PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, **119**: 122–126, 2007 January

A Strong Radio Transient at High Galactic Latitude

M. KUNIYOSHI,[1] N. MATSUMURA,[1] K. TAKEFUJI,[2] K. NIINUMA,[2,3] S. KIDA,[2] A. TAKEUCHI,[2] R. NAKAMURA,[2] S. SUZUKI,[2] T. TANAKA,[2] K. ASUMA,[1,4] AND T. DAISHIDO[1,2,3]
Received 2006 November 13; accepted 2006 November 28; published 2007 January 24

ABSTRACT. Radio transient surveys at high Galactic latitudes have not been conducted until now, as they require long periods of observation. We have constructed a full-time survey facility, the eight-element Nasu Spherical Dish Array, for radio transients and pulsars. The observing frequency is 1.4 GHz, and the bandwidth is 20 MHz. We started the radio transient survey project in 2004 and have detected some radio transients. In this paper, we report the first radio transient detected in this project. During 11 days of drift-scan observations in 2004, an outburst of approximately 1.6 Jy, which we are calling WJN J1737+3808, was detected on May 20, 15:59 UT, at $\alpha = 17^{\rm h}37^{\rm m}02^{\rm s} \pm 05^{\rm s}$, $\delta = 38°08' \pm 0.4°$ (J2000.0), ($l = 63°12'$, $b = 30°19'$). We have not yet identified the object as a known celestial object.

1. INTRODUCTION

In the early 1970s, triggered by the identification of X-ray sources discovered with the X-ray satellite *Uhuru*, radio emissions from X-ray binaries and optical binaries were detected with the Green Bank three-element interferometer of NRAO, the Westerbork interferometer in the Netherlands, the Algonquin Radio Observatory in Canada, and the Kashima radio telescope of the Communications Research Laboratory (CRL) in Japan. The radio-emitting objects included Cyg X-1 (Miley et al. 1971) and Sco X-1 and Algol (Hjellming 1971).

The discovery of large radio outbursts from Cyg X-3 (Gregory et al. 1972, 1975; Daishido et al. 1974) was an important factor in the creation of projects to search for radio transients. The Canadian group carried out surveys of the Galactic plane repeatedly to detect transient radio sources with the Green Bank 90 m telescope (Gregory & Taylor 1981, 1986). They discovered several Galactic transient radio sources, such as LSI +61 303.

In Japan, a wide-field radio patrol camera was designed, and an Mk1 pilot system was built to find Galactic and non-Galactic radio transients (Daishido et al. 1983). Recently, we constructed Mk4, a full-time radio survey interferometer consisting of an eight-spherical-dish array (20 m diameter) to search for transient radio sources and pulsars (Daishido et al. 1996, 2000; Ichikawa et al. 2004; Takeuchi et al. 2005). The Mk4 covers the Galactic plane, as well as high Galactic latitudes.

Here we report the discovery of a strong radio transient, WJN J1737+3808, at high Galactic latitude. In § 2, we describe the 20 m spherical dish array (Mk4) used to detect the radio transient. In § 3, we discuss WJN J1737+3808, including an analysis of the results. We conclude in § 4 with a summary.

2. OBSERVATIONS

We have constructed an eight-element drift-scan array 160 km north of Tokyo, arranged in a line from east to west at regular intervals (see Fig. 1). The observing frequency is 1.4 GHz, and the bandwidth is 20 MHz. The antenna temperature is approximately 100 K, and the half-power beamwidth (HPBW) is nearly 0.8°. Information on polarization has not been collected. Each element is a 20 m spherical dish observing the directions 5° from zenith, using an asymmetrical Gregorian subreflector (Takeuchi et al. 2005). Each feed horn and the subreflector are synchronously rotatable around the azimuth axis. The observable declination is consequently $32° < \delta < 42°$.

The signal power from radio sources is coupled to the receiver by a spherical antenna and is transferred to the cascading receivers (not cooled) with a gain on the order of nearly 100 dB. After the signal passes through the mixer, it is added to another signal from the second antenna in two-element fringe observations. The added signal then passes through the detector and is digitalized with an analog-to-digital (A/D) converter at 100 Hz sampling. The signal is recorded to a hard disk after the integration of 100 points. Observations are made with a 1 Hz phase switch that generates two different data (off-switch and on-switch). Fringe data are produced by subtracting the off-switch data from the on-switch data (Kuniyoshi et al. 2006). In two-element fringe observation, the detection limit is approximately 0.2 Jy.

