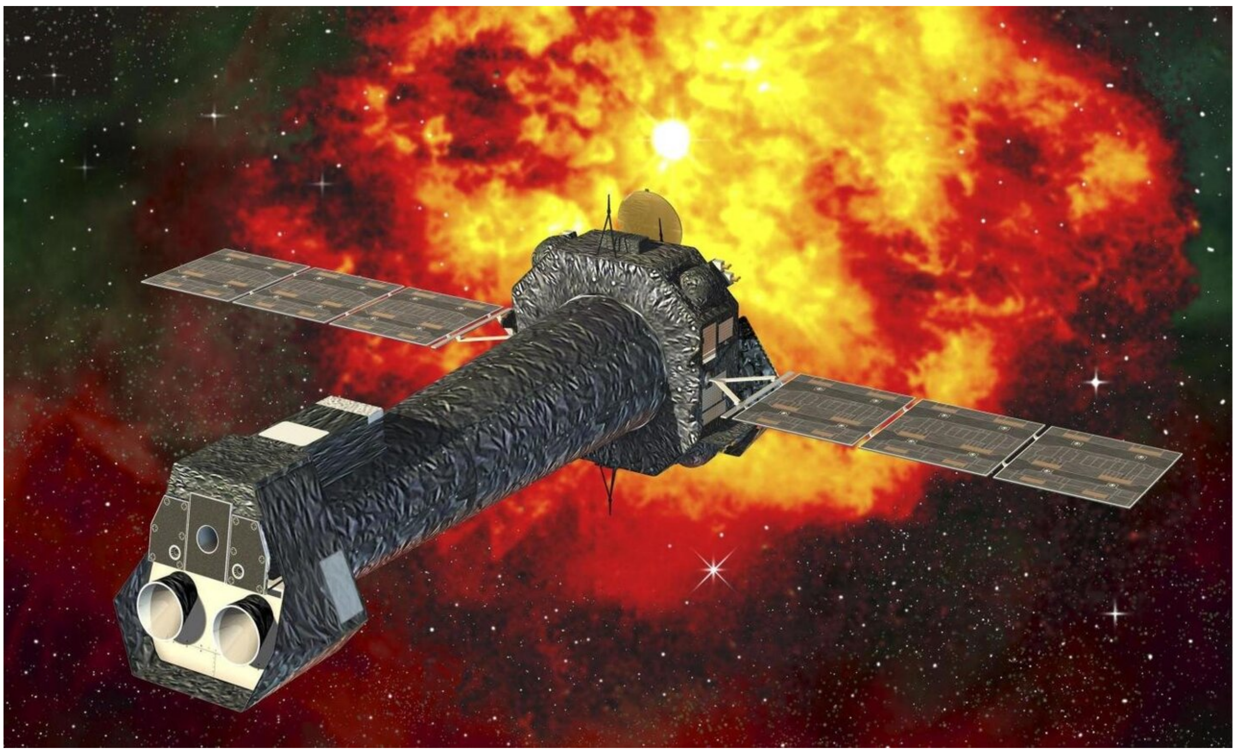
X-rays surrounding 'Magnificent 7' may be traces of sought-after particle

January 15 2021



An artistic rendering of the XMM-Newton (X-ray multi-mirror mission) space telescope. A study of archival data from the XMM-Newton and the Chandra X-ray space telescopes found evidence of high levels of X-ray emission from the nearby Magnificent Seven neutron stars, which may arise from the hypothetical particles known as axions. Credit: D. Ducros; ESA/XMM-Newton, CC BY-SA 3.0 IGO

A new study, led by a theoretical physicist at the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab), suggests that never-before-observed particles called axions may be the source of unexplained, high-energy X-ray emissions surrounding a group of neutron stars.

First theorized in the 1970s as part of a solution to a fundamental particle physics problem, axions are expected to be produced at the core of stars, and to convert into particles of light, called photons, in the presence of a magnetic field.

Axions may also make up dark matter—the mysterious stuff that accounts for an estimated 85 percent of the total mass of the universe, yet we have so far only seen its gravitational effects on ordinary matter. Even if the X-ray excess turns out not to be axions or dark matter, it could still reveal new physics.

A collection of neutron stars, known as the Magnificent 7, provided an excellent test bed for the possible presence of axions, as these stars possess powerful magnetic fields, are relatively nearby—within hundreds of light-years—and were only expected to produce low-energy X-rays and ultraviolet light.

