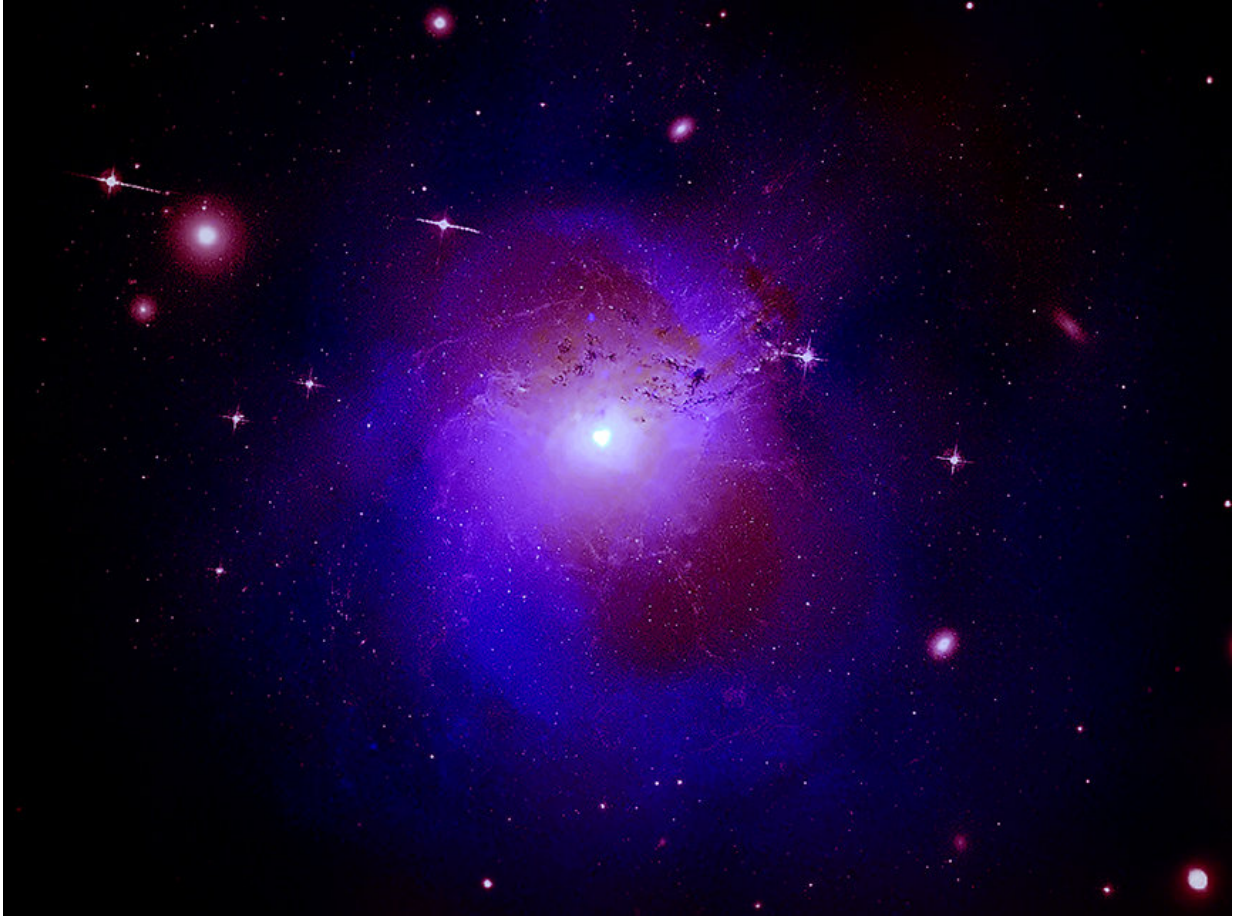


A new twist in the dark matter tale

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Credit: X-ray: NASA/CXO/Oxford University/J. Conlon et al. Radio: NRAO/AUI/NSF/Univ. of Montreal/Gendron-Marsolais et al. Optical: NASA/ESA/IOA/A. Fabian et al.; DSS

An innovative interpretation of X-ray data from a cluster of galaxies

could help scientists fulfill a quest they have been on for decades: determining the nature of dark matter.

The finding involves a new explanation for a set of results made with NASA's Chandra X-ray Observatory, ESA's XMM-Newton and Hitomi, a Japanese-led X-ray telescope. If confirmed with future observations, this may represent a major step forward in understanding the nature of the mysterious, invisible substance that makes up about 85% of matter in the universe.

