Limits of Knowledge and Knowing

The Boundaries of Science

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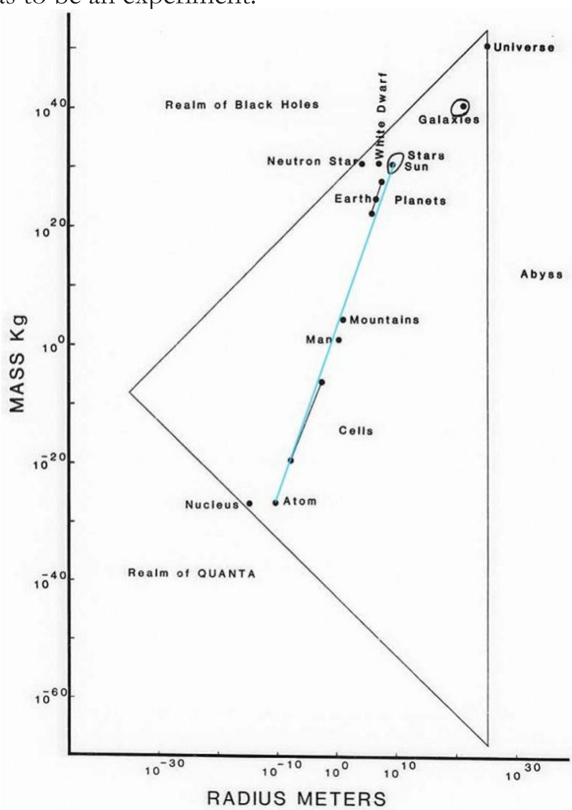
Science is a process for finding out about the Universe. A core part of science is based on the results of repeatable experiments. In order to perform an experiment an observer must be able to detect the results of that experiment. Over the history of science, scientists have encountered limits to what they can observe, these limits are the boundaries of experiment-based science. Three of the current limits to science can be seen if we plot objects in the Universe on a graph of mass (M) versus radius (R), an MR diagram. On this diagram we can plot every physical object that we know. These objects appear within three boundaries, which form a triangle, the edges of this triangle prevent us from acquiring complete information about what is beyond the edge. The edges are: the edge of the visible Universe, the event horizon of a black hole, and the Compton wavelength of an object. These boundaries of experimental science illustrate that science defines itself as incapable of answering a wide variety of questions about the Universe. Questions outside of these three boundaries, and other boundaries as well, must be dealt with by theoretical science or other knowledge-seeking philosophies.

Paul Doherty: I'd like to thank the monastic graduates—the *geshes*—for being my students and teaching me for the last two weeks.

Science has boundaries and today I'm going to take you on a tour of a few of them. There are many boundaries to science and it's important to realize that there are things beyond those boundaries. The boundaries I'm talking about are the boundaries of physical science. I'll give you an idea of why they are the boundaries.

Science began in the late 1600s about the time the Royal Society was formed. There was lots of knowledge about the world before then; some of it right, and some of it wrong. How do you find the true from the false? The Royal Society's motto, in Latin, says, *Nullius in verba* or "don't take anyone's word for it," including mine. Do an experiment. Any time you see a scientist and they say anything, you can always ask them, "How do you know that?" The answer to that question has to be an experiment.



To do an experiment, you must get the results. Out there in the Universe, there are barriers to information flow: we don't see information flowing across the edge of the Universe, we don't see information flowing out of black holes, and there are quantum mechanical limits to information. The history of science has been the history of pushing back those boundaries, and those are the boundaries we have today in the physical sciences. But there are more boundaries beyond that. I look forward to us pushing back some of those boundaries.

You can't get information beyond the edge of the Universe, you can't get information out of a black hole—you can dump it in, but you can't get it out—you can't get information smaller than the quantum limit. These are not perfect boundaries. Scientists now wonder if there are other universes out there beyond ours. We might learn about them if they expand and we begin to see them appearing in our Universe. It hasn't happened yet. The boundary of the black hole, I can't get information out, but there are some things that leak out, we'll find out what those are later. Consider the entire Universe known to physics. On the bottom axis of this graph is the radius in meters of an object, and the center little tick-mark there is ten to the zero; that's a scientist's way of writing one meter. Going up from there is a man, one meter in size. On the left is a man's mass, or about 100 kilograms. A man's length, about one meter, and his mass about 100 kilograms. And a mountain is 1,000 meters, or an increase in size by a factor of one thousand.

