The most incomprehensible thing about the world is that it is comprehensible. Those are some of Albert Einstein's most celebrated words. The phrase is also a statement Professor of Physics Jeff Martoff chose to have wallpapered onto the glass wall adjacent to his office door in the Science Education and Research Center (SERC) on Main Campus. Einstein's quote doesn't stand alone—it's paired with a mural of a galaxy that features the scientist's head, in case there's any question about whom to credit for the sentiment. It's not a surprise that physicists like Martoff are drawn to Einstein's remarks. They have studied and analyzed our world and universe for more than 100 years. They understand how almost everything works, from atoms to the solar system, in great mathematical detail. But there's something brewing in the cosmos that could irk physicists.

Enter: the incomprehensible.

Dark matter—it's the perplexing mass that is believed to comprise two-thirds of the universe. And it's what Martoff is working to bring to light with the support of a prestigious $1.2 million grant from the W.M. Keck Foundation. Physics professor Jeff Martoff is inching closer to solving the universe's biggest mystery.
Martoff's father was a machinist, and he's been known to head to the shop to make his own bit himself.

“When you look at the orbital motion of things in the solar system, it makes absolute sense," Martoff says. “Since Newton's time, it's been understood exactly why the planets move at the speeds that they do. Dark mat-
ter is believed to exist because when you start looking at everything going on around our galaxy, it just doesn't compute.”

Or, it just doesn't compute in an expected way. When physicists examine the orbital speeds of different visible parts of a galaxy, such as its stars and gas clouds, the results reveal a much larger mass than what we expect from adding up the masses of the vis-
ible parts. The unexplained mass is not visi-
table with any telescope and so was dubbed dark matter. Its presence is also betrayed by the bending of light passing by distant galax-
ies, an effect predicted by Einstein’s general theory of relativity and confirmed in our own solar system using the sun.

“The way that galaxies move tells us that there is a lot more matter out there than what we can see with a telescope," Martoff says. “So, if we know that dark matter is not [made up of] stars, it isn’t gas, it isn’t brown dwarf dead planets; it can’t be made of protons or neutrons; and it can’t be made of ordinary particles ... what is the hell is it?"

That’s what no one exactly knows. Yet. “Right now, no stable particle is known that could be dark matter.” Martoff continues. “We’re led to look for other kinds of particles that it can be made of.”

When Martoff says “stable,” he’s referring to a particle with a long lifetime—long enough to still be around since the Big Bang.

If you try to explain dark matter in terms of a particle that’s an electron, proton or neutron—the only stable particles with mass—what’s left is a particle that no one has discovered.

TWO BELIEVERS

Martoff’s quest to identify dark matter started nearly 30 years ago. Though there was some evidence that supported the exis-
tence of dark matter in the 1950s, the idea of it was just becoming mainstream in the sci-
ence world by the late ’70s and early ’80s—the same time Martoff was an assistant profes-
sor at Stanford.

He spent his time experimenting in nuclear physics while a group of low-temp-

erature physicists also at Stanford decided to delve into the unknown. It wasn’t long before Martoff, too, dove in.

The low-temperature physicists mastered how to create frigid environments, but that alone wouldn’t lead anyone to dark matter. They needed someone who understood nuclear radiation. Someone like Martoff.

Defined by their area of study, low-temp-

erature physicists deal with temperatures well below anything found in our usual experience—hundreds of degrees below zero on the Fahrenheit scale. A paper was pub-
lished that led these physicists to believe that increased experimental particle detectors could be created by exploiting phenomena that occur at these exceptionally low temperatures.

“A lot of fairly weird things happen below one Kelvin,” Martoff explains.

Among the group of investigators, the name of the game was to make extremely sensitive thermometers. Martoff suggested using superconductors.

“Then you look for radiation where there should be none. It’s the lab at the end of the rainbow," Martoff says as he looks at a picture of soft lines of pastel colors grazing the side of Gran Sasso, a mountain near the center of Italy.

A superhighway tunnels through the mountain’s rocky interior for close to 2 miles, and inside there’s an off ramp marked INFN. It stands for Italian Nuclear Physics Institute and is the only entry point for the Laboratorio Nazionale Gran Sasso, a particle physics laboratory a mile deep into the earth.

Martoff served as a principal investigator in the National Science Foundation-funded DarkSide search for WIMP (weakly

A SHOT IN THE DARK

interacting massive particle) dark matter. In 2012, he helped assemble DarkSide-10, an earlier version of the current DarkSide

WIMP detector, housed in the Laboratorio Nazionale Gran Sasso. Since then he has been an analysis coordinator for the successor experiment, DarkSide-50.

“WMIPS fit the bill for dark matter,” Martoff says. “The game here is to build the most sensitive particle detector you can, put it down in the deepest mine you can find, surrounded by the best shielding possible. Then you look for radiation where there should be none. Now, how true is this? You’ve done all of the above, and you’ve worked it on for 20 years, and the Universe still start seeing something. Who’s to say that it’s dark matter?”

Martoff says. “It could be anything it turns into. It could be electronic noise, or some other kind of radiation that has nothing to do with dark matter. Who the hell knows? A possible way to know if it’s dark matter is to create a directional sensitive detector. However, it’s difficult to build such a detect-
tor that’s large enough to maintain the high level of sensitivity.

So, these non-directional detectors that operate in deep underground mines continue to get bigger and bigger, and more and more sensitive—but they’re not finding WIMPs.

And that was a problem, mostly for Martoff. He gets wrapped up in solving problems—everyone does, different ways to pursue things. Though the DarkSide search pressed on, it was time to change courses.

THE OTHER SIDE OF THE SPECTROMETER

Martoff has spent most of his life looking at things from different angles than most people do. In junior high, he wrote a com-
puter program to teach a second-grader multiplication without a teacher. In college he taught his friend organic chemistry on a California beach over a case of beer. That friend is now a full professor of chemistry. Now, with support of the Keck award, he’s going to test a new, highly interdisci-
plinary technique to search for a different candidate for dark matter—sterile neutrinos.

Neutrinos are very light stable particles that have never been detected directly (and

neither have WIMPs). However, the mathe-
matical structure of particle physics theories strongly suggests that sterile neutrinos and WIMPs do exist. Together with investigators from UCLA and Houston, Martoff’s team at Temple is working to construct a 12-foot-long “table-
top” spectrometer to search for the pres-
ence, or absence, of sterile neutrinos. They believe the existence, or nonexis-
tence, of sterile neutrinos can be detected in the laboratory by measuring the energy and mass of the particles—e.g., a neutr-

tron and an X-ray—produced by a specific kind of radioactive decay and then examin-

ing to see if it’s missing. The decay also pro-

duces a neutrino, which may be the

ordinary type or the sought-after sterile type with nonzero mass.

“We believe we can conduct an extremely sensitive and precise measurement of the energy and momentum of these particles,” explains Martoff. “This will reveal missing energy and momentum from which we can compute the masses of the undetected neutrinos.”

Identifying a sterile neutrino would fill a gaping hole in the known particle spectrum, but a filled hole doesn’t necessarily solve the universe’s biggest mystery.

“If we ever find sterile neutrinos, we won’t be proving it’s dark matter,” explains Martoff. “But, they’re a natural candidate for dark matter. We’d be getting closer.”

How do you prove a particle is dark mat-
ter? That’s the next problem to solve. And

anyone is up to the challenge, it’s Martoff.