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Dancing with Pythagoras

Megan Scudellari, *Science Writer*

To the steady beat of drums, three ballerinas pirouette and plié toward the center of a stage. Two make contact, embracing and spinning in apparent joy. The third does not reach them in time, and she trails away to one side, alone.

It is the opening scene of the evocative, though dryly titled “Interpretations of the Pythagorean problem,” a dance created by astrophysicist Gregory Laughlin and choreographer Edward Warburton of the University of California, Santa Cruz.

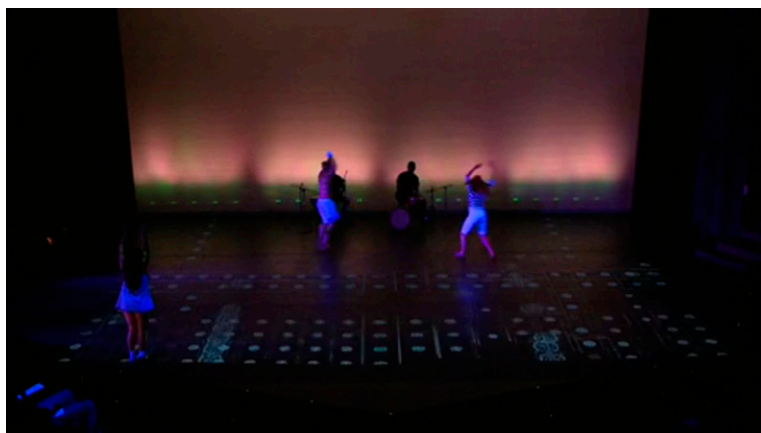
The two met in 2010 when Laughlin approached Warburton at the end of a university committee meeting with an idea for a dance. Warburton smiled politely, shook Laughlin’s hand, and left with no plans to follow up. A few months later, a persistent Laughlin reached out again and stated the classic physics problem behind his idea: Imagine three bodies with masses 3, 4, and 5 at the corners of a 3-4-5 Pythagorean right triangle, each body at rest opposite the side of its respective length. When the bodies are released to move freely, what happens?

Initially, Laughlin explained, the three fall toward one another, attracted by gravity. However, they do not collide, and that’s when things get interesting. The bodies move in increasingly complex patterns: so complex, in fact, that the Pythagorean three-body problem stymied physicists from its first description in 1893 until 1967, when it was solved with the help of a computer (1).

Laughlin described the concept to Warburton not as a math problem but as a beautiful, tragic narrative of three interacting parties torn asunder in the end when the two heavy bodies remain and the third is ejected dramatically into space. “This narrative of competition, redemption, and ultimately loss was compressed into something so austere that it fascinated me,” says Laughlin.

This time, Warburton was inspired. In 2012, the duo premiered a 3-minute 45-second performance of “Three Bodies” at ZERO Biennial, a digital art and new media festival in Silicon Valley. Three dancers, choreographed by Warburton, moved through the classic solution to the problem as calculated by Laughlin. The performance was laden with technology: Each dancer wore LED-equipped tracers tracked by a camera to detect and project their movement onto a screen behind them.

After that performance, Laughlin and Warburton discussed additional variations to the three-body problem, situations in which the initial positions of



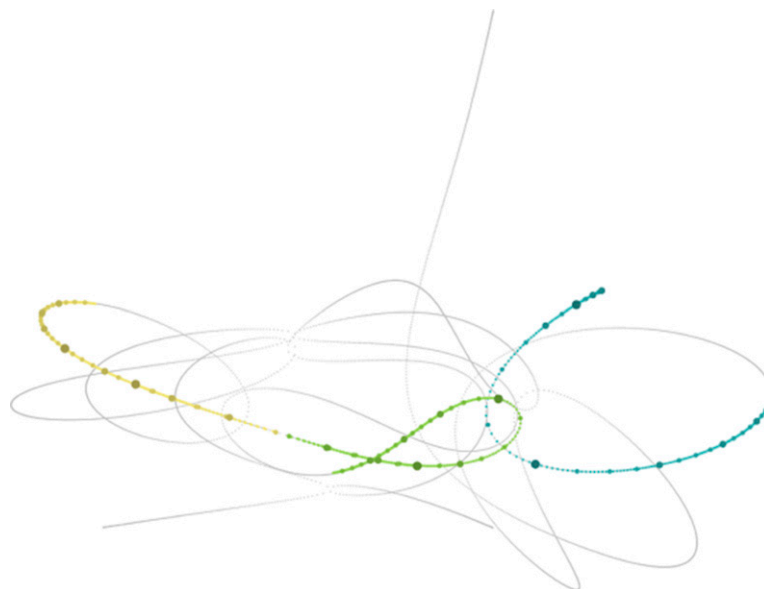
A collaboration between an astrophysicist and a choreographer resulted in an elaborate dance evoking competition, redemption, and loss. Here the dance is performed at a University of California, Santa Cruz dance festival in 2013. For the full video of this performance, see <https://vimeo.com/75623011>. Image courtesy of Ted Warburton (University of California, Santa Cruz, CA).

