2 Powers of ten

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A few years ago, astronomers and astrophysicists did not agree on the age of the universe. Some said it might be 10 billion years old, others said 20 billion. You might think that we were completely clueless, not to know by a factor of two how old the universe is. But you have to consider that no-one was arguing the universe might be a trillion years old, or a quadrillion years, or a hundred years old. We were only within a factor of two of each other, and this was a pretty good thing. We knew we were nearing agreement. In fact the most recent data indicate an age of 14 billion years, plus or minus one or two. In the universe, quantities of time, size, temperature and distance come in such a vast range that factors of two between friends are not important.

Introducing powers of ten

In this chapter, we're going to cover that whole vast range. But if we're going to get through the entire universe in a few pages, factors of ten are the smallest differences we should worry about.

$$10^0 = 1$$

We'll start here, the number 1. This needs no introduction. The number 1 has no zeros to follow it, so we can write it as ten to the zeroth power. That zero tells us how many zeros follow the 1, if you're going to write it out. This fact turns out to be very important later on. Now let's go up by powers of a thousand.

$$10^3 = 1000$$

One with three zeros is one thousand. We have the international system of prefixes – *kilo*. And of course we use this regularly: kilometre, one thousand

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metres, that's fine. This number needs no introduction, because it exists in our everyday lives.

$$10^6 = 1\,000\,000$$

Add another three zeros, to get ten to the power of six, a million. *Mega*. The population of New York city is about 8 million. London might be 10 million. We've seen these numbers before. Being a millionaire is not what it used to be, I'm told, by those who are. But it's certainly better than being a thousandaire.

$$10^9 = 1\,000\,000\,000$$

Let's go up another three zeros. Nine zeros, ten to the power of nine, *giga*, a billion. Billion is an important number in astronomy, because it shows up everywhere. There are a hundred billion stars in the galaxy. There are a hundred billion galaxies. We hear about billions on Earth from time to time: the net worth of Bill Gates is in the hundred billion category. He hasn't quite reached a hundred billion, but he'll get there, if he lives a natural life.

$$10^{12} = 1\,000\,000\,000\,000$$

In fact, Bill Gates will become the world's first trillionaire. Even if he sold all his Microsoft stock and bought conservative savings bonds, he would still be a trillionaire before he dies. A trillion has another three zeros: ten to the power of twelve, or *tera*. In the year that you turn 31 years old, you will live your billionth second. But you can't count to a trillion. It would take you 31 000 years. A trillion is about how many seconds have elapsed since cavemen roamed the earth.

$$10^{15} = 1\,000\,000\,000\,000\,000$$

Quadrillion. Working our way up the international system of prefixes: *peta*. Ten to the fifteenth power. You can calculate how many words could come out of someone's mouth. We often say that, in politics, a lot of words come out of a lot of people's mouths. Now if you add up all the sounds and words uttered by all the human beings that ever lived since the dawn of the human species, you'd get a hundred quadrillion. And this even includes what goes on in Parliament.

$$10^{18} = 1\,000\,000\,000\,000\,000\,000$$

My favourite number is this: quintillion, with the prefix *exa*. This figure is the estimated number of grains of sand on an average beach. You might ask how I know? There are ways to approximate this. You count how many grains of sand are in a cubic centimetre, then you estimate how many cubic centimetres are on the beach. We do this back of the envelope calculation (or back of the bathing-suit calculation) all the time in the sciences.

$10^{21} = 1\,000\,000\,000\,000\,000\,000\,000$

Sextillion. This is the estimated number of stars in the universe. It outstrips the number of grains of sand on the beach, and the number of sounds and words ever uttered by human beings. The scale of the universe is enormous. This number makes a powerful argument if you're debating the existence of life elsewhere in the universe. If you are so egocentric as to presume that life on Earth is the only life in the universe, just spend a night alone with this number.

$10^{-3} = 0.001$

You can of course go in the opposite direction, calculating fractions by powers of ten. Decimal places get shifted to the left now. One-tenth, 0.1, has its decimal point shifted one place to the left, so is written 10^{-1}. The standard prefix *deci* comes from the same origin as the decimal point – they both describe tenths. 10^{-2}, 0.01 or one-hundredth, is shifted another place to the left – *centi*. A centimetre is one hundredth of a metre. An American coin is called the cent because there are a hundred to the dollar. And one more decimal place, 10^{-3}, *milli*, is one-thousandth. The millimetre is small, but it's still useful in everyday life.

