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# Sporadic radio pulses from a white dwarf binary at the orbital period

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## Supplementary information

Discussion of ILT J1101 + 5521 in the context of similar systems and supplementary figures to the Method section.

### Comparison to AR Scorpii and J1912–4410

AR Scorpii [13] and J1912–4410 [14] are examples of white dwarf binaries that show periodic radio emission. These systems are both in a binary with an M dwarf, with orbital periods of 3.56 and 4.03 hours, respectively. For AR Scorpii the radio pulses are modulated by the orbital period and the beat of the white dwarf’s spin period [18], for J1912–4410 the period of the radio pulses follows the white dwarf spin period but the radio pulses only appear around orbital phase 0.5 [14]. ILT J1101 + 5521 is thus similar to the aforementioned systems since there is an orbital period modulation to the radio pulses, however in contrast to AR Sco and J1912 there seems to be no additional spin period modulation. For AR Scorpii there are two emission components with different polarisation properties that contribute to the radio emission. These two components are likely to be the spin-down from the rapidly rotating, highly magnetised (up to 500 MG) white dwarf and the magnetic interactions between the M dwarf and the white dwarf [2]. We note that for a system with synchronised spin and orbital period, the two components, would vary at the same timescale, and only one component would be seen (as is the case for ILT J1101 + 5521). The steep spectral index for ILT J1101 + 5521 (brightest pulse  $\alpha = -4.1 \pm 1.1$ ) seems consistent with what was found for and J1912 [14], where the in-band spectra suggest a steep negative spectral index of  $\sim -3$ . However, the spectral index of AR Sco seems phase-dependent and varies around  $\alpha = 0.3 \pm 0.2$ ). In terms of pulse duration and luminosity the radio properties of J1912, AR Sco and ILT J1101 + 5521 are similar, as illustrated in Extended Data Figure 4. Although both ILT J1101 + 5521 and the aforementioned systems are M dwarf – white dwarf binaries, ILT J1101 + 5521 is likely to be in a different evolutionary state than AR Scorpii and J1912–4410 because of the shorter orbital period and because the radio pulses are seen at only the orbital period instead.

### Comparison to other known long-period transient radio sources

The first instance of a long-period radio source was the ‘Galactic Centre Radio Transient’ (GCRT), which initially showed pulses with a 10-minute duration on a period of 77 minutes [10]. Follow-up observations revealed fainter and shorter 2-minute pulses [11]. Two more recent discoveries are GLEAM-X J1627–52 [7] and GPM J1839–10 [8], which were found to have pulse periods of 18 and 21 minutes, respectively, with pulses that last for half a minute to 5 minutes. These aforementioned long-period sources are all thought to feature a neutron star or white dwarf, as a coherent emission mechanism is required to create radio emission with the observed brightness temperatures. Finally, ASKAP J1935+2148 was recently reported with a 54-minute period [3]. For ASKAP J1935+2148, two types of radio pulses are observed, one with extremely bright tens of seconds wide, highly linearly polarised pulses, and one with weaker pulses that last only hundreds of milliseconds and are highly circularly polarised. The different emission states are similar to changes in emission that have been observed for pulsars, and the authors argue that for ASKAP J1935+2148 a neutron star scenario is most likely. In contrast to ILT J1101 + 5521, none of the aforementioned long-period radio sources are known to be in a binary system.

The radio pulses from ILT J1101 + 5521 appear to be similar to the radio emission observed from other long-period sources in terms of timing, polarization and spectral properties. This is shown by the clustering of these sources in terms of radio luminosity and duration (see Extended Data Figure 4). Additionally, we find ILT J1101 + 5521 to be active for over 5 years, which again fits with the other long-period sources as GPM J1839–10 was found in archival data spanning 30 years. Finally, the lack of X-ray emission from ILT J1101 + 5521 ( $L < (1 - 1.6) \cdot 10^{30} \cdot \left[\frac{d}{504 \text{ pc}}\right]^2 \text{ erg s}^{-1}$ ) is consistent with the lack of X-ray emission from GLEAM-X J1627–52 and GPM J1839–10 ( $\leq 10^{32-33} \text{ erg s}^{-1}$  [7, 8]) and ASKAP J1935+2148 ( $< 4 \cdot 10^{30} \text{ erg s}^{-1}$  [3]).

