

The one and the only: The pulsar-white dwarf system in NGC 6749

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ABSTRACT

PSR J1905+0154A is a binary millisecond pulsar (MSP) located in the globular cluster (GC) NGC 6749. It was discovered in 2004 in a search for pulsars in GCs carried out with the Arecibo 305-m radio telescope. The pulsar has a spin period of 3.2 ms, an orbital period of 0.81 days, and is in a low-eccentricity orbit with a low-mass white dwarf (WD) companion. By combining timing data from the early Arecibo observations of NGC 6749 with timing data from observations of this GC made with the Five-hundred-meter Aperture Spherical Telescope (FAST), we derived a phase-coherent timing solution for this pulsar, which now spans 20 years. This solution includes a precise measurement of the astrometric, spin, and orbital parameters of the system. The small range of predicted accelerations expected from the gravitational field of this GC allows us to give an estimate of the intrinsic spin-down: the inferred magnetic field at the surface ($2.2\text{--}2.4 \times 10^8$ G) and characteristic age (2.8–3.5 Gyr) are typical of what one finds among MSPs in the Galactic field. The position of this pulsar, the only confirmed to date in this GC, coincides with the position of one of the very few candidate WDs in the whole HST dataset on this GC. The position of the companion in the colour-magnitude diagram is consistent with a helium WD with a mass of $0.17\text{--}0.19 M_{\odot}$ (which implies an orbital inclination between 28 and 40 degrees), a cooling age of 0.4–0.7 Gyr, and a surface temperature of 11 600–14 800 K. A comparison with the characteristic age of the pulsar indicates that at the time of Roche lobe detachment, the spin period was between 1.98 and 2.62 ms. The relatively large proper motion difference relative to the motion of the GC, which is 4.5σ significant and an order of magnitude larger than the escape velocity, raises the possibility that, despite its location close to the centre of the GC, the pulsar might not be associated with it. Finally, our effort to confirm a second pulsar candidate in this GC did not yield a positive confirmation, nor the discovery of any additional pulsar in this GC.

Key words. binaries: general – stars: neutron – white dwarfs – pulsars: individual: PSR J1905+0154A – globular clusters: individual: NGC 6749

1. Introduction

Globular clusters (GCs) in our Galaxy have been great hunting grounds for pulsars, with 360 discoveries in a total of 46 clusters¹. The pulsar populations in each GC are different in size, with denser and nearby GCs having generally more known pulsars; however, the characteristics of the pulsar populations of similarly dense GCs can also be different as well, and sometimes strikingly so. Many of the denser GCs, especially core-collapsed clusters, have a large predominance of isolated pulsars, like NGC 6522 (Abbate et al. 2023), NGC 6624 (Abbate et al. 2022),

NGC 6752 (Corongiu et al. 2024), M15 (Wu et al. 2024; Dai et al. 2025), NGC 6517 (Lynch et al. 2011; Yin et al. 2024), and Terzan 1 (Singleton et al. 2024). Other very dense non-core-collapsed clusters are either dominated (as in the case of NGC 1851, Ridolfi et al. 2022, and Terzan 5, Ransom et al. 2005; Padmanabh et al. 2024) or entirely populated (as in the case of M62, Vleeschower et al. 2024) by binary pulsars.

For the lower-density GCs, the pulsar population resembles the Galactic population of millisecond pulsars (MSPs), which is dominated by binary systems with low-mass companions in low-eccentricity orbits. Examples of this are GCs like M3 (Li et al. 2024), M5 (Zhang et al. 2023), M13 (Wang et al. 2020), M53 (Lian et al. 2023, 2025a), and M71 (Lian et al. 2025b). This is thought to be a consequence of the low stellar interaction

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¹ For an up-to-date list, see <https://www3.mpifr-bonn.mpg.de/staff/pfreire/GCpsr.html>

rate per binary in these clusters (Verbunt & Freire 2014): once a neutron star–main sequence star system is formed (in globular clusters, this happens via exchange encounters), it evolves undisturbed into a low-mass X-ray binary and then into a MSP system similar to those seen in the Galaxy.

Apart from M53 and M71 (Lian et al. 2023, 2025b), NGC 6749 is the least dense GC where pulsars have been discovered. Some of its parameters are provided in Table 2. It has one known pulsar, PSR J1905+0154A (henceforth NGC 6749A), which was discovered in a survey of GCs made with the Arecibo 305-m radio telescope (Hessels et al. 2007) using the L-wide receiver and the Wideband Arecibo Pulsar Processor (WAPP, Dowd et al. 2000) autocorrelator, which had a bandwidth of 100 MHz. This was centred at 1175 and 1475 MHz, depending on the expected dispersion measure (DM) for the GC.

The pulsar was found in an observation made on 2002 August 8. It has a spin period of 3.199 ms and a DM of $\sim 193.7 \text{ cm}^{-3} \text{ pc}$; it was shown by subsequent observations to be in a binary system with an orbital period of 0.81 days and a projected semi-major axis of 0.59 s. This implies a mass function of $3.3 \times 10^{-4} M_{\odot}$, which, if we assume a pulsar mass of $1.35 M_{\odot}$ and a median orbital inclination of 60 deg, results in a median value of the companion mass of $0.103 M_{\odot}$. The orbit had no detectable eccentricity, furthermore no eclipses of any sort were detected, although it should be kept in mind that the orbital coverage near superior conjunction was relatively poor. For these reasons, the companion was thought to be a white dwarf (WD).

