Active supermassive black holes revealed in merging galaxies

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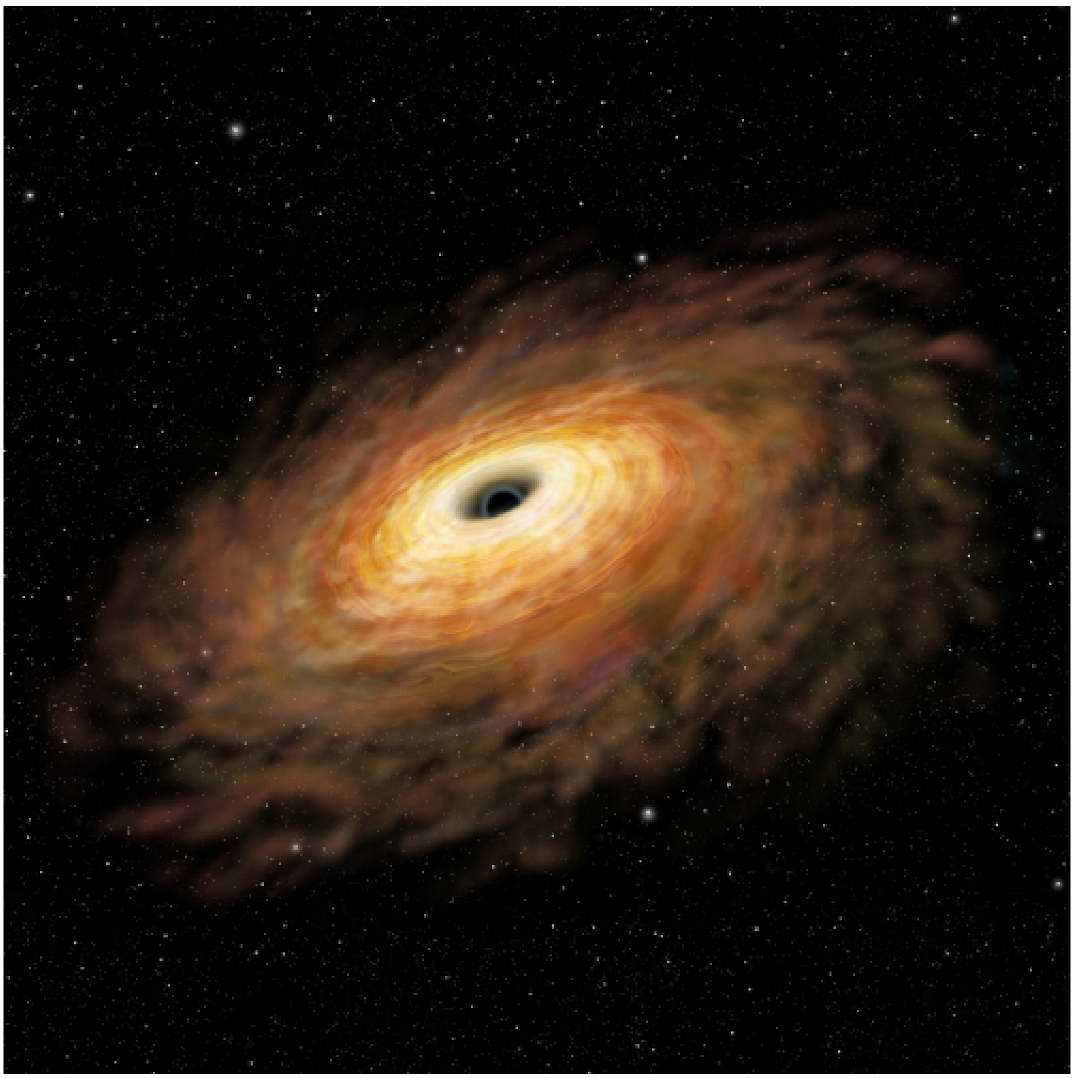

Figure 1: Artist's rendition of an active, mass-accreting black hole in a luminous, gas-rich merging galaxy. Credit: NAOJ

(Phys.org) —A team of astronomers has conducted infrared observations of luminous, gas-rich, merging galaxies with the Subaru Telescope to study active, mass-accreting supermassive black holes (SMBHs). They found that at least one SMBH almost always becomes active and luminous by accreting a large amount of material. However, only a small fraction of the observed merging galaxies show multiple, active SMBHs. These results suggest that local physical conditions near SMBHs rather than general properties of galaxies primarily determine the activation of SMBHs.

