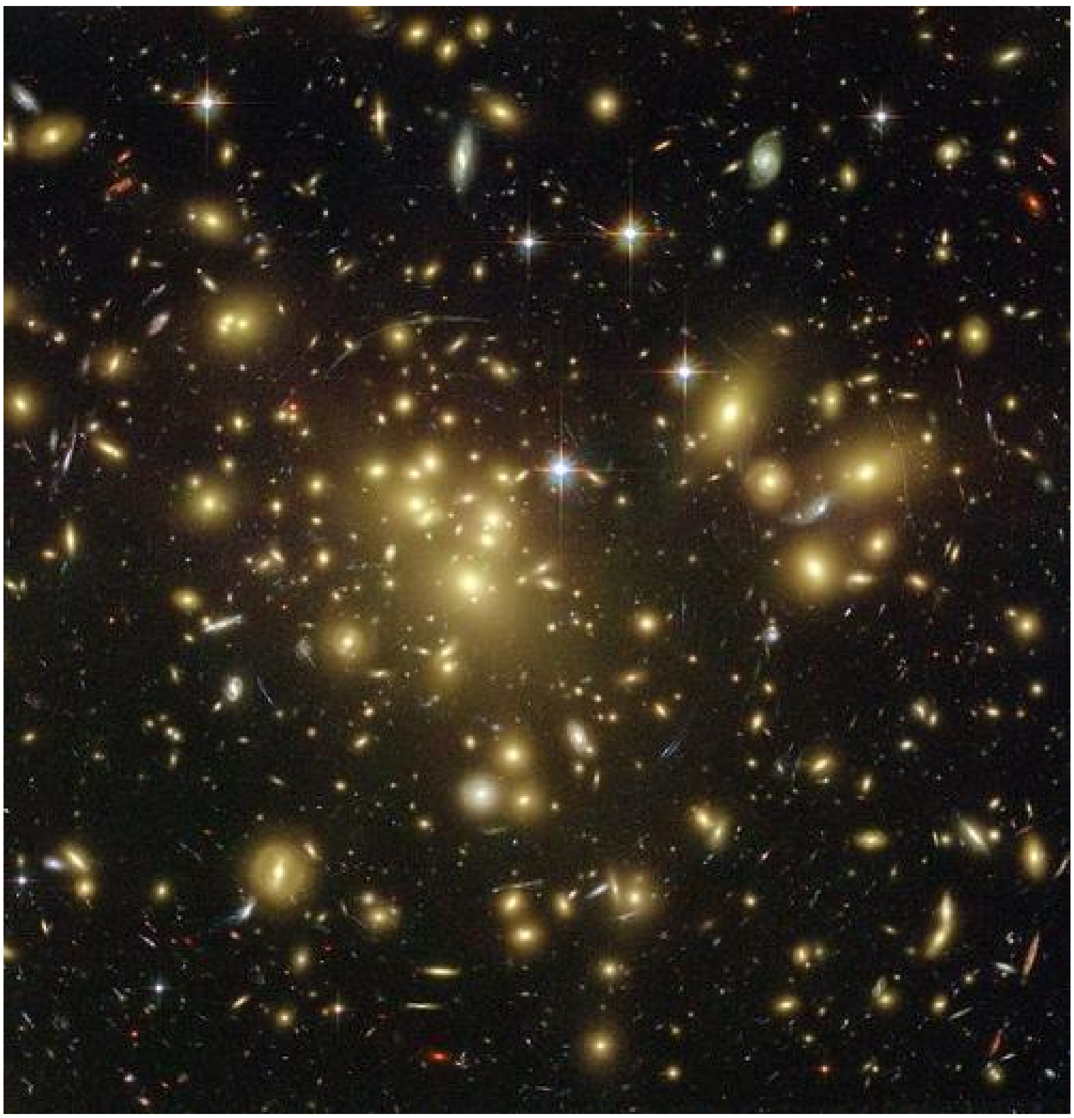
Superconductors could detect superlight dark matter

February 9 2016, by Lisa Zyga



A massive cluster of yellowish galaxies, seemingly caught in a red and blue spider web of eerily distorted background galaxies, makes for a spellbinding picture from the new Advanced Camera for Surveys aboard NASA's Hubble

