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A Proposal for Constructing a New VLBI Array, Horizon Telescope

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Abstract. The existence of a black hole in the universe has become very clear and is now one of our common sense in astronomy. But the direct image of a black hole showing relativistic phenomena around the event horizon was still beyond our reach in the previous century. The apparent sizes of black holes are too small to observe. Sagittarius A* is the closest massive black hole at our galactic center. Even the Schwarzschild radius of SgrA* is only about 6μarcseconds. Early in the 21st century, however, the development of VLBI techniques and millimeter and sub-millimeter radio astronomy will soon reach the point to make such observations of black holes possible. We here propose to construct a new VLBI array that should be named as the Event Horizon Telescope.

1. The Existence of Black Holes Was Confirmed Last Century

The existence of black hole in the universe is now really confirmed from observations using the Hubble Space Telescope and the VLBA and ground based IR telescopes (Miyoshi et al. 1995; Macchetto et al. 1997; Herrnstein et al. 1999; Ghez et al. 2000). One of best examples is in NGC4258, which has a massive black hole with mass of $3.9 \times 10^7 M_\odot$ at its center, while another good case is for SgrA* at our galactic center, whose mass is measured to be $2.6 \times 10^6 M_\odot$. In both cases, the masses are measured from dynamical motion around the black holes, namely from proper motions of a rotating molecular gas disk, and from orbiting stars with a velocity of more than 1000 km/s, respectively. It is too difficult to deny the existence of black holes in the universe today.

2. Can We Watch Black Holes?

Though some observations suggest the existence of a surrounding disk or matter at the parsec scale around central black holes (Dayton et al. 2001; Kameno et al. 2001), the vicinities of black holes are still veiled observationally. We now know of their existence, but nothing about their real nature. Only theorists have investigated how black holes look like at a scale of several Schwarzschild radii (Fukue & Yokoyama 1988; Usui et al. 1998; Takahashi & Mineshige 2002).

3. Apparent Sizes of Black Holes

Once we get a new telescope with higher resolution, which object is the best candidate so that we can observe the black hole vicinity? From the mass and distance of black holes we can calculate the apparent angular size of their Schwarzschild radii, and the diameter of the shadow. The Schwarzschild radius of a stellar black hole with 1 solar mass at 1 pc is only 0.02μarcseconds (20 nano-arcseconds), and hence a stellar black hole would be too small to observe even in 21-st century. Most of massive black holes at several Mpc also show very small apparent sizes, less than 1μas.

4. Best Candidate, SgrA*

The black hole of SgrA* at our galactic center has the largest apparent size ($R_{\rm S} = 6\mu$as, $D_{\rm shadow} = 30\mu$as), and hence SgrA* is the best candidate we select to observe a black hole vicinity.

Though SgrA* is quite a low luminosity AGN ($L \sim 10^{-8.5} L_{\rm Edd}$), recent X-ray observations reveal its short-time burst with a timescale of a few hours (Baganoff et al. 2001) and further Zhao et al. (2001) reported the periodic change about $T \sim 106$ days in radio flux density; both of them suggest that SgrA* is really the closest massive black hole worthy of monitoring deeply.

Previous VLBI observations at the centimeter to millimeter region were already performed to watch the nature of SgrA*, but in vain. This is because the plasma gas surrounding SgrA* washed away the true image of the black hole (Lo et al. 1999). At sub millimeter wavelengths, however, the effect of the plasma is reduced with λ^{-2} and the true face of the black hole can be seen (Falcke et al. 2000)

In this century, we should construct a sub-mm VLBI array for observing the black hole vicinity of SgrA*. The Horizon Telescope will testify general relativity at strong gravity, and at the same time make a new field of observational black-hole astronomy.

5. Horizon Telescope for Monitoring the Black Hole at SgrA*

In order to obtain the black hole image of SgrA*, the Horizon Telescope must be a sub-millimeter VLBI system. Below we show the minimum specifications of the Horizon Telescope.

