Physicists posit quantum gravity's rainbow

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Quantum particles of different energies sense different properties of spacetime. The effect is similar to the dispersion of light in prism: photons of different energies sense the same prism as having slightly different properties. (Source: FUW, jch) Credit: Source: FUW, jch

When white light is passed through a prism, the rainbow on the other side reveals a rich palette of colors. Theorists from the faculty of physics, University of Warsaw have shown that in models of the universe using any of the quantum theories of gravity there must also be a 'rainbow' of sorts, composed of different versions of spacetime. The mechanism predicts that instead of a single, common spacetime, particles of different energies essentially sense slightly modified versions thereof.

When white light passes through a prism, it splits to form a rainbow. This is because white light is, in fact, a mixture of photons of different energies, and the greater the energy of the photon, the more it is deflected by the prism. Thus, we might say that the rainbow arises because photons of different energies sense the same prism as having slightly different properties. For years now, it has been suspected that particles of different energies in models of the quantum universe essentially sense spacetimes with slightly different structures. Earlier hypotheses were not derived from quantum theory, however, but based on guesses. Currently, a group of physicists from the faculty of physics, University of Warsaw, led by Prof. Jerzy Lewandowski, has formulated a general mechanism responsible for the emergence of such a spacetime rainbow.

"Two years ago we reported that in our quantum cosmological models, different types of particles feel the existence of spacetimes with slightly different properties. Now, it turns out that the situation is even more complicated. We have discovered a truly generic mechanism, whereby the fabric of spacetime felt by a given particle must vary depending not only on its type, but even on its energy," says Prof. Lewandowski.

In the current discussion, the Warsaw physicists are using a cosmological model that contains just two components: gravity and one type of matter. Under the general theory of relativity, a gravitational field is described by deformations of spacetime, whereas matter is represented as a scalar field (the simplest type of field where every point in space is assigned only one value).

"Today there are many competing theories of quantum gravity. Therefore, we formulated our model in very general terms so that it can be applied to any of them. Someone might assume the kind of gravitational field—which in practice means spacetime—that is posited by one quantum theory, and someone else might assume another. Some mathematical operators in the model will then change, but this will not change the nature of the phenomena occurring in it," says Ph.D. student Andrea Dapor.

The model so devised was then quantized—in other words, continuous values, which may differ from one another in terms of any arbitrarily small amount, were converted to discrete values, which may only differ by specific intervals (quanta). Research on the dynamics of the quantized model revealed an amazing result: processes modeled using the quantum theory on quantum spacetime turned out to exhibit the same dynamics as when the quantum theory takes place in a classical continuous spacetime, i.e. the kind we know from everyday experience.

"This result is simply astonishing. We start with the fuzzy world of quantum geometry, where it is even difficult to say what is time and what is space, yet the phenomena occurring in our cosmological model still look as if everything was happening in ordinary spacetime!", says Ph.D. student Mehdi Assanioussi.

Things took a more interesting turn when physicists looked at excitations in the scalar field, which are interpreted as particles. Calculations showed that in this model, particles that differ in terms of energy interact with quantum spacetime somewhat differently—much as photons of different energies interact with a prism somewhat differently. This result means that even the effective structure of classical spacetime sensed by individual particles must depend on their energy.

The occurrence of a normal rainbow can be described in terms of a refractive index, the value of which varies depending on the wavelength of light. In the case of the analogous spacetime rainbow, a similar relationship has also been proposed: the beta function, a measure of the extent to which the structure of classical spacetime differs as experienced by different particles. This function reflects the degree of non-classicalness of quantum spacetime: In conditions similar to classical, it is close to zero, whereas in truly quantum conditions, its value is close to one. Today, the universe is in a classical-like state, so now, the beta value should be near zero, and estimates performed by other groups of physicists suggest that it does not exceed 0.01. This small value for the beta function means that currently, the spacetime rainbow is very narrow and cannot be detected experimentally.

The study by the UW Physics theorists, funded by grants from Poland's National Science Centre, has yielded another interesting conclusion. The spacetime rainbow is a result of quantum gravity. Physicists generally share the view that effects of this type only become visible at gigantic energies near the Planck energy, millions of billions of times the energy of particles now being accelerated in the Large Hadron Collider (LHC). However, the beta function value depends on time, and at moments close to the Big Bang it could have been much higher. When beta is close to one, the spacetime rainbow expands considerably. As a result, under such conditions the rainbow effect of quantum gravity could potentially be observed, even at energies of particles hundreds of times smaller than the energy of protons in today's LHC.

More information: Mehdi Assanioussi et al. Rainbow metric from quantum gravity, *Physics Letters B* (2015). DOI: 10.1016/j.physletb.2015.10.043

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