A Wave from Einstein

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A MUSIC FROM EINSTEIN

A new discovery in astrophysics opens a window into the way science advances

By Marilyn Ferdinand

On Sept. 14, 2015, a very exciting discovery in astrophysics was made. Scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) in Livingston, La., and Hanford, Wash., detected gravitational waves—ripples in space-time—produced some 1.3 billion years ago by the merger of two black holes into one massive black hole. Fittingly, the discovery occurred on the 100th anniversary of the publication of Albert Einstein’s general theory of relativity, which predicted the existence of these waves.

Since that first discovery, the LIGO Scientific Collaboration and the Virgo Collaboration, which together represent international working groups of more than 1,300 scientists, have detected three more events that have produced these waves, including the collision of two neutron stars. Their success has launched the new field of gravitational wave astronomy. It also provides a unique window into the way science advances.
THE EVOLUTION OF SCIENTIFIC DISCOVERY

Although the results of scientific advances are all around us—the cars we drive, the cellphones we use, even the foods we eat—many of us left the pursuit of scientific knowledge behind us after we completed our schooling and may no longer know or care about how our modern world continues to evolve. The world of the scientist may seem mysterious, even suspect.

“I don’t think people understand how self-critical scientists can be,” says Mark Potosnak, associate professor of environmental science and studies. “Scientists are very constrained by data and observations. When they jump ‘outside the box,’ they’re hopping out just a little bit, maybe rebuilding the box a little bit further.”

Indeed, the sciences consist of bodies of knowledge that may extend back many hundreds of years and that have undergone repeated revision. “It’s very easy for us to focus on one individual or one figure,” says Anuj Sarma, associate professor of physics, speaking about the popular image of a lone scientist achieving a “Eureka!” moment. “Very few people, in my experience, are inclined to focus on entire communities of scientists that are working together to advance a common goal.”

The discovery of gravitational waves is an example of knowledge building on knowledge, how various pieces of a puzzle emerge and come together.

Through the centuries, what astronomers have known about the universe has come in the form of electromagnetic waves, primarily optically visible light. In the 20th century, technological innovations added other wavelengths of electromagnetic radiation to the astronomer’s toolbox, including radio, infrared, ultraviolet and X-ray.

In his general relativity theory, Einstein introduced the idea that gravitational waves exist. He theorized that the presence of matter curves and distorts space-time. Very high-mass objects like black holes and neutron stars orbiting each other would produce such violent distortions that ripples in the fabric of space-time would spread outward much like waves radiating from a stone thrown into a lake. These waves would carry information not only about their violent origins, but also about the nature of gravity itself. The waves, however, are tiny and very difficult to detect. These gravitational waves predicted by Einstein represent an entirely new and independent window into the universe, and scientists and engineers worked decades to build an instrument capable of perceiving them.

Because black holes do not generate electromagnetic radiation, no traditional astronomical tool can independently confirm and study black hole mergers. More exciting, therefore, was the additional discovery on Aug. 17, 2017, of gravitational waves coming from the merger of two neutron stars. Since such mergers of neutron stars are less massive than those of black holes, both gravitational waves and electromagnetic radiation across a spectrum of wavelengths should be produced when they merge. Observation proved this to be true.

“There were three observatories that were able to pick up the gravitational wave detection, but also there was a so-called gamma-ray burst, a GRB, which is an electromagnetic wave,” says Sarma. “This is now the important part—there is a simultaneous observation, gravitational and electromagnetic.”

Several major observatories in the world—optical, X-ray, radio, gamma-ray—are part of a coordinated system designed to maximize the number of instruments focused on any unusual event in the sky, in particular, to determine the direction of the event and localize it to as narrow a segment of the sky as possible. “The system was in place to move really quickly. When they got the information about this neutron star detection and the fact that there was a GRB, everything zeroed in on this location, and they were able to get simultaneous detection. They have been studying it ever since,” Sarma enthuses.

“Understanding uncertainty doesn’t mean that it’s all false, just that very rarely are we 100 percent certain about something.”

