Article

The One-World-Per-Observer Paradigm of Modern Cosmology

James Kowall*

Abstract

Recent discoveries in cosmology have resulted in a remarkable paradigm shift. This paradigm shift is based on measurements of the cosmological constant, the exponential expansion of space, and a cosmic horizon. The cosmic horizon is a bounding surface of space that surrounds the observer at the central point of view. Interpreted in the context of the holographic principle and horizon complementarity, these discoveries lead to the one-world-per-observer paradigm.

Key Words: cosmic horizon, dark energy, holographic principle, role of the observer.

You know many things, but the knower you do not know.
Find out who you are, the knower of the known.
Whatever you see, hear or think, you are not what happens, you are to whom it happens. The perceived cannot be the perceiver.
Delve deeply into the sense 'I am' and you will discover that the perceiving center is universal. All that happens in the universe happens to you, the silent witness.
Whatever is done is done by you, the universal and inexhaustible energy.
There can be no universe without the witness, no witness without the universe.
Nisargadatta Maharaj

If the holographic principle was as far as we could go with our description of the world, this principle would remain a big source of curiosity, but it would not give us a full description of the world. Another discovery made around the same time the holographic principle was discovered allows for a fuller description. This critical discovery has led to a radical revision in the way we see the world. This paradigm shattering discovery is the exponential expansion of space.

This remarkable recent discovery in cosmology is that the observer's world is characterized by the exponential expansion of space, dark energy, and a cosmic horizon. The cosmic horizon is a spherical surface in space that is as far out in space as the observer at the central point of view can see things in space due to the limitation of the speed of light. Dark energy is like a force of anti-gravity. The expansion of space is literally accelerating away from the central point of view of the observer. Due to the exponential expansion of space, at the cosmic horizon things appear to move away from the observer at the speed of light [2].

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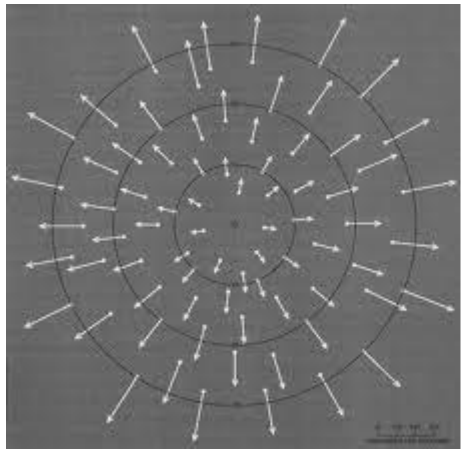
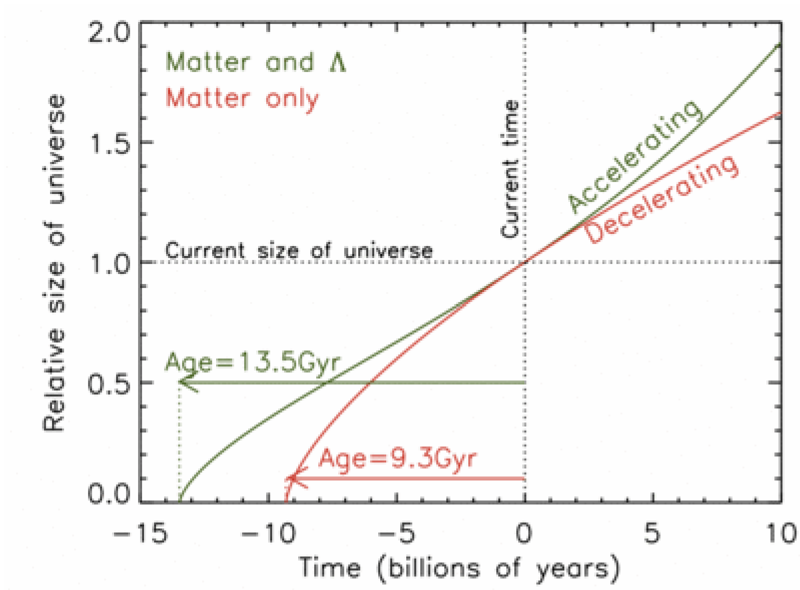


Each of us lives in an exponentially expanding world. This has been confirmed through the observation of the motion of distant galaxies. There is the idea that galaxies are moving away from each other since they were thrown apart in the explosion called the big bang event that created the world. If there was no force of gravity, the velocity of separation should be proportional to the distance of separation.

