Detecting Axion-Like Dark Matter with the JWST

Measurements made by the JWST observatory could be used to detect photons emitted by the decay of a hypothetical form of dark matter particle known as the axion.

By **Elisa Todarello**

The standard model of particle physics classifies all known elementary particles and describes how they interact. Its predictions have been confirmed with extremely high precision by all laboratory experiments carried out so far. However, the standard model cannot explain everything we observe, especially when we look at beyond-Earth observations of the Universe. In particular, we know from many independent astrophysical observations that 85% of the matter in the Universe is not made of the particles that appear in the standard model. Now two independent teams have proposed using the JWST observatory to detect photons that might be produced by axions, hypothetical particles that could make up this missing matter [**1**, **2**].

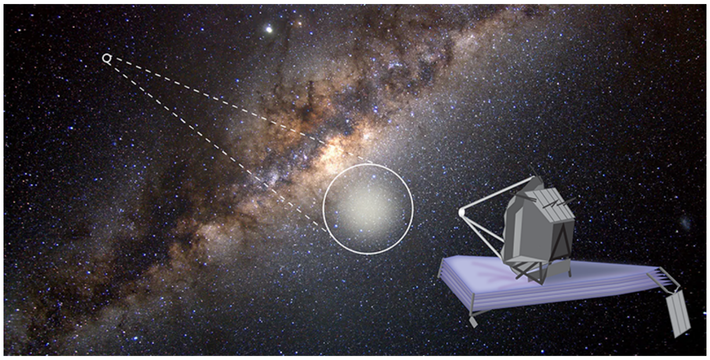

Figure 1: Hypothetical dark matter axions in the Milky Way's dark halo could decay into photons that might be detectable with the JWST observatory.
Credit: APS/Carin Cain; NASA

One of the first observations of dark matter's presence was accomplished by physicist Vera Rubin in the 1970s [**3**]. She found that stars and gas in the outskirts of galaxies were orbiting faster than expected based on the amount of visible matter. The results suggested that there must be a massive dark halo surrounding the luminous matter, providing the gravitational pull necessary to keep stars and gas in orbit.

Despite being compelling, none of the evidence supporting the existence of dark matter tells us what this elusive material is made of. Physicists have put forward many creative ideas. One particularly attractive possibility is that dark matter is made of a new fundamental particle called the quantum chromodynamics axion [**4**–**6**]. The existence of these particles would also explain why the strong nuclear force unexpectedly preserves so-called charge–parity symmetry. Other kinds of axions, called axion-like particles, have also been proposed, but they would not solve the strong-force mystery.

The interaction of axions with light is predicted to be extremely feeble, as it should be for any dark matter candidate. Nevertheless, axions and axion-like particles would produce light at a very low rate through a process called decay, where the axion transforms into a pair of photons. The likelihood of this happening depends on how strongly axions and photons interact, which is quantified by a parameter called the axion–photon coupling strength. The axion–photon coupling strength is so small that most axion particles should take longer than the current age of the Universe to decay. However, because each single decay happens randomly, a tiny fraction of axions should decay today. In addition, if dark matter is made of axions, there must be an immense number of them, so some of the photons they produce could be detectable with telescopes such as the JWST (Fig. **1**).

Ideal observational targets contain a lot of dark matter and little luminous matter. Ryan Janish and Elena Pinetti of Fermi National Accelerator Laboratory in Illinois [**1**] and Sandip Roy of Princeton University and colleagues [**2**] all consider the dark halo of our own Galaxy. In the Milky Way, dark matter particles move with speeds of the order of 200 km/s, a small fraction of the speed of light. This low speed implies that the typical kinetic energy of the particles is much smaller than their rest energy, the energy stored in the form of mass. When a particle decays into two photons, each photon carries away half of the particle's total energy, which, in this case, is very close to half the particle's mass. Moreover, if all dark matter particles have the same mass, photons from the decay of different particles will have the same energy. Owing to these two factors, the signal of any decaying axion should be a narrow spectral line centered at an energy equal to half the axion's mass. Depending on the unknown value of the mass, the spectral line could be detectable with a telescope.