In radio transient search mode, observations are carried out

[1] Institute for Astrophysics; and Project Research Institutes, Comprehensive Research Organization, Waseda University, Shinjuku-ku, Tokyo, Japan; kmasaya@gmail.com.

[2] Institute for Astrophysics; and Department of Pure and Applied Physics, Graduate School of Science and Engineering, Waseda University, Shinjuku-ku, Tokyo, Japan.

[3] Department of Science, School of Education, Waseda University, Shinjuku-ku, Tokyo, Japan.

[4] Kuki High School, Kuki City, Japan.

FIG. 1.—Nasu Pulsar Observatory operated by Waseda University.

simultaneously using four fringe beams generated by four pairs of antennas with a baseline length of 84 m. Each fringe beam is trained on four different declinations to cover a wide field (0.8° × 3.2°). This lasts for 2 weeks, and then each observed declination is changed. Approximately 10 weeks are required to cover the whole observable region in this mode, as the observation is performed at 0.5° steps in the observable declination.

We carried out observations with a two-element fringe beam (84 m baseline) to a declination line of 38° for 11 days in a row, beginning on 2004 May 16. It was realized that a transient fringe (WJN J1737+3808) was detected at high Galactic latitude on 2004 May 20, 15:59 UT, located at $\alpha = 17^{\mathrm{h}}37^{\mathrm{m}}02^{\mathrm{s}} \pm 05^{\mathrm{s}}$, $\delta = 38°08' \pm 0.4°$ (J2000.0) ($l = 63°12'$, $b = 30°19'$). The R.A. position was fixed by comparing the fringe phase of a steady source, B1633+3814, with that of WJN J1737+3808. The error of 5 s in R.A. was due to noise. The error in declination was determined to be within 0.8° (HPBW).

Additional follow-up observations were performed on the same declination line for 23 days, beginning on 2005 January 26. In addition to these observations, further follow-up observations were carried out for 23 days, beginning on 2006 January 6; however, WJN 1737+3808 did not reappear.

3. RESULTS AND DISCUSSION

To establish that WJN J1737+3808 was real, we carried out a 200 s autocorrelation function analysis[5] on the fringes of a steady source, B1633+3814,[6] and that of WJN J1737+3808 from 2006 May 16 to 26 and compared them as shown in Figure 2. While B1633+3814 was observed during 11 days, WJN J1737+3808 appeared at more than 5 σ only on May 20, clearly lasting five periods long ($\simeq$200 s), and with the same fringe frequency as that of B1633+3814. This is also consistent with the astronomical model $\cos\,[2\pi Y_\lambda \omega_e \cos\,(\delta)\cos\,(H)t]$,[7] where Y_λ is the 83.6 m east-west baseline measured in the wavelength at the frequency of 1.42 GHz, ω_e is the rotation velocity of the Earth, δ is the declination of WJN J1737+3808, and $H = 6°$ the hour angle of WJN J1737+3808.

If WJN J1737+3808 were caused by a satellite or an airplane, its fringe frequency would be different from that of the celestial objects observed at the declination line (drift-scan line) of 38°, as the fringe frequency depends on the baseline length of two antennas and the declination of the observed radio source. It was obvious that WJN J1737+3808 was not caused by those motions.

In addition, we measured the radiometer noise for several weeks to examine the probability of getting one that fitted the astronomical model by chance. However, the 5 σ coherent sine wave, lasting for five periods like WJN J1737+3808, was not generated from the radiometer noise test. Furthermore, we performed a simulation test with Gaussian noise (random noise) with a range of strengths, and the 5 σ coherent sine wave could not be generated.

[5] The 200 s standardized autocorrelation was done because celestial objects take nearly 200 s to pass through the HPBW at 0.8°.

[6] Data for B1633+3814 (2694 mJy) taken from the FIRST survey catalog.

[7] The north-south baseline = 0 because the antennas are arranged in a line from east to west.

