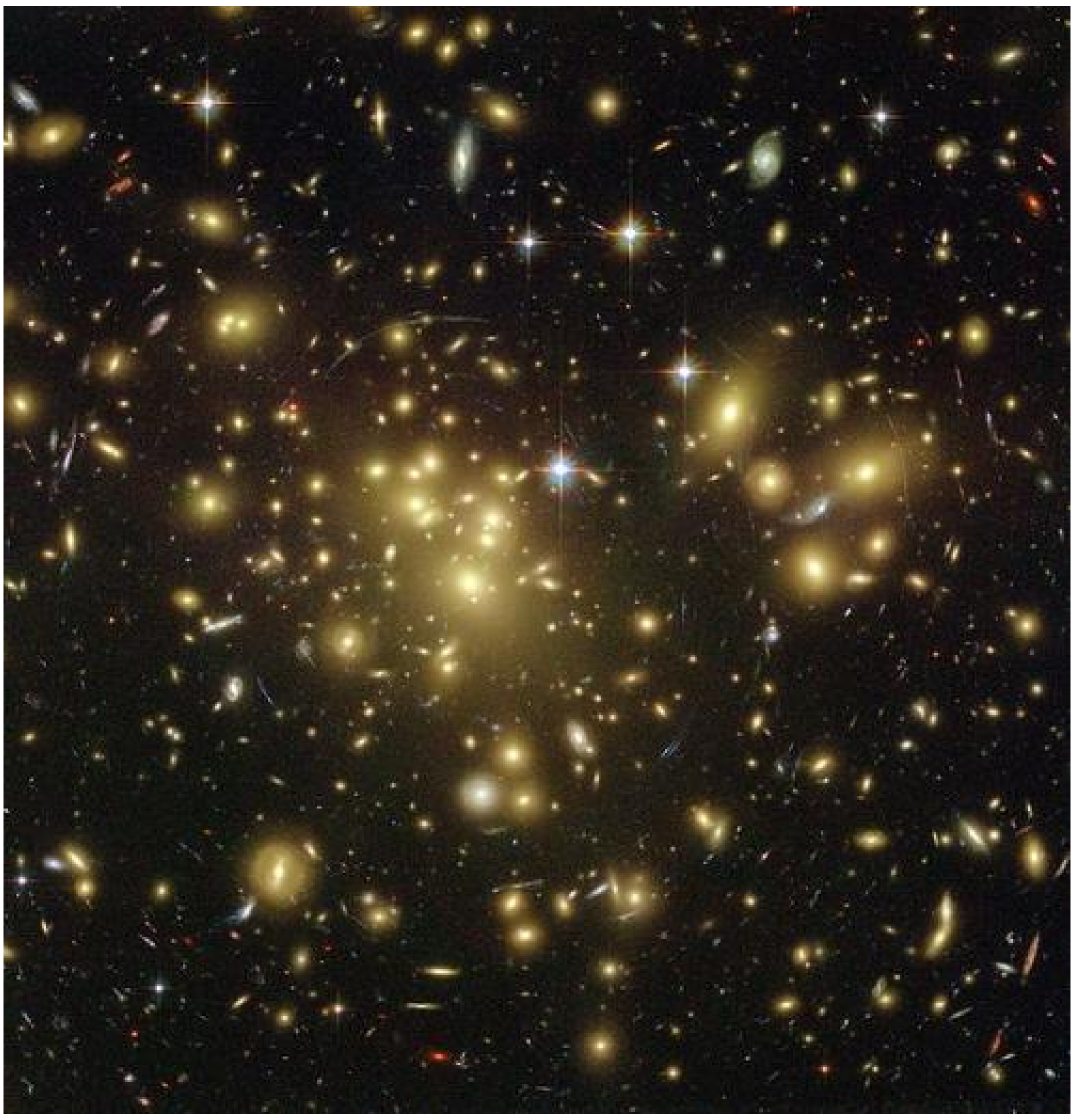
Model-independent measurement of dark matter mass could lead to future discoveries

July 29 2013, 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) —Determining the mass of dark matter particles requires accounting for several factors, one of which is the velocity distribution of the particles. Most current estimates of dark matter mass involve assumptions regarding the velocity distribution, since this distribution involves a high degree of uncertainty. In a new paper, physicists have presented a model-independent method for determining the dark matter mass that doesn't require any assumptions about the velocity distribution, marking the first time that the dark matter mass can be accurately measured in an unbiased way. The physicists predict that this tool will be invaluable for the analysis of future experimental data.