Despite many follow-up observations of NGC 6749 with the Arecibo telescope (described below), which resulted in detections of the pulsar in all observations, only a partial solution could be derived (Hessels et al. 2007). This partial solution restricted the position to be within $1'$ of the cluster centre, a strong indication of the association of the pulsar with this GC. We carried out later attempts to connect the dataset using Dracula² (Freire & Ridolfi 2018); but this resulted in many possible solutions and confirmed that the combination of density and precision of the pulsar times of arrival (ToAs) obtained from the Arecibo timing was not enough to determine the rotation count unambiguously.

A second candidate, NGC 6749B, was detected in a single observation, made on 2003 October 9, with a spin period of 4.960 ms and a DM of $192 \text{ cm}^{-3} \text{ pc}$. However, it was not possible to confirm this candidate in any of the other Arecibo observations (Hessels et al. 2007).

More recently, the Five-hundred-meter Aperture Spherical Telescope (FAST) resumed observations of NGC 6749. The increased sensitivity of FAST compared to Arecibo made the discovery of additional pulsars in this GC a likely event, however, as we describe here, no additional pulsars have been found to date. Importantly, NGC 6749B was not confirmed in these observations either.

Despite this, these FAST observations were useful because they enabled a detailed characterisation of NGC 6749A. In this paper, we present a joint analysis of the FAST and Arecibo data on this pulsar. The observations and their processing, which include a search for additional pulsars in the FAST observations, are described in Section 2. The 20-year timing solution of NGC 6749A based on both FAST and Arecibo timing is presented in Section 3, in which section we also discuss some of the timing parameters. The multi-wavelength follow-up of NGC 6749A is presented in Section 4, the highlight is the

optical identification of the pulsar’s companion. We summarise our findings in Section 5.

2. Observations and data processing

2.1. Early radio observations at Arecibo

The Arecibo data used in this work is the same as the data used and listed by Hessels et al. (2007) to characterise NGC 6749A. These data result from 21 observations taken with the L-wide between 2004 March 06 and 2007 April 20. During this campaign, four WAPP back-ends became available, three of which were used. Within the band of the L-wide receiver (1120–1730 MHz), these were normally centred at frequencies of 1170, 1420, and 1520 MHz; the frequency gap between the 1170 and 1420 MHz bands was to avoid persistent radio frequency interference (RFI) between 1220 and 1360 MHz. No data were taken using the fourth WAPP at 1620 MHz because of persistent RFI above 1570 MHz. The lag data from each autocorrelator were then Fourier transformed into ‘Filterbank’ data, with 512-channel total intensity spectra recorded every 128 μs . At the DM of NGC 6749A (195 pc cm^{-3}), the intra-channel dispersive smearing is 110 μs ; if we add the time resolution in quadrature, we obtain an effective time resolution of 169 μs .

Hessels et al. (2007) describe how these data were then folded and how the resulting pulse profiles were used to estimate pulse times of arrival. Posteriorly, and in a similar way to the analysis done for the pulsars in M5 (Zhang et al. 2023), we shifted the frequency channels by half of the channel width ($100 \text{ MHz} / 512 / 2 = 0.098 \text{ MHz}$). This depends on the band being down-converted: for the first set of observations (MJD 53070–53247), we subtracted half a channel bandwidth from the ToA frequency. For all subsequent Arecibo data there was a band inversion, which then led to the addition of half a channel to the reported ToA frequencies. This significantly reduced the residual rms for these data.

2.2. Recent observations with FAST

NGC 6749 was observed by FAST nineteen times, the first observation happening on 2019 September 14 and the last one on 2024 November 03. These observations are listed in Table 1. The total observing time was about 18 h.

All of these observations share the same basic setup parameters. They used the central beam of the FAST 19-beam receiver, which has a bandwidth of 500 MHz centred at a frequency of 1250 MHz. This band was divided in a total of 4096 channels, hence each channel had a bandwidth of $\sim 122.07 \text{ kHz}$. The 4096-channel power spectra were accumulated and written to disk every 49.152 μs . At the DM of NGC 6749A, the channel bandwidth results in an intra-channel dispersive smearing of 101 μs at 1250 MHz. Adding the time resolution in quadrature, we obtain an effective time resolution of 112 μs . In all these observations, we only obtained total intensity data (Stokes I), with the exception of the last one where full Stokes data were taken. The observation on 2021 October 23 was conducted in Snapshot mode, where the observation was split into four equal segments, and only the third segment was pointed at the cluster centre.

2.3. Search for additional pulsars in NGC 6749 in the FAST data

All the FAST observations were thoroughly searched for new pulsars using the standard acceleration-search procedures

² See <https://github.com/pfreire163/Dracula>

Table 1. List of observations of the globular cluster NGC 6749 with FAST.

Date	Observation length (s)
2019-09-14	1800
2019-10-26	3600
2019-12-10	10 800
2020-08-31	1800
2020-09-21	7200
2021-01-13	900
2021-10-23	3000
2022-11-19	3000
2022-12-19	3000
2023-01-22	7200
2023-01-30	7200
2023-03-02	3600
2023-04-02	3600
2023-05-06	4200
2023-10-05	4800
2023-11-03	3000
2024-03-10	6600
2024-05-04	8400
2024-11-03	4200

Notes. The observation on 2023 March 02 produced no detection. The last observation was taken with full Stokes data.

adopted in the FAST GC survey (see e.g. Lian et al. 2025b). To improve sensitivity to pulsars in compact binary systems, we also performed segmented searches following the general strategy adopted in recent FAST GC searches for compact binaries (Yin et al. 2025). To account for the varying observation durations across epochs, all data were split into equal segments of approximately 900–3600 s for acceleration searches, using the Multiple Observation Segment Search (MOSS) script³ (Yin et al. 2025). Each segment was then searched independently with an acceleration of $z_{\max} = 200$. Apart from the re-detection of NGC 6749A, these searches yielded neither any additional pulsar detections nor a confirmation of NGC 6749B.

