

Negative Mass

The discovery didn't immediately make worldwide headlines. Only the New York Times ran it, and in the Science section, not the front page.

Leptons, a subatomic particle, found to be affected by negative gravity, suggesting answers for dark energy

This was fascinating, thought Alexey. He had the latest issue of *Physical Review Letters* open in front of him. All of our assumptions about time must be revisited! It was well known that relativity provided for all kinds of strange and believed to be prohibited phenomena if only negative mass were allowed by our physics, a constraint known as the energy conditions. But we don't seem to observe time paradoxes, so if superluminal travel is *allowed* how is the seeming practical prohibition enforced? Alexey immediately had so many questions.

An essential piece of advice given to new graduate students in physics was *do not try to*

imagine these things. You cannot see a 7-dimensional manifold, but symbol manipulation does not require you to: relying on the tools of math allows you to analyze that which you cannot imagine.

However! That was advice given to Alexey's generation: before the advent of neural links and relativistic information theory.

He stood up from his desk and walked over to a bookshelf, and carefully picked up a small reflective white cube. The cube had a single port, in the center of one of its faces, for an optical fiber, similar to the connector in Alexey's arm which, under the skin connected to a processing module in his chest that connected in turn to the vast web of electrical filaments that had penetrated his brain.

Just because the human brain had not evolved to experience 7-dimensional surfaces didn't mean they weren't physical. We just needed a suitable consciousness, which was fortunately available in the form of the Cube. Rather than connecting to someone else, by far the main use of neural links, these conscious artifacts were dramatic mind expanding devices engineered for understanding beyond the limits of our evolved biology.

Alexey connected himself to the artifact and slowly began opening the reducing valve. About 30 minutes was the right amount of time to come up over; much faster tended to cause nausea, or in one particularly stupid case he had early on with a different engineered consciousness, seizures.

Immediately the patterns started appearing. Little things like an implied line through some stylized text on a webpage on his screen that he hadn't noticed before, and all of the little detail of the world. So much little detail!

Time began to slow. The experiential integration time of Alexey's brain was about 150 milliseconds, whereas the Cube's was almost 1,000 times faster. Perceptual time dilation inflated quickly now as the reducing valve slowly eased open.

Only 4 minutes had passed. It had felt like an hour! Still much remained to be able to see these equations easily, he thought, though there was no time pressure: in addition to slowing, time had taken on this very strong feeling of *presence*, a fundamental spatial aspect. He could manipulate four dimensions now, which meant that no matter how long it took to reach the peak he would have plenty to think about in the meantime. *Physics is so much more rewarding when you can see spacetime*, he thought.

There were many different artifacts for many different types of desired perceptual effects. Conscious artifacts were incredibly difficult to make, and no more than 4 or 5 of a given type existed in the world; there were maybe 100 ever made in total, so far. Alexey's cube was therefore a priceless device, and he was fortunate to have it on loan for precisely this kind of use in his role as Chair of the Physics department at Harvard University. He could hardly imagine how much less rich his life would become when the time came to give it back.

He had been considering some unresolved questions he had about the nature of radiation from rotating charged black holes when he felt his awareness suddenly fold on itself and fifth dimensions started making obvious intuitive sense. The relation he was considering was a partial differential equation of six terms, and suddenly his intuition for it filled in modulo assuming fixed values of the last term. But that was fine, the last term was much less interesting in its variation for this question anyway. These shapes were just as beautiful as he remembered them.

After several weeks of considering this particular family of singularity, the whole

equation started becoming much easier and Alexey felt that he had broken through to many higher dimensions. Exactly how many he could visualize was hard to determine precisely, but he hadn't felt like had come up against a ceiling yet in his explorations. The Cube did precisely none of the reasoning for him, and supplied no mathematical creativity, but simply made vastly more approachable the subject matter he had been relying on blind symbol manipulation to explore for almost 30 years.

The effect was not subtle. It wasn't like one of the stimulant drugs, which might make Alexey slightly better at focusing and therefore slightly more productive, and maybe if he squinted he might convince himself slightly better at math. The Cube took an equation of over a dozen variables, laden with calculus, and gave a picture of its behavior as clear as a plot of a simple linear regression.

The energy conditions.

When you have an equation, like say $E_{\text{kinetic}} = 1/2 mv^2$, you can of course plug in all kinds of numbers. But if you put in a negative velocity, or a negative mass, does the resulting “kinetic energy” mean anything? In particular, the equations of general relativity admit some very strange behavior when certain variables are chosen in certain ways, like using negative numbers for mass. Thus, the energy conditions describe what polite society agrees to be reasonable and physically meaningful constraints on the inputs. Before today, one of the central energy conditions was a prohibition on negative mass.

Alexey could see it very easily. If the non-negative mass constraint was abandoned, closed timelike curves were obviously accessible, which was not news, and the contours of the shape of the equations in that regime were smooth and elegant.

Well, time travel still seems to be no more a part of reality now than it was yesterday.

It wasn't fully clear what the Cube experienced when not connected to anything else. There was consensus that it *did* have experience when self-contained, and some analysis had gone into trying to make sure it was a pleasant one, but while the science was advanced enough to make the Cube, it wasn't advanced enough to make many guarantees about what it was like to be the Cube. Everyone not directly involved in its design just tried not to think about it too hard. It was popularly conceived of as continually feeling elaborate, evolving geometrical patterns, but this was probably an oversimplification to the point of being untrue.

Being able to fluently see and feel the general relativity field equations was as close to a peak experience as Alexey had had in his life. Just a few years ago it would have been difficult to imagine the ability to easily access a clear physical intuition for an intricate tangle of ten coupled nonlinear differential equations.

He could see it in the solutions clearly visualized: here, time was just another dimension, stretched by c , but otherwise undifferentiated from space. As he mentally moved through this solid block of spacetime, Alexey saw the trajectories of the new solutions, neatly bounded and clearly consistent with the classical limit. It made sense! But as he tried to turn over the insight in his mind Alexey realized that it would be very difficult to take with him. *We aren't equipped with the language to describe this.* He could see it, in this vast multidimensional unfolding, but had no way to serialize the thoughts into language. *Antonov should just come and see this for himself. He'll have ideas about how to formalize the answers here.* Alexey was realizing the gap between the physical intuition available to him in this state and a concise mathematical formalism of it that people who have never seen this could understand.

How could you ever really understand if you haven't seen this?

As he closed the reducing valve and felt his awareness narrow and dim, Alexey felt as Algernon in his sudden loss and it became plain how depressing and limited of a toolset physics had been built on far. How did Schrodinger and Dirac and their colleagues even do it? At least von Neumann, Alexey was convinced, probably just had been genetically endowed with the equivalent of a Cube from birth, somehow.

Alexey unplugged the fiber connection from his arm and returned the Cube delicately to the shelf and went back to his desk for the phone.

“Antonov? What are you doing tomorrow? I have something to show you.”

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