In this Universe, dark matter has a much higher mass than luminous matter, and it dominates the formation of galaxies and their large-scale structures. The widely accepted, cold-dark-matter based galaxy formation scenario posits that collisions and mergers of small gas-rich galaxies result in the formation of massive galaxies seen in the current Universe. Recent observations show that SMBHs with more than one-million solar masses ubiquitously exist in the center of galaxies. The merger of gas-rich galaxies with SMBHs in their centers not only causes active star formation but also stimulates mass accretion onto the existing SMBHs. When material accretes onto a supermassive black hole (SMBH), the accretion disk surrounding the black hole becomes very hot from the release of gravitational energy, and it becomes very luminous. This process is referred to as active galactic nucleus (AGN) activity; it is different from the energy generation activity by nuclear fusion reactions within stars. Understanding the difference between these kinds of activities is crucial for clarifying the physical processes of galaxy formation. However, observation of these processes is challenging, because dust and gas shroud both star-formation and AGN activities in merging galaxies. Infrared observations are indispensable for this type of research, because they substantially reduce the effects of dust extinction.

To better understand these activities, a team of astronomers at the National Astronomical Observatory of Japan (NAOJ), led by Dr.

Masatoshi Imanishi, used Subaru Telescope's Infrared Camera and Spectrograph (IRCS) and its adaptive optics system to observe infrared luminous merging galaxies at the infrared K-band (a wavelength of 2.2 micrometers) and L'-band (a wavelength of 3.8 micrometers). They used imaging data at these wavelengths to establish a method to differentiate the activities of deeply buried, active SMBHs from those of star formation. The radiative energy-generation efficiency from active, mass-accreting SMBHs is much higher than that of the nuclear fusion reactions inside stars. An active SMBH generates a large amount of hot dust (several 100 Kelvins), which produces strong infrared L'-band radiation; the relative strengths of the infrared K- and L'-band emission distinguish the active SMBH from star-forming activity. Since dust extinction effects are small at these infrared wavelengths, the method can detect even deeply buried, active SMBHs, which are elusive in optical wavelengths. Subaru Telescope's adaptive optics system enabled the team to obtain high spatial resolution images that allowed them to effectively investigate emission that originates in active SMBHs in the nuclear regions of galaxies by minimizing emission contamination from galaxy-wide, star-forming activity.

