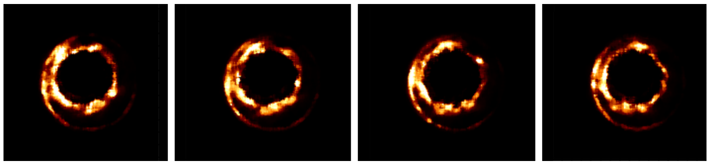
Predicting Black Hole Radio-Wave Hot Spots

Simulations of the plasma around a black hole indicate that "magnetic reconnection" could induce radio-wave hot spots that orbit the black hole, a prediction future Event Horizon Telescope measurements could test.

By **Katherine Wright**

Characterized by just three parameters—mass, spin, and charge—black holes could be considered one of the Universe's simpler astrophysical objects. Yet, the number of open problems related to how the dark behemoths behave also marks them as one of the most enigmatic. One puzzle is why the plasma around black holes glows so brightly. Now, in 3D simulations of the magnetic fields within this plasma, Benjamin Crinquand of Princeton University and colleagues think they have found the answer: the breaking and reconnecting of magnetic-field lines [**1**]. The simulations predict that, under certain conditions, magnetic-field instabilities can induce radio-wave hot spots that rotate around the shadow of the black hole. This prediction could be tested by future versions of the Event Horizon Telescope (EHT)—the network of radio dishes used to capture the first black hole images (see **Research News: First Image of the Milky Way's Black Hole**).

There are several mechanisms that physicists think could be behind a black hole's light. One of those is so-called accretion power, where friction-like forces in the infalling plasma heat the plasma, leading to the emission of photons. Models of this process predict constant emission signals, which doesn't seem to fit with observations of high-intensity bursts of gamma rays from black holes.



Simulations showing the time evolution of magnetically induced radio-wave emission from a black hole plasma. Radio-wave hot spots rotate clockwise around the black hole shadow. For M87*, the first black hole to be imaged, a complete rotation takes about 5 days.
Credit: B. Crinquand/Princeton University

Another possibility—and the one that Crinquand and his colleagues consider—is that the energy needed to create this light is extracted from the magnetic field that threads through the plasma. When the lines associated with this field break apart and then reconnect—a process known as magnetic reconnection—magnetic-field energy can convert into plasma-kinetic energy that is then emitted as photons. This model would not replace the accretion one, but act in tandem with it.

In 2D simulations, the team previously found that such a magnetic process could lead to the emission of gamma-ray flares—potentially explaining the observed bursts. Now they turn to 3D simulations and consider radio-wave emission, which ties into the black hole observations made by EHT. "We want to get more realistic images that we could potentially compare to experimental data," Crinquand says.

The team assumes that black holes occasionally enter a so-called flaring plasma state, in which most of the plasma becomes force free—meaning that the magnetic forces are so high that they mask the effects of the friction-like forces in accretion. The team simulates the dynamics of the plasma's particles and of its magnetic fields, looking at the energy transfer between the particles and the fields. The model accounts for all currents flowing in the plasma—as well as general relativistic effects that were left out of previous studies, Crinquand says.

The team's simulations show that the magnetic-field lines are constantly in motion, bending, splitting apart, and joining back up as they move through the plasma and interact with its particles. As in their previous work with 2D simulations, the researchers find that magnetic-field energy is converted into plasma-kinetic energy during the reconnection of field lines.

The team models the radio waves emitted from the energized plasma and uses a ray-tracing technique to visualize how that radiation would appear to an observer on Earth. They find that the radio-wave emission is dominated by ring-like structures, whose intensities fluctuate over time. Those fluctuations appear as radio-wave hot spots that rotate around the shadow of the black hole. For the case of a large black hole such as the one at the center of the galaxy M87, the hot spots are predicted to have an orbital radius that is around 3 times the black hole radius and an orbital period of roughly 5 days.

Crinquand notes that the current version of the EHT is unlikely to capture the emission patterns that he and his colleagues predict because the telescope's spatial and time resolutions are too low to tease out these features. He also notes that the transient nature of these patterns means that they won't always be detectable, even with higher resolution imaging capabilities. "From time to time the accretion flow recedes and that is when we expect the plasma to be in the flaring state and for these hot spots to become visible," he says. Even with the next iteration of the EHT, researchers would need "a lot of luck" to image these features, Crinquand says. But he holds out hope that the right conditions will all come together. "I would love to see the EHT capture a black hole emitting hot spots."

This study is "an important step" toward capturing the processes responsible for the radiation emitted from around black holes, says Amir Levinson, a black hole physicist at Tel Aviv University, Israel. "Detailed analysis of the dynamics and emission of the magnetosphere is a formidable challenge that, if successfully completed, could advance our knowledge of basic physics and astrophysics." Levinson adds that that while there is still a long way to go to tease out all the processes occurring inside a black hole's enveloping plasma, "the direction pursued [by Crinquand and colleagues] seems promising."

Katherine Wright is the Deputy Editor of ***Physics Magazine***.

REFERENCES

1. B. Crinquand *et al.*, "Synthetic images of magnetospheric reconnection-powered radiation around supermassive black holes," **Phys. Rev. Lett. 129, 205101 (2022).**