Evidence for a rotational velocity field about the white dwarf of V347 Puppis

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ABSTRACT

We present time-resolved optical spectroscopy of the deeply eclipsing nova-like binary V347 Pup, which provides evidence for a rotational velocity field in the low-excitation lines, as expected from accretion disc emission. The low-excitation line profiles are a composite of the disc and the irradiated inner-face of the donor star. This picture is remarkably simple compared to the other members of the eclipsing nova-like family. Unsatisfactory radial velocity solutions for the accreting object provided by standard methods encourage us to apply a technique developed to measure stellar motion from tomographic reconstructions of the time-dependent line profiles. We find some evidence for a spiral pattern over the disc and for disc-overflow accretion. If the emission distribution proves to be a long-term feature, V347 Pup will provide an opportunity to study disc kinematics with greater confidence than allowed by the other eclipsing nova-like objects.

Key words: accretion, accretion discs – line: profiles – binaries: eclipsing – binaries: spectroscopic – stars: individual: V347 Pup – novae, cataclysmic variables.

1 INTRODUCTION

The cataclysmic variables (CVs) consist of white dwarf stars accreting from Roche lobe-filling companions. As a consequence of their short orbital periods, proximity and brightness, they provide the most accessible stellar objects with which to study accretion kinematics. In particular, the quiescent dwarf novae have proved to be excellent case studies, where the accretion disc about the white dwarf primary star dominates the optical emission lines of H and He I. Orbitally-resolved line profile variations allow indirect velocity mapping of the gas flow (Marsh & Horne 1988). More significantly, in high-inclination objects, fully kinematical maps of line distributions can be constructed from the spatial information which is provided by eclipses of the disc by the mass-losing secondary star (Marsh 1988; Billington 1996). In these cases we observe a velocity disturbance, the so-called ‘Z-wave’, in time-resolved emission-line profiles, where the blue wings of the lines are eclipsed before the red. This is consistent with a source in a prograde-rotating accretion disc (Marsh, Horne & Shipman 1987). Needless to say, the identification of a new eclipsing dwarf nova is generally followed by a wealth of observational experiments. However, the equally populous class of nova-like variables (e.g. Dhillon 1996) are less well observed. These objects have accretion rates generally an order of magnitude larger than the dwarf novae, which ensures thermal stability within the accretion disc (Osaki 1974). Consequently, the nova-likes do not undergo the semiregular eruptions displayed by dwarf novae (e.g. Kaitchuck, Mansperger & Hantzos 1988; Rutten et al. 1992b). Nova-likes provide attractive observational targets but, unfortunately, line-mapping experiments are generally handicapped because of the complexity of the emission-line profiles, which cannot be reconciled with the expected velocity field of the accretion disc (Dhillon, Marsh & Jones 1991; Kaitchuck et al. 1995). The optical lines appear to be composites of emission and absorption features whose origins are often open to more than one interpretation. Previous observational studies have suggested line origins in the inner accretion disc (Rutten et al. 1994), a disc wind powered by radiation pressure (Honeycutt, Schlegel & Kaitchuck 1986), the ‘bright spot’ impact between gas stream from the secondary star and outer disc rim (Still 1996a), a gas stream spilling over the disc rim (Heller & Robinson 1994) and the irradiated inner face of the secondary star (Beuermann & Thomas 1990). Such diversity often prompts investigators to call for revisions to the nova-like classification scheme (e.g. Thorstensen et al. 1991). Although there has been an occasional weak detection in these objects (Honeycutt et al. 1986), the general absence of emission-line Z-waves in eclipsing nova-likes has prompted some authors to claim that accretion does not occur via discs (Williams 1989). Instead, accreting material is threaded on to the magnetic fields of the primary stars.

V347 Pup (= LB1800) is a deeply eclipsing, 13th magnitude cataclysmic variable (Buckley et al. 1990, hereafter B90). The identification of strong HeI emission and smooth eclipse profiles in the optical combined with negligible polarization from the object favour a nova-like classification. The radial velocity and eclipse analysis of B90 indicates an orbital inclination of 87° ± 3° and a
Table 1. Journal of observations. \( E \) is the cycle number plus binary phase with respect to the ephemeris of Baptista & Cieslinski (1991).

