Cosmic Connections

A talk given by Bill Baylis to the UU Church of Olinda on May 27, 2018

Life is resilient. Through natural selection it has "learned" how to reproduce and avoid peril. A portion of brain activity, especially in humans and other large-brained beings, seeks causes for events so that perilous ones can be circumvented. That strategy, although often over-emphasizing individual influence, has been enormously successful in driving curiosity-based learning and technological advances, even if some of those advances end up threatening our very existence.

A societal religious impulse is driven by the desire to understand where we came from and where we are going. There are answers in the stars. Studies of the heavens provided basis for calendar and allowed agriculture to flourish. Not only 4600 years ago in the Nile valley, tracking the timing of the floods, and 5100 years ago at Stone Henge, which seems to have marked winter solstice and perhaps equinox times, but earlier, 11,000 years ago in SE Turkey at Gøbekli Tepe. This amazing colossal monument, the world's first major temple, constructed long before the use of wheels and even before pottery and at the beginning of farming, has well-preserved carvings of animals on its 200 10-ton, 6-m high column pillars, some of which have recently been identified with constellations as arranged 2000 years earlier showing a comet, presumably the one that broke into pieces and struck the Earth in the Great Lakes regions, caused massive fires over a quarter of the Earth's surface, and from the resulting smoke and ash that blocked sunlight, evidently started the refreezing of the 1200-yr long Younger Dryas period. That sudden climate change wiped out the megafauna as well as the Clovis culture in North America. I will return to evidence for this cosmic collision below.

Our understanding of the cosmos and its evolution started with Galileo's first telescopic observations in 1609, when he saw that the Milky Way was a dense band of stars. In 1785, musician-astronomer William Herschel reasoned that the Milky Way had the shape of a flat disk. But it wasn't until the "Great Debate" in 1920 (between Harlow Shapley and Heber Curtis) that most astronomers became convinced of the existence of other galaxies like the Andromeda. By then, Schwarzchild had found the static black hole solution of Einstein's equations, but the existence of black holes were taken seriously only in the 1960s. Now we know that our own galaxy, the Milky Way, has over 200 billion stars, a supermassive black hole of 4.3 million solar masses at its centre with some 10,000 solar- mass blackholes evidently swarming about it, and that there are roughly a trillion galaxies in the cosmos, some with over 100 trillion stars.

Such numbers and distances and sizes are mind-boggling. It helps to measure large distances in units of time: how long it would take light to traverse that distance. The speed of light is large, almost 300,000 km/s and a million times faster than sound in air at room temperature and pressure. The time it takes light to get to us from the sun, some 150 M km away, is 500 s (8.33 minutes). In these units, the sun is 8.33 light-minutes away. The closest star to the sun is just over 4 light-years (ly) from us and the most distant is over 13 billion ly distant. The age of the Universe, since its formation in the Big Bang, is 13.8 billion years.

The main message of my talk today is that in spite of such huge separations in time and space, and in spite of the fact that information and influences cannot travel faster than light, we are connected to the cosmos, both materially and through quantum entanglement. We should endeavor to fathom our awe-inspiring cosmos and celebrate our ability to comprehend our existence in it.

As we read in the responsive reading, “we are of the stars, the dust of explosions cast across space”. At the big bang, practically all the matter in the cosmos was in the form of a plasma of protons and electrons, ionized hydrogen atoms, with a few helium nuclei as well. The plasma formed neutral atoms of H and He about 380,000 years after the big bang, and the microwave background radiation we can now observe is the remnant of the plasma from that age. All of the other atoms in our bodies, the O, C, N, P,… were made in the nuclear furnaces of stars. H fused to He and then to C, O, and heavier elements, and if the was sufficient mass the star would collapse before exploding in a supernova and scattering its guts into space. (OK, star dust is more poetic than guts, but it was really guts.) Theories of stellar nucleosynthesis, about how much of each element was produced and when, worked pretty well until you got to the heavy elements, those well above iron. Heavier elements need more neutrons, and as more neutrons are added, the generally less stable the atomic nuclei become. If you try to force more neutrons into nuclei like some isotopes of uranium or plutonium, they split into smaller nuclei plus a few neutrons. Atomic bombs are based on chain reactions of such fission processes, of course. It is difficult to imagine how stellar furnaces could produce the concentrations of gold, platinum, and other heavy atoms that we observe on Earth or in the stars.

