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Dark matter can solve the supermassive black-hole formation puzzle

Press Release

High-precision measurements of stellar orbits in galaxies' outskirts and central regions, together with theoretical progress combining particle physics and general relativistic galaxy modeling carried out in the last decade at ICRANet, including the explanation of the orbital motion of the closest stars around the Milky Way's center, Sagittarius (Sgr) A, have revealed the possible nature of the dark matter particles to be fermions with a mass in the sub-MeV range, likely about one-fifth of the electron's mass. The question of how supermassive black holes (SMBHs) get so massive so rapidly in the early universe challenges the current standard cosmological model. Such tension is increasing with the daily observations of the James Webb Space Telescope (JWST), whose exploration of our universe in the dawn of stellar and galaxy formation at cosmological redshifts* $z \approx 10$–15*, is unveiling a population of SMBHs heavier than ten million times solar masses. No current model provides a clear explanation of how such SMBHs have formed in a time as short as a hundred million years after the Big Bang. In a new research to be published in The Astrophysical Journal Letters, scientists from ICRANet, La Plata National University, and CONICET have shown that, once again, dark matter can rescue cosmology. This opens new synergy research from cosmology, astrophysics, and terrestrial laboratories in the quest to identify such a light sub-MeV particle. In this line, there are ongoing collaborations between ICRANet and the most intense high-energy sources on planet Earth, the Deutsches Elektronen-Synchrotron (DESY), the European Hard X-ray Free Electron Laser (EuXFEL), both in Hamburg, and the Extreme Light Infrastructure (ELI) in Prague.*

How SMBHs form and grow at high cosmological redshifts has remained elusive for years. The relevance of getting a satisfactory answer exponentially increases with the advent of the JWST's new, deep observations of the universe at high cosmological redshifts, e.g., $z \gtrsim 10$. In traditional scenarios, the BHs in the high-z universe should form from the gravitational collapse of hypothetical population III massive stars or gaseous configurations. In the most extreme assumptions, the BHs in these channels do not reach more than a hundred solar masses in the former and a hundred thousand in the latter mechanism. The further growth of the BH requires the accretion of ordinary matter from the galactic environment and the occurrence of galaxy mergers. But these BH seeds are either too light or the environmental conditions too rare to satisfactorily explain the SMBH population at the centers of the farthest quasars as observed by JWST, thus challenging our current cosmological understanding.

In a previous article published early in 2023 in the Monthly Notices of the Royal Astronomical Society journal, this research team had shown that the gravitational collapse of dense cores of dark matter made of fermions would form SMBHs of tens to hundred million solar masses if the fermion has a mass in the range of 50–100 keV, i.e., between one-tenth and one-fifth of the electron's mass. In that article, the authors showed that these SMBH seeds could comfortably grow by accretion up to a billion solar masses in timescales of a hundred million years. Therefore, this scenario could solve the SMBH formation problem in the high-z universe, providing one can answer the following crucial questions: how does an initially stable dark matter core reach gravitational collapse conditions, how long could that process take, and are those conditions realized in the required moment of the cosmological evolution?

The authors answered these questions using the fact that galaxy halos are not only made of dark matter but also ordinary (baryonic) matter. The baryonic matter infall and sedimentation in the dark matter core could trigger its gravitational collapse for a threshold amount of baryons that *instabilizes* the core since baryons provide mass but little pressure. The publication shows, for example, that a dark matter core that has gained about 35% of its final budget in baryonic matter collapses, forming SMBHs of about a hundred million solar masses. This amount of baryonic matter could be gained in a hundred million-year timescale from a baryonic environment of one solar mass per cubic centimeter of density and a hundred kilometers per second of velocity. See the Figure below for details. These values are typically found in cosmological hydrodynamical simulations of high-z halos and observed in the central regions of distant galaxies. The new publication focuses on the viability of the baryon-induced collapse mechanism in three cases: the SMBH formation in the Seyfert galaxy TXS 2116–077 merging with a nearby galaxy, the farthest quasar ever observed, located at $z = 10.3$ at the center of the JWST-galaxy UHZ1, and the so-called *little red dots*, the population of JWST-SMBHs at $z \approx 4$–6.

