Description of gravity using discrete values A depiction of the cGh cubeDepicted as a Venn diagram Quantum gravity (QG) is a field of theoretical physics that seeks to describe gravity according to the principles of quantum mechanics. It deals with environments in which neither gravitational nor quantum effects can be ignored,[1] such as in the vicinity of black holes or similar compact astrophysical objects, as well as in the early stages of the universe moments after the Big Bang.[2] Three of the four fundamental forces of nature are described within the framework of quantum mechanics and quantum field theory: the electromagnetic interaction, the strong force, and the weak force; this leaves gravity as the only interaction that has not been fully accommodated. The current understanding of gravity is based on Albert Einstein's general theory of relativity, which incorporates his theory of special relativity and deeply modifies the understanding of concepts like time and space. Although general relativity is highly regarded for its elegance and accuracy, it has limitations: the gravitational singularities inside black holes, the ad hoc postulation of dark matter, as well as dark energy and its relation to the cosmological constant are among the current unsolved mysteries regarding gravity,[3] all of which signal the collapse of the general theory of relativity at different scales and highlight the need for a gravitational theory that goes into the quantum realm. At distances close to the Planck length, like those near the center of a black hole, quantum fluctuations of spacetime are expected to play an important role.[4] Finally, the discrepancies between the predicted value for the vacuum energy and the observed values (which, depending on considerations, can be of 60 or 120 orders of magnitude)[5][6] highlight the necessity for a quantum theory of gravity. The field of quantum gravity is actively developing, and theorists are exploring a variety of approaches to the problem of quantum gravity, the most popular being M-theory and loop quantum gravity.[7] All of these approaches aim to describe the quantum behavior of the gravitational field, which does not necessarily include unifying all fundamental interactions into a single mathematical framework. However, many approaches to quantum gravity, such as string theory, try to develop a framework that describes all fundamental forces. Such a theory is often referred to as a theory of everything. Some of the approaches, such as loop quantum gravity, make no such attempt; instead, they make an effort to quantize the gravitational field while it is kept separate from the other forces. Other lesser-known but no less important theories include causal dynamical triangulation, noncommutative geometry, and twistor theory.[8] One of the difficulties of formulating a quantum gravity theory is that direct observation of quantum gravitational effects is thought to only appear at length scales near the Planck scale, around 10−35 meters, a scale far smaller, and hence only accessible with far higher energies, than those currently available in high energy particle accelerators. Therefore, physicists lack experimental data which could distinguish between the competing theories which have been proposed.[n.b. 1][n.b. 2] Thought experiment approaches have been suggested as a testing tool for quantum gravity theories.[9][10] In the field of quantum gravity there are several open questions – e.g., it is not known how spin of elementary particles sources gravity, and thought experiments could provide a pathway to explore possible resolutions to these questions,[11] even in the absence of lab experiments or physical observations. In the early 21st century, new experiment designs and technologies have arisen which suggest that indirect approaches to testing quantum gravity may be feasible over the next few decades.[12][13][14][15] This field of study is called phenomenological quantum gravity. Unsolved problem in physics How can the theory of quantum mechanics be merged with the theory of general relativity / gravitational force and remain correct at microscopic length scales? What verifiable predictions does any theory of quantum gravity make? More unsolved problems in physics Diagram showing the place of quantum gravity in the hierarchy of physics theories Much of the difficulty in meshing these theories at all energy scales comes from the different assumptions that these theories make on how the universe works. General relativity models gravity as curvature of spacetime: in the slogan of John Archibald Wheeler, "Spacetime tells matter how to move; matter tells spacetime how to curve."[16] On the other hand, quantum field theory is typically formulated in the flat spacetime used in special relativity. No theory has yet proven successful in describing the general situation where the dynamics of matter, modeled with quantum mechanics, affect the curvature of spacetime. If one attempts to treat gravity as simply another quantum field, the resulting theory is not renormalizable.[17] Even in the simpler case where the curvature of spacetime is fixed a priori, developing quantum field theory becomes more mathematically challenging, and many ideas physicists use in quantum field theory on flat spacetime are no longer applicable.[18] It is widely hoped that a theory of quantum gravity would allow us to understand problems of very high energy and very small dimensions of space, such as the behavior of black holes, and the origin of the universe.