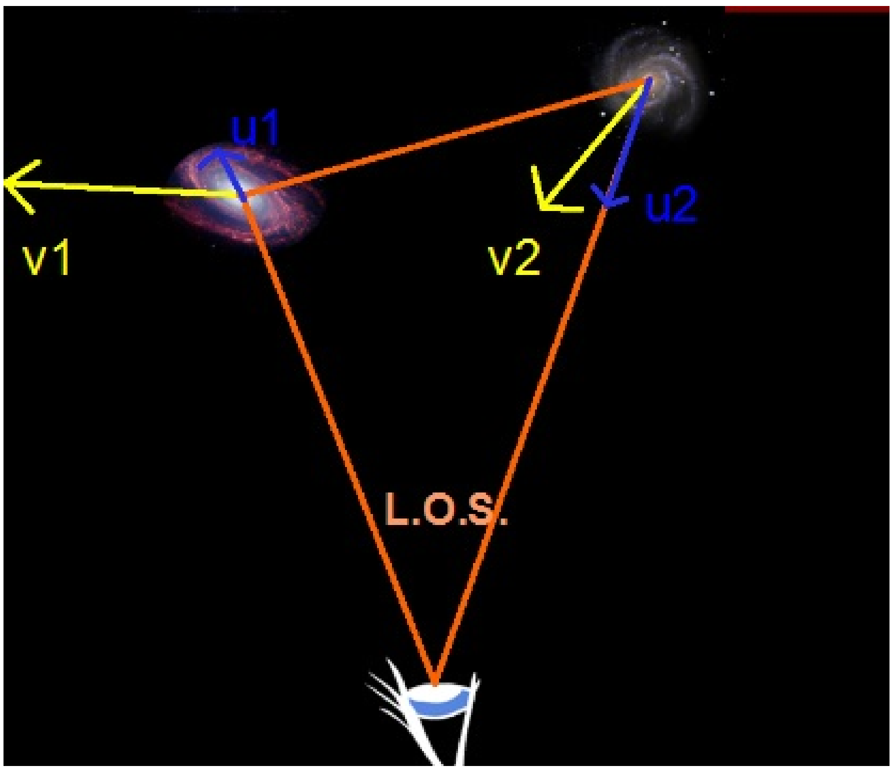
New test may provide 'smoking gun' for modified gravity

June 20 2014, by Lisa Zyga



A schematic picture of how researchers can observe galaxy peculiar velocities, “a cosmic dance of galaxies.” Credit: Wojciech A. Hellwing

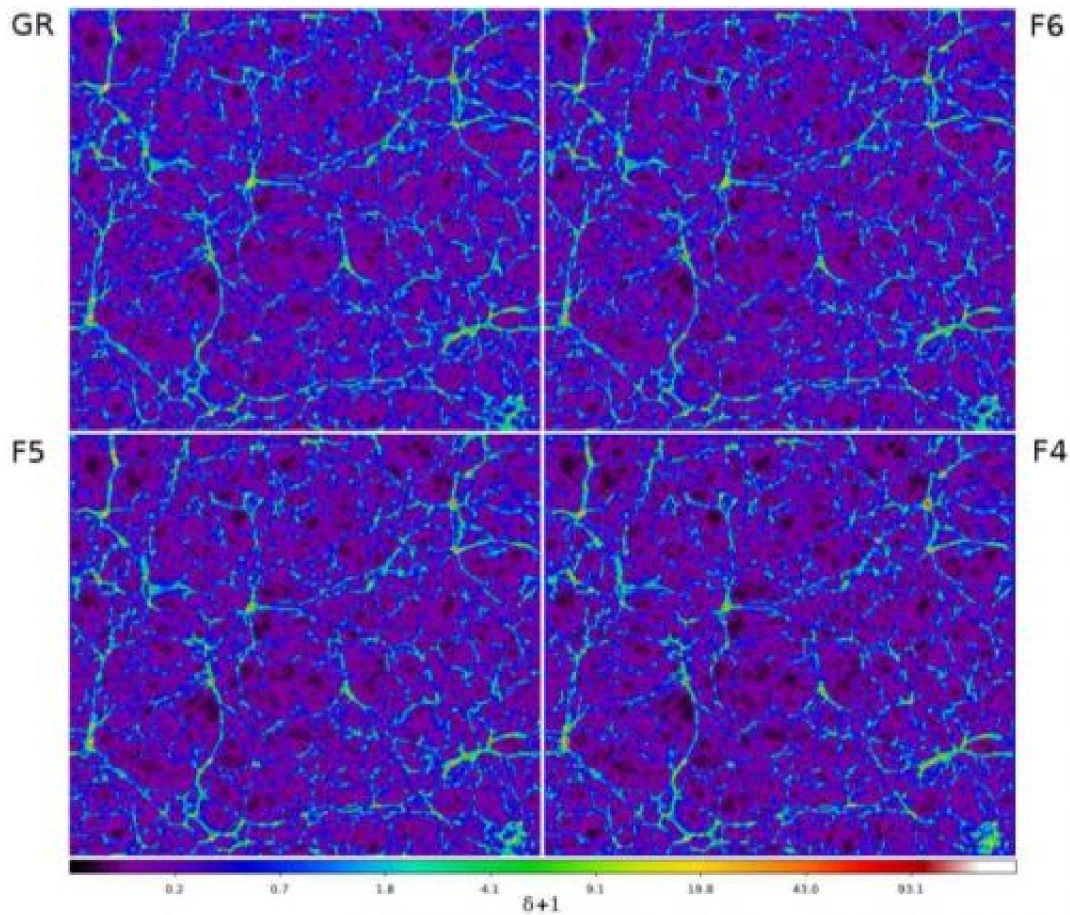
(Phys.org) —Since 1916, general relativity has provided a description of gravity that can explain many observations, including objects in free fall, gravitational lensing by massive objects, and black holes. Despite the success of the theory for nearly 100 years, scientists have been looking at ways to modify general relativity in order for it to better explain certain observations—particularly the accelerated expansion of the universe. Although these modifications can be very different from one another, they generally fall into the category of "modified gravity."