With an attractive force of gravity we would expect the velocity of separation to slow down over time, and so the velocity of separation should not be a straight line as a function of the distance of separation, but should bend downwards. Strangely, that is not what is observed. The velocity of separation bends upward as a function of the distance of separation, as though the galaxies are repelling each other and flying apart even faster over the course of time. This repulsive force, which is like a force of anti-gravity, is called the force of dark energy [3].

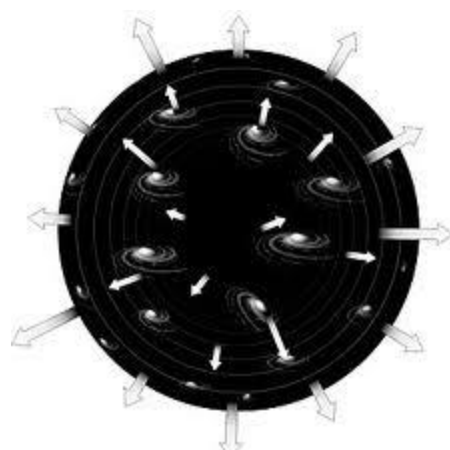


In relativity theory, this repulsive force is understood as a cosmological constant. The principle of equivalence tells us every force is equivalent to the accelerated frame of reference of an observer, so what exactly is accelerating with the force of dark energy? The answer is very bizarre. Space itself is accelerating away from the central point of view of the observer.

Space is exponentially expanding away from the big bang event. The exponential expansion of space is what drives the expansion of the observer's world from the big bang. In the sense of the principle of equivalence, this is the acceleration of space itself. The expansion of space is accelerating away from the central point of view of the observer. Even more bizarre, that central point of view is the point of singularity that we call the big bang event. Stranger still, every observer is at the central point of view of an exponentially expanding space accelerating away from the observer, and every observer's world always begins in a big bang event.

This is predicted by Einstein's equations with a cosmological constant Λ. The proper time that characterizes the accelerated worldline of an observer in an exponentially expanding space with coordinates (x, y, z, t) is written as $\tau=\int ds$, where $ds^2=dt^2-e^{at}(dx^2+dy^2+dz^2)$ and $a=\sqrt{\Lambda}$. The strange aspect of exponential expansion is the observer's accelerated worldline arises from the expansion of space itself. Space expands away from the central point of view of the observer.

In an exponentially expanding world with the force of dark energy, every observer is surrounded by a cosmic horizon. The cosmic horizon is a spherical surface in space surrounding the observer where things appear to move away from the observer at the speed of light. Things move away from the observer due to the repulsive force of dark energy. The farther out, the faster things appear to move away. At the cosmic horizon things appear to move away at the speed of light [4].



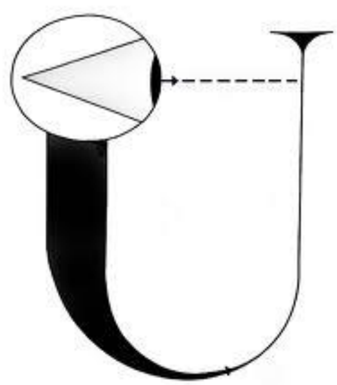
Since nothing can travel faster than the speed of light, the cosmic horizon is as far out in space as the observer at the central point of view can see things in space. Fundamentally, this is due to the limitation of the speed of light, which is like the maximal rate of information transfer in a computer network. The cosmic horizon is a bounding surface of space that surrounds the observer and limits the observer's observations within that bounded space.