$10^{-6} = 0.000\,001$

One-millionth. *Micro* – they invented the microscope to see really small things. You'd think they could have invented the megascope to see big things. That would be a much more impressive name than telescope.

$10^{-9} = 0.000\,000\,001$

Here's a word that we're hearing a lot these days. *Nano*. One-billionth. Nanotechnologies are the attempt to create tools that will let us manipulate molecules. A nanosecond – a billionth of a second – is the time that it takes light to travel 1 foot. That's a good way to remember the speed of light: 1 foot per nanosecond.

$10^{-12} = 0.000\,000\,000\,001$

Let's keep going down. One-trillionth, *pico*. Do you know that there is nothing in the universe that measures one-trillionth of a metre in size? There's a gap in how big things are. A picometre is smaller than an atom, and bigger than an atom's nucleus. I've encountered this gap in my work, as you'll see later in this chapter.

$$10^{-15} = 0.000\,000\,000\,000\,001$$

Ten to the power of minus 15 is about the size of the proton. We're getting down to fundamental particles now. *Femto*. A femtometre, ten to the minus fifteen metres, is one-quadrillionth of a metre.

$$10^{-18} = 0.000\,000\,000\,000\,000\,001$$

Ten to the power of minus 18. There is nothing measured that's this small, although there are things that we are pretty sure are smaller than this, like electrons, or quarks. We have yet to measure the dimensions of an electron. We know their behaviour, we know where they've been, we know where they're going. You'll never see one, but they're there. In modern science, were left behind the idea that seeing is believing. Evidence is not seeing, evidence is measuring – your retina is irrelevant to science.

$$10^{-21} = 0.000\,000\,000\,000\,000\,000\,001$$

One-sextillionth. I have no idea what in the physical universe this could represent, but we do have a standard prefix for it – *zepto*.

Table 2.1 recaps the international standard prefixes. We've got 48 powers of ten here. The measured sizes of all things that exist in the universe extend over 40 powers of ten. So everything in the universe fits within the range of names that we already have, and there are some to spare. That's kind of fascinating, or perhaps wishful thinking, that we might go on to measure things big enough or small enough that we need to use those extra words.

$$10^{81}$$

If you take all the atoms in a star, and multiply that number by all the stars in a galaxy, and then multiply that number by all the galaxies in the universe, you get this number. This is the total number of atoms there are, plus or minus a power of ten. The total number of atoms in the universe. Could you possibly need a number bigger than this? What would you be counting that wouldn't be contained within this number? As far as I know, this number hasn't been named, although I might vote for "totillion."

Table 2.1. *Forty-eight powers of ten.*

yocto	y	10^{-24}
zepto	z	10^{-21}
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deka	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}
zetta	Z	10^{21}
yotta	Y	10^{24}

10^{100}

This next number does have a name. Ten to the hundredth power. *Googol* is the official name of this number. It dwarfs the number of atoms in the universe, by 19 further powers of ten. So why would anyone need it? Well, it's just a fun number, and it's got a fun name. By the way, the search engine on the Internet, they have misspelled it 'G-o-o-g-l-e'. 'Googol' is the correct spelling.

$10^{10^{100}}$

Numbers can get still higher. This is one of the biggest numbers ever named, *googolplex*. Googol is ten to the hundredth power – that was 1 followed by a hundred zeros. But a googolplex is ten to the power of a googol. That's a one with a googol zeros. A googol zeros is more zeros than there are atoms in the universe. Nobody could ever write this number out . . . where would they get the ink?

You know how you can get even bigger numbers in nature? You don't keep counting objects, you count events. For example, if you're playing chess, how many possible chess games can there be? Far, far more than the number of chess pieces. So you're not counting things, you're counting configurations or events.

$10^{10^{10^{34}}}$

This gives us a number that dwarfs the googolplex! Skewes' number. Ten to the 10 to the 10 to the 34th power. And why do we have a number this size? If you imagine the universe, with all of its atoms, as a cosmic chessboard, and you ask the question how many possible combinations of configurations of atoms exist in the universe, you get this number. So in a way, this number is a measure of the total information content of the visible universe, because information relates to configuration of the states of matter. Either in your brain, in a computer, in a beaker, or in the whole universe.