The four known long-period sources are all located towards the Galactic Plane (Galactic latitudes between  $-3^\circ$  and  $+1^\circ$ ), complicating follow-up at optical and infrared wavelengths. None of the previously known long-period sources has a confirmed optical counterpart<sup>1</sup>. We note that there might be a bias to finding long-period radio sources towards the Galactic Plane because of the nature of the surveys that were used to find them. For GLEAM-X J1627–52, the lack of an optical/infrared counterpart at the estimated distance of 1.3 kpc does not rule out a lower-mass, main-sequence companion [7], and an AR Scorpii-like system could pass unnoticed if it has a relatively large extinction. [17]. For GPM J1839–10, the optical limits are not strong enough to rule out a binary companion given its larger distance ( $d = 5.7 \pm 2.9 \text{ kpc}$ ) [8], and a similar situation holds for ASKAP J1935+2148 [3] ( $d = 4.85 \text{ kpc}$ ).

Fast radio bursts (FRBs) are coherent radio flashes seen from other galaxies [15]. One repeating FRB source, FRB 20180916B, has a well-established 16.33-day activity period, where the observed bursts systematically occur at lower radio frequencies at later times during the activity window [1, 6]. Another repeating FRB source, FRB 20121102A, has a candidate activity period of about 160 days [16, 5]. The periodic activity of these FRB sources is theorized to originate from orbital motion, rotation, or precession (Ref. [19] and references therein). The discovery of ILT J1101 + 5521 presents a possible analogy for periodically active FRBs, which could originate from highly magnetised neutron stars (potentially ‘magnetars’) interacting with a massive stellar companion [19], and which would have greatly scaled-up energetics compared with a white dwarf system. FRB 20180916B is at a luminosity distance of about 150 Mpc, and its millisecond-duration bursts are at least trillions of times more luminous than ILT J1101 + 5521 [12]. The 16.33-day activity period of FRB 20180916B is comparable to the orbital periods of high-mass binaries known to harbour a neutron star. For instance, LS I +61° 303 has an orbital period of about 26.5 days and has recently been shown to harbour a neutron star producing sporadic pulsations with a period of 269 ms [20]. In contrast to LS I +61° 303, however, the periodic burst activity of FRB 20180916B could be related to the orbital period of the system and share some of the viewing geometry and magnetic interaction effects we propose to explain ILT J1101 + 5521 .

## References

- [1] M Amiri, BC Andersen, KM Bandura, M Bhardwaj, PJ Boyle, C Brar, P Chawla, T Chen, JF Cliche, D Cubranic, et al. Periodic activity from a fast radio burst source. *Nature*, 582(7812): 351–355, 2020.
- [2] DAH Buckley, PJ Meintjes, SB Potter, TR Marsh, and BT Gänsicke. Polarimetric evidence of a white dwarf pulsar in the binary system ar scorpii. *Nat. Astron.*, 1(2):0029, 2017.
- [3] M Caleb, E Lenc, DL Kaplan, T Murphy, YP Men, RM Shannon, L Ferrario, KM Rajwade, TE Clarke, S Giacintucci, et al. An emission-state-switching radio transient with a 54-minute period. *Nat. Astron.*, pages 1–10, 2024.

