Oscillation Phenomena in the Disk around the Massive Black Hole Sagittarius A*

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The existence of black holes has been definitely established while zooming-in the relativistic region is still in difficulty though promising in near future. Sagittarius A* (Sgr A*), the most convincing massive black hole at the Galactic center, shows short time flares with quasiperiodic oscillations (QPO) with P = 17, 22, & 33 min in near-infrared and X-ray regions originated from near the central black hole.

Here we report the detection of radio QPOs with structure changes using the Very Long Baseline Array (VLBA) at 43 GHz [1]. We found conspicuous patterned changes of the structure with P = 16.8, 22.2, 31.4, &56.4 min, roughly in a 3 : 4 : 6 : 10 ratio. The first two periods show a rotating one-arm structure, while the P = 31.4 min shows a rotating 3-arm structure, as if viewed edgeon. At the central 50 μas the P = 56.4 min period shows a double amplitude variation of those in its surroundings. Spatial distributions of the oscillation periods indicate that the disk of Sgr A* is presumably almost edge-on, rotating around an axis with $PA = -10°$. The observed VLBI images of Sgr A* remain several features of the black hole accretion disk of Sgr A* in spite of being obscured and broadened by scattering of surrounding plasma.

If the QPOs originate in a strong gravity field where the relativistic effect plays an important role, the periods of QPOs should depend on the mass and the spin of a massive black hole. Recent theories of disk seismology predict that peak frequencies of QPOs can be scaled by a mass of central black holes as an analogy to QPOs in black hole X-ray binaries (BXB). For example, in GRO J1655-40, a peak frequency of high frequency QPOs is about $3 \times 10^2 (6.0-6.6\, M_\odot / M_{\rm BH})$ Hz (where $M_\odot$ is a solar mass), with the result that a corresponding peak frequency using the mass of Sgr A* derived from the orbital motions of surrounding stars ($3.6 \pm 0.3 \times 10^6\, M_\odot$) is about 5.1×10^{-4} Hz (P = 32 min), which is one of our findings. Detailed analysis with the obtained four QPO periods and wave-warp resonant oscillation model predicts the spin of Sgr A* to be 0.44 ± 0.08 and the black hole mass to be $(4.2 \pm 0.4) \times 10^6\, M_\odot$ [2].

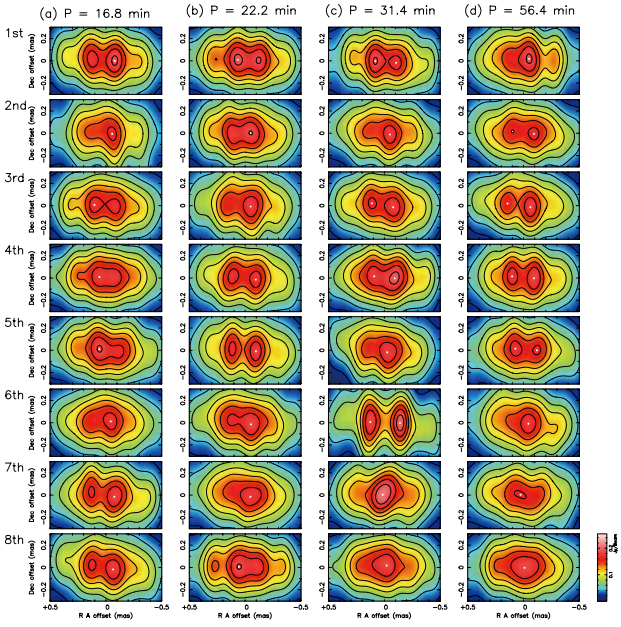

Figure 1: The slit-modulation-imaging (SMI) [3] maps with the 4 periods P = 16.8(a), 22.2(b), 31.4(c), *and* 56.4 min (d). The 8 maps show the images in phase frame series with respective periods. The white filled circles mark the intensity peak position in each map. In P = 31.4 & 56.4 min, second peaks are also marked with circles. Total amplitudes of respective periods are 22 mJy (P = 16.8 min), 24 mJy (P = 22.2 min), 24 mJy (P = 31.4 min), and 20 mJy (P = 56.4 min), which obtained by Fourier transform.

References

[1] Miyoshi, M., Shen, Z.-Q., Oyama, T., Takahashi, R., Kato, Y.: 2011, *PASJ*, **63**, 1093-1116.
[2] Kato, Y., Miyoshi, M., Takahashi, R., Negoro, H., Matsumoto, R.: 2010, *MNRAS*, **402**, L74-L78.
[3] Miyoshi, M.: 2008, *PASJ*, 60, 1371-1386.