Stochastic resonance, chaos transfer shown in an optomechanical microresonator

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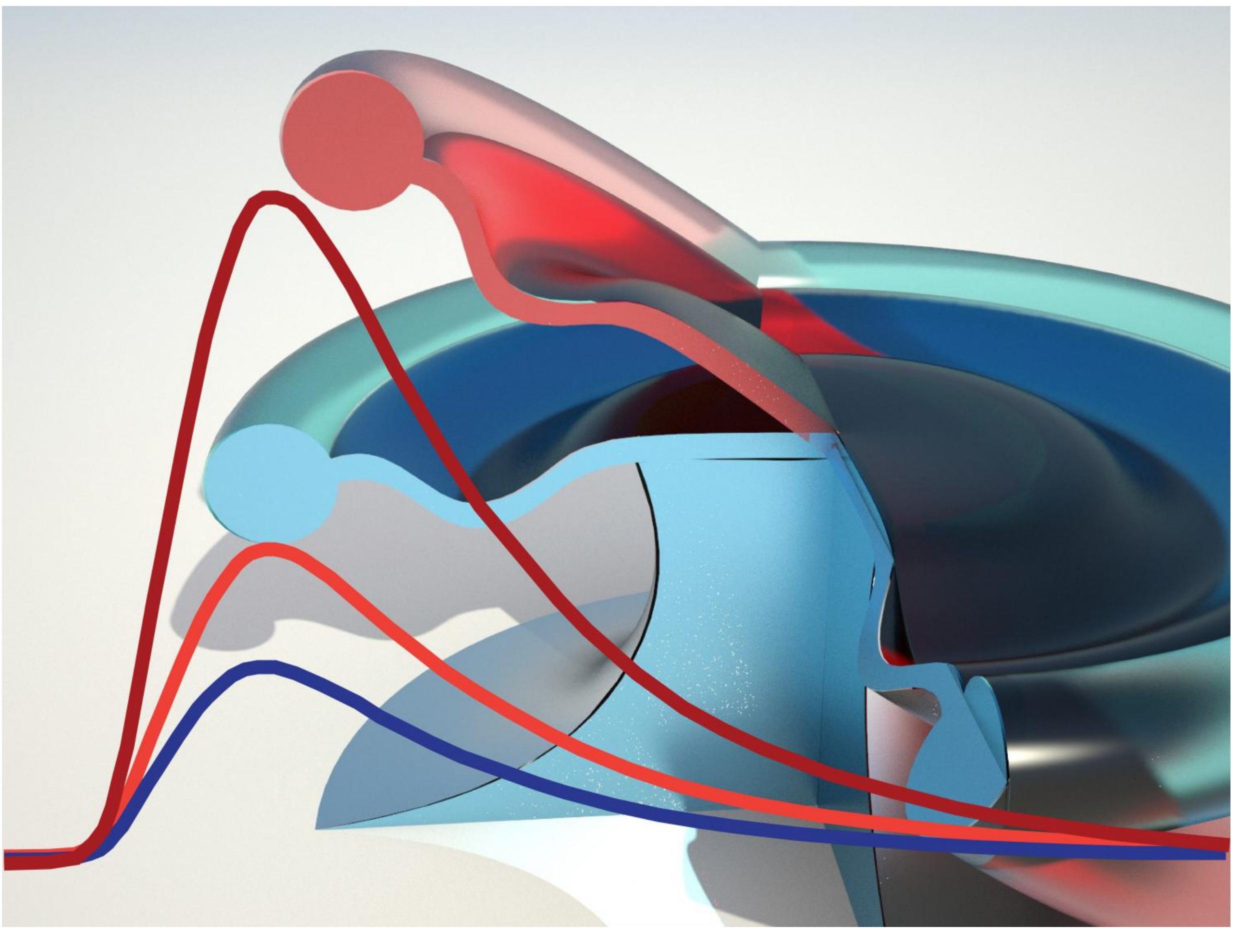

An artist's view of the stochastic resonance (SR) in an optomechanical resonator. The circular ring on the pillar resembles cross-section of a microtoroid resonator undergoing periodic mechanical oscillations (depicted as up (red) and down (blue) flapping) due to radiation pressure of light circulating within the structure. The bell-shaped curves represent the SNR as a function of noise in the system. Mechanical oscillations create a nonlinear system for the optical field and drive it into periodic and then to chaotic regime. Chaos with the help of optomechanical backaction noise enhances the signal-to-noise ratio (SNR) of a weak optical signal in the same resonator. Stochastic resonance occurs when the peaks in the noise coincide with the peaks of the weak signal. The SNR rises sharply to a maximum where SR occurs and then gradually decreases as the amount of noise is increased. Credit: B. Peng, S. K. Ozdemir, F. Monifi, L. Yang

Researchers in the School of Engineering & Applied Science at Washington University in St. Louis have discovered a novel route to encode chaos on light in an optomechanical microresonator system.

