



A Long Period Stellar-mass Black Hole Binary in ω Centauri

Matthew Whitaker¹, Evan Kerr¹, Anil Seth¹, Maximilian Häberle², Jay Strader³, Jay Anderson⁴, Andrea Bellini⁴, Callie Clontz⁵, Zack Freeman¹, Massimo Griggio⁴, Sebastian Kamann⁶, Mattia Libralato⁷, Nadine Neumayer⁵, Elena González Prieto^{8,9}, Carl L. Rodriguez¹⁰, Sara Saracino¹¹, Peter Smith⁵, Glenn van de Ven¹², and

Zixian Wang¹

¹ Department of Physics and Astronomy, University of Utah, Salt Lake City, UT 84112, USA; matthew.whitaker@utah.edu

² European Southern Observatory, Germany

³ Michigan State University, USA

⁴ Space Telescope Science Institute, USA

⁵ Max-Planck-Institut für Astronomie, Germany

⁶ Liverpool John Moores University, UK

⁷ INAF—Padova, Italy

⁸ Northwestern University, USA

⁹ Center for Interdisciplinary Exploration & Research in Astrophysics (CIERA), USA

¹⁰ University of North Carolina at Chapel Hill, USA

¹¹ Osservatorio Astrofisico di Arcetri, Italy

¹² University of Vienna, Austria

Received 2026 May 4; revised 2026 June 1; accepted 2026 June 7; published 2026 July 13

Abstract

Modern simulations of stellar dynamics in globular clusters peg a dominant role for stellar-mass black holes, but direct evidence for black holes in clusters remains limited. We present the discovery of an astrometric stellar-mass black hole–main sequence star binary in ω Centauri, the most massive Galactic globular cluster, using Hubble Space Telescope data from the oMEGACat project and additional JWST data that span a total of 23 yr. The luminous companion to the black hole is a main-sequence turnoff star, and has a period of 94^{+63}_{-42} yr, a semimajor axis of 31^{+15}_{-12} au, and an eccentricity of $e = 0.72^{+0.08}_{-0.13}$. Since we observe the binary during periastron, the mass of the black hole is well constrained even though we only observe a partial orbit: the inferred black hole mass is $4.46^{+1.22}_{-1.01} M_{\odot}$. We call this black hole oMEGACat BH-2. This is the first astrometric discovery of a stellar-mass black hole in a globular cluster, and is the longest-period black hole binary system yet discovered. The low mass of this black hole is perhaps surprising given the low metallicity of the cluster, and shows that at least some low-mass black holes form at metallicity $Z < 10^{-3}$. We find that the binary is almost certainly dynamically formed and is soft, with an expected binary disruption timescale of ~ 800 Myr. While the total number of black hole binaries in ω Centauri is uncertain, we show that existing surveys only cover a small area of parameter space, and that the presence of additional detectable black hole binaries is likely.

Unified Astronomy Thesaurus concepts: [Stellar mass black holes \(1611\)](#); [Black holes \(162\)](#); [Globular star clusters \(656\)](#); [Astrometric binary stars \(79\)](#); [Binary stars \(154\)](#); [Astrometry \(80\)](#)

Materials only available in the [online version of record](#): machine-readable table

1. Introduction

For at least 50 yr, it has been evident that globular clusters contain an overabundance of X-ray sources formed through dynamical interactions (G. W. Clark 1975; A. C. Fabian et al. 1975; J. I. Katz 1975). Subsequent observational work (e.g., P. Hertz & J. E. Grindlay 1983) showed that luminous X-ray sources in Galactic globular clusters—both persistent and transient—are mostly or entirely accreting neutron stars.

Some of the massive stars formed early in the lives of star clusters should have left stellar-mass black holes upon their deaths rather than neutron stars. The black holes with small natal kicks will remain in the cluster and mass segregate within a fraction of the relaxation time of the cluster (D. Merritt 2013), typically < 1 Gyr. For decades, it was predicted that these mass-segregated black holes would interact to form binaries and mutually eject each other, leading to few or no

black holes remaining in current Galactic globular clusters (e.g., L. Spitzer 1969; S. R. Kulkarni et al. 1993; S. Sigurdsson & L. Hernquist 1993).

Gradually, it was realized that black holes do not fully decouple from the other stars, but instead interact efficiently with the surrounding cluster. This leads to less efficient black hole ejection than previously argued and suggests the possibility of ongoing black hole populations in some clusters (e.g., A. D. Mackey et al. 2008; M. Morscher et al. 2013; A. C. Sippel & J. R. Hurley 2013). Parallel observational work identified candidate accreting black holes in both extragalactic and Galactic globular clusters (e.g., T. J. Maccarone et al. 2007; J. Strader et al. 2012; L. Chomiuk et al. 2013; J. C. A. Miller-Jones et al. 2015). These theoretical and observational efforts took on a broader significance with the gravitational-wave discovery that black hole–black hole mergers are common (B. P. Abbott et al. 2016) and the realization that many of these systems could have dynamically formed in massive star clusters (e.g., C. L. Rodriguez et al. 2016). Modern modeling of globular cluster structural properties or dynamics gives indirect evidence for black hole



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populations in some clusters (e.g., N. C. Weatherford et al. 2020; E. Vitral et al. 2022; N. Dickson et al. 2024).

The contemporary theoretical view of the dynamical evolution of globular clusters now puts black holes at the center, both literally and figuratively. Clusters with large cores are thought to have retained a substantial population of black holes, while traditional “core collapse” is only possible once all (or nearly all) black holes have been ejected (e.g., P. G. Breen & D. C. Heggie 2013; D. C. Heggie & M. Giersz 2014; L. Wang et al. 2016; K. Kremer et al. 2018, 2019).

While the dynamics of black holes are relatively straightforward, the expected starting black hole population is uncertain, as it depends on several poorly constrained physical parameters. For example, the dependence of the initial mass function of massive stars on metallicity is poorly constrained (e.g., A. J. Cameron et al. 2024), as is the mapping between initial mass and remnant mass (e.g., L. Boccioli & G. Fragione 2024). Another uncertainty is the distribution of kick velocities; at least some black holes receive either natal or Blaauw kicks sufficiently large to remove them from globular clusters (see the recent review of S. Popov et al. 2025).

Perhaps surprisingly, large variations in black hole populations are not necessarily predicted to translate into comparable differences in the number of observable black hole–visible star binaries in these clusters, with theoretical studies predicting weak (e.g., M. Morscher et al. 2015) or no (e.g., S. Chatterjee et al. 2017) correlation between these quantities. This is a consequence of the forecasted effects of black holes on the central dynamics: when a large black hole population is present, the central stellar density is expected to be low, such that black holes rarely interact with stars. But once most black holes have been ejected, the central stellar density increases, and the few remaining black holes are much more likely to form binaries with normal stars.

Despite the broad implications of this shift in the theoretical view of cluster dynamics, there remains scant direct observational proof of the presence of black holes in globular clusters. Only two stellar-mass black holes have been dynamically confirmed in Galactic globular clusters: both in the metal-poor cluster NGC 3201, via an untargeted radial-velocity survey (B. Giesers et al. 2018, 2019). These are both detached binaries with main-sequence secondaries, one in a 167 day, very eccentric orbit, and the other in a 2.2 day, low-eccentricity orbit. While the black hole masses are uncertain up to an inclination factor, they are not too large ($\lesssim 10M_{\odot}$) unless the orbits are face-on. In addition to these systems, there is strong evidence that Gaia BH 3, which hosts a $33M_{\odot}$ black hole in a wide 11.6 yr orbit (Gaia Collaboration et al. 2024), is associated with a very metal-poor dissolved globular cluster tidal stream (E. Balbinot et al. 2024) and, hence, could reasonably be included in a globular cluster black hole census.

Radial-velocity studies with data comparable to that for NGC 3201 have been undertaken for 47 Tuc (J. Müller-Horn et al. 2025) and ω Centauri (S. Saracino et al. 2025), but uncovered no candidate black hole binaries. These findings are intriguing given that, as discussed above, the occurrence of observable black hole binaries is predicted to be mostly independent of the present-day black hole population. This would imply similar numbers of black hole–visible star binaries should be found in most massive clusters.

However, these radial-velocity surveys are incomplete: they are insensitive to longer orbital periods and miss fainter stars (in both clusters, the 50% completeness of the binary search was around the main-sequence turnoff). Since models for dynamical formation of black hole–visible star binaries predict a wide range of secondary masses (K. Kremer et al. 2018), surveys that cannot reach typical cluster main-sequence stars are expected to miss most black hole–non-black-hole binaries.

Astrometric searches for black hole–non-black-hole binaries are complementary to radial-velocity searches. Hubble Space Telescope (HST) or JWST data typically have sensitivity to much fainter and lower-mass stars than ground-based radial velocities. In addition, astrometric searches are more sensitive to longer periods.

The highest-quality space-based astrometric dataset for any Galactic globular cluster is for ω Centauri (ω Cen): M. Häberle et al. (2024a) presented hundreds of epochs of HST astrometric measurements over a typical baseline of more than 20 yr. This remarkable dataset has already been used to demonstrate the existence of an intermediate-mass black hole at the center of ω Cen (M. Häberle et al. 2024b). These same data are also ideal to search for astrometric binaries in the cluster.

Fortuitously, ω Cen also likely hosts the largest population of stellar-mass black holes of any cluster in the Milky Way. This is for three reasons: first, it is the most massive cluster, so plausibly had the highest initial black hole population; second, the high escape velocity¹³ enables retention of black holes after natal or merging kicks, and third, the cluster has a long core relaxation time (a few Gyr; G. van de Ven et al. 2006), slowing dynamical ejection of black holes.

Indeed, dynamical modeling of cluster kinematics and pulsar accelerations in ω Cen suggest the presence of $\mathcal{O}(10^4)$ black holes (H. Baumgardt et al. 2019; A. Zocchi et al. 2019; N. Dickson et al. 2024; A. Bañares-Hernández et al. 2025). Since these papers did not self-consistently include an intermediate-mass black hole of the mass inferred by M. Häberle et al. (2024b) together with a separate population of stellar-mass black holes, this population approximation is likely an overestimate. Nonetheless, for the reasons given above, the black hole population is still expected to be large.

ω Cen’s large spread in metallicity (J. E. Norris et al. 1996; C. I. Johnson & C. A. Pilachowski 2010) and age (C. Clontz et al. 2024), and the detection of a central intermediate-mass black hole (M. Häberle et al. 2024a), make a strong case that it is a stripped nuclear star cluster from an early merger in the Milky Way’s history (e.g., K. Bekki & K. C. Freeman 2003; J. Pfeffer et al. 2021; G. Limberg et al. 2022). The deep potential wells of nuclear star clusters, as well as the presence of central massive black holes, can impact the dynamical evolution of stellar-mass black holes in these systems (e.g., D. Merritt 2009; F. Antonini & F. A. Rasio 2016; G. Fragione et al. 2019; T. Panamarev et al. 2019). In addition, because nuclear star clusters can assemble via repeated cluster accretion or star formation events (see review by N. Neumayer et al. 2020), this assembly history may impact the compact object population in the cluster. For example, progenitor star

¹³ The current escape velocity is 62 km s^{-1} (M. Häberle et al. 2024b), compared to a median of 28 km s^{-1} for Galactic globular clusters (O. Y. Gnedin et al. 2002). However, the ω Cen escape velocity was potentially $\gtrsim 100 \text{ km s}^{-1}$ when the black holes formed, as clusters lose substantial mass due to stellar evolution, two-body relaxation, and shocks (e.g., S. M. Fall & Q. Zhang 2001).

clusters with shorter relaxation times could mass segregate before falling into the nuclear star cluster, leading to a more dynamically evolved compact object population in the nuclear cluster than would otherwise be expected based solely on its present mass and radius (e.g., A. Rantala et al. 2024; M. C. i. Bernadich et al. 2026).

Despite the likely presence of many stellar-mass black holes in ω Cen, none have been detected so far. This is despite deep radio (E. Tremou et al. 2018; A. D. Mahida et al. 2025) and X-ray surveys (D. Haggard et al. 2013) that would be sensitive to accreting black holes (e.g., J. Strader et al. 2012; L. Chomiuk et al. 2013), as well as radial velocity and astrometric searches for binary stars with black hole companions (I. Platais et al. 2024; F. Wragg et al. 2024; S. Saracino et al. 2025).

I. Platais et al. (2024) used an independent reduction of a subset of the long-baseline ω Cen HST astrometric dataset to identify four candidate astrometric binaries with “dark” companions, which they inferred to be white dwarfs or possibly neutron stars.

We have undertaken a new search for astrometric binaries in ω Cen using the more extensive M. Häberle et al. (2024a) HST dataset, augmented with new JWST data. The binaries found from this effort will be presented in an upcoming paper (M. Whitaker et al. 2026, in preparation). One of the highest significance binaries found in our search is a recovery of one of the “dark” companion candidates identified by I. Platais et al. (2024), who suggested a likely neutron star companion. However, here we show that it is in fact a stellar-mass black hole–main sequence star binary with a long (94^{+63}_{-42} yr) orbital period.

