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Linking radio flares with spots on the active binary UX Arietis

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Abstract. Signs of stellar activity such as large surface spots and radio flares are often related to binarity. UX Arietis is one of the most active members of the RS CVn class of binaries in which spin-up of a sub-giant/giant star by a close companion leads to the creation of magnetic fields. UX Arietis exhibits these signs of activity, originating mostly on the K0 sub-giant primary component. We measured the orbit with the CHARA interferometer and made images of a single large spot rotating in and out of view over a month in 2012. The rotation of the stars is synchronous with the orbit, and long-term photometric observations show that the spot or spots do not move much during intervals of a year. Our aim is to relate the positions of the stars and the spots on the primary to astrometry of the radio components observed during outbursts.

Keywords. techniques: interferometric, stars:activity, stars:flare, stars: magnetic fields

1. Introduction

Radio emission of active stars is caused by the gyro-synchrotron process in plasma contained by the large scale magnetic fields (Franciosini & Chiuderi Drago 1995) in the coronae of these stars. The geometry and extent of magnetospheres in magnetically active stars controls stellar winds and therefore the angular momentum evolution in binary systems. Detailed modeling of the radio sources for past and future epochs requires an unambiguous understanding of the stellar alignment in the system and absolute sub-milliarcsecond astrometry. With orbital periods between a few days and a few weeks, RS CVn stars are resolved only by optical interferometry (or in the radio by VLBI).

Radio emission of UX Arietis may be modeled by a single radio component related to the active sub-giant (Peterson *et al.* 2011), or can be modeled by two distinct sources separated by angles commensurate with the optical orbit size (Mutel *et al.* 1985; Ros & Massi 2007). In the former case, Peterson *et al.* (2011) were able to measure the absolute motion of the single radio component around the common center of mass of the close binary and determine a preliminary orbit. Hummel *et al.* (2017) determined the final orbital elements using near-IR interferometry with CHARA (ten Brummelaar *et al.* 2005). They also observed a co-rotating large spot on the primary component.

To explain the double-peaked radio emission of HR 1099, Ransom *et al.* (2002) considered two models where a magnetic loop structure is attached to the poles or equatorial regions of the cooler K star, or is part of a joint magnetosphere of both stars in the binary. Observations of the radio emission of Algol by Peterson *et al.* (2010) detected a large coronal loop straddling a radio-bright KIV subgiant. This observation clearly is only consistent with the predictions of the polar loop model.

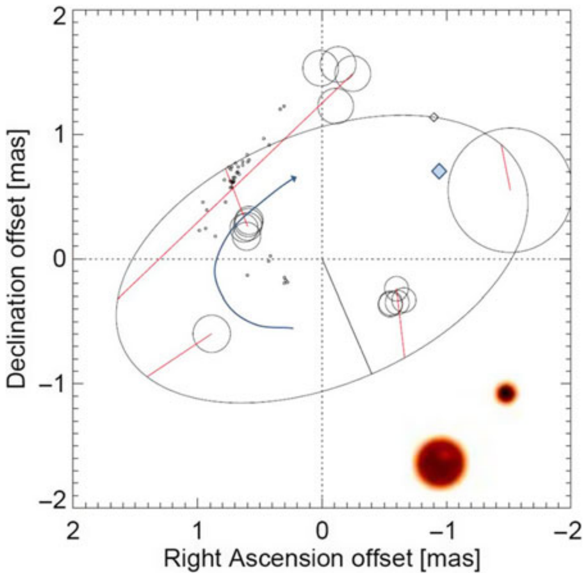

Figure 1. Retrograde orbit of the G0V secondary around the spotted K0IV primary at the center. Locations of the secondary star are connected with a red line to the position of its radio counterpart at epochs when two radio components were observed. The big circle to the upper right is the measurement by Mutel *et al.* (1985), with the size of the circle indicating the synthesized beam size. The single small circle to the lower left is due to Beasley et al. (in prep.). Three clusters of small circles correspond to the daily averages of observations by Ros & Massi (2007), with the size of the circles indicating the RMS of the scatter during the observations. While the average radio position is near (but inside) the position of secondary on Sep 23 and 26, the radio position on Sep 25 is nowhere near it. The small dots correspond to hourly averages during a major flare on the last day moving outwards from the K0IV primary (lower right inset, with spot appearing) in a clock-wise fashion (blue curved arrow) towards the secondary's position marked with a small diamond. The image at the lower right shows the positions of the stars during the flare and a spot on the sub-giant (from modelling light-curves). The color scale of the image is *inverted* heat.

In the following, we reconstruct the relative positions of the optical components in UX Arietis during radio observations which were modelled with two emission components. The earliest radio map produced by VLBI observations of UX Arietis during an outburst was presented by Mutel *et al.* (1985) and shows two components, the eastern one associated with the K0IV primary and a western "halo" component associated with the secondary component (or the joint magnetosphere of the system), the alignment having been described as "conjectural" by the authors, but now confirmed by our orbit. Observations with the VLBA of the quiet and flaring radio emission at four epochs within less than a week was obtained by Ros & Massi (2007), who also used a model of two Gaussian components. The emission during the last epoch of observations was dominated by a flare, causing the radio components to move significantly with respect to each other in a 6 hour period. The relative astrometry also showed significant dispersion during the second, while the first and third epoch observations showed very stable relative positions.

As shown in Fig. 1, where we adopt an identification of one of the two radio component as potentially associated with the optical secondary, during four observations the secondary radio component indeed was located close to the optical secondary. However, there are exceptions, both during an observation of the quiescent radio emission, and during a flare. Intriguingly, the location of the radio secondary appeared to move during the flare in an arc-shaped path from a location near the optical primary towards

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the location of the optical secondary. Hence, our reconstruction of the alignment of the optical components during radio observation appears to support the model that radio emission in UX Arietis may flow along magnetic flux-tubes between the stars. In this case, the two components would be directly related to the two stars in a scenario where they are magnetically coupled, i.e., where the main site of the energy release is on the more active subgiant close to the mid-latitude spot groups, while the magnetic field of the dwarf star acts as a passive magnetic foot print, bright in microwaves because the field is enhanced there. The magnetic loop model of Franciosini & Chiuderi Drago (1995), on the other hand, would predict separations between the radio components much smaller than between the binary components and is therefore inconsistent with pattern seen in Fig. 1.

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