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Radio pulsations from a neutron star within the gamma-ray binary LS I +61° 303

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LS I +61° 303 is one of the rare gamma-ray binaries¹, emitting most of their luminosity in photons with energies beyond 100 MeV². The ~26.5 d orbital period is clearly detected at many wavelengths²⁻⁴. Additional aspects of its multi-frequency behavior make it the most interesting example of the class. The morphology of high-resolution radio images changes with orbital phase displaying a cometary tail pointing away from the high-mass

star⁵. LS I +61° 303 also shows superorbital variability^{3,6-9}. A couple of energetic ($\sim 10^{37}$ erg s⁻¹), short, magnetar-like bursts have been plausibly ascribed to it¹⁰⁻¹³. LS I +61° 303's phenomenology has been put under theoretical scrutiny for decades, but the lack of certainty regarding the nature of the compact object in the binary has prevented advancing our understanding of the source. Here, using observations done with the Five-hundred-meter Aperture Spherical radio Telescope (*FAST*), we report on the existence of transient radio pulsations from the direction of LS I +61° 303. We find a period $P = 269.15508 \pm 0.00016$ ms at a significance of $> 20\sigma$. This is the first evidence for pulsations from this source at any frequency, and strongly argues for the existence of a rotating neutron star in LS I +61° 303.

LS I +61° 303 locates at a distance of 2.65 ± 0.09 kpc¹⁴ and contains a compact object orbiting a rapidly-rotating B0Ve star every 26.5 days^{3,15}. The dynamical mass of the compact object is between 1 and 4 M_{\odot} ; thus, just from dynamical arguments, it could either be a neutron star or a low-mass black hole¹⁵⁻¹⁷. Models involving an accreting black hole launching a relativistic jet (a microquasar) see e.g.,¹⁸; a rotationally-powered neutron star emitting a relativistic wind of particles in interaction with the stellar wind of the companion, see e.g.,¹⁹, and a neutron star alternating between a rotationally-powered emission and propeller ejection of the mass lost by the companion, see e.g.,²⁰, have been proposed to explain the multi-frequency phenomenology. Despite modern incarnations of these models were able to provide a framework where to interpret the growing number of observations, the fact that they are based on dissimilar compact object scenarios stagnated progress.

Prior deep searches in the radio^{21,22}, X-ray²³, and gamma-ray band²⁴ were not successful in finding pulsations. This is in fact not surprising: free-free absorption -which may have a complex temporal behavior according to binary conditions- can easily wash out the pulses in the radio band, see e.g.,²⁵. Also, the radio cone of emission may altogether point in a different direction from Earth. In X-rays, the imposed pulsed fraction upper limit of $\sim 10\%$ (at 3σ confidence level) could well be larger than the actual pulsed fraction of the source, as is the case for other pulsars. In fact, only a few dozen pulsars out of the ~ 300 detected in gamma rays and the ~ 3000 in radio have non-thermal X-ray pulsations detected. Finally, in gamma-rays, LS I +61° 303 lies in a complex and populated region, and not only the diffuse background, but the likely origin of at least part of the GeV emission beyond the magnetosphere of the putative pulsar may preclude detecting pulses. Additionally, the relatively large uncertainty in the orbital parameters reduces the sensitivity of blind searches across all frequencies when long integration times are needed²⁶. The best chance to ever detect pulsations from LS I +61° 303 was to try observing at a large radio sensitivity in the orbital region where the free-free absorption effect due to the stellar wind (or disk) would naturally

be the lowest ²².

FAST is the largest single-aperture radio telescope located in a naturally deep and round karst depression in Southwest China’s Guizhou province (see **Methods**). *FAST* executed four observations towards LS I +61° 303, with a total exposure time of ~ 10.2 hours (see Table 1): one at the orbital phase of ~ 0.07 and three around the orbital phase of ~ 0.6 . The zero of orbital phase of LS I +61° 303 is defined at $\text{MJD}_0 = 43,366.275$, and the orbital period is estimated as $P = 26.4960$ days (e.g., see ³). In quoting orbital phases, we have assumed that the orbital phase of periastron is $\phi_{\text{peri}} = 0.23^{17}$ as is common in the study of this source (but see **Methods** for further discussion of orbital uncertainties).

