

Merging boson stars could explain massive black hole collision and prove existence of dark matter

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Artistic impression of the merger of two boson stars. Credit: Nicolás Sanchis-Gual and Rocío García Souto.

An international team of scientists led by the Galician Institute of High Energy Physics (IGFAE) and the University of Aveiro shows that the heaviest black hole collision ever observed, produced by the gravitational-wave GW190521, might actually be something even more mysterious: the merger of two boson stars. This would be the first evidence of the

existence of these hypothetical objects, which are a candidate for dark matter, believed to comprise 27% of the mass in the universe.

Gravitational waves are ripples in the fabric of spacetime that travel at the speed of light. These originate in the most violent events of in the universe, carrying information about their sources. Since 2015, the two LIGO detectors in the U.S. and the Virgo detector in Cascina, Italy, have detected and interpreted [gravitational waves](#). To date, these detectors have already observed around 50 gravitational-wave signals. All of these originated in the collisions and mergers of black holes and [neutron stars](#), allowing physicists to deepen the knowledge about these objects.

However, the promise of gravitational waves goes much further than this, as these should eventually provide us with evidence for previously unobserved and even unexpected objects, and shed light on current mysteries like the nature of dark matter. The latter may, however, have already happened.

In September 2020, the LIGO and Virgo collaboration (LVC) announced to the world the gravitational-wave signal GW190521. According to their analysis, the signal was consistent with the collision of two heavy black holes, of 85 and 66 times the mass of the sun, which produced a final black hole with 142 solar masses. The resulting black hole was the first of a new, previously unobserved black hole family: intermediate-mass black holes. This discovery is of paramount importance, as such black holes were the missing link between two well-known black-hole families: stellar-mass black holes that form from the collapse of [stars](#), and supermassive black holes that reside in the center of almost every galaxy, including the Milky Way.

In addition, this observation came with an enormous challenge. If what we think we know about how stars live and die is correct, the heaviest of the colliding black holes (85 solar masses) could not form from the

collapse of a star at the end of its life, which opens up a range of doubts and possibilities about its origins.

In an article published today in *Physical Review Letters*, a team of scientists lead by Dr. Juan Calderón Bustillo at the Galician Institute of High Energy Physics (IGFAE), joint center of the University of Santiago de Compostela and Xunta de Galicia, and Dr. Nicolás Sanchis-Gual, a postdoctoral researcher at the University of Aveiro and the Instituto Superior Técnico (Univ. Lisboa), together with collaborators from University of Valencia, Monash University and The Chinese University of Hong Kong, has proposed an alternative explanation for the origin of the signal GW190521: the collision of two exotic objects known as [boson](#) stars, which are one of the most likely candidates to explain dark matter. In their analysis, the team was able to estimate the mass of a new particle constituent of these stars, an ultra-light boson with a mass billions of times smaller than electrons.

The team compared the GW190521 signal to computer simulations of boson-star mergers, and found that these actually explain the data slightly better than the analysis conducted by LIGO and Virgo. The result implies that the source would have different properties than stated earlier. Dr. Calderón Bustillo says, "First, we would not be talking about colliding black holes anymore, which eliminates the issue of dealing with a 'forbidden' black hole. Second, because boson star mergers are much weaker, we infer a much closer distance than the one estimated by LIGO and Virgo. This leads to a much larger mass for the final black hole, of about 250 solar masses, so the fact that we have witnessed the formation of an intermediate-mass black hole remains true."

Dr. Nicolás Sanchis-Gual says, "Boson stars are objects almost as compact as black holes but, unlike them, do not have a 'no-return' surface. When they collide, they form a boson star that can become unstable, eventually collapsing to a black hole, and producing a signal

consistent with what LIGO and Virgo observed. Unlike regular stars, which are made of what we commonly know as matter, boson stars are made up of what we know as ultralight bosons. These bosons are one of the most appealing candidates for constituting what we know as dark matter."

The team found that even though the analysis tends to favor the merging black-holes hypothesis, a boson star merger is actually preferred by the data, although in a non-conclusive way. Prof. Jose A. Font from the University of Valencia says, "Our results show that the two scenarios are almost indistinguishable given the data, although the exotic boson star hypothesis is slightly preferred. This is very exciting, since our boson-star model is, as of now, very limited, and subject to major improvements. A more evolved model may lead to even larger evidence for this scenario and would also allow us to study previous gravitational-wave observations under the boson-star merger assumption."

This result would not only involve the first observation of boson stars, but also that of their building block, a new particle known as an ultralight boson. Prof. Carlos Herdeiro from University of Aveiro says, "One of the most fascinating results is that we can actually measure the mass of this putative new dark-matter particle, and that a value of zero is discarded with high confidence. If confirmed by subsequent analysis of this and other gravitational-wave observations, our result would provide the first observational evidence for a long-sought dark matter candidate."

More information: Juan Calderón Bustillo, Nicolas Sanchis-Gual, Alejandro Torres-Forné, José A. Font, Avi Vajpeyi et al. "GW190521 as a merger of Proca stars: a potential new vector boson of 8.7×10^{-13} eV". Phys. Rev. Lett 126, 081101. [journals.aps.org/prl/abstract/ ...
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