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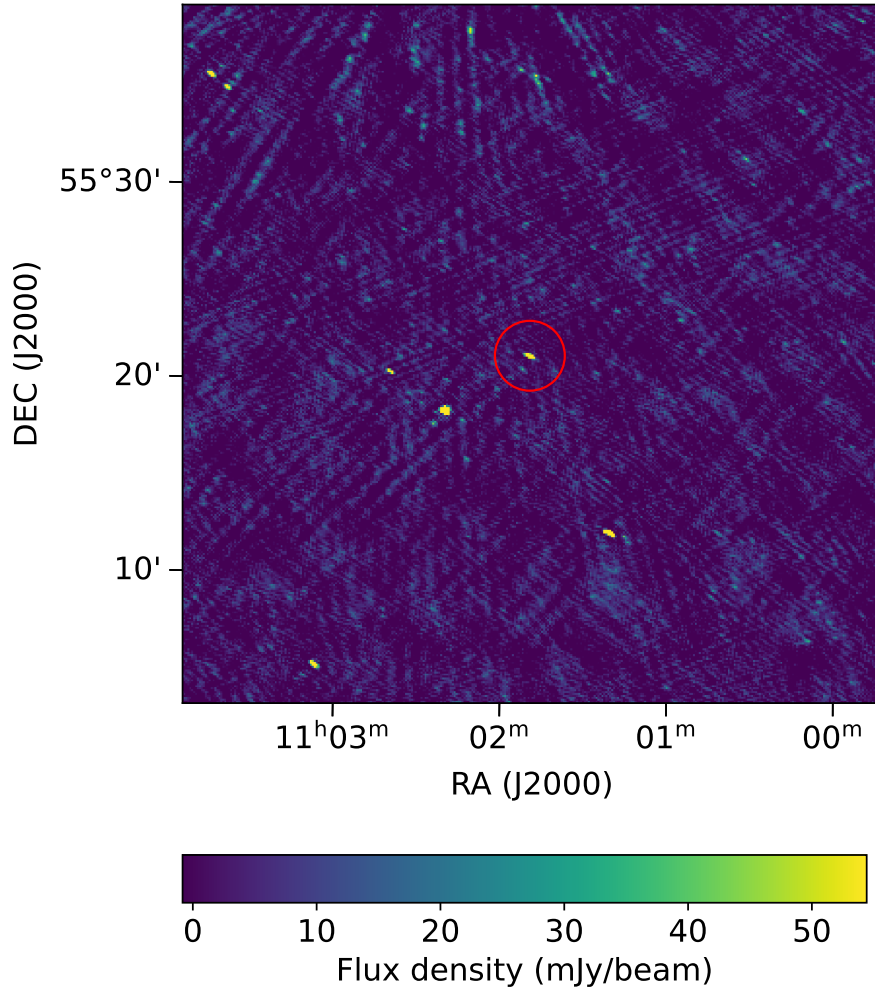
<sup>1</sup>After submitting this work, a new long-period radio source has been announced [9], with an optical counterpart, suggestive of an M dwarf - white dwarf interpretation.