Section 2 describes the data and simulations used in this discovery and its interpretation. Section 3 contains a detailed analysis of the properties of the main-sequence star, which are needed to interpret the orbital properties of the binary. Section 4 describes our constraints on the binary properties. In Section 5, we explore the implications of this discovery for the black hole population in ω Cen and in other massive clusters. Throughout the Letter, we use a distance to ω Cen of 5494 ± 61 pc (M. Häberle et al. 2025). At this distance, 1 mas yr^{-1} translates to 26.06 km s^{-1} and 1 mas is 5.494 au .

2. Data and Simulations

This section describes the data used in the astrometric discovery of a long-period black hole–main sequence binary in ω Cen. The evidence for this classification is presented in Section 4.

2.1. Space-based Astrometry and Photometry

2.1.1. HST Astrophotometric Data

Here we briefly describe the reduction of the HST images and refer readers to M. Häberle et al. (2024a) for a detailed description.

The individual charge transfer efficiency corrected `*_flt.fits` images are first processed with `hstlpass` (J. Anderson 2022), which refines library effective point-spread function (ePSF) models for each image. After applying geometric distortion corrections, this gives an initial catalog of sources for each image. These single-image catalogs are then cross-matched with Gaia EDR3 (Gaia Collaboration et al. 2021; L. Lindegren et al. 2021) to determine the transformations that bring each image to a Gaia-based astrometric master

frame. Then, the code `KS2` (see A. Bellini et al. 2017) is used to perform PSF photometry using the refined ePSF from `hstlpass`, including source detection in combined images and iterative neighbor subtraction. `KS2` yields astrometric measurements in the raw detector frame of each individual image. These are iteratively transformed to the astrometric master frame during the proper-motion determination, yielding a position in the master frame in pixel coordinates and a photometric measurement for each observed star at each single-image epoch.

For this work, we utilize the same epochs used for astrometry by M. Häberle et al. (2024a); that paper did not include individual exposure astrometry, instead combining astrometry into a single proper-motion catalog. Of the 672 possible astrometric measurements, we cull out data with (1) short (5 s) exposure times, (2) those in which our black hole binary candidate (ID 285597 in the M. Häberle et al. 2024a catalog) is not on the detector or not detected, (3) those where diffraction spikes from bright stars are present, and (4) those impacted by persistent noisy pixels. In total, we are left with 351 HST epochs spanning 20.5968 yr. We also use an updated, empirical HST astrometric uncertainty model derived from repeat measurements that depends both on instrumental magnitude and accounts for the impact of crowding. The quality cuts and astrometric uncertainty model are further detailed in our upcoming work (M. Whitaker et al. 2026, in preparation). Figure 1 shows multiband HST imaging of our black hole binary candidate. It lies in the crowded core of the cluster, but is brighter than any other star within $0''.5$. Table 1 contains the HST astrometric data used. The HST data is available from the Mikulski Archive for Space Telescopes (MAST) at the Space Telescope Science Institute. The utilized observations can be accessed via doi:10.17909/26qj-g090.

2.1.2. JWST Astrometry

To augment the existing HST astrometry for our candidate, we use two epochs of JWST NIRCам Short Wavelength Channel observations. The star is present in the F200W images at epoch 2024.5219 (GO 4343; O. Y. Kargaltsev et al. 2023; S. Chen et al. 2026; four dithers totaling 515 s of exposure time). It is also present in F115W and F200W images at epoch 2025.5777 in the astrometric monitoring program of the center of ω Cen (GO 8322; M. Häberle et al. 2025; four dithers of 419 s exposures in each filter). We do not use the existing long-wavelength channel observations due to their lower spatial resolution, which leads to decreased astrometric precision. The details of the JWST data reduction will be described in a future publication (M. Häberle et al. 2026, in preparation), but they overall follow the same strategy as for the HST observations. The JWST data are processed using the JWST pipeline up to Stage 2 (`*.cal.fits`), i.e., they are flat-fielded and flux-calibrated, but not remapped. An initial photometry pass is performed on the individual images using `jwstlpass` (see J. Anderson 2022; M. Libralato et al. 2023) and public library geometric distortion corrections and empirical PSF models.¹⁴ We then use a modified version of `KS2` to perform our final astrophotometric measurements.

To cross-match and transform the new JWST positions to the same reference frame as the M. Häberle et al. (2024a) HST data, we use the same set of well-measured cluster-member

¹⁴ <https://www.stsci.edu/~jayander/JWST1PASS/LIB/>

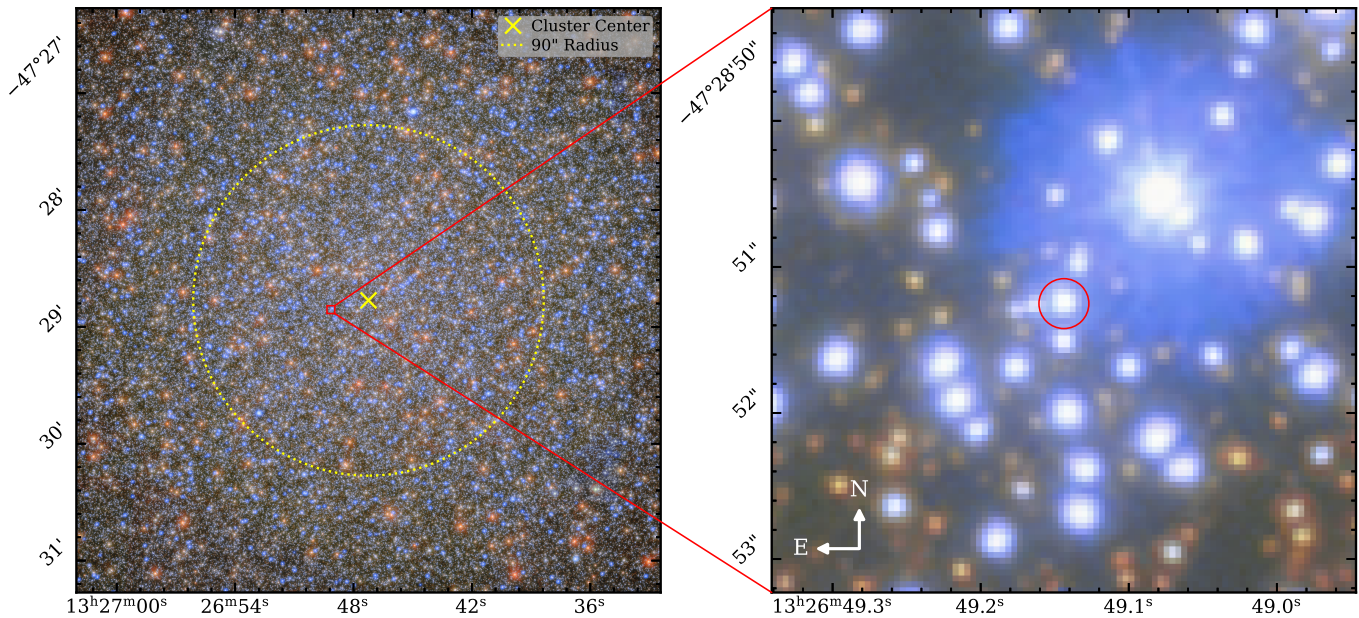


Figure 1. Stacked HST composite image of ω Cen. Left: location of the visible star relative to the cluster center (J. Anderson & R. P. van der Marel 2010; M. Häberle et al. 2024b). Right: a closer view of the visible star and its neighbors, including a bright horizontal branch star $\sim 1''$ to the northwest. Image credit: ESA/Hubble, NASA, Maximilian Häberle (MPIA).

stars, propagated to the respective JWST epoch. For each star, we determine the closest 50 of these reference stars and determine the best-fit linear six-parameter transformations to transform detector coordinates to reference frame coordinates. This yields a total of 12 individual astrometric measurements for the black hole binary candidate.

To calculate the uncertainties for each measurement, we measure the standard deviation (with $N - 1$ degrees of freedom) of the positions from the four images in each epoch and filter. These standard deviations are between 0.129 and 0.777 mas. The more precise measurements are from the 2024 data, while the 2025 data have larger scatter due to a different detector readout strategy, for which this fairly bright star was only unsaturated in the “Frame 0” read. The individual JWST astrometric measurements can be found at the end of Table 1. The specific JWST observations analyzed can be accessed from MAST via DOI: [10.17909/32xm-hy79](https://doi.org/10.17909/32xm-hy79).

2.2. MUSE Spectroscopy

The visible star has 31×15 s MUSE exposures taken on 12 distinct dates ranging from 2015 April 23 to 2022 May 31. These data have already been analyzed and described in M. S. Nitschai et al. (2023) (MUSE Star ID: 4420) and S. Saracino et al. (2025), and we refer readers to those papers for reduction details. Spectra were obtained using the PSF fitting software PampelMUSE (S. Kamann et al. 2013), which enables extraction of stellar spectra in crowded fields, especially when the positions of those stars are well known from HST imaging.

2.3. Simulation Outputs

To provide context for the black hole binary, we use outputs from recent dynamical simulations of an ω Cen-like cluster by E. González Prieto et al. (2025). These Cluster Monte Carlo simulations include an intermediate-mass black hole and have been fit to ω Cen’s present-day properties. We analyze the simulation that started with a $500 M_{\odot}$ central BH seed here; at

the end of the simulation, this seed has grown to an intermediate-mass black hole with a mass of $4.7 \times 10^4 M_{\odot}$, and the cluster contains 2459 stellar-mass black holes. The simulation tracks the formation and destruction of binaries, including those involving black holes. The simulation includes nine visible star–black hole binaries at the ending time stamp of the simulation (12.5 Gyr) with black hole companions ranging from 9 – $27 M_{\odot}$. To further increase number statistics on the simulated population of visible star–black hole binaries, we also analyzed 50 snapshots taken every 20 Myr over the last Gyr of the simulation, yielding 474 measurements of visible star–black hole binaries. Available data on these simulated binaries includes their star and black hole masses, the orbital period and semimajor axis of the binary system, and their position and velocity within the cluster.

We use the 1D velocity dispersion of all 474 visible star–black hole binaries (12.6 km s^{-1}) to set a prior on the proper motion of the system (Section 4.1); this value is lower than the velocity dispersion observed for the stars due to partial energy equipartition. We also use the simulations to gauge the expected lifetime of the detected binary (Section 5.2.2), and to understand whether binary systems like the one we detect here are consistent with predictions from these simulations (Section 5.3).

2.4. Multiwavelength Constraints

We show in this Letter that star 285597 from M. Häberle et al. (2024a) is in a long-period binary with a stellar-mass black hole. Given the long orbital period and that the secondary is a $\sim 0.8 M_{\odot}$ main-sequence star, no accretion onto the black hole is expected. Nonetheless, for completeness, here we consider multiwavelength constraints on accretion.

2.4.1. X-Ray

The binary is in the region of the cluster covered by the Chandra/ACIS-I survey of S. Henleywillis et al. (2018), which reached an unabsorbed limiting depth of

Table 1
HST and JWST Astrometric Measurements of the Visible Star

Year	Δ R.A. (mas)	Δ Decl. (mas)	Δ R.A. Err (mas)	Δ Decl. Err (mas)	Instr.	Filter	Flag
2002.48916	−0.832	−0.296	1.014	1.014	ACS	F625W	...
2009.53802	−1.472	−2.496	1.430	1.430	UVIS	F336W	...
2010.03538	−0.352	−0.496	0.453	0.453	UVIS	F606W	...
2010.0403	0.048	−1.216	0.506	0.506	UVIS	F336W	...
2010.3243	−0.472	−1.096	0.489	0.489	UVIS	F555W	...
2010.3272	−0.472	−0.976	0.548	0.548	UVIS	F814W	...
2010.50723	1.168	−0.776	0.510	0.510	UVIS	F336W	...
2011.12553	−0.552	−0.336	0.453	0.453	UVIS	F606W	2
2011.21868	−0.032	−0.456	0.454	0.454	UVIS	F606W	2
2012.18571	−0.952	−0.456	0.456	0.456	UVIS	F606W	...
2012.6314	−1.152	1.304	0.383	0.383	ACS	F435W	...
2013.95214	−0.432	1.744	0.433	0.433	ACS	F814W	...
2015.43183	0.768	0.464	0.454	0.454	UVIS	F606W	...
2016.20181	0.928	3.144	0.456	0.456	UVIS	F606W	2
2019.16645	2.808	2.464	0.386	0.386	UVIS	F814W	...
2021.00775	4.648	2.984	1.095	1.095	UVIS	F606W	4
2022.03218	4.168	1.904	0.424	0.424	UVIS	F606W	...
2025.5777	6.300	1.332	0.596	0.777	NIRCAM	F115W	...