[1] One major obstacle is that for quantum field theory in curved spacetime with a fixed metric, bosonic/fermionic operator fields supercommute for spacelike separated points. (This is a way of imposing a principle of locality.) However, in quantum gravity, the metric is dynamical, so that whether two points are spacelike separated depends on the state. In fact, they can be in a quantum superposition of being spacelike and not spacelike separated.[citation needed] Main article: Graviton The observation that all fundamental forces except gravity have one or more known messenger particles leads researchers to believe that at least one must exist for gravity. This hypothetical particle is known as the graviton. These particles act as a force particle similar to the photon of the electromagnetic interaction. Under mild assumptions, the structure of general relativity requires them to follow the quantum mechanical description of interacting theoretical spin-2 massless particles.[19][20][21][22][23] Many of the accepted notions of a unified theory of physics since the 1970s assume, and to some degree depend upon, the existence of the graviton. The Weinberg–Witten theorem places some constraints on theories in which the graviton is a composite particle.[24][25] While gravitons are an important theoretical step in a quantum mechanical description of gravity, they are generally believed to be undetectable because they interact too weakly.[26] Further information: Renormalization and Asymptotic safety in quantum gravity General relativity, like electromagnetism, is a classical field theory. One might expect that, as with electromagnetism, the gravitational force should also have a corresponding quantum field theory. However, gravity is perturbatively nonrenormalizable.[27][28] For a quantum field theory to be well defined according to this understanding of the subject, it must be asymptotically free or asymptotically safe. The theory must be characterized by a choice of finitely many parameters, which could, in principle, be set by experiment. For example, in quantum electrodynamics these parameters are the charge and mass of the electron, as measured at a particular energy scale. On the other hand, in quantizing gravity there are, in perturbation theory, infinitely many independent parameters (counterterm coefficients) needed to define the theory. For a given choice of those parameters, one could make sense of the theory, but since it is impossible to conduct infinite experiments to fix the values of every parameter, it has been argued that one does not, in perturbation theory, have a meaningful physical theory. At low energies, the logic of the renormalization group tells us that, despite the unknown choices of these infinitely many parameters, quantum gravity will reduce to the usual Einstein theory of general relativity. On the other hand, if we could probe very high energies where quantum effects take over, then every one of the infinitely many unknown parameters would begin to matter, and we could make no predictions at all.[29] It is conceivable that, in the correct theory of quantum gravity, the infinitely many unknown parameters will reduce to a finite number that can then be measured. One possibility is that normal perturbation theory is not a reliable guide to the renormalizability of the theory, and that there really is a UV fixed point for gravity. Since this is a question of non-perturbative quantum field theory, finding a reliable answer is difficult, pursued in the asymptotic safety program. Another possibility is that there are new, undiscovered symmetry principles that constrain the parameters and reduce them to a finite set. This is the route taken by string theory, where all of the excitations of the string essentially manifest themselves as new symmetries.[30][better source needed] Main article: Effective field theory In an effective field theory, not all but the first few of the infinite set of parameters in a nonrenormalizable theory are suppressed by huge energy scales and hence can be neglected when computing low-energy effects. Thus, at least in the low-energy regime, the model is a predictive quantum field theory.[31] Furthermore, many theorists argue that the Standard Model should be regarded as an effective field theory itself, with "nonrenormalizable" interactions suppressed by large energy scales and whose effects have consequently not been observed experimentally.[32] By treating general relativity as an effective field theory, one can actually make legitimate predictions for quantum gravity, at least for low-energy phenomena. An example is the well-known calculation of the tiny first-order quantum-mechanical correction to the classical Newtonian gravitational potential between two masses.[31] Another example is the calculation of the corrections to the Bekenstein-Hawking entropy formula.