An Earliest Black Hole Imager at Andes

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Abstract

We are planning to construct a sub-mm VLBI system at Andes only dedicated to the detection of event horizon of SgrA*black hole. Using two of fixed large spherical dishes and a mobile small station, we sample sufficient u-v coverage, aim to image and detect the event horizon of SgrA*.

1 Introduction

Sagittarius A^* (SgrA*) is the most convincing massive black hole candidate with a mass of $4 \times 10^6 M_\odot$ hidden at the Galactic center. Because of its proximity of only 8 kpc from the sun and its quite large mass, the black hole in SgrA*has the largest apparent Schwarzschild radius of $6 \sim 10\mu as$. Relativistic phenomena at a few Schwarzschild radii around a black hole should be observed in very near future VLBI at sub millimeter wavelength (Falcke et al. 2000, Miyoshi et al. 2004, 2007, Doeleman et al. 2008). A black hole can be seen as a shadow at the center of a bright accretion disk. Because the shadow shape depends on the physical parameters of black holes (mass, spin and charge) without their respective degeneracies, we can measure these parameters from imaging the shadow shape. SgrA*is now the most promising massive black hole for testing general relativity at strong gravity. (Takahashi 2005)

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2 Horizon Telescope

Miyoshi et al. (2004, 2007) performed array simulations and found that a sub-mm VLBI array at the Southern Hemisphere is the best for observing SgrA*black hole[2]. It is quite natural because the SgrA*is located at -30° in declination. In Figure 2, we show the comparison of array performances of imaging SgrA*. The array simulations also showed that 10 observing stations and 8000-km array size are required to obtain a good image of SgrA*black hole shadow. In practice, however, the cost of such array construction is very expensive. We therefore have to begin with a low-cost instrument.

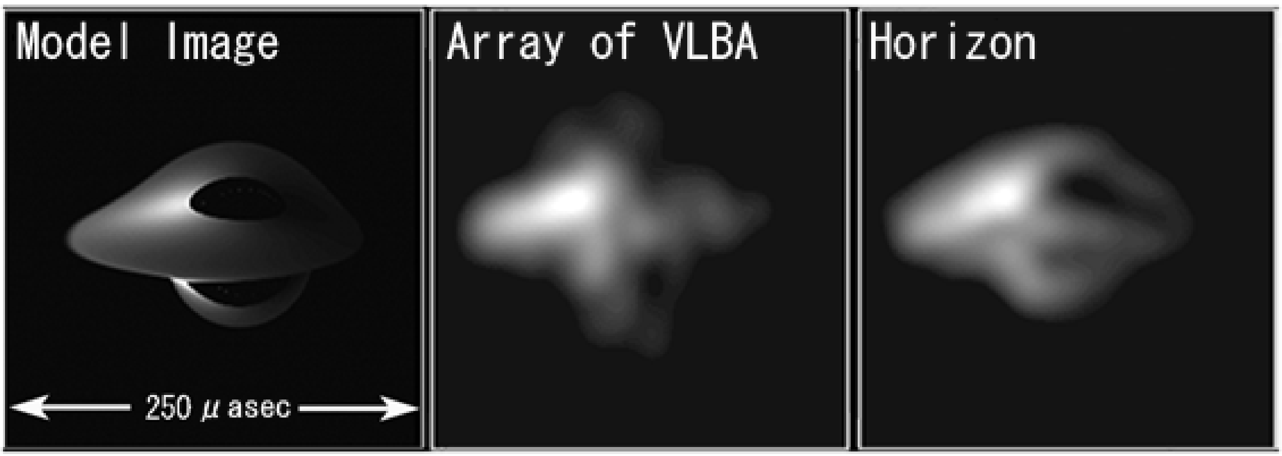

Figure 1: VLBI imaging simulations at 230GHz. Comparisons of array performances. A model image of SgrA*(center). Corresponding result by the array configuration of VLBA (center). Corresponding result by the array configuration of assumed Horizon telescope at the Southern Hemisphere. Both arrays are composed of 10 stations, and have the same array size of 8000 km (right). [The VLBA has no observing system at 230GHz and the weather conditions at the VLBA stations are not suitable for observing sub-mm wavelengths.]

