

# Back to Mach

Want a theory of quantum gravity? Then look to the man who inspired Einstein, says Julian Barbour.

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**News**

by **KATE BECKER**

FQXi Awardee: Julian Barbour

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**F**or someone who believes time doesn't exist, Julian Barbour sure has a head for dates. He remembers exactly when he started to have doubts about time: It was October 18, 1963, and he was reading the newspaper. He spotted an article about the physicist Paul Dirac and his quest for a theory of quantum gravity—a theory linking Einstein's ideas about gravity to the clashing doctrine of quantum mechanics.

Today, Barbour is on that same mission to unite gravity with quantum mechanics. In order to succeed, he believes that we not only need to re-examine our understanding of time, but also question the conventional wisdom that the universe is expanding.

## Off the Clock

Happily for me, Barbour doesn't take advantage of his skepticism about time to shrug off appointments. After picking up the phone precisely on time for this interview, he asked for seven minutes exactly to finish the remaining third of his cup of coffee, and was ready and waiting for my call, coffee cup drained, 560 seconds later.

*I've been taken much more seriously saying that time doesn't exist than that the universe isn't expanding.*

*- Julian Barbour*

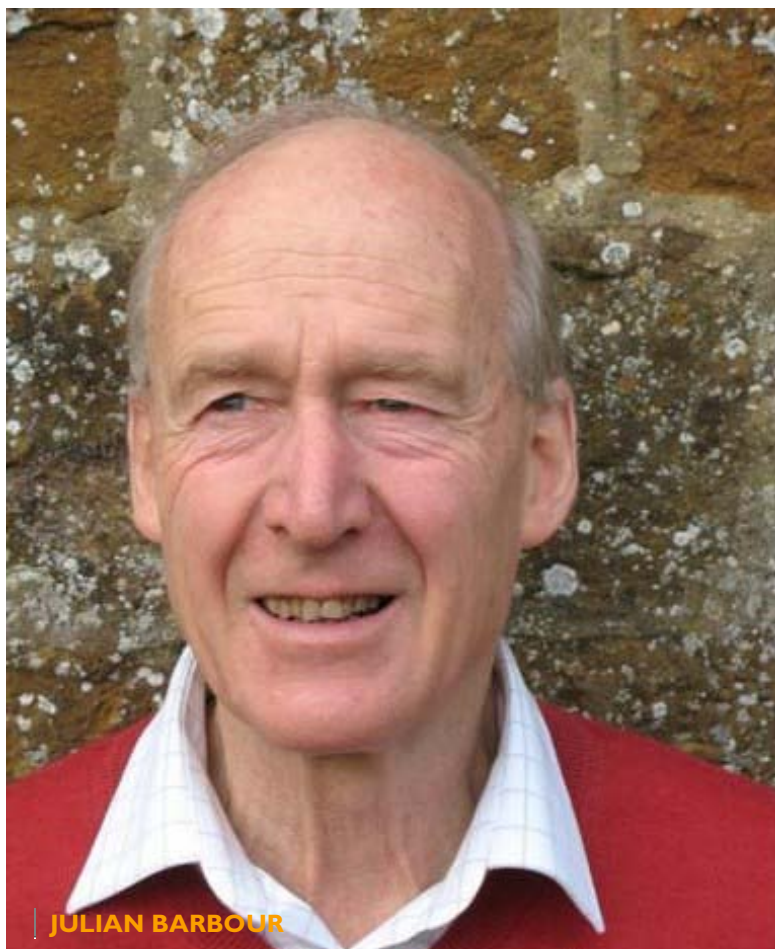
Barbour's certainly not the first physicist to question our understanding of time; Einstein was a skeptic, too. If Barbour had told Einstein to give him a call back in seven minutes, Einstein might have asked: Your minutes or mine? If

Barbour had been calling, say, from a spaceship moving at close to the speed of light, or one perched at the lip of a black hole, Einstein would find that each of Barbour's minutes would last far longer than his. There is no universal reference clock that both Barbour and Einstein could agree on.

But, asks Barbour, what if it isn't just time that has no universal reference—what if position is all relative, too? Ernst Mach—the multi-talented scientist who

discovered the sound barrier and gave his name to the eponymous numbers—suggested something similar in the late 1800s, rejecting “absolute” measurements and replacing them with relative, or relational, ones.

