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In Search of Darkness:
The quest to observe one of nature's most curious astronomical constructions

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Imagine walking through a carnival. You hear laughing children, the bustle of the crowd, and a man shouting, "Witness the immeasurable strength of the ultimate attraction between matter and light! Behold the inescapable grip that pervades the Universe! Only a dollar a head!" Intrigued, you pay the small fee and enter a trailer. You find a table in the center of the room with a black opaque glass case. You stare baffled, waiting for something to happen, until you glance at the label and read in big black letters, "THE BLACK HOLE." You realize you've been had... or have you?

How could you tell? If physicists and astrophysicists have developed the theory of black holes correctly, then it seems that a black hole will never be "observed." By definition, light cannot escape the surface, or event horizon, of a black hole. When you consider that to see an object, light has to be either emitted or reflected by it, determining whether a black opaque glass case harbors a black hole seems an impossible task.

Theoretically, any object could become a black hole. However, it is not easy. For a black hole to exist, the velocity required to break free from the black hole's gravitational bind must be greater than the speed of light. From the escape velocity we can calculate the maximum radius a given mass must occupy to be a black hole. For instance, to turn the earth into a black hole would require compressing it to the size of a sphere with a radius less than 10 millimeters. Similarly, if all the mass of the Sun were contained in a sphere with a radius less than 3 kilometers it would become a black hole. The current size of the sun is more than 690,000 kilometers.

How can mass be compressed to such a high density? How would an object that does not emit any light be observed? As it turns out, astronomers now know how black holes form and how to observe them. Black holes were formulated as a theoretical solution to Einstein's theory of general relativity. Astronomers came up with the idea that a black hole could be formed during the death of large stars. The theory plays out like this: During the lifetime of a star, its core is constantly converting hydrogen to helium. This conversion releases tons of energy, creating an outward radiation pressure. The gravity of the star's mass wants to compress the star inward. Most of a star's lifetime is spent in thermodynamic equilibrium, where the outward radiation pressure equals the inward gravitational compression. Eventually, as a star exhausts its supply of hydrogen, it loses the tug-of-war to gravity. Gravity's victory results in a gravitational collapse. A massive star undergoing gravitational collapse will crash down with enough momentum to press matter beyond physical boundaries, forming a black hole.

So, going back to the black opaque case at the carnival, if a table is able to support it, chances are it does not contain a black hole. If we assume the black holeâs mass is small enough to be supported by the table, its gravitational collapse would not have enough momentum to form a black hole and it would just destroy the object. But if it did manage to form, it would be a microscopic black hole that would pass through the molecules of the glass and the ground on its way to the earthâs core.

So how does one observe a black hole? By calculating and predicting what the consequences of a black hole are on the surrounding matter. The surrounding matter can be observed because its light can escape. A black hole's gravity will accrete, or gather matter, onto its surface, which is called an event horizon. The effect of this is similar to water draining from a sink. The water swirls around outside of the drain, and as it approaches the drain, it eventually spirals into it. With a black hole, gases orbit around the black holeâs center and remain in a stable orbit around the black hole, called an accretion disk. Friction heats and ionizes the atoms, which release high-energy photons, or x-ray light. These photons escape because they are not at the event horizon. The photons reach the earth and are collected by x-ray satellite observatories.

Occasionally a blob of gas will break from the stable orbit and enter a chaotic orbit that takes the blob of gas on a wild spiraling path toward the event horizon. If the angle of the accretion disk and event horizon is just right, astronomers can observe the photons from the blob spiral around the front and back of the event horizon. These "pulse trains" can be used to characterize the rotation and size of the black hole. The intensity dims as the blob is occulted, or blocked, by the event horizon, similar to a solar eclipse where the moon blocks the sun's light. Once the blob reappears on the other side of the event horizon, its intensity increases again. The maximum peak in these fluctuations decreases as the blob's orbit shrinks and the blob approaches the event horizon.

In order for astronomers to observe the accretion disk around a black hole, there must be a plentiful supply of matter for the black hole to accumulate. The best supply of mass comes by way of another star orbiting the center of mass of the black hole/star binary system. An old, dying, expanding star, also called a Red Giant, can provide an adequate source of mass that can be readily accreted by the black hole. The gravitational dynamic dance between the members of a binary system is mathematically well understood. For a black hole/star binary system, the star is usually bright and visible, but the black hole remains unseen. By understanding the dynamics of such a binary system, astronomers can determine upper and lower limits for the mass of each object. If the mass of the unseen object is greater than three times the mass of our sun then it is large enough to be converting hydrogen to helium and should be easily seen. If it is not seen, it is dynamically determined to be a black hole.

To date, there are only a handful of stellar mass black hole candidates. They are only candidates because the current observations are either not sensitive enough to determine if the masses are definitely black hole masses, or the observations havenât been corroborated. Two concrete examples are Cygnus X-1 and GRO J1655-40. These two objects were first identified by their x-ray emissions. Astronomers could not find optical counterparts, or visible stars corresponding to the location of the x-ray sources. Instead, they discovered that the x-ray sources were the unseen companions of a binary system. By determining the dynamic properties of each system, astronomers deduced that the unseen companions, the black holes, each have masses so large they could not be anything but black holes.

Astronomers are searching for - and finding - one of nature's most curious constructions despite the obvious difficulty posed by their absence of light. The indirect clues (x-ray emissions detected by x-ray satellite observatories, orbital dynamics, and pulse trains) are adding up and the only information missing from the picture is that of the actual event horizon. The path to this Holy Grail is along the chaotic orbits that create pulse trains. With advancing x-ray observation technology and multi-wavelength observations, the realization of this seemingly impossible task is here, and astronomers, as always, are embracing the darkness.

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