Accretion Stream Mapping

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Abstract. We present a new mapping algorithm, the Accretion Stream Mapping, which uses the complete emission-line light curve to derive spatially resolved intensity distributions along the stream on a surface created as a duodecadon shaped tube. We successfully test this method on artificial data and then applied it to emission line light curves in Hβ, Hγ and He II 4686 of the magnetic CV HU Aqr. We find Balmer emission near the threading point in the stream facing the white dwarf and Helium emission all over the magnetic part of the stream.

1. Introduction

The light curves of eclipsing magnetic CVs contain a wealth of information about the objects and in particular about the stream. The emission from various parts of the system (the white dwarf, the stream and the secondary), however, are superposed onto each other making it usually difficult to distinguish the various sources. The identification of the location of emission in the stream, one the other hand, may help in solving problems concerning the interaction of the plasma in the stream with the magnetic field of the white dwarf.

Assuming one can model or neglect emission from other parts of the system, the light curve is dominated by emission from different parts along the stream. Depending on where exactly in the stream material is heated and emitting radiation, structures will appear in the light curve at certain phases and particularly (however not only) in the shape of eclipse profile.

Analogically to the eclipse mapping of non-magnetic CVs (Horne 1985), a tomographic method which allows one to reconstruct the intensity distribution in the accretion disc by fitting the eclipse profile, we apply a similar maximum entropy method (MEM) to magnetic CVs. This technique shall distinguish the locations of emission, e.g. near the threading point where the stream material couples to the magnetic field of the white dwarf or near the white dwarf.

A similar method was applied by Hakala (1995) and later by Harrop-Allin et al. (1997 and these proceedings) using a genetic algorithm to derive the intensity distribution along the stream using eclipse profiles measured in broad-band filters and more or less simplified accretion stream geometries. In analysing U and UBVR light curves, respectively, of HU Aqr, they find that the intensity increases towards the white dwarf in the stream with a second local maximum near the inner Lagrangian point in the high state (Harrop-Allin et al.).
2. The method and application to artificial data

The stream we use for our Accretion Stream Mapping techniques follows a ballistic trajectory down to the threading region and then couples to a dipolar field line (Fig. 1). It is assumed to be a non-transparent 12 sided tube. While the system is rotating, the pixels appear under varying angles and are eclipsed at certain phases either by the stream itself or by the secondary. This justifies the use of the full observed light curve.

For the reconstruction of real accretion streams, four parameters (mass ratio, inclination angle, location of the threading point, orientation of the magnetic axis) have to be determined which describe the geometry of the stream. The parameters, however, often can be determined quite well from Doppler Tomography (see Schwope, these proceedings).

We constructed a stream geometry for a CV with the system parameters: \( i = 85 \), \( q = 0.2 \), a rather strong magnetic field and an axis almost parallel to the orbital axis (20° away and 45° from the binary axis). Between the radii 0.4 and 0.5, shortly before the connecting point, we placed a bright spot facing the white dwarf otherwise the stream emits only 10% of the spot intensity. For this artificial stream we calculated the light curve (Fig. 2, left) and analysed it with the Accretion Stream Mapping method.

Fig. 3 shows gray-scale images of the original and reconstructed intensity distributions. The location of the spot is reconstructed very well, it is only smeared out due to the MEM algorithm, leading as well to a different spot profile and lower spot intensity (see also Fig. 3, right).

We tested this method also against picking wrong values for one to three of the four system parameters values. The spot is in some cases reconstructed, but (additional) spots at other locations emerged occasionally.

These tests, however, show the advantage of using the full light curve, since it indeed constrains the system parameters fairly well. In comparison, Hakala

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1 Pixel 1 is always facing upwards, i.e. the area normal is parallel or closest to the orbital axis. Pixel 4 facing outwards and pixel 10 inwards.
Figure 2.  **Left:** The light curve of the artificial intensity distribution with the fit. **Right:** The original (small dots) and reconstructed (larger dots) radial intensity profile on the stream surface. The abzissa gives the distance from the white dwarf and the ordinate the intensity distribution offset by 0.2 for each pixel row. The short row of dots at 1.4 intensity units belongs to the original intensity distribution in row 10. The vertical dotted line at $0.43R_{L}$ denotes the location where the magnetic part of the stream starts.