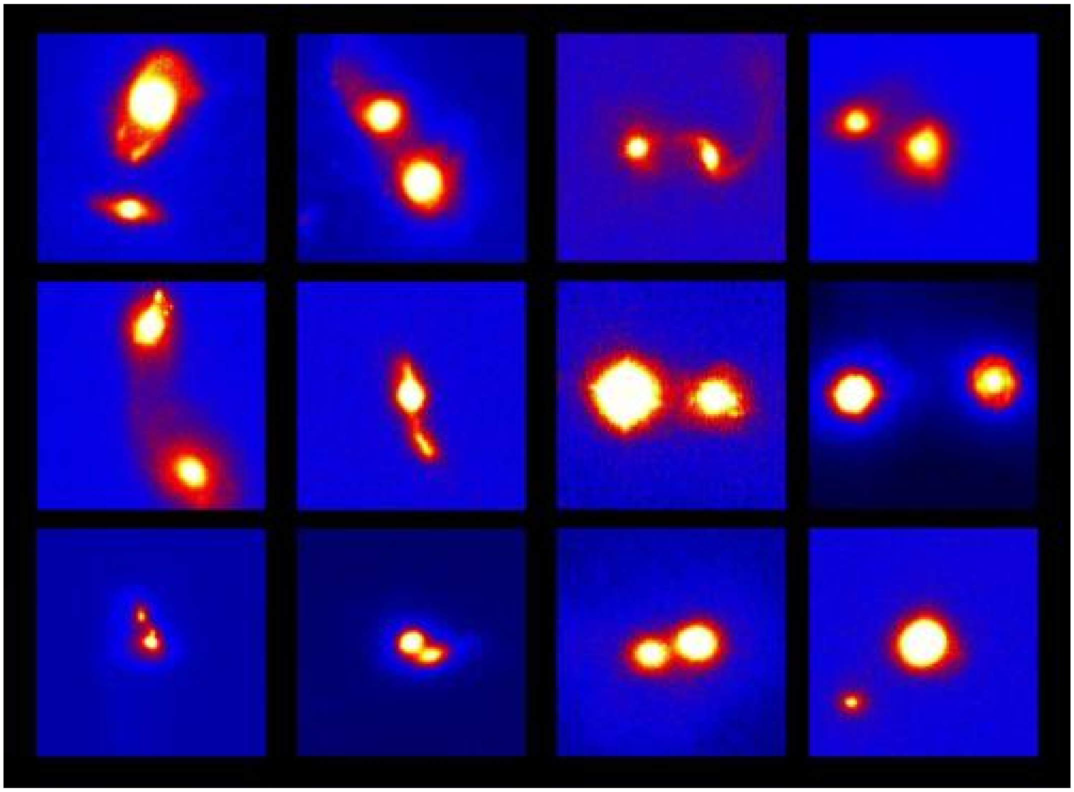

Figure 2: Examples of infrared K-band images of luminous, gas-rich, merging galaxies. The image size is 10 arc seconds. North is up, and east is to the left. The individual images clearly show aspects of the merging process, such as interacting double galaxy nuclei and extended/bridging faint emission structure. Credit: NAOJ

The team observed 29 infrared luminous gas-rich merging galaxies. Based on the relative strength of the infrared K- and L'-band emission at galaxy nuclei, they confirmed that at least one active SMBH occurs in every galaxy but one (Figure 2). This indicates that in gas-rich, merging galaxies, a large amount of material can accrete onto SMBHs, and many such SMBHs can show AGN activity.

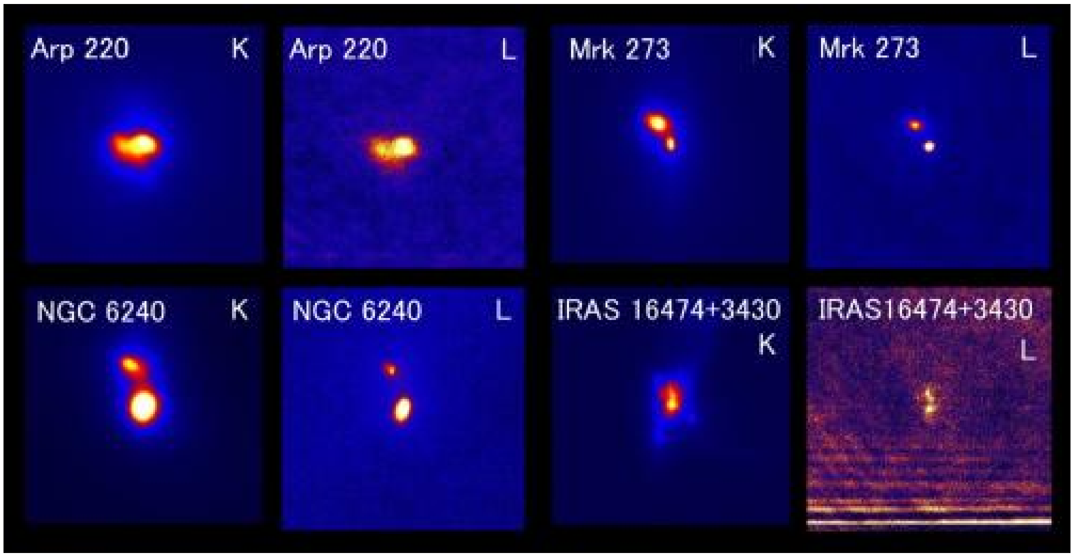

Figure 3: Infrared K-band and L'-band images of four luminous, gas-rich, merging galaxies that display multiple, active SMBHs. The image size is 10 arc seconds. North is up, and east is to the left. They show emission from multiple galaxy nuclei. The infrared K-band to L'-band emission strength ratios characterize emission of AGN-heated hot dust, not a star-formation-related one. Credit: NAOJ

However, only four merging galaxies display multiple, active SMBHs (Figure 3). If both of the original merged galaxies had SMBHs, then we would expect that multiple SMBHs would occur in many merging galaxies. To observe these SMBHs as luminous AGN activity, the SMBHs must actively accrete material. The team's results mean that not all SMBHs in gas-rich merging galaxies are actively mass accreting, and that multiple SMBHs may have considerably different mass accretion rates onto SMBHs. Quantitative measurement of the degree of mass accretion rates of SMBHs is usually based on the brightness of AGNs per unit SMBH mass (Figure 4). Comparison of SMBH-mass-normalized AGN luminosity (=AGN luminosity divided by SMBH mass) among multiple nuclei confirms the scenario of different mass accretion rates onto multiple SMBHs in infrared-luminous, gas-rich merging galaxies.

