Compact Objects and Binaries in Dense Star Clusters
Proceedings IAU Symposium No. 398, 2026
H. M. Lee, J. Hong & R. Spurzem, eds.
doi:10.1017/S1743921325103906

Astrometric Binaries in ω Centauri

Matthew Whitaker

University of Utah
email: matthew.whitaker@utah.edu

Abstract. The globular cluster ω Centauri, likely the remnant core of an accreted dwarf galaxy, is massive with complex stellar populations. Recent work has shown disagreement between the expected and actual number of binaries with long orbital periods in ω Centari. The cluster likely contains a large population of stellar-mass black holes, but so far none have been detected. In this work, we utilize data from a new astrophotometric catalog of stars in ω Centauri to perform an astrometric search for binaries, especially those with potential black hole companions. Using synthetic observations of simulated binaries, we measure the detection efficiency of our approach. We report a high detection efficiency for our approach which increases with increasing companion mass. We also report on the ongoing work to characterize these candidate binaries and the tentative detection of a binary with a $\sim 5\,M_\odot$ black hole companion.

Keywords. Binaries, Globular Clusters, Black Holes

1. Introduction

ω Centauri (NGC 5139, herafter ω Cen) is the most massive globular cluster in the Milky Way (Baumgardt and Hilker 2018) and hosts several distinct stellar populations (Bellini et al. 2017, e.g.). Due to this complexity and ω Cen's characteristic prograde orbit, it is believed to be the remnant core of a dwarf galaxy accreted primarily during the Gaia-Enceladus merger event (Limberg et al. 2022).

Recent spectroscopic studies of the binary population in ω Cen have identified an excess of long-period binaries (>10 days) relative to model predictions (Wragg et al. 2024; Saracino et al. 2025). However, due to data limitations, these studies were not very sensitive to binaries with orbital periods $>10^3$ days, and so it was unclear whether this excess continues to these longer orbital periods. Being able to detect and characterize such long-period binaries will be critical to informing improved models of the formation and evolution of dense star clusters. Platais et al. (2024) performed an astrometric search for binaries in ω Cen and discovered four long-period binaries, including one star orbiting a potential neutron star. They did not perform any sort of completeness analysis, so from this study alone, we can't say much about the long-period binary population.

ω Centauri is expected to contain $\sim 10^4$ stellar-mass black holes (Baumgardt et al. 2019; Zocchi et al. 2019), but to this point none have been detected. The detection of an IMBH from bound fast stars (Häberle et al. 2024b) suggests that the dynamical evidence for dark mass in this cluster may be primarily due to a single black hole rather than a cluster of stellar-mass black holes.

Astrometric measurements are most sensitive to binaries with massive companions, especially those with longer orbital periods. Since existing studies have not identified any stellar-mass black holes, we hope that our deeper astrometric study will reveal this elusive population.

© The Author(s), 2026. Published by Cambridge University Press on behalf of The International Astronomical Union. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

https://doi.org/10.1017/S1743921325103906 Published online by Cambridge University Press

