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A transient, flat spectrum radio pulsar near the Galactic Centre

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ABSTRACT

Recent studies have shown possible connections between highly magnetized neutron stars (‘magnetars’), whose X-ray emission is too bright to be powered by rotational energy, and ordinary radio pulsars. In addition to the magnetar SGR J1745−2900, one of the radio pulsars in the Galactic Centre (GC) region, PSR J1746−2850, had timing properties implying a large magnetic field strength and young age, as well as a flat spectrum. All characteristics are similar to those of rare, transient, radio-loud magnetars. Using several deep non-detections from the literature and two new detections, we show that this pulsar is also transient in the radio. Both the flat spectrum and large amplitude variability are inconsistent with the light curves and spectral indices of three radio pulsars with high magnetic field strengths. We further use frequent, deep archival imaging observations of the GC in the past 15 yr to rule out a possible X-ray outburst with a luminosity exceeding the rotational spin-down rate. This source, either a transient magnetar without any detected X-ray counterpart or a young, strongly magnetized radio pulsar producing magnetar-like radio emission, further blurs the line between the two categories. We discuss the implications of this object for the radio emission mechanism in magnetars and for star and compact object formation in the GC.

Key words: stars: magnetars – pulsars: individual: PSR J1746−2850 – Galaxy: centre.

1 INTRODUCTION

The pulsed radio emission from neutron stars (pulsars) is thought to be powered by their rotation. In some rare, young neutron stars with high magnetic field strengths (anamalous X-ray pulsars, AXPs and soft-gamma repeaters, SGRs, $B \sim B_{\rm crit} \gtrsim 4.4 \times 10^{13}$ G, e.g. Turolla, Zane & Watts 2015), the observed X-ray luminosity can exceed the magnetic dipole spin-down luminosity. According to the ‘magnetar’ model, this X-ray emission is instead powered by dissipation of the magnetic field (Thompson, Lyutikov & Kulkarni 2002). Observationally (e.g. Rea et al. 2014), magnetars have relatively large spin periods ($P \simeq 0.3$–12 s) and period derivatives ($\dot{P} \sim 10^{-15}$–10^{-10} s s^{-1}), typical X-ray luminosities of $L_{\rm X} \sim 10^{31-35}$ erg s^{-1} and experience episodes of enhanced X-ray activity that can be either a long-lived ‘outburst’ (lasting months to years; transient magnetars) or short-lived bursts and flares (lasting seconds to minutes).

The discoveries of radio pulsars with high inferred dipolar magnetic fields (high-B pulsars, Camilo et al. 2000; McLaughlin et al. 2003) of magnetars with low dipolar field strength $B < B_{\rm crit}$ (e.g. Rea et al. 2010) and of transient pulsed radio emission from magnetars (Camilo et al. 2006) show that these sources are not separated solely by the inferred dipolar magnetic field strength. The recent discovery of X-ray outbursts from a high-B radio pulsar suggests that objects can be hybrids between classes (Archibald et al. 2016; Gogus et al. 2016). The pulsed radio emission from four (PSR J1622−4950, 1E 1547.0−5408, XTE J1810−197, SGR J1745−2900, Camilo et al. 2006, 2008; Levin et al. 2010; Eatough et al. 2013) out of 28[1] magnetars (all transient) is associated with X-ray outbursts (Burgay et al. 2006; Crawford, Hessels &

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[1] http://www.physics.mcgill.ca/pulsar/magnetar/main.html