Figure 3.  **Left:** The original intensity distribution: In the spot the pixel have an intensity value of 1 (arbitrary units), while the other pixel have an intensity value of 0.1. The horizontal dotted line at pixel 65 denotes the location where the magnetic part of the stream starts, the white dwarf is at the top, the secondary at the bottom. **Right:** The reconstructed intensity distribution.
Figure 4. The light curves in the emission lines H\(\beta\), H\(\gamma\) and He II 4686 with the fits. In the bottom of each plot the residuals are given.

(1995) found not much difference for his reconstruction of the accretion stream for different sets of system parameters.

3. Application to emission line data of HU Aqr

Since the analyses of broad band photometry would force us to include absorption and reprocession effects, we applied it first only to light curves in various emission lines and therefore also excluded the white dwarf as a source of light. We used high time and high spectral resolution spectra of the magnetic CV HU Aqr in the high state taken at Calar Alto, Spain in 1993 (Schwope, Mantel, Horne 1997). The integrated line profiles of H\(\beta\), H\(\gamma\), and He II 4686 were corrected for emission originating on the irradiated surface of the secondary. The remaining emission is regarded to originate solely from the accretion stream; the resulting light curves are shown in Fig. 4.
Figure 5. The reconstructed intensity distributions on the surface of the accretion stream as gray-scale plots. The horizontal dotted line at pixel 76 denotes the threading location.

Accretion Stream Mapping was applied to these light curves using the following system parameters: mass ratio $q = 0.25$, inclination $i = 85^\circ$, field orientation as in the test ($20^\circ$, $45^\circ$) and location of the threading point as determined via Doppler Tomography (Schwope, Mantel, Horne 1997). The Accretion Stream Mapping method reached very good fits (Fig. 4). The somewhat high $\chi^2$'s of 5 and 7 are mainly due to the large scatter of the individual points in the light curve partly because of difficulties in identifying the NEL. The overall shape of the light curve was reconstructed very well, except for the eclipse profile. Unfortunately, during the egress (which is determined by the orientation of the magnetic field) only a few data points were retrieved.

The reconstructions show a clear bright spot for the Balmer lines at the threading region facing the white dwarf. A similar bright spot was also found by Hakala (1995), however, his geometry did not allow to distinguish between the illuminated and the non-illuminated sides of the stream. At this point, the matter is drawn out of the orbital plane, dissipation of kinetic energy is likely to occur resulting in enhanced line emission. The location on the inner side of
the stream shows that the material must also be heated by the white dwarf and dissipating this energy.

The intensity map in the He II line appears much different from the Balmer emission. Though, the light curve shows a worse S/N ratio, clear differences in the light curve are seen which are reflected in the intensity distribution: The difference between the maxima is less pronounced for the Helium line and the eclipse depth and profile differs significantly.

The reconstruction shows a much smoother intensity distribution than the ones for the Balmer line. The side facing the white dwarf (pixel rows 9 to 11) is everywhere bright. Also the magnetic part of the stream appears bright. This is unexpected, because the white dwarf is not able to directly irradiate (all) those regions. It appears that in the magnetic part of the stream the line opacity is not negligible (otherwise the stream would show no variation in intensity) but significantly lower than in the ballistic part. However, since the fits around eclipse are not perfect, yet, this conclusion is only preliminary.

A similarly bright magnetic stream was found by Hakala and Harrop-Allin et al. using broad band photometry. However, Doppler Tomography suggest a much more prominent ballistic stream, especially in the high state (Schwope et al.). Clearly, one needs to take into account both methods, Doppler Tomography and Accretion Stream Mapping, since Doppler maps yield only the velocity of the material, not the spatial location, and emission structures may be smeared out significantly in velocity space. We intend, therefore, to build a consistent picture including both techniques.

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