Space Telescope. To make this unprecedented image of the cosmos, Hubble peered straight through the center of one of the most massive galaxy clusters known, called Abell 1689. The gravity of the cluster's trillion stars — plus dark matter — acts as a 2-million-light-year-wide lens in space. This gravitational lens bends and magnifies the light of the galaxies located far behind it. Some of the faintest objects in the picture are probably over 13 billion light-years away (redshift value 6). Strong gravitational lensing as observed by the Hubble Space Telescope in Abell 1689 indicates the presence of dark matter. Credit: NASA, N. Benitez (JHU), T. Broadhurst (Racah Institute of Physics/The Hebrew University), H. Ford (JHU), M. Clampin (STScI),G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA

(Phys.org)—Many experiments are currently searching for dark matter—the invisible substance that scientists know exists only from its gravitational effect on stars, galaxies, and other objects made of ordinary matter. On Earth, scientists are using particle accelerators such as the Large Hadron Collider (LHC) to search for dark matter, while keeping an eye out elsewhere with detectors in space and even detectors located thousands of feet underground. Although scientists have covered all of their bases location-wise, these detectors may not be sensitive enough to detect dark matter if the mass of the dark matter is less than about 10 GeV (10 billion electron volts).

To address this problem, physicists are working on developing ever more sensitive dark matter detectors. In a new paper, researchers have proposed a new type of dark matter detector made of superconductors—materials that conduct electricity with zero resistance at ultracold temperatures—that may offer the highest sensitivity yet for detecting "superlight" dark matter. Superlight dark matter has a mass at the low end of the range of 1 keV (1000 electron volts) to 10 GeV, or in other words, up to a million times lighter than the proton.

The physicists, Yonit Hochberg and Kathryn M. Zurek at Lawrence Berkeley National Laboratory and the University of California, Berkeley, and Yue Zhao at Stanford University (now at the University of Michigan), have published a paper on the superconducting detectors in a recent issue of *Physical Review Letters*.

"The greatest significance of our work is the potential ability to detect dark matter with mass between a thousand to a million times lighter than the mass of the proton," Zurek told *Phys.org*. "Current dark matter direct detection experiments and other proposed methods are not sensitive to such light dark matter. Superconducting detectors are the only (proposed) game in town for dark matter in this mass range."

Although most of the time dark matter does not interact with anything, scientists have to assume it interacts with ordinary matter somehow, or else they could not detect it in the lab. But it's unclear whether dark matter interacts with electrons, nuclei, both, or something else.

In general, dark matter detectors are based on the principle that, if a dark matter particle were to hit the detector and interact with it, the collision would produce another type of particle such as a photon or phonon (a quanta of vibration) at a specific energy. The detector material is extremely important, as the interaction between dark matter and the detector determines the specific properties of the particle that is produced. Some of the most highly sensitive detectors today are made of liquid xenon (LZ detector), germanium crystal (SuperCDMS), and other similar materials.

In the new paper, the physicists showed that a dark matter detector made out of a superconducting material, such as ultrapure aluminum, could be the most sensitive material yet, capable of detecting dark matter with a mass of a few hundred keV or less. The sensitivity arises from the fact that superconductors have a zero or near-zero band gap, which is the energy gap that electrons must cross to allow a material to conduct electricity. Aluminum, for example, has a tiny band gap of 0.3 meV (0.0003 eV).

"Superconducting detectors are more sensitive than other detectors due to their tiny energy gap," Hochberg said. "This tiny gap means that they are sensitive to very small energy depositions, which in turn means that they are sensitive to very light dark matter masses, down to a million times lighter than the proton. This is in contrast to, for example, standard semiconductors, which (due to their thousand-times-larger band gap) can be sensitive to dark matter only down to a thousand times lighter than the proton."

The idea is that one of the dark matter particles that are thought to be constantly flowing through the Earth will scatter off a free electron in the superconductor. In a superconductor, the free electrons are bound into Cooper pairs with a binding energy of a little less than 1 meV. If a dark matter particle has enough energy to pull an electron above the material's band gap, it will break the Cooper pair. In this way, the superconductor absorbs the energy of the incoming dark matter particle. Then a second device (a calorimeter) measures the heat energy deposited in the absorber, providing direct evidence of the dark matter particle.

The physicists predict that reasonable improvements in current detector technology could make this concept feasible in the near future. One of the biggest challenges (as in all dark matter detectors) will be to reduce the noise from non-dark-matter sources, such as thermal and environmental noise. If the superconductor detector can be built, it would provide the most sensitive test of dark matter to date and give scientists a better chance of finding out what the majority of matter in the universe is made of.

More information: Yonit Hochberg, Yue Zhao, and Kathryn M.

Zurek. "Superconducting Detectors for Superlight Dark Matter." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.116.011301 , Also at arXiv:1504.07237 [hep-ph]