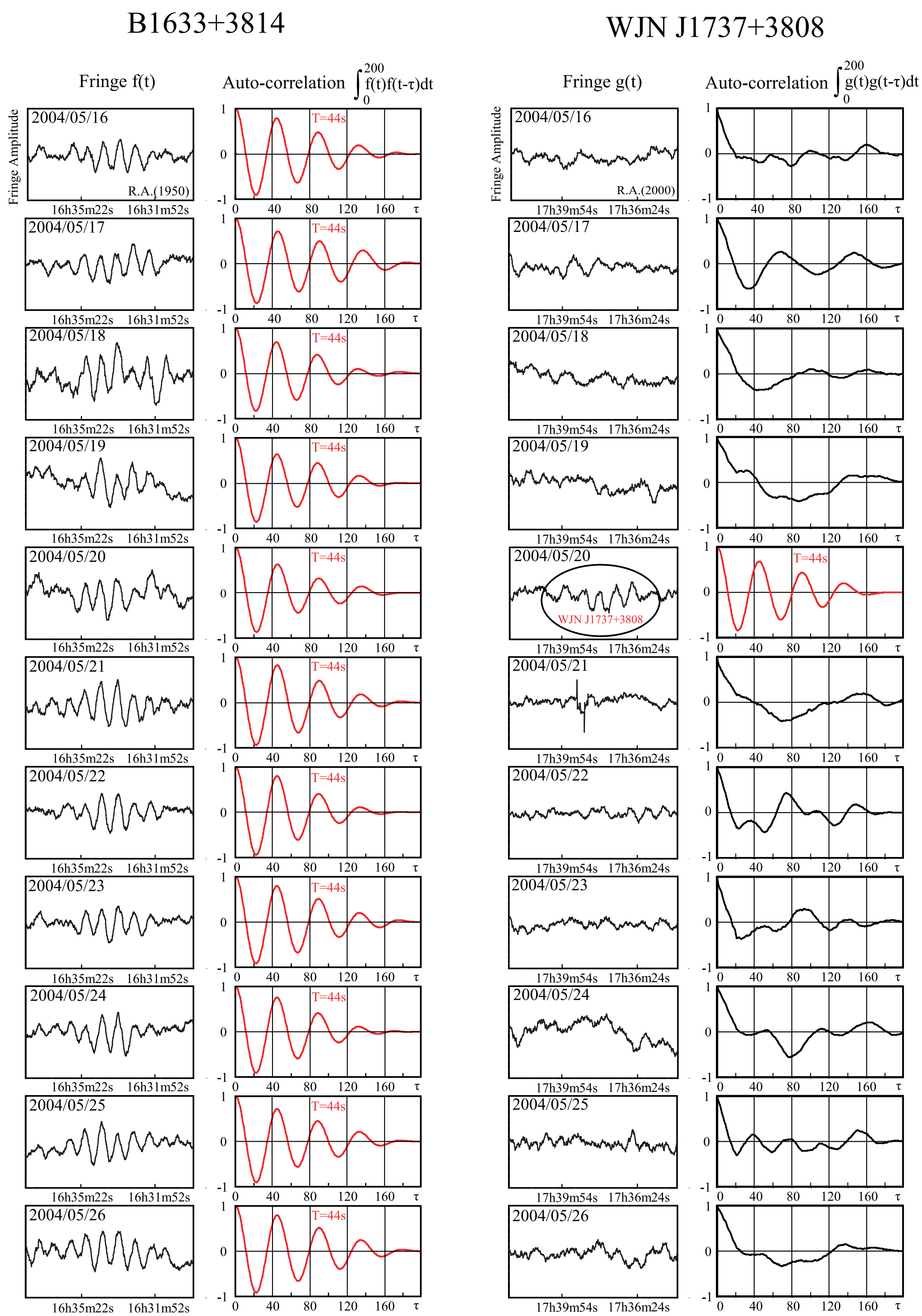

FIG. 2.—Comparison of steady fringes (B1633+3814) and a transient fringe (WJN J1737+3808) using the standardized autocorrelations for 200 s from the center of the fringe during 11 days of observations. WJN J1737+3808 has the same fringe frequency as that of B1633+3814.