The scientists, Bradley J. Kavanagh and Anne M. Green at the University of Notthingham, have published their paper on the model-independent measurement of dark matter mass in a recent issue of *Physical Review Letters*.

Although physicists don't know exactly what dark matter is, one promising candidate is weakly interacting massive particles (WIMPs). Scientists can detect WIMPs in the lab, both directly and indirectly through their annihilation products. In one type of direct detection experiment, scientists can measure the nuclear recoils produced by WIMPs when they interact with atomic nuclei, and this data can provide a way to measure the WIMP mass.

In order to extract the mass data, however, scientists must make assumptions about the velocity distribution of the dark matter particles within the Milky Way halo. This velocity distribution encodes the speeds of the dark matter particles and determines the recoil energies observed in experiments.

Usually, scientists use the simplest model of the Milky Way halo, called the standard halo model, to make assumptions about the velocity distribution. But as the physicists point out, some recent simulations suggest that this model is incorrect. For one thing, the standard halo model does not account for the effect of baryons, which is not fully understood. The differences can lead to uncertainties in the velocity distribution that cause significant bias in measurements of the WIMP mass. Although several different approaches have been proposed to account for this uncertainty, they all still have significant shortcomings, and some of them make other assumptions.

Here, the physicists have presented an approach that allows the WIMP mass to be measured without any prior assumptions, using only data that will be available soon from upcoming experiments. To demonstrate the approach, the physicists generated three mock data sets and used them to reconstruct the WIMP mass in different scenarios. They showed that, although the method does lead to an unavoidable uncertainty in the cross section (a factor that involves particle interaction), it can still accurately recover the WIMP mass.

"Prior to this work, it has been necessary to make at least some assumptions about the velocity distribution in order to extract information on the dark matter mass," Kavanagh told *Phys.org*.

"However, with no way of knowing how accurate these assumptions are, we would have no way of knowing whether the dark matter mass we extract is correct. We have shown for the first time that in a variety of scenarios, we can analyze data without making such assumptions and therefore that the dark matter mass can be recovered reliably from direct detection experiments.

As the physicists explain, this ability to measure the WIMP mass without making assumptions of the velocity distribution will be very useful when analyzing data from many other dark matter experiments.

"Dark matter cannot be accounted for by any of the known particles in the Standard Model of particle physics," Kavanagh said. "This means that dark matter must be in the form of a new species of particle, governed by new physics beyond the Standard Model. Knowing the dark matter particle's mass can give us an insight into this new physics, for example allowing us to rule out theories which do not predict the correct value.

"At present, no confirmed dark matter signal has been observed in any direct detection experiments. This allows us to place bounds on how weakly dark matter particles interact with ordinary nuclei. However, with larger detectors and longer exposure times, we can probe weaker and weaker interactions and it is hoped that a signal will be observed sometime in the near future at current and upcoming detectors. Once this happens, our method will allow us to combine data from several direct detection experiments in order to reliably extract both the dark matter mass and velocity distribution."

In the future, the physicists plan to further text and extend their method, and are hoping to see a dark matter signal in the near future.

"We are currently working on testing the method using even more mock data sets, representing a wider variety of underlying velocity distributions and WIMP masses," Kavanagh said. "We also hope to extend the method to the analysis of directional data. Directional detectors measure both the energy and direction of nuclear recoils and therefore allow us to probe the full three-dimensional velocity distribution, rather than the one-dimensional speed distribution. This in turn will allow us to probe the dynamics of the Milky Way halo using directional experiments.

"Unfortunately, we do not know how strongly (or weakly) dark matter interacts with ordinary nuclei, so we do not know when a WIMP signal will be observed. With the advent of ton-scale detectors in the next few years, we should be able to test dark matter interactions 100 times weaker that what can currently be probed. If we're lucky, this means we could see a dark matter signal within the next few years."

More information: Bradley J. Kavanagh and Anne M. Green. "Model Independent Determination of the Dark Matter Mass from Direct Detection Experiments." *PRL* 111, 031302 (2013). DOI: 10.1103/PhysRevLett.111.031302