# Ultralight ALP dark matter and 21 cm absorption signals in new physics

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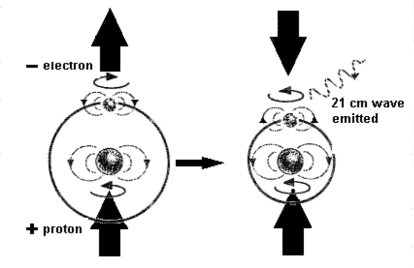
Friday 25 October 2024 at 16:30 P.M.

**The 7th International Conference on Particle Physics and Astrophysics (ICPPA-2024)**

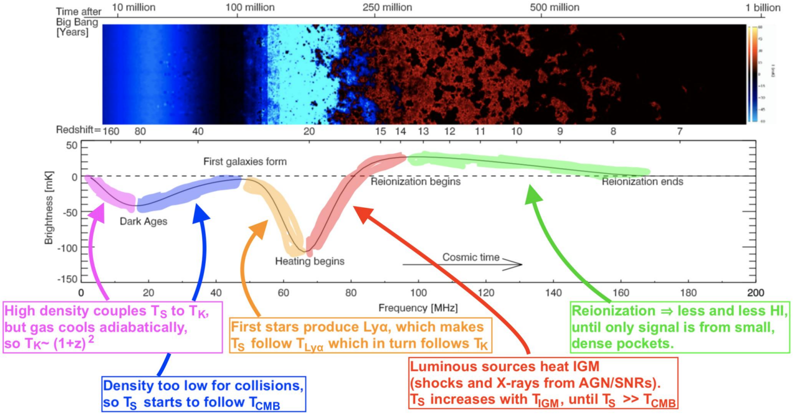
Gravitation and cosmology

# 21 centimeter Hydrogen line



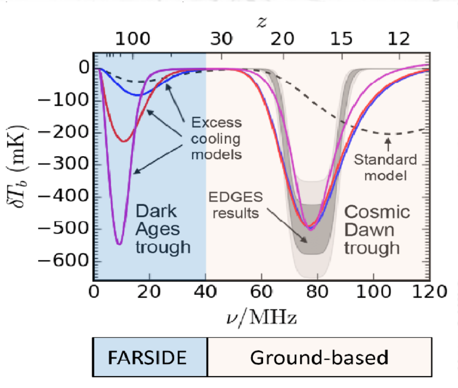

A shift in the energy state of isolated, electrically neutral hydrogen atoms produces the hydrogen line, also known as the 21 centimeter line or the H I line. A spin-flip transition occurs, where the electron's spin aligns with the opposite direction of the proton's. This is a quantum state transition between the hydrogen 1 s ground state's two hyperfine levels. This line is being produced by electromagnetic radiation with a frequency of 1420.405751768(2) MHz (1.42 GHz), or a wavelength of 21.106114054160(30) cm in a vacuum. With a mean lifetime of about 11 million years in the excited state and a low transition rate of $2.9 \times 10^{-15}$ s$^{-1}$, this transition is severely prohibited.

# 21 centimeter Cosmology



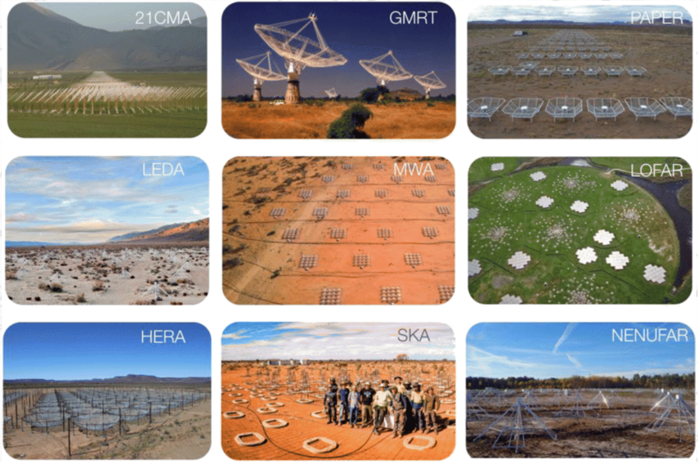

The line is significant in Big Bang cosmology as it provides the sole method to investigate the cosmological "dark ages" from recombination, when stable hydrogen atoms initially created, to reionization. Considering the redshift, this line will be detected at frequencies ranging from 200 MHz to approximately 15 MHz on Earth.