This is exactly the nature of the holographic principle [2]. The cosmic horizon has a temperature and emits Hawking radiation as a form of thermal radiation, but only from the accelerated perspective of the observer at the central point of view. Just like for gravity, an observer in a state of free fall sees no horizon and no particles of Hawking radiation. The same kind of horizon complementarity that applies to a black hole horizon also applies to a cosmic horizon.

The only way to make sense of this state of affairs is the holographic principle. The cosmic horizon is a bounding surface of space that acts as a holographic screen and encodes bits of information for whatever is observed in the space bounded by the horizon. Everything observed in that bounded space, all the observable objects in that space, are like the projection of images from the screen to the central point of view of the observer.

The inevitable conclusion of this state of affairs is the one-world-per-observer paradigm. Every observer is surrounded by its own cosmic horizon, and all the bits of information for everything the observer can observe within that bounded space are ultimately encoded on the ultimate bounding surface of that space.

The cosmic horizon is a bounding surface of space that limits observations in the observer's world due to the limitation of the speed of light, but also acts like a holographic screen that encodes bits of information for everything observed in the space bounded by the horizon. Those perceivable images are animated over a sequence of events that arise on the observer's accelerated worldline. Each observational event on that worldline is like a screen output from the observer's holographic screen. The observer itself is nothing more than the consciousness present at the central point of view of its world, which is always limited by its cosmic horizon [5].



Amanda Gefter [6] has written about the one-world-per-observer paradigm in her essay on Cosmic Solipsism. She can only describe the observer as a frame of reference, but the nature of the exponential expansion of space from the big bang event makes it perfectly clear that the observer is the consciousness present at the center of the cosmic horizon, which ultimately defines the observer's world. Only that presence of consciousness has its own sense of being present, or its own sense of 'I am', which is the nature of solipsism. The only true knowledge the observer can ever know about itself is that 'it exists'.

Tom Banks [7] also has written about cosmic solipsism in his formulation of quantum gravity in an exponentially expanding space, which he calls holographic space-time. He states the holographic formulation gives an inherently "observer-centric description" of observable reality. As Banks puts it: "The philosophical stance of the theory is thus one of extreme positivism; one might even say solipsism. Space-time is an emergent construction, which results from an infinite set of solipsistic observers, and consistency conditions between them". Banks is telling us that in an exponentially expanding space that is characterized by a positive cosmological constant, also called de Sitter space, every observer is at the center of its own world.

In an exponentially expanding world with the force of dark energy every observer is surrounded by a cosmic horizon limiting observations. The cosmic horizon acts as the ultimate holographic screen that encodes information for everything observed in that bounded space. The cosmic horizon is a bounding surface of space surrounding the observer at the central point of view. Everything observed in that bounded space is like the holographic projection of images from the screen to the central point of view of the observer. In this sense, everything in the observer's world is defined on its own holographic screen. That is where all the information for things is defined. In a very real sense, the observer has its own world defined on its own holographic screen. Everything the observer perceives in its world is like an animated image projected from its screen to the central point of view of the observer. It is as though the observer inhabits its own private world, which is very much like its own private theater of consciousness.

The observer's holographic screen only arises because the observer is in an accelerated frame of reference. That acceleration is how an event horizon arises that encodes information and acts as a holographic screen. Fundamentally, that acceleration arises from the acceleration of space itself. Only the exponential expansion of space drives the expansion of the observer's world from the big bang event and places the observer in an accelerated frame of reference. The acceleration of space is the force of dark energy that gives rise to the observer's cosmic horizon, which is the ultimate bounding surface of space in the observer's world. All observations in the observer's world are ultimately limited by its cosmic horizon. In this sense, the cosmic horizon is the edge of the observer's world.