<table>
<thead>
<tr>
<th>Date (1995 Jan)</th>
<th>Start (UT)</th>
<th>End</th>
<th>Start ( (E - 12000) )</th>
<th>End</th>
<th>No. of spectra</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/11</td>
<td>20.10</td>
<td>01.80</td>
<td>466.27</td>
<td>467.29</td>
<td>98</td>
</tr>
<tr>
<td>12/13</td>
<td>18.91</td>
<td>01.32</td>
<td>474.68</td>
<td>475.83</td>
<td>55</td>
</tr>
<tr>
<td>14/15</td>
<td>20.35</td>
<td>01.65</td>
<td>483.56</td>
<td>484.51</td>
<td>88</td>
</tr>
<tr>
<td>15/16</td>
<td>19.38</td>
<td>01.94</td>
<td>487.74</td>
<td>488.88</td>
<td>163</td>
</tr>
<tr>
<td>16/17</td>
<td>19.59</td>
<td>01.87</td>
<td>492.05</td>
<td>493.17</td>
<td>145</td>
</tr>
</tbody>
</table>

The average of all out-of-eclipse exposures is presented in Fig. 1, where an estimate of the white dwarf motion has been removed from individual frames (Section 2.4). This displays similarities with both typical nova-like and dwarf nova spectra. The low-excitation lines of H and Hei are clearly double-peaked features as in the dwarf novae, and as expected from accretion disc emission (e.g. Horne & Marsh 1986) – although note that the core of the Hy feature drops to the level of the continuum, and that B90 provide evidence for a strong orbitally dependent absorption reversal in the Balmer cores. This reversal is common in nova-like variables (Szkody & Picklo 1990; Still, Dziiblon & Jones 1995) and could be the phenomenon shaping the average profiles of V347 Pup. The small equivalent widths are typical of the nova-likes (la Dous 1993) whose accretion discs are bright in the continuum compared to dwarf novae. The high-excitation lines such as Hei \( \lambda 4686 \) \( \AA \) and the Ciii/Niii \( \lambda \lambda 4640–50 \) \( \AA \) Bowen blend are rare in dwarf novae except during outburst (Marsh & Horne 1990).

2 SPECTROSCOPY OF V347 PUP

2.1 Observations and reduction

V347 Pup was observed on the nights beginning 1995 January 10, 12 and 14–16 with the Cassegrain spectrograph on the SAAO 1.9-m telescope at Sutherland, South Africa. Exposure times were consistently 120 s with 10 s deadtime for data transfer. The detector was the two-channel Reticon Photon Counting System. A grating ruled at 1200 line mm\(^{-1}\) was employed, providing a resolution of 1.8 \( \AA \). Table 1 summarizes the observations. CuAr arc lamp exposures were taken every 30 min, except during primary eclipse, in order to calibrate the wavelength scale and correct for instrumental flexure. A flux standard was observed through a wide-slit to correct for instrumental response. Seeing was generally too poor to provide photometric accuracy.

Medium-scale sensitivity variations were removed with a balance frame prepared from tungsten lamp flat-fields, while coherent small-scale signal was effectively removed by microscanning coils. Polynomial fits were made to the arc lines providing a wavelength scale, and instrumental drift was corrected by interpolating between consecutive fits. Sky subtraction was handicapped by leakage between channels, which amounts to \( \sim 10 \) per cent of total flux at the edges of the detector. This was removed by clipping the data to provide a wavelength coverage of \( \lambda \lambda 4170–5100 \) \( \AA \). Instrumental response was corrected for, using the flux standard spectrum.

The average out-of-eclipse spectrum of V347 Pup. An attempt has been made to shift out the primary orbital motion from individual spectra.
Similar humps are common in nova-likes and dwarf novae, and are each night, which is consistent with the findings of B90 and M94. Within the intrinsic scatter and a pre-eclipse hump is present on transparency. However, the almost-total eclipse is observed summing over line-free wavelengths. Since spectrophotometry was taken on faith, a binary synthesis using the code described in Still et al. (1997) indicates that the back of the disc is fully eclipsed at $\phi = 0.0$, but the blue and red outer edges of the disc are visible from behind the companion. Consequently, the residual continuum light may also have an accretion disc origin.

