Long-term monitoring of Sgr A* at 43 GHz (7 mm) with VERA and KVN+VERA (KaVA)

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Monitoring observations with VERA in 2005 - 2008

(Akiyama et al. 2013, PASJ)

Observations with VERA and KaVA from 2013

(Akiyama, Kino, Sohn & KaVA AGN WG et al.)
What is the Galactic Center Sgr A*?

- The nearest SMBH (8 kpc / 4 x 10^6 M_{Solar})
- Largest angular size of the Event horizon (1 Rs = 0.01 mas)
- The best laboratory to study an environment around SMBH
Introduction: Intrinsic structure of Sgr A* at cm/mm

$\lambda$ -dependence of intrinsic size

\[ \propto \lambda^{1.3 \pm 0.1} \]

(Doeleman et al. 2008)
Introduction: Intrinsic structure of Sgr A* at cm/mm

$\lambda$-dependence of intrinsic size

Sub-mm Bump

$\tau \sim 1$ at several $\times 100$ GHz

(Doeleman et al. 2008)

(Broderick et al. 2009)
Introduction: Intrinsic structure of Sgr A* at cm/mm

\(\lambda\) -dependence of intrinsic size

- Radio emission of Sgr A* comes from \(\lambda\) -dependent photosphere (e.g. Ozel et al. 2000, Loeb & Waxman 2007, Falcke et al. 2009)

- The photosphere size at 43 GHz has a variability (Bower et al. 2004)
Introduction: Long term trend of radio flux variation
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- The correlation between spectrum index and flux density
  (e.g. Herrenstein et al. 2004, Li et al. 2009, Lu et al. 2011)
- Difficult to explain them by simple scattering theory (Rickett 1990)

Such a kind of radio flares would originate in Sgr A*
Introduction: Long term trend of radio flux variation

The relation between such a radio flare and VLBI structure has not been investigated.

What's happen in VLBI scale (few 10 Rs) around flares?

- changes in its size?

Where is the location of an origin of flares?

- photosphere ?
  (probably related with global and steady structure of the accretion Flow or the jet base)

- newly emerged component ? (e.g. a jet component?)
Sgr A* observations in 2005 – 2008

Array: VERA (VLBI Exploration of Radio Astrometry)
Frequency: 43 GHz (7 mm)
Observing epoch: 2005 - 2008 (Total 10 epochs)
Spatial Resolution: 0.6 mas x 1.2 mas (same as previous VLBA observations)
Results: Sgr A* images from 2005 - 2008

Sgr A* had been single component.
Results: The major axis size does not correlated with the radio flux.

Light curve of VERA + VLBA shows radio flare in May 2007

- VLBI size at 7 mm was not changed significantly.
- Indicating an increase in the brightness temperature similarly to 230 GHz VLBI results (Fish et al. 2011)
Discussion: newly emerged component or photosphere?

1. Origin of a radio flare: newly emerged component?

Flare occurred at 22 / 43 / 86 GHz (Lu+2011)

- The flare would have occurred at various “layers” of the photosphere from ~10 Rs (86 GHz) to ~60 Rs (22 GHz).
- Continuous electron heating would be required.

The emerged component should be outside of the 22 GHz photosphere

- changes in intrinsic size at 43 GHz
- We may see this spot separately at higher frequencies (e.g. 43, 86 GHz)

2. Possible implementation from Synchrotron cooling timescale

Assuming a magnetic field strength of ~10 G (estimated value in IDV studies),
- synchrotron cooling timescale < 1 day @ 86 GHz << Flare duration (10 days)

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Sgr A* will encounter the main part of the G2 cloud in 2014

- The point of the G2 Head already passed pericenter in April 2013
  
  (Gillessen et al. 2013b)

- Main part of the G2 cloud will arrive at pericenter in early 2014
  
  (Phifer et al. 2013 / Gillessen et al. 2013b)

Figure 7: Three-color overlay of the position-velocity diagrams for 2008, 2011 and 2012 as shown in figure 6.

Figure 8: Br- map of G2. The image was obtained from the 2012 SINFONI data set by extracting 25 channel maps from 2.1695 µm to 2.1815 µm in the yellow rectangle, each with a spectral smoothing of 5 pixels and subtracting the spectrally neighboring channels. In each channel map then a -clipping at = 1.5 was applied. Finally, for each pixel the brightest value of the 25 channel maps was selected (since the gas at different positions is at different velocities), and the image was smoothed with a Gaussian beam with FWHM=3 pix. The head and the tail are marked with arrows.