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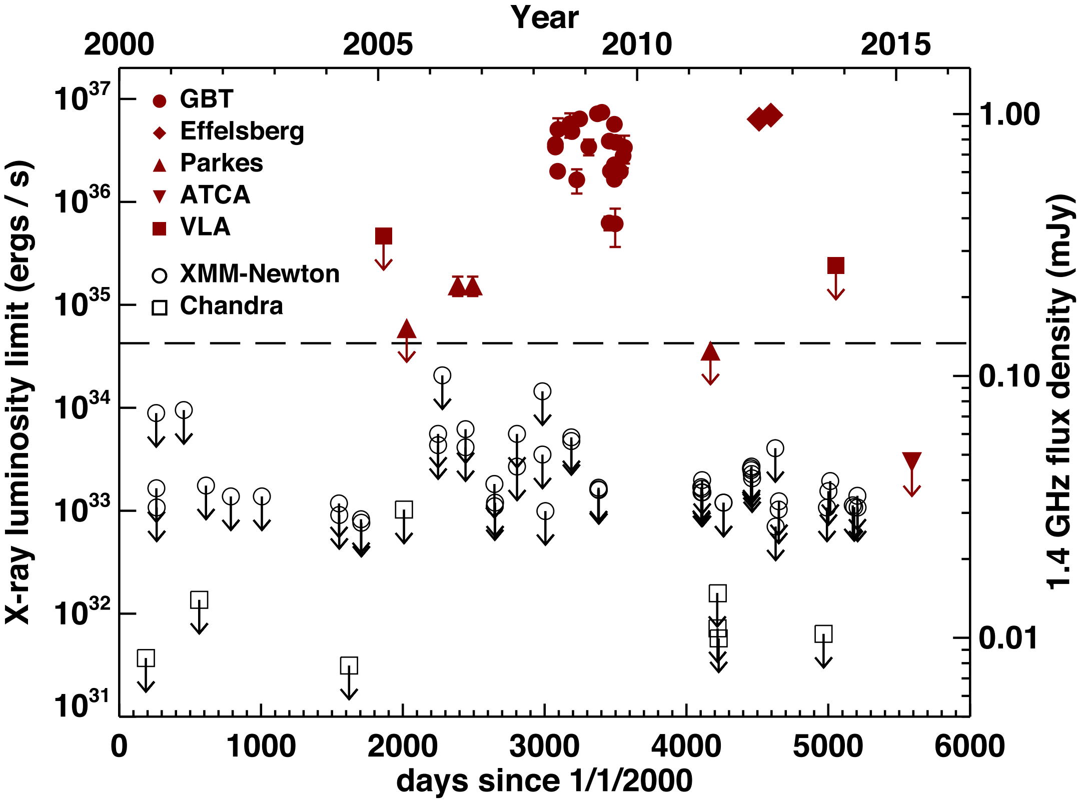

Figure 1. Radio light curve of PSR J1746−2850 from pulsar timing and searches (solid points, right-hand axis) and imaging (squares), as well as X-ray non-detections (open points, left-hand axis). The pulsar was originally detected and timed in GBT radio observations in 2008 and 2009 (Deneva et al. 2009), and was later also found in Parkes survey data from 2006 (Bates et al. 2011). It was not detected in a previous Parkes survey in 2005 (Johnston et al. 2006) or in 2011 (Ng et al. 2015), but was then detected at a high flux density in 2012 with Effelsberg. Since then there have been upper limits from VLA images (Ludovici et al. 2016) and gated ATCA images (Schnitzeler et al. 2016). PSR J1746−2850 has not been detected in the X-ray, despite dense, deep imaging of the GC region since 2000, leading to many upper limits (open points). The limits have been converted to unabsorbed X-ray luminosity, assuming a GC distance of 8.3 kpc (e.g. Chatzopoulos et al. 2015; Gillessen et al. 2017) and using the column density ($N_{\rm H} \simeq 1.9 \times 10^{23}$ cm^{-2}) and spectrum ($kT_{\rm bb} \simeq 1$ keV) towards the nearby GC magnetar SGR J1745−2900 (Coti Zelati et al. 2015). All limits rule out a magnetar outburst in the X-rays ($L_{\rm X} > \dot{E} \simeq 4.2 \times 10^{34}$ erg s^{-1}, long dashed line).

Kaspi 2007; Lazarus et al. 2012). It provides important clues to the outburst mechanism and magnetospheric structure, but remains poorly understood. This radio emission is distinct from that of ordinary radio pulsars, with a flat spectrum (e.g. Camilo et al. 2008) and large amplitude flux variability (e.g. Lazaridis et al. 2008). All known radio-loud magnetars have low quiescent X-ray luminosities below the spin-down rate (Rea et al. 2012).

The radio pulsar PSR J1746−2850 (Deneva, Cordes & Lazio 2009), one of six known pulsars within 15 arcmin ($\simeq$ 25 pc in projected distance) of Sgr A* in the Galactic Centre (GC), was found to have timing properties ($P \simeq 1.1$ s, $\dot{P} \simeq 1.3 \times 10^{-12}$ s s^{-1}) implying a young age ($T \simeq 13$ kyr) and a high magnetic field strength ($\simeq 4.2 \times 10^{13}$ G), as well as a flat radio spectrum ($\alpha \simeq -0.3$). All properties are characteristic of transient magnetars (e.g. Camilo et al. 2006; Torne et al. 2015). Using archival radio data and reported limits from the literature, we compile a light curve of PSR J1746−2850 to show that it is a transient radio pulsar (Section 2). We then analyse densely sampled *XMM–Newton* archival data of the GC to place limits on the X-ray luminosity going back to 2000 (Section 3) and a deep archival *Chandra* image to place a deep limit on its quiescent X-ray luminosity. We further show that the spectral indices and light curves of three high-*B* pulsars are similar to those of the ordinary pulsar population and inconsistent with those of PSR J1746−2850 (Section 5). We argue that either PSR J1746−2850 is a transient magnetar, in which case it would be the second to be detected from its radio emission and the only one for which no X-ray emission has been detected to date, or a new hybrid with magnetar-like radio emission but no X-ray outbursts. This object further blurs the line between magnetars and ordinary radio pulsars, and we discuss its implications for the magnetar radio emission mechanism and for future high-frequency pulsar searches of the GC (Section 6).

