SMBH mass estimation from rotating gas inside nearby galaxies

Kyoko Onishi[1], Satoru Iguchi[1,2], Takeshi Okuda[3]

1. The Graduate University for Advanced Studies (SOKENDAI)
2. National Astronomical Observatory of Japan
3. Nagoya University

Mystery about SMBH

stellar mass black hole:

$M_{BH} = 3 - 10^3 M_\odot$

How do they evolve?

Super-Massive Black Hole(SMBH):

$M_{BH} = 10^6 - 10^{10} M_\odot$

Clue: Mass of the SMBH!

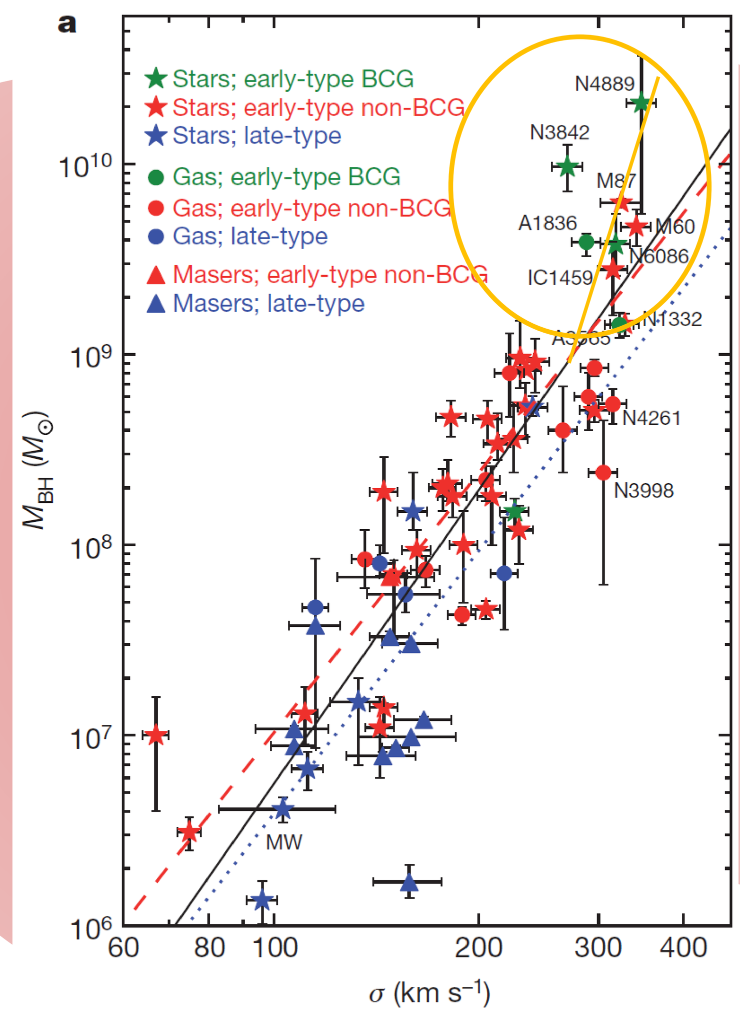
Why? See next!→

$M_{BH} - \sigma$ relation

$M_{BH} - \sigma$ relation is the empirical relation between the black hole mass and the central velocity dispersion, defined as the velocity dispersion in the central 100 pc of its host galaxy.

This important relation shows *the connection between black hole and its host galaxy.*

The relation was first claimed in Ferrarese and Merritt (2000), and recently updated by McConnell et al. (2011) (right figure).



This figure shows the relation between M_{BH} and σ in log-log scale. We can see the plots are off the fit line (solid black line) in the orange-circled area ($M_{BH} \geq 10^9 M_\odot$), and showing a new trend (orange line).

We propose this as the *two-trend idea*, which might shed more light into the evolution scenario of heavier SMBH and its host galaxy.

We can also see a lot of early-type galaxies (red and green points) in the heavier range in this figure.

Our aim

- ✓ Observe more giant elliptical
- ✓ Determine SMBH mass
- ✓ Make a plot in the figure
- ✓ Restrict the $M_{BH} - \sigma$ relation (two-trend or not?)

- ➢ This study can help us reach to the scenario how SMBHs developed
- ➢ The two-trend idea is unique

Collaboration of ALMA...

Recently ALMA achieved 0.1" angular resolution, which is enough helpful to derive SMBH mass (For the method, see below).

As discussed in below, we propose to observe gas kinematics in high angular resolution. At radio wavelength, we can obtain molecular gas rotation.

and Subaru telescope...

Optical and Infrared observation provides us ionized gas rotational structure.

Question1: Does the ionized gas rotates along with molecular gas?