[33][34] Main article: Background independence A fundamental lesson of general relativity is that there is no fixed spacetime background, as found in Newtonian mechanics and special relativity; the spacetime geometry is dynamic. While simple to grasp in principle, this is a complex idea to understand about general relativity, and its consequences are profound and not fully explored, even at the classical level. To a certain extent, general relativity can be seen to be a relational theory,[35] in which the only physically relevant information is the relationship between different events in spacetime. On the other hand, quantum mechanics has depended since its inception on a fixed background (non-dynamic) structure. In the case of quantum mechanics, it is time that is given and not dynamic, just as in Newtonian classical mechanics. In relativistic quantum field theory, just as in classical field theory, Minkowski spacetime is the fixed background of the theory. Interaction in the subatomic world: world lines of point-like particles in the Standard Model or a world sheet swept up by closed strings in string theory String theory can be seen as a generalization of quantum field theory where instead of point particles, string-like objects propagate in a fixed spacetime background, although the interactions among closed strings give rise to space-time in a dynamic way. Although string theory had its origins in the study of quark confinement and not of quantum gravity, it was soon discovered that the string spectrum contains the graviton, and that "condensation" of certain vibration modes of strings is equivalent to a modification of the original background. In this sense, string perturbation theory exhibits exactly the features one would expect of a perturbation theory that may exhibit a strong dependence on asymptotics (as seen, for example, in the AdS/CFT correspondence) which is a weak form of background dependence. Loop quantum gravity is the fruit of an effort to formulate a background-independent quantum theory. Topological quantum field theory provided an example of background-independent quantum theory, but with no local degrees of freedom, and only finitely many degrees of freedom globally. This is inadequate to describe gravity in 3+1 dimensions, which has local degrees of freedom according to general relativity. In 2+1 dimensions, however, gravity is a topological field theory, and it has been successfully quantized in several different ways, including spin networks.[citation needed] Main articles: Quantum field theory in curved spacetime and Semiclassical gravity Quantum field theory on curved (non-Minkowskian) backgrounds, while not a full quantum theory of gravity, has shown many promising early results. In an analogous way to the development of quantum electrodynamics in the early part of the 20th century (when physicists considered quantum mechanics in classical electromagnetic fields), the consideration of quantum field theory on a curved background has led to predictions such as black hole radiation. Phenomena such as the Unruh effect, in which particles exist in certain accelerating frames but not in stationary ones, do not pose any difficulty when considered on a curved background (the Unruh effect occurs even in flat Minkowskian backgrounds). The vacuum state is the state with the least energy (and may or may not contain particles). Main article: Problem of time A conceptual difficulty in combining quantum mechanics with general relativity arises from the contrasting role of time within these two frameworks. In quantum theories, time acts as an independent background through which states evolve, with the Hamiltonian operator acting as the generator of infinitesimal translations of quantum states through time.[36] In contrast, general relativity treats time as a dynamical variable which relates directly with matter and moreover requires the Hamiltonian constraint to vanish.[37] Because this variability of time has been observed macroscopically, it removes any possibility of employing a fixed notion of time, similar to the conception of time in quantum theory, at the macroscopic level. There are a number of proposed quantum gravity theories.[38] Currently, there is still no complete and consistent quantum theory of gravity, and the candidate models still need to overcome major formal and conceptual problems. They also face the common problem that, as yet, there is no way to put quantum gravity predictions to experimental tests, although there is hope for this to change as future data from cosmological observations and particle physics experiments become available.[39][40] Main article: String theory Projection of a Calabi–Yau manifold, one of the ways of compactifying the extra dimensions posited by string theory The central idea of string theory is to replace the classical concept of a point particle in quantum field theory with a quantum theory of one-dimensional extended objects: string theory.[41] At the energies reached in current experiments, these strings are indistinguishable from point-like particles, but, crucially, different modes of oscillation of one and the same type of fundamental string appear as particles with different (electric and other) charges. In this way, string theory promises to be a unified description of all particles and interactions.[42] The theory is successful in that one mode will always correspond to a graviton, the messenger particle of gravity; however, the price of this success is unusual features such as six extra dimensions of space in addition to the usual three for space and one for time.[43] In what is called the second superstring revolution, it was conjectured that both string theory and a unification of general relativity and supersymmetry known as supergravity[44] form part of a hypothesized eleven-dimensional model known as M-theory, which would constitute a uniquely defined and consistent theory of quantum gravity.