NO MICROWAVE FLARE OF SAGITTARIUS A* AROUND THE G2 PERIASTRON PASSING

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ABSTRACT

In order to explore any change caused by the G2 cloud approaching, we have monitored the flux density of Sgr A* at 22 GHz from 2013 February to 2014 August with a sub-array of the Japanese Very Long Baseline Interferometry Network. The observation period included the expected periastron dates. The number of observation epochs was 283 days. We have observed no significant microwave enhancement of Sgr A* in the whole observation period. The average flux density in the period is $S_\nu = 1.23 \pm 0.33$ Jy. The average is consistent with the usually observed flux density range of Sgr A* at 22 GHz.

Key words: galaxies: nuclei – Galaxy: center – ISM: individual objects (G2)

1. INTRODUCTION

Sagittarius A* (Sgr A*) is a compact source from radio to X-ray wavelengths associated with the Galactic center supermassive black hole (GCBH), which is located just at the dynamical center of the Galaxy (Reid & Brunthaler 2004) and has a mass of $M_{\odot} \sim 4 \times 10^6 M_\odot$ (Ghez et al. 2008; Gillessen et al. 2009). The observed size of Sgr A* is proportional to the inverse square of the observation frequency $\Delta \nu [\text{mas}] = 1.3 \lambda [\text{cm}]^{-2}$ in microwave and millimeter ranges (Lo et al. 1985). The relation indicates that the real picture of Sgr A* has been hidden by electron scattering around itself, although submillimeter very long interferometer (VLBI) is now developing quickly to break the barrier (e.g., Doebleman et al. 2008).

Recently, it was found by IR precision astrometry observations that a small gas cloud is approaching Sgr A* (Gillessen et al. 2012). The cloud, called “G2,” has an estimated mass of $3M_\odot$. It was predicted that G2 would come closer the periastron distance of $R_{\text{peri}} \simeq 2000 R_\odot \simeq 200$ AU in the spring of 2014 ($2014.25 \pm 0.06$; Gillessen et al. 2013, 2014.21 $\pm 0.14$; Phifer et al. 2013). The approach of the G2 cloud to Sgr A* is a golden opportunity to explore the vicinity of the GCBH, using it as a test probe. There were some predictions of an increase in emission from Sgr A* induced by the interaction of G2 with the prior existing accretion flow (e.g., Narayan et al. 2012; Sadowski et al. 2013a) or tidal heating of the cloud around the GCBH (e.g., Saitoh et al. 2014). Although the nature of G2 is still controversial, G2 is expected to be a gas cloud or a star with a dusty envelope (e.g., Scoville & Burkert 2013). Nevertheless, it is understandable that G2 may give some perturbation to the accretion flow around the GCBH because G2 is seen to be somewhat extended. If any emission enhancement begins, it is very important for the study of the mechanism of the event to detect the initial raising phase by ourselves and to alert the worldwide community to observe the phenomenon. Therefore, the project monitored Sgr A* using VLBI at 22 GHz as frequently as possible.

2. TELESCOPES AND OBSERVATIONS

We have monitored the flux density of Sgr A* at 22 GHz from 2013 February to 2014 August with a sub-array of the Japanese VLBI Network (JVN; Doi et al. 2006) in order to explore any change caused by the G2 cloud approach. The sub-array consists of the Mizusawa 10 m radio telescope (RT), the Takahagi/Hitachi 32 m RT, and the Gifu 11 m RT, and the observed data were recorded via the K5/VSSP32 VLBI data acquisition (DAQ) system (Kondo et al. 2006). The Tsukuba 32 m RT and the Kashima 34 m RT were also utilized when they met the observation schedules. The DAQ system at each RT temporarily stored VLBI data with two-bit sampled 32 MHz bandwidth (128 M bps data rate) in commercially
used hard disk drives. Immediately after every observation, the data were transmitted via the Internet to the ISAS, where a software cross correlator developed by NICT (Kondo et al. 2004) was running. We could obtain the correlation results within a half day after a daily observation was performed. The details of the observation system will be presented in another publication.

The angular size of Sgr A* at 22.2 GHz is expected to be $\Delta \theta = 2$ mas by the relation mentioned above. Because the sub-array has projected baselines of 150–300 km or a beam size (fringe spacing) of about 13 mas, we can observe the flux density of Sgr A*, avoiding the flux density decrease by partially resolving it out. On the other hand, Sgr A* is embedded in the strong extended emission surrounding itself. The high spatial resolution is required to selectively observe the flux density of Sgr A* itself, suppressing the contamination from the extended structure. Therefore, the sub-array of the JVN is most suitable for the daily flux density monitoring of Sgr A*.