The Earth is an even bigger jump. This Earth is 10 million me's lined up side to side to get from the middle to the edge, and the mass is one with twenty four zeros, it's a huge mass. It's a tremendous jump. It's this beautiful blue sphere out in space. There are other planets: Jupiter is 1,000 times the volume of the Earth, 11 Earths across, 300 Earth masses. The slide shows a giant storm that Galileo saw in his telescope 400 years ago, still running. Now there's a storm! That's the biggest planet in our solar system. Here is the smallest dwarf planet; we have dwarf planets. It would be nice if we discovered two more, then there would be seven of them. One of the dwarf planets is called Vesta. We just went there. We have a spacecraft orbiting Vesta taking pictures. Vesta is nice and spherical; its gravity has pulled it into a sphere. So, there are small planets, there are big planets, we are now finding planets beyond our solar system. When you look out at the stars, within a hundred light years of Earth, as of this month there are 687 planets going around 474 stars. The smallest we've found so far is 1.6 times the mass of the Earth, and the biggest is 31 times the mass of Jupiter. That's the range of all the planets, and so if I look on this graph, you can see Earth and all the planets on a little straight line up there.

We are moving our way towards black holes and the edge of the Universe. But bigger than the planets is the Sun, and the Sun is 700,000 kilometers in radius and two times ten with thirty zeros kilograms, and yet our Sun is just a middle-sized star. There are bigger stars, there are smaller stars, and as stars age there's a lot of mass there, there's a lot of gravity pulling it in. Inside the Sun, there is nuclear fusion heating up the atoms, making them dance around, pushing out on the gas, keeping it from going out. If you look at the very top line of this diagram, you will see the Sun, an average star, lives its life—billions of years—swells up as the nuclear combustion comes towards the surface, blows off matter, and then what's left behind is the mass of the Sun in the size of the Earth. A thing called a White Dwarf. And then, if the star is more massive than the Sun, gravity really wins out. It blows up into a Red Giant, it explodes into something called a Super Nova, and then it collapses into one of two things: if it's under three times the mass of the Sun, it becomes a Neutron star, and if it's more than three solar masses, it becomes a black hole. Black holes are where I'm going to go with this talk. You can see that a White Dwarf is the size of the Earth and the mass of the Sun. The Neutron star is several times the mass of the Sun and the size of Delhi. The mass of the Sun fitting into the size of Delhi, that's really hard. And the black hole is more than three times the mass of the Sun and about thirty kilometers across.

On the graph, there is a blue line up the middle, and that blue line connects everything you know from every day and a little bit beyond every day. Everything on that line is made of atoms. Richard Feynman said if all scientific knowledge was going to be erased from the world, and he had one sentence to convey/save, that sentence would be, "all the world is made of atoms, small particles, continuously in motion." He thought that would be the best start. And this blue line connects everything that's made of atoms that are touching. Stars are made of atoms that are touching, they've lost some electrons, but they are mostly atoms, likewise planets, mountains, men, and cells, and then the atom itself. But now you'll notice some things off that line. Up on top of the stars, to the left, you see the White Dwarf with the mass of the star, but smaller. And to the left of that, there's the Neutron star, with the mass of a star, but smaller still. And to the left of that is a black line. You see these three lines on here, this triangle of lines, that upper left line that goes up from left to right, that's the line that tells you when any given mass turns into a black hole. If I started at man, and I go left to that line at ten to the minus twenty-three meters, that's almost a billion times smaller than an atom. If you squeezed me down that small, I would become a black hole. We don't know of any black holes that size, but that line shows me where they would occur. The black holes we know of are just to the left of that Neutron star and up the line a bit.

We don't have any pictures of black holes. They're hard to photograph. For one, they're black. Two, they're surrounded by bright glowing matter, which shields them. A black hole has a sharp boundary around it. The gravity of the black hole is so great that it bends light; when light comes around the black hole, it bends. In fact, when light goes by any planet or star, it gets bent. The black hole just happens to be very small, very massive, and it bends light a lot. At the center of our galaxy, which we will see shortly, there is a black hole. It's a super massive black hole, 4 million solar masses. It's a gigantic black hole. And this is an image taken through a telescope and the arrows here show you are pointing to the middle of the galaxy; you cannot see the black hole. How do we know it's there if we can't see it? The nearby stars have been photographed for over a decade, and we can see them orbiting nothingness in space. There must be something there pulling on them with gravity, so we know that the black hole is there.