Comprehending powers of ten

Can we use these numbers to help people appreciate the universe? There is a famous educational film, ten minutes long, called *Powers of Ten*. It's a zoom out from the Earth to the edge of the universe, and then back down into an atom, which is sitting in someone's hand on the beach. That video has a precedent that goes back to 1915. Henry Norris Russell, head of the department of astrophysics at Princeton, wrote a letter to the head of the American Museum of Natural History, where I work:

> Professor Osborne, your friendly interest in some of the ideas I spoke of the other day leads me to send you a sketch of my idea for a series of models or diagrams, of progressively smaller scales, to illustrate astronomical distances and the like. The enclosed scheme is entirely tentative, but might serve as a basis for consideration. It suggests the construction of a set of diagrams and models, each one one-hundredth the scale of the last.

10^2 to 10^{10}

In his letter, he goes on to cover some of the ground that we have reviewed. At 100, 10^2, he suggests a plan of the hall in which the exhibit is situated. The hall is a hundred times bigger than the plan, so you get to compare the two. 10^4– a map of Manhattan Island, showing the location of the museum. 10^6 – sheets of the new "international map," a famous project at the time that included the first complete map of the Arctic and Antarctica. 10^8 – a model of the Earth and the moon, showing the diameter of the Earth relative to distance to the moon, and models of the planets on the same scale. 10^{10} – a model of the Earth, moon and sun, with models of the satellite systems of the planets, and diameters of the largest orbits, up to a trillion, a model of the whole solar system. He only goes out to Neptune. Why does he stop at Neptune? Because Pluto hadn't been discovered. It was another 15 years before they discovered Pluto. Of course in the last few years, we've demoted it from its planet status. So he was actually right at the time, with the planets of the solar system ending at Neptune.

10^{-2} to 10^{-10}

Then he goes on down into the atom: 'Though it is outside my field, I can hardly refrain from adding the suggestion of a set of diagrams in the other direction.' A magnification of 100 and of 10 000 times would be registered in the field of microscopy. A million times would be ultra-microscopic particles. 100 000 000 times would illustrate molecular diameters and crystal structure. 10 000 000 000 times could perhaps illustrate 'Rutherford's nucleus atom', as he describes it.

Powers of 10 at the Hayden Planetarium

I've spent several years working on an exhibition space along the lines that were imagined by Henry Russell. We spent $210 million rebuilding the Hayden Planetarium at the American Museum of Natural History. The planetarium is in the form of a giant sphere, which stands within the Rose Center for Earth and Space (Figure 2.1). In the upper half, there is a space theatre, with a Zeiss fibre-optic projector simulating the stars in such clarity of detail that if you go in there with binoculars, you will see the stars even better than with your naked eye. But in the base of the sphere, you can see a whole different universe. We show the beginning of it all, the Big Bang.

10^{18} seconds ago

This is the beginning of time, 14 or so billion years ago. You step out of the Big Bang, and you take a walkway through time. We have laid down 14 billion years of cosmic time on a spiral 100 metres long. And on the walkway we've placed images of astronomical objects whose light hails from that time in the life of the universe. So at the 3-billion-year mark, you see a picture of an object whose light was emitted 3 billion years from the beginning and has been travelling ever since. Because when you look up at the night sky, you see the cosmos not as it is, but as it once was. Even light takes time to get to you across the universe.

10^{15} seconds

So every image shows an object from the history of the universe. Since it's a linear scale, one step taken by an average-sized visitor spans 70 million years. What does that mean? The dinosaurs became extinct 65 million years ago. So if I go to the end of this ramp, and take a single step back, that's when the dinosaurs became extinct. That's yesterday on the cosmic timescale. When did the dinosaurs arrive? They came in some 300 million years ago, which is a mere three steps beyond that.

10^{12} seconds

At the very end of the ramp, we've got to show civilization. We have mounted a single strand of human hair there. The left side of that hair was a trillion seconds ago. Cave paintings by cavemen. The right side of that hair is the modern day. All that we call human culture occupies the thickness of a human hair at the end of our ramp.

