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An interaction creates an enriched nebula around a massive magnetic binary system

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Abstract. Understanding the interactions of stars in multiple systems is critical if we wish to understand the fates of massive stars. Here, we present the case of the binary system HD 148937. This O-star binary system is a rarity amongst its class, displaying magnetism and harbouring a extended, complex bipolar nebula enriched with CNO process elements. Using a combination of spectrointerferometric and spectroscopic data, we find that one star in the system appears significantly different to its companion despite their almost identical brightnesses - the primary star alone is magnetic and when placed on a Hertzsprung-Russell diagram appears ∼1.5 Myr younger than its companion. Comparing our results with stellar coalescence models, we determine that this star and the surrounding nebula were likely formed through a stellar merger, and that the system was likely originally a triple system.

Keywords. stellar magnetism, massive stars, multiplicity, stellar interactions

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This talk presented the work of Frost et al. (2024). We take this opportunity to highlight how the results of our paper have consequences for the topic of the FM4 - namely, how both interactions and magnetism in massive stars can have serious effects on their final fates. We invite the reader to consider the full paper for the complete details of our work.

Massive stars are known for their large output (for example in terms of stellar winds) and it is this output that makes them so influential from local to galactic scales. The huge stellar winds of massive stars, particularly those late in their lives such as Wolf-Rayet stars, are a key mechanism of mass-loss. However, if a massive star has a strong B field this can limit stellar mass loss, as material can become magnetically confined (Babel & Montmerle 1997). It has been shown through magnetohydrodynamical modelling that just small amounts of wind confinement can cause a significant retention in stellar material (ud-Doula & Owocki 2002). This can therefore have similarly significant effects on the fate of the star. Whether a massive star creates a neutron star vs. a black hole vs. a heavy-mass black hole (Petit et al. 2017) is intrinsically linked to its mass, as is whether the star creates a core-collapse supernovae at the end of its life and, if it does, its type (Obergaulinger et al. 2014). Therefore, determining the origins of magnetic fields in massive stars is important. Indeed, massive stars are not expected to host magnetic fields in the same was as low-mass stars due to their mostly radiative envelopes which cannot well-sustain a dynamo effect. Despite this, ∼7% of massive stars show strong, ordered magnetic fields, making understanding the origin of these fields evermore intriguing. This is why we find our results to be exciting.

HD 148937, the subject of our study, had long been known to be a rare O-type system, showing lines such as CIII, NIII and variable Balmer line emission which have since been attributed to magnetism (e.g. Walborn 1972) and a strong dipolar magnetic field intensity has been determined for the system of 1020^{-380}_{+310}G (Wade 2012). Parametric modelling of data from the K-band GRAVITY instrument at the Very Large Telescope Interferometer (VLTI) show that the strong Brγ emission present in the normalised flux of the system had to be associated solely with the primary star of the system. This was strange, as the stars are of similar brightness, so why should one be magnetic whilst the other is not? This prompted a reanalysis of the properties of the two stars and the binary as a whole. From further interferometric data we had astrometric monitoring over close to a decade, which we combined with existing radial velocity data from archival spectra. This confirmed a long-period (∼29yr), eccentric (e=0.77) orbit for the binary, and importantly gave us a reliable total mass for the system of 56.52±0.75 $M_{\odot}$. Using the archival optical spectra and a grid-disentangling method (corroborated by a shift-and-add disentangling technique) we split the archival spectra into a spectrum from the primary and secondary star for each epoch, guided by the parameters derived from the orbital fitting, and then used CMFGEN models to determine the properties of the two stars from these disentangled spectra. In addition, dynamical masses were derived from the total mass and final semi-amplitudes, and SED fitting was used to get the luminosities.

When putting the derived temperatures and luminosities into a H-R diagram, it is clear that the primary star looks younger than the secondary and this was further confirmed by BONNSAI stellar evolution models of each star (Schneider et al. 2014). HD 148937 is also unique amongst O stars because it has a nebula, a nebula which is enriched with CNO-process elements no less (Mahy et al. 2017). Nebulae around low-mass stars in the form of red novae are potentially associated with merger events (e.g. Pastorello et al. 2019; MacLeod et al. 2018). Furthermore, recent theoretical work has shown that rejuvenation and can both be caused by the resultant mixing in the merged core of a star (Schneider et al. 2016, 2019). As a result, we tested this scenario for HD 148937 and using

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the models of (Schneider et al. 2019) found that mergers of two stars with a total mass of 35 $M_\odot$ can explain the observed rejuvenation and the age of the secondary star as seen today (used as a reference). The estimated mass of the nebula of 1.6 $M_\odot$ to 12.6 $M_\odot$ (Mahy et al. 2017) overlaps nicely with the 1.7 and 8.2 $M_\odot$ that would have to have been lost during the merger event according to the models. The nebula is also thought to be very young (7.5 kyr according to the work of Lim et al. 2024). Therefore, we conclude that the magnetism in the primary star and the nebula surrounding the system are likely both results of a very recent stellar merger, and that HD 148937 was originally a triple system.

References

Babel, J., Montmerle, T., 1997, *A&A*, 323, 121.
Frost, A. J., et al. 2024, *Science*, 384, 6692, 214.
Lim, B., et al. 2024, *ApJ*, 961, 1.
MacLeod, M., et al. 2018, *ApJ*, 868(2), 136.
Mahy, L., et al. 2017, *A&A*, 599, A61.
Obergaulinger, M., Janka, H. T., Aloy, M. A., 2014, *MNRAS*, 445, 3, 3169.
Pastorello, A., et al. 2019, *A&A*, 630, A75.
Petit, V., et al., 2017, *MNRAS*, 466, 1, 1052.
Schneider, F. R. N., et al. 2014, *A&A*, 570, A66.
Schneider, F. R. N., et al. 2016, *MNRAS*, 457, 3, 2355.
Schneider, F. R. N., et al. 2019, *Nature*,574, 7777, 211.
ud-Doula, A., Owocki, S. P., 2002, *ApJ*, 576, 1, 413.
Wade, et al. 2012, *MNRAS*, 419, 2459.
Walborn, N. R., 1972, *AJ*, 77, 312.

Discussion

Briel: Thank you very much for the talk. Do you see an effect of the companion on the nebula?

Frost: The nebula's very complex and has lots of kinds of structure. The bipolar lobe is probably one of the most symmetric elements, but there is clear asymmetry in the inner regions. In the paper by Lim et al 2024 where they did some dynamical study of the nebula using integral field spectroscopy they derived an age of 7500yrs for it and they used an axisymmetric model in their interpretation which didn't account for that inner asymmetry. [Given the predicted young age of the nebula, I am not sure whether there has been enough time for the companion to cause precession effects (like those seen in the bipolar outflows of more embedded protobinary systems for example) but potentially in the innermost regions of the nebula this will indeed eventually be seen. Or, it could be waiting to be characterised through a more sophisticated modelling approach.]

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