To further enhance the sensitivity to very faint pulsars, we also divided all observations into 3600 s segments and incoherently stacked their power spectra. This method resulted in a very high signal-to-noise ratio (S/N) detection of NGC 6749A, but again revealed no evidence of any additional pulsars in the cluster.

2.4. Optical observations with the Hubble Space Telescope

NGC 6749 was observed with Hubble Space Telescope (HST) for the first time in 2024 using the Wide Field Camera of the Advanced Camera for Surveys, as part of the Hubble Missing Globular Cluster Survey (GO: 17435, PI: Massari, see Massari et al. 2025). Observations consist of F606W and F814W exposures, with eight images per filter and exposure times ranging from 80 s to 699 s. Point Spread Function (PSF) photometry was performed on the calibrated flic⁴ images following the well-established workflow outlined in various papers focused on high-precision astrometry and photometry with HST images

³ <https://github.com/ydejiang/MOSS>

⁴ A flic file is a standard, fully calibrated HS image that has undergone pixel-based Charge Transfer Efficiency (CTE) correction. It is primarily used for WFC3 and ACS data to recover charge lost to detector degradation.

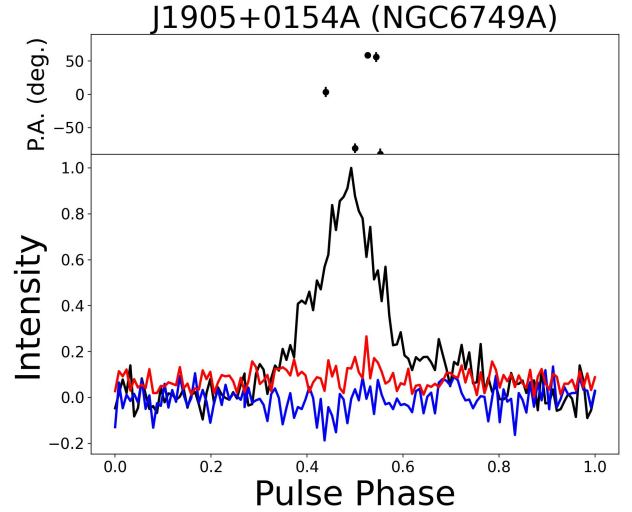


Fig. 1. Polarized profile for NGC 6749A at L band obtained from polarimetric data.

(e.g. Bellini et al. 2017; Libralato et al. 2022). The procedure has been optimised for the detection of faint and blue sources, such as typical MSP companions (for full details, see Rosignoli et al. 2026). Photometry was calibrated to the VEGAMAG system using appropriate zero points and aperture corrections. Following the prescriptions of Kozhurina-Platais et al. (2015), source positions were aligned to the International Celestial Reference System (ICRS) by cross-matching with Gaia data release 3 (DR3) (Gaia Collaboration 2023), achieving a 1σ astrometric accuracy with a root-mean-square residual of ~ 15 mas. Since the cluster lies in a region of the Galaxy that is strongly affected by differential extinction (see e.g. Cadelano et al. 2020b, 2024), magnitudes were corrected for this effect using the widely adopted technique presented by Milone et al. (2012).

3. Timing solution of NGC 6749A

As in the previous Arecibo observations, NGC 6749A can be detected reliably in our FAST observations. A polarimetric profile, resulting from a single polarimetric observation taken on 2024 November 03, is displayed in Fig. 1. This shows the broad profile of the pulsar at L band; this and the low S/N of the detection result in the relatively low precision of the timing. No significant polarisation, either linear or circular, were detected in the signal.

From the ToAs of NGC 6749A, we derived a unique timing solution using the FAST data for the first time for this pulsar. This was then verified to unambiguously connect the early Arecibo ToAs, which means that we now have an ephemeris with a baseline of 20 years. The derived timing solution, which takes all the available data into account, is presented in Table 2. In this analysis, we used the TEMPO timing package⁵. This solution has a reduced χ^2 of 1.06, which was derived as follows: for a preliminary version of the final timing solution, all parameters were kept fixed, and the reduced χ^2 of each dataset were estimated using TEMPO. Then the ToA uncertainties were increased by a factor of h in order to obtain a reduced χ^2 of 1.0 for each dataset. For each dataset, the respective h factor was then taken into account in the derivation of the full solution, by refitting all relevant timing parameters.

⁵ <https://tempo.sourceforge.net>

Table 2. Parameters of the GC NGC 6749 and the NGC 6749A system.

