PRESS RELEASE

Keio University

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Keio University

Evidence of Past Explosions at the Center of the Milky Way
—Is It Another Super Massive Star Cluster ?—

A research team centered around Shiho Tsujimoto at Keio University's Graduate School of Science and Technology (1st year doctoral student) and Professor Tomoharu Oka of the Department of Physics at the Faculty of Science and Technology discovered a peculiar molecular cloud with an unusually broad velocity width at the center of the Milky Way about 30,000 light-years away from the Solar System. This peculiar molecular cloud is roughly 50 light-years in size, containing at least 5 expanding spherical shell structures. It is thought that these are the result of a massive explosion that occurred here approximately 100,000 years ago. The energy released from the explosion is the equivalent of about 10 supernova explosions, and it is speculated that a super massive star cluster with a mass of several hundred thousand solar masses is embedded inside. Within these super massive star clusters located at the center of the Milky Way, it is thought that intermediate-mass black holes are formed through the repeated merging of stars and black holes. The super massive star cluster that was discovered this time is thought to be a "cradle" candidate for these intermediate-mass black holes and it is the second example to be found in the Milky Way following the earlier discovery of a star cluster by the same team in 2012.
The findings of this research were published in the March 28 issue of the American scientific journal *The Astrophysical Journal*.

1．Main Points of Research

・ Discovery of a peculiar molecular cloud with evidence of multiple explosions at the center of the Milky Way that occurred approximately 100,000 years ago.
・ The energy released from the explosion corresponds to about 10 supernovae, suggesting that a super massive star cluster exists here.
・There is a possibility that this could be the second example of a "cradle" for intermediate-mass black holes in the Milky Way.

2．Background of Research

It is thought that at the center of many galaxies, including the Milky Way, there are massive black holes whose masses are over several million solar masses (*1). However, the origins of these central supermassive black holes are not yet understood. One theory suggests that intermediate-mass black holes (*2), which are formed by the runaway merging of massive stars within a dense massive star cluster, 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 actual existence of intermediate-mass black holes and dense massive star clusters in the vicinity of the center of the galaxy.

The Keio University research team discovered 4 peculiar molecular clouds with unusual physical states and broad velocity widths (L=+1.3° molecular cloud, L=0.0° molecular cloud, L=–0.4° molecular cloud, and L=–1.2° molecular cloud) in the central region of the Milky Way through observational results using the Nobeyama Radio Observatory 45 m telescope and the Atacama Submillimeter Telescope Experiment (ASTE) 10 m telescope, and reported this in a paper in 2012 (figure 1a). The team has been carrying out detailed studies into these and has achieved the following results.

- It was concluded that the L=+1.3° molecular cloud, characterized by its enormous kinetic energy and numerous expanding shells, is a structure resulting from a large number of supernova explosions that occurred within a massive star cluster with a mass of several hundred thousand solar masses or more. This indicated the possibility of having indirectly detected a massive star cluster that could be a "cradle" for intermediate-mass black holes (2012 press release) [1].
- It was found that the L=0.0° molecular cloud is a rotating gas disk that surrounds "Sagittarius A* (star)," the nucleus of the Milky Way, and traces of past nuclear activities were confirmed from its chemical composition (2014 press release) [2].
- It was discovered that the kinematics of the L=–0.4° molecular cloud could be explained by gravitational scattering due to a 100,000-solar mass point-like gravitational source, suggesting that an intermediate-mass black hole exists inside (2016 press release) [3]. Later, an intermediate-mass black hole candidate, CO–0.40–0.22*, was found near the center of the molecular cloud (2017 press release) [4].