"We expect that this result will either be hugely important or a total dud," said Joseph Conlon of Oxford University who led the new study. "I don't think there is a halfway point when you are looking for answers to one of the biggest questions in science."

The story of this work started in 2014 when a team of astronomers led by Esra Bulbul (Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass.) found a spike of intensity at a very specific [energy](#) in Chandra and XMM-Newton observations of the hot gas in the Perseus galaxy [cluster](#).

This spike, or [emission](#) line, is at an energy of 3.5 kiloelectron volts (keV). The intensity of the 3.5 keV emission line is very difficult if not impossible to explain in terms of previously observed or predicted features from astronomical objects, and therefore a [dark matter](#) origin was suggested. Bulbul and colleagues also reported the existence of the 3.5 keV line in a study of 73 other galaxy clusters using XMM-Newton.

The plot of this dark matter tale thickened when only a week after Bulbul's team submitted their paper a different group, led by Alexey Boyarsky of Leiden University in the Netherlands, reported evidence for an emission line at 3.5 keV in XMM-Newton observations of the galaxy M31 and the outskirts of the Perseus cluster, confirming the Bulbul et al.

result.

However, these two results were controversial, with other astronomers later detecting the 3.5 keV line when observing other objects, and some failing to detect it.

The debate seemed to be resolved in 2016 when Hitomi especially designed to observe detailed features such as line emission in the X-ray spectra of cosmic sources, failed to detect the 3.5 keV line in the Perseus cluster.

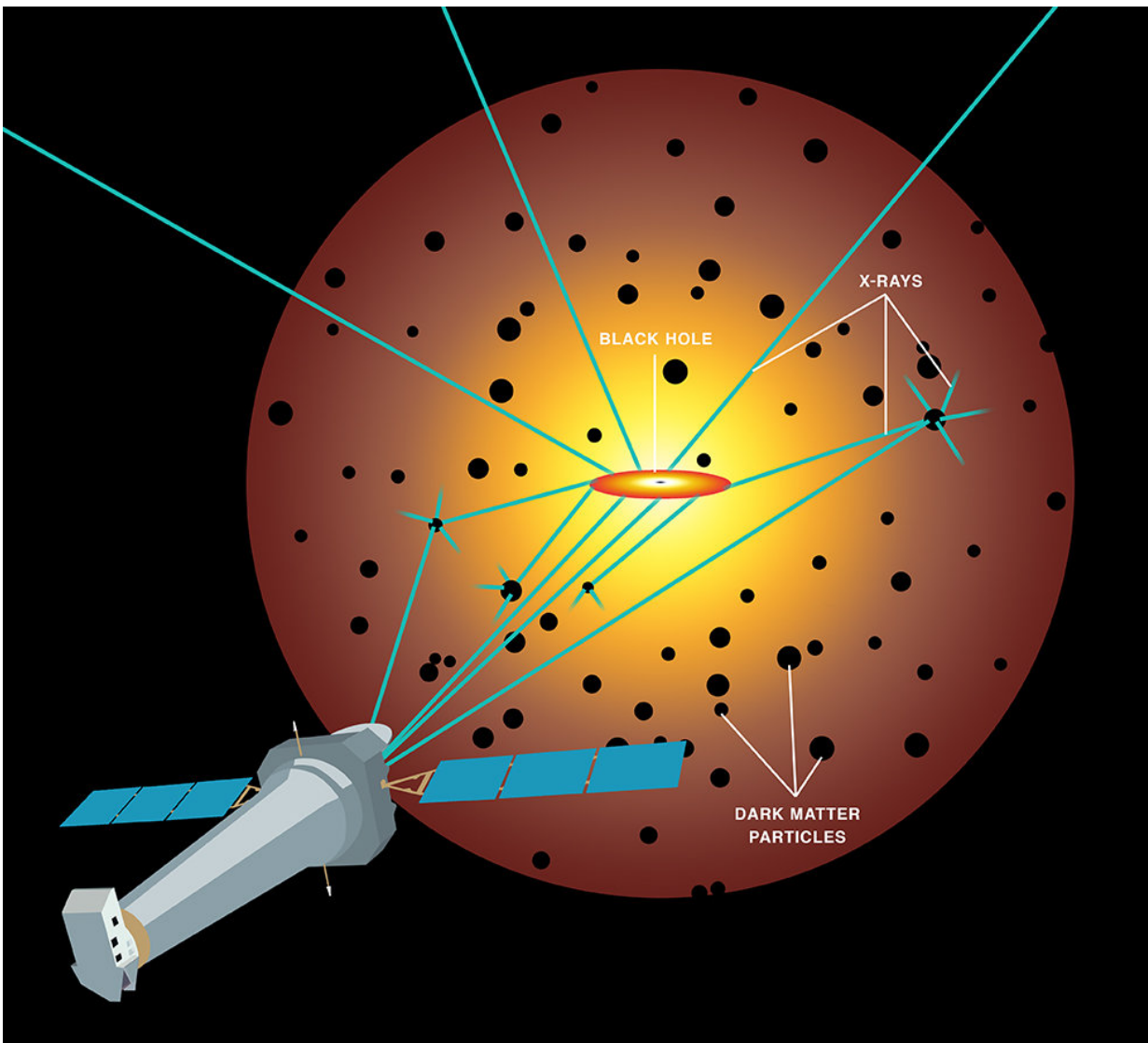
"One might think that when Hitomi didn't see the 3.5 keV line that we would have just thrown in the towel for this line of investigation," said co-author Francesca Day, also from Oxford. "On the contrary, this is where, like in any good story, an interesting plot twist occurred."