After dividing the data by spline fits to the continuum, EWs were computed by summing across the line profiles. The frames were averaged into 100 equally sized orbital bins in order to reduce noise. The resulting curves are also plotted in Fig. 2. The low-excitation lines provide a consistent picture, where EWs are approximately constant out-of-eclipse until $\phi = 0.7$ when we see a decrease before primary eclipse. This is to be expected if an orbital hump in the continuum is not reproduced in the line source. However Section 2.3 provides evidence that the intrinsic line fluxes are also partly responsible for the dip. An increase in EW is observed during eclipse. This is a common phenomenon in nova-like variables, and is often considered as evidence that the line source is a wind above the disc plane (Honeycutt et al. 1986). We expect the continuum from an optically thick disc to have a steeper radial dependence than line emission (e.g. Rutten, van Paradijs & Tinbergen 1992a; Marsh & Horne 1990), and the outer disc to be partially visible during mid-eclipse. Therefore a vertically extended source is not necessarily required to explain the EW increase during eclipse. We will show in Section 2.3 that a wind source is also not required to explain the low-excitation line profiles of V347 Pup. EW increases during eclipse by the high-excitation features are also found, but in these cases no pre-eclipse dip is observed. Possibly the bright spot contributes to the integrated line flux and/or the profiles do not undergo the self-reversal displayed by the low-excitation features.

### 2.3 Doppler tomography

Profile variations of the Balmer lines are plotted in the top panel of Fig. 3. An identical orbital binning as in Section 2.2 was used, but to reduce noise further the two Balmer lines were averaged with weights (signal/noise)$^2$. These profiles display a broad double-peaked component, typical of disc emission found in dwarf novae (Marsh & Horne 1990). Moving in the opposite sense is a narrow, transient feature which is strongest at $\phi = 0.5$. This is a characteristic of emission from the irradiated inner face of the secondary star (Beuermann & Thomas 1990). As noted by B90, the line core undergoes self-reversal before primary eclipse. This reversal suggests some caution when interpreting the double-peaked component as emission from a rotating source. Despite this, the profile displays a marked Z-wave during eclipse – the blue wing being eclipsed before the red. These results combined with those of Section 2.2 strongly suggest that the majority of emission has a source in prograde-rotating gas confined closely to the orbital plane, as expected from an accretion disc.

The line reconstruction method of Doppler tomography (Marsh & Horne 1988) has more relevance to this object than other members of the class which may contain vertical flows. This method involves mapping the velocity–phase data $(V, \phi)$ to a velocity–velocity field $(V_x, V_y)$ via:

$$f(V, \phi) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I(V_x, V_y)$$

$$\times g(V - V_x, \cos \phi - V_y, \sin \phi) dV_x dV_y,$$

(2)

where $f$ is the line intensity at velocity $V$ and orbital phase $\phi$, $I$ is the emission distribution of the resulting map in velocity coordinates $(V_x, V_y)$, $\gamma$ is the systemic velocity, and $g(V)$ is the local line profile. Since the profile has an absorption component, the preferred method is that of Fourier-filtered back-projection (Horne 1992),

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**Table 2.** Equivalent widths and velocity widths of a sample of lines from the averaged, out-of-eclipse spectrum of V347 Pup. FWHM and peak separations were determined from Gaussian fits, whereas FWZIs are eye estimates with objective error estimates.

