PROCEEDINGS OF SCIENCE

MeerKAT Observations of J1912−4410 — the second white dwarf pulsar

E Meintjes,[a,*] **PA Woudt,**[a] **M Geyer,**[b] **I Heywood,**[c,d,e,f] **V Prayag,**[a,b] **B Stappers,**[g] **DAH Buckley,**[a,h,i] **M Caleb,**[j,k] **R Fender**[a,d] **and I Pelisoli**[l]

[a] *Department of Astronomy, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa*
[b] *High Energy Physics, Cosmology & Astrophysics Theory (HEPCAT) Group, Department of Mathematics and Applied Mathematics, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa*
[c] *SKA Observatory, Jodrell Bank, Lower Withington, Macclesfield, SK11 9FT, UK*
[d] *Astrophysics, Department of Physics, University of Oxford, Keble Road, Oxford, OX1 3RH, UK*
[e] *Department of Physics and Electronics, Rhodes University, PO Box 94, Makhanda, 6140, South Africa*
[f] *South African Radio Astronomy Observatory, 2 Fir Street, Black River Park, Observatory 7925, South Africa*
[g] *Jodrell Bank centre for Astrophysics, Department of Physics and Astronomy, the University of Manchester, Oxford Road, Manchester, M13 9Pl, UK*
[h] *South African Astronomical Observatory, PO Box 9, Observatory, 7935, Cape Town, South Africa*
[i] *Department of Physics, University of the Free State, PO Box 339, Bloemfontein 9300, South Africa*
[j] *Sydney Institute for Astronomy, School of Physics, The University of Sydney, Sydney, NSW 2006, Australia*
[k] *ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), Hawthorn, VIC 3122, Australia*
[l] *Department of Physics, University of Warwick, Gibbet Hill Road, Coventry CV4 7AL, UK*

E-mail: emilmeintjes@gmail.com

White dwarf radio pulsars (WD pulsars) are a fascinating, newly established class of compact binary systems. These are defined as detached white dwarf + M dwarf compact binaries ($P_{\rm orb}$ ∼ 4 hours) that exhibit pulsed multi-wavelength emission (from X-ray to radio) associated with a rapid rotation of the white dwarf. Only three such systems have been spectroscopically confirmed: AR Sco, J1912−4410 and J2306+2440. Since its discovery in 2016, AR Sco has spurred debate about the nature and origin of WD pulsars, particularly regarding the formation of their presumably strong magnetic fields. J1912−4410's radio emission is sharp and narrow, resembling that of a canonical pulsar much more than AR Sco does. It offers a crucial opportunity to refine our understanding of WD pulsar formation and of their place in the broader context of magnetic cataclysmic variable (mCV) evolution. Here, we demonstrate how MeerKAT's 2-second timing resolution provides a powerful means of probing the nature of the pulsed radio emission from J1912−4410. We present the preliminary results of the first long-term monitoring of J1912−4410 at radio wavelengths — in particular, we determine a precise white dwarf spin period of 5.32339264(40) minutes and highlight the differences of its radio emission to that of AR Sco.

High Energy Astrophysics in Southern Africa (HEASA2025)
16-20 September, 2025
University of Johannesburg, South Africa

*Speaker

https://pos.sissa.it/

PoS(HEASA2025)061

1. A white dwarf radio pulsar

Canonical radio pulsars are characterised as rapidly rotating neutron stars that exhibit regular, but short-lived, pulsed emissions. The standard model attributes the radio pulsar emission to the curvature radiation from charged, relativistic particles that travel along the curved magnetic field lines of the neutron star [1] [2] [3]. These emitted pulses may vary substantially on an individual basis, but when averaged, show a stable pulse profile. The time between successive pulses is a measure of the spin period of the neutron star, while the rate at which the neutron star's spin period changes (its period derivative) corresponds to the spin-down power of the neutron star. The characteristics of these pulse profiles provide insight into the fundamental physics that creates them.

While radio transient phenomena are familiar features in many astrophysical systems, neutron stars were long thought to be the only sources of pulsed radio emission. However, in 2016, Marsh et al. identified AR Scorpii (AR Sco) [4] as a radio-pulsing white dwarf. Initially misclassified as a $\delta-$Scuti variable in the 1970s based on the appearance of the optical light curve, AR Sco warranted follow-up observations when Marsh et al. noticed clear scatter in its optical brightness at certain orbital phases compared to others. Optical photometry revealed a binary system containing a cool M-dwarf and a compact object, but also revealed pulsations at a fundamental period of 117 seconds and a beat period of 118 seconds.

