Press Release

KANAGAWA UNIVERSITY | National Astronomical Observatory of Japan | Keio University

March 6, 2023

Keio University
National Astronomical Observatory of Japan
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"Tadpole" Molecular Cloud Discovered near the Center of the Milky Way
―Interacting with a Black Hole?―

A team of researchers has identified an isolated "Tadpole" molecular cloud near Sagittarius A* at the galactic nucleus of the Milky Way. The discovery was made by Miyuki Kaneko, a 2nd Year Master's student in the Graduate School of Science and Technology at Keio University, and Professor Tomoharu Oka who works in the Department of Physics at the Faculty of Science and Technology at the same school. Researchers from the National Astronomical Observatory of Japan and Kanagawa University also contributed to the study. The molecular cloud they discovered is shaped like an arc in space and its radial velocity clearly varies monotonically along this arc. The researchers were able to replicate this spatial-velocity behavior by using a Keplerian orbit modeled around a point-like massive object (point mass) estimated to have a mass 100,000 times that of the Sun. Examinations of other wavelengths did not reveal any luminous counterpart, meaning that this point mass is not a high-density stellar cluster. At this point in time, the most likely explanation is that the point mass is an intermediate-mass black hole[1]. This object may be the most convincing candidate for an intermediate-mass black hole among any that have been discovered from molecular gas kinematics.

This paper was published in the January 10 issue of *The Astrophysical Journal*, an American academic journal that specializes in astrophysics research.

1. Main Points of Research

- Researchers have discovered a molecular cloud with a tadpole-like structure in position–velocity space near the galactic nucleus of the Milky Way.
- This position-velocity structure can be reproduced by Keplerian motion around a point mass of 100,000 times that of the Sun.
- The discovered point-like massive "object" may, in fact, be an intermediate-mass black hole due to its assumed mass and the absence of such corresponding objects in that vicinity.

2. Background of Research

Black holes with millions of times more mass than the Sun lurk at the center of most galaxies in our universe. These "supermassive" black holes are believed to form and grow through smaller black holes merging. However, scientists have yet to confirm the existence of intermediate-mass black holes (those with 10^2–10^5 solar masses)[2] which should appear during the formation of a supermassive black hole, although several potential candidates have been proposed.

The nucleus of our Milky Way Galaxy, Sagittarius A*, also harbors a supermassive black hole with a mass of 4 million times that of the Sun. There is a cluster of stars in this vicinity known as "IRS 13E" which was suggested to have an intermediate-mass black hole (of several thousand solar masses). However, this hypothesis has not been proved and there are other competing explanations. The group conducting this current study, though, has pointed out the possibility that multiple intermediate-mass black holes could exist in the same general area other than IRS 13E, based on the discovery of compact clouds with unusually broad velocity widths[3] (ref. July

18, 2017, press release) in the Central Molecular Zone[4]. These phenomena, however, may not be caused by a black hole either. It is possible for other objects and factors to generate similar molecular clouds, meaning that it is still open to interpretation. To confirm their hypothesis, they must be able to detect and accurately reproduce the gas kinematics that are produced by a gravitational mass point that resembles a black hole. This type of research is vital because it sheds light on the formation and evolution of the supermassive black holes at galactic nuclei.

