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The Colliding-wind Binary HD 168112

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Abstract

HD 168112 is a non-thermal radio emitter that has only recently been confirmed as a spectroscopic binary by Putkuri et al. (2023, DOI: 10.1093/mnras/stad2657). We use an independent set of spectroscopic observations to determine its orbital parameters. We also analyse radio observations we collected around its periastron passage. While other orbital phases clearly show non-thermal emission, the phases near periastron are thermal and are dominated by the free–free emission in the colliding-wind region.

Keywords: binaries: spectroscopic, stars: early-type, stars: individual (HD 168112), radio continuum: stars

Résumé

La binaire à vent en collision HD 168112. HD 168112 est un émetteur radio non thermique qui n'a été que récemment confirmé comme binaire spectroscopique par Putkuri et al. (2023, DOI : 10.1093/mnras/stad2657). Nous utilisons des observations spectroscopiques indépendantes pour déterminer les paramètres orbitaux. Nous analysons également les observations radio que nous avons recueillies lors de son passage au périastre. Alors que les autres phases orbitales montrent clairement une émission non thermique, les phases proches du périastre sont thermiques et sont dominées par le *bremsstrahlung* dans la région de la collision des vents.

Mots-clés : binaires spectroscopiques, étoiles massives, étoiles individuelles (HD 168112), émission radio stellaire

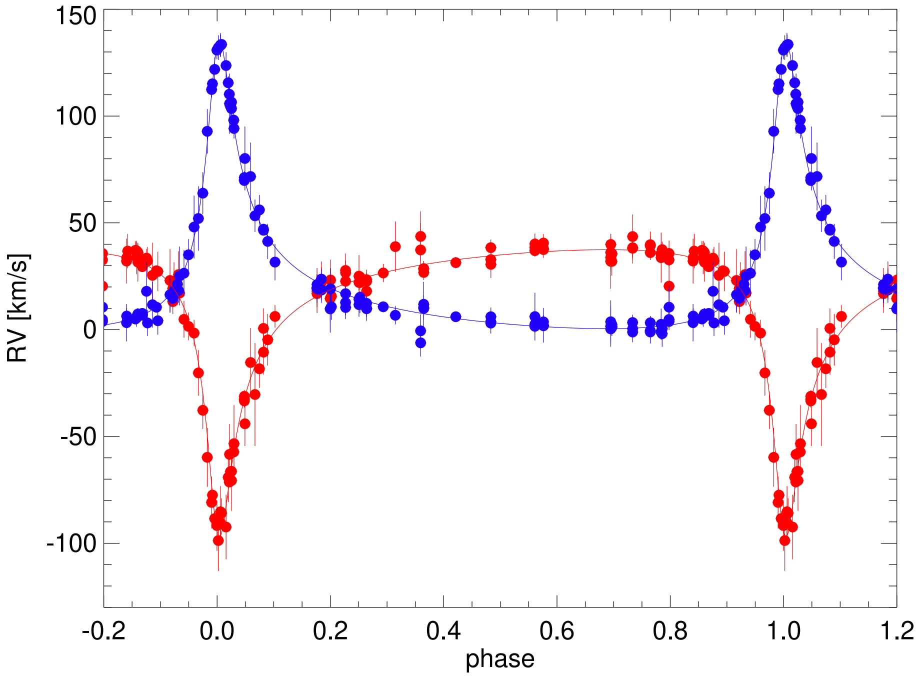

Figure 1: Observed radial velocities (symbols) are fitted by our orbital solution (solid line). Blue indicates the primary component, red the secondary component.

1. Introduction

Almost all known non-thermal radio emitters among the early-type stars have been shown to be colliding-wind binaries. For Wolf–Rayet stars this was argued by Dougherty and Williams (2000), while for O-type stars it was shown in a series of detailed studies of individual O-stars (Leitherer et al., 1987; De Becker et al., 2004b, 2006; Nazé et al., 2008; Rauw et al., 2016). However, for a long time, for HD 168112 there were only hints from radio and X-ray observations that it is a colliding-wind binary (De Becker et al., 2004a; Blomme et al., 2005). Finally, Putkuri et al. (2023) showed it to be a highly eccentric spectroscopic binary with a period of 513.52 days.

