LOW-FREQUENCY RADIO TRANSIENTS IN THE GALACTIC CENTER

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ABSTRACT

We report the detection of a transient source, GCRT J1746−2757, located only $1.^\circ1$ north of the Galactic center. This transient was detected at 0.33 GHz in 1998 September but not in 1998 March or November. No X-ray counterpart was detected, suggesting that either the radio emission was highly Doppler boosted or that GCRT J1746−2757 is a member of a class of radio transients with no X-ray emission. The few previously detected radio transients in the Galactic center had timescales on order of a few months. We describe our current VLA monthly monitoring program for finding additional radio transients in the Galactic Center.

INTRODUCTION

Known classes of highly variable and transient radio sources include radio counterparts of X-ray sources and microquasars. Although there are many examples of variable radio sources discovered as a result of high-energy observations, there are surprisingly few radio surveys for highly variable or transient sources. A radio survey of the Galactic plane discovered 4 variable sources including GT 0236+610, a Galactic X-ray binary, and 1 candidate transient [1]. The MIT-Green Bank surveys [2, 3, 4] discovered a number of variable sources (< 40% variable). An on-going program at NRAO Green Bank monitors the Galactic plane at 8.4 and 14.4 GHz [5].

The Galactic center (GC) is a promising region in which to search for highly variable and transient sources. The stellar densities are high, and neutron star and black hole binaries appear as (transient or variable) X-ray sources concentrated toward the GC [6]. Previous surveys have been ill-suited for detecting radio transients toward the GC, however. Typically, they have utilized either single dish instruments, which suffer from confusion in the inner Galaxy, or they have utilized the VLA[3] for only a single epoch (e.g.,[7, 8]). The first two radio transients detected toward the GC were A1742−28 [9] and the Galactic Center Transient (GCT,[10]). These two transients had similar radio properties, but only the former was associated with an X-ray source. More recently, radio counterparts to the X-ray transients, XTE J1748−288 [11, 12, 13] and GRS 1739−278 [14] have been detected in the GC.

OBSERVATIONS

We have used recent advances in low-frequency and 3-dimensional imaging to produce a wide-field image ($\approx 2.^\circ5$) of the GC, with uniform and high resolution across the field, from 0.33 GHz VLA observations made between 1986 and 1989 [15]. A second image, designed to exploit the increase in number and quality of the 0.33 GHz receivers on the VLA since the acquisition of the data used by [15], is in progress and will be reported elsewhere [16]. However, these two epochs are already sufficient to begin a search for variable and transient radio sources. Table 1 summarizes the observations that form our new GC imaging program (see also [17]). Wide-field imaging was used to compensate for the non-coplanar geometry of the VLA [18]. We identified one source on a 1998 image (GCRT J1746−2757) that did not appear in the image of [15]. Additional 1.42 and 4.86 GHz continuum observations of this source were acquired in 2000 July and December.

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Table 1: Database of Radio Observations

Epoch	VLA Config.	Frequency (GHz)	Bandwidth (MHz)	Integration Time (hr)	RMS Noise (mJy beam^{-1})
1996 October 19	A	0.33	2.9	5.8	4
1996 October 24	A	1.4	25	0.4	7
1998 March 14	A	0.33	3.1	5.6	6
1998 September 25	B	0.33	3.1	6.7	11
1998 November 29	C	0.33	3.1	6.3	52
2000 July 15, 19	C/D	1.42	50	1.4	6
2000 July 15, 19	C/D	4.86	50	1.1	0.15
2000 December 11	A	1.42	50	2.3	0.08
2000 December 11	A	4.86	50	1.2	0.03

GCRT J1746−2757

Fig. 1 compares images of a region approximately 1° north of Sgr A* from the observations acquired during 1986–1989 and in 1998 September. Clearly evident ($\simeq 20\sigma$) in the later image is a bright (216 ± 20 mJy), unresolved source, GCRT J1746−2757. Because GCRT J1746−2757 appears in only a single epoch, we have conducted a number of tests in order to establish that our detection of GCRT J1746−2757 is robust. First, we verified that the source is not an imaging or self-calibration artifact. GCRT J1746−2757 is visible on a dirty image, prior to any deconvolution or self-calibration. The source was also present regardless of the number of facets (9 *vs.* 49 *vs.* 357) or location in each facet, used in the wide-field imaging. A second test was made by imaging sections of the data. We split the data in both time and frequency. We again find the transient flux density measurements to be consistent. Taken together, we conclude that our detection of GCRT J1746−2757 is robust.

