PRESS RELEASE

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Unveiling the origins of merging black holes in galaxies like our own

Harnessing advanced simulation tools, a team of scientists from UNIGE, Northwestern University and University of Florida shed light on the enigmatic nature of these celestial "beasts".
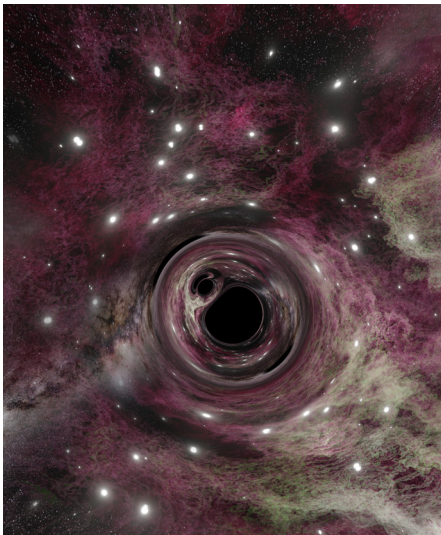
A 31.5 solar-mass black hole with an 8.38 solar-mass black hole companion viewed in front of its (computer generated) stellar nursery prior to merging. The distant band of the Milky Way can be seen toward the lower-left of the black hole pair. Light is warped nearby the black holes due to their strong gravity.

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High resolution pictures

Black holes, some of the most captivating entities in the cosmos, possess an immense gravitational pull so strong that not even light can escape. The groundbreaking detection of gravitational waves in 2015, caused by the coalescence of two black holes, opened a new window into the universe. Since then, dozens of such observations have sparked the quest among astrophysicists to understand their astrophysical origins. Thanks to the POSYDON code's recent major advancements in simulating binary-star populations, a team of scientists, including some from the University of Geneva (UNIGE), Northwestern University and the University of Florida (UF) predicted the existence of merging massive, 30 solar mass black hole binaries in Milky Way-like galaxies, challenging previous theories. These results are published in _Nature Astronomy_.

Stellar-mass black holes are celestial objects born from the collapse of stars with masses of a few to low hundreds of times that of our sun. Their gravitational field is so intense that neither matter nor radiation can evade them, making their detection exceedingly difficult. Therefore, when the tiny ripples in spacetime produced by the merger of two black holes were detected in 2015, by the Laser Interferometer Gravitational-wave Observatory (LIGO), it was hailed as a watershed moment. According to astrophysicists, the two merging black holes at the origin of the signal were about 30 times the mass of the sun and located 1.5 billion light-years away.

Bridging Theory and Observation

What mechanisms produce these black holes? Are they the product of the evolution of two stars, similar to our sun but significantly more massive, evolving within a binary system? Or do they result from black holes in densely populated star clusters running into each other by chance? Or might a more exotic mechanism be involved? All of these questions are still hotly debated today.

The POSYDON collaboration, a team of scientists from institutions including the University of Geneva (UNIGE), Northwestern and the University of Florida (UF) has made significant strides in simulating binary-star populations. This work is helping to provide more accurate answers and reconcile theoretical predictions with observational data. "As it is impossible to directly observe the formation of merging binary black holes, it is necessary to rely on simulations that reproduce their observational properties. We do this by simulating the binary-star systems from their birth to the formation of the binary black

hole systems," explains Simone Bavera, a post-doctoral researcher at the Department of Astronomy of the UNIGE's Faculty of Science and leading author of this study.

Pushing the Limits of Simulation

Interpreting the origins of merging binary black holes, such as those observed in 2015, requires comparing theoretical model predictions with actual observations. The technique used to model these systems is known as "binary population synthesis". "This technique simulates the evolution of tens of millions of binary star systems in order to estimate the statistical properties of the resulting gravitational-wave source population. However, to achieve this in a reasonable time frame, researchers have until now relied on models that use approximate methods to simulate the evolution of the stars and their binary interactions. Hence, the oversimplification of single and binary stellar physics leads to less accurate predictions," explains Anastasios Fragkos, assistant professor in the Department of Astronomy at the UNIGE Faculty of Science.

POSYDON has overcome these limitations. Designed as open-source software, it leverages a pre-computed large library of detailed single- and binary-star simulations to predict the evolution of isolated binary systems. Each of these detailed simulations might take up to 100 CPU hours to run on a supercomputer, making this simulation technique not directly applicable for binary population synthesis. "However, by precomputing a library of simulations that cover the entire parameter space of initial conditions, POSYDON can utilize this extensive dataset along with machine learning methods to predict the complete evolution of binary systems in less than a second. This speed is comparable to that of previous-generation rapid population synthesis codes, but with improved accuracy," explains Jeffrey Andrews, assistant professor in the Department of Physics at UF.

Introducing a New Model

"Models prior to POSYDON predicted a negligible formation rate of merging binary black holes in galaxies similar to the Milky Way, and they particularly did not anticipate the existence of merging black holes as massive as 30 times the mass of our sun. POSYDON has demonstrated that such massive black holes might exist in Milky Way-like galaxies," explains Vicky Kalogera, a Daniel I. Linzer Distinguished University Professor of Physics and Astronomy in the Department of Physics and Astronomy at Northwestern, director of the Center of Interdisciplinary Exploration and Research in Astrophysics (CIERA), and co-author of this study.

Previous models overestimated certain aspects, such as the expansion of massive stars, which impacts their mass loss and the binary interactions. These elements are key ingredients that determine the properties of merging black holes. Thanks to fully

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self-consistent detailed stellar-structure and binary-interaction simulations, POSYDON achieves more accurate predictions of merging binary black hole properties such as their masses and spins.

This study is the first to utilize the newly released open-source POSYDON software to investigate merging binary black holes. It provides new insights into the formation mechanisms of merging black holes in galaxies like our own. The research team is currently developing a new version of POSYDON, which will include a larger library of detailed stellar and binary simulations, capable of simulating binaries in a wider range of galaxy types.