- [4] Manisha Caleb, Ian Heywood, Kaustubh Rajwade, Mateusz Malenta, Benjamin Willem Stappers, Ewan Barr, Weiwei Chen, Vincent Morello, Sotiris Sanidas, Jakob Van Den Eijnden, et al. Discovery of a radio-emitting neutron star with an ultra-long spin period of 76 s. *Nat. Astron.*, 6(7):828–836, 2022.
- [5] M Cruces, LG Spitler, P Scholz, R Lynch, A Seymour, JWT Hessels, C Gouiffés, GH Hilmarsson, M Kramer, and S Munjal. Repeating behaviour of frb 121102: Periodicity, waiting times, and energy distribution. *Mon. Not. R. Astron. Soc.*, 500(1):448–463, 2021.
- [6] A Gopinath, CG Bassa, Z Pleunis, JWT Hessels, P Chawla, EF Keane, V Kondratiev, D Michilli, and K Nimmo. Propagation effects at low frequencies seen in the lofar long-term monitoring of the periodically active frb 20180916b. *Mon. Not. R. Astron. Soc.*, 527(4):9872–9891, 2024.
- [7] N Hurley-Walker, X Zhang, A Bahramian, SJ McSweeney, TN O’Doherty, PJ Hancock, JS Morgan, GE Anderson, GH Heald, and TJ Galvin. A radio transient with unusually slow periodic emission. *Nature*, 601(7894):526–530, 2022.
- [8] N Hurley-Walker, N Rea, SJ McSweeney, BW Meyers, E Lenc, I Heywood, SD Hyman, YP Men, TE Clarke, F Coti Zelati, et al. A long-period radio transient active for three decades. *Nature*, 619(7970):487–490, 2023.
- [9] N Hurley-Walker, S\_J McSweeney, A Bahramian, N Rea, C Horváth, S Buchner, A Williams, B.W Meyers, Jay Strader, Elias Aydi, et al. A 2.9 hr periodic radio transient with an optical counterpart. *Astrophys. J. Lett.*, 976(2):L21, 2024.
- [10] Scott D Hyman, T Joseph W Lazio, Namir E Kassim, Paul S Ray, Craig B Markwardt, and Farhad Yusef-Zadeh. A powerful bursting radio source towards the galactic centre. *Nature*, 434(7029):50–52, 2005.
- [11] Scott D Hyman, Subhashis Roy, Sabyasachi Pal, T Joseph W Lazio, Paul S Ray, Namir E Kassim, and Sanjay Bhatnagar. A faint, steep-spectrum burst from the radio transient gcrt j1745–3009. *Astrophys. J.*, 660(2):L121, 2007.
- [12] Benito Marcote, Kenzie Nimmo, JWT Hessels, SP Tendulkar, CG Bassa, Z Paragi, A Keimpema, M Bhardwaj, R Karuppusamy, VM Kaspi, et al. A repeating fast radio burst source localized to a nearby spiral galaxy. *Nature*, 577(7789):190–194, 2020.
- [13] TR Marsh, BT Gänsicke, S Hümmerich, F-J Hamsch, K Bernhard, C Lloyd, E Breedt, Elizabeth R Stanway, DT Steeghs, SG Parsons, et al. A radio-pulsing white dwarf binary star. *Nature*, 537(7620):374–377, 2016.
- [14] Ingrid Pelisoli, TR Marsh, David AH Buckley, I Heywood, Stephen B Potter, Axel Schwöpe, Jaco Brink, Annie Standke, PA Woudt, SG Parsons, et al. A 5.3-min-period pulsing white dwarf in a binary detected from radio to x-rays. *Nat. Astron.*, 7(8):931–942, 2023.
- [15] E Petroff, JWT Hessels, and DR Lorimer. Fast radio bursts at the dawn of the 2020s. *Astron. Astrophys. Rev.*, 30(1):2, 2022.
- [16] KM Rajwade, MB Mickaliger, BW Stappers, Vincent Morello, Devansh Agarwal, CG Bassa, RP Breton, Manisha Caleb, Aris Karastergiou, EF Keane, et al. Possible periodic activity in the repeating frb 121102. *Mon. Not. R. Astron. Soc.*, 495(4):3551–3558, 2020.
- [17] Nanda Rea, F Coti Zelati, Clara Dehman, Natasha Hurley-Walker, Domitilla de Martino, Arash Bahramian, David AH Buckley, Jaco Brink, Adela Kawka, José A Pons, et al. Constraining the nature of the 18 min periodic radio transient gleam-x j162759. 5-523504.3 via multiwavelength observations and magneto-thermal simulations. *Astrophys. J.*, 940(1):72, 2022.

