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Gravity isn't like the other forces

Gravity's origin falling into place

Newton and Einstein only described gravity. Have we now found hints of its root cause?

Martijn van Calmthout

WHAT exactly is gravity? Everybody experiences it, but pinning down why the universe has gravity in the first place has proved difficult.

Although gravity has been successfully described with laws devised by Isaac Newton and later Albert Einstein, we still don't know how the fundamental properties of the universe combine to create the phenomenon.

Now one theoretical physicist is proposing a radical new way to look at gravity. Erik Verlinde of the University of Amsterdam, the Netherlands, a prominent and internationally respected string theorist, argues that gravitational attraction could be the result of the way information about material objects is organised in space. If true, it could provide the fundamental explanation we have been seeking for decades.

Verlinde posted his paper to the pre-print physics archive earlier this month, and since then many physicists have greeted the proposal as promising (arxiv.org/abs/1001.0785). Nobel laureate and theoretical physicist Gerard 't Hooft of Utrecht University in the Netherlands stresses the ideas need development, but is impressed by Verlinde's approach. "[Unlike] many string theorists Erik is stressing real physical concepts like mass and force, not just fancy abstract mathematics," he says. "That's encouraging from my perspective as a physicist."

Newton first showed how gravity works on large scales by treating it as a force between objects (see "Apple for your eyes"). Einstein refined Newton's ideas with his theory of general relativity. He showed that gravity was better described by the way an object warps the fabric of the universe. We are all pulled towards the Earth because the planet's mass is curving the surrounding space-time.

Yet that is not the end of the story. Though Newton and Einstein provided profound insights, their laws are only mathematical descriptions. "They explain how gravity works, but not where it comes from," says Verlinde. Theoretical physics has had a tough time connecting gravity with the other known fundamental forces in the universe. The standard model, which has long been our best framework for describing the subatomic world, includes electromagnetism and

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the strong and weak nuclear forces – but not gravity.

Many physicists doubt it ever will. Gravity may turn out to be delivered via the action of hypothetical particles called gravitons, but so far there is no proof of their existence. Gravity's awkwardness has been one of the main reasons why theories like string theory and quantum loop gravity have been proposed in recent decades.

Verlinde's work offers an alternative way of looking at the problem. "I am convinced now, gravity is a phenomenon emerging from the fundamental properties of space and time," he says.

To understand what Verlinde is proposing, consider the concept of fluidity in water. Individual molecules have no fluidity, but collectively they do. Similarly, the force of gravity is not something ingrained in matter itself. It is an extra physical effect, emerging from the interplay of mass, time and space, says Verlinde. His idea of gravity as an "entropic force" is based on these first principles of thermodynamics – but works within an exotic description of space-time called holography.

Holography in theoretical physics follows broadly the same principles as the holograms on a banknote, which are three-dimensional images embedded in a two-dimensional surface. The concept in physics was developed

"Like the fluidity of water, gravity is not ingrained in matter itself. It is an extra physical effect"

in the 1970s by Stephen Hawking at the University of Cambridge and Jacob Bekenstein at the Hebrew University of Jerusalem in Israel to describe the properties of black holes. Their work led to the insight that a hypothetical sphere could store all the necessary "bits" of information about the mass within. In the 1990s, 't Hooft and Leonard Susskind at Stanford University in California proposed that this framework might apply to the whole universe. Their "holographic principle" has proved useful in many fundamental theories.

Verlinde uses the holographic principle to consider what is happening to a small mass at a certain distance from a bigger mass, say a star or a planet. Moving the small mass a little, he shows, means changing the information content, or entropy, of a hypothetical holographic surface between both masses. This change of information is linked to a change in the energy of the system.

Then, using statistics to consider all possible movements of the small mass and the energy changes involved, Verlinde finds movements toward the bigger mass are thermodynamically more likely than others. This effect can be seen as a net force pulling both masses together. Physicists call this an entropic force, as it originates in the most likely changes in information content.

This still doesn't point directly to gravity. But plugging in the basic expressions for information content of the holographic surface, its energy content and Einstein's relation of mass to energy leads directly to Newton's law of gravity. A relativistic version is only a few steps further, but again straightforward to derive. And it seems to apply to both apples and planets. "Finding Newton's laws all over again could have been a lucky coincidence," says Verlinde. "A relativistic generalisation shows this is far deeper than a few equations turning out just right."

Verlinde's paper has prompted praise from some physicists. Robbert Dijkgraaf, a prominent mathematical physicist also at the University of Amsterdam, says he admires the elegance of Verlinde's concepts. "It is amazing no one has come up with this earlier, it looks just so simple and yet convincing," he says.

