An Application of the *Mayrit* Catalogue: very Wide Binaries in the σ Orionis Cluster

J.A. Caballero

Abstract The young σ Orionis cluster in the Orion Belt is an incomparable site for studying the formation and evolution of high-mass, solar-like, and low-mass stars, brown dwarfs, and substellar objects below the deuterium burning mass limit. The first version of the Mayrit catalogue was a thorough data compilation of cluster members and candidates, which is regularly used by many authors of different disciplines. I show a new application of the catalogue and advance preliminar results on very wide binarity in σ Orionis. The making-up of a new version of the Mayrit catalogue with additional useful data is in progress.

1 The *Mayrit* catalogue

The fourth brightest star in the Orion Belt, about 2 mag fainter than the three main stars, is σ Ori. The star, which is actually the hierarchical multiple Trapezium-like stellar system that illuminates the famous Horsehead Nebula, has taken a great importance in the last decade. Its significance lies in the very early spectral type of the hottest component (σ Ori A, O9.5V) and in the homonymous star cluster that surrounds the system (Garrison 1967). The σ Orionis star cluster, re-discovered due to its large number of X-ray emitters (Wolk 1996), contains one of the best known brown dwarf and planetary-mass object populations (Béjar et al. 1999; Zapatero Osorio et al. 2000; Caballero et al. 2007), and is an excellent laboratory to study the evolution of discs and angular momenta (Reipurth et al. 1998; Caballero et al. 2004; Scholz & Eislöffel 2004; Oliveira et al. 2006; Hernández et al. 2007). Approximate canonical ages, heliocentric distances and visual extinctions are $\tau \sim$ 3 Ma, $d \sim 385$ pc and $A_V \sim 0.3$ mag.

José A. Caballero
Departamento de Astrofísica y Ciencias de la Atmósfera, Facultad de Física, Universidad Complutense de Madrid, E-28040 Madrid, Spain, e-mail: caballero@astrax.fis.ucm.es

Table 1 Visual systems in σ Orionis with probability of alignment by chance of $\sim$1 %.

System	Primary	Secondary	ρ [arcsec]	θ [deg]	Δ [AU]	M_1 [$M_\odot$]	M_2 [$M_\odot$]	U_g [10^{35} J]
1[a]	Mayrit 528005 AB	Mayrit 530005	7.63±0.10	287.1±0.8	2940	1.6+?	0.61	–5.9
2[b]	Mayrit 1415279 AB	Mayrit 1416280	12.18±0.10	4.4±0.5	4690	1.3+?	0.24	–1.2
3[c]	Mayrit 397060	Mayrit 410059	14.12±0.10	40.4±0.5	5440	1.1	0.19	–0.68

[a] System 1 – AB: [W96] 4771–899 AB, C: S Ori J053847.5–022711. Firstly proposed by Caballero (2005).
[b] System 2 – AB: OriNTT 429 AB, C: [SWW2004] 22. Firstly suggested by López-Santiago & Caballero (2008).
[b] System 3 – A: V507 Ori, B: S Ori 7. Firstly proposed by Caballero (2006).

The knowledge of the whole stellar and substellar populations in a cluster in general, and in σ Orionis in particular, has serious implications on the accuracy of the determination of some observational parameters that are fundamental for the theoretical scenarios that predict the formation of stars, brown dwarfs, and planets. The Mayrit catalogue of stars and brown dwarfs in the σ Orionis cluster, built by Caballero (2008b), was an effort to compile key data on confirmed and candidate cluster members with DENIS and 2MASS data. The Mayrit catalogue has turned out to be a very useful tool for studying those observational parameters, such as the spatial distribution (Caballero 2008a; Bouy et al. 2008), disc frequency as a function of stellar mass (Luhman et al. 2008), and X-ray emission in the σ Orionis cluster (López-Santiago & Caballero 2008; E. Franciosoni et al., in prep.). In this proceeding, I advance some preliminar results on a new specific topic: very wide binarity.