Question2: Is it good to estimate BH mass from a single wavelength?

In order to discuss in detail, comparing ALMA and Optical-IR observation is necessary!

How to estimate SMBH mass?

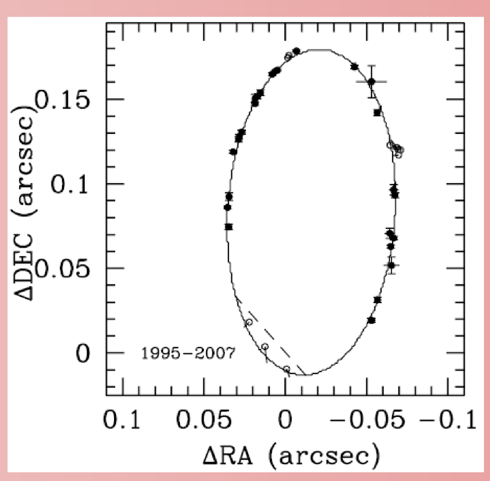
1. Milky Way method

- Find stars rotating around the BH
- Fit orbits into Keplerian rotation, and derive BH mass

example: SgrA* = $(4.1 \pm 0.6) \times 10^6 M_\odot$

(Ghez+ 2008)

Invalid because: We need to observe stars around the BH precisely.



Ghez et al(2008)

2. Mega maser method

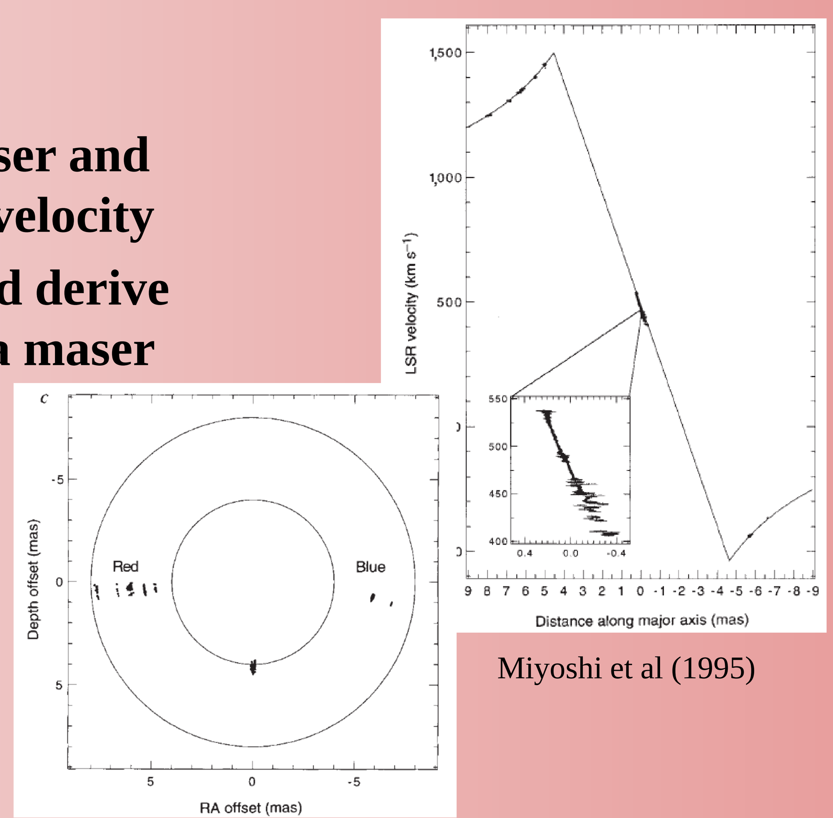
- Observe spectral line of mega maser and determine its position and radial velocity
- Fit them into Keplerian model and derive BH mass in the center of the mega maser

example: NGC 4258 $M_{BH} = 3.6 \times 10^7 M_\odot$

(Miyoshi+ 1995)

Invalid because: Observed megamaser Black holes are $M_{BH} < 10^8 M_\odot$

(see ▲ plots in $M_{BH} - \sigma$ figure.)