The PRESTO (PulsAR Exploration and Search TOolkit package²⁷ was used to search for the periodic signal. The Dispersion Measure (DM) in the direction of LS I +61° 303, as predicted by the YMW16 model²⁸ is $138.58 \text{ pc cm}^{-3}$, while its upper limit is $316.59 \text{ pc cm}^{-3}$. To avoid missing the signal, and considering the error, the DM range for our search was 0 to 500 pc cm^{-3} . Since the orbital period is much longer than the exposure time, the Doppler effect is negligible. We have carried out the acceleration search with $z_{\text{max}} = 200$, we also used the routine BEAR for single pulse search (see details in **Methods**).

An unambiguous pulse signal (a single-trial significance of $\sim 22.4\sigma$, see **Methods**) with a single-peak profile emerges from the data taken on 2020 January 7th ($\text{MJD} = 58,855.5278$, Figure 1). The period, pulse width and DM of this pulsar are $269.15508(16) \text{ ms}$, $33.30 \pm 0.96 \text{ ms}$, and 240.1 pc cm^{-3} , respectively (see also Supplementary Figure 1). The pulsations disappeared in the 3rd and 4th observations (one-day apart of each other), taken several months after the positive detection, at a similar orbital phase. A single pulse search was conducted for our observation, and more than 40 were detected in the second observation (where the radio pulsation is visible), but none were seen in the other three (see **Methods**).

Given that our observations are short in comparison to the orbital period of the binary, and the pulsation appears to be non-steady in nature, the orbital imprint cannot be detected in our data. In addition, the angular resolution (L-band) of *FAST* is of $\sim 2.9'$. As for other *FAST* observations in the same band, we cannot therefore formally exclude the presence of a pulsar just behind LS I +61° 303, unrelated to it, that is responsible for the pulsed emission. This is deemed unlikely, however (**Methods**).

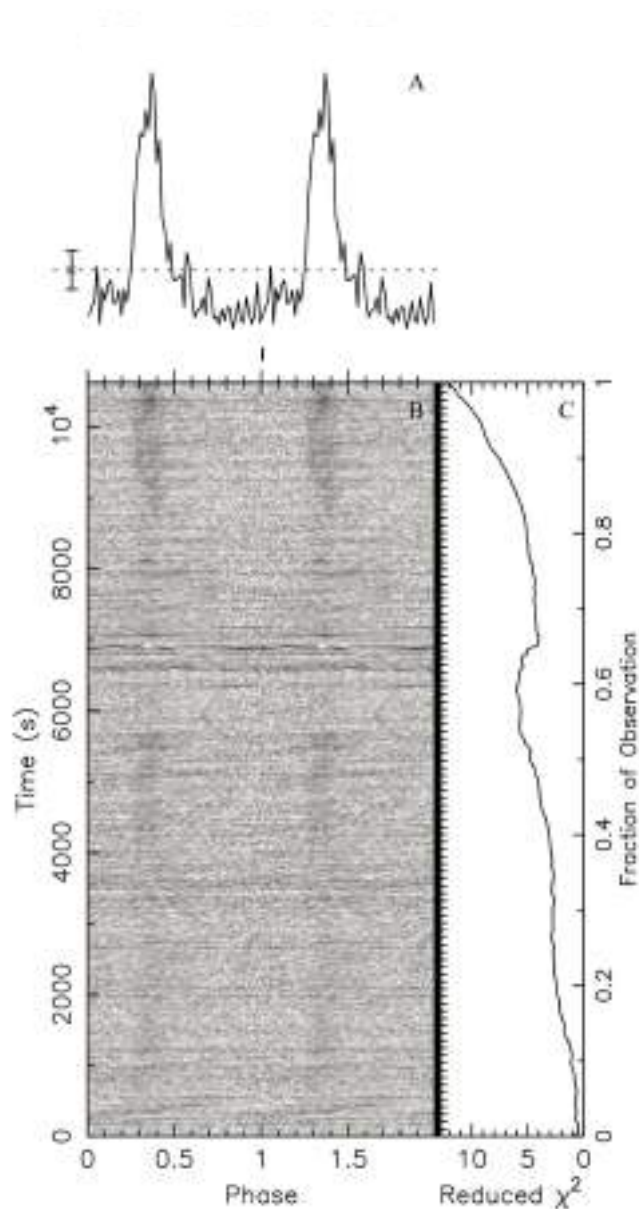


Figure 1: **Radio pulsations were recorded in the FAST data recorded on 2020 January 7th.** The data are folded over the period of $P = 269.15508$ ms, and the reduced χ^2 (i.e. the significance of the pulsation) is computed with the folded profile compared to the average value of the folded profile. The integrated pulse profile is plotted in A. The intensity (gray-scale) of the pulse and the reduced χ^2 as a function of the pulse phase and the observational time are shown in B and C, respectively.