Notes. Measurements are relative to the M. Häberle et al. (2024a) catalog position and do not include the motion of ω Cen. Entries with a nonzero flag are not used in the orbital fit. Flag descriptions: 1: Large ($>5\sigma$) outlier; 2: Overlapping diffraction spike; 3: Centroid falls on noisy pixel; 4: Short (<5 s) exposure time.

(This table is available in its entirety in machine-readable form in the [online article](#).)

$\sim 2 \times 10^{-16}$ erg s $^{-1}$ cm $^{-2}$ (0.5–4.5 keV) near the cluster center. There is no X-ray source within $\sim 30''$ of the binary. Assuming a typical power-law index photon flux ($N_E \propto E^{-\Gamma}$ with $\Gamma = 1.8$), the nondetection flux limit is equivalent to a 1–10 keV luminosity limit of $\lesssim 9 \times 10^{29}$ erg s $^{-1}$ at the distance of ω Cen. This upper limit is comparable to the faintest black hole X-ray binaries known (e.g., J. Rodriguez et al. 2020) and is >2 orders of magnitude below the candidate black hole X-ray binaries identified in M62 (L. Chomiuk et al. 2013) and 47 Tuc (J. C. A. Miller-Jones et al. 2015), though, as stated above, no accretion from the visible companion is expected.

2.4.2. Radio

The region containing the binary is covered by a number of existing deep centimeter radio continuum images of the cluster. It is not detected in 29.4 hr of on-source imaging with the Australia Telescope Compact Array at a central frequency of 7.25 GHz, giving a 3σ upper flux density limit $< 8.8 \mu\text{Jy}$ (E. Tremou et al. 2018; V. Tudor et al. 2022). This flux density limit is equivalent to radio luminosity $L_R \lesssim 2.3 \times 10^{27}$ erg s $^{-1}$ at 7.25 GHz, or $L_R \lesssim 1.6 \times 10^{27}$ erg s $^{-1}$ at the standard comparison frequency of 5 GHz, if a flat radio spectrum between 7.25 and 5 GHz is assumed. The recent deeper Australia Telescope Compact Array 7.25 GHz image of A. D. Mahida et al. (2025) also does not appear to detect a source at the location of the binary (see their Figure 1). Given their 3σ limit of $< 3.3 \mu\text{Jy}$, this would lower these upper limits by a factor of about 2.7, to a 5 GHz limit of $L_R \lesssim 6.0 \times 10^{26}$ erg s $^{-1}$. As for the X-ray data, these limits are deep, within a factor of a few of the very low-level radio emission detected from quiescent stellar-mass black holes such as A0620-00 (E. Gallo et al. 2006; T. Dinçer et al. 2018).

3. Results: Properties of the Visible Star

To determine the properties of the luminous star in the binary, we use existing oMEGACat data, including both multiband photometry and astrometry from M. Häberle et al. (2024a) and MUSE spectroscopic analysis from M. S. Nitschai et al. (2023). As we show below (Section 5.2), the binary is likely dynamically formed; thus, the visible star’s properties are important primarily to constrain the stars mass in the binary orbital fit.

3.1. HST Astrophotometric Measurements

From the catalog of M. Häberle et al. (2024a), the visible star is located at ICRS (R.A., decl.) of (13^h26^m49^s.1457528, −47°28′51″.231396) at an Epoch of 2002.5,¹⁵ 20'' (0.5 pc) southeast of the cluster center defined by J. Anderson & R. P. van der Marel (2010) (Figure 1). We note this cluster center is also consistent with the position of the intermediate-mass black hole (M. Häberle et al. 2024b). The visible star’s HST photometry (M. Häberle et al. 2024a) indicates it is near the main-sequence turnoff, with a Wide Field Camera 3 (WFC3)/UVIS F814W magnitude of 17.557 ± 0.006 ; assuming a reddening of $E(B - V) = 0.185$ (C. Clontz et al. 2024), the extinction-corrected magnitude is $F814W = 17.214$. Its position in an $F275W - F814W$ versus $F814W$ color–magnitude diagram (CMD) is shown in the left panel of Figure 2; the star occupies a comparable relative position in other CMDs we examined with the available seven-band photometry.

¹⁵ Due to setup of the reference frame that is comoving with Omega Centauri, the reference epoch for absolute positions is 2002.5, while for position changes due to internal-motions it is 2012.0; see M. Häberle et al. (2024a) for details.

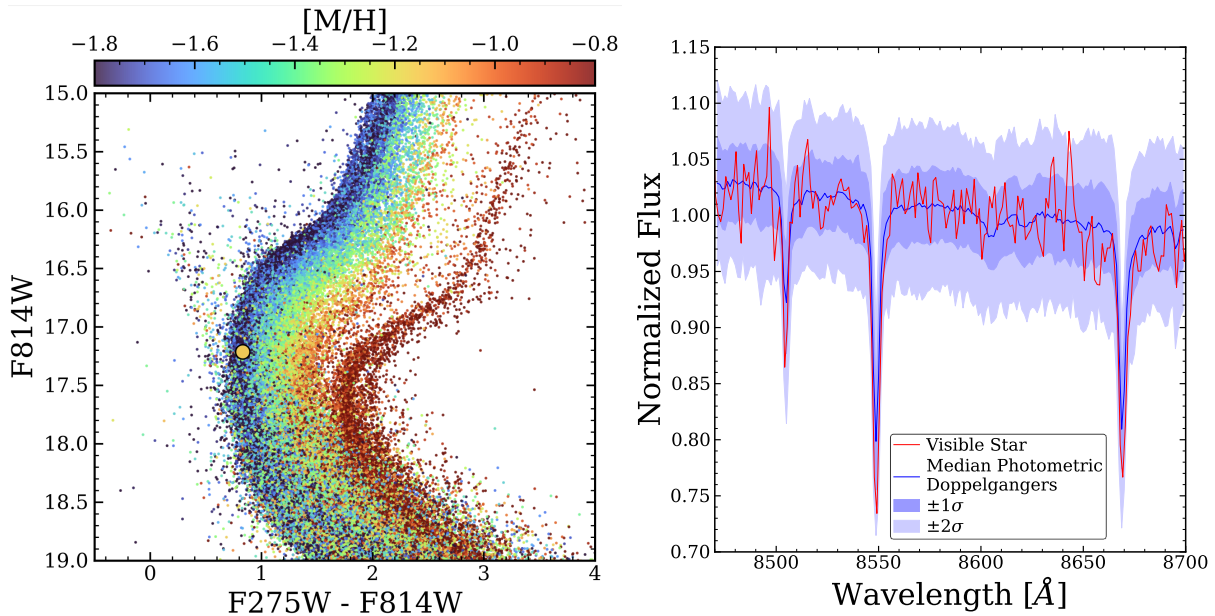


Figure 2. Visible star properties. Left: extinction-corrected color-magnitude diagram (CMD) combining photometry from M. Häberle et al. (2024a) and spectroscopic metallicities from M. S. Nitschai et al. (2023). Based on its position in the CMD, it is a turnoff star with $[M/H] = -1.75 \pm 0.25$. Right: MUSE spectra of the visible star (red) vs. other stars with similar color (blue). The blue line and shaded regions show the median, 1σ , and 2σ range of the 260 stellar spectra selected as photometric doppelganglers (within 0.02 mag in both color and magnitude in the left CMD). The red line shows the calcium triplet lines are slightly deeper than for stars of similar color, and most consistent with $[M/H] = -1.5$. The combined photometric and spectroscopic data suggest $[M/H]$ in the range -1.75 to -1.5 .

The star is a proper-motion member of the cluster, and the catalog proper motion implies a 2D velocity of 11 km s^{-1} relative to the cluster mean. However, as we discuss below, this proper-motion measurement is partially degenerate with the binary motion of the visible star. For our best fit, we find a slightly lower total proper motion of 7 km s^{-1} (Section 4.2).

Time-series photometry shows no significant variations: the star does not show any evidence of being a variable star. Note that 182 measurements are available in the WFC3/UVIS F606W filter, and these show no significant brightening or dimming over 13 yr; colors are also constant between epochs. The star is several PSF FWHM ($0''.2$) away from the nearest star and is brighter than all stars within $0''.9$ (Figure 1), so uncontaminated photometric measurements of its properties are expected.

Figure 1 also shows that there is a luminous hot horizontal branch star located $\sim 1''$ northwest of the star (M. Häberle et al. 2024a Star ID: 390029). While this star has no meaningful effect on the photometry or astrometry,¹⁶ it does complicate our ground-based spectroscopy of the target star, as discussed below in Section 3.2. For this reason, a metallicity determined from stars that are photometrically similar to the visible star may be more accurate than the single measurement for the star itself. To determine a robust metallicity, we select cluster-member stars within 0.02 mag of the CMD position of the visible star that also have MUSE spectroscopic metallicities, giving a sample of 260 similar stars (henceforth, we call these “doppelganglers”). This sample of photometric doppelganglers has a mean $[M/H] = -1.75 \pm 0.02$ and $\sigma = 0.25$ (all metallicity values quoted here have atomic diffusion corrections applied; M. S. Nitschai et al. 2023).

The “chromosome map” made from HST photometry can also provide some information on the helium content of the visible star (C. Clontz et al. 2025). The star’s position on this diagram compared to other stars of similar brightness suggests it is a member of either the P1 (primordial) or Im (intermediate) cluster populations, consistent with either no or modest helium enrichment, and excluding high helium enrichment.

3.2. MUSE Spectroscopic Measurements

M. S. Nitschai et al. (2023) analyzed a signal-to-noise ratio (S/N)-weighted mean spectrum of all available MUSE exposures for the visible star, finding a radial velocity of $237.1 \pm 4.2 \text{ km s}^{-1}$. This value is close to the systemic velocity of the cluster ($V_{\text{sys}} = 233 \text{ km s}^{-1}$; M. S. Nitschai et al. 2023), independently confirming its cluster membership.

However, there is an apparent mismatch in its metallicity; the spectroscopic $[M/H]$ derived for the star is -1.15 ± 0.09 , noticeably higher than the photometric doppelganglers (Figure 2).

To investigate this, we first compared the MUSE spectrum to that of the photometric doppelganglers, finding that the visible star’s MUSE spectrum is much bluer. Visual inspection of the MUSE data cubes shows that at blue wavelengths, there is an overlap between the PSFs of the visible star and of the nearby hot horizontal branch star mentioned above. This is only an issue in the blue; the stars are well-separated at redder wavelengths. Inspection of the spectra extracted from individual MUSE exposures of the visible star shows a wide variation in the continuum slopes blueward of $\sim 7000 \text{ Å}$, further suggesting the possibility of contamination by the horizontal branch star at bluer wavelengths in some of the data.

We therefore focus on the reddest end of the MUSE spectra, in the region of the calcium triplet ($\lambda \sim 8550 \text{ Å}$). We can confirm that contamination from the horizontal branch star is

¹⁶ All neighboring stars, including this horizontal branch star, contribute minimal contaminating light ($<6\%$ across all wavelengths even without PSF modeling). We also see no filter-dependent offsets in the astrometry.

negligible at these wavelengths, as the hot star shows strong Paschen absorption that is not detected in the spectra of the visible star. A comparison of the calcium triplet region between the visible star and the photometric doppelgangers is shown in the right panel of Figure 2. We find that the visible star has slightly deeper calcium triplet lines than the doppelgangers, suggesting a cooler and/or more metal-rich star. Compared to MUSE spectra of stars at similar magnitudes, we find the best match with stars that are redder by ~ 0.2 mag in F275W – F814W and have $[M/H] \sim -1.5$. This value is consistent with the scatter of the metallicities of the doppelgangers ($[M/H] = -1.75$; $\sigma = 0.25$) but inconsistent with the much higher spectroscopic metallicity of -1.15 ± 0.09 in M. S. Nitschai et al. (2023); this high value may perhaps be due to the neighbor contamination at bluer wavelengths. We therefore suggest that the spectroscopic catalog value is likely incorrect and that the true value is somewhere in the range ~ -1.75 (the photometric estimate above calibrated from spectroscopy) to -1.5 (the calcium triplet spectroscopy estimate here). For context, the median metallicity of the cluster is $[M/H] = -1.61$ (M. S. Nitschai et al. 2024); thus, the star is likely consistent with the cluster’s dominant metallicity population.

Finally, we note that S. Saracino et al. (2025) derived radial velocities for the visible star in five separate epochs from the MUSE data. While these measurements show no significant changes from the mean value presented in M. S. Nitschai et al. (2023), they could potentially be affected by the contaminating hot star in the blue. Hence, we have re-derived velocities from these data using a two-step process. We first created a template in the calcium triplet region iteratively, starting from the highest-S/N exposure, and then using cross-correlation to find the best-fit velocity offset for each spectrum, putting all at a common velocity. A weighted mean of these offset spectra was used to make the final template. We then used this template to get the relative velocity of the star in each individual exposure. We find 17 velocities over 12 nights with $S/N > 5$, and summarize these measurements in Table 2. A linear model fit to the velocities as a function of time finds a slope that is insignificant ($< 1\sigma$), so there is no evidence for a linear trend in the velocities. Given the large uncertainties on the measurements, we do not incorporate these data directly into our orbital fits in Section 4, but do use them as consistency checks in Section 6.1.

