NASA telescopes work out black hole's feeding schedule

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Credit: NASA/CXC/M.Weiss

By using new data from NASA's Chandra X-ray Observatory and Neil Gehrels Swift Observatory as well as ESA's XMM-Newton, a team of researchers has made important headway in understanding how—and

when—a supermassive black hole obtains and then consumes material.

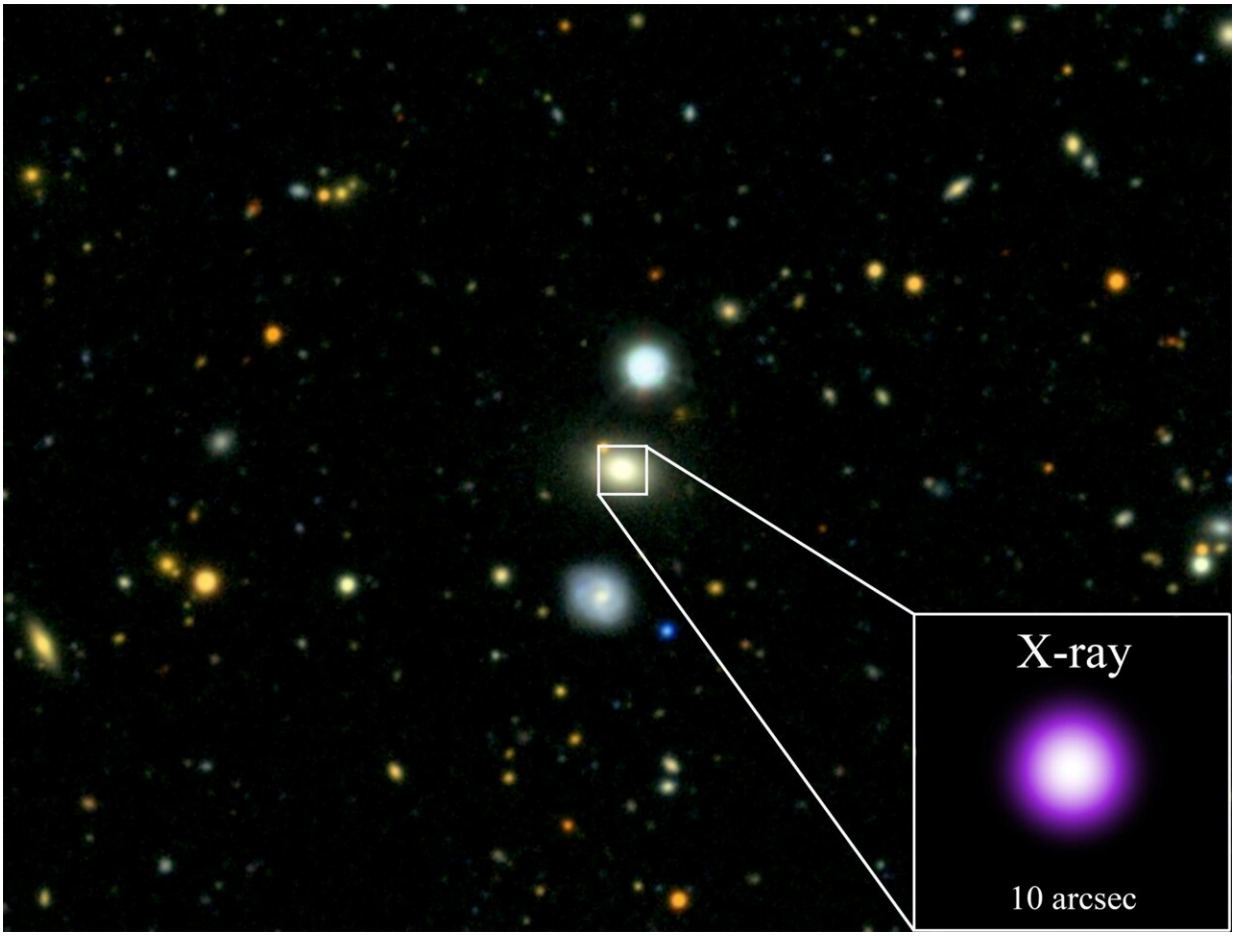
A paper describing these results appears on the *arXiv* preprint server, and will be published in *The Astrophysical Journal*. The authors are Dheeraj Passam (Massachusetts Institute of Technology), Eric Coughlin (Syracuse University), Muryel Guolo (Johns Hopkins University), Thomas Wevers (Space Telescope Science Institute), Chris Nixon (University of Leeds, UK), Jason Hinkle (University of Hawaii at Manoa), and Ananaya Bandopadhyay (Syracuse).