[45][46] As presently understood, however, string theory admits a very large number (10500 by some estimates) of consistent vacua, comprising the so-called "string landscape". Sorting through this large family of solutions remains a major challenge. Main article: Loop quantum gravity Simple spin network of the type used in loop quantum gravity Loop quantum gravity seriously considers general relativity's insight that spacetime is a dynamical field and is therefore a quantum object. Its second idea is that the quantum discreteness that determines the particle-like behavior of other field theories (for instance, the photons of the electromagnetic field) also affects the structure of space. The main result of loop quantum gravity is that there is a granular structure of space at the Planck length. This is derived from the following considerations: In the case of electromagnetism, the quantum operator representing the energy of each frequency of the field has a discrete spectrum. Thus the energy of each frequency is quantized, and the quanta are the photons. In the case of gravity, the operators representing the area and the volume of each surface or space region likewise have discrete spectra. Thus area and volume of any portion of space are also quantized, where the quanta are elementary quanta of space. It follows, then, that spacetime has an elementary quantum granular structure at the Planck scale, which cuts off the ultraviolet infinities of quantum field theory. The quantum state of spacetime is described in the theory by means of a mathematical structure called spin networks. Spin networks were initially introduced by Roger Penrose in abstract form, and later shown by Carlo Rovelli and Lee Smolin to derive naturally from a non-perturbative quantization of general relativity. Spin networks do not represent quantum states of a field in spacetime: they represent directly quantum states of spacetime. The theory is based on the reformulation of general relativity known as Ashtekar variables, which represent geometric gravity using mathematical analogues of electric and magnetic fields.[47][48] In the quantum theory, space is represented by a network structure called a spin network, evolving over time in discrete steps.[49][50][51][52] The dynamics of the theory is today constructed in several versions. One version starts with the canonical quantization of general relativity. The analogue of the Schrödinger equation is a Wheeler–DeWitt equation, which can be defined within the theory.[53] In the covariant, or spinfoam formulation of the theory, the quantum dynamics is obtained via a sum over discrete versions of spacetime, called spinfoams. These represent histories of spin networks. There are a number of other approaches to quantum gravity. The theories differ depending on which features of general relativity and quantum theory are accepted unchanged, and which features are modified.[54][55] Such theories include: Asymptotic safety in quantum gravity Euclidean quantum gravity Integral method[56] Causal dynamical triangulation[57] Causal fermion systems Causal Set Theory Covariant Feynman path integral approach Dilatonic quantum gravity Double copy theory Group field theory Wheeler–DeWitt equation Geometrodynamics Hořava–Lifshitz gravity MacDowell–Mansouri action Noncommutative geometry Path-integral based models of quantum cosmology[58] Regge calculus Shape Dynamics String-nets and quantum graphity Supergravity Twistor theory[59] Canonical quantum gravity As was emphasized above, quantum gravitational effects are extremely weak and therefore difficult to test. For this reason, the possibility of experimentally testing quantum gravity had not received much attention prior to the late 1990s. However, since the 2000s, physicists have realized that evidence for quantum gravitational effects can guide the development of the theory. Since theoretical development has been slow, the field of phenomenological quantum gravity, which studies the possibility of experimental tests, has obtained increased attention.[60] The most widely pursued possibilities for quantum gravity phenomenology include gravitationally mediated entanglement,[61][62] violations of Lorentz invariance, imprints of quantum gravitational effects in the cosmic microwave background (in particular its polarization), and decoherence induced by fluctuations[63][64][65] in the space-time foam.[66] The latter scenario has been searched for in light from gamma-ray bursts and both astrophysical and atmospheric neutrinos, placing limits on phenomenological quantum gravity parameters.[67][68][69] ESA's INTEGRAL satellite measured polarization of photons of different wavelengths and was able to place a limit in the granularity of space that is less than 10−48 m, or 13 orders of magnitude below the Planck scale.[70][71][better source needed] The BICEP2 experiment detected what was initially thought to be primordial B-mode polarization caused by gravitational waves in the early universe. Had the signal in fact been primordial in origin, it could have been an indication of quantum gravitational effects, but it soon transpired that the polarization was due to interstellar dust interference.