Integrating over its Spectral Energy Distribution (SED) showed a clear luminosity excess ($\bar{L} \approx 1.7 \times 10^{25}$ W) that is an order of magnitude larger than that of its thermal components ($L_* \approx 4.4 \times 10^{24}$ W). Accretion or the spin-down power of a rotating compact object can explain this luminosity excess. The lack of observational evidence for accretion suggests the latter. Marsh et al. show that AR Sco's luminosity excess can be driven by the spin-down luminosity of a rapidly rotating white dwarf. This, coupled with its low X-ray luminosity excess, points towards the compact object being a white dwarf rather than a neutron star. Evidence for the presence of weak spectral features between pulses and the detection of broadened Lyman-α lines during pulsed emission from observations made by the Hubble Space Telescope enabled Garnavich et al. [5] to later confirm the compact object in AR Sco to be a white dwarf.

Subsequent multi-wavelength observations confirmed the presence of pulsed emission at 117-second intervals in X-ray, ultraviolet, optical and infrared wavelengths. Furthermore, the additional detection of radio modulations at the same spin and beat period [6] prompted AR Sco to be later reclassified by Buckley et al. as the first white dwarf radio pulsar [7].

2. The discovery of J191213.72−441045.1

Nearly a decade after AR Sco's discovery, Pelisoli et al. revealed their results [8] of a targeted search for white dwarf + M dwarf binaries that share similar non-thermal infrared colours, variability, and location in the Gaia colour-magnitude diagram to that of AR Sco [9]. Many candidates were found, but GAIA J191213.72−441045.1 (J1912−4410 henceforth) piqued interest because it was also independently flagged as a compact binary candidate by eROSITA [10]. Follow-up observations using MeerKAT in the L-band for radio, ULTRACAM using the Sloan u, g and i filters for optical and *XMM*-NEWTON for X-ray observations confirmed pulsed emissions across the electromagnetic spectrum. This firmly established WD pulsars as a unique and rare class of compact binary systems.

PoS(HEASA2025)061

Initial investigations of J1912−4410 challenge the formation models put forth that the study of AR Sco alone could not reveal. In particular, the rotation- and crystallisation-driven magnetic dynamo model [11] becomes unlikely because J1912−4410's effective temperature, $T_{\rm eff} \simeq 11485$ K, is too high for core crystallisation to have occurred. However, mass transfer could potentially explain the high temperature as a result of compressional heating. Furthermore, J1912−4410 shows possible evidence for flaring, which could be indicative of mass transfer — this could suggest that J1912-4110 is in a propeller-like state similar to that of AE Aquarii [12]. However, Pelisoli et al. [12] note that further observations are needed to confirm this because similar flaring has not been observed in AR Sco.

3. Long-term monitoring of J1912−4410 using MeerKAT

This work presents the preliminary results of the first long-term radio observations of J1912−4410 using MeerKAT's fast imaging at 2-second integrations. To determine a precise timing solution and establish a long-term baseline, J1912-4410 is monitored roughly once per month through MeerKAT's Open Time projects (ID: SCI-20230907-PW-01 and SCI-20241101-PW-01). While most observations are done using the UHF band (544 to 1088 MHz), one observation was performed using the S band (1.75 to 3.50 GHz). In addition to this, each of these observations also includes PTUSE Beamformer data for timing purposes [13]. Referring to panel **(a)** in Figure 2 of the discovery paper [8], we notice that the radio pulses only occur between orbital phases 0.4 and 0.6. Consequently, all of our observations were obtained over this interval to maximise the number of pulses captured.

These observations were processed, and snapshot images were created using the newly developed PolKAT pipeline [**?**] installed on the ilifu research cloud. The peak brightness within a small radius around J1912−4410's position is extracted for each snapshot image to create a radio light curve. The light curve for three separate observations is shown in Figure (1). Each light curve is phase folded according to the orbital ephemeris as presented in [8],

$$\mathrm{BJD(TDB)} = 2459784.98308(19) + 0.16811989(36)E, \tag{1}$$

where 2459784.98308 (19) is the reference time chosen as the inferior conjunction of the M-dwarf companion star, 0.16811989 (36) is the orbital period in days, E is the integral cycle number, and BJD is the Barycentric Julian Date (in Barycentric Dynamical Time scale) [8]. The numbers in parentheses denote the one-sigma uncertainties in the last two digits quoted.