GCRT J1746−2757 does not appear on the image of [15] nor on the 1996 or other 1998 images. We obtained targeted, follow-up VLA observations at higher frequencies on 2000 July 15 and 19 and 2000 December 11. However, even with the high resolution ($0.81'' \times 0.37''$) and sensitivity (0.03 mJy beam^{-1}) achieved in the latter observations at 4.86 GHz, the transient was not recoverable. Fig. 2 shows the limits on the light curve of GCRT J1746−2757.

A conservative lower limit on the brightness temperature of GCRT J1746−2757 is 5×10^4 K; it was a nonthermal source. We have no spectral information on GCRT J1746−2757, as it was detected at only a single frequency. We shall assume that its spectral index was the same as that for the GCT, $\alpha = -1.2$ ($S_\nu \propto \nu^\alpha$). The rapid growth and decline in brightness of GCRT J1746−2757 is consistent with that for the GCT and the radio counterpart to the X-ray transient A1742−28. For frequencies between 1.36 GHz and 1.67 GHz, the GCT decreased to approximately 12% of its peak flux density in only a month [10].

Assuming that GCRT J1746−2757 decayed according to a power law ($S_\nu \propto [t - t_0]^\beta$) with the same index as the GCT, $\beta = -0.67$ [10],and that the peak occurred no later than one day prior to our detection, we would expect its 1.4 GHz flux density to have been no less than about 1 mJy in 2000 December. As the noise level of our 2000 December 11 follow-up 1.4 GHz observations was much less (0.08 mJy beam^{-1}) than this extrapolated value, we conclude that GCRT J1746−2757 decayed much faster than the GCT, its spectrum was steeper, or both.

We have also searched for counterparts to GCRT J1746−2757 at other wavelengths. Searches of the All-Sky Monitor on the Rossi X-ray Timing Explorer All-Sky Monitor (RXTE/ASM) database and of deep exposures made with the Wide Field Camera aboard BeppoSax were kindly performed by R. Remillard and E. Kuulkers & Jean in't Zand, respectively. No X-ray counterpart was detected in 146 snapshots made by RXTE/ASM in 1998 September. Similarly, BeppoSax yielded no detections 2 days before, and 3, 6, and 11 days after the radio detection. Therefore, based on these null detections, GCRT J1746−2757 is unlikely to have been a "fast" transient, with a timescale of order days (e.g., V4641 Sgr; CI Cam). However, it may have been a more typical X-ray transient, with a time scale of order weeks to months, whose X-ray emission was simply too faint to detect.

Although no X-ray counterparts of GCRT J1746−2757 were found in these searches, a comparison of our radio measurements with the upper limit on the X-ray emission can be used to help constrain the nature of the source. Assuming that GCRT J1746−2757 does have an X-ray counterpart, the RXTE/ASM 5-12 Kev band upper limit derived for 1998

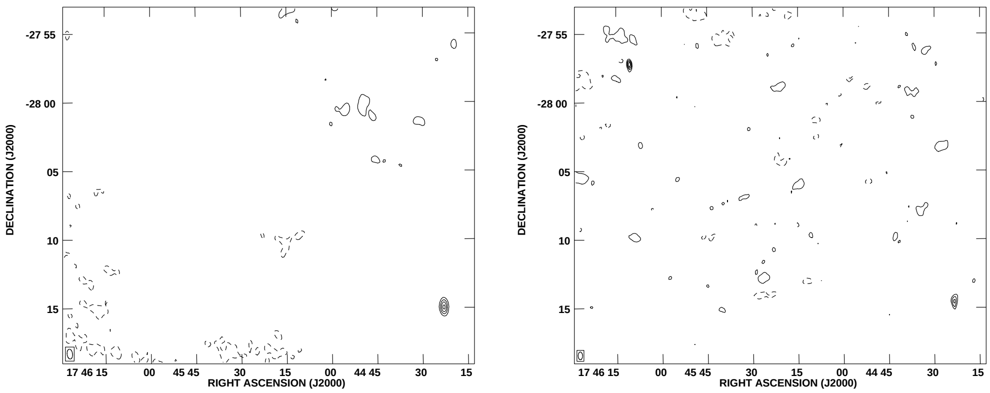

Figure 1: The field containing the GC radio transient, GCRT J1746−2757, at 0.33 GHz. (a) Late 1980s [15]. The resolution is $43'' \times 24''$. The rms noise level is 10 mJy beam^{-1}, and the contour levels are 15 mJy beam^{-1} $\times$ -5, -3, 3, 5, 7, 9, and 12. (b) 1998 September 25. The resolution is $30''\times 15''$. The rms noise level is 11 mJy beam^{-1}, and the contour levels are the same as those in (a). GCRT J1746−2757 is located in the northeast corner of the image.

