Antimatter gravity could explain Universe's expansion

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It’s possible that antimatter could exist in the voids between galaxy clusters and superclusters. Image credit: NASA and ESA.

(PhysOrg.com) -- In 1998, scientists discovered that the Universe is expanding at an accelerating rate. Currently, the most widely accepted explanation for this observation is the presence of an unidentified dark energy, although several other possibilities have been proposed. One of these alternatives is that some kind of repulsive gravity – or antigravity – is pushing the Universe apart. As a new study shows, general relativity predicts that the gravitational interaction between matter and antimatter is mutually repulsive, and could potentially explain the observed expansion of the Universe without the need for dark energy.

Ever since antimatter was discovered in 1932, scientists have been investigating whether its gravitational behavior is attractive – like normal matter – or repulsive. Although antimatter particles have the opposite electric charge as their associated matter particles, the masses of antimatter and matter particles are exactly equal. Most importantly, the masses are always positive. For this reason, most physicists think that the gravitational behavior of antimatter should always be attractive, as it is for matter. However, the question of whether the gravitational interaction between matter and antimatter is attractive or repulsive so far has no clear answer.

In the new study, Massimo Villata of the Osservatorio Astronomico di Torino (Observatory of Turin) in Pino Torinese, Italy, has shown that an answer can be found in the theory of general relativity. As Villata explains, the current formulation of general relativity predicts that matter and antimatter are both self-attractive, yet matter and antimatter mutually repel each other. Unlike previous antigravity proposals – such as the idea that antimatter is gravitationally self-repulsive – Villata's proposal does not require changes to well-established theories. The study is published in a recent issue of *EPL* (Europhysics Letters).

"The significance of this study is actually twofold," Villata told *PhysOrg.com*. "On one side, that of physics in general, it is to have shown that one of the most heretical concepts debated in the last several decades, i.e., that of antigravity, can be found as a prediction of the coupling of two of the best-established theories of the last century, providing the extension of general relativity to antimatter, considered as space-time-reversed matter, as requested by CPT symmetry. On the other side, the cosmological implications of this finding have shown antigravity as an alternative to (or explanation of) the wooly concept of dark energy for the accelerated expansion of the Universe."

Repulsive gravity

At first, the idea of repulsive gravity between matter and antimatter seems to go against intuition, since we usually consider mass to be the only component determining an object's gravitational behavior. But as Villata explains, there is more than just mass involved in gravity. In this case, time and parity are involved.

The idea is based on the concept that all physical laws have CPT (charge, parity, and time) symmetry. CPT symmetry means that, in order to transform a physical system of matter into an equivalent antimatter system (or vice versa) described by the same physical laws, not only must particles be replaced with corresponding antiparticles (C operation), but an additional PT transformation is also needed.

From this perspective, antimatter can be viewed as normal matter that has undergone a complete CPT transformation, in which its charge, parity and time are all reversed. Even though the charge component does not affect gravity, parity and time affect gravity by reversing its sign. So although antimatter has positive mass, it can be thought of as having negative gravitational mass, since the gravitational charge in the equation of motion of general relativity is not simply the mass, but includes a factor that is PT-sensitive and yields the change of sign.

As Villata explains, CPT symmetry means that antimatter basically exists in an inverted spacetime (the P operation inverts space, and the T operation inverts time). He gives the following analogy: if an anti-apple falls onto the head of an anti-Newton sitting on an anti-Earth, it would fall in exactly the same way as if all of these objects were made of normal matter. But if an anti-apple falls on the (normal) Earth, or a (normal) apple falls on an anti-Earth, then the result is different. In both cases, a minus sign arises in the equation of motion, which reverses the gravitational interaction between the anti-apple and Earth, or apple and anti-Earth, making it repulsive.

Observations and experiments

The theoretical prediction of antigravity between matter and antimatter could have significant consequences, if it's true. Whenever matter and antimatter meet, they annihilate and produce photons. But if matter and antimatter repel each other, then they would tend to isolate themselves apart from each other and not annihilate. The force of this matter-antimatter repulsion could explain why the Universe is expanding at an accelerating rate, eliminating the need for dark energy and possibly dark matter.

Villata suspects that antimatter could exist in the Universe in large-scale voids that have been observed in the distribution of galaxy clusters and superclusters. Previous studies have found that these voids can originate from small negative fluctuations in the primordial density field, which repel surrounding matter – as if they have a negative gravitational mass. With diameters of tens of megaparsecs (about a hundred million light years), these voids are the largest structures in the Universe. The problem is that, so far, researchers have not observed antimatter in these locations. Villata plans to investigate this question in a future study on the invisibility of antimatter in voids.

"The relevant ideas are there, but I'm looking for the best way to formalize them," he said. "However, you can find anticipations on this and many other features of matter traveling backwards in time in the novel by Max Wells (which is my literary pseudonym, in honor of J. C. Maxwell and H. G. Wells), *The Dark Arrow of Time*, which is currently published only in Italian (*La freccia oscura del tempo*), but I hope to find an English publisher soon."

As for testing the possibility of antigravity between matter and antimatter, the upcoming AEGIS experiment at CERN could provide some answers. The experiment will compare how the Earth's gravity affects hydrogen and antihydrogen atoms, and could give scientists a better understanding of antimatter's gravitational properties.

"Antigravity has always been controversial, and likely it will still be so until we can get an experimental (or observational) response," Villata said. "However, I hope that my work, in the meantime, can at least dissipate some prejudices against antigravity."

More information: M. Villata. "CPT symmetry and antimatter gravity in general relativity." *EPL (Europhysics Letters)*, 94 (2011) 20001. DOI:10.1209/0295-5075/94/20001