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Axion clouds around neutron stars could reveal dark matter origins

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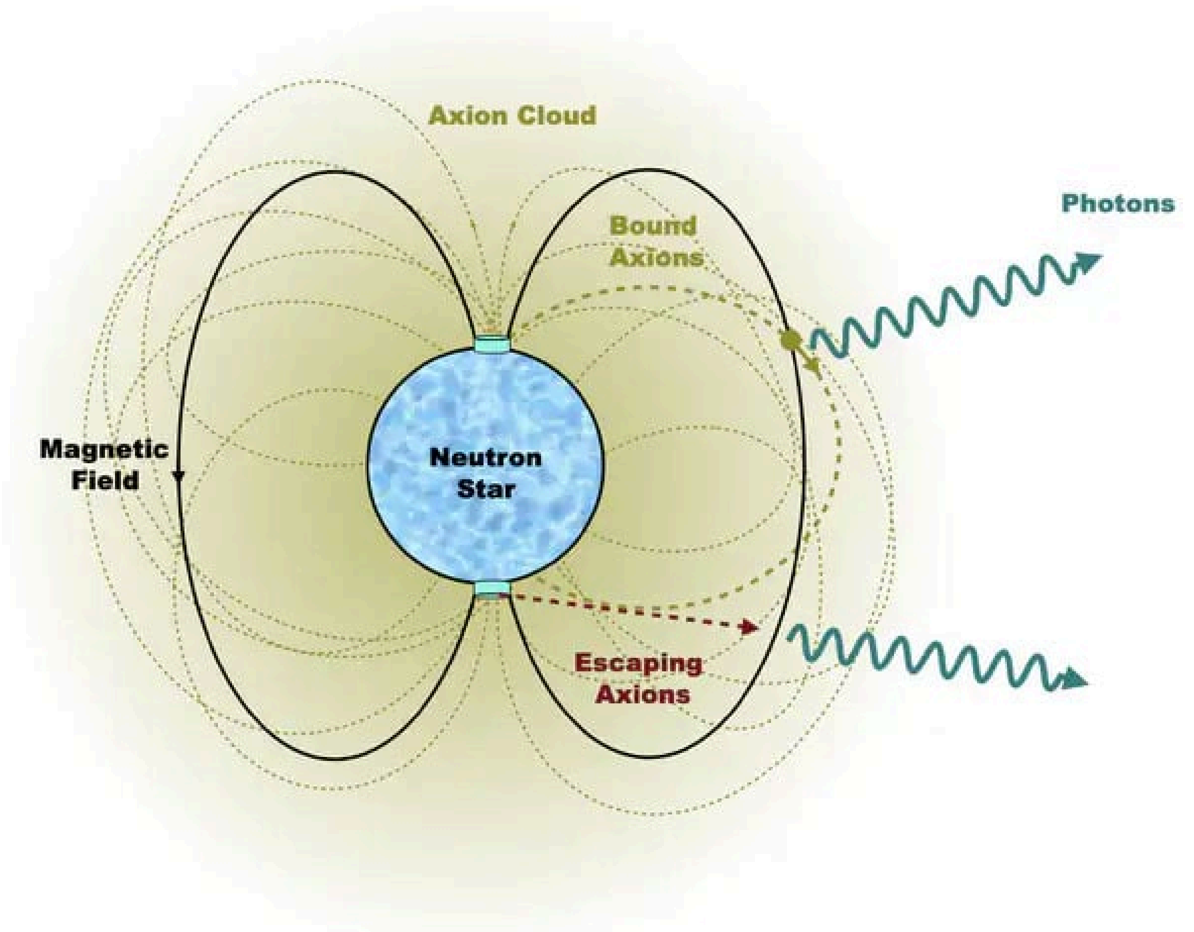

Cloudy with a chance of axions: An axion cloud around a neutron star. While some axions escape the star's gravitational pull, many remain bound to the star. Over a long period of time, a cloud of axions forms and interacts with the neutron star's strong magnetic field. This causes some axions to convert into radiofrequency photons that telescopes on Earth could detect. (Courtesy: University of Amsterdam)

Hypothetical particles called axions could form dense clouds around neutron stars – and if they do, they will give off signals that radio telescopes can detect, say researchers in the Netherlands, the UK and the US. Since axions are a possible candidate for the mysterious substance known as dark matter, this finding could bring us closer to understanding it.

