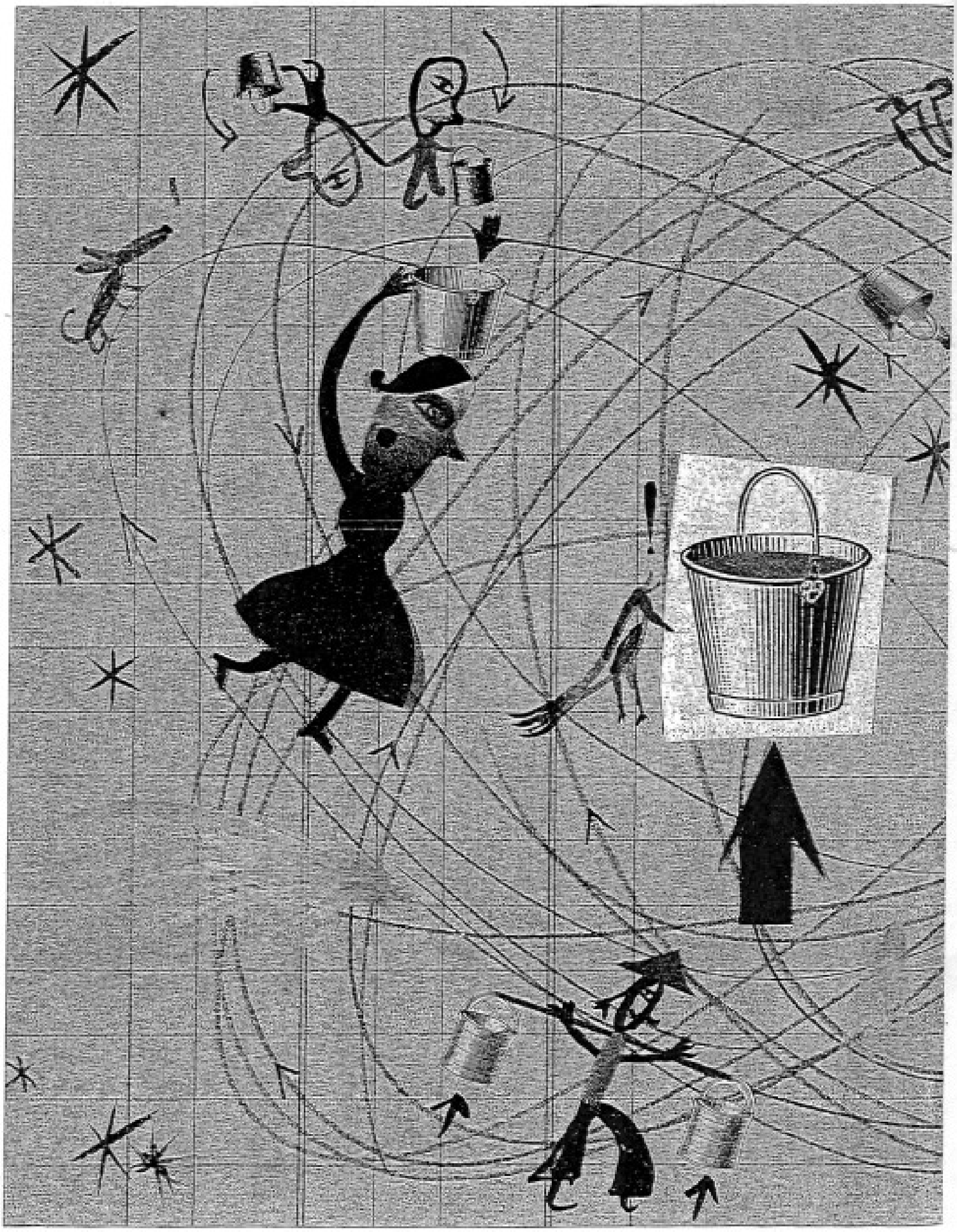
Can you feel it?

What's the link between a bucket of water and all the stars in the Universe? It's an old question with an intriguing new answer, says Paul Wesson

IT IS one of those simple yet fundamental problems that have puzzled people for centuries. Take a bucket filled with water and set it spinning like a top. As you will see, although the bucket tends to drag the water at the edge with it, most of the contents stay put. Why? The problem, generally referred to as Newton's bucket experiment, has an appealing simplicity. You can do it at negligible cost in your own backyard with a rusty pail – unlike most other modern experiments, which tend to cost millions and require enormous laboratories with sophisticated particle accelerators. There are even books about Newton's bucket. But why does the water stand still?

Ernst Mach, a 19th-century Austrian physicist, was first to suggest an answer: that the mass of everything on Earth, including you



