# A COMPACT RADIO COUNTERPART TO THE ENERGETIC X-RAY PULSAR ASSOCIATED WITH THE TEV GAMMA-RAY SOURCE J1813-178

Sergio Dzib, Luis F. Rodríguez, and Laurent Loinard

Centro de Radioastronomía y Astrofísica
Universidad Nacional Autónoma de México, Morelia, Mexico

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RESUMEN

Reportamos la detección de una fuente de radio compacta y variable coincidente con CXOU J181335.1–174957, el pulsar de rayos-X localizado cerca del centro de la remanente de supernova joven G12.82–0.02, la cual traslapa con la fuente TeV compacta HESS J1813–178. La fuente de radio compacta, que llamamos VLA J181335.1–174957, fue detectada en observaciones hechas a 4.86 GHz con el VLA en 2006. Nuevas observaciones hechas con el VLA en 2009 no detectan la fuente a un nivel 1.9±0.7 veces (2.8$\sigma$) más bajo que el de 2006. Sugerimos que VLA J181335.1–174957 podría estar relacionada con alguna de las recientemente detectadas clases de pulsares de radio variables, pero no podemos alcanzar una conclusión más sólida.

ABSTRACT

We report the detection of a time-variable, compact radio source coincident with CXOU J181335.1–174957, the X-ray pulsar near the center of the young radio supernova remnant G12.82–0.02, which overlaps the compact TeV source HESS J1813–178. The compact radio source, named VLA J181335.1–174957, was detected in 4.86 GHz VLA observations made in 2006. New VLA observations made in 2009 do not detect the source at a level 1.9±0.7 times (2.8$\sigma$) lower than that of 2006. We suggest that VLA J181335.1–174957 may be related to one of the recently detected classes of variable radio pulsars but cannot reach a firmer conclusion.

*Key Words:* ISM: individual (G12.82–0.02) — ISM: supernova remnants — pulsars: individual (CXOU J181335.1–174957)



## 1. INTRODUCTION

Given that classic radio pulsars are manifestly stable in flux density (e.g., Lyne, Manchester, & Taylor 1985; Stinebring et al. 2000), the recent detection of highly variable radio emission from isolated pulsars is quite surprising. At present, several types of variable pulsars are known. The rotating radio transients (RRATs) were discovered by McLaughlin et al. (2006) and are characterized by single, dispersed bursts having durations between 2 and 30 ms. The intermittent radio pulsars, of which PSR B1931+24 is the first detected and the prototype (Kramer et al. 2006), turn on and off with quasi-periods of tens of days. Finally, the transient anomalous X-ray pulsars (TAXPs) also show variable radio emission, as discovered by Halpern et al. (2005) and Camilo et al. (2007).

We present here the detection of variable radio emission from an unlikely candidate, the recently discovered young, energetic X-ray pulsar CXOU J181335.1–174957. This 44.7 ms X-ray pulsar was discovered by Gotthelf & Halpern (2009), who used XMM-Newton observations to estimate that this rotation-powered pulsar is the second most energetic in the Galaxy (after the Crab), with a spin-down luminosity of $\sim 7 \times 10^{37}$ erg s$^{-1}$. On the other hand, a deep radio timing search made at 1.4 GHz on 2005 September 8 with the Australia Telescope National Facility (ATNF) Parkes telescope failed to detect pulsations (Helfand et al. 2007). CXOU J181335.1–174957 is associated with one of the brightest and most compact objects located by the HESS Galactic Plane Survey (Aharonian et al. 2005), the TeV source HESS J1813–178. Within the TeV extent of this source lies G12.82–0.02, a previously uncataloged young shell-type radio SNR with a diameter of $\sim 2'$ (Brogan et al. 2005; Helfand, Becker, & White 2005). The HESS source has been associated with continuum high-energy emission from X-rays to gamma rays (Reimer et al. 2008; Ubertini et al. 2005; Abdo et al. 2009; Albert et al. 2006).

In this paper, we present archival and new radio observations of CXOU J181335.1–174957 which suggest it is associated with a variable radio source. In this paper we report this detection as well as new observations made by us with the Very Large Array (VLA) to further study this radio source. In § 2 we present the observations, while in § 3 we discuss the interpretation and results. Our conclusions are given in § 4.