To be clear about things, every observer's world begins in a big bang, and that world expands from the big bang due to the exponential expansion of space. It is simply not the case that there is a single world that begins in a big bang. Every observer is at the center of its own world, and every observer's world begins in a big bang event. This is the one-world-per-observer paradigm. Every observer's world is its own unique frame of reference limited by the observer's own cosmic horizon. That frame of reference arises from the acceleration of space itself.

The normal flow of energy in the observer's world arises as the observer enters into an accelerated frame of reference and follows a time-like worldline. This accelerated frame of reference arises from the expansion of space, which accelerates away from the central point of view of the observer and drives the expansion of the observer's world from the big bang event.

There are two closely related phenomena that have to do with the exponential expansion of space. The first is the rate of the exponential expansion of space hypothesized to have occurred at the time of the big bang, a topic of research called inflationary cosmology and supported by measurements of the cosmic background radiation left over from the big bang. The second is the current measured rate of the exponential expansion of space that we see in terms of the motion of distant galaxies that appear to move away from us ever faster the farther out we look.

The difference in these two phenomena is the magnitude of the cosmological constant. At the time of the big bang event, the value of Λ was about 1 in natural Planck units, while the current measured value of Λ is about 10^{-123}. Although this seems like a humongous discrepancy, it is precisely this change in the value of the cosmological constant over the course of time that explains the normal flow of energy in the world.

This normal flow of energy is the essence of the second law of thermodynamics. The second law simply reflects that hotter objects radiate away more heat than colder objects, and so heat tends to flow from a hotter to a colder object over the course of time. This is a direct consequence of kinetic theory. Temperature only measures the random kinetic energy of particles, while heat is electromagnetic radiation that arises from the motion of charged particles.

Thermodynamic properties of cosmic horizons naturally explain the second law, since the horizon temperature becomes lower as the horizon expands in size. This thermodynamic property is predicted by relativity theory, since the cosmic horizon radius is determined in terms of the cosmological constant as $(R/\ell)^2=3/\Lambda$ for three extended dimensions of space, and the temperature of the horizon is related to its radius as $kT=\hbar c/2\pi R$. As the cosmological constant decreases in value over the course of time, the cosmic horizon radius increases and the temperature of the horizon decreases. Thus, it is natural for heat to flow in this direction over the course of time, thereby explaining the normal flow of energy in the world.

Inflationary cosmology tells us that the normal flow of energy in the observer's world arises as the observer’s world inflates in size from a Planck length to its current size of about 15 billion light years, and is the basis for the second law of thermodynamics. This normal flow of energy arises as heat tends to flow from the very hot big bang event to all colder states of the observer’s world defined by an inflated cosmic horizon. The flow of heat is perceived as energy tends to become dispersed into lower frequencies. Since energy is quantized in terms of frequency as $E=hf$, this dispersion of energy into lower frequencies results in an increase in the number of degrees of freedom, which is called an increase in entropy. Each photon of electromagnetic radiation is an independent degree of freedom, and the number of photons increases as heat is dispersed into lower frequencies.

In terms of the holographic principle, each independent degree of freedom is ultimately encoded as a bit of information on a bounding surface of space. The total number of bits of information encoded on a spherical surface of radius R and surface area $A=4\pi R^2$ is given by $n=A/4\ell^2$, which gives the maximum entropy of the region of space bounded by that surface. The fundamental reason entropy can increase in the observer's world over the course of time is due to the fact that the observer’s cosmic horizon encodes more bits of information as it inflates in size. This increase in entropy is related to the normal flow of heat that arises as the cosmic horizon inflates in size and cools in temperature. This process directs the normal flow of energy that drives all physical and biological processes in the observer’s world.

The normal flow of energy arises in the observer’s world as heat tends to flow from hotter to colder objects. This normal flow of energy is related to an increase in the number of degrees of freedom, called an increase in entropy. Ultimately, the number of degrees of freedom can only increase if the observer’s cosmic horizon inflates in size and encodes more bits of information.

