New possibilities for detecting Hawking radiation emitted by primordial black holes

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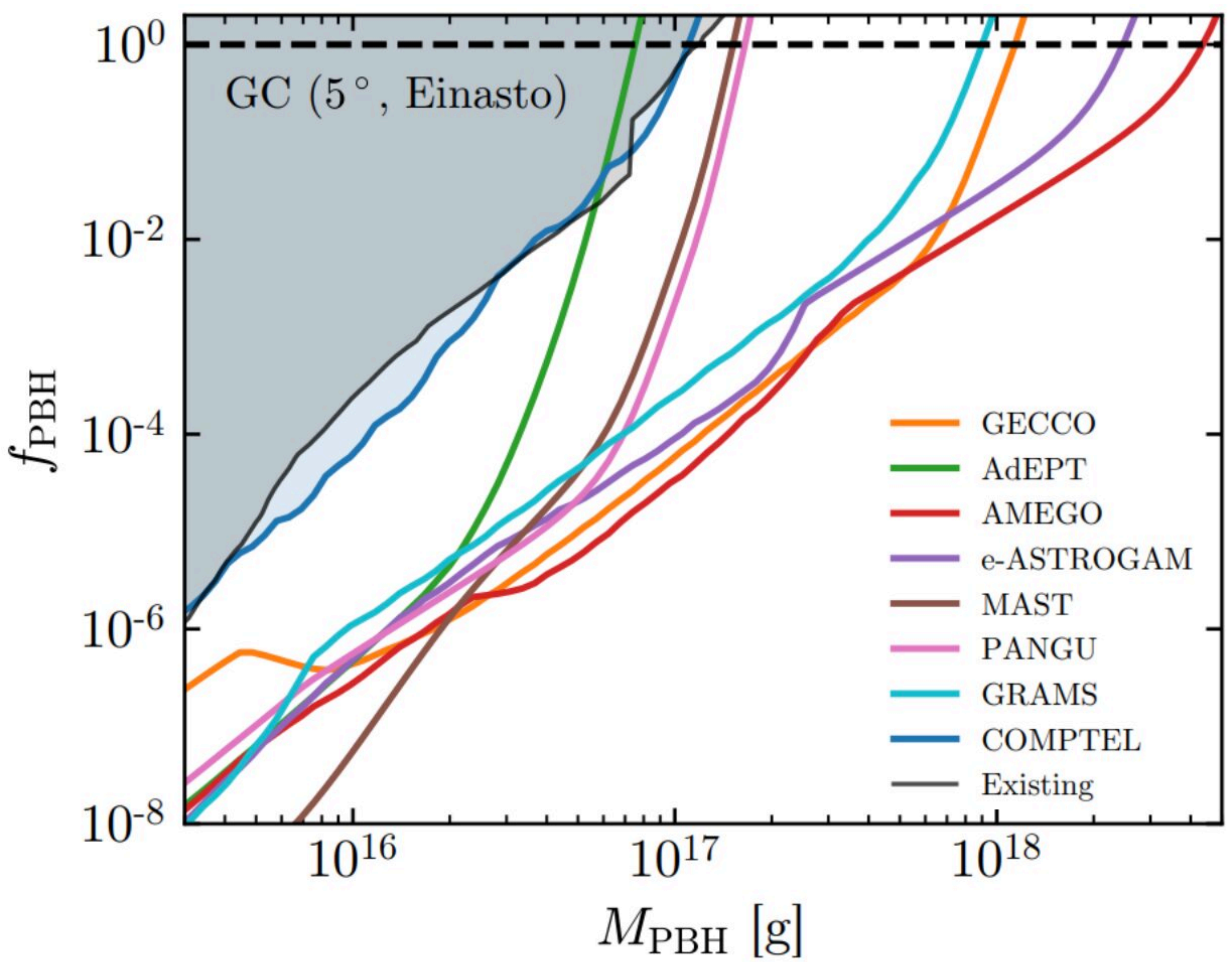

New PBH constraint based on COMPTEL data (dark blue), projections of the discovery reach of future MeV gamma ray telescopes (other colored curves) and existing constraints (shaded grey regions). Credit: Coogan et al.

While many physicists have predicted the existence of dark matter, a type of matter that does not absorb, reflect or emit light, so far no one has been able to observe it experimentally or determine its fundamental nature. Light primordial black holes (PBHs), black holes the formed in the early universe, are among the most promising dark matter candidates. However, the existence of these black holes has not yet been confirmed.

