Vacuum technology makes gravitational waves detectable

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You probably didn't notice the gravitational wave that propagated through the Earth in the early morning of Jan. 4, 2017, but thanks to a sophisticated use of vacuum technology, a pair of extremely sensitive laser interferometers, one in Washington State and the other in Louisiana, detected the faint rumble from two colliding black holes some 3 billion light-years away.

In a presentation during the AVS 64th International Symposium and Exhibition, being held Oct. 31-Nov. 2, 2017, in Tampa, Florida, astrophysicists Rai Weiss (who, along with two others, was awarded the 2017 Nobel Prize in physics) and Michael Zucker of the Laser Interferometer Gravitational-Wave Observatory (LIGO), operated by Caltech and the Massachusetts Institute of Technology, will describe how LIGO scientists and engineers designed and constructed LIGO's ingenious, ultra-high vacuum system. The system is an integral part of what makes it possible to identify gravitational waves, minute distortions in the fabric of space and time that propagate at the speed of light.

"The gravitational waves generated by the acceleration of a pair of black holes move outward like waves in a pond," Weiss said. "The distortions of space they induce get weaker inversely proportional to their distance away from the source, so waves travelling billions of light-years to earth can only be detected if one can measure a distance of 10^-18 meter —1/10,000th the width of a proton—which is the tiny amount our interferometer's mirrors are moved by a passing wave."

To accomplish the Herculean task, Weiss explained, the mirrors are suspended at both ends of the LIGO interferometer's two 4-kilometer arms. The mirrors form an optical cavity in which light can bounce back and forth along the arms many times. A laser beam is sent through a splitter at the junction of the arms, separating the light into two beams. The optical cavities reflect the beams back to the splitter where they are merged into a single entity, which then strikes a photodetector.

"If the split beams have traveled the same distance in both optical cavities, the two beams will 'destructively interfere,' that is, cancel each other at the photodetector," Zucker said. "But if the arm lengths change so that one beam spends more time in its cavity while the second beam spends less time in the other—as they will a tiny bit when a gravitational wave passes through the system—the light waves are not canceled and some light is recorded at the photodetector."

So, how does vacuum technology play a role in making this happen? Weiss said that molecules of any gas present in the interferometer arms could scatter the laser light or produce a dominating noise that would mask the small-time changes in the beams due to gravitational waves. Operating in a vacuum eliminates these problems, as well as the additional hazard of thermally generated gas molecules causing fluctuations in the length of the cavities.

The daunting task for the LIGO team, Zucker said, was to design and construct an efficient, yet economical, system that could achieve the extreme vacuum needed for the interferometer: 100 nanopascals, one-trillionth of one atmosphere and equivalent to the near-absence of pressure in low Earth orbit.

In their presentation, Weiss and Zucker will focus on the fundamental physics and engineering expertise needed to build and run the world's second-largest ultrapure vacuum system, meeting challenges such as 40 days of constant "pumpdown" to achieve the optimal operating pressure, 30 days of heating the tubes (arms) to drive out residual gases, and the 24/7 operation and monitoring of ion pumps and liquid nitrogen cryopumps that keep the LIGO interferometer free of contaminants.

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