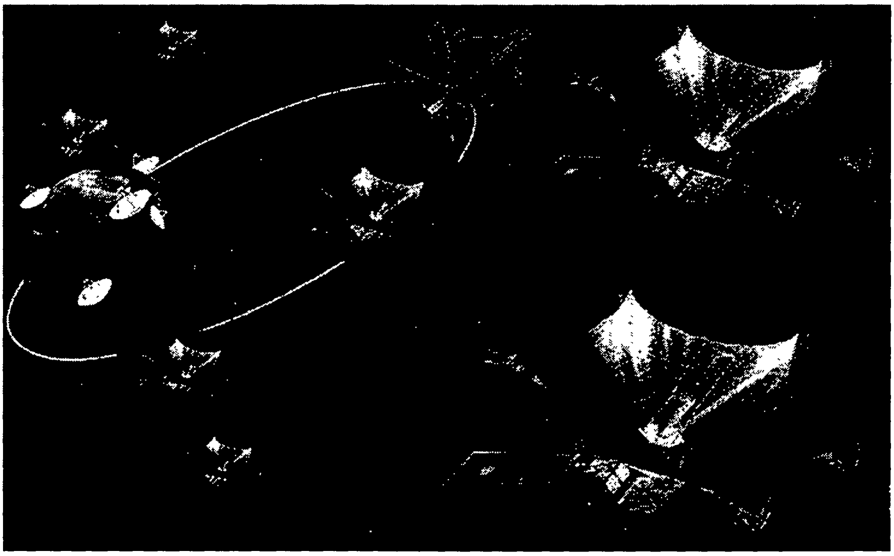

Figure 1. Horizon Telescope in the Near Future

- Observing Frequency: 350 GHz to 800 GHz (sub-millimeter) – to escape from the scattering effect of circum-nuclear plasma;
- Observing site: (1) space, or (2) southern hemisphere highlands or the Antarctic – to receive sub-mm radio emission from SgrA* (low declination);
- Stations: more than 10 like VLBA – for getting sufficient uv coverage to obtain high dynamic range in image;
- Array size: more than 8000 km at 500 GHz – to attain less than 10μas resolution.

6. A New Possibility for SgrA*

Recently Miyoshi et al. (2002) found a jet activity in SgrA* with 43-GHz VLBA observations at one burst epoch, at the end of 2001 July. The jet elongated during the observing time of 7 hours with apparent velocity $v \sim 0.1c$. They confirmed the reliability of the detection by means of phase referencing mapping of the in-beam SiO maser source, IRS10EE. Then the detection means that we can begin the watching the black hole and its related activity of SgrA* with ground-based mm-VLBI.

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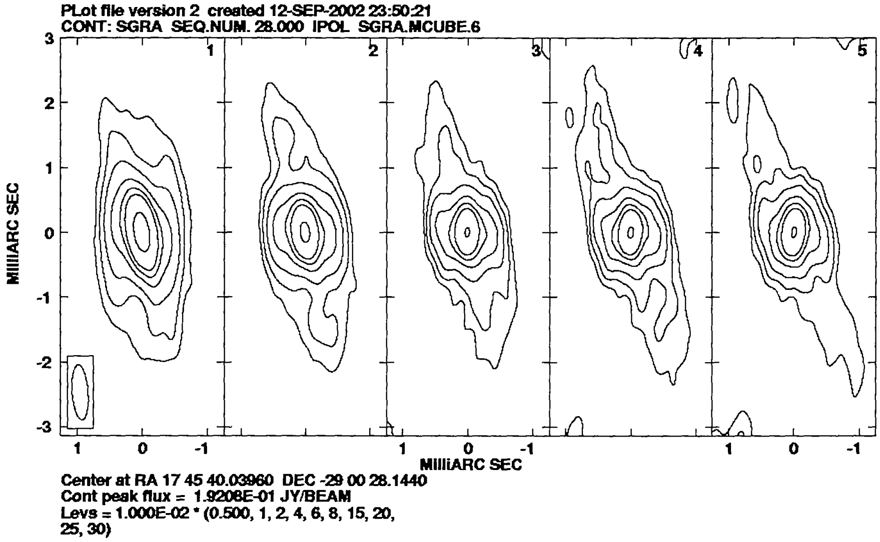

Figure 2. SgrA* observed at a burst epoch (from Miyoshi et al. 2002). Every map is integrated for 3 hours, overlapping 2 hours with adjacent maps.

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