A Search for Single Radio Pulses and Bursts from Southern AXPs

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Abstract. We observed four southern AXPs in 1999 near 1400 MHz with the Parkes 64-m radio telescope to search for periodic radio emission. No Fourier candidates were discovered in the initial analysis, but the recent radio activity observed for the AXP XTE J1810−197 has prompted us to revisit these data to search for single radio pulses and bursts. The data were searched for both persistent and bursting radio emission at a wide range of dispersion measures, but no detections of either kind were made. These results further weaken the proposed link between rotating radio transient sources and magnetars. However, continued radio searches of these and other AXPs at different epochs are warranted given the transient nature of the radio emission seen from XTE J1810−197, which until very recently was the only known radio-emitting AXP.

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INTRODUCTION AND MOTIVATION

The detection of pulsed radio emission from the anomalous X-ray pulsar (AXP) XTE J1810−197 in 2006 [1], and more recently from a second AXP, 1E 1547.0−5408 [2], has renewed interest in searching for radio emission from these objects. In both of these cases, the radio activity is believed to be connected to the X-ray variability of the sources and is transient in nature (or at least highly variable). Given this transient behavior and that both persistent periodic emission and single pulses were detected from both AXPs, renewed searches of archival radio search data of AXPs at different epochs may reveal previously undetected radio signals from these sources.

OBSERVATIONS AND ANALYSIS

Three southern AXPs and one AXP candidate were observed in July and August 1999 with the Parkes 64-m radio telescope. The four targets observed were:

- 1E 1048.1−5937
- AX J1845−0258 (AXP candidate only)
- 1E 1841−045
- 1RXS J170849.0−400910

All observations were conducted with the center beam of the multibeam receiver [3] at a center frequency of 1374 MHz. 288 MHz of bandwidth was split into 96 frequency channels. This is the same observing setup as was used for the Parkes Multibeam Survey [4] and the AXP search observations reported by [5]. None of the four targets was in a state of X-ray outburst at the time of observation.

The data were processed using the PRESTO[1] suite of pulsar analysis tools [6, 7]. First, the raw data were excised of radio frequency interference (RFI). This is particularly important given the slow rotation rates of the AXPs and the pernicious effect of RFI at low modulation frequencies. Typically, 15-25% of the frequency channels and $\sim$ 5% of the integration time were discarded in this process. Note that this data excision increases our sensitivity limits by $\sim$ 10% and is not included in the estimates presented in Table 1. Standard Fourier searches of the data were previously reported [8], but no signals were confirmed in that analysis.

In both the folding search and single pulse analysis reported here, the data were dedispersed at a wide range of dispersion measures (DMs). The DMs ranged from 0 to 4000-8000 pc cm^{-3}, depending on the spin period of the AXP. The dedispersed time series were searched for both persistent periodic emission and single pulses and bursts.

To detect periodic emission from these sources, the data were divided into 9 MHz subbands, and each subband was dedispersed at a trial DM of 500 pc cm^{-3}. Each subband was then folded at the known neutron star spin period using the X-ray timing ephemeris (where available). In the case of AX J1845−0258, where no

[1] http://www.cv.nrao.edu/~sransom/presto

ephemeris was available, the discovery period was used. The full range of trial DMs was created by shifting the subbands with respect to each other in pulse phase. We also folded the data allowing for a search in period ±5-10 ms from the predicted period (depending on the spin period). Additionally, separate folds were made for each target using overlapping separate shorter segments of the full observation; each of these segments was 20% of the full observation length and started at intervals of 10% of the data length. This accounted for possible scintillation, strong transient RFI near the AXP spin period, and pulse strength variability on time-scales shorter than the observation length.

For the single pulse search, the raw data were again dedispersed at a set of trial DMs ranging from 0 to 4000-8000 pc cm^{-3}. Using the 0.25 ms native sampling of the data, each dedispersed time series was searched for candidate signals having a signal-to-noise ratio greater than 6.5. This threshold was chosen to avoid confusion with the RFI background. To maintain sensitivity to pulses of width greater than 0.25 ms, a matched filter was employed using a boxcar function of varying width (ranging from 1 to 30 samples). To enhance sensitivity to even longer pulses and bursts, the dedispersed time series was downsampled by combining the original samples into contiguous blocks of 2, 4, 8, 16, and 32 samples, and the same boxcar filtering was then used. This provided sensitivity to bursts with durations up to 240 ms.

RESULTS AND CONCLUSIONS

We found no convincing radio signals in either the folding or single pulse searches. The derived upper limits on the radio emission from our AXP targets are presented in Table 1. These are the most stringent radio upper limits to date for these sources. The estimated 1400 MHz luminosity limits on the periodic radio emission ($\lesssim 1$ mJy kpc^2) are 2-3 times lower than those established for XTE J1810−197 prior to outburst. However, it is still conceivable that weak radio pulses are being emitted, but that they are below our detection threshold.

The luminosity limits presented here for the periodic emission are lower by about two orders of magnitude than the 1400 MHz luminosity of the periodic pulsed radio emission from XTE J1810−197 soon after the radio emission was first detected (~ 80 mJy kpc^2) [1]. Thus we would expect to be able to easily detect comparably strong radio emission if it were beamed toward us.

Our luminosity limits on single radio pulses from our sources range from 22 to 69 Jy kpc^2 in the most conservative case, which is below the 1400 MHz luminosity of $\gtrsim 100$ Jy kpc^2 derived from the pulse strengths reported for XTE J1810−197 in its radio discovery paper [1]. Since single pulses were detected from almost every rotation of XTE J1810−197, it is likely that we would have detected a large number of comparable pulses during our observations if such pulses were beamed toward us.

Our non-detection of single pulses further weakens the hypothesis that rotating radio transients (RRATs) [9] and magnetars are linked. This has been weakened by two other recent results. First, the X-ray detection of the RRAT J1819−1458 shows that its emission is more typical of middle-aged pulsars than it is of magnetars [10]. Second, the nearby, rotation-powered pulsar PSR B0656+54 would probably have been identified as an RRAT if it were farther away [11].

We conclude from our results that any periodic or bursting radio emission from the four target AXPs is either very weak (below our detection thresholds), not beamed toward us, or non-existent or sporadic at the epoch of observation. This last possibility is suggested by the connection between the X-ray and radio activity observed for the two known radio-emitting magnetars to date. Continued radio searches of AXPs are therefore warranted given the apparent transient nature of the radio emission. Further details of this work and a more complete discussion of the results are presented in a recent journal article [12].

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TABLE 1. Radio Search Parameters and Results

	1E 1048.1−5937	**AX J1845−0258***	**1E 1841−045**	**1RXS J170849.0−400910**
Spin period (s)	6.45	6.97	11.77	11.00
Ephemeris reference	[13]	[14]†	[15]	[16]
Galactic longitude, latitude (deg)	288.26, −0.52	29.52, 0.07	27.39, −0.01	346.47, 0.03
T_{sky} (K)**	9.1	12.3	13.2	16.3
Observation MJD	51378	51391	51382	51379
Observation date	1999 Jul 19	1999 Aug 1	1999 Jul 23	1999 Jul 20
S_{1400} (mJy)‡	$\lesssim 0.02$	$\lesssim 0.02$	$\lesssim 0.02$	$\lesssim 0.02$
S_{1400} single (mJy)§	$\lesssim$ 875-50	$\lesssim$ 975-60	$\lesssim$ 1000-60	$\lesssim$ 1085-65
Distance (kpc)¶	~ 5?	~ 8?	~ 7	~ 8?
L_{1400} (mJy kpc^2)‖	$\lesssim 0.5$	$\lesssim 1.3$	$\lesssim 1.0$	$\lesssim 1.3$
L_{1400} single (Jy kpc^2)††	$\lesssim$ 22-1.3	$\lesssim$ 62-3.7	$\lesssim$ 49-2.9	$\lesssim$ 69-4.1

* AXP candidate only
† No period derivative available
** 1374 MHz sky temperature estimated from [17] assuming a spectral index of −2.6
‡ 1400 MHz flux density limit on pulsed emission estimated using the modified radiometer equation and an assumed duty cycle of 2.7%
§ Range of single-pulse 1400 MHz flux limits for pulse time-scales 0.25-240 ms
¶ Taken from [5]. Question marks indicate significant uncertainty in the value
‖ 1400 MHz luminosity limit on pulsed emission, assuming a 1 sr beaming fraction
†† Range of 1400 MHz luminosity limits on single pulses for pulse time-scales 0.25-240 ms

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