3.3. Visible Star Mass Estimate

Based on the information above, we can infer the mass of the visible star. Following M. Häberle et al. (2025), we use Dartmouth isochrones (A. Dotter et al. 2008) to estimate stellar masses. For our fiducial mass estimate, we assume an age of 12 Gyr, the median age of the cluster (C. Clontz et al. 2024), an $[Fe/H]$ of -1.7 and an $[\alpha/Fe]$ of 0.3 (C. I. Johnson & C. A. Pilachowski 2010) (corresponding to $[M/H] \sim -1.5$) and $Y = 0.25$ (a normal helium abundance for a metal-poor star). Using the F814W extinction-corrected magnitude of 17.214, this isochrone yields a mass for the visible star of $0.78 M_{\odot}$. The uncertain age and metallicity of the star create a small uncertainty on the stellar mass, but a much larger uncertainty comes from the uncertainty in the helium abundance.

Stars in ω Cen can be enriched in helium (e.g., G. Piotto et al. 2005), with a substantial population of stars having

Table 2
MUSE Radial-velocity Measurements of Visible Star

Year	V_r (km s^{-1})	V_r err (km s^{-1})	S/N
2015.3075	1.9	5.8	16.1
2015.3075	−6.2	6.2	5.8
2016.0909	−4.4	12.7	5.2
2016.0938	5.4	7.3	6.5
2017.0749	−0.2	9.2	11.3
2017.0750	8.7	6.9	12.7
2017.0832	−2.7	6.5	8.0
2017.0832	−6.0	7.6	6.7
2017.3123	−2.4	7.5	8.9
2017.3124	2.7	7.7	13.0
2018.1214	6.4	11.4	5.7
2018.2799	0.5	9.0	5.6
2018.3593	4.8	6.0	5.3
2019.1764	−14.6	13.7	5.2
2022.4083	8.5	13.8	8.6
2022.4083	4.7	9.2	9.3
2022.4113	−1.7	11.3	7.1

Note. All measurements are relative to a template with a velocity of $235.7 \pm 1.8 \text{ km s}^{-1}$; this should be added to the V_r value to get the barycentric velocity.

$Y \sim 0.4$ (often referred to as “2G” or “P2” stars). At the metallicity of the visible star, roughly half of stars have these high helium values (C. Clontz et al. 2025). As noted above, the chromosome map for this star suggests it is unlikely to be strongly helium-enhanced. However, for completeness, we also derive the mass under the assumption that the star is part of the helium-enriched population. Using an isochrone with identical parameters to that above, but with $Y = 0.4$, we find a mass of $0.60 M_{\odot}$, $\sim 0.18 M_{\odot}$ lower than the inferred mass for a star with $Y = 0.25$. In Section 4.2.2 we consider the impact on the mass of the black hole if the star is helium-enriched.

4. Results: Orbital Fitting

Using the combined astrometric data from HST and JWST, we see that our star (ID 285597) has a clear nonlinear motion across the sky (Figure 3). The strong acceleration of this source previously detected by I. Platais et al. (2024) is strengthened by the inclusion of the earlier Advanced Camera for Surveys (ACS) data, additional non-F606W images, and the new epochs of JWST data. The observed motion is a combination of the proper motion of the binary and the orbit of the visible star around the binary center of mass.

4.1. Orbital Fits

To determine the orbital characteristics of this system, we used Markov Chain Monte Carlo (MCMC) techniques to fit an 11-parameter orbital model to the astrometric data. Our model includes seven parameters for the binary:

1. the orbital period (P)
2. semimajor axis of the visible star (a_{vis})
3. cosine of the inclination angle ($\cos i$)
4. eccentricity (e)
5. longitude of the ascending node (Ω)
6. argument of periastron (ω)
7. time of periastron passage (T_0)

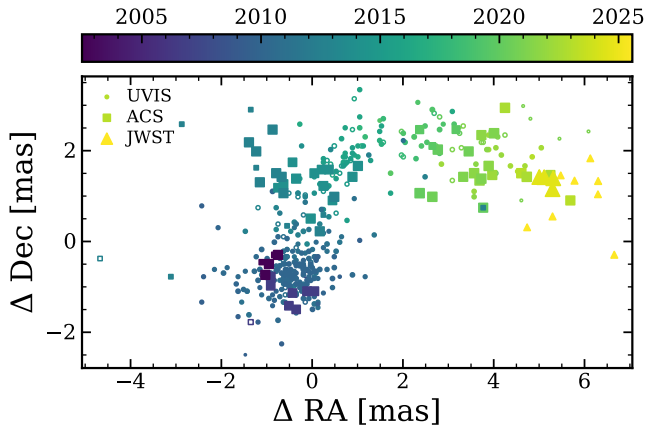


Figure 3. Visible star astrometry. Stellar positions measured by HST ACS/WFC (squares), WFC3/UVIS (circles), and JWST NIRC2 (triangles). Color indicates the date of observation. The size of each marker is inversely proportional to the measurement’s uncertainty. Open markers indicate epochs that were removed due to short (<5 s) exposure time, potential contamination from overlapping diffraction spikes from a neighboring bright star, or the PSF falling on a more noisy pixel (Section 2.1).

In addition, there are four parameters accounting for the proper motions relative to the mean motion of the cluster and astrometric offsets relative to the M. Häberle et al. (2024a) catalog position. The catalog proper motions are $\mu_{\text{cat,RA}} = -0.38886 \text{ mas yr}^{-1}$ and $\mu_{\text{cat,Dec}} = 0.28154 \text{ mas yr}^{-1}$. Because each measurement is made relative to the cluster itself, we expect no significant parallax signal for cluster-member stars.

Our model uses the Thiele-Innes elements (L. B. Lucy 2014), which are transformations of a_{vis} , i , Ω , and ω , to calculate the apparent ellipse of the luminous companion around the barycenter. We include the proper motions and astrometric offsets through a linear model for the R.A. and decl. The astrometric offset term accounts for small corrections to the catalog position and for the fact that unresolved binary positions are measured with respect to the photocenter. In our case, we assume the companion is dark, so the photocenter coincides with the luminous star. This implies that the observed astrometric motion traces the orbit of the luminous visible star around the barycenter, with a_{vis} corresponding to its semimajor axis (I. Platais et al. 2024). This a priori assumption that the companion is dark may not hold true. However, if the companion is indeed luminous, the true mass of the object will be higher than what we infer (I. Platais et al. 2024, their Equation (4)). For neutron stars and black holes in wide binaries, the expectation is that they make no appreciable contribution to the photocenter position.

As this analysis is carried out within a Bayesian framework, we introduce a log-prior, $\ln(\text{prior})$, which encodes our assumptions and constraints on the model parameters. Our prior choices are shown in Table 3, where we use uniform priors across most quantities to ensure our model is primarily data driven. The exception is for the proper motions, where we also place an additional constraint based on the velocity dispersion of black hole binaries from the simulations (Section 2.3) that each component follows a normal distribution with a 1D velocity of 12.6 km s^{-1} , translating to $0.484 \text{ mas yr}^{-1}$ centered around the mean motion of the cluster. The sensitivity of our results to this prior are discussed in Section 4.2.1.

Table 3
Priors for the Orbital Parameters of oMEGACat BH-2

Parameter	Prior
Eccentricity, e	$\mathcal{U}(0, 0.95)$
Inclination, $\cos i$	$\mathcal{U}(0, 1)$
Semimajor axis, a_{vis} (au)	$\mathcal{U}(1, 100)$
Period, P (yr)	$\mathcal{U}(0.5, 200)$
Longitude of ascending node, Ω	$\mathcal{U}(0, 2\pi)$
Argument of periastron, ω	$\mathcal{U}(0, 2\pi)$
Time of periastron passage, T_0	$\mathcal{U}(-\frac{P}{2}, \frac{P}{2})$
Astrometric offsets, $\Delta R.A.$, $\Delta \text{decl.}$ (au)	$\mathcal{U}(-50, 50)$
Proper motions, μ_{RA} , μ_{Dec} (mas yr^{-1})	$\mathcal{U}(-2, 2) + \mu_{\text{cat}}$ & $\mathcal{N}(0, 0.484)$

Note. An additional normal prior is applied to the proper motions with a 1D velocity of $0.484 \text{ mas yr}^{-1}$, centered around the mean motion of the cluster (see Section 4.1). For numerical stability, we limit the e to 0.95 and proper motions to be within 2 mas yr^{-1} of the catalog value μ_{cat} .

We used the `emcee` package (D. Foreman-Mackey et al. 2013) to sample the posterior probability distribution. We run the sampler with 350 chains over 150,000 iterations and use a combination of moves: 80% of the moves are done with the “stretch move” ensemble method and 20% are done with the differential evolution Snooker move. This combination ensures that we sufficiently explore the whole parameter space and avoid becoming stuck in local minima. The effectiveness of this choice is reflected in our effective sample size (ESS), which for each parameter is $\gtrsim 1000$, which indicates we have a sufficient amount of independent samples and our chains are well mixed. A more in-depth discussion of our orbital fitting methods will be presented in M. Whitaker et al. (2026, in preparation).

4.2. The Best-fit Model

Table 4 presents the best-fit solution for our 11 orbital parameters. The reported values represent the medians of the marginalized posterior distribution. The Table also presents 1σ and 2σ uncertainties for each parameter. Our best fit yields a long-period binary system with $P = 94^{+63}_{-42} \text{ yr}$, a semimajor axis of $a_{\text{vis}} = 31^{+15}_{-12} \text{ au}$, an eccentricity of $e = 0.72^{+0.08}_{-0.13}$, and implies a mass of the dark component of $4.46^{+1.22}_{-1.01} M_{\odot}$; we examine the full range of our inferred masses more in Section 4.2.2.

The long orbital period and high eccentricity imply that the visible companion spends most of its orbit at large separations from the dark companion. This is consistent with the smaller astrometric changes found at later epochs as seen in Figure 4, which shows the median parameter orbital fit compared to the data. As we discuss below in Section 4.4, this binary was detected at high significance only because the HST data happened to catch the periastron of the visible star. Despite significant uncertainty on the period, the time of periastron passage is very well constrained: $T_0 = 2012.2^{+0.32}_{-0.36}$. The small fractional uncertainty in T_0 suggests that the most dramatic orbital motion is observed over our baseline. We empirically calculated the on-sky velocity and acceleration over time and find both peak at the inferred periastron passage time.

Our best fits find a significant offset in the decl. proper motion relative to the catalog proper motion, because the catalog fit captured a combination of binary and systemic motion. Hence, the inferred decl. proper motion is covariant

Table 4
Orbital Parameters of oMEGACat BH-2

Parameter	This Work	-2σ	-1σ	$+1\sigma$	$+2\sigma$	P24
e	0.72	0.45	0.58	0.80	0.83	0.3 ± 0.2
$\cos i$	0.43	0.36	0.39	0.47	0.53	...
a_{vis} [au]	31.1	12.7	18.7	46.6	56.4	4.7 ± 0.4
P [yr]	94	34	52	157	192	13 ± 2
Ω	2.87	2.75	2.81	2.92	2.97	...
ω	1.60	1.44	1.53	1.67	1.75	...
T_0 [yr]	2012.2	2011.4	2011.8	2012.5	2012.8	...
ΔRA [mas]	0.24	0.00	0.11	0.38	0.54	...
ΔDec [mas]	0.46	0.14	0.30	0.61	0.75	...
μ_{RA} [mas yr $^{-1}$]	−0.01	−0.07	−0.03	0.02	0.04	...
μ_{Dec} [mas yr $^{-1}$]	−0.26	−0.41	−0.34	−0.15	−0.04	...
M_{vis} [$M_{\odot}$]	0.78	...	...	...	...	0.78 ± 0.01
M_{comp} [$M_{\odot}$]	4.46	2.69	3.44	5.68	7.26	$1.36^{+0.36}_{-0.26}$

Note. The last column includes a comparison to the fit by I. Platais et al. (2024, their HSToC-4). Uncertainties given by I. Platais et al. (2024) are formal fitting errors only, whereas we report the 16th and 84th percentiles from the sampled posterior distribution. Priors for the fit parameters are given in Table 3.

with the semimajor axis and period; this covariance is shown in Figure 5. This parameter degeneracy is examined further below in Section 4.2.1.