An induced synchrotron flux with the G2 cloud approaching must be centered around the bow shock by the G2 gas cloud in the accretion flow of the GCBH (Sadowski et al. 2013a, 2013b). The angular separation between Sgr A* itself and the possible bright spot is expected to be up to 25 mas around the G2 periastron passing, assuming that the distance to the Galactic center is 8 kpc. The two spots can be detected separately with an additional observation by the sub-array. If a new adjoining spot is detected in the flare, this proves that the expected electron acceleration is occurring via the interaction between the G2 gas cloud and the accretion flow.

Typical system noise temperatures of RTs of the sub-array were 100–200 K except during the summer season. The observing time was 10 minutes for each object. Three quasars, NRAO530, J1626-2951, and J1924-2914, were observed per day as flux calibrators in the monitoring. Sgr A* was observed twice per day. The flux calibrators are bright quasars located near Sgr A*, but they are certainly variable on a timescale of several months. Unfortunately, not all RTs of the sub-array have a beam switch system for the measurement of the total flux density. Therefore, the flux densities of the quasars were calibrated by comparison with NGC 7027 using the Nobeyama 45 m telescope in order to guarantee the absolute flux density accuracy during the periastron passing. NGC 7027 is a bright young planetary nebula with a flux density assumed to be $S_0 = 5.5$ Jy at 22.2 GHz (e.g., Perley & Butler 2013). The procedure for obtaining the flux density of Sgr A* is as follows. All 30 m class RTs of the sub-array are closely located in the same prefecture—the Ibaraki prefecture. The baselines between them are not sufficient to suppress the contamination from the surrounding extended emission around Sgr A*. On the other hand, two 10 m class RTs, the Mizusawa 10 m RT and the Gifu 11 m RT, are geographically located 300 km to the north and 300 km to the west of the 30 m class RTs, respectively. Therefore, correlated amplitudes for the two baselines of the Mizusawa 10 m RT, a 30 m class RT, and the Gifu 11 m RT, a 30 m class RT, were used. They are averaged to improve the signal-to-noise ratio. The flux density of Sgr A*, $S_0(\text{Sgr A}^*)$, is given by

$$S_0(\text{Sgr A}^*) = A(\text{Sgr A}^*) \sqrt{\frac{S_0(\text{QSO1})S_0(\text{QSO2})S_0(\text{QSO3})}{A(\text{QSO1})A(\text{QSO2})A(\text{QSO3})}}.$$  

where $A(\text{QSO})$ is the averaged correlated amplitude of a quasar. $S_0(\text{QSO})$ is the flux density calibrated by the method based on NGC 7027 using the Nobeyama 45 m telescope, as mentioned above. The geometric mean is useful for suppressing the effect of an unexpected change in flux of the quasars. The absolute calibration uncertainty of the observation is estimated to be $\sim 20\%$, which is larger than the statistical error.

3. RESULTS

Figure 1 shows the light curve of Sgr A* at 22.2 GHz in this monitoring (see also Tsuibo et al. 2013a, 2013b, 2013c, 2013d, 2014a, 2014b). The horizontal axis is the elapsed day (DOY) from 2013 January 1. The monitoring was performed from 2013 February 25 to 2014 August 12. The number of observation epochs was 238 days. The error bars show only the statistical errors ($\pm 1\sigma$) of each data set. First, we observed no strong microwave flare of Sgr A* around the expected G2 periastron epochs, which are DOY = 456.25 $\pm$ 32.85 day (solid arrow in Figure 1; Gillessen et al. 2013) and DOY = 441.65 $\pm$ 51.10 day (dashed arrow in Figure 1; Phifer et al. 2013), respectively. The average flux densities during the expected periastron periods are $S_0(26) = 1.19 \pm 0.21$ Jy and $S_0(48) = 1.13 \pm 0.19$ Jy, respectively. The errors show the standard deviation of the observed flux densities. The number in the parentheses is the number of observations in the epoch. The observed flux densities are consistent with those of the NRAO public data with JVLA (open circles in Figure 1; Chandler & Sjouwerman 2013a, 2013b, 2013c; Sjouwerman & Chandler 2013).

It has been reported that the radio flux induced by the bow shock will peak seven or nine months before the periastron epoch because the bow shock in the accretion flow precedes the G2 cloud itself on the orbit (Sadowski et al. 2013b). According to the prediction, the flux density for the bow shock should increase remarkably during DOY $\sim$ 200–280 day (dotted arrow in Figure 1). Because this epoch unfortunately corresponds to the summer rainy season in Japan, there is a long intermission of observations for DOY = 210–245 day. Significant enhancement was not detected in the observed flux densities of Sgr A* in the epochs of DOY = 200–210 day and DOY = 245–280 day. In addition, there is the NRAO public data at 21.2 GHz of $S_0 = 1.27 \pm 0.13$ Jy at DOY = 220 day. Although a flare with a short duration cannot be ruled out by these data, the expected significant enhancement with long duration did not occur.