Miyoshi et al (1995)

3. Stellar kinematics method

- Observe elliptical galaxies and make velocity dispersion maps of them
- Fit the velocity dispersion into orbit superposition model (Schwarzschild 1979) and derive BH mass

example:

NGC 3842

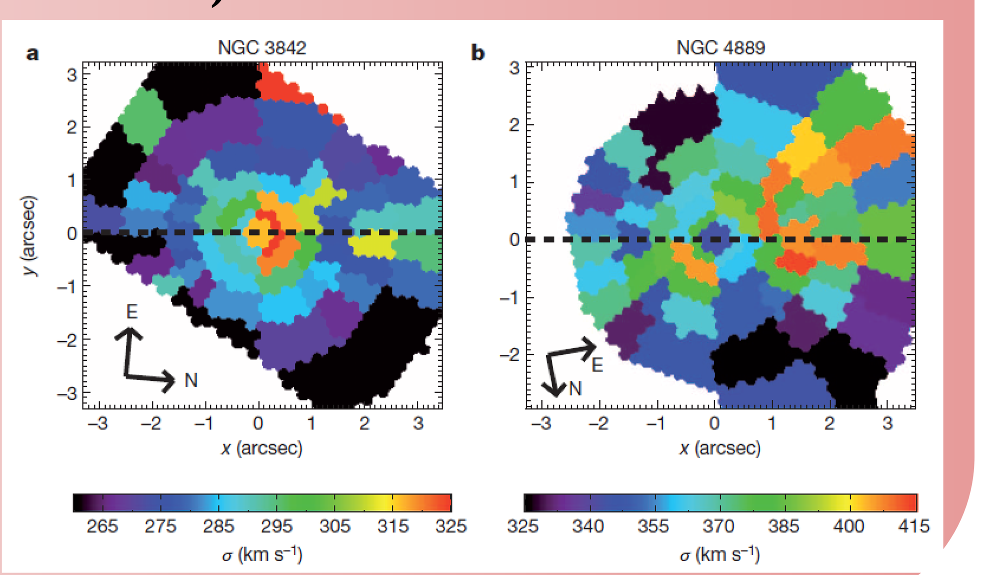
$M_{BH} = (9.95 \pm 2.75) \times 10^9 M_\odot$

NGC 4889

$M_{BH} = (18.4 \pm 8.6) \times 10^9 M_\odot$

(McConnell+ 2011)

Invalid because: This method requires stellar velocity dispersion, which is not available from radio observation.



McConnell et al (2011)

The best method for us to derive SMBH mass

4.Gas kinematics method

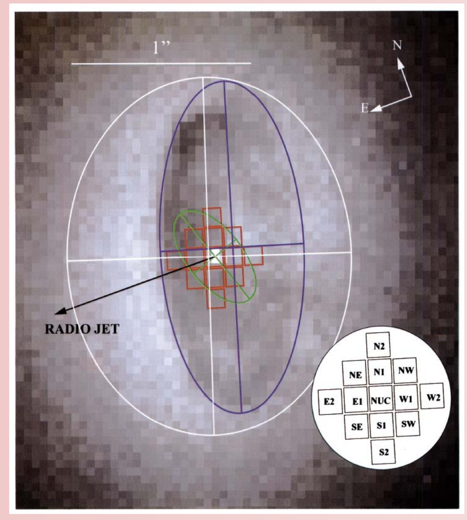
- Observe atomic emission line velocity
- Fit the velocity distribution into Keplerian rotation model

example: NGC 4261

$M_{BH} = (4.9 \pm 1.0) \times 10^8 M_\odot$

(Ferrarese and Jaffe 1996)

Valid!

