Relics of Galaxy Merging: Observational Predictions for a Wandering Massive Black Hole and Accompanying Star Cluster in the M31 Halo

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References: Kawaguchi T., Saito Y., Miki Y., Mori M., 2014, ApJL, 789, L13; Miki Y., Mori M., Kawaguchi T., Saito Y., 2014, ApJ, 783, 87

Abstract

Galaxies and massive black holes (BHs) are presumed to grow via galactic merging events and subsequent BH coalescence. We investigate the merging event between the Andromeda galaxy (M31) and a satellite galaxy (Miki et al. 2014). We compute the expected observational appearance of the massive BH and stars around it that were at the center of the satellite galaxy prior to the merger, and are currently wandering in the M31 halo (Kawaguchi et al. 2014). The expected broadband spectrum of an accretion flow onto the BH indicates that the radio band (with JVLA, ALMA and SKA) is the best frequency range to detect the emission. We also evaluate the mass and the luminosity of the stars bound by the wandering BH and find that such a star cluster is sufficiently luminous that it could be detected by Hyper Suprime-Cam at a distance up to 80Mpc. The discovery of a relic massive BH wandering in a galactic halo will provide a direct means to investigate in detail the coevolution of galaxies and BHs. It also means a new population of BHs (off-center massive BHs).

1. Galaxy Merging and Evolution of Black Holes

◎ Galaxies have increased their masses by colliding/merging with nearby galaxies.

Hubble Space Telescope, Subaru

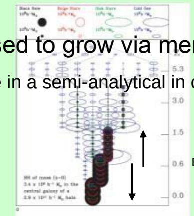
Bullock & Johnston 2005

◎ Massive black holes (BHs) also supposed to grow via merging.

◆ Multiple massive black holes ◆ Merging tree in a semi-analytical in colliding galaxies: model (Malbon+07)

e.g., NGC6240 (Komossa+03)

Chandra(5-8keV) 10"



Black: Massive black hole of each galactic center (with the size indicating the mass)

higher-z

Time

◆ Jet core orbital motion (Sudou+03),

◆ Double BLRs (Boroson+Bauer 09)

◎ "Merging and Growth of Massive Black Holes via Galaxy Merging" hypothesis: Not yet confirmed.

2. Galaxy Merging in M31 (Andromeda galaxy)

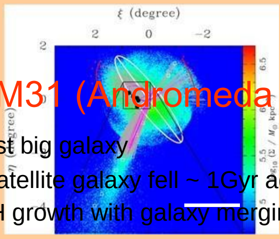
◎ Extremely close to us: Nearest big galaxy

◎ Stellar structures indicate a satellite galaxy fell ~ 1Gyr ago.

Best laboratory to see the BH growth with galaxy merging

McConnachie+09

2 deg.



Miki+ 2014

2 deg.

◎ Hunting the massive BH that resided in the satellite galaxy's center

◎ If we really find it :

◆ First example to see the BH evolution via galaxy merging, from both observational and theoretical sides.

◆ New population of BHs: Many wandering massive BHs missing

→ Revision of the Soltan argument ◆ Clean laboratory for imaging of BHs : Little effect of scattering

◎ Agenda

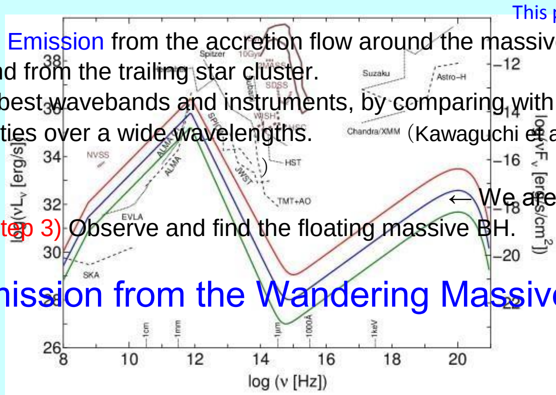
Step 1) M31 stellar structures constrain the orbit of the satellite galaxy and location of the wandering massive BH. (Miki et al. 2014)

This poster

Step 2) Emission from the accretion flow around the massive BH and from the trailing star cluster.

Find best wavebands and instruments, by comparing with the sensitivities over a wide wavelengths. (Kawaguchi et al. 2014)

← We are now here. Step 3) Observe and find the floating massive BH.



3. Emission from the Wandering Massive BH

◎ Hoyle-Lyttleton accretion of interstellar medium (ISM) of M31 onto the BH assumed

$$\dot{M}_{HL} \propto M_{BH}^2 \rho \, (v^2 + c_s^2)^{-3/2}$$

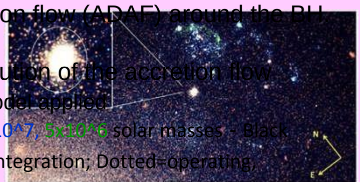
BH (M_{BH}), ISM (ρ, c_s), v

◎ Expected gas accretion rate is ~4 dex smaller than the Eddington rate (~0.2 M_{sun}/yr) even at the highest accretion rates.

→ Advection-dominated accretion flow (ADAF) around the BH.

◎ Expected spectral energy distribution of the accretion flow

- Mahadevan (1997) ADAF model applied.
- Assumed BH mass: 2x10^7, 10^7, 5x10^6 solar masses. Black lines = Sensitivities (10s in 10^4 sec integration; Dotted=operating, Dashed=planed)



Kawaguchi+ 2014

◎ Detectable at radio (JVLA, ALMA, SKA) ⇒ Explore the floating BH and examine the "BH growth via galaxy merging" hypothesis

4. Remnant of the satellite galaxy

◎ Most part of the satellite galaxy → straggled via tidal force
(→ Andromeda stream etc)

◎ Central part of the satellite galaxy, survived against the tidal destruction

→ A star cluster harboring a massive black hole, traveling at the M31 outskirt

Right: Example of a star cluster that could be a remnant of satellite galaxy
(Annibali+ 12)

◎ Mass of the remnant star cluster: determined by the impact parameter (pericentric passage)

Simulations ⇔Observed stellar structures
→ Satellite galaxy passed ~1kpc away from the M31 center.
→ Stellar mass inside the Hill radius around the satellite's central BH
~ 10% of BH mass ~ 10^6 solar masses

◎ Those stars were born in the bottom of gravitational potential of satellite galaxy → Metal-rich compared with usual globular clusters

◎ Stellar synthesis model (Fioc et al. 1997) for 1-10Gyr stars:
Expected spectral energy distribution of the trailing star cluster (Thick lines in the upper figure).

→ Brightness (*V*-band) ~ 14 --16 mag in AB magniture
→ Hyper-SuprimeCam and WISH can go farther (~80Mpc)