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RU Peg and AE Aqr: two contrasting CVs with one thing in common

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Abstract. Roche tomography is a powerful tool for imaging the surfaces of stars. We have applied it to two contrasting systems, a normal dwarf nova, RU Peg, and the peculiar intermediate polar AE Aqr. Despite these differences, the Roche tomograms of the cool stars in the two systems are remarkably similar. We compare them with tomograms of two other stars, and discuss the differences and similarities. The rotation speed may be critical in determining the surface appearance, and it is strongly recommended that a Roche tomogram be obtained for the bright CV SS Cygni, which would be the fastest-rotating secondary to be studied. In addition, V426 Oph should be re-observed.

Key words. binaries: close – novae, cataclysmic variables – Stars: imaging – Stars: individual: RU Peg – Stars: individual: AE Aqr – starspots

1. Introduction

Roche tomography (Rutten & Dhillon 1994; Dhillon & Watson 2001; Watson & Dhillon 2001) is an indirect imaging technique which has been developed to reveal the surface line intensity distribution on the secondary stars in cataclysmic variables (CVs) using phase-resolved spectra. It uses maximum entropy techniques to produce the best-fitting map of the surface, assuming a uniform default map. To obtain good maps, it requires the best available spectral resolution (preferably using echelle spectra) and the highest possible signal-to-noise (S/N). The signature of a spot is a bump in an absorption line profile, which moves across the profile as the star rotates (following the binary orbital motion). However, single-line data have relatively low S/N and reveal only gross features, such as irradiation by the disc and white dwarf. To see spots, it is necessary to improve the S/N by finding the average line profile for all the absorption lines in the spectrum, which typically number several thousand in an echelle spectrum. This Least Squares Deconvolution (LSD) technique, originally developed for single stars (Donati & Collier Cameron 1997), can improve the S/N by a factor of 30 or more. Good flux calibration, to remove the variable contributions of white dwarf and disc, is also required, which for echelle spectra means that simultaneous photometry is highly desirable. The combination provides enough signal for spots to be revealed (Watson et al. 2006, 2007a). This paper

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Table 1. RU Peg and AE Aqr compared

Property	RU Peg	AE Aqr
Orbital period (h)	8.99	9.87
V magnitude (quiescence)	12.5	10.7
Mass of WD ($M_\odot$)	1.06	0.74
Mass of secondary ($M_\odot$)	0.96	0.50
Orbital inclination (^{o})	43	66
Magnetic white dwarf?	No (standard DN)	Yes (peculiar IP)

reports the detection of starspots on RU Peg and compares the results with published maps for three other CVs.

2. Introducing RU Peg and AE Aqr

Both RU Peg and AE Aqr are long-period CVs, but are otherwise somewhat different, as can be seen in Table 1. AE Aqr is 2 magnitudes brighter, it has less massive components and a larger inclination – but perhaps most significantly it has a magnetic white dwarf. Because it is one of the brightest CVs, it was the first to reveal starspots, and the AE Aqr maps remain the best available, although BV Cen and V426 Oph (Watson et al. 2007a,b) have also been imaged by the same team.

3. Results

3.1. One-line results

The first observations were reduced using the profile of a single strong line that clearly showed a bump crossing the profile. The resulting maps showed surface features, but the resolution was too low to reveal spots. However, they did clearly demonstrate the effects of irradiation near the L_1 point. Four objects were observed by Watson et al. (2003); for three of those – AM Her, IP Peg and QQ Vul – the Na I absorption doublet at 8183, 8195 Å was used, while for HU Aqr the He II emission line at 4686 Å was used. The HU Aqr image showed that the irradiation of the cool component was asymmetric about the L_1 point, implying shielding by the accretion stream and curtain in this polar.

3.2. AE Aqr

The first LSD results were published briefly by Watson & Dhillon (2004) for AE Aqr. The mean absorption line profile at most phases clearly shows several bumps, which track across the profile as the star rotates, as is easily seen in trailed spectra. These first maps revealed a strong high-latitude spot, together with other weaker features at lower latitudes.They were based on data obtained in 2001 August using the UES on the 4-m WHT on La Palma, plus simultaneous photometry on the 1-m JKT.

Full details were published by Watson et al. (2006). The lower-latitude features were confirmed and a total spot coverage of ∼18 % was deduced. The reality of all the features was demonstrated by showing separate maps for two independent datasets (odd- and even-numbered spectra).

Later spectra, obtained in 2004 with the 6.5-m Magellan telescope, confirmed the earlier maps at lower resolution but much larger S/N, and in particular showed clearly, as had been suspected before, that the high-latitude spot was on the trailing hemisphere. These data were presented by Watson at the 2009 CV meeting in Tucson (Watson 2009).