Now stars become supernovae and leave black holes only if they start with masses of over 10 solar masses. Otherwise, when they collapse as a white dwarf, for example, their remnants are either white dwarfs or neutron stars. Neutron stars can carry the mass of the sun in a ball only 10 km in diameter. The Earth has a diameter of 13,000km and the Sun is 100 times larger across. The density of neutron stars must be on the order of 10^{15} that of water, and a teaspoon of neutron star would weigh $5x10^{15}$ g (that’s 5 trillion tonnes!) instead of 5 g. If neutron stars collided, they could easily create heavy atoms like iridium, platinum and gold (Z= 77, 78, and 79). But nobody had ever seen a collision of neutron stars, at least not until last year!

First a couple of black hole collisions were observed when LIGO detectors were upgraded in Washington State and Louisiana. These were amazing experiments made possible by hypersensitive interferometers that could see tiny vibrations with amplitudes $1/10,000^{th}$ the radius of a proton. The fact that two well separated detectors saw the same oscillation patterns at almost the same time gave physicists the confidence that they were really detecting a distant event, and the pattern observed could only have been caused by a black hole collision. Triangulation gave some information about the location of the collision in space, but only enough to identify a broad band in the heavens where it happened.

The real break came on August 17, 2017, shortly after a third detector with sufficient sensitivity came online in Italy. Triangulation could now locate the next collision in space. Telescopes around the world focused on the location and saw the aftermath in light and other electromagnetic radiation of a “kilonova.” A new age of astronomy, combining electromagnetic and gravitational waves, had begun! From the combined observations, astrophysicists could see that neutron stars of 1.1 and 1.6 solar masses had collided and they estimated the amount of gold and platinum produced. It was impressive! Such collisions really could account for the all the gold, iridium, and platinum found on Earth. It is pretty sure that the gold in your wedding band arose from such collisions many millions or even billions of lightyears away. Such are our intimate connections with the distant cosmos.

Let’s return to the Younger Dryas period 13 millenia ago and the subsequent construction of Gøbekli Tepe in Turkey. The cause of the sudden return to ice-age conditions is still being debated, but the key piece of evidence for many specialists was the increase in platinum concentrations by a factor of 100 in ice cores from Greenland at the very start of the Younger Dryas. The most reasonable explanation of such an increase is the bombardment of Earth by comet or asteroid pieces, bodies that were split out of a collision of neutron stars. It was a similar argument that convinced most researchers that the end of the dinosaurs was triggered by an asteroid collision: the Alvarez team noted an unusual layer of iridium in soil around the world about 66 million years ago, just as the large dinosaurs were wiped out. That convinced them, as they described in a 1980 paper, that it was an asteroid collision with Earth that set off the massive extinction event at the K-T (now K-Pg) boundary. But it took the discovery and dating of the 180 km wide Chicxulub crater in 1991 that finally brought most scientists on board. It must have been caused by a 10 km wide asteroid.

An entirely different type of connection has been proposed based on a quantum effect called entanglement. Although entanglement (I will describe it in a moment) presents interesting possibilities with regard to information content at black holes—a favorite topic of Steven Hawking—popular speculation about instantaneous influences over large distances is based on misunderstanding of the physics. Einstein’s term “spooky action at a distance” has misled many. The confusion arises from implicit assumptions of locality that quantum phenomena do not generally obey. However, the type of connection that quantum nonlocality allows is one of amplitude correlation, not causation.

The simplest example of entanglement is a system of two particles. States of the system involve both particles. It is simplest to work with “normal modes” or “steady states” of the system, in which all parts oscillate together, but any superposition of such states is also a possible state. In a steady state, the properties of the two particles are correlated as amplitudes. Observations of the system usually reveal it to be in one of its steady states. After the observation, the system is described by a single steady state and no longer as a superposition. The particles in the entangled state may be separated by large distances and the observations may be concentrated on only one of the particles. What we know about the entire system is changed by the measurement. This is the weirdness of the quantum world. Is there any physical change in distant parts? None that we can detect or use for sending signals.

As an example, consider a collection of pairs of balls. In each pair, one of the balls is white and the other is black. The two balls in a pair are correlated, but in quantum systems, we deal with a correlation in amplitudes. If we look at one of the balls and see that it is white, we know the other must be black. This is the type of correlation that may occur in quantum entanglement, except that it is only an amplitude correlation. An observation or measurement is needed to determine the state. There is no sudden transfer of information.

This topic deserves more time than I have now for discussion. It is an important effect, but one fully consistent with causality and relativistic constraints on the speed of information transfer.

In summary, the cosmos is vast in time and space, full of an enormous variety of amazing phenomena. That we are intimately connected to it and able to comprehend it is fully worthy of our amazement, wonder, appreciation, and further study!

References

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