Massive Stars Near and Far
Proceedings IAU Symposium No. 361, 2024
J. Mackey, J. S. Vink, & N. St-Louis, eds.
doi:10.1017/S1743921322002745

Massive stars and their large-separation low-mass companions in Sco OB1

T. Pauwels, M. Reggiani, A. Rainot and H. Sana

Institute of Astronomy, KU Leuven, Celestijnenlaan 200D, 3001, Leuven, Belgium
email: tinne.pauwels@kuleuven.be

Abstract. Exploring the low-mass end of the companion mass function around massive stars is of crucial importance to constrain massive star formation theories. We present a high-contrast imaging study of 20 O- and early B-type stars in the Scorpius OB1 association. From the analysis of VLT/SPHERE data, we identify a total of 789 sources. The data probe the brown dwarf regime around massive stars, resulting in the discovery of large-separation multiple systems with mass-ratios as low as 0.001 (comparable to Jupiter-Sun mass-ratio).

Keywords. stars: early-type, stars: low-mass, brown dwarfs, binaries: general, stars: formation

1. Introduction

As an important outcome parameter of star formation, the multiplicity characteristics of massive stars put crucial constraints on massive star formation theories. The large variety of mass-ratios and companion separations demand the use of various observational techniques to characterise all companions. Previous multiplicity studies mainly focused on spectroscopy, interferometry and classical imaging, demonstrating that almost all massive stars are found in binary and multiple systems (Sana et al. 2012, 2013, 2014; Sota et al. 2014). Recently, the high-contrast imaging instrument SPHERE on the VLT enabled us to investigate the multiplicity properties of massive stars at relatively large separations (0.15" and 6") and up to much higher contrast magnitudes ($\Delta K \sim 14$ mag) than what previous studies of massive stars have been able to probe (Rainot et al. 2020, 2022; Reggiani et al. 2022). Here, we present SPHERE observations of 13 O-type and 7 early B-type stars in the active star forming region Sco OB1, which is located at a distance of 1.53 kpc (Mel'nik & Dambis 2017) and is 4-8 Myr old (Sung et al. 2013).

2. Detecting low-mass companions around massive stars

We analyse the SPHERE data using the python Vortex Imaging Processing package VIP (Gomez Gonzalez et al. 2017) which allows us to perform angular and spectral differential imaging through a principal component analysis approach.

A total of 789 sources is detected around the 20 stars in our sample. However, the data are highly contaminated by background sources. To distinguish true companions from background contaminants, we calculate the spurious association probability (=probability that a source is not bound to the central star) based on the magnitude-dependent source density in the local region around the central star. We adopt a combination of 2MASS (K<14 mag) (Cutri et al. 2003) and the Besançon Galaxy model (K>14 mag) (Czekaj et al. 2014). Figure 1 shows that the SPHERE data are probing the brown dwarf regime around massive stars, however not yet the planet regime.

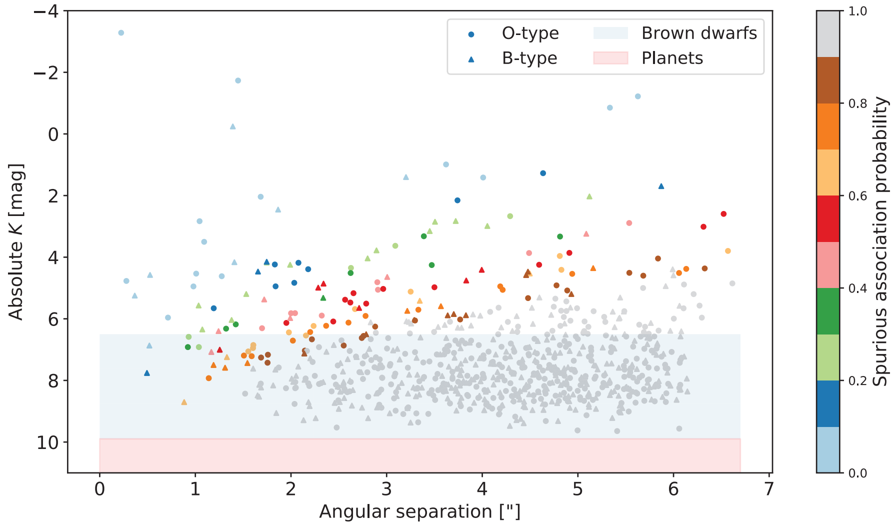

Figure 1. All sources detected in the sample. The brown dwarf and planet regimes are estimated as the average K-band magnitude for a 6 Myr old 0.08 $M_{\odot}$ and 0.012 $M_{\odot}$ object respectively.

Taking into account the spurious association probability, the (not yet bias-corrected) high-contrast imaging companion fraction (=average number of companions per star) for O-type stars in our sample is 2.8 ± 0.5. For B-type stars, we find a significantly larger companion fraction of 4.6 ± 0.8, although it could be due to an observational bias, since B-type stars are intrinsically less bright than O-type stars.

3. Conclusions

Since many of the stars in our sample already have known close companions, the addition of the high-contrast imaging companions would make them quadruple or even higher-order multiple systems. Some of the companions are at the stellar/substellar boundary, making them some of the lowest-mass companions ever discovered around OB-type stars.

Acknowledgements

T.P. and M.R. thank the Research Foundation - Flanders (FWO) for the PhD fellowship 1164522N and the postdoctoral fellowship 1280121N respectively.

The research leading to these results has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement numbers 772225: MULTIPLES).

References

Cutri, R. M., et al. 2003, VizieR Online Data Catalog, II/246
Czekaj, M. A., Robin, A. C., Figueras, F., Luri, X., & Haywood, M. 2014, A&A, 564, A102
Gomez Gonzalez, C. A., et al. 2017, AJ, 154, 7
Mel'nik, A. M., & Dambis, A. K. 2017, MNRAS, 472, 3887
Rainot, A., Reggiani, M., Sana, H., Bodensteiner, J., & Absil, O. 2022, A&A, 658, A198
Rainot, A., et al. 2020, A&A, 640, A15
Reggiani, M., et al. 2022, A&A, 660, A122
Sana, H., et al. 2012, Science, 337, 444

—. 2013, A&A, 550, A107
—. 2014, ApJS, 215, 15
Sota, A., Maíz Apellániz, J., Morrell, N. I., Barbá, R. H., Walborn, N. R., Gamen, R. C., Arias, J. I., & Alfaro, E. J. 2014, ApJS, 211, 10
Sung, H., Sana, H., & Bessell, M. S. 2013, AJ, 145, 37