Around 85% of the universe's mass consists of matter that appears "dark" to us. We can observe its gravitational effect on structures such as galaxies, but we cannot observe it directly. This is because dark matter hardly interacts with anything as far as we know, making it very difficult to detect. So far, searches for dark matter on Earth and in space have found no evidence for any of the various dark matter candidates.

The new research raises hopes that axions could be different. These neutral, bosonic particles are extremely light and hardly interact with ordinary matter. They get their name from a brand of soap, having been first proposed in the 1970s as a way of "cleaning up" a problem in quantum chromodynamics (QCD). More recently, astronomers have suggested they could clean up cosmology, too, by playing a role in the formation of galaxies in the early universe. They would also be a clean start for particle physics, providing evidence for new physics beyond the Standard Model.

Signature signals

But how can we detect axions if they are almost invisible to us? In the latest work, researchers at the University of Amsterdam, Princeton University and the University of Oxford showed that axions, if they exist, will be produced in large quantities at the polar regions of neutron stars. (Axions may also be components of dark matter "halos" believed to be present in the universe, but this study investigated axions produced by neutron stars themselves.) While many axions produced in this way will escape, some will be captured by the stars' strong gravitational field. Over millions of years, axions will therefore accumulate around neutron stars, forming a cloud dense enough to give off detectable signals.

To reach these conclusions, the researchers examined various axion cloud interaction mechanisms, including self-interaction, absorption by neutron star nuclei and electromagnetic interactions. They concluded that for most axion masses, it is the last mechanism – specifically, a process called resonant axion-photon mixing – that dominates. Notably, this mechanism should produce a stream of low-energy photons in the radiofrequency range.

The team also found that these radio emissions would be connected to four distinct phases of axion cloud evolution. These are a growth phase after the neutron star forms; a saturation phase during normal life; a magnetorotational decay phase towards the later stages of the star's existence; and finally a large burst of radio waves when the neutron star dies.

Turn on the radio

The researchers say that several large radio telescopes around the globe could play a role in detecting these radiofrequency signatures. Examples include the Low-Frequency Array (LOFAR) in the Netherlands; the Murchison Widefield Array in Australia; and the Green Bank Telescope in the US. To optimize the chances of picking up an axion signal, the collaboration recommends specific observation times, bandwidths and signal-to-noise ratios that these radio telescopes should adhere to. By following these guidelines, they say, the LOFAR setup alone could detect up to four events per year.

Dion Noordhuis, a PhD student at Amsterdam and first author of a *Physical Review X* paper on the research, acknowledges that there could be other observational signals beyond those explored in the paper. These will require further investigation, and he suggests that a full understanding will require complementary efforts from multiple branches of physics, including particle (astro)physics, plasma physics and observational radioastronomy. "This work thereby opens up a new, cross-disciplinary field with lots of opportunities for future research," he tells *Physics World*.

Sankarshana Srinivasan, an astrophysicist from the Ludwig Maximilian University in Munich, Germany, who was not involved in the research, agrees that the QCD axion is a well-motivated candidate for dark matter. The Amsterdam-Princeton-Oxford team's biggest achievement, he says, is to realize how axion clouds could enhance the signal, while the team's "state-of-the-art" modelling makes the work stand out. However, he also urges caution because all theories of axion-photon mixing around neutron stars make assumptions about the stars' magnetospheres, which are still poorly understood.

Martijn Boerkamp is a science writer based in the Netherlands