Researchers at University of Amsterdam and University of California-Santa Cruz have recently carried out a study aimed at improving existing constraints on the allowed parameter space of PBHs as dark matter. In their paper, published in *Physical Review Letters*, they also propose a possible method that could be used to directly detect Hawking radiation in dark matter dense regions and potentially enable the discovery of PBH dark matter.

Hawking radiation is the thermal radiation that Stephen Hawking predicted to be spontaneously emitted by black holes. This radiation is hypothesized to arise from the conversion of quantum vacuum fluctuations into pairs of particles, one escaping the black hole and the other trapped inside its event horizon (i.e., the boundary around black holes from which no light or radiation can escape).

"PBHs comprising more than a few percent of the dark matter would need to have mass between about 10^{16} grams and 10^{35} grams," Adam Coogan, one of the researchers who carried out the study, told Phys.org. "Over most of that range, various observations exclude them from making up 100% of the dark matter. However, there is a notable gap in the constraints: PBHs with masses around that of an asteroid (~10^{17} grams to 10^{22} grams) could still make up all the dark matter."

Identifying methods to constrain the allowed parameter space of PBHs or detect the Hawking radiation emanating from them could be an important step towards the observation or discovery of PBH dark matter. Coogan, in collaboration with his colleagues Logan Morrison and Stefano Profumo, thus set out to examine the potential of MeV gamma-ray telescopes as tools to detect PBH Hawking radiation.

"The main idea behind our work was to think about a particular way of looking for asteroid-mass PBHs," Coogan explained. "Light PBHs are expected to emit Hawking radiation consisting of a mix of photons and other light particles, such as electrons and pions. Telescopes can then search for this radiation by observing our galaxy or other galaxies. The goal of our paper was to understand how well upcoming telescopes would be able to observe this radiation and consequentially how much of the asteroid-mass PBH parameter space they could probe."

While trying to estimate the masses of PBHs that emerging telescopes could help to constrain, Coogan and his colleagues discovered that previous studies had not yet analyzed data collected by the COMPTEL telescope, a gamma-ray telescope launched by NASA onboard of the Compton Gamma Ray Observatory (CGRO). This data, however, could help to constrain the abundance of PBHs slightly below the asteroid-mass gap (i.e., below 10^{17} grams). While constraints already exist in this mass range thanks to observations of Hawking radiation gathered by Voyager 1 and the INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL) satellite, the new constraints introduced by the researchers were found to be the strongest to date.

"The key input for computing constraints and making projections is to compute the spectrum of Hawking radiation produced by a single PBH," Coogan said. "We refined this calculation in comparison with existing tools in the literature by improving how radiation produced by electrons and pions is accounted for in the spectrum. The rest of the calculations are quite typical for dark matter searches."

Assuming that PBHs of a specific mass make up a given fraction of the total dark matter in space, the calculations carried out by Coogan and his colleagues would allow researchers to compute their contribution to the spectrum of photons emitted by an astrophysical object believed to contain a substantial amount of dark matter, such as the center of the Milky Way. If the spectrum estimated by these calculations was far brighter than the observed spectrum, for instance, one could rule out the possibility that PBHs of that specific mass make up a specific fraction of dark matter.

"Making projections for the performance of future telescopes follows along similar lines, though there is no observed spectrum to compare to," Coogan explained. "In this case, the spectrum of photons emitted by PBHs is compared with a model for the expected astrophysical background of photons."

The recent study by Coogan, Morrison and Profumo set the strongest constraints on low-mass PBHs to date, using data collected as part of an experiment that was completed 20 years ago. In addition, the researchers showed that upcoming telescopes capable of observing MeV-energy gamma rays could help to probe asteroid-mass PBHs, which is a very difficult part of the PBH parameter space to probe.

"The astronomy community has been considering several proposals for such telescopes in recent years and I think our paper provides another solid motivation for constructing them," Coogan added. "Aside from PBHs, we have been studying how upcoming MeV gamma-ray telescopes could probe different models of particle dark matter. We recently finished another paper where we computed the gamma-ray spectra for a few particular such models and are working with other collaborators to refine these calculations."

Coogan, Morrison and Profumo have recently also been collaborating with Alexander Moiseev, a Research Scientist at NASA, who is developing a telescope called the Galactic Explorer with a Coded Aperture Mask Compton Telescope (GECCO). Together with Moiseev, they have been trying to map out ways in which GECCO could aid the search for dark matter.

More information: Direct detection of Hawking radiation from Asteroid-mass primordial black holes. *Physical Review Letters*(2021). DOI: 10.1103/PhysRevLett.126.171101.

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