https://www.youtube.com/watch?v=pn3euL8Tbfw&t=1213s

How Big Is The Universe?

Jak velký je vesmír?

Cool Worlds

696 tis. odběratelů

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Is the Universe infinite? Or does it somehow fold in on itself? And if so in what shape? Join us today as explore the size of the Universe. Written and presented by **Prof David Kipping**, with special thanks to cosmologist **Prof Colin Hill** for fact checking. You can support our research program and **the Cool Worlds Lab at Columbia University: →**

← Je vesmír nekonečný? Nebo se to nějak poskládá samo? A pokud ano v jakém tvaru? Připojte se k nám ještě dnes a prozkoumejte velikost vesmíru. Napsal a uvedl prof. David Kipping, se zvláštním poděkováním kosmologovi prof. Colinu Hillovi za ověření faktů. Můžete podpořit náš výzkumný program a laboratoř Cool Worlds Lab na Kolumbijské univerzitě:

https://www.coolworldslab.com/support Get Stash here! https://teespring.com/stores/cool-wor... Thank-you to our supporters T. Widdowson, D. Smith, M. Sloan, L. Sanborn, C. Bottaccini, D. Daughaday, A. Jones, S. Brownlee, M. Lijoi, Z. Star, T. Zanjonc, C. Wolfred, F. Rebolledo, L. Skov, E. Wilson, M. Elliot, B. Daniluk, J. Patrick-Saunders, M. Forbes, S. Vystoropskyi, S. Lee, Z. Danielson, C. Fitzgerald, V. Alexandrov, L. Macchia, C. Souter, M. Gillette, T. Jeffcoat, H. Jensen, F. Linker, J. Rockett, N. Fredrickson, B. Mlazgar, D. Holland, J. Alexander, E. Hanway, J. Molnar & I. Sandaljian.

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(01)- In 1823, German astronomer Heinrich Olbers looked up at the night sky and saw darkness. He wondered, if the universe were infinite and eternally static, surely the night sky should shine with the light of infinite stars - a dazzling brilliant sky. Olbers' paradox was so compelling that many considered it proof of a finite universe, a cosmos that at some point simply ends. It wasn't until a century later, when Edwin Hubble observationally established the reality of an expanding universe, that Olber's paradox was firmly solved - Olber's second assumption was wrong, the universe is not static. But what does modern astronomy have to say about the size of the universe though? Is it finite and if so does that meanthere's an edge? Or, could be infinite? An endless ocean of space, with challenging philosophical consequences if so. How big is the universe? It's the sort of question that a child often asks when they first encounter the concept of space, and yet, it is one which continues to perplex and haunt astronomers. It's often said that studying the cosmos is a humbling experience, for whilst early thinking considered the Earth Sun and Moon to be the de-facto universe, our modern understanding establishes one that it is unimaginably larger. At each stage in

science's journey of revelation, humanity has had to swallow another great demotion, quietly ushered down to an ever lower seat in the great cosmic hierarchy. These demotions began with in the 16th century with Copernicus and Kepler, challenging the geocentric view of their time and revealing that Earth is just another planet. Next, in 1838, Freidrich Bessel pioneered the parallax method to measure the distance to the star 61 Cygni - a staggering distance of more than 10 light years, or approximately 100 trillion km. In 1920, famed astronomers Harlow Shapley and Heber Curtis debated at the Smithsonian Museum of Natural History as to whether distant nebulae were small clouds on the outset of our galaxy or entirely separate galaxies far further away. Soon after Edwin Hubble established that Curtis was right by proving that Andromeda was in fact far outside of the Milky Way galaxy, at a distance of 2.5 million light years. Equipped with far superior telescopes, modern astronomy has pushed our observations to distances unimaginable even to these pioneering astronomers. For example, look at this image. It is one of the most incredible photos ever taken. You are looking at the most distant galaxy ever observed, GN-z11. This galaxy is so far away, that the light forming this image left it 13.4 billion years ago. A photographic time machine. The Universe itself was just a few hundred million years old at this time, and so GN-z11 is a glimpse at what the first galaxies to ever form looked like. If we could see GN-z11 as it is now, it would probably be unrecognizable, and in fact likely have merged with other galaxies along the way. GN-z11 is estimated to be 32 billion light years away from Earth. At first, this seems impossible, if the light left 13.4 billion years ago, surely it's 13.4 billion light years away. But that's again falls into Olber's fallacy, the universe is not static. In fact, GN-z11 has been hurtling away from us ever since the light from this image left, or more accurately I should say space has been expanding, and so a correct calculation of its current distance needs to account for that fact. Objects like GN-z11 can thus be thought of as establishing a minimum size of the Universe. But, given that it's 13.4 billion years old, and the Universe is 13.8 billion years old, then surely it should be possible to image an object that's even older and thus further away and that would extend this minimum size yet more. It's at this point it's useful to talk about two distinct concepts. The visible universe and the observable universe. Neither of these really have anything to do with telescope capabilities but rather true limits dictated by spacetime. The observable universe would be the distance to an object that was present at the very dawn of the universe itself and whose light was now just reaching us. Of course the universe didn't have any stars or galaxies at the very beginning so there are no objects to detect. Nevertheless, based on the expansion rate of the universe, as measured using telescopes like ESA' Planck mission, we estimate that this distance would be 45 billion light years away. If something was further away than this, there simply wouldn't have been enough time yet in the universe for it's light to reach us. We often say such objects lie beyond our horizon, like a ship that has dipped below the ocean's horizon. There's simply no way to see them whether they exist or not. In fact, the horizon of the observable universe has a special name - the particle horizon. The visible universe is actually subtly different from this. For the first few hundred thousand years after the Big Bang,

