WIKIPEDIA

Quantum foam

Quantum foam (also known as **spacetime foam** or **spacetime bubble**) is a theoretical quantum fluctuation of spacetime on very small scales due to quantum mechanics. Matter and antimatter are constantly created and destroyed. These subatomic objects are called virtual particles.[1] The idea was devised by John Wheeler in 1955.[2][3]

Contents

Background

With an incomplete theory of quantum gravity, it is impossible to be certain what spacetime would look like at small scales. However, there is no definitive reason that spacetime needs to be fundamentally smooth. It is possible that instead, in a quantum theory of gravity, spacetime would consist of many small, ever-changing regions in which space and time are not definite, but fluctuate in a foam-like manner.[4]

Wheeler suggested that the uncertainty principle might imply that over sufficiently small distances and sufficiently brief intervals of time, the "very geometry of spacetime fluctuates".[5] These fluctuations could be large enough to cause significant departures from the smooth spacetime seen at macroscopic scales, giving spacetime a "foamy" character.

Experimental results

What Hendrik Casimir predicted and can be verified with the Casimir experiment is strong evidence that virtual particles do exist. Another measurement supports the virtual particle idea by predicting the strength of a magnet formed by an electron or muon. The g2 experiment targets this measurement.[1]

In 2005 MAGIC (Major Atmospheric Gamma-ray Imaging Cherenkov) telescopes detected that, among gamma-ray photons arriving from the blazar Markarian 501, some photons at different energy levels arrived at different times, suggesting that some of the photons had moved more slowly and thus contradicting the theory of special relativity's notion of the speed of light being constant, a discrepancy which could be explained by the irregularity of quantum foam.[6] More recent experiments were, however, unable to confirm the supposed variation on the speed of light due to graininess of space.[7][8]

Other experiments involving the polarization of light from distant gamma ray bursts have also produced contradictory results.[9] More Earth-based experiments are ongoing[10] or proposed.[11]

Constraints and limits

The large fluctuations characteristic of a spacetime foam would be expected to occur on a length scale on the order of the Planck length ($1.616255(18)\times10^{-35}$ m).[12] A foamy spacetime would have limits on the accuracy with which distances can be measured because the size of the many quantum bubbles through which light travels will fluctuate. Depending on the spacetime model used, the spacetime uncertainties accumulate at different rates as light travels through the vast distances.

X-ray and gamma-ray observations of quasars used data from NASA's Chandra X-ray Observatory, the Fermi Gamma-ray Space Telescope and ground-based gamma-ray observations from the Very Energetic Radiation Imaging Telescope Array (VERITAS) show that spacetime is uniform down to distances 1000 times smaller than the nucleus of a hydrogen atom.

Observations of radiation from nearby quasars by Floyd Stecker of NASA's Goddard Space Flight Center have placed strong experimental limits on the possible violations of Einstein's special theory of relativity implied by the existence of quantum foam.[13] Thus experimental evidence so far has given a range of values in which scientists can test for quantum foam.

Random diffusion model

The Random Diffusion Model predicted that photons could diffuse randomly through spacetime foam, similar to light diffusing by passing through fog. However, the observations made of quasars at distances of billions of light years by the Chandra X-ray observatory has ruled out this model, as the light was not observed to defuse in the way the model predicted.[14]

Holographic model

Measurements of quasars at shorter gamma-ray wavelengths with the Fermi and VERITAS space telescopes, ruled out a second model, called the holographic model, which predicted less diffusion than the Random Diffusion Model.[15][16][17][18]

Relation to other theories

The vacuum fluctuations provide vacuum with a non-zero energy known as vacuum energy.[19]

Spin foam theory is a modern attempt to make Wheeler's idea quantitative.

See also

- Geon
- Hawking radiation
- Holographic principle
- Lorentzian wormhole
- Planck time
- Stochastic quantum mechanics
- String theory
- Wormhole
- Loop quantum gravity