## 2. OBSERVATIONS

The field containing CXOU J181335.1-174957 was imaged using the Very Large Array of the NRAO[1] radio synthesis telescope on 2006 February 25 as part of project AL673. Continuum data were collected at 4.86 GHz using the 35 km A configuration. The source 1331+305 was used as an absolute amplitude calibrator (with an adopted flux density of 7.49 Jy). The source 1811-209 was used as the phase calibrator (with a bootstrapped flux density of 0.319±0.001 Jy). The total on-source time was 168 minutes. The archive data were calibrated following the standard VLA procedures, using the software package AIPS of NRAO.

In Figure 1 we show an image made with natural weighting to obtain the highest sensitivity. A faint unresolved source, with total flux density of 0.18±0.02 mJy, is clearly detected with a statistical significance of $9\sigma$. Its coordinates, $\alpha(2000) = 18^h\ 13^m\ 35\overset{s}{.}18$; $\delta(2000) = -17^\circ\ 49'\ 57\overset{''}{.}5 \pm 0\overset{''}{.}1$, are displaced $0\overset{''}{.}2$ from the Chandra X-ray position ($\alpha(2000) = 18^h\ 13^m\ 35\overset{s}{.}166$; $\delta(2000) = -17^\circ\ 49'\ 57\overset{''}{.}48 \pm 0\overset{''}{.}3$) reported by Helfand et al. (2007), consistent with the $0\overset{''}{.}3$ uncertainty in their X-ray measurement. The *a priori* probability of finding a background 0.18 mJy radio source at 4.86 GHz in the error box of the Chandra observation ($0\overset{''}{.}6 \times 0\overset{''}{.}6$) is only $5 \times 10^{-6}$ (Fomalont et al. 1991), and we consider the radio source to be physically associated with the X-ray source. We refer to the new radio source as VLA J181335.1–174957.

To study the nature of this source, we did new VLA observations at 1.43, 4.86, and 8.46 GHz on 2009 March 24 under project AR688. The array was

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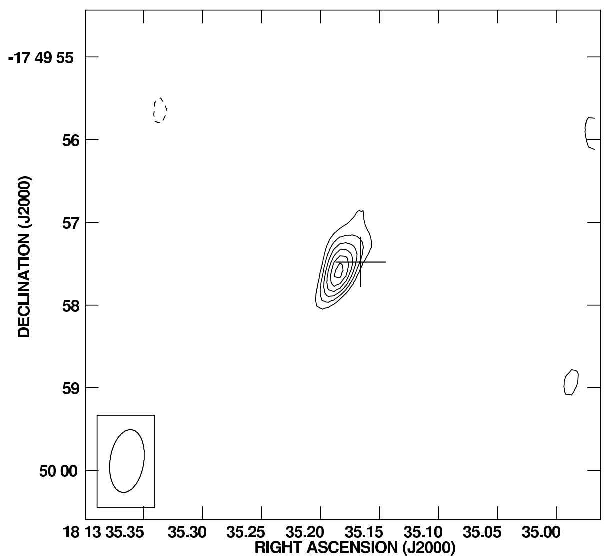


Fig. 1. VLA image at 4.86 GHz of the radio source associated with CXOU J181335.1–174957, the X-ray pulsar near the center of the young radio supernova remnant G12.82–0.02. Contours are −3, 3, 4, 5, 6, 7, and 8 times 19 $\mu$Jy beam$^{-1}$, the rms noise of the image. The synthesized beam, shown in the bottom left corner, has half power full width dimensions of $0\overset{''}{.}77 \times 0\overset{''}{.}41$, with the major axis at a position angle of $-9^\circ$. The cross marks the location and errors of the Chandra position.

then in the B configuration. The absolute amplitude calibrator was 1331+305, with adopted flux densities of 14.71, 7.49, and 5.21 Jy at 1.43, 4.86, and 8.46 GHz, respectively. At 1.43 and 4.86 GHz the phase calibrator was 1811-209, with bootstrapped flux densities of 0.723±0.004 and 0.302±0.001 Jy, respectively. At 8.46 GHz the phase calibrator was 1825-173, with a bootstrapped flux density of 0.348±0.001 Jy. The total on-source times were 58 (1.43 GHz), 57 (4.86 GHz), and 58 minutes (8.46 GHz), respectively. The 2006 and 2009 databases were calibrated and analyzed by us using the same methods.