Space

The space around the sphere is not just the housing for the space theatre; the sphere is an exhibit in itself. Spheres are a fairly common shape in the cosmos, because the laws of physics conspire to give you spheres. So we've put a walkway around our sphere, and we give a powers of ten walking tour, comparing the sizes of many different objects and spaces across the size scales of the cosmos. There are a series of models mounted alongside the walkway, so that at each stage we can stand by the model, and say that if this model was expanded to be the size of the whole sphere, then some far smaller object – which can be seen in the next display along the walkway – would only be so big by comparison. One step at a time, visitors can imagine themselves walking through all these different scales (Figure 2.2).

10^{24} metres

We start with the observable universe. If the planetarium sphere was the size of the whole observable universe – including light that comes to us from 14 billion years ago – then relative to that size we can show the extent of space that contains the thousands of galaxies in the Virgo supercluster. In our exhibit, we show those galaxies as flecks within a solid glass ball right next to the walkway. Our own Milky Way is a member of the Virgo supercluster of galaxies. We can't look at the entire Virgo supercluster with a telescope, because we are in the middle of it, but we can see other superclusters around us.

10^{22} metres

If we made the planetarium sphere the size of the Virgo supercluster, a small globe on the railing would be big enough to contain our local group of galaxies. The Milky Way, the Andromeda galaxy, the Magellanic clouds, and a few other galaxies – our cousins, and brothers and sisters.

10^{20} metres

Now let's make our local group of galaxies the size of the planetarium sphere. Once we've done that, our own galaxy is on the scale of an exhibit by the walkway. So we live in a big family – the volume occupied by our family is large. The diameter of a galaxy is a hundred thousand light years. There's a (faint) picture of our galaxy in Figure 2.2. This is actually not a photograph, it's a constructed model of the light distribution of our Milky Way. It's very flat, and you can't see very far across because there are so many stars, but to see the rest of the universe, you can look out above or below the flat disk.

10^{18} metres

So now the planetarium sphere is the bounding volume of our galaxy, and we have a glass sphere the size of a baseball mounted on the railing of the walkway. This is a cluster of stars. We put about a hundred thousand specks in that ball, each speck representing a star. It's a globular star cluster. There are a couple of hundred of these clusters in our galaxy, and they orbit in big looping trajectories. Figure 2.2 shows an actual picture of a globular cluster that has about a hundred thousand stars. This is a photo taken by the Hubble Space Telescope.

10^{16} metres

Let's keep going. Now the planetarium sphere is that globular cluster of a hundred thousand stars. And another sphere slightly bigger than a cricket ball represents the volume of comets that orbit the sun – a volume of comets predicted to be there by the Danish astronomer Jan Oort. They comprise the Oort cloud. These are comets that come raining down on the inner solar system, but have orbits of tens of thousands, hundreds of thousands of years. You only ever see these once in a lifetime. Not like Halley's comet that comes around every 76 years. This is a cloud of comets. Trillions upon trillions of comets. And our solar system would be deep in the centre of this sphere. So now we're localized to the volume occupied by the gravitational influence of a single star, within the volume of that star cluster.

10^{14} metres

Now take that Oort cloud of comets, make that the sphere, and we have a little hockey-puck-sized exhibit. This contains our entire solar system – the orbits of all the planets. On the hockey puck we have a circle that is the orbit of Neptune. Then Uranus, Saturn and Jupiter. Mercury, Venus, Mars and the Asteroid Belt are in a tiny circle around the Sun. And there is another reservoir of comets, distinct from the far wider Oort cloud. This was predicted by Gerard Kuiper in the mid twentieth century, and it is known as the Kuiper belt of comets. Do you know who orbits out here among the Kuiper belt of comets? Pluto. Do you know what Pluto is more than half made of? Ice. Like all the other stuff out there. So Pluto has finally found a home. It's not just an oddball in the solar system, smaller than all the other planets, with this weird orbit that crosses the orbit of other planets. Do you know if Pluto was where the Earth is right now, the heat from the Sun would make it grow a tail. Now what kind of behaviour is that for a planet? So we've taken Pluto out of the pantheon of the planets, and put it with the comets. It's the biggest known object of the Kuiper belt. It's the king of the Kuiper belt! I think it's happier there, actually, being the biggest fish in a pond of small fish.