2 PSR J1746−2850 RADIO EMISSION AND RECENT NON-DETECTIONS

We compile a radio light curve (solid points and upper limits, right-hand axis of Fig. 1) of PSR J1746−2850 using a mix of archival and new data and published results. We estimate flux densities from the folded pulse profile data from the timing observations reported in Deneva et al. (2009), using the observed signal-to-noise ratio and the estimated noise at the GBT. We have removed epochs that were clearly affected by radio frequency interference, leaving observations at 2.0, 4.8 and 9.0 GHz. From those data, we confirm the Deneva et al. (2009) spectral index measurement of $\alpha = -0.3$ (see Section 5 for details), and use that to scale all flux densities to 1.4 GHz in Fig. 1. Some *RFI contamination is still present and so

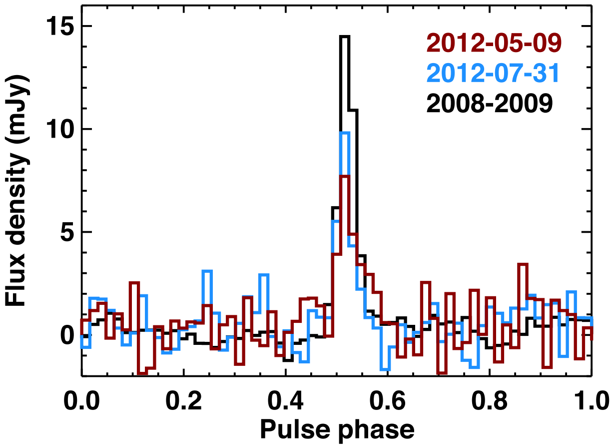

Figure 2. Pulse profiles of PSR J1746−2850 measured at Effelsberg in 2012 May and July (red and blue lines) compared with an averaged 2 GHz profile (black line, Deneva et al. 2009). The pulsar was detected with a flux density comparable to that of its peak during 2008–2009, despite multiple, deep non-detections before and since.

the intrinsic source variability is likely less than the scatter in the data.

Fig. 2 shows the average pulse profiles from detections of PSR J1746−2850 in two previously unpublished observations at $\nu \simeq 2.7$ GHz from Effelsberg in 2012 May and July using the new PSRIX backend (see Lazarus et al. 2016, for more details), compared with the best profile from GBT observations. The data were flux calibrated using observations of on- and off-source scans of radio sources with known, stable flux densities. From the calibrated pulse profiles, we estimate average flux densities of 0.79 ± 0.18 and 0.82 ± 0.16 mJy, comparable to the brightest flux densities seen with the GBT (two latest detections in Fig. 1) and with a very similar pulse profile.

Next we add flux densities and upper limits from the literature, also shown scaled to 1.4 GHz. The earliest detection of PSR J1746−2850 was in 2006 October from a Parkes multibeam survey (Bates et al. 2011). It was not found in a previous GC pulsar survey (Johnston et al. 2006) from 2005 July. In 2011 June, the pulsar was not detected using Parkes (Ng et al. 2015). PSR J1746−2850 should have been seen by both of these surveys if it was active at the time: even the lowest flux density seen by Bates et al. (2011) would have provided a signal-to-noise ratio of ∼15. Schnitzeler et al. (2016) observed this source with gated ATCA observations in 2015. The 6σ peak flux density limit was <0.5 mJy at 5 GHz (Schnitzeler et al. 2016), a limit ≃15–30 × smaller than the average from 2008–2009 and 2012 (Fig. 1). We scale this peak flux density limit to an average flux density <0.04 mJy by assuming the 2012 pulse profile (deep, recent radio upper limit in Fig. 1). There have been further non-detections since 2013 with the GBT (Siemion et al., private communication), ATCA, Effelsberg and Parkes, both from folded and search mode data. These are not shown in Fig. 1 because observation epochs and/or flux density limits are not available.