To get a handle on Mach's viewpoint, imagine a particle spinning out in space. If there were no stars forming a backdrop against which to measure the particle's motion, can we really say that the particle is moving? To Mach, the answer



was no, in an empty space there is no distinction between the particle spinning and the particle being stationary.

If this doesn't seem revolutionary, try seeing it from Newton's perspective. When Newton penned his laws of motion, Barbour explains, "He thought he'd seen 'the anatomy of God.'" And to Newton, God looked pretty much like three-dimensional graph paper. On top of this invisible coordinate grid, balls rolled, apples dropped, planets orbited.

To Newton, our particle could definitely be said to be spinning, because it was moving relative to the fixed grid of space. All one needed to understand the universe was full knowledge of where each object was on the grid, and when, according to the ticking of an invisible absolute clock.

## The expansion of space (is)...a surprising vestige of Newton's absolute space.

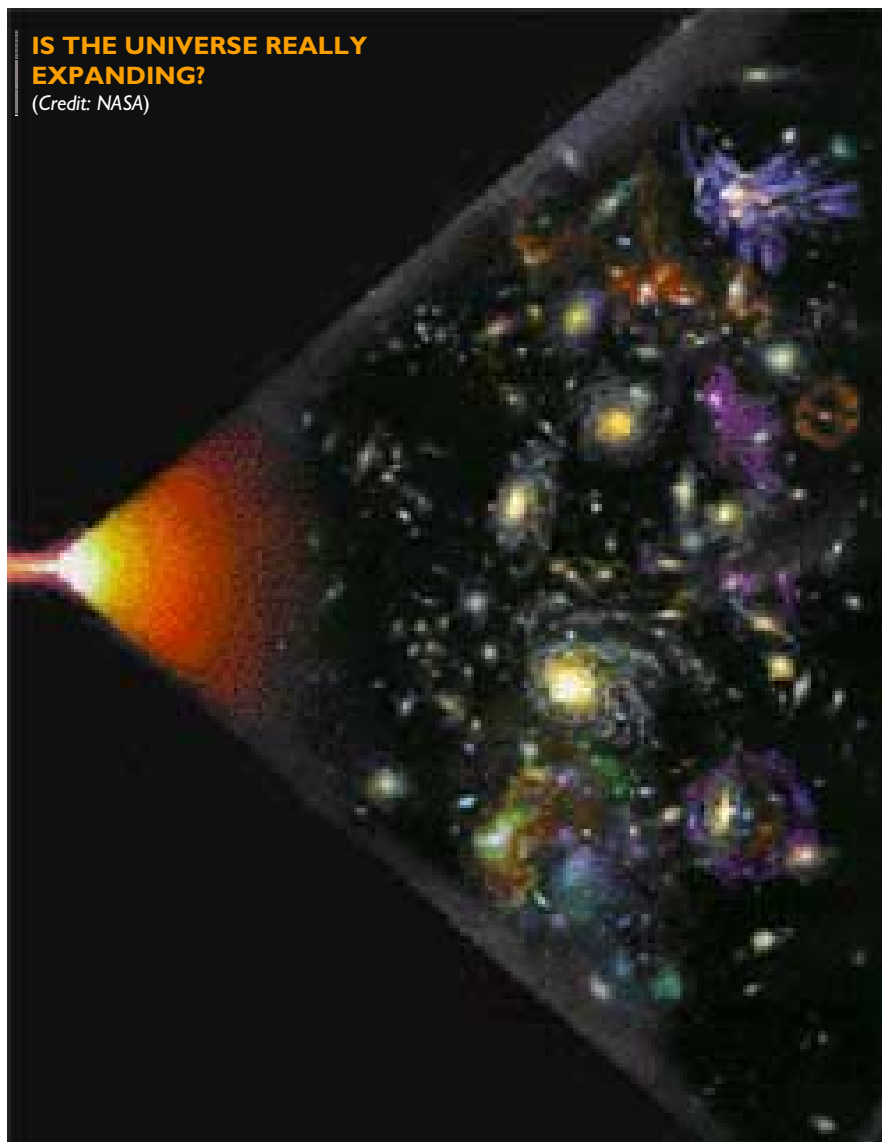
- *Julian Barbour*

Newton's "theory of change" was "phenomenally successful," says Barbour. Its weakness: "The invisible background grid and clock."

"My life's work has been about finding an alternative theory of change," says Barbour, one that is purely "Machian"—that is, a theory that does away with the grid and clock. Such a theory, he believes, might open the door to quantum gravity.

