Six Strong Radio Transients with Isotropic Distribution

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Abstract

The Waseda Nasu Observatory, which is composed of eight 20 m elements, was constructed for observing radio transients over a wide field at 1400 MHz. We report on six radio transients. Six radio transients exhibited flux densities in excess of 1 Jy, and the burst durations were up to three days. The distribution was verified by making a logN-logS plot. As a result, the distribution of the radio transients that we observed might have an isotropic distribution. Counterparts of the six WJN transients included X-ray sources in four events and had a consistency of 66%. The consistency of γ-ray, PGC Galaxy, NVSS, and FIRST sources was concentrated at about 50%. The 2σ upper probability limit for detection of transients of 1000 mJy or more is 0.0049[deg^{-2} yr^{-1}]. We cannot yet identify these two radio transients, because their features are different from any radio bursts observed in the past.

1. Introduction

Many transient phenomena have been observed by UHURU, Newton, ROSAT, INTEGRAL, etc. since the beginning of the 1970s. However, almost all observations have been transient *X*-rays and γ-rays; there have been very few radio observations. A large-scale radio burst, Cyg X-3, was observed by Daishido et al. (1983) and Gregory (1972, 1975). In addition, radio observations were made at the Green Bank Telescope by Gregory and Taylor (1981, 1986), and at the VLA by Hyman et al. (2005) [5, 10]. These observations detected the burst of LSI+61 303, the radio transient GCRT J1745-3009 of 1 Jy class, and others. An archival study of NVSS and FIRST was conducted by Levinson et al. (2002) [6], and a follow-up study was conducted by Gal-Yam et al. (2006) [12], who identified several radio transients. Recently, Rotating Radio Transients (RRATs) were detected with the Parkes Radio Telescope [11]. Ten radio transients were detected from archival data of the VLA [16]. However, the origin of these ten radio transients is unknown.

The radio bursts detected in the past were observed mostly at the Galactic center and the Galactic plane. Observation has focused on these regions, whereas high Galactic latitudes have generally been neglected. With the interferometer that we constructed at the Nasu Pulsar Observatory of Waseda University, the high Galactic region can be observed in a similar manner to observations in the Galactic plane. Since 2004, we have been using this interferometer to carry out a wide-field survey to search for variable radio sources, that is, those exhibiting changes with time scales of several days to several months.

2. Observation

The Nasu Pulsar Observatory of Waseda University was originally constructed by our laboratory. It is therefore available at any time for our own research. Eight 20 m diameter spherical dish antennas are arrayed from east to west and can observe continuously for 24 hours when configured as two elements×4 interferometers. Four declinations can be observed at the same time. Our observation method is the drift-scanning by phase switching method. The observation frequency is 1400 MHz and the bandwidth is 20 MHz. The observable declination is $32^o < \delta < 42^o$ (a part of $-20^o < b < +85^o$). Refer to Kuniyoshi et al. (2007) [13] for details.

3. Results

We detected two radio transients, WJN J1039+3200 and WJN J0645+3200, with declination 32 degrees from February to April, 2005. As a result of data analysis, these two radio transients had the same fringe cycle as the standard source DA 344 (Fig. 1). The method of evaluating the fringe cycle was as described in Section 3. The transient WJN J1039+3200 was detected on March 4, 2005 (UT 13:43:20) at high Galactic latitude (b = 66^{o}), and the flux density was about 1700 mJy. The transient WJN J0645+3200 was detected on March 19, 2005 (UT 08:34:40) at medium Galactic latitude (b = 13^{o}), and the flux density was about 1200 mJy.

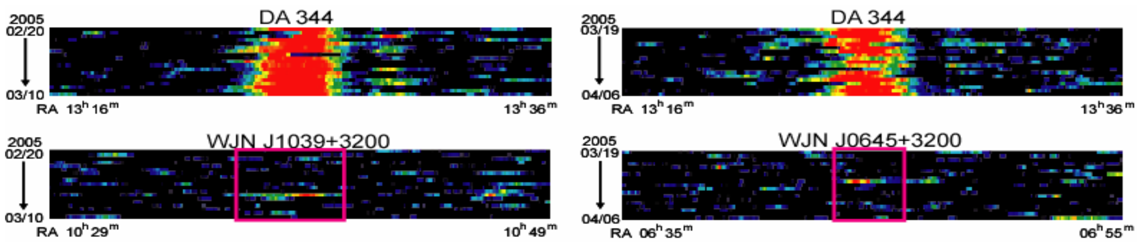

Fig. 1. Daily color map of DA 344, WJN J1039+3200, and WJN J0645+3200 (K. Takefuji et al. 2007). Strength increases in the order black, blue, green, yellow, and red. Red shows 3σ. Though a color that seems to be a candidate source appeared, analysis indicated that it was different from the fringe of the source.