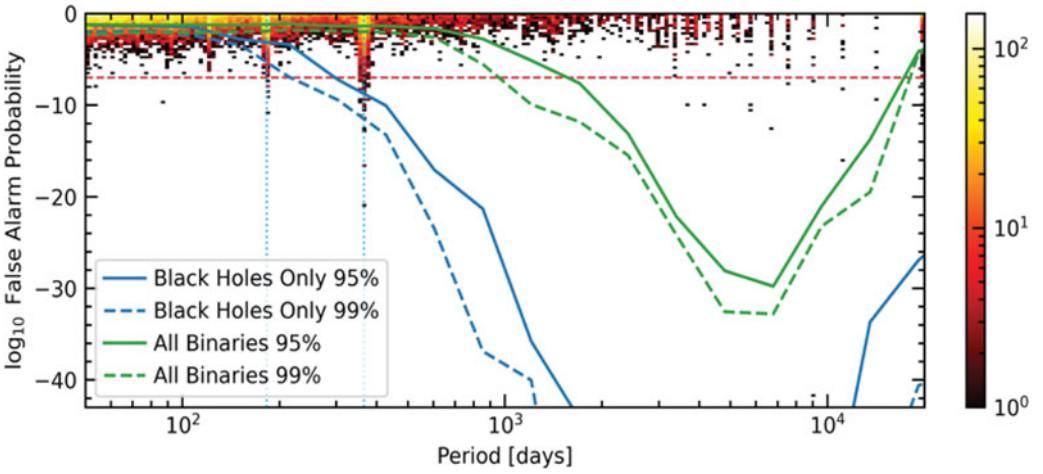


Figure 1. A 2D histogram showing the period and false alarm probability (FAP) of a high-quality subset of our dataset. The synthetic binary datasets are described in Section 3. Note the pileup of significant detections at 1 year and 0.5 years, which are marked. As in Platais et al. (2024), these 1 year signals arise due to observational and instrumental effects rather than a true binary signal.

The *Hubble Space Telescope* has observed the central regions of ω Cen over 500 times over the past 20+ years. These observations were recently compiled by Häberle et al. (2024a) into a new astrophotometric catalog. The individual time-series astrometric measurements that were used to create this catalog give us the ability to search for binaries (including potential compact-object companions) in ω Cen astrometrically.

In this work we describe our search for binaries using a generalized Lomb-Scargle periodogram (Section 2). Then we describe the creation of synthetic observations of simulated binaries that allow us to test the completeness of our astrometric binary search (Section 3). We conclude by describing ongoing work to characterize the detected binaries (Section 5).

2. Periodogram Analysis to Detect Binaries

At the distance of ω Cen, binary members can't be resolved individually, but we can detect a measurable periodic wobble in the photocenter of bright stars orbiting a fainter (or dark) companion. After fitting for the proper motion of each star, we aim to detect this periodic motion and distinguish it from observational noise in the astrometry.

The periodogram is often used in astronomy to detect periodic signals in noisy, unevenly spaced time-series data. For example, Platais et al. (2024) used a periodogram in their search for astrometric binaries. A similar approach is utilized here using the Lomb-Scargle periodogram (Lomb 1976; Scargle 1982). The power of a periodogram at a given period essentially measures the goodness of fit (in a least-squares sense) of a sinusoid of that period to the data. The largest peak of the periodogram typically corresponds to the true period of a time-series signal, although spurious peaks can appear due to the observational cadence, a signal that isn't sinusoidal in shape, or correlated noise (VanderPlas 2018). To measure the significance of a given peak, the "false-alarm probability" (FAP) is estimated using a bootstrap method. The FAP can be thought of as the probability that a peak with a given power could have arisen due to random noise in the data.

The results of our periodogram analysis on a high-quality subset of our data are shown in Figure 1.

https://doi.org/10.1017/S1743921325103906 Published online by Cambridge University Press

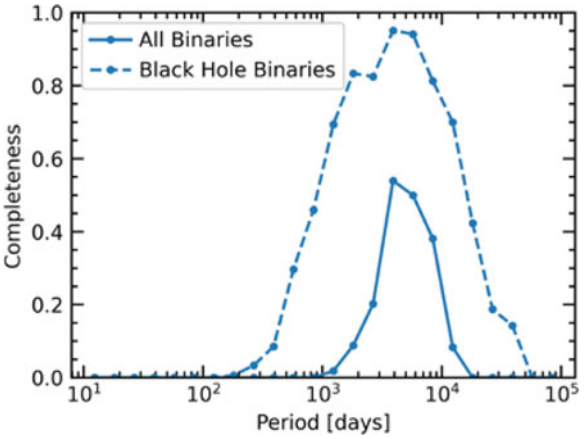


Figure 2. Detection completeness as a function of period for the same high-quality subset of our synthetic dataset.

