Press Release

Keio University

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Keio University

First Detection of an Intermediate-Mass Black Hole Candidate in the Milky Way

Professor Tomoharu Oka of the Department of Physics, Faculty of Science and Technology, Keio University and his research team carried out a detailed radio wave observations using the Atacama Large Millimeter/submillimeter Array (ALMA; ALMA telescope) on the peculiar molecular cloud CO–0.40–0.22, which was discovered in the central region of the Milky Way. This peculiar molecular cloud lies about 200 light-years away from Sagittarius A* (star), the nucleus of the Milky Way, and inside it's unusually broad velocity width, the researchers identified the possibility of an intermediate-mass black hole with a mass 100,000 times greater than the sun. From the observations, a point-like radio source CO–0.40–0.22* (star), as well as a highly dense and compact molecular cloud near the center of CO–0.40–0.22, were detected. The luminosity of the detected point-like radio source is 1/500 of Sagittarius A*, and it has a radiation spectrum that is distinctly different from that of thermal plasma or interstellar dust. Results of gravitational N-body simulations that placed a 100,000-solar mass point-like mass at the location of CO–0.40–0.22* showed that the distribution and motion of gas in the adjacent area could be reproduced very well. From these findings, it can be thought that the point-like radio source CO–0.40–0.22* is the intermediate-mass black hole that has been suggested to exist within the peculiar molecular cloud CO–0.40–0.22. This is the first detection of an intermediate-mass black hole candidate within the Milky Way galaxy in which we exist.
The results of this research were published in the September 4 issue of the British scientific journal *Nature Astronomy*.

1. Main Points of Research

- A detailed radio wave observation using the Atacama Large Millimeter/submillimeter Array (ALMA; ALMA telescope) was carried out on the peculiar molecular cloud CO–0.40–0.22 that was discovered in the central region of the Milky Way.
- A point-like radio source CO–0.40–0.22*, as well as a highly dense and compact molecular cloud near the center of CO–0.40–0.22, were detected.
- The unusual spectrum of the point-like radio source CO–0.40–0.22* and the results of gravitational N-body simulations led to the conclusion that this may be the intermediate-mass black hole whose existence has been previously suggested.

2. Background of Research

It is thought that at the centers of many galaxies, including the Milky Way, there are supermassive black holes whose masses are over several million solar masses (*1). However, the origins of these supermassive black holes are not yet understood. One theory suggests that intermediate-mass black holes (*2), which are formed by runaway coalescence of stars, repeatedly merge and form a supermassive black hole at the center of the galaxy. To verify this theory, there is a need to confirm the existence of intermediate-mass black holes. There have been many reports of detections of intermediate-mass black hole candidates before now but none of these have been definitive.

The research team discovered a peculiar molecular cloud, CO–0.40–0.22, in the central region of the Milky Way through observational results using the 45 m radio telescope at the Nobeyama Radio Observatory (NRO) and the 10 m Atacama Submillimeter Telescope Experiment (ASTE) telescope. CO–0.40–0.22 has an extremely broad velocity width (90 km/s) and an elliptical spatial structure with a diameter of about 10 light-years. No distinct corresponding astronomical objects could be seen in the same direction as the molecular cloud, and thus no energy was supplied locally through an explosion, etc. From these observed facts and the results of the gravitational N-body simulations, the research team suggested the possibility of a 100,000-solar mass intermediate-mass black hole hidden at the center of the peculiar molecular cloud CO–0.40–0.22. (January 15, 2016 Keio University Press Release)