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(**01)-** In 1823, German astronomer Heinrich Olbers looked up at the night sky and saw darkness. He wondered, if the universe were infinite and eternally static, surely the night sky should shine with the light of infinite stars - a dazzling brilliant sky. Olbers' paradox was so compelling that many considered it proof of a finite universe, a cosmos that at some point simply ends. It wasn't until a century later, when Edwin Hubble observationally established the reality of an expanding universe, that Olber's paradox was firmly solved - Olber's second assumption was wrong, the universe is not static. But what does modern astronomy have to say about the size of the universe though? Is it finite and if so does that meanthere's an edge? Or, could be infinite? An endless ocean of space, with challenging philosophical consequences if so. How big is the universe? It's the sort of question that a child often asks when they first encounter the concept of space, and yet, it is one which continues to perplex and haunt astronomers. It's often said that studying the cosmos is a humbling experience, for whilst early thinking considered the Earth Sun and Moon to be the de-facto universe, our modern understanding establishes one that it is unimaginably larger. At each stage in science's journey of revelation, humanity has had to swallow another great demotion, quietly ushered down to an ever lower seat in the great cosmic hierarchy. These demotions began with in the 16th century with Copernicus and Kepler, challenging the geocentric view of their time and revealing that Earth is just another planet. Next, in 1838, Freidrich Bessel pioneered the parallax method to measure the distance to the star 61 Cygni - a staggering distance of more than 10 light years, or approximately 100 trillion km. In 1920, famed astronomers Harlow Shapley and Heber Curtis debated at the Smithsonian Museum of Natural History as to whether distant nebulae were small clouds on the outset of our galaxy or entirely separate galaxies far further away. Soon after Edwin Hubble established that Curtis was right by proving that Andromeda was in fact far outside of the Milky Way galaxy, at a distance of 2.5 million light years. Equipped with far superior telescopes, modern astronomy has pushed our observations to distances unimaginable even to these pioneering astronomers. For example, look at this image. It is one of the most incredible photos ever taken. You are looking at the most distant galaxy ever observed, GN-z11. This galaxy is so far away that the light forming this image left it 13.4 billion years ago. The statement is incorrect. If this is so, then the **light would have to catch up to the Earth for 13.4 billion years**, meaning that the Earth must have been further than the emitter for the entire 14 billion years... Photographic time machine. The universe itself was only a few hundred million years old at this time, and thus the emitted photon had to fly here and there throughout the universe and wait until the Earth was at a distance of 31 billion light years and then tap Earth…yeah? and so GN-z11 is a glimpse of what the first galaxies ever formed looked like. If we saw GN-z11 as it is now, it would likely be unrecognizable, and in fact it would likely merge with other galaxies along the way. GN-z11 is estimated to be 32 billion light from Earth flight. At first this seems impossible, if the light left 13.4 billion years ago, surely it is 13.4 billion light years away. But this again falls into Olber's fallacy, the universe is not static. In fact, GN-z11 has been hurtling away from us since the light left this image, or more accurately I should say space is expanding, so a proper calculation of its current distance must take this into account. Thus, objects like GN-z11 can be considered to set the minimum size of the universe. But given that it is 13.4 billion years old and the universe is 13.8 billion years old, then surely it should be possible to image an object that is even older and therefore more distant, and that would extend this minimum size even further. At this point it is useful to talk about two distinct concepts. **Visible** universe and **observable universe**. Neither has anything to do with the capabilities of the telescope, but rather the actual limits dictated by space-time. The observable universe would be the distance to an object - a quasar that was present at the very dawn of the universe itself and whose light was just reaching us. …the emitted photon had to fly back and forth across the universe and wait until the earth was 31 billion light years away and then hit the earth…right? Of course, the universe had no stars or galaxies at the very beginning, so there are no objects , which could be detected. However, based on the rate of expansion of the universe, measured using telescopes such as the ESA Planck mission, we estimate that this distance would be 45 billion light years away. If anything were further than this, there simply wouldn't be enough time in space yet for the light to reach us. A photon would have to fly back and forth for 15 billion years to catch up with Earth. Yes??? We often say that such objects lie beyond our horizon, they lie beyond the horizon of observability because global space-time rotates, i.e. expands… http://www.hypothesis-of-universe.com/docs/c/c_239.jpg ; http://www.hypothesis-of-universe.com/docs/c/c_032.gif light is emitted from such a quasar "an fas", radial to our station… like a ship that has sunk below the ocean horizon . There is simply no way to see if they exist or not. In fact, the horizon of the observable universe has a special name - the particle horizon. The visible universe is actually subtly different from that. The first few hundred thousand years after the Big Bang