Like any scientific prediction, modified gravity must be experimentally tested in order for scientists to confirm its validity. Although significant progress has been achieved in recent years in designing observational tests of gravity's effects in the universe that might reveal the presence of modified gravity, there is still no conclusive evidence for its existence.

Now in a new paper published in *Physical Review Letters*, Wojciech A. Hellwing, et al., have proposed a new test of modified gravity that is based on measuring the tendency of well-separated galaxies to approach each other. This movement is called the galaxy pairwise velocity.

The physicists show that the galaxy pairwise velocity distribution of many galaxies with a wide range of masses is expected to deviate from the predictions of general relativity by significant amounts: between 5 and 10 standard deviations or higher, depending on the model. Due to these large deviations, this proposed test could potentially offer the strongest evidence in support of modified gravity to date.

"Modified gravity (MG) theories have gained a lot of attention in the last decade," Hellwing, a researcher at Durham University in the UK and the University of Warsaw in Poland, told *Phys.org*. "Mostly because this class of theories provides an alternative explanation of the late-time accelerated expansion of the universe, while avoiding some conceptual problems related to the classical general relativity (GR) picture in which Einstein's cosmological constant is supposed to drive this acceleration. In the classical GR picture, one needs to have a very small value of the cosmological constant, which is hard to reconcile with quantum field theory. MG theories provide an alternative explanation, but in most of these theories modifications to gravity not only can account for accelerated expansion but also can produce non-negligible enhancement to gravity at cosmic scales relevant to galaxy formation and dynamics. Therefore it is of utmost importance to find observational evidence that could distinguish between these two scenarios (GR or MG)."



A thin slice of the large-scale cosmic density field (the clustering of dark matter and galaxies) is depicted for four models: GR and three different MG models. The side of the box corresponds to ~360 Mega parsecs (Mpc) or ~1.16 billion of light years. Credit: Baojiu Li, et al. "The non-linear matter and velocity power spectra in f(R) gravity. Credit: " *Monthly Notices of the Royal Astronomical Society*, Volume 428, Issue 1, p.743-755

Although one possible type of observational evidence of MG is related to the clustering of luminous galaxies, Hellwing explained that these observations have been plagued by ambiguities connected to non-linear baryonic physics responsible for galaxy formation and clustering. The complications make it very difficult to find a clear and measurable signal that could help researchers distinguish between GR and MG scenarios.

"In our paper we have shown that the peculiar velocities of galaxies bear a significant signal of the underlying theory of gravity," Hellwing said. "The advantage here is that the galaxy velocities are much less prone to the effects of the non-linear baryonic physics of galaxy formation. We also show this in our paper, when we present that the MG signal is present for galaxies of all masses and can also be measured both on large and small cosmological scales. Thanks to these unique features connected to the statistics of the galaxy velocity field, these kinds of observables pose a clean 'smoking gun'-like signature of either GR or MG."

The physicists explain that the MG signal can be measured in two ways because it involves two different observational data sets. One set consists of the data of galaxy peculiar velocities, the other the clustering of galaxies in so-called redshift space. In the latter, the galaxy positions (clustering) are affected by their peculiar velocities and in the former the galaxy velocities are measured directly.

"Both data sets call for a different approach," Hellwing said. "However, the quality of the current data should allow for a clear measurement of the signal we discuss. Redshift space data is very abundant but it needs an extra theoretical effort to model properly the expected signal in GR and MG. The velocity data can be interpreted directly but it is much sparser and contained by much larger observational errors. A program aimed to extract the signal we have predicted theoretically is already in progress."

If experiments confirm that a modified version of general relativity can explain observations better than the original version, the results could shed light on some fundamental cosmological questions.

"The implications of measuring the signal we have found are very profound," Hellwing said. "Firstly the GR commonly adopted as a crucial ingredient of the standard cosmological model has only being tested at scales corresponding to the Solar System. Einstein's theory was never directly tested on cosmological scales (relevant to galaxy velocities). Confirming that the GR is a valid theory of gravitation also on intermediate cosmological scales is very important. On the other hand, if the measured signal will indicate that GR is not enough to explain the observed motion of galaxies, then we will be dealing with a paradigm shift and a real breakthrough in modern cosmology and physics, comparable in magnitude to the accelerated expansion discovered in the late '90s of the 20th century."

More information: Wojciech A. Hellwing, et al. "Clear and Measurable Signature of Modified Gravity in the Galaxy Velocity Field." *PRL* 112, 221102 (2014). DOI: 10.1103/PhysRevLett.112.221102