10^{10} metres

Now we make the planetarium sphere the Kuiper belt. And we have a little sphere on the railing of the walkway. This is the relative size of a blue super-giant star. They are called this because . . . they are very big and they are blue. The particular one that we've placed here is a blue super-giant called Rigel, the left kneecap in the constellation Orion. Two principal stars are his left kneecap, and his right shoulder area, Betelgeuse, a red super-giant star. Betelgeuse roughly translates as 'armpit of the great one'.

10^9 metres

So now, the planetarium sphere becomes a super-giant, and, by the walkway, we have the sun. The sun is tiny compared to some other stars, but one day the sun will grow to be a giant, and in so doing, it will engulf the orbits of Mercury, Venus and Earth. We'll be a charred ember, turning deep within its surface.

10^7 metres

When we make the sphere the sun, we have Mercury, Venus, Earth and Mars sitting on the rail, each smaller than the size of a soccer ball. They're not very impressive. They look like debris in the solar system compared to the size of the Sun. If the Sun were hollow, you could fill it with more than a million Earths, and have room left over.

10^5 metres

So now the planetarium sphere is Earth, and we show one of the moons of Saturn along the rail. Once the sphere is that satellite of Saturn, then we have a clay model of that famous crater in Arizona, made by a meteor – we call it Meteor Crater. If you played a football game in the bottom of Meteor Crater, you'd have seating for 2 million people around the rim.

10^3 metres

Now if the sphere is Meteor Crater, then on the railing we have a model of the asteroid that made that crater. The asteroid is very small compared to the crater. It came in with a lot of kinetic energy. That energy's got to go somewhere – some of it vaporizes the asteroid, the rest of it thrusts the Earth's crust out of that hole, and tosses it far and wide.

How about the crater responsible for the dinosaurs' extinction, 2×10^{15} seconds ago? It's centred on Yucatan, off the tip of Mexico, in the southern part of North America. The Yucatan crater is 200 miles in diameter, but the splash zone went as far as Minnesota, nearly a thousand miles north of there. So if you're a dinosaur, your choice would be either to stand right where the asteroid is going to hit, getting vaporised instantaneously, or go somewhere else: where it's raining fire; dust is thrown into the stratosphere; cloaks the Earth's surface from sunlight; knocks out the base of the food chain, and then you starve. I'd rather go quickly. It took out all the dinosaurs, no matter where they were on Earth.

10^0 metres

Here we have a one to one scale, which is kind of weird – you have to go through that at some point. So now, the sphere is the sphere. And our exhibit is a brain, the actual size of your brain. I like to pause here, and realise, as frail as we are in time and space, and as tiny as we are, and as small as our brain is, this brain actually figured all this stuff out. We're doing all right for ourselves.

10^{-4} metres

Let's keep going. Now the sphere is your brain, and we have a model which is an enlarged raindrop. Real raindrops are actually very small. Now let's go inside the raindrop, and see what can fit in there.

10^{-6} metres

Make the sphere a raindrop, and what we have is a red blood cell the size of your hand. Now you get a sense of how tiny cells are, compared with just a drop of water. Surely Anton von Leeuvenhoek was astonished putting the drop of pond water under his first microscope, and seeing a whole universe of creatures. You get a sense of how big, how much of a universe a single drop of water represents, if you're this small.

10^{-8} metres

Now make a red blood cell the size of the sphere, and we get the size of a virus along the rail, where we place a model of a rhinovirus, the cause of the common cold. Now you see how small viruses are compared with cells (Figure 2.2 shows the influenza virus). Most people do not appreciate how much tinier a virus is than bacteria and other cells. So the ways that you have to combat it in your body are very different from the ways you fight bacteria.

10^{-10} metres

Here's my favourite part of the entire journey. The rhinovirus is now the size of the sphere. And if the sphere is a rhinovirus, our display model shows the size of a hydrogen atom. What's remarkable to me is that when you construct a building out of bricks, those bricks are smaller compared to the building, than our model hydrogen atom is compared to the planetarium sphere. So imagine if we did have the tools to assemble atoms. It's not unrealistic to believe that we can create something like a virus from individual atoms, when we do something just as complex every day on a construction site.

