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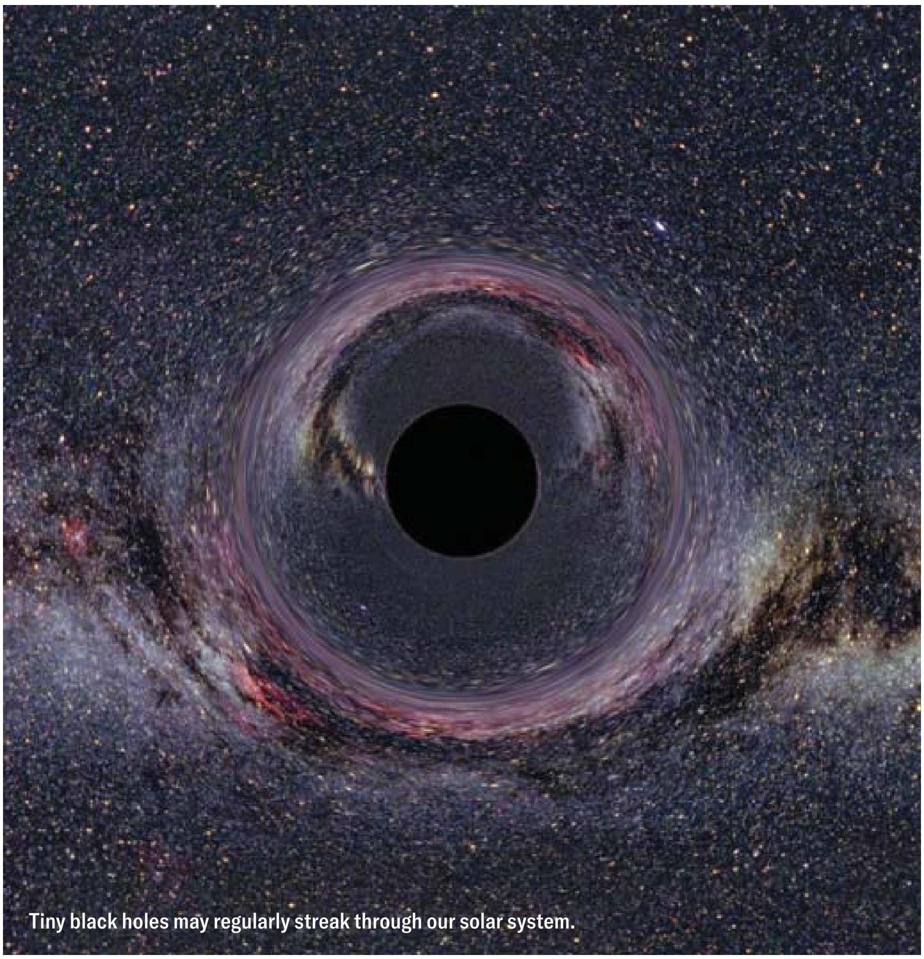
Missing dark matter could be atom-size black holes

BLACK HOLES the size of an atom that contain the mass of an asteroid may be flying through the inner solar system about once a decade. Theoretically created just after the big bang, these examples of so-called primordial black holes could explain the missing dark matter thought to dominate our universe. And if they sneak by the moon or Mars, scientists should be able to detect them, a new study shows.

Such black holes could have arisen easily right after the universe was born, when space is thought to have expanded hugely in a fraction of a second. During this expansion, tiny quantum fluctuations in space's density would have grown larger, and some spots might have become so dense that they collapsed into black holes scattered throughout the cosmos. If dark matter were fully explained by such black holes, their most likely mass, according to some theories, would range from 10^{17} to 10^{23} grams—about that of a large asteroid, packed into the size of an atom.

If primordial black holes are responsible for dark matter, one probably zips through the solar system about every 10 years, according to a recent study in *Physical Review D*. And if such a black hole comes near a planet or a large moon, it should nudge the body off course enough for the change to be measurable by current instruments. "As it passes by, the planet starts to wobble," says study co-author Sarah R. Geller, a theoretical physicist now at the University of California, Santa Cruz. "The wobble will grow over a few years, but eventually it will damp out and go back to zero."



Tiny black holes may regularly streak through our solar system.

Study lead author Tung X. Tran, then an undergraduate student at the Massachusetts Institute of Technology, built a computer model of the solar system to see how the distance between Earth and nearby objects would change after a black hole flyby. He found that such an effect would be most noticeable for Mars, whose distance from Earth scientists know within about 10 centimeters. A black hole in the middle of the predicted mass range, weighing 10^{21} grams, would produce one meter of variation in 10 years, Tran says—"way above the threshold of precision that we can measure."

If scientists detect a disturbance, they must determine whether the planet was pushed by a black hole or just a plain old asteroid. By tracking the wobble pattern over time, they can trace the culprit's trajectory and predict where it will head in the future. "We'd need to convince ourselves that it's really a black hole by telling observers where to look," says study co-author Benjamin V. Lehmann of M.I.T. Asteroids should be visible by telescope and would probably orbit on the same plane as the planets. A primordial black hole, in contrast, would be coming from far away with a trajectory likely to differ from an asteroid's.

