Hubble hunts for intermediate-sized black hole close to home

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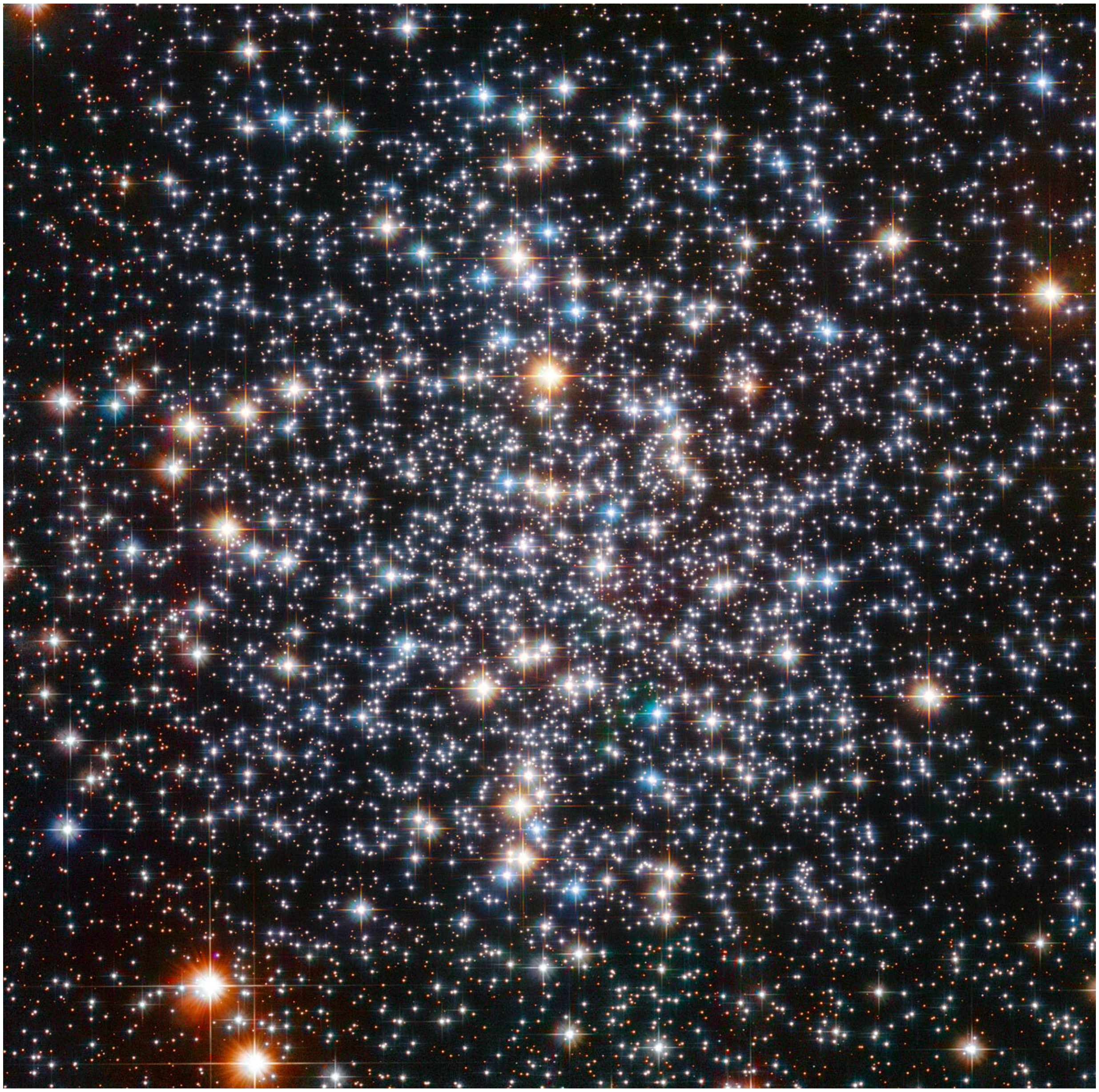

A Hubble Space Telescope image of the globular star cluster, Messier 4. The cluster is a dense collection of several hundred thousand stars. Astronomers suspect that an intermediate-mass black hole, weighing as much as 800 times the mass of our Sun, is lurking, unseen, at its core. Credit: ESA/Hubble & NASA

Astronomers using the NASA/ESA Hubble Space Telescope have come up with what they say is some of their best evidence yet for the presence of a rare class of intermediate-sized black holes, having found a strong candidate lurking at the heart of the closest globular star cluster to Earth, located 6,000 light-years away.