The orbital fit with the median parameters (Figure 4) results in a reduced chi-squared of $\chi^2_{\nu} \sim 1.65$. Examining the residuals, we find that our χ^2_{ν} value is inflated by the presence of outliers (3σ – 5σ). However, the bulk of our data are fully consistent with the orbital fit: the 16th/84th percentiles of the error normalized residuals (i.e., $(x_{\text{obs}} - x_{\text{model}})/\sigma$) are $[-0.85, 0.97]$ and $[-0.93, 0.77]$ in the R.A. and decl. directions, respectively, consistent with a good fit to the data.

We also check the fit’s robustness by performing an alternate fit using the nested sampling technique. Nested sampling is effective at discovering multimodal solutions (J. Buchner 2023). We use UltraNest (J. Buchner 2021) with the same priors as the MCMC fit (Table 3). However, in order to reduce the search space and allow UltraNest to converge, we use only eccentricity, period, and time of periastron as our primary parameters. The remaining parameters are all linear, and can be solved using ordinary least-squares. We propagated the uncertainties of the linear parameters from the posterior samples of the three directly constrained parameters. Despite the very different method, the results of this fit were consistent with the results from MCMC and show no multimodalities. Hence, we present only the MCMC results here.

4.2.1. Examining the Degeneracy in Orbital Parameters

Our best fit is a long-period system with our baseline covering less than 40% of the median inferred period—a regime that can lead to major complications in binary characterization (L. B. Lucy 2014). However, because our data capture the periastron passage around early 2012, the observations provide a significantly higher dynamical signal than observations at other orbital phases, thus allowing us to constrain the binary parameters more effectively.

The primary degeneracy in our best-fit solution is between μ_{Dec} , a_{vis} , and P . This degeneracy arises because if the visible star has a high proper motion, especially in decl. (μ_{Dec}), the data can be well fit by a larger orbit (with both increased a_{vis} and a longer period). For such fits, the observed data represent

a smaller fraction of the orbit. Figure 5 demonstrates this degeneracy in the parameter fits. We note that the velocity dispersion prior on the proper motion has a mild effect on the posterior, disfavoring the highest proper-motion (and hence longest-period) solutions. Omitting this prior results in only a slightly higher semimajor axis and period, with the inferred mass rising by $\sim 0.1 M_{\odot}$.

To further explore this degeneracy, we select the orbital fits corresponding to the median, $\pm 1\sigma$ and $\pm 2\sigma$ values of the joint 2D probability distribution of a_{vis} and P along the line of maximum degeneracy (see stars in Figure 5). Selected parameters for these fits are presented in Table 5. The masses found in the table for the $\pm 1\sigma$ and $\pm 2\sigma$ values are calculated directly from the corresponding sample. The most compact orbits correspond to periods of about 25 yr and modest eccentricity ($e \sim 0.3$), while the most extended orbits reflect 200 yr periods with high eccentricity ($e \sim 0.8$). Increasing the maximum value allowed by the orbital period prior continues the trend shown in Table 5, allowing more long-period solutions with higher proper motions, eccentricities, and orbital periods that lead to larger inferred masses. However, for extremely long-period solutions, it becomes increasingly unlikely that we captured periastron passage in our dataset (see Section 4.4).

4.2.2. Mass Constraints

The masses of the binary components are not directly included in the above MCMC fits, but must be separately inferred from the posterior samples of P and a_{vis} , which determine the total mass of the binary. For each sample, the mass of the unseen binary companion is uniquely determined for a given assumed mass of the observed main-sequence star. For our best-fit model, we assume a mass of $0.78 M_{\odot}$ as derived in Section 3.3. Figure 6 shows the inferred companion masses M_{comp} from our orbital fits; the best-fit median mass is $4.46 M_{\odot}$, with a 1σ range of 3.44 – $5.68 M_{\odot}$, and a 2σ range of 2.69 – $7.26 M_{\odot}$.

These mass ranges indicate that the invisible companion is almost certain to be a black hole. The highest-mass neutron star with a precisely measured mass has $2.08 \pm 0.07 M_{\odot}$ (E. Fonseca et al. 2021); slightly higher masses are claimed for

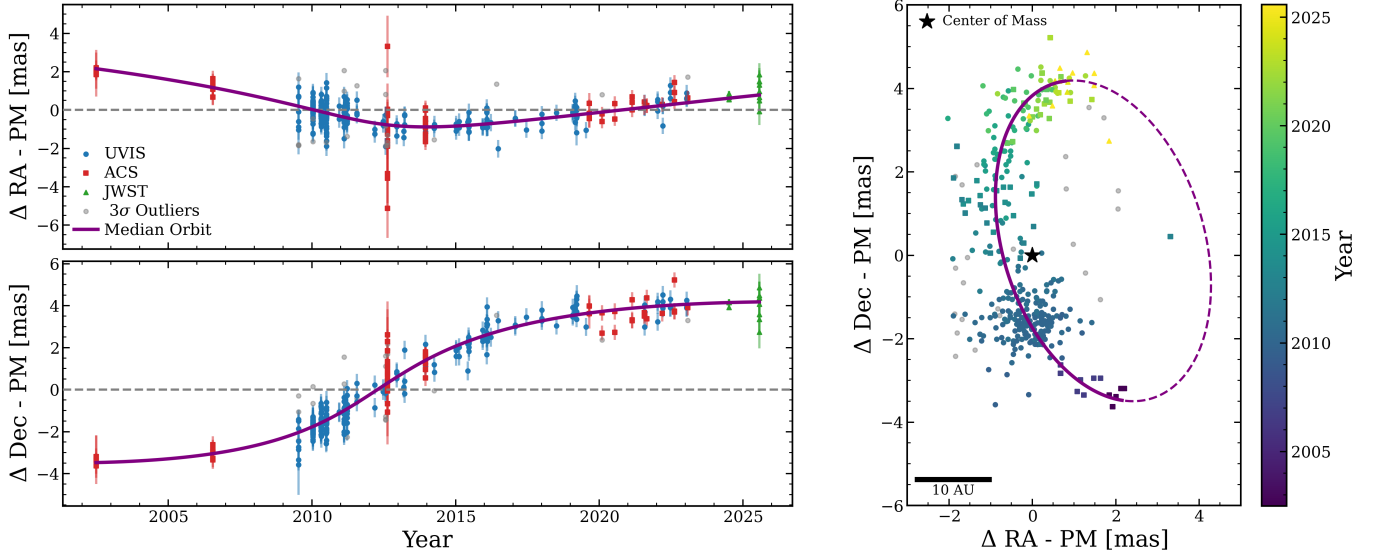


Figure 4. Best-fit orbital model. Left: our median model (purple line) shown compared to the data after subtracting out the derived proper motion. The marker shape and color correspond to the instrument used for measurement, and the gray points represent 3σ outliers from the median fit. Right: our median orbital model plotted with the on-sky data in the proper-motion subtracted frame colored by observation date; the orbit is shown as a dashed line outside our observation window.

some “spider” neutron star binaries (R. W. Romani et al. 2026), but these suffer from modeling challenges and are less certain. Hence, there is potentially a tiny sliver of parameter space for which an unusually massive neutron star cannot be excluded with 100% certainty with our existing data; such solutions would also correspond to the shortest orbital periods, so can be ruled out with only a couple more years of JWST astrometry (see Section 6.1).

We also cannot fully rule out scenarios where the invisible object is itself a rare compact object binary containing two neutron stars, a neutron star and a massive white dwarf, or two massive white dwarfs. Several compact binaries with a high total mass are known in globular clusters that contain a pulsar and a compact object companion, such as M15C (total mass $2.7M_{\odot}$; B. A. Jacoby et al. 2006), Ter5ao (total mass $3.2M_{\odot}$; P. V. Padmanabh et al. 2024), and NGC 1851E (total mass $3.9M_{\odot}$; E. D. Barr et al. 2024); in the latter case, the invisible object could be either a massive neutron star or a stellar-mass black hole. Any massive neutron star is likely a millisecond pulsar with its mass increased by the recycling process (e.g., T. M. Tauris 2011), so this scenario is also disfavored by the lack of a pulsar detection at this location (M. C. i. Bernadich et al. 2026). Additional evidence against a millisecond pulsar is the lack of an X-ray source (Section 2.4.1), since millisecond pulsars are expected to be X-ray sources detectable in deep data, as is true for most of the known ω Cen pulsars (J. Zhao & C. O. Heinke 2023).

Potential contaminating compact binaries are also rare in the E. González Prieto et al. (2025) simulation snapshot, with zero such systems at any radii $>2.7M_{\odot}$ and only five $>2.5M_{\odot}$ (four of these are white dwarf–white dwarf binaries; one is a neutron star–neutron star binary). Hence, the predicted abundance of potential contaminating compact binaries is $\sim 0.2\%$ that of black holes. While the prescriptions for neutron star formation and mass accretion used in these simulations are likely imperfect, the observed scarcity of compact binaries with high total mass in other clusters suggests such binaries are truly uncommon.

For the remainder of the Letter, we assume the very likely black hole identity of the companion, referring to it as oMEGACat BH-2, as this is the second black hole in ω Cen discovered in the oMEGACat project data, after the central intermediate-mass black hole (M. Häberle et al. 2024b).

As noted in Section 3.3, there is an uncertainty in the mass of the visible star due to the possibility it may be helium enriched, even though the data disfavor this. To quantify the impact of this potential systematic, we repeat our fit using the helium-rich visible star mass estimate of $0.60 M_{\odot}$. This reduces the mass of M_{comp} by about 6%, giving a median value of $4.19 M_{\odot}$, and a 2σ range of $2.50\text{--}7.00 M_{\odot}$. Thus, even with this relatively large difference in the mass of the visible star, there is not a significant effect on the inferred companion mass or any qualitative change in our conclusions. Any systematic uncertainties due to stellar properties apart from the helium abundance will have an even smaller impact on the inferred companion mass.

4.3. Comparison with I. Platais et al. (2024)

This system was identified previously by I. Platais et al. (2024) as a candidate neutron star–main sequence star binary. A comparison between their orbital parameters and the orbital parameters derived in this work is shown in Table 4. The masses of the visible components are not significantly different, but the other values show strong inconsistencies.

The primary difference in these estimates comes from our more complete dataset, spanning from 2002–2025. The HST data we used includes both ACS/WFC and UVIS/WFC3 images in all available filters plus the new JWST NIRCcam images. I. Platais et al. (2024) include only UVIS/WFC3 F606W images taken from 2009 July 15 through 2022 January 11. Notably, the earliest epochs in our data—taken before the installation of WFC3 in 2009 May—provide the strongest constraints on the orbital parameters and require a longer orbital period than the 13 yr period found by I. Platais et al. (2024). Hence, the new data allow us to fully exclude the

