Organic Molecules in Asteroid Ryugu Characterized by AFM

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Extraterrestrial organic matter holds essential clues to the origin and evolution of our solar system because such materials are thought to carry chemical signatures from interstellar molecular clouds and early planetary processes. Consequently, researchers in the field of astrochemistry have been working to identify extraterrestrial molecules [1]. However, some molecules may be overlooked due to limitations in the analytical techniques they have used, such as mass spectrometry.

AFM with a CO-functionalized tip has emerged as a powerful tool to directly image the chemical structure of individual organic molecules [2]. This capability enables the characterization of complex, high-molecular-weight, or highly isomeric molecules that are difficult to identify using conventional ensemble methods. In recent years, a variety of natural organic molecules, including even those in a meteorite, have been identified by AFM [3].

In this study, we analyzed the organic matter in the sample returned from the asteroid Ryugu by the Hayabusa2 spacecraft [4]. Organic matter was extracted using organic solvents and then deposited onto a clean Cu(111). All experiments were conducted using AFM/STM based on a qPlus sensor, operated at 5 K under ultra-high vacuum.

Through high-resolution AFM imaging, we successfully visualized 22 individual polycyclic aromatic hydrocarbons (PAHs). These PAHs showed a striking diversity in size and shape. Many of them consisted of more than 50 fused rings, with the largest exceeding 100, far larger than those identified by mass spectrometry [5]. The observed molecules also showed complex non-planar geometries consisting of five-, seven-, and even eight-membered rings as well as conventional six-membered rings. These large PAHs were identified for the first time only by using AFM. This result demonstrates that AFM can provide new insights that are complementary to conventional techniques in astrochemistry, opening a new window for understanding the evolution of extraterrestrial organic molecules.

References

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