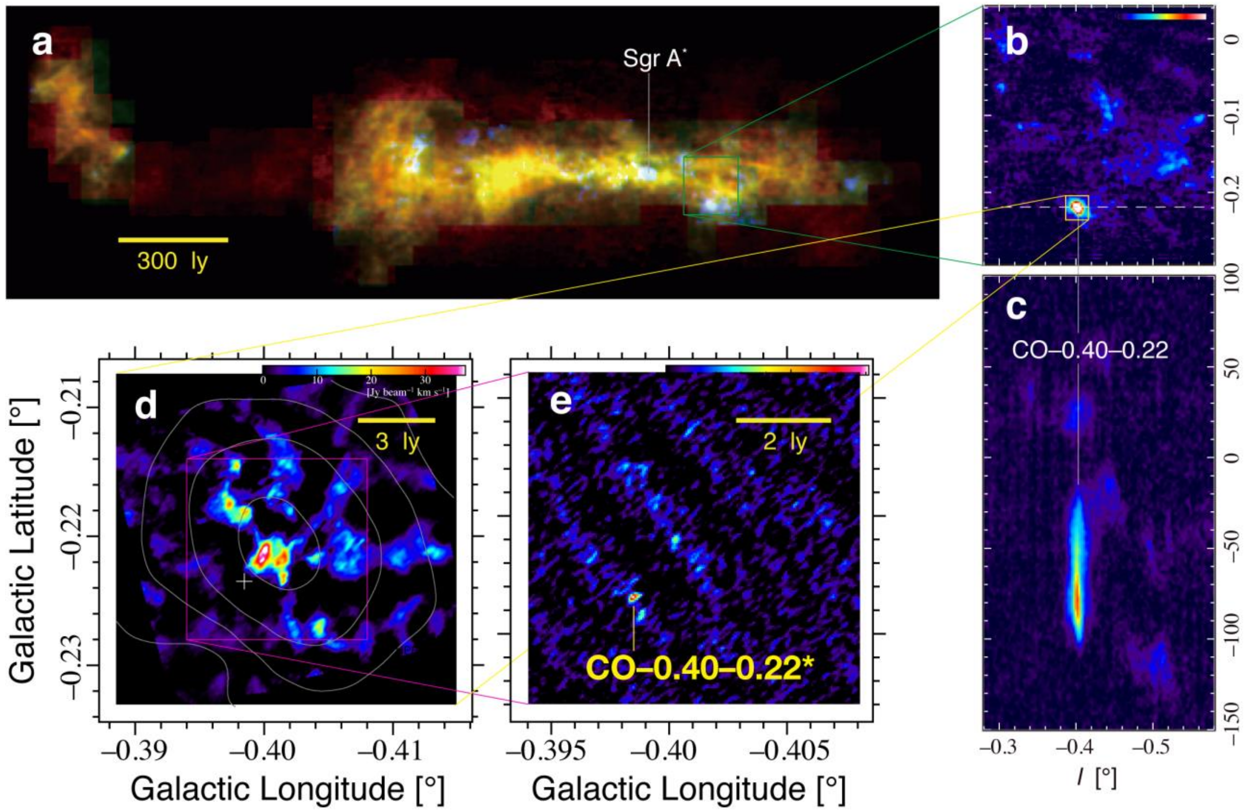

Figure 1: (a) Wide-area composite image of carbon monoxide (CO) rotational transition line intensity at 115 GHz and 346 GHz obtained with the NRO 45 m radio telescope and the ASTE 10 m telescope, respectively. (b) Integrated intensity map and (c) longitude–velocity map of hydrogen cyanide (HCN) rotational transition line at 355 GHz obtained with the ASTE telescope. (d) Integrated intensity map of HCN rotational transition line at 266 GHz and (e) 266 GHz continuum emission intensity map obtained with the ALMA telescope.

3. Results

This time, the research team used the Atacama Large Millimeter/submillimeter Array (ALMA; ALMA telescope; *3, *4) located in Chile to carry out detailed radio frequency observations of the peculiar molecular cloud CO–0.40–0.22. The observations were made for spectral lines emitted by carbon monoxide (CO) and Hydrogen cyanide (HCN) molecules at 231 GHz and 266 GHz and for continuum emission at the respective frequency bands. From these observaions, a highly dense and compact molecular cloud about 1.5 light-years in size, near the center of CO–0.40–0.22, and a point-like radio continuum source CO–0.40–0.22* adjacent to it were detected. The highly dense and compact molecular cloud has a broad velocity width of over 100 km/s, and a steep velocity gradient toward the direction of CO–0.40–0.22*, it suddenly gains high velocity. The luminosity of the point-like radio source CO–0.40–0.22* is 1/500 of the nucleus of the Milky Way (Sagittarius A*), and it has a radiation spectrum that is distinctly different from that of thermal plasma or interstellar dust.

Using these results, the research team carried out more detailed gravitational N-body simulations to attempt to reproduce the distribution and motion of molecular gas within the peculiar molecular cloud CO–0.40–0.22. By placing a 100,000-solar mass point-like mass at the location of CO–0.40–0.22* and releasing many particles that resembled clouds from a distance of 30 light-years away, it was discovered that the distribution and motion of the particles that passed close to the CO–0.40–0.22* represented the observed distribution and motion of gas very well. This means that the CO–0.40–0.22* can be explained by it being an unknown astronomical object with a mass that is 100,000 times greater than the sun.