2 Very wide binaries in σ Orionis

I have used the first version of the Mayrit catalogue in Caballero (2008b) as a basis to create an updated version of the catalogue, Mayrit 2.0, which will be published in a forthcoming paper. I have incorporated the latest spectroscopic results from Gatti et al. (2008), Sacco et al. (2008), Maxted et al. (2008), González-Hernández et al. (2008), and Caballero et al. (2008). The new catalogue contains coordinates, UKIDSS $YZJHK$ magnitudes, radial velocities, and lithium equivalent widths for about 350 σ Orionis members and candidates.

I have searched for very wide ($\Delta > 1000$ AU) systems among cluster members and candidates in the the Mayrit 2.0 catalogue following a simple statistical approach. The method is based on the study of the variation of the separation to the nearest neighbour, $\rho_{\rm min}$, with the separation to the cluster centre, r, and is illustrated in Fig. 1 (see also Caballero et al. 2006). The shorter the $\rho_{\rm min}$ between two objects is, the larger the probability to be bound is. However, a pair of cluster members can be separated by a short angular separation but be located at different heliocentric dis-

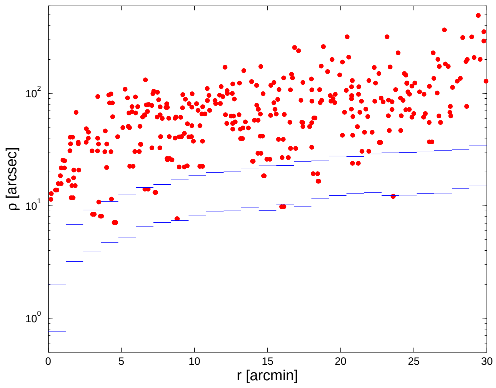

Fig. 1 Separation to the nearest Mayrit neighbour as a function of the angular separation to the σ Orionis centre (defined by σ Ori [AFB]). The segmented curves denote probabilities of alignment by chance of 5 (top) and 1 % (bottom).

tances due to a projection effect. I have estimated the values of $\rho_{\rm min}$ that correspond to probabilities of random alignments of 5 and 1 % for a configuration with the same (symmetrical) radial profile as σ Orionis. For that, I have used 1000 Monte Carlo simulated distributions following the power-law radial distribution quantified in Caballero (2008a), that corresponds to a volume density proportional to r^{-2}. Three σ Orionis pairs of objects, listed in Table 1 (equatorial coordinates in Caballero 2008b), have probabilities of random alignment of $\sim$1 % . The three of them had been proposed or suggested before, but this is the first time to perform an exhaustive search of wide binaries in the cluster and to quantify their low probability of alignment by chance.

Projected physical separations of the three systems, assuming a common heliocentric distance of d = 385 pc, vary in the range $\Delta \sim$ 3000–5500 AU, which are not rare in the solar neighbourhood. Compare these values with $\Delta = 1700 \pm 300$ AU ($\rho \approx 4.6$ arcsec), which is the separation between the σ Orionis X-ray brown dwarf [SE2004] 70 and the L5$\pm$2-type, planetary-mass, object candidate S Ori 68 (Caballero et al. 2006 – the secondary was too faint to be tabulated in the Mayrit catalogue).

Theoretical masses of each component in Systems 1, 2 and 3 were computed from the 2MASS J-band magnitudes using the 3 Ma-old isochrones of Schaller et al. (1992) and Baraffe et al. (1998). The absolute values of the derived binding energies, $U_g \approx -GM_1M_2\Delta^{-1}$, are several orders of magnitude larger than some wide ultracool binaries in the solar vicinity (Caballero 2007; Artigau et al. 2007).

Interestingly, two of the σ Orionis "pairs" are hierarchical triple system candidates: Mayrit 528005 AB (in System 1) is a close binary ($\rho = 0.40 \pm 0.08$ arcsec) resolved by means of adaptive optics by Caballero (2005) and Mayrit 1415279 AB (in System 2) is a spectroscopic binary discovered by Lee et al. (1994). As a result, actual binding energies are larger than derived ones, which supports membership in gravitationally bound systems.

Finally, one might miss another known visual binary candidates in σ Orionis with separations of $\rho \sim 10$ arcsec that have not arisen in my analysis, such as

HD 294271 ABC, HD 294272 AB and, especially, σ Ori [AFB]CD. Although their binding energies are probably very high (all the listed stars have early types, i.e. high masses, of up to $45\,M_\odot$ in the triple system σ Ori [AFB]), they are located very close to the cluster centre, where the probability of alignment by chance is also very high.