This artist's impression above shows a star that has partially been disrupted by such a black hole in the system known as AT2018fyk. The supermassive black hole in AT2018fyk—with about 50 million times more mass than the sun—is in the center of a galaxy located about 860 million light-years from Earth.

Astronomers have determined that a star is on a highly elliptical orbit around the black hole in AT2018fyk so that its point of farthest approach from the black hole is much larger than its closest. During its closest approach, tidal forces from the black hole pull some material from the star, producing two tidal tails of "stellar debris."

The illustration shows a point in the orbit soon after the star is partially destroyed, when the tidal tails are still in close proximity to the star. Later in the star's orbit, the disrupted material returns to the black hole and loses energy, leading to a large increase in X-ray brightness occurring later in the orbit (not shown here).

This process repeats each time the star returns to its point of closest approach, which is approximately every 3.5 years. The illustration depicts the star during its second orbit, and the disk of X-ray emitting gas around the black hole that is produced as a byproduct of the first tidal encounter.



Credit: X-ray: NASA/SAO/Kavli Inst. at MIT/D.R. Pasham; Optical: NSF/Legacy Survey/SDSS

Researchers took note of AT2018fyk in 2018 when the optical ground-based survey ASAS-SN detected that the system had become much brighter. After observing it with NASA's NICER and Chandra, and XMM-Newton, researchers determined that the surge in brightness came from a "tidal disruption event," or TDE, which signals that a star was completely torn apart and partially ingested after flying too close to a black hole. Chandra data of AT2018fyk is shown in the inset of an

optical image of a wider field-of-view.

When material from the destroyed star approached close to the black hole, it became hotter and produced X-ray and ultraviolet (UV) light. These signals then faded, agreeing with the idea that nothing was left of the star for the black hole to digest.

However, about two years later, the X-ray and UV light from the galaxy became much brighter again. According to astronomers, this meant that the star likely survived the initial gravitational grab by the black hole and then entered a highly elliptical orbit with the black hole. During its second close approach to the black hole, more material was pulled off and produced more X-ray and UV light.

These results were published in a 2023 paper in the *Astrophysical Journal Letters* led by Thomas Wevers from the Space Telescope *Science* Institute in Baltimore.

"Initially we thought this was a garden-variety case of a black hole totally ripping a star apart," said Wevers. "But instead, the star appears to be living to die another day."

Based on what they had learned about the star and its orbit, Wevers and his team predicted that the black hole's second meal would end in August 2023, and applied for Chandra observing time to check.

"The telltale sign of this stellar snack ending would be a sudden drop in the X-rays and that's exactly what we see in our Chandra observations on Aug. 14, 2023," said Dheeraj Pasham of the Massachusetts Institute of Technology, the leader of the new paper on these results. "Our data show that in August last year, the black hole was essentially wiping its mouth and pushing back from the table."

The new data obtained by Chandra and Swift after the 2023 paper was completed gives the researchers an even better estimate of how long it takes the star to complete an orbit, and future mealtimes for the black hole. They determine that the star makes its closest approach to the black hole about once every three and a half years.

"We think that a third meal by the black hole, if anything is left of the star, will begin between May and August of 2025 and last for almost two years," said Eric Coughlin, a co-author of the new paper, from Syracuse University in New York. "This will probably be more of a snack than a full meal because the second meal was smaller than the first, and the star is being whittled away."

The authors think that the doomed star originally had another star as a companion as it approached the black hole. When the stellar pair got too close to the black hole, however, the gravity from the black hole pulled the two stars apart. One entered orbit with the black hole, and the other was tossed into space at high speed.

"The doomed star was forced to make a drastic change in companions—from another star to a giant black hole," said co-author Muryel Guolo of Johns Hopkins University in Baltimore. "Its stellar partner escaped, but it did not."

The team plans to keep following AT2018fyk for as long as they can to study the behavior of such an exotic system.

More information: Dheeraj Pasham et al, A Potential Second Shutoff from AT2018fyk: An updated Orbital Ephemeris of the Surviving Star under the Repeating Partial Tidal Disruption Event Paradigm, *arXiv* (2024). DOI: 10.48550/arxiv.2406.18124

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