"They are known to be very 'boring,'" and in this case it's a good thing, said Benjamin Safdi, a Divisional Fellow in the Berkeley Lab Physics Division theory group who led a study, published Jan. 12 in the journal *Physical Review Letters*, detailing the axion explanation for the excess.

Christopher Dessert, a Berkeley Lab Physics Division affiliate, contributed heavily to the study, which also had participation by researchers at UC Berkeley, the University of Michigan, Princeton University, and the University of Minnesota.

If the neutron stars were of a type known as pulsars, they would have an active surface giving off radiation at different wavelengths. This radiation would show up across the electromagnetic spectrum, Safdi noted, and could drown out this X-ray signature that the researchers had found, or would produce radio-frequency signals. But the Magnificent 7 are not pulsars, and no such radio signal was detected. Other common astrophysical explanations don't seem to hold up to the observations either, Safdi said.

If the X-ray excess detected around the Magnificent 7 is generated from an object or objects hiding out behind the neutron stars, that likely would have shown up in the datasets that researchers are using from two space satellites: the European Space Agency's XMM-Newton and NASA's Chandra X-ray telescopes.

Safdi and collaborators say it's still quite possible that a new, non-axion explanation arises to account for the observed X-ray excess, though they remain hopeful that such an explanation will lie outside of the Standard Model of particle physics, and that new ground- and space-based experiments will confirm the origin of the high-energy X-ray signal.

"We are pretty confident this excess exists, and very confident there's something new among this excess," Safdi said. "If we were 100% sure that what we are seeing is a new particle, that would be huge. That would be revolutionary in physics." Even if the discovery turns out not to be associated with a new particle or dark matter, he said, "It would tell us so much more about our universe, and there would be a lot to learn."

Raymond Co, a University of Minnesota postdoctoral researcher who collaborated in the study, said, "We're not claiming that we've made the discovery of the axion yet, but we're saying that the extra X-ray photons can be explained by axions. It is an exciting discovery of the excess in the X-ray photons, and it's an exciting possibility that's already consistent with our interpretation of axions."

If axions exist, they would be expected to behave much like neutrinos in a star, as both would have very slight masses and interact only very rarely and weakly with other matter. They could be produced in abundance in the interior of stars. Uncharged particles called neutrons move around within neutron stars, occasionally interacting by scattering off of one another and releasing a neutrino or possibly an axion. The neutrino-emitting process is the dominant way that neutron stars cool over time.

Like neutrinos, the axions would be able to travel outside of the star. The incredibly strong magnetic field surrounding the Magnificent 7 stars—billions of times stronger than magnetic fields that can be produced on Earth—could cause exiting axions to convert into light.

Neutron stars are incredibly exotic objects, and Safdi noted that a lot of modeling, data analysis, and theoretical work went into the latest study. Researchers have heavily used a bank of supercomputers known as the Lawrencium Cluster at Berkeley Lab in the latest work.

Some of this work had been conducted at the University of Michigan, where Safdi previously worked. "Without the high-performance supercomputing work at Michigan and Berkeley, none of this would have been possible," he said.

"There is a lot of data processing and data analysis that went into this. You have to model the interior of a neutron star in order to predict how many axions should be produced inside of that star."

Safdi noted that as a next step in this research, white dwarf stars would be a prime place to search for axions because they also have very strong magnetic fields, and are expected to be "X-ray-free environments."

"This starts to be pretty compelling that this is something beyond the Standard Model if we see an X-ray excess there, too," he said.

Researchers could also enlist another X-ray space telescope, called NuStar, to help solve the X-ray excess mystery.

Safdi said he is also excited about ground-based experiments such as CAST at CERN, which operates as a solar telescope to detect axions converted into X-rays by a strong magnet, and ALPS II in Germany, which would use a powerful magnetic field to cause axions to transform into particles of light on one side of a barrier as laser light strikes the other side of the barrier.

Axions have received more attention as a succession of experiments has failed to turn up signs of the WIMP (weakly interacting massive particle), another promising dark matter candidate. And the axion picture is not so straightforward—it could actually be a family album.

There could be hundreds of axion-like particles, or ALPs, that make up dark matter, and string theory—a candidate theory for describing the forces of the universe—holds open the possible existence of many types of ALPs.

More information: Malte Buschmann et al, Axion Emission Can Explain a New Hard X-Ray Excess from Nearby Isolated Neutron Stars, *Physical Review Letters* (2021). DOI: 10.1103/PhysRevLett.126.021102

Provided by Lawrence Berkeley National Laboratory

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