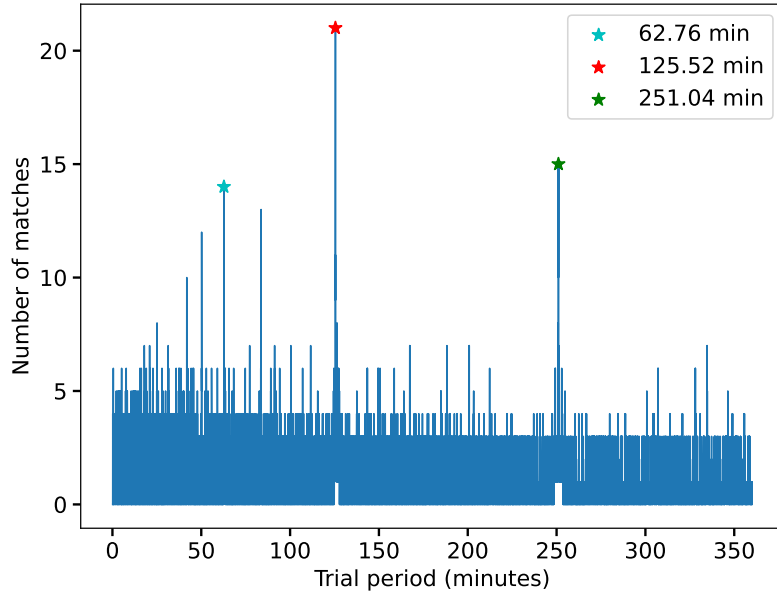
- [18] Elizabeth R Stanway, TR Marsh, Paul Chote, BT Gänsicke, D Steeghs, and Peter J Wheatley. Vla radio observations of ar scorpii. *Astron. Astrophys.*, 611:A66, 2018.
- [19] Shriharsh P Tendulkar, Armando Gil de Paz, Aida Yu Kirichenko, Jason WT Hessels, Mohit Bhardwaj, Fernando Ávila, Cees Bassa, Pragya Chawla, Emmanuel Fonseca, Victoria M Kaspi, et al. The 60 pc environment of frb 20180916b. *Astrophys. J. Lett.*, 908(1):L12, 2021.
- [20] Shan-Shan Weng, Lei Qian, Bo-Jun Wang, Diego F Torres, Alessandro Papitto, Peng Jiang, Renxin Xu, Jian Li, Jing-Zhi Yan, Qing-Zhong Liu, et al. Radio pulsations from a neutron star within the gamma-ray binary ls i+ 61 303. *Nat. Astron.*, 6(6):698–702, 2022.

Parameter	Timing Model 1	Timing Model 2
$F_0$ ( $s^{-1}$ )	$1.3277 \times 10^{-4} \pm 2.4 \times 10^{-10}$	$1.3277 \times 10^{-4} \pm 3.6 \times 10^{-9}$
$N_{\text{ToA}}$	7	6
PEPOCH (MJD)	56583.794823681	56583.794823681

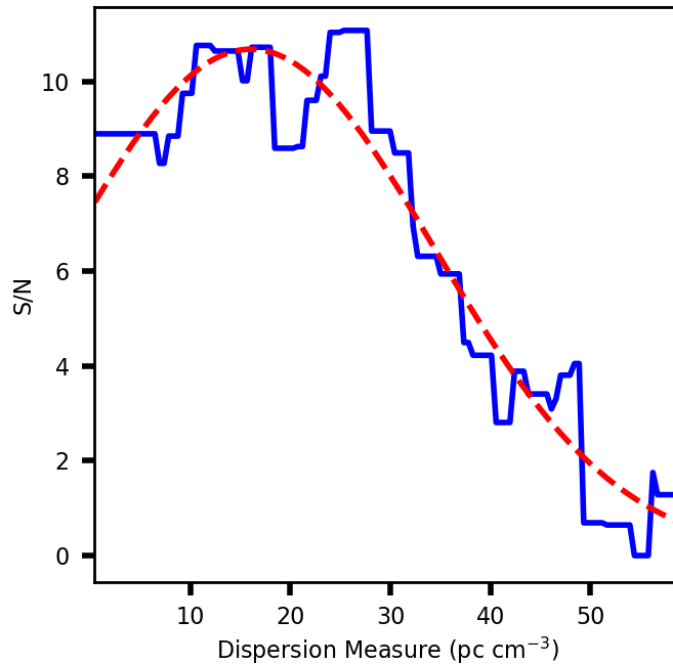
**Supplementary Table 1: Best-fit timing solutions with different number of ToAs.** Timing model 1 includes all 7 ToAs, while model 2 includes 6 ToAs from December 2020.



