Mass limits of dark matter derived from 'strange' stars

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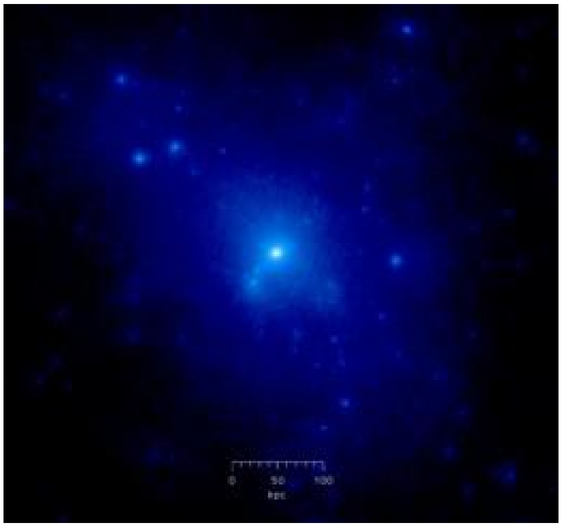

A simulated dark matter halo. Physicists have put a new limit on WIMP mass by investigating how WIMPs can convert neutron stars into strange stars. Image credit: Wikimedia Commons.

(PhysOrg.com) -- Much of the matter in our universe may be made of a type of dark matter called weakly interacting massive particles, better known as WIMPs. Although some scientists predict that these hypothetical particles possess many of the necessary properties to account for dark matter, so far scientists have not been able to make any definite predictions of their mass. Now, in a new study, physicists have derived a limit on the WIMP mass by calculating how these dark matter particles can transform neutron stars into stars made of strange quark matter, or "strange" stars.

The physicists, Dr. M. Angeles Perez-Garcia from the University of Salamanca in Salamanca, Spain, along with Dr. Joseph Silk of the University of Oxford and Dr. Jirina R. Stone of the University of Oxford and the University of Tennessee, have published their study in a recent issue of Physical Review Letters.

“We have proposed a mechanism to put an additional constraint on the WIMP mass based on the possibility of WIMP self-annihilation as a procedure to create strangelets in the interior of neutron stars, which could trigger a transition to a quark star,” Perez-Garcia told *PhysOrg.com*. “WIMP mass is an important quantity to know since WIMPS are considered to be constituents of dark matter. Dark matter is presently thought to form most of the matter in the universe. By knowing this value, we would be able to put another piece of fundamental information on our current knowledge of the building blocks of our universe and after that see, for example, how dark matter interacts with regular matter, how it is distributed spatially, etc.”

As dark matter particles, WIMPs are thought to be largely located in the halos of galaxies. Although galaxy halos are not visible, they contain most of a galaxy's mass in the form of the heavy WIMPs. In their study, the scientists focused on what happens when WIMPs from galactic halos are captured by neutron stars located deeper within the galaxy.

Neutron stars are known for their extreme density: although a typical neutron star has a radius of only 10 km, it has more mass than our Sun. Theories predict that neutron stars and black holes are gravitational accretors of dark matter. Some models even discuss that WIMPs could have formed the first stars in our universe, known as dark stars, powered by dark matter annihilation instead of nuclear fusion.

In their study, the scientists theoretically showed that, when a neutron star gravitationally captures nearby WIMPs, the WIMPs may trigger the conversion of the neutron star into a strange star. The conversion occurs as a result of the WIMPs seeding the neutron stars with long-lived lumps of strange quark matter, or strangelets. When WIMPs are captured in the neutron star's core, they self-annihilate, releasing energy in the process. The exact energy released depends on the properties of the WIMPs, such as the WIMPs' mass. At certain energy levels, the energy will partly convert into heat that causes thermal fluctuations, which in turn can “burn” the star's nucleons into quark bubbles that eventually become strangelets.

Some of these strangelets decay rapidly and have no effect on the neutron star. But if the strangelets have a high enough baryon number, they can live up to several days. Previous research has shown that it takes about 100 seconds to convert a neutron star into a strange star, a process that could potentially be triggered by long-lived strangelets.

By figuring out the minimum required baryon number and efficiency rate for a strangelet to trigger the conversion of a neutron star into a strange star, the scientists could calculate the parent WIMP mass as a function of this baryon number. In this relationship, the more massive the WIMPs are, the higher the conversion rate from neutron star to strange star.

As the scientists note, the predicted WIMP mass limits can be investigated with current observational and experimental searches. For example, observing a strange star and measuring simultaneously its mass and radius could provide more constraints on strangelets' properties. There are currently two NASA missions in preparation that have the objective to provide this information with much improved precision than currently available data. The Space Interferometry Mission (SIM Lite), which is under development, will accurately determine distances and directly map orbits of X-ray binaries. The NASA ESA JAXA IXO (International X-ray Observatory), which has a planned launch in 2021, will determine the radius and mass of several neutron stars to within several percent, providing a strong constraint on their composition. Also, terrestrial experiments at the Large Hadron Collider (LHC) and the Relativistic Heavy Ion Collider (RHIC) may be able to identify the formation of strangelets and further investigate their properties.

“Strangelets have been searched for so far in experiments like E864 and E896 at BNL in the US and NA52 at CERN,” said Perez-Garcia. “Currently, they are being searched for at RHIC in BNL and LHC at CERN. Their observation is difficult since we do not yet know their electrical charge nor their lifetime before they decay into other products. The proof for observation would be a large point-like signal in the zero-degree calorimeter (due to the large charge of these objects, they travel mostly straight when produced); there are some computational simulations of how this would look like.

“The strange stars have not been observed so far, and very useful information would be provided by current missions on X-ray satellites that measure luminosity of these objects (mostly in binary systems) to deduce mass and radius. In this way, we could have information of its interior composition through measuring an unusual small value of the radius of this star with a mass slightly bigger that one solar mass.”

Perez-Garcia, Silk, and Stone also predict that the neutron star conversion process could generate detectable gamma-ray bursts. In the future, the physicists hope to investigate whether WIMP annihilation inside neutron stars has other observable consequences, such as altering its temperature and rotation patterns.

More information: M. Angeles Perez-Garcia, Joseph Silk, and Jirina R. Stone. “Dark Matter, Neutron Stars, and Strange Quark Matter.”

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