<table>
<thead>
<tr>
<th>Line</th>
<th>EW</th>
<th>FWHM</th>
<th>FWZI</th>
<th>Peak sep.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Å</td>
<td>km s$^{-1}$</td>
<td>km s$^{-1}$</td>
<td>km s$^{-1}$</td>
</tr>
<tr>
<td>H$\beta$</td>
<td>9.8 ± 0.1</td>
<td>1030 ± 20</td>
<td>2300 ± 400</td>
<td>850 ± 20</td>
</tr>
<tr>
<td>H$\gamma$</td>
<td>6.8 ± 0.1</td>
<td>1090 ± 30</td>
<td>2200 ± 500</td>
<td>940 ± 20</td>
</tr>
<tr>
<td>He I $\lambda$4471</td>
<td>2.4 ± 0.1</td>
<td>1210 ± 30</td>
<td>1800 ± 600</td>
<td>882 ± 30</td>
</tr>
<tr>
<td>He I $\lambda$4921</td>
<td>4.7 ± 0.1</td>
<td>1740 ± 40</td>
<td>2000 ± 400</td>
<td>960 ± 60</td>
</tr>
<tr>
<td>He I $\lambda$5015</td>
<td>0.5 ± 0.3</td>
<td>–</td>
<td>–</td>
<td>790 ± 70</td>
</tr>
<tr>
<td>He II $\lambda$4686</td>
<td>9.3 ± 0.1</td>
<td>1428 ± 25</td>
<td>4000 ± 400</td>
<td>–</td>
</tr>
<tr>
<td>CIII–NIII</td>
<td>6.2 ± 0.1</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

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thereby avoiding the positivity constraint demanded on reconstructions by the maximum entropy method. Superposed over the image which is plotted in the middle panel of Fig. 3 is an approximate binary configuration, where \( K_{\text{WD}} = 166 \text{ km s}^{-1} \) and \( q = 0.6 \). \( K_{\text{WD}} \) is the radial velocity of the white dwarf, and \( q \) is the mass ratio of the stellar components, \( M_s/M_{\text{WD}} \). These quantities are calculated from parameters measured by B90 and from Section 2.4, but are probably subject to large systematic error. The secondary Roche lobe is plotted with the trajectory of the accretion stream originating at the inner Lagrangian point, and another curve originating from the vicinity of the secondary stars centre of mass. This second trajectory represents the velocity of a Keplerian accretion disc coincident with the idealized spatial coordinates of the stream. The three crosses represent the centres of mass for the secondary star, binary and primary star.

The rotating component is mapped to a ring centred approximately about the primary centre of mass. Though blended with the rotating source associated with the primary, the narrow emission appears to be confined within the predicted Roche lobe of the secondary. This feature is biased towards the inner face of the star, which is expected if it is the result of irradiation. However, it is also biased towards the trailing side of the star. Uncertainties in the orbital ephemeris of Baptista & Cieslinski (1991) are too small to explain this, unless it is subject to large systematic errors. Similar results have been found for several other objects (Southwell et al. 1995; Schwöpe, Mantel & Horne 1997). In these cases this is due to the presence of magnetically threaded, optically thick material between the two stars shielding a portion of the secondary’s surface. A similar model is difficult to envisage in a non-magnetic system unless perhaps the bright spot or accretion stream has a vertical structure extending to several disc scaleheights. We discuss this point further in Section 3.2.

The trailed spectrogram constructed by reprojecting the Doppler map is shown in the bottom panel of Fig. 3. This provides a qualitative impression of the goodness of fit. Time-variable intensities in local line elements cannot be reproduced by this method, and so the eclipse has been removed from the time series.

Fig. 4 presents the trailed spectrogram for the \( \text{He} \text{II} \lambda 4686 \) emission line. A tomogram is not provided, since it provides no extra information. The profile is essentially featureless, although the eclipse is suggestive of a slight rotational disturbance. Consequently, there may be a contribution to the line from a rotating source – perhaps the disc, or a disc-wind (Hoare 1994). We note the linewidth is similar to the Balmer features. However, no fine detail has been resolved in the profile, and this is more typical of the nova-like variables (e.g. Dhillon et al. 1991).

2.4 A primary velocity determination

In the absence of strong contributions from either stellar component, the standard method for determining orbital parameters of a particular system is by measuring the radial velocities of the emission lines. The biasing properties of localized emission from, e.g., the bright spot and the irradiated secondary is a well-known problem where the centre of light does not correspond to the centre of primary mass. A consistently applicable solution to this may never be found. The bias is more problematic for the nova-like variables compared to the dwarf novae because of the larger fraction of emission from sources not axisymmetrically distributed about the white dwarf. The likelihood that the majority of emission from V347 Pup arises in the accretion disc means that a radial velocity determination can be attempted with some optimism. In this section
we apply the standard method of radial velocity determination to
the current data (Schneider & Young 1980; Shafter 1985), and also a
relatively new method employing the symmetric characteristics of
Doppler tomograms (Still 1996b; Still, Duck & Marsh 1998). Previous
tries to measure the white dwarf motion of V347 Pup
have been made by B90 and M94.

