The Mysterious “Dark Core” of Abell 520

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In 1933, Swiss astronomer Fritz Zwicky noted something very strange when studying the masses and motions of distant galaxies. Zwicky estimated the total mass of a group of galaxies by measuring the collective brightness of its stars. Then, when he measured the same galaxies’ velocities, he found that they were moving much too fast to be gravitationally bound to one another. If the only mass present in the observed galaxy cluster came from the stars in the galaxies, he figured the galaxies should have flown apart long ago. To hold together, the cluster needed 400 times more mass than was evident from its stars.

This became known as the “the missing mass problem.” Over time, astronomers began to realize that large amounts of hidden mass were needed to support the most popular theories about the origin and structure of the universe. Galaxy clusters increasingly appeared to be tied to a “scaffold” made from an invisible form of matter, now simply called dark matter.

Scientists still do not know what dark matter is. It is not the same kind of matter that makes up nebulas, stars, and planets, yet it appears to account for most of the mass in the universe. Many experiments are underway in large particle accelerators throughout the world to find the elusive dark-matter particle or particles. To date, none have announced a conclusive result.

Meanwhile, modern telescopes—and particularly Hubble—have the ability to detect gravitational lensing, the bending of distant starlight...
caused by the gravitational influence of a large, intervening mass (like a galaxy cluster). Since the amount of bending, or lensing, depends upon mass, measuring this effect allows astronomers to independently assess the total mass of a galaxy cluster. Zwicky realized this was possible, but the telescopes of his time did not have sufficient acuity or sensitivity to detect the phenomenon.

Researchers can now view and plot the uneven strength of the gravitational lensing that occurs across a galaxy cluster by looking for patterns of distortion in the shapes and orientations of background galaxies. Astronomers use this weak lensing...
data to determine the distribution of all the mass within the cluster, and—accounting for the amount of lensing produced by normal matter—map out the distribution of dark matter.

Further, by analyzing collisions among galaxy clusters, astronomers now have a way to probe the inherent properties of dark matter itself. When clusters collide, astronomers expect their galaxies to be found in the same vicinity as the clusters’ dark matter—as if the two were tethered. In contrast, they expect any associated clouds of intergalactic gas to plow into one another, slow down, and lag behind the impact area. Recent visible-light and X-ray observations of a collision between two galaxy clusters called the Bullet Cluster appear to confirm this understanding. This galactic grouping made headlines in the last decade as an example of how dark matter within colliding clusters should behave—theoretically.

In 2007, however, astronomers observed two merging galaxy clusters whose dark matter appeared to behave in a contrary fashion. In fact, the initial findings were so unusual that astronomers dismissed them as non-credible, attributing them to poor data. The troubling merger, named Abell 520, is located approximately 2.4 billion light-years away. Observations of Abell 520 show an area of hot, X-ray-emitting gas at its center that is collocated with a concentration of dark matter (as determined through weak lensing). Unlike the Bullet Cluster, the galaxies in Abell 520 are not found at its center with the dark matter, but are located at its periphery.