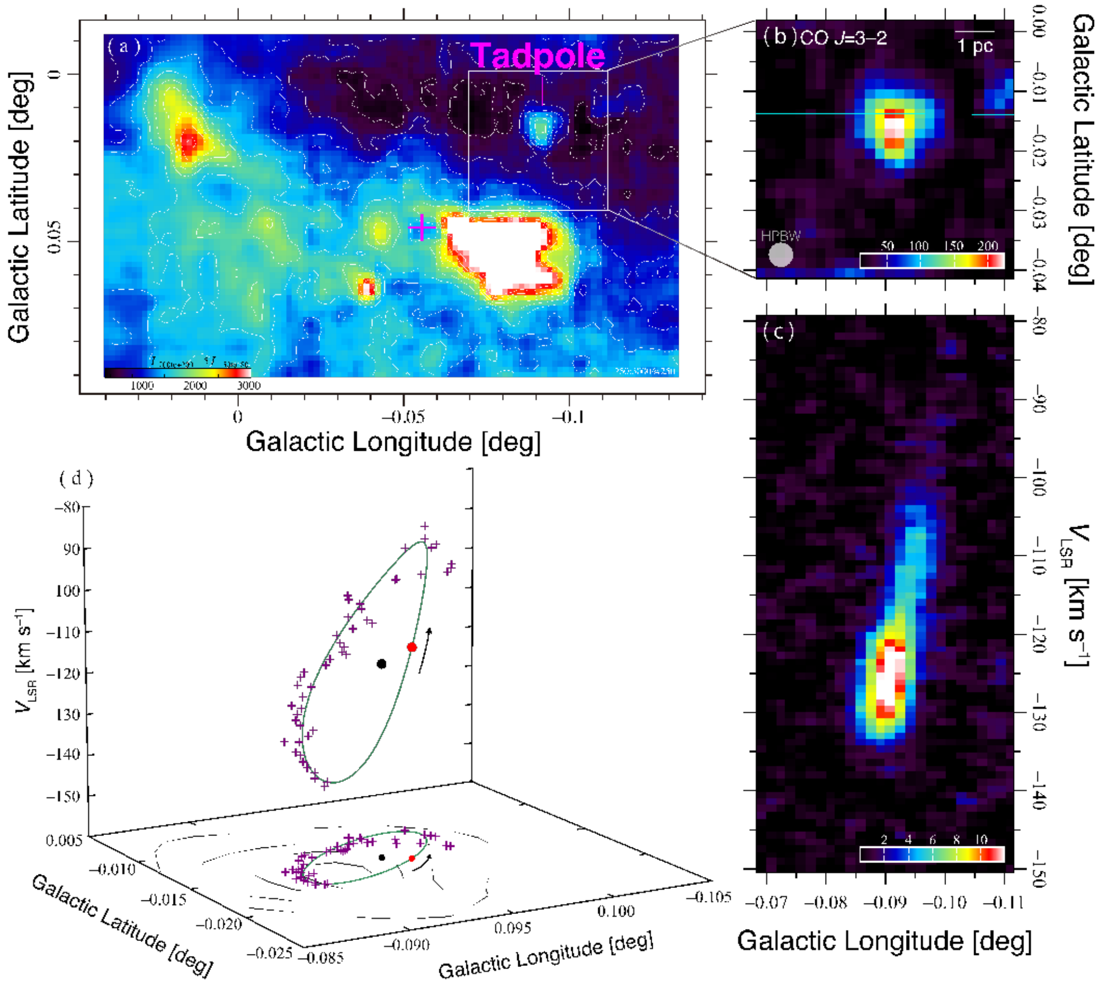

Figure 1: (a) Map of velocity-integrated CO 346 GHz emission near the galactic nucleus (Sagittarius A* is marked by a +). (b) Zoomed map of the area around the "Tadpole." (c) Position-velocity map along the light blue line in Figure (b). (d) 3D diagram of intensity peak positions at each velocity (purple crosses) and Keplerian orbits (solid green lines).

3. Research Design and Findings

The research team used the James Clerk Maxwell Telescope[5] to gather data on carbon monoxide (CO) line spectra and searched specifically for molecular clouds that were both compact and had broad velocity widths, characteristics they believed would imply the workings of a point mass as a source of gravity. One of their findings included a peculiar molecular cloud that was to the northwest of Sagittarius A*, about three arcminutes away (equivalent to 20 light years). This molecular cloud was clearly isolated and had a distinctive tadpole-like shape in position-velocity space (Figure 1: a-c). They were able to corroborate the existence of this object by using CO and CS line data from the Nobeyama Radio Observatory's 45m telescope.

Detailed analysis revealed that the discovered molecular cloud is shaped like an arc in space and its radial velocity clearly varies monotonically along this arc. (Figure 1: d). This spatial velocity structure suggests that the molecular gas is moving and being distributed along a single closed orbit. The team was also able to reproduce this when using a Keplerian orbit around a presumed point mass of 100,000 times the mass of the Sun. This implies that the "Tadpole" is orbiting a point-like gravitational source that has enormous mass. In addition, the behavior of physical conditions suggested by the spectral line intensity ratios also demonstrates that the gas is being trapped by a point-like gravitational source.