Notes

1. Quantum Foam (https://www.youtube.com/watch?v=nYDokJ2A_vU), Don Lincoln, Fermilab, 2014-10-24.
2. Wheeler, J. A. (January 1955). "Geons". *Physical Review*. **97** (2): 511–536. Bibcode:1955PhRv...97..511W (https://ui.adsabs.harvard.edu/abs/1955PhRv...97..511W). doi:10.1103/PhysRev.97.511 (https://doi.org/10.1103%2FPhysRev.97.511).
3. Minsky, Carly (24 October 2019). "The Universe Is Made of Tiny Bubbles Containing Mini-Universes, Scientists Say - 'Spacetime foam' might just be the wildest thing in the known universe, and we're just starting to understand it" (https://www.vice.com/en_us/article/j5yngp/the-universe-is-made-of-tiny-bubbles-containing-mini-universes-scientists-say). *Vice*. Retrieved 24 October 2019.
4. See Derek Leinweber's QCD animations of spacetime foam, as exhibited in Wilczek lecture (https://www.youtube.com/watch?v=914jzZ4LXcU&t=2887)
5. Wheeler, John Archibald; Ford, Kenneth Wilson (2010) [1998]. *Geons, black holes, and quantum foam : a life in physics*. New York: W. W. Norton & Company. p. 328. ISBN 9780393079487. OCLC 916428720 (https://www.worldcat.org/oclc/916428720).
6. "Gamma Ray Delay May Be Sign of 'New Physics' " (http://www.news.ucdavis.edu/search/news_detail.lasso?id=8364).
7. Vasileiou, Vlasios; Granot, Jonathan; Piran, Tsvi; Amelino-Camelia, Giovanni (2015). "A Planck-scale limit on spacetime fuzziness and stochastic Lorentz invariance violation" (https://doi.org/10.1038%2Fnphys3270). *Nature Physics*. **11** (4): 344–346. Bibcode:2015NatPh..11..344V (https://ui.adsabs.harvard.edu/abs/2015NatPh..11..344V). doi:10.1038/nphys3270 (https://doi.org/10.1038%2Fnphys3270).
8. Cowen, Ron (2012). "Cosmic race ends in a tie". *Nature*. doi:10.1038/nature.2012.9768 (https://doi.org/10.1038%2Fnature.2012.9768). S2CID 120173051 (https://api.semanticscholar.org/CorpusID:120173051).
9. Integral challenges physics beyond Einstein / Space Science / Our Activities / ESA (http://www.esa.int/Our_Activities/Space_Science/Integral_challenges_physics_beyond_Einstein)
10. Moyer, Michael (17 January 2012). "Is Space Digital?" (http://www.scientificamerican.com/article.cfm?id=is-space-digital). *Scientific American*. Retrieved 3 February 2013.
11. Cowen, Ron (22 November 2012). "Single photon could detect quantum-scale black holes" (http://www.nature.com/news/single-photon-could-detect-quantum-scale-black-holes-1.11871). *Nature News*. Retrieved 3 February 2013.
12. Hawking, S.W. (November 1978). "Spacetime foam". *Nuclear Physics B*. **144** (2–3): 349–362. Bibcode:1978NuPhB.144..349H (https://ui.adsabs.harvard.edu/abs/1978NuPhB.144..349H). doi:10.1016/0550-3213(78)90375-9 (https://doi.org/10.1016%2F0550-3213%2878%2990375-9).
13. "Einstein makes extra dimensions toe the line" (http://www.nasa.gov/centers/goddard/news/topstory/2003/1212einstein.html). NASA. Retrieved 9 February 2012.
14. "NASA Telescopes Set Limits on Spacetime Quantum "Foam" " (https://www.nasa.gov/mission_pages/chandra/nasa-telescopes-set-limits-on-spacetime-quantum-foam.html). 28 May 2015.
15. "Chandra Press Room :: NASA Telescopes Set Limits on Space-time Quantum "Foam":: 28 May 15" (http://chandra.si.edu/press/15_releases/press_052815.html). *chandra.si.edu*. Retrieved 2015-05-29.
16. "Chandra X-ray Observatory - NASA's flagship X-ray telescope" (http://chandra.si.edu/). *chandra.si.edu*. Retrieved 2015-05-29.
17. Perlman, Eric S.; Rappaport, Saul A.; Christensen, Wayne A.; Jack Ng, Y.; DeVore, John; Pooley, David (2014). "New Constraints on Quantum Gravity from X-ray and Gamma-Ray Observations". *The Astrophysical Journal*. **805**: 10. arXiv:1411.7262 (https://arxiv.org/abs/1411.7262). Bibcode:2015ApJ...805...10P (https://ui.adsabs.harvard.edu/abs/2015ApJ...805...10P). doi:10.1088/0004-637X/805/1/10 (https://doi.org/10.1088%2F0004-637X%2F805%2F1%2F10). S2CID 56421821 (https://api.semanticscholar.org/CorpusID:56421821).
18. "Chandra :: Photo Album :: Space-time Foam :: May 28, 2015" (http://chandra.si.edu/photo/2015/quantum/). *chandra.si.edu*. Retrieved 2015-05-29.
19. Baez, John (2006-10-08). "What's the Energy Density of the Vacuum?" (http://math.ucr.edu/home/baez/vacuum.html). Retrieved 2007-12-18.

References

- Minkel, JR (24 November 2003). "Borrowed Time: Interview with Michio Kaku" (http://www.scientificamerican.com/article.cfm?id=borrowed-time-interview-w). *Scientific American*
- Swarup, A. (2006). "Sights set on quantum froth" (https://www.newscientist.com/article/dn8738-sights-set-on-quantum-froth/). *New Scientist*, 189, p. 18, accessed 10 February 2012.