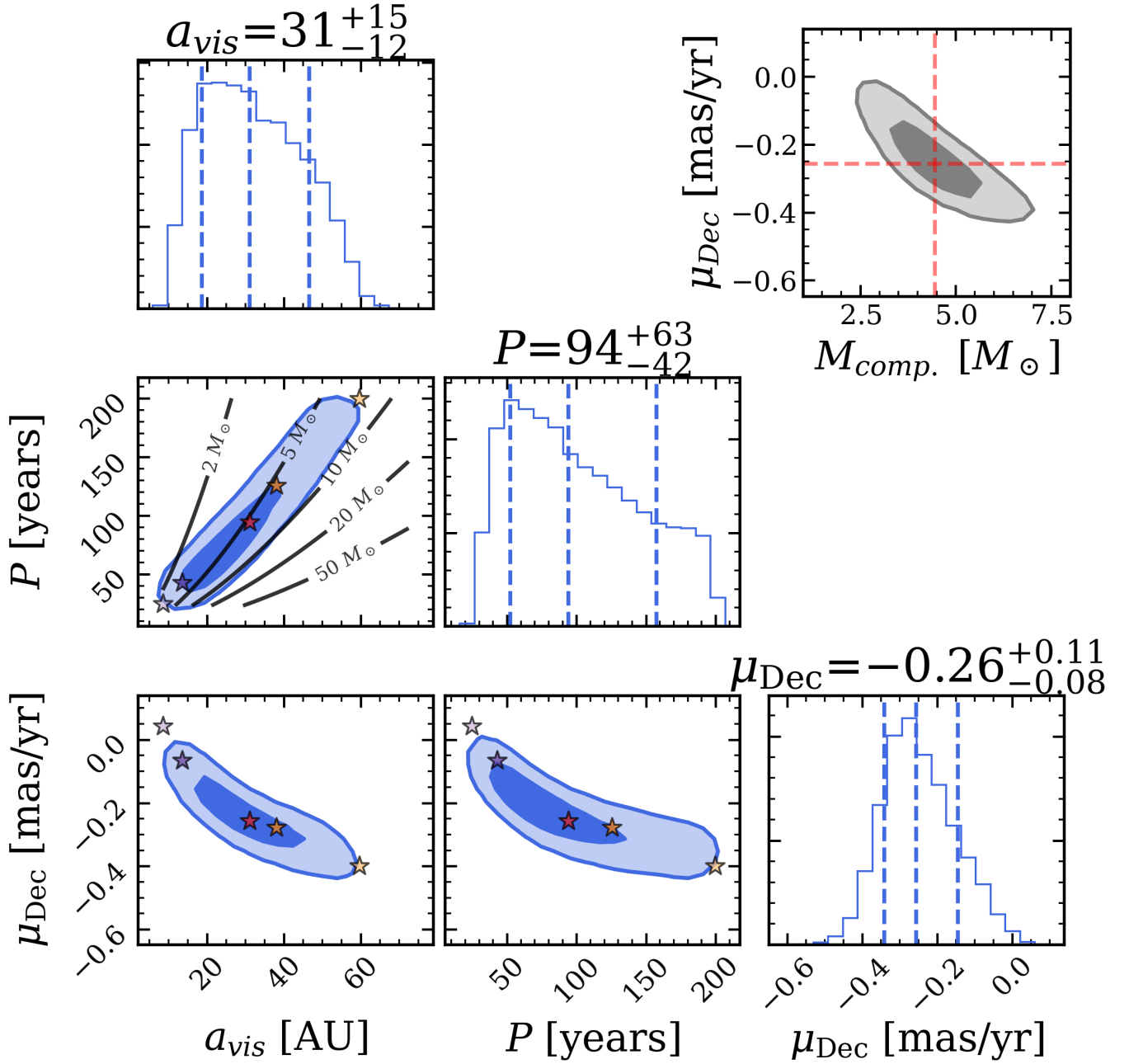


Figure 5. Degeneracies corner plot. Corner plot showing the degeneracies between period (P), semimajor axis (a_{vis}), and the decl. proper motion. The cutout in the top right shows the degeneracy between the companion mass and the decl. proper motion (μ_{Dec}). The contours on the a_{vis} vs. P subplot represent a constant mass corresponding to M_{comp} , showing the spine of the ellipse closely follows along the $5 M_{\odot}$ contour. The stars in each panel represent the orbital solutions corresponding to the median, $\pm 1\sigma$ and $\pm 2\sigma$ of the joint 2D probability distribution of a_{vis} and P .

I. Platais et al. (2024) solution, favoring a longer period and higher-mass companion.

Another difference between our studies is the method used for orbital fitting. I. Platais et al. (2024) uses an unspecified maximum-likelihood algorithm to fit their combined orbital and proper-motion model. They noted that the algorithm tends to converge to the shortest period compatible with the data and caution that long-period solutions could still be correct. In contrast, the MCMC method we used allows us to explore the full parameter space by sampling the posterior distribution.

Although the astrometric data from I. Platais et al. (2024) is not available, we tested using our MCMC method on our

UVIS/WFC3 F606W data within the temporal baseline of their observations. The inferred mass of the companion was less well determined in this fit, and is consistent with both the result we present here and the neutron star mass presented by I. Platais et al. (2024).

4.4. Black Hole Population Completeness

As described in Section 4.2, we observed oMEGACat BH-2 as it underwent periastron passage, which was likely critical in its discovery. To understand how this may impact our ability to detect other black hole binaries, we used synthetic astrometric observations of simulated binaries.

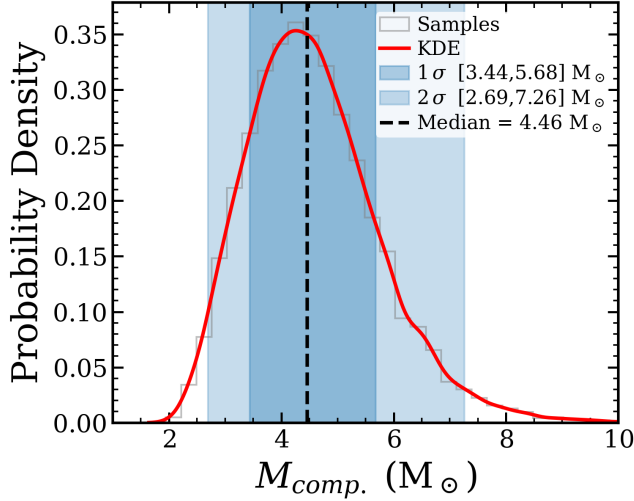


Figure 6. Companion mass. A histogram showing the posterior distribution of the unseen companion mass and its kernel density estimate. These mass samples are derived from samples drawn from the a_{vis} and P joint posterior distribution.

Table 5
Representative Orbits along the a_{vis} versus P Ellipse

Fit	Period (yr)	a_{vis} (au)	μ_{Dec} (mas yr $^{-1}$)	e	M_2 ($M_{\odot}$)
-2σ	24	8.57	0.04	0.31	2.01
-1σ	42	13.5	-0.07	0.56	2.37
Median	94	31.1	-0.26	0.72	4.46
$+1\sigma$	125	38.1	-0.28	0.79	4.73
$+2\sigma$	199	59.6	-0.40	0.81	6.63

To create synthetic observations, we first subtract the proper motion and median model from the astrometric data of our visible star to get a realistic observational cadence and characteristic noise. We then inject the orbital signal that arises from the sampled set of orbital parameters. To determine whether this orbital signal would be detectable, we first re-fit the proper motion, using the same method as M. Häberle et al. (2024a), and then we apply the same detection method described in our upcoming binary search paper (M. Whitaker, et al. 2026, in preparation). In short, we use a Lomb–Scargle periodogram on the proper-motion residuals of the F606W UVIS astrometric data. From the periodogram, we compute a false-alarm probability. We consider any system with a false-alarm probability $<10^{-10}$ to be a detection. For context, the false-alarm probability of oMEGACat BH-2 is 10^{-28} , and our binary search finds no other strong black hole binary candidates (M. Whitaker et al. 2026, in preparation).

We first perform this experiment for the oMEGACat BH-2 system using the posterior samples from our orbital fits but varying the time of periastron passage uniformly over the orbital period. The results are shown in Figure 7. For orbits near our median period of 94 yr, we find we detect the system 15%–20% of the time; this percentage rises toward shorter periods and falls toward longer periods. In essence, we only detect the binary if its periastron is within the dataset and thus our probability of detecting the binary is very similar to the fractional coverage of the orbit. This would tend to favor one of two possibilities: (i) the binary has an orbital period at

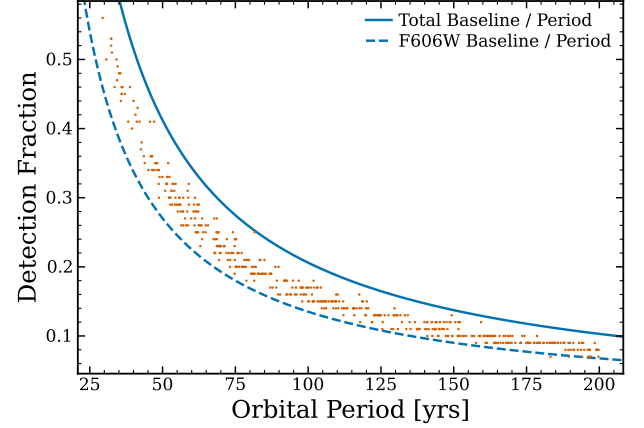


Figure 7. Detection Fraction. The fraction of orbits similar to our posterior samples detected with varying times of periastron passage (see Section 4.4). For comparison, we show the fraction of the total orbital period covered by the temporal baseline of all of our HST observations (20.6 yr) and the F606W UVIS observations only (13.5 yr); these were the primary data used to do initial detections.

the shorter end of the allowed range, or (ii) multiple long-period black hole binaries are present in the cluster. In either of these cases, detecting a single periastron passage in our dataset becomes more likely.

To get a first sense for the sensitivity of our observations to other binary black holes, we used the same data residuals (thus assuming the same visible star in the binary), but then evaluated the detectability of systems across a grid of orbital periods and companion masses between 2 and $40 M_{\odot}$. We randomly sampled the remaining orbital parameters. Eccentricities were drawn from the eccentricities of the simulated black hole–star binaries described in Section 2.3, and the remaining parameters are sampled uniformly in the ranges described by our orbital fit priors in Table 3. We repeated the process 1000 times per grid point.

The results are shown as the background of Figure 8, which plots the detection probability as a function of binary period and black hole mass. We have a high completeness for black hole binary systems of all black hole masses for periods between ~ 5 and 30 yr. At higher black hole masses, the completeness extends to shorter-period systems due to the larger amplitude of the orbital signal; Gaia BH 3 like objects would be detectable down to ~ 1 yr periods. As found above, the completeness becomes low at long orbital periods, since coverage of periastron is needed to securely detect the binary.

We note that these completeness estimates are based on residuals for the visible star in oMEGACat BH-2, which is a typical turnoff star, but nonetheless is brighter than the average star in ω Cen. Hence, these results do not represent survey-wide completeness. Nonetheless, this test provides us with a useful understanding of our sensitivity to black hole binaries. We discuss this further in Section 5.3.

5. Discussion

5.1. oMEGACat BH-2 in Context: Confirmed Stellar-mass Black Holes in Massive Star Clusters

oMEGACat BH-2 is the first black hole identified astrometrically in a globular cluster, and the longest-period black hole binary system known. oMEGACat BH-2 is also the first stellar-mass black hole identified in ω Cen, despite the

expectation from dynamical models that the cluster contains $\mathcal{O}(10^4)$ black holes within the core of the cluster (H. Baumgardt et al. 2019; A. Zocchi et al. 2019; A. Bañares-Hernández et al. 2025).

The only other known stellar-mass black holes in a globular cluster are the two systems discovered and characterized using radial velocities in the cluster NGC 3201 (B. Giesers et al. 2018, 2019). With $[\text{Fe}/\text{H}] = -1.59$ (W. E. Harris 1996), NGC 3201 has a similar metallicity to the dominant population of stars in ω Cen. While the masses of these two NGC 3201 black holes are uncertain due to the unknown inclination of their orbits, they both likely have masses below $10 M_\odot$ (Figure 8; blue violins). Combined with the $<7.26 M_\odot$ (2σ upper limit) on oMEGACat BH-2, these masses stand in contrast to expectations of high-mass black holes being generated in low-metallicity populations based on stellar evolution models. For example, M. Spera et al. (2015) found that for $Z = 2 \times 10^{-4}$ to 2×10^{-3} , spanning the median metallicity of both clusters, the peak black hole mass should be in the range $\sim 20\text{--}40 M_\odot$, depending on the prescription used. This contrast can also be seen in Figure 8 in the difference between the high mass of simulated black holes ($\sim 10\text{--}30 M_\odot$) in the ω Cen-like cluster from E. González Prieto et al. (2025) and the low mass of oMEGACat BH-2 and the two NGC 3201 objects. This mismatch is present despite the higher completeness for more-massive black holes in both radial velocity and astrometric searches (see Figure 8 and S. Saracino et al. 2025).

We draw two conclusions from these observations. First, there must be at least one channel that produces lower-mass black holes in low-metallicity systems with modest natal kicks. This could be via a low-compactness progenitor that ejects nearly the entire envelope (e.g., L. Boccioli & G. Fragione 2024), or via fallback (e.g., T. Ertl et al. 2020). Such black holes may be common rather than rare.

Second, we observe a *lack* of massive black holes in these two typical metal-poor ($[\text{Fe}/\text{H}] \lesssim -1.5$) globular clusters. Given the large number of massive black hole–black hole mergers observed in gravitational waves (The LIGO Scientific Collaboration et al. 2025), as well as compelling evidence that the $33 M_\odot$ binary Gaia BH 3 (Gaia Collaboration et al. 2024) was formed in a very low-metallicity ($[\text{Fe}/\text{H}] \sim -2.5$) globular cluster (E. Balbinot et al. 2024), stellar-mass black holes must sometimes form with the predicted high masses at low metallicity. Further, since the most massive black holes in dense clusters are expected to be preferentially ejected through dynamical interactions (e.g., M. Morscher et al. 2013), it is possible that such interactions have substantially depleted the high end of the black hole mass distribution in both ω Cen and NGC 3201. Nevertheless, simulations intended to reproduce the properties of these clusters (K. Kremer et al. 2018; E. González Prieto et al. 2025) all have higher black hole masses than observed. This represents preliminary but increasing evidence that revisions may be needed in the initial black hole mass distribution.

5.2. The Dynamical Evolution of oMEGACat BH-2

In a star cluster, the dynamical evolution of binaries is governed by a balance between their internal binding energy and the kinetic energy in cluster stars. When the former is larger, the binaries are called “hard,” while in the reverse case they are called “soft.” The standard view of binaries in star clusters follows Heggie’s Law: that hard binaries become

harder, while soft binaries become softer over time, until they eventually are disrupted (D. C. Heggie 1975). However, the law itself is silent on the timescale for the evolution, which will depend on the density of stars.

