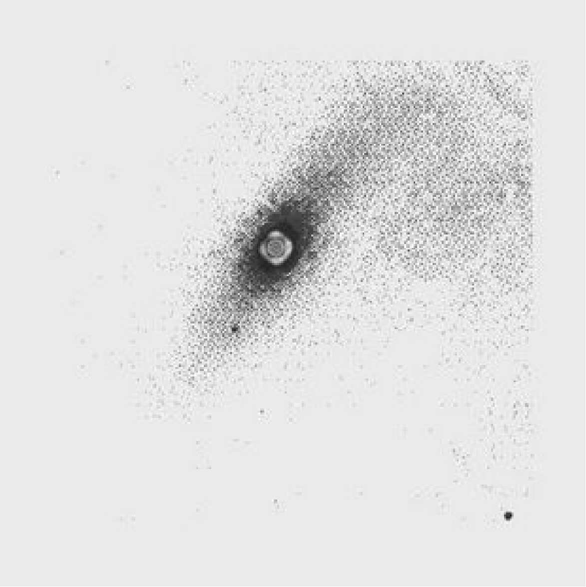
How foamy is spacetime?



This image is a linear combination of two images first observed by Perlman et al. for research studying the relationship between this quasar and its galaxy. In the image, the ring surrounds the nucleus of the galaxy, making it look iris-like rather than just pseudo-point-like. Image courtesy of Eric Perlman.

Maybe not as foamy as some scientists thought, as a fresh look at a quasar first observed in 1998 by the Hubble Space Telescope (HST) shows. Physicists observed a diffraction pattern called an Airy ring around the image of a distant quasar-like object. This ring persuades physicists that the light from this distant object has traveled through a relatively calm – rather than extremely frothy – spacetime.

The idea that space is composed of ever-changing arrangements of bubbles, called spacetime foam, dates back to the 1960s. On a small (Planck) scale, foamy bubbles result from the uncertainty principle, which allows virtual particles to spontaneously pop into and out of existence. Although quantum foam violates the law of conservation of energy on ultra-short timescales, nanoscale devices have measured the effects of these tiny virtual particles on the vacuum in other contexts. Further, many physicists believe that some model of quantum foam must exist in any theory of quantum gravity, which unites quantum mechanics and general relativity.

“The detection of spacetime foam will give us a glimpse of the ultimate structure of spacetime,” said Y. Jack Ng, member of the team that observed the ring. “The observational results may also point physicists to the correct theory of quantum gravity.”

Ng and his colleagues, W.A. Christiansen and H. van Dam from the University of North Carolina, have narrowed down the possible models of quantum foam into the least foamy variations. The team compared two spacetime foam models based on quantum fluctuations in spacetime geometry. The first model is consistent with the holographic principle, which stipulates that the maximum amount of information that any region of space can store is proportional to its surface area instead of its volume, like a hologram. The second model, called the random-walk model, stipulates that successive fluctuations are random, totally uncorrelated. The holographic model enables a less turbulent spacetime compared with the random-walk model, which involves greater fluctuations.

The team chose to analyze the quasar-like object PKS1413 + 135 to search for an Airy ring because the presence of a ring limits the amount of light scattering that could be caused by spacetime foam. The quasar is 1.2 gigaparsecs – or about 4 billion light years – away from the Milky Way, allowing the physicists to accumulate the effects of the fluctuations over a distance, necessary for amplifying the tiny effects of the foam.

“Searching for spacetime foam effects is limited to point-like objects like PKS1413 +135 because objects greater than point-like size – such as galaxies – can contain an intrinsic structure that masks the effects of quantum foam,” said Christiansen.

The HST’s high-resolution image of the Airy ring surrounding the quasar ruled out the random-walk model, but lacked sufficient resolution to test the holographic model.

“By using this image, they’ve shown that the archives of all the great telescopes -- both the interferometers as well as single telescopes like the HST -- can be used to make very fundamental measurements about the structure of our universe,” said Eric Perlman, physicist at the University of Maryland who initially observed the quasar.

Telescopes currently being built could capture even higher resolution images for future studies.

“In the next few years, interferometers – such as the Very Large Telescope Interferometer in Chile or the Keck Interferometer in Hawaii – could test the holographic model by observing more distant quasars with their large apertures and long baselines,” said Christiansen.

Cosmological Implications

However, the team didn’t depend on further observations to deduce another cosmological implication in addition to measuring quantum foam.

Observationally ruling out the random-walk model, coupled with restrictions from computational physics, has repercussions on the matter of spacetime. Because ordinary matter only contains an amount of information dense enough to map out spacetime at a level consistent with the random-walk model, the physicists suggest that “there must be other kinds of matter or energy with which the Universe can map out its spacetime geometry (to a finer spatial accuracy than is possible with the use of conventional matter).

“This line of reasoning strongly hints at the existence of dark matter and dark energy, independent of the evidence from recent cosmological observations.”

Although the universe may not be quite as foamy as some scientists previously suspected, the team has put constraints on the foaminess of spacetime, and supplied another parameter with which to probe unconventional matter and energy. The group has also holds high hopes for learning more about spacetime structure in the near future.

“I think there is a close relation between quantum foam and dark matter and dark energy,” said Ng. “More work on holographic-foam-inspired cosmology is now in progress. Stay tuned.”

Citation: Christiansen, W.A., Ng, Y. Jack, and van Dam, H. **Probing Spacetime Foam with Extragalactic Sources**. *Physical Review Letters*. 96, 051301 (2006).

By Lisa Zyga, Copyright 2006 PhysOrg.com