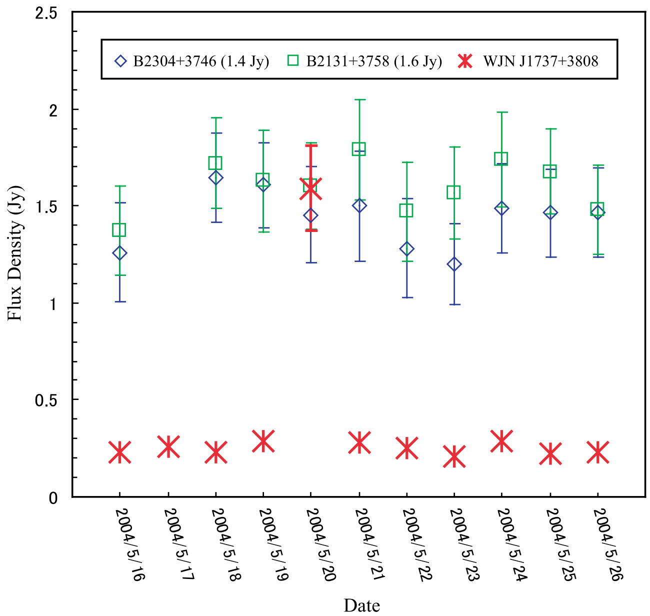

FIG. 3.—Light curves of steady sources B2304+3746 (*diamonds*) and B2131+3758 (*squares*) and the radio transient WJN J1737+3808 (*asterisks*) for 11 days of observations. For WJN J1737+3808, we plotted the rms noise level, excluding May 20. Note that the lack of data on B2304+3746 and B2131+3758 on May 17 is due to radio frequency interference.

If human-generated radio frequency interference (RFI) around the antennas produced WJN J1737+3808 accidentally, the other antennas observing other declinations also should have caught WJN J1737+3808, because human-generated RFI would have been too strong. However, we could find no such coherent sine wave from the data of the other antennas on 2004 May 20, 15:59 UT. All things considered, we concluded that WJN J1737+3808 was generated by a point source that was stationary on the celestial sphere.

We found that the flux density of WJN J1737+3808 was 1.6 ± 0.23 Jy as a result of calibration with steady radio sources (see Fig. 3), even though there was a possibility that WJN J1737+3808 was not detected at the peak flux. From the detection limit ($\simeq$0.2 Jy), the flux density of WJN J1737+3808 increased at least $\simeq$1 Jy within a day and decreased more than $\simeq$1 Jy within a day.

We have searched for counterparts to WJN J1737+3808 using the NASA/IPAC Extragalactic Database and the HEASARC Database. Some counterparts to WJN J1737+3808 in γ-ray, infrared, and radio are shown in Table 1. No X-ray counterpart appears in those databases. In γ-ray, GUSBAD 961008.222 and 4B 930602 are γ-ray bursts detected by the Burst and Transient Source Experiment (BATSE).[8] In the infrared, 2MASX J17370398+3749367 appears, which was observed by 2MASS (Two Micron All Sky Survey). In radio, although NVSS J173701+381111 and J173707+380012[9] ($\simeq$1 mJy) are found, neither is likely to be WJN J1737+3808, because they are far below our detection limit (0.2 Jy). A reliable counterpart is not found from these databases.

Since our observation, some strong radio transients like WJN J1737+3808 have been detected. These will be reported soon in the *Astronomical Journal* (Matsumura et al. 2007) and in *Astrophysical Journal Letters* (Niinuma et al. 2007). Their features are that they are detected at high Galactic latitudes, and the flux density grows rapidly and fades steeply, like that of WJN J1737+3808.

Recently, strong radio flares were detected with a flux density at 8.3 GHz as high as 1.17 Jy in β Per, and 1.44 Jy in V711 Tau (Richards et al. 2003), which were almost the same flux as WJN J1737+3808. Although we searched for flare stars in the observed error box, no flare stars were found.

As typical flare strengths of brown dwarfs are of an order of micro- to millijanskies at the frequencies of 5–8 GHz (Berger 2002), the flux of brown dwarfs is not consistent with that of WJN J1737+3808.