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(02)- the universe was so hot it was an ionized plasma which essentially acted like a thick fog. Light couldn't traverse the universe without interacting with one of these ions. It's only when the universe cooled enough for atoms to form, clearing the fog away in an epoch known as re-ionization, that light can freely travel. So the visible universe is a little bit smaller than than observable one, by about a billion light years. This is a truly mind bogglingly big number, no words or analogies really do justice to just how preposterously large the universe is. But it could be even bigger? Take the observable universe, corresponding to a distance 45 billion light years away. Usually, at this point, video like this take that number and double it and call it the diameter of the observable universe. We have to be a little careful about that because what if we see another GN-z11 over in the opposite direction, not a galaxy similar to GN-z11 but the actual GN-z11. For example, if the universe has a positive curvature like a sphere, then it's quite possible we would see the same galaxies and patterns in different directions. If that were true, doubling this distance wouldn't correspond to the diameter but something more like the circumference of the universe. These repeating patterns seem to offer a possible way, then, for the universe to be smaller than we might naively have guessed. To answer this, let's return that moment of re-ionization in the early universe. This is the oldest light we can observe and it comes from all directions, after all the entire universe was filled with this ionized plasma. The light is known as the cosmic microwave background, or CMB, and it encodes the temperature of the universe at this time. Any patch of the CMB more than 2 degrees away from another patch is too far away to have had time for light to travel between them, at least given the age of the universe at the time, just 380,000 years. So, if we see a particular pattern or ripple repeated in the CMB but separated by several degrees or more, that could reveal the universe wraps around itself - implying a smaller universe. Detailed studies of the CMB reveal no such repeating structures though. The lack of such structure can be used to put lower limits on the size of the universe, but not surprisingly these limits essentially correspond to the approximately size of the observable universe. So the full universe really does appear to be at least as large as the observable part. Now let's suppose someone lives in the galaxy GN-z11, they would be able to look back along that line of sight and see the proto Milky Way, as a faint distant galaxy too. But what if they looked in the opposite direction? Would they see an edge or some kind of physical boundary? Whilst we cannot truly know what they might see, a basic assumption in astronomy is the so-called cosmological principle, which states that we do not live in a special part of the universe. So what we see is typical and by extension what GN-z11 inhabitants see is likely not much different from us, at least on the largest of scales. The cosmological principle does not rigorously prove anything about the size of the universe, but rather forms a logical argument. By it, inhabitants at the edge of the observable universe should themselves be able to see another entire observable universe around them. Filling out across the edges, this would give us a volume 180 billion light years across. We have to tread carefully here though, because the size of the universe could still be smaller than this if it somehow wraps around itself. Consider in this direction at the edge of our observable universe we have Alice. Alice looks out in that same direction and can see at the very edge of her observable universe someone else, let's call him Carlos. Now let's go back to Earth and look in the opposite direction. Over at the particle horizon here we see Bob. As before, Bob looks out in the same direction and sees someone else, just like Alice did. However, Bob is in fact looking at Carlos again. To each individual observer, there is no repetition, but Alice and Bob are in fact both able to see the same person, Carlos. And since Alice and Bob live far beyond each other's particles horizons, there's no way they can communicate this to each other. No-one is able to tell that the universe repeats and thus are left non the wiser. So we can't really use the cosmological principle to argue for a much larger size to the universe, all we can say is that we don't see repetition within our horizon and thus the universe must be at least 2 x 45 billion light years in extent, or 90 billion light years. Repeating patterns are not the only way to place limits on size though, already I've mentioned the concept of curvature and here perhaps we might finally have a clue unto it's true size.