the bodies were slightly altered. In one case, called the periodic solution, the three bodies are positioned so that they come back precisely to where they started. In another, the smallest body is slightly nudged to the side at the start, initiating a butterfly effect that alters all of the resulting motions.

Laughlin and Warburton began to plan a new performance including all three interpretations. This time, they let go of the technology used in the previous performance, replacing it with just a brief description of the three-body problem projected on a screen before the dance. “It just felt like we were trying too hard to make everyone see [the solution] and understand,” says Warburton. “We realized it’s not necessarily about someone having an epiphany—‘Oh! That’s what the three-body problem means’—but about the underlying emotional tone.”

So the lights, tracers, and composed music were exchanged for two drums and an austere stage. For each of the three problems, Laughlin calculated solutions: solving a set of differential equations describing the location and movement of the bodies in space at a given time. He translated those numbers into graphs and diagrams for Warburton and the dancers, and created animations to project on the rehearsal floor to cue the dancers.

With the timing, space, and dramatic narrative constrained by the math, Warburton and his dancers focused on exploring and applying movement dynamics.



The three-body problem can play out in a multitude of ways, including a periodic solution. This occurs, for example, when bodies four and five experience a perfect head-on collision while body three simultaneously comes to a complete stop, leading to the bodies rebounding back along their trajectories of approach. The motion retraces, therefore repeating endlessly, as diagrammed here. Image courtesy of Gregory Laughlin (University of California, Santa Cruz, CA).

"It gave me a greater appreciation for the rigors of choreography," he says. The performance premiered in May 2013 at Blueprints, a University of California, Santa Cruz dance show. In the first act, three ballerinas in white trace the classic Pythagorean solution with leaps, spins, and twirls. In the second, a man and two women perform a free-flowing, contemporary dance thick with animalistic movements to depict the unpredictable "butterfly" solution. In the third, three dancers tango in a loop of precise, intricate gestures to the "periodic" solution, ending precisely where they began. (For a full video of this dance, see <https://vimeo.com/75623011>.)

Finally, all nine dancers come onstage to perform the three variations at the same time. Here, the creators simply wanted to see what would happen. The three solutions sometimes came together, coalescing into similar patterns or speeds, then split anew. It was "like magic," say Laughlin. "With this superposition of the three outcomes, you get a sense of the way in which nature works, in which things start out similarly and then diverge and bifurcate."

It is no surprise that math and dance intertwine so fluidly, says dancer and math professor Karl Schaffer of DeAnza College in Cupertino, California. "Mathematics has been described as the science of patterns, and in dance you're constantly manipulating and playing with patterns," says Schaffer, who codirects a dance company specializing in performances based on mathematical ideas (2). "Mathematical ideas are a paint on the choreographic pallet."

Neither Warburton nor Laughlin desired to use the dance to teach math. "We simply wanted to do an interesting project," says Laughlin. Warburton concurs: "It's a new avenue for developing work, where you have these specific constraints and you don't always know how it will come out."

Next, Laughlin and Warburton hope to work with other choreographers and dancers to create additional versions of the three-body problem. "You can talk colloquially about choreography discovering something, but in this piece that's literally true. The dancers discover what actually exists in some abstract form," says Laughlin. "We think [this approach] can inform a lot of different projects with choreography."

1 Szebehely V, Peters CF (1967) Complete solution of a general problem of three bodies. *Astron J* 72(7):876–883.

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