[72] De Sitter relativity Dilaton Doubly special relativity Gravitational decoherence Gravitomagnetism Hawking radiation List of quantum gravity researchers Orders of magnitude (length) Penrose interpretation Planck epoch Planck units Swampland (physics) Virtual black hole Weak Gravity Conjecture ^ Quantum effects in the early universe might have an observable effect on the structure of the present universe, for example, or gravity might play a role in the unification of the other forces. Cf. the text by Wald cited above. ^ On the quantization of the geometry of spacetime, see also in the article Planck length, in the examples ^ a b Rovelli, Carlo (2008). "Quantum gravity". Scholarpedia. 3 (5): 7117. Bibcode:2008SchpJ...3.7117R. doi:10.4249/scholarpedia.7117. ^ Kiefer, Claus (2012). 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S2CID 12984346. Lämmerzahl, Claus, ed. (2003). Quantum Gravity: From Theory to Experimental Search. Lecture Notes in Physics. Springer. ISBN 978-3-540-40810-9. Rovelli, Carlo (2004). Quantum Gravity. Cambridge University Press. ISBN 978-0-521-83733-0. Wikiquote has quotations related to Quantum gravity. Weinstein, Steven; Rickles, Dean. "Quantum Gravity". In Zalta, Edward N. (ed.). Stanford Encyclopedia of Philosophy. "Planck Era" and "Planck Time" Archived 2018-11-28 at the Wayback Machine (up to 10−43 seconds after birth of Universe) (University of Oregon). "Quantum Gravity", BBC Radio 4 discussion with John Gribbin, Lee Smolin and Janna Levin (In Our Time, February 22, 2001) Portals: Physics Science Retrieved from " Quantum gravity is a theoretical framework that attempts to reconcile the theories of quantum mechanics, which describes the fundamental forces of nature at small scales, with general relativity, which describes gravity and the large-scale structure of the universe. The goal is to develop a quantum theory of gravity that can explain phenomena at all scales. However, a complete theory of quantum gravity has not yet been established.Analogy / Example All the fundamental forces of the universe are known to follow the laws of quantum mechanics, save one: gravity. Finding a way to fit gravity into quantum mechanics would bring scientists a giant leap closer to a “theory of everything” that could entirely explain the workings of the cosmos from first principles. A crucial first step in this quest to know whether gravity is quantum is to detect the long-postulated elementary particle of gravity, the graviton. In search of the graviton, physicists are now turning to experiments involving microscopic superconductors, free-falling crystals and the afterglow of the big bang.Quantum mechanics suggests everything is made of quanta, or packets of energy, that can behave like both a particle and a wave—for instance, quanta of light are called photons. Detecting gravitons, the hypothetical quanta of gravity, would prove gravity is quantum. The problem is that gravity is extraordinarily weak. To directly observe the minuscule effects a graviton would have on matter, physicist Freeman Dyson famously noted, a graviton detector would have to be so massive that it collapses on itself to form a black hole.“One of the issues with theories of quantum gravity is that their predictions are usually nearly impossible to experimentally test,” says quantum physicist Richard Norte of Delft University of Technology in the Netherlands. “This is the main reason why there exist so many competing theories and why we haven’t been successful in understanding how it actually works.”On supporting science journalismIf you're enjoying this article, consider supporting our award-winning journalism by subscribing. By purchasing a subscription you are helping to ensure the future of impactful stories about the discoveries and ideas shaping our world today.In 2015, however, theoretical physicist James Quach, now at the University of Adelaide in Australia, suggested a way to detect gravitons by taking advantage of their quantum nature. Quantum mechanics suggests the universe is inherently fuzzy—for instance, one can never absolutely know a particle's position and momentum at the same time. One consequence of this uncertainty is that a vacuum is never completely empty, but instead buzzes with a “quantum foam” of so-called virtual particles that constantly pop in and out of existence. These ghostly entities may be any kind of quanta, including gravitons.Decades ago, scientists found that virtual particles can generate detectable forces. For example, the Casimir effect is the attraction or repulsion seen between two mirrors placed close together in vacuum. These reflective surfaces move due to the force generated by virtual photons winking in and out of existence. Previous research suggested that superconductors might reflect gravitons more strongly than normal matter, so Quach calculated that looking for interactions between two thin superconducting sheets in vacuum could reveal a gravitational Casimir effect. The resulting force could be roughly 10 times stronger than that expected from the standard virtual-photon-based Casimir effect.Recently, Norte and his colleagues developed a microchip to perform this experiment. This chip held two microscopic aluminum-coated plates that were cooled almost to absolute zero so that they became superconducting. One plate was attached to a movable mirror, and a laser was fired at that mirror. If the plates moved because of a gravitational Casimir effect, the frequency of light reflecting off the mirror would measurably shift. As detailed online July 20 in Physical Review Letters, the scientists failed to see any gravitational Casimir effect. This null result does not necessarily rule out the existence of gravitons—and thus gravity’s quantum nature. Rather, it may simply mean that gravitons do not interact with