To Solve a Cosmic Mystery, FQXi Awardees Think Outside the Box

fq(x) News

Justin Khoury and Maulik Parikh dust off an old idea from Ernest Mach – the speed-of-sound guy – to update Einstein's relativistic view of space and time.

by MIKE MARTIN

FQXi Awardee: Justin Khoury, Perimeter Institute and Maulik Parikh, Columbia University June 15, 2007

Albert Einstein's cosmos is a box without walls, a universe containing an abundant bounty of accelerating objects—spinning electrons, orbiting planets, rotating stars, and swirling galaxies-- but no walls to contain that bounty.

Walls and boundaries don't figure in Einstein's theory of relativity, where the only constant is the speed of light and all motion is relative. According to that theory, unless you measure your position with respect, say, to a planet or a spaceship, you can't tell you're moving at a constant speed.

> Einstein's Relativity Principle states that uniform motion is relative to the reference frame in which it's measured. Mach's Principle requires that accelerated motion is also relative to a reference frame.
>
> *- George Spagna, Randolph-Macon College*

But relativity contains an important exception. Regardless of where you are, the minute you speed up, slow down or rotate-- that is, you accelerate--you know you're in motion. Even in empty space, without any way to gauge your position or speed, you can feel the change in motion.

To incorporate this exception into the Theory of Relativity, and solve a puzzle worthy of Pandora, FQXi Awardees Justin Khoury and Maulik Parikh think Einstein's box must have walls after all. They've set out to prove it by dusting off a century-old idea many physicists had long ago discarded.

Wish Upon A Distant Star

Better known for Mach speed—the famous namesake measure of speeds higher than the speed of sound—Austrian physicist Ernst Mach first conceived the notion that even accelerated motion could be relative. According to Mach, all the matter in the universe influences earthly accelerations.

Mach suggested that mass there—what he termed "distant stars"—affects motion here, creating a reference frame by which an observer can ascertain whether something is rotating or otherwise accelerated. With the Earth's gravity pulling everything down, something else, Mach reasoned, must be causing a tetherball to rise as it swings, or water to press against the sides of a bucket at the end of a rotating rope.

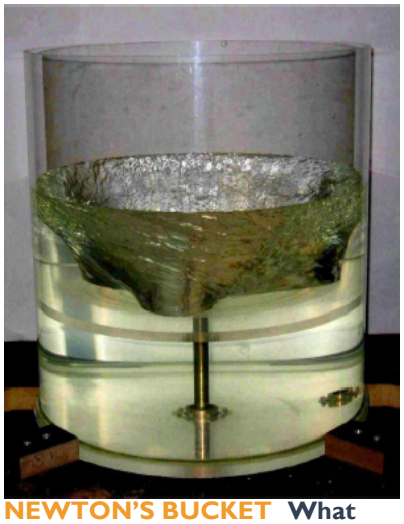
Einstein called this idea Mach's Principle, initially regarding it "as one of the foundational pillars of General Relativity" his remarkable theory of gravity, Parikh says.

General Relativity showed that acceleration and gravity were equivalent. Knowing that mass and energy are responsible for gravity, Einstein shared Mach's conclusion: Somehow, mass and energy must be responsible for acceleration, too.

Essentially, without matter there can be no acceleration "because there is nothing to accelerate with respect to," Khoury explains.

Keeble Observatory director George Spagna puts it another way.

"Einstein's Relativity Principle states that uniform motion is relative to the reference frame in which it's measured," says Spagna, who also chairs the Randolph-Macon College physics department. "Mach's Principle requires that accelerated motion is also relative to a reference frame."



NEWTON'S BUCKET What causes water to press against the sides of a bucket? Image Credit: physicsweb.org

Despite all the excitement of Einstein's day, today Mach's Principle is "under-appreciated," says Perimeter Institute physicist Lee Smolin, who also serves as a Scientific Advisor to FQXi. After nearly a century of scientific trial and error, Mach's Principle remains unproven, prompting Khoury to lament that many physicists now regard Mach's Principle as

"one of those tantalizingly beautiful ideas that sadly are not realized in nature."

Outside The Box

Khoury and Parikh's innovative ideas have catapulted them into and beyond a series of prestige universities - Princeton, Berkeley, MIT, and Columbia. Khoury is now ensconced at the world-renowned Perimeter Institute in Waterloo, Ontario. Parikh is on the faculty of the Inter-University Centre for Astronomy and Astrophysics in Pune, India, one of the world's top astrophysics research institutions.

Beyond-the-box thinking comes naturally to the two physicists, who had to do just that to make Mach—finally—work.

"Many previous attempts to put flesh on Mach's Principle have failed," Parikh says, but for a simple reason: Distant stars are inside the box, not along its walls. No matter how far out, every distant star is still part of the contents.

When Einstein tried to justify Mach's Principle, he ran into similar problems. His gravitational field equations only accounted for "the stuff inside the box—bulk matter," Parikh explains.

To make Mach matter in Einstein's universe, Khoury and Parikh consider the nature of the box's walls, so-called "boundary matter," Parikh says. "The beauty of it is that boundary matter does not spoil Einstein's equations in the middle of the box, where we presumably are."

But if distant stars aren't boundary matter, what is? To answer this question, Parikh and Khoury built an elegant universe, with walls like the ends of a rainbow—boundaries you can visualize but never actually reach.

A Beautiful Brane

With such powerful gravitational fields that they swallow anything that ventures near, black holes in space are better off avoided. But Khoury and Parikh used what they call a "beautiful idea"—the "black hole membrane paradigm"—to sketch the framework of their universal wall.

EXPLORING MACH'S PRINCIPLE IN GENERAL RELATIVITY **Maulik Parikh**

"The black hole membrane paradigm says that, surprisingly, equations describing a black hole can be transformed into equations that describe a fictitious membrane around the black hole, like a soap bubble," Parikh says.

By wrapping the universe in a similar membrane, Khoury and Parikh use a "mathematical trick" George Spagna says, to put Machian matter where it really belongs—on the walls of the box rather than inside it.

"The Khoury-Parikh work shows that in a region of space and time, all external gravitational influences can be represented by some matter distributed on the boundary of the region," adds Tufts University cosmologist and FQXi Awardee Alexander Vilenkin. "This matter is totally fictitious, but it does give a faithful representation of what is going on inside the region."

Boundary Quandary

But a thin membrane isn't much of a wall—it needs real substance, like plaster over lathe, or drywall over a wooden frame.

To finish their construction project, Khoury and Parikh looked to Einstein again. Like the parable of the lost men who count themselves but keep coming up one man short (because the man doing the counting forgets to count himself), Einstein neglected to count the effect of gravity on, well, gravity.

For Khoury and Parikh, this omission was the pot of gold at the end of the rainbow. Gravitational energy from distant stars—rather than distant stars themselves—turned out to be precisely the boundary matter they needed to plaster their wall. And befittingly, gravitational energy is not found inside the box. "It lives at the boundary," Parikh says.

Discovering that one man's distant stars were another man's gravitational fields, Khoury and Parikh created a match made in the heavens. Marrying the work of two masters, Parikh says they were able to show how matter determines the geometry of space and time "just as Mach and Einstein would have wished."

To properly visualize moving at a constant speed, you have to eliminate bumps, friction, and other tactile sensations from your mental picture. So, don't try to imagine yourself in a car or train; instead, think jumbo jet in a turbulence-free sky. Once you're at cruising altitude and no longer accelerating, close the window panel. You can't tell you're moving, even though you're zooming along at hundreds of miles per hour! How else do you think they hand out all those drinks?