In summary, I have used an updated version of the Mayrit catalogue of Caballero (2008b) to search for very wide binaries in the σ Orionis cluster. I have identified three systems (two triples, one double) with probabilities of alignment by chance of $\sim$1 % and projected physical separations in the range $\Delta \sim$ 3000–5500 AU. Even if their common spatial velocities are measured in the future, it is not known whether the systems will survive the gravitational field of the young cluster.

Acknowledgements Partial financial support was provided by the Spanish Ministerio Educación y Ciencia, the Comunidad Autónoma de Madrid, the Universidad Complutense de Madrid, the Spanish Virtual Observatory, and the European Social Fund.

References

1. É. Artigau, D. Lafrenière, R. Doyon et al., *ApJ* **659**, L49 (2007).
2. I. Baraffe, G. Chabrier, F. Allard, P. H. Hauschildt, *A&A* **337**, 403 (1998).
3. V. J. S. Béjar, M. R. Zapatero Osorio, R. Rebolo, *ApJ* **521**, 671 (1999).
4. H. Bouy, N. Huélamo, E. L. Martín et al., *A&A* in press, arXiv:0808.3890 (2008).
5. J. A. Caballero, *AN* **326**, 1007 (2005).
6. J. A. Caballero, PhD thesis, Universidad de La Laguna, Tenerife, Spain (2006).
7. J. A. Caballero, *A&A* **462**, L61 (2007).
8. J. A. Caballero, *MNRAS* **383**, 375 (2008a).
9. J. A. Caballero, *A&A* **478**, 667 (2008b).
10. J. A. Caballero, V. J. S. Béjar, R. Rebolo, M. R. Zapatero Osorio, *A&A* **424**, 857 (2004).
11. J. A. Caballero, E. L. Martín, P. D. Dobbie, D. Barrado y Navascués, *A&A* **460**, 635 (2006).
12. J. A. Caballero, V. J. S. Béjar, R. Rebolo et al., *A&A* **470**, 903 (2007).
13. J. A. Caballero, L. Valdivielso, E. L. Martín et al., *A&A* DOI: 10.1051/0004-6361:200810616, arXiv:0809.0996 (2008).
14. R. F. Garrison, *PASP*, **79**, 433 (1967).
15. B. M. González-García, M. R. Zapatero Osorio, V. J. S. Béjar et al., *A&A*, **460**, 799 (2006).
16. T. Gatti, A. Natta, S. Randich, L. Testi, G. Sacco, *A&A* **481**, 423 (2008).
17. J. Hernández, L. Hartmann, T. Megeath et al., *ApJ* **662**, 1067 (2007).
18. J. López-Santiago, J. A. Caballero, *A&A* in press, arXiv:0809.0990 (2008).
19. K. L. Luhman, J. Hernández, J. J. Downes, L. Hartmann, C. Briceño, *ApJ* in press, arXiv:0808.0471 (2008).
20. P. F. L. Maxted, R. D. Jeffries, J. M. Oliveira, T. Naylor, R. J. Jackson, *MNRAS* **385**, 2210 (2008).
21. N. J. Mayne, T. Naylor, *MNRAS* **386**, 261 (2008).
22. J. M. Oliveira, R. D. Jeffries, J. Th. van Loon, M. T. Rushton, *MNRAS* **369**, 272 (2006).
23. G. G. Sacco, E. Franciosini, S. Randich, R. Pallavicini, *A&A* **488**, 167 (2008).
24. G. Schaller, D. Schaerer, G. Meynet, A. Maeder, *A&AS* **96**, 269 (1992).
25. A. Scholz, J. Eislöffel, *A&A* **419**, 249 (2004).
26. W. H. Sherry, F. M. Walter, S. J. Wolk, N. R. Adams, *AJ* **135**, 1616 (2008).
27. S. J. Wolk, PhD thesis, State University New York at Stony Brook, NY, USA (1996).
28. M. R. Zapatero Osorio, V. J. S. Béjar, E. L. Martín et al., *Science* **290**, 103 (2000).