2. Spectroscopic Data

We obtained a set of spectroscopic observations that are independent of those of Putkuri et al. (2023), and used these to determine the orbital parameters of HD 168112. Figure 1 shows the observed radial velocities and the fit of our orbital model. We find that the system has a 512-day period, a high eccentricity (0.75), and a mass ratio close to one. Using the Sana et al. (2014) optical interferometry observation, we could derive an inclination angle of $\sim 63^\circ$ and a mass for both components of $\sim 26 M_\odot$.

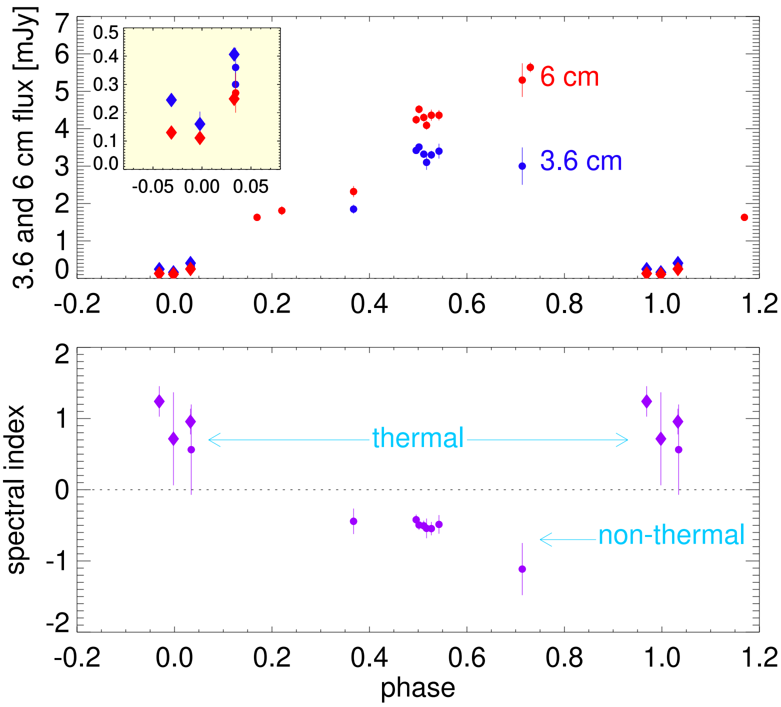

Figure 2: The *top panel* plots the 3.6 cm (blue) and 6 cm (red) radio fluxes. The dot-shaped symbols show the data from Blomme et al. (2005), the diamond-shaped symbols the new data. The *inset* zooms in on the phase range around periastron. The *bottom panel* shows the corresponding spectral index α.

3. Radio Data

We also obtained Karl G. Jansky Very Large Array radio observations at three epochs near HD 168112's periastron passage. We combined these with the archive data analysed by Blomme et al. (2005). Figure 2 shows the radio fluxes, which are clearly correlated with the orbital phase. The fluxes are at minimum near periastron, and the new observations are in excellent agreement with the older data discussed by Blomme et al. (2005).

From (nearly) simultaneous observations at two different wavelengths, the spectral index α can be derived, where $F_\nu \propto \nu^\alpha$. Negative values of α indicate non-thermal emission, and this is indeed seen at orbital phases far from periastron. The non-thermal emission is due to synchrotron photons that are created in shocks around the colliding-wind region. However, close to periastron, the emission is thermal. Thermal emission is due to free–free processes in the ionized material of the stellar wind.