NASA’s Chandra X-ray Observatory initially detected the hot gas. Astronomers then used the Canada-France-Hawaii and Subaru telescopes atop Mauna Kea to infer the location of dark matter through gravitational lensing. These observations found that the system’s core was rich in dark matter and hot gas but contained no luminous galaxies. The astronomers later used Hubble’s Wide Field Planetary Camera 2, which can detect weak-lensing distortions in the images of background galaxies. This data was used to map the dark-matter distribution. To astronomers’ surprise, the Hubble observations confirmed the 2007 findings.
The large image is a composite of Abell 520 created by combining images from different telescopes in various wavelengths. The visible-light image of the galaxies was taken with Hubble’s Wide Field Planetary Camera 2 (WFPC2). Galactic starlight from observations by the Canada-France-Hawaii Telescope is colored orange. (Most of the galaxies in the image outside of the orange-tinted regions are not members of the cluster, but are far behind it.) The green-tinted regions show hot gas detected by NASA’s Chandra X-ray Observatory. The blue areas indicate the location of most of the mass in the cluster, as determined by weak gravitational lensing seen in WFPC2 data from Hubble. These areas consist mainly of dark matter. (Image credit: NASA, ESA, CFHT, CXO, M. Jee (University of California, Davis), and A. Mahdavi (San Francisco State University))
Gravitational lensing data indicates that the dark matter in Abell 520 has collected into a puzzling “dark core” far from its former companion galaxies. California-based astronomer Myungkook James Jee, lead author of a March 2012 research paper on these results, concedes that the dark matter is not behaving as predicted, and that it is difficult to explain these observations within the current theoretical framework of galaxy formation in a universe dominated by dark matter. Astronomers have mapped the distribution of dark matter in about half a dozen other cases of high-speed galaxy cluster collisions, but the Bullet Cluster and Abell 520 show the clearest evidence of recent mergers and are the easiest to analyze—yet they yield opposite results.

Although no single theory explains the different behavior of dark matter in these two collisions, the team has proposed several explanations for its findings. One is that the Abell 520 encounter is a more complicated case than the Bullet Cluster. Abell 520 may have formed from a collision between three galaxy clusters instead of just two, as in the case of the Bullet Cluster.

Another possible explanation is that dark matter (or perhaps some subset of dark matter) may be inherently more cohesive than previously thought. When normal matter collides, it slows down; its pieces also gravitationally interact and clump together. Dark-matter concentrations, however, were thought to pass through each other during encounters without slowing down. The new findings suggest that at least some dark matter interacts with itself and stays behind when galaxy clusters collide.
A third possibility is that Abell 520’s core actually contains many galaxies that are too dim to be seen, even by Hubble. Using computer simulations, researchers are studying the likelihood of this scenario, recognizing that such galaxies must contain many fewer stars than typical galaxies, or they would be visible.

The mystery of this “dark core” took a surprising turn in late 2012. Using Hubble data, Ohio-based astronomer Douglas Clowe, who previously studied the Bullet Cluster, reported that he and his collaborators did not find an unusually dense clump of dark matter at Abell 520’s core. Using a different instrument, the Advanced Camera for Surveys (ACS), Clowe’s team found that the signature of weak gravitational lensing inferred the presence of dark matter in and around the galaxies rather than the core. Their results are consistent with how scientists expect dark matter to behave.

In light of this new result, Clowe is encouraging other scientists to conduct fresh studies of the archived data with the hope of reaching scientific consensus on its meaning. Further study of these conflicted findings may have important implications in identifying the nature and properties of dark matter, and thus improve astrophysicists’ basic understanding of this material that mysteriously fills and shapes the universe.
Further Reading


Dr. Myungkook James Jee was born in Seoul, South Korea and is now a permanent resident in Davis, California. He received his doctorate from The Johns Hopkins University in 2005. His primary research interests include observational cosmology, gravitational lensing, and astronomical instrumentation. Currently, Dr. Jee is a staff scientist at the University of California, Davis, working on the Large Synoptic Survey Telescope (LSST) project. The LSST will be used to create a 3D map of the universe with unprecedented depth and detail to help characterize the properties of dark matter and dark energy.

Dr. Douglas Clowe is an observational cosmologist who uses weak gravitational lensing to study clusters of galaxies and their surrounding media. His work on the Bullet Cluster provided the first direct evidence that dark matter must exist independently of any assumptions about how gravity works on cosmic scales. Born in St. Louis, Missouri, he grew up in Boulder, Colorado, and Euless, Texas. Dr. Clowe was an undergraduate at the California Institute of Technology and earned his doctorate from the University of Hawaii. He held postdoctoral positions at the Max Planck Institute for Astrophysics, the University of Bonn, and the University of Arizona before joining the faculty at Ohio University in 2006. (Photo credit: Ohio University)