An optomechanical microresonator system combines optics and mechanics in a very small area to study the nature and activities of light affected by the mechanical movement of the system.

As in the famous Robert Frost poem, the road to chaos diverges out of a world of noise and forks in a branch called a bifurcation route. The light beams took the fork in the road, both following the same paths to chaos. Unlike the Frost setting—so quiet one can hear the snow land—the optomechanical microresonator used the noise within itself to boost the light signals so that they can be detected.

This use of what is called stochastic (random) resonance—a response of a system to periodic pulses or signals with the aid of usually undesired energy called noise—is the first reported indication of the phenomenon in an optomechanical system.

Chaos—or sensitivity to initial conditions, which, in theory, can have major effects on complex systems—and noise in nature happen in the same manner that bad things arise in life: often randomly, out of nowhere and with few tools to control it. Thus, it's not surprising that most researchers look askance at the duo.

Yet the School of Engineering's Lan Yang, the Edwin H. & Florence G. Skinner Professor of Electrical & Systems Engineering, and ?ahin K. Özdemir, research associate professor in Electrical & Systems Engineering, along with collaborators in China and Japan, have shown that they can actually encode chaos on a weak light signal and did so with the help of optical radiation and mechanical oscillation, or vibration.

Their findings, published in *Nature Photonics* May 9, could have implications for secure optical communications, where information is encoded on individual light packets, or photons, that are sent in space or through optical fibers and for high-performance sensing.

Yang and Özdemir manipulate and mediate light in a state-of-the-art microresonator called a whispering gallery mode resonator (WGMR) because it works similarly to the renowned whispering gallery in London's St. Paul's Cathedral, where a person on one side of the dome can hear a message spoken to the wall by another person on the other side. Their device does much the same thing, with light frequencies rather than audible ones.

Faraz Monifi, then a doctoral student in Yang's lab, and Jing Zhang, a visiting researcher from Tsinghua University in China, used two lasers: a control of 1.5 micrometer wavelength, called a pump; and a probe of 980 millimeters in the WSMR, itself just 60 microns.

The pump drives the operation and is very powerful, comprised of millions of photons; the probe is very weak and would languish in the system without the pump to force action. The pump, which is used continuously, creates mechanical motion (vibration) on the walls of the resonator (the changes in the momentum of the pump photons trigger radiation force in the WGMR), which then begets optical nonlinearity, and because the two light fields are in the same nonlinear medium of the WGMR, things literally heat up (photons carry momentum and their intensity promotes radiation in the WGMR), and they start affecting each other. Eventually, after periodic bursts, both the pump and probe skedaddle down a two-pronged path to chaos.

"In this work we use the mechanical mode of vibration to provide a new route to chaos," Yang said. "The oscillation, referred to as radiation-caused mechanical vibration, mediates the optical field. We couple the two optical fields, which are far away from each other, one in short wavelengths, the other in long ones. You would think that they would not have anything to do with each other, but they become coupled and take the same paths to chaos."

The weak probe signal would go undetected at the output of the optomechanical system without the assistance of stochastic resonance, Özdemir said.

"For stochastic resonance, you need three things in a system," he said. "One is nonlinearity, another is random noise, and the third is a periodic input signal so weak that you can hardly observe it. In this way, you can make use of noise to boost the signal-to-noise ratio of the system so that even very weak signals can be detected. However, there is an optimal level of noise beyond which the performance of the system starts to deteriorate."

Yang said that chaos is commonly seen in optomechanical systems where there is mechanical oscillation.

"The novelty that we bring with this paper is the route to chaos creation," she said. "No one has used one beam to get another beam to follow the same path to chaos in an optomechanical system."

"The question we wanted to ask was, Can we create a chaotic system with a very weak driving field?" Özdemir said. "You can't do that with a weak optical field in an optomechanical resonator. But instead of creating chaos directly with a weak field, we aimed at creating chaos in a strong field, the pump, and transferring that chaos into a weak field, the probe. And we succeeded."

Yang, Özdemir and their collaborators said the observed stochastic resonance and their capability to generate, transfer and control chaos in an optomechanical resonator not only contribute to the understanding of nonlinear phenomena and chaos, but also hold the potential for developing photonic devices that exploit the sensitivity of chaos to initial conditions, for improving the detection of otherwise undetectable weak signals in optomechanical systems, and for secure communication.

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More information: *Nature Photonics*, DOI: 10.1038/nphoton.2016.73

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