The narrow, sharply defined peaks in Figure (1) show clear variation in pulse strength both within and between observations. We typically see the strengths of pulses vary between 25 mJy/beam and 200 mJy/beam, but may be as weak as 3 mJy/beam or as strong as 380 mJy/beam as seen near phase 0.417 and 0.526 in panel **(a)**, respectively. This is in stark contrast with that of AR Sco, which shows much weaker emission at lower radio frequencies. Pulse strengths are seen to vary between 2 mJy/beam and 15 mJy/beam at 1.5 GHz [6], but between 50 mJy/beam and 200 mJy/beam at 220 GHz [14]. Furthermore, we note that the duty cycle of AR Sco is much larger than that of J1912−4410, which means that J1912−4410's radio emission appears more similar to that of a canonical pulsar. We also see clear evidence of a leading pulse component that varies in strength, a component also not seen in AR Sco's radio light curve (cf., Figure 6 in [6]). Interestingly,

PoS(HEASA2025)061

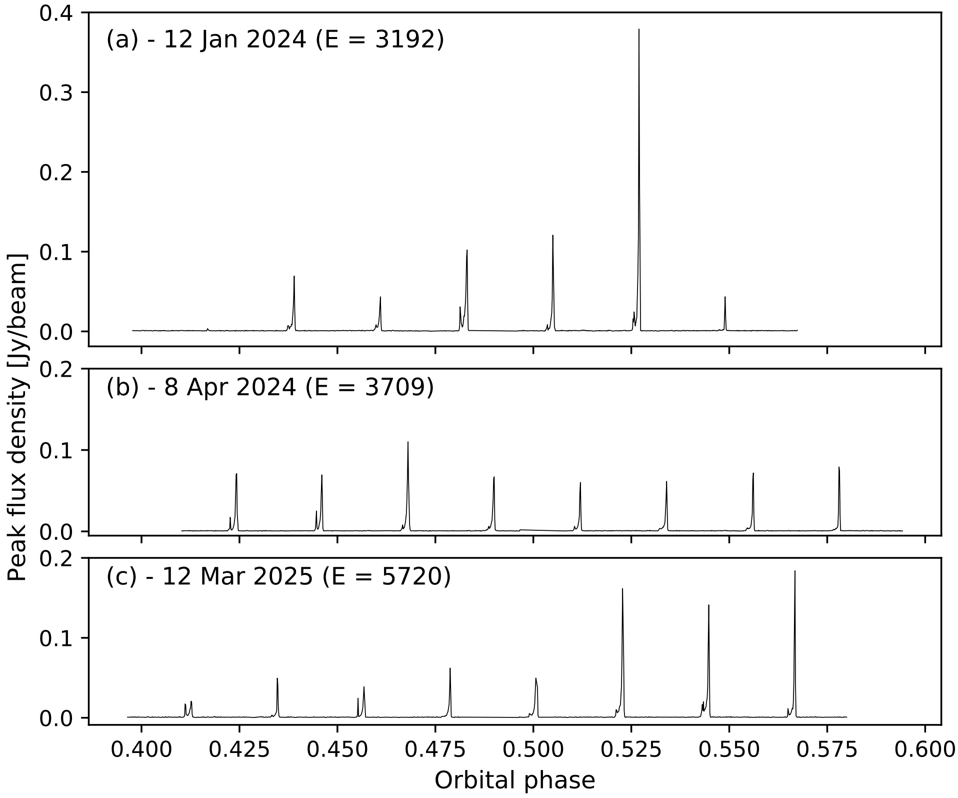

Figure 1: Three observations of J1912−4410 in the UHF band. Panel **(a)** is an observation from the 12^{th} of January 2024, panel **(b)** is an observation from the 8^{th} of April 2024 and panel **(c)** is an observation from the 12^{th} of March 2025. Each of these observations is phase-folded on the ephemeris of the binary given in Eqn (1), and their respective binary cycle number is indicated in each panel. Since the orbital period is not an integer number of spin periods, the pulses appear at different orbital phases across observing epochs and should therefore not be interpreted as a measure of J1912−4410's period derivative.

the strength of this leading pulse does not appear to correlate with the strength of the main pulse peak.