Globular cluster parameters	
Right ascension, α_{GC} (J2000)	19:05:15.36
Declination, δ_{GC} (J2000)	01:54:3.6
Distance, D (kpc)	7.24^{+69}_{-57}
Proper motion in α , $\mu_{\alpha,GC}$ (mas yr $^{-1}$)	-2.829 ± 0.028
Proper motion in δ , $\mu_{\delta,GC}$ (mas yr $^{-1}$)	-6.006 ± 0.027
Core radius (arcmin)	0.62
Central velocity dispersion, σ_V (km s $^{-1}$)	2.64
Escape velocity, V_{esc} (km s $^{-1}$)	11.8
a_{GC} (10 $^{-9}$ m s $^{-2}$)	-0.218
Definitions of the timing solution	
Terrestrial time standard	TT(BIPM2023)
Time units	TDB
Solar system ephemeris	DE440
Span of timing data (MJD)	53 070–60 617
Reference epoch (MJD)	60378
Number of TOAs	253
Weighted rms residual (μ s)	27.8
χ^2	235.3
Reduced χ^2 (χ^2/n_{free})	1.006
Reduced Weighted rms residual (μ s)	27.8
Spin and astrometric parameters	
Right ascension, α (J2000)	19:05:14.69052(19)
Declination, δ (J2000)	01:54:48.274(8)
Proper motion in α , μ_{α} (mas yr $^{-1}$)	$-2.52(24)$
Proper motion in δ , μ_{δ} (mas yr $^{-1}$)	$-9.4(8)$
Spin frequency, ν (Hz)	313.190896837(10)
First spin frequency derivative, $\dot{\nu}$ (10 $^{-15}$ Hz s $^{-1}$)	$-1.885(17)$
Dispersion measure, DM (cm $^{-3}$ pc)	195.0(3.3)
First DM derivative, DM001 (cm $^{-3}$ pc yr $^{-1}$)	0.06(36)
Second DM derivative, DM002 (cm $^{-3}$ pc yr $^{-2}$)	0.012(21)
Third DM derivative, DM003 (cm $^{-3}$ pc yr $^{-3}$)	0.0054(9)
Fourth DM derivative, DM004 (cm $^{-3}$ pc yr $^{-4}$)	0.00069(13)
Orbital parameters	
Orbital period, P_b (day)	0.8125524389(21)
Projected semi-major axis of pulsar orbit, $x \equiv a_p \sin i/c$ (s)	0.5886568(41)
Time of ascending node, T_{asc}	60378.0292965(21)
$\epsilon_1 \equiv e \sin \omega$	-0.000031(13)
$\epsilon_2 \equiv e \cos \omega$	0.000002(12)
Observed orbital period derivative, $\dot{P}_b$ (10 $^{-12}$ s s $^{-1}$)	0.4(6)
Optical parameters of companion WD	
Reddening-corrected F606W magnitude, m_{F606W}	26.08(6)
Reddening-corrected F814W magnitude, m_{F814W}	24.78(5)
White dwarf temperature	11 600–14 800
White dwarf mass ($M_{\odot}$)	0.17–0.19
Cooling age (Gyr)	0.4–0.7
Derived parameters	
Galactic longitude of the cluster centre, ℓ (deg)	36.201
Galactic latitude of the cluster centre, b (deg)	-2.205
DM Distance, d_{NE2001} (kpc)	3.4
DM Distance, d_{YMW16} (kpc)	5.5
DM Distance, d_{NE2025} (kpc)	3.8
Offset of pulsar from the centre of the cluster (')	0.76
Offset of pulsar from the centre of the cluster (core radii)	1.25
Projected distance of from the centre of the cluster (pc)	1.6
Total proper motion, μ_T (mas yr $^{-1}$)	9.7(7)
Position angle of proper motion, J2000, Θ_{μ} (deg)	195.0(18)
Proper motion relative to the cluster (mas yr $^{-1}$)	3.5(8)
Transverse velocity relative to the cluster (km s $^{-1}$)	123(34)
Spin period, P (ms)	3.19294082330(10)
Spin period derivative, $\dot{P}_{obs}$ (10 $^{-20}$ s s $^{-1}$)	1.922(17)
Cluster contribution to $\dot{P}_{obs}$ (10 $^{-20}$ s s $^{-1}$)	± 0.18
Galactic acceleration contribution to $\dot{P}_{obs}$ (10 $^{-20}$ s s $^{-1}$)	-0.23
Proper motion contribution to $\dot{P}_{obs}$ (10 $^{-20}$ s s $^{-1}$)	$+0.52$
Intrinsic spin period derivative, $\dot{P}_{int}$ (10 $^{-20}$ s s $^{-1}$)	1.64 ± 0.18
Characteristic age (Gyr)	2.8–3.5
Surface magnetic field (10 8 G)	2.2–2.4
Orbital eccentricity, e	0.000032(12)
Epoch of periastron, T_0 (MJD)	60378.667(55)
Longitude of periastron, ω (deg)	282(25)
Mass function f ($M_{\odot}$)	0.000331716(7)
Minimum companion mass, $M_{c,min}$	0.088
Median companion mass, $M_{c,med}$	0.103
Orbital inclination for $m_c = 0.18 M_{\odot}$	30.7

Notes. The timing parameters were derived using TEMPO with the ELLIH binary model. The values in the parenthesis indicate the 1σ uncertainties on the last digit. The minimum and median companion masses and orbital inclination are estimated assuming a pulsar mass of $1.35 M_{\odot}$. The linear distances and velocities relative to the centre of the GC assume the distance estimated for the GC.