3.3. Other systems?

AE Aqr was the obvious first target, being the brightest of the suitable systems at V = 10.7. Looking for other targets, it is found that several of the other bright CVs are novalikes, with bright discs that obscure the secondary and make mapping difficult. The best other targets are dwarf novae (in quiescence) or polars, where the secondary makes a significant contribution to the light.

Watson et al. (2007a,b) have observed BV Cen (DN, UG, P = 14.7 h, V = 12.6) and V426 Oph (DN, ZC, IP?, P = 6.85 h, V = 13.5); the latter is the fastest rotating CV secondary so far mapped. Smith and Dunford (Dunford et al. 2012) have observed RU Peg (DN, UG, P = 8.99 h, V = 12.5).

Thus, of the three mapped systems other than AE Aqr, two are about 2 magnitudes fainter than AE Aqr and the third is nearly 3 magnitudes fainter. However, there is an obvious candidate which is only about half a magnitude fainter, namely SS Cygni (DN, UG, P = 6.60 h, V = 11.2) – and yet no-one has mapped it. It would be the fastest rotating CV secondary to be mapped, and it should certainly be mapped, especially as there is indirect evidence (Webb et al. 2002) from observations of TiO in SS Cyg that the spot coverage may be as high as 22%.

The results for BV Cen are quite similar to those for AE Aqr: it also has a high-latitude spot, and apparently a rather higher spot coverage (~25%) than AE Aqr, possibly because of higher S/N data. Independent ANU data by Smith & Dunford, low in resolution and S/N, also appear to show a polar spot. V426 Oph is slightly different, showing only low-latitude spots, and not so many of them – however, it was observed when it was in an unusual low state (Watson et al. 2007b), so that may account for the difference; it needs to be re-observed. Usefully, the fact that it does *not* show a polar spot suggests that the presence of a polar spot on all the other mapped stars is not just an artefact of the mapping technique.

3.4. RU Peg

The first map that was produced for RU Peg has never been published but appeared in Stpehen Davey's thesis (Davey 1994), using a simple Na I flux deficit mapping technique described by Davey & Smith (1992, 1996). The data were obtained in 1988 using the INT+IDS (Friend et al. 1990). The map is shown in Fig. 1. It shows irradiation at the L_1 point but curiously seems also to show higher intensity over the whole trailing hemisphere. In view of our current results, and the fact that this early map has no resolution in latitude, we now believe that this may be early evidence for a high-latitude spot on the trailing hemisphere.

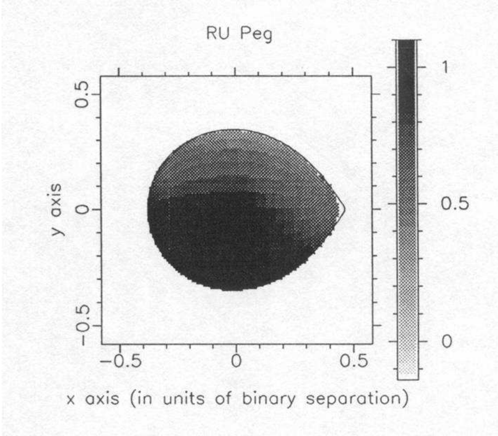

Fig. 1. A one-spot model of RU Peg, from Stephen Davey's Sussex DPhil thesis (Davey 1994). The white dwarf is off the image to the right. There is clear irradiation around the L_1 point, which also seems to extend over the whole trailing hemisphere.

Our only successful observing session on RU Peg was in July 2004, using the 4.2-m WHT + the ISIS double-beam spectrograph; follow-up observations in August 2006, using the TNG and the SARG echelle to obtain higher resolution, were wiped out by bad weather and technical problems. However, even our relatively low-resolution Roche tomograms show clear evidence for spots, including a dominant one at high latitude, again on the trailing hemisphere. The map from the ISIS blue arm is shown in Fig. 2. The map from the red-arm data is almost identical.

3.5. Comparisons

Four stars have now had good Roche tomograms produced. For three of these, AE Aqr, BV Cen and RU Peg, there is clear evidence of a high-latitude spot on the trailing hemisphere; the asymmetry may be caused by Coriolis or tidal displacement of the magnetic flux tubes.