We can calculate the radius of a black hole. The gravity becomes so strong that light shot upward from the surface of the black hole cannot escape. If I shoot light up from the Earth, it escapes. If I throw a spacecraft out of the Earth at escape velocity, it escapes. Newton was misquoted saying, "What goes up must come down." It's really, what goes up at less than escape velocity must come down, but even light cannot escape a black hole. John Wheeler said of black holes, "Black holes have no hair." It reminds me of monks, but what he meant is that information does not leak out of the black hole. We can only know its mass by dropping objects into it and watching how they fall. We can know their electric charge, and we can know if they are spinning or not, their angular momentum, because as they spin they rotate the vacuum of space around them. But information cannot get out of that black hole. I can drop in, crossing the event horizon, but then there's no trace except for my mass, my charge, my spin left behind. When you hear scientists talking about the inside of a black hole, you have to realize that it's theory, and theory is great, it helps us, it guides us to where to do experiments, but it's not experimental science.

Above the line on the top left of the graph you see the words, "realm of the black holes." Now, let's go to the edge of the Universe. If you go out at night, on a clear night, you might see a bright band in the sky, that's the Milky Way. That bright band we now know is stars, and glowing gas, and dust. And dust gets in the way of creating a black band. The indigenous people in South America make their constellations out of the black regions of the Milky Way. They use the solid black in the Milky Way to make their shapes and figures, whereas European traditions connect the dots from star to star. By looking at infrared light coming from the Milky Way, we see that we are out in the suburbs of the galaxy. We're out on the rim, looking in at our galaxy.

As we look out to the galaxy and beyond there's an important rule of physics; looking out in space is looking back in time. When I look at Geshe Nyima, it takes ten nanoseconds for the light to get to me from Geshe Nyima. Ten nanoseconds. He could do anything in that ten nanoseconds, that's 10 billionths of a second, a very short time indeed. But you can go out and look at the Moon and you see it where it was one and a half seconds ago. You don't see the Moon where it is; you see it where it was. And when you look at the Sun, you see it where it would have been eight minutes ago. It's moved. The light takes time to get to you. This gets really exciting when you look at the stars. When you look at the nearest star, other than the Sun, you see it where it was, and as it was, four years ago. It could have exploded and you wouldn't know for four years. Light from the Andromeda Nebula takes two million years to get here, so you're seeing it way in the past.

If you were to look with a radio telescope at radio waves, you can actually look back to the beginning of time. You can look back and see the light that left the Big Bang, 13.7 billion years ago. Galaxies formed 13 billion years ago, and we know this is only 700 million years after the Big Bang, so the galaxies had time to form in 700 million years. On the right hand edge is the edge of the Universe, that vertical line on the right, a constant radius, 13.7 billion light years. You can see the dot at the top there for mass and size of the Universe, and it was discovered in New Jersey, in 1965, by these two gentlemen: Arno Penzius and Bob Wilson. Their radio telescope was used to hear the radio song from the Big Bang.

The fact that the Big Bang started out with hot and cold places created the Universe we see today. In fact, this pattern also tells us that the world we know—those atoms that I was happy and so proud to tell you about—only makes up 4% of the Universe. This pattern just hit scientists and told them, "You thought you understood the Universe?" Twenty-three percent of the Universe is something called dark matter, and we don't know what it is. We know it exerts gravity and attracts things. We can find out places where it exists, and we are on a tremendous search right now to find it. What could it be?

But even worse than that, 73% of the energy of the Universe is in the form of something we call dark energy, and that's gravitationally repulsive, it pushes things apart, and we don't have the slightest idea how to look for that.