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(02)- the universe was so hot that it was an ionized plasma that essentially acted like a thick fog. Light could not travel through space without interacting with one of these ions. Light can only spread freely when the universe cools enough to form atoms and remove the haze in an epoch known as reionization. So the **visible** universe is slightly smaller than the **observable** one, about a billion light years. This is truly an enormously large number, no words or analogies really do justice to how absurdly large the universe is. But could it be even bigger? Consider the observable universe, which corresponds to a distance of 45 billion light years away. Usually at this point a video like this takes that number and doubles it and calls it the average of the observable universe. We have to be a little careful about that, because what if we see another GN-z11 in the opposite direction, not a GN-z11-like galaxy, but a real GN-z11. For example, if the universe has positive curvature like a sphere, don't say universe, say spacetime. This is where the author comes close to my vision that the universe = spacetime is expanding. It was extremely curved after the BB and as it "ages" the time dimensions expand ,.., then we reach the current age of 13.8 billion years and the universe is already almost flat. http://www.hypothesis-of-universe.com/docs/c/c_283.jpg Even possibly the "measured" age of 13.8 is not true, because we measure it, or evaluate it incorrectly = space-time still continues behind the "visible universe" in the structure of a more and more crooked state of dimensions and we arrive at another age of the observable universe, 14.24 billion years. I arrived at this figure 35 years ago, when the age was still set in the range of 10-20 billion years. 14.24 billion years I found out, but for another 10 years I didn't find evidence "why this is so", then it is quite possible that we would see the same galaxies and patterns in different directions. If this were true, doubling this distance would correspond not to the diameter, but to something more like the circumference of the universe. These repeating patterns seem to offer a possible way for the universe to be smaller than we might have naively suspected. To answer this, let's go back to the moment of reionization in the early universe. This is the oldest light we can observe and it comes from all directions, after all the entire universe was filled with this ionized plasma. The light is known as the cosmic microwave background, or CMB, and encodes the temperature of the universe at that moment. Any CMB region more than 2 degrees celsius from another region is too far for light to have time to travel between them, at least given the then age of the universe, only 380,000 years. So if we see a certain pattern or ripple repeating itself in the CMB, but separated by a few degrees or more, it could reveal that the universe is wrapping around itself – suggesting a smaller universe. However, detailed studies of the CMB have not revealed any such repeating structures. The absence of such structure can be used to set lower limits on the size of the universe, but unsurprisingly these limits roughly correspond to the size of the observable universe. **Thus the whole universe indeed appears to be at least as large as the observable part**. Now suppose someone lives in the GN-z11 galaxy, they could look back along this line and therefore see the Milky Way as a faint distant galaxy. But what if they looked the other way? Would they see an edge or some physical boundary? While we can't really know what they might see, a fundamental assumption in astronomy is the so-called cosmological principle, which says we don't live in a special part of the universe. So what we're seeing is typical, and by extension what the inhabitants of GN-z11 are seeing probably isn't too different from us, at least on the grandest scale. The cosmological principle does not consistently prove anything about the size of the universe, but rather constitutes a logical argument. Because of this, the inhabitants of the edge of the observable universe alone should be able to see another entire observable universe around them. Filled to the brim, this would give us a volume of 180 billion **light** years in diameter.

We have to tread carefully here, though, because the size of the universe can still be smaller than this if it wraps around somehow. Let's consider along these lines that ... that at the edge of our observable universe we have Alice. (missile commander who left Earth…aka blah blah twin paradox) **Alice** at v = 0.99c looks in the same direction and sees someone else at the very edge of her observable universe, a quasar = Carlos, which according to Hubble is also moving away at a speed of v = 0.99c let's call him **Carlos**. Now let's return to Earth and look in the opposite direction. Here on the particle horizon we see **Bob**. As before, Bob looks in the same direction and sees someone else, as does Alice. However, Bob is actually looking at Carlos again. There is no repetition for each individual observer, but Alice and Bob are actually both able to see the same person, Carlos. Space-time rotates and the information = photon from Carlos and Bob brings a "tinted" redshift due to the rotation >of the flying body's own system< from the Earth Observer http://www.hypothesis-of-universe.com/docs/c /c_230.jpg . And since Alice and Bob live far beyond their particle horizons, there is no way they can communicate this to each other. However, "at the time" Carlos and Bob sent the photon towards the Earth, they could both be very close, i.e. "next to each other" even beyond the particle horizon... No one is able to say that the universe repeats itself and therefore is none the wiser. So we can't really use the cosmological principle to argue for a much larger size of the universe, all we can say is that we don't see a repeat on our horizon and therefore the universe must be at least 2 x 45 billion light years. on average. In range or 90 billion light years. Repeating patterns aren't the only way to limit size though, I already mentioned the curvature concept !!! and here we might finally have a clue as to its true size. Over the horizon there is already sharp curvature, the curvature of dimensions and np approaches the state of foamy plasma = space-time with n-times warped dimensions.

