A UC Irvine ghost story

How a spectral subatomic particle may help crack one of the biggest cold cases in physics.

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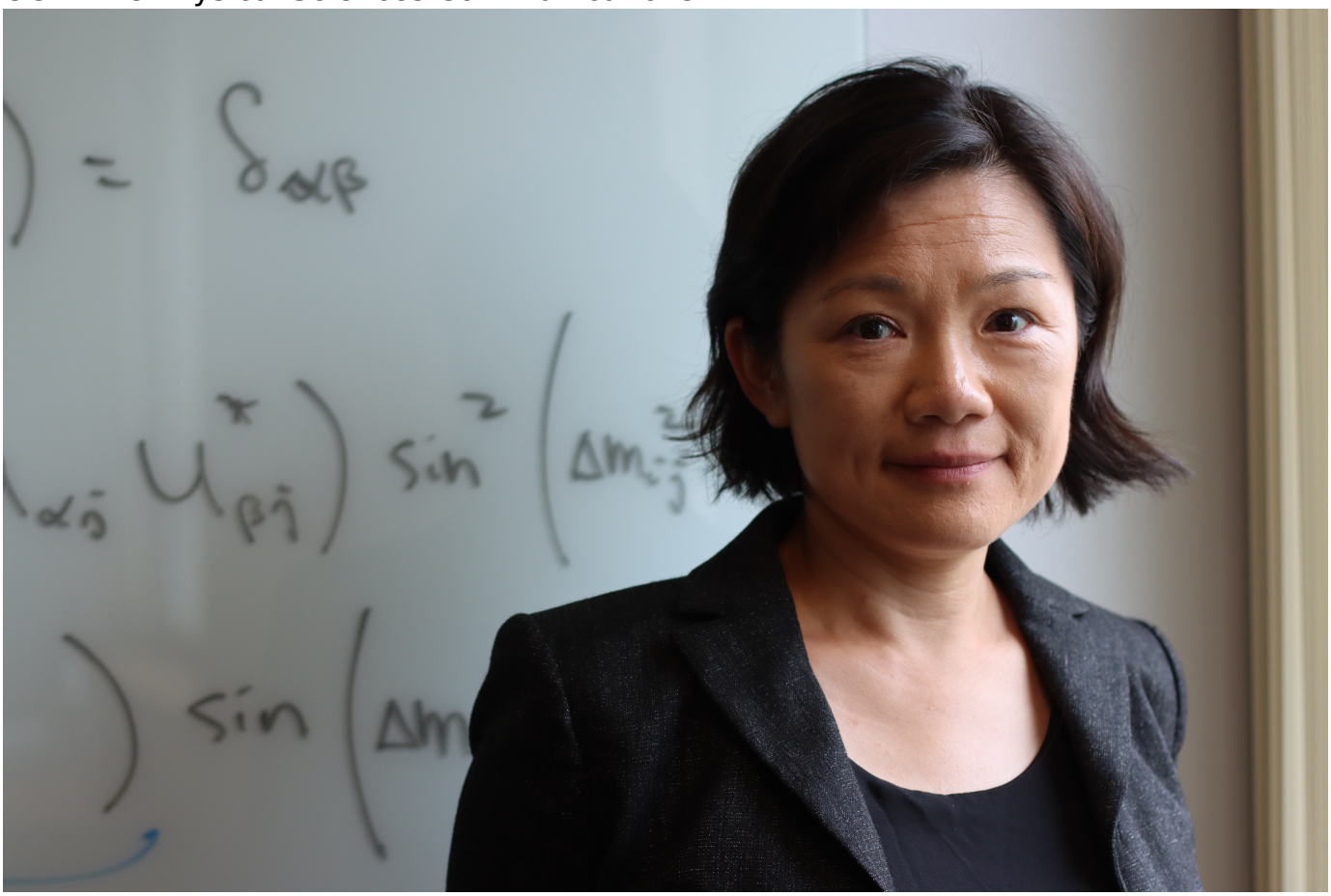

Professor Mu-Chun Chen of the UC Irvine Department of Physics & Astronomy is trying to figure out how a so-called 'ghost particle' fits in to the story of all the universe's missing antimatter.

