Spacetime crystals proposed by placing space and time on an equal footing

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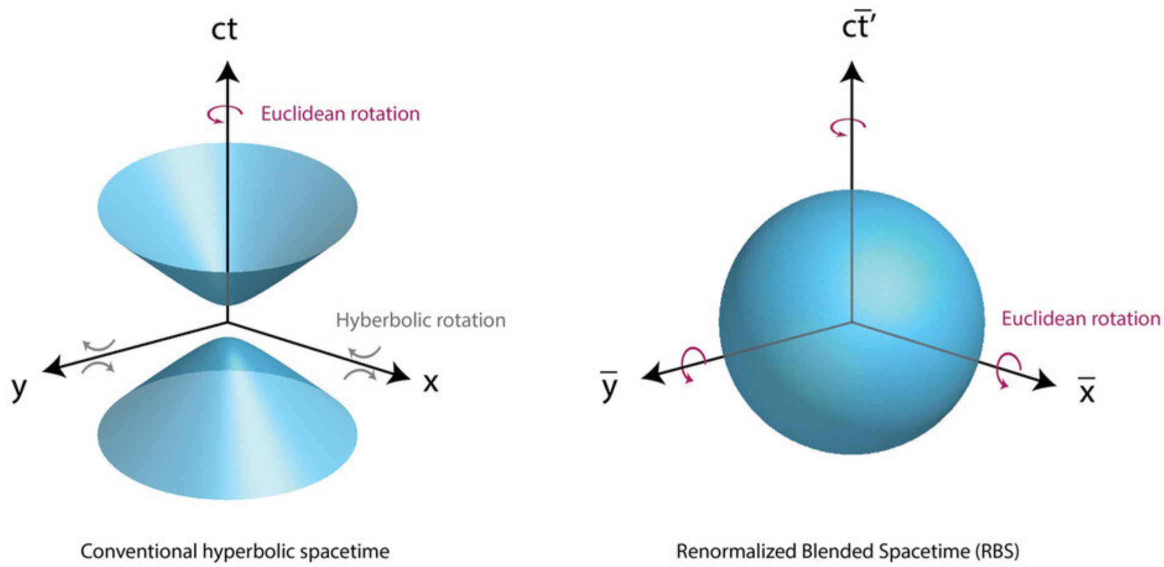

A diagram showing the process of creating "renormalized blended spacetime." Penn State scientist Venkatraman Gopalan is studying crystal structures and has developed a new mathematical formula that may solve a decades-old problem in understanding spacetime, the fabric of the universe proposed in Einstein's theories of relativity. Credit: Hari Padmanabhan, Penn State

A Penn State scientist studying crystal structures has developed a new mathematical formula that may solve a decades-old problem in understanding spacetime, the fabric of the universe proposed in Einstein's theories of relativity.

"Relativity tells us space and time can mix to form a single entity called spacetime, which is four-dimensional: three space-axes and one time-axis," said Venkatraman Gopalan, professor of materials science and engineering and physics at Penn State. "However, something about the time-axis sticks out like sore thumb."

For calculations to work within relativity, scientists must insert a negative sign on time values that they do not have to place on space values. Physicists have learned to work with the negative values, but it means that spacetime cannot be dealt with using traditional Euclidean geometry and instead must be viewed with the more complex hyperbolic geometry.

Gopalan developed a two-step mathematical approach that allows the differences between space and time to be blurred, removing the negative sign problem, serving as a bridge between the two geometries.

"For more than 100 years, there has been an effort to put space and time on the same footing," Gopalan said. "But that has really not happened because of this minus sign. This research removes that problem at least in special relativity. Space and time are truly on the same footing in this work." The paper, published today (May 27) in the journal *Acta Crystallographica A*, is accompanied by a commentary in which two physicists write that Gopalan's approach may hold the key to unifying quantum mechanics and gravity, two foundational fields of physics that are yet to be fully unified.

"Gopalan's idea of general relativistic spacetime crystals and how to obtain them is both powerful and broad," said Martin Bojowald, professor of physics at Penn State. "This research, in part, presents a new approach to a problem in physics that has remained unresolved for decades."

In addition to providing a new approach to relate spacetime to traditional geometry, the research has implications for developing new structures with exotic properties, known as spacetime crystals.

Crystals contain repeating arrangement of atoms, and in recent years scientists have explored the concept of time crystals, in which the state of a material changes and repeats in time as well, like a dance. However, time is disconnected from space in those formulations. The method developed by Gopalan would allow for a new class of spacetime crystals to be explored, where space and time can mix.

"These possibilities could usher in an entirely new class of metamaterials with exotic properties otherwise not available in nature, besides understanding the fundamental attributes of a number of dynamical systems," said Avadh Saxena, a physicist at Los Alamos National Laboratory.

Gopalan's method involves blending two separate observations of the same event. Blending occurs when two observers exchange time coordinates but keep their own space coordinates. With an additional mathematical step called renormalization, this leads to "renormalized blended spacetime."

"Let's say I am on the ground and you are flying on the space station, and we both observe an event like a comet fly by," Gopalan said. "You make your measurement of when and where you saw it, and I make mine of the same event, and then we compare notes. I then adopt your time measurement as my own, but I retain my original space measurement of the comet. You in turn adopt my time measurement as your own, but retain your own space measurement of the comet. From a mathematical point of view, if we do this blending of our measurements, the annoying minus sign goes away."

More information: Venkatraman Gopalan, Relativistic spacetime crystals, *Acta Crystallographica Section A Foundations and Advances* (2021). DOI: 10.1107/S2053273321003259

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