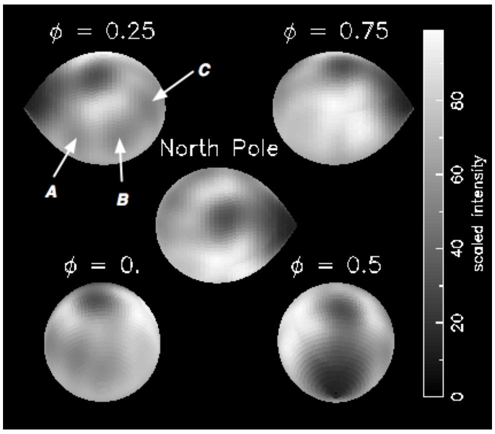

Fig. 2. The Roche tomogram of RU Peg using the data from the blue arm of ISIS; the independent red-arm data give a very similar map. The dark areas represent regions of lower absorption. The maps are presented as seen at an inclination of 43°, except for the central image, which looks down on the north pole. There is clear evidence for a high-latitude spot on the trailing hemisphere, and there are three other less definite features (A, B, C).

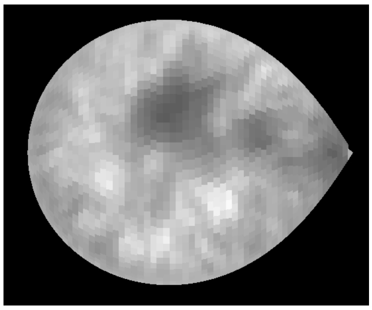

Fig. 3. The polar view of an AE Aqr tomogram, for comparison with Fig. 4. It shows a very clear high-latitude spot, on the trailing hemisphere, and several other features.

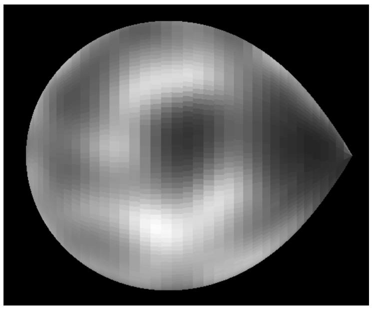

Fig. 4. The polar view of the blue map of RU Peg, for comparison with Fig. 3. Despite the lower resolution, the two maps are quite similar.

The highest spot coverage is shown by BV Cen, which also has the longest orbital period, so that the rotation speed of the secondary is the slowest. The fastest rotator is V426 Oph, which shows no high-latitude spot, and fewer features of any kind, apart from irradiation around the L_1 point. AE Aqr and RU Peg, which are the most similar in orbital period (9.9 h and 9.0 h respectively) and so the most similar in rotation speed, are also the most similar in appearance (Figs 3, 4). This seems to indicate that the spot pattern is independent of the magnetic field of the white dwarf and depends only on properties of the secondary. Perhaps the surface spot pattern is a function of rotation speed? If so, SS Cyg should have a smaller spot fraction than any of the others – although that is not what was deduced by Webb et al. (2002) from the strength of the TiO lines. Perhaps it is more likely that the apparent differences are caused by differences in S/N; low S/N would smear out small spots that would be included in the TiO data.

4. Conclusions

The Roche tomogram for the secondary of RU Peg is remarkably similar to that of AE Aqr. For the four stars with observed spots, there is an apparent anti-correlation between rotation speed and spot coverage. Observations of SS Cygni, which would be the fastest rotator to be mapped, and of V426 Oph in a normal state, would allow a test of this relationship against a more plausible model linking spot coverage to surface activity and a dynamo-driven field, which would predict that these two stars had the highest spot coverage.

5. Discussion

MICHELE MONTGOMERY: Can you tell if the spots move?

ROBERT SMITH: No, our resolution is not high enough, and anyway no-one yet has data taken at appropriate intervals of a week or two.
MICHELE MONTGOMERY: As a follow-up point – if the resolution improves, and spot motion can be detected, I would be interested in the Rossiter-McLaughlin effect and these spots.
PIETER MEINTJES: If the starspots are associated with the surface magnetic field structures on the secondary, it may have a significant effect on mass transfer, maybe fragmenting it? This may result in our having to rethink the mass transfer process from secondary stars. Maybe there will be a blobby flow from secondary stars.
ROBERT SMITH: Whether that is important depends on the still unknown strength and structure of the global magnetic field.. But blobby flow is a possible explanation of spot 'trails' towards L_1 on BV Cen and AE Aqr.
GAGIK TOVMASSIAN: Another good candidate to look for spots on the secondary is EV Cyg, a system with a ~12-hr orbital period. We did some V, R, I photometry and we see different patterns of the light curves from epoch to epoch. I believe it is a signature of an active secondary and a spotted surface.
ROBERT SMITH: It depends on how bright it is. [*JUAN ECHEVARRÍA: 15.*] At 15th magnitude it would be too faint to attempt Roche tomography, unless you can get Keck time.
MIKHAIL REVNIVTSEV: Do you see a shadow of the disc on the star?
ROBERT SMITH: No, we do not see that. But that may just be the result of the resolution not yet being high enough.

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