New Theory of the Universe Marries Two of its Biggest Mysteries

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Physicists have devised a theory that unifies two widely studied mysteries of the universe: why there is an imbalance between regular matter and anti-matter (scientists expect to see equal amounts of each, but observe less anti-matter), and the identity of “dark matter” – the enigmatic particles thought to account for the extra gravitational pull observed in distant galaxies.

“We propose that at some point in the very early universe, dark matter interacted with regular matter in a particular way so as to shift the balance between matter and anti-matter ever so slightly towards matter, a process known as baryogenesis,” said Jeff Jones, a University of California-Santa Cruz physicist involved in the work, to *PhysOrg.com*. “We have proposed a new mechanism for baryogenesis that ties together these two mysteries, which are usually assumed to be unrelated.”

The prefix “baryo” in baryogenesis comes from “baryon,” a class of particles made of three quarks. Protons and neutrons are the most common examples of baryons. By extension, ordinary matter – atoms, in other words, which are primarily protons and neutrons – is therefore essentially made of baryons. Similarly, anti-matter is mostly anti-baryons.

The Russian physicist Andrei Sakharov, father of the Russian hydrogen bomb and advocate of peaceful coexistence between the Soviet and western systems, pointed out in the 1960s that in order for baryogenesis to take place there had to be a violation of CP symmetry.” CP symmetry is a physics concept stating that if ordinary particles are replaced by anti-particles in any physical process, and the particles' "handedness" is simultaneously reversed (sort of like how I'm right-handed but my mirror image, my "anti-self," is a lefty), the result should be an equally feasible process occurring at the same rate as the first. Of the four known fundamental forces – strong, weak, electromagnetic, and gravity – scientists have only seen the weak force violate CP symmetry in experiments. However, when that violation results in the production of baryons, it also always generates anti-baryons. So there is no imbalance produced.

There must be, then, a process that does not conserve the total number of baryons involved and also violates CP symmetry. The Standard Model of particle physics – a theory describing the relationship between the strong, weak, and electromagnetic forces, and the particles that feel those forces – predicts that there is such a process. Known as the sphaleron process, it would only take place at temperatures far too high to achieve in a lab, but would have existed during the early universe. The sphaleron process allows for the possibility of matter being generated without the corresponding anti-matter, but it's still not a complete solution. But, Jones says, "The universe had no reason to *prefer* matter over anti-matter, so in the long run you would expect it to eventually even out. Mysteriously, it hasn't, and that's where our work comes in."

He and his colleagues show in their paper (which appears in the November edition of the *Journal of High Energy Physics*) that if the dark-matter particle has certain properties it would have interacted with regular matter. When added to the rest of the equations in the Standard Model (dark matter is not currently part of it), this interaction could have caused a preference for matter over antimatter. Like the sphaleron process, this interaction would only take place at the very high temperatures of the early universe and would "turn off" as the universe cooled down. This not only explains how more baryons than anti-baryons could be generated momentarily, but also why there would be more baryons in the long run. But for this to work, the sphaleron process would have to turn off before the dark matter/regular matter interaction did. If it occurred in the opposite order, the excess baryons in the early universe would be annihilated by the new anti-baryons produced by the sphaleron process.

The group came up with these ideas as they were studying an extension of the Standard Model known as the Pentagon model, which involves theoretical particles dubbed pentaquarks, which tend to combine together in groups of five. Scientists can only verify the Standard Model for particles with energies achievable in man-made experiments, which, relatively, are not very high. At high energies, many scientists suspect that the Standard Model breaks down and there is new physics at play. The Pentagon model, on the other hand, leaves room for unknown forces and holds at energies in which the Standard Model fails.

The researchers say that their theory of baryogenesis could still be valid if the Pentagon model turns out to be incorrect, provided that their assumptions about the identity and nature of dark matter are true.

"Ultimately, in order to know whether our theory is really the right explanation, it will need to be tested. Because it involves connections between many different kinds of physical processes, there will be more opportunities to test it and this may in some ways make it easier to test," says Jones. "However, it has a certain advantage over alternatives in that it manages to kill two birds with one stone."

Citation: Tom Banks, Sean Echols and Jeff L. Jones, "Baryogenesis, dark matter and the pentagon." *J. High Energy Phys.* JHEP11 (2006) 046