Since the original timing solution was successfully used to detect the pulsar in 2012, it seems unlikely that the non-detections could be due to timing irregularities. Another possible explanation for non-detections in timing observations is time-variable scattering. All pulsars observed to date in the GC region exhibit large amounts of temporal broadening (Johnston et al. 2006; Deneva et al. 2009; Spitler et al. 2014), $\tau \simeq 1$–3 s scaled to 1 GHz assuming $\tau \propto \nu^{-4}$. When $\tau \simeq P$, the pulse is smeared and becomes difficult to detect with time domain or gated observations. However, the upper limits discussed for PSR J1746−2850 are from observations at 3.1–5 GHz (or even >10 GHz; Siemion, private communication), where this degree of scattering is negligible. Further, the source has been detected over the full range of 1.4–8.4 GHz at multiple epochs. There is therefore no evidence for time variability in the scattering medium that could produce a degree of temporal broadening ∼2 orders of magnitude larger.

To further check these possible explanations, we looked for PSR J1746−2850 in deep VLA images. Two archival, high resolution observations covering the location of PSR J1746−2850 were available, taken in 2005 and 2013 (see Fig. 1). The 2005 February data were taken at 8.4 GHz with 100 MHz of total bandwidth and 2.2-h integration time in AB configuration. No point source was identified within 2σ of the timing position of PSR J1746−2850 (10 × 6 arcsec). The highest peak within this region was ≃ 0.14 mJy beam^{-1}, and we place a 3σ upper limit of 0.21 mJy at 8.4 GHz. The 2013 observations covered multiple VLA configurations from DnC to BnA, with an instantaneous bandwidth of 2 GHz centred on 5 GHz (Ludovici et al. 2016). Again no point source was found near the timing position of PSR J1746−2850. The highest peak of the image was 0.12 mJy beam^{-1} within this region, leading to a 3σ upper limit of 0.18 mJy. The point source sensitivity in both images is limited by significant diffuse emission in the region. None the less, the limits are factors of ≃1.5 and 2 lower than the average flux densities measured with the GBT at 5 and 8.4 GHz. There could be additional systematic errors on the pulsar timing position, and there are somewhat higher peaks nearby. However, these appear to be from diffuse emission. While the imaging limits are not as deep as those from timing, they cannot be affected by uncertainties in the timing solution. Since it is the most likely explanation, we conclude that the non-detections are due to intrinsic source variability and that PSR J1746−2850 is a transient pulsar.

3 ARCHIVAL X-RAY DATA

We looked for an X-ray counterpart to PSR J1746−2850 in archival images of the GC. The position is in the field of view of *XMM–Newton*/EPIC imaging observations of Sgr A*, providing a large number of observations from 2000 to the present, totalling ≃2.4 Msec of exposure time. Almost all images were obtained with the PN camera, while a handful was from MOS1. No source was detected within <20 arcsec ($\gtrsim 3\sigma$) of the position of PSR J1746−2850 in any of the images. We used the default pipeline output sensitivity maps to obtain upper limits on the observed source flux. These values were then converted to unabsorbed (intrinsic) luminosity limits (open circles in Fig. 1) using the column density ($N_{\rm H} \simeq 1.9 \times 10^{23}$ cm^{-2}) and spectrum (blackbody with $kT \simeq 1$ keV) of the GC magnetar SGR J1745−2900 (Rea et al. 2013; Coti Zelati et al. 2015), and a distance of 8.3 kpc to the GC (e.g. Chatzopoulos et al. 2015; Gillessen et al. 2017). Accounting for the spectral shape and absorption leads to a correction by factors of 2.5–5 depending on the camera and filter used for each observation.

The radio position of PSR J1746−2850 is not within the field of view for *Chandra* when centred on Sgr A*, but its position was still observed in offset pointings at several epochs with the ACIS-I instrument, totalling 392 ksec of exposure time. No counts were observed from near this source position. The closest point sources detected by Muno et al. (2009) are $\gtrsim$20 arcsec away, $\gtrsim 3\sigma$ from the pulsar timing position and far enough that the false positive rate for finding an X-ray point source becomes high. We estimate

