Black Hole Mass Measurement in Nearby Galaxy Using Molecular Gas Dynamics

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Abstract— A new method is carried out to measure SuperMassive Black Hole (SMBH) mass in the center of nearby galaxy NGC 1097, by using dense molecular gas dynamics traced with HCN(J=1–0). The dynamics is observed with Atacama Large Millimeter/submillimeter Array (ALMA). This work demonstrates the capability of radio interferometers to measure SMBH mass, which helps to better understand the evolution of black holes and hence their host galaxies. The original paper is published by Astrophysical Journal in June 2015 [1]. Here we quote the published paper and our related works.

Introduction— Observations and studies particularly in the last two decades have shown that every stellar spheroids harbor SuperMassive Black Holes (SMBHs; larger than $10^6 M_\odot$ where $M_\odot$ is the mass of the sun) in their centers [2]. Meanwhile, developed observing facilities allowed us to measure the SMBH mass in some of the nearby galaxies by using different dynamical methods. The measured SMBH mass ($M_{\rm BH}$) are empirically known to be tightly correlated to host galaxy bulge properties such as central velocity dispersion of stars (known as $M_{\rm BH} - \sigma$ relation, [2,3,4,5]). These correlations, together with recent numerical simulations, suggest that galaxy and black hole evolves by influencing each other. SMBH mass is thus considered to be the key parameter to better understand the growth of galaxy and SMBH. SMBH mass measuring method using molecular gas dynamics, observed with radio interferometers, enables one to measure more SMBH mass in this Atacama Large Millimeter/submillimeter Array (ALMA) era. Reference [1] and [6] started this method with newly developed radio interferometers. With a larger sample realized with this new method, correlations such as $M_{\rm BH} - \sigma$ relation are expected to be better constrained, and eventually makes the co-evolutionary process of galaxy and black hole to be better understood.

Data— NGC 1097 is a nearby Type-1 Seyfert galaxy at a distance of 14.5 Mpc [7] (~70 pc arcsecond^{-1}). The nucleus is located at *RA* (J2000.0) = $02^{\rm h}46^{\rm m}18^{\rm s}.96$, *DEC* (J2000.0) = $-30°16'28''.9$ [8]. The SMBH mass in NGC 1097 is estimated to be $(1.2 \pm 0.2) \times 10^8 M_\odot$ by using the empirical $M_{\rm BH} - \sigma$ relation from [3] with an observed $\sigma = 196 \pm 5\ {\rm km\,s^{-1}}$ [9].

SMBH mass measurement— We measure the SMBH mass in NGC 1097 by using molecular gas dynamics observed with ALMA. The method is described in reference [1], while we give a short summary here. A Position-Velocity Diagram (PVD) is cut along the galaxy major axis (P.A = 130°) from the observed data to compare with the model velocity field, calculated by MGE_circular_velocity method [10] and Kinematic Molecular Simulation (KinMS) [6]. The model considers a mass-to-light ratio (M/L) and SMBH mass as free parameters. We run a grid simulation to obtain $M_{\rm BH} = 1.40^{+0.27}_{-0.32} \times 10^8 M_\odot$, M/L = $5.14^{+0.03}_{-0.04}$ with a reduced chi-square $\chi^2_{\rm red} = 1.09$ realized by the best fit (see Figure).

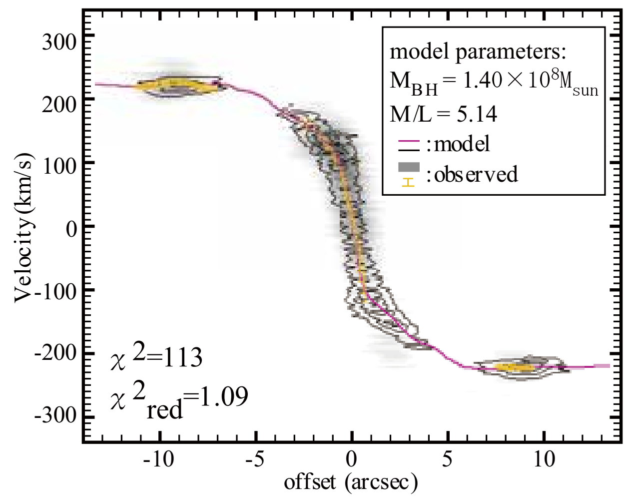

Figure 1: Comparison of the observed PVD and the model (grey scale filled contours and yellow points) and the model (black contours and purple lines). Model parameters are set to be $M_{\rm BH} = 1.40 \times 10^8 M_\odot$, M/L = 5.14. The reduced chi-square is $\chi^2_{\rm red} = 1.09$ with the degree of freedom of 104.

References

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