Inflationary cosmology tells us that the amount of dark energy in the world is not a constant, but decreases over time. This decrease in the amount of dark energy in the world over the course of time is often described as a process of symmetry breaking, like a process of burning that burns away the dark energy. As the dark energy burns away, the cosmic horizon inflates in size. This is the fundamental process that drives the normal flow of energy in the observer's world.

We all experience this normal flow of energy. The flow of energy from the sun to the earth is driven by this fundamental process, which also drives all physical and biological processes in the observer's world. The best way to understand this process is in terms of the dispersion of energy into lower frequencies [8]. As heat tends to flow from a hotter to a colder body, energy tends to become dispersed into lower frequencies. The nature of that heat energy is typically a photon of electromagnetic radiation. A photon is a quantum of electromagnetic radiation.

The energy of each photon is quantized as E=hf. As heat tends to flow from a hotter to a colder body, photons are dispersed into lower frequencies. As long as total energy is conserved, this means more photons must be created as energy is dispersed into lower frequencies. Each photon acts like a particle, but these independent degrees of freedom are ultimately encoded as bits of information on a bounding surface of space. This is possible since more degrees of freedom are created as heat tends to flow in the normal temperature gradient established by the inflation of the cosmic horizon from the big bang event. This temperature gradient only arises because the cosmic horizon inflates in size as dark energy burns away. More degrees of freedom can only be created because the cosmic horizon encodes more bits of information as it inflates in size. This fundamental process is what drives the normal flow of energy in the observer's world [8].

Where does this increase in information come from? As the dark energy burns away the cosmic horizon inflates in size and encodes more bits of information. The flow of time in the observer's world is directly related to this burning away of dark energy, but so too is the flow of energy. The best way to see this is in terms of thermodynamic principles. The second law of thermodynamics tells us that heat tends to flow from a hotter to a colder body. The reason is quite simple, as a hotter body tends to radiate away more heat than a colder body, and so heat tends to flow from the hotter to colder body over the course of time. We can even say that the direction of the flow of time is directed by this normal flow of heat.

The key insight that solves this puzzle about the direction of time's arrow is the temperature of the cosmic horizon. Nothing is hotter than a Planck size cosmic horizon arising with the big bang event, and nothing is colder than a maximally inflated cosmic horizon resulting from the exponential expansion of an observer's world. As the size of a cosmic horizon approaches infinity, its temperature approaches absolute zero. The holographic principle specifies the absolute temperature of the horizon in terms of its radius R as $kT=\hbar c/2\pi R$. This in turn is determined by the value of the cosmological constant Λ. Relativity theory specifies the radius of the cosmic horizon as $R^2/\ell^2=3/\Lambda$. At the time of the big bang event, R is about a Planck length, Λ is about 1, and a Planck size cosmic horizon has an absolute temperature of about 10^{32} degrees Kelvin. As the value of the cosmological constant decreases over time, the radius of the cosmic horizon inflates in size and the horizon cools in temperature.

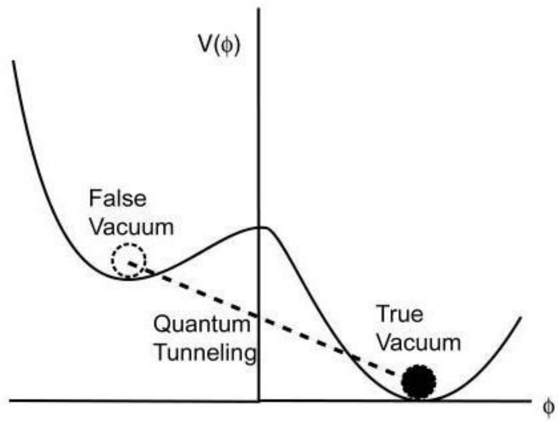
The predictions of inflationary cosmology have been confirmed by measurements of the cosmic background radiation left over from the big bang event, which is Hawking radiation from the cosmic horizon. Inflationary cosmology is related to the discovery of the exponential expansion of space, confirmed by measurements of the motion of distant galaxies. These two discoveries are best understood together in the sense of the natural evolution of the world.