Mark Potosnak, associate professor of environmental science and studies

Sarma looks at the observed proof of gravitational waves as a classic example of the collaborative nature of scientific discovery. “Einstein, of course, predicted them, but even he was not very confident that they would be able to be detected. It’s a tribute to all the people who worked in that field that they had the confidence to build these observatories and actually search for gravitational waves.”
SCIENCE AS A WAY OF KNOWING

This achievement in astrophysics is inspiring and offers the public a chance to understand how science really works. This understanding is particularly important as skepticism about the value of science and its conclusions has gained momentum in the past few decades. Thus, educators have begun to develop courses that teach science as a way of knowing (SWK).

Unlike specific problem-solving in fields such as biology, physics and chemistry, SWK is the study of science as an intellectual and social endeavor. The first SWK-designated courses in the liberal studies program that all DePaul undergraduate students are required to take debuted during the fall 2015 quarter. The SWK courses and labs cross disciplines, from physics and environmental science to education and digital cinema.

Sitting on the committee that oversees SWK learning outcomes is Maggie Workman, instructor/laboratorian in environmental science and studies and STEM studies. She says, “You would think that doing a lab course would allow students to see how science is done and the nature of science, but it really doesn’t, especially because a lot of labs are what we call ‘cookbook labs’ where students follow instructions. A lot of research is showing that you need to teach explicitly the process of science. It’s not about ‘What’s the structure of a cell?’ It’s about ‘How do we know what the structure of a cell looks like? How do we know how the cell works?’”

What Potosnak, who chairs the committee that oversees SWK learning outcomes, and his colleagues hope to instill in students is the scientific worldview and the nature and process of science. “We start with the basics—predictions and theories and hypotheses. But it’s placed more in context so students will be able to evaluate the role of creativity.”

Sarma says, “In that sense, you’re almost like an artist. You play an instrument for the joy of playing...
the instrument. Here the effort is to also highlight all the different ways in which these ideas come up.” For example, one scientist may talk to another about an idea that is not panning out, and that conversation could spark a new line of thought that leads them to a breakthrough.

Workman adds that putting scientific processes in context can help students understand that it can take many years for a theory to become accepted. She gives the example of German polar researcher, geophysicist and meteorologist Alfred Wegener’s theory of plate tectonics, which states that continents slowly drift around the face of the earth, and discusses how it took years and the accumulation of new data for the scientific community to accept the idea. She says students told her, ‘We missed that whole background of the process becoming accepted.’ So I know they really appreciated that process a lot more.”

“Another big outcome would be that students can recognize uncertainty,” says Potosnak. “Some of the attack on science to me reflects the fact that we haven’t done a good job of teaching how science really works and what science can and cannot tell us about things. Understanding uncertainty doesn’t mean that it’s all false, just that very rarely are we 100 percent certain about something.”

Science also is influenced by the social environment in which it is done. Sarma plans to introduce the discovery of gravitational waves into his SWK course Einstein’s Peculiar Ideas. “The course now involves not just the facts about Einstein’s discoveries, but also thinking about all these different things that Einstein did and connecting them to personal events in his life. We learn not just the facts of science, but also the process and environment in which science is done,” Sarma says.

**SCIENCE AS HUMAN ENDEAVOR**

Potosnak sees SWK as particularly relevant in helping people excel on the job, no matter what field they are in. “From a plain old job skills point of view, I think this rich understanding of science is important. You can put business students into a science class because we want well-rounded people and have them learn about atoms, electrons and molecules. They walk away with a little content.

“But in their job, someone’s asking about enzymes, and they think, ‘Oh, I know about electrons, but not enzymes,’ and are kind of at a loss,” he continues. “If you learn the process of science and really have a rich appreciation for the process, then you’re still not going to know what an enzyme is, but you might be able to better evaluate how to start, who to ask.”

“I think the story of science is a story of human endeavor. Sometimes you fail, sometimes you win,” Sarma says. “I hope that at the end [of my course], students are taking this with them, not just a grade. Hopefully, this will broaden their horizons. Hopefully, they will learn to see this as yet another human endeavor, where you go off in different directions. You will see many different things along the way.”