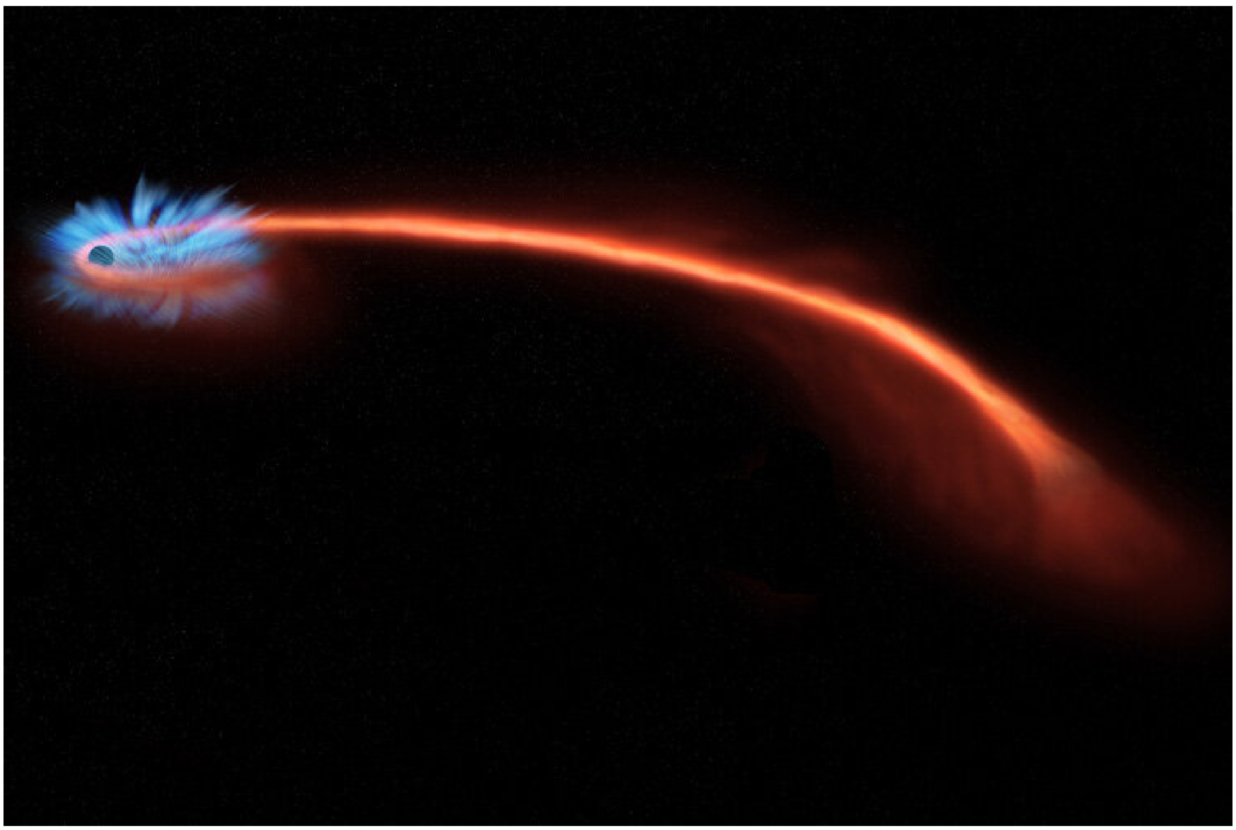
The ultimate fate of a star shredded by a black hole

July 11 2022, by Robert Sanders



If a star (red trail) wanders too close to a black hole (left), it can be shredded, or spaghettified, by the intense gravity. Some of the star's matter swirls around the black hole, like water down a drain, emitting copious X-rays (blue). Recent studies of these so-called tidal disruption events suggest that a significant fraction of the star's gas is also blown outward by intense winds from the black hole, in some cases creating a cloud that obscures the accretion disk and the high-energy events happening within. Credit: NASA/CXC/M. Weiss

In 2019, astronomers observed the nearest example to date of a star that was shredded, or "spaghettified," after approaching too close to a massive black hole.

That tidal disruption of a sun-like star by a black hole 1 million times more massive than itself took place 215 million light years from Earth. Luckily, this was the first such event bright enough that astronomers from the University of California, Berkeley, could study the optical light from the stellar death, specifically the light's polarization, to learn more about what happened after the star was torn apart.

Their observations on Oct. 8, 2019, suggest that a lot of the star's material was blown away at high speed—up to 10,000 kilometers per second—and formed a spherical cloud of gas that blocked most of the high-energy emissions produced as the black hole gobbled up the remainder of the star.

