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Not Just One "Bullet" Piercing the Milky Way: The Case for a Cluster of Compact Objects, Possibly Including a Black Hole

A team of Keio University astronomers has discovered that the mysterious ultra-high-velocity molecular feature in the Milky Way known as the "Bullet" is not alone. Located about 10,000 light-years from the Sun, the Bullet exhibits an extraordinarily broad velocity width of about 120 km s^{-1} and an enormous amount of kinetic energy. Because of these extreme properties, scientists have proposed that the Bullet may have been formed by an isolated black hole without a companion star.

Using the Atacama Large Millimeter/submillimeter Array (ALMA), the team identified eight additional high-velocity components, dubbed "Petit-Bullets," which surround the main Bullet. Analysis of their spatial distribution and velocity structures indicates that these Petit-Bullets likely share a common origin with the Bullet. The team's discovery suggests that these features were not produced by a single compact object, but rather by a group of compact massive objects plunging at high speed into a molecular cloud.

This study presents the first high-resolution observational evidence of the interaction between a high-velocity object group, possibly including a black hole, and a molecular cloud in the galactic disk. The findings suggest that high-velocity molecular features may serve as indicators of otherwise invisible object populations in our Galaxy, offering new insights into the distribution of black holes and their role in galactic evolution.

These findings were published in *The Astrophysical Journal Letters* on February 23, 2026.

1. Key Points of the Study

- High-resolution observations with ALMA[*1] have revealed eight new high-velocity components, termed "Petit-Bullets," surrounding the ultra-high-velocity molecular feature "Bullet" in the disk of the Milky Way.
- Analysis of the spatial distribution and velocity structures of the Petit-Bullets suggests that their origin is better explained not by a single compact object, but rather by a group of compact massive objects plunging into a molecular cloud.
- This study provides the first high-resolution observational evidence of a high-velocity object group, which may include a black hole, interacting with a molecular cloud in the galactic disk. The findings offer important insights into the search for otherwise invisible object populations within the Galaxy, as well as into the distribution of black holes and galactic evolution.

2. Research Background

The "Bullet" is a spatially compact, ultra-high-velocity feature that was discovered within a molecular cloud in the disk of the Milky Way and is located approximately 10,000 light-years from the Sun. Despite its compact size of only about 2 light-years in diameter, it exhibits an exceptionally broad velocity width of about 120 km s^{-1}, extending counter to the rotation of the Galactic disk (Keio University press release, August 9, 2013; Sashida et al. 2013). Subsequent detailed imaging observations of molecular spectral lines conducted with the 10-m Atacama Submillimeter Telescope Experiment (ASTE) and the Nobeyama 45-m Radio Telescope revealed that the Bullet has a mass of approximately 7.5 solar masses and an enormous kinetic energy of about 10^{48} erg[*2]. This is extraordinarily large for a sub-parsec-scale molecular structure. From its expansion velocity and physical size, the Bullet's age is estimated to be between about 5,000–8,000 years. These extreme properties do not easily map onto any known type of astronomical object. Another remarkable feature of the Bullet is its distinct "Y-shaped" structure in position–velocity space[*3]. These results suggested that the Bullet was formed when an isolated black hole without a companion star[*4] plunged into a dense molecular cloud, accelerating the surrounding gas through its gravity (Keio University press release, January 16, 2017).

3. Findings

The research team conducted high-spatial-resolution observations of the Bullet using ALMA. As a result, they discovered eight new ultra-high-velocity molecular components in its vicinity, termed "Petit-Bullets" (Fig. 1). Each of the Petit-Bullets is extremely compact and exhibits a broad, "V-shaped" velocity structure in position–velocity space. This characteristic closely resembles the Y-shaped structure seen in the main Bullet component, suggesting that they share a common origin.

A detailed analysis of their spatial distribution and velocity structures indicates that the Petit-Bullets were likely driven not by a single object, but by multiple point-like gravitational sources plunging collectively at high speed into a molecular cloud. The mass scale inferred from the velocity dispersion of the Petit-Bullets is comparable to that of a typical globular cluster. In contrast, for the main Bullet component, an estimate of the lower mass limit based on momentum conservation suggests that it was most likely formed by a single black hole.

These findings represent the first observational evidence capturing the imprint of a high-velocity object group, which may include a black hole, interacting with a molecular cloud.