A Lomb-Scargle Fourier Analysis was performed on all the MeerKAT data between January 2024 and July 2025. A Gaussian fit was performed on the tallest peak to determine the fundamental frequency of pulsations; the width of the Gaussian is used to estimate the uncertainty of this frequency. This results in a spin period of the white dwarf of 5.32339264 (40) minutes. We find that this is consistent with the spin period determined by Pelisoli et al. in their discovery paper [8] as well as their UV observations [12], but is far more precise. The Lomb-Scargle periodogram of this work is shown in Figure (2).

Having determined a precise spin period, we next aim to constrain the period derivative. It will involve (1) an (O–C) analysis of pulse arrival times of the fast imaging data, and (2) a long-term timing solution derived with PSRCHIVE from the PTUSE Beamformer data.

4. Conclusion

This work demonstrates the importance of long-term monitoring of J1912−4410 to determine a precise spin period for the white dwarf. Furthermore, this shows that MeerKAT's superb 2-second

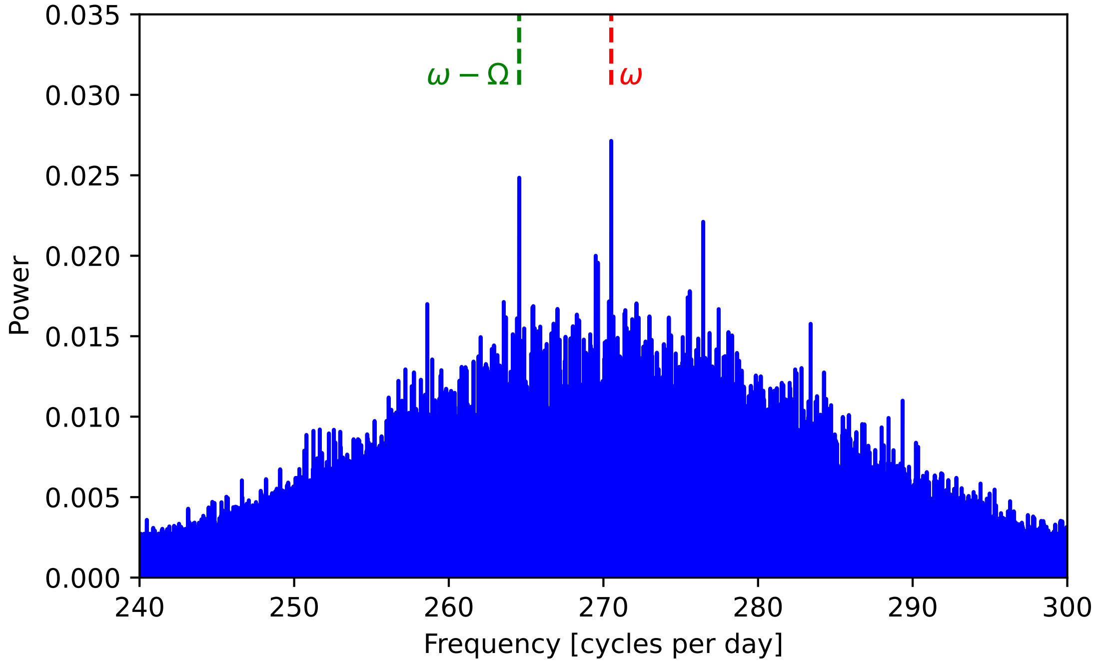

Figure 2: The Lomb-Scargle Periodogram obtained from the radio light curve of J1912−4410. The dashed, red, vertical line, labelled ω, indicates the spin frequency of the white dwarf. The beat frequency, a component arising from our biased observations to a particular part of J1912−4410's orbital period, is shown by the dashed, green, vertical line, labelled $\omega - \Omega$ [12], where Ω is the orbital frequency. We fit a Gaussian to the tallest peak and find that it is centered at 270.504287(20) cycles per day. We interpret this as the spin frequency of the white dwarf, which results in a period of 5.323392264(40) minutes.

instantaneous integrations are essential to place tight constraints on the white dwarf's parameters, in particular its spin period and eventually its period derivative. We show that J1912−4410's sharp, narrow pulses offer a unique opportunity to study low-frequency radio emissions, using both imaging and timing backends, that have not yet been possible for AR Sco. Future analysis of the polarisation of pulses will help place further constraints on emission mechanisms and emission geometries.

