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Insights from mid-infrared interferometric observations of the symbiotic nova RS Ophiuchi

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Abstract. RS Oph is one of the best studied recurrent novae, with its last outburst in 2021 triggering an extensive observational campaign across the whole electromagnetic spectrum, which led to the accumulation of an impressive amount of data. Here, we present the preliminary results of our analysis of interferometric data, which allowed us to provide insights into the structure and kinematics of the expanding nova shell.

Key words: optical interferometry – symbiotic novae – cataclysmic variables

1. Introduction

The stellar components of the RS Oph symbiotic binary system are a M2III red giant (Zamanov et al., 2018) and a massive, carbon-oxygen white dwarf ($M_{WD} = 1.2{-}1.4\,M_\odot$), with the system having an orbital period of 453.6 days (Brandi et al., 2009). Due to the high mass of the white dwarf, close to the Chandrasekhar limit, RS Oph is considered one of the most likely candidates to eventually explode in a type Ia supernova event (Mikołajewska & Shara, 2017). Historically, RS Oph has experienced seven recorded outbursts, with the most recent occurring in 2021. Additionally, a review of archival data by Schaefer (2010) suggests the possibility of two previously undocumented outbursts.

In this poster, we present the results of our analysis of spectro-interferometric data gathered using the VLTI/MATISSE instrument (Lopez et al., 2022) at two different epochs: 5.5 days and 24.5 days post-outburst. These observations were conducted across three mid-infrared (MIR) bands: L ($2.8-4.2\,\mu$m), M ($4.5-5.0\,\mu$m), and N ($8.0-13.0\,\mu$m). However, after reducing and calibrating the data, only the L-band data proved to be of sufficient quality to be included in the subsequent analysis.

2. Methodology

1. Initially, we created single-component models for RS Oph, one for each emission component (L-band continuum, as well as Pfδ 3.30 μm, Pfγ 3.74 μm, and Brα 4.05 μm lines). To achieve this, we utilized the LITpro modelling software (Tallon-Bosc et al., 2008). We employed elongated uniform disks and elongated Gaussian ellipses to fit visibilities of the continuum and the individual lines. With the position of each component fixed at (0, 0) and the total flux normalized to 1, the only adjustable parameters were the position angle of the major axis, the elongation ratio, and, depending on the model used, the minor axis diameter or FWHM.

2. The single-component models were centro-symmetric, meaning that the closure phase of these models was equal to zero - a reasonable assumption for the continuum and the Pfδ and Pfγ lines, given that their closure phases did not significantly deviate from zero. However, these models cannot be used for the Brα line-component, as the shape of its closure phase curve indicated a departure from centro-symmetry. This observation led us to adopt a two-component model for the Brα line-component. This approach involved simultaneously fitting geometric models to the visibilities of the continuum- and Brα line-forming regions. The parameters previously determined for the continuum in the single-component modelling were kept fixed, as was the component's position at (0, 0). However, the parameters for the Brα line-forming region, including the major axis position angle, elongation ratio, minor axis diameter/FWHM, and the component's position relative to the continuum, were allowed to vary freely. The results of two-component modelling are presented on Fig. 1.

3. Modelling results

1. The closure phase values for the continuum-, Pfδ- and Pfγ-forming regions are close to zero, suggesting that these components are centro-symmetric. In contrast, the region associated with the emission of the Brα line shows a clear deviation from centro-symmetry.

2. In the models obtained for the 1st epoch, the continuum-forming region has a position angle of $160°\pm2°$, similar to the Pfδ- and Pfγ-forming regions ($158°\pm4°$ and $151°\pm6°$, respectively). These observations track ma-

terial ejected in the event of the nova outburst, which is expanding in the orbital plane of the binary system.

3. The position angle of the Brα line-forming region, determined from the two-component modelling of data from the 1st epoch, is $132° \pm 8°$ - a difference of $\sim 30°$ compared to the continuum-forming region. Such a difference suggests that this component tracks bipolar ejection within the system.

4. The position angle of all emission components from the 2nd epoch observations is $170° - 180°$. After 24.5 days since the nova outburst, only the emission of material expanding in the orbital plane of RS Oph remains detectable in these data.

5. Model fits for the 2nd epoch demonstrate a significant size increase in the case of all components (they are $\sim 2-3$ times larger compared to models obtained for the 1st epoch), indicating the expansion of the envelope following the nova outburst.

Our findings demonstrate that the structure of an expanding material is more complex than a simple model of spherical ejection. Indeed, similar conclusions emerge from the analysis of observational data collected during the last two outbursts of RS Oph. Near-infrared observations conducted only 5.5 days after detection of 2006 outburst by VLTI/AMBER interferometer revealed ring-like structure expanding with velocity of $v_{\rm rad} \sim 1800\,{\rm km\,s^{-1}}$ and faster ($v_{\rm rad} \sim 2500 - 3000\,{\rm km\,s^{-1}}$) structure expanding in the East-West direction (Chesneau et al., 2007). The similar structure, now understood as an expanding bipolar outflow, can also be seen at radio (e.g., O'Brien et al. 2006; Sokoloski et al. 2008; Rupen et al. 2008; Munari et al. 2022) and X-ray wavelengths (Montez et al., 2022). The asymmetric geometry of ejected material can be traced as early as only 2 days after the outbursts, as evident from spectro-polarimetric observations of Nikolov et al. (2023).

We note that in our contribution we summarise the preliminary findings from the analysis of MATISSE data, and a thorough investigation of the velocity distribution of the expanding nova ejecta is beyond the scope of this paper. It will, however, constitute a part of a more comprehensive analysis of MIR interferometric data of RS Oph and the results of which will be presented soon (Kaczmarek et al., in prep.).

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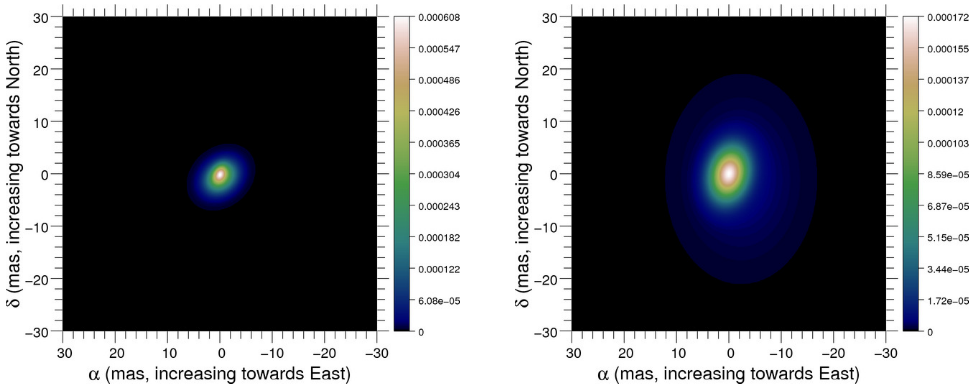

Figure 1. Geometry of the continuum- and Brα line-emitting regions derived from two-component modelling of 2021 outburst of RS Oph. The model used is an elongated Gaussian ellipse. The left panel shows results obtained for 1st epoch, while the right panel - for 2nd epoch.

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