Earlier, other observations of optical light from the blast, called AT2019qiz, revealed that much of the star's matter was launched outward in a powerful wind. But the new data on the light's polarization, which was essentially zero at visible or optical wavelengths when the event was at its brightest, tells astronomers that the cloud was likely spherically symmetric.

"This is the first time anyone has deduced the shape of the gas cloud around a tidally spaghetiffied star," said Alex Filippenko, UC Berkeley professor of astronomy and a member of the research team.

The results support one answer to why astronomers don't see high-energy radiation, such as X-rays, from many of the dozens of tidal disruption events observed to date: The X-rays, which are produced by material ripped from the star and dragged into an accretion disk around the black hole before falling inward, are obscured from view by the gas blown outward by powerful winds from the black hole.

"This observation rules out a class of solutions that have been proposed theoretically and gives us a stronger constraint on what happens to gas around a black hole," said UC Berkeley graduate student Kishore Patra, lead author of the study. "People have been seeing other evidence of wind coming out of these events, and I think this polarization study definitely makes that evidence stronger, in the sense that you wouldn't get a spherical geometry without having a sufficient amount of wind. The interesting fact here is that a significant fraction of the material in the star that is spiraling inward doesn't eventually fall into the black hole—it's blown away from the black hole."

Polarization reveals symmetry

Many theorists have hypothesized that the stellar debris forms an eccentric, asymmetric disk after disruption, but an eccentric disk is expected to show a relatively high degree of polarization, which would mean that perhaps several percent of the total light is polarized. This was not observed for this tidal disruption event.

"One of the craziest things a supermassive black hole can do is to shred a star by its enormous tidal forces," said team member Wenbin Lu, UC Berkeley assistant professor of astronomy. "These stellar tidal disruption events are one of very few ways astronomers know the existence of supermassive black holes at the centers of galaxies and measure their properties. However, due to the extreme computational cost in numerically simulating such events, astronomers still do not understand the complicated processes after a tidal disruption."

A second set of observations on Nov. 6, 29 days after the October observation, revealed that the light was very slightly polarized, about 1%, suggesting that the cloud had thinned enough to reveal the asymmetric gas structure around the black hole. Both observations came from the 3-meter Shane telescope at Lick Observatory near San Jose, California, that is fitted with the Kast spectrograph, an instrument that can determine the polarization of light over the full optical spectrum. The light becomes polarized—its electrical field vibrates primarily in one direction—when it scatters off electrons in the gas cloud.

"The accretion disk itself is hot enough to emit most of its light in X-rays, but that light has to come through this cloud, and there are many scatterings, absorptions and reemissions of light before it can escape out of this cloud," Patra said. "With each of these processes, the light loses some of its photon energy, going all the way down to ultraviolet and optical energies. The final scatter then determines the polarization state of the photon. So, by measuring polarization, we can deduce the geometry of the surface where the final scatter happens."

Patra noted that this deathbed scenario may apply only to normal tidal disruptions—not "oddballs," in which relativistic jets of material are expelled out the poles of the black hole. Only more measurements of the polarization of light from these events will answer that question.

"Polarization studies are very challenging, and very few people are well-versed enough in the technique around the world to utilize this," he said. "So, this is uncharted territory for tidal disruption events."

Patra, Filippenko, Lu and UC Berkeley researcher Thomas Brink, graduate student Sergiy Vasylyev and postdoctoral fellow Yi Yang reported their observations in a paper that has been accepted for publication in the journal *Monthly Notices of the Royal Astronomical Society*.

A cloud 100 times larger than Earth's orbit

The UC Berkeley researchers calculated that the polarized light was emitted from the surface of a spherical cloud with a radius of about 100 astronomical units (au), 100 times farther from the star than Earth is from the sun. An optical glow from hot gas emanated from a region at about 30 au.

The 2019 spectropolarimetric observations—a technique that measures polarization across many wavelengths of light—were of AT2019qiz, a tidal disruption event located in a spiral galaxy in the constellation of Eridanus. The zero polarization of the entire spectrum in October indicates a spherically symmetric cloud of gas—all the polarized photons balance one another. The slight polarization of the November measurements indicates a small asymmetry. Because these tidal disruptions occur so far away, in the centers of distant galaxies, they appear as only a point of light, and polarization is one of few indications of the shapes of objects.

"These disruption events are so far away that you can't really resolve them, so you can't study the geometry of the event or the structure of these explosions," Filippenko said. "But studying polarized light actually helps us to deduce some information about the distribution of the matter in that explosion or, in this case, how the gas—and possibly the accretion disk—around this black hole is shaped."

More information: Kishore C Patra et al, Spectropolarimetry of the tidal disruption event AT 2019qiz: a quasispherical reprocessing layer, *Monthly Notices of the Royal Astronomical Society* (2022). DOI: 10.1093/mnras/stac1727

Provided by University of California - Berkeley