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(03)- Standing on the Earth, we can’t directly see its curvature because the radius of curvature is just so vast. But the curvature can be detected with some geometry, as was famously done so by Eratosthenes of Cyrene two millennia ago by comparing the lengths of shadows of sticks in the midday Sun at two different locations. In an analogous way, astronomers can use the CMB radiation and some geometry to measure the curvature of the universe itself. A simple way to think about this on a positively curved surface, like a sphere, two parallel lines will eventually meet. For example, if we both head straight north, no matter where you live, I will eventually bump into you at the north pole. On a flat surface the lines stay true and parallel forever, but on a negatively curved surface, like a saddle, they diverge. So how curved is the universe? The curvature parameter, known as Omega_k, has been refined ever more over the years thanks to missions studying the CMB. The earliest estimate, done by the Boomerang experiment in 2000, found it to be flat to within 6%. Eighteen years later, ESA’s Planck mission published our current most precise estimate to date, which is again flat to within 0.19%. It is truly an amazing technical feat by legions of astronomers involved that we can measure the curvature of space at this level. But what does this really mean? Let’s consider that the number is indeed exactly 0, a flat universe. It’s at this point, that many often look at that flatness and interpret it to mean the universe must be infinite. Look, it’s perfectly reasonable to suggest the universe is infinite as a possible hypothesis, but it’s not true it’s the only explanation. It’s a non-sequitor that flatness requires infinite space. To cosmologists flatness doesn’t really mean what we might naively think and a flat universe can be finite. In fact we’ve already discussed an example of such a universe. Let’s go back to our friends Alice, Bob and Carlos and imagine the universe really is 2-dimensional, like a sheet of paper depicted here. If we had a warp drive, we could fly from Earth in the direction of Alice, and when we cross Carlos we would re-emerge on the other side and be heading home again. This is probably familiar to any computer gamers, games like Pac-Man and Asteroids would often feature this rule. Since the the left-side and right-side really correspond to the same line, the universe wraps around itself here. If up and down go on forever, then what we essentially have is an infinite cylinder. In fact, since I made this cylinder from a 2-dimensional sheet, it’s really a 2-cylinder. The 2-cylinder is really defined by left-goes-to-right Pac-Man rule operating on the original 2D sheet, what is known as the fundamental domain. That’s what makes it a 2-cylinder. When we roll it up in 3-dimensions, we’re embedding the 2-cylinder into 3-dimensional space, but that’s just us embedding it into 3D. So even though it looks curved when embedded in 3D, that’s just a product of the embedding, it’s actually still a flat geometry in it’s fundamental domain. Now this 2-cylinder doesn’t really save us from an infinite universe because it’s length extends out to infinity. So let’s go back to our fundamental domain and look at our rules one more time. What if we add another rule that going past the upper edge takes you back to the lower edge. Now we truly have full Pac-Man rules. A fundamental domain described by these two rules is no longer an infinite 2-cylinder, but a finite 2-torus. We call it a torus because if you imagine re-rolling it back up, we first get the cylinder as before, and then we have to connect these two ends together. In practice, if I try to do this I’d have to stretch out the material, distorting the plane, but we can see that it should form something like a donut shaped torus. Now at this point it’s useful to discuss John Nash, who you probably know from the biopic A Beautiful Mind. The fact you have to stretch and distort the original plane to create the torus shape means that you failed to isometrically embed it. And that isometric part is key because without it distances are distorted in a way we don’t see in the universe around us. But John Nash proved the it was in fact possible to isometrically embed a a 2-torus into three-dimensions, by adding waves and waves of tiny corrugations during the embedding procedure. This was a beautiful proof but it didn't actually reveal what this 2-torus embedded into 3D would actually look like. In 2012, a French team used supercomputers to finally calculate what the shape looked like. This stunning morphology is in fact flat in the fundamental domain and adheres to the 2-torus Pac-Man style rules.

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(03)- When we stand on the Earth, we cannot directly see its curvature because the radius of curvature is so huge. It's a parabola. But curvature can be detected using some geometry, as Eratosthenes of Cyrene famously did two millennia ago by comparing the lengths of the shadows of rods in the midday sun at two different locations. In an analogous way, astronomers can use CMB radiation and certain geometry to measure the curvature of the universe itself. A simple way to think about it is that on a positively curved surface like a sphere, two parallel lines will eventually meet. For example, if we both head straight north, no matter where you live, I'll end up bumping into you at the North Pole. On a flat surface the lines stay true and parallel forever, but on a negatively curved surface like a saddle they diverge. So how is the universe curved? Foamy state of 3+3D space-time after the Big Bang = plasma a) expands (geometrically apparently into a parabola) and b) packs into packages-balls, which will be presented as elementary particles of matter. (How plain Sherlock Holmes). The curvature parameter, known as Omega_k, has been increasingly refined over the years by missions studying the CMB. The earliest estimate made by the Boomerang experiment in 2000 found that it is flat today at 13.8 billion years old with an accuracy of 6%. 18 years later, the ESA Planck mission published our current most accurate estimate to date, which is again flat with an accuracy of 0.19% It is truly an amazing feat of engineering by the multitudes of astronomers involved that we can measure the curvature of the universe **at this level**. (!) i.e. the curvature of the macro-universe = global space-time. http://www.hypothesis-of-universe.com/docs/c/c_485.jpg Even at the time of 13.8 billion years there is = reigns = a micro world with levels of 10-40 m where space-time "boils" like now after the Big Bang. The micro world is linear (n+m dimensional) ... the macro world is non-linear (parabola, expanding the number according to the parabola), But what does this actually mean? Consider that the number is indeed **exactly 0**, i.e. a flat universe. **Exactly zero** is the state of spacetime before the Big Bang… It is at this point that many often look at this flatness and interpret it to mean that the universe must be infinite. OK and it is !!!, the one before Třesk. However, after the Big Bang, a "new location" will be presented = our universe, finite with an infinite curvature of dimensions, which will immediately "inflationally" decrease to a >reasonable curvature< and in which the flow-flow of time begins, that expansion-unpacking begins and the collapse of dimensions begins into "balls" that will be matter http://www.hypothesis-of-universe.com/index.php?nav=e , + field states + the sequence of emergence of new laws, rules, principles... Look, it's perfectly reasonable to claim , that the universe is infinite as a possible hypothesis, but it is not true that it is the only explanation. It is a non-sequitor that flatness requires infinite space. (!) For cosmologists, flatness doesn't really mean what we might naively think, and a flat universe may be finite. In fact, we have already discussed an example of such a universe. Let's go back to our friends Alice, Bob, and Carlos and imagine that the universe is truly two-dimensional, like the sheet of paper pictured here. If we had warp drive, we would fly from Earth towards Alice, and when we cross Carlos, we would re-