### Goodbye Old Grid

Einstein took a big step in deconstructing Newton's old grid. In his theory of General Relativity, Einstein reimagined the grid as pliable, allowing space itself to arch and flex under the influence of gravity. And because objects are in constant motion, Einstein saw the grid as dynamic, changing with time as gravity adjusted its grip. Einstein even coined the term "Mach's Principle" to describe the ideas that inspired him.



But for a "Machian" thinker, there is a problem: Following astronomer Edwin Hubble's measurements in the 1920s and 1930s, which showed that other galaxies seem to be receding from ours, Einstein accepted that the universe is expanding. Yet, with no absolute ruler to measure that expansion, how would it be possible to know that the universe is any bigger today than it was yesterday? "When you look at General Relativity, it is beautifully Machian," says Barbour. "But the expansion of space that it allows presupposes an absolute ruler. That's a surprising vestige of Newton's absolute grid."

Barbour explains with a geometrical analogy. Suppose the whole un-

iverse just consisted of a triangle. You could measure the angles of the triangle with respect to each other and classify the triangle as equilateral, isosceles, or scalene (providing, that is, that you remembered your seventh-grade geometry). You could say, hey, the angles of a triangle add up to 180 degrees! But if you wanted to judge the size of the triangle, you'd need a second triangle to make a comparison.

Barbour's conclusion: "Shape is much more fundamental than size. I conjecture an alternative cosmology in which the universe is merely changing its shape—becoming more structured—and not doing that as well as expanding."

Another way to put it: “We swim in nothing,” says Barbour. Not in a rigid grid; not with an absolute clock and ruler. “But precisely *how* do we swim in nothing?”

### Back to Basics

To answer that question, Barbour set out to reformulate physics, this time leaving out both the absolute size and the universal clock. With his hands thus mathematically tied, he began at the beginning, with Newton and the law of inertia (“objects at rest tend to stay at rest, objects in motion tend to stay in motion”—you remember).

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Barbour likes to start with his intuition, and then dig in to the math with help from collaborators like Bruno Bertotti at the University of Pavia, Italy, and Niall Ó Murchadha at University College Cork, Ireland. “I’m very much an intuitive thinker,” says Barbour. “I was never much good at mathematics—wasn’t in the class of the superstars.” (Of course, you’ll want to take this with a grain of salt—he did receive his degree in mathematics from Cambridge with honors.)

Barbour’s first insight was that Newton’s laws of motion could, indeed, be completely rewritten without absolute time or absolute distance. Then, he and his collaborators showed that general relativity is perfectly relational—except for the niggling problem of that un-Machian expansion.

But his search for an alternative explanation that does away with the expansion of the universe has been met with skepticism: “I have been taken much more seriously saying time doesn’t exist than that the universe isn’t expanding!”

Then, of course, comes quantum mechanics. Barbour’s dream is that elimination of expansion might reveal a new route to quantum gravity. He’ll investigate this possibility with the help of a \$99,563 grant from the Foundational Questions Institute, and

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his collaborators Joseph Silk at the University of Oxford, UK, Edward Anderson at the University of Cambridge, UK, and Hans Westman and Sean Gryb, at the Perimeter Institute (PI) in Waterloo, Ontario. Barbour admits it’s a long shot—he estimates the probability he’ll turn out to be *wrong* is greater than 90%. “But should I be right, I would be assured a place in history,” he laughs.

Lee Smolin, a theoretical physicist at PI, says that Barbour has already carved out a comfortable place in the history of quantum gravity. Smolin calls Barbour a scientific “seer,” adding that he has provided the rigorous mathematical structure upon which to build clock- and ruler-less theories.

Olaf Dreyer, a quantum gravity researcher at the Massachusetts Institute of Technology, in Cambridge, sits on the opposite side to Barbour on the

debate over time, but he salutes his work: “[Barbour] is one of the few people who really thinks about the foundations of general relativity,” which Dreyer describes as nearly “virgin territory.”

Barbour isn’t counting on a speedy payoff. “I don’t believe there will be a quick breakthrough,” he says. “It will keep the young people busy all their lives.” To pass some of his knowledge on to those young people, Barbour is also in the process of writing a book which, he says, “will present more or less everything that I think I have learned about two basic questions: What is time? What is motion? The answers to these two questions permeate the whole of modern physics in a way that few researchers realize.” It will be “a new perspective that they won’t find in any textbook.”