The key that ties them together is the nature of dark energy, or a cosmological constant. The force of dark energy is like a force of anti-gravity that drives the exponential expansion of space from the big bang event. In the sense of the principle of equivalence, this force is equivalent to the acceleration of space itself. Every observer is at the center of its own exponentially expanding world and is in an accelerated frame of reference due to the expansion of space. Inflationary cosmology tells us that the amount of dark energy in the world is not a constant, but decreases over time. In other words, the cosmological constant is not really a constant, but decreases from a very high value to a very low value.

The current measured value of the cosmological constant is about $\Lambda=10^{-123}$, which corresponds to a cosmic horizon radius R of about 15 billion light years or 10^{62} Planck lengths. Inflationary cosmology postulates that at the time of the big bang event, Λ was about equal to 1 and R was about a Planck length. The natural evolution of the world occurs as the cosmological constant decreases in value, the concentration of dark energy in the world decreases in value, and the cosmic horizon inflates in size and cools in temperature. As the cosmic horizon inflates in size, more bits of information are encoded and entropy increases. Since $n=A/4\ell^2=4\pi R^2/4\ell^2=3\pi/\Lambda$, at the current time about 10^{124} bits of information are encoded on the inflated cosmic horizon.

The way the amount of dark energy changes is described as symmetry breaking, which is the nature of a phase transition. Unlike the process of melting of ice into water, this phase transition is more like a process of burning, as a state of high potential energy transitions into a state of lower potential energy. Unlike a process of melting where heat must be applied, in a process of burning heat is released and is radiated away, but both are examples of symmetry breaking as a system transitions from a highly organized state of coherent organization into a more disorganized state. In the case of burning, the system is characterized by a high amount of potential energy and a potential barrier. The phase transition occurs through a process of tunneling through the potential barrier and reaching a state of lower potential energy.

In that phase transition, some of the potential energy is converted into kinetic energy, and is then radiated away as heat. In a very real sense, the amount of dark energy in the observer's world decreases over the course of time as dark energy burns away and heat is radiated away as all the usual forms of matter and energy the observer currently finds in its world [9].



The key idea in the burning away of the dark energy is the concept of a meta-stable state. A state with a high amount of dark energy, as occurred at the time of the big bang event, is a meta-stable state characterized by a potential barrier. The potential barrier separates the meta-stable state, often called a false vacuum, from a more stable state.

The potential barrier is like a hill that separates two valleys and must be climbed before the system can settle into the more stable state, which is the lower valley. Not only does the system have to climb the potential barrier, but in order to settle into the more stable state the system also has to burn and radiate away some of its kinetic energy as heat. Like the myth of Sisyphus, if the system does not burn and radiate away heat, it is doomed to climb the hill again and again.

Quantum uncertainty in position and momentum allows for a tunneling event through the potential barrier as an alternative to climbing the barrier, but even then the system still has to burn and radiate away heat in order to settle into the more stable state. In the process of burning, potential energy is converted into kinetic energy and is radiated away as thermal energy. This process of burning always represents a change in the phase of the system, which is described as a phase transition or a process of symmetry breaking.

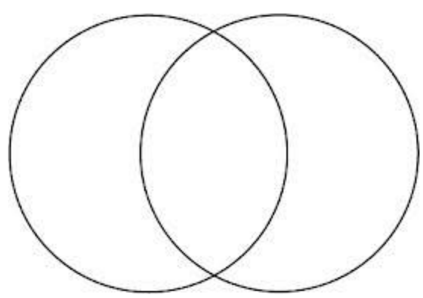
The construction and deconstruction of meta-stable states is common in nature. The construction of a meta-stable state requires the construction of a potential barrier that separates a less stable state of higher energy from a more stable state of lower energy. For example, in the process of photosynthesis the directed energy of a photon is converted into the electromagnetic potential energy of high energy bonds in a carbohydrate molecule. These chemical bonds are a potential barrier that separates the less stable state of the carbohydrate molecule from the more stable state of carbon dioxide and water molecules. Photosynthesis is a process of constructing this potential barrier. Burning the carbohydrate molecule is a process of deconstructing the potential barrier, as electromagnetic potential energy is converted back into kinetic energy. Just as the directed energy of a photon is absorbed in the construction process, heat energy is radiated away in the form of lower frequency photons in the deconstruction process. Burning is a process that radiates away heat and disperses energy into lower frequencies.

