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A Proposal for Constructing a New Sub-mm VLBI Array, Horizon Telescope – Imaging Black Hole Vicinity

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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 at the previous century because the sizes of black holes are too small to observe. Sagittarius A* (SgrA*) is the closest massive black hole at our galactic center. The Schwarzschild radius of SgrA* is about 6 μarcseconds. Early in the 21st century developments of VLBI techniques and millimeter and sub-millimeter radio astronomy will soon reach the point to make such observations of black hole possible. We here propose to construct a new VLBI array that should be named as (Event) Horizon Telescope.

1. The Existence of Black Holes Are Confirmed Last Century

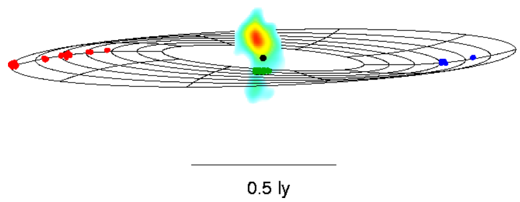
The existence of a black hole in the universe is now really confirmed from observations using the Hubble Space Telescope and the VLBA and ground based IR telescopes [1][2][3][4]. One of best examples is NGC4258 that has a massive black hole with mass of $3.9 \times 10^7 M_{sun}$at its center, another best case is the SgrA* at our galactic center whose mass is measured to be $2.6 \times 10^6 M_{sun}$. In the both case, the masses are measured from dynamical motion around the black holes, namely from proper motions of rotating molecular gas disk and orbiting stars with velocity more than 1000 km/sec respectively. It is too difficult to deny the existence of black holes in the universe today.

2. Can We Watch Black Holes?

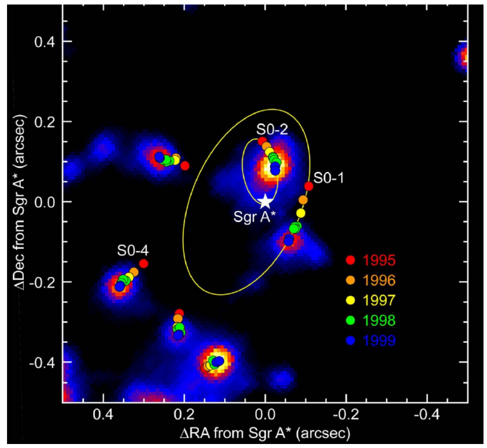
Though some observations suggest the existence of surrounding disk or matter at parsec scale around central black holes [6][5], the vicinities of black holes are still veiled observationally. We now know the existence of them but nothing about their real faces. Only theorists have investigated how black holes look at several Schwarzschild radii scale [11][9][10].

2.1. Apparent Sizes of Black Holes

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



Disk around black hole in NGC4258[3]



The Orbital Motions of high velocity stars around the SgrA*[4]

Figure 1. **The NGC 4258 and SgrA* the best confirmed case of existing black holes** [2][4].

Mass of Black Holes and the sizes

object	mass of BH in solar mass	Distance (kpc)	Schwarzchild radius Rs in km	Rs in Astronomical Unit (au)	apparent angular size (μ as)	diameter of the shadow (μ as)
Stellar BH	1	0.001	2.95×10^{3}	1.97×10^{-8}	1.97×10^{-2}	0.10
M82 medium size BH (max)	1×10^{6}	3700	2.95×10^{9}	1.97×10^{-2}	5.32×10^{-3}	0.03
Galactic Center Sgr A*	2.6×10^{6}	8	7.67×10^{9}	5.11×10^{-2}	6.39	31.97
M31	3.5×10^{7}	800	1.03×10^{11}	6.89×10^{-1}	8.61×10^{-1}	4.30
mega maser galaxy NGC4258	3.9×10^{7}	7200	1.15×10^{11}	7.67×10^{-1}	1.07×10^{-1}	0.53
M87	3.2×10^{9}	16100	9.44×10^{12}	6.30×10^{-1}	3.91	19.55

