In a first, astronomers watch a black hole's corona disappear, then reappear

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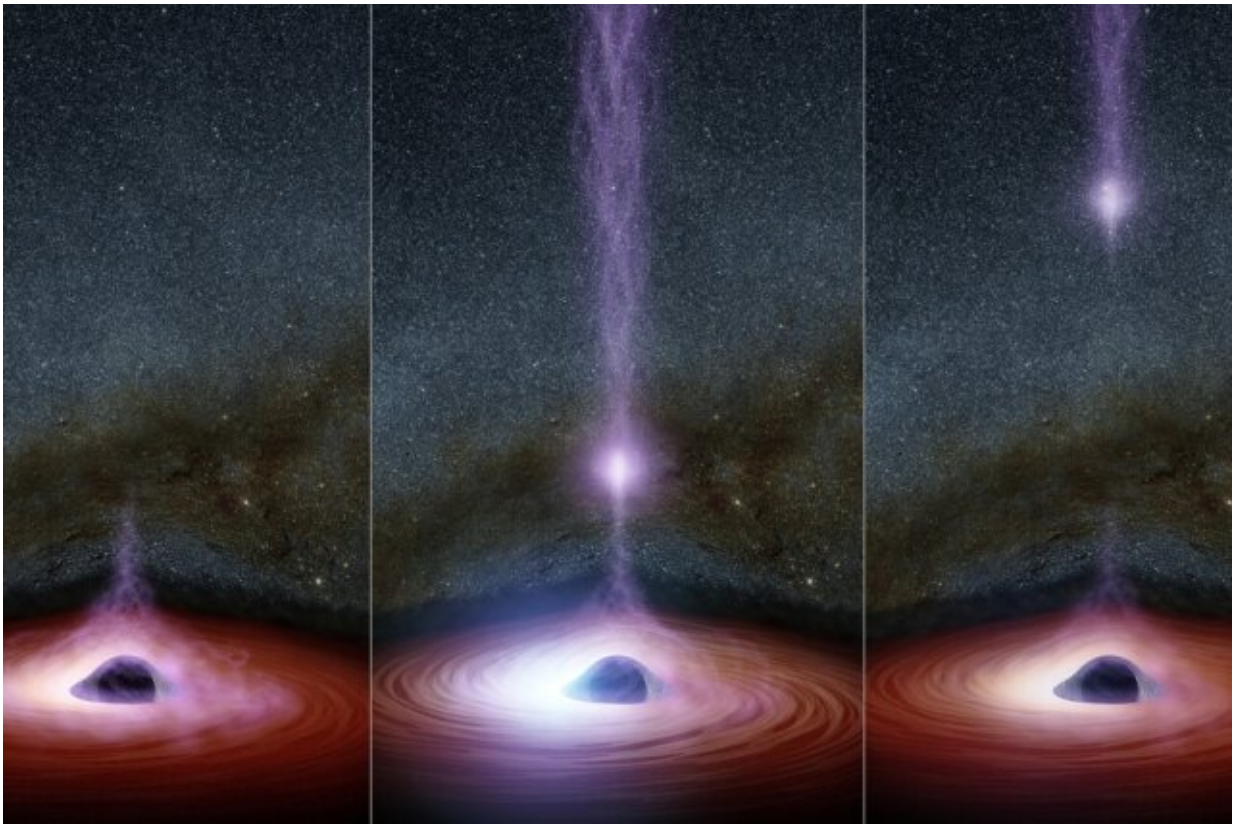

This diagram shows how a shifting feature, called a corona, can create a flare of X-rays around a black hole. The corona (feature represented in purplish colors) gathers inward (left), becoming brighter, before shooting away from the black hole (middle and right). Astronomers don't know why the coronas shift, but they have learned that this process leads to a brightening of X-ray light that can be observed by telescopes. Credit: NASA/JPL-Caltech

It seems the universe has an odd sense of humor. While a crown-encrusted virus has run roughshod over the world, another entirely different corona about 100 million light years from Earth has mysteriously disappeared.

For the first time, astronomers at MIT and elsewhere have watched as a supermassive black hole's own corona, the ultrabright, billion-degree ring of high-energy particles that encircles a black hole's event horizon, was abruptly destroyed.

The cause of this dramatic transformation is unclear, though the researchers guess that the source of the calamity may have been a star caught in the black hole's gravitational pull. Like a pebble tossed into a gearbox, the star may have ricocheted through the black hole's disk of swirling material, causing everything in the vicinity, including the corona's high-energy particles, to suddenly plummet into the black hole.

The result, as the astronomers observed, was a precipitous and surprising drop in the black hole's brightness, by a factor of 10,000, in under just one year.