# 21 centimeter Cosmology



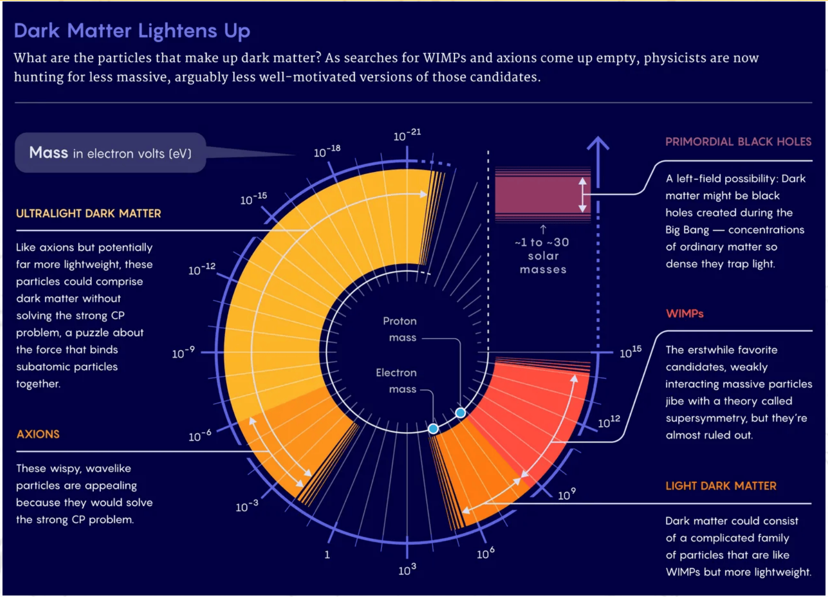

There are two possible uses for it. First, it can theoretically give a very accurate image of the matter power spectrum in the post-recombination phase by mapping the intensity of redshifted 21-centimeter light. Second, because neutral hydrogen ionized by star or quasar radiation will show up as holes in the 21 cm background, it can give an image of how the universe was re-ionized.

# 21 centimeter Experiments




In no specific sequence, the panel of 21-cm signal studies, both planned and ongoing (PAPER is decommissioned), focuses primarily on investigating the late Cosmic Dawn ($z < 25$) and the Epoch of Reionization ($z \sim 6 - 10$).