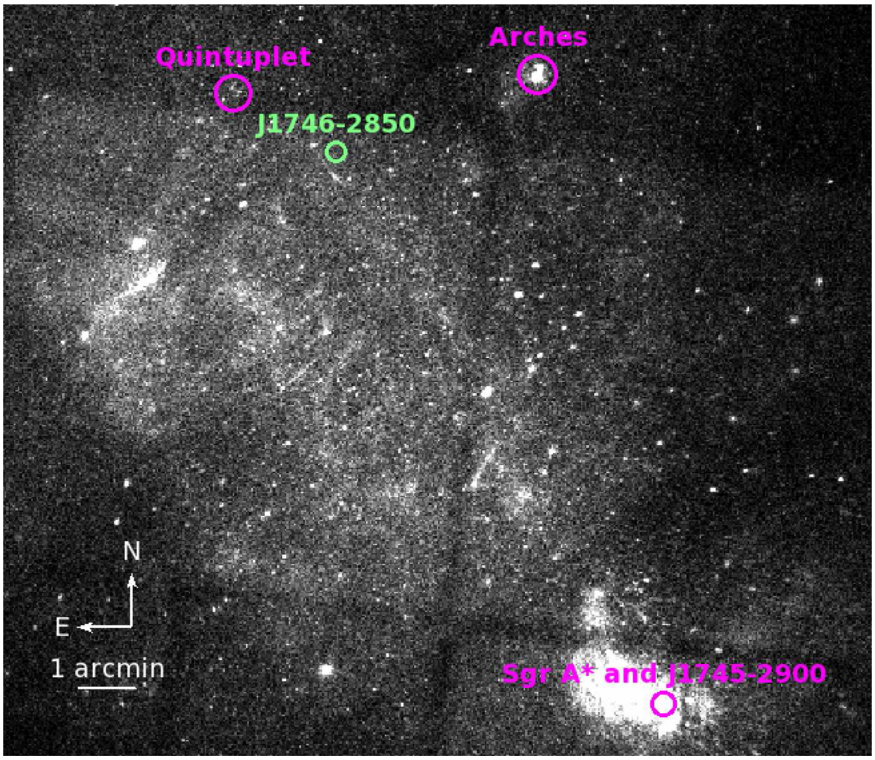

Figure 3. Composite *Chandra* ACIS-I 392 ksec image of the GC, with the radio location of PSR J1746−2850 and its 5σ uncertainty marked by the green circle (towards top left-hand side). No source is detected near the expected position, leading to stringent limits on its absorbed X-ray luminosity $\lesssim 10^{30}$ erg s^{-1}(but weaker limits on the intrinsic unabsorbed bolometric luminosity for a thermal spectrum, see Table 1). The pulsar could have been produced in the nearby, young Arches or Quintuplet clusters (Deneva et al. 2009). The positions of Sgr A* and SGR J1745−2900 are shown for comparison.

Table 1. *Chandra* upper limits on the quiescent temperature and luminosity of PSR J1746−2850 for assumed values of R, $N_{\rm H}$.

R (km)	$N_{\rm H}$ (10^{22} cm^{-2})	kT_{bb} (keV)	$L_{\rm bol}$ (10^{33} erg s^{-1})
10	1.0	0.08	0.5
10	19	0.18	14
1	1.0	0.12	0.03
1	19	0.27	0.7

upper limits by conservatively assuming three photons at the source position (e.g. Gehrels 1986). We converted the count rate limits to unabsorbed luminosity limits (open squares in Fig. 1) for the same parameters as above. For ACIS-I, the correction for the expected spectrum and column density is a factor $\simeq$2.5.

The *Chandra* data provide much deeper limits than *XMM* due to the very low instrumental background. We created a combined image (Fig. 3) and used this long exposure to obtain a limit of 1.2×10^{-5} counts s^{-1}. Neglecting interstellar absorption, this corresponds to a quiescent luminosity limit of $L_{\rm X} < 10^{30}$ erg s^{-1}. We convert this into an intrinsic neutron star temperature by assuming a blackbody spectrum along with fiducial values for the GC column density and neutron star emission radius. These are $N_{\rm H} = 19$, 1×10^{22} cm^{-2} as observed towards SGR J1745−2900 and towards lower absorption regions of the GC (Muno et al. 2009), and $R = 1$, 10 km corresponding to the polar cap or neutron star surface. The results are given in Table 1. The limits on intrinsic, quiescent luminosity are $\lesssim 10^{33}$ erg s^{-1}, lower than or comparable to the measured values for many transient magnetars and high-B pulsars (e.g. Rea et al. 2012).