3 Caravan System

In order to image the event horizon of SgrA*by sub-mm VLBI, however, it is necessary to add shorter baselines around 1000 to 2000 km to the present sub-mm VLBI stations for enhancing imaging quality. Figure 2 shows several imaging simulations indicating that the difficulty of getting correct images by a tentative present sub-mm VLBI array because of the lack of shorter baselines.
To cover shorter baselines it is appropriate to construct new stations at Andes mountains. To satisfy the technical requirement, we are planning 3-stations VLBI array at Andes, moreover with very low cost of around 10^7 US dollars, because we are in the big monetary crisis occurred once a century.
Figure 3 is an illustration showing the concept of the sub-mm VLBI, Caravan observing system. To attain cost down largely, we dare to abandon general capability and expansivity of the system and dedicate its purpose to observe SgrA*in order to detect the event horizon of SgrA*.

The Caravan is composed of two large fixed dishes and one small but mobile station. For two large fixed dishes, we are planning to use ground-fixed spherical dishes, which give us sensitivity. Spherical main reflector has no focus itself, but devising the shape of sub reflector, we can make a focus. By shifting the sub reflector, it is possible to perform tracking observations for a few hours. Because the main reflector is fixed on the ground all time, we are free from the worry about the deformation of the large main reflector due to the self weight that must be considered in cases of Az-EL mount telescopes. Unlike

[2]Why sub-mm VLBI? Circumnuclear plasma around the SgrA*black hole blurs its intrinsic image. This effect is called as λ -square law, because the observed size of SgrA*by VLBI is proportional to the observing λ^2. At sub-mm wavelength, the law will become negligible, we can expect to observe the intrinsic figure of SgrA*.

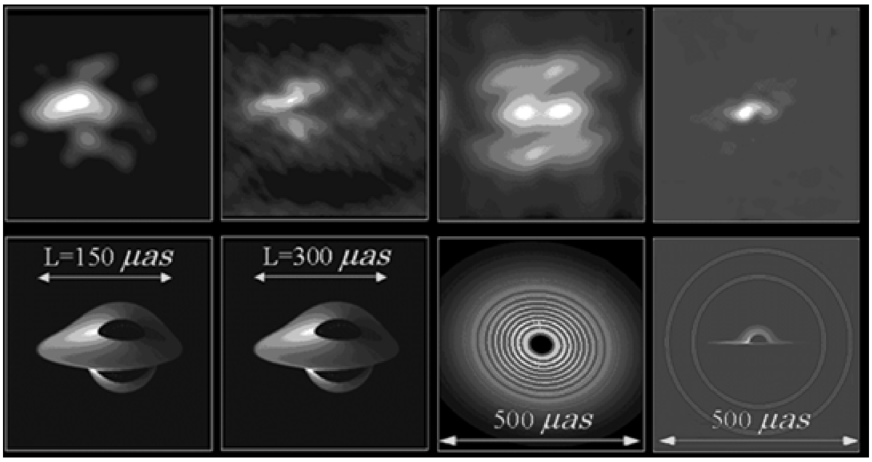

Figure 2: VLBI imaging simulations assuming with five sub-mm telescopes. At the lower panels several model images of SgrA*are shown while at the upper panels are shown corresponding resultant images. Here we assume an array including 5 stations located at Hawaii, West Coast of US, ALMA, Peru, and Closed SEST position.

the surface panels of parabola, those of spherical antennas have a common curvature, we can achieve cost down by mass production of the panels. In Japan, Daishido's spherical telescopes at Waseda[3] are famous (Daishido et al. 2000). We can follow his knowledge and experience about spherical telescope.
For cost down, it is best to construct the fixed stations at existing observatory. The Huancayo observatory (IGP[4]) in Peru and the Chacaltaya Cosmic-ray Observatory[5] in Bolivia are now candidate for the location of the fixed stations of the Caravan system. These two observatories are 3300m and 5300 m in altitude respectively, suitable for sub-mm radio observations.

In order to sample various baseline vectors, we plan to make a small but mobile station, Caravan. The mobile Caravan station moves around Andes mountains, and changes its observing site position. At the new site, we open the antenna, set up the observing system. Geodetic measurement of the site position by GPS is important to obtain baseline vector. And then we perform VLBI observations between the two large fixed dishes. (We here do not mean that the observations are performed with driving the Caravan car!)

In Japan, the NICT Kashima has been developed such kinds of mobile stations for geodetic VLBI use for more than 20 years (Ichikawa et al., 2008, 2009). The sensitivity in interferometer is proportional to the product of the diameters of both antennas. If one antenna is large enough, the diameter of another can be small. We estimate the effective diameters to be 30m and 4 m for fixed and mobile stations respectively. Sampling various baseline vectors by changing observing position of the mobile Caravan will let us image the event horizon of SgrA*with better quality.