emerge on the other side and head home again. This is probably familiar to all computer gamers, games like Pac-Man and Asteroids would often include this rule. Since the left and right sides actually correspond to the same line, the universe wraps around itself here. ??
If it goes up and down forever, then what we essentially have is an infinite cylinder. Actually, since I made this cylinder from 2-dimensional sheet metal, it really is a 2-cylinder. The 2-cylinder is actually defined by Pac-Man's left-goes-right rule operating on the original 2D sheet, which is known as the fundamental domain. That makes it a 2 cylinder. When we roll it into 3-dimensions, we put a 2-cylinder into 3-dimensional space, but that's just us putting it in 3D. So even when it looks curved when it's embedded in 3D, it's just a product of the embedding, =actually it's still flat geometry= in its base domain. This 2-cylinder doesn't actually save us from an infinite universe, because its length goes to infinity. So let's go back to our base domain and look at our rules one more time. What if we add another rule that going past the top edge will bring you back to the bottom edge. We now have the truly complete Pac-Man rules. The fundamental domain described by these two rules is no longer an infinite 2-cylinder, but a finite 2-torus. http://www.hypothesis-of-universe.com/docs/c/c_423.gif We call it a torus because if you imagine winding it back up again, we first get a cylinder like before and then we have to join the two ends together. In practice, if I tried to do this, I would have to stretch the material, which would distort the plane, but we can see that it should form something like a donut-shaped torus. Now at this point it is useful to discuss **John Nash** who you probably know from the biopic A Beautiful Mind. The fact that you have to stretch and deform the original plane to create the torus shape means that you failed to insert it isometrically. And that isometric part is key, because without it, distances are distorted in a way that we don't see in the space around us. However, **John Nash** proved that it is actually possible to isometrically embed a 2-torus in three dimensions by adding ripples and ripples during the embedding process. That was a nice proof, but it didn't really reveal what this 2-torus embedded in 3D would actually look like. In 2012, a French team finally calculated what the shape looked like using supercomputers. This stunning morphology is actually flat in the fundamental domain and follows the 2-torus Pac-Man style rules. OK.
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(04)- The French team went a step further and even uploaded a 3D print design up on their website. Thanks to those corrugations, it’s a formidable 3D print to actually pull off though. I asked around several New York printing agencies about this and they all basically just said straight up no. If there was anyone that could pull this off, it was going to be Joel, also known as the 3D Printing Nerd - an awesome YouTube channel that explores everything 3D print related. He took this on and has even created an awesome video describing this feat, please do check it out when you’re done here. So here it is, a 3D embedded 2-torus. It’s even more beautiful to hold and touch than the renderings. And what’s truly mind blowing is that I may actually be holding the universe in my hands. A finite flat cosmos embedded in some higher dimensional space. Of course, remember that this is a 2-torus, it’s made from a two-dimensional plane. Since our universe has three spatial dimensions, the universe would need to be a 3-torus, so a kind of hyper-dimensional extension of this incredible shape. The 3-torus is in fact just one of ten different possible manifolds that could represent a flat, finite universe. Six of these are called orientable and include the 3-torus. But four are so-called non-orientable manifolds, and include this thing, the bizarre Klein bottle - a mind bending shape off technically zero embedded volume. This orientability property is best understood by looking