4 EXTREME PULSAR VARIABILITY

As described above, the radio emission from PSR J1746−2850 appears to be transient. In addition to radio-loud magnetars, the known classes of radio pulsars with high amplitude variability on long time-scales include transitional millisecond pulsars that switch between pulsed radio and X-ray emission (e.g. Archibald et al. 2009; Papitto et al. 2013) and intermittent pulsars (Kramer et al. 2006). Since PSR J1746−2850 has a long period $\simeq$ 1s and no detected X-ray emission, we exclude the former possibility.

Intermittent pulsars are objects with 2–3 distinct states of radio emission with large differences in flux density. The duty cycles for the bright states can be short ($\simeq$10–20 per cent, e.g. Young et al. 2013), and a wide range of intermittency periods are seen. Hence, the radio light curve of PSR J1746−2850 would be roughly compatible with ‘on’ and ‘off’ periods of duration $\simeq$1 yr, similar to those of the intermittent pulsars PSR J1832+0029 (Lorimer et al. 2012) and J1841−0500 (Camilo et al. 2012).

We disfavour this interpretation, because other than their transience, the intermittent pulsars discovered to date have characteristic ages, magnetic field strengths and radio spectra comparable to normal radio pulsars (e.g. Lyne et al. 2016). As a young, high magnetic field object with a flat radio spectrum, PSR J1746−2850 differs in all three of these diagnostics.

5 PSR J1746−2850: A TRANSIENT, FLAT SPECTRUM, HIGH-*B* RADIO PULSAR

The large period and period derivative of PSR J1746−2850 (Deneva et al. 2009) imply a high surface magnetic field strength, young age and high spin-down luminosity, which classify it either as a high-B