5.2.1. Critical Velocity

To understand the dynamical evolution of our black hole binary, we first calculate the critical velocity (v_c) for the binary (P. Hut & J. N. Bahcall 1983) in the context of a binary–single encounter

$$v_c^2 = G \frac{M_{\text{comp}} M_{\text{vis}}}{M_{\text{inc}}} \frac{M_{\text{comp}} + M_{\text{vis}} + M_{\text{inc}}}{M_{\text{comp}} + M_{\text{vis}}} \frac{1}{a}, \quad (1)$$

where M_{inc} is the mass of the incoming single star. This is the minimum relative velocity between the binary and single star that can unbind the binary. To calculate v_c , we use the posterior samples of M_{comp} and a measured in Section 4 and $M_{\text{vis}} = 0.78 M_\odot$ from Section 3. For M_{inc} , H. Baumgardt et al. (2023) derive the observed single-star mass function for ω Cen, finding it is well fit by a two-component power law with a break at $0.42 M_\odot$, $\alpha = -0.20$ below the break, and $\alpha = -1.37$ above the break (for $N \propto m^\alpha$). Assuming a minimum mass of $0.08 M_\odot$ and a maximum mass of $0.8 M_\odot$, this distribution has a mean mass of $0.37 M_\odot$. We draw samples from this distribution for M_{inc} .

Using these samples, we find $v_c = 16.5_{-3.9}^{+7.6} \text{ km s}^{-1}$. Given that the 3D velocity dispersion in the core of the cluster is $\sim 35 \text{ km s}^{-1}$ (M. Häberle et al. 2025), it is immediately clear that the black hole binary is *soft* and, hence, is susceptible to disruption.

5.2.2. Simulations

To understand the dynamical evolution of the binary, we conducted a set of binary–single scattering experiments using *Fewbody* (J. M. Fregeau et al. 2004). In addition to the parameters already discussed, we determined the initial relative velocity at infinity v_∞ by sampling a 1D velocity dispersion of 12.6 km s^{-1} for the black hole binary and 20 km s^{-1} for the incoming single star, typical for stars at this projected radius (M. Häberle et al. 2025); each of these was cut off at the observed escape velocity of 62 km s^{-1} (M. Häberle et al. 2024b). For each binary, the distance of closest approach was drawn from 0 to $5a$, weighted by area to enable a cross-section calculation. To determine the encounter rate, we calculate the number density n of stars within a 3D radius of 0.7 pc (based on the binary’s projected radius of 0.5 pc). We find $n = 5 \times 10^3 \text{ pc}^{-3}$ using the 12 Gyr snapshot from the E. González Prieto et al. (2025) simulations discussed in Section 2.3; we include normal stars and white dwarfs but exclude black holes for this calculation (see below). The normal star masses are drawn from the observed mass function and the white dwarf masses from the simulation.

While the encounter timescale is short ($\sim 5 \text{ Myr}$ within $2a$), most encounters have a minimal effect on the binary, due to the typical low mass of the perturbing star and the fly-by nature of the encounter. Overall, we found that single-encounter ionization is possible but rare, with an expected ionization timescale of about 4.5 Gyr .

Given how long this single-encounter ionization timescale is, we also ran sequential scattering experiments, where the

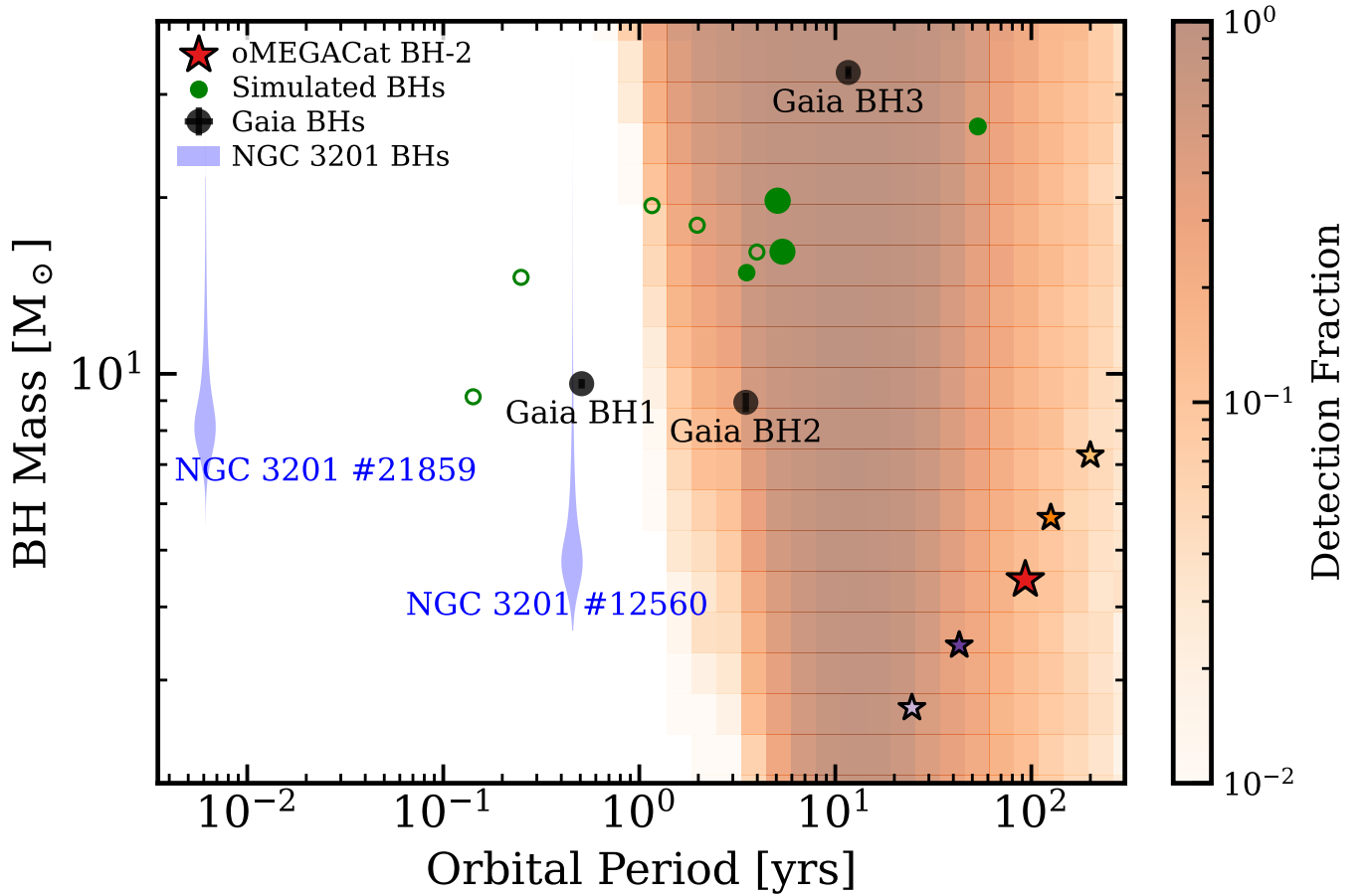


Figure 8. Black Hole Binary Summary. A comparison of dynamically detected black hole–star binaries and oMEGACat BH-2. For oMEGACat BH-2, in addition to the median fit (red star), we show the representative orbits from Table 5, using the same colors as Figure 5. For the other observed systems, spectroscopically detected binaries in the globular cluster NGC 3201 (B. Giesers et al. 2018, 2019) are shown as violin plots to represent the mass-inclination degeneracy, and the three Gaia BHs are also shown (K. El-Badry et al. 2023a, 2023b; Gaia Collaboration et al. 2024). The detection fraction shown in the background assumes a binary with the same secondary mass and observational cadence and uncertainties as for oMEGACat BH-2 and is described in Section 4.4. We also add simulated binaries (green circles; calculated in Section 5.3) from the ω Cen simulations in Section 2.3. The size of the marker corresponds to its detection fraction, and open circles indicate no detection; exact values are given in Table 6.

initial binary properties are the same, but the binary separation and eccentricity are updated after each encounter and then used as input for the next encounter. These sequential scatterings should more accurately capture the gradual softening and disruption of the binary due to the summed effect of many encounters. We find that the median (mean) disruption timescale is about 820 Myr (1.2 Gyr). The disruption timescale has a mild dependence on the initial binary properties; the closest (lowest initial a) 25% of binaries have a median disruption timescale of 1.4 Gyr, compared to 480 Myr for the 25% most separated (highest initial a) binaries. Since this is much shorter than the single-encounter ionization timescale, gradual softening is clearly the dominant process in eventually disrupting the binary. In addition to gradual softening, exchange encounters also occur, but owing to the high masses of the binary components compared to typical cluster stars, they are uncommon.

These scattering experiments did not include neutron stars or stellar-mass black holes as the incoming object. Neutron stars are not numerous enough (only 28 at a 3D radius < 0.7 pc) to be relevant. The situation for stellar-mass black holes is less certain. In the E. González Prieto et al. (2025) simulation, the mass density of stellar-mass objects within the central 0.7 pc is dominated by stellar-mass black holes; it is a

factor of 2 higher than normal stars + white dwarfs. As discussed in Section 5.1, these black holes are also massive, with a median mass of $18M_{\odot}$, so can efficiently ionize binaries in encounters.

We re-ran the scattering experiments assuming an incoming population of black holes with masses and a number density drawn from the E. González Prieto et al. (2025) simulation; they are assumed to have an identical velocity dispersion to the target black hole binary. We obtain somewhat different results: many encounters result in an ionization, with a median timescale to ionization of 170 Myr, a factor of 5 faster than found above for non-black-hole encounters. This is mostly determined by the high masses of the black holes: if we instead assume the black holes all have masses like our observed object ($4.5M_{\odot}$) then the lifetime becomes much longer, about 660 Myr, comparable to the non-black-hole disruption timescale.

These exact numbers should not be taken too seriously; the black holes in the simulation are more centrally concentrated than the stars, so the encounter frequency between oMEGACat BH-2 and other black holes will depend crucially on the actual orbit of the binary. In addition, we already have evidence from the low mass of oMEGACat BH-2 that the black hole mass distribution in the simulations is likely inaccurate. The true

Table 6
Simulated BH Detectability

M_{vis} ($M_{\odot}$)	M_{comp} ($M_{\odot}$)	P (yr)	a (au)	e	R_{proj} (pc)	f_{astro}	f_{RV}
0.249	17.94	1.97	4.14	0.88	0.036	0.0	0.0
0.308	26.45	53.3	42.4	0.97	0.351	0.041	0.0
0.516	16.16	5.37	7.84	0.59	1.009	0.818	0.271
0.127	16.14	3.98	6.37	0.95	0.748	0.0	0.0
0.566	19.75	5.08	8.06	0.76	2.126	0.847	0.047
0.368	9.138	0.142	0.577	0.85	0.596	0.0	0.0
0.429	14.89	3.53	5.76	0.82	1.428	0.014	0.0
0.468	19.37	1.16	2.99	0.44	2.268	0.0	0.0
0.593	14.61	0.249	0.981	0.69	2.459	0.0	0.016

Note. The visible star mass M_{vis} , companion mass M_{comp} , orbital period P , semimajor axis a , eccentricity e , on-sky distance from the center R_{proj} , astrometric detection fraction f_{astro} , and spectroscopic detection fraction f_{RV} are shown for each of the BH-star binaries (Section 5.3). Values are shown only for the last snapshot of the simulation.

number of stellar-mass black holes is also uncertain. These simulations do suggest that the survival of soft binaries in the core of ω Cen can potentially set limits on the population of invisible stellar-mass black holes, but this would require understanding the formation rate of soft binaries as well.

5.2.3. A Soft Binary with a Long Enough Life

The ~ 800 Myr median timescale to disruption is sufficiently short that it is very unlikely the black hole binary could be primordial, but instead was almost certainly formed dynamically. On the other hand, the timescale is sufficiently long that we are not observing it at a particularly privileged time in the cluster: despite the fact that the binary is soft, it can survive long enough to be observed.

5.3. The Total Black Hole Population in ω Cen

We have already assessed how detectable oMEGACat BH-2 is as a function of orbital period and black hole mass in Section 4.4. To further understand what the detection of oMEGACat BH-2 means for the total black hole population in ω Cen, we create synthetic astrometric and spectroscopic observations of each black hole from the simulation of E. González Prieto et al. (2025) to determine a detection probability for each system. These simulated black hole binaries differ in several ways from oMEGACat BH-2: in addition to having more-massive black holes, they have shorter orbital periods, as well as a wide range of visible star masses.