superconductors as strongly as prior work estimated, says quantum physicist and Nobel laureate Frank Wilczek of the Massachusetts Institute of Technology, who did not participate in this study and was unsurprised by its null results. Even so, Quach says, this “was a courageous attempt to detect gravitons.”Although Norte’s microchip did not discover whether gravity is quantum, other scientists are pursuing a variety of approaches to find gravitational quantum effects. For example, in 2017 two independentstudies suggested that if gravity is quantum it could generate a link known as “entanglement” between particles, so that one particle instantaneously influences another no matter where either is located in the cosmos. A tabletop experiment using laser beams and microscopic diamonds might help search for such gravity-based entanglement. The crystals would be kept in a vacuum to avoid collisions with atoms, so they would interact with one another through gravity alone. Scientists would let these diamonds fall at the same time, and if gravity is quantum the gravitational pull each crystal exerts on the other could entangle them together.The researchers would seek out entanglement by shining lasers into each diamond’s heart after the drop. If particles in the crystals’ centers spin one way, they would fluoresce, but they would not if they spin the other way. If the spins in both crystals are in sync more often than chance would predict, this would suggest entanglement. “Experimentalists all over the world are curious to take the challenge up,” says quantum gravity researcher Anupam Mazumdar of the University of Groningen in the Netherlands, co-author of one of the entanglement studies.Another strategy to find evidence for quantum gravity is to look at the cosmic microwave background radiation, the faint afterglow of the big bang, says cosmologist Alan Guth of M.I.T. Quanta such as gravitons fluctuate like waves, and the shortest wavelengths would have the most intense fluctuations. When the cosmos expanded staggeringly in size within a sliver of a second after the big bang, according to Guth’s widely supported cosmological model known as inflation, these short wavelengths would have stretched to longer scales across the universe. This evidence of quantum gravity could be visible as swirls in the polarization, or alignment, of photons from the cosmic microwave background radiation.However, the intensity of these patterns of swirls, known as B-modes, depends very much on the exact energy and timing of inflation. “Some versions of inflation predict that these B-modes should be found soon, while other versions predict that the B-modes are so weak that there will never be any hope of detecting them,” Guth says. “But if they are found, and the properties match the expectations from inflation, it would be very strong evidence that gravity is quantized.”One more way to find out whether gravity is quantum is to look directly for quantum fluctuations in gravitational waves, which are thought to be made up of gravitons that were generated shortly after the big bang. The Laser Interferometer Gravitational-Wave Observatory (LIGO) first detected gravitational waves in 2016, but it is not sensitive enough to detect the fluctuating gravitational waves in the early universe that inflation stretched to cosmic scales, Guth says. A gravitational-wave observatory in space, such as the Laser Interferometer Space Antenna (LISA), could potentially detect these waves, Wilczek adds.In a paper recently accepted by the journal Classical and Quantum Gravity, however, astrophysicist Richard Lieu of the University of Alabama, Huntsville, argues that LIGO should already have detected gravitons if they carry as much energy as some current models of particle physics suggest. It might be that the graviton just packs less energy than expected, but Lieu suggests it might also mean the graviton does not exist. “If the graviton does not exist at all, it will be good news to most physicists, since we have been having such a horrid time in developing a theory of quantum gravity,” Lieu says.Still, devising theories that eliminate the graviton may be no easier than devising theories that keep it. “From a theoretical point of view, it is very hard to imagine how gravity could avoid being quantized,” Guth says. “I am not aware of any sensible theory of how classical gravity could interact with quantum matter, and I can't imagine how such a theory might work.” Quantum gravity is an attempt to unite the incompatible worlds of quantum mechanics and gravity. It does so by modifying one or both theories to reconcile the models.Our understanding of physics is far from complete. On small scales, we have the theory of quantum mechanics. A paradigm of quantum mechanics is the Standard Model, which explains many of the smallest particles and how they behave. On large scales, the main force governing objects is gravity, described by general relativity. But when trying to reconcile these two models together, scientists have fallen short; quantum mechanics and general relativity are not compatible with each other. Quantum gravity is that unknown key — the way to make the quantum world and the world of gravity work well together. You may like Quantum gravity FAQsQuantum gravity is an attempt to reconcile two theories of physics — quantum mechanics, which tells us how physics works on very small scales — and gravity, which tells us how physics works on large scales.Not