The average flux density in the whole observation period is $S_0 = 1.23 \pm 0.33$ Jy. The observed flux densities are consistent with those of the NRAO public data, $S_0 = 1.10 \pm 0.17$ Jy. Meanwhile, the average flux density for the three-year monitoring with the VLA (Herbst et al. 2004) is $S_0 = 0.93 \pm 0.16$ Jy. Although the average and standard deviation of the measured flux densities in this monitoring are practically consistent with the values for the three-year monitoring, our values are slightly larger than the three-year values. Sgr A* in our monitoring may be relatively active. However, the activity should be within the previously observed range (e.g., Yusef-Zadeh et al. 2006). We have observed no unusual events for Sgr A* in the whole observation epoch.

4. DISCUSSION

There is no significant enhancement of Sgr A* at 22.2 GHz during the periods including the expected periastron and the expected intensity peaks. The straightforward and convincing interpretation of the negative detection is probably that G2 is a star or a tightly bounded star cluster, although it may have a
of the flux density of Sgr A* at 22.2 GHz with the JVN monitor (filled circles). The horizontal axis is the elapsed day (DOY) from 2013 January 1. The monitoring was performed from 2013 February 25 to 2014 August 12. The error bars show only statistical errors (±1σ) of each data. We have observed no significant enhancement of the flux density of Sgr A* at 22.2 GHz in the whole monitoring epoch. Open circles show the flux densities of Sgr A* at 21.2 GHz from the NRAO public data.

Figure 1. Light curve of Sgr A* at 22.2 GHz with the JVN monitor (filled circles). The horizontal axis is the elapsed day (DOY) from 2013 January 1. The monitoring was performed from 2013 February 25 to 2014 August 12. The error bars show only statistical errors (±1σ) of each data. We have observed no significant enhancement of the flux density of Sgr A* at 22.2 GHz in the whole monitoring epoch. Open circles show the flux densities of Sgr A* at 21.2 GHz from the NRAO public data.

This possibility had been discussed by several authors (e.g., Phifer et al. 2013; Eckart et al. 2013; Zajaˇcek et al. 2014; Scoville & Burkert 2013). This interpretation is also consistent with the surviving image of G2 around the periastron obtained by the latest IR observations (Witzel et al. 2014). The destruction condition of the dusty envelope by tidal forces of the GCBH is roughly given by

$$\frac{R_{\text{peri}}}{r_{G2}} \lesssim \left( \frac{M_{G2}}{m_{G2}} \right)^{1/3},$$

where $m_{G2}$ is the mass of G2 and $r_{G2}$ is the radius of the dusty envelope around G2. If G2 is a star, it must have a mass of $m_{G2} \gtrsim 1 M_{\odot}$. The destruction condition is not satisfied for the inner envelope with $r_{G2} < 1$ AU; $R_{\text{peri}}/r_{G2} = (M_{G2}/m_{G2})^{1/3}$, even around the periastron distance, $R_{\text{peri}} \sim 200$ AU, although the condition for the outer envelope with $r_{G2} > 2$ AU is barely satisfied (see also Murray-Cla & Loeb 2012). In this case, G2 hardly induces the expected microwave enhancement because it has small cross section. A tightly bounded star cluster also corresponds to such a case.

In the case where G2 is a gas cloud, as reported initially, which is still supported by a recent IR observation (Pfuhl et al. 2014), there may be several possibilities to explain it. One is that the magnetic field in the accretion flow is too strong to make the bow shock wave in the accretion flow. The bow shock preceding the G2 cloud plays a critical role in the acceleration of synchrotron-emitting relativistic electrons (Sadowski et al. 2013a, 2013b). A microwave enhancement is not caused if the bow shock is drowned out in the accretion flow. When the Alfvén velocity around Sgr A*, $V_A$, is faster than the velocity of the G2 cloud, $V_{G2}$, the shock wave is suppressed. $V_A$ is given by

$$V_A [\text{km s}^{-1}] = \frac{2200 H [\text{mG}]}{\sqrt{n_{H} [\text{cm}^{-3}]}}.$$ 

Because the gas density at the Bondi radius of Sgr A* is estimated to be $n_{H}(R_B) \sim 130 \text{ cm}^{-3}$ from X-ray observations (Baganoff et al. 2003), the Alfvén velocity is $V_A [\text{km s}^{-1}] \sim 200 H [\text{mG}]$. On the other hand, $V_{G2}$ is estimated by

$$V_{G2} \sim \sqrt{\frac{2GM_{G2}}{r}}.$$ 

Then the velocity of the G2 cloud is $V_{G2} \sim 6000 \text{ km s}^{-1}$ around the periastron distance, which is similar to the Bondi radius of Sgr A*, $R_{\text{peri}} \sim R_B$. The condition $V_{G2} \lesssim V_A$ suggests the lower limit of the magnetic field around the periastron distance, $H \gtrsim 30$ mG.

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**Facility:** JVN

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