Era of astronomical discovery

8 July 2014, by Leda Zimmerman

Nergis Mavalvala (pictured) aims to detect elusive gravitational waves. Credit: Len Rubenstein

For much of her professional life, MIT professor Nergis Mavalvala has been devoted to a singular goal: creating a device to detect gravitational waves. These ripples in the fabric of space-time—the signature of violent cosmic events—are "extremely aloof," Mavalvala says. In fact, gravitational waves have been dodging elaborate efforts by scientists to track them down since Einstein predicted their existence a century ago.

But last March brought a possible breakthrough: Astronomers at the Harvard-Smithsonian Center for Astrophysics discovered what appears to be the first direct evidence of gravitational waves. For Mavalvala, the Curtis and Kathleen Marble Professor of Astrophysics, the news could not be more thrilling. She believes it may herald a new era of astronomical discovery. "It will be exciting beyond measure, and the greatest excitement will be finding things we can't yet imagine," she says.

Mavalvala is certainly ready. Since her graduate school days in the early 1990s at MIT, she has been helping design and build the Laser Interferometer Gravitational-Wave Observatory (LIGO). For helping design this complex and finely tuned scientific tool for detecting gravitational waves, Mavalvala won a MacArthur Fellowship in 2010.

Many large heavenly bodies and events in the universe, such as the birth and death of stars, generate energy in different wavelengths of light, which existing telescopes can find, she says. But compact astrophysical objects—such as neutron stars and light-eating black holes, which are believed to produce energy in the form of gravitational wave radiation—remain concealed from human view. These waves, unlike light, she says, "flow through everything, because matter is basically transparent to them. They come to us unobstructed right from the source." For Mavalvala, gravitational waves are "a clean messenger bearing information about how the universe is put together."

LIGO's instrument for detecting the extremely faint signature of gravitational waves is "an exquisitely sensitive interferometer," Mavalvala says. It measures the time it takes for light beamed from a laser to strike a mirror four kilometers away and reflect back. Theoretically, a gravitational wave arriving on earth and passing between laser and mirror will slow down the light as it bounces, thus changing the distance between the two infinitesimally. LIGO is built to identify a change in distance of 10 to -18 meters—1,000 times smaller than a proton.

Members of an international team, Mavalvala, and her lab colleagues have been refining the laser interferometer, specifically the optical sensing and control system. In the past several years, two observatories have started up—one in Washington state and the other in Louisiana—but have not yet yielded results. LIGO researchers are now sharpening their focus by a factor of 10. "This allows us to be sensitive either to weaker gravitational waves, or to the same sources, such as a pair of neutron stars colliding, but farther out," Mavalvala says.

Engaged with LIGO's second-generation detectors, Mavalvala is contending with a critical problem involving the instrument's measuring precision. But she has some clever tricks to sidestep these constraints. One deploys "squeezed light sources"—laser beams whose quantum properties are manipulated to reduce noise fluctuations—that may improve the sensitivity of the LIGO detectors and render more accurate measurements.

"The big picture mission drives you. When you work in the lab, [it's like] you bang your head against the wall for weeks at a time, working on a state-of-the-art circuit, for example," Mavalvala says. "Yet this is what enables scientific discovery, when the smaller to bigger pieces of experiments succeed, when the whole thing does what it is supposed to, and then you hope nature gives you the event you've been waiting for."

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