From the resolution of the ALMA telescope, it was found that the radius of CO–0.40–0.22* was much less than 0.07 light-years. If a mass of 100,000 solar masses is concentrated here, it would make it over 100 times greater than the mass density at the central part of the M15 globular cluster, which is the most densely packed globular cluster in the Milky Way. When this is put together with the fact that the characteristics of the spectra cannot be explained by the assembly of normal high density gas or stars, the possibility that the point-like radio source CO–0.40–0.22* is the intermediate-mass black hole, which has been suggested to exist within the peculiar molecular cloud CO–0.40–0.22, is very high.

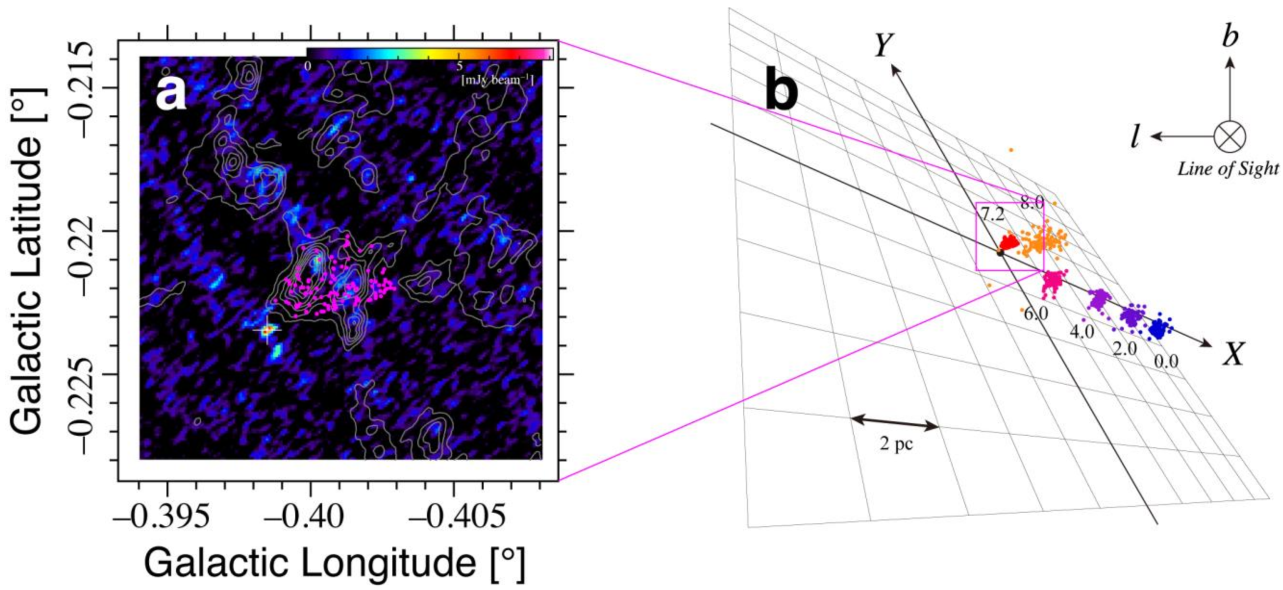

Figure 2: (a) The results of gravitational N-body simulations superimposed (pink dots) on the HCN rotational transition line integrated intensity map at 266 GHz obtained with ALMA. The contour lines represent the HCN integrated intensity rotational transition line at 266 GHz. (b) Results of the gravitational N-body simulations. The line of sight is represented by the depth. A 100,000-solar

mass point-like mass was place at the point (X,Y) = (0,0), and the initial location and initial velocity vector of the center of gravity of the cloud is on the plane shown in the figure. Particle distribution for each time step are shown in different colors. Time is represented in 100,000-year units.

4. Significance of Results

From this research, the exact location of the 100,000-solar mass black hole candidate, whose existence within the peculiar molecular cloud CO–0.40–0.22 has been suggested previously, has been identified. This is the first detection of an intermediate mass black hole candidate within the Milky Way. By confirming the existence of an intermediate-mass black hole 200 light-years away from the nucleus, which is a relatively close distance, supports the merging scenario for the formation and evolution of a central supermassive black hole. In other words, it can be said that the intermediate-mass black hole identified by this research should contribute to the formation and growth of supermassive black holes in galactic centers.

In addition, this research demonstrated the validity of using spectral line observations to confirm the existence of inactive, isolated stray black holes, which were difficult to find by traditional methods. The research team detected high-velocity gas clumps similar to CO–0.40–0.22 not only in the center of the Milky Way but also in the Galactic disk, and much of these are thought to be driven by stray black holes (January 16, 2017 and July 18, 2017 Keio University Press Release). There is a theoretical prediction that 100 million to 1 billion black holes floating within the Milky Way, and the use of the method in this research will increase the number of black hole candidates dramatically. The detailed research on black hole candidates will provide essential knowledge, including the verification of general relativity, which will greatly contribute to the advancement of modern physics.

