Physicists detect the undetectable: 'baby' solitary waves

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When University at Buffalo theorist Surajit Sen published his prediction that solitary waves, tight bundles of energy that travel without dispersing, could break into smaller, "baby" or secondary solitary waves, experts in the field acclaimed it as a fine piece of work.
They also felt that these waves might never be seen experimentally.
But in a paper published this week in *Physical Review Letters*, Sen and his co-authors report that they have done just that.

The new results contribute to a better understanding of how energy propagates through strongly nonlinear systems, where nearly every detail of the system matters and that make up many of the systems of interest to scientists.

"A central theme behind the physics of any system is how its particles share and transmit energy," explained Sen. "This work goes to the heart of nonlinear systems because it provides insights into how such systems propagate energy."

The current research also may overturn completely the generally accepted idea that equilibrium states – or at least a similar type of state – cannot easily occur in nonlinear systems.

"Solitary waves are, by definition, energy bundles, which do not fall apart," Sen explained. "They are not supposed to be easily breakable because they are energy bundles, so they generally travel intact and don't transform."

But in papers Sen published previously, (in 2001 in Physical Review E 63, pp. 016614-1-6 and in 2002, in Physical Review E 66, pp. 016616-11), his computer simulations predicted that in fact, solitary waves could break, forming many secondary or "baby" solitary waves .

Unfortunately, the magnitude of the baby solitary waves that Sen predicted was much less than one percent of the energy carried by the entire solitary wave, far below detectable experimental limits.

"When we published our papers, I also didn't believe these phenomena would be detectable," admitted Sen.

His predictions were based on a collision of two solitary waves.

"My assumption was that when two solitary waves in a granular system collide head-on, the physics is similar to bouncing a solitary wave off an infinitely hard wall," he said.

But the experiment conducted at Universidad de Santiago by Sen's co-authors in fact produced "baby" solitary waves that were as large as 15 or 20 per cent of the energy propagated through the entire system.

What allowed the team to produce such large secondary waves, and therefore verify the predictions, was the decision by Francisco Melo, Ph.D., professor of physics at the Universidad de Santiago, to collide solitary waves traveling through a chain of 20 identical stainless beads against a wall made of a soft material.

Melo, his post-doctoral researcher, Stephane Job (now an assistant professor at Institute Superieur de Mecanique de Paris), and UB undergraduate physics major Adam Sokolow, also a co-author, embedded non-intrusive force sensors into one bead and the reflecting wall.

The beads were bounced against the wall and the sensor then recorded the amount of force with which the last bead hit the soft wall.

"To observe large baby solitary waves, the idea is that by introducing a large mismatch of mechanical properties at the wall, the reflected solitary wave needs to adapt more dramatically, thus producing such large baby solitary waves," explained Melo.

This set-up resulted in successfully amplifying the effect Sen had predicted so greatly that it was experimentally verifiable.

"This work proves that these solitary waves, or energy bundles can be made to 'leak,' in a sense, producing these secondary or baby waves," said Sen.

Even more interestingly, he said, the work indicates that it may be possible to control that leakage, potentially leading to a new understanding of how a physical state akin to equilibrium may exist in nonlinear systems.

"For physicists and mathematicians, systems in equilibrium are like the ocean, they are in a tranquil, settled state," explained Sen. "But when you talk about solitary waves propagating in a system, you're as far away from a system in equilibrium as you can be because these systems carry significant amounts of energy as propagating energy bundles, sort of like a propagating shock front.

"Our work shows that a system can propagate a huge pulse of energy as in a shock wave, but if placed between two walls, the original energy you gave to the system can get broken down," he said. "Since that energy can end up being shared by all grains or spheres in the system, there is some semblance of equilibrium here."

The experiment also resulted in an unexpected finding about a materials constant called the Youngs modulus – which describes the ability to stretch or squeeze a material-- that is usually more the concern of mechanical and materials engineers than physicists, Sen said.

"Bouncing a solitary wave against a surface provides an accurate and non-invasive way to measure the Youngs modulus of a surface," he explained.

UB undergraduate Adam Sokolow, who was awarded a UB Undergraduate Research and Scholarly Award of Distinction for this work, spent the summer of 2004 at the Universidad de Santiago, acting as a bridge between the simulations performed by his UB mentor, Surajit Sen, and the complex experimental work, which was carefully controlled by post-doctoral researcher Job.

Sokolow's stay was funded by the Consortium of the Americas for Interdisciplinary Science of the University of New Mexico, designed to facilitate collaborations between scientists in New Mexico and throughout the United States with those in Latin America.

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