The standard method was applied to the combined Balmer and
He II λ4686-Å data presented in Figs 3 and 4, which were recast into
30 orbital phases bins. This involves convolving a double-Gaussian
bandpass with the line profile and determining the minimum of the
convolution function. By adopting bandpasses of small widths
relative to the line profiles, σ, and varying discretely the bandpass
separation, s, it is possible to sample the motion of emission as a
function of velocity in the line profile. σ was chosen to be 80 km s⁻¹,
and velocities were sampled by varying s from 400 to 3000 km s⁻¹
in discrete steps of 200 km s⁻¹. Functions of the form
\[ V = \gamma - K \sin(2\pi(\phi - \phi_0)) \]

were fitted to the resultant data. \( V \) denotes radial velocity, \( \gamma \) the
systemic velocity, \( K \) the radial velocity semi-amplitude, \( \phi \) the
orbital phase, and \( \phi_0 \) the offset of the red-to-blue zero-crossing
phase from mid-eclipse. Data during eclipse phases were ignored
by the fit. Best fits are summarized in the diagnostic diagram
(Shafter 1985) of Fig. 5. The \( \phi_0 \) parameter remains relatively
constant at intermediate separations, where the secondary star
contribution to the Balmer feature is small and noise does not
dominate the profile. Otherwise the variation of these parameter sets
with separation does not provide confidence in any one fit.

Sources of non-axisymmetric emission are generally low-
velocity structures, and so fits to the line wings are generally
regarded as more reliable than those closer to the core. However,
noise can dominate the wings, and therefore the set of parameters
adopted for stellar mass determinations are often those which
display the smallest relative statistical error. In this case we
objectively choose \( s = 1600 \text{ km s}^{-1} \) to be the optimum separation,
providing a fit to the Balmer line of \( K = 156 \pm 10 \text{ km s}^{-1} \),
\( \gamma = 16 \pm 10 \text{ km s}^{-1} \) and \( \phi_0 = 0.00 \pm 0.03 \), and a fit to the
He II λ4686-Å line of \( K = 125 \pm 13 \text{ km s}^{-1} \), \( \gamma = 15 \pm 12 \text{ km s}^{-1} \)
and \( \phi_0 = -0.02 \pm 0.05 \). These are plotted in Fig. 6. For compar-
ison, B90 found \( K = 134 \pm 9 \text{ km s}^{-1} \) and M94 found \( K = 122 \pm 19 \text{ km s}^{-1} \), both from fits to Hβ. Clearly, our optimum \( s \) is
determined by the quality of data and not through any certainty that
we are measuring the white dwarf motion. The fundamental
problem for this method is that it is searching for one–dimensional
symmetry across the velocity axis in individual observations. In the
majority of noise–limited cases, double-Gaussian convolution will
not work (e.g. Marsh 1988).

An alternative approach employs Doppler tomograms and is
related to the light-centre method used by Marsh (1988). Symmetry
determination becomes a two-dimensional problem in this case.
Ideally, we expect the centre of the axisymmetric component of the
map to correspond to the velocity coordinates of the white dwarf.
To measure these coordinates we construct an image, \( M(m,n) \), from
the azimuthally symmetric component about a given point \((x,y)\) of
the tomogram \( T(m,n) \), where \( x = 1,...m \) and \( y = 1,...n \). This
symmetric contribution is the median value of $T(m,n)$ at discrete radial distances from $(x,y)$. A test is performed between the two images of the form

$$R(x,y) = W \sum_{x=1}^{n} \sum_{y=1}^{m} \frac{[T(x,y) - M(x,y)]^2}{w(x,y)M(x,y)},$$

where $w(x,y)$ are statistical weights and $W = \sum w$. These can be chosen so as to place less significance on pixels which are known a priori to contain non-axisymmetric flux contributions. In this way a map of the $R$-statistic can be constructed. Ideally, the minimum in

the $R$-distribution corresponds to the white dwarf location. The advantages of this method are that the whole data set is used to determine a single velocity, and that non-axisymmetric emission from bright spots, etc. are often confined to a smaller subspace of the data. The main disadvantage of the technique is that it relies greatly on the accurate reconstruction of data in the tomogram which is difficult to quantify. The approach fails when asymmetric components are not localized azimuthally, although this is also true for the Gaussian convolution method. This problem can be countered by pixel weighting.