３．Content of Research and Results

This time, the research team carried out observations on the L=–1.2° molecular cloud, the last of the 4 peculiar molecular clouds mentioned above. The telescopes used for this study were the Nobeyama Radio Observatory 45 m telescope and the James Clerk Maxwell Telescope at Mauna Kea Observatory in Hawaii. From the carbon monoxide molecule rotational spectral line intensity distribution (figure 1b, c), it became evident that (1) it has an elliptical shape with a diameter of about 50 light-years, (2) it contains at least 5 expanding shells, and (3) it possesses kinetic energy corresponding to around 10 supernova explosions. From the size and expansion velocity of the expanding shells, these were calculated to be about 60,000 to 110,000 years old. In addition, a silicon monoxide molecule rotational spectral line was detected at the edge of the youngest expanding shell. This means that violent explosive phenomena that produce dissociative shock waves are deeply involved with the acceleration of the L=–1.2° molecular cloud.

If it were assumed that this is a supernova explosion, it means that a supernova explosion occurs here once every tens of thousands of years. Supernova explosions occurring at such frequencies in a limited region in space suggests that there is a massive star cluster and it can be estimated to have a mass of several hundred thousand solar masses. When compared with the star cluster associated with the L=+1.3° molecular cloud, it is somewhat smaller, but this is still a star cluster with one of the largest masses in the Milky Way. This means that the L=–1.2° molecular cloud can be considered the second example of a "cradle" candidate that forms intermediate-mass black holes at the center of the Milky Way.

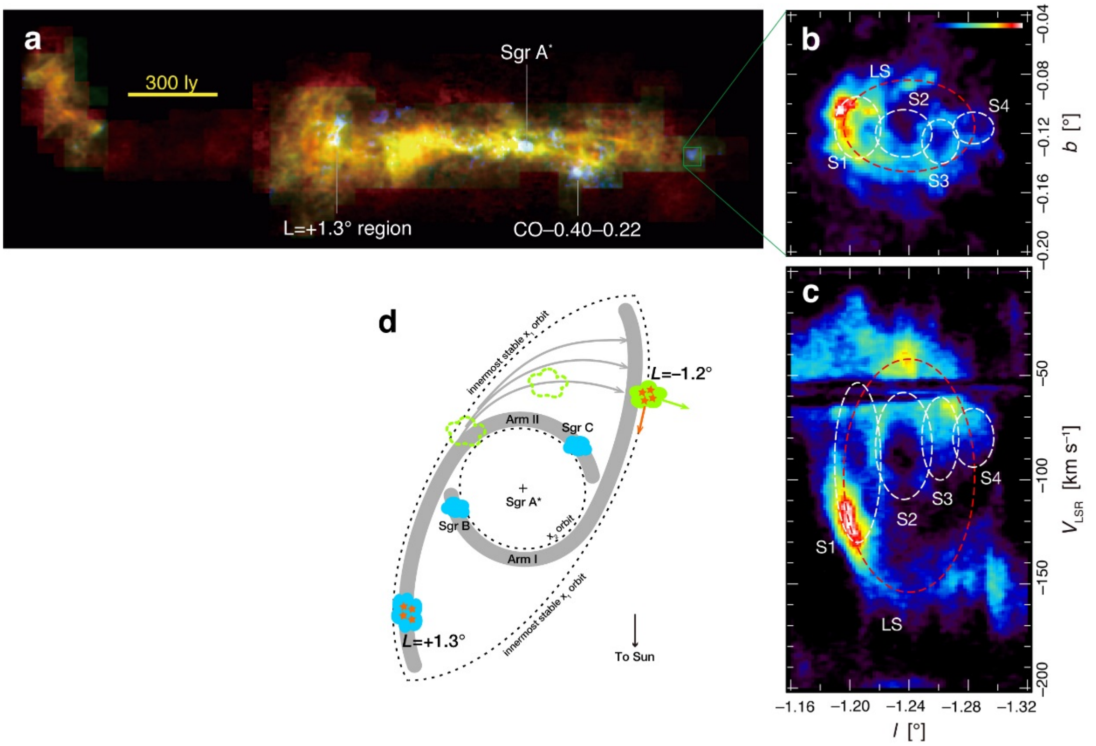

Figure 1: (a) Composite image of molecular line emissions toward the Galactic center region. The distribution of dense and/or warm gas is shown in white. (b) Spatial distribution of warm gas. (c) Position-velocity distribution of warm gas. (d) Schematic face-on view of the Galactic center region. The black cross indicates the location of the Galactic nucleus. The orange and green arrows indicate the directions along which the massive star cluster and molecular gas are moving, respectively.

