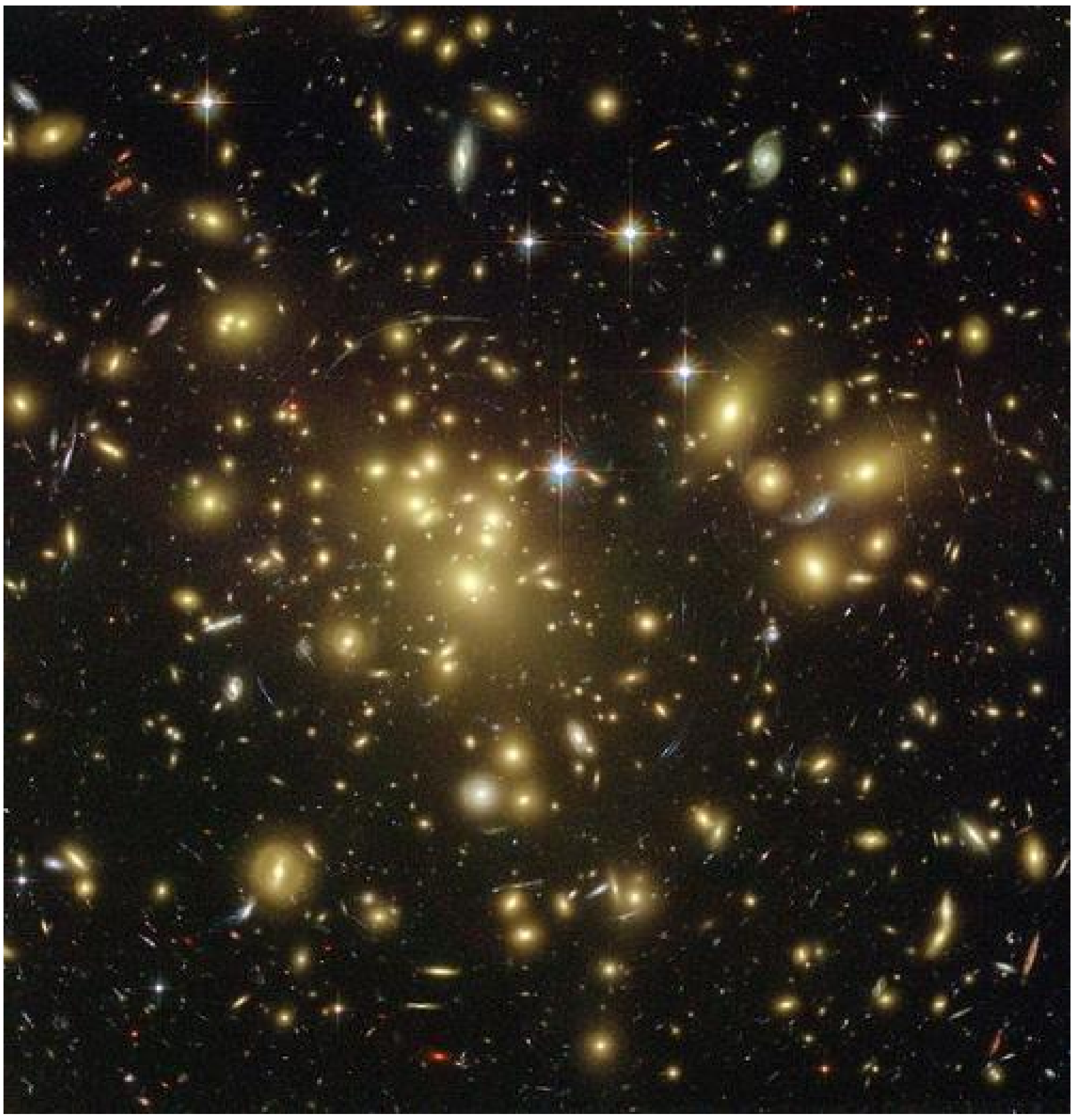
A detector shines in search for dark matter

August 20 2015, by Elizabeth K. Gardner



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

Results of the XENON100 experiment are a bright spot in the search for dark matter. The team of international scientists involved in the project demonstrated the sensitivity of their detector and recorded results that challenge several dark matter models and a longstanding claim of dark matter detection. Papers detailing the results will be published in upcoming issues of the journals *Science* and *Physical Review Letters*.

Dark matter is an abundant but unseen matter in the universe considered responsible for the gravitational force that keeps the Milky Way galaxy together, said Rafael Lang, an assistant professor of physics at Purdue University who was involved in the research.

"Our galaxy spins like an incredibly fast merry-go-round, and the stars, planets and other objects would go flying off in different directions if it wasn't for gravitational pull," he said. "When we calculate the gravity of every known mass, it is nowhere near enough force to keep the galaxy together. Dark matter is the stuff that makes up the difference."