If we detected radio transients mainly on the Galactic plane, they would be microquasars, pulsars such as rotating radio transients (RRATs; McLaughlin et al. 2006), or a new type of radio transient varying on timescales of minutes to hours, like that recently detected near the Galactic center (Hyman et al. 2005). There are various types of radio transients in our Galactic plane. However, the radio transients we have detected are not at the Galactic plane, but instead are mainly at high Galactic latitudes.

Considering that typical radio afterglows are $\simeq$millijanskies

[8] BATSE is a high-energy astrophysics experiment in orbit around Earth on NASA's *Compton Gamma Ray Observatory*.

[9] The NVSS catalog was generated with the Very Large Array at 1.4 GHz.

TABLE 1
COUNTERPARTS

Source	R.A. (J2000.0)	Decl. (J2000.0)	Band
GUSBAD 961008.222	17 40	+38	γ-ray
4B 930602	17 32.9	+37 40	γ-ray
2MASX J17370398+3749367	17 37 04.0	+37 49 37	Infrared
NVSS J173701+381111	17 37 01.1	+38 11 11	Radio
NVSS J173707+380012	17 37 07.3	+38 00 12	Radio

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

and fade over months in radio, they are not likely to be radio afterglows. Because of the features of the strong radio transients we started detecting, they have a possibility of being a hitherto unknown type of radio transients.

4. SUMMARY AND CONCLUSION

We have constructed a full-time transient survey facility consisting of an eight-element spherical dish and detected a radio transient (WJN J1737+3808) at high Galactic latitude ($l = 63°13'$, $b = 30°16'$) on 2004 May 20, 15:59 UT.

The flux density of WJN J1737+3808 was 1.6 ± 0.23 Jy as a result of calibration with steady radio sources, although there is a possibility that it was not detected at the peak flux. It has the feature of a rapid increase ($\simeq 1$ Jy) in flux density within 1 day, and a decrease ($\simeq 1$ Jy) within 1 day.

Some strong radio transients have been detected since we started the full-time transient survey project. As those are also observed mainly at high Galactic latitudes, they might be cosmological objects. We are currently developing an alert system. When it is completed, these radio transients could be better understood.

This research has made use of the NASA/IPAC Extragalactic Database, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. It has also made use of data obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA Goddard Space Flight Center. It was supported by Grant-in-Aid for Scientific Research (A)14204027, an Academic Frontier Project for Private Universities matching-fund subsidy from MEXT (Ministry of Education, Culture, Sports, Science, and Technology), and the 21st Century COE Program at Waseda University.

REFERENCES

Berger, E. 2002, ApJ, 572, 503
Braes, L. L. E., & Miley, G. K. 1971, Nature, 232, 246
Daishido, T., et al. 1974, Nature, 251, 36
———. 1983, in Indirect Imaging: Measurement and Processing for Indirect Imaging, ed. J. A. Roberts (Cambridge: Cambridge Univ. Press), 81
———. 1996, in ASP Conf. Ser. 105, Pulsars: Problems and Progress, ed. S. Johnston, M.A. Walker, & M. Bailes (San Francisco: ASP), 19
———. 2000, Proc. SPIE, 4015, 73
Gregory, P. C., & Taylor, A. R. 1981, ApJ, 248, 596
———. 1986, AJ, 92, 371
Gregory, P. C., et al. 1972, Nature, 239, 440
Gregory, P. C., et al. 1975, ApJ, 199, 467
Hjellming, R. M., & Wade, C. M. 1971, ApJ, 164, L1
Hyman, S. D., Lazio, W. J., & Kassim, E. N. 2005, Nature, 434, 50
Ichikawa, H., et al. 2004, in Frontier in Astroparticle Physics and Cosmology (Tokyo: Universal Academy Press), 391
Kuniyoshi, M., et al. 2006, PASP, 118, 901
Matsumura, N., et al. 2007, AJ, in press
McLaughlin, M. A., et al. 2006, Nature, 439, 817
Niinuma, K., et al. 2007, ApJ, in press
Richards, M. T., Waltman, E. B., Ghigo, F. D., & Richards, D. St. P. 2003, ApJS, 147, 337
Takeuchi, H., et al. 2005, PASJ, 57, 815