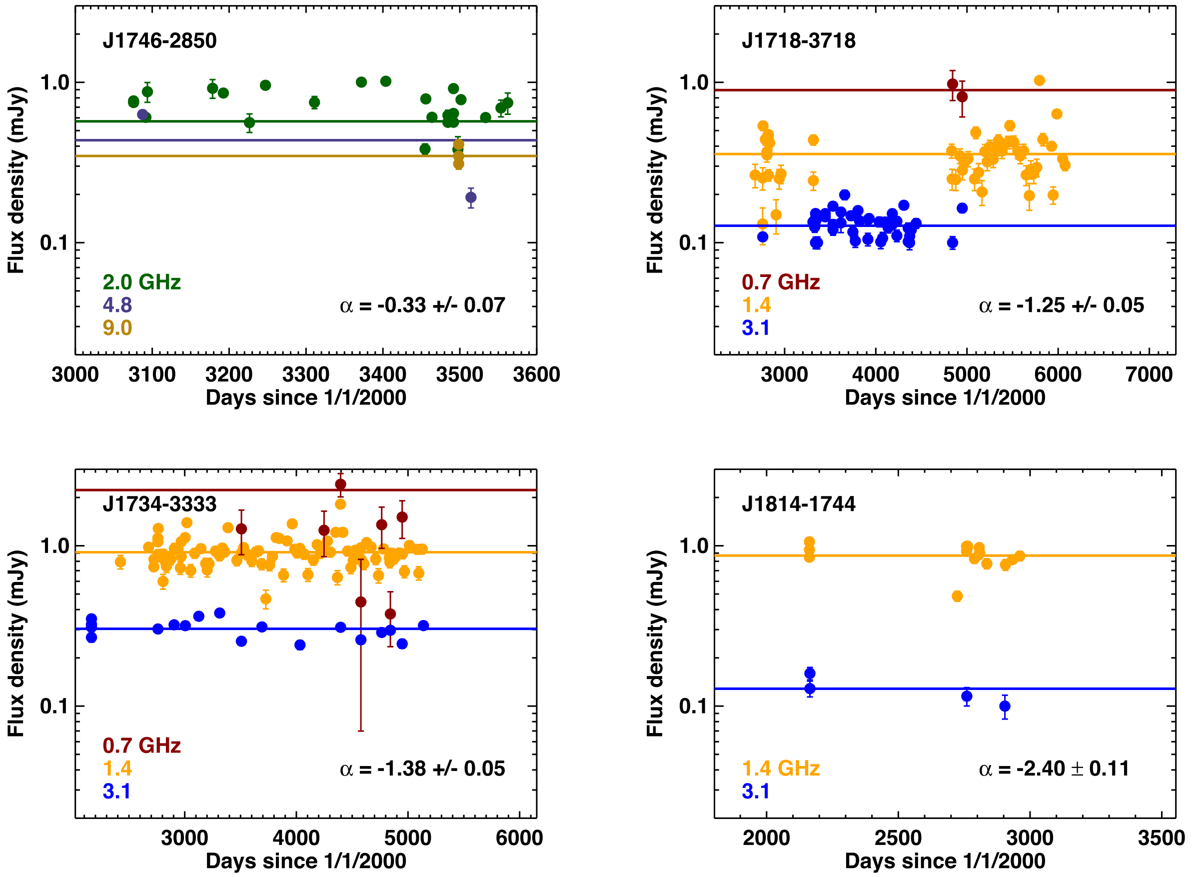

Figure 4. Light curves from timing observations of PSR J1746−2850 with the GBT in 2008–2009 (top left-hand panel, Deneva et al. 2009) and three high-*B* pulsars (other panels) with Parkes. The radio spectrum (measured from the averages at each frequency, horizontal lines) of PSR J1746−2850 was flat ($\alpha \simeq -0.3$), as seen in radio-loud magnetars. The other high-*B* pulsars have steep radio spectra ($\alpha \sim -1.2$ to -2.5), within the normal range for ordinary pulsars, and have been detected consistently over several years unlike PSR J1746−2850 (see Fig. 1).

pulsar (Camilo et al. 2000) or as a transient magnetar (SGR source). We have further shown that this radio emission is transient and has a flat spectrum, similar to that seen in the four radio-loud magnetars.

The X-ray constraints over many epochs described in Section 2 rule out steady magnetar activity and constrain the duration of any magnetar outbursts with $L_{\rm X} > \dot{E} \simeq 4 \times 10^{34}$ erg s^{-1} to several months, where $\dot{E} \propto \dot{P}/P^3$ is the magnetic dipole spin-down luminosity. X-ray outbursts with roughly exponential decay profiles have been found to precede the radio emission from magnetars (e.g. Rea & Esposito 2011). In order to trigger the radio detections in 2006, 2008–2009 and/or 2012 and not have been detected, an X-ray outburst would have had to have a decay time $\tau < 100$ d for any possible start time. This is shorter than usual outbursts in radio-loud magnetars: $\tau \sim 100$–600 d (Gavriil & Kaspi 2004; Gotthelf & Halpern 2007; Anderson et al. 2012; Coti Zelati et al. 2015), although the magnetar 1E 1547.0−5408 has shown X-ray outbursts that fade on few week time-scales (Israel et al. 2010). The defining feature of magnetars is X-ray emission exceeding the spin-down luminosity, and so the absence of any X-ray detection and strict limits on even one possible outburst preceding the radio detections in 2006, 2008–2009 or 2012 prevent us from conclusively classifying PSR J1746−2850 as a radio-loud, transient magnetar.

We then ask whether other known high-*B* pulsars show transient, flat spectrum radio emission. We measured light curves and spectra for three pulsars with surface dipolar $B \simeq 3.2 \times 10^{19} \sqrt{P \dot{P}}$ G $> 2 \times 10^{13}$ G observed at 1.4 and 3.1 GHz from Parkes monitoring observations (Fig. 4). The spectral indices range from −2.5 to −1.2, similar to those of ordinary radio pulsars (Lorimer et al. 1995; Bates, Lorimer & Verbiest 2013) and significantly steeper than the $\alpha \simeq -0.3$ of PSR J1746−2850 (top left-hand panel of Fig. 4). The sources in this sample vary in radio flux density by factors of a few over $\simeq$8 yr, similar to PSR J1746−2850 during 2008–2009. However, none were found to drop by more than an order of magnitude in flux for months or years, as is required to explain the many radio non-detections of PSR J1746−2850 (Fig. 1).

Each of the four known radio-loud magnetars, on the other hand, produces transient, flat spectrum radio emission with $\alpha \sim 0$ (e.g. Camilo et al. 2007, 2008; Levin et al. 2012; Torne et al. 2015). This mode of radio emission is ‘magnetar-like’ and not commonly seen in high-*B* pulsars. Its magnetar-like radio emission and timing properties (large P and $\dot{P}$) make PSR J1746−2850 a candidate radio-loud magnetar, even without an X-ray detection. SGR J1622−4950 was initially detected in X-ray quiescence (Levin et al. 2010) before being shown to have had an apparent X-ray outburst 2–3 yr earlier (Anderson et al. 2012). The radio emission of SGR J1745−2900 has shown no signs of fading after a few years, and has already outlasted the X-ray outburst. It is therefore possible that we missed a long ago or short duration X-ray outburst from PSR J1746−2850, and/or that an outburst will be seen in the future.