"We expect that luminosity changes this big should vary on timescales of many thousands to millions of years," says Erin Kara, assistant professor of physics at MIT. "But in this object, we saw it change by 10,000 over a year, and it even changed by a factor of 100 in eight hours, which is just totally unheard of and really mind-boggling."

Following the corona's disappearance, astronomers continued to watch as the black hole began to slowly pull together material from its outer edges to reform its swirling accretion disk, which in turn began to spin up high-energy X-rays close to the black hole's event horizon. In this way, in just a few months, the black hole was able to generate a new corona, almost back to its original luminosity.

"This seems to be the first time we've ever seen a corona first of all disappear, but then also rebuild itself, and we're watching this in real-time," Kara says. "This will be really important to understanding how a black hole's corona is heated and powered in the first place."

Kara and her co-authors, including lead author Claudio Ricci of Universidad Diego Portales in Santiago, Chile, have published their findings today in *Astrophysical Journal Letters*. Co-authors from MIT include Ron Remillard, and Dheeraj Pasham.

A nimble washing machine

In March 2018, an unexpected burst lit up the view of ASSASN, the All-Sky Automated Survey for Super-Novae, that surveys the entire night sky for supernova activity. The survey recorded a flash from 1ES 1927+654, an active galactic nucleus, or AGN, that is a type of supermassive black hole with higher-than-normal brightness at the center of a galaxy. ASSASN observed that the object's brightness jumped to about 40 times its normal luminosity.

"This was an AGN that we sort of knew about, but it wasn't very special," Kara says. "Then they noticed that this run-of-the-mill AGN became suddenly bright, which got our attention, and we started pointing lots of other telescopes in lots of other wavelengths to look at it."

The team used multiple telescopes to observe the black hole in the X-ray, optical, and ultraviolet wave bands. Most of these telescopes were pointed at the the black hole periodically, for example recording observations for an entire day, every six months. The team also watched the black hole daily with NASA's NICER, a much smaller X-ray telescope, that is installed aboard the International Space Station, with detectors developed and built by researchers at MIT.

"NICER is great because it's so nimble," Kara says. "It's this little washing machine bouncing around the ISS, and it can collect a ton of X-ray photons. Every day, NICER could take a quick little look at this AGN, then go off and do something else."

With frequent observations, the researchers were able to catch the black hole as it precipitously dropped in brightness, in virtually all the wave bands they measured, and especially in the high-energy X-ray band—an observation that signaled that the black hole's corona had completely and suddenly vaporized.

"After ASSASN saw it go through this huge crazy outburst, we watched as the corona disappeared," Kara recalls. "It became undetectable, which we have never seen before."

A jolting flash

Physicists are unsure exactly what causes a corona to form, but they believe it has something to do with the configuration of magnetic field lines that run through a black hole's accretion disk. At the outer regions of a black hole's swirling disk of material, magnetic field lines are more or less in a straightforward configuration. Closer in, and especially near the event horizon, material circles with more energy, in a way that may cause magnetic field lines to twist and break, then reconnect. This tangle of magnetic energy could spin up particles swirling close to the black hole, to the level of high-energy X-rays, forming the crown-like corona that encircles the black hole.

Kara and her colleagues believe that if a wayward star was indeed the culprit in the corona's disappearance, it would have first been shredded apart by the black hole's gravitational pull, scattering stellar debris across the accretion disk. This may have caused the temporary flash in brightness that ASSASN captured. This "tidal disruption," as

astronomers call such a jolting event, would have triggered much of the material in the disk to suddenly fall into the black hole. It also might have thrown the disk's magnetic field lines out of whack in a way that it could no longer generate and support a high-energy corona.

This last point is a potentially important one for understanding how coronas first form. Depending on the mass of a black hole, there is a certain radius within which a star will most certainly be pulled in by a black hole's gravity.

"What that tells us is that, if all the action is happening within that tidal disruption radius, that means the magnetic field configuration that's supporting the corona must be within that radius," Kara says. "Which means that, for any normal corona, the magnetic fields within that radius are what's responsible for creating a corona."

The researchers calculated that if a star indeed was the cause of the black hole's missing corona, and if a corona were to form in a supermassive black hole of similar size, it would do so within a radius of about four light minutes—a distance that roughly translates to about 75 million kilometers from the black hole's center.

"With the caveat that this event happened from a stellar tidal disruption, this would be some of the strictest constraints we have on where the corona must exist," Kara says.

The corona has since reformed, lighting up in high-energy X-rays which the team was also able to observe. It's not as bright as it once was, but the researchers are continuing to monitor it, though less frequently, to see what more this system has in store.

"We want to keep an eye on it," Kara says. "It's still in this unusual high-flux state, and maybe it'll do something crazy again, so we don't want to

miss that."

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