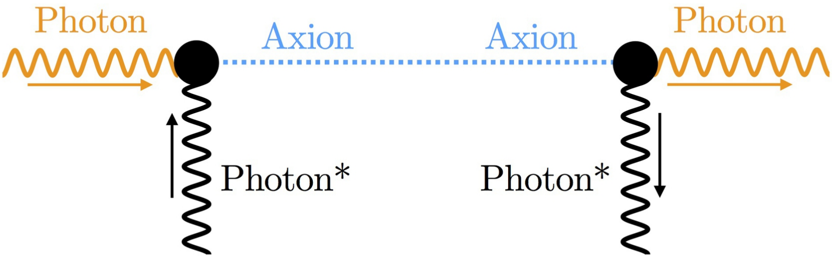
# Dark matter candidates



# Axion

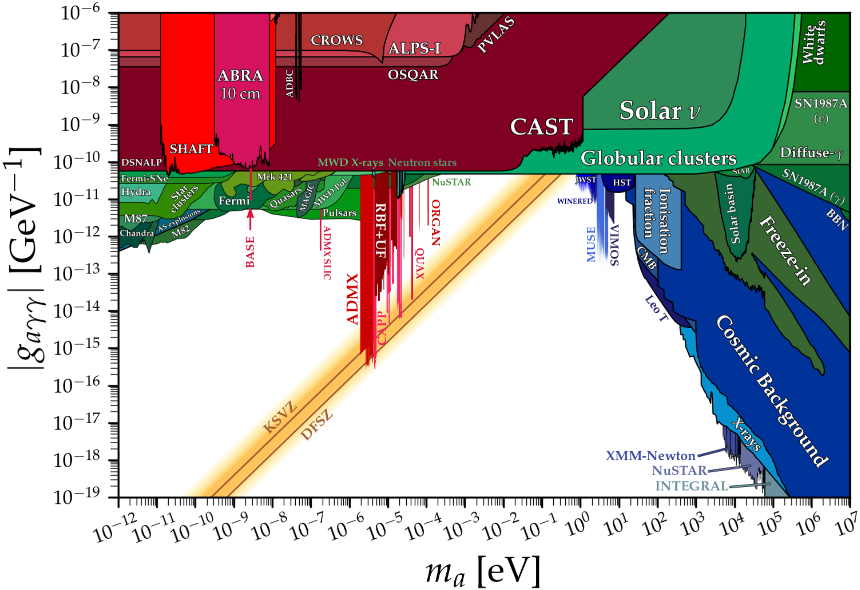
- Axions are hypothesized elementary particles that would resolve a troublesome exception to a rule regarding so-called CP symmetry if they were real.
- Additionally, its presence may help solve another puzzling scientific riddle: dark matter, the unseen extra material that keeps galaxies together.
- The aggravating thing is that when quarks are confined in groups by the strong force, such as inside protons and neutrons, we do not observe the CP violation.
- Physicists Roberto Peccei and Helen Quinn developed a solution in 1977 that would only introduce a new type of field to explain the difference.
- In an attempt to tidy up their mess, they gave it the humorous moniker of an axion, which is derived from laundry detergent.
- Nothing tangible has been discovered, despite decades of searching for particles that resemble axions.
- Given their excellent match, the results of an experiment in 2020 named XENON1T are enticing to interpret as axions.
- An unexpected glimmer of distant darkness seen by the New Horizons probe in 2022 may also be explained by the glow of axions in magnetic fields. (Phys.Rev.Lett. 129, 231301)

# Axion

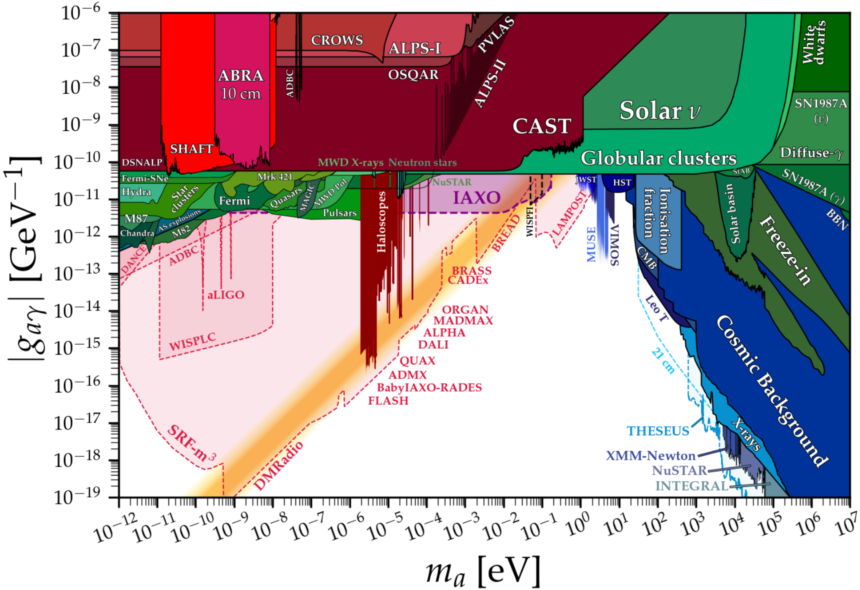



One approach is to search for particles that, as they move through a magnetic field, transform into photons. Some experiments continue to raise the potential of this phenomenon, whereas others have found no evidence of it.