The JWST is the state-of-the-art telescope for deep-infrared observations, with unprecedented capabilities for detecting extremely faint objects. Janish and Pinetti and Roy and colleagues consider two scientific instruments on board the JWST: the Near-Infrared Spectrograph (NIRSpec) and the Mid-Infrared Instrument (MIRI). Both instruments include a spectrograph capable of accurately distinguishing light of different energies, making them ideal tools for searching for a spectral line.

Although a search for axion dark matter is not among the main science goals of the JWST observatory, extensive data relevant to such a search should be available at the end of the JWST mission. When astronomers observe a target, such as a faraway galaxy, they need to know what fraction of the light received comes from the object of interest and how much is due to backgrounds and foregrounds. For observations made from space, the main foreground at infrared wavelengths comes from sunlight scattered by interplanetary dust. A reliable way to measure, and then subtract, this signal—as well as other diffuse emissions—is to point the telescope slightly away from the main target, toward a region with no bright sources. Such observations are called blank-sky observations. Both NIRSpec and MIRI can be operated in a mode called the observing integral field unit (IFU) to make these blank-sky observations. The IFU measures a spectrum for each pixel. If the main target is a compact source, pixels neighboring those of the source can be used as a blank sky. Blank-sky observations are well suited to search for the incredibly faint emission from the dark halo because they contain no bright sources. In addition, since we are immersed in the dark halo, all blank-sky observations probe the proposed signal from dark matter decay.

Roy and colleagues estimate that, after 10 years of operation, the NIRSpec and the MIRI should have made months of blank-sky observations in the IFU mode. Thanks to these data, the researchers predict it will be possible to discover or exclude axion dark matter with masses from 0.18 to 2.6 eV and with axion–photon coupling strengths up to a factor of 10 smaller than those currently excluded by other methods [**7**]. Meanwhile, Janish and Pinetti explore two NIRSpec observations that are already available. The absence of a spectral line above statistical fluctuations allowed the duo to exclude the existence of axion particles with masses in the range 0.8–2.5 eV and coupling strengths about a factor of 2 below current exclusion limits.

Both studies point out the potential of the JWST observatory in searching for dark matter and possibly solving the mystery of its nature. At the end of the JWST mission, it should be possible to probe axion–photon coupling strengths to up to a factor of 10 below the current limits. Importantly, this achievement will be possible without a dedicated observational campaign, using blank-sky observations originally intended for background and foreground subtraction.

Elisa Todarello: School of Physics and Astronomy, University of Nottingham, Nottingham, UK

REFERENCES

1. R. Janish and E. Pinetti, "Hunting dark matter lines in the infrared background with the James Webb Space Telescope," **Phys. Rev. Lett. (2024).**
2. S. Roy *et al.*, "Sensitivity of JWST to eV-scale decaying axion dark matter," **Phys. Rev. Lett. (2024).**
3. V. C. Rubin and W. K. Ford, Jr., "Rotation of the Andromeda Nebula from a spectroscopic survey of emission regions,"

Astrophys. J. 159, 379 (1970).

4. R. D. Peccei and H. R. Quinn, “*CP* Conservation in the presence of pseudoparticles,” **Phys. Rev. Lett. 38, 1440 (1977).**
5. S. Weinberg, “A new light boson?” **Phys. Rev. Lett. 40, 223 (1978).**
6. F. Wilczek, “Problem of strong *P* and *T* invariance in the presence of instantons,” **Phys. Rev. Lett. 40, 279 (1978).**
7. A. Ayala *et al.*, “Revisiting the bound on axion-photon coupling from globular clusters,” **Phys. Rev. Lett. 113, 191302 (2014).**