The timing residuals (ToA minus model prediction) are presented in Figure 2. No trends are visible in the residuals, either as a function of time or orbital phase; this means that the timing solution in Table 2 provides a good description of the data. The orbital model used was the ELLIH model (Lange et al. 2001; Freire & Wex 2010), which uses the Laplace-Lagrange parameters (T_{asc} , ϵ_1 , ϵ_2) to describe the orbit and the orthometric parameters of the Shapiro delay (h_3 and ς) to describe the relativistic light propagation delay (Shapiro 1964) in the spacetime of the binary pulsar. Relative to the Damour-Deruelle timing formula (Damour & Deruelle 1986) and its parameters, the previous parameters avoid the strong correlations between the time of passage of periastron (T_0) and the longitude of periastron (ω) observed for low-eccentricity systems and between the range (r) and shape (s) of the Shapiro delay observed for low-inclination systems. In what follows we discuss the significance of some of these timing parameters.

One of the features of this GC (and its pulsar) is the large DM, which is a consequence of the large electron column density. As seen for other pulsars, the larger the DM, the larger are its variations. In this work, we model them as a Taylor expansion with four DM derivatives. Using these reduced the value of χ^2 from, successively, 284.9, 273.2, 270.0, 264.8, and finally to 235.3. Adding further DM derivatives (up to the ninth) does not significantly decrease the value of χ^2 .

3.1. Position and proper motion of the pulsar relative to the cluster

The position of the centre of NGC 6749, its distance, and its proper motion listed in Table 2 were taken from Vasiliev & Baumgardt (2021). The core radius, central velocity dispersion, and escape velocity were taken from Baumgardt & Hilker (2018). Using these values, we find that the pulsar is 0.76 arcminutes from the centre of the cluster, or about 1.25 core radii. This confirms the preliminary conclusion by Hessels et al. (2007) on the pulsar being close to the GC centre. At a distance of 7.24 kpc, this corresponds to a projected distance of 1.6 pc. This kind of distance is very typical of what has been found for other GCs where the pulsars are found to have a dynamically relaxed distribution, i.e. where mass segregation has run its course (see e.g. Freire et al. 2017; Abbate et al. 2018; Prager et al. 2017; Zhang et al. 2023; Li et al. 2024; Vleschower et al. 2024; Lian et al. 2023, 2025b,a). The precise position determined from timing allowed the identification of the companion in optical images of the GC that are discussed in detail in the next section.

However, the proper motion differences (pulsar – globular cluster) in right ascension and declination are $0.31(24)$ mas yr $^{-1}$ and $-3.4(8)$ mas yr $^{-1}$ respectively, for a total difference of $3.4(8)$ mas yr $^{-1}$. This translates, at the distance to the GC, to a velocity difference of 116 ± 26 km s $^{-1}$, which has a significance of about 4.5σ and is certainly larger than the escape velocity from the centre of the GC, which is about 11.8 km s $^{-1}$. If this is confirmed, then the pulsar is not associated with the cluster; the probability of a chance coincidence with the GC is discussed in detail below. However, one should keep in mind that DM variations introduce systematic biases in parameters that require long timing baselines such as the proper motion.

3.2. Acceleration, spin-down, and orbital parameters

For pulsars in GCs, the observed spin period derivative is given by

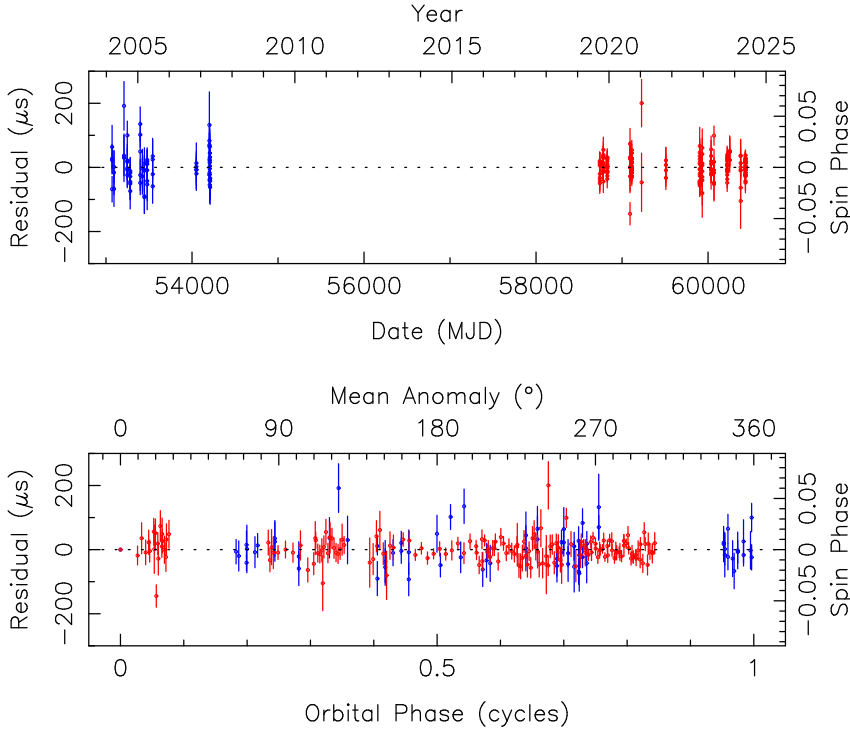


Fig. 2. Time of arrival residuals obtained with our set of ToAs and the timing solution in Table 2. The early ToAs (in blue) were obtained with the Arecibo observing setup; the latter (in red) were obtained with the FAST observing setup. The top plot shows the residuals as a function of time and the lower plot shows them as a function of orbital phase relative to ascending node. No trends are visible in the residuals, which means that the timing solution in Table 2 provides a good description of the data. Furthermore, no eclipses are seen at superior conjunction, which occurs at an orbital phase of 0.25.