We create synthetic astrometric observations of these binaries using the same process described in Section 4.4. However, unlike those simulations, here we use real observations of randomly selected stars with a similar mass to the secondary stars in the simulation, after checking that any real stars with potential orbital signals are excluded. This ensures we have a realistic noise profile and observational cadence for stars of different masses in the simulation. We note that because all of the simulated black holes are found in a radial range with relatively uniform astrometric coverage, we do not match the data to simulations explicitly in distance from the cluster center. The component masses, semimajor axis, orbital period, and eccentricity are specified for each system from the

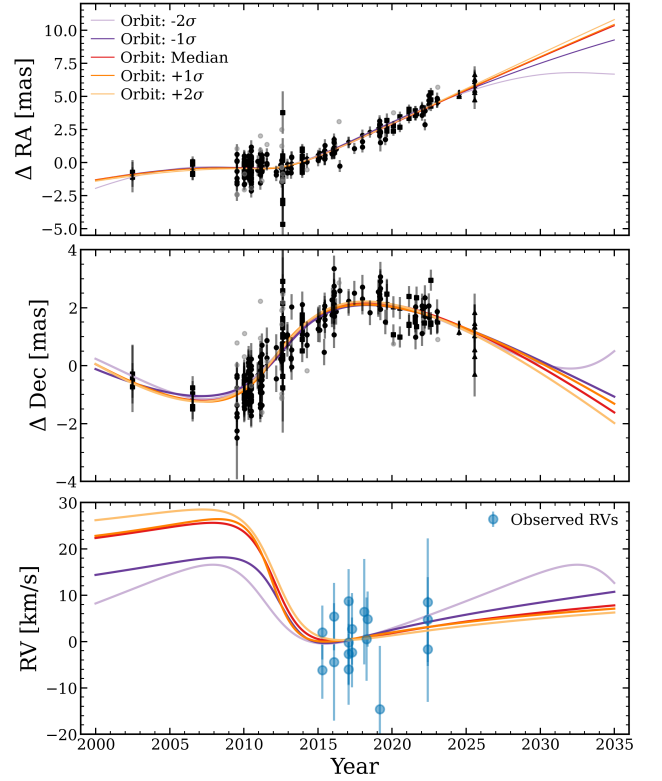


Figure 9. Future model constraints. Orbital fits corresponding to the median and the $\pm 1\sigma$ and $\pm 2\sigma$ for the joint 2D probability distribution of a_{vis} and P as given in Table 5. The models are extended to 2035 to illustrate the utility of future measurements to further constrain the orbit. Top and middle panels: these show the relative position over time without removing the proper motion; data points are plotted using the same symbols as Figure 4. Bottom panel: predicted radial-velocity curves for the same five orbits. The modeled curves include a fitted offset to the observed velocities (Table 2).

simulations, but the other orbital parameters are randomly sampled as before to get the simulated orbital signal.

We repeat this 1000 times and measure the detection fraction for each simulated binary using the same $\log(\text{FAP}) < -10$ threshold discussed in Section 4.4. These fractions are listed in Table 6 and shown in Figure 8 as the marker size for each simulated black hole. Only four of the nine systems in the simulated snapshot have a nonzero detection fraction. Two of the systems are detected $\sim 80\%$ of the time, and the other two are detected $< 5\%$ of the time. Three undetected systems have an orbital period < 1.5 yr, so the orbital signal is small, and the other two have visible star masses $< 0.25 M_{\odot}$, so the star is faint, causing noisier astrometry. To improve the statistics, we repeated this process using all 50 simulation snapshots, yielding 474 total black hole–visible star binaries. Overall, we find that the expected number of black hole–visible star binaries detectable in our astrometric dataset is 1.5 ± 0.4 ; the listed uncertainty is the scatter among epochs.

F. Wragg et al. (2024) found 275 objects with variable radial velocities in ω Cen that were likely binaries. S. Saracino et al. (2025) were able to characterize 19 of these, finding the rest could not be characterized (i.e., the binary parameters could not be determined using the available data). No black hole candidates were identified in these data. To interpret these radial-velocity nondetections, we performed a parallel analysis to that done for the astrometry, injecting the simulated orbital

signal from the simulation into the S. Saracino et al. (2025) radial velocities for ω Cen, and determining detectability using the criteria described by F. Wragg et al. (2024). Unlike the case for the astrometry, since the radial-velocity data have a limited radial extent that does not fully cover the region where the black hole–star binaries are found in the simulations, an areal completeness correction is needed. This was computed by taking 100 radial bins and counting what fraction of 1000 uniformly sampled points in each bin falls within the radial-velocity observational footprint. After applying this correction, we find that the expected number of spectroscopically detected black hole–star systems is 0.4 ± 0.1 . The corrected detection fractions for each simulated black hole–star system in the final snapshot and the simulated on-sky radius of each system are shown in Table 6. Only one of the systems with no astrometric detectability is detectable via radial velocities, while two of the four systems detected via astrometry do have some velocity detection probability.

To summarize, based on the simulation predictions, the expected number of black hole–star binaries detectable in this astrometric survey is 1.5 ± 0.4 (compared to one observed), while in radial velocities, the predicted population is 0.4 ± 0.1 (compared to zero observed). Thus, the detection of one astrometric black hole in the existing astrometric and radial velocity of ω Cen is consistent with the number of black hole binaries in the E. González Prieto et al. (2025) simulations.

How to interpret this agreement is unclear: there is already a known mismatch between the non-black-hole-binary period distributions of Cluster Monte Carlo simulations relative to the observed period of binaries (C. S. Ye et al. 2022; J. Müller-Horn et al. 2025; S. Saracino et al. 2025), with the simulations overpredicting the number of short-period binaries relative to the observations. This could lead to a similar overprediction of the number of velocity-detectable black hole–star binary systems. In addition, we already noted in Section 5.1 the mismatch between the mass distribution of the simulated black holes and observations.

Nonetheless, both the mock analysis of the simulations presented here, as well as the detection analysis presented in Section 4.4, show that there is at least a small population of black hole binaries in ω Cen, of which oMEGACat BH-2 is only the first system to be discovered. This can be readily seen even apart from the uncertainty in the period distribution of binaries: black holes are expected to pair with a range of low-mass secondaries, seen in simulations of both NGC 3201 (K. Kremer et al. 2018) and ω Cen (E. González Prieto et al. 2025). Hence, the detection of turnoff stars as secondaries in two of the three of these binaries likely reflects an observational bias. Binaries with less-massive secondaries are present, but are harder to discover.

Taking the larger step of translating this inferred population of black hole–visible star binaries to the dominant population of single black holes is even more challenging, given the predicted lack of correlation between black hole binaries and the parent population of black holes (M. Morscher et al. 2015; S. Chatterjee et al. 2017; C. E. O’Connor et al. 2026). It seems noteworthy that black holes have as of yet only been discovered in the low-density clusters expected to have the largest current black hole populations, which is perhaps in mild tension with the dynamical prediction that the number

black hole–visible star binaries should not strongly depend on the number of black holes.

6. Conclusions and Future Directions

We have presented the discovery of a low-mass black hole binary in ω Cen, the first stellar-mass black hole discovered in a globular cluster via astrometry and only the third to be dynamically confirmed in a Galactic globular cluster.

6.1. Improved Mass Constraints on oMEGACat BH-2

Despite the wealth of data we have on the binary, the lack of a complete orbit translates to a degeneracy between proper motion and mass. Here we discuss how other existing and future data can help us further constrain the mass of oMEGACat BH-2.

Future JWST data will be useful. The existing JWST program (GO 8322) provided a first epoch used here, and this program will obtain two more years of observations, likely in 2027 and 2028. These data will likely already be sufficient to rule out (or favor) the shortest-period orbits currently consistent with our data. The shortest periods correspond to the lowest masses, so these JWST data could also exclude much of the parameter space for the unlikely (but not impossible) potential contaminant scenarios involving other compact objects discussed in Section 4.2.2.

Another potential angle is radial velocities. The bottom panel of Figure 9 shows the expected radial velocity from the five orbits (median, $\pm 1\sigma$, $\pm 2\sigma$) presented in Table 5. Unfortunately, the existing MUSE data are not useful: these data show reduced χ^2 values ranging between 0.43 and 0.45 for the five models plotted. We note a sign degeneracy of the astrometric fit means that the radial velocities can be flipped; we presently choose the family of orbits where the current trend is toward positive velocities. Future, precise radial velocities could determine the correct family of solutions, and could also help constrain the shorter orbital periods.

6.2. Other Black Holes in ω Cen and Beyond

As discussed above, the existing radial-velocity and astrometric surveys of ω Cen are insensitive to the majority of the predicted black hole–visible star binaries.

Owing to the long time baseline of the existing astrometric dataset, it is difficult to improve on its sensitivity to long-period orbits any time soon. JWST offers improved precision, especially of fainter stars, so a JWST astrometric monitoring program with $\gtrsim 10$ epochs could enable the detection of black hole binaries with less-massive secondaries down to periods of ~ 100 days.

Looking to other globular clusters, no comparable HST astrometric datasets exist, but new more sensitive JWST observations spanning a few years would enable detection of black hole binaries with periods $\mathcal{O}(1 \text{ yr})$. Existing HST astrometry can also play a useful role: we have shown here that the proper-motion uncertainty plays a significant role in transforming the observed on-sky accelerations into mass constraints. Therefore, using JWST to target clusters that have long-baseline HST astrometry can also enable identification of longer-period black holes like oMEGACat BH-2. Even without getting new data, existing limited HST astrometric datasets could still show evidence for black hole binaries, especially in lower-density clusters where long-period systems

may be present. Indeed, that oMEGACat BH-2 was discovered in a soft orbit shows that the simplistic hard/soft boundary should not be taken too literally when considering binary searches.

Other approaches and facilities may also yield additional cluster black hole binary detections. Gaia DR4 is widely expected to identify many black hole binaries (P. Nagarajan et al. 2025). However, due to crowding, Gaia typically performs poorly in cluster cores (M. Häberle et al. 2024a). Given the expectation that cluster black holes will mass segregate to cluster cores, this suggests that Gaia will not be sensitive to most cluster black hole binaries, but this expectation should certainly be tested explicitly.

Existing radial-velocity searches for binaries in globular clusters have been enabled through multiepoch MUSE measurements in NGC 3201, ω Cen, and 47 Tuc (B. Giesers et al. 2019; F. Wragg et al. 2024; J. Müller-Horn et al. 2025), but have only detected the two BHs in NGC 3201. Many of the detected radial-velocity binaries in ω Cen do not have strong constraints on their orbits, but short-period (< 1 yr) black hole binaries should be characterizable with these data as long as the visible companion is a brighter star (S. Saracino et al. 2025). Analysis of existing data on additional clusters and additional monitoring could both lead to new black hole binary detections.

In any case, making further progress on characterizing the population of black holes in globular clusters will require new detections. The identification of oMEGACat BH-2 shows that the age of astrometric black hole discovery in globular clusters has begun.

Acknowledgments

We acknowledge useful comments from an anonymous referee that helped improve the Letter. Work on this Letter by M.W., E. K., A.S., and Z.F. was supported by a Hubble Space Telescope archival grant HST-AR-17033, A.S. also acknowledges support from JWST-GO-08322. J.S. acknowledges support from NASA grant 80NSSC21K0628. S.S. acknowledges funding from the European Union under the grant ERC-2022-AdG, “StarDance: the noncanonical evolution of stars in clusters,” grant agreement 101093572, PI: E. Pancino. This research was supported in part by grant NSF PHY-2309135 to the Kavli Institute for Theoretical Physics (KITP). We acknowledge useful conversations at KITP with Kareem El-Badry, Casey Lam, Jeff Andrews, and Jessica Lu. We thank Kareem El-Badry, Jessica Lu, and Johanna Müller-Horn for helpful comments on a draft that improved the Letter. The support and resources from the Center for High Performance Computing at the University of Utah are gratefully acknowledged.

ORCID iDs

Matthew Whitaker  <https://orcid.org/0009-0007-3015-9900>
 Evan Kerr  <https://orcid.org/0009-0006-3217-8796>
 Anil Seth  <https://orcid.org/0000-0003-0248-5470>
 Maximilian Häberle  <https://orcid.org/0000-0002-5844-4443>
 Jay Strader  <https://orcid.org/0000-0002-1468-9668>
 Jay Anderson  <https://orcid.org/0000-0003-2861-3995>
 Andrea Bellini  <https://orcid.org/0000-0003-3858-637X>
 Callie Clontz  <https://orcid.org/0009-0005-8057-0031>
 Zack Freeman  <https://orcid.org/0009-0002-5295-8504>

Massimo Griggio  <https://orcid.org/0000-0002-5060-1379>
 Sebastian Kamann  <https://orcid.org/0000-0001-6604-0505>
 Mattia Libralato  <https://orcid.org/0000-0001-9673-7397>
 Nadine Neumayer  <https://orcid.org/0000-0002-6922-2598>
 Elena González Prieto  <https://orcid.org/0000-0002-0933-6438>
 Carl L. Rodriguez  <https://orcid.org/0000-0003-4175-8881>
 Sara Saracino  <https://orcid.org/0000-0003-4746-6003>
 Peter Smith  <https://orcid.org/0000-0002-7489-5244>
 Glenn van de Ven  <https://orcid.org/0000-0003-4546-7731>
 Zixian Wang  <https://orcid.org/0000-0003-2512-6892>

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