Either way, PSR J1746−2850 is a transient, flat spectrum, high-*B* radio pulsar. The magnetar-like radio emission and lack of X-ray outbursts place it as a hybrid source between magnetars and high-*B* pulsars. Along with recent findings of magnetar X-ray outbursts from a pulsar with a relatively low surface dipole field strength (Rea et al. 2010) and an otherwise ordinary high-*B* radio pulsar (Archibald et al. 2016; Gogus et al. 2016), our findings suggest that there is no distinct boundary between transient magnetars and the high-*B* end of the ordinary pulsar population.

6 DISCUSSION

PSR J1746−2850 is the fifth object to show magnetar-like flat spectrum radio outbursts, the second to be discovered in the radio, and the only one with no detected X-ray emission (quiescent or outburst) thus far. It is either an 'X-ray-quiet' transient magnetar or a high-*B* pulsar with magnetar-like radio emission. This finding has implications for the connections between high-*B* pulsars and magnetars, the magnetospheric physics of neutron stars, and for star formation, pulsar populations and the detection of additional flat spectrum radio pulsars near the GC.

6.1 Magnetar emission mechanism

The leading paradigm for magnetar outbursts posits that they are produced by dissipation of magnetospheric energy caused by motions of the neutron star crust (e.g. Thompson et al. 2002). The deep, densely sampled non-detections of an X-ray outburst from PSR J1746−2850 provide further evidence that the radio emission from transient magnetars can be produced independent of the X-ray outburst. Evidently, it may either persist many years after an X-ray outburst, or may require only a very weak or short duration outburst (or none at all). If the radio emission is triggered due to a re-arrangement of the structure of the magnetosphere following an outburst, either the time-scale for further evolution should be long or the re-arrangement should require only a small amount of dissipated energy.

Like the GC magnetar SGR J1745−2900, PSR J1746−2850 has a low observed $L_{\mathrm{X,qui}}/\dot{E} < 10^{-2}$. Depending on the column and emission radius, the resulting limit on the surface temperature is as weak as $kT < 0.3$ keV (Table 1), but none the less is another example where the quiescent X-ray emission from high-*B* pulsars / transient magnetars can be consistent with that of ordinary pulsars, unlike the persistent high X-ray luminosities seen in many magnetars (especially AXPs).

6.2 GC star formation

The GC region has a large star formation and supernova rate, implying a large birth rate of compact objects and radio pulsars. To date only six have been detected, including the GC magnetar SGR J1745−2900. Young, high-*B* objects showing magnetar-like radio outbursts make up 2/6 of the known pulsars, suggesting either efficient magnetar formation in the GC or selection effects biasing surveys against the detection of ordinary, steep spectrum radio pulsar emission.

A radio proper motion study of SGR J1745−2900 showed that it is likely associated with the young stars in the central parsec of the Galaxy (Bower et al. 2015). The origin of the other GC pulsars, including PSR J1746−2850, is less clear. Given its young age, PSR J1746−2850 may be associated with the Quintuplet (or possibly the Arches) cluster (Fig. 3). For a typical neutron star kick velocity, PSR J1746−2850 could have reached its radio position in its short lifetime (Deneva et al. 2009). Alternatively, the progenitor star itself could have been stripped from one of the clusters and would have had more time to travel to the observed radio position (Habibi, Stolte & Harfst 2014). If the source again re-brightens in the radio, its proper motion should be measurable and could distinguish between these scenarios.

An association with one of these clusters would be additional evidence that they are old enough to produce neutron stars (Figer, McLean & Morris 1999), as well as an additional association of a high-*B* pulsar or magnetar with young and massive stellar populations (e.g. Gaensler et al. 2005; Muno et al. 2006).

6.3 Predictions

SGR J1622−4950 was first detected from its flat spectrum radio emission, potentially similar to PSR J1746−2850. Two years later it underwent an X-ray outburst and was confirmed to be a transient magnetar. Future X-ray observations could find a magnetar outburst from PSR J1746−2850. Further radio observations may also find a further re-brightening or a change of spectral slope that might point to connections with other known high-*B* pulsars. We therefore encourage further monitoring of the source in the radio and X-ray.

SGR J1745−2900 showed a similarly flat radio spectrum as PSR J1746−2850, and has now been detected up to high frequency ($\nu = 291$ GHz, Torne et al. 2016). Future high sensitivity observations with IRAM, the LMT and/or phased ALMA could constrain the population of neutron stars with magnetar-like radio emission, providing a new method for finding these rare objects.

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