What I'm telling you is that scientists have a really good idea about 4% of the Universe; the other 96% we're looking into. I think people have the wrong idea about science. They think that we know everything, and we don't, we really don't. The radius of the visible Universe, out to that edge that you saw, is 13.7 billion light years, and as Chris mentioned the other day, you can actually look beyond that wall. That wall is a wall to light, you can't see beyond it with light, but if you look beyond it with particles, you can actually see the particles that come and have been created back to one tenth of one billionth of a second after the Big Bang. Well, the Universe expands. What's it expanding into? Nothing. It turns out that you may have this picture of the galaxies rushing apart from each other, but in fact, the modern scientific view is that the galaxies are not moving through space; the galaxies have new space appearing between them and us. New spaces, a new vacuum is appearing, that's the modern view of the expansion of the Universe.

In fact, here's a view that's likely to be disturbing. If you look at the star you see it in the past, remember? You see stars in the past, and in the past the Universe was smaller. If you look where there's no star, when you look in that direction, you see the light that came along that curved path from the Big Bang. If you look out in that direction, you'll see the birth of the Universe. And what is it? It's a point. In fact, as I look at all places in the blackness of space, I see a point, in the four dimensions of space-time we are surrounded by a point. A very strange idea indeed, and that's why it's hard to see beyond the edge, because beyond the edge is the inside of a point. That hurts your brain. We are surrounded by a point beyond the edge of the visible Universe.

There's one more line left, and that's the bottom left line. That bottom left line is the limit of quantum knowledge. We've discovered that all particles behave as waves. In 1801, Thomas Young did the two-slit experiment, which I'll tell you about. Richard Feynman again said, "All of quantum mechanics is contained in the two-slit experiment. Unfortunately, no one understands the two-slit experiment," and we heard that mentioned earlier today. It's not esoteric; you can do it. If you put a laser through a slit and have it pass through two slits, the light makes a pattern on the wall. If you open a second slit, which Thomas Young did in 1801, a different pattern appears, blackness appears. What he discovered was light plus light equals dark. Light from one slit, when you add a second slit, created darkness in some places. In fact, even if you shoot one particle of light—light is a particle and a wave—if you shoot one particle of light at a time through the two slits, it passes through both slits in some way and makes the pattern by itself. You only need one particle at a time to do this. This picture shows you a photograph of the two slits with light going through it, one particle at a time. We've done the two-slit experiment with light, photons, electrons, neutrons, atoms and bucky balls, which are groups of sixty atoms.

This means that all of those things that you may think of as particles are also waves, and they interfere with themselves. And because they are waves, they have a wavelength, and things that are going faster have shorter wavelengths. The shortest wavelength possible is called the Compton wavelength. It's reached as particles approach the speed of light. You cannot ask questions about the structure of particles that are smaller than that Compton wavelength. There's a limit to the size, and the questions you can ask. That is the quantum limit, and when you hear scientists talking about things that are smaller than the quantum limit, they are pushing the edges of science. The theory can go there, and then the experiment must follow. They are doing it; they're pushing that edge all the time.

There are other limits to science. What is consciousness? What is mind? There's the speed of light limit. And you might have read recently that scientists may have observed neutrinos, a particle going faster than light, and everyone got really excited, because whenever you approach one of these limits we get really excited about pushing beyond the limit. Other scientists will have to repeat that experiment, because we don't take anyone's word for it. We must do the experiment. So if you hear scientists talking about what's inside a black hole, what's beyond the edge of the Universe, what's smaller than one wavelength of a particle, of particles that go faster than light, realize that they are pushing the edges of experimental science. That's a good thing. That's what scientists have always done, and scientists themselves have to remember that there are things beyond the simple world of physics that we must investigate.

Is this the end of science, or the beginning of the new science? I hope it's the beginning of the new science. To show the kinds of things that might be at the beginning of science, I now point you to the places on the diagram where the lines come together. At the very top, there's a black hole with the radius of the Universe. You will notice that the Universe we know, that black dot that I labeled Universe, shows that we are not in a black hole, the Universe is not a black hole. That's a nice thing to know. On the left where the two lines meet, that's a quantum black hole, a black hole that is a wave, and that black hole is right at the edge of science. The theoreticians are really working at that. You might have heard of it, it's called String Theory. The upper left line, the black hole line, is described by a wonderful physics theory called General Relativity, which has never been shown to be wrong. The bottom left line is Quantum Electrodynamics, a wonderful theory, never been shown to be wrong within the limits of measurement. But where they meet, they disagree. We have these two completely correct theories that have been tested, and they come together and they disagree. We know there's great science there, and the theorists are poking at that science. The experimentalists have to catch up with it. At the bottom is a mass, a tiny mass, which has only one wavelength that fits in the entire Universe. That's so far beyond anything we've explored.