A landscape of the $R$-statistic determined from Balmer line profiles of V347 Pup is presented in Fig. 7. The tomogram position...
Figure 9. As for Fig. 3, but featuring a Balmer line averaged from the Hβ and Hγ emission features from spectroscopy obtained in 1987 January. Details of these observations may be found in B90.

Figure 10. As for Fig. 3, but featuring a Balmer line averaged from the Hβ and Hγ features from spectroscopy obtained in 1988 January. Details of these observations may be found in M94.
about which there is maximum axisymmetry is marked with the symbol ‘x’ and corresponds to \( K = 166 \text{ km s}^{-1} \) and \( \phi_0 = -0.014 \). If the orbital ephemeris of Baptist & Cieslinski (1991) remains accurate, the white dwarf motion is not expected to have a \( V_x \) component. Although the measurement is close to \( V_x = 0 \), the offset is significant and places doubt on the measurement. Subtraction of the best-determined axisymmetric component from the tomogram (Fig. 8) shows extended features in the residual emission. The origin of these features is discussed in Section 3.1. Similar measurements from the tomograms of Figs 9 and 10 are not significant enough to provide improvement over the current estimate. For this reason we do not provide a formal mass solution using these values.

3 DISCUSSION

We discuss two features of the current data that merit special comment. However, our interpretation should be considered conjecture until further data are obtained.

3.1 Spiral waves in the accretion disc?

In the top panel of Fig. 8 the symmetric component determined in Section 2.4 has been subtracted from the 1995 Balmer tomogram. The remaining structure belongs to the secondary star component plus two antiphased arcs distributed about the white dwarf. In Section 2.2 we find a dip in the emission-line equivalent widths of the balmer lines before primary eclipse. This may be caused by a short-lived absorption event within the emission profiles. This would lead to some spurious structure within the tomogram. To test this, the tomogram was recomputed using only phases 0.2–0.7 in order to avoid dip-phases. The map is presented in the lower panel of Fig. 8 and still displays two arcs. Therefore this antiphased structure cannot result from the dip event. This structure resembles the spiral pattern found on several occasions in the accretion disc of the dwarf nova IP Peg on the rise to outburst (Harlafitis & Steeghs 1997; Steeghs, Harlafitis & Horne 1997). Modelling shows that spiral density waves can grow over CV accretion discs, provided there is a suitably large torque between the outer disc and secondary star (Sawada, Matsuda & Hachisu 1986; Spruit et al. 1987). Spiral density waves provide constraints on the physical structure of accretion discs, the nature of dwarf nova outburst cycles and the mode of angular momentum redistribution in accreting binaries. It has been proposed by Steeghs et al. (1997) that the spiral pattern in IP Peg is generated on the rise to outburst because the disc increases in size and temperature, as predicted by thermal instability theory (Osaki 1974). Furthermore the disc radius has been observed to decay post-outburst by Wolf et al. (1993). Using the binary parameters determined by B90 and the pressure-less disc models of Paczyński (1977), we predict that the accretion disc in V347 Pup must be larger than the tidal radius of 0.41\( a \) to maintain spiral structure, where \( a \) is the stellar separation. The only measurement of disc size to date has found a radius of 0.31 ± 0.02\( a \) (B90). However, the binary parameters used to determine this number are expected to have large systematic uncertainties.

The spiral structure in Fig. 8 is a direct result of enhanced line intensity between orbital phases \( \sim 0.2 \) and 0.5. This feature is permanent and fixed in the orbital frame during the run. However, the data are not of good enough quality to make a convincing case that density waves have been found in this accretion disc. Confirmation by further observations of improved signal and spectral resolution would be valuable. This would allow us to study density waves in a thermally stable accretion disc, which is more convenient than attempting to catch dwarf novae on the rise to outburst.