Conlon and colleagues noted that the Hitomi telescope had much fuzzier images than Chandra, so its data on the Perseus cluster are actually comprised of a mixture of the X-ray signals from two sources: a diffuse component of hot gas enveloping the large galaxy in the center of the cluster and X-ray emission from near the supermassive black hole in this galaxy. The sharper vision of Chandra can separate the contribution from the two regions. Capitalizing on this, Bulbul et al. isolated the X-ray signal from the hot gas by removing point sources from their analysis, including X-rays from material near the [supermassive black hole](#).

In order to test whether this difference mattered, the Oxford team re-analyzed Chandra data from close to the black hole at the center of the Perseus cluster taken in 2009. They found something surprising: evidence for a deficit rather than a surplus of X-rays at 3.5 keV. This suggests that something in Perseus is absorbing X-rays at this exact energy. When the researchers simulated the Hitomi spectrum by adding

this absorption line to the hot gas' emission line seen with Chandra and XMM-Newton, they found no evidence in the summed spectrum for either absorption or emission of X-rays at 3.5 keV, consistent with the Hitomi observations.

The challenge is to explain this behavior: detecting absorption of X-ray light when observing the black hole and emission of X-ray light at the same energy when looking at the hot gas at larger angles away from the black hole.



The latest work shows that absorption of X-rays at an energy of 3.5 keV is detected when observing the region surrounding the supermassive black hole at the center of Perseus. This suggests that dark matter particles in the cluster are both absorbing and emitting X-rays. If the new model turns out to be correct, it could provide a path for scientists to one day identify the true nature of dark matter. For next steps, astronomers will need further observations of the Perseus cluster and others like it with current X-ray telescopes and those being planned for the next decade and beyond. Credit: NASA/CXC/M. Weiss

In fact, such behavior is well known to astronomers who study stars and clouds of gas with optical telescopes. Light from a star surrounded by a cloud of gas often shows absorption lines produced when starlight of a specific energy is absorbed by atoms in the gas cloud. The absorption kicks the atoms from a low to a high energy state. The atom quickly drops back to the low energy state with the emission of light of a specific energy, but the light is re-emitted in all directions, producing a net loss of light at the specific energy—an absorption line—in the observed spectrum of the star. In contrast, an observation of a cloud in a direction away from the star would detect only the re-emitted, or fluorescent light at a specific energy, which would show up as an emission line.

The Oxford team suggests in their report that dark matter particles may be like atoms in having two energy states separated by 3.5 keV. If so, it could be possible to observe an absorption line at 3.5 keV when observing at angles close to the direction of the black hole, and an [emission line](#) when looking at the cluster hot gas at large angles away from the black hole.

"This is not a simple picture to paint, but it's possible that we've found a way to both explain the unusual X-ray signals coming from Perseus and uncover a hint about what dark matter actually is," said co-author

Nicholas Jennings, also of Oxford.

To write the next chapter of this story, astronomers will need further observations of the Perseus cluster and others like it. For example, more data is needed to confirm the reality of the dip and to exclude a more mundane possibility, namely that we have a combination of an unexpected instrumental effect and a statistically unlikely dip in X-rays at an energy of 3.5 keV. Chandra, XMM-Newton and future X-ray missions will continue to observe clusters to address the dark matter mystery.

A paper describing these results was published in *Physical Review D* on December 19, 2017 and a preprint is [available online](#).

More information: Consistency of Hitomi, XMM-Newton and Chandra 3.5 keV data from Perseus, arXiv:1608.01684 [astro-ph.HE] arxiv.org/abs/1608.01684

Provided by Chandra X-ray Center

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