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It’s October, and odds are decent you’ll glimpse someone dressed as a ghoul, goblin or ghost darting around campus.

But there’s another costume that deserves to join the growing Halloween parade at UC Irvine: the neutrino.

The neutrino is a subatomic particle co-discovered by the late UCI physicist and Nobel laureate Frederick Reines during a scientific mission called Project Poltergeist. Born from the top-secret Manhattan Project that led to the creation of the first atomic bomb, the Project Poltergeist team set out to detect the neutrino – something many considered impossible.

Also called the ‘ghost particle,’ the neutrino very rarely interacts with other matter. Indeed, much like phantoms, countless neutrinos made in places like the core of our sun are drifting through you as you read this.

Reines and his colleague Clyde Cowan detected the neutrino in 1956. Now, almost 70 years later, their ghost particle may be the key to solving one of the greatest cold cases in all physics: the apparent disappearance of all the universe’s antimatter.

When the universe came into being during the Big Bang billions of years ago, all the matter that would go on to comprise everything there is, from the planets to the stars and galaxies, also appeared. At the same time matter formed (roughly 10^{-12} to 10^{-6} seconds after the Big Bang), so too did antimatter – matter that’s the counterpart to the matter we can see, but which has an opposite electric charge.

But then something happened: as soon as it formed, all of the antimatter vanished, and physicists aren’t sure why. (It’s a lucky thing it vanished, because when matter and antimatter touch each other, they transform into an explosion of light.)

For all that antimatter to vanish, you need something to make it disappear, and according to Professor Mu-Chun Chen of the UC Irvine Department of Physics & Astronomy, the ghost particle may be to blame.

“After the Big Bang, equal amounts of both matter and antimatter would have been created," said Chen. “Why we live in a world made of matter but not antimatter remains one of the universe’s greatest mysteries."

Discoveries about neutrino oscillations — how they change from one type of neutrino to another as they travel through space — suggest these elusive particles might violate certain fundamental properties in ways that could explain why our matter-dominated universe exists the way it does, explained Chen.

“Specifically, the imbalance could be created through a so-called ‘leptogenesis’ mechanism, where the interactions responsible for neutrino mass generation also create the imbalance between matter and antimatter,” said Chen.

There’s a concept in physics called Charge-Parity (CP) symmetry, which posits that, regardless of whether a particle is a matter particle or an antimatter particle, both obey the same physical laws.

One of the primary goals of particle physicists is to find out whether neutrinos violate such fundamental symmetries, because a violation of CP symmetry is required to generate the matter-antimatter asymmetry seen in the universe.

“My research aims to explain why neutrinos oscillate the way they do, how neutrino masses are generated and the origin of matter-antimatter asymmetry,” Chen said. “I construct novel models based on new symmetries.”

In 1998, UC Irvine physicists lead the experiment that determined that neutrinos oscillate, and, thus, have mass. Then, in 2009, Chen proposed a new fundamental origin for CP violation. Specifically, “CP violation can arise due to the mathematical structure of the symmetries needed to explain the oscillation pattern,” said Chen. “I have also proposed several leptogenesis models that explain simultaneously both neutrino oscillation and matter-antimatter asymmetry.”

The models suggest that in the early universe, neutrino decay created slightly more matter particles than antimatter particles.

But while this could explain what happened to antimatter, the models still face significant challenges.

“These hypothetical neutrinos are extremely difficult to detect, and theory requires precise conditions that are hard to verify experimentally,” Chen said. “Future directions need to include advanced neutrino experiments, improved theoretical calculations of the early universe and searches for indirect signatures through cosmic observations. But the payoff could be significant, as success on this front could revolutionize our understanding of fundamental physics and cosmic evolution.”

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