Einstein's theory fights off challengers (w/ Video)

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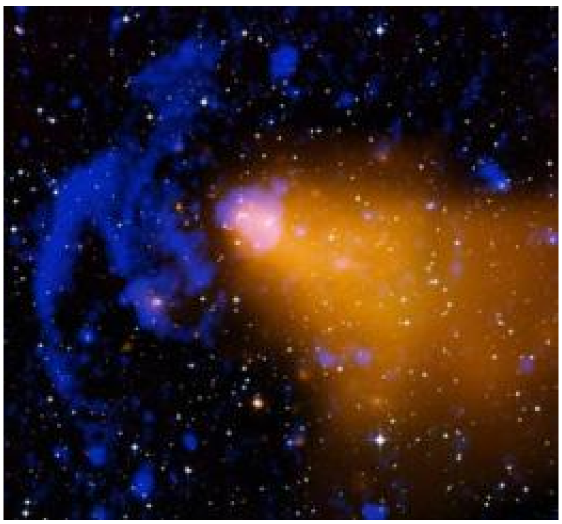

This composite image of the galaxy cluster Abell 3376 shows Chandra and ROSAT X-ray data (gold), an optical image from the Digitized Sky Survey (red, green and blue), and a radio image from the VLA (blue). Two different teams used Chandra observations of galaxy clusters -- including Abell 3376 -- to study the properties of gravity on cosmic scales and test Einstein's theory of General Relativity. Such studies are crucial for understanding the evolution of the universe, both in the past and the future, and for probing the nature of dark energy, one of the biggest mysteries in science. Credit: X-ray: NASA/CXC/SAO/A. Vikhlinin; ROSAT Optical: DSS Radio: NSF/NRAO/VLA/IUCAA/J.Bagchi

(PhysOrg.com) -- Two new and independent studies have put Einstein's General Theory of Relativity to the test like never before. These results, made using NASA's Chandra X-ray Observatory, show Einstein's theory is still the best game in town.

Each team of scientists took advantage of extensive Chandra observations of galaxy clusters, the largest objects in the Universe bound together by gravity. One result undercuts a rival gravity model to General Relativity, while the other shows that Einstein's theory works over a vast range of times and distances across the cosmos.

The first finding significantly weakens a competitor to General Relativity known as "f(R) gravity".

"If General Relativity were the heavyweight boxing champion, this other theory was hoping to be the upstart contender," said Fabian Schmidt of the California Institute of Technology in Pasadena, who led the study. "Our work shows that the chances of its upsetting the champ are very slim."

In recent years, physicists have turned their attention to competing theories to General Relativity as a possible explanation for the accelerated expansion of the universe. Currently, the most popular explanation for the acceleration is the so-called cosmological constant, which can be understood as energy that exists in empty space. This energy is referred to as dark energy to emphasize that it cannot be directly detected.

In the f(R) theory, the cosmic acceleration comes not from an exotic form of energy but from a modification of the gravitational force. The modified force also affects the rate at which small enhancements of matter can grow over the eons to become massive clusters of galaxies, opening up the possibility of a sensitive test of the theory.

Schmidt and colleagues used mass estimates of 49 galaxy clusters in the local universe from Chandra observations, compared them with theoretical model predictions and studies of supernovas, the cosmic microwave background, and the large-scale distribution of galaxies.

They found no evidence that gravity is different from General Relativity on scales larger than 130 million light years. This limit corresponds to a hundred-fold improvement on the bounds of the modified gravitational force's range that can be set without using the cluster data.

"This is the strongest ever constraint set on an alternative to General Relativity on such large distance scales," said Schmidt. "Our results show that we can probe gravity stringently on cosmological scales by using observations of galaxy clusters."

The reason for this dramatic improvement in constraints can be traced to the greatly enhanced gravitational forces acting in clusters as opposed to the universal background expansion of the universe. The cluster-growth technique also promises to be a good probe of other modified gravity scenarios, such as models motivated by higher-dimensional theories and string theory.

