Did LIGO detect black holes or gravastars?

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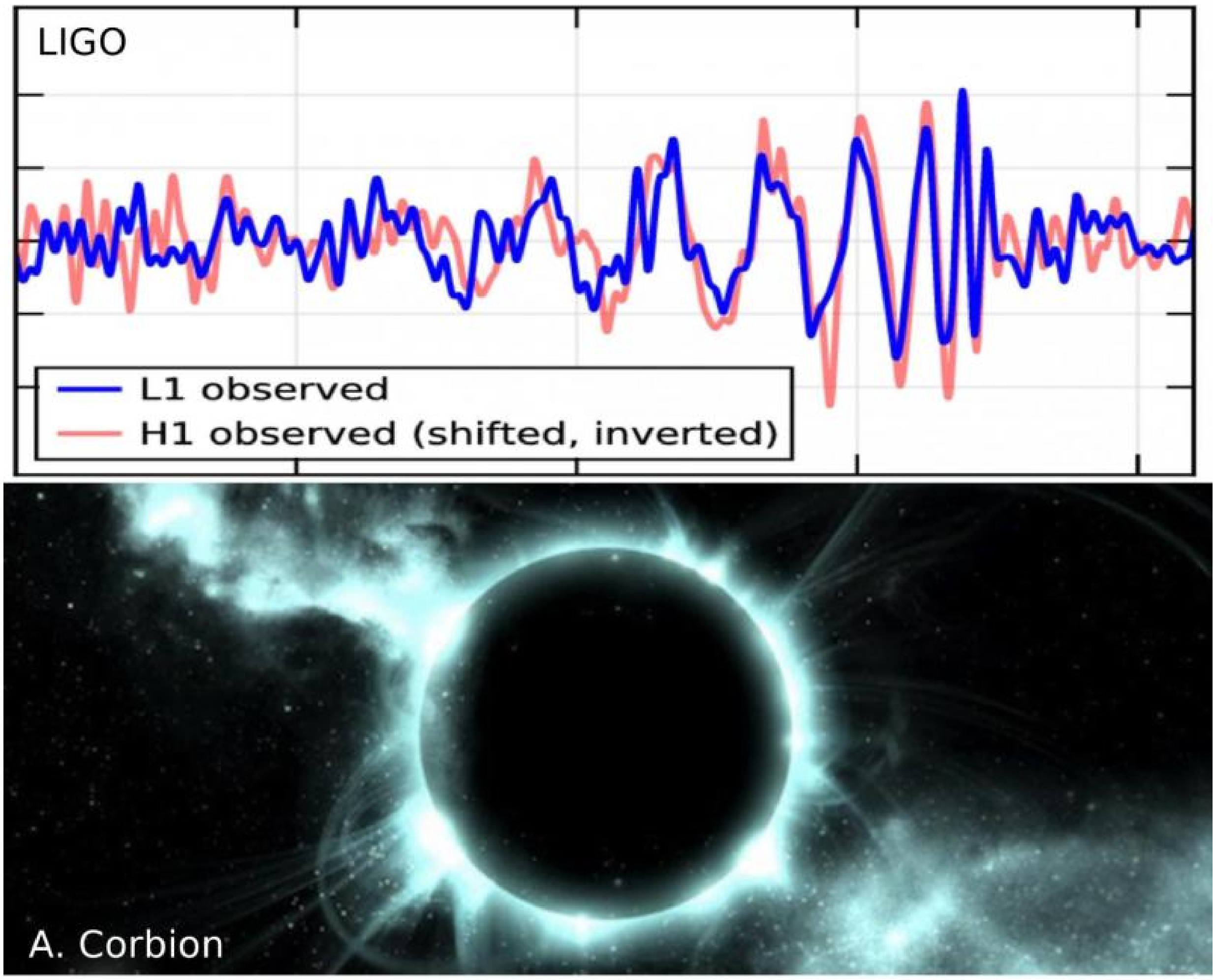

Gravitational wave signal from GW150914 as measured in the two detectors at Livingston and Hanford (top panel); artistic rendering of a gravastar (lower panel). Credit: Goethe University Frankfurt am Main

After the first direct detection of gravitational waves that was announced last February by the LIGO Scientific Collaboration and made news all over the world, Luciano Rezzolla (Goethe University Frankfurt, Germany) and Cecilia Chirenti (Federal University of ABC in Santo André, Brazil) set out to test whether the observed signal could have been a gravastar or not. The results were recently resented in a paper published on *Physical Review D.*

The idea of black holes has been around for a long time. From the original "dark stars" suggested by John Michell and Pierre Laplace 200 years ago, to ubiquitous sci-fi movies and TV series like Star Trek, the black hole (whose name was coined by John Wheeler in the 1960's) has become a familiar concept, albeit not so well understood.

And that also goes for physicists and astrophysicists working with them. Some of the strange mathematical properties of black holes, coming from Karl Schwarzschild's first solution of the Einstein field equations of general relativity in 1915, still puzzle the scientists. The existence of an event horizon and a central singularity, leading to conundrums like the information paradox, have inspired some researchers to propose alternative theories.

One of the alternative models is the gravastar (a gravitational vacuum condensate star) proposed by Pawel Mazur and Emil Mottola in 2001. A gravastar would be made of a core of exotic matter similar to dark energy, that prevents the collapse of a matter shell surrounding it, made of the normal matter that once made up a star. When the star started to collapse at the end of its life, a phase transition would happen that could create this exotic matter before the event horizon could be formed. This speculative object would be almost as compact as a black hole, but the tiny difference between them would be enough to prevent the formation of the event horizon and the conceptual questioning that comes with it.

How, then, could we tell a gravastar from a black hole? It would be almost impossible to "see" a gravastar, because of the same effect that makes a black hole "black": any light would be so deflected by the gravitational field that it would never reach us. However, where photons would fail, gravitational waves can succeed! It has long since been known that when black holes are perturbed, they "vibrate" emitting gravitational waves. Indeed, they behave as "bells," that is with a signal that progressively fades away, or "ringsdown." The tone and fading of these waves depends on the only two properties of the black hole: its mass and spin. Gravastars also emit gravitational waves when they are perturbed, but, interestingly, the tones and fading of these waves are different from those of black holes. This is a fact that was alreadyknown soon after gravastars were proposed.

When considering the strongest of the signals detected so far, i.e. GW150914, the LIGO team has shown convincingly that the signal was consistent with the a collision of two black holes that formed a bigger black hole. The last part of the signal, which is indeed the ringdown, is the fingerprint that could identify the result of the collision. "The frequencies in the ringdown are the signature of the source of gravitational waves, like different bells ring with different sound," explains Professor Chirenti.

After modelling the expected sound from a gravastar that would have the same characteristics of the final black hole, the two researchers have concluded that it would be very hard to explain the frequencies observed in the ringdown of GW150914 with a gravastar. To use the same language introduced before, although the gravitational-wave signals from gravastars are very similar to those of black holes, the tones and fadings are different. Just like two keys in a piano emit different notes, the "notes" measured with GW150914 simply do not match those that can be produced by gravastars. Hence, the signal measured cannot have been produced by two gravastars merging into another and larger gravastars. This result was recently resented in a paper published on *Physical Review D*.

"As a theoretical physicist I'm always open to new ideas no matter how exotic; at the same time, progress in physics takes place when theories are confronted with experiments. In this case, the idea of gravastars simply does not seem to match the observations," says Professor Rezzolla.

More information: Cecilia Chirenti et al. Did GW150914 produce a rotating gravastar?, *Physical Review D* (2016). DOI: 10.1103/PhysRevD.94.084016

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