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Black-hole mergers cast kaleidoscope of shadows

The objects would bend light around them into a 'fractal' as they spiral into each other.

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Merging black holes
Pairs of tightly orbiting black holes eventually spiral into each other and collide. With computer models similar to those used to create the special effects for the recent science-fiction film *Interstellar*, astrophysicists produced the first realistic simulation of what this merger would actually look like to an observer.

In *Interstellar*, the science-fiction film out this week, Matthew McConaughey stars as an astronaut contending with a supermassive black hole called Gargantua. The film's special effects have been hailed as the most realistic depiction ever made of this type of cosmic object.

But astrophysicists have now gone one better. They have calculated for the first time what an observer would see if two black holes — each drastically warping the fabric of space and time according to Albert Einstein's general theory of relativity — spiralled into each other and merged. The researchers' simulations (see video above) reveal how the image of each black hole circles around the other and gets multiplied in a rapidly shape-shifting kaleidoscope. Andy Bohn of Cornell University in Ithaca, New York, and his colleagues unveiled the results on 30 October in a paper posted on the arxiv.org repository[1].

Kip Thorne, a general-relativity theorist at the California Institute of Technology in Pasadena, says that, as far as he is aware, “there have never been any previous visualizations of gravitational lensing of colliding and merging black holes”. He calls the results “fascinating”. It was Thorne's idea for a film that eventually grew into *Interstellar*, and he served as an adviser during its production (see 'Q&A: Space-time visionary'). Thorne co-founded the Caltech relativity-theory group that collaborated with Cornell astrophysicists on the latest simulations, but he was not involved in the study by Bohn and colleagues.

Shadowplay

Bohn’s team started from existing simulations of how spiralling black holes deform space-time[2]. On this backdrop, they calculated the path of light rays backwards from the lens of a camera, as the rays journeyed through the heavily distorted space-time. In previous studies of such optical effects, researchers had examined only weak gravitational lensing, in which the path of a light ray is deflected by no more than 0.003 degrees, Bohn notes.

As expected, each black hole cast its own large shadow, either ring-shaped or blobby, as a result of background light that each gravitational beast absorbed and prevented from reaching the camera. And many smaller shadows, shaped like eyebrows, appeared when the shadow of one of the black holes was distorted by the gravity of the other. But the work also revealed some surprises. There seemed to be an infinite number of such eyebrows, each corresponding to light rays orbiting the merging black holes a different number of times before the light reached the camera.

For merging black holes that have identical masses, Bohn and his colleagues found an intriguing feature: as the physicists zoomed in to smaller and smaller spatial scales in their simulation, the eyebrows repeated the same structural pattern. This self-similar, or 'fractal', pattern is unexpected for such a complex system, Bohn says.

“This work is important because many of the most astrophysically important dynamical space-times, like merging black holes, can only be explored using computer simulations,” notes astrophysicist Geoffrey Lovelace of California State University in Fullerton, who was not part of the discovery team. Although several research groups have simulated merging black holes, “the new and exciting thing here is that Bohn and collaborators have devised a way to trace light rays as they travel through these simulated space-times, to see what a nearby observer would see,” he adds.

The visualizations in *Interstellar* are also portrayed through gravitational lensing, and use a similar ray-tracing technique, but at the much-higher resolution required for an IMAX movie, Thorne notes. The imagery in the film shows a supermassive black hole surrounded by an accretion disk — a swirling disk of matter that feeds the monster, whereas Bohn’s team examined two colliding black holes without accretion disks. Typical black holes, which weigh roughly as much as a large star, don't necessarily have accretion disks, says Bohn. (Supermassive black holes can weigh as much as millions or billions of Sun-like stars.)

Bohn sees his team’s study as a stepping stone to exploring what an observer would see if a dead, compact star known as a neutron star merged with a black hole. That is a more complex problem, because researchers would have to account for the neutron star’s own light, which is emitted in explosive outbursts as the star is ripped apart by the black hole.

The ray-tracing technique should enable the team to produce detailed images of these mergers, Bohn says. This might produce optical fingerprints that astronomers could search for as they scour the heavens for these rare but important collisions.

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Corrections

Corrected: A previous version of this article stated that earlier simulations allowed gravitational lensing by no more than 3,000ths of a degree. In fact, it should have said no more than 0.003 degrees.

References

1. Bohn, A. *et al.* available at http://arxiv.org/abs/1410.7775 (2014).
2. Taylor, N. W. *et al. Phys. Rev. D* **88**, 124010 (2013).