The source VLA J181335.1–174957 was not detected during these observations at $3\sigma$ levels of 1.26 mJy (1.43 GHz), 0.096 mJy (4.86 GHz), and 0.084 mJy (8.46 GHz). The poor upper limit at 1.43 GHz results from the presence of the very bright SNR G012.8–00.2, located about $10'$ to the southeast of the radio source. This supernova should not be confused with SNR G12.82–0.02, the source around CXOU J181335.1–174957. Our main conclusion from this second set of observations is that the 4.86 GHz radio source is variable, since in 2009 it was observed at levels a factor of $1.9 \pm 0.7$ times below those of 2006.

## 3. INTERPRETATION AND RESULTS

### 3.1. *Observed Flux Density*

We first address the question of whether or not the 4.86 GHz mean flux density of 0.18 mJy observed in 2006 from VLA J181335.1–174957 is consistent with what is known of pulsars. Unfortunately, there are few observations of pulsars made at the relatively high frequency of 4.86 GHz and we have to extrapolate our results to 1.4 GHz. We then assume that if the source is a pulsar, it is expected to have a spectral index at radio wavelengths of $\alpha = -1$ to $-3$ (Manchester et al. 2005), where the flux density, $S_\nu$ is given by $S_\nu \propto \nu^\alpha$. We then expect VLA J181335.1–174957, when on, to have a mean flux density in the range of 0.6 to 7.5 mJy at 1.4 GHz. Furthermore, we adopt the distance of 4.7 kpc proposed by Messineo et al. (2008). This gives a 1.4 GHz mean luminosity in the range of 13 to 166 mJy kpc$^2$ for VLA J181335.1–174957. In Figure 2 we show, from the catalog of Manchester et al. (2005), a histogram with the number of pulsars as a function of the logarithm of the mean 1.4 GHz luminosity. From this figure it can be seen that most of the pulsars fall in the range of 2 to 200 mJy kpc$^2$. We then conclude that the flux density observed in 2006 from VLA J181335.1–174957 is consistent with the typical values for a pulsar.

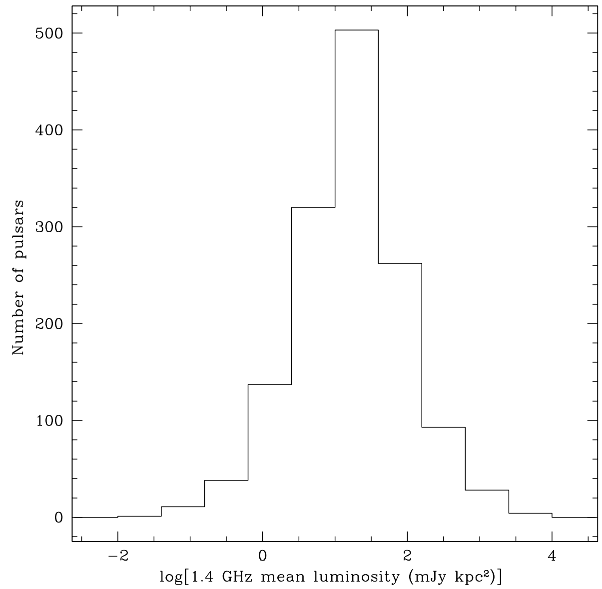


Fig. 2. Histogram of the number of pulsars as a function of the logarithm of the mean 1.4 GHz luminosity, from the catalog of Manchester et al. (2005).

### 3.2. *Variability*

In this section we discuss on the variability observed in the radio source VLA J181335.1–174957. Most pulsars are known to be nearly constant luminosity radio sources ($\leq$ 5% variability) over time spans of several days to several years (Lyne et al. 1985; Stinebring et al. 2000).

There are, however, clear examples of time variation in pulsars. The observed average pulsed radio emission from a pulsar can fluctuate for several different reasons. These include effects from the pulsar itself, as in nulling (e.g., Backer 1970), its environment, as in eclipsing binary pulsars (e.g., Fruchter, Stinebring, & Taylor 1988), or the interstellar medium, as in scintillation (e.g., Rickett 1970). Even though the scarce data available for VLA J181335.1–174957 do not allow us to firmly rule out any of the possibilities, it can be argued that scintillation (an effect that scales with the wavelength) is not expected to be important at 4.86 GHz. Eclipsing binary pulsars are rare, with only about a dozen known (e.g., Freire 2005).