at a simpler manifold, the Mobius strip. If travel along the Mobius, after one circuit your left and right have switched over - you've become a mirror version of yourself. If the universe is truly one of these non-orientable manifolds, it would have some bizarre consequences for a hypothetical warp ship. Leave Earth and travel in one direction long enough and you return home. Arriving back on Earth, you would at first feel the familiarity and relief of being back home, but would quickly realize something was off. Your family's faces were mirror versions of before, their watches ticked anti-clockwise. But from their perspective, it would you who was changed, and taking you to the doctor for a medical examination they'd discover your heart was now on the right-hand side. All ten of these manifolds are perfectly consistent with our observations, and all are finite. So any of these could be true, but there is another possibility. The universe could be truly infinite, either an infinite flat fundamental domain in all directions, or a negatively curved infinite saddle-shaped universe. Either way, we are forced to face an ontological crisis. What if the universe is infinite? Infinities are uncomfortable to physicists because they bring along some disturbing consequences. Given infinite possibilities, everything that can happen must happen, an infinite number of times. In seeking a way out of this, one might consider that yes, perhaps space is indeed infinite, but, at some point its nature radically changes. There is an end to the universe. Indeed, there is some theoretical work that might at first seem to fit the bill. In the so-called eternal inflation model, our local universe is a bubble-like region where the hyper-expansion phase known as inflation subdued, but travel far enough and you'd enter a region where the inflationary field has a different state, expanding space so much that each bubble universe is separated by unimaginable distances. However, since the entire landscape is still infinite, there would be an infinite number of these bubble universes. So, in truth this doesn't really solve our dilemma. So let's just stop hiding and face the possibility head on. An infinite cosmos. Infinities disrupt probability theory, since all events have a probability of occurring an infinite number of times, like infinite monkeys on infinite typewriters. It challenges the cosmological principle, because what does it really mean to assume you're typical if there's an infinite number of outcomes out there. At a human level, this infinite universe opens the door to some unsettling consequences. Because it means that there is an infinite number of you's out there. Not just similar, but yous with the exact same arrangement of molecules and atoms, right down to the quantum states of your subatomic particles. That immediately provides a kind of way out of the no-cloning theorem, a quantum theory proved by James Part that states that its impossible to ever create an independent and identical copy of an arbitrary quantum state. If these clones share every single quantum state to you, surely that is you? And indeed these doppelgängers would sit inside an entire universe that was identical to our own right down to the last atom.
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(04)- The French team went one step further and even uploaded a 3D printing design to their website. However, these undulations make it an impressive 3D print that really pulls off. I asked several New York news agencies about this and they all pretty much said no. If there was anyone who could do it, it would be Joel, also known as the 3D Printing Nerd – an awesome YouTube channel that explores all things 3D printing. He took it upon himself and even made an awesome video describing the feat, check it out when you're done. So there you have it, a 3D nested 2-torus. It is even more beautiful to hold and touch than the renders. And what's really amazing is that I may actually hold the universe in my hands. A finite flat universe set in some higher dimensional space. Of course, don't forget that this is a 2-torus, it is made of a two-dimensional plane. Since our universe has three spatial dimensions, the universe would have to be a 3-torus, a kind of hyperdimensional extension of this incredible shape. The 3-torus is actually just one of ten different possible varieties that could represent a flat, finite universe. Six of them are called orientable and include the 3-torus. But four are so-called non-orientable distributions and include this thing, the bizarre Klein bottle - a mind-bending shape and technically zero embedded volume. This property of orientation is best understood by looking at a simpler pipe, the Mobius belt. If you're traveling Mobius, after one circuit your left and right have swapped – you've become a mirror version of yourself. If the universe really is one of these non-orientable manifolds, that would have some bizarre implications for a hypothetical warp ship. Leave Earth and travel in one direction long enough and you will return home. Upon returning to Earth, you would at first feel familiar and relieved to be back home, but you would quickly realize that something is wrong. Your family's faces were mirror versions of the previous ones, their watches ticking counterclockwise. But from their point of view, it would be you who has changed, and when they take you to the doctor for a medical examination, they will find that your heart is now on the right side. All ten of these varieties match our observations perfectly, and they are all finite. So any of these could be true, but there is another possibility. The universe can be truly infinite, either an infinite flat fundamental domain in all directions, or a negatively curved infinite saddle-shaped universe. Either way or another, we are forced to face an ontological crisis. What if the universe is infinite? Infinities are inconvenient for physicists because they carry some troubling implications. Given the infinite possibilities, everything that can happen must happen, an infinite number of times. Looking for a way out of this, one might reason that yes, maybe space is indeed infinite, but at some point its nature will **radically change**. Well, that's exactly the vision in HDV "**of a naked jump = changes of state**" from flatness 3+3D to extreme curvature (n+m)D - big bang.** There is an end to the universe. In fact, there is some theoretical work that might seem appropriate at first glance. In the so-called ~~perpetual inflation/ model~~, our local universe is a bubble-like region, = a location with curved dimensions of two quantities, while the construction of matter will be carried out from these dimensions http://www.hypothesis-of-universe.com/index.php?nav=e ; in this model, no kind of inflation applies, but a "change of state" of curvature,