As shown in Figure 2, we cannot get a good image if the VLBI array has no sufficient uv coverage (i. e. sum of baseline vector components projected to the observing source). However, if we can assume an image model from theories and/or other observing results, an estimation of the image shape and size can be performed. Such model fittings were performed frequently at the early era of radio interferometers. Miyoshi et al.(2004, 2007) also expected the use in order to detect the black hole shadow. Actually, Doeleman et al. (2008) used the model fitting method to their data.The Caravan system will cover the dense uv coverage up to 2000 km in baseline length. Within the uv coverage, the first null point of fringe amplitude will be included, from which we can estimate the rough size of black hole shadow.

[3]http://www.astro.phys.waseda.ac.jp/index.html
[4]http://www.igp.gob.pe/
[5]http://en.wikipedia.org/wiki/Chacaltaya

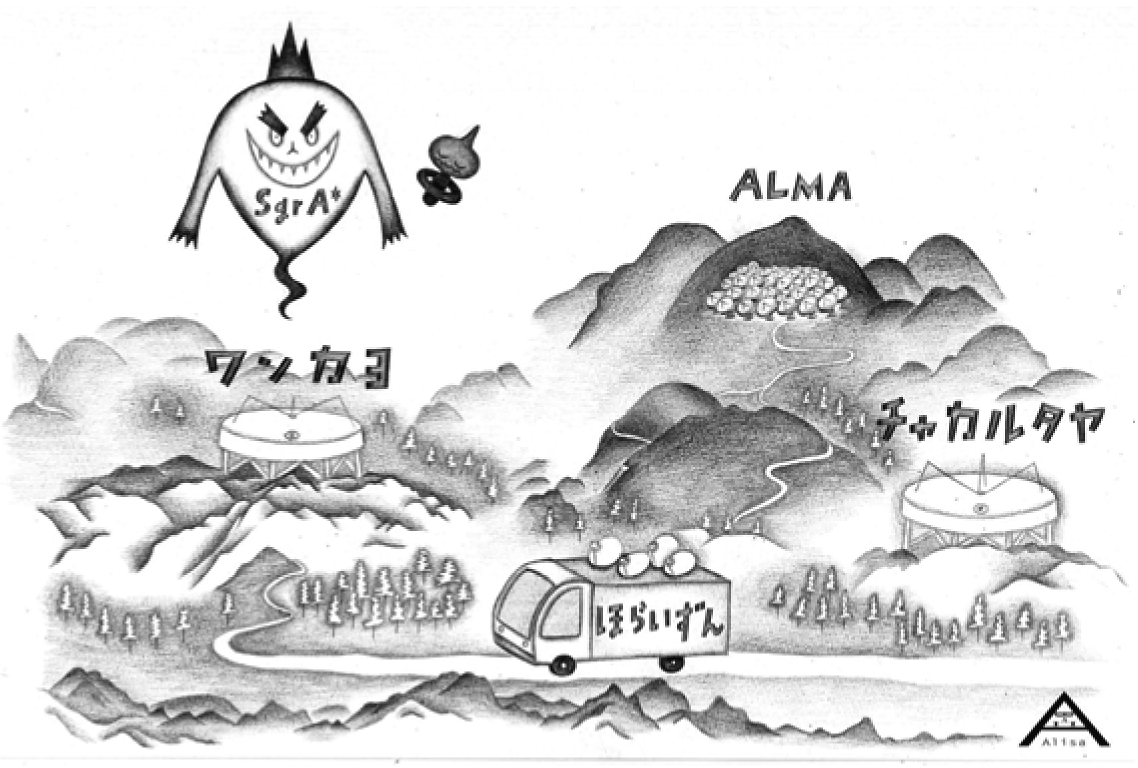

Figure 3: Concept of our sub-mm VLBI, Caravan system (illustration by A. Haba). Here we assume the Huancayo observatory (3300 m in altitude) in Peru and the Chacaltaya Cosmic-ray Observatory(5300 m) in Bolivia as the stations of the two large dishes. Practical figure of Caravan mobile station is not determined but here we illustrated like a Satellite News Gathering system in TV hookup. ALMA at Atacama (4800 m) is also drawn. Its use as VLBI station in future is also expected.

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