The team then tried to identify this point mass by examining various wavelength images of the area surrounding the Tadpole. However, they were unable to find any luminous objects in the predicted vicinity, meaning that it is very unlikely the point mass is a star cluster. Furthermore, the lower limit to the mass density derived from the orbital parameters is enormous, suggesting the point mass is an intermediate-mass black hole. Taken together, these facts provide evidence that the "Tadpole" is a molecular cloud accelerated by the gravitational interaction with an inactive black hole of approximately 100,000 solar masses.

4. Future Developments

This research paper reveals the discovery of a new candidate intermediate-mass black hole in the vicinity of the galactic nucleus, Sagittarius A*. Their proof is the existence of a "Tadpole" molecular cloud which is clearly isolated from other molecular clouds, and which has a monotonous spatial velocity structure. This rules out the possibility that the Tadpole's unusual velocity width could be caused by anything other than an interaction with a point-like gravitational source. Therefore, the Tadpole's is the most convincing candidate for an intermediate-mass black hole that has been discovered from molecular gas kinematics thus far. Due to its extremely close proximity to Sagittarius A*, it is likely that the intermediate-mass black hole which drives the Tadpole will eventually be swallowed by the supermassive black hole at the galactic nucleus.

The research team from this paper plans to make high-resolution observations using the ALMA[6]. This may allow them to delineate the spatial velocity structure of molecular gas in a Keplerian orbit more clearly. Once this detailed structure is obtained, the scientists hope to determine its precise orbital parameters. In a similar previous study, high-resolution observations have captured emission from the immediate vicinity of a candidate intermediate-mass black hole (Press Release, September 27, 2017). Following these examples, the team's ALMA observations and search for counterparts may unveil the nature and entity of the point mass that has formed the Tadpole.

Fig. 2: An artistic depiction of the "Tadpole" orbiting a black hole

References

- Keio University Press Release (July 18, 2017)
  Two New Possible "Rogue Black Holes" found in the Center of the Milky Way
  https://www.keio.ac.jp/ja/press-releases/2017/7/18/28-21984/ (Japanese language only)
- 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 Journal Article

This paper was published in the January 10 issue of *The Astrophysical Journal*, an American academic journal that specializes in astrophysics research. Below is the official title of the paper as well as the names and affiliations of its authors.

"Discovery of the Tadpole Molecular Cloud near the Galactic Nucleus"

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The Astrophysical Journal, January 10, 2023, vol. 942, Number 1, 46 (8pp)
https://iopscience.iop.org/article/10.3847/1538-4357/aca66a
doi: 10.3847/1538-4357/aca66a

Glossary and References

*1 Black Hole
A dark astronomical object that has such a strong gravitational pull that it distorts space-time so that not even light can escape. Its existence was predicted by Einstein's general theory of relativity.

*2 Solar Mass
A unit of mass used in astronomy. 1 Solar Mass = 1.99×10^{30} kg.

*3 Velocity Width
Observed spectral lines are deviated in frequency according to the relative velocity (line-of-sight or radial velocity) between the object and observer due to the Doppler effect. An object's radial velocity can be determined by measuring the amount of change in this frequency. A spectral line width expressed in frequencies can also be converted into radial velocity, which is then called "velocity width."

*4 Central Molecular Zone
A region of the Milky Way Galaxy extending around Sagittarius A* with a radius of approximately 1,000 light years.

*5 James Clerk Maxwell Telescope
Submillimeter-wavelength radio telescope at the Mauna Kea Observatory in Hawaii. It is currently operated by the East Asia Observatory.

*6 The Atacama Large Millimeter/submillimeter Array (ALMA)
A large radio interferometer on a plateau 5,000 meters above sea level in the Atacama Desert of northern Chile. The project is an international collaboration promoted by countries around the world with East Asia represented by the National Astronomical Observatory of Japan, the U.S represented by the North American Union, and Europe represented by the European Southern Observatory.

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