Acknowledgements

EM acknowledges the financial assistance of the South African Radio Astronomy Observatory (SARAO) toward this research. PAW acknowledges financial support from UCT and the NRF. MG acknowledges funding from the South African Research Chairs Initiative of The Department of Science and Technology and the National Research Foundation of South Africa (grant no. 98626). Furthermore, we acknowledge the use of the ilifu cloud computing facility. The ilifu facility is supported by contributions from the Inter-University Institute for Data Intensive Astronomy, the Computational Biology division at UCT and the Data Intensive Research Initiative of South Africa (DIRISA). Additionally, PTUSE was developed with support from the Australian SKA Office and Swinburne University of Technology.

References

[1] V. Radhakrishnan and D.J. Cooke, *Magnetic poles and the polarization structure of pulsar radiation*, *Astrophysical Letters* **3** (1969) 225.

[2] A. Lyne and R. Manchester, *The shape of pulsar radio beams*, *Monthly Notices of the Royal Astronomical Society* **234** (1988) 477.

[3] J.M. Rankin, *Toward an empirical theory of pulsar emission. VI-The geometry of the conal emission region*, *Astrophysical Journal* **405** (1993) 285.

[4] T. Marsh, B. Gänsicke, S. Hümmerich, F.-J. Hambsch, K. Bernhard, C. Lloyd et al., *A radio-pulsing white dwarf binary star*, *Nature* **537** (2016) 374.

[5] P. Garnavich, C. Littlefield, M. Lyutikov and M. Barkov, *Peeking between the pulses: the far-UV spectrum of the previously unseen white dwarf in AR Scorpii*, *The Astrophysical Journal* **908** (2021) 195.

[6] E.R. Stanway, T. Marsh, P. Chote, B. Gänsicke, D. Steeghs and P.J. Wheatley, *VLA radio observations of AR Scorpii*, *Astronomy & Astrophysics* **611** (2018) A66.

[7] D.A. Buckley, S.B. Potter, P.J. Meintjes, T.R. Marsh and B.T. Gänsicke, *Polarimetric evidence of the first white dwarf pulsar: The Binary System AR Scorpii*, *Galaxies* **6** (2018) 14.

[8] I. Pelisoli, T.R. Marsh, D.A.H. Buckley, I. Heywood, S.B. Potter, A. Schwope et al., *A 5.3-min-period pulsing white dwarf in a binary detected from radio to X-rays*, *Nature Astronomy* **7** (2023) 931.

[9] I. Pelisoli, T. Marsh, G. Tovmassian, L. Amaral, A. Aungwerojwit, M. Green et al., *A targeted search for binary white dwarf pulsars using Gaia and WISE*, *Monthly Notices of the Royal Astronomical Society* **540** (2025) 821.

[10] A. Schwope, T. Marsh, A. Standke, I. Pelisoli, S. Potter, D. Buckley et al., *X-ray properties of the white dwarf pulsar eRASSU J191213. 9- 441044*, *Astronomy & Astrophysics* **674** (2023) L9.

[11] M.R. Schreiber, D. Belloni, B.T. Gänsicke, S.G. Parsons and M. Zorotovic, *The origin and evolution of magnetic white dwarfs in close binary stars*, *Nature Astronomy* **5** (2021) 648.

[12] I. Pelisoli, S. Sahu, M. Lyutikov, M. Barkov, B.T. Gänsicke, J. Brink et al., *Unveiling the white dwarf in J191213. 72- 441045.1 through ultraviolet observations*, *Monthly Notices of the Royal Astronomical Society* **527** (2024) 3826.

[13] M. Bailes, A. Jameson, F. Abbate, E. Barr, N. Bhat, L. Bondonneau et al., *The MeerKAT telescope as a pulsar facility: System verification and early science results from MeerTime*, *Publications of the Astronomical Society of Australia* **37** (2020) e028.

[14] P.E. Barrett and M.A. Gurwell, *Submillimeter observations of the white dwarf pulsar AR Sco*, *The Astrophysical Journal* **986** (2025) 78.

PoS(HEASA2025)061