There's so much more to look at in science. So, I leave you with the idea that science does have boundaries, and I urge you to go look for them.

Discussion

Chris Impey (Moderator): That was great. We have a short time for questions, so I'll invite the *geshes* to start.

Monastic Graduate: Thank you. I only have one month's background in science so I don't think I need to stress how fortunate I feel to be able to sit here with you and in front of you. I would also like to thank today's speakers. They have both been very kind for taking the time to teach us, especially a novice like myself. I was going to speak in my native language, Tibetan, but some of my friends somehow convinced me I could pull this off in English. I'm not sure I can but I'm going to pretend that I'm not scared and you can pretend that I'm making sense! My first question is to Dr. Doherty: As a physicist, how would you connect the dots between cosmology and consciousness? Maybe you can present a different view than Rajesh did yesterday.

Paul Doherty: The fact that the human consciousness can conceive of this Universe, can look out at the Universe, and come up with some simple ideas that begin to describe it, and not its entirety but just a hint of it, can create the idea of the Universe, requires the conscious to look out. There is a great story that in the early days astronomers looked at the planet Mars through a telescope, and on the planet Mars they saw canals. Schiaparelli wrote a paper in which he said, "I see canals on Mars." As telescopes got better, the canals vanished. There were no canals, and it turned out the canals were created by the human eye and brain; the dark patches on Mars, these faint dark patches seen through bad telescopes, the brain immediately made into lines. I believe it was Carl Sagan who said that the canals on Mars were the sign of conscious life. At first, we thought the conscious life was on Mars carving the canals, but in the end we know it was the conscious life on Earth creating them, the human mind seeing the canals that were not there.

Monastic Graduate: When we talk about the limits of knowledge, we are actually talking about whether our consciousness can know all the knowable things in the Universe. In Buddhism, there is an example in one of the mind-training texts, which says that if there is a land that is filled with thorns and you want to get rid of those thorns you can't pick them one by one and throw them away. Rather than picking the thorns, you should wear metal boots so that you won't be harmed by the thorns on the ground. This example is telling us that if you want to know all the knowable phenomena in the Universe, you better look inside yourself and try to refine your consciousness, or your mind, instead of trying to find phenomenon one by one. If you are able to refine your mind by removing the two obscurations, then you will know the whole physical world. Knowledge will appear to you without knowing. You don't need to find knowledge one bit at a time.

In physics, we talk about the limits of knowledge and Dr. Doherty has given four examples, like the limits of the black hole and the horizon of the visible Universe. A question related to this concept is that if the event-horizon of the black hole is a limit to knowledge, what has the scientific community done to make this understandable to the general community? Second, because of scientific achievements we have made so much progress in areas like economic and material development. I feel that if we can direct these achievements towards the betterment of society or a more peaceful society, it would be more meaningful. What is your stance on this?

Paul Doherty: I like the idea of the steel boots stomping down the thorns of science, and in fact physical scientists are guilty of picking the points and bits of knowledge one at a time. But then we gather them together and look at them as a whole and try to make rules and new ideas that encompass the whole Universe, like the law of conservation of energy, which we apply everywhere.

I'll use that one right now to jump to the last point, because if you understand the law of conservation of energy then you will understand a lot about the power system that you use to power your homes; the gas and the electricity. If you understand that law, as science teachers should impart the understanding of that law, then people that come to you and promise you free energy or free energy for a price—which is what they tend to do—you will know whether they are lying or not.

It's not just the science, it's the science teaching that is needed; it's taking the big ideas that we assemble from the small ideas and spreading it to people. Everyday some newspaper in the United States mentions the term "black hole." It's in common usage around the United States. I think we really are trying to bring these ideas to everyone, and there are people who specialize—science journalists—in bringing these ideas to the world. Indeed, my answer is "yes," I agree with the points that you made, but scientists are not finished yet. Scientists still have things to learn, and that's why we are here listening to these ideas from Buddhist monastics about looking at the world as a whole.