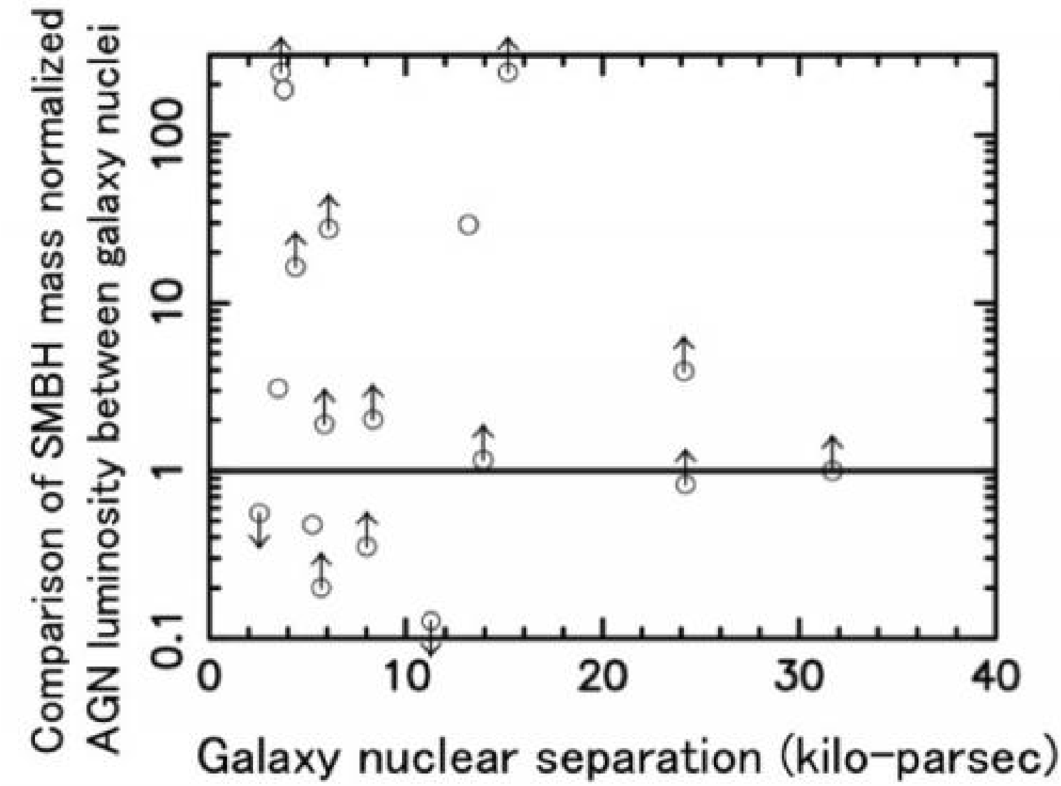

Figure 4: The vertical axis is the comparison of SMBH-mass-normalized AGN luminosity (= AGN luminosity divided by SMBH mass) between multiple nuclei. The horizontal axis is the apparent separation of galaxy nuclei. 1 kilo-parsec corresponds to 30000 trillion kilometers (19000 trillion miles). The supermassive black-hole (SMBH) masses are derived from stellar emission luminosity at individual galaxy nuclei, because SMBH mass and galaxy stellar emission luminosity are found to correlate in nearby galaxies. If both SMBHs have the same mass accretion rate, when normalized to the SMBH mass, then such objects are distributed around the horizontal solid line, at the value of unity in the vertical axis. Objects above the horizontal solid line are SMBHs with larger mass and show more active mass accretion, while those below have a smaller mass and show less active mass accretion.Credit: NAOJ

The findings demonstrate that local conditions around SMBHs rather than general properties of galaxies dominate the mass accretion process onto SMBHs. Since the size scale of mass accretion onto SMBHs is very small compared to the galaxy scale, such phenomena are difficult to predict based on computer simulations of galaxy mergers. Actual observations are crucially important for best understanding the mass accretion process onto SMBHs that occurs during galaxy mergers.

More information: Imanishi, M. & Saito, Y. 2014 "Subaru Adaptive-optics High-spatial-resolution Infrared K- and L'-band Imaging Search for Deeply Buried Dual AGNs in Merging Galaxies", *Astrophysical Journal*, Volume 780, article id. 106. arXiv:1312.2031

Provided by Subaru Telescope

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