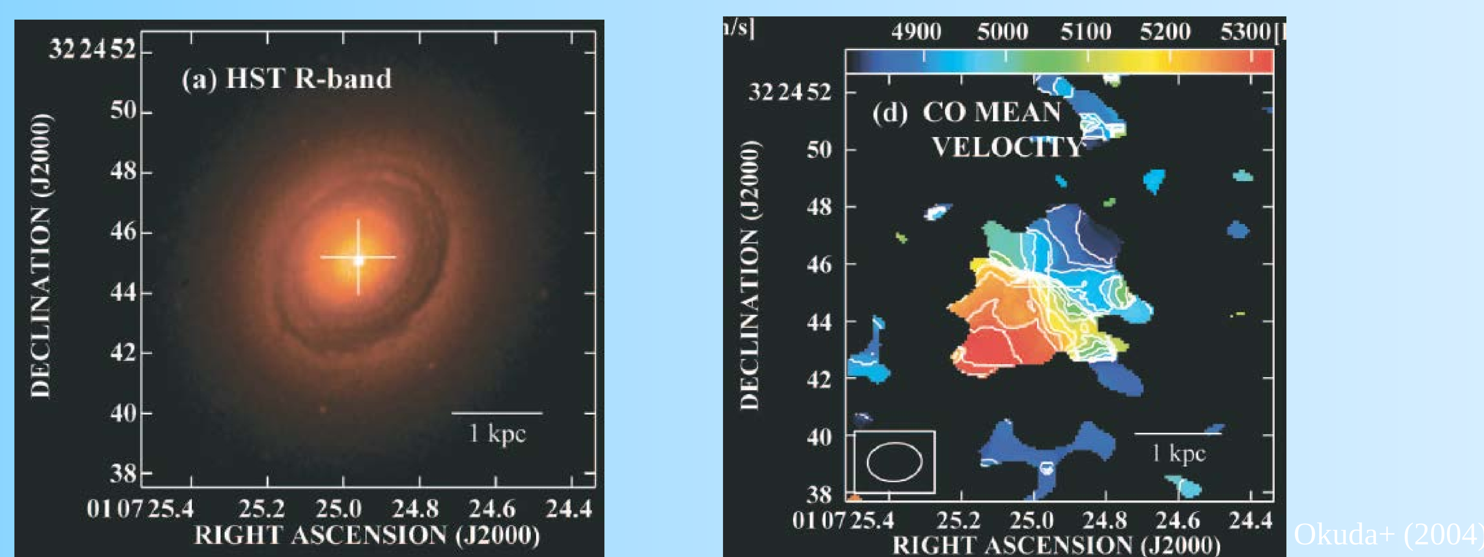


Ferrarese and Jaffe (1996)

Candidate: The giant elliptical 3C 31

We have discovered the rotating structure of CO gas with NMA Rainbow observation (Okuda et al. 2004). However, it was impossible to apply "Gas kinematics method" (see the column above!) and derive black hole mass, because of its poor angular resolution and sensitivity.

Rotating structure observed!



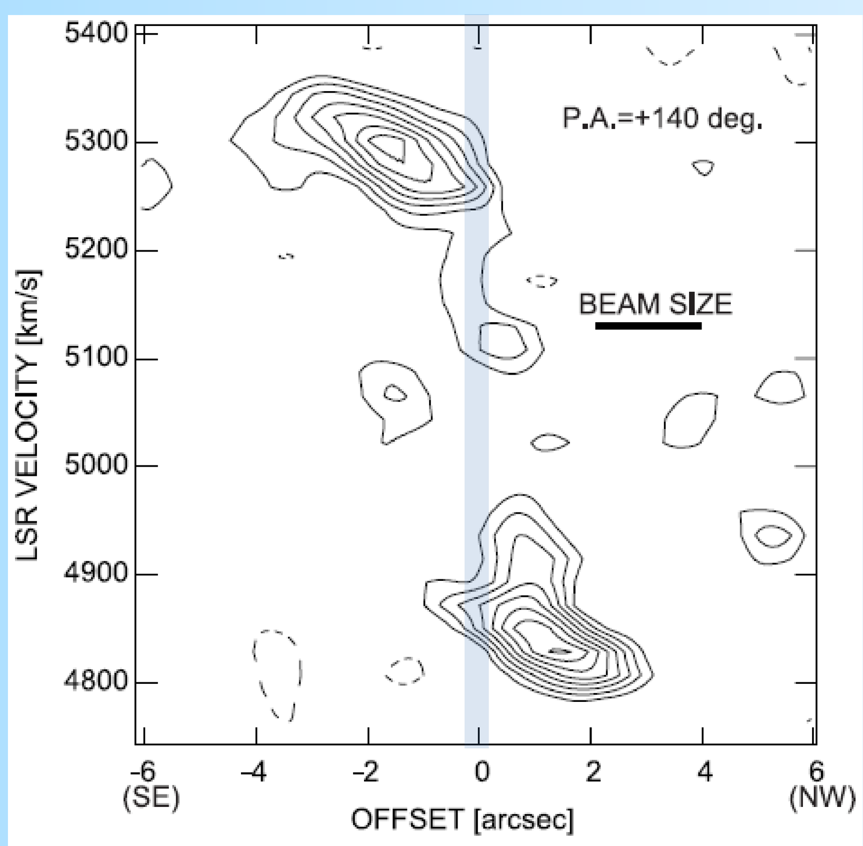
Left: NMA Rainbow observation of the giant elliptical 3C 31 by Okuda et al. (2004) shows a clear CO(2-1) rotation along the disk-like structure shown with HST R-band(*Right*).

molecular line from inner few parsec

The position-velocity map from NMA observation (right figure) shows a galactic rotation of 3C 31.

In order to derive black hole mass, we need to observe the inner part that is directly affected by the central black hole mass.

As candidate lines to observe, we propose recombination line, highly excited molecular… etc.



→ need higher angular resolution and higher sensitivity!

Future work

In order to observe the inner part of the galaxy, HCN, HCO^+ molecular line will be adequate at radio wavelength. This is supported by the ALMA Cycle0 result of NGC 1097 (yet published).

Also we propose to observe ionized gas with Subaru telescope to confirm the estimated SMBH mass.

Our plan is to observe the inner 10 pc, which resolution is roughly 0.1" at z=0.01.