Japan Academy Prize to:

Naomasa Nakai

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for "Study of Active Galactic Nuclei and Super-Massive Black Holes based on VLBI Observations of Water-Vapor Maser Emission"

Outline of the work:

The quasars and radio galaxies discovered in the 1960s' are now understood to be the active nuclei of galaxies, their structures having been elucidated. To explain the huge energy emitted from these active nuclei, the existence of super-massive black holes has been conjectured. Now, such black holes are thought to exist even in normal galaxies like our Galaxy.

The detailed structure of active galactic nuclei had been investigated by observing their non-thermal emissions with Very Long Baseline Interferometry (VLBI), a radio interferometer comprising antennas separated by several thousand kilometers, capable of achieving extremely high angular resolution. Due, however, to its low sensitivity, VLBI can detect only very bright emissions of ten million Kelvin. Accordingly, astronomers had so far only used it to study active nuclei by observing the non-thermal emission of their synchrotron radiation (continuum spectrum).

Dr. Naomasa Nakai, however, developed a unique approach: He used VLBI to observe the line spectrum of water-vapor maser emission (22.235 GHz rest frequency and 1.35 cm wavelength) radiated from active nuclei, making it possible to directly measure the motion of gas in the galactic nuclei with a milli-arcsecond angular resolution. As a result, he was able to study the structure and motion of the active nuclei and detected super-massive black holes.

In 1992, Dr. Nakai detected water-vapor maser emission in the nucleus of the galaxy NGC 4258, offset by $\pm$1000 km/s (74.0 MHz in frequency) from the velocity of the nucleus itself, using the Nobeyama 45-m radio telescope of the National Astronomical Observatory of Japan. Such an extremely high velocity of neutral gas had theretofore neither been known nor expected within galaxies. He regarded the origin of this maser emission to be a gas disk rotating around the center of the nucleus with a very high rotating velocity, but could not determine the detailed structure or the radius of the gas disk using the 45-m telescope.

Dr. Nakai and his collaborators tried to measure the radius using a domestic VLBI system but failed due to its insufficient angular resolution and sensitivity. Then, observing the maser emission with the Very Long Baseline Array of US National Radio Astronomical Observatory, they successfully imaged the gas disk. The inner and outer radii of the disk were measured as 0.46 and 0.91 light years, respectively, one over a hundred thousand of the radius of the galaxy, and the rotating speed and revolution period were derived as 1080 and 770 km/s and 750 and 2100 years at the inner and outer radii, respectively. The thickness of the disk was determined to be 0.01 light years, extremely thin.

These results showed the gas disk to conform to Kepler's rotation law in the same way as do the planets in our solar system, indicating the existence of a compact and massive object in the nucleus. The measured radius and rotation velocity of the disk revealed the mass of that object to be 3.9×10^7 times the mass of our sun. It is estimated, however, that if a cluster of such a huge number of stars is confined within such a very compact region, it could easily disappear due to collision and/or scattering among the stars within several ten million years, a much shorter period than the age of the galaxy. In addition, no emission is detectable from the nucleus of the galaxy. These results strongly suggest the existence of a black hole of 3.9×10^7 solar mass in the center of the nucleus. Namely, Dr. Nakai's research provided the first reliable evidence of the existence of a super-massive black hole.

Generally, it is very difficult to determine the distance to distant celestial bodies. However, using observational data, Dr. Nakai and his collaborators were able to determine the distance to galaxy NGC 4258 as being 23 million light years geometrically. In the process, they developed a new method to measure directly and accurately the distance to galaxies.

In follow up to Dr. Nakai's discovery of a super-massive black hole in NGC 4258, many groups around the world started to make observations of water-vapor masers in active galactic nuclei. As a result, intense water masers have been detected in about sixty active galactic nuclei with single dishes, and evidence of super-massive black holes in seven nuclei has also been found by research groups at the Smithsonian Astrophysical Observatory and Harvard University besides Dr. Nakai's group. Among them, black holes in four galaxies (NGC 4258, IC 2560, NGC 3079, IC 1481) have been detected by Dr. Nakai's group. The black hole in galaxy IC 2560 exhibits one of the most reliable sources of evidence of a super-massive black hole, next to NGC 4258.

Along with his research on black holes themselves, Dr. Nakai has worked to elucidate the physical state surrounding them. To date, his group has found that the more gas there is around an active nucleus, the more energy that is released; and that the rotation direction of a compact maser disk around a black hole is generally different from that of a galactic disk. Such results are expected to contribute to advancing research on the structure of active galactic nuclei and the evolution of galaxies.

Although it had been theorized that super-massive black holes exist in galactic nuclei, Dr. Nakai's unique concepts and observations have for the first time produced reliable evidence of such super-massive black holes, making a milestone contribution to the progress of research on galactic formation and evolution as well as on the galactic nuclei.