4. Thermal vs. Non-thermal

One would expect that, in this eccentric binary, the collision at periastron would be stronger, and therefore more synchrotron radiation would be emitted. But that is not what we observe. The reason is the free–free absorption of both stellar winds, as shown in Fig. 3. The left panel shows the situation far from periastron. The extent of the stellar wind absorption is represented

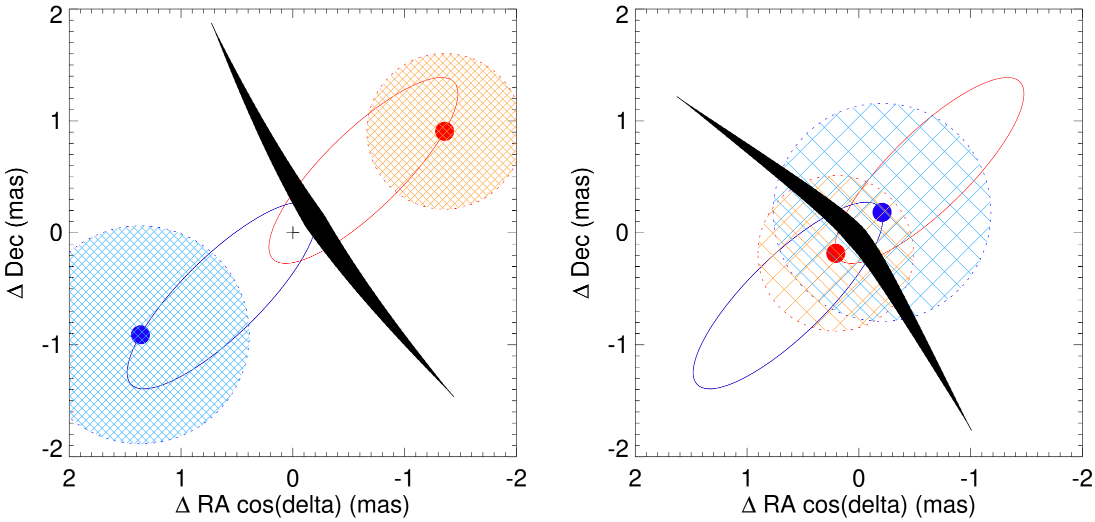

Figure 3: Orbits of both binary components projected on the sky (blue=primary component; red=secondary component). The circles with the crosshatch pattern indicate the $\tau = 1$ surface. The position of the colliding-wind region is indicated in black. The *left panel* shows the situation far from periastron, where the synchrotron photons from the colliding-wind region can easily escape. The *right panel* shows the situation near periastron, where the synchrotron photons are absorbed in the stellar winds.

by the surface where its optical depth $\tau = 1$. Far from periastron, the colliding-wind region is well outside the free–free absorption of both stellar winds. The synchrotron photons emitted in the colliding-wind region can therefore easily escape and be detected. Near periastron (right panel of Fig. 3), the colliding-wind region is well inside the free–free absorption of both stellar winds. The synchrotron photons therefore cannot escape, which explains why we do not see non-thermal emission near periastron.

However, when we estimate the total free–free emission of both stellar winds, we find a value that is substantially below the observed flux at periastron. This can only be explained by the colliding-wind region that is also contributing to the (thermal) free–free emission. Such effect was predicted by the theoretical models of Pittard (2010).

5. Conclusion

The switch from non-thermal to thermal emission near periastron passage, as well as the thermal contribution from the colliding-wind region can be expected to occur in other colliding-wind binaries as well. Further details about the analysis of the HD 168112 data can be found in Blomme et al. (2024).

Further Information

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Author contributions

RB reduced the spectroscopic and radio data. MA-M provided additional spectroscopic data. All authors contributed to the interpretation of the results.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

Blomme, R., Rauw, G., Volpi, D., Nazé, Y., and Abdul-Masih, M. (2024) The colliding-wind binary HD 168112. *A&A*, **687**, A106. https://doi.org/10.1051/0004-6361/202450227.

