Dark matter hiding in stars may cause observable oscillations

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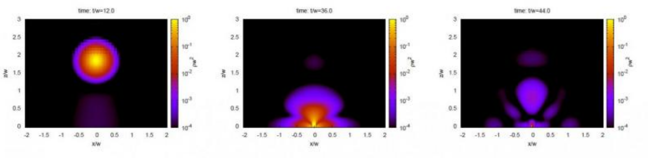

This sequence shows snapshots of a star's density when two dark matter cores collide, where the x-axis is the plane of collision (only half the space is shown, but the remaining space can be obtained by symmetry). Although the final configuration is more compact and massive than the original, the star does not collapse into a black hole because it ejects some of its mass, slowing down its growth so that it remains stable. Credit: Brito, et al. ©2015 American Physical Society

(Phys.org)—Dark matter has never been seen directly, but scientists know that something massive is out there due to its gravitational effects on visible matter. One explanation for how such a large amount of mass appears to be right in front of our eyes yet completely invisible by conventional means is that the dark matter is hiding in the centers of stars.

In a new study, physicists have investigated the possibility that large amounts of hidden mass inside stars might be composed of extremely lightweight hypothetical particles called axions, which are a primary dark matter candidate. The scientists, Richard Brito at the University of Lisbon in Portugal; Vitor Cardoso at the University of Lisbon and the Perimeter Institute for Theoretical Physics in Waterloo, Ontario, Canada; and Hirotada Okawa at Kyoto University and Waseda University, both in Japan, have published their paper on dark matter in stars in a recent issue of *Physical Review Letters*.

"Our work studies how dark matter piles up inside stars if the dark matter is composed of massive bosonic particles (axions are an example of such particles)," Brito told *Phys.org*. "Our results show that dark matter accretion by stars does not lead to gravitational collapse; instead it may give rise to characteristic vibrations in stars."

The researchers theoretically showed that, if numerous axions were to pile up inside normal stars, then the dark matter core would oscillate. The oscillating core would in turn cause the star's fluid to oscillate in tune with it at a specific frequency related to the star's mass, or at multiples of this frequency. For a typical axion mass, the oscillating stars would emit microwave radiation and might have observable effects.

"What oscillates is the fluid density and its pressure, but it's probably correct as well to say that the entire star is oscillating," Brito explained. "These are like sound waves propagating through the fluid, with a very specific frequency. Oscillations of this kind could, for example, lead to variations in the luminosity or in the temperature of the star, and these are quantities that we can measure directly.

"In fact, there is already a whole branch of physics called asteroseismology, which studies the internal structure of stars by observing their oscillation modes. This is very much like the way scientists study the internal structure of the Earth by looking at seismic waves. It is possible that the oscillations of a star driven by a dark matter core could also be observed using similar methods. Given the very specific frequencies at which these stars would vibrate, this could be a smoking gun for the presence of dark matter. Asteroseismology is still in its infancy but it will, almost certainly, become a very precise way of observing stars in the future."

In previous research on dark matter stars, it has often been assumed that stars accreting dark matter will continue to grow until they become so dense that they collapse into black holes. However, in the new study the physicists' simulations showed that these stars actually appear to be stable and do not become black holes. Their stability arises from a self-regulatory mechanism called "gravitational cooling" in which the stars eject mass to slow down and stop their growth before they approach the critical Chandrasekhar limit, the point at which they collapse into black holes.

As the scientists explain, the finding that dark matter stars are stable makes a surprising contribution to the research in this area.

"Although it was known for some time that dark matter can be accreted by stars and form dark matter cores at their center, those studies were all phenomenological," Brito said. "In addition, basically all these studies suggested that, if enough dark matter is accreted by a star, it will eventually trigger gravitational collapse and a black hole would form, eventually eating all the star.

"We set about checking these claims, using a rigorous fully relativistic framework, i.e., solving the full Einstein's equations. This is important if we want to understand how the dark matter core behaves for large densities. Well, it turns out that our results show that black hole formation can, in principle, be avoided by ejecting excessive mass: the dark matter core starts 'repelling' itself when it is too massive and compact, and is unable to grow past a certain threshold. This is, as far as we know, something that was ignored in previous works.

"The above results are quite generic. Because any self-gravitating massive bosonic field can form compact structures, any such putative dark matter component would lead to the kind of effects we discuss in our paper. In this sense it proposes another way to search for these kinds of particles that can be complementary to observations coming from cosmology, for example. Given the lack of information that we have about the nature of dark matter, we think that it might be worth the effort to further develop this subject."

The scientists hope that the results here may help guide future research by suggesting where to look for dark matter and what methods to use to detect it.

"We don't know much about dark matter," Brito said. "The only thing we do know is that all kinds of matter (be it regular matter or dark, invisible matter) fall in the same way in gravitational fields. This is Einstein's equivalence principle in action. Thus, dark matter also falls in the usual way. It seems therefore appropriate to look for effects of dark matter in regions where gravity is strong, like neutron stars, black holes, etc. We are now trying to understand how dark matter behaves generically in regions of strong gravity.

"At this precise moment, we are working on a long version of this letter. We want to understand in depth how the dark matter core grows for different kind of scenarios, and how viscosity in the star's material affects the development of the accretion process."

More information: Richard Brito, Vitor Cardoso, and Hirotada Okawa. "Accretion of dark matter by stars." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.115.111301, Also at arXiv:1508.04773 [gr-qc]