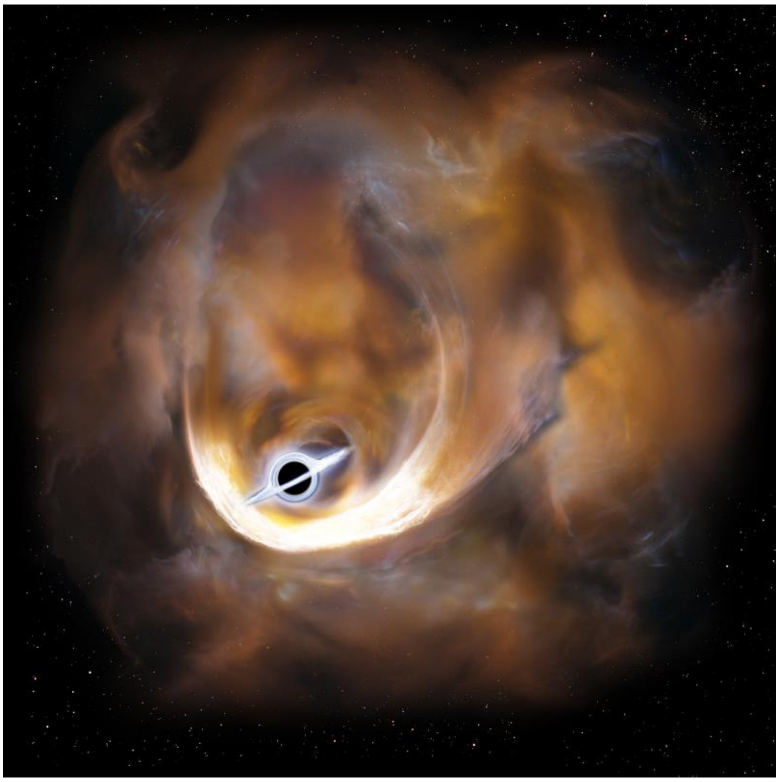

Figure 3: An image of clouds accelerating due to gravitational scattering caused by the intermediate-mass black hole.

5. Details of Journal Article

The results of this research were published in the September 4 issue of the British scientific journal *Nature Astronomy*. The title of the paper, the authors, and their affiliation at the time are as follows:

"Millimeter-wave Emission from an Intermediate-Mass Black Hole Candidate in the Milky Way"

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Reference

Atacama Large Millimeter/submillimeter Array (ALMA)
https://alma-telescope.jp

Keio University Faculty of Science and Technology OKA-Laboratory
http://aysheaia.phys.keio.ac.jp/index.html (Japanese language only)

Related Research

Keio University Press Release (January 15, 2016)
Second Largest Black Hole in the Milky Way Discovered
https://www.keio.ac.jp/ja/press_release/2015/osa3qr000001bq8l.html (Japanese language only)

Keio University Press Release (January 16, 2017)
Supersonic "Bullet" Shooting the Milky Way Discovered—Is It a Stray Black Hole?
https://www.keio.ac.jp/ja/press-releases/2017/1/16/28-19413/ (Japanese language only)

Keio University Press Release (July 18, 2017)
Two More Stray Black Hole Candidates Discovered in the Center of the Milky Way
https://www.keio.ac.jp/ja/press-releases/2017/7/18/28-21984/ (Japanese language only)

Glossary

*1 Solar mass: unit of mass used in astronomy. 1 solar mass $=1.99\times10^{30}$ kg

*2 Intermediate-mass black hole: black holes with intermediate masses that are in between stellar-mass black holes, which are remnants of massive stars (mass of these are several tens of times greater than the sun), and supermassive black holes, which are found at the nuclei of galaxies (mass of these are more than several million times greater than the sun).
*3 Interferometer: an observation instrument that achieves high resolutions by arranging several radio telescopes away from each other and combining the collected signals.
*4 Atacama Large Millimeter/submillimeter Array (ALMA; ALMA telescope): a giant radio telescope located at a height of about 5,000 meters above sea level in the Atacama Desert in northern Chile. It is a joint international project between the European Southern Observatory representing Europe, National Radio Astronomy Observatory representing the North American Union, and National Astronomical Observatory of Japan representing East Asia.

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