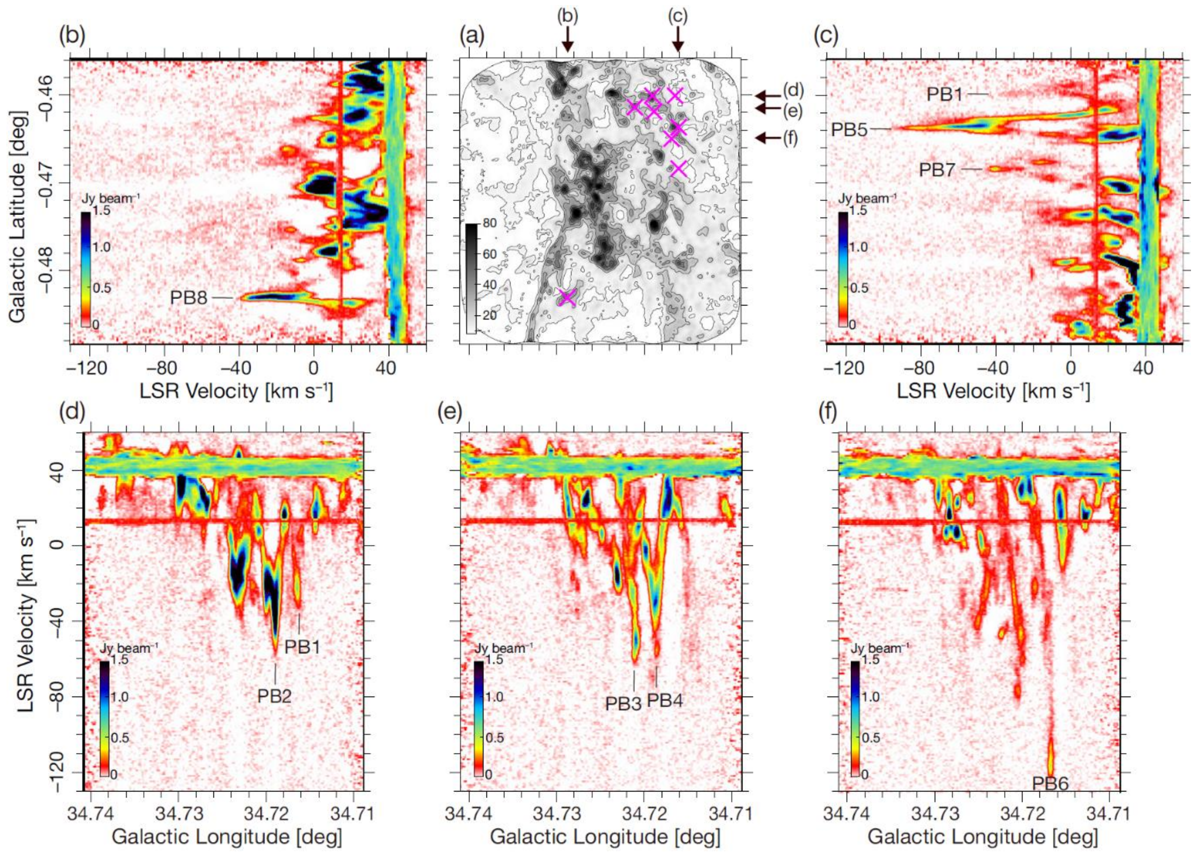

Figure 1. (a) Velocity-integrated map of the CO *J*=3–2 emission line obtained with ALMA. The previously known ultra-high-velocity molecular feature "Bullet" is located at the center of this panel. Magenta crosses denote the positions of the eight newly found broad-velocity components, or "Petit-Bullets." Black arrows outside the map mark the galactic coordinates from which the position–velocity maps in panels (b)–(f) are extracted. (b)–(c) galactic latitude–velocity maps of the CO *J*=3–2 line intensity at galactic longitudes 34.7161° and 34.7288°, respectively. (d)–(f) galactic longitude–velocity maps of the CO *J*=3–2 line intensity at galactic latitudes −0.4601°, −0.4615°, and −0.4650°, respectively. The color scale represents the CO line intensity, while the broad extent along the velocity axis indicates the extremely large velocity dispersion of the gas. These diagrams reveal a characteristic "V-shaped" broad-velocity structure seen in all eight Petit-Bullets (PB1–PB8).

Figure 2. Schematic diagram of molecular clouds into which a high-velocity compact object group, including a black hole, has plunged.

4. Future Prospects

These findings open a new pathway for discovering unseen object populations in the Milky Way and offer important insights into the distribution of black holes, which are believed to exist in large numbers throughout the Galaxy, and their role in its evolution.

In future work, the team plans to conduct further ALMA observations targeting molecular emission lines that trace denser gas, enabling a more detailed investigation of the internal velocity structures and physical conditions within the Petit-Bullets. These observations are expected to place tighter constraints on their motions and formation processes.

Deep near-infrared imaging will also be carried out to attempt the direct detection of stars or star clusters potentially associated with the Petit-Bullets. If successful, such detections would test the proposed formation scenario and establish a new method for identifying invisible gravitational objects through their dynamical impact on molecular clouds.

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5. Publication Information

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Related Publications:

- Sashida et al. 2013, *The Astrophysical Journal*, 774, 10
  URL: https://iopscience.iop.org/article/10.1088/0004-637X/774/1/10
  DOI: 10.1088/0004-637X/774/1/10
- Keio University Press Release (January 16, 2017) [in Japanese]
  "Discovery of a Supersonic 'Bullet' Piercing the Milky Way – Is It a Rogue Black Hole?"
  https://www.keio.ac.jp/ja/press-releases/2017/1/16/28-19413/

Glossary

*1. ALMA (Atacama Large Millimeter/submillimeter Array): A large radio interferometer located on a plateau at an altitude of approximately 5,000 meters in the Atacama Desert in northern Chile. ALMA is operated as an international collaboration among East Asia, North America, and Europe.

*2. erg: A unit of energy. 1 erg = 10^{-7} J.

*3. Position–velocity space: A diagram or conceptual framework that simultaneously represents the position of celestial objects or gas on the sky and their velocity along the line of sight. It is used to visualize where an object is located and how fast it is moving.

*4. Companion star: In a binary system, a star that orbits a primary object due to gravity. If a black hole has a companion star, material from the companion can accrete onto the black hole, producing strong electromagnetic radiation that makes the system easier to detect. In contrast, an isolated black hole without a companion emits little radiation and is therefore difficult to observe.

*5. Globular cluster: A spherical collection of tens of thousands to millions of stars bound together by strong gravity. Many globular clusters surround the Milky Way, and their total masses typically range from tens of thousands to millions of solar masses.

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