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Possible Detection of Quasi-Periodic Oscillations from Sgr A* at 43 GHz

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Abstract. Quasi-periodic oscillations (QPOs) are believed to be indirect evidence for black holes. Several authors have reported detections of QPOs from Sgr A*, the nucleus of our Galaxy, in infrared and X-ray wavelength during flare-ups. Miyoshi *et al.* (2011) reported a tentative detection of QPOs in the 43 GHz light curve of Sgr A* obtained with the Very Long Baseline Array (VLBA). To confirm their detection, we reanalysed their VLBA data very conservatively. The 43 GHz flux was calculated for every 15 seconds by assuming a two-dimensional Gaussian-shape spatial structure. The Lomb-Scargle periodogram of the 43 GHz flux just after a millimeter wave flare of Sgr A*, shows three apparent peaks at 10.2, 14.6 and 32.1 min. Two of them are barely consistent with the previously reported QPOs. Using the resonant oscillation model, we estimated the spin parameter of the Sgr A* black hole to be 0.56 assuming the mass of $4.3 \times 10^6 M_\odot$.

Keywords. accretion, accretion disks, black hole physics, Galaxy: center

1. Introduction

Sagittarius A* (Sgr A*) at the Galactic center is a compact radio source, which is the most convincing candidate of supermassive black hole (SMBH) with a mass of $\sim 4 \times 10^6\ M_\odot$ (Ghez *et al.* 2008; Gillessen *et al.* 2009). Sgr A* shows short term variability and flaring activities in millimeter-wave, infrared, and X-ray bands. Detections of quasi-periodic oscillation (QPO), which is indirect evidence for the presence of a black hole, has been reported by near-infrared and X-ray observations during flaring events of Sgr A* (e.g., Genzel *et al.* 2003; Yusef-Zadeh *et al.* 2006).

The oscillation periods should be related to the Keplerian period at the innermost stable circular orbit (ISCO) of the accretion disk around the SMBH. One promising mechanism of generating QPOs is a disk oscillation excited by the resonance between geodesic modes of the accretion disk due to general relativity (Kato & Fukue 2006). The periods of quasi-oscillation should be linear combination of Keplerian orbital frequency $\Omega_{\rm K}$ and the epicyclic frequency κ at the resonant radius where $\Omega_{\rm K} = 2\kappa$. Given these parameters, we are then able to determine the resonant frequencies of $m\Omega_{\rm K} \pm \kappa$, or $m\Omega_{\rm K}$ $(m = 1, 2, 3, \ldots)$.

In the radio band, multiple QPOs, whose periods are 16.8, 22.2, 31.4 and 56.4 min, have been observed at 43 GHz with the Very Long Baseline Array (VLBA), analyzing the patterned changes of the structure in Sgr A* (Miyoshi *et al.* 2011). The observations were performed on 2004 March 8, 37–44 hours just after a millimeter wave flare of Sgr A* was detected with the Nobeyama Millimeter Array (Miyazaki *et al.* 2006). Here, we present the results of reanalyzing the same data more conservatively.

2. Result

To obtain the flux densities averaged every 15 seconds for a light curve, we applied a fixed elliptical Gaussian function (full width at half maximum of 712 μas $\times$ 407 μas, $PA = 79.^{\circ}8$; Bower *et al.* 2004) to the visibility data using the AIPS task UVFIT. We performed periodicity analyses using the Lomb-Scargle (L-S) method (Scargle 1982) to search for any periodic behavior in the light curve. As a result, we see three characteristic periods at 10.2, 14.6 and 32.1 min (Figure 1).

In order to examine the effect of the unequal sampling to the periodgram, we performed Gaussian noise simulation. Performing a periodic analysis of Gaussian noise, the unequal sample spacing does not affect the L-S periodogram. On the other hand, we found that the 10.2 min peak can be induced by the 32.1 min oscillation.

We thus concluded that 14.6 and 32.1 min periods are real. Based on the resonant disk oscillation model, we estimated the black hole parameters. Periods of 32.1 and 14.6 min may correspond to $\Omega_{\rm K}$ and $2\Omega_{\rm K}$ respectively (Figure 2). This identification gives an estimate of spin parameter, $a_* = 0.56 \pm 0.15$, assuming that the mass of Sgr A* is $(4.31 \pm 0.66) \times 10^6 \ M_{\odot}$ (Gillessen *et al.* 2009). This relatively small spin parameter possibly suggests the existence of a spin-down process, such as may be caused by a magnetic field (Kato *et al.* 2010).

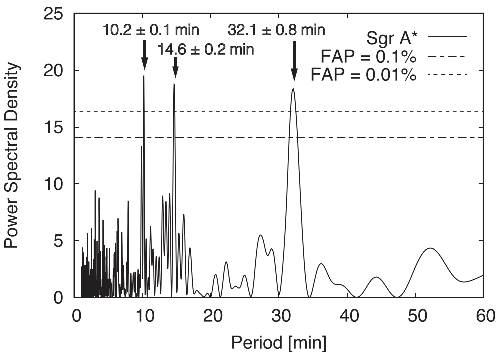

Figure 1. Comparison between the L-S periodogram of Sgr A* flux at 43 GHz (solid line) and false alarm probabilities (FAPs). Dotted line and dashed line are levels of FAP = 0.1 and 0.01%, respectively.

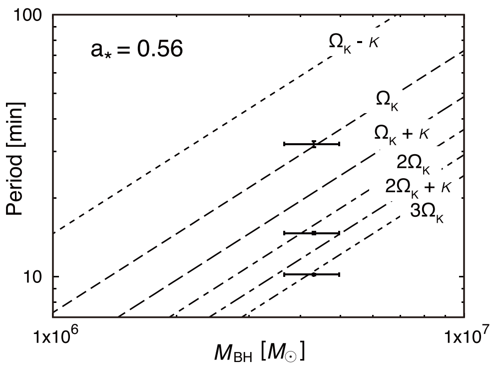

Figure 2. Observed QPOs of Sgr A* as a function of its mass. Lines show $\Omega_{\rm K} - \kappa$, $\Omega_{\rm K}$, $\Omega_{\rm K} + \kappa$, $2\Omega_{\rm K}$, $2\Omega_{\rm K}$, $2\Omega_{\rm K} + \kappa$ and $3\Omega_{\rm K}$, which are expected with the resonant disk oscillation model (Kato *et al.* 2010).

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