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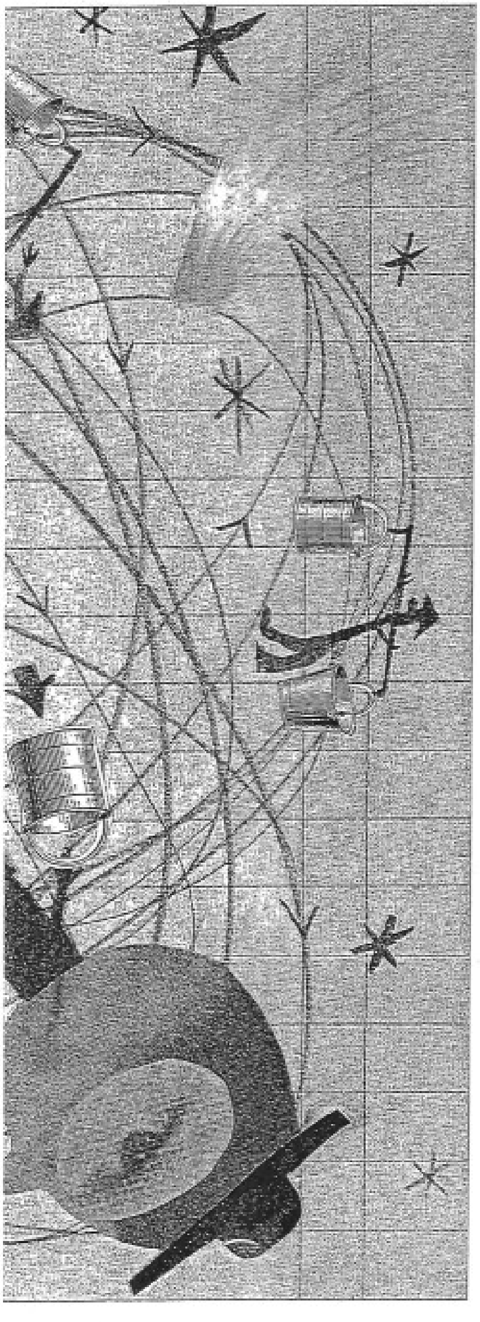
and me, is intimately connected with the mass of everything else, even distant astronomical objects. Matter simply "knows" that it should stay still with respect to the rest of the stuff out there in a vast and ancient Universe. Similarly, a particle with mass resists acceleration – it has inertia – because it is in some way "connected" to the myriad objects in the cosmos. This concept is known as Mach's principle, and no one has ever been able to construct a theory of the Universe that justifies it.

Einstein thought a lot about Mach's principle. It was his main inspiration for inventing the theory that space-time is curved by massive bodies, the theory we now know as general relativity. This mind-boggling intellectual tour de force works extremely well: the motion of the planet Mercury; the bending and time delay of light passing near the Sun; the red shift of radiation from our own and other stars; and the gradual decay of the orbits of the neutron stars in a binary pulsar system are all examples that have been seen to confirm the predictions Einstein laid out in general relativity.



Disappointingly, however, Einstein never managed to incorporate Mach's principle into his theory of general relativity. Neither did another eminent believer in the principle, Dennis Sciama. The English astrophysicist made a well-regarded attempt to turn Mach's principle into a theory in the 1950s, published in the *Monthly Notices of the Royal Astronomical Society*. The paper was well received by physicists, and Sciama promised that another one with more details was on the way. Unfortunately, it never arrived; Sciama died in December 1999, before he had successfully formalised his ideas.

A trio of cosmologists, myself among them, entered the frame in 2002. The history of physics is littered with anecdotal stories about how new theories have been jotted down on serviettes in restaurants, and our experience adds to the tally. Sitting in a chintzy Waterloo restaurant, Hongyia Liu, originally of the Dalian University of Technology in China, my colleague Sanjeev Seahra of the University of Waterloo in Canada and I demonstrated that, although Einstein never found it, there is a way to incorporate Mach's principle into general relativity. While the serviette has long since been consigned to the trash, our formal proof was published last year (*International Journal of Modern Physics D*, vol 11, p 1347).

Our argument starts from one of the well-known basic tenets of general relativity: a particle that has mass and is moving through space-time deforms the surrounding space-time as it goes. The equation that describes this deformation contains a numerical variable that is normally what mathematicians call a "real" number. We, however, took the controversial step of supposing it was "complex": composed of real and imaginary parts, where the imaginary part is a multiple of *i*, the square root of -1. Complex numbers are indispensable in many areas of physics, such as Maxwell's electromagnetism. Electronics engineers routinely use complex numbers to describe the behaviour of their circuits, for example. But in the theory of gravity, it's not generally considered necessary.

Any fears that taking this theoretical step would lead to a hideously complicated outcome quickly disappeared. We found that everything worked out with remarkable harmony. When our test particle moves through the "complex" space-time, what comes out, after working through Einstein's equations, are physical quantities which are all real. The imaginary parts of the complex numbers disappear.

Introducing complex numbers into general relativity also forced us to alter the standard way of describing the matter we were interested in. Instead of using an approximation in which we considered a large number of particles and "smoothed" them out into a fluid, we concentrated on the locality of one specific particle. Again, this step was unconventional but turned out to give physically reasonable results.

We also incorporated the quantum idea that our particle can simultaneously be considered as a wave, with a wavelength related to its mass and its momentum. This, in complex space-time, changes the nature of our particle. It means that the particle's mass can be thought of as extending throughout space-time as a wave, with the result that the global geometry of space – its curvature throughout the Universe – depends on the properties of that wave. With a description of space-time that admits complex numbers, and without violating Einstein's framework for relativity, we have an explanation for Mach's suggestion. It is not insane to believe that all matter on Earth could be linked to the stars, including people and buckets of water.

> "Although Einstein never found it, there is a way to incorporate Mach's principle into standard relativity"

Better yet, we believe our idea can be tested. Our theory predicts a specific relationship between the mass of a particle and the curvature of the space that it inhabits. We are currently looking into the feasibility of observing the effect in the properties of the space surrounding a hydrogen atom.

Any successful proof of this idea could have even more extraordinary implications. The effect of mass on space-time curvature that we have proposed is calculated from classical principles and works in four dimensions, the three spatial dimensions and one of time. But the effect is similar to the proposed effects of certain theories, including the various string theories for example, that aim to mesh relativity with quantum mechanics and produce a "theory of everything". These ideas invoke extra spatial dimensions and if we do manage to observe the relation between space-time curvature and mass that we have proposed, we think our theory may be just the shadow of something that occurs in many extra dimensions.

Our conclusion is that Mach's principle may not only be feasible, it may be rather important. The connection between the atoms in our bodies and the atoms in a distant star could have a fundamental part to play in our final description of how the Universe works. ●

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