3. A Synthetic Binary Population

To quantify the completeness of our periodogram detection method and determine an appropriate FAP threshold to constitute a detection, we generated datasets with synthetic observations of simulated binaries. The synthetic data we generated included a set of binaries with only black hole companions and a set of binaries with a realistic population of companion masses. For both sets, we followed a similar procedure to that used by Wragg et al. (2024) to determine the orbital parameters for each binary. To preserve realistic noise in our synthetic data, we inject the simulated orbital motion into the existing data for stars in the cluster. Given the small fraction of expected binaries in ω Cen, we don't expect many of the original stars to have an existing orbital signal, but to ensure that any such signal is removed, we shuffle the proper motion residuals before injecting the orbital motion.

After creating the synthetic datasets, we run them through our periodogram analysis. We find that a relatively strict FAP threshold $\log_{10}(\mathrm{FAP}) < -7$ yields no false positives for orbital periods > 1 year. With this threshold, we get the completeness shown in Figure 2. We can consistently detect binaries with periods between 2×10^3 and 10^4 days, with greater completeness and a wider range of periods for black hole binaries.

4. Conclusion and Future Work

Applying the $\log_{10}(\mathrm{FAP}) < -7$ threshold we determined from our synthetic data, we find ~ 30 candidate binaries with an orbital period > 1 year. This is a ~ 7x increase over the number of binaries found astrometrically by Platais et al. (2024). An example of two new candidate binaries and their periodogram fit are shown in Figure 3.

Work is ongoing to characterize these binaries to determine their mass and other orbital parameters using Markov-Chain Monte Carlo fitting. We also report the tentative detection of a binary with a $\sim 5\,\mathrm{M}_\odot$ black hole companion. We are also working to make our quality cuts less strict so that we achieve greater overall completeness. As in Saracino et al. (2025), we don't expect to be able to characterize all the binaries in our list of detections due to the many degeneracies that arise when fitting orbits using noisy low-amplitude data, but we expect that the characterizability depends strongly on the strength of the signal, so black hole candidates with quality data should be characterizable.

https://doi.org/10.1017/S1743921325103906 Published online by Cambridge University Press

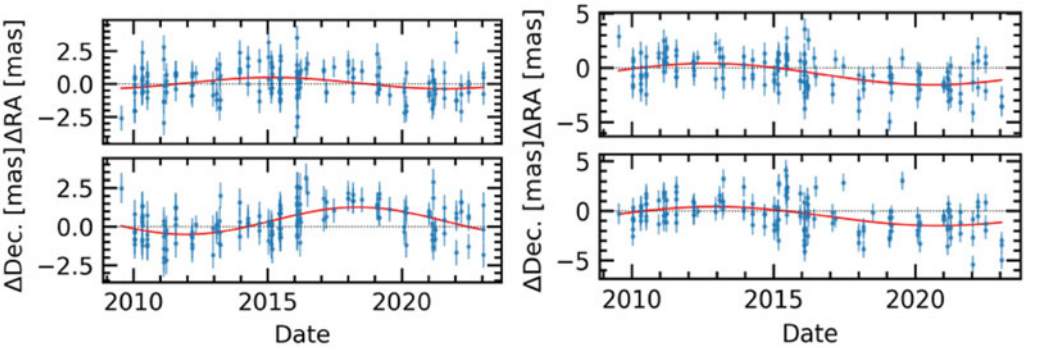


Figure 3. Examples of newly discovered candidate binaries and their best periodogram fit.

Acknowledgements

Also contributing: Anil C. Seth, Maximilian Häberle, Evan Kerr, Andrea Bellini, Callie Clontz, Zack Freeman, Sebastian Kamann, Mattia Libralato, Nadine Neumayer, Carl Rodriguez, Jay Strader, Doga Veske, John Zaris. This project was funded in part by Hubble Space Telescope archival grant AR 17033 and the University of Utah Physics & Astronomy Summer Undergraduate Research Fellowship (SURF).

References

Baumgardt, H., He, C., Sweet, S. M., Drinkwater, M., Sollima, A., Hurley, J., Usher, C., Kamann, S., Dalgleish, H., Dreizler, S., & Husser, T. O. 2019, No evidence for intermediate-mass black holes in the globular clusters ω Cen and NGC 6624. *MNRAS*, 488(4), 5340–5351.