We then concentrate our discussion on variability considered to be intrinsic to the pulsar. First, there are giant radio pulses first observed in the Crab pulsar (Staelin & Reifenstein 1968) and later in about a dozen other pulsars (e.g., Kuzmin 2007). These are extremely bright pulses, reaching flux densities hundreds or even thousands of times the peak flux density of regular pulses. One could propose that the possible pulsar traced by VLA J181335.1–174957 is usually very dim, and that during the 2006 observations it produced one of these pulses, that averaged over the run appeared as a weak but detectable source. However, we have analyzed the time behavior of the flux density of the new radio source along the approximately 3.4 hours of the observations, going down to the 10 second integration time of the individual scans, and failed to detect pulses above the average flux density. We used the same procedure to search, unsuccessfully, for pulses in the new (2009) VLA data.

Another variable type of pulsars are the rotating radio transients (RRATs), discovered by McLaughlin et al. (2006). These are sources characterized by single, dispersed bursts having durations between 2 and 30 ms. Over 20 of these objects are currently known (Deneva et al. 2008; Keane et al. 2010), with characteristic ages ranging from 0.1 to 4 Myr. These ages are much longer than that of 3.3–7.5 Kyr estimated for CXOU J181335.1–174957 (Gotthelf & Halpern 2009). Furthermore, they have periods in the range of seconds, in contrast with CXOU J181335.1–174957, which has a periodicity of only

44.7 ms. In addition, these bursts should have been detected in our time analysis of the 2006 emission.

There are also the intermittent radio pulsars, of which PSR B1931+24 is the first detected and the prototype (Kramer et al. 2006). This pulsar is characterized by a 0.8 s pulsation, which turns on and off quasi-periodically every ∼35 d, with a duty cycle of ∼10 per cent. This long term variability would be consistent with the behavior of VLA J181335.1–174957, in particular, with its non detection in 2005 (Helfand et al. 2007) and 2009 (this paper), and its detection in 2006 (this paper). However, these intermittent radio pulsars appear to have longer periods and ages than CXOU J181335.1–174957.

A similar problem is present in the case of the anomalous X-ray pulsars, isolated neutron stars with magnetic fields 100–1000 times stronger than those of the typical neutron stars observed as radio pulsars. As discovered by Halpern et al. (2005) and Camilo et al. (2007), the transient anomalous X-ray pulsars (TAXPs) can show transient radio emission but their spin periods are in the range of 2 to 12 seconds (Mereghetti 2008), much longer than the value reported for CXOU J181335.1–174957. In particular, the first two cases reported, XTE J1810-197 and 1E 1547.0-5408 have periods of 5.54 and 2.069 s, respectively (Halpern et al. 2005; Camilo et al. 2007).

Finally, we speculate that the radio emission observed in 2006 from VLA J181335.1–174957 may be related to the transient radio emission observed after the two giant flares of the soft gamma-ray repeaters SGR 1900+14 (Frail, Kulkarni, & Bloom 1999) and SGR 1806–20 (Cameron et al. 2005; Gaensler et al. 2005). It has been proposed that this emission has a synchrotron nature and originates from shocks in mildly relativistic matter ejected during the giant flares (Granot et al. 2006). However, soft gamma-ray repeaters are also slow rotators (Mereghetti 2008) and this does not fit with the short period of CXOU J181335.1–174957.

## 4. CONCLUSIONS

We present VLA observations of the SNR G12.82–0.02. We report the detection of a compact radio source, VLA J181335.1–174957, that coincides in position with CXOU J181335.1–174957, the X-ray pulsar that probably produces the TeV source HESS J1813–178. This radio source appears to be time variable and we suggest that it may be related to one of the recently detected classes of variable radio pulsars, but cannot reach a firmer conclusion.

Clearly, additional observations are required to better understand the nature of VLA J181335.1–174957. In particular, new deep radio timing searches may detect the pulsar during its "on" phase and determine its radio parameters. Simultaneous EVLA observations will help determine if the source is pulsing or not during its active periods.

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Sergio Dzib, Laurent Loinard, and Luis F. Rodríguez: Centro de Radiostronomía y Astrofísica, Universidad Nacional Autónoma de México, Apdo. Postal 3-72 (Xangari), 58089 Morelia, Michoacán, Mexico (s.dzib, l.loinard, l.rodriguez@crya.unam.mx).