3.2 Disc-overflow accretion?

The reconstructed data plotted in the bottom panel of Fig. 3 display a narrow, high-velocity absorption feature cutting through the profile. This attains a maximum red velocity at \( \phi = 0.75 \). The feature is also found within the data of the top panel. This component may be responsible for the dip seen in the low-excitation equivalent widths before primary eclipse (Fig. 2) or, alternatively, the dip may be the result of obscuration of the disc by its outer rim close to the bright spot (Smak 1994). Because of its nature the narrow feature makes little impact on the tomogram distribution. Significantly the velocity and phasing of this feature rules out an origin in the bright spot. They are closer to what is expected from material which has been able to stream over the surface of the disc and collide with it at closest approach to the white dwarf. This has been modelled by Lubow (1989) and Armitage & Livio (1996), and has been used by Hellier & Robinson (1994) to explain many of the puzzling phenomena found in nova-like variables. The Doppler coordinates of this feature lie close to the predicted coordinates of the impact indicated by asterisks on the ballistic and Keplerian trajectories of Fig. 3, although note that the binary parameters used to predict these trajectories are not well determined. It is plausible that an overflowing stream provides the optically thick material required to bias the distribution of irradiated flux towards the trailing side of the secondary star (Section 2.3). Clearly data of superior quality are required.

3.3 Long-term behaviour

In its high-state, the nova-like DW UMa displays complex line profiles (Shafer, Hessman & Zhang 1988). However, during periods of low mass accretion the Balmer lines were found to be very similar to V347 Pup – composites of weak double-peaked emission and strong emission from the secondary star (Dhillon, Marsh & Jones 1994). A concern is whether we have found V347 Pup in a similar low-state and whether its current emission behaviour is atypical for the object. The low-state of DW UMa was characterized in the optical by a 3-mag decrease in brightness and the absence of high-excitation emission. Although we cannot comment on the brightness of V347 Pup in the current data, the presence of strong high-excitation emission suggests that the object is in a state of high activity. In Figs 9 and 10 we present two data sets of V347 Pup Balmer emission from 1987 January and 1988 January, which consist of all the previously published spectroscopy for this object. See B90 and M94 for further details. Cast into 20 and 40 orbital phase bins respectively, these are accompanied by tomograms and reconstructed trails. Despite being of reduced resolution and signal-to-noise ratio, these data provide good matches to the current observations. This sample of three epochs covering 8 yr, suggests that the current state of V347 Pup is normal. Note that we find no strong evidence for spiral waves in either of the older time series. By degrading the 1995 data in phase resolution, spectral resolution and signal-to-noise ratio to match the two other epochs, we find that the spiral structure in a filtered back-projection is degraded to such an extent that it is no longer detectable.
4 CONCLUDING REMARKS

We have provided direct evidence of a rotational disturbance in the line emission of V347 Pup during primary eclipse. The line distribution can be interpreted as a composite of emission from the accretion disc and secondary star. This distribution is surprising, because the complexity of emission lines in high-inclination nova-like variables is often regarded as a general feature. Clearly, the simplicity of the line behaviour in this, the most highly inclined example, is not compatible with the suggestion that many of the puzzling features of nova-like line emission are sampling effects which result from the high inclinations of the most-observed members of the class (Dhillon 1996).

The relative simplicity of the velocity field found in the Balmer lines provided enough confidence to make radial velocity measurements worthwhile. Despite this, the standard measurement method did not yield a reliable orbital solution. A further solution was provided by searching for symmetry in the Balmer tomogram, although it seems likely that this also is unreliable.

The outcome of this work is that we find the emission line distribution from V347 Pup to be far simpler than the other eclipsing nova-like members. We have found some indications that V347 Pup may undergo disc-overflow accretion, and that the disc is tidally influenced by the secondary star. Data of much improved quality are required to confirm this. V347 Pup provides an excellent opportunity to study the kinematics of accretion using spectrophotometric observations of the optical emission lines, as is standard for the dwarf novae.

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REFERENCES

Baptista R., Cieslinski D., 1991, IAU Circ. 5407
Harlaftis E. T., Steeghs D., 1997, Spectrum, 13, 4

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