Interestingly, the required fermionic cores playing the role of BH seeds are those of the *dense core-diluted halo* dark matter configurations predicted by the Ruffini-Argüelles-Rueda (RAR) model. A series of previous publications have shown the reliability of such a dark matter candidate as its core-halo dark matter galactic configurations explain a variety of observables, including the galactic rotation curves, observational universal relations of galaxies, and the motion of the innermost stars near the Milky Way's center, Sgr A*.

Therefore, SMBH formation, galactic dynamics, and structure formation point to a non-interacting neutral, massive, spin 1/2 fermion with a rest mass of $\sim$ 100 keV as the dark matter particle. Does this fermion fit any candidate proposed in particle physics? A possibility is the right-handed sterile neutrino, but not only. Promising direct dark matter searches in terrestrial laboratories via dark matter interactions with electrons and nucleons are already looking for tens of keV fermion. This opens new synergy research from cosmology, astrophysics, and terrestrial laboratories in the quest for such a *light* sub-MeV particle.

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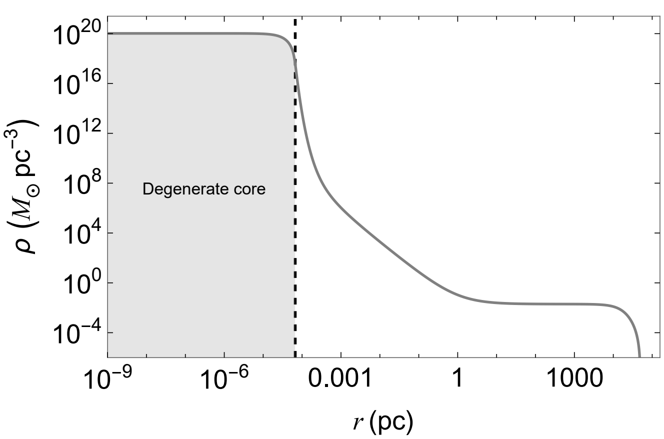
Figures:



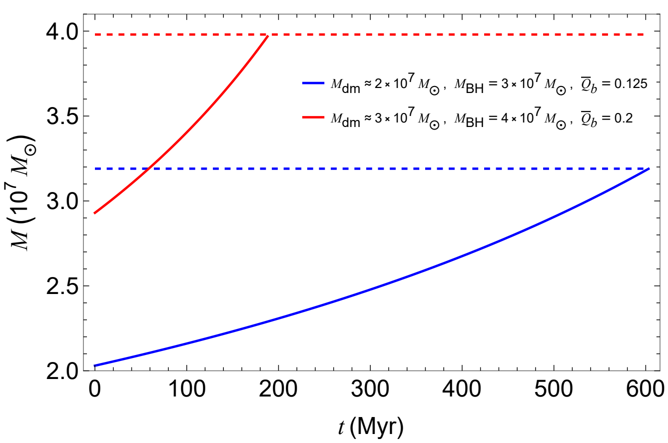


FIG. 1. Left: Initial pure-dark-matter core-hallo configuration with central density $\rho = 0.0068$ g cm^{-3} $= 1.01 \times 10^{20} M_\odot$ pc^{-3}, for 100 keV fermions. The total halo mass is $5 \times 10^{11} M_\odot$. The degenerate quantum core (filled gray region) has a mass $M_{\rm dm} = 2.03 \times 10^7 M_\odot$ and radius $R_c = 6.67 \times 10^{-5}$ pc. Right: Time evolution of the dark matter core mass while accreting baryonic matter for two examples. The blue curve is the evolution of the dark matter core of the left panel figure. The dashed lines indicate the SMBH mass formed.