Massive Stars Near and Far
Proceedings IAU Symposium No. 361, 2024
J. Mackey, J. S. Vink, & N. St-Louis, eds.
doi:10.1017/S1743921322002216

HR 6819 – a post-interaction binary system originally thought to be a triple system containing a black hole

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Abstract. In 2020, HR 6819 was reported to be a triple system containing the closest black hole to Earth. However, these results were contested, with an alternative explanation of a post-interaction binary suggested. Using new integral field spectroscopic and interferometric data, we have been able to determine the true nature of this exotic source.

Keywords. stars: early-type, stars: binaries, stars: fundamental parameters

1. Introduction

The majority of main-sequence (MS) massive OB-type stars belong to binary or higher-order multiple systems, among which close binaries (P <10 yr) are common (e.g. Sana et al. 2012; Villaseñor et al. 2021) which will most likely interact and leave the involved stars chemically and physically altered (e.g. de Mink et al. 2013). One type of object which potentially shows the effects of such interactions are Be stars. Be stars are non-supergiant B-type stars that exhibit Balmer emission lines such as Hα (see e.g., Zorec & Briot 1997; Rivinius et al. 2013). This emission is associated with a circumstellar decretion disk, of order stellar radii in size, around the equatorial plane of the star (e.g. Struve 1931). While the origin of such Be stars is uncertain, a binary formation channel seems a likely candidate. When the slightly more massive star in the system expands to its giant phase, Roche Lobe overflow can occur. The subsequent transfer of mass and momentum can spin up the other star in the system, turning it into a Be star. The donor star would appear altered by such an interaction as well, with most of its envelope material removed so that it appears more like the core of a star or 'stripped'.

One system which shows Be star signatures is HR 6819 (d=350pc, V=5.4mag), which made headlines in 2020 when it was claimed to be a triple system containing 'The nearest black hole to Earth' by Rivinius et al. (2020). These authors postulated, based on the analysis of FEROS spectra, that one star in the system (a B star) was on a 40 day orbit with an unseen companion of $4M_\odot$ - a stellar mass black hole (BH) and other emission line signatures present in spectra were coming from a Be star that was on a much wider orbit. However, other authors (Bodensteiner et al. 2020; El-Badry & Quataert 2021) disagreed with these findings. Bodensteiner et al. (2020) reanalysed the FEROS spectra and found that other emission lines associated with the Be star show subtle anti-phase movement with respect to the B star. Therefore, these two stars could be in the 40 day orbit visible in the spectra. The caveat for these findings was that the B star in the system had to have been stripped and of low-mass, in order to explain the orbital velocities of the lines associated with the B star. With these spectral data alone, no definitive distinction between the two scenarios could be made. If the system was a triple, we would expect a bright source at ∼100mas separation (the Be star) and one bright source at 1mas scales (B star) which would be orbiting the invisible stellar mass BH. If the system was a binary, we would expect no bright source at ∼100mas and two bright sources separated on mas scales, which would be the B and Be star, on the 40 day orbit detected in the spectra. In order to determine the true nature of the source, we (Frost et al. 2022) revisited HR 6819 using MUSE data to trace the 100mas scales of HR 6819 and infrared interferometry to trace the mas scales.

2. Results

In order to probe the system at large, 100mas scales, the first observation we used was the Multi Unit Spectroscopic Explorer (MUSE) situated at the Very Large Telescope (VLT). MUSE is an integral field spectrograph operating over visible wavelengths (480-930nm). The MUSE data were taken using the narrow-field mode (NFM) which covers a 7.5" × 7.5" field of view (or ∼2550 AU (or ∼0.12 pc) with a spatial sampling of 0.025" × 0.025". When the data from all the IFUs are stacked and combined, we retrieve an image of the source. A single source is seen at 100mas scales, meaning that there is no evidence that a Be star is orbiting the central source of HR 6819 at the large orbit required for the black-hole scenario.

In order to constrain the inner regions of the system, we use GRAVITY/VLTI. GRAVITY is a spectro-interferometer, meaning that it not only provides information on the spatial extent and orientation/asymmetry of the system (from the interferometric observables visibility and phases respectively) but that we can also gain spectral information of the source. These observables were all fit using geometric models from the code PMOIRED (Mérand 2022). From this least-square fitting process, we determined that the system was composed of two point sources at (on average, across the two obtained epochs of data) 1.15±0.03mas. Furthermore, thanks to PMOIRED's ability to assign emission line features to individual model components, we determined that the Brackett Gamma (Brγ) emission seen in the total flux (Figure 1) was associated with the brighter, and therefore likely more massive, star in the system. The Brγ line shows a double-peaked profile, indicative of rotation. We were able to fit a Keplerian disk (Figure 1) model which well fit this profile, as well as the differential phases, within the datasets, with the star hosting the disk being almost twice as bright as the other star. We conclude that this is

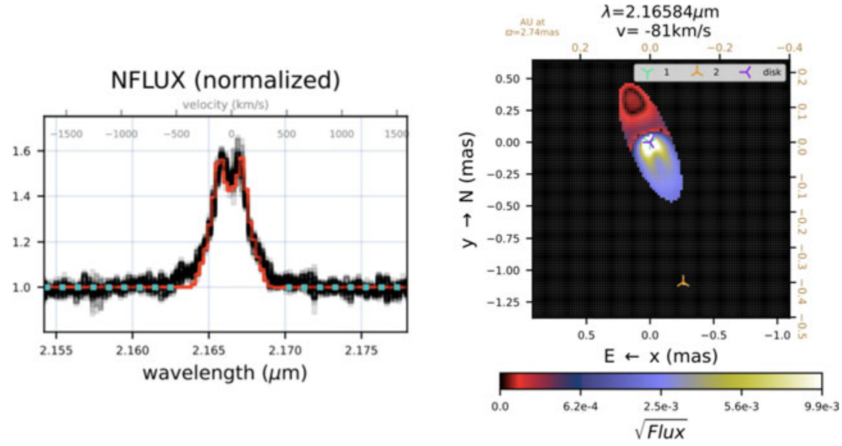

Figure 1. The Brγ line as seen in the normalised flux (NFLUX) from the GRAVITY data (left) and the Keplerian disk model which assisted in its fitting (right).

likely to be the Be star decretion disk. Therefore, the binary scenario appears to explain both our MUSE and GRAVITY data, and HR 6819 is most likely a post-interaction Be+stripped B star binary system, with no black hole.

3. Conclusions

Our new data show that HR 6819 is a binary system and that the presence of a BH on a short-period orbit in this system can be rejected. HR 6819 therefore constitutes a perfect source for investigating the origin of Be stars and their possible formation through a binary channel. In future work, further monitoring of the system with GRAVITY will be crucial. Not only can the orbit be better constrained, but these measurements will provide distance and precise mass estimates of what is likely a newly post-interaction, bloated stripped object and its associated Be star for the first time. Together with higher-resolution spectroscopy (e.g. from UVES), abundances of both stars could be derived. With this information, HR 6819 would constitute a corner-stone object for comparing binary evolution models.

Acknowledgements

This research has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement number 772225: MULTIPLES). JB and MH are supported by an ESO fellowship. TS acknowledges funding received from the European Union's Horizon 2020 under the Marie Skłodowska-Curie grant agreement No. 101024605. We also thank the team behind QFitsView for developing their tool which allowed easy handling of our MUSE data.

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https://doi.org/10.1017/S1743921322002216 Published online by Cambridge University Press

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