Figure 9: L'-band (3.8 µm) image of the Galactic Center obtained with NACO at the VLT on July 6, 2011. Note the 2.6''-long dust feature to the Southeast, roughly along the direction from which G2 approached Sgr A*. The brighter gas streamer from the Northeast towards the Southwest is the so-called mini-spiral.
Expected flares related with G2 encounter

1. Flare of recombination lines (in NIR) before pericenter passage (early 2014?)

2. Flare of the G2 bow shock (in radio) around pericenter passage (early 2014?)
   Possibly detected with VLBI

3. Flare in Sgr A* (in radio, NIR, X-ray) after pericenter passage (middle/late 2014?)
   Increase in its radio flux and size visible jet?
Expected timeline and observations of our groups

1) Monitoring Project (Jan. 2013 ~ )
   1) VERA Monitor of the radio flux and size at 43 GHz (an interval of 3 weeks)
   2) Single Dish Monitor (Weekly/bi-weekly):
      - 1.4/2.4/8 GHz using Medicina/Noto 32 m Telescopes (Giroletti et al.)
      - 22/43/86 GHz (with polarization) in KVN (MOGABA project; Sohn & Lee et al.)

2) Baseline measurements with KaVA (VERA + KVN) at 22/43 GHz
   Quasi-simultaneous observations with EHT 230 GHz (Doeleman et al.)
   and GMVA 86 GHz (Trippe et al.) in March/May 2013

3) ToO observations: astrometric observations with KaVA at 22/43 GHz
Preliminary results of VERA Monitor at 43 GHz until Aug. 2013

Although the head part of the G2 cloud passed pericenter before April 2013, no obvious variations appeared in the nucleus of Sgr A* until August 2013.

Radio flux: 8 % variation

Major: < 1 % variation  Minor: 7 % variation
Preliminary results of VERA Monitor at 43 GHz until Aug. 2013

Freefall time scale from pericenter to Sgr A* ~ few months

some fraction of the head part of the G2 gas might arrive at Sgr A* in the middle of 2013.

Luminosity of the central engine

Accretion disk : \( L \propto \dot{M}^2 \) (Self-similar ADAF; Mahadevan 1997)
Jet base : \( L \propto \dot{M}^{1.4} \) (Falcke et al. 1995)

Size at mm-wavelength

Accretion disk : size \( \propto \dot{M} \) (Self-similar ADAF; Mahadevan 1997)
Jet base : (?)

The absence of variability in mas-scale structure indicates current feeding rate from the G2 cloud to the inner most region was lower than typical mass accretion rate.
Future observations with KaVA (March 2014 - )

VERA monitor --> KaVA Monitor
- More accurate determination of the size
- Better imaging quality (for possible formation of jet and bowshock)
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- More accurate determination of the size
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We will continue on looking at the “dinner” of the galactic supermassive black hole

We are very happy to collaborate with multi-wavelength observations!

If you have interests, please contact us!
supporting slides
Flare in Sgr A*

1) increase in its luminosity (detectable in Radio, IR, X-ray)

Accretion disk: \( L \propto \dot{M}^2 \) (Mahadevan 1997)
Jet case: \( L \propto \dot{M}^{1.4} \) (Falcke et al. 1995)

2) increase in its size at mm-wavelength

Accretion disk: size \( \propto \dot{M} \) (Mahadevan 1997)
Jet case: (?)

3) first discovery of the jet ejection from the Sgr A*
The size of shocked region \( \sim \) several \( \times 10^3 \) \( R_{sch} \) \( \sim \) several \( \times 10 \) mas

possibly detected with VLBI
KVN: Korean VLBI Network

- 3 stations in Korea
- 21 m dishes
- 22 / 43 / 86 / 120 GHz
  -- record 4 bands simultaneously (not frequency switching!)
  -- dual polarization
- Short baselines (300–500 km)

KaVA (KVN+VERA): Combined array

- 7 stations (3:KVN, 4:VERA)
- 3 x 21 m & 4 x 20m dishes
- 22 / 43 GHz
  -- dual polarization (5 stations)
- baseline length : 300–2000 km