A very similar burning process is hypothesized to occur in inflationary cosmology, and allows dark energy to burn away. In this process, the cosmological constant undergoes a decrease in its value, which leads to an inflation in the size of the cosmic horizon, and drives the normal flow of energy in the observer's world. The inflation of the observer's world is fundamentally a deconstruction process. The mystery of the construction process is wrapped up in the very high value of the cosmological constant that occurs with the creation of the observer's world in a big bang event. This is the mystery of the exponential expansion of space itself.

The normal flow of energy in the observer’s world naturally arises as heat tends to flow from the very hot big bang event to all colder states of the observer’s world defined by an inflated cosmic horizon. The inflation of the cosmic horizon is the same as burning away of dark energy. As dark energy burns away, heat is radiated away and the observer’s cosmic horizon inflates in size. As the cosmic horizon cools in temperature, heat tends to flow in this temperature gradient.

The normal flow of energy arises in the observer’s world as the comic horizon inflates in size, cools, and heat tends to flow in this universal temperature gradient from the very hot big bang event to all colder states of the observer’s world defined by an inflated cosmic horizon. This naturally occurs as the dark energy burns away. That burning away of dark energy not only drives the normal flow of energy in the observer’s world, but also the flow of time. The flow of time is only a sequence of events on the observer's accelerated worldline.

Every observer's world is limited by its own cosmic horizon. The cosmic horizon is the ultimate bounding surface of space limiting the observer's world and the ultimate holographic screen encoding information for whatever the observer perceives in its world. How is it possible for a consensual reality to arise that different observers can share with each other? Modern cosmology gives an answer in terms of the overlapping nature of different cosmic horizons [7].



Each observer is surrounded by its own cosmic horizon that encodes information for everything perceived in its world, but different cosmic horizons can overlap with each other and share information due to quantum entanglement, just like entangled spin variables that share information with each other. This allows different observers to share a consensual reality with each other. The sharing of information on overlapping cosmic horizons is also what allows the different observers to interact with each other. Each observer only observes its own holographic screen, but those screens can overlap and share information.

Different observers not only share information with each other if their cosmic horizons overlap, but they also share in the normal flow of energy, since the exponential expansion of space and the burning away of dark energy is what drives the inflation of each observer's world.

It is simply not the case that there are multiple observers inhabiting a single world. Every observer inhabits its own world and has its own unique frame of reference with its own cosmic horizon. Horizon complementarity tells us that what appears to exist for one observer in its world need not agree with what appears to exist for another observer in its world. Different observers can observe very different things in their own worlds, and what appears to exist for one observer in its world may not appear to exist at all for another observer in its world. As long as it is impossible for the different observers to ever compare their differing observations, there is no real disagreement.

What about the problem of a consensual reality? The nature of the cosmic horizon solves this problem. Every observer is surrounded by its own cosmic horizon that is a bounding surface of space that limits observations within that bounded space, but those bounded spaces can overlap with each other. Each bounding surface acts as a holographic screen that encodes information. To the degree the bounded spaces overlap with each other, those bounding surfaces can become entangled and share information. This phenomena is called quantum entanglement. Different observers can share a consensual reality and share information with each other to the degree their bounded spaces overlap and their holographic screens become entangled with each other.

This entanglement has a nice metaphor in the net of Indra. The jewel present at the center of each net is the observer, the consciousness present at the center of its own world. A consensual reality arises because the world perceived by each observer can share information with the worlds perceived by other observers to the degree their holographic screens become entangled.

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