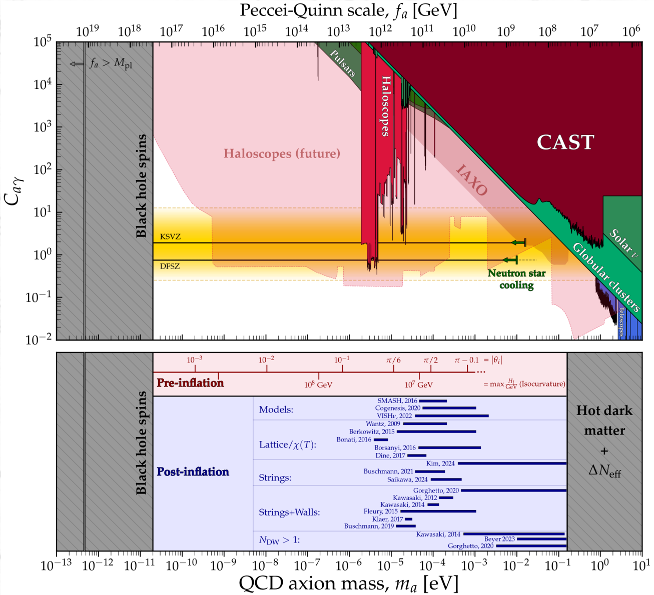
# Axion-photon coupling



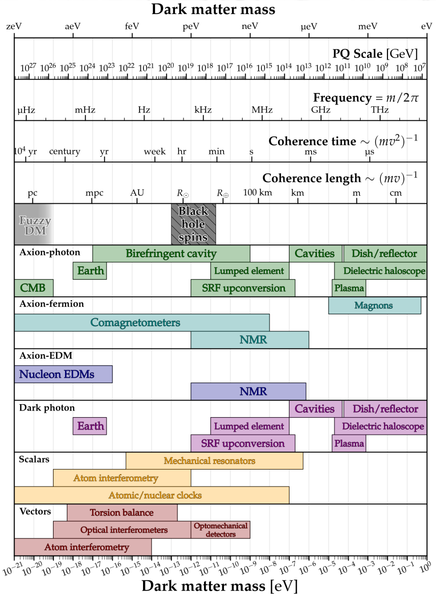
# Axion-photon coupling



# Axion DM predictions



# Dark matter cheatsheet

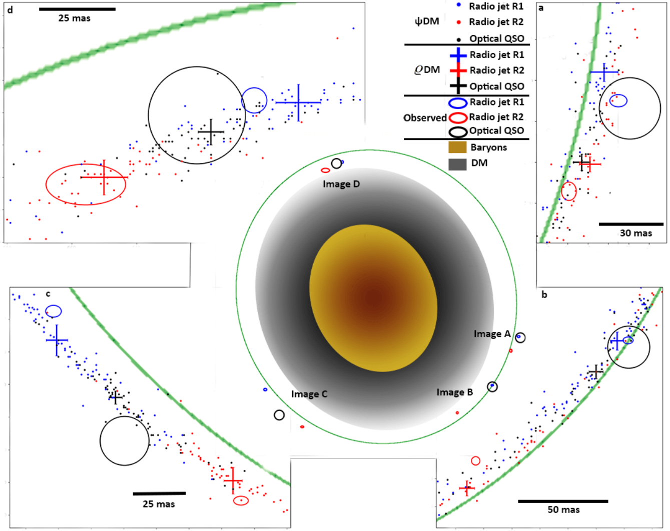


# Ultralight dark matter

- The ultralight dark matter mass (ULDM), which has been proposed in numerous references, is theoretically feasible and can have a very small mass ($m \sim 10^{-23}$ eV).
- Astrophysical evidence for $< 10^{-22}$ eV:

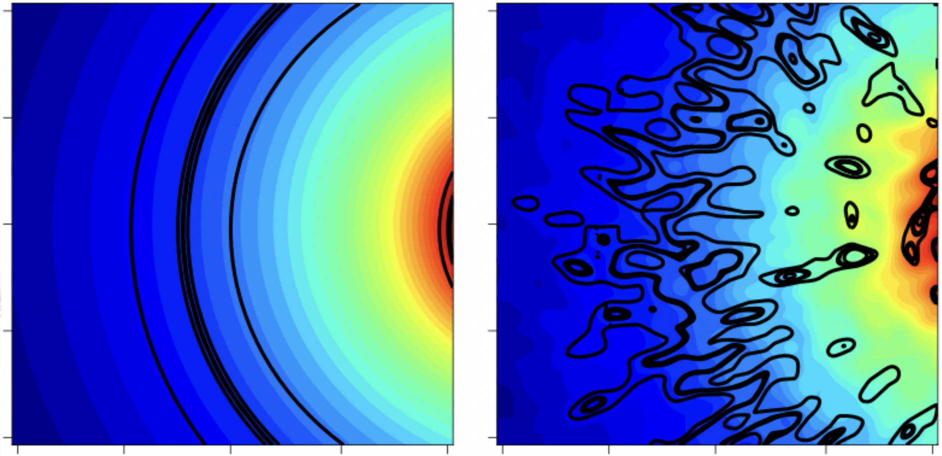
  *Einstein rings modulated by wavelike dark matter from anomalies in gravitationally lensed images,*
  *Alfred Amruth et. al,*
  *Nature Astronomy,* **7**, *736–747 (2023)*.
- Typical mass range interesting for us $[10^{-33} - 10^{-23}$ eV$]$.

# ULDM $10^{-22}$ eV, Nature Astronomy, **7**, 736–747 (2023)



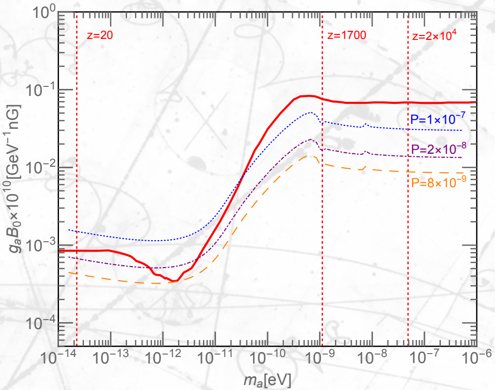

$\psi$DM versus $\varrho$DM model predictions for HS 0810+2554.

# ULDM $10^{-22}$ eV, Simulation



WIMP-based dark matter, modeled at left, leads to a smooth distribution from high (red) to low (blue) as you move farther from a galaxy's core.
With axions (right), quantum interference creates a far more irregular pattern.

# Cold dark matter ALPs make thermal contact with baryons




Under the influence of the primordial black hole or intergalactic magnetic fields, the dark radiation composed of ALPs can resonantly transform into photons, significantly heating up the radiation in the frequency range relevant for the 21 cm tests. arXiv: 1804.10378

# Both heating and cooling

- However, it is extremely vulnerable to further heating or cooling. A deeper depth of absorption line is produced by a model with more cooling. Particularly, models with decaying or self-annihilating dark matter experience heating, while models with dark matter whose particles interact with baryonic matter via the weak Coulomb-like force experience cooling. The redshifted 21 cm absorption line becomes shallow or becomes an emission line as a result of heating baryonic materials.
- Simultaneously, under the influence of the primordial black hole or intergalactic magnetic fields, the dark radiation composed of ALPs can resonantly transform into photons, significantly heating up the radiation in the frequency range relevant for the 21 cm tests.