Baumgardt, H. & Hilker, M. 2018, A catalogue of masses, structural parameters, and velocity dispersion profiles of 112 Milky Way globular clusters. *MNRAS*, 478(2), 1520–1557.

Bellini, A., Milone, A. P., Anderson, J., Marino, A. F., Piotto, G., van der Marel, R. P., Bedin, L. R., & King, I. R. 2017, The State-of-the-art HST Astro-photometric Analysis of the Core of ω Centauri. III. The Main Sequence's Multiple Populations Galore. *ApJ*, 844(2), 164.

Häberle, M., Neumayer, N., Bellini, A., Libralato, M., Clontz, C., Seth, A. C., Nitschai, M. S., Kamann, S., Alfaro-Cuello, M., Anderson, J., Dreizler, S., Feldmeier-Krause, A., Kacharov, N., Latour, M., Milone, A. P., Pechetti, R., van de Ven, G., & Voggel, K. 2024a, oMEGACat. II. Photometry and Proper Motions for 1.4 Million Stars in Omega Centauri and Its Rotation in the Plane of the Sky. *ApJ*, 970a(2), 192.

Häberle, M., Neumayer, N., Seth, A., Bellini, A., Libralato, M., Baumgardt, H., Whitaker, M., Dumont, A., Alfaro-Cuello, M., Anderson, J., Clontz, C., Kacharov, N., Kamann, S., Feldmeier-Krause, A., Milone, A., Nitschai, M. S., Pechetti, R., & van de Ven, G. 2024b, Fast-moving stars around an intermediate-mass black hole in ω Centauri. *Nature*, 631b(8020), 285–288.

Limberg, G., Souza, S. O., Pérez-Villegas, A., Rossi, S., Perottoni, H. D., & Santucci, R. M. 2022, Reconstructing the Disrupted Dwarf Galaxy Gaia-Sausage/Enceladus Using Its Stars and Globular Clusters. *ApJ*, 935(2), 109.

Lomb, N. R. 1976, Least-Squares Frequency Analysis of Unequally Spaced Data. *ApSS*, 39(2), 447–462.

Platais, I., Sahlmann, J., Girardi, L., Kozhurina-Platais, V., Kamann, S., Pourbaix, D., Wragg, F., Lemson, G., & Mitschang, A. 2024, Discovery of Astrometric Accelerations by Dark Companions in the Globular Cluster ω Centauri. *ApJ*, 963(1), 60.

Saracino, S., Kamann, S., Wragg, F., Dreizler, S., Kremer, K., Latour, M., Müller-Horn, J., Neumayer, N., Seth, A. C., van de Ven, G., & Häberle, M. 2025, Studying binary systems in Omega Centauri with MUSE - II. Observational constraints on the orbital period distribution. *MNRAS*, 538(4), 3189–3209.

https://doi.org/10.1017/S1743921325103906 Published online by Cambridge University Press

Scargle, J. D. 1982, Studies in astronomical time series analysis. II. Statistical aspects of spectral analysis of unevenly spaced data. *ApJ*, 263, 835–853.

VanderPlas, J. T. 2018, Understanding the Lomb-Scargle Periodogram. *ApJS*, 236(1), 16.

Wragg, F., Kamann, S., Saracino, S., Latour, M., Dreizler, S., Martens, S., Seth, A., Vaz, D., & van de Ven, G. 2024, Studying binary systems in Omega Centauri with MUSE - I. Detection of spectroscopic binaries. *MNRAS*, 535(1), 781–792.

Zocchi, A., Gieles, M., & Hénault-Brunet, V. 2019, The effect of stellar-mass black holes on the central kinematics of ω Cen: a cautionary tale for IMBH interpretations. *MNRAS*, 482(4), 4713–4725.

https://doi.org/10.1017/S1743921325103906 Published online by Cambridge University Press