10^{-12} metres

We're running out of universe now. We descend into the zone smaller than the electron orbitals that define the size of a hydrogen atom. We're inside the space of the atom and there are no known objects of this size. Atoms are so empty. There's a story about Ernest Rutherford. He was trying to find out how much space atoms take up, so he took thin gold leaf, and fired particles through it, to see how often they would slam into the stuff that was there. You'd assume that with solid material, particles would be hitting and bouncing off all the time. But nearly all of his particles went straight through, as though there was no gold leaf in front of them at all. Rutherford concluded, correctly, that atoms were mostly empty space. This was one of the first revelations in the world of modern physics. Rutherford, as a classical physicist, had to contend with that fact. It is rumoured that the next morning, when he woke up, he was afraid to step onto the ground, because he alone knew how empty solid matter was.

10^{-14} metres

Now we can show a model that represents the size of the uranium nucleus. It's one of the biggest nuclei of the periodic table, densely packed with 92 protons and nearly 150 neutrons.

10^{-15} metres

At this scale, if this sphere is now the size of the hydrogen atom that we saw earlier, then how big is a proton? We know it's going to be small. In our exhibit we drew a picture of it, accompanied by a caption on the picture. You know, even compared to the whole sphere of our planetarium, the proton is smaller than the dots that are on the "i" of its display caption.

10^{-18} metres

We know that electrons are smaller than this. So too are quarks. The proton is not fundamental matter. Quarks and electrons are, as far as we know. We still don't have a size measure for them. All we can say is that they are smaller than this measure.

Looking upward and outward

In our show at the planetarium, as we ascend from Earth, we see three other planets in the inner solar system, and then the sun. If we look very deeply into the night sky, in the Milky Way, we see an uncountable number of stars. Yet there are still no other galaxies in this picture, only our own galaxy.

In Figure 2.3 we see, across the plane of our galaxy, the hundred billion stars that are the Milky Way. Now, in our show, we ascend up out of the Milky Way, looking back toward it. This is the entire extent of stars whose existence we have visual confirmation of. Every star you can see in the night sky is contained within this volume, around us at the centre – in this random suburban corner of a spiral arm of the Milky Way. All the splotches are other galaxies, each containing a hundred billion stars of its own. Take another step back, and our own galaxy continues to recede into the distance. We can see our neighbour, the Andromeda galaxy. Our local group is here. Then we start to see the Virgo cluster coming into view. And we continue to ascend to the outer universe.

We enter the realm of one of the most famous images ever taken by the Hubble Space Telescope. It's called 'The Hubble Deep Field'. This contains some of the most fascinating structural information of galaxies ever recorded. Almost every smudge is a galaxy, as far as your telescope can see. Big ones, small ones, blue ones, red ones. Perhaps there are civilizations there, looking back to us, with a photograph that is a counterpart of ours. If we ascend a little farther out into space, whole clusters of galaxies are now nodes in a webwork of matter as it is distributed throughout the cosmos. The last part of figure 2.3 is a computer simulation of the clustering of galaxies as it appears in the universe. This is about a 10 per cent chunk of the total visible universe.

I think to myself: there was a time, in this expanding universe, where all the matter, all the energy, was contained in a volume the size of a proton.

That moment was the Big Bang. And so when I look at the cosmos from its beginning to its end, the very largest of scales owe their origin to something that was the size of a proton 14 billion years ago. So we have particle physics meeting astrophysics right back at the beginning of the cosmos. It's that perspective that I carry with me every day. When I look back from this image of the Universe and I ask 'where's Earth?' – back here in the Virgo cluster. Where's the Virgo cluster? Right here – these thousand galaxies. Where's the Milky Way? Somewhere in there. Where's Earth? Somewhere in that. On the scale of the Universe, we're lost among these powers of ten.

Let me leave you with one final thought: that the very chemistry of our bodies – the hydrogen, the oxygen, the carbon, the nitrogen – these elements are common throughout space. They are forged in the centres of high-mass stars that exploded and spread that enrichment throughout the cosmos. And from that enrichment, solar systems are born, and planets forged out of the debris – people, and life. And so yes, it's possible to feel small in the Universe, but I also feel large. Because I know that it's not as if I'm here and the Universe is there. It's not as though that is someplace else. It's not simply that we live in the Universe. It is also true, when we look across these 40 powers of ten, that the Universe lives in us.