4. Future Developments

Where were these two super massive star clusters formed? One clue is that the locations of them are roughly symmetric with respect to the center of the Milky Way. Considering the gas kinematics in the central region of the Milky Way, this may also mean that these massive star clusters are on a single closed orbit (figure 1d). On this orbit, there is a possibility that an active star formation (starburst) occurred tens of millions of years ago. The intermediate-mass black holes formed in these star clusters fall toward the center together with these star clusters and contribute to the formation and growth of supermassive black holes.

One big question still remains unanswered. These two massive star clusters whose existence is suggested in the center of the Milky Way cannot be seen at all with other wavelengths such as infrared. This suggests that the mass distribution of the stars in the star cluster may be completely different from what is normally found. It is also possible that it contains a large quantity of the “remnants” of the stellar evolution, such as neutron stars and white dwarfs. As for explosions, not only supernovae, but the merging process between neutron stars may also greatly contribute to this, making this a research topic of great interest.

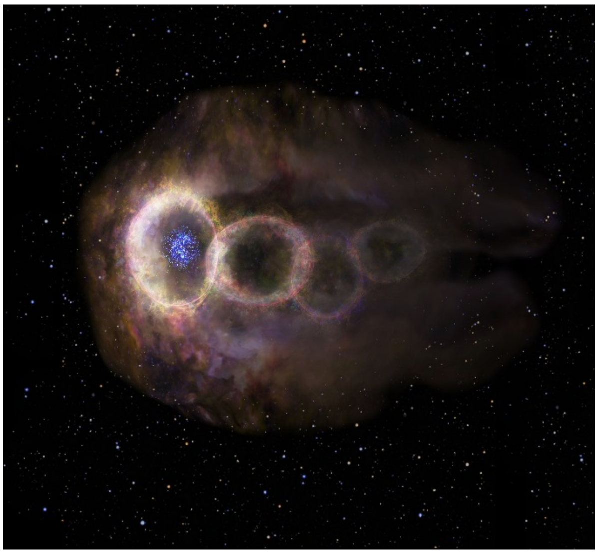

Figure 2: Artist's concept of the massive star cluster colliding with ambient molecular gas. Supernova explosions occurred in the cluster generate expanding shells on a line.

＜Reference＞
[1] Keio University Press Release (July 20, 2012)
"Seed" of a Massive Black Hole Found at the Center of the Milky Way
https://www.keio.ac.jp/ja/press_release/2012/kr7a4300000arvju.html (Japanese language only)
[2] Keio University Press Release (September 18, 2014)
Chemical Composition of the Circumnuclear Disk Orbiting a Massive Black Hole at the Center of the Milky Way Identified for the First Time
https://www.keio.ac.jp/ja/press_release/2014/osa3qr0000009jpx.html (Japanese language only)
[3] 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)
[4] Keio University Press Release (September 27, 2017)
First Detection of an Intermediate-Mass Black Hole Candidate in the Milky Way
https://www.keio.ac.jp/en/press-releases/2017/Sep/27/49-24314/

＜Details of Original Paper＞
The findings of this research were published in the March 28 issue of the American scientific journal of astrophysics *The Astrophysical Journal*. The title of the paper, authors, and their affiliation at the time are as follows:
"Detection of Another Molecular Bubble in the Galactic Center"

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＜Glossary＞
*1 Solar mass: unit of mass used in astronomy. 1 solar mass =1.99×10^{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 massive black holes, which are found at the nuclei of galaxies (mass of these are more than several million times greater than the sun).

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