Although the team did not detect dark matter, the capabilities demonstrated by the XENON100 detector are encouraging. The high sensitivity shown in the experimental results could free the international research team from the need to constrain analysis to only a portion of the data captured, Lang said.

"Imagine the search for a very weak and elusive dark matter signal within many events from various sources of background," Lang said. "It's like looking for a needle in a haystack. While most experiments have a huge pile of hay, our detector is so sharp and the background is so low, that our haystack is small and we can easily look at every piece of hay. We don't have to pick and choose what portion of the data we evaluate; we can look at every event. This opens the door for us to find evidence of dark matter in an unexpected place or in a form we didn't consider, which is good because no one yet knows what exactly dark matter is."

Scientists from a dark matter project named Dark Matter Large Sodium Iodide Bulk for Rare Processes, and referred to as the DAMA/LIBRA project, claimed to have detected dark matter in 1998. The team observed a signal

that varied with the seasons, as is expected for dark matter as the Earth's orbit around the sun changes the speed at which it passes through a halo of dark matter that envelops the Milky Way, Lang said.However, other teams searching for dark matter did not observe the same signal. The DAMA/LIBRA team suggested that other groups could be blind to the signal because the dark matter was interacting with the atoms of the detector in an unexpected way. It was suggested that the dark matter could be leptophilic, meaning it prefers to interact with electrons, he said.

"Traditionally the 'smoking gun' signature of dark matter was considered to be scattering of dark matter particles on the nuclei of the atoms of the detector material," said Joachim Kopp, a professor of theoretical elementary particle physics at Johannes Gutenberg University Mainz who is not part of the XENON collaboration. "Indeed, this is what many well-motivated dark matter models, such as supersymmetry, predict. However, in recent years, we have begun to appreciate more and more the fact that dark matter could behave very differently in many ways."

Experimental anomalies like the controversial annual modulation signal observed in the DAMA/LIBRA project cannot be explained by traditional dark matter scattering on atomic nuclei, but could be accommodated more easily if dark matter scatters predominantly with electrons or if most of the energy released in dark matter scattering is in the form of photons, he said.

"For a long time, it was considered unfeasible to test such a model since the scattering of dark matter particles on electrons or the emission of photons is much more difficult to distinguish from radioactive backgrounds," Kopp said. "Liquid noble gas detectors like XENON100 are now setting the new gold standard in this endeavor."

The XENON100 experiment was able to examine theories others could not because of the low level of background events it achieved, said Luke Goetzke, a postdoctoral researcher at Columbia University who was a lead researcher on the XENON100 experiment detailed in Physical Review Letters.

"The material used in the XENON100 detector and the material used in the DAMA/LIBRA project are very similar in terms of their electron configurations, so if dark matter interacts with one, it would interact in nearly the same way with the other," he said. "However, the XENON100 detector is so amazingly sensitive that the signal would be much more clear. We did not see it, and given our current knowledge and understanding of physics, because we did not see it, there is no way to explain the mysterious signal as leptophilic dark matter."

While the XENON100 data did not show the same signal as that observed by the DAMA/LIBRA project, the data did show a different and faint annual modulation, he said.

"The modulation we observed raises some questions, and to me that is thrilling," Goetzke said. "This means we are pushing the limits of our understanding and that is what makes physics research fun. I am very excited to see the first data from the XENON1T experiment, which will push far beyond the already amazing results from XENON100."

The experiment is conducted by an international collaboration of 120 scientists from 22 institutions around the world and is led by Elena Aprile, a professor of astrophysics at Columbia University.

This fall the team will will deploy a next-generation detector called XENON1T, which is expected to be 100 times more sensitive than XENON100. The detector itself will be 20 times bigger and include a series of technological improvements, she said.

"From the XENON100 results we know a lot more about what dark matter is not, which is very valuable information in the field of particle physics," Aprile said. "We've ruled out models with the strongest expected dark matter interactions, and with the XENON1T detector we will be able to test those with weaker expected interactions and capture even the most feeble hint of a dark matter. The results of these experiments mean that if this is the right place to look for the signature of dark matter, we should be able to see it."

The goal of XENON100 and XENON1T experiments is to capture signatures of dark matter that flow through the Earth as it moves through space. To shield the detectors from cosmic radiation that could create background events, they are located under a mountain in the Gran Sasso National Laboratory in Italy, the world's largest underground laboratory. The detectors use the noble gas xenon, kept liquid in a stainless steel container shielded and buried beneath one mile of rock. The detector is equipped with electronics that can detect even individual electrons and photons generated anywhere within the xenon, Lang said.

The XENON experiment is a collaboration of 120 scientists, representing 24 different nationalities and 22 institutions across the world. In addition, around 60 graduate students are working in the collaboration, he said.

More information: "Exclusion of leptophilic dark matter models using XENON100 electronic recoil data," by The XENON Collaboration. www.sciencemag.org/lookup/doi/ … 1126/science.aab2069

XENON Project website: xenon.astro.columbia.edu/index.html

Provided by Purdue University

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