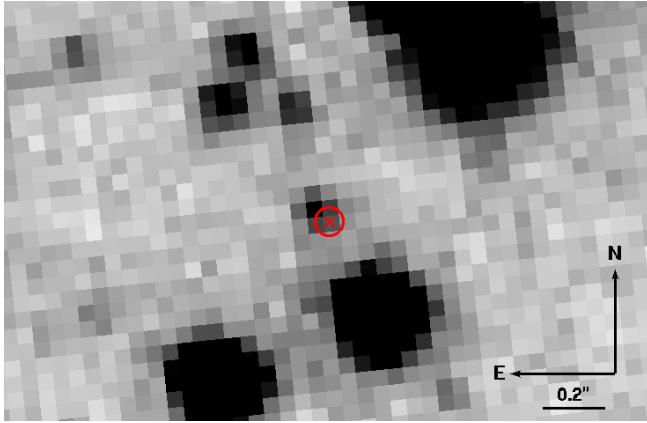


Fig. 3. Finding chart of the region surrounding NGC 6749A in the F606W filter. The red cross marks the pulsar position, while the circle represents the 3σ uncertainty radius from the combined optical and radio positional error. The only detected star within this region is the candidate companion to the pulsar.

$$\left(\frac{\dot{P}}{P}\right)_{\text{obs}} = \left(\frac{\dot{P}}{P}\right)_{\text{int}} + \frac{a_{\text{Gal}} + a_{\text{GC}}}{c} + \frac{\mu^2 d}{c}, \quad (1)$$

where $\dot{P}_{\text{int}}$ is the intrinsic spin period derivative, a_{Gal} and a_{GC} are the accelerations of the binary system in the gravitational fields of the Galaxy and the GC respectively, and the last term is the Shklovskii effect (Shklovskii 1970). A similar equation can be written for $\dot{P}_b$. Generally the terms a_{Gal}/c and $\mu^2 d/c$ are of the same order, and in this case partially cancel each other; they are listed in Table 2, where the Galactic acceleration term for the pulsar and the GC is estimated using the McMillan (2017) Galactic acceleration model.

The unknown contributions arise from $\dot{P}_{\text{int}}/P$ and a_{GC}/c . For a_{GC} , we can calculate the extremes at the position of the pulsar using a simple analytical King model (Freire et al. 2005), see Table 2. In most GCs, a_{GC} is the dominant term, however, given

the very low density of the core of NGC 6749, the dominant term is $\dot{P}_{\text{int}}/P$, with a_{GC}/c contributing less than 10% of the observed $\dot{P}_{\text{int}}/P$, and unusually, by an amount that is similar to that of a_{Gal}/c and $\mu^2 d/c$. This situation is very similar to what has been observed for other GCs like M53 (Lian et al. 2023) and M71 (Lian et al. 2025b). This means that, after taking into account all other terms, and considering the extreme a_{GC} , we can deduce $\dot{P}_{\text{int}}$ with about 10% accuracy; from these, we derive a characteristic age between 2.8 and 3.5 Gyr and a magnetic field between 2.2 and 2.4×10^8 G. These numbers are very typical of the Galactic MSP population. They are nonetheless interesting since, in general, they cannot easily be measured in more massive GCs, unless one has a very precise measurement of the acceleration of the binary via $\dot{P}_b$ (see e.g. Freire et al. 2017; Dutta et al. 2025) or the GC acceleration is much smaller than $\dot{P}_{\text{int}}$ (Abbate et al. 2022; Lian et al. 2023; Zhou et al. 2024; Wu et al. 2024; Lian et al. 2025b).

Re-writing Eq. (1) for $\dot{P}_b$, we obtain a prediction of $0.06(4) \times 10^{-12} \text{ s s}^{-1}$ for the contribution of the kinematic terms to $\dot{P}_b$. According to general relativity, and assuming pulsar masses on the order of $1.4 M_{\odot}$ and companion masses on the order of $0.18 M_{\odot}$ (see Section 4), the contribution from orbital decay due to the emission of gravitational waves for this system is an order of magnitude smaller than this prediction; this is taken into account in this estimate. The observed value of $\dot{P}_b$ is, within its large error bar, consistent with this prediction; however, its uncertainty is still an order of magnitude more than the predicted effect.

4. Multi-wavelength follow-up

4.1. X-rays

From the HEASARC archive⁶, we find the deepest X-ray limits at NGC 6749A's timing position from a 4.7 ks Swift/XRT observation on 2009 October 30, which detected no source near

