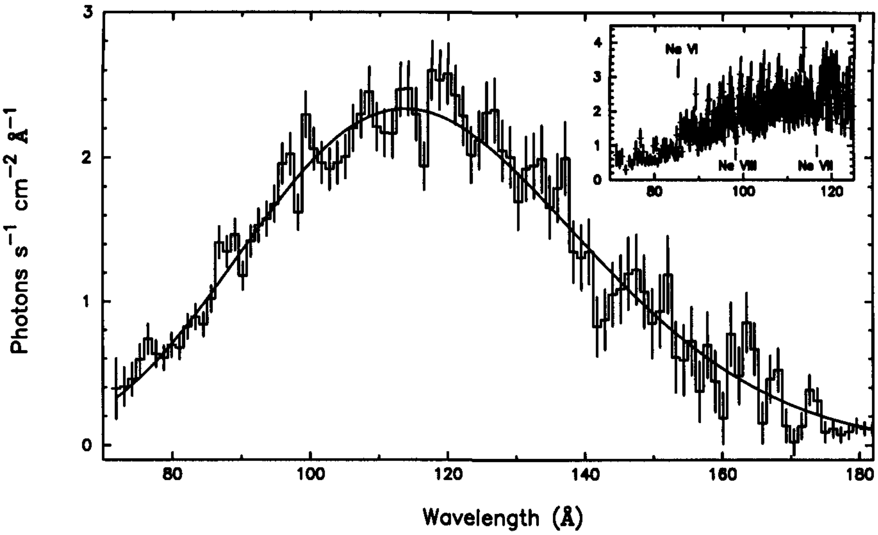


FIGURE 2. The average *EUVE* spectrum of QS Tel accumulated into 1Å bins. The solid line represents the best fitting blackbody curve (kT=15 eV, $N_H = 4.4 \times 10^{19}$ cm$^{-2}$). The inset shows the more finely resolved data, highlighting a possible absorption edge at 85Å (NeVI) and lines at 98Å (NeVIII) and 116Å (perhaps NeVII)

flare-like event during its latter stages (the EUV and optical dips were not observed simultaneously). The CTIO observation, obtained just 3 days later, shows a somewhat different morphology to the SAAO data and again shows no obvious connection with the *EUVE* light curve—there is also no conspicuous dip that aligns with the EUV feature. The lack of a deep (>25%) optical dip corresponding to the EUV event, together with the slow EUV ingress and EUV flaring behaviour at mid-dip, suggests that the dip is not due to an eclipse by the companion star. The ANU spectra provided important radial velocity information. The optical emission lines contain three components, as previously noted by Schwope et al. (1995). We can only usefully determine the motion of the broad component in our data, finding that it reaches maximum redshift at about the time of the EUV dip. This indicates that the accreting material is flowing most directly away from us (i.e., that the flow is passing through inferior conjunction) at about this time, which is at least qualitatively consistent with the notion that it is the accretion flow that shadows the accretion site. We note that although phase zero supposedly represents inferior conjunction of the secondary star (Schwope et al., 1995), neither the association of the narrow emission line component with the secondary star, or its phasing are yet sufficiently secure to contradict the stream occultation scenario as the cause of the EUV dip.

## 5. Discussion

The pronounced changes in the EUV light curve of QS Tel presumably reflect alterations in its accretion geometry. In conjunction with a pointed *ROSAT* observation (Clayton et al. 1995; Rosen et al., 1995) which found it in a single pole mode and the optical data of Schwope et al. (1995) which contained evidence of cyclotron emission

https://doi.org/10.1017/S0252921100036186 Published online by Cambridge University Press

from two poles, it appears that such changes occur frequently in QS Tel. The most likely causes are 1) increases in the accretion rate which allow material to penetrate more deeply into the magnetosphere and hence reach the second pole, 2) alteration of the balance between the instabilities at the magnetosphere which dictate whether the material is predominantly clumpy or homogeneous when it enters the magnetosphere or 3) asynchronous rotation of the white dwarf relative to the secondary star. The first two possibilities are related to the accretion rate. In either of these cases, with further observations we might expect to recognize a correlation between accretion mode (one or two pole) and the luminosity. The *EUVE* observations presented above apparently observed the system in a bright state (in contrast, the PV phase *EUVE* observation (Warren et al. 1994) found the star in a deep low state, its light curve being dominated by two flare events). If, on the other hand, asynchronism is the cause of the transformation in the accretion geometry, we anticipate that further observations will eventually unveil an evolution of the light curve which is recurrent on the beat period between the binary and white dwarf rotation periods. With its apparently frequent alterations of accretion geometry, QS Tel offers an excellent opportunity to probe the origin of these changes.

The dip observed in the *EUVE* data is structurally complex. Current evidence suggests that this feature arises from occultation of the white dwarf's emission region by the accretion flow rather than via an eclipse by the companion star. The lack of an accompanying hardness ratio change during the dip probably disfavours photoelectric absorption as the dominant absorbing mechanism. Alternative possibilities include electron scattering or partial covering, perhaps by a clumpy medium. Electron scattering would require a column density $\sim 5 \times 10^{24}$ cm$^{-2}$ and a corresponding accretion rate probably in the range form $4\times10^{16}$ gs$^{-1}$ to $4\times10^{17}$ gs$^{-1}$, to explain the depth of the dip. The inhomogeneous picture is at least qualitatively in agreement with blob bombardment scenario proposed to explain AM Her systems with large EUV excesses. Finally, the observed dip profile might arise from obscuration by two parts of the accretion flow—we doubt that even the latter part of the dip ($0.08 \leq \phi \leq 0.10$) could be explained by an eclipse by the companion star since even at 30–40 s, the duration of dip egress is probably too slow to represent the uncovering of a small ($r \ll R_{WD}$) emission region. If an eclipse is ruled out, the flaring during ingress and around mid-dip might respectively represent the covering and uncovering of the source by that part of the stream that first shadows the source (probably close to the white dwarf), the latter part of the profile being caused as the trailing part of the stream (further out) shadows the source. This would require some curvature or splitting of the stream but this is not perhaps unreasonable. For example, such a trajectory might ensue if the dipole were not centred and/or if there is continued azimuthal drift of the material relative to the field lines once it has begun to thread.

## REFERENCES

BUCKLEY, D. A. H., ET AL. 1993, MNRAS, 262, 93

CLAYTON, K. L., ET AL. 1995, Cape Workshop on Magnetic Cataclysmic Variables, ed. D. Buckley, & B. Warner, in press

CROPPER, M. S. 1990, Space Sci. Rev., 54, 195

FRANK, J., KING, A. R., & LASOTA, J. -P. 1988, A&A, 193, 113

POUNDS, K. A., ET AL. 1992, MNRAS, 260, 77

ROSEN, S. R., ET AL. 1995, in prereparation

SCHWOPE, A., ET AL. 1995, A&A, 293, 764

WATSON, M. G. 1993, Adv. Space Res., 13(12), 125