A second, independent study also bolsters General Relativity by directly testing it across cosmological distances and times. Up until now, General Relativity had been verified only using experiments from laboratory to Solar System scales, leaving the door open to the possibility that General Relativity breaks down on much larger scales.

To probe this question, a group at Stanford University compared Chandra observations of how rapidly galaxy clusters have grown over time to the predictions of General Relativity. The result is nearly complete agreement between observation and theory.

"Einstein's theory succeeds again, this time in calculating how many massive clusters have formed under gravity's pull over the last five billion years," said David Rapetti of the Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) at Stanford University and SLAC National Accelerator Laboratory, who led the new study. "Excitingly and reassuringly, our results are the most robust consistency test of General Relativity yet carried out on cosmological scales."

Rapetti and his colleagues based their results on a sample of 238 clusters detected across the whole sky by the now-defunct ROSAT X-ray telescope. These data were enhanced by detailed mass measurements for 71 distant clusters using Chandra, and 23 relatively nearby clusters using ROSAT, and combined with studies of supernovas, the cosmic microwave background, the distribution of galaxies and distance estimates to galaxy clusters.

Galaxy clusters are important objects in the quest to understand the Universe as a whole. Because the observations of the masses of galaxy clusters are directly sensitive to the properties of gravity, they provide crucial information. Other techniques such as observations of supernovas or the distribution of galaxies measure cosmic distances, which depend only on the expansion rate of the universe. In contrast, the cluster technique used by Rapetti and his colleagues measure in addition the growth rate of the cosmic structure, as driven by gravity.

"Cosmic acceleration represents a great challenge to our modern understanding of physics," said Rapetti's co-author Adam Mantz of NASA's Goddard Space Flight Center in Maryland. "Measurements of acceleration have highlighted how little we know about gravity at cosmic scales, but we're now starting to push back our ignorance."

f(R) Gravity

One possible way to explain the observed acceleration in the expansion of the universe is to change Einstein's theory of General Relativity. The simplest modification is to introduce a cosmological constant, which can be explained by energy that exists in the vacuum. In f(R) gravity and other modified gravity models, scientists go beyond this simple modification. In the f(R) gravity model, spacetime reacts differently to the matter in the universe than it does in General Relativity.

In General Relativity, gravity is a manifestation of the curvature of space and time, where the source of this curvature are all of the forms of mass and energy in the universe. In the absence of any mass or energy spacetime can become completely flat. What f(R) gravity does is allow spacetime to act as a source of its own curvature, so there can still be some curvature even if spacetime is completely empty and the energy is zero. So, as the universe expands and empties out, some curvature remains, resulting in cosmic acceleration.

By making this modification to gravity an additional ("5th") force is introduced. By comparing observations of the masses of galaxy clusters with the predictions of f(R) gravity, the range of this 5th force can be estimated. On distance scales smaller than this range, gravity is stronger than predicted by Einstein's equations. The smaller that this range is, the less effect that this modification to gravity has on the growth of galaxy clusters.

If the cosmological constant is the explanation for cosmic acceleration then the acceleration will continue forever and all galaxies outside the Local Group should eventually disappear from view, resulting in a lonely universe. If f(R) gravity applies then the 5th force will die away in the far future, cosmic expansion will slowly decelerate and a lonely universe will be avoided. It will be many billions of years before either one of these future scenarios can play out.

More information: The paper by Fabian Schmidt was published in

Physics Review D, Volume 80 in October 2009 and is co-authored by Alexey Vikhlinin of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, and Wayne Hu of the University of Chicago, Illinois. The paper by David Rapetti was recently accepted for publication in the *Monthly Notices of the Royal Astronomical Society* and is co-authored by Mantz, Steve Allen of KIPAC at Stanford and Harald Ebeling of the Institute for Astronomy in Hawaii.

Provided by Chandra X-ray Center

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