The jury is still out for many others. Some believe that Verlinde is using circular reasoning in his equations, by "starting out" with gravity. Others have expressed concern about the almost trivial mathematics involved, leaving most of the theory based on very general concepts of space, time and information.

Stanley Deser of Brandeis University in Waltham, Massachusetts, whose work has expanded the scope of general relativity, says Verlinde's work appears to be a promising avenue but adds that it is "a bombshell that will take a lot of digesting, challenging all our dogmas from Newton and Hooke to Einstein."

Verlinde stresses his paper is only the first on the subject. "It is not even a theory yet, but a proposal for a new paradigm or framework," he says. "All the hard work comes now." ■

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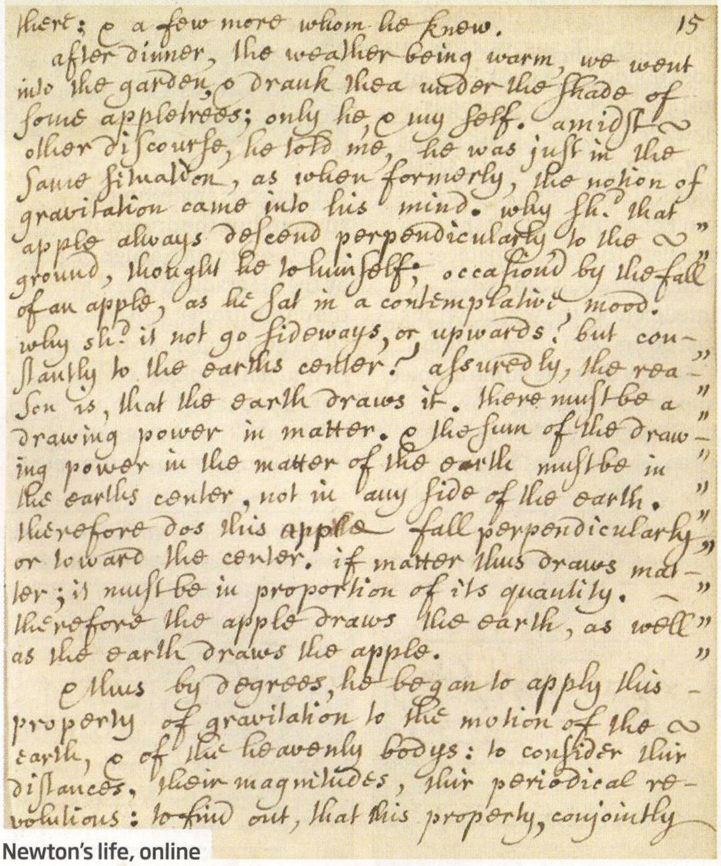
APPLE FOR YOUR EYES

"We went into the garden and drank thea, under some apple trees... he told me he was just in the same situation, when the notion of gravitation came into his mind. 'Why should that apple always descend perpendicularly to the ground,' thought he to himself."

So wrote archaeologist and biographer William Stukeley in 1752, recounting the famous story as told to him by a young Isaac Newton. Newton went on to show that, on a large scale, two masses are attracted in proportion to their individual mass, and the force between them falls off with the square of their distance.

Now the original manuscript featuring the story, entitled *Memoirs of Sir Isaac Newton's Life*, is available for all to read. As part of its 350th anniversary celebration, London's Royal Society has published a digital version of the document, which is tucked away in their archives. See royalsociety.org/turning-the-pages. Amanda Gefter

THE ROYAL SOCIETY


there; & a few more whom he knew. 15
after dinner, the weather being warm, we went
into the garden, & drank thea under the shade of
some appletrees; only he, & my self. amidst
other discourse, he told me, he was just in the
same situation, as when formerly, the notion of
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apple always descend perpendicularly to the
ground, thought he to himself; occasion'd by the fall
of an apple, as he sat in a contemplative mood.
why sh.d it not go sideways, or upwards? but con-
stantly to the earths center? assuredly, the rea-
son is, that the earth draws it. there must be a
drawing power in matter. & the sum of the draw-
ing power in the matter of the earth must be in
the earths center, not in any side of the earth.
therefore dos this apple fall perpendicularly
or toward the center. if matter thus draws mat-
ter; it must be in proportion of its quantity.
therefore the apple draws the earth, as well
as the earth draws the apple.
& thus by degrees, he began to apply this
property of gravitation to the motion of the
earth, & of the heavenly bodys: to consider their
distances, their magnitudes, their periodical re-
volutions: to find out, that this property, conjointly

Newton's life, online