Like intense gravitational potholes in the fabric of space, virtually all black holes seem to come in two sizes: small and humongous. It's estimated that our galaxy is littered with 100 million small black holes (several times the mass of our sun) created from exploded stars. The universe at large is flooded with supermassive black holes, weighing millions or billions of times our sun's mass and found in the centers of galaxies.

A long-sought missing link is an intermediate-mass black hole, weighing roughly 100 to 100,000 times our sun's mass. How would they form, where would they hang out, and why do they seem to be so rare?

Astronomers have identified other possible intermediate-mass black holes using a variety of observational techniques. Two of the best candidates—3XMM J215022.4-055108, which Hubble helped discover in 2020, and HLX-1, identified in 2009—reside in the outskirts of other galaxies. Each of these possible black holes has the mass of tens of thousands of suns, and may have once been at the centers of dwarf galaxies.

Looking much closer to home, there have been a number of suspected intermediate-mass black holes detected in dense globular star clusters orbiting our Milky Way galaxy. For example, in 2008, Hubble astronomers announced the suspected presence of an intermediate-mass black hole in the globular cluster Omega Centauri. For a number of reasons, including the need for more data, these and other intermediate-mass black hole findings still remain inconclusive and do not rule out alternative theories.

Hubble's unique capabilities have now been used to zero-in on the core of the globular star cluster Messier 4 (M4) to go black-hole hunting with higher precision than in previous searches. "You can't do this kind of science without Hubble," said Eduardo Vitral of the Space Telescope Science Institute in Baltimore, Maryland, and formerly of the Institut d'Astrophysique de Paris (IAP, Sorbonne University) in Paris, France, lead author on a paper published in the *Monthly Notices of the Royal Astronomical Society*.

Vitral's team has detected a possible intermediate-mass black hole of roughly 800 solar masses. The suspected object can't be seen, but its mass is calculated by studying the motion of stars caught in its gravitational field, like bees swarming around a hive. Measuring their motion takes time, and a lot of precision. This is where Hubble accomplishes what no other present-day telescope can do. Astronomers looked at 12 years' worth of M4 observations from Hubble, and resolved pinpoint stars.

ESA's Gaia spacecraft also contributed to this result with scans of over 6000 stars that constrained the global shape of the cluster and its mass. Hubble's data tend to rule out alternative theories for this object, such as a compact central cluster of unresolved stellar remnants like neutron stars, or smaller black holes swirling around each other.

"Using the latest Gaia and Hubble data, it was not possible to distinguish between a dark population of stellar remnants and a single larger point-like source," says Vitral. "So one of the possible theories is that rather than being lots of separate small dark objects, this dark mass could be one medium-sized black hole."

"We have good confidence that we have a very tiny region with a lot of concentrated mass. It's about three times smaller than the densest dark mass that we had found before in other globular clusters," he continued. "The region is more compact than what we can reproduce with numerical simulations when we take into account a collection of black holes, neutron stars, and white dwarfs segregated at the cluster's center. They are not able to form such a compact concentration of mass."

A grouping of close-knit objects would be dynamically unstable. If the object isn't a single intermediate-mass black hole, it would require an estimated 40 smaller black holes crammed into a space only one-tenth of a light-year across to produce the observed stellar motions. The consequences are that they would merge and/or be ejected in a game of interstellar pinball.

"We measure the motions of stars and their positions, and we apply physical models that try to reproduce these motions. We end up with a measurement of a dark mass extension in the cluster's center," said Vitral. "The closer to the central mass, the more randomly the stars are moving. And, the greater the central mass, the faster these stellar velocities."

Because intermediate-mass black holes in globular clusters have been so elusive, Vitral cautions, "While we cannot completely affirm that it is a central point of gravity, we can show that it is very small. It's too tiny for us to be able to explain other than it being a single black hole. Alternatively, there might be a stellar mechanism we simply don't know about, at least within current physics."

"Science is rarely about discovering something new in a single moment. It's about becoming more certain of a conclusion step by step, and this could be one step towards being sure that intermediate-mass black holes exist," explains Gaia mission scientist Timo Prusti. "Data from Gaia Data Release 3 on the proper motion of stars in the Milky Way were essential in this study. Future Gaia Data Releases, as well as follow-up studies from the Hubble and James Webb Space Telescopes could shed further light."

More information: Eduardo Vitral et al, An elusive dark central mass in the globular cluster M4, *Monthly Notices of the Royal Astronomical Society* (2023). DOI: 10.1093/mnras/stad1068

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