4. Discussion and Conclusion

4.1. New radio transients

We compared the two newly observed WJN radio transients with various radio transients that have been reported in the past in order to determine their origin. We considered the possibility that the two WJN radio transients were from flare stars, Rotating Radio Transients (RRATs), or GRB radio afterglows. Those possibilities are discussed below.

First, we assumed that the WJN radio transients originated from flare stars or brown dwarfs. AD Leo, L726-8A, and LP944-20 [3] have been observed in the vicinity of 1400 MHz. According to those reports, the flux density was in the several mJy range, and the burst duration was from minutes to hours. Because flare stars and brown dwarfs in the vicinity of the solar system radiate chiefly from tens of megahertz to hundreds of megahertz, the flux density should be very weak at our observational frequency of 1400 MHz. Because the flux densities of the WJN radio transients exceeded 1 Jy, they cannot originate from flare stars or brown dwarfs.

Second, we considered the possibility of RRATs discovered by the Parkes pulsar survey at 1400 MHz [11]. The flux density of RRATs is 0.1--3.6 Jy at 1400 MHz. Because a strong electric wave is radiated from the rotating neutron star producing the RRATs, it is periodically observed. The periodicity of RRATs is about 0.4--7 s, and the burst duration is 2--30 ms, much shorter than that of our observed WJN transienst, and it has been confirmed that they are concentrated in the Galactic plane. Therefore, RRATs cannot be the origin of the observed radiation.

Third, we considered the possibility of GRB radio afterglows, because the WJN radio transients were observed at medium and high Galactic latitudes. However, radio afterglows are continuously observed from 1 to 3 months, and the flux densities are in the micro-Jy to milli-Jy range, based on past observations. These characteristics are different from those of the observed WJN radio transients.

In addition, we considered the possibilities that the WJN radio transients were due to the influence of scintillation and gravitational lensing. The variation in flux density by scintillation was reported by Rickett et al. (1995) [2] and Jauncey et al. (2001) [4] to be at most about 10% at 1400 MHz. This does not agree with the large observed variation of the WJN radio transients. If, depending on the effect of gravitational lensing, the variation does not depend on the observational frequency, then the same variation should be observed. In addition, the light curve is sure to be symmetrical for an eclipse. Because we used drift scanning, however, a detailed light curve cannot be obtained. Nevertheless, the burst is likely to be observed not as one lasting only one day, like the WJN radio transients, but as a slower change. Therefore, these possibilities are also untenable.

From the above discussion, we conclude that the radio sources for the observed WJN radio transients have as yet not been clarified. Many radio observations at the Galactic center and Galactic plane have been performed. However, wide-field observation of the area left of the Galactic plane has received little attention. Therefore, radio transients at high and medium Galactic latitude, like the WJN radio transients, might not have been observed. Our observations are very rare and have important consequences.

4.2. New population

Several radio transients with features similar to WJN J1039+3200 and WJN J0645+3200 reported here have been detected at the Nasu Observatory [13-15]. Table 1 shows the profiles of the two newly detected radio transients and four radio transients that have already been reported.

Table 1: WJN Radio Transients

Name	RA	Dec	b	Date	Flux[Jy]	Duration	Counterpart
WJN J0445+4130	04 45 17	+41 30	-2	2005/1/10	1.8	4m～2days	X , γ×4
WJN J0645+3200*	06 45 15	+32 00	+12	2005/3/27	1.2	4m～2days	Br, X, G
WJN J1039+3200*	10 39 43	+32 00	+66	2005/3/4	1.7	4m～2days	Fr×2, Br×3, G
WJN J1043+4130	10 43 06	+41 00	+60	2005/1/2	1.7	4m～2days	γ×2
WJN J1443+3439	14 43 22	+34 39	+65	2005/02/13,14	1.7,3.2	2days～3days	Fr×4, Br×2, IR, X×2
WJN J1737+3808	17 37 17	+38 08	+30	2004/3/20	1	4m～2days	Br, X, G×2

Note.- This table shows profiles of six WJN transients. × in the counterpart column shows the number. * indicates new transients observed in this study. Because WJN J1443+3539 was detected on two successive days, two values of flux are given.

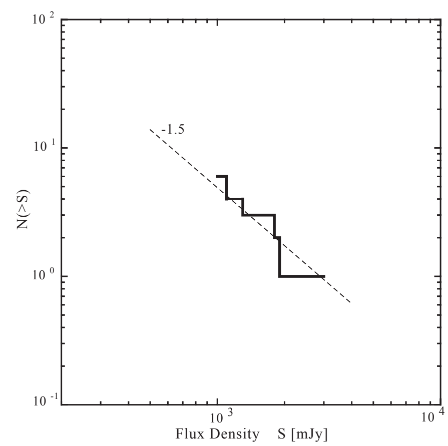

Fig. 2 logN-logS plot of WJN radio transients. The high correlation between the transients and a straight line of slope -3/2 shows an isotropic distribution.