only is quantum gravity possible; it is necessary to fill in the gaps in our understanding of physics. There are many possible models of quantum gravity, but so far, none have been proven. Quantum gravity can help us understand the physics within black holes and the moments right after the birth of the universe. It can also aid us in understanding quantum entanglement, condensed matter physics and quantum information.Standard Model vs. general relativityIn quantum mechanics, values such as position, momentum, energy and spin are "quantized," which means they can only take on certain discrete values rather than any value.To picture this, imagine you are creating a picture with a box of 64 crayons. This may sound like a lot of colors, but for this particular example, you can’t blend colors. You are always limited to 64 discrete colors.Gravity, described by Einstein's theory of general relativity, is not like this. Instead, it is classical, with particles or objects taking whatever values they choose. In our example, "Classical" colors are more like paint — they can be blended into an infinite range of colors, and can take on a hue in-between ones you find in your crayon box. There are other differences between the two theories. In quantum mechanics, the properties of particles are never certain. Instead, they are described by "wave functions," which give only probabilistic values. Again, in general relativity, this uncertainty does not exist. Finally, the Standard Model explains how three of the four fundamental forces of nature work — the electromagnetic force, the weak force and the strong force. Each of these forces is mediated by a boson — a photon for the electromagnetic force, a W or Z boson for the weak force, or a gluon for the strong force). These bosons act as "delivery" particles, carrying the force between other particles. The fourth force of nature, gravity, again is where the problem lies. Gravity is not known to have a particle that mediates its interactions, and so far, searches for this particle — the hypothetical graviton — have come up empty-handed. Why we need quantum gravityWe don't know how to write the laws of quantum mechanics in curved space-time. (Image credit: coffeekai via Getty Images)Both general relativity and the Standard Model work extraordinarily well in their own regimes and have stood up to test after test. Yet the physics is incomplete when each of these theories steps outside its regime — for example, in extreme environments like the centers of black holes or the first moments of the universe.Another example arises if you imagine a photon traveling through the universe. General relativity tells us this photon would follow a classical path that aligns with the curves and contours of space-time from the gravity of planets, stars and galaxies. Yet this photon also follows the rules of the electromagnetic force, governed by quantum mechanics — and we don't know how to write the laws of quantum mechanics in curved space-time. All of this means our understanding of physics is incomplete. If we want to understand the universe, we need a way to unite incompatible theories, and quantum gravity does that. This sometimes involves attempts to "quantize" gravity, or modify it in some way to be compatible with quantum mechanics. Other attempts to find a theory of quantum gravity modify quantum mechanics to agree more with gravity, while other theories combine the two approaches.Is quantum gravity string theory?String theory suggests that particles are infact tiny strings. (Image credit: PASIEKA via Getty Images)String theory is one of many attempts to develop a quantum gravity model. String theory suggests that particles are actually tiny strings. Imagine a guitar string; various modes of vibration create different notes. Similarly, in string theory, modes of vibrations create different particles. One of these vibrations describes a graviton, which behaves in a way that reconciles quantum mechanics and gravity. There are other models of quantum gravity as well. Holographic duality, a theory spawned from string theory, suggests that there is a projection of this universe — a hologram — with no gravity. In this projection, the Standard Model works smoothly. Another theory, called loop quantum gravity, proposes that the universe is made up of small, interconnected loops that essentially quantize space-time. Ways to test for quantum gravityResearchers have proposed many ways to probe the regime of quantum gravity. Many of these involve quantum entanglement, small changes from quantum fluctuations, spin interferometers. New generations of quantum gravitational wave detectors may also find evidence of quantum gravity in mergers of black holes, which may have quantum effects or evidence in the cosmic microwave background.Future experiments may lead to new insights about quantum gravity. In the meantime, it illustrates that there is still a lot we don't understand about the universe. Additional resourcesMore detail on quantum gravity can be found in the Stanford Encyclopedia of Philosophy. Watch these videos to learn more about loop quantum gravity and whether the string theory is the final solution for all of physics' questions. BibliographySiegel, Ethan. "The fundamental problem with gravity and quantum physics," Big Think. The Standard Model," CERN, Quantum Gravity," Stanford Encyclopedia of Philosophy, Breaking space news, the latest updates on rocket launches, skywatching events and more!