⁶ <http://heasarc.gsfc.nasa.gov/db-perl/W3Browse/w3browse.pl>

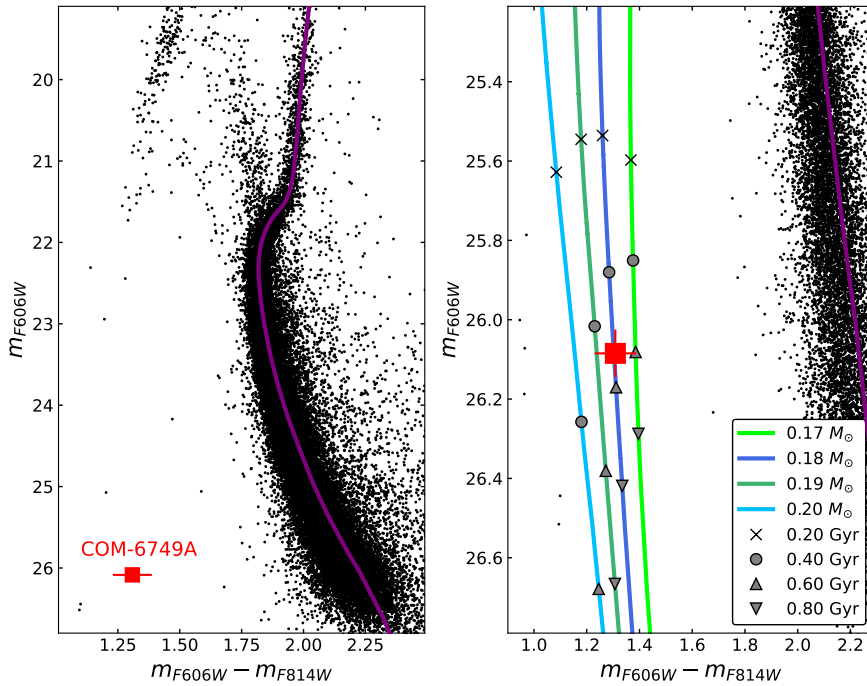


Fig. 4. Left-hand panel: colour-magnitude diagram of NGC6749 in a combination of the F606W and F814W. The red square is the position of the counterpart to NGC6749A. The purple curve is a 13-Gyr isochrone calculated at the cluster metallicity, distance, and extinction. Right-hand panel: same as the left-hand panel, but zoomed in on the companion CMD position. The coloured curves are He WD cooling tracks from Istrate et al. (2014, 2016). The tracks are for WDs with masses in the range between $0.17M_{\odot}$ and $0.2M_{\odot}$, with decreasing masses from left to right, as reported in the legend. Different points are also highlighted with different markers along the tracks that correspond to different cooling ages.

the pulsar position. Assuming a power law with a photon index of 2, $N_H = 7 \times 10^{21} \text{ cm}^{-2}$, and $d = 7.9 \text{ kpc}$, we estimate a rough limit of $L_X(0.5\text{--}10 \text{ keV}) = 4 \times 10^{32} \text{ erg/s}$ (C. Heinke, priv. comm.). The X-ray luminosities of MSPs with He WD companions are typically $10^{30\text{--}31} \text{ erg/s}$ (Zhao & Heinke 2022), so the non-detection of NGC 6749A is not surprising.

4.2. Optical identification of the companion

To identify the optical counterpart of the binary pulsar, we inspected all the stellar sources within a $1'' \times 1''$ region surrounding the pulsar position. As shown in Figure 3, there is a star compatible with the pulsar displaced by only $0.04''$ from the pulsar position, thus within 3σ of the combined optical and radio uncertainties. In the colour-magnitude diagram (CMD), the star is located in a blue region, with a colour similar to that of blue horizontal branch stars, which is consistent with the expected location of WDs. In fact, this is the only clearly detected WD in the cluster, which is not surprising given its distance and the significant extinction that make the detection of hot stars particularly challenging. The good positional coincidence and the CMD location, indicative of a WD nature, strongly suggest that this source is indeed the companion to NGC 6749A. The differential reddening-corrected magnitudes of the companion are: $m_{F606W} = 26.08 \pm 0.06$ and $m_{F814W} = 24.78 \pm 0.05$.

The multi-band magnitudes can be used to infer the physical properties of the WD, such as its mass, surface temperature, and cooling age, by comparison with appropriate He WD cooling tracks. We adopted the models from Istrate et al. (2014, 2016), which follow the evolution of a neutron star binary through the entire mass transfer phase, the proto-WD stage, and the WD cooling phase. These tracks have been extensively used in our previous studies to characterise MSP companions (e.g. Cadelano et al. 2020a; Chen et al. 2023; Etorre et al. 2025). Figure 4 shows these cooling tracks along with a 13-Gyr isochrone (solid purple curve) extracted from the Bag of Stellar Tracks and Isochrones (BaSTI) database (Hidalgo et al. 2018; Pietrinferni et al. 2021), assuming a cluster metallicity of $[Fe/H] = -1.6$ (Harris 1996,

2010). We adopted a cluster distance modulus of $(m - M)_0 = 14.40$ and an average colour excess of $E(B - V) = 1.37$, in reasonable agreement with the values reported by Harris (1996, 2010).

As shown in the figure, the model successfully reproduces the entire cluster evolutionary sequence, from the red-giant branch down to the faint main sequence, which also confirms the He WD nature of the companion star. However, the companion is a faint source detected in only two optical filters in a challenging environment characterised by strong differential reddening. Given these limitations, we conservatively infer its properties by bracketing its CMD position within the range of expected magnitudes and colour from the cooling tracks. As shown in the right panel of Figure 4, its location in the CMD is consistent with a He WD with a mass of $0.17M_{\odot}$ – $0.19M_{\odot}$, a cooling age of $0.4\text{--}0.7 \text{ Gyr}$, and a surface temperature of $11,600\text{--}14,800 \text{ K}$. A more detailed analysis, similar to that presented in Cadelano et al. (2019, 2020a), would require additional multi-band observations, particularly in the blue and near-UV bands. This companion mass and the mass function of the system imply a low orbital inclination: assuming a companion mass of $0.18M_{\odot}$ and pulsar masses of 1.35 and $2.0M_{\odot}$, the orbital inclinations are 30.7 and 40.2 degrees.