curvature = 0 to **curvature = infinity** . This is not unscientific, nor is it non-mathematical or non-physical !!§ One can even consider "the first three dimensions **3+3 as physical**, and the other "extra" dimensions **as "n+m mathematical**" where the phase /~~hyperexpansion known as inflation has dampened but traveled far enough and you would enter a region where the inflation field has a different state, it is expanding. So much space that each bubble universe is separated by unimaginable distances~~. However, since the entire landscape is still infinite, there would be an infinite number of these bubble universes. There wouldn't even be infinite bubble universes, which again is a more natural vision. Location = "Our universe" after big-bang would expand (curvature dimensions would expand) until the state **curvature$_{x,y,z}$ = 0** and again there would be a "change of state", a jump transformation **curvature$_{x,y,z}$ = infinity** …and looping again… So, in reality, it doesn't really solve our dilemma. HDV solves this dilemma… So let's stop hiding and face this possibility head on. Infinite universe. Infinities violate the theory of probability, ??? because all events have a probability of occurring infinitely, in a "broth-system" … like infinite monkeys on infinite typewriters. It challenges the cosmological principle because what does it really mean to assume you are typical if there are an infinite number of outcomes. At the human level, this infinite universe infinite flat SPACE-TIME !, not infinite universe **with matter**, no that's wrong opens the door to some disturbing implications. Because that means there are infinitely many of you out there. Scary model. Not just similar, but you with the exact same arrangement of molecules and atoms, right down to the quantum states of your subatomic particles. This immediately provides a sort of departure from the no-cloning theorem, the quantum theory proved by **James Part**, which states that it is impossible to create an independent and identical copy of any quantum state. Sure…in the HDV model, **Big Bang** #2 and other packages for elementary particles and thus other interactions will appear…etc. So >another world< …then comes **Big Bang** no.3, … **Big Bang** no.4 etc…, **Big Bang** no.5…… .If these clones share every single quantum state with you, surely they are you? And these doppelgängers would indeed sit inside an entire universe that was identical to ours down to the last atom. Ha-Ha.

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(05)- Each one watching this video right now, each one their jaw dropping, their sense of self dissolving, as they challenge the very meaning of who they are. Yet more, in the past, in the future, there are infinite doppelgängers of you slightly offset in time. A version of you one day behind, two weeks ahead. You are everywhere. And you never end. Despite the existential crisis this carries, it perhaps provides some relief in other ways. For our close loved ones that we've lost continue to live somewhere. Both offset in time, but also through different choices. An infinite number of loved doppelgängers who didn't get in the car that day, who decided not to take those terrible drugs, who got to hospital in time. Still out there, somewhere, just preposterously distant. At the same time, an infinite universe can also, paradoxically, feel empty and nihilistic. For many, we define our goals in life in terms of our impact on the world. But that impact dissolves away in infinity. For example, if your mission is to reduce suffering amongst humanity, it is challenged by the fact that in an infinite universe there is infinite suffering. And whatever you subtract from infinity, it's still infinity. And likewise there is infinite happiness, so if your goal is to increase happiness, surely your actions are utterly futile. As we look further and further out, we perhaps finally turn back to inner space. We can't affect an infinite universe, or even realistically the infinitely smaller one we see around us. Rather than trying to derive meaning from our impact on the cosmic scale, the ensemble of space, meaning might actually be much closer to home. Because whilst there might be an infinite number of yous, only you can control your actions today, how you choose to live your life, how you treat others, and so even the smallest acts of kindness carry infinite

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weight. So until the next video, stay thoughtful and stay curious.

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(05)- Everyone watching this video right now will have their jaw dropped, their sense of self dissolved as they question the very meaning of who they are. ☺ Even more, in the past, in the future, there are infinitely many doppelgangers, ☺ who are slightly shifted in time. A version of you one day behind, two weeks ahead. ☺ You are everywhere. And you never stop. Despite the existential crisis it entails, perhaps it brings some relief in other ways. The loved ones we lost are still living somewhere. Babylon and the brothel… Both are offset in time, but also by different choices. Infinite amounts of beloved doppelgängers who didn't get in the car that day, who chose not to take those horrible drugs, ☺ who got to the hospital in time. Still there somewhere, just absurdly far away. At the same time, the infinite universe can paradoxically seem empty and nihilistic. Λ For many, we define our life goals in terms of our impact on the world. But that impact fades into infinity. For example, if your mission is to reduce suffering among humanity, it is challenged by the fact that in an infinite universe there is infinite suffering. And whatever you subtract from infinity is still infinity. And likewise, there is infinite happiness, so if your goal is to increase happiness, surely your actions are completely futile. ☹ As we look further and further, we may finally return back to the inner **??** space. We cannot influence the infinite universe, nor realistically the infinitely smaller one we see around us. Rather than trying to derive meaning from our impact on a cosmic scale, a set of space, meaning may actually be much closer to home. Because even though there may be an infinite number of you, only you can control your actions today, how you choose to live your life, how you treat others, and so even the smallest acts of kindness carry infinite weight. 29:24h. So until the next video, stay thoughtful and stay curious.

→ to HDV JN, 16/03/2024