Figure 2. **Mass of Black Holes and their apparent Diameter.**

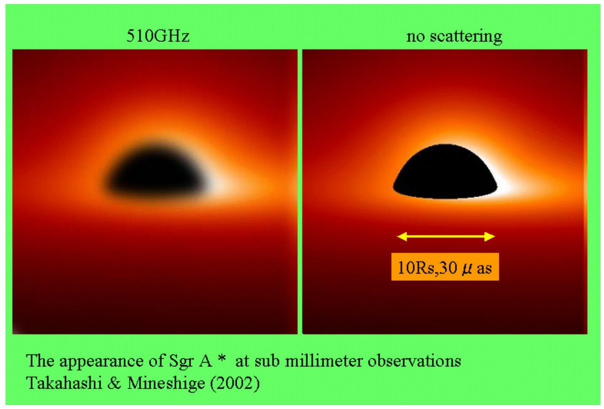


Figure 3. **A View Model of SgrA* at sub milli meter observations** [10].

2.2. Best Candidate, SgrA*

The black hole of SgrA* at our galactic center has the largest apparent size ($R_s = 6$ μarcsec, $D_{shadow} = 30$ μasec), then the SgrA* is the best candidate we can observe black hole vicinity.

Previous VLBI observations at centimeter to millimeter region were already performed to watch the face of SgrA* but in vain. Because of plasma gas surrounding the SgrA* washed away the true image of the black hole [8]. At sub millimeter wavelength, however, the effect of plasma is reduced by lamda-2 and the true face of the black hole can be seen [7][10]. Let's construct a sub-mm VLBI array and observe the black hole vicinity. Such observations will testify to general relativity at strong gravity, and at the same time make a new field of observational black hole astronomy.

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

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

- Observing Frequency: 350 GHz to 800 GHz (sub millimeter) - to escape from the scattering effect of circumnuclear 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 10 μ arc seconds resolutions

4. Acknowledgements

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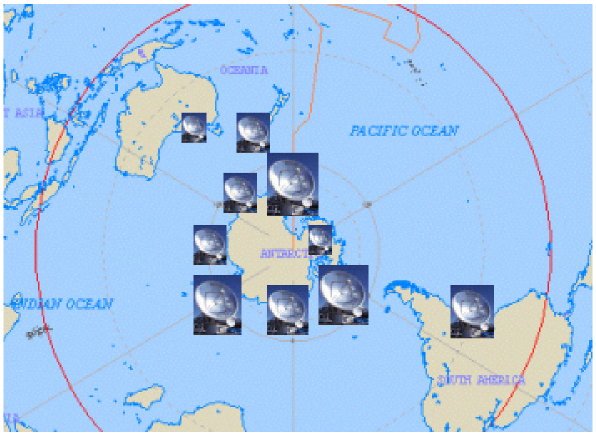

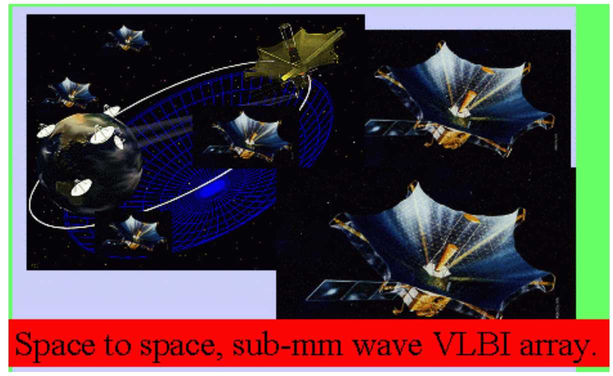

Antarctic Sub-MM VLBI Array

Space to Space Sub-MM VLBI Array

Figure 4. **Two Examples of Horizon Telescope - Ground or Space**

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