5. Summary and conclusions

In this work, we present the results of recent FAST observations of NGC 6749. Apart from the previously known pulsar, NGC 6749A, we have not been able to detect any additional pulsars in this GC. In particular, we have not been able to confirm NGC 6749B. The reasons for this are not clear. It is possible it is not a real pulsar, but it is also possible that it is an eclipsing binary that appears very rarely. Alternatively, it might be located outside the narrow FAST beam, but still be located at the outer margin of the wider Arecibo beam.

The previously known pulsar NGC 6749A was detected consistently, from which we could obtain a timing solution for

this binary pulsar. This timing solution allowed us to connect the early Arecibo data, which resulted in a timing baseline of 20 years.

The acceleration of the system in the field of the GC is so small that even with 20 years of data, its effect on the orbital period derivative remains undetected; nevertheless the precise measurement of the spin period derivative and the small expected accelerations result in a relatively well-estimated value for the spin-down of the pulsar, one of the few well-measured cases in GCs. This is small and results in a characteristic age between 2.8 and 3.5 Gyr and a magnetic field at the surface between 2.2 and 2.4×10^8 G, which implies a relatively normal MSP. Nevertheless, this is one of the few intrinsic spin-down ages and characteristic ages measured for pulsars in GCs.

The precise position of the pulsar allowed us to identify one of the few candidate WDs in this cluster as the pulsar's companion, thus confirming it as a WD. There are three objects near the CMD position of the companion ($25 < m_{606} < 26.5$ and colour < 1.25) that might or might not be WDs; they could also be sources with bad photometry or sources not associated with the cluster, such as quasars. Therefore, the companion of NGC 6749A is the only confirmed WD in this GC. The latter's photometric characteristics are consistent with a He WD with a mass of $0.17M_{\odot}$ – $0.19M_{\odot}$, a surface temperature of 11,600–14,800 K, and a cooling age of 0.4–0.7 Gyr. According to Eq. (1) in [Istrate et al. \(2014\)](#), for the mass of this WD companion, the proto-WD age, i.e. the phase after Roche-lobe detachment during which the WD contracts before entering the cooling sequence, lasted 0.6–1.2 Gyr, which implies a time between 1.0 and 1.9 Gyr since Roche lobe detachment.

This age is consistent with (i.e. of a similar magnitude but not larger than) the characteristic age of the pulsar. Using the equation for the change of the spin period with time,

$$p(t) = P \left[(n-1) \frac{\dot{P}}{P} t + 1 \right]^{\frac{1}{n-1}}, \quad (2)$$

where n is the braking index. A constant magnetic field ($n = 3$) and the nominal value of $\dot{P}_{\text{int}}$ would imply that, at the time of Roche lobe detachment, the spin period was between 1.98 and 2.62 ms. Such values are well within the range of observed MSP spin periods. An interesting aspect of this measurement is that it can be used to constrain the braking index. In particular, for $n = 4$ and $t = -1.9$ Gyr, the initial spin period would be 1.35 ms, which would be shorter than any observed to date ([Hessels et al. 2006](#)).

The only unanswered question raised by the current work is the large difference between the proper motion of the pulsar and the GC, at least in declination. If confirmed, this could imply that the system is not associated with the cluster. Given the possibility of systematics due to DM variations, we consider this unlikely, especially given the close proximity to the centre of the GC, 0.76. However, it cannot be excluded for two additional reasons. First, for the coordinates of this pulsar and its DM, the three most used DM models (NE2001, [Cordes & Lazio 2002](#), YMW16, [Yao et al. 2017](#), and NE2025, [Ocker & Cordes 2026](#)) predict distances that range from 3.4 to 5.5 kpc (see Table 2); these fall systematically short of the estimated distance to the GC of 7.24^{+69}_{-57} kpc. However, given the large uncertainties of these models, which also fail to predict the distances to other GCs from the DMs of well-established pulsar members of those clusters, this is not a strong argument against the association. Second, for a region of the sky of about 60 square degrees around the position of NGC 6749A with $|b| < 3^\circ$ and $31^\circ < \ell < 41^\circ$,

the Australia Telescope National Facility catalogue ([Manchester et al. 2005](#)) currently lists 359 pulsars, with 49 of them having spin periods smaller than 10 ms. This represents pulsar densities of about 6 and 0.8 per square degree, respectively. Thus, the possibility of having a pulsar, and in particular a millisecond pulsar, within any particular beam of the Arecibo telescope (which at L band had a full width at half maximum of about 3 arcminutes, or 0.05 degrees) is about 1.2 and 0.16%, respectively. These probabilities increase if we consider the great depth of the Arecibo observation that found this pulsar, which had an integration time of several hours.

If the pulsar were located at these smaller distances, the WD companion would be significantly fainter, which would imply larger WD masses (0.20 – $0.25 M_{\odot}$) and possibly much smaller cooling ages. These would still be consistent with the observed mass function, but would result in lower orbital inclinations. If we assume a pulsar mass of $1.35 M_{\odot}$ and companion masses of 0.20 and $0.25 M_{\odot}$, the inclinations would be 27.6 and 22.3 degrees. Future measurements should significantly improve the precision and the accuracy of the proper motion measurement and clarify the association.

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