Blomme, R., Van Loo, S., De Becker, M., Rauw, G., Runacres, M. C., Setia Gunawan, D. Y. A., and Chapman, J. M. (2005) Non-thermal radio emission from O-type stars. I. HD 168112. *A&A*, **436**(3), 1033–1040. https://doi.org/10.1051/0004-6361:20042383.

De Becker, M., Rauw, G., Blomme, R., Waldron, W. L., Sana, H., Pittard, J. M., Eenens, P., Stevens, I. R., Runacres, M. C., Van Loo, S., and Pollock, A. M. T. (2004a) Quasi–simultaneous *XMM-Newton* and VLA observation of the non-thermal radio emitter HD 168112 (O5.5III(f_+)). *A&A*, **420**(3), 1061–1077. https://doi.org/10.1051/0004-6361:20041030-1.

De Becker, M., Rauw, G., and Manfroid, J. (2004b) A spectroscopic study of the non-thermal radio emitter Cyg OB2 #8A: Discovery of a new binary system. *A&A*, **424**(3), L39–L42. https://doi.org/10.1051/0004-6361:200400049.

De Becker, M., Rauw, G., Manfroid, J., and Eenens, P. (2006) Early-type stars in the young open cluster IC 1805. II. The probably single stars HD 15570 and HD 15629, and the massive binary/triple system HD 15558. *A&A*, **456**(3), 1121–1130. https://doi.org/10.1051/0004-6361:20065300.

Dougherty, S. M. and Williams, P. M. (2000) Non-thermal emission in Wolf–Rayet stars: are massive companions required? *MNRAS*, **319**(4), 1005–1010. https://doi.org/10.1046/j.1365-8711.2000.03837.x.

Leitherer, C., Forbes, D., Gilmore, A. C., Hearnshaw, J., Klare, G., Krautter, J., Mandel, H., Stahl, O., Strupat, W., Wolf, B., Zickgraf, F.-J., and Zirbel, E. (1987) Photometry and spectroscopy of the O-type variable HD 167971. *A&A*, **185**(1-2), 121–130. https://ui.adsabs.harvard.edu/abs/1987A&A...185..121L.

Nazé, Y., De Becker, M., Rauw, G., and Barbieri, C. (2008) A binary signature in the non-thermal radio–emitter Cyg OB2 #9. *A&A*, **483**(2), 543–546. https://doi.org/10.1051/0004-6361:200809491.

Pittard, J. M. (2010) 3D models of radiatively driven colliding winds in massive star binaries – II. Thermal radio to submillimetre emission. *MNRAS*, **403**(4), 1633–1656. https://doi.org/10.1111/j.1365-2966.2010.15516.x.

Putkuri, C., Gamen, R., Morrell, N. I., Maíz Apellániz, J., Arias, J. I., Simón-Díaz, S., Ferrero, G. A., Rodríguez, C. N., Sota, A., Benvenuto, O. G., and Barbá, R. H. (2023) The spectroscopic orbit of HD 168112 A,B in NGC 6604: another massive binary target for interferometry. *MNRAS*, **525**(4), 6084–6096. https://doi.org/10.1093/mnras/stad2657.

Rauw, G., Blomme, R., Nazé, Y., Spano, M., Mahy, L., Gosset, E., Volpi, D., van Winckel, H., Raskin, G., and Waelkens, C. (2016) Testing the theory of colliding winds: the periastron passage of 9 Sagittarii: I. X-ray and optical spectroscopy. *A&A*, **589**, A121. https://doi.org/10.1051/0004-6361/201526871.

Sana, H., Le Bouquin, J.-B., Lacour, S., Berger, J.-P., Duvert, G., Gauchet, L., Norris, B., Olofsson, J., Pickel, D., Zins, G., Absil, O., de Koter, A., Kratter, K., Schnurr, O., and Zinnecker, H. (2014) Southern massive stars at high angular resolution: Observational campaign and companion detection. *ApJS*, **215**(1), 15. https://doi.org/10.1088/0067-0049/215/1/15.