We combined the detection results and performed statistical analysis. Isotropic distributions of the WJN radio transients were verified by making logN-logS plots. If the sources are isotropically distributed, the slope is -3/2 when the logarithm of N (number of sources) is plotted on the vertical axis and the logarithm of S (flux density of source) is plotted on the horizontal axis. The volume where the source is included is proportional to the third power of the distance, and the flux density of the source is proportional to the negative second power of the distance. Figure 2 shows a logN-logS plot of the detected WJN radio transients. The correlation coefficient *r* of the observed data and the straight line of slope -3/2 is 0.93. The correlation is higher than that for a logN-logS plot for GRBs, which are known to have an isotropic distribution. As a result, it is quite reasonable to assume that the WJN radio transients are isotropically distributed.

The observable area of the Nasu Observatory is 7% of the entire celestial sphere. It is assumed that the distribution in the entire celestial sphere is isotropic, based on the observation that the distribution is isotropic within our observable area. Based on this assumption, we calculated the detection probability of the WJN transients per square degree per year. In addition, the distribution of flux density with respect to detection probability, as well as the upper limit, were calculated by using the Kaplan-Meier method (Fig. 3). As a result, the 2σ upper limit for the probability that transients of 1000 mJy or more are detected is 0.0049 deg^{-2} yr^{-1}. In addition, the upper limit of the WJN radio transients was compared with the upper limits of Carilli et al. 2003, Frail et al. 2003, the 1.4 GHz NVSS-FIRST surveys [12], and the 5 GHz and 8.4 GHz VLA archival data [16] (Fig. 3). From the results of only the WJN transients, the upper limit fits with γ=-1.5. However, from the other survey results, it does not fit with γ=-1.5; from the other survey results except NVSS-FIRST, it fits with γ~1. Neither our results nor the result of a fit to γ=1.5 [16] are consistent. The reason might be the influence of the spectral index because of the difference in the observation frequency. In addition, other surveys used a limited time and archival data, whereas we observed transients by drift-scanning observation every day. This difference might influence the detection probability. The number of available samples of high-galactic-latitude radio transients is still small. For example, the number of WJN samples is only 6, the number of VLA samples is only 10, and the number of NVSS-FIRST samples is only 9. If the number of samples increases in future surveys, it may be possible to fit the results to a straight line. The observation frequency of WJN and NVSS was the

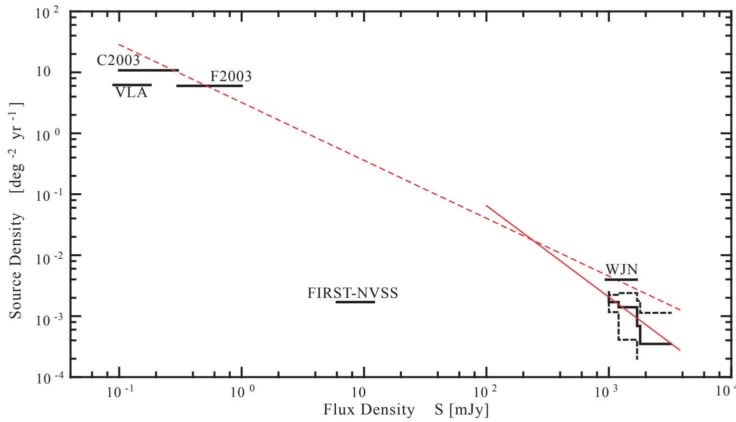

Fig. 3. The source density of transients per square degree per year as a function of flux density. The solid black line shows the source density of the WJN transients. The dotted black line shows 1σ upper and lower limits. The short black straight line shows the 2σ upper limit for transients from comparison with the VLA archival data [14], the NVSS-FIRST surveys [12], the Carilli et al. (2003) [8] surveys, and the Frail et al. (2003) [7] surveys. The red solid lines show $S^{-1.1}$, and the red dashed lines show $S^{-1.5}$.

same, and the detection probability was almost the same, though our detection flux densities were about 100 times larger. It is difficult to fit the NVSS-FIRST survey with other surveys. The reason for the mismatch might be that the NVSS-FIRST survey is perhaps still incomplete.

The feature of the six WJN transients that should be emphasized is the observation on only one day or two days. Only one transient was detected in two successive days, and its flux density was the strongest, exceeding 3 Jy. The flux densities of the other transients during one day were about 1--1.8 Jy. We assume from the above that the correlation of duration and burst strength of the WJN transients might tend toward increased strength through long duration.

There has not yet been further detection through follow-up observation. Clarification of the origin will advance if as much as only one burst is detected by follow-up observation, just as for the initial GRB observation. Since our intention is to clarify the origin of the WJN radio transients, we will continue wide-field observation at radio wavelengths.

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