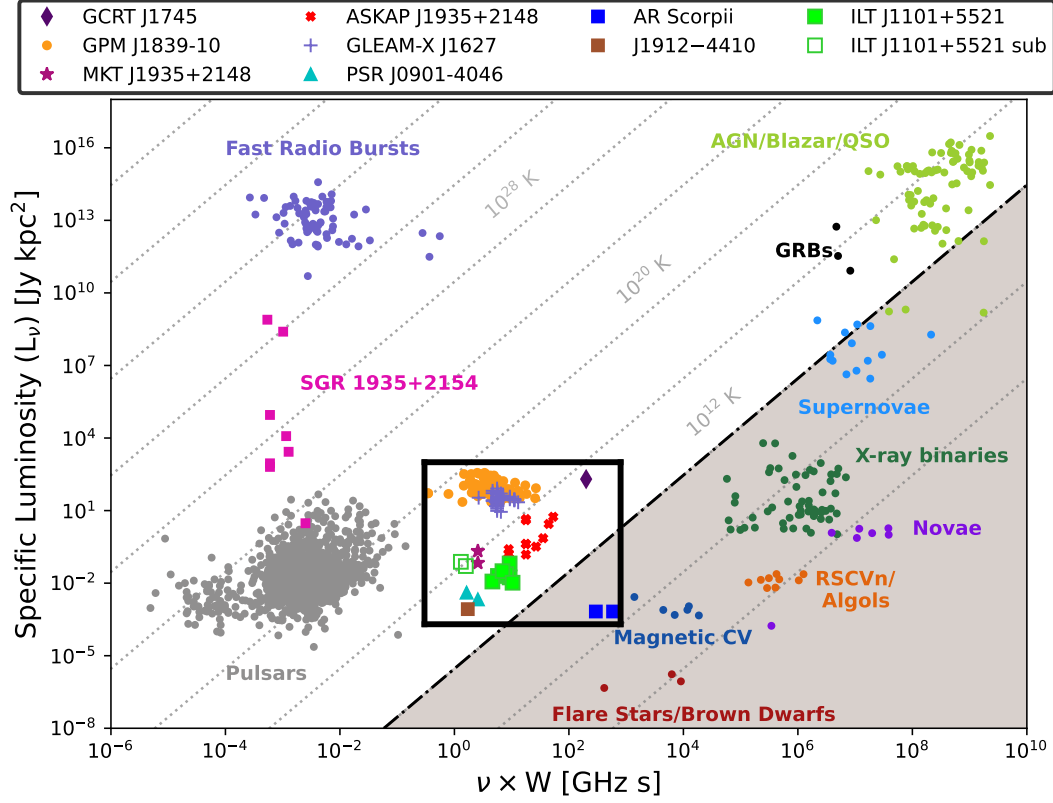
**Supplementary Figure 1: Snapshot image, in which ILT J1101 + 5521 was flaring.** This 8-second snapshot is taken during the brightest flare (observation ID L801324). The location of ILT J1101 + 5521 is indicated with a red circle.



**Supplementary Figure 2: Number of matched time differences between pulse ToAs as a function trial period in minutes.** The red star shows the preferred period of 125.52 minutes, while the cyan and green star show the (sub)harmonics of the preferred period.



**Supplementary Figure 3: Signal-to-noise ratio of the brightest pulse as a function of DM.** Frequency averaged, peak signal-to-noise ratio of the bright pulse presented in Figure 1b (Main) as a function of assumed dispersion measure in blue. The red dashed curve shows a Gaussian fit to the data.



**Supplementary Figure 4: The luminosity of different types of radio transients as a function of their width ( $W$ ) and frequency ( $\nu$ ).** Figure adapted from [3]. Diagonal lines represent constant brightness temperatures. The brightness temperature of  $10^{12}$  K roughly separates coherent emitters from the incoherent ones, with the shaded region (lower-right triangle) encapsulating the incoherent emitters. The long-period sources presented in [10, 4, 8, 3] and white dwarf - M dwarf binaries AR Scorpii [13, 18] and J1912-4410 [14], shown in the legend, appear to cluster together as indicated by the box, which is merely to highlight the sources and does not have a physical significance. The pulses from ILT J1101 + 5521 are indicated with the green squares. The green squares with a white face colour are the two sub-pulses as resolved in the higher time resolution data, see Figure 1b (Main).