Another potential way to look for primordial black holes in the solar system would be to analyze the fine movements of asteroids such as Bennu, which has been tracked very precisely by the ongoing space mission OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer). After reading the new study, "I think we can try to dig into OSIRIS-REx data to see if we can see this effect," says Yu-Dai Tsai, a particle physicist at Los Alamos National Laboratory. Tsai and his colleagues studied how the probe's Bennu measurements could be used to look for other forms of dark matter in a recent paper in *Nature Communications Physics*.

Primordial black holes are an increasingly appealing solution to the puzzle of dark matter, an invisible form of mass that physicists think makes up most of the matter in our universe. Because they can "see" this substance only through its gravitational effects on regular matter, its identity

Photo 12/Getty Images

has remained elusive as many favored theories have failed to pan out. For decades physicists thought dark matter was likely to take the form of so-called weakly interacting massive particles (WIMPs). Yet generations of ever more sensitive experiments meant to find these particles have come up empty, and particle accelerators have also seen no sign of them. “Everything is on the table because WIMPs have been put in such a corner, and they were the dominant paradigm for decades,” says astrophysicist Kevork N. Abazajian of the University of California, Irvine, who wasn’t involved in the *Physical Review D* study. “Primordial black holes are really gaining popularity.”

Physicists are also recognizing that dark matter may not interact with regular matter through any force other than gravity. Unlike WIMPs, which could also touch regular matter through the weak nuclear force, black holes would be detectable only through their gravitational pull. “Given that we are still searching for the correct way to detect dark matter interacting with ordinary matter, it is particularly important to explore probes based on the gravitational force it produces, which is the only interaction of dark matter whose strength is already known and the only interaction we are sure exists,” says theoretical physicist Tim M. P. Tait of U.C. Irvine, who was also not involved in the study.

That same issue of *Physical Review D* also happened to include a paper about a different team’s search for signs of primordial black holes flying near Earth. The researchers’ simulations found that such signals could be detectable in orbital data from Global Navigation Satellite Systems, as well as gravimeters that measure variations in Earth’s gravitational field. The two papers are complementary, says David I. Kaiser of M.I.T., a co-author of the study on interplanetary distance measurements.

Although these black holes could be passing relatively nearby, the chances that one could move through a human body are incredibly low. If that were to happen to you, though, it wouldn’t be fun: as the tiny black hole moved through you, it would tug everything toward it, crushing cells together in a deadly fashion. Its minuscule volume, however, would at least prevent you from getting sucked in. —*Clara Moskowitz*

Ghost Image Quantum entanglement reveals plants in action

QUANTUM PHYSICS Imagine watching a time-lapse video of a garden you had filmed over the course of a year: you’d see details of flowers transitioning from day to night and season to season. Scientists would love to watch similar transitions on a molecular scale, but the intense light used to snap microscopic pictures of plants disrupts the processes biologists want to observe—especially at night. In the journal *Optica*, physicist Duncan Ryan of Los Alamos National Laboratory (LANL) and his colleagues recently demonstrated a tool for imaging live plant tissues while exposing them to less light than they’d receive under the stars.

A technique called ghost imaging, first demonstrated in 1995, involves splitting a light source to create two streams of photons with different wavelengths at precisely the same times and locations. Each pair of photons is entangled—a quantum phenomenon that allows researchers to infer information about one particle in a set by measuring the other. Thus, a sample can be probed at one wavelength and imaged at another.

For plants, that means researchers can record visible-light photons, whose position can be measured accurately, and get knowledge about infrared photons that interact with water-rich molecules important to biological functions in the plants. In the new study, the team directed a stream of infrared photons at a plant in a transparent box with a photon counter behind it, and at the same time they aimed those particles’ visible counterparts at an empty box at the same distance with a multipixel camera behind it. Each visible photon directed at the empty box hit a pixel and was detected in its exact location—a measurement with much more precision than an infrared camera could achieve. Meanwhile the infrared photons traveled to the plant box, but not all of them were counted: the plant absorbed some percentage of photons at a given spot. A computer logged the position of a pixel only when a photon hit both the camera and the counter simultaneously, revealing how much infrared light made it through each point. This way, the researchers could construct an image of a leaf using photons that never touched it, essentially forming an infrared image on a visible camera. “It’s like a game of Battleship,” Ryan says.

Ghost imaging has proved successful in capturing pictures of simpler test designs. But for low-light-transmission samples such as plants, microscopic features often differ in absorption by just a few percent. The new study was possible because of an extremely sensitive detector developed at LANL that tracks the arrival of each infrared photon with trillionth-of-a-second precision—letting the scientists map leaf tissues and peer into live plants’ nighttime activities. “We saw [leaf pores called] stomata closing as the plants reacted to darkness,” Ryan says.

Ghost imaging “creates possibilities for long-timescale dynamic imaging that does not damage live samples,” says laser spectroscopy and quantum optics researcher Audrey Eshun of Lawrence Livermore National Laboratory, who calls the new investigation a “truly innovative study.”

These kinds of observations make it possible to track how plants use water and sunlight throughout their circadian cycle. “We’re watching plants react to their environment,” Ryan says, “and not to our observations of them.” —*Rachel Berkowitz*