Simulations predict the existence of black hole radio-wave hot spots

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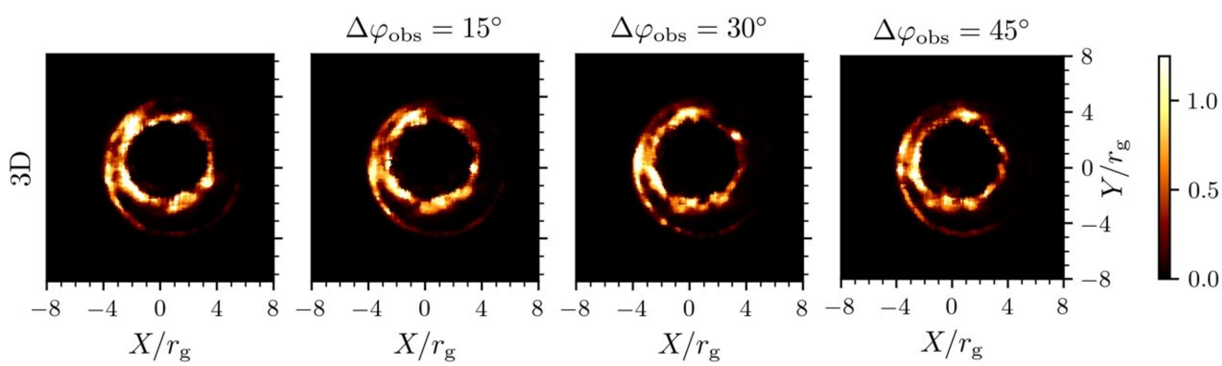

Some of the synthetic images produced by the researchers, showing that the hot spots rotate as an observer rotates around the spin axis of the black hole. Credit: Crinquand et al

Black holes, regions in spacetime where gravity is so strong that nothing can escape from them, are among the most fascinating and widely studied cosmic phenomena. While there are now countless theories about their formation and underlying physics, many questions remain unanswered.

One of the long-standing questions in the study of black holes is why the plasma surrounding them glows so brightly, as shown by the few direct telescope images collected so far. In a paper published in *Physical Review Letters*, researchers at Université Grenoble Alpes-CNRS, Trinity

College Dublin and University of Maryland presented computer simulations that offer a viable explanation.

"We were very impressed by the recent publication of images of the supermassive black hole M87* by the Event Horizon Telescope (EHT) collaboration," Benjamin Crinquand, one of the researchers who carried out the study, told Phys.org. "This observation took place when this black hole was at a historically low luminosity (it was 'quiescent'). However, M87* is known to produce bursts/flares of emission at various wavelengths, up to gamma-rays."

The key objective of the recent study by Crinquand and his colleagues was to make predictions about how images of the black hole M87* collected by the EHT collaboration would look like if they were collected during one of its common outbursts of emission. To do this, they performed a series of kinetic plasma simulations, representing the vicinity of a spinning black hole during such outbursts.

"This novel simulation tool for understanding plasma behavior in such an extreme environment was developed very recently," Crinquand explained. "Its goal is to treat the plasma from first principles and to include relevant microphysics, which would be washed out in the common fluid framework (magnetohydrodynamic simulations). Then one needs to know how matter is coupled to radiation, which is ultimately observed from Earth."

Theoretical and experimental studies have showed that in black hole environments, photons do not propagate in straight lines, due to their strong gravity. In their kinetic simulations, Crinquand and his colleagues tried to account for this by implementing a ray-tracing module, which traces the light emitted by the plasma around a black hole from the simulation to an observer.

Overall, the simulations carried out by this team of researchers suggest that under certain conditions, magnetic-field instabilities can lead to the production of radio-wave hot spots, which would rotate around a black hole's shadow. The team predicted that for large black holes, such as M87*, the orbital radius of these hotspots would be approximately three times larger than the radius of the black hole, and the hotspots would take around five days to orbit the black hole.

"Our main contribution is the realization that when the black hole is in such a state, the image should display hot spots, which are expected to rotate with time," Crinquand said. "These hot spots are the signature of 'plasmoids,' closed magnetic structures in the black-hole magnetosphere. We also expect the image to shrink within the 'photon ring,' which is commonly invoked as being the shadow observed by the EHT in 2019."

The simulations run by this team of researchers introduce an interesting theoretical hypothesis that could be verified by future astronomical observations. Specifically, they predict that the radiation emission patterns observed around black holes could be due to the breaking of magnetic fields and resulting formation of radio-wave hot spots.

The current version of the EHT might not be sensitive enough to capture the emission patterns they simulated, due to its limited spatial and temporal resolution. Nonetheless, Crinquand and his colleagues hope that future versions of the telescope will help to validate their theory.

"In the future, we wish to pursue two lines of research," Crinquand added. "Firstly, we are updating our module to account for the polarization of the emitted radiation, to increase the predictive power of our model. In 2021, the EHT released polarized observations of M87*, so the time is now ripe for theorists to make such predictions. On a theoretical side, we also want to better understand what drives this transition between a quiescent and a flaring state. We will especially need to understand the associated time scales: recurrence time of the flares, typical rising, time, etc."

More information: Benjamin Crinquand et al, Synthetic Images of Magnetospheric Reconnection-Powered Radiation around Supermassive Black Holes, *Physical Review Letters* (2022). DOI: 10.1103/PhysRevLett.129.205101

Kyle Parfrey et al, First-Principles Plasma Simulations of Black-Hole Jet Launching, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.122.035101