September is 0.011 Crab. Reference [19] find that the peak radio and X-ray fluxes of a sample of black hole and neutron star candidate transients are correlated significantly. In determining the radio to X-ray peak ratios, they used 5 GHz measurements when available, and extrapolations assuming a spectral index of $\alpha = -0.5$ when not. Using the X-ray upper limit and a similarly extrapolated 5 GHz radio flux density, we calculate a ratio of 5500 mJy/Crab. This ratio is significantly greater than almost all those obtained for neutron star (ratio = 2.6 $\pm$ 1.5) and black hole candidate transients (ratio = 230 $\pm$ 150) by [19]. Also, since we likely did not detect GCRT J1746−2757 at its peak, it is very possible that the peak radio to X-ray ratio of any undetected X-ray counterpart is much higher. Thus, unless the radio emission of GCRT J1746−2757 is significantly Doppler boosted compared to the X-ray emission, due to the chance alignment of our line-of-sight with a radio jet, we conclude that GCRT J1746−2757 could very well be an examplar of a population of radio transients that have no X-ray counterpart.

In contrast to the GCT and A1742−28, both of which were within $1'$ or so of Sgr A*, GCRT J1746−2757 is located over 1° away, but at a low Galactic latitude ($b = 0\overset{\circ}{.}4$). At about 150 pc from Sgr A* in projection, GCRT J1746−2757 is almost certainly in the Galactic bulge, if not in the GC itself.

CONCLUSIONS

We have detected a new radio transient in the Galactic center, GCRT J1746−2757 (Fig. 1). This source is nonthermal and had a rapid temporal evolution. Although limited, our spectral and temporal constraints indicate that its characteristics were similar to that of previous GC radio transients, though its temporal evolution must have been faster, its spectrum

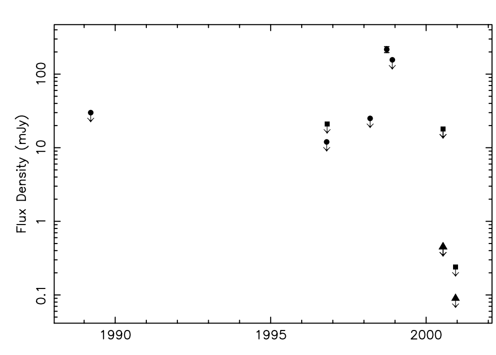

Figure 2: Measurements of the new radio transient, GCRT J1746−2757. All data are 3σ upper limies except the datum at 1998.734. The circles, squares, and triangles are measurements at 0.33, 1.4, and 4.86 GHz, respectively.

steeper, or both. No counterparts at other wavelengths were found. The lack of an X-ray detection suggests that either there was only very faint X-ray emission, compared to highly Doppler boosted radio emission, or that GCRT J1746−2757 is a member of a class of radio transients with no associated X-ray emission.

The observations we present here, combined with previous GC radio transients, suggest that the GC may harbor a population(s) of radio transients. However, our observations also indicate that the rapid brightening and fading of transient sources requires much more extensive and frequent observations in order to detect and monitor a large number of radio sources. These measurements can then be used to determine, e.g., the angular distribution and typical timescale of the source population toward the GC. Such statistics and other individual and group properties are necessary to constrain the nature of the transient and variable source population(s).

An efficient transient monitoring program requires high-resolution, high dynamic range, large field-of-view images. VLA observations at 0.33 GHz of the GC present a near optimal means to achieve these goals. The large field of view ($2.^{\circ}5$) allows the entire GC to be imaged with a single observation. In its extended configurations (A and B), the VLA provides an angular resolution of $20''$ or better and a sensitivity of 10 mJy beam^{-1} or better for a 6-hr synthesis. In our current VLA program we are monitoring the GC monthly in the A and B configurations for one to two hours per observation. We are developing an algorithm to detect accurately source variations relative